IIHE
Annual Report
2020 - 2021 - 2022

Interuniversity Institute for High Energies
ULB - VUB

Interuniversity Institute for High Energies

ANNUAL REPORT
2020 - 2021 - 2022

B. Clerbaux - J. D'Hondt - L. Favart
Directors

https://iihe.ac.be

Contents

1 Introduction

1.1 The Interuniversity Institute for High Energies

The Interuniversity Institute for High Energies IIHE (ULB-VUB) was created in 1972 at the initiative of the academic authorities of the Université Libre de Bruxelles and the Vrije Universiteit Brussel. It is devoted to experimental research in elementary particle physics, using mainly high energy particle accelerators, and in astroparticle physics with non-accelerator experiments. The main goal of the experiments at accelerators, notably LHC at CERN, is the understanding of the strong, electromagnetic and weak interactions between the elementary building blocks of matter, which form the standard model of particle physics. Prominent in this endeavour are precision measurements of the fundamental interactions and particle properties, the search for missing pieces in the standard model and the search for physics beyond the standard model, possibly related to the dark matter in the Universe and to cosmology. Astroparticle physics is devoted to the study of the structure of the Universe, using particles as messengers of astrophysical activities in the Universe and using the techniques developed in particle physics. All these experiments are performed in the framework of large to very large international collaborations with several hundreds to several thousands of physicists and engineers.

Fundamental contributions to the understanding of the Universe, particle and astroparticle physics with experiments imply major R&D developments concerning particle detectors, computing and networking systems, frontier technologies in various fields (electronics, superconductivity, cryogenics, etc.), which lead to break-through progress in industrial and medical applications.

1.2 Overview of the IIHE activities in 2020-2022

The report presents the research activties performed at the IIHE in the years 2020-2022. This 3-year period is characterised by the COVID pandemic in the world, which deeply affected the way of working at the institute. The IIHE complied with the health rules from Belgian government and from the ULB and VUB autorities during this difficult time. In several periods of time, this mainly implies working from home, meeting via remote sessions, participating to virtual conferences, and organising social events in a different way. However the work activities continued at the IIHE in the years 2020-2022, including research from the smallest accessible scales, below 10^{-19} m for e.g. the Brout-Englert-Higgs boson, quarks and neutrinos, to the largest scales above hundreds of thousands of light years for e.g. the source of ultra-high energy neutrinos detected by IceCube.

The IIHE is deeply involved in the CMS experiment since its design phase in the early 1990's, and actively contributed to all aspects of this experimental project, i.e. building, operating and maintaining the CMS detector as well as to the data analysis for searches for new physics and precision measurements of the fundamental interactions and particle properties. All aspects of this work were done in collaboration with other Belgian and international teams. Since the first collisions in 2009, the LHC has performed extremely well. The so-called LHC run 1 accumulated proton-proton interactions at integrated luminosities of 5.1 fb^{-1} at 7 TeV in 2010 and 2011, and of 19.6 fb^{-1} at 8 TeV in 2012. The 4-year run 2 period took place in 2015-18, with a total integrated luminosity of 162.9 fb^{-1}. After a shutdown period in 2019-2021, the machine restarted with the run 3 data taking, at the record energy of 13.6 TeV, with 42 fb^{-1} delivered in 2022. During years 2020-2022, in addition to operational activities around the detector and its continuous survey and calibration, the Brussels team in CMS contributed to physics analyses with developments of reconstruction methods for objects detected in the final state as well as the identification and trigger techniques to differentiate the physics objects. With these reconstructed objects physics measurements and searches are performed related to the Brout-Englert-Higgs boson, top quark physics, dark matter, supersymmetry and in general new physics phenomena. Precision measurements of the strong interaction (QCD) and the electro-weak interaction (EW) provided as well numerous new results.

The LHC phase-2 program approved by the CERN council in 2016 will provide increased luminosity by a factor 5-7 above the present design parameters. The data taking expected to start around 2030 will allow a precise study of the scalar sector, as well as extending the discovery potential of the LHC for rare beyond-the-standard-model processes. To meet this luminosity challenge the CMS tracker must be completely replaced. The Belgian groups from the IIHE, from Universiteit Antwerpen, the Université Catholique at Louvain-la-Neuve, and from Universiteit Gent have decided to build together one endcap of the CMS phase-2 outer tracker. At the IIHE, about 1500 modules will be assembled and tested, before they are integrated onto the tracker endcap support structures. The module assembly has to be performed in controlled conditions of temperature, humidity and dust. In 2018, a large clean room of 122 m^2 was deployed at the IIHE and has been equipped to be ready for the pre-production and the production of the modules.

The IIHE is also participating since 2011 to the CMS forward muon GEM upgrade. In 2019 and 2020, a total of 144 new triple-GEM detectors have been installed in the most forward part of the CMS spectrometer (the so-called station GE1/1). After commissioning, the first muons were recorded in the station G21/1 in 2022. Two additional triple-GEM stations (GE2/1 and M0) will be installed in CMS.

The IIHE has a long history of research in the field of neutrino physics. The IIHE has initiated together with national and international colleagues the SoLid experiment at the BR2 nuclear reactor at the SCK-CEN (Mol, Belgium). The complete phase-1 detector data taking has started in 2018. SoLid data are taken in two phases: phase 1 between June 2018 and July 2020, and phase 2 between November 2020 and August 2023, after an upgrade of its Silicon PhotoMultiplier photon sensors. The phase-1 data are analysed by the IIHE group in close collaboration with the Universiteit Antwerpen to determine the detector response and background contamination. The intention is to measure neutrino oscillation processes at very short distances between 5 and 10 meter from the reactor source.

The JUNO experiment consists of a large liquid scintillator detector aiming to measure antineutrinos from a nuclear reactor at a distance of 53 km and having as main goal to determine the neutrinos mass hierarchy after 6 years of data taking. Located in China, the detector will be at 700 m overburden and consists of 20 kton of liquid scintillator contained in a 35 m diameter sphere, instrumented by 20000 20-inch photomultiplier tubes (PMT). The required energy resolution to discriminate between the normal and inverted neutrinos hierarchies at 3-4 sigma of CL for about 6 years of data taking is 3% at an energy of 1 MeV. The start of the data taking is expected in 2024. The IIHE joined JUNO in 2016 and is contributing to the development and the construction of the electronic readout system.

In the field of astroparticle physics, the IIHE has been involved in the search and measurement of interactions of ultra-high energy neutrinos from cosmic origin in the South Pole ice, since the start of this quest in the late 1990's with the AMANDA and IceCube experiments. Since 2011 the fully deployed IceCube observatory operates as the largest ever particle detector (1 km^3). The most prominent research topics of the IIHE team are: the search for cosmic point sources, dark matter, high-energy neutrinos from transient events, from supernovae and from solar flares. The first hints of extra-galactic high-energy neutrinos came in April 2012 with the observation of two very high energy events (above 1000 TeV). Since then, with an intensified search more events have been found. This achievement marks the birth of neutrino astronomy.

The IceCube neutrino detector has shown the potential of the neutrino as a cosmic messenger. Detecting the TeV-PeV cosmic neutrino flux, as well as the first possible source identification allowed us to have a first look into the extremely energetic processes of the most violent phenomena in our universe. Beyond PeV energies, however, IceCube runs low in statistics, due to the steeply falling cosmic particle flux as function of energy. High-energy cosmic-neutrino induces particle cascades that produce in a medium a net macroscopic charge excess leading to coherent radio emission in the MHz-GHz regime. The detection of the corresponding radio signal would allow cosmic neutrino detection above 100 PeV. The IIHE made strong contributions to the first project of that kind, at the South Pole, in the Askaryan Radio Array (ARA) experiment. Since 2018 the IIHE is one of the main leading groups and contributor of the Radio Neutrino Observatory Greenland (RNO-G) project. As a pathfinder for the radio component of the proposed IceCube-Gen2 facility, this detector is complementary to ARA and aims to detect the cosmogenic neutrino flux with peak sensitivity at EeV energies. First stations of the RNO-G detector are expected to be deployed in 2023.

The IIHE is active in the radio observation of air showers with LOFAR and the SKA. LOFAR has played a crucial role in the development of the radio detection technique, showing that it can be used to determine the energy and atmospheric depth of the air shower with good precision.

Since 2016, the IIHE has contributed the Pierre Auger Collaboration to study cosmic rays. The IIHE group analyses the ultra-high energy cosmic rays, which are messengers of the most violent phenomena in the Universe, to elucidate the origin of cosmic rays by performing mass-enhanced anisotropy studies and mass composition studies. In 2019 Belgium has joined officially the Pierre Auger Collaboration.

Being devoted to experimental particle physics, the IIHE has always been very active in technical developments and instrumentation. This tradition points back to automatized bubble chambers and nuclear emulsion measurements, with important contributions to detectors at high-energy particle colliders (DELPHI at LEP, H1 at HERA and CMS at the LHC), in neutrino oscillation experiments (CHARM II, CHORUS, OPERA, JUNO, SoLid) as well as in the more recent astroparticle experiments (AMANDA, IceCube, ARA, RNO-G, LOFAR and AUGER). Over the recent years, R&D activities are centred on the development of multi-purpose, very high-rate, robust and low-cost, industry-based data acquisition systems, aimed for particle and astroparticle experiments. The contributions have taken place in the framework of generic DAQ systems for future experiments at colliders, for the ARA experiment, and for the upgrade of the CMS central tracker and muon spectrometer in the forward region. Also in the medical area the IIHE keeps on contributing to neutron metrology and fast DAQ systems for future proton therapy centres. The technical developments and instrumentation work is performed with the use of the mecanical and electronics workshops at the IIHE, and thanks to the dedication of the IIHE engineers and technicians team.

To link the activities of the theoretical and experimental particle physics groups, a phenomenology group has been settled by the VUB in 2014 through a Strategic Research Program, namely HEP@VUB. The main topics of research are new physics models and their signatures at the LHC, as well as early universe physics and the phenomenology of cosmic rays propagation. Since 2020 several members of the phenomenology group became members of the Virgo collaboration, establishing a new connection between IIHE and gravitational wave physics. The group contributed to the study of stochastic gravitational wave background (SGWB) of astrophysical and cosmological origin.

Finally, large computing resources are required by the experiments, in particular IceCube and CMS. The IceCube collaboration uses the IIHE cluster for large simulations of the optical structure of the ice at the South Pole. For CMS computing, a “Tier-2” cluster installed at the ULB-VUB Computing Centre is fully integrated in the Worldwide LHC Computing Grid, with very high performance and stability.

Research at IIHE has been mainly supported by : the Université Libre de Bruxelles (ULB), the Vrije Universiteit Brussel (VUB); the Fonds de la Recherche Scientifique (F.R.S.-FNRS), the Fonds voor Wetenschappelijk Onderzoek-Vlaanderen (FWO), and their associated funds; the Belgian Federal Science Policy Office; the Wallonia, Flanders and Brussels regions; and the ERC Grant programme of H2020. Since 2015 the IIHE benefits from the support of the China Scholarship Council (CSC), providing PhD scholarships to Chinese students or post-doctoral stay scholarships to come to the IIHE.

1.3 The IIHE team in 2020

1.3.1 The ULB personnel (2020)

Academic and scientific personnel

Juan Antonio AGUILAR SANCHEZ	Chargé de cours	IceCube
Yannick ALLARD	Logisticien de Recherche ULB (half-time)	
Isabelle ANSSEAU	Assistante ULB until September	IceCube
Sebastian BAUR	Post-doc (IISN) until September	IceCube
Diego BEGHIN	PhD student (Aspirant FNRS) until December	CMS
Bugra BILIN	Post-doc (IISN) until August; Collaborateur scientifique (FNRS) from September	CMS
Itana BUBANJA	PhD student (co-PhD University of Montenegro) since September	CMS
Koun CHOI	Post-doc (IISN) until June	Auger
Barbara CLERBAUX	Professeure et Directrice de Recherche FNRS honoraire	CMS, JUNO
Marta COLOMER MOLLA	Post-doc (IISN) since October	JUNO
Paramita DASGUPTA	Post-doc (IISN) since September	ARA
Gilles DE LENTDECKER	Maître de Recherche FNRS; Maître d'Enseignement	CMS, DAQ R&D
Wendi DENG	PhD student (CSC scholarship - CNNU University)	CMS, DAQ R&D
Laurent FAVART	Directeur de Recherche FNRS; part-time Chargé de Cours; IIHE co-director	H1, CMS
Nicolas GONZALEZ	Post-doc (IISN) since November	Auger
Anastasia GREBENYUK	Collaborateur scientifique until September	CMS
Dmytro HOHOV	Post-doc (IISN) since March	CMS
Nadège IOVINE	PhD student (FRIA)	IceCube
Aamir IRSHAD	PhD student (IISN)	CMS DAQ R&D
Amandeep Kaur KALSI	Post-doc (IISN) until October	CMS
Tomas KELLO	PhD student (EOS)	CMS
Ali KHALILZADEH	PhD student (IISN)	CMS
Fakhri Alam KHAN	PhD student since October	CMS DAQ R&D
Kyeongpil LEE	Post-doc (IISN) since September	CMS
Mostafa MAHDAVIKHORRAMI	PhD student (EOS)	CMS
Inna MAKARENKO	Chargée de Recherche FNRS	CMS
Ioana MARIS	Chargée de Cours	IceCube, Auger
Daniela MOCKLER	Post-doc (IISN)	IceCube, Auger
Louis MOUREAUX	PhD student (FRIA)	CMS
Santiago PAREDES SAENZ	Post-doc (IISN) since August	CMS
Pierre-Alexandre PETITJEAN	PhD student (Assistant ULB)	JUNO
Laurent PETRE	PhD student (FRIA)	CMS DAQ R&D
Yves PIERSEAUX	Collaborateur scientifique	Hist. of Science
Andrey POPOV	Post-doc (EOS) until October	CMS
Nicolas POSTIAU	PhD student (Assistant ULB)	CMS

Christoph RAAB	PhD student (IISN)	IceCube
Giovanni RENZI	PhD student (IISN)	IceCube
Rachel SIMONI	PhD student (Amsterdam University); collaborateur scientifique	
Zixuan SONG	PhD student (CSC scholarship - CCNU University) until September	CMS, DAQ R&D
Elizabeth STARLING	PhD student (FRIA) until December	CMS
Laurent THOMAS	Chargé de Recherche FNRS until December	CMS
Simona TOSCANO	Chercheuse Qualifiée FNRS	IceCube, RadNu
Max VANDEN BEMDEN	PhD student (Assistant ULB)	CMS
Catherine VANDER VELDE	Professeure de l'Université	CMS
Pascal VANLAER	Professeur	CMS
Hanwen WANG	PhD student (CSC scholarship - BUAA University)	CMS
Peng WANG	Post-doc (CSC scholarship - CCNU University) util December	JUNO
Liam WEZENBEEK	PhD student (EOS - co-PhD UGent)	CMS
Gaston WILQUET	honorary Maître de Recherche FNRS; Professeur invité	OPERA
Orazio ZAPPARRATA	PhD student (IISN)	IceCube, Auger

Master students

Daniel GOMEZ DE GRACIA	physics, since September	JUNO
Ali SAFA	physics, until June	CMS DAQ R&D
Lucas WEINBER	physics, since September	CMS
Jieren WU	physics, since September	JUNO

Engineers, Technical and Logistic Personnel

Patrick DE HARENNE	technician, general support
Benoît DENÈGRE	technician, electronics (half-time)
Denis DUTRANNOIS	computer scientist
Michael KORNTHEUER	electronics
Shkelzen RUGOVAC	computer scientist
Adriano SCODRANI	computer scientist
Audrey TERRIER	secretariat
René VANDERHAEGEN	technician, electronics
Yifan YANG	ULB electronics/computing

1.3.2 The VUB personnel (2020)

Academic and scientific personnel

Aqeel Ahmed	EOS scientific collaborator (postdoc)	PHENO
Simone Blasi	VUB scientific collaborator (postdoc)	PHENO
Freya Blekman	ZAP hoofddocent	CMS
Emil Bols	FWO scientific collaborator (PhD student)	CMS
Nordin Breugelmans	VUB scientific collaborator (PhD student)	CMS
Stijn Buitink	ZAP hoofddocent	LOFAR

Simranjit Singh Chhibra	FWO scientific collaborator (postdoc)CMS	CMS
Paul Coppin	FWO scientific collaborator (PhD student)	IceCube
Pablo Correa	FWO aspirant (PhD student)	IceCube
Arthur Corstanje	ERC scientific collaborator (postdoc)	LOFAR
Catherine De Clercq	professor emeritus	IceCube
Simon De Kockere	BAAP scientific collaborator (PhD student)	IceCube, RadNu
Martin Delcourt	VUB scientific collaborator (postdoc)	CMS
Mitja Desmet	VUB scientific collaborator (PhD student)	LOFAR
Krijn de Vries	ZAP research professor	IceCube, RadNu
Jorgen D'Hondt	ZAP hoogleraar, IIHE co-director	CMS
Hesham El Faham	Joint PhD UCL	CMS
Jörg Hörandel	guest professor	LOFAR
Tim Huege	10% ZAP research professor	LOFAR
Enrique Huesca Santiago	ERC scientific collaborator (PhD student)	Icecube, RadNu
Sam Junius	Joint PhD ULB (PhD student)	PHENO
Rijeesh Keloth	VUB scientific collaborator (postdoc)	SoLid
Godwin Komla Krampah	ERC scientific collaborator (PhD student)	LOFAR
Kumiko Kotera	10% ZAP research professor	GRAND, IceCube
Uzair Latif	VUB postdocoral researcher	ARA,RadNu, RNO-G
Steven Lowette	ZAP hoofddocent	CMS, milliQan
Vesna Lukic	postdoctoral researcher	LOFAR, RadNu
Alberto Mariotti	ZAP docent	PHENO
Yarno Merckx	VUB scientific collaborator (PhD student)	IceCube
Pragati Mitra	ERC scientific collaborator (PhD student)	LOFAR
Alexandre Morton	VUB scientific collaborator (postdoc)	CMS
Denise Muller	FWO research fellow (postdoc)	CMS
Katharine Mulrey	FWO research fellow (postdoc)	LOFAR
Seth Moortgat	FWO research fellow (postdoc)	CMS
Saereh Najjari	VUB scientific collaborator (postdoc)	PHENO
Hershal Pandya	ERC scientific collaborator (postdoc)	LOFAR
Jörg Paul Rachen	ERC scientific collaborator (postdoc)	LOFAR
Abanti Ranadhir Sahasransu	EOS scientific collaborator (PhD student)	CMS
Aaron Rase	VUB scientific collaborator (PhD student)	PHENO
Olaf Scholten	10% ZAP research professor	IceCube
Rose Stanley	ERC scientific collaborator	IceCube, RadNu
Nicolas Stylianou	Joint PhD Bristol (PhD student)	CMS
Stefaan Tavernier	Proffesor emeritus	Crystal Clear
Kevin Turbang	FWO scientific collaborator(PhD student)	PHENO
Dieder Van den Broeck	VUB scientific collaborator(PhD student)	RadNu
Walter Van Doninck	Proffesor emeritus	CMS
Nick van Eijndhoven	ZAP gewoon hoogleraar	IceCube, RadNu
Petra Van Mulders	FWO research fellow (postdoc)	CMS, SoLid

Master students

Max Lalleman	Student in Physics	PHENO
Heda Shoudoueva	Student in Physics	

Lode Vanhecke	Student in Physics

Engineers, Technical and Logistic Personnel

Olivier Devroede	Computer scientist 80%
Stéphane Gerard	Computer scientist VSC
Marleen Goeman	Management assistant
Annemie Morel	Engineer 50%
Romain Rougny	Computer scientist – UA
Rosette Vandenbroucke	Collaborator
Sophie Vandenbussche	Management assistant

1.4 The IIHE team in 2021

1.4.1 The ULB personnel (2021)

Academic and scientific personnel

Juan Antonio AGUILAR SANCHEZ	Chargé de cours	IceCube
Yannick ALLARD	Logisticien de Recherche ULB (half-time)	
Bugra BILIN	Collaborateur scientifique (FNRS) until September	CMS
Itana BUBANJA	PhD student (co-PhD University of Montenegro)	CMS
Barbara CLERBAUX	Professeure et Directrice de Recherche FNRS honoraire; IIHE co-director since October	CMS, JUNO
Marta COLOMER MOLLA	Post-doc (IISN)	JUNO
Soumya DANSANA	PhD student (IISN - co-PhD VUB) since January	CMS
Paramita DASGUPTA	Post-doc (IISN)	ARA
Jaydeep DATTA	Post-doc (IISN) since September	JUNO
Gilles DE LENTDECKER	Maître de Recherche FNRS; Maître d'Enseignement	CMS, DAQ R&D
Wendi DENG	PhD student (CSC scholarship - CNNU University) until June	CMS, DAQ R&D
Mai EL SAWY	Post-doc (Marie Curie grant) since November	CMS
Laurent FAVART	Directeur de Recherche FNRS; part-time Chargé de Cours; IIHE co-director until October	H1, CMS
Nicolas GONZALEZ	Post-doc (IISN)	Auger
Dmytro HOHOV	Post-doc (IISN)	CMS
Nadège IOVINE	PhD student (FRIA)	IceCube
Aamir IRSHAD	PhD student (IISN)	CMS DAQ R&D
Johny JARAMILLO GALLEGO	Post-doc (IISN) since February	CMS DAQ R&D
Tomas KELLO	PhD student (EOS)	CMS
Ali KHALILZADEH	PhD student (IISN)	CMS
Fakhri Alam KHAN	PhD student	CMS DAQ R&D
Kyeongpil LEE	Post-doc (IISN)	CMS
Mostafa MAHDAVIKHORRAMI	PhD student (EOS)	CMS
Inna MAKARENKO	Chargée de Recherche FNRS	CMS
Andrea MALARA	Post-doc (IISN) since December	CMS

Ioana MARIS	Chargée de Cours	IceCube, Auger
Daniela MOCKLER	Post-doc (IISN)	IceCube, Auger
Louis MOUREAUX	PhD student (FRIA) until September	CMS
Santiago PAREDES SAENZ	Post-doc (IISN)	CMS
Pierre-Alexandre PETIT-JEAN	PhD student (Assistant ULB)	JUNO
Laurent PETRE	PhD student (FRIA)	CMS DAQ R&D
Yves PIERSEAUX	Collaborateur scientifique	Hist. of Science
Nicolas POSTIAU	PhD student (Assistant ULB)	CMS
Christoph RAAB	PhD student (IISN) until June	IceCube
Giovanni RENZI	PhD student (IISN)	IceCube
Katarina SIMKOVA	PhD student (Co-PhD VUB)	Auger
Rachel SIMONI	PhD student (Amsterdam University); collaborateur scientifique	
Mauricio SUAREZ DURAN	Post-doc (IISN) since January	Auger
Laurent THOMAS	Collaborateur Scientifique FNRS	CMS
Simona TOSCANO	Chercheuse Qualifiée FNRS	IceCube, RadNu
Max VANDEN BEMDEN	PhD student (Assistant ULB)	CMS
Catherine VANDER VELDE	Professeure de l'Université	CMS
Pascal VANLAER	Professeur	CMS
Hanwen WANG	PhD student (CSC scholarship - BUAA University)	CMS
Liam WEZENBEEK	PhD student (EOS - co-PhD UGent)	CMS
Gaston WILQUET	honorary Maître de Recherche FNRS; Professeur invité	OPERA
Orazio ZAPPARRATA	PhD student (IISN)	IceCube, Auger

Master students

Damien DELATTRE	physics, since September	CMS
Daniel GOMEZ DE GRACIA	physics, until September	JUNO
Antoine MARECHAL	physics, since September	CMS
Ali SAFA	physics	CMS DAQ R&D
Lucas WEINBER	physics, until September	CMS
Jieren WU	physics, until September	JUNO

Engineers, Technical and Logistic Personnel

Patrick DE HARENNE	technician, general support
Benoît DENÈGRE	technician, electronics (half-time)
Denis DUTRANNOIS	computer scientist
Michael KORNTHEUER	electronics
Shkelzen RUGOVAC	computer scientist
Adriano SCODRANI	computer scientist
Audrey TERRIER	secretariat
René VANDERHAEGEN	technician, electronics until July (deceased)
Yifan YANG	ULB electronics/computing

1.4.2 The VUB personnel (2021)

Academic and scientific personnel

Simone Blasi	VUB scientific collaborator (postdoc)	PHENO
Freya Blekman	ZAP hoofddocent	CMS
Emil Bols	FWO scientific collaborator (PhD student)	CMS
Nordin Breugelmans	VUB scientific collaborator (PhD student)	CMS
Stijn Buitink	ZAP hoofddocent	LOFAR
Paul Coppin	FWO scientific collaborator (PhD student)	IceCube
Pablo Correa	FWO aspirant (PhD student)	IceCube
Arthur Corstanje	ERC scientific collaborator (postdoc)	LOFAR
Catherine De Clercq	professor emeritus	IceCube
Simon De Kockere	BAAP scientific collaborator (PhD student)	IceCube, RadNu
Martin Delcourt	VUB scientific collaborator (postdoc)	CMS
Mitja Desmet	VUB scientific collaborator (PhD student)	LOFAR
Krijn de Vries	ZAP research professor	IceCube, RadNu
Jorgen D'Hondt	ZAP hoogleraar, IIHE co-director	CMS
Hesham El Faham	Joint PhD UCL	CMS
Kunal Gautam	VUB scientific collaborator (PhD student)	Future colliders
Jörg Hörandel	guest professor	LOFAR
Tim Huege	10% ZAP research professor	LOFAR
Enrique Huesca Santiago	ERC scientific collaborator (PhD student)	Icecube, RadNu
Djunes Janssens	VUB scientific collaborator (PhD student)	DAQ R&D
Sam Junius	Joint PhD ULB (PhD student)	PHENO
Rijeesh Keloth	VUB scientific collaborator (postdoc)	SoLid
Godwin Komla Krampah	ERC scientific collaborator (PhD student)	LOFAR
Kumiko Kotera	10% ZAP research professor	GRAND, IceCube
Uzair Latif	VUB postdocoral researcher	ARA,RadNu, RNO-G
Steven Lowette	ZAP hoofddocent	CMS, milliQan
Vesna Lukic	postdoctoral researcher	LOFAR, RadNu
Alberto Mariotti	ZAP docent	PHENO
Yarno Merckx	VUB scientific collaborator (PhD student)	IceCube
Pragati Mitra	ERC scientific collaborator (PhD student)	LOFAR
Alexandre Morton	VUB scientific collaborator (postdoc)	CMS
Denise Muller	FWO research fellow (postdoc)	CMS
Katharine Mulrey	FWO research fellow (postdoc)	LOFAR
Seth Moortgat	FWO research fellow (postdoc)	CMS
Xander Nagels	VUB scientific collaborator (PhD student)	PHENO
Hershal Pandya	ERC scientific collaborator (postdoc)	LOFAR
Eduardo Ploerer	VUB scientific collaborator (PhD student)	Future colliders
Abanti Ranadhir Sahasransu	EOS scientific collaborator (PhD student)	CMS
Aaron Rase	VUB scientific collaborator (PhD student)	PHENO
Olaf Scholten	10% ZAP research professor	IceCube
Katarina Simkova	FWO scientific collaborator (PhD student)	AUGER
Rose Stanley	ERC scientific collaborator (PhD student)	IceCube, RadNu
Jethro Stoffels	VUB scientific collaborator	RNO-G
Nicolas Stylianou	Joint PhD Bristol (PhD student)	CMS

Stefaan Tavernier	Proffesor emeritus	Crystal Clear
Kevin Turbang	FWO scientific collaborator(PhD student)	PHENO
Dieder Van den Broeck	VUB scientific collaborator(PhD student)	RadNu
Walter Van Doninck	Proffesor emeritus	CMS
Nick van Eijndhoven	ZAP gewoon hoogleraar	IceCube, RadNu
David Vannerom	FWO research fellow (postdoc)	CMS, milliQan

Master students

Max Lalleman	Student in Physics	PHENO
Heda Shoudoueva	Student in Physics	
Lode Vanhecke	Student in Physics	

Engineers, Technical and Logistic Personnel

Olivier Devroede	Computer scientist 80%
Stéphane Gerard	Computer scientist VSC
Annemie Morel	Engineer 50%
Romain Rougny	Computer scientist – UA
Rosette Vandenbroucke	Collaborator
Sophie Vandenbussche	Management assistant

1.5 The IIHE team in 2022

1.5.1 The ULB personnel (2022)

Academic and scientific personnel

Juan Antonio AGUILAR SANCHEZ	Chargé de cours	IceCube
Yannick ALLARD	Logisticien de Recherche ULB (half-time)	
Itana BUBANJA	PhD student (co-PhD University of Montenegro)	CMS
Nhan CHAU	Post-doc (IISN) since April	IceCube
Barbara CLERBAUX	Full Professeure et Directrice de Recherche FNRS honoraire; IIHE co-director	CMS, JUNO
Marta COLOMER MOLLA	Post-doc (IISN)	JUNO
Soumya DANSANA	PhD student (IISN - co-PhD VUB)	CMS
Paramita DASGUPTA	Post-doc (IISN)	ARA
Jaydeep DATTA	Post-doc (IISN) until September	JUNO
Gilles DE LENTDECKER	Maître de Recherche FNRS; Maître d'Enseignement	CMS, DAQ R&D
Mai EL SAWY	Post-doc (Marie Curie grant) until September	CMS
Hugues EVARD	PhD student (IISN) since September	CMS
Laurent FAVART	Directeur de Recherche FNRS; part-time Chargé de Cours	H1, CMS
Feng GAO	Post-doc (IISN) since September	JUNO
Nicolas GONZALEZ	Post-doc (IISN) until December	Auger
Dmytro HOHOV	Post-doc (IISN) until December	CMS
Nadège IOVINE	PhD student (FRIA) until February	IceCube
Aamir IRSHAD	PhD student (IISN) until December	CMS DAQ R&D

Johny JARAMILLO GALLEGO	Post-doc (IISN)	CMS DAQ R&D
Indrani JAYAM	PhD student (Protherwal) since February	Proton therapy
Tomas KELLO	PhD student (EOS)	CMS
Ali KHALILZADEH	PhD student (IISN)	CMS
Fakhri Alam KHAN	PhD student	CMS DAQ R&D
Kyeongpil LEE	Post-doc (IISN)	CMS
Mostafa MAHDAVIKHORRAMI	PhD student (EOS)	CMS
Inna MAKARENKO	Chargée de Recherche FNRS until October	CMS
Andrea MALARA	Post-doc (IISN)	CMS
Ioana MARIS	Chargée de Cours	IceCube, Auger
Daniela MOCKLER	Post-doc (IISN) until January	IceCube, Auger
Santiago PAREDES SAENZ	Post-doc (IISN)	CMS
Pierre-Alexandre PETITJEAN	PhD student (Assistant ULB)	JUNO
Laurent PETRE	PhD student (FRIA)	CMS DAQ R&D
Yves PIERSEAUX	Collaborateur scientifique	Hist. of Science
Nicolas POSTIAU	PhD student (Assistant ULB) until October	CMS
Giovanni RENZI	PhD student (IISN) until December	IceCube
Felix SCHLÜTER	Post-doc (IISN) since September	IceCube, RadNu
Katarina SIMKOVA	PhD student (Co-PhD VUB)	Auger
Rachel SIMONI	PhD student (Amsterdam University); collaborateur scientifique until January	
Mauricio SUAREZ DURAN	Post-doc (IISN) until December	Auger
Laurent THOMAS	Collaborateur Scientifique FNRS and Chercheur Qualifié FNRS since October	CMS
Simona TOSCANO	Chercheuse Qualifiée FNRS	IceCube, RadNu
Max VANDEN BEMDEN	PhD student (Assistant ULB)	CMS
Catherine VANDER VELDE	Professeure de l'Université	CMS
Pascal VANLAER	Professeur	CMS
Hanwen WANG	PhD student (CSC scholarship - BUAA University)	CMS
Liam WEZENBEEK	PhD student (EOS - co-PhD UGent)	CMS
Gaston WILQUET	honorary Maître de Recherche FNRS; Professeur invité	OPERA
Orazio ZAPPARRATA	PhD student (IISN)	IceCube, Auger

Master students

Alexandre CALIKTOR	physics, since September	CMS
Damien DELATTRE	physics, until September	CMS
Théo GUIDE	physics, since September	JUNO
Mathias QUENON	physics, since September	CMS
Antoine MARECHAL	physics, until September	CMS
Danaé VALDENAIRE	physics, since September	IceCube

Engineers, Technical and Logistic Personnel

Patrick DE HARENNE	technician, general support
Benoît DENÈGRE	technician, electronics (half-time)
Denis DUTRANNOIS	computer scientist
Michael KORNTHEUER	electronics
Shkelzen RUGOVAC	computer scientist
Adriano SCODRANI	computer scientist
Audrey TERRIER	secretariat
Yifan YANG	ULB electronics/computing

1.5.2 The VUB personnel (2022)

Academic and scientific personnel

Simone Blasi	VUB scientific collaborator (postdoc)	PHENO
Freya Blekman	guest professor	CMS
Emil Bols	FWO scientific collaborator (PhD student)	CMS
Nordin Breugelmans	VUB scientific collaborator (PhD student)	CMS
Stijn Buitink	ZAP hoofddocent	LOFAR
Paul Coppin	FWO scientific collaborator (PhD student)	IceCube
Pablo Correa	FWO aspirant (PhD student)	IceCube
Arthur Corstanje	ERC scientific collaborator (postdoc)	
Catherine De Clercq	professor emeritus	IceCube
Simon De Kockere	BAAP scientific collaborator (PhD student)	IceCube, RadNu
Martin Delcourt	VUB scientific collaborator (postdoc)	CMS
Mitja Desmet	VUB scientific collaborator (PhD student)	LOFAR
Krijn de Vries	ZAP research professor	IceCube, RadNu
Jorgen D'Hondt	ZAP hoogleraar, IIHE co-director	CMS
Hannah Duval	Scientific collaborator	PHENO
Hesham El Faham	Joint PhD UCL	CMS
Felix Heyen	VUB scientific collaborator (PhD student)	CMS
Kunal Gautam	VUB scientific collaborator (PhD student)	Future colliders
Jörg Hörandel	guest professor	LOFAR
Tim Huege	10% ZAP research professor	LOFAR
Enrique Huesca Santiago	ERC scientific collaborator (PhD student)	Icecube, RadNu
Djunes Janssens	VUB scientific collaborator (PhD student)	
Sam Junius	Joint PhD ULB (PhD student)	PHENO
Rijeesh Keloth	VUB scientific collaborator (postdoc)	SoLid
Godwin Komla Krampah	ERC scientific collaborator (PhD student)	LOFAR
Kumiko Kotera	10% ZAP research professor	GRAND, Ice-Cube
Uzair Latif	VUB postdocoral researcher	ARA,RadNu, RNO-G
Steven Lowette	ZAP hoofddocent	CMS, milliQan
Vesna Lukic	postdoctoral researcher	LOFAR, RadNu
Inna Makarenko	VUB postdoctoral researcher	CMS
Alberto Mariotti	ZAP docent	PHENO
Yarno Merckx	VUB scientific collaborator (PhD student)	IceCube
Pragati Mitra	ERC scientific collaborator (PhD student)	LOFAR
Alexandre Morton	VUB scientific collaborator (postdoc)	CMS
Denise Muller	FWO research fellow (postdoc)	CMS

Katharine Mulrey	FWO research fellow (postdoc)	LOFAR
Xander Nagels	VUB scientific collaborator (PhD student)	PHENO
Hershal Pandya	ERC scientific collaborator (postdoc)	LOFAR
Eduardo Ploerer	VUB scientific collaborator (PhD student)	Future colliders
Abanti Ranadhir Sahasransu	EOS scientific collaborator (PhD student)	CMS
Alba Romero	VUB postdoctoral researcher	PHENO
Olaf Scholten	10% ZAP research professor	IceCube
Katarina Simkova	FWO scientific collaborator (PhD student)	AUGER
Rose Stanley	ERC scientific collaborator	IceCube, RadNu
Jethro Stoffels	VUB scientific collaborator	RNO-G
Nicolas Stylianou	Joint PhD Bristol (PhD student)	CMS
Stefaan Tavernier	Proffesor emeritus	Crystal Clear
Kevin Turbang	FWO scientific collaborator(PhD student)	PHENO
Dieder Van den Broeck	VUB scientific collaborator	RadNu
Walter Van Doninck	Proffesor emeritus	CMS
Nick van Eijndhoven	ZAP gewoon hoogleraar	IceCube, RadNu
David Vannerom	FWO research fellow (postdoc)	CMS, milliQan
Senne Van Putte	VUB scientific collaborator (postdoc)	
Miguel VanVlasselaer	VUB postdoctoral researcher	PHENO

Master students

Carla De Smedt	Student in Physics	
Elisa Tassan-Din	Student in Physics	LOFAR
Heda Shoudoueva	Student in Physics	
Lode Vanhecke	Student in Physics	

Engineers, Technical and Logistic Personnel

Olivier Devroede	Computer scientist 80%
Stéphane Gerard	Computer scientist VSC
Annemie Morel	Engineer 50%
Romain Rougny	Computer scientist – UA
Rosette Vandenbroucke	Collaborator
Sophie Vandenbussche	Management assistant

1.6 Associated institutes

The following members of the Particle Physics Group of Antwerp University (UA) have been working in close collaboration with the IIHE Institute:

Prof. Em. Dr. Eddi De Wolf, Prof. Dr. Pierre Van Mechelen, Prof. Dr. Nick Van Remortel, Prof. Dr. Hans Van Haevermaet, Prof. Dr. Albert De Roeck, Prof. Dr. Francesco Hautmann, Dr. Yamiel Abreu, Dr. Xavier Janssen, Dr. Aleksandra Lelek, Dr. Romain Rougny, Dr. Pieter Taels, , Dr. Simon Vercaemer, Mohamed Darwish, Davide Di Croce, Kamiel Janssens, Lissa Keersmaekers, Tomas Kello, Anoop Koushik, Kumar Kukkadapu, Pengbo Li, Maxim Pieters, Haifa Rejeb Sfar, Safura Sadeghi Barzani, Aron Mees van Kampen, Senne Van Putte, Maja Verstraeten, Ir. Wim Beaumont, Ir. Eric Roose, Sarah Van Mierlo

The following members of Antwerp university are also members of CMS:
W. Beaumont, A. De Roeck, Eddi De Wolf (emeritus), Davide di Croce, X. Janssen, Ola Lelek, Mohamed

Rashad Darwish, Haifa Rejeb Sfar, H. Van Haevermaet, T. Kello, M. Pieters, P. Van Mechelen, S. Van Putte, N. Van Remortel.

1.7 A selection of IIHE events during 2020-2022

- 18/03/2020 is the start of the confinement in Belgium due to the coronavirus disease (COVID-19) pandemic
- 18/05/2020, members attended the IIHE general meeting held online, where the IIHE news were presented, as well as the COVID regulations at ULB and VUB and the new procedure to enter the institute
- 22/06/2020 : Excellence of Science (EOS) solstice meeting (remote)
- December 2020 : the CMS center and the eurodemo room are being renovated and refurbished as a meeting room and a lecture room respectively
- 18/12/2020: IIHE annual meeting held online with the news from the directors, introduction to newcomers, highlight talks from CMS and Icecube, and a special event : all IIHE members received a IIHE cup and apron
- end of 2020 : After 46 years of service, Marleen Goeman did her last day at the IIHE. Her retirement celebration takes place at the IIHE-50 party in 2022 after the COVID time
- 08/01/2021 : IIHE new year event (online)
- From January to June 2021 every Friday at 15h : "IIHE online coffee break"
- 17/02 and 20/02/2021 : CMS masterclass (online)
- 21/02/2021 : IceCube masterclass (online)
- 01/01/2021 : Barbara Clerbaux takes over from Laurent Favart as the director of the IIHE-ULB
- 29/10/2021 : COSPA - Cosmos and Particle (Astrophysics and Astroparticle Physics in Belgium) meeting at ULB
- 16/11/2021 and 23/11/2021 : two IIHE colloquia on activities update at the institute, to re-start in-person activities at the IIHE
- 20/12/2021 : IIHE 2021 end of year event (online) : News from the institute, introduction of newcomers and special event : the IIHE picture carousel (gift at home: cookies/tea/beer/bag)
- 22/12/2021 : Excellence of Sciences (EOS) solstice meeting at ALMA
- during year 2021 : the renovated ad refurbished CMS center and the Eurodemo room have been given new names : "the Z room" and "the neutrno room" respectively
- 19-21/01/2022 : organisation of the RNO-G collaboration meeting at Brussels
- 14-20/05/2022 : organisation of the IceCube collaboration meeting at Brussels
- 01/07/2022 : Celebration of the 50th year of the IIHE (IIHE-50), party at Usquare. We celebrate also the retirement of Marleen Goeman

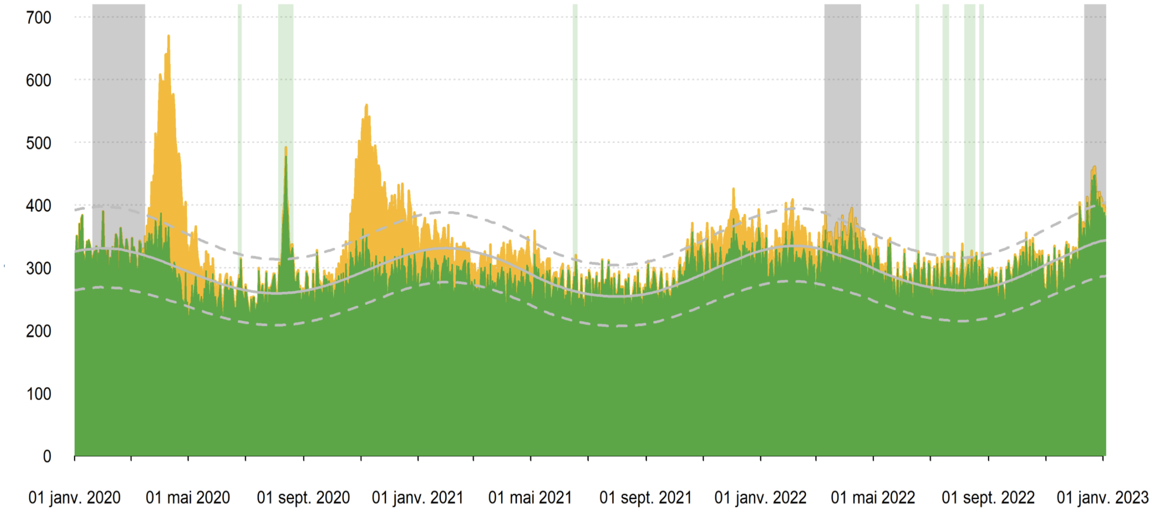

Figure 1: Evolution from January 2020 to january 2023 of the number of decease per day in Belgium, due to COVID (yellow) and due to other sources (green). The vertical light green lines indicate heat wave in Belgium and the grey bands the influenza epidemy periods.

- 14/09/2022 : Celebration of the 50th year of the IIHE (IIHE-50), Colloquium "50 years of particle physics research" at the Royal Academy.

  At the agenda, we had the pleasure to have the following presentations : Welcome from the ULB and VUB authorities Marius Gilbert and Karin Vanderkerken, the inspirational talk, the lansdape of high energy physics by Daniela Bortoletto, the birth of the institute by Daniel Bertrand, the IIHE 50 years of scientific exploration by Laurent Favart, the institute short video was projected, the word from the funding agencies by Caroline Volckaert and Véronique Halloin.

  In the afternoon we were honored to have the following scientific presentations : The CMS experiment at CERN by Luca Malgeri, the IceCube experiment at the South Pole by Francis Halzen, the instrumentation for HEP and society by Ian Shipsey, the high-energy universe by Julia Tjus Becker, the plasma accelerator : can small be the next big thing by Wim Leemans and data processing for large research infrastructures by Frédéric Hemmer. At the occasion of the IIHE-50, a booklet was prepared as well as a video presenting the scientific activities at the institute

- 01/10/2022 : Laurent Thomas started his academic permanent position as a "chercheur qualifié" FNRS at the IIHE (ULB)

- 12/12/2022 : IIHE Christmass party at the Complex (VUB)

- 21/12/2022 : Excellence of Science (EOS) solstice meeting at ULB

- During years 2020-2022 a total of 36 invited seminars was organised at the IIHE (some of them being online).

Figure 2: Party for the 50th year of the IIHE at Usquare on the 01/07/2022. We also celebrate the retirement of Marleen Goeman after 46 years of dedicated work at the institute.

Figure 3: Celebration of the 50th year of the IIHE (IIHE-50) with the colloquium "50 years of particle physics research" at the Royal Academy, on September 14, 2022.

1.8 PhD thesis defenses

- **Jarne De Clercq** (28/01/2020) The Upgraded Outer Tracker for the CMS Detector at the High Luminosity LHC, and Search for Composite Standard Model Dark Matter with CMS at the LHC (CMS - VUB)
- **Elizabeth Starling** (14/12/2020) Detection and Mitigation of Propagating Electrical Discharges Within the Gas Electron Multiplier Detectors of the CMS Muon System for the CERN HL-LHC (CMS - ULB)
- **Diego Beghin** (17/12/2020) Search for new high mass resonances or quantum black holes decaying to lepton flavor violating final states with the CMS detector" (CMS - ULB)
- **Pragati Mitra** (20/04/2021) High Precision Reconstruction of Air Shower Properties With Dense Radio Arrays (LOFAR - VUB)
- **Christophe Raab** (09/06/2021) Searches for Neutrino Emission from Blazar Flares with IceCube (IceCube - ULB)
- **Louis Moureaux** (24/09/2021) Measurement of the transverse momentum of Drell-Yan lepton pairs over a wide mass range in proton-proton collisions at 13 TeV in CMS (CMS - ULB)
- **Wendi Deng** (11/2021) Development of fast trigger algorithms on FPGA-base trigger boards for the CMS upgrades (CMS - ULB)
- **Aamir Irshad** (21/12/2021) The CMS GEM detector front-end electronics – characterization and implementation (CMS - ULB)
- **Nadège Iovine** (22/02/2022) Searches for Dark Matter in the Centre of the Milky Way with the IceCube Neutrino Telescope (IceCube - ULB)
- **Paul Coppin** (22/04/2022) Investigation of the precursor phase of gamma-ray bursts through gamma-ray and high-energy neutrino observations (IceCube VUB)
- **Emil Bols** (07/07/2022) Machine Learning For Top Quark Physics (CMS - VUB)
- **Pablo Correa** (09/09/2022) Merging Neutrino Astronomy with the Extreme Infrared Sky (IceCube - VUB)
- **Giovanni Renzi** (06/12/2022) Search for dark matter from the center of the earth with 10 years of IceCube data (iceCube - ULB)

1.9 Necrology

Over the past three years, we were deeply saddened to learn of the passing of the following colleagues:

- **Jacques Lemonne** (27/02/2020)
- **Ghislaine Coremans-Bertrand** (07/08/2020)
- **Jean Sacton** (13/02/2021)
- **René Vanderhaegen** (04/07/2021)
- **Pierre Vilain** (23/03/2022)

2 Research activities, development and support

2.1 Instrumentation

(Y. Allard, P. De Harenne, G. De Lentdecker, P. Denègre, M. Korntheuer, Y. Yang, I. Jayam)

2.1.1 Data Acquisition

Over the last decade, the IIHE became specialized in digital electronics and data acquisition system design, using the most advanced progresses from commercial FPGAs and from the telecommunication industry (xTCA). This led the IIHE to strongly contribute to the design of the electronics and the data acquisition (DAQ) systems of the CMS GEM project, the JUNO experiment and the CMS Tracker project whose the IIHE significantly contributed to the DAQ firmware and software. Besides those developments which target particular experiments, the IIHE always keeps a generic R&D activity in this domain. Namely the development of fast real time tracking algorithms and the implementation of Neural Networks on FPGAs.

2.1.2 Protontherapy

For many years, the IIHE collaborates with Ion Beam Applications S.A. (IBA), on the development of simulations and tools for the dose monitoring in protontherapy applications. Recently the IIHE has started to study the behavior of gaseous Ionization Chambers (IC) to measure with high precision the dose provided to patients for the FLASH protontherapy. FLASH protontherapy uses dose rates up to one hundred times higher than conventional protontherapy. That is several tens of Gy per second. Preliminary studies of the FLASH mode indicate a differential effect of the dose rate on the cells: cancer cells seem more sensible than healthy cells to very high dose rate. Given the harsh conditions implied by the FLASH mode, we easily understand that all the conventional monitoring devices have to be adapted. In conventional IC's the charge deposited by the proton beam is so high that electron-ion recombinations occur before the charge are separated and reach the readout electrode. This results in a loss of detection efficiency and in the alteration of the dose measurement. The IIHE is studying the various theoretical models which describe the charge recombination in ionization chambers. Confronting those models to experimental data recorded in IBA protontherapy centers we aim to identify which model fit better the data or what are their limitations and how the recombination could be corrected directly within the FPGA-based readout electronics.

2.2 The CMS experiment at the CERN LHC

(D. Beghin, F. Blekman, B. Bilin, E. Bols, N. Breugelmans, I. Bubanja, S. S. Chhibra, B. Clerbaux, S. Dansana, J. D'Hondt, G. De Lentdecker, W. Deng, H. El Faham, M. El Sawy, H. Evard, L. Favart, A. Grebenyuk, F. Heyen, A. Irshad, A. K. Kalsi, T. Kello, F.A. Khan, K. Lee, S. Lowette, M. Mahdavikhorrami, A. Malara, S. Moortgat, A. Morel, A. Morton, L. Moureaux, D. Muller, S. Paredes Saenz, L. Petré, N. Postiau, A. Popov, A.R. Sahasransu, Z. Song, E. Starling, N. Stylianou, L. Thomas, W. Van Doninck, M. Vanden Bemden, P. Van Mulders, C. Vander Velde, P. Vanlaer, D. Vannerom, H. Wang, L. Wezenbeek)

The Compact Muon Solenoid, or CMS experiment, is a general-purpose detector at the Large Hadron Collider (LHC) at CERN. Designed around the turn of the millennium, the construction of this 14000 ton instrument with various precision particle detectors was completed in 2008 to record proton collisions at the highest energies ever achieved in a laboratory. During a first multi-year LHC Run (2009-2013), the international scientific collaboration of about 5000 researchers collected data at a collision energy of 7-8 TeV, corresponding to a total integrated luminosity of about 29 fb^{-1} delivered by the machine to the experiments. The most important breakthrough in the LHC Run 1 is the observation of the last missing part of the Standard Model (SM), the H scalar boson predicted by R. Brout, F. Englert and P. Higgs. A second LHC Run (2018-2020) was successfully completed at 13 TeV collision energy with a total delivered luminosity of 162.9 fb^{-1}, while the ongoing third LHC Run started in 2022 with an energy record of 13.6 TeV. In the Long-Shutdown period between the second and third LHC Runs, numerous upgrades were made at the level of the particle detector and the LHC accelerator, some in preparation of the High-Luminosity LHC (HL-LHC) program that will begin with a fourth LHC Run from 2030 aiming to collect a tenfold of collision data compared to the initial entire LHC program. Recently confirmed in the updated European Strategy for Particle Physics, the LHC and soon the HL-LHC programs remain the European flagships in particle physics.

In the years 2020-2022, members of the IIHE have made impactful contributions to the physics analyses of the collision data and to the developments of novel detector instruments. While the discovery of the SM scalar boson is definitely the highlight of Run 1, the high-energy and high-intensity Run 2 dataset extends the phase space for discoveries. It enables physicists to study in more detail the newly-discovered scalar particle, to perform various precise SM measurements, and to search for new physics beyond the SM.

2.2.1 Study of scalar bosons

Since its discovery in 2012, the study of the SM scalar (spin-0) boson H now involves questions such as whether this particle is the only element to be added to the SM in order to give masses to the elementary particles, and questions regarding the consistency of the discovered particle with respect to SM predictions. The H boson could also interact with particles yet to be discovered, such as dark matter particles. Measurements of the properties of the SM scalar boson are thus essential. The large amount of data provided by the LHC Run 2 dataset taken in 2015-18 at 13 TeV provides a significant increase in sensitivity compared to Run 1.

Since 2018, the study of the scalar interactions in Belgium enjoyed a four-year support from the Excellence of Science (EOS) project be.h called “The H boson portal to physics beyond the standard model”, which funds several research positions and supports collaborative efforts among the Belgian research groups.

In the 2020-2022 period, IIHE members made leading contributions to the studies of the H boson studies in several important areas.

- A team contributed to the most precise measurement of the H boson lifetime, leading to a precision of 50% on this fundamental parameter, and to the long-awaited evidence for the destructive interference between different types of interaction of massive gauge bosons: the H-boson mediated interaction, and other types of interactions. These results have been published in the prestigious journal Nature Physics [1] and have been the PhD topic of three students at the IIHE. A candidate event where a pair of Z bosons is accompanied by two high-energy jets is shown in Figure 4 (left). The likelihood curve leading to the evidence for the contribution of the H-boson mediated interaction is shown Figure 4 (right).

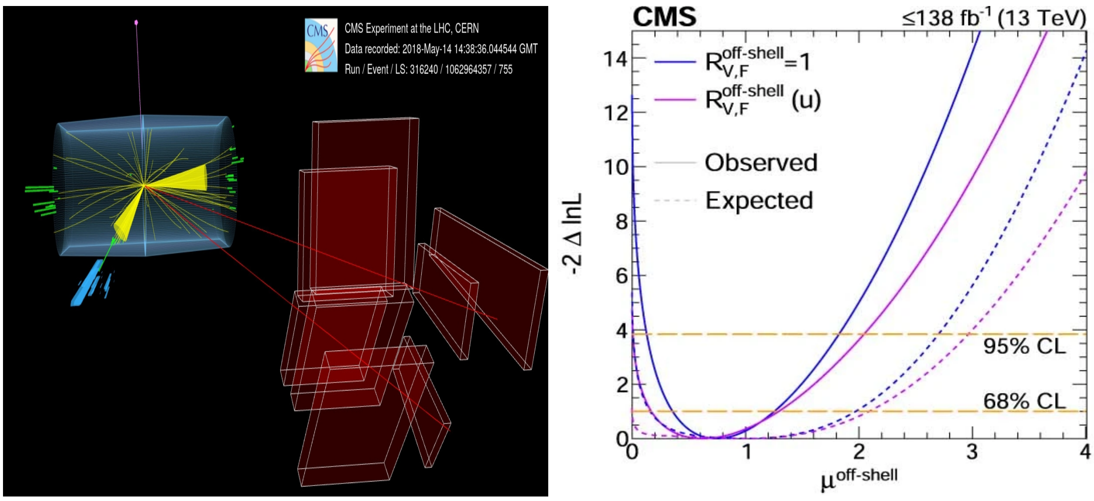

Figure 4: Left: Display of a candidate event where two Z bosons are produced accompanied with 2 high-energy jets (yellow cones). One of the Z bosons decayed into a muon-antimuon pair, and the other Z boson decayed into a neutrino-antineutrino pair detected as a momentum imbalance in the transverse plane (magenta arrow). Right: The expected and observed likelihood curves as a function of the strength of the H boson contribution to the production of a pair of Z bosons, shown respectively as dashed and full lines. The blue and magenta lines correspond to two different models tested.

- A complementary result is provided by the direct search for desintegration modes where the H boson decay products cannot be detected (so-called ”invisible decays”). In fact, when a H boson decays into such particles, it still leaves a signature into the detector, as the invisible particles escape undetected, and the laws of energy conservation seem to be violated. By exploiting such a signature combined with the production of high-energy particle jets, an upper limit of 18% on the rate of occurence of such decays was set. The results were published in Physics. Rev. D. in 2022 [2]. Laurent Thomas, who recently obtained a position as a permanent researcher, lead this analysis as a postdoctoral researcher.

References

[1] The CMS Collaboration, Measurement of the Higgs boson width and evidence of its off-shell contributions to ZZ production, arXiv:2202.06923, Nat. Phys. 18 (2022) 1329–1334

[2] The CMS Collaboration, Search for invisible decays of the Higgs boson produced via vector boson fusion in proton-proton collisions at 13 TeV, arXiv:2201.11585, Phys. Rev. D 105 (2022) 092007

2.2.2 Searches for high-mass resonances

Many scenarios beyond the SM predict the existence of new heavy resonances, with a mass around or above 1 TeV. For example, massive gravitons or new massive gauge bosons, Kaluza-Klein recurrences, are expected in the framework of extra spatial dimension models, as well as new heavy Z bosons in Grand Unified Theories. Additional scalar (spin-0) resonances are also theoretically motivated. Since the LHC startup, the IIHE team has been involved in searches for such resonances in the dilepton final state. While our initial focus was on narrow resonances decaying into a pair of light leptons (electrons, muons) of the same flavour, our search has expanded to probe broader resonances and non resonant phenomena, as well as to consider final states involving a pair of lepton of different flavours. In the past years we analyzed the Run 2 data set recorded at a proton-proton center of mass energy of 13 TeV. In the absence of deviation with respect to the SM, we set stringent limits on the production cross section times branching ratios of a variety of new physics phenomena.

- **Search for heavy resonances decaying to a lepton pair:** Since 2006, physicists from the IIHE play a leading role in this channel; they initiated the creation of the HEEP (High Energy Electron Pairs) working group and were strongly involved in every step of the Run 1 CMS data analysis at 7 TeV and 8 TeV, as well as on the Run 2 data taking and analysis (data collected in 2015-2018) at 13 TeV. The results of the analysis including the full Run 2 data set have been published in JHEP [1]. In addition to narrow width resonances, the analysis now also considers resonances of finite width, up to 10% of the resonance mass. Non-resonant signals have also been probed, exploiting the pronounced forward-backward asymmetry predicted for the leading SM background, the Drell-Yan process. The dielectron and dimuon channel results have been combined for all interpretations. For the first time, the ratio of the dielectron over dimuon production cross section have been measured up to 3 TeV. For a variety of new physics models, the constraints set by this analysis are the strongest to date.
- **Searches for new heavy resonances decaying with LFV:** A similar search for a narrow resonance as the one discussed above was conducted for a final state consisting of an electron and a muon with the 2012 data set and then a part of the Run 2 data set. This effort started in collaboration with ULB theorists who pointed out the existence of various models where decays of heavy new particles that violate lepton flavour conservation are allowed. This search was further extended to include tau-lepton and the full Run 2 data set was analyzed. The invariant mass distributions for the electron-muon channel, and the collinear mass distributions for the electron-tau and muon-tau channels are presented in Figure 5. The results were published in 2023 [2]. The analysis took in particular advantage of recent developments in the identification of hadronically decaying tau-lepton, exploiting a new multi-class deep neural network (DeepTau). Stringent limits were set on new physics parameters for different models such as those involving the production of quantum black holes or supersymmetric neutralinos.

References

[1] The CMS Collaboration, Search for resonant and nonresonant new phenomena in high-mass dilepton final states at $\sqrt{s} = 13$ TeV, arXiv:2103.02708 [hep-ex], JHEP 07 (2021) 208

[2] The CMS Collaboration, Search for heavy resonances and quantum black holes in eμ, eτ, and $\mu\tau$ final states in proton-proton collisions at $\sqrt{s} = 13$ TeV, arXiv:2205.06709 [hep-ex], JHEP 05 (2023) 227

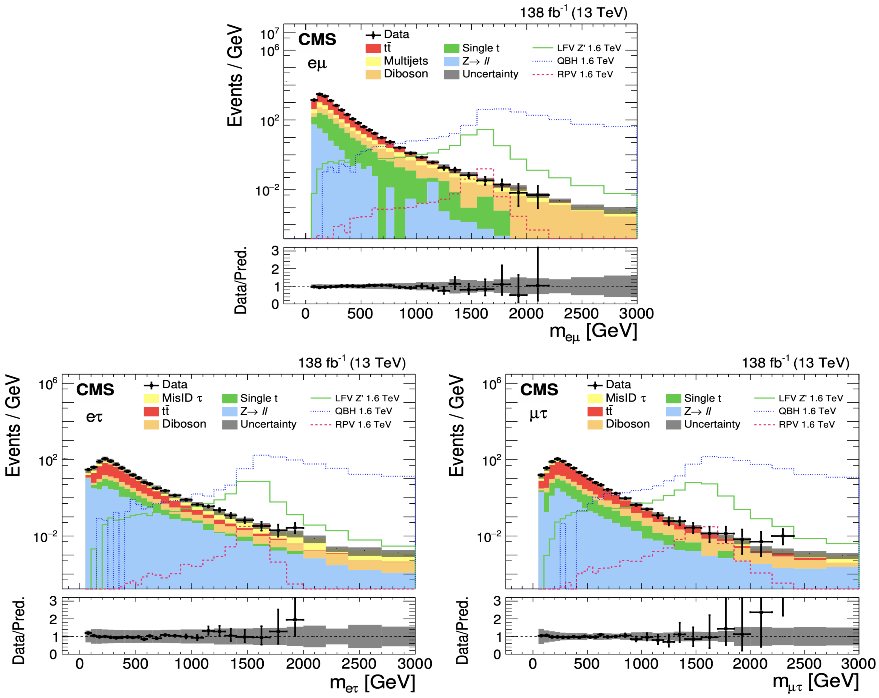

Figure 5: Invariant mass distributions for the electron-muon channel (upper), and collinear mass distributions for the electron-tau (lower left) and muon-tau (lower right) channels. In addition to the observed data (black points) and the SM prediction (filled histograms), the expected signal distributions for three models are shown: RPV SUSY model, LFV Z' boson and the QBH signal expectation.

2.2.3 Top quark and related physics

The top quark is the heaviest known particle in the SM of particle physics and therefore an intriguing object to measure precisely in the search for potential cracks in the theory. From LHC Run 1 to LHC Run 2, the increase in top quark production cross section from a collision energy of 7-8 TeV to 13 TeV along with the fivefold increase in integrated luminosity, enabled a much larger collection of collision events in which top quarks appear. In almost 100% of the cases, a top quark decays into a bottom quark and a W boson. To reconstruct a top quark, it is vital to reconstruct and identify the bottom quark in the final state of the proton-proton collision. The flavour of the quark that gave rise to the observed particle jet has emerged is identified using state of the art Deep Neural Networks (DNN) to which members of the IIHE have made leading contributions since the early days of the CMS experiment. Advanced DNN methods continue to improve the performance of bottom- and charm-jet identification. Members of the IIHE developed the first-ever charm-tagger in the CMS collaboration. In addition, members of the IIHE played a leading role in the validation, commissioning and calibration of new flavour taggers.

In a PhD thesis project, advanced DNN methods have been used to develop novel analysis methods to improve the precision at which one can measure the top quark mass, an essential parameter to verify the validity of the SM which is today dominated by systematic rather than statistical uncertainties. According to the observed variables of the collision event, events have been classified by DNN methods according to their individual contribution to the systematic uncertainty on the top quark mass measurement. For the first time, this motivated additional event selection criteria that have been shown to have the potential to drastically reduce the overall uncertainty in the measurement of the top quark mass.

In another PhD thesis project, the very first measurement of the cross section of top quark pair production with additional charm quarks was performed. The resulting cross sections have been compared to those of the production of top quarks with additional bottom quarks, and the obtained values have been interpreted in the context of an effective field theory (EFT). Based on Machine Learning techniques, a novel method was developed to improve how one can pinpoint specific EFT operators and accordingly expand the constraints for the presence of new physics.

The new LHC Run 2 dataset enabled increased sensitivity to very rare processes in proton collisions. A first glimpse of the process in which four top quarks appear has been observed. This milestone achievement unlocks the step towards a precision study of this process which has a unique sensitivity to physics beyond the SM (BSM). Members of the IIHE have contributed to various stages of this advanced analysis. One potential BSM process that can contribute to the measured cross section of four top quark production is the production of a new heavy particle X in association with a top quark pair, with X itself subsequently decaying into a top quark pair. In this ongoing project, members of the IIHE are involved.

Another ongoing project at the IIHE is the search for the rarest SM production mode of single top quarks, namely the s-channel mode. This process has not been observed so far in proton collisions, thus the full LHC Run 2 dataset is a great opportunity for finding the s-channel process and for probing this production mode for BSM physics.

Since the start of data taking with the CMS experiment, the IIHE has been prominently active in developing new heavy-flavour tagging methods, especially for the identification of b-quark and c-quark jets. During the last years the IIHE had a leading role to integrate Machine Learning algorithms in these tagging methods. Recently, the IIHE initiated the development of the first c-quark taggers and the first deep-learning networks. The impact of the latest developments is shown in Figure 6.

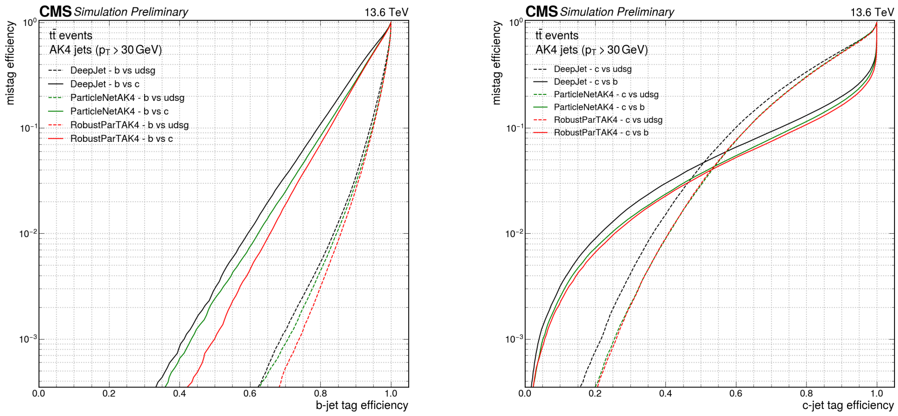

Figure 6: The performance of identifying b-quark (left) and c-quark (right) jets with machine learning algorithms for the recently started LHC Run-3 period.

2.2.4 SM precision measurements and QCD effects

Cross-section predictions for the H boson production, as well as for most studied processes at the LHC, rely on QCD (Quantum Chromodynamics) factorization, which allows the cross-section calculation to be broken down into three parts: 1) the parton distribution functions (PDFs) of quarks and gluons in the proton; 2) the calculation of matrix elements (MEs) that lead to the partonic (or hard) cross-section; 3) the QCD evolution between the proton scale (its mass, about 1 GeV) and the hard interaction scale (125 GeV in the case of the H boson). Thanks to HERA measurements, the PDFs are known with an accuracy close to 2–3%. As for the MEs, significant progress has been made over the past 10 years and they are now known up to NNLO for the most studied processes, and even NNNLO for the H boson production and the Drell-Yan process. The most limiting factor in terms of precision - because it's the least well understood - is QCD evolution and the inclusion of numerous gluon or quark radiations it implies. Monte Carlo simulations have also greatly improved. The *multileg* approach generates, at a given order in perturbation theory (LO or NLO), a process containing a given number of partons (0,1,2,. . .) in the final state. This simulation of the so-called "hard" process is complemented by "soft" radiations using an approximate method called *Parton Showers*, as well as by the hadronization of partons and soft multiple interaction processes.

The Drell-Yan (DY) process involves the annihilation of a quark and an anti-quark (from protons), producing a Z/γ^* that decays into two charged leptons (primarily using the e^+e^- and $\mu^+\mu^-$ channels), as illustrated in left panel of Figure 7. The high cross-section of this process (especially for dilepton invariant masses near the Z peak—with a dataset of several million events for CMS Run 2) and the purity of the sample (little background noise) make it a central process at the LHC. The dependence of the DY cross-section on the Z boson transverse momentum (p_T) contains much information about QCD radiation and higher-order corrections, and remains difficult to predict precisely (as is also the case for H production).

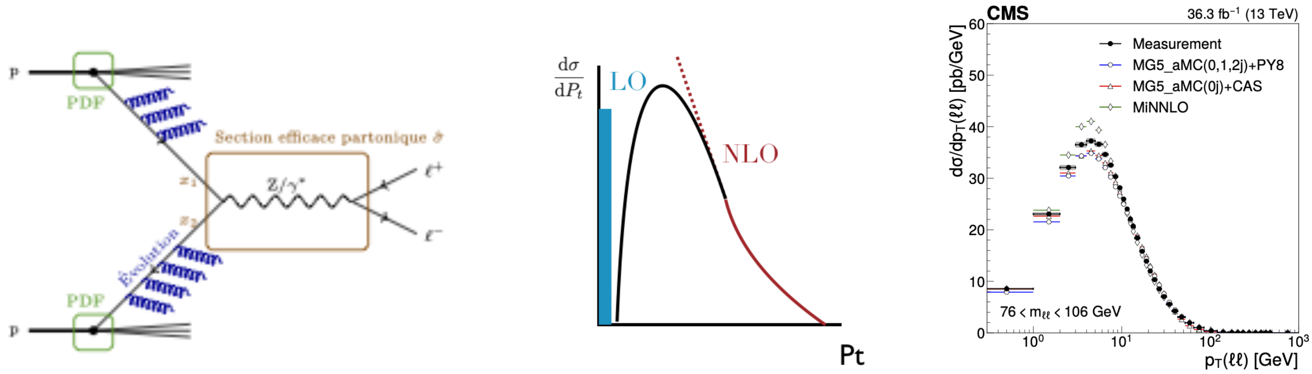

Figure 7: Left: Drell-Yan process diagram; Middle: DY transverse momentum spectrum prediction at LO and NLO (see text); Right: Measured DY transverse momentum spectrum compared to various predictions [1, 2] (see text).

A calculation using LO MEs and PDFs (evolved to the correct scale) predicts no transverse momentum at all, which is not the case in reality. At NLO, hard radiation helps describe the spectrum at high p_T, but it diverges at low values - see middle panel of Figure 7. A realistic description requires accounting for the large number of initial-state QCD radiations. There are three approaches for this: a) analytical calculations by resumming an infinite number of radiations and retaining only the leading (logarithmic) terms (LL, NLL,...); b) simulation by adding these radiations (in a factorized way) using *Parton Showers* (PS); c) using PDFs that also include information on transverse momentum generated during evolution, called *Transverse Momentum Distributions* (TMDs). In the vast majority of cases, the PS approach is used. Analytical resummation exists in some cases, like DY and H production (up to NNNLL), but it does not integrate easily into Monte Carlo simulations. The TMD approach is fairly new and extremely promising. Measuring the p_T dependence of DY allows testing, refining, and evaluating the precision of different predictions. Measuring it at different DY (dilepton pair) mass values allows variation in the "length" of QCD evolution and makes the test significantly more constraining.

The IIHE measured the DY cross-section differential in p_T using 2016 data (13 TeV, 36 fb^{-1}), for 5 invariant mass values between 50 GeV and 1 TeV [3] - see the right panel of Figure 7 for a mass between 76 and 106 GeV [1, 2]. In Figure 8 these measurements are compared to different resummation approaches for the 5 mass intervals. The left panel, showing the most common procedure based on Parton Showers, reveals a disagreement of nearly 10% at $p_T < 10$ GeV. This approach is improved by adding Sudakov Factors - see the center panel. The right panel, based on TMDs, shows the best agreement across the spectrum.

In parallel, the group started contributing to TMD development. A group from DESY, the Universities of Antwerp and Oxford developed a TMD model called *Parton Branching TMDs* (PB-TMD), which is simple and has been highly successful, being the only one to describe DY p_T distributions measured so far - from low-energy fixed-target experiments up to the LHC - without any parameter tuning. These are estimated purely from independent deep inelastic scattering data from HERA. The IIHE contributed to the development of TMD-related tools [3].

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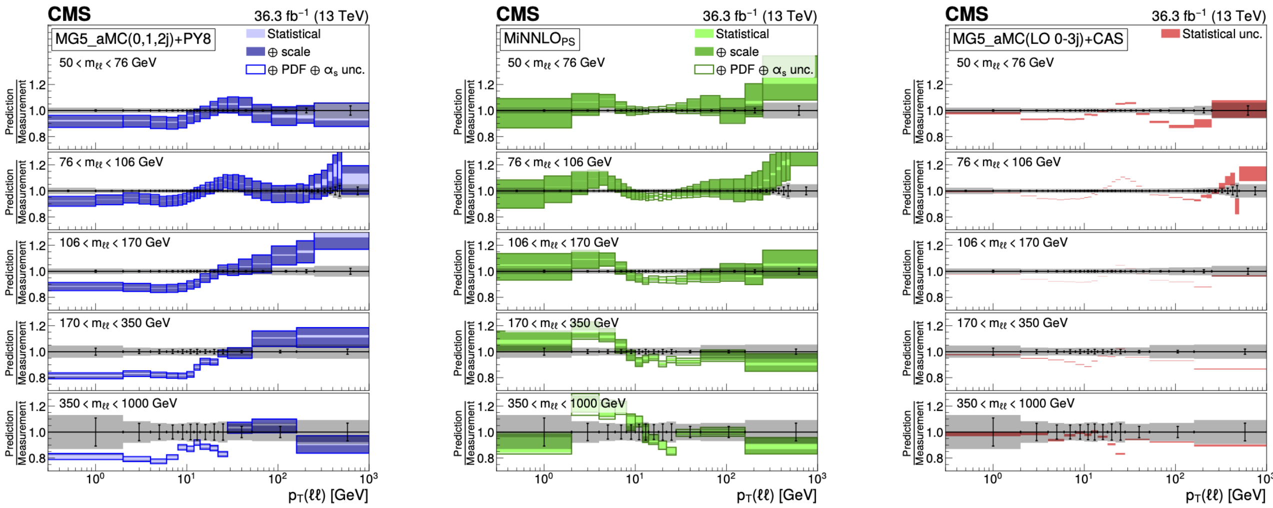

Figure 8: Left: Comparison of our measurements to different resummation approaches for the 5 mass intervals : Parton Showers (left); adding Sudakov Factors (middle); based on TMDs (right) [3].

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2.2.5 The milliQan experiment

In 2019, the VUB joined the milliQan experiment, a small experiment dedicated to the search for particles with electric charge smaller than the electron charge, as small as millicharge. The detector consists of an array of 60 cm long plastic scintillators, called bars, with a front face of 5 cm by 5 cm, read out by photomultiplier tubes (PMTs) with a good single-photoelectron sensitivity. The detector is placed in a small tunnel 33 m above the CMS detector with the bars pointing towards the CMS collision point, with 17 m of rock shielding it from the particle background produced in the collisions in CMS. Finally, the bars in the detector are arranged in four consecutive layers, where by asking for coincidence in all layers the dark rate background of the PMTs can be reduced to negligible levels.

The concept of the detector has been tested with a prototype detector during LHC Run 2, and the analysis of these preliminary data already achieved a first novel sensitivity in the phase space of Drell-Yan production of a millicharged particle, as function of its charge and mass, see Reference [1]. Based on the lessons learned, the initial detector proposal was updated, and the expected performance was projected to the LHC Run 3 and beyond, as reported in the publication from the MilliQan Collaboration [2]. In 2021, sufficient funds had finally been collected to assemble a detector for LHC Run 3, and throughout 2022 detector assembly has been ongoing first in the various institutes involved, and subsequently at CERN. IIHE joined in this construction effort, supporting an engineer at CERN and with an FWO postdoc partly dedicated to this experiment. From 2023 onwards, we now look forward to stable data taking during LHC Run 3, with a view to this new very sensitive probe for millicharged particles.

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2.3 Contributions to the CMS upgrades

In the years 2020 and beyond, CERN will further increase the LHC luminosity. In these extremely intense experimental conditions, new detector technologies are needed, to which IIHE physicists are contributing.

2.3.1 The GEM upgrade

(G. De Lentdecker, Y. Yang, J. Jaramillo, L. Petré)

In 2019 and 2020, CMS has installed 144 new Triple-GEM detectors in the most forward part of the muon spectrometer. It is the first time that long (> 1m) Triple-GEM detectors will be used at LHC. The goals of this CMS upgrade are to improve the muon reconstruction and trigger for the High Luminosity LHC (HL-LHC). As shown in Figure 9 (left), these 144 detectors are installed in the inner ring of the inner station of the muon spectrometer which counts 4 stations. This project is called GE1/1. It is the precursor of 2 additional Triple-GEM stations which will be installed later in CMS: GE2/1 in 2024 and ME0 in 2026. The IIHE participates to this project since 2011. The IIHE has mainly contributed in the design, the production, the quality control and the commissioning of the GE1/1 electronics.

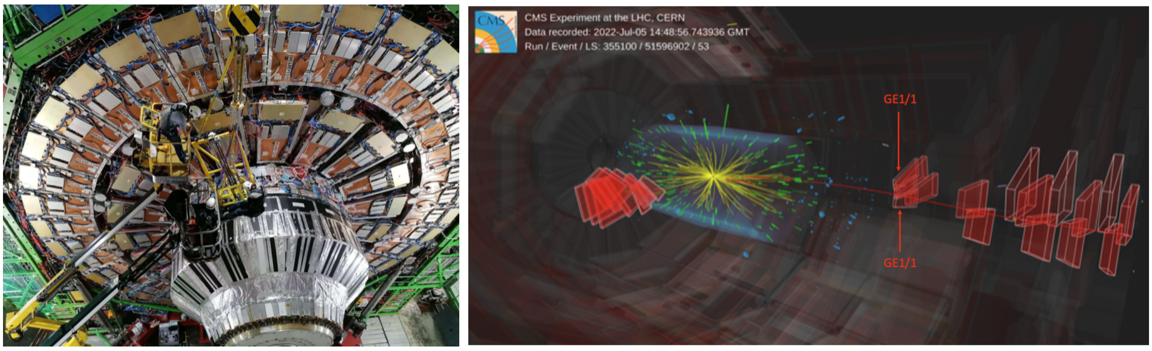

Figure 9: Left : Installation of the last GE1/1 detector in the CMS endcaps; Right : First muon from LHC Run 3 collisions, detected by the new GE1/1 detectors.

After a long commissioning, GE1/1 has recorded its first muons coming from LHC proton-proton collisions at 13 TeV on July 5th 2022. Figure 9 (right) shows a CMS event display of that day where a muon (red curve) hits several muon detectors in the GE1/1 system and afterwards in the Cathode Strip Chambers. The Collaboration is now analyzing in details the data to assert the performance of this new CMS sub-system and is preparing the upcoming installation of GE2/1.

2.3.2 The Tracker Phase-2 upgrade

(Y. Allard, W. Beaumont, J. Declercq, M. Delcourt, G. De Lentdecker, B. Denègre, L. Favart, J. D'Hondt, D. Hohov, T. Janssen, T. Kello, A. Khalilzadeh, M. Korntheuer, S. Lowette, I. Makarenko, A. Morel, D. Muller, F. Robert, E. Roose, P. Vanlaer, S. Van Putte)

From 2030 on, CERN has the goal to further increase the LHC luminosity by a factor 5-7 above the present design parameters. The aim is to allow a precise study of the scalar sector, as well as extending the discovery potential of the LHC for rare beyond-the-standard-model processes.

To meet the challenging data taking conditions at the HL-LHC, the CMS tracker must be completely replaced, for 3 reasons: first, the silicon sensors and their readout electronics must be more radiation-tolerant than those of the current tracker; second, the tracker data must be used in real time at the first level of event selection (L1 trigger) every 25 ns; and third, the tracker coverage must be extended towards the beam line (up to a pseudo-rapidity range $\eta < 4$) to optimize the potential of the experiment. The use of tracker data at L1 trigger level sets stringent requirements on the reliability of the outer tracker. The technical design report (TDR) describing the baseline technical choices for the building of the phase-2 tracker was submitted to the LHCC review committee beginning of July 2017, and approved in December 2017.

The Belgian groups from the IIHE (ULB-VUB), from Universiteit Antwerpen, the Université Catholique de Louvain-la-Neuve, and from Universiteit Gent have decided to build together one endcap of the phase-2 outer tracker. At the IIHE, 1512 modules + spares will be assembled and tested, before they are integrated onto the tracker endcap support structures. These so-called 2S modules are composed of a stack of 2 silicon strip sensors of about 10x10 cm^2 size, read out on each side by a front-end hybrid (FEH) equipped with 8 amplifier ASICs of the CBC type, with 254 channels each, a concentrator chip (CIC) and serviced by a powering and optical transceiver hybrid. The correlation of the signals from both sensors inside the CBC chips allows the measurement of the particle incident angle and therefore the suppression of signals from low-momentum particles at the L1 trigger level.

The assembly of the modules is performed in controlled conditions of temperature, humidity and dust. In 2018, a large clean room of 120 m^2 was deployed at the IIHE, with the help of the VUB technical services. At the Belgian level, regular Tracker phase-2 workshops are being held, to organise the work and to monitor the progress of the different teams. From 2020 till end 2022, seven fully-functional 2S module prototypes have been assembled and tested in Brussels. All of them meet the assembly quality criteria defined by the CMS collaboration. This success marks an important milestone for the Belgian module production line. The modules were made using final prototypes of the assembly tools and test systems, several of which are developed by the Belgian team of physicists and engineers. One of these modules can be seen in Figure 10.

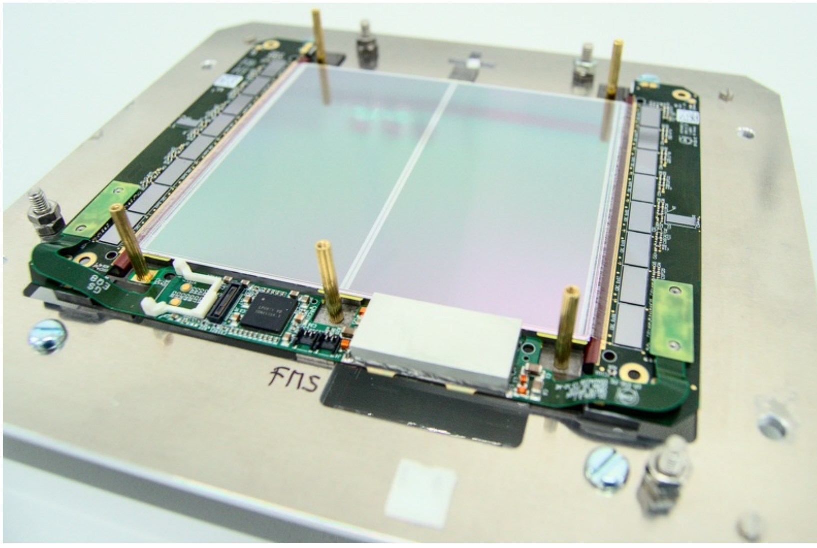

Figure 10: One of the fully-functional 2S module prototypes assembled at the IIHE by a team of Belgian physicists, resting on its aluminium carrier plate. The large shiny grey surface is the top silicon strip sensor. The strips are read out on both sides by 8 CBC binary chips and 1 CIC concentrator chip (grey rectangles), mounted on multi-layer flex printed circuit boards (green circuits). Services such as sensor bias voltage, electronics powering and optical data transfer is ensured by the circuit at the bottom of the image.

Those modules are presently being used in various integration tests (thermal cycling setup development in Brussels and UCLouvain, tracker barrel ladder integration in Strasbourg, tracker endcap dee integration in UCLouvain). Two modules were used at CERN in 2022 in beam tests common to the CMS tracker community and to the MUonE collaboration. The MUonE experiment aims for a precise measurement of the leading hadronic contribution to the muon magnetic moment, by measuring muon scattering on target electrons. The measurement of the scattering angle at high particle rate will be performed using the real-time stub data provided by modules of the CMS 2S type. The analysis of those test beam data is lead by IIHE people. Those beam tests are providing valuable information in view of the commissioning of both the MUonE and CMS trackers, and a joint paper by the CMS tracker community and the MUonE collaboration is foreseen.

In the period 2020-2022, three PhD students who had made significant contributions to the development of the tracker upgrade project in Belgium graduated, Jarne Declercq (VUB), Martin Delcourt (UCLouvain) and Senne Van Putte (Universiteit Antwerpen). Several articles have been published in peer-reviewed journals. The contribution of IIHE people can also be gauged by their responsibilities and recognition. In 2020, a postdoctoral researcher from Brussels, Inna Makarenko, received a CMS achievement award "For her crucial contributions to the Data Acquisition for the Outer Tracker, enabling critical tests for ASICs and hybrids". In 2021, Inna Makarenko was also selected as a coordinator of the Outer Tracker wire bonding task force, with the mission to validate the bonding capacity of the different assembly centers. As to the operation of the present tracker, to which the IIHE also strongly contributed, Martin Delcourt, a postdoctoral researcher from Brussels, was selected as a convener of the "SiStrip local reconstruction, simulation and calibration" subgroup of the tracker detector performance group, with an important responsibility regarding the calibration of the tracker data. At the IIHE, the CMS upgrade project is coordinated by Pascal Vanlaer.

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[6] Y. Allard et al., Development of a compact test board for silicon sensors IV/CV characterization, JINST 16 (2021) C12006

[7] CMS Tracker Group, Selection of the silicon sensor thickness for the Phase-2 upgrade of the CMS Outer Tracker, JINST 16 (2021) P11028

2.4 Future accelerators

In 2020, an update of the European Strategy for Particle Physics was endorsed by CERN Council and published. As ECFA chairperson in the period 2018-2020, J. D'Hondt has had a leading role in the process enabling this update. A clear priority for a successful completion of the LHC program was noted and for its high-luminosity program in preparation.

Despite the excellent predictive powers of the SM it is vital to realise that it is only an effective theory that will not work at substantially higher energy than the LHC. The SM also does not address a list of observed phenomena, such as dark matter and the difference between the amount of matter and antimatter in the universe. It has been noted that about all of these open questions related in one way or another to the H boson sector of the SM. The European strategy puts priority in examining the H boson sector with the greatest precision and accordingly identifies a Higgs factory as the next priority collider beyond the LHC and HL-LHC programs. An inclusive program of electron-positron (ee), electron-proton (eh) and proton-proton (hh) collisions emerged in the Future Circular Collider project at CERN.

In 2020, ECFA initiated the organisation of the Higgs Factory study enabling researchers from around the world to collaborate on specific items that have synergies between circular and linear colliders, as well as the development of the Detector R&D Roadmap which was successfully published in 2021 leading to the creation of new Detector R&D Collaborations.

IIHE member F. Blekman was involved as convener of top quark physics and made a leading contribution to the feasibility studies determining the physics and develop the detectors possible at the FCC-ee, the potential future electron-positron circular collider at CERN. The FCC-ee will run at different energies where it will produce Z bosons and top quarks and will produce more H bosons than ever before, in conditions that make them much easier to study. J. D'Hondt was assigned Spokesperson of the FCC-eh program as well as the similar program for electron-proton collisions at the LHC, namely the LHeC project which recently published an updated Conceptual Design Report, and was assigned Coordinator of the European R&D Roadmap for Energy Recovery Linacs (ERL) being one of the five accelerator technologies prioritised by the updated European Strategy. Two PhD projects are ongoing at the IIHE with the objective to develop adjacent to bottom- and charm-tagger also strange-quark tagger in the context of electron-positron Higgs factories. Using simulated collisions, the potential added value of these novel tagger is being demonstrated in specific physics analysis. In addition, the interplay between the physics performance and specific vertex detector requirements is mapped to guide the developments of novel vertex detector technologies and designs.

2.5 The SoLid experiment

(L. Kalousis, R. Keloth, P. Van Mulders, S. Vercaemer)

The SoLid collaboration unites about 45 researchers from 10 institutes in the UK, France, US and Belgium. The researchers involved in the SoLid experiment aim to search for Short baseline neutrino Oscillations with a novel Lithium-6 composite scintillator (SoLid). The highly segmented plastic scintillation detector coated with Lithium-6 is designed to provide a measurement of the rate of electron antineutrinos at very short baseline distances between 5 and 11 metres from the BR2 research reactor core in SCK-CEN at Mol. This measurement will provide confirmation or exclusion of the so-called reactor anomaly present in the ratio of the observed to predicted number of electron antineutrino events at short baseline distances.

The detector consists of PVT scintillator cubes of 5cmx5cmx5cm coated with $^6LiF : ZnS$ to detect $\bar{\nu_e}+p \rightarrow n+e^+$. The antineutrinos produced by the reactor interact with the protons of the detector material and produce a neutron and positron. The positron will quickly annihilate with one of the electrons in the detector. While the neutron will be captured by the Lithium-6 ($n +^6 Li \rightarrow^3 H + \alpha + 4.78$ MeV). The combination of the electromagnetic scintillation (ES) signal from the positron annihilation and the delayed neutron capture giving rise to nuclear scintillation (NS) allows for a clear identification of the antineutrino interaction. Fibers pass through each cube to read it out in two directions, which provides a precise localization of where the interaction happened. The light is collected at the fiber end using Multi-Pixel Photon Counters (MPPCs).

The collected data is transferred on a daily basis from the server at SCK-CEN to the computing center in Brussels. From the computing center in Brussels, the data is transferred to Imperial College in London and to the French computing centre in Lyon.

SoLid took data in two phases: Phase 1 between June 2018 and July 2020, and Phase 2 between November 2020 and August 2023, after an upgrade of its Silicon PhotoMultiplier photon sensors. The energy resolution in phase 2 is 9% at 1 MeV, compared to 12% during phase 1, with a detectable neutrino rate of order 100/day and a signal to background ratio, S/B, of order 1/3 after final IBD (Inverse Beta Decay) selection, thus yielding a final dataset of order 30.000 neutrino candidates in each data taking phase.

The collaboration has successfully completed the anti-neutrino selection process by thoroughly testing the analysis framework and simulation. Multiple stages were involved, and background processes were studied to refine the simulation. A significant background source, the so-called BiPo decay chain, which was effectively removed using a dedicated background subtraction method that discriminated between neutron and alpha candidates in the detector. Extensive background studies were conducted by Rijeesh Keloth (Vrije Universiteit Brussel) using BiPo on the Phase 1 reactor-off data to test and tune the simulation. Rijeesh's primary focus lies on the Neutrino Oscillation analysis framework where sensitivity studies are being conducted to accurately detect and measure neutrino oscillations. The study explores the impact of systematic uncertainties on the detector's oscillation sensitivity and examines the effect of the "5 MeV bump" in the anti-neutrino energy spectrum through simulations and testing with different oscillation fitting methods. Members of the IIHE have also played a part in data operational and data quality coordination to optimize processes and ensure the integrity and quality of the collected data. Rijeesh assumed the role of data transfers coordinator, overseeing the management and organization of the experiment's data to facilitate its accessibility and usability for further analysis. An updated poster on the calibration, reconstruction and simulation tuning of the detector has been presented in the Neutrino-2022 conference at Seoul, S. Korea. The final technical notes on the data quality and oscillation fit are in the collaboration review for unblinding process of the entire Phase 1 reactor-on data. The unblinding of the entire dataset is expected in 2023.

Overflowing readout channels have been an issue since Phase 1, but significantly increased in Phase 2. Simon Vercaemer (Universiteit Antwerpen) studied the impact of these dying channels, finding comparable losses of accessible cubes and reconstructed neutron signals between the two phases. Simon has effectively reproduced this effect in the simulation to match the real data.

2.6 The JUNO experiment at Jiangmen (China)

(B. Clerbaux, M. Colomer Molla, J. Datta, B. Denègre, F. Gao, D. Gomez de Gracia, T. Guide, S. Hang, P-A Petitjean, P. Wang, J. Wu, Y. Yang)

Since 2015, the IIHE is participating to the Jiangmen Underground Neutrino observatory (JUNO) experiment, based in China. The experiment uses a large liquid scintillator detector aiming at measuring antineutrinos issued from nuclear reactors at a distance of 53 km. A near detector called TAO is also forseen. The precise measurement of the antineutrino energy spectrum will allow determining the neutrino mass hierarchy (NMH) and reducing the uncertainty below 1% on solar oscillation parameters, after 6 years of data taking. The JUNO detector is also capable of observing neutrinos/antineutrinos from terrestrial and extra-terrestrial sources, including geoneutrinos, atmospheric neutrinos, solar neutrinos, supernova neutrinos, and diffuse supernova neutrino background and to search for new physics beyond the standard model, as for example sterile neutrinos. The JUNO detector is located at 700 m underground and consists of 20 ktons of liquid scintillator contained in a 35 m diameter acrylic sphere, instrumented by more than 18000 20-inch photomultiplier tubes (PMT). Two cosmic muon vetoes will be installed: a 20 ktons ultrapure water Cerenkov pool around the central detector and a muon tracker on top of the detector. The top muon veto will use the OPERA experiment target tracker, in which IIHE has been a contributor. The detector is in its construction phase, see Figure 11(left), and the start of the data taking is expected at the end of 2025.

The JUNO group activities is divided into two main area: the work related to the electronics readout system (back-end cards) and trigger system, and physics analyses performed in preparation to the data taking using simulations.

- The JUNO electronics system will have to cope with signals from 18000 large (20-inch) PMTs and 25600 small (3-inch) PMTs of the central detector as well as 2400 PMTs installed in the surrounding water pool. It consists of mainly two parts: (i) the front-end electronics system performing analog signal processing, and (ii) the back-end electronics system, sitting outside water and consisting of DAQ and trigger units for digital signal processing. Due to the large amount of connections between the front-end and back-end electronics systems and the complexity of the signal combination, the IIHE group proposed to use back-end cards (BEC) as a concentrator and a bridge between the two parts, see Figure 11(bottom). The IIHE group were responsible of the design, tests, production and deployment on site of the BECs.

  Since 2019, the team has studied an alternative JUNO global trigger using a machine learning method, specifically a small-scale multilayer perceptron neural network. This model was subsequently implemented using Verilog and was incorporated into a Kintex 7 FPGA. The preliminary results were promising and published in the IEEE Transactions on Nuclear Science [1]. In collaboration with the Nanjing University of Aeronautics and Astronautics (NUAA) in China, we developed an automatic testing system for the BEC. The details and results of this work have been published in the IEEE Transactions on Nuclear Science. In 2021, to further tap into the potential of modern neural network applications in trigger decision-making, we began to investigate the use of GPUs. In 2022, our research direction expanded to include the implementation of slow control modules based on the Azure platform.

- Since 2020, several analyses have been performed using JUNO simulation in three main domains: (1) Contribution to the Core-Collapse Supernovae (CCSN) neutrino detection studies, with a focus on the analysis of the neutrino time profile (lightcurve). This is crucial to infer information on the CCSN physics. The JUNO group at ULB is contributing to the evaluation and optimisation of the trigger performance for the case of CCSN neutrino physics, as well as the detector capabilities to constrain different CCSN parameters; (2) Contribution to the atmospheric neutrino studies, with a careful evaluation of the signal and background expectation at the detector using the latest simulation version. The goal is to use atmospheric neutrino oscillations to enhance the JUNO sensitivity to the NMH with respect to using only the information from reactor neutrinos. Work started on the event selection and the development of precise (energy and direction) reconstruction algorithms for the atmospheric neutrino energy range (1 to 10 GeV), which is different to those of reactor and supernova neutrinos, Figure 11(right); (3) Contribution to sterile neutrino studies in the context of the EOS be.h program, prospect of the search for sterile neutrinos, using the full JUNO simulation software, has been performed. The analysis selects inverse beta decay (IBD) events using both information from the positron and the neutron capture signal. The sensitivity to detect of a fourth neutrino family in the low mass square difference domain ($10^{-5} < \Delta m^2_{41} < 10^{-2}$ eV^2) has been performed.

A few key milestones for the IIHE JUNO group were: in May 2020, the final electronic and mechanical design,

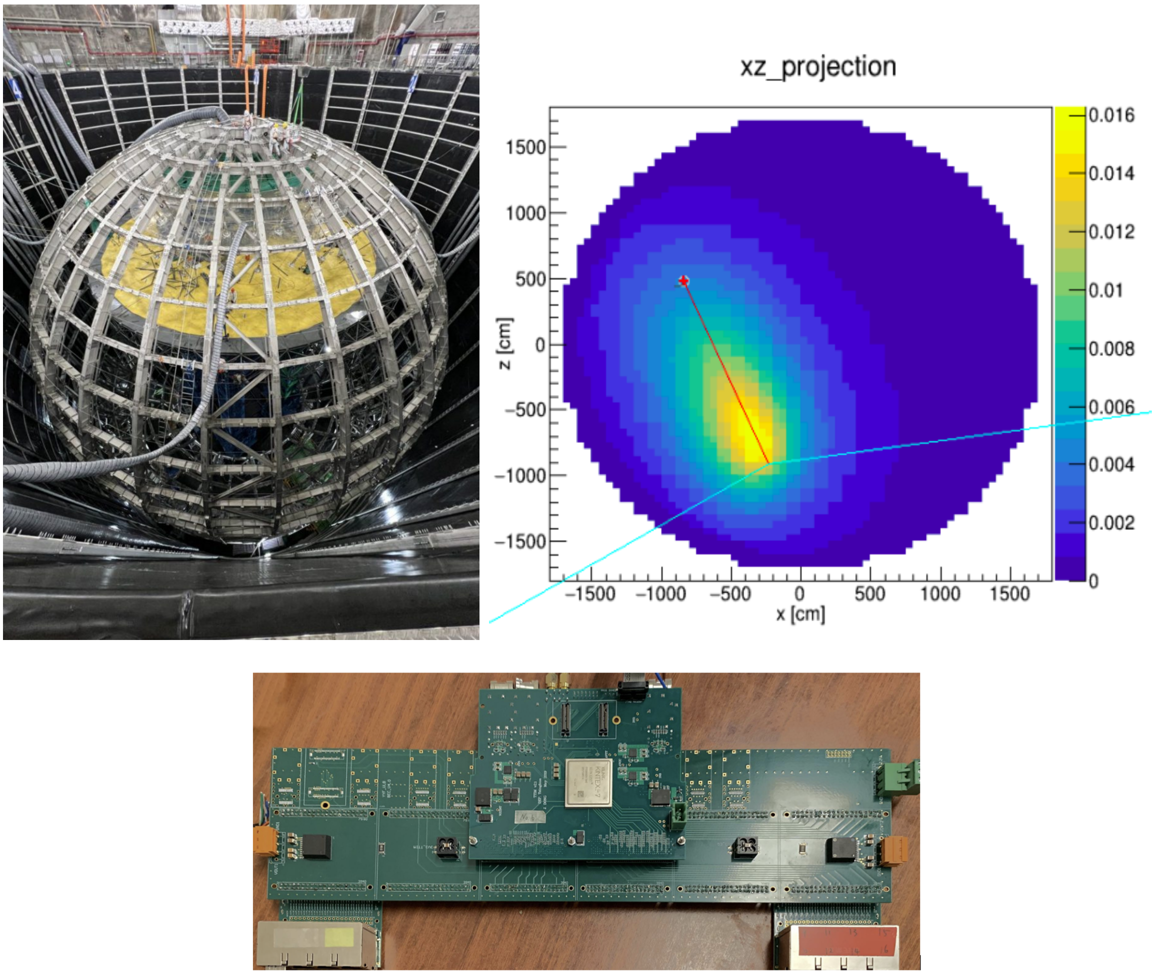

Figure 11: Left: The JUNO detector under construction (photo taken by the Belgian team on site on October 31, 2022; Right: atmospheric neutrino event reconstructed in JUNO (simulation); Bottom: the BEC v4.0 designed at the IIHE.

version 4.2, was completed. By August 2021, the production phase saw the creation of 180 base boards, 1080 mezzanine boards, and 200 BEC mechanical boxes. By the end of 2021, all electronic boards had undergone rigorous testing and assembly, followed by the successful assembly and comprehensive functional testing with the mechanical structures. In the middle of 2022, we executed joint tests with the front-end electronics at the Kunshan base. The year concluded with the transportation of all the backend electronic boxes, followed by post-transportation testing and system installation. See a selection of results on the BEC work in Refs. [2, 3, 4].

Concerning physics the main highlights have been: (i) proving that it is possible to reconstruct the energy and direction of high-energy (few GeV) events with JUNO [5]; (ii) showing the capability of JUNO to discriminate between different core-collapse supernova (CCSN) models; (iii) first comparisons of different trigger conditions and its effect in CCSN lightcurve analysis in the multi-messenger context [6]; (iv) including JUNO detector simulation into an open source widely used CCSN neutrino generator; (v) evaluating the sensitivity to sterile neutrinos of JUNO including the full electronics effects in the detector response.

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2.7 Astroparticle Physics with the IceCube Neutrino Observatory

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Astroparticle Physics revolves around phenomena that involve (astro)physics under the most extreme conditions. Black holes with masses a billion times greater than the mass of the Sun, accelerate particles to velocities close to the speed of light. The produced high-energy particles may be detected on Earth and as such provide us insight in the physical processes underlying these cataclysmic events.

Having no electrical charge and interacting only weakly with matter, neutrinos are special astronomical messengers. They can carry information from violent cosmological events at the edge of the observable Universe and point back to the sources were they are generated. Furthermore, since they are hardly hindered by intervening matter, they are the only messengers that can provide information about the central cores of cosmic accelerators like Gamma Ray Bursts (GRBs) and Active Galactic Nuclei (AGN), which are believed to be the most violent cosmic events and the sources of the most energetic Cosmic Rays. Identification of related neutrino activity would unambiguously indicate hadronic activity and as such provide clues to unravel the nature of these mysterious phenomena.

Another mystery of the Universe is the illustrious Dark Matter, which has not yet been identified but which would explain various observed phenomena. According to some models, this dark matter may consist of Weakly Interacting Massive Particles (WIMPS) which can annihilate among themselves. In these annihilation processes some of the produced particles are high-energy neutrinos. Since these WIMPS are expected to get trapped in gravitational fields, there may be large concentrations of them at the center of massive objects like the Earth, the Sun or the Galactic Center. Consequently, observation of high-energy neutrinos from these objects could provide indirect evidence for the existence of these dark matter particles.

At the IIHE, we are involved in a world wide effort to search for high-energy neutrinos originating from cosmic phenomena or from dark matter particles. For this we use the IceCube neutrino observatory at the South Pole, the world's largest neutrino telescope which has now been taking data for several years.

2.7.1 The IceCube observatory

IceCube (http://www.icecube.wisc.edu) is a neutrino telescope consisting of an array of optical sensors, located in the icecap of the South Pole at depths between 1450 and 2450 m. The sensors are arrayed on vertical cables, called strings, each of which comprises 60 sensors spaced by 17 m. In the horizontal plane, the strings are arranged in a triangular pattern such that the distance between adjacent strings is always 125 m. The overall configuration (see Figure 12 (left)) exhibits a hexagonal structure, which is the result of extensive optimization procedures based on simulation studies. At the end of 2010 the full 86-string detector, including its DeepCore extension (see here after), was completed and started taking data, representing an operational observatory with an instrumented volume of 1 km^3. Due to the geometrical configuration outlined above, the energy sensitivity for IceCube is ranging from a few hundred GeV up to several PeV.

Sensitivity to lower energies can be obtained by a smaller spacing between adjacent sensors. IceCube is equipped with a denser sub-array, called DeepCore, consisting of 8 strings arranged around the central IceCube volume with an inter-string spacing of 72 m as opposed to the 125 m standard IceCube string spacing. Each DeepCore string has 50

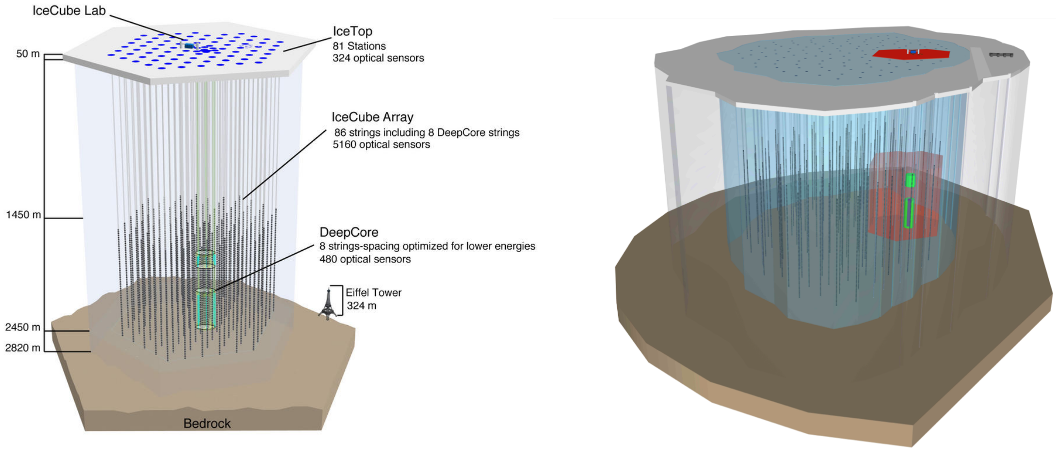

Figure 12: Left : The IceCube observatory; Right : A possible *IceCube-Gen2* configuration. IceCube, in red, and the infill subdetector DeepCore, in green, show the current configuration.

sensors at 7 m spacing covering depths between 2100 and 2450 m and 10 sensors at 10 m spacing between 1750 and 1860 m. Aside the in-ice instrumentation IceCube is also equipped with a surface cosmic-ray detector called IceTop. This surface array consists of 162 tanks of ice, each instrumented with two standard IceCube sensors, to detect showers of secondary particles generated by interactions of high-energy cosmic rays in the atmosphere.

Most of the high-energy neutrinos detected in IceCube originate from cosmic-ray particle interactions in the Earth's atmosphere. However, in 2013 IceCube detected a neutrino flux component incompatible with the atmospheric background hypothesis. This achievement was awarded the title *Breakthrough of the year 2013* by the Physics World magazine. Since then IceCube has observed more than 100 cosmic neutrino candidates of which the majority has a deposited energy > 60 TeV, which is incompatible with an atmospheric origin beyond the commonly accepted 5 sigma detection threshold. The level of observed extraterrestrial neutrino flux of 10^{-8} GeV cm^{-2} s^{-1} sr^{-1} per neutrino flavor (Science 342 (2013) 1242856) implies a much richer hadronic activity in the non-thermal Universe than previously expected. The neutrino energy density matches the one observed for photons, indicating a much larger role of protons relative to electrons than previously anticipated.

The origin of these astrophysical neutrinos is not yet known. Clustering analyses performed on the sample are thus far unable to resolve statistically significant hot spots, or areas of event accumulation beyond the expectation of an isotropic flux. However, in 2017, the observation of a gamma-ray flare from the blazar TXS 0506+056 (an active galaxy with a jet pointing at Earth) in spatial and temporal coincidence with an alert (IC170922A) of a high-energy neutrino event observed by IceCube may be the first evidence (at a 3σ level) of an extragalactic cosmic ray source (Science 361 (2018) eaat1378). Analysis of IceCube archival data also revealed enhanced neutrino activity of this same source in december 2014 (Science 361 (2018) 147), however that period did not display enhanced gamma-ray activity.

The current size of the IceCube observatory limits its ability to identify the sources of these high-energy neutrinos. For this reason expansions of the current detector are already planned. The second generation of IceCube, dubbed *IceCube-Gen2*, will be a future installation including a 10 km^3 volume expansion of detection volume of the clear Antarctic ice (Figure 12 (right)) as well as a hybrid surface scintillator/radio array for cosmic-ray detection, and an in-ice Radio Array to explore the highest energies.

IceCube has already initiated the next stage of the project with the construction of the IceCube Upgrade. The IceCube Upgrade consists of seven new strings of photosensors, densely embedded near the bottom center of the existing IceCube array. Besides the study of neutrino properties, the objectives of the IceCube Upgrade include the recalibration and re-analysis of IceCube data, as well as to serve as a platform for the R&D efforts of *IceCube-Gen2*. The installation of the IceCube Upgrade is planned for the austral summer of 2024/25 after being delayed for 2 years due to the current COVID pandemic.

2.7.2 Research areas at the IIHE

Concerning research with the IceCube Neutrino Observatory, the IIHE has been involved in the following (astro)physics topics:

- **Search for high-energy neutrinos from transient events**
  This study is aimed at the identification of high-energy neutrino production in relation with Gamma Ray Bursts, flares from Active Galactic Nuclei or any transient phenomena. The activities of the IIHE in this field are several:

  - **Stacking search for AGNs flares**
    Active Galactic Nuclei are among the main candidates for particle acceleration to the highest energies of the Cosmic Ray spectrum. They are also sources of violent transient phenomena, in particular AGN with jets pointing to us (called Blazars) exhibit a high variability in their photon flux with sudden sequences of multiple flares that may last from minutes to months. Starting in 2015 we initiated an analysis using the light-curve information from γ-rays as a time-template to search for neutrinos. The novelty of this analysis compared to previous analyses in IceCube, is that the list of AGN is also stacked in order to search for a combined signal of all selected AGN during their flaring periods. The interest in this analysis is further increased given the recent correlation of a flaring blazar with one of the high-energy neutrinos of IceCube. If flaring blazars are sources of cosmic rays, then the question arises why they have not been observed before in correlation with the cosmic neutrinos observed by IceCube. One possible answer is that this particular blazar belongs to a special sub-category of blazars, or that only a small fraction of the IceCube astrophysical flux comes indeed from flaring blazars.

  - **GRB searches**
    Gamma-ray burst (GRBs) are the most powerful outbursts of electromagnetic radiation in our universe. Apart from gamma-rays, prevailing models predict that GRBs are also sources of high-energy cosmic rays and neutrinos. Initial IceCube analyses (e.g. Nature 484 (2012) 351) were not yet been able to uncover a significant neutrino signal from GRBs and therefore constrained the allowed GRB neutrino flux. These analyses generally focussed solely on the prompt emission. However, it has been suggested that the GRB precursor phase, observed in 10% of all GRBs, is the main stage at which neutrinos are emitted. We have developped an analysis (PRD 102 (2020) 103014) to identify precursor flashes in the data from the Fermi-GBM satellite, allowing us to construct a catalog of GRB precursor events. We then developed an IceCube analysis to look for neutrinos related to these precursors, using novel techniques to improve our sensitivity compared to previous IceCube searches. Based on the results from this search, we will be able to either characterize or constrain the neutrino flux from GRB precursors.

- **Search for steady sources of neutrino emission**
  Apart from the correlation studies using timing information, we have at the IIHE also worked on an analysis searching for steady sources of neutrino emission. Here the strategy is to search for an accumulation of events in a particular direction of the sky in a way incompatible with the isotropic atmospheric background. The identification of such "hot spots" or "hot regions" on the neutrino sky would enable us to locate the sources of the most energetic cosmic ray particles.

  - **Search for neutrino emission from Dust Obscured Sources**
    Diffuse observations of Fermi-Lat and IceCube indicate that the energy budget seen in gamma rays and neutrinos is similar. Most of the diffuse gamma-ray flux originates from blazars. However, dedicated searches for neutrinos from blazars have put stringent constraints on the contribution of Fermi blazars to the diffuse neutrino flux. This tension can be resolved if the sources of the astrophysical neutrinos observed by IceCube are opaque to gamma rays, i.e. they are gamma-ray obscured. Various studies have been performed at the IIHE on the topic of gamma-ray obscured neutrino sources. During the past year, an IceCube analysis was finalized searching for neutrinos from Ultra-Luminous Infrared Galaxies (ULIRGs). With an infrared luminosity that exceeds $L_{\odot}^{12}$, ULIRGs have a vast energy budget which may serve to possibly accelerate cosmic rays, which will on their turn produce gamma-rays and neutrinos. ULIRGs are mainly powered by starbursts and can also contain an active galactic nucleus, which can both host the environments where this hadronic acceleration takes place. Moreover, the bright infrared luminosity indicates the presence of large amounts of dust, which might block the gamma-rays on their way out of the sources while enhancing the neutrino production. This makes ULIRGs ideal gamma-ray obscured neutrino source candidates. However, no neutrino emission from ULIRGs was found in the IceCube analysis, resulting in upper limits on the neutrino flux from the full ULIRG source population. A

followup study is currently being set up to model and search for the neutrino emission of the less luminous but more numerous Luminous Infrared Galaxies (LIRGs, $L_{\mathrm{IR}} \geq L_{\odot}^{11}$), which have similar properties to LIRGs. Therefore, LIRGs are also a candidate class of gamma-ray obscured neutrino sources.

- **Dark matter searches**
  In addition to astrophysical neutrino searches, IceCube has proven to be an excellent Beyond-the-Standard-Model detector producing very interesting and competitive results on dark matter searches and sterile neutrinos. At the IIHE we are also working on indirect searches of dark matter from the center of the Galaxy and the center of the Earth. If dark matter consists of (supersymmetric) particles, it is interesting to search for annihilation signals of these particles from massive celestial objects in which an excess of dark matter is expected. The products of these annihilations are standard model particles among which we can find neutrinos. The dark matter searches in IceCube focused on the search for neutrino signatures from the center of our Earth, the Sun or the Galactic Center.

  - **Dark matter from the center of the Earth**
    A renovated effort has been initiated in the search for dark matter from the center of the Earth. A search including 8 years of IceCube data is on-going. The first sensitivities were presented at the ICRC conference in July 2019. Adding energy information and optimizing the number of bins has shown improvements in the sensitivity results. A poster at the Neutrino 2020 conference with the latest sensitivities has been presented. A new likelihood (JHEP 06 (2019) 030) has been implemented to take into account the uncertainties of the data distribution. During 2022 Giovanni Renzi (PhD-ARC) finalized his analysis on the search for DM from the center of the Earth. Final results were presented at the 33rd Rencontres de Blois 2022, and a manuscript summarizing the results is under preparation.
  - **Dark matter from the Galactic Center**
    Since a high dark matter density is assumed to be present at the centre of the Milky Way, we expect a strong signal of neutrino from dark matter annihilation coming from this region. During the past couple of years, various searches for dark matter in the Galactic Centre have been conducted by IIHE members. These include the first combined search for neutrino annihilation in the Galactic Centre with the ANTARES and IceCube neutrino telescopes. For dark matter masses ranging from 50 to 1000 GeV, IceCube limits are comparable to the much smaller detector that is the ANTARES neutrino telescope. The results of this analysis have been recently published in a paper common to ANTARES and IceCube collaborations [Phys. Rev. D 102 (2020) 082002]. Two other IceCube analyses with focus on dark matter in the Galactic Centre were also conducted at the IIHE. The first of which consists of a search for neutrino from dark matter annihilation into the neutrino channel. This analysis, which was therefore optimized for the search of nu-lines, was unblinded in 2021, and the results were presented for the first time at the Dark Ghost workshop in Granada, Spain in 2022, a paper is also in preparation. The other analysis is a low energy neutrino search for dark matter annihilation in the Galactic Centre conducted with 8 years of Deep Core data. This search is focusing on dark matter masses ranging between 5 and 1000 TeV and the sensitivities show considerable improvement with respect to previous IceCube results.

- **R&D for future upgrades**
  The discovery of cosmic high-energy neutrinos has triggered feasibility studies for the extension of the existing IceCube observatory by an order of magnitude in size. This upgraded facility will increase the event rates of cosmic events from hundreds to thousands over several years making it possible to study the energy spectrum in more detail, identify the sources of astrophysical neutrinos as well as possibly the detection of cosmogenic neutrinos generated by ultra-high energy cosmic rays interactions during their travel towards the Earth. This major neutrino observatory facility has been dubbed *IceCube-Gen2*, a name that builds on the idea of a step forward in neutrino astronomy from the successful results of IceCube. In addition to the in-ice extension, the future observatory envisages as well the construction of an extension at the surface. This surface array will consist of scintillator panels in combination with radio antennas, deployed to complement the existing IceTop component to measure cosmic air showers and explore vetoing capabilities in order to reduce the large contamination of the atmospheric muon background in the Southern Sky. The facility also seeks to improve the sensitivity to neutrinos in the $10^{16} - 10^{20}$ eV energy range with the construction of an in-ice Radio Array. Because of the kilometer–scale attenuation length of radio waves in ice, a radio array that explores the coherently enhanced radio emission due to the Askaryan effect, can be built in a cost-effective way to detect neutrinos of energies of about $\sim$ 100 PeV and above.

– **Surface scintillator array and SiPM**
As part of the *IceCube-Gen2* facility a Surface Scintillator Array is being proposed. To complement c.q. improve the current technology used in IceTop, i.e. water tanks, the collaboration is exploring the possibility of using scintillator panels with a read-out consisting on SiPMs. A first phase will consist of upgrading the current IceTop detector with 37 scintillator panels. Several prototypes of these panels have been deployed at the South Pole. At the IIHE we are interested in the characterization and study of the charge response of these novel photodetector devices, the SiPMs. To this end, an optical lab has been installed at the IIHE where SiPM measurement will take place.

– **Radio Detection Techniques** The Askaryan Radio Array (ARA) is a first generation radio detector deployed at the South Pole aiming at the radio detection of cosmic neutrino interactions within the antarctic ice at about 100 PeV and above. On the other hand, IceCube is sensitive to high energy neutrinos up to several PeV, and consequently the energy region between PeV-EeV is largely unexplored. To fill this gap, novel detection techniques are being investigated at the IIHE towards a second generation radio detector, like the RNO-G array in Greenland. Further details about the radio detection of neutrino induced particle cascades can be found in a dedicated section elsewhere in this report.

2.8 Astroparticle Physics with the Pierre Auger Observatory

(S. Buitink, K. Choi, M. Suarez Duran, N. Gonzalez, I. C. Mariş, D. Mockler, K. Mulrey, K. Simkova, O. Zapparrata)

2.8.1 Ultra High Energy Cosmic Rays

Extremely energetic particles, ultra-high energy cosmic rays (UHECRs), are entering the Earth's atmosphere constantly. Cosmic rays together with gamma rays, neutrinos, and gravitational waves are part of the multi-messenger approach to investigate the highest energy phenomena in the Universe. After a century of experimental toil, the origin, the mass, and the acceleration mechanisms of cosmic ray particles to energies above 10^{20}eV still constitute one of the main puzzles of modern astrophysics. Besides the astrophysical importance, these particles provide a unique way to study fundamental physics, like testing the Lorentz invariance violation and studying particle physics interactions at the center of mass energies beyond the ones reached by man-made accelerators.

The Pierre Auger Observatory is a state-of-the-art experiment to measure UHECRs. It measures air-showers produced by cosmic rays with energies from $10^{17}eV$ to above $10^{20}eV$. The results published by the Pierre Auger collaboration have contributed significantly to the understanding of cosmic rays via the measurements of their energy distribution, their arrival directions and their mass composition. Based on the results of the Pierre Auger Observatory it is clear now that the flux of cosmic rays is suppressed above 100EeV. The composition is evolving from a light one, dominated by proton at around 3EeV to a mixture of intermediate components. The arrival directions show a dipolar structure above 8EeV, with the dipol direction pointing in a different direction than the galactic center. This is a clear proof that the UHECRs are of extragalactic origin. The results of the photon limits have excluded the topological defects and the super heavy dark matter as origin of UHECRs. The Pierre Auger collaboration has also published the measurement of the proton-air and proton-proton cross-sections at a center of mass energy of 57TeV well above the energies reached at LHC, which allows this collaboration to test fundamental interactions at energies never reached by laboratory experiments.

Even though there has been an important advance in the UHECRs physics, several questions remain unanswered. The sources of cosmic rays have not been unveiled. This is a very difficult task as during the propagation UHECRs not only lose their energy in interactions with the cosmic microwave background, but also, being charged, they are deflected by the galactic and extragalactic magnetic fields. A hint that the UHECRs follow the starburst galaxies distribution ($\approx 4\sigma$) exists, but more statistics and a separation of the light component is required to be able to make a further step in this inquiry.

2.8.2 Research areas at IIHE

The IIHE has joined the Pierre Auger collaboration in February 2017 and in 2019 Belgium became a full membership country with two institutes VUB and ULB. The research is focused on the data analysis with a final goal to perform mass-enhanced anisotropy studies. A previous work on the energy spectrum of the UHERCs is also continued, with a focus on the comparison with the Telescope Array measurements.

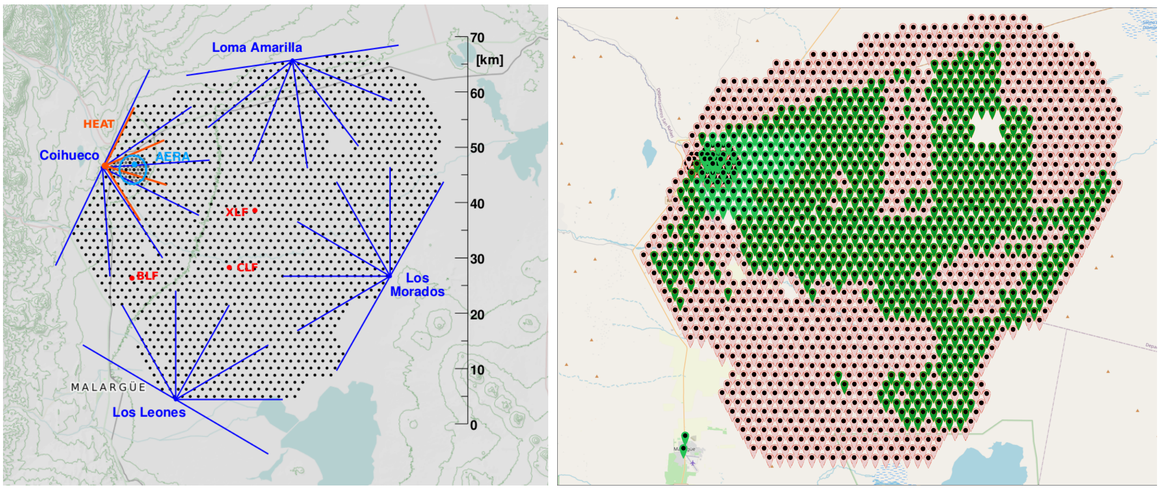

Figure 13: (left) The layout of the Pierre Auger Observatory. Each dot represents a surface detector, blue and red lines represent the field of view of the fluorescence telescopes. The red dots show the location of the atmosphere monitoring instruments. (right) The status of the deployment of *AugerPrime* in December 2019, green markers represent the stations equipped with a scintillator.

The Pierre Auger Observatory exploits the phenomenon of extensive air-showers. Upon entering the atmosphere, a cosmic ray interacts with air nuclei and generates a cascade of secondary particles, a so called air-shower. The Observatory is built as a hybrid detector, utilizing three complementary techniques to measure air-showers: the observation of the fluorescence signal produced by the secondary particles in the atmosphere, the measurement of a sample of the particles that reach the ground and the measurement of the radio emission. The layout of the detector is illustrated in Figure 13(left). The distribution of particles on the ground is measured with 1664 water-Cherenkov detectors placed on a triangular grid over a surface of 3000km^2 (SD) with a spacing of 1500m between the detectors. The longitudinal development of the air-showers is observed with 24 fluorescence telescopes (FD) placed on the border of the array. The Observatory was completed in 2008 and has since undergone some enhancements: an SD infill array with reduced detector spacing, a high elevation telescope (HEAT), buried scintillators (AMIGA) and a radio array (AERA). This allowed for extending the measurements of air-showers down to cosmic ray energies of less than $10^{17}eV$ with multiple techniques.

The Observatory is currently undergoing the upgrade to *AugerPrime* to improve the composition sensitivity at the highest energies. A big part of the upgrade is the deployment of plastic scintillators on top of the surface detectors, assembling the so called Surface Scintillator Detector (SSD). The deployment has started in 2019 and there are currently 726 scintillators deployed (60%), as shown in Figure 13(right). This upgrade aims at improving the capabilities of the surface detector to separate the muonic and electromagnetic components of the air-showers and thus to have a better resolution on mass sensitive variables.

Currently, the FD measurements provide a good sensitivity to the mass composition studies. However, as the FD operation is limited to moonless nights, the FD duty cycle is about 10%, and thus it cannot provide the statistics needed at the highest energies. The surface detector has a duty cycle of 100% and increasing its composition resolution will benefit the statistics at the highest energies. While upgrading the SD with scintillator detectors, the readout electronics of each SD detector is updated at the same time. With these upgrades, the Observatory is currently planning on running until 2030.

- **Long term performance of the Observatory** With an expected lifetime of the Observatory until 2030, the possible ageing and/or degradation of the surface detectors might influence the quality of data. I.C.Mariş is the task leader of the long term performance studies and the IIHE group, mostly Koun Choi and Orazio Zapparrata, have had a significant contribution to assess the evolution of the detector and predict the possible long-term effects on data quality. Two internal Auger notes have been written in the group related to the ageing of the detector. The studies related to the time evolution of the area over the peak of the signals showed that even if the average signal shape changes, this change will not affect too much the functioning of the surface detector. On the other hand, if the time distributions of the signals are exploited in the analysis, the systematic uncertainties might be significant. The latter is currently investigated. The results of the first study have been presented at the ICRC by Koun Choi for the Pierre Auger collaboration. This work has also been discussed in presentations at three collaboration meetings.

- **Towards the mass composition of UHECRs and AugerPrime** The AugerPrime scintillator data are currently taken using the old electronics. New electronics are being developed and Ioana Mariç was one of the members of the committee for the critical design review, being involved thus in the evaluation of the new FPGA boards. The new electronics are now in production phase and will be installed in the field within the next year. The IIHE has also been involved in the construction of the scintillators and two technicians from IIHE have been working for one month at the production site from the University of Grenoble. Almost all the SSDs have been produced and tested (90%) with about 60% of them installed in la Pampas Amarilla. The Observatory has already been taking data with these SSD and a first look at data and simulations is possible. A large effort within the collaboration is to develop methods that use deep neural networks (DNNs) to determine the mass composition of the cosmic rays. The training of the networks is based on ideal simulations that do not take into account the time evolution of the array. In this case, as the DNNs are fed with the time distribution of the signals in detectors, they might be sensitive to the ageing of the detectors. For the quatification of this effect Orazio Zapparrata is implementing as a novelty in Auger time-dependent simulations. The use of DNNs will provide a very good resolution on the determination of the mass composition of cosmic rays and the muon number in air-showers. This is the main research direction of the group.
- **Mass enhanced full sky anisotropies** The second line of research at IIHE comprises of combining the measurements of the Telescope Array and the Pierre Auger Observatory with the aim at an analysis of the anisotropy with a full sky coverage. This work is done in collaboration with Peter Tinyakov (ULB), member of the Telescope Array collaboration. The energy spectra of the two experiments are very important for setting the relative energy scale of the two experiments which plays a crucial role. The group at IIHE consists of experts on the determination of the energy spectrum of Auger and the comparison of the energy scales. Daniela Mockler and Ioana Mariş were involved in the analysis for the two energy spectra papers which are just being submitted by the collaboration. Moreover, based also on her previous expertise, Daniela presented at the ICRC the performance of the data reconstruction which is highly related to the energy spectrum. The spectra from the two experiments show a different flux shape at the highest energies. The group has been involved in understanding the differences between the two experiments: is it due to the observation of different parts of the sky or is it an experimental effect? The results are not conclusive by now, and the analysis is ongoing. Koun Choi started the analysis to assess the increase in sensitivity for the large scale anisotropies dipole by using a combined sky as well as the effect of including the mass composition information.
- **Radio detection of air-showers** The VUB Auger group, Stijn Buitink and Katie Mulrey, is involved in the radio detection of air-showers and has two principal aims. The first is the cross-calibration of the energy scales between different experiments, which can be achieved using radio measurements of the radiation energy in an air shower. To this end, a paper is being prepared that compares the energy scales of LOFAR and Auger. A portable radio array is also being developed that will measure air showers at Auger and other sites, to make direct comparisons of the energy scales with low systematic uncertainties. The second aim is to participate in the deployment of the radio upgrade within AugerPrime. The radio emission is produced by the electromagnetic part of the air-showers and thus will help in the separation of the muonic and electromagnetic components of air-showers and as a result increase the resolution of mass sensitive parameters.

2.9 Radio observations of air showers with LOFAR and the SKA

(S. Buitink, A. Corstanje, M. Desmet, J. Hörandel, T. Huege, G. Krampah, V. Lukic, P. Mitra, K. Mulrey, H. Pandya, J. Rachen)

The LOFAR Cosmic Ray Key Science Project is an international team of researchers, that uses the LOFAR radio telescope for the detection of extended air showers. LOFAR has played a crucial role in the development of the radio detection technique, demonstrating that it can be used to determine the energy and the atmospheric depth of the shower maximum (Xmax) with a similar precision as other state-of-the-art techniques, most notably fluorescence detection. Since LOFAR is designed as an astronomical observatory, its antenna density is much higher than that of dedicated cosmic-ray experiments, offering unique opportunities for detailed verification of simulation predictions and high-resolution reconstruction of air shower properties. Plans to use the same approach on the Square Kilometre

Array (SKA), for which construction will soon start, are now in an advanced stage. The VUB team plays a leading role in the hardware construction, software development and data analysis for the LOFAR cosmic-ray research, as well as development of the science case for observations with the SKA. Here we list some recent highlights of the results from IIHE researchers.

2.9.1 The cosmic-ray energy scale

Cosmic-ray research is one of the few science cases in LOFAR that uses the raw antenna voltages at the original sampling rate rather than integrated quantities. Most calibration approaches used for other LOFAR observations are therefore not applicable to air shower measurements. We developed a new technique that uses the Galactic background emission as a calibration source. Energy reconstructions based on this new technique agree well with the previously used energy estimates from the LORA particle detector array but are more precise. Moreover, we demonstrated how radiation energy can be used to compare the energy scales of different experiments. The radiation energy scales quadratically with the electromagnetic energy in an air shower, which can in turn be related to the energy of the primary particle. Once the local magnetic field is accounted for, the radiation energy allows for a direct comparison between the LORA particle-based energy scale and that of the Pierre Auger Observatory. They are shown to agree to within 6% for a radiation energy of 1 MeV, where the uncertainty on the comparison is dominated by the antenna calibrations of each experiment [1].

2.9.2 Mass composition of cosmic rays

To determine the origin and acceleration mechanisms of cosmic rays it is crucial to measure their mass composition. While the mass of the primary cosmic-ray cannot be directly determined from reconstruction of the air shower that it initiates, it is possible to statistically study the mass composition by observing the atmospheric depth at which the shower reaches its maximum, called Xmax. Protons and light nuclei on average penetrate deeper into the atmosphere than heavy nuclei. LOFAR was the first observatory to publish high-resolution mass composition results based on radio observations. Our 2021 publication on the mass composition [2] incorporates many improvements in the calibration, simulation, reconstruction and statistical techniques, and constitutes our most advanced analysis to date (see Figure 14).

2.9.3 Influence of the atmospheric variations

One of the main sources of systematic uncertainties in the reconstruction of air shower parameters is the variation of atmospheric conditions. For radio detection, the most important aspect is the atmospheric refractivity profile. To obtain more accurate results, we developed a simulation approach in which we compile event-specific atmospheric profiles for observed air showers using the GDAS weather database. These profiles are read in by the CORSIKA and CoREAS simulation codes to generate dedicated simulation sets for each measured shower, greatly reducing our systematic uncertainties. The GDAStools code that constructs atmospheric profiles and prepares corresponding CORSIKA steering files was developed at the IIHE and is now publicly available and widely used [3].

2.9.4 Preparing for the SKA

The low-frequency segment of the Square Kilometre Array in Australia will consist of nearly sixty thousand antennas concentrated in an area of roughly a km^2. It offers unique possibilities for high-resolution observations of air showers. Compared to LOFAR, it will have a much more homogeneous ground coverage, an increased frequency bandwidth (50-350 MHz), and the possibility to continuously observe with nearly 100% duty cycle.

The VUB group is one of the founding members of the SKA High Energy Cosmic Particle Science Working Group in which we tackle the technical challenges of preparing the SKA for air shower observations, and explore the science case. A prototype particle detector was successfully deployed and the design is enhanced further to adhere to the strict low-noise requirements of the SKA site.

The SKA will observe air showers in the range 10^{16} eV - 10^{18} eV with a reconstruction resolution on Xmax below 10 g/cm^2. This allows for a high-precision study of mass composition in the energy regime where a transition is expected from Galactic to extragalactic origin. In addition, SKA will be able to put constraints on hadronic interaction models, which is crucial for interpreting the data in this complex energy range [4].

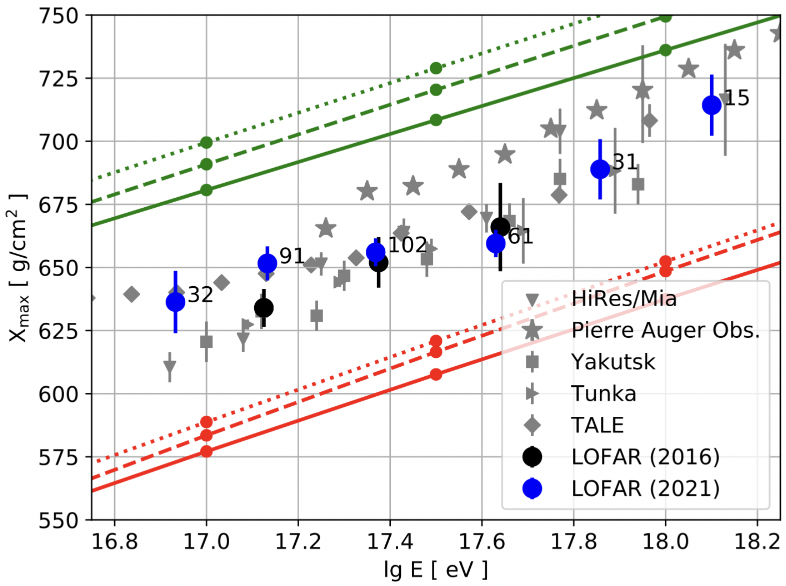

Figure 14: The average depth of shower maximum Xmax, as a function of primary particle energy. The annotated numbers indicate the number of showers in each bin, and the error margins indicate the uncertainty on the mean of the Xmax distribution. The upper lines indicate the mean values expected for protons, from simulations with QGSJetII-04 (solid), EPOS-LHC (dashed) and Sibyll-2.3d (dotted). The lower lines show the mean predicted values for iron nuclei.

2.9.5 Template Synthesis

Current state-of-the-art simulation techniques give very accurate predictions of the radio emission from air showers but require heavy computational resources: a single shower simulation will run for days on typical computer cluster hardware. With the increased data rate and antenna density of the SKA it has become crucial to develop faster simulation techniques. Template Synthesis is an approach to simulation based on applying fast rescaling to fully simulated showers to obtain the radio emission from showers with a user-defined longitudinal development. To achieve high-accuracy is it necessary to divide showers into thin slices of 5 g/cm^2, and apply scaling relations on each slice separately. The method was first implemented for a limited geometry of strictly vertical showers, yielding an excellent accuracy with errors on the pulse amplitude below 5% [5]. The method will be generalized further to allow for other geometries.

2.9.6 NuMoon: a search for ultra-high-energy cosmic rays and neutrinos

When ultra-high-energy (UHE) cosmic rays or neutrinos hit the Moon they produce a cascade just below the surface. These cascades produce radio emission through the Askaryan effect which can - under favorable geometries - escape from the Moon and be observed with radio telescopes on Earth. Even with the most sensitive telescopes the energy threshold is rather high (around 10^{20} - 10^{21} eV), making the technique interesting for a study of the end of the cosmic-ray spectrum and a search for UHE neutrinos produced in top-down scenarios like superheavy dark matter or cosmological defects. We have developed a simulation code to trace the radio emission through the Moon (including surface effects) to calculate the sensitivity of LOFAR [6].

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[2] A. Corstanje et al., Depth of shower maximum and mass composition of cosmic rays from 50 PeV to 2 EeV measured with the LOFAR radio telescope, arXiv:2103.12549, Phys.Rev.D 103 (2021) 10, 102006

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2.10 Radio and radar detection of cosmic particles

Radio/radar-based experiments aim to detect cosmic neutrinos at previously unexplored energy levels, beyond the flux observed by IceCube. Although primarily designed for neutrino detection, these experiments are also capable of detecting particle showers generated in the ice by cosmic rays. The detection of these particles serves as both a proof of concept for the radio/radar detection technique and an invaluable source of calibration. In this section, we summarize our efforts in building and commissioning novel detectors, as well as in developing simulation and analysis tools.

2.10.1 The Radio Neutrino Observatory in Greenland

(N. van Eijndhoven, S. Toscano, K. de Vries, J. A. Aguilar, S. Buitink, O. Scholten, T. Huege, K. Mulrey, S. de Kockere, P. Dasgupta, M. Vilarino Fostier, D. van den Broeck, J. Stoffels)

The Radio Neutrino Observatory - Greenland (RNO-G) is currently under construction at Summit Station in Greenland. RNO-G is a next-generation radio neutrino detector aiming at the detection of astrophysical and cosmogenic neutrino flux at energies beyond the reach of IceCube. The full detector will comprise 35 stations spaced along a regular grid within a distance of 1.25 km, observing nearly independent volumes of ice. Due to its geographical location, RNO-G will have a larger sky coverage compared to a detector located at the South Pole and it is complementary to IceCube in terms of field-of-view, making a strong case for "multi-energy" observations of neutrinos from transient sources. The recently formed RNO-G collaboration includes Belgium (with major funds through the FWO IRI program and from FNRS through the IISN convention 4.4502.20), Germany, Sweden and US, namely UChicago, UW-Madison, OSU and PennState. Figure 15 shows the layout for one RNO-G station: the main string, called the power string has been equipped with a phased-array of 4 VPol antennas, to lower the trigger threshold down to a few tens of PeV, similar to what is done in ARA. Additional antennas on the power string are used for neutrino vertex reconstruction. The other two support strings include antennas of both vertical and horizontal polarization to help with direction and energy reconstruction of the incoming neutrinos. Each RNO-G station includes a surface component with 9 Log-Periodic Dipole Antennas (LPDAs), out of which three are upward-facing for cosmic-ray detection and veto. Autonomous power and wireless communication have been chosen to simplify logistics. Each station is powered by two solar panels, with a total maximum power output of 300 W, and a 5 kWh sealed lead-acid battery bank that provides three days of full-system (24 W) running capacity during cloudy or inclement conditions. The total science uptime is expected to be $\sim$70% averaged over the full year.

Initially planned for Summer 2020, deployment was delayed due to COVID restrictions. During the first deployment season in 2021, the RNO-G collaboration successfully installed three stations. In the 2022 season, an additional four stations were deployed, bringing the total number of stations currently online and taking data to seven.

People involved in field work:

- 2021: U. Latif (drill team), K. Murlay (science team)
- 2022: P. Dasgupta (science team)

[1] J. A. Aguilar et al. (RNO-G Collaboration), Design and Sensitivity of the Radio Neutrino Observatory in Greenland (RNO-G), JINST 16 P03025 2021

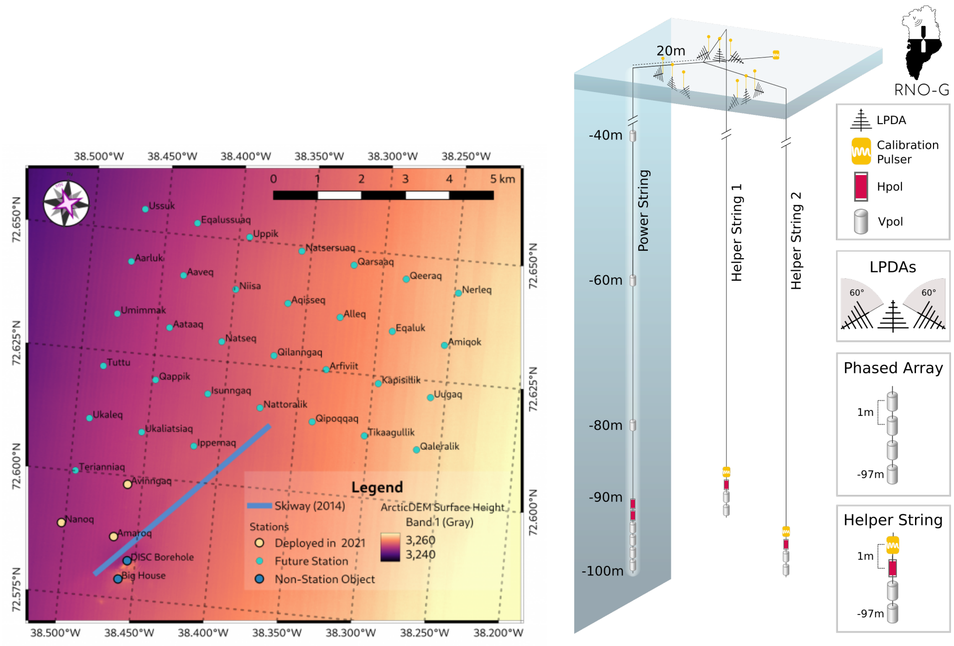

Figure 15: *Left*: Map of the planned RNO-G array at Summit Station; yellow points indicate the three stations deployed in 2021. *Right*: A single RNO-G station consists of three strings of antennas (Hpol and Vpol) plus surface antennas (LPDAs), as well as three calibration pulsers located both deep in the ice and also at the surface.

2.10.1.1 First reconstruction of the local calibration pulser in RNO-G Station 22

A relative timing calibration between antennas of the $\mathcal{O}ns$, and a geometrical location accuracy of $\mathcal{O}10cm$ are required to achieve a precise vertex reconstruction, which is essential for neutrino identification and astrophysical research. RNO-G station calibration is currently being discussed within the collaboration. A calibration working group has been created with the goal of providing a general calibration procedure for all stations. Our group is currently working on a first step towards the antenna calibration, aiming at the estimation of the surveyed position uncertainties using the local calibration pulser of Station 21 (Amaroq). We reconstruct the pulser location using the arrival time in pair of antennas and compare with the expectation from radio signal propagation in ice. Out results show that the reconstruction resolution ($\Delta\phi \sim 0.1°$, $\Delta\theta \sim 0.3°$) is better in the azimuth direction, due to a smaller lever arm in the zenith direction, as well as the fact that variations of the index of refractions are dominant in the z-direction. Moreover our analysis shows that a systematic shift is present. This can hint to an error in antenna positions or incorrect model of the index of refraction. Work to establish the origin of this systematic uncertainty and quantification of the position uncertainties is on-going.

2.10.2 The Askaryan Radio Array

(N. van Eijndhoven, S. Toscano, K. de Vries, P. Dasgupta, S. de Kockere, U. Latif)

The Askaryan Radio Array (ARA) is a radio neutrino detector located a few kilometers grid-west of the geographic South Pole in Antarctica, next to the IceCube experiment. Its main goal is the detection of ultra-high energy (UHE) neutrinos based on the Askaryan emission from neutrino-induced particle showers. Figure 16 shows the layout of the ARA detector, consisting of 5 independent stations, with a 2 km spacing, each equipped with a total of 16 antennas detecting vertically- and horizontally- polarized radiation, VPol and HPol respectively. Antennas are sensitive to radiation in the 150-850 MHz band and they are deployed at the bottom of 200 m depth holes in four strings. Two calibration strings deployed about 40 m away from the center of the station are used to perform "in-situ" calibration of the station geometry and timing.

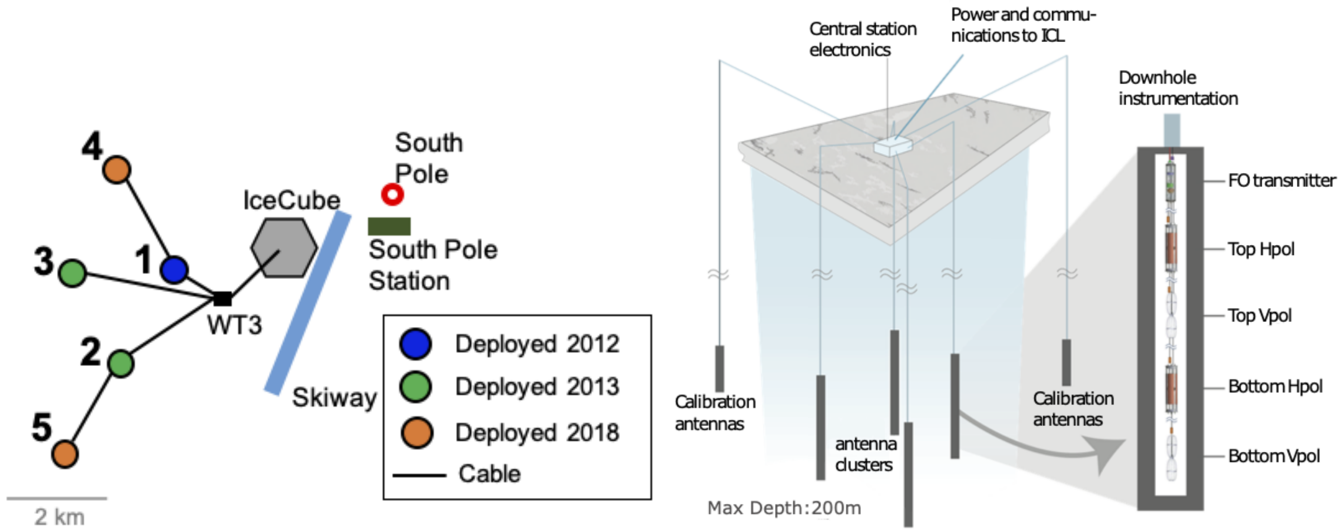

Figure 16: *Left*: Layout of the ARA5 array, showing the positions and the year of deployment for each station as well as local landmarks. Stations are cabled to the IceCube Counting Laboratory (ICL) for power and network. *Right*: Schematic of an ARA station, showing the layout of the downhole instrumentation.

2.10.2.1 Timing and antenna positioning of the ARA4 station

Signals received at the antennas are processed and sent to the surface through fibers. Once the signal arrives at the surface it is stored in the circular buffer of a custom integrated circuit, the IceRaySampler 2 (IRS2) chip, with a sampling speed tuned to 3.2 GS/s, allowing for a buffering capability of up to 10 μs. In the IRS2 chip data are sampled through a Switched Capacitor Array (SCA). The SCA consists of 128 sampling capacitors per channel, equally divided into even and odd samples on two delay lines and each with a delay element requiring individual calibration in timing. In addition to that, the ADC-to-voltage conversion gain needs to be determined for each of the 32768 buffer elements on each channel to obtain a proper voltage calibration. Calibration of the digitizer is performed using pre-deployment sine waveforms, fed directly into the system. The obtained time resolution is of the $\mathcal{O}100ps$.
In addition to that, a precise calibration of the antenna positions, is crucial to exploit ARA capabilities of reconstructing the interaction vertex, which is key for neutrino identification and astrophysical searches. Antenna positions must be known to within a few cm so that the signals coherently sum across the entire frequency band. This means that positions, usually surveyed to the meter, must be corrected using several local (calpulser) and global (SPICE core and IceCube Deep pulsers) calibration sources. Signals from several sources are observed at different times in different antennas, depending mainly on the incoming direction. Hence, information on antenna positions and ice properties can be extracted looking at the time delays between pairs of channels receiving the signal and comparing to expectations from ray-tracing algorithms. Our process of finding the antenna positions in ice involves simultaneously fitting the cable delays, antenna positions, and the local ice model, each carrying their own approximate uncertainties.
[1] P. Dasgupta and K. Hughes for the ARA Collaboration, The Calibration of the Geometry and Antenna delay in Askaryan Radio Array Station 4 and 5, In Proceedings of the 37th Int. Cosmic Ray Conf. (ICRC 2021), 12-23 July 2021, Berlin (Germany), PoS(ICRC2021)1086

2.10.3 The RadNu project and The Radar Echo Telescope

(N. van Eijndhoven, S. Toscano, K. de Vries, S. Buitink, O. Scholten, T. Huege, K. Mulrey, S. de Kockere, R. Stanley, E. Huesca Santiago, U. Latif, V. Lukic, J. Stoffels, D. van den Broeck)

Radar detection of high-energy particle cascades and the formation of the Radar Echo Telescope (RET) collaboration: The RadNu project started with the data analysis for the T-576 beam-test experiment performed at the Stanford Linear Accelerator Center. This analysis showed, for the first time in history, a radar reflection from a high-energy particle cascade [1]. This major breakthrough for the RadNu project, providing the prove-of-principle for the radar method to probe high-energy particle cascades, lead to the formation of the RET collaboration. The collaboration is led by K.D. de Vries (IIHE-VUB) and S. Prohira (Ohio State University, Kansas University) and consists of members from 10 Universities located in Europe, the U.S., and Taiwan. Webpage:www.radarechotelescope.org.

The goal of the RET collaboration is the same as the RadNu project main objective: to show the proof-of-principle of the radar detection technique to probe cosmic-neutrino-induced particle cascades in ice. To achieve this goal, an intermediate step is envisioned to show the proof-of-principle of the method in nature, by detecting high-energy cosmic-ray induced particle cascades penetrating a high-altitude ice layer through the RET-CR experiment. This detection channel is chosen, as detection and reconstruction of the in-air particle cascade using a cosmic-ray surface detector is a well-known process. For this we will use a combination of scintillators and radio detection stations. This surface system will subsequently provide an external trigger for our radar detector to probe the in-ice continuation of the particle cascade using an in-ice radar detector. If successful, the RET-CR experiment will be expanded into the RET-N experiment that aims to detect the cosmic-neutrino flux at the highest energies.

2.10.3.1 Simulation and reconstruction of radar signals from high-energy particle cascades

To model the process of a cosmic-ray induced particle cascade moving into a high-altitude ice layer and its subsequent in-ice radar detection, a simulation framework has been developed. This framework, for the first time, combines the CORSIKA air shower simulation code to describe the in-air particle cascade, the GEANT4 particle physics simulation code to describe its continuation in ice and the RadioScatter radar reflection code to model the radar reflection of the in-ice cascade. Using this simulation, we optimized the RET-CR detector layout, and estimated the expected event rate [2,3]. Furthermore, reconstruction studies for the neutrino detection channel are initiated. A macroscopic radar reflection model, MacroScatter, is currently being finalized. Initial results of this model, along with first simulation studies on the reconstruction of the neutrino interaction vertex and neutrino energy from the observed radar signal modeled by the microscopic RadioScatter simulation, have been presented at the 2021 International Cosmic Ray Conference (ICRC2021) [4]. These advancements allowed us to perform preliminary neutrino sensitivity studies for RET-N providing extremely promising sensitivities that were also shown at ICRC2021 [5].

2.10.3.2 Experimental developments

The cosmic-ray surface system for RET-CR is currently being prototyped at IIHE. Three stations, each consisting out of two scintillator detectors and one radio detection station, were prepared and tested in the lab and are currently installed on the VUB rooftops and taking data. The installment of this set-up and successful detection of cosmic-rays is a major milestone within the RadNu project.

The in-ice radar detection system, which is to be triggered by the surface system, is currently being tested at the Ohio State University (Columbus, United States), in close collaboration with RadNu members. Integration of the surface system with the in-ice radar detection system is foreseen in the near future. Installment at Summit Camp, Greenland is subsequently foreseen in the 2022-2024 timeframe, where it should be noted that logistical delay due to the covid-19 pandemic make this timeframe somewhat uncertain.

2.10.3.3 Direct radio emission high-energy particle cascades, a (background) signal

The cosmic-ray or neutrino induced particle cascade will also emit direct radio emission while propagating in air or through the ice. Understanding these emissions is crucial for RET-CR as well as RET-N, as they pose a possible (background)-signal that can be observed next to the sought after radar signal. Within the RadNu project, several efforts on understanding, detecting, and reconstructing these emissions have been performed. These studies furthermore are used to provide direct input for the ARA and RNO-G collaborations, that aim to detect cosmic-neutrinos through the direct Askaryan radio emission from a neutrino-induced particle cascade [3,6].

2.10.3.4 Radio signal propagation

One of the major uncertainties in our radar and radio signal predictions is the propagation of radio-waves in the Arctic ice. Due to its non-uniform density profile, radio waves will be bend, refracted or reflected on their path to our detector. Investigating these non-linear propagation modes lead to the application of so-called parabolic equation (PE) solvers to this problem. In [9], within the RET collaboration, we indeed show that standard ray-propagators are insufficient to provide a full description of the expected and observed radio emission.

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2.11 Phenomenology

(A. Ahmed, S. Blasi, S. Junius, H. Duval, A. Mariotti, X. Nagels, S. Najjari, A. Rase, A. Romero, K. Turbang, M. Vanvlasselaer)

The phenomenology of Beyond Standard Model (BSM) physics is an elemental topic of investigation in current high energy physics. The Standard Model of particle physics, even though it provides an excellent agreement with the current experiments, still contains open questions, such as the precise structure of the BEH scalar, the fermion mass hierarchies, the neutrino masses. In addition, the Standard Model of cosmology also contains puzzles, notably the origin of dark matter and of dark energy, with the dark matter puzzle naturally providing a link with particle physics questions.

There are several experiments that are exploring the frontier of fundamental physics. The Large Hadron Collider (LHC) at CERN is exploring particle physics at very high energy and will provide new information about the dynamics at the base of the electroweak scale (EW). Moreover, different experiments are attempting to understand the nature of the dark matter that populates our universe, through direct and indirect detection. Very recently, the detection of gravitational waves by the LIGO-Virgo-Kagra collaboration has opened a new way to explore the early stages of our universe and potentially high energy physics, providing a direct connection with cosmology. The Pheno group at IIHE pursues outstanding research on BSM phenomenology and cosmology, exploring novel ideas to address the open problems in the SM and looking for their footprints in collider signatures in the stochastic gravitational wave background (SGWB).

The Pheno group started in 2010 under the initiative titled "Supersymmetric models and their signatures at the Large Hadron Collider" financed through a five-year "Geconcerteerde Onderzoeksactie" (GOA) research project at the VUB. Now it is part of the Strategic Research Program "High Energy Physics" (HEP@VUB) whose purpose it to strengthen the research activity in high energy physics among the existing groups at VUB: Collider physics (CMS), Astroparticle physics (IceCube), High-energy Astrophysics (LOFAR), and Theoretical high-energy physics (TENA). In addition, since summer 2020 several members of the IIHE Pheno group became members of the Virgo collaboration, establishing a new concrete connection between the IIHE and gravitational wave physics. Over the last few years, they have actively contributed, within the LIGO/Virgo collaboration, to the work of the stochastic group, whose goal is to study and detect the stochastic gravitational wave background (SGWB) of astrophysical and cosmological origin. In Figure 17 a plot displays the state of the art of the SGWB, showing the energy density in the SGWB over the critical one as a function of the frequency. Limits as well as illustrative cosmological signals for BSM theories are also shown in the Figure.

In the following, a few highlights are presented over results obtained in the different research areas pursued by the group:
− In [1], it was shown that collider signatures of dark matter can be characterized by the presence of displaced vertices in scenarios where dark matter is produced in the early universe via the freeze-in mechanism. An interplay between these signatures and the reheating temperature of our universe was established.
− In [2], an alternative search to the standard continuous cross-correlation search for an astrophysical GW background is proposed. As the signal from binary black holes is expected to be popcorn-like, properly modeling its intermittent nature results in a significant time reduction until detection. It is shown for a series of toy models that the proposed intermittent search performs better than the standard continuous search, illustrating the potential of such a method.
− In [3], it was proposed that the EW phase transition occurs through the nucleation of bubbles catalyzed by the presence of topological defects, and it was shown that this actually is the preferred channel for the EW phase transition

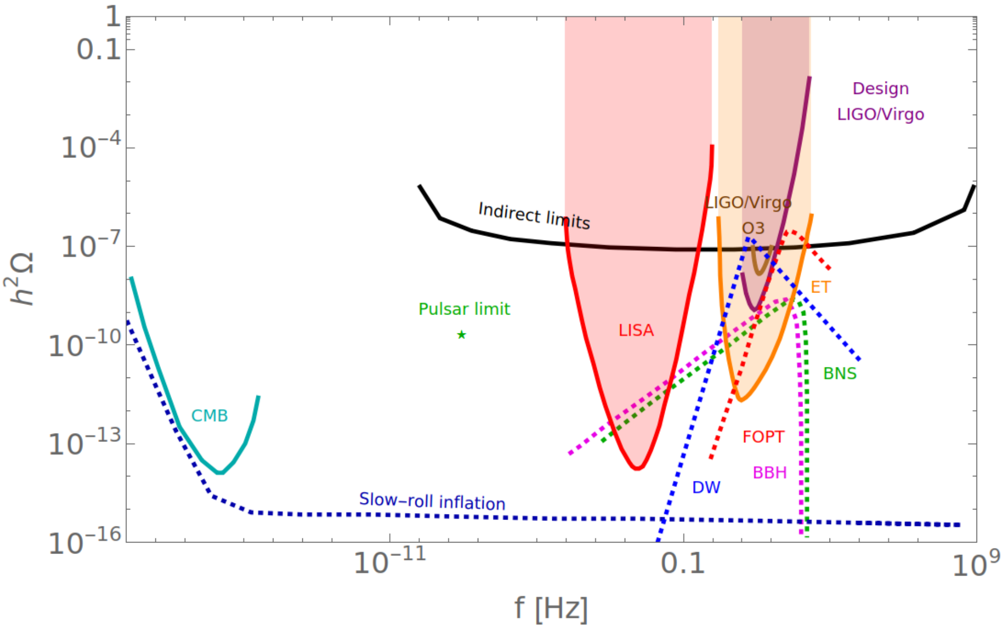

Figure 17: Energy of the stochastic gravitational wave background over the critical one, as a function of the frequency. Solid lines represent current and future (direct and indirect) limits from different experiments. Dashed lines represent signal predictions from different models. *Credit: K. Turbang*

in a popular minimal extension of the SM. In comparison with the most studied case where the bubbles nucleate in vacuum, this scenario can have novel implications for EW baryogenesis as well as for the SGWB emitted.
− In [4], it was shown that particle friction in the cosmic plasma can significantly affect the dynamics of domain walls in the early universe. Domain walls are an important class of SGWB sources (see DW line in Figure 17) that can emerge in BSM scenarios. It was shown that friction can modify the expected GW signals and hence their detectability in current and future GW experiments.

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[4] S. Blasi, A. Mariotti, A. Rase, A. Sevrin and K. Turbang, Friction on ALP domain walls and gravitational waves, arXiv:2210.14246 [hep-ph], JCAP 04 (2023) 008

2.12 Computing and networking

(O. Devroede, D. Dutrannois, S. Gérard, S. Rugovac, R. Rougny, A. Scodrani, P. Vanlaer)

The IIHE operates both local computing services, and a computing cluster that can be used through the GRID or via a local batch system. All our servers are running on FOSS: either directly on a RedHat based OS or virtualized via KVM.

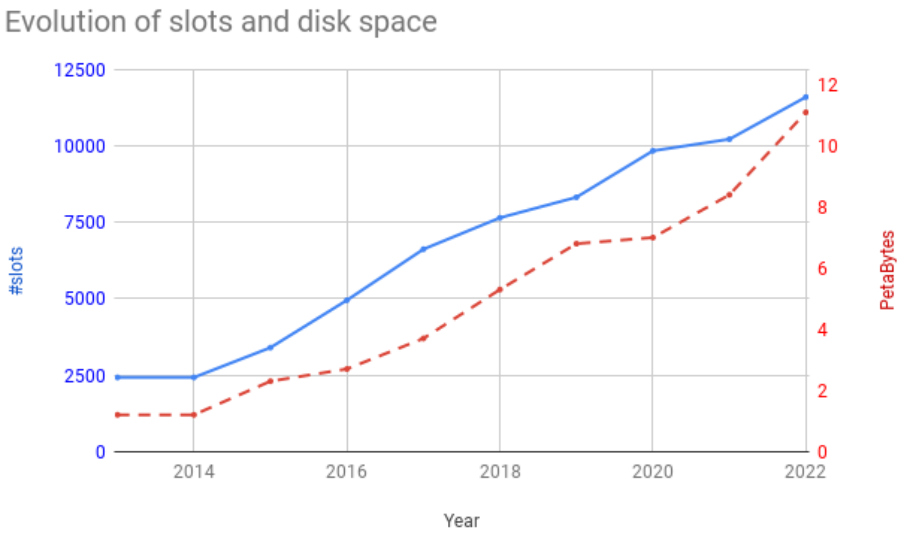

Figure 18: The evolution of the number of slots and available disk space at T2B since 2012.

2.12.1 General computing services

The IIHE hosts a range of generic IT services like DNS servers, web servers for the official IIHE websites as well as all the intranet services. Furthermore, we host the Indico conference tool and room booking software used for the lab. This infrastructure runs on several hypervisors (for redundancy) as well as a High Availability (HA) storage and is managed via the OpenNebula orchestrator. The IT group possesses a fleet of laptops and private computers that are managed via DRBL (Diskless Remote Boot in Linux). These laptops are crucial to the organization of both conferences and student sessions. The IT group also provides support for these two activities for the IIHE members. The IT support group consists of two full-time IT people: D. Dutrannois and A. Scodrani.

To ensure easy communication during the pandemic, the IT team set up a team collaboration tool called RocketChat. This allows easy communication in the form of text and video chats. The latter is powered by Jitsi. Since the pandemic rendered the rooms at the IIHE unused, a major renovation of 2 rooms was undertaken. The IT group was involved in this effort both for the furniture and the teleconferencing equipment. Both the Z-room and the neutrino room have been equipped with a Logitech Rally video-conferencing system. This system comprises a camera and room speakers that are used via plug-and-play in all major operating systems. In the Z-room this was combined with a 75” ETX-7520 touchscreen powered by Android. Management of both wifi and cabled network has been transferred to the central VUB network services. A concerted effort between the VUB and IIHE teams made this as seamless as possible for the end users.

2.12.2 The T2B cluster

The IIHE operates a GRID-enabled computing cluster, together with a large-scale storage solution. The computing cluster offers resources and support to several large international collaborations (CMS, IceCube, SoLid, Auger, ENMR, LOFAR, RNO-G). The Brussels HTC/Grid team comprises four IT scientists (S. Rugovac, FNRS; O. Devroede, VUB; S. Gérard, VSC, part time; Romain Rougny, UGent/UAntwerpen). Pascal Vanlaer (ULB) is in charge of the Belgian federated Tier2 sites and is the Belgian representative to the WLCG and CMS computing boards.

T2B, Hardware: Between 2019 and 2022, the storage capacity of T2B was increased by 86%, reaching 11PB. The bulk of this storage (50%) was used by the CMS experiment. Datasets that were placed at our facility by the experiment now amount to almost 4PB. The number of available job slots was raised by 35% to 11600. Hardware upgrades greatly benefited from the density increase of available solutions. Disk nodes went from 30 to 60 disks, while disks increased from 6TB to 12TB. For CPU, the density increase was obtained through the new EPYC solutions proposed by AMD. It allowed an increase to 32 cores per CPU from the previous 14 cores on Intel Xeon processors.

This tripled the HepSpecs per node. All those important hardware evolutions also resulted in a halving of prices per TB for disks or per HepSpec for compute. This worked well for T2B hardware procurements as it balanced the price spikes observed during Covid due to Worldwide shortages, as well as compensated the ever-increasing requirements of CMS storage and compute needs. The evolution of the available resources since 2012 can be seen in Figure 18.

T2B, Software: Due to scaling issues with the previously used batch system (PBS), a replacement was found in HTCondor, a specialized workload management system for compute-intensive jobs. It is used in many grid clusters, especially those dedicated to high-energy physics. It scales well beyond 100k jobs, making it the ideal choice for T2B. The switch to HTCondor made us reconsider our preferred configuration manager. Our choice settled on the widely used Puppet. We are gradually moving from a solution solely based on Quattor to a dual solution Quattor/Puppet. Now only provisioning of the machines is done in Quattor while the final configuration is done using Puppet. In order to better manage user code, precious data, as well as the many virtual machines owned by T2B, a new storage system based on ceph was introduced. Ceph is a free and open-source software-defined storage platform that provides high data redundancy, completely distributed disk operations without a single point of failure, and scalability to the exabyte level. At this moment, specific hardware has been bought to host this system. Installation and scaling tests have been performed, confirming it will be able to hold the load we expect to expose it to.

3 IIHE activities

3.1 Activities in 2020

3.1.1 Contributions to experiments

3.1.1.1 Responsibilities in experiments

Yannick Allard

- Convener for IIHE's "Glue Systems" and "Vacuum Systems" working groups for the Tracker Phase 2 upgrade

Isabelle Ansseau

- Monitoring week for IceCube

Juan Antonio Aguilar Sánchez

- IceCube Beyond Standard Model working group lead
- IceCube local group leader and IceCube Institutional Board member
- Member of the IceCube Publication Committee

Diego Beghin

- Contact person for the EXO high mass LFV analysis

Freya Blekman

- First ever CMS Physics Communications Officer (in Physics Coordination team)

Stijn Buitink

- Co-chair of SKA High Energy Cosmic Particles Focus Group
- PI of the LOFAR Cosmic Ray Key Science Project

Barbara Clerbaux

- Member and Chair of various Analysis Review Committees (ARC) in EXO, B2G, Higgs and Top groups in CMS
- Member of the JUNO Financial Board
- Member of the publication committee board (PUBCOM) for the EXOTICA and B2G groups
- President of the JUNO scientific award committee
- ULB Deputy representative at the CMS board
- ULB representative at the JUNO board
- PI of FNRS IISN conventions
- PI of the ULB-exp group for the Excellence Of Science (EOS) : The H boson gateway to physics beyond the Standard Model

Paul Coppin

- Maintainer of the GRBweb online tool

Jorgen D'Hondt

- Member of the CMS Collaboration Board
- PI of the Big Science project related to the Flemish contribution to the CMS experiment
- PI of the Hercules/EWI project related to the Belgian contribution to the CMS Tracker Upgrade project

Paramita Dasgupta

- The Calibration of the Geometry and Antenna delay in Askaryan Radio Array Station 4

Simon De Kockere

- Decommission of CODALEMA antenna units (France)

Gilles De Lentdecker

- Convener of the CMS GEM DAQ & Electronics Working Group

Laurent Favart

- Co-PI of the EoS project be.h
- Internal referee for CMS (ARC)
- Member of the CMS Publication Committee Board FSQ and PRF
- Member of the H1 Physics Board
- PI or co-PI of 4 FNRS IISN conventions

Tim Huege

- Task Leader Auger-Analysis-Foundations
- Task Leader Auger-Radio Detection Activities

Tomáš Kello

- JetMET expert and contact person for the CMS HWW group
- Tracker Upgrade: Responsible for SW development for sensor TestBox
- Validation expert in CMS Tracker alignment group

Rijeesh Keloth

- Developing Signal - background discriminants using ML to select HNL events in SoLid experiment.
- Engaged in the detector calibration using phase–2 calibration data in SoLid experiment.
- Participated in taking control room shifts in SoLid experiment.

Kumiko Kotera

- co-spokesperson of GRAND

Kyeongpil Lee

- Muon object contact for Standard Model Physics group in CMS

Steven Lowette

- Flemish representative to the CMS Tracker Upgrade Steering Group
- VUB representative to the CMS Tracker Institution Board

Vesna Lukic

- Postdoc in Krijns group - working on neutrino energy reconstruction when using radar directed at a particle cascade

Alberto Mariotti

- Convener of WP3 (New scalar resonances) in EOS - BEH consortium

Ioana Maris

- Chair interim of the Auger publication committee
- Editorial board member for six Auger papers
- Task leader of the long term performance of the Pierre Auger Observatory

Daniela Mockler

- IceCube monitoring shift

Seth Moortgat

- L2 convener of the BTV physics object group in CMS

Denise Muller

- CMS Phase-2 tracker upgrade: metrology of 2S modules built at IIHE (since September 2020)
- Development of b-tagging commissioning framework based on nanoAOD samples and coffea software package (CMS service work)

Katie Mulrey

- Leader for new Cross-Calibration Array for cosmic-ray energy scales

Hershal Pandya

- LOFAR Cosmic Ray Scintillator Array Data Acquisition

Abanti Ranadhir Sahasransu

- L3 PdMV Release Validation Convenor at CMS

Simona Toscano

- Local PI of the ARA (Askaryan Radio Array) experiment
- Local PI of the RNO-G (Radio Neutrino Observatory - Greenland) experiment
- Member of the IceCube publication committee

Nick Van Eijndhoven

- Coordination of the development of the Radio Neutrino Observatory in Greenland
- Member of the IceCube collaboration board
- PI of the VUB IceCube group

Catherine Vander Velde

- Member of a Publication Committee in CMS, for SUSY papers (SUS PubCom)

Pascal Vanlaer

- Academic person in charge of the ULB-VUB CMS Tier-2 computing cluster
- CMS ULB team leader
- CO-PI of EoS project be.h
- Co-coordinator of work package 2 of EoS be.h project
- Co-promotor of FNRS IISN convention CMS phase-2 upgrade 4.4502.17
- Co-promotor of FNRS IISN convention Frontier physics at the LHC 4.4502.15
- Main promotor of FNRS IISN convention CMS Tier-2 4.4505.05

- Member and chair of CMS analysis review committees (ARCs)
- Member of the CMS PhD award committee
- Member of the CMS Tracker Institution Board

Yifan Yang

- JUNO BEC - L3 management

3.1.1.2 Presentations in collaboration meetings

Paul Coppin

- A GRB precursor catalog for neutrino searches - IceCube - Virtual meeting) 08/05/2020
- GRB stacking analysis for neutrinos from GRB precursors - IceCube - Virtual meeting 16/09/2020

Pablo Correa

- Analysis results (plenary): "Search for High-Energy Neutrinos from Ultra-Luminous Infrared Galaxies" - IceCube - Virtual Meeting 22/09/2020
- Analysis update (parallel): "Ultra-Luminous Infrared Galaxies Analysis Update" - IceCube - Virtual Meeting 07/05/2020

Paramita Dasgupta

- ARA Analysis Call - ARA experiment - online 02/11/2020

Tim Huege

- Status of Radio activities in Auger Analysis Foundations - Pierre Auger - Zoom 16/03/2020
- Summary of Radio activities in Auger Analysis Foundations - Pierre Auger - Zoom 15/11/2020

Nadège Iovine

- Search for dark matter in the Galactic Centre with OscNext - IceCube Collaboration - Online 28/04/2020
- Search for dark matter in the Galactic Centre with OscNext - IceCube Collaboration - Online 14/09/2020

Djunes Janssens

- Signals in Resistive MPGDs: an introduction - RD51 collaboration - Virtual only 05/10/2020

Tomáš Kello

- Approval: CMS Tracker Alignment Performance results for full Run 2 Legacy reprocessing - CMS - CERN, virtual 14/02/2020

Orazio Zapparrata

- Interpretation of the WCD ageing using simulations - Auger - Brussels, Belgium (online meeting) 09/11/2020
- Investigating the A/P dependency on the liner reflectivity - Auger - Brussels, Belgium (online meeting) 14/04/2020

3.1.2 Completed Master and PhD theses

Yannick Allard

- Ali Safa
  Characterisation of the new tracker sensors for the CMS experiment at CERN
  Master thesis, ULB, June 2020.

Barbara Clerbaux

- Diego Beghin
  Search for high mass resonances or quantum black holes decaying to lepton flavor violating final states with the CMS detector
  Phd thesis, ULB, December 2020.

Gilles De Lentdecker

- Elizabeth Starling
  Study of the Triple-GEM detector performance in CMS forward muon spectrometer
  Phd thesis, ULB, December 2020.

Alberto Mariotti

- Kevin Turbang
  The strong CP problem and gravitational waves
  Master thesis, VUB, June 2020.

3.1.3 Representation in scientific councils and committees

Juan Antonio Aguilar Sánchez

- Member of the Scientific Committee of the Centre de Physique des Particules de Marseille (CPPM) France

Freya Blekman

- Chairperson ATLAS-Canada Standing Review Committee, Natural Sciences and Engineering Research Council of Canada (NSERC), Canada
- Review panel on fundamental physics and astronomy, FCT, Portugal
- Review panel on physics, RCN, Norway
- Visiting Professor at Oxford University

Stijn Buitink

- Member of Scientific Program Committee CRI for 37th International Cosmic Ray Conference (2020/2021)

Barbara Clerbaux

- Belgian representative to the European Committee for Future Accelerators (ECFA)
- Member of the APPEC-ECFA-NUPECC working group on recognition of individuals
- Member of the FWO (Fonds Wetenschappelijk Onderzoek) selection committee (expert)
- Member of the ULB selection committee for permanent position (academic chaire)
- President or member of various PhD committees, ULB
- Referee for the Phys. Lett. B Journal

Pablo Correa

- IIHE-VUB representative in the committee for the organisation of the Solvay colloquia

Jorgen D'Hondt

- Chair of the European Committee for Future Accelerators (ECFA)
- Deputy PI of the be.h Excellence of Science project
- FWO delegate in the International Oversight Funding Group (IOFG) of the IceCube experiment
- Member and representing Europe in the International Committee for Future Accelerators (ICFA)
- Member of ApPEC
- Member of NuPECC
- Member of several international advisory boards for conferences and workshops
- Member of the CERN Council
- Member of the CERN Finance Committee
- Member of the CERN Science Policy Committee
- Member of the Dutch Panel for Large-Scale Research Infrastructures (the Netherlands)
- Member of the ECFA working group on Higgs at Future Colliders
- Member of the European Physical Society (HEPP) board
- Member of the European Strategy Group of the European Strategy for Particle Physics
- Member of the International Advisory Board of NIKHEF
- Member of the Physics Preparatory Group of the European Strategy for Particle Physics
- Member of the Secretariat of the European Strategy for Particle Physics
- Member of the VUB committee for Future Education Innovations
- Member of the VUB steering group for setting up an Honour Program
- Member of the review panel of the Spanish funding agency related to high-energy physics
- Permanent member of the International Advisory Board of the workshop series on Top Quark Physics
- Promotor of the Strategic Research Program HEP@VUB

Gilles De Lentdecker

- Referee for the Agence Nationale de Recherche (ANR), France
- Referee for the IEEE Journal
- Vice-President of the Belgian Physical Society

Laurent Favart

- FNRS delegate to the IOFG (International Oversight and Finance Group) of the IceCube experiment
- FNRS representation in the Finance Board of the Pierre Auger Collaboration
- Member of the Belgian committee for the selection of CERN fellows
- Member of the FRIA selection committee
- Representative of the FNRS at the ApPEC (Astroparticle Physics European Consortium)

Tim Huege

- Member of the International Advisory Board of the ARENA workshop series

Tomáš Kello

- PhD representative for EoS be.h program

Kumiko Kotera

- CNRS hiring committee

Steven Lowette

- Member of the organizing committee for the Belgian-Dutch-German Graduate School in Particle Physics

Seth Moortgat

- Belgian representative of the Early Career Reasearchers (ECR) panel for the European Committee for Future Accelerators (ECFA)

Louis Moureaux

- ECFA Young Scientists Forum

Nick Van Eijndhoven

- Adviser for the National Research Foundation (NRF) of South Africa
- Belgian representative in the HEP board of the European Physical Society
- Member of the IceCube Collaboration Board
- Scientific Programme Committee member of the International Cosmic Ray Conference

Pascal Vanlaer

- Referee for Physics Letters B
- Representative of the ULB in the CECI interuniversity high-performance computing infrastructure (FUNDP, UCL, ULB, ULg, UMons)

3.1.4 Diffusion of scientific results

3.1.4.1 Oral presentations at conferences and schools

Juan Antonio Aguilar Sánchez

- BSM searches in Neutrino Telescopes, TMEX 2020 - 16th Rencontres du Vietnam - Qui Nhon from 05/01/2020 to 11/01/2020

Stijn Buitink

- Constraining the cosmic-ray mass composition by measuring the shower length with SKA, ARENA 2022 - Santiago de Compostela 09/06/2022
- Cosmic Ray observations with LOFAR 2.0 and SKA, LOFAR meeting 2022 - Keulen 16/06/2022
- Performance of SKA as an air shower observatory, ICRC 2021 - Berlin from 12/07/2021 to 23/07/2021

Gilles De Lentdecker

- CMS GEM Electronics, ACES 2020 - Seventh Common ATLAS CMS Electronics Workshop for LHC Upgrades - CERN, Geneva from 26/05/2020 to 28/05/2020
- GE2/1 Electronics Overview, CMS GE2/1 Procurement Readiness Review - CERN, Geneva 30/07/2020

Xuyang Gao

- Observation of the Y(4626) and other Y states at Belle, The 6th China XYZ particle conference - Fudan University, Shanghai, China 16/01/2020
- Search for high-mass resonance Z' in the di-lepton final states at CMS, Fudan 115th anniversary workshop of modern physics - Fudan University, Shanghai, China 11/05/2020

Nadège Iovine

- Indirect search for dark matter in the Galactic Centre with IceCube, KASHIWA DARK MATTER SYMPOSIUM 2020 - Online 18/11/2020

Sam Junius

- Displaced physics at colliders and pre-BBN cosmology, Invited talk - ITP Heidelberg 23/06/2020
- Displaced physics at colliders and pre-BBN cosmology, Searching for long-lived particles at the LHC: Seventh workshop of the LHC LLP Community - Virtually from 25/05/2020 to 27/05/2020

Tomáš Kello

- Constraints on the anomalous HVV couplings of the Higgs boson in pp collisions at 13TeV, EoS PhD Day 2020 (student workshop) - online 27/11/2020

Kumiko Kotera

- Pulsars and magnetars as the highest energy particle sources, YITP workshop - Kyoto, Japan from 07/12/2020 to 10/12/2020
- UHE neutrinos, Cosmic ray and neutrino workshop - APC, Paris from 07/12/2020 to 11/12/2020

Alberto Mariotti

- Low energy SUSY breaking and gravitational waves, Belgian GW meeting - virtual 27/10/2020

Seth Moortgat

- First measurement of the cross section of top quark pair production with additional charm jets using dileptonic final states in pp collisions at $\sqrt{s} = 13TeV$., 13th International Workshop on Top Quark Physics (TOP 2020) - Virtual (Organized by IPPP Durham) from 14/09/2020 to 18/09/2020

Denise Muller

- Recent $t\bar{t}$ and single top inclusive cross section results in CMS, ICHEP2020 - Prague (virtual-only) 28/07/2020

Katie Mulrey

- Detecting Cosmic Rays with LOFAR, Sparse Digital Radio Arrays - Moscow (remote) 24/03/2020

Abanti Ranadhir Sahasransu

- Soft displaced leptons at the LHC, Searching for long-lived particles at the LHC: Seventh workshop of the LHC LLP Community - Virtually worlwide from 25/05/2020 to 27/05/2020

Elizabeth Starling

- Electrical Discharge Mitigation Strategies for Future CMS GEM Systems GE2/1 and ME0, ICHEP2020: 40th International Conference on High Energy Physics - Prague, but really Zoom 29/07/2020
- Measurement of the Z Boson Cross-Section with Taus, CMS Virtual Data Analysis School - CERN, but really Zoom from 23/09/2020 to 30/09/2020

Yifan Yang

- Study of using machine learning for level 1 trigger decision in JUNO experiment, realtime 2020 - online from 12/10/2020 to 23/10/2020

3.1.4.2 Poster presentations at conferences and schools

Paul Coppin

- GRBweb - A Catalogue of GRBs and their Precursors, Cosmic Rays and Neutrinos in the Multi-Messenger Era - Virtual meeting 07/12/2020

Simon De Kockere

- The Radar Echo Telescope, Cosmic Rays and Neutrinos in the Muti-Messenger Era - Paris (virtual) from 07/12/2020 to 11/12/2020
- The Radar Echo Telescope, Neutrino2020 - Chicago (virtual) from 22/06/2020 to 02/07/2020

Dieder-Jan Van den Broeck

- RET poster, Cosmic Rays and Neutrinos in the multi-messenger era - Online from 07/12/2020 to 11/12/2020
- RET poster, Neutrino 2020 - Online from 22/06/2020 to 02/07/2020

3.1.5 Scientific training

3.1.5.1 Attendance to conferences and workshops

Paul Coppin

- Cosmic Rays and Neutrinos in the Multi-Messenger Era - Virtual meeting from 07/12/2020 to 11/12/2020

Alexandre De Moor

- 4th IML Machine Learning Workshop - 4th IML Machine Learning Workshop - Online from 19/10/2020 to 23/10/2020

Sam Junius

- Searching for long-lived particles at the LHC and beyond: Eighth workshop of the LHC LLP Community - Virtually from 16/11/2020 to 20/11/2020

Tomáš Kello

- CMS Tracker Week - CMS Tracker Week - CERN, Switzerland from 24/02/2020 to 28/02/2020
- Intensive Course of Statistics for HEP - Intensive Course of Statistics for HEP - online from 07/12/2020 to 11/12/2020
- Workshop: Leadership and Teamwork - Leadership and Teamwork - online from 12/05/2020 to 10/06/2020

Ali Khalilzadeh

- Conference FLA2020 and workshops - Conference FLA2020 and workshops - Online from 31/08/2020 to 04/09/2020
- Module assembly workshop - Module assembly workshop - Online 09/06/2020
- Tracker week at CERN - Tracker week - CERN from 24/02/2020 to 28/02/2020

Alberto Mariotti

- LIGO-Virgo-KAGRA Collaboration Meeting - LIGO-Virgo-KAGRA Collaboration Meeting - Virtual from 14/09/2020 to 17/09/2020
- 8th workshop LHC LLP community - Long Lived particles at LHC - virtual from 16/11/2020 to 20/11/2020

Daniela Mockler

- CORSIKA Cosmic Rays Simulation Workshop - virtual from 22/06/2020 to 25/06/2020

- IceCube collaboration meeting - virtual from 14/09/2020 to 25/09/2020
- IceCube collaboration meeting - virtual from 09/05/2020 to 15/05/2020
- Cosmic Rays and Neutrinos in the Multi-Messenger Era - virtual from 07/12/2020 to 11/12/2020
- APS meeting - virtual from 18/04/2020 to 21/04/2020

Denise Muller

- ICHEP2020 - High energy particle physics - Prague (virtual-only) from 28/07/2020 to 06/08/2020
- TOP2020 - Top quark physics - Durham (virtual-only) from 14/09/2020 to 18/09/2020

Abanti Ranadhir Sahasransu

- ICHEP 2020 - ICHEP 2020 - Virtual 28/07/2020

Rose Stanley

- APS Virtual April Meeting - Virtual Conference from 18/04/2020 to 21/04/2020
- CODALEMA Working Visit and Workshop - Nancay Radio Observatory, France from 11/03/2020 to 13/03/2020

Kevin Turbang

- The Intensive Course on Statistics for HEP - Statistics workshop - Online from 07/12/2020 to 11/12/2020

Orazio Zapparrata

- Cosmic Rays and Neutrinos in the Multi-Messenger Era - Online event from 07/12/2020 to 11/12/2020
- Online Linux training on Hydra - Linux training - Online event 29/04/2020
- Auger Machine Learning Days - Machine Learning Workshop - Online event from 03/11/2020 to 04/12/2020

3.1.5.2 Attendance to schools

Isabelle Ansseau

- SENSE DETECTOR SCHOOL - low lights detectors - Ringberg Castel from 19/06/2019 to 22/06/2019

Ali Khalilzadeh

- CMS induction course - CMS induction course - Online from 10/06/2020 to 12/06/2020

Santiago Paredes Saenz

- Virtual CMS Data Analysis School 2020 - Virtual CMS Data Analysis School 2020 - Online only from 23/09/2020 to 30/09/2020

Abanti Ranadhir Sahasransu

- CMS Virtual Data Analysis School @CERN 2020 - CMS Virtual Data Analysis School @CERN 2020 - CERN (Virtual) from 01/09/2020 to 30/09/2020

Rose Stanley

- International School of Trigger and Data Acquisition 2020 - Valencia, Spain from 13/01/2020 to 22/01/2020

Elizabeth Starling

- Fermilab-CERN Hadron Collider Physics Summer School - Fermilab, but really Zoom from 06/08/2020 to 17/08/2020

Orazio Zapparrata

- 2020 Inverted CERN School of Computing - CERN School of Computing - Online event from 28/09/2020 to 02/10/2020

3.1.6 Teaching and academics activities

3.1.6.1 Teaching activities

Isabelle Ansseau

- ULB - PHYSF210 : Laboratoires, statistique appliquée à la physique expérimentale et projet , (0/0/72/99) BA2 BA2 physique
- ULB - physf104 : Physique, (0/48/0/25) BA1 BA1 pharma et géologie
- ULB - PhysF103 : Physique, (0/24/0/20) BA1 BA1 informatique
- ULB - PHYSF205 : Physique 2, (0/0/44/80) BA2 BA2 biologie, géologie et géographie
- ULB - PHYSF110 : Physique générale I et II, (0/0/52/99) BA1 BA1 chimie et physique

Juan Antonio Aguilar Sánchez

- ULB - PHYS-F314 : Electronique, (12/0/0/0) BA3
- ULB - PHYS-F210 : Laboratoires, statistique appliquée à la physique expérimentale et projet, (0/0/72/40) BA2
- ULB - PHYS-F311 : Laboratoires et Stage de recherche , (0/0/72/30) BA3
- ULB - PHYS-F467 : Physique des Astroparticules , (24/24/0/24) MA1 MA2

Diego Beghin

- ULB - PHYS-F311 : Laboratoire, (0/0/32/0) BA3 Temps de vie du muon

Simone Blasi

- VUB - 1015267BNR : Statistical Physics, (0/24/0/0) BA3

Freya Blekman

- VUB - WE-DNTK-mobility : Coordinator external mobility, (0/0/0/20) MA1 MA2 coordinate the assignment of the obligatory mobility courses (6 ECTS credits)
- VUB - WE-DNTK-12965 : EXPERIMENTELE FYSICA, (10/0/70/40) BA1 This is the obligatory experimental physics laboratory for students in the first year of the Ba1
- VUB - IR-BIO-6763 : Measurement Techniques in Nuclear Science, (20/0/0/40) MA1 MA2 Optional course for students in the Master Biomedical Engineering
- VUB - WE-DNTK-7136 : Simulation of Physics Phenomena and Detectors in Modern Physics, (15/25/10/20) MA1 MA2 Course preparing students for their masters project, combining simulation/computing with physics to
- Other - University of Oxford : Top quark physics at the LHC and beyond, (10/0/0/10) Postgraduate lectures part of the obligatory doctoral training

Stijn Buitink

- VUB - WE-DNTK-4904 : Astroparticle Physics, (16/0/0/0) MA1 MA2
- VUB - WE-DNTK-6509 : Computational Physics, (26/0/0/0) MA1
- VUB - WE-DNTK-11702 : Experimentele Fysica, (20/60/0/0) BA1
- VUB - WE-DNTK-6355 : Fysica: Inleiding Mechanica, (20/0/0/0) BA1
- VUB - WE-DNTK-6508 : High-Energy Astrophysics, (26/0/0/0) MA1
- VUB - WE-DNTK-10891 : Radioastronomie, (14/0/0/0) BA2 BA3

Barbara Clerbaux

- ULB - PHYS-F416 : Interactions fondamentales et particules, (18/12/12/0) MA1
- ULB - PHYS-F311 : Laboratoires et stage de recherche, (0/0/12/36) BA3
- ULB - PHYS-F104 : Physique Générale, (24/00/0/0) BA1

Paul Coppin

- VUB - WE-DNTK-1001388CNR : Experimentele stralings- en kwantumfysica, (0/0/48/32) BA2
- VUB - WE-DNTK-1015456BNR : Experimentele studie van de micro- en macrokosmos, (0/0/0/15) BA3

Pablo Correa

- VUB - WE-DNTK-12965 : Experimentele fysica, (10/0/70/40) BA1

Simon De Kockere

- VUB - WE-DNTK-6323 : Physics: Electromagnetism, (0/0/30/18) BA2
- VUB - WE-DNTK-6355 : Physics: Introduction to Mechanics, (0/28/16/50) BA1
- VUB - WE-DNTK-6317 : Physics: mechanics waves and thermodynamics, (0/48/15/35) BA1
- VUB - WE-DNTK-6438 : Seminar on Current Science and Society, (20/0/0/20) BA1

Gilles De Lentdecker

- ULB - PHYS-F314 : Electronics, (12/6/18/0) BA3 Introduction to electronics
- ULB - PHYS-F205 : General Physics II, (0/12/0/0) BA2 Exercices of electromagnetism for Biologists
- ULB - PHYS-F312 : Particle Physics Laboratory, (0/0/36/0) BA3 Laboratory in Particle Physics
- ULB - PHYSF482 : Techniques Avancées en Physique Expérimentale, (4/0/0/0) MA1

Olivier Devroede

- VUB - WE-DNTK-14101 : Experimentele Fysica, (0/12/0/0) BA1 First Matlab Course
- VUB - 4015950FNR : Object Oriented Programming (C++) for Physicists, (12/12/12/60) MA1 MA2

Laurent Favart

- ULB - PHYS-F305 : Introduction à la Physique des Particules, (24/0/0/0) BA3 Physique
- ULB - PHYS-F477 : Physique auprès des collisionneurs, (24/0/0/0) MA1 MA2 Physique

Sam Junius

- ULB - PHYS-F469-202021 : Extensions of the standard model, (0/16/0/0) MA2

Steven Lowette

- VUB - 4015948FNR : Experimental Techniques in Particle Physics, (36/0/0/20) MA1 MA2
- VUB - 4012730CNR : Extensions of the Standard Model, (24/12/0/0) MA2
- VUB - 4015029ENR : External Mobility B, (0/0/0/0) MA1 MA2
- VUB - 1019736ANR : Seminarie Actuele Wetenschappen en Samenleving, (13/13/0/13) BA1

Alberto Mariotti

- VUB - 1015267BNR : Statistical Physics, (26/0/0/0) BA3
- VUB - 4015689FNR : Subatomic Physics 2, (26/0/0/0) MA1

Ioana Maris

- ULB - PHYS-F-467 : Astroparticle physics, (24/12/0/0) MA1
- ULB - PHYS-F205 : Electricity and magnetism, (24/0/0/0) BA2
- ULB - PHYS-F210 : Laboratoires, statistique appliquée à la physique expérimentale et projet , (0/0/72/0) BA2
- ULB - PHYS-F311 : Laboratoires et Stage de recherche, (0/0/36/0) BA3
- ULB - PHYS-F-420 : Partcile detectors, data acquisition and analysis, (16/12/0/0) MA1

Seth Moortgat

- VUB - WE-DNTK-1001388CNR : Experimentele stralings- en kwantumfysica, (0/0/40/0) BA2
- VUB - WE-DNTK-1010221BNR : Statistische verwerking van experimentele gegevens, (0/12/0/0) BA2

Louis Moureaux

- ULB - PHYS-F305 : Introduction à la physique des particules, (0/12/0/0) BA3
- ULB - PHYS-F210 : Laboratoire de physique générale, (0/0/36/0) BA2

Hershal Pandya

- VUB - WE-DNTK-6509 : Computational Physics, (0/30/0/0) BA3

Abanti Ranadhir Sahasransu

- VUB - 006510 : Subatomic Physics II - 006510, (26/26/0/0) MA1

Rose Stanley

- VUB - WE-DNTK-1017196BNR : Inleiding tot de Astrofysica, (0/30/0/60) BA2

Simona Toscano

- ULB - PHYS-F210 : Laboratoires, statistique appliquée a la physique expérimentale et projet, (0/0/12/0) BA2
- ULB - PHYS-F311 : Laboratoires et stages de recherche, (0/0/72/0) BA3

Kevin Turbang

- VUB - 1017198BNR : Inleiding Kwantumfysica, (0/26/0/0) BA2 Exercises for Inleiding Kwantumfysica
- VUB - 1010183ANR : Mechanica, (0/26/0/0) BA1 Exercises for Mechanica

Nick Van Eijndhoven

- VUB - WE-DNTK-6406 : Experimental Study of the Micro and Macrocosmos, (13/13/0/0) BA3
- VUB - WE-DNTK-6331 : Subatomic Physics I : Introduction to Nuclear and Particle Physics, (26/26/0/0) BA3

Pascal Vanlaer

- ULB - PHYS-F420 : Détection de particules, acquisition et analyse de données, (12/0/24/0) MA1 MA2 Physique
- ULB - PHYS-F-110 : Physique générale, (48/0/60/0) BA1
- ULB - PHYS-F482 : Techniques avancées de la physique expérimentale, (24/0/24/0) MA1

3.1.6.2 Membership to academic juries of Master and Phd theses

Laurent Favart

- Phd thesis, - ULB, December 2020 - Elizabeth Rose Starling : Detection and Mitigation of Propagating Electrical Discharges Within the Gas Electron Multiplier Detectors of the CMS Muon System for the CERN HL-LHC
Secretary
- Master thesis, - ULB, September 2020 - Sébastien Verkercke : Variabilité et prévisibilité de la dynamique atmosphérique extratropicale sous l'influence du phenomène ENSO
Referee

Alberto Mariotti

- Phd thesis, - VUB, October 2020 - Lana Descheemaeker : MODELING BIOLOGICAL NETWORKS
President

3.1.6.3 Representation in academic councils and committees (in universities)

Yannick Allard

- Représentant CORSI au Département de Physique (Faculté des Sciences), ULB

Isabelle Ansseau

- Conseil et bureau du département de physique, ULB
- commission de l'enseignement, ULB

Freya Blekman

- Chairperson of the Opleidingsraad (Education council) of the VUB Bachelor and Master of Physics and Astronomy, VUB
- IIHE website coordinator, Other

Barbara Clerbaux

- Elected as the representative of Academic Staff at the ULB Assemblée plénière (AP), ULB
- Elected as the representative of Academic Staff at the ULB university board (CA), ULB
- Member of the administrative ULB committee (commission administrative), ULB

Pablo Correa

- OAP representative in the DNTK department council, VUB
- OAP representative in the DNTK education council, VUB
- OAP representative in the Sciences and Bio-Engineering Sciences faculty board, VUB
- OAP representative in the Sciences and Bio-Engineering Sciences faculty council, VUB

Gilles De Lentdecker

- Membre de la commission enseignement du département de physique, ULB
- Membre de la commission enseignement du département de physique, ULB
- Membre de la commission finance du département de physique, ULB
- Membre de la commission finance du département de physique, ULB

Tim Huege

- External Member of Selection Committee at UC Louvain, Other

Steven Lowette

- DNTK delegate to the faculty's doctoral committee, VUB
- DNTK delegate to the faculty's internationalisation committee, VUB
- President of the examination committee for the VUB Bachelor in de fysica en sterrenkunde , VUB
- Secretary of the examination committee for the VUB Master in physics and astrophysics, VUB

Alberto Mariotti

- Master examination committee voorzitter, VUB

Ioana Maris

- Secretaire du Jury de Bachelier, ULB

Louis Moureaux

- Conseil de la faculté des sciences, ULB
- Conseil du département de physique, ULB

Denise Muller

- Co-organiser HEP@VUB seminar, VUB

Kevin Turbang

- Student representative on the Opleidingsraad and DNTK raad, VUB

Nick Van Eijndhoven

- Astroparticle Physics programme leader , VUB
- Chair of the curriculum board of the VUB dept. of Physics and Astronomy, VUB
- Member of the public relations board of the VUB Faculty of Science, VUB
- President or member of various PhD committees, VUB
- Responsible for plagiarism control of the VUB dept. of Physics and Astronomy, VUB

Pascal Vanlaer

- Coordinator of the Physics department in the AEQES higher-education quality assessment process in the French community, ULB
- Member of the Diploma Equivalence Committee - section Sciences for the Walloon-Brussels Federation , Other
- Member of the Observatory of the 1st year bachelor studies in sciences, ULB
- Member of the Physics department committee for teaching assistants hirings, ULB

3.1.7 Vulgarisation and outreach

Paul Coppin

- IceCube Masterclass - IIHE, Brussels, Belgium, 19/02/2020

Pablo Correa

- IceCube Masterclass organisation - IIHE, 19/02/2020
- Rosie & Gibbs comics translation to Dutch - IceCube, 16/10/2020

Simon De Kockere

- IceCube Masterclass - VUB - IIHE, 19/02/2020

Enrique Huesca Santiago

- IceCube Masterclass - IIHE, 20/02/2020

Nadège Iovine

- IceCube Masterclass - iihe - Brussels, 19/02/2020
- Talk about Dark Matter Search in the Galactic Centre with IceCube during Dark Matter Day 2020 – WIPAC and IceCube - Online, 29/10/2020

Daniela Mockler

- IceCube Masterclass - Brussels, 19/02/2020

Seth Moortgat

- Keynote speaker at the Next Year Event of the Belgian Nuclear Forum: ”Submerge into the subatomic world, the building blocks of the universe. https://www.youtube.com/watch?v=WVBSx941tUo” - Bozar (Brussels, Belgium), 10/02/2020

Rose Stanley

- IceCube Masterclass - VUB Campus Etterbeek, 19/02/2020

Simona Toscano

- IceCube Masterclass - Bruxelles, 19/02/2020

Kevin Turbang

- Reviewer and translation of the science summary of the Isotropic Stochastic GW Background paper (LIGO/Virgo) - Online, from 20/12/2020 to 31/12/2020

Nick Van Eijndhoven

- IceCube masterclass for high school students - IIHE Brussels, 19/02/2020

Yifan Yang

- Invited seminar for Nanjing University of Aeronautics and Astronautics - online, 30/10/2020

Orazio Zapparrata

- IceCube Masterclass - IIHE, Brussels, Belgium, 19/02/2020

3.2 Activities in 2021

3.2.1 Contributions to experiments

3.2.1.1 Responsibilities in experiments

Yannick Allard

- Convener for IIHE's "Glue Systems" and "Vacuum Systems" working groups for the Tracker Phase 2 upgrade

Juan Antonio Aguilar Sánchez

- Deputy Analysis Coordinator
- IceCube local group leader and IceCube Institutional Board member

Barbara Clerbaux

- Member and Chair of various Analysis Review Committees (ARC) in EXO, B2G, Higgs and Top groups in CMS
- Member of the JUNO Financial Board
- Member of the publication committee board (PUBCOM) for the EXOTICA and B2G groups
- President of the JUNO scientific award committee
- ULB Deputy representative at the CMS board
- ULB representative at the JUNO board
- PI of FNRS IISN conventions
- PI of the ULB-exp group for the Excellence Of Science (EOS) : The H boson gateway to physics beyond the Standard Model

Marta Colomer Molla

- Convener of the SNEWS detector response working group

Paramita Dasgupta

- The Calibration of the IRS2 Digitiser chips in ARA Station 4

Gilles De Lentdecker

- Convener of the CMS GEM DAQ & Electronics Working Group

Martin Delcourt

- Strip Local Reconstruction, simulation and calibration convener

Laurent Favart

- Co-PI of the EoS project be.h
- Internal referee for CMS (ARC)
- Member of the CMS Publication Committee Board FSQ and PRF
- Member of the H1 Physics Board
- PI or co-PI of 4 FNRS IISN conventions

Nicolas Gonzalez

- Remote operation room of the Auger fluorescence detector

Tim Huege

- Task Leader Auger-Analysis-Foundations
- Task Leader Auger-Radio Detection Activities

Tomáš Kello

- JetMET expert and contact person for the CMS HWW group
- Tracker Upgrade: Responsible for SW development for sensor TestBox
- Validation expert in CMS Tracker alignment group

Rijeesh Keloth

- Conducted detailed BiPo background studies in non-signal region and MC tuning for the simulation: PVT Light Yield, Cube Light Leakage and ZnS Light Yield studies to tune MC in SoLid experiment.
- Data Manager of SoLid Experiment: Ensuring smooth data transfers from BR2 server to T2B, Lyon and Imperial clusters.
- Developed Signal - background discriminants using ML to select HNL events in SoLid experiment.
- Engaged in the detector calibration using phase–2 calibration data in SoLid experiment.
- Ops/DQ Group Convener of SoLid Experiment
- Participated in taking control room shifts in SoLid experiment.
- Wrote Data Quality tech-note with other collaborators.

Kyeongpil Lee

- Muon object contact for Standard Model Physics group in CMS

Ioana Maris

- Member of the Auger publication committee

Alexander Morton

- Pattern Recognition Convenor for Phase 2 Tracker Upgrade activities at the IIHE

Denise Muller

- CMS Phase-2 tracker upgrade: metrology of 2S modules built at IIHE (CMS service work)
- Development of b-tagging commissioning framework based on nanoAOD samples and coffea software package (CMS service work)
- HLT trigger development for BTV (CMS service work)
- L3 convener of the B Tag & Vertexing physics object (BTV) software and algorithms subgroup in CMS (since September 2021)

Santiago Paredes Saenz

- Contact person for the CMS search for $H^{++}H^{--} \rightarrow lep$ data analysis
- Group leader (convener) of the CMS Jets+MET Trigger group

Abanti Ranadhir Sahasransu

- L3 PdMV Release Validation Convenor at CMS

Nick Van Eijndhoven

- Coordination of the development of the Radio Neutrino Observatory in Greenland
- Member of the IceCube collaboration board

- PI of the VUB IceCube group

Catherine Vander Velde

- Member of a Publication Committee in CMS, for SUSY papers (SUS PubCom)

Pascal Vanlaer

- Academic person in charge of the ULB-VUB CMS Tier-2 computing cluster
- CMS ULB team leader
- CO-PI of EoS project be.h
- Co-coordinator of work package 2 of EoS be.h project
- Co-promotor of FNRS IISN convention CMS phase-2 upgrade 4.4502.17
- Co-promotor of FNRS IISN convention Frontier physics at the LHC 4.4502.15
- Main promotor of FNRS IISN convention CMS Tier-2 4.4505.05
- Member and chair of CMS analysis review committees (ARCs)
- Member of the CMS PhD award committee
- Member of the CMS Tracker Institution Board

Yifan Yang

- JUNO BEC - L3 management

Orazio Zapparrata

- FD Shift - Auger (31 May - 19 June)

3.2.1.2 Presentations in collaboration meetings

Marta Colomer Molla

- Supernova neutrino lightcurve studies in JUNO - JUNO-EU - Aachen from 13/09/2021 to 14/09/2021
- Supernova neutrino lightcurve studies in JUNO - JUNO - remote from 09/07/2021 to 23/07/2021
- Supernova neutrino lightcurve studies in JUNO - JUNO-EU - remote from 17/05/2021 to 20/05/2021

Paramita Dasgupta

- Update on the ARA4 Digitiser Calibration - Askaryan Radio Array (ARA) - Online meeting 03/05/2021

Gilles De Lentdecker

- First experience with GEM detectors in CMS - CMS - CERN 01/06/2021
- GE1/1 commissioning and Run 3 readiness - CMS - CERN 21/09/2021

Martin Delcourt

- Tracker DPG Status Report at the Tracker General Meeting - CMS - CERN, remotely 04/10/2021

Nicolas Gonzalez

- Performance of the 433 m surface array of the Pierre Auger Observatory - Pierre Auger - Online 01/03/2021
- Photon-Hadron discrimination with the UMD-433 - Pierre Auger - Online 01/11/2021
- Reconstruction of photon events with the SD-433 - Pierre Auger - Online 01/03/2021

Dmytro Hohov

- Energy over momentum (E/p) Alignment Validation Tool - CMS - Tracker Alignment Meeting 03/11/2021

Tim Huege

- Status of Radio activities in Auger Analysis Foundations - Pierre Auger - Zoom 11/2021
- Status of Radio activities in Auger Analysis Foundations - Pierre Auger - Zoom 03/2021

Djunes Janssens

- An update to the modelling of signal formation in detectors with resistive elements - RD51 collaboration meeting - remote only 17/11/2021
- Modeling of signal formation in detectors with resistive elements: contribution of material specific conductivity - RD51 collaboration - remote only 17/07/2021

Rijeesh Keloth

- Status of the BiPo background data/MC study - SoLid - Paris 10/11/2021

Alexander Morton

- Searching with CMS for low-mass dark scalars through the Higgs portal - EOS be.h consortium - Virtual (Zoom) 16/12/2020

Louis Moureaux

- SMP-20-003 approval - CMS - Online 09/04/2021

Orazio Zapparrata

- Modelling the SD ageing with simulations - Auger - Brussels, Belgium (online event) 08/11/2021
- Modelling the WCD ageing with simulations - Auger - Brussels, Belgium (online event) 02/03/2021

3.2.2 Completed Master and PhD theses

Barbara Clerbaux

- Daniel Gomez de Gracia
  Design of an IoT based multi-channel temperature monitoring system
  Master thesis, ULB, June 2021.

Gilles De Lentdecker

- Wendi Deng
  Development of fast trigger algorithms on FPGA-base trigger boards for the CMS upgrades
  Phd thesis, ULB, November 2021.
- Aamir Irshad
  The CMS GEM Detector Front-end Electronics – Characterization and Implementation
  Phd thesis, ULB, December 2021.

Mitja Desmet

- Mitja Desmet
  Structure recognition in LOFAR lightning data
  Master thesis, VUB, June 2021.

Laurent Favart

- Louis Moureaux
  Measurement of the transverse momentum of Drell-Yan lepton pairs over a wide mass range in proton-proton collisions at $\sqrt{s} = 13$ TeV in CMS
  Phd thesis, ULB, September 2021.

- Lucas Weinberg
  Study of the Drell-Yan Process Associated with Multijet Production at the LHC
  Master thesis, ULB, August 2021.

Alberto Mariotti

- Aaron Rase
  Gravitational waves from domain walls dynamics
  Master thesis, VUB, June 2021.
- Max Lalleman
  Probing a model of freeze-in dark matter with gravitational waves
  Master thesis, VUB, June 2021.

Aaron Rase

- Aäron Rase
  Gravitational Waves from Domain Wall Dynamics
  Master thesis, VUB, June 2021.

3.2.3 Representation in scientific councils and committees

Barbara Clerbaux

- Belgian representative to the European Committee for Future Accelerators (ECFA)
- External expert for the National Science Centre, Poland (NSC), for the ST2 area Fundamental Con- stituents of Matter
- Member of the APPEC-ECFA-NUPECC working group on recognition of individuals
- Member of the BNCPAP (Belgium National Committee of Pure and Applied Physics) of the royal academies for science and the arts of Belgium
- Member of the FWO (Fonds Wetenschappelijk Onderzoek) selection committee (expert)
- Member of the IUPAP (International Union of Pure and Applied Physics), C11: Particles and Fields
- Member of the ULB selection committee for permanent position (academic chaire)
- President or member of various PhD committees, ULB
- Referee for the Phys. Lett. B Journal

Gilles De Lentdecker

- Referee for the Agence Nationale de Recherche (ANR), France
- Referee for the IEEE Journal
- Vice-President of the Belgian Physical Society

Laurent Favart

- FNRS delegate to the IOFG (International Oversight and Finance Group) of the IceCube experiment
- FNRS representation in the Finance Board of the Pierre Auger Collaboration
- Member of ULB Selection Committee (commission universitaire de classement - CUC)
- Member of the Belgian committee for the selection of CERN fellows
- Member of the FRIA selection committee

Tim Huege

- Member of the International Advisory Board of the ARENA workshop series

Tomáš Kello

- PhD representative for EoS be.h program

Louis Moureaux

- ECFA Young Scientists Forum

Nick Van Eijndhoven

- Adviser for the National Research Foundation (NRF) of South Africa
- Belgian representative in the HEP board of the European Physical Society
- Member of the IceCube Collaboration Board
- Scientific Programme Committee member of the International Cosmic Ray Conference

Pascal Vanlaer

- Referee for Physics Letters B
- Representative of the ULB in the CECI interuniversity high-performance computing infrastructure (FUNDP, UCL, ULB, ULg, UMons)

3.2.4 Diffusion of scientific results

3.2.4.1 Oral presentations at conferences and schools

Simone Blasi

- Cosmic strings and pulsar timing , 16th Marcell Grossmann Meeting - online 10/07/21

Barbara Clerbaux

- CMS Physics Highlights - Recent results, Seminar at the Rutherford Appleton Laboratory (RAL) - United-Kingdom 17/03/2021
- Overview of CMS results - Recent highlights, XXVII Cracow EPIPHANY Conference on Future of Paticle Physics - Online from 07/01/2021 to 10/01/2021

Marta Colomer Molla

- JUNO detector status and physics prospects, Rencontres de Blois - Blois, France from 17/10/2021 to 22/10/2021
- SNEWS: the supernova early warning system in the multimessenger era, TAUP2021 - remote from 26/08/2021 to 03/09/2021

Simon De Kockere

- Simulation of the propagation of comsic ray air shower cores through ice, ICRC 2021 - virtual from 12/07/21 to 23/07/21

Nicolas Gonzalez

- Performance of the 433 m surface array of the Pierre Auger Observatory, International Cosmic-Ray Conference 2021 - Berlin (online). Co-author 01/07/2021
- Performance of the 433 m surface array of the Pierre Auger Observatory, International Cosmic-Ray Conference 2021 - Berlin (online). Co-author 01/07/2021

Tomáš Kello

- Status of On-shell $H \to WW$ anomalous couplings (AC) studies, EOS be.h Equinox meeting - Antwerp 09/09/2021

Rijeesh Keloth

- Neutrino Searches @ SoLid Experiment, IIHE Colloquium - IIHE/HEP@VUB 23/11/2021

Kyeongpil Lee

- Measurement of the Drell-Yan transverse momentum dependence over a wide mass range with CMS, Resummation, evolution and factorization workshop 2021 - virtual world from 15/11/2021 to 19/11/2021

Louis Moureaux

- CMS Inclusive vector bosons results including Drell-Yan measurements in a wide mass range, EPS-HEP 2021 - Online 26/07/2021
- Measurement of the Drell-Yan transverse momentum dependence over a wide mass range at 13 TeV from CMS, QCD Evolution Workshop 2021 - Online 10/05/2021

Santiago Paredes Saenz

- Extending $HH \to b\bar{b}b\bar{b}$ searches into the HL-LHC era, Machine Learning Workshop at the International Conference on the New Frontiers in Physics 2021 - Kolimbari, Greece 25/08/2021
- Higgs self couplings at HL-LHC, EOS be.h Equinox Meeting - Antwerp, Belgium (attended online) 09/09/2021
- New approaches for $HH \to b\bar{b}b\bar{b}$ as a probe of Higgs self-coupling, Higgs Conference 2021 - Online conference 19/10/2021

Kevin Turbang

- Stochastic search for intemittent gravitational-wave backgrounds, Belgian Gravitational Wave Meeting - ULB 03/11/2021

3.2.4.2 Poster presentations at conferences and schools

Marta Colomer Molla

- JUNO detector design and status, NuFact2021 - remote from 06/09/2021 to 11/09/2021

Simon De Kockere

- The Radar Echo Telescope for Cosmic Rays, ICRC 2021 - virtual from 12/07/21 to 23/07/21

Dmytro Hohov

- Development of a compact test board for silicon sensors IV/CV characterization , iWoRID2021 - Ghent (Online) from 27/06/2021 to 01/07/2021

Yifan Yang

- Design of a IoT based multi-channel temperature monitoring system, TWEPP - online 21/09/2021
- The JUNO experiment and its electronics readout system, TWEPP - online 20/09/2021

Orazio Zapparrata

- Simulations of the time evolution of the behavior of the surface detector of the Pierre Auger Observatory, General Scientific Meeting of the Belgian Physical Society - Hasselt, Belgium 02/12/2021

3.2.5 Scientific training

3.2.5.1 Attendance to conferences and workshops

Soumya Dansana

- CMS Exotica Workshop 2021 - CERN from 22/11/2021 to 24/11/2021
- EOS be.h Equinox meeting - Antwerp 09/09/2021

Simon De Kockere

- 11th CosPa meeting - Astrophysics and Astroparticle Physics in Belgium - Brussels, Belgium 29/10/2021

Tomáš Kello

- Workshop: Personal Effectiveness - Personal Effectiveness - online from 06/12/2021 to 17/12/2021

Alberto Mariotti

- Belgian Physics Society meeting - Chair of parallel session Fundamental Interactions - Hasselt U. 02/12/2021
- Kick Off Workshop of the ET Observational Science Board - Kick Off Workshop of the ET Observational Science Board - on-line from 21/09/2021 to 22/09/2021
- Muon collider physics potential meeting - Round Table SUSY @ muon collider - remote 24/06/2021

Louis Moureaux

- XXVIII International Workshop on Deep-Inelastic Scattering and Related Subjects - Online from 12/04/2021 to 16/10/2021

Denise Muller

- TOP2021 - Top quark physics - virtual-only from 13/09/2021 to 17/09/2021

Abanti Ranadhir Sahasransu

- Be HEP Annual Meeting - Be HEP Annual Meeting - Virtual 22/06/020
- CMS Exotica workshop - CMS Exotica workshop - Virtual 22/09/2021
- CMS PPD workshop fall 2020 - CMS PPD workshop fall 2020 - Virtual 19/10/2020
- Nano Workshop on Displaced Particles - Nano Workshop on Displaced Particles - Virutal from 08/06/2020 to 19/06/2020

Orazio Zapparrata

- General Scientific Meeting of the Belgian Physical Society - Hasselt, Belgium 02/12/2021
- ICRC: The Astroparticle Physics Conference - Brussels, Belgium (online event) from 12/07/2021 to 23/07/2021

3.2.6 Teaching and academics activities

3.2.6.1 Teaching activities

Juan Antonio Aguilar Sánchez

- ULB - PHYS-F314 : Electronique, (12/0/0/0) BA3
- ULB - PHYS-F210 : Laboratoires, statistique appliquée à la physique expérimentale et projet, (0/0/72/40) BA2
- ULB - PHYS-F311 : Laboratoires et Stage de recherche , (0/0/72/30) BA3
- ULB - PHYS-F467 : Physique des Astroparticules , (24/24/0/24) MA1 MA2

Simone Blasi

- VUB - 1015267BNR : Statistical Physics, (0/24/0/0) BA3

Barbara Clerbaux

- ULB - PHYS-F416 : Interactions fondamentales et particules, (18/12/12/0) MA1
- ULB - PHYS-F311 : Laboratoires et stage de recherche, (0/0/12/36) BA3
- ULB - PHYS-F104 : Physique Générale, (24/00/0/0) BA1

Simon De Kockere

- VUB - WE-DNTK-6323 : Physics: Electromagnetism, (0/0/30/18) BA2
- VUB - WE-DNTK-6355 : Physics: Introduction to Mechanics, (0/28/16/50) BA1
- VUB - WE-DNTK-6317 : Physics: mechanics waves and thermodynamics, (0/48/15/35) BA1
- VUB - WE-DNTK-6438 : Seminar on Current Science and Society, (20/0/0/20) BA1

Gilles De Lentdecker

- ULB - PHYS-F314 : Electronics, (12/6/18/0) BA3 Introduction to electronics
- ULB - PHYS-F205 : General Physics II, (0/12/0/0) BA2 Exercices of electromagnetism for Biologists
- ULB - PHYS-F312 : Particle Physics Laboratory, (0/0/36/0) BA3 Laboratory in Particle Physics
- ULB - PHYSF482 : Techniques Avancées en Physique Expérimentale, (4/0/0/0) MA1

Olivier Devroede

- VUB - WE-DNTK-14101 : Experimentele Fysica, (0/12/0/0) BA1 First Matlab Course
- VUB - 4015950FNR : Object Oriented Programming (C++) for Physicists, (12/12/12/60) MA1 MA2

Laurent Favart

- ULB - PHYS-F305 : Introduction à la Physique des Particules, (24/0/0/0) BA3 Physique
- ULB - PHYS-F477 : Physique auprès des collisionneurs, (24/0/0/0) MA1 MA2 Physique

Alberto Mariotti

- VUB - 1003981BNR : Quantum Physics, (26/0/0/0) BA3
- VUB - 1015267BNR : Statistical Physics, (26/0/0/0) BA3
- VUB - 4015689FNR : Subatomic Physics 2, (26/0/0/0) MA1

Ioana Maris

- ULB - PHYS-F-467 : Astroparticle physics, (24/12/0/0) MA1
- ULB - PHYS-F205 : Electricity and magnetism, (24/0/0/0) BA2
- ULB - PHYS-F210 : Laboratoires, statistique appliquée à la physique expérimentale et projet , (0/0/72/0) BA2
- ULB - PHYS-F311 : Laboratoires et Stage de recherche, (0/0/36/0) BA3
- ULB - PHYS-F-420 : Particle detectors, data acquisition and analysis, (16/12/0/0) MA1

Louis Moureaux

- ULB - PHYS-F305 : Introduction à la physique des particules, (0/12/0/0) BA3
- ULB - PHYS-F210 : Laboratoire de physique générale, (0/0/36/0) BA2

Abanti Ranadhir Sahasransu

- VUB - WE-DNTK-006510 : Sub-atomic physics II, (0/30/0/20) MA1

Kevin Turbang

- VUB - 1010183ANR : Mechanica, (0/26/0/0) BA1 Exercises for Mechanica

Nick Van Eijndhoven

- VUB - WE-DNTK-6406 : Experimental Study of the Micro and Macrocosmos, (13/13/0/0) BA3

Dieder-Jan Van den Broeck

- VUB - WE-DNTK : Toegepaste statistiek, (0/24/0/0) BA1
- VUB - WE-DNTK : Vaste Stof en stralingsfysica, (0/30/0/0) BA2

Pascal Vanlaer

- ULB - PHYS-F420 : Détection de particules, acquisition et analyse de données, (12/0/24/0) MA1 MA2 Physique
- ULB - PHYS-F-110 : Physique générale, (48/0/60/0) BA1
- ULB - PHYS-F482 : Techniques avancées de la physique expérimentale, (24/0/24/0) MA1

3.2.6.2 Membership to academic juries of Master and Phd theses

Barbara Clerbaux

- Phd thesis, - ULB, September 2021 - Jérôme Vandecasteele : Aspects of Dark Matter Phenomenology
  President
- Phd thesis, - VUB, September 2021 - Jael Pauwels : High-performance optical reservoir computing based on spatially extended systems
  President

Laurent Favart

- Phd thesis, - ULB, June 2021 - Christoph Raab : Searches for Neutrino Emission from Blazar Flares with IceCube
  President
- Phd thesis, - Université Paris-Saclay, December 2021 - Brian Ventura : Study of Deeply Virtual Compton Scattering at COMPASS at CERN
  Referee
- Phd thesis, - ULB, December 2021 - Aamir Irshad : The CMS GEM Detector Front-end Electronics Characterization and Implementation
  President

Alberto Mariotti

- Phd thesis, - VUB, May 2021 - Marine De Clerck : Integrable structures and probes of quantum chaos in resonant systems, spin chains and holography
  Secretary
- Phd thesis, - UCLouvain, August 2021 - Luca Mantani : Searches for new interactions within the SMEFT framework at present and future colliders
  Referee
- Phd thesis, - ULB, June 2021 - Pierluigi Niro : Strong coupling in 2+1 dimensions from dualities, holography, and large N
  Referee

Kevin Turbang

- Master thesis, - VUB, June 2021 - Aäron Rase : Gravitational waves from domain wall dynamics
  Referee
- Master thesis, - VUB, June 2021 - Max Lalleman : Probing a freeze-in dark matter model with gravitational waves
  Referee

Yifan Yang

- Master thesis, - ULB, June 2021 - Daniel Gomez de Gracia : Design of a IoT based multi-channel temperature monitoring system
  Referee
- Phd thesis, - ULB, November 2021 - Aamir IRSHAD : The CMS GEM Detector Front-end Electronics - Characterization and Implementation
  Referee

3.2.6.3 Representation in academic councils and committees (in universities)

Yannick Allard

- Représentant CORSI au Département de Physique (Faculté des Sciences), ULB

Barbara Clerbaux

- Elected as the representative of Academic Staff at the ULB Assemblée plénière (AP), ULB
- Elected as the representative of Academic Staff at the ULB university board (CA), ULB

Gilles De Lentdecker

- Membre de la commission enseignement du département de physique, ULB
- Membre de la commission finance du département de physique, ULB

Alberto Mariotti

- Master examination committee voorzitter, VUB

Ioana Maris

- Secretaire du Jury de Bachelier, ULB

Louis Moureaux

- Conseil de la faculté des sciences, ULB
- Conseil du département de physique, ULB

Denise Muller

- Co-organiser HEP@VUB seminar, VUB

Kevin Turbang

- Student representative on the Opleidingsraad and DNTK raad, VUB

Nick Van Eijndhoven

- Astroparticle Physics programme leader , VUB
- Chair of the curriculum board of the VUB dept. of Physics and Astronomy, VUB
- Member of the public relations board of the VUB Faculty of Science, VUB
- President or member of various PhD committees, VUB

Pascal Vanlaer

- Coordinator of the Physics department in the AEQES higher-education quality assessment process in the French community, ULB
- Member of the Diploma Equivalence Committee - section Sciences for the Walloon-Brussels Federation , Other
- Member of the Observatory of the 1st year bachelor studies in sciences, ULB
- Member of the Physics department committee for teaching assistants hirings, ULB

3.2.7 Vulgarisation and outreach

Barbara Clerbaux

- Co-organiser of the Ilya Prigogine colloquium, La 5G en question - vers une société de l'hyper- connectivité ? - ULB, 05/02/2021
- Cours-conférence Collège de Belgique : D'un boson à l'univers, et ensuite ? - Online, 10/02/2021
- Cours-conférence Collège de Belgique : D'un boson à l'univers, et ensuite ? Le débat - Online, 23/10/2021

Simon De Kockere

- IceCube Masterclass 2021 - virtual, 21/04/2021

Nicolas Gonzalez

- IIHE activities at the Pierre Auger Observatory - IIHE Annual Colloqium; ULB, 01/11/2021
- IceCube Online Masterclass - Brussels, 01/04/2021

Djunes Janssens

- Talk for second- and third-year bachelor students in physics of the VUB and the UHasselt on my personal experience of working at CERN as a summer and doctoral student. - virtual presentation, 16/04/2021

Santiago Paredes Saenz

- CMS Master Class (expert assistant, online) - Brussels, 17/02/2021

Abanti Ranadhir Sahasransu

- CMS Masterclass - VUB, 21/03/2021
- PhD VUB Buddy - VUB, 01/09/2021
- VUB Doctoral Derby - VUB, 20/03/2021

Dieder-Jan Van den Broeck

- Participation in SID-IN - Online, 12/01/2021
- Presentation on studying physics at VUB during the VUB info days - VUB (pleinlaan), from 22/05/2021 to 23/05/2021

Orazio Zapparrata

- IIHE Masterclass - IIHE (online event), 21/04/2021

3.3 Activities in 2022

3.3.1 Contributions to experiments

3.3.1.1 Responsibilities in experiments

Yannick Allard

- Convener for IIHE's "Glue Systems" and "Vacuum Systems" working groups for the Tracker Phase 2 upgrade

Juan Antonio Aguilar Sánchez

- Analysis Coordinator
- IceCube local group leader and IceCube Institutional Board member

Barbara Clerbaux

- Member and Chair of various Analysis Review Committees (ARC) in EXO, B2G, Higgs and Top groups in CMS
- Member of the JUNO Financial Board
- Member of the Publication Committee Board of the JUNO Collaboration
- Member of the publication committee board (PUBCOM) for the EXOTICA and B2G groups
- President of the JUNO scientific award committee
- ULB Deputy representative at the CMS board
- ULB representative at the JUNO board
- PI of FNRS IISN conventions
- PI of the ULB-exp group for the Excellence Of Science (EOS) : The H boson gateway to physics beyond the Standard Model

Marta Colomer Molla

- Coordinator of the JUNO atmospheric neutrino physics working group

Soumya Dansana

- CMS Trigger Shifts

Gilles De Lentdecker

- CMS GEM deputy PM

Martin Delcourt

- Strip Local Reconstruction, simulation and calibration convener

Mitja Desmet

- Lead developer on LOFAR analysis software

Laurent Favart

- Co-PI of the EoS project be.h
- Internal referee for CMS (ARC)
- Member of the CMS Publication Committee Board FSQ and PRF
- Member of the H1 Physics Board
- PI or co-PI of 4 FNRS IISN conventions

Tim Huege

- Project coordinator for CORSIKA 8
- Task Leader Auger-Analysis-Foundations
- Task Leader Auger-Radio Detection Activities

Tomáš Kello

- JetMET expert and contact person for the CMS HWW group
- Tracker Upgrade: Responsible for SW development for sensor TestBox
- Validation expert in CMS Tracker alignment group

Rijeesh Keloth

- Conducted detailed BiPo background studies in non-signal region and MC tuning for the simulation.
- Conducted detailed neutrino oscillation sensitivity studies by comparing different fitting methods
- Data Manager of SoLid Experiment: Ensuring smooth data transfers from BR2 server to T2B, Lyon and Imperial clusters.
- Engaged in the detector calibration using phase–1 calibration data in SoLid experiment.
- Engaged in the detector calibration using phase–2 (period 1) calibration data in SoLid experiment.
- Ops/DQ Group Convener of SoLid Experiment
- PVT Light Yield, Cube Light Leakage and ZnS Light Yield studies to tune MC in SoLid experiment.
- Participated in taking control room shifts in SoLid experiment.
- The effect of a bump in electron-anti neutrino energy spectrum on the oscillation analysis in the SoLid experiment.
- Wrote technical notes on SoLid for Data quality and oscillation analysis jointly with other collaborators.

Kyeongpil Lee

- CMS Shift for the trigger system during the data taking
- Muon object contact for Standard Model Physics group in CMS

Andrea Malara

- JERC L3 convener in the CMS experiment
- JetMET contact for the B2G subgroup in the CMS experiment

Ioana Maris

- Chair interim of the Auger publication committee

Denise Muller

- CMS Phase-2 tracker upgrade: metrology of 2S modules built at IIHE (CMS service work)
- Early Run 3 commissioning of b-tagger inputs using BTV coffea framework (CMS service work)
- L3 convener of the B Tag & Vertexing physics object (BTV) software and algorithms subgroup in CMS

Santiago Paredes Saenz

- Contact person for the CMS search for $H^{++}H^{--} \to lep$ data analysis
- Group leader (convener) of the CMS Jets+MET Trigger group

Abanti Ranadhir Sahasransu

- L3 PdMV Release Validation Convenor at CMS

Alba Romero

- Co-Group leader of the isotropic GWB group at the LIGO-VIRGO-KAGRA collaboration
- Co-Group leader of the mock data challenge (MDC) for isotropic GWB group at the LIGO-VIRGO-KAGRA collaboration

Laurent Thomas

- Contact person of the analysis
- Convener of the Level 1 Trigger performance group of CMS (Level 2 position)
- Level 2 convener of the JetMET group of CMS
- Level 2 convener of the JetMET group of CMS

Nick Van Eijndhoven

- Coordination of the development of the Radio Neutrino Observatory in Greenland
- Member of the IceCube collaboration board
- PI of the VUB IceCube group

Catherine Vander Velde

- Member of a Publication Committee in CMS, for SUSY papers (SUS PubCom)

Pascal Vanlaer

- Academic person in charge of the ULB-VUB CMS Tier-2 computing cluster
- CMS ULB team leader
- CO-PI of EoS project be.h
- Co-coordinator of work package 2 of EoS be.h project
- Co-promotor of FNRS IISN convention CMS phase-2 upgrade 4.4502.17
- Co-promotor of FNRS IISN convention Frontier physics at the LHC 4.4502.15
- Main promotor of FNRS IISN convention CMS Tier-2 4.4505.05
- Member and chair of CMS analysis review committees (ARCs)
- Member of the CMS PhD award committee
- Member of the CMS Tracker Institution Board

Yifan Yang

- JUNO BEC - L3 management

Orazio Zapparrata

- SD Shift - Auger (16-30 June)

3.3.1.2 Presentations in collaboration meetings

Marta Colomer Molla

- Atmospheric neutrino analysis in JUNO - JUNO - remote from 17/01/2022 to 21/01/2022
- Atmospheric neutrino analysis in JUNO - JUNO - remote from 18/07/2022 to 29/07/2022
- Atmospheric neutrino reconstruction in JUNO - JUNO-EU - Nantes from 17/05/2022 to 18/05/2022
- Atmospheric neutrinos: Online event classification and topological reconstruction - JUNO-EU - Ferrara from 24/10/2022 to 27/10/2022
- Signal prediction connection with snewpdag: generators, triangulation and distance estimate - SNEWS - USA from 01/08/2022 to 05/08/2022
- Supernova neutrino lightcurve studies - JUNO - remote from 18/07/2022 to 29/07/2022
- Supernova neutrino lightcurve studies in JUNO - JUNO-EU - Nantes from 17/05/2022 to 18/05/2022
- Supernova neutrino lightcurve studies in JUNO - JUNO - remote from 17/01/2022 to 28/01/2022
- Supernova neutrinos: rates for different triggers and event selection - JUNO-EU - Ferrara from 24/10/2022 to 27/10/2022

Simon De Kockere

- Simulation of the propagation of CR air shower cores in ice - RNO-G - Erlangen, Germany from 17/10/2022 to 21/10/2022
- Simulation of the propagation of comsic ray air shower cores through ice - RET - Columbus (Ohio), USA from 01/04/2022 to 04/04/2022
- Simulation of the propagation of comsic ray air shower cores through ice - RNO-G - Chicago (Illinois), USA from 06/04/2022 to 08/04/2022

Nicolas Gonzalez

- A method to estimate bad periods for the UMD-433 - Pierre Auger - Malargue, Argentina 01/11/2022
- Data selection and exposure for the SD433 - Pierre Auger - Wuppertal, Germany 01/07/2022
- Photon search with the 433 m arrays above 10 PeV - Pierre Auger - Wuppertal, Germany 01/07/2022
- Search for ultra-high energy photons below 10 17 eV: overview and next steps - Pierre Auger - Malargue, Argentina 01/11/2022
- Status of the data selection criteria of the SD+UMD photon search - Pierre Auger - Malargue, Argentina 01/11/2022

Dmytro Hohov

- Energy over momentum (E/p) Alignment Validation Tool - CMS - Tracker Alignment Meeting 22/02/2022

Tim Huege

- Status of Radio activities in Auger Analysis Foundations - Pierre Auger - Wuppertal 07/2022
- Status of Radio activities in Auger Analysis Foundations - Pierre Auger - Zoom 11/2022
- Status of Radio activities in Auger Analysis Foundations - Pierre Auger - Zoom 03/2022

Djunes Janssens

- Update on numerical signal modelling in detectors with resistive elements - RD51 collaboration - CERN 15/07/2022

Indrani Jayam

- Dosimetry for FLASH Proton therapy - Louvain-la-neuve 12/12/2022

Rijeesh Keloth

- International Conference on High Energy Physics (ICHEP) - HEP - Bologna, Italy from 06/07/2022 to 13/07/2022
- Status of the BiPo Data/MC studies - SoLid - Paris 14/04/2022

Aaron Rase

- Gravitational Waves from Domain Wall Dynamics - LIGO-Virgo collaboration - online 07/06/2022
- Gravitational Waves from Domain Wall Dynamics - BelGrav - online 13/10/2022

Felix Schlueter

- NuRadioMC Interface for IceTray - Radio Neutrino Observatory - Greenland - Erlangen from 17/10/2022 to 21/10/2022

Laurent Thomas

- Jets and MET critical tasks for SMP Hadronic analyses (Workshop of the CMS Standard Model Hadronic group) - CMS - CERN (remotely) 11/02/2020
- Report from Physics Coordination, talk at the opening plenary during CMS week - CMS - CERN 21/06/2021
- Report of the JetMET group on the Run 2 Legacy Reprocessing (Workshop of the CMS Physics Performances and Datasets group) - CMS - Online 16/03/2020
- VBF$\rightarrow$ H $\rightarrow$invisible team experience with Ultra Legacy data reprocessing (talk at the Physics Performance and Dataset general meeting) - CMS - CERN 03/06/2021

Dieder-Jan Van den Broeck

- Signal propagation with raytracing - RET-Colloboration meeting - OSU (Columbus, Ohio) 01/04/2022

Orazio Zapparrata

- Describing time evolutions with simulations - Auger - Malargue, Argentina 14/11/2022
- Modeling the aging using shape histograms - Auger - Brussels, Belgium (online event) 14/03/2022
- Outreach activities in Brussels - Auger - Wuppertal, Germany 22/07/2022
- Updates of the analysis on the shape histograms - Auger - Wuppertal, Germany 18/07/2022
- Updates on the aging studies - Auger - Malargue, Argentina 14/11/2022

3.3.2 Completed Master and PhD theses

Juan Antonio Aguilar Sánchez

- Nadège Iovine
  Indirect Searches for Dark Matter in the Centre of the Milky Way with the IceCube Neutrino Telescope
  Phd thesis, ULB, February 2022.
- Giovanni Renzi
  Search for dark matter from the centre of the Earth with ten years of IceCube data
  Phd thesis, ULB, December 2022.

Alberto Mariotti

- Xander Nagels
  Gravitational waves from rst order phase transitions
  Master thesis, VUB, June 2022.
- Sam Junius
  Searching for feebly interacting dark matter at colliders and beam-dump experiments
  Phd thesis, VUB, December 2022.

3.3.3 Representation in scientific councils and committees

Juan Antonio Aguilar Sánchez

- Evaluation Committee of Ramon & Cajal Program

Barbara Clerbaux

- Belgian representative to the European Committee for Future Accelerators (ECFA)
- Member of the APPEC-ECFA-NUPECC working group on recognition of individuals
- Member of the BNCPAP (Belgium National Committee of Pure and Applied Physics) of the royal academies for science and the arts of Belgium
- Member of the FNRS IISN selection committee
- Member of the FWO (Fonds Wetenschappelijk Onderzoek) selection committee (expert)
- Member of the IUPAP (International Union of Pure and Applied Physics), C11: Particles and Fields
- Member of the ULB selection committee for permanent position (academic chaire)
- President or member of various PhD committees, ULB
- Referee for the Phys. Lett. B Journal

Gilles De Lentdecker

- Referee for the Agence Nationale de Recherche (ANR), France
- Referee for the IEEE Journal
- Vice-President of the Belgian Physical Society

Laurent Favart

- FNRS delegate to the IOFG (International Oversight and Finance Group) of the IceCube experiment
- FNRS representation in the Finance Board of the Pierre Auger Collaboration
- Member of ULB Selection Committee (commission universitaire de classement - CUC)
- Member of the Belgian committee for the selection of CERN fellows
- Member of the FRIA selection committee

Tim Huege

- Member of the International Advisory Board of the ARENA workshop series

Tomáš Kello

- PhD representative for EoS be.h program

Nick Van Eijndhoven

- Adviser for the National Research Foundation (NRF) of South Africa
- Member of the IceCube Collaboration Board
- Scientific Programme Committee member of the International Cosmic Ray Conference

Pascal Vanlaer

- Referee for Physics Letters B
- Representative of the ULB in the CECI interuniversity high-performance computing infrastructure (FUNDP, UCL, ULB, ULg, UMons)

3.3.4 Diffusion of scientific results

3.3.4.1 Oral presentations at conferences and schools

Juan Antonio Aguilar Sánchez

- BSM searches with the IceCube neutrino telescope, International Conference on Neutrinos and Dark Matter, - Sharm El-Sheikh, Egypt from 25/09/2022 to 28/09/2022
- Searches for Dark Matter with IceCube, Dark Matters Workshop - Brussels, Beglium from 30/11/2022 to 02/12/2022

Simone Blasi

- Domain walls seeding the electroweak phase transition, PASCOS 2022 - Heidelberg 20/07/22
- Exploring the electroweak phase transition at FCC, FCC BSM Physics Programme Workshop - CERN 15/09/22

Marta Colomer Molla

- JUNO physics prospects and detector status, Rencontres du Vietnam 2022 - Vietnam from 18/07/2022 to 22/07/2022
- The multi-messenger astrophysics potential of the JUNO experiment, PUMA 2022: Probing the Univers with MM astrophysics - Sestri Levante from 26/09/2022 to 30/09/2022

Simon De Kockere

- Simulation of the propagation of cosmic ray air shower cores through ice, Acoustic & Radio EeV Neutrino Detection Activities 2022 - Santiago de Compostela, Spain from 07/06/2022 to 10/06/2022

Mitja Desmet

- Template synthesis approach for radio emission from extensive air showers, The 9th International Workshop on Acoustic and Radio EeV Neutrino Detection Activities (ARENA 2022) - Santiago de Compostela, Spain from 07/06/2022 to 10/06/2022

Laurent Favart

- Measurement of the Drell-Yan transverse momentum dependence over a wide mass range at 13 TeV, LHC-EW WG General Meeting - CERN (Genève) from 15/11/2022 to 17/11/2022
- Perturbative and colorful lectures on Strong Interactions, Joint Belgian Dutch German Graduate School (BND 2022) - Callantsoog (NL) from 05/09/2022 to 16/09/2022

Kunal Gautam

- Jet-Flavour Tagging at Future e+e- Colliders, FCC Week 2022 - Paris from 30/05/2022 to 03/06/2022

Nicolas Gonzalez

- Search for ultra-high energy photons and neutrinos with the Pierre Auger Observatory, 27th European Cosmic Ray Symposium - Nijmegen, The Netherlands 01/07/2022

Dmytro Hohov

- Belgian 2S module assembly center status report, 2S Module Workshop - KIT Campus North, Karlsruhe, Germany from 13/06/2022 to 15/06/2022

Djunes Janssens

- Studying signals in particle detectors with resistive elements such as the 2D resistive strip bulk MM, The 7th International Conference of Micro Pattern Gaseous Detectors 2022 - Weizmann Institute of Science, Rehovot, Israel from 11/12/2022 to 16/12/2022

Tomáš Kello

- Constrains on anomalous Higgs boson couplings in production and decay using $H \to WW$ leptonic final state, CMS HWW workshop - Madrid, Spain from 23/05/2022 to 25/05/2022

Kyeongpil Lee

- Measurement of mass dependence of the transverse momentum of lepton pairs in Drell-Yan production at 13 TeV, Diffraction and low-x workshop 2022 - Corigliano Calabro, Italy from 24/09/2022 to 30/09/2022

Denise Muller

- Measurement of $t\bar{t}$ and single top quark production cross sections in CMS, ICHEP2022 - Bologna (Italy) 07/07/2022

Santiago Paredes Saenz

- DNNs and Jet Substructure for Improved Double-Higgs Searches at the HL-LHC and Beyond, Latin American Symposium on High Energy Physics (SILAFAE) 2022 - Quito, Ecuador 14/11/2022
- Recent results on jet-based anomaly detection at the LHC, International Symposium for Multi-particle Dynamics 2022 - Pitlochry, Scotland 02/08/2022

Abanti Ranadhir Sahasransu

- Triggers (CMS), XI International Conference on New Frontiers in Physics - Crete, Grece 07/09/2022

Aaron Rase

- Gravitational Waves from Domain Wall Dynamics, Rethinking Beyond the Standard Model - Cargèse Summer School - Cargèse, Corsica from 25/07/2022 to 06/08/2022
- Gravitational Waves from Domain Wall Dynamics, Virgo Week - Cascina, Italy from 07/11/2022 to 11/11/2022
- Gravitational Waves from Domain Wall Dynamics, - Institute for Basic Science (South-Korea) 26/09/2023

Alba Romero

- Implications for the formation of primordial black holes from the third LIGO-Virgo observing run, Messengers of the very early universe: Gravitational Waves and Primordial Black Holes - Padova from 12/12/2022 to 14/12/2022

Felix Schlueter

- Interferometric Reconstruction of Xmax with realistic antenna arrays, GLOW 2022 - Berlin from 02/11/2022 to 04/11/2022

Laurent Thomas

- Exotica searches at CMS, International Conference on New Frontiers in Physics (ICNFP 2020) - Online from 04/09/2020 to 11/09/2020
- Performance improvements (on-going and for Run 3) at CMS, Dark Matter at the LHC Workshop 2020 (DM 2020) - Online from 02/06/2020 to 05/06/2020
- Rejecting beam induced background at the HL-LHC (CMS perspective), Ninth workshop of the Long Lived Particle Community - CERN from 25/05/2021 to 28/05/2021
- Selected topics in searches for new physics, Rencontres de Blois - Blois, France from 17/10/2021 to 22/10/2021

Dieder-Jan Van den Broeck

- Radio propagation in non-uniform media, ARENA - Santiago de Compostela 07/06/2022

Yifan Yang

- The Jiangmen Underground Neutrino observatory (JUNO), VCI - online 21/02/2022

Orazio Zapparrata

- Deep Learning for the Study of Ultra High Energy Cosmic Rays, General Scientific Meeting of the Belgian Physical Society - Tabloo, Dessel, Belgium 18/05/2022

3.3.4.2 Poster presentations at conferences and schools

Soumya Dansana

- Poster: Triggers for Higgs to low-mass scalars search in Run-2 & Run-3, Be.HEP Summer Solstice Meeting 2022 - Ghent 21/06/2022

Simon De Kockere

- Simulation of the propagation of cosmic ray air shower cores in ice, Neutrinos in the Multi-Messenger Era - Louvain-la-Neuve, Belgium from 30/11/2022 to 02/12/2022

Mitja Desmet

- Structure recognition in LOFAR lightning data, Nederlandse Astronomen Conferentie - Blankenberge, Belgium from 30/05/2022 to 01/06/2022

Kunal Gautam

- Incorporation of LCFIPlus Vertexing Module in FCCAnalyses, FCC Week 2022 - Paris from 30/05/2022 to 03/06/2022
- Jet-Flavour Tagging at FCC-ee, ICHEP 2022 - Bologna from 06/07/2022 to 13/07/2022

Djunes Janssens

- Induced signals in particle detectors with resistive elements: modelling novel structures, Vienna Conference on Instrumentation 2022 - remote only from 21/02/2022 to 25/02/2022

Rijeesh Keloth

- Reconstruction and Calibration for the SoLid Reactor Neutrino Detector, Neutrino 2022 - Virtual -Seoul, South Korea from 30/05/2022 to 04/06/2022

Aaron Rase

- Gravitational Waves from Domain Wall Dynamics, Gravitational Wave Orchestra - UCLouvain 08/09/2022

Felix Schlueter

- Neutrinos in the Multi-Messenger Era, Neutrinos in the Multi-Messenger Era - Louvain-la-Neuve from 29/11/2022 to 02/12/2022

Kevin Turbang

- Stochastic search for intermittent gravitational-wave backgrounds, Gravitational wave orchestra - UCLouvain from 08/09/2022 to 09/09/2022

Orazio Zapparrata

- Modeling the behavior of the surface detector of the Pierre Auger Observatory, ISCRA Summer School - Erice, Italy 03/08/2022

3.3.5 Scientific training

3.3.5.1 Attendance to conferences and workshops

Soumya Dansana

- Scientific Symposium to celebrate the 10th anniversary of the Higgs boson discovery - CERN 04/07/2022
- CMS JetMET Workshop - Florence, Italy from 11/04/2022 to 13/04/2022

Simon De Kockere

- IIHE colloquium - 50 years of particle physics research at the IIHE - Brussels, Belgium 14/09/2022
- CORSIKA 8 Air-Shower Simulation and Development Workshop - CORSIKA 8 Air-Shower Simulation and Development - Heidelberg, Germany from 12/07/2022 to 15/07/2022
- Belgian Physical Society meeting 2022 - Physics research in Belgium - Dessel, Belgium 18/05/2022

Hannah Duval

- Virgo Week 2022 - Cascina, at the European Gravitational Observatory from 07/11/2022 to 11/11/2022

Hugues Evard

- CMS week - CERN from 05/12/22 to 09/12/22
- CMS week - CERN from 19/09/2022 to 23/09/2022

Laurent Favart

- REF 2022 - Co-organiser of the Workshop on Resummation, Evolution, Factorization - Montenegro - virtual meeting from 31/10/2022 to 04/11/2022

Kunal Gautam

- 5th FCC Physics Workshop - Liverpool (Remote) from 07/02/2022 to 11/02/2022
- FCC Week 2022 - Paris from 30/05/2022 to 03/06/2022
- First ECFA Workshop on on e+e- Higgs/EW/Top Factories - DESY, Hamburg from 05/10/2022 to 07/10/2022
- ICHEP 2022 - Bologna from 06/07/2022 to 13/07/2022
- ECFA WHF WG1: 1st Workshop of the Higgs/Top/EW group - CERN, Geneva from 20/04/2022 to 22/04/2022
- Swiss FCC Workshop - Fostering Swiss collaboration towards a future circular collider - Zurich from 25/08/2022 to 26/08/2022

Nicolas Gonzalez

- 27th European Cosmic Ray Symposium - Cosmic Rays - Nijmegen, The Netherlands 01/07/2022
- Workshop on Machine Learning - Machine Learning - University of Delaware, United States (Online) 01/02/2022

Djunes Janssens

- Vienna Conference on Instrumentation 2022 - Instrumentation and techniques conference - remote only from 21/02/2022 to 25/02/2022
- The 7th International Conference of Micro Pattern Gaseous Detectors 2022 - Micro Pattern Gaseous Detectors conference - Weizmann Institute of Science, Rehovot, Israel from 11/12/2022 to 16/12/2022

Indrani Jayam

- FLASH Radiotherapy & Particle Therapy (FRPT 2022) - Barcelona, Spain from 30/11/2022 to 02/12/2022

Alberto Mariotti

- Be.HEP Summer Solstice 2022 - Be.HEP Summer Solstice 2022 - Gent 21/06/2022
- Belgian Physical Society meeting - General scientific meeting - Dessel 18/05/2022
- Cosmological Frontiers in Fundamental Physics 2022 Workshop - Organizer committee - Solvay Institutes from 26/04/2022 to 28/04/2022

Denise Muller

- FSP CMS Workshop 2022 - Convener for top quark physics session of the German CMS workshop - Aachen (Germany) from 28/09/2022 to 30/09/2022

- ICHEP2022 - High energy particle physics - Bologna (Italy) from 06/07/2022 to 13/07/2022

Abanti Ranadhir Sahasransu

- CMS PPD workshop - CMS PPD workshop - Virtual 19/01/2022

Felix Schlueter

- IceCube Collaboration Meeting - IceCube Collaboration Meeting - Madison, US from 18/09/2022 to 23/09/2022

Kevin Turbang

- Gravitational wave orchestra - Stochastic gravitationnal wave backgrounds - UCLouvain from 08/09/2022 to 09/12/2022

Miguel Vanvlasselaer

- What the heck happens when the universe boils - Electroweak baryogenesis - IPMU Japan from 05/12/2022 to 09/12/2022

Orazio Zapparrata

- General Scientific Meeting of the Belgian Physical Society - Tabloo, Dessel, Belgium 18/05/2022
- Workshop on Machine Learning for Cosmic-Ray Air-Showers - Brussels, Belgium (online event) from 31/01/2022 to 03/02/2022
- International School of Cosmic Ray Astrophysics - Erice, Italy from 30/07/2022 to 07/08/2022

3.3.5.2 Attendance to schools

Soumya Dansana

- BND Graduate School - Netherlands from 05/09/2022 to 16/09/2022

Simon De Kockere

- INTERNATIONAL SCHOOL OF COSMIC RAY ASTROPHYSICS 22nd Course - Cosmic ray astrophysics - Erice, Italy from 30/07/2022 to 07/08/2022

Mitja Desmet

- International school of cosmic-ray astrophysics “Maurice M. Shapiro” - From cosmic particles to gravitational waves: now and to come - Erice, Italy from 30/07/2022 to 07/08/2022

Kunal Gautam

- BND Graduate School - Callantsoog from 05/09/2022 to 16/09/2022

Aaron Rase

- Galileo Galilei Institute - GGI Lectures on the Theory of Fundamental Interactions - Firenze, Italy from 10/01/2022 to 28/01/2022
- Cargèse Summer School - Rethinking Beyond the Standard Model - Cargèse, Corsica from 25/07/2022 to 06/08/2022

Kevin Turbang

- Summer school - Beyond the Standard Model physics - Institut Scientifique de Cargèse from 25/07/2022 to 05/08/2022
- GGI - The theory of fundamental interactions - Online from 10/01/2022 to 28/01/2022

Dieder-Jan Van den Broeck

- Erice summer school - INTERNATIONAL SCHOOL OF COSMIC RAY ASTROPHYSICS “MAURICE M. SHAPIRO” 22nd Course - Erice from 30/07/2022 to 07/08/2022

3.3.6 Teaching and academics activities

3.3.6.1 Teaching activities

Juan Antonio Aguilar Sánchez

- ULB - PHYS-F314 : Electronique, (12/0/0/0) BA3
- ULB - PHYS-F210 : Laboratoires, statistique appliquée à la physique expérimentale et projet, (0/0/72/40) BA2
- ULB - PHYS-F311 : Laboratoires et Stage de recherche , (0/0/72/30) BA3
- ULB - PHYS-F467 : Physique des Astroparticules , (24/24/0/24) MA1 MA2
- ULB - PHYS-F482 : Techniques avancées de physique expérimentale -, (12/12/0/12) MA1 MA2

Simone Blasi

- VUB - 1015267BNR : Statistical Physics, (0/24/0/0) BA3

Barbara Clerbaux

- ULB - PHYS-F416 : Interactions fondamentales et particules, (18/12/12/0) MA1
- ULB - PHYS-F311 : Laboratoires et stage de recherche, (0/0/12/36) BA3
- ULB - PHYSF-311 : Organisation of the CERN visit for the BA3 students, (0/0/0/36) BA3 in March 2022
- ULB - PHYS-F104 : Physique Générale, (24/00/0/0) BA1

Simon De Kockere

- VUB - WE-DNTK-6323 : Physics: Electromagnetism, (0/0/30/18) BA2
- VUB - WE-DNTK-6355 : Physics: Introduction to Mechanics, (0/28/16/50) BA1
- VUB - WE-DNTK-6317 : Physics: mechanics waves and thermodynamics, (0/48/15/35) BA1
- VUB - WE-DNTK-6438 : Seminar on Current Science and Society, (20/0/0/20) BA1

Gilles De Lentdecker

- ULB - PHYS-F314 : Electronics, (12/6/18/0) BA3 Introduction to electronics
- ULB - PHYS-F312 : Particle Physics Laboratory, (0/0/36/0) BA3 Laboratory in Particle Physics
- ULB - PHYSF482 : Techniques Avancées en Physique Expérimentale, (4/0/0/0) MA1

Olivier Devroede

- VUB - WE-DNTK-14101 : Experimentele Fysica, (0/12/0/0) BA1 First Matlab Course
- VUB - 4015950FNR : Object Oriented Programming (C++) for Physicists, (12/12/12/60) MA1 MA2

Laurent Favart

- ULB - PHYS-F305 : Introduction à la Physique des Particules, (24/0/0/0) BA3 Physique
- ULB - PHYS-F477 : Physique auprès des collisionneurs, (24/0/0/0) MA1 MA2 Physique

Alberto Mariotti

- VUB - 1003981BNR : Quantum Physics, (26/0/0/0) BA3
- VUB - 1015267BNR : Statistical Physics, (26/0/0/0) BA3
- VUB - 4015689FNR : Subatomic Physics 2, (26/0/0/0) MA1

Ioana Maris

- ULB - PHYS-F-467 : Astroparticle physics, (24/12/0/0) MA1
- ULB - PHYS-F205 : Electricity and magnetism, (24/0/0/0) BA2
- ULB - PHYS-F210 : Laboratoires, statistique appliquée à la physique expérimentale et projet , (0/0/72/0) BA2
- ULB - PHYS-F311 : Laboratoires et Stage de recherche, (0/0/36/0) BA3
- ULB - PHYS-F-420 : Particle detectors, data acquisition and analysis, (16/12/0/0) MA1

Denise Muller

- VUB - 4015689FNR : Subatomic Physics II, (0/13/0/0) MA1

Abanti Ranadhir Sahasransu

- VUB - WE-DNTK-006510 : Sub-atomic physics II, (0/30/0/20) MA1

Aaron Rase

- VUB - 1001388CNR : Experimentele stralings- en kwantumfysica, (15/0/22/18) BA2 Lectures and lab
- VUB - 1001388CNR : Experimentele stralings- en kwantumfysica, (15/0/22/18) BA2

Laurent Thomas

- ULB - PHYS-F416 : Fundamental Interactions and particles , (36/12/0/0) MA1 MA2 Exercise sessions (analysis of CMS data)
- ULB - PHYS-F416 : Fundamental Interactions and particles , (36/12/0/0) MA1 MA2 Exercise sessions (analysis of CMS data)

Kevin Turbang

- VUB - 1010183ANR : Mechanica, (0/26/0/0) BA1 Exercises for Mechanica

Nick Van Eijndhoven

- VUB - WE-DNTK-6406 : Experimental Study of the Micro and Macrocosmos, (13/13/0/0) BA3

Dieder-Jan Van den Broeck

- VUB - WE-DNTK : Toegepaste statistiek, (0/24/0/0) BA1
- VUB - WE-DNTK : Vaste Stof en stralingsfysica, (0/30/0/0) BA2

Pascal Vanlaer

- ULB - PHYS-F-110 : Physique générale, (48/0/60/0) BA1
- ULB - PHYS-F482 : Techniques avancées de la physique expérimentale, (24/0/24/0) MA1

3.3.6.2 Membership to academic juries of Master and Phd theses

Barbara Clerbaux

- Phd thesis, - ULB, February 2022 - Nadège Iovine : Indirect Searches for Dark Matter in the Centre of the Milky Way with the IceCube Neutrino Telescope
  President
- Phd thesis, - ULB, January 2022 - Giovanni Renzi : Search for Dark Matter from the center of the earth with 10 years of Icecube data
  President

Alberto Mariotti

- Phd thesis, - VUB, July 2022 - Emil Bols : Machine Learning for Top Quark Physics
  Secretary
- Phd thesis, - UCLouvain, August 2022 - Hesham El Faham : Top quark interactions in the Standard Model Effective Field Theory
  Secretary

Denise Muller

- Phd thesis, - UCLouvain and VUB, September 2022 - Hesham El Faham : Top quark interactions in the Standard Model Effective Field Theory
  Referee

Laurent Thomas

- Phd thesis, - ULB, December 2022 - Diego Beghin : Search for new high mass resonances or quantum black holes decaying to lepton flavor violating final states with the CMS detector
  Secretary

Kevin Turbang

- Master thesis, - VUB, June 2022 - Xander Nagels : Gravitational waves from first order phase transitions
  Referee

3.3.6.3 Representation in academic councils and committees (in universities)

Yannick Allard

- Représentant CORSI au Département de Physique (Faculté des Sciences), ULB

Barbara Clerbaux

- Elected as the representative of Academic Staff at the ULB Assemblée plénière (AP), ULB
- Elected as the representative of Academic Staff at the ULB university board (CA), ULB

Alberto Mariotti

- Master examination committee voorzitter, VUB

Ioana Maris

- Secretaire du Jury de Bachelier, ULB

Denise Muller

- Co-organiser HEP@VUB seminar, VUB
- Selection comittee for VUB faculty position, VUB

Kevin Turbang

- Student representative on the Opleidingsraad and DNTK raad, VUB

Nick Van Eijndhoven

- Astroparticle Physics programme leader , VUB
- Member of the public relations board of the VUB Faculty of Science, VUB
- President or member of various PhD committees, VUB

Pascal Vanlaer

- Coordinator of the Physics department in the AEQES higher-education quality assessment process in the French community, ULB
- Member of the Diploma Equivalence Committee - section Sciences for the Walloon-Brussels Federation , Other
- Member of the Observatory of the 1st year bachelor studies in sciences, ULB
- Member of the Physics department committee for teaching assistants hirings, ULB

3.3.7 Vulgarisation and outreach

Barbara Clerbaux

- Participation to the organisation of the NCPAP (National Committee for Pure and Applied Physics) colloquium : Gravitational waves and exoplanets - Palais des Académies, Brussels , 02/04/2022

Simon De Kockere

- Particles from the Cosmos Masterclass - Brussel (IIHE), 27/04/2022
- Wetenschapskamp (Solutio) - Brussel (IIHE), 18/08/2022

Martin Delcourt

- La physique moderne, vue par un expérimentateur - Lycée Maria Assumpta, 14/09/2022

Nicolas Gonzalez

- Astrophysics Masterclass - IIHE, 01/04/2022
- IF@ULB workshop - ULB, 01/05/2022

Denise Muller

- Video for the 50-year celebration of the IIHE (explaining my work at CMS) - Brussels (Belgium), 14/09/2022

Kevin Turbang

- Gravitational wave backgrounds - Solvay Institutes for Physics and Chemistry annual report, 01/04/2022

Orazio Zapparrata

- IIHE Masterclass - Particles from the Cosmos - IIHE, Brussels, Belgium, 27/04/2022

4 Publications

4.1 IIHE publication in 2020

4.1.1 AUGER

1. *A Search for Ultra-high-energy Neutrinos from TXS 0506+056 Using the Pierre Auger Observatory*
   Aab, A et al. [AUGER Collaboration] Astrophys. J. 902 (2020) 105
2. *Cosmic-ray anisotropies in right ascension measured by the Pierre Auger Observatory*
   Aab, A et al. [AUGER Collaboration], Astrophys. J. 891 (2020) 142
3. *Direct measurement of the muonic content of extensive air showers between* 2×10^{17} *and* 2×10^{18} *eV at the Pierre Auger Observatory*
   Aab, A et al. [AUGER Collaboration], Eur. Phys. J. C 80 (2020) 751
4. *Features of the Energy Spectrum of Cosmic Rays above* 2.510^{18} *eV Using the Pierre Auger Observatory*
   Aab, A et al. [AUGER Collaboration], Phys. Rev. Lett. 125 (2020) 121106
5. *Measurement of the cosmic-ray energy spectrum above* $2.5{\times}10^{18}$ *eV using the Pierre Auger Observatory*
   Aab, A et al. [AUGER Collaboration], Phys. Rev. D 102 (2020) 062005
6. *Reconstruction of events recorded with the surface detector of the Pierre Auger Observatory*
   Aab, A et al. [AUGER Collaboration], JINST 15 (2020) P10021
7. *Search for magnetically-induced signatures in the arrival directions of ultra-high-energy cosmic rays measured at the Pierre Auger Observatory*
   Aab, A et al. [AUGER Collaboration], JCAP 06 (2020) 017
8. *Studies on the response of a water-Cherenkov detector of the Pierre Auger Observatory to atmospheric muons using an RPC hodoscope*
   Aab, A et al. [AUGER Collaboration], JINST 15 (2020) P09002

4.1.2 CMS

1. *A measurement of the Higgs boson mass in the diphoton decay channel*
   Sirunyan, A et al. [CMS Collaboration], Phys. Lett. B 805 (2020) 135425
2. *A search for bottom-type, vector-like quark pair production in a fully hadronic final state in proton-proton collisions at* $\sqrt{s} = 13$ *TeV*
   Sirunyan, A et al. [CMS Collaboration], Phys. Rev. D 102 (2020) 112004
3. *Beam test performance of prototype silicon detectors for the Outer Tracker for the Phase-2 Upgrade of CMS*
   Adam, W et al. [CMS Collaboration], JINST 15 (2020) P03014
4. *Combination of the W boson polarization measurements in top quark decays using ATLAS and CMS data at* $\sqrt{s} = 8$ *TeV*
   Aad, G et al. [CMS Collaboration], JHEP 08 (2020) 051
5. *Dependence of inclusive jet production on the anti-*k_T *distance parameter in pp collisions at* $\sqrt{\mathrm{s}} = 13$ *TeV*
   Sirunyan, A et al. [CMS Collaboration], JHEP 12 (2020) 082
6. *Evidence for Top Quark Production in Nucleus-Nucleus Collisions*
   Sirunyan, A et al. [CMS Collaboration], Phys. Rev. Lett. 125 (2020) 222001
7. *Experimental Study of Different Silicon Sensor Options for the Upgrade of the CMS Outer Tracker*
   Steinbruck, G et al. [CMS Collaboration], JINST 15 (2020) P04017
8. *Identification of heavy, energetic, hadronically decaying particles using machine-learning techniques*
   Sirunyan, A et al. [CMS Collaboration], JINST 15 (2020) P06005
9. *Inclusive search for highly boosted Higgs bosons decaying to bottom quark-antiquark pairs in proton-proton collisions at* $\sqrt{s} = 13$ *TeV*
   Sirunyan, A et al. [CMS Collaboration], JHEP 12 (2020) 085

10. *Investigation into the event-activity dependence of Υ(nS) relative production in proton-proton collisions at $\sqrt{s}$ = 7 TeV*
Sirunyan, A et al. [CMS Collaboration], JHEP 11 (2020) 001

11. *Measurement of $B_c(2S)^+$ and $B_c^*(2S)^+$ cross section ratios in proton-proton collisions at $\sqrt{s} = 13$ TeV*
Sirunyan, A et al. [CMS Collaboration], Phys. Rev. D 102 (2020) 092007

12. *Measurement of CKM matrix elements in single top quark t-channel production in proton-proton collisions at $\sqrt{s} = 13$ TeV*
Sirunyan, A et al. [CMS Collaboration], Phys. Lett. B 808 (2020) 135609

13. *Measurement of quark- and gluon-like jet fractions using jet charge in PbPb and pp collisions at 5.02 TeV*
Sirunyan, A et al. [CMS Collaboration], JHEP 07 (2020) 115

14. *Measurement of the Υ(1S) pair production cross section and search for resonances decaying to $\Upsilon(1S)\mu^+\mu^-$ in proton-proton collisions at $\sqrt{s} = 13$ TeV*
Sirunyan, A et al. [CMS Collaboration], Phys. Lett. B 808 (2020) 135578

15. *Measurement of the associated production of a Z boson with charm or bottom quark jets in proton-proton collisions at $\sqrt{s}$=13 TeV*
Sirunyan, A et al. [CMS Collaboration], Phys. Rev. D 102 (2020) 032007

16. *Measurement of the cross section for $t\bar{t}$ production with additional jets and b jets in pp collisions at $\sqrt{s} = 13$ TeV*
Sirunyan, A et al. [CMS Collaboration], JHEP 07 (2020) 125

17. *Measurement of the cross section for electroweak production of a Z boson, a photon and two jets in proton-proton collisions at $\sqrt{s} = 13$ TeV and constraints on anomalous quartic couplings*
Sirunyan, A et al. [CMS Collaboration], JHEP 06 (2020) 076

18. *Measurement of the top quark Yukawa coupling from* $\mathrm{t\bar{t}}$ *kinematic distributions in the dilepton final state in proton-proton collisions at $\sqrt{s} = 13$ TeV*
Sirunyan, A et al. [CMS Collaboration], Phys. Rev. D 102 (2020) 092013

19. *Measurements of* $\mathrm{t\bar{t}}$*H Production and the CP Structure of the Yukawa Interaction between the Higgs Boson and Top Quark in the Diphoton Decay Channel*
Sirunyan, A et al. [CMS Collaboration], Phys. Rev. Lett. 125 (2020) 061801

20. *Measurements of production cross sections of WZ and same-sign WW boson pairs in association with two jets in proton-proton collisions at $\sqrt{s} = 13$ TeV*
Sirunyan, A et al. [CMS Collaboration], Phys. Lett. B 809 (2020) 135710

21. *Measurements of the W boson rapidity, helicity, double-differential cross sections, and charge asymmetry in pp collisions at $\sqrt{s} = 13$ TeV*
Sirunyan, A et al. [CMS Collaboration], Phys. Rev. D 102 (2020) 092012

22. *Measurements with silicon photomultipliers of dose-rate effects in the radiation damage of plastic scintillator tiles in the CMS hadron endcap calorimeter*
Sirunyan, A et al. [CMS Collaboration], JINST 15 (2020) P06009

23. *Observation of electroweak production of $W\gamma$ with two jets in proton-proton collisions at $\sqrt{s} = 13$ TeV*
Sirunyan, A et al. [CMS Collaboration], Phys. Lett. B 811 (2020) 135988

24. *Observation of the $B_s^0 \rightarrow X(3872)\phi$ decay*
Sirunyan, A et al. [CMS Collaboration], Phys. Rev. Lett. 125 (2020) 152001

25. *Observation of the Production of Three Massive Gauge Bosons at $\sqrt{s}$ =13 TeV*
Sirunyan, A et al. [CMS Collaboration], Phys. Rev. Lett. 125 (2020) 151802

26. *Performance of the CMS Level-1 trigger in proton-proton collisions at $\sqrt{s} = 13$ TeV*
Sirunyan, A et al. [CMS Collaboration], JINST 15 (2020) P10017

27. *Pileup mitigation at CMS in 13 TeV data*
Sirunyan, A et al. [CMS Collaboration], JINST 15 (2020) P09018

28. *Reconstruction of signal amplitudes in the CMS electromagnetic calorimeter in the presence of overlapping proton-proton interactions*
Sirunyan, A et al. [CMS Collaboration], JINST 15 (2020) P10002

29. *Search for a light charged Higgs boson in the $H^{\pm} \to cs$ channel in proton-proton collisions at $\sqrt{s} = 13$ TeV*
Sirunyan, A et al. [CMS Collaboration], Phys. Rev. D 102 (2020) 072001

30. *Search for a light pseudoscalar Higgs boson in the boosted $\mu\mu\tau\tau$ final state in proton-proton collisions at $\sqrt{s} = 13$ TeV*
Sirunyan, A et al. [CMS Collaboration], JHEP 08 (2020) 139

31. *Search for an excited lepton that decays via a contact interaction to a lepton and two jets in proton-proton collisions at $\sqrt{s} = 13$ TeV*
Sirunyan, A et al. [CMS Collaboration], JHEP 05 (2020) 052

32. *Search for charged Higgs bosons decaying into a top and a bottom quark in the all-jet final state of pp collisions at $\sqrt{s} = 13$ TeV*
Sirunyan, A et al. [CMS Collaboration], JHEP 07 (2020) 126

33. *Search for decays of the 125 GeV Higgs boson into a Z boson and a ρ or ϕ meson*
Sirunyan, A et al. [CMS Collaboration], JHEP 11 (2020) 039

34. *Search for disappearing tracks in proton-proton collisions at $\sqrt{s} = 13$ TeV*
Sirunyan, A et al. [CMS Collaboration], Phys. Lett. B 806 (2020) 135502

35. *Search for physics beyond the standard model in events with jets and two same-sign or at least three charged leptons in proton-proton collisions at $\sqrt{s} = 13$ TeV*
Sirunyan, A et al. [CMS Collaboration], Eur. Phys. J. C 80 (2020) 752

36. *Search for resonant pair production of Higgs bosons in the $bbZZ$ channel in proton-proton collisions at $\sqrt{s} = 13$ TeV*
Sirunyan, A et al. [CMS Collaboration], Phys. Rev. D 102 (2020) 032003

37. *Search for supersymmetry in pp collisions at $\sqrt{s} = 13$ TeV with 137 fb^{-1} in final states with a single lepton using the sum of masses of large-radius jets*
Sirunyan, A et al. [CMS Collaboration], Phys. Rev. D 101 (2020) 052010

38. *Search for supersymmetry in proton-proton collisions at $\sqrt{s} = 13$ TeV in events with high-momentum Z bosons and missing transverse momentum*
Sirunyan, A et al. [CMS Collaboration], JHEP 09 (2020) 149

39. *Study of central exclusive $\pi^+\pi^-$ production in proton-proton collisions at $\sqrt{s} = 5.02$ and 13 TeV*
Sirunyan, A et al. [CMS Collaboration], Eur. Phys. J. C 80 (2020) 718

40. *Study of excited Λ_b^0 states decaying to $\Lambda_b^0\pi^+\pi^-$ in proton-proton collisions at $\sqrt{s} = 13$ TeV*
Sirunyan, A et al. [CMS Collaboration], Phys. Lett. B 803 (2020) 135345

41. *The production of isolated photons in PbPb and pp collisions at $\sqrt{s_{NN}} = 5.02$ TeV*
Sirunyan, A et al. [CMS Collaboration], JHEP 07 (2020) 116

42. *W^+W^- boson pair production in proton-proton collisions at $\sqrt{s} = 13$ TeV*
Sirunyan, A et al. [CMS Collaboration], Phys. Rev. D 102 (2020) 092001

4.1.3 H1

1. *Measurement of Exclusive $\pi^+\pi^-$ and ρ^0 Meson Photoproduction at HERA*
Andreev, V et al. [H1 Collaboration], Eur. Phys. J. C 80 (2020) 1189

4.1.4 ICECUBE

1. *A search for IceCube events in the direction of ANITA neutrino candidates*
Aartsen, M et al. [ICECUBE Collaboration] Astrophys. J. 892 (2020) 53

2. *A Search for MeV to TeV Neutrinos from Fast Radio Bursts with IceCube*
Aartsen, M et al. [ICECUBE Collaboration] Astrophys. J. 890 (2020) 111

3. *A Search for Neutrino Point-source Populations in 7 yr of IceCube Data with Neutrino-count Statistics*
Aartsen, M et al. [ICECUBE Collaboration] Astrophys. J. 893 (2020) 102

4. *ANTARES and IceCube Combined Search for Neutrino Point-like and Extended Sources in the Southern Sky*
Albert, A et al. [ICECUBE Collaboration] Astrophys. J. 892 (2020) 92

5. *Characteristics of the diffuse astrophysical electron and tau neutrino flux with six years of IceCube high energy cascade data*
Aartsen, M et al. [ICECUBE Collaboration] Phys. Rev. Lett. 125 (2020) 121104

6. *Combined search for neutrinos from dark matter self-annihilation in the Galactic Center with ANTARES and IceCube*
Albert, A et al. [ICECUBE Collaboration] Phys. Rev. D 102 (2020) 082002

7. *Combined sensitivity to the neutrino mass ordering with JUNO, the IceCube Upgrade, and PINGU*
Aartsen, M et al. [ICECUBE Collaboration] Phys. Rev. D 101 (2020) 032006

8. *Constraints on neutrino emission from nearby galaxies using the 2MASS redshift survey and IceCube*
Aartsen, M et al. [ICECUBE Collaboration] JCAP 07 (2020) 042

9. *Cosmic ray spectrum from 250 TeV to 10 PeV using IceTop*
Aartsen, M et al. [ICECUBE Collaboration] Phys. Rev. D 102 (2020) 122001

10. *Design and Performance of the first IceAct Demonstrator at the South Pole*
Aartsen, M et al. [ICECUBE Collaboration] JINST 15 (2020) T02002

11. *Development of an analysis to probe the neutrino mass ordering with atmospheric neutrinos using three years of IceCube DeepCore data*
Aartsen, M et al. [ICECUBE Collaboration] Eur. Phys. J. C 80 (2020) 9

12. *eV-Scale Sterile Neutrino Search Using Eight Years of Atmospheric Muon Neutrino Data from the IceCube Neutrino Observatory*
Aartsen, M et al. [ICECUBE Collaboration] Phys. Rev. Lett. 125 (2020) 141801

13. *IceCube Search for High-Energy Neutrino Emission from TeV Pulsar Wind Nebulae*
Aartsen, M et al. [ICECUBE Collaboration] Astrophys. J. 898 (2020) 117

14. *IceCube Search for Neutrinos Coincident with Compact Binary Mergers from LIGO-Virgo's First Gravitational-wave Transient Catalog*
Aartsen, M et al. [ICECUBE Collaboration] Astrophys. J. Lett. 898 (2020) L10

15. *In-situ calibration of the single-photoelectron charge response of the IceCube photomultiplier tubes*
Aartsen, M et al. [ICECUBE Collaboration] JINST 15 (2020) P06032

16. *Neutrinos below 100 TeV from the southern sky employing refined veto techniques to IceCube data*
Aartsen, M et al. [ICECUBE Collaboration] Astropart. Phys. 116 (2020) 102392

17. *Searching for eV-scale sterile neutrinos with eight years of atmospheric neutrinos at the IceCube Neutrino Telescope*
    Aartsen, M et al. [ICECUBE Collaboration] Phys. Rev. D 102 (2020) 052009

18. *Time-Integrated Neutrino Source Searches with 10 Years of IceCube Data*
    Aartsen, M et al. [ICECUBE Collaboration] Phys. Rev. Lett. 124 (2020) 051103

19. *Velocity Independent Constraints on Spin-Dependent DM-Nucleon Interactions from IceCube and PICO*
    Aartsen, M et al. [ICECUBE Collaboration] Eur. Phys. J. C 80 (2020) 819

4.1.5 JUNO

1. *TAO Conceptual Design Report: A Precision Measurement of the Reactor Antineutrino Spectrum with Subpercent Energy Resolution*
   Abusleme, A et al. [JUNO Collaboration], arXiv:2005.08745

4.1.6 LOFAR

1. *Determining Electric Fields in Thunderclouds With the Radiotelescope LOFAR*
   Trinh, T et al. [LOFAR Collaboration], J. Geophys. Res. Atmos. 125 (2020) e2019JD031433
2. *On the cosmic-ray energy scale of the LOFAR radio telescope*
   Mulrey, K et al. [LOFAR Collaboration], JCAP 11 (2020) 017
3. *Reconstructing air shower parameters with LOFAR using event specific GDAS atmosphere*
   Mitra, P et al. [LOFAR Collaboration], Astropart. Phys. 123 (2020) 102470

4.1.7 PHENO

1. *Ripples in Spacetime from Broken Supersymmetry*
   Craig, N et al. [PHENO Collaboration], JHEP 21 (2020) 184

4.2 Publications in 2021

4.2.1 AUGER

1. *Deep-learning based reconstruction of the shower maximum X_{max} using the water-Cherenkov detectors of the Pierre Auger Observatory*
   Aab, A et al. [AUGER Collaboration], JINST 16 (2021) P07019

2. *Design and implementation of the AMIGA embedded system for data acquisition*
   Aab, A et al. [AUGER Collaboration], JINST 16 (2021) T07008

3. *Extraction of the muon signals recorded with the surface detector of the Pierre Auger Observatory using recurrent neural networks*
   Aab, A et al. [AUGER Collaboration], JINST 16 (2021) P07016

4. *Measurement of the Fluctuations in the Number of Muons in Extensive Air Showers with the Pierre Auger Observatory*
   Aab, A et al. [AUGER Collaboration], Phys. Rev. Lett. 126 (2021) 152002

5. *The energy spectrum of cosmic rays beyond the turn-down around 10^{17} eV as measured with the surface detector of the Pierre Auger Observatory*
   Abreu, P et al. [AUGER Collaboration], Eur. Phys. J. C 81 (2021) 966

6. *The FRAM robotic telescope for atmospheric monitoring at the Pierre Auger Observatory*
   Aab, A et al. [AUGER Collaboration], JINST 16 (2021) P06027

4.2.2 CMS

1. *Combined searches for the production of supersymmetric top quark partners in protonproton collisions at $\sqrt{s} = 13\ TeV$*
   Tumasyan, A et al. [CMS Collaboration], Eur. Phys. J. C 81 (2021) 970

2. *Comparative evaluation of analogue front-end designs for the CMS Inner Tracker at the High Luminosity LHC*
   Adam, W et al. [CMS Collaboration], JINST 16 (2021) P12014

3. *Constraints on anomalous Higgs boson couplings to vector bosons and fermions in its production and decay using the four-lepton final state*
   Sirunyan, A et al. [CMS Collaboration], Phys. Rev. D 104 (2021) 052004

4. *Constraints on the Initial State of Pb-Pb Collisions via Measurements of Z-Boson Yields and Azimuthal Anisotropy at $\sqrt{s_{NN}} = 5.02 TeV$*
   Sirunyan, A et al. [CMS Collaboration], Phys. Rev. Lett. 127 (2021) 102002

5. *First measurement of large area jet transverse momentum spectra in heavy-ion collisions*
   Sirunyan, A et al. [CMS Collaboration], JHEP 05 (2021) 284

6. *Hard color-singlet exchange in dijet events in proton-proton collisions at $\sqrt{s}$ = 13 TeV*
   Sirunyan, A et al. [CMS Collaboration], Phys. Rev. D 104 (2021) 032009

7. *In-medium modification of dijets in PbPb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV*
   Sirunyan, A et al. [CMS Collaboration], JHEP 05 (2021) 116

8. *Measurement of differential $t\bar{t}$ production cross sections in the full kinematic range using lepton+jets events from proton-proton collisions at $\sqrt{s}$ = 13 TeV*
   Tumasyan, A et al. [CMS Collaboration], Phys. Rev. D 104 (2021) 092013

9. *Measurement of prompt open-charm production cross sections in proton-proton collisions at $\sqrt{s}$ = 13 TeV*
   Tumasyan, A et al. [CMS Collaboration], JHEP 11 (2021) 225

10. *Measurement of the electroweak production of $Z\gamma$ and two jets in proton-proton collisions at $\sqrt{s}$ = 13 TeV and constraints on anomalous quartic gauge couplings*
    Tumasyan, A et al. [CMS Collaboration], Phys. Rev. D 104 (2021) 072001

11. *Measurement of the inclusive and differential $t\bar{t}$ γ cross sections in the single-lepton channel and EFT interpretation at $\sqrt{s}$ = 13 TeV*
    Tumasyan, A et al. [CMS Collaboration], JHEP 12 (2021) 180

12. *Measurement of the top quark mass using events with a single reconstructed top quark in pp collisions at $\sqrt{s}$ = 13 TeV*
Tumasyan, A et al. [CMS Collaboration], JHEP 12 (2021) 161

13. *Measurement of the $W\gamma$ Production Cross Section in Proton-Proton Collisions at $\sqrt{s}$ = 13 TeV and Constraints on Effective Field Theory Coefficients*
Sirunyan, A et al. [CMS Collaboration], Phys. Rev. Lett. 126 (2021) 252002

14. *Measurements of angular distance and momentum ratio distributions in three-jet and Z + two-jet final states in pp collisions*
Sirunyan, A et al. [CMS Collaboration], Eur. Phys. J. C 81 (2021) 852

15. *Measurements of Higgs boson production cross sections and couplings in the diphoton decay channel at $\sqrt{\mathrm{s}}$ = 13 TeV*
Sirunyan, A et al. [CMS Collaboration], JHEP 07 (2021) 027

16. *Measurements of production cross sections of the Higgs boson in the four-lepton final state in protonproton collisions at $\sqrt{s} = 13$ TeV*
Sirunyan, A et al. [CMS Collaboration], Eur. Phys. J. C 81 (2021) 488

17. *Measurements of the differential cross sections of the production of Z + jets and γ + jets and of Z boson emission collinear with a jet in pp collisions at $\sqrt{s}$ = 13 TeV*
Sirunyan, A et al. [CMS Collaboration], JHEP 05 (2021) 285

18. *Measurements of the electroweak diboson production cross sections in proton-proton collisions at $\sqrt{s}$ = 5.02 TeV using leptonic decays*
Tumasyan, A et al. [CMS Collaboration], Phys. Rev. Lett. 127 (2021) 191801

19. *Measurements of the $pp \to W^{\pm}\gamma\gamma$ and $pp \to Z\gamma\gamma$ cross sections at $\sqrt{s}$ = 13 TeV and limits on anomalous quartic gauge couplings*
Tumasyan, A et al. [CMS Collaboration], JHEP 10 (2021) 174

20. *Observation of a New Excited Beauty Strange Baryon Decaying to $\Xi_{\mathrm{b}}^{-}\pi^{+}\pi^{-}$*
Sirunyan, A et al. [CMS Collaboration], Phys. Rev. Lett. 126 (2021) 252003

21. *Observation of tW production in the single-lepton channel in pp collisions at $\sqrt{s}$ = 13 TeV*
Tumasyan, A et al. [CMS Collaboration], JHEP 11 (2021) 111

22. *Performance of the CMS muon trigger system in proton-proton collisions at $\sqrt{s}$ = 13 TeV*
Sirunyan, A et al. [CMS Collaboration], JINST 16 (2021) P07001

23. *Precision luminosity measurement in proton-proton collisions at $\sqrt{s}$ = 13 TeV in 2015 and 2016 at CMS*
Sirunyan, A et al. [CMS Collaboration], Eur. Phys. J. C 81 (2021) 800

24. *Probing effective field theory operators in the associated production of top quarks with a Z boson in multilepton final states at $\sqrt{s}$ = 13 TeV*
Lee, K et al. [CMS Collaboration], JHEP 12 (2021) 083

25. *Search for a heavy Higgs boson decaying into two lighter Higgs bosons in the $\tau\tau bb$ final state at 13 TeV*
Tumasyan, A et al. [CMS Collaboration], JHEP 11 (2021) 057

26. *Search for a heavy resonance decaying to a top quark and a W boson at $\sqrt{s}$ = 13 TeV in the fully hadronic final state*
Sirunyan, A et al. [CMS Collaboration], JHEP 12 (2021) 106

27. *Search for a heavy vector resonance decaying to a Z boson and a Higgs boson in proton-proton collisions at $\sqrt{s} = 13$ TeV*
Sirunyan, A et al. [CMS Collaboration], Eur. Phys. J. C 81 (2021) 688

28. *Search for charged Higgs bosons produced in vector boson fusion processes and decaying into vector boson pairs in protonproton collisions at $\sqrt{s} = 13$ TeV*
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