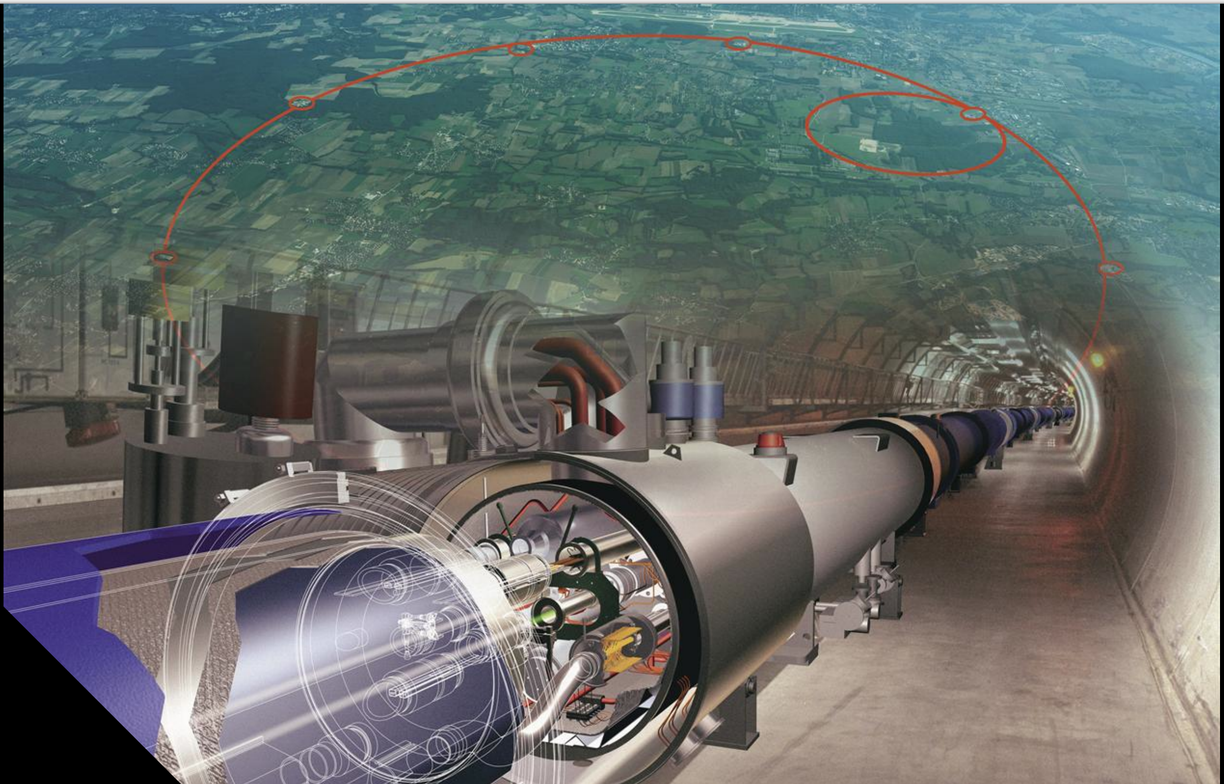
Particle Physics from the European Region
- focus on future colliders -



Jorgen D’Hondt
Vrije Universiteit Brussel
ECFA chairperson
(https://ecfa.web.cern.ch)

X CPAN Days 2018
29-31 October
Salamanca

HEP@VUB
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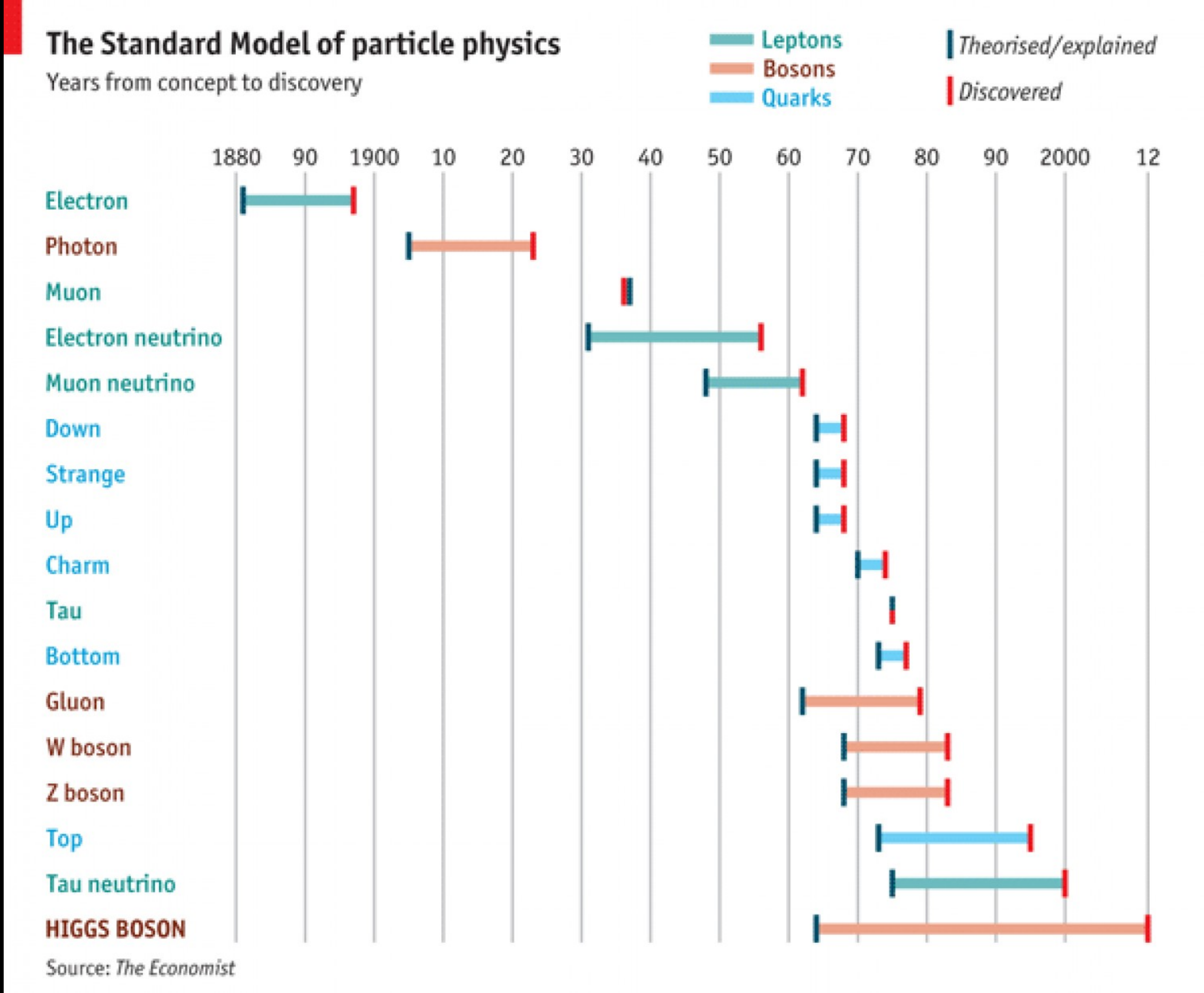
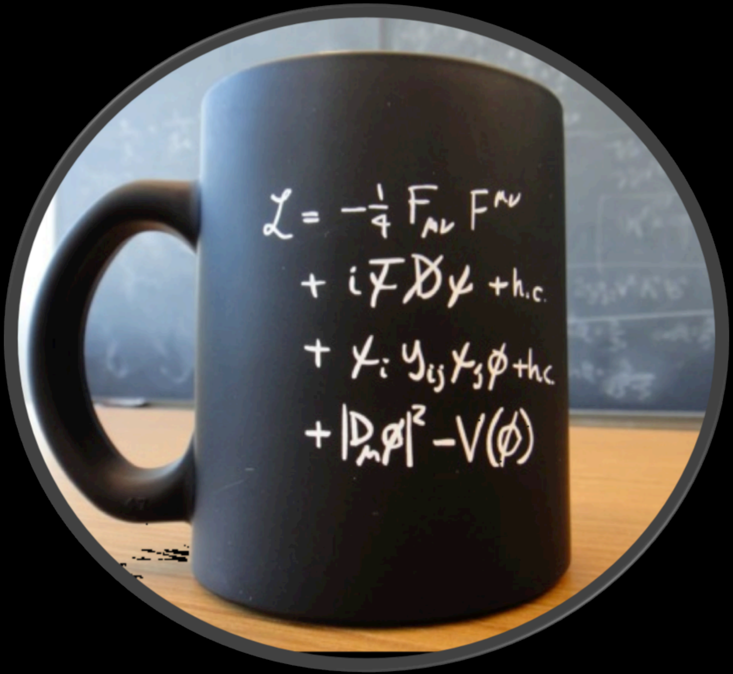
BRUXELLES BRUSSEL

July 4, 2012

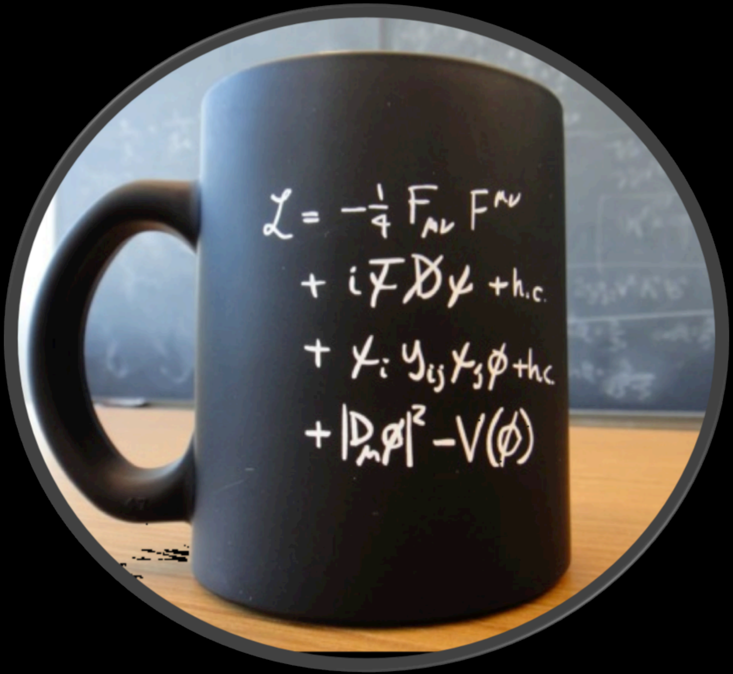
Source:
The Economist
July 4th, 2012



Particle Physics today

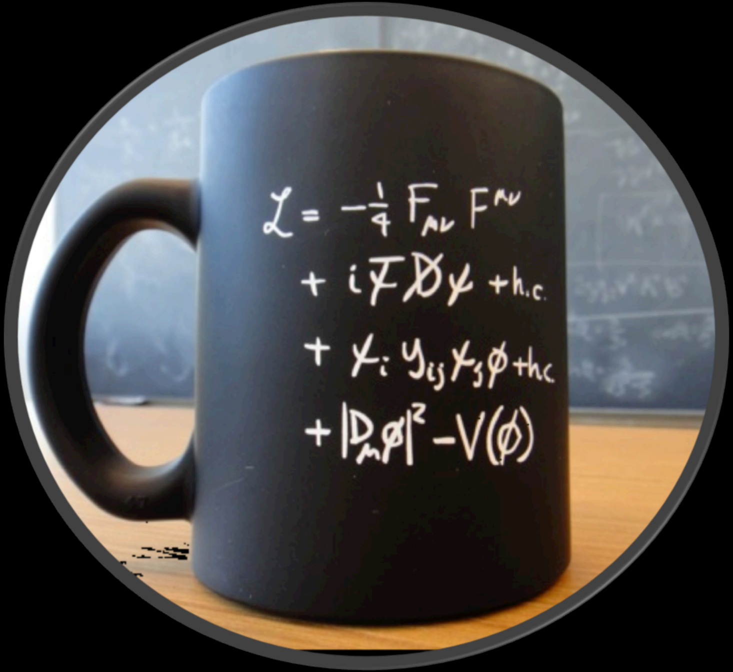


Particle Physics today



description ≠ understanding

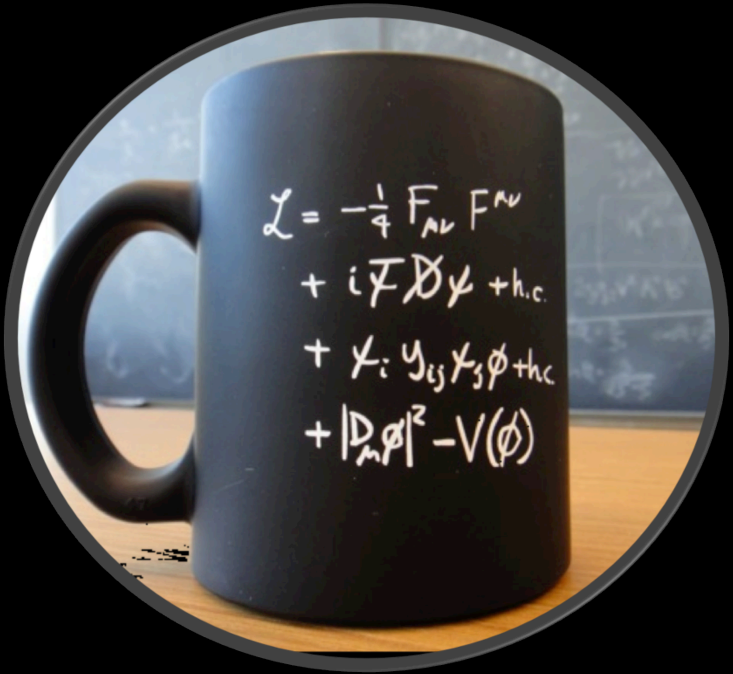
Particle Physics today



description ≠ understanding

new physics

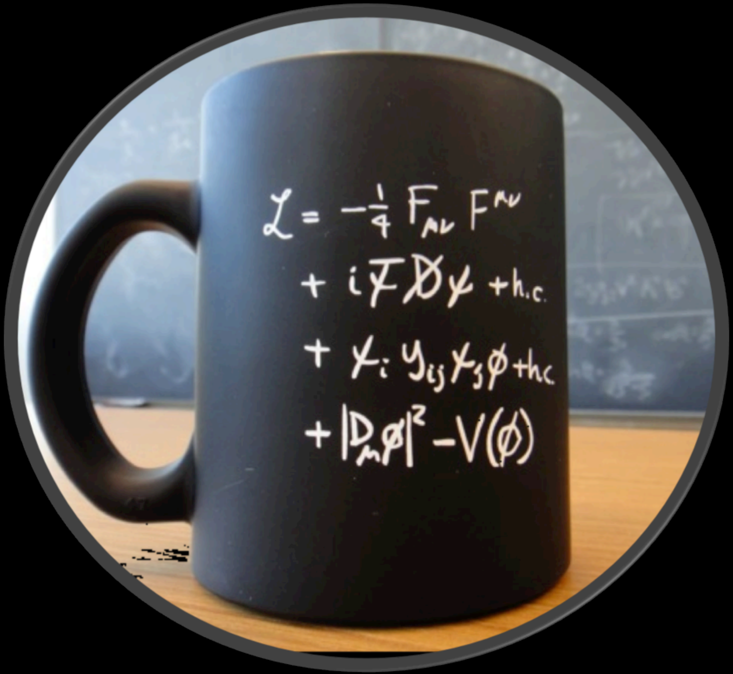
Particle Physics today



description ≠ understanding

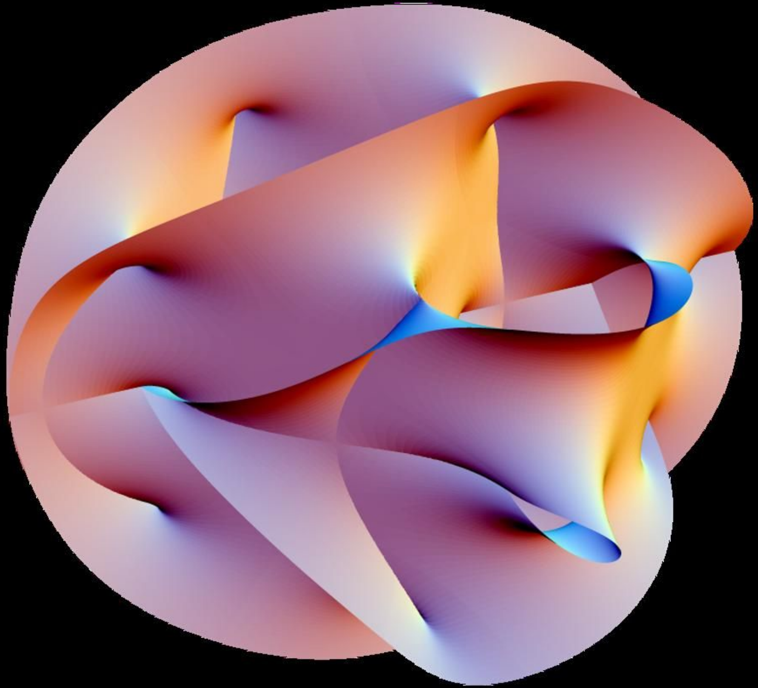
new physics

Particle Physics today



description ≠ understanding

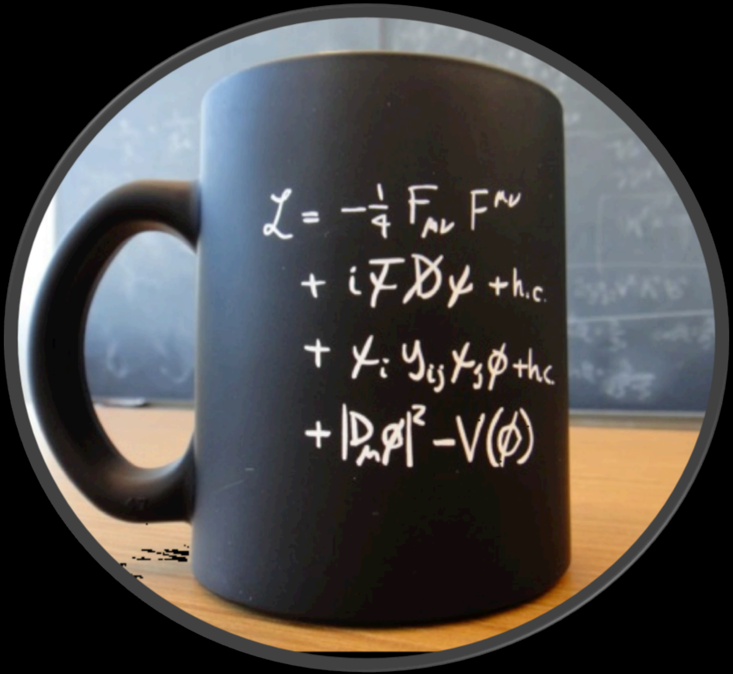
or more elegant ?



new physics

Particle Physics today

or more surreal?



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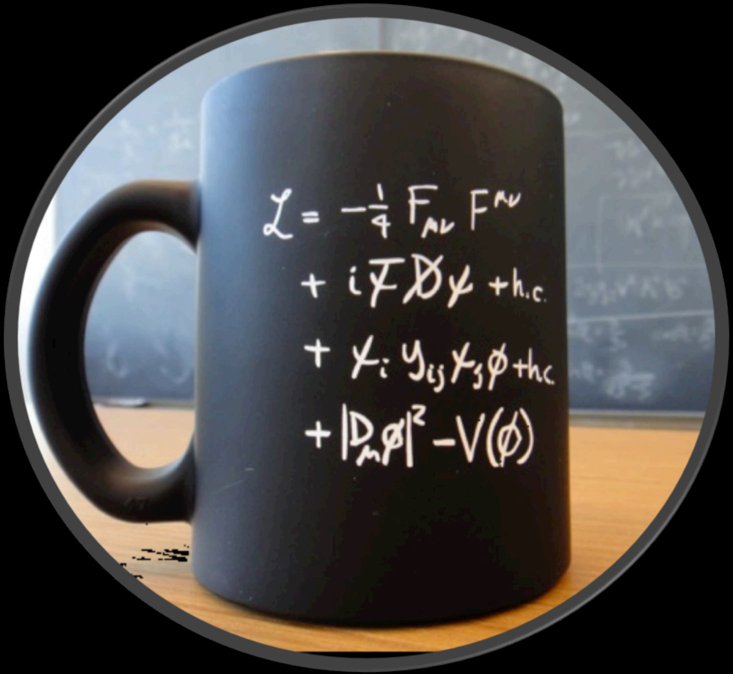
Particle Physics today



connection

description ≠ understanding

new physics

Need to agree on a long-term strategy for Particle Physics

European Particle Physics Strategy (2013)

TODAY

Higgs discovery (2012)

Start data taking at the LHC (2010)

The European Particle Physics Strategy 2013

With the highest priority

① Europe's top priority should be the exploitation of the full potential of the LHC, including the high-luminosity upgrade of the machine and detectors with a view to collecting ten times more data than in the initial design, by around 2030. This upgrade programme will also provide further exciting opportunities for the study of flavour physics and the quark-gluon plasma.

② CERN should undertake design studies for accelerator projects in a global context, with emphasis on proton-proton and electron-positron high-energy frontier machines. These design studies should be coupled to a vigorous accelerator R&D programme, including high-field magnets and high-gradient accelerating structures, in collaboration with national institutes, laboratories and universities worldwide.

③ Europe looks forward to a [ILC] proposal from Japan to discuss a possible participation.

④ CERN should develop a neutrino programme to pave the way for a substantial European role in future long-baseline experiments. Europe should explore the possibility of major participation in leading long-baseline neutrino projects in the US and Japan.

The European Particle Physics Strategy 2013

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see talk on Neutrinos by Pilar Hernandez

The European Particle Physics Strategy 2013

Other scientific activities essential to the particle physics programme

① Europe should support a diverse, vibrant theoretical physics programme, ranging from abstract to applied topics, in close collaboration with experiments and extending to neighbouring fields such as astroparticle physics and cosmology. Such support should extend also to high-performance computing and software development.

② Experiments in Europe with unique reach should be supported, as well as participation in experiments in other regions of the world. Examples: quark flavour physics, dipole moments, charged-lepton flavour violation, etc.

③ Detector R&D programmes should be supported strongly at CERN, national institutes, laboratories and universities. Infrastructure and engineering capabilities for the R&D programme and construction of large detectors, as well as infrastructures for data analysis, data preservation and distributed data-intensive computing should be maintained and further developed.

④ In the coming years, CERN should seek a closer collaboration with ApPEC on detector R&D with a view to maintaining the community's capability for unique projects in this field.

⑤ The CERN Laboratory should maintain its capability to perform unique experiments. CERN should continue to work with NuPECC on topics of mutual interest.

The European Particle Physics Strategy 2013

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see theory talk of Veronica Sanz

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see many other talk, e.g. Angela Bracco on the Long Range Plan of NuPECC

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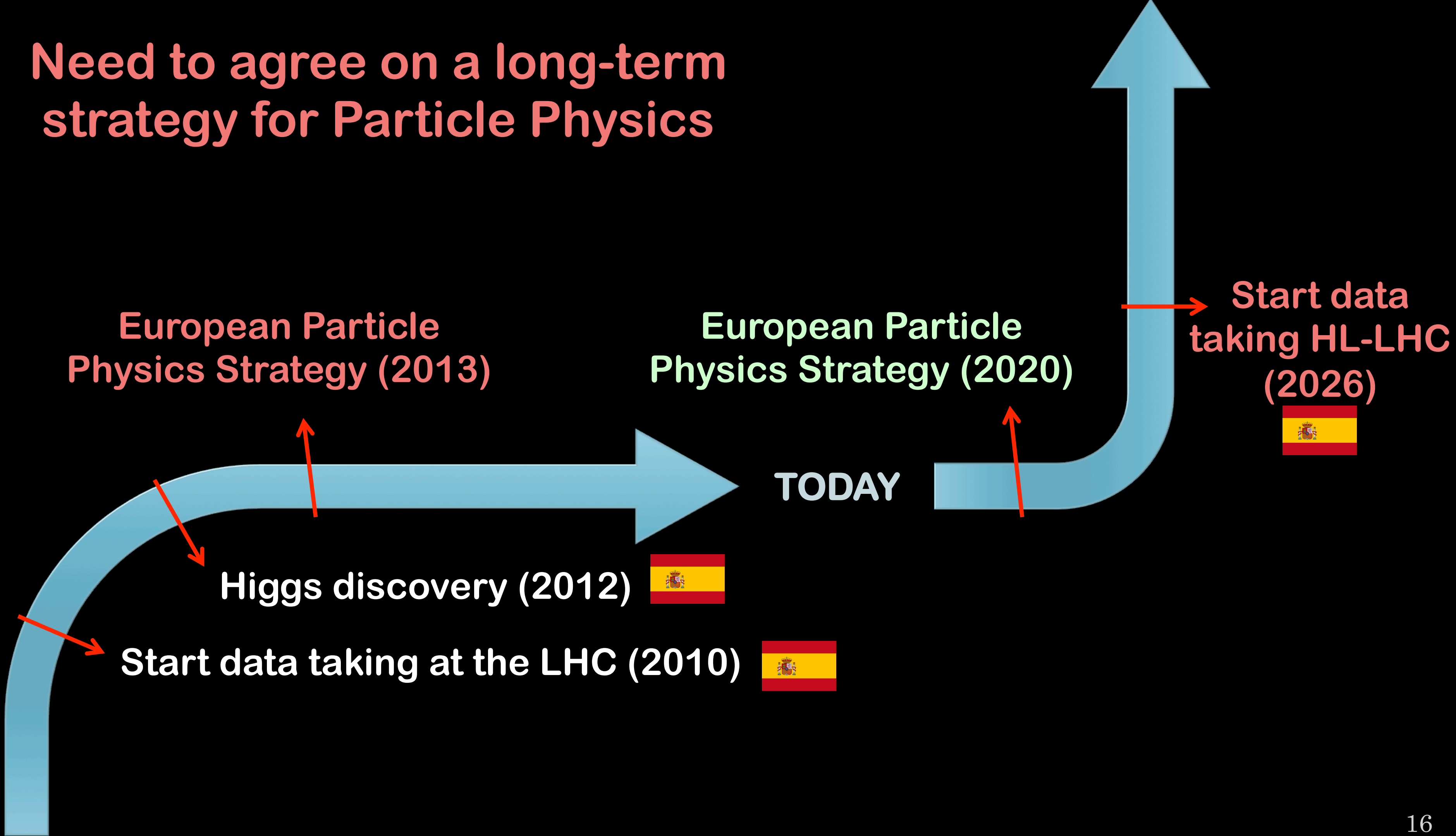
Need to agree on a long-term strategy for Particle Physics



Need to agree on a long-term strategy for Particle Physics

Start data taking at the LHC (2010)

Higgs discovery (2012)

European Particle Physics Strategy (2013)

TODAY

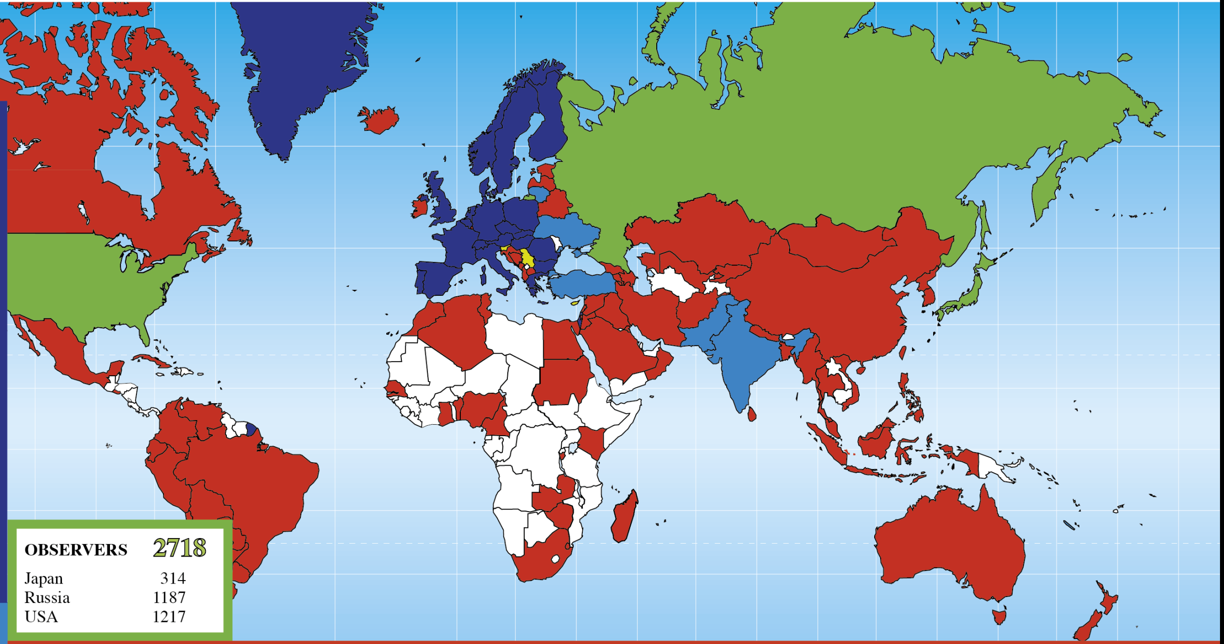
European Particle Physics Strategy (2020)

Start data taking HL-LHC (2026)

Future

CERN, the European Laboratory for global collaboration

Distribution of All CERN Users by Nationality on 24 January 2018



MEMBER STATES 7889

Austria	117
Belgium	120
Bulgaria	96
Czech Republic	244
Denmark	67
Finland	111
France	868
Germany	1342
Greece	237
Hungary	76
Israel	65
Italy	2045
Netherlands	168
Norway	67
Poland	350
Portugal	127
Romania	134
Slovakia	124
Spain	447
Sweden	85
Switzerland	228
United Kingdom	771

OBSERVERS 2718

Japan	314
Russia	1187
USA	1217

ASSOCIATE MEMBERS 745

India	357
Lithuania	35
Pakistan	65
Turkey	173
Ukraine	115

ASSOCIATE MEMBERS IN THE PRE-STAGE TO MEMBERSHIP 118

Cyprus	26
Serbia	57
Slovenia	35

OTHERS 1872

Afghanistan	1
Albania	3
Algeria	14
Argentina	27
Armenia	19
Australia	31
Azerbaijan	10
Bangladesh	11
Belarus	48
Benin	1
Bolivia	4
Bosnia & Herzegovina	2
Brazil	135
Burundi	1
Cameroon	1
Canada	161
Chile	20
China	510
Colombia	45
Croatia	41
Cuba	12
Ecuador	6
Egypt	31
El Salvador	1
Estonia	15
Georgia	46
Ghana	1
Hong Kong	1
Iceland	3
Indonesia	11
Iran	51
Iraq	1
Ireland	16
Jordan	1
Kazakhstan	5
Kenya	3
Korea Rep.	185
Kyrgyzstan	1
Latvia	2
Lebanon	23
Luxembourg	2
Madagascar	4
Malaysia	15
Malta	9
Mauritius	1
Mexico	82
Mongolia	2
Montenegro	11
Morocco	20
Myanmar	1
Nepal	10
New Zealand	5
Nigeria	3
North Korea	1
Oman	3
Palestine (O.T.)	7
Paraguay	2
Peru	7
Philippines	3
Saint Kitts and Nevis	1
Saudi Arabia	2
Senegal	1
Singapore	4
South Africa	56
Sri Lanka	6
Sudan	1
Swaziland	1
Syria	1
Taiwan	51
Thailand	22
T.F.Y.R.O.M.	2
Tunisia	5
Uruguay	1
Uzbekistan	4
Venezuela	10
Viet Nam	13
Zambia	1
Zimbabwe	2

13342 users

60% from member states

European institutions are involved in Particle Physics experiments worldwide

The 2013 European Particle Physics Strategy

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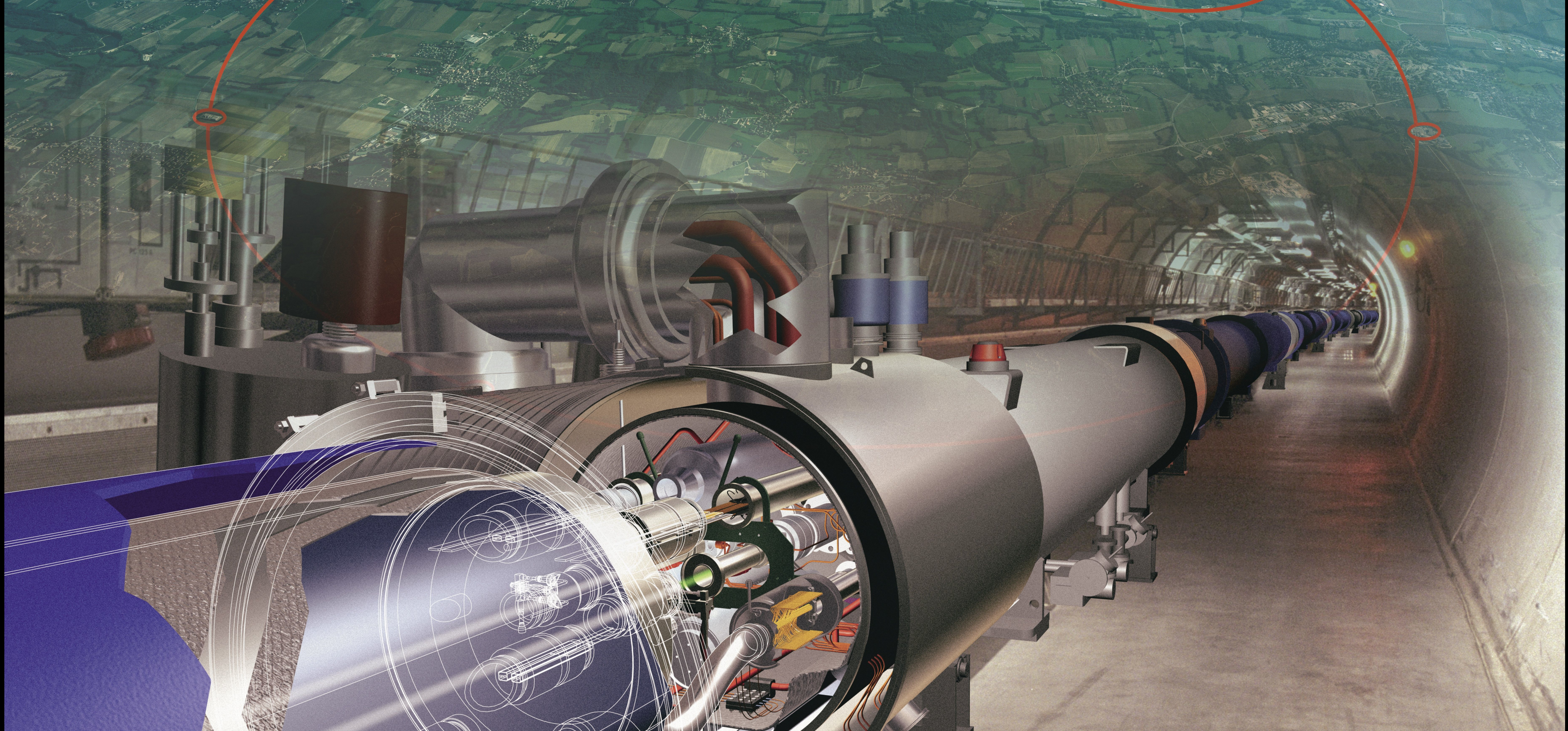
CERN and the LHC – colliding protons & ions

- Running at 13 TeV, beyond design luminosity, goal is 300/fb by end of Run3
- HL-LHC approved by Council in June 2016, goal is 3000/fb by ~2037
- Accelerator and detector upgrades on schedule for timely installation



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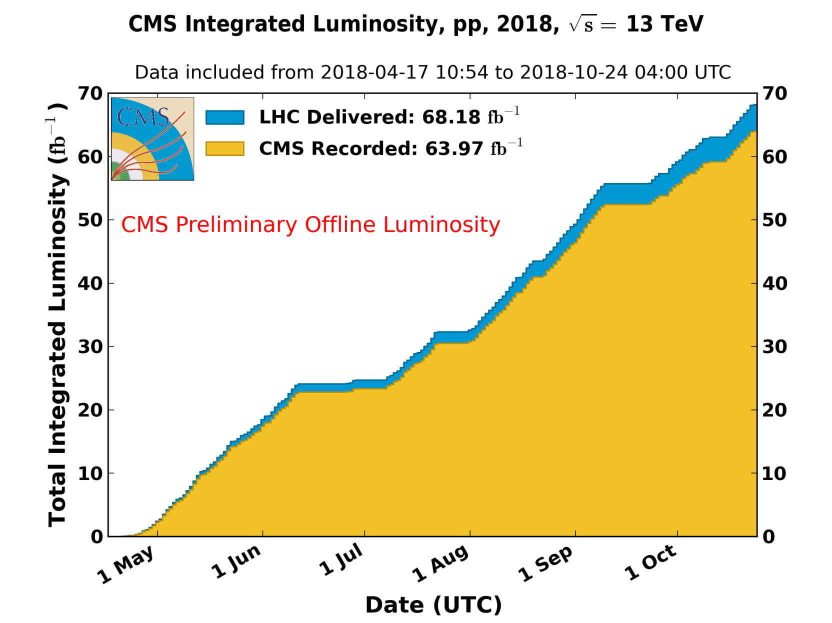

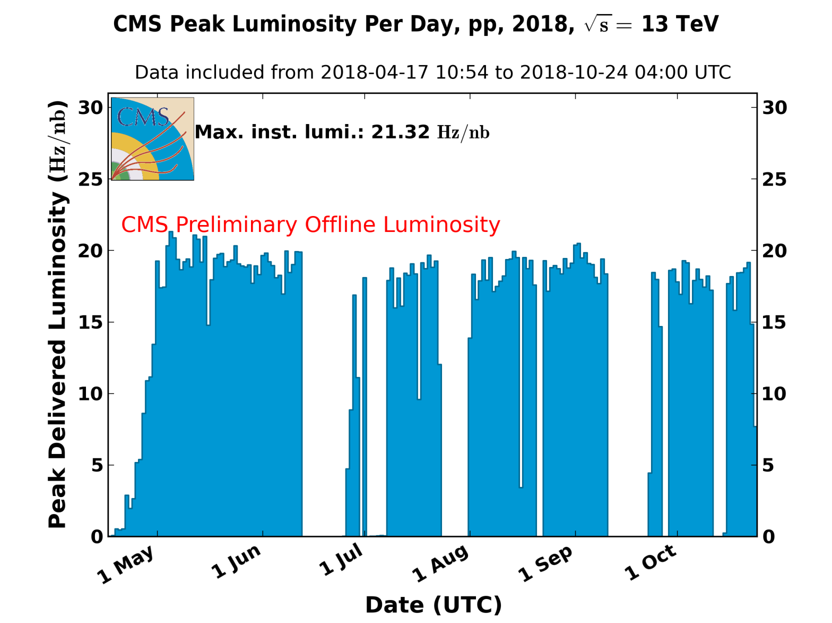

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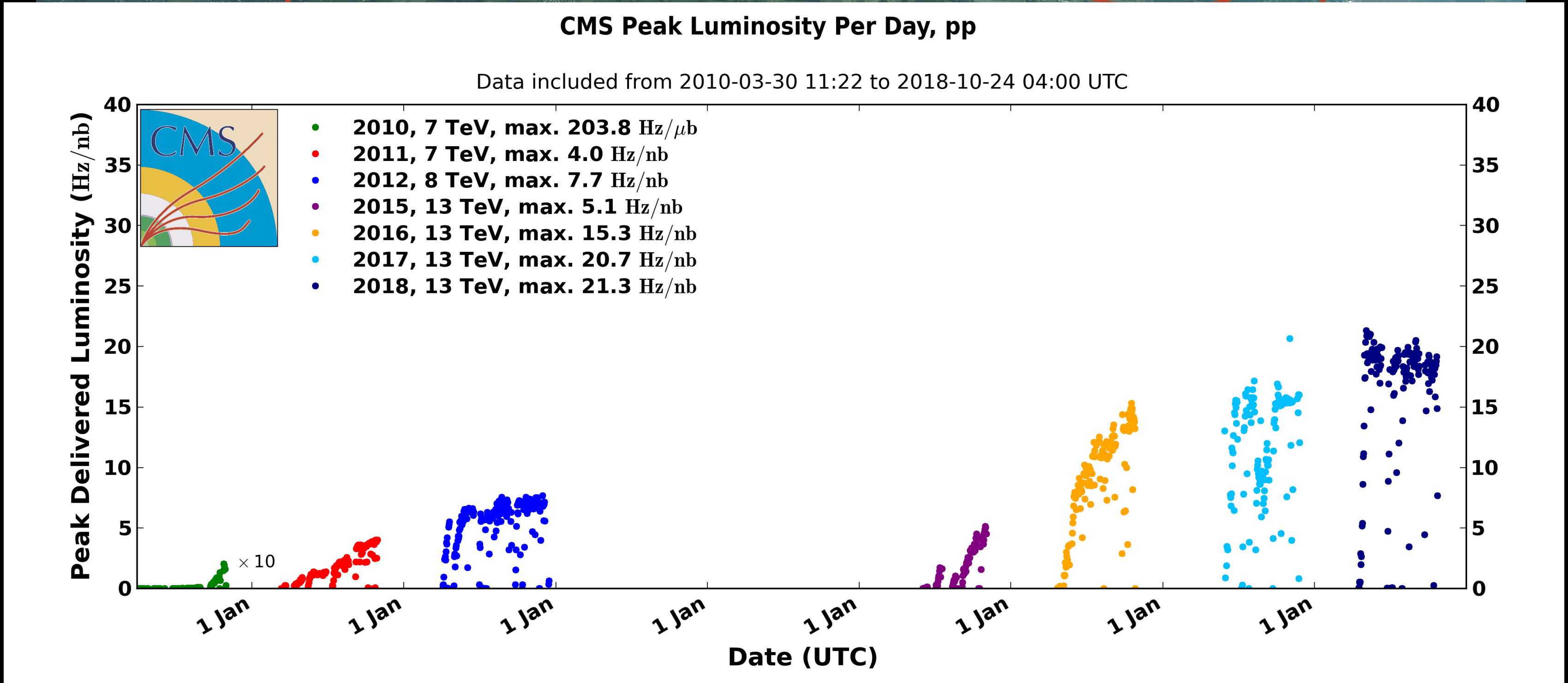

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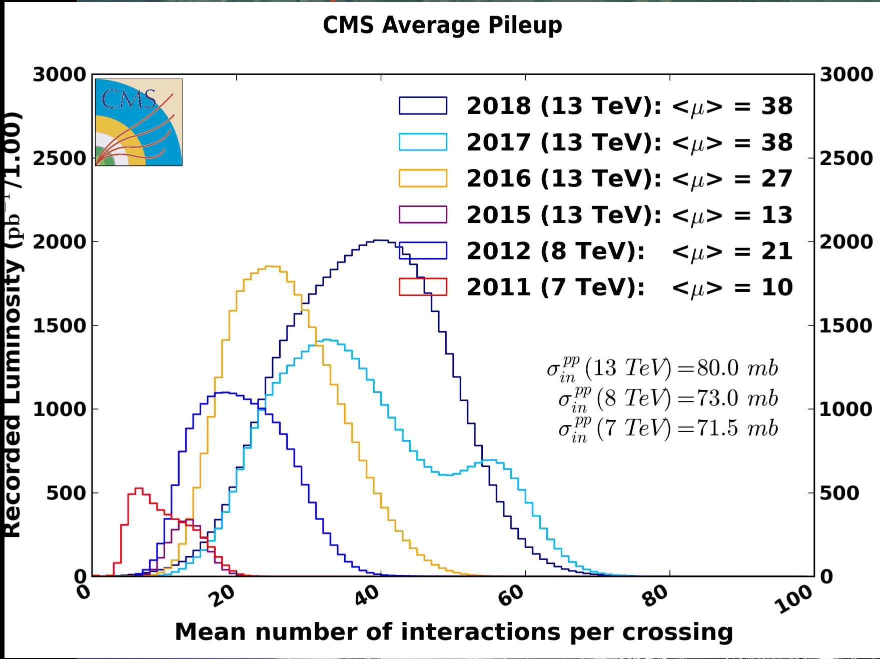
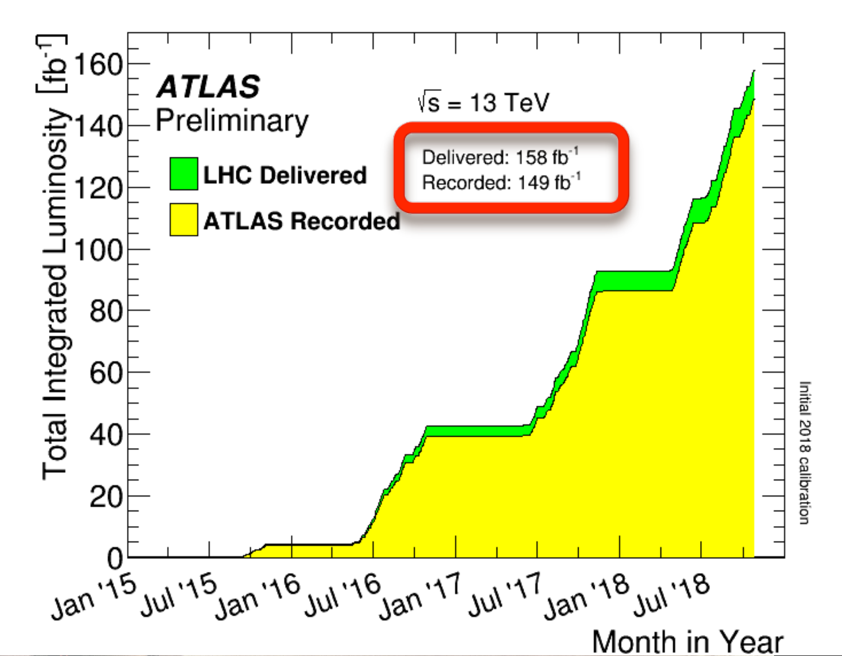
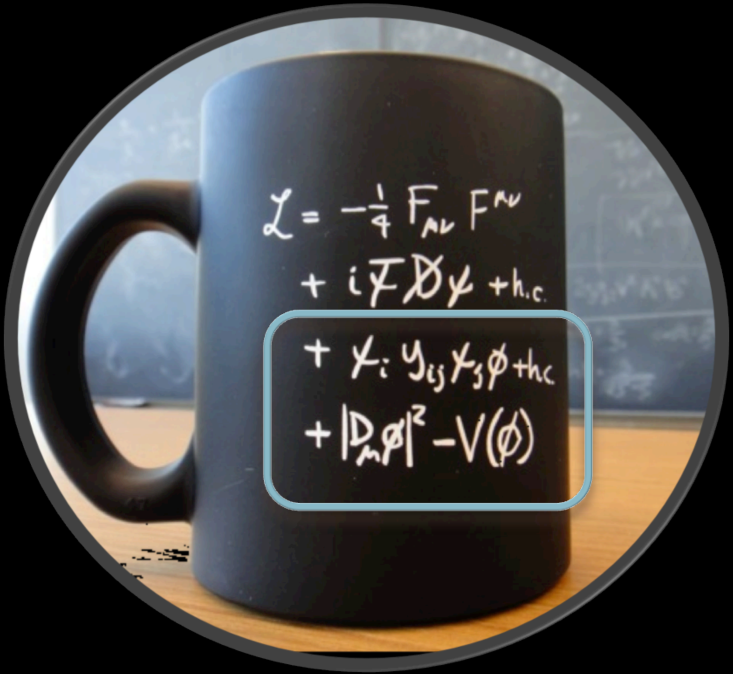




The role of the LHC

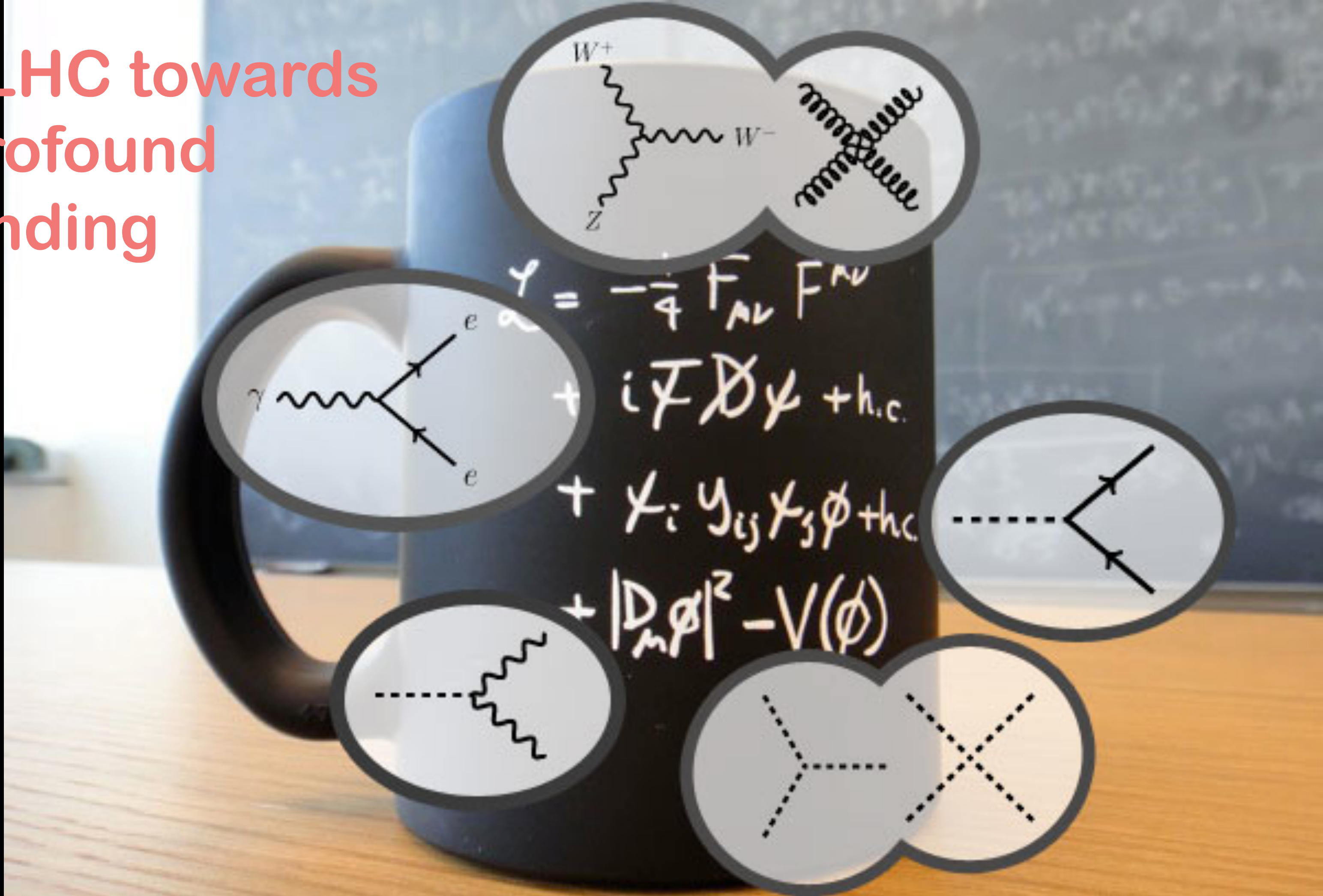


a MORE PRECISE and more COMPLETE description

connection

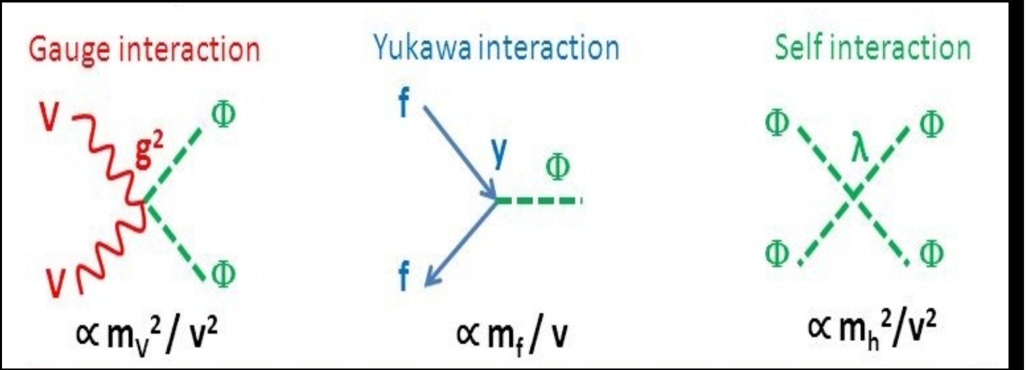
new physics

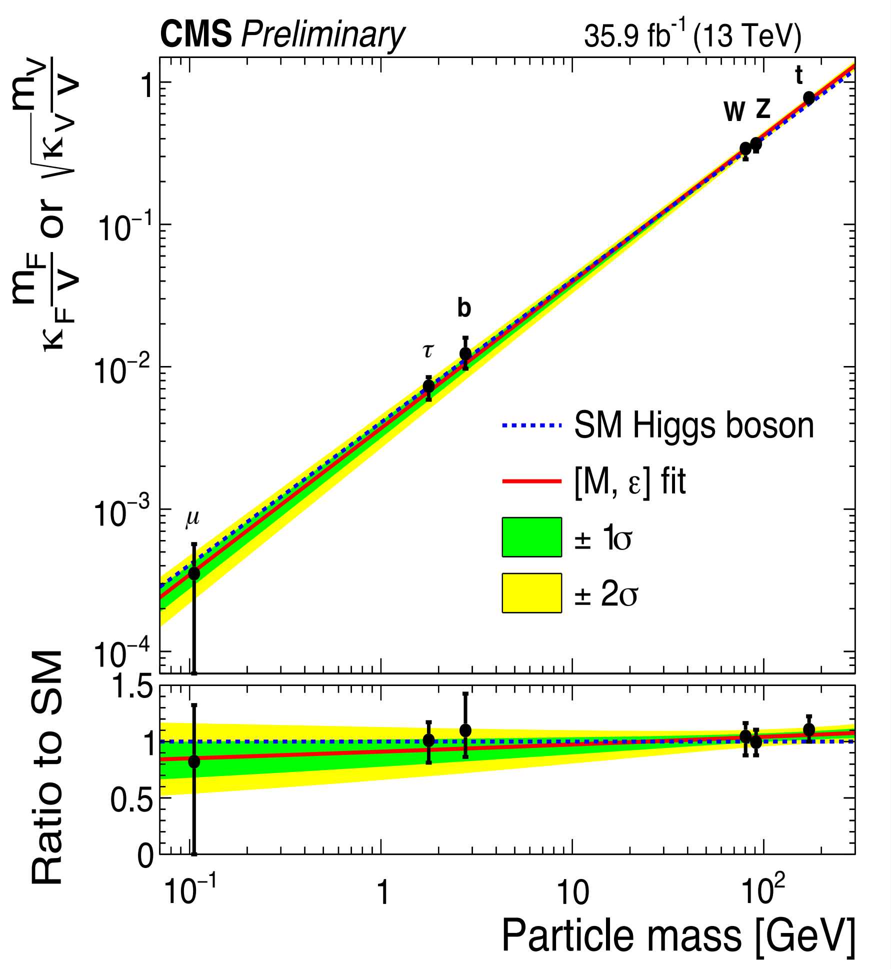
With the LHC towards a more profound understanding



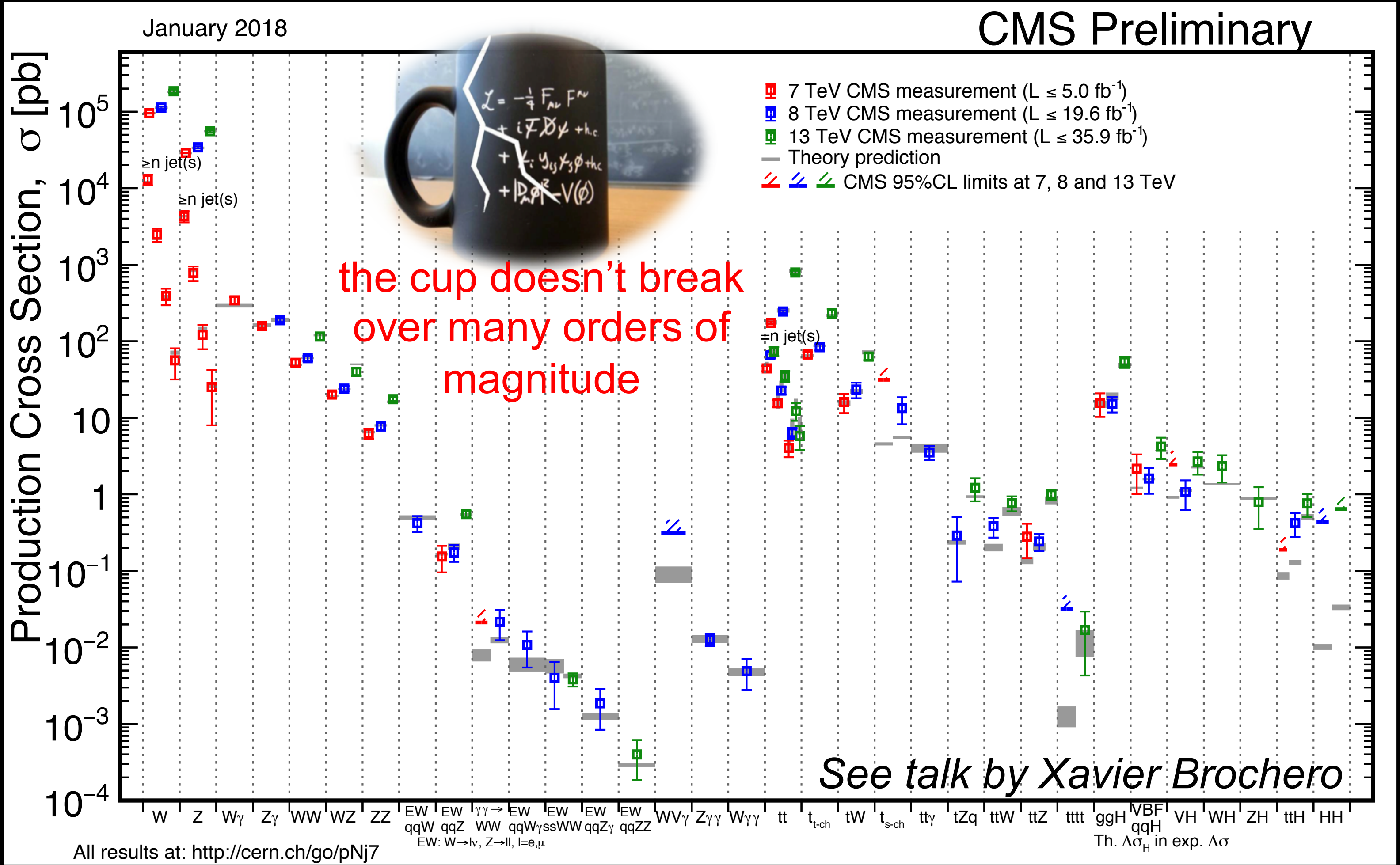
Picture from Flip Tanedo @ Quantum Daires

Some physics results of the LHC – scalar sector





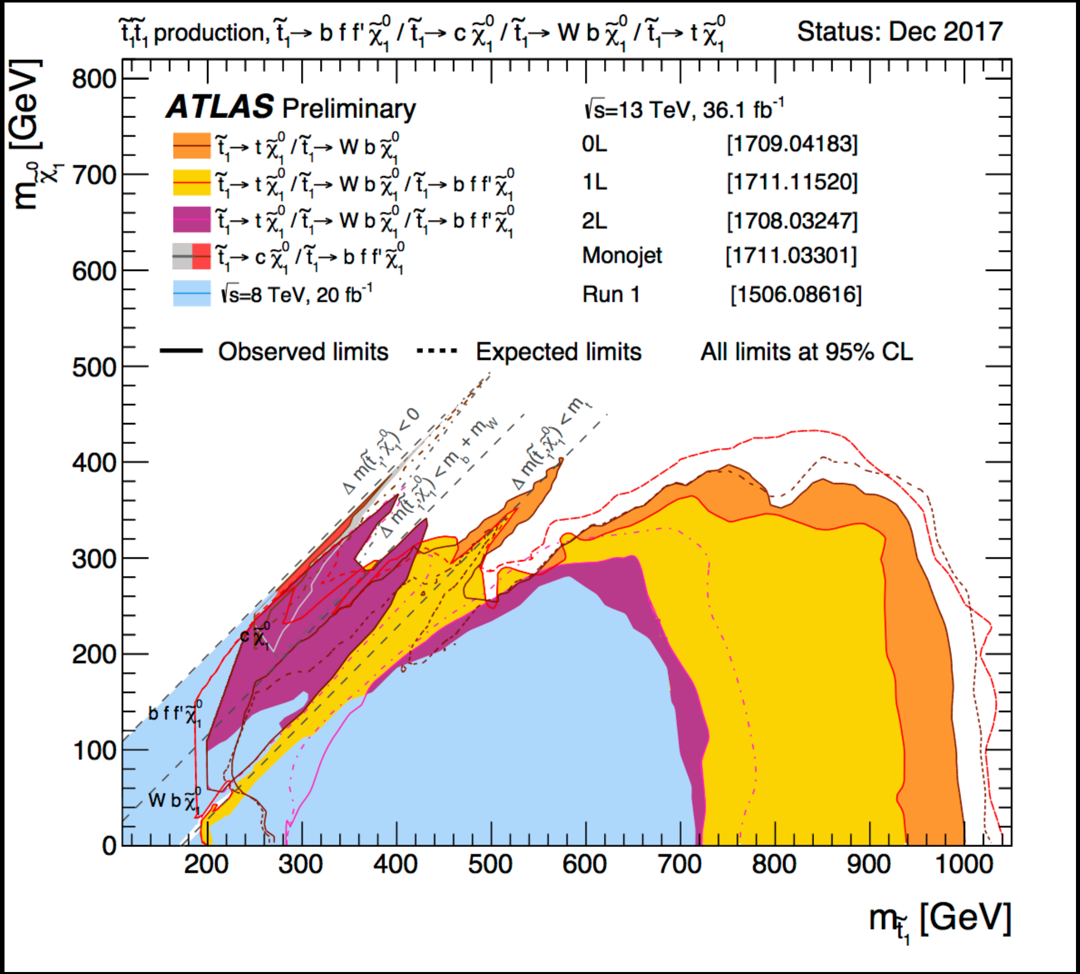
Some physics results of the LHC – Standard Model



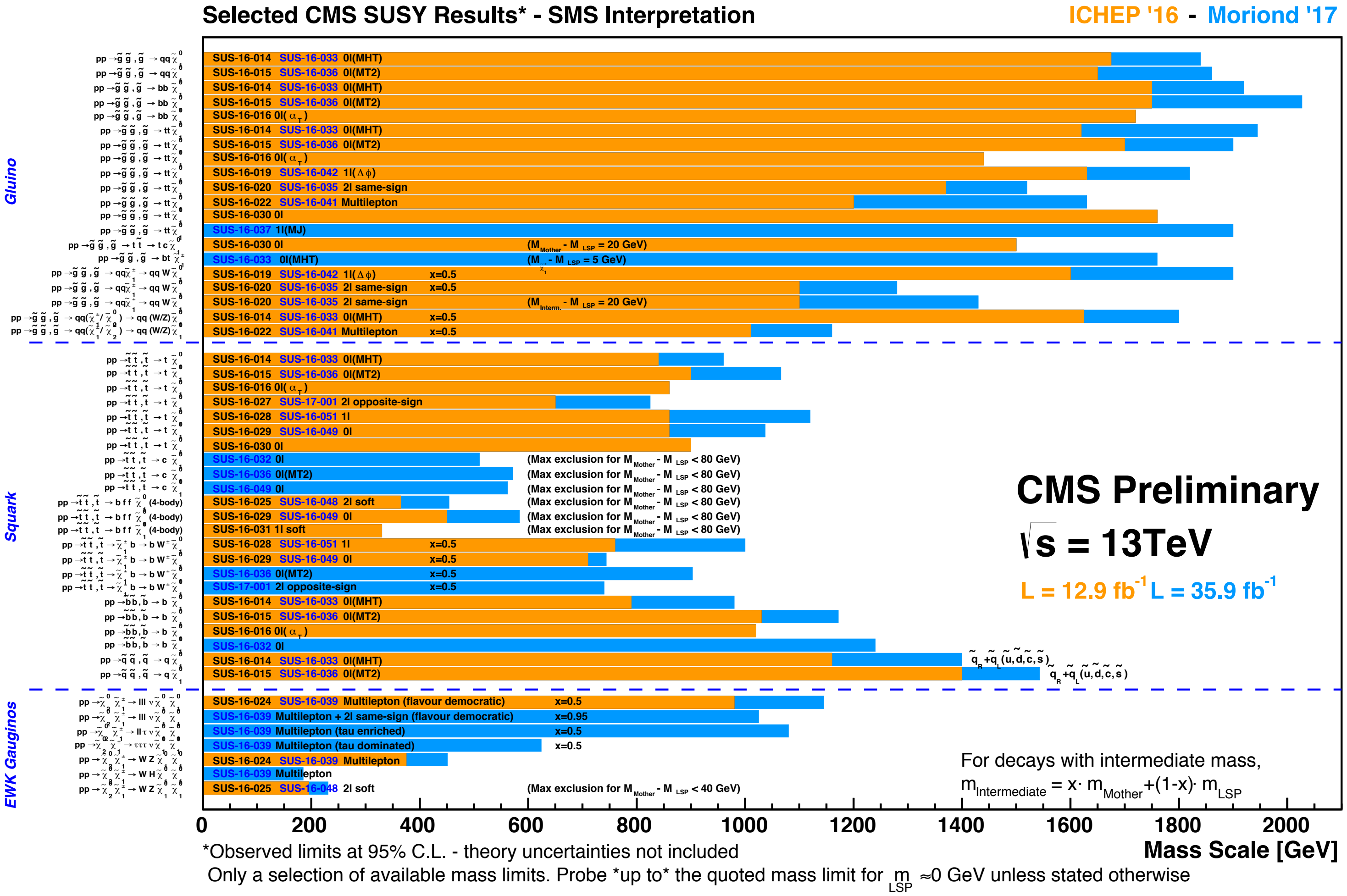
Some physics results of the LHC – SUSY searches

Several strategies to search phenomena of supersymmetry.

The production of a pair of stop quark pairs is searched for in several decay channels.



A broad range of ongoing SUSY searches



ATLAS Exotics Searches* - 95% CL Upper Exclusion Limits

Status: July 2017

ATLAS Preliminary

$\int \mathcal{L}\, dt = (3.2 - 37.0)$ fb^{-1} $\sqrt{s}$ = 8, 13 TeV

	Model	ℓ, γ	Jets†	E_T^{miss}	$\int \mathcal{L}\, dt$[fb^{-1}]	Limit		Reference
Extra dimensions	ADD $G_{KK} + g/q$	0 e, μ	1 – 4 j	Yes	36.1	M_D 7.75 TeV	$n = 2$	ATLAS-CONF-2017-060
	ADD non-resonant $\gamma\gamma$	2 γ	–	–	36.7	M_S 8.6 TeV	$n = 3$ HLZ NLO	CERN-EP-2017-132
	ADD QBH	–	2 j	–	37.0	M_{th} 8.9 TeV	$n = 6$	1703.09217
	ADD BH high $\sum p_T$	≥ 1 e, μ	≥ 2 j	–	3.2	M_{th} 8.2 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	1606.02265
	ADD BH multijet	–	≥ 3 j	–	3.6	M_{th} 9.55 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	1512.02586
	RS1 $G_{KK} \to \gamma\gamma$	2 γ	–	–	36.7	G_{KK} mass 4.1 TeV	$k/\overline{M}_{Pl} = 0.1$	CERN-EP-2017-132
	Bulk RS $G_{KK} \to WW \to qq\ell\nu$	1 e, μ	1 J	Yes	36.1	G_{KK} mass 1.75 TeV	$k/\overline{M}_{Pl} = 1.0$	ATLAS-CONF-2017-051
	2UED / RPP	1 e, μ	≥ 2 b, ≥ 3 j	Yes	13.2	KK mass 1.6 TeV	Tier (1,1), $\mathcal{B}(A^{(1,1)} \to tt) = 1$	ATLAS-CONF-2016-104
Gauge bosons	SSM $Z' \to \ell\ell$	2 e, μ	–	–	36.1	Z' mass 4.5 TeV		ATLAS-CONF-2017-027
	SSM $Z' \to \tau\tau$	2 τ	–	–	36.1	Z' mass 2.4 TeV		ATLAS-CONF-2017-050
	Leptophobic $Z' \to bb$	–	2 b	–	3.2	Z' mass 1.5 TeV		1603.08791
	Leptophobic $Z' \to tt$	1 e, μ	≥ 1 b, ≥ 1J/2j	Yes	3.2	Z' mass 2.0 TeV	$\Gamma/m = 3\%$	ATLAS-CONF-2016-014
	SSM $W' \to \ell\nu$	1 e, μ	–	Yes	36.1	W' mass 5.1 TeV		1706.04786
	HVT $V' \to WV \to qqqq$ model B	0 e, μ	2 J	–	36.7	V' mass 3.5 TeV	$g_V = 3$	CERN-EP-2017-147
	HVT $V' \to WH/ZH$ model B	multi-channel			36.1	V' mass 2.93 TeV	$g_V = 3$	ATLAS-CONF-2017-055
	LRSM $W'_R \to tb$	1 e, μ	2 b, 0-1 j	Yes	20.3	W' mass 1.92 TeV		1410.4103
	LRSM $W'_R \to tb$	0 e, μ	≥ 1 b, 1 J	–	20.3	W' mass 1.76 TeV		1408.0886
CI	CI $qqqq$	–	2 j	–	37.0	Λ 21.8 TeV η^-_{LL}		1703.09217
	CI $\ell\ell qq$	2 e, μ	–	–	36.1	Λ 40.1 TeV η^-_{LL}		ATLAS-CONF-2017-027
	CI $uutt$	2(SS)/≥3 e,μ	≥1 b, ≥1 j	Yes	20.3	Λ 4.9 TeV	$\lvert C_{RR} \rvert = 1$	1504.04605
DM	Axial-vector mediator (Dirac DM)	0 e, μ	1 – 4 j	Yes	36.1	m_{med} 1.5 TeV	g_q=0.25, g_χ=1.0, $m(\chi) < 400$ GeV	ATLAS-CONF-2017-060
	Vector mediator (Dirac DM)	0 e, μ, 1 γ	≤ 1 j	Yes	36.1	m_{med} 1.2 TeV	g_q=0.25, g_χ=1.0, $m(\chi) < 480$ GeV	1704.03848
	$VV\chi\chi$ EFT (Dirac DM)	0 e, μ	1 J, ≤ 1 j	Yes	3.2	M_* 700 GeV	$m(\chi) < 150$ GeV	1608.02372
LQ	Scalar LQ 1st gen	2 e	≥ 2 j	–	3.2	LQ mass 1.1 TeV	$\beta = 1$	1605.06035
	Scalar LQ 2nd gen	2 μ	≥ 2 j	–	3.2	LQ mass 1.05 TeV	$\beta = 1$	1605.06035
	Scalar LQ 3rd gen	1 e, μ	≥1 b, ≥3 j	Yes	20.3	LQ mass 640 GeV	$\beta = 0$	1508.04735
Heavy quarks	VLQ $TT \to Ht + X$	0 or 1 e, μ	≥ 2 b, ≥ 3 j	Yes	13.2	T mass 1.2 TeV	$\mathcal{B}(T \to Ht) = 1$	ATLAS-CONF-2016-104
	VLQ $TT \to Zt + X$	1 e, μ	≥ 1 b, ≥ 3 j	Yes	36.1	T mass 1.16 TeV	$\mathcal{B}(T \to Zt) = 1$	1705.10751
	VLQ $TT \to Wb + X$	1 e, μ	≥ 1 b, ≥ 1J/2j	Yes	36.1	T mass 1.35 TeV	$\mathcal{B}(T \to Wb) = 1$	CERN-EP-2017-094
	VLQ $BB \to Hb + X$	1 e, μ	≥ 2 b, ≥ 3 j	Yes	20.3	B mass 700 GeV	$\mathcal{B}(B \to Hb) = 1$	1505.04306
	VLQ $BB \to Zb + X$	2/≥3 e, μ	≥2/≥1 b	–	20.3	B mass 790 GeV	$\mathcal{B}(B \to Zb) = 1$	1409.5500
	VLQ $BB \to Wt + X$	1 e, μ	≥ 1 b, ≥ 1J/2j	Yes	36.1	B mass 1.25 TeV	$\mathcal{B}(B \to Wt) = 1$	CERN-EP-2017-094
	VLQ $QQ \to WqWq$	1 e, μ	≥ 4 j	Yes	20.3	Q mass 690 GeV		1509.04261
Excited fermions	Excited quark $q^* \to qg$	–	2 j	–	37.0	q^* mass 6.0 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1703.09127
	Excited quark $q^* \to q\gamma$	1 γ	1 j	–	36.7	q^* mass 5.3 TeV	only u^* and d^*, $\Lambda = m(q^*)$	CERN-EP-2017-148
	Excited quark $b^* \to bg$	–	1 b, 1 j	–	13.3	b^* mass 2.3 TeV		ATLAS-CONF-2016-060
	Excited quark $b^* \to Wt$	1 or 2 e, μ	1 b, 2-0 j	Yes	20.3	b^* mass 1.5 TeV	$f_g = f_L = f_R = 1$	1510.02664
	Excited lepton ℓ^*	3 e, μ	–	–	20.3	ℓ^* mass 3.0 TeV	$\Lambda = 3.0$ TeV	1411.2921
	Excited lepton ν^*	3 e, μ, τ	–	–	20.3	ν^* mass 1.6 TeV	$\Lambda = 1.6$ TeV	1411.2921
Other	LRSM Majorana ν	2 e, μ	2 j	–	20.3	N^0 mass 2.0 TeV	$m(W_R) = 2.4$ TeV, no mixing	1506.06020
	Higgs triplet $H^{\pm\pm} \to \ell\ell$	2,3,4 e, μ (SS)	–	–	36.1	$H^{\pm\pm}$ mass 870 GeV	DY production	ATLAS-CONF-2017-053
	Higgs triplet $H^{\pm\pm} \to \ell\tau$	3 e, μ, τ	–	–	20.3	$H^{\pm\pm}$ mass 400 GeV	DY production, $\mathcal{B}(H^{\pm\pm}_L \to \ell\tau) = 1$	1411.2921
	Monotop (non-res prod)	1 e, μ	1 b	Yes	20.3	spin-1 invisible particle mass 657 GeV	$a_{non-res} = 0.2$	1410.5404
	Multi-charged particles	–	–	–	20.3	multi-charged particle mass 785 GeV	DY production, $\lvert q \rvert = 5e$	1504.04188
	Magnetic monopoles	–	–	–	7.0	monopole mass 1.34 TeV	DY production, $\lvert g \rvert = 1g_D$, spin 1/2	1509.08059

$\sqrt{s}$ = 8 TeV $\sqrt{s}$ = 13 TeV

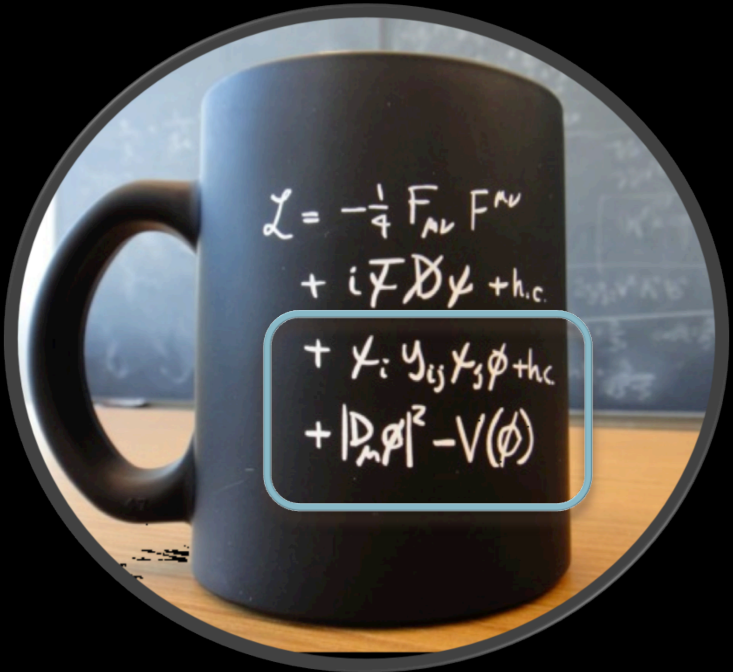
10^{-1} 1 10 **Mass scale [TeV]**

*Only a selection of the available mass limits on new states or phenomena is shown.

†Small-radius (large-radius) jets are denoted by the letter j (J).

The role of the LHC

See talk on BSM by Judita Mamuzic

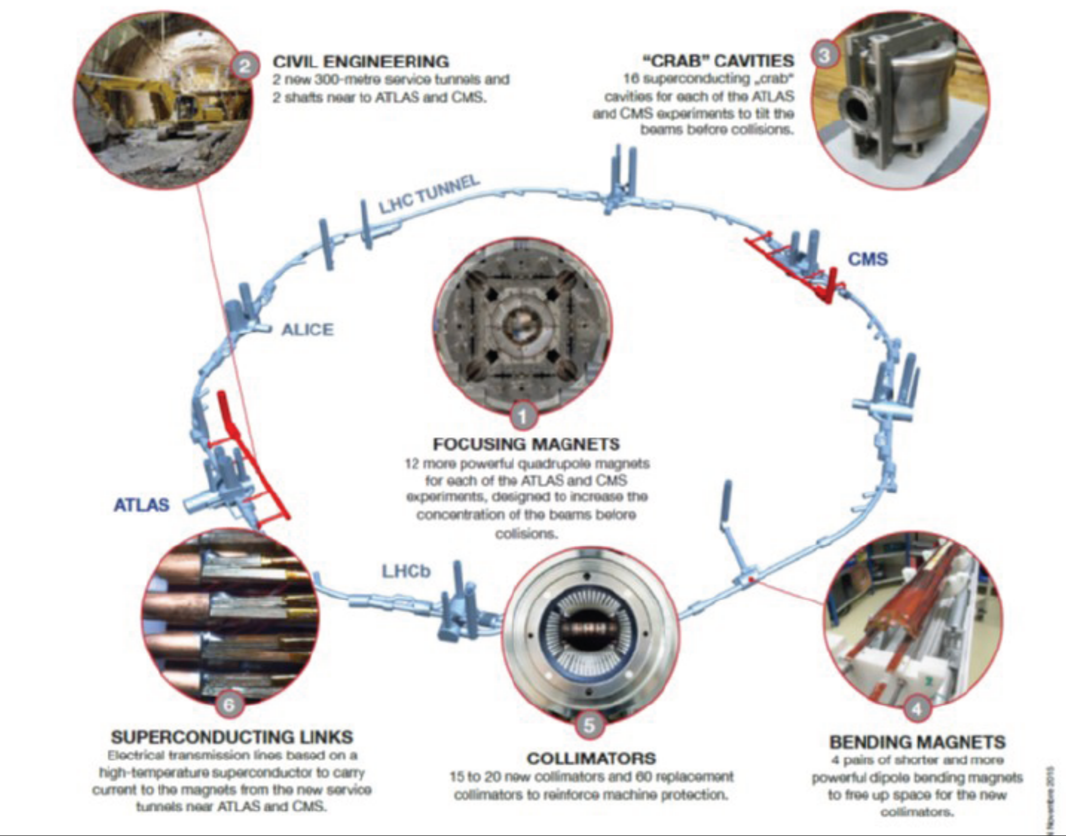


connection

from a BETTER description towards a more PROFOUND understanding

new physics

High-Luminosity LHC: 300/fb (by 2023) → 3000/fb (by 2037)



New IR-quads Nb_3Sn (inner triplets)

New 11 T Nb_3Sn (short) dipoles

Collimation upgrade

Cryogenics upgrade

Crab Cavities

Cold powering

Machine protection

Civil engineering

Formal approval by CERN Council (June 2016)

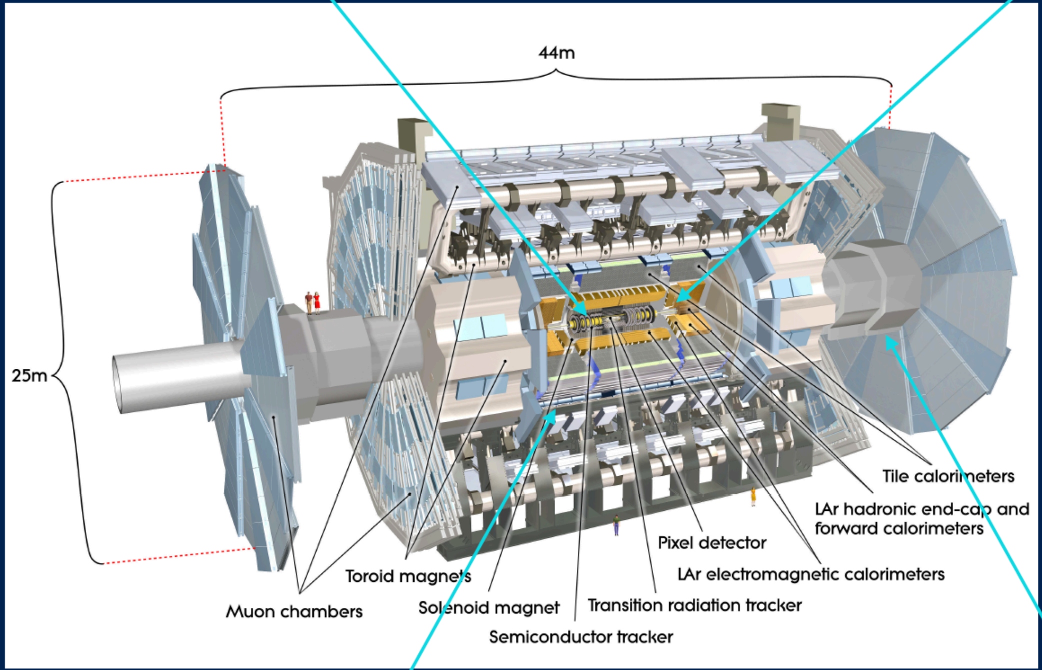
Cost to Completion : 950 MCHF (material)

Detector upgrades are well planned as well

ATLAS – Upgrade Phase II

NEW ALL-SILICON INNER TRACKER (ITK) WITH ETA COVERAGE UP TO 4

HIGH GRANULARITY TIMING DETECTOR (HGTD) IN FORWARD REGION (OPTION)



TDAQ OFF-DETECTOR ELECTRONICS:

- L0 HARDWARE TRIGGER:
  - L0 CALORIMETER
  - L0 TOPOLOGICAL
  - L0 MUON
  - L0 GLOBAL
- L1 HARDWARE TRIGGER (OPTION):
  - L1 GLOBAL
  - L1 TRACK TRIGGER
- READOUT SYSTEM
- HLT

NEW MUON CHAMBERS IN THE INNER BARREL REGION

FORWARD MUON TAGGER (OPTION)

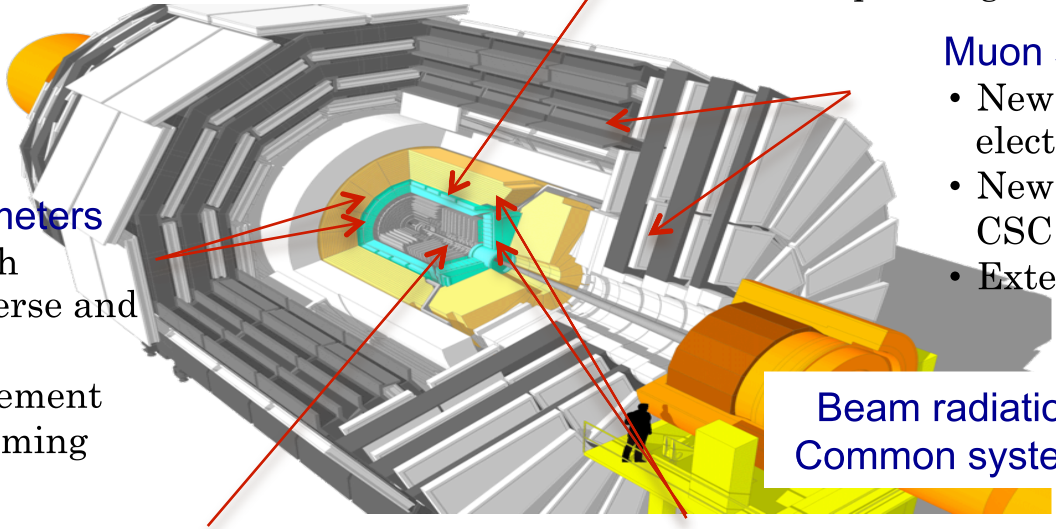
CMS – Upgrade Phase II

Trigger/HLT/DAQ (interim TDR submitted)

- Track information in trigger at 40 MHz
- 12.5 μs latency
- HLT input/output 750/7.5 kHz

Barrel EM calorimeter

- New FE/BE electronics for full granularity readout at 40 MHz - with improved time resolution
- Lower operating temperature (8°)



Muon systems

- New DT & CSC FE/BE electronics
- New station to complete CSC at $1.6 < \eta < 2.4$
- Extended coverage to $\eta \simeq 3$

New Endcap Calorimeters

- Rad. tolerant - High granularity transverse and longitudinal
- 4D shower measurement including precise timing capability

Beam radiation and luminosity
Common systems and infrastructure

New Tracker

- Rad. tolerant - increased granularity - lighter
- 40 MHz selective readout (strips) for Trigger
- Extended coverage to $\eta \simeq 3.8$

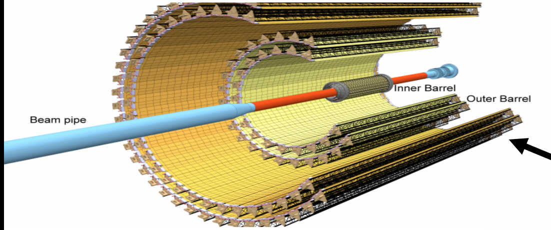
MIP precision Timing Detector

- Barrel layer: Crystal + SiPM
- Endcap layer: Low Gain Avalanche Diodes

ALICE – Upgrade LS2 – *study Quark-Gluon Plasma formed in nuclear collisions*

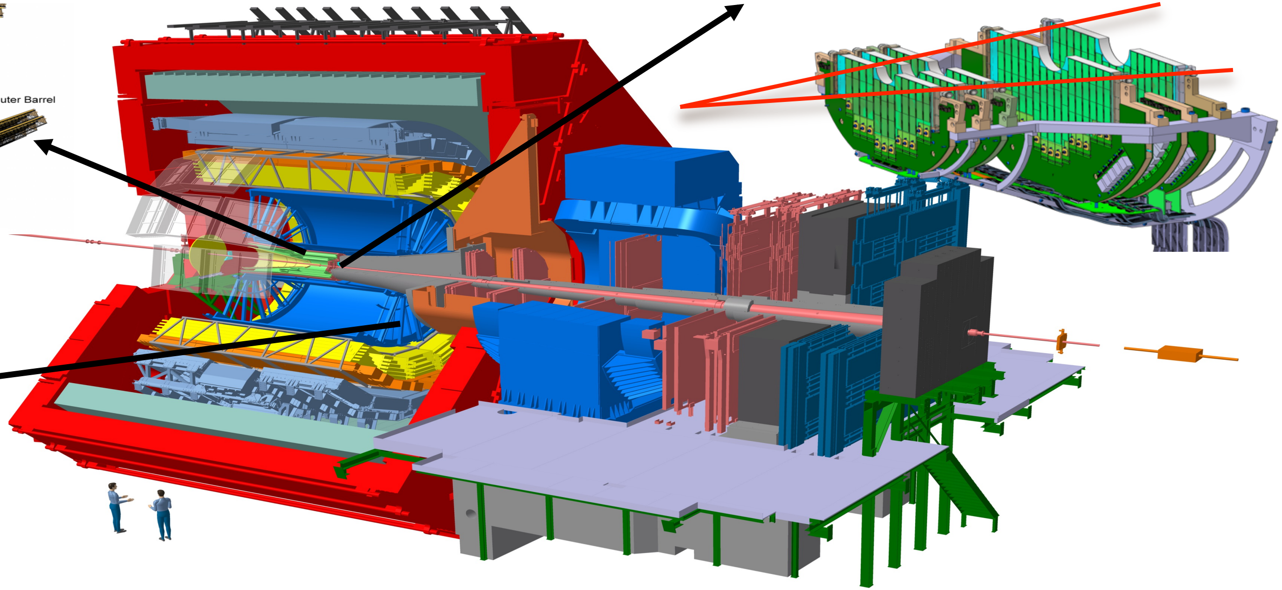
Monolythic-pixel Inner Tracking System

→ x3-5 better tracking precision



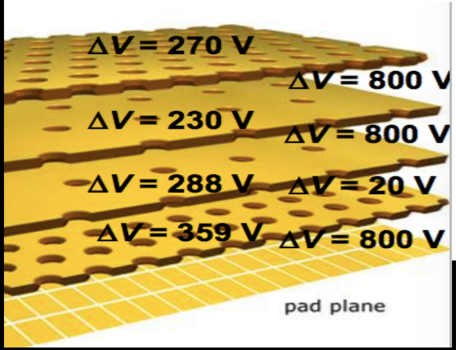
Pixel Muon Forward Tracker

→ non-prompt muons from B decays



GEM-based TPC readout

→ x100 readout rate in Pb-Pb



- Low-p_T heavy-flavour mesons/baryons: characterize QCD with heavy quarks
- Low-p_T charmonia: c-cbar melting and re-generation in deconfined system
- Low-mass di-electrons: QGP thermal radiation via virtual photons

LHCb – Upgrade LS2

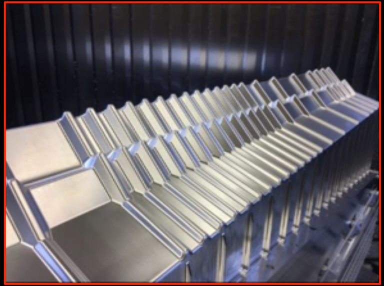
See talk on LHCb by Xavier Vilasis-Cardona

Construction well advanced
aim at installation in 2019

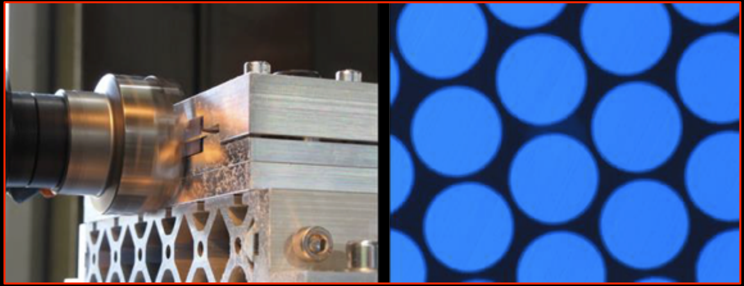
- Will collect 50 fb^{-1} at instantaneous lumi of $2 x 10^{33} cm^{-2} s^{-1}$
- Full software trigger
- New tracking detectors
- New RICH photon detectors
- New electronics read out at 40 MHz

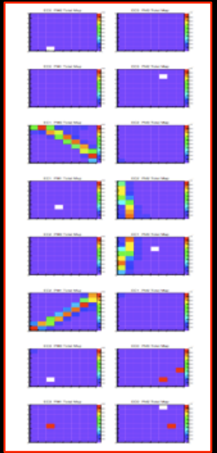
Prototypes of DAQ board (PCIe40)

VELO RF-foil (250 um thick machined aluminum foil)

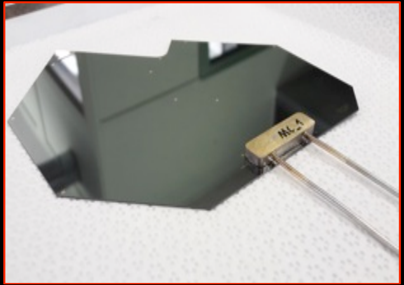


Machining and light scan of the scintillating fiber mats for the fibre tracker

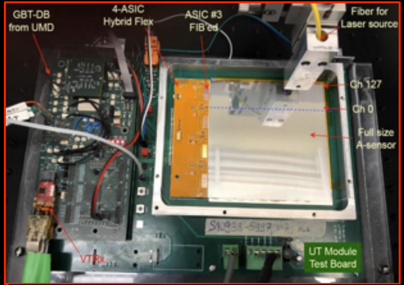




Cherenkov ring from a full RICH MaPMT module

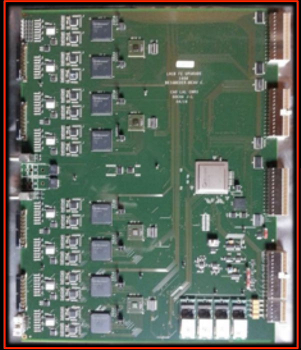


Si mchannel cooling plate for VELO with soldered connector



Upstream Tracker silicon sensor module under test

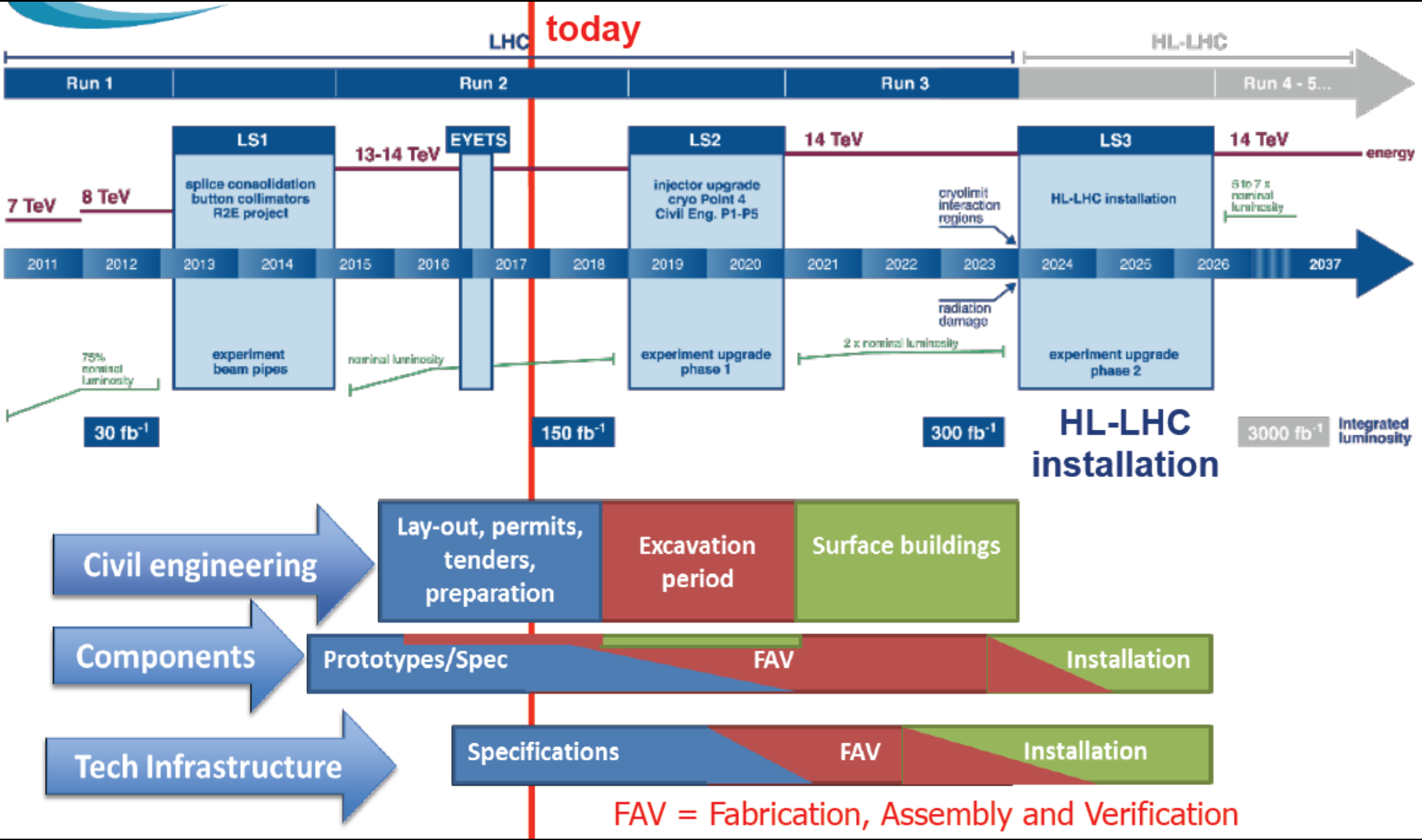
First scintillating fibre modules arriving at CERN



Calorimeter front-end board

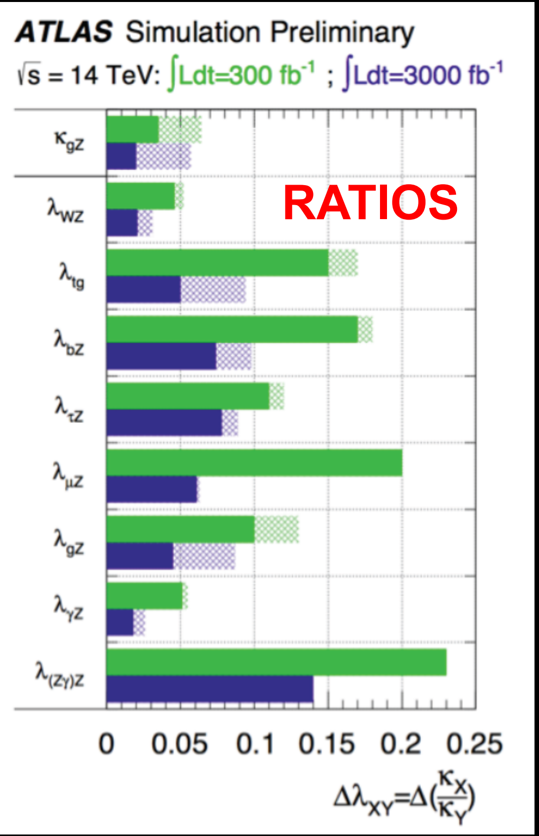
Muon system readout ASIC

High-Luminosity LHC – preparations at CERN



LHC → HL-LHC

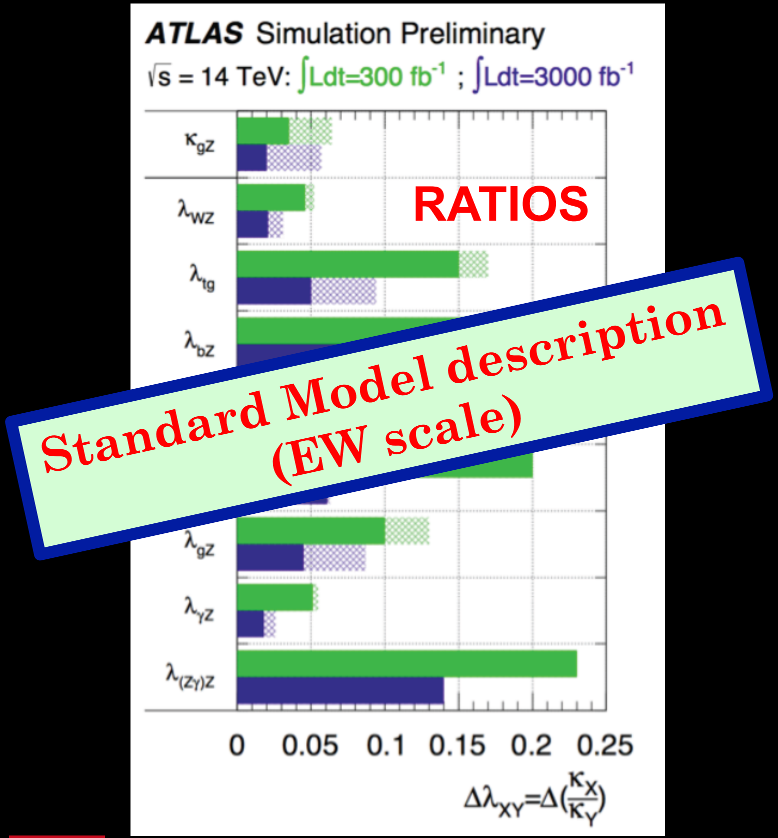
(factor 1-3)



ATL-PHYS-PUB-2013-014

LHC → HL-LHC

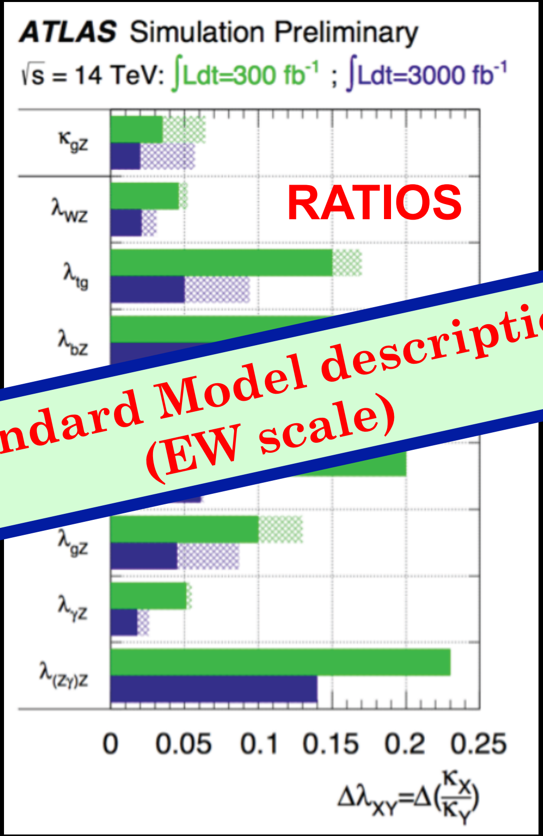
(factor 1-3)



ATL-PHYS-PUB-2013-014

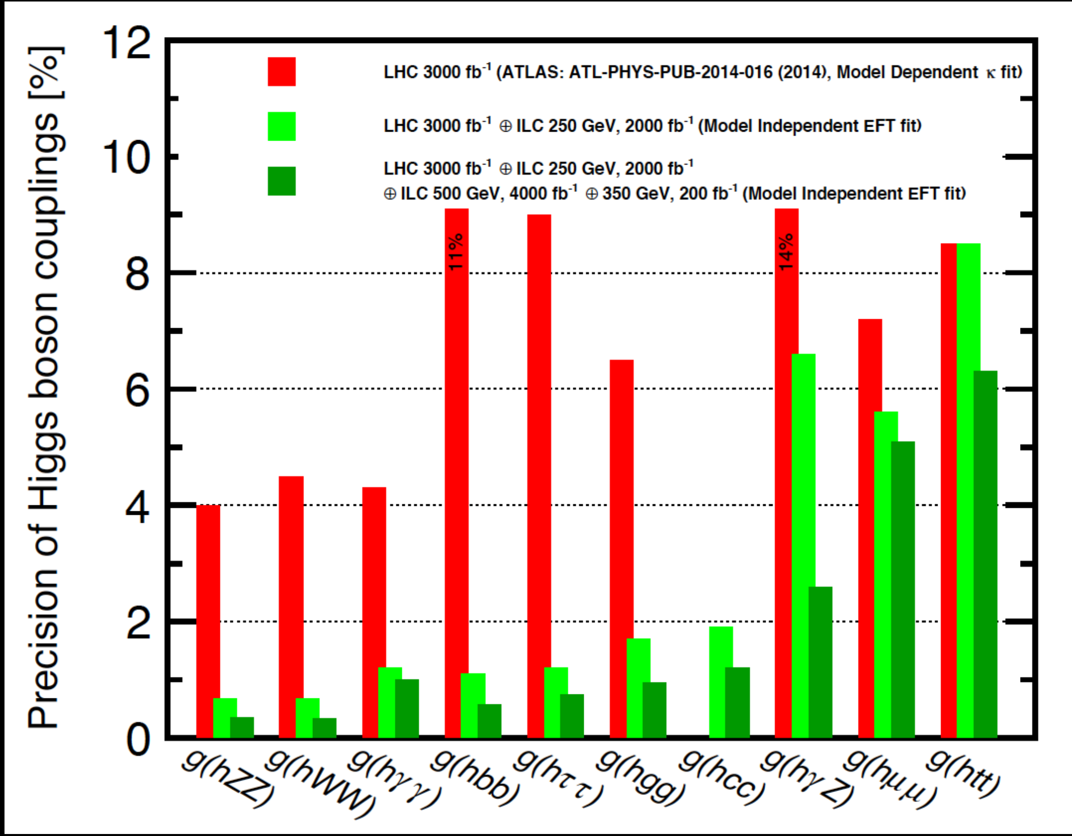
LHC → HL-LHC
(factor 1-3)

HL-LHC → ILC@250
(factor 1-10)



Standard Model description (EW scale)

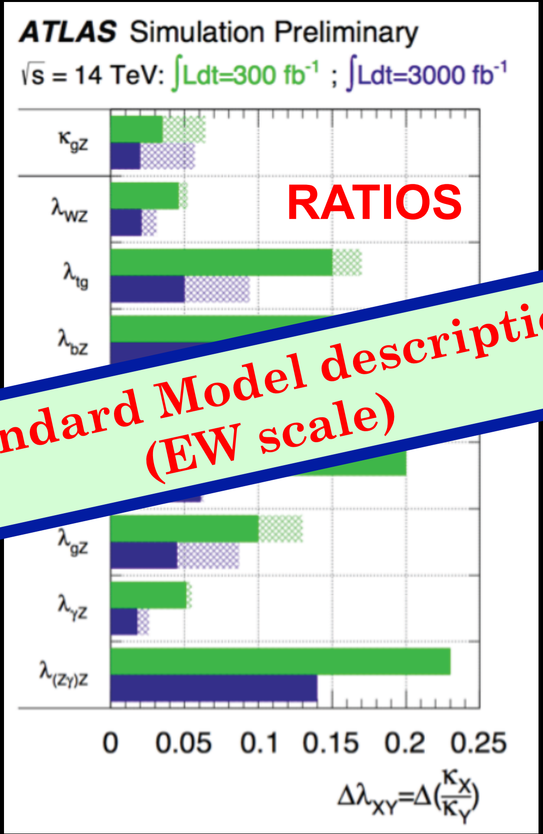
ATL-PHYS-PUB-2013-014



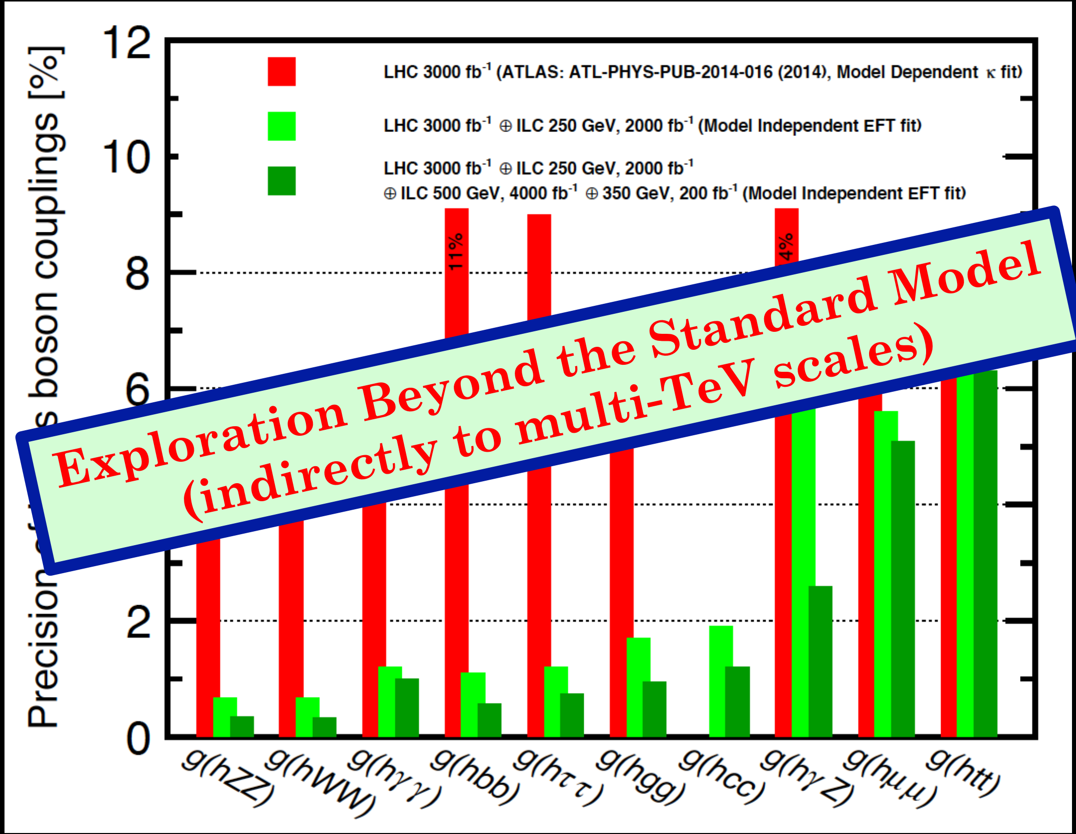
Physics Case for the 250 GeV Stage of the ILC, arXiv:1710.07621v3

LHC → HL-LHC
(factor 1-3)

HL-LHC → ILC@250
(factor 1-10)



ATL-PHYS-PUB-2013-014



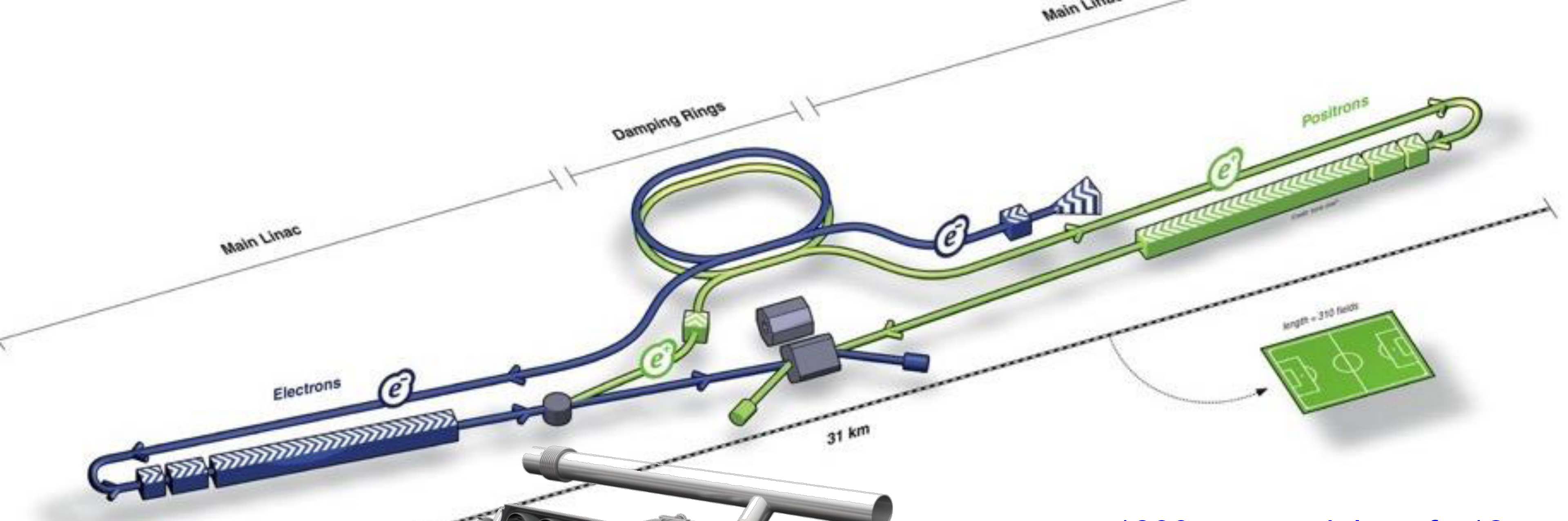
Physics Case for the 250 GeV Stage of the ILC, arXiv:1710.07621v3

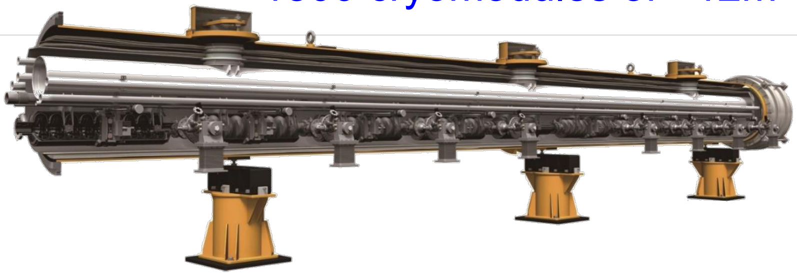
The 2013 European Particle Physics Strategy

③ *There is a strong scientific case for an electron-positron collider, … Europe looks forward to a proposal from Japan to discuss a possible participation.*

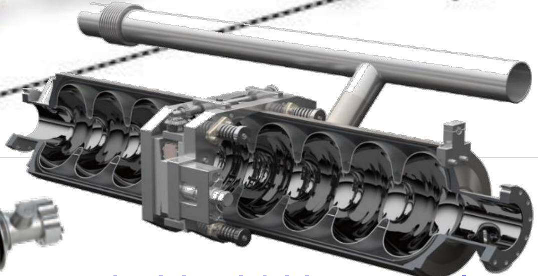
Waiting for a conclusive statement from the Japanese Government for their willingness to host ILC before end of 2018

International Linear Collider (ILC)





~1800 cryomodules of ~12m

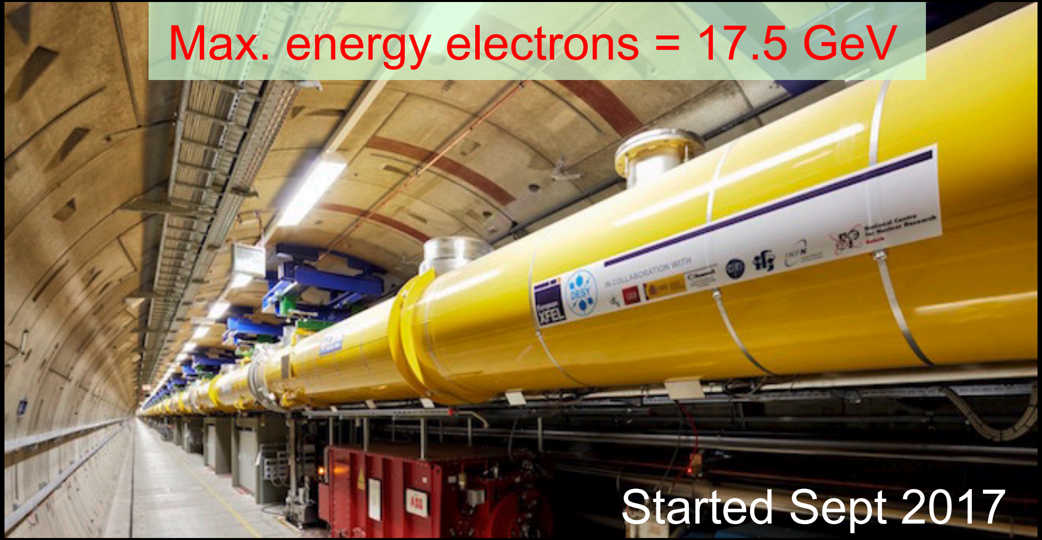


in Liquid He vessel

~16000 superconductive cavities of ~1m

Technology connection with the European XFEL at DESY

The 3.4 km long European XFEL generates extremely intense X-ray flashes to be used by researchers from all over the world.



First mass production in industry of SC radio frequency TESLA technology (from about 100 accelerator modules at the XFEL to about 2000 at ILC).

XFEL : 80% of the cavities reach a gradient of 33 MV/m
ILC : 90% of the cavities need a gradient of 35 MV/m

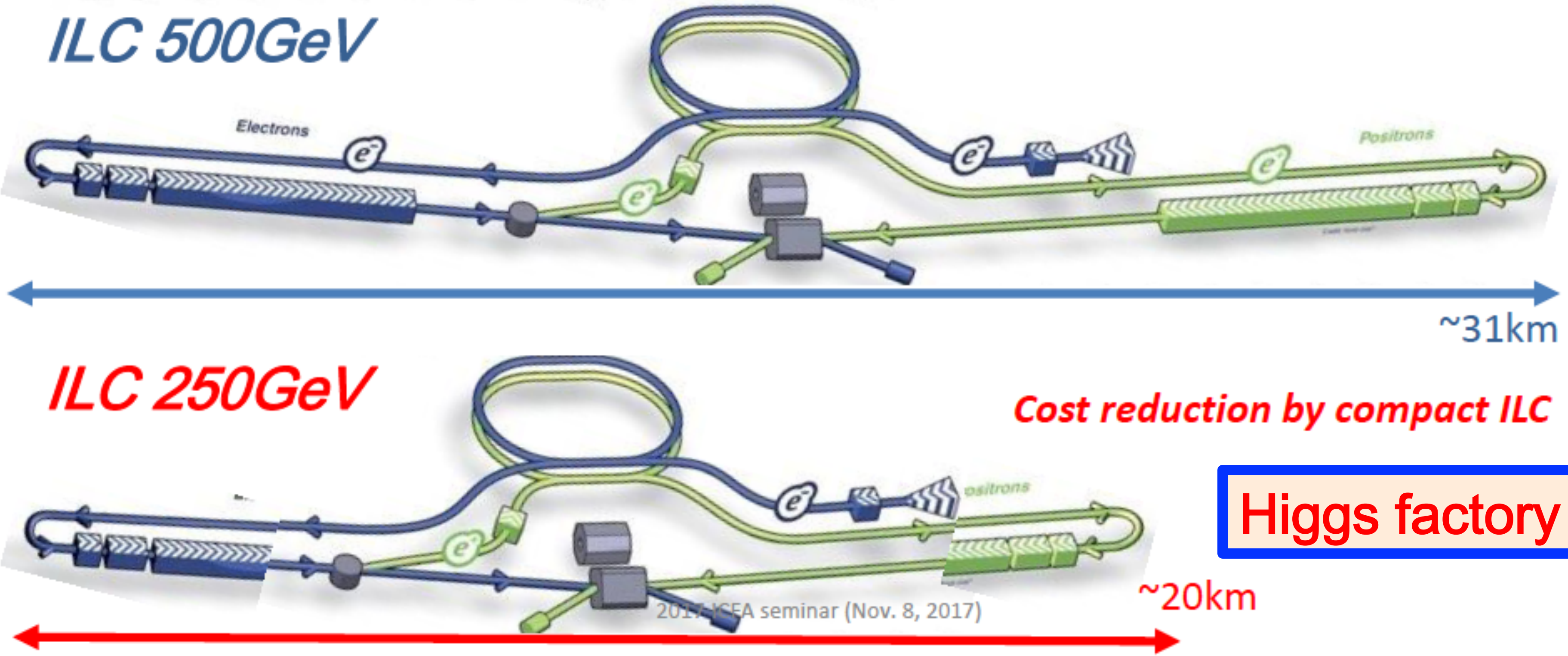
Denis Kostin @ LCWS2017, Oct 24

This demonstrates the goal for the ILC is potentially achievable.

International Linear Collider (ILC) – 500 GeV → 250 GeV

Cost reduction both by scaling from 500 GeV to 250 GeV with a focus on Higgs physics, and by technological innovations on the superconducting materials (Nb) and cavity construction (surface process).

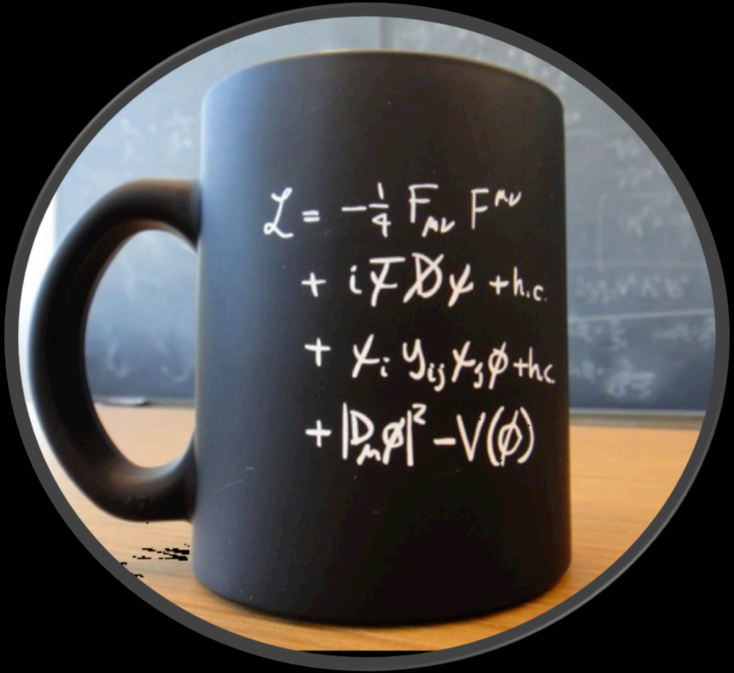
Physics Case for the 250 GeV Stage of the ILC, arXiv:1710.07621



Higgs factory

International Linear Collider (ILC) – physics potential

	ILC250 2 ab^{-1} w. pol.	ILC250+500 full ILC 250+500 GeV
$g(hb\bar{b})$	1.1	0.58
$g(hc\bar{c})$	1.9	1.2
$g(hgg)$	1.7	0.95
$g(hWW)$	0.67	0.34
$g(h\tau\tau)$	1.2	0.74
$g(hZZ)$	0.68	0.35
$g(h\gamma\gamma)$	1.2	1.0
$g(h\mu\mu)$	5.6	5.1
$g(hbb)/g(hWW)$	0.88	0.46
$g(hWW)/g(hZZ)$	0.07	0.05
Γ_h	2.5	1.6
$BR(h \to inv)$	0.32	0.29
$BR(h \to other)$	1.6	1.2

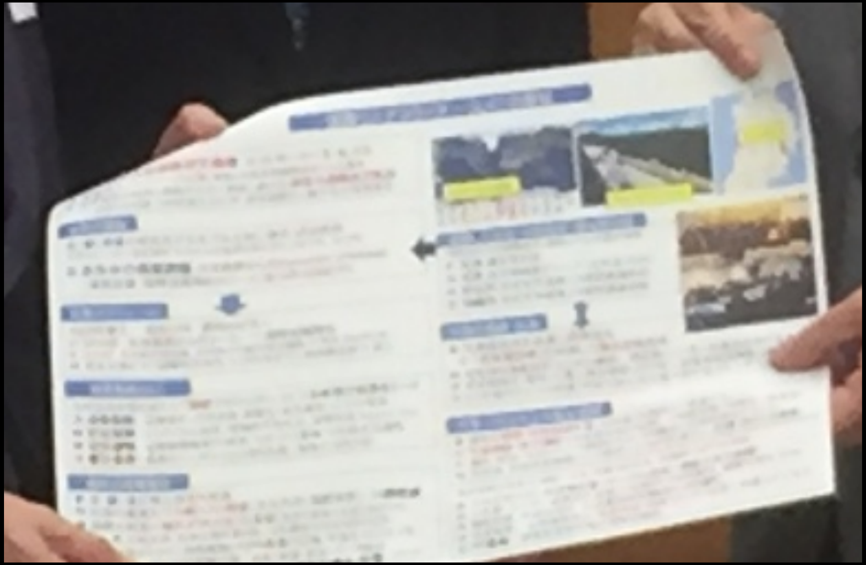


With linear colliders one has excellent zoom-in capabilities for many terms

Physics Case for the 250 GeV Stage of the ILC, arXiv:1710.07621

International Linear Collider (ILC) – July 5th, 2018

Satoru Yamashita, Uni. of Tokyo



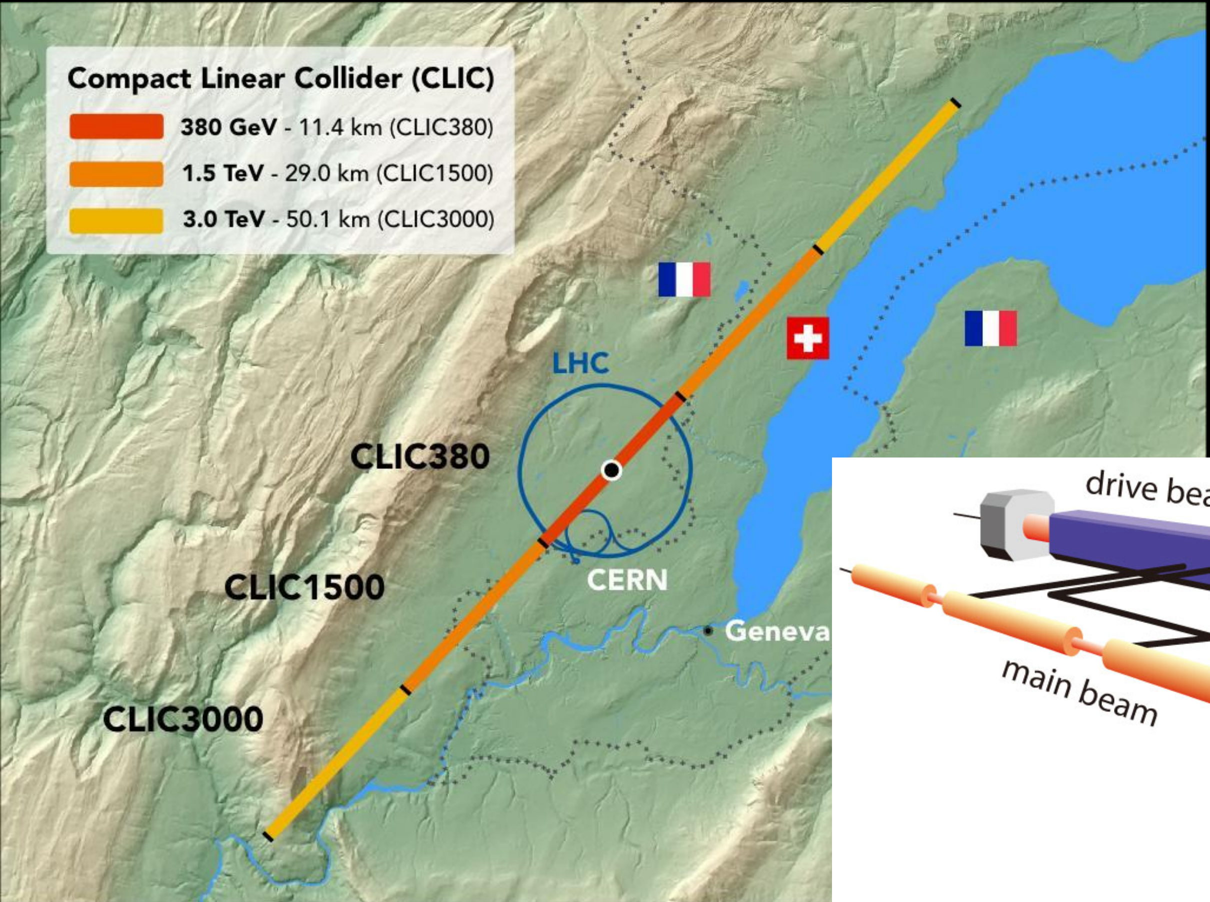
The 2013 European Particle Physics Strategy

② *CERN should undertake design studies for accelerator projects in a global context, with emphasis on proton-proton and electron-positron high-energy frontier machines. These design studies should be coupled to a vigorous accelerator R&D programme, including high-field magnets and high-gradient accelerating structures, in collaboration with national institutes, laboratories and universities worldwide.*

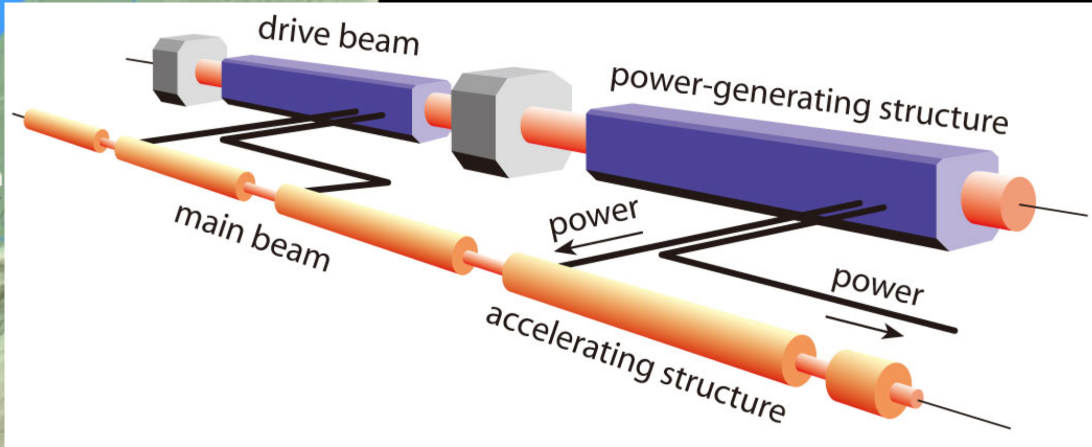
Compact Linear Collider (CLIC)

CERN-2016-004

arXiv:1608.07537



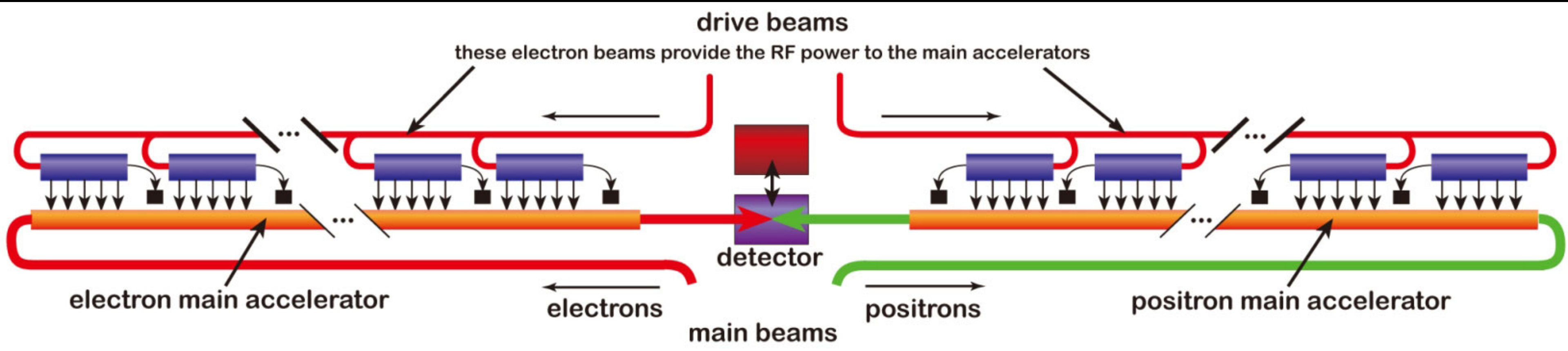
CLIC aims at an acceleration gradient of 100 MV/m. A drive beam is decelerated in dedicated Power Extraction and Transfer Structures (PETS), and the generated RF power is transferred to the main beam.



Compact Linear Collider (CLIC)

CERN-2016-004

arXiv:1608.07537



CLIC – some physics highlights

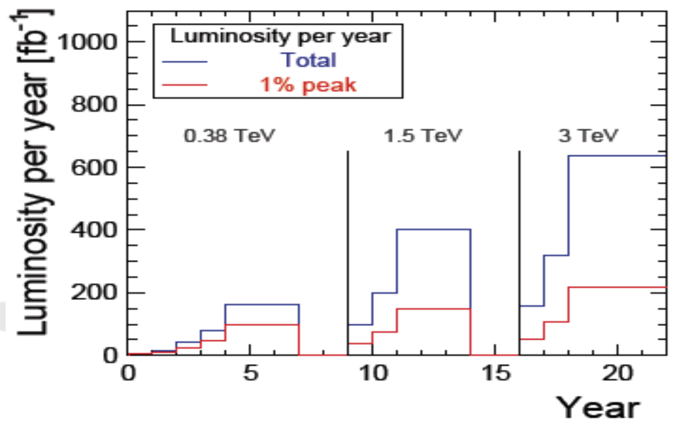
P. Burrows @ ICFA Seminar 2017

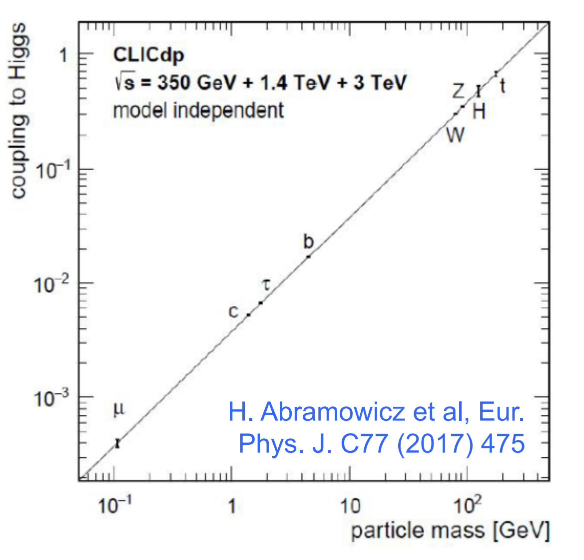
Higgs characterization

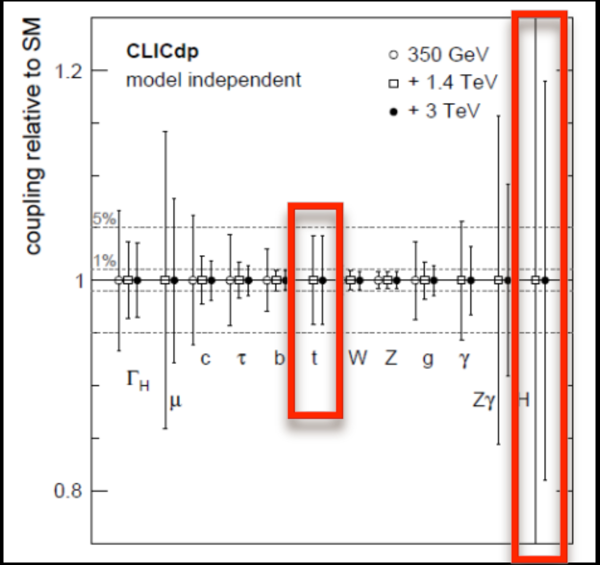
Precision on top quark Yukawa of ~4% and Higgs self-coupling of ~20%.

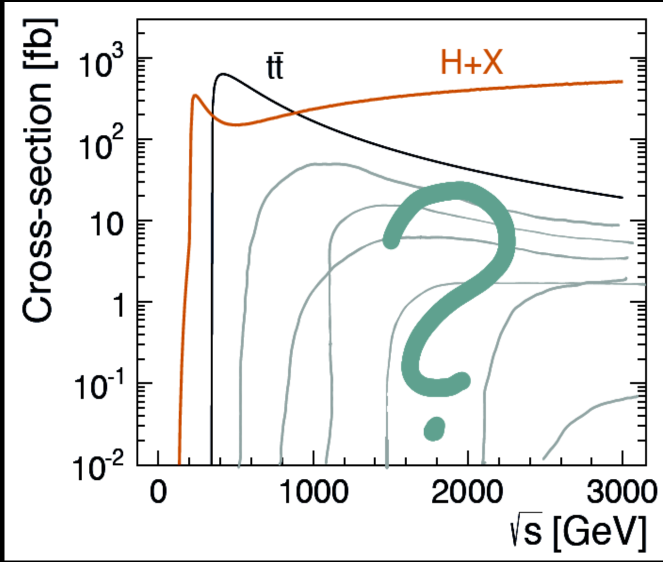
Staged approach

First period around the top quark pair threshold, thereafter increase the energy up to 3 TeV to search for new phenomena.









CLIC roadmap

2013 - 2019 Development Phase

Development of a Project Plan for a staged CLIC implementation in line with LHC results; technical developments with industry, performance studies for accelerator parts and systems, detector technology demonstrators

2020 - 2025 Preparation Phase

Finalisation of implementation parameters, preparation for industrial procurement, Drive Beam Facility and other system verifications, Technical Proposal of the experiment, site authorisation

2026 - 2034 Construction Phase

Construction of the first CLIC accelerator stage compatible with implementation of further stages; construction of the experiment; hardware commissioning

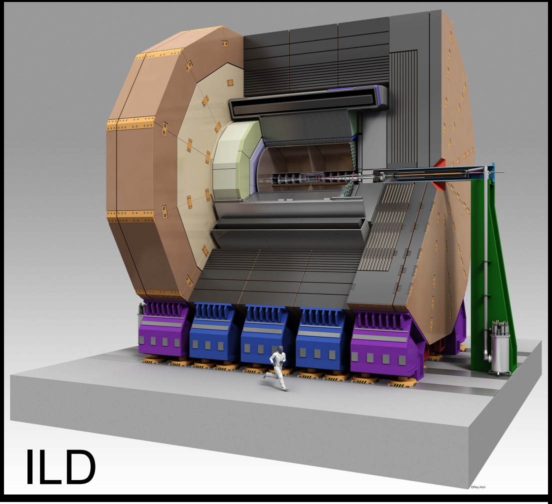
2019 - 2020 Decisions

2025 Construction Start

2035 First Beams

CLIC working on an implementation plan & cost reduction as input to European Particle Physics Strategy

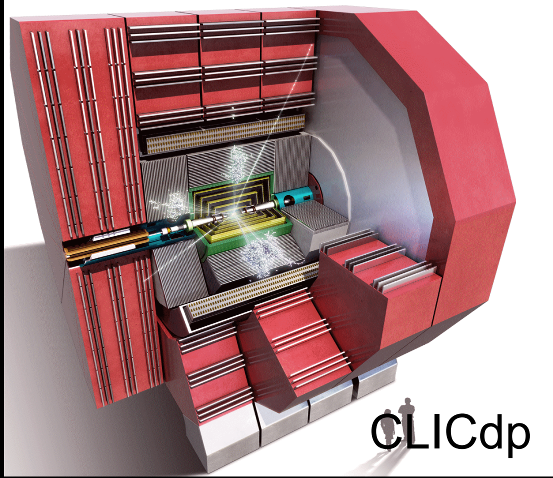
Linear Collider detector & physics studies: Europe engaged

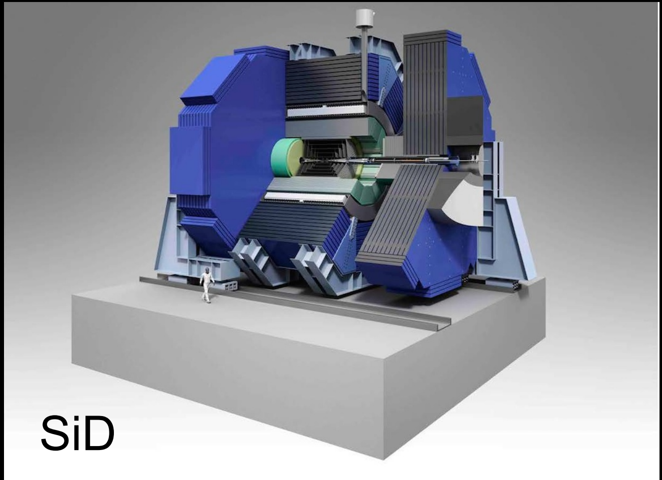


The LCC physics & detector directorate is responsible for activities that advance the physics and detectors of the linear collider.

Three detector concepts:

- ILD: 71 institutions mostly from the European Region
- SiD: 24 institutions many from the European Region
- CLICdp: 29 institutions mostly from the European Region



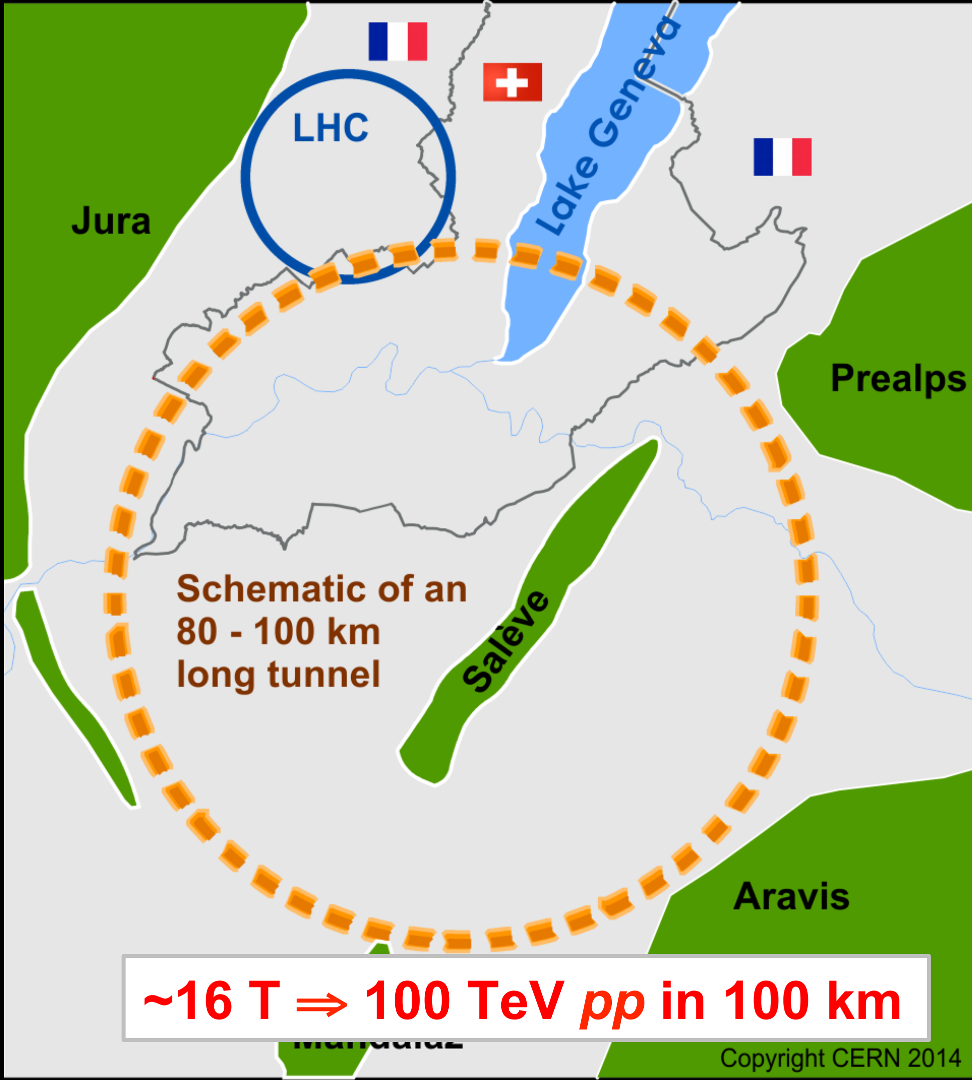


Three detector R&D groups:

- CALICE: 57 institutions mostly from the European Region
- LCTPC: 32 institutions many from the European Region
- FCAL: 14 institutions mostly from the European Region

Future Circular Collider (FCC)

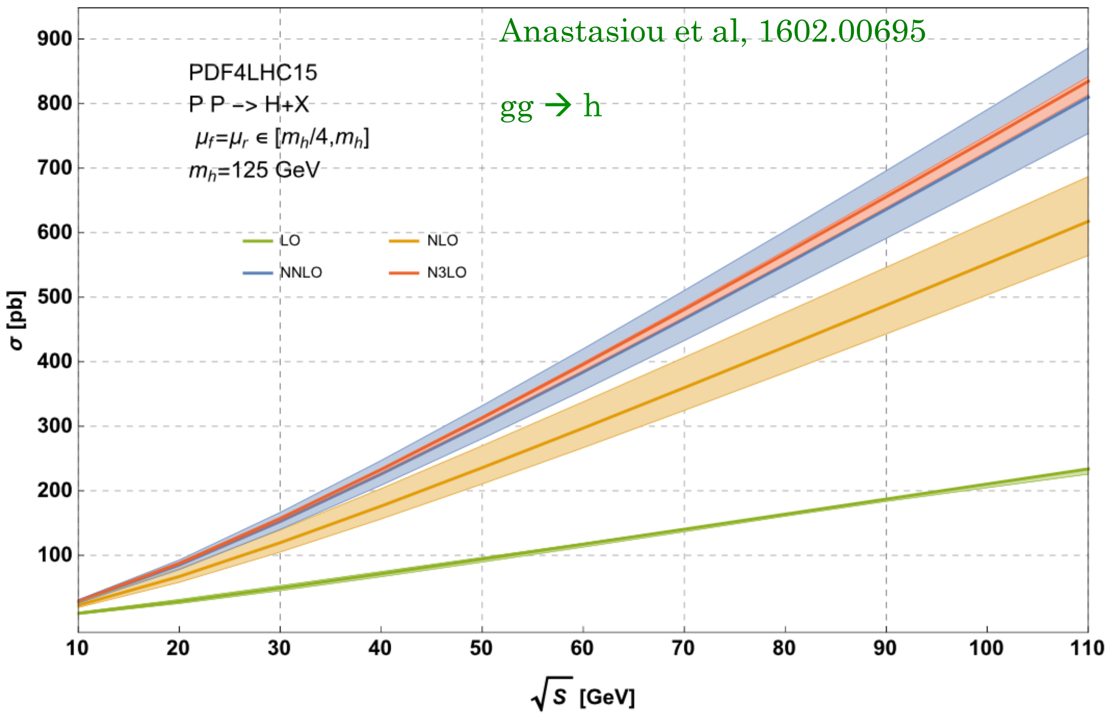
- ***pp*-collider (*FCC-hh*)**
  main emphasis, defining infrastructure requirements
- **e^+e^- collider (*FCC-ee*)**
  as potential first step
- **HE-LHC** with *FCC-hh* technology
- ***p-e* collider (*FCC-he*)** option
- **$\mu\mu$ colider (*FCC-$\mu\mu$*)** option



Future Circular Collider (FCC) – proton collider

Higgs production

Compared to LHC at 14 TeV the cross section increases with a factor of about 16 at NNNLO. Together with a larger luminosity, one can expect 60-400x more events.



Top Yukawa coupling

Measurement to 1% precision

Higgs self-coupling

Measurement to 3-5% precision

Higgs invisible decay Branching Ratio

Sensitivity down to 3-5 x 10^{-4}

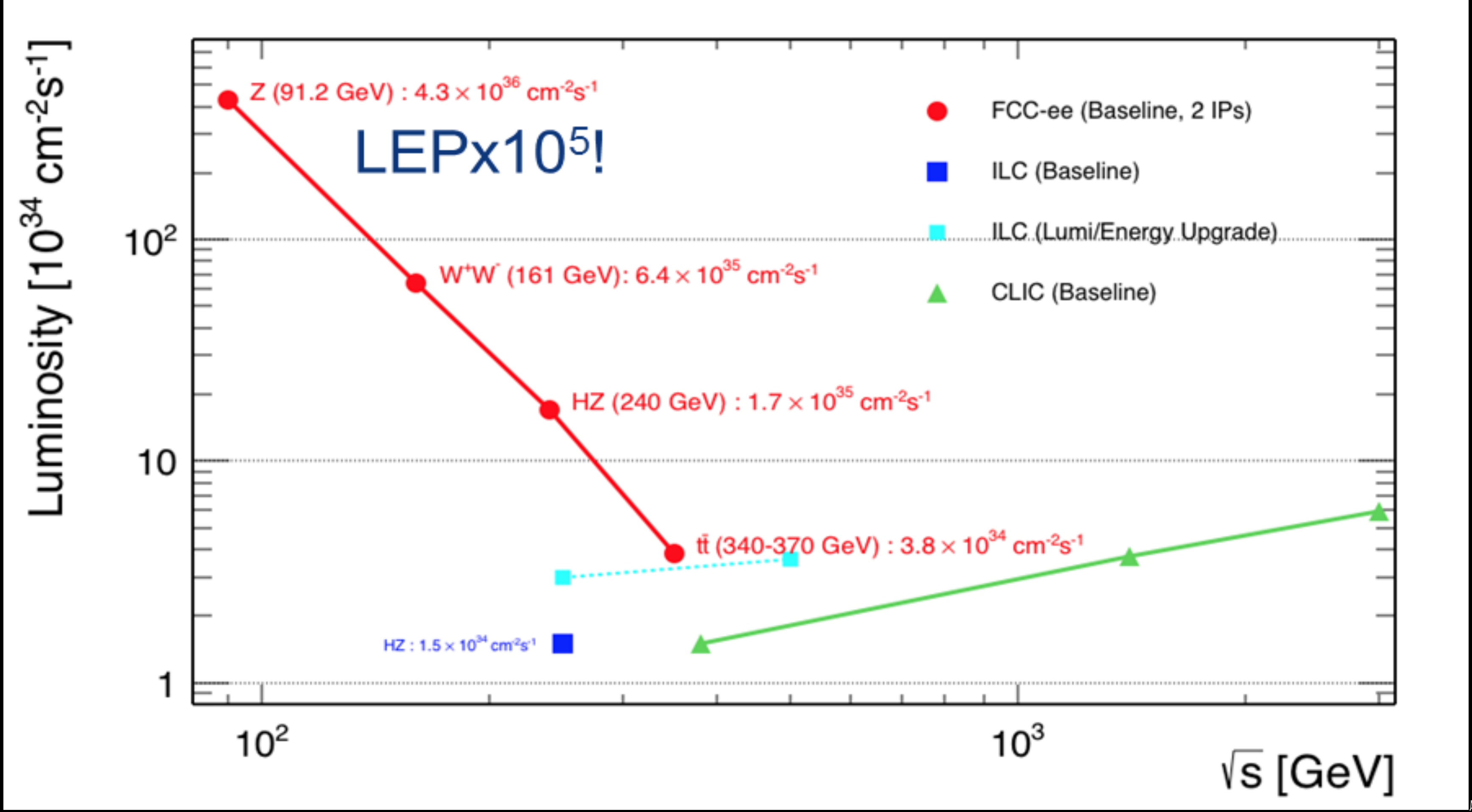
Top quark production

Cross section increases x35 compared to LHC at 14 TeV, and might collect up to 10^{12} top quarks

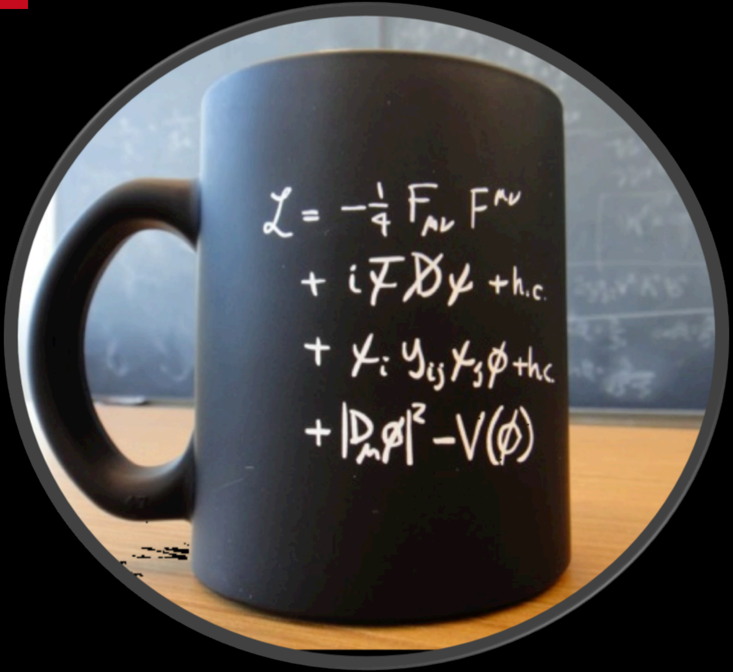
New physics phenomena

In general direct sensitivity to processes with mass scales up to 10-40 TeV.

Future Circular Collider (FCC) – lepton collider luminosities



FCC – some physics objectives

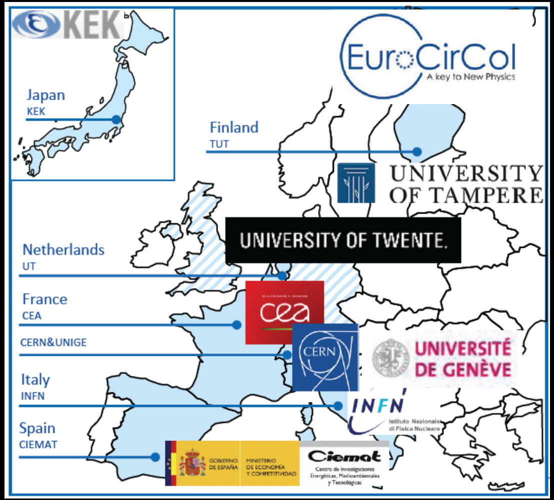


extreme zoom-in capabilities
for about all terms

SC Magnet R&D – *16 T magnets would allow doubling the energy of the LHC machine (HE-LHC)*

EuroCirCol WP5 (until 2019)

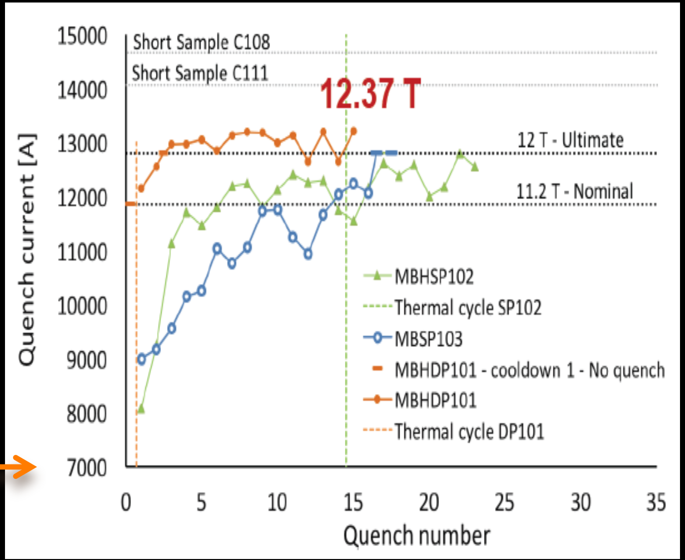
Feed the FCC CDR with a baseline design and a cost model for 16 T magnets

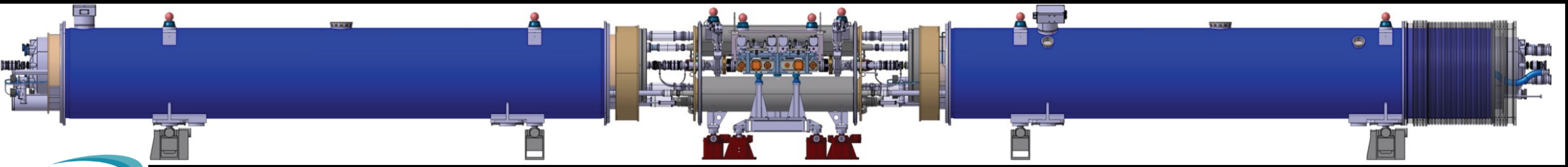


HiLumi LHC

To make space for the new HL-LHC collimators, replace a standard dipole by a pair of shorter 11 T dipoles producing the same integrated field

demonstrator short dipoles perform well





HiLumi HL-LHC PROJECT

SC Magnet R&D – *16 T magnets would allow doubling the energy of the LHC machine (HE-LHC)*

FRESCA2 @ CERN

Test new superconductive cables

Dipole magnet
1.5 m long, 1 m diameter, 10 cm aperture

Nominal 13 T design, with an ultimate goal of 15 T, and reached 14.6 T, a record for a magnet with a "free" aperture, and with only few quenches

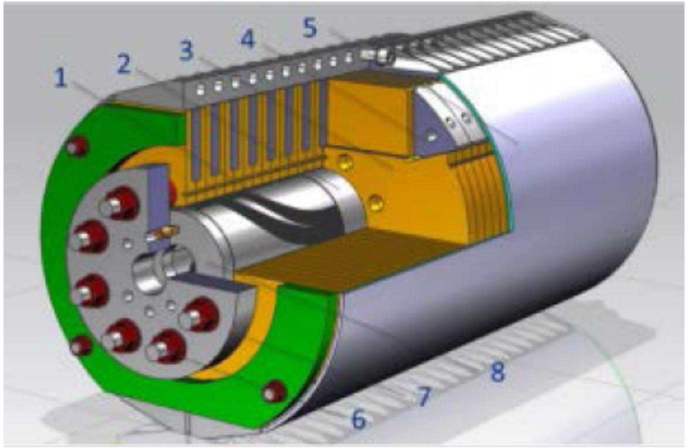
SC Magnet R&D – *16 T magnets would allow doubling the energy of the LHC machine (HE-LHC)*

R&D on High-field magnets

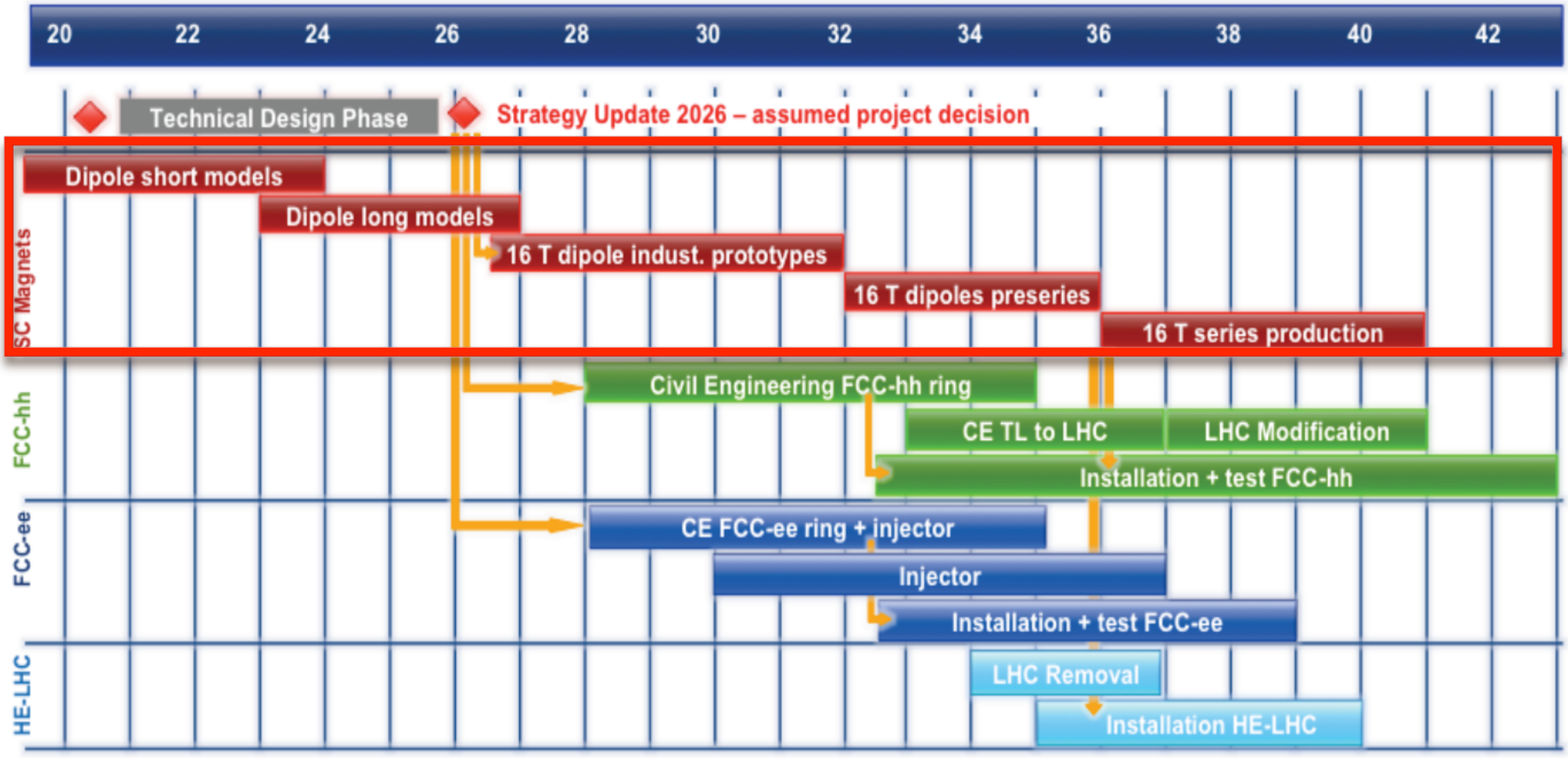
(from https://indico.cern.ch/event/686555/contributions/2962534/)

- Presently there is no viable alternative, development of the Nb_3Sn magnet technology is crucial for the future hadron collider where 12-20 T fields are essential.
- The current density achieved in the state of the art Nb_3Sn materials is adequate for reaching the fields up to 20 T, however the stress/strain tolerances are not.
- The main technical challenge for a >16 T dipole magnet is the structural integrity of the coil.

15 T Nb_3Sn dipole fabrication at FNAL and will be tested later this year.



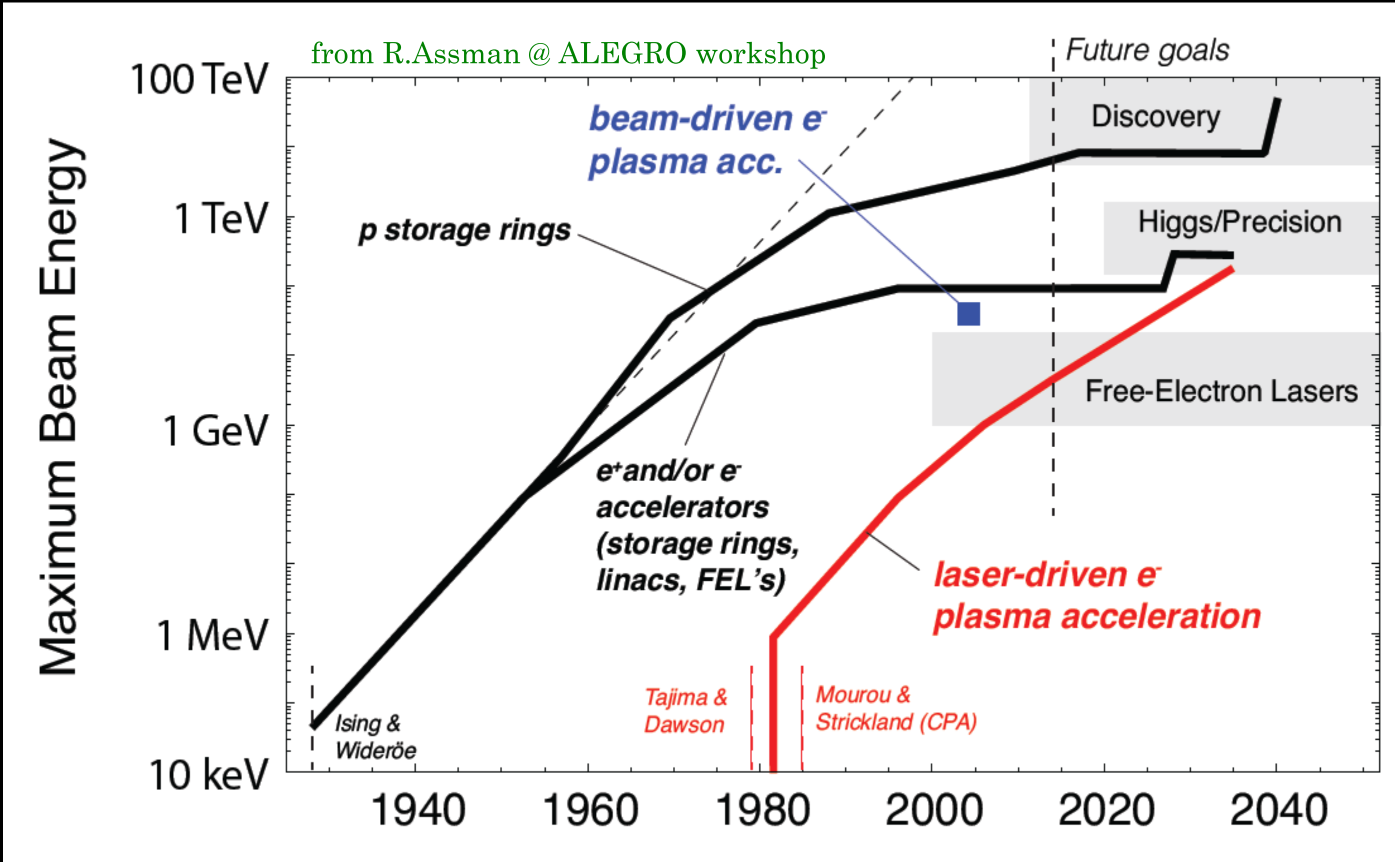
Future Circular Collider (FCC) – *technical schedule*



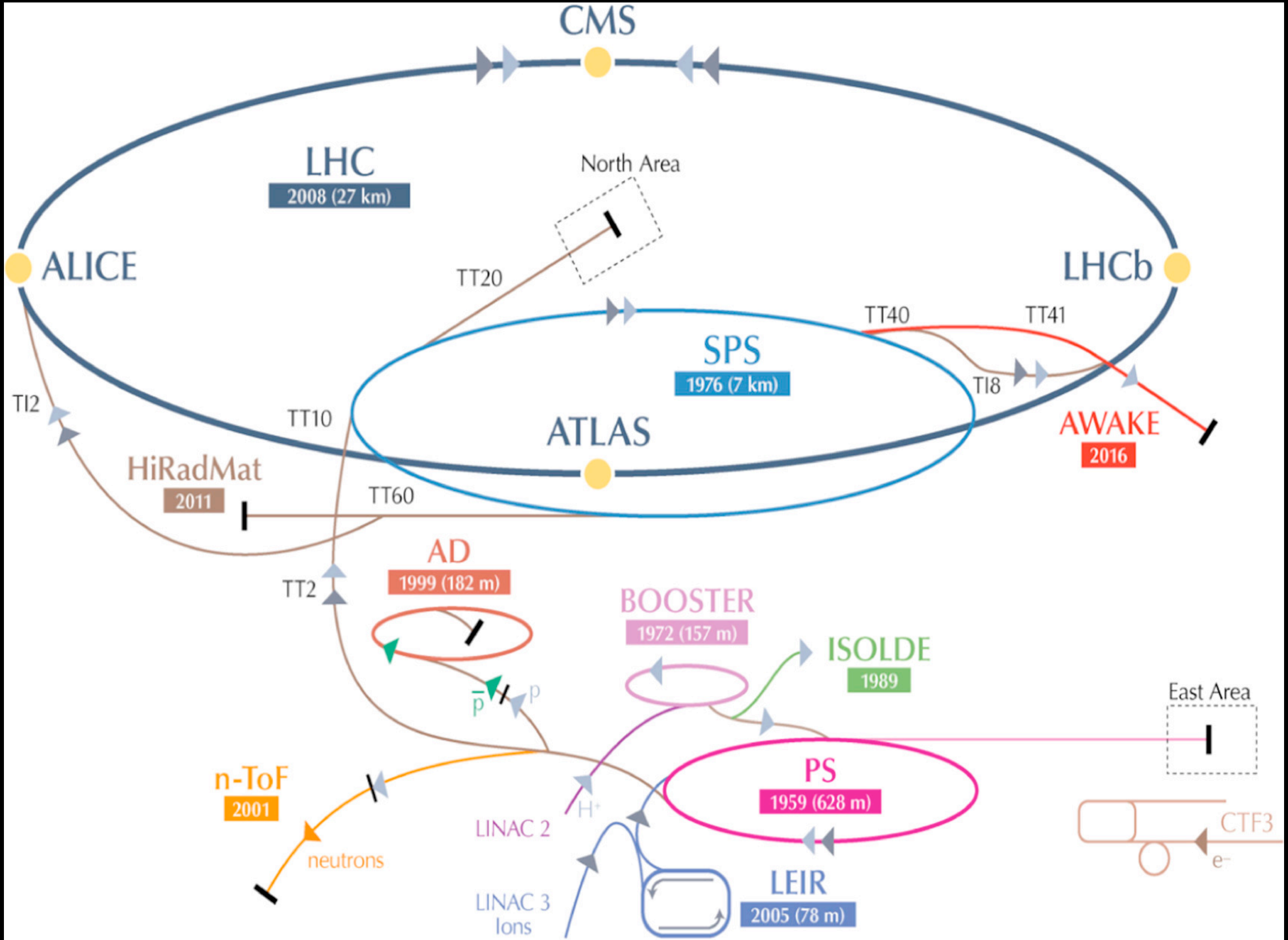
Accelerator R&D – Advanced Novel Accelerators (ICFA Panel)

ALEGRO (Advanced LinEar collider study GROup, for a multi-TeV Advanced Linear Collider) Workshop (March 2018 in Oxford): http://www.physics.ox.ac.uk/confs/alegro2018/index.asp

The objective of this first ALEGRO workshop was to prepare and deliver, by the end of 2018, a document detailing the international roadmap and strategy of Advanced Novel Accelerators (ANAs) with clear priorities as input for the European Particle Physics Strategy Update.



Accelerator R&D – Advanced Proton Driven Plasma Wakefield Acceleration Experiment (AWAKE)



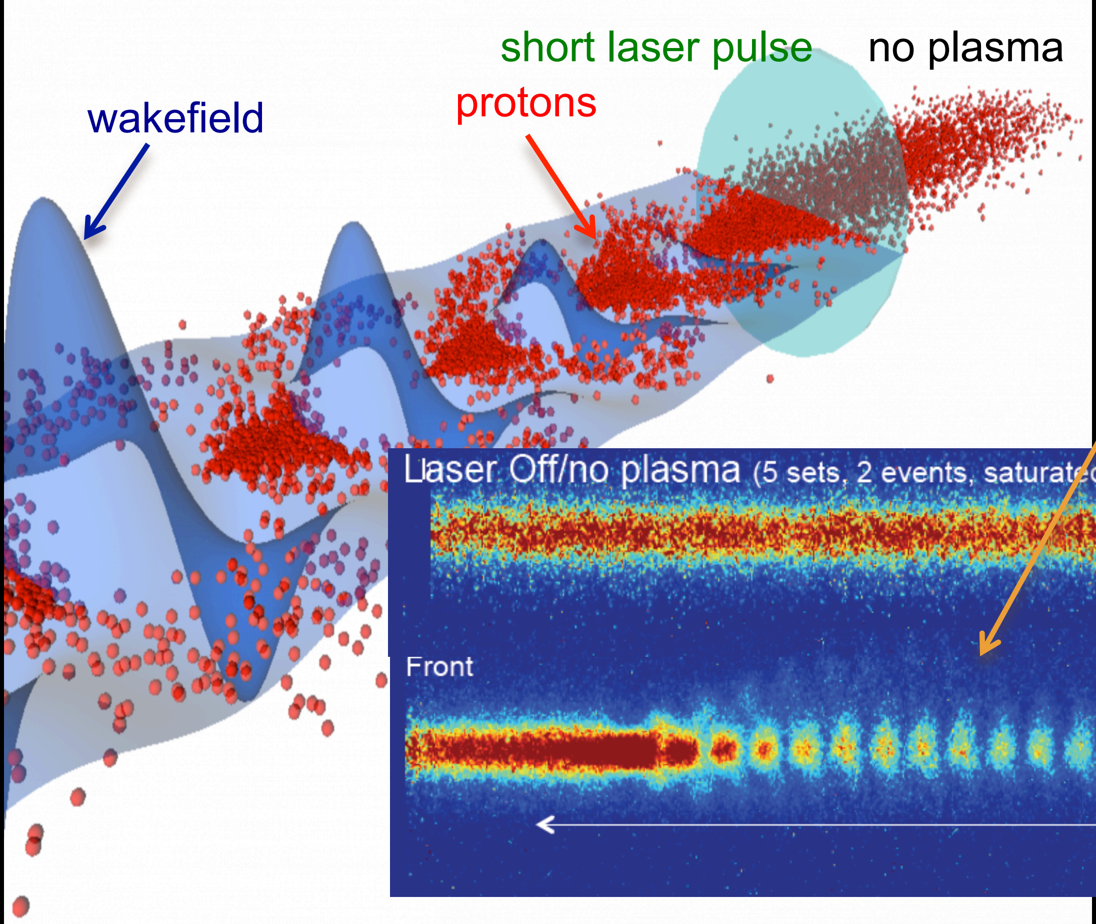
The AWAKE project is a demonstrator experiment for plasma wakefield acceleration.

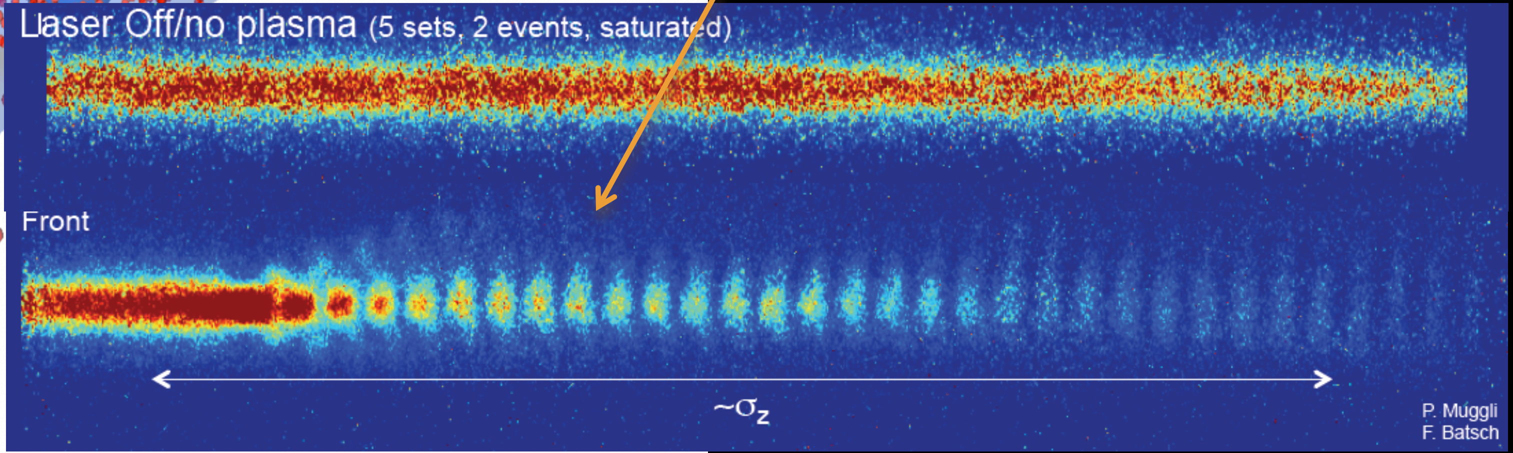
The objective is to accelerate an electron beam to few GeV in a 10m plasma cell using 400 GeV proton beams from the Super Proton Synchrotron at CERN.

AWAKE Collaboration:
16 institutes worldwide

Accelerator R&D – Advanced Proton Driven Plasma Wakefield Acceleration Experiment (AWAKE)

Patric Muggli, SPSC presentation, Oct 2017

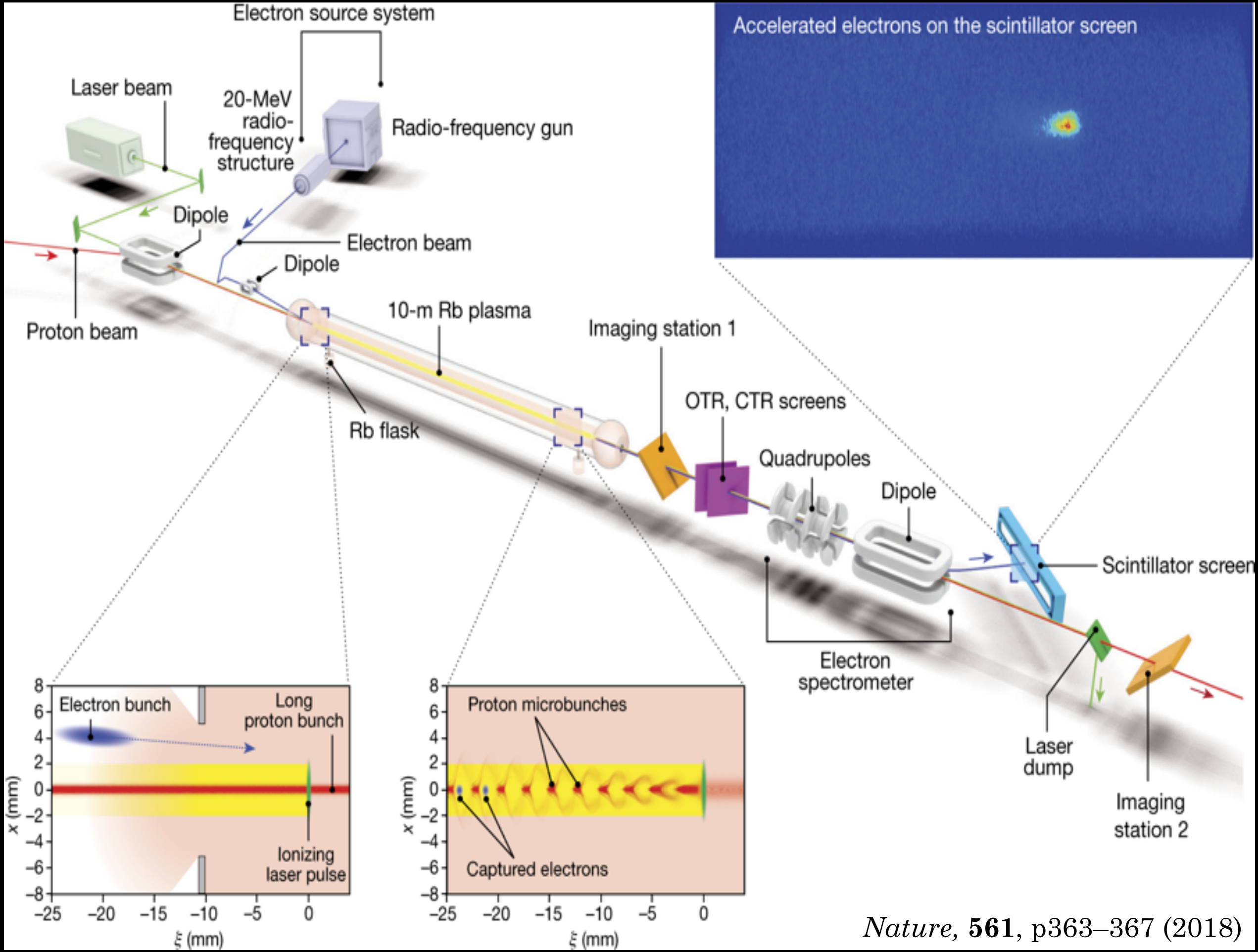


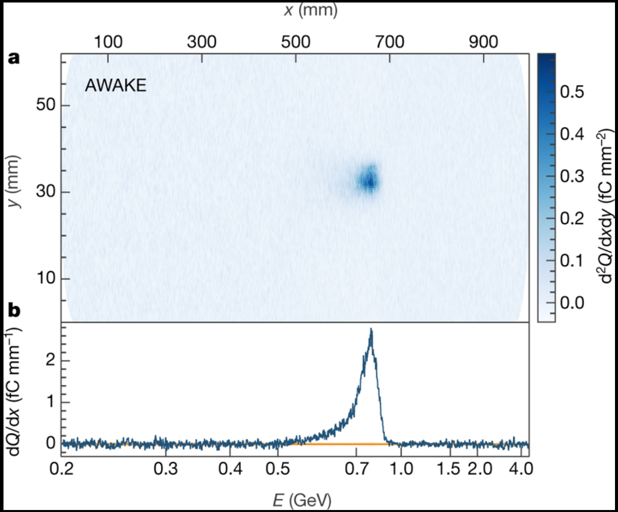


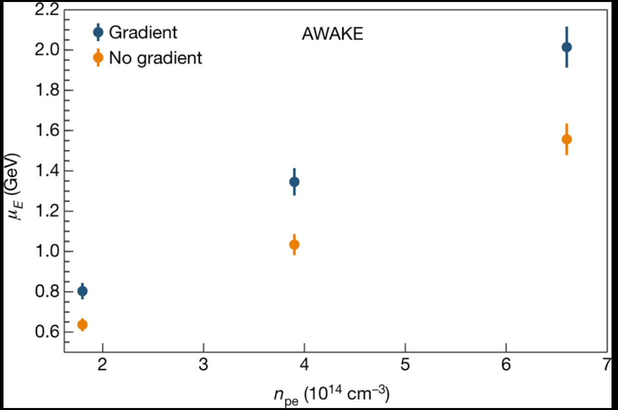
Clear observation of the modulation

After this observation the objective was to accelerate electrons

Accelerator R&D – Advanced Proton Driven Plasma Wakefield Acceleration Experiment (AWAKE)







Nature, **561**, p363–367 (2018)

Accelerator R&D – Muon Ionization Cooling Experiment @ RAL (MICE)

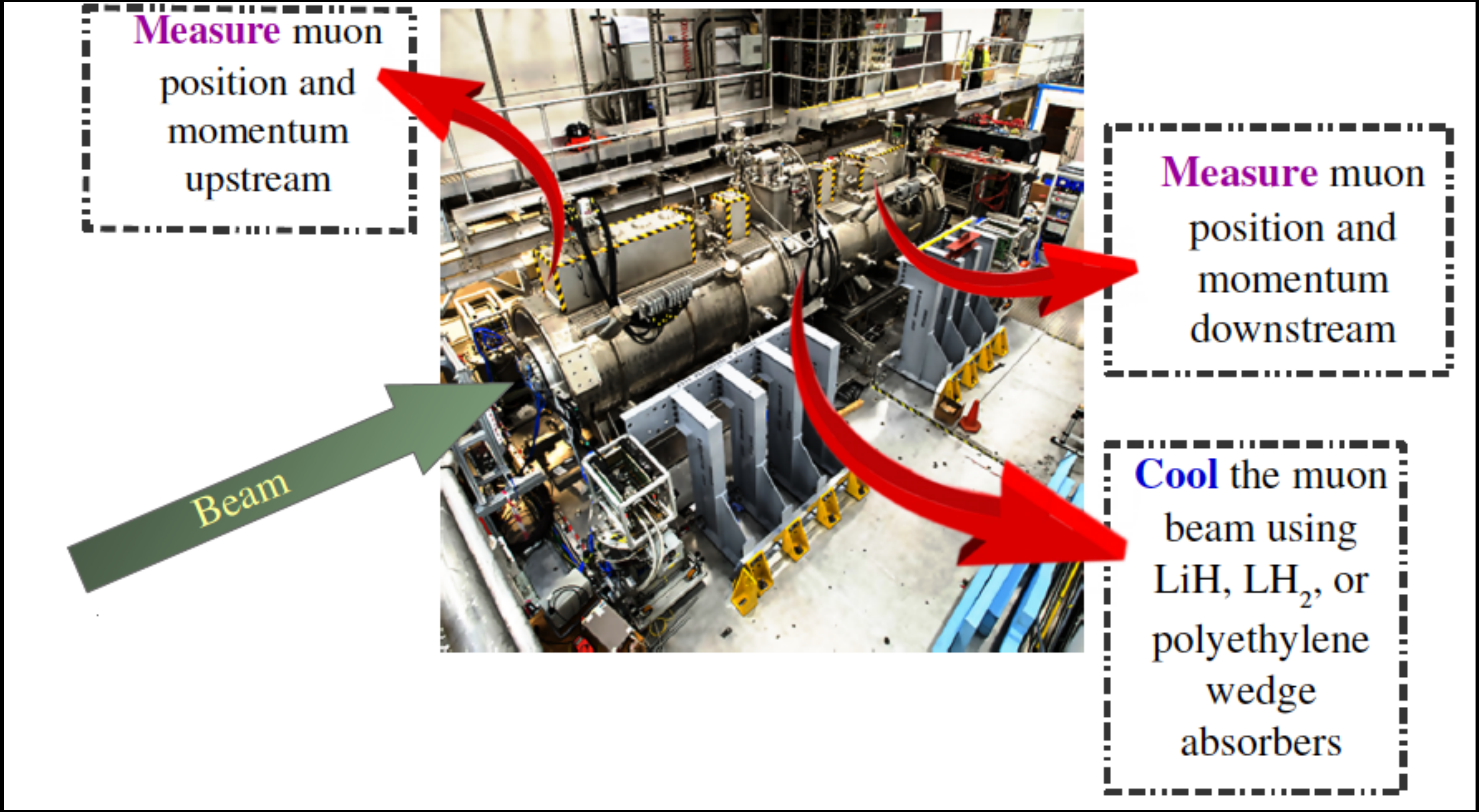
(from https://indico.cern.ch/event/686555/contributions/2962529/)
(also in CERN Courier, https://cerncourier.com/muons-cooled-for-action/)

Aim to demonstrate ionization cooling principle by observing an increased inherent beam brightness, operational at the ISIS synchrotron at RAL since 2008.

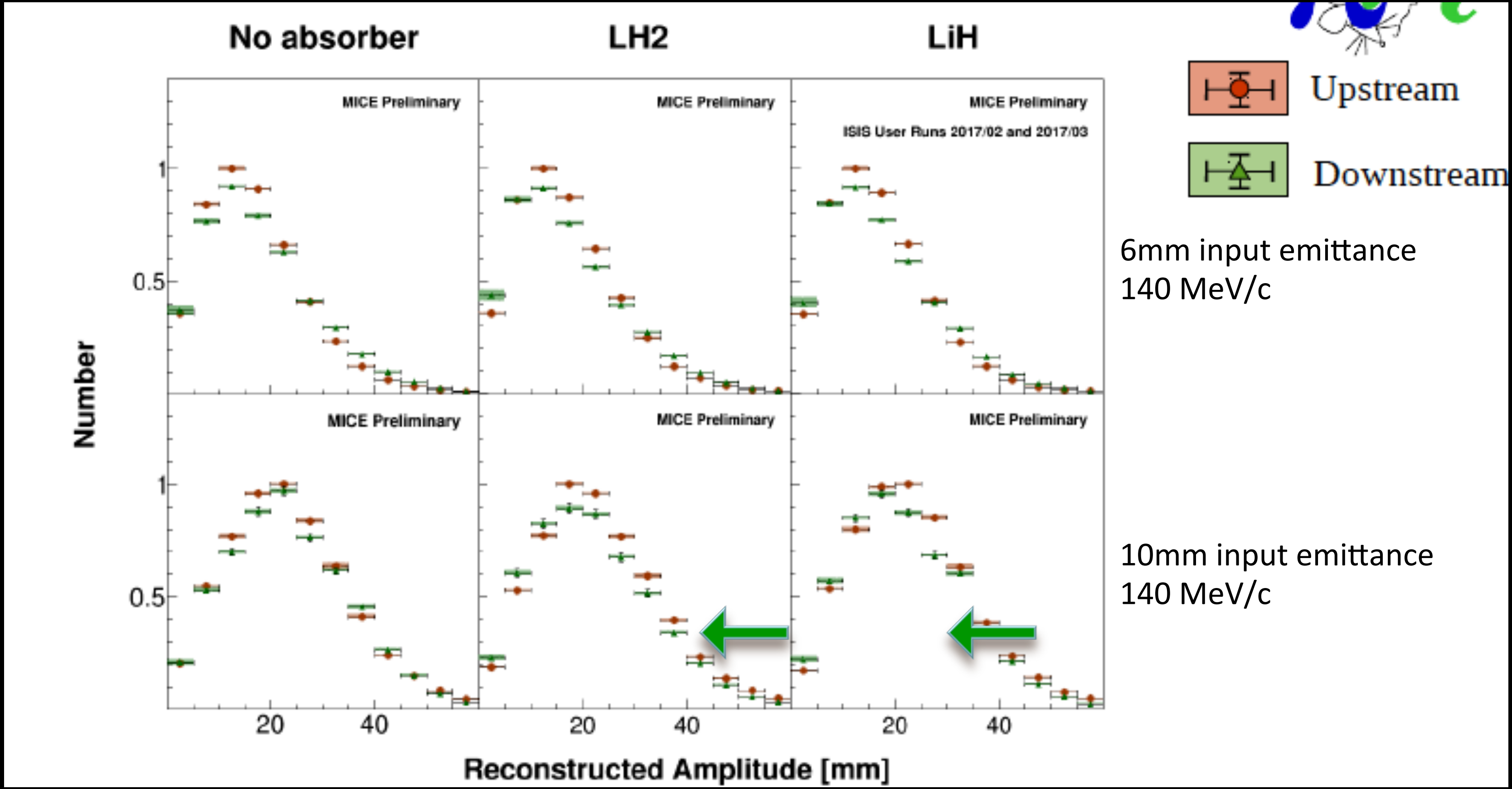
① Muons lose longitudinal and transverse momentum through ionization energy loss in an absorber.

② Multiple scattering degrades the cooling effect, but mitigated by low-Z absorber and tight focusing.
③ Muons regain only longitudinal momentum in RF cavities.

Accelerator R&D – Muon Ionization Cooling Experiment @ RAL (MICE)



Accelerator R&D – Muon Ionization Cooling Experiment @ RAL (MICE)

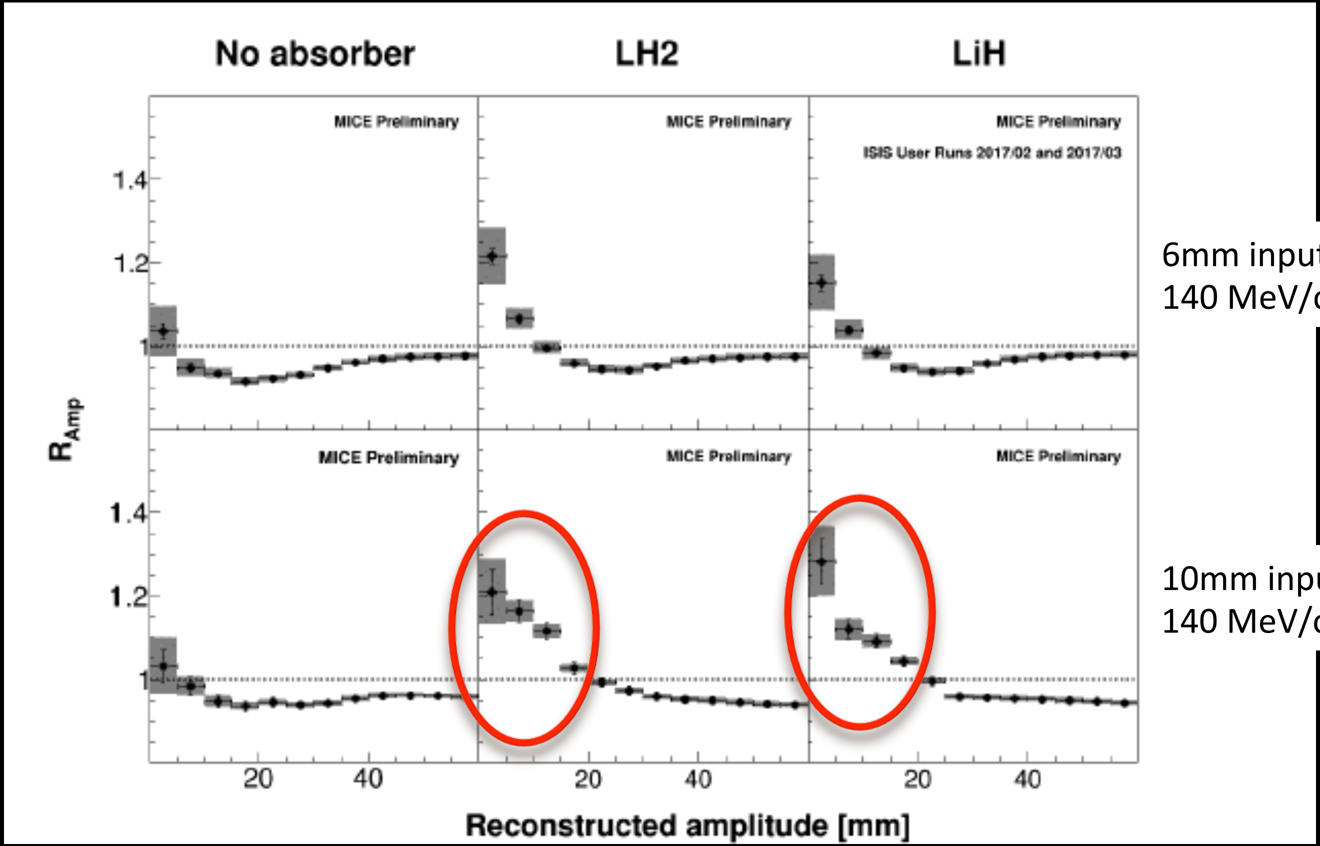


6mm input emittance
140 MeV/c

10mm input emittance
140 MeV/c

Accelerator R&D – Muon Ionization Cooling Experiment @ RAL (MICE)

Ratio of distributions



6mm input emittance
140 MeV/c

10mm input emittance
140 MeV/c

Accelerator R&D – R&D for Superconducting RF cavities

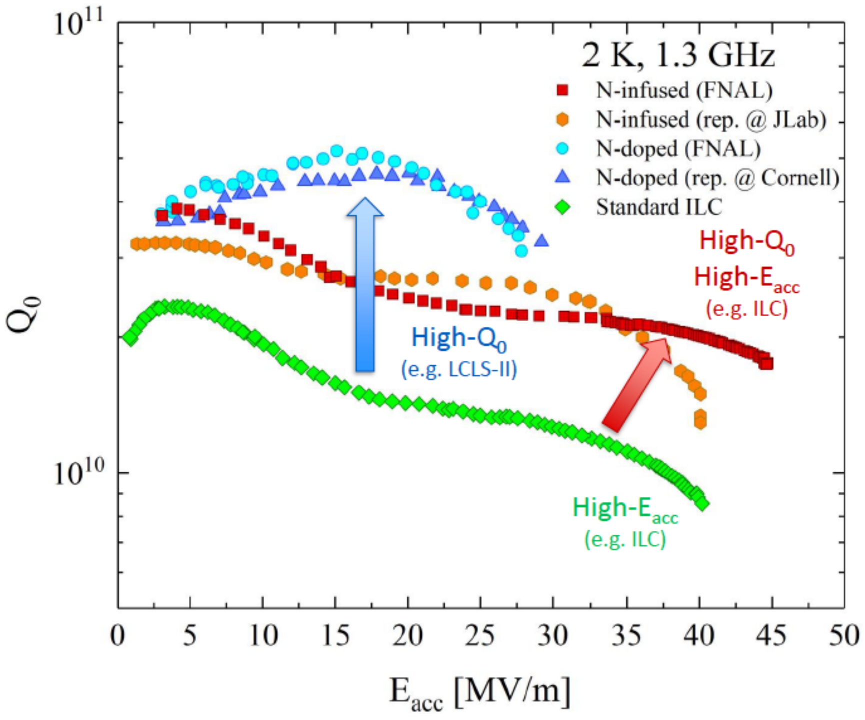
(from https://indico.cern.ch/event/686555/contributions/2962536/)

- Need a high Q-factor (Q_0) related to the cavity achievable efficiency.
- Increase the accelerator gradient (E_{acc}).
- Both are related to cost reduction avenues for linear colliders.

- The process of Nitrogen doping of the Nb cavities combined with 120 C baking increases the Q-factor.

- Important progress in the field.

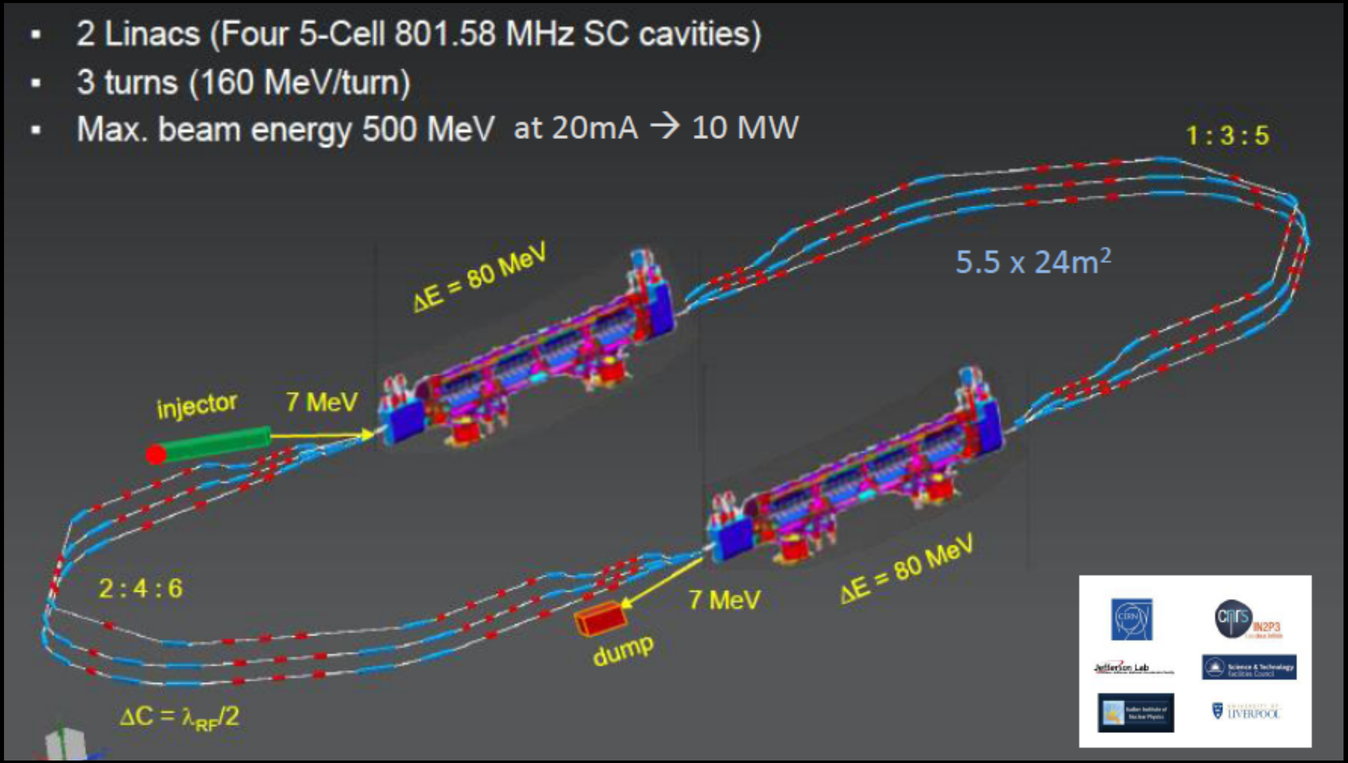
(ILC TDR mentions a 31.5 MV/m gradient)
(https://arxiv.org/pdf/1306.6327.pdf)



Accelerator R&D – Energy Recovery Linac (ERL), PERLE @ Orsay (CDR: J.Phys. G45 (2018) no.6, 065003)

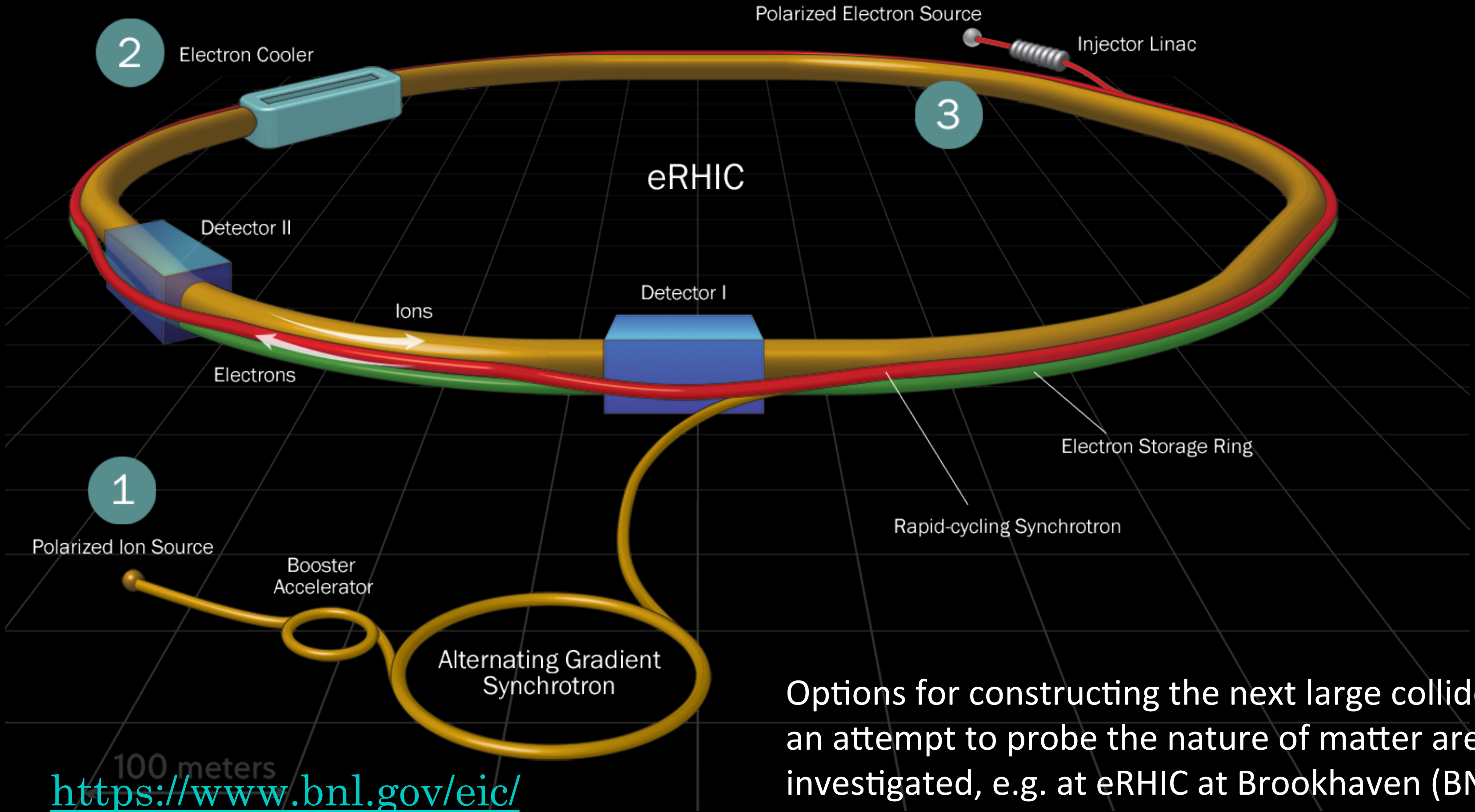
A first SC cavity of 802 MHz frequency has been built (J-LAB) and tested showing stability up to 29 MV/m and a weak Q_0-gradient dependence around 3 10^{10}, exceeding the design goal.

Depending on the phase electrons pass the SC cavities, they are accelerated (increase the kinetic energy using the RF field) or decelerated (use the kinetic energy to increase the RF field).



(from https://indico.cern.ch/event/686555/contributions/2962555/)

Accelerator R&D – U.S.-Based Electron Ion Collider Science

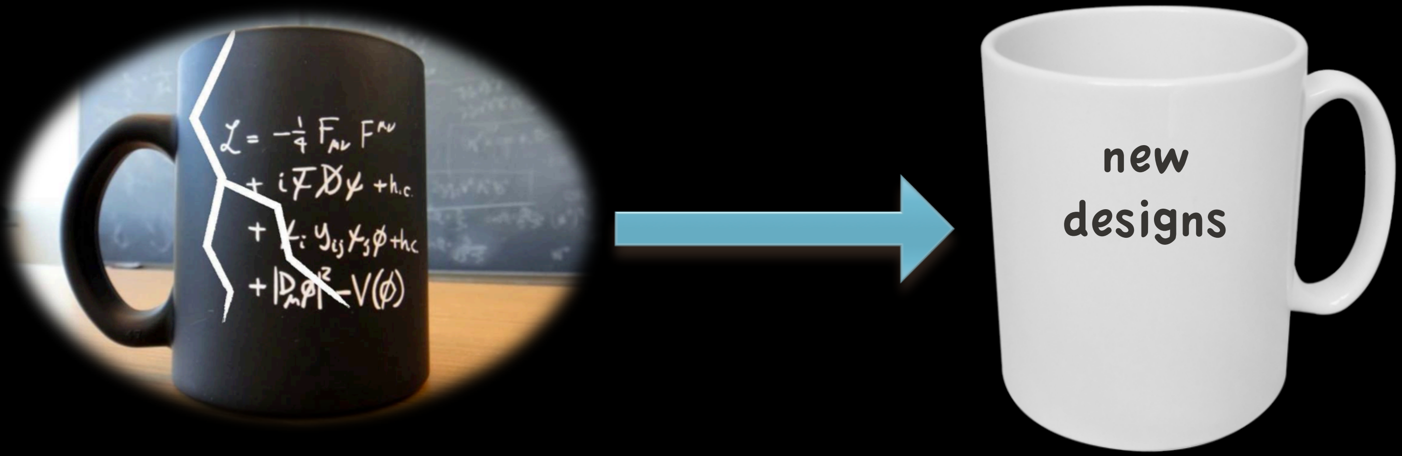


https://www.bnl.gov/eic/

Options for constructing the next large collider facility in an attempt to probe the nature of matter are being investigated, e.g. at eRHIC at Brookhaven (BNL).

The 2013 European Particle Physics Strategy

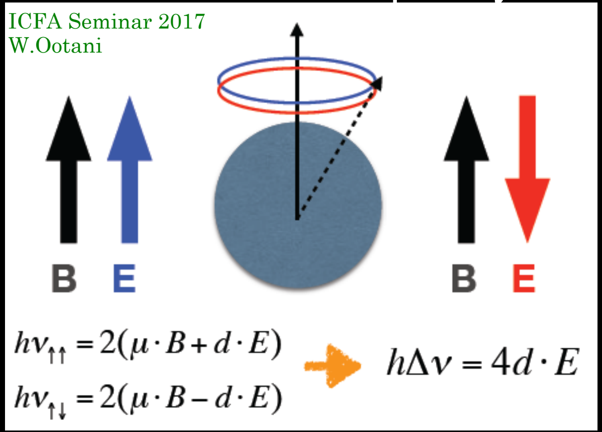
"Experiments studying quark flavour physics, dipole moments, charged-lepton violation and performing other precision measurements ... with neutrons, muons and antiprotons may give access to higher energy scales than direct particle production ... They can be based in national laboratories, with a moderate cost … Experiments in Europe with unique reach should be supported, as well as participation in experiments in other regions of the world."



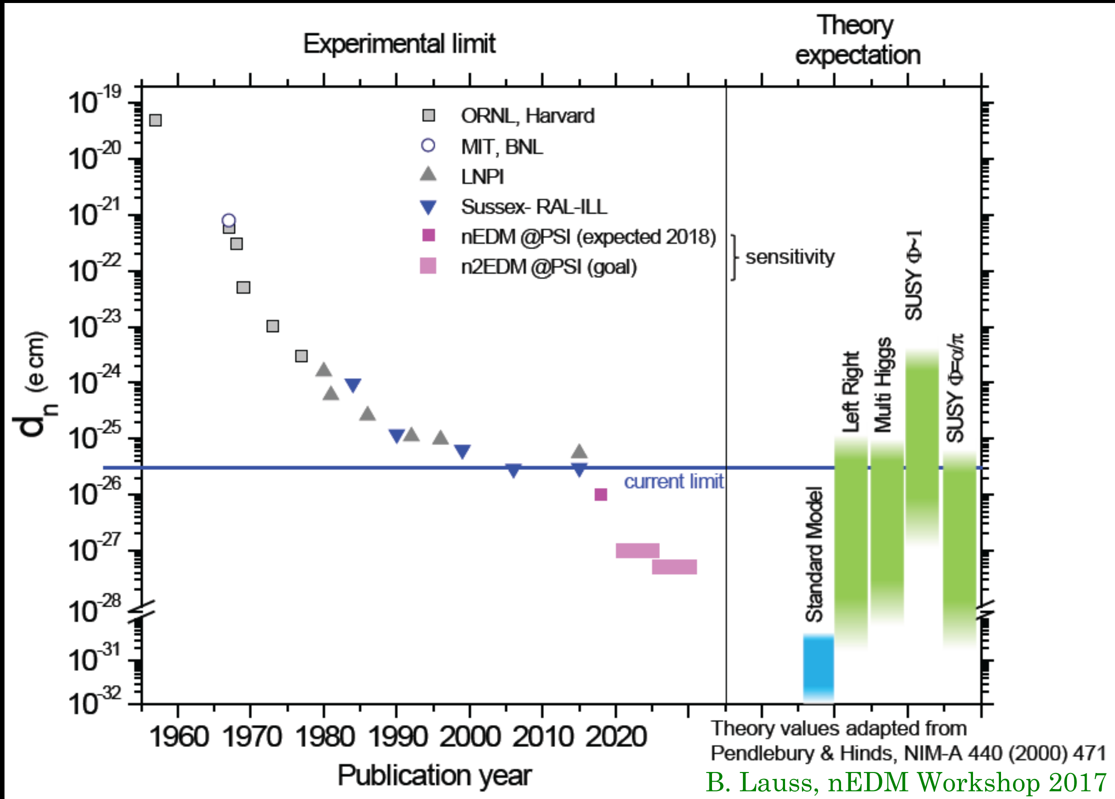
Electric Dipole Moment (EDM)

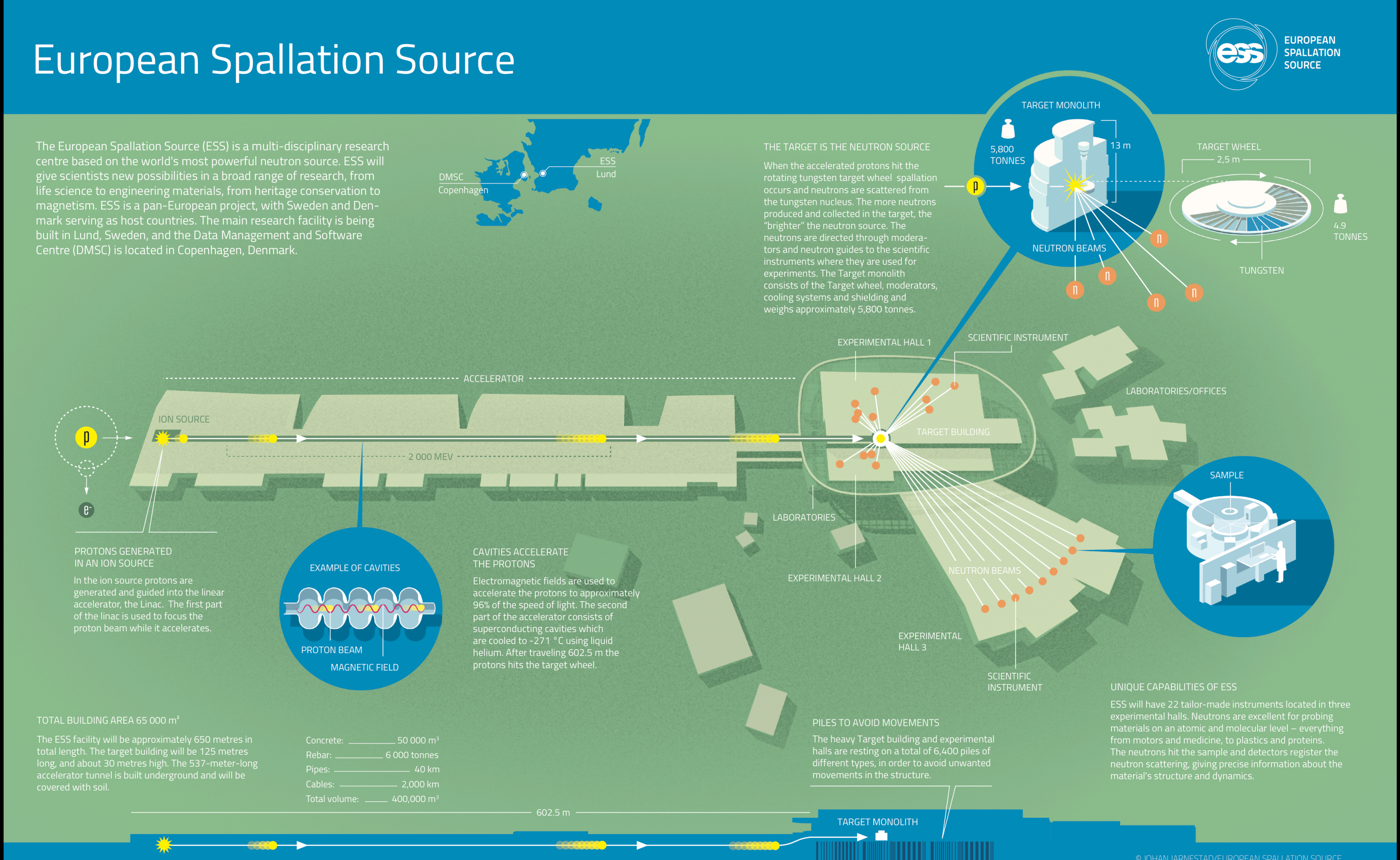
Separation of particle charge along angular momentum axis.
The EDM in the Standard Model is negligible (SM EDM electron 10^{-38} e-cm, best limit is 8.7×10^{-29} e-cm at 90% CL), if non-zero it violates symmetries like P, T, CP.

Measure Larmor frequency shift



Variety of systems used from neutrons and electrons to atoms and molecules.





Credit: Johan Jarnestad / ESS

Aerial view October 2017

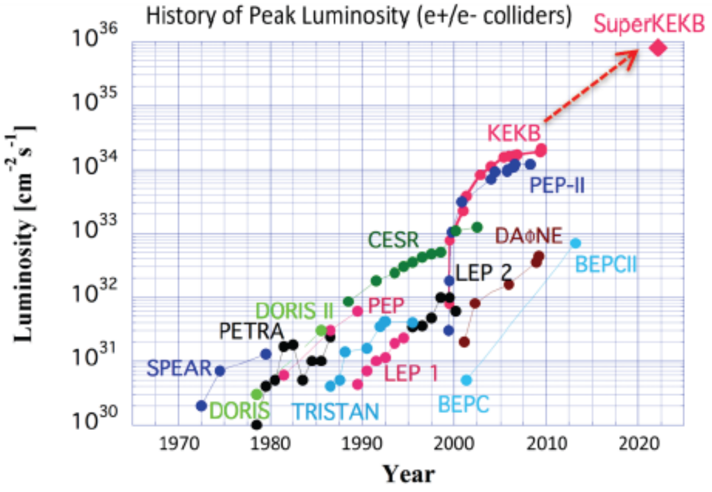
Construction Financing	BUDGET	HOST COUNTRIES SWEDEN & DENMARK	NON-HOST MEMBERS	IN-KIND CONTRIBUTIONS
	€1.843 Billion	47.5%	52.5%	€747.5 Million

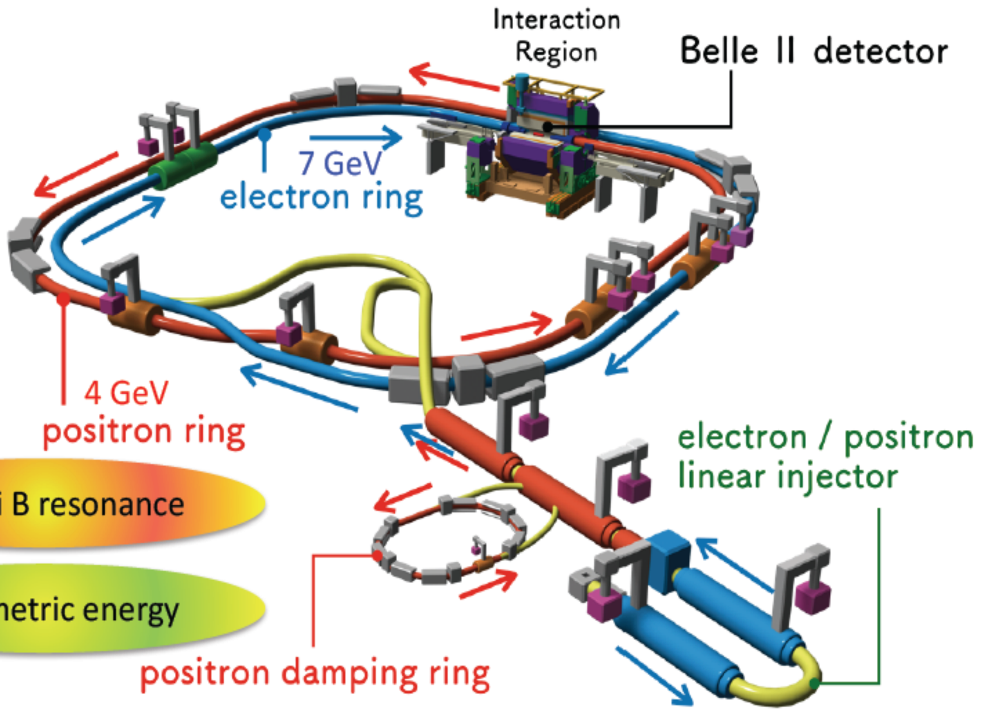
ESS is working with 15 nations, nearly 40 European in-kind partner institutions, and more than 130 collaborating institutions worldwide.

SuperKEKB and BELLE-II started

(from https://indico.cern.ch/event/686555/contributions/3028068/attachments/1683219/2705296/3-2._ICHEP18_SuperKEKB_Akai.pdf)

- Started physics run in 2018
- Pioneering the luminosity frontier
- Nano-beam collider scheme
- First collisions on April 26, 2018
- First “re-discoveries” made of beauty and charm





B - anti B resonance

asymmetric energy

strong European participation

The 2013 European Particle Physics Strategy

In the coming years, CERN should seek a closer collaboration with ApPEC on detector R&D with a view to maintaining the community' s capability for unique projects in this field.

European Astroparticle Physics Strategy 2017-2026

http://www.appec.org/roadmap

A major puzzle is the presence of
Dark Matter in the Universe

See talk by Javier Redondo

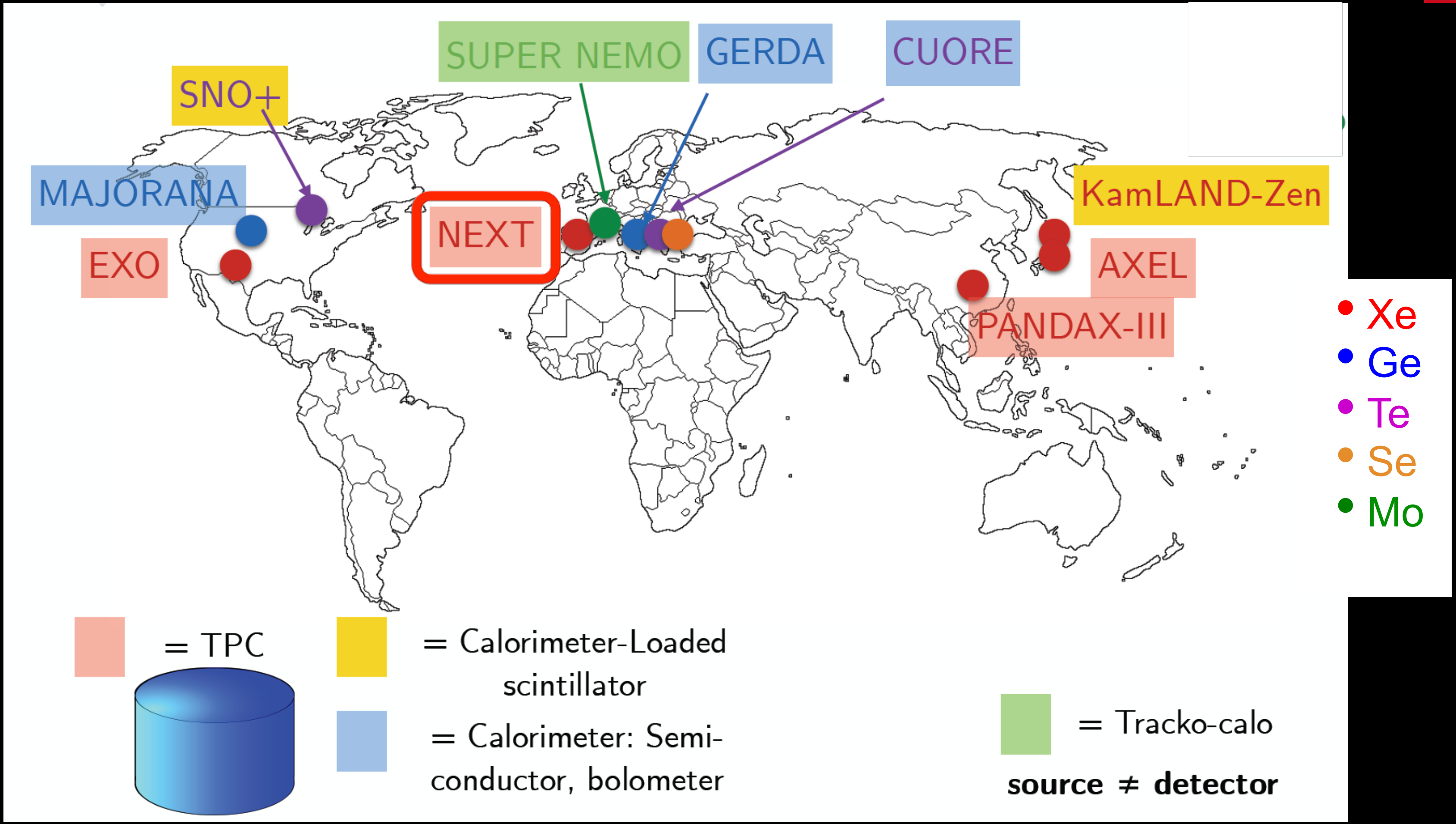
The multimessenger window on our Universe

See talk by Maurizio Spurio

Underground facilities for Particle Physics

image courtesy of Susana Cebrián, "Science goes underground"

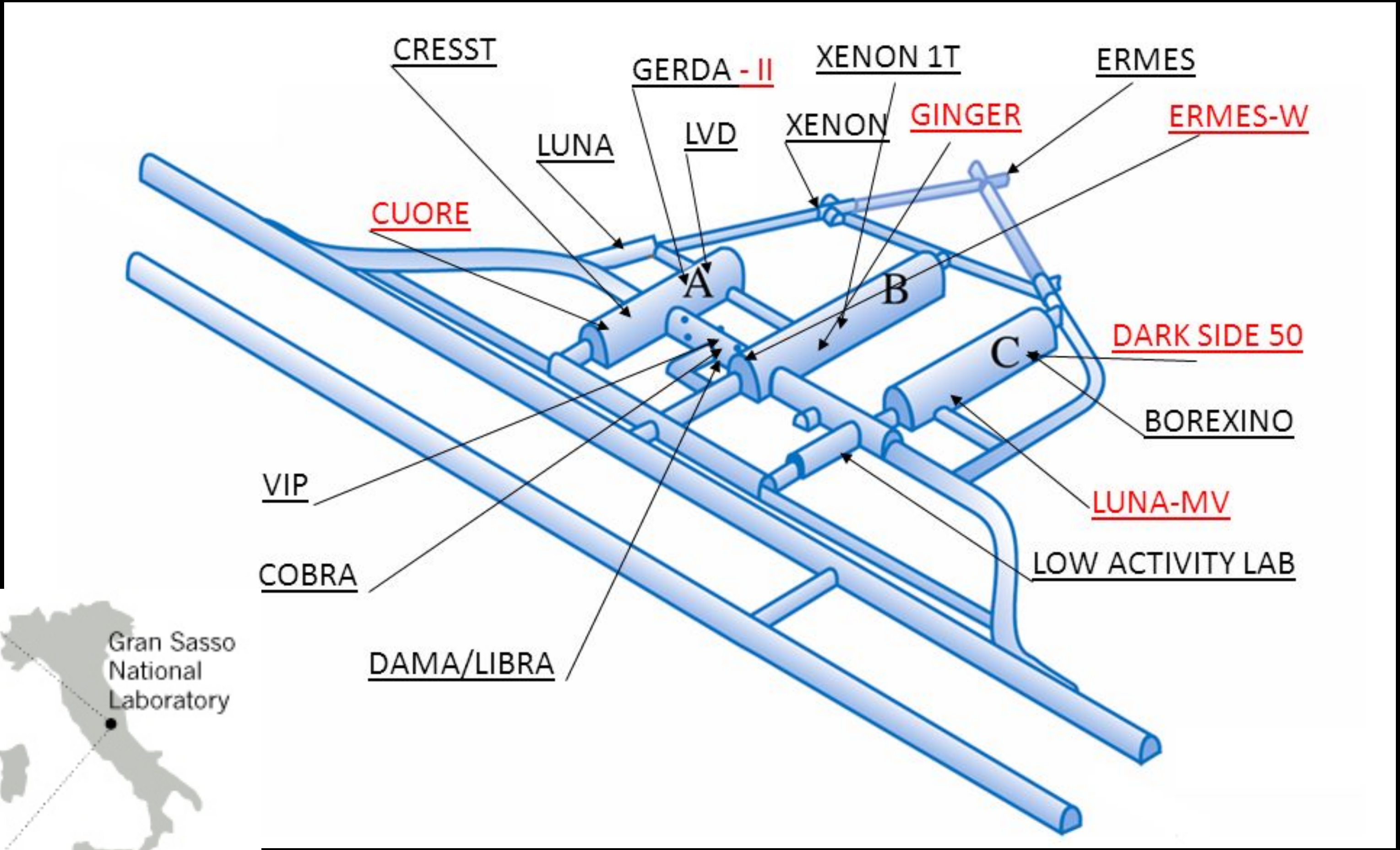
Neutrinoless Double Beta Decay

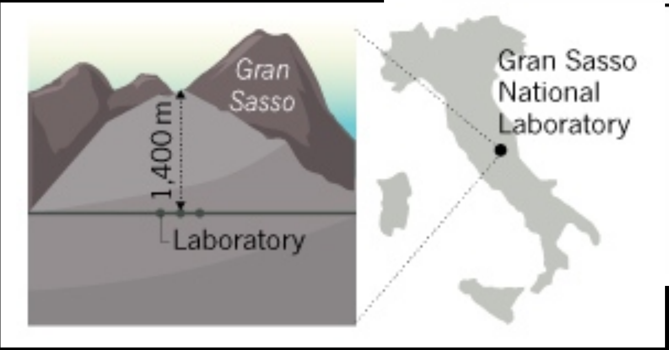


from N. Lopez (Kyoto HE seminar)

Underground facilities for Particle Physics

Gran Sasso laboratory in Italy



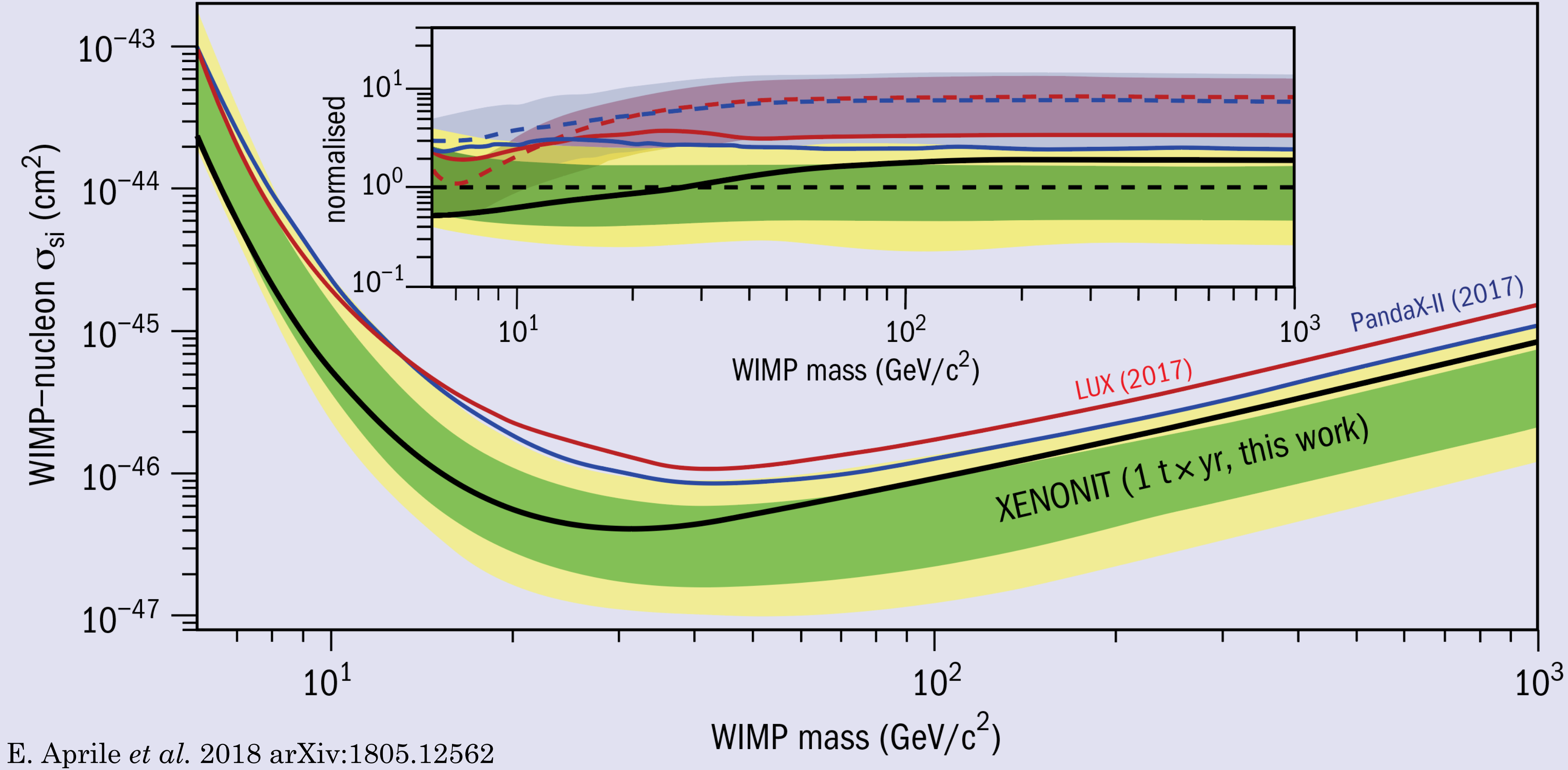


Underground facilities for Particle Physics

The XENON1T experiment at the Laboratori Nazionali del Gran Sasso (LNGS) is the first WIMP dark matter detector operating with a liquid xenon target mass above the ton-scale.

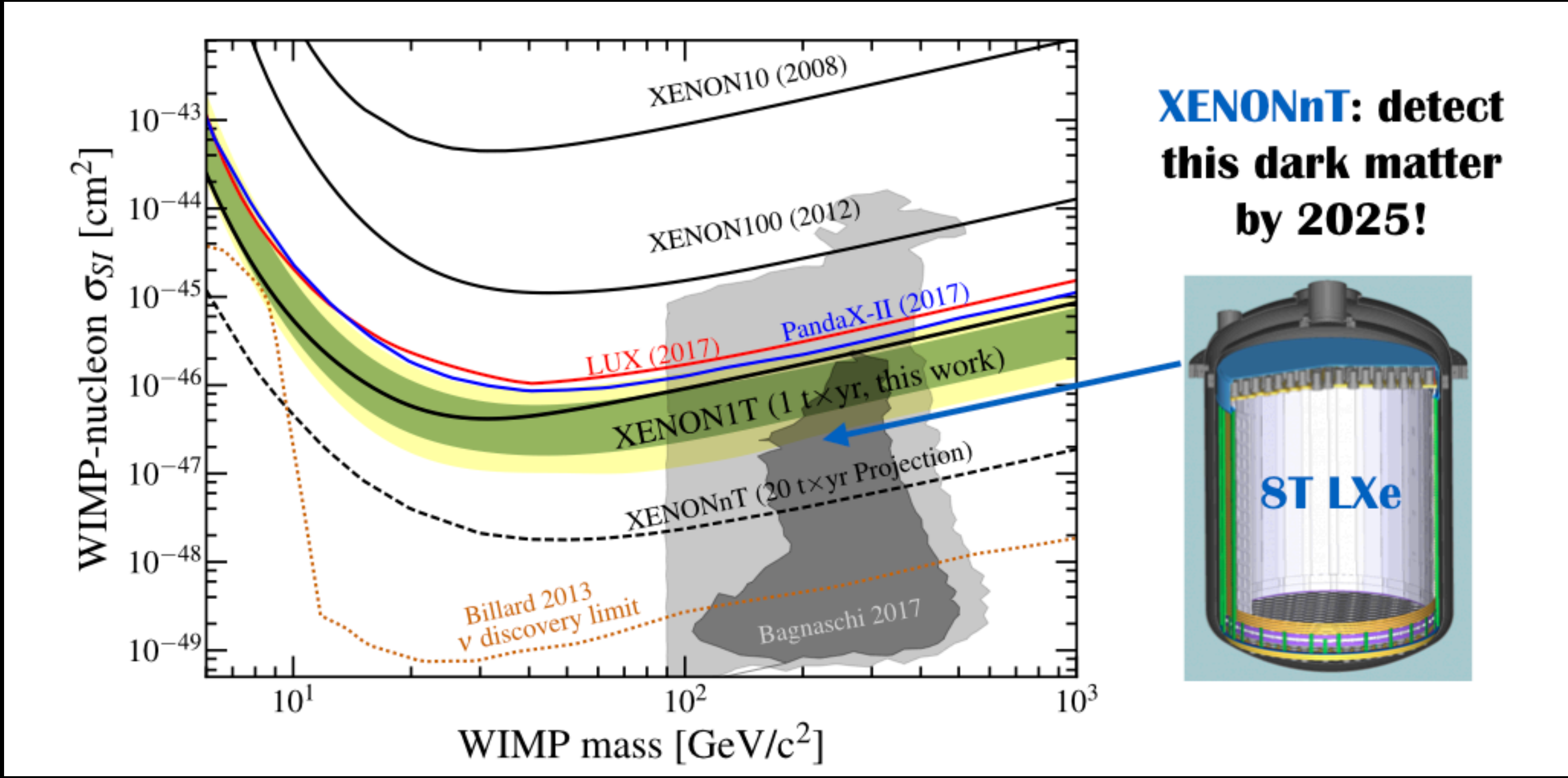
“The Xenon1T Dark Matter experiment”
arXiv:1708.07051v1

Underground facilities for Particle Physics



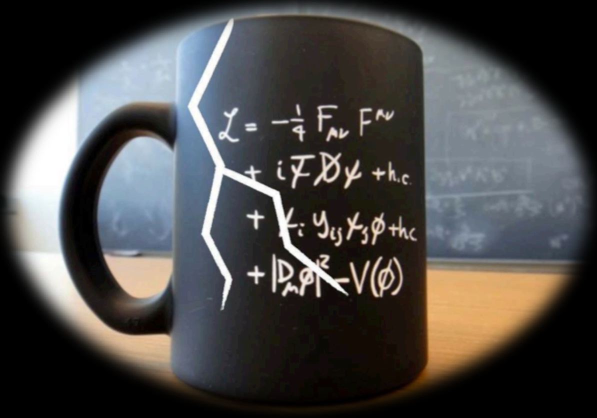
E. Aprile *et al.* 2018 arXiv:1805.12562

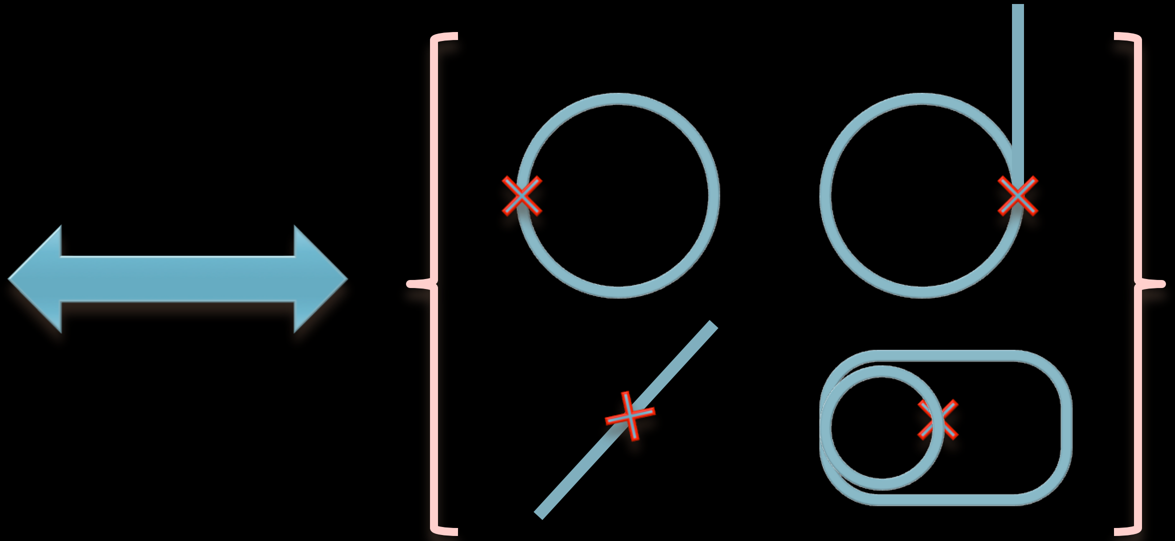
Underground facilities for Particle Physics



Kaixuan Ni, at the 6th Symposium on Neutrinos and Dark Matter in Nuclear Physics (NDM 2018)

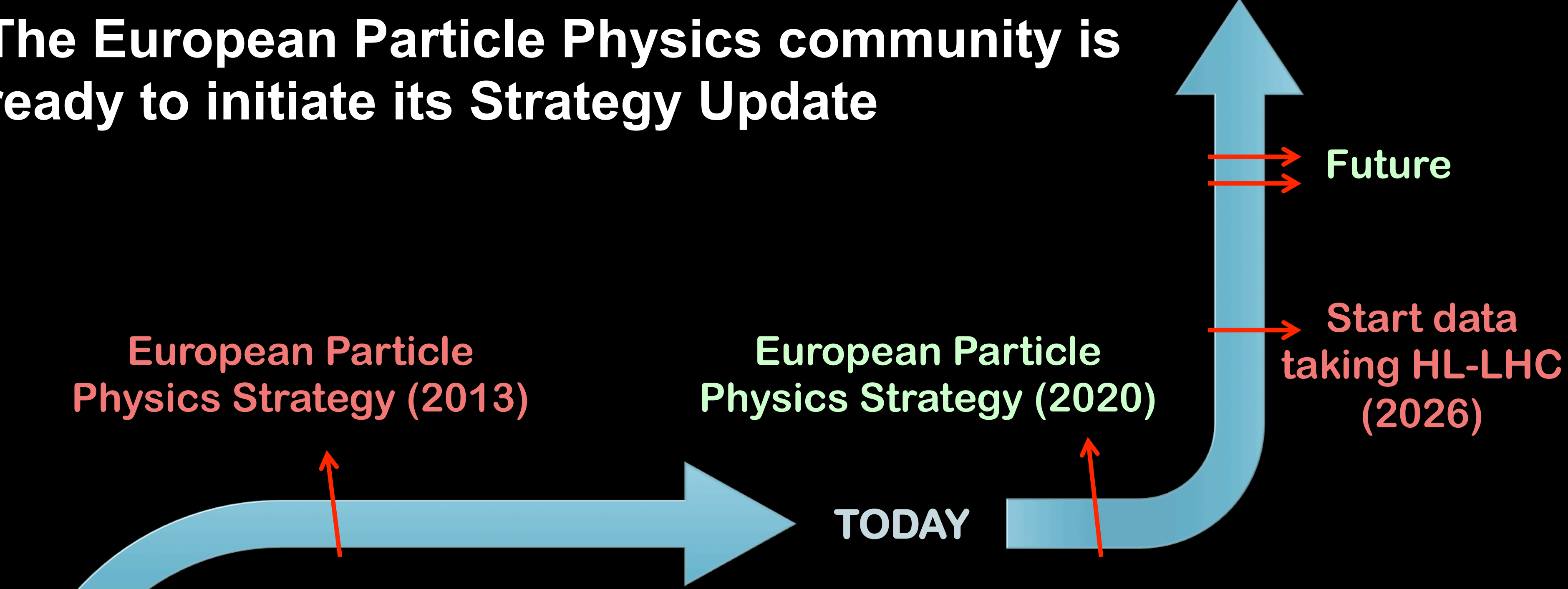
If these (non-collider) experiments would provide hints where to look for new physics, it would be interesting if we can address these with current and future colliders





<u>In general</u>: explore the synergies of the physics potential of non-collider and collider experiments

The European Particle Physics community is ready to initiate its Strategy Update



Key objectives set by CERN Council

- Deliver by May 2020 an update of the European Particle Physics Strategy in a global context
- This strategy or vision will thereafter be a roadmap for funding agencies and laboratories to define concrete research programmes

Update of the European Strategy for Particle Physics
(https://europeanstrategy.cern)

Press release :
https://home.cern/about/updates/2018/10/towards-new-shared-vision-particle-physics-europe

European Strategy Update

CERN Council approved the Strategy Secretariat

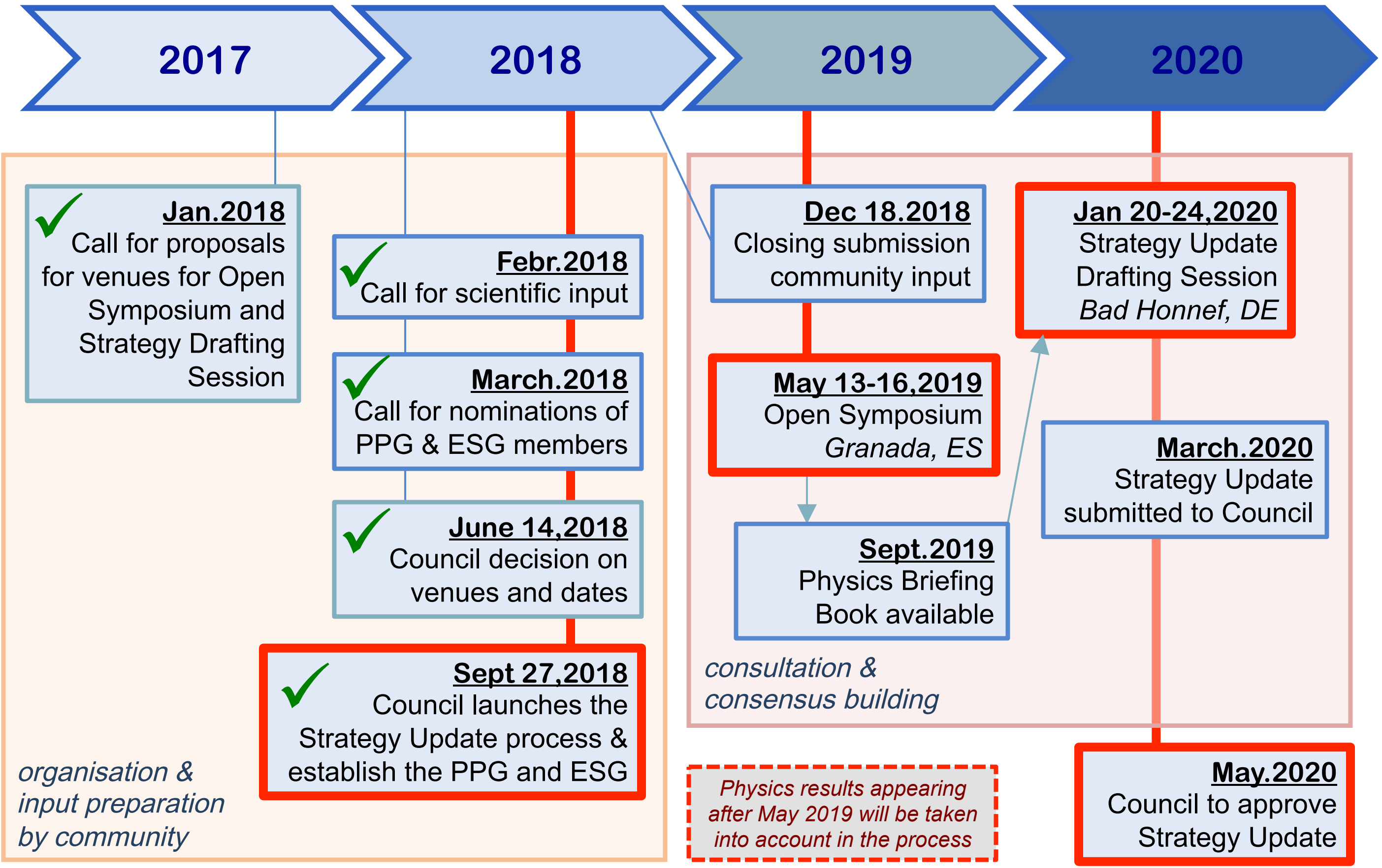
Council appointment, September 2017:

- H. Abramowicz (Chairperson)
- J. D'Hondt (ECFA Chairperson, *ECFA: European Committee for Future Accelerators*)
- K. Ellis (SPC Chairperson, *SPC: Science Policy Committee @ CERN*)
- L. Rivkin (European LDG Chairperson, *LDG: Lab Directors Group*)

- Contact: EPPSU-Strategy-Secretariat@cern.ch

Responsible for the organisation of the process.

European Particle Physics Strategy *Update*



Composition of the PPG

Physics Preparatory Group (PPG), Council appointment, September 2018:

- H. Abramowicz, J. D'Hondt, K. Ellis, L. Rivkin (*Strategy Secretary*)
- C. Biscari (ES), Belen Gavela (ES), Beate Heinemann (DE), Krzysztof Redlich (PL)
- Stan Bentvelsen (NL), Paris Sphicas (GR), Marco Zito (FR), Antonio Zoccoli (IT)
- Gian Giudice (*CERN*)
- Shoji Asai and Xinchou Lou (*delegates from Asia*)
- Marcela Carena and Brigitte Vachon (*delegates from the Americas*)

Responsible to organise the Open Symposium and to deliver to the European Strategy Group (ESG) a Briefing Book.

Composition of the ESG

European Strategy Group (ESG) composition, adopted by Council, December 2013:

- the Strategy Secretary (acting as Chairperson),
- one representative appointed by each CERN Member State,
- one representative for each of the Laboratories participating in the major European Laboratory Directors' meeting, including its Chairperson,
- the CERN Director-General,
- the SPC Chairperson,
- the ECFA Chairperson.

Responsible to deliver a draft Strategy Update to Council.

Invited:

- the President of the CERN Council,
- one representative from each of the Associate Member States,
- one representative from each Observer State,
- one representative from the European Commission and JINR,
- the Chairpersons of ApPEC, FALC, ESFRI, and NuPECC,
- the members of the Physics Preparatory Group.

Most members are named

Call for input

General considerations by the Strategy Secretariat:

- The Strategy Update process follows a bottom-up approach
- To facilitate the bottom-up approach an Open Call for input reaching out to all members of the particle physics community is issued; including research groups, research networks or collaborations, laboratories, universities, (inter)national institutions and/or organisations.
- The aim is to gather all relevant input, e.g. on scientific projects, position papers, national roadmaps, etc.

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- The aim is to gather all relevant input, e.g. on scientific projects, position papers, national roadmaps, etc.

Deadline: December 18th, 2018

Pragmatically, general guidelines are provided to facilitate both the collection of the input and its use by the PPG and the ESG; i.e. be brief, comprehensive and self-contained.

Guidelines for submitting input

Cover page (1 page)
Each document submitted should carry a single cover page containing no more than the title, the contact person(s) and an abstract.

Comprehensive overview (maximum 10 pages)
This core part of the document must be no more than 10 pages long (excluding the cover page) and must provide a comprehensive and self-contained overview of the proposed input. It should address:

- scientific context,
- objectives,
- methodology,
- readiness and expected challenges.

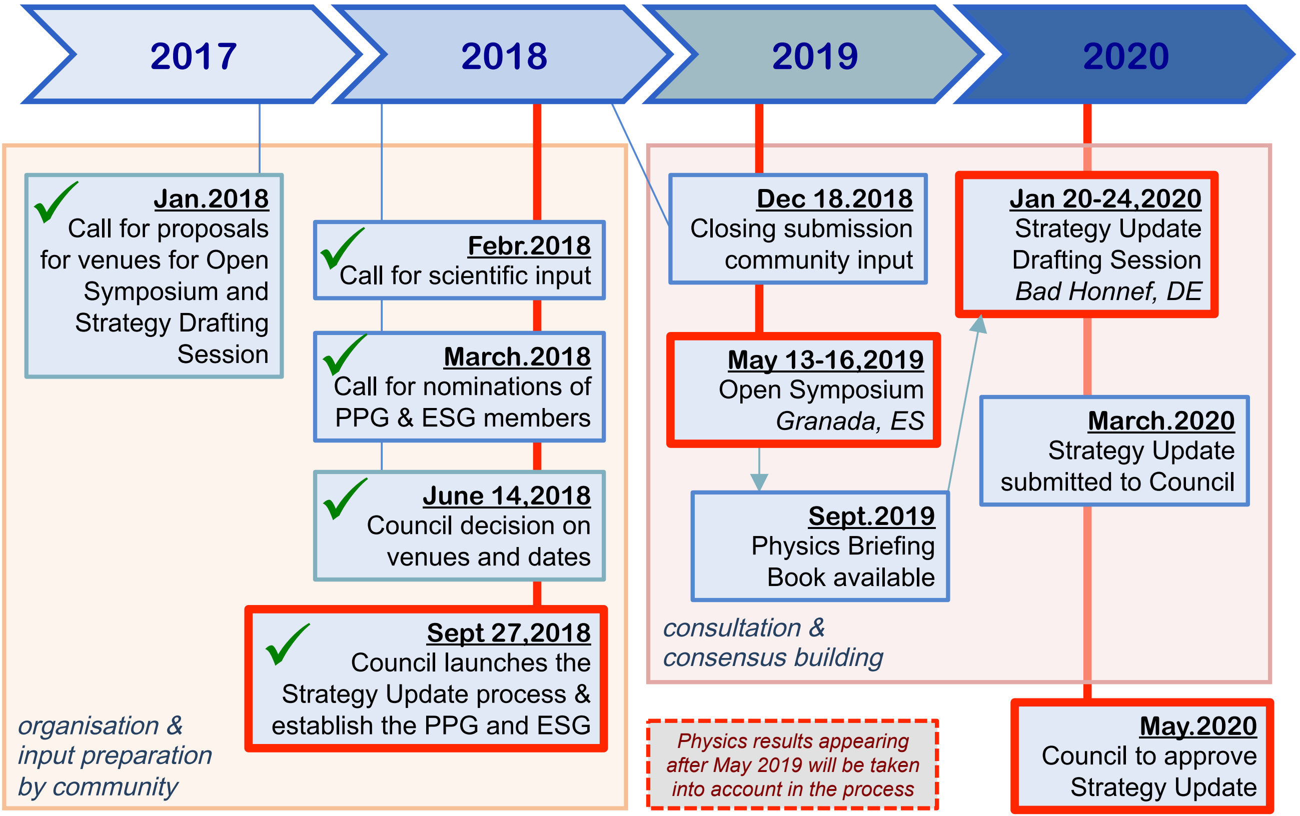
For the sub-structure of the 10-pages "comprehensive overview" we provide additional guidance that might be useful especially for scientific projects.

Addendum
A separate addendum is to be provided addressing the following topics (where relevant):

- interested community,
- timeline,
- construction and operational costs (if applicable),
- computing requirements.

The mandatory addendum has no strict page limit, but should be comprehensive and self-contained.

Thank you for your attention



Additional slides

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Composition of the PPG

Physics Preparatory Group (PPG) composition, adopted by Council, December 2013:

- The Strategy Secretary (acting as Chairperson),
- four members appointed by the Council on the recommendation of the SPC,
- four members appointed by the Council on the recommendation of ECFA,
- the SPC Chairperson,
- the ECFA Chairperson,
- the Chairperson of the European Laboratory Directors' meeting,
- one representative appointed by CERN,
- two representatives from Asia appointed by the respective regional representatives in ICFA,
- two representatives from the Americas appointed by the respective regional representatives in ICFA.

Responsible to organise the Open Symposium and to deliver to the European Strategy Group (ESG) a Physics Briefing book.

Open call to all members of the particle physics community

Extract from the Open call circulated within the community

The CERN Council has set itself the objective of updating the European Strategy for Particle Physics by May 2020. To achieve this, it has established a Strategy Secretariat to which it has assigned the task of organising the update process.

The Strategy update process will include two major events: an “Open Symposium” and a “Strategy Drafting Session”.

At the Open Symposium, to be held in the second half of May 2019, the community will be invited to debate the scientific input into the Strategy update, which will take the form of a “Briefing Book”. This will be prepared over the summer of 2019 by a Physics Preparatory Group (PPG) and submitted to the European Strategy Group (ESG) for consideration before and during its Strategy Drafting Session to be held in the second half of January 2020.

To prepare the Open Symposium, the Strategy Secretariat hereby calls upon the particle physics community in universities, laboratories, national institutes and institutions to submit written input following the enclosed guidelines.

The deadline for input is **18 December 2018**.

Input should be submitted via a portal that will be created on the Strategy update website, which will be available from the beginning of October 2018, once the Strategy update has been formally launched by the CERN Council. The link to this website will appear on the CERN Council’s web pages - https://council.web.cern.ch/en - and be widely communicated through the appropriate channels.

The Strategy Secretariat
Update of the European Strategy for Particle Physics
EPPSU-Strategy-Secretariat@cern.ch

Practical instructions for submitting input

Format and deadline for submission

The cover page and the comprehensive overview are to be submitted as a single file, the "main document", in portable document format (pdf) by 18 December 2018. The addendum is to be submitted as a separate file by the same deadline. A dedicated submission portal will be available on the EPPSU website as of October 2018, once the Strategy update has been formally launched by the Council at its September 2018 Session. The link to the EPPSU website will appear on the CERN Council's web pages - https://council.web.cern.ch/en - and be widely communicated through the appropriate channels.

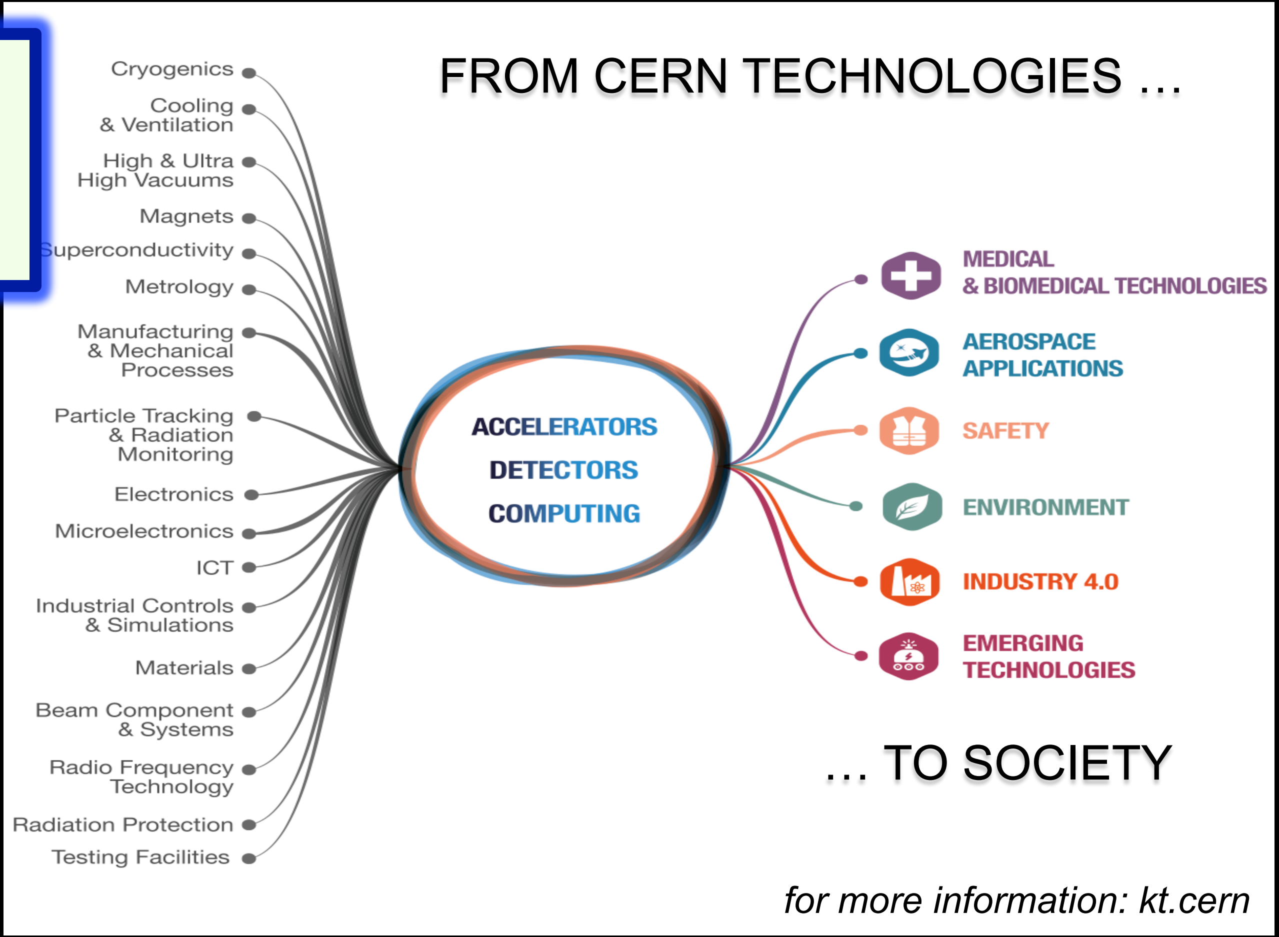
Distribution

Both documents submitted (main and addendum) will be passed on to the Physics Preparatory Group (PPG) and the European Strategy Group (ESG). Unless explicitly requested otherwise, they will also be made public. The option not to make either document public will be available upon submission via the dedicated portal.

Important as well for the European Part. Phys. Strategy

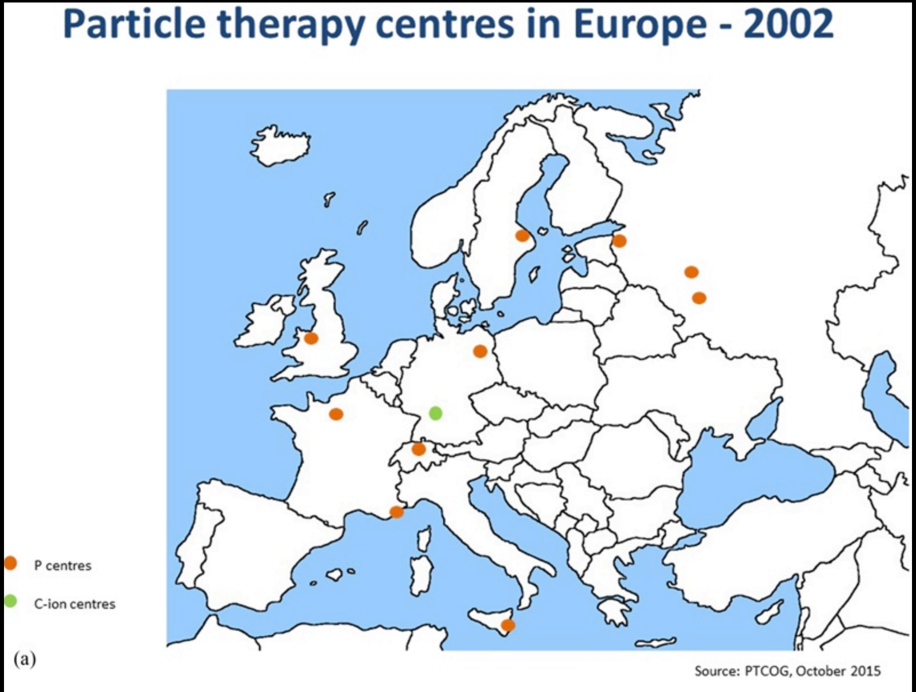
Applications in society are as well important to motivate large scale experiments.

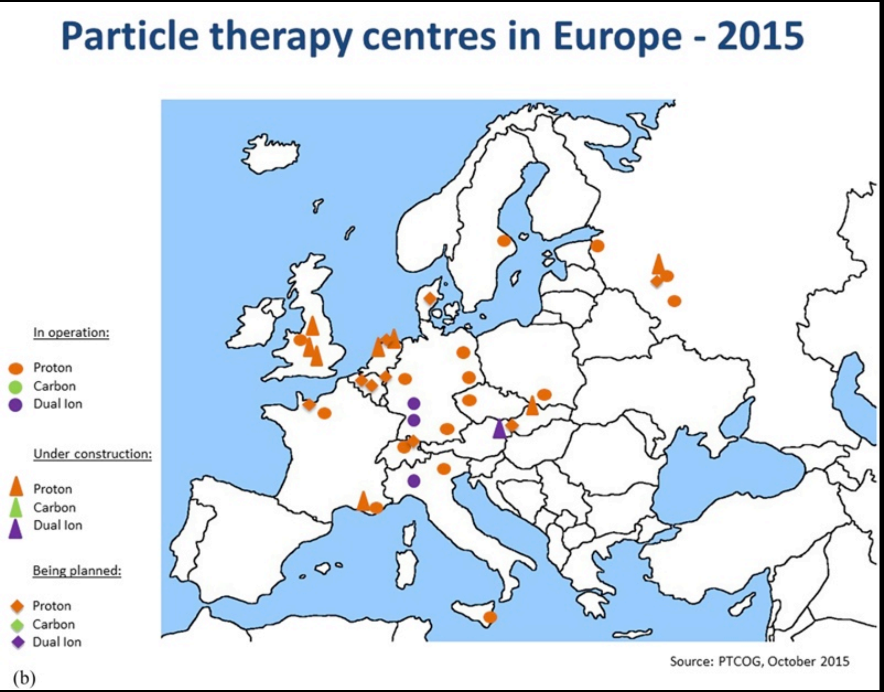
- Since 2011 CERN signed more than 250 licenses and other kind of agreements with industry and other partners
- Ever year several tens of new technology disclosures (91 in 2016)
- 18 new start-ups are using CERN technologies since 2012



European Particle Physics and Particle Therapy

European Network for Light Ion Therapy (ENLIGHT) since 2002





information from Manjit Dosanjh, "From Particle Physics to Medical Applications", IOP Publishing 2017, Bristol, UK

European Particle Physics and Particle Therapy

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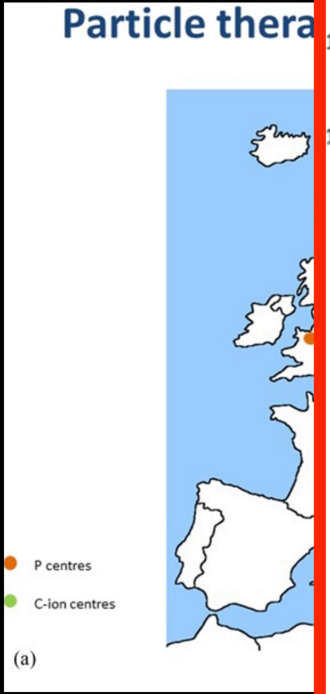
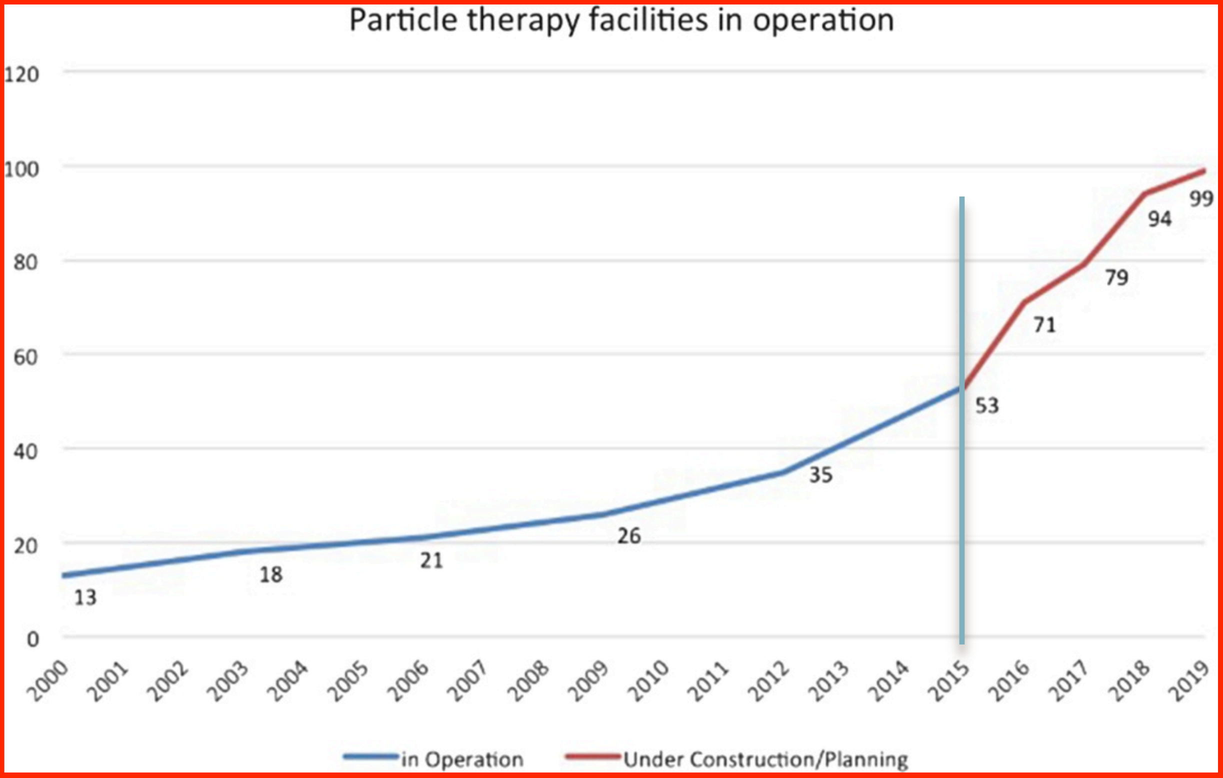
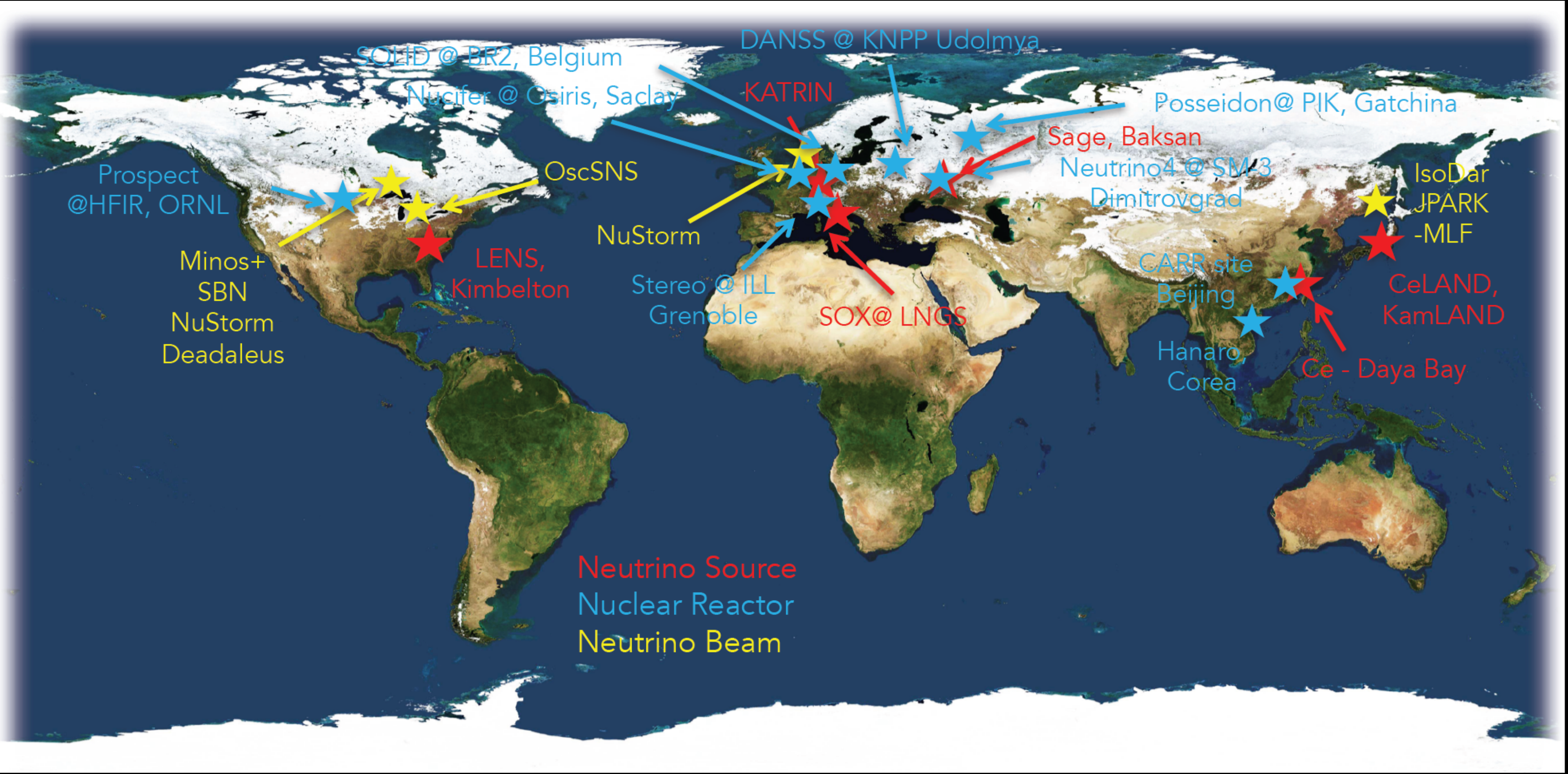


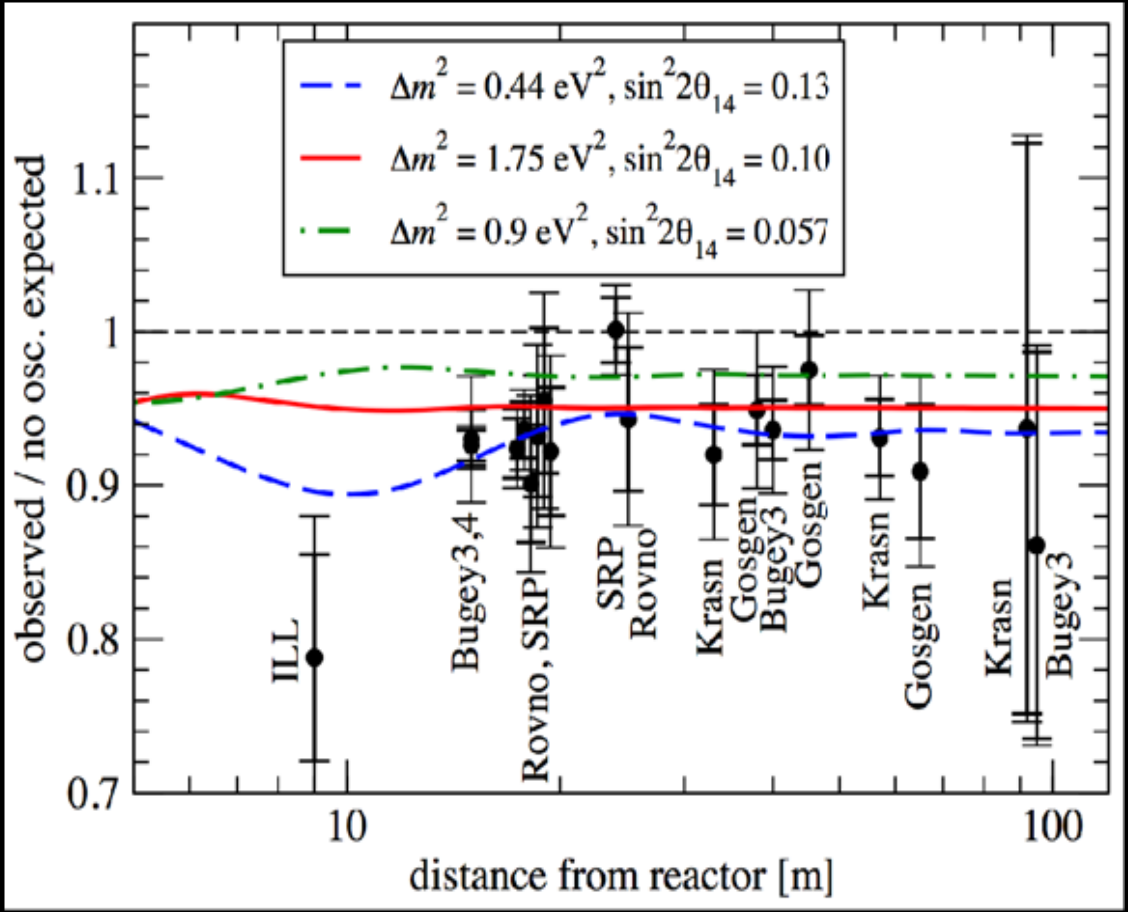


information from Manjit Dosanjh, "From Particle Physics to Medical Applications", IOP Publishing 2017, Bristol, UK

Neutrino research



Anomaly at short distance



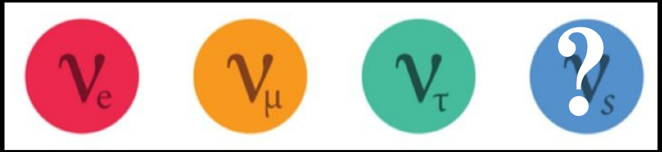
Nuclear Reactor

Production of electron neutrinos can be calculated, but uncertainty in the prediction of the flux.

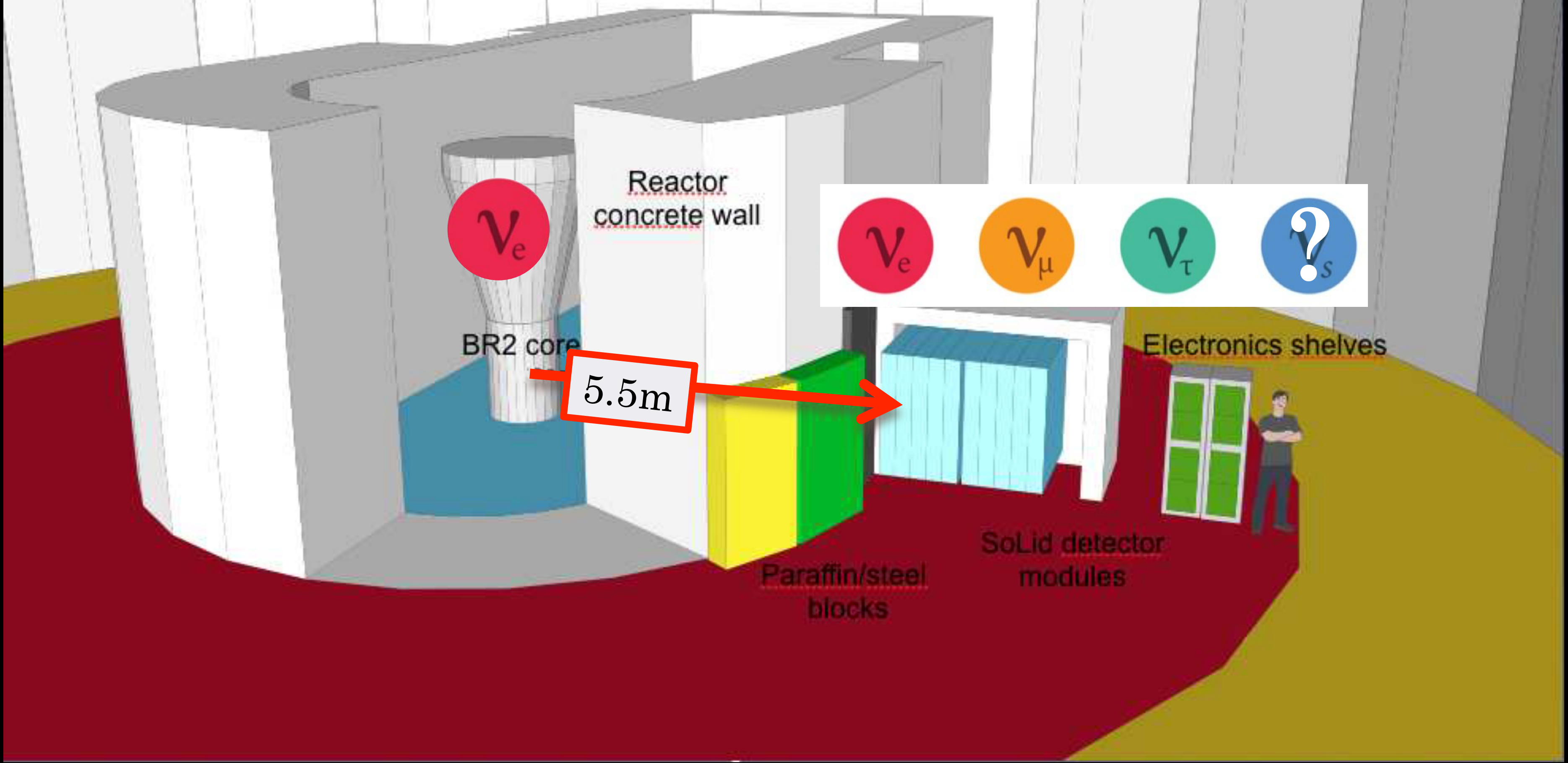
Detector

Measure the amount of neutrinos coming out of the reactor with a dedicated experiment.

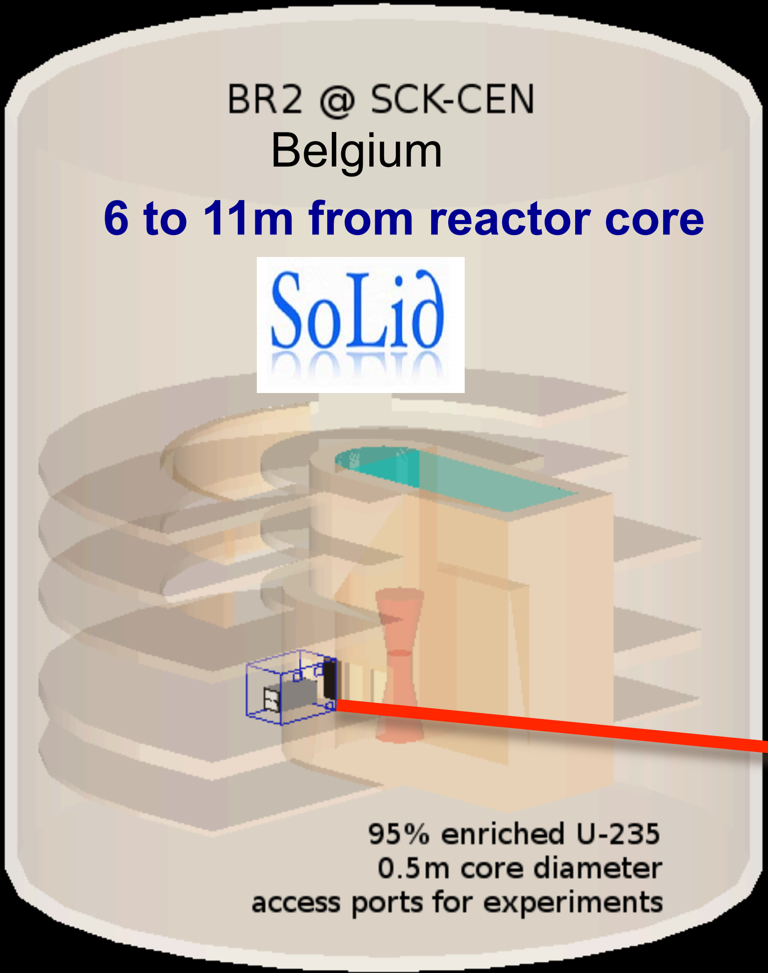
Disagreement between both… are there more than four neutrino species?

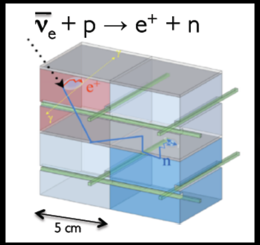


Potential to discover oscillations to a fourth kind of neutrino particle

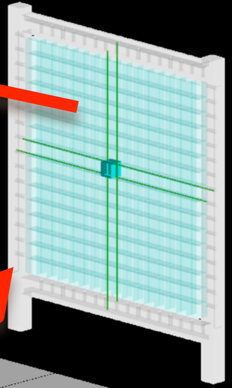


Reactor facilities for Particle Physics

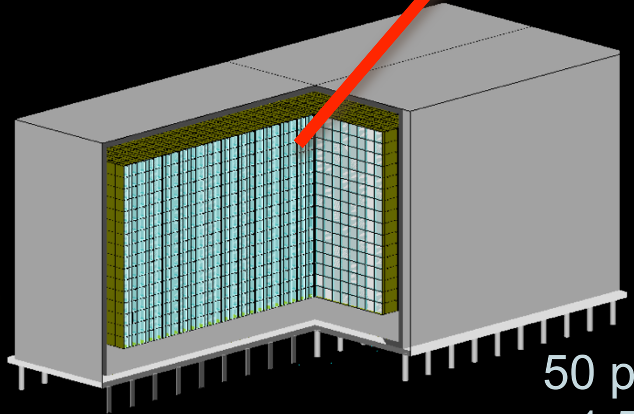




12800 cubes
3200 readout fibers

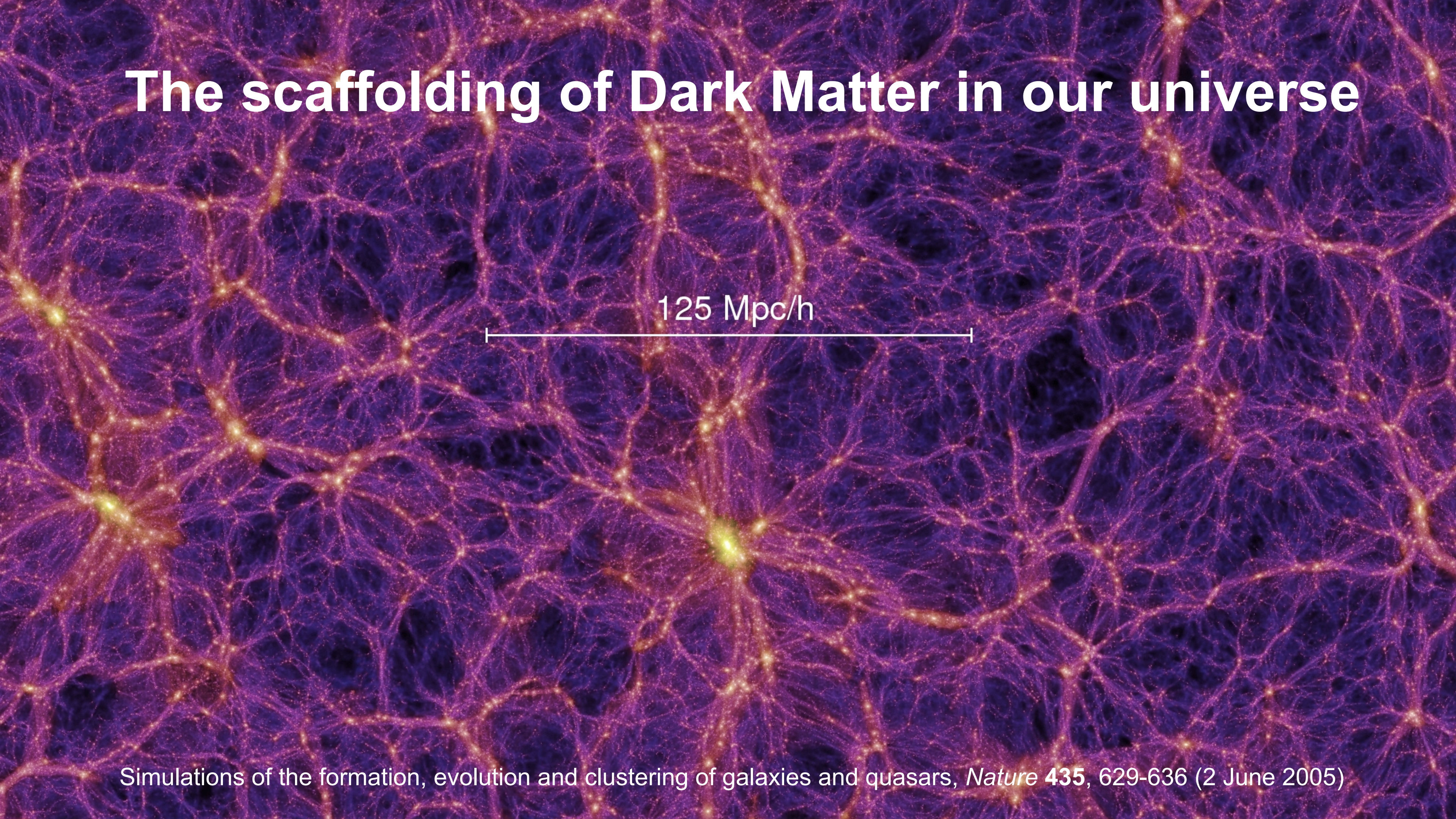


Taking data



50 planes
1.5 ton

The scaffolding of Dark Matter in our universe



Simulations of the formation, evolution and clustering of galaxies and quasars, *Nature* **435**, 629-636 (2 June 2005)

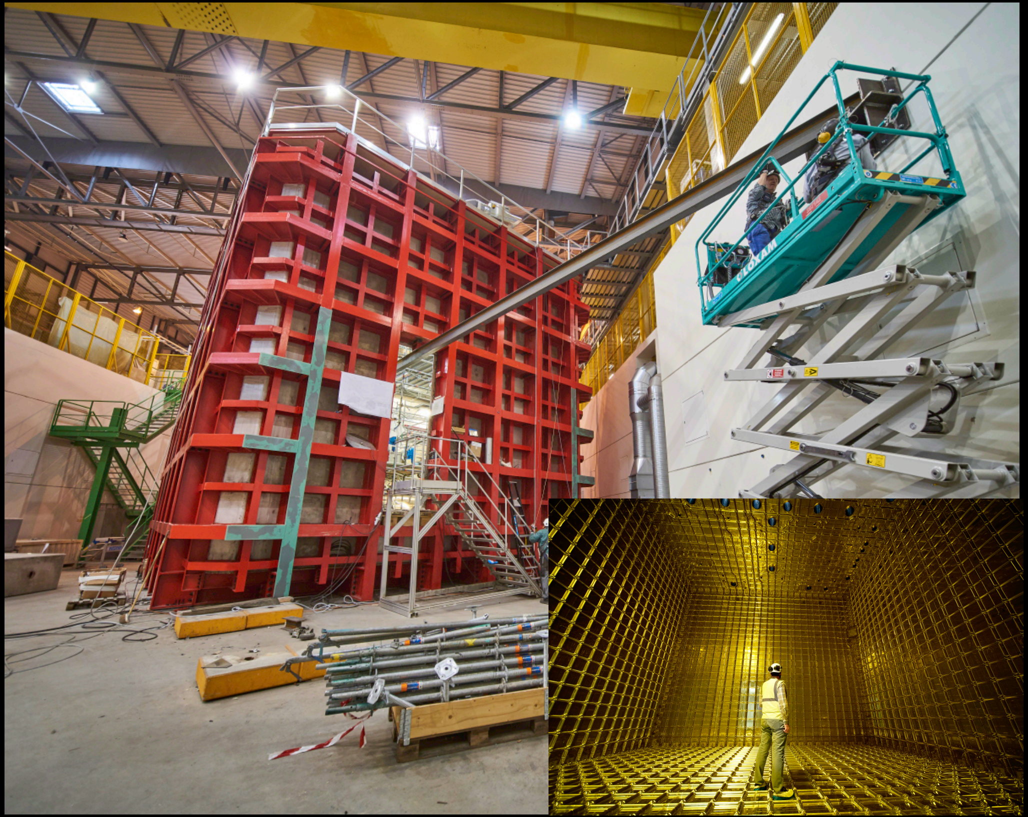
The 2013 European Particle Physics Strategy

CERN should develop a neutrino programme to pave the way for a substantial European role in future long-baseline experiments. Europe should explore the possibility of major participation in leading long-baseline neutrino projects in the US and Japan.

See talk on Neutrinos by Pilar Hernandez

CERN’s Neutrino Platform as a European “portal” to accelerator-based neutrino facilities worldwide

protoDUNE detectors at CERN



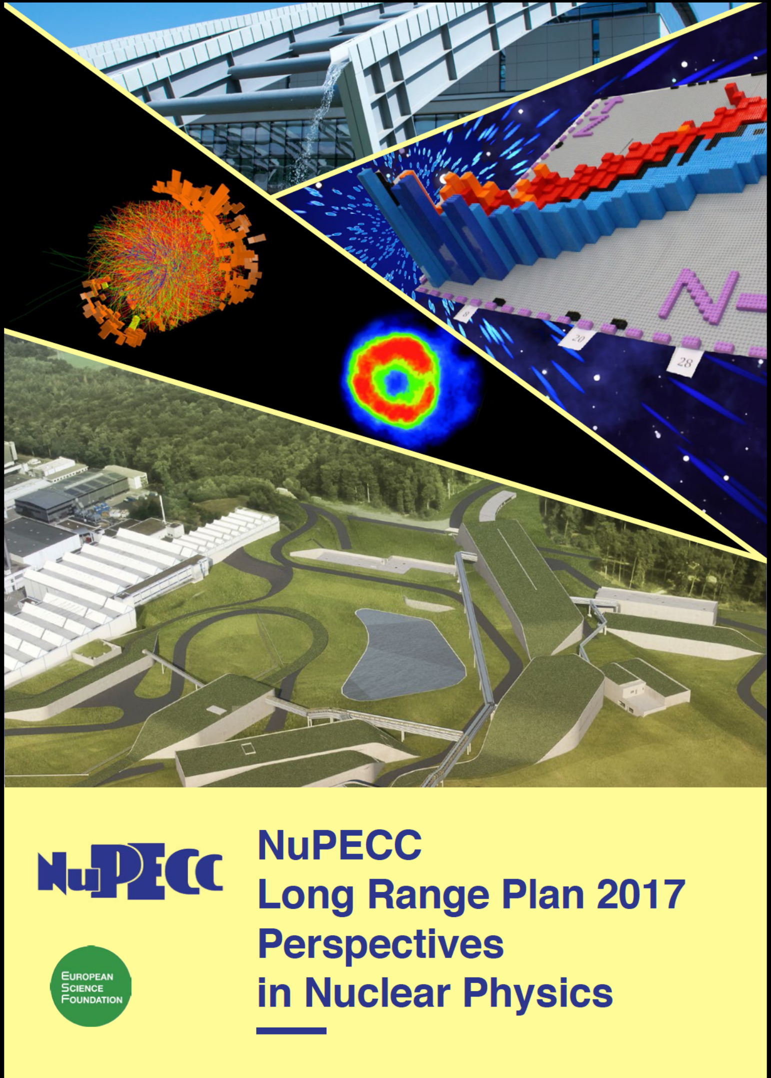
Baby MIND from CERN to Japan

The Neutrino Platform is CERN’s undertaking to foster and contribute to fundamental research in neutrino physics at particle accelerators worldwide.

Neutrino PLATFORM

The 2013 European Particle Physics Strategy

A variety of research lines at the boundary between particle and nuclear physics require dedicated experiments. The CERN Laboratory should maintain its capability to perform unique experiments. CERN should continue to work with NuPECC on topics of mutual interest.



European Nuclear Long Range Plan 2017

http://www.nupecc.org

See talk by Angela Bracco

CERN and the HIE-ISOLDE facility: Phase-2 (2017-2018)

The new energy window gives the opportunity to address new physics questions → 35 experiments approved