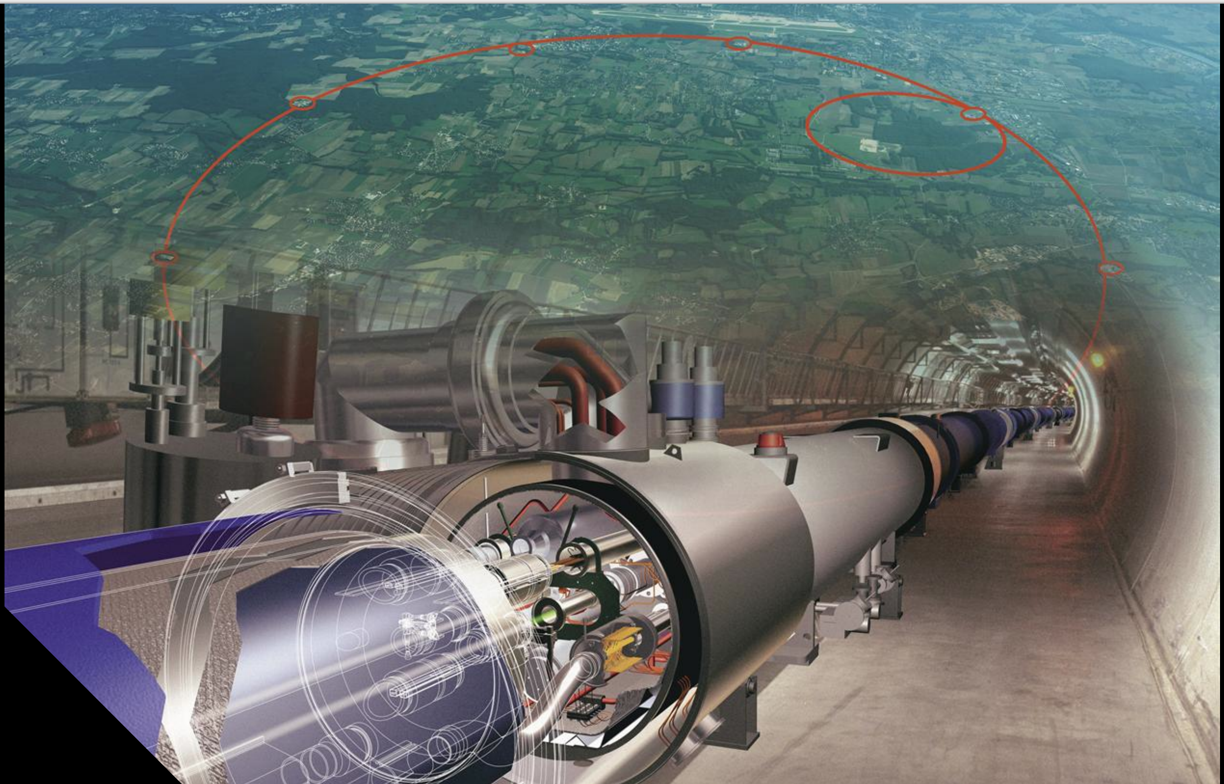
Road to an update of the European HEP Strategy



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

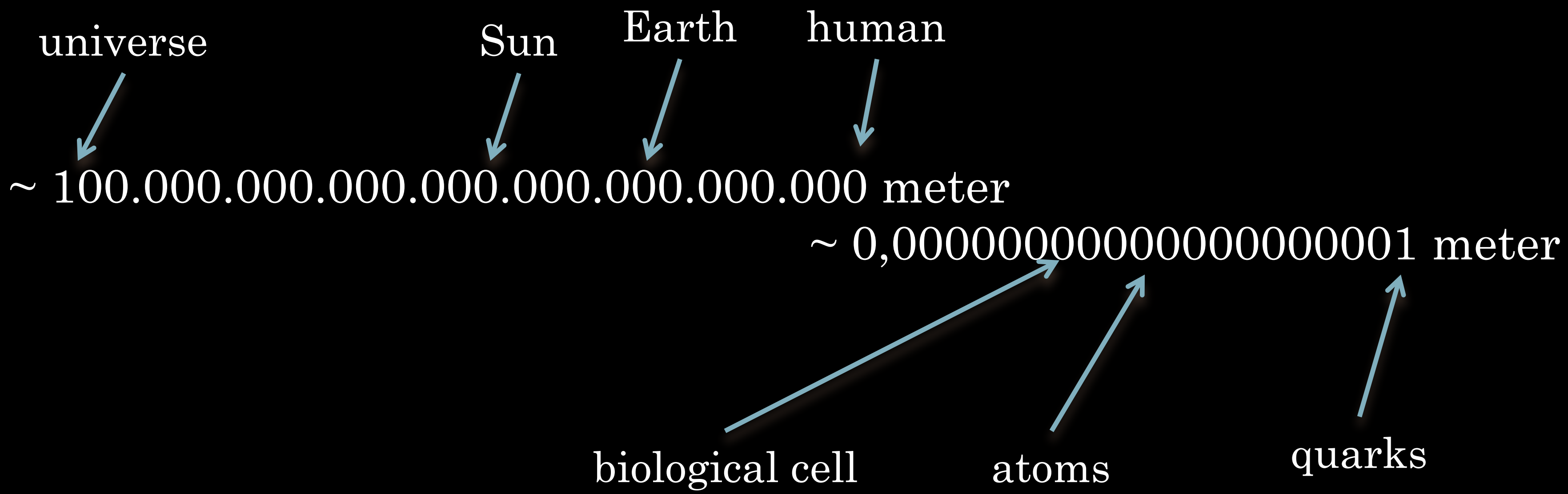
IAS High Energy Physics
21-24 January 2019
Hong Kong

HEP@VUB BRUSSELS

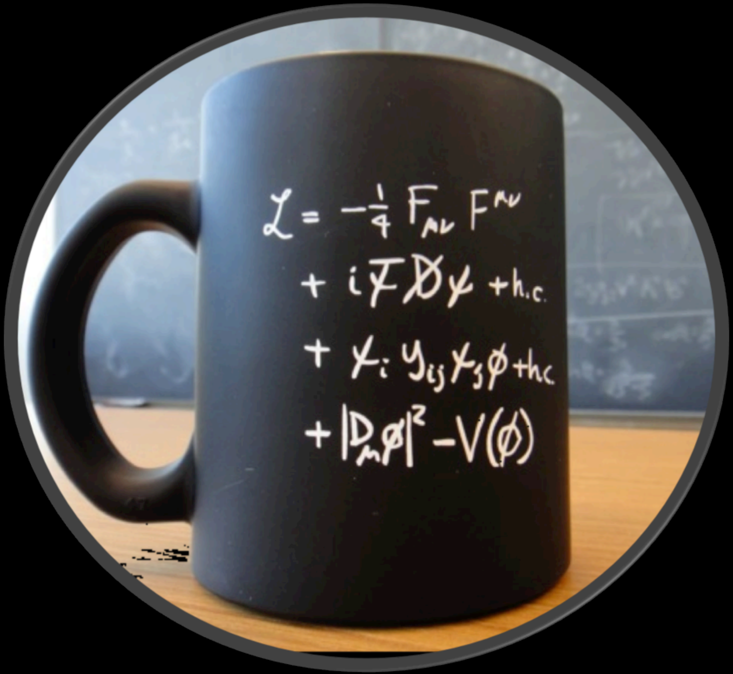
VUB

iihe BRUXELLES BRUSSEL

understand nature at the
largest and the smallest scales


universe
Sun
Earth
human
~ 100.000.000.000.000.000.000.000.000 meter
~ 0,0000000000000000001 meter
biological cell
atoms
quarks

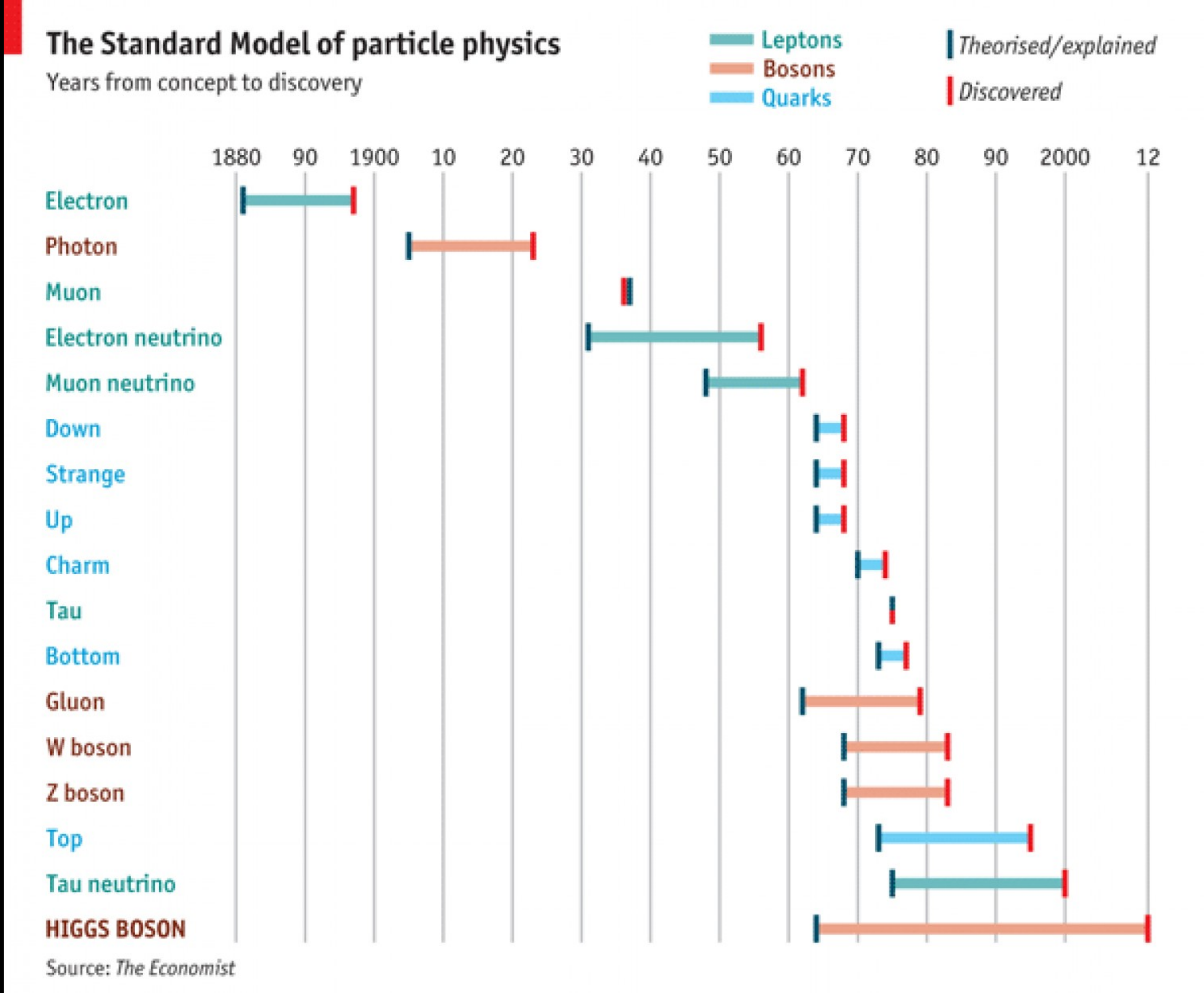
Particle Physics today



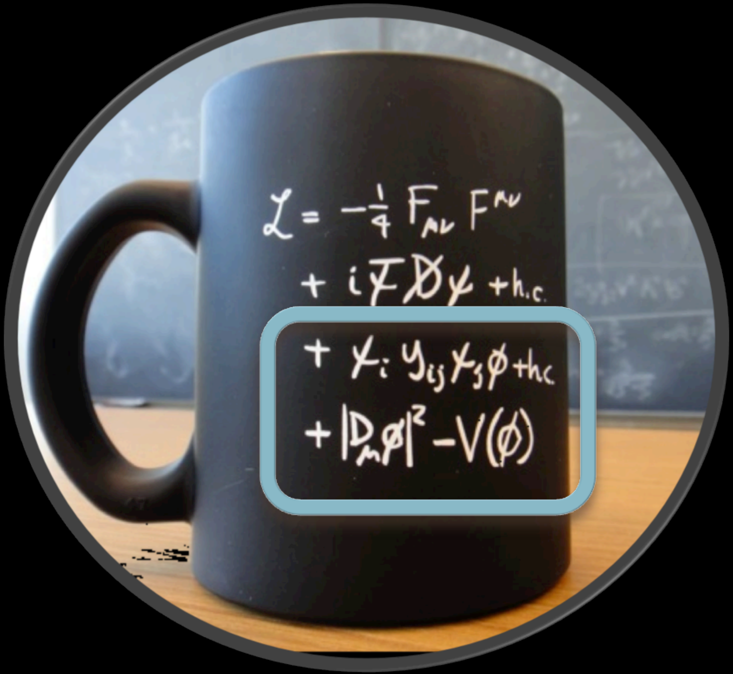
enormous success in describing matter at the smallest scales

July 4, 2012

Source:
The Economist
July 4th, 2012

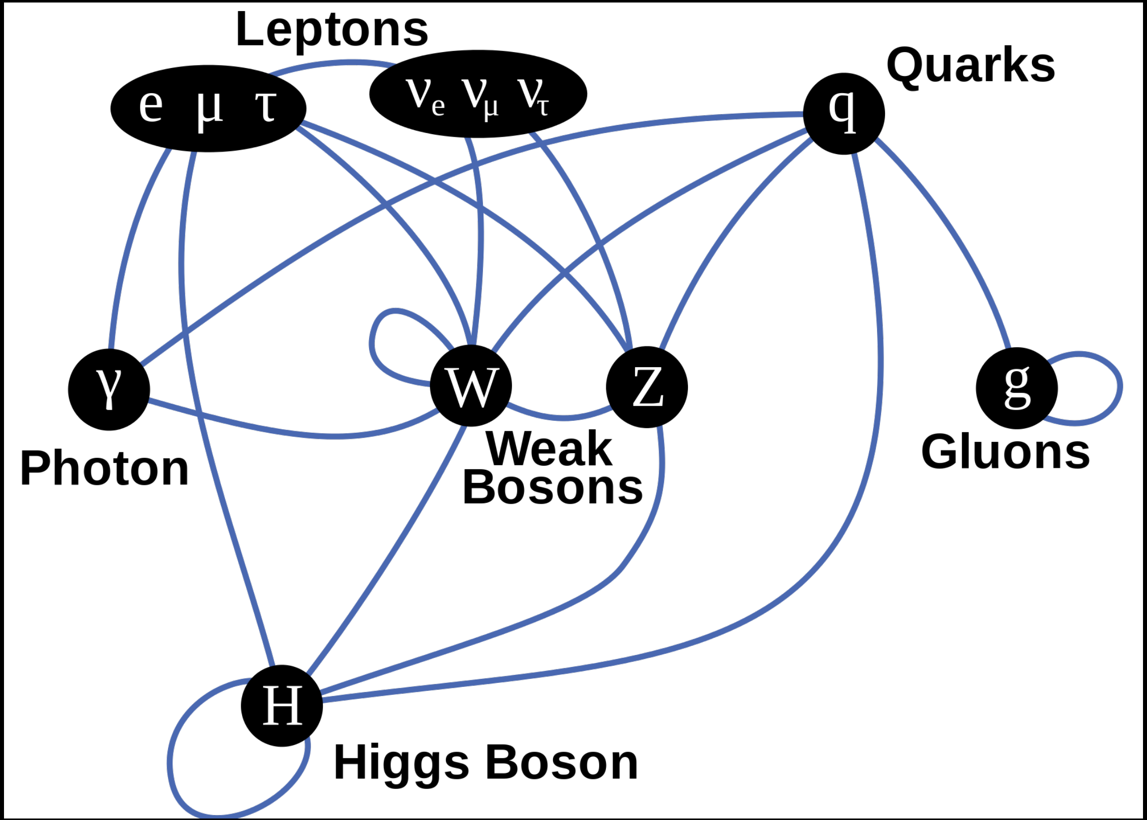


Particle Physics today



enormous success in describing matter at the smallest scales

Particle Physics today

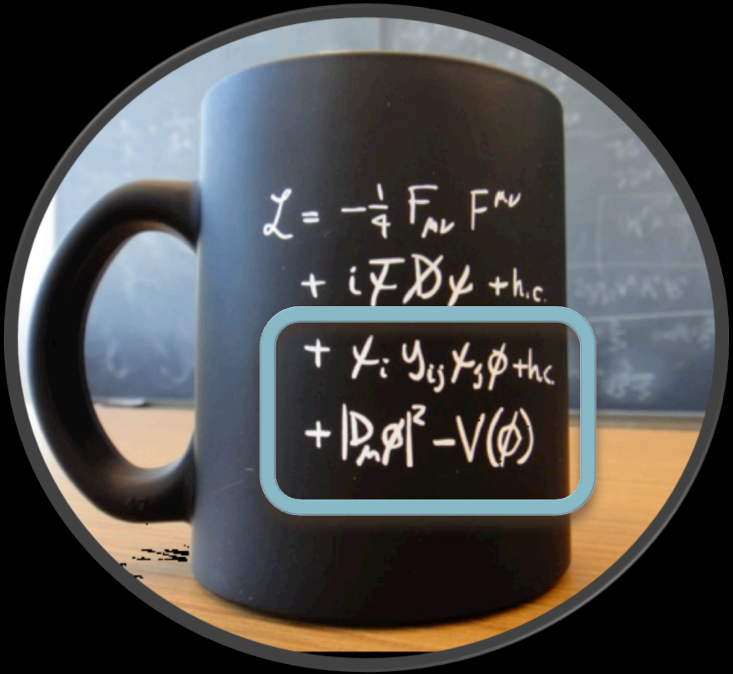


- the Higgs particle is confirmed in 2012 and its interactions with other particles are step by step being discovered

- Higgs – Z boson (2012)
- Higgs – W boson (2014)
- Higgs – tau lepton (2016)
- Higgs – top quark (2018)
- Higgs – bottom quark (2018)

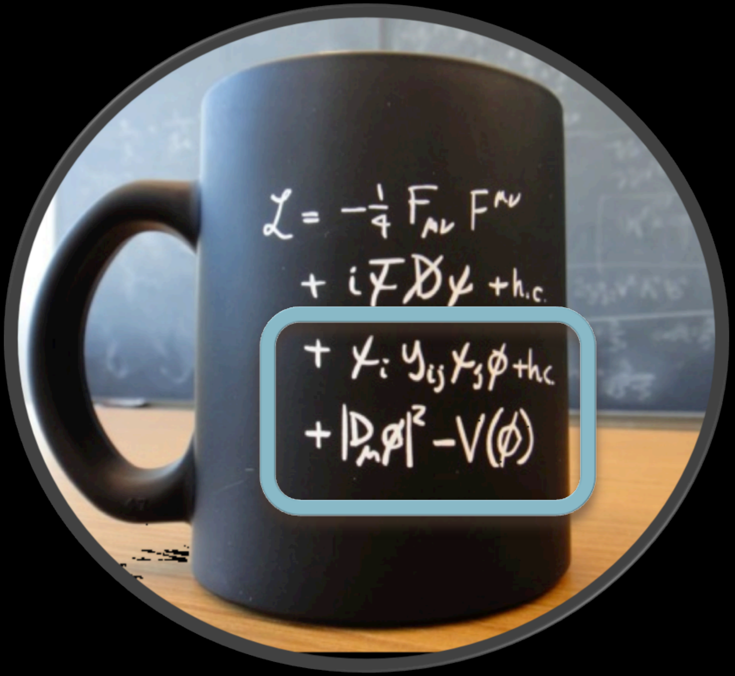
- Higgs – muons, electrons, charm quark, self-coupling, etc. yet to come

Particle Physics today



enormous success in describing matter at the smallest scales

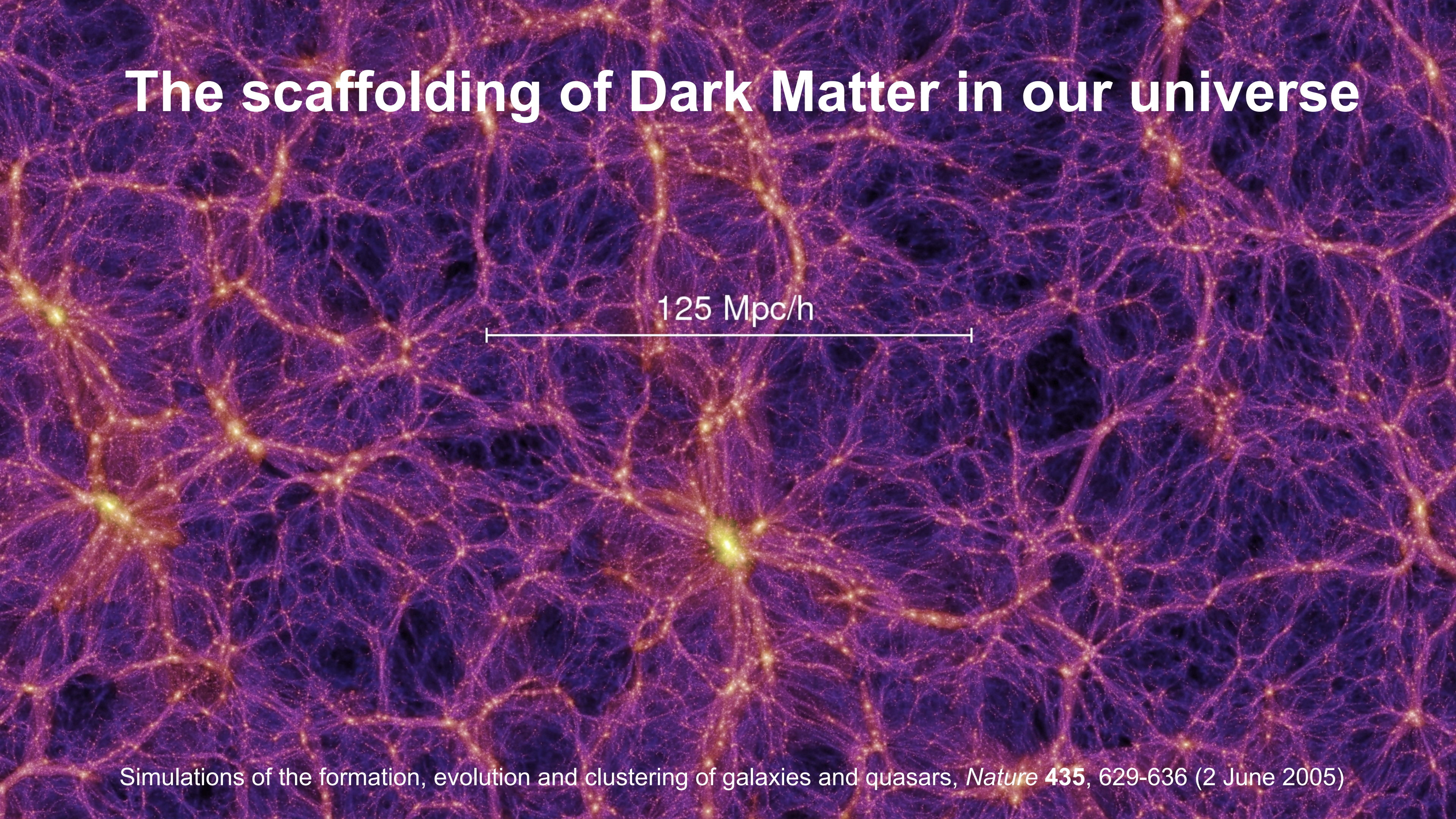
Particle Physics today



enormous success in describing matter at the smallest scales

describing $\neq$ understanding

The scaffolding of Dark Matter in our universe



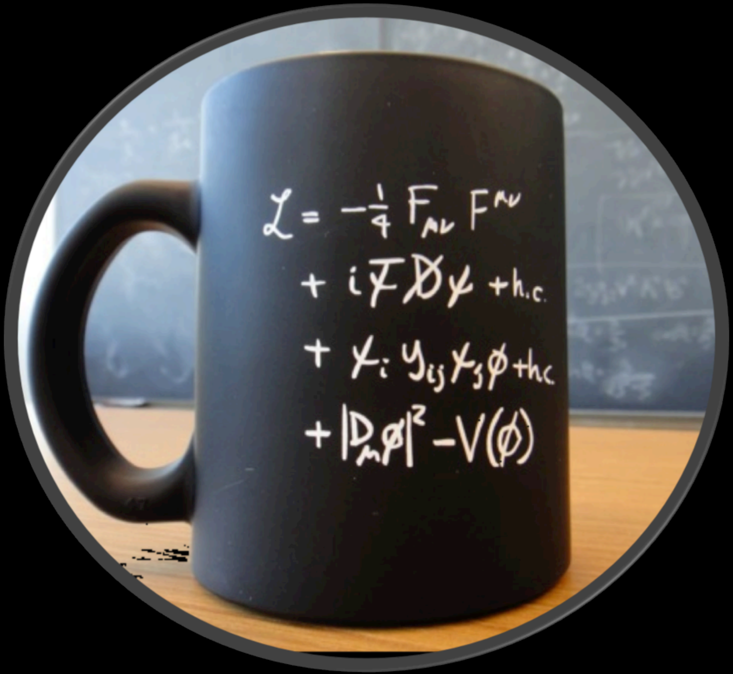
Simulations of the formation, evolution and clustering of galaxies and quasars, *Nature* **435**, 629-636 (2 June 2005)

The scaffolding of Dark Matter in our universe

80% of the matter in the universe is dark

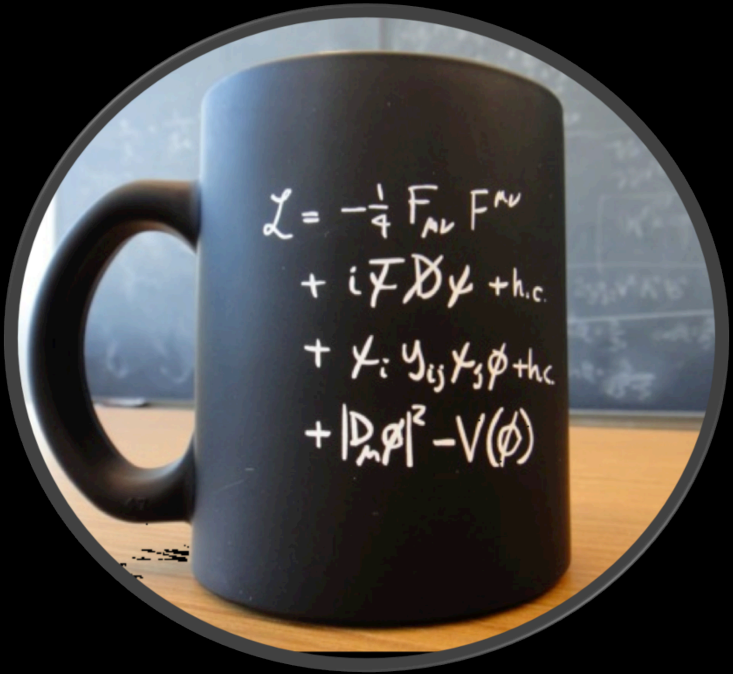
Simulations of the formation, evolution and clustering of galaxies and quasars, *Nature* **435**, 629-636 (2 June 2005)

Particle Physics today



new physics

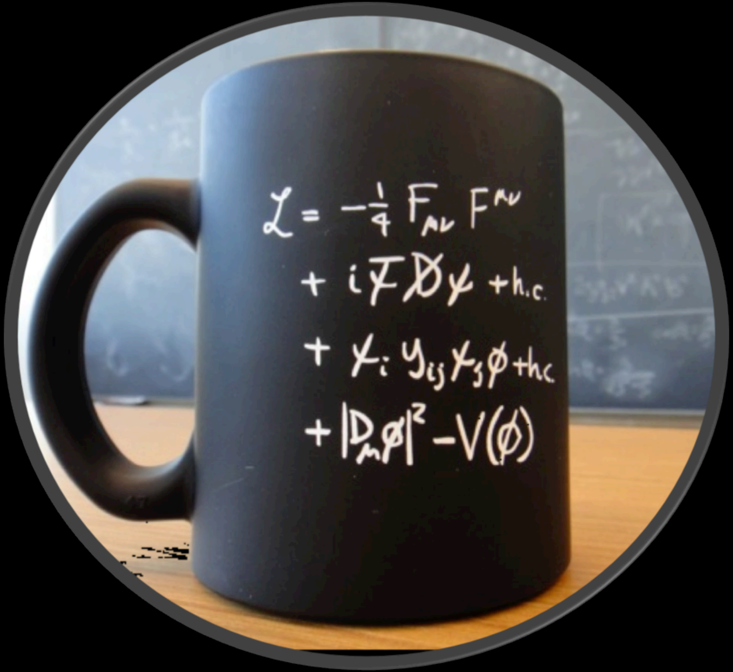
Particle Physics today



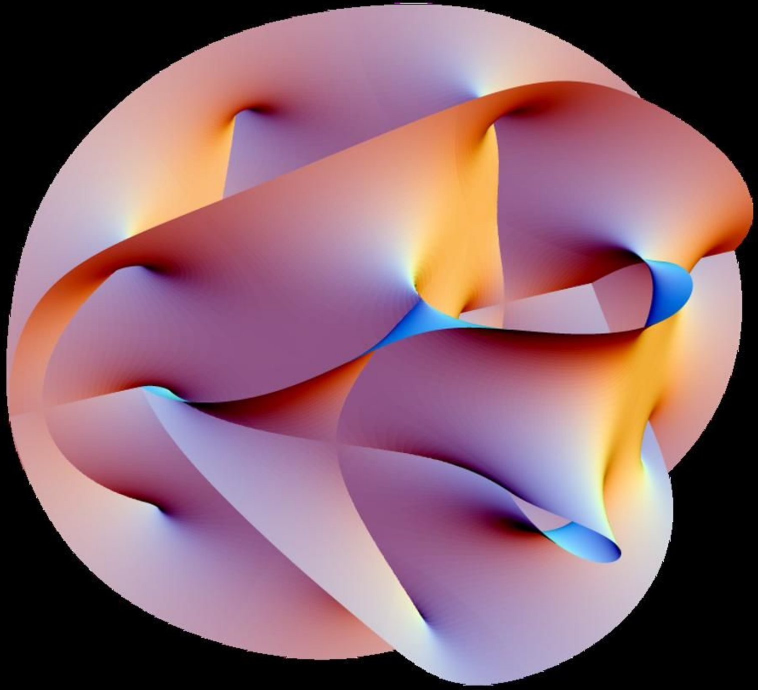
a simple design?

new physics

Particle Physics today

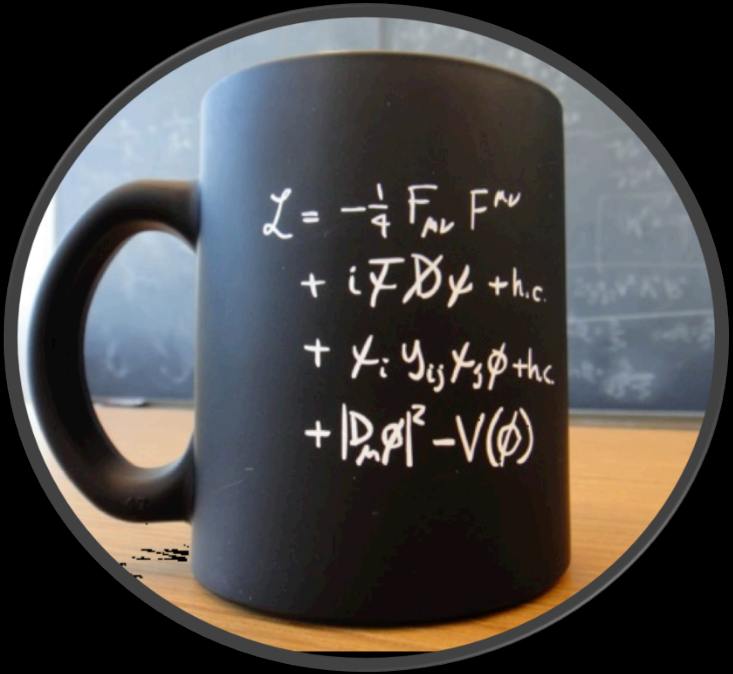


or more elegant ?



new physics

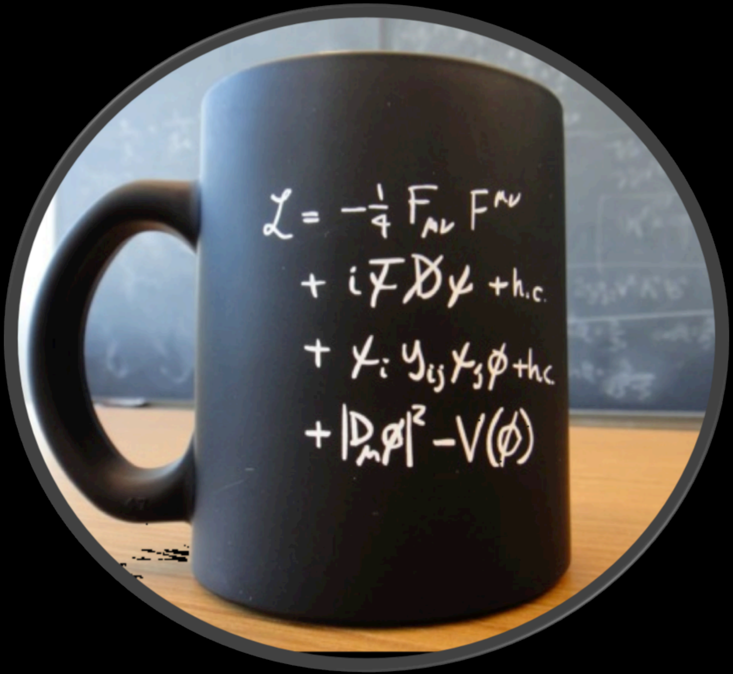
Particle Physics today



or more surreal?

new physics

Particle Physics today



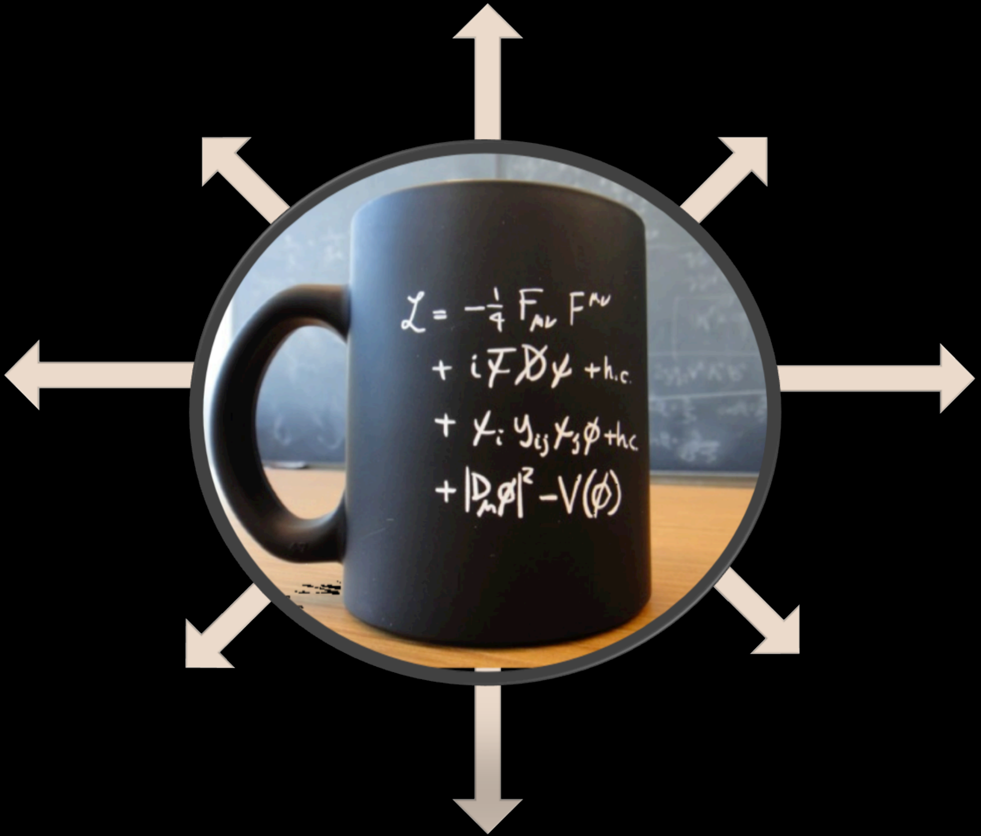
connection

new physics

although there is no lack of novel theoretical ideas, there are no clear indications where new physics is hiding although there is no lack of novel theoretical ideas, there are no clear indications where new physics is hiding

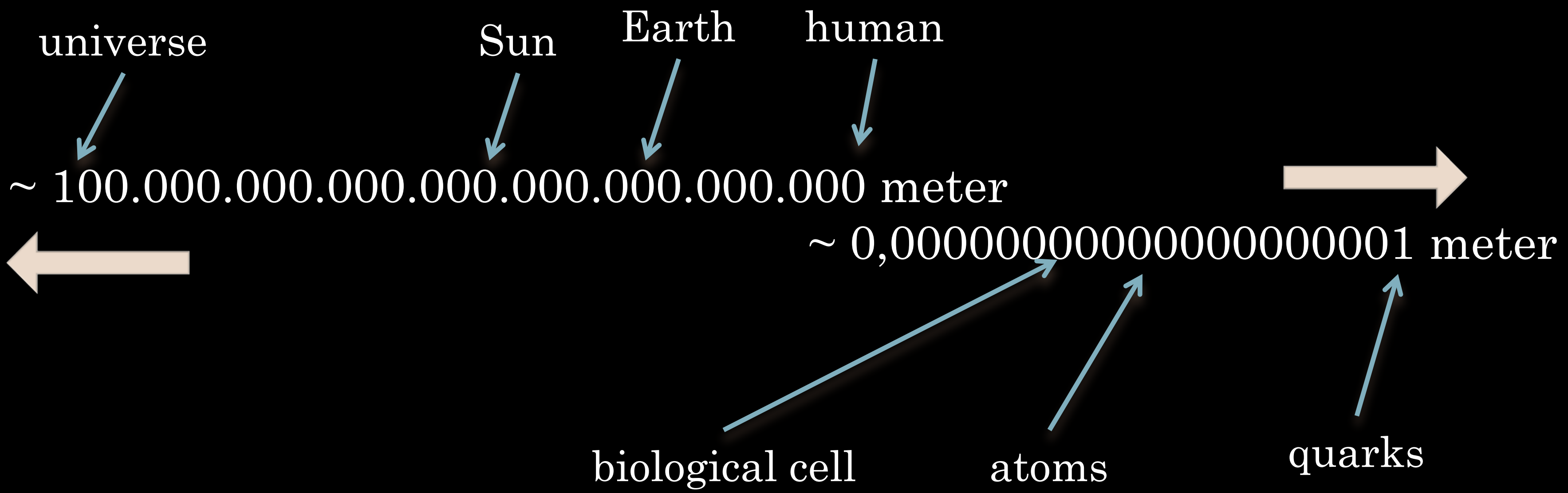
need a strong and diverse, yet coherent and concerted empirical exploration higher energy interactions in the lab

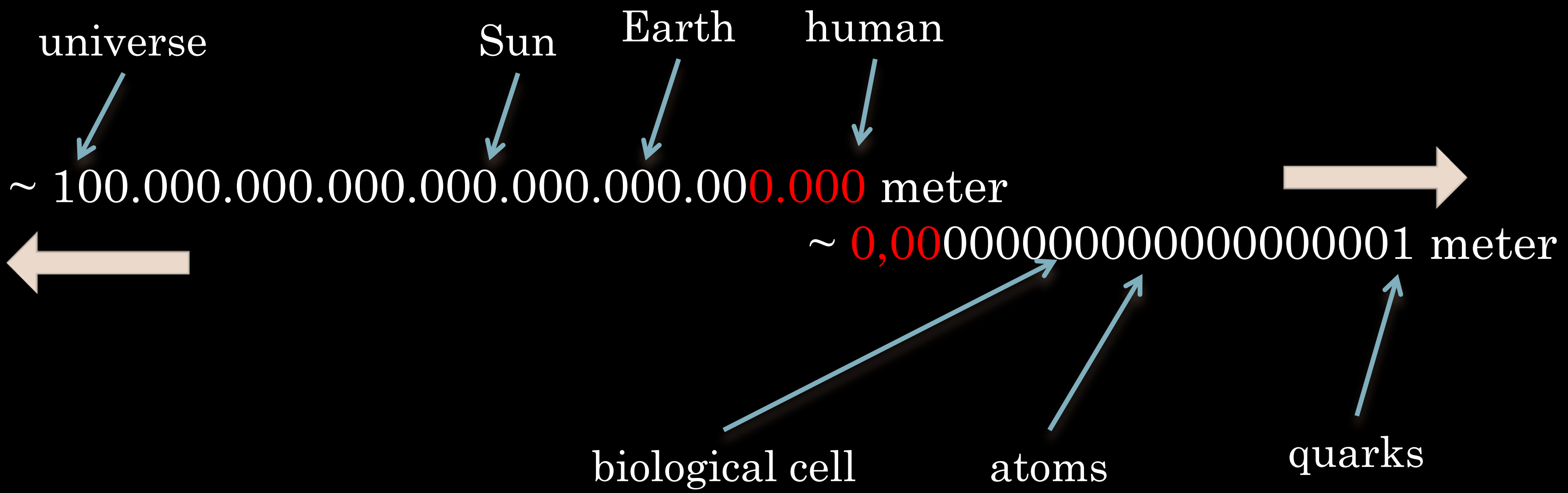
earlier universe



rarer processes

higher energetic phenomena in the universe


universe
Sun
Earth
human
~ 100.000.000.000.000.000.000.000.000 meter
~ 0,000000000000000001 meter
biological cell
atoms
quarks


universe
Sun
Earth
human
~ 100.000.000.000.000.000.000.000.000 meter
~ 0,0000000000000000000001 meter
biological cell
atoms
quarks

make the invisible visible

we can only explore our aspirations
when we innovate technology

we can only explore our aspirations
when we innovate technology

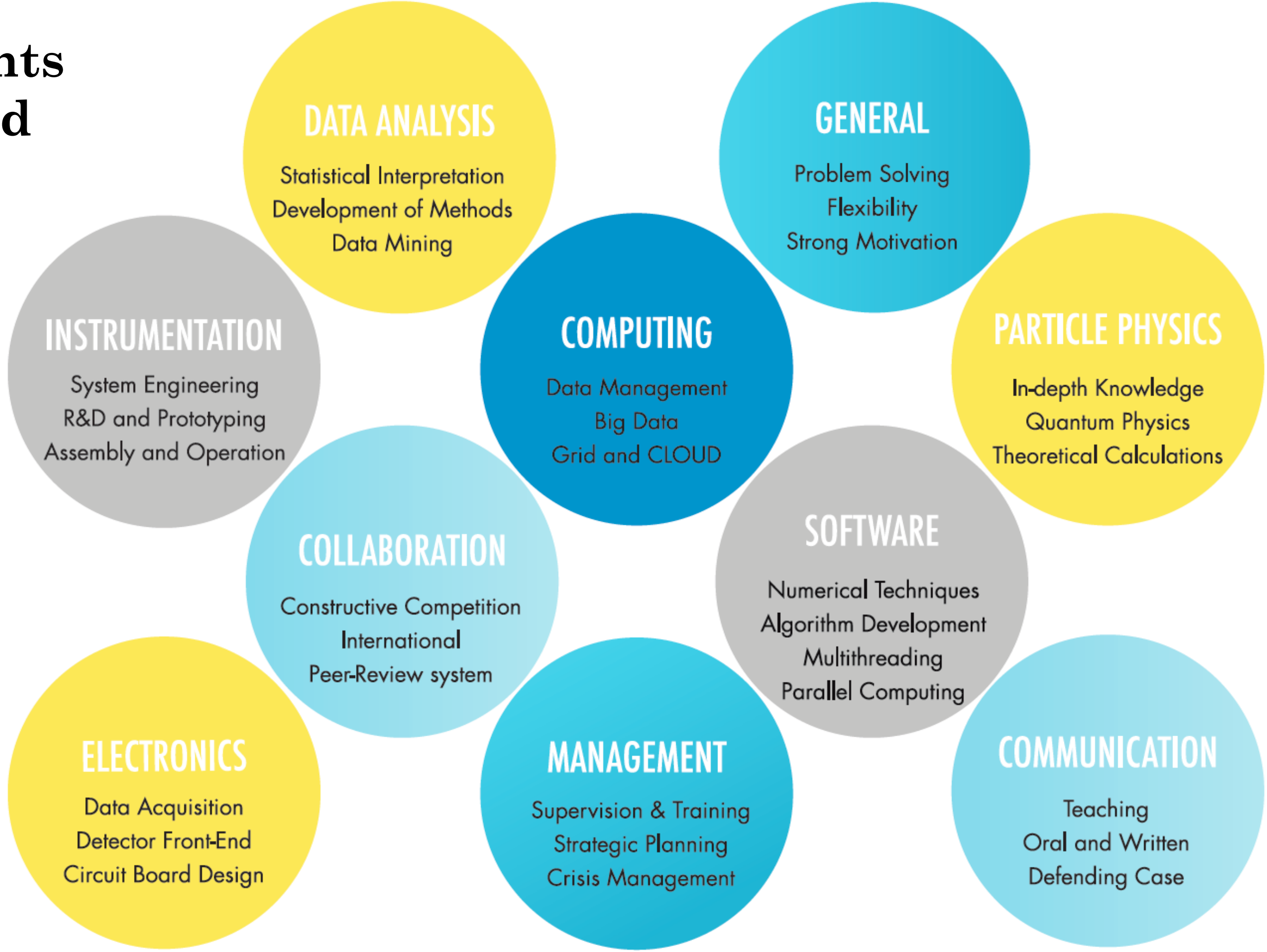
we can only explore our aspirations
when we innovate technology

*our field of high-energy physics is
driven by our innovations in
technology*

from challenges to opportunities

foster the most talented researchers
with aspirations in instrumentation,
computing and software

Our experiments require a broad set of skills



from challenges to opportunities

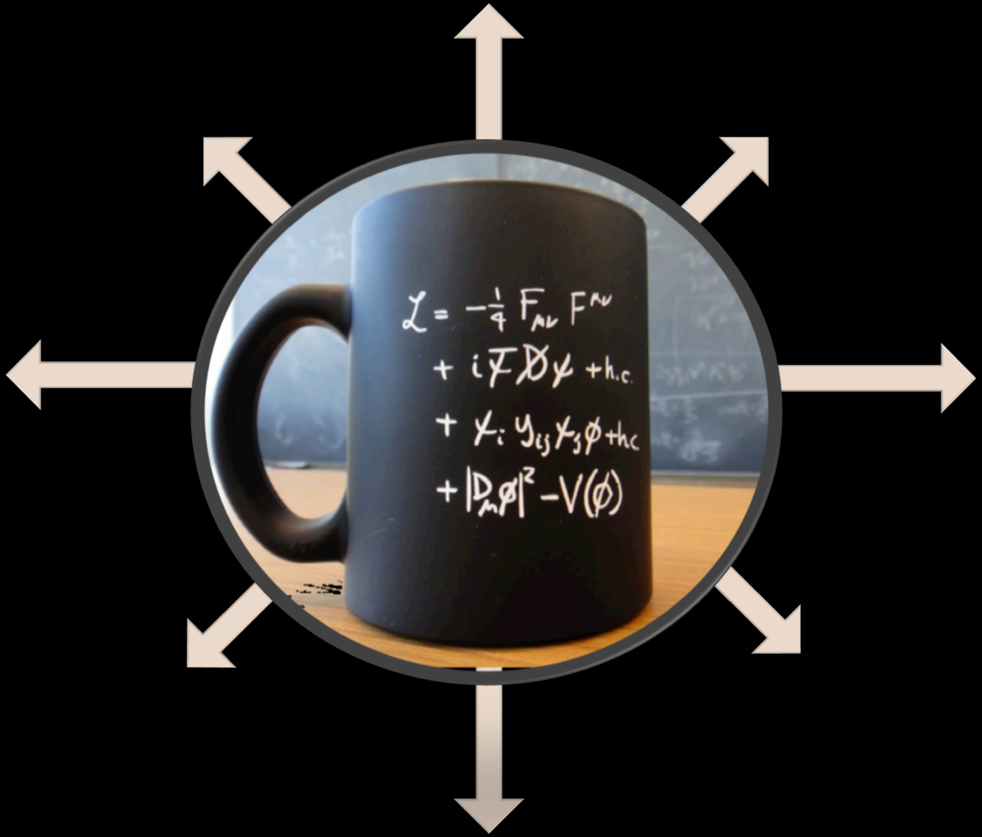
foster the most talented researchers with aspirations in instrumentation, computing and software

foster global R&D programs for technology and synergies with disciplines facing equivalent challenges from challenges to opportunities

What is out there on our technology front?

higher energy interactions in the lab

earlier universe

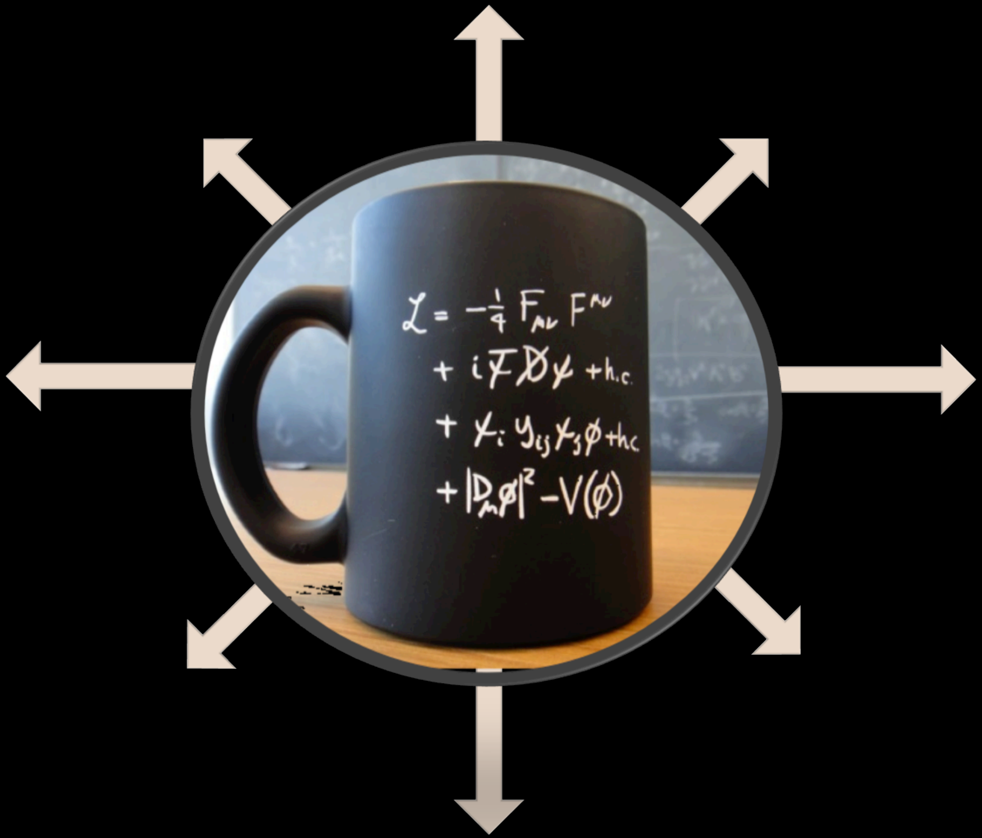


rarer processes

higher energetic phenomena in the universe

RF cavities, high-field magnets, plasma wakefield acceleration

earlier universe



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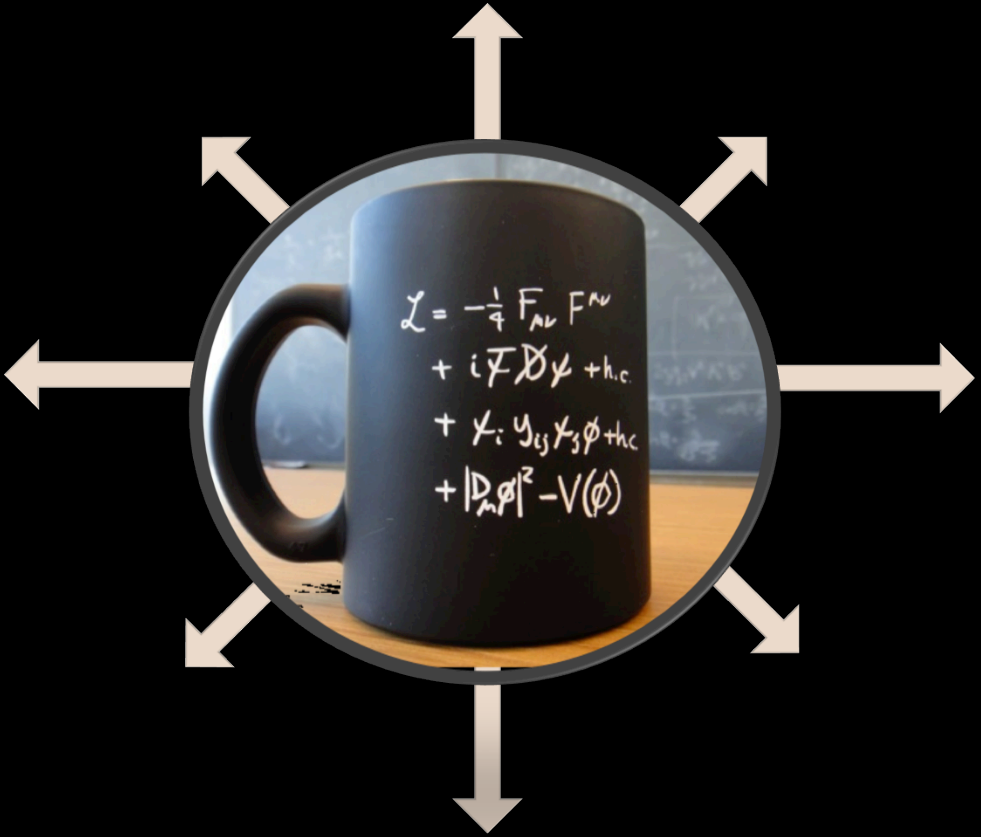
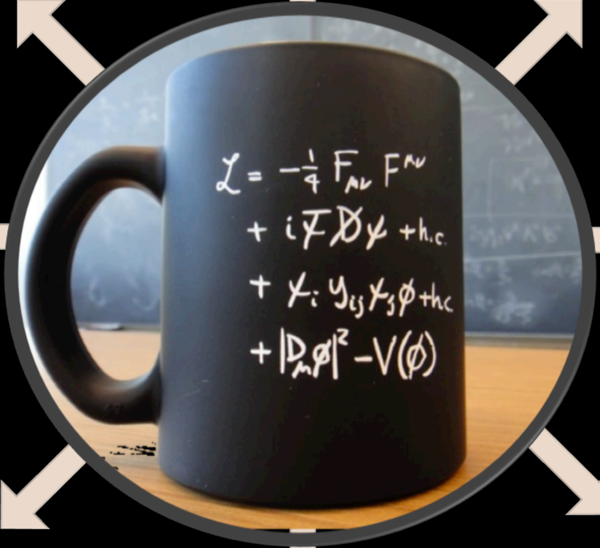


solid-state devices
with fast read-out
electronics

higher energetic phenomena in the universe

RF cavities, high-field magnets, plasma wakefield acceleration

earlier universe

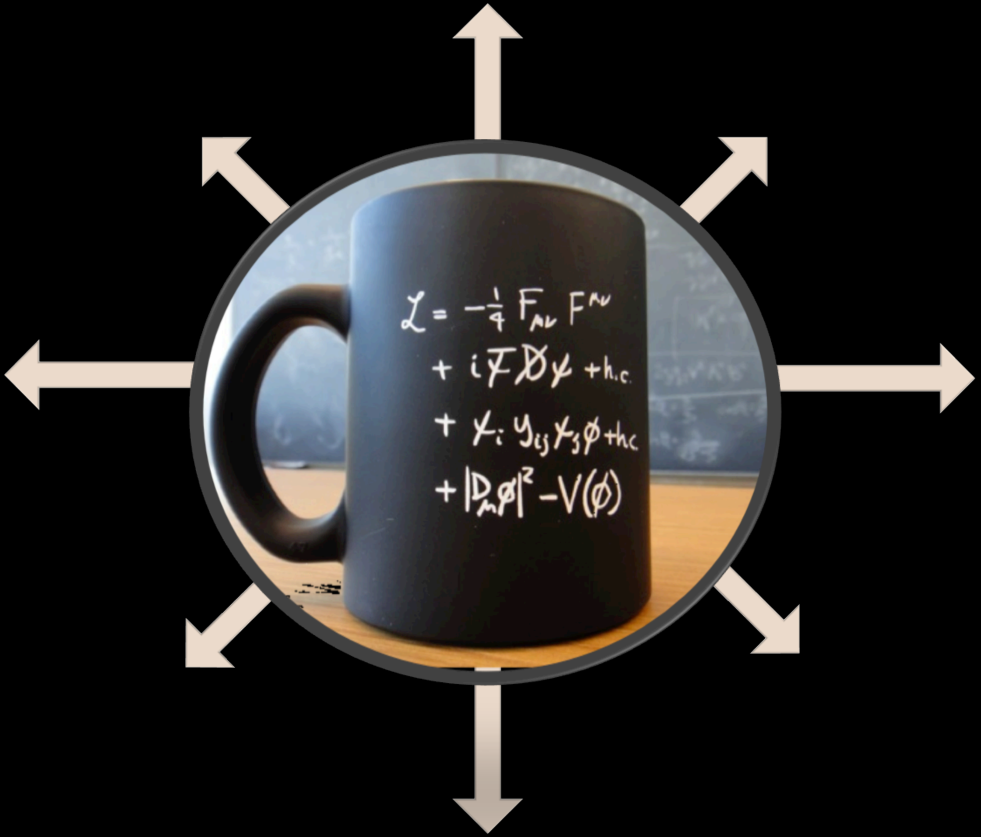


solid-state devices
with fast read-out
electronics

computing and software challenge for
multi-messenger and multi-instrument astrophysics

RF cavities, high-field magnets, plasma wakefield acceleration

squeezed-light sources to deal with quantum noise in gravitational-wave detectors

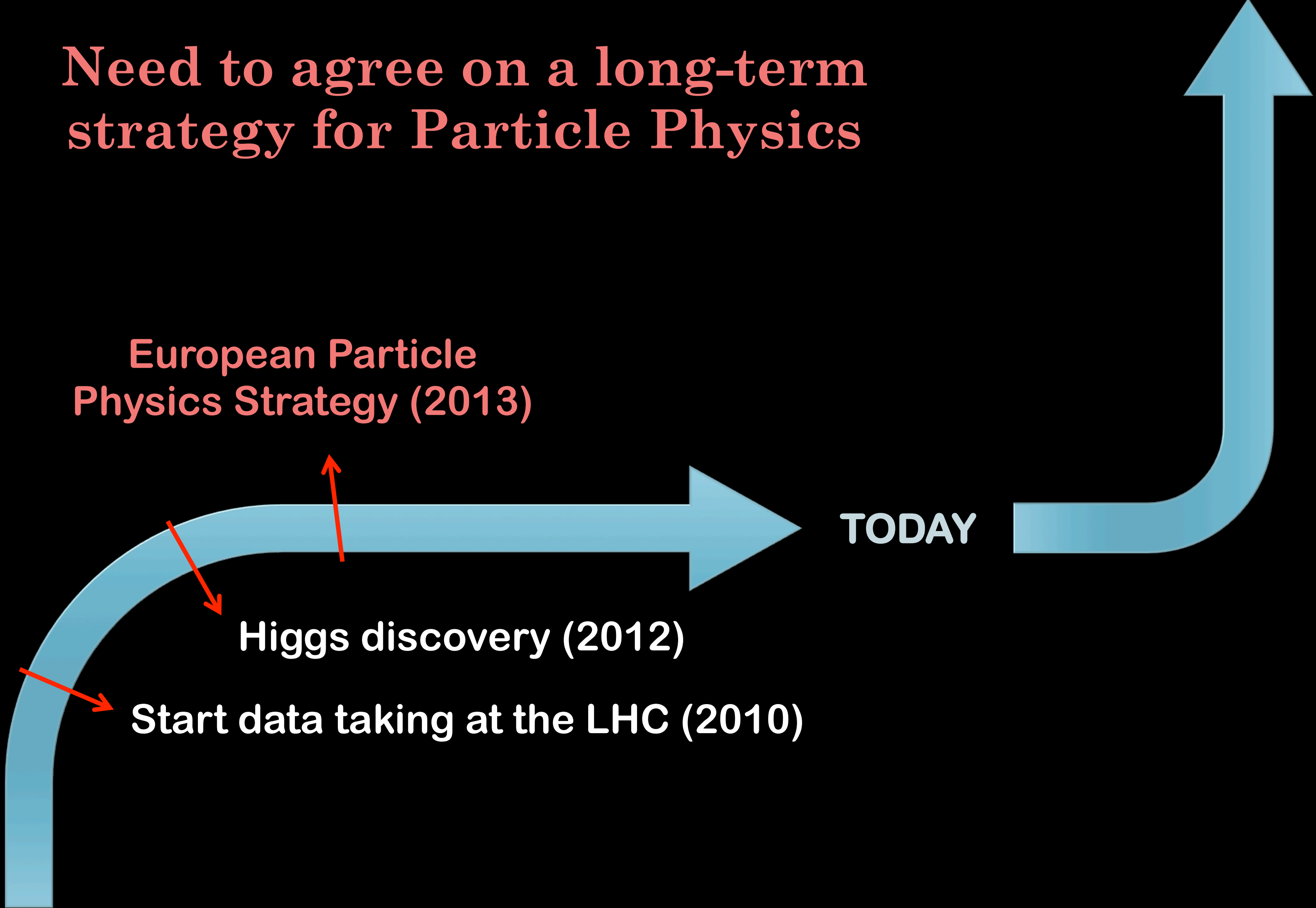


solid-state devices with fast read-out electronics

computing and software challenge for multi-messenger and multi-instrument astrophysics

On the basis of our strong and global R&D investments in technology we can design the most appropriate research facilities

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



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

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.

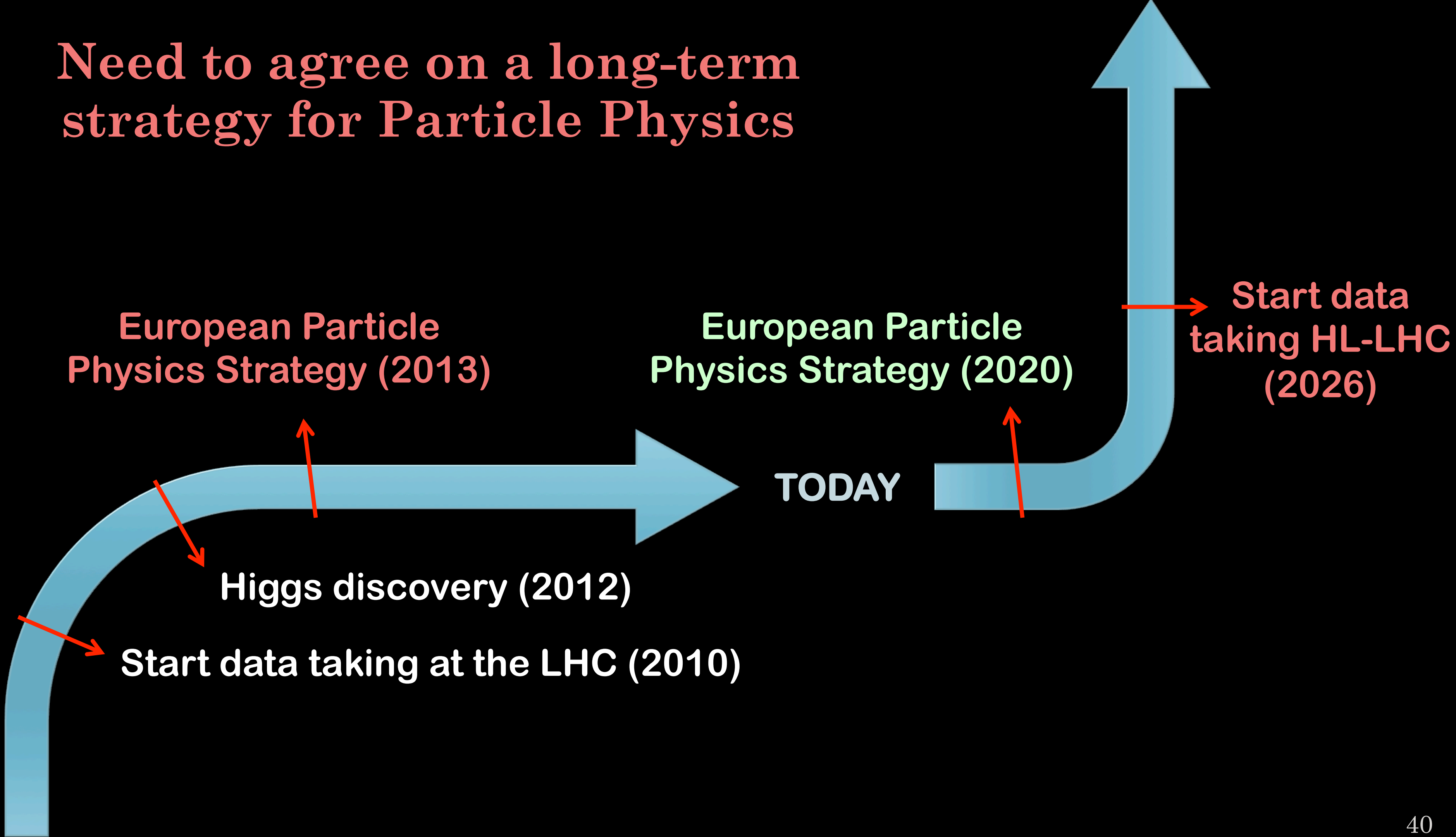
② Experiments in Europe with unique reach should be supported, as well as participation in experiments in other regions of the world. Examples: quark flavour physics, dipole moments, charged-lepton flavour violation, etc.

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.

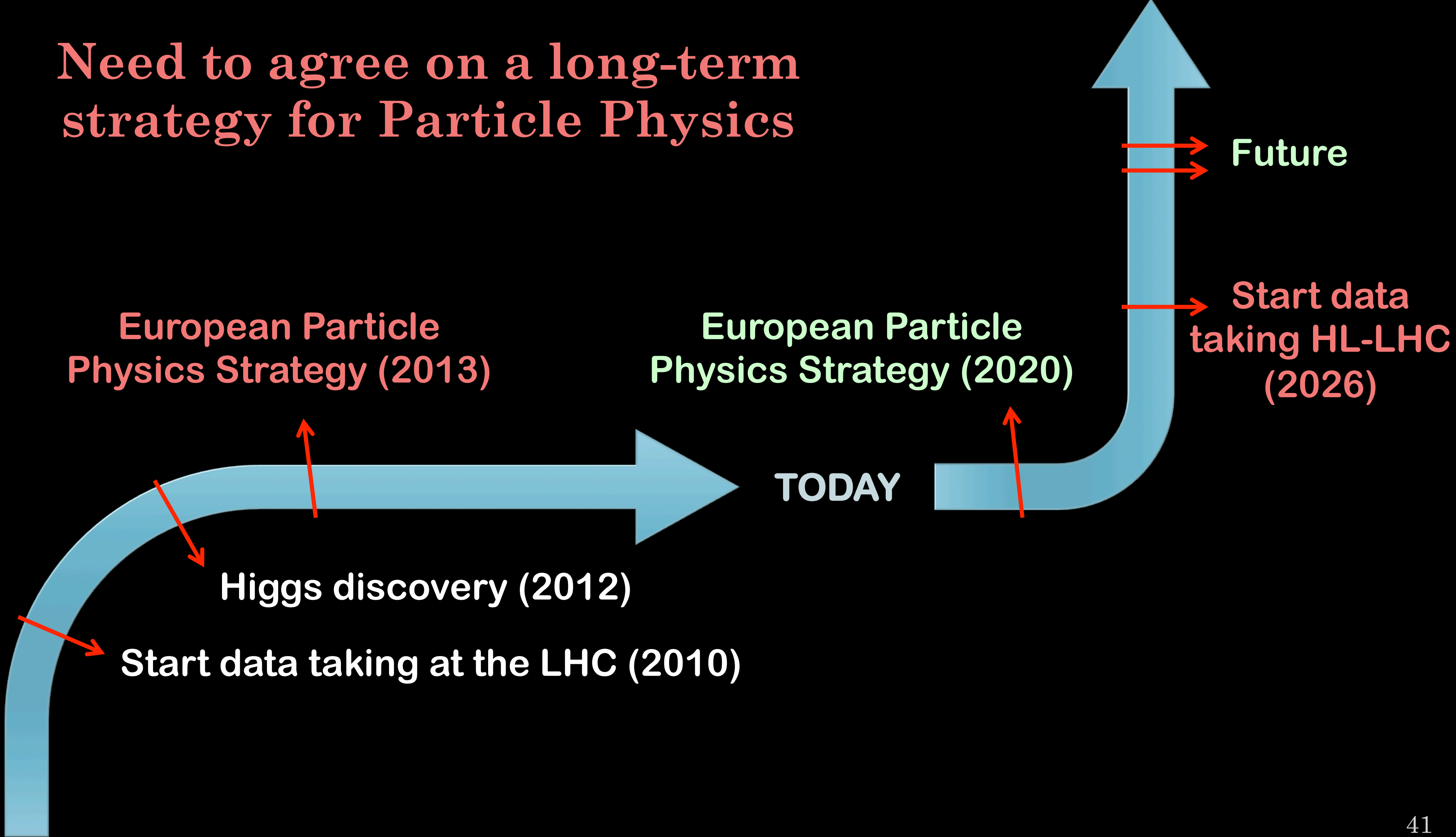
④ In the coming years, CERN should seek a closer collaboration with ApPEC on detector R&D with a view to maintaining the community's capability for unique projects in this field.

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

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

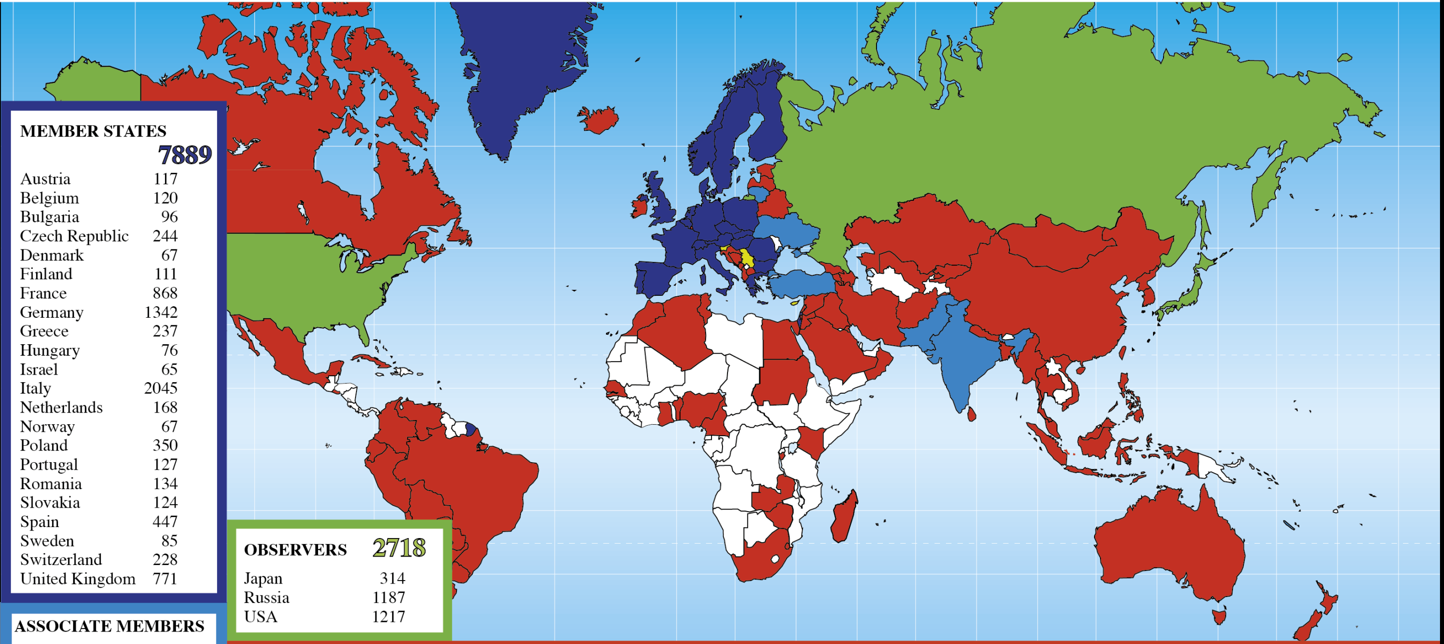


Need to agree on a long-term strategy for Particle Physics



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

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

OBSERVERS 2718

Japan	314
Russia	1187
USA	1217

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

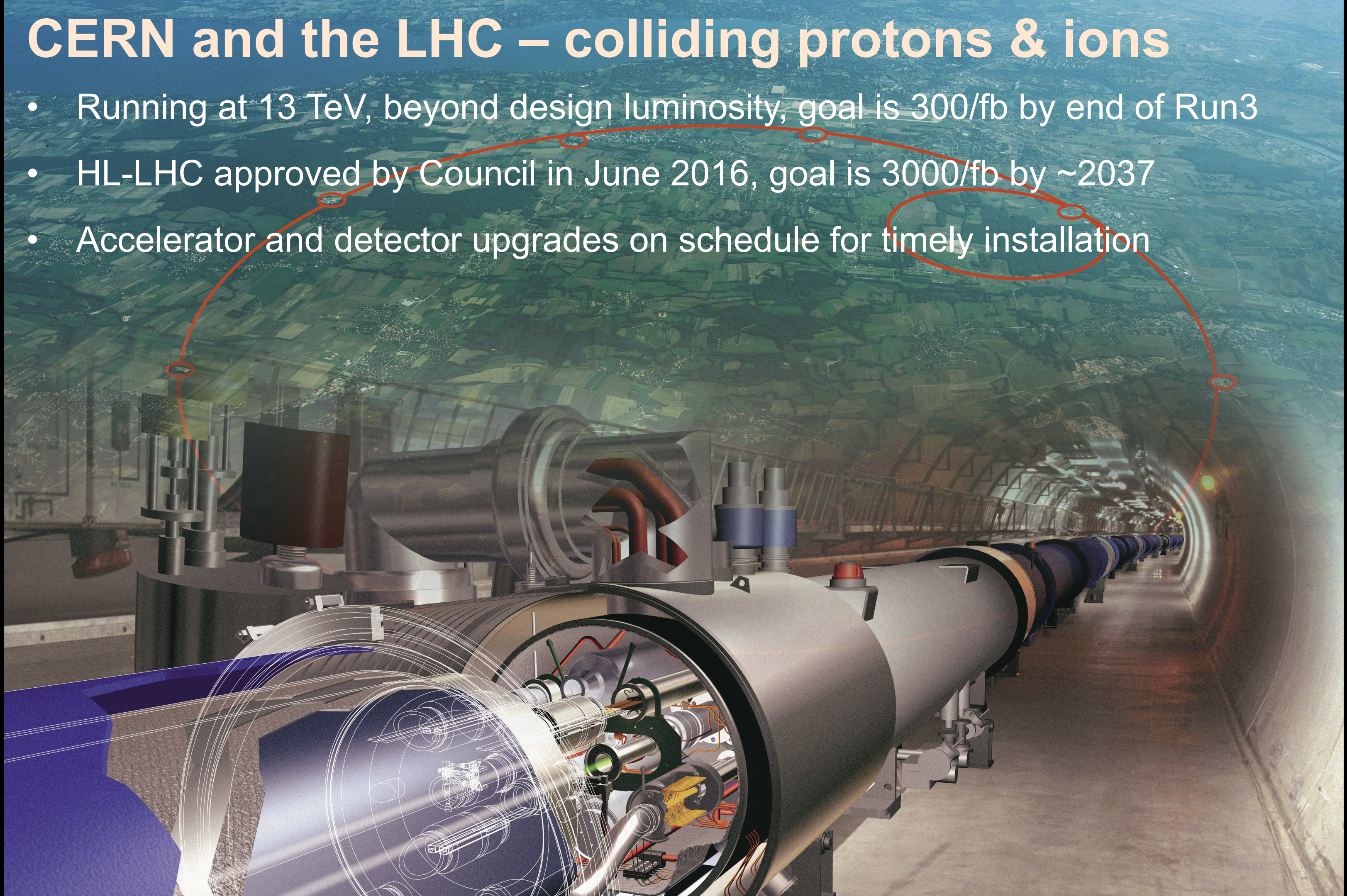
European institutions are involved in Particle Physics experiments worldwide

The 2013 European Particle Physics Strategy

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.*

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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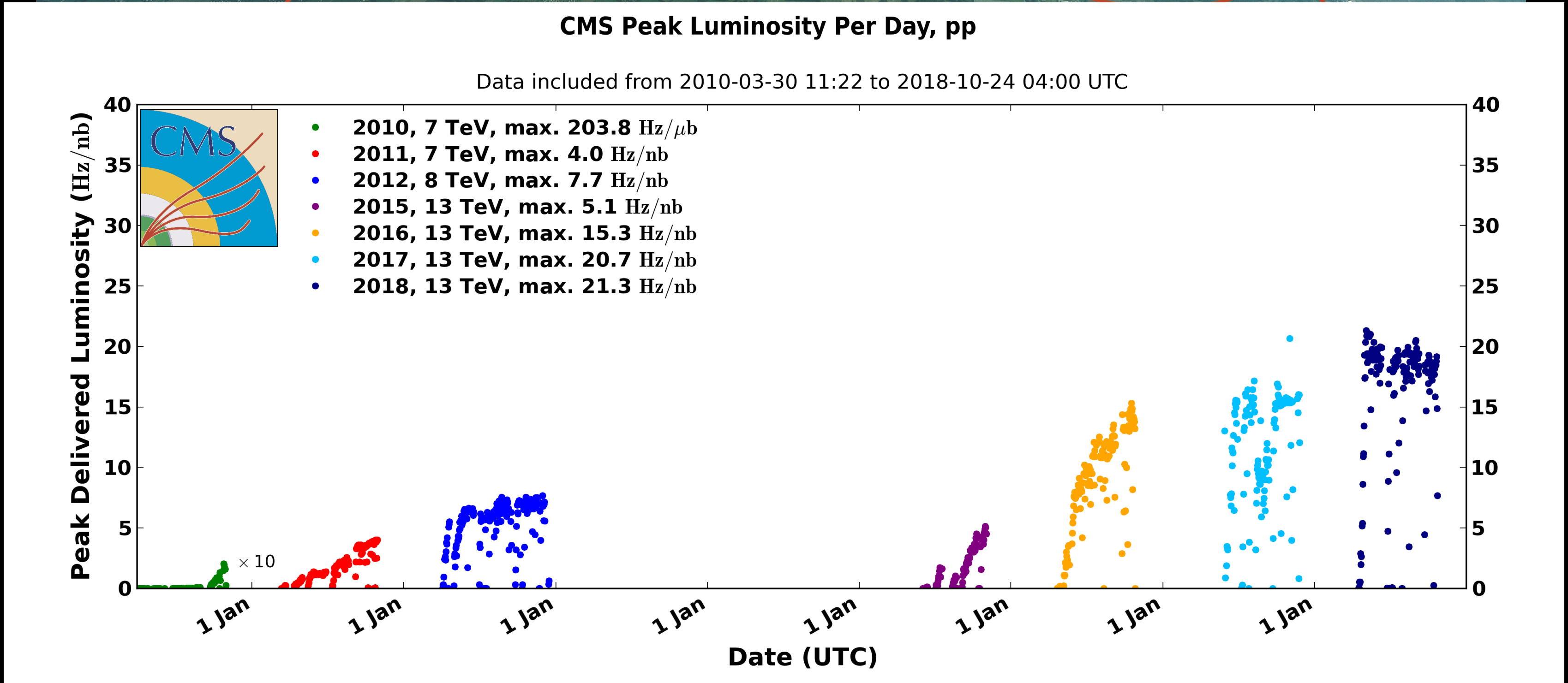

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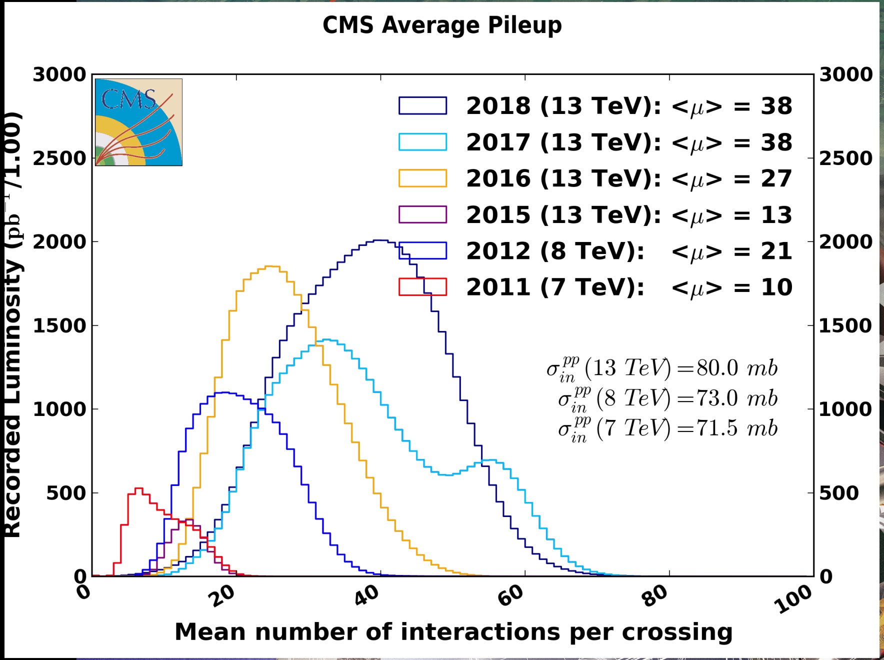
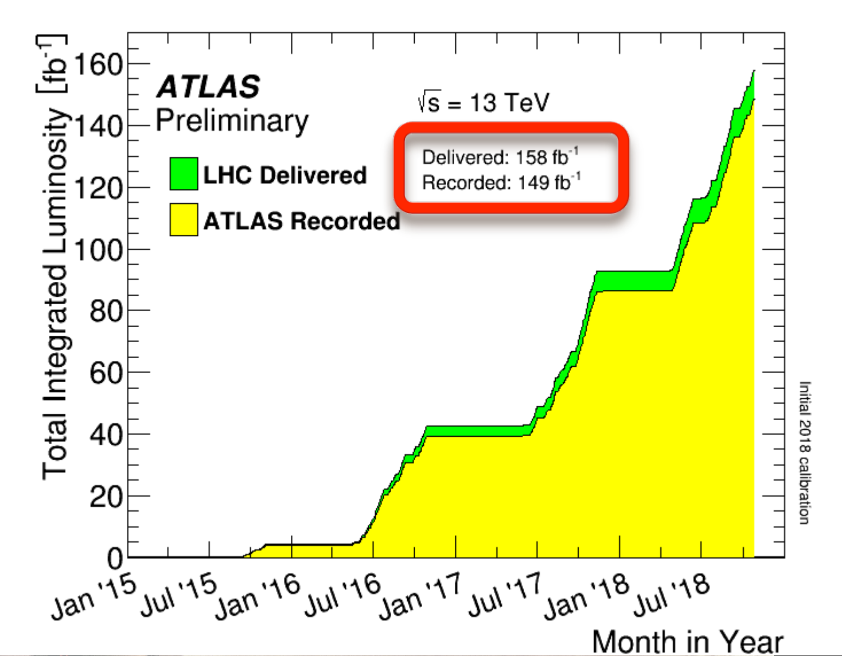
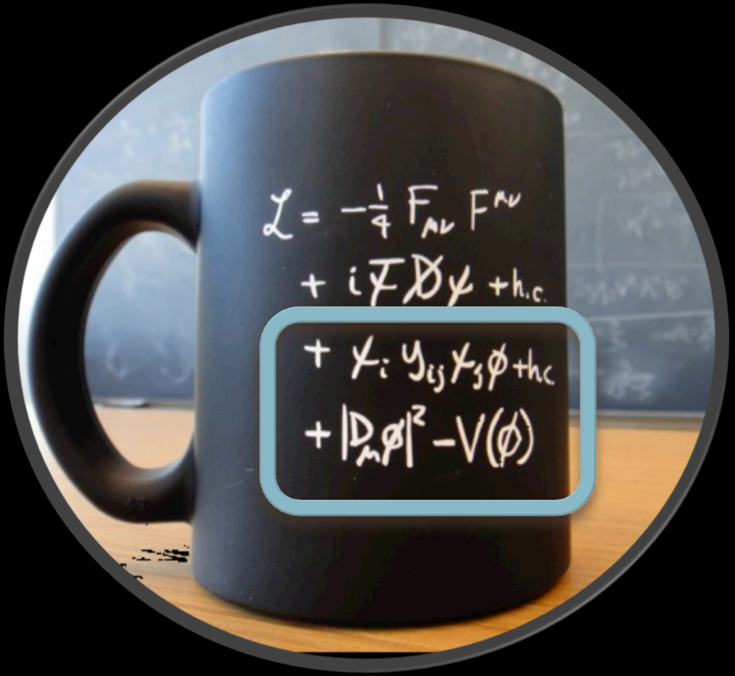




The impact of the LHC

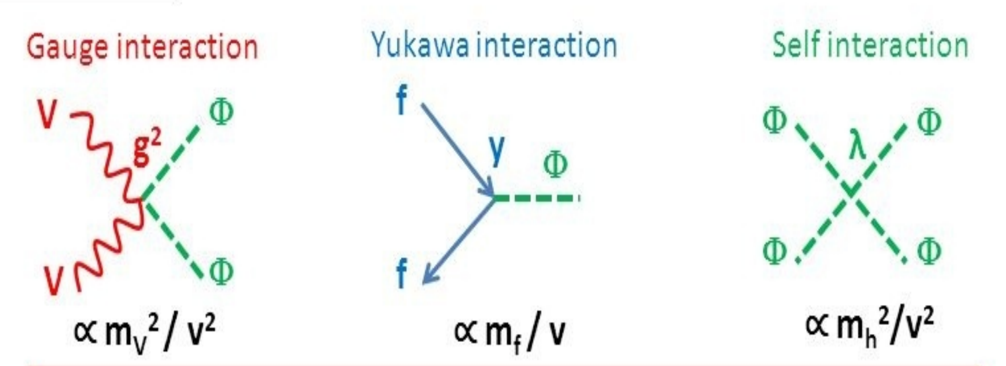


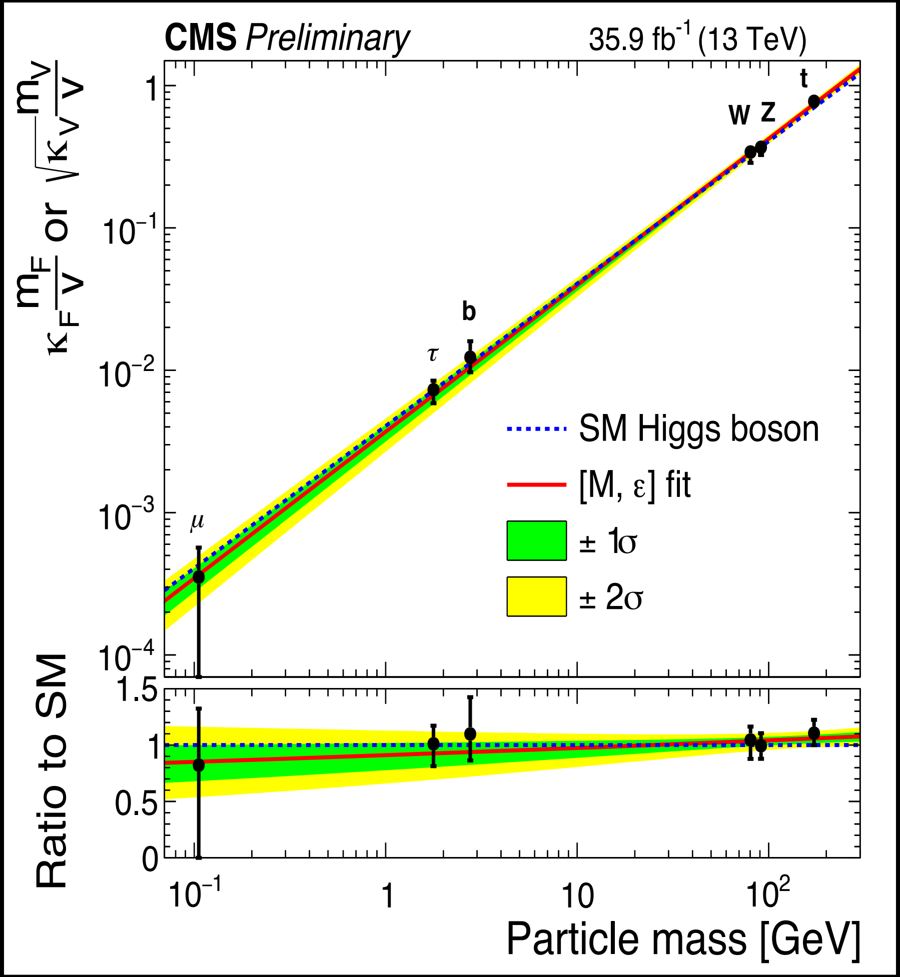
connection

a MORE PRECISE and more COMPLETE description

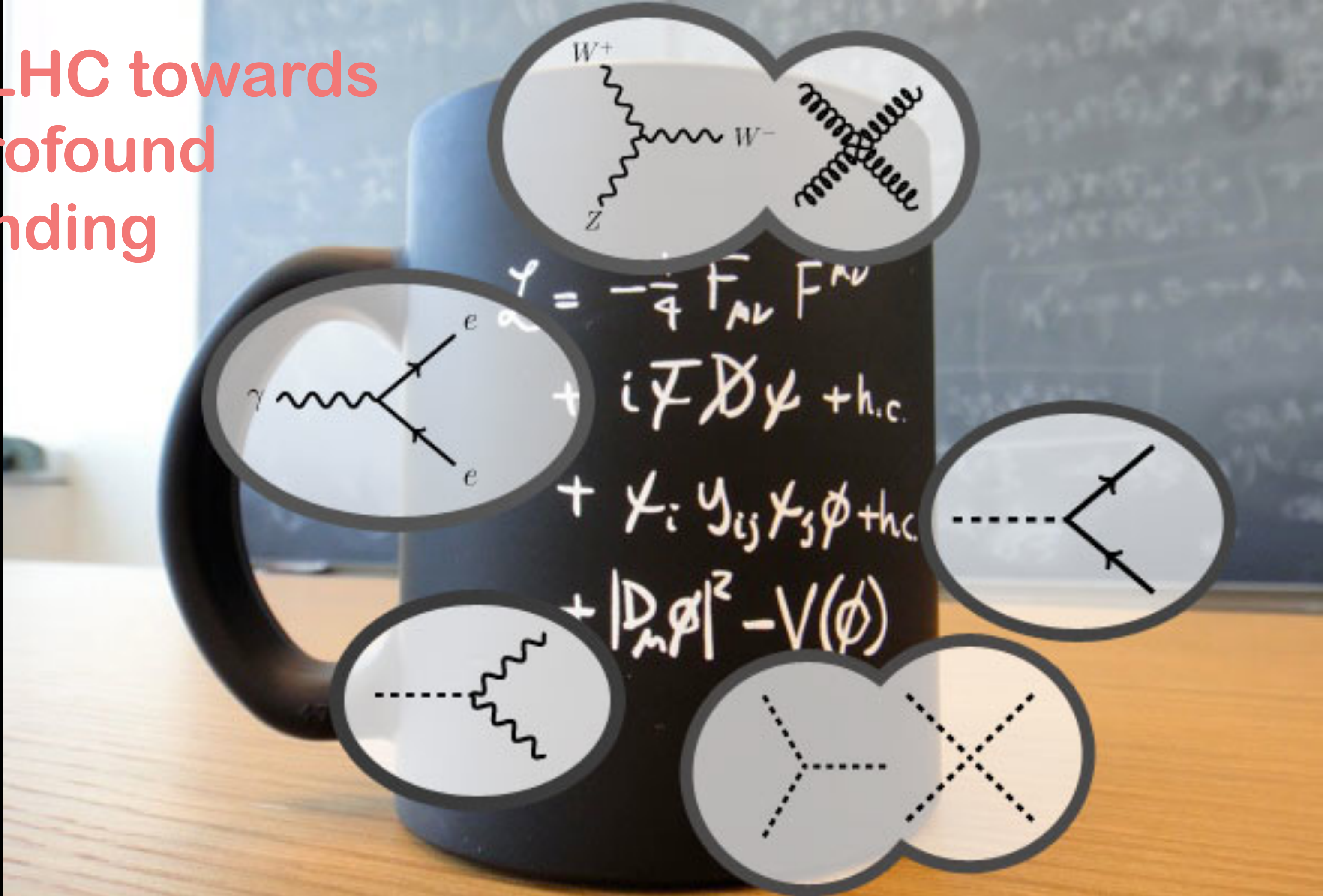
new physics

Some physics results of the LHC – scalar sector



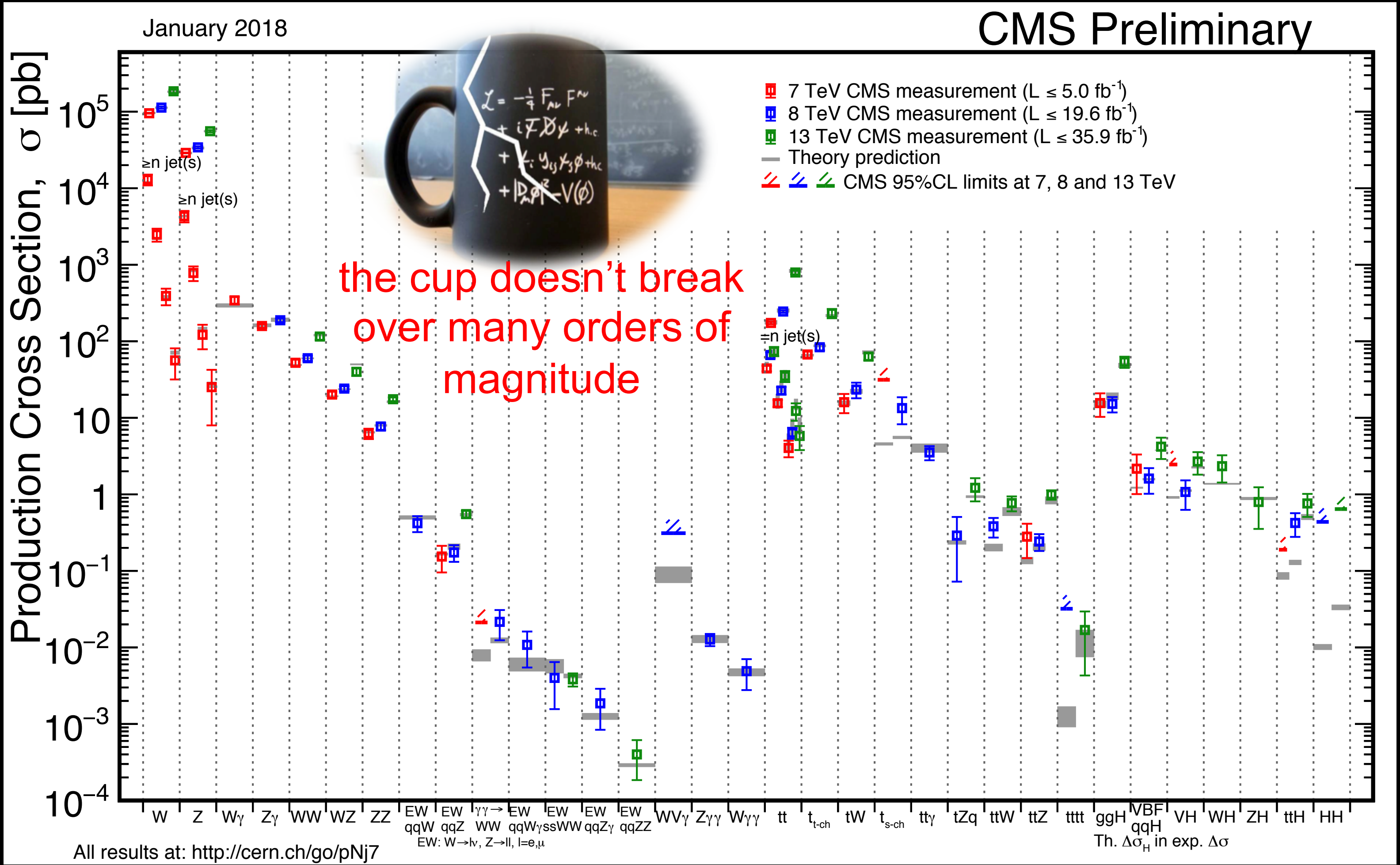


With the LHC towards a more profound understanding

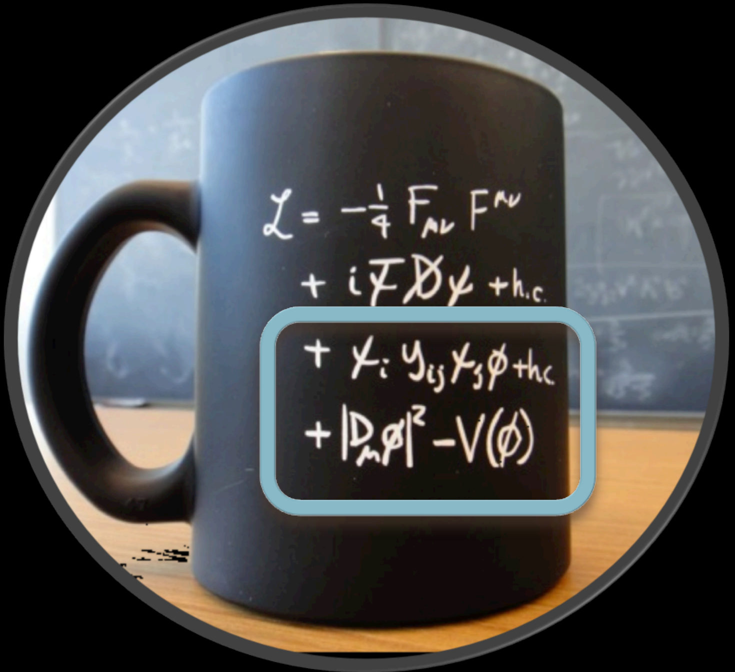


Picture from Flip Tanedo @ Quantum Daires

Some physics results of the LHC – Standard Model



The role of the LHC



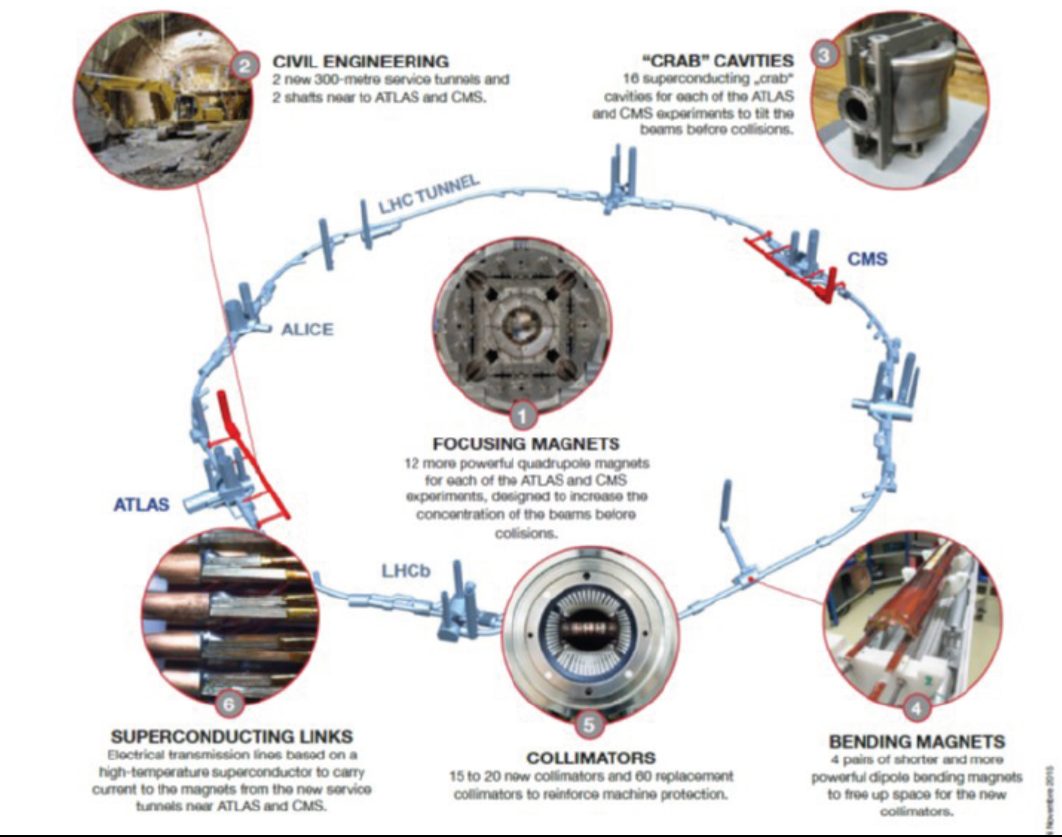
from a BETTER description
towards a more PROFOUND
understanding

connection

new physics

more data is needed
more data is coming

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



HiLumi HL-LHC PROJECT

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)

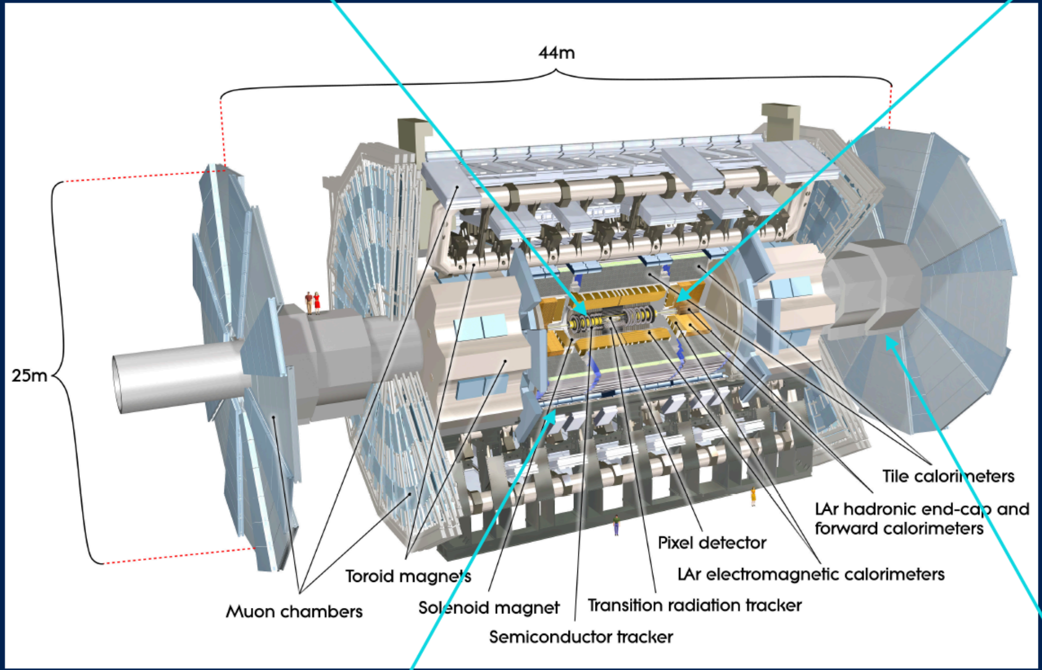
Cost to Completion : 950 MCHF (material)

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)

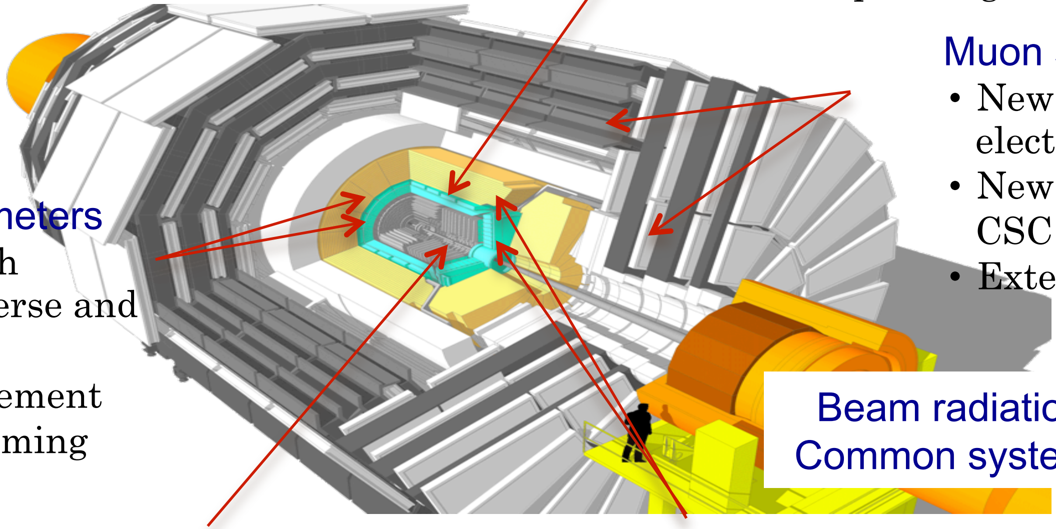
CMS – Upgrade Phase II

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

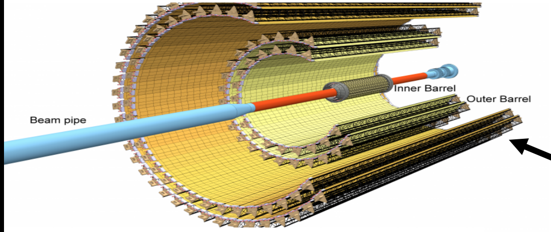
New Tracker
- Rad. tolerant - increased granularity - lighter
- 40 MHz selective readout (strips) for Trigger
- Extended coverage to $\eta \simeq 3.8$

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*

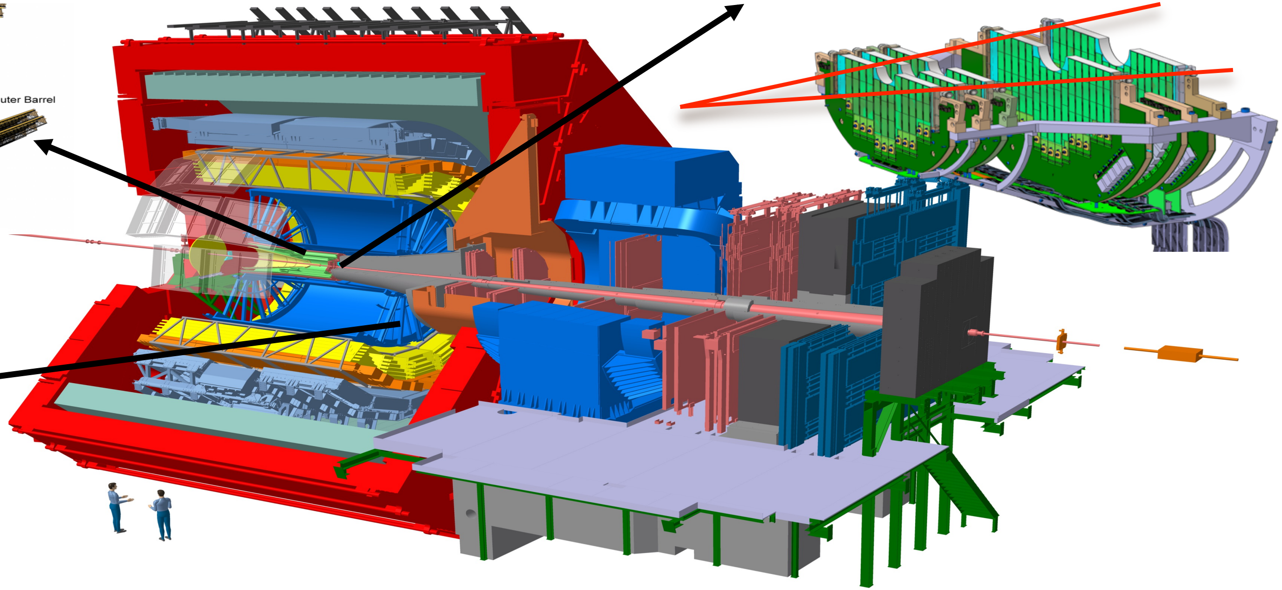
Monolythic-pixel Inner Tracking System

→ x3-5 better tracking precision



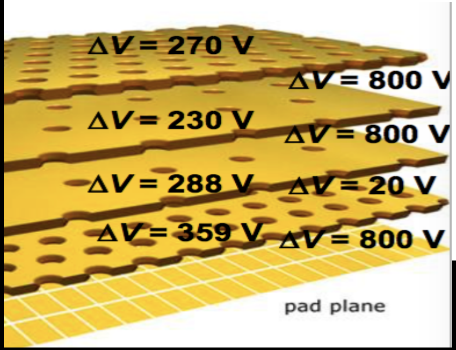
Pixel Muon Forward Tracker

→ 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

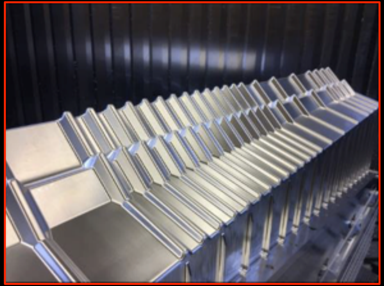
LHCb – Upgrade LS2

Construction well advanced
aim at installation in 2019

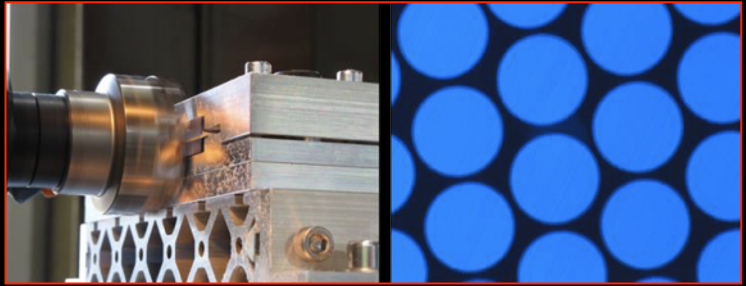
- Will collect 50 fb^{-1} at instantaneous lumi of $2x10^{33} cm^{-2}s^{-1}$
- Full software trigger
- New tracking detectors
- New RICH photon detectors
- New electronics read out at 40 MHz

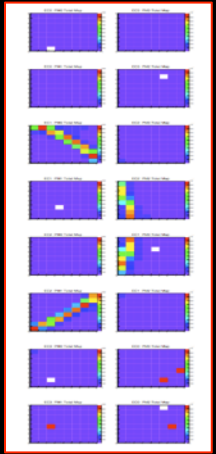
Prototypes of DAQ board (PCIe40)

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

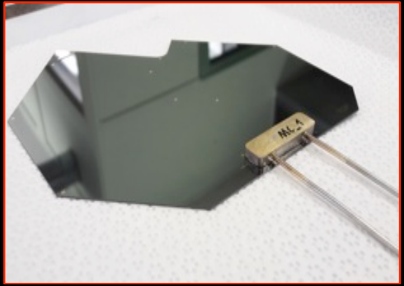


Machining and light scan of the scintillating fiber mats for the fibre tracker

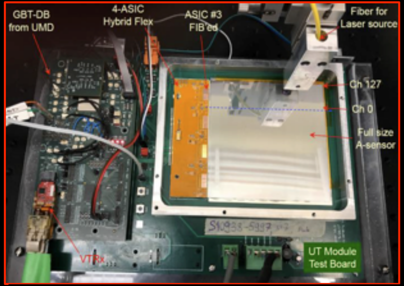




Cherenkov ring from a full RICH MaPMT module

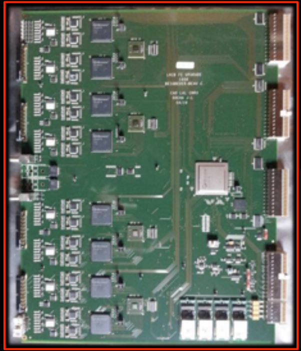


Si mchannel cooling plate for VELO with soldered connector



Upstream Tracker silicon sensor module under test

First scintillating fibre modules arriving at CERN



Calorimeter front-end board

Muon system readout ASIC

Beyond the potential of the LHC data (2010-2023), with the HL-LHC data (2026-2037) important progress can be expected on

Standard Model physics
Higgs physics
Beyond the Standard Model physics
Flavour physics
High-density QCD

HL-LHC and HE-LHC Physics reports (Dec 2018):
https://twiki.cern.ch/twiki/bin/view/LHCPhysics/HLHELHCWorkshop

Zooming into the scalar sector
from LHC to HL-LHC

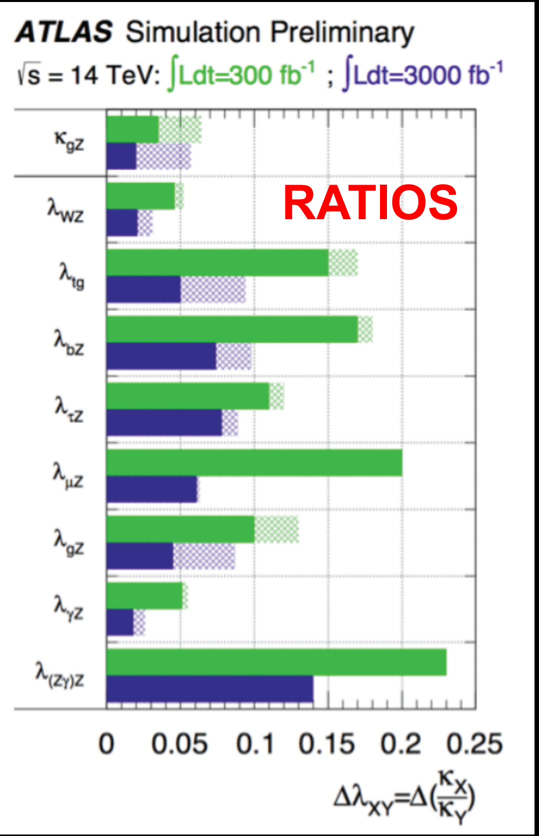
LHC

HL-LHC

HL-LHC and HE-LHC Physics reports (Dec 2018):
https://twiki.cern.ch/twiki/bin/view/LHCPhysics/HLHELHCWorkshop

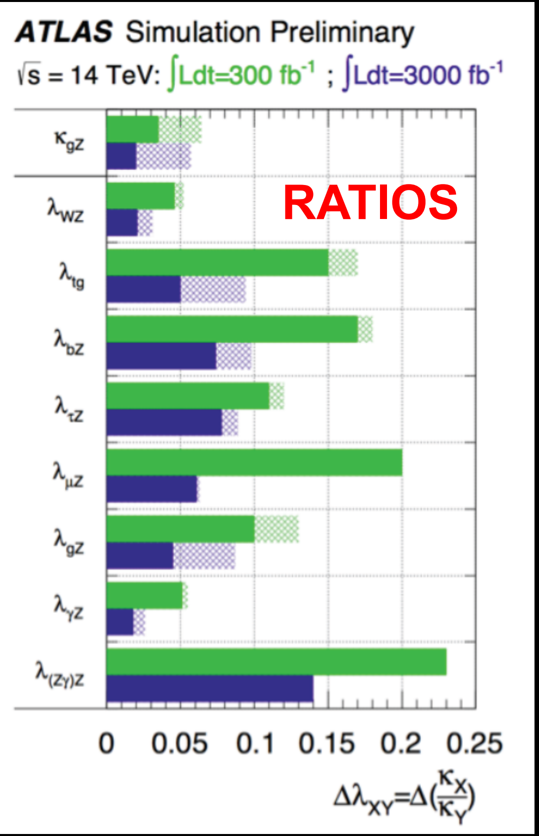
LHC → HL-LHC

(factor 1-3)



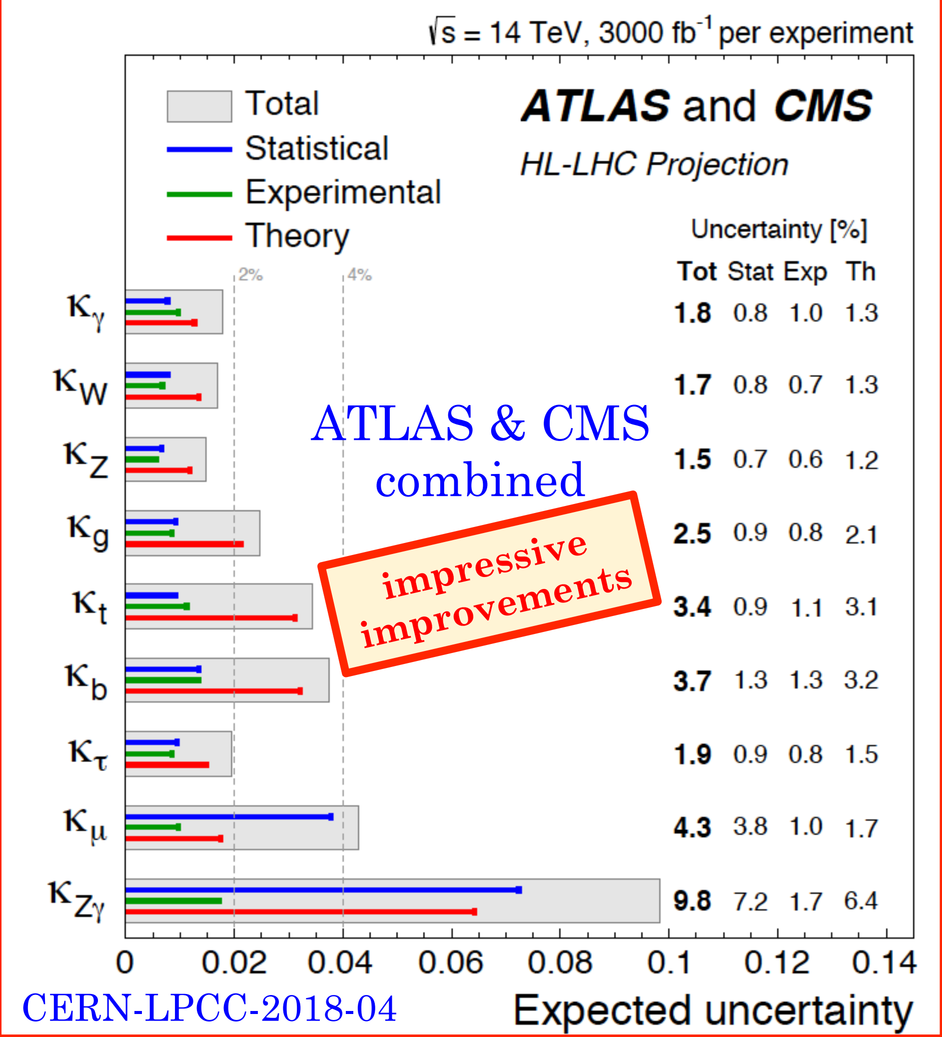
ATL-PHYS-PUB-2013-014

LHC → HL-LHC
(factor 1-3)



ATL-PHYS-PUB-2013-014

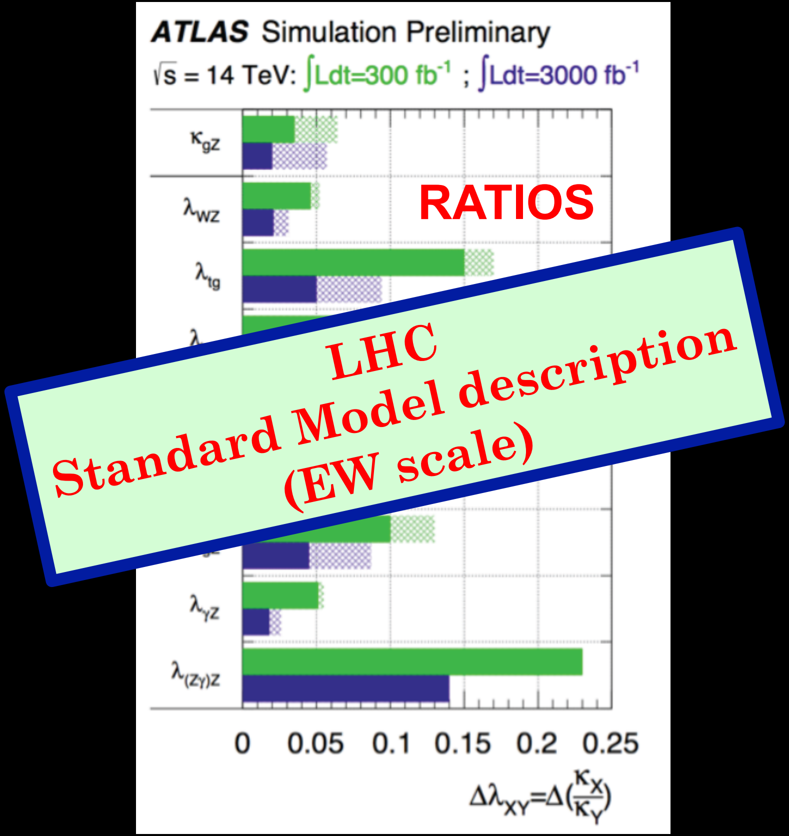
recent updates



CERN-LPCC-2018-04

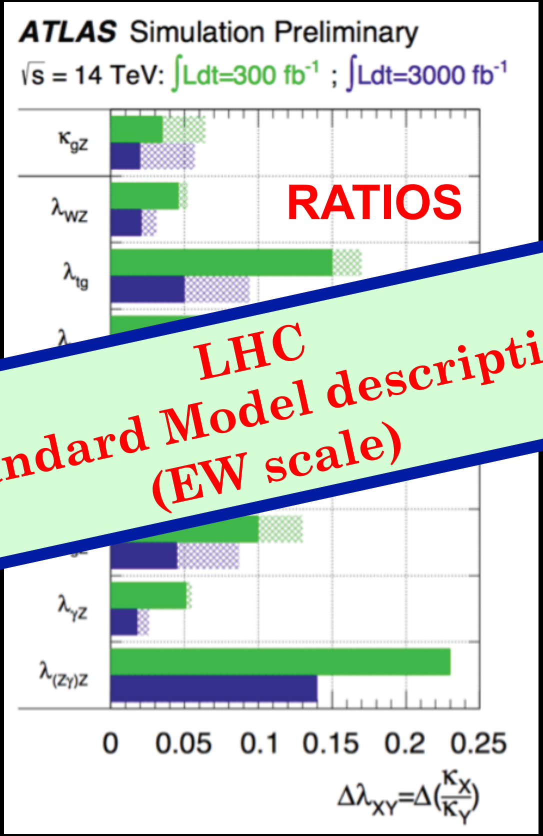
LHC → HL-LHC

(factor 1-3)



ATL-PHYS-PUB-2013-014

LHC → HL-LHC
(factor 1-3)



LHC
Standard Model description
(EW scale)

ATL-PHYS-PUB-2013-014

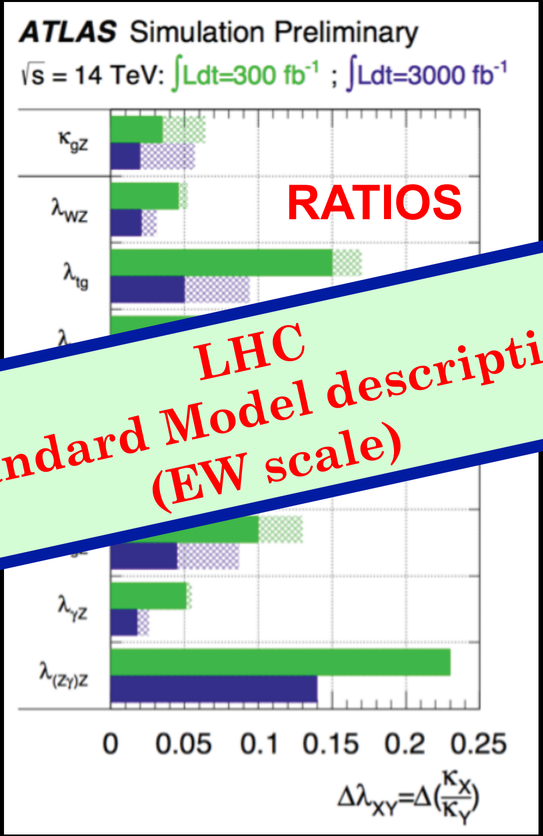
HL-LHC ~ ILC@250

Collider	HL-LHC	ILC_{250}
Lumi (ab^{-1})	3	2
Years	25	15
$\delta\Gamma_H/\Gamma_H$ (%)	SM	3.6
$\delta g_{HZZ}/g_{HZZ}$ (%)	1.3	0.3
$\delta g_{HWW}/g_{HWW}$ (%)	1.4	1.7
$\delta g_{Hbb}/g_{Hbb}$ (%)	2.9	1.7
$\delta g_{Hcc}/g_{Hcc}$ (%)	SM	2.3
$\delta g_{Hgg}/g_{Hgg}$ (%)	1.8	2.2
$\delta g_{H\tau\tau}/g_{H\tau\tau}$ (%)	1.8	1.9
$\delta g_{H\mu\mu}/g_{H\mu\mu}$ (%)	4.4	14.1
$\delta g_{H\gamma\gamma}/g_{H\gamma\gamma}$ (%)	1.6	6.4
$\delta g_{Htt}/g_{Htt}$ (%)	2.5	–
BR_{EXO} (%)	SM	< 1.7

Taken from the FCC CDR, CERN-ACC-2018-0057

LHC → HL-LHC

(factor 1-3)



ATL-PHYS-PUB-2013-014

LHC
Standard Model description
(EW scale)

HL-LHC ~ ILC@250

Collider	HL-LHC	ILC_{250}
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$\delta\Gamma_H/\Gamma_H$ (%)	SM	3.6
$\delta g_{HZZ}/g_{HZZ}$ (%)	1.3	[illegible]
$\delta g_{HWW}/g_{HWW}$ (%)	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	1.8	2.2
$\delta g_{H\tau\tau}/g_{H\tau\tau}$ (%)	1.8	1.9
$\delta g_{H\mu\mu}/g_{H\mu\mu}$ (%)	4.4	14.1
$\delta g_{H\gamma\gamma}/g_{H\gamma\gamma}$ (%)	1.6	6.4
$\delta g_{Htt}/g_{Htt}$ (%)	2.5	–
BR_{EXO} (%)	SM	< 1.7

HL-LHC and ILC
Exploration Beyond the Standard Model
(indirectly to multi-TeV scales)

Taken from the FCC CDR, CERN-ACC-2018-0057

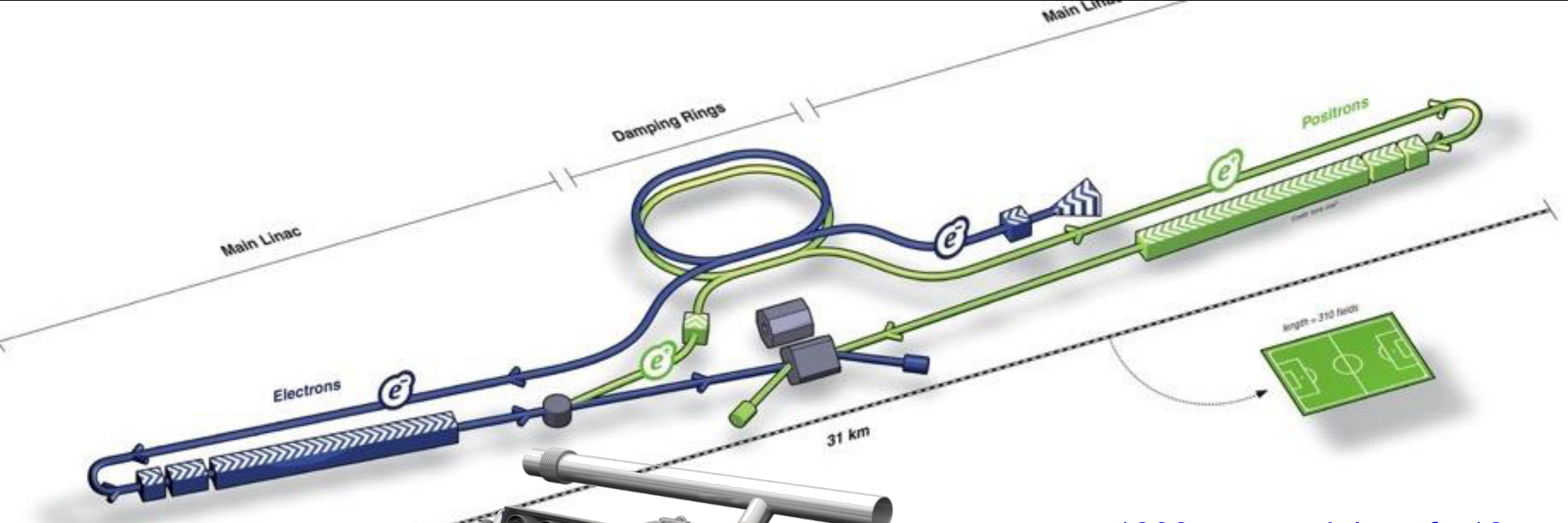
The 2013 European Particle Physics Strategy

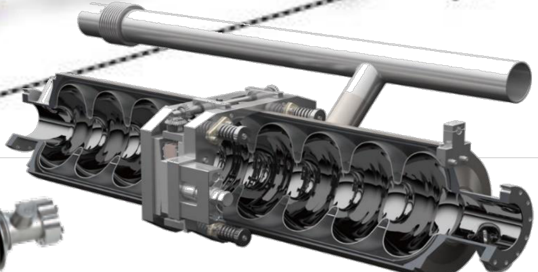
③ *There is a strong scientific case for an electron-positron collider, … Europe looks forward to a proposal from Japan to discuss a possible participation.*

Waiting now urgently for a conclusive statement from the Japanese Government for their willingness to host ILC

(an ICFA meeting is planned early March to conclude)

International Linear Collider (ILC) – e^+e^- collisions at 250 GeV





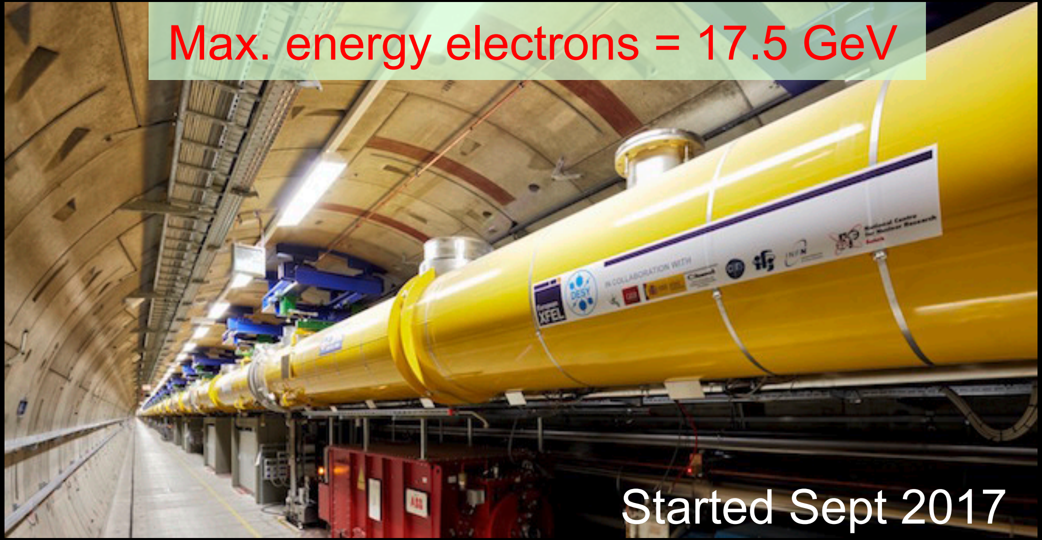
in Liquid He vessel

~16000 superconductive cavities of ~1m

~1800 cryomodules of ~12m

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.

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

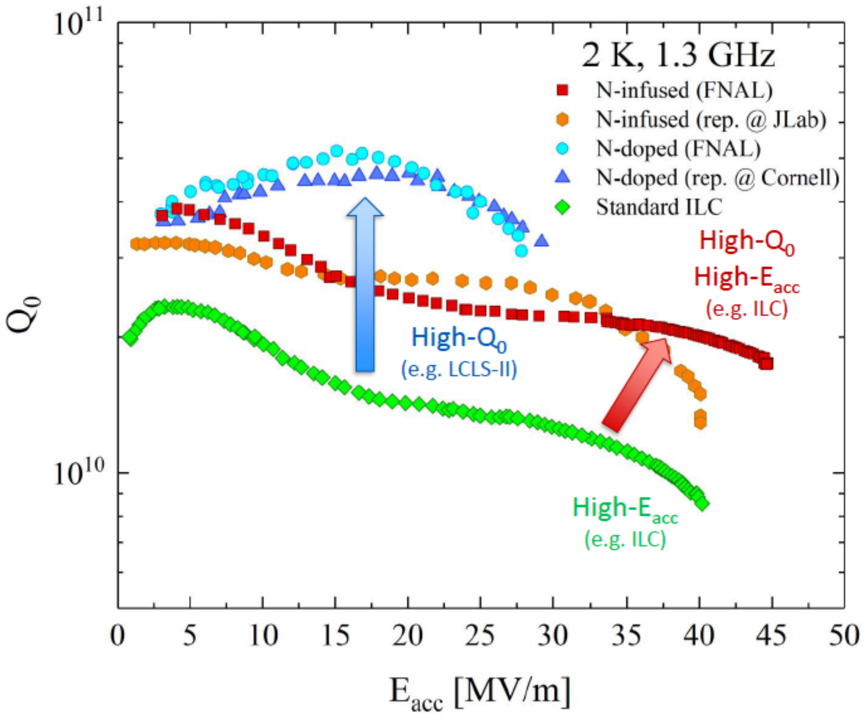
(from O. Napoly @ Plenary ECFA meeting Nov 2018)

- 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.

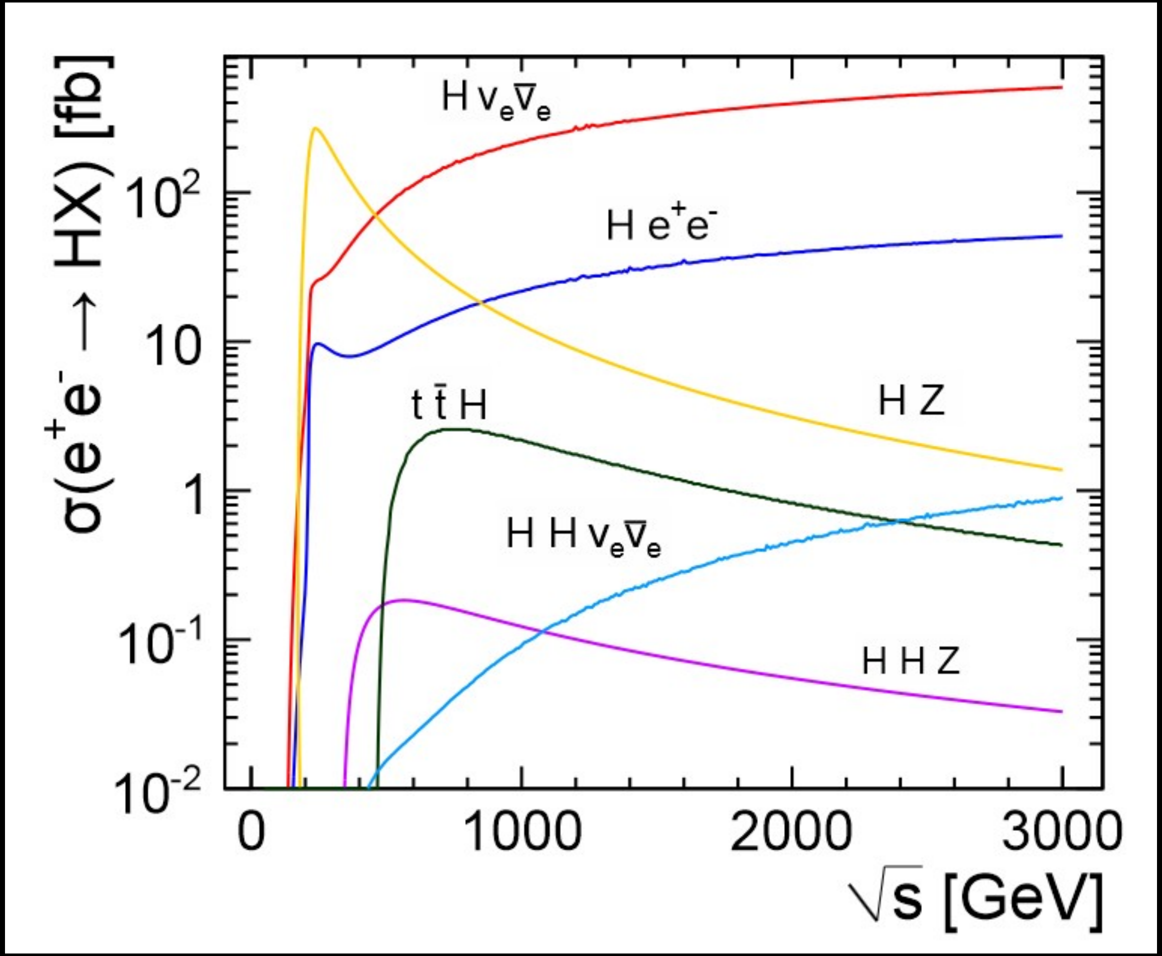
- Important progress in the field.

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



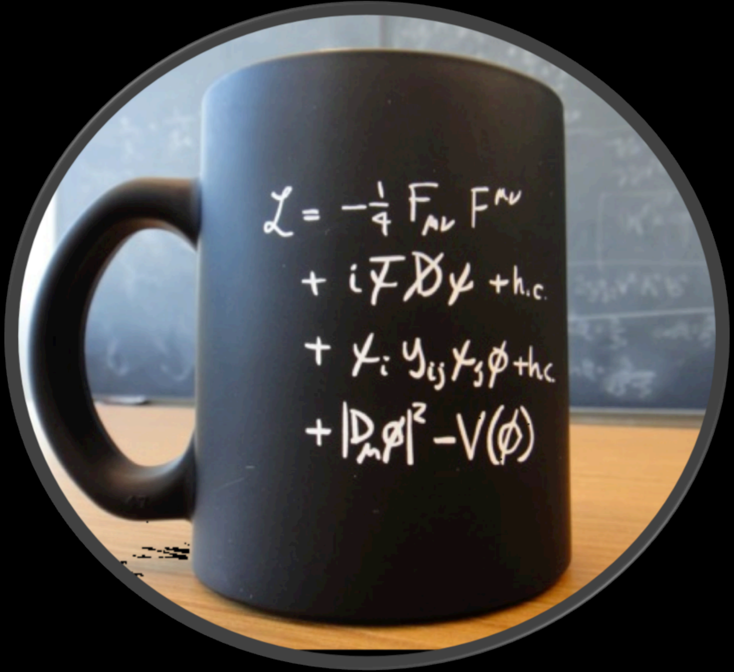
Could we aim to reach eventually higher energies ?

Opening additional channels relevant to explore new physics via the scalar sector



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

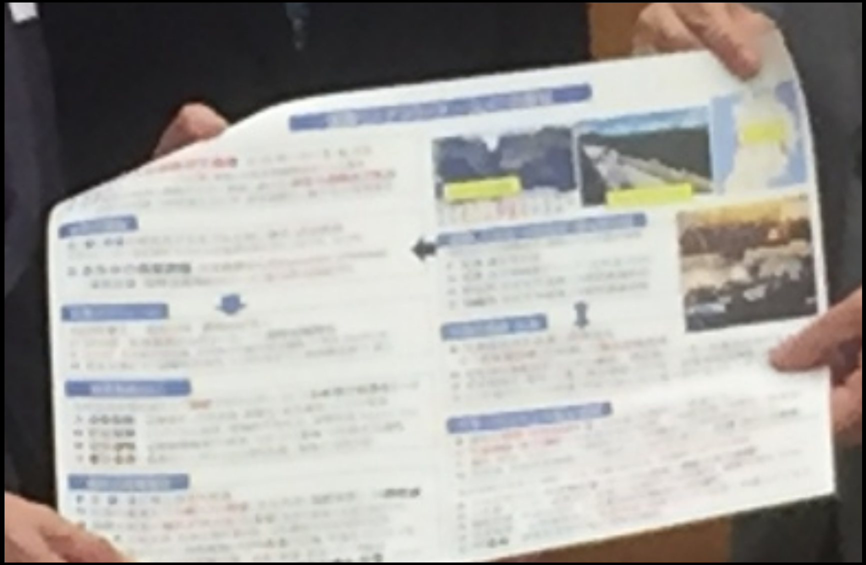


The ILC has excellent zoom-in capabilities for several terms in the scalar sector

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

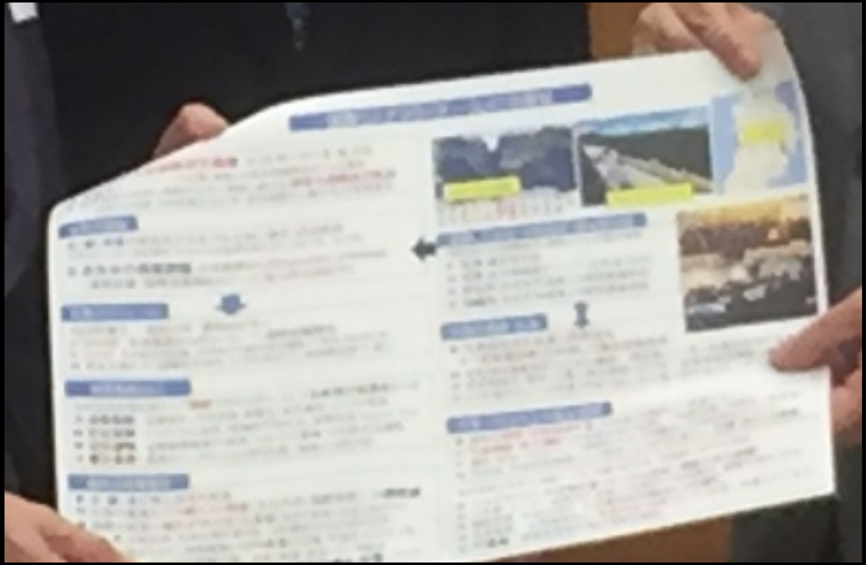
International Linear Collider (ILC) – July 5th, 2018

Satoru Yamashita, Uni. of Tokyo



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.*

Key options studied at CERN

LHeC (ep), http://lhec.web.cern.ch

J. Phys. G: Nucl. Part. Phys. 39 (2012) 075001 [arXiv:1206.2913]

HE-LHC (pp, pA, AA, ep), https://fcc-cdr.web.cern.ch/

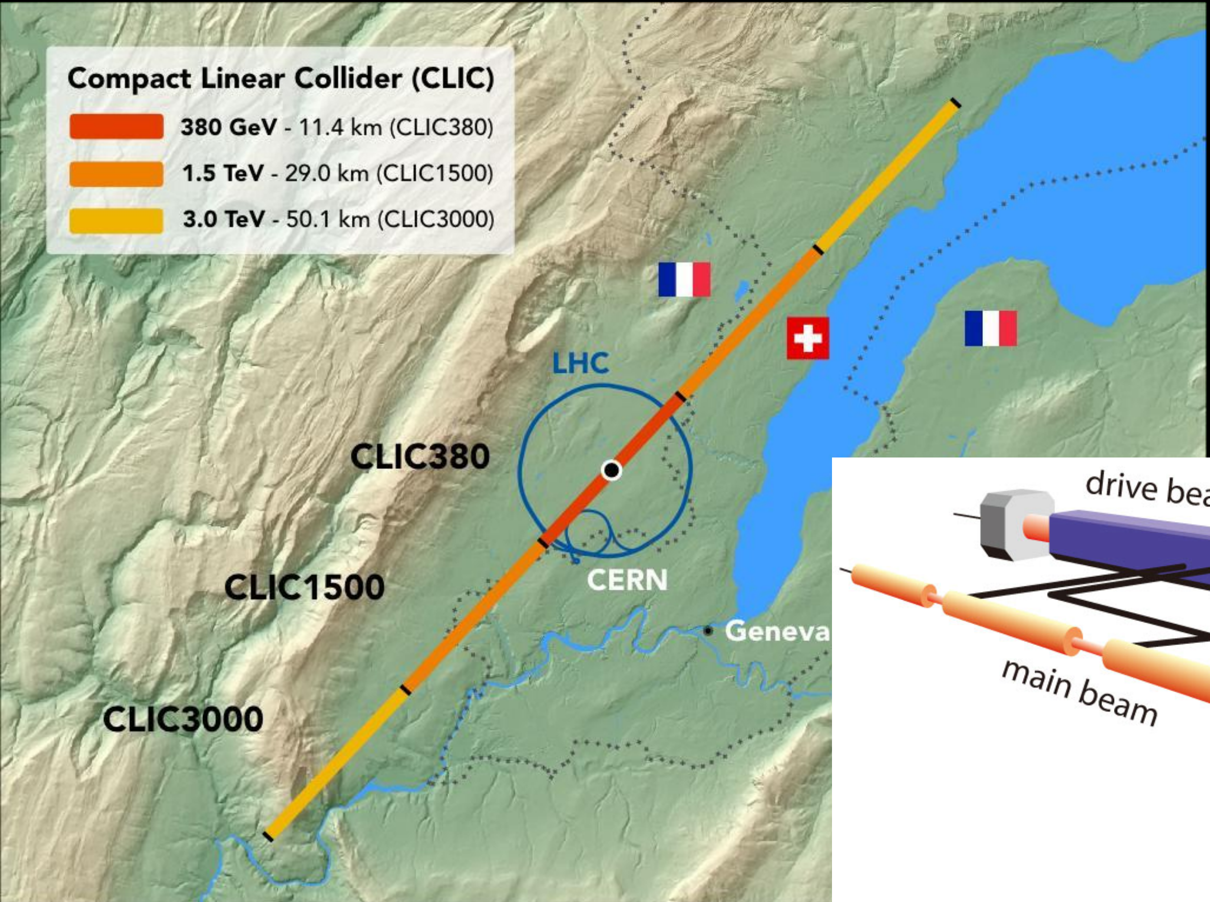
CLIC (ee), http://clic-study.web.cern.ch/

FCC (ee, ep, pp, pA, AA, eA), https://fcc-cdr.web.cern.ch/

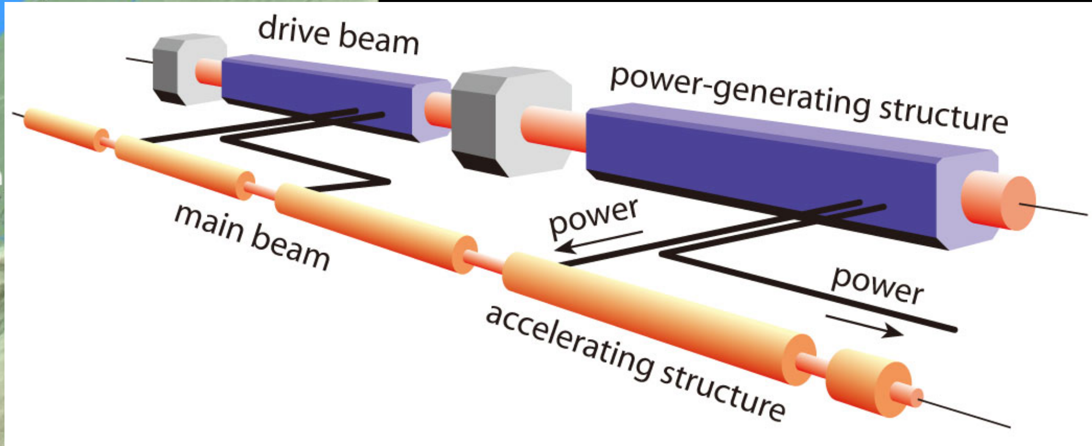
Compact Linear Collider (CLIC)

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.



CLIC – some physics highlights

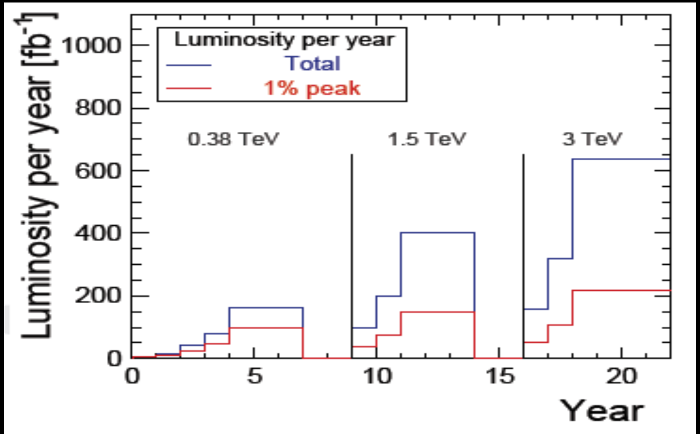
P. Burrows @ ICFA Seminar 2017

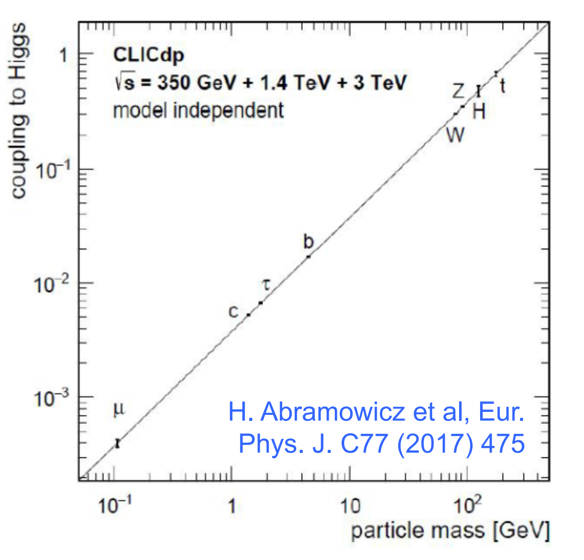
Higgs characterization

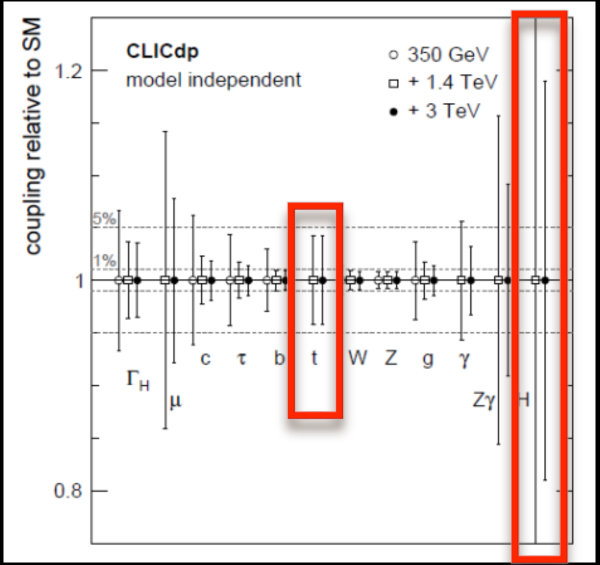
Precision on top quark Yukawa of ~4% and Higgs self-coupling of ~20%.

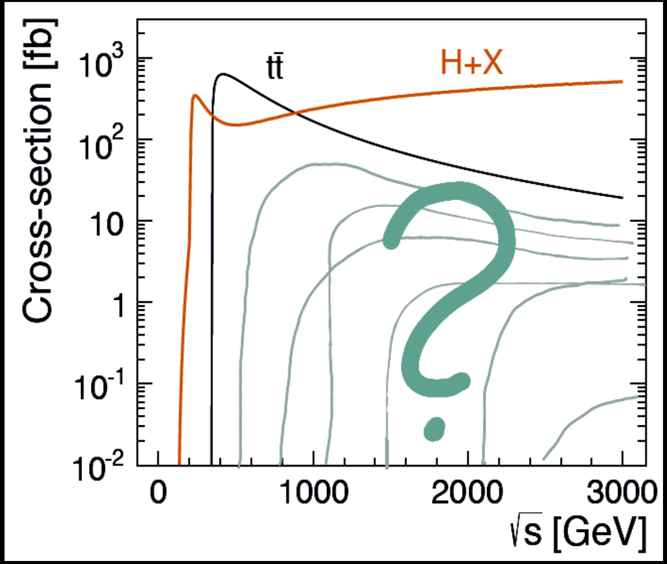
Staged approach

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

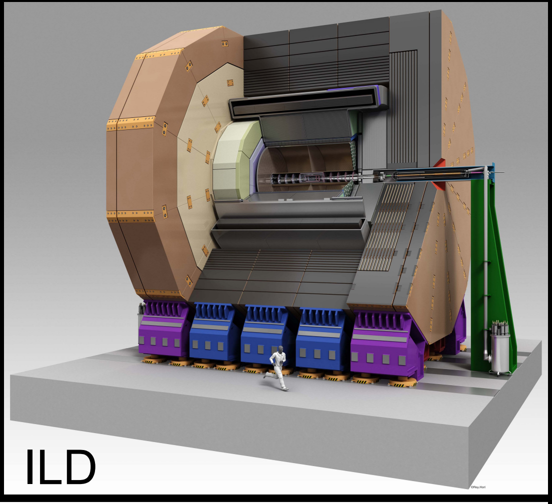
2019 - 2020 Decisions

2025 Construction Start

2035 First Beams

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

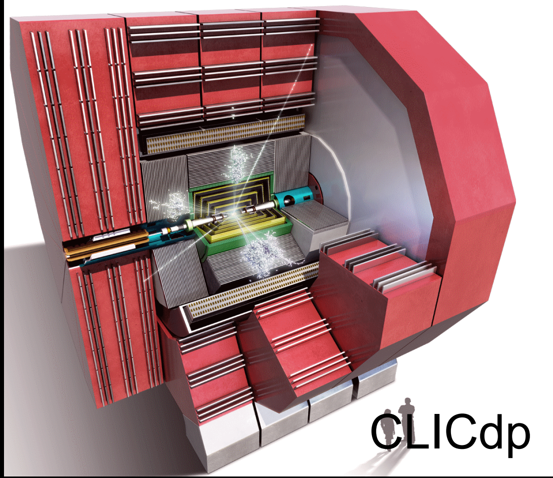
Linear Collider detector & physics studies: Europe engaged

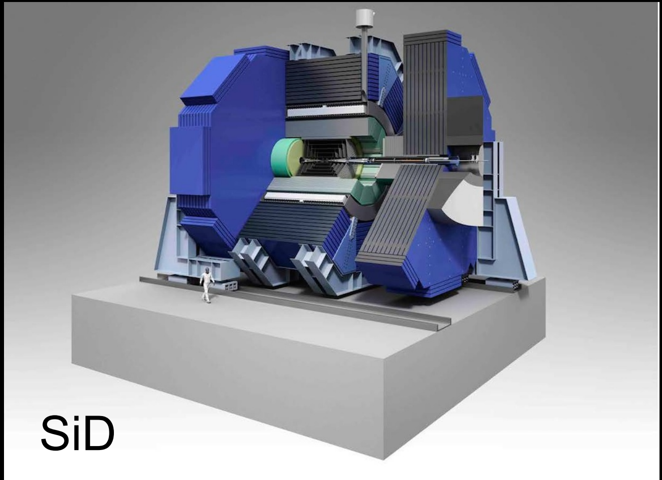


The LCC physics & detector directorate is responsible for activities that advance the physics and detectors of the linear collider.

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



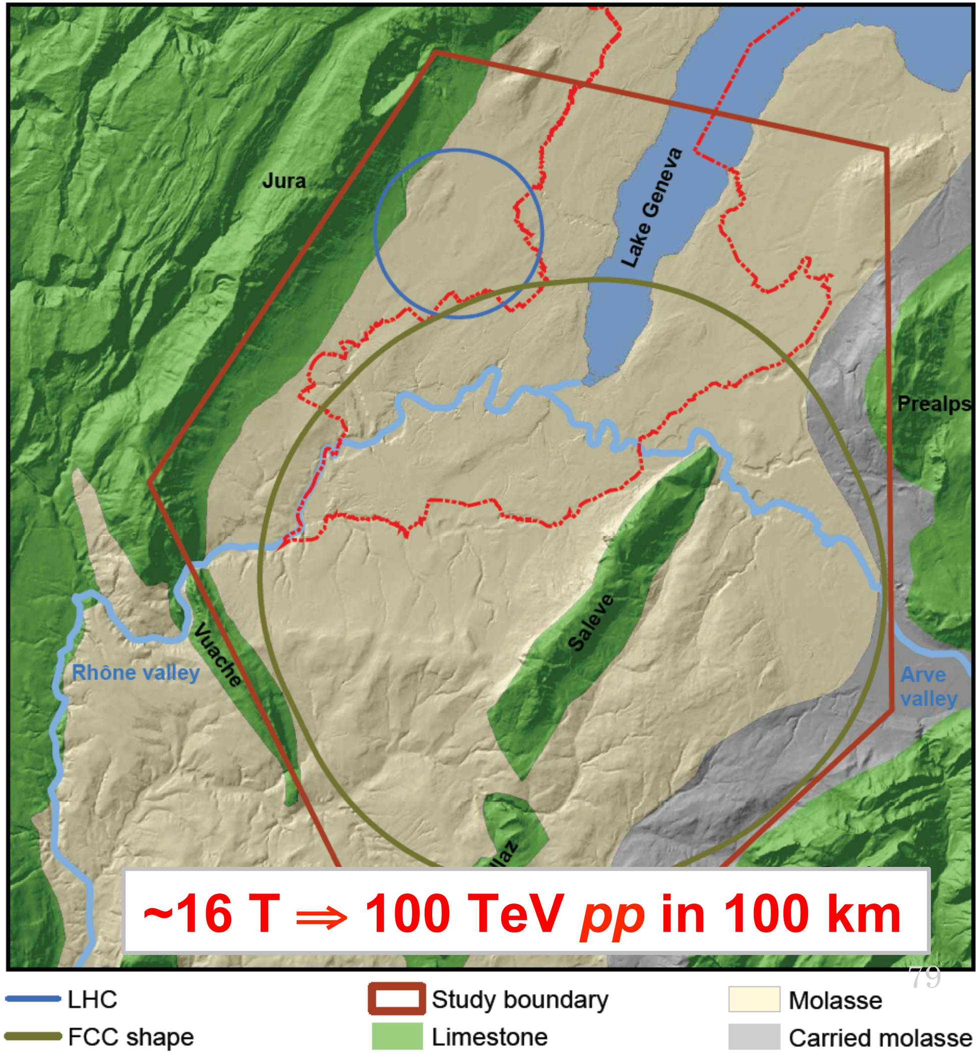


Three detector R&D groups:

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

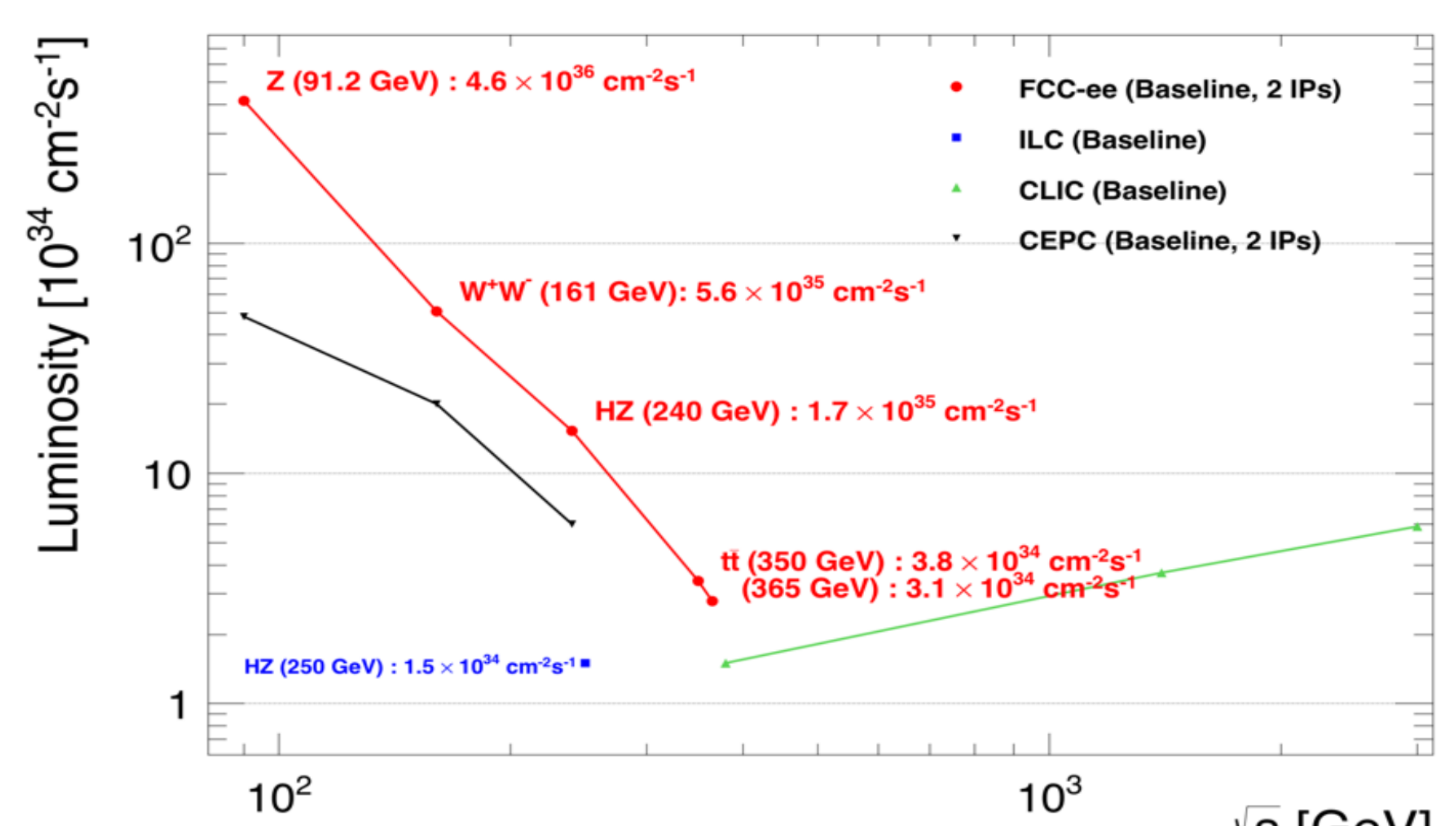
Future Circular Collider

- *pp*-collider (***FCC-hh***)
- **e^+e^- collider (*FCC-ee*)** as potential first step
- **HE-LHC** with *FCC-hh magnets*
- ***p*-e collider (*FCC-he*)** option
- **$\mu\mu$ colider (*FCC-$\mu\mu$*)** option
- AA, Ap, Ae options



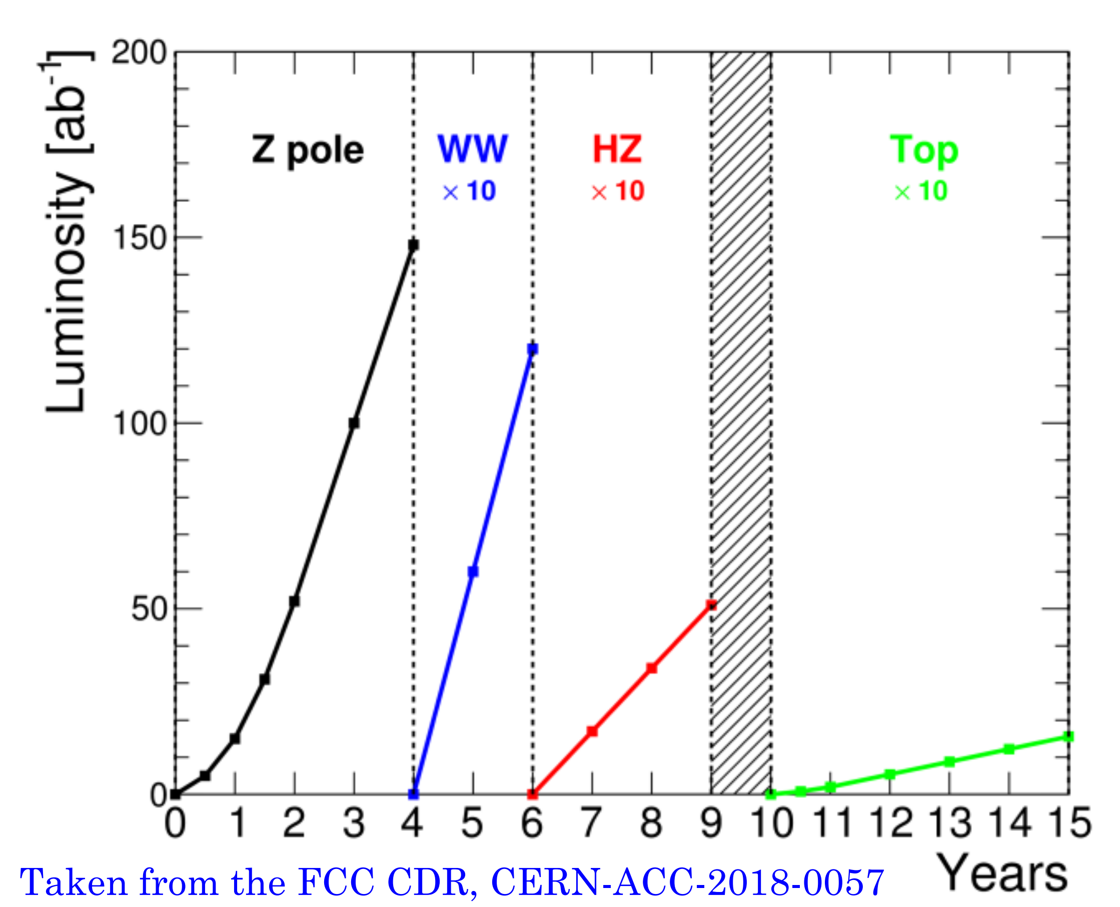
FCC CDRs (Jan 2019): https://fcc-cdr.web.cern.ch/

Future Circular Collider (FCC-ee) – luminosities

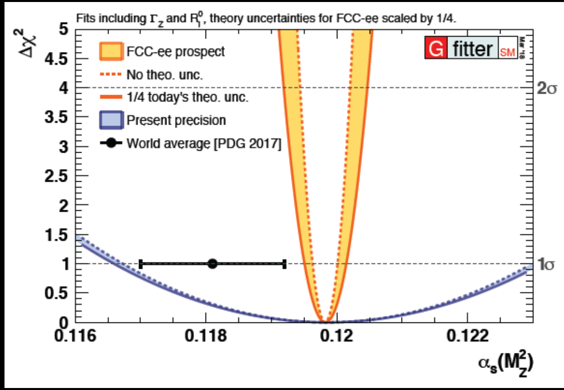


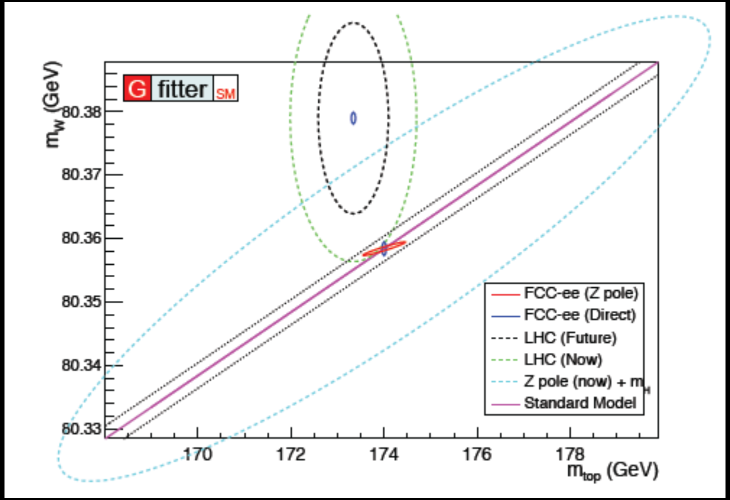
Taken from the FCC CDR, CERN-ACC-2018-0056

Future Circular Collider (FCC-ee) – EW physics



Taken from the FCC CDR, CERN-ACC-2018-0057



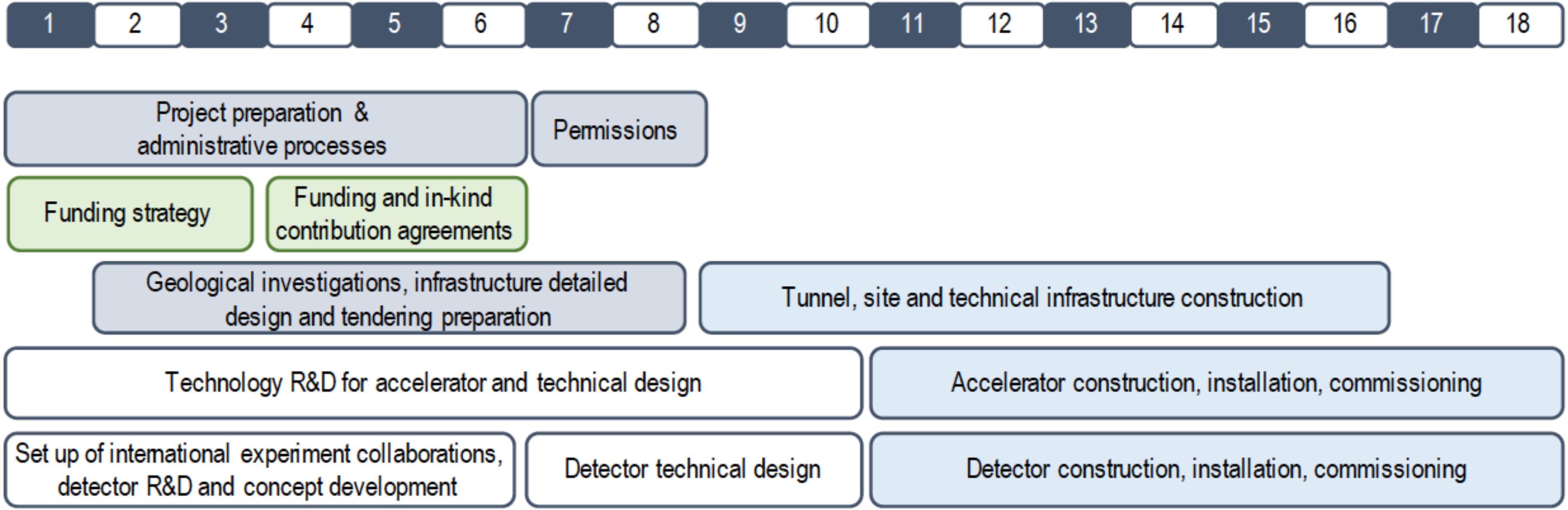


Future Circular Collider (FCC-ee) – Higgs physics

Collider	HL-LHC	ILC_{250}	$CLIC_{380}$	$LEP3_{240}$	$CEPC_{250}$	$FCC\text{-}ee_{240+365}$		
Lumi (ab^{-1})	3	2	1	3	5	5_{240}	$+1.5_{365}$	+ HL-LHC
Years	25	15	8	6	7	3	+4	
$\delta\Gamma_H/\Gamma_H$ (%)	SM	3.6	4.7	3.6	2.8	2.7	**1.3**	1.1
$\delta g_{HZZ}/g_{HZZ}$ (%)	1.3	0.3	0.60	0.32	0.25	0.2	**0.17**	0.16
$\delta g_{HWW}/g_{HWW}$ (%)	1.4	1.7	1.0	1.7	1.4	1.3	**0.43**	0.40
$\delta g_{Hbb}/g_{Hbb}$ (%)	2.9	1.7	2.1	1.8	1.3	1.3	**0.61**	0.55
$\delta g_{Hcc}/g_{Hcc}$ (%)	SM	2.3	4.4	2.3	2.2	1.7	**1.21**	1.18
$\delta g_{Hgg}/g_{Hgg}$ (%)	1.8	2.2	2.6	2.1	1.5	1.6	**1.01**	0.83
$\delta g_{H\tau\tau}/g_{H\tau\tau}$ (%)	1.8	1.9	3.1	1.9	1.5	1.4	**0.74**	0.64
$\delta g_{H\mu\mu}/g_{H\mu\mu}$ (%)	4.4	14.1	n.a.	12	8.7	10.1	**9.0**	3.9
$\delta g_{H\gamma\gamma}/g_{H\gamma\gamma}$ (%)	1.6	6.4	n.a.	6.1	3.7	4.8	**3.9**	1.1
$\delta g_{Htt}/g_{Htt}$ (%)	2.5	–	–	–	–	–	–	2.4
BR_{EXO} (%)	SM	< 1.7	< 2.1	< 1.6	< 1.2	< 1.2	< 1.0	< 1.0

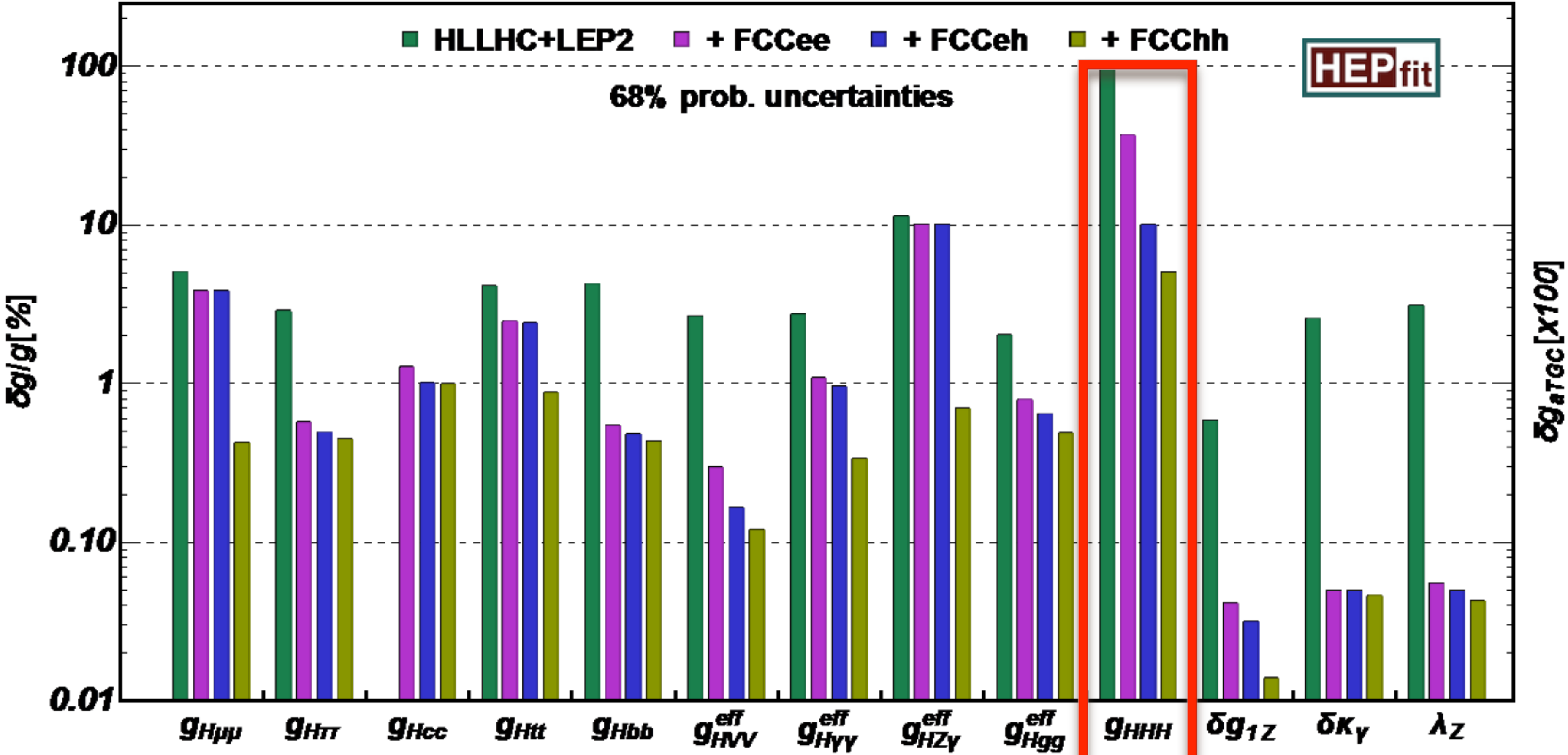
Taken from the FCC CDR, CERN-ACC-2018-0057

Future Circular Collider – FCC-ee timeline



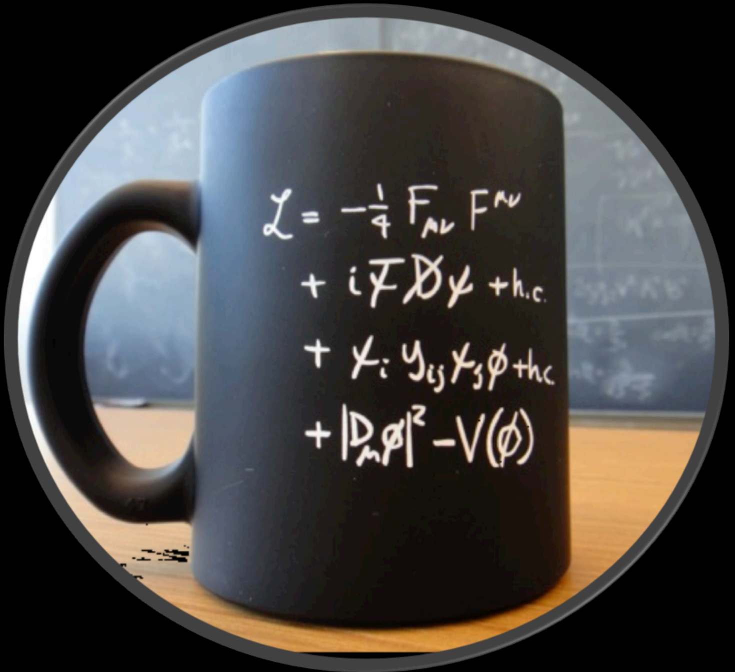
Technical schedule for FCC-ee reaching physics operation from 2039

Future Circular Collider (FCC) – Higgs physics



Taken from the FCC CDR, CERN-ACC-2018-0056

FCC – some physics objectives

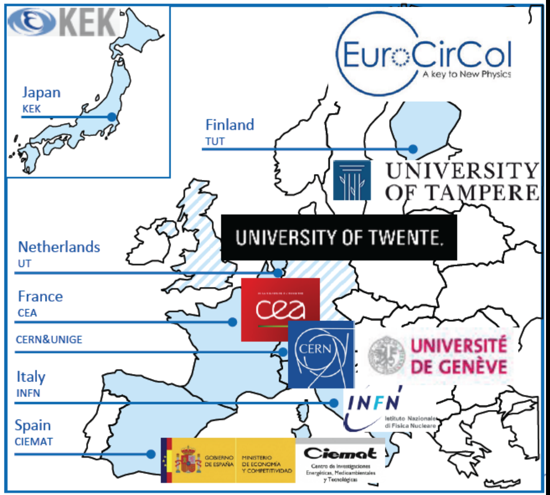


extreme zoom-in capabilities
for about all terms

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

EuroCirCol WP5 (until 2019)

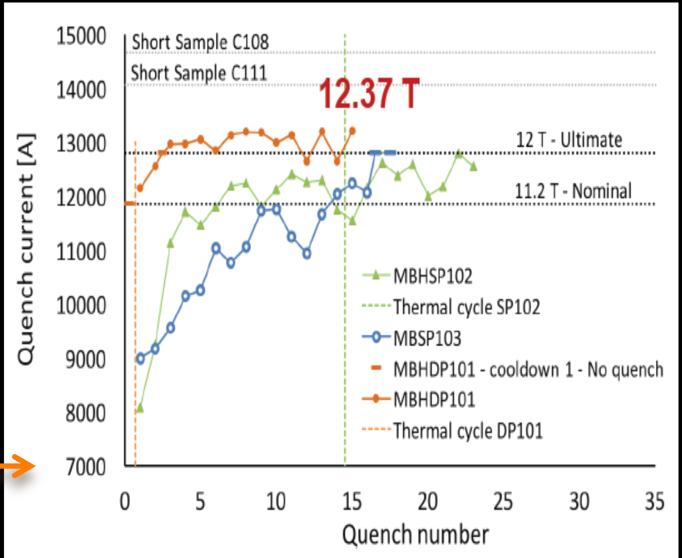
Feed the FCC CDR with a baseline design and a cost model for 16 T magnets

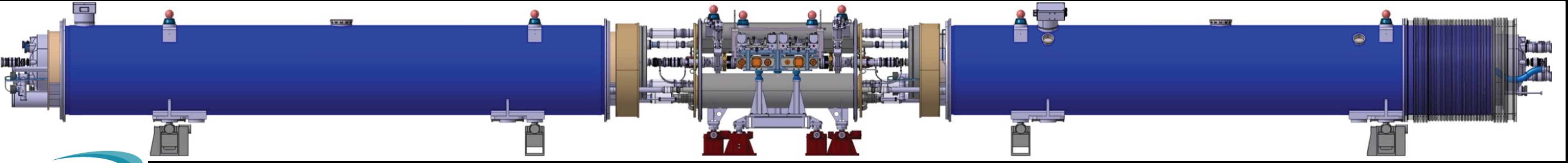


HiLumi LHC

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

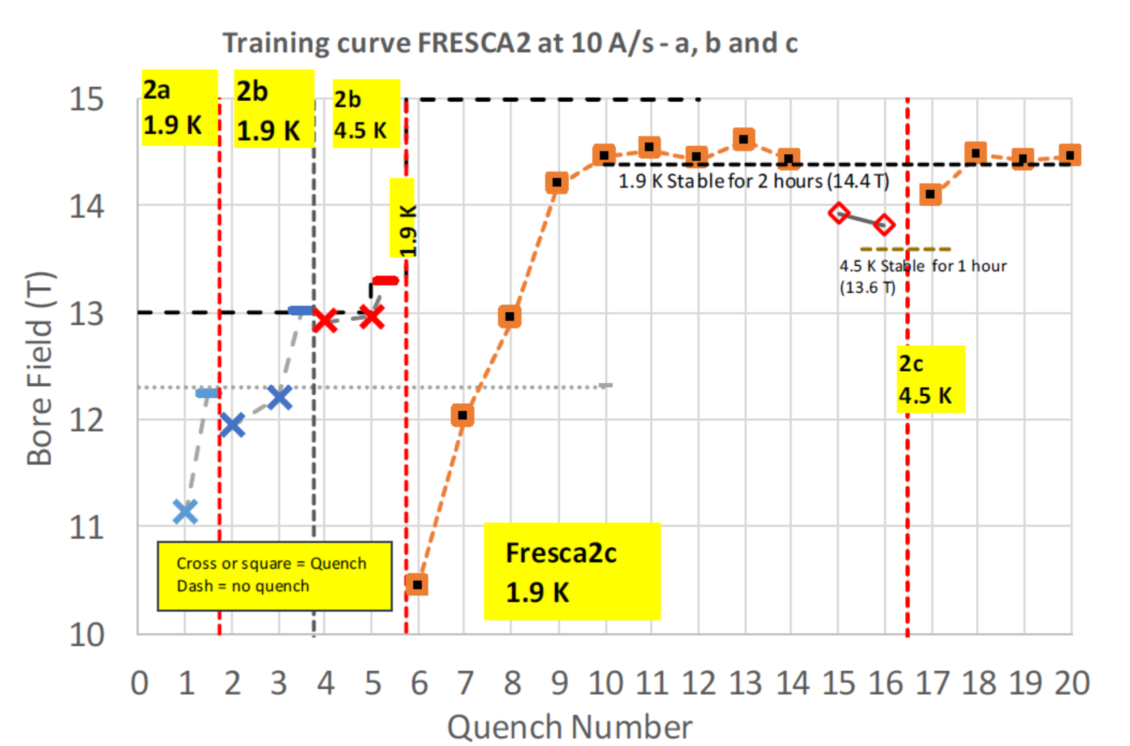
Test new superconductive cables (Nb_3Sn)

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 (April 2018), 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)*

FRESCA2 @ CERN



F. Toral @ Plenary ECFA meeting Nov 2018

SC Magnet R&D – *main challenges to develop a 16 T magnet*

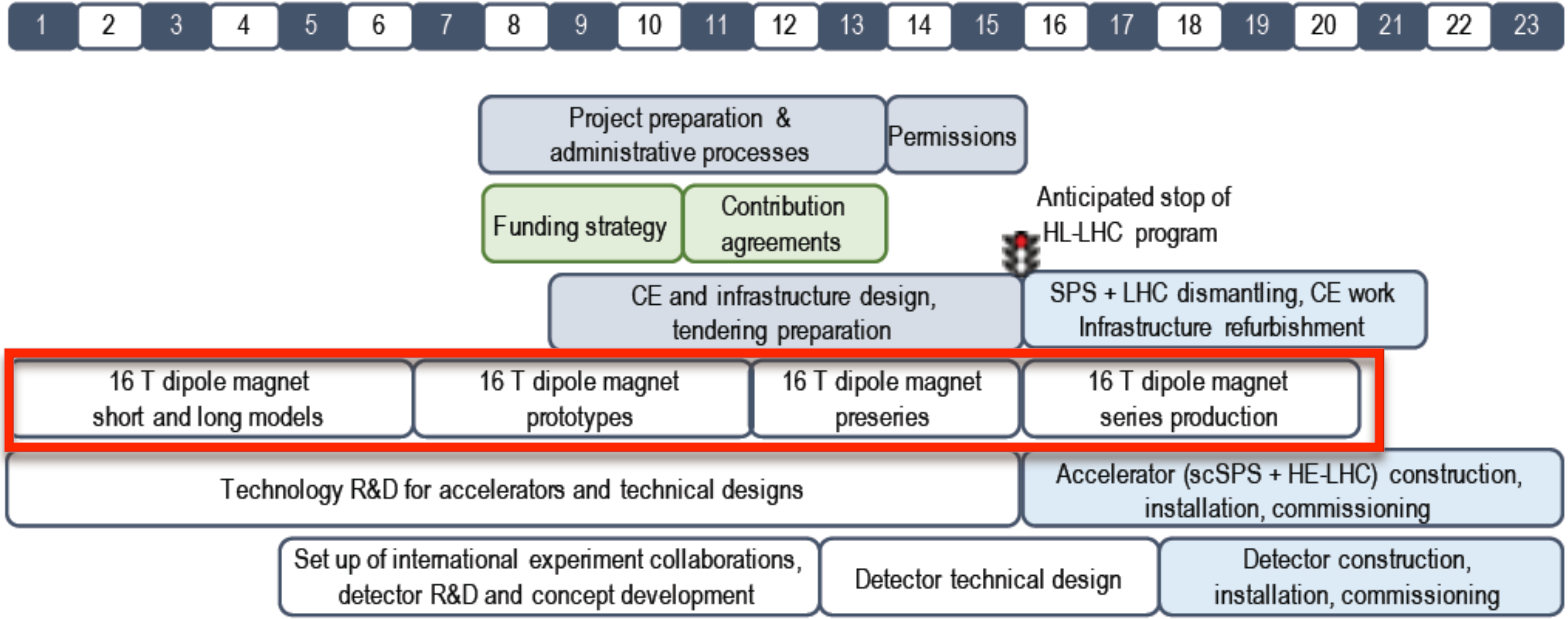
Properties (J_c) and cost (EUR/kAm) of the conductor

Cost-effective design of mechanical support structure

Training curve (# quenches) and magnet protection

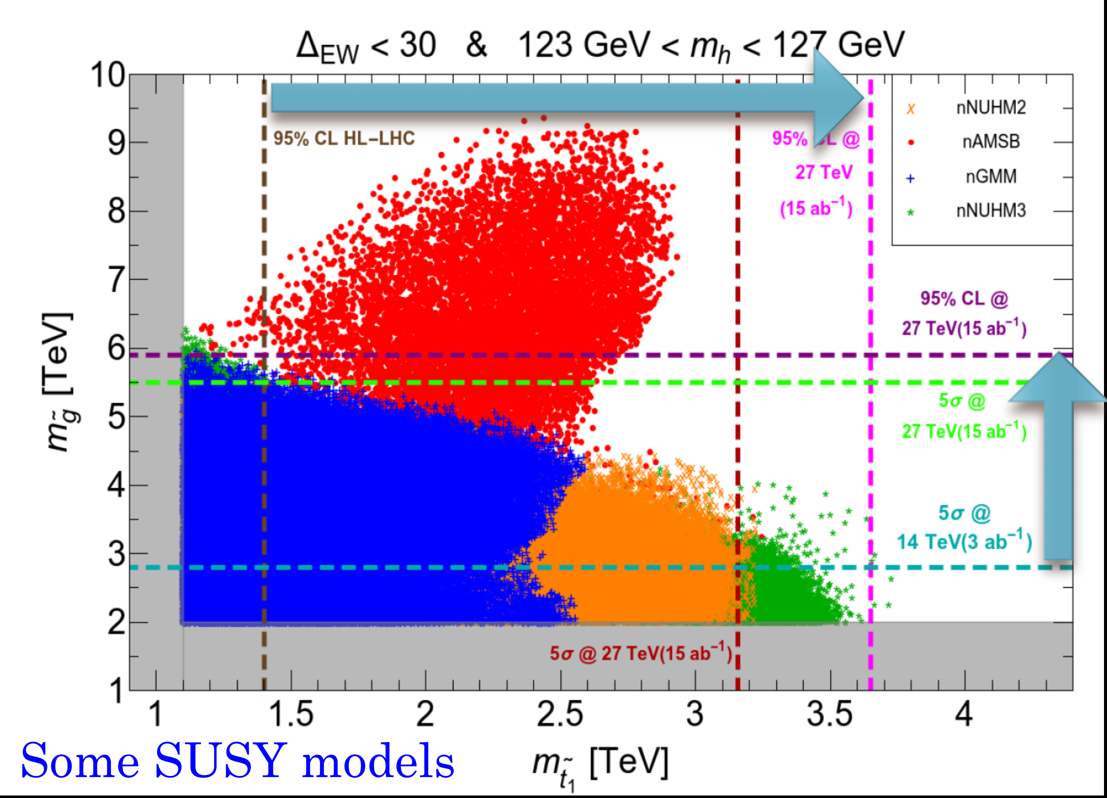
➔ *need to sustain a world-wide R&D effort*

Future Circular Collider (HE-LHC) – *technical schedule*

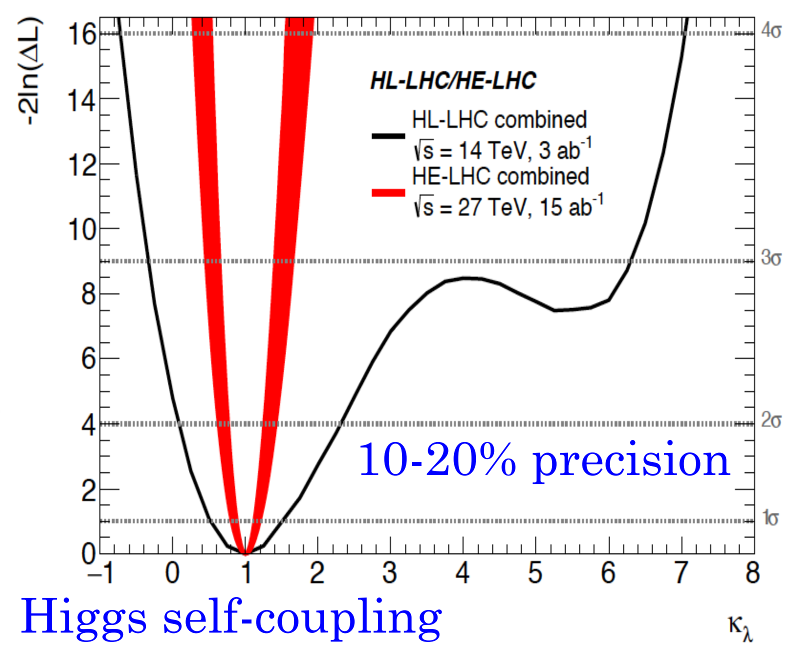


Technical schedule for HE-LHC with FCC-hh like 16 T magnets
Physics operation possible from the mid 2040ies

Future Circular Collider (HE-LHC) – *physics potential*



Some SUSY models

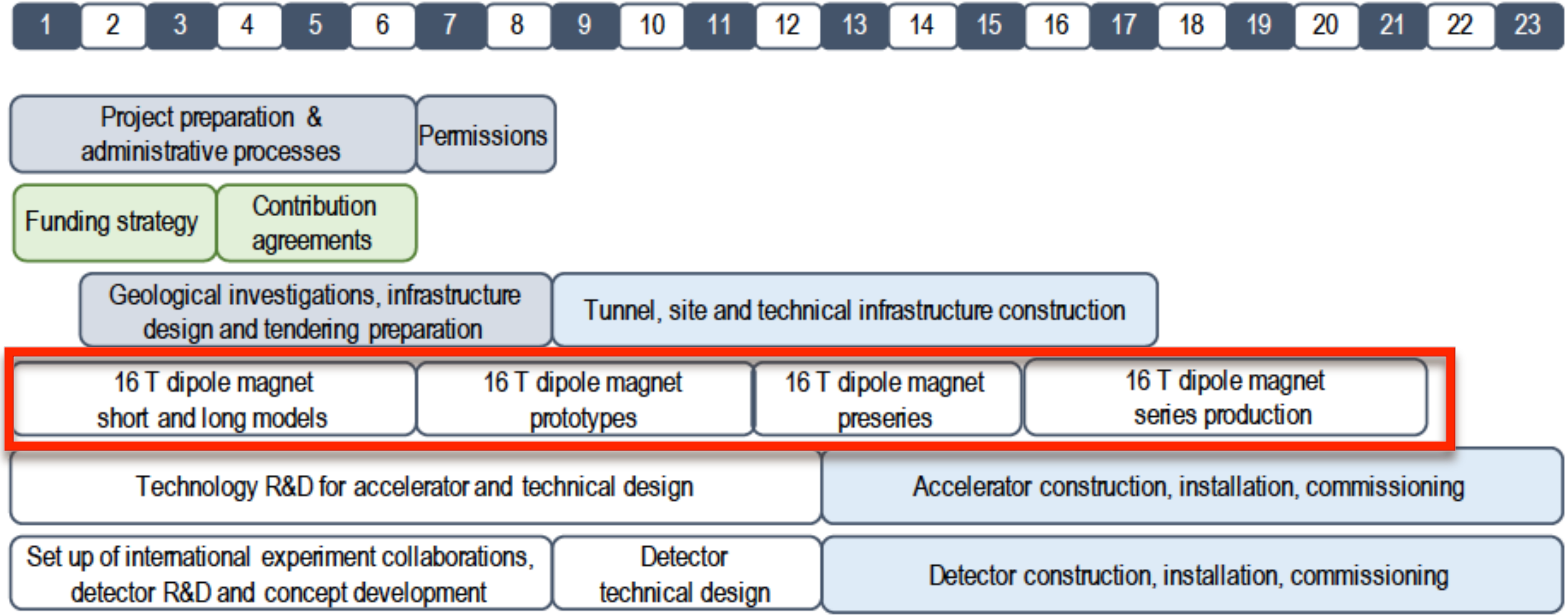


10-20% precision

Higgs self-coupling

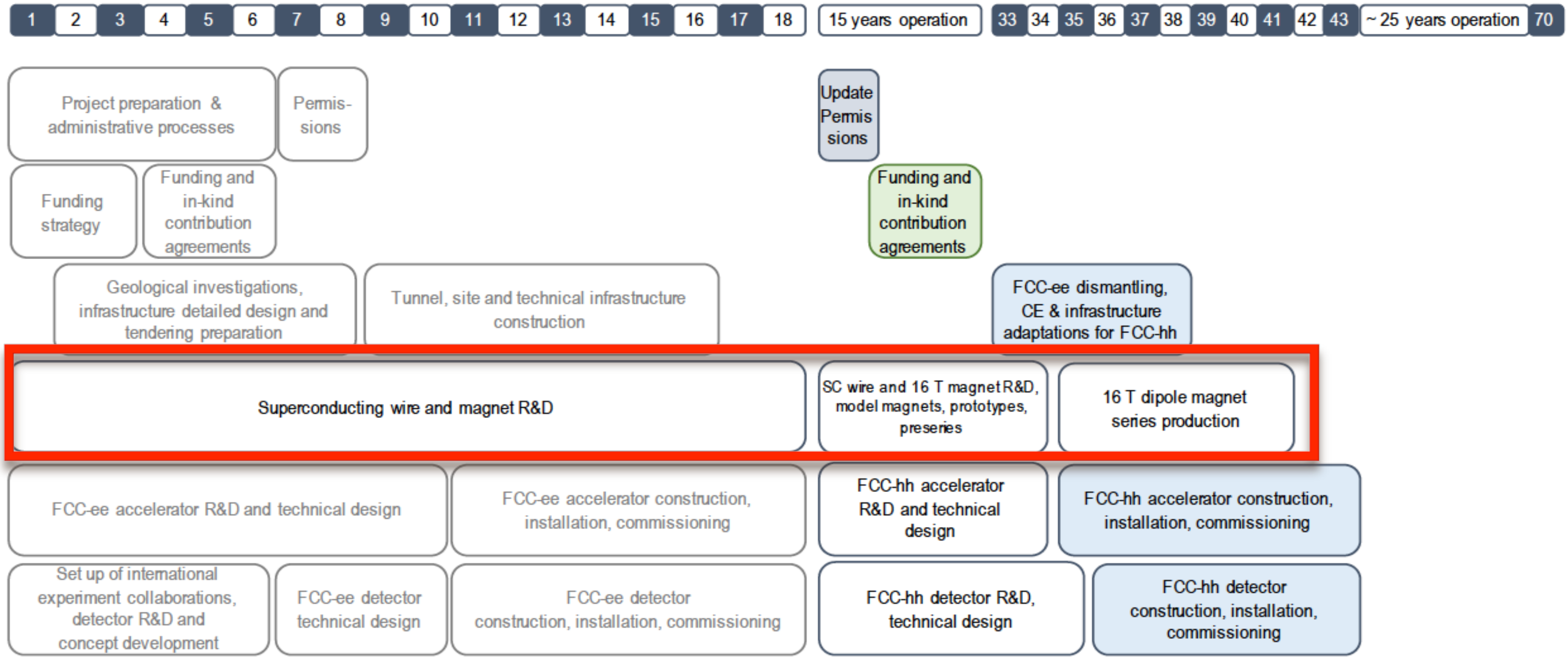
Taken from the FCC (HE-LHC) CDR, CERN-ACC-2018-0059

Future Circular Collider (FCC-hh) – *technical schedule*



Technical schedule for FCC-hh without prior FCC-ee
Physics operation possible from the mid 2040ies

Future Circular Collider (FCC-hh) – *technical schedule*

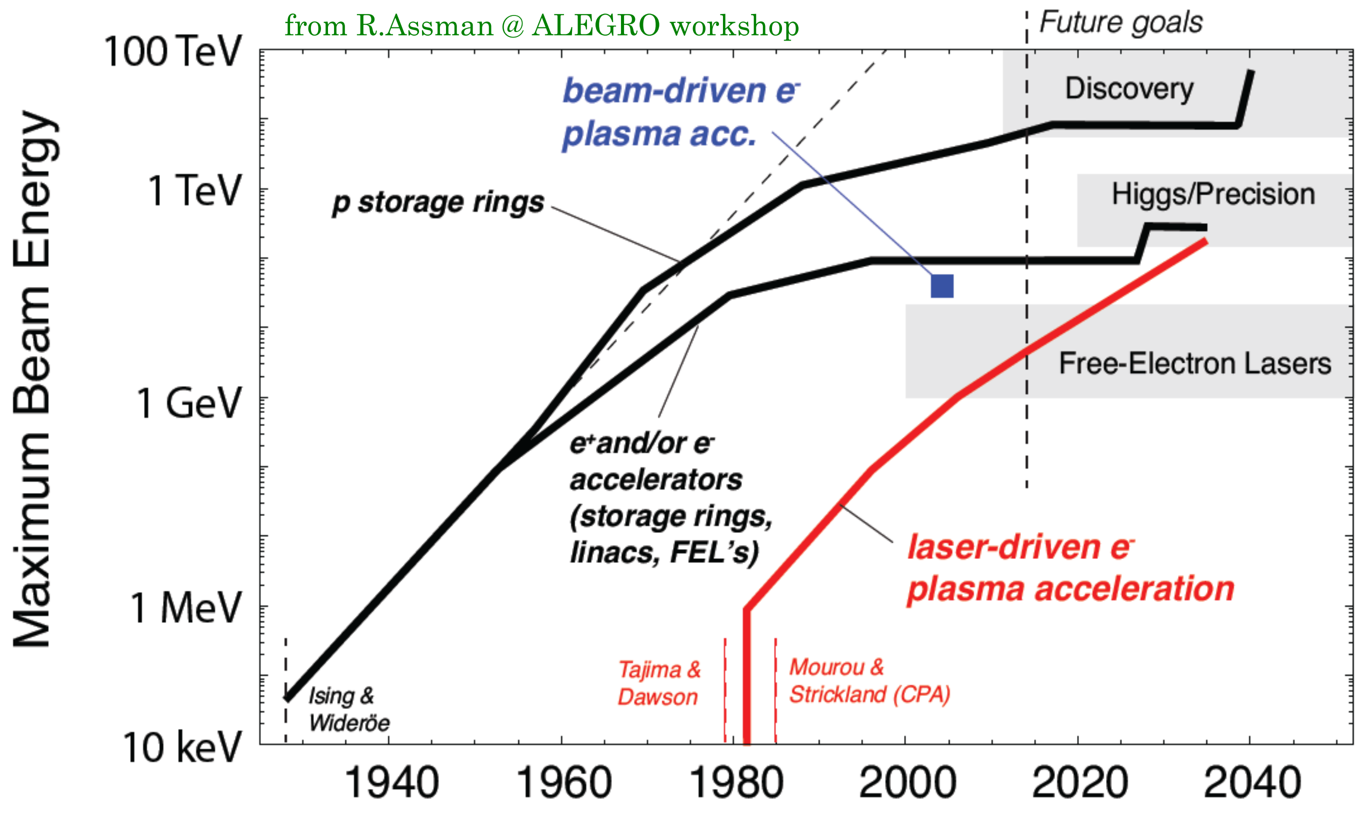


Technical schedule for FCC-hh with prior FCC-ee
Physics operation would start from the mid 2060ies

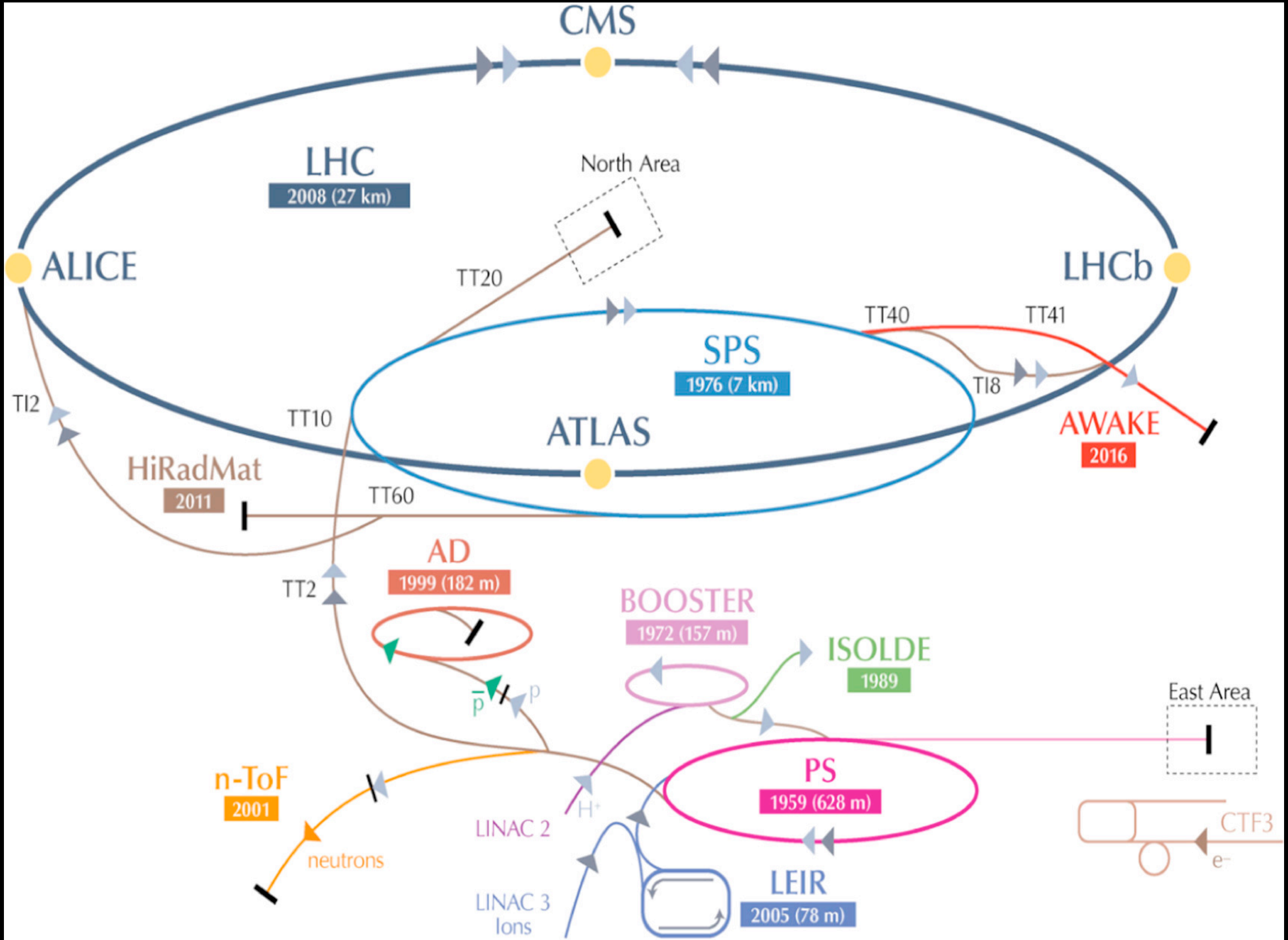
Accelerator R&D – Advanced Novel Accelerators (ICFA Panel)

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)



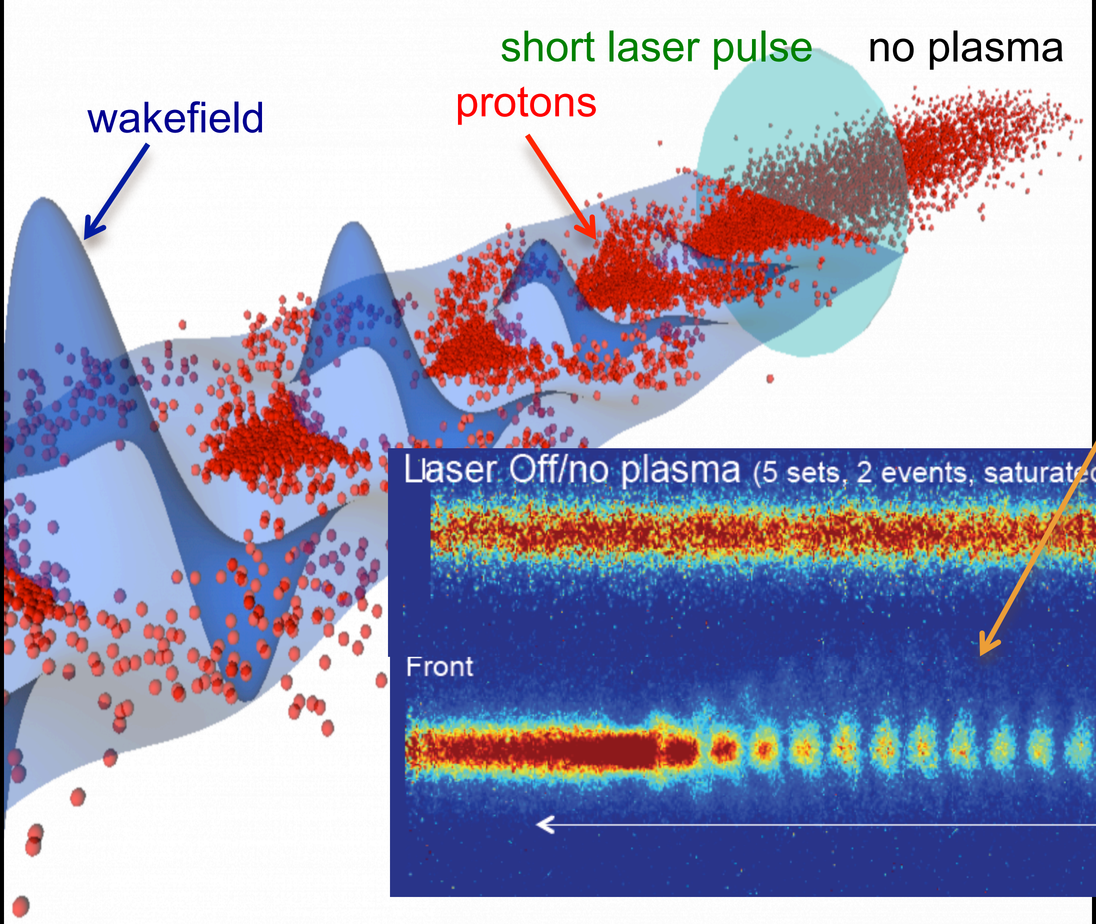
The AWAKE project is a demonstrator experiment for plasma wakefield acceleration.

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

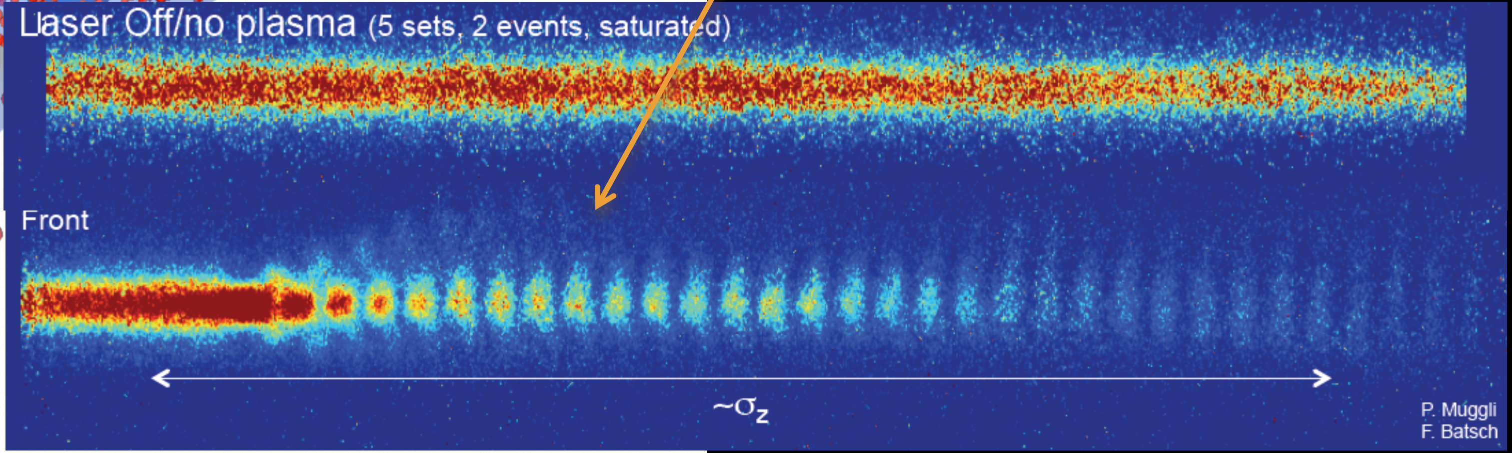
Accelerator R&D – Advanced Proton Driven Plasma Wakefield Acceleration Experiment (AWAKE)

Patric Muggli, SPSC presentation, Oct 2017

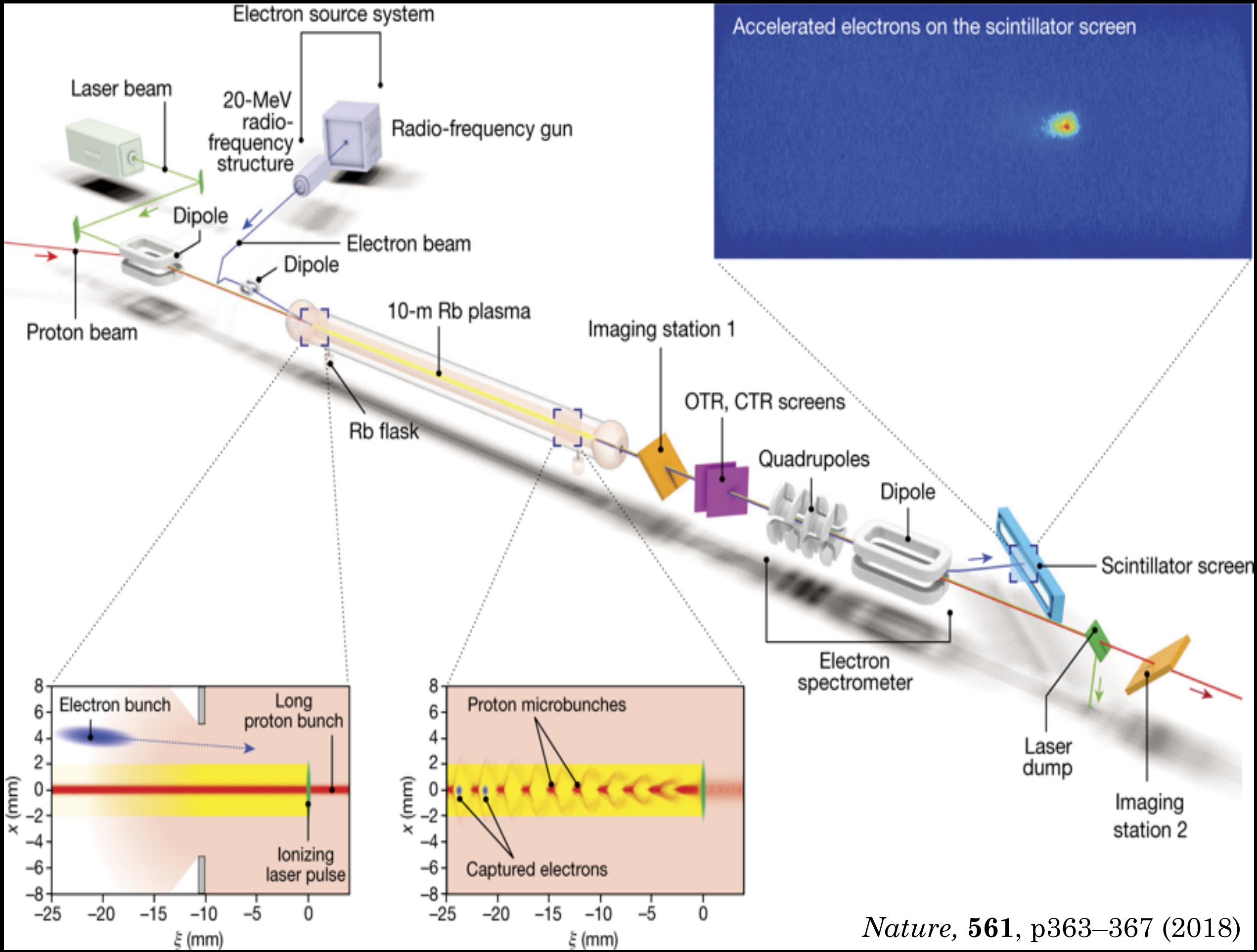


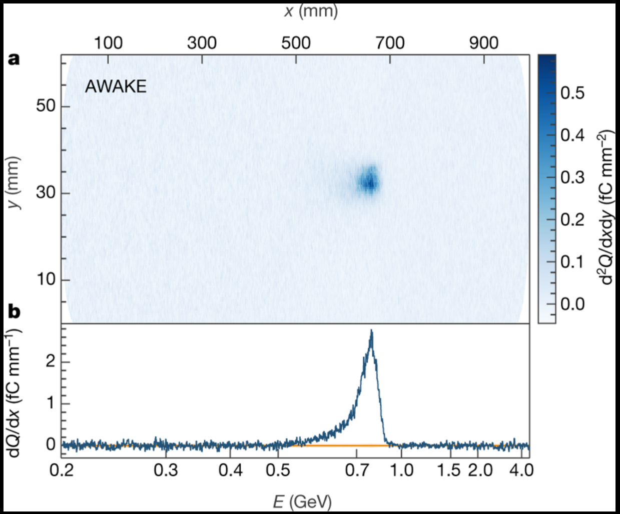
Clear observation of the modulation

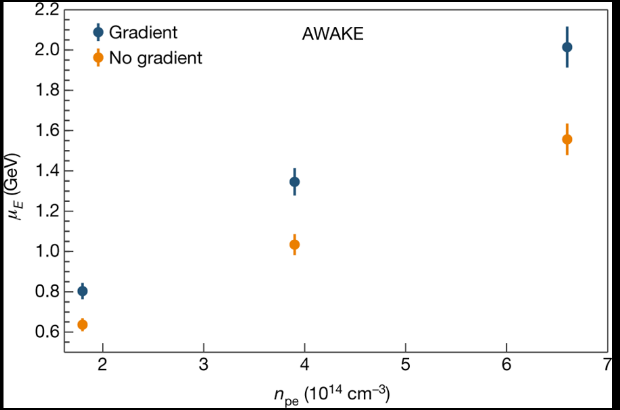
After this observation the objective was to accelerate electrons



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



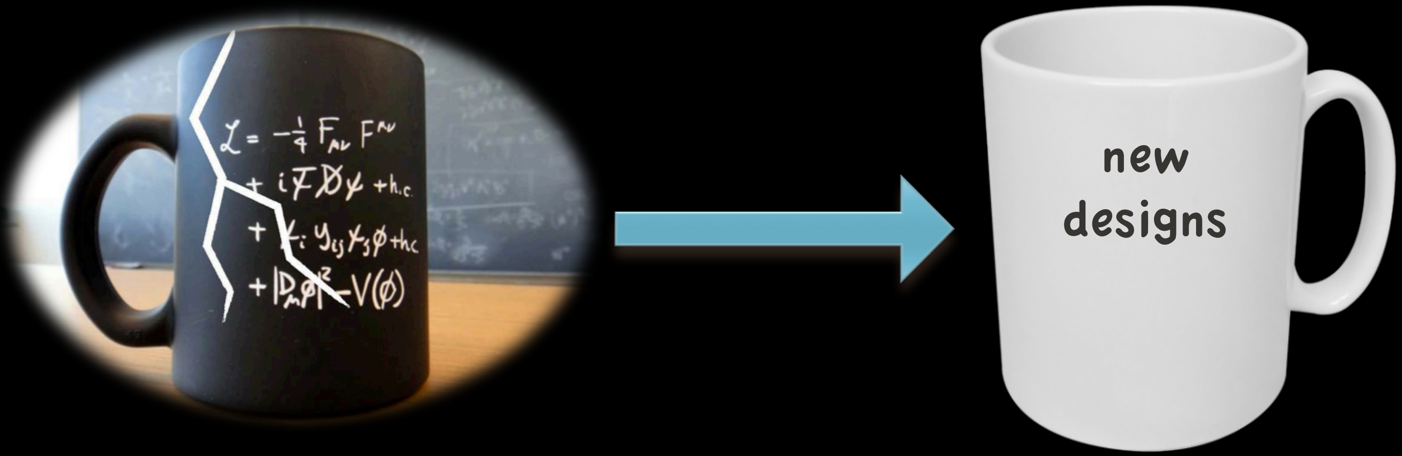




Nature, **561**, p363–367 (2018)

The 2013 European Particle Physics Strategy

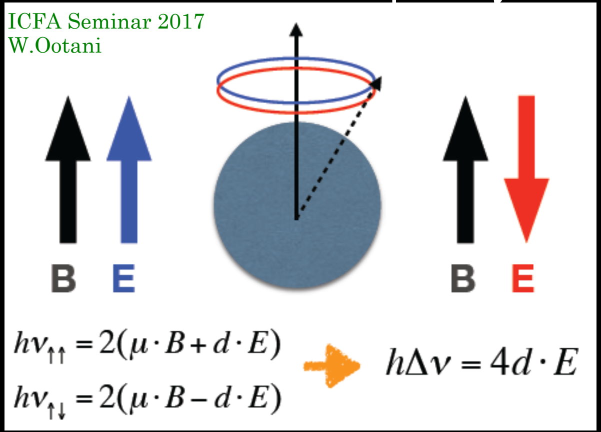
"Experiments studying quark flavour physics, dipole moments, charged-lepton violation and performing other precision measurements ... with neutrons, muons and antiprotons may give access to higher energy scales than direct particle production ... They can be based in national laboratories, with a moderate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



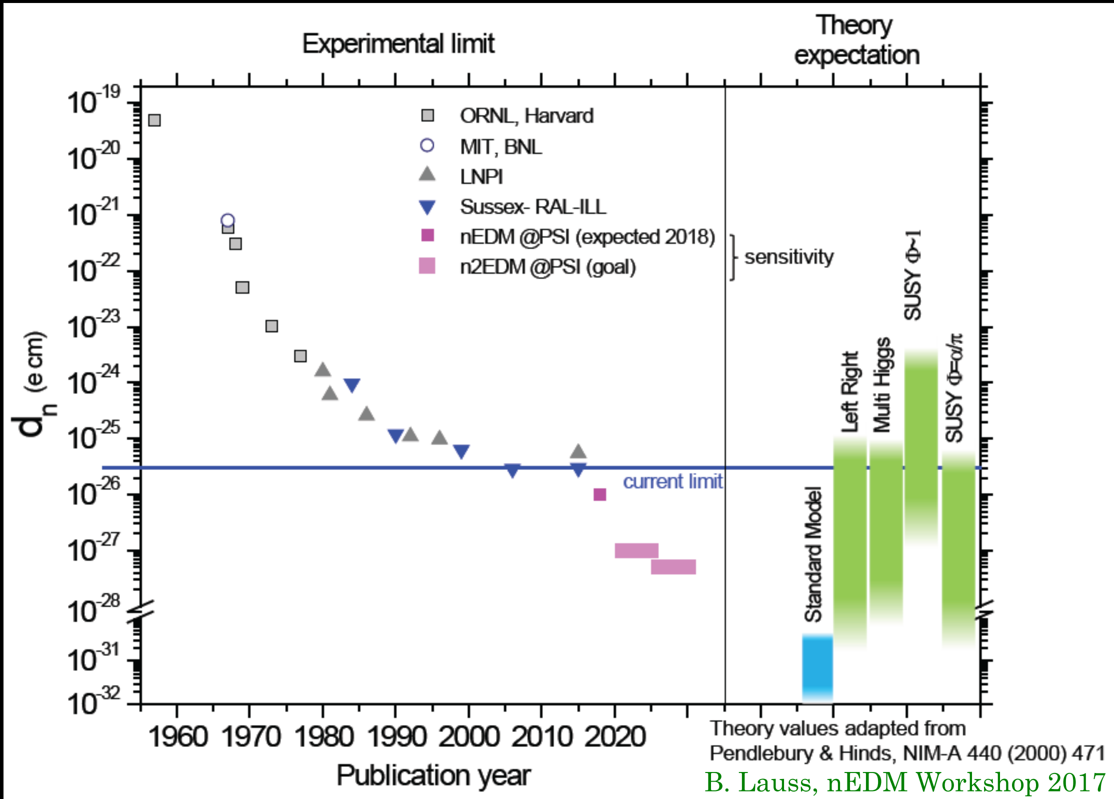
Electric Dipole Moment (EDM)

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 x 10^{-29} e-cm at 90% CL), if non-zero it violates symmetries like P, T, CP.

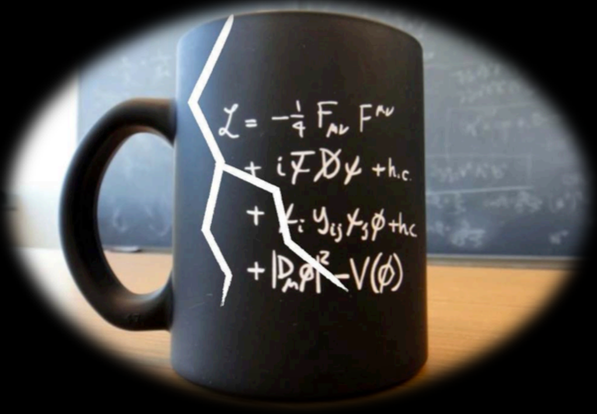
Measure Larmor frequency shift

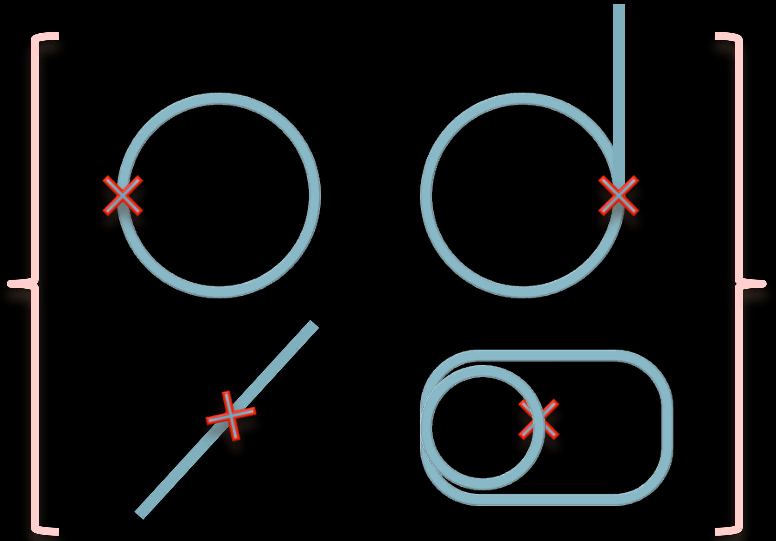


Variety of systems used from neutrons and electrons to atoms and molecules.



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

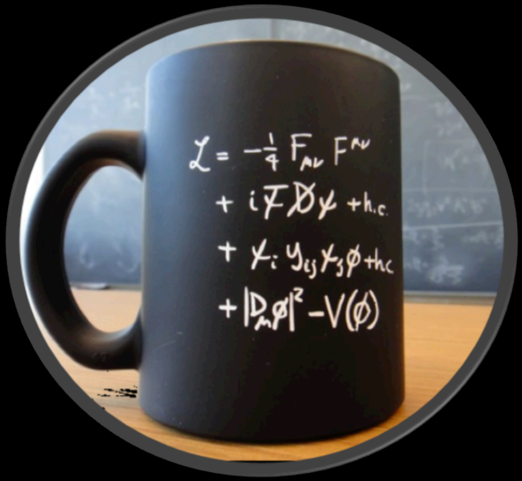




In general: explore the synergies of the physics potential of non-collider and collider experiments

There is new physics out there!

and it should be our main objective to discover it



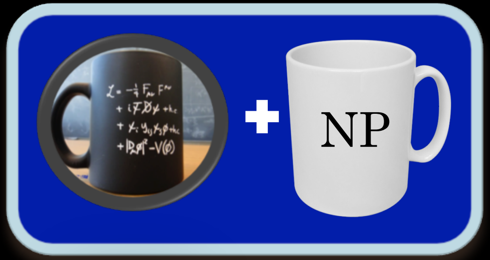
The exploration of the scalar sector
is only one avenue to search for it

There is new physics out there!

and it should be our main objective to discover it

data

model



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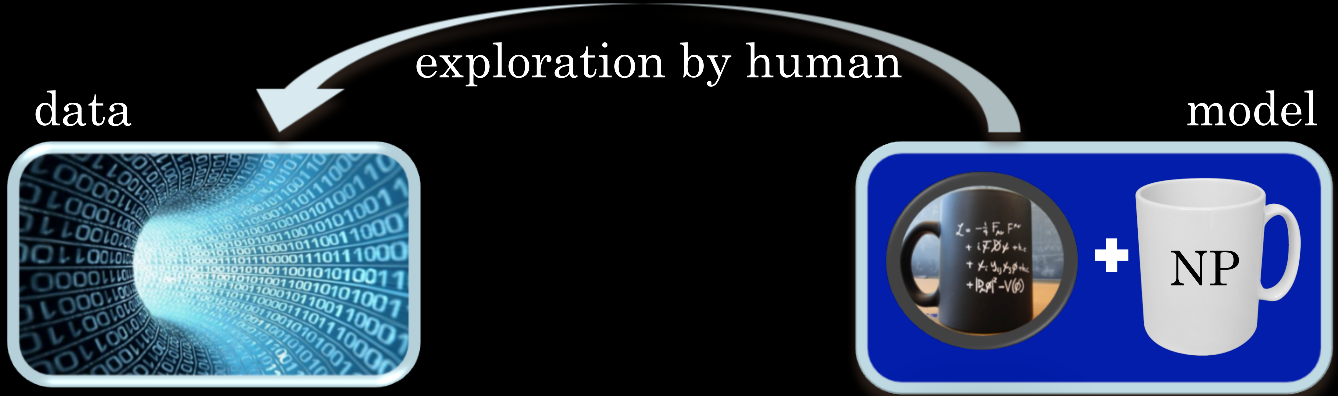

There is new physics out there!

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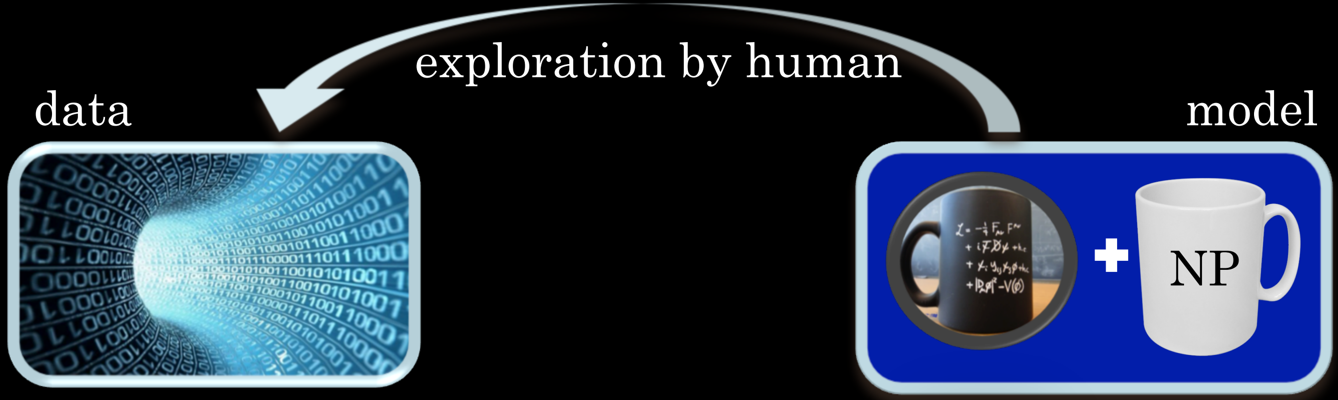
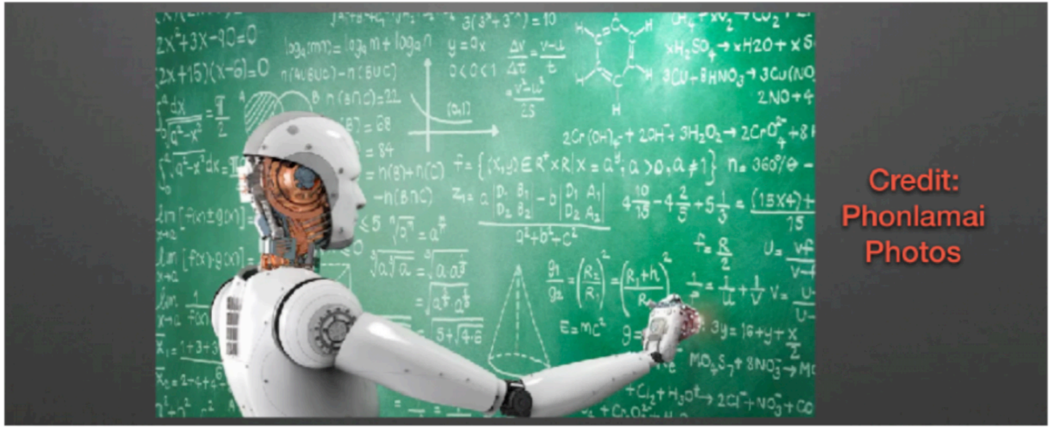


Data will have to guide us to the new physics

There is new physics out there!

and it should be our main objective to discover it

Magic of machine learning



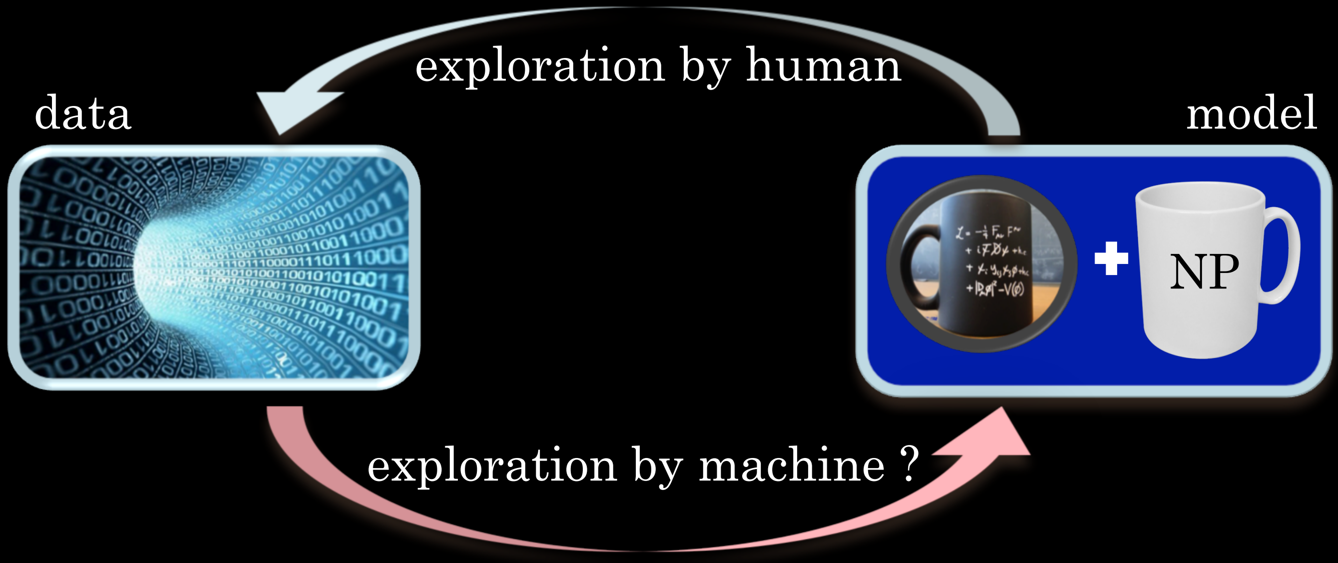
S. Chang, M. Spannowsky, M. Nojiri, Y. Li ...

- Won't get into it here. (Not an expert)
- Perhaps a machine can summarize this better?

Slide from LianTao Wang @ IAS-HEP2019

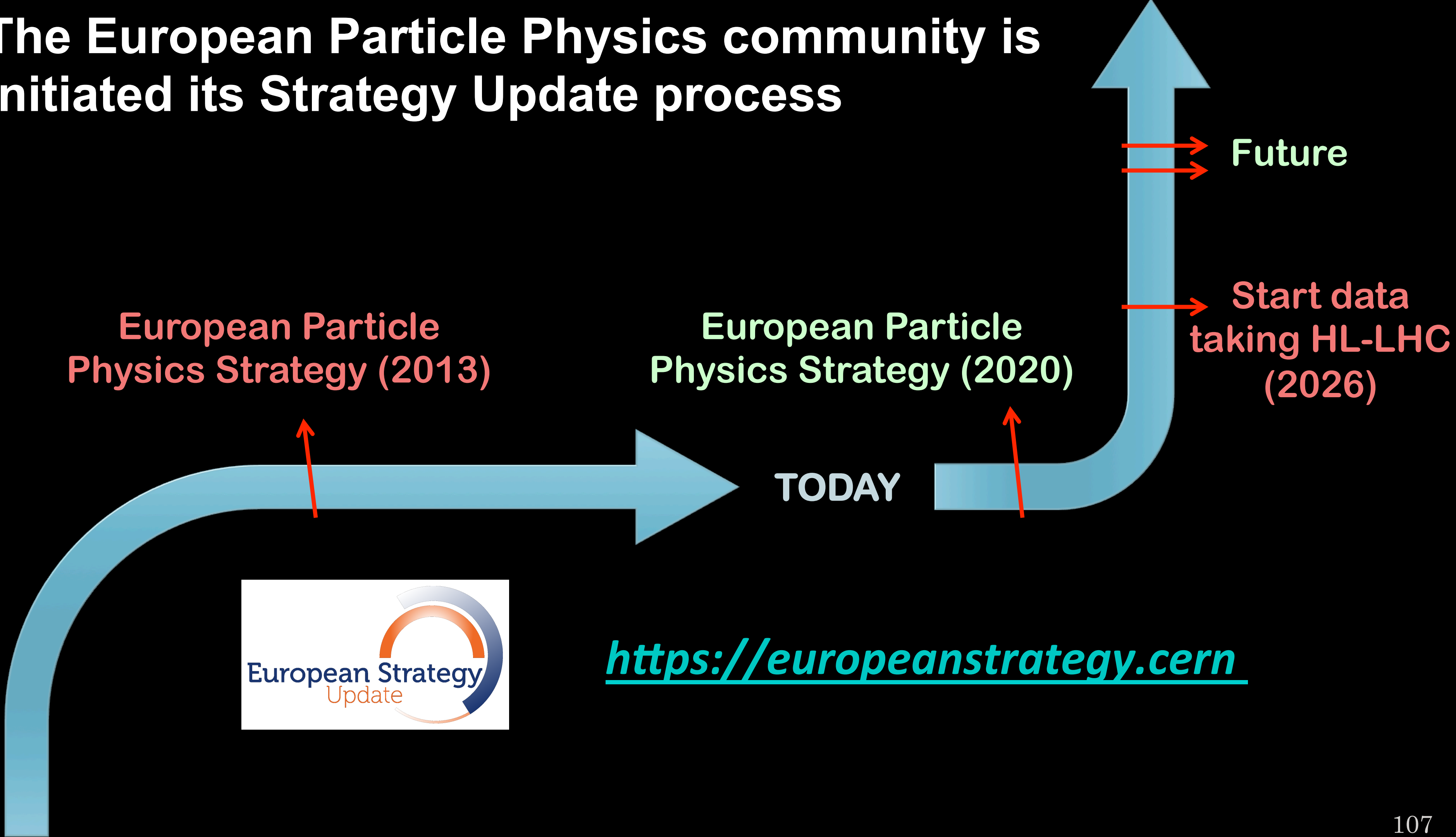
There is new physics out there!

and it should be our main objective to discover it

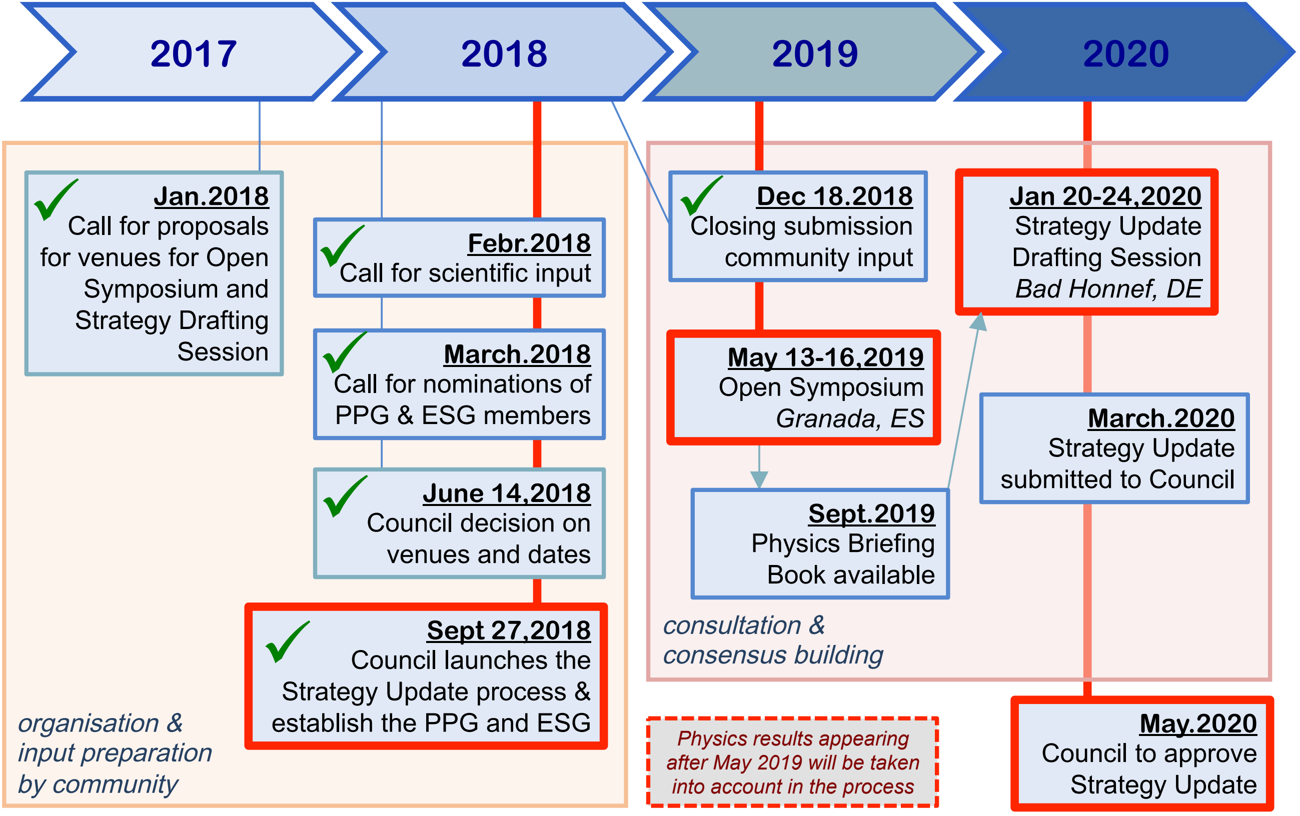


Shifting the paradigm to reach an understanding of the physics of the smallest and largest structures

The European Particle Physics community is initiated its Strategy Update process

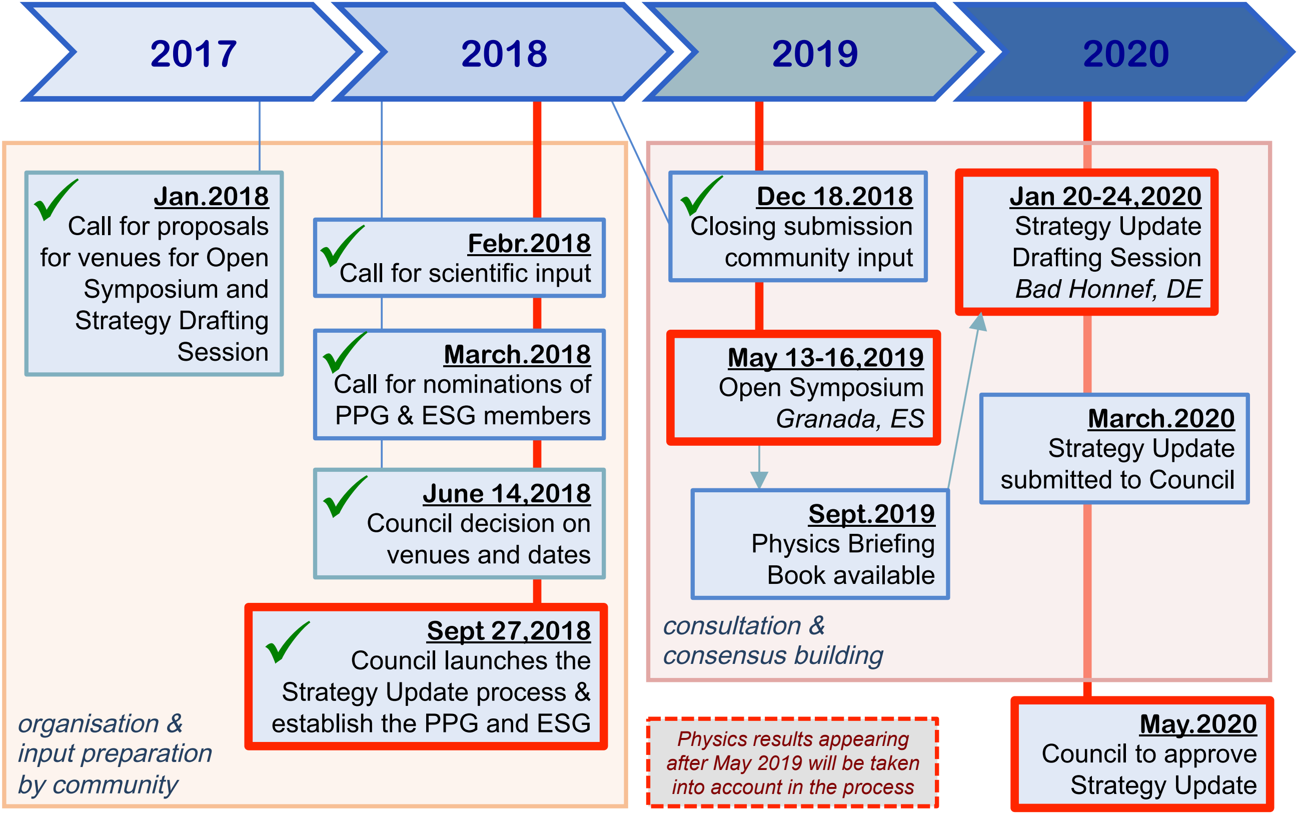


https://europeanstrategy.cern



2017
2018
2019
2020
Jan.2018
Call for proposals for venues for Open Symposium and Strategy Drafting Session
Febr.2018
Call for scientific input
March.2018
Call for nominations of PPG & ESG members
June 14,2018
Council decision on venues and dates
Sept 27,2018
Council launches the Strategy Update process & establish the PPG and ESG
organisation & input preparation by community
Dec 18.2018
Closing submission community input
May 13-16,2019
Open Symposium
Granada, ES
Sept.2019
Physics Briefing Book available
consultation & consensus building
Physics results appearing after May 2019 will be taken into account in the process
Jan 20-24,2020
Strategy Update Drafting Session
Bad Honnef, DE
March.2020
Strategy Update submitted to Council
May.2020
Council to approve Strategy Update

Thank you for your attention



Strategy Secretariat

- 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.

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.