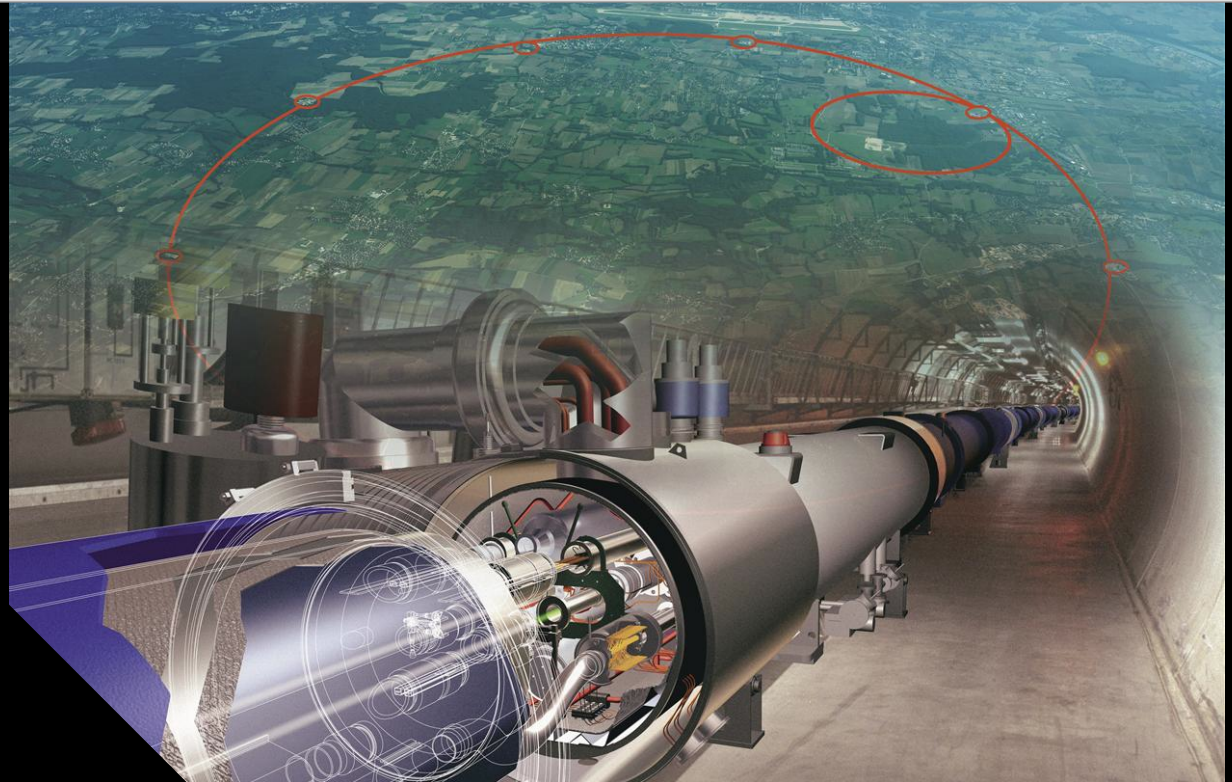


Towards an update of the European Strategy for Particle Physics

*Jorgen D'Hondt
Vrije Universiteit Brussel
ECFA chair*

*Early-Career Researchers
CERN Main Auditorium
15 Nov*



fwo

HEP@VUB
BRUSSELS

VUB *iihe*
BRUXELLES BRUSSEL



✓ 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

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

Physics results appearing after May 2019 will be taken into account in the process



Open Symposium

Towards updating the European Strategy for Particle Physics

May 13-16, 2019, Granada, Spain

<https://cafpe.ugr.es/epps2019/>

~600 participants

Information captured in 8 thematic summary talks

Joint session ECFA and EPS-HEPP

“Towards an update of the European Particle Physics Strategy”

Agenda, 13 July 2019 – <https://indico.cern.ch/event/845382/>

- 1) Overview of the ESPP Open Symposium – *Halina Abramowicz*
 - 2) Technology path towards future colliders – *Caterina Biscari*
 - 3) Community challenges and opportunities for detector R&D – *Ariella Cattai*
 - 4) Higgs at Future Colliders – *Christophe Grojean*
(new version H@FC WG report at <https://arxiv.org/abs/1905.03764>)
- 1) Physics Beyond Colliders – *Claude Vallee*
 - 2) Synergies between astroparticle, particle and nuclear physics – *Caterina Doglioni*
 - 3) Computing and Software challenges – *Graeme Stewart*

Physics Briefing Book

Physics Preparatory Group

- Overviewing the submitted input and the discussions in Granada
- Excluding references etc. about 200 pages
- The work of many!
- <http://cds.cern.ch/record/2691414>

Physics Briefing Book



Input for the European Strategy for Particle Physics Update 2020

Electroweak Physics: Richard Keith Ellis¹, Beate Heinemann^{2,3} (*Conveners*)
Jorge de Blas^{4,5}, Maria Cepeda⁶, Christophe Grojean^{7,9}, Fabio Maltoni^{8,9}, Alejandro Nisati¹⁰,
Elisabeth Petit¹¹, Riccardo Rattazzi¹², Wouter Verkerke¹³ (*Contributors*)

Strong Interactions: Jorgen D'Hondt¹⁴, Krzysztof Redlich¹⁵ (*Conveners*)
Anton Andronic¹⁶, Ferenc Siklér¹⁷ (*Scientific Secretaries*)
Nestor Armesto¹⁸, Daniel Boer¹⁹, David d'Enterria²⁰, Tetyana Galatyuk²¹, Thomas Gehrmann²²,
Klaus Kirch²³, Uta Klein²⁴, Jean-Philippe Lansberg²⁵, Gavin P. Salam²⁶, Gunar Schnell²⁷,
Johanna Stachel²⁸, Tanguy Pierog²⁹, Hartmut Wittig³⁰, Urs Wiedemann²⁰ (*Contributors*)

Flavour Physics: Belen Gavela³¹, Antonio Zoccoli³² (*Conveners*)
Sandra Malvezzi³³, Ana Teixeira³⁴, Jure Zupan³⁵ (*Scientific Secretaries*)
Daniel Aloni³⁶, Augusto Ceccucci³⁰, Avital Dery³⁶, Michael Dine³⁷, Svetlana Fajfer³⁸, Stefania Gori³⁷,
Gudrun Hiller³⁹, Gino Isidori²², Yoshikata Kuno⁴⁰, Alberto Lusiani⁴¹, Yosef Nir³⁶,
Marie-Helene Schune⁴², Marco Sozzi⁴³, Stephan Paul⁴⁴, Carlos Pena³¹ (*Contributors*)

Neutrino Physics & Cosmic Messengers: Stan Bentvelsen⁴⁵, Marco Zito^{46,47} (*Conveners*)
Albert De Roeck²⁰, Thomas Schwetz²⁰ (*Scientific Secretaries*)
Bonnie Fleming⁴⁸, Francis Halzen⁴⁹, Andreas Haungs²⁰, Marek Kowalski², Susanne Mertens⁴⁴,
Mauro Mezzetto⁵, Silvia Pascoli⁵⁰, Bangalore Sathyaprakash⁵¹, Nicola Serra⁷² (*Contributors*)

Beyond the Standard Model: Gian F. Giudice²⁰, Paris Sphicas^{20,52} (*Conveners*)
Juan Alcaraz Maestre⁶, Caterina Dogliani⁵³, Gaia Lanfranchi^{20,54}, Monica D'Onofrio²⁴,
Matthew McCullough²⁰, Gilad Perez³⁶, Philipp Roloff²⁰, Veronica Sanz⁵⁵, Andreas Weiler²⁴,
Andrea Wulzer^{4,12,20} (*Contributors*)

Dark Matter and Dark Sector: Shoji Asai⁵⁶, Marcela Carena⁵⁷ (*Conveners*)
Babette Döbrich²⁰, Caterina Dogliani⁵³, Joerg Jaeckel²⁸, Gordan Krnjaic⁵⁷, Jocelyn Monroe⁵⁸,
Konstantinos Petridis⁵⁹, Christoph Weniger⁶⁰ (*Scientific Secretaries*)

Accelerator Science and Technology: Caterina Biscari⁶¹, Leonid Rivkin⁶² (*Conveners*)
Philip Burrows²⁰, Frank Zimmermann²⁰ (*Scientific Secretaries*)
Michael Benedikt²⁰, Edda Geschwendtner²⁰, Erk Jensen²⁰, Mike Lamont²⁰, Wim Leemans²,
Lucio Rossi²⁰, Daniel Schulte²⁰, Mike Seidel⁶², Vladimir Shiltsev⁶³, Steinar Stapnes²⁰,
Akira Yamamoto^{20,64} (*Contributors*)

Instrumentation and Computing: Xinchou Lou⁶⁵, Brigitte Vachon⁶⁶ (*Conveners*)
Roger Jones⁶⁷, Emilia Leogrande²⁰ (*Scientific Secretaries*)
Ian Bird²⁰, Amber Boehnlein⁶⁸, Simone Campana²⁰, Ariella Cattai²⁰, Didier Contardo⁶⁹,
Cinzia Da Via⁷⁰, Francesco Forti⁷¹, Maria Gironi²⁰, Matthias Kasemann², Weidon Li⁶⁵,
Lucie Linssen²⁰, Felix Sefkow², Graeme Stewart²⁰ (*Contributors*)

Editors: Halina Abramowicz⁷², Roger Forty²⁰, and the Conveners

Open Plenary ECFA session

“Advanced Accelerator Technologies”

at CERN, Council Chamber, 14 November 2019

<https://indico.cern.ch/event/847002/overview>

- 1) Towards colliders using plasma wakefields (2 hours)
- 2) Towards a muon collider (2 hours)
- 3) Towards using accelerator HTS magnets in HEP colliders (2 hours)

*Webcasted and webrecorded, and will appear in the ECFA Newsletter #4
(more on ECFA Newsletters at <https://ecfa.web.cern.ch/content/ecfa-newsletters>)*



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

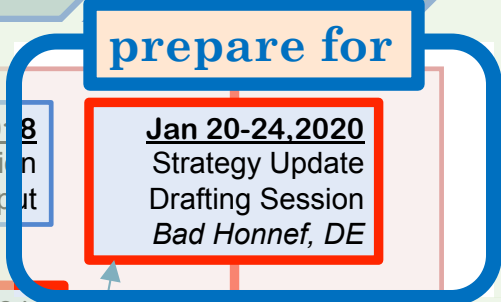
consultation & consensus building

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

Physics results appearing after May 2019 will be taken into account in the process



Accelerator technology at Granada

Not written in stone, but on the collider front we might identify three eras

- the *immediate future* (2020-2040)
e.g. the HL-LHC era
- the *mid-term future* (2040-2060)
e.g. the Z/W/H/top-factory era
- the *long-term future* (2060-2080)
e.g. the energy frontier era

2020-2040
HL-LHC era

2040-2060
Z/W/H/top-factory era

2060-2080
energy frontier era

our
technology

SCRF ~ 30 MV/m
B ~ 11 T

SCRF ~ 50 MV/m
B ~ 14 T
plasma demo
muon demo

SCRF ~ 70 MV/m
B > 16 T (HTS?)
plasma collider
muon collider

other
technology

AI for new physics
quasi-online analysis
digital imaging
new transistors

quantum computing
self-learning
simulation

...

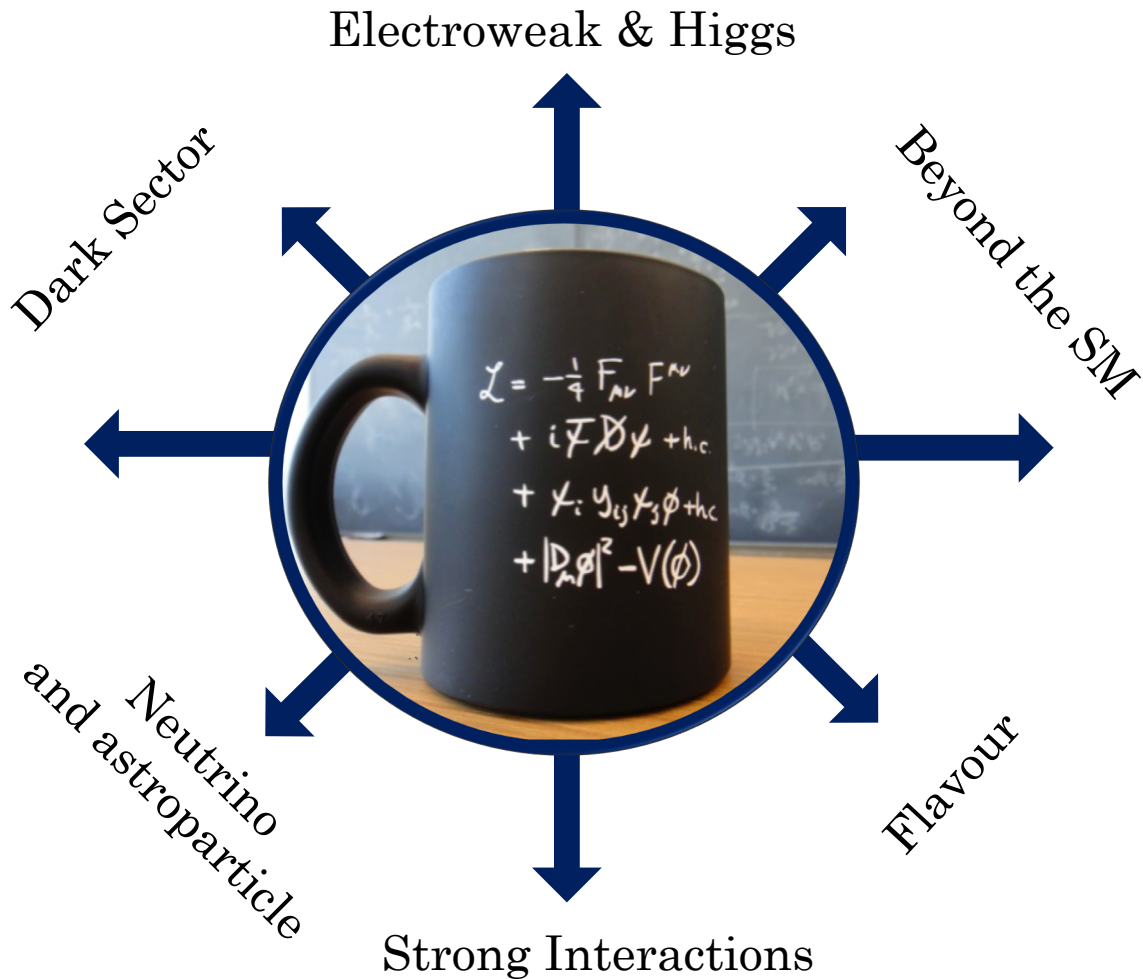
societal
threats

eco friendly gases
careers at mega-
research facilities

energy consumption
long-term engagement
global vs sustained
collaboration

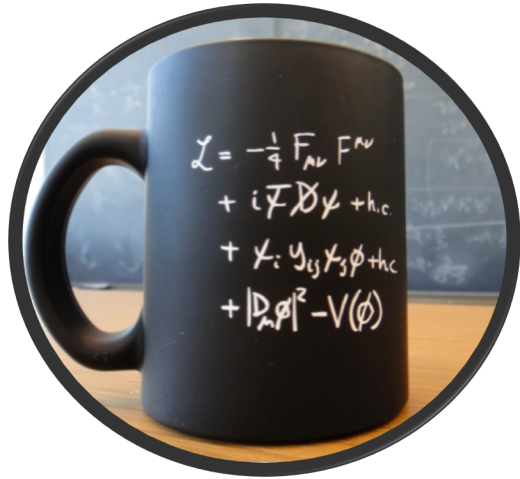
human vs machine

The Granada
physics themes



There is “new physics” out there!

and it should be our main objective to discover it
in an effort to understand fundamental interactions



**The exploration of the scalar sector with colliders
is only one avenue to search for new physics**

Not written in stone, but several avenues towards the discovery of new physics

- *indirect exploration at the precision frontier*
- *breaking the Standard Model*
- *direct searches of hidden & visible sectors*
- ...

Not written in stone, but several avenues towards the discovery of new physics

- *indirect exploration at the precision frontier*
- *breaking the Standard Model*
- *direct searches of hidden & visible sectors*
- ...

Some examples on the next slide

	2020-2040 <i>HL-LHC era</i>	2040-2060 <i>Z/W/H/top-factory era</i>	2060-2080 <i>energy frontier era</i>
precision frontier	H couplings to few % ν mass/mixing/nature QGP phase-transition b/c-physics	H couplings to % EW & QCD & top QGP vs Lattice QCD b/c/ τ -physics	H couplings to ‰ H self-coupling to ‰ proton structure di-boson processes
breaking the SM	next-gen K-beams proton precision e & n EDM lepton flavor ($\mu \rightarrow e$)	p EDM storage rings	rare top decays small-x physics
direct searches	Beam Dump Facility eSPS (light DM) Long-Lived Signals / ALPs DM vs neutrino floor	heavy neutral lepton	new high-mass part. next-gen hidden exp. low-mass DM

One can debate, but with a granularity of 20 years and in the absence of clear indications for new physics, the following general principle is probably wise:

in each era you would want to take important steps forward for the largest variety of directions where new physics can be found

One can debate, but with a granularity of 20 years and in the absence of clear indications for new physics, the following general principle is probably wise:

in each era you would want to take important steps forward for the largest variety of directions where new physics can be found

With the input from the Physics Briefing Book, and with a view of updating the current strategy, the next step is to define some overall long-term scenarios and discuss their coverage, feasibility and community support

Scenarios with a view to update the Strategy

Scenarios with a view to **update** the Strategy



start from the current Strategy

The European Particle Physics Strategy 2013

<https://cds.cern.ch/record/1567258/files/esc-e-106.pdf> - 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

<https://cds.cern.ch/record/1567258/files/esc-e-106.pdf> - 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 accelerators in a global context, with emphasis on proton-proton and electron-positron colliders. These design studies should be coupled to a vision for future accelerators, including high-field magnets and high-gradient accelerators. 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.

FRONT PAGE

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

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. Topics include neutrino physics, dipole moments, charged-lepton flavour violation, etc.
- ③ Detector R&D programmes should be strongly supported 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.

SECOND PAGE

1st priority

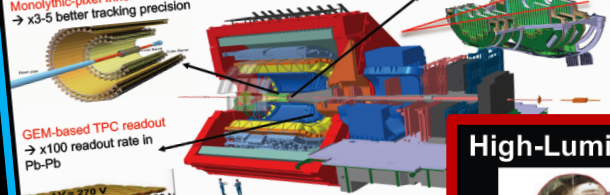
LHC and HL-LHC

FRONT PAGE

Upgrades

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

Monolithic-pixel Inner Tracking System
→ x3-5 better tracking precision



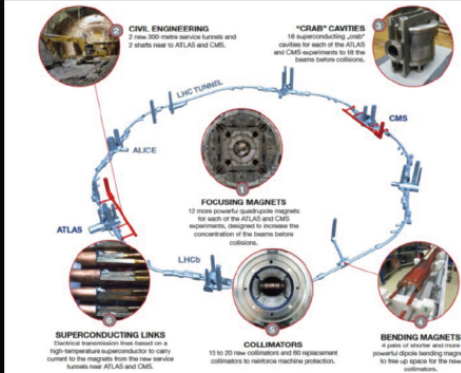
GEM-based TPC readout
→ x100 readout rate in Pb-Pb

$\Delta V = 270\text{ V}$ $\Delta V = 500\text{ V}$
 $\Delta V = 230\text{ V}$ $\Delta V = 50\text{ V}$
 $\Delta V = 280\text{ V}$ $\Delta V = 20\text{ V}$
 $\Delta V = 300\text{ V}$ $\Delta V = 200\text{ V}$

- Low- p_T heavy-flavour mesons/baryons;
- Low- p_T charmonia: c-bar melting and
- Low-mass di-electrons: QGP thermal

Pixel Muon Forward Tracker
→ non-prompt muons from B decays

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



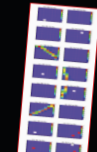
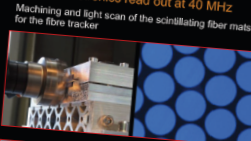
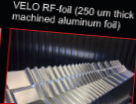
- New IR-quads Nb_3Sn (inner triplets)
- New 11 T Nb_3Sn (short) dipoles
- Collimation upgrade
- Cryogenics upgrade
- Crab Cavities
- Cold powering
- Machine protection
- Civil engineering

Formal approval by CERN Council (June 2016)
Cost to Completion : 950 MCHF (material)

Detector plan

LHCb – Upgrade LS2

Construction well advanced



Will collect 50 fb⁻¹ at instantaneous lumi of 2x10³³cm⁻²s⁻¹
Full software trigger
New tracking detectors
New RICH photon detectors
New electronics read out at 40 MHz

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

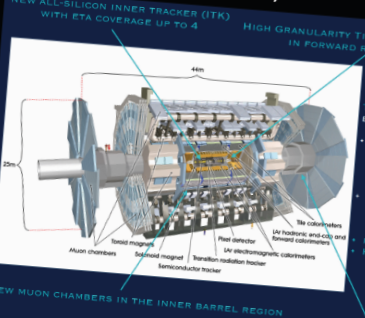
Beam Tracker silicon module under test

First scintillating fibre modules arriving at CERN

Calorimeter front-end board

Muon system readout ASIC

ATLAS – Upgrade Phase II (LS3)



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

HIGH GRANULARITY TRACKING IN FORWARD REGION

ITDAQ OFF-DETECTOR ELECTRONICS:

- LO HARDWARE TRIGGER
- LO CALORIMETER
- LO TOPOLOGICAL
- LO MUON
- LO GLOBAL
- L1 HARDWARE TRIGGER (OPTIONAL)
- L1 GLOBAL
- L1 TRACK TRIGGER
- READOUT SYSTEM
- HLT

NEW MUON CHAMBERS IN THE INNER BARREL REGION

FORWARD MUON TRACKER (OPTIONAL)

CMS – Upgrade Phase II (LS3)

Trigger/HLT/DAQ (interim TDR submitted)

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

New Endcap Calorimeters

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

New Tracker

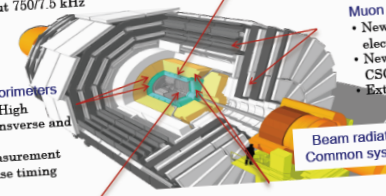
- Rad. tolerant - increased granularity - lighter
- 40 MHz selective readout (strips) for Trigger
- Extended coverage to $\eta \approx 3.8$

Barrel EM calorimeter

- New FE/BE electronics for full granularity readout at 40 MHz - with improved time resolution
- Lower operating temperature ($\delta >$)

Muon systems

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

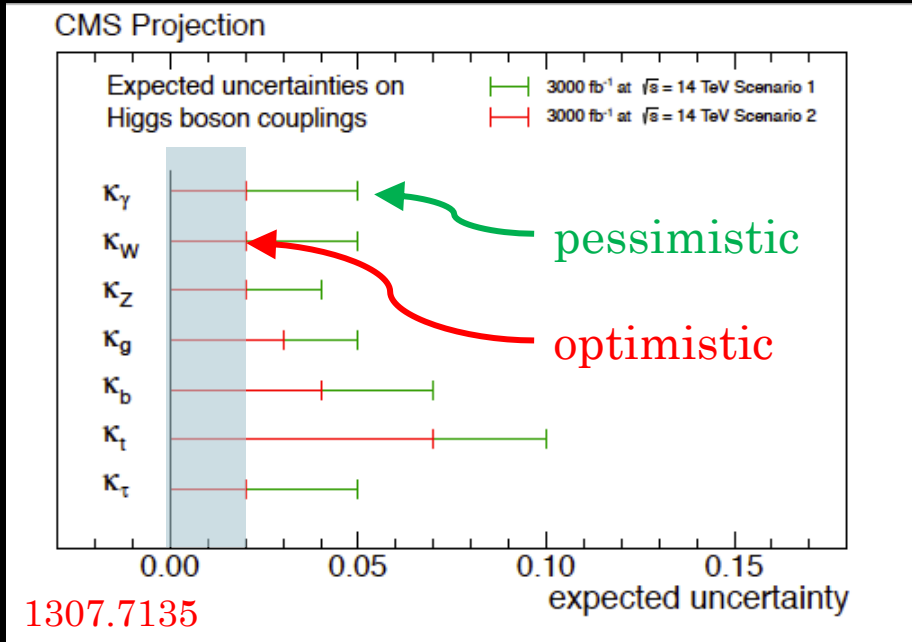


Beam radiation and luminosity Common systems and infrastructure

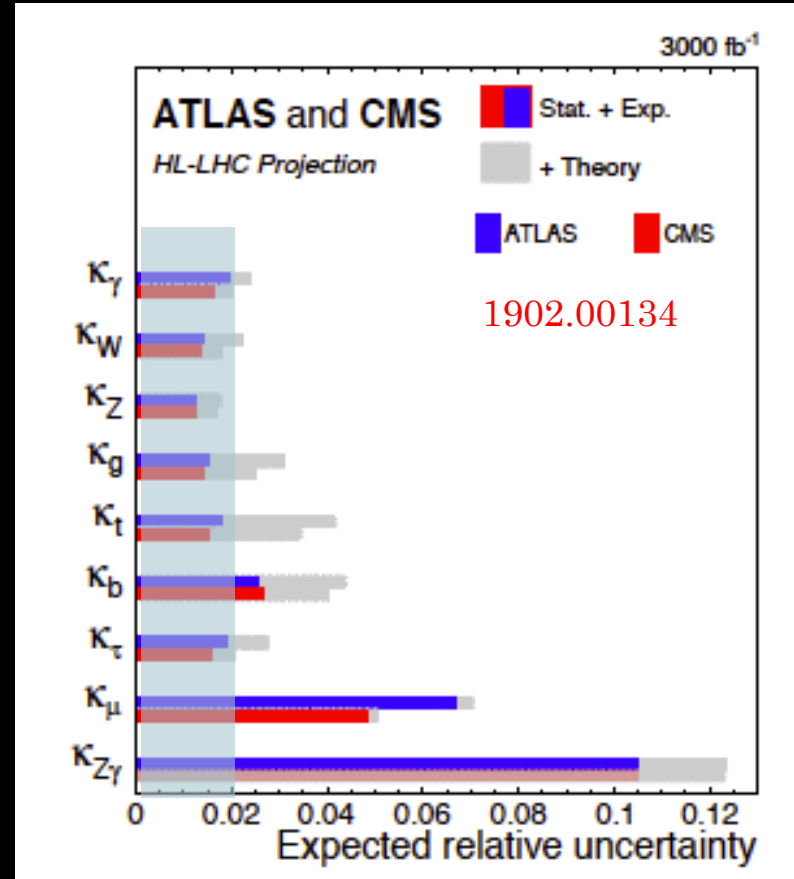
MIP precision Timing Detector

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

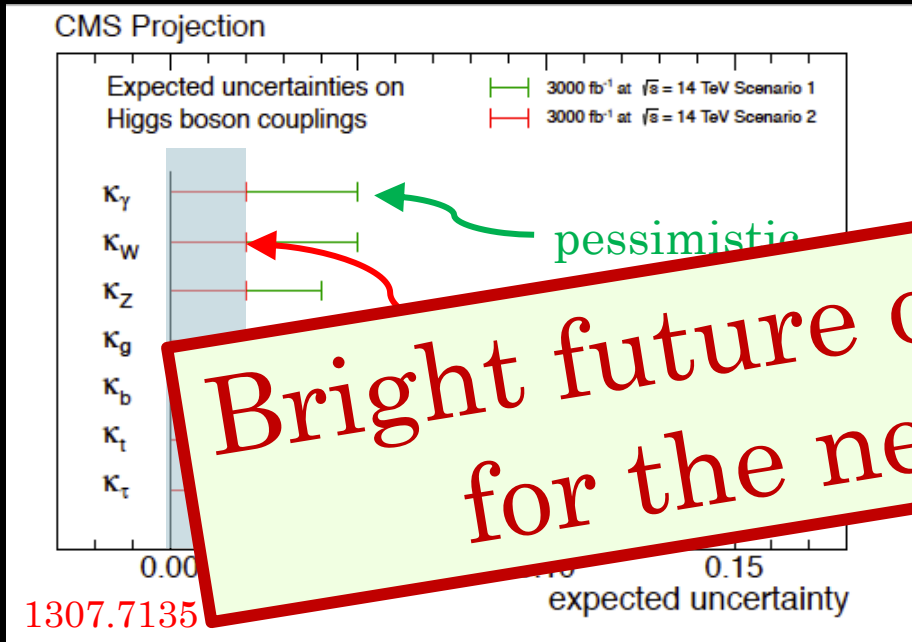
Potential HL-LHC performance in Higgs couplings *anno 2013 versus anno 2019*



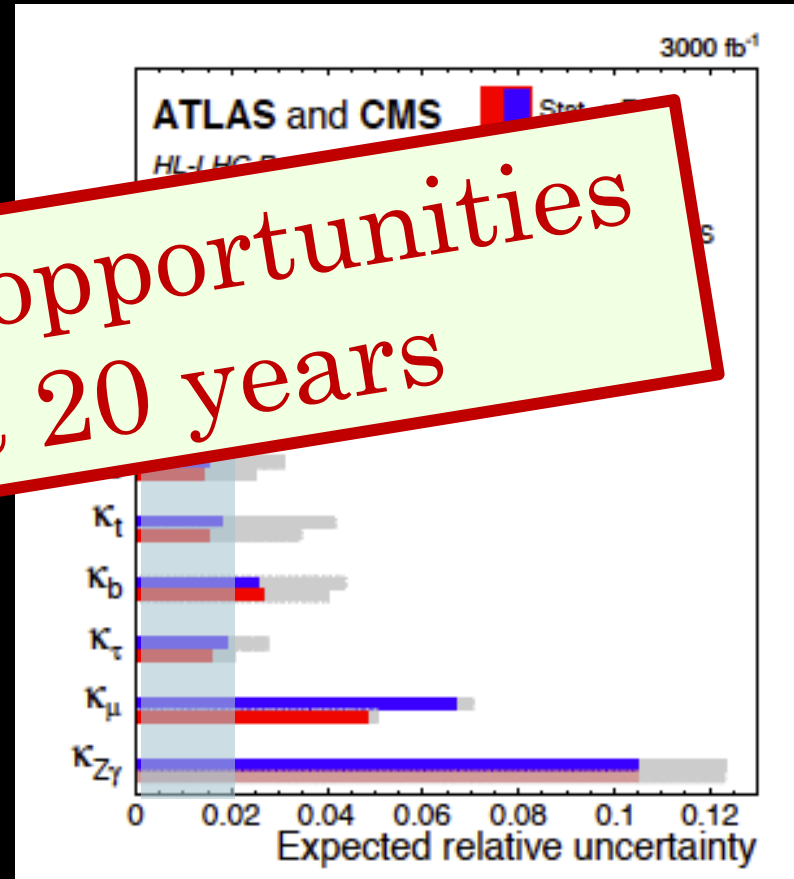
Taking into account innovative thoughts and research experience, what was optimistic in 2013 seems realistic in 2019.



Potential HL-LHC performance in Higgs couplings *anno 2013 versus anno 2019*



Bright future of opportunities
for the next 20 years



Taking into account innovative thoughts and research experience, what was optimistic in 2013 seems realistic in 2019.

Competition for the Interaction Region at Point-2@LHC: next generation
Heavy Ion experiment beyond LS4 and the LHeC ?

This is a very important choice with potentially a major impact.
Two very strong communities in Europe.

Both options are at the proposal stage.

Strategy input document

(Id110) “*A next-generation
LHC heavy-ion experiment*”

Emerging from the current ALICE
collaboration

Strategy input document

(Id159) “*Exploring the Energy Frontier
with Deep Inelastic Scattering at the
LHC*” (i.e. LHeC and PERLE)

after peer review now in print J.Phys.G

Following a call from the CERN-DG
CDRs: arXiv:1206.2913 and arXiv:1705.08783

Workshop on LHeC/PERLE/FCCeh 24-25 Oct
<https://indico.cern.ch/event/835947/>

3rd priority

ILC at Japan

FRONT PAGE

Towards an update of the strategy

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

ICFA meeting, Tokyo, 6-8 March 2019

- We were informed about the position of MEXT on the ILC project. We heard as well as a speech from Hon. Kawamura from the Federation of Diet Members for the ILC.
<https://www.kek.jp/en/newsroom/2019/03/13/2100/>
- In response, the ICFA statement: https://icfa.fnal.gov/wp-content/uploads/ICFA_Tokyo_Statement_March2019.pdf
- The letter from the Linear Collider Board (LCB):
https://icfa.fnal.gov/wp-content/uploads/LCB_letter_to_MEXT-signed.pdf



“MEXT has not yet reached declaration for hosting the ILC in Japan at this moment”

“MEXT will pay close attention to the progress of the discussions at the European Strategy for Particle Physics Update”

“MEXT will continue to discuss the ILC project with other governments while having an interest in the ILC project”

4th priority

Neutrino Platform

FRONT PAGE

Towards an update of the 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.

Since 2014 the CERN Neutrino Platform fosters the collaboration of ~90 European institutions in detector R&D and construction.
e.g. DUNE@LBNF (US) and ND280@T2K (Japan)

Upgrades are considered in due time for these long-baseline neutrino projects.
e.g. doubling the beam power at DUNE (from 1.2MW to 2.4 MW)

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. Topics include neutrino physics, dipole moments, charged-lepton flavour violation, etc.
- ③ Detector R&D programmes should be strongly supported 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.

SECOND PAGE

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 **Would it be adequate to move the diversity program to the front page?**
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.

Scientific Diversity Program

(both at CERN and elsewhere in Europe)

Listed below those facilities/experiments in Europe in the realm of particle physics

- Beam Dump Facility (SHiP, TauFV)
- eSPS (LDMX)
- COMPASS/AMBER as QCD facility, MUonE, KLEVER, nuSTORM, MATHUSLA, FASER, CODEX-b, milliQan, LHCSpin, REDTOP, DIRAC, ...
- CPEDM@Julich, ESSvSB@ESS, PERLE@Saclay, LFV@PSI, ...

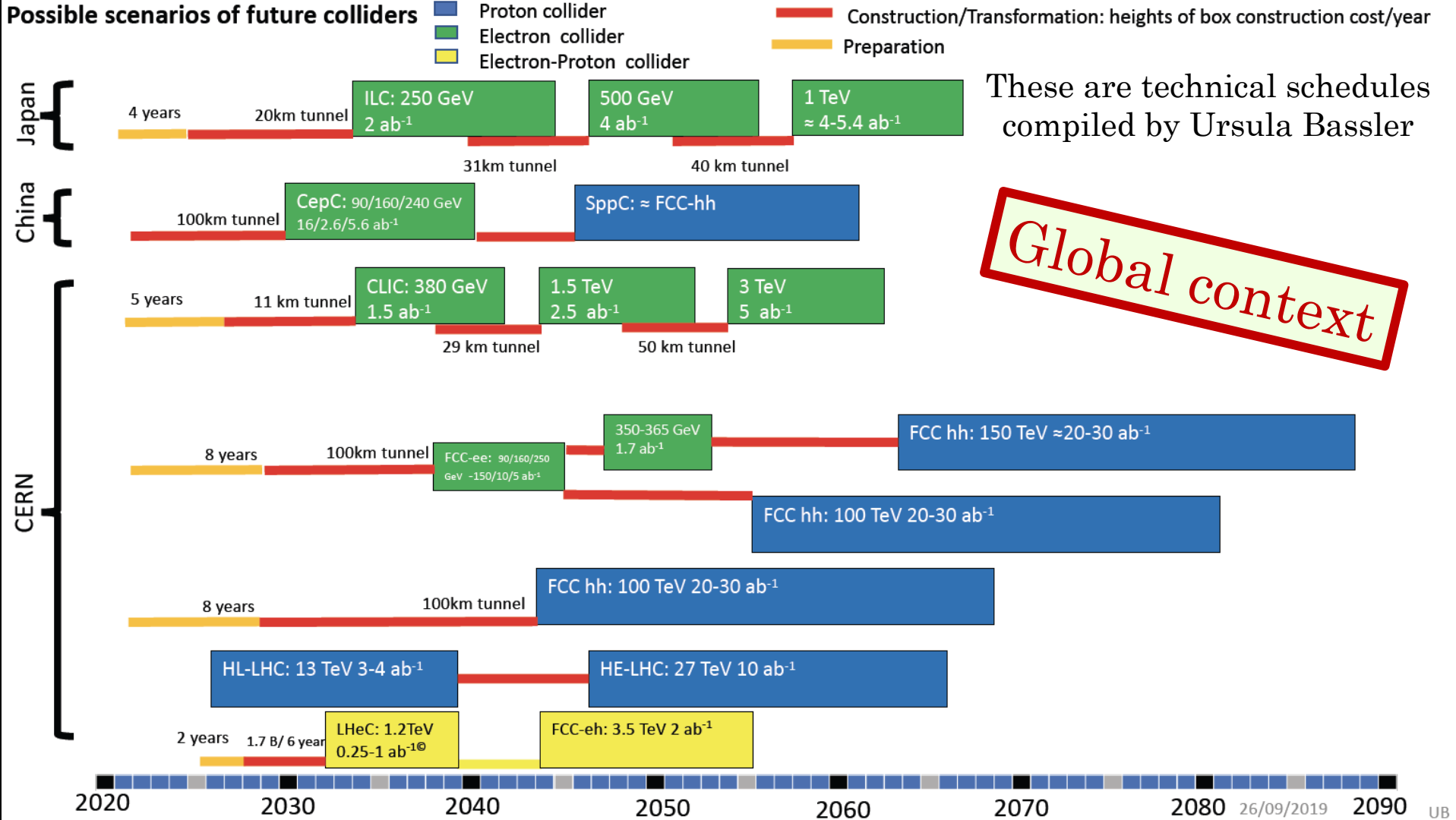
2nd priority

Future colliders at CERN
Accelerator R&D

FRONT PAGE

Towards an update of the strategy

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.



Towards an update of the strategy

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.

CLIC

FCC

LHeC
(1.7GCHF)

Physics opportunities and major technology challenges in the PBB.

Some key elements one can consider in an overall ambition

- to deliver to the research community a compelling scientific program which includes the global aspiration for a Higgs factory but in general exploring new territories in the search for new physics at the precision, the intensity and the high-energy frontiers
- because a new collider is essential to make progress, to have a new major collider facility operational at CERN as soon as possible after the HL-LHC program
- allow for options for the long-term future
- to support major **accelerator R&D** to prepare for the 1st and 2nd generation colliders, i.e. the 2040-2060 and 2060-2080 eras
- to support a **scientific diversity program** to complement the physics reach achievable with colliders

Embrace these thoughts into “scenarios” with future colliders in Europe.

With a strawman view to update the current strategy and to prepare the discussion within the European Strategy Group (ESG), “scenarios” can be defined revolving around future colliders at CERN.

- Each scenario has a 1st generation collider in the 2040-2060 era and options for the 2nd generation collider in the 2060-2080 era.
- Some scenarios might depend on decisions made outside of Europe, i.e. to be verified on the occasion of the next European Strategy update, typically within 7 years (around the start of the HL-LHC).
- For the 2nd generation colliders, advanced accelerator technologies might come in (e.g. plasma, muon, HTS magnets), depending on the performance of the advanced technologies in for example demonstrator facilities.
- Accordingly each scenario has a moment in time to verify the readiness of the advanced accelerator technologies, i.e. at the moment when concrete decisions are to be made about the 2nd generation collider.

A landscape for colliders in Europe

	2020-2040	2040-2060	2060-2080
		1st gen technology	2nd gen technology
CLIC-all	HL-LHC	CLIC380-1500	CLIC3000 / other tech
CLIC-FCC	HL-LHC	CLIC380	FCC-h/e/A (Adv HF magnets) / other tech
FCC-all	HL-LHC	FCC-ee (90-365)	FCC-h/e/A (Adv HF magnets) / other tech
LE-to-HE-FCC-h/e/A	HL-LHC	LE-FCC-h/e/A (low-field magnets)	FCC-h/e/A (Adv HF magnets) / other tech
LHeC-FCC-h/e/A	HL-LHC + LHeC	LHeC	FCC-h/e/A (Adv HF magnets) / other tech

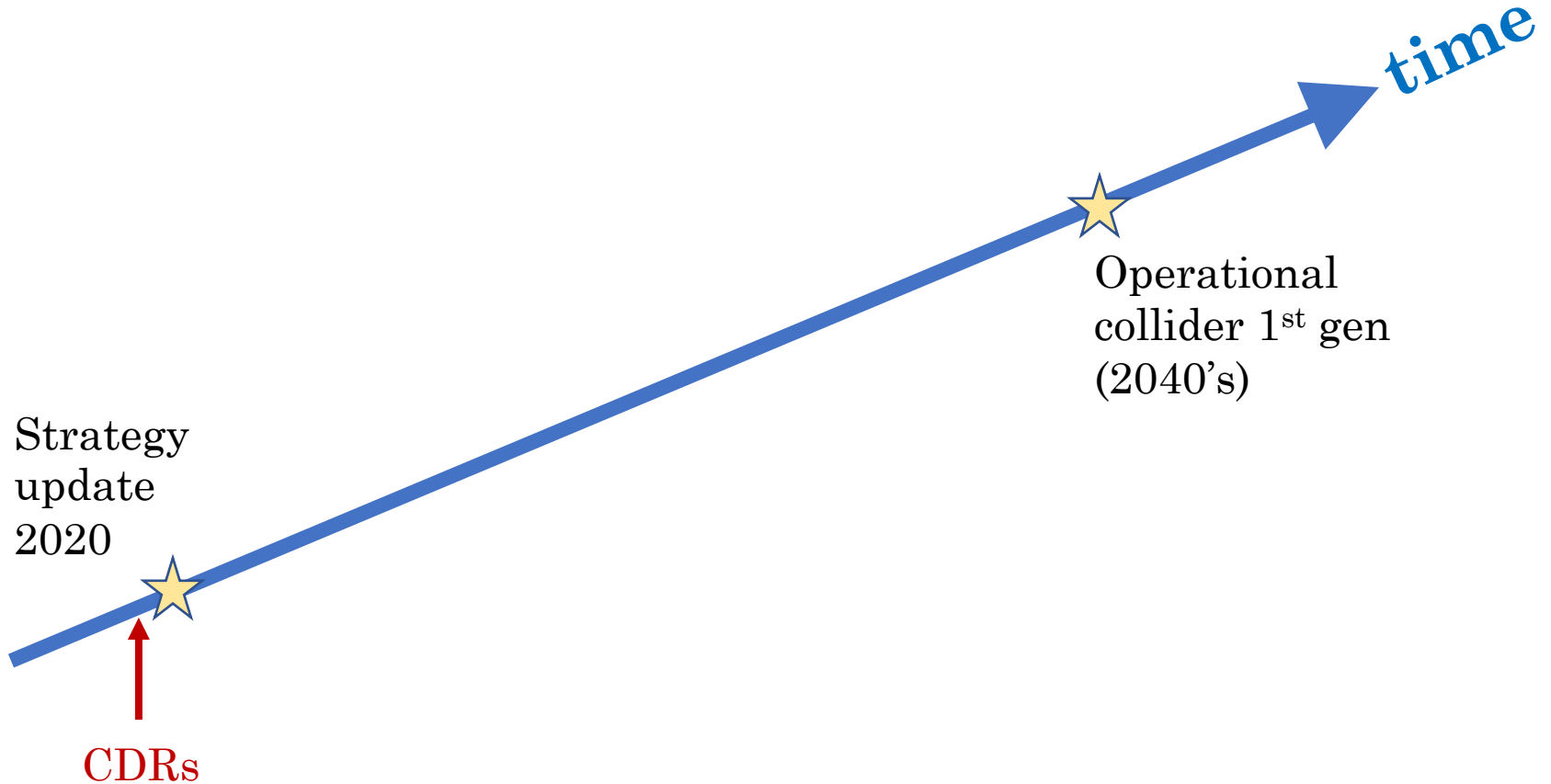
- All elements related to the CLIC, FCC and LHeC proposals are discussed in their CDRs.
- The LE-to-HE-FCC-hh(e/A) scenario with the hadron collider version of the FCC moves from initially lower-field magnets to higher-field magnets, potentially HTS magnets.
- The LHeC+FCC-h/e/A scenario includes the LHeC (could be included in all scenarios) and foresees FCC-h/e/A at a later stage directly with high-field magnets.

A landscape for colliders in Europe

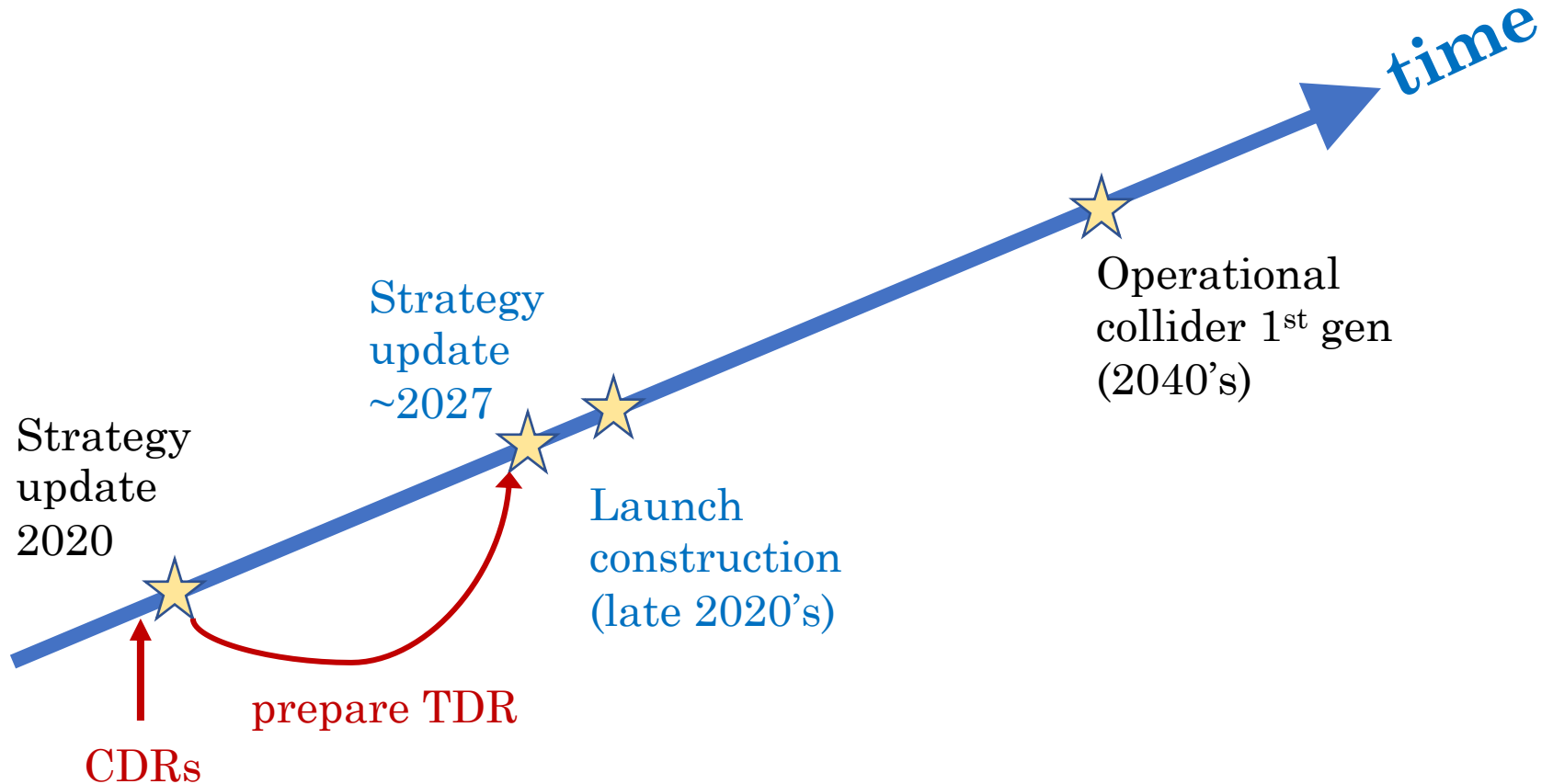
	2020-2040	2040-2060	2060-2080
		1st gen technology	2nd gen technology
CLIC-all	HL-LHC	CLIC380-1500	CLIC3000 / other tech
CLIC-FCC	HL-LHC	CLIC380	FCC-h/e/A (Adv HF magnets) / other tech
FCC-all	HL-LHC	FCC-ee (90-365)	FCC-h/e/A (Adv HF magnets) / other tech
LE-to-HE-FCC-h/e/A	HL-LHC	LE-FCC-h/e/A (low-field magnets)	FCC-h/e/A (Adv HF magnets) / other tech
LHeC-FCC-h/e/A	HL-LHC + LHeC	LHeC	FCC-h/e/A (Adv HF magnets) / other tech

- Need to provide guidance in this strategy update for the technology for the 1st generation collider at CERN, leaving open options to deploy other technologies for the 2nd generation.
- Accordingly, around 2045 the community will have to consider which technologies are available for high-energy and high-luminosity colliders in the 2060-2080 era.
- While planning for success, the chosen scenario will have to be verified at the time of the next strategy update, taking into account the global context (e.g. ILC, CEPC, EIC, etc).

Typical path: select a scenario and plan for success



Typical path: select a scenario and plan for success



Nothing is written in stone at this stage
*for new colliders in Europe, the European Strategy Group
will discuss at least these strawman scenarios with a
focus on the 1st generation collider*

	2020-2040	2040-2060	2060-2080
		1st gen technology	2nd gen technology
CLIC-all	HL-LHC	CLIC380-1500	CLIC3000 / other tech
CLIC-FCC	HL-LHC	CLIC380	FCC-h/e/A (Adv HF magnets) / other tech
FCC-all	HL-LHC	FCC-ee (90-365)	FCC-h/e/A (Adv HF magnets) / other tech
LE-to-HE-FCC-h/e/A	HL-LHC	LE-FCC-h/e/A (low-field magnets)	FCC-h/e/A (Adv HF magnets) / other tech
LHeC-FCC-h/e/A	HL-LHC + LHeC	LHeC	FCC-h/e/A (Adv HF magnets) / other tech

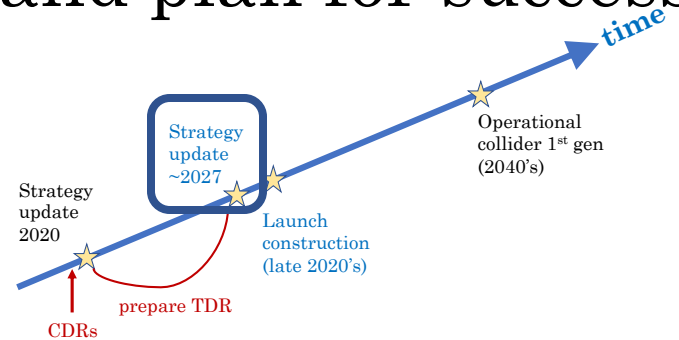
Nothing is written in stone at this stage
*for new colliders in Europe, the European Strategy Group
 will discuss at least these strawman scenarios with a
 focus on the 1st generation collider*

	2020-2040	2040-2060	2060-2080
		1st gen technology	2nd gen technology
CLIC-all	HL-LHC	CLIC380-1500	CLIC3000 / other tech
CLIC-FCC	HL-LHC	CLIC380	FCC-h/e/A (Adv HF magnets) / other tech
FCC-all	HL-LHC	FCC-ee (90-365)	FCC-h/e/A (Adv HF magnets) / other tech
LE-to-HE-FCC-h/e/A	HL-LHC	LE-FCC-h/e/A (low-field magnets)	FCC-h/e/A (Adv HF magnets) / other tech
LHeC-FCC-h/e/A	HL-LHC + LHeC	LHeC	FCC-h/e/A (Adv HF magnets) / other tech

Thank you for your attention!

Typical path: select a scenario and plan for success

To realize a particular scenario, the following objectives could be considered in the overall strategy update.



Main expectations of the next Strategy update (in about 7 years)

- Receive the TDR for 1st generation of the scenario for final approval
- Decide to concretely engage in the 1st generation of the scenario, or to adapt according to the global context
- Decide on the strategy for further development of high-field magnets
- Decide on the basis of CDRs to construct a muon and/or plasma-based collider demonstration facility

Typical path: select a scenario and plan for success

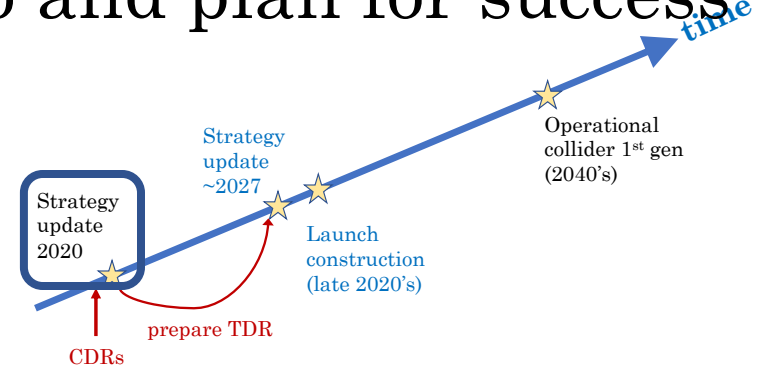
Goals to reach by the time of the next Strategy update (within ~7 years)

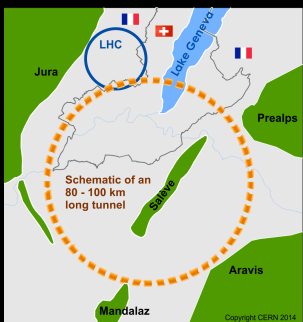
- Concrete technical and administrative plans for the civil engineering for the 1st generation scenario, including cost optimization studies
- Concrete financial organization plan for civil engineering, accelerator and experiments for 1st generation scenario, including cost optimization studies
- In the context of the particular scenario, set up proto-collaborations for experiments to propose initial detector designs
- Verify the technical feasibility and cost optimization for alternative scenarios
- CDRs for demonstration collider facilities for a muon collider and a plasma-based collider

Typical path: select a scenario and plan for success

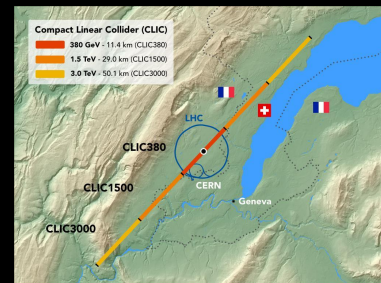
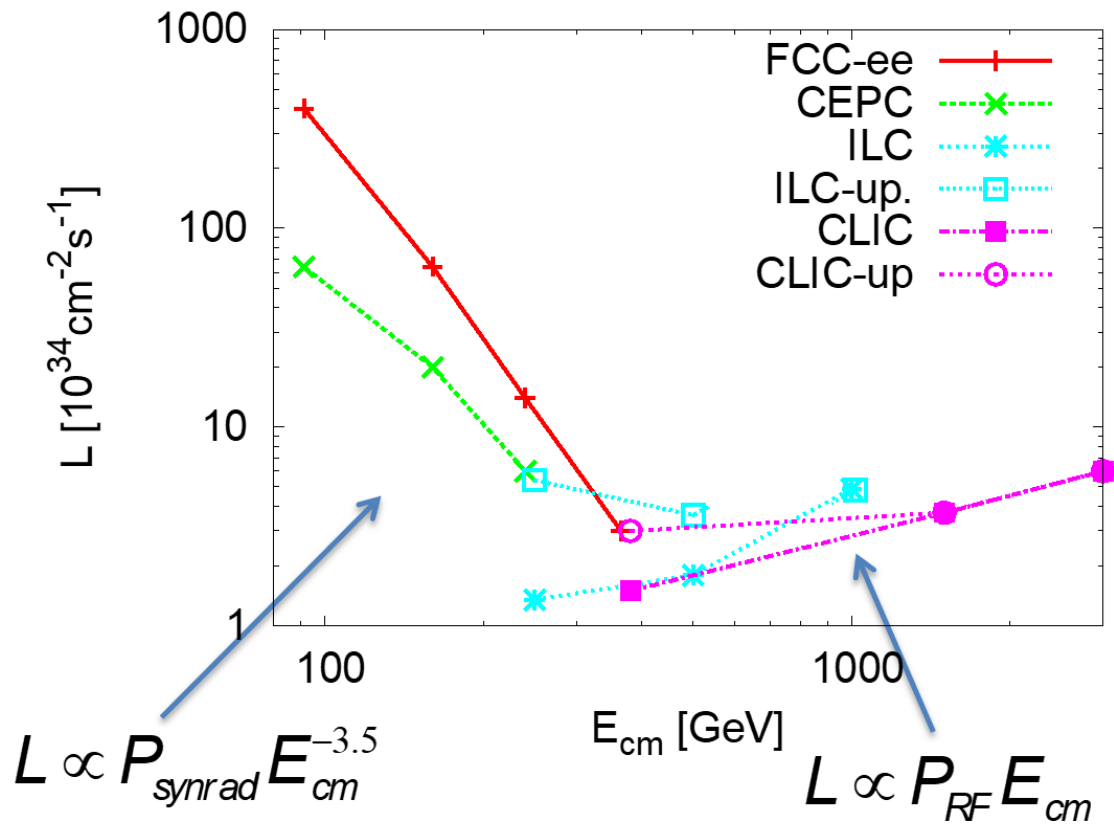
Would require from the 2020 Strategy update

- Strong statement to investigate the full program of the scenario, including technical and administrative plans, and commission a TDR for the 1st generation of the scenario
- Commission CDRs for demonstration facilities for a muon collider and a plasma-based collider, and support statements for the development of high-field magnets
- Openness towards opportunities for a major collider outside Europe





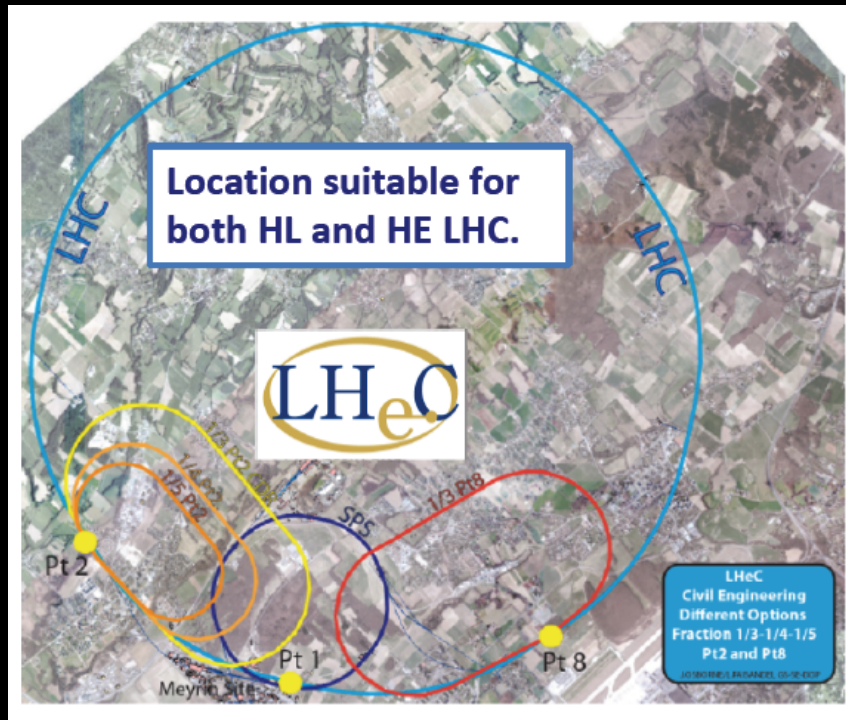
Luminosity per facility



Concrete collider options studied at CERN

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

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

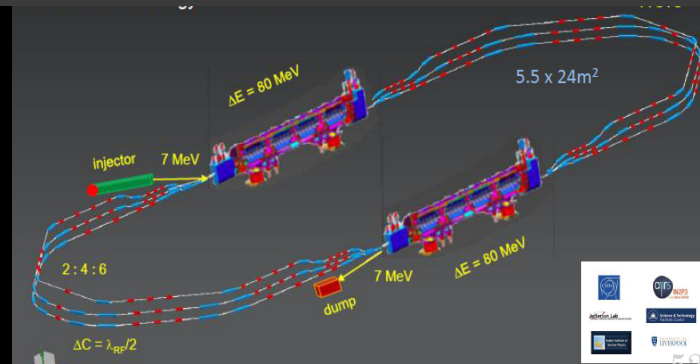


LHeC (60 GeV e- from ERL)

$$E_{cms} = 0.2 - 1.3 \text{ TeV}$$

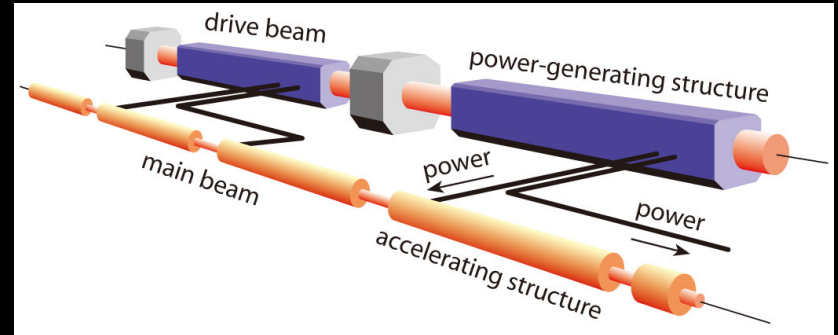
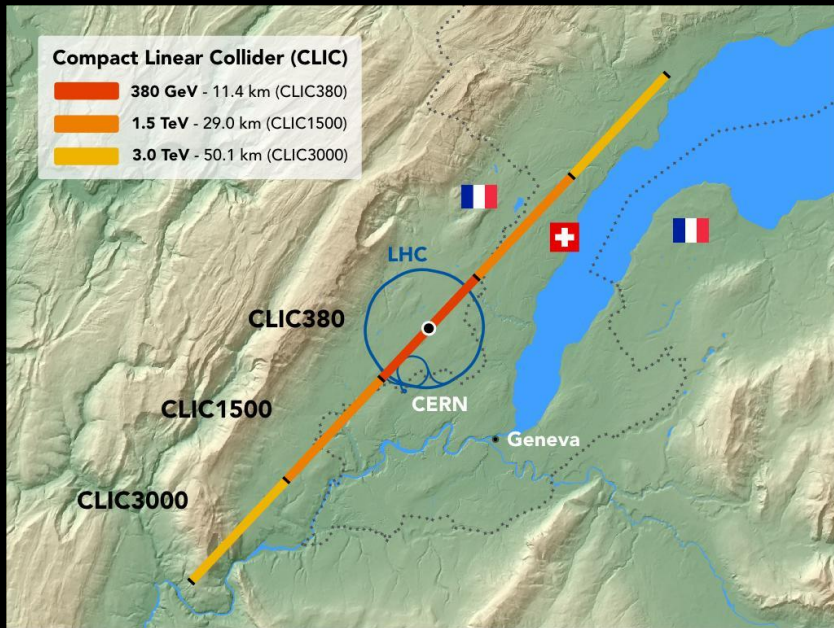
run with the HL-LHC (\gtrsim Run5)

Energy Recovery Linac (ERL)
R&D demonstrator at Orsay, PERLE



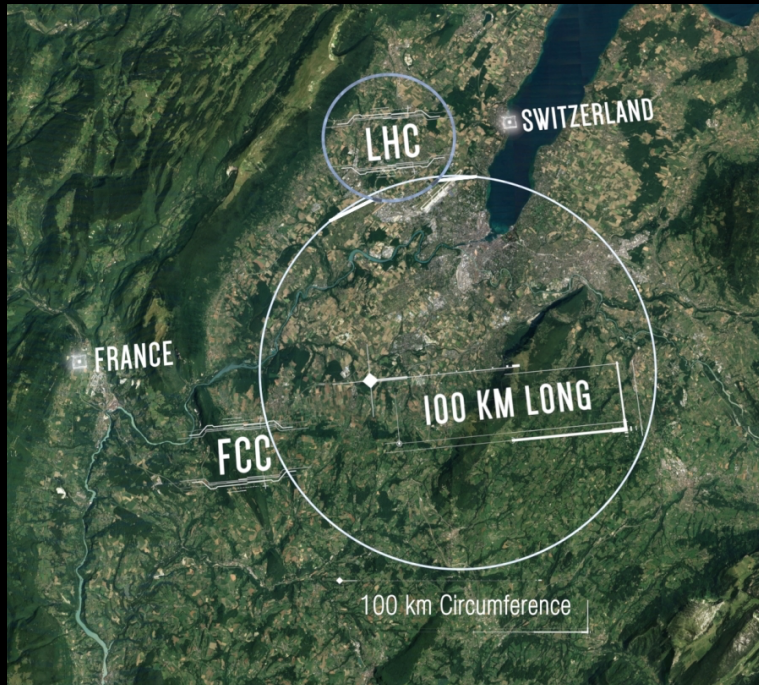
Concrete collider options studied at CERN

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



Concrete collider options studied at CERN

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



- e^+e^- collider (**FCC-ee**) @ 90-365 GeV
as potential first step
(ERL-technology, CLIC injector, ...)
- pp -collider (**FCC-hh**) @ 100 TeV
- p - e collider (**FCC-he**)
- **HE-LHC** with *FCC-hh* magnets
- $\mu\mu$ collider (**FCC- $\mu\mu$**) option
- AA, Ap, Ae options