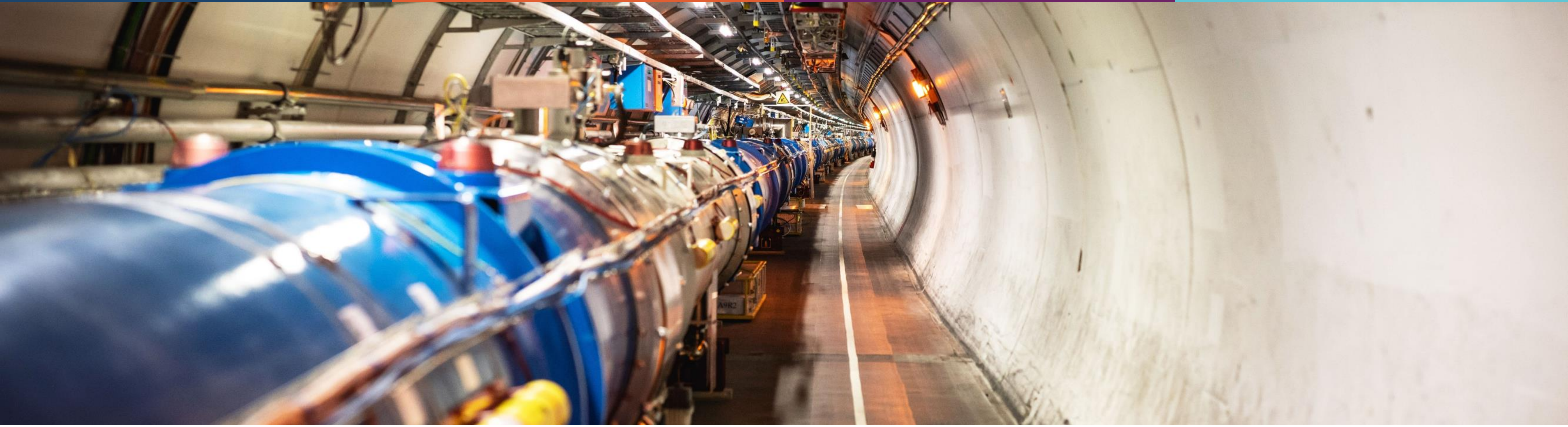
CERN



CERN view, status and plans

Manfred Krammer
Head of the Experimental Physics Department

7 June 2024

CERN was founded in 1954 with 12 European Member States as a treaty-based intergovernmental organisation

Brazil joined in March 2024 as the first Associate Member state from Latin America

Estonia will soon join as 24th full Member State
Ratification process completed

23 Member States

Austria – Belgium – Bulgaria – Czech Republic
Denmark – Finland – France – Germany – Greece
Hungary – Israel – Italy – Netherlands – Norway
Poland – Portugal – Romania – Serbia – Slovakia
Spain – Sweden – Switzerland – United Kingdom

3 Associate Member States in the pre-stage to membership

Cyprus – Estonia – Slovenia

8 Associate Member States

Brazil – Croatia – India – Latvia – Lithuania – Pakistan
Türkiye – Ukraine

6 Observers

Japan – Russia (suspended) – USA
European Union – JINR (suspended) – UNESCO

Around 50 Cooperation Agreements with non-Member States and Territories

Albania – Algeria – Argentina – Armenia – Australia – Azerbaijan – Bangladesh – Belarus – Bolivia
Bosnia and Herzegovina – Canada – Chile – Colombia – Costa Rica – Ecuador – Egypt – Georgia – Honduras
Iceland – Iran – Jordan – Kazakhstan – Lebanon – Malta – Mexico – Mongolia – Montenegro – Morocco – Nepal
New Zealand – North Macedonia – Palestine – Paraguay – People's Republic of China – Peru – Philippines – Qatar
Republic of Korea – Saudi Arabia – Sri Lanka – South Africa – Thailand – Tunisia – United Arab Emirates – Vietnam

CERN in a few numbers

> 70 running experiments/facilities
Publications (2023): > 760 papers (experiments + theory, ~ 300 from LHC)

Annual Budget: ~ 1.3 BCHF
(shared by Member States based on their net national income)

CERN's community: > 17500 people (> 110 nationalities), **increasing!**

- 2666 staff
- 1002 graduates (technical students, post-docs, etc.)
- 12370 users,1513 other associates
- > 3700 PhD students from all over the world
- ~ 4500 young people trained at CERN at any time
- US population: 2007 users (+100 since last year) from 142 Institutes

2 main sites in CH and France, 15 smaller satellite sites
630 hectares, 700 buildings
70 km underground tunnels, > 30 caverns
1000 km technical galleries/trenches
500 hotel rooms
3000 meals served daily
4000 contractors' personnel
9000 people on site every day

Every year:
150000 visitors until now → 340000 expected now with Science Gateway
170000 press cuttings
5 million visitors to CERN website
130 million CERN social media views

CERN's scientific vision and programme

- A “flagship” project. Currently operating and upgrading the world leading facility at the energy frontier: LHC and HL-LHC

- A broad diverse scientific programme, complementary to the collider and carried out mainly at the injectors and in dedicated facilities.

- Currently preparing for the next major project, commensurate with the Lab's scientific ambition, expertise, community and infrastructure, to ensure a bright future for CERN
  Preferred direction from 2020 European Strategy for Particle Physics (ESPP): Future Circular Collider (FCC)
  R&D and design studies for alternatives options (linear colliders, muon colliders) also being pursued.

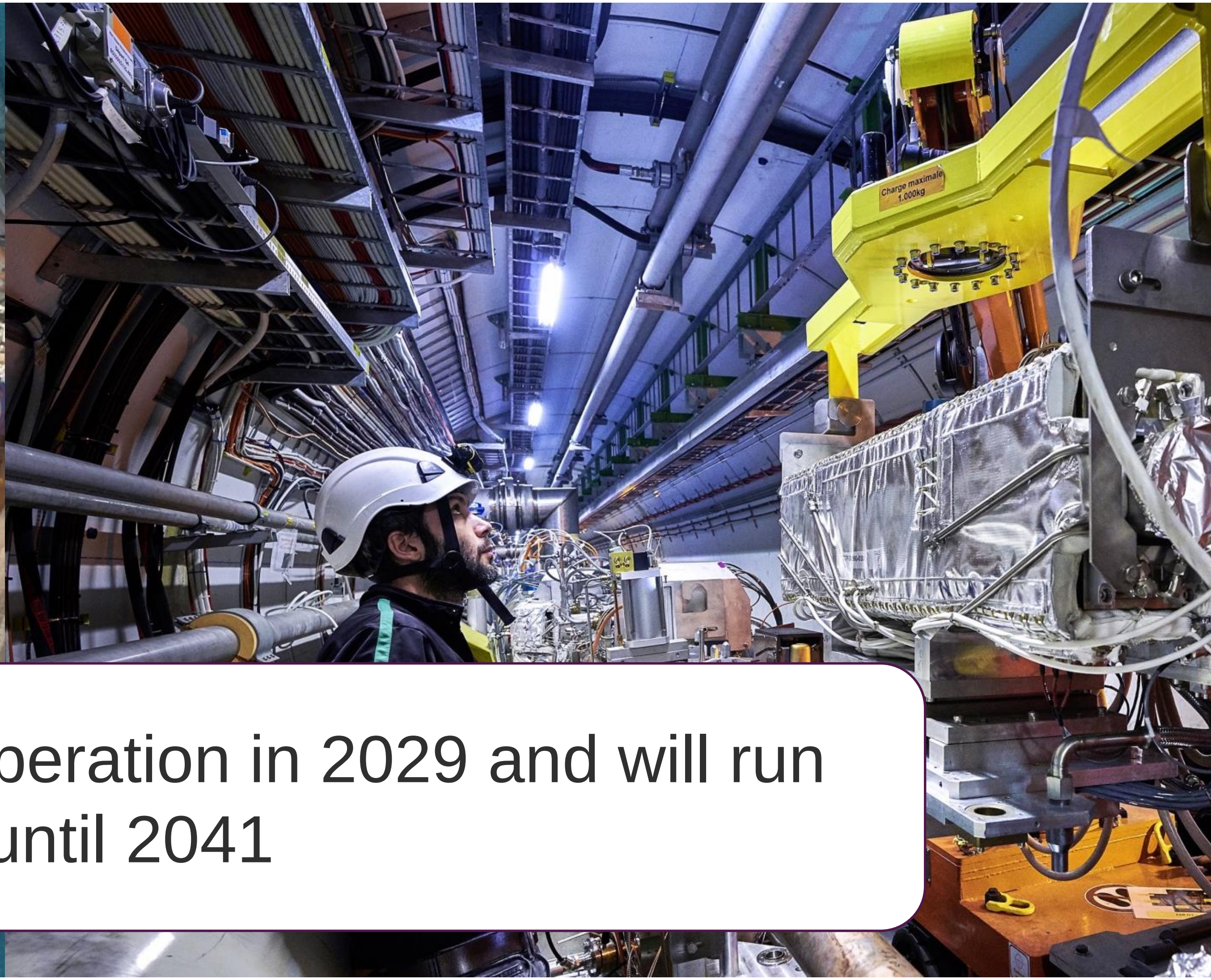
- A vigorous and broad Accelerator R&D programme covering the technologies needed for the future of the field (superconducting high-field magnets, warm and superconducting accelerating structures, muon colliders, plasma wakefield).
  Carried out within the European Accelerator R&D Roadmap

- An ambitious Detector R&D programme to prepare the instruments needed for future projects.
  Carried out within the European Detector R&D Roadmap

- Computing developments to support the increasingly challenging requirements of the field (HL-LHC and beyond) and explore new technologies such as Quantum Computing and AI

- Inspiring and motivating research in theory, opening new avenues of exploration

LHC and HL-LHC - CERN’s Flagship Project



HL-LHC will start operation in 2029 and will run until 2041

LHC Experiment Upgrades for HL-LHC

In LS3 (2026-2028)

ATLAS

ITK, HGTD, New Muon Chambers, Trigger, DAQ, Electronics Upgrade

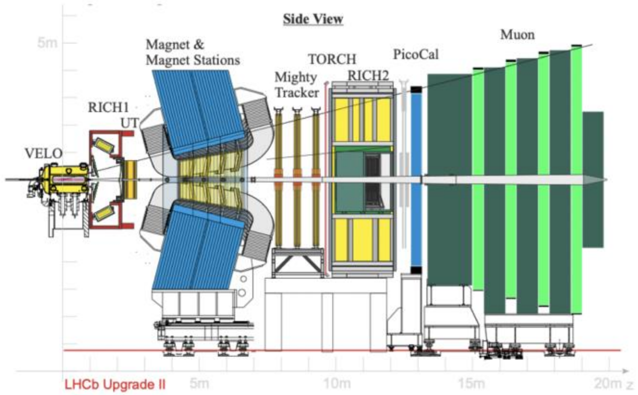
CMS

Tracker, HGCAL, MTD, BRIL, Muon Upgrade, L1 Trigger, DAQ, HLT

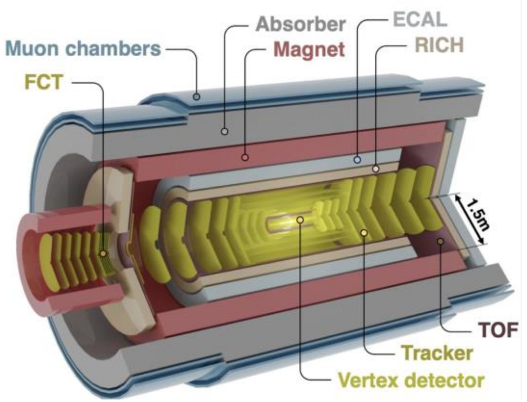
Moving into production of detector components

In LS4 (2033/34)

LHCb Upgrade II

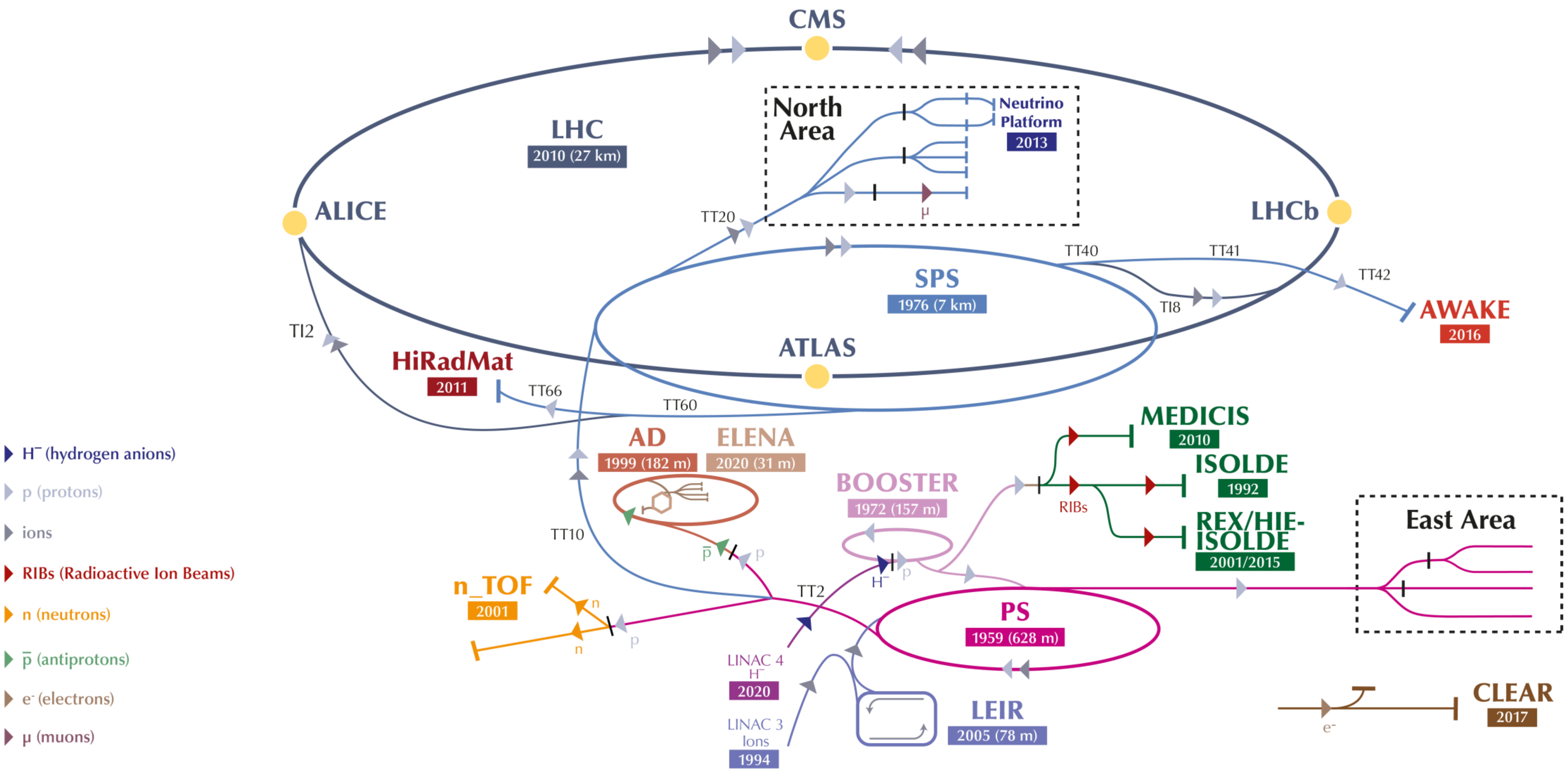


ALICE 3



Scoping documents under preparation to be reviewed by LHCC

The CERN accelerator complex

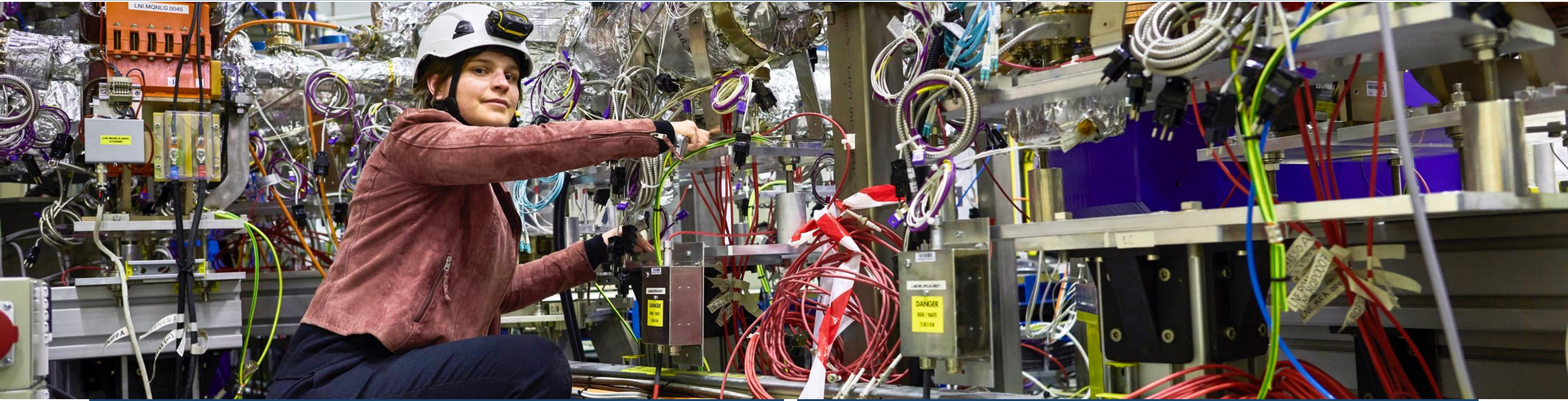


CERN has a large diverse scientific programme

Nuclear Physics
(ISOLDE, n-TOF)

Antimatter Research
(Antiproton Decelerator)

Cosmic rays and cloud formation
(CLOUD)



Fixed-target experiments,
which include searches for rare phenomena

Contribution to the Long Baseline
Neutrino Facility in the USA (LBNF)

Future Opportunities

Future of the the diversity programme nurtured in Physics Beyond Colliders Study group

1st workshop 2016

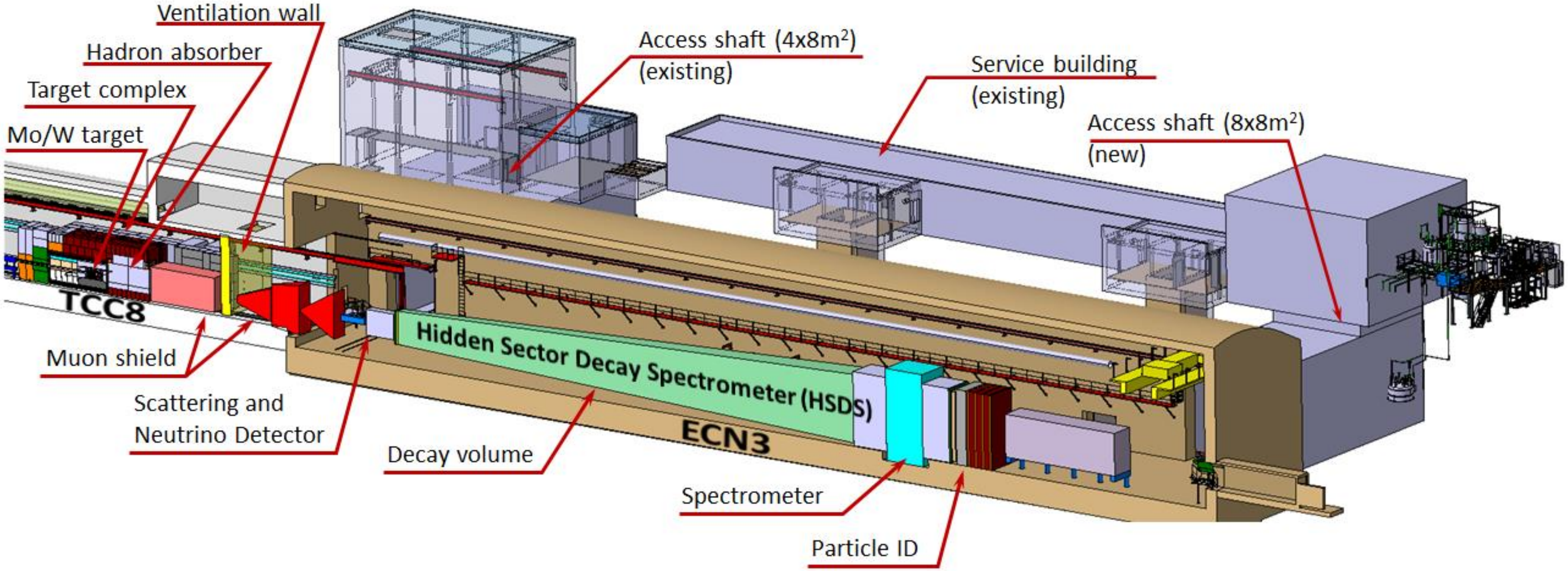
Topics include:

- ❑ Accelerator complex capabilities
- ❑ Low energy facilities
- ❑ Opportunities for gamma-factory
- ❑ Forward Physics Facility
- ❑ Precision measurement and rare decays
- ❑ High energy beam dumps
- ❑ Low energy hidden sector (Axions, EDM)
- ❑ QCD and Heavy Ion

https://pbc.web.cern.ch

ECN3 and SHiP

Newly approved facility at CERN (RB 6 March 2024):
ECN3 Beam line will be upgraded to very high intensity (400 GeV and 4×10^{19} PoT per year),
BDF Beam Dump Facility
Experiment SHiP: main scientific goal is search for feebly interacting GeV-scale particles



Timeline: Sub-detector TDRs 2027, production/construction/installation, start operation 2031

Neutrino Platform and LBNF/DUNE

At CERN two main activities for the LBNF/DUNE project in the US:

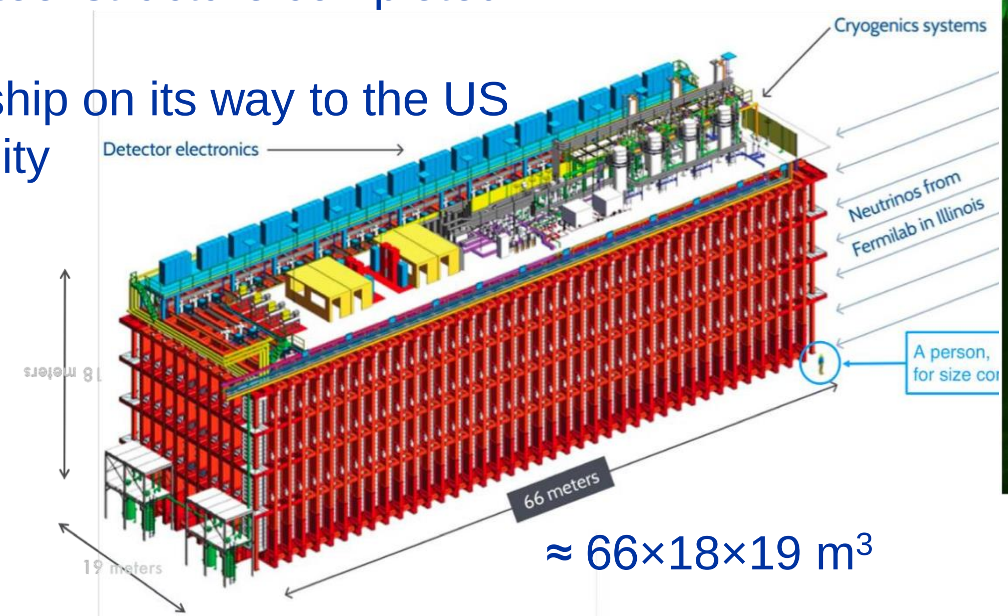
1) Construction of two large cryostats for the DUNE far detectors, detector components for first 2 modules: part of HV system, RRT (Reconstruction, Readout and Trigger) system, and CRP (Charge Readout Planes) for vertical drift module

- Production of warm steel structure completed for cryostat #1
- On board of a cargo ship on its way to the US
- 135 trucks to Rapid City

2) 2 ProtoDUNE detectors: Validation of the final prototypes of the DUNE far detectors (horizontal and vertical drift concepts)

Update status NP04:

- NP04 cryostat filling completed end April
- Purification has started



≈ 66×18×19 m^3

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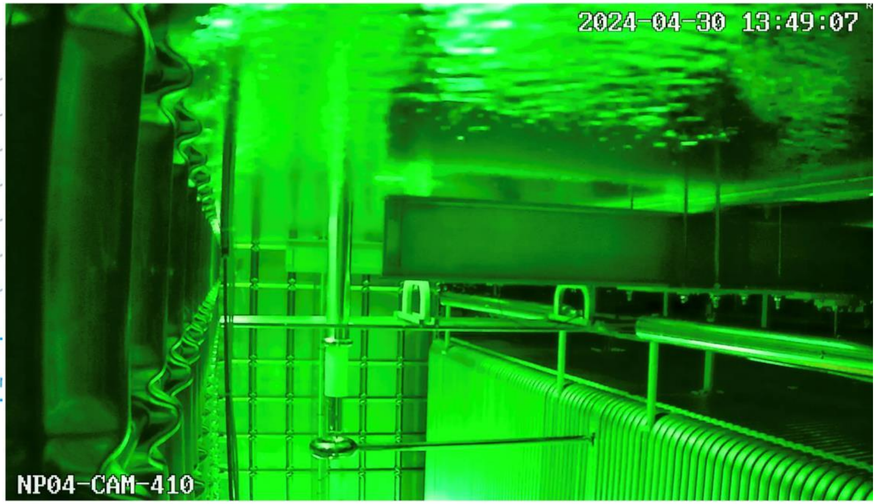


2020 Update of the European Strategy for Particle Physics

- “An electron-positron Higgs factory is the highest-priority next collider.”
- “For the longer term, the European particle physics community has the ambition to operate a proton-proton collider at the highest achievable energy.”
- “Europe, together with its international partners, should investigate the technical and financial feasibility of a future hadron collider at CERN with a centre-of-mass energy of at least 100 TeV and with an electron-positron Higgs and electroweak factory as a possible first stage.”
- “Such a feasibility study of the colliders and related infrastructure should be established as a global endeavour and be completed on the timescale of the next Strategy update.”

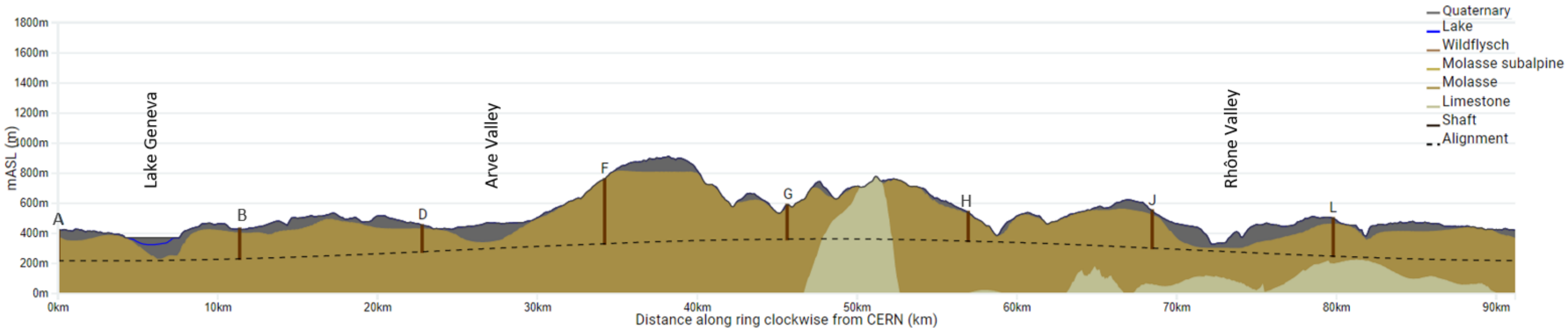
↓

Launch FCC Feasibility Study in 2021:

- will be completed in March 2025 with Feasibility Study Report
- mid-term review to assess progress completed in Feb 2024

FCC Feasibility Study 2021-2025: main objectives

- ❑ Demonstration of the geological, technical, environmental and administrative feasibility of the tunnel and surface areas and optimisation of the placement and layout of the ring and related infrastructure.
- ❑ Pursuit, together with the Host States, of the preparatory administrative processes required for a potential project approval.
- ❑ Optimisation of FCC-ee and FCC-hh design and their injector chains, supported by R&D to develop the needed key technologies.
- ❑ Elaboration of a sustainable operational model for the colliders and experiments in terms of human and financial resource needs, as well as environmental aspects and energy efficiency.
- ❑ Development of a consolidated cost estimate, as well as the funding and organisational models needed to enable the project's technical design completion, implementation and operation.
- ❑ Identification of substantial resources from outside CERN's Budget for the implementation of the first stage (tunnel and FCC-ee).
- ❑ Consolidation of the physics case and detector concepts and technologies for both colliders.

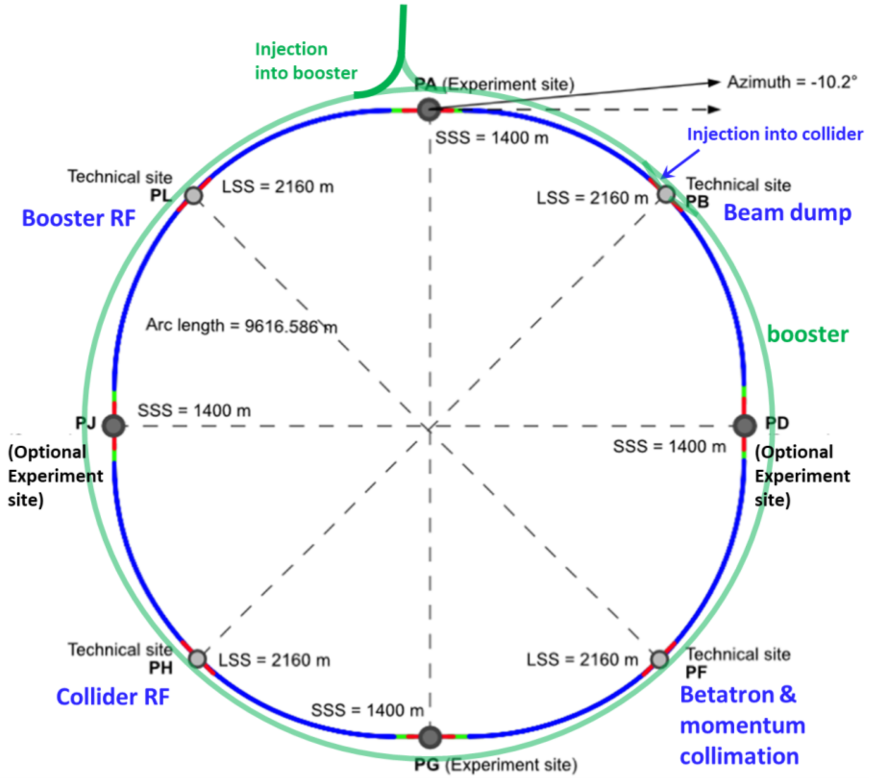


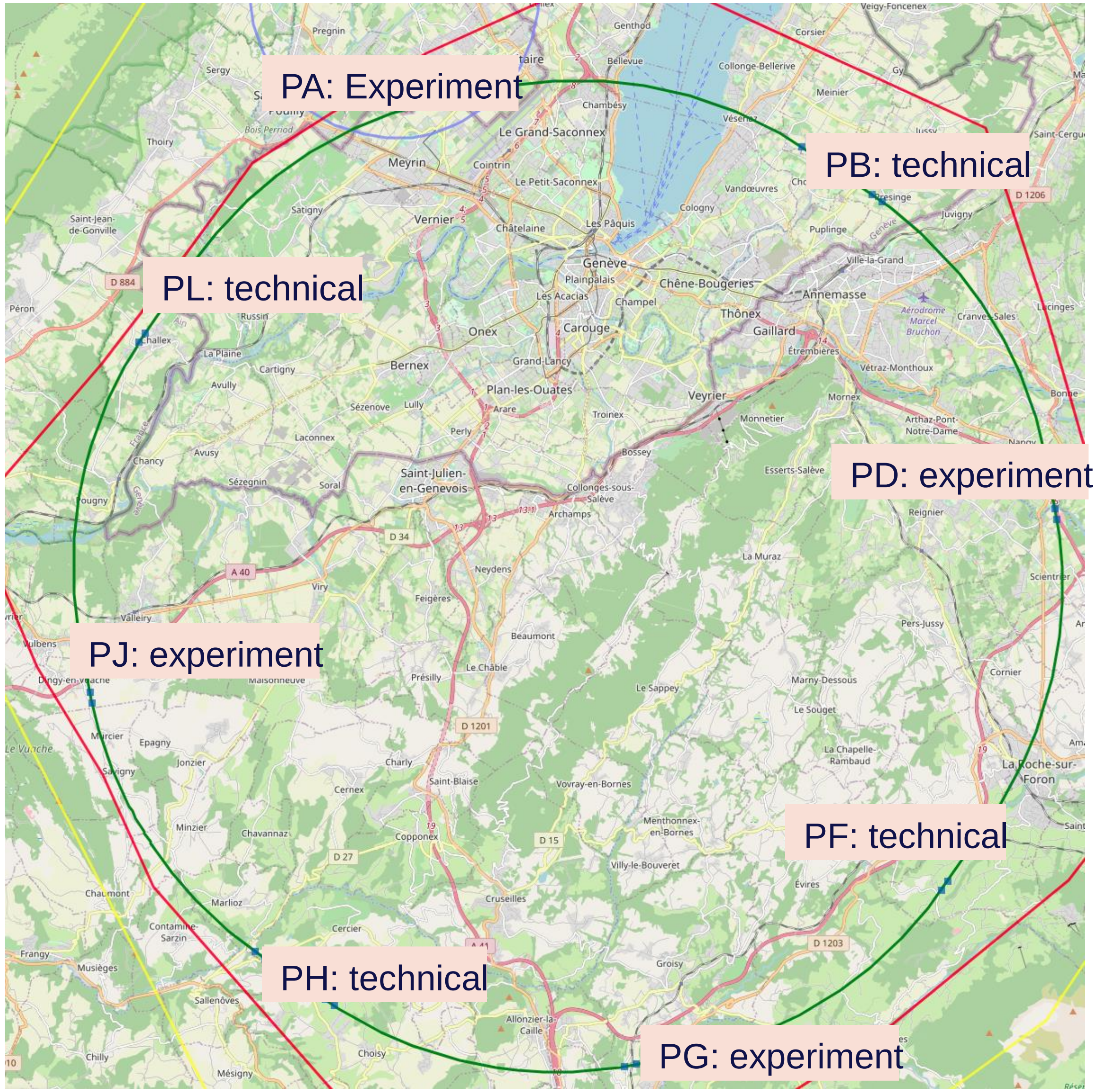
FCC Ring Parameters and Placement

Layout chosen out of ~ 100 initial variants, based on **geology** and **surface constraints** (land availability, access to roads, etc.), **environment,** (protected zones), **infrastructure** (water, electricity, transport), **machine performance** etc.

Overall lowest risk baseline: 90.7 km ring, 8 surface points
< 40 ha of land needed and < 4 km of additional roads

Whole project has been adapted to this placement





Manfred Krammer

FCC-ee: machine parameters and physics potential

Parameter	Z	WW	H (ZH)	ttbar
beam energy [GeV]	45	80	120	182.5
beam current [mA]	1280	135	26.7	5.0
number bunches/beam	10000	880	248	36
bunch intensity [10^{11}]	2.43	2.91	2.04	2.64
SR energy loss / turn [GeV]	0.0391	0.37	1.869	10.0
total RF voltage 400/800 MHz [GV]	0.120/0	1.0/0	2.08/0	4.0/7.25
long. damping time [turns]	1170	216	64.5	18.5
horizontal beta* [m]	0.1	0.2	0.3	1
vertical beta* [mm]	0.8	1	1	1.6
horizontal geometric emittance [nm]	0.71	2.17	0.64	1.49
vertical geom. emittance [pm]	1.42	4.34	1.29	2.98
horizontal rms IP spot size [μm]	8	21	14	39
vertical rms IP spot size [nm]	34	66	36	69
luminosity per IP [10^{34} $cm^{-2}s^{-1}$]	182	19.4	7.3	1.33
total integrated luminosity / year [ab^{-1}/yr] 4 IPs	87	9.3	3.5	0.65
beam lifetime (rad Bhabha + BS+lattice)	8	18	6	10
	4 years 5 x 10^{12} Z LEP x 10^5	2 years > 10^8 WW LEP x 10^4	3 years 2 x 10^6 H	5 years 2 x 10^6 tt pairs

Currently assessing technical feasibility of changing operation sequence (e.g. starting at ZH energy)

- x10-50 improvements on all EW observables
- up to x10 improvement on Higgs coupling (model-indep.) measurements over HL-LHC
- x10 Belle II statistics for b, c, τ
- indirect discovery potential up to ~ 70 TeV
- direct discovery potential for feebly-interacting particles over 5-100 GeV mass range

Up to 4 interaction points → robustness, statistics, possibility of specialised detectors to maximise physics output

FCC-hh: machine parameters and physics potential

Parameter	FCC-hh	
collision energy cms [TeV]	80-116	
dipole field [T]	14 (Nb_3Sn) – 20 (HTS/Hybrid)	
circumference [km]	90.7	
beam current [A]	0.5	
bunch intensity [10^{11}]	1	1
bunch spacing [ns]	25	25
synchr. rad. power / ring [kW]	1020-4250	
SR power / length [W/m/ap.]	13-54	
long. emit. damping time [h]	0.77-0.26	
beta* [m]	1.1	0.3
normalized emittance [μm]	2.2	
peak luminosity [10^{34} $cm^{-2}s^{-1}$]	5	30
events/bunch crossing	170	1000
stored energy/beam [GJ]	6.1-8.9	
integrated luminosity [fb^{-1}]	20000	

Formidable physics reach, including:
- ❑ Direct discovery potential up to ~ 40 TeV
- ❑ Measurement of Higgs self to ~ 5% and ttH to ~ 1%
- ❑ High-precision and model-indep (with FCC-ee input) measurements of rare Higgs decays ($\gamma\gamma$, $Z\gamma$, μμ)
- ❑ Final word about WIMP dark matter
- ❑ Insight into EW phase transition in early universe

Formidable challenges:
- ❑ high-field superconducting magnets: 14 - 20 T
- ❑ power load in arcs from synchrotron radiation: 4 MW → cryogenics, vacuum
- ❑ stored beam energy: ~ 9 GJ → machine protection
- ❑ pile-up in the detectors: ~1000 events/xing
- ❑ energy consumption: 4 TWh/year → R&D on cryo, HTS, beam current, …

If FCC-hh after FCC-ee: significantly more time for high-field magnet R&D aiming at highest possible energies

FCC Mid-term review- next ESPP Update

FCC Mid-term report presented end of 2023

Deliverables (approved by Council in Sept 2022):

- D1 : Definition of the baseline scenario
- D2 : Civil engineering
- D3 : Processes and implementation studies with the Host States
- D4 : Technical infrastructure
- D5 : FCC-ee accelerator
- D6: FCC-hh accelerator
- D7: Project cost and financial feasibility
- D8: Physics, experiments and detectors

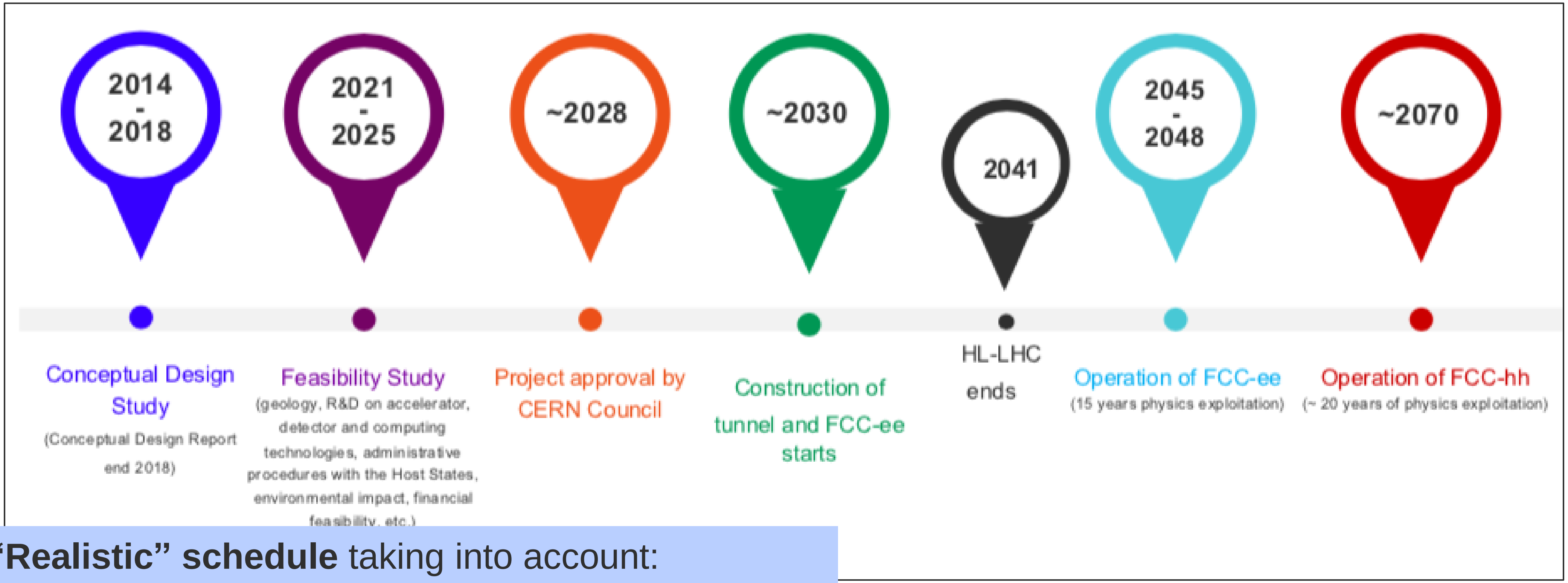
Conclusion
Very positive feedback by all committees.
No technical show-stopper found at this stage.

Review steps:
- Oct 2023: FCC Scientific Advisory Committee (scientific and technical aspects) and Cost Review Panel (ad hoc committee; cost and financial aspects)
- Nov 2023: SPC and FC
- 2 Feb 2024: Council

Timeline for next Update of the European Strategy for Particle Physics

- ❑ March 2024 Council anticipated next update by one year
- ❑ 2024: preparatory year where all committees are established and venues of meetings chosen
- ❑ 2025: March submission of scientific input by community, June community Open Symposium, December drafting of Strategy document
- ❑ March and June 2026: Council discussion and update of the Strategy

Realistic FCC Schedule



"Realistic" schedule taking into account:
- ❑ past experience in building colliders at CERN
- ❑ preparation work of the feasibility study
- ❑ approval timeline: ESPP, Council decision
- ❑ that HL-LHC will run until ~ 2041

→ **ANY future collider at CERN cannot start physics operation before ~ 2045** (but construction will proceed in parallel to HL-LHC operation)

Care should be taken when comparing to other proposed facilities, for which in some cases only the (optimistic) technical schedule is shown

Is FCC the best facility for CERN?

1) Physics : best overall physics potential of all proposed future colliders

- ❑ FCC-ee : ultra-precise measurements of the Higgs boson, indirect exploration of next energy scale (~ x10 LHC)
- ❑ FCC-hh : only machine able to explore next energy frontier directly (~ x10 LHC)
- ❑ Also provides heavy-ion collisions and, possibly, ep/e-ion collisions

2) Timeline

- ❑ FCC-ee technology is mature → construction in parallel to HL-LHC operation and physics can start few years after end of HL-LHC operation (2045-2048) → This would keep the community, in particular the young people, engaged and motivated.
- ❑ FCC-ee before FCC-hh would also allow:
  - cost of the (more expensive) FCC-hh machine to be spread over more years
  - 20 years of R&D work towards affordable magnets providing the highest achievable field (high-T superconductors!)
  - optimization of overall investment : FCC-hh will reuse same civil engineering and large part of the technical infrastructure

3) It's the only facility commensurate to the size of the CERN community (4 major experiments)

Is it feasible? Isn't it too ambitious?

- ❑ Ongoing Feasibility Study showing spectacular progress
- ❑ FCC is big, audacious project, but so were LEP and LHC when first conceived → they were successfully built and performed far beyond expectation → demonstration of capability of our community to deliver on very ambitious projects
- ❑ FCC is best project for future of CERN (for above reasons) → we have to work to make it happen

Joint Statement of CERN and US

Joint Statement of Intent between the US and CERN concerns future planning for large research infrastructures, advanced scientific computing and open science signed in Washington DC April 2024

Concerning the proposed Future Circular Collider, FCC-ee, the text states:

“Should the CERN Member States determine the FCC-ee is likely to be CERN’s next world-leading research facility following the high-luminosity Large Hadron Collider, the United States intends to collaborate on its construction and physics exploitation, subject to appropriate domestic approvals.”

CERN Director-General, Fabiola Gianotti (right), and Principal Deputy US Chief Technology Officer, Deirdre Mulligan, of the White House Office of Science and Technology (left) at the signing ceremony. (Image: US Department of State, Bureau of Oceans and International Environmental and Scientific Affairs)

Summary

CERN has an exciting, unique scientific programme now and in the future, with numerous challenges and great prospects, supported by a remarkable accelerator complex and other world-leading infrastructure and services, backed by profound technology base and outstanding personnel expertise.

The contributions of countries from all over the world to CERN’s scientific programme are and will continue to be crucial to accomplish CERN’s mission.
In particular the support to, and trust and confidence in, CERN and its personnel by CERN’s Member and Associate Member States is important now and for future projects.

The large and diverse CERN scientific community, from all continents and from many physics and engineering disciplines, is at the heart of all the successes achieved at CERN. The FCC will provide them the best physics opportunities for the future.

Thank you

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