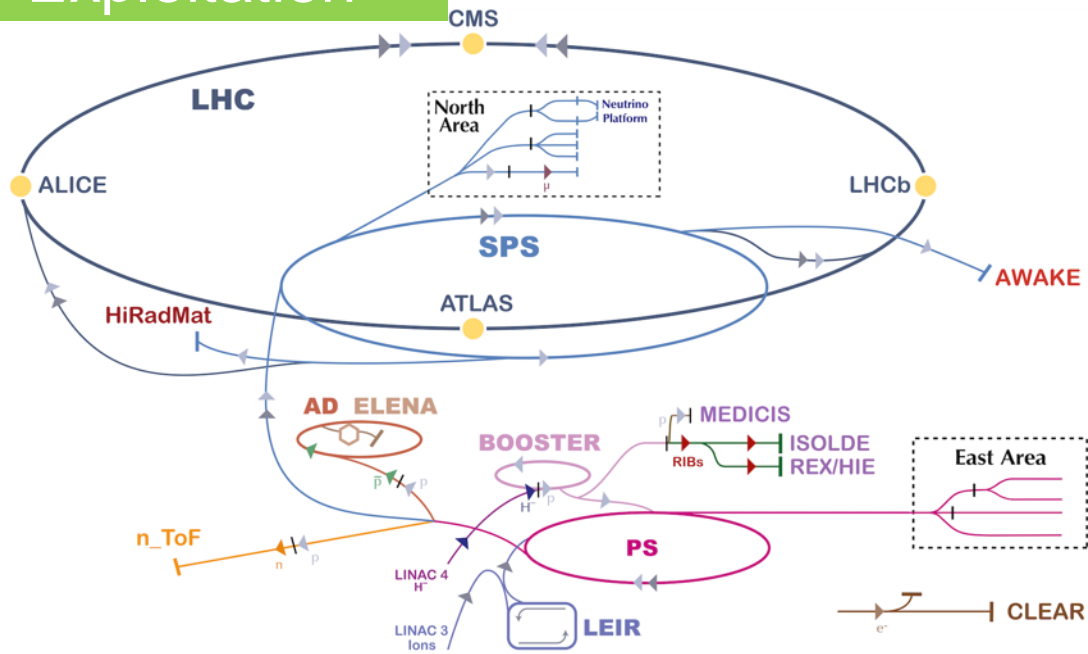




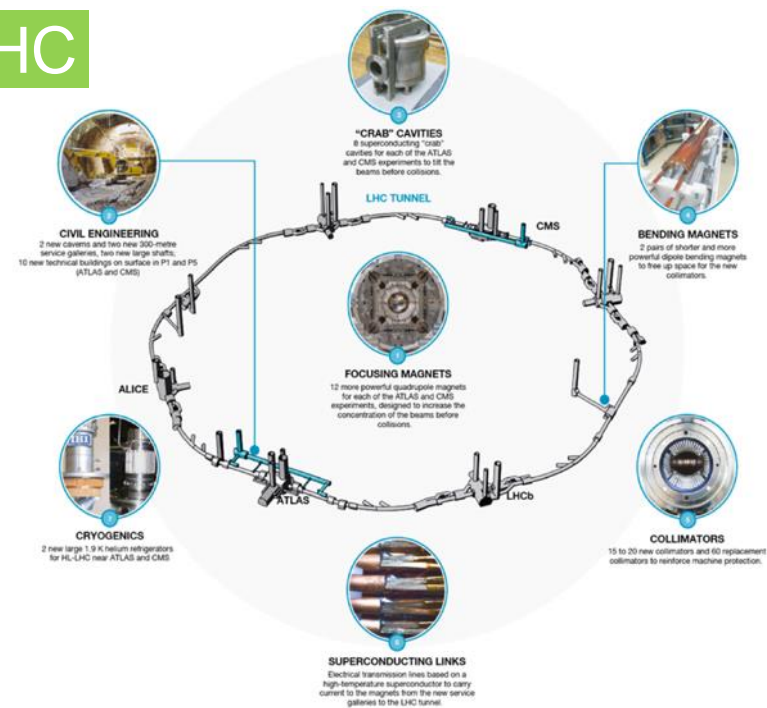
# CERN's Collider Options: The Path Forward

Mike Lamont  
Particle Accelerators and Beams Conference  
30<sup>th</sup> June 2023

# Exploitation



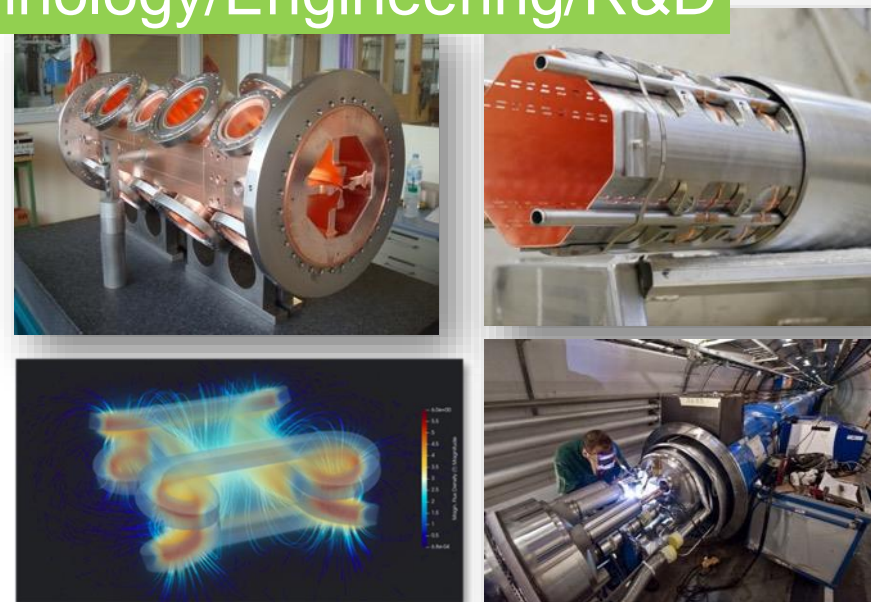
# HL-LHC



# Future Options



# Technology/Engineering/R&D



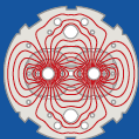
# European Strategy for Particle Physics 2020 Update

*The successful completion of the high-luminosity upgrade of the machine and detectors should remain the **focal point of European particle physics**, together with continued innovation in experimental techniques.*

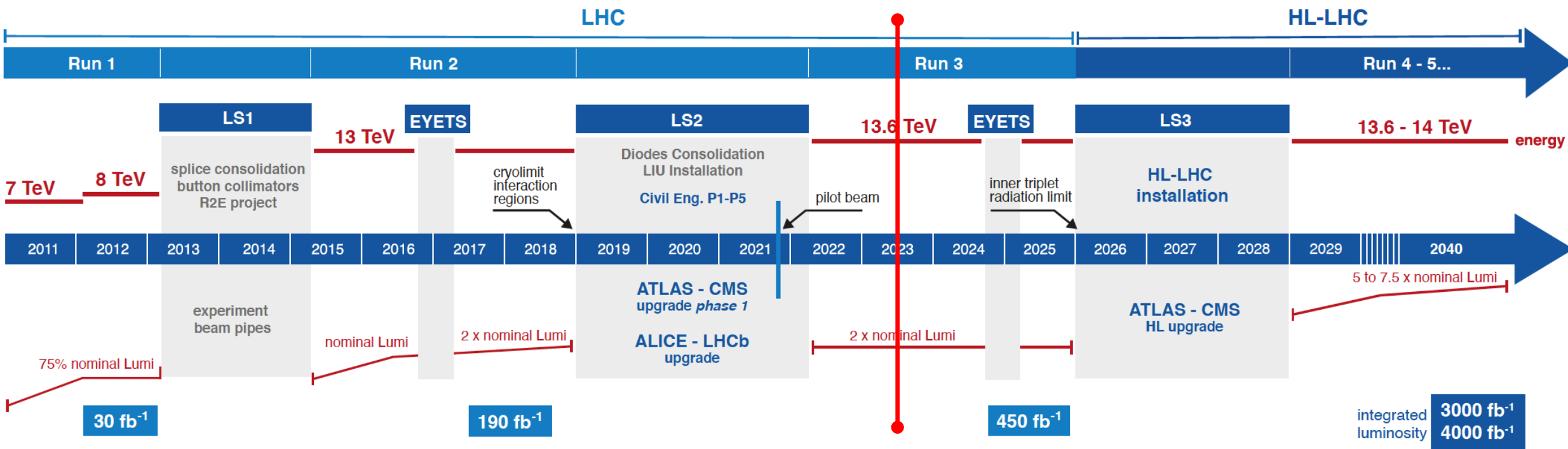
*The full physics potential of the **LHC and the HL-LHC**, including the study of flavour physics and the quark-gluon plasma, should be exploited.*

## 2022 Snowmass Energy Frontier Summary

***Our highest immediate priority accelerator and project is the HL-LHC**, the successful completion of the detector upgrades, operations of the detectors at the HL-LHC, data taking and analysis, including the construction of auxiliary experiments that extend the reach of HL-LHC in kinematic regions uncovered by the detector upgrades.*



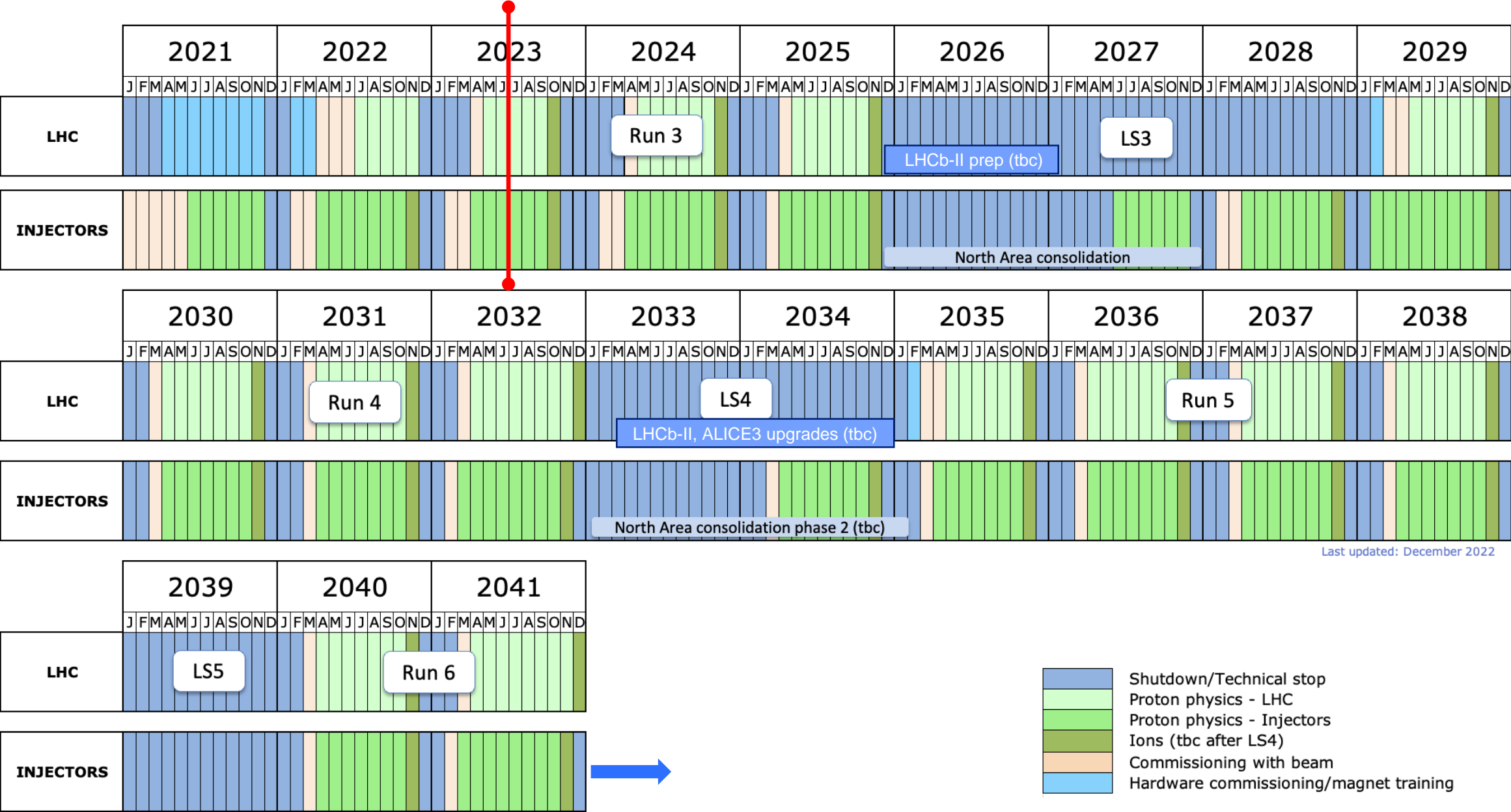
# LHC / HL-LHC Plan



## HL-LHC TECHNICAL EQUIPMENT:

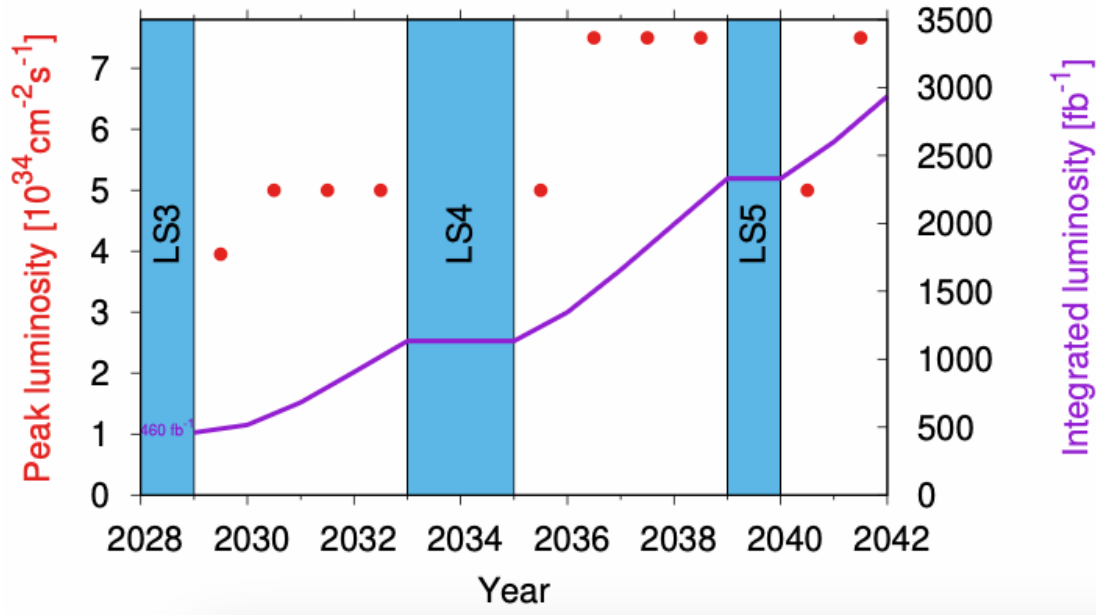


# Securing the medium-term future



Last updated: December 2022

# LHC: diverse physics programme



**The HL-LHC offers a unique opportunity to test BSM physics**

Opportunities	Open problem in particle physics
<b>Higgs &amp; electroweak symmetry breaking</b> Precision program, rare events, CPV	EWSB
<b>New particles</b> New resonances, squeezed spectra, long lived particles	hierarchy problem
<b>Heavy New Physics</b> Effective field theories & effects in distributions at high energy	Dark matter, baryon anti-baryon asymmetry, strong CP problem,
<b>Dark Matter/dark sector</b> Light dark resonances at the LHC/LHCb!	flavor puzzle
<b>Flavor sector</b> Indirect tests of flavorful New Physics	

**Headline deliverable is  $3 \text{ ab}^{-1} \text{ p-p}$**  but the physics programme promises to be impressively diverse...

Ions (ALICE3 proposed for LS4)

b-physics (LHCb-II upgrade proposed for LS4)

Forward physics (CMS-PPS2)

Neutrinos (SND, FASERnu, *Forward Physics Facility*)

Long Lived Particles (GPDs, FASER, MoEDAL, *milliQan*, *FPF*, *CODEX-b*, *MATHUSLA*, *ANIBUS*)

Fixed target (SMOG-2, *Crystal-FT*)

# ESPPU2022 also said...

**“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.”**

**CLIC, Muon Collider, ILC also in the mix**

# Future Collider options

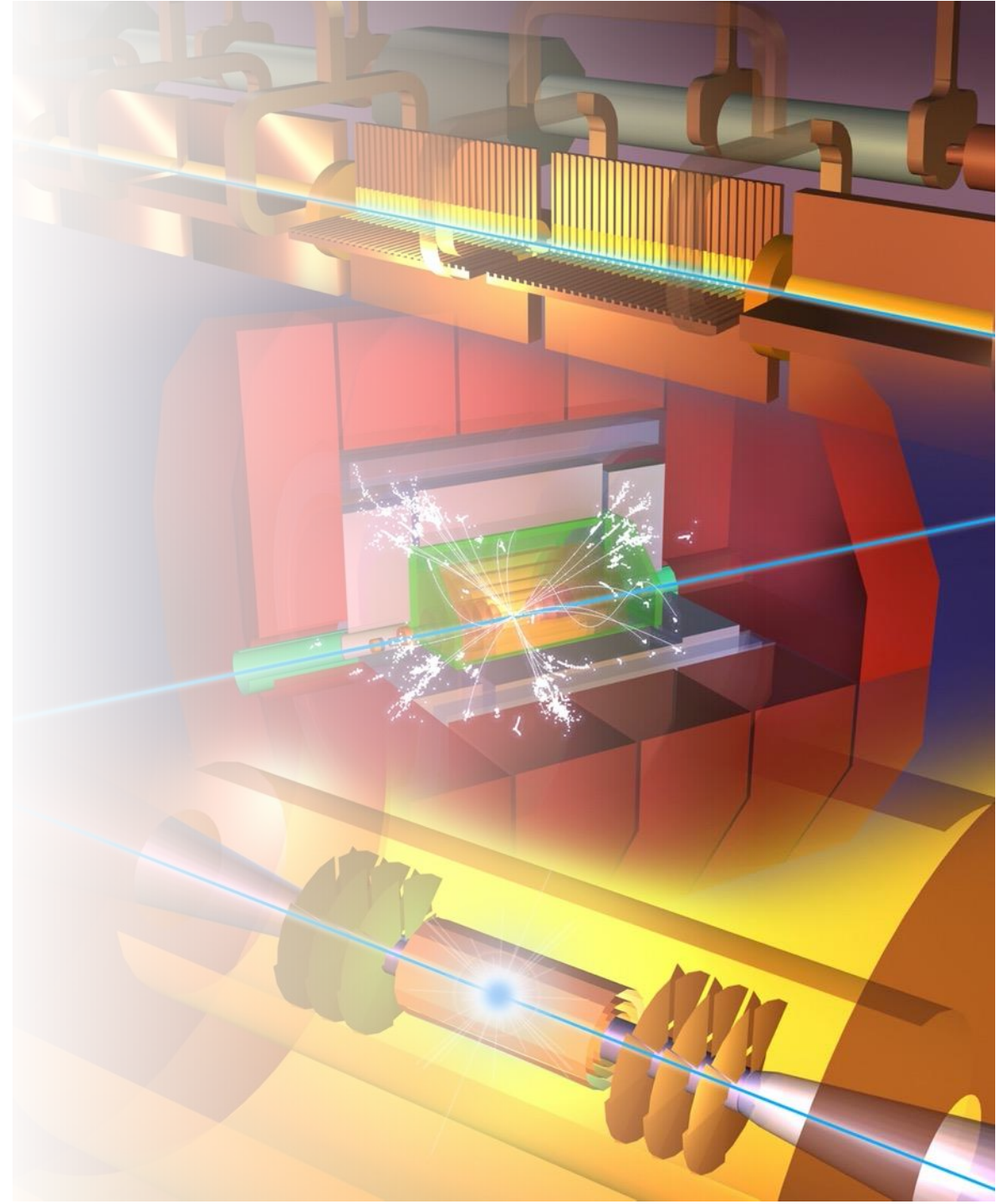
## Higgs factory

- Plan A1: **FCC-ee**
- Plan A2: **ILC in Japan**
- Plan B: **CLIC**
- Plan C: CepC, C<sup>3</sup>

## Multi-TeV

- e+e- : **CLIC**, C<sup>3</sup>
- muons: **Muon Collider**
- protons: **FCC-hh**, SppC

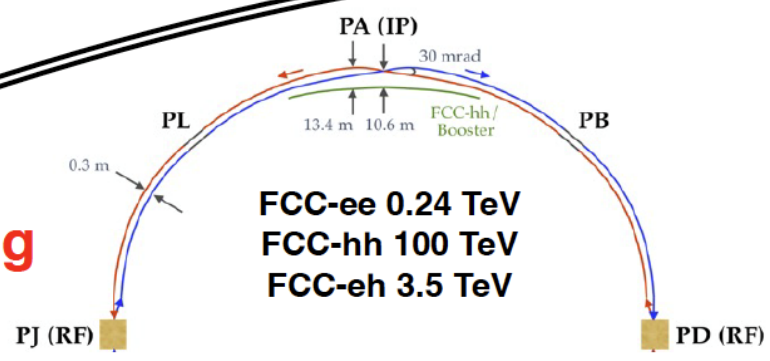
**Options** under consideration at CERN given by  
European Strategy for Particle Physics Update 2020





# Future collider proposals: 0.125 – 500 TeV; e+e-, hh, eh, μμ, γγ, ...

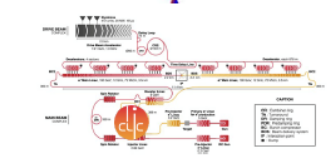
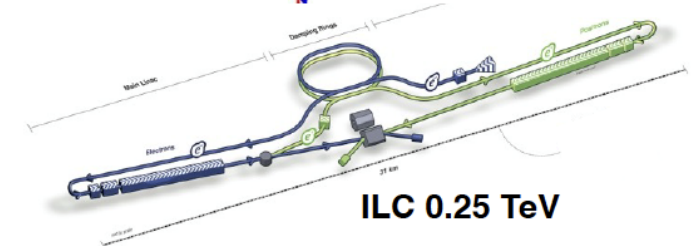
**Storage ring colliders**



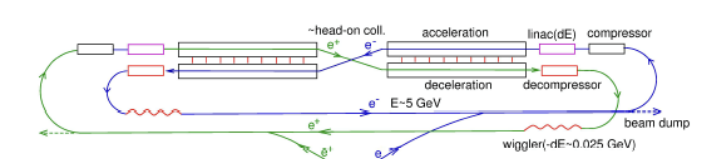
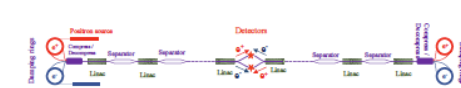
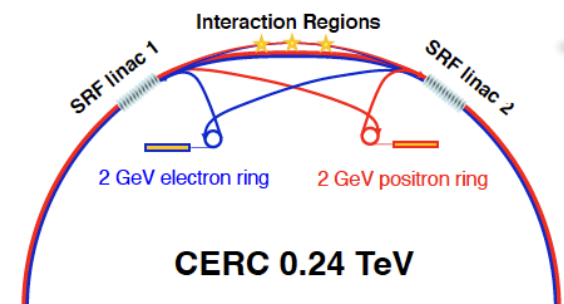
**CEPC 0.24 TeV**  
**SPPC 125 TeV**  
**SPPC-CEPC 5.5 TeV**

**Collider-in-the-sea 500 TeV**

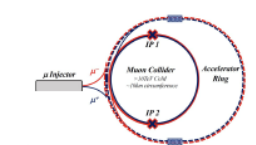
**Linear colliders**



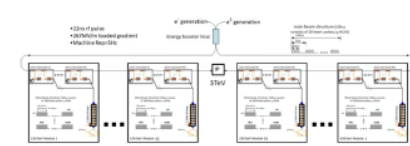
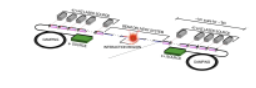
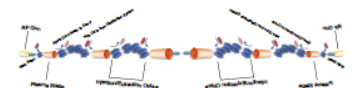
**ERL colliders**



**Muon collider**



**Wakefield colliders**



10 km

**Snowmass'21  
Collider Implementation  
Task Force**

# Recall Context

On the ground, the HL-LHC baseline schedule foresees operation until to the end 2041.

**CERN/European Physics Community is positioning themselves to be able to start operating a new major facility in the second half of the forties (2045 - 2050).**

That major new facility should be an e+e- Higgs factory.

Next ESPP update: ~2026-2027 – confirmation of priorities – down-selection

This could imply approval and resource commitment in the 2028 – 2030 timeframe, with subsequent project preparation and execution in the following decade.

There are clear implications for the necessity to bring to maturity any requisite technology for the alternatives under consideration. Given the projected large scale component production in the thirties, associated accelerator and detector technologies would need to be relatively mature as one moves into that phase.

# Options at CERN

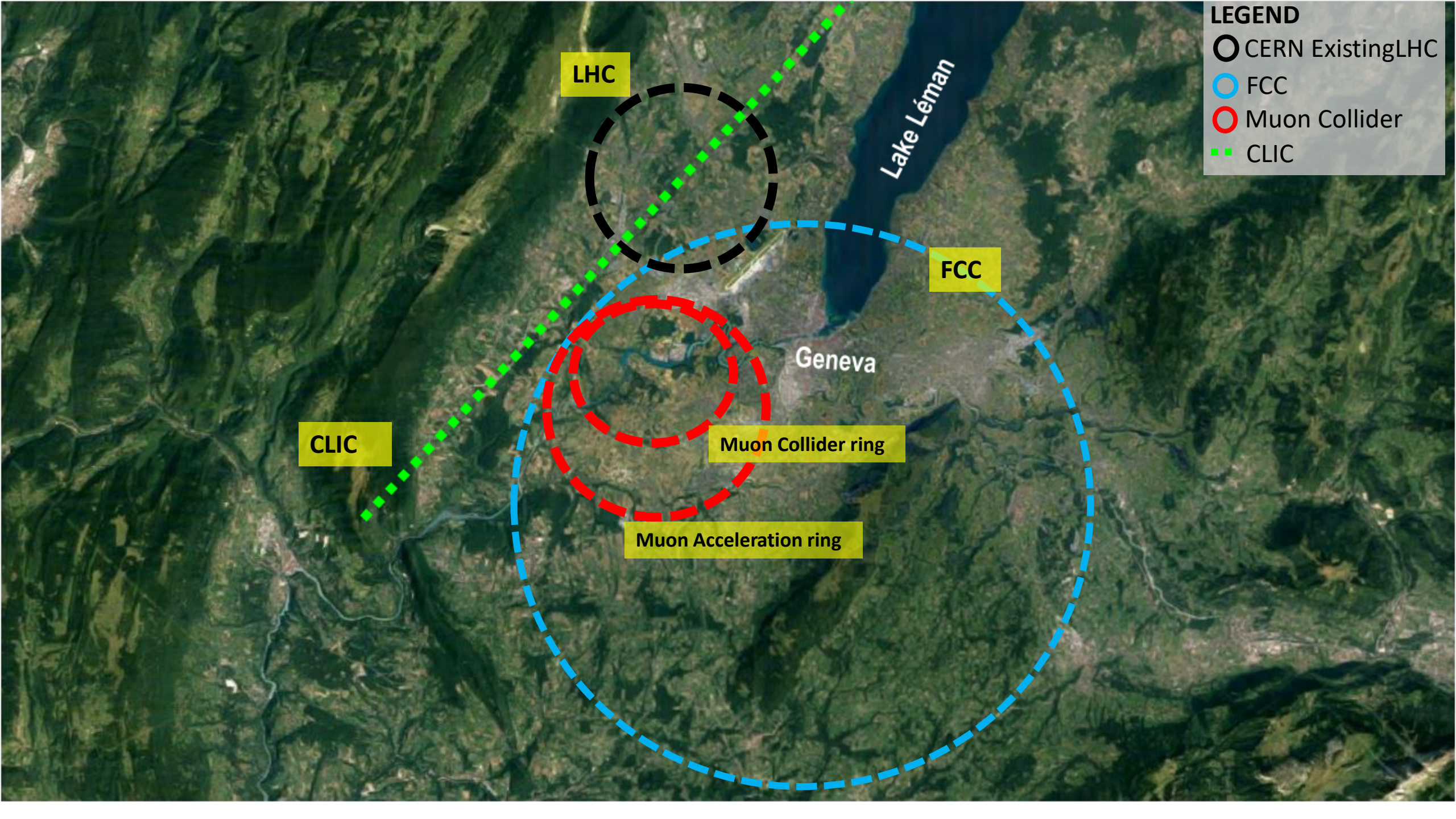
## Options within specified timeframe

- **FCC-ee**
- **CLIC-380**
- **(ILC-250)**
- **(LEP3, LHeC, HE-LHC)**

## Options outside specified timeframe

- **Muon Collider**
- **FCC-hh (natural follow-on to FCC-ee)**
- **++**

**Options possibly in timeframe not at CERN: ILC, CEPC, C<sup>3</sup>**



**LEGEND**

- CERN Existing LHC
- FCC
- Muon Collider
- CLIC

LHC

FCC

CLIC

Muon Collider ring

Muon Acceleration ring

Geneva

Lake Léman

# In brief...

Option	Status
<b>FCC feasibility study</b>	Good progress – delivery of study foreseen end 2025 Serious mid-term review – Q4 2023
<b>ILC</b>	Mature design, slow progress moving to Pre-lab phase Targeted R&D phase as a bridge (ITN)
<b>CLIC</b>	Mature design, X-band KT, luminosity optimization, sustainability studies Project Readiness Report as a step toward a TDR for next ESPPU
<b>Muon collider</b>	International Study established, collaboration up and running Successful INFRA-DEV bid (MuCol), lively interest
<b>Physics Beyond Colliders</b>	Numerous smaller scale initiatives, medium scale projects under active consideration (ECN3 options, Forward Physics Facility)

# Accelerator R&D



## Accelerator technologies and R&D

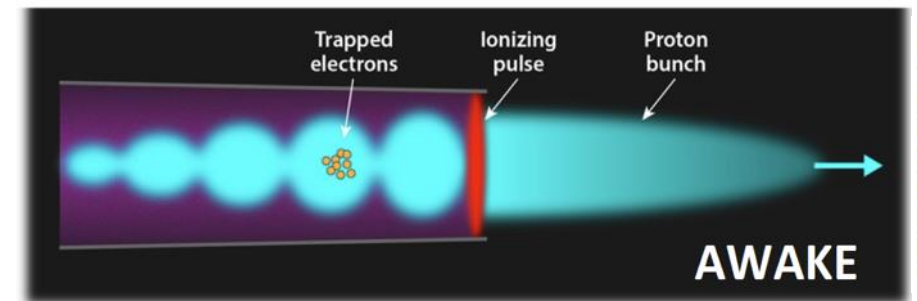
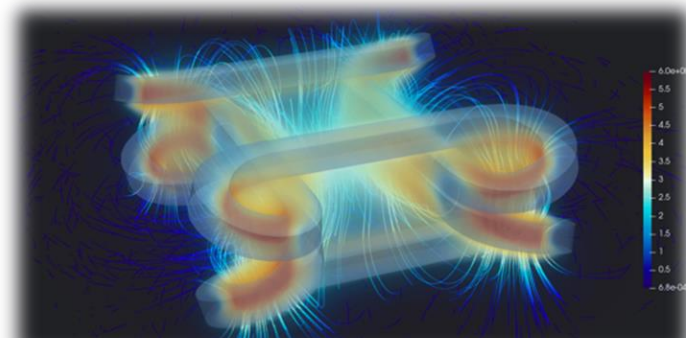
RF technologies R&D (SRF, X-band)

High-field superconducting accelerator magnets R&D

Proton-driven plasma wakefield acceleration (AWAKE)

CERN Linear Electron Accelerator for Research (CLEAR)

Other accelerator R&D



# **FCC Feasibility Study 2021-2025: main objectives**

**Geological, technical, environmental and administrative feasibility**

**Optimisation of placement and layout of the ring and related infrastructure**

**Preparatory administrative processes**

**Optimisation of the design of FCC-ee and FCC-hh**

**Sustainable operational model for the machine and experiments**

**Consolidated cost estimate, as well as the funding and organisational models**

**Identification of substantial resources from outside CERN's budget**

**Consolidation of the physics case and detector concepts and technologies**

**Serious mid-term review (including cost) incoming this year**

FCC Week 2023

473 participants

362 in person  
and 111 remote

Great progress  
everywhere!

A wonderful energetic &  
competent team and it's  
getting younger.





# Optimized placement and layout for feasibility study

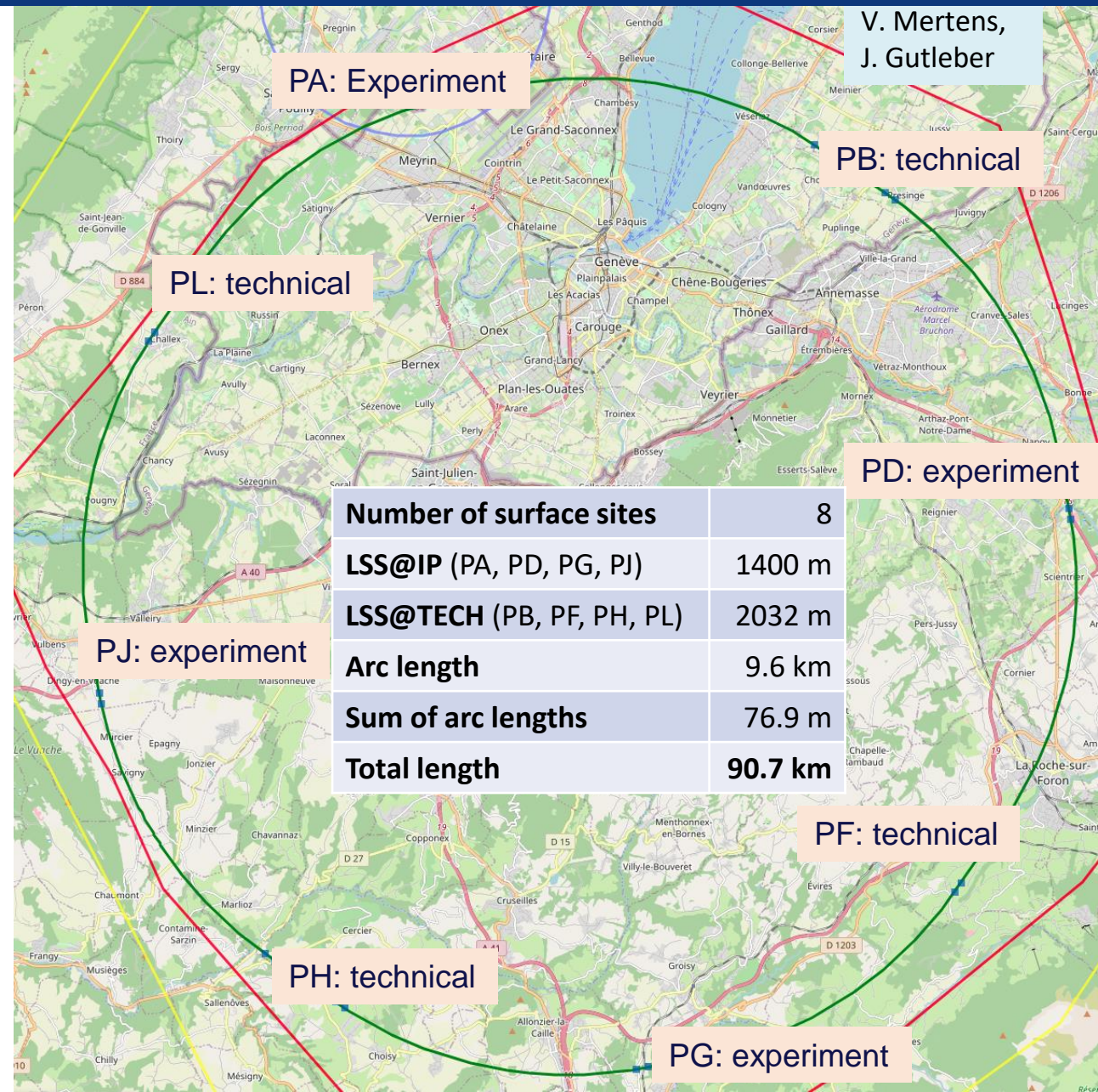
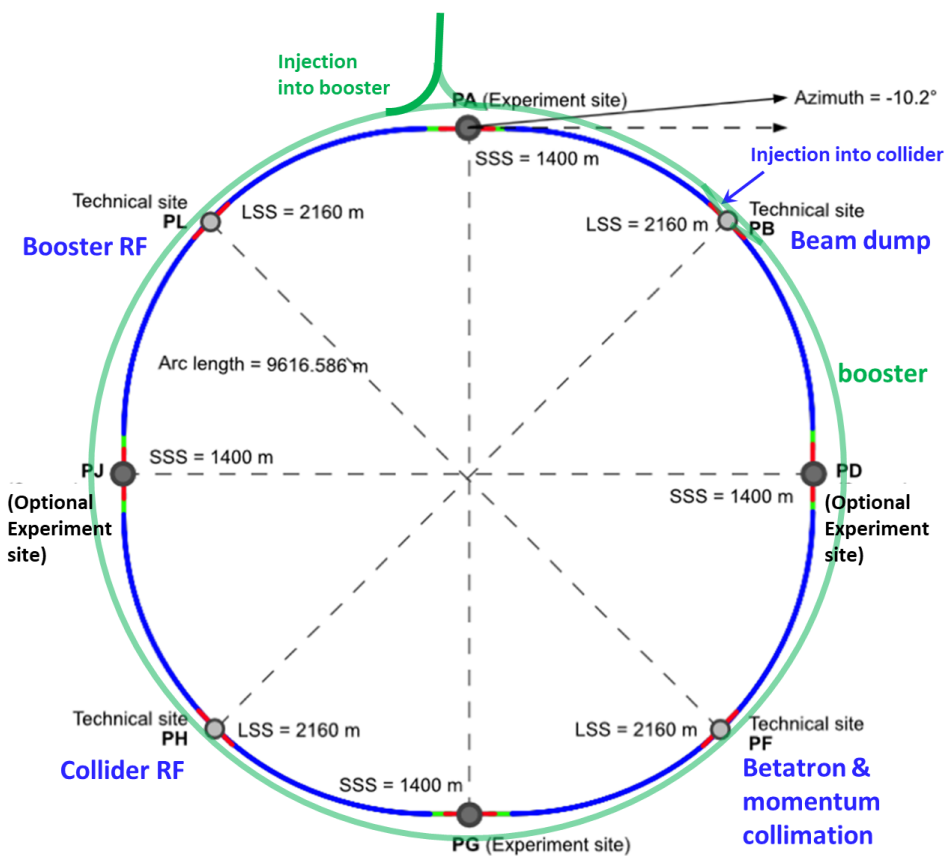
## Major achievement: optimization of the ring placement

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), etc.

“Éviter, réduire, compenser” principle of EU and French regulations

## Lowest-risk baseline: 90.7 km ring, 8 surface points, 4-fold superperiodicity, possibility of 2 or 4 IPs

Whole project now adapted to this placement



V. Mertens,  
J. Gutleber

<b>Number of surface sites</b>	<b>8</b>
<b>LSS@IP (PA, PD, PG, PJ)</b>	<b>1400 m</b>
<b>LSS@TECH (PB, PF, PH, PL)</b>	<b>2032 m</b>
<b>Arc length</b>	<b>9.6 km</b>
<b>Sum of arc lengths</b>	<b>76.9 m</b>
<b>Total length</b>	<b>90.7 km</b>

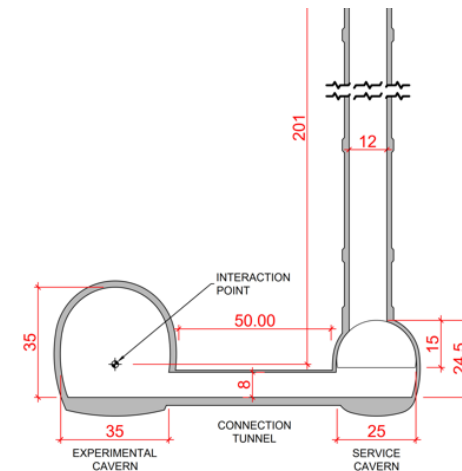
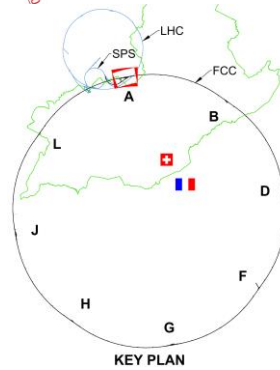
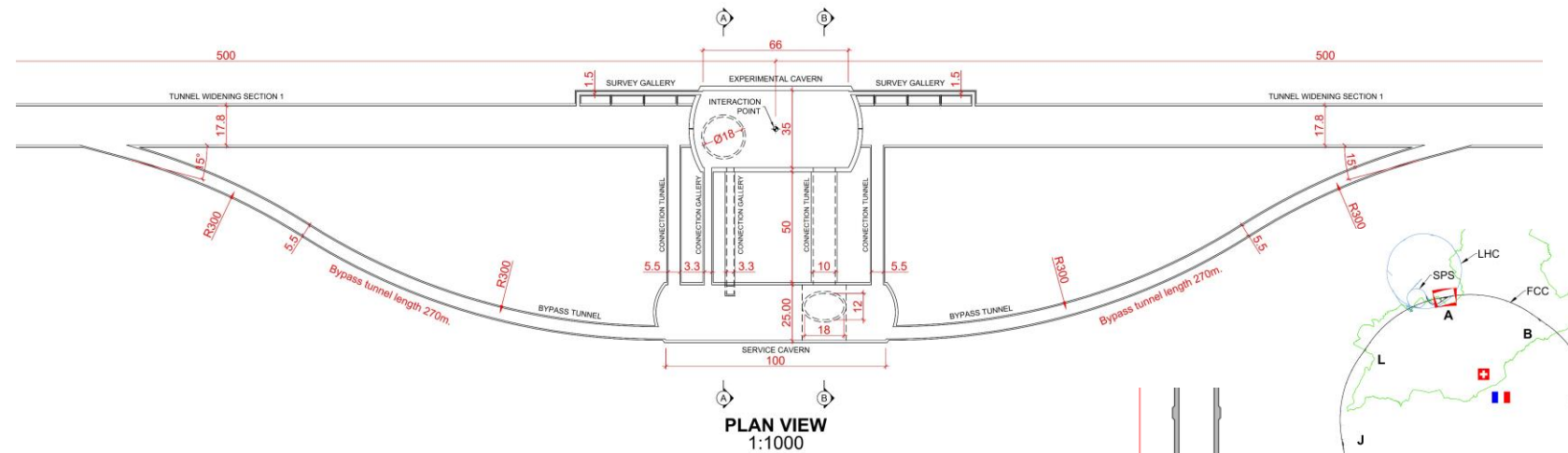
# CE underground progress

- Full 3D model of underground structures as basis for costing exercises

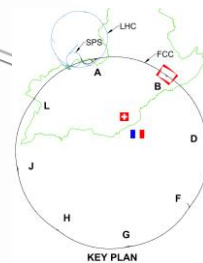
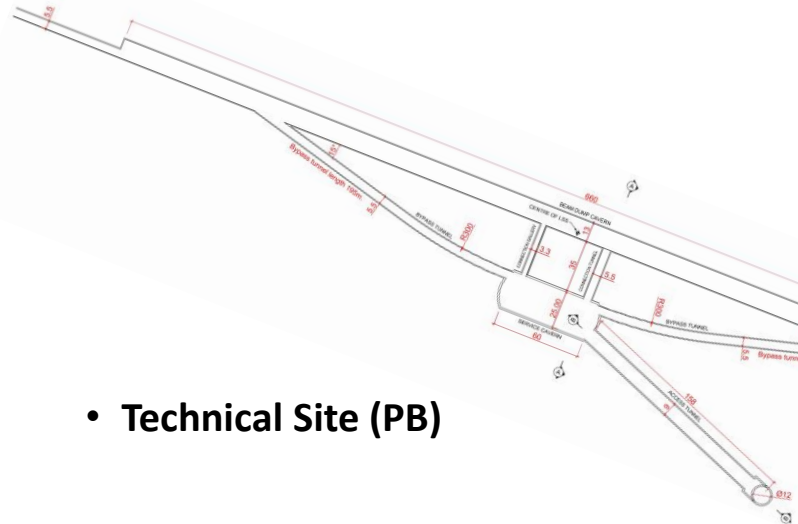
- Update of scheduling and costing with external consultant ongoing

- Independent second costing exercise based on same bill of quantities will be done

## • Experiment Site (PA)



## • Technical Site (PB)

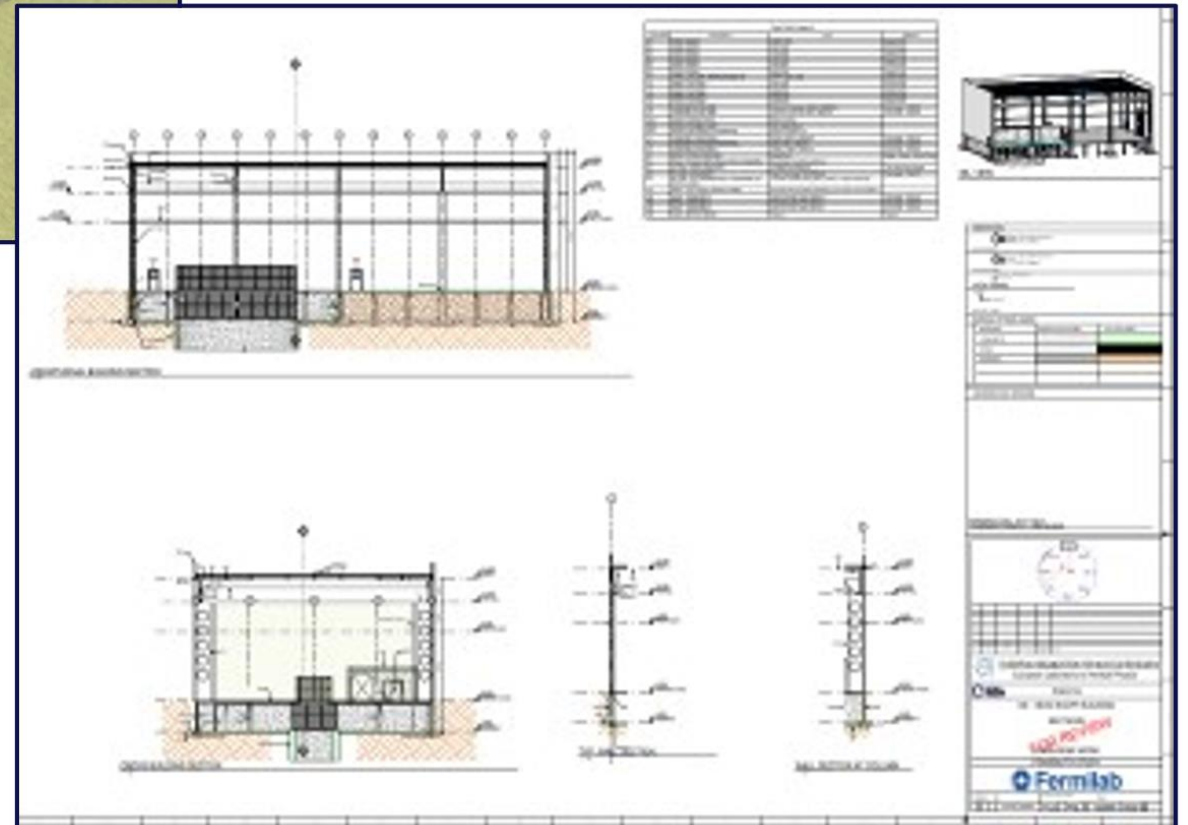




**Generic study of experiment site  
and technical site by FNAL**

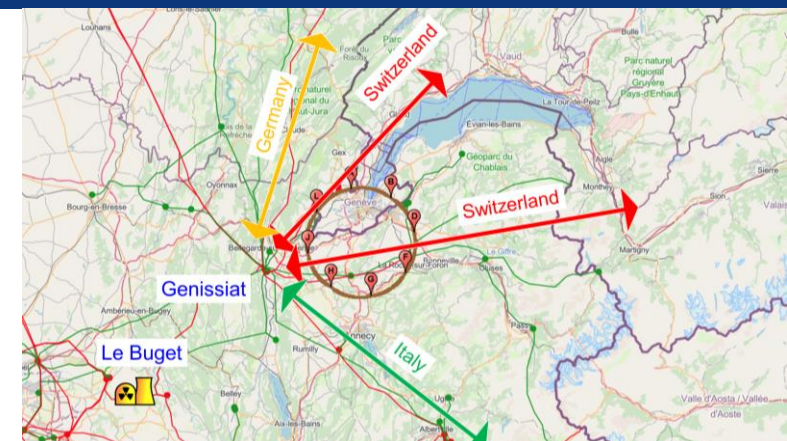
## Examples of Fermilab Deliverables

- Bills of quantities extracted from FNAL designs
- Basis for cost estimate by consultant with experience on industrial constructions in CH-FR area.



## Updated FCC-ee energy consumption

	Z	W	H	TT
Beam energy (GeV)	45.6	80	120	182.5
Max. power during beam operation (MW)	222	247	273	357
Average power / year (MW)	122	138	152	202
<b>Total yearly consumption (TWh)</b>	<b>1.07</b>	<b>1.21</b>	<b>1.33</b>	<b>1.77</b>

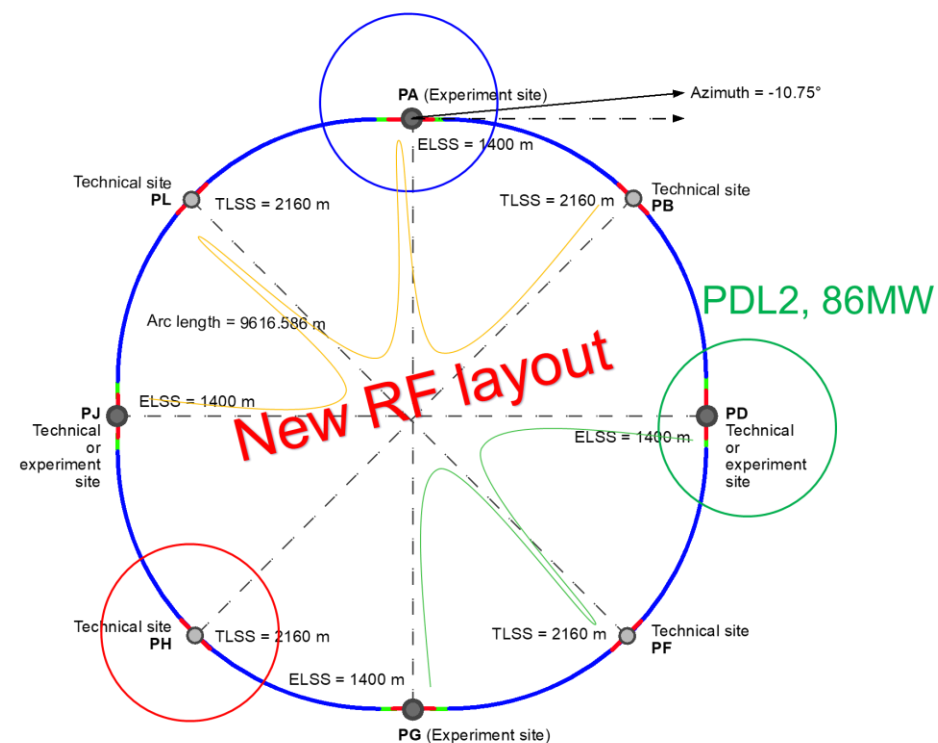


## Powering concept and max power load by sub-stations:

The loads could be charged on the three sub-stations (optimum connections to existing regional HV grid):

- **Point D, with a new sub-station** covering PB – PD – PF – PG
- **Point H with a new dedicated sub-station** for collider RF
- Point L, with a sub-station covering PJ – PL – PA
- → Alternative to new sub-station at Point L is **reusing the existing CERN Preveession station to PA**
- **All options pursued with RTE**
- **Powering concept and max. power rating of the three sub-stations compatible FCC-hh.**

PDL1, 69MW



PDL3, 201MW

## Meetings with municipalities concerned in France (31) and Switzerland (10)

**PA – Ferney Voltaire (FR) – site experimental**

**PB – Présinge/Choulex (CH) – site technique**

**PD – Nangy (FR) – site technique et experimental**

**PF – Roche sur Foron/Etaux (FR) – site technique**

**PG – Charvonnex/Groisy (FR) – site experimental**

**PH – Cercier (FR) – site technique**

**PJ – Vublens/Dingy en Vuache (FR) site technique et experimental**

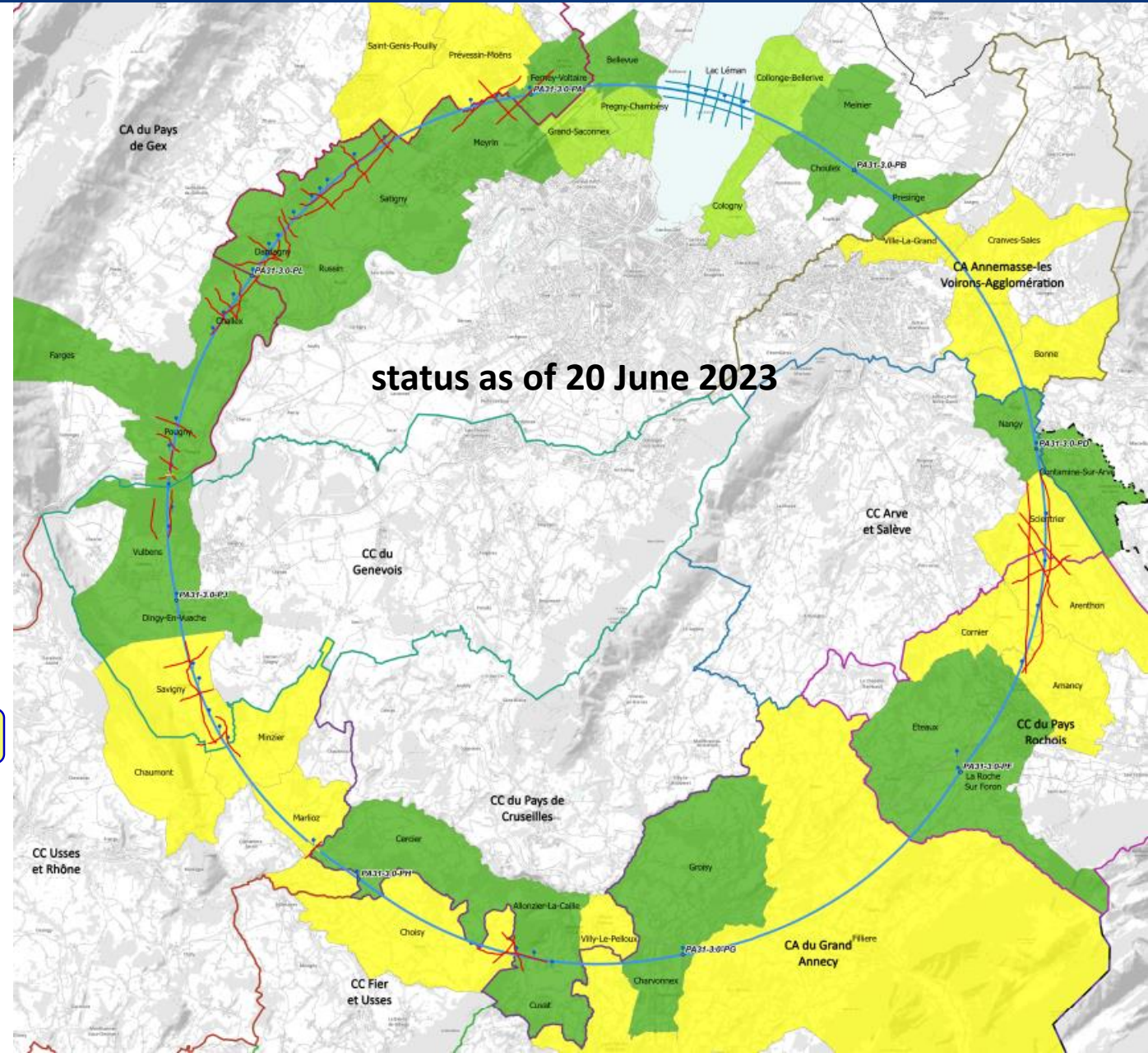
**PL – Challex (FR) – site technique**

Rencontrée individuellement

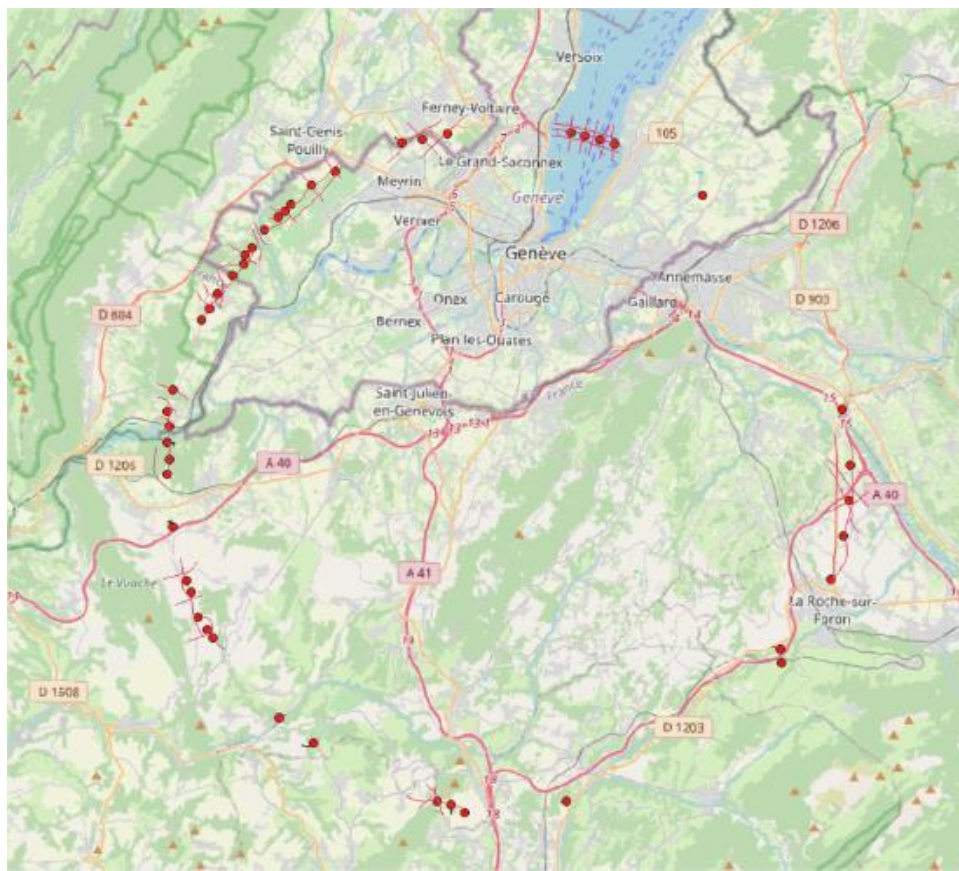
Rencontre collective

Rendez-vous proposé / programmé

- FCC study positively received by all communes
- Willingness to work on optimization of surface sites and development of synergies
- **Particular thanks to the Host State authorities**



- Environmental studies on all surface sites ongoing since February 2023
- Site investigations planned for 2024 and 2025 in areas with uncertain geological conditions:
  - Optimisation of localisation of drilling locations ongoing with site visits since end 2022.
  - Direct interaction with land plot owners only after agreement with communes concerned.
  - **Interaction with host states on authorisation procedures ongoing → critical for start of drillings in March 2024.**
  - Localisation of sites:



Sondage A89 (2007) incliné de 45° de 125 ml (surface plateforme estimée : 12 x 12 m soit environ 150 m<sup>2</sup>)

- **Composition**

  - Director General of CERN,

  - Permanent Representative of Switzerland to the international organizations in Geneva

  - Geneva State Councilor in charge of the territory

  - Prefect of the Auvergne-Rhône-Alpes region

  - Permanent Representative of France to the international organizations in Geneva.

- **Topics discussed in the 3rd meeting on 30 May 2023**

  - Progress on field studies, dialogue with communes, interaction with local media, launch of reflections on the public consultation process in France

  - Placement report and progress on surface site optimization

- **Outlook and follow-up topics**

  - Obtain authorizations for exploratory drilling from the authorities and landowners

  - Implementation of measures to preserve the land for surface sites

  - Update the placement report and surface site constraints in autumn 2023

- ❑ Implementation scenario well defined and all design parameters adapted to new layout
- ❑ Significant progress with host states at departmental/cantonal and local level. Direct exchange with communes concerned by surface sites as basis for detailed optimization. Environmental studies ongoing.
- ❑ 3D underground civil engineering model established for scheduling and costing.
- ❑ Significant effort in FCC-ee lattice design with two complete optics solutions. Major progress towards full performance simulations including beam-beam and full optics with alignment errors.
- ❑ Siting study for implementation of FCC-ee pre-injector on CERN Prévessin site. Flexible transfer line solutions for FCC-ee and hh for potential use of SPS tunnel/scSPS.
- ❑ FCC-ee SRF configuration and layout further optimized and international R&D collaborations being prepared
- ❑ FCC powering concept defined in cooperation with French network operator RTE.



# The path forward

**The vision is for another major project commensurate with the laboratory's capabilities, communities, and resources to assure the future of CERN for the next 50+ years**

- Engine for continued investment, innovation, R&D and scientific engagement
- CERN remains a world leading Research Infrastructure
- CERN remains a prestigious symbol of worldwide collaboration, scientific excellence at the leading edge
- Geopolitical implications

**The preferred direction for a future collider at CERN is the FCC**

- As mandated by the European Strategy for Particle Physics
- Feasibility study to be delivered end 2025 – expect full and detailed scrutiny
- This a big, hairy, audacious goal – but then so was LEP, so was the LHC

**There is a plan B**

# Remaining fully aligned with ESPPU2020

**Full, safe, exploitation of the remarkable potential of CERN's complex**

**HL-LHC - flagship machine at the energy frontier out to end ~2041**

**Future Colliders with FCC as the leading option – significant progress**

**Execution of a European Accelerator R&D Roadmap (High Field Magnets, RF, Muon Collider, Plasma Wakefield Acceleration)**

**Scientific diversity programme exploiting complex and facilities via Physics Beyond Colliders. Enthusiastic and ambitious user communities.**

**Sustainability and Societal impact, Outreach and Education as part of our mission. Nexus of an impressive collaborative ecosystem.**

**Thanks!**