

# Future Circular Colliders

## HEP research infrastructure for the 21st century

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on behalf of the FCC collaboration

LHC

PS

SPS

FCC



FUTURE  
CIRCULAR  
COLLIDER  
Innovation Study



<http://cern.ch/fcc>



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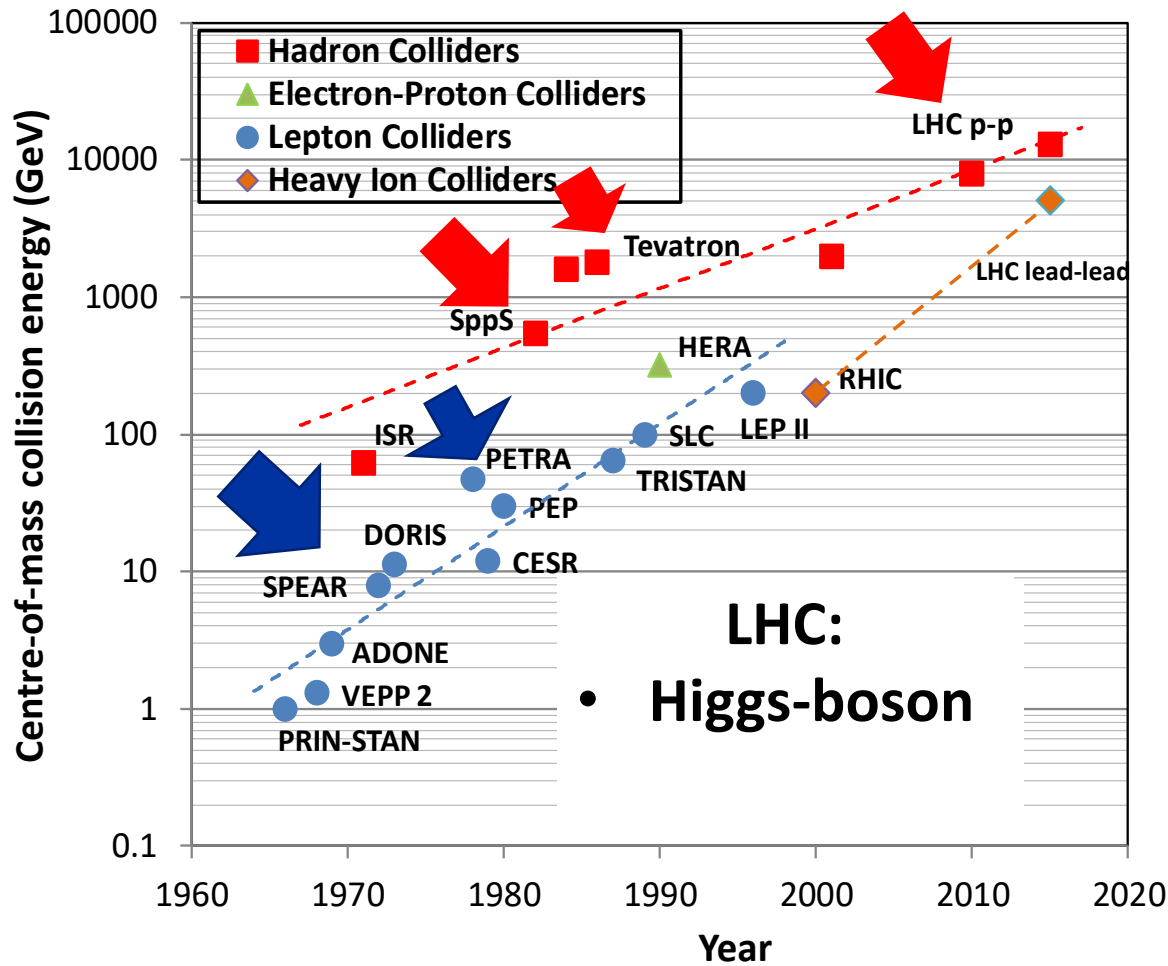


European  
Commission

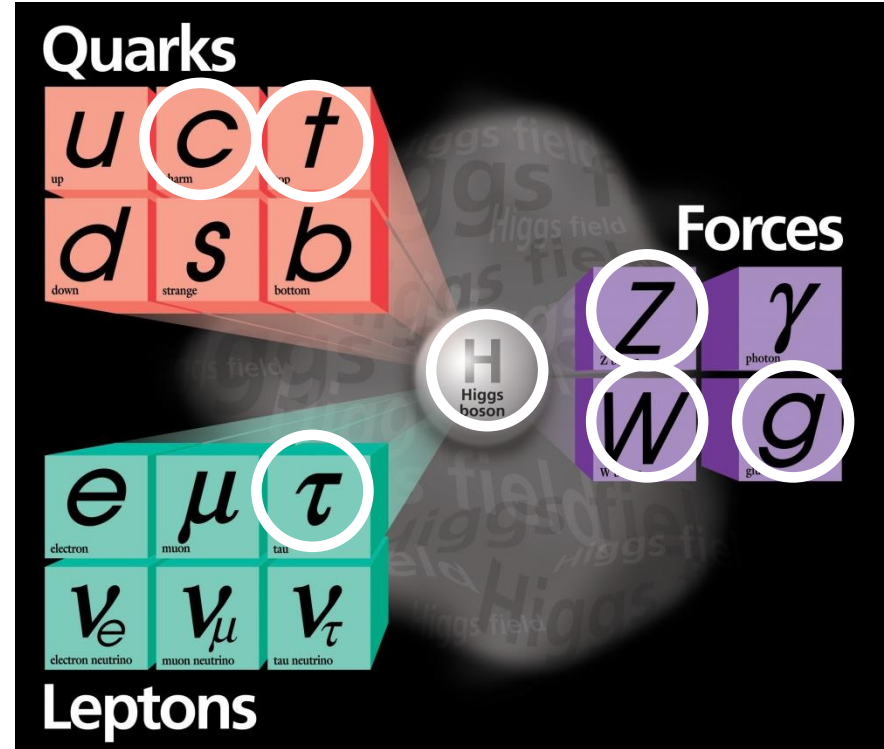
Horizon 2020  
European Union Funding  
for Research & Innovation

photo: J. Wenninger

# Discoveries with colliders



## Standard Model Particles and forces



**Colliders are powerful instruments in HEP for particle discoveries and precision measurements**

# OPEN QUESTIONS

Despite of impressive progress and discoveries in the past decades several fundamental question remain open:

Today 80 % of the mass of the universe is unknown.  
What is the universe made of?

Is there only a single type of Higgs boson and does it behave exactly as predicted?

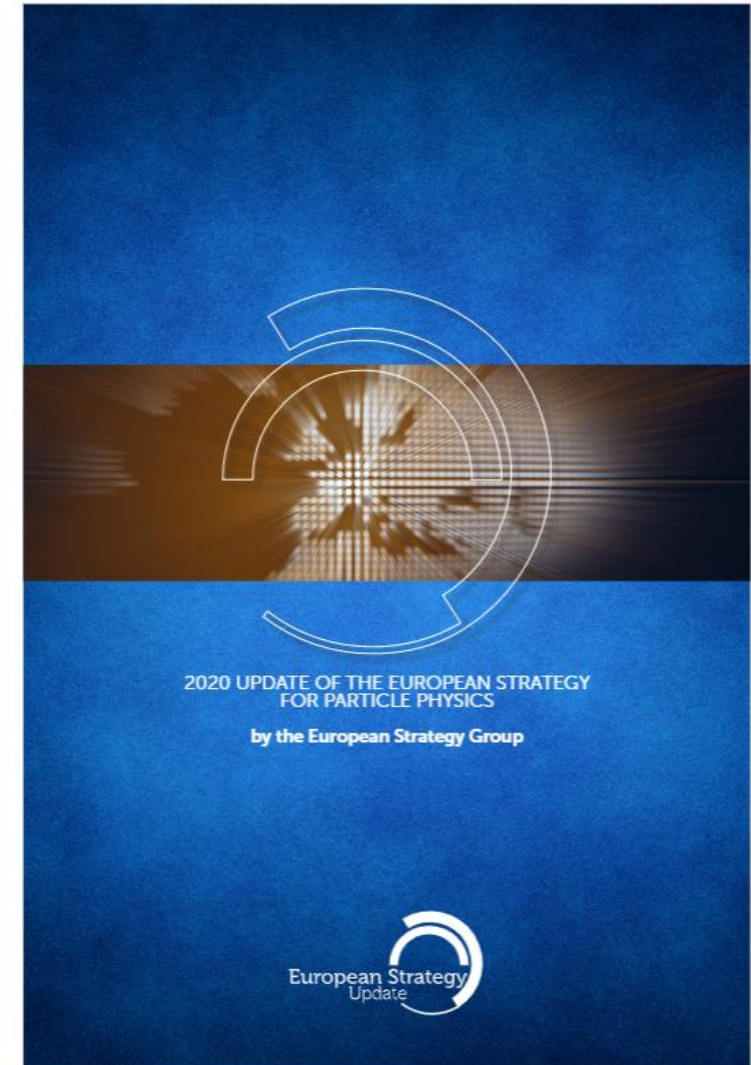
Why is the universe composed only of matter? Where has the anti-matter gone that was produced simultaneously in the big bang?

Why is the gravitation so much smaller than the other forces?  
How to reconcile gravitation with quantum mechanics?

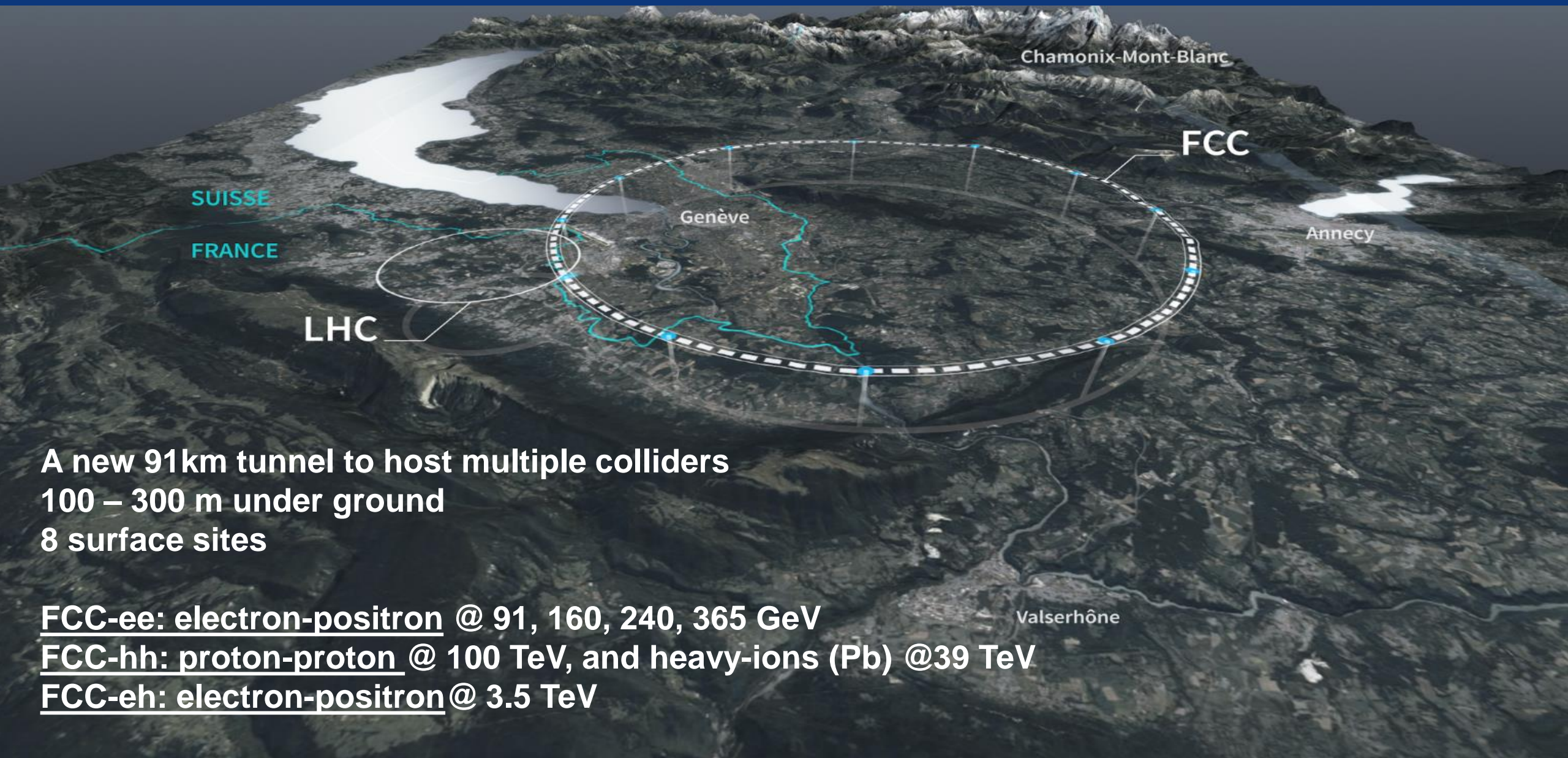


## Recommendations of the 2020 update of the European Strategy for Particle Physics (ESPP):

- Full exploitation of the high-luminosity LHC upgrade
- 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.**







A new 91km tunnel to host multiple colliders  
100 – 300 m under ground  
8 surface sites

FCC-ee: electron-positron @ 91, 160, 240, 365 GeV

FCC-hh: proton-proton @ 100 TeV, and heavy-ions (Pb) @39 TeV

FCC-eh: electron-positron@ 3.5 TeV

# The FCC integrated program inspired by successful LEP – LHC programs at CERN

comprehensive long-term program maximizing physics opportunities

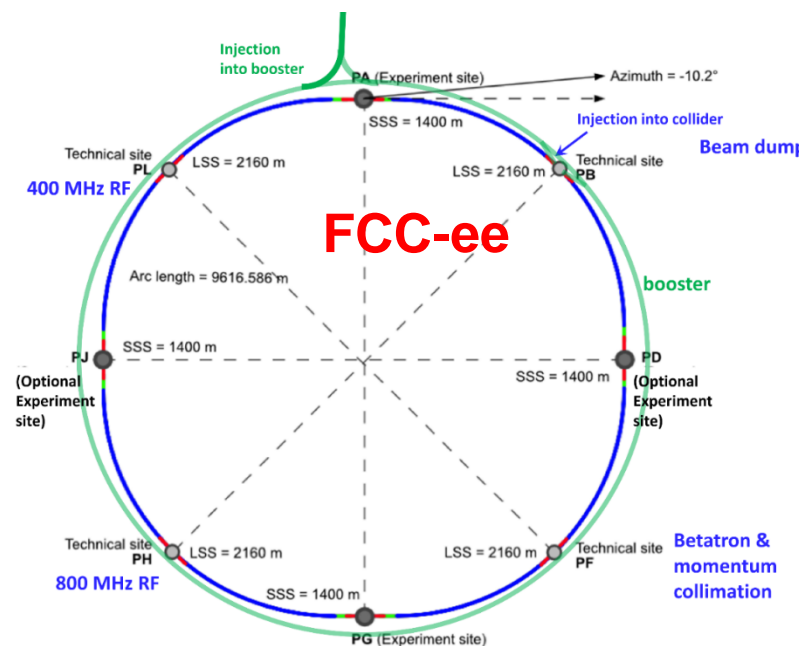
- common civil engineering and technical infrastructures, building on and reusing CERN's existing infrastructure

stage 1: FCC-ee: high-intensity electron-positron collider for detailed study of the Higgs boson ( $10^6$ ), top-quark ( $10^6$ ), W ( $10^8$ ), Z ( $10^{12}$ ) → indirect sensitivity to new physics up to ~ 70 TeV (> 10 times LHC)

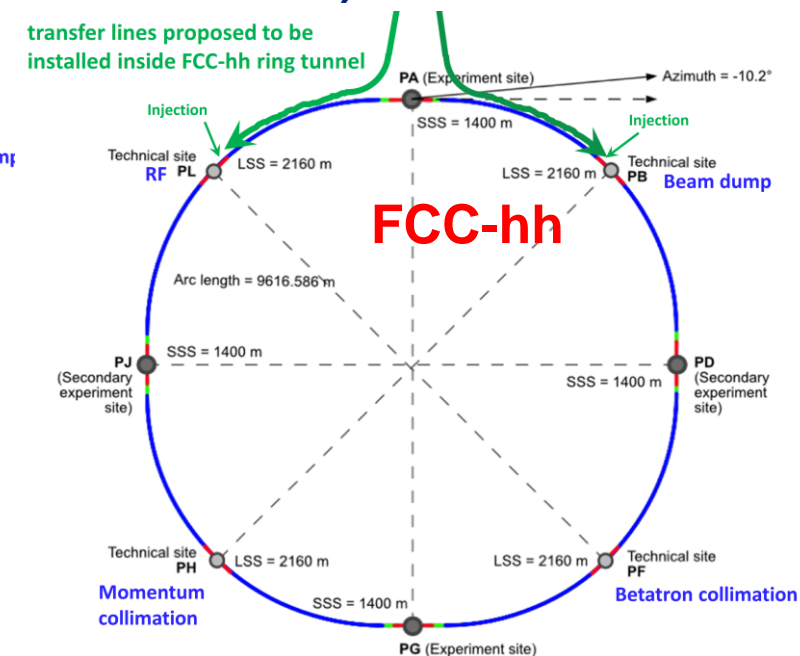
stage 2: FCC-hh: proton-proton collider with collision energy of at least 100 TeV  
→ direct discovery potential for new physics up to ~ 40 TeV (~ 10 times the LHC)



2020 - 2040



2045 - 2060

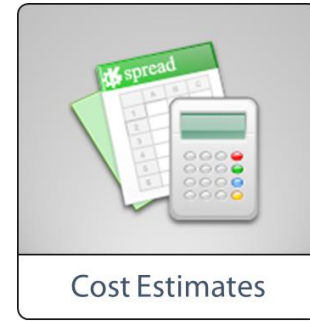
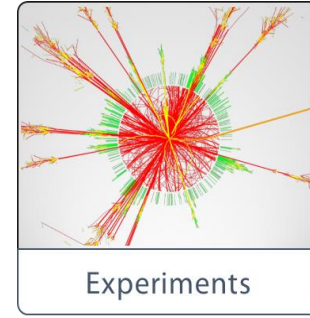
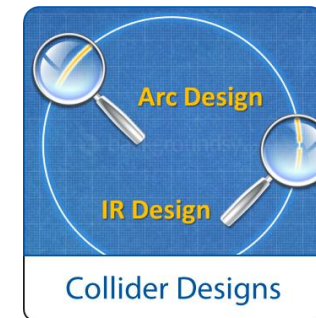
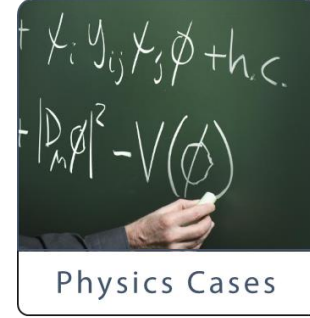
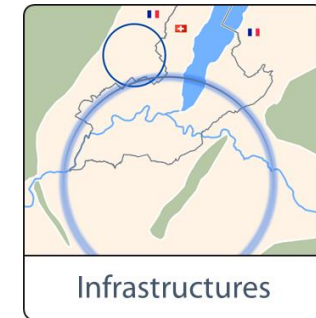


2070 - 2090++

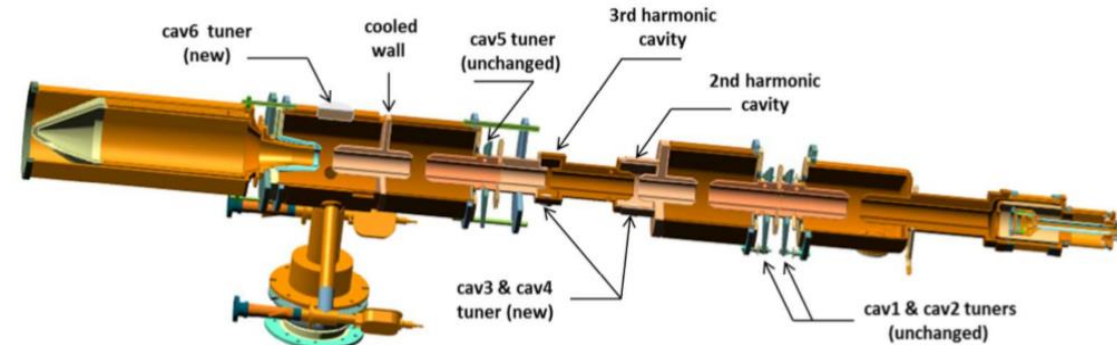


# High-level goals of the FCC Study

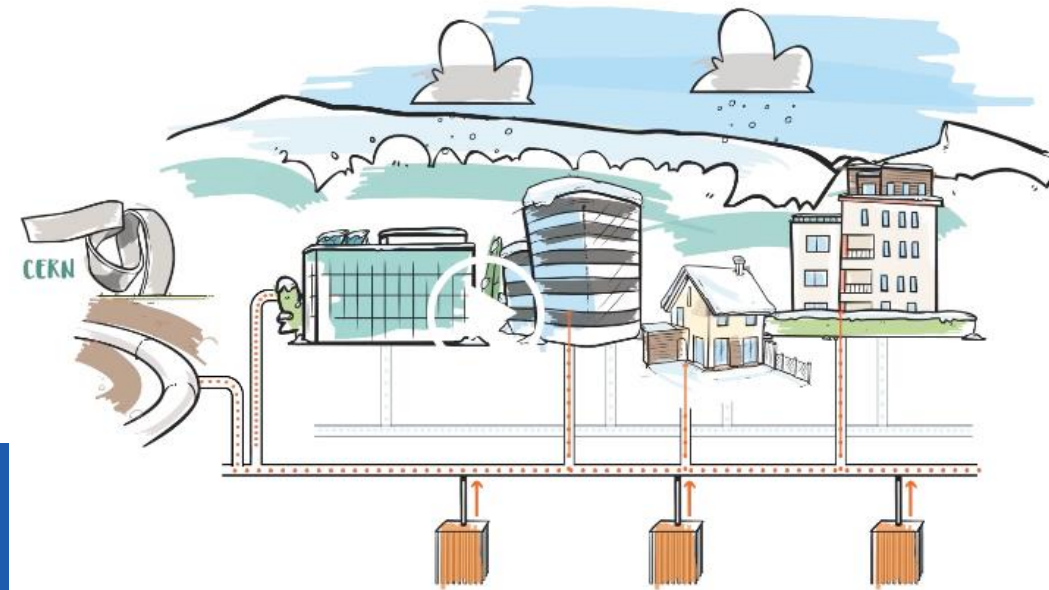
- together with the Host States, **optimisation of placement and layout of the ring**, and demonstration of the geological, technical, environmental and administrative feasibility of the tunnel and surface areas;
- **consolidation of the physics case** and detector concepts, optimisation of the **design of the colliders and their injector chains**, supported by targeted **R&D to develop the needed key technologies**;
- development of the technical infrastructure concepts and integration with territorial constraints and identification of opportunities for co-construction;
- elaboration of a **sustainable operational model for the colliders** and experiments in terms of human and financial resource needs, **environmental aspects and energy efficiency**;
- **identification of substantial resources** from outside CERN's budget for the implementation of the first stage of a possible future project;
- Final deliverable is a **Feasibility Study Report by end 2025**.



- **Technology R&D with industry**
  - Radio-frequency power production efficiency
  - Efficiency of cryogenics plants, new coolants e.g. Helium, etc.
- **Optimisation of collider operation modes**
  - Adapt operation mode and energy consumption to the availability of electrical energy on the regional grid.
- **Waste heat reuse (few 100 GWh/y potential)**
  - Identification of opportunities in the region,
  - Co-construction with local communes and regional industry. (LHC P8, 40 GWh/year).

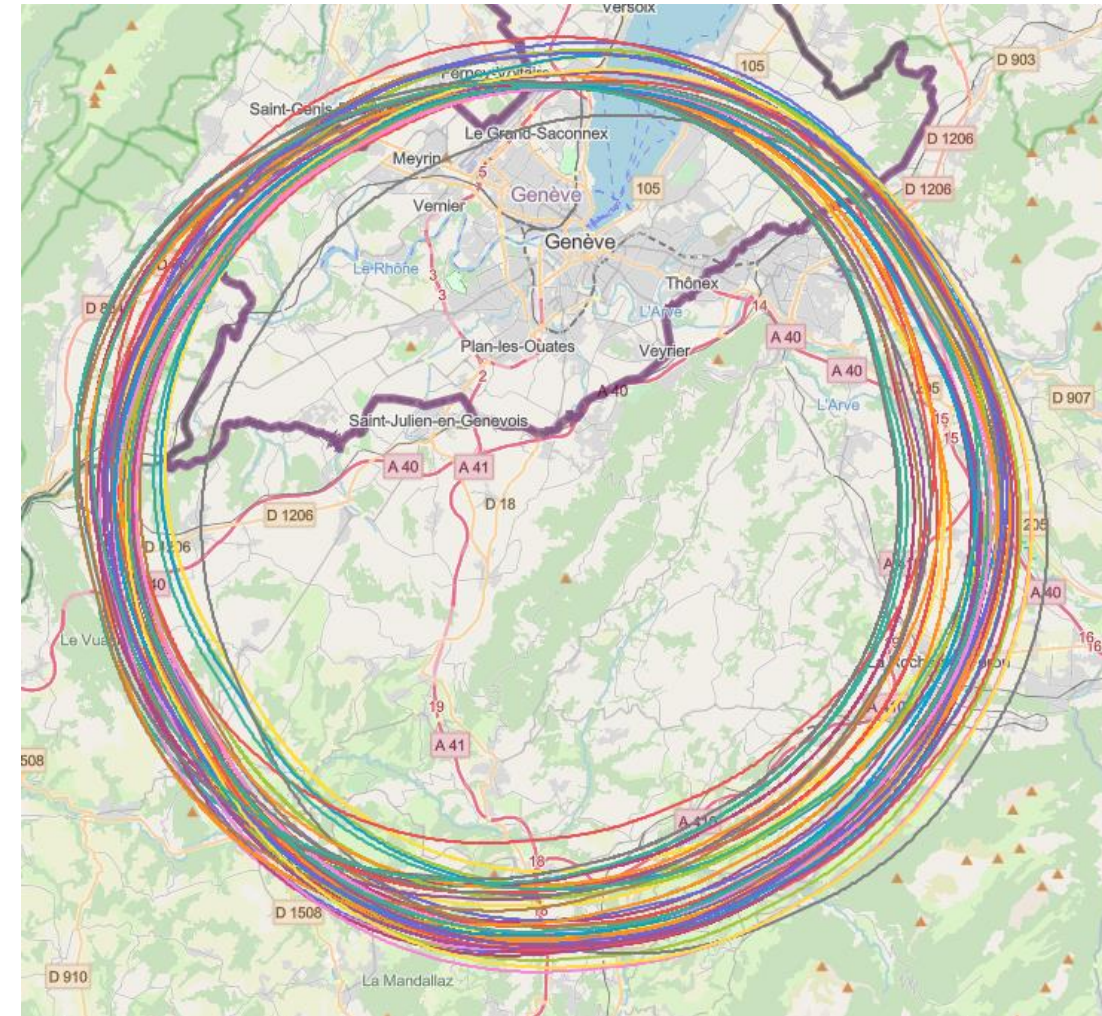


Parameter	present TH2167	CSM upgrade
Frequency [MHz]	400	
Beam voltage [kV]	54	
Saturated RF power [kW]	300	350
Efficiency [%]	60	70





- layout & placement optimisation across both host states, Switzerland and France;
- following **"avoid-reduce-compensate"** directive of European & French regulatory frameworks;
- diverse requirements and constraints:
  - **technical feasibility of civil engineering** and subsurface geological constraints
  - **territorial constraints on surface** and subsurface
  - **nature, accessibility**, technical infrastructure, resource needs & constraints
  - **optimum machine performance and efficiency**
  - economic factors including benefits for, and synergies, with the **regional developments**
  - ...
- **collaborative effort: FCC technical experts, government-notified bodies, consulting companies**

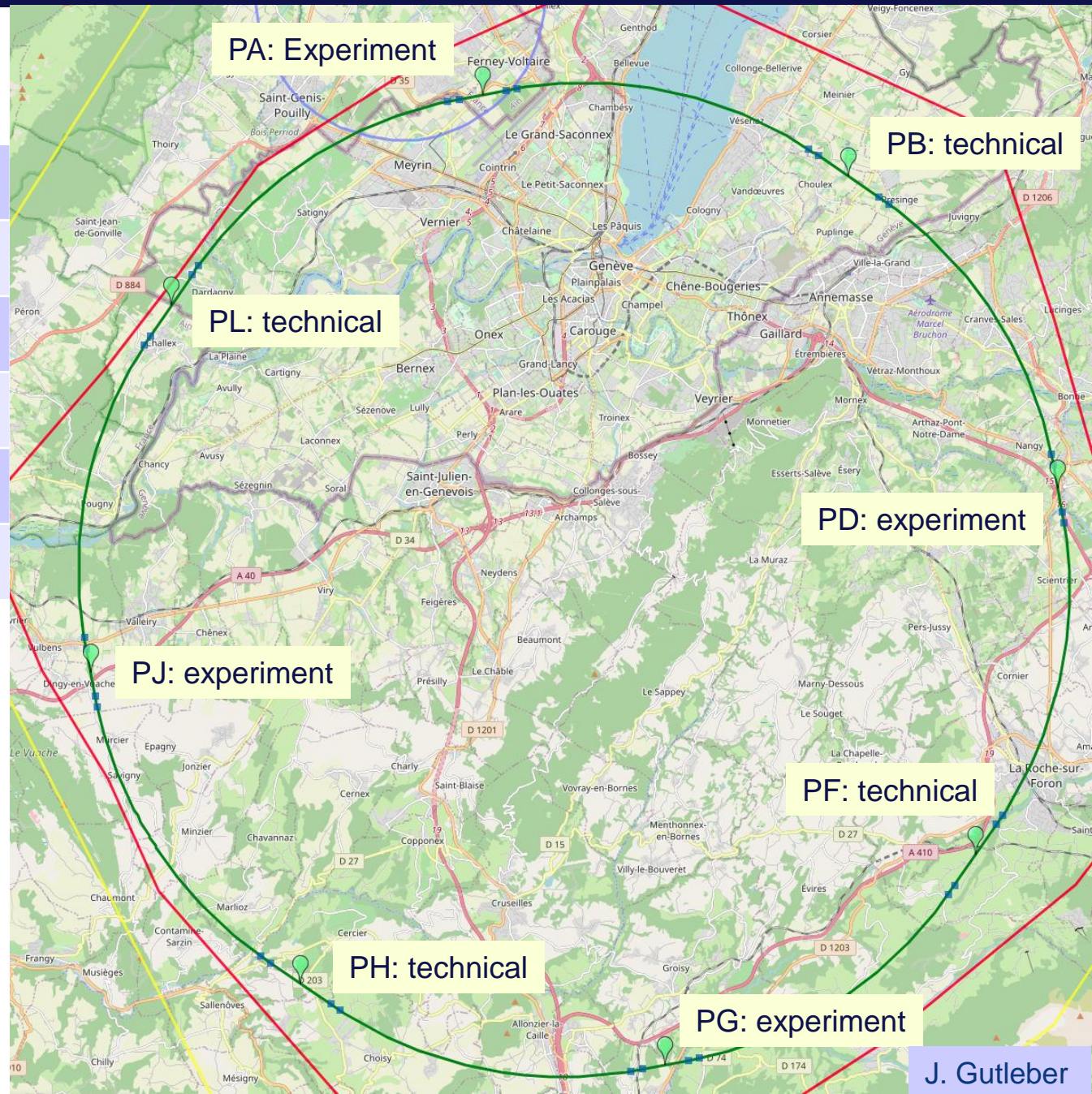




# 8-site baseline "PA31"

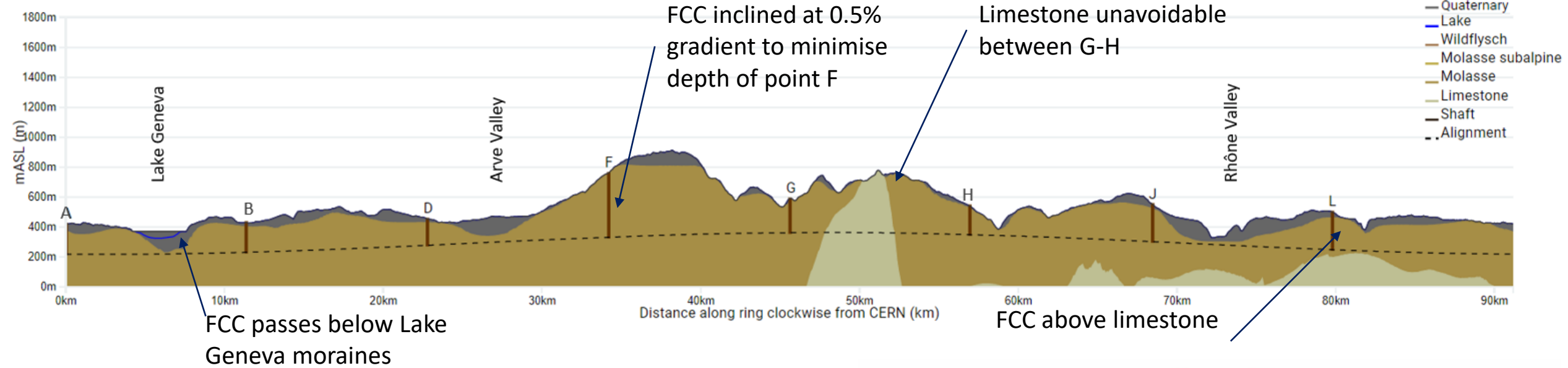
Number of surface sites	8
LSS@IP (PA, PD, PG, PJ)	1400 m
LSS@TECH (PB, PF, PH, PL)	2143 m
Arc length	9.6 km
Sum of arc lengths	76.9 m
Total circumference	91.1 km

- 8 surface sites <40 ha total land use
- Possibility for 4 experiment sites
- All sites close to road infrastructures (< 5 km of new road constructions required)
- Vicinity of several sites to 400 kV grid lines





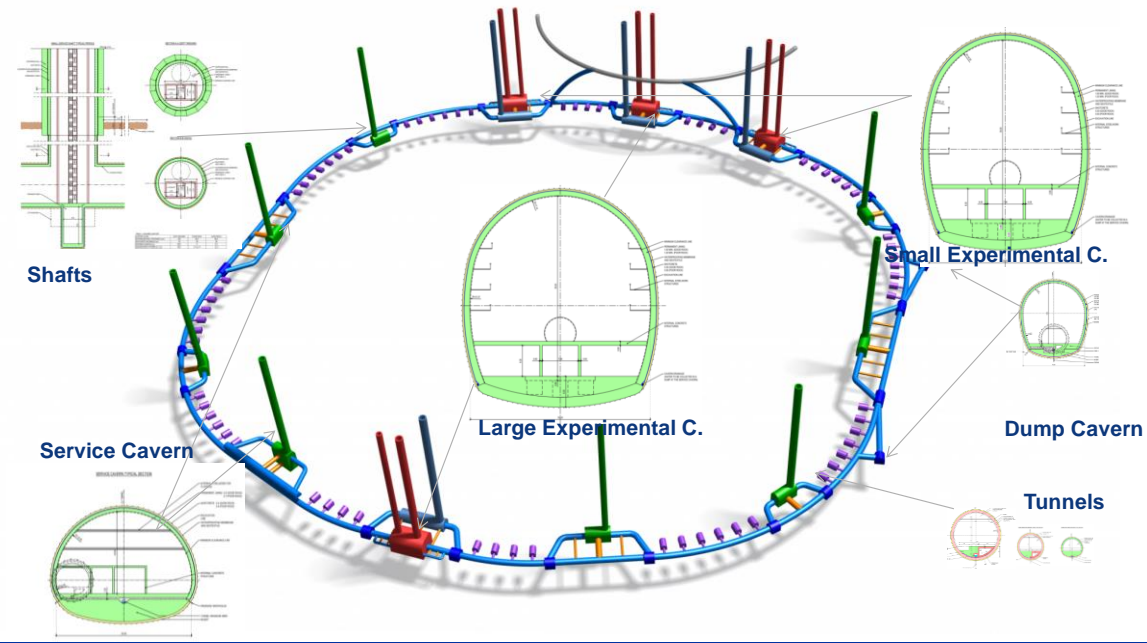
# FCC tunnel - geological conditions



**Tunneling mainly in moraine layer (soft rock), well suited for fast, low-risk TBM construction.**

**7 – 8 million m<sup>3</sup> excavation material**

**Site investigations campaign planned for 2024 – 2025: ~40-50 drillings, 100 km of seismic lines**



# Status of Global FCC Collaboration

Increasing international collaboration as a prerequisite for success

147  
Institutes

30  
Companies

34  
Countries





# Conclusions

- The European Particle Physics Strategy Update 2020 issued the request for a feasibility study of the FCC integrated programme to be delivered for the next Strategy Update.
- The FCC Feasibility Study should inform about technical, territorial and financial feasibility of the FCC project and bring all elements needed to decide about a potential project.
- Strengthening links with science, research & development, high-tech industry and society at large will be essential to further advance and prepare the implementation of FCC as a long-term sustainable world-leading HEP research infrastructure for the 21<sup>st</sup> century to push the particle-physics precision and energy frontiers far beyond present limits.



Thank you  
for your attention.