# FCC Feasibility Study Status

## Workshop on Standard Model and Beyond
## Corfu Summer Institute
## 27 August 2024

**Ghislain ROY, CERN**

on behalf of FCC collaboration & FCCIS DS team

and with slides from M. Benedikt, F. Zimmermann, E. Tsesmelis et al.

FUTURE CIRCULAR COLLIDER Innovation Study | EuroCirCol A key to New Physics | EASITrain | iFAST | E-JADE | EAJADE | CHART Swiss Accelerator Research and Technology | http://cern.ch/fcc | CERN

*Work supported by the **European Commission** under the **HORIZON 2020 projects EuroCirCol**, grant agreement 654305; **EASITrain,** grant agreement no. 764879; **iFAST**, grant agreement 101004730, **FCCIS**, grant agreement 951754; **E-JADE,** contract no. 645479; **EAJADE**, contract number 101086276; and by the Swiss **CHART** program*

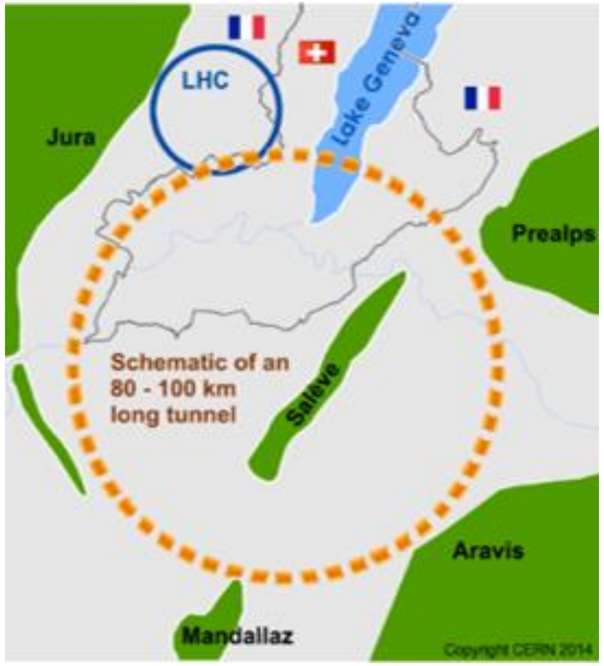
European Commission | Horizon 2020 European Union funding for Research & Innovation

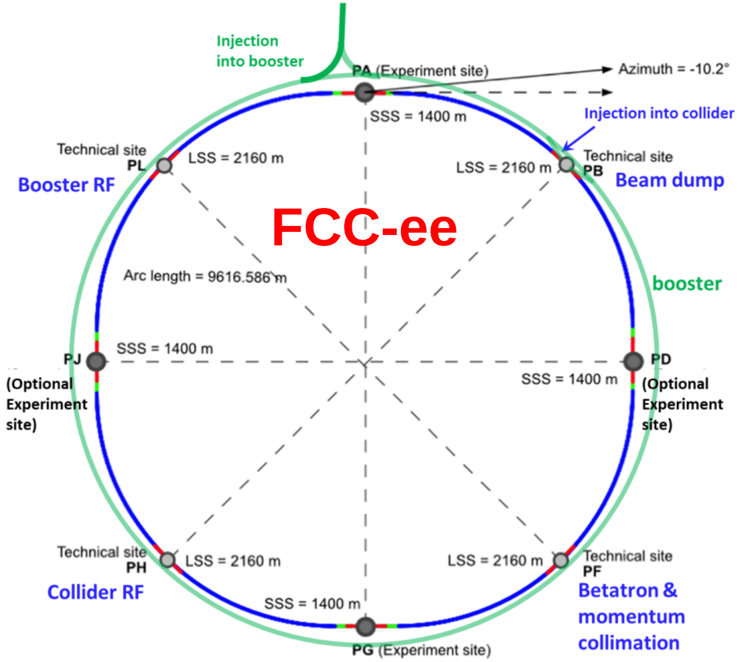
photo: J. Wenninger

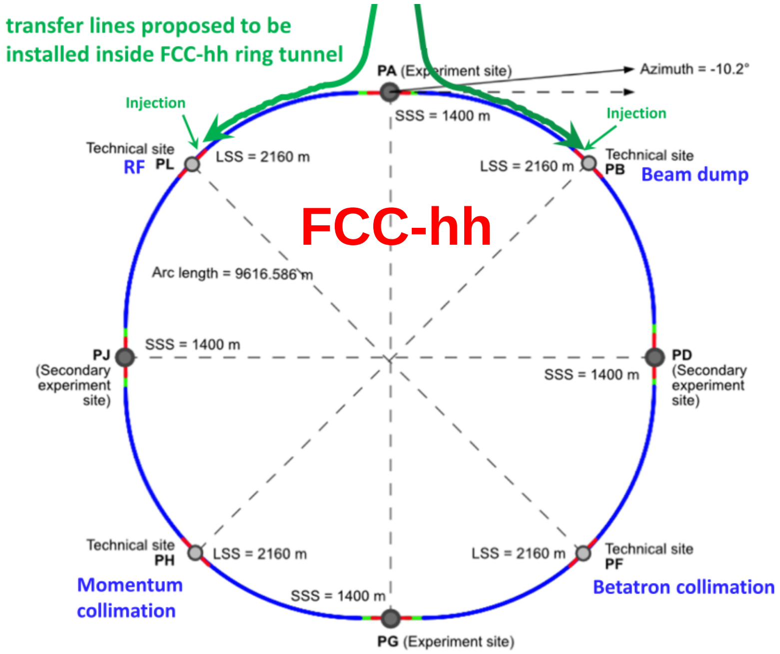
# FCC integrated program

**comprehensive long-term program maximizing physics opportunities**

- **stage 1: FCC-ee (Z, W, H, $t\bar{t}$) as Higgs factory, electroweak & top factory at highest luminosities**
- **stage 2: FCC-hh (~100 TeV) as natural continuation at energy frontier, pp & AA collisions; e-h option**
- highly synergetic and complementary programme boosting the physics reach of both colliders
- common civil engineering and technical infrastructures, building on and reusing CERN's existing infrastructure
- FCC integrated project allows the start of a new, major facility at CERN within a few years of the end of HL-LHC

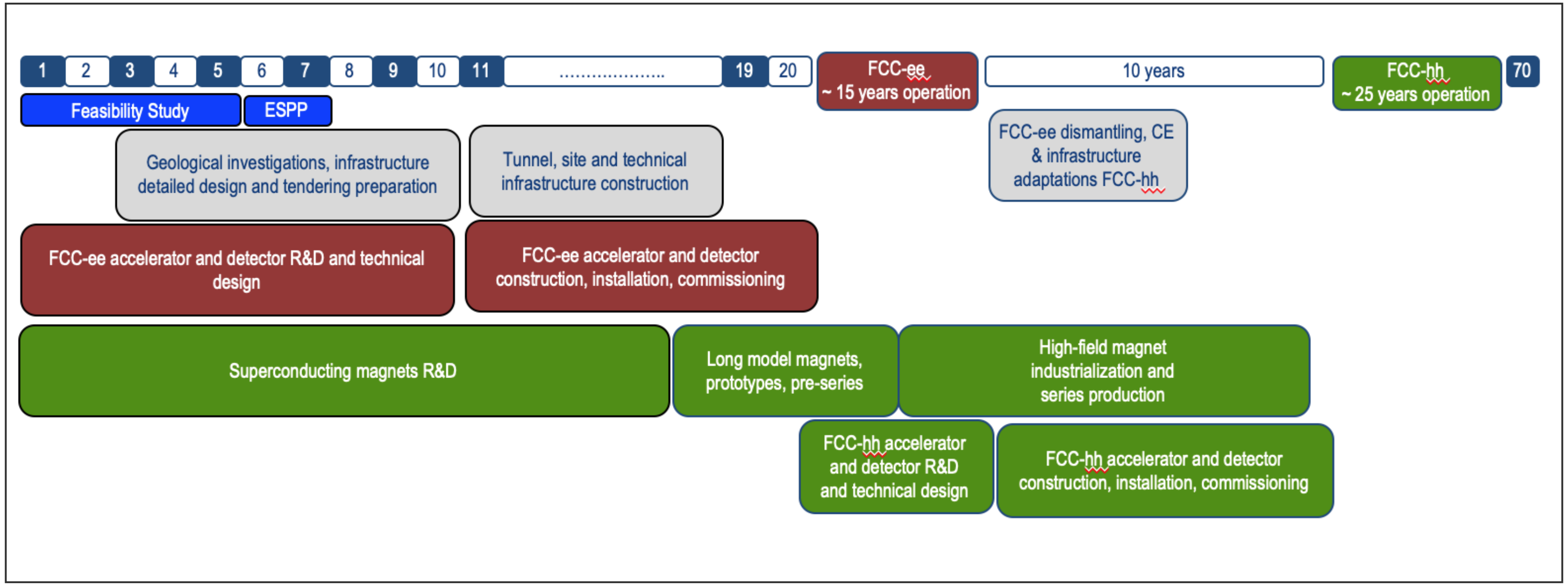


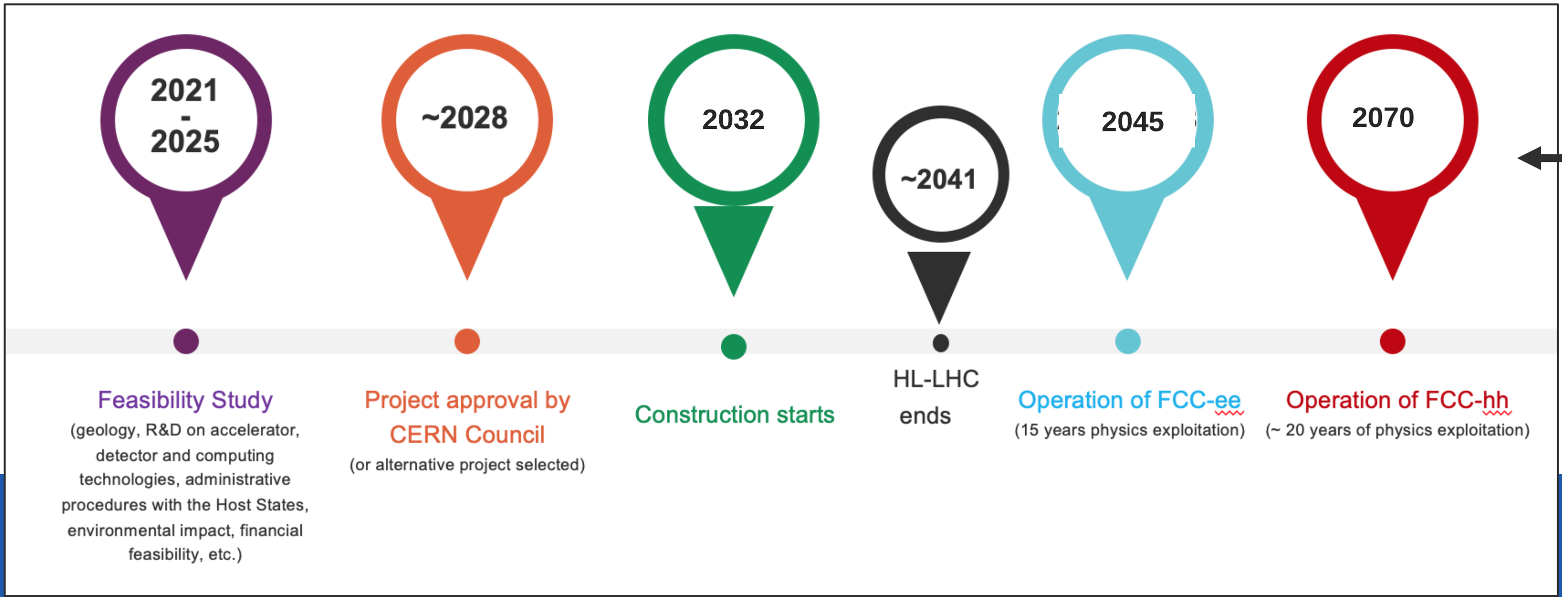




**2020 - 2046** | **2045 - 2060** | **2070 -**

# FCC integrated program - timeline




Note: FCC Conceptual Design Study started in 2014 leading to CDR in 2018




**"Realistic" schedule** taking into account:
- ❑ past experience in building colliders at CERN
- ❑ approval timeline: ESPP, Council decision
- ❑ that HL-LHC will run until 2041

Can be accelerated if more resources available

# European Strategy for Particle Physics

## 2013 Update of European Strategy for Particle Physics:

***"CERN should undertake design studies for accelerator projects in a global context, with emphasis on proton-proton and electron-positron high-energy frontier machines."***

## → FCC Conceptual Design Reports (2018/19)


**Vol 1 Physics, Vol 2 FCC-ee, Vol 3 FCC-hh, Vol 4 HE-LHC**

CDRs published in **European Physical Journal C (Vol 1) and ST (Vol 2 – 4)**

EPJ C 79, 6 (2019) 474 , EPJ ST 228, 2 (2019) 261-623 ,
EPJ ST 228, 4 (2019) 755-1107 , EPJ ST 228, 5 (2019) 1109-1382

## 2020 Update of European Strategy for Particle Physics:

***"Europe, together with its international partners, should investigate 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."***

# FCC Feasibility Study (2021-2025): high-level objectives

- demonstration of the geological, technical, environmental and administrative feasibility of the tunnel and surface areas and optimisation of 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 to identify and remove any showstopper;
- optimisation of the design of the colliders 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 of a possible future project (tunnel and FCC-ee);
- consolidation of the physics case and detector concepts for both colliders.

**Results will be summarised in a Feasibility Study Report to be released at end 2025**

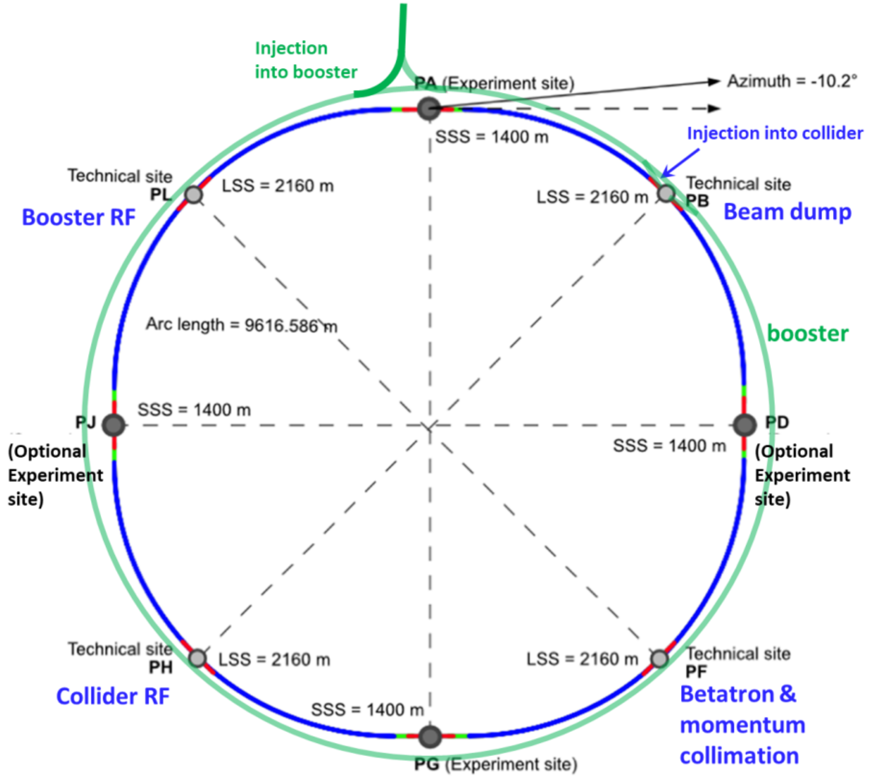
F. Gianotti

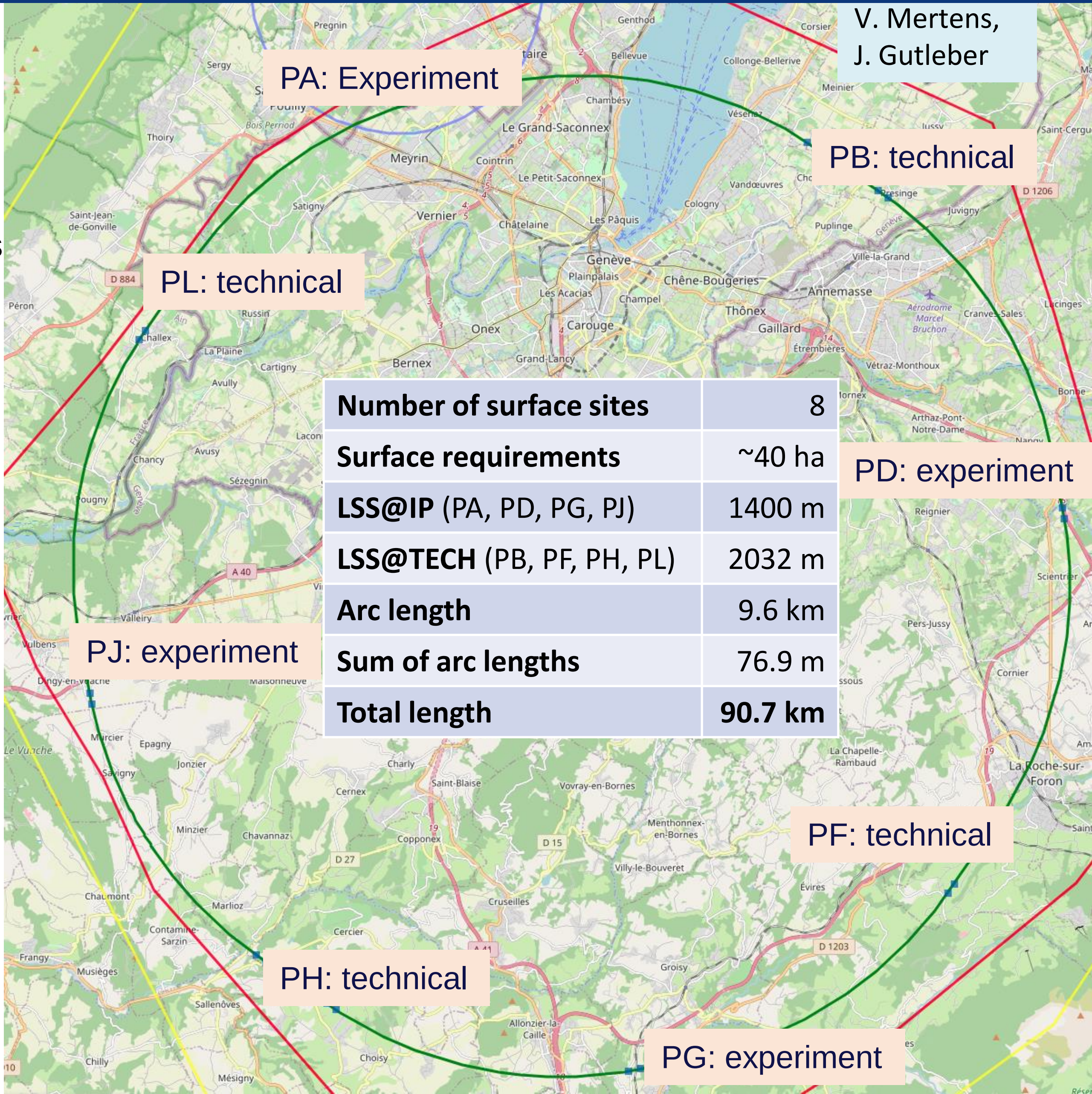
# Optimized placement and layout for feasibility study

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.

**"Avoid-Reduce-Compensate"** principle of EU and French regulations

**Overall lowest-risk baseline: 90.7 km ring, 8 surface points,**
Whole project now adapted to this placement




| | |
|---|---|
| **Number of surface sites** | 8 |
| **Surface requirements** | ~40 ha |
| **LSS@IP** (PA, PD, PG, PJ) | 1400 m |
| **LSS@TECH** (PB, PF, PH, PL) | 2032 m |
| **Arc length** | 9.6 km |
| **Sum of arc lengths** | 76.9 m |
| **Total length** | **90.7 km** |

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# Regional implementation activities

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

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

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

**PD – Nangy (FR)** – experiment site

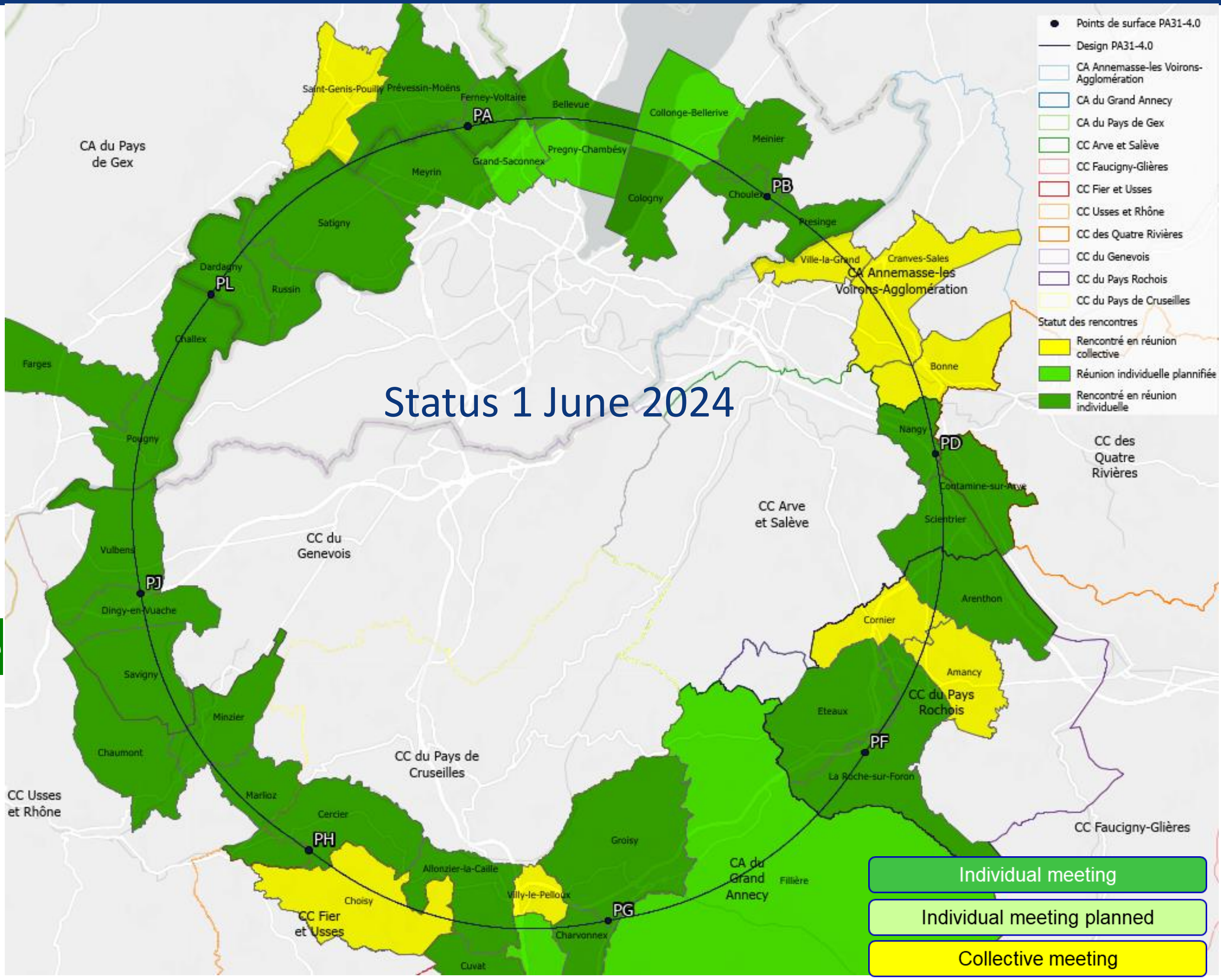
**PF – Roche sur Foron/Etaux** (FR) – technical site

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

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

**PJ – Vulbens/Dingy en Vuache** (FR) experiment site

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

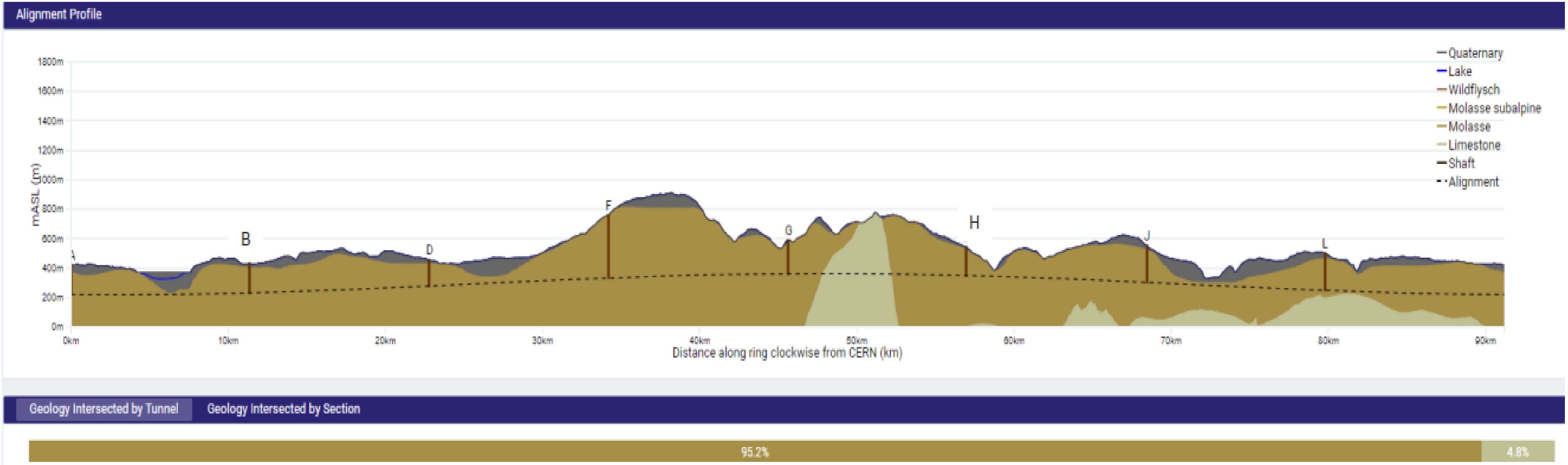



## Detailed work with municipalities and host states

- identify land plots for surface sites
- understand specific aspects for design
- identify opportunities (waste heat, tec.)
- reserve land plots until project decision

**The support of the host states is greatly appreciated and essential for the study progress!**

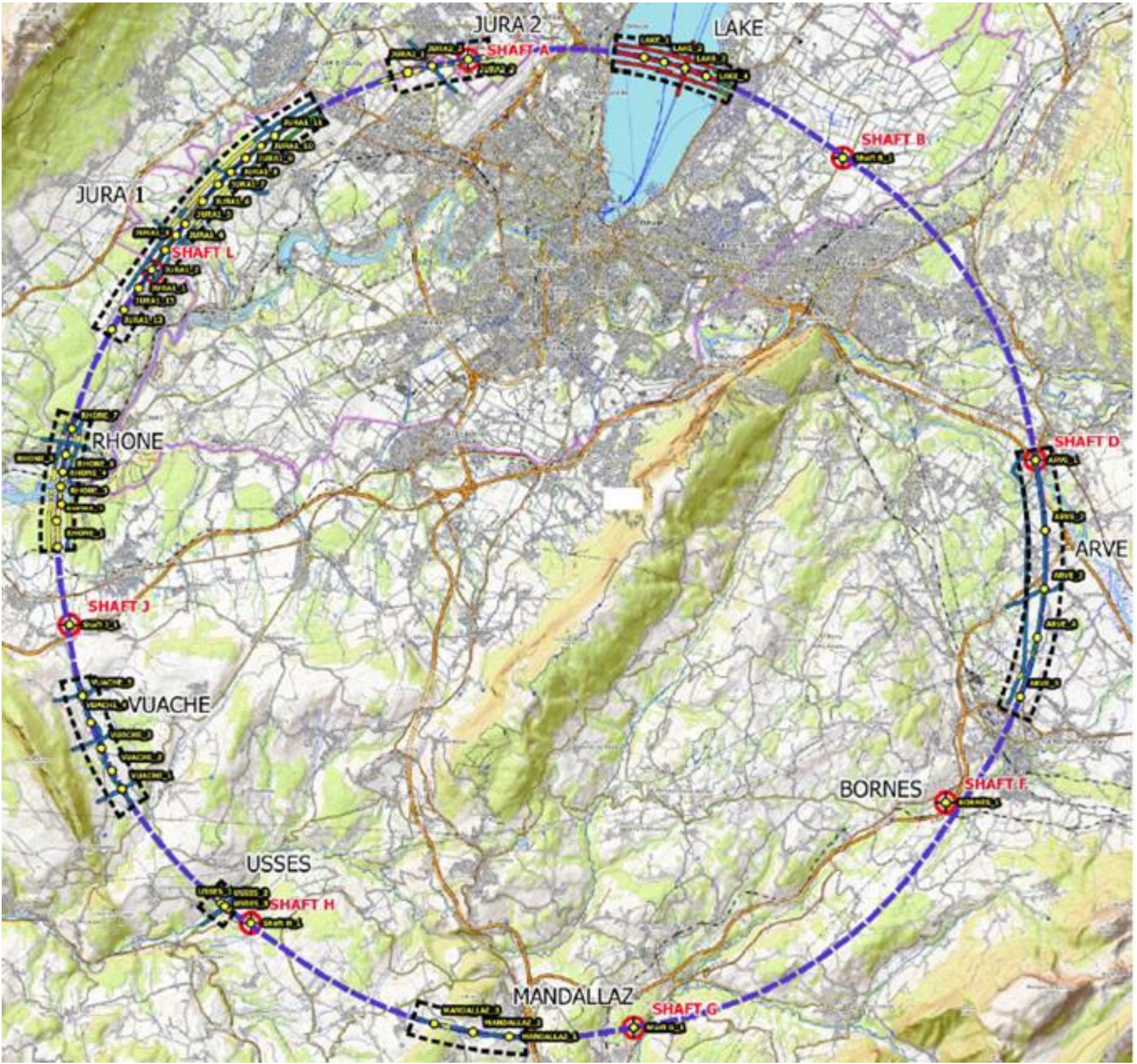
# FCC tunnel implementation




## Tunnel implementation summary

- 91 km circumference
- 95% in molasse geology for minimising tunnel construction risks
- Site investigations in zones where tunnel is close to geological interfaces: moraines-molasse-limestone

# Status site investigations




**Site investigations to identify exact location of geological interfaces:**

- Molasse layer vs moraines/limestone
- ~30 drillings and
- ~100 km seismic lines
- Start in July 2024

→ **Vertical position and inclination of tunnel**

Sondage A89 (2007) incliné de 45° de 125 ml (surface plateforme estimée : 12 x 12 m soit environ 150 m²)

Drilling works on the lake

# Start of public information & engagement sessions

## First public information and discussion meeting at the Science Gateway on the 24th April at CERN.


The meeting was organised for the local community of our Host States, France and Switzerland, in the Science Gateway. The "Progress of the feasibility study of the Future FCC circular collider" was followed by a discussion with the participants.

## La Roche-sur-Foron - Haute Savoie international fair April 27 to May 6

**Unveiling the science of tomorrow: FCC Study takes centre stage at La Roche-sur-Foron exhibition**

The Future Circular Collider team discussed the project's status and aspirations with a large number of attendees

15 MAY, 2024 | By Zoe Nikolaidou



CERN's participation in the International Fair of Haute-Savoie/Mont Blanc, enhanced by the valuable help of volunteers from the FCC team, resulted in meaningful discussions with more than 2000 members of the local community on topics ranging from the required technological advancements to sustainability measures.

## On 15 May, RTS (Radio Télévision Suisse) broadcasted a special program celebrating CERN's 70th anniversary and hosted at CERN's Science Gateway.

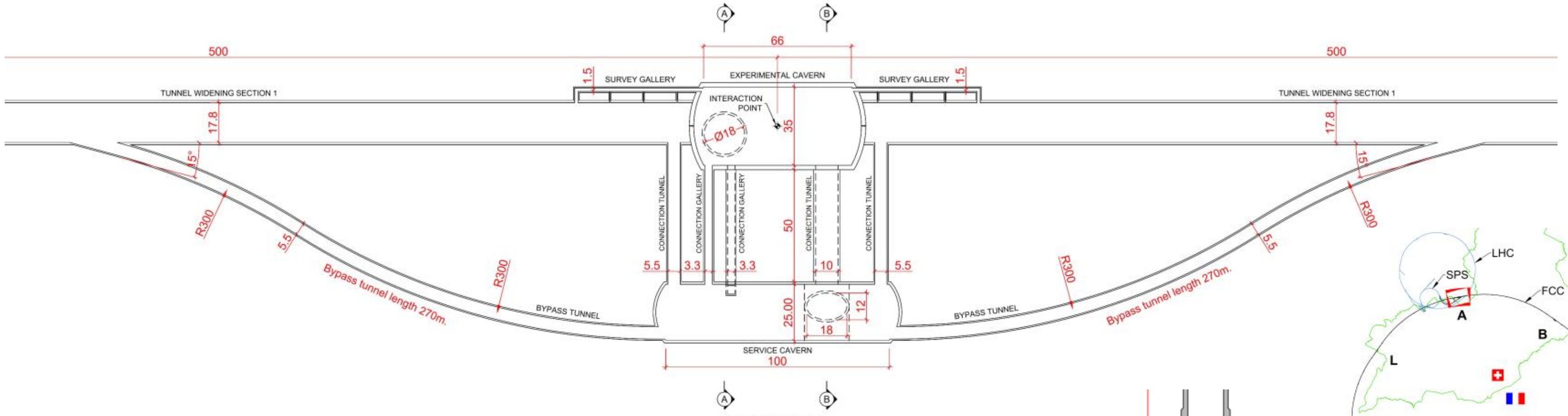

The event featured a comprehensive look at CERN's illustrious history, groundbreaking achievements, and future ambitions, including the prominently featured Future Circular Collider (FCC) project with study experts interacting with the audience.

# CE underground progress

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

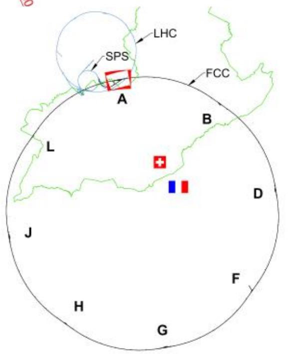

- **Experiment Site (PA)**

PLAN VIEW
1:3000

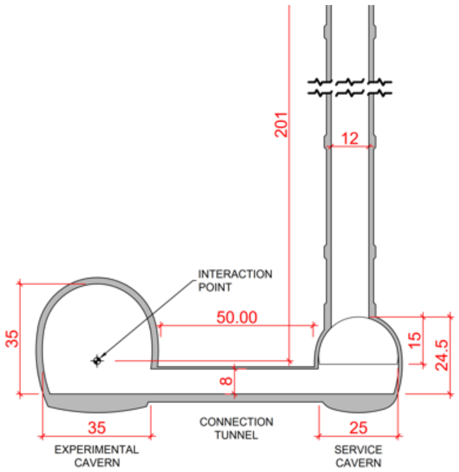


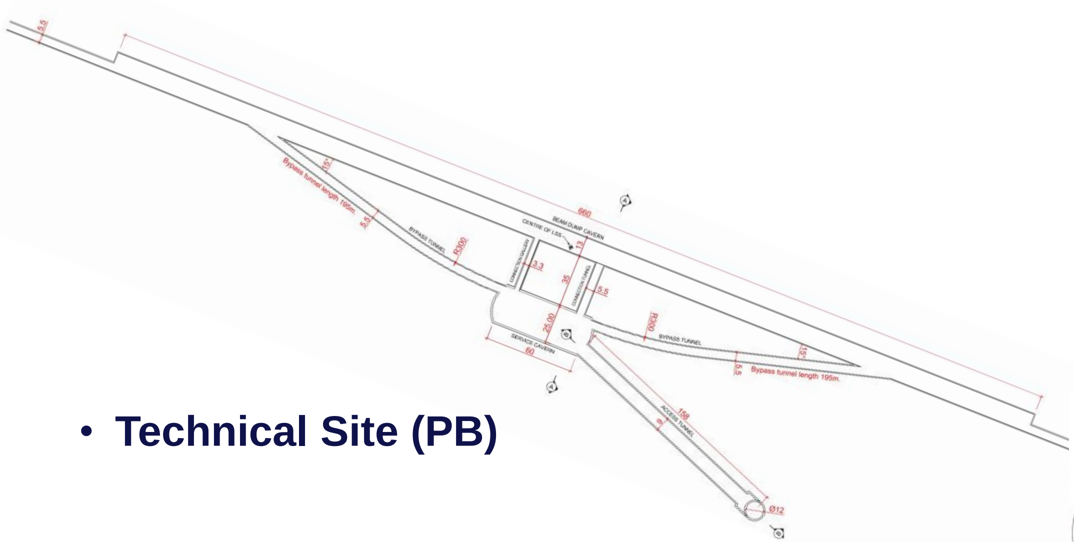

PLAN VIEW
1:1000

- **Update of scheduling and costing with external consultant ongoing**
- **Independent second costing exercise based on same bill of quantities will be done**

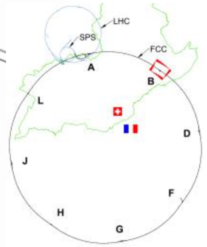



KEY PLAN



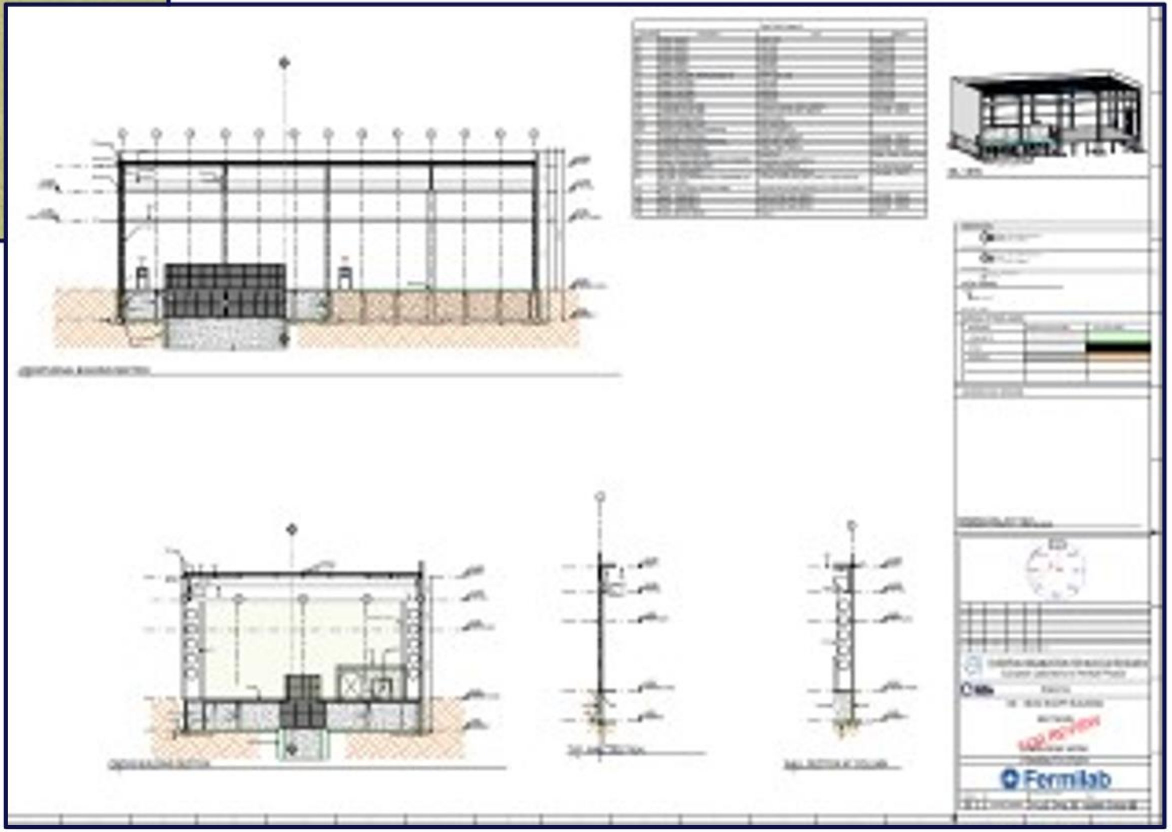

- **Technical Site (PB)**




KEY PLAN

# CE surface progress

Generic study of experiment site and technical site by FNAL



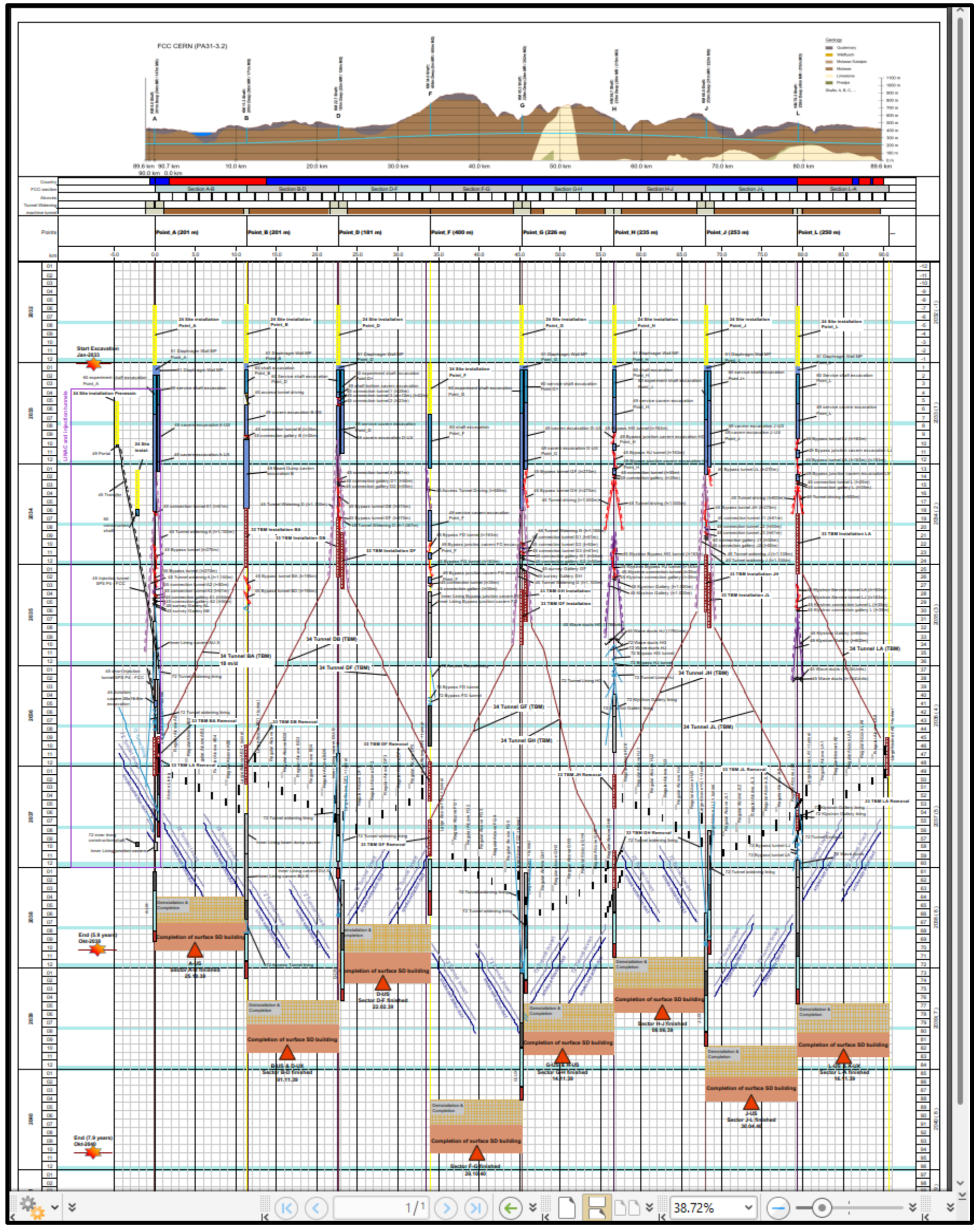
**Examples of Fermilab Deliverables**

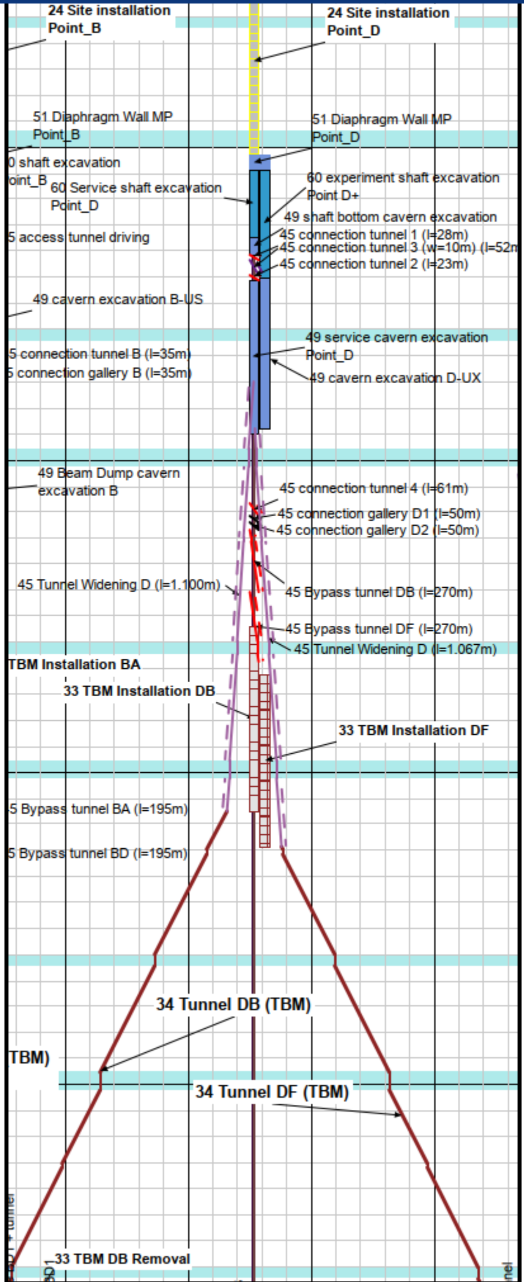
- bills of quantities extracted from FNAL designs
- basis for cost estimate by consultant with experience on industrial constructions in CH-FR area.

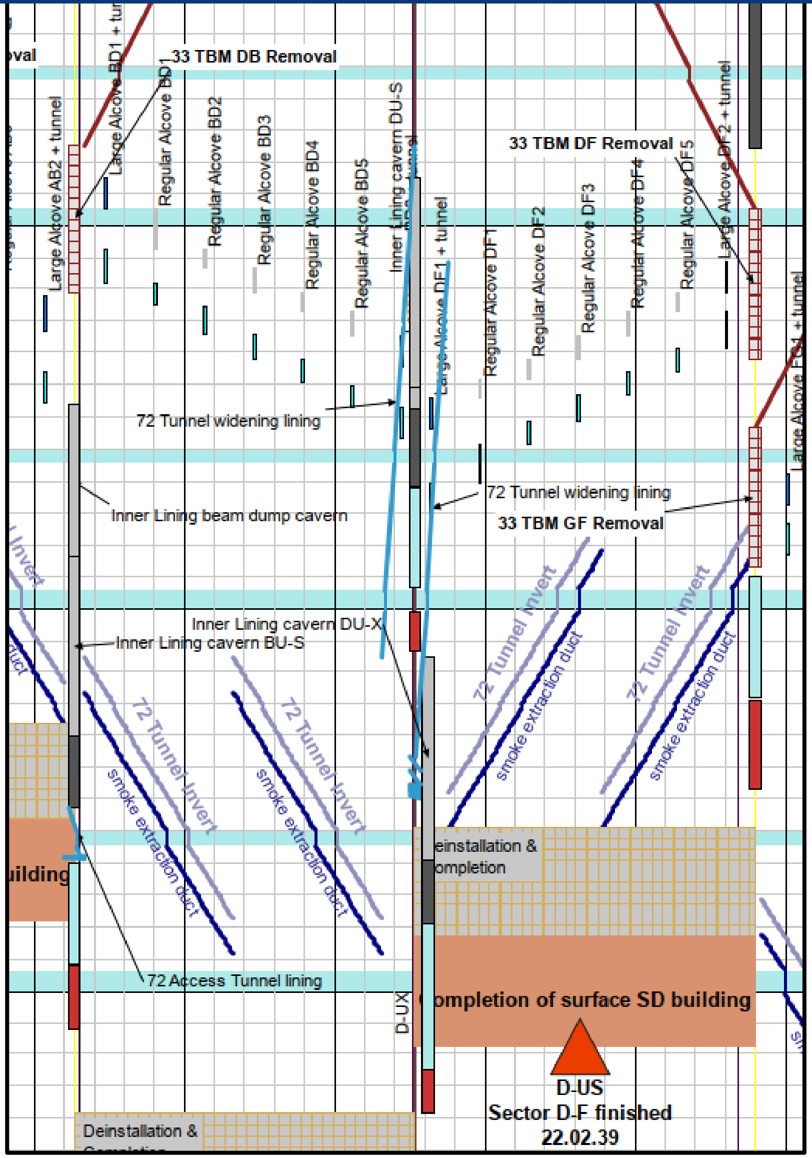
# CE construction schedules (example)

T. Watson

## CE linear construction schedule




Point D – Example of linear schedule

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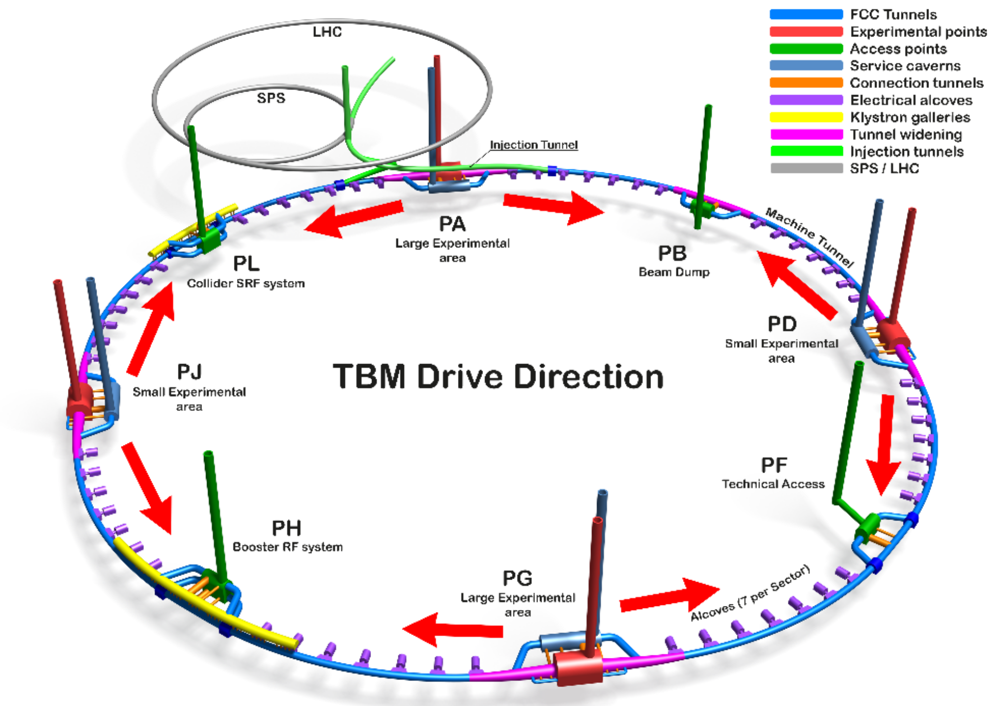
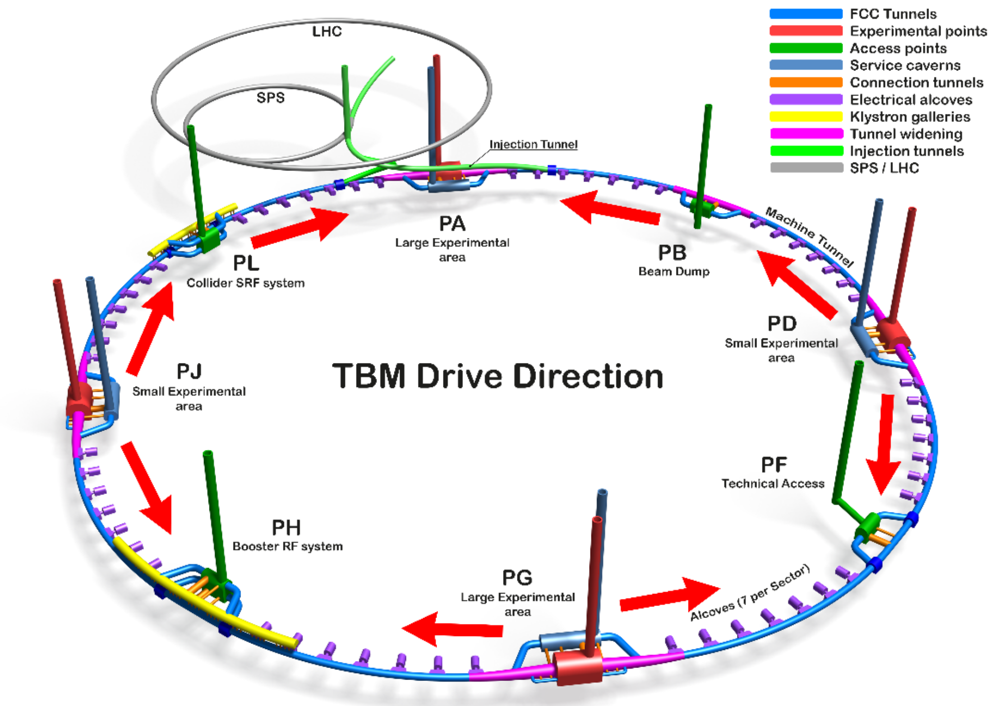
# Studies on excavation strategy and material quantities

## 2 TBMs from each experimental point




| | Limestone (m3) | Molasse (m3) | Moraine (m3) | Total (*in-situ*) (m3) | Total (*Bulk factor 1.3*) (m3) | % | Start Excavation | End Excavation |
|---|---|---|---|---|---|---|---|---|
| PA | - | 1,315,336 | 62,721 | 1,378,058 | 1,791,475 | 22% | Jan-33 | Jun-38 |
| PB | - | 137,379 | 10,473 | 147,852 | 192,207 | 2% | Jan-33 | Jul-35 |
| PD | - | 1,248,824 | 24,925 | 1,273,749 | 1,655,874 | 20% | Jan-33 | Jun-37 |
| PF | - | 165,213 | - | 165,213 | 214,777 | 3% | Jan-33 | Apr-35 |
| PG | 141,175 | 1,193,094 | 30,829 | 1,365,098 | 1,774,628 | 22% | Jan-33 | Jun-38 |
| PH | - | 304,083 | 7,482 | 311,565 | 405,034 | 5% | Jan-33 | Dec-35 |
| PJ | - | 1,258,608 | 29,910 | 1,288,518 | 1,675,073 | 20% | Jan-33 | Sep-37 |
| PL | - | 227,088 | 13,468 | 240,556 | 312,723 | 4% | Jan-33 | Dec-35 |
| Inj | - | 122,329 | - | 122,329 | 159,028 | 2% | Jan-33 | Jun-36 |
| **Total** | **141,175** | **5,971,954** | **179,808** | **6,292,937** | **8,180,819** | **100%** | | |

## Alternative with no TBMs from PA




| | Limestone (m3) | Molasse (m3) | Moraine (m3) | Total (*in-situ*) (m3) | Total (*Bulk factor 1.3*) (m3) | % | Start Excavation | End Excavation |
|---|---|---|---|---|---|---|---|---|
| PA | - | 562,457 | 62,721 | 625,178 | 812,731 | 10% | Jan-33 | Jun-38 |
| PB | - | 499,592 | 10,473 | 510,066 | 663,085 | 8% | Jan-33 | Jul-35 |
| PD | - | 1,248,824 | 24,925 | 1,273,749 | 1,655,874 | 20% | Jan-33 | Jun-37 |
| PF | - | 165,213 | - | 165,213 | 214,777 | 3% | Jan-33 | Apr-35 |
| PG | 141,175 | 1,193,094 | 30,829 | 1,365,098 | 1,774,628 | 22% | Jan-33 | Jun-38 |
| PH | - | 304,083 | 7,482 | 311,565 | 405,034 | 5% | Jan-33 | Dec-35 |
| PJ | - | 1,258,608 | 29,910 | 1,288,518 | 1,675,073 | 20% | Jan-33 | Sep-37 |
| PL | - | 617,754 | 13,468 | 631,222 | 820,589 | 10% | Jan-33 | Dec-35 |
| Inj | - | 122,329 | - | 122,329 | 159,028 | 2% | Jan-33 | Jun-36 |
| **Total** | **141,175** | **5,971,954** | **179,808** | **6,292,937** | **8,180,819** | **100%** | | |

# Excavation material management

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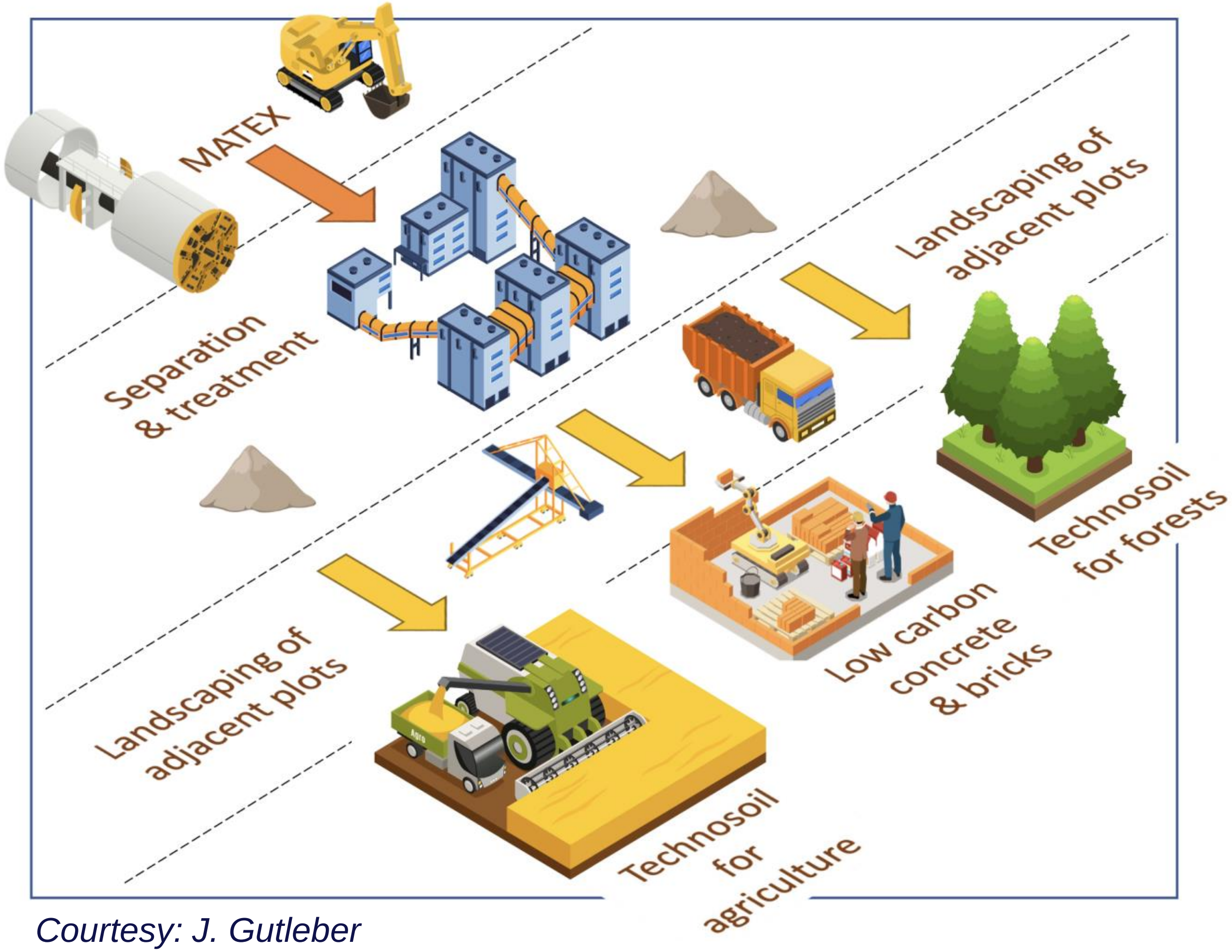
## An innovative local approach for excavated materials:




*Courtesy: J. Gutleber*

**Excavated material from FCC subsurface infrastructures: 6.5 Mm³ in situ, 8.4 Mm³ excavated** (bulk factor 1.3)

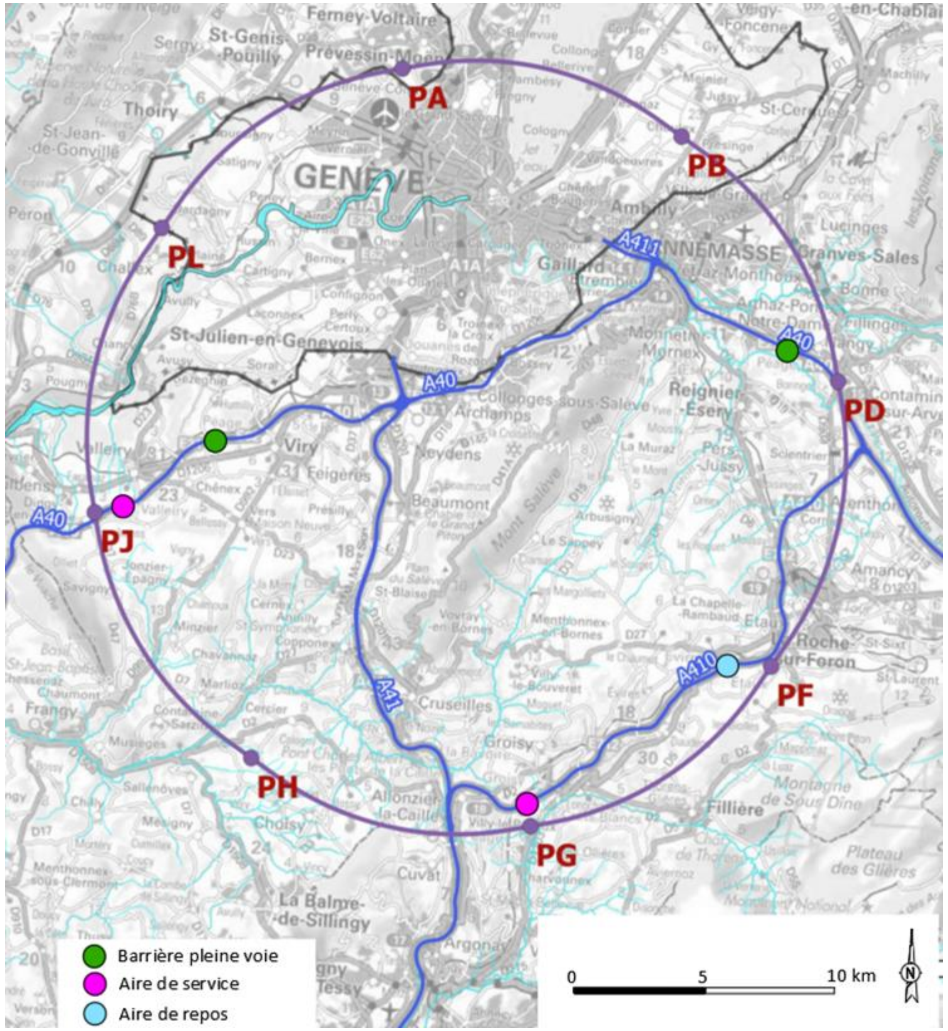
2021-2022: International competition " **Mining the Future"**, launched with the support of the EU Horizon 2020 grant agreement 951754**, to find innovative and realistic ideas for the reuse of Molasse (95% of excavated materials)**

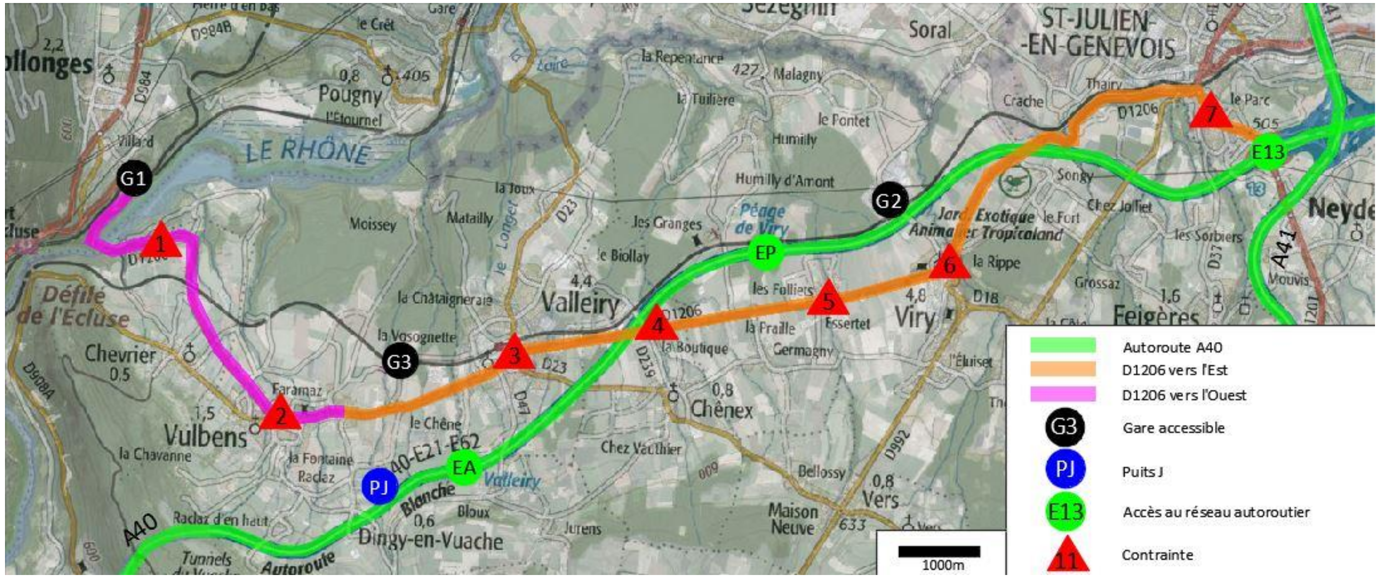
2023: **Definition of the "OpenSky Laboratory" project:**

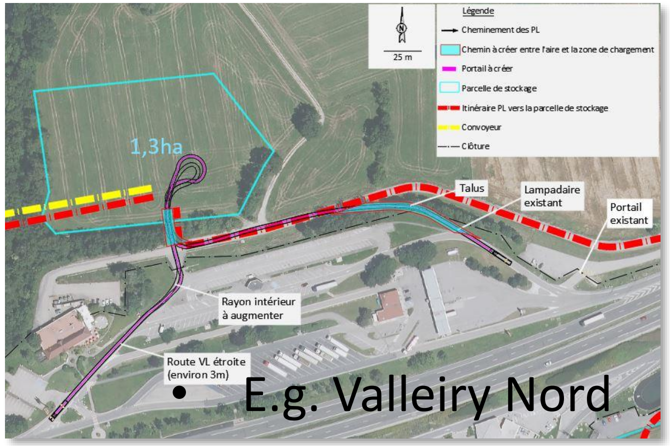
- **Objective**: Develop and test an innovative process to transform sterile "molasse" into fertile soil for agricultural use and afforestation.
- Duration: **4 years (2024-2027)**
- **CERN LHC point 5 CMS**

# Connections to transport infrastructure

- Road accesses identified and documented for all 8 surface sites
- Four possible highway connections defined (materials transport)
- Total amount of new roads required < 4 km (at departmental road level)



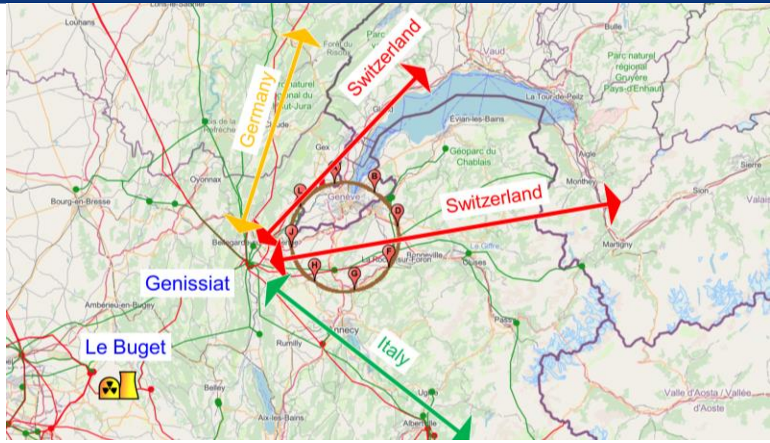




E.g. Valleiry Nord

Detailed road access scenarios & highway access creation study **carried out by Cerema, including regulatory requirements in France**

# Connections to electrical grid infrastructure

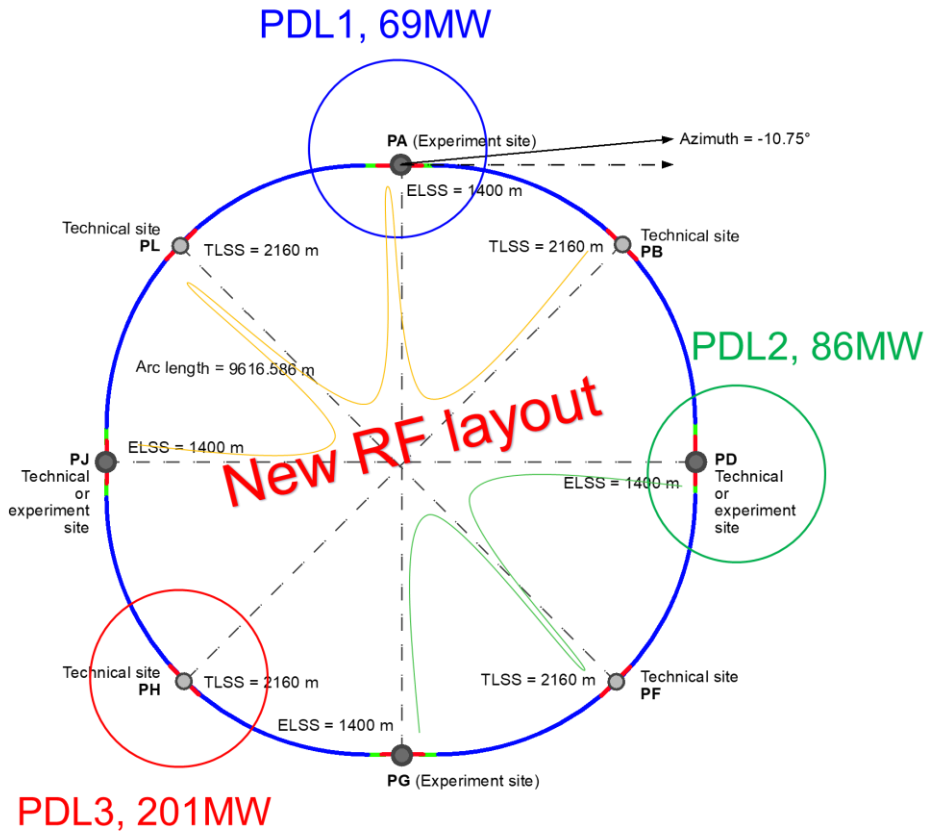
| Updated FCC-ee energy consumtion | Z | W | H | TT |
|---|---|---|---|---|
| Beam energy (GeV) | 45.6 | 80 | 120 | 182.5 |
| Max. Power during beam operation (MW) | 222 | 247 | 273 | 357 |
| Average power / year (MW) | 122 | 138 | 152 | 202 |
| **Total FCC-ee yearly consumption (TWh)** | **1.07** | **1.2** | **1.33** | **1.77** |
| Yearly consumption CERN & SPS (TWh) | 0.70 | 0.70 | 0.70 | 0.70 |
| **Total yearly consumpt. CERN & SPS & FCC-ee (TWh)** | **1.77** | **1.90** | **2.03** | **2.47** |



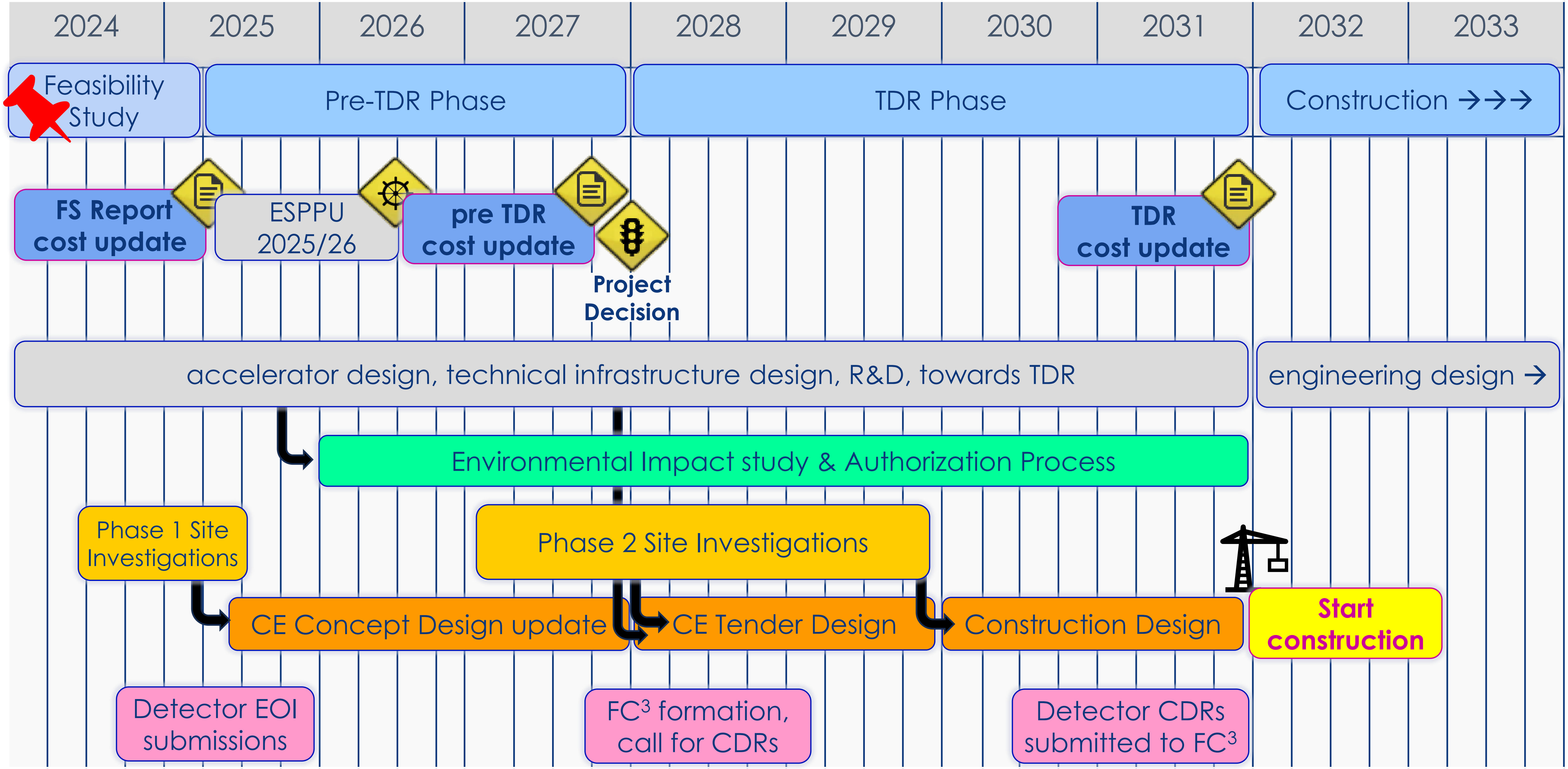

The loads could be distributed on three main sub-stations (optimally connected to existing regional HV grid):

- **Point D with a new sub-station** covering PB – PD – PF – PG
- **Point H with a new dedicated sub-station** for collider RF
- **Point A with existing CERN station** covering PB – PL – PJ

- **Connection concept was studied and confirmed by RTE (French electrical grid operator) ➔ requested loads have no significant impact on grid**
- **Powering concept and power rating of the three sub-stations compatible with FCC-hh**
- **R&D efforts aiming at further reduction of the energy consumption of FCC-ee and FCC-hh**



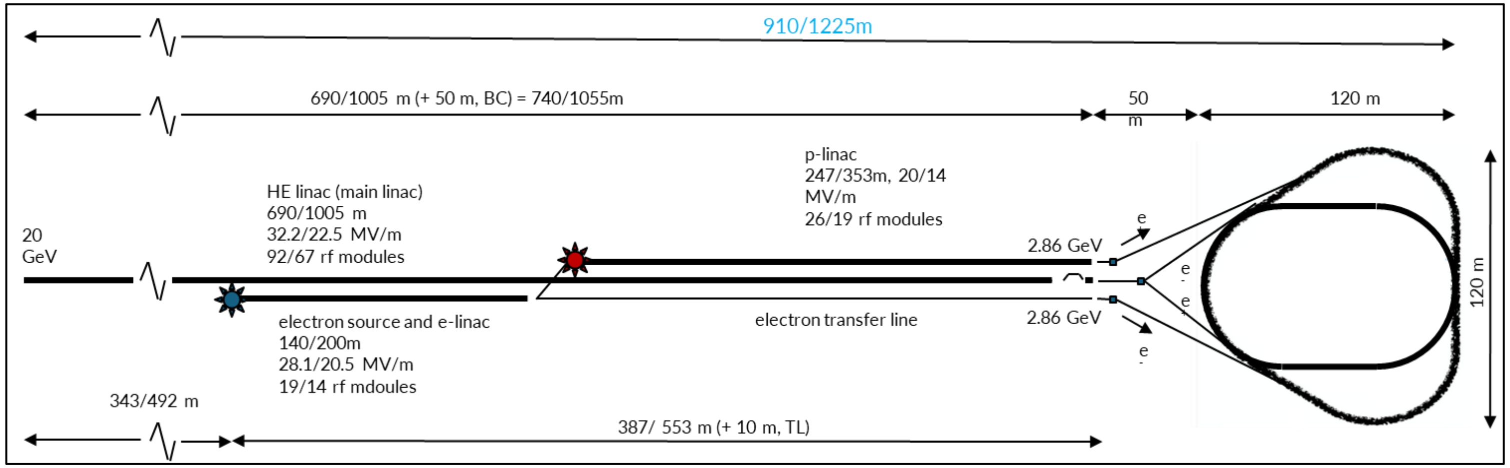
# Expected time line till start of construction



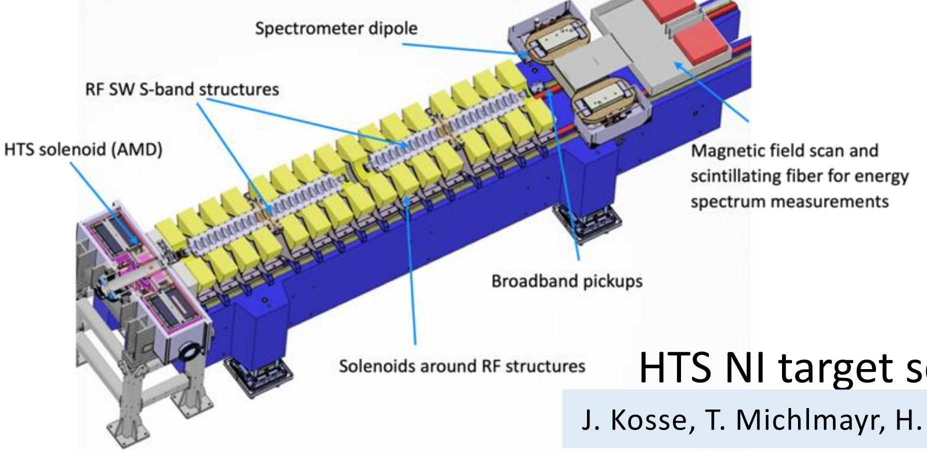
# FCC-ee Injector

## Overall injector parameter optimisation

- Operation frequency, gradient, etc…
- Positron production energy, damping ring energy

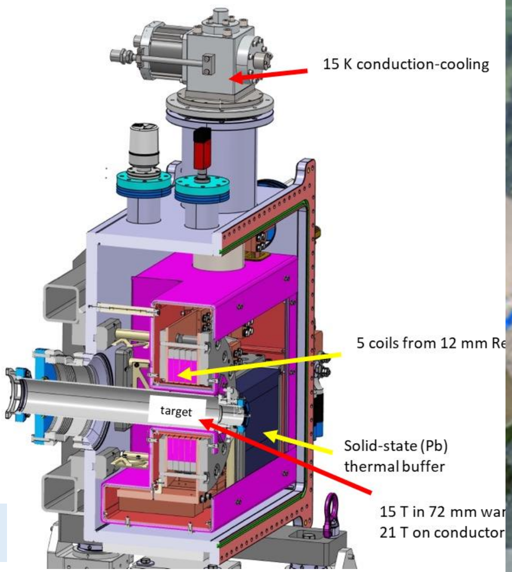



**"Positron production experiment" at PSI's SwissFEL, beam tests from 2025/26**

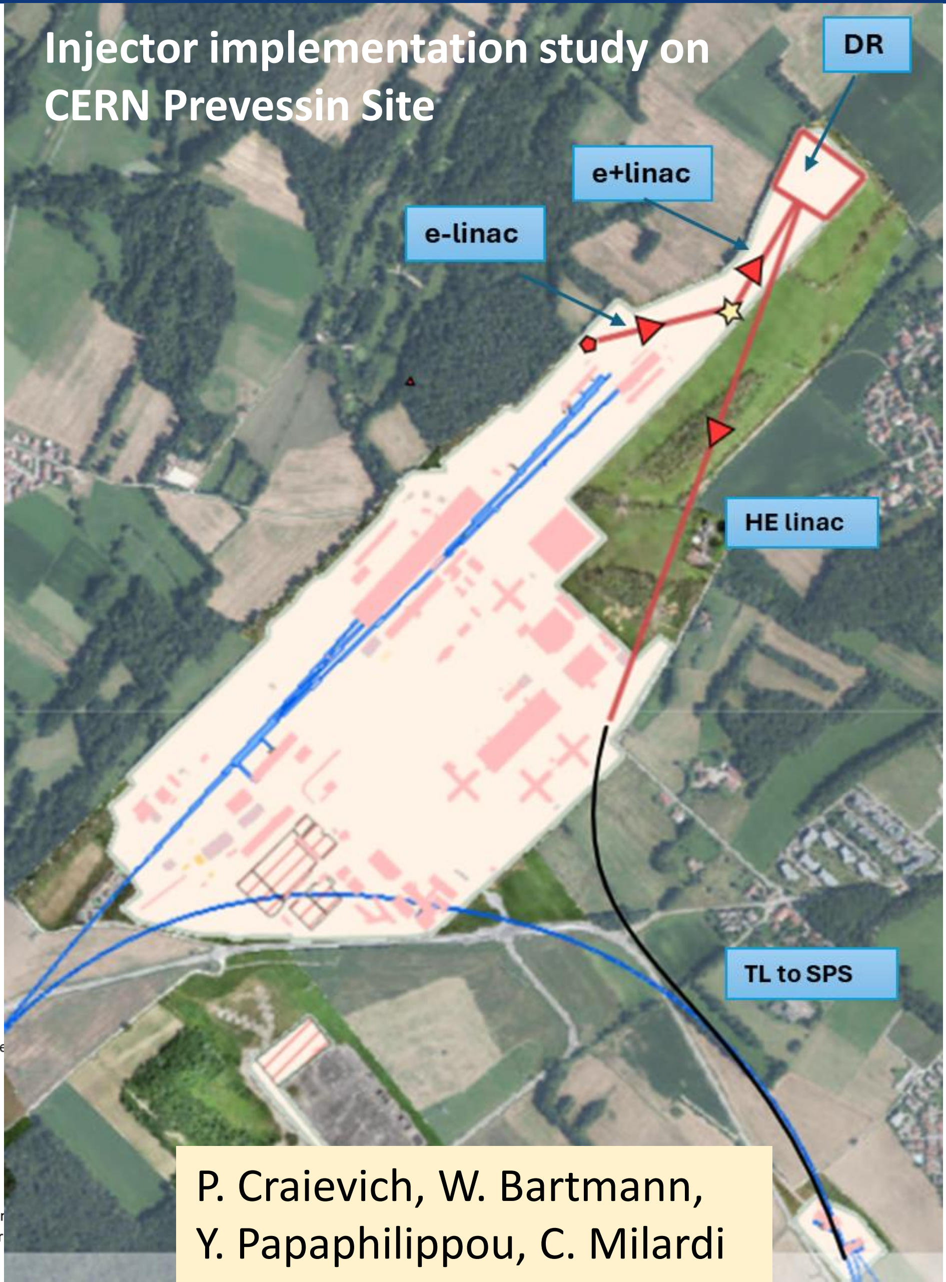



HTS NI target solenoid

J. Kosse, T. Michlmayr, H. Rodrigues




**Injector implementation study on CERN Prevessin Site**

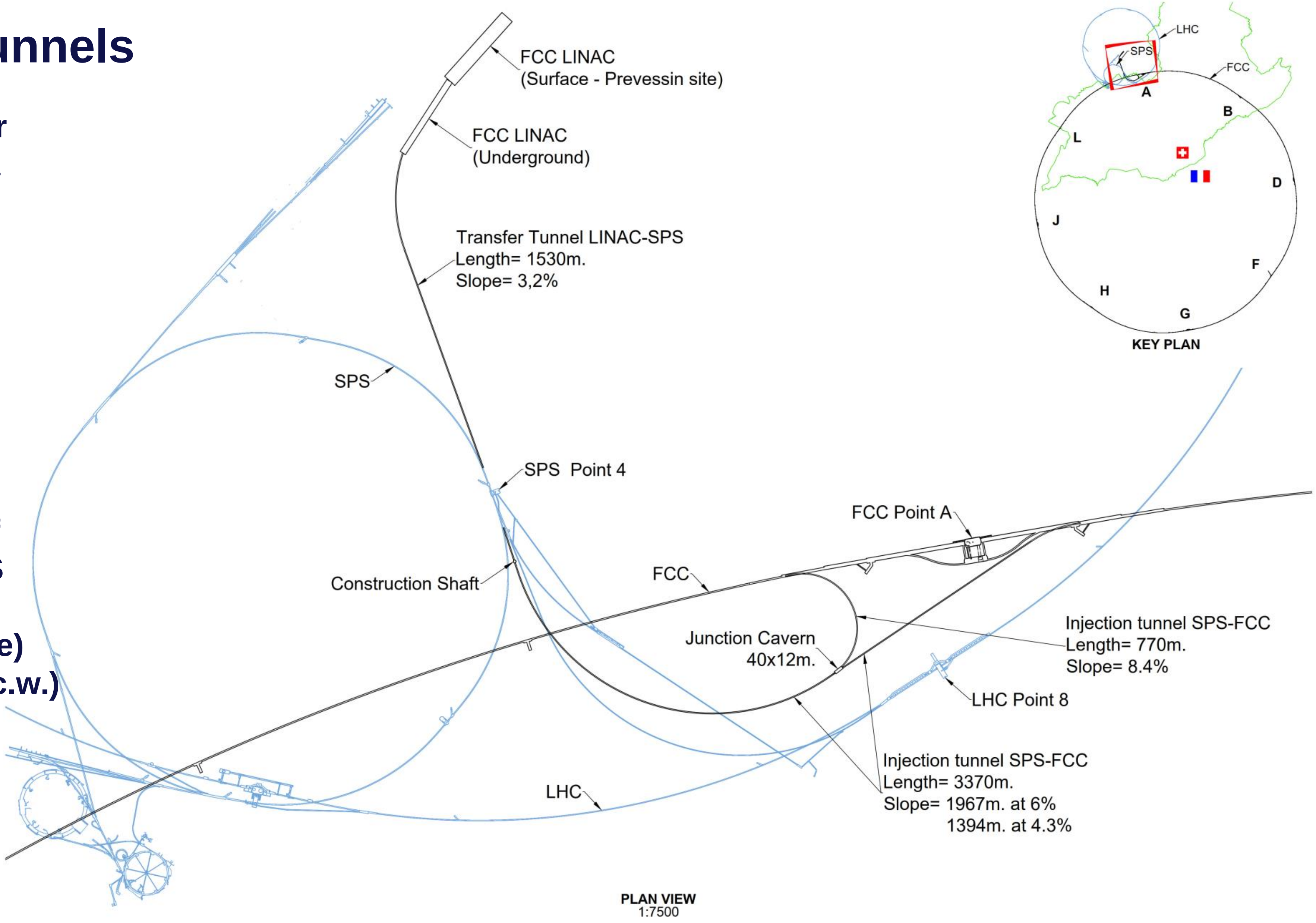



P. Craievich, W. Bartmann, Y. Papaphilippou, C. Milardi

# Transfer line FCC-ee (option with SPS for FCC-hh)

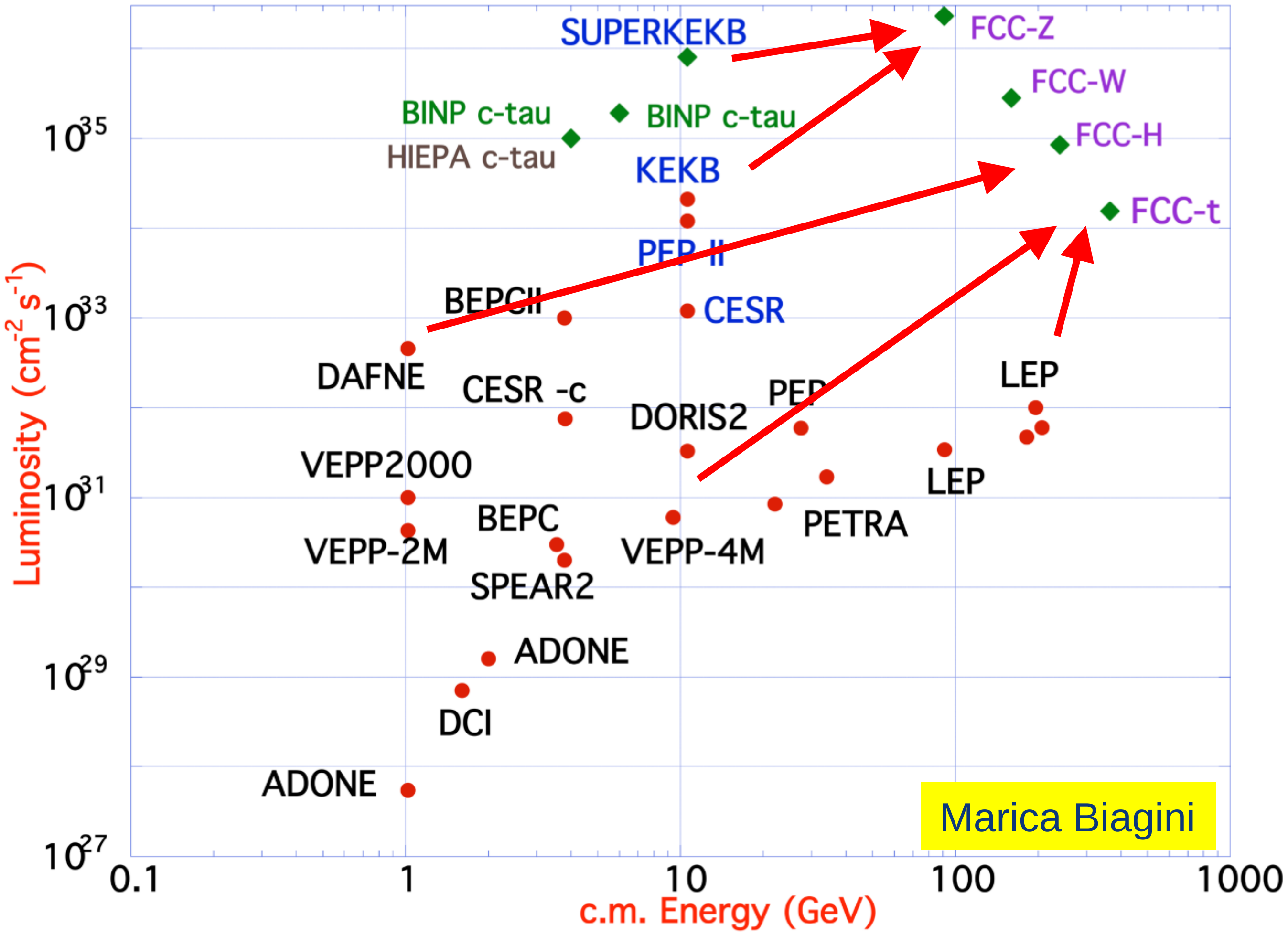
## LINAC and Injection Tunnels

- **Designed to enable injection either from SPS as pre-booster or from a new HE Linac sited at Prevessin**
- **Single tunnel with spur to enable anti-clockwise injection**
- **Design allows re-use for FCC-hh if injector in the SPS tunnel (SC-SPS option)**
  - **SPS Point 4 to FCC (clockwise)**
  - **SPS Point 6 to FCC (counter-c.w.)**



# FCC-ee Design Concept

## Based on lessons and techniques from past colliders (last 40 years)




***B-factories:*** **KEKB & PEP-II:**
- **double-ring lepton colliders,**
- **high beam currents,**
- **top-up injection**

**DAFNE: crab waist, double ring**

**S-KEKB: low $\beta_y$*, crab waist**

**LEP: high energy, SR effects**

**VEPP-4M, LEP: precision E calibration**

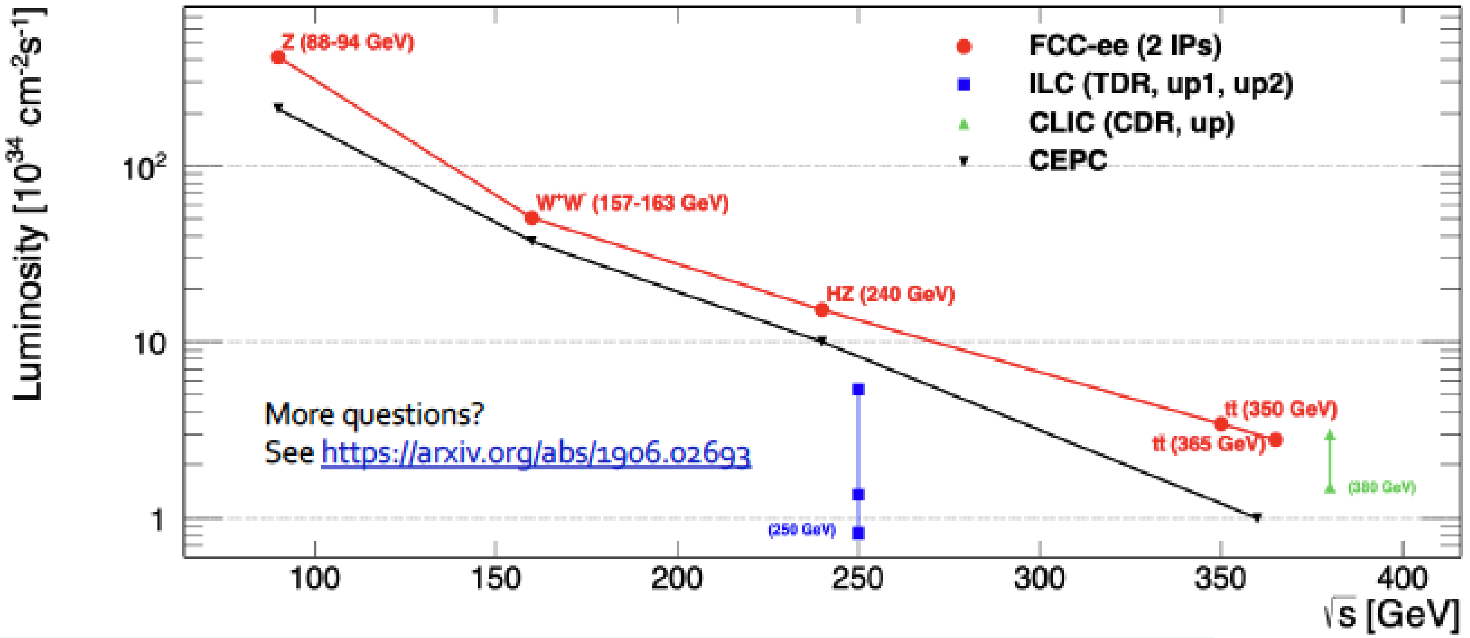
**KEKB: *e*$^+$ source**

**HERA, LEP, RHIC: spin gymnastics**

**combining successful ingredients of several recent colliders → highest luminosities & energies**

# FCC-ee Higgs and Electroweak Factory

- Great energy range for the SM heavy particles + highest luminosities + √s precision




| | | | | $E_{CM}$ errors: |
|---|---|---|---|---|
| Z peak | $E_{cm}$ ~ 91 GeV | $5 \times 10^{12}$ e+e- → Z | LEP x $10^5$ | <100 keV |
| WW threshold+ | $E_{cm} \geq$ 161 GeV | $> 10^8$ e+e- → WW | LEP x $10^3$ | <300 keV |
| ZH threshold | $E_{cm}$ : 240 GeV | $10^6$ e+e- → ZH | Never done | 2 MeV |
| $\bar{t}t$ threshold | $E_{cm}$ ~ 350 GeV | $10^6$ e+e- → $\bar{t}t$ | Never done | 5 MeV |

P. Janot

# FCC-ee main machine parameters

FUTURE CIRCULAR COLLIDER

| Parameter | Z | WW | H (ZH) | ttbar |
|---|---|---|---|---|
| beam energy [GeV] | 45.6 | 80 | 120 | 182.5 |
| beam current [mA] | 1270 | 137 | 26.7 | 4.9 |
| number bunches/beam | 11200 | 1780 | 440 | 60 |
| bunch intensity [$10^{11}$] | 2.14 | 1.45 | 1.15 | 1.55 |
| SR energy loss / turn [GeV] | 0.0394 | 0.374 | 1.89 | 10.4 |
| total RF voltage 400/800 MHz [GV] | 0.120/0 | 1.0/0 | 2.1/0 | 2.1/9.4 |
| long. damping time [turns] | 1158 | 215 | 64 | 18 |
| horizontal beta* [m] | 0.11 | 0.2 | 0.24 | 1.0 |
| vertical beta* [mm] | 0.7 | 1.0 | 1.0 | 1.6 |
| horizontal geometric emittance [nm] | 0.71 | 2.17 | 0.71 | 1.59 |
| vertical geom. emittance [pm] | 1.9 | 2.2 | 1.4 | 1.6 |
| vertical rms IP spot size [nm] | 36 | 47 | 40 | 51 |
| beam-beam parameter $\xi_x$ / $\xi_y$ | 0.002/0.0973 | 0.013/0.128 | 0.010/0.088 | 0.073/0.134 |
| rms bunch length with SR / BS [mm] | 5.6 / 15.5 | 3.5 / 5.4 | 3.4 / 4.7 | 1.8 / 2.2 |
| luminosity per IP [$10^{34}$ cm$^{-2}$s$^{-1}$] | 140 | 20 | ≥5.0 | 1.25 |
| total integrated luminosity / IP / year [ab$^{-1}$/yr] | 17 | 2.4 | 0.6 | 0.15 |
| beam lifetime rad Bhabha + BS [min] | 15 | 12 | 12 | 11 |

| | Z | WW | H (ZH) | ttbar |
|---|---|---|---|---|
| | 4 years<br>5 x $10^{12}$ Z<br>LEP x $10^5$ | 2 years<br>> $10^8$ WW<br>LEP x $10^4$ | 3 years<br>2 x $10^6$ H | 5 years<br>2 x $10^6$ tt pairs |

**Design and parameters to maximise luminosity at all working points:**

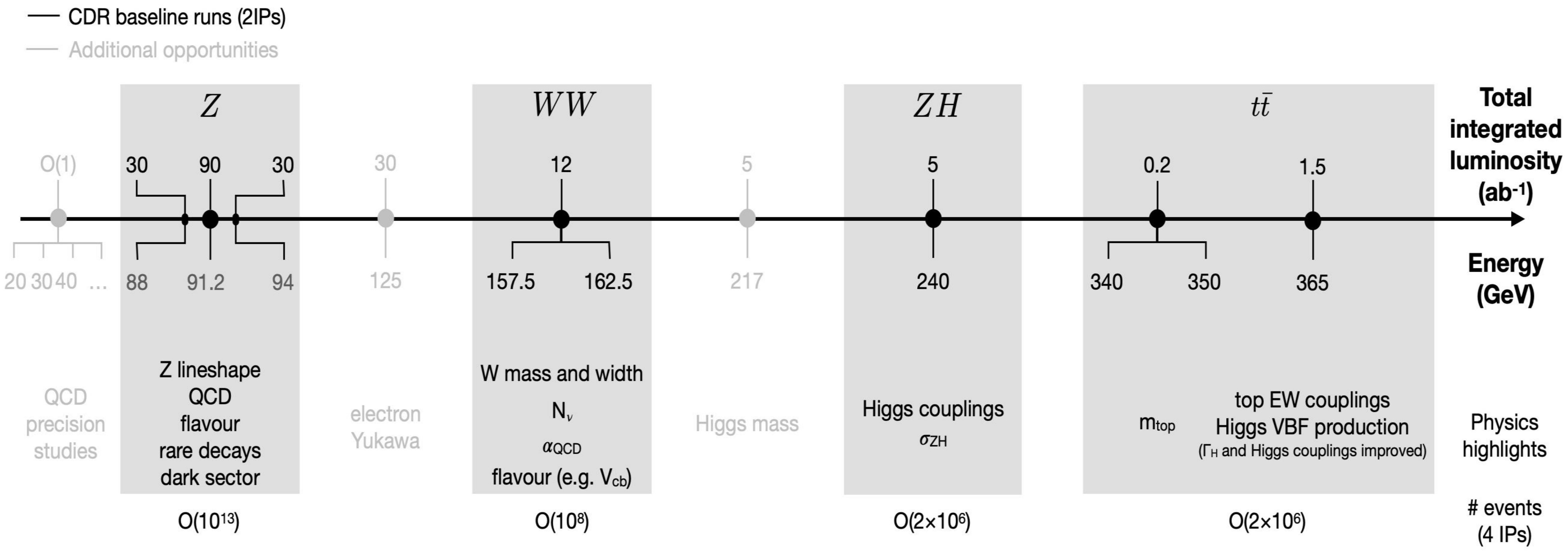
- allow for 50 MW synchrotron radiation per beam.
- Independent vacuum systems for electrons and positrons
- full energy booster ring with top-up injection, collider permanent in collision mode

- ❑ x 10-50 improvements on all EW observables
- ❑ up to x 10 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

F. Gianotti

# FCC-ee Collider Programme




- **Opportunities** beyond the baseline plan (√s below Z, 125GeV, 217GeV; larger integrated lumi…)
- **Opportunities** to exploit FCC facility differently (to be studied more carefully):
  - using the electrons from the injectors for beam-dump experiments,
  - extracting electron beams from the booster,
  - reusing the synchrotron radiation photons.

C. Grojean

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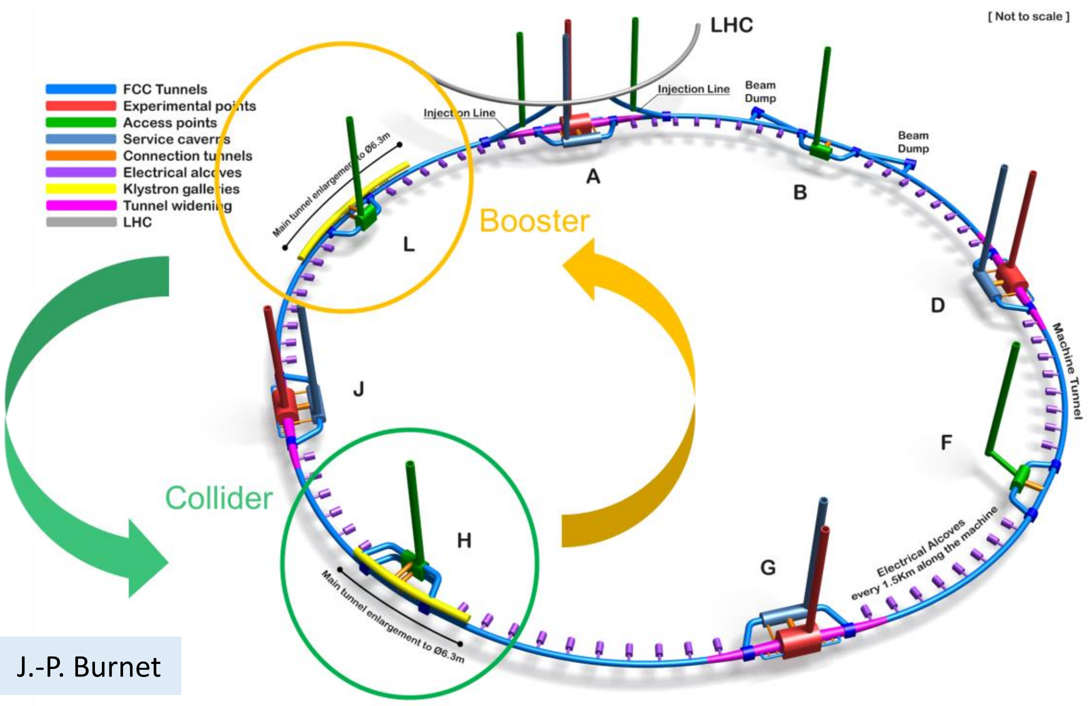
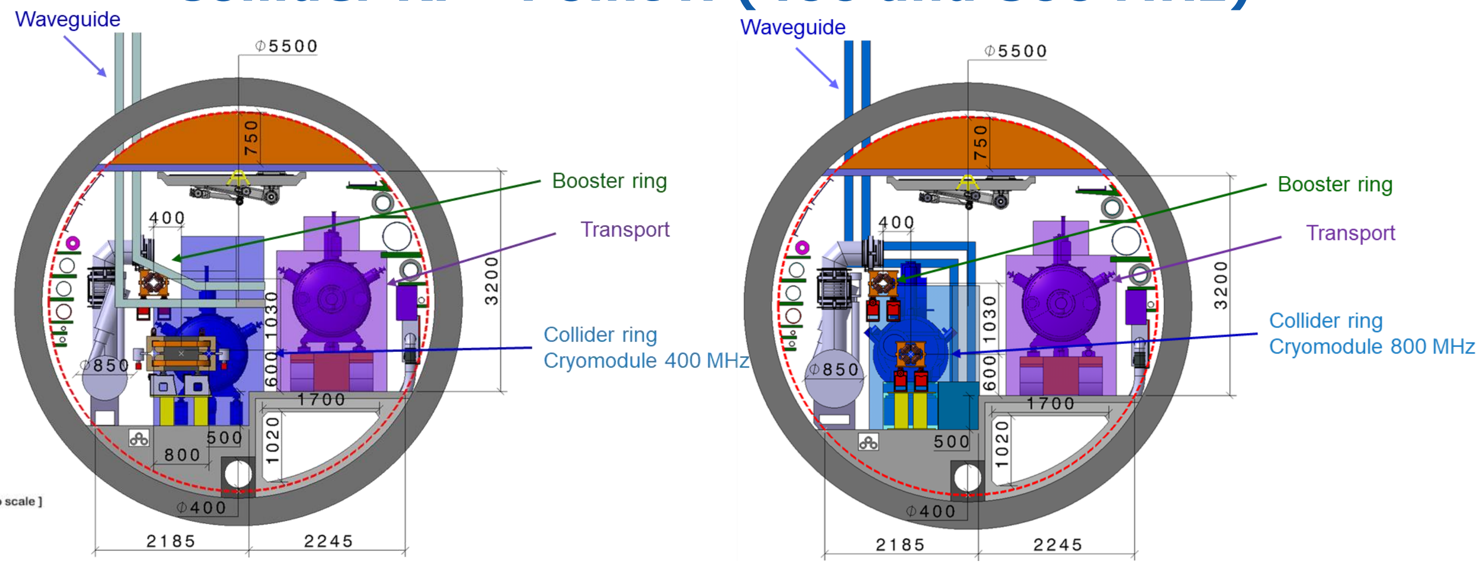
# modified FCC-ee RF layout

- RF for collider and booster in separate straight sections H and L.
- fully separated technical infrastructure systems (cryogenics)
- collider RF (highest power demand) in point H with optimum connection to existing 400 kV grid line and better suited surface site

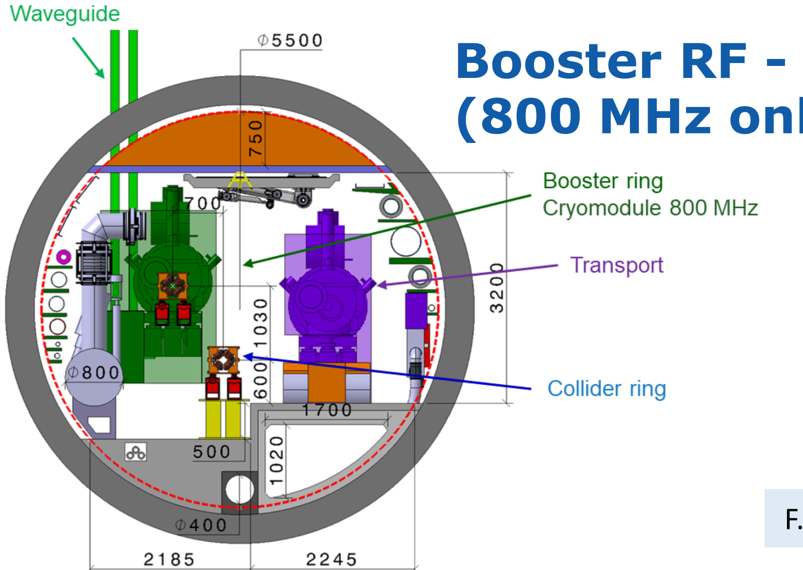



J.-P. Burnet

## Collider RF - Point H (400 and 800 MHz)

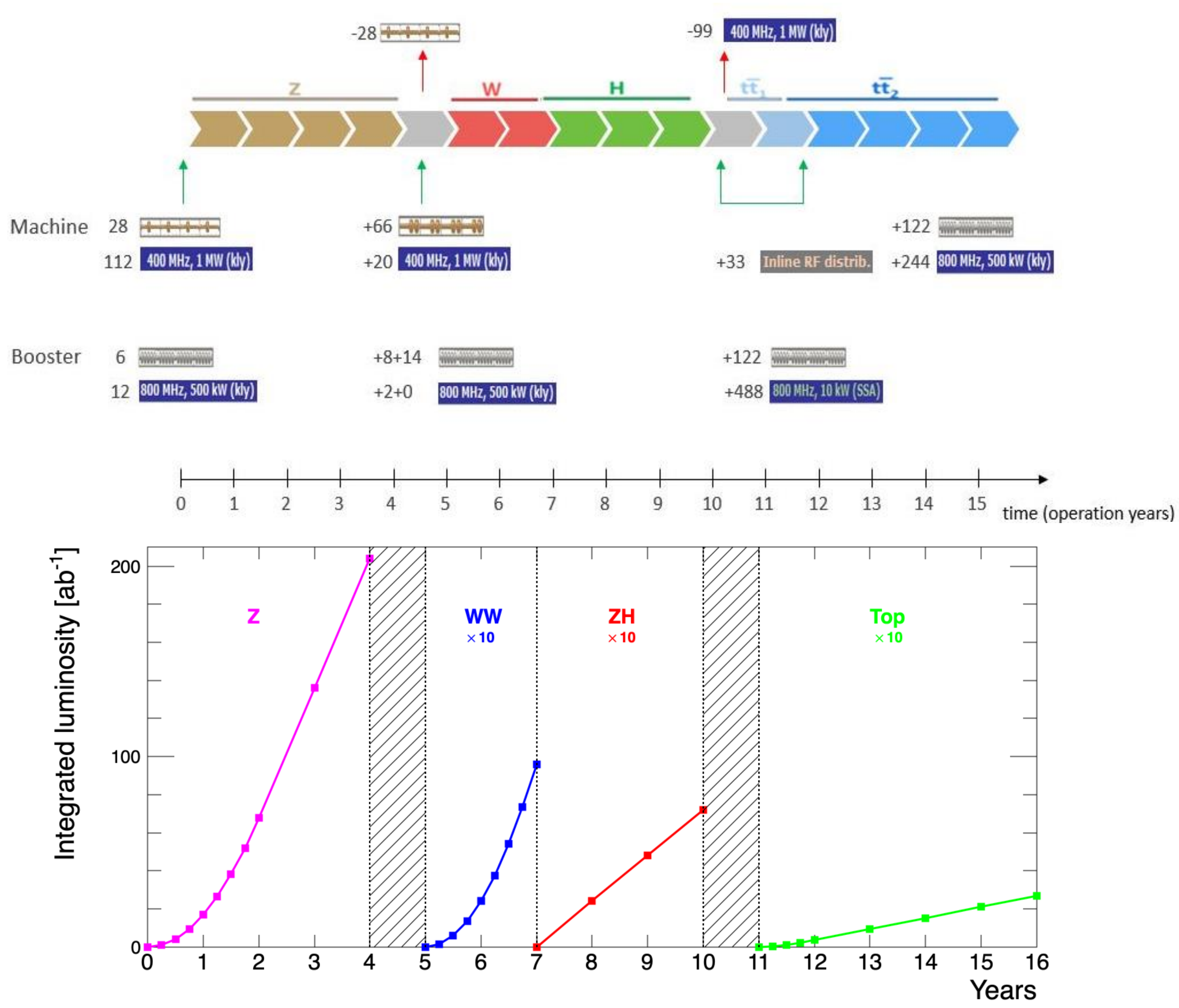


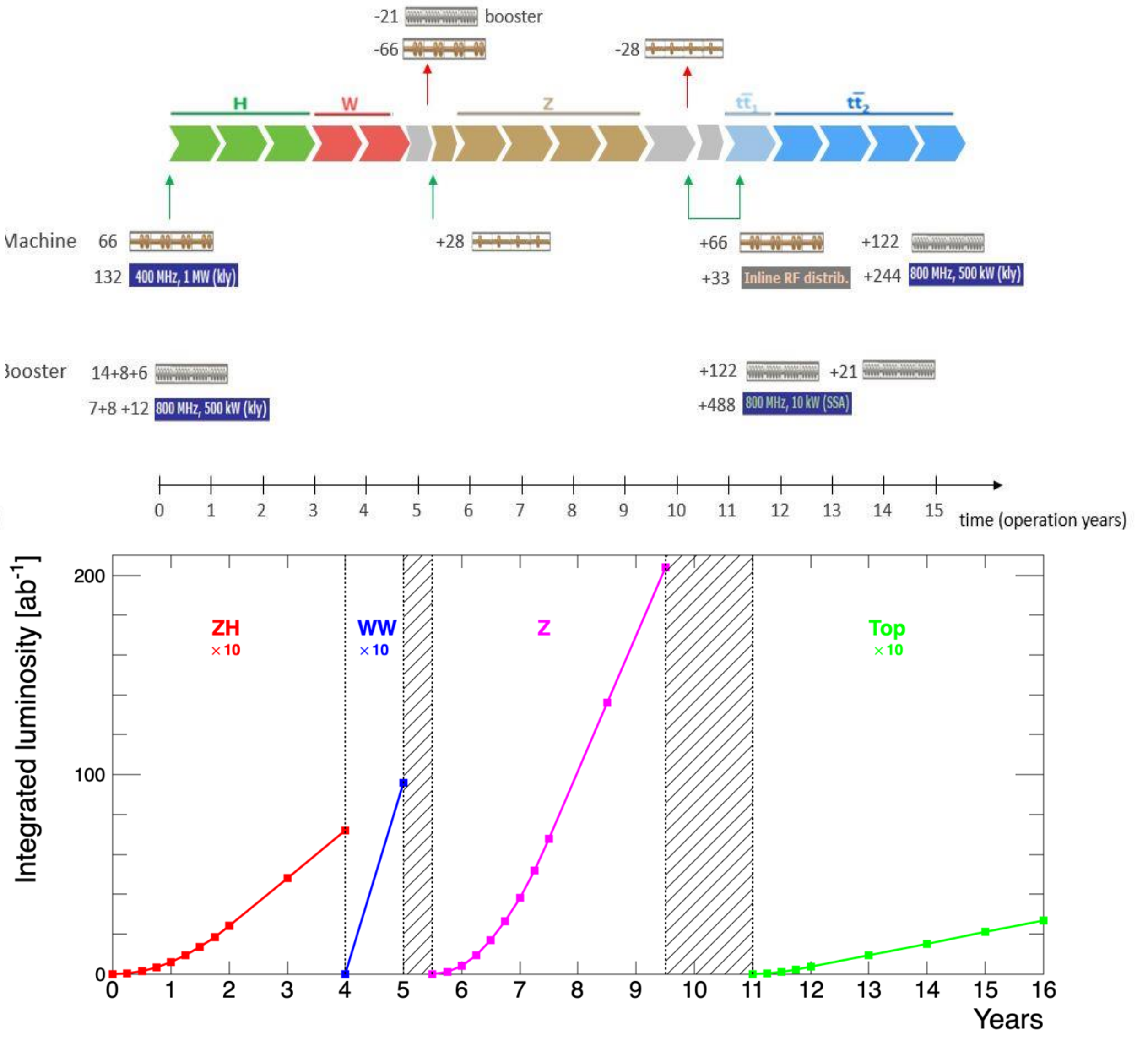

## Booster RF - Point L (800 MHz only)




F. Valchkova, F. Peauger

# Operation sequences for FCC-ee and RF configuration




- **Evolution of RF configuration of collider and booster with beam energies and physics operation points**
- **Long-term R&D for SRF, 400 MHz Nb on Cu, 800 MHz bulk Nb system**

# RF R&D activities

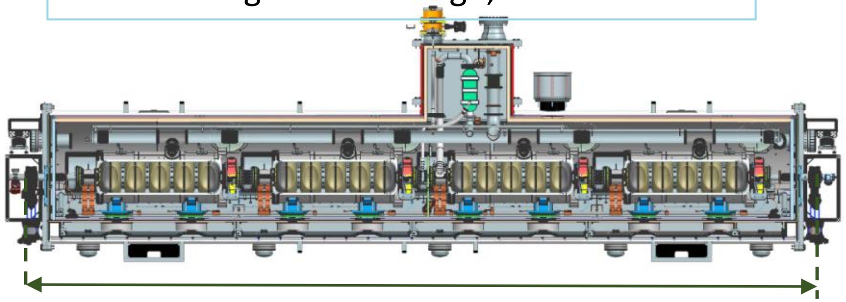
## RF system R&D is key for increasing energy efficiency of FCC-ee

- Nb on Cu 400 MHz cavities, seamless cavity production, coating techniques
- Bulk Nb 800 MHz cavities, surface treatment techniques, cryomodule design
- RF power source R&D in synergy with HL-LHC.

### 800 MHz cavity and CM design

collaborations with **JLAB and FNAL**

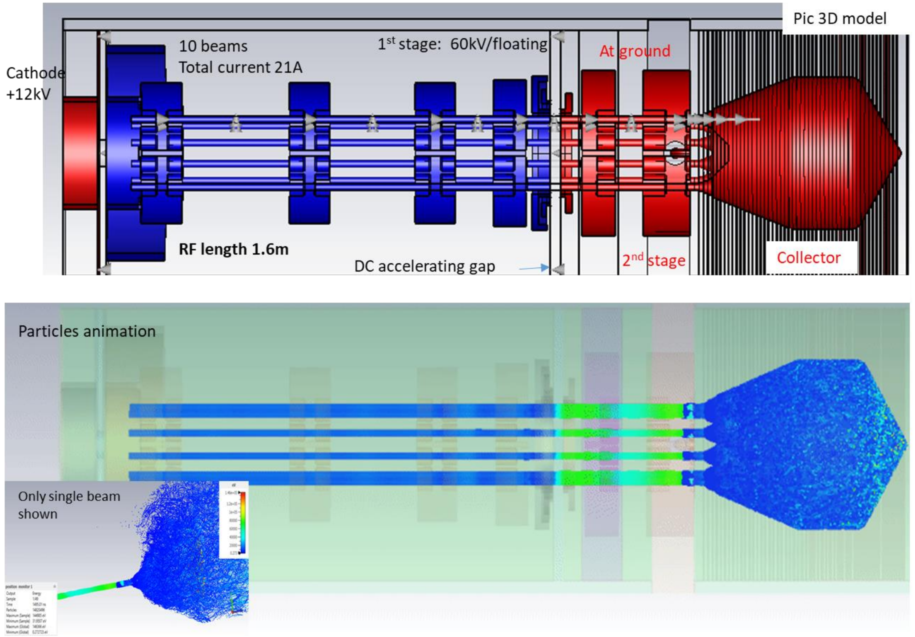
800 MHz segmented design, based on PIP-II




### high-efficiency klystron R&D

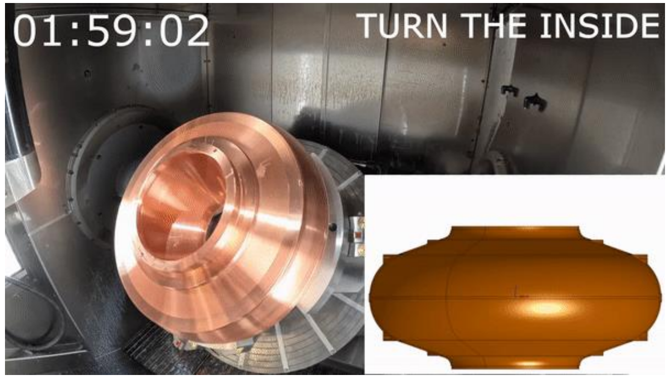
in collaborations with **THALES & CANON**

Novel two-stage MBK klystron: CW, 400MHz, 1.28MW.




### 400 MHz cavity production

in collaboration with **KEK**



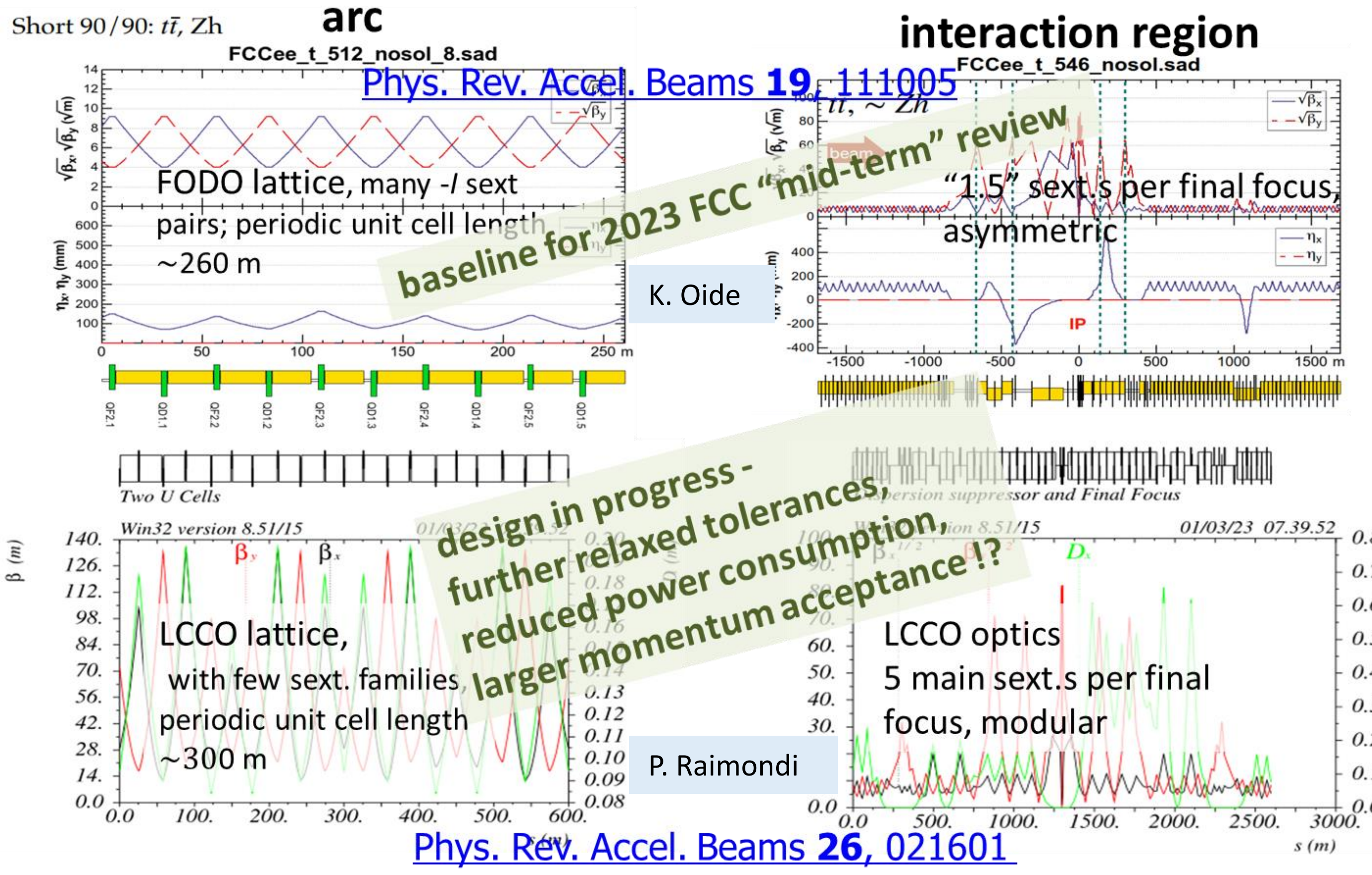

# Collider and Booster design

## Complete accelerator design and layout

- consolidated beam parameters throughout entire chain & different operation modes
- definitive collider and booster, optics and layout
- beam-based alignment procedures, tolerances and requirements
- complete impedance models for booster and collider rings

➔ **specifications for design of components and technical infrastructure**

➔ **full inventory for integration studies and requirements for civil engineering**

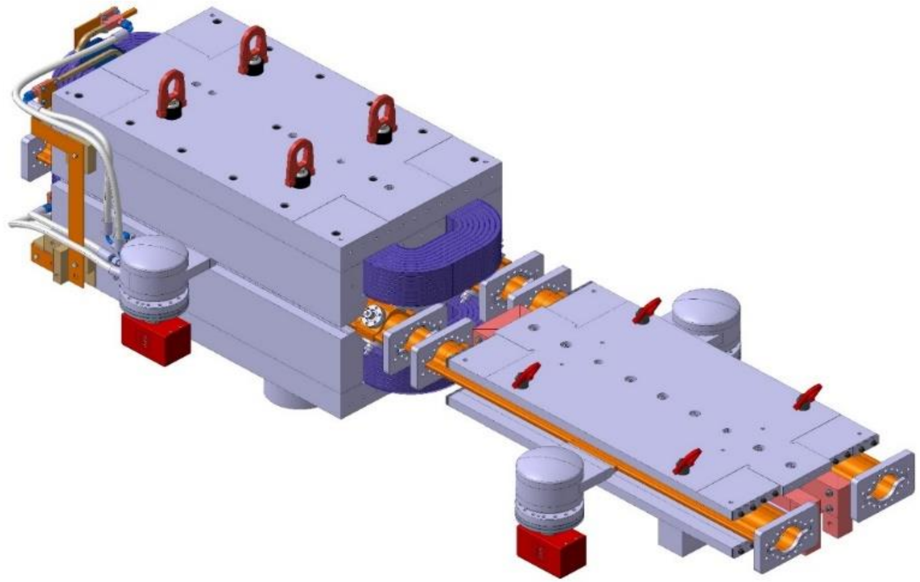


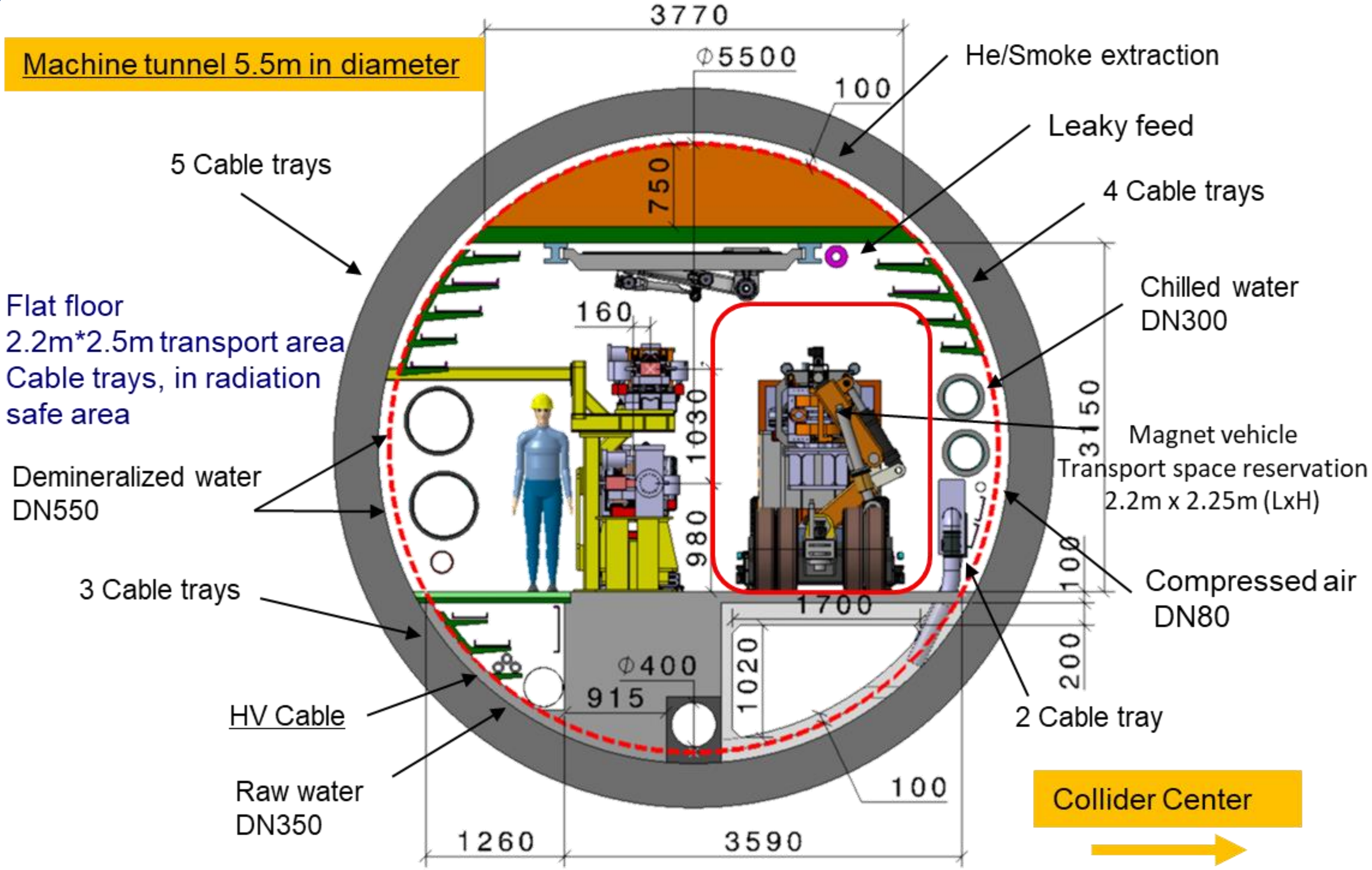
# Arc layout and integration optimization

## Arc cell optimisation – 80 km total length, dedicated working group active.

- Including support, girder and alignment systems, shielding systems
- vacuum system with antechamber + pumps, dipole, quadrupole + sext. magnets, BPMs,
- cabling, cooling & technical infrastructure interfaces.
- Safety aspects, access and transport concept,
  → Confirmation of tunnel diameter

## FCC-ee arc half-cell mock up

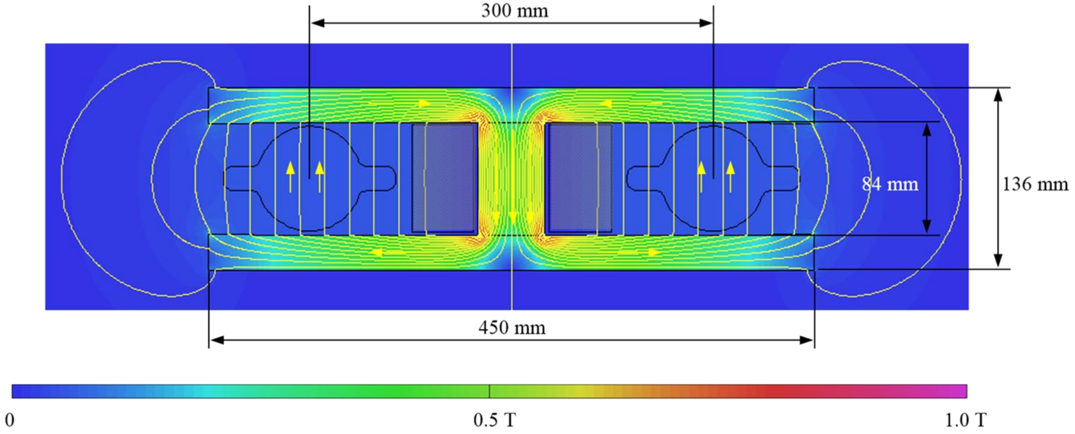


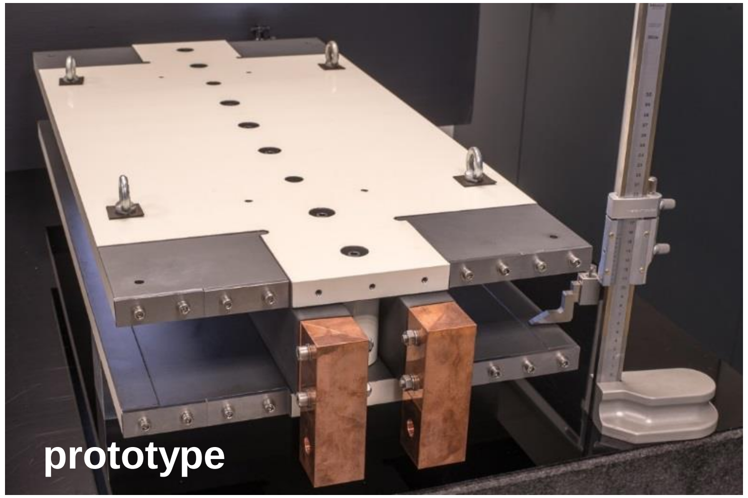


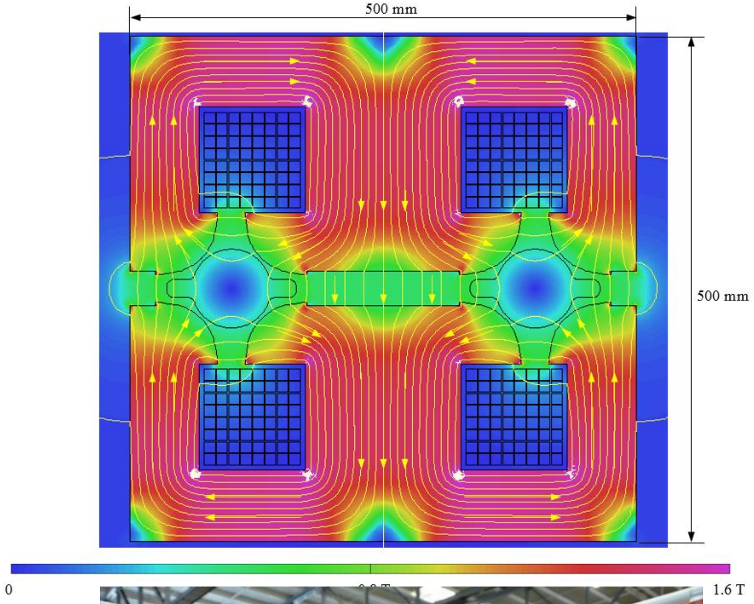

F. Carra, CERN; F. Valchkova

# prototypes of FCC-ee low-power magnets

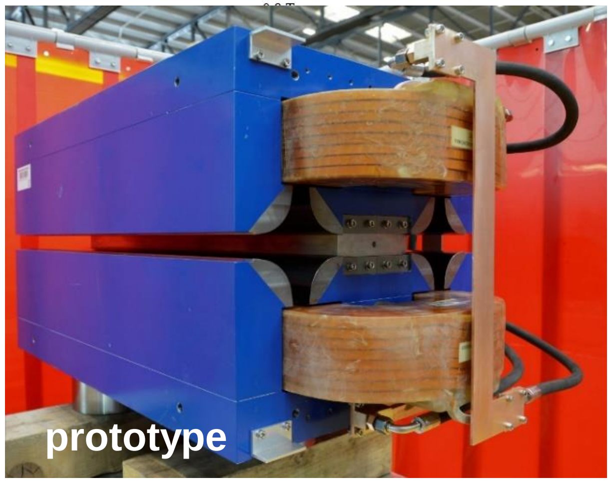
**Twin-dipole design with 2× power saving**
**16 MW (at 175 GeV), with Al busbars**




**Twin F/D arc quad design with 2× power saving 25 MW (at 175 GeV), with Cu conductor**




even more efficient alternative magnet designs are being explored

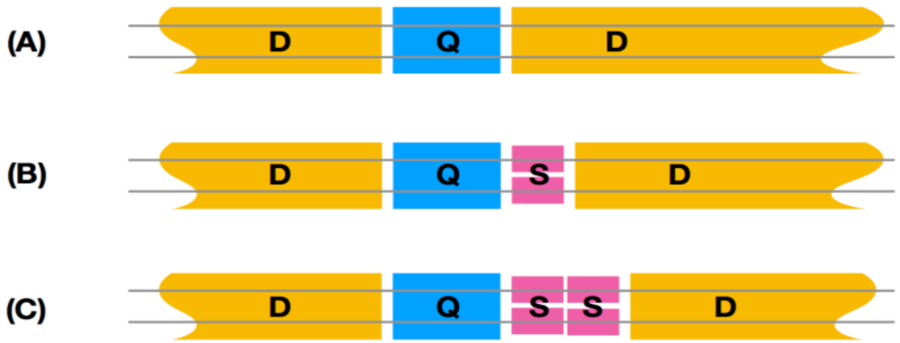
# HTS option for FCC-ee arc quads and sextupoles



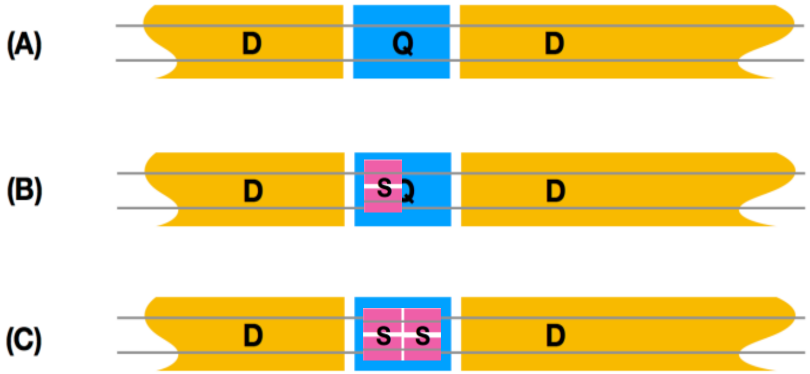
## CDR: 2900 quads & 4700 sextupoles

- Normal conducting, ~50 MW @ ttbar
- 3 different types of short straight sections

### CDR arc lattice



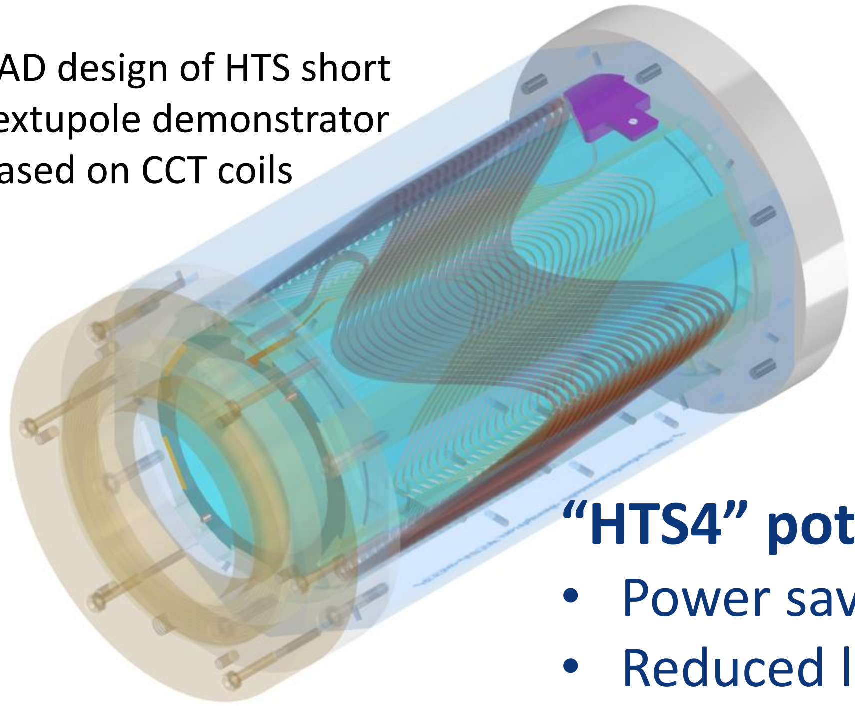

### HTS option

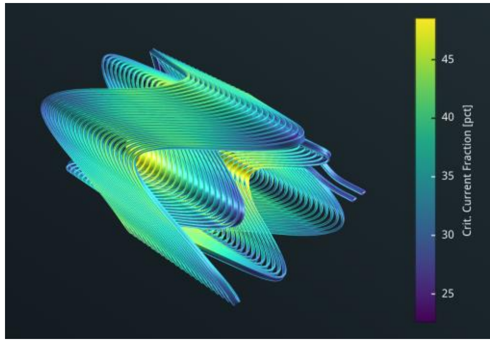



## "HTS4" project within CHART collaboration

- Nested SC sextupole and quadrupole.
- HTS conductors operating at around 40K.
- Cryo-cooler supplied cryostat
- Produce a ~1m prototype by 2026

CAD design of HTS short sextupole demonstrator based on CCT coils






M. Koratzinos, B. Auchmann

## "HTS4" potential

- Power saving
- Reduced length and increased dipole filling factor
- Optics flexibility

# Synchrotron radiation in tunnel

| | LEP-II (1999-2000) | FCC-ee Z | FCC-ee W | FCC-ee ZH | FCC-ee ttbar |
|---|---|---|---|---|---|
| Beam energy | 98-104.5 GeV | 45.6 GeV | 80 GeV | 120 GeV | 182.5 GeV |
| Bending radius | 3.1 km | 10 km | | | |
| Beam current | 6.2 mA (@98 GeV) | 2 x 1270 mA | 2 x 137 mA | 2 x 26.7 mA | 2 x 4.86 mA |
| Energy loss/turn (arcs) | 2.6 GeV (@98 GeV)<br>3.4 GeV (@104.5 GeV) | 0.04 GeV | 0.37 GeV | 1.9 GeV | 10.3 GeV |
| Power loss (arcs) | 16 MW (@98 GeV)* | 100 MW | | | |
| Total arc length | 23 km | 77 km | | | |
| Power loss/unit length (arcs) | 0.7 kW/m (@98 GeV)* | 1.3 kW/m | | | |
| Critical energy | 0.7 MeV – 0.8 MeV | 0.02 MeV | 0.1 MeV | 0.4 MeV | 1.3 MeV |

**Indicative value (beam current decreased from 98 GeV to 104.5 GeV)*

A. Lechner et al.

- **Source term comparable to LEP operation, higher critical energy for ttbar run.**
- **Baseline with distributed (water cooled) photon stops every ~6 m.**
- **Different shielding strategies for (Z, W, ZH) vs ttbar?**

# Machine detector interface

FUTURE CIRCULAR COLLIDER

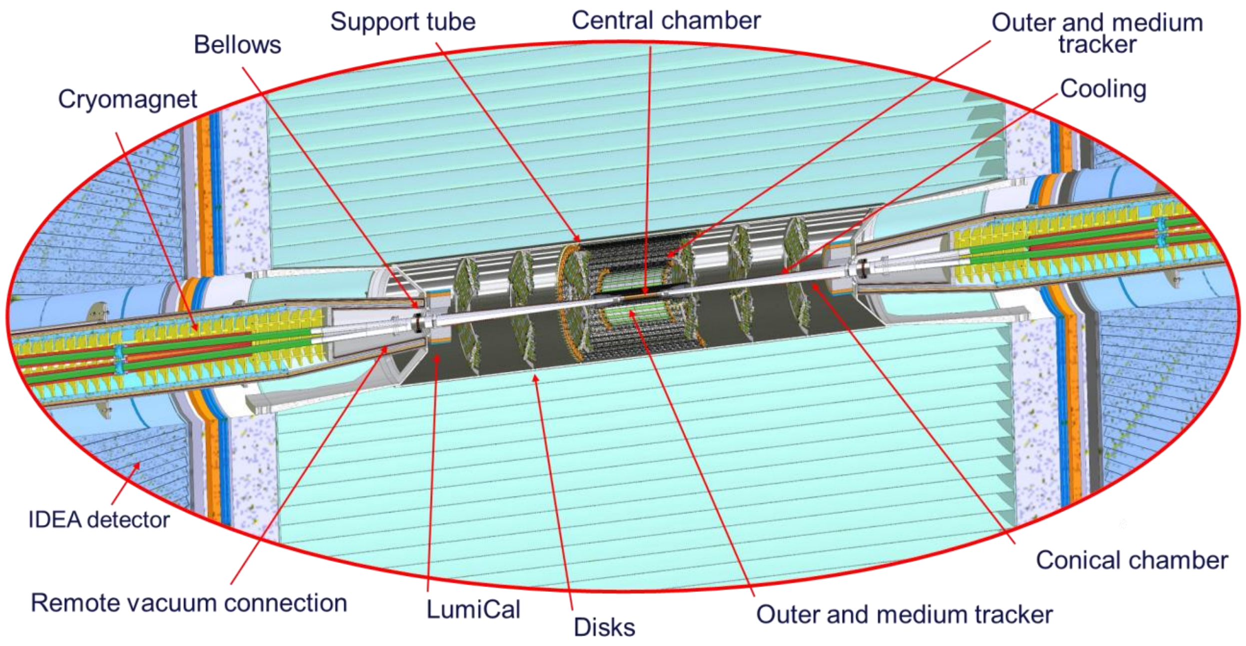
**Key topics:**

- SC IR magnet system &Cryostat design
- 3D integration
- IR mock-up / INFN

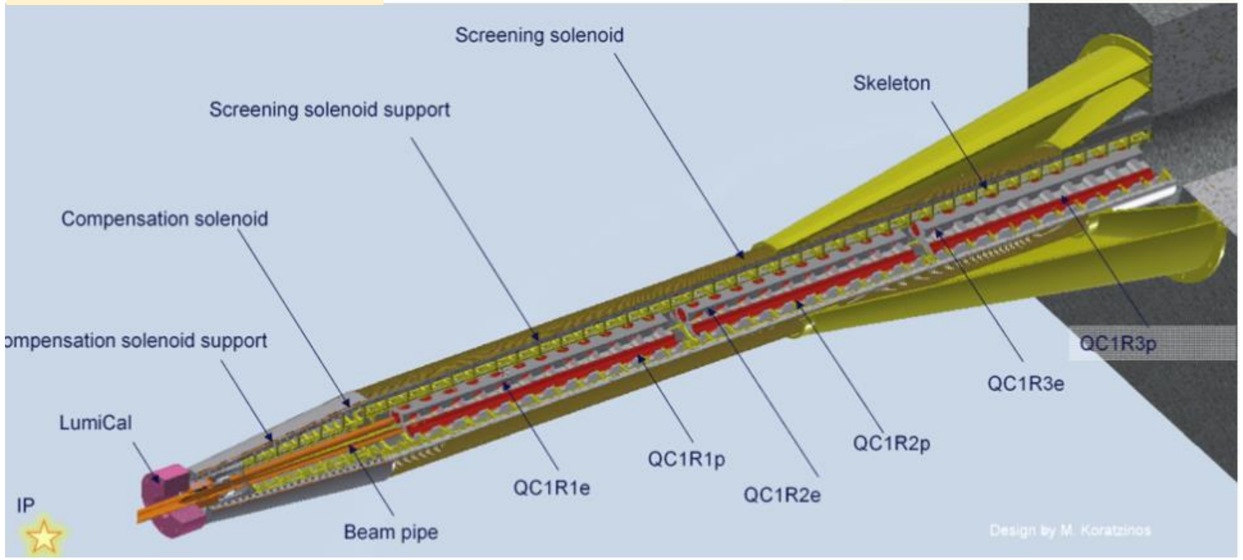
| Machine | | FCCee | CEPC | ILC | SuperKEKB |
|---|---|---|---|---|---|
| Crossing-angle | mrad | 30 | 33 | 14 | 83 |
| L* | m | 2.2 | 1.9 | 3.5 | 0.935 |
| Vertical $\beta_y$* at IP | mm | 0.7-1.6 | 0.9-2.7 | 0.4 | 0.3 |
| Detector soln field | T | 2/3 | 3 | 3.5/5 | 1.5 |
| Detector stay clear | mrad | 100 | 118/141 | 90 | 350/436 |
| Two beam $\Delta$X at L* | mm | 66 | 62.7 | 49 | 77.6 |
| He temperature | K | 1.9 | 4.2 | 4.5 | 4.5 |


M. Koratzinos, PSI

J. Seeman, SLAC
P. Tavares , CERN




M. Boscolo, F. Palla, INFN



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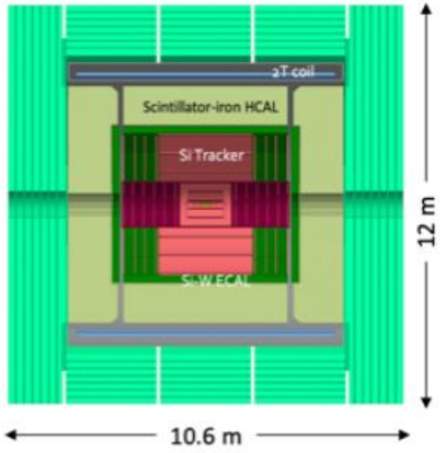
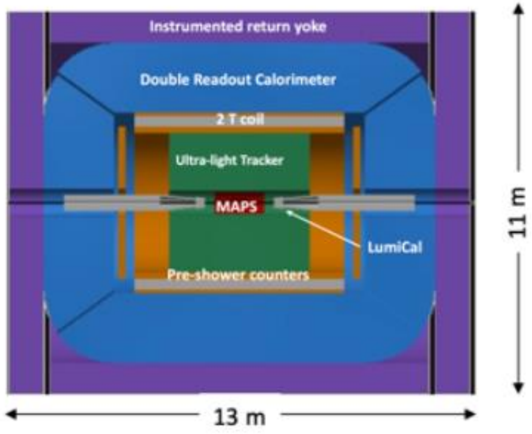
# FCC-ee detector concepts under study

## CLD

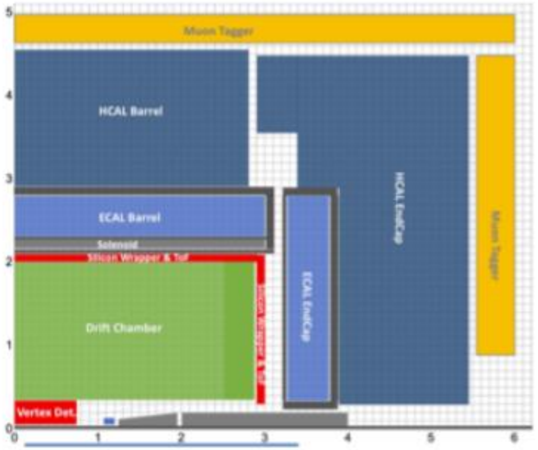



CDR

## IDEA




## Noble Liquid ECAL based




new

**CLD**

- Well established design
  - ILC -> CLIC detector -> CLD
- Full Si vtx + tracker; CALICE-like calorimetry; large coil, muon system
- Engineering and R&D needed for
  - reduction of tracker material budget
  - operation with continous beam (no power pulsing: cooling of Si sensors for tracking + calorimetry)
- Possible detector optimizations
  - Improved $\sigma_p/p$, $\sigma_E/E$
  - PID: timing and/or RICH?

**IDEA**

- Less established design
  - But still ~15y history: ILC 4th Concept
- Si vtx detector; ultra light drift chamber w powerfull PID; compact, light coil; monolitic dual readout calorimeter; muon system
  - Possibly augmented by crystal ECAL
- Active community
  - Prototype designs, test beam campains, …

**Noble Liquid ECAL based**

- A design in its infancy
- High granularity Noble Liquid ECAL is core
  - Pb+LAr (or denser W+LCr)
- Drift chamber; CALICE-like HCAL; muon system.
- Coil inside same cryostat as LAr, possibly outside ECAL
- Active Noble Liquid R&D team
  - Readout electrodes, feed-throughs, electronics, light cryostat, …
  - Software & performance studies

M. Dam, et al.

FUTURE CIRCULAR COLLIDER

# FCC-hh main machine parameters

| parameter | FCC-hh | HL-LHC | LHC |
|---|---|---|---|
| collision energy cms [TeV] | 84 – 120 | 14 | |
| dipole field [T] | 14 – 20 | 8.33 | |
| circumference [km] | 90.7 | 26.7 | |
| arc length [km] | 76.9 | 22.5 | |
| beam current [A] | 0.5 | 1.1 | 0.58 |
| bunch intensity [$10^{11}$] | 1 | 2.2 | 1.15 |
| bunch spacing [ns] | 25 | 25 | |
| synchr. rad. power / ring [kW] | 1020 - 4250 | 7.3 | 3.6 |
| SR power / length [W/m/ap.] | 13 - 54 | 0.33 | 0.17 |
| long. emit. damping time [h] | 0.77 – 0.26 | 12.9 | |
| peak luminosity [$10^{34}$ $cm^{-2}s^{-1}$] | ~30 | 5 (lev.) | 1 |
| events/bunch crossing | ~1000 | 132 | 27 |
| stored energy/beam [GJ] | 6.1 - 8.9 | 0.7 | 0.36 |
| Integrated luminosity/main IP [$fb^{-1}$] | 20000 | 3000 | 300 |

**With FCC-hh after FCC-ee: significant amount of time for high-field magnet R&D, aiming at highest possible collision energies**

- Target field range for cryo-magnet R&D

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
- ❑ optimization of energy consumption: → R&D on cryo, HTS, beam current, …

Formidable physics reach, including:

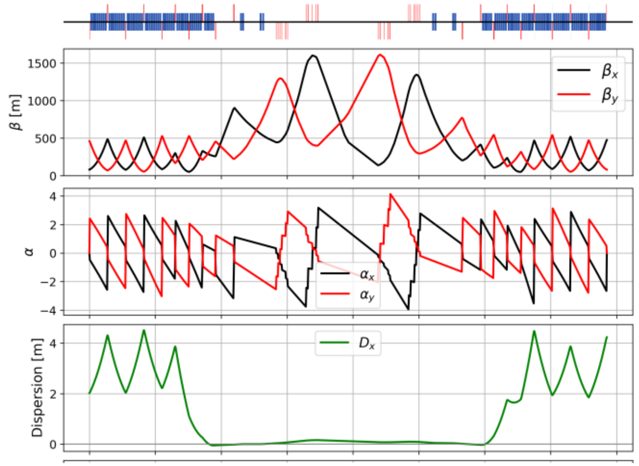
- ❑ Direct discovery potential up to ~ 40 TeV
- ❑ Measurement of Higgs self to ~ 5% and ttH to ~ 1%
- ❑ High-precision and model-indep (with FCC-ee input) measurements of rare Higgs decays ($\gamma\gamma$, $Z\gamma$, μμ)
- ❑ Final word about WIMP dark matter

F. Gianotti

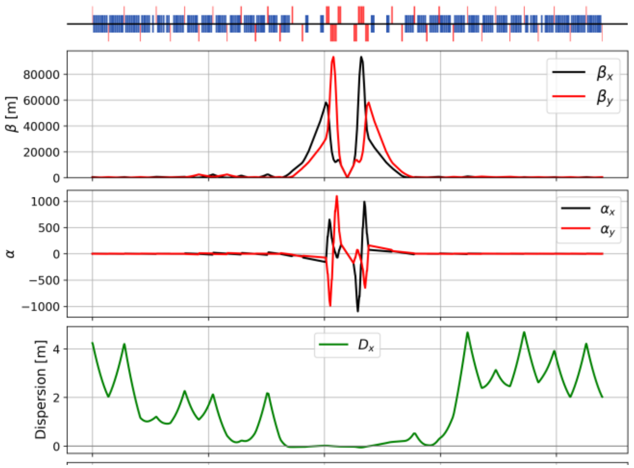
# Key activities on FCC-hh: cryo magnet system, optics design

## Optics design activities:

- adaptation to new layout and geometry
- shrink β collimation & extraction by ~30%
- optics optimisation (filling factor etc.)

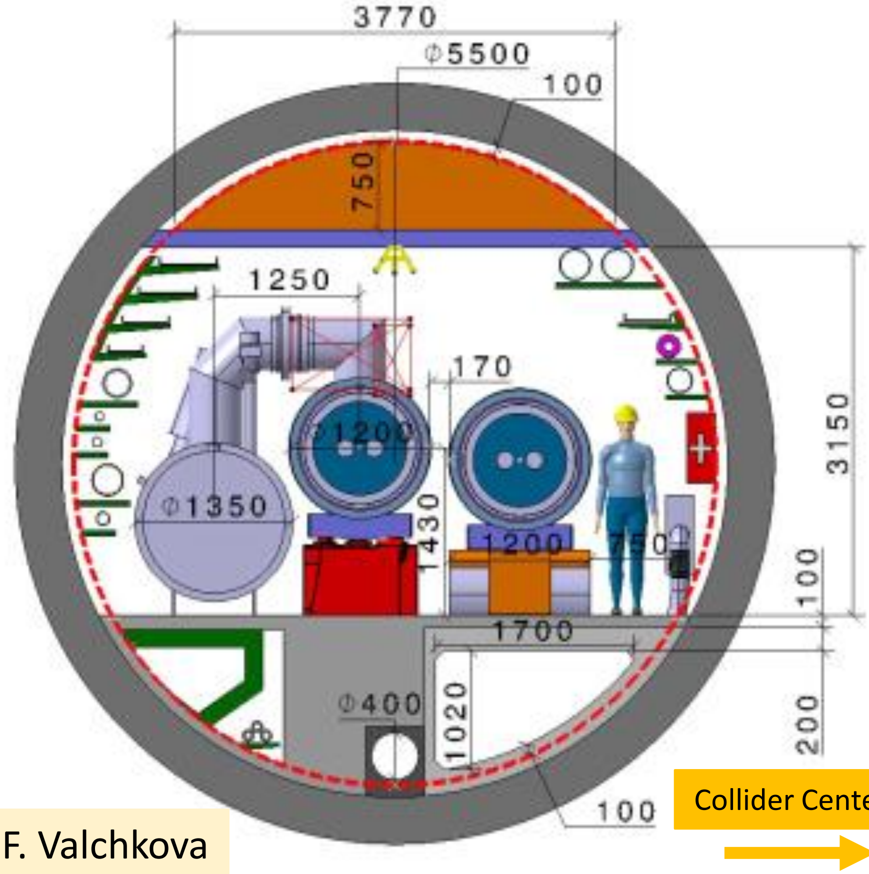



betatron collimation straight




experimental straight

M. Giovannozzi. G. Perez, T. Risselada




Collider Center

F. Valchkova

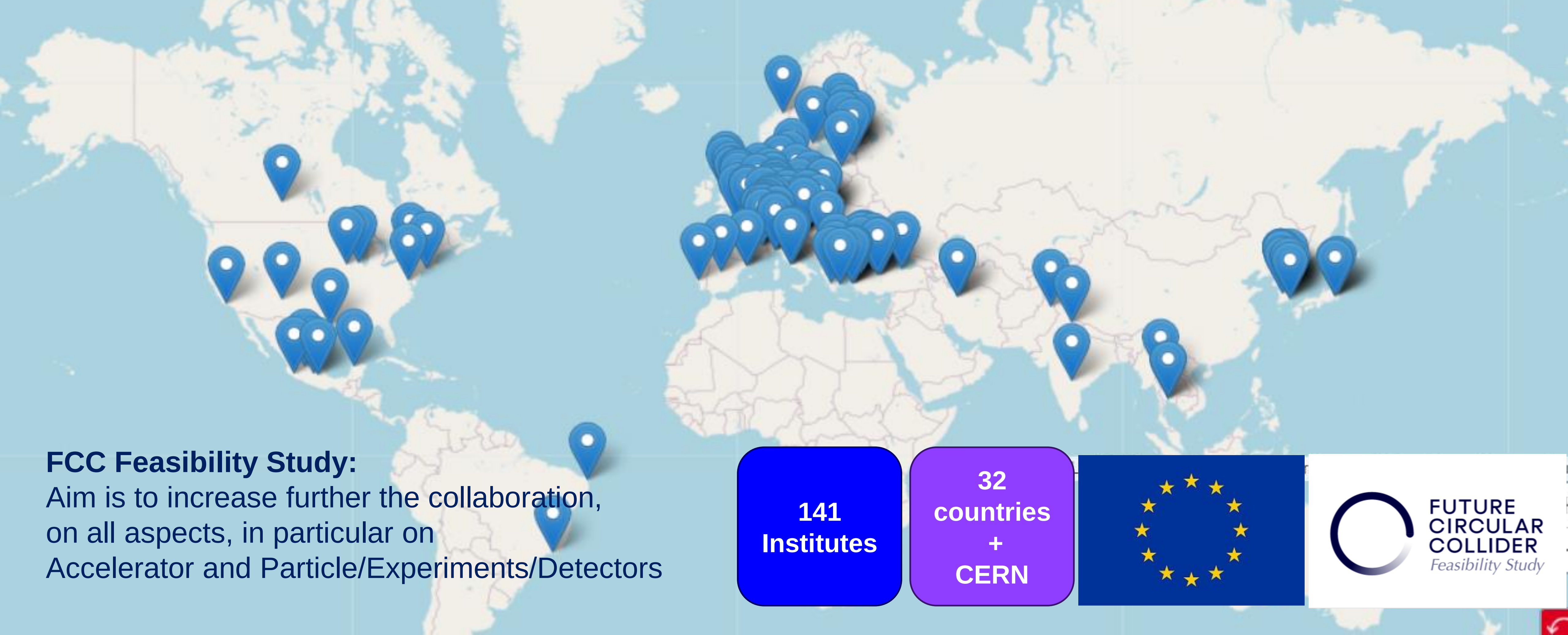
## High-field cryo-magnet system design

- Conceptual study of cryogenics concept and temperature layout for LTS and HTS based magnets, in view of electrical consumption.
- Update of integration study for the ongoing HFM designs and scaling to preliminary HTS design.
  → **Confirmation of tunnel diameter!**
- HFM R&D (LTS and HTS) on technology and magnet design, aiming also at bridging the TRL gap between HTS and $Nb_3Sn$.

# Status of FCC global collaboration

**Increasing international collaboration as a prerequisite for success:**

→links with **science, research & development** and **high-tech industry** will be essential to further advance and prepare the implementation of FCC



**FCC Feasibility Study:**

Aim is to increase further the collaboration, on all aspects, in particular on Accelerator and Particle/Experiments/Detectors

**141 Institutes**

**32 countries + CERN**

FUTURE CIRCULAR COLLIDER *Feasibility Study*

# FCC Week 2024

FUTURE CIRCULAR COLLIDER

**The complete status of the FCC and all the latest advancements were presented at the Future Circular Collider (FCC) Week 2024, in San Francisco:**

**https://fccweek2024.web.cern.ch/**


# Progress on international collaboration

FUTURE CIRCULAR COLLIDER

★ ★ ★

## Joint Statement of Intent between The United States of America and The European Organization for Nuclear Research concerning Future Planning for Large Research Infrastructure Facilities, Advanced Scientific Computing, and Open Science

The United States and CERN intend to:

- Enhance collaboration in future planning activities for large-scale, resource-intensive facilities with the goal of providing a sustainable and responsible pathway for the peaceful use of future accelerator technologies;
- Continue to collaborate in the feasibility study of the Future Circular Collider Higgs Factory (FCC-ee), the proposed major research facility planned to be hosted in Europe by CERN with international participation, with the intent of strengthening the global scientific enterprise and providing a clear pathway for future activities in open and trusted research environments; and
- Discuss potential collaboration on pilot projects on incorporating new analytics techniques and tools such as artificial intelligence (AI) into particle physics research at scale.

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.

26 April 2024

White House Office of Science and Technology Policy Principal Deputy U.S. Chief Technology Officer Deirdre Mulligan signed for the United States while Director-General Fabiola Gianotti signed for CERN.

# Early Career Researchers – session at FCCW2024

## A possible FCC career

*Run 3* — **2029** — *Run 4* — **2033** — *Run 5* — **2040**

**ESPP Update** | **Detector CDRs** | **FCCee Construction** | **FCCee Installation**

**PhD**

- Physics on Run 3
- Successful installation & commissioning of HL-LHC
- Detector R&D (CPAD), ECFA studies

**Postdoc**

- HL-LHC physics & operations
- Experiment-specific detector prototypes for FCCee

**Faculty & Tenure**

- Physics on HL-LHC
- Build FCCee detectors
- FCCee experimental leadership/project

An LHC→FCC career trajectory with lots of physics publications, hardware experience, and leadership opportunities!



**Julia Gonski**

FUTURE CIRCULAR COLLIDER

# FCC Main Goals for Coming Years

- **Next milestone: completion of the FCC Feasibility Study by March 2025**
- **By 2027-2028, possible FCC project approval, start of CE design contract:**
  - specifications to enable CE tender design by 2028
  - refined input for environmental evaluation and project authorisation process
  - requires overall integration study and designs based on technical pre-design of accelerators, technical infrastructure and detectors
- **By 2031-32, possible start of CE construction:**
  - CE groundbreaking
  - TDR to enable prototyping, industrialization towards component production
- **Strong collaboration with US and further international partners is essential for success!**

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