FCC General Overview

“Educational Outreach Activity at CERN”, 8 April 2024

Frank Zimmermann, CERN
on behalf of FCC collaboration

with many warm thanks to Sehban Kartal and Michael Benedikt

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*

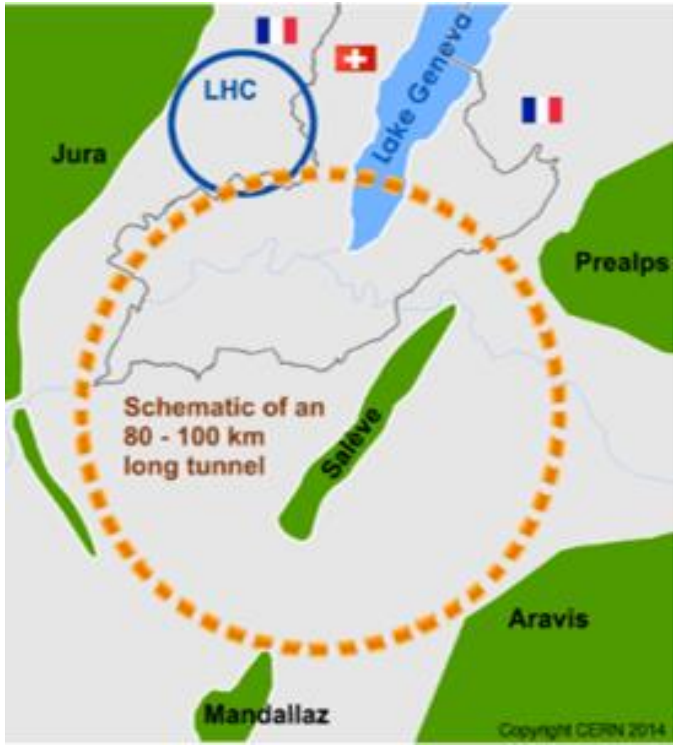
European Commission | Horizon 2020 European Union funding for Research & Innovation

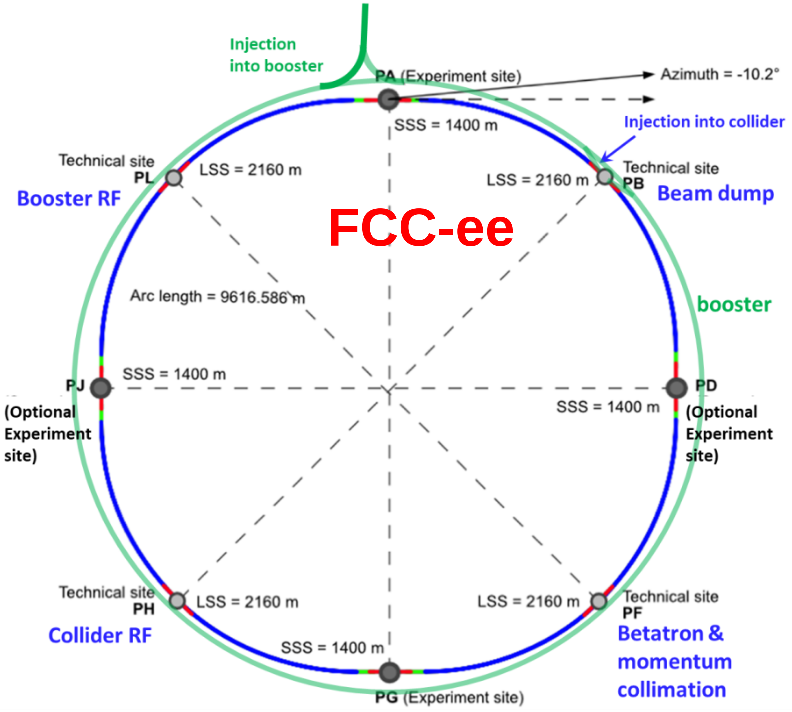
photo: J. Wenninger

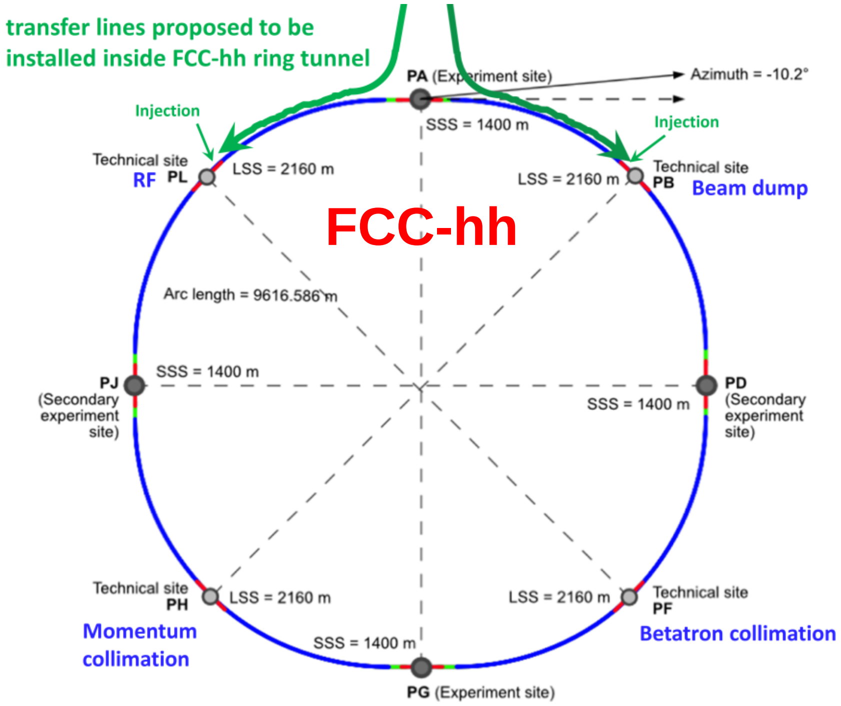
FCC integrated program

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







a similar two-stage project CEPC/SPPC is under study in China

FCC integrated program - timeline

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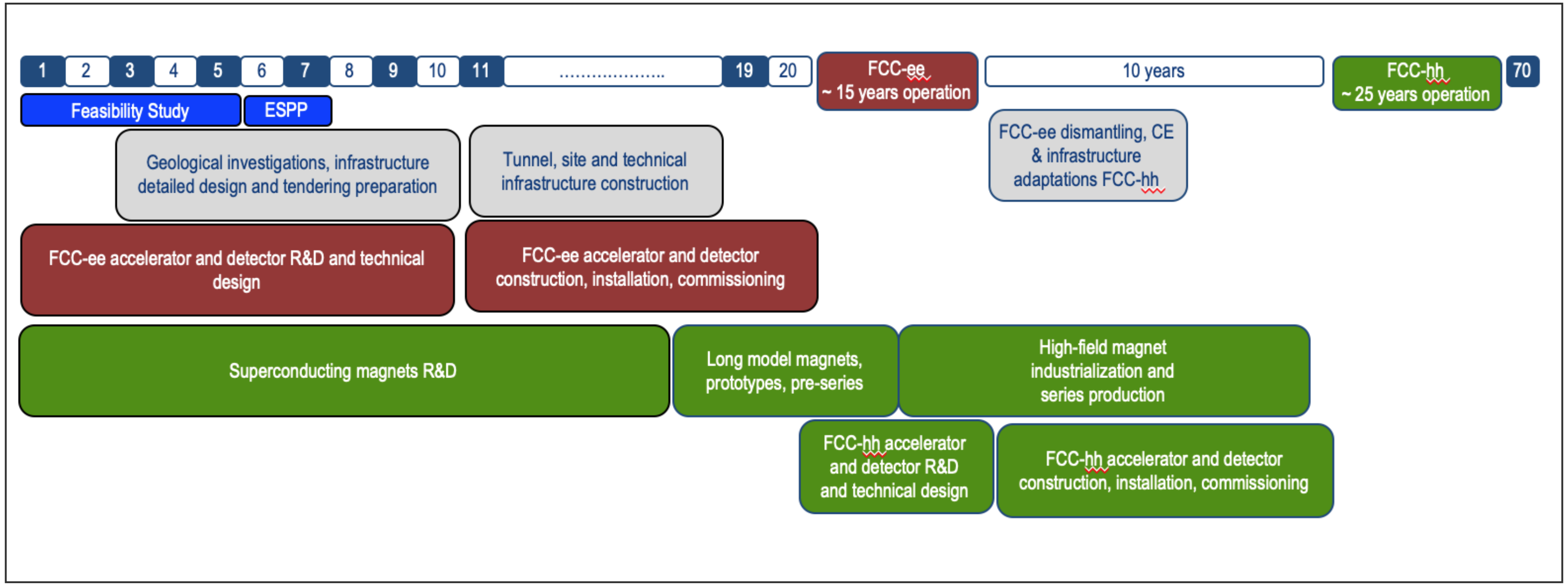
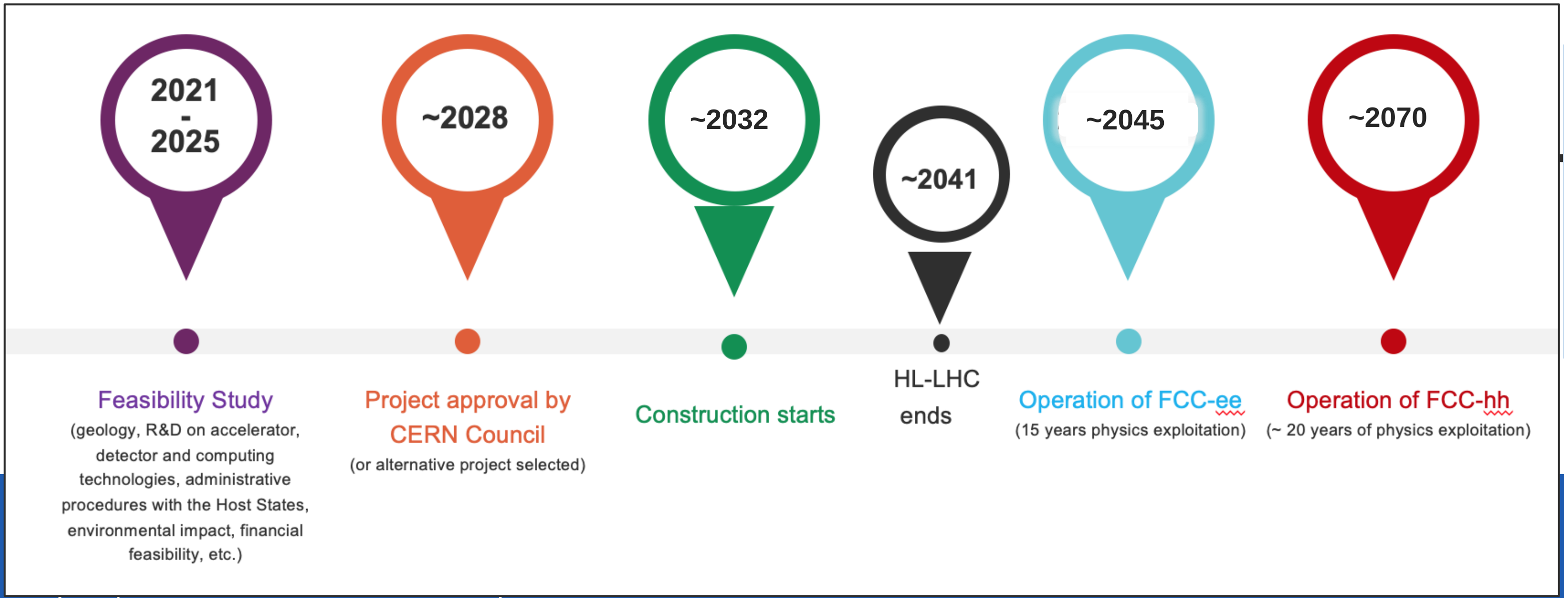


Note: FCC Conceptual Design Study started in 2014 leading to CDR in 2018



Ambitious schedule taking into account:

- ❑ past experience in building colliders at CERN
- ❑ approval timeline: ESPP, Council decision
- ❑ that HL-LHC will run until 2041
- ❑ **project preparatory phase with adequate resources immediately after Feasibility Study**

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

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- 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 by March 2025

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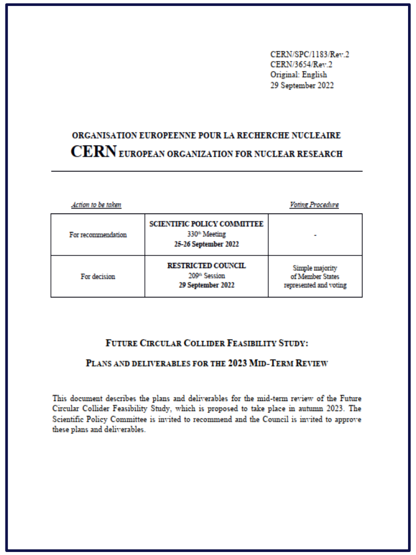
FCC FS mid-term review

The goal of the FCC FS mid-term review is to assess the progress of the Study towards the final report.
Deliverables approved by the Council in September 2022:

https://indico.cern.ch/event/1197445/contributions/5034859/attachments/2510649/4315140/spc-e-1183-Rev2-c-e-3654-Rev2_FCC_Mid_Term_Review.pdf

Deliverables:
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

← Many thanks to the Host States for their strong support!


CERN/SPC/1183/Rev.2
CERN/3654/Rev.2
Original: English
29 September 2022

ORGANISATION EUROPEENNE POUR LA RECHERCHE NUCLEAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Action to be taken		Voting Procedure
For recommendation	SCIENTIFIC POLICY COMMITTEE 330th Meeting 25-26 September 2022	-
For decision	RESTRICTED COUNCIL 209th Session 29 September 2022	Simple majority of Member States represented and voting

FUTURE CIRCULAR COLLIDER FEASIBILITY STUDY:
PLANS AND DELIVERABLES FOR THE 2023 MID-TERM REVIEW

This document describes the plans and deliverables for the mid-term review of the Future Circular Collider Feasibility Study, which is proposed to take place in autumn 2023. The Scientific Policy Committee is invited to recommend and the Council is invited to approve these plans and deliverables.

Documents:
- ❑ Mid-term report (all deliverables except D7)
- ❑ Executive Summary of mid-term report
- ❑ Updated cost assessment (D7)
- ❑ Funding model (D7)

Review process:
- ❑ Oct 2023: 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

Many thanks to the SAC, CRP, SPC, FC and the Council for the very useful reviews!

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FCC Feasibility Study mid-term report

Full Report

8 Chapters/Deliverables
~ 700pp document
~ 16 editors
~ 500 contributors

Future Circular Collider
Midterm Report

February 2024

Edited by:
B. Auchmann, W. Bartmann, M. Benedikt, J.P. Burnet, P. Craievich, M. Giovannozzi, C. Grojean, J. Gutleber, K. Hanke, P. Janot, M. Mangano, J. Osborne, J. Poole, T. Raubenheimer, T. Watson, F. Zimmermann

This project has received funding under the European Union's Horizon 2020 research and innovation programme under grant agreement No 951754.

This document has been produced by the organisations participating in the FCC feasibility study. The studies and technical concepts presented here do not represent an agreement or commitment of any of CERN's Member States or of the European Union for the construction and operation of an extension to CERN's existing research infrastructures.
The midterm report of the FCC Feasibility Study reflects work in progress and should therefore not be propagated to people who do not have direct access to this document.

Executive Summary

8 Chapters/Deliverables
~ 45pp document
~ 16 editors

Executive Summary of the
Future Circular Collider
Midterm Report

February 2024

Edited by:
B. Auchmann, W. Bartmann, M. Benedikt, J.P. Burnet, P. Charitos, P. Craievich, M. Giovannozzi, C. Grojean, J. Gutleber, K. Hanke, P. Janot, M. Mangano, J. Osborne, J. Poole, T. Raubenheimer, A. Unnervik, T. Watson, F. Zimmermann

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Both documents are available to the CERN community at:
https://doi.org/10.17181/mhas5-1f263

Please note that the midterm report of the FCC Feasibility Study reflects work in progress and should therefore not be propagated to people without direct access to this page.

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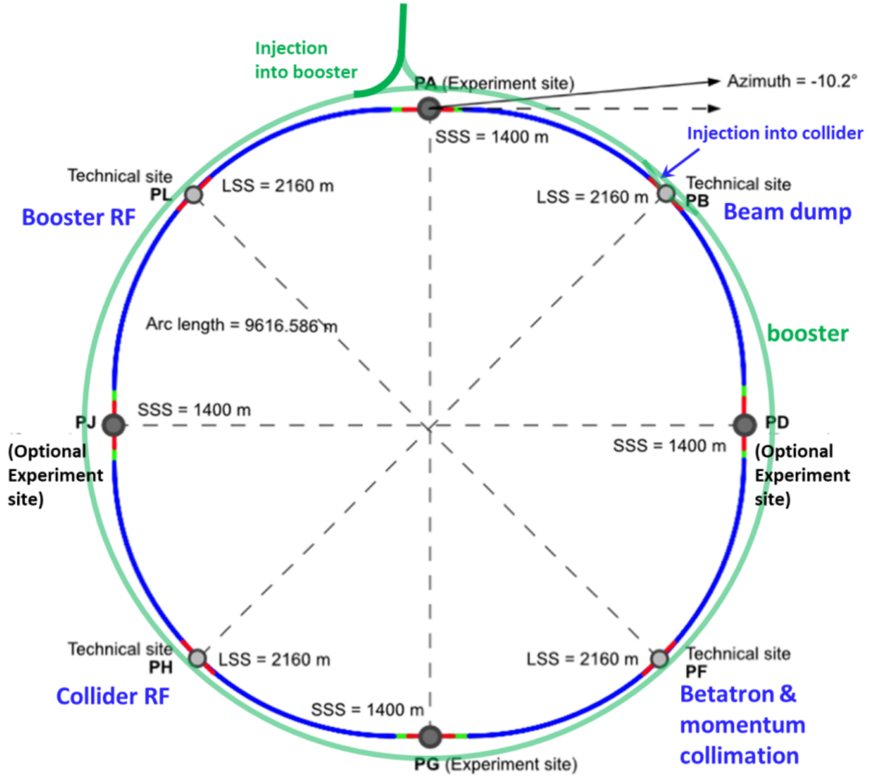
For questions on access please contact the FCC Secretariat: fcc.secretariat@cern.ch

Optimized placement and layout for feasibility study

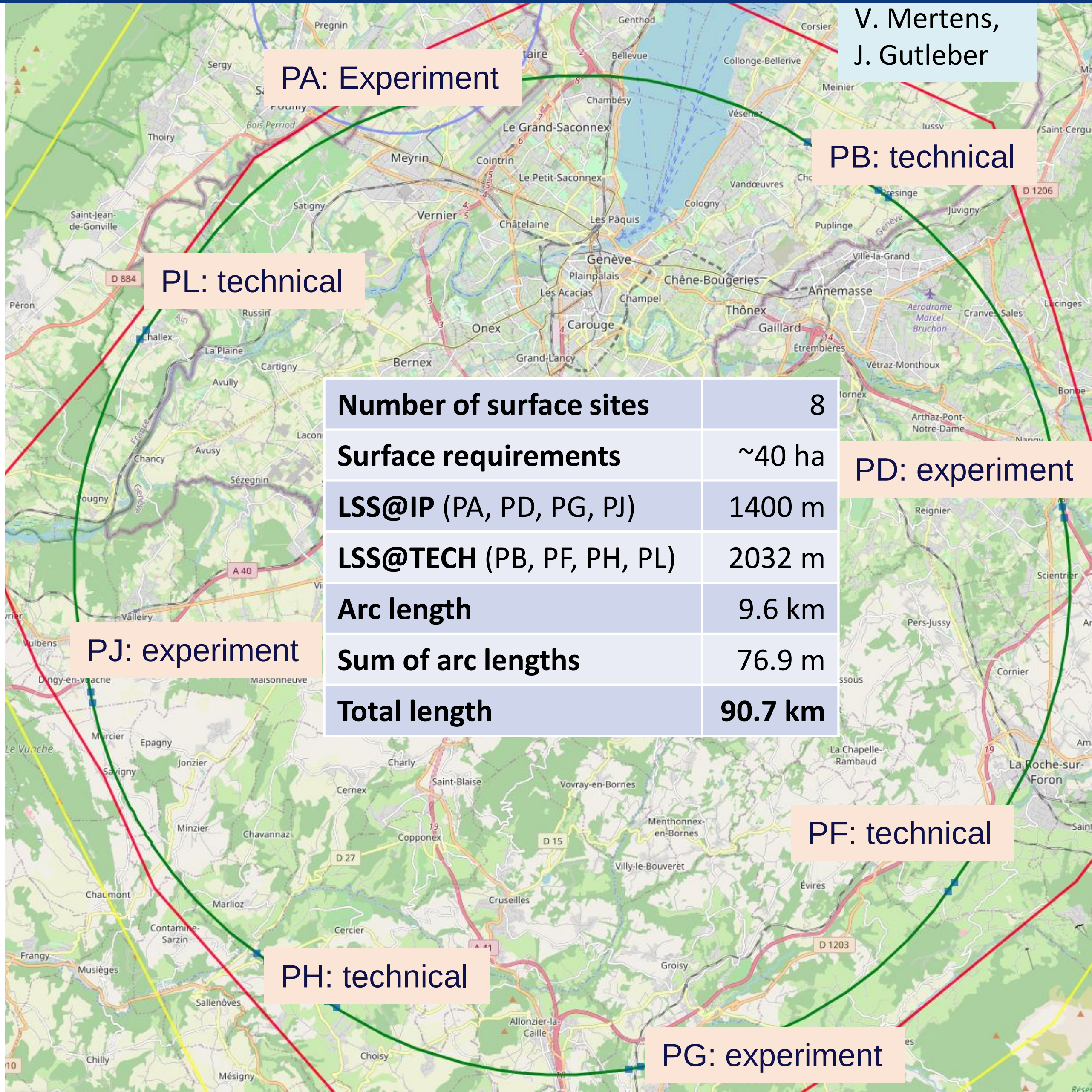
Layout chosen out of ~ 100 initial variants, based on **geology** and **surface constraints** (land availability, access to roads, etc.), **environment,** (protected zones), **infrastructure** (water, electricity, transport), **machine performance** etc.

“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



V. Mertens, J. Gutleber



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**

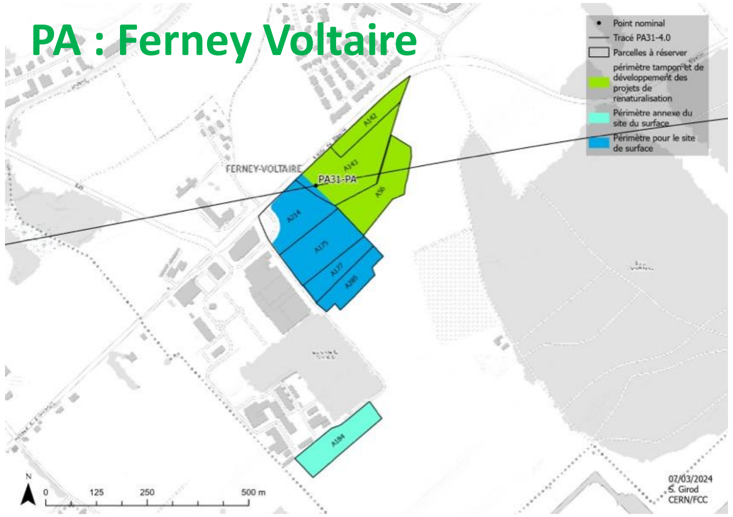
Surface sites development and reservation of land-plots

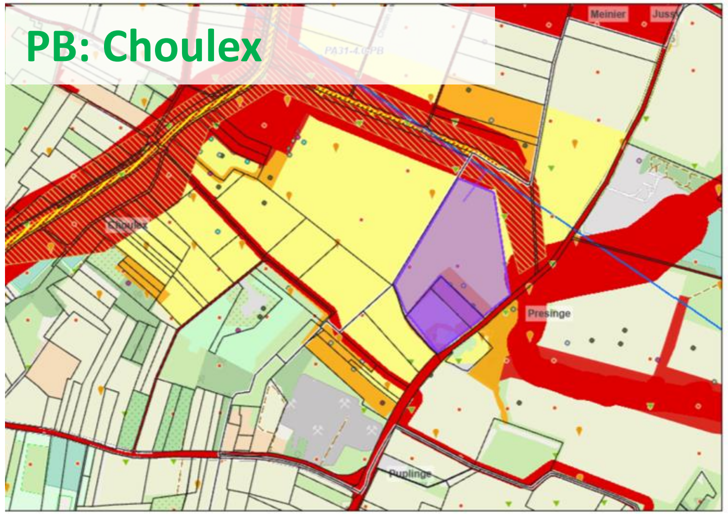
Meetings ongoing with all communes concerned by surface sites to identify individual land-plots for development of surface site layout and land reservation.

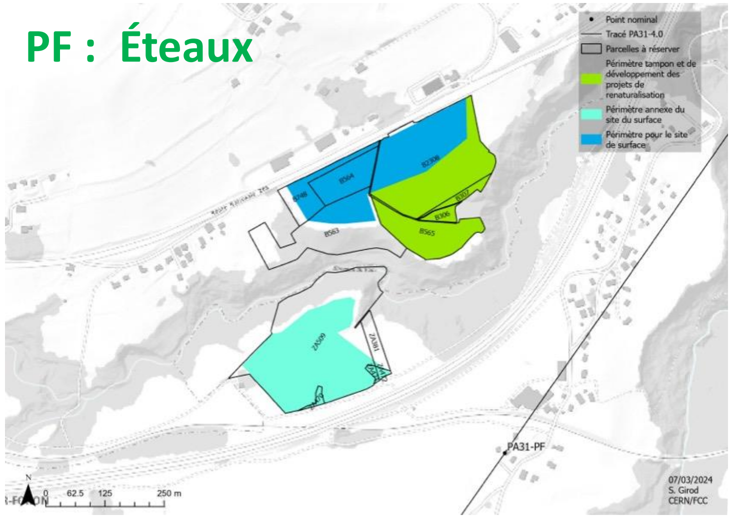
- PA : Ferney Voltaire: 01/2024
- PB: Choulex : 12/2023
- PB: Presinge : 01/2024, plenary session with community council 04/2024
- PD : Nangy: 05/2024
- PF : Éteaux : 03/2024
- PG : Groisy / Charvonnex: 04/2024
- PH : Marlioz / Cercier : 02/2024
- PJ : Vulbens / Dingy en Vuache : 09/2023, 01/2024
- PL : Challex: 03/2024, further meetings in Q2/24 to identify best site location

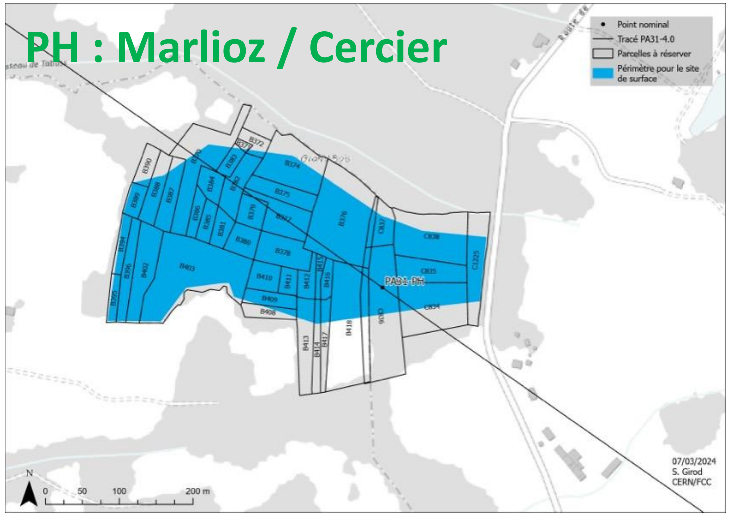
Green: parcelles identified and agreed

Blue: ongoing









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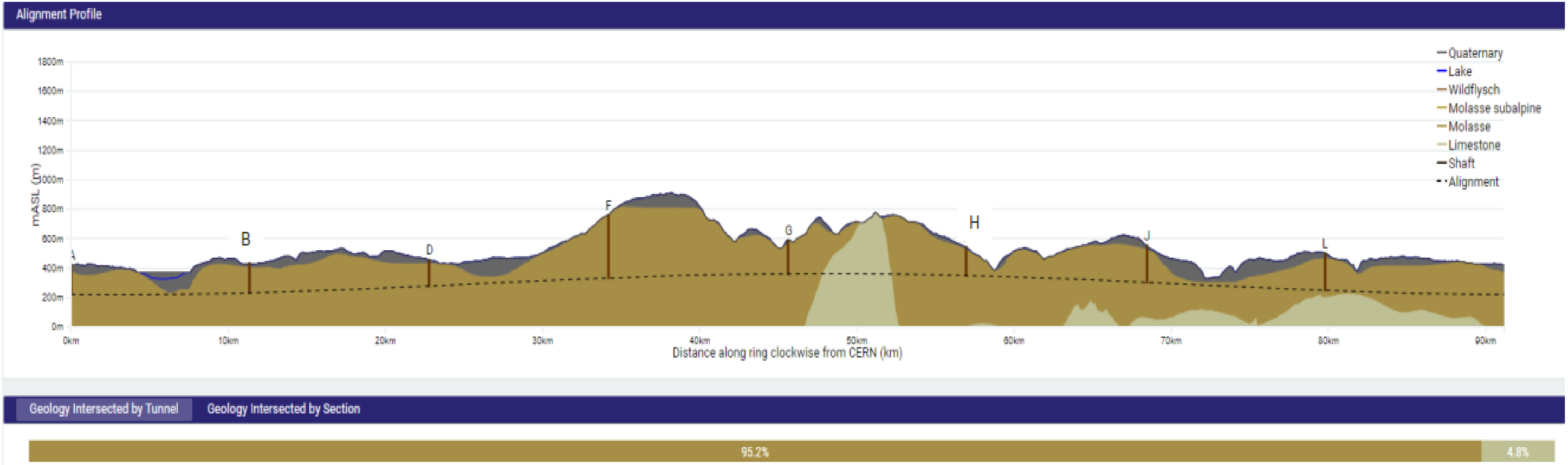
FCC tunnel implementation



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

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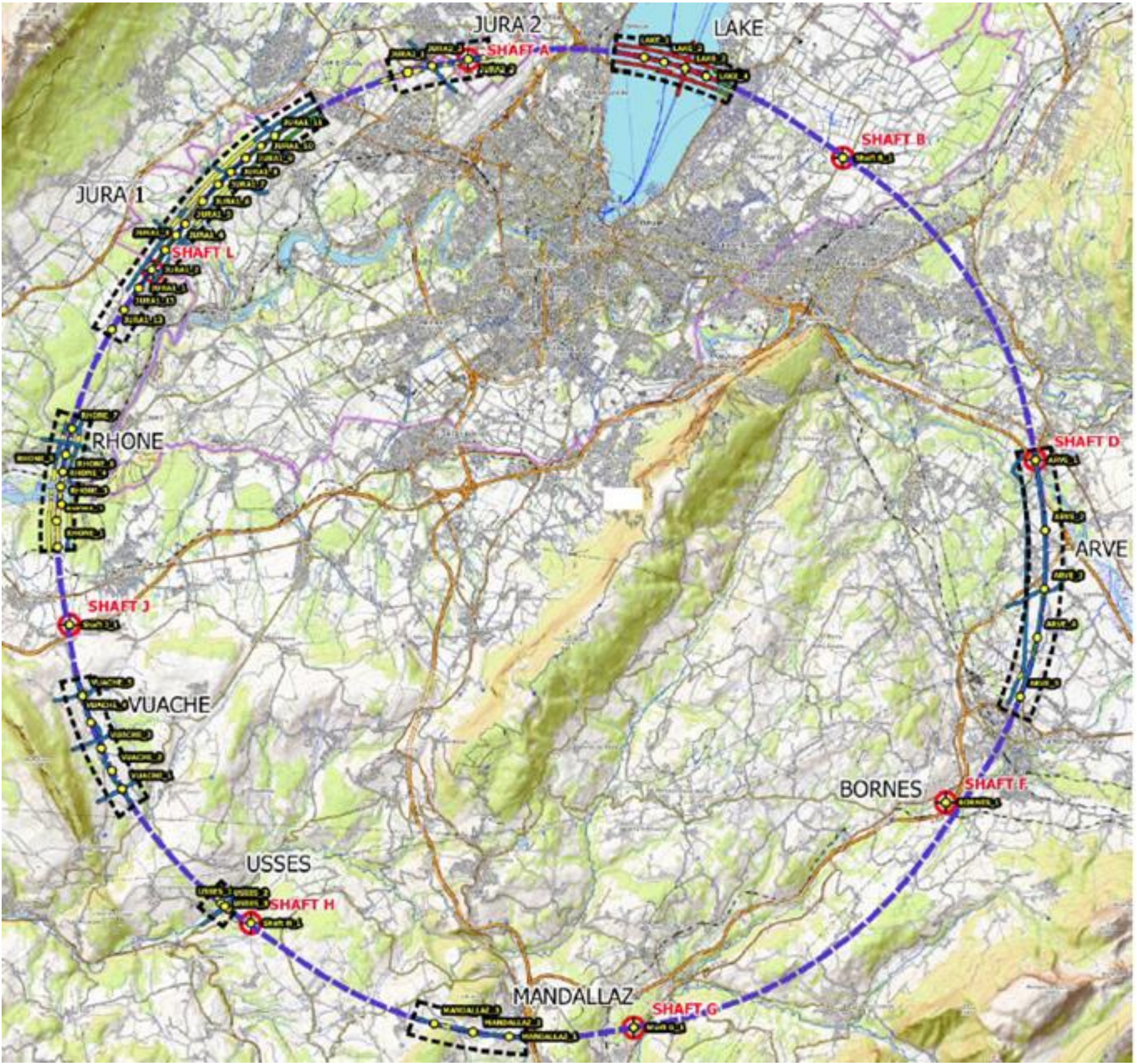
Status site investigations



- **Site investigations in areas with uncertain geological conditions:**
  - Optimisation of localisation of drilling locations ongoing with site visits since end 2022.
- **Contracts Status:**
  - Contract for engineering services and role of Engineer during works, active since July 2022
  - Contracts for drillings and seismics in final negotiation round.
  - Start of work in Q2/2024.

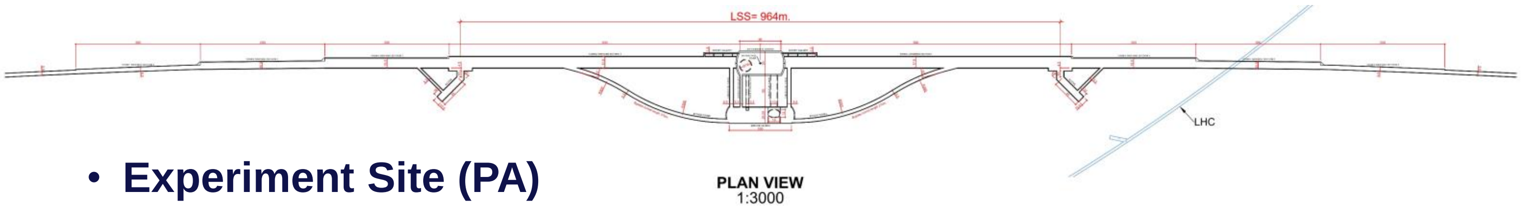
Sondage A89 (2007) incliné de 45° de 125 ml (surface plateforme estimée : 12 x 12 m soit environ 150 m²)

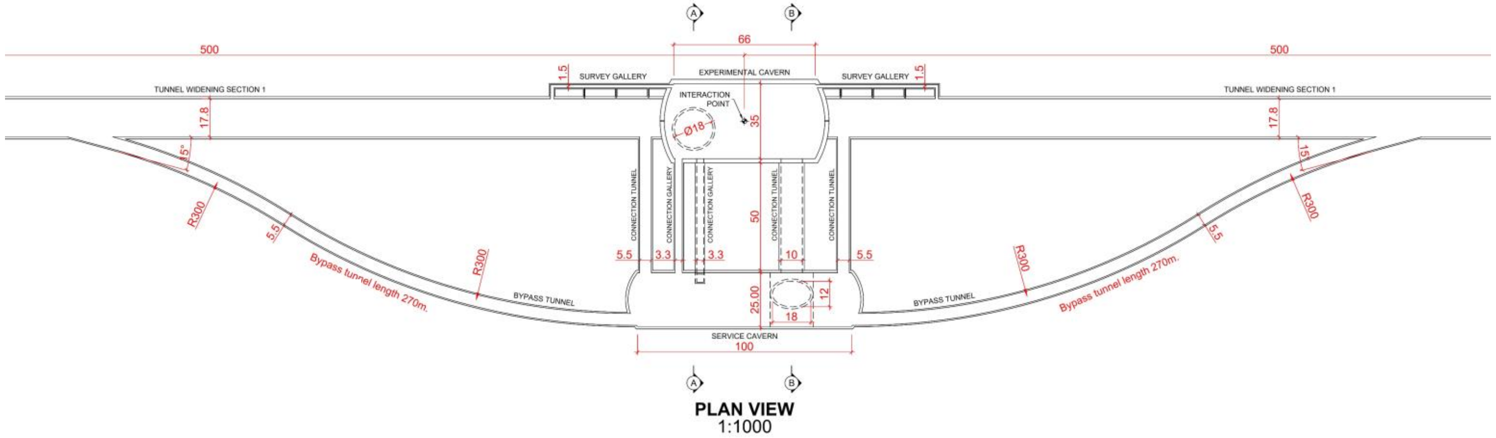
Drilling works on the lake

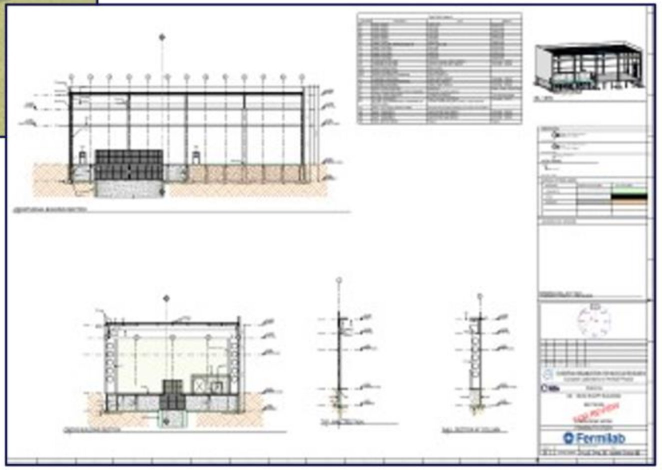
CE underground and surface progress

- **Full 3D model of all underground structures as basis for costing and scheduling exercises with external consultant.**

- **Experiment Site (PA)**





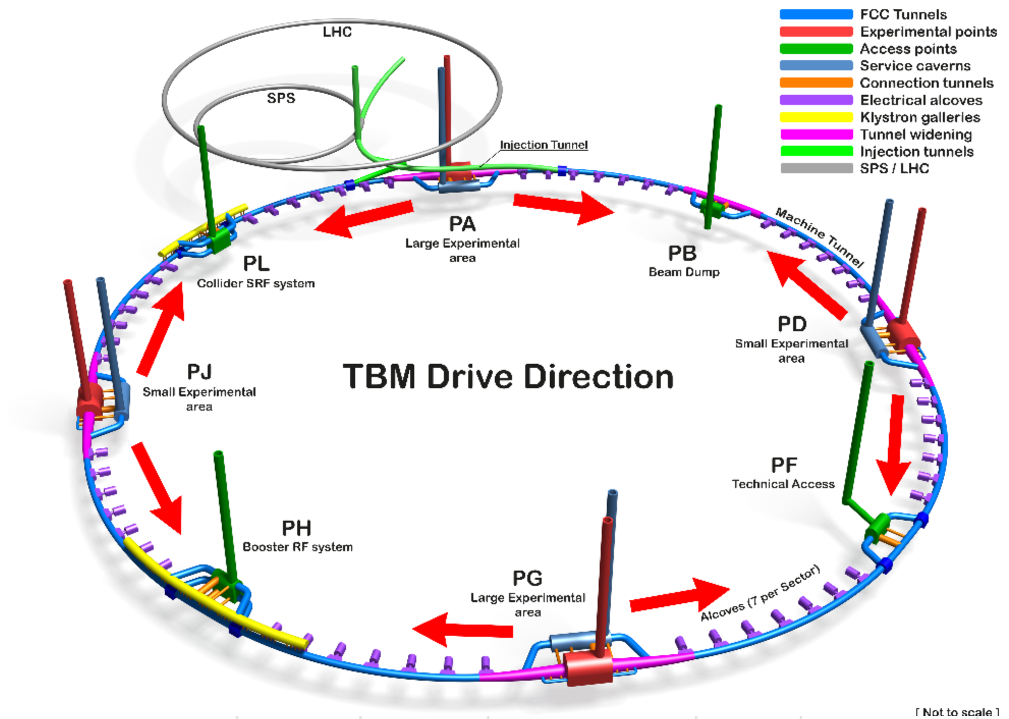


Examples of Fermilab Deliverables

- **Generic study of experiment site and technical site done by FNAL**
- **bills of quantities extracted from FNAL designs**
- **basis for cost estimate by consultant with experience on industrial constructions in CH-FR area.**

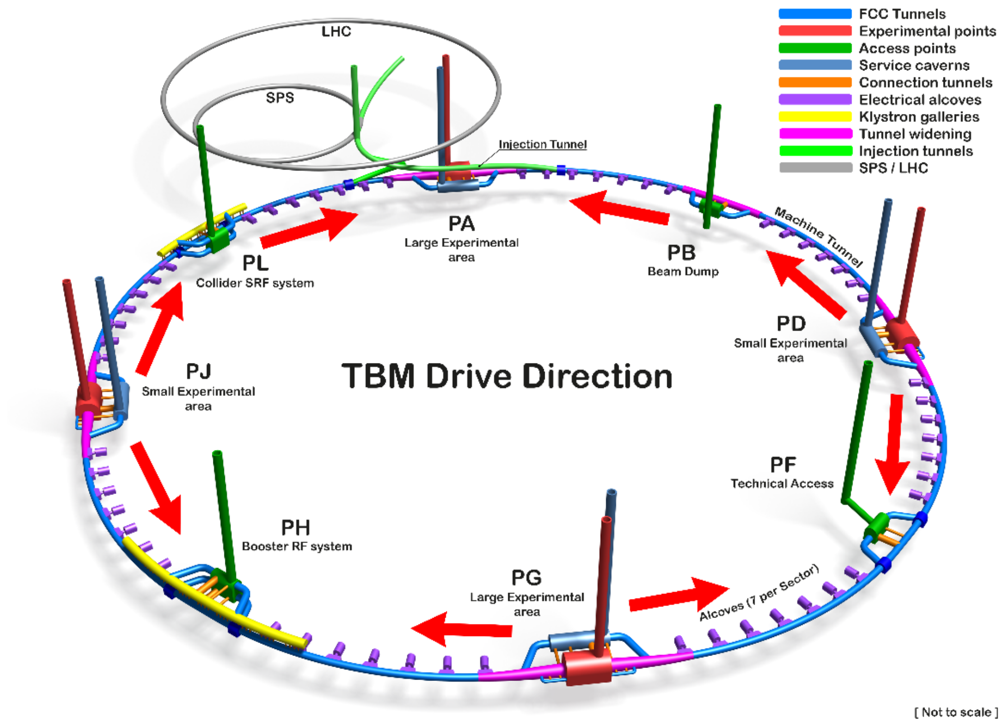
Studies on excavation strategy and material quantities

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
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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%		

OpenSky Laboratory: demonstrate molasse reuse cases

GOAL: demonstrate the feasibility to transform Molasse (excavated material) into fertile soil.

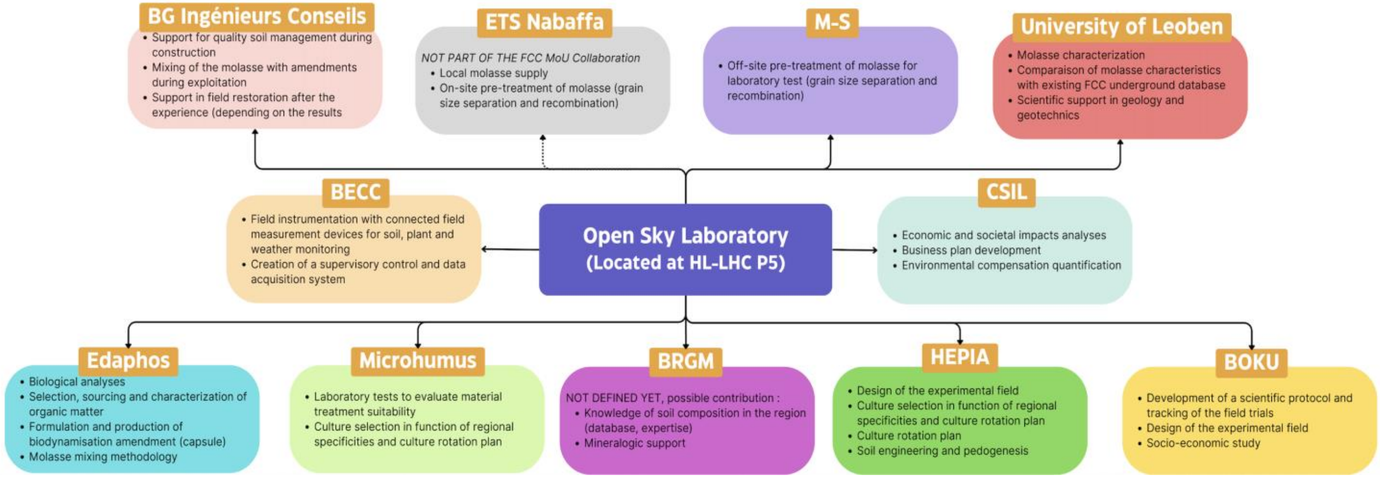
- **Project launched in January 2024**
- **10000 m^2 near LHC P5 in Cessy, France.**

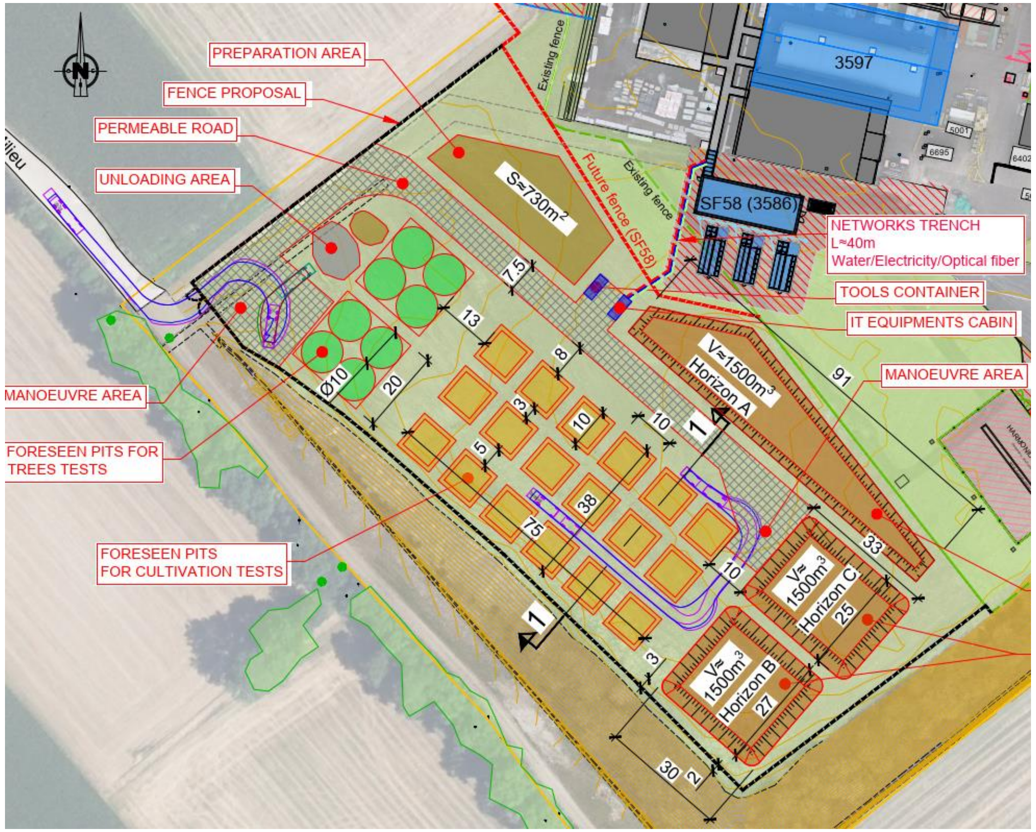
Project phases:

1) Laboratory tests to **identify** the **most suitable mix** of molasse and amendments.

2) **Field tests** in a **controlled environment** (plants selected in function of regional specificities and possible soil reuse cases)

International collaboration with partners from academia and industry specialised in agronomy, soil paedogenesis, phytoremediation



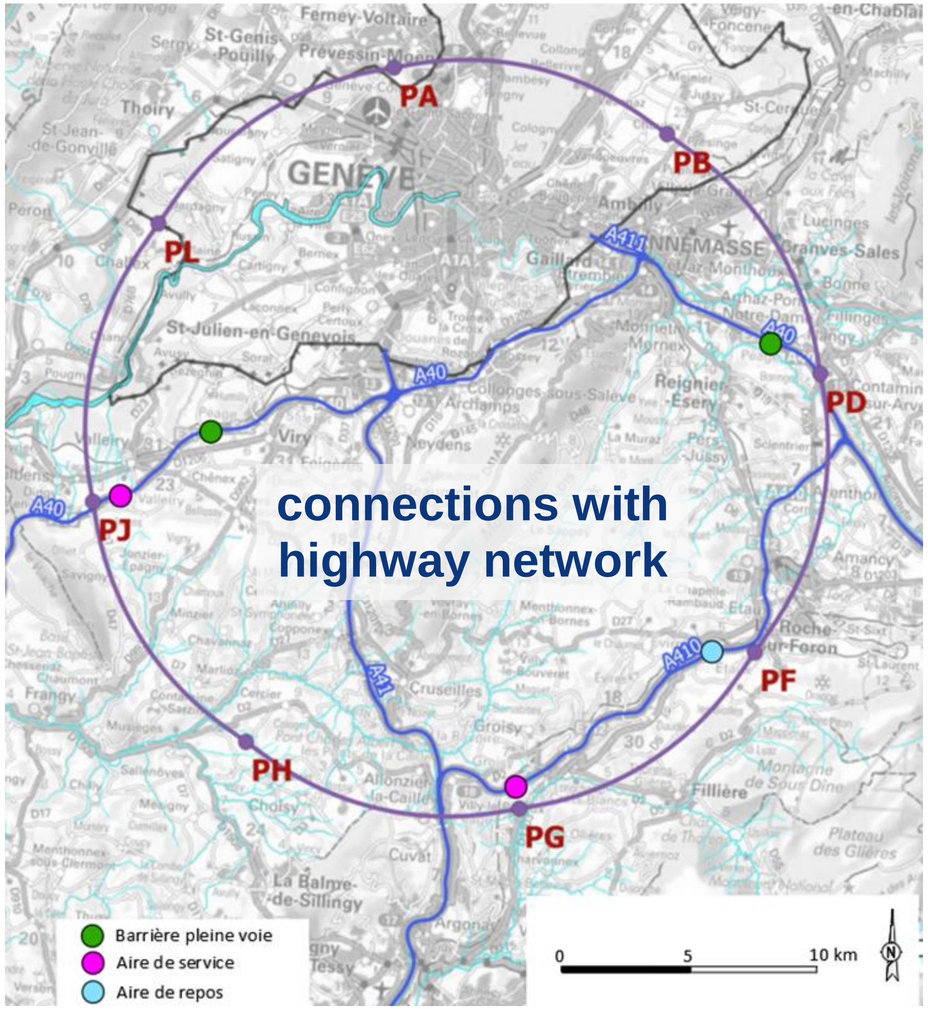


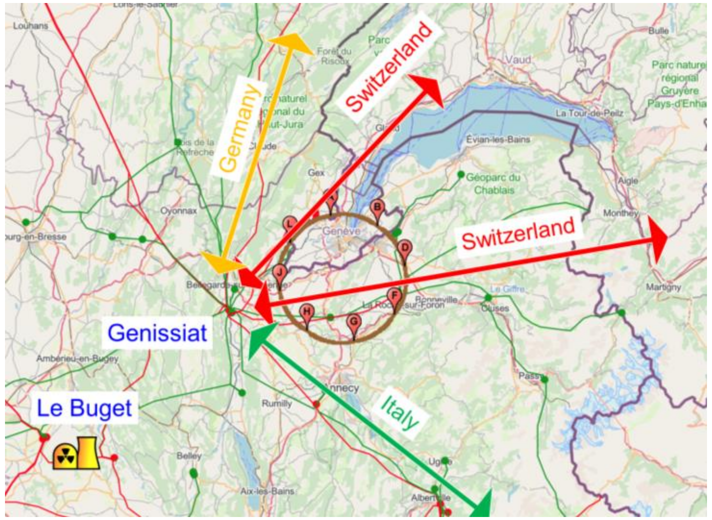
Status - March 2024:

- **Project approved at CERN level**
- **Collaboration agreements being signed**
- **Definition of the laboratory and field tests**

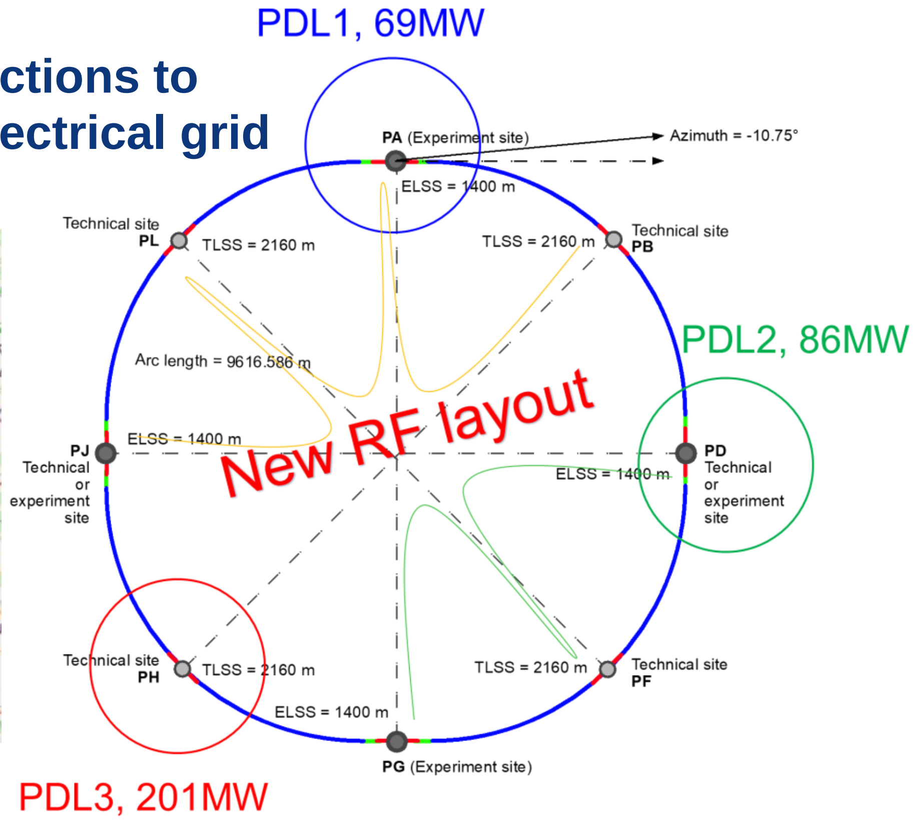
Connections with regional infrastructure

- Road accesses developed for all 8 surface sites
- Four possible highway connections defined
- Less than 4 km new departmental roads required





connections to
French electrical grid

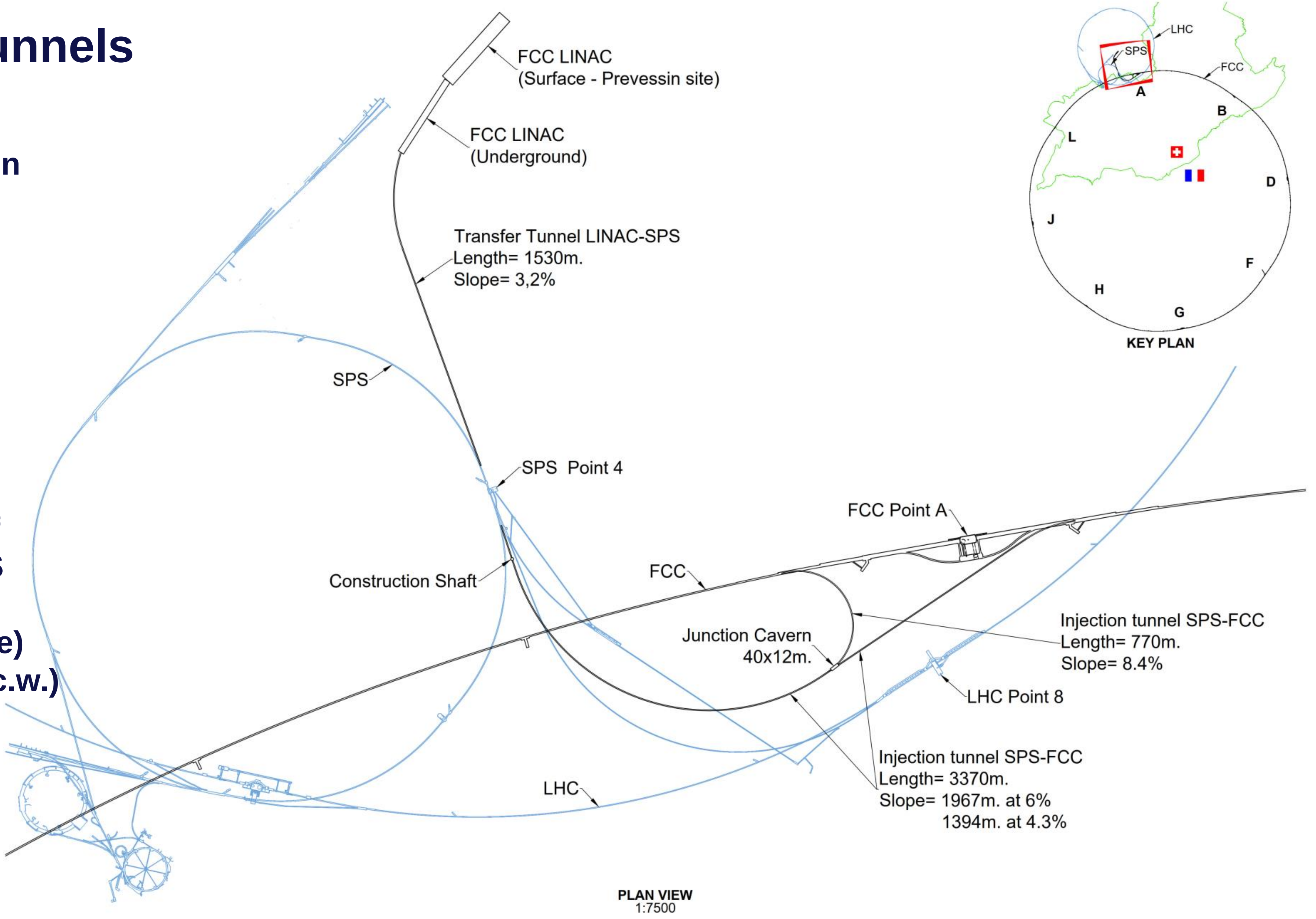


- Electrical connection concept studied by RTE (French electrical grid operator) ➔ requested loads have no significant impact on grid
- Powering concept and power rating of the three sub-stations compatible with FCC-hh
- R&D efforts aiming at further reduction of the energy consumption of FCC-ee and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

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

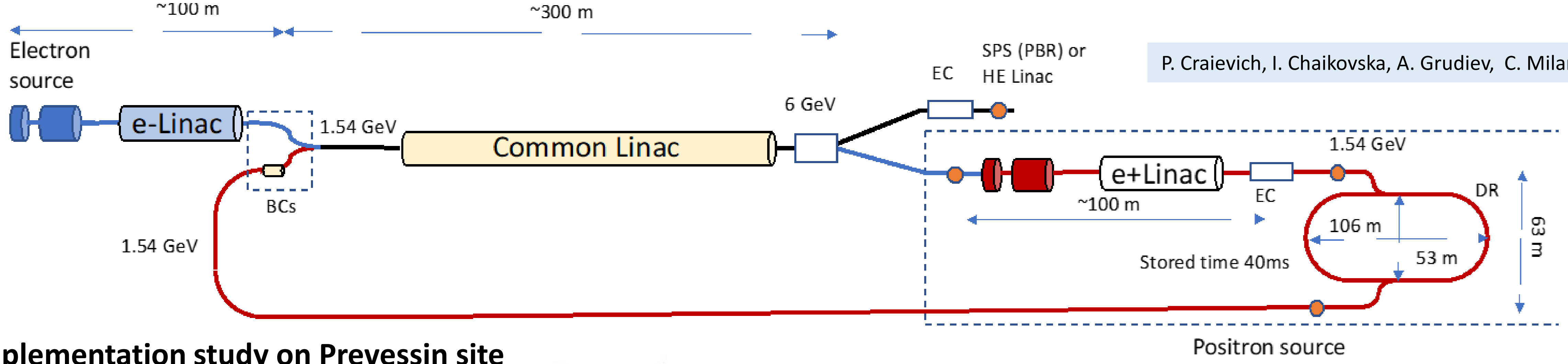
LINAC and Injection Tunnels

- **Injector with ~20 GeV HE Linac sited on surface at CERN-Prevessin**
- **Single transfer tunnel to FCC Booster 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.)**

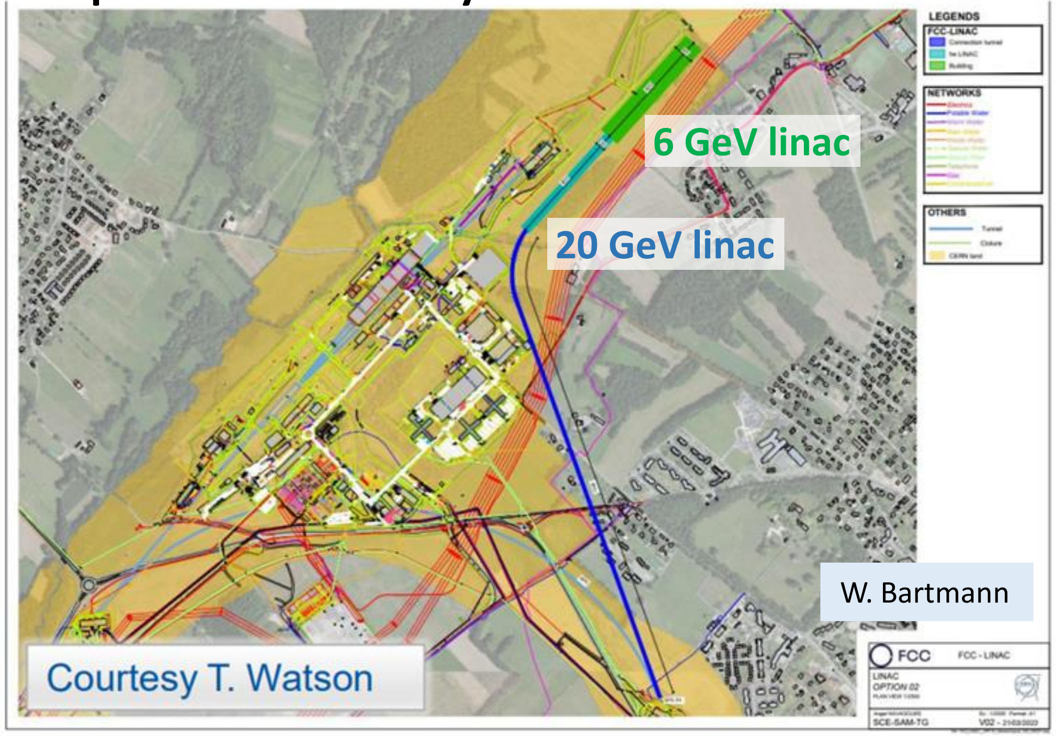


FCC-ee injector layout & implementation

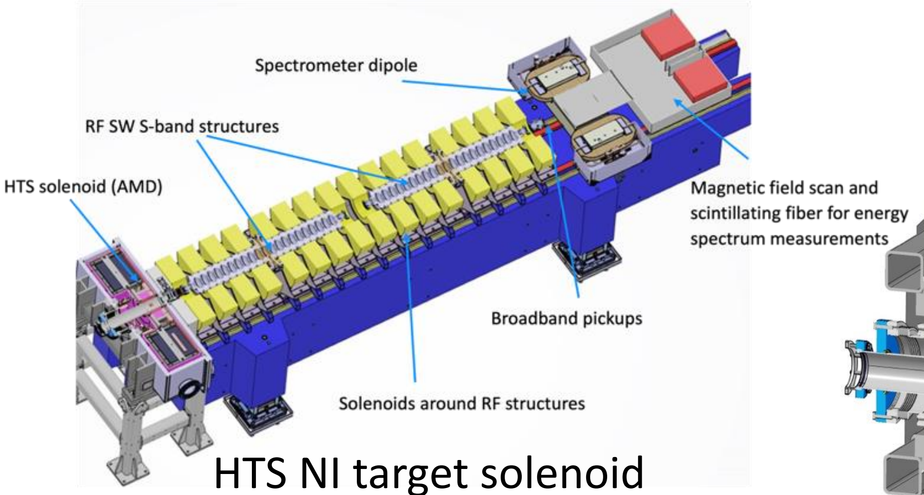
P. Craievich, I. Chaikovska, A. Grudiev, C. Milardi, et al

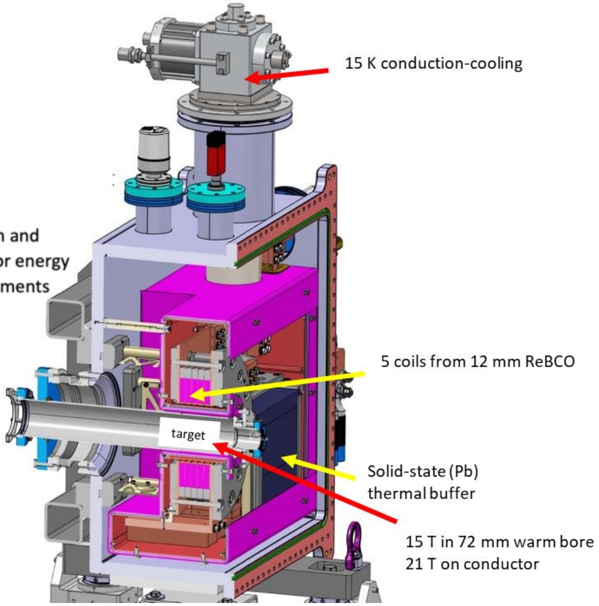


implementation study on Prevessin site



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





HTS NI target solenoid

J. Kosse, T. Michlmayr, H. Rodrigues

FCC-ee: main machine parameters

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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
horizontal rms IP spot size [μm]	9	21	13	40
vertical rms IP spot size [nm]	36	47	40	51
beam-beam parameter ξ_x / ξ_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
	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

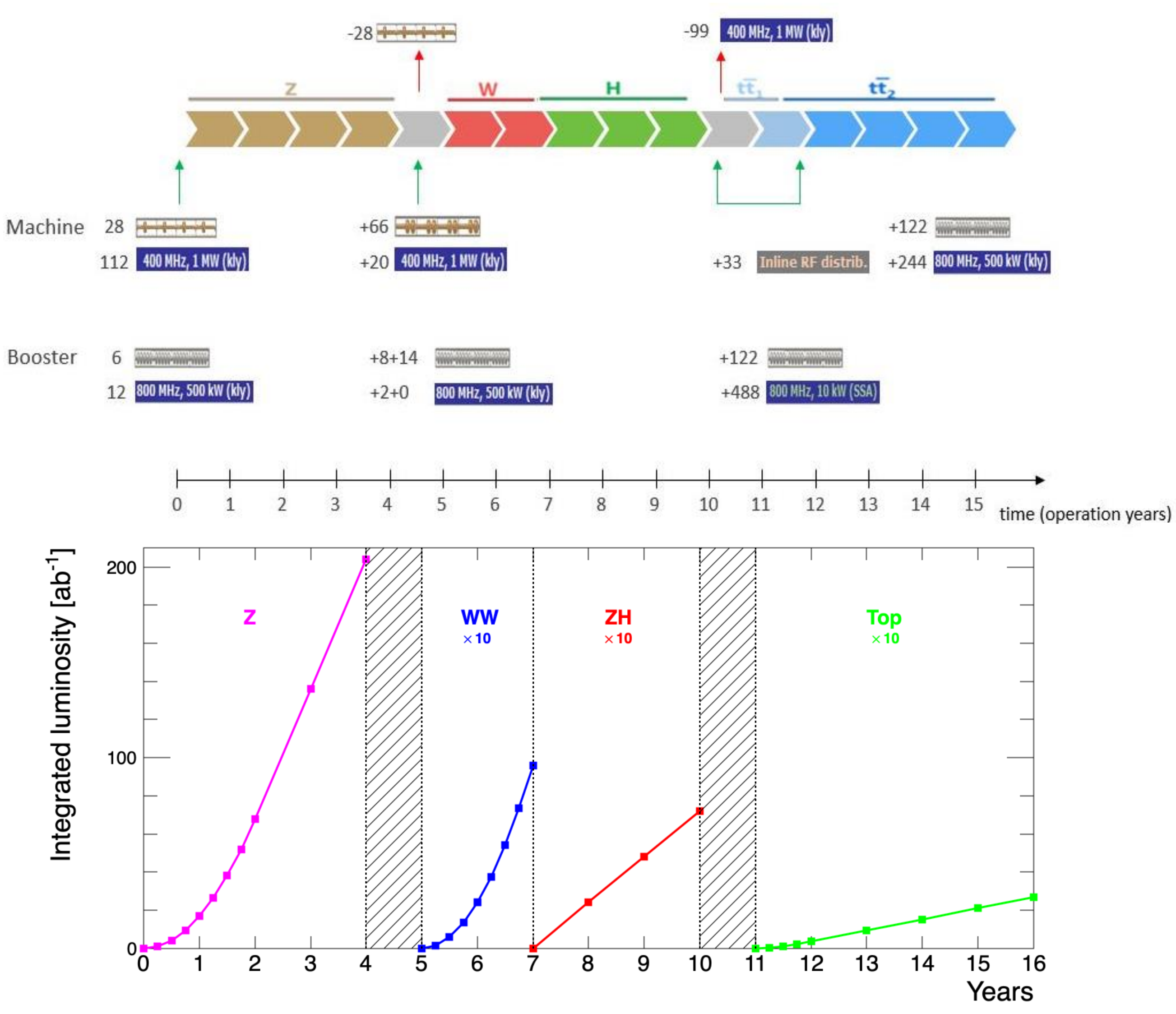
Design and parameters dominated by the choice to allow for 50 MW synchrotron radiation per beam.

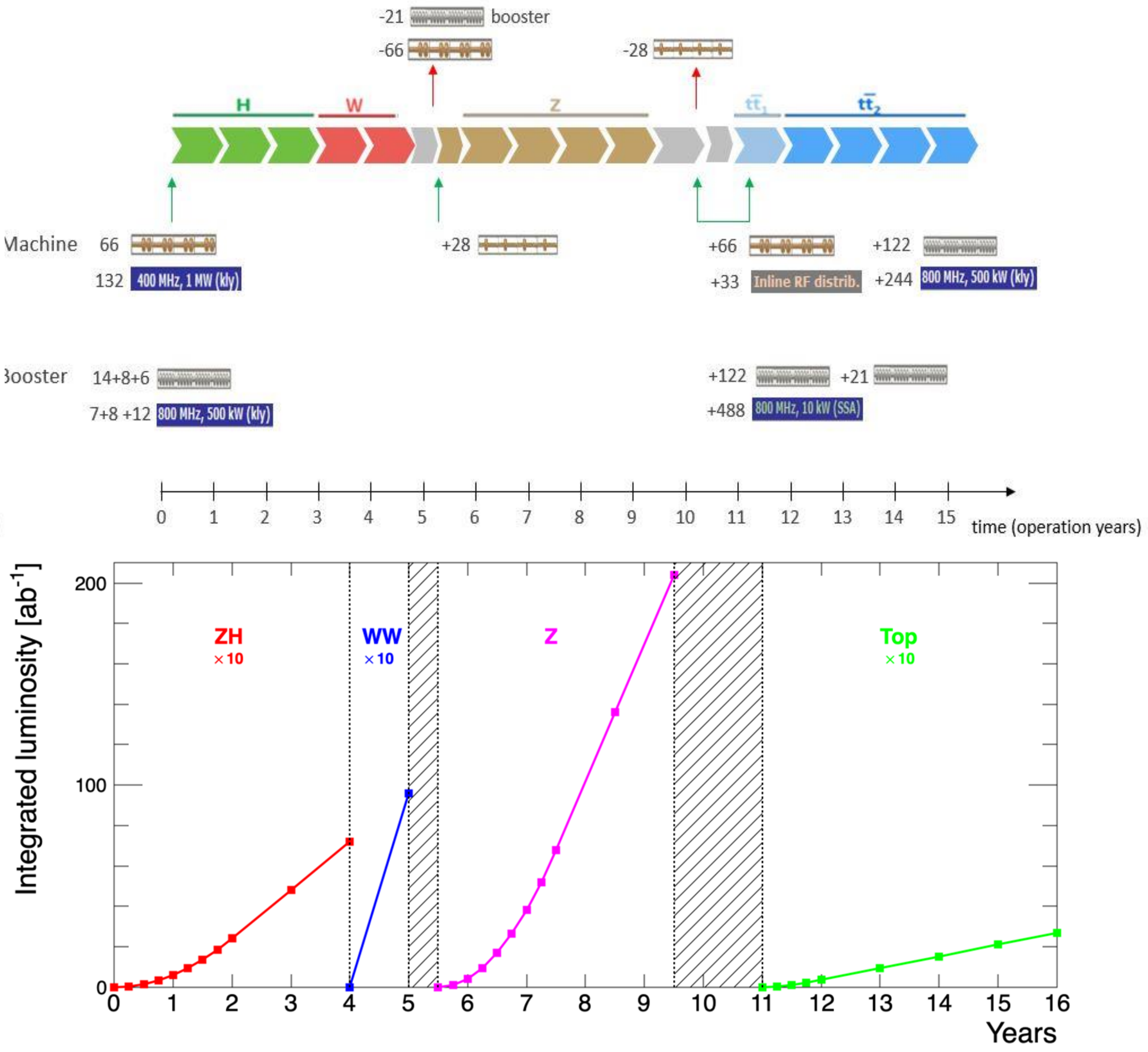
- x 10-50 improvements on all EW observables
- up to x 10 improvement on Higgs coupling (model-indep.) measurements over HL-LHC
- x10 Belle II statistics for b, c, τ
- indirect discovery potential up to ~ 70 TeV
- direct discovery potential for feebly-interacting particles over 5-100 GeV mass range

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

F. Gianotti

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, in particular for the 800 MHz system**

RF R&D activities

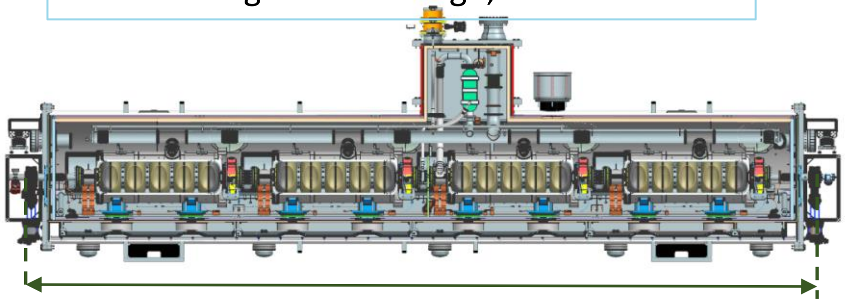
RF system R&D is key for increasing energy efficiency of FCC-ee

- 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

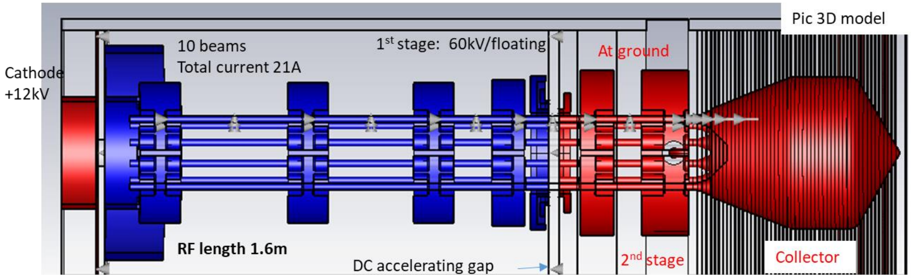


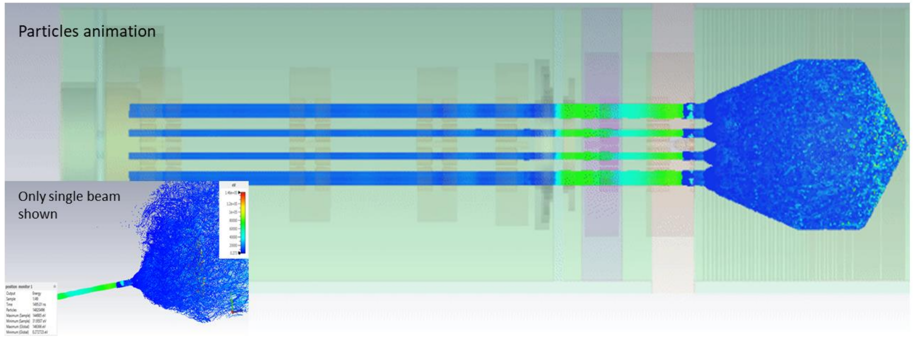
~7 m

high-efficiency klystron R&D

in collaborations with **THALES & CANON**

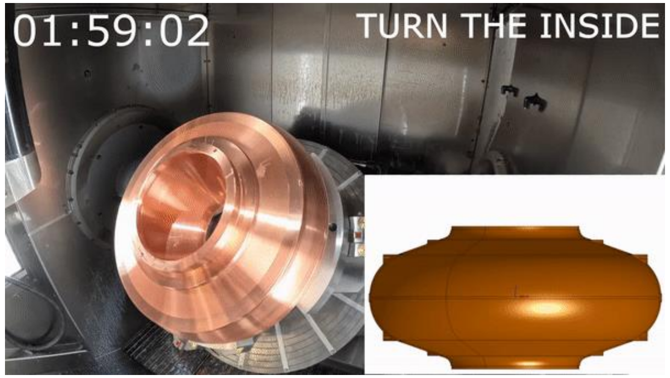
Novel two-stage MBK klystron: CW, 400MHz, 1.28MW.





400 MHz cavity production

in collaboration with **KEK**

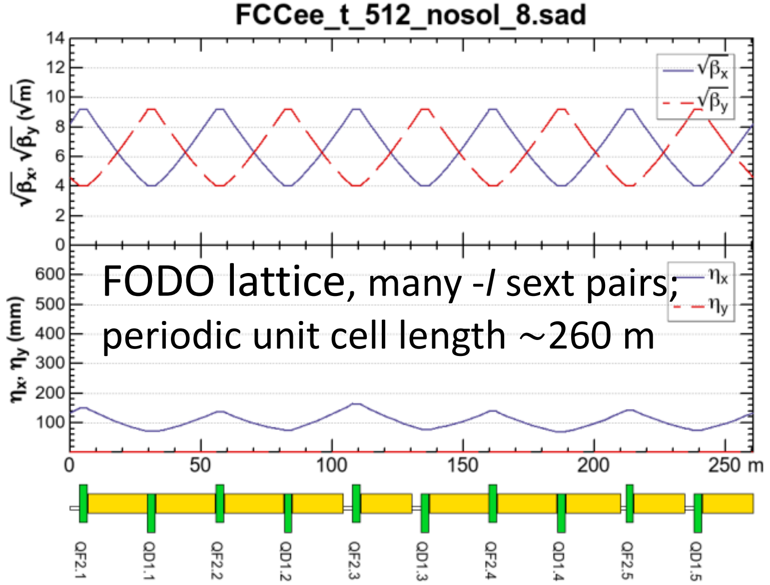


FCC-ee optics baseline & further evolution(s)

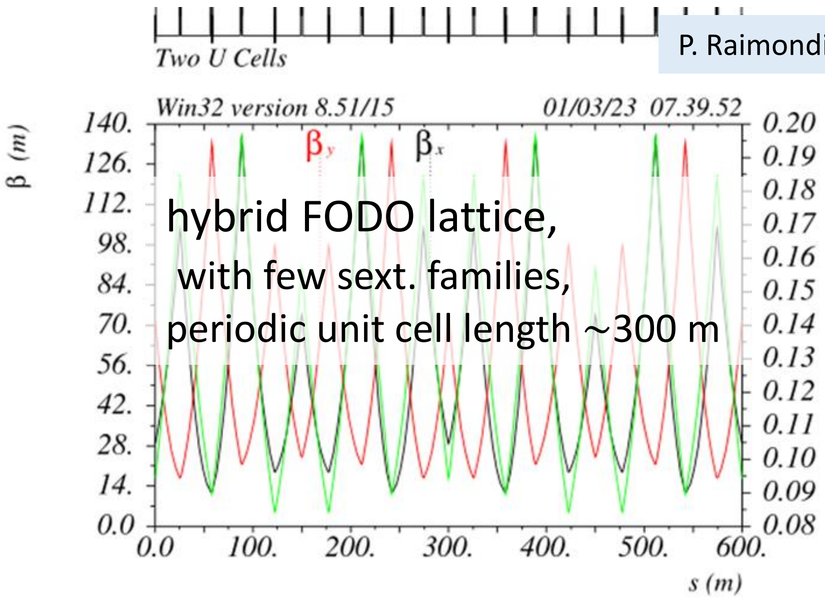
regular arc

K. Oide

Short 90/90: $t\bar{t}$, Zh



FODO lattice, many -*I* sext pairs;
periodic unit cell length ~260 m

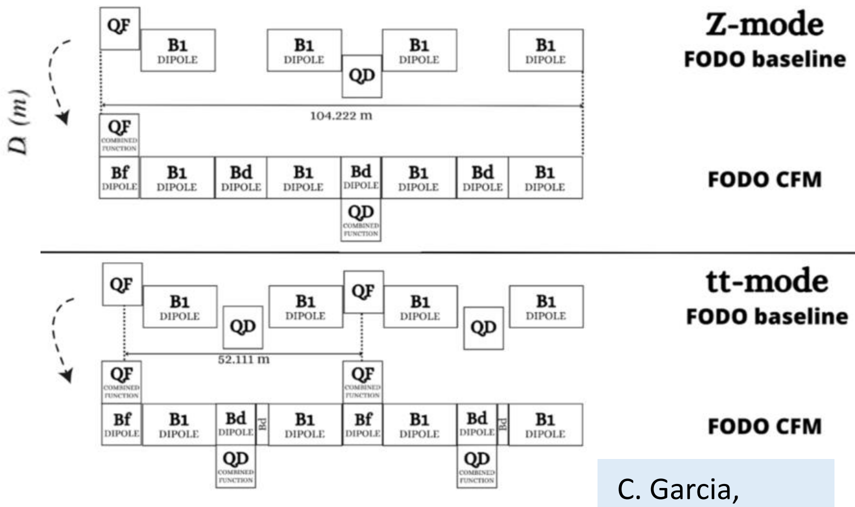


hybrid FODO lattice,
with few sext. families,
periodic unit cell length ~300 m

P. Raimondi

optimisation goals:

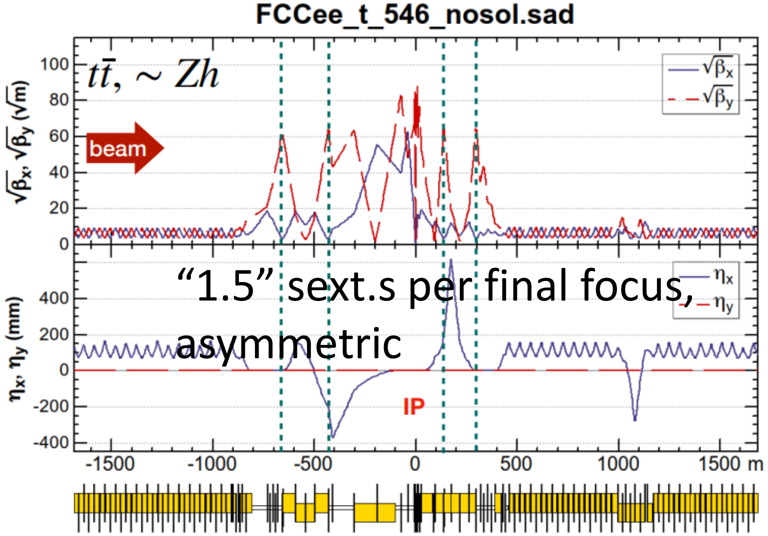
- reduced power consumption
- lower SR energy loss
- increased momentum acceptance
- relaxed tolerances
- larger dynamic aperture
- simplified powering schemes



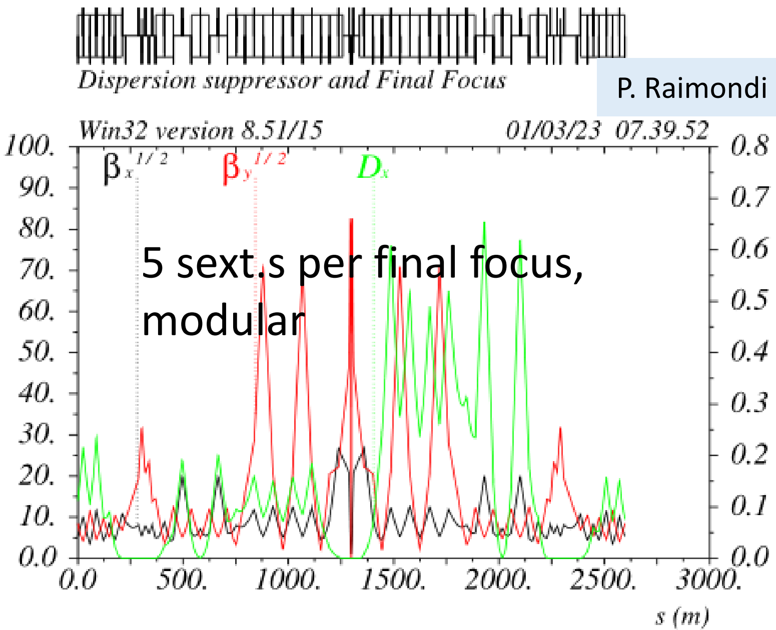
C. Garcia,
R. Tomas, et al.

interaction region

K. Oide



"1.5" sext.s per final focus,
asymmetric



5 sext.s per final focus,
modular

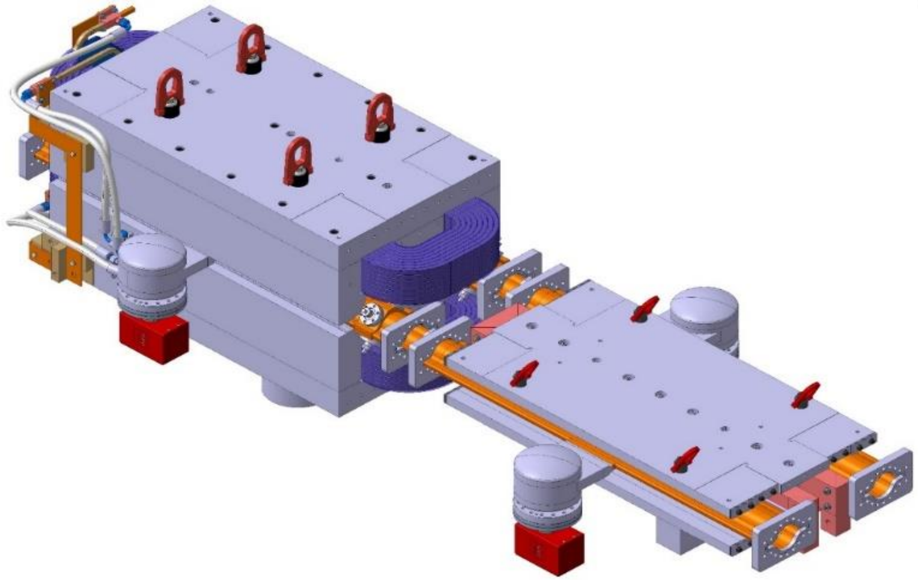
P. Raimondi

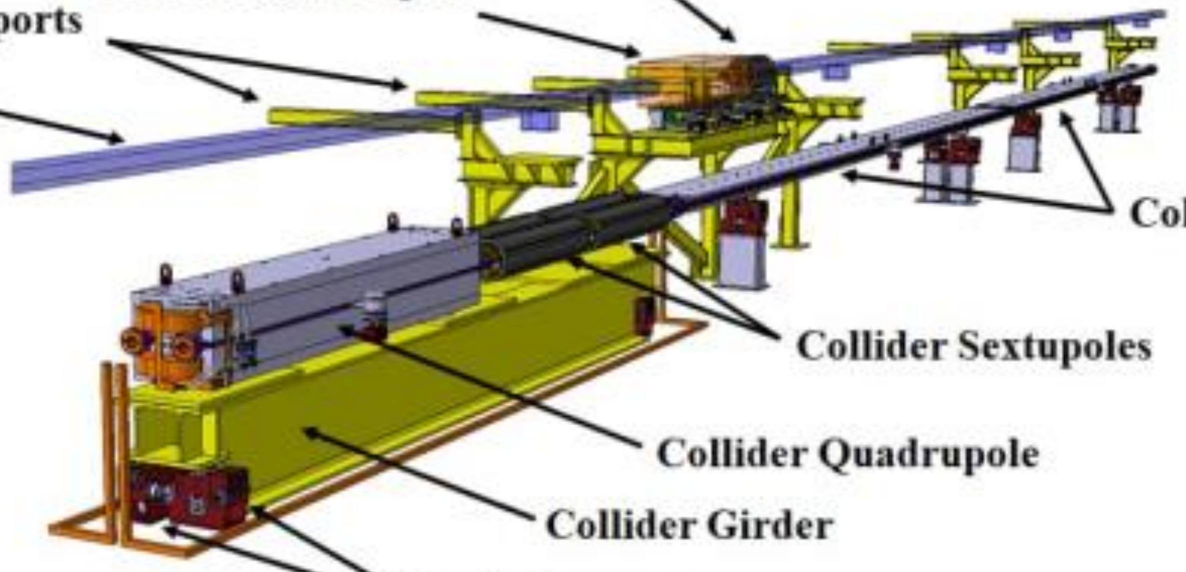
Arc layout and integration optimisation

Arc cell optimisation – 80 km total system 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,

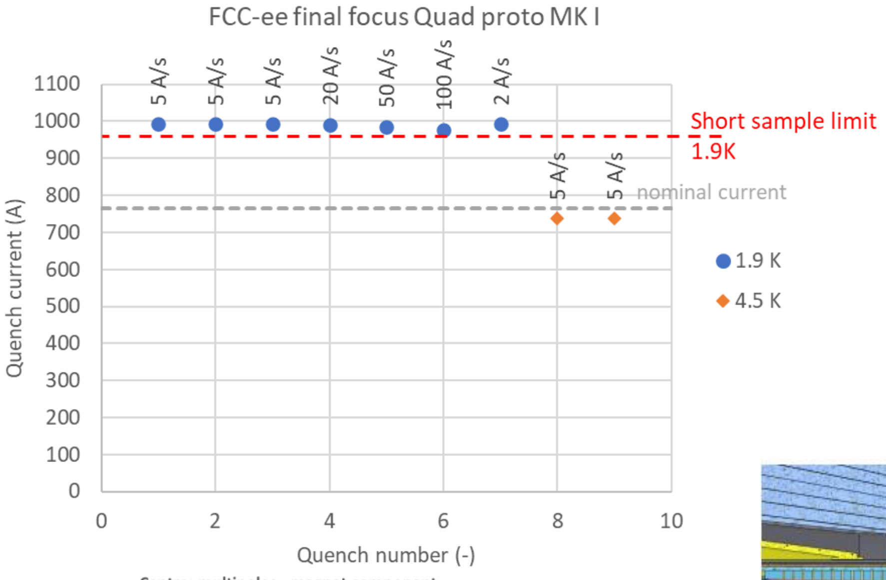
FCC-ee arc half-cell mock up

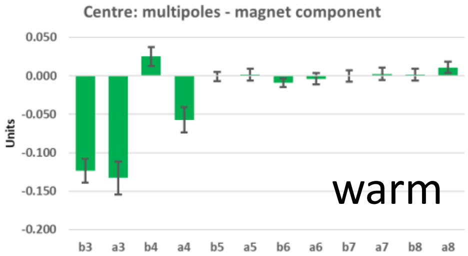


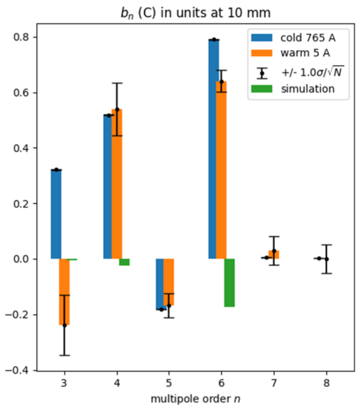


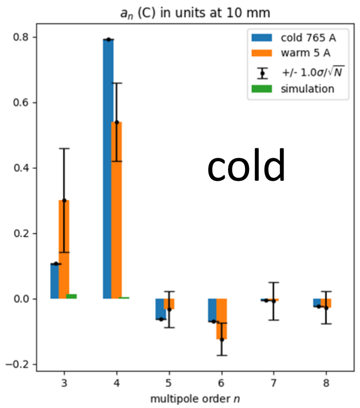
FUTURE CIRCULAR COLLIDER

Prototype Q1 (left) & Interaction Region Mock-Up (right)





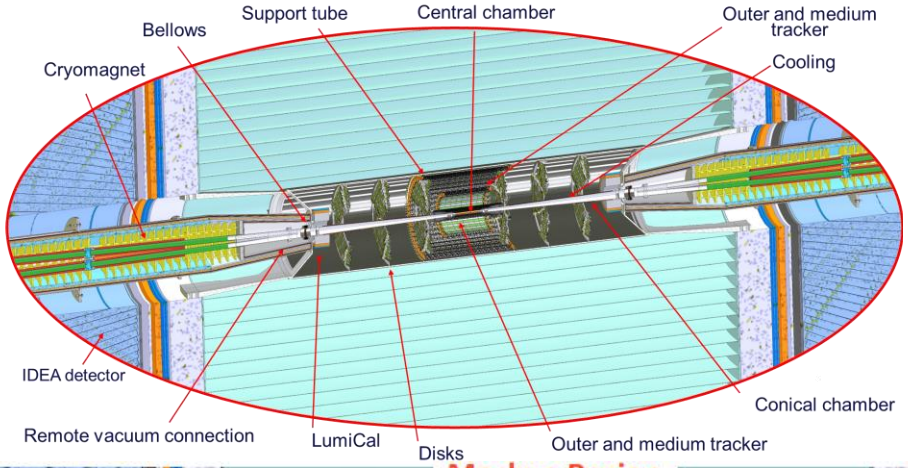




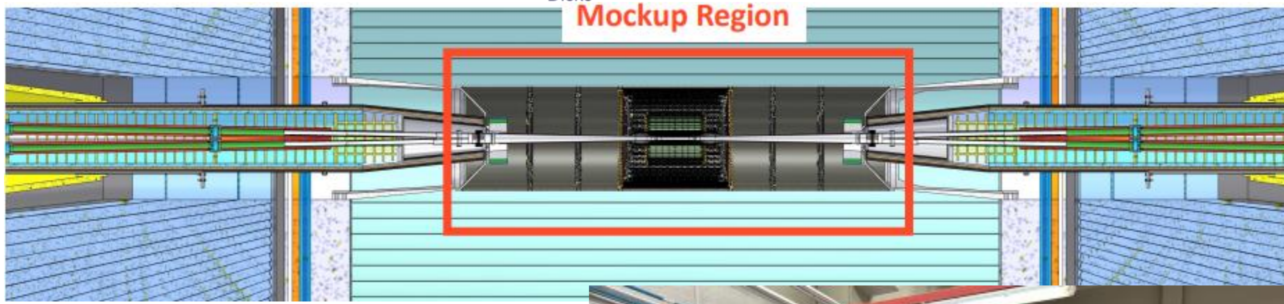
field quality:
all multipole errors
<1 unit !

CERN-PSI collaboration

PAUL SCHERRER INSTITUT
PSI



INFN-LNF, CERN and INFN-Pisa collaboration



INFN
LNF
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

FCC-ee IR mock-up assembly & test lab at INFN Frascati

FUTURE CIRCULAR COLLIDER

FCC-hh parameters

parameter	FCC-hh	HL-LHC	LHC
collision energy cms [TeV]	81 - 115	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: significantly more time for high-field magnet R&D aiming at highest possible energies

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, …

Formidable physics reach, including:

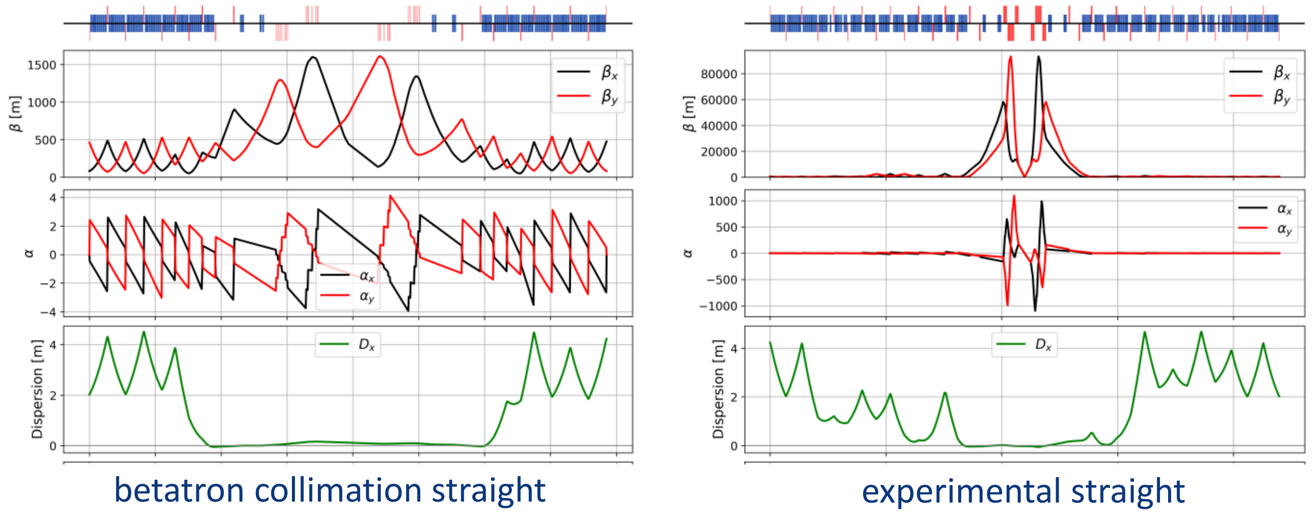
- ❑ Direct discovery potential up to ~ 40 TeV
- ❑ Measurement of Higgs self to ~ 5% and ttH to ~ 1%
- ❑ High-precision and model-indep (with FCC-ee input) measurements of rare Higgs decays ($\gamma\gamma$, $Z\gamma$, μμ)
- ❑ Final word about WIMP dark matter

F. Gianotti

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

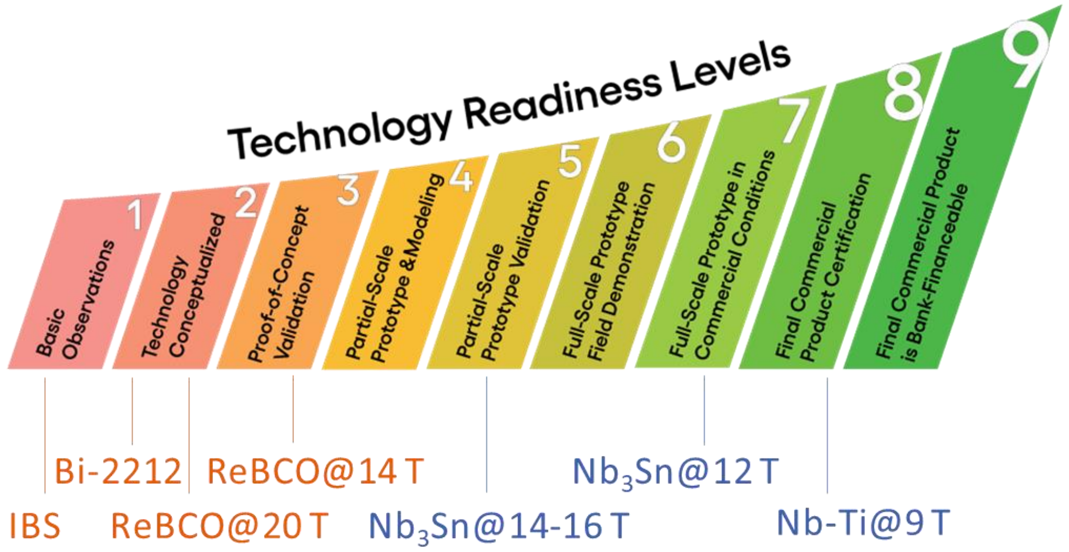
Optics design activities:

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



High-field cryo-magnet system activities

- Conceptual study of cryogenics concept and temperature layout for LTS and HTS based magnets, in view of electrical consumption.
- HFM R&D (LTS and HTS) on technology and magnet design, aiming also at bridging the TRL gap between HTS and Nb_3Sn.
- Integration studies for HFM designs (LTS and HTS) to ensure compatibility with tunnel.



Status of FCC global collaboration

FUTURE CIRCULAR COLLIDER

The CERN Council reviewed the work undertaken in a fruitful meeting on 2 February 2024.
It congratulated and thanked all the teams involved in the study for the excellent and significant work done so far and for the impressive progress, and looks forward to receiving the final report in 2025.

From Türkiye 15 FCC Collaboration members: **Giresun** University, **IYTE** Urla Izmir, **Izmir University of Economics**, **Istanbul University**, **TOBB** University of Economics and Technology Ankara, **Istanbul Aydin** U., **Piri Reis** Üniversitesi Tuzla/Istanbul, Izmir University Bakırcay (**IBU**), **Isik** University Sile/Istanbul, **Bursa Uludağ** University Nilüfer, **Ege** University Bornova-Izmir, **Ankara U** Tandogan/Ankara, **İstinye** University Istanbul, **Kirikkale** University, Kirikkale, **AIBU** Bolu

150 Institutes

32 Companies

33 Countries

EC H2020

FCC Feasibility Study: Aim is to increase further the collaboration, on all aspects, in particular, on Accelerator and Particle/Experiments/Detectors (PED).

FCC workshops organized by Turkish FCC community

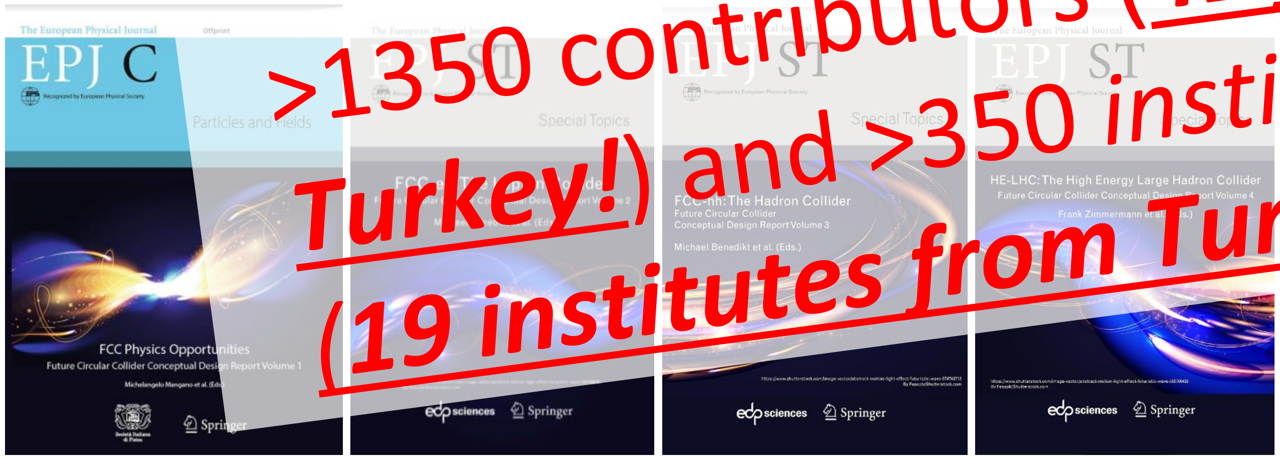
European Strategy for Particle Physics

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)**

>1350 contributors (41 from Turkey!) and >350 institutes (19 institutes from Turkey!)



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."

Physics Publications by FCC groups in Turkey (to be updated)

1) The 28 GeV Dimuon Excess in Lepton Specific 2HDM, A. Cici, S. Khalil, B. Niş, C. S. Un, arXiv:1909.02588v1 [hep-ph]

2) Study on Anomalous Neutral Triple Gauge Boson Couplings from Dimension-eight Operators at the HL-LHC, A. Senol, H. Denizli, A. Yilmaz, I. Turk Cakir, O. Cakir., arXiv:1906.04589 [hep-ph].

3) Sensitivity on Anomalous Neutral Triple Gauge Couplings via ZZ Production at FCC-hh, A. Yilmaz, A. Senol, H. Denizli, I. Turk Cakir, O. Cakir., arXiv:1906.03911 [hep-ph].

4) Top quark anomalous FCNC production via tqg couplings at FCC-hh, K.Y. Oyulmaz, A. Senol, H. Denizli, O. Cakir, Phys.Rev. D99 (2019) no.11, 115023. 10.1103/PhysRevD.99.115023.

5) Testing for observability of Higgs effective couplings in triphoton production at FCC-hh, H. Denizli, K.Y. Oyulmaz, A. Senol., arXiv:1901.04784 [hep-ph]

6) Linac and Damping Ring Designs for the FCC-ee, S. Ogur et al., Proceedings of International Particle Accelerator Conference (IPAC 2019), pp. 420-423, 2019

7) FCC-ee: The Lepton Collider : Future Circular Collider Conceptual Design Report Volume 2, FCC Collaboration (A. Abada et al.)., Eur.Phys.J.ST 228 (2019) no.2, 261-623, 10.1140/epjst/e2019-900045-4.

8) FCC-hh: The Hadron Collider : Future Circular Collider Conceptual Design Report Volume 3, FCC Collaboration (A. Abada et al.)., Eur.Phys.J.ST 228 (2019) no.4, 755-1107, 10.1140/epjst/e2019-900087-0.

9) HE-LHC: The High-Energy Large Hadron Collider, FCC Collaboration (A. Abada et al.)., Eur.Phys.J.ST 228 (2019) no.5, 1109-1382. 10.1140/epjst/e2019-900088-6.

10) FCC Physics Opportunities : Future Circular Collider Conceptual Design Report Volume 1, FCC Collaboration (A. Abada et al.)., Eur.Phys.J. C79 (2019) no.6, 474. 10.1140/epjc/s10052-019-6904-3.

11) Probing anomalous tq\gamma and tqg couplings via single top production in association with photon at FCC-hh, K.Y. Oyulmaz, A. Senol, H. Denizli, A. Yilmaz, I. Turk Cakir, O. Cakir. Eur.Phys.J. C79 (2019) no.1, 83. 10.1140/epjc/s10052-019-6593-y.

12) Probing top quark FCNC tq\gamma and tqZ couplings at future electron-proton colliders, O. Cakir, A. Yilmaz, I. Turk Cakir, A. Senol, H. Denizli, Nucl.Phys. B944 (2019) 114640. ,10.1016/j.nuclphysb.2019.114640.

13) Probing the Effects of Dimension-eight Operators Describing Anomalous Neutral Triple Gauge Boson Interactions at FCC-hh, A. Senol, H. Denizli, A. Yilmaz, I. Turk Cakir, K.Y. Oyulmaz, O. Karadeniz, O. Cakir., Nucl.Phys. B935 (2018) 365-376, 10.1016/j.nuclphysb.2018.08.018.

14) Light stops and fine-tuning in MSSM, A. Çiçi, Z. Kırca, C. S. Ün; , Eur. Phys. J. C (2018) 78: 60. https://doi.org/10.1140/epjc/s10052-018-5549-y

15) Probing the Anomalous FCNC Couplings at Large Hadron Electron Collider , I. Turk Cakir, A. Yilmaz, H. Denizli, A. Senol, H. Karadeniz, O. Cakir. Adv.High Energy Phys. 2017 (2017) 1572053.

15) Top quark FCNC couplings at future circular hadron electron colliders , H. Denizli, A. Senol, A. Yilmaz, I. Turk Cakir, H. Karadeniz, O. Cakir. Phys.Rev. D96 (2017) no.1, 015024.

16) Probing Charged Higgs Boson Couplings at the FCC-hh Collider , I.T. Cakir, S. Kuday, H. Saygin, A. Senol, O. Cakir. , Phys.Rev. D94 (2016) 015024.

17) Single production of the excited electrons in the future FCC-based lepton–hadron colliders, Abdullatif Caliskan, Seyit Okan Kara., Int.J.Mod.Phys. A33 (2018) no.24, 1850141.

18) Layout and Performance of the FCC-ee Pre-Injector Chain, Salim Ogur et al., DOI: 10.18429/JACoW-IPAC2018-MOPMF034.

19) Pre-Booster Ring Considerations for the FCC e^+e^- Injector, Ozgur Etisken, Fanouria Antoniou, Abbas Çiftçi, Yannis Papaphilippou, DOI: 10.18429/JACoW-IPAC2018-MOPMF002.

20) Bunch Schedules for the FCC-ee Pre-injector, Salim Ogur, Katsunobu Oide, Yannis Papaphilippou, Dmitry Shatilov, Frank Zimmermann. DOI: 10.18429/JACoW-IPAC2018-MOPMF001.

21) First Look at the Physics Case of TLEP , TLEP Design Study Working Group (M. Bicer et al.). , JHEP 1401 (2014) 164.

22) Excited muon searches at the FCC based muon-hadron colliders , A. Caliskan, S.O. Kara, A. Ozansoy. arXiv:1701.03426 [hep-ph]. Adv.High Energy Phys. 2017 (2017) 1540243

23) Azimuthal Angular Decorrelation of Jets at Future High Energy Colliders , I. Hos, H. Saygin, S. Kuday. arXiv:1809.01505 [hep-ph].

24) Projections for Neutral Di-Boson and Di-Higgs Interactions at FCC-he Collider , S. Kuday, H. Saygın, İ. Hoş, F. Çetin., Nucl.Phys. B932 (2018) 1-14. 10.1016/j.nuclphysb.2018.05.002.

25) FCC Based Lepton-Hadron and Photon-Hadron Colliders: Luminosity and Physics, Y. C. Acar, A. N. Akay, S. Beser, H. Karadeniz, U. Kaya, B. B. Oner, S. Sultansoy, Nucl.Instrum.Meth. A871 (2017) 47-53

26) Color Octet Electron Search Potential of the FCC Based e-p Colliders , Y. C. Acar, U. Kaya, B. B. Oner, S. Sultansoy, J. Phys. G44, no. 4, 045005 (2017).

27) Excited neutrino search potential of the FCC-based electron-hadron colliders, A. Caliskan, Adv.High Energy Phys. 2017 (2017) 4726050

28) Excited muon searches at the FCC based muon-hadron colliders, A. Caliskan, S.O. Kara, A. Ozansoy, Adv.High Energy Phys. 2017 (2017) 1540243

29) Resonant production of leptogluons at the FCC based lepton-hadron colliders, Y. C. Acar, U. Kaya, B. B. Oner, S. Sultansoy, Acta Phys.Polon. B49 (2018) 1763

30) I Probing Anomalous WW γ and WWZ Couplings with Polarized Electron Beam at the LHeC and FCC-ep Collider, . Turk Cakir, A. Şenol, A. T. Tasci and O. Cakir. World Academy of Science, Engineering and Technology International Journal of Chemical, Molecular, Nuclear, Materials and Metallurgical Engineering (2015) Vol:9, No:1.

31) Search for Flavour Changing Neutral Current Couplings of Higgs-up Sector Quarks at Future Circular Collider (FCC-eh), I. Turk Cakir, B. Hacisahinoglu, S. Kartal, A. Yilmaz, A. Yilmaz, Z. Uysal, O. Cakir, World Academy of Science, Engineering and Technology, Open Science Index 132, International Journal of Physical and Mathematical Sciences (2017), 11(12), 525-529.

32) The Search of Anomalous Higgs Boson Couplings at the Large Hadron Electron Collider and Future Circular Electron Hadron Collider, I. Turk Cakir, M. Altinli, Z. Uysal, A. Senol, O. Yalcinkaya, A. Yilmaz, World Academy of Science, Engineering and Technology, Open Science Index 132, International Journal of Physical and Mathematical Sciences (2017), 11(12), 519-524.

FCC-Turkey team extremely active and productive

FCC theses by students from Turkish universities

PhD theses

Ozgur ETISKEN, Ankara University, "Pre-Booster Ring Design for FCC-e^+e^- Injector complex", CERN/Ankara PhD 2021

Kaan Yuksel OYULMAZ, Bolu Abant Izzet Baysal University, "Upgrade and performance studies of CMOS sensors for future colliders," PhD 2022, now U. of Edinburgh

Umit KAYA, Ankara U / TOBB, "Search for Color Octet Electron (e8) at TeV Energy Scale Colliders", PhD 2019

Salim OGUR, Bogazici University, "Linac and Damping Ring Designs of the future Circular e+e- Collider of CERN", CERN/Bogazici PhD April 2019 – later CERN fellow, now JLAB

numerous FCC graduates
- to be updated

MSc theses

Yunus Emre OKYAYLI, 2018, "Search for R-parity violation interactions of scalar leptons at future circular collider", Istanbul U.

Gökhan HALİMOĞLU, 2018, "Measurement of lepton + jets at 100 TeV at future circular collider", Istanbul U.

Rokia Omar Ali ALAMIN, 2017, "Anomalous heavy down type b quark production at the future circular collider", Kastamonu University

Burak HACIŞAHİNOĞLU, 2017, "Search for flavour changing neutral current couplings of higgs-up sector quarks at electron-proton colliders", Istanbul U.

Murat ALTINLI, 2017, "Investigation of gauge boson anomalous couplings with higgs particle at electron-proton colliders", Istanbul U.

Çağla ÇAĞLAR, 2019, "Search for quarkonium consists of E6 model predicted isosinglet quark at future colliders,", Ege University

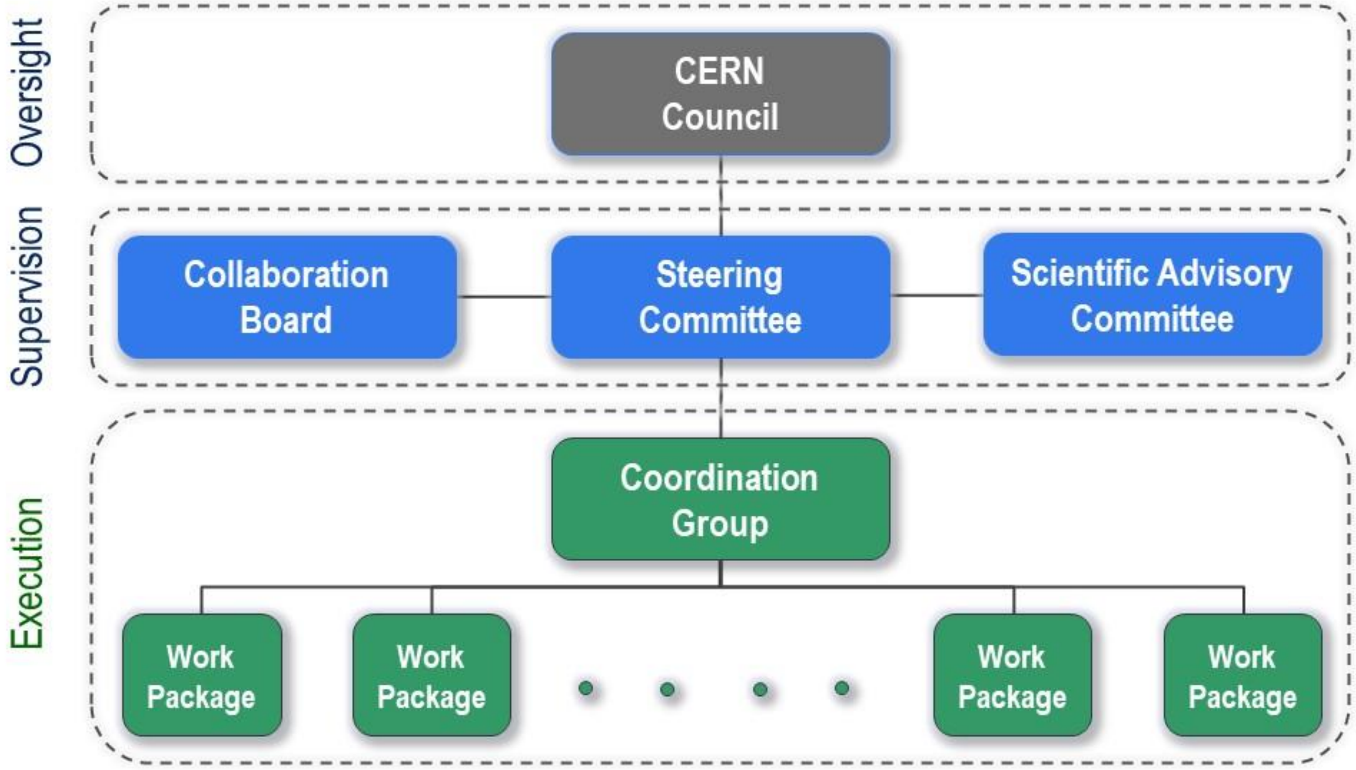
Alev Ezgi DEMİRCİ, 2017, "Production and decay channels of charged higgs boson at high energy hadron colliders", Ankara U.

FUTURE CIRCULAR COLLIDER

FCC organizational structure and collaboration framework

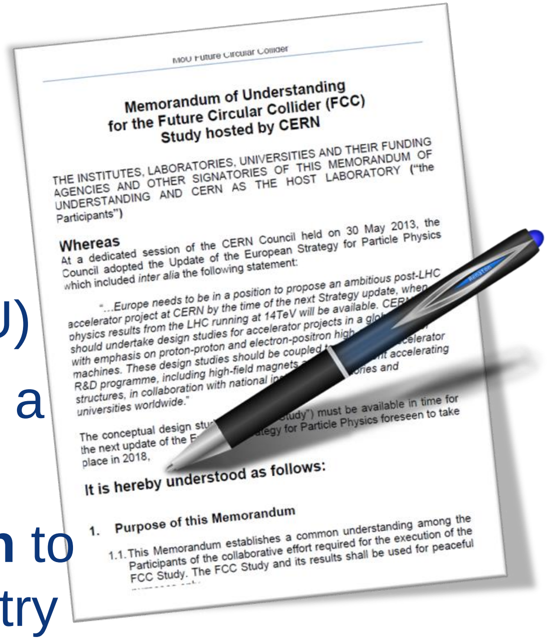
Organisational Structure of the FCC Feasibility Study – approved by CERN Council in June 2021

http://cds.cern.ch/record/2774006/files/English.pdf



FCC collaboration framework during CDR and FS phases

- A **consortium** of partners based on a Memorandum Of Understanding (MoU)
- Working together on a **best effort basis**
- **Incremental & open** to academia and industry
- Individual **projects** defined in **specific addenda**



FCC Feasibility Study – summary and outlook

FUTURE CIRCULAR COLLIDER

- **The first half of the FCC Feasibility Study has been completed with the mid-term review**
  - placement & layout was defined, and entire project adapted to the new geometry
  - dialogue with local-regional actors and stakeholders for implementation established and ongoing
  - all deliverables met, list of recommendations from committees towards final Feasibility Study
- **Progress was made possible by a fruitful collaboration between scientific & technical actors, in close cooperation with the host state services concerned.**
- **Next milestone is completion of the FCC Feasibility Study by March 2025 to enable advancing project decision and project start date:**
  - Complete technical work for FCC FS by end 2024
  - Implementation of recommendations of the mid-term review with focus on “feasibility items” and items with important impact on cost/performance
  - Full design iteration in view of technical and cost optimisation of entire project.
  - Update of cost estimate
  - Further development of an affordable funding model and related governance implications (with Council).
  - Setup structure for preparatory phase

Main goals during preparatory phase until 2031/32

- **By 2027-2028, project approval, start of CE design contract:**
  - provision of requirements and specifications to enable CE tender design to start from 2028 (underground) and 2029 (surface)
  - requires overall integration study and designs based on technical pre-design of accelerators, technical infrastructure and detectors
  - refined input for environmental evaluation and project authorization process.

- **By 2031-32, start of CE construction:**
  - CE groundbreaking
  - TDR to enable prototyping, industrialization towards component production

teşekkür ederim

- **Strong collaborations with Türkiye are important for the success of the Feasibility Study and will be even more so for the FCC project to go ahead. Thank you for your contributions and looking forward to further collaboration.**

FUTURE
CIRCULAR
COLLIDER

FCC Week 2024

Future Circular Collider (FCC) Week 2024, at the **Westin St. Francis in San Francisco.**

From **Monday 10 June to Friday 14 June 2024**.
Registration is open !

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

We look forward to welcoming you in San Francisco for what promises to be an exciting and informative event!

CERN

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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."

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EPJ ST 228, 4 (2019) 755-1107 , EPJ ST 228, 5 (2019) 1109-1382

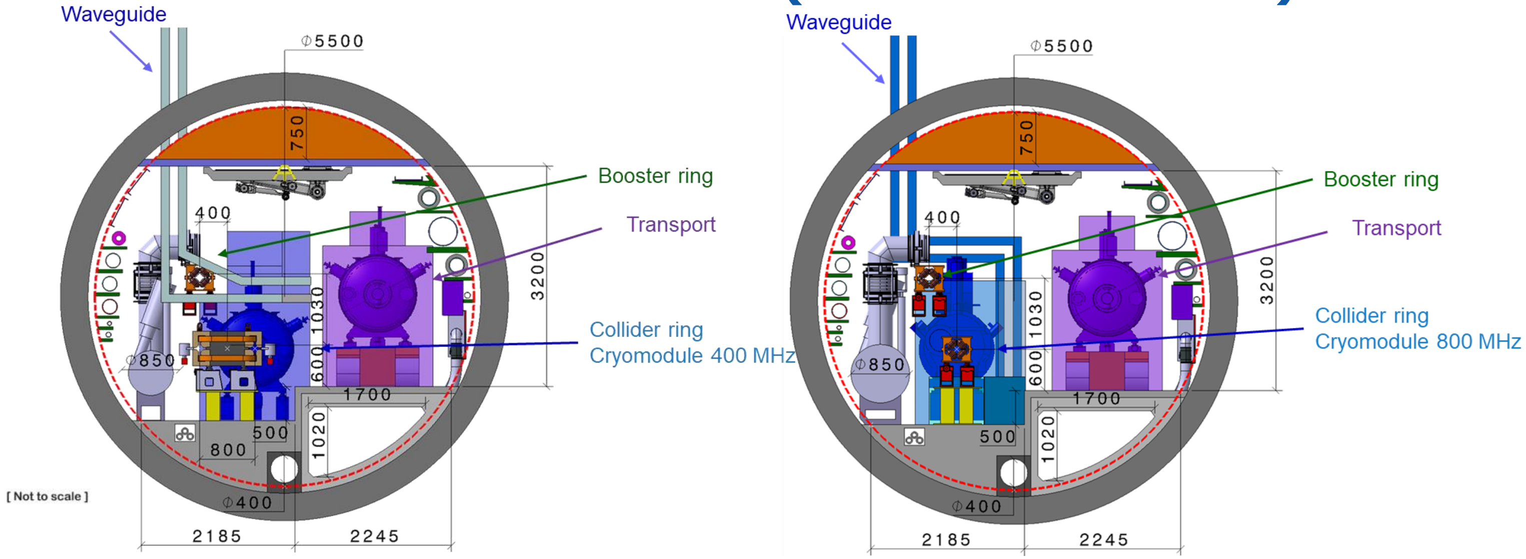
2020 Update of European Strategy for Particle Physics:

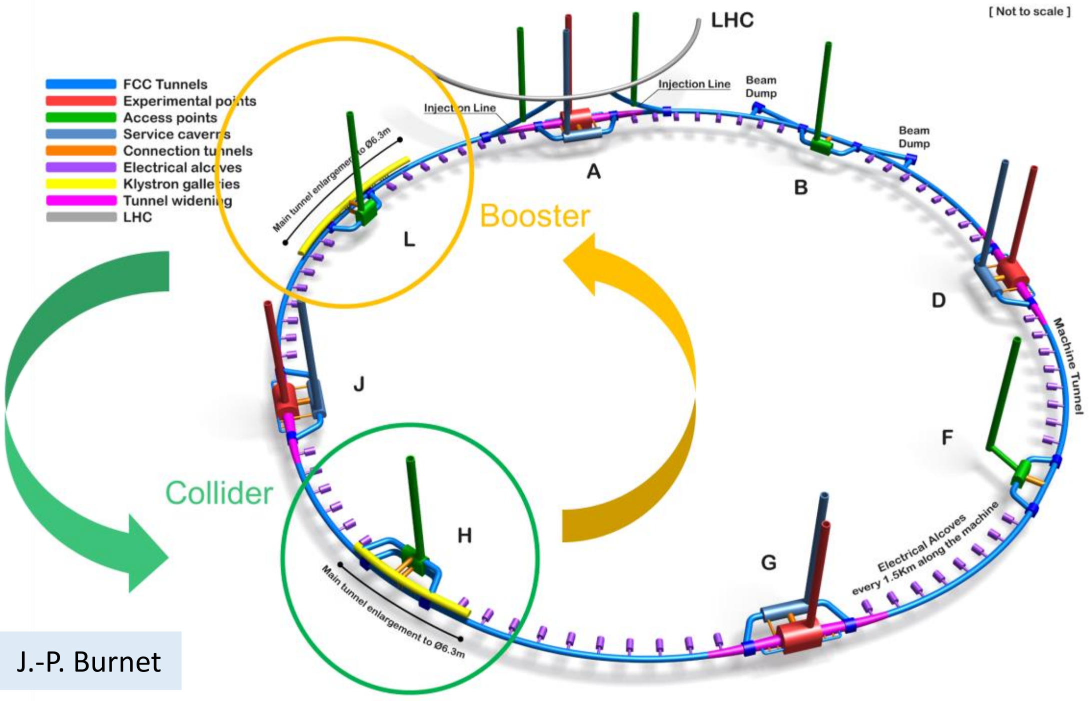
"Europe, together with its international partners, should investigate technical and financial feasibility of a future hadron collider at CERN with a centre-of-mass energy of at least 100 TeV and with an electron-positron Higgs and electroweak factory as a possible first stage."

FCC-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

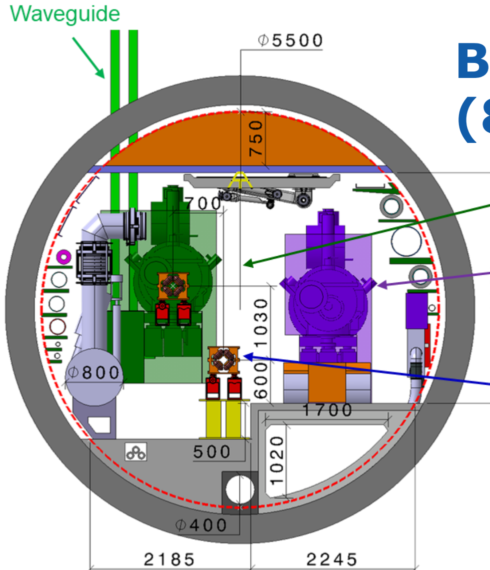
Collider RF - Point H (400 and 800 MHz)





J.-P. Burnet

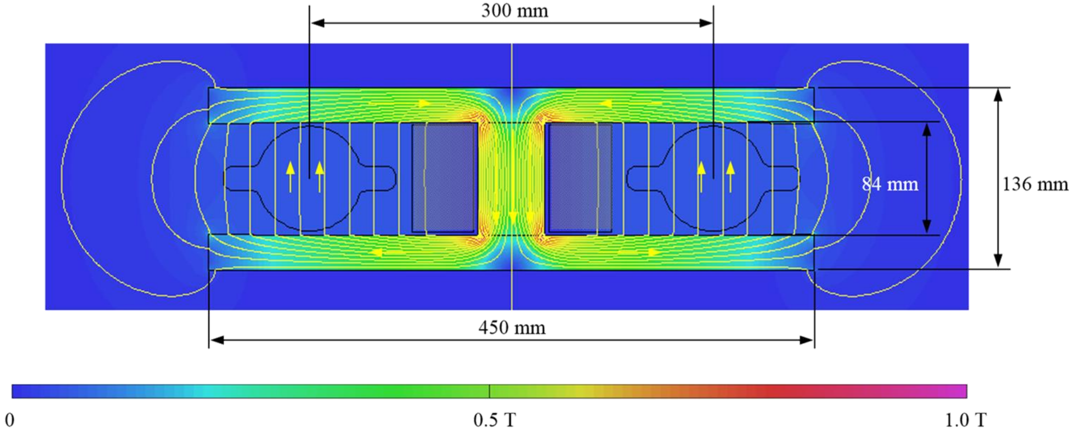
Booster RF - Point L (800 MHz only)

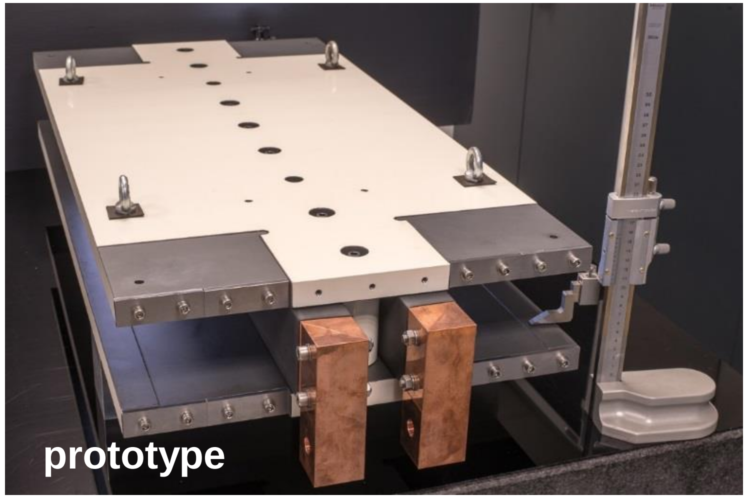


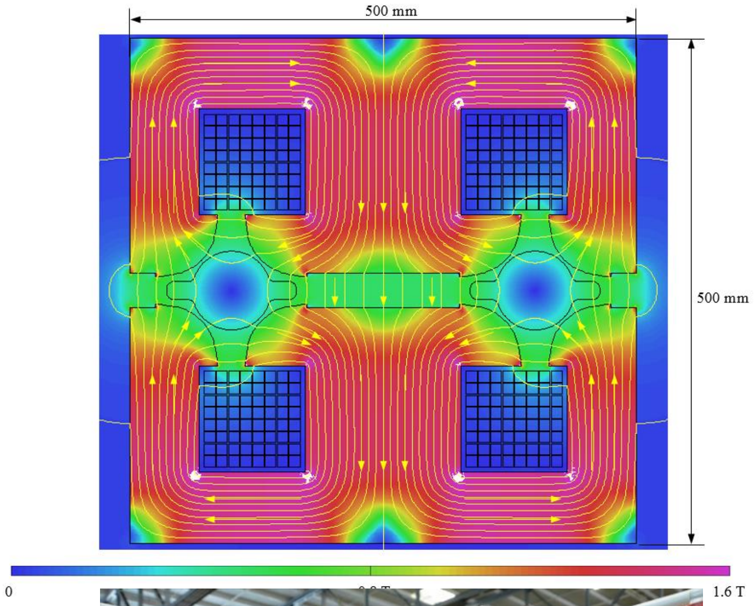
F. Valchova, F. Peauger

prototypes of FCC-ee low-power magnets

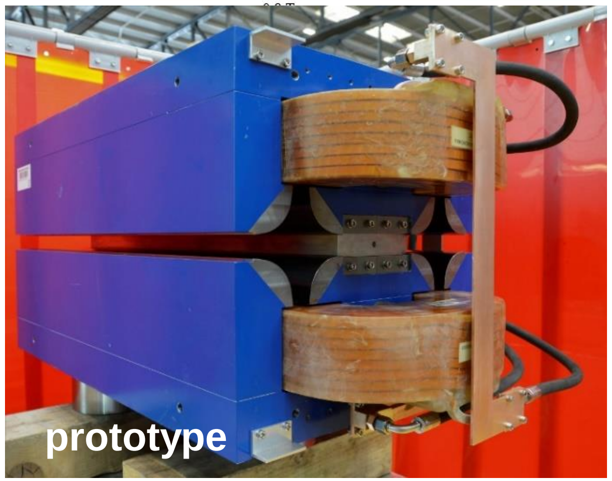
Twin-dipole design with 2× power saving 16 MW (at 175 GeV), with Al busbars







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



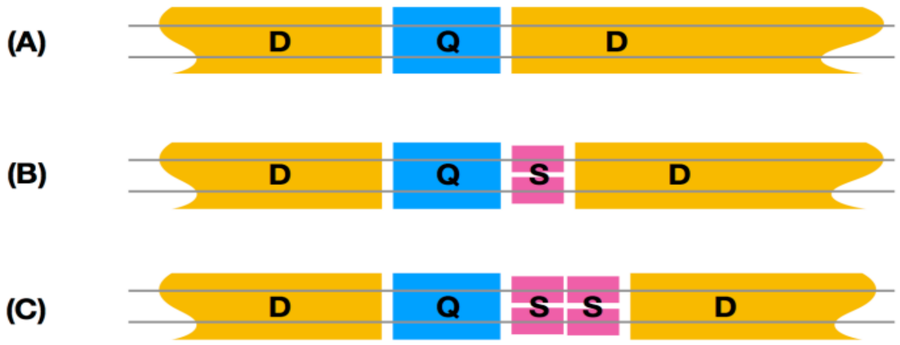
even more efficient alternative magnet designs are being explored

HTS option for FCC-ee arc quads and sextupoles

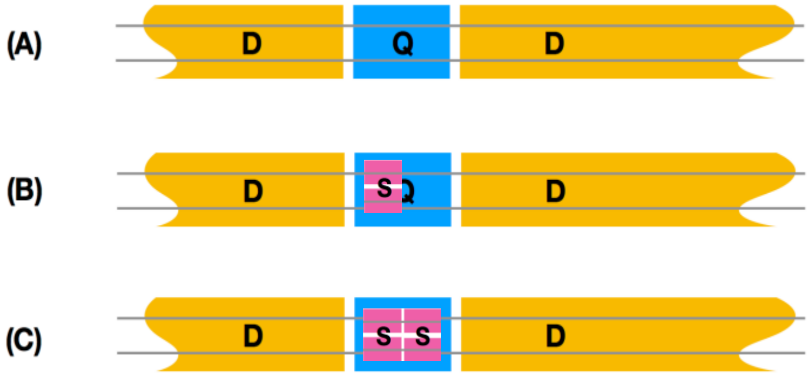
CDR: 2900 quads & 4700 sextupoles

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

CDR arc lattice



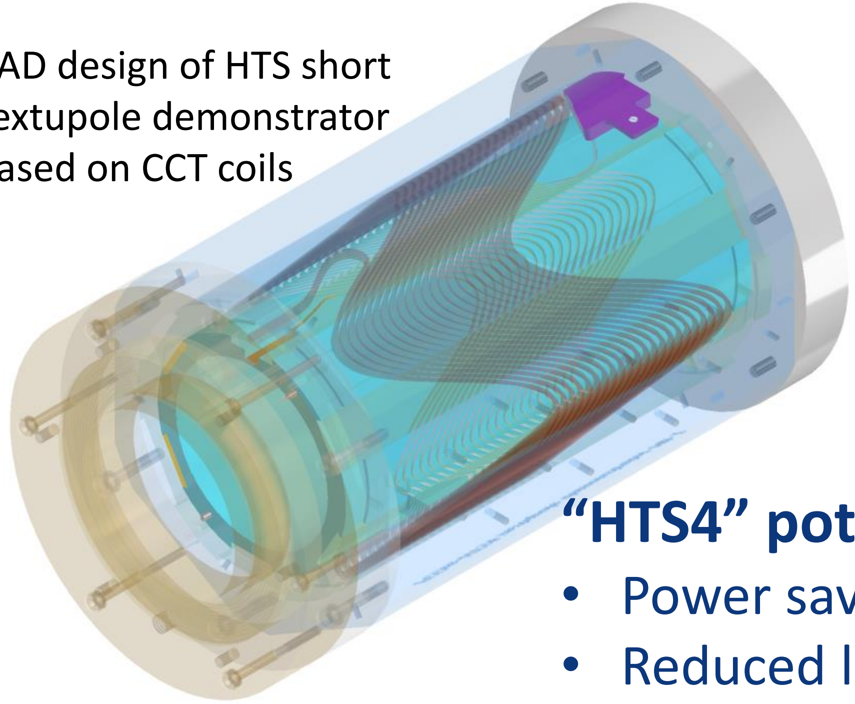
HTS option

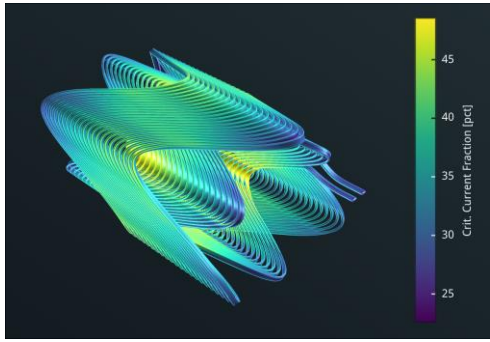


"HTS4" project within CHART collaboration

- 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





"HTS4" potential

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

M. Koratzinos, B. Auchmann