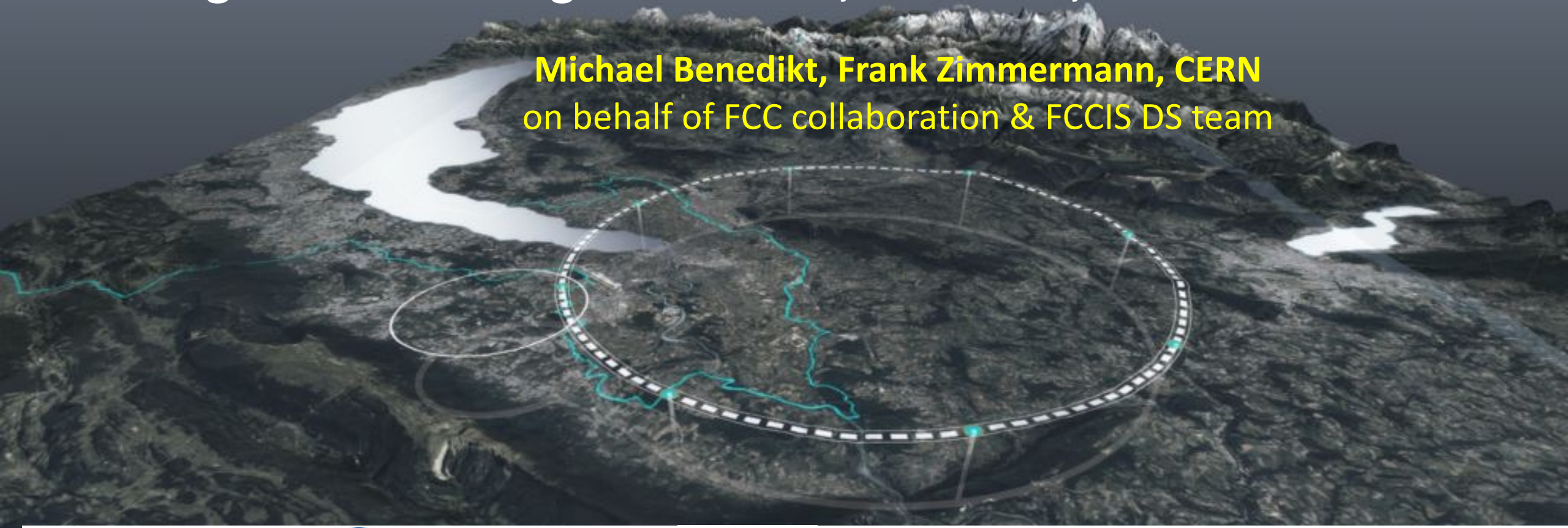
The FCC Integrated Program

Strategic Joint Meeting of the HFCC, New York, 8 November 2024

Michael Benedikt, Frank Zimmermann, CERN
on behalf of FCC collaboration & FCCIS DS team



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

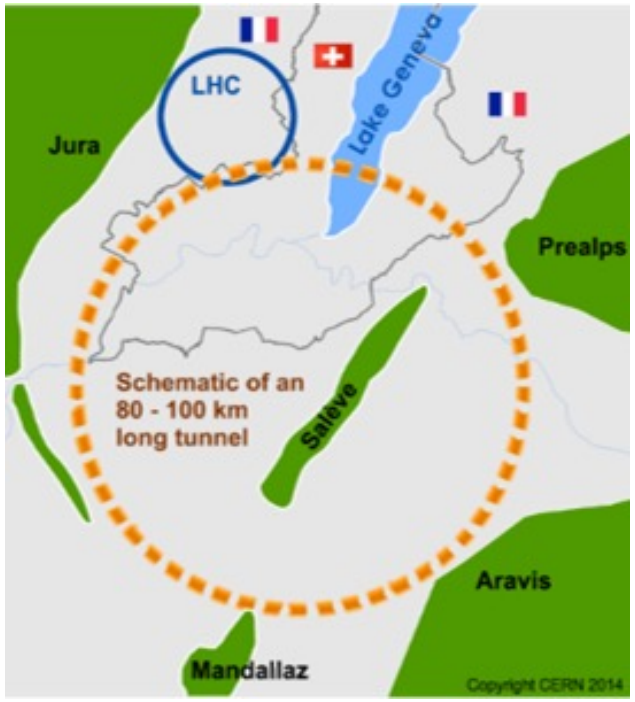
photo: J. Wenninger

FUTURE CIRCULAR COLLIDER

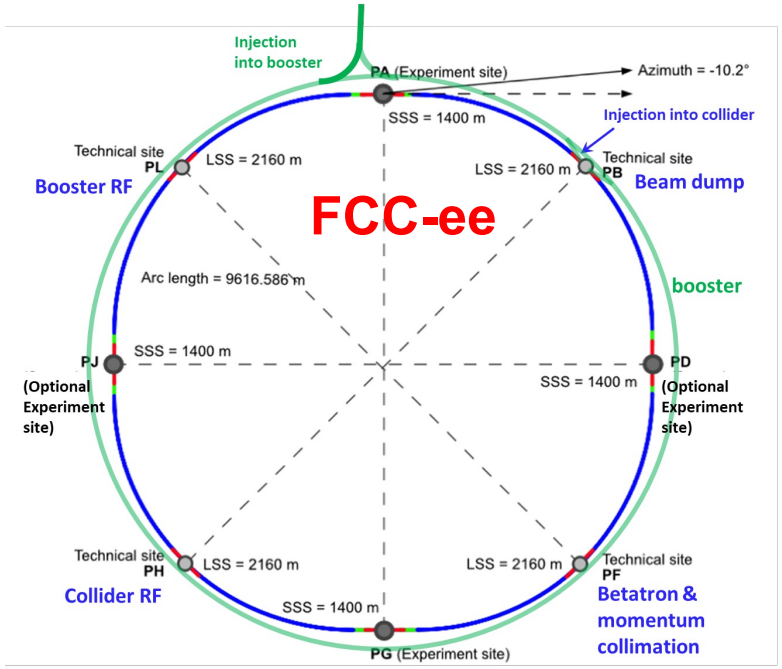
FCC integrated program

comprehensive long-term program maximizing physics opportunities

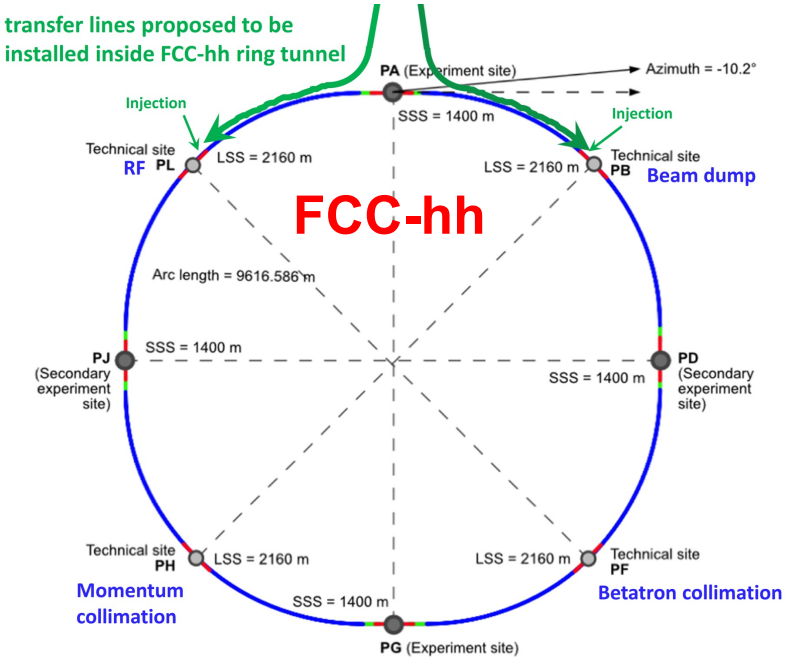
- **stage 1: FCC-ee (Z, W, H, $t\bar{t}$) as Higgs factory, electroweak & top factory at highest luminosities**
- **stage 2: FCC-hh (~100 TeV) as natural continuation at energy frontier, pp & AA collisions; e-h option**
- highly synergetic and complementary programme boosting the physics reach of both 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 - 2045

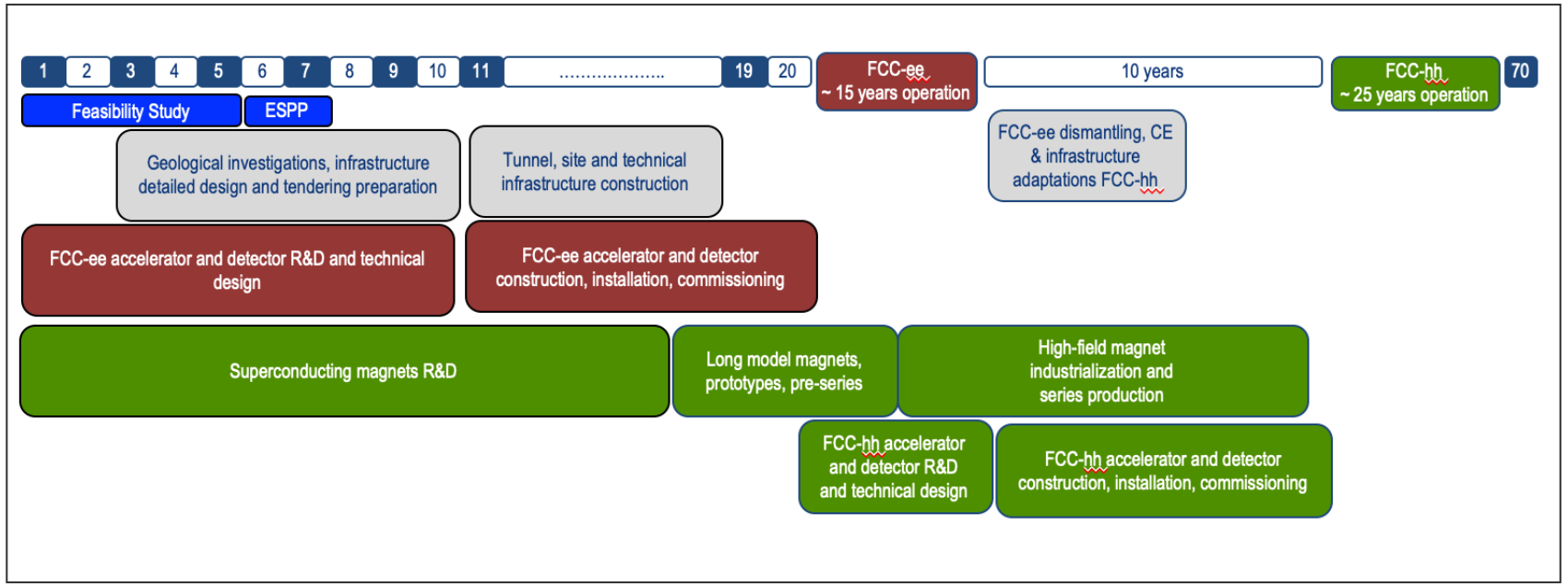


2045 - 2065

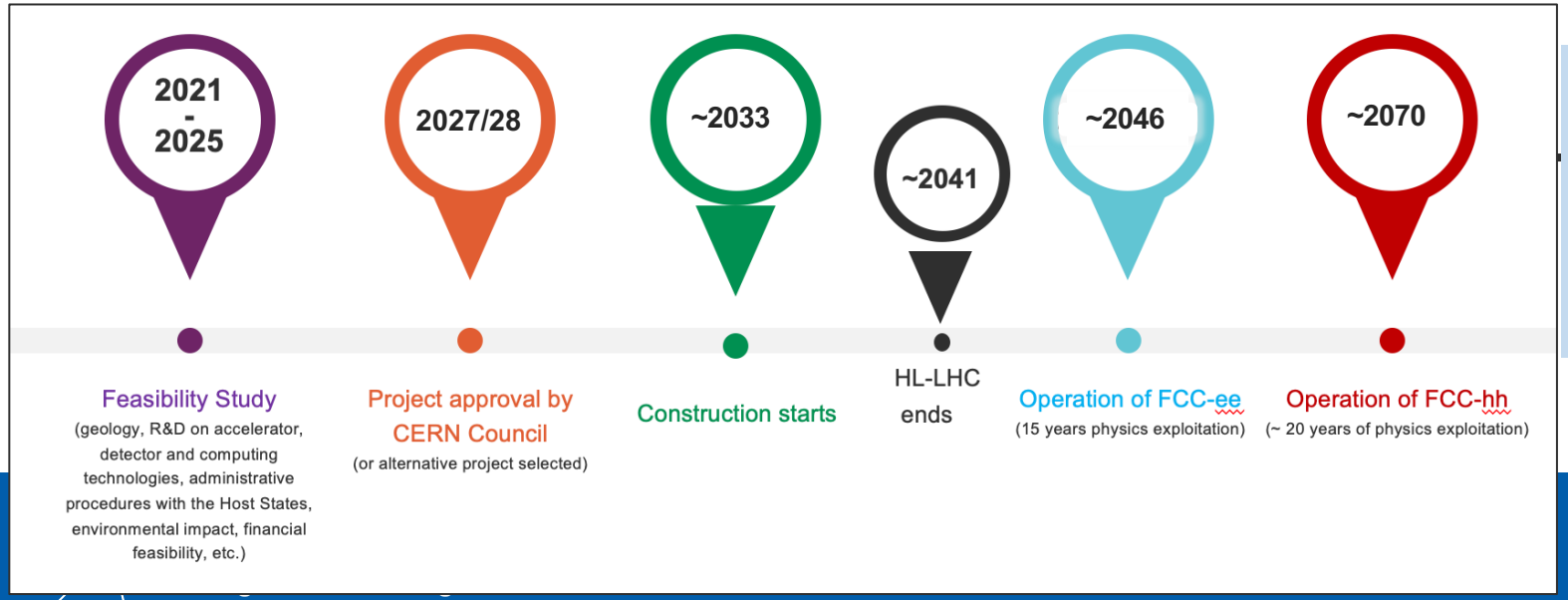


2070 -

FCC integrated program - timeline



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**

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 FS Council Documents, June ‘21

Organisational Structure of the FCC Feasibility Study

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

CERN/SPC/1155/Rev.2
CERN/3566/Rev.2
Original: English
21 June 2021

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Action to be taken		*Voting Procedure*
For decision	**RESTRICTED COUNCIL** 203rd Session **17 June 2021**	Simple majority of Member States represented and voting

FUTURE CIRCULAR COLLIDER FEASIBILITY STUDY:

PROPOSED ORGANISATIONAL STRUCTURE

This document sets out the proposed organisational structure for the Feasibility Study of the Future Circular Collider, to be carried out in line with the recommendations of the European Strategy for Particle Physics updated by the CERN Council in June 2020. It reflects discussion at, and feedback received from, the Council in March 2021 and is now submitted for the latter’s approval.

Main Deliverables and Timeline of the FCC Feasibility Study

http://cds.cern.ch/record/2774007/files/English.pdf

CERN/SPC/1161
CERN/3588
Original: English
21 June 2021

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Action to be taken		*Voting Procedure*
For information	**RESTRICTED COUNCIL** 203rd Session **17 June 2021**	-

FUTURE CIRCULAR COLLIDER FEASIBILITY STUDY:

MAIN DELIVERABLES AND MILESTONES

This document describes the main deliverables and milestones of the study being carried out to assess the technical and financial feasibility of a Future Circular Collider at CERN. The results of this study will be summarised in a Feasibility Study Report to be completed by the end of 2025.

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;
- consolidation of the physics case and detector concepts for both colliders
- 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);

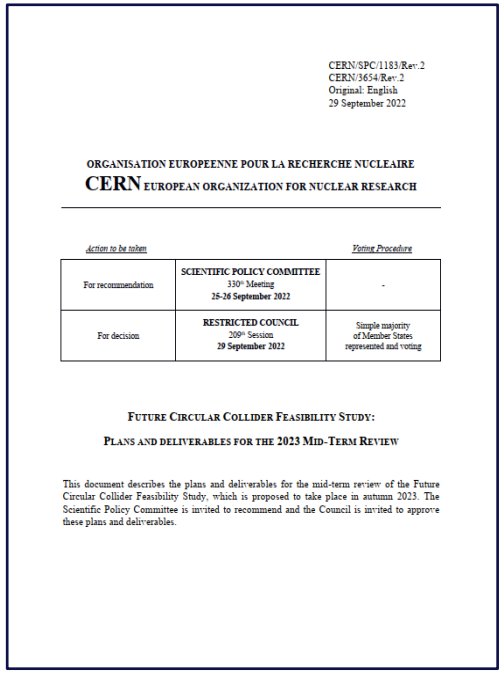
Results will be summarised in a Feasibility Study Report to be released in March 2025

F. Gianotti

FCC FS mid-term review

Mid-term review setup and deliverables are defined in CERN/SPC/1183/Rev.2:

- *the scientific and technical results be reviewed by the FCC FS Scientific Advisory Committee, augmented by additional experts as needed;*
- *the cost and financial feasibility, which will focus on the first-stage project (tunnel, technical infrastructure, FCC-ee machine and injectors), be reviewed by a committee including external experts, as proposed in CERN/3588;*



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.

FCC Scientific Advisory Committee

Riccardo Bartolini (DESY), Alain Chabert (Société Française du Tunnel Routier Fréjus), Heinz Ehrbar (HEP), Brigitte Fargevieille (Électricité de France), Belen Gavela Legazpi (UAM), Gudrun Hiller (Dortmund), Srinivas Krishnagopal (BARC), Peter Krizan (Ljubljana), Philippe Lebrun (CERN, retired), Peter McIntosh (STFC), Michiko Minty (BNL), **Andrew Parker** (**Chair**, Cambridge), Kyo Shibata (KEK), Roberto Tenchini (Pisa)

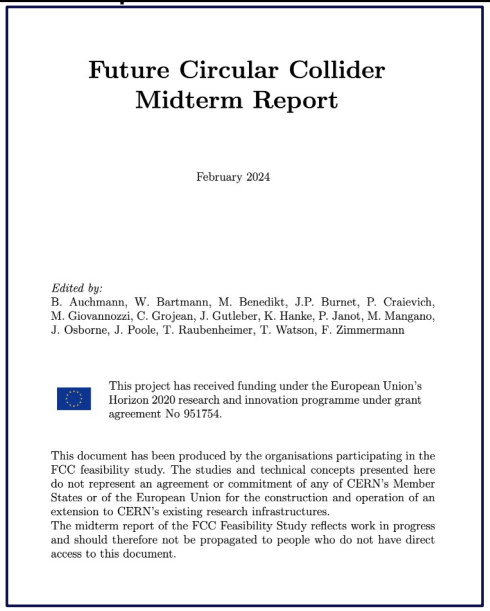
FCC Cost Review Panel

Carlos Alejaldre (Fusion for Energy), Austin Ball (CERN, retired), Umberto Dosselli (INFN), Heinz Ehrbar (HEP) Vincent Gorgues (CEA), **Norbert Holtkamp** (**Chair**, Stanford), Christa Laurila (National Audit Office, Finland), Ursula Weyrich (German Cancer Research Centre), Jim Yeck (BNL), Thomas Zurbuchen (ETH Zürich)

Feasibility Study Mid-Term Review passed !

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


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.

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

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

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

All deliverables met, no technical showstoppers

→70-80 recommendations

Feasibility Study Report for March 2025

Structure:Three Volumes

- ***Vol. 1:*** *Physics, Experiments and Detectors (~200 pages)*
- ***Vol. 2:*** *Accelerators, Technical Infrastructures, Safety Concepts (~400 pages)*
- ***Vol. 3:*** *Civil Engineering, Implementation & Sustainability (~200 pages)*
- - **Executive Summary of the FCC Feasibility Study: ~40 pages**

Input for Update of European Strategy for Particle Physics

to be prepared with Overleaf & published by EPJ (Springer-Nature) – FCCIS members

In addition:

a. Documentation on Cost Estimate – Funding Models

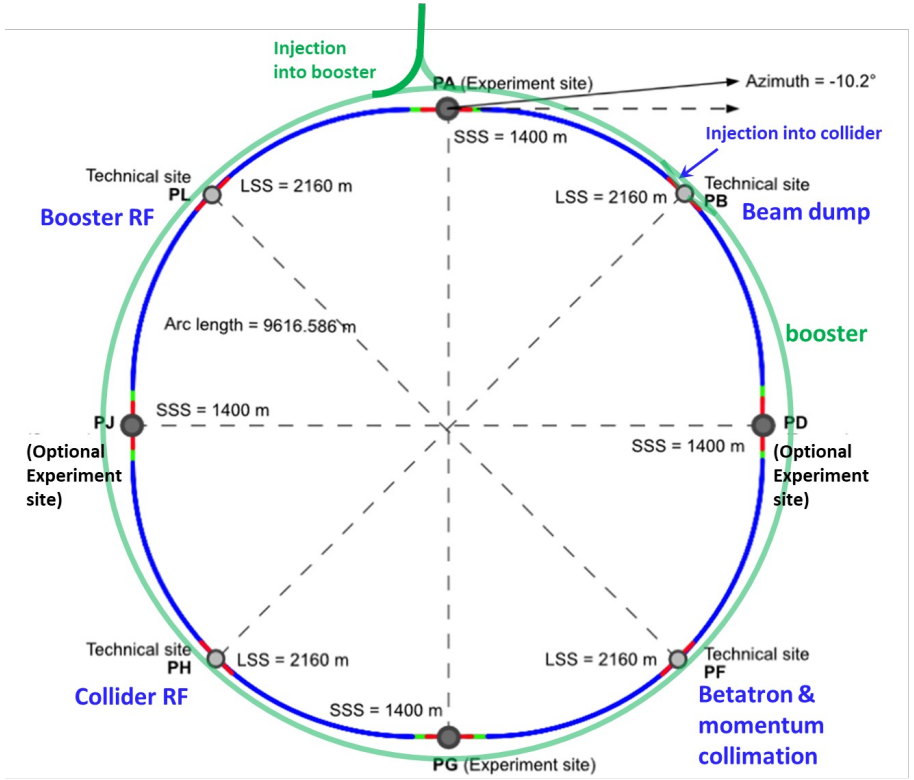
b. Environmental Report

Reference layout and implementation: PA31 - 90.7 km

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, 4-fold symmetry



V. Mertens, J. Gutleber

PA: Experiment

PB: technical

PL: technical

PD: experiment

PJ: experiment

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**

4 experiments

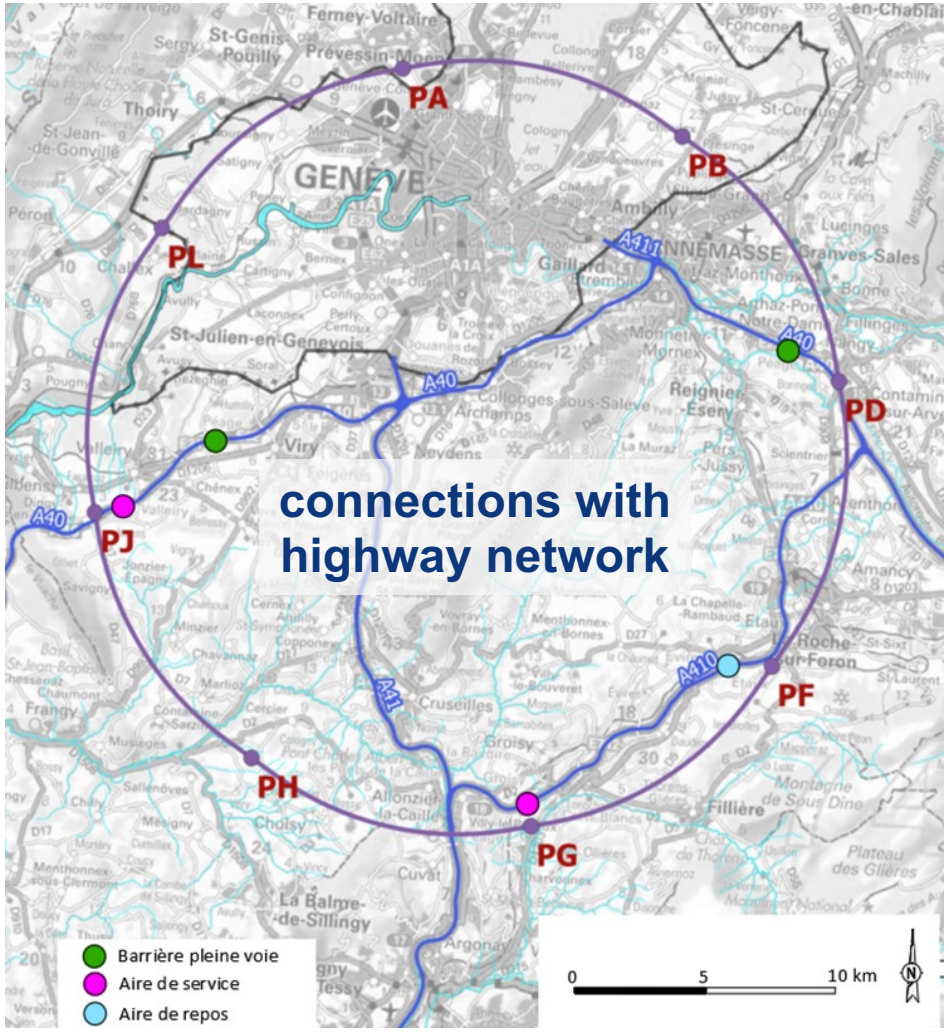
PF: technical

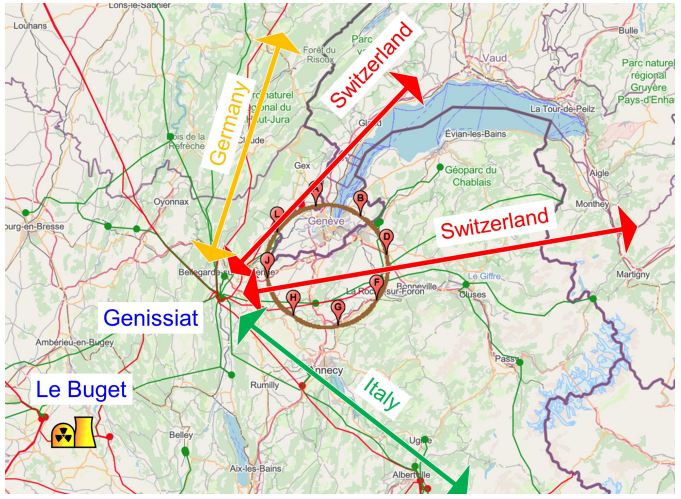
PH: technical

PG: experiment

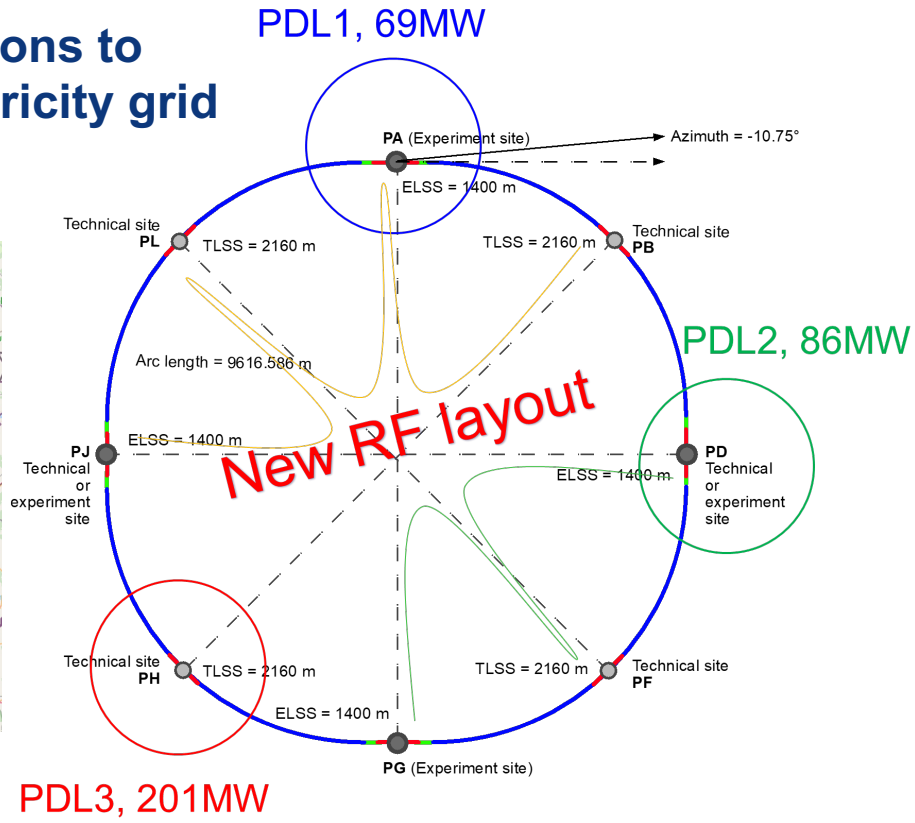
Integration with regional infrastructures

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





Connections to French electricity grid



- Electrical connection concept developed with RTE (French electricity grid operator)
- Three HV supply points, two new stations & CERN Prevessin
  ➔ requested loads have no significant impact on grid
- R&D efforts aiming at reduction of the energy consumption of FCC-ee and FCC-hh

FUTURE CIRCULAR COLLIDER

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

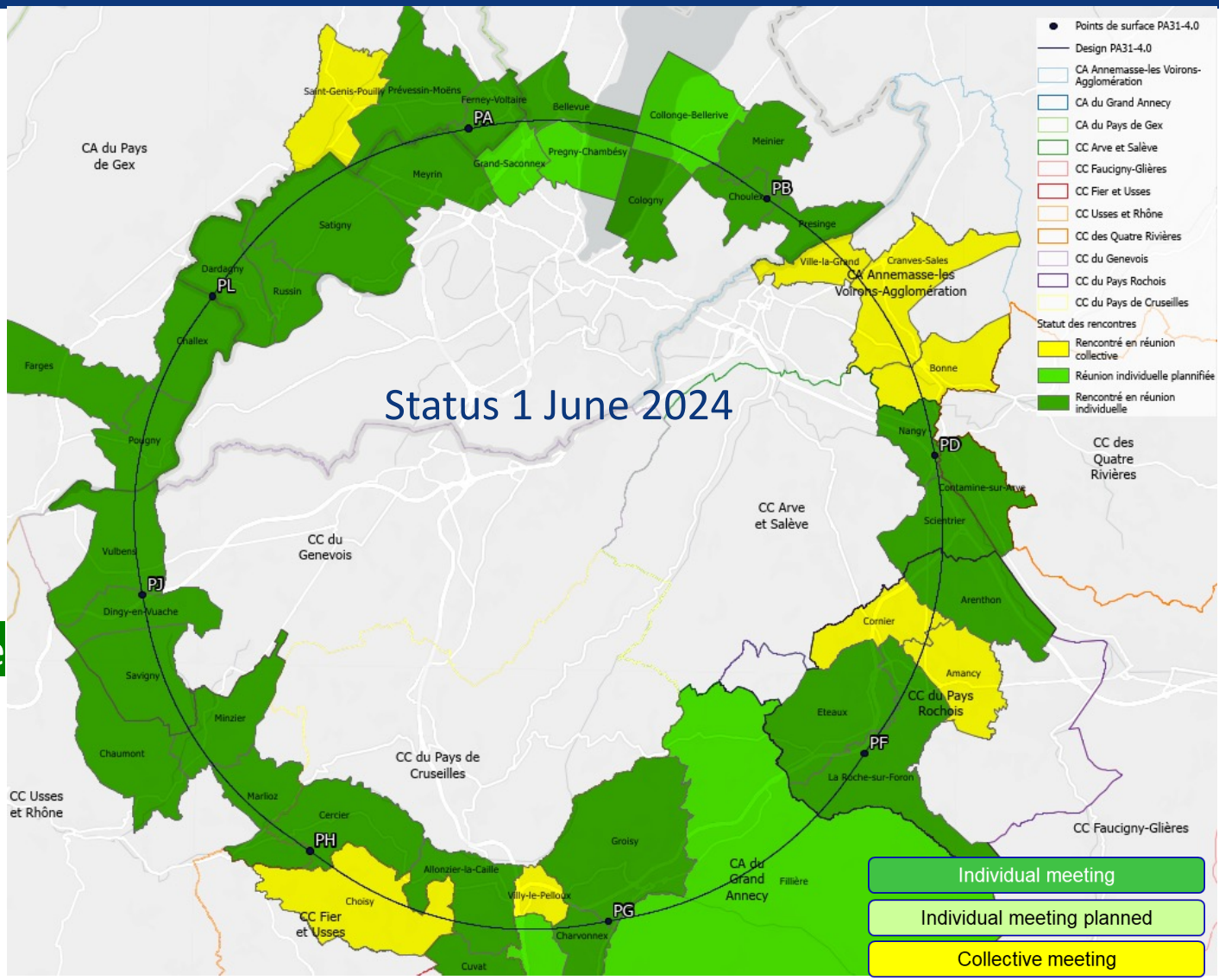
PH – Cercier (FR) – technical site

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

PL – Challex (FR) – technical site

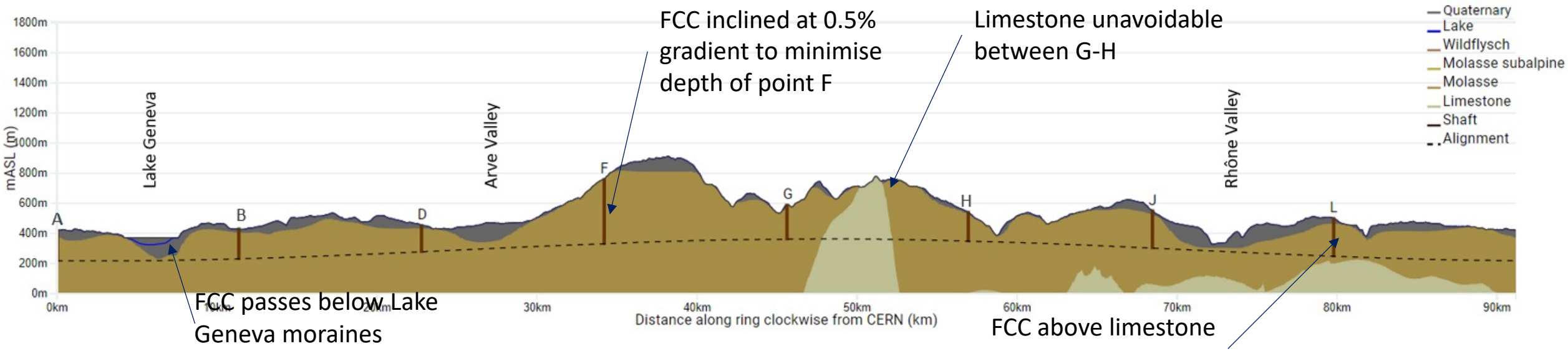
Detailed work with municipalities and host states

- 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- geological conditions



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

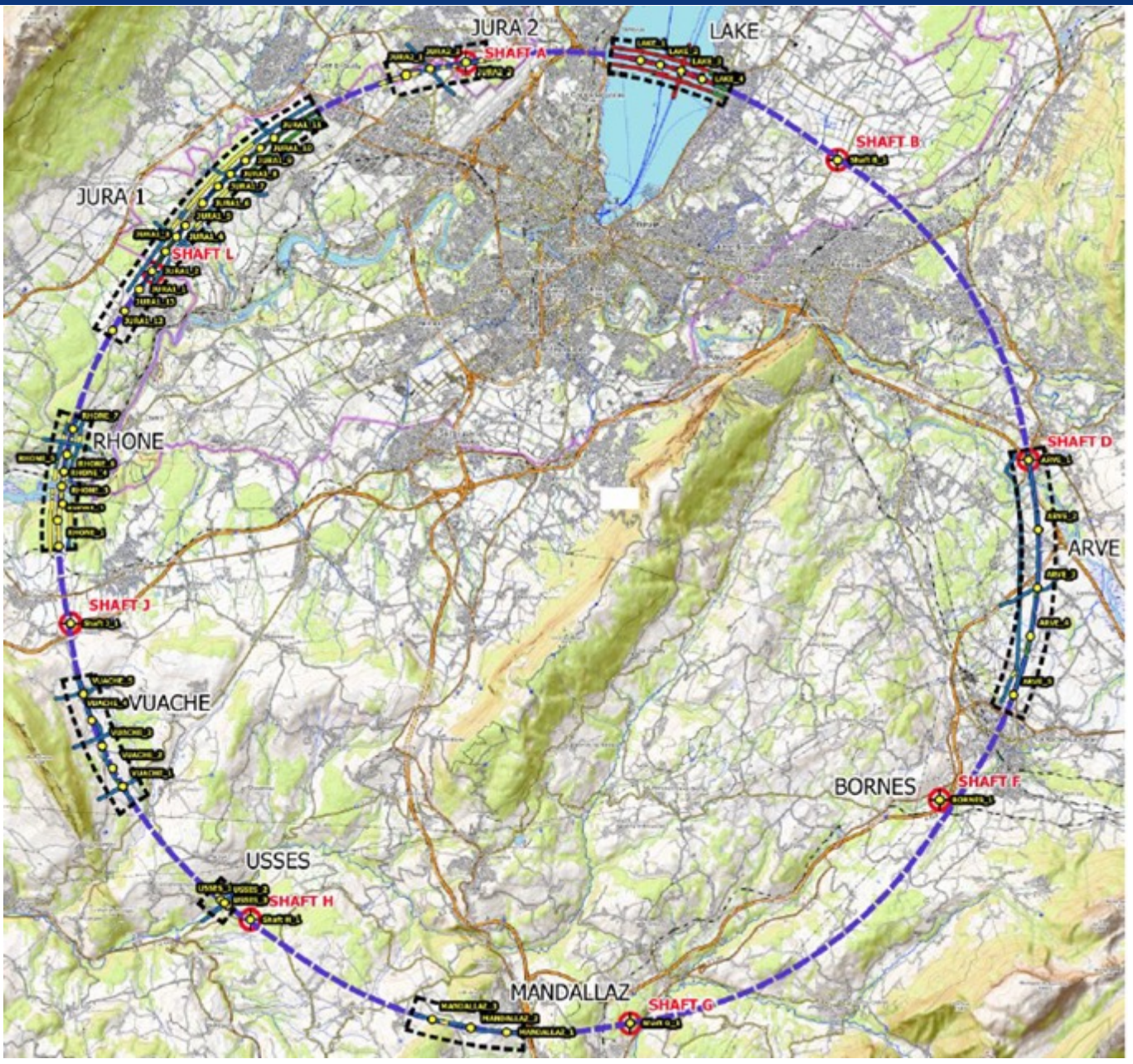
6 million m^3 excavated volume → 8.5 million m^3 excavation material on surface

CE Designs of all underground structures developed

To fix the vertical position of the tunnel, interfaces between geological layers have to be known

FUTURE CIRCULAR COLLIDER

First series of site investigations



Site investigations to identify exact location of geological interfaces:

- Molasse layer vs moraines/limestone
- ~30 drillings and ~90 km seismic lines

→ **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)

example of drilling works on a lake the lake

Start of site investigations – seismic investigations

First seismic line :

Seismic line SL_USSES_02 :

Acquisition date : 01/10/2024

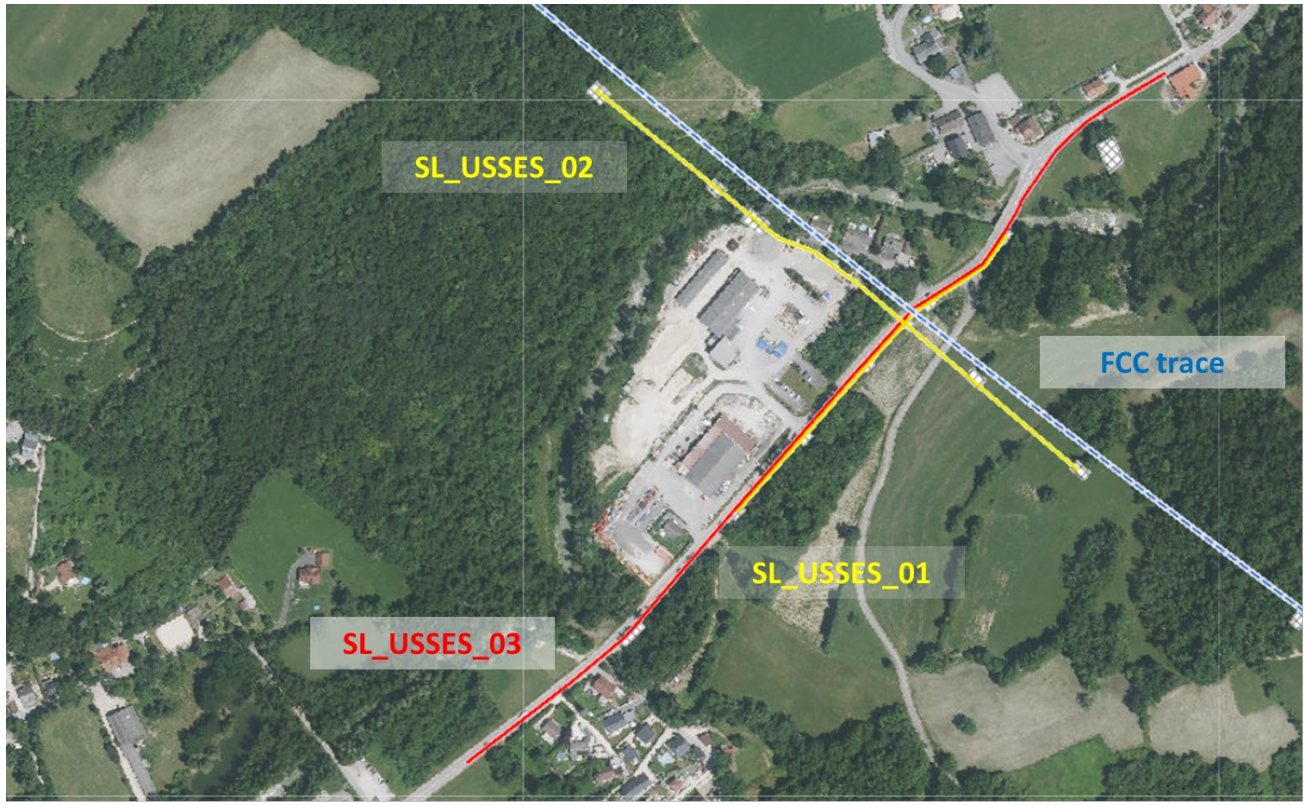
Length : 480 meters
Method(s) : Explosive and Seismic gun
Geophones : 96 units (5 meters of spacing)
Shot points : 13 shot points in total

Second seismic line :

Seismic line SL_USSES_01 :

Acquisition date : 02/10/2024

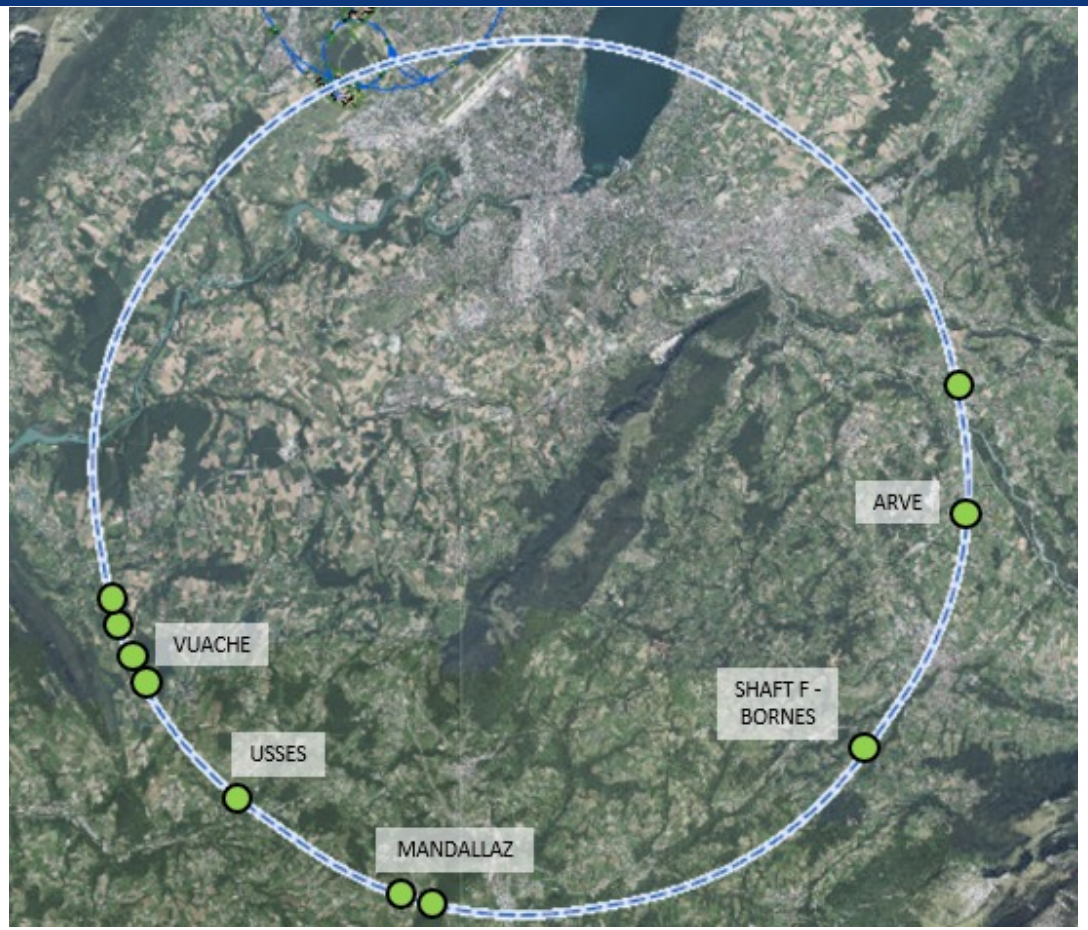
Length : 300 meters
Method(s) : Weight drop
Geophones : 60 units (5 meters of spacing)
Shot points : 15 shot points in total



Extract from the FCC GIS – 20/09/2024

FUTURE CIRCULAR COLLIDER

Status of site investigations – drilings



Drilling for first borehole has commenced on 14/10/2024

The drilling (USSES 2) is within the commune of Marlioz

The drill site is located within the storage yard of a private construction company (Besson).

Drilling Depth = 70m

Fully cored recovery

Drill time should be about 2 weeks

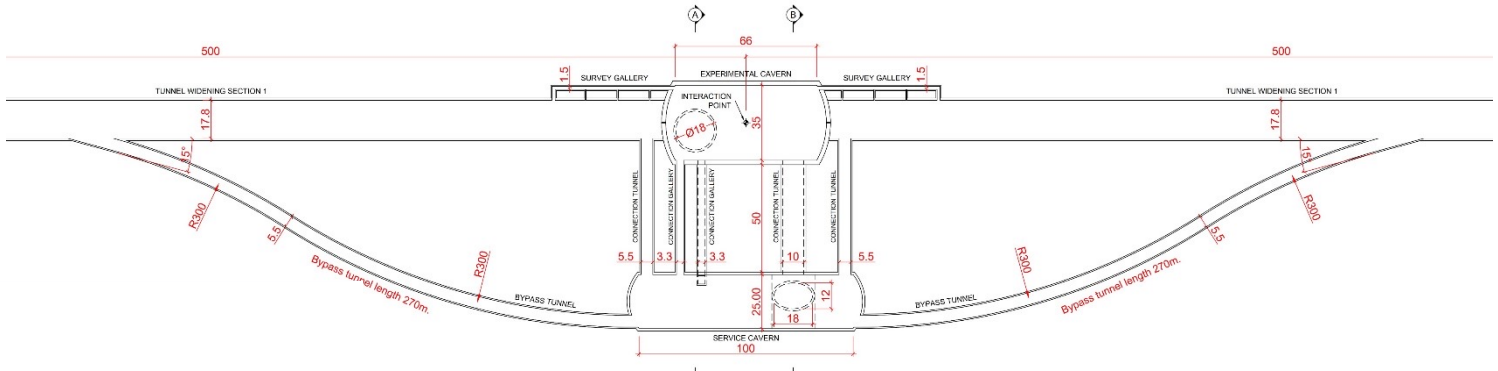
Equipped with Piezometer

CE underground and surface progress

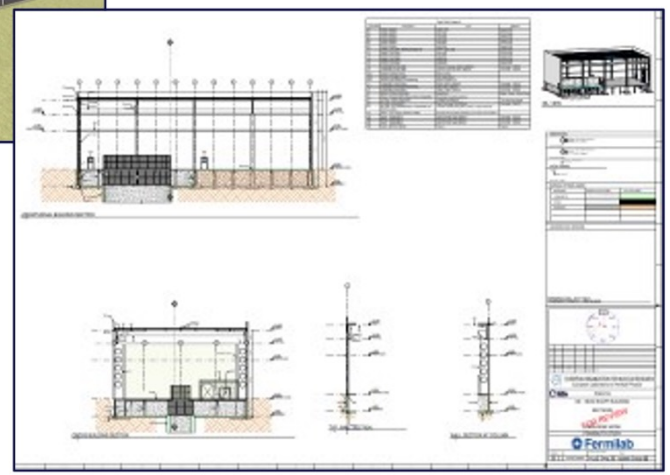
- **Full 3D model of all underground structures as basis for costing and scheduling exercises with external consultant.**

PLAN VIEW
1:3000

- **Experiment Site (PA)**



PLAN VIEW
1:1000

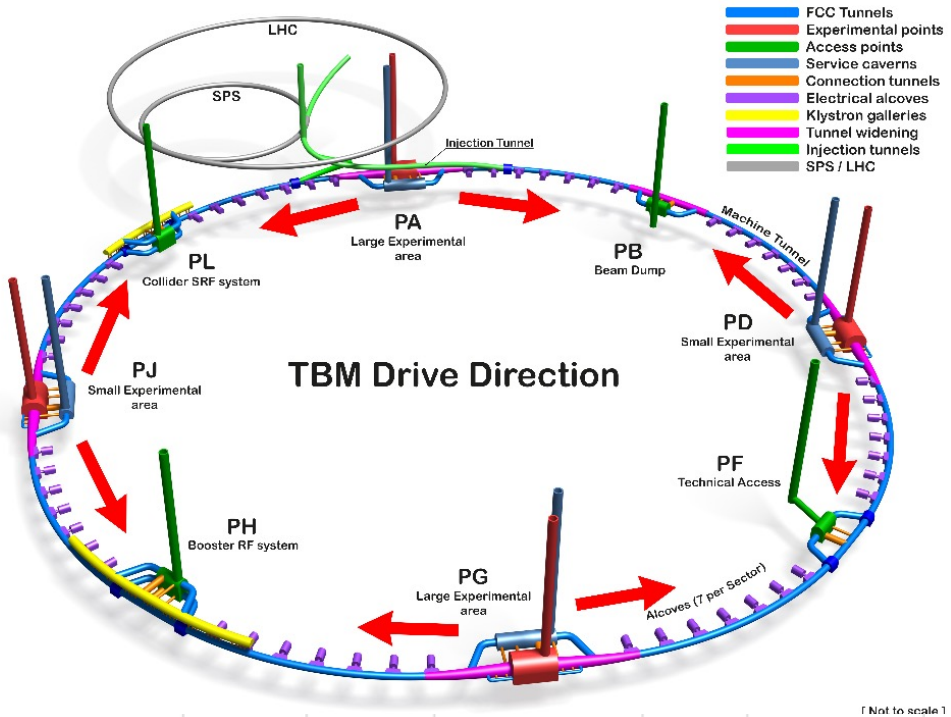


Examples of Fermilab Deliverables

- **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

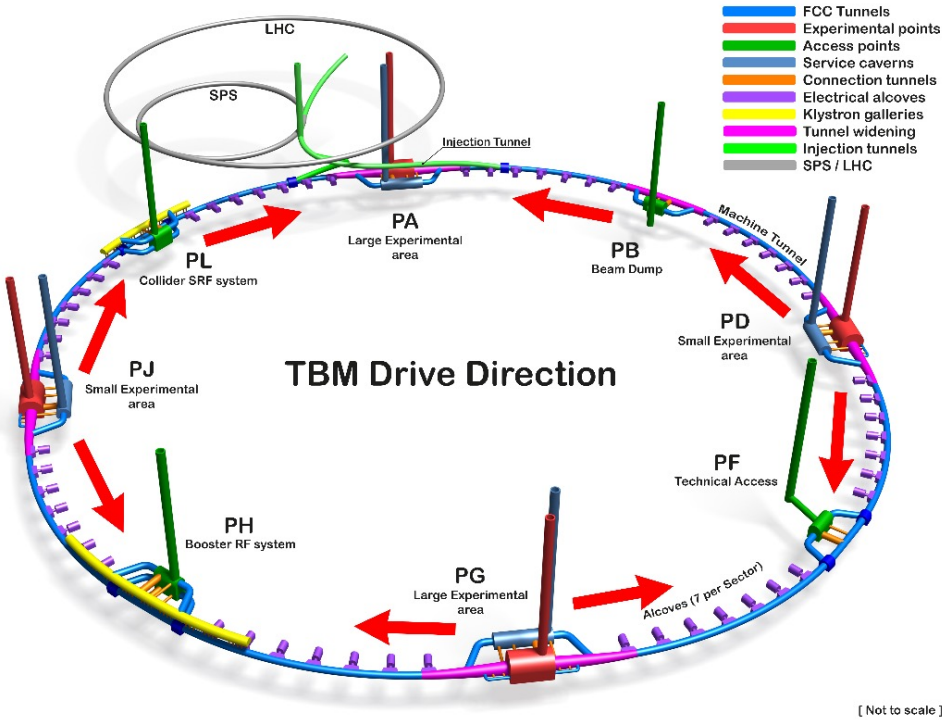
2 TBMs from each experimental point



[Not to scale]

	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



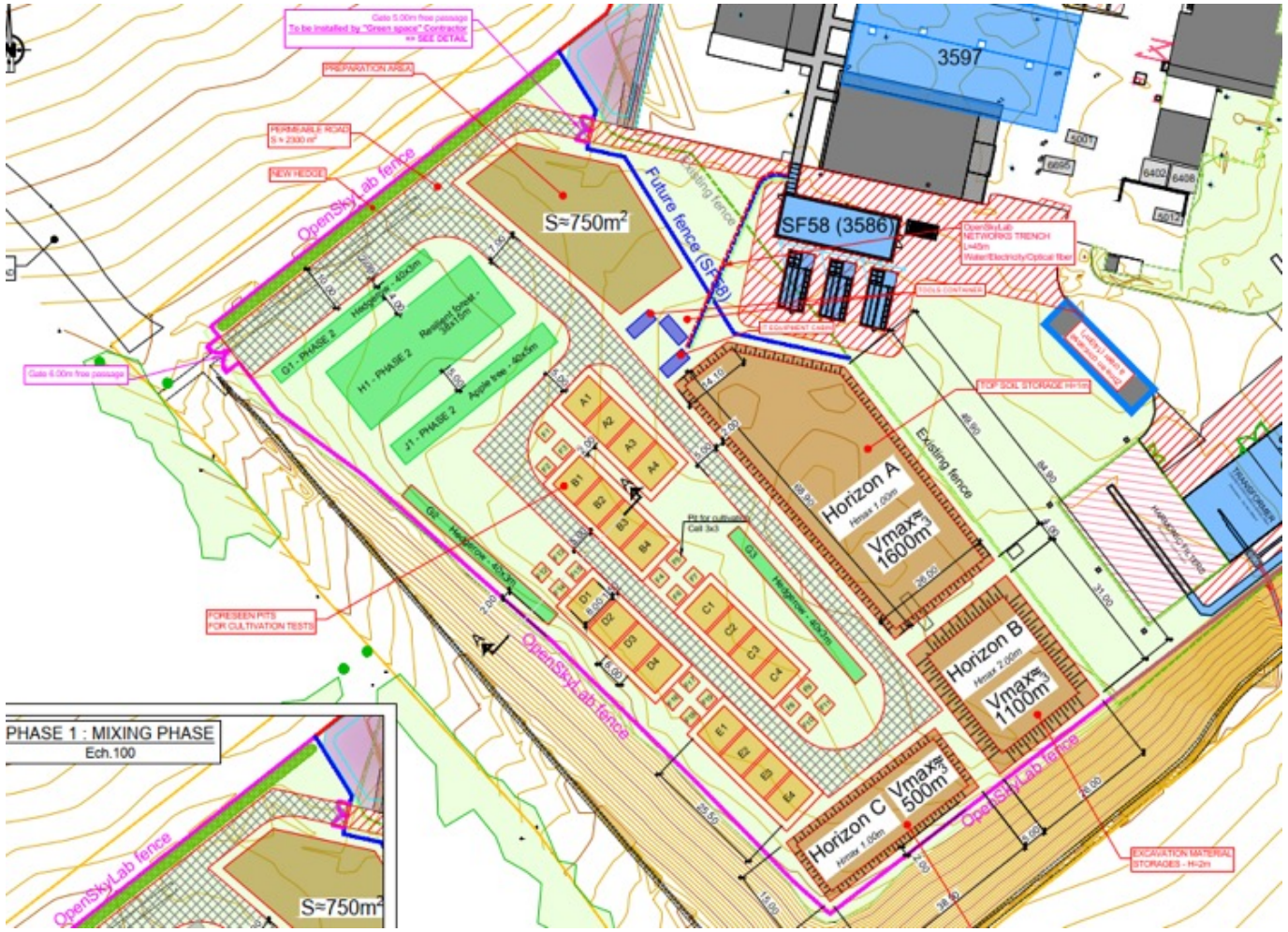
[Not to scale]

	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%		

FUTURE CIRCULAR COLLIDER

Development of excavation material re-use opportunities
OpenSkyLab: academic and industrial collaboration @LHC P5 CMS

- **Transformation of Molasse (FCC ~8 Mm³ volume) into fertile soil for agricultural and other uses**
- **Materials: Molasse from the HL-LHC construction**
- **Duration: 4+ years (2024 -)**
- **Trials with 5 000 t molasse**
  - Soil fertilisation process (micro-organisms, mixing with fertile soil, etc.)
  - Development of ferilisation mix products
  - Development of quality managed processes
  - Experimental phase with scientific protocol and field monitoring and control system support



hepia Haute école du paysage, d'ingénierie et d'architecture de Genève
brgm Géosciences pour une Terre durable
EDAPHOS
BOKU UNIVERSITY
micro humus Ingénierie des sols
MONTAN UNIVERSITÄT LEOBEN
BECC EST 2018
Csil
BG

FUTURE CIRCULAR COLLIDER

OpenSkyLab status and progress

FUTURE CIRCULAR COLLIDER

Environmental studies to document present status of potential FCC surface site areas

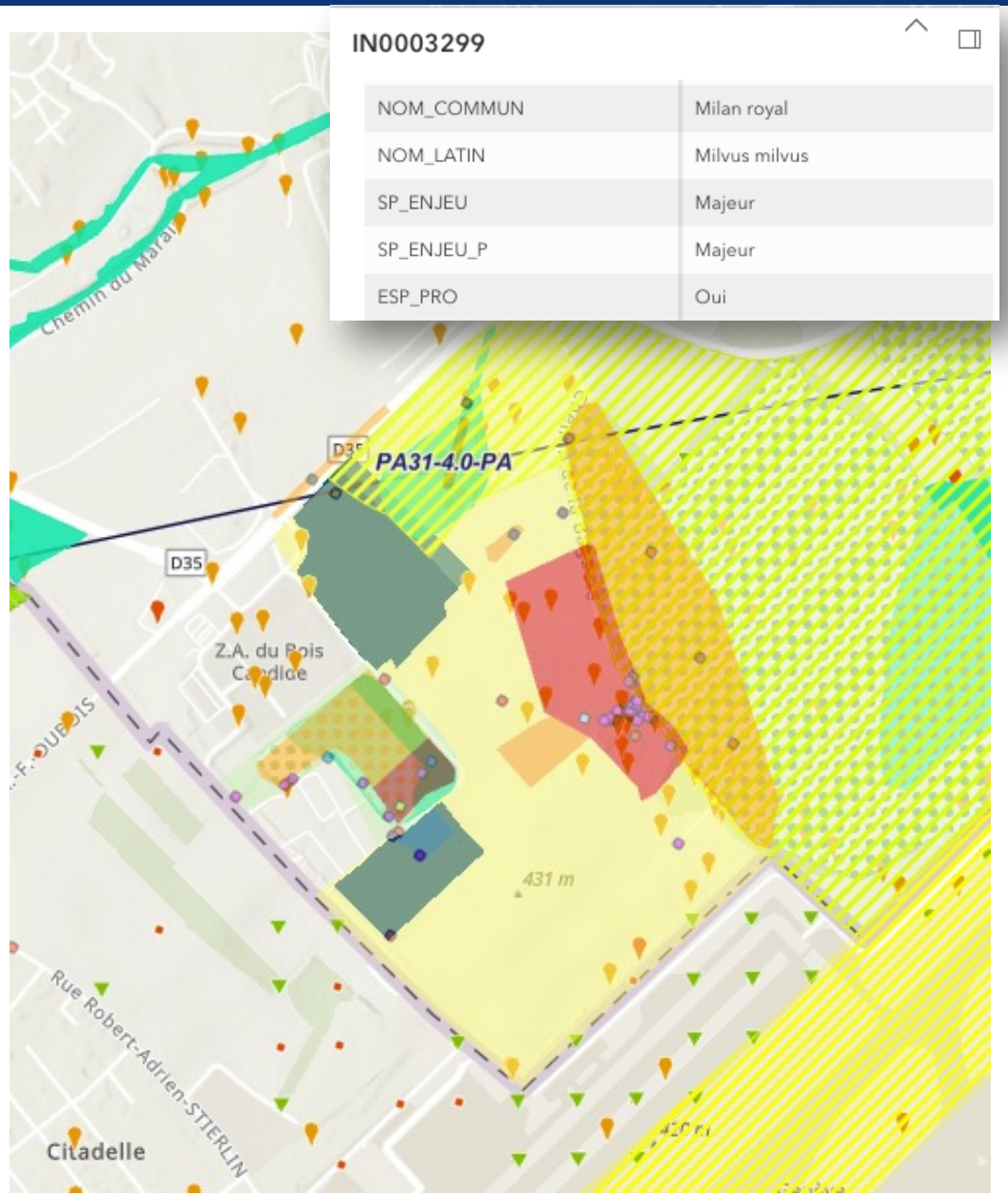
Short term goals for FCC Feasibility Study:

- Establish a state of the current environmental conditions at the surface site locations based on the actual situation, complementing the map and database investigations.
- Confirm the territorial feasibility in principle.
- Support the environmental impact studies for the geotechnical and geophysical investigations (i.e. boreholes and seismic lines).

Long term goals <u>anticipating impact assessment works</u>:

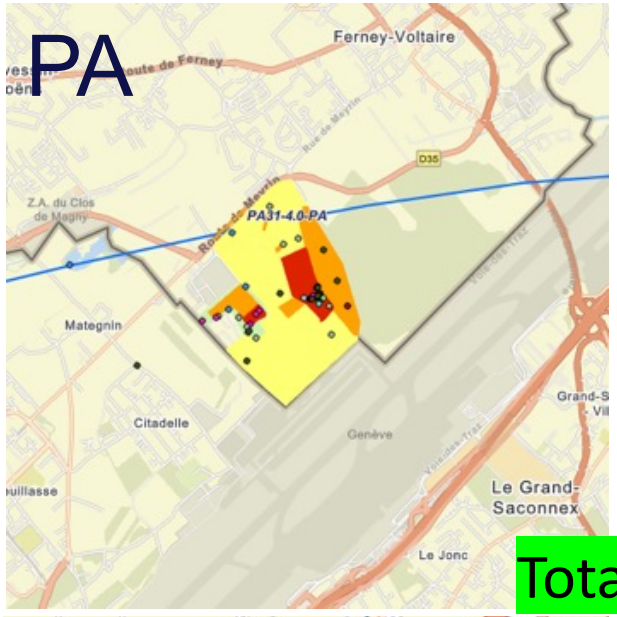
- **Comply with the regulatory reporting requirements** in the frame of the authorisation process.
- Identify and **document the environmental stakes exhaustively**.

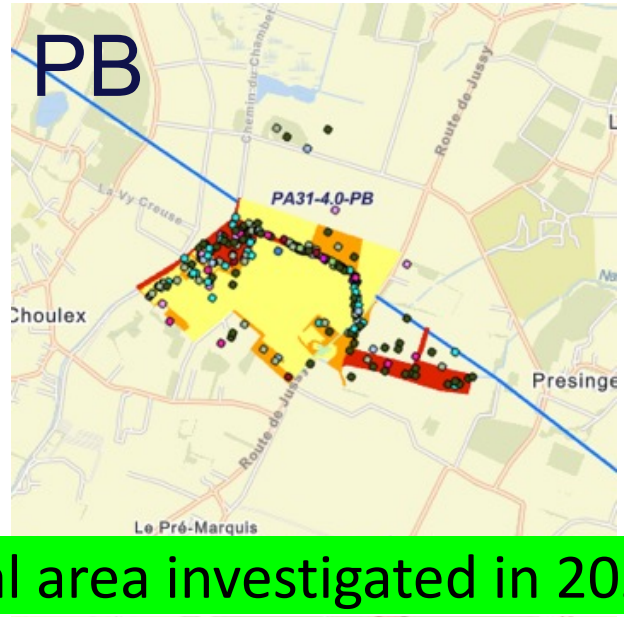
Definition of environmental strategy and guiding principles for Ecodesign to be considered by infrastructure and equipment designers in technical design phase.

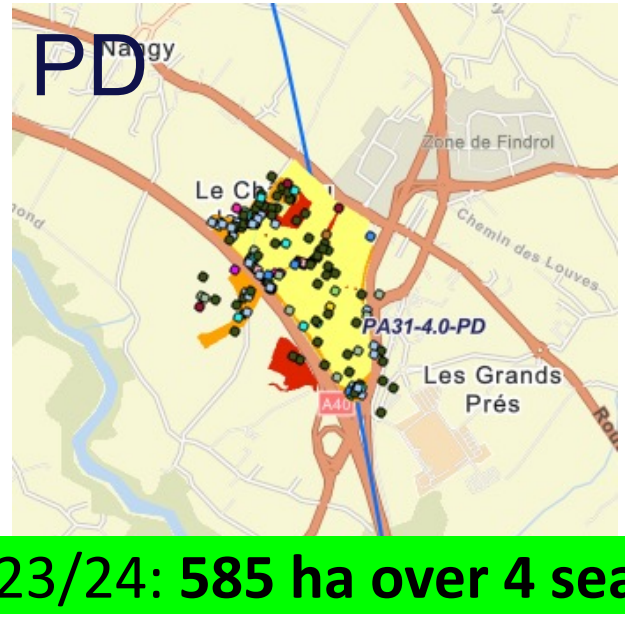


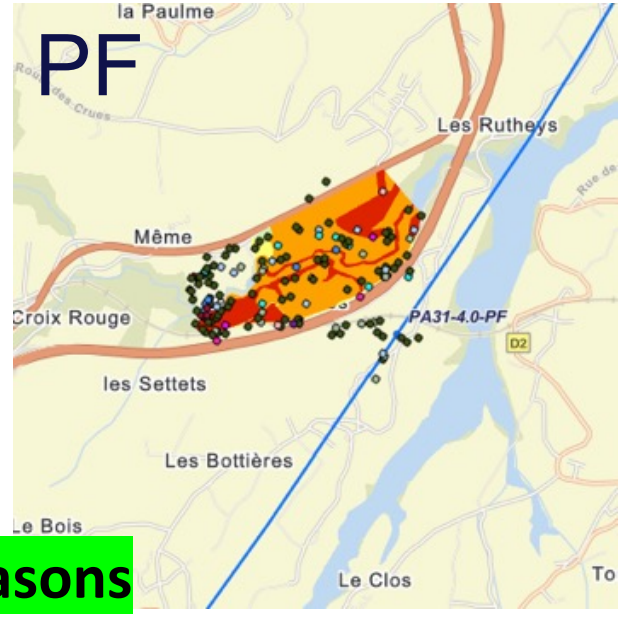
FUTURE CIRCULAR COLLIDER

Environmental studies around surface areas

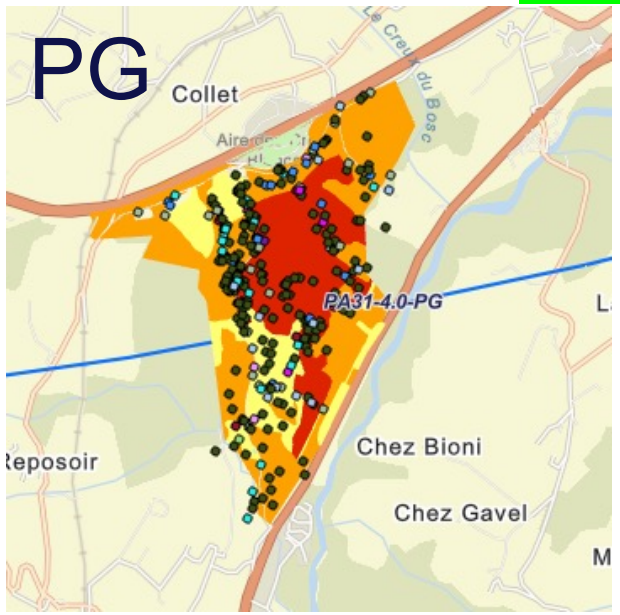


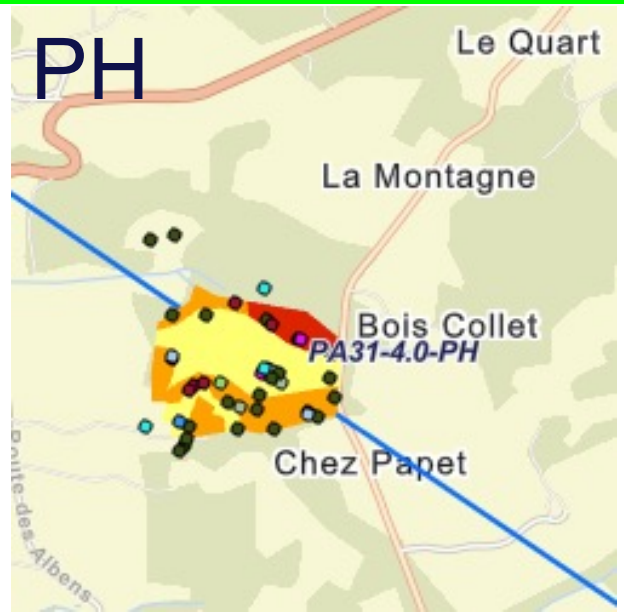


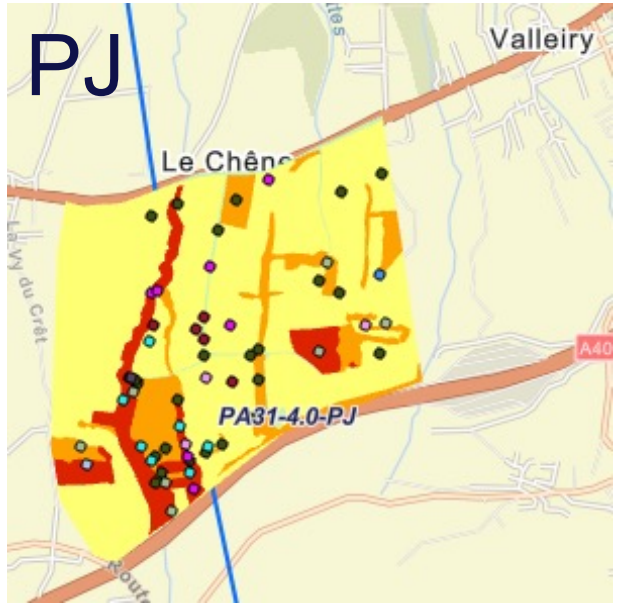


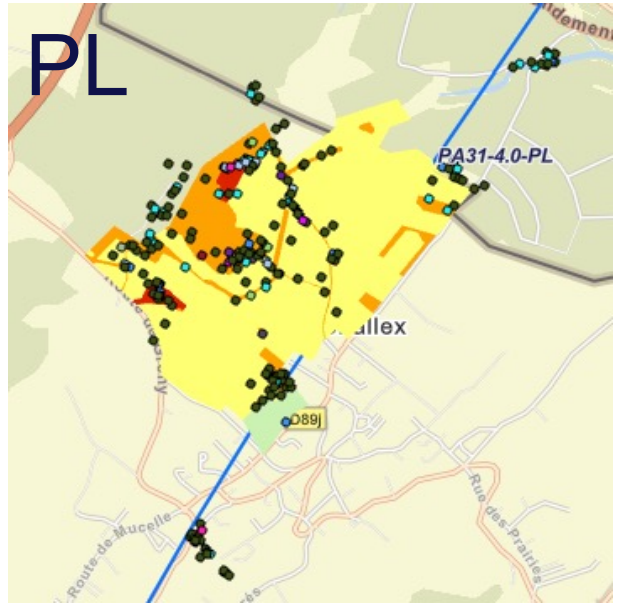


Total area investigated in 2023/24: **585 ha over 4 seasons**









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 fare 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.

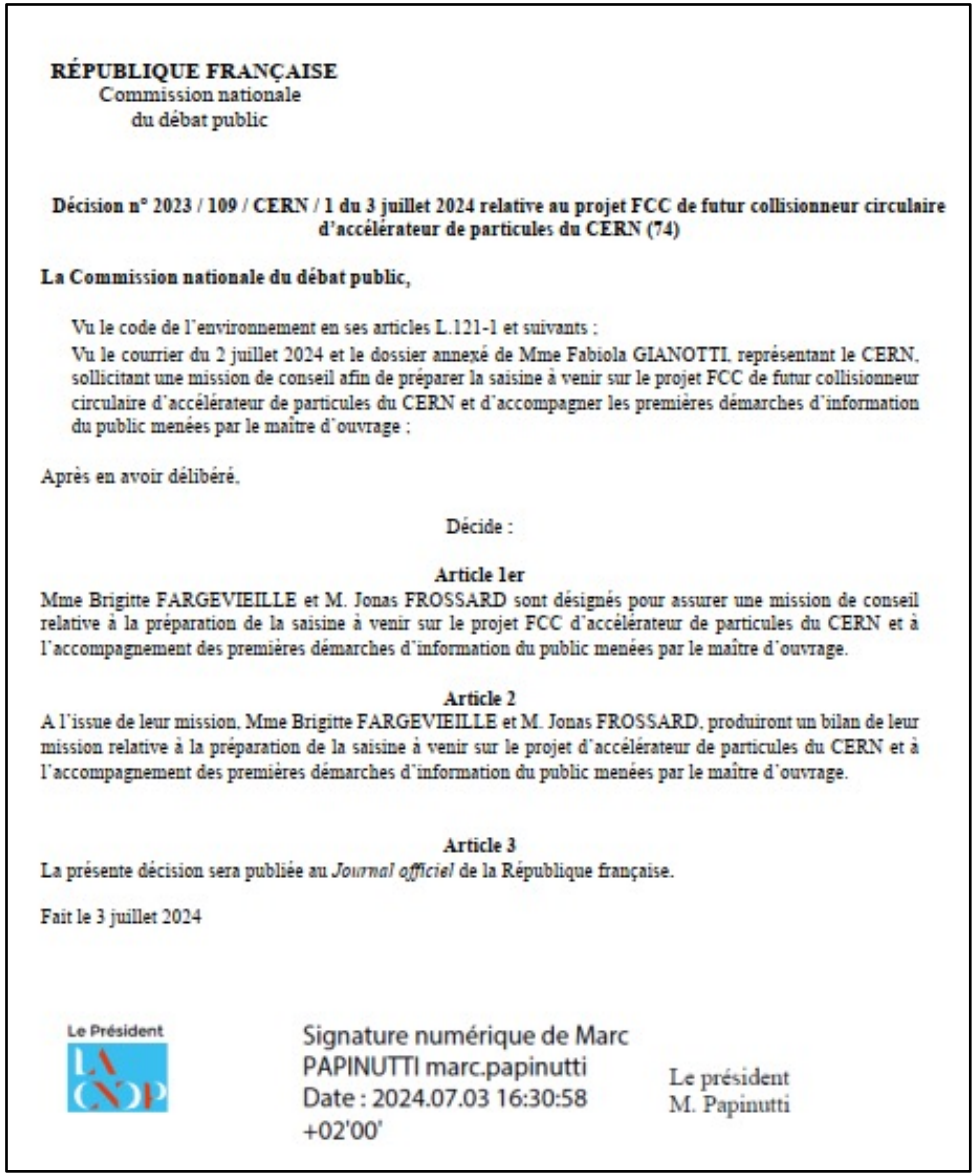
The event featured a comprehensive look at **CERN's illustrious history**, **groundbreaking achievements, and future ambitions**, including the prominently featured Future Circular Collider (FCC) project with **study experts interacting with the audience.**

Commission Nationale de Debat Public (CNDP) mission and public information meetings

The CNDP, created in 1995, is an **independent French authority that ensures public participation in the definition and decision process of major projects in France,** impacting the environment by providing a neutral and transparent framework for discussions between decision-makers and citizens.

On July 2, 2024, the **CERN DG requested the CNDP to undertake an advisory mission** on public participation for the FCC. On July 3, the president of the CNDP appointed two guarantors to:

- **Assist CERN in preparing the first information meetings** on the ongoing studies in the region.
- **Provide non-binding advice to CERN** on the next steps for **public participation regarding the FCC**.



RÉPUBLIQUE FRANÇAISE
Commission nationale
du débat public

Décision n° 2023 / 109 / CERN / 1 du 3 juillet 2024 relative au projet FCC de futur collisionneur circulaire d'accélérateur de particules du CERN (74)

La Commission nationale du débat public,

Vu le code de l'environnement en ses articles L.121-1 et suivants ;
Vu le courrier du 2 juillet 2024 et le dossier annexé de Mme Fabiola GIANOTTI, représentant le CERN, sollicitant une mission de conseil afin de préparer la saisine à venir sur le projet FCC de futur collisionneur circulaire d'accélérateur de particules du CERN et d'accompagner les premières démarches d'information du public menées par le maître d'ouvrage ;

Après en avoir délibéré,

Décide :

Article 1er
Mme Brigitte FARGEVIEILLE et M. Jonas FROSSARD sont désignés pour assurer une mission de conseil relative à la préparation de la saisine à venir sur le projet FCC d'accélérateur de particules du CERN et à l'accompagnement des premières démarches d'information du public menées par le maître d'ouvrage.

Article 2
A l'issue de leur mission, Mme Brigitte FARGEVIEILLE et M. Jonas FROSSARD, produiront un bilan de leur mission relative à la préparation de la saisine à venir sur le projet d'accélérateur de particules du CERN et à l'accompagnement des premières démarches d'information du public menées par le maître d'ouvrage.

Article 3
La présente décision sera publiée au *Journal officiel* de la République française.

Fait le 3 juillet 2024

Le Président

Signature numérique de Marc PAPINUTTI marc.papinutti
Date : 2024.07.03 16:30:58 +02'00'

Le président
M. Papinutti

CNDP decision for the Advisory Mission

FCC-ee basic design choices

Double ring e+ e- collider

Common footprint with FCC-hh,

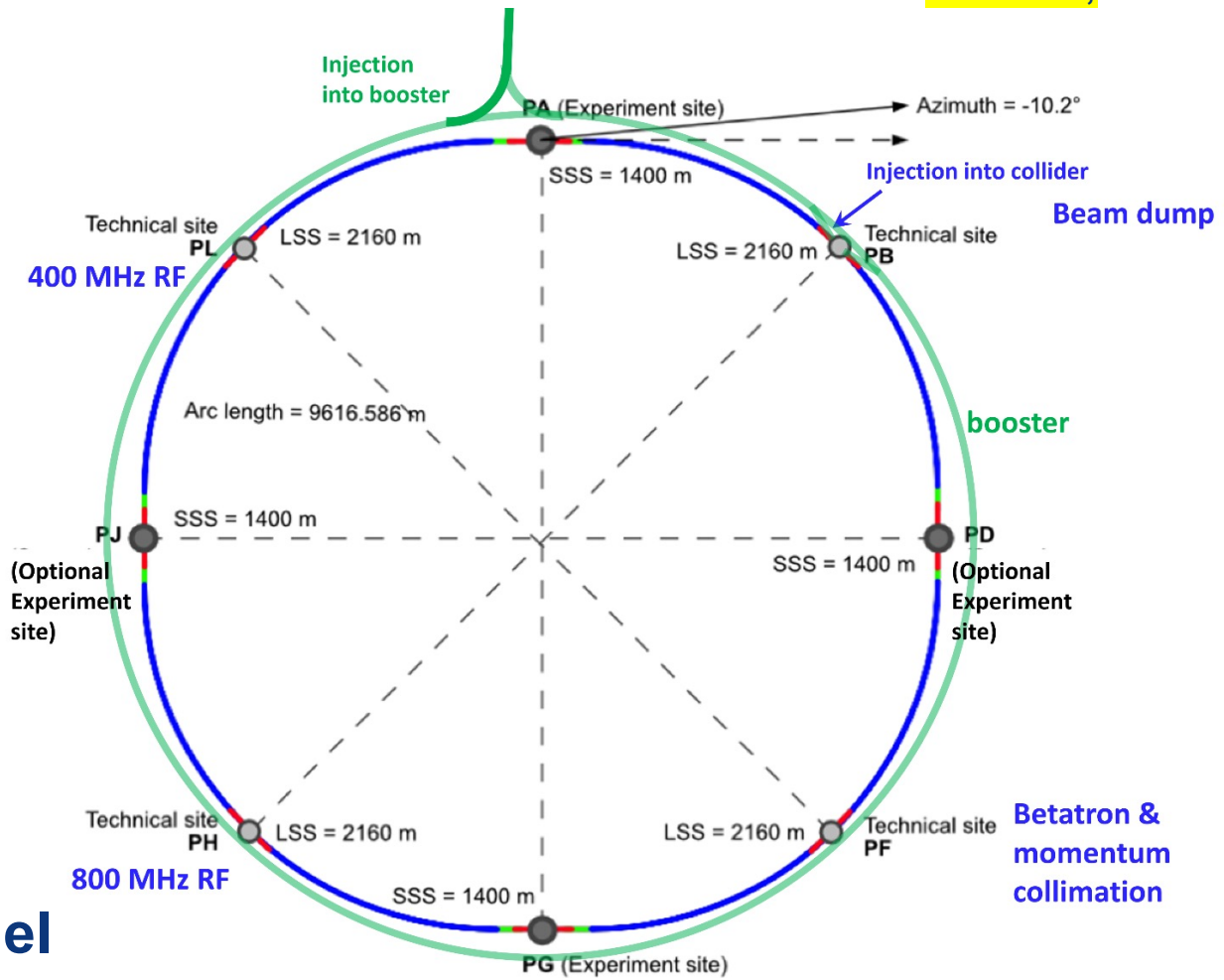
Asymmetric IR layout and optics to limit synchrotron radiation towards the detector

Perfect 4-fold superperiodicity allowing 2 or 4 IPs; large horizontal crossing angle 30 mrad, crab-waist collision optics

Synchrotron radiation power 50 MW/beam at all beam energies.

Top-up injection scheme for high luminosity
Requires **booster synchrotron in collider tunnel**

K. Oide,



FUTURE CIRCULAR COLLIDER

FCC-ee main machine parameters

Parameter	Z	WW	H (ZH)	ttbar
beam energy [GeV]	45.6	80	120	182.5
beam current [mA]	1283	135	26.8	5.0
number bunches/beam	11200	1852	300	64
bunch intensity [10^{11}]	2.16	1.38	1.69	1.48
SR energy loss / turn [GeV]	0.0390	0.369	1.86	9.94
total RF voltage 400/800 MHz [GV]	0.079/0	1.0/0	2.09/0	2.1/9.2
long. damping time [turns]	1171	218	65.4	19.4
horizontal beta* [m]	0.11	0.22	0.24	0.9
vertical beta* [mm]	0.7	1.0	1.0	1.4
horizontal geometric emittance [nm]	0.7	2.16	0.66	1.51
vertical geom. emittance [pm]	1.9	2.0	1.0	1.36
vertical rms IP spot size [nm]	36	47	40	51
beam-beam parameter ξ_x / ξ_y	0.0022/0.0977	0.013/0.129	0.0108/0.130	0.065/0.136
rms bunch length with SR / BS [mm]	5.57 / 15.6	3.46 / 5.28	3.26 / 5.59	1.91 / 2.32
luminosity per IP [10^{34} $cm^{-2}s^{-1}$]	143	20	7.5	1.38
total integrated luminosity / IP / year [ab^{-1}/yr]	17	2.4	0.9	0.17
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 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 100 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 ~ 100 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

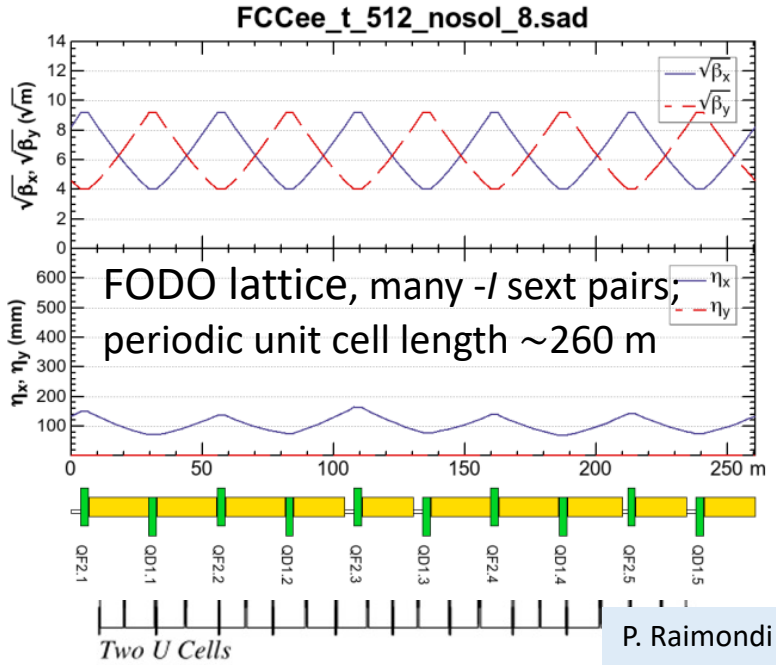
F. Gianotti

FCC-ee optics baseline & further evolution(s)

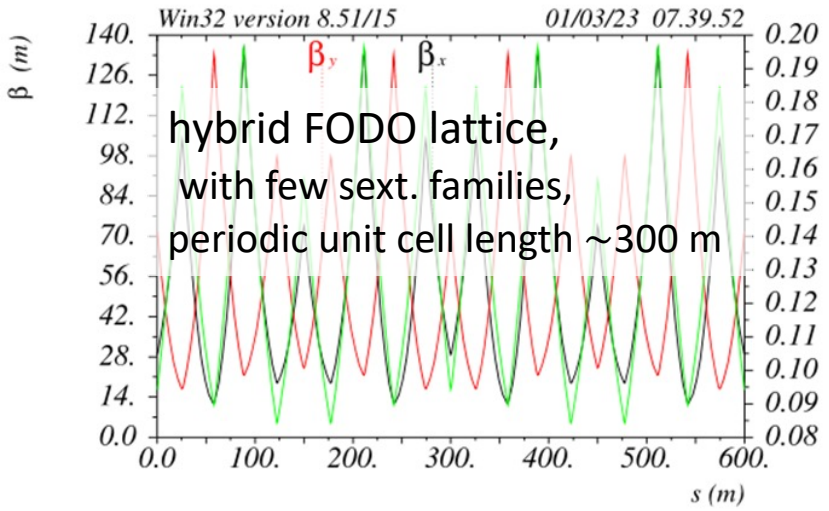
Short 90/90: $t\bar{t}$, Zh

regular arc

K. Oide

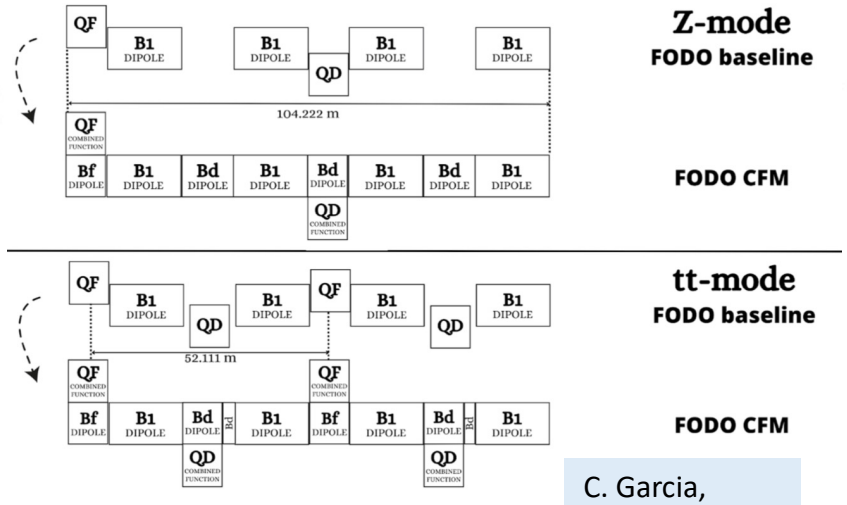


P. Raimondi



optimisation goals:

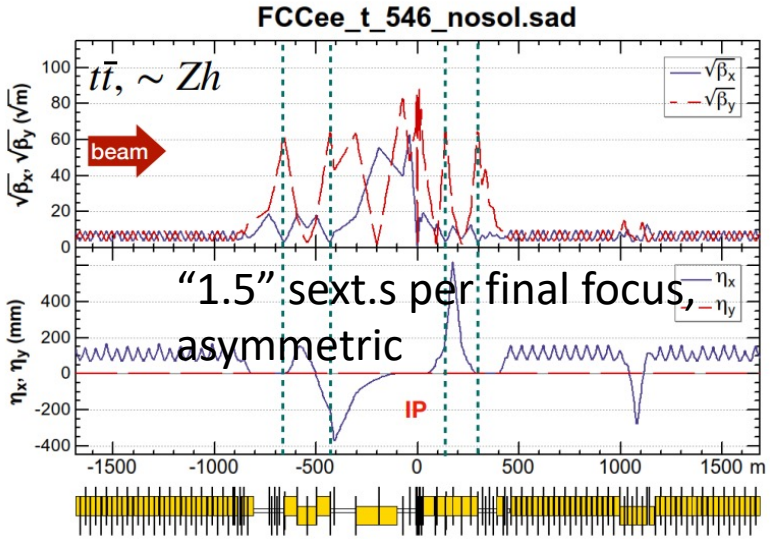
- reduced power consumption
- lower SR energy loss
- increased momentum acceptance
- relaxed tolerances
- larger dynamic aperture
- simplified powering schemes



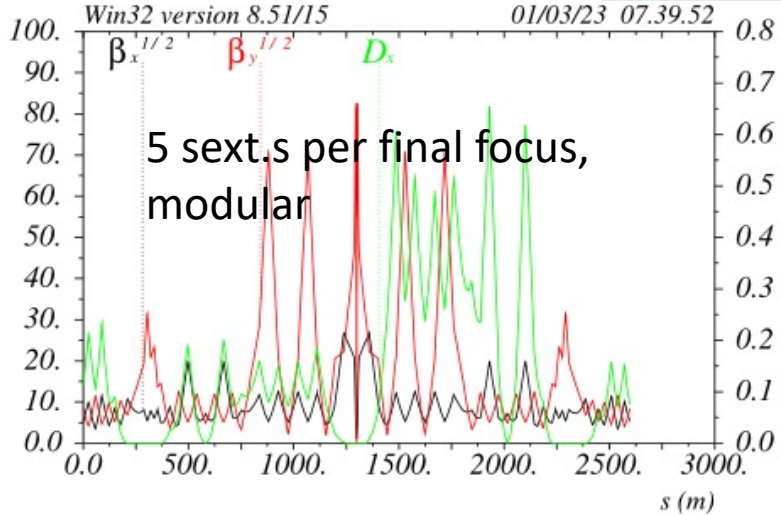
C. Garcia,
R. Tomas, et al.

interaction region

K. Oide



P. Raimondi



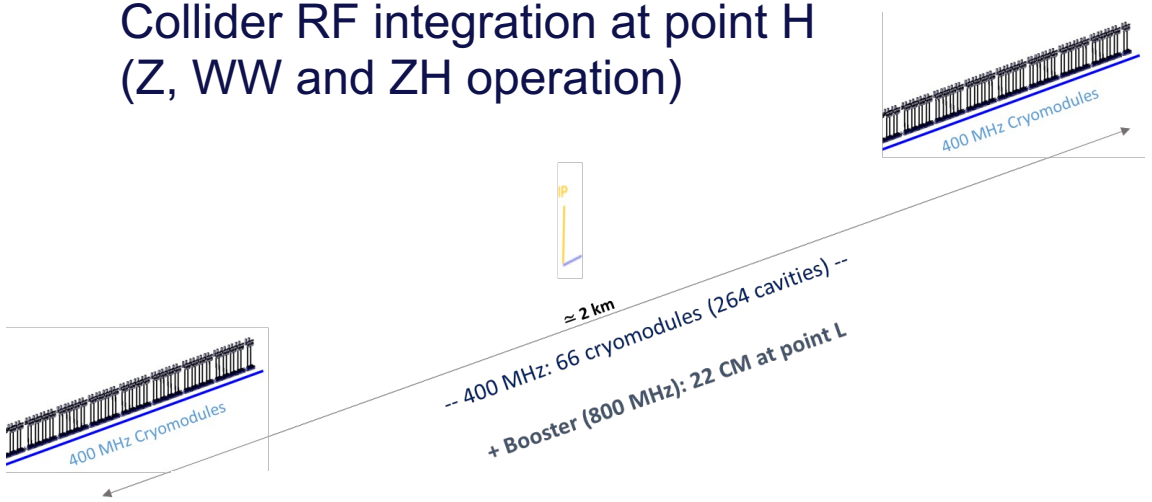
Optimisation for operation: 400 MHz SRF and beam switchyard

Beam switching between (Z, W) and ZH operation

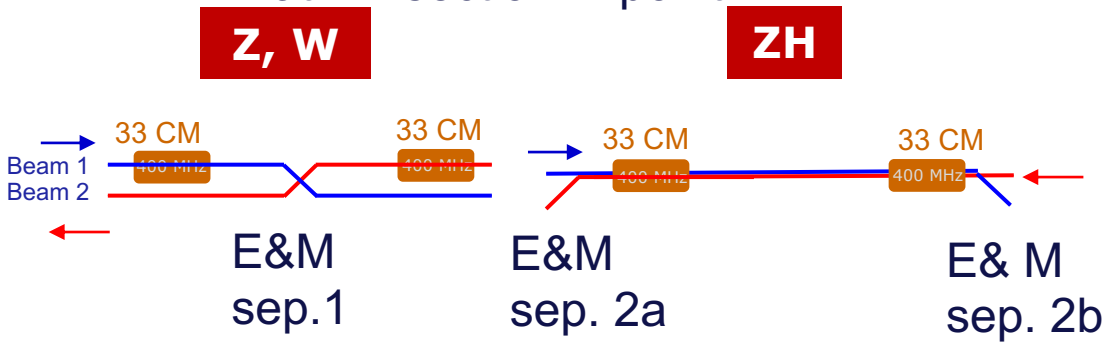
- 2-cell 400 MHz cavities for all three working points, identical configuration
- ES separators + magnetic field for switching beams
- Allows quasi “instantaneous” switching between Z, W, ZH

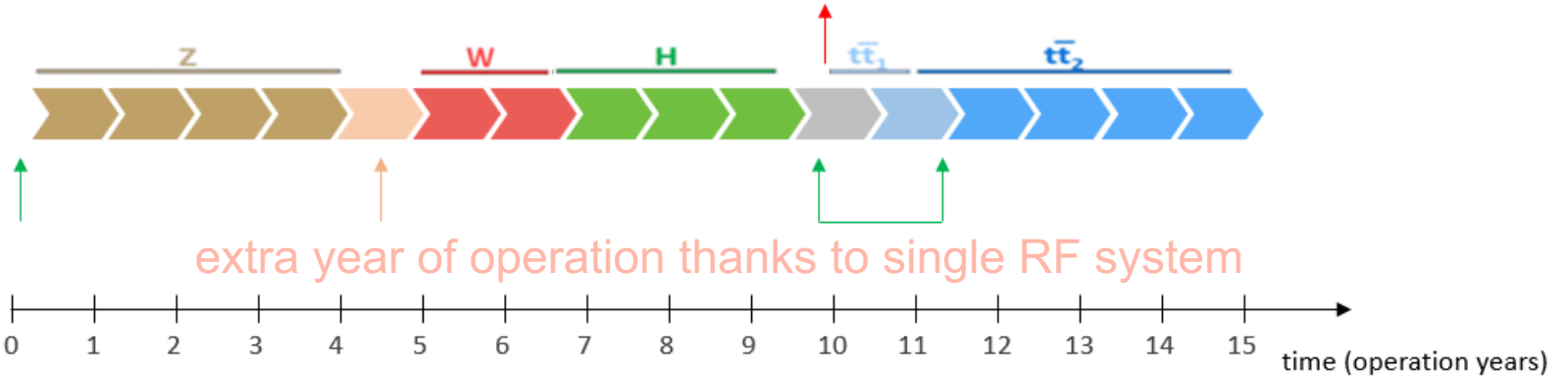
	Energy (GeV)	Current (mA)	RF voltage (GV)
Z	45.6	1280	0.08
W	80	135	1
H	120	26.7	2.08
ttb	182.5	5	11.67

Collider RF integration at point H
(Z, WW and ZH operation)



Beam crossing and combination
at RF section in point H



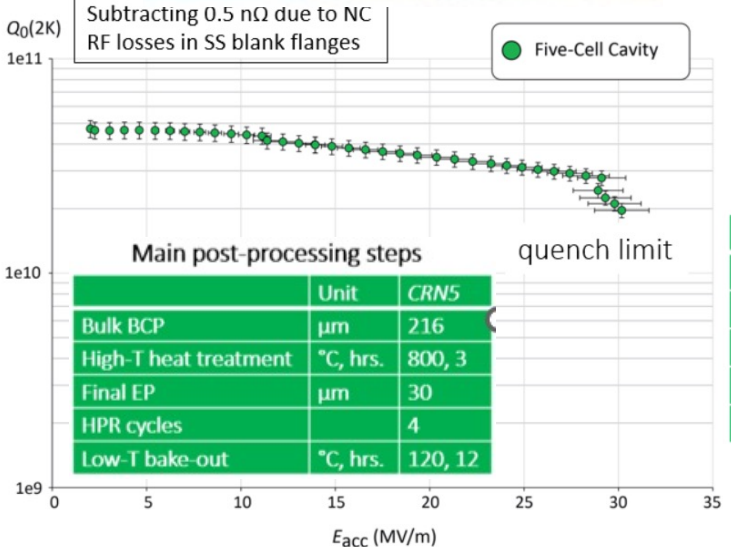


RF R&D activities

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

- Nb on Cu 400 MHz cavities (KEK as R&D partner), seamless cavity production, coating techniques
- Bulk Nb 800 MHz cavities and cryomodule, surface treatment techniques (JLAB, FNAL as R&D partners)
- RF power source R&D in synergy with HL-LHC.

5-cell 800 MHz cavity development collaboration with JLAB

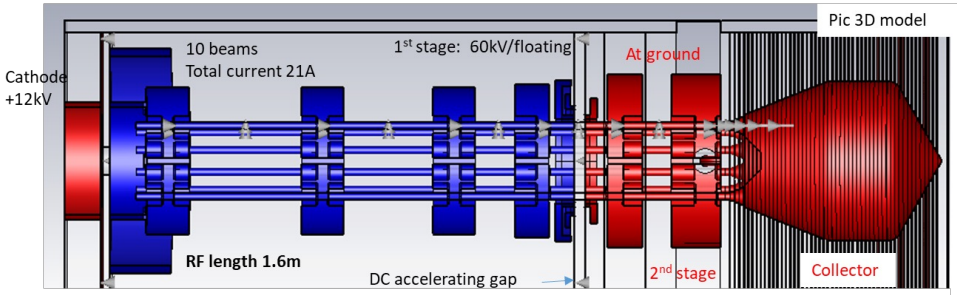


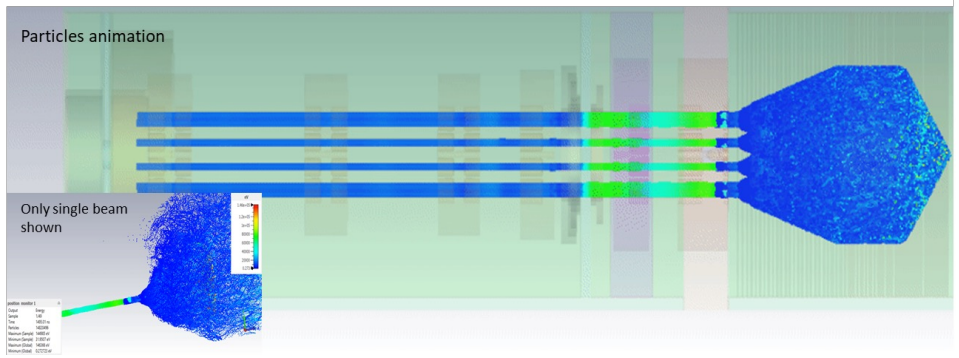
Main post-processing steps

	Unit	CRN5
Bulk BCP	µm	216
High-T heat treatment	°C, hrs.	800, 3
Final EP	µm	30
HPR cycles		4
Low-T bake-out	°C, hrs.	120, 12

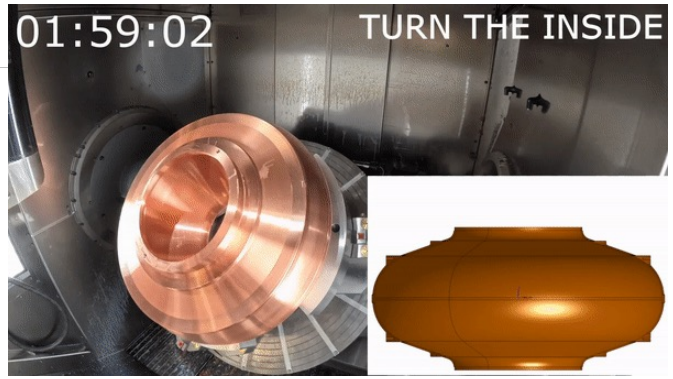
high-efficiency klystron R&D

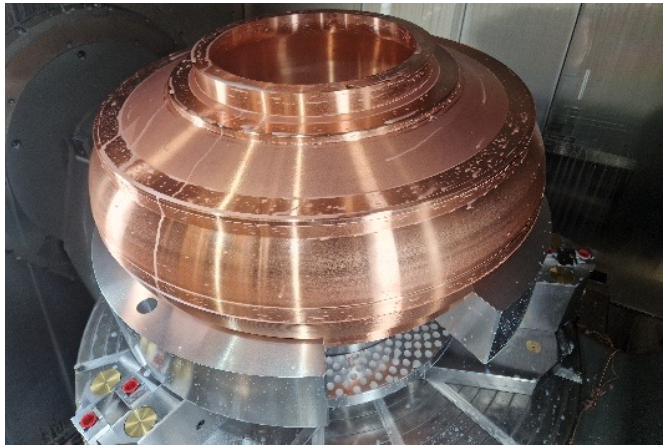
Novel two-stage MBK klystron: CW, 400MHz, 1.28MW.





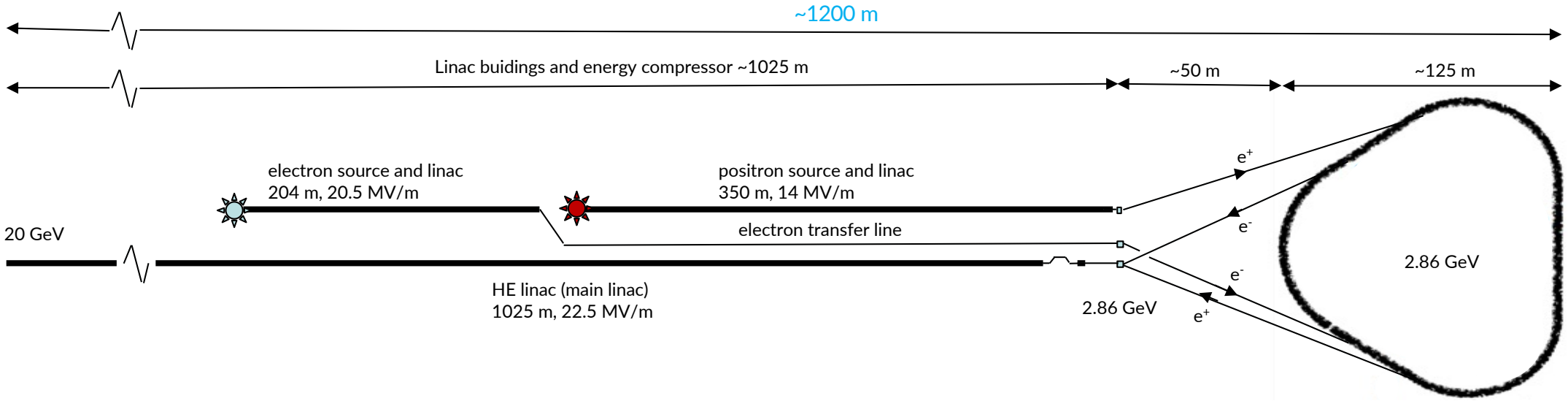
400 MHz monoblock prototype





Optimized injector concept and parameters

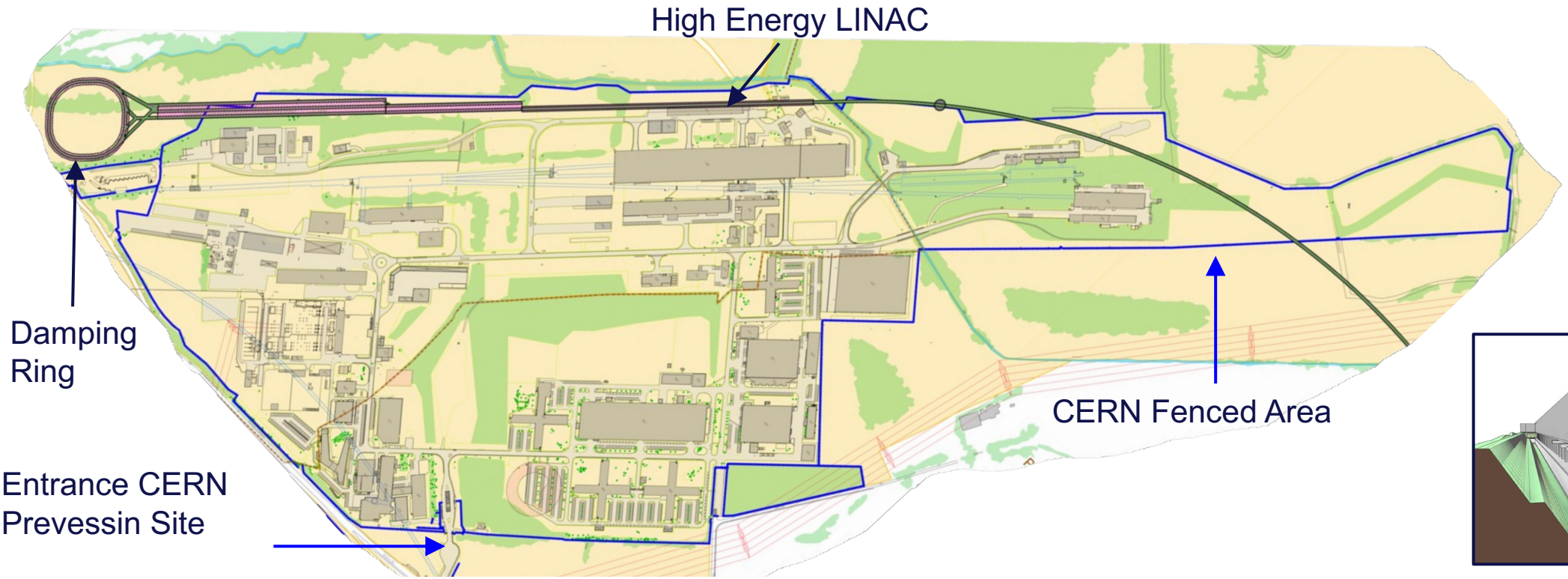
- **Mid-term review recommendations to reduce gradients and repetition rate → new linac optimization in terms of cost and power density**

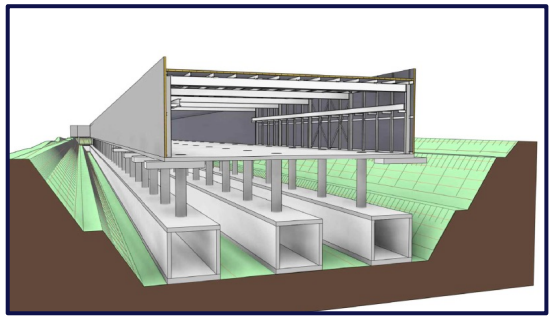


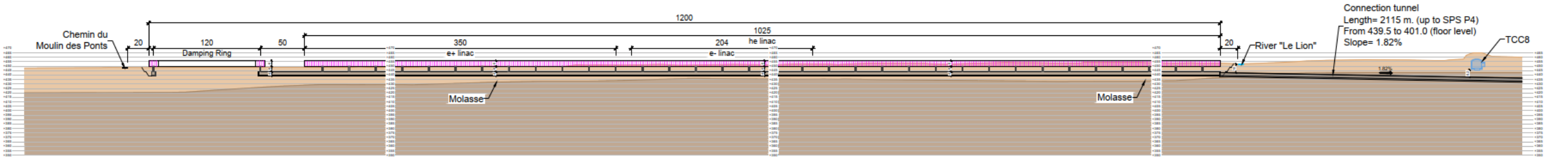
- Overall power consumption (for linacs) is reduced by **more than a factor 3** by means of:
  - new accelerating structures with higher shunt impedance;
  - lower gradient (29.5 MV/m → 22.5/20.5 MV/m);
  - lower repetition rate (200/400 Hz → 100 Hz).
- Repetition rate of **100 Hz with 4 bunches** per rf pulse
- New layout: **Damping Ring at higher energy 2.86 GeV**, no common linac with 2x repetition rate.

Optimised injector implementation at Prevessin site

- Good integration with existing CERN Prevessin Site and strongly reduced visibility from outside.
- Ideal connection to existing experimental halls.
- Good conditions for construction.







LONGITUDINAL PROFILE

FUTURE CIRCULAR COLLIDER

FCC-hh main machine 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: 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, …

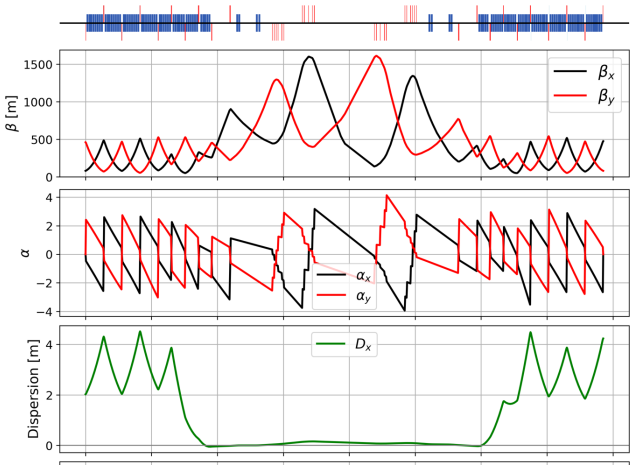
Formidable physics reach, including:

- ❑ 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 ($\gamma\gamma$, $Z\gamma$, $\mu\mu$)
- ❑ Final word about WIMP dark matter

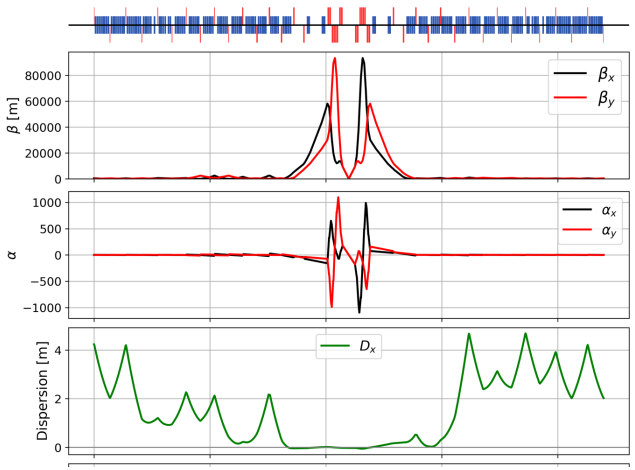
Key activities on FCC-hh: cryo magnet system, optics design

Optics design activities:

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

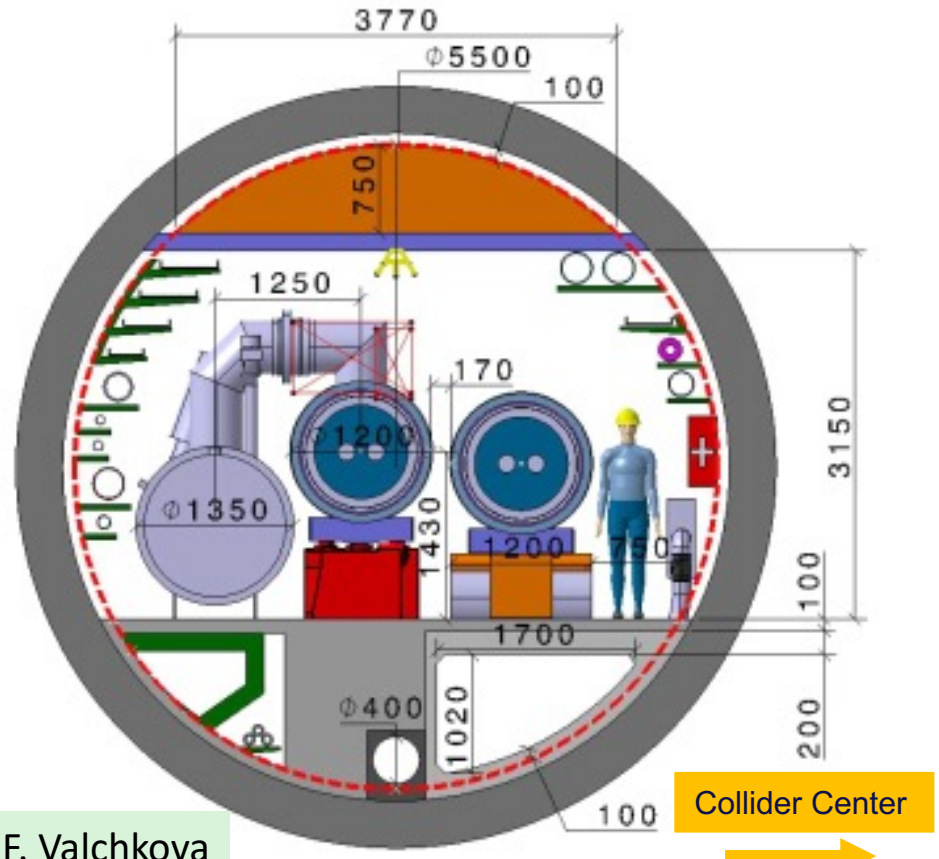


betatron collimation straight



experimental straight

M. Giovannozzi. G. Perez, T. Risselada



F. Valchkova

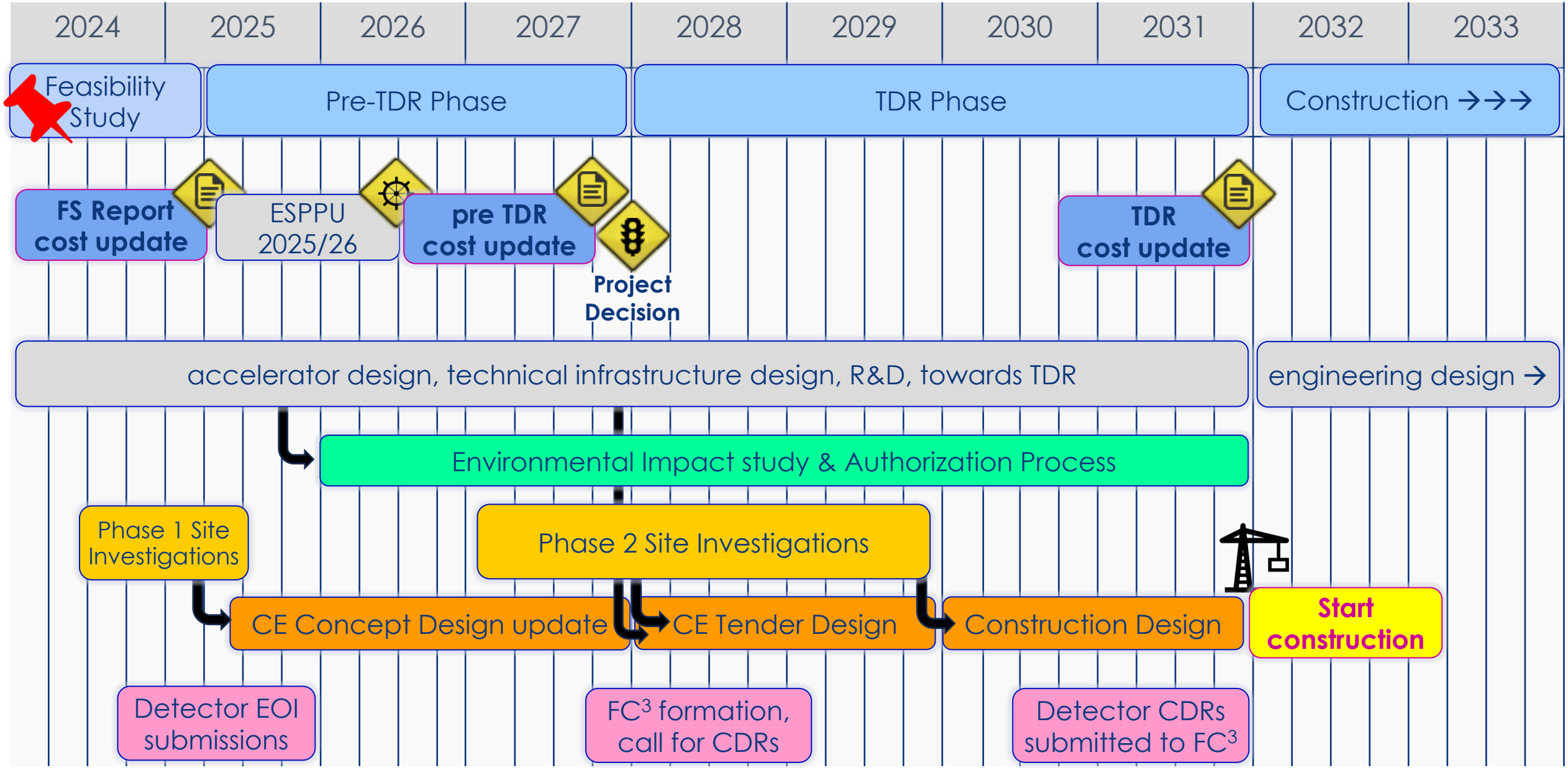
High-field cryo-magnet system design

- 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.

FUTURE CIRCULAR COLLIDER

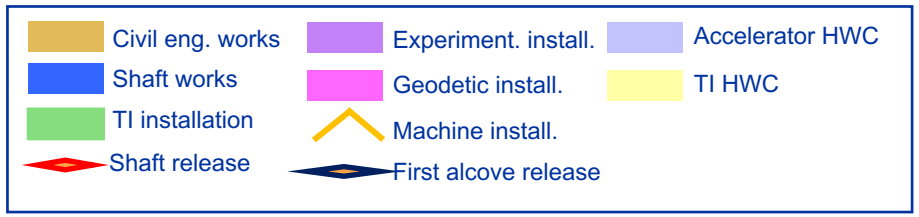
Possible time line till start of construction

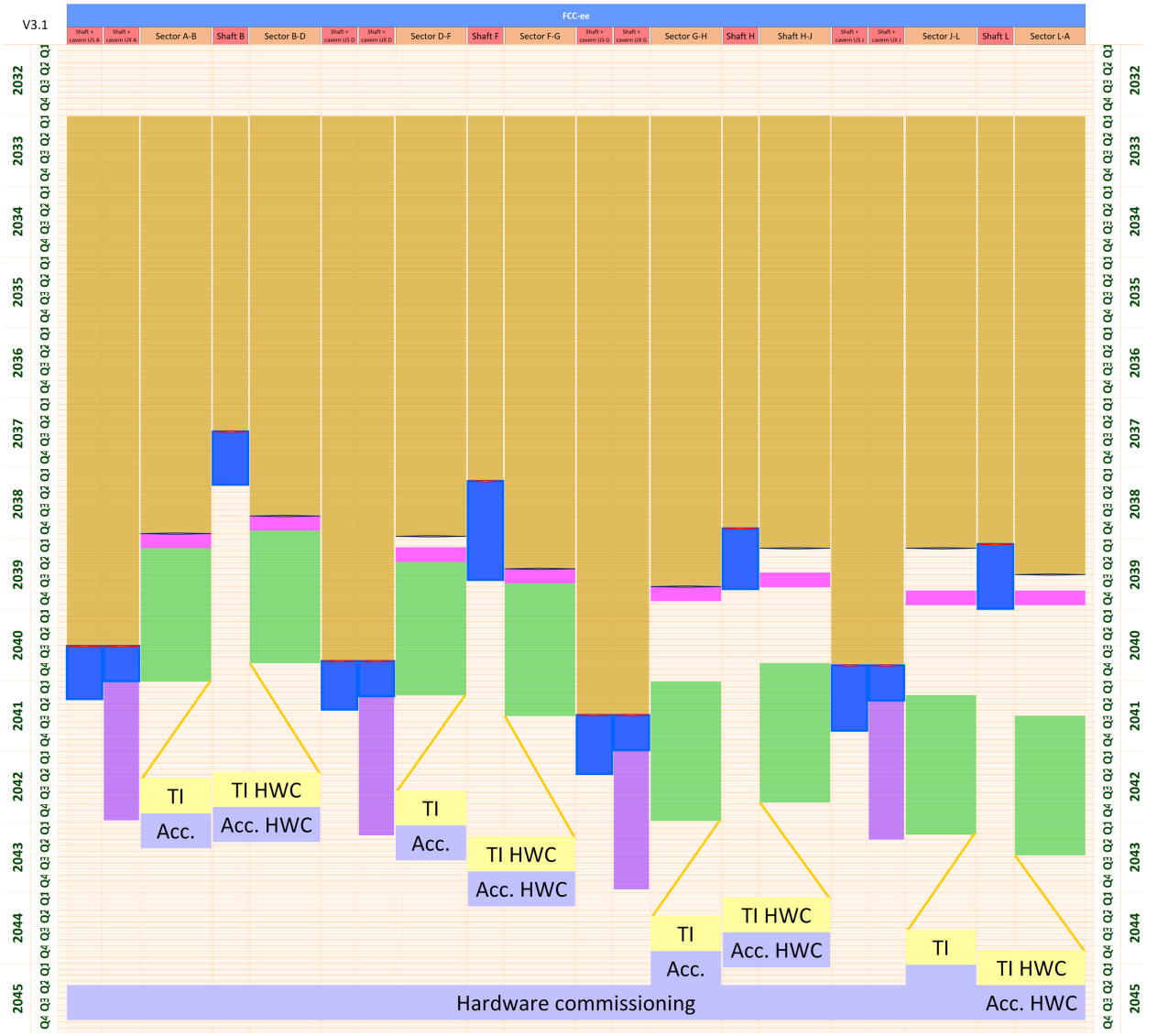


Construction and installation planning stage 1

Baseline stage 1 FCC-ee schedule

- Q1 2033, Start of CE construction work
- Q2 2041, Completion of last lot of CE construction
- Q2 2043, Overall completion of TI installation
- Q4 2044, Accelerator installation completed
- Q4 2045, HW commissioning completed
- Q1 2046, First beams
- Q1 2048, Start of nominal operation
- Q3 2041 – Q3 2044, Experiment installation
- Q1 2046, Start beam commissioning





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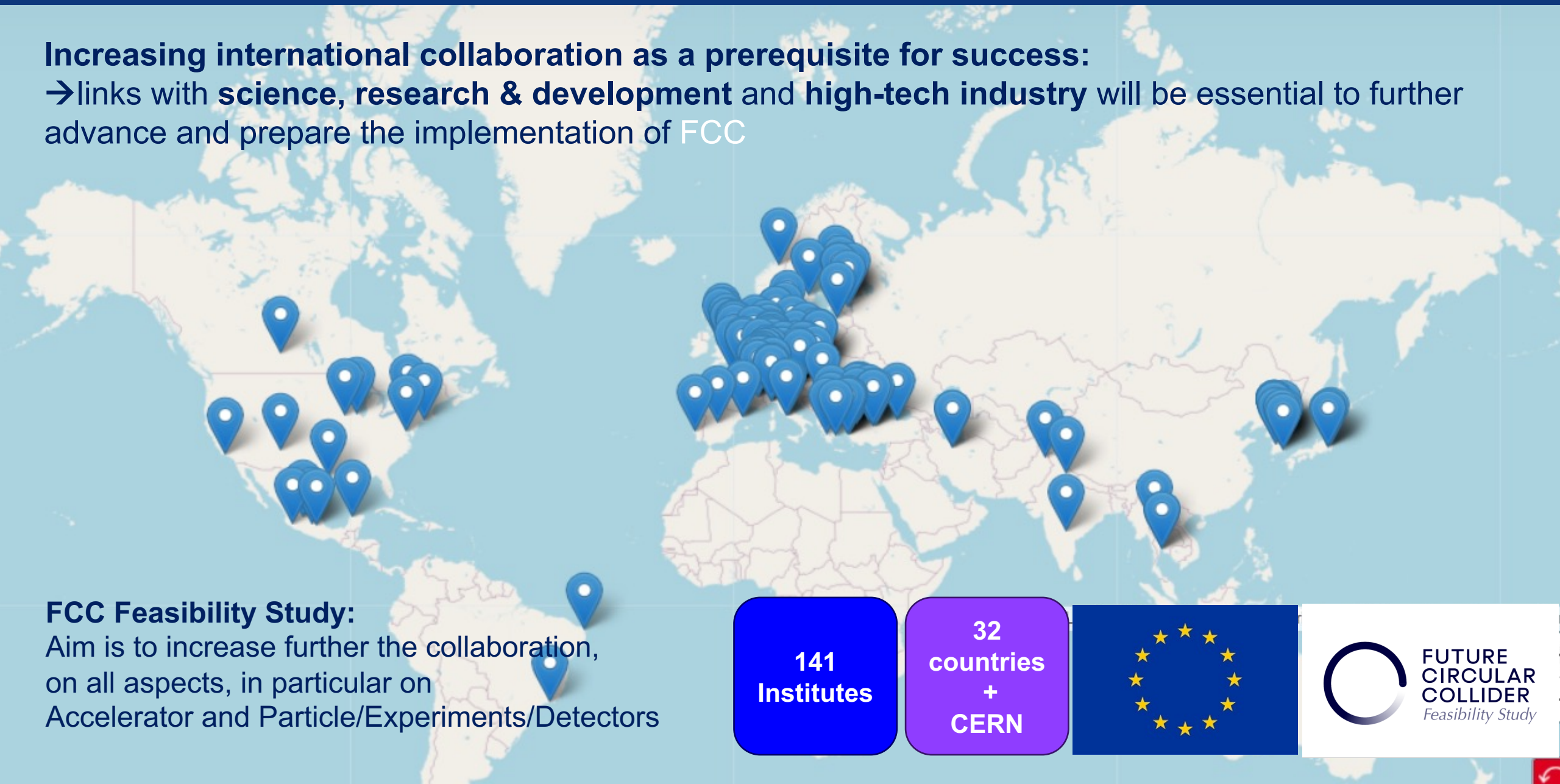
Status of FCC global collaboration

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

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Feasibility Study

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FCC Week 2024 - San Francisco – 10 to 14 June

449 participants, 50 public sessions, 216 oral presentations, 32 posters

US efforts getting organized, towards completing the FS by March 2025

Progress on international collaboration

★ ★ ★

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.

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EU Competitiveness Report

edited by Mario Draghi, and officially handed over to Ursula von der Leyen in September 2024

https://commission.europa.eu/topics/strengthening-european-competitiveness/eu-competitiveness-looking-ahead_en

"One of CERN's most promising current projects, with significant scientific potential, is the construction of the Future Circular Collider (FCC): a 90-km ring designed initially for an electron collider and later for a hadron collider..

Refinancing CERN and ensuring its continued global leadership in frontier research should be regarded as a top EU priority*, given the objective of maintaining European prominence in this critical area of fundamental research, which is expected to generate significant business spillovers in the coming years."*

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Supporting statements at CERN's 70 anniversary

"….No European country alone could have built the world's largest particle collider. CERN has become a global hub because it rallied Europe and this is even more crucial today.

I am proud that we have financed the feasibility study for CERN's Future Circular Collider (FCC). This could preserve Europe's scientific edge and could push the boundaries of human knowledge even further. *And as the global science race is on, I want Europe to switch gears. To do so, European unity is our greatest asset. …."*

Ursula von der Leyen, President of the European Commis*sion*

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Summary from Feasibility Study

- **CERN Council launched in 2021 the feasibility study for FCC FS to provide input by 2025, required for further discussion, and in view of a potential project decision by end 2027/begin 2028.**
- **Focus on implementation scenario developed with host state authorities**
  - Surface site areas identified and individual landplots reserved
  - Electrical supply concept developed with FR and CH grid operators
  - Road and highway connections identified and designs established
  - Environmental initial state analysis for all surface sites completed
- **Colliders and technical infrastructures**
  - Two collider lattice variants established, optimization ongoing
  - R&D activites started on main technologies (RF for FCC-ee, HFM for FCC-hh)
  - Injector design optimized and implementation at CERN Prevessin site developed
  - Technical infrastructures (EL, CV) system layouts developed
- **Cost estimate (by FCC FS) and funding model (CERN Council and Directorate)**

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FCC Main Goals for Coming Years

- **Upcoming milestone for FCC is the completion of the Feasibility Study by March 2025 as input for the Update of the ESPP.**
- **The following pre-TDR phase should prepare for a possible project approval by 2027-2028 and enable the subsequent start of CE design contract:**
  - Updated cost and schedule studies
  - specifications to enable CE tender design by mid 2027
  - 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
- **Possible start of CE construction would then be 2032-33:**
  - CE groundbreaking
  - TDR to enable prototyping, industrialization towards component production
- **Strong international collaboration is essential for success!**

FCC Week 2025 - Vienna

- **Venue**: **Hofburg Palace**, a historical and cultural landmark in **Vienna, Austria**.
- **Dates**: **Monday 19 to Friday 23 May 2025**
- **Presentation of the Feasibility Study Report and review of its findings and opportunities for future R&D projects**
- **Please save the date and join us in Vienna**