Status of the FCC

IAS Programme on HEP 2024
HKUST, Jan 8-26 2024

Michelangelo Mangano, CERN TH
on behalf of FCC collaboration & FCCIS DS team

Special thanks to Michael Benedikt and Frank Zimmermann, whose slides from earlier talks I fully relied upon. Any mistake/misunderstanding is entirely my fault

FUTURE CIRCULAR COLLIDER Innovation Study

Swiss Accelerator Research and Technology

http://cern.ch/fcc

*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

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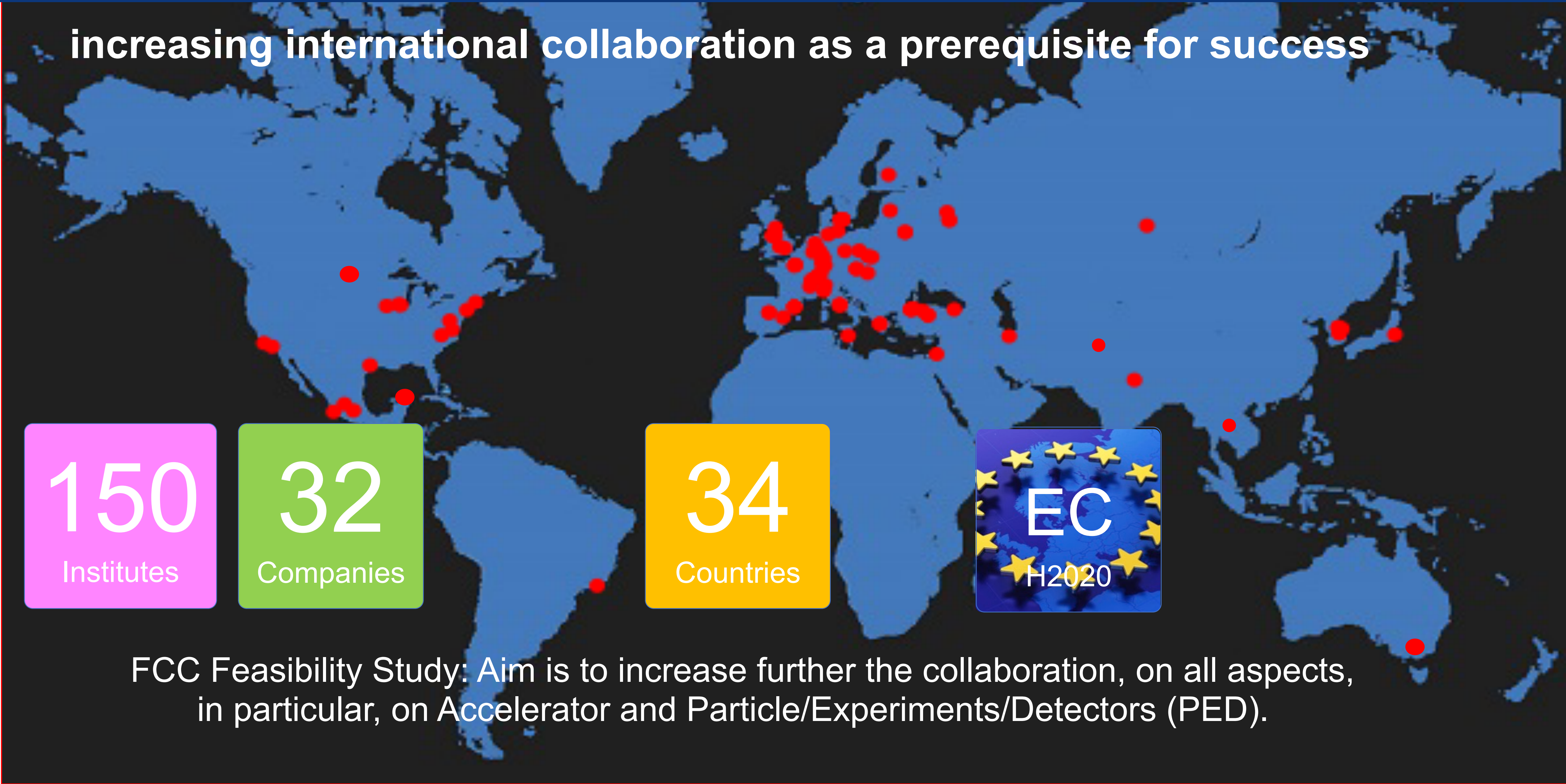
Status of FCC global collaboration

increasing international collaboration as a prerequisite for success



150 Institutes

32 Companies

34 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).

FUTURE CIRCULAR COLLIDER

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

- demonstration of the geological, technical, environmental and administrative feasibility of the tunnel and surface areas and optimisation of placement and layout of the ring and related infrastructure;
- pursuit, together with the Host States, of the preparatory administrative processes required for a potential project approval to identify and remove any showstopper;
- optimisation of the design of the colliders and their injector chains, supported by R&D to develop the needed key technologies;
- elaboration of a sustainable operational model for the colliders and experiments in terms of human and financial resource needs, as well as environmental aspects and energy efficiency;
- development of a consolidated cost estimate, as well as the funding and organisational models needed to enable the project's technical design completion, implementation and operation;
- identification of substantial resources from outside CERN's budget for the implementation of the first stage of a possible future project (tunnel and FCC-ee);
- consolidation of the physics case and detector concepts for both colliders.

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

F. Gianotti

FUTURE CIRCULAR COLLIDER

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

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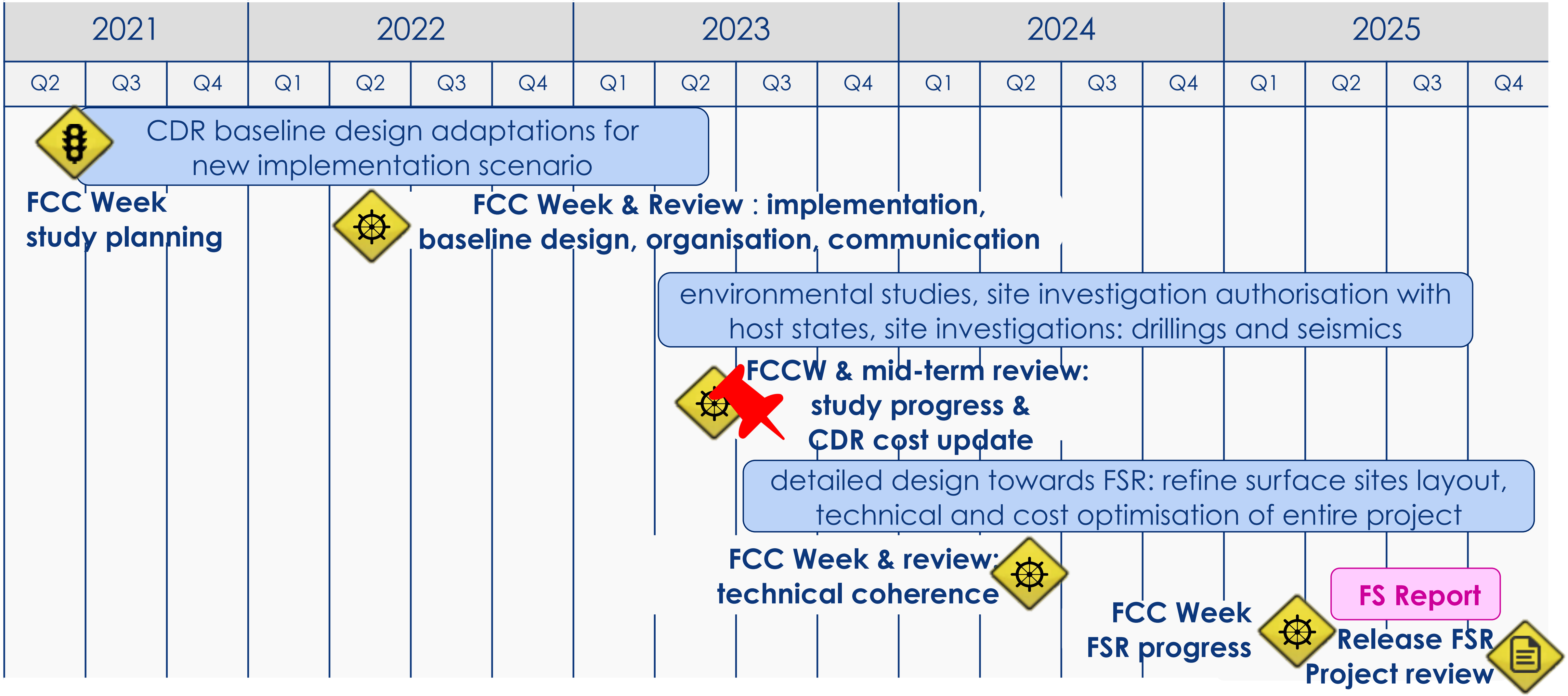
FUTURE CIRCULAR COLLIDER FEASIBILITY STUDY:

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.

Feasibility Study timeline and main activities/milestones

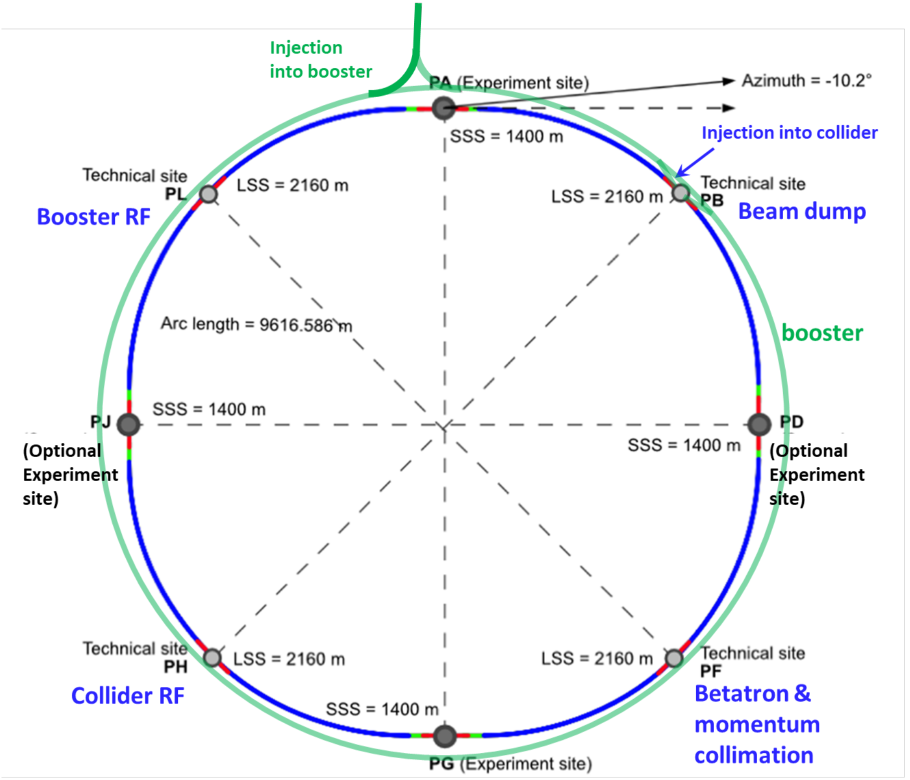


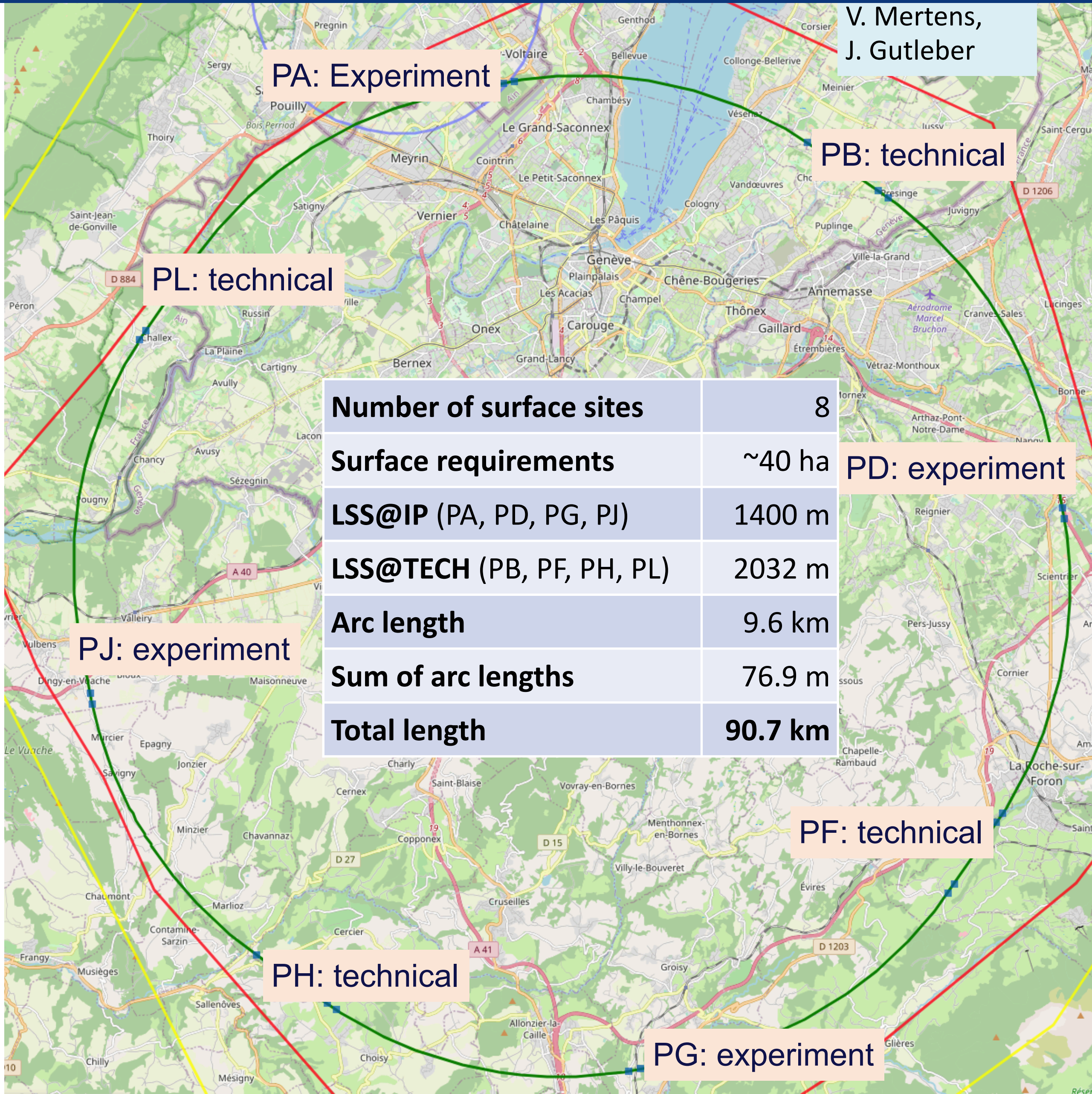
Optimized placement and layout for feasibility study

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

“Avoid-reduce -compensate” principle of EU and French regulations

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





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

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progress with implementation baseline PA31 90.7 km

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

PA – Ferney Voltaire (FR) – site experimental

PB – Présinge/Choulex (CH) – site technique

PD – Nangy (FR) – site experimental

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

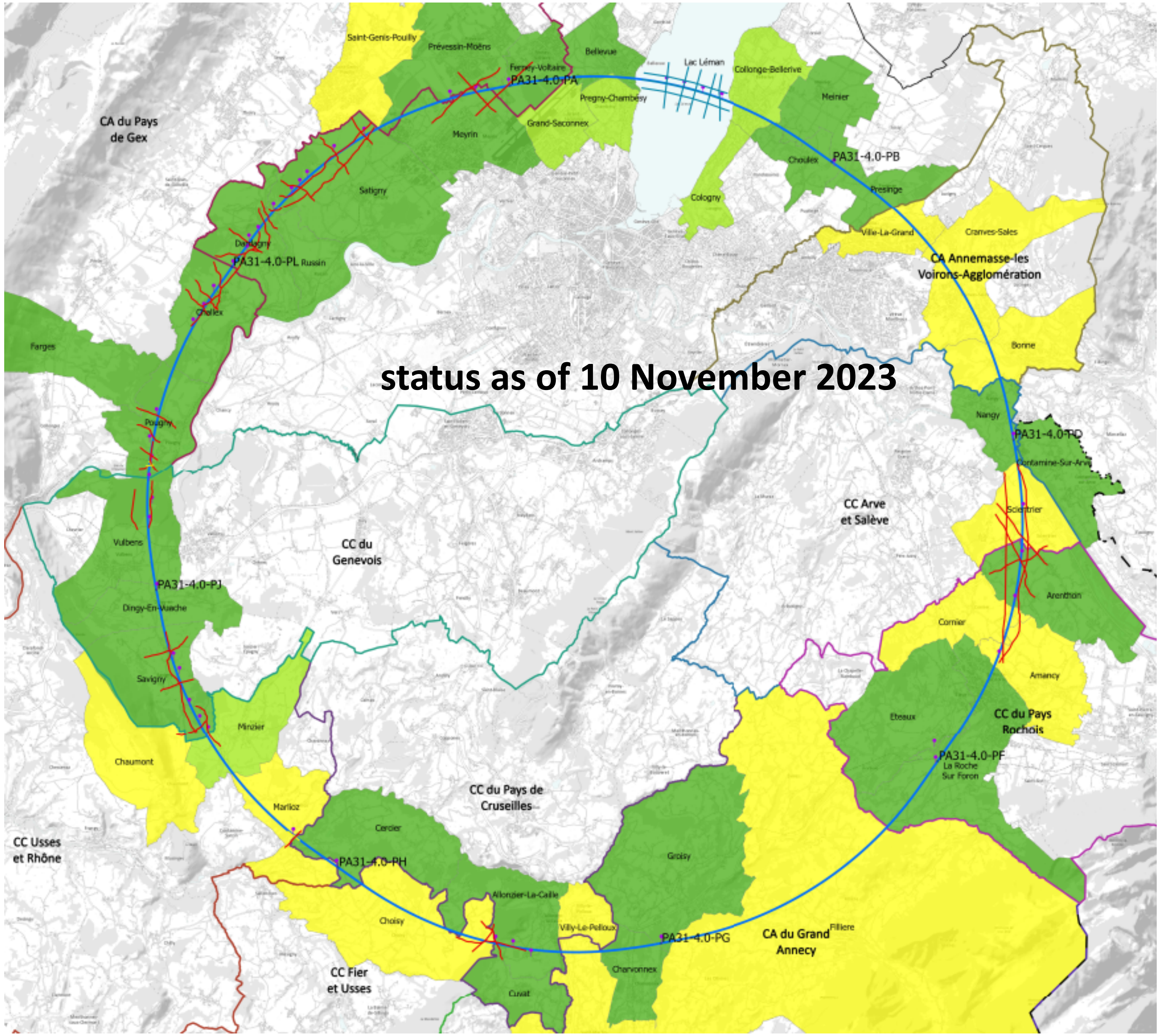
PG – Charvonnex/Groisy (FR) – site experimental

PH – Cercier (FR) – site technique

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

PL – Challex (FR) – site technique

- Individual meeting
- Individual meeting planned
- Collective meeting



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

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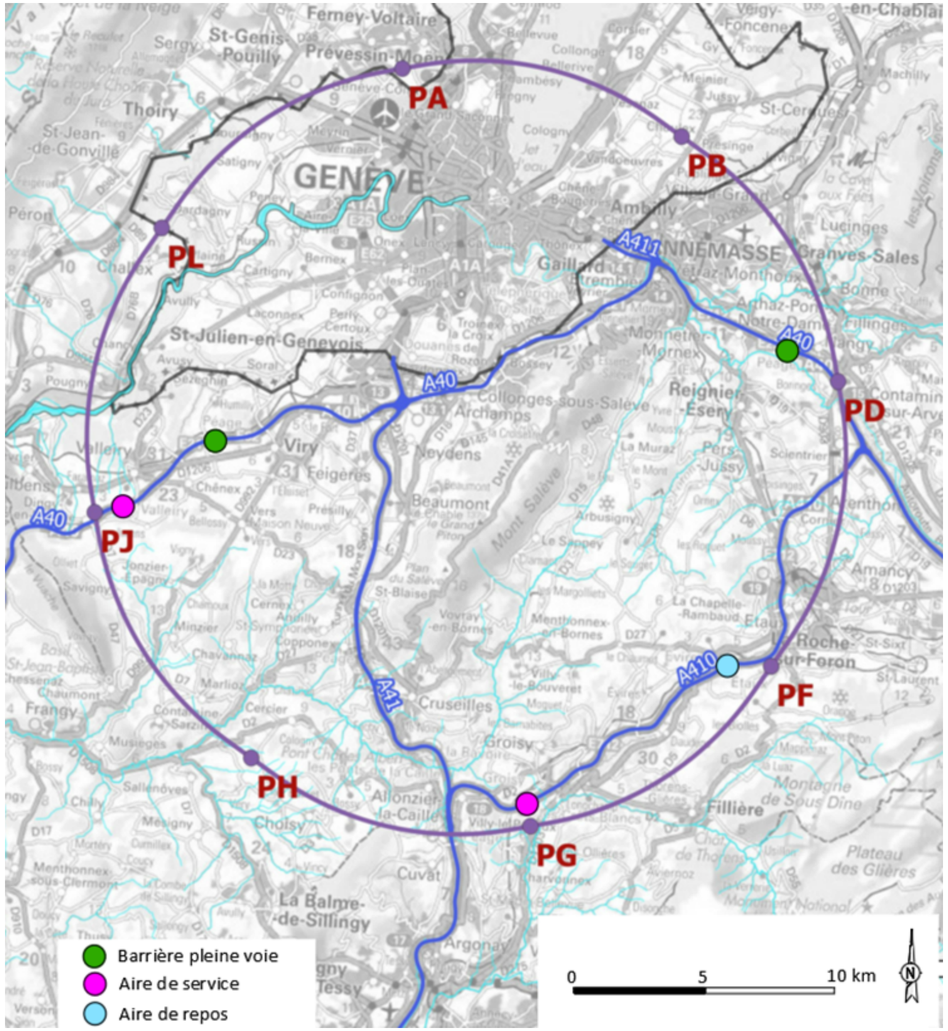
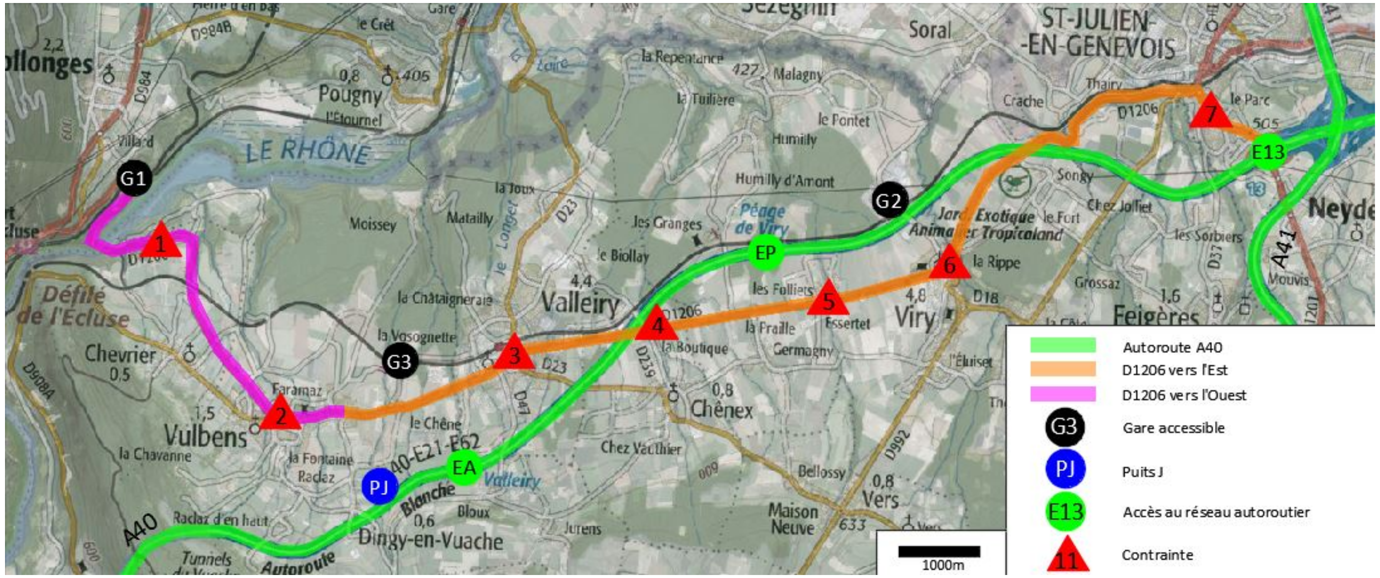
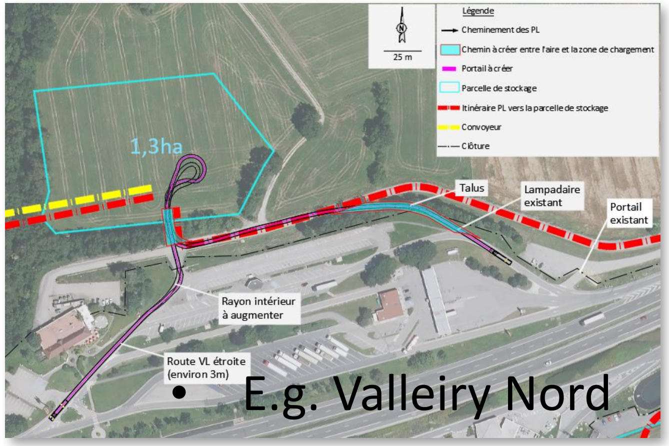
Connections to transport infrastructure

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



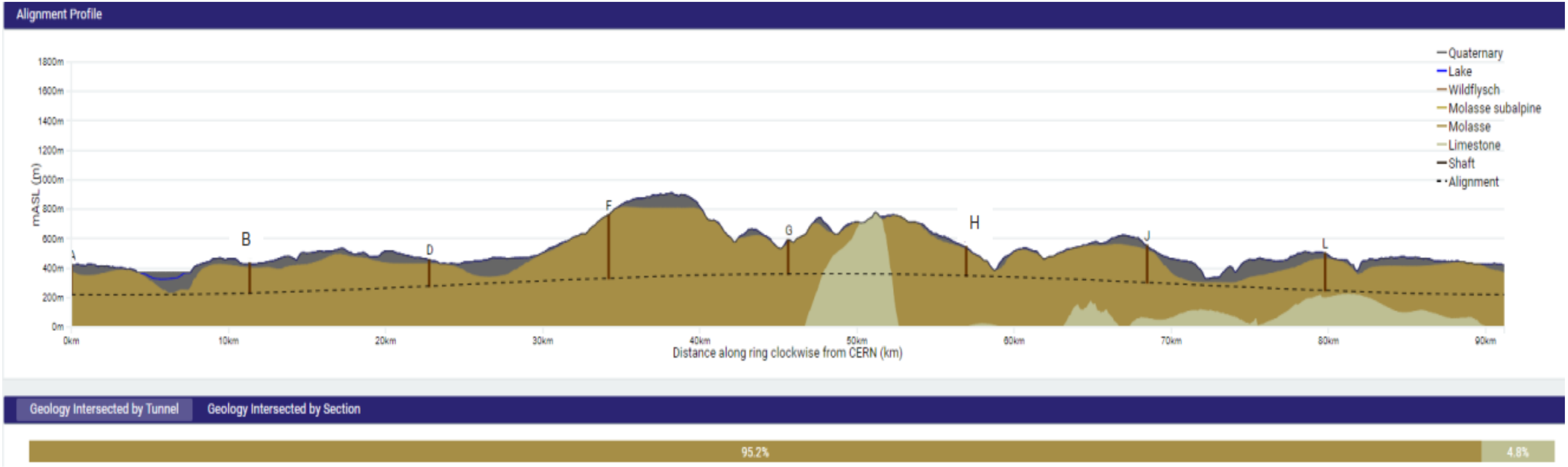




Detailed road access scenarios & highway access creation study **carried out by Cerema*, including regulatory requirements in France**

* Centre for Studies and Expertise on Risks, the Environment, Mobility and Urban Planning. CEREMA is **the major French public agency for developing public expertise in the fields of urban planning, regional cohesion and ecological and energy transition** for resilient and climate-neutral cities and regions.

FCC tunnel implementation

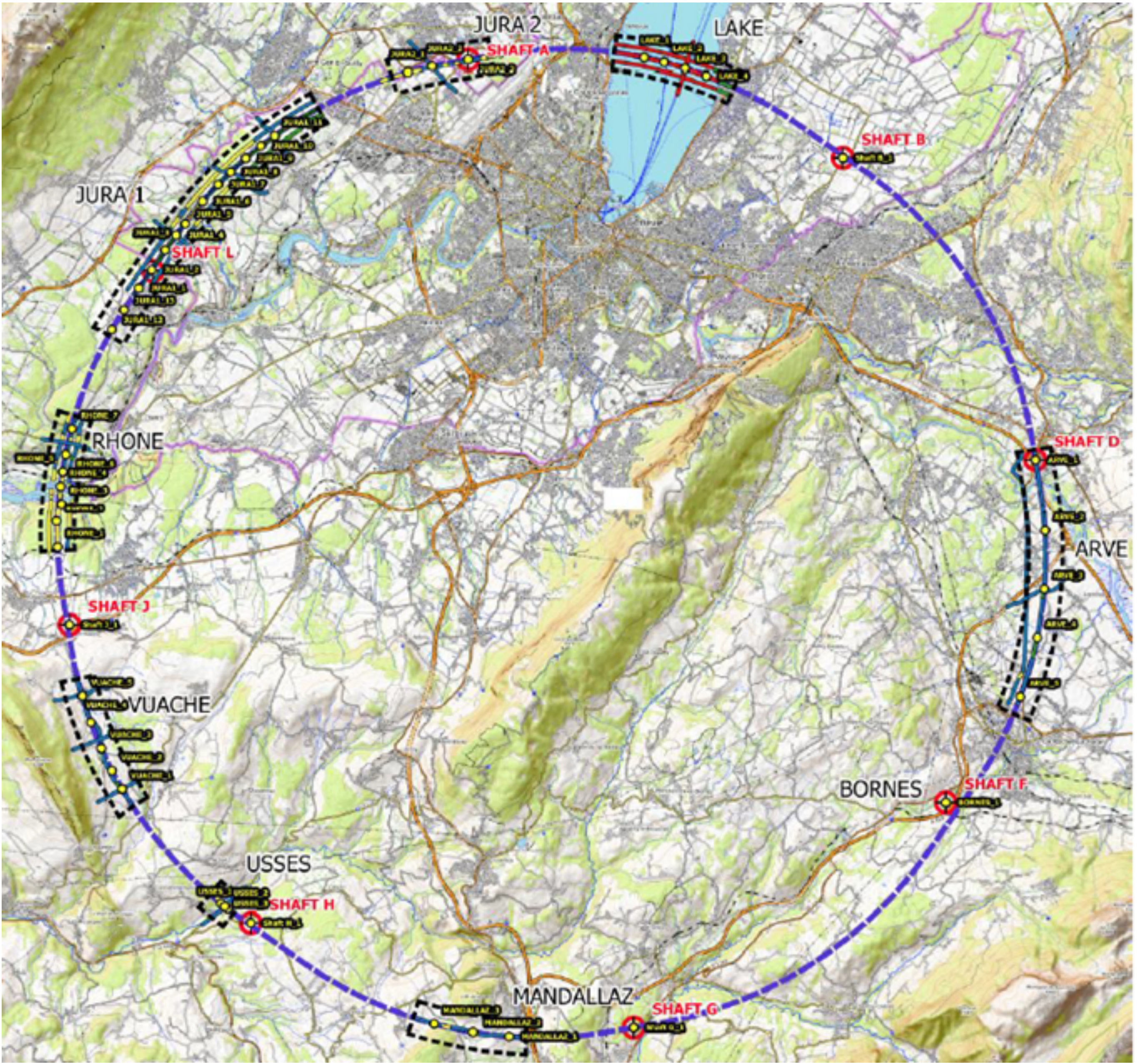


Tunnel implementation summary

- 91 km circumference
- 95% in molasse geology for minimising tunnel construction risks
- 8 surface sites with ~5 ha area each.

FUTURE CIRCULAR COLLIDER

Status site investigations



- **Site investigations in areas with uncertain geological conditions:**
  - Optimisation of localisation of drilling locations ongoing with site visits since end 2022.
  - **Alignment with FR and CH on the process for obtaining autorisation procedures. Ongoing for start of drillings in Q2/2024.**
- **Contracts Status:**
  - Contract for engineering services and role of Engineer during works, active since July 2022
  - Site investigations: contract placement **approved** by Council in December 2023 and mobilization from January 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

Studies of environmental aspects ongoing

- **Studies of relevant environmental aspects over 18 months (> 4 seasons to see full cycle) with a consortium of specialized companies**
- **Necessary inventory for the "Avoid-reduce-compensate" approach and costing (compensation measures)**
- **Input for surface site designs, installation and operation aspects**
- **Pre-requisite for the required initial state report, before an environmental impact assessment**
- **Exhaustive list of topics covered:**
    - Topography, geology, hydrogeology, surface water, natural risks, urbanistic planning, fauna & flora survey, habitats and wetland analysis, soil quality and pollution, noise, light, radiation, technological risks, demography, economic activities, landscape and visibility, patrimony
- **Central management of all data in an "Environmental Information System" to be able to document the evolutions of the territory, the civil construction designs and the technical infrastructure development integrated with classical "Geographical Information System"**

Examples for field investigations and environmental studies

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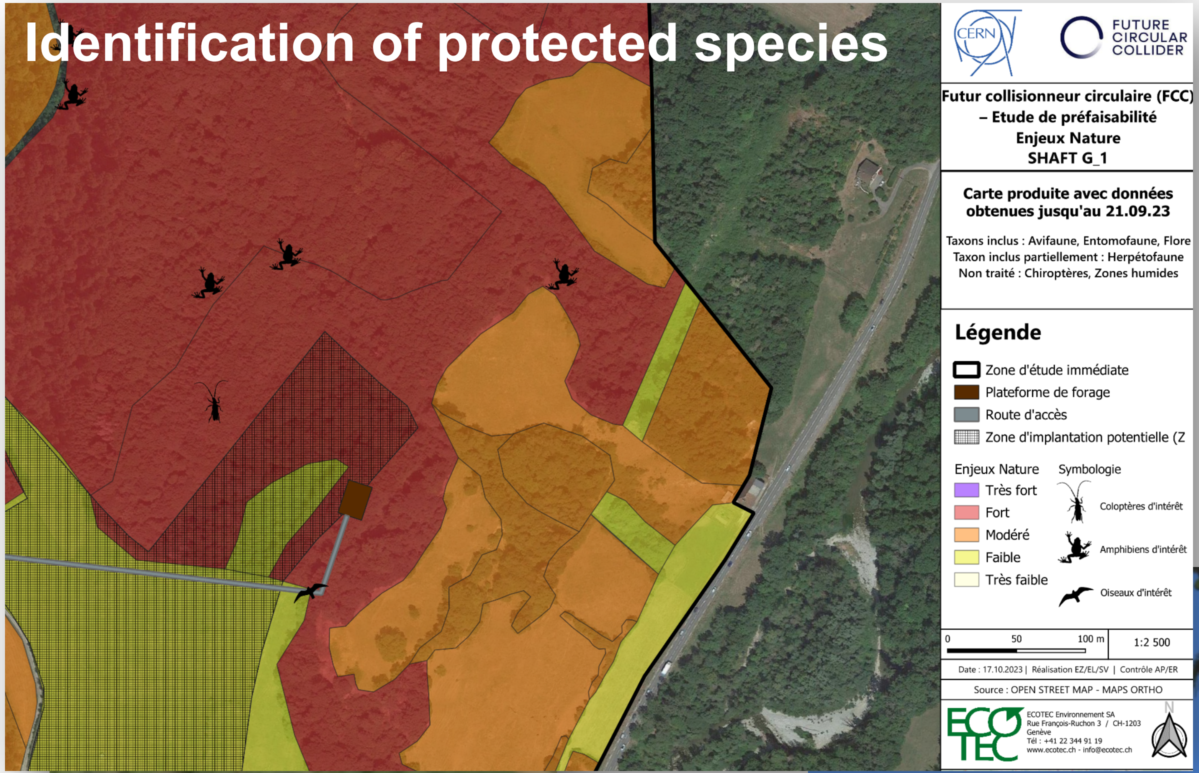
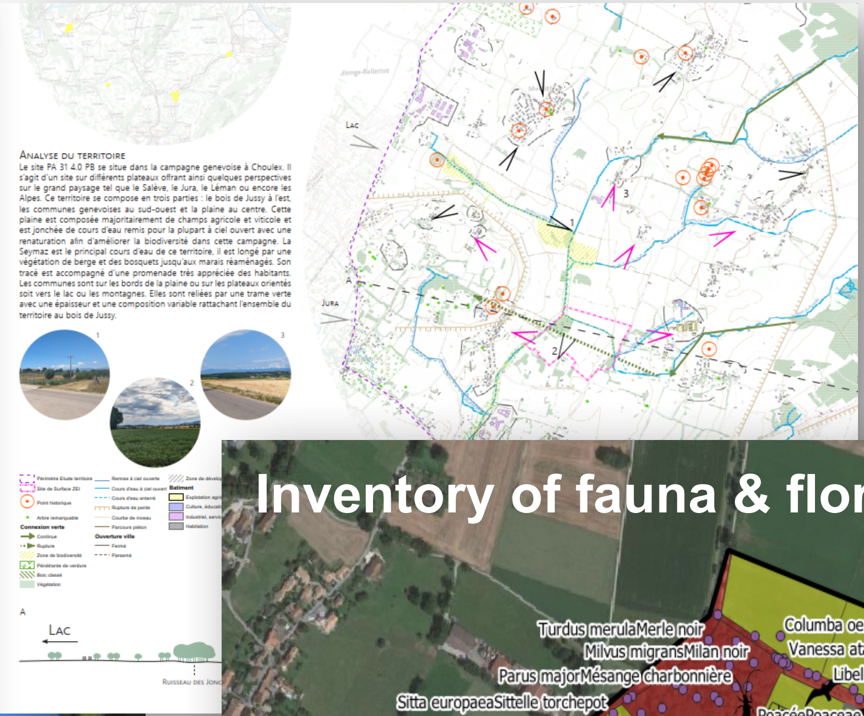
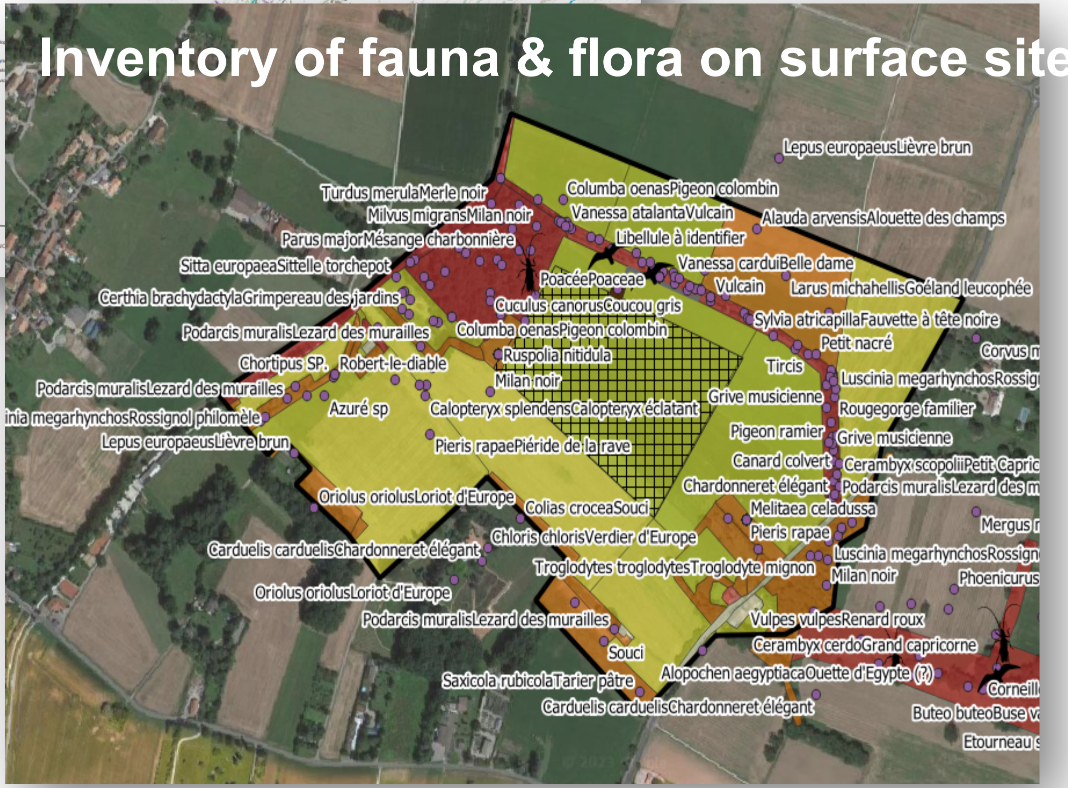
Identification of protected species





Description of **surrounding, views to be preserved, architectural aspects** to be Considered.

Inventory of fauna & flora on surface site



Determination of quality of the top soil and potential pollution, determination of the economic land value

Excavation material management

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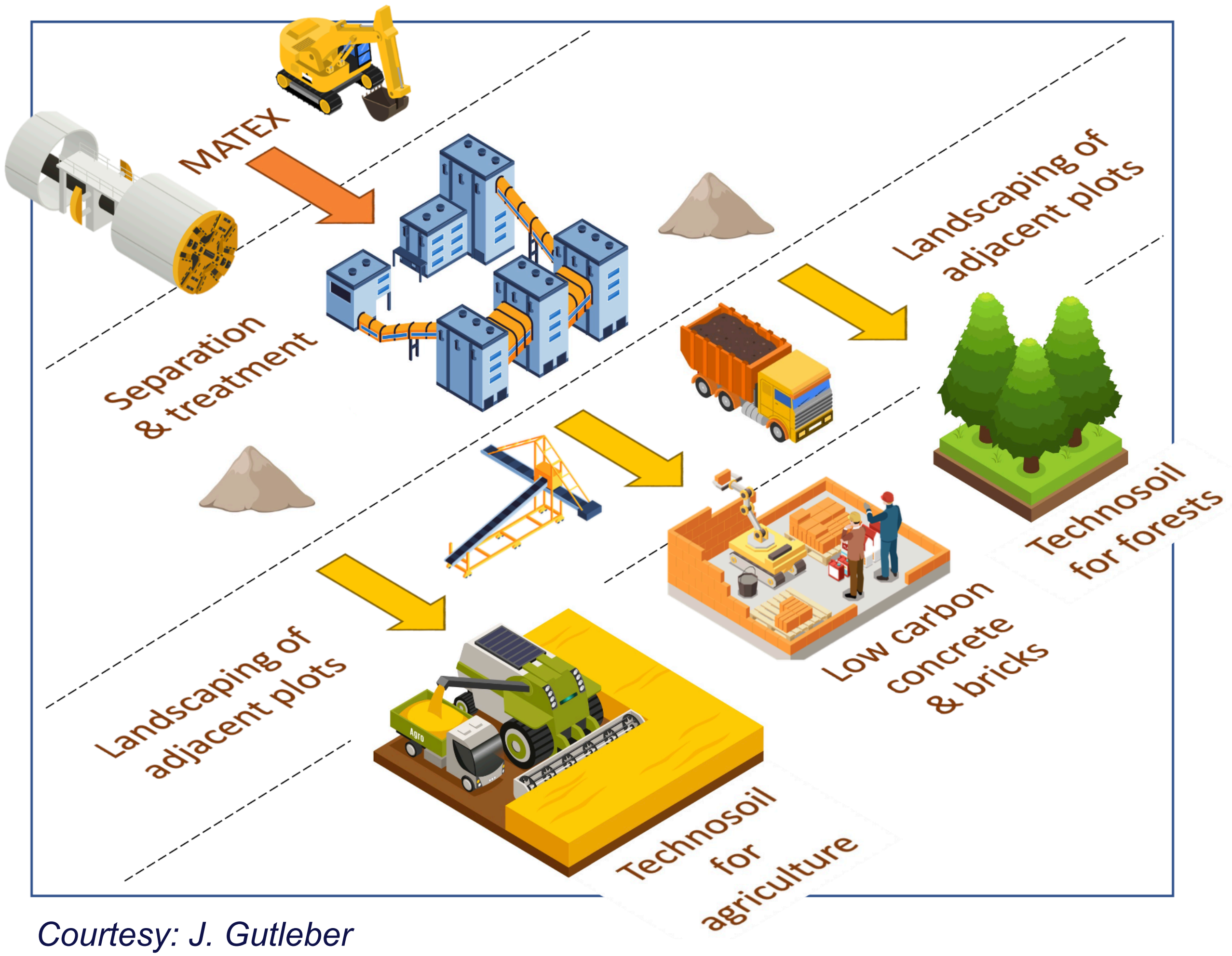
An innovative local approach for excavated materials:



Courtesy: J. Gutleber

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

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

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

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

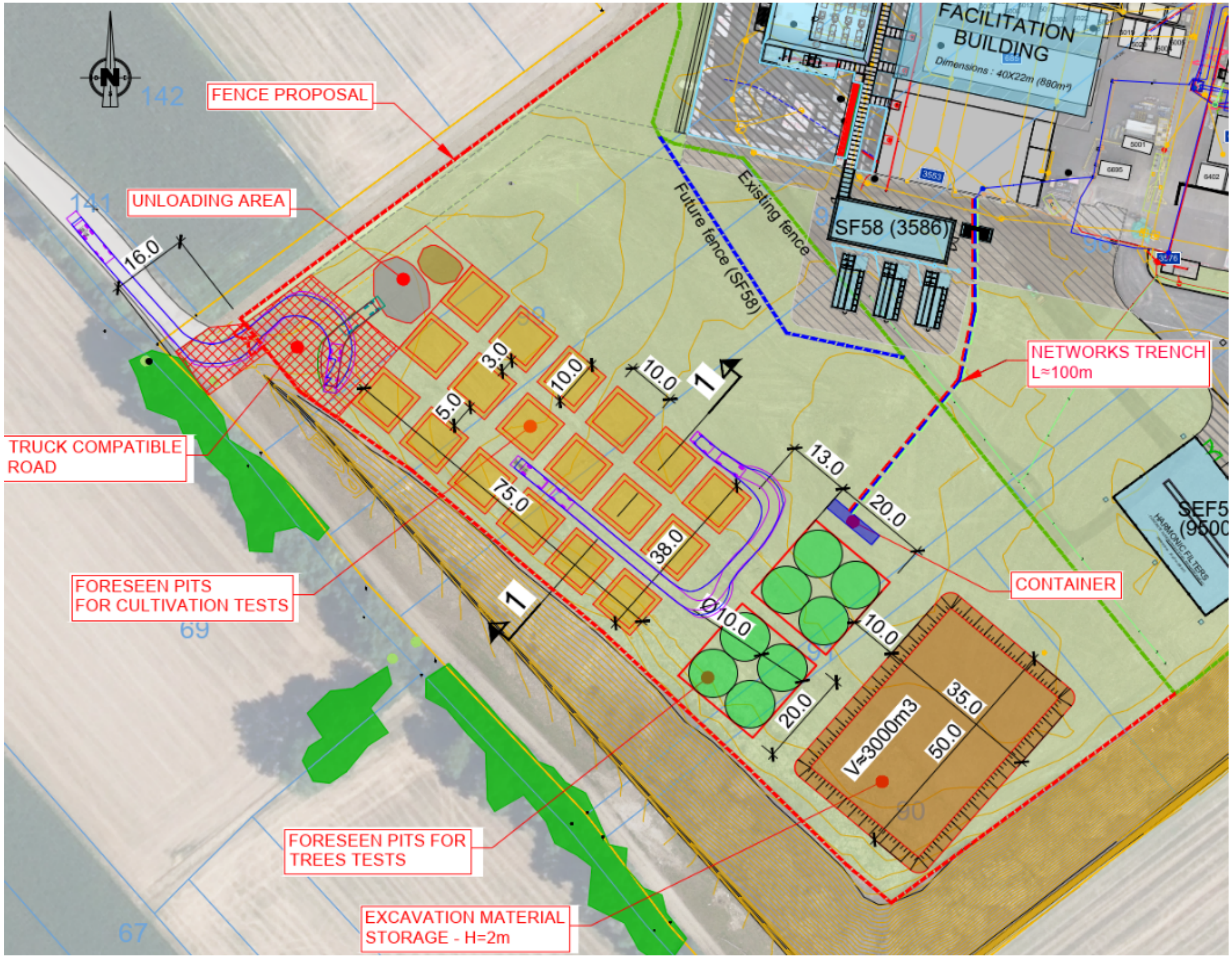
OpenSky Laboratory : HOW?

- 3'000 m² at LHC P5 in Cessy, France.
- **Trial with 5 000 t of excavated local molasse**
- 18 cells for agriculture trials (10*10 m)
- 2 cells for forestry trials (20*20 m)
- Different types of plants selected as function of regional specificities

1) Initial laboratory analysis to **identify** the **most suitable mixing** of molasse and amendments,

2) **Mixing/spreading** of the molasse with amendments on the trial cells,

3) **Planting and treatment with monitoring** of the field conditions in a **controlled environment.**



OpenSky Laboratory : WHO?

A collaborative effort of industry and academic/educational institutes

Open Sky Laboratory (Located at HL-LHC P5)

Molasse Pre-Treatment

BG Ingénieurs Conseils
- Support for quality soil management during construction
- Mixing of the molasse with amendments during exploitation
- Support in field restoration after the experience (depending on the results

ETS Nabaffa
NOT PART OF THE FCC MoU Collaboration
- Local molasse supply
- On-site pre-treatment of molasse (grain size separation and recombination)

M-S
- Off-site pre-treatment of molasse for laboratory test (grain size separation and recombination)

University of Leoben
- Molasse characterization
- Comparaison of molasse characteristics with existing FCC underground database
- Scientific support in geology and geotechnics

BECC
- Field instrumentation with connected field measurement devices for soil, plant and weather monitoring
- Creation of a supervisory control and data acquisition system

CSIL
- Economic and societal impacts analyses
- Business plan development
- Environmental compensation quantification

Molasse Treatment

Edaphos
- Biological analyses
- Selection, sourcing and characterization of organic matter
- Formulation and production of biodynamisation amendment (capsule)
- Molasse mixing methodology

Microhumus
- Laboratory tests to evaluate material treatment suitability
- Culture selection in function of regional specificities and culture rotation plan

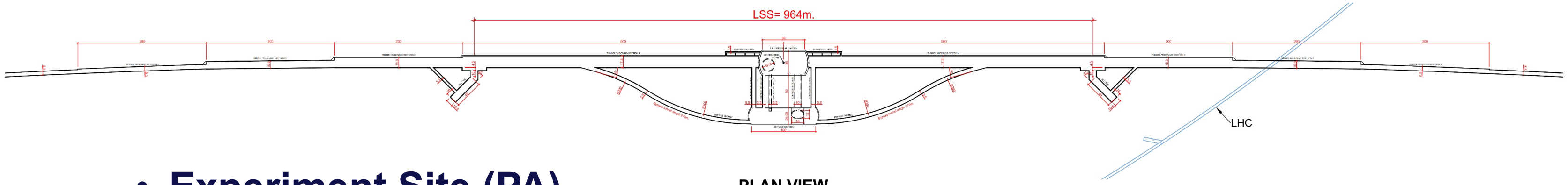
HEPIA
- Design of the experimental field
- Culture selection in function of regional specificities and culture rotation plan
- Culture rotation plan
- Soil engineering and pedogenesis

BOKU
- Development of a scientific protocol and tracking of the field trials
- Design of the experimental field
- Socio-economic study

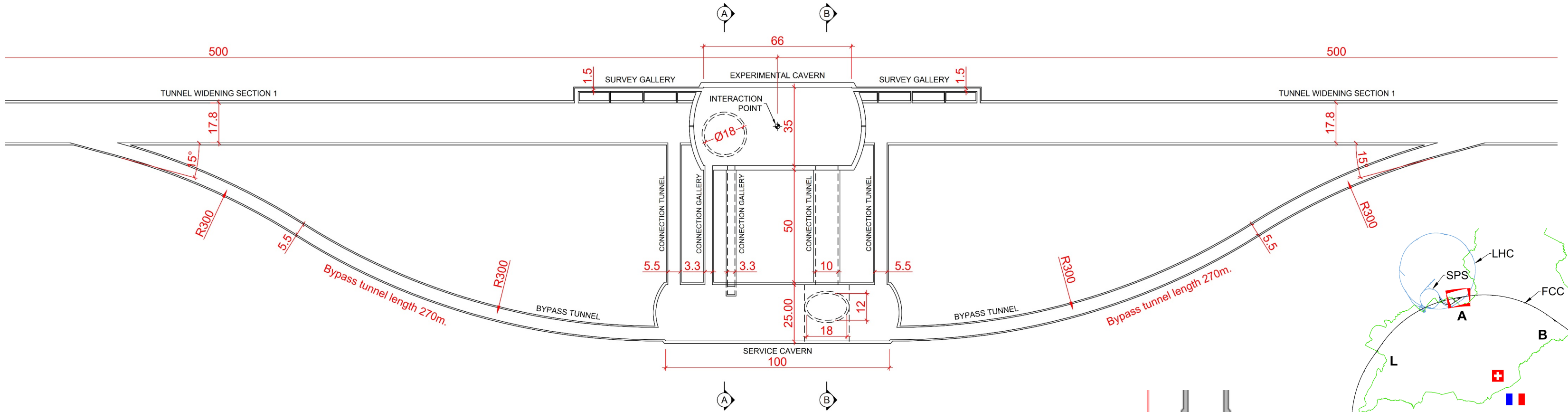
CE underground progress

- **Full 3D model of underground structures as basis for costing exercies**
- **Update of scheduling and costing with external consultant ongoing**
- **Independent second costing exercise based on same bill of quantities will be done**

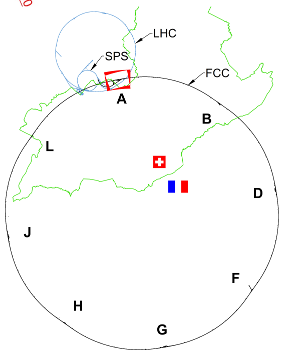
- **Experiment Site (PA)**



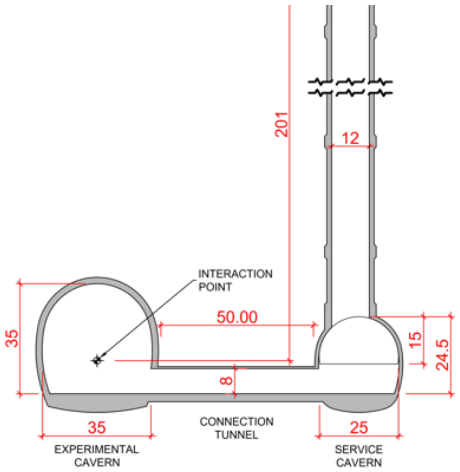
PLAN VIEW
1:3000

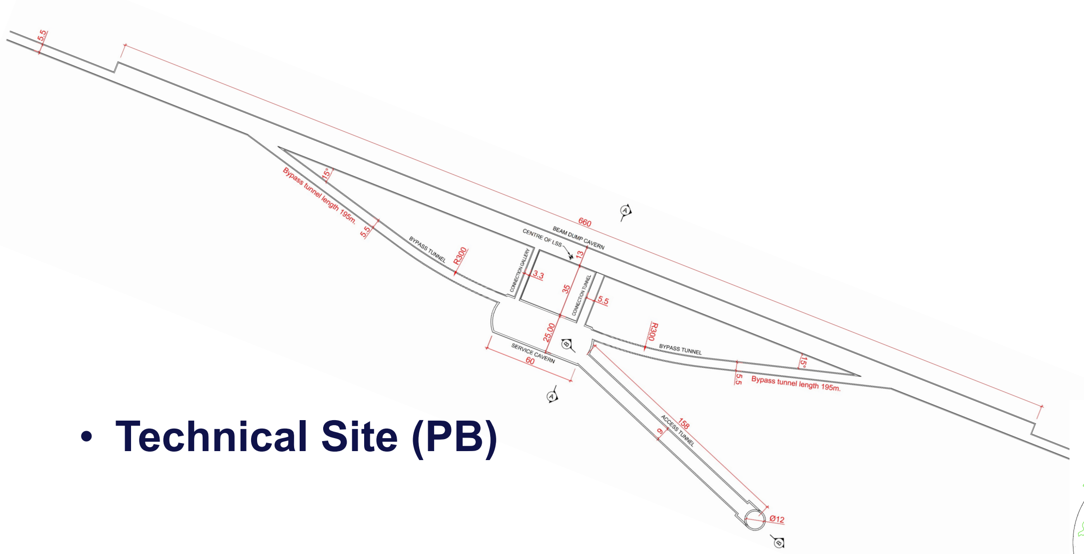


PLAN VIEW
1:1000

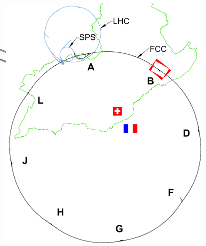


KEY PLAN





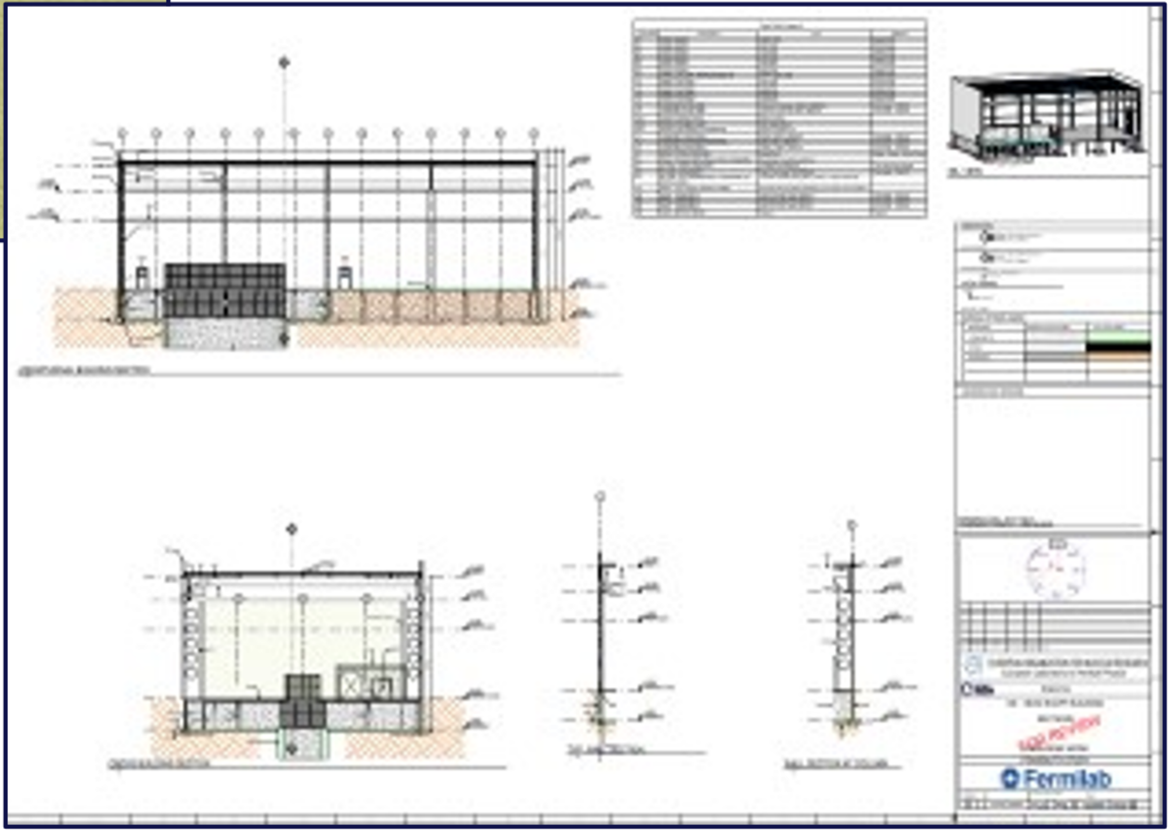
- **Technical Site (PB)**



KEY PLAN

CE surface progress

Generic study of experiment site and technical site by FNAL



Examples of Fermilab Deliverables

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

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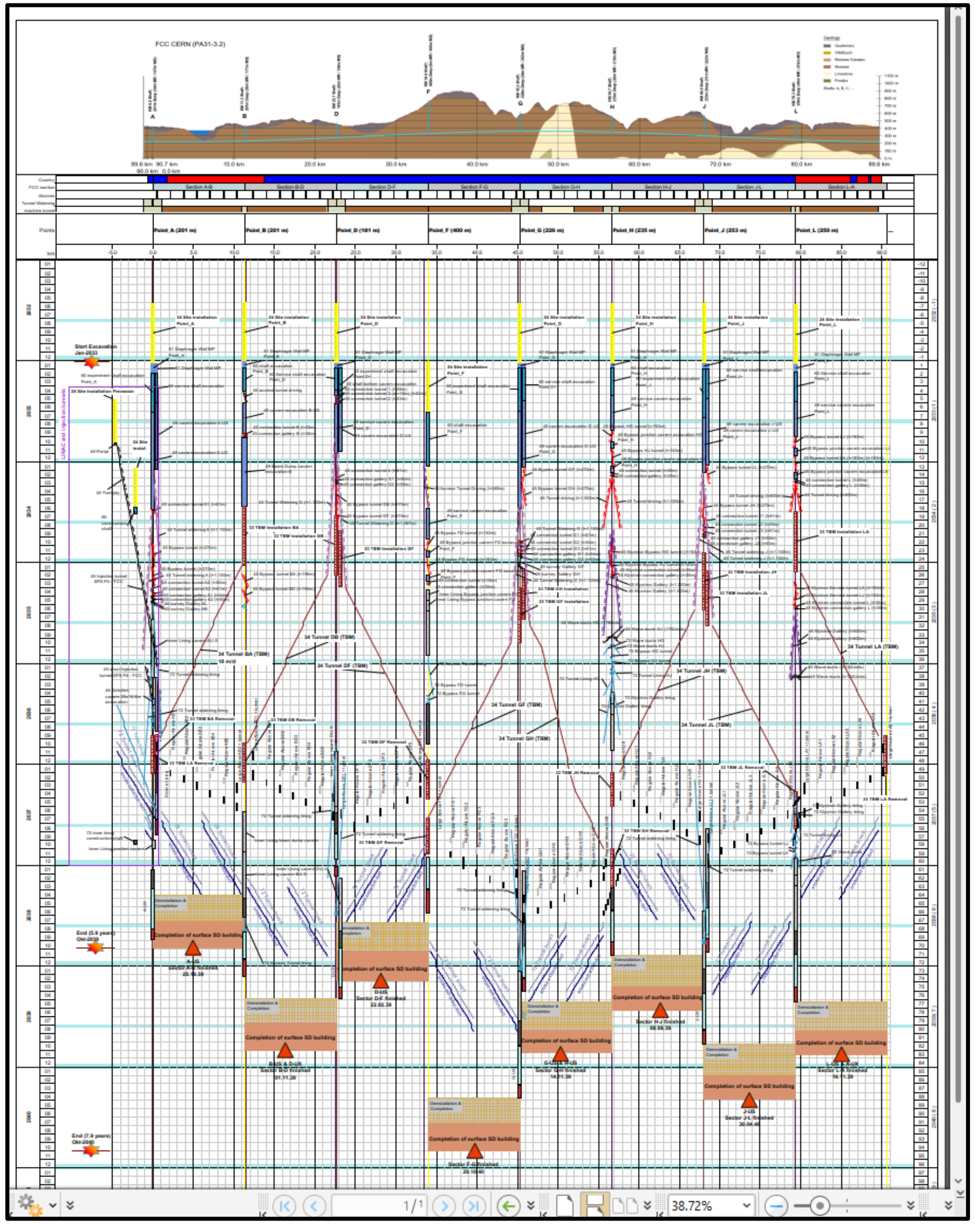
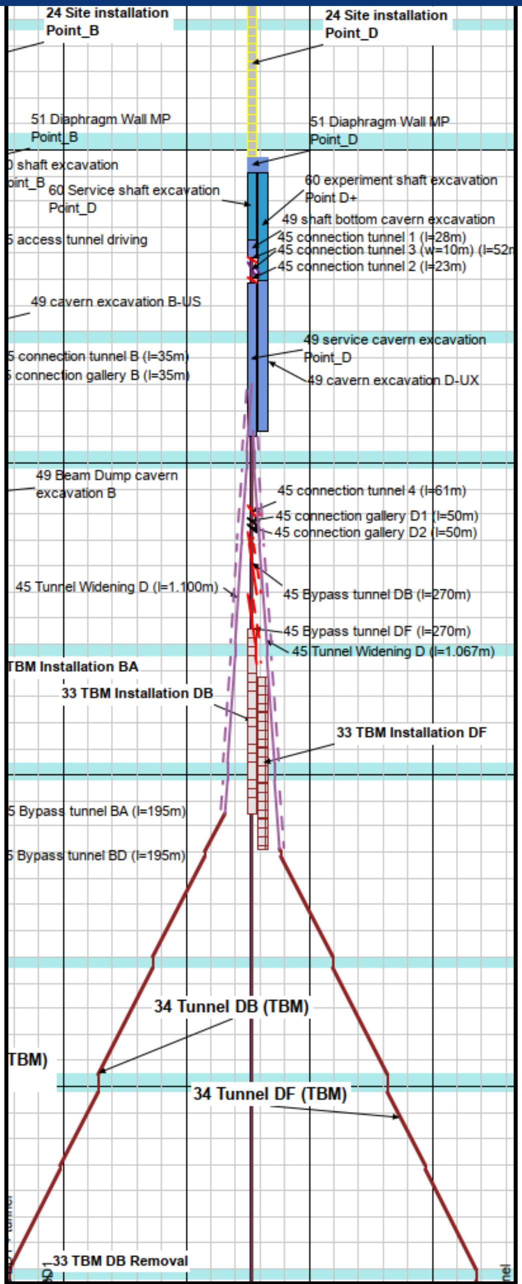
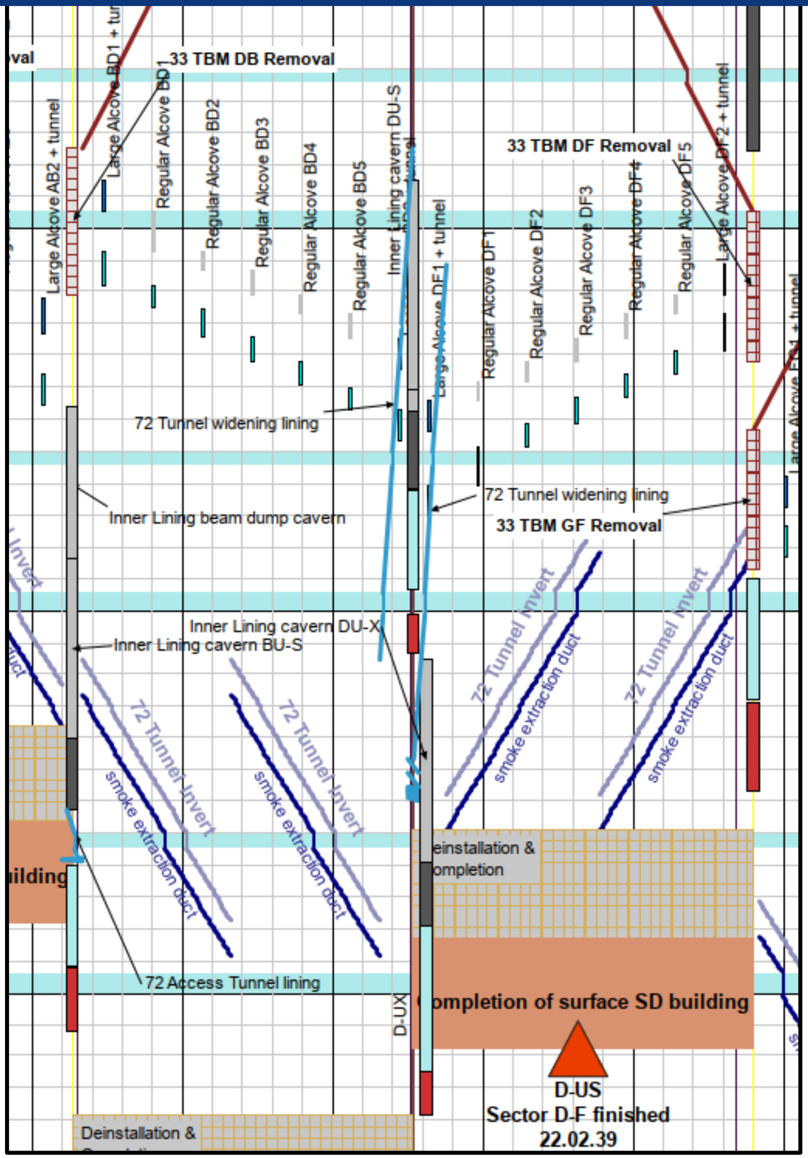
CE construction schedules (example)

T. Watson

CE linear construction schedule







Point D – Example of linear schedule

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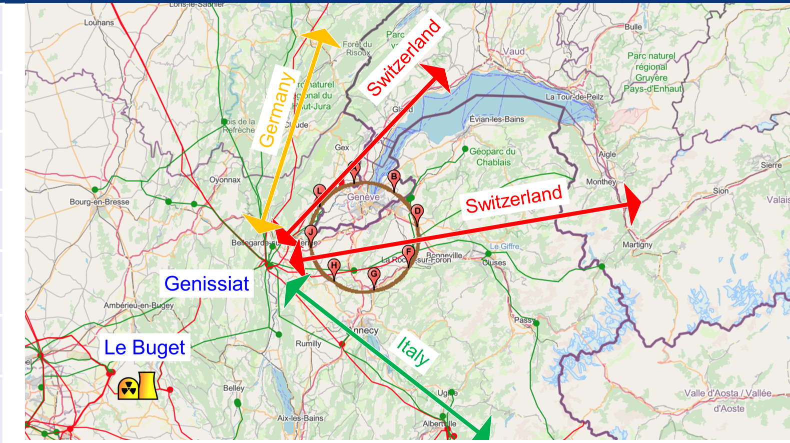
Preparatory phase planning - authorisations and CE

To start the excavation of the first shafts in 2033, a significant amount of preparatory work is required. An initial consideration of these preparatory works including scheduling and resource aspects has been made:

2025-2026	**Permits and authorization for complementary site investigations**
	Tendering for environmental impact and authorisation processes contract, tendering for subsurface investigations
2027-28	**Complementary subsurface investigations**
	Tendering for CE consultants, environmental impact studies, public concertation
2028	**Project approval**
	Award of CE consultant contracts
2029-30	**Tender design**
	Preparing calls for tenders for CE construction,
	Project authorisations in France and Switzerland obtained, preparations of infrastructures for construction
2031 mid 2032	**Construction design, Tendering for construction**
mid 2032	**Award of CE construction contracts**
	Preparation of site completed (road access, electricity, water…)
2033	**Ground breaking**

Connections to electrical grid infrastructure

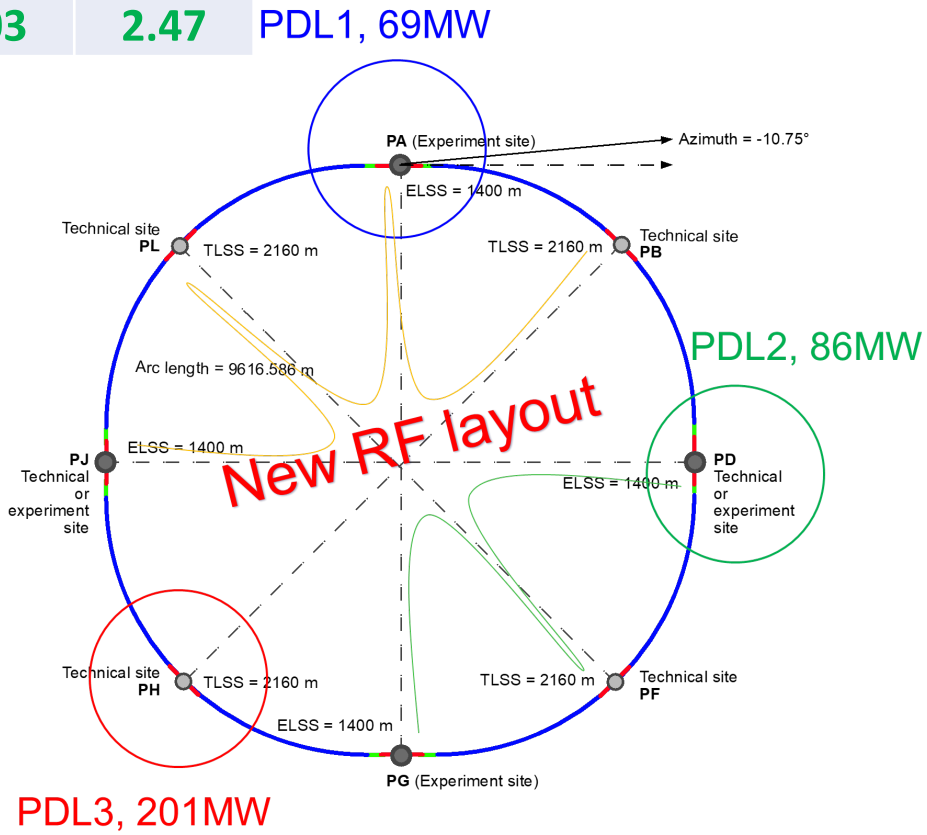
Updated FCC-ee energy consumtion	Z	W	H	TT
Beam energy (GeV)	45.6	80	120	182.5
Max. Power during beam operation (MW)	222	247	273	357
Average power / year (MW)	122	138	152	202
Total FCC-ee yearly consumption (TWh)	**1.07**	**1.2**	**1.33**	**1.77**
Yearly consumption CERN & SPS (TWh)	0.70	0.70	0.70	0.70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



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

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

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



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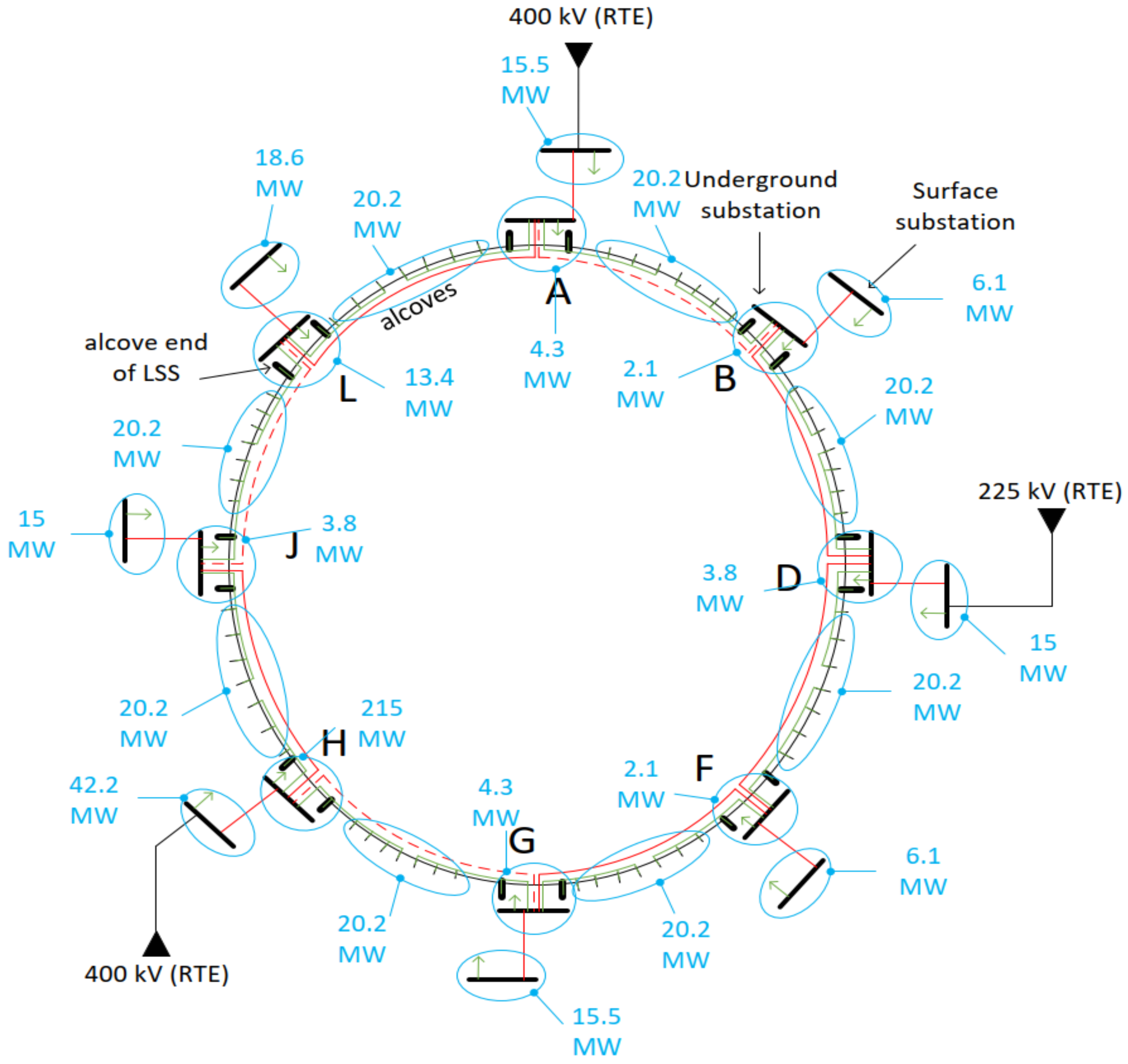
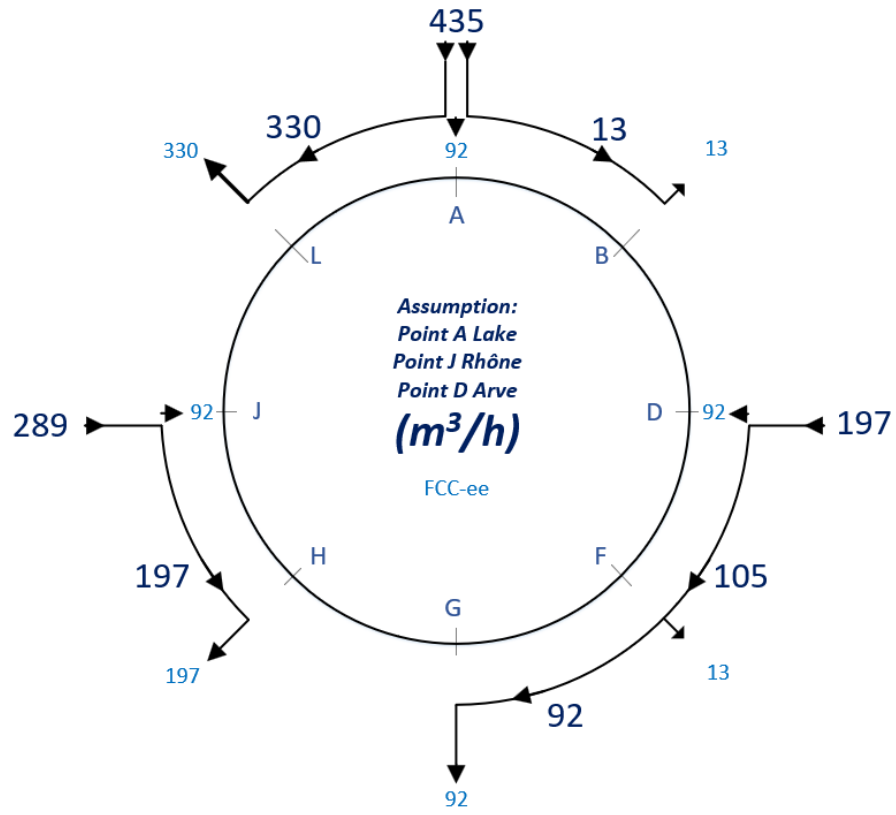
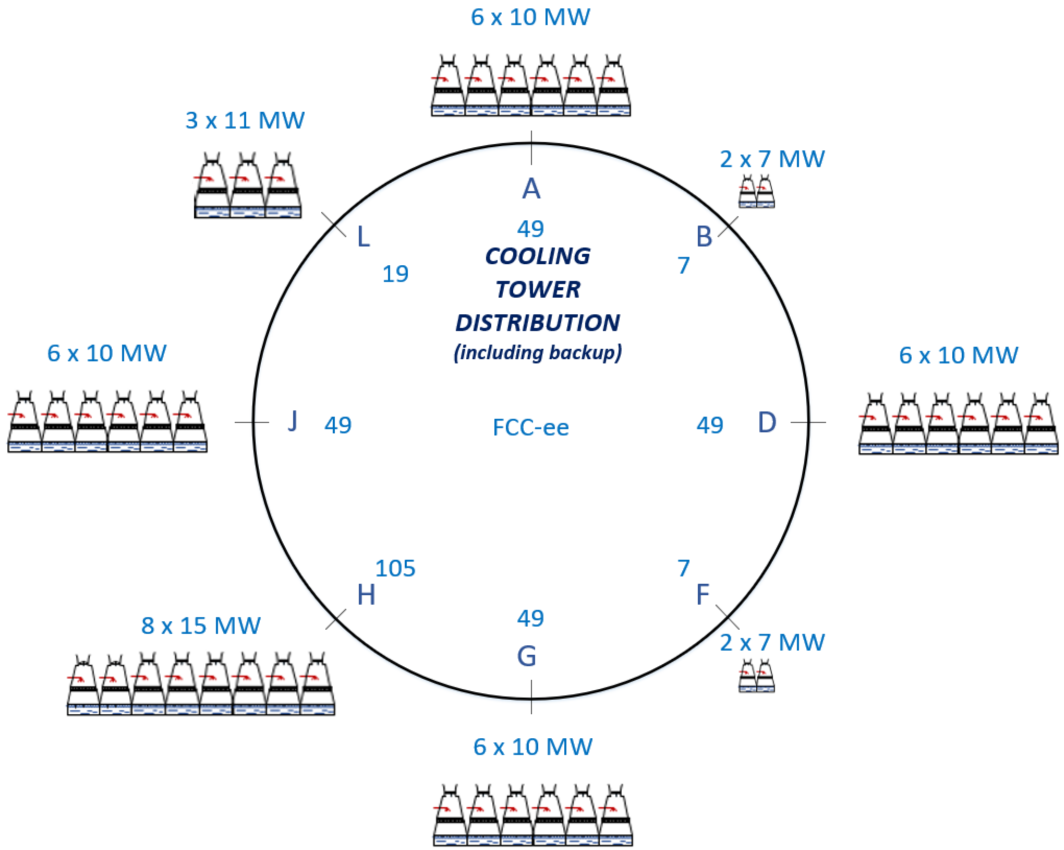
Electrical network

- **Electrical Power from the French network fed into the FCC at three points (A, H and D).**
- **Further distribution via the FCC ring.**
- **Covers all configurations of FCC-ee without need to build new sub-stations.**



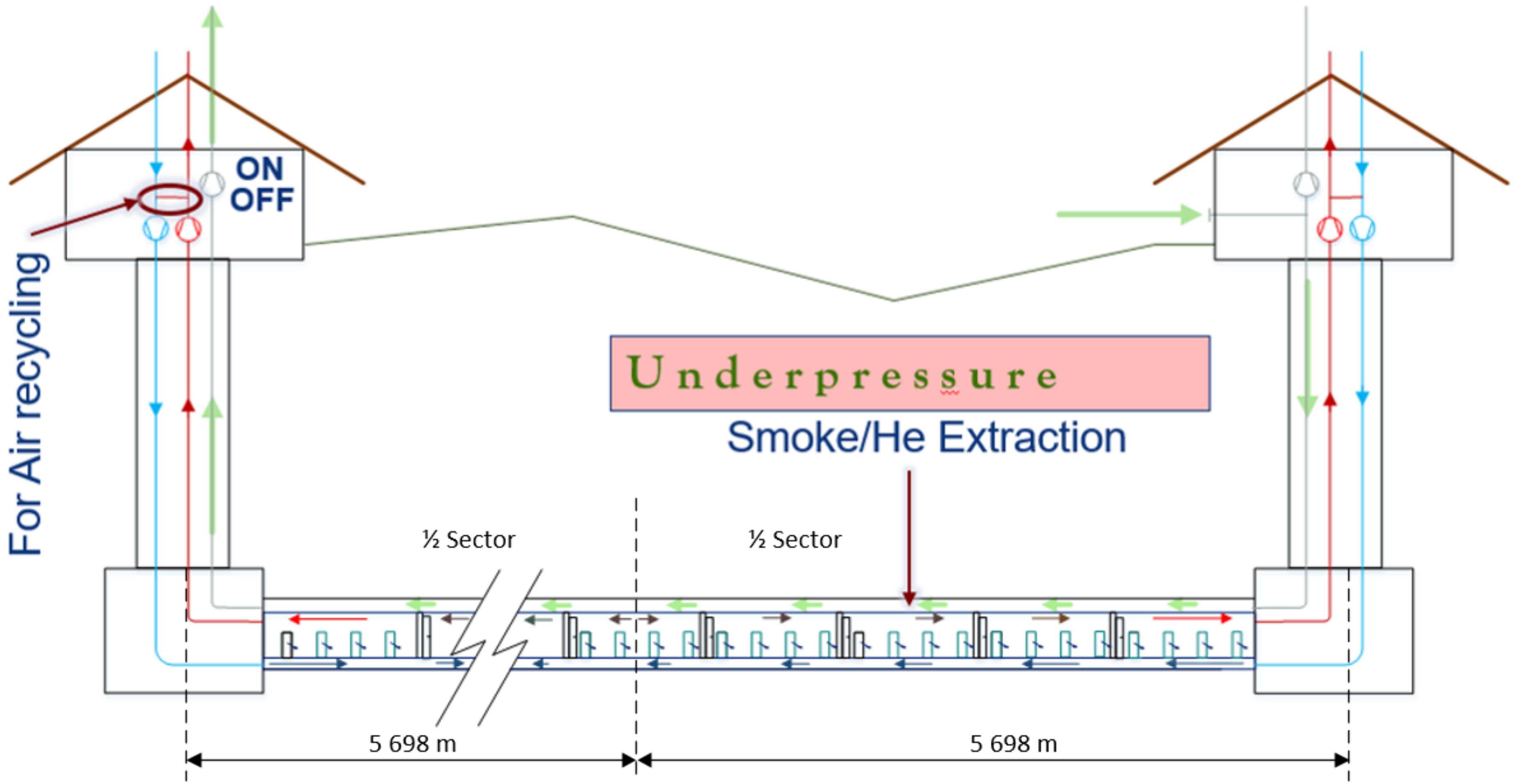
Cooling water supply concept





- **Potential sources of cooling water Geneva lake (PA), Rhone (PJ) and Arve (PD).**
- **Existing line with lake water provided by SIG (Service Industriel del Geneve) to CERN LHC P8 (LHCb) sufficient for FCC-ee.**
- **Pipework in the tunnel will connect the remaining points to points PA, PD and PJ.**
- **Main cooling towers placed at experiment points (PA, PD, PG, PJ), and RF sites (PL, PH).**

Ventilation concept



- Operation of the ventilation elements in one sector of the machine tunnel during normal operation.
- Smoke and helium extraction in green, general extraction in red and air supply in blue
- Compartmentalization via fire doors every ~400 m following arc cell structure.

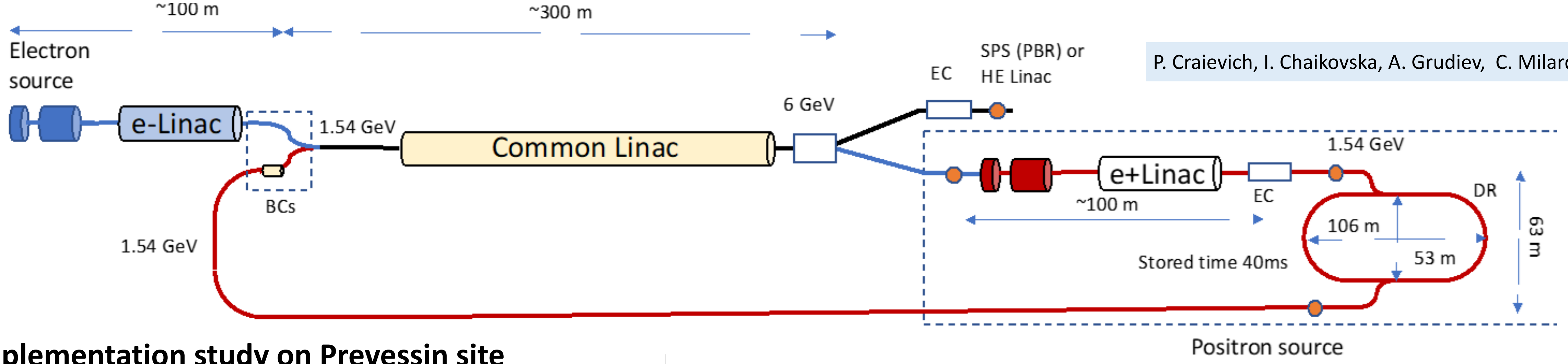
SPS as alternative to high-energy linac as pre-booster ct'd

- **HE linac delivers beam with 4x smaller energy spread and 16x smaller transverse emittance**. The Booster injection will be difficult and will need additional time at max energy to damp.
- Collective effects in the SPS have not been evaluated for the FCC-ee bunch train (5 nC!) but estimates of transverse mode coupling instability (TMCI) are well above threshold: https://journals.aps.org/prab/abstract/10.1103/PhysRevAccelBeams.26.081601
- **HE linac allows for higher injection energy into the booster** (e.g., 20 GeV versus 16 GeV from SPS) and injection into the booster would be much more flexible (low magnetic field at booster injection and impedance effects)
  - ➢ further energy increases through linac extensions could be possible AND would be fully independent of any hadron beam operation, and the linac could serve for many additional applications.
  - ➢ the construction and commissioning could proceed in parallel to any SPS or LHC hadron beam operation, while the reconstruction and use of the SPS could not begin before the end of the HL-LHC
- **SPS as a pre-booster during Z running would be used most of the time for lepton operation.** HE linac would not impact hadron beam operation. **SPS option would have major repercussions for any hadron beam programme in the SPS**, and also implications for any use of the SPS as a future hadron beam injector to the LHC or FCC-hh

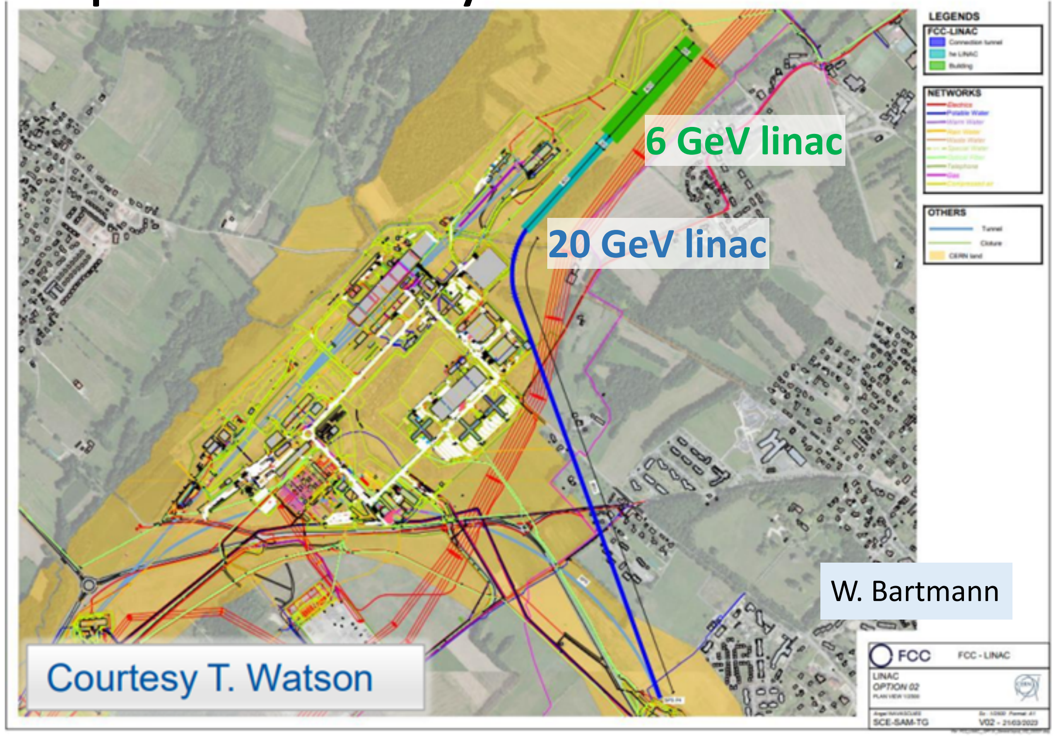
H. Bartosik. O. Etisken, Y. Papaphilippou, T. Raubenheimer, F. Zimmermann

FCC-ee injector layout & implementation

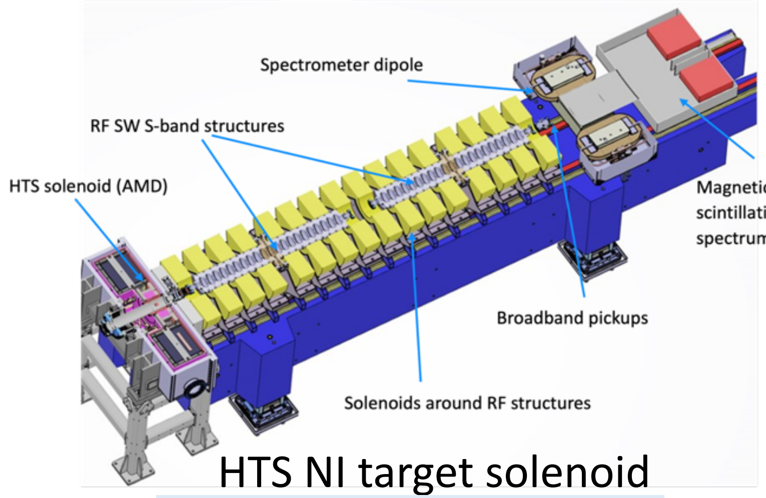
P. Craievich, I. Chaikovska, A. Grudiev, C. Milardi, et al

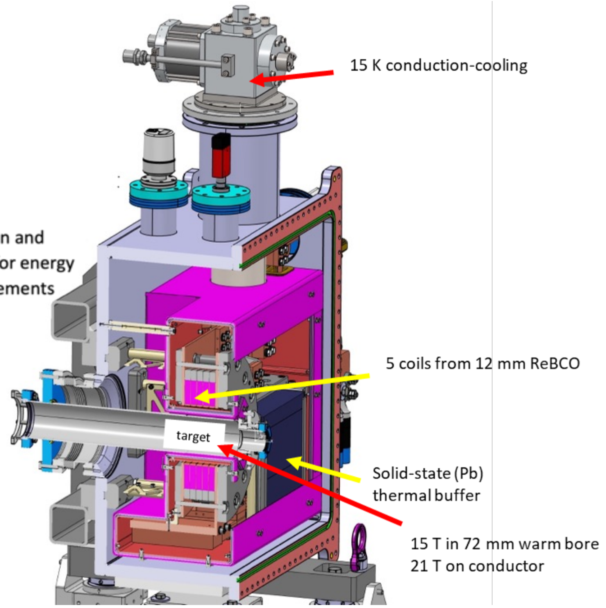


implementation study on Prevessin site



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





HTS NI target solenoid

J. Kosse, T. Michlmayr, H. Rodrigues

SPS as alternative to high-energy linac as pre-booster

- SPS: major upgrades and changes to the ring would be required (e.g., synchrotron radiation absorption, improved vacuum pumping, additional RF cavities and significant RF power sources, in particular for the Z mode)

Table 102 Synchrotron radiation power in the SPS.

Parameter	SPS for LEP	SPS for FCCee
Extraction energy [GeV]	20	16
SR - dipole magnets only [W/m]	1.85	198
Averaged SR- dipole magnets only [W/m]	0.024	8.1
SR - dipole and damping wiggler [W/m]	-	809
Averaged SR - dipole and damping wiggler [W/m]	-	107
Beam current [mA]	0.45	160

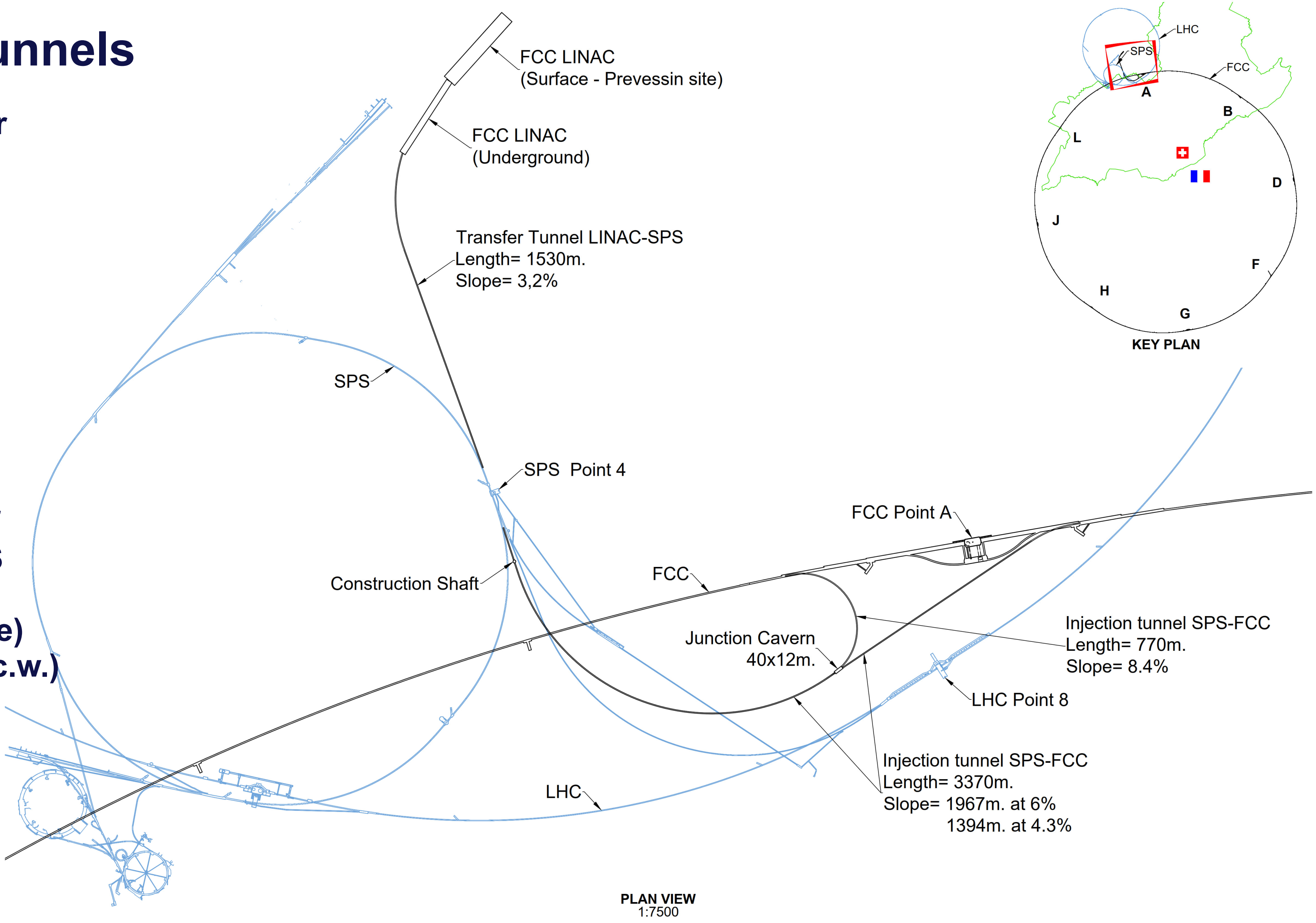
- The SR masking added to the SPS for LEP have been removed. Likely need entirely new vacuum chamber with new injection extraction kickers and requires new 140 MV, 400 MHz RF systems. Masks, RF, and kicker may have a negative impact on impedance for proton operation.

H. Bartosik, R. Kersevan, Y. Papaphilippou, et al.

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

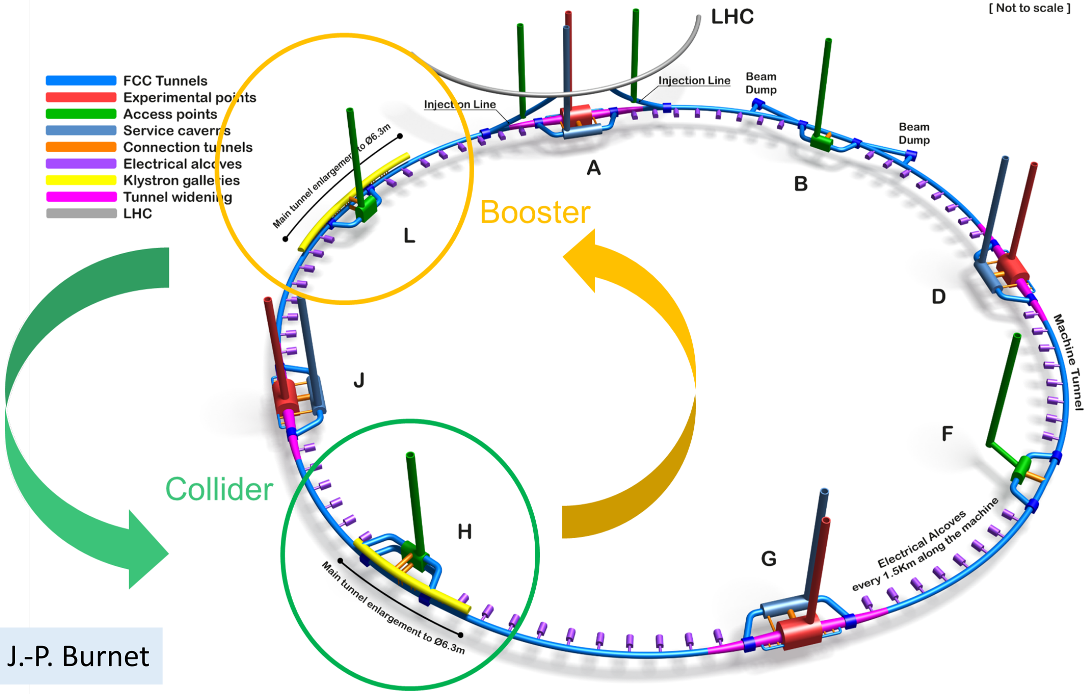
LINAC and Injection Tunnels

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



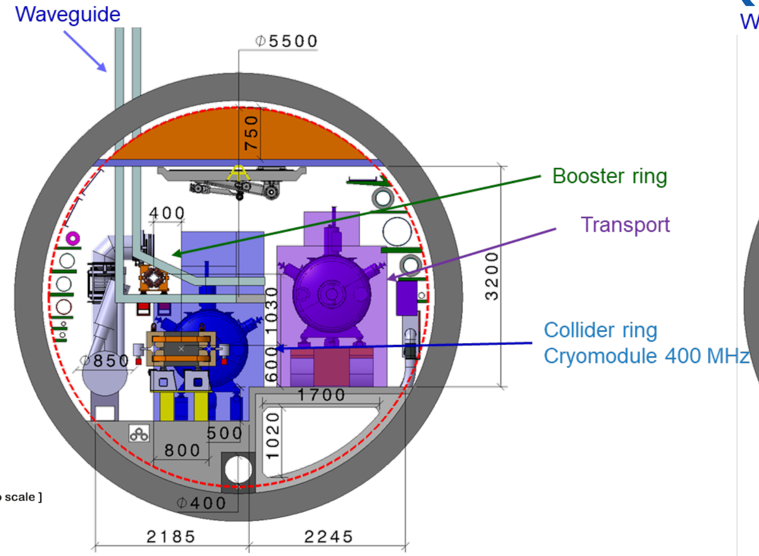
Modified FCC-ee RF layout

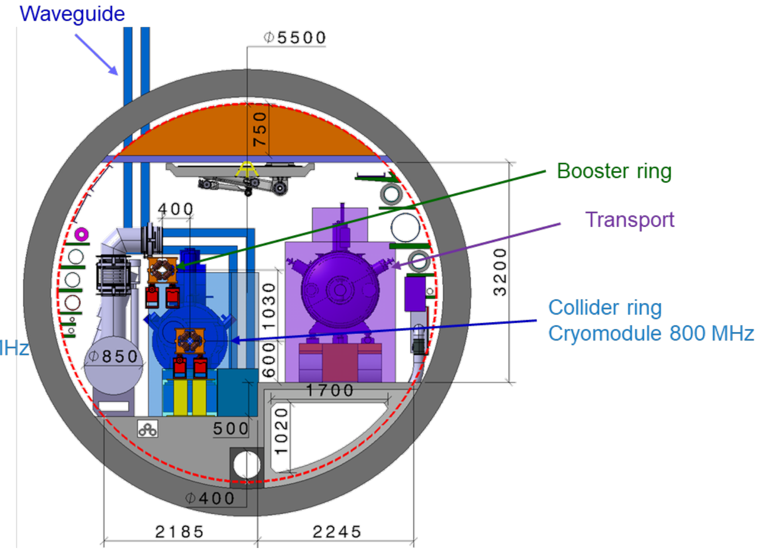
- RF for collider and booster in separate straight sections H and L.
- fully separated technical infrastructure systems (cryogenics)
- collider RF (highest power demand) in point H with optimum connection to existing 400 kV grid line and better suited surface site



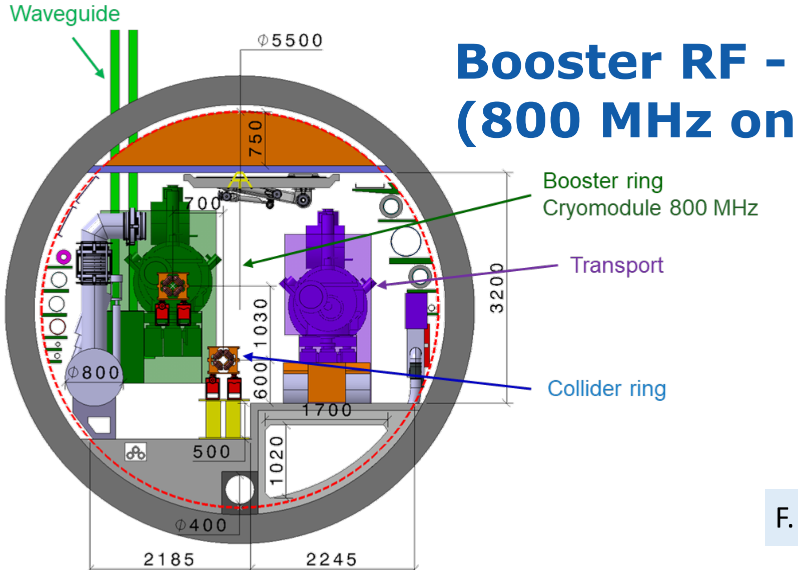
J.-P. Burnet

Collider RF - Point H (400 and 800 MHz)





Booster RF - Point L (800 MHz only)



F. Valchkova, F. Peauger

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]	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

currently assessing technical feasibility of changing operation sequences (e.g. starting at ZH energy)

Z	WW	H (ZH)	ttbar
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

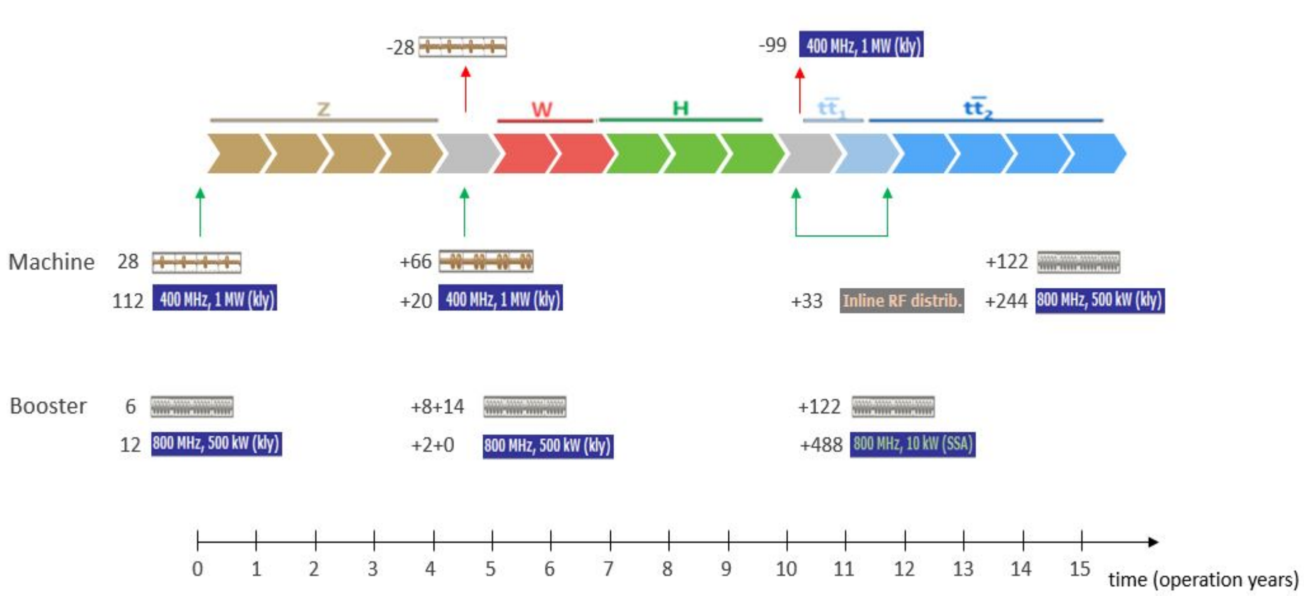
- x 10-50 improvements on all EW observables
- up to x 10 improvement on Higgs coupling (model-indep.) measurements over HL-LHC
- x10 Belle II statistics for b, c, τ
- indirect discovery potential up to ~ 70 TeV
- direct discovery potential for feebly-interacting particles over 5-100 GeV mass range

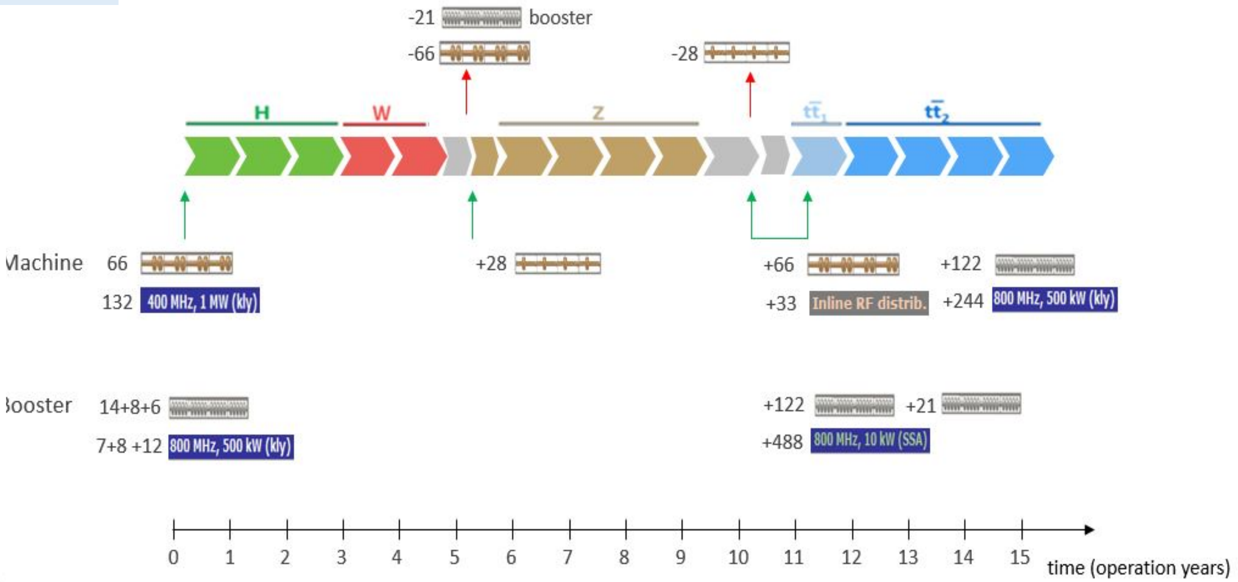
Up to 4 interaction points → robustness, statistics, possibility of specialised detectors to maximise physics output

F. Gianotti

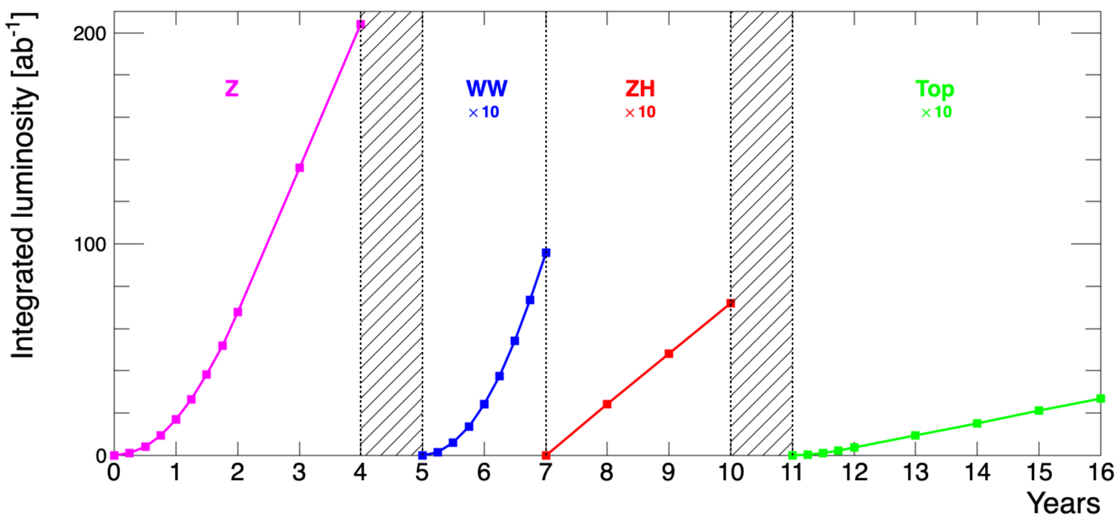
operation sequences for FCC-ee

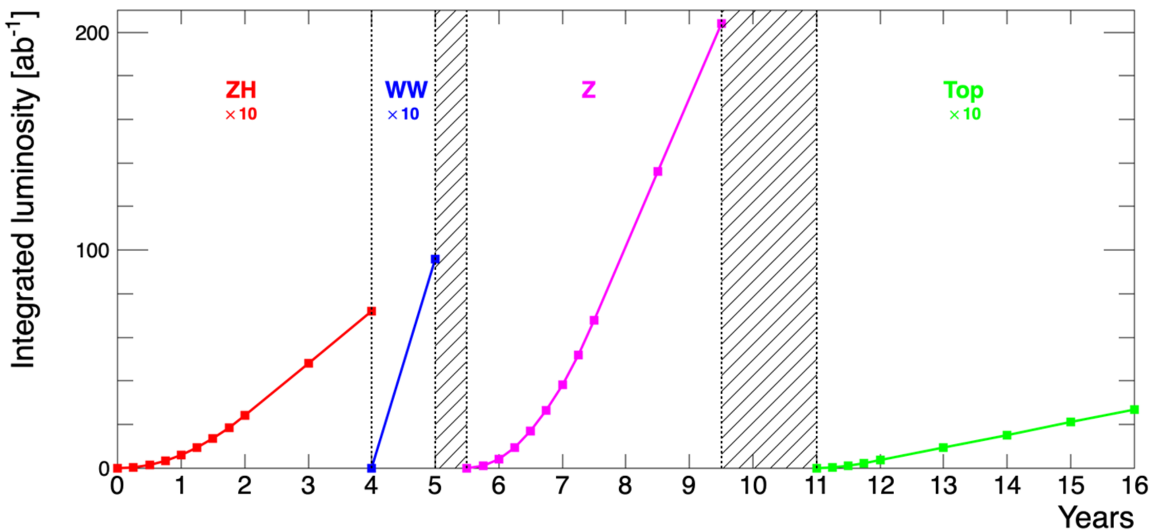
O. Brunner, F. Peauger





P. Janot



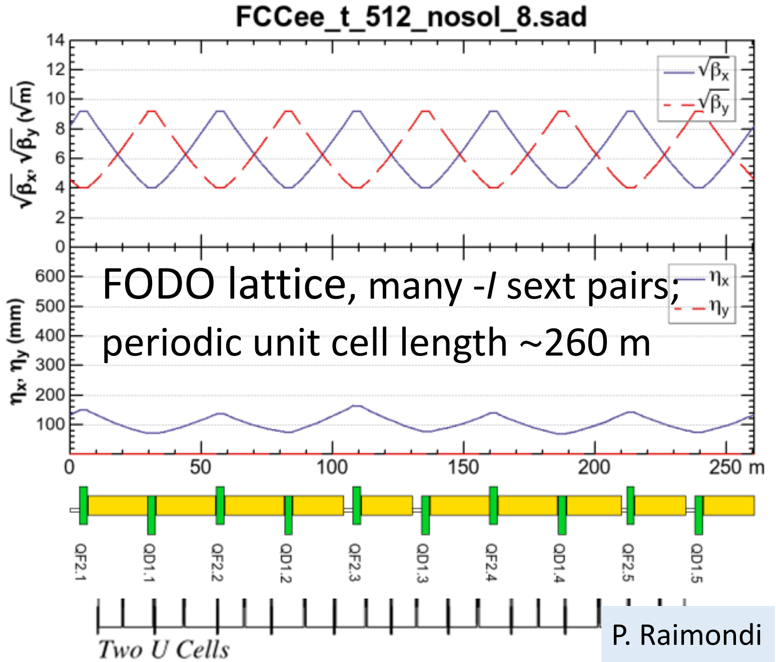


FCC-ee optics baseline & further evolution(s)

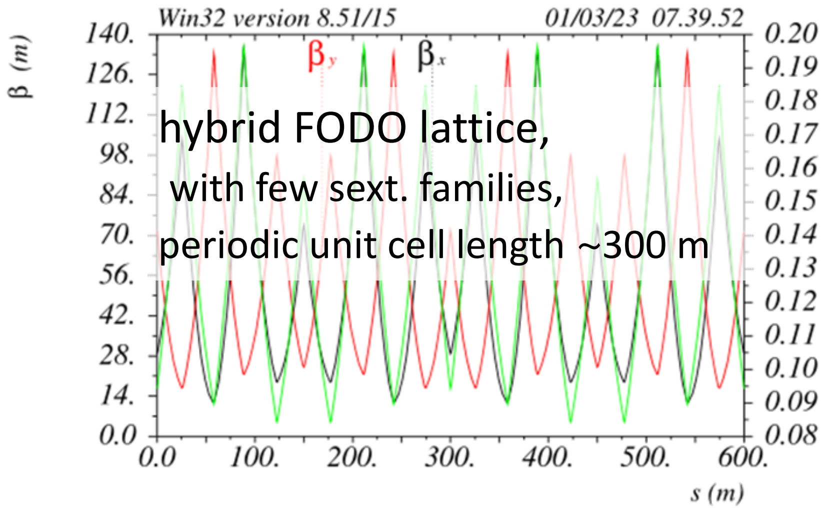
regular arc

K. Oide

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



P. Raimondi

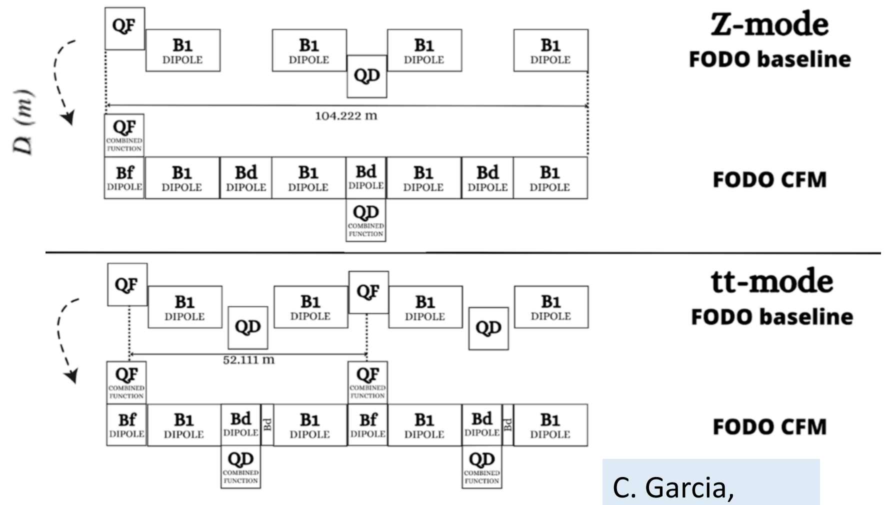


baseline for 2023 FCC "mid-term" review

optimisation goals:

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

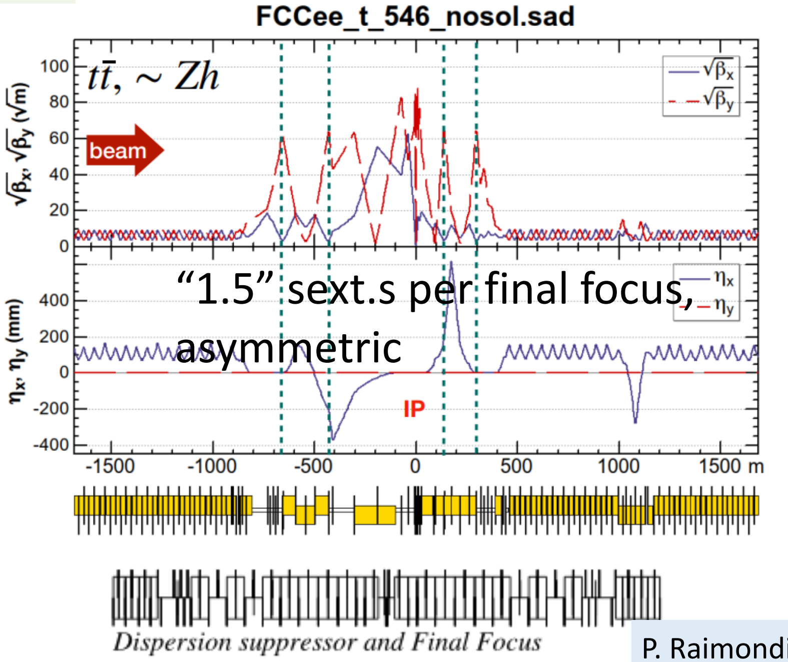
design in progress



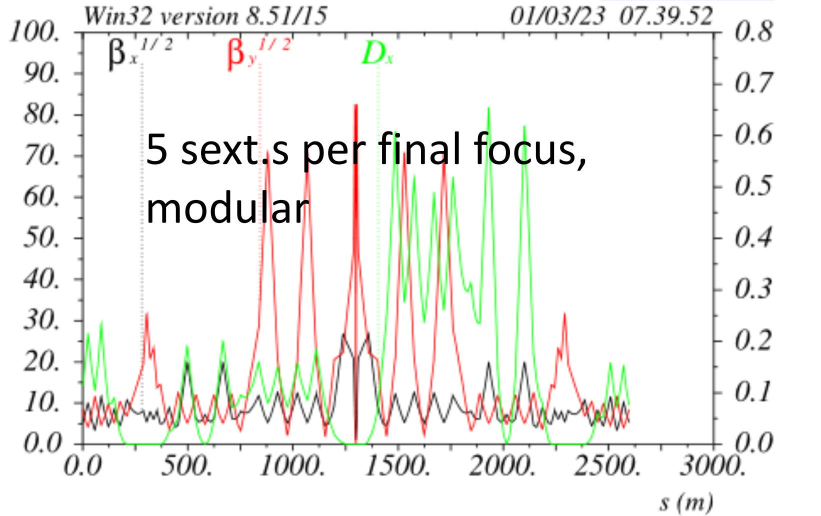
C. Garcia,
R. Tomas, et al.

interaction region

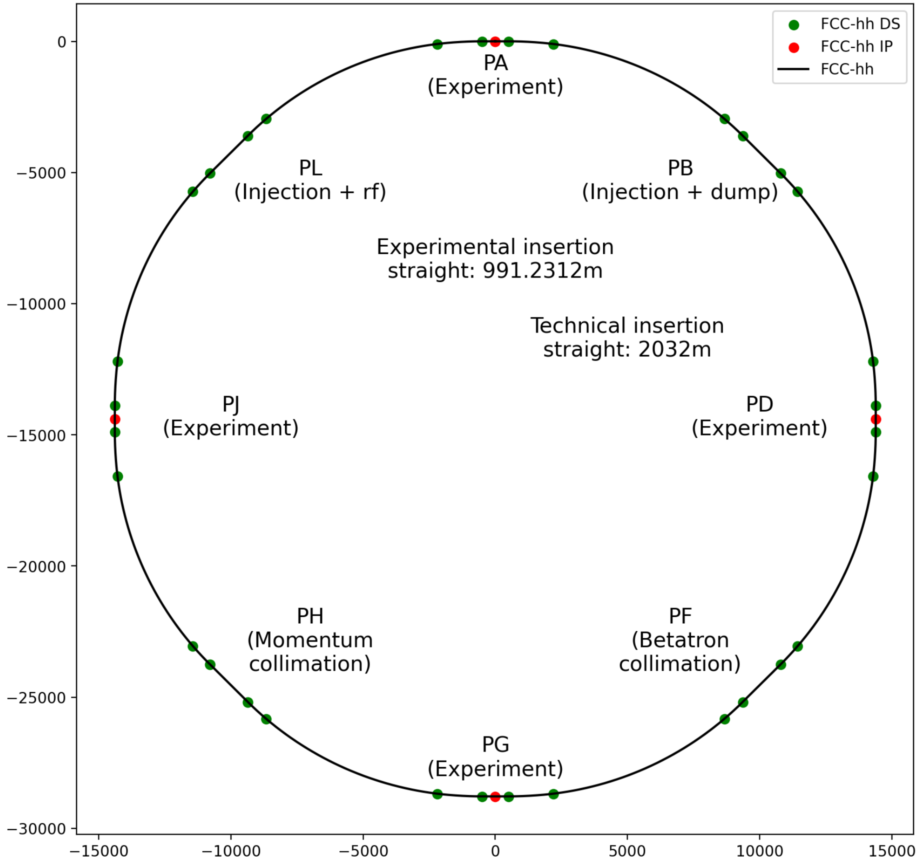
K. Oide



P. Raimondi



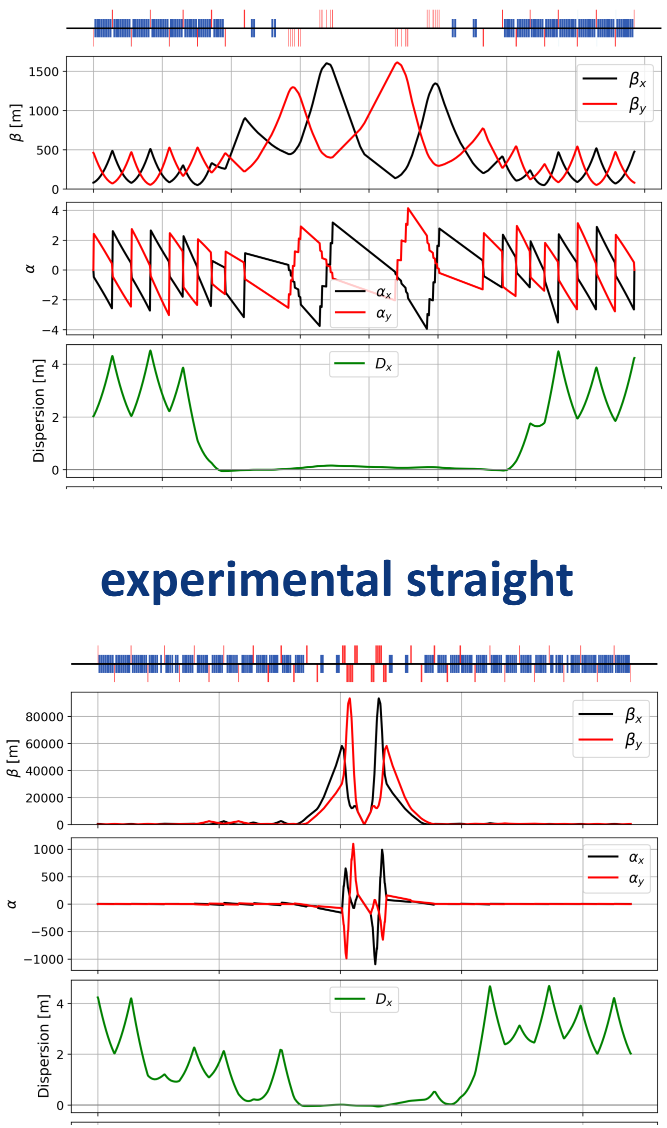
FCC-hh layout, optics work, geom. integration



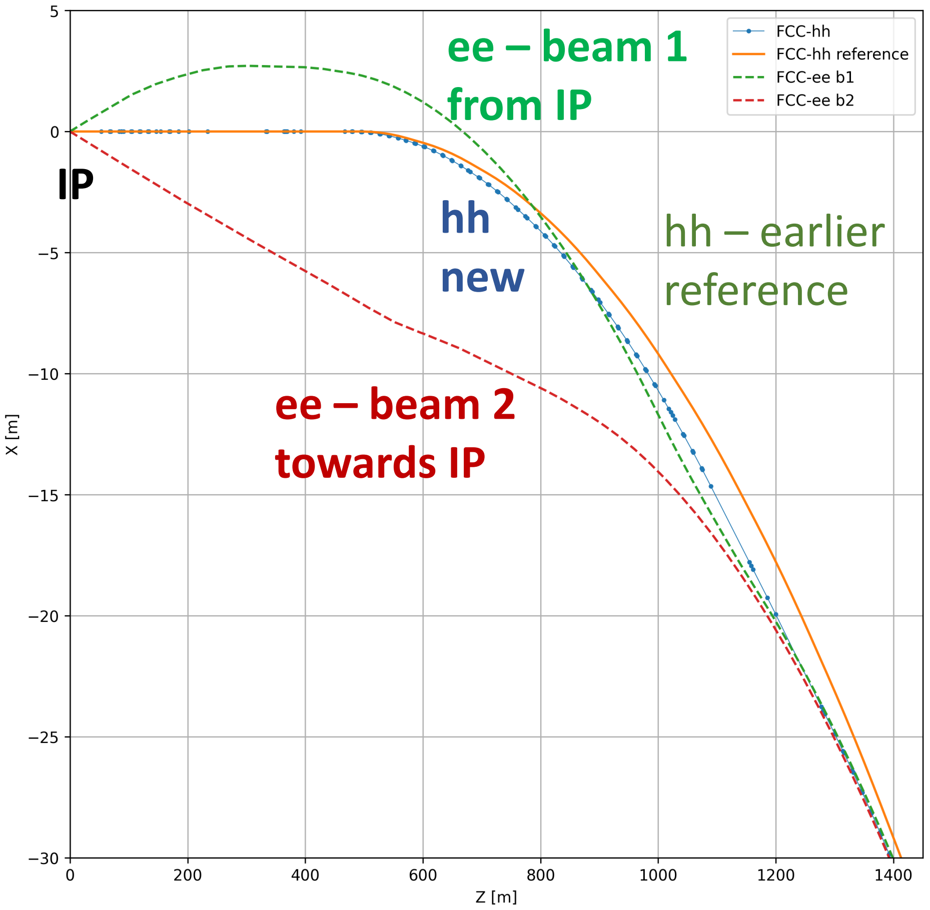
- adaptation to new layout and geometry
- shrink β collimation & extraction by ~30%
- optics optimisation (filling factor etc.)
- move hh IPs on top of ee IP to optimise tunnel and cavern widths.

betatron collimation straight

experimental straight



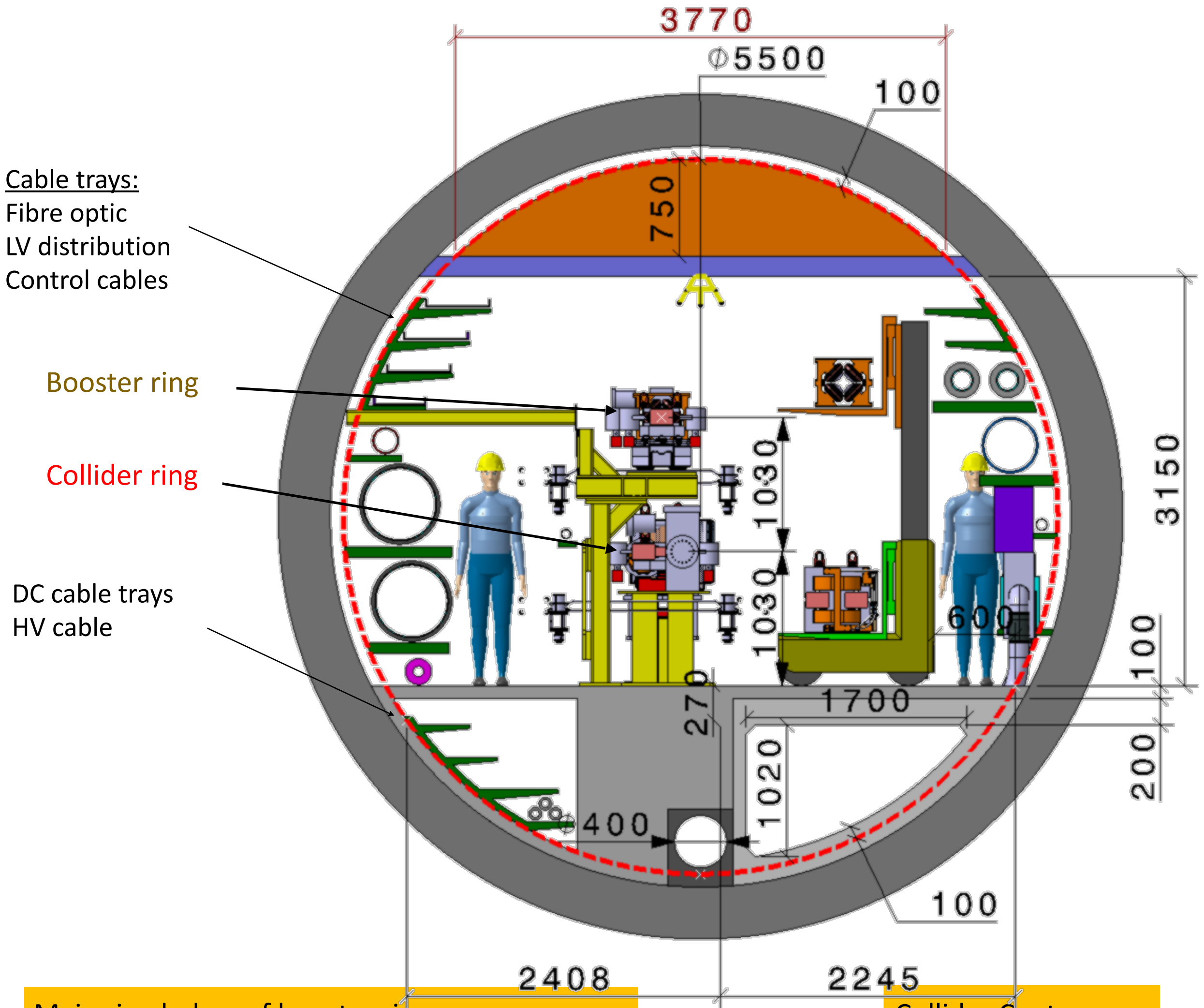
3 - beam footprint at interaction point



M. Giovannozzi, T. Risselada, G. Perez Segurana, M. Hofer, K. Oide

regular arc tunnel cross section & element integration

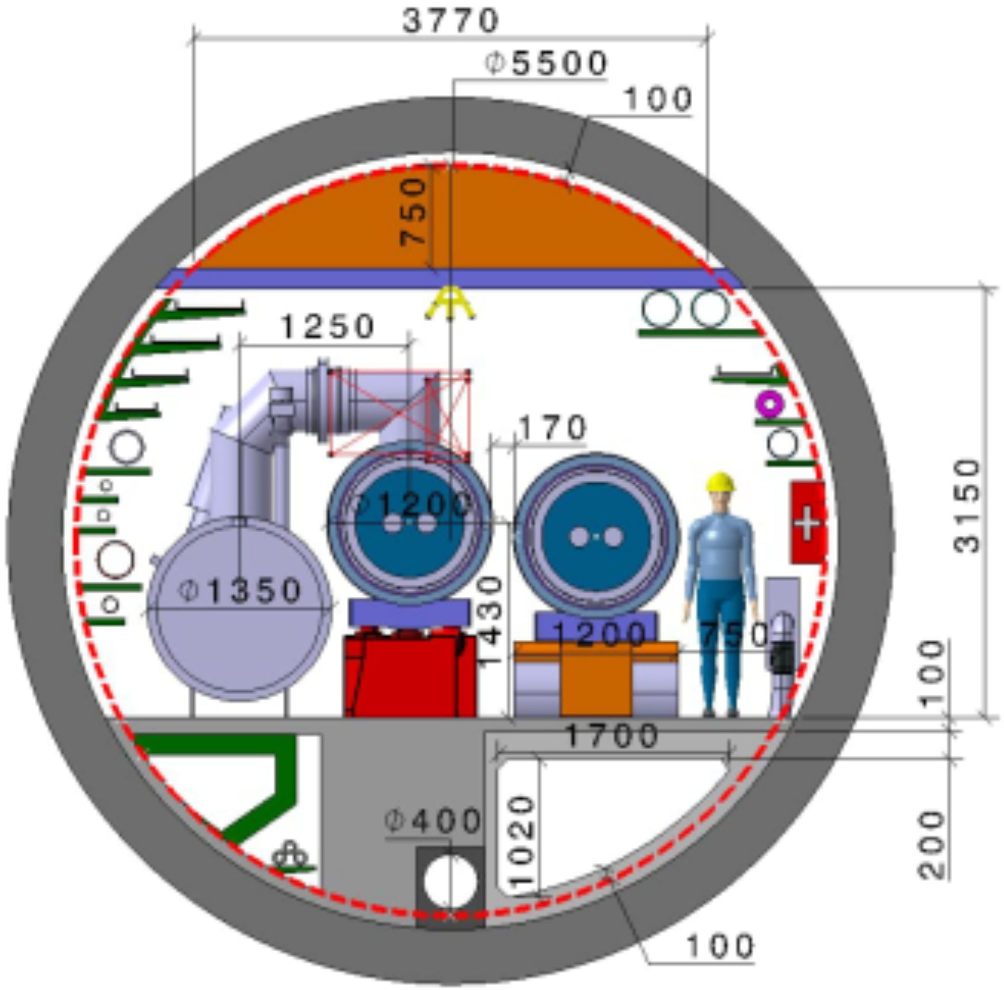
FCC-ee



Main ring below of booster ring
Main ring and booster ring 1.03 m apart

Collider Center

FCC-hh



F. Valchkova

Collider Center

FCC-hh parameters

FUTURE CIRCULAR COLLIDER

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, …

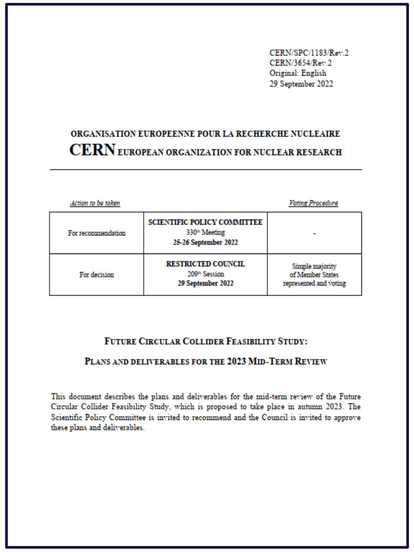
Formidable physics reach, including:
- ❑ Direct discovery potential up to ~ 40 TeV
- ❑ Measurement of Higgs self to ~ 5% and ttH to ~ 1%
- ❑ High-precision and model-indep (with FCC-ee input) measurements of rare Higgs decays ($\gamma\gamma$, $Z\gamma$, μμ)
- ❑ Final word about WIMP dark matter

F. Gianotti

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.

SAC: review of deliverables 1, 2, 3, 4, 5, 6, 8

- D1: Definition of the baseline scenario
- D2: Civil engineering
- D3: Processes and implementation studies with the Host States
- D 4: Technical infrastructure
- D5: FCC-ee accelerator
- D6: FCC-hh accelerator
- D7: Project cost and financial feasibility
- D8: Physics, experiments and detectors

Cost Review Panel Mandate

- Review the methodology and assumptions used in producing the cost estimates
- Identify inaccurate or missing cost information
- Check the consistency of the cost estimates with respect to applicable reference work, e.g., recent large-scale infrastructure and accelerator projects
- Review the uncertainty estimates
- Identify potential areas of savings and cost mitigation for future work
- Advise the FCC study team on matters of cost estimation in view of preparation of the final Feasibility Study Report for end 2025

FCC Feasibility Study – mid-term status summary

The first half of the FCC Feasibility Study completed with the mid-term review

- Sept - October 2023: SAC and CRP review of mid-term report
- 20 – 22 November 2023: SPC and FC review meetings on mid-term review
  - ➡ the reviews of SAC and CRP have confirmed an excellent progress of the study, also appreciated by the SPC and FC.

- **2 February 2024**: CERN Council meeting on mid-term review, to endorse the findings/conclusions of SAC/CRP/SPC/FC

Focus 2024 - 2025:

- Subsurface investigations, further optimization of implementation, surface sites, synergies, etc.
- Full design iteration in view of technical and cost optimisation of entire project.

FUTURE CIRCULAR COLLIDER

Total Estimated Cost at Mid-Term Review

Domain	2 IP, without ttbar MCHF	4 IP, without ttbar MCHF Additional	4 IP, incl ttbar MCHF Additional
Total, Accelerators	3,847	60	1,144
Total, Injectors and transfer lines	585		
Total, Civil engineering	5,538	480	
Total, Technical infrastructures	2,490	28	321
Total, Experiments	150	142	
Total, Territorial Development	191		
FCC-ee TOTAL	**12,801**	**710**	**1,465**

A. Unnervik

FUTURE CIRCULAR COLLIDER

Visit of Swiss President A. Berset and French President E. Macron on 16 November 2023

F. Gianotti

President Macron’s declaration:

"Si j’ai voulu venir là aujourd’hui c’est pour témoigner ma confiance aux équipes et notre volonté, notre ambition de conserver la première place dans ce domaine.” [“My visit here bears witness to my trust in CERN personnel and France’s will and ambition to keep the leadership in this domain.”]

Enlarging the Collaboration - setup

FCC Global Collaboration Working Group (FGC)

International Forum of National Contacts (IFNC)

Two approaches, one globally-oriented (FGC), the other more PED oriented (IFNC), both to engage with countries with mature communities, a long-standing participation in CERN's programmes and the potential to contribute substantially to the Organization's long-term scientific objectives, to facilitate opportunities for national participation in the Feasibility Study

- **Work with national laboratories, institutes and universities as well as industry to :**
  - Encourage an expanded membership.
  - **Explore opportunities for future prospective participants, in particular on the Accelerator side**
  - Support new participants in application process.
  - Assist the new participants in **defining areas of collaboration** and conclude relevant agreements.
  - Facilitate the integration process.
  - **Facilitate interest in CERN non-core areas –e.g. geology, geodesy, logistics, materials science.**
  - Prepare the foundations for research and contributions by industry.
  - Liaise with National Contact persons

Convened by Emmanuel Tsesmelis (CERN international relations)

- **Contact directly Physics groups in a country,** typically from LHC or Future Colliders groups to ask them **to join as new institution**
  - Discuss the physics case and the opportunities
    - → To study **R&D/ Detector concepts** for FCC
    - → To expand the FCC Physics scope via the study of **physics case studies**
    - → To improve the **theoretical calculations** to exploit the FCC physics potential
  - Help **forming a national FCC group**, with strong PED component, which can hold its national FCC meetings, including the Accelerator community when possible
  - Identify at least one **National Contact** to exchange information between country situation and FCC management, and to strengthen the national community
  - Exchange experience across countries (**IFNC meetings**)

Convened by Gregorio Bernardi and Tadaeus Lesziak (National Contacts)

FCC Physics/experiments/detector activities

Home page (join the mailing lists, events, mtgs, etc): https://fcc-ped.web.cern.ch/

Indico category: https://indico.cern.ch/category/5251/

WGs

Physics programme and performance

- Electroweak Physics
- Higgs physics
- Top-quark physics
- Flavour physics
- QCD and γγ physics
- BSM physics

Performance web page: https://hep-fcc.github.io/FCCeePhysicsPerformance/

Detector concepts

Software and computing

Machine-Detector Interface

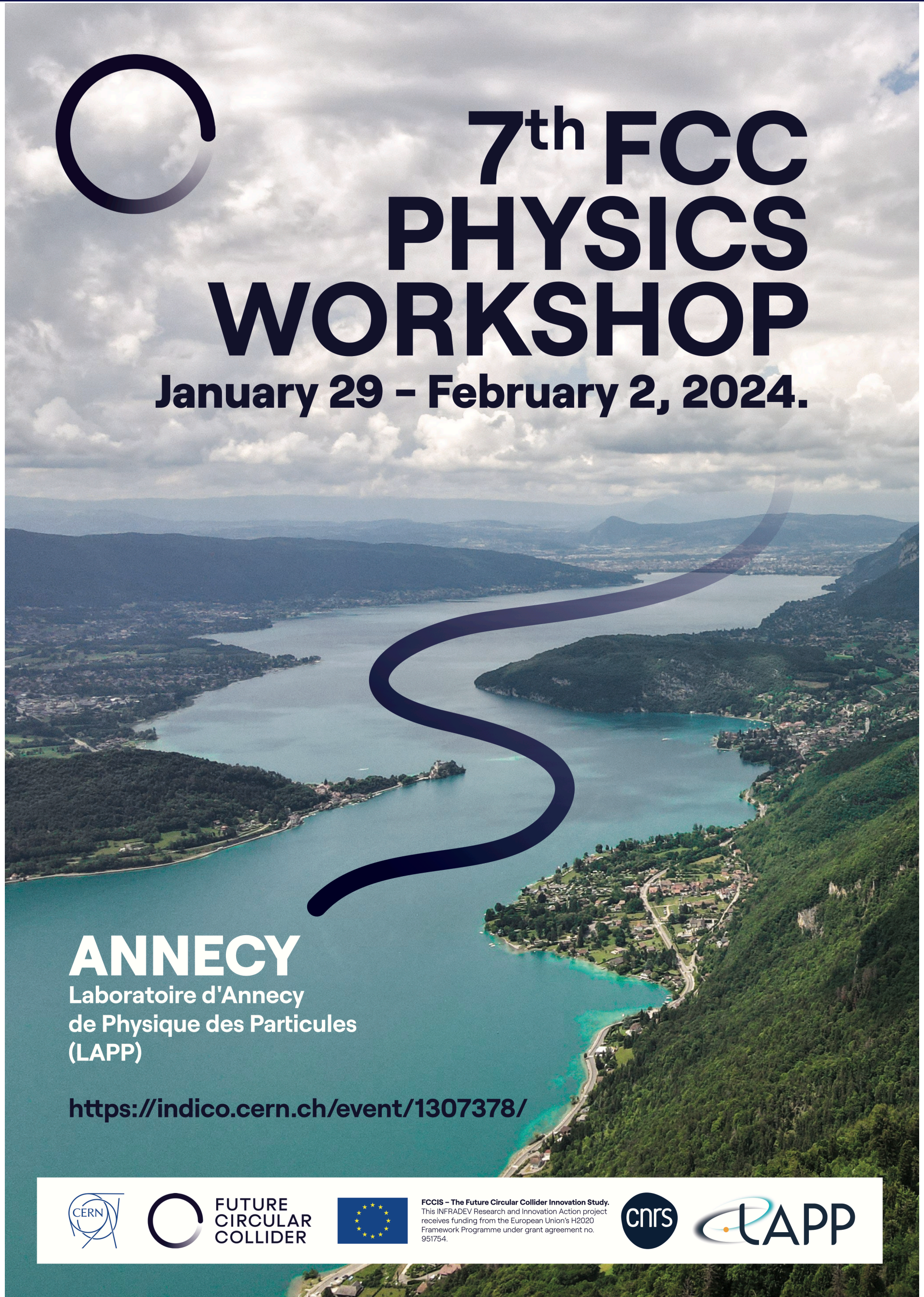
Beam energy calibration etc

global engagement

International forum of National contacts

National Institute meetings

FCC Physics/experiments/detector activities



https://indico.cern.ch/event/1307378/

7th FCC physics workshop

Annecy FCC Physics Workshop: Jan. 29-Feb. 2, 2024					
	Monday 29.01	**Tuesday 30.01**	**Wednesday 31.01**	**Thursday 01.02**	**Friday 02.02**
9:00-10:30	Arrival at LAPP Registration	Phys. Prog. (Big picture, cosmo, interplay) Jt Dectector & MDI SW (Key4HEP)	MDI SW (Generators) Jt Phys. Perf. & Detectors	SW (Reconstruction) ~~Jt Phys. Perf. & Dectectors~~	Summaries/Highlights
10:30-11:00		Coffee break	Coffee break	Coffee break	Coffee break
11:00-12:30		Phys. Prog. & Perf. (BSM) Detectors (Calorimeters and PID) SW (Analysis)	Phys. Prog. & Perf. (QCD+Flavour) Jt Detectors/SW MDI	Phys. Prog. & Perf. (Higgs/EW) EPOL SW (Ressources)	The way forward
12:30-14:00	Lunch	Lunch	Lunch	Lunch	Lunch
14:00-15:30	General FCC meeting	Precision challenges the Z lineshape	Precision challenges Luminosity measurements	Precision challenges Other topics	Departure from LAPP
15:30-16:00	Coffee break	Coffee break	Coffee break	Coffee break	
16:00-17:30	Status of PED feasibility study	Precision challenges Flavours	Precision challenges FCC-hh	Precision challenges BSM sensitivity	
17:30-18:30 could be extended till 19:00	IFNC	Phys. Perf.	Detectors (Tracking and Vertexing) MDI Phys. Prog. (overflow QCD+flavour)	Detectors (Electronics, trigger and DAQ) EPOL Phys. Prof. (overflow Higgs/EW)	
19:30-22:30	Welcome reception			Workshop Dinner	

FCC Physics/experiments/detector activities

From the Medium Term Report

The absolutely unique statistical power of circular e+e– colliders

$e^+e^- \to Z$	$e^+e^- \to WW$	$\tau(\leftarrow Z)$	$b(\leftarrow Z)$	$c(\leftarrow Z)$	$e^+e^- \to tt$
$5\ 10^{12}$	10^{8}	$3\ 10^{11}$	$1.5\ 10^{12}$	10^{12}	10^{6}

=> $O(10^5)$ larger statistics than LEP at the Z peak and WW threshold

Flavour statistics from Z decays:

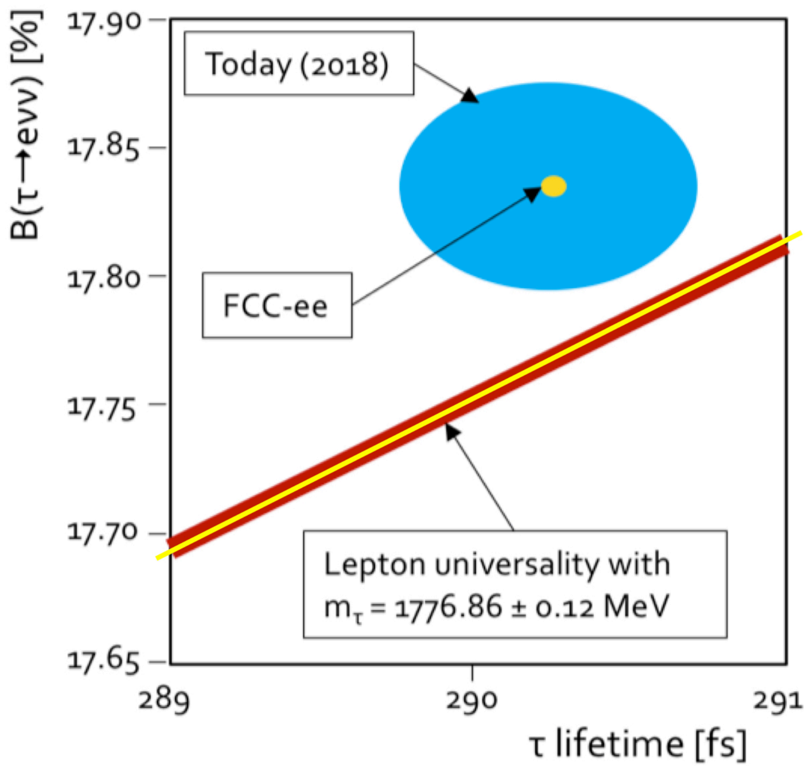
S. Monteil, FCC PED Week 2023

Working point	Lumi. / IP $[10^{34}\ \text{cm}^{-2}.\text{s}^{-1}]$	Total lumi. (2 IPs)	Run time	Physics goal
Z first phase	100	26 ab^{-1} /year	2	
Z second phase	200	52 ab^{-1} /year	2	150 ab^{-1}

Particle production (10^9)	B^0 / $\overline{B}^0$	B^+ / B^-	B^0_s / $\overline{B}^0_s$	Λ_b / $\overline{\Lambda}_b$	$c\bar{c}$	τ^-/τ^+
Belle II	27.5	27.5	n/a	n/a	65	45
FCC-*ee*	300	300	80	80	600	150

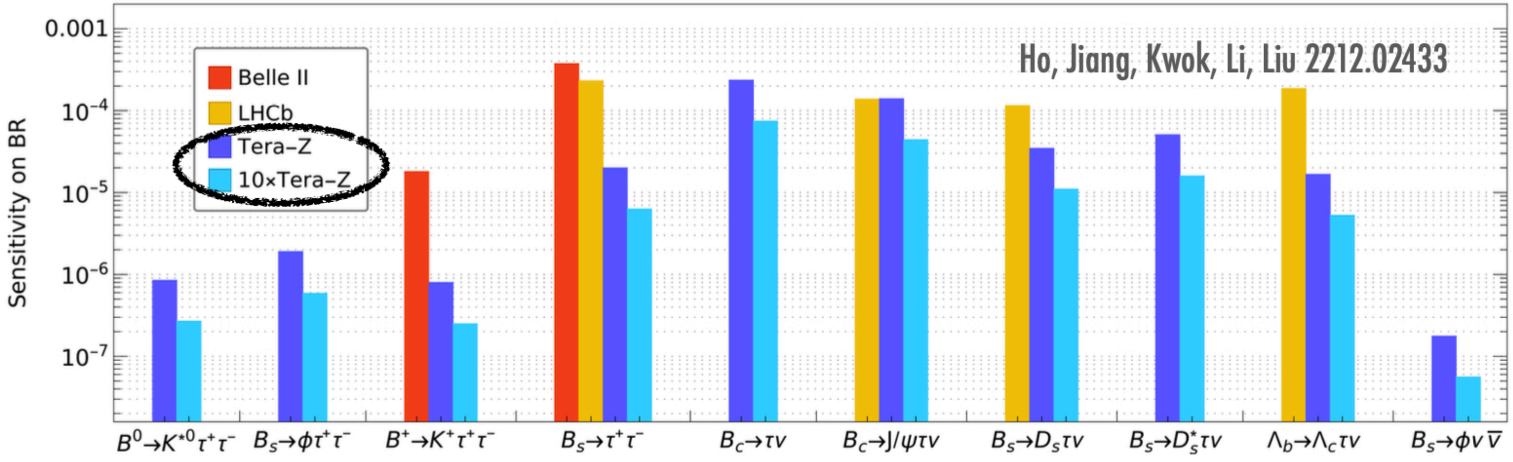
Additional bonus wrt B factory: (i) Lorentz boost (ii) B hadrons not accessible at the Υ(4S,5S) thresholds

Flavour probes: eg lepton universality in tau decays



Lorentz boost crucial!

Observable	Measurement	Current precision	FCC-ee stat.	Possible syst.	Challenge
m_τ [MeV]	Threshold / inv. mass endpoint	1776.86 ± 0.12	0.004	0.04-0.1	Mass scale
τ_τ [fs]	Flight distance	290.3 ± 0.5 fs	0.001	0.04	Vertex detector alignment
$B(\tau\to e\nu\nu)$ [%]	Selection of $\tau^+\tau^-$, identification of final state	17.82 ± 0.05	0.0001	0.003	Efficiency, bkg, Particle ID
$B(\tau\to\mu\nu\nu)$ [%]		17.39 ± 0.05			



For details about the potential of the flavour programme at the Z pole, see Jernej's overview at the 2023 FCC week

05 - 09 June
FCC WEEK 2023

Flavour Programme
Jernej F. Kamenik

1 Leptonic and semileptonic b decays

2 Rare leptonic and semileptonic b decays

3 CPV in b decays and mixing

4 Tau physics

5 Charm physics

6 Flavour @ high-pT

Direct discovery opportunities at FCC-ee

Focus on "low-mass/elusive" scenarios:

LLP, ALPs, HNL and exotic H decays, challenging for HL-LHC and FCC-hh

See e.g.
LLP: Blondel, et al.. https://doi.org/10.3389/fphy.2022.967881
HNL: Blondel et al., https: //doi.org/10.1016/j.nuclphysbps.2015.09.304
FCC LLP working group: https://indico.cern.ch/category/5664/

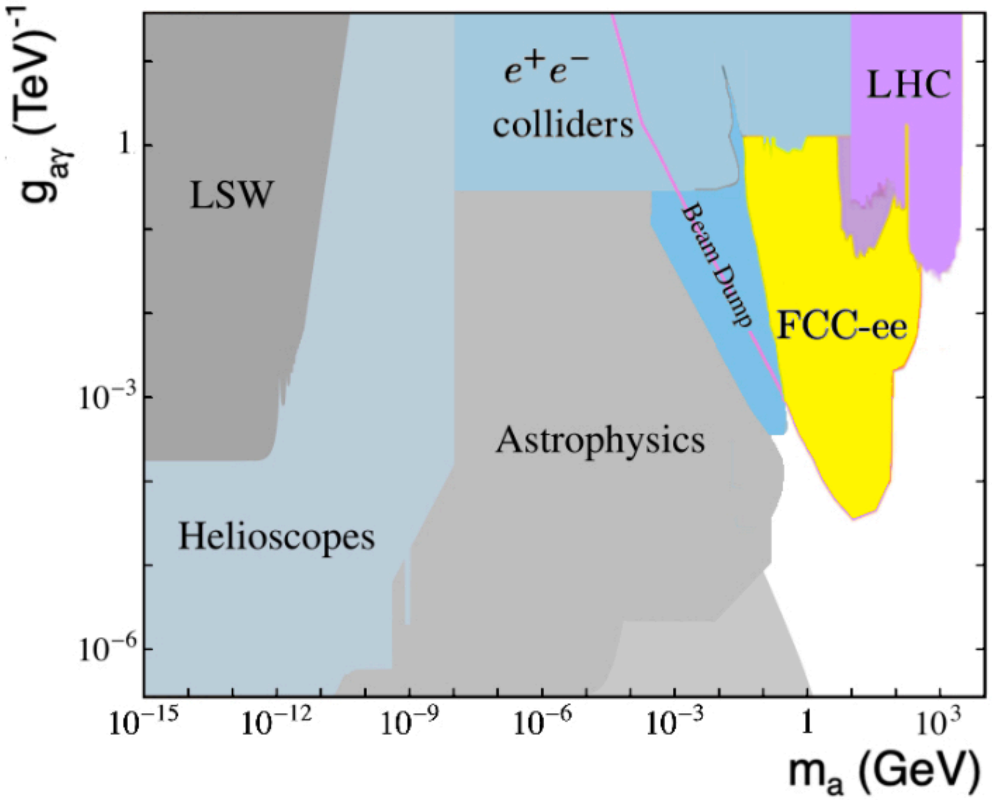
Axion-like particles

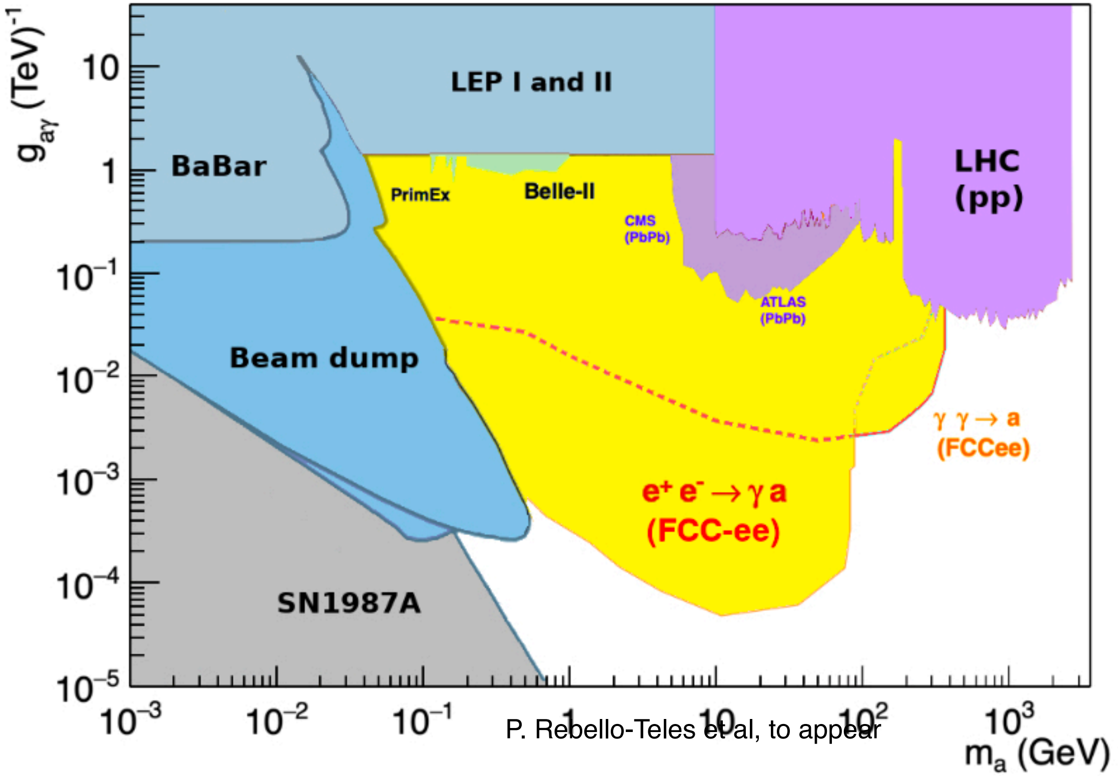
In the run at the Z pole, exploit possible channels such as

$$e^+e^- \to a\gamma \qquad\qquad e^+e^- \to e^+e^-a$$

with

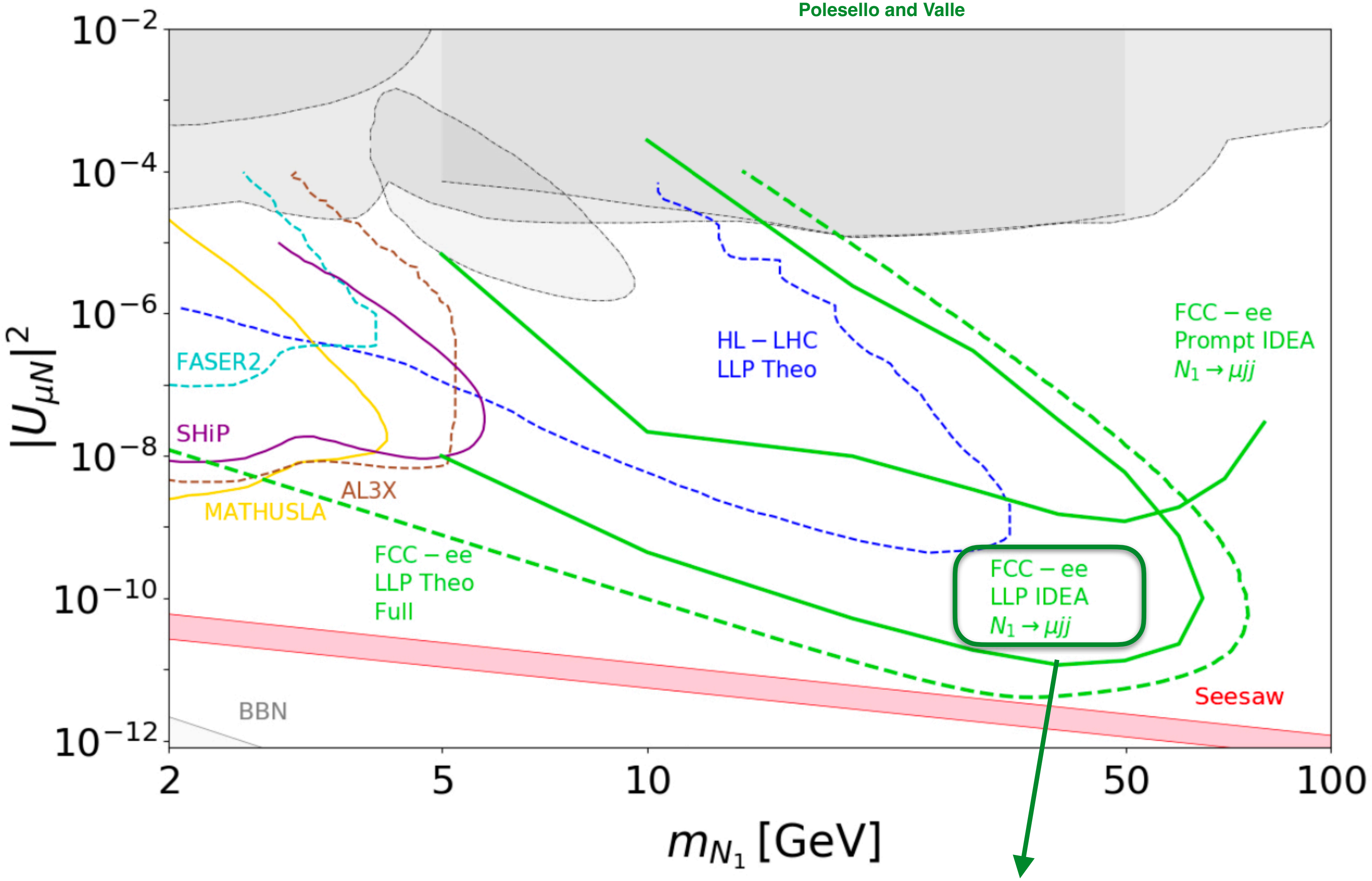
$$a \to \gamma\gamma$$





Heavy Neutral Leptons

$$e^+e^- \to Z \to \nu N \qquad N \to \ell W^* \to \ell jj$$



dedicated search for decay lengths in the 1mm-2m range

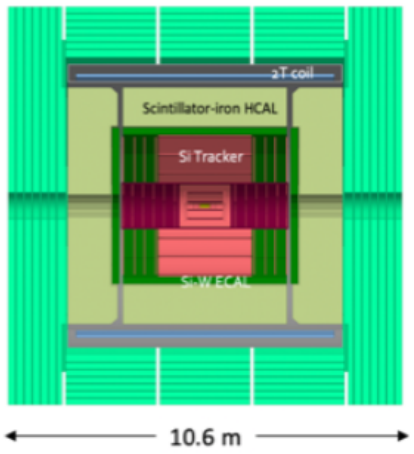
Homework for the rest of the feasibility study

- **Consolidate the PED studies for the key components of the FCC-ee programme (Higgs, EW/QCD, flavour, searches),** *including a strategy for precision TH calc's*
- **Further develop FCC-ee detector concepts leading to multiple detector/ collaboration LoIs for the next Strategy**
- **Review the FCC-hh physics potential:**
  - *complementarity/synergy with FCC-ee*
  - *E_{CM} range*
  - *consider non-general-purpose detectors (eg for LLPs, etc)*

FUTURE CIRCULAR COLLIDER

FCC-ee detector concepts under study

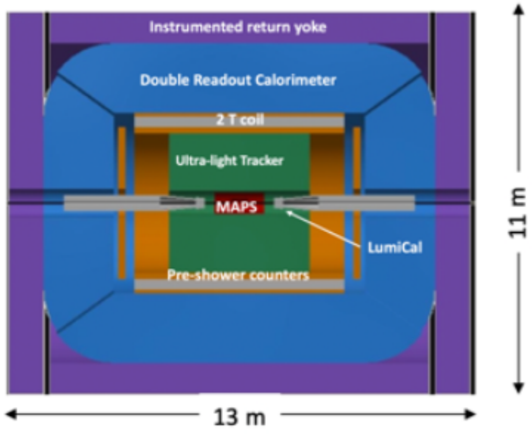
CLD



CDR

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

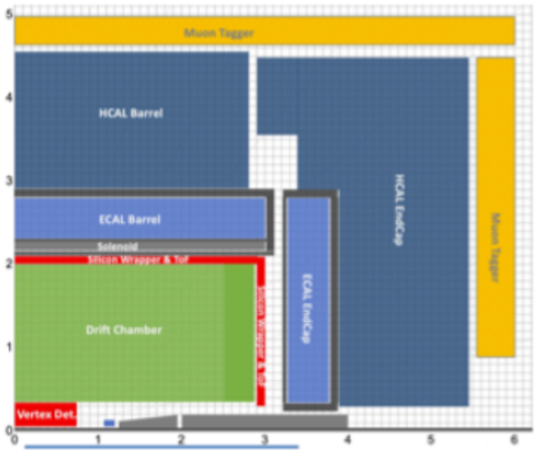
IDEA



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

Noble Liquid ECAL based

new

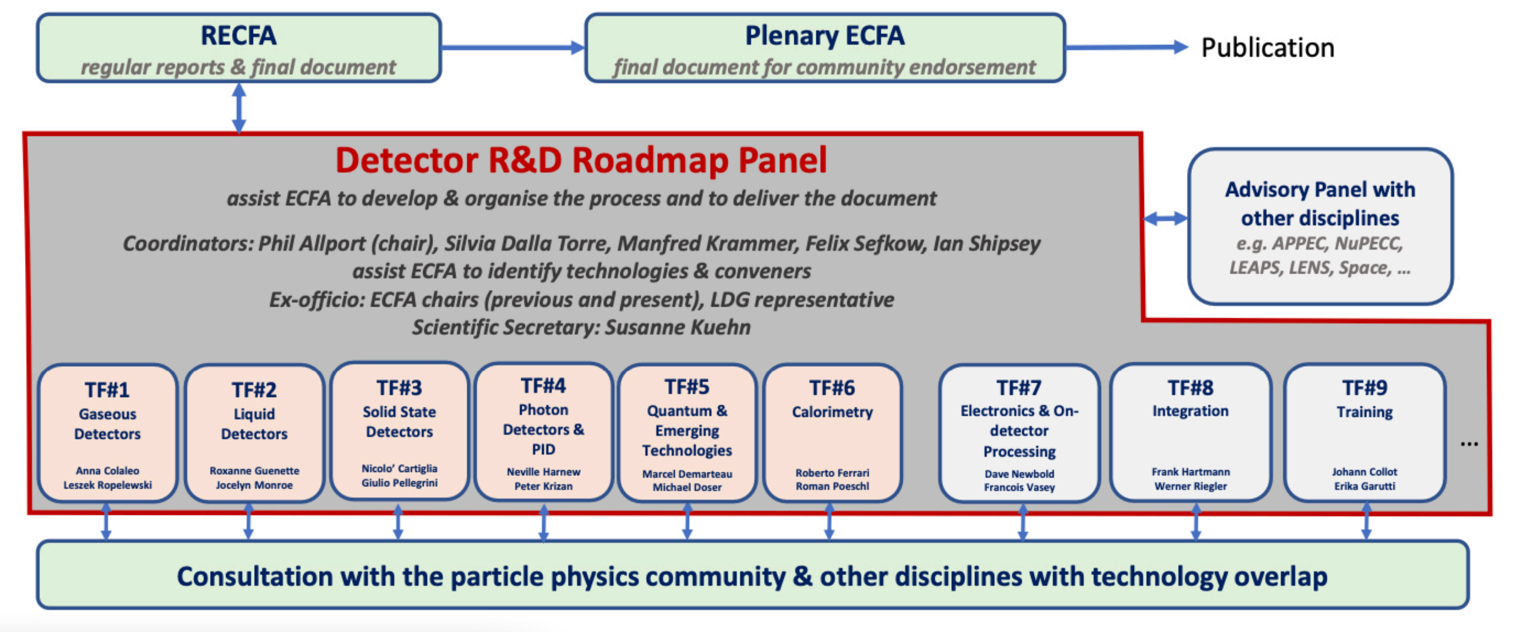


- A design in its infancy
- High granularity Noble Liquid ECAL is core
  - Pb+LAr (or denser W+LCr)
- Drift chamber; CALICE-like HCAL; muon system.
- Coil inside same cryostat as LAr, possibly outside ECAL
- Active Noble Liquid R&D team
  - Readout electrodes, feed-throughs, electronics, light cryostat,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

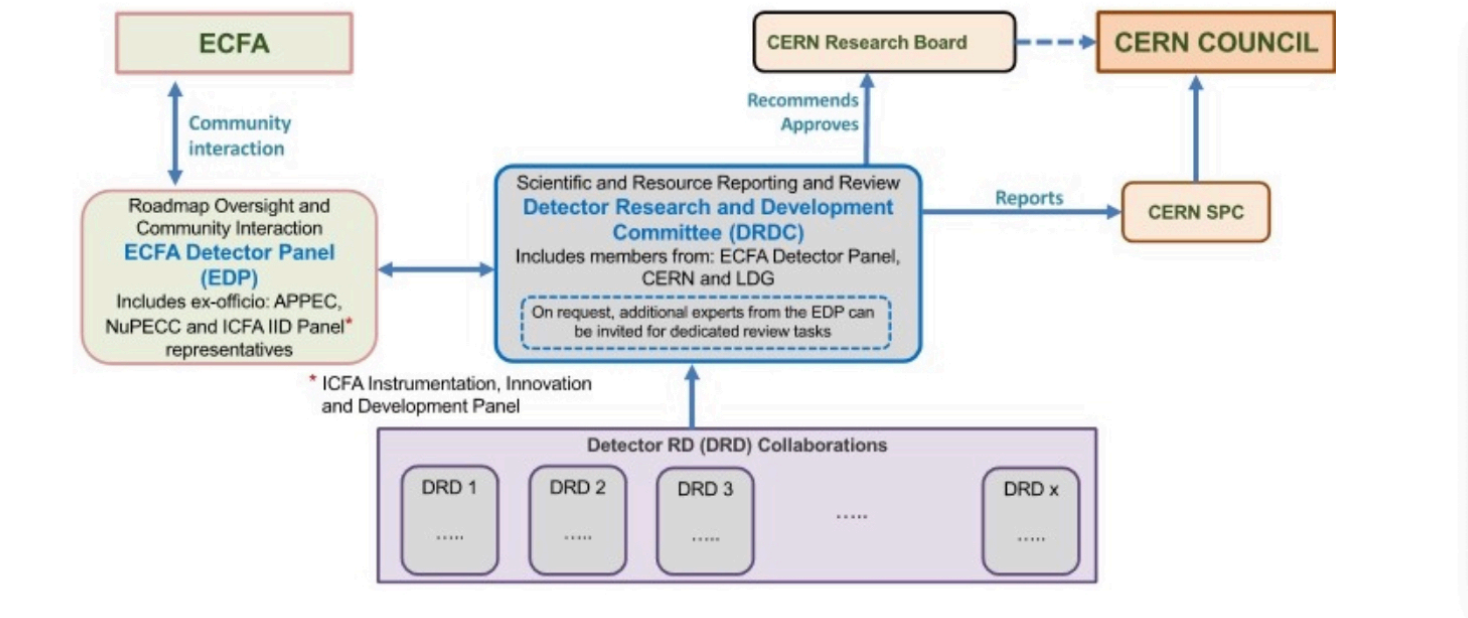
M. Dam, et al.

PED initiatives on future colliders in Europe: detector R&D

Roadmap and implementation reports prepared by Roadmap Panel, https://ecfa-dp.desy.de (chair P.Alport)
endorsed by CERN Council Sept 2022



Implementation path: DRDC (http://committees.web.cern.ch/drdc, T. Bergauer chair)



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Status of Proposed DRD Collabs.

(T. Bergauer)

Collab.	Topic	Initial Proposal Submission	Seeking approval	comment
DRD 1	Development of Gaseous Detectors	July 2023	Dec. 2023	Former RD51
DRD 2	Liquid Detectors	July 2023	Dec. 2023	
DRD 3	Solid State Detectors	3 Oct. 2023	Dec. 2023	Former RD50
DRD 4	Photon Detectors and Particle Identification Techniques	July 2023	Dec. 2023	
DRD 6	Calorimetry	July 2023	Dec. 2023	CALICE, CrystalClear
DRD 5	Quantum and Emerging Technologies		later	
DRD 7	R&D Collaboration for Electronic Systems	LoI submitted	later	
TF 8	Integration	-	later	Workshop on 6th Dec.

- DRD 1, 2, 4, 6 approved by RB in December 2023

- DRD3 to be redicussed in March '24 RB mtg
- DRD 5, 7 expected to be submitted by March

Following steps
(T. Bergauer)

- A coherent picture of **resources across all DRDs** so that funding agencies get the total demand
  - Discussions on national level started
  - Currently, the strategic funding listed in the proposal is just "wishful thinking"
- Better **coordination between different DRDs** to **reduce duplications** and **synchronize activities**, especially for electronics (e.g. CMOS sensors)
- Coordinated approach on how **to involve industry** (IP topics) and **non-European groups**

ECFA Higgs/Top/EW Factory Study

[HiggsTopEW gitlab wiki]

ECFA e^+e^- Higgs/Top/EW Factory Study

WG1 physics performance

Coordinators: Jorge de Blas, Patrick Koppenburg, Jenny List, Fabio Maltoni

Global interpretations (GLOB) Conveners: Jorge de Blas, Sven Heinemeyer, Alexander Grohsjean, Junping Tian, Marcel Vos

Precision (PREC): Conveners: Ayres Freitas, Paolo Azzurri, Adrian Irles, Andreas Meyer

Higgs/Top/EW: Conveners: Chris Hays, Karsten Köneke, Fabio Maltoni

Flavour (FLAV): Conveners: David Marzocca, Stéphane Monteil, Pablo Goldenzweig

Searches (SRCH): Conveners: Roberto Franceschini, Rebeca Gonzalez Suarez, Filip Zarnecki

WG2 Physics Analysis Methods

Conveners: Patrizia Azzi, Fulvio Piccinini, Dirk Zerwas

WG3 Detector R&D

Conveners: Mary Cruz Fouz, Giovanni Marchiori, Felix Sefkow https://agenda.infn.it/event/34841/

Focus topics report

Contents

https://arxiv.org/abs/2401.07564

Final words

- The mid-term report of the feasibility study will be reviewed next week by Council, following the positive assessment and constructive feedback from Scientific Advisory Committee and Cost Review Panel
- **The feasibility of the FCC project is getting closer and closer to the real axis**