FCC

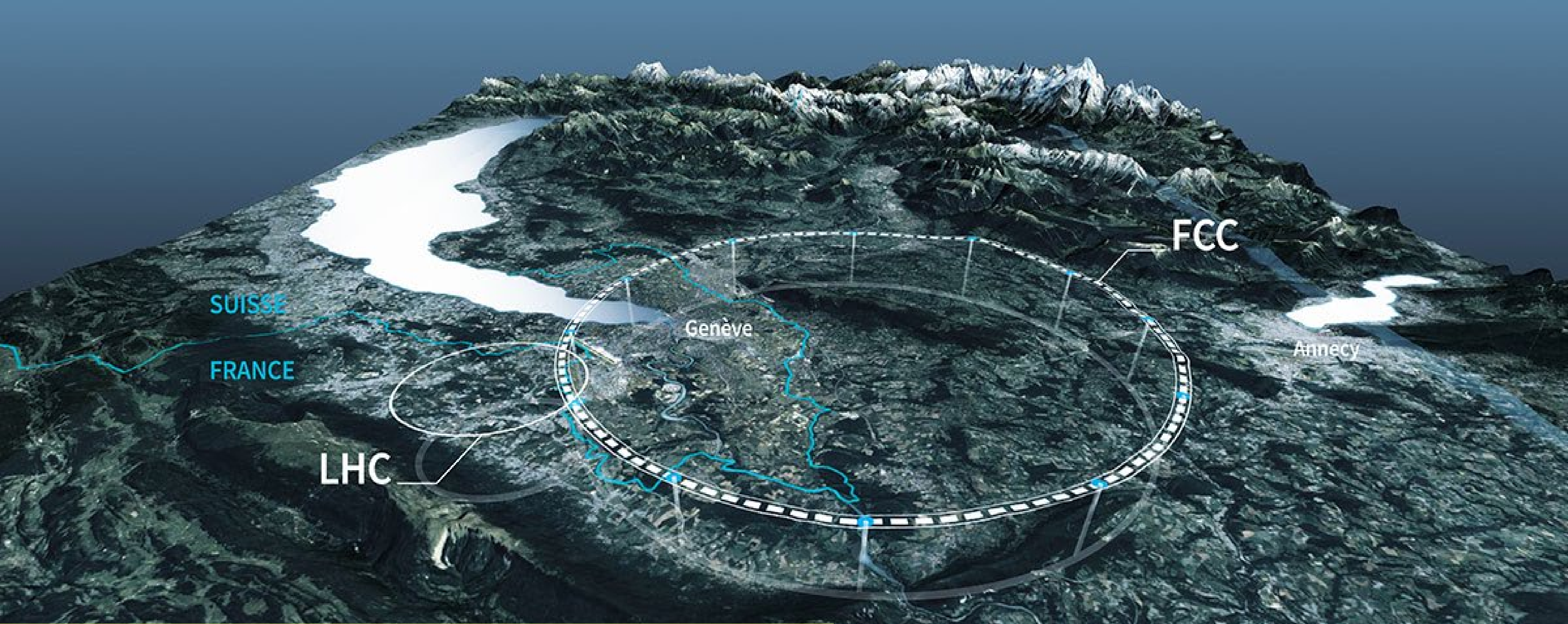
Challenges of the Future Circular Collider (FCC) project

SPAS 2024, 21st October 2024

Marek Gąsior

Beam Instrumentation Group, CERN

SPAS 2024



Timeplan

The Integrated FCC Project offers a research program spanning more than 70 years, until the end of the 21st century.

FCC - ee (Total: 35 years)	8	years for preparatory phase
	10	years of construction
	15	years of operation
FCC - hh (Total: 35 years)	10	years for installation and commissioning
	25	years of operation

Why FCC ?

1) Physics

Immense physics potential (best overall physics potential of all proposed future colliders)
A multi-stage facility at the energy and intensity frontier

- ❑ FCC-ee : highest luminosity at Z, W, ZH energies of all proposed Higgs and EW factories → ultra-precise measurements of Higgs boson and other EW parameters → indirect exploration of next energy scale (~ x10 LHC)
- ❑ FCC-hh : only machine able to explore next energy frontier directly (~ x10 LHC); unparalleled measurements of several Higgs couplings
- ❑ Also provides heavy-ion collisions and, possibly, ep/e-ion collisions
- ❑ 4 collision points → robustness; specialized experiments for maximum physics output

2) Timeline

- ❑ FCC-ee technology ~ mature → construction can proceed in parallel to HL-LHC operation and physics can start few years after end of HL-LHC operation (~ 2045) → This would allow ensure continuity of expertise and keep the community, in particular the young people, engaged and motivated.
- ❑ FCC-ee before FCC-hh would also allow:
  - cost of (more expensive) FCC-hh to be spread over more years
  - 20 years of R&D work towards affordable magnets providing the highest achievable field (HTS!)
  - optimization of overall investment: FCC-hh will reuse same civil engineering and large part of FCC-ee technical infrastructure

3) Community

It's the only facility commensurate to the size of the current CERN community (4 major experiments).
Note: for the future of the field, it's crucial to have facililites that expand (or at least maintain) the worldwide HEP community by offering a broad enough programme of exciting physics, experiments and technology, with the goal of attracting many new young talents

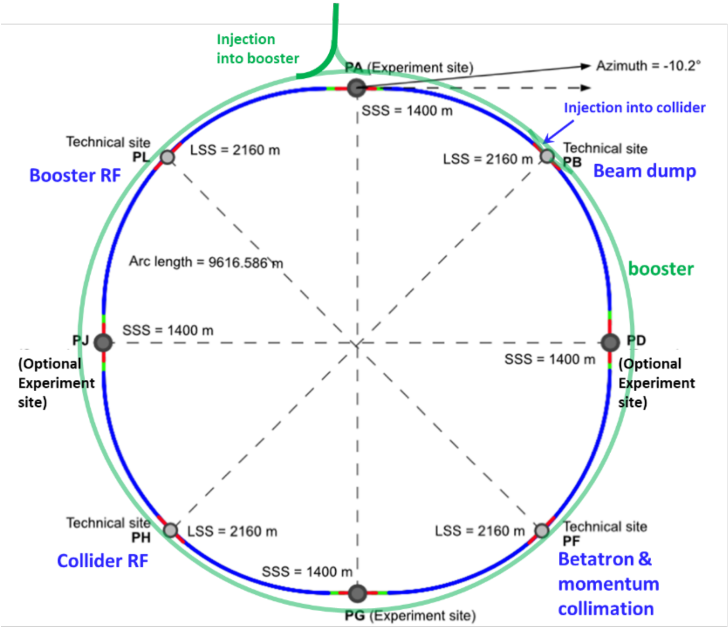
F. Gianotti, FCC 2024 Week, San Francisco

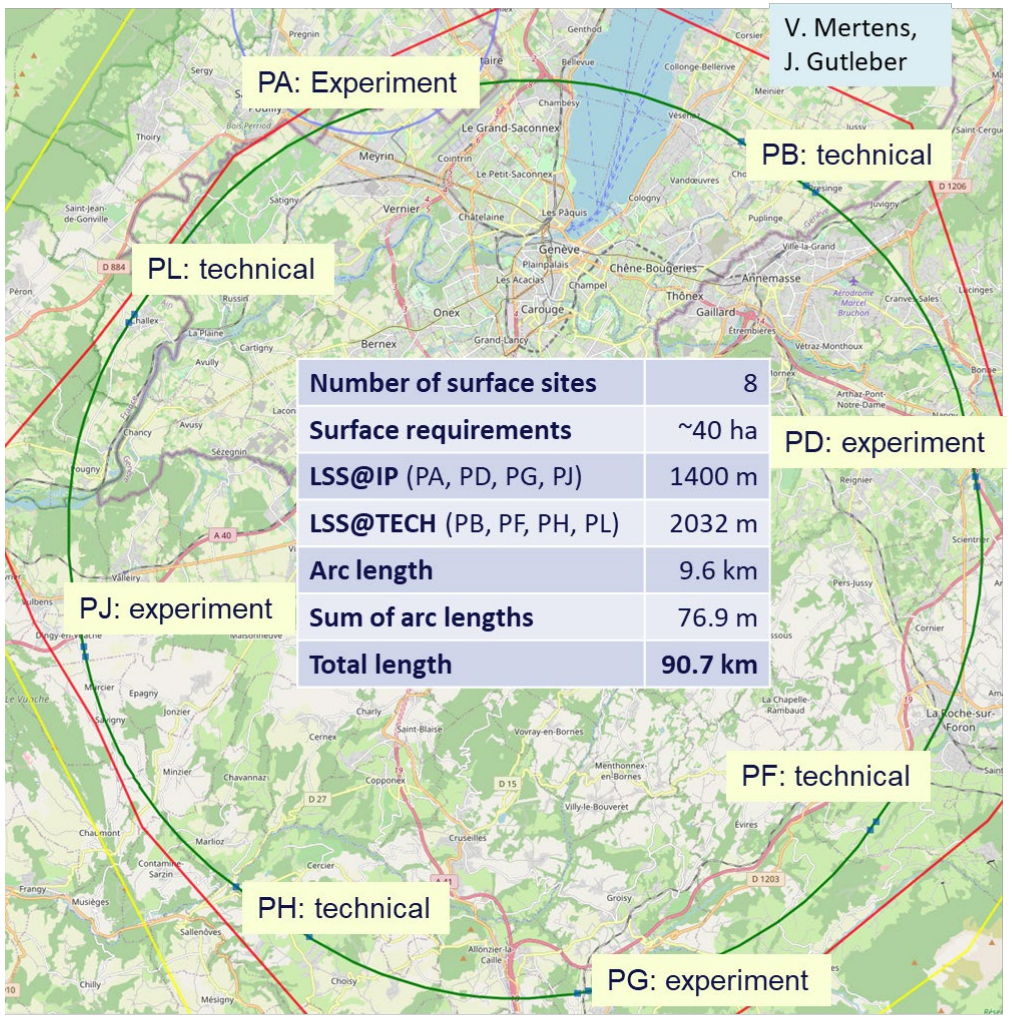
Reference layout PA31 – 90.7km

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





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**

FCC-ee underground schematics

Tunnel Circumference: 90.7 km

Excavated vol: 6.2M m^3 (In the ground)

Access shafts: 12

Construction shafts: 1

Large experiment sites: 2

Small experiment sites: 2

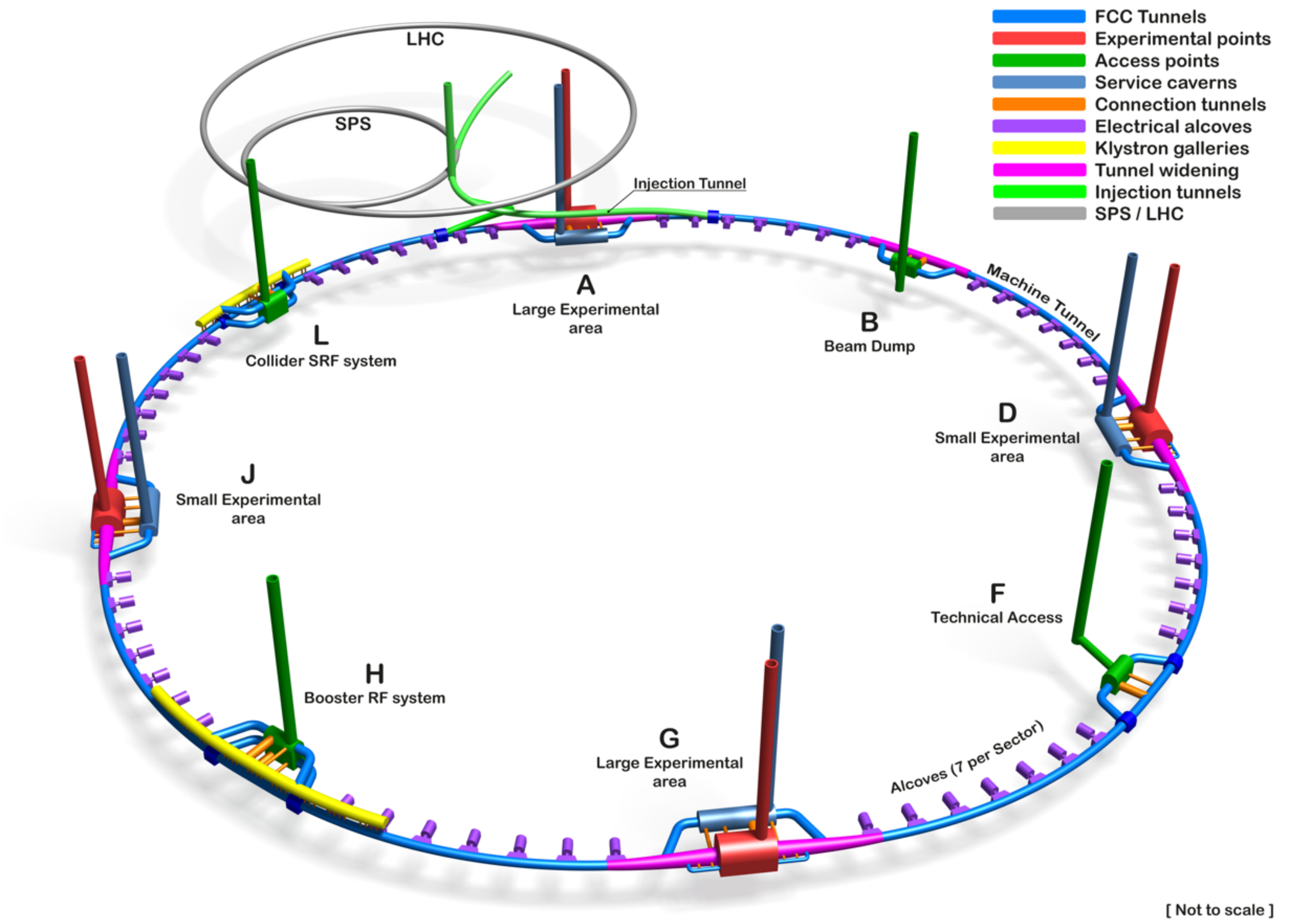
Technical sites: 4

Deepest shaft: 400m

Average shaft depth: 243m

Total concrete volume: 1.9 M m^3

Steel weight: 130,000 metric tonnes



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.

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
vertical rms IP spot size [nm]	36	47	40	51
beam-beam parameter ξ_x / ξ_y	0.002/0.0973	0.013/0.128	0.010/0.088	0.073/0.134
rms bunch length with SR / BS [mm]	5.6 / 15.5	3.5 / 5.4	3.4 / 4.7	1.8 / 2.2
luminosity per IP [10^{34} cm^{-2}s^{-1}]	140	20	≥5.0	1.25
total integrated luminosity / IP / year [ab^{-1}/yr]	17	2.4	0.6	0.15
beam lifetime rad Bhabha + BS [min]	15	12	12	11
	4 years 5 x 10^{12} Z LEP x 10^5	2 years > 10^8 WW LEP x 10^4	3 years 2 x 10^6 H	5 years 2 x 10^6 tt pairs

Design and parameters to maximise luminosity at all working points:

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

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

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

F. Gianotti

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

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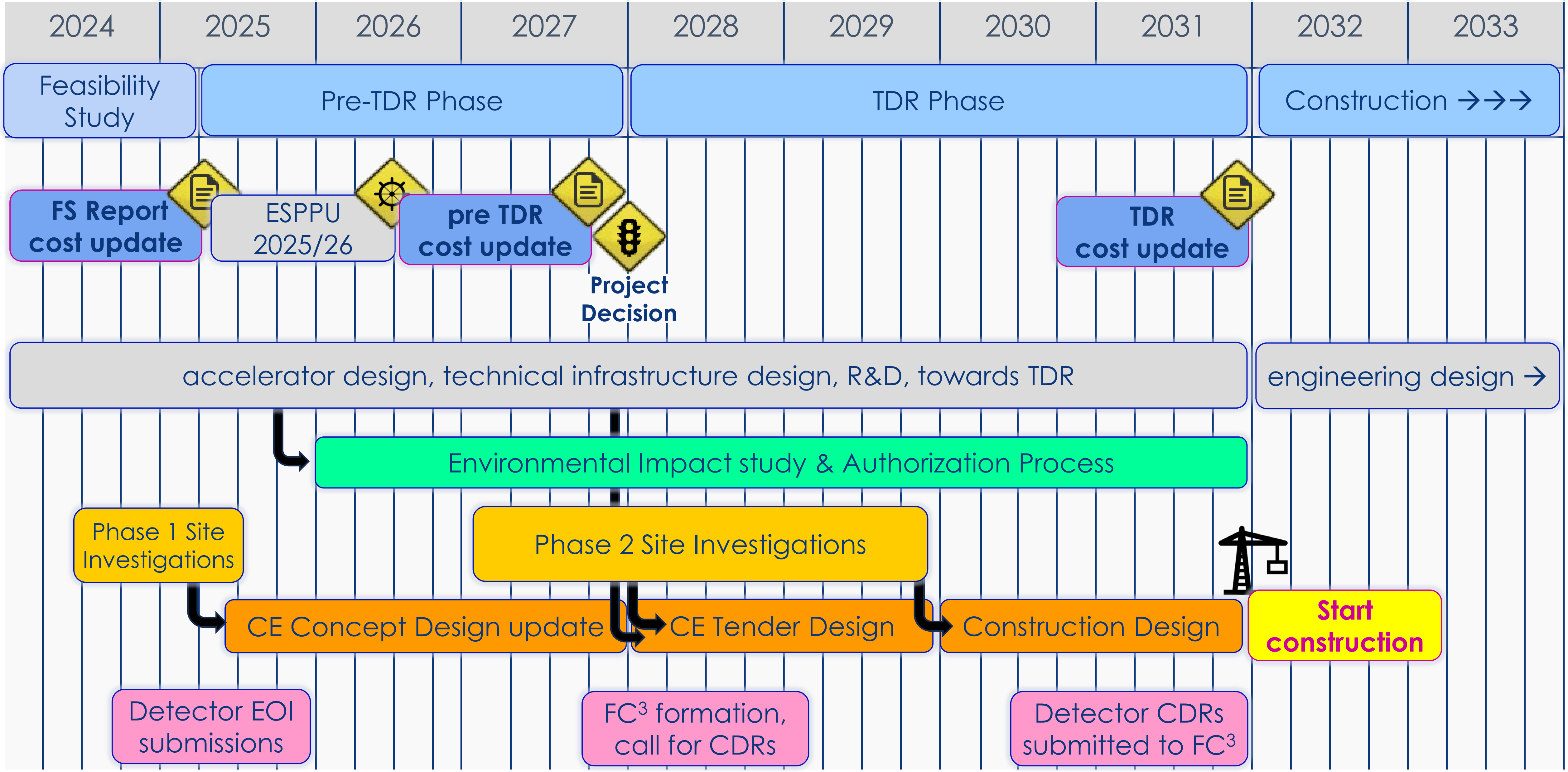
FUTURE CIRCULAR COLLIDER

Expected time line till start of construction



Environment report: 2 Volumes

Non-technical presentation of the FCC and the environment it would be embedded in.
In french **for administrative services, the public and as basis for pre-project phase activities**.

Volume 1: Environmental aspects

High level descriptions of all infrastructures, collider and experiment subsystems.

Identification of aspects that may lead to noteworthy environmental impacts as far as the current level of concepts allow (**prioritisation**).

Functional descriptions of surface sites and needed territorial developments.

Description of the construction activities.

Description of the installation activities.

Volume 2: Environmental initial state

Non-technical presentation of **the FCC motiviation**, study and a potential project.

Environmental strategy and guiding principles for Ecodesign to be considered by infrastructure and equipment designers in pre-TDR phase.

Environmental analysis of perimeter:

- Climate, air, water, soil, geology, biodiversity, habitats, urbanism, mobility, economic activities, patrimony (cultural, architectural, archeological, natural), landscape, noise, vibration, artificial light pollution, radiation, natural risks, technical risks, potentially conflicting and synergetic projects.
- **Evolution of the territory without FCC**.

Sustainability and key environmental aspects

Electricity consumption on average: 1.3 TWh / year
- In ballpark of CERN, ¼ of BASF Ludwigshafen plant (5.3 TWh) or 1 hyperscale data centre
- Renewable Energy Supply Feasibility Analysis (https://zenodo.org/doi/10.5281/zenodo.8074976)
- Construction with renewable energy set as the baseline.

Water consumption with 3 million m^3/year less than CERN in 2022.
- Feasibility with single intake from lake confirmed by local water supplier (SIG).
- Study being engaged to explore opportunities for use of wastewater (site PD).

Land surface needs reduced from ~ 100 ha with 12 sites to ~ 40 ha with 8 sites.
- No conflict with environmental protection zones. Fauna & flora analysed in 2023.
- In principle feasibility verified, land value estimated, agricultural economic loss estimated in 2024.
- Compensation actions to be developed with accompaniement of host states at later stage.
- Potentials for renaturalisation, wetland protection, biodiversity improvements identified.

Strategy for management of excavated materials (16.4 Mt over 8 years in 2 countries) developed.
- Entire volume can in principle be used for quarry backfill (valid for horizon 2030).
- To reduce CO_2 footprint, cost and nuisances, alternative approaches are being developed.

Sustainability and key environmental aspects

Waste heat:

- Potential to **supply > 30% of the heat** to local consumers (300 to 400 GWh/year)
- **Requires site-specific concept developments** to address most suitable consumers nearby and stimulate developments around the sites.
- **Requires** the development of an **adaptive operation concept**.

Carbon footprint:

- **LCA study for construction phase** launched with industrial partner to establish reference baseline.
- Optimisation of the civil engineering concepts as most effective way to lower carbon footprint.
- Carbon footprint is highly depending on local project implementation scenario. Therefore, study relies on specific resources and processes with EN 15804 Environmental Product Declarations (EPD).
- Results to be included in the feasibility study report.

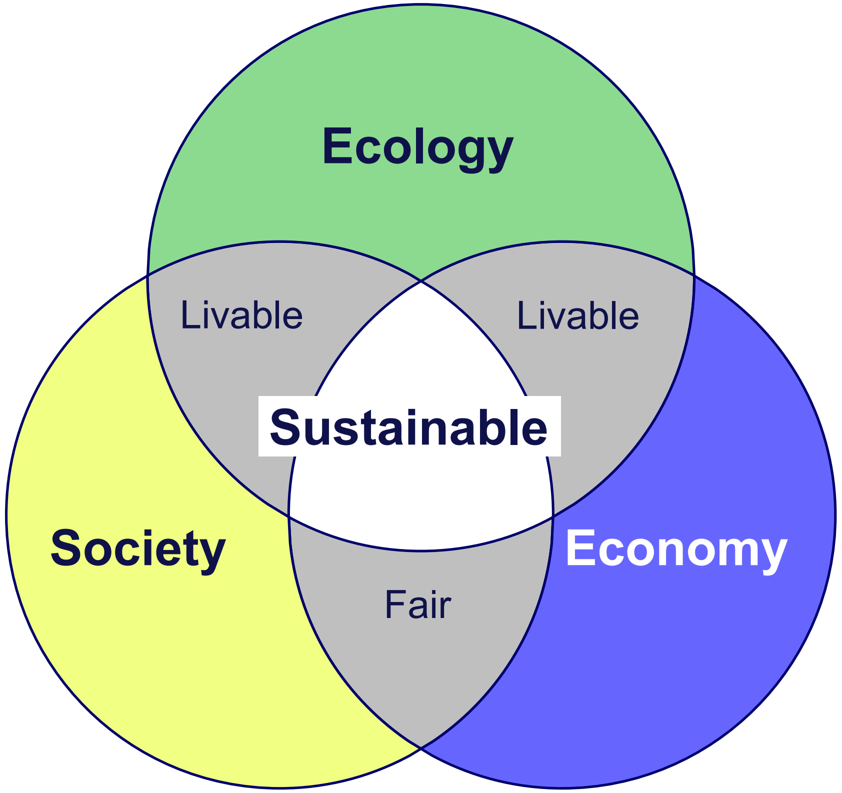
Progress on impact studies

Comprehensive socio-economic impact analysis is requested explicitly by both host states in writing and by the EC.

Is the methodology to determine the long-term sustainability of the research infrastructure by estimating the **Net Present Value**, the **Benefit/Cost** ratio and the Internal Return Rate.

Contents:

- **full cost** (CAPital EXpenditure + OPerational EXpenses) - integrated
- **positive impact potentials** - integrated
- **negative externalities** and additional positive impacts will be integrated until the end of the study – to be integrated



Results so far: Benefit/Cost ratio = 1.66

Report Version 1.0: https://doi.org/10.5281/zenodo.10653396

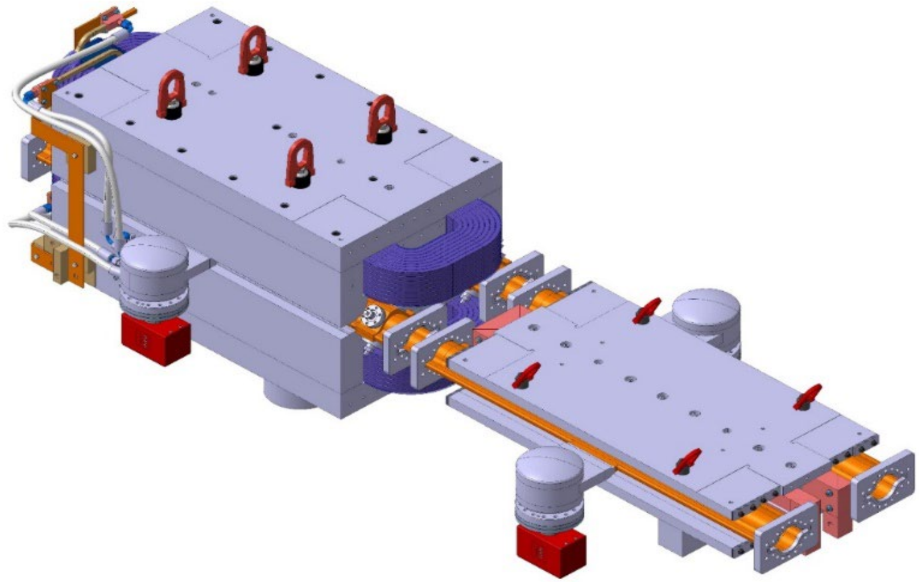
Arc layout and integration optimization

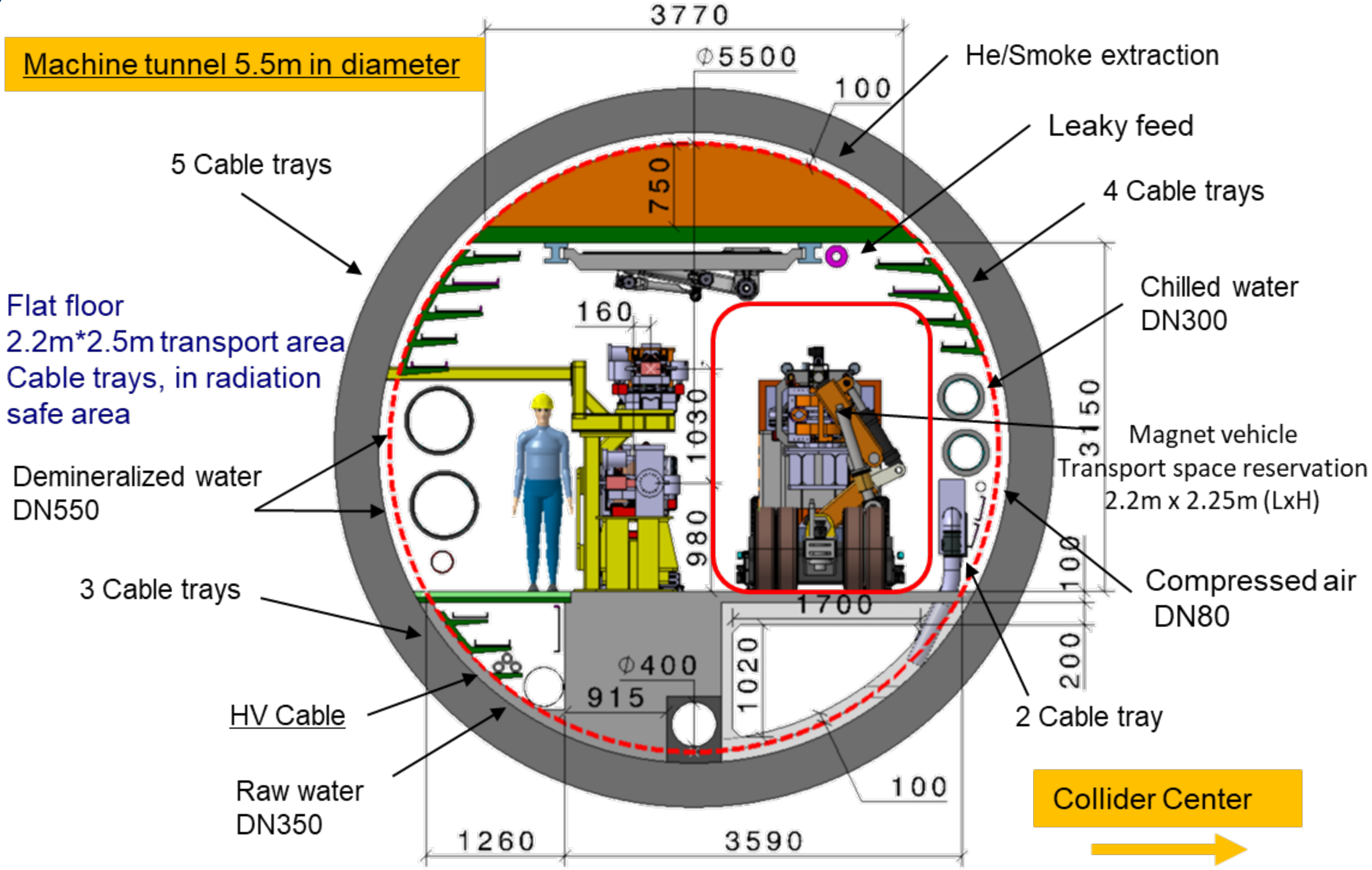
Arc cell optimisation – 80 km total length, dedicated working group active.

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

    → Confirmation of tunnel diameter

FCC-ee arc half-cell mock up



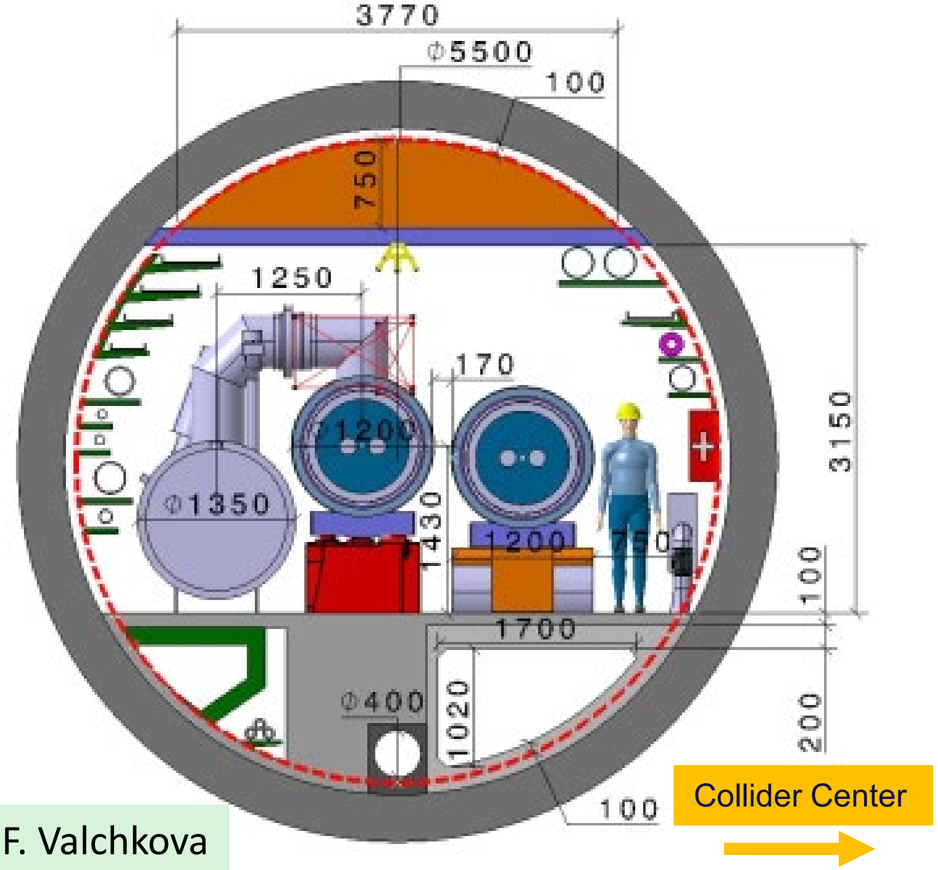


F. Carra, CERN; F. Valchkova

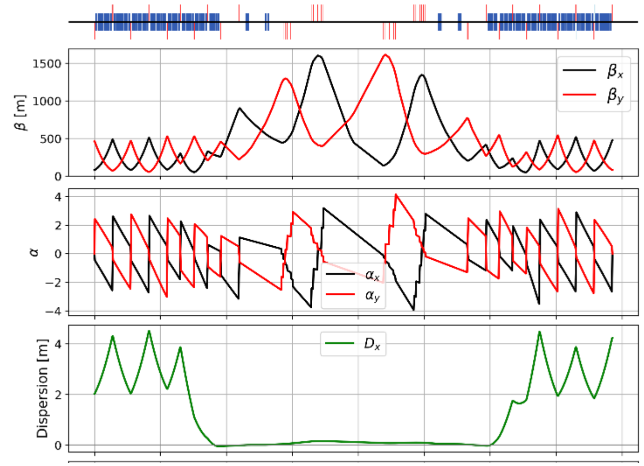
Key activities on FCC-hh: cryo magnet system, optics design

Optics design activities:

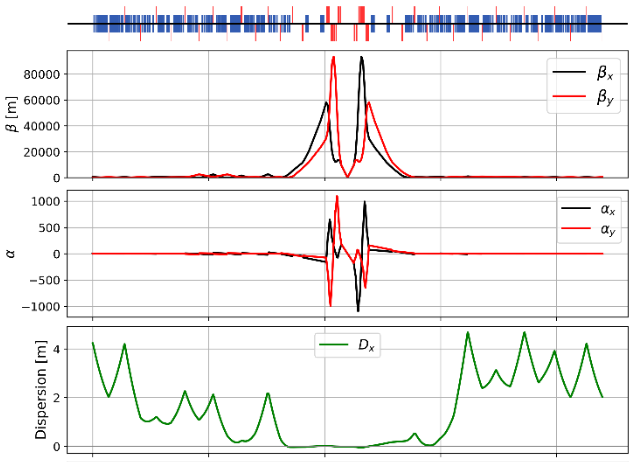
- adaptation to new layout and geometry
- shrink β collimation & extraction by ~30%
- optics optimisation (filling factor etc.)



F. Valchkova



betatron collimation straight



experimental straight

M. Giovannozzi. G. Perez, T. Risselada

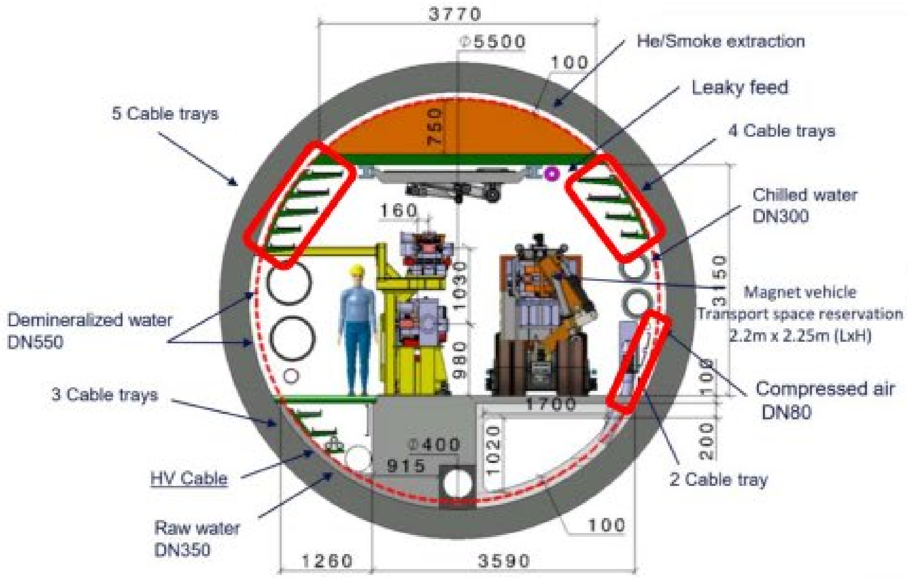
High-field cryo-magnet system design

- 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.

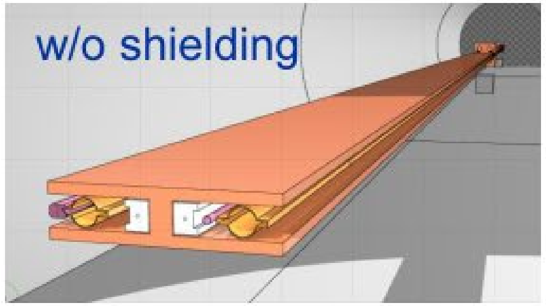
Shielding material for full ring	
Dipoles	2580
Photon stoppers	10
Shielding weight per stopper	400 kg
Total weight	10320 tons

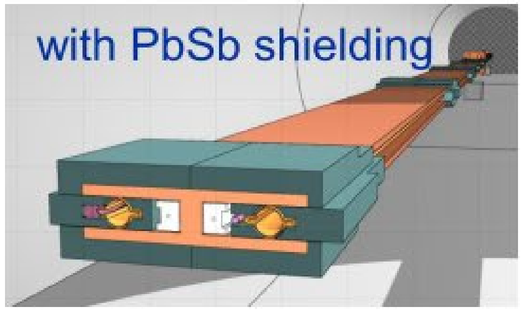
Effect of shielding: cumulative dose (ttbar)

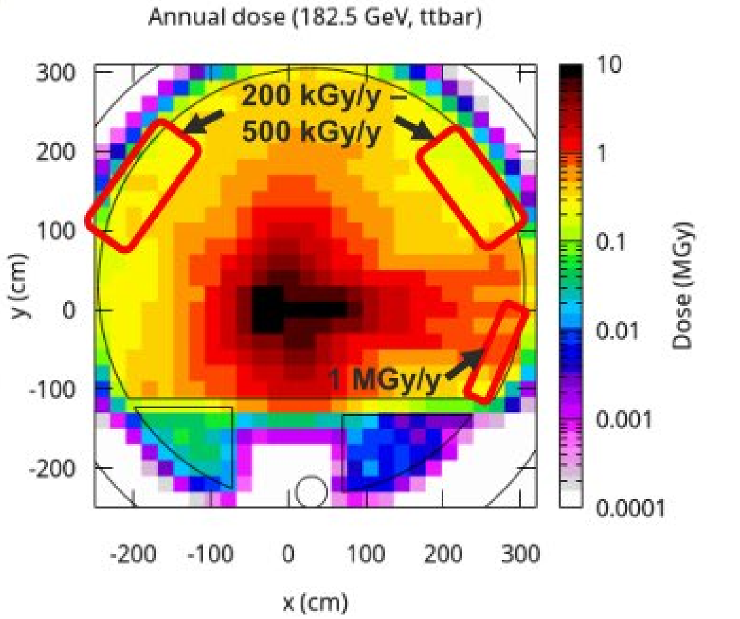
$O(10^2)$ reduction of dose levels in tunnel

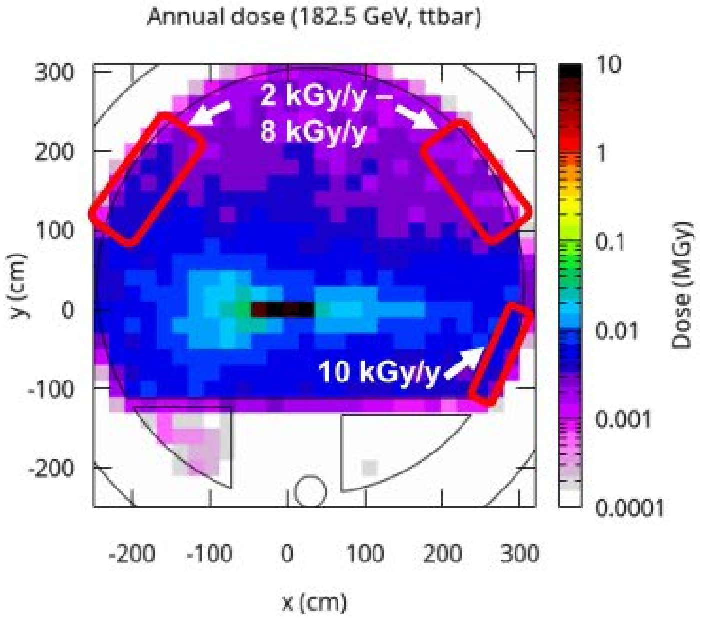


Photon stoppers include W-alloy layer in both cases



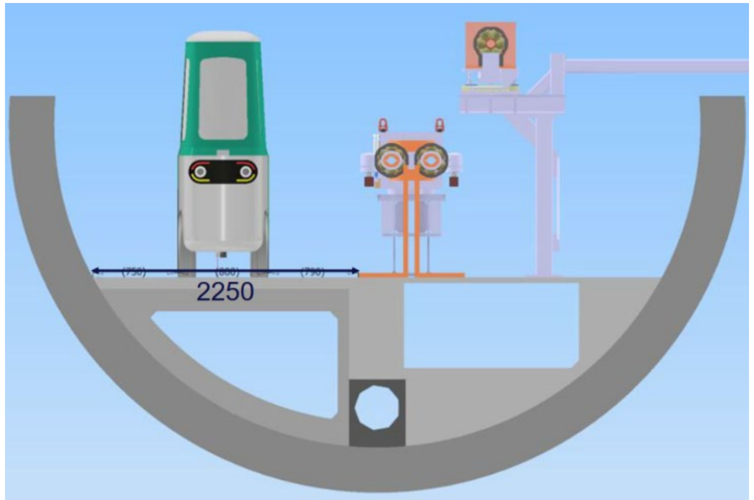


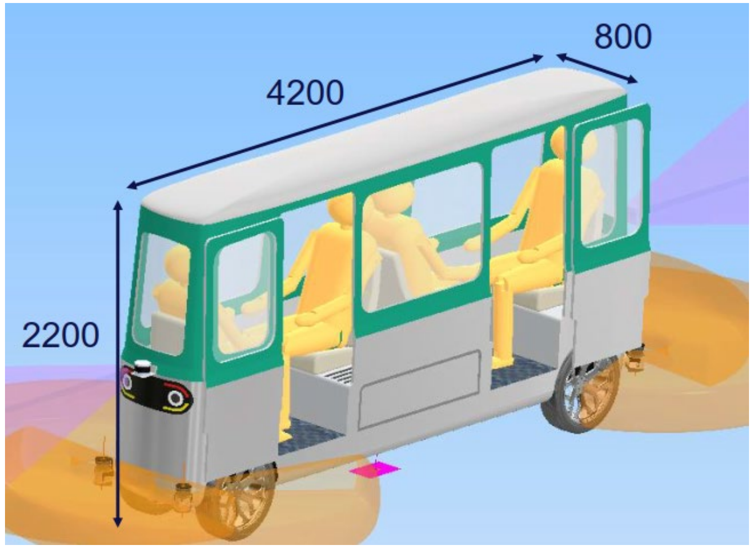


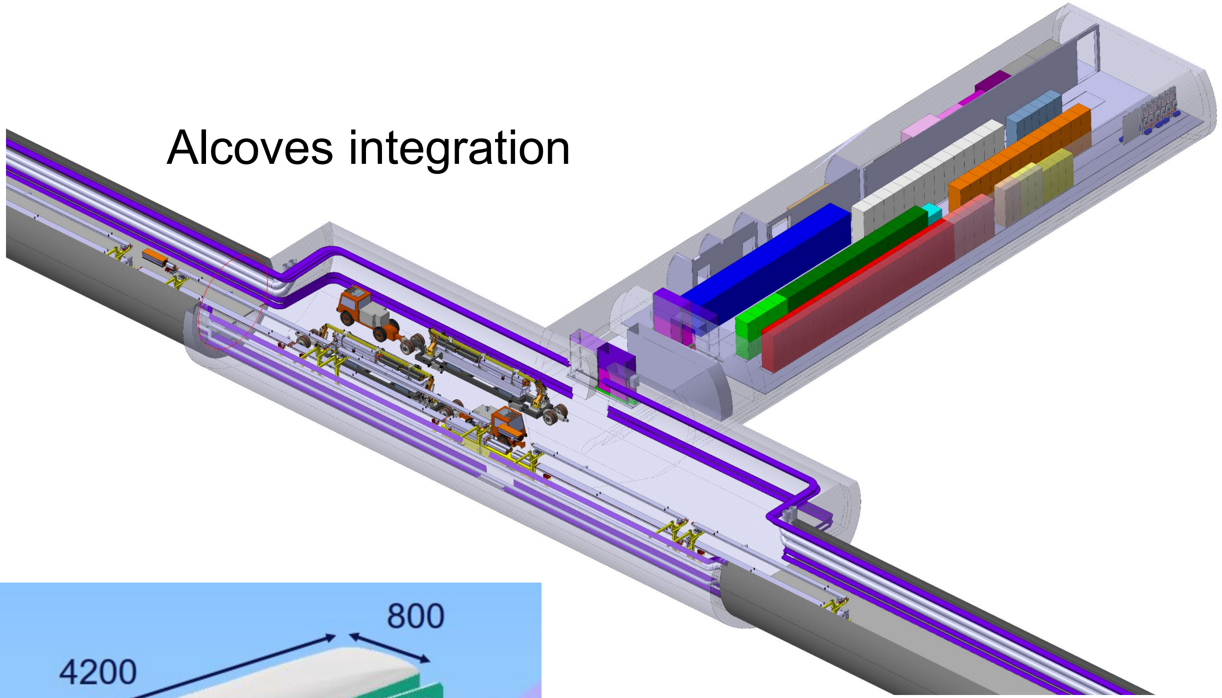


Personnel transport

- People transport vehicle

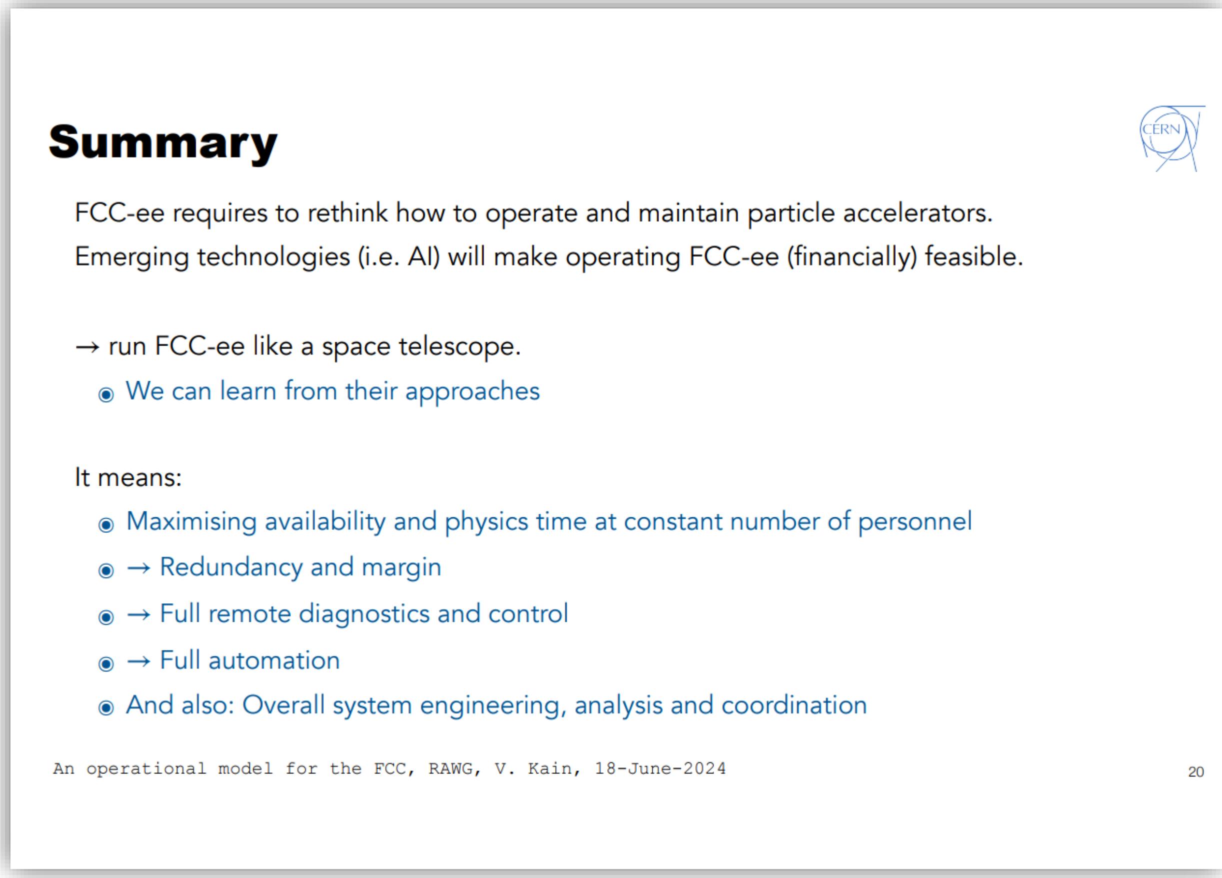


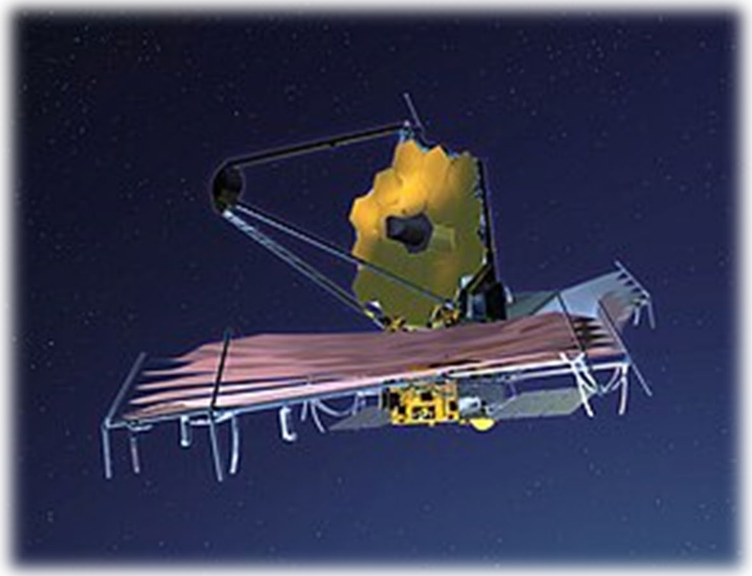




FCC-ee operational model

The design of kickers and septa systems is based on the new FCC operational model, which aims to maximize availability and reliability, while reducing maintenance and intervention needs, enhancing automation and AI integration.



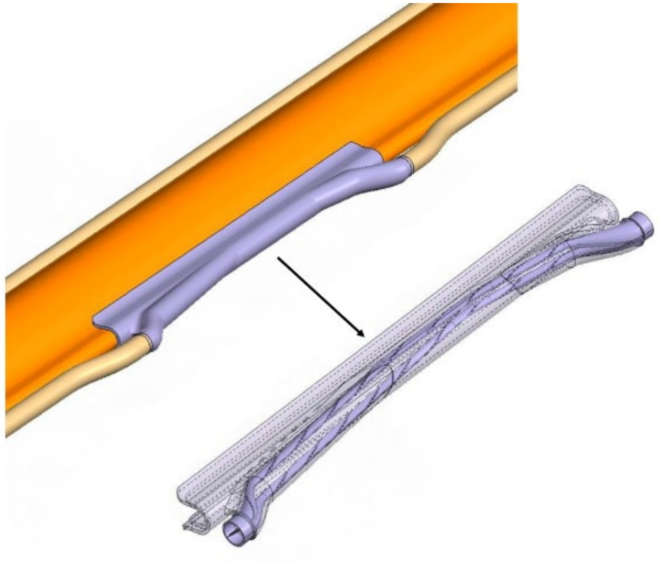


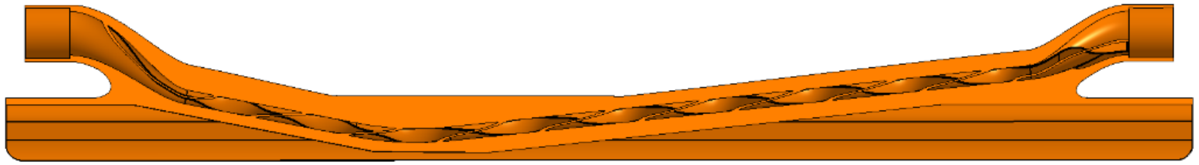
Courtesy of V. Kain

Vacuum innovation

Courtesy C. Garion, M. Morrone

Synchrotron Radiation Absorber 3D printed



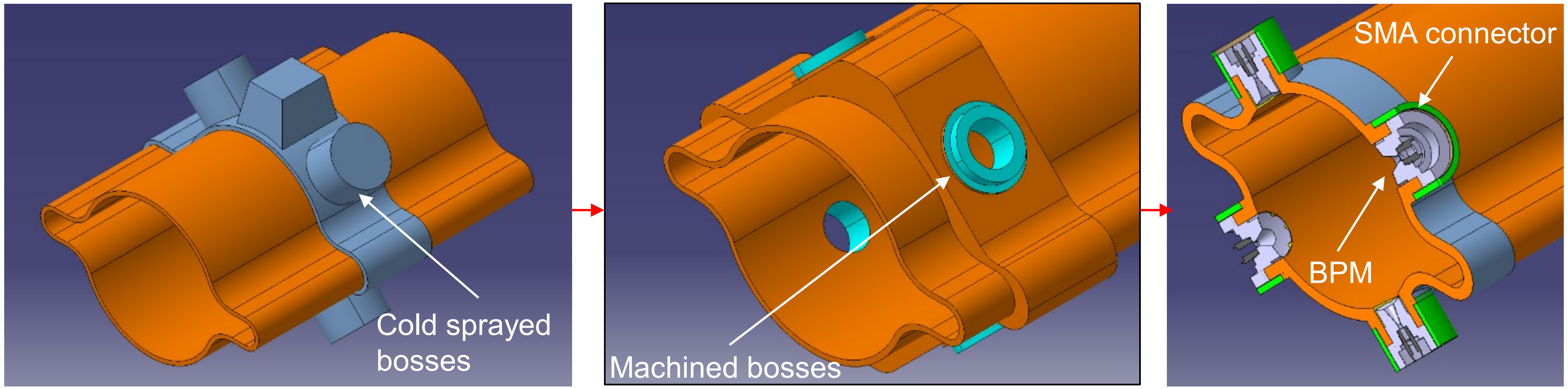


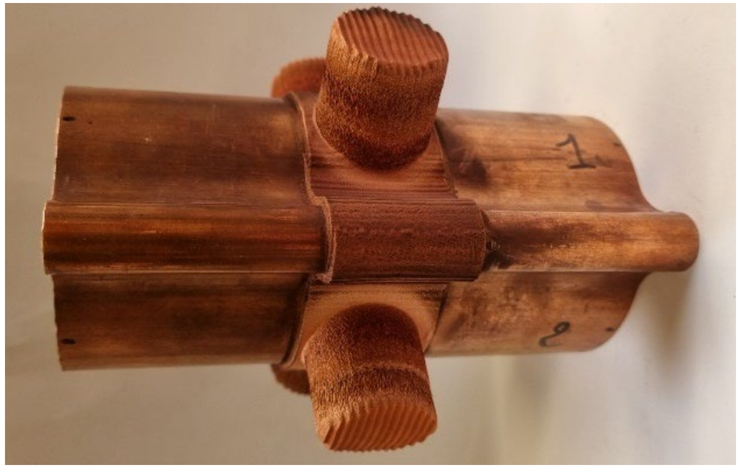
Laser Powder Bed Fusion (LPBF) has been selected as the method for the first prototype. This is the first copper 3D printed synchrotron radiation absorber.

Vacuum innovation

Courtesy C. Garion, M. Morrone

Cold-spray for Beam Position Monitors (BPM)

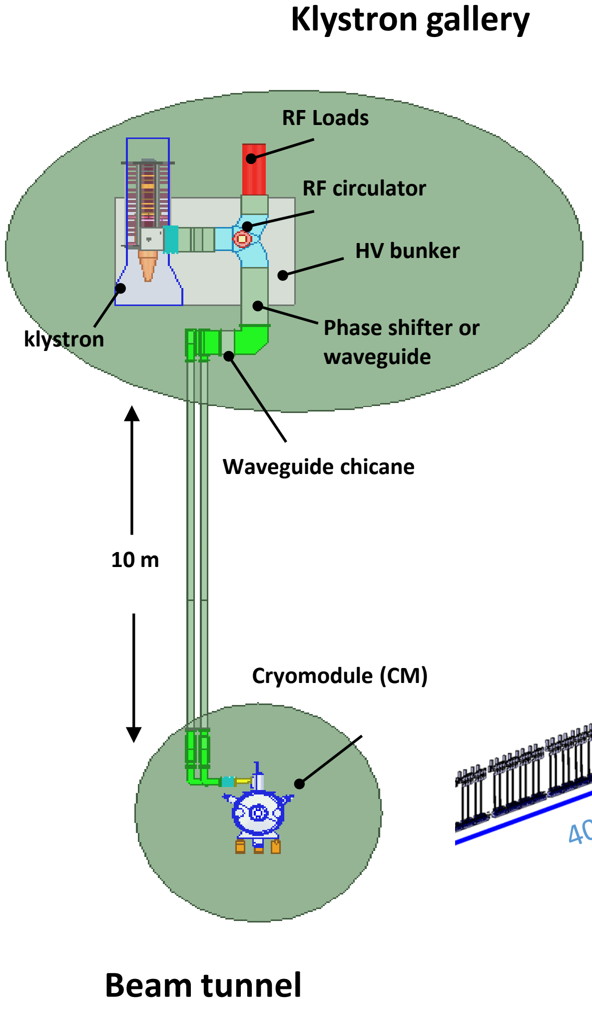


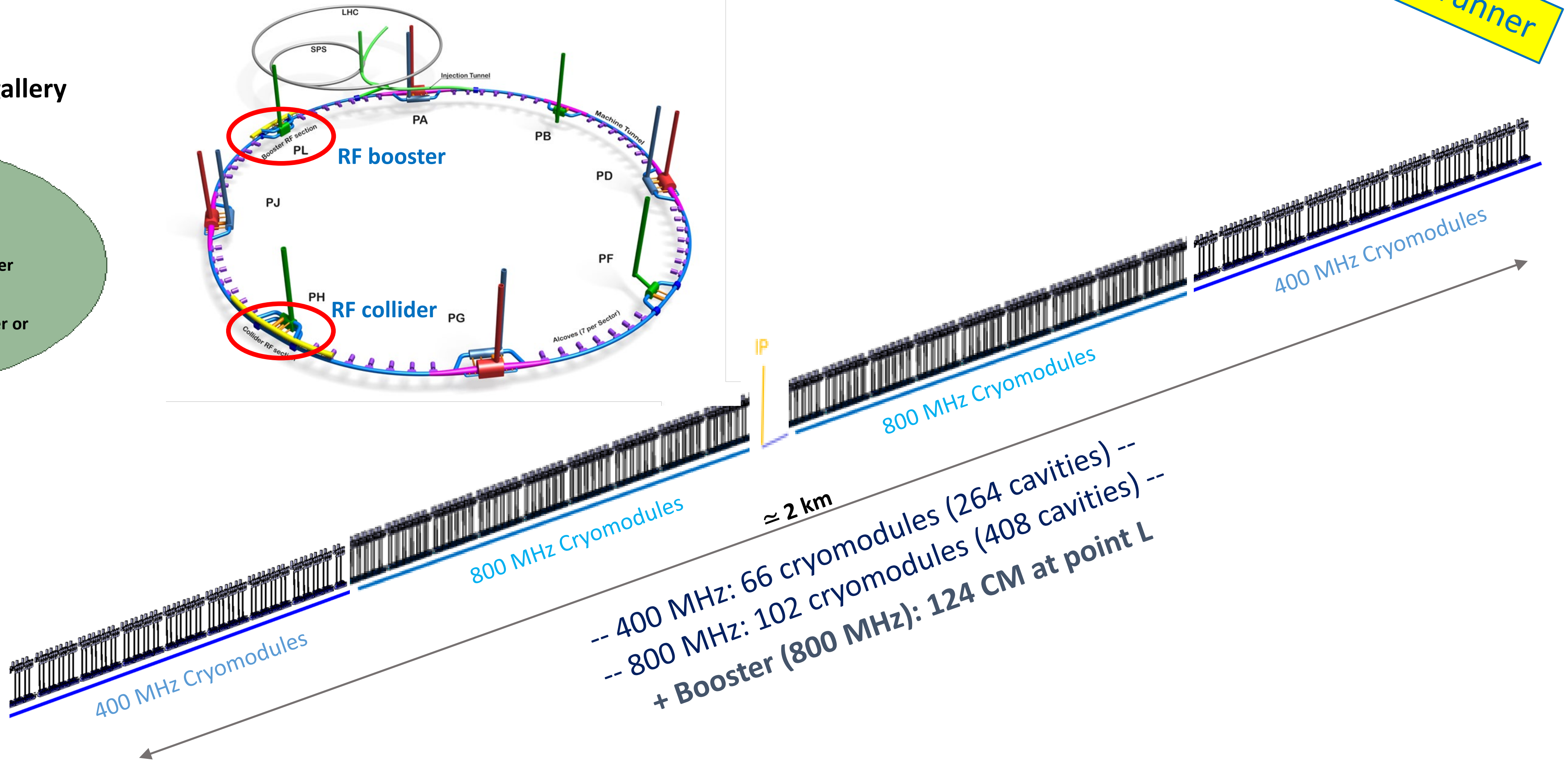


FCCee

RF configuration at PH (ttbar)

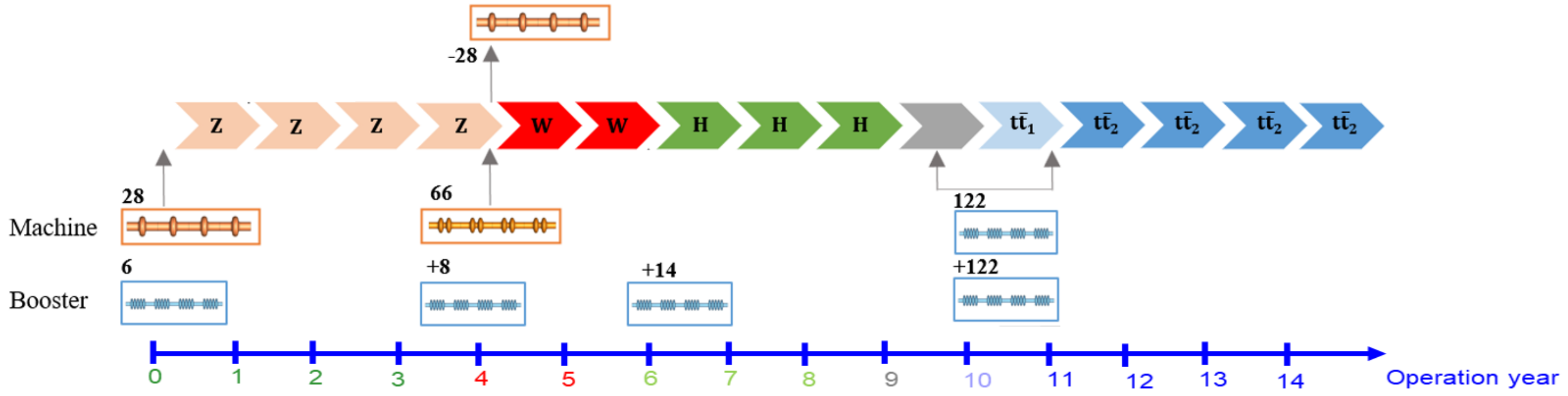
Courtesy O. Brunner





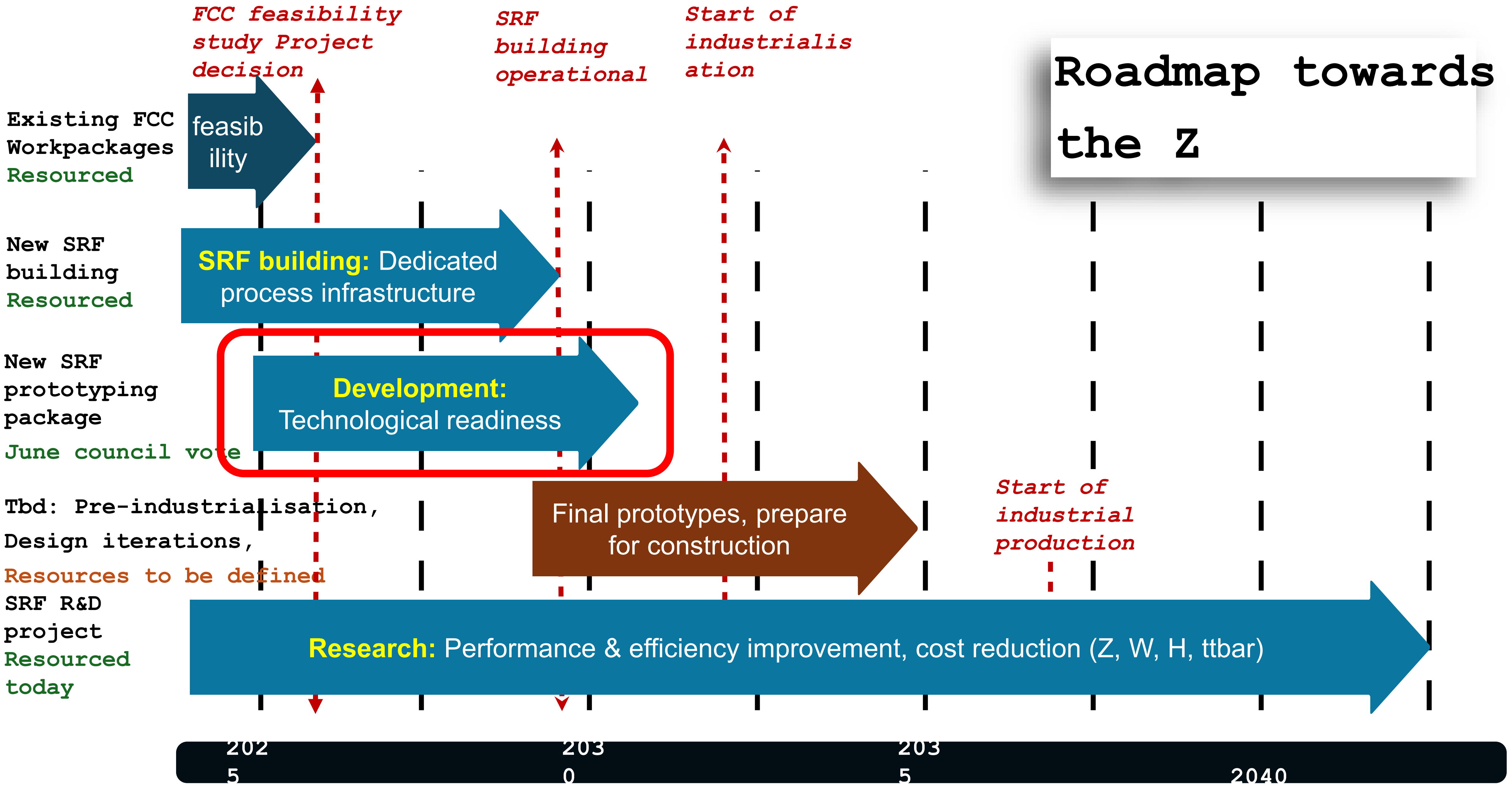
-- 292 cryomodules → ≃ 3 x LEP RF system !! --

RF system layout - Baseline



- Physics schedule – number and type of cryomodules to be installed:
- 400MHz single-cell (Nb/Cu): 28 CM @4.5K, removed after the Z working point
- 400MHz two-cell (Nb/Cu): 66 CM @4.5K
- 800MHz five-cell (bulk Nb): 272 CM @2K, 122 CM for the collider and 150 CM for the booster.

Roadmap towards the Z



Overview of BI for FCCee

	Dump line	Main ring	Booster ring	Injection line	20GeV linac	Common linac	e- linac	e+ DR	e+ TL	e+ linac	Total
Quadrupole BPM	20	5800	2944	420	82	35	11	258	30	17	**9617**
Special BPM (tune, chromaticity,..)		20	5					4			**29**
Collimator BPM		66		5							**71**
BLM fast	20	100		200							**320**
BLM arc cell monitoring		1468									**1468**
Fast BCT, WCM	3	4	2	1	2	2	2	1	4	2	**23**
DC BCT		4	2					1			**7**
Tranverse profile											**0**
Screen (OTR/ODR)	6	6	2	20	2	2	2	2	4	2	**48**
Synchrotron rad.		4	1					1			**6**
Laser Wire Scanner		2									**2**
Longitudinal profile											**0**
b/b profile (EOS, Streak)		2	1		1	1	1	1	1	2	**10**
LDM, Coherent rad.		2	1		1	1	1	1	1	2	**10**
Beamstrahlung / luminosity		8									**8**
Polarimeter		2									**2**
											11621

Curtesy of S. Mazzoni

Beam instrumentation workpackage

Task 4 - Beam Position Monitoring

Design and prototype of a low impedance pick-up

- Electro-magnetic simulations, Heat load simulations and design of water cooling system
- Mechanical design integrated in the machine layout including alignment tolerances
- Prototyping and validation by laboratory and beam tests

Design a cost-efficient bunch-by-bunch and turn-by-turn data acquisition system

- System architecture and cost including radiation hardness, ORAMS aspects
- Prototyping – laboratory and beam tests

Years:	T_0-15				T_0-10				T_0-5				T_0-1
R&D													
Design + prototyping													
Industrialization + pre-series													
Series prod. + testing													

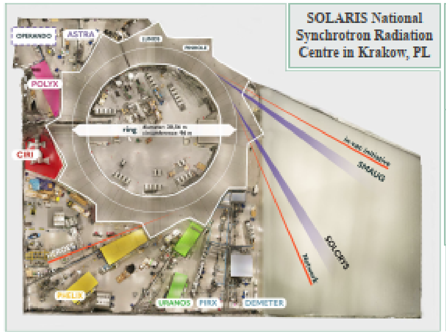
Curtesy of S. Mazzoni

FIRST RESULTS WITH A BASE BAND TUNE (BBQ) MEASUREMENT SYSTEM AT SOLARIS

Marek Gasior, CERN, Geneva, Switzerland
Mateusz Szczepaniak, Adriana Wawrzyniak, Roman Panas, SOLARIS NSRC, Krakow, Poland

13th International Beam Instrumentaton Conference 2024, Beijing, China

SOLARIS CENTER FACILITY OVERVIEW



SOLARIS National Synchrotron Radiation Centre in Krakow, PL

600 MeV Linac
- RF Thermionic Gun
- 6 S-band accelerating structures
- Accelerating gradient: 20 MV/m
- 3 RF Units & SLED cavities
- Operating Energy :534 MeV

1.5GeV Storage ring
- Max. electron current: 500 mA
- 100 MHz +300MHz RF system
- Emittance h/v: 6.0/0.06 nmrad
- Harmonic number: 32
- Tune h/v: 11.22/ 3.15
- 7 Operating Beamlines

BASE BAND TUNE MEASUREMENT SYSTEM INSTALLATION

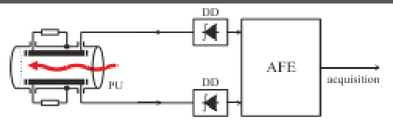


Diagram of one channel of the Solaris BBQ installation.

- Solaris BBQ system for TUNE measurement based on a 4-port stripline pick-up (PU) with output ports connected via short coaxial cables to four diode detectors (DD), directly interfaced with the inputs of an analog front end (AFE).
- The PU planes are positioned at a 45° rotation relative to the machine planes, assuring equal sensitivity to both horizontal and vertical beam oscillations.
- The downstream ports connected by short cables with high-power terminators that dissipate the signal reflected from the detectors.
- The entire system mounted on a frame that facilitates free airflow, improving cooling efficiency.

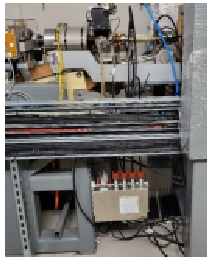
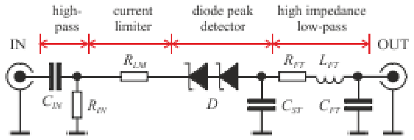


Photo of the Solaris BBQ installed in the storage ring.

SOLARIS BBQ DETECTORS



Block diagram of the Solaris BBQ detector.

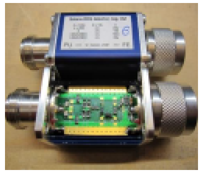
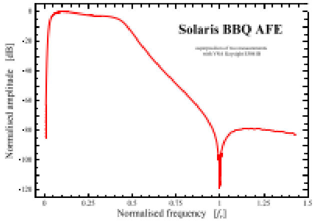


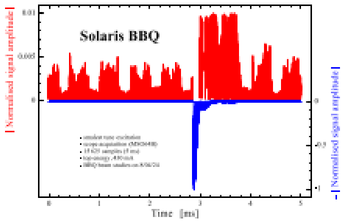
Photo of the Solaris BBQ detector.

- The diode detector consists of a simple input high-pass filter (C_{IN}, R_{IN}), current limiting resistor (R_{LM}), protecting the RF Schottky diodes (D, HSMS280C) when the paralel capacitors (C_{ST}, C_{FT}) have not yet fully charged, during the first injection.
- To prevent saturation of the AFE inputs, which have a relatively small dynamic range, output signals are filtered by a high impedance output low-pass filter (R_{FT}, L_{FT}, C_{FT}).

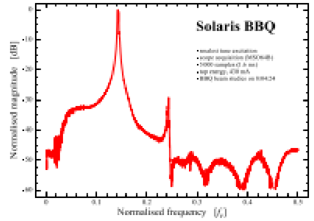
BEAM MEASUREMENTS



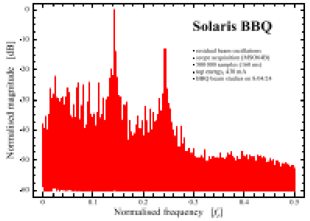
Frequency characteristic of Solaris BBQ analog front-end.



An oscilloscope record of the smallest tune excitation.

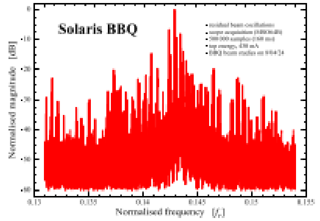


Beam spectrum containing the forced tune oscillations.

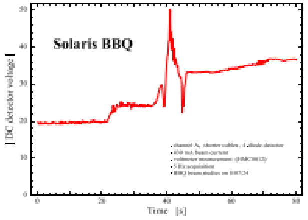


Spectrum of the residual beam oscillation.

- The spectra reveal that the SNR for the lower-frequency vertical tune peak is comparable in both cases.
- The higher-frequency horizontal tune peak exhibits improved quality in the residual oscillation spectrum.
- Maintaining small, continuous beam oscillations produces better tune spectra than inducing forced beam oscillations for short durations.



A part of the beam spectrum zoomed on the vertical tune region.



An evolution of the detector DC voltage during bunch length manipulation at the end of the energy ramp.

- The measurements reveals the complexity of vertical tune. Analysis of this spectrum for an electron machine such as Solaris may improve the beam quality.
- The detector DC signals are essential for optimising the BBQ system and monitoring bunch length variations

Proc. 13th International Beam Instrumentation Conference,Beijing JACoW Publishing
ISBN: 978-3-95450-249-3 ISSN: 2673-5350 doi: 10.18429/JACoW-IBIC2024-THP59

FIRST RESULTS WITH A BASE BAND TUNE (BBQ) MEASUREMENT SYSTEM AT SOLARIS

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M. Szczepaniak, A. I. Wawrzyniak, R. Panas, Solaris NSRC, Krakow, Poland

Abstract

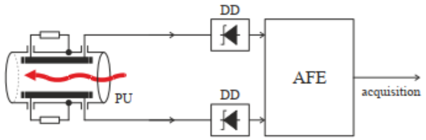
All CERN circular accelerators are equipped with Base Band Tune (BBQ) measurement systems, based on the direct diode detection technique, allowing to measure the tunes of hadron beams by employing their residual betatron oscillations or very small external excitation. In the framework of the Future Circular Collider (FCC) project, a study was launched to optimise such a system for operation with short electron bunches. A prototype system has been recently installed in Solaris light source. The system has immediately allowed an unprecedented detection of residual betatron oscillations, whose amplitudes, estimated to be in the 100 nm range, are more than two orders of magnitude lower than the smallest beam oscillations used for tune measurements with the Beam Position Monitoring (BPM) system. The residual oscillations allowed reliable continuous tune measurements, which have also revealed spectral content never observed before. This paper provides an overview of the installed BBQ system and describes beam measurement results obtained so far. The aim of the paper is to disseminate new results in the light source community and provide information that may help in building and installing similar systems. It is hoped that wider usage of BBQ systems will help in better understanding the observed spectra of electron beam residual oscillations.

HARDWARE

The Solaris BBQ installation, illustrated in Fig. 1 with a block diagram of one of its planes and a photograph, consists of a stripline Pick-Up (PU) with four electrodes whose output ports are connected by short coaxial cables to four Diode Detectors (DD) mounted directly on the inputs of an Analog Front-End (AFE). The coaxial cables act as low-pass filters stretching the lengths and lowering the amplitudes of the short electron beam pulses to values adequate for the detectors.

The diode detectors, illustrated in Fig. 2, are built as high impedance circuits, to minimise the power dissipated in small, high-frequency circuitry. As a result, the incoming beam pulses are reflected and ultimately dissipated in high-power RF terminators connected to the downstream ports of the stripline through short cables.

The diode detector has a simple input high-pass filter (C_{IN}, R_{IN}) blocking potential low-frequency interference. The current limiting resistor (R_{LM}) protects the following RF Schottky diodes (D, HSMS280C) during the first injections of the beam, when the detector parallel capacitors (C_{ST}, C_{FT}) have not yet been charged. With high current beams the capacitors may charge to a hundred



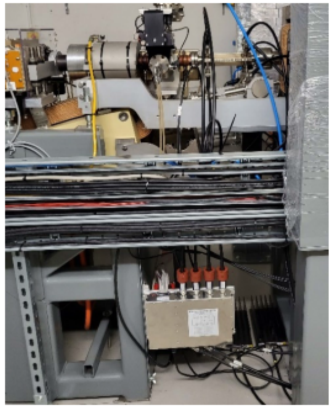


Figure 1: Diagram of one channel (top) and a photograph (bottom) of the Solaris BBQ installation.

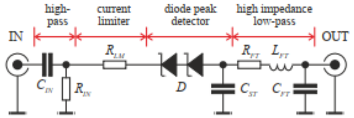


Figure 2: Block diagram (top) and a photograph (bottom) of the Solaris BBQ detector.

Summary and (most of all) outlook

FCC is scientifically the most compelling of all proposed future colliders and the one with the broadest physics programme
In the same tunnel and with the same technical infrastructure: e+e-, pp, heavy-ion collisions; potentially also e-p, e-ion
→ 2020 ESPP recommended it for feasibility study

It's also a big, audacious project, but so were LEP, Tevatron, LHC when they were first conceived.
They were successfully built, and performed beyond expectation → demonstration of capability of HEP community to deliver on very ambitious projects

Cost and funding are major challenges (as for any future collider) → crucial to work with all stakeholders (including new ones for HEP) to make it happen. The strong interest of and "pressure" from the community will be absolutely crucial.

Mid-term review of Feasibility Study successfully completed in Feb 2024 → no technical showstopper identified

Next steps:
- ❑ Feasibility Study final report to be completed March 2025
- ❑ Next update of the European Strategy June 2026
- ❑ Council decision on next project hopefully end 2027 or beg 2028

https://indico.cern.ch/event/1298458/

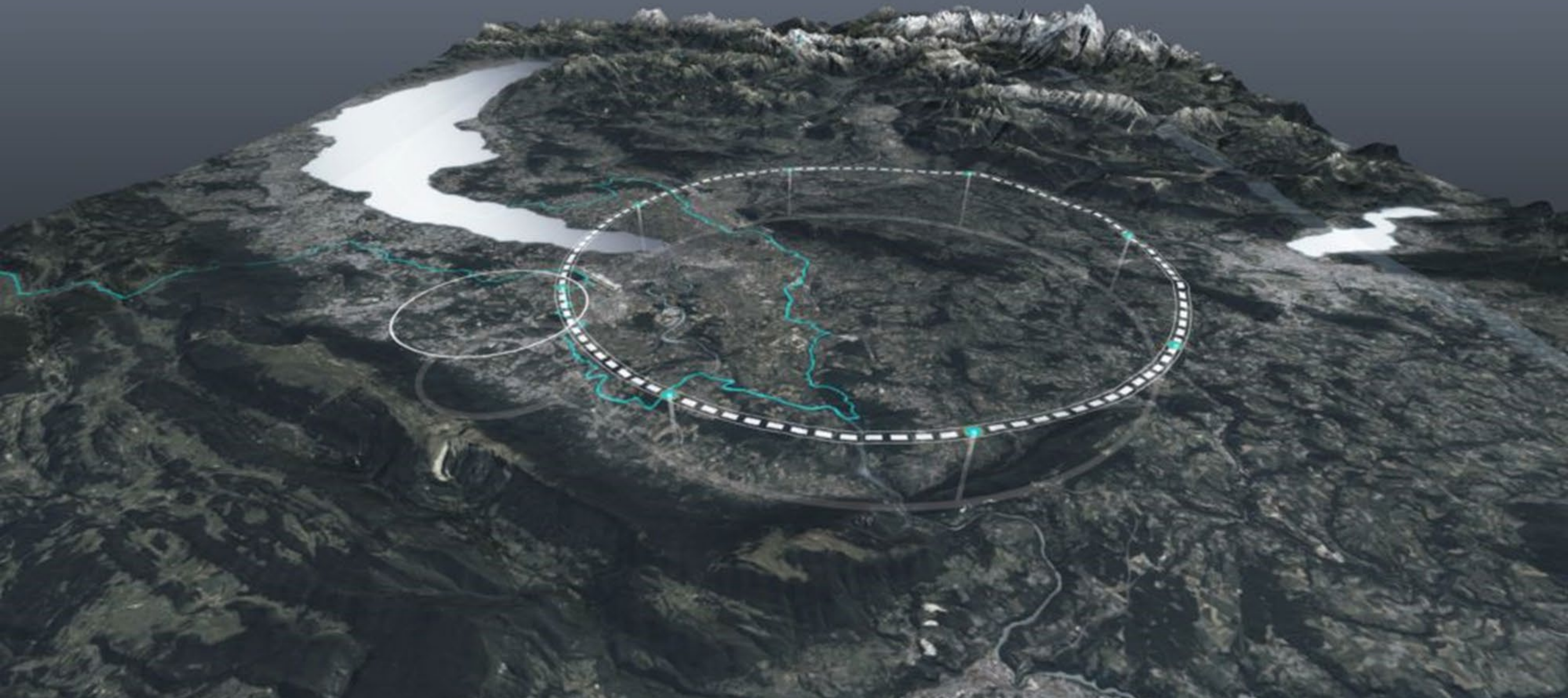
SY-FCC workshop

4.10.24

https://indico.cern.ch/event/1449294/


VIENNA
HOFBURG
19 – 23 May 2025
19-23 MAY
FCC
WEEK
2025

Spare slides

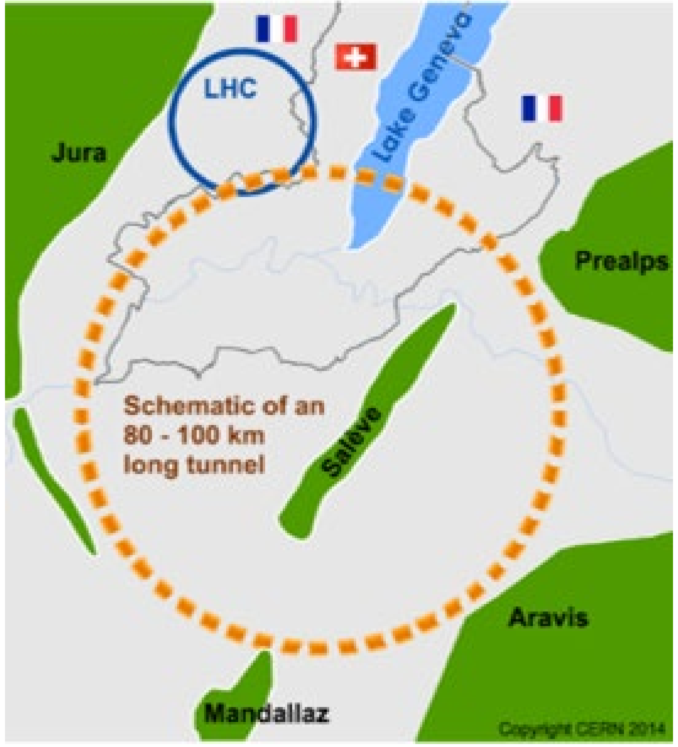


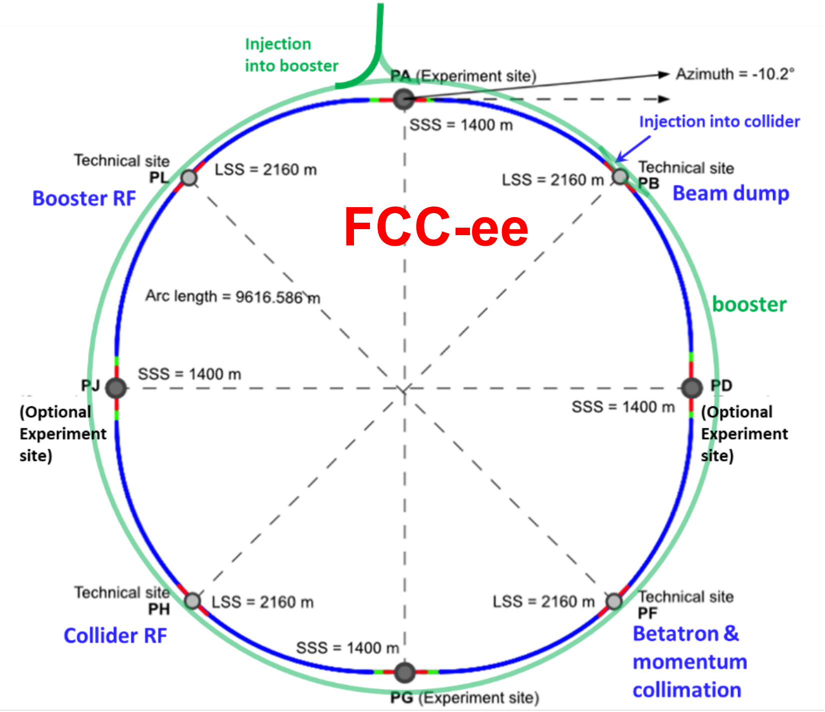
FCC integrated program

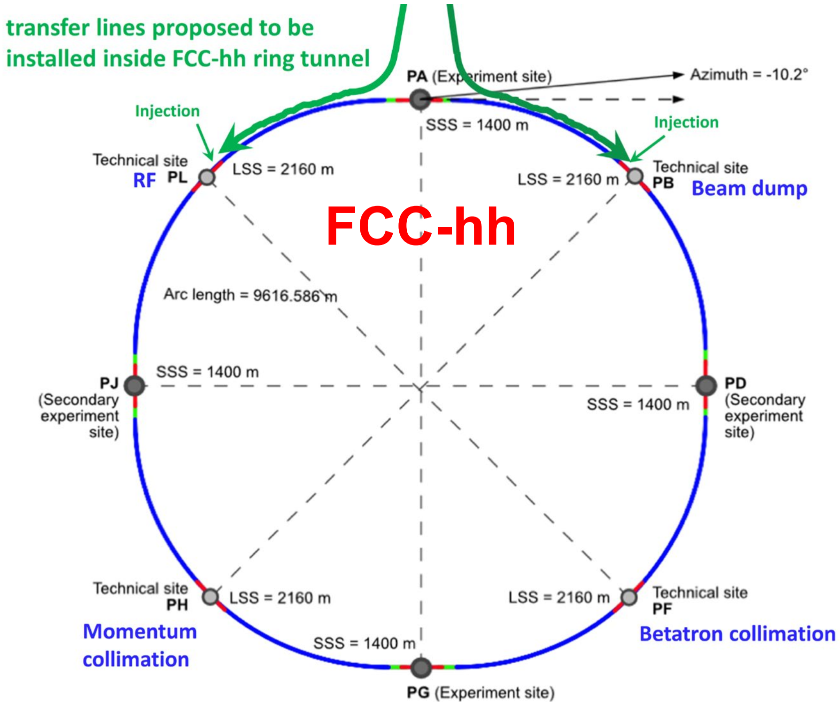
FUTURE CIRCULAR COLLIDER

comprehensive long-term program maximizing physics opportunities

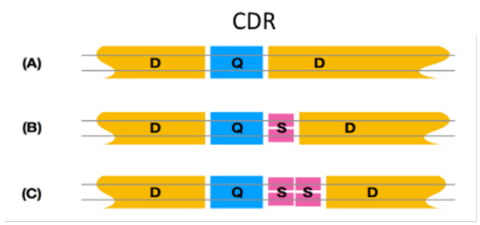
- **stage 1: FCC-ee (Z, W, H, $t\bar{t}$) as Higgs factory, electroweak & top factory at highest luminosities**
- **stage 2: FCC-hh (~100 TeV) as natural continuation at energy frontier, pp & AA collisions; e-h option**
- highly synergetic and complementary programme boosting the physics reach of both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

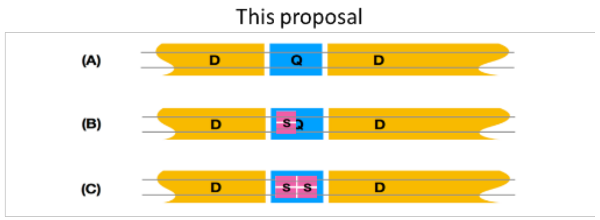






Superconducting magnet alternative HTS4

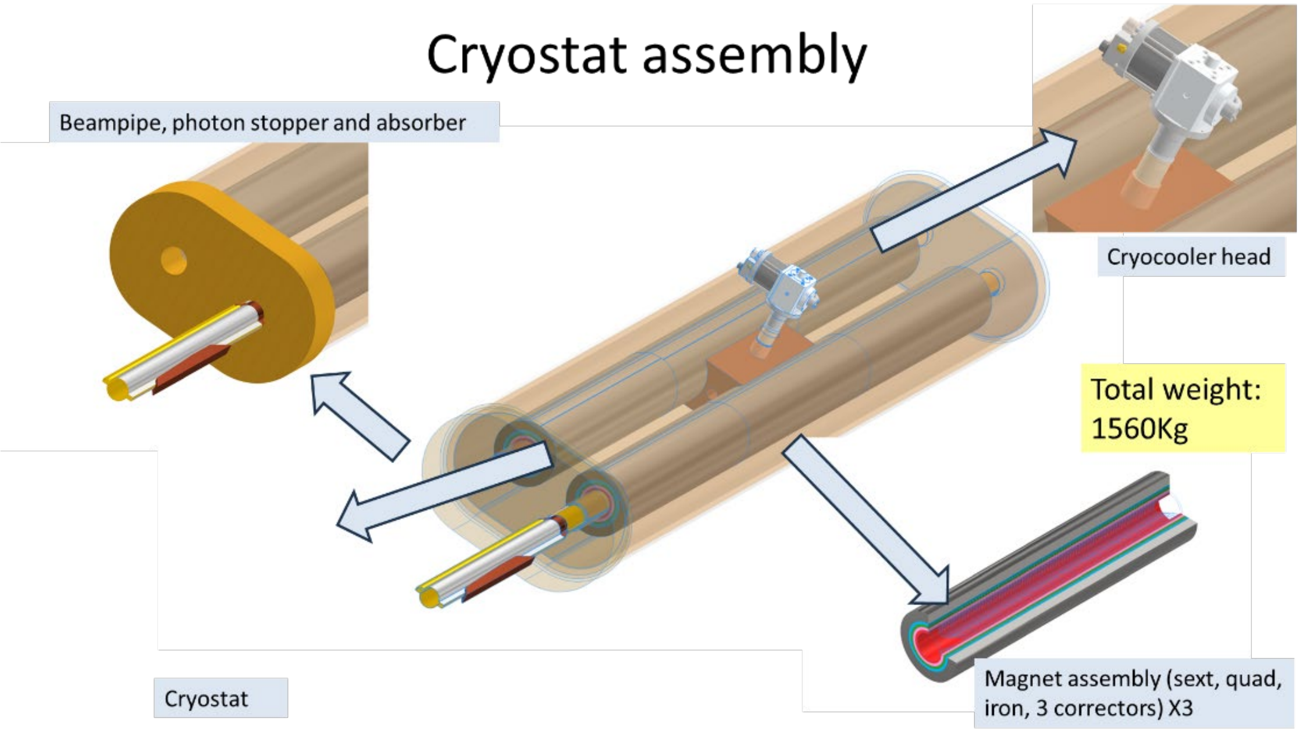




Half cell length: 27.9 m

Courtesy M. Koratzinos

CHART
Swiss Accelerator Research and Technology



CCT demonstrator:
- Formers manufactured
- Quality control done
- HTS tape purchased

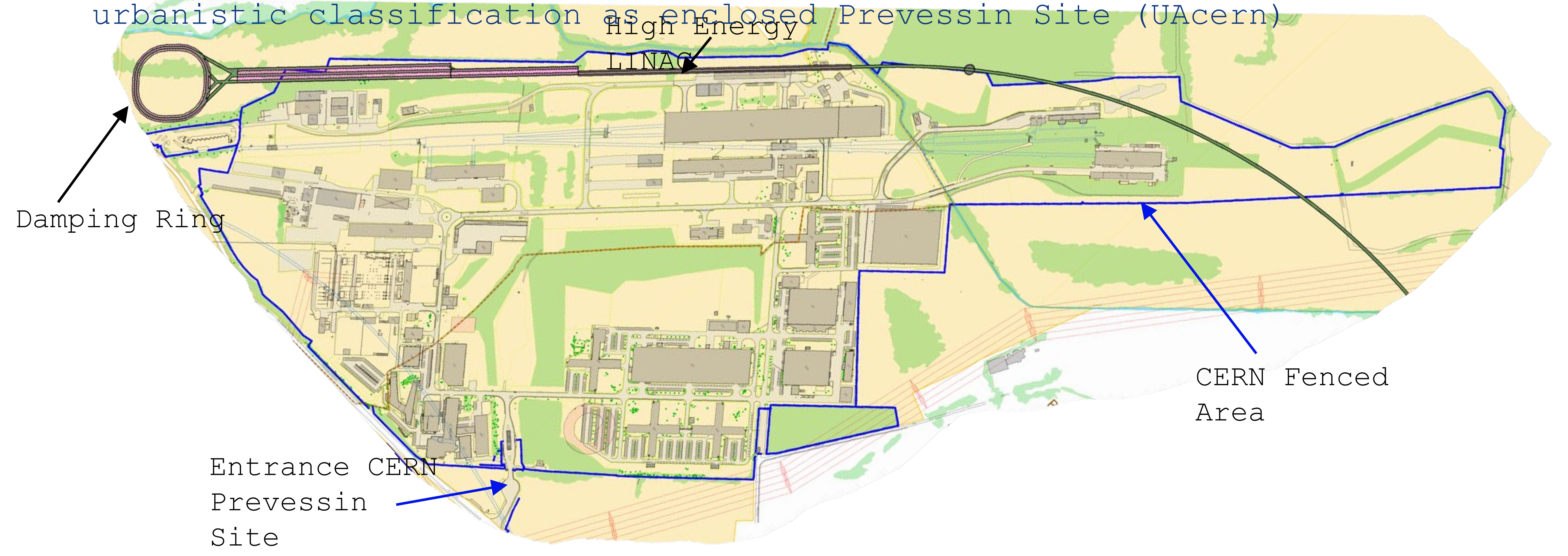
Sustainability

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).
  - Rep. rate of **100 Hz with 4 bunches** per rf pulse, beam loading compensation and long range wakefield suppression;
  - Total length of the injector complex is longer, but operation will be more reliable;
  - New layout: **Damping Ring at higher energy 2.86 GeV**, no common linac (would require doubling repetition rate).

Optimised injector implementation at Prevessin site

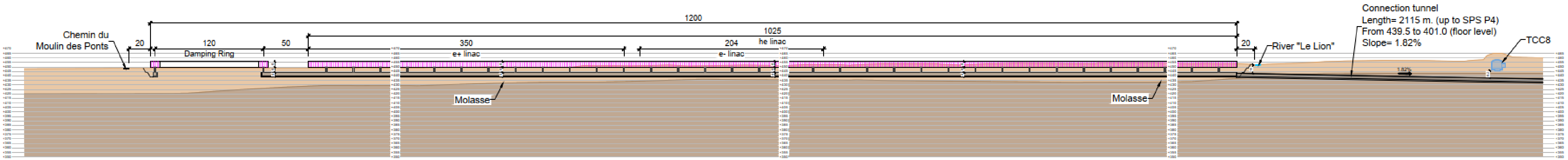
- Better integration with existing CERN Prevessin Site and strongly reduced visible impact from outside.
- Ideal connection to existing experimental halls.
- Good conditions for construction (see next slide).
- CERN dedicated land, small part outside fenced area but with same urbanistic classification as enclosed Prevessin Site (UAcern)



Injector construction concept

OPTION 9

DAMPING RING NEXT TO "DECHETERIE"

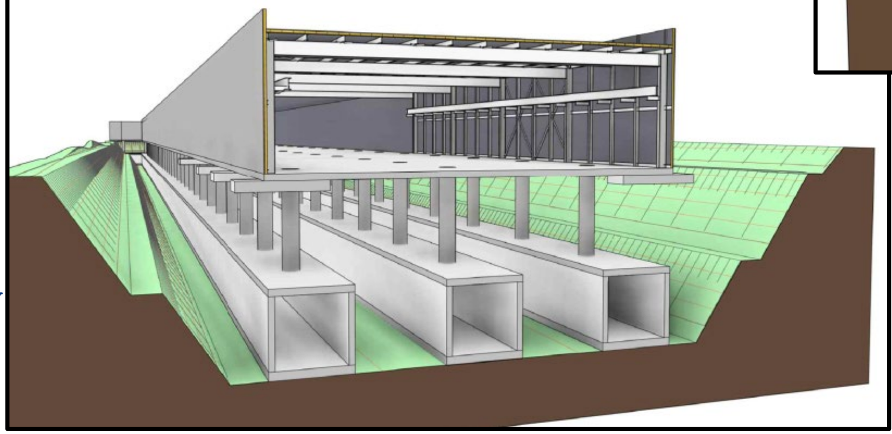


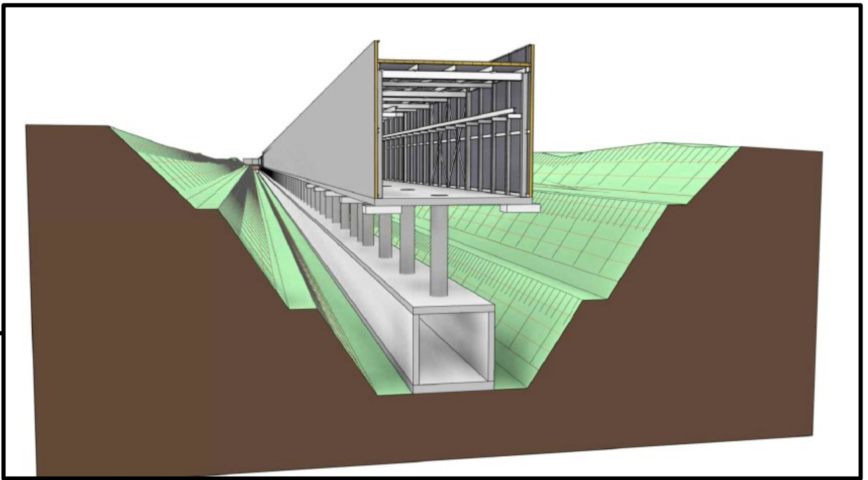
LONGITUDINAL PROFILE

Longitudinal Section

- Less than 5m elevation change over the 1200 m of terrain provides **ideal conditions for “cut and cover technique”**
- Most efficient and cheapest way of building shallow underground construction
- Excavated material largely re-used as backfill above the tunnel

HE LINAC Line + Electron and Positron Lines





HE LINAC Line

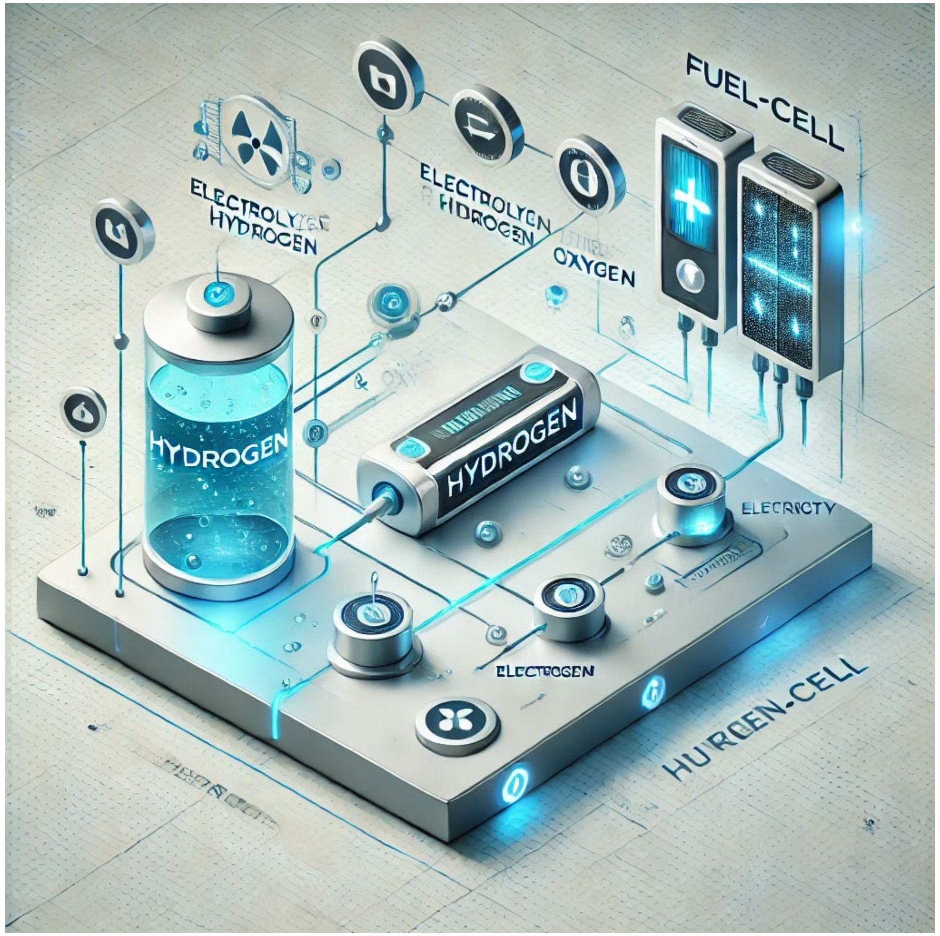
Collaborations

- **In contact with industrial partners for the main power converter (centralised MMC)**
  - Probable collaboration with Siemens & Hitachi
- **EPC delegation + Jean-Paul will be visiting a 1 GW/640 kV station in Spain this Nov.**
- **Collaborations with Universities**
  - Tallinn University of Technology (TalTech), Estonia - via a PhD – to evaluate efficient solutions to offer voltage trimming to each klystron in FCC.
  - Polytechnic University of Valencia, Spain - via Professors support on the HV DC distribution

Collaborations

Collaboration with LAPLACE lab. In Toulouse to evaluate multi purpose use of hydrogen in FCC

- **Energy Storage for:**
  - Reducing integration costs of purchased renewables MWhs
  - UPS (necessary for safety systems)
  - Back up diesel generators (for longer periods)
  - Better integration of local renewables (i.e. solar panels on surface sites)
- **Enhancing heat recovery**
  - Elevate accelerator waste heat for residential use, etc.
- **Absorption cooling**
  - Create cooling (needed for the accelerator) from heat dissipated by fuel-cells

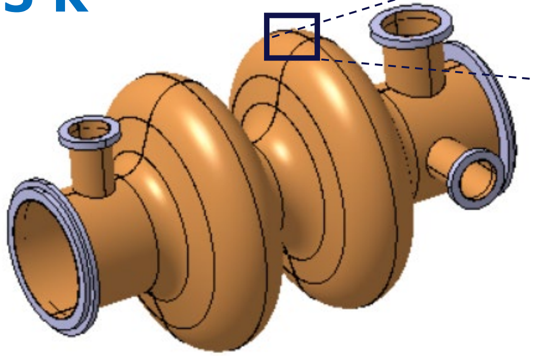


R&D strategy on SRF materials

Courtesy F. Peauger

Material	λ(nm)	ξ(nm)	κ	T_c(K)	H_{c1}(T)	H_c(T)	H_{sh}(T)
Nb	40	27	1.5	9	0.13	0.21	0.25
Nb_3Sn	111	4.2	26.4	18	0.042	0.5	0.42

4.5 K



400 MHz cavity

Liquid helium
Cu substrate
Nb film
RF field

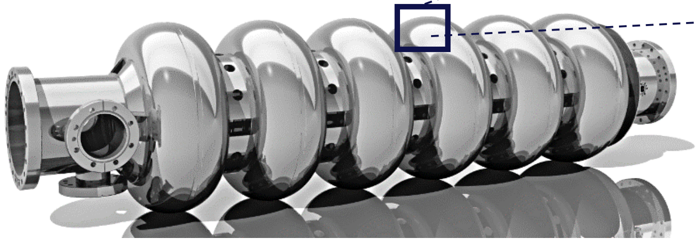
or

Liquid helium
Cu substrate
Nb3Sn film
RF field

Baseline option: advanced fabrication technics, advanced coating (HiPIMS) & advanced surface preparation recipes

Alternative option to improve the accelerating gradient E_{acc} and the Q_0 factor

2 K (→ 4.5 K?)



800 MHz cavity

Liquid helium
Bulk Nb (doped)
RF field

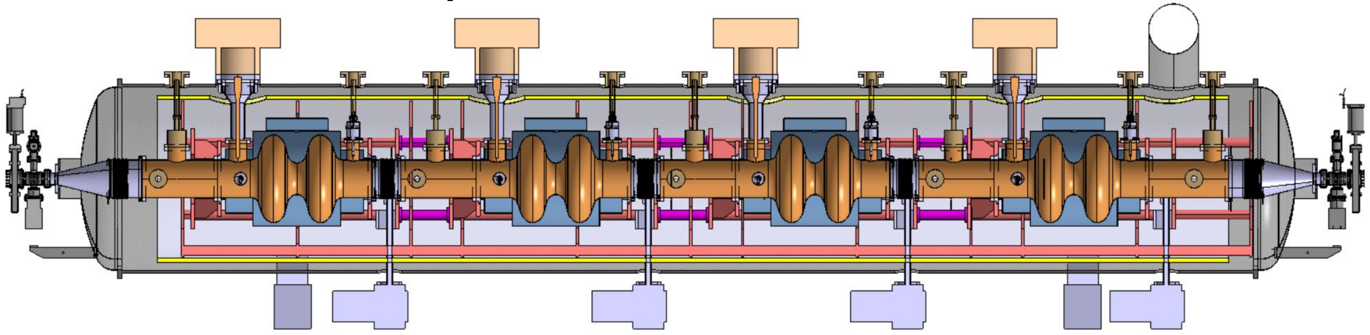
or

Liquid helium
Nb substrate
Nb3Sn film
RF field

Baseline option: special surface processing (doping) to improve the Q_0 factor

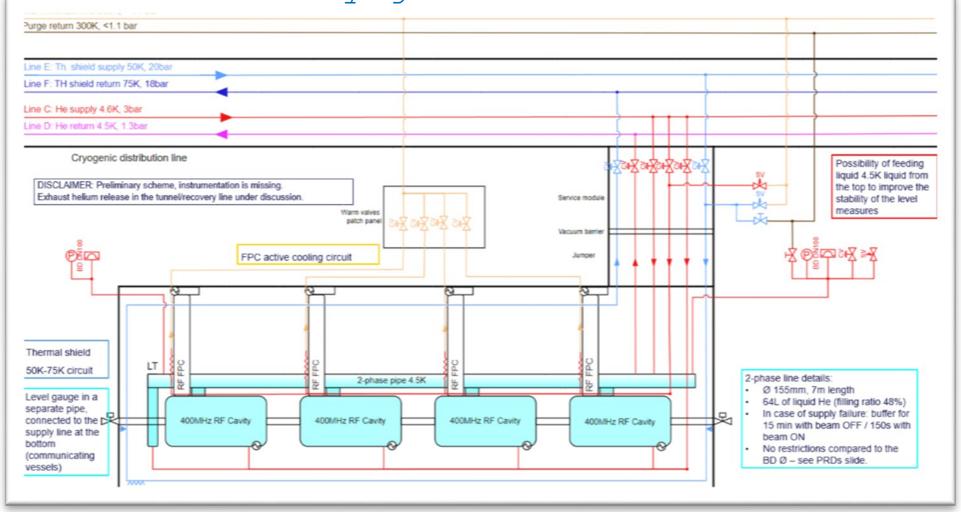
Alternative option cavities to operate at 4.5 K instead of 2 K

400 MHz CM conceptual and integration studies



- 400 MHz CM (based on LHC) for W to ttbar (also Z? >> FPC and HOM power extraction)
- Prototype to be built at CERN (under SRF-D project)

Cryogenic schemes

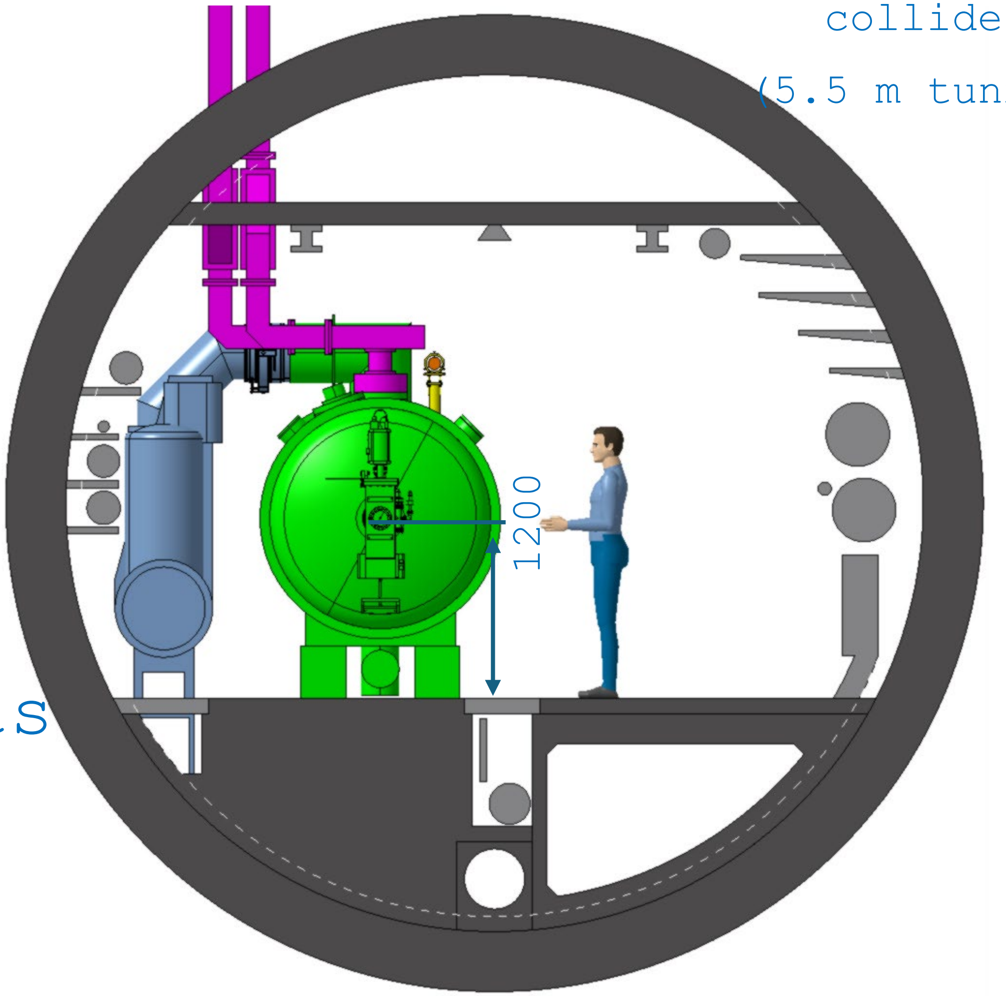


K. Canderan, SY-RF

M.Timmins, F. Cottenot, EN-MME

400 MHz in collider

(5.5 m tunnel)



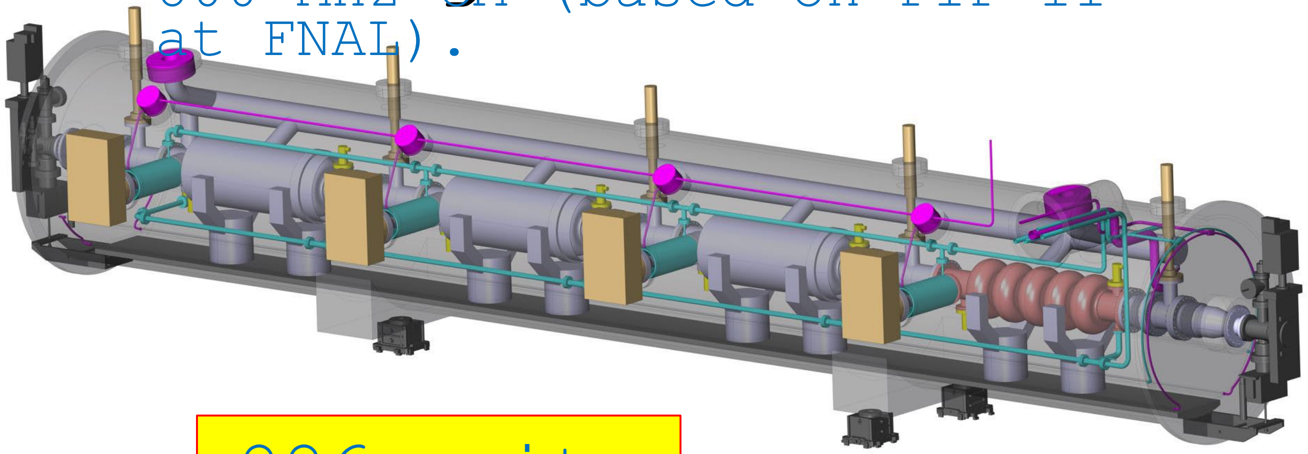
66 units

beam height in RF points : 1200mm > 980mm beam height in the arcs

→ can be matched with ~ 0.15% tunnel slope in separation/recombination zones (150m long)

800 MHz CM conceptual and integration studies

800 MHz CM (based on PIP II at FNAL).

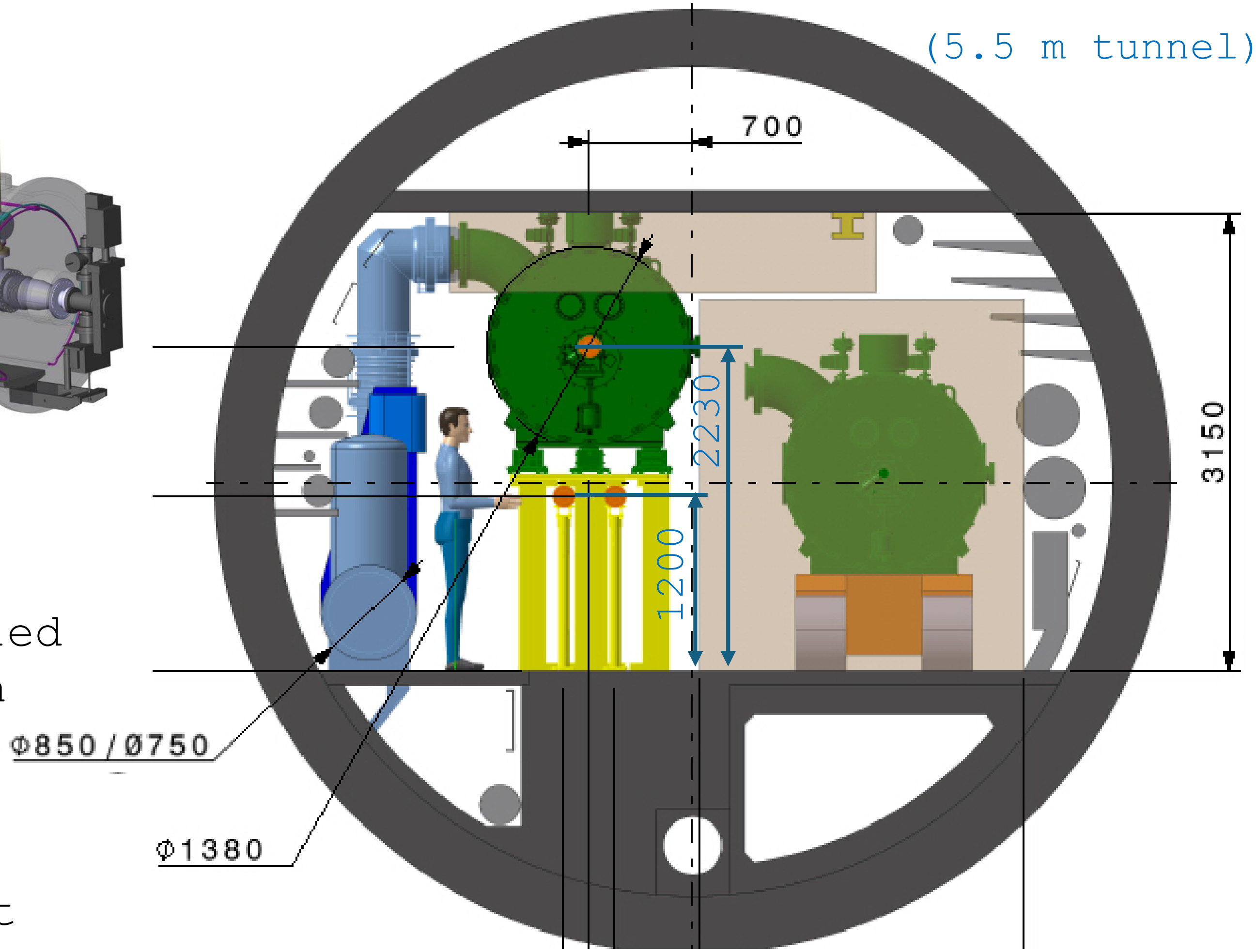


226 units (over 10 yrs)

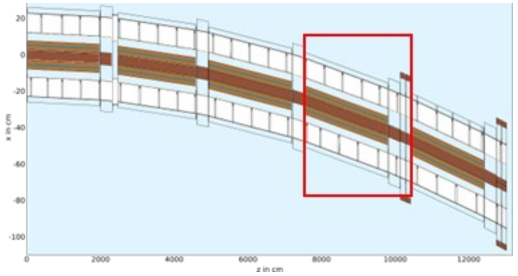
- ✓ Some integration issue still to be tackled (ceiling height, robot space reservation to be reviewed)
- ✓ MOU CERN/FNAL in preparation:
  - ➤ 800 MHz CM prototype by FNAL by about 2031
  - ➤ In view of a potential significant US contribution to FCC

800 MHz booster

(5.5 m tunnel)



R2E: radiation to electronics



order of magnitude levels and effects

Electronics in the tunnel need extra shielding

stochastic High-energy hadron fluence (cm^{-2} $year^{-1}$)	*cumulative* Total Ionizing Dose for 10 years (Gy)	Effects on Electronics
10^5	<<1	Possible SEE impact for commercial systems with MANY units and VERY demanding availability and reliability requirements
10^7	<1	SEE impact for systems with multiple units and demanding availability and reliability requirements
10^9	10	SEE mitigation (e.g. redundancy) at system level; cumulative effects can start to play a role
10^{11}	1 kGy	SEE mitigation (e.g. redundancy) at system level, very challenging TID level for COTS
10^{15}	10 MGy	Rad-hard by design ASICs

LHC R2E

Rubén García Alía | R2E perspectives for FCC-ee

Collider vacuum design

Courtesy R. Kersevan

Machine / optics design

- High Synchrotron Radiation (SR) photon flux generating **high photon-stimulated desorption** (PSD) gas load
- Rather **low specific conductance** of the vacuum chamber (dictated by the size of the quadrupole/sext opening)
- Requirement of **fast vacuum conditioning** so that a large integrated luminosity can be achieved
- Need for a vacuum system that **minimizes e-cloud** (e+ beam) and **ion-trapping** (e- beam) (to preserve the quality of the beam)

This leads to (Requirements):

- Efficient **removal of the 50 MW/beam** SR power load
- Vacuum surfaces (materials, thin-films, treatments) having a low PSD yield, **minimizing gas-beam interactions**
- **Efficient pumping**, both in cost and in performance
- **Minimization of the high-energy component of the Compton-scattered primary SR fan** (for energies W, H, T), as per FLUKA simulations/results

We can satisfy these requirements if we design a vacuum system based on:

- **NEG-coating** (thin, ~200 nm, to reduce resistive-wall impedance contribution)
- Primary SR fans intercepted by **localized SR absorbers**, rather than a LEP-like configuration where the SR fans are distributed more or less uniformly along the external side of the vacuum chamber

Feasibility