FUTURE
CIRCULAR
COLLIDER

OVERVIEW OF THE FCC-EE COLLIDER DESIGN

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On behalf of the FCC collaboration

FUTURE CIRCULAR COLLIDER Innovation Study

EuroCirCol A key to New Physics

CHART Swiss Accelerator Research and Technology

iFAST E-JADE EAJADE EASITrain CERN

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

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The FCC integrated program

Stage 1: FCC-ee (Z, W, H, $t\bar{t}$) as Higgs factory, electroweak & top factory at highest luminosities, other operation modes such as direct Higgs production under study.

Stage 2: FCC-hh (~100 TeV) as natural continuation at energy frontier, proton-proton (pp) and ion-ion (AA) collisions, includes eh collision option, *see G. Segurana's talk today !*

- Program highly synergetic and complementary enhancing the physics potential of both colliders.
- Common civil engineering and technical infrastructures, building on and reusing CERN's existing infrastructure.
- FCC integrated project allows the development of a significant new facility at CERN, within a few years of the completion of HL-LHC.

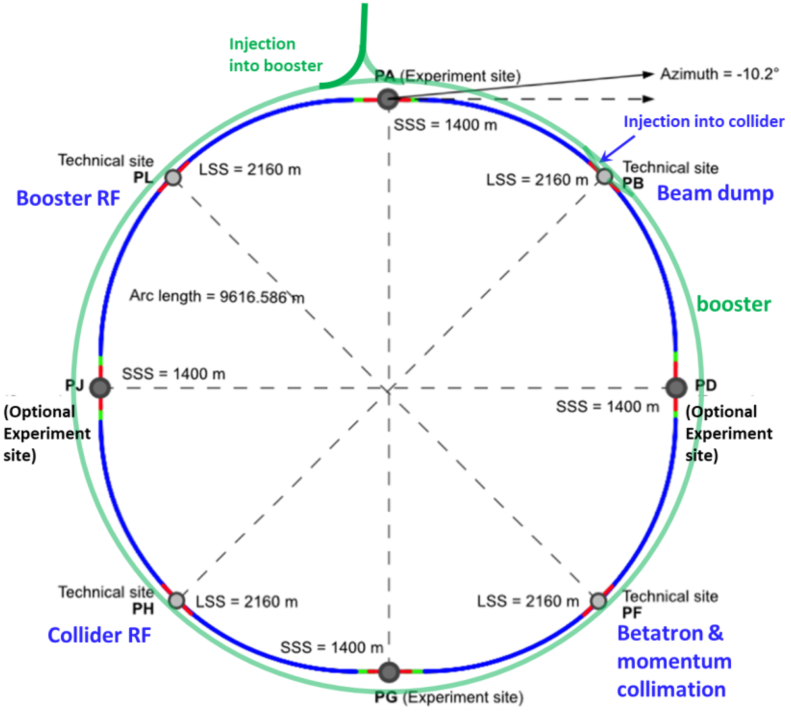
The FCC feasibility study (2021-2025)

In 2020, the European Strategy for Particle Physics update stated: “An electron-positron Higgs factory is the highest-priority next collider”. The FCC feasibility study has concluded its mid-term report, and its completion by March 2025 will be the next milestone ahead of the next ESPPU in June 2026.

- **Feasibility and optimization:** Geological, technical, environmental and administrative feasibility of the tunnel and surface areas, and optimisation of the placement and layout of the ring and related infrastructure; collaboration with Host States to prepare for a potential project approval and identify possible showstoppers;
- **Design and R&D:** Optimisation of collider and injector chain designs, supported by R&D to develop key technologies;
- **Sustainable operational model:** Development of a model for the colliders and experiments, considering human and financial resources, environmental aspects and energy efficiency;
- **Cost and funding:** Development of a consolidated cost estimate, funding strategies and organisational models to support the project’s technical design, implementation and operation;
- **Physics & detectors:** Consolidation of the physics case and detector concepts.

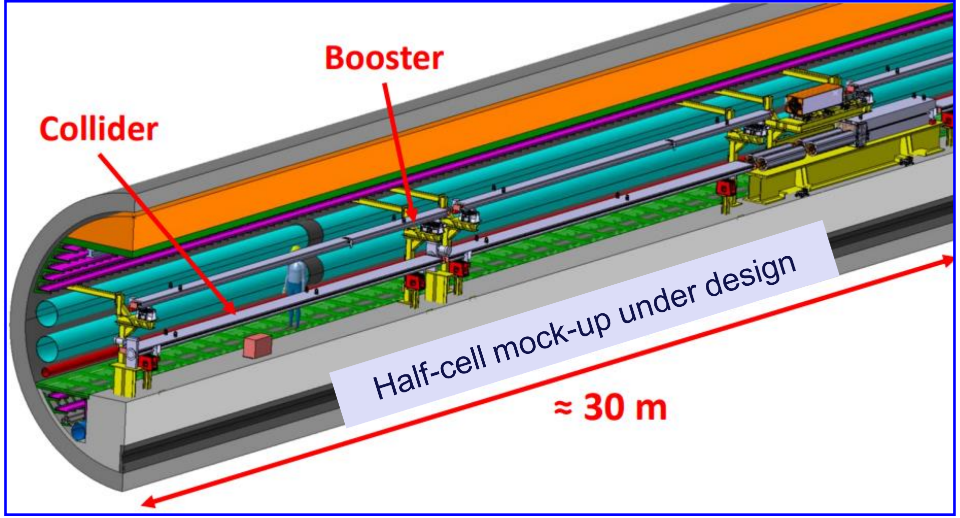
FCC-ee layout overview

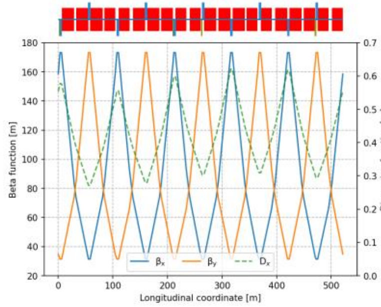
- **Double ring configuration:** The e^+e^- collider features independent vacuum system encompassing a 90.7km circumference.
- **Four experimental points:**
  - Asymmetric interaction region design to limit synchrotron radiation towards the particle detector.
  - 30 mrad horizontal crossing angle and crab waist collision scheme.
- **Operational flexibility:** Design allowing minimal changes between operation modes and is compatible with the hadron collider.
- **RF power consumption:** Synchrotron radiation power limited to 50MW per beam across all energies.
- **Full-energy booster:** Booster ring in the same tunnel to provide top-up injection.



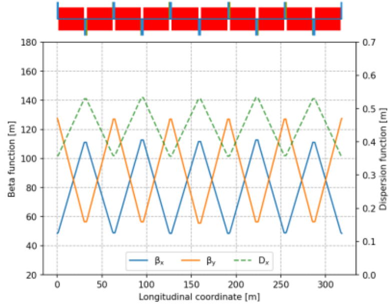
FCC-ee arc lattice and optics design

- Arc optics based on FODO or HFD, balancing smallest α_c at lower energies mitigating collective instability vs. minimal emittance at higher energies.
- Magnet design with twin quadrupole and SC nested quad. and sext. under study to reduce power consumption.
- Magnet tapering compensates sawtooth

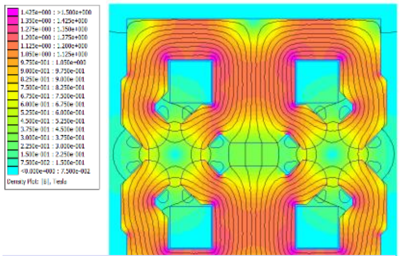




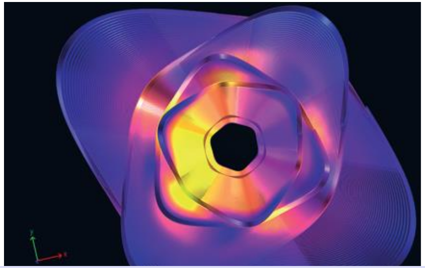
FODO optics



HFD optics

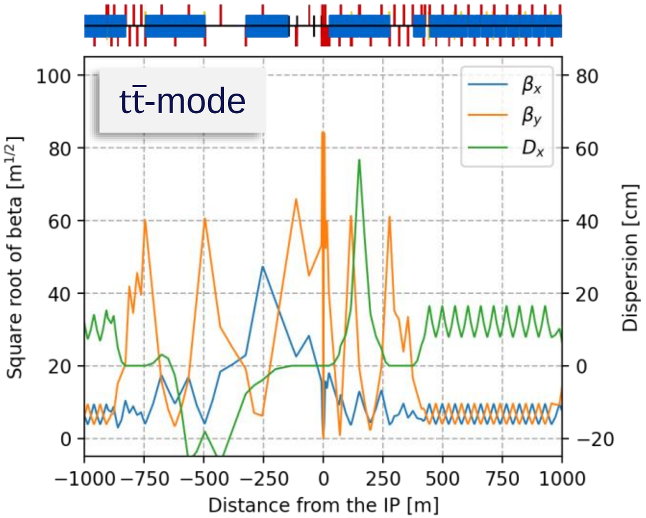


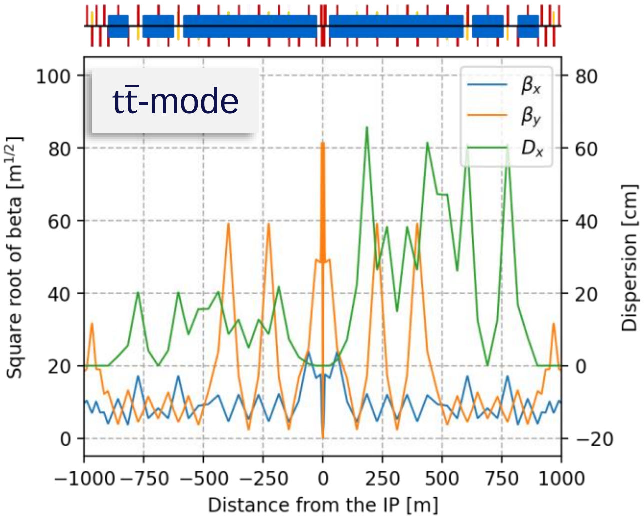
Twin aperture quadrupole



SC nested quad.+sext. (HTS4)

FCC-ee Interaction Region





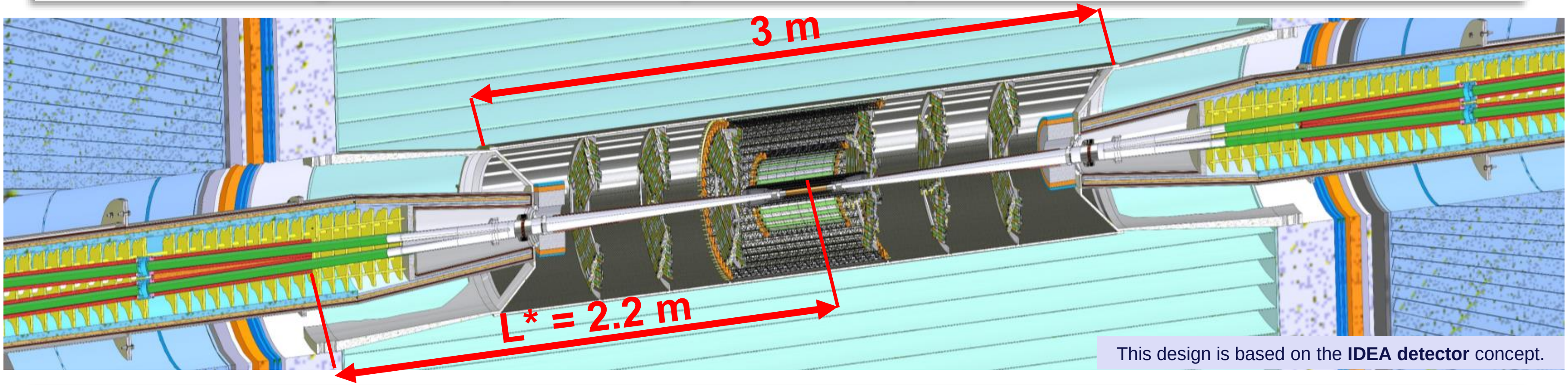
Oide's design: Asymmetric IR optics, **virtual** crab sextupoles obtained by detuning the local **vertical** chromaticity correction.

Raimondi's design: Symmetric IR optics, **horizontal** and **vertical** local chromaticity correction and **independent** crab sextupoles.

→ 2T detector solenoid compensated **locally** by anti-solenoid or <u>**distributed**</u> with anti-solenoids placed ±20m from the IP.

Machine Detector Interface

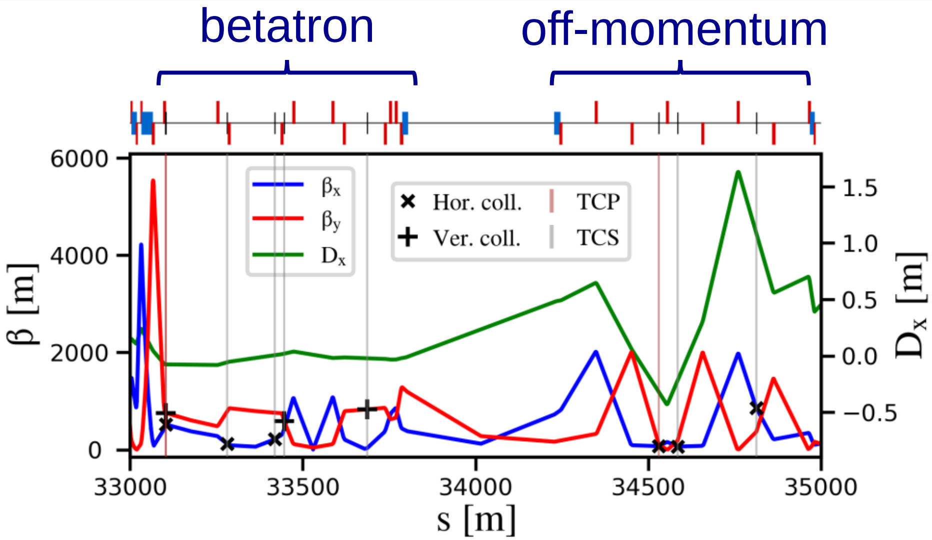
Ongoing efforts to optimize the material budget, impedance and thermal analysis, Moreover progress on the mechanical integration including the superconducting quadrupoles, cryostats, LumiCal, diagnostics, bellows, services, supports, etc…
An Interaction Region mock-up is currently under development at INFN Frascati.

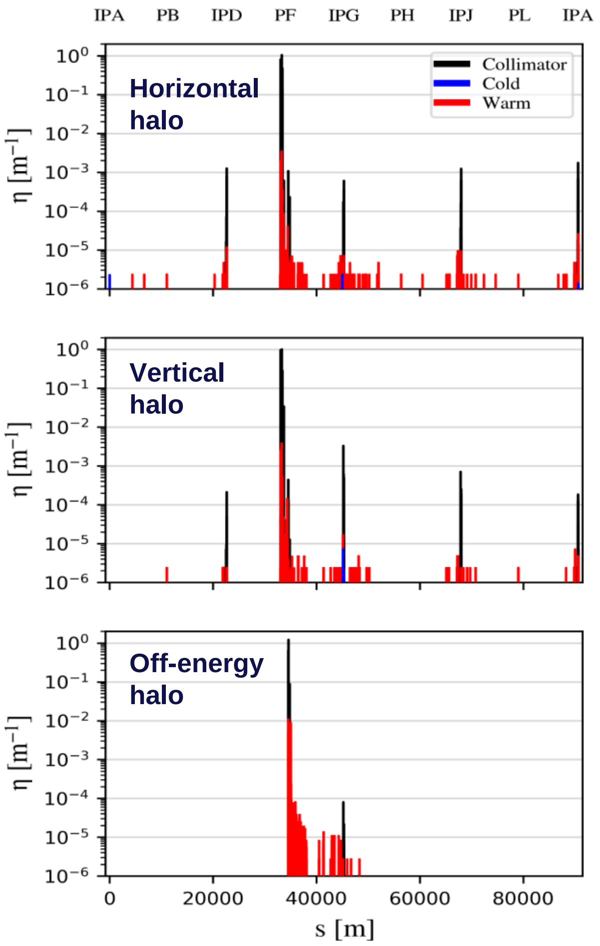


Multiple studies focused on various backgrounds, comprised of synchrotron radiation, Bhabha radiation, beamstrahlung, and beam halo losses. These backgrounds drive the design of shielding, collimation strategy, and beamstrahlung photon dump.

FCC-ee collimation

High stored beam energy during the Z operation mode of about 17.5 MJ, driving the development of a halo collimation system to **protect sensitive components** (*e.g.* SC final focus quadrupoles) from beam losses and **reduce the background in the experiment.**



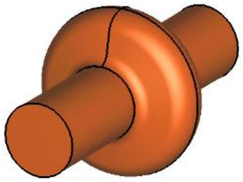


FCC-ee Radio-Frequency system

Z

1-cell
400 MHz,
Nb/Cu

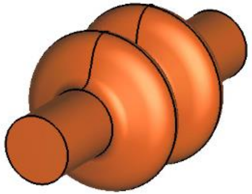
Low R/Q, HOM damping, powered by 1 MW RF coupler and high efficiency klystron



W, H

2-cell
400 MHz,
Nb/Cu

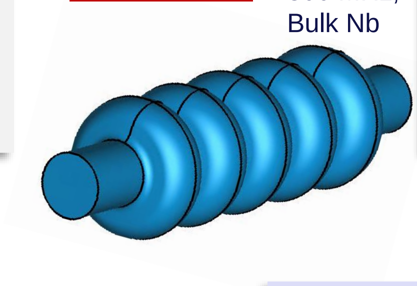
Moderate gradient and HOM damping requirements; 500 kW / cavity, allowing reuse of klystrons already installed for Z

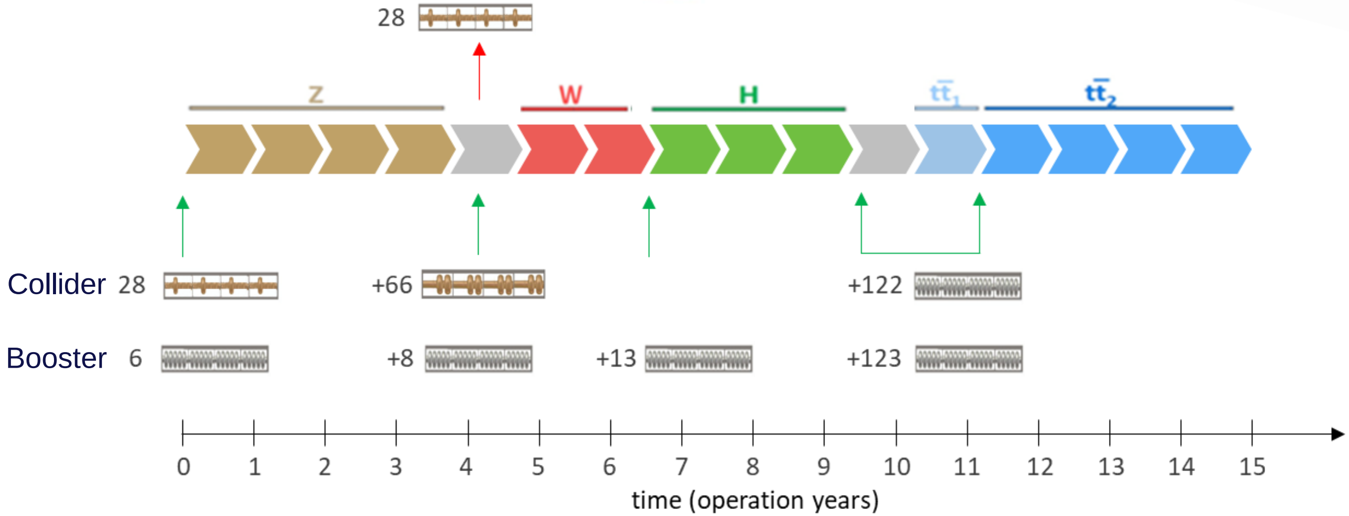


$t\bar{t}$, booster

5-cell
800 MHz,
Bulk Nb

High RF voltage and limited footprint thanks to multicell cavities and higher RF frequency; 200 kW / cavity



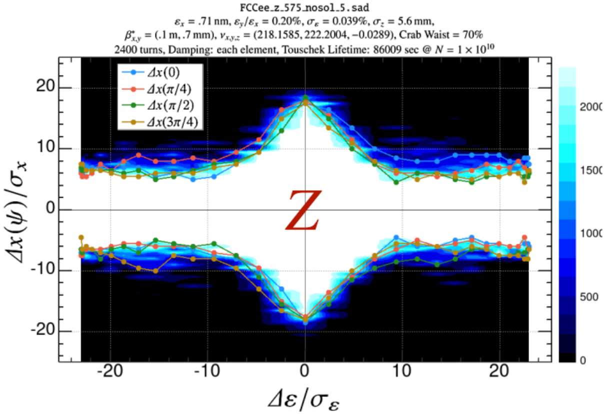


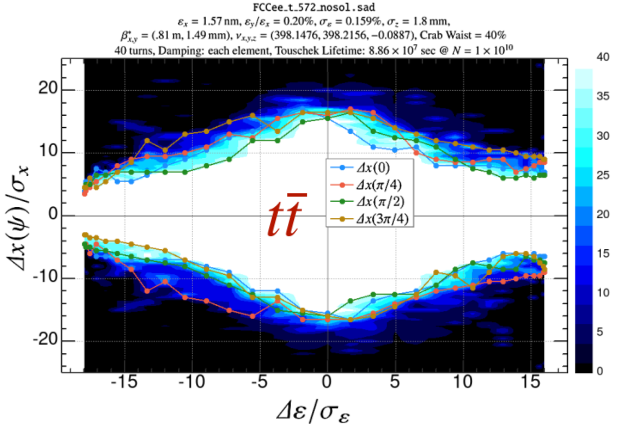
2-cell RF cavities under study for Z operation.

- Flexibility in physics running mode
- Simplify installation sequence
- 2 RF cavity types to develop

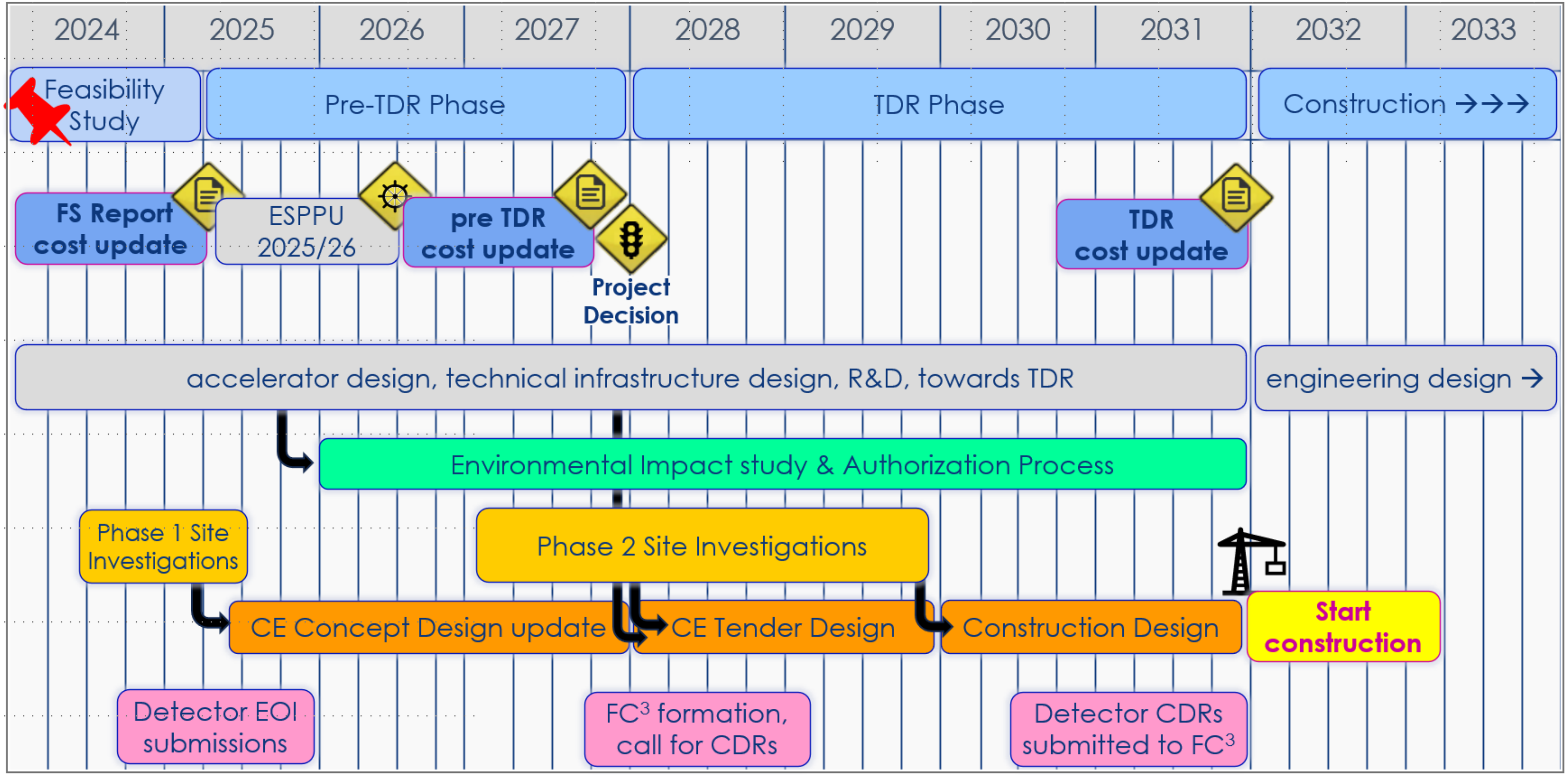
Dynamic aperture & momentum acceptance

- The current DA & MA correspond to a beam lifetime that is satisfactory at all energies.
- Sufficient momentum acceptance is required for:
  - Off-momentum injection for the Z mode operation at 1%
  - Large energy spread due to beamstrahlung at $t\bar{t}$ requiring [-2.8%, 2.5%] momentum acceptance.
- The DA optimization uses sextupole pairs in the arcs with constraints from chromaticity and chromatic optics at the IP.
- Without errors targets are met, however, errors strongly affect DA/MA and further optimization studies including errors are ongoing.



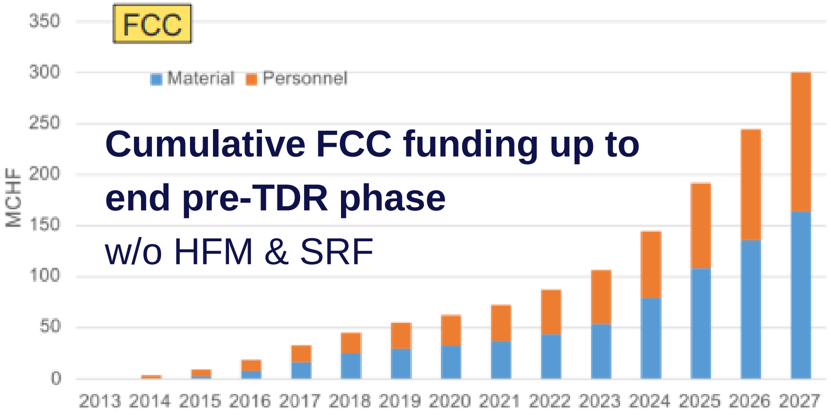


Tentative timeline



Recent decisions by CERN council

- **February 2024**: special Council meeting: **successful Mid-Term Review**; all objectives met, lots of praise & positive feedback, recommendations & guidance.
- **March 2024: ESPPU schedule 2025/2026** approved with input by March 2025, conclusions mid 2026; **compatible with "accelerated" FCC schedule.**
- **June 2024: approval of modified CERN Medium Term Plan (MTP), including more resources for FCC-FS completion and for FCC pre-TDR phase**.



Additional expenses in June 2024 MTP to prepare for CERN's future.

Future Circular Collider (FCC)
Additional resources for the Feasibility Study → 13 MCHF
(**until March 2025**, when final report will be submitted)
Funding for "pre-TDR phase" → 82 MCHF (April 2025 - 2027)

Superconducting radiofrequency technology (SRF)
Ramp up R&D for future accelerators (until now 2.3 MCHF/year)
→ 9.7 MCHF (2025-2027)

Summary & outlook

Profiting from many accelerator developments in the past decades, the FCC-ee aims at electron-positron collision with unprecedented energies and record luminosity as first stage, prior to an energy-frontier hadron collider.

The facility scale and ambitious parameter set provide compelling challenges for the accelerator design and hardware optimization.

Next steps entail to provide a consistent baseline design for the Feasibility Study by March 2025 following recommendations from the mid-term review, while investigating alternative options with significant impact on cost or performance to define required R&D.

Strong collaboration with the US and further international partners is essential for success.

Thank you
for your attention.

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 x_x / x_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

F. Gianotti

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

Improvements:

- ❑ x10-50 on all EW observables
- ❑ up to x 10 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

MDI mechanical model

This design is based on the **IDEA detector** concept.