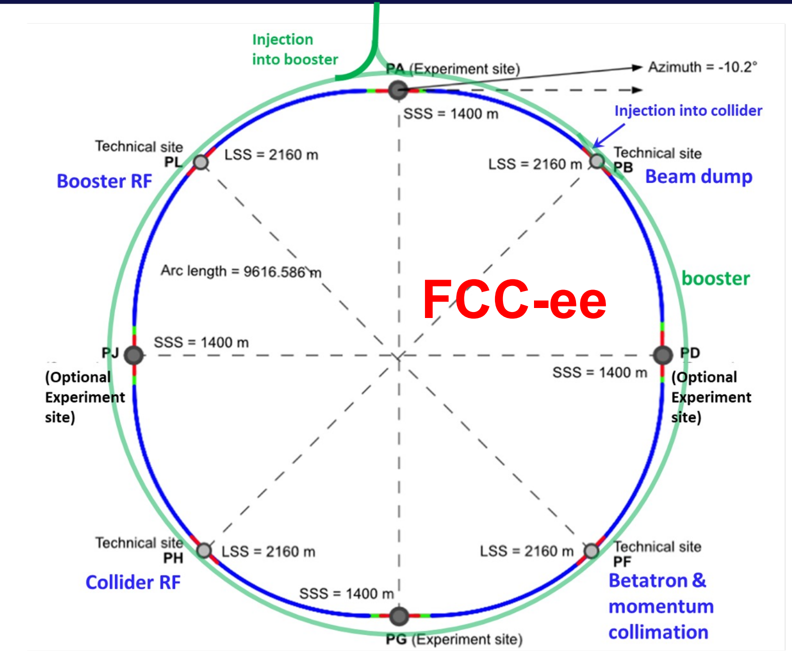
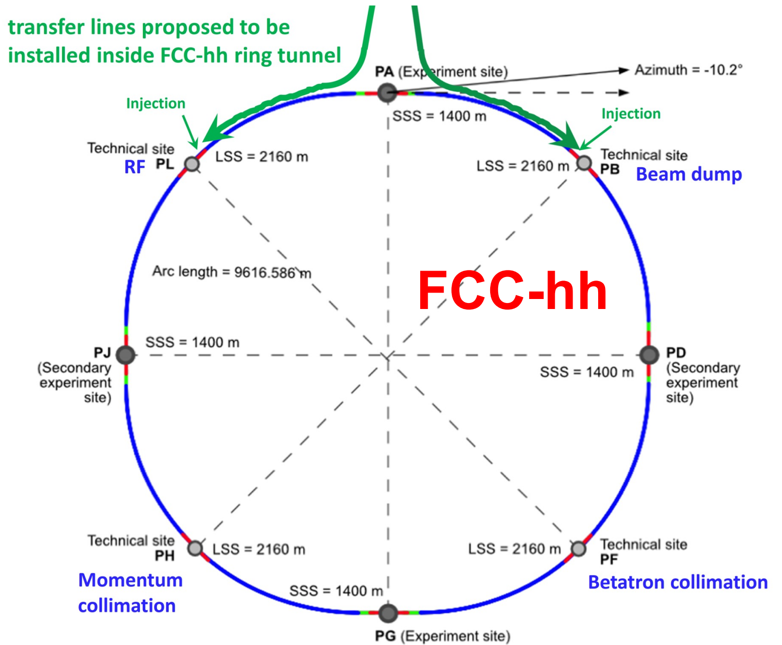
The FCC Project

Andrea Ciarma
on behalf of the FCC collaboration

This project is supported from the European Union's Horizon 2020 research and innovation programme under grant agreement No 951754.

The FCC Integrated Project





The Future Circular Collider is **comprehensive long-term program** aimed at maximizing physics opportunities.

The integrated program envisions **two accelerator machines**:

1st stage: **FCC-ee** ($Z, W, H, t\bar{t}$)
- extremely high **luminosity** Higgs factory, EW, top factory

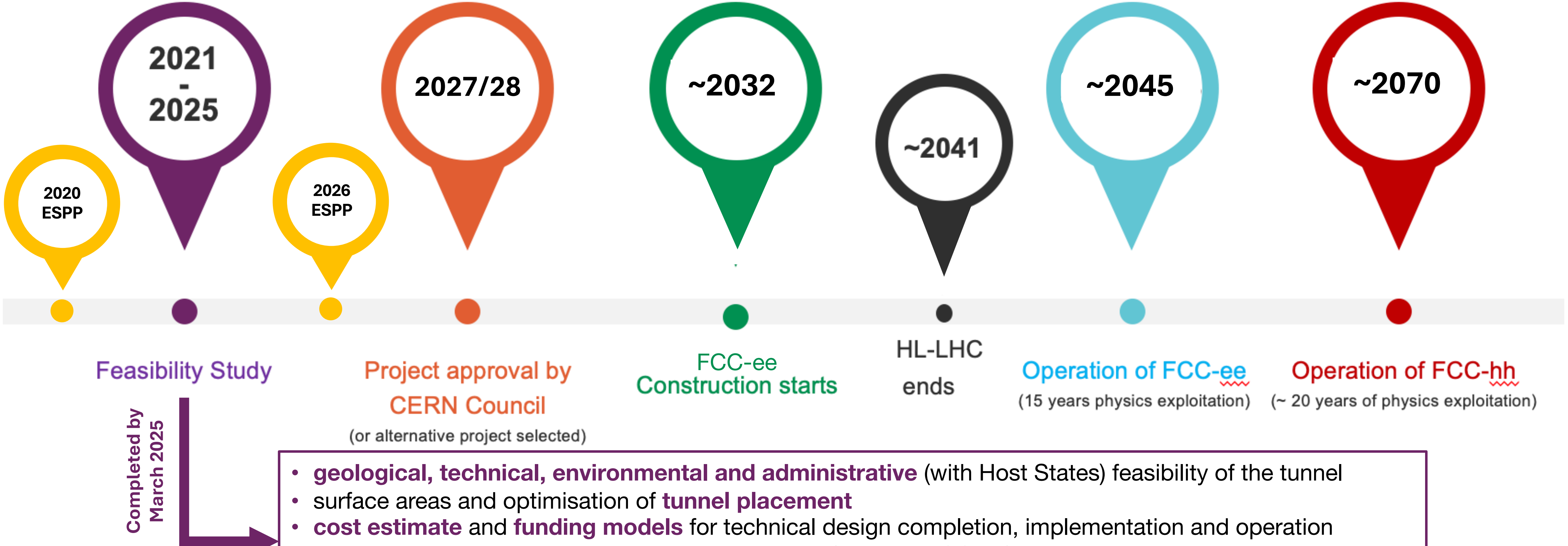
2nd stage: **FCC-hh** ($\sim 100\, TeV$)
- natural evolution, pushing the **energy frontier**
- pp and AA collisions, possibility for ep / e-ion

Strong synergy between the two colliders: **common** facilities and infrastructures, **complementary** physics programme.

The FCC Integrated Project allows the start of a **new major HEP programme at CERN** within a few years of the end of HL-LHC.

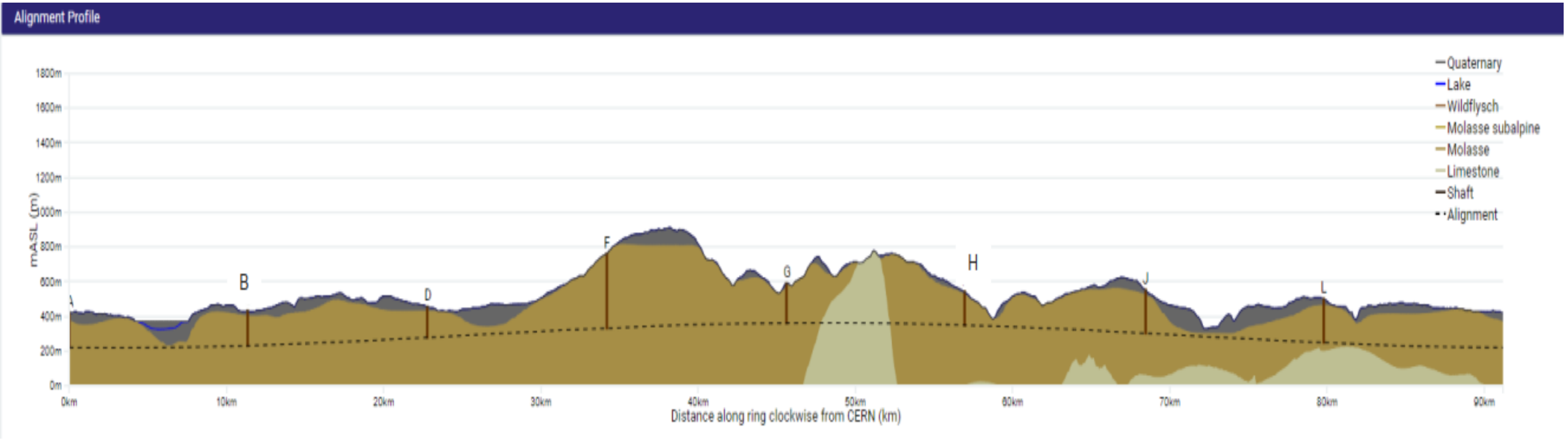
The FCC Integrated Program - Timeline

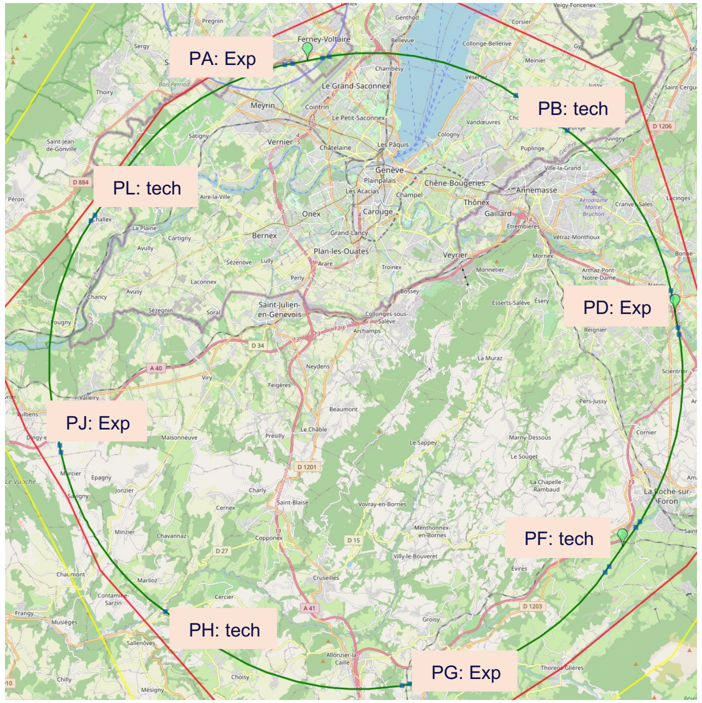
M. Benedikt – FCCWeek24



- **geological, technical, environmental and administrative** (with Host States) feasibility of the tunnel
- surface areas and optimisation of **tunnel placement**
- **cost estimate** and **funding models** for technical design completion, implementation and operation
- identification of **external resources** for first stage (tunnel + FCC-ee)
- **collider design optimisation**, injector chains, R&D to develop needed key technologies
- consolidation of the **physics case** and **detector concepts** for both colliders

Optimization of tunnel layout





Tunnel and infrastructures common for the two stages. Optimal layout chosen out of ~100 initial variants, based on **geology surveys** and **surface constraints.**

Overall lowest-risk baseline: 90.7 km ring, 8 surface points (4IPs)

Road access to surface sites and connections to highway defined. Electrical **connection to power grid** developed, with no significative impact from requested loads. Strong R&D effort to further reduce consumption.

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**

Why FCC ?

F. Gianotti

1) Physics

Immense physics potential

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

FCC-ee

Novel research infrastructure based on a **highest-luminosity energy frontier** electron-positron collider.
High precision machine for the continued in-depth exploration of nature at the smallest scales.

FCC-ee is optimized to study with high precision the **Z, W, Higgs** and **Top** particles.

High intensity at Z pole replicate LEP1 in the first few minutes.

- 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

F. Gianotti

M. McCullough

Observable	Present value	±	error	FCC-ee (statistical)	FCC-ee (systematic)
m_Z (keV/c^2)	91 186 700	±	2200	5	100
Γ_Z (keV)	2 495 200	±	2300	8	100
R_ℓ^Z ($\times 10^3$)	20 767	±	25	0.06	1
$\alpha_s(m_Z)$ ($\times 10^4$)	1196	±	30	0.1	1.6
R_b ($\times 10^6$)	216 290	±	660	0.3	<60
σ^0_{had} ($\times 10^3$) (nb)	41 541	±	37	0.1	4
N_ν($\times 10^3$)	2991	±	7	0.005	1
$\sin^2\theta_W^{eff}$($\times 10^6$)	231 480	±	160	3	2–5
$1/\alpha_{QED}(m_Z)$($\times 10^3$)	128 952	±	14	4	Small
$A_{FB}^{b,0}$ ($\times 10^4$)	992	±	16	0.02	<1
$A_{FB}^{pol,\tau}$ ($\times 10^4$)	1498	±	49	0.15	<2
m_W (keV/c^2)	803 500	±	15 000	600	300

FCC-ee Parameters

FCC-ee collider parameters for the GHC lattice as of May 29, 2024.

Beam energy	[GeV]	45.6	80	120	182.5
Layout		PA31-3.0			
# of IPs		4			
Circumference	[km]	90.658728			
Bend. radius of arc dipole	[km]	10.021			
Energy loss / turn	[GeV]	0.0390	0.369	1.86	9.94
SR power / beam	[MW]	50			
Beam current	[mA]	1283	135	26.8	5.0
Colliding bunches / beam		11200	1852	300	64
Colliding bunch population	[10^{11}]	2.16	1.38	1.69	1.48
Hor. emittance at collision ε_x	[nm]	0.70	2.16	0.66	1.51
Ver. emittance at collision ε_y	[pm]	1.9	2.0	1.0	1.36
Lattice ver. emittance $\varepsilon_{y,\mathrm{lattice}}$	[pm]	0.87	1.20	0.57	0.94
Arc cell		Long 90/90		90/90	
Momentum compaction α_p	[10^{-6}]	29.2nx		7.52	
Arc sext families		75		146	
$\beta^*_{x/y}$	[mm]	110 / 0.7	220 / 1	240 / 1	900 / 1.4
Transverse tunes $Q_{x/y}$		218.158 / 222.220	218.185 / 222.220	398.150 / 398.220	398.148 / 398.215
Chromaticities $Q'_{x/y}$		0 / +5	0 / +5	0 / 0	0 / 0
Energy spread (SR/BS) σ_δ	[%]	0.039 / 0.110	0.069 / 0.105	0.102 / 0.176	0.152 / 0.184
Bunch length (SR/BS) σ_z	[mm]	5.57 / 15.6	3.46 / 5.28	3.26 / 5.59	1.91 / 2.32
RF voltage 400/800 MHz	[GV]	0.079 / 0	1.00 / 0	2.09 / 0	2.1 / 9.20
Harm. number for 400 MHz		121200			
RF frequency (400 MHz)	MHz	400.787129			
Synchrotron tune Q_s		0.0289	0.0809	0.0334	0.0881
Long. damping time	[turns]	1171	218	65.4	19.4
RF acceptance	[%]	1.06	3.32	2.06	3.06
Energy acceptance (DA)	[%]	±1.0	±1.0	±1.9	-2.8/+2.5
Beam crossing angle at IP θ_x	[mrad]	±15			
Crab waist ratio	[%]	70	55	50	40
Beam-beam ξ_x/ξ_y [a]		0.0022 / 0.0977	0.013 / 0.129	0.0108 / 0.130	0.065 / 0.136
Piwinski angle $(\theta_x \sigma_{z,\mathrm{BS}})/\sigma^*_x$		26.6	3.6	6.6	0.94
Lifetime (q + BS + lattice)	[sec]	11800	4500	6000	7700
Lifetime (lum) [b]	[sec]	1330	960	600	670
Luminosity / IP	[10^{34}/cm^{2}s]	143	20	7.5	1.38

45.6 GeV	80 GeV	120 GeV	182.5 GeV
4 years 5×10^{12} Z LEP x 10^5	2 years > 10^8 WW LEP x 10^4	3 years 2×10^6 H	5 years 2×10^6 tt

Machine design and beam parameters driven by 50MW SR per beam constraint

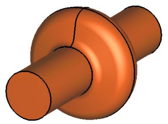
Extremely **high luminosity** achieved via **Crab Waist** collision scheme (large crossing angle, nanobeam scheme) and **top-up injection** for continuous collisions (booster in collider tunnel).

Four-fold symmetric lattice allows installation of up to **4 experiments**, for general purpose and specialized detectors.

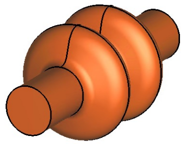
Monochromatization could allow **direct Higgs production** $e^+e^- \rightarrow H$ (s=125GeV) to directly measure e-Yukawa coupling

Operations sequence for FCC-ee

Three sets of RF cavities are proposed to cover **all operation modes** for the FCC-ee collider rings and booster:



Z – 400 MHz Nb/Cu (4.5K) mono-cell cavities

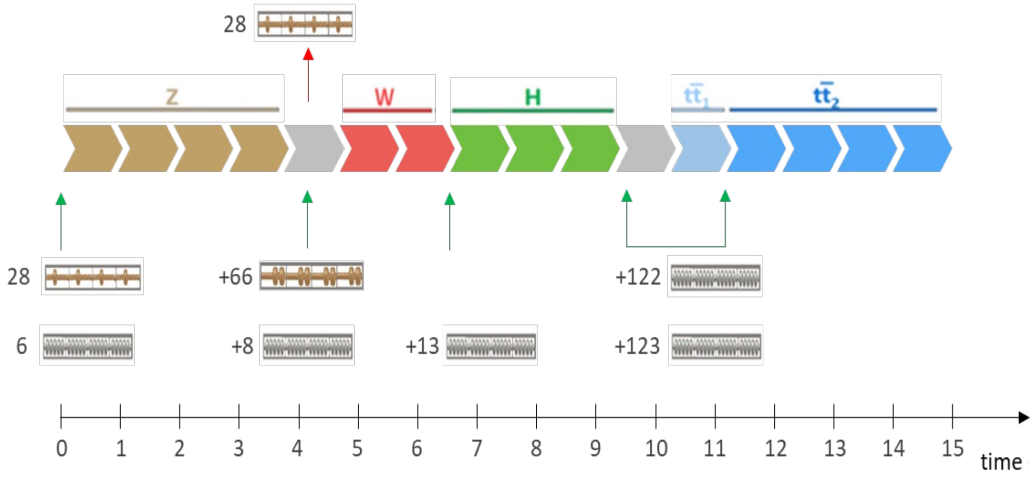


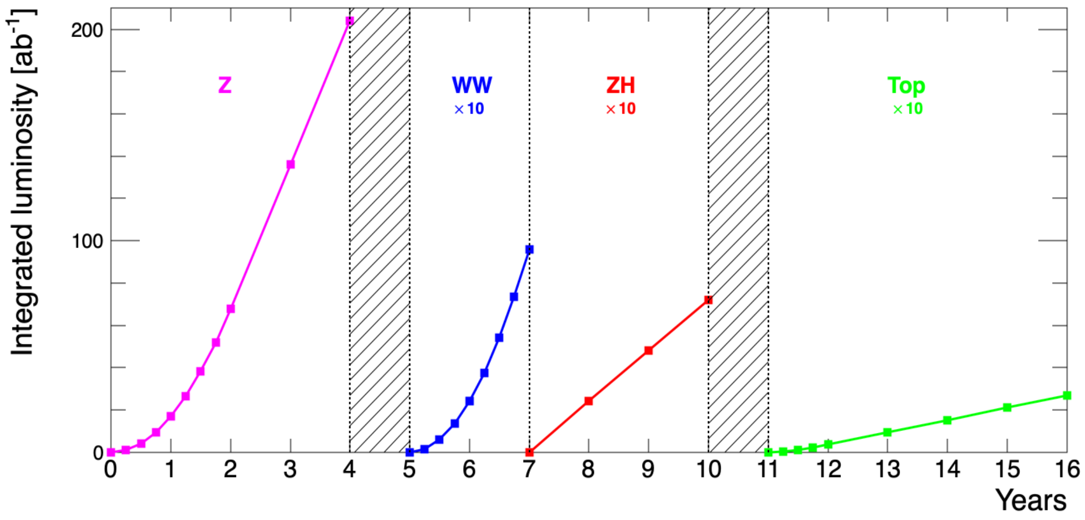
W, ZH – 400 MHz Nb/Cu 4-cell cavities

ttbar, booster – 800 MHz bulk Nb (SRF 2K) 5-cell cavities

Evolution of RF configuration with beam energy and physics operations.

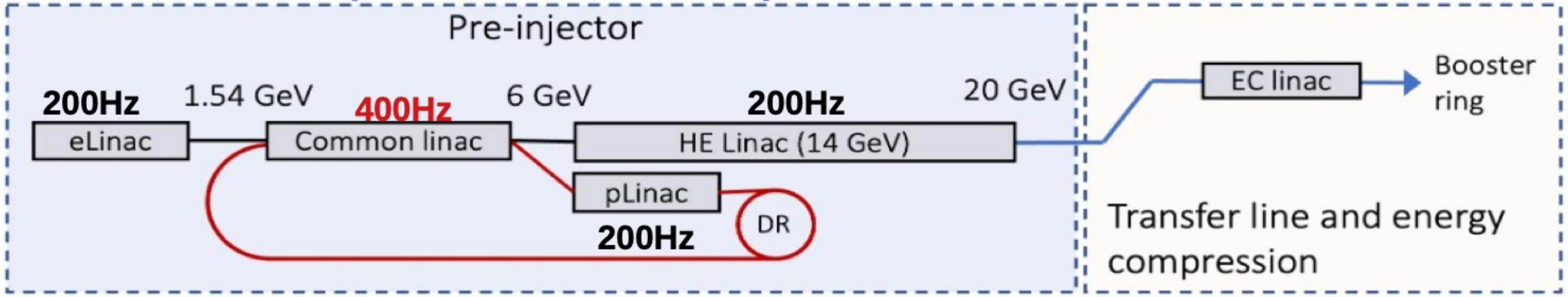
Cryomodules installation sequence will happen during **long shutdowns**, comparable with LEP



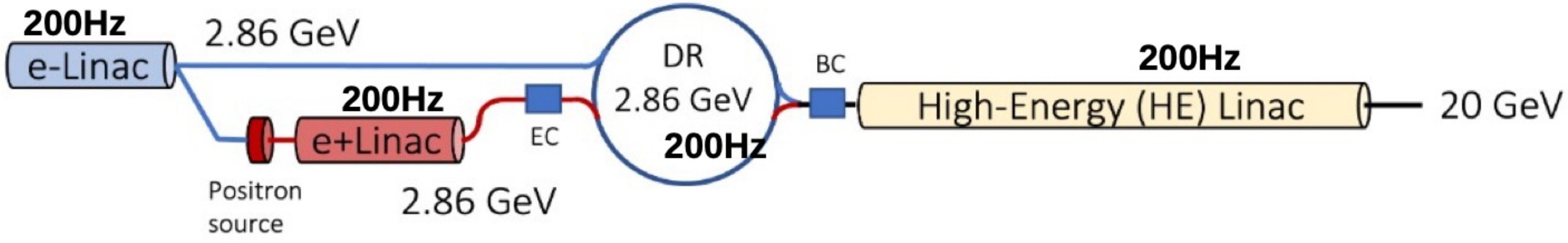


FCC-ee injector layout

Current Baseline (Mid-Term Cost Review)

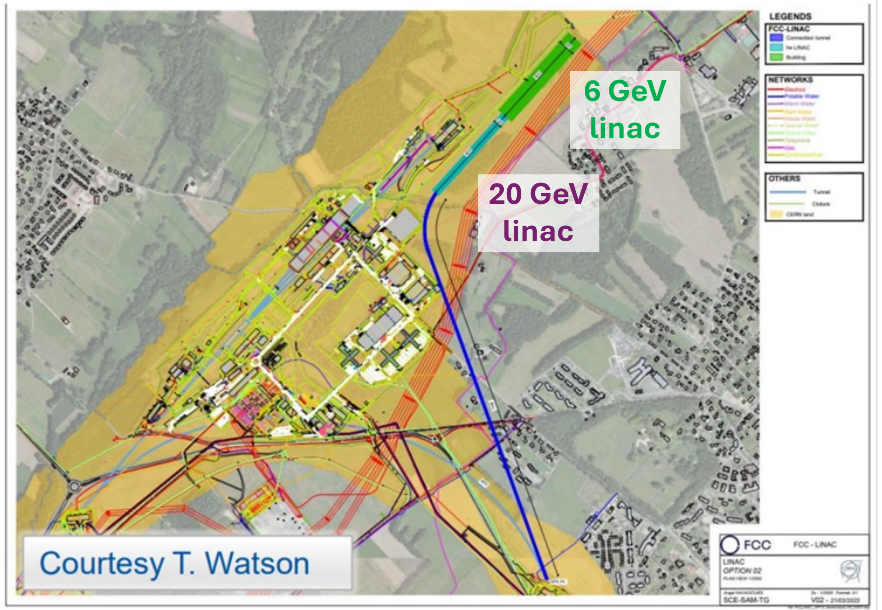


High-Energy DR option (NEW! under study)



Overall injector parameter optimisation, following mid-term review recommendations

- Operation frequency, operation gradient vs number of structures/overall length
- Positron production energy, damping ring energy



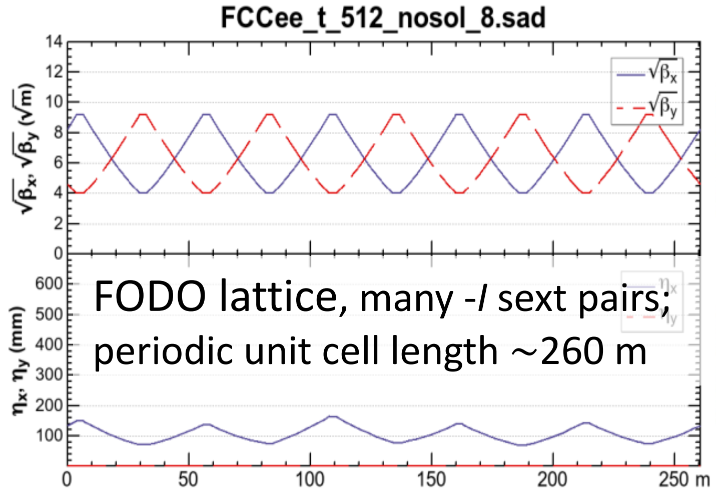
Injector layout and implementation study on CERN Prevessin Site

- Technical infrastructure pre-design & integration with services
- Injector cost estimate update

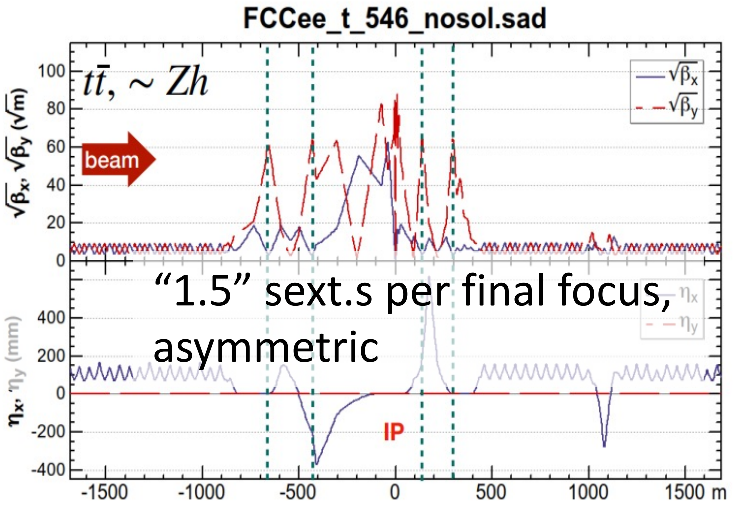
FCC-ee optics: baseline and further evolutions

GHC (K. Oide)

Main Arcs

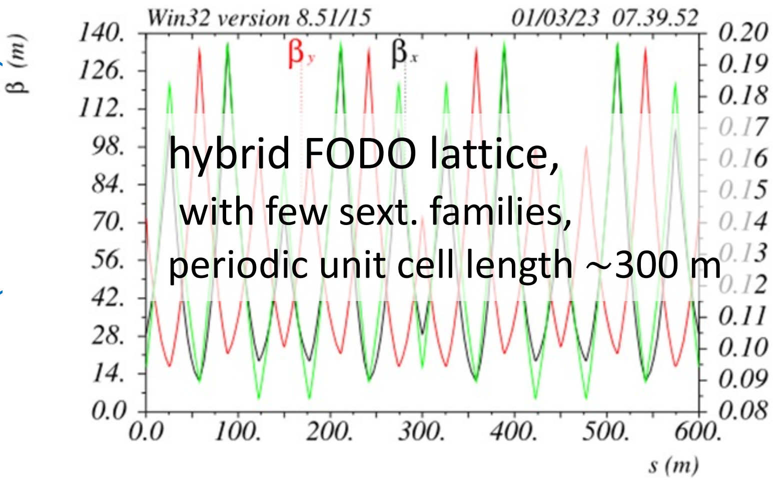


Interaction Region

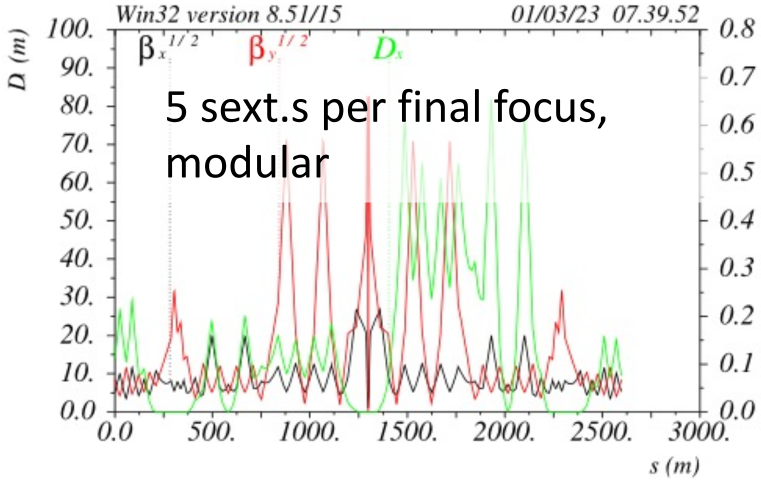


LCC (P. Raimondi)

Main Arcs



Interaction Region



GHC: baseline lattice for 2023 FCC mid-term review.

- Consolidated **beam parameters** at different operation modes
- definitive **collider layout**
- **beam-based alignment** procedures, **tolerances** and requirements
- complete **impedance models** for collider rings

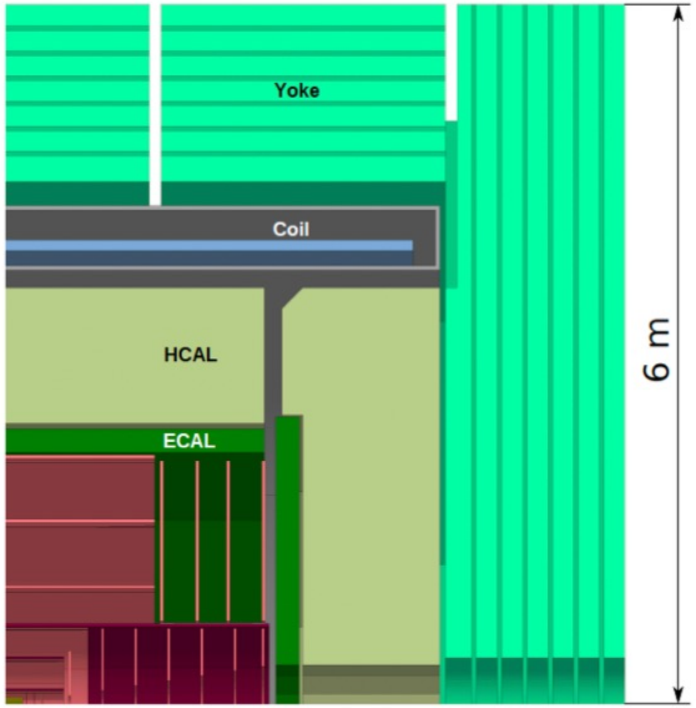
LCC: alternative lattice, design in progress.

- Further **relaxed tolerances**
- reduced **power consumption**
- larger **momentum acceptance**

Detector concepts for FCC-ee

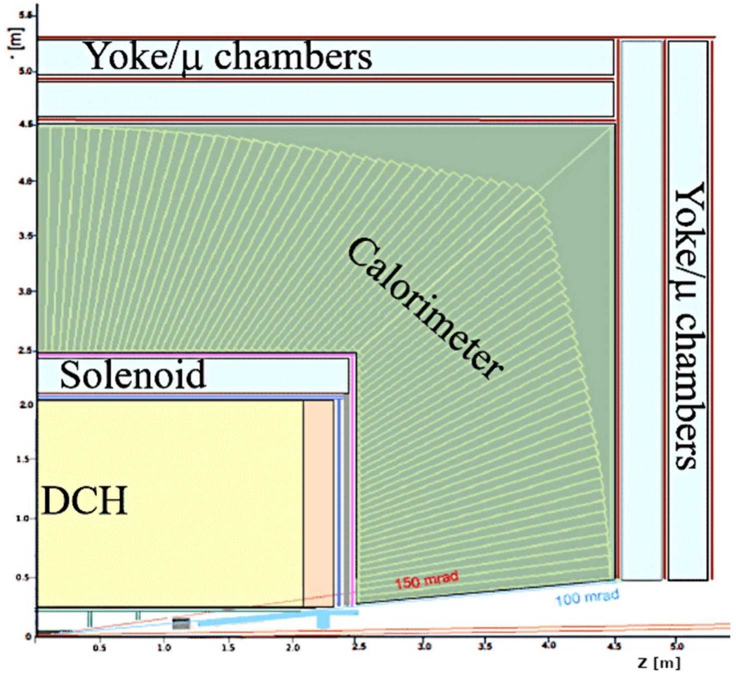
Three general purpose detector concepts currently developing:

CLD



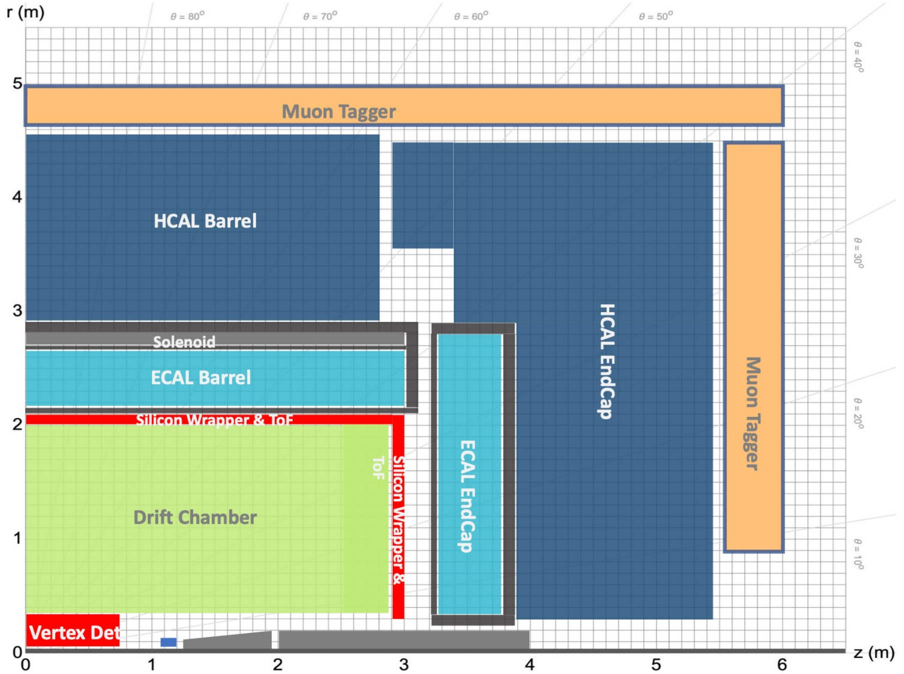
- Evolution of the ILC/CLIC detector.
- Full Si VTX-TRK
- CALICE-like calorimetry

IDEA



- Si VTX + Ultralight Drift Chamber
- Monolithic dual readout calo
- Very active community (INFN)

ALLEGRO

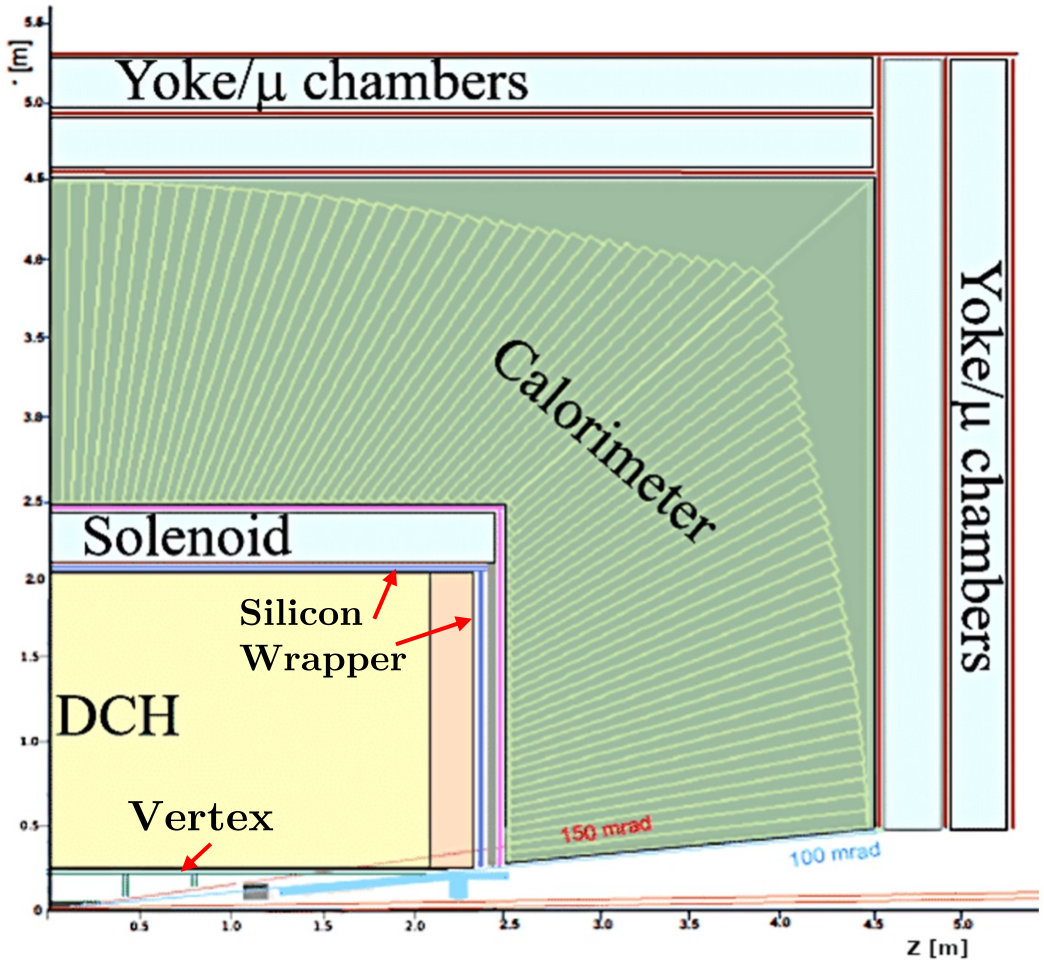


- Si VTX + Ultralight Drift Chamber
- High granularity Noble Liquid ECAL (LAr)
- Very active Noble Liquid R&D (electronics, SW, performance)

The IDEA concept

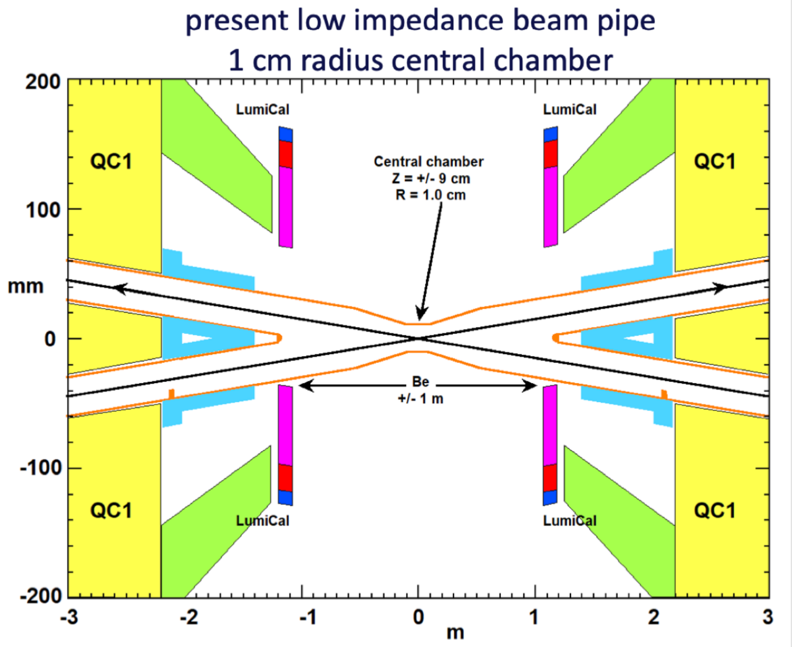
Large effort from INFN community, international collaborations and synergies (DRD-ECFA) on this detector concept: software R&D, physics studies and structured detector R&D

- **Vertex pixel detector**: ARCADIA, AtlasPix3, ALICE ITS3 – **MI, TO, PI**
- **Vertex MDI implementation**: – **LNF, PI**
- **Silicon wrapper**: AtlasPix3, Resistive LGADs – **GE, TO**
- **Drift chamber**: design, cluster counting – **LE, BA**
- **Muon chambers**: µRwell – **LNF**
- **Calorimeter**: DR fiber, crystals – **MI, PV**



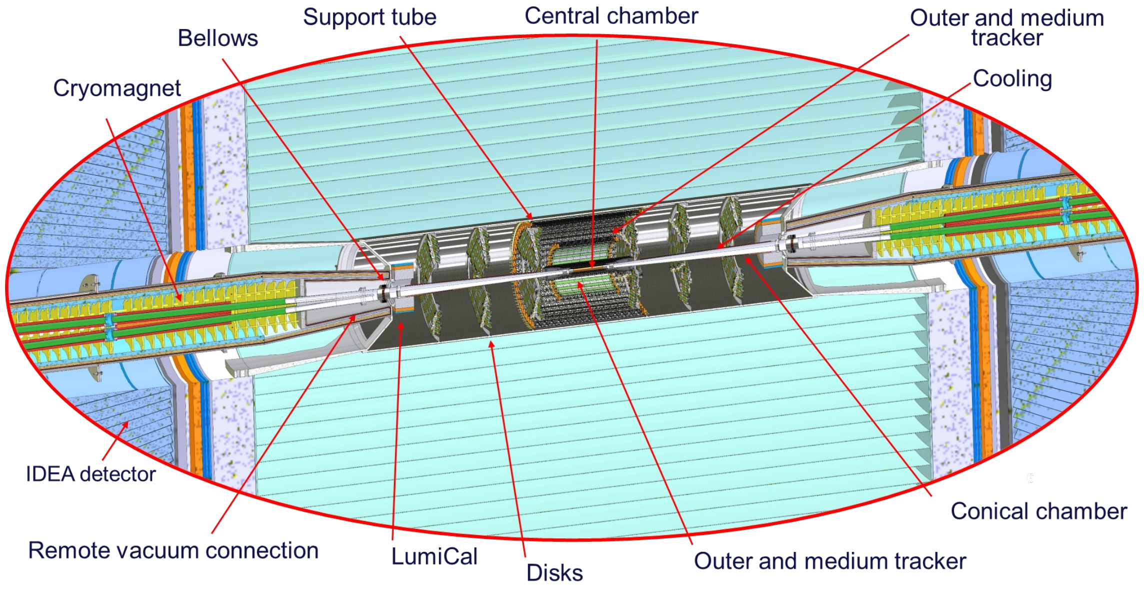
More details on this F. Bedeschi talk

FCC-ee Machine Detector Interface



FCC-ee MDI is a region dense with elements – and mechanical constraints!

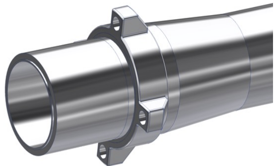
- L* = 2.2m, 30mrad crossing angle
- **SiW LumiCal** – measure forward bhabhas in **50~100mrad** acceptance
- **-5T anti-solenoid** at s = ±1.23m to cancel **coupling from detector** 2T field
- **Cryostats** for anti-solenoids and SC final focus quadrupoles
- **Central Chamber**: R=10mm, L=18cm
- **Support tube** in carbon fiber for **Vertex/Inner Tracker integration**

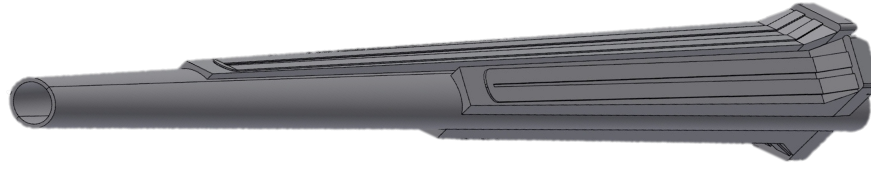


Engineered design of the **IR AlBeMet beam pipe:**

- **optimization of cooling manifolds** to minimize impact on LumiCal precision
- **low impedance** beam pipe separation region and bellows
- **Beryllium** under evaluation to reduce L/X0

IR Mock-up @LNF: prove state-of-the-art technological solutions and test feasibility → see F. Fransesini this afternoon!





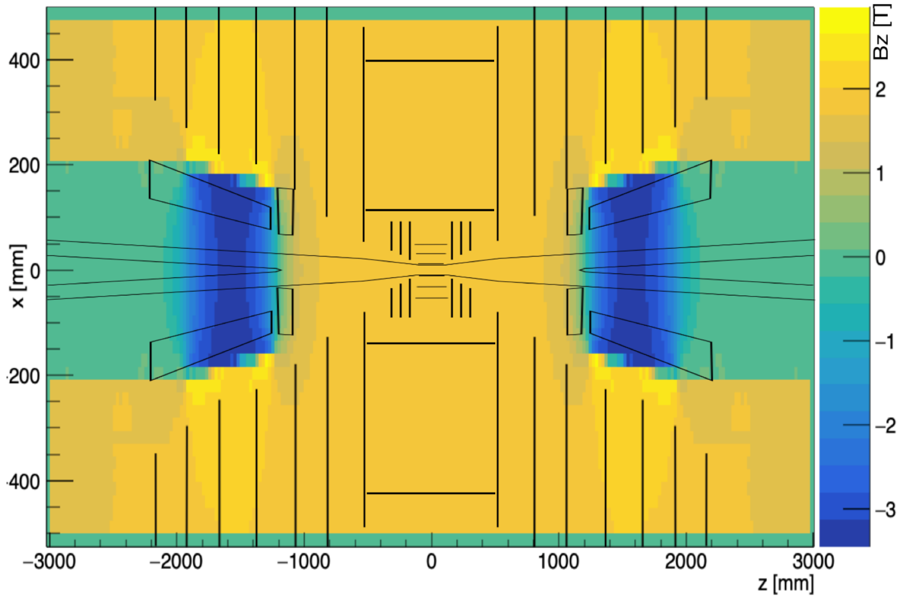
Background assesment at FCC-ee

Estimation of beam induced backgrounds is a **driver element** for the design of detectors and MDI region.

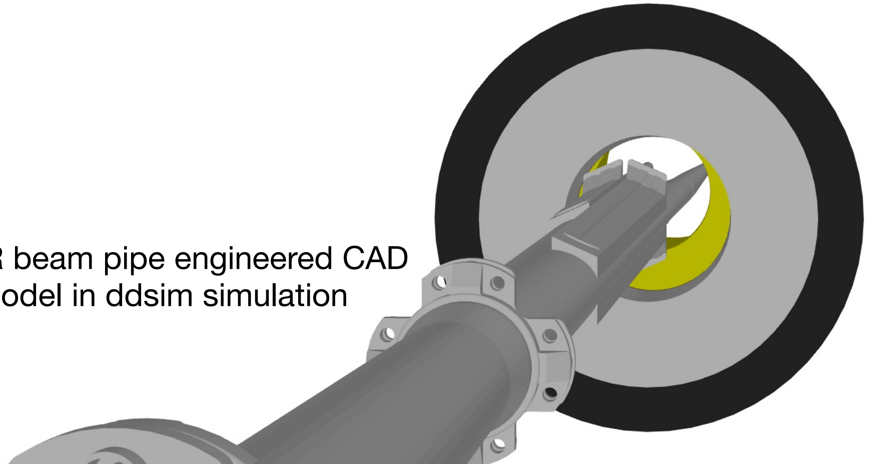
A **streamlined procedure** for occupancy calculation in each subdetector is a key feature under development in the FCCSW framework:

- **repository** with primary particles for each **background source** at the four FCCee energies
- **detector description** for the three experiments and common **MDI elements**
- particle tracking performed using G4 based tool **ddsim**

Key aspects:
- MDI modelization (pipe, cooling, supports, fields, etc)
- identification of appropriate event generators



IR beam pipe engineered CAD model in ddsim simulation



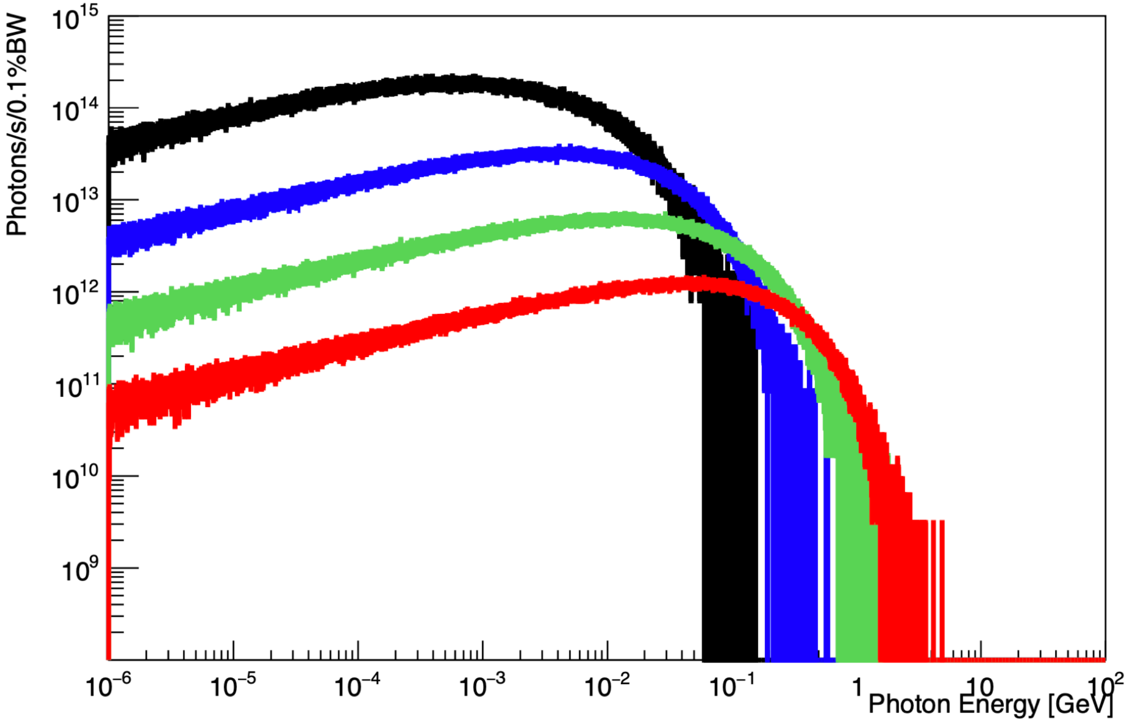
Beamstrahlung Radiation Characterisation

Radiation emitted by a beam particle curved under the EM field of the opposing bunch.

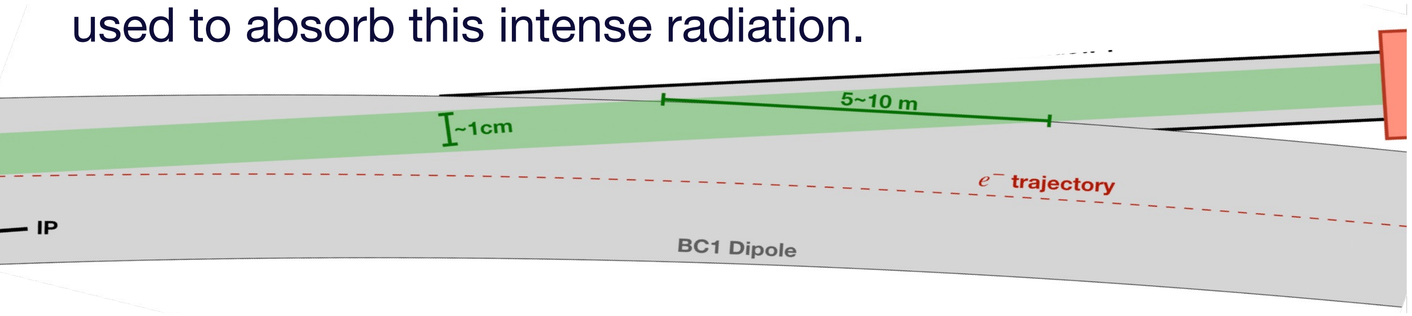
The photons are emitted **collinear to the beam** with an angle proportional to the beam-beam kick.

This radiation is extremely intense **O(100kW)** and directed along the downstream beam pipe.

A **dedicated extraction line** and photon beam dump is used to absorb this intense radiation.

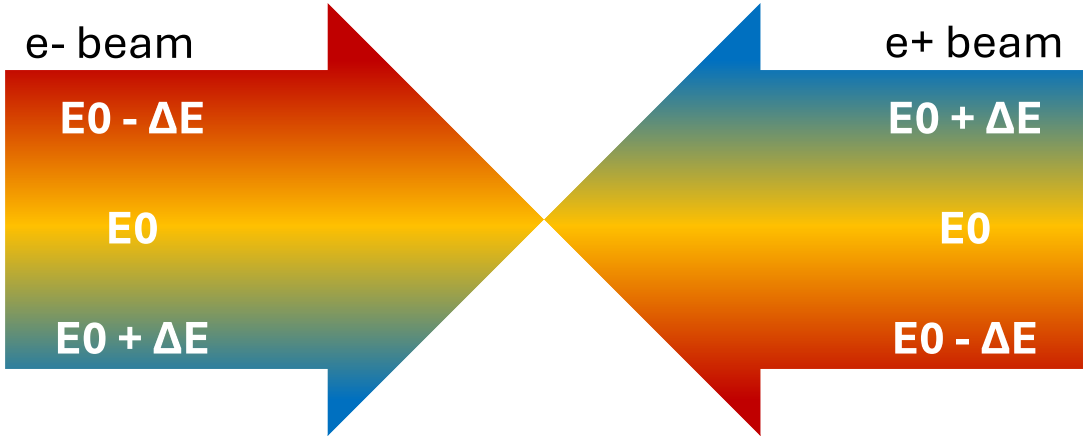


	Total Power [kW]	Mean Energy [MeV]
Z	370	1.7
WW	236	7.2
ZH	147	22.9
Top	77	62.3



M. Boscolo and A. Ciarma, “Characterization of the beamstrahlung radiation at the future high-energy circular collider” Phys. Rev. Accel. Beams **26**, 111002

Monochromatization and direct Higgs production



Opposite correlation between energy offset and transverse position achieved by dispersion at the IP

$$D_{x,y}^{e^+} = -D_{x,y}^{e^-}$$

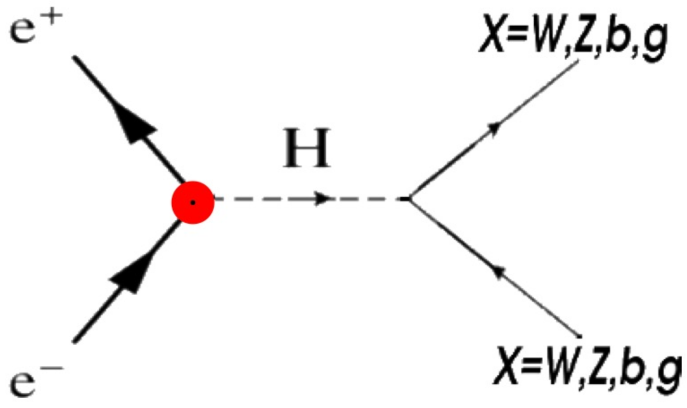
$$\sqrt{s} = 2E_0 + O(\Delta E)^2$$

$$\sigma_{\sqrt{s}} = \frac{\sqrt{2}E_0\sigma_E}{\lambda} \qquad L = \frac{L_0}{\lambda}$$

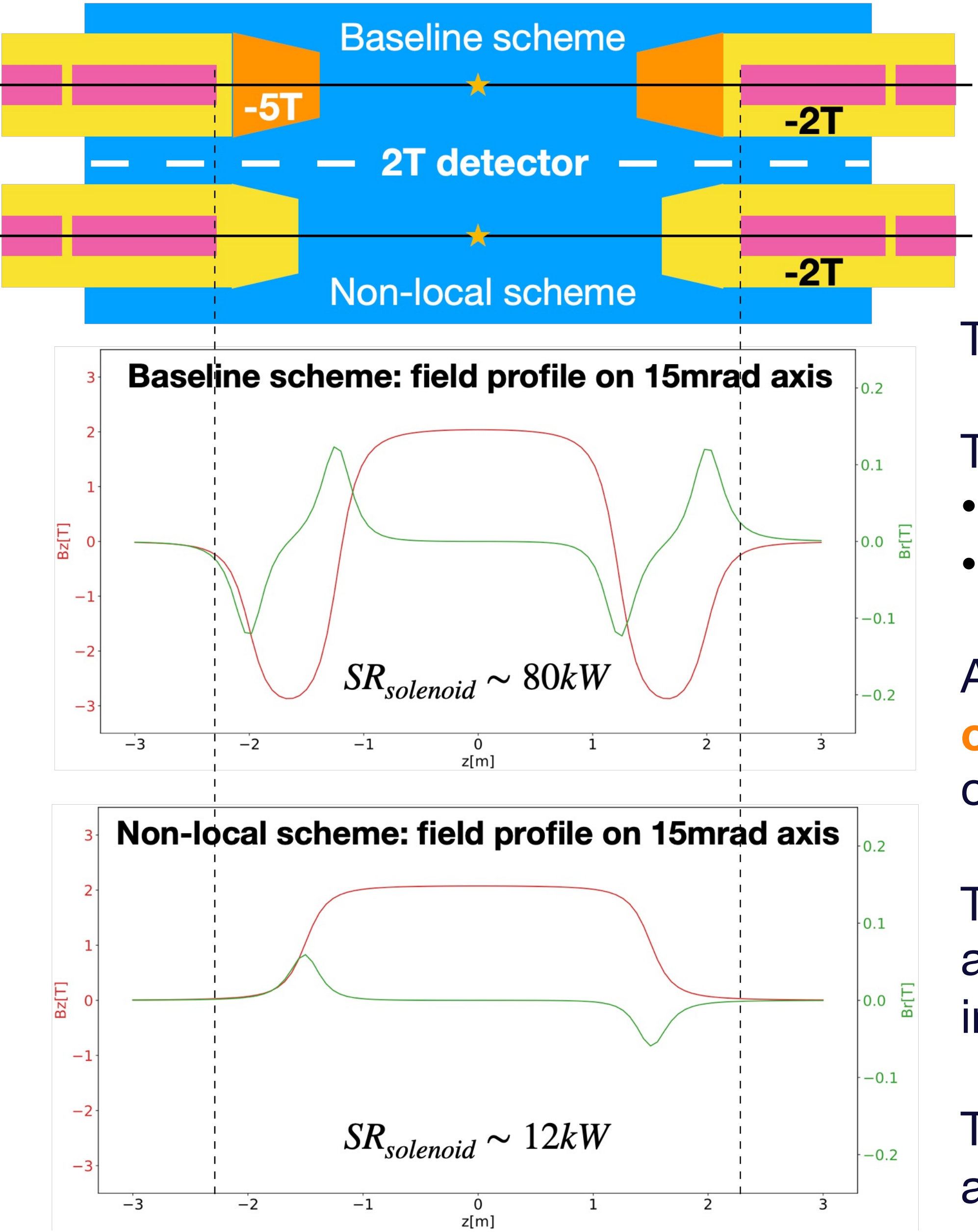
$$\lambda = \left(1 + \sigma_E^2\left(\frac{D_x^{*2}}{\sigma_{\beta x}^{*2}} + \frac{D_y^{*2}}{\sigma_{\beta y}^{*2}}\right)\right)^{\frac{1}{2}}$$

A **monochromatization scheme** at FCC-ee is currently under study, which would allow to greatly reduce the collision **center of mass energy spread** (~50 MeV).

Reducing this spread to be comparable with the **natural width of the Higgs** boson $\Gamma_H = 4.2\ MeV$ could allow **direct production** of the Higgs boson in s-channel annihilation $e^+e^- \rightarrow H$ at **125 GeV,** offering the only known path to measuring **the electron-Yukawa coupling**.



Alternative Solenoid Coupling Correction Scheme



The **2T detector solenoids** induce coupling in the FCCee lattice.

The current correction scheme uses:

- **-5T compensating solenoids** to cancel the magnetic field integral
- **-2T screening solenoids** to shield the **FFQs** from the detector field

A **non-local correction scheme** would allow to remove the **compensating solenoids** from the IR and correct coupling with skew components of the final focus quadrupoles.

This would be beneficial in terms of **space in the IR**, technical R&D of a -5T compact magnet and **Synchrotron Radiation** produced by the intense fringe fields in the B-field transition region (~80kW).

This scheme is compatible with monochromatization, and may also allow to further increase the experiment B field.

FCC-hh beam parameters

parameter	FCC-hh	HL-LHC	LHC
collision energy cms [TeV]	81 - 115	14	
dipole field [T]	14 - 20	8.33	
circumference [km]	90.7	26.7	
arc length [km]	76.9	22.5	
beam current [A]	0.5	1.1	0.58
bunch intensity [10^{11}]	1	2.2	1.15
bunch spacing [ns]	25	25	
synchr. rad. power / ring [kW]	1020 - 4250	7.3	3.6
SR power / length [W/m/ap.]	13 - 54	0.33	0.17
long. emit. damping time [h]	0.77 – 0.26	12.9	
peak luminosity [10^{34} cm^{-2}s^{-1}]	~30	5 (lev.)	1
events/bunch crossing	~1000	132	27
stored energy/beam [GJ]	6.1 - 8.9	0.7	0.36
Integrated luminosity/main IP [fb^{-1}]	20000	3000	300

With FCC-hh after FCC-ee: significantly more time for high-field magnet R&D aiming at highest possible energies

Formidable 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 ($\gamma\gamma$, Zγ, μμ)
- ❑ WIMP dark matter

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, …

F. Gianotti

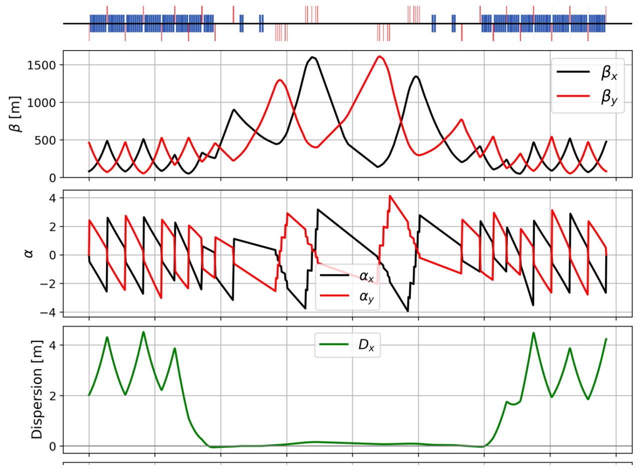
Key activities on FCC-hh

Optics design activities:

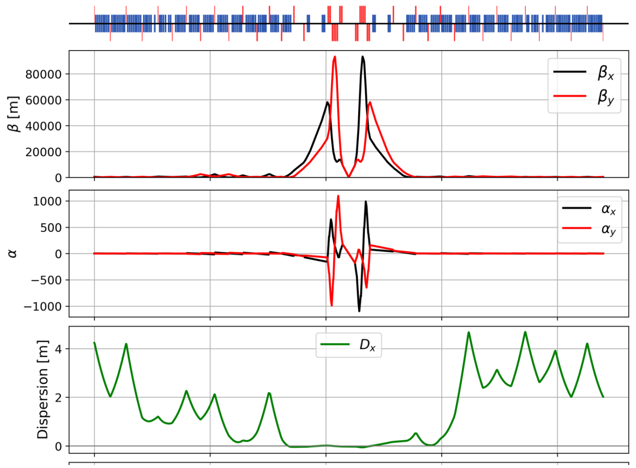
- adaptation to **new layout** and geometry
- shrink b collimation & extraction by ~30%
- **optics optimisation** (filling factor etc.)

High-field cryo-magnet system activities

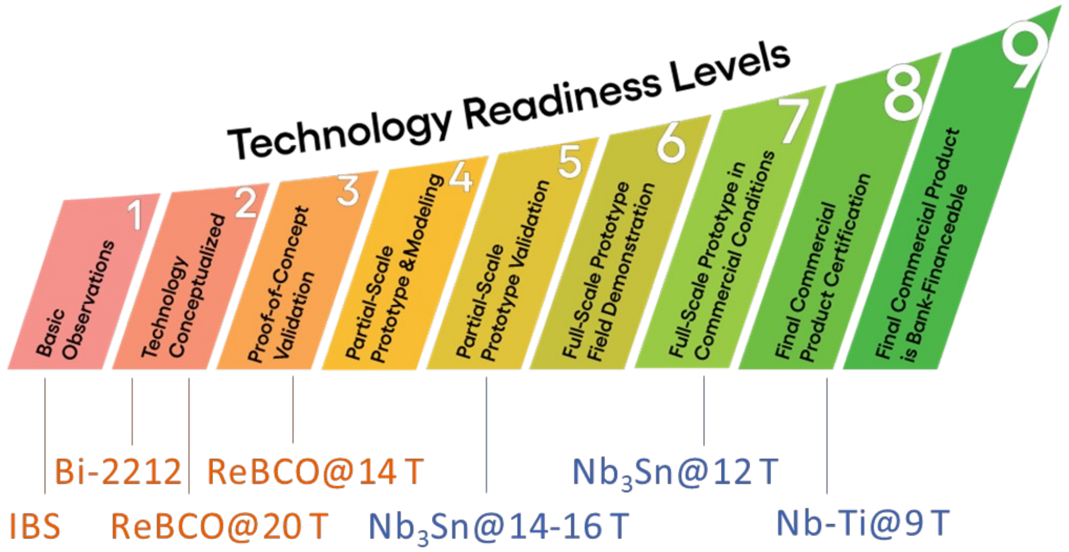
- Conceptual study of **cryogenics** concept and temperature layout for **LTS and HTS** based magnets, in view of electrical consumption.
- **High Field Magnets (HFM) R&D** on technology and magnet design, aiming also at bridging the TRL gap between HTS and Nb_3Sn.
- **Integration studies** for HFM designs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



betatron collimation straight

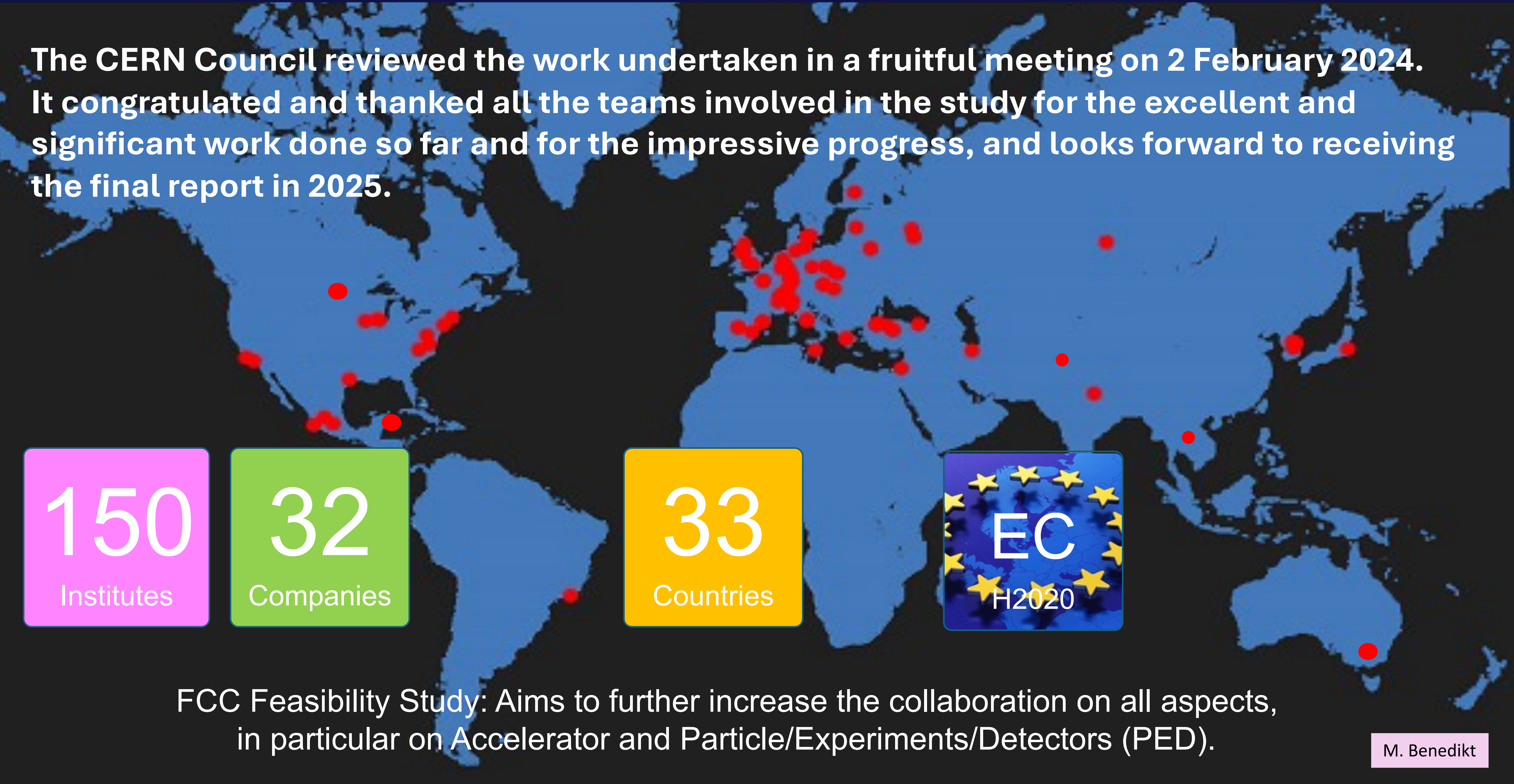


experimental straight



M. Benedikt

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



150 Institutes

32 Companies

33 Countries

EC H2020

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

M. Benedikt

Joint Statement of Intent between The United States of America and The European Organization for Nuclear Research concerning Future Planning for Large Research Infrastructure Facilities, Advanced Scientific Computing, and Open Science

The United States and CERN intend to:

- Enhance collaboration in future planning activities for large-scale, resource-intensive facilities with the goal of providing a sustainable and responsible pathway for the peaceful use of future accelerator technologies;
- Continue to collaborate in the feasibility study of the Future Circular Collider Higgs Factory (FCC-ee), the proposed major research facility planned to be hosted in Europe by CERN with international participation, with the intent of strengthening the global scientific enterprise and providing a clear pathway for future activities in open and trusted research environments; and
- Discuss potential collaboration on pilot projects on incorporating new analytics techniques and tools such as artificial intelligence (AI) into particle physics research at scale.

Should the CERN Member States determine the FCC-ee is likely to be CERN's next world-leading research facility following the high-luminosity Large Hadron Collider, the United States intends to collaborate on its construction and physics exploitation, subject to appropriate domestic approvals.

M. Benedikt

26 April 2024

White House Office of Science and Technology Policy Principal Deputy U.S. Chief Technology Officer Deirdre Mulligan signed for the United States while Director-General Fabiola Gianotti signed for CERN.

Summary

The FCC integrated project is **scientifically compelling** and capable of a **broad physics programme.**

In the **same tunnel and technical infrastructures** for different machines:

- ➢ **high luminosity** lepton collider **FCC-ee**: precision measurements for EW, Higgs, indirect discovery
- ➢ **energy frontier** hadron collider **FCC-hh**: pp, heavy-ion collisions; potentially also e-p, e-ion

2020 ESPP recommendation started the **FCC Feasibility Study**:

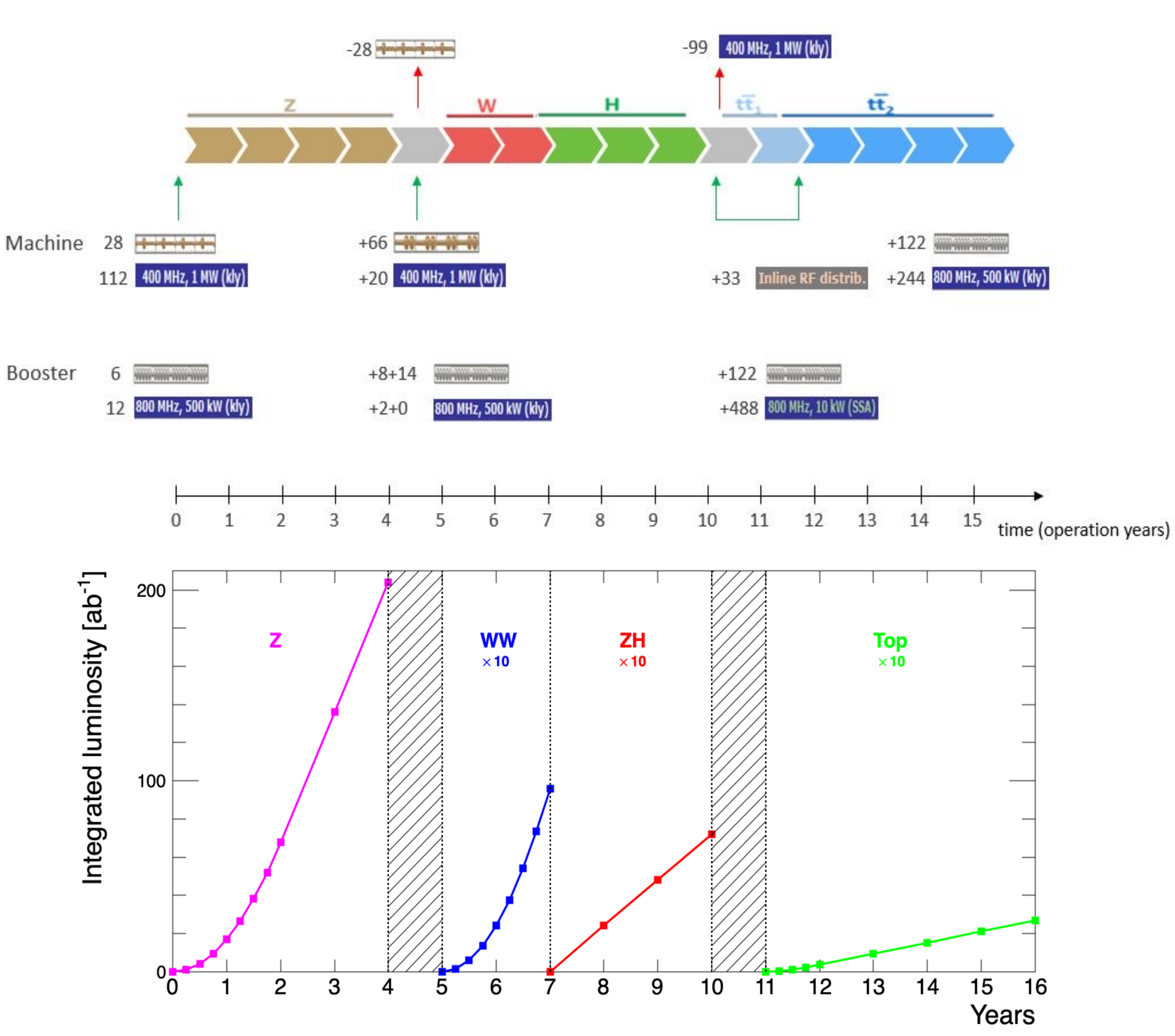
- **mid-term review** succesfully completed Feb'24, finding **no technical showstoppers**
- **tunnel** placement and layout defined
- **all deliverables met**, moving to final FS report ~Mar'25 → possible approval **2027/2028**

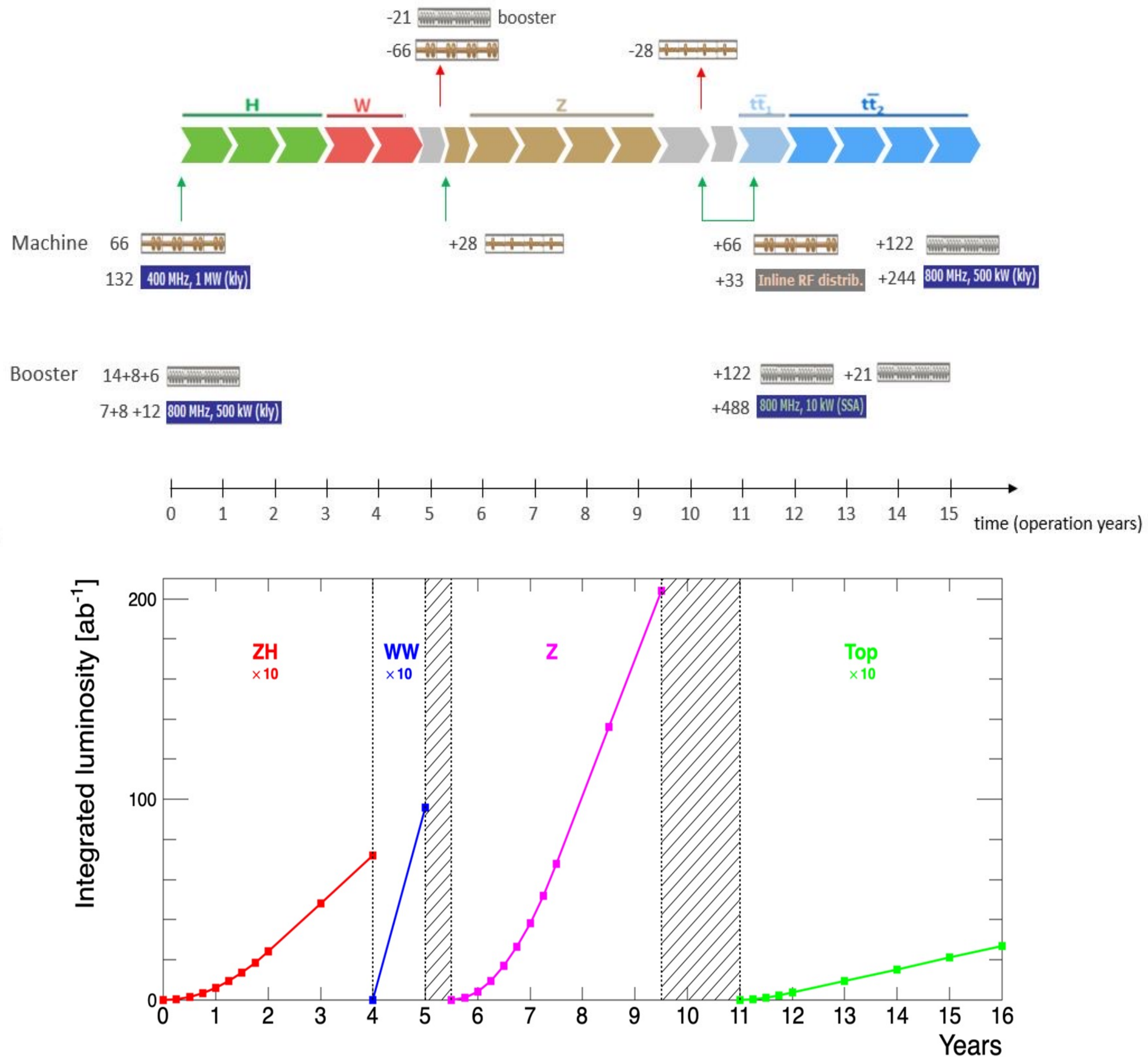
The **FCC community** keeps getting larger! Increasing international collaborations is a prerequisite for success:

- **US-CERN** Joint Statement-of-Intents
- links with **science**, **research & development** and **high-tech industry**
- **INFN** community structured in **RD_FCC,** organized in Work Packages

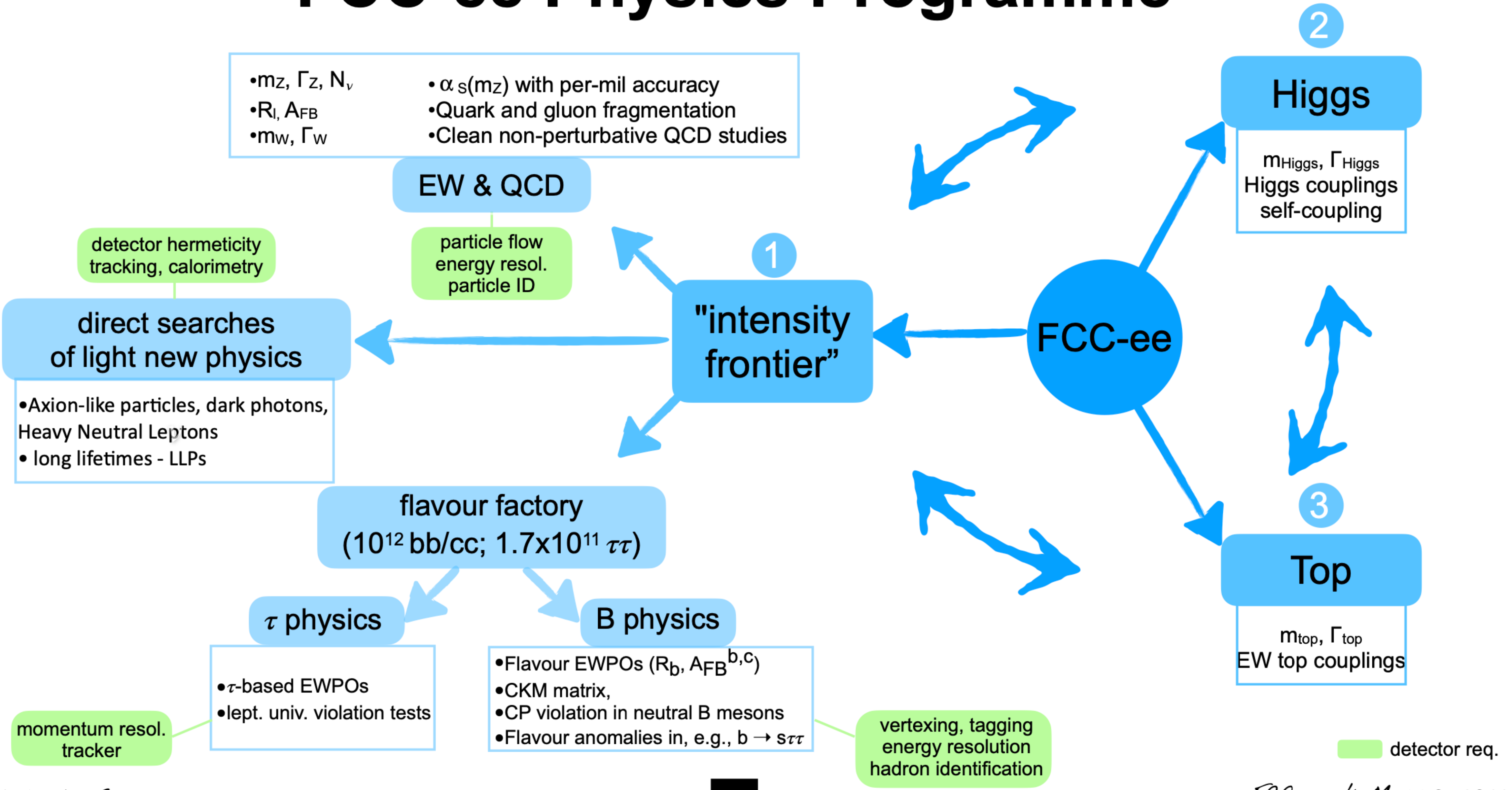
Backups

Possible operation sequences for FCC-ee





FCC-ee Physics Programme

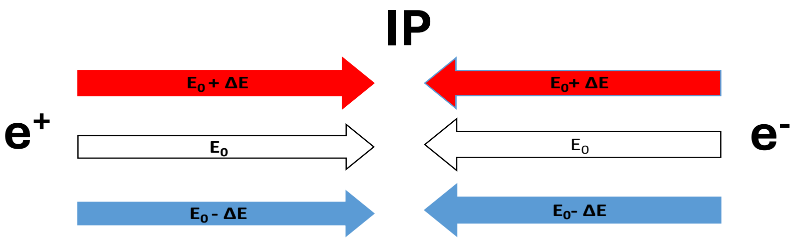


Christophe Grojean 9 FCC week, May 30, 2022

Monochromatization Principle

A. Faus-Golfe

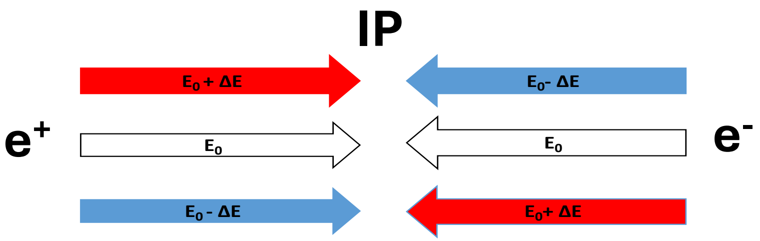
Standard



$D^*_{x,y}=0$

correlation between transverse spatial position and energy deviation

Monochromatization



$D^*_{x+} = - D^*_{x-} = D^*_x$

$D^*_{y+} = - D^*_{y-} = D^*_y$

Opposite correlations between transverse spatial position and energy deviation

CM energy

Standard: $$w = 2(E_b + \Delta E)$$

Monochromatization: $$w = 2E_b + O(\Delta E)^2$$

Spread of the CM energies

Standard: $$\sigma_w = \sqrt{2}E_b\sigma_\delta$$

Monochromatization: $$\sigma_w = \frac{\sqrt{2}E_b\sigma_\delta}{\lambda}$$

Monochromatization factor

Standard: $$\lambda = 1$$

Monochromatization: $$\lambda = \left(1 + \sigma_\delta^2\left(\frac{D_x^{*2}}{\sigma_{x\beta}^{*2}} + \frac{D_y^{*2}}{\sigma_{y\beta}^{*2}}\right)\right)^{1/2}$$

Luminosity

Standard: $$L_0 = \frac{k_b f_r N_+ N_-}{4\pi\sigma^*_{x\beta}\sigma^*_{y\beta}}$$

Monochromatization: $$L = \frac{L_0}{\lambda}$$

$$\sigma^*_{x,y} = \sqrt{\beta^*_{x,y}\epsilon_{x,y} + (D^*_{x,y}\sigma_\delta)^2}$$

betatronic beam sizes at the IP

dispersive beam size at the IP

Enhancement of energy resolution, and sometimes increase of the relative frequency of the events at the center of of the distribution but **luminosity loss !!!!**

Sources of Background in the MDI area

Luminosity backgrounds

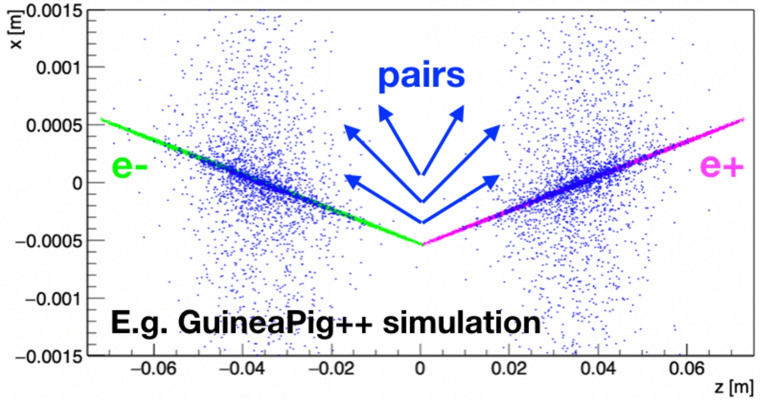
- **Incoherent Pairs Creation (IPC)**: Secondary e^-e^+ pairs produced via the interaction of the beamstrahlung photons with real or virtual photons during bunch crossing.
- **Radiative Bhabha:** beam particles which lose energy at bunch crossing and exit the dynamic aperture

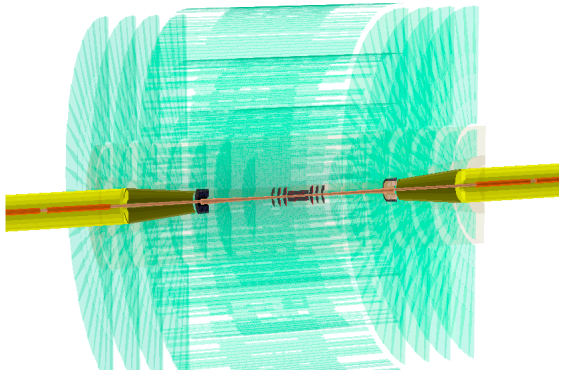
Single beam induced backgrounds:

- **Beam losses from failure scenarios:** high rate of beam losses in the IR coming from halo (transverse or longitudinal) being diffused by the collimators after lifetime drop
- **Synchrotron Radiation:** photons escaping the tip of the upstream SR mask at large angles
- **Beam-gas** (elastic, inelastic), Compton scattering on **thermal photons**: preliminary studies exist, needs to be replicated for new beam parameters

Background assessment: workflow with Key4hep

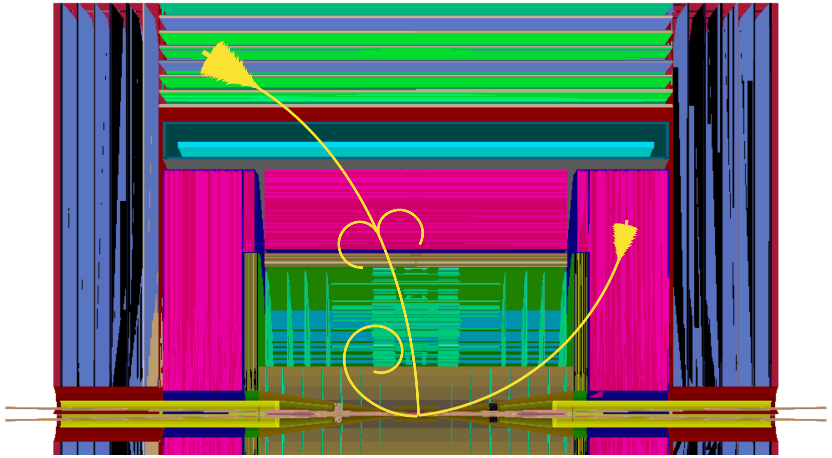
Primaries produced by **external generators** (GuineaPig++, BDSim, Xtrack, …)



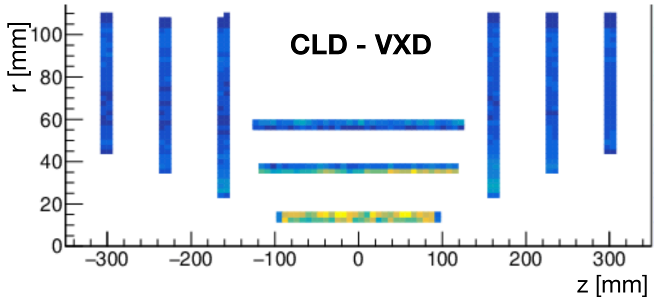


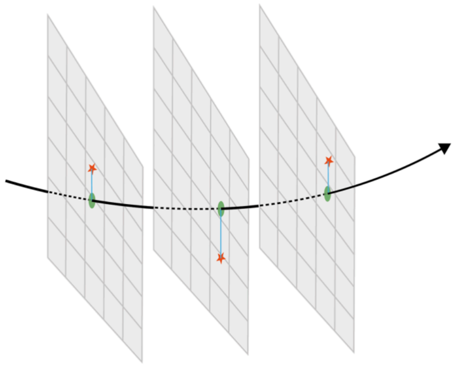
Detector and MDI geometry description in **DD4hep:** public common git repo

Tracking particles in the detector performed by **turnkey software Key4hep** - Geant4 physics libraries, DD4hep implementation, magnetic field map, …



Hits collected for analysis and occupancy determination





Signal **reconstruction**

FCC-ee cost and funding

FCC-ee construction cost up to operation at ZH : ~ 15 BCHF

Includes:
- ❑ Civil engineering (tunnel, experimental caverns, surface sites, etc.)
- ❑ FCC-ee collider and injectors
- ❑ Technical infrastructure
- ❑ Other infrastructure (roads, power lines, land, etc.)
- ❑ 4 detectors

Does not include upgrade to ttbar operation (~ 1.5 BCHF)

Updated cost assessment made in 2023, reviewed by dedicated Cost Review Panel of experts (chair N. Holtkamp), which concluded:
- ❑ cost estimates are appropriate for this stage of the study
- ❑ uncertainty estimates are realistic; most items are class 4 (- 30% to + 50%) or class 3 (-20% to +30%).
  Aim at class 3 for all main items at the end of the Feasibility Study

Funding

CERN Budget can cover more than half of the cost. Contributions expected from non-Member States with interested communities (e.g. US) and from Member States (beyond their contributions to CERN Budget).
Other contributions may come from the European Commission and private donors.

Preliminary funding model (including construction and operation expenses) and funding scenarios studied
→ will be further developed in the coming year based on discussions in Council and with potential partners.

F. Gianotti