FCC-EE
MACHINE DETECTOR INTERFACE

Manuela Boscolo

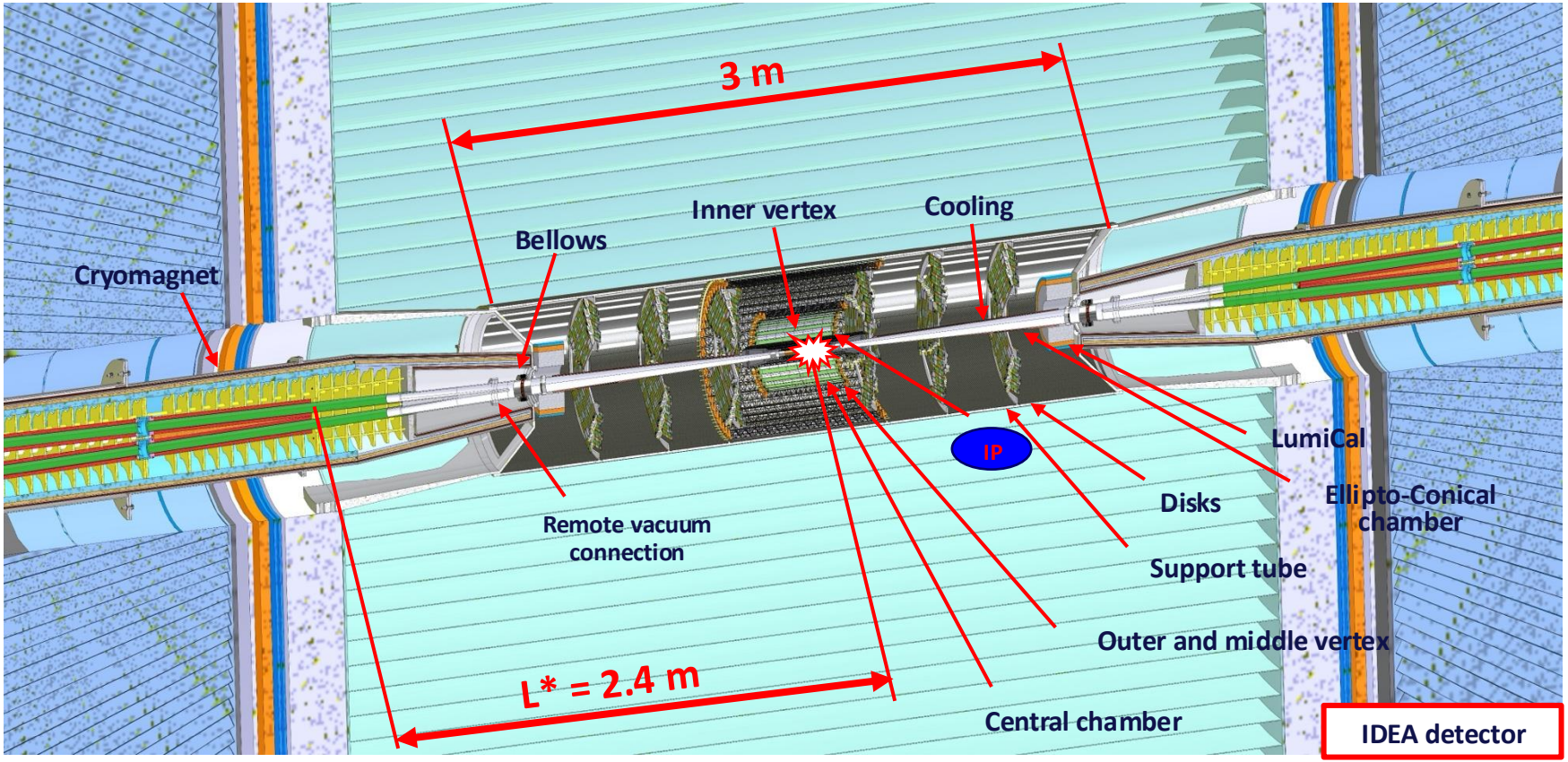
INFN- Frascati, Italy

The 2026 CEPC International Workshop
24 October 2026

Outline

- Introduction
- Requirements on MDI
- Mechanical layout of the Interaction Region
- Magnetic elements
- Background studies
- Prospects

MDI mechanical model



High-level Requirements for the IR and MDI region

One common IR for all energies and all Detectors, flexible design with a constant detector field

Vey high Luminosity of ~ 10^{36} $cm^{-2}s^{-1}$ is required at the Z-pole

- This luminosity can be obtained with the crab-waist scheme (nano-beams & **30 mrad crossing angle**)
- Implies having a Final Focus Quadrupole (FFQ) system close to the Interaction Point **(L*=2.4 m)**
- Continuous **top-up injection** is required with few percent of current drop to keep a constant luminosity

Cone angle of 100 mrad to separate collider elements to detector required for physics

Solenoid coupling compensation

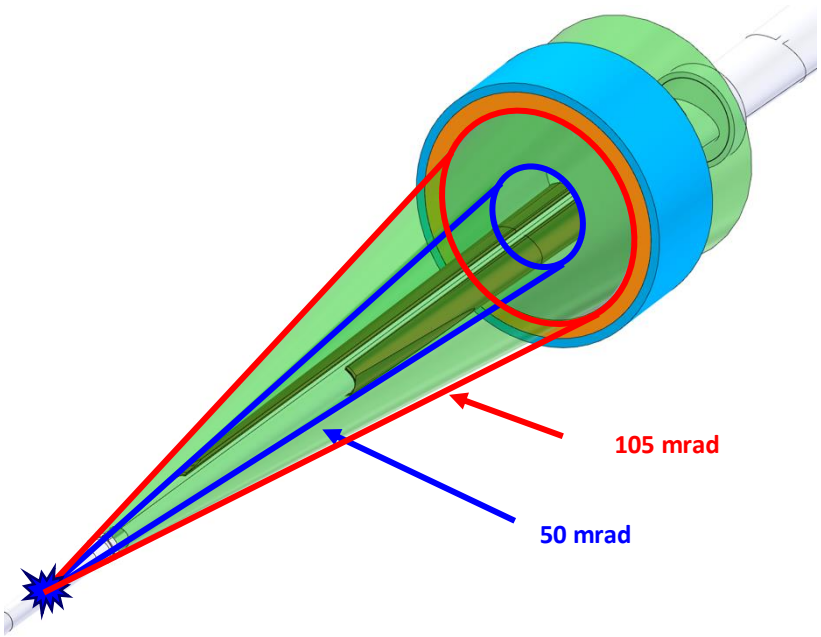
- The integral $\int B_z ds = 0$ to avoid vertical emittance blow-up (decrease of the luminosity)

Minimization of the Synchrotron Radiation impacting on the IR

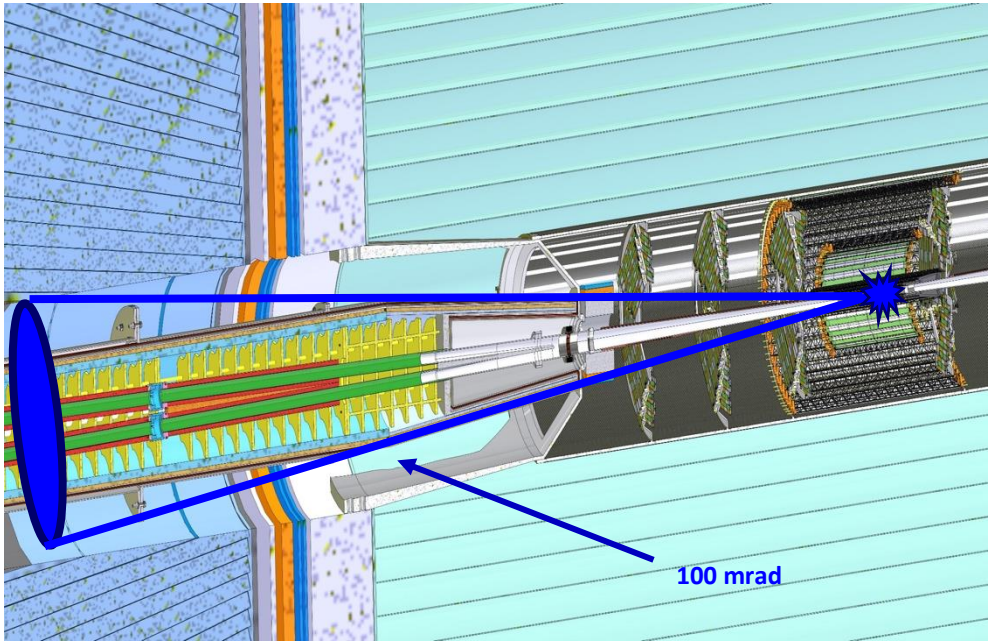
- Optics design constraint: weak bends upstream the IR (and strong ones downstream, to produce the horizontal crossing angle), having an asymmetric optics wrt IP
- Optimisation of the SR collimators and shielding, optics tuning in particular to cope with SR from the FFQ.

Spatial constraints

Low material budget within the LumiCal acceptance (between **50 mrad** and **105 mrad** centered on the outgoing beam pipe).

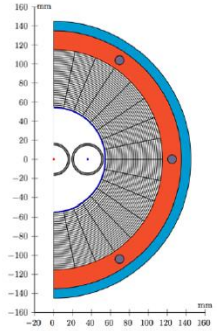


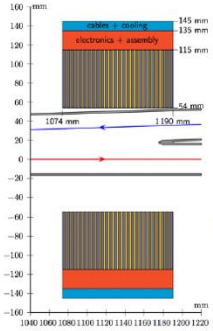
Every component of the MDI must stay inside the **100 mrad detector acceptance** cone.

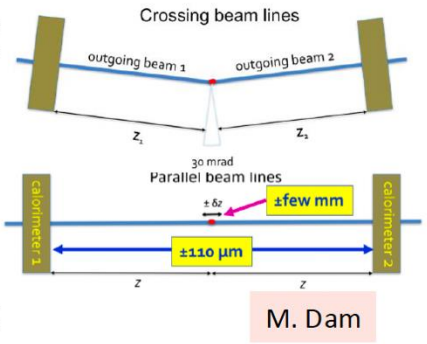


Small angle luminosity calorimeter

- **Goal: absolute luminosity measurement 10^{-4} at the Z**
- **Standard process Bhabha scattering**
- Bhabha cross section 12 nb at Z-pole with acceptance **62-88 mrad** wrt the outgoing pipe
- Requires **50-120 mrad clearance to avoid spoiling the measurement**
- The LumiCals are centered on the outgoing beamlines with their faces perpendicular to the beamlines
- Requirements for alignment
  - few hundred μm in radial direction
  - few mm in longitudinal direction

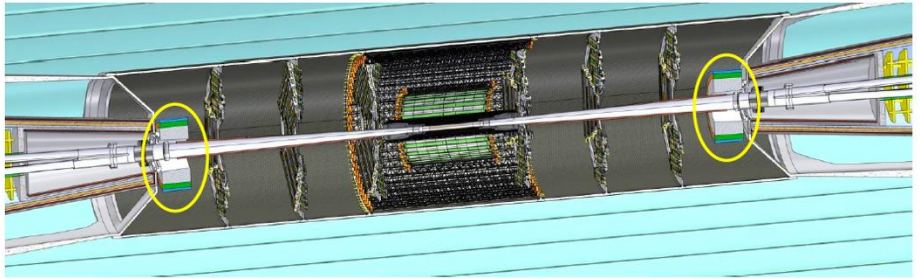






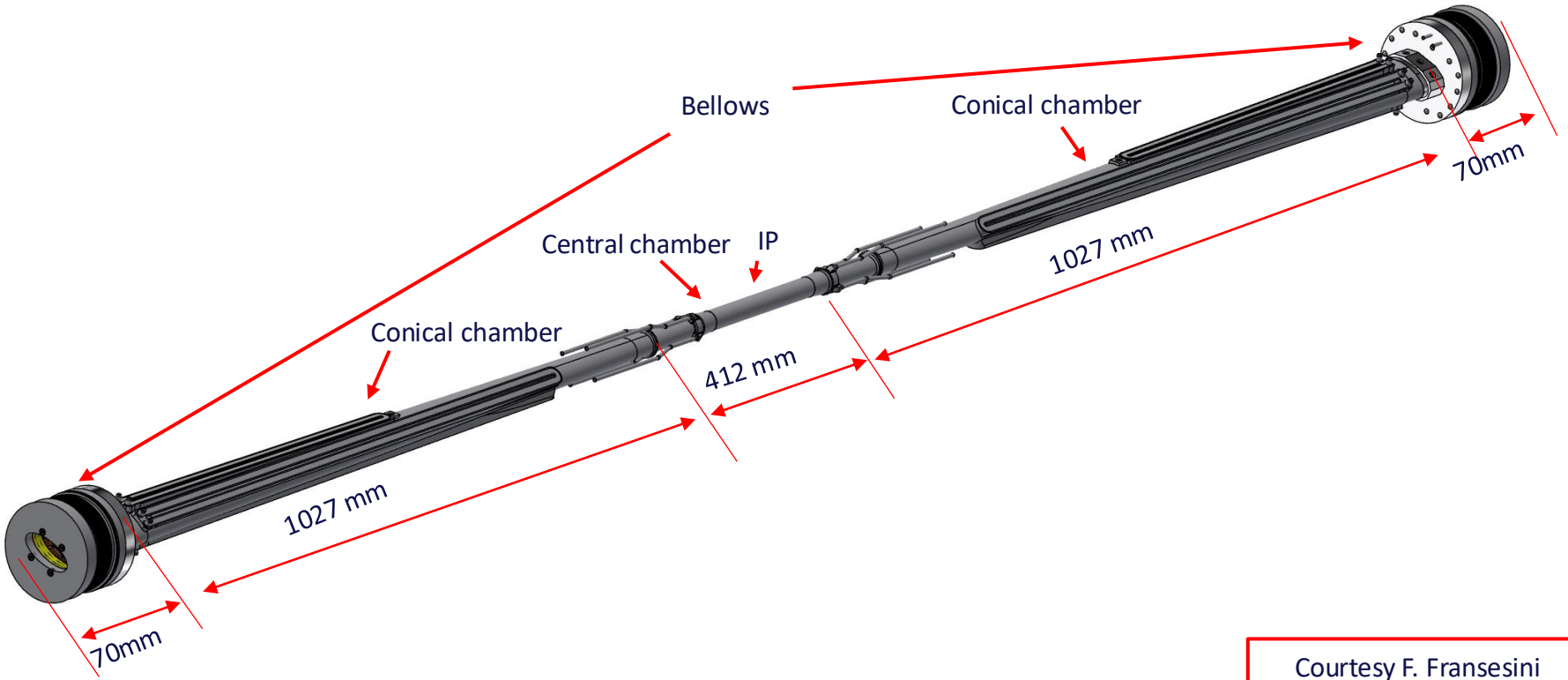
Lumical integration:

- **Asymmetrical cooling system** in conical pipe to provide angular acceptance to lumical
- **LumiCal held by a mechanical support structure**



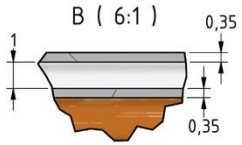
Engineered Vacuum Chambers

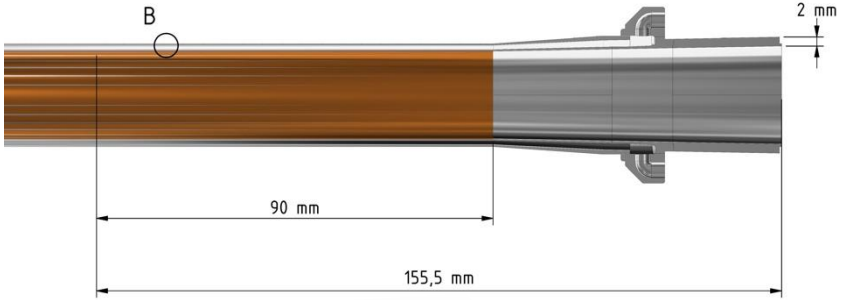
The current baseline is the trade-off between mechanical design requirements, material budget and radial dimension reduction.



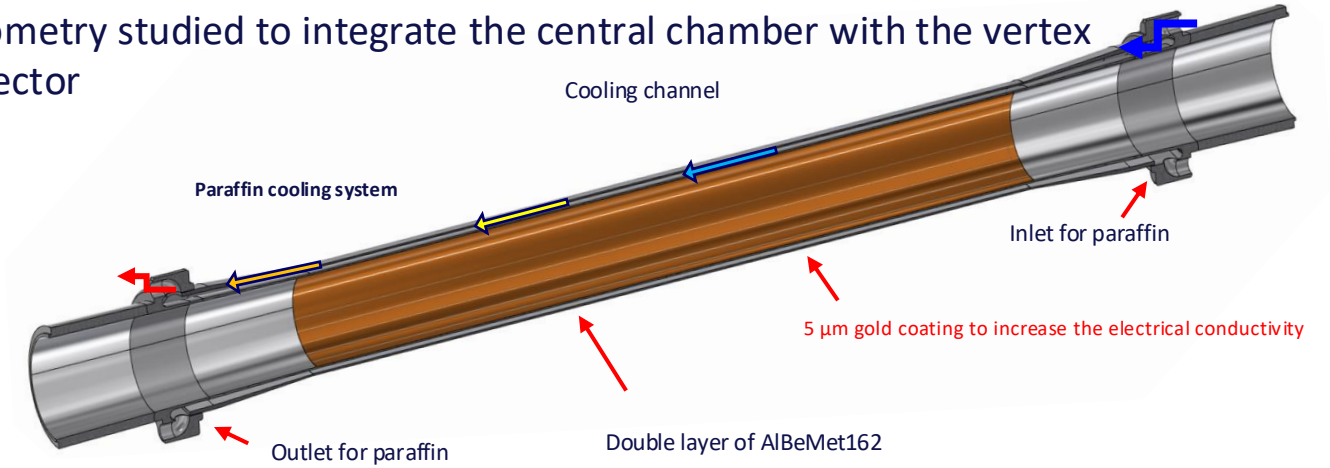
Courtesy F. Fransesini

Central vacuum chamber – Design



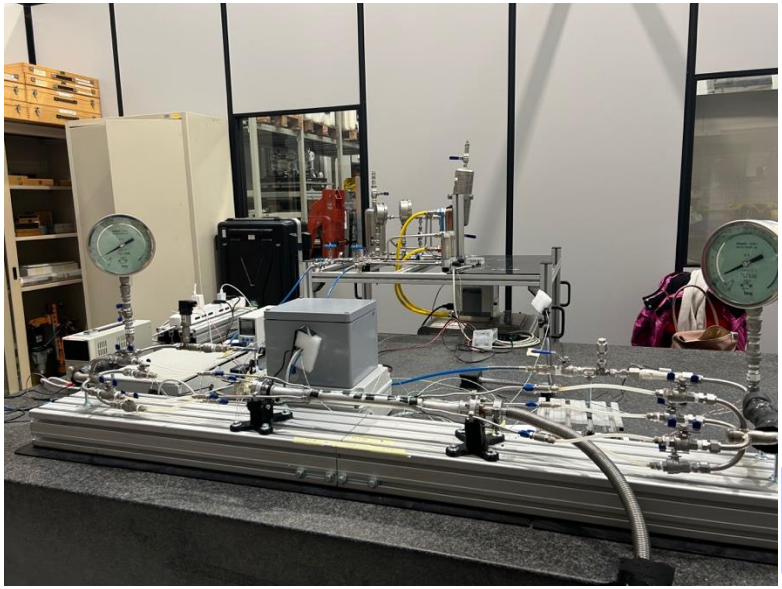


- **AlBeMet 162** as main material
- **Three layers in z** ±90 mm from IP
  - ➢ 0.35 mm of AlBeMet162 (62% Be, 38% Al)
  - ➢ 1 mm gap for Paraffin
  - ➢ 0.35 mm of AlBeMet162
- Liquid paraffin as coolant
- Geometry studied to integrate the central chamber with the vertex detector



FCC-ee Interaction Region Mock-up at INFN-Frascati

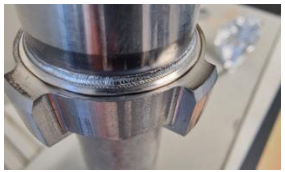
Experimental validation of the IR beam pipes manufacturing and cooling system, vertex and LumiCal integration, vertex cooling, services and routings, and assembly.

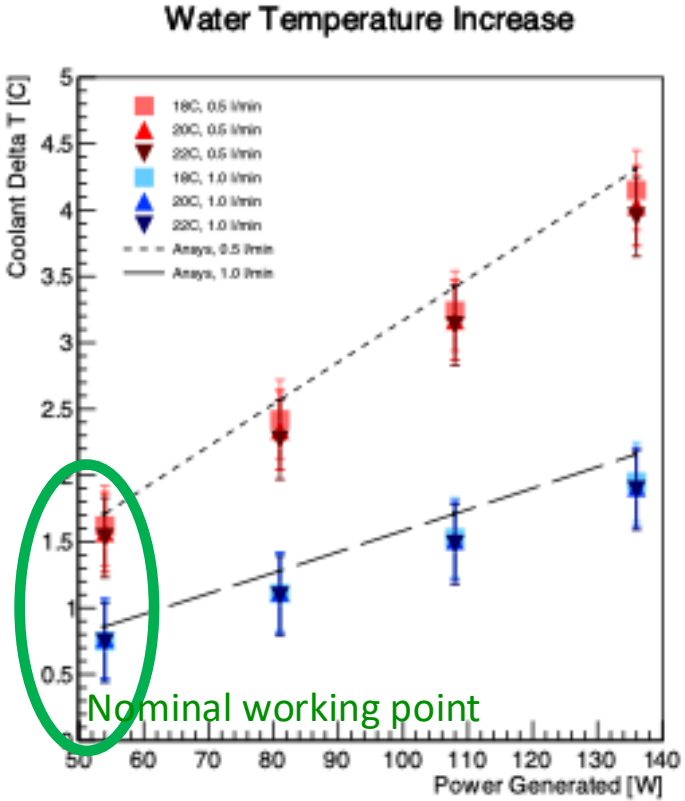




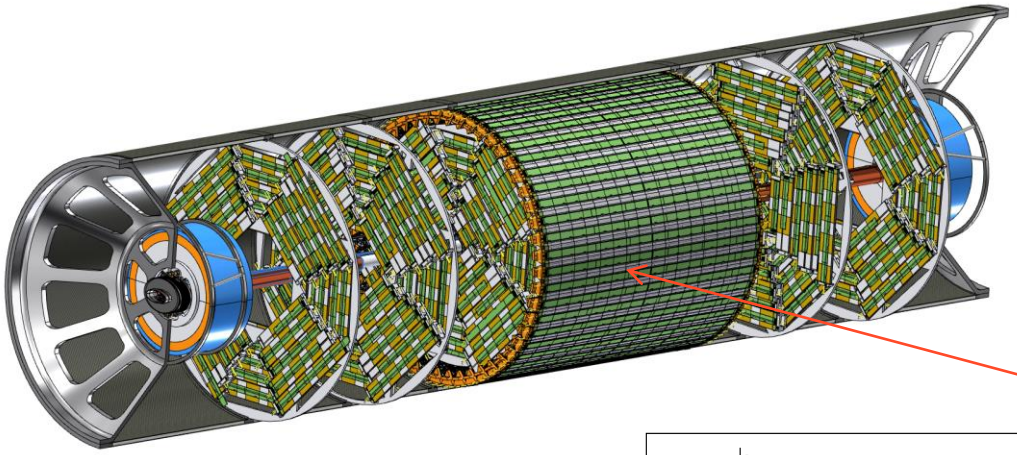
cooling pipes manifolds





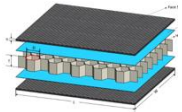


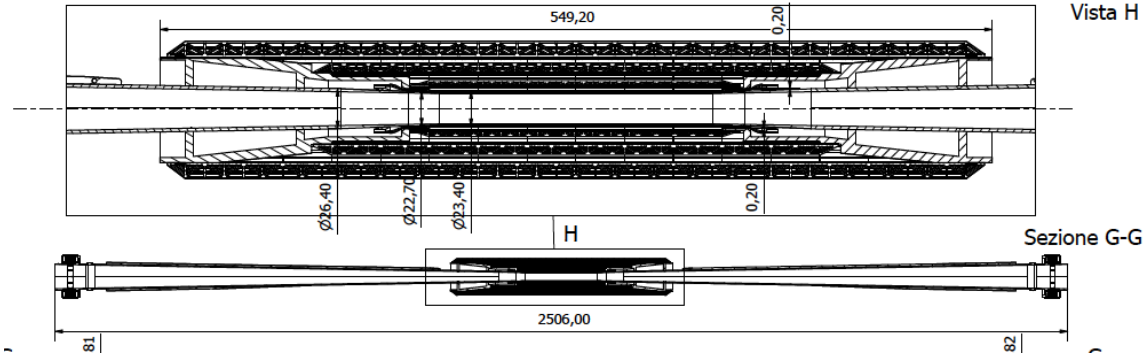
FCC-ee IR: vertex detector integration



Support tube provides a rigid structure for the integration of the beam pipes, vertex, and LumiCal detectors

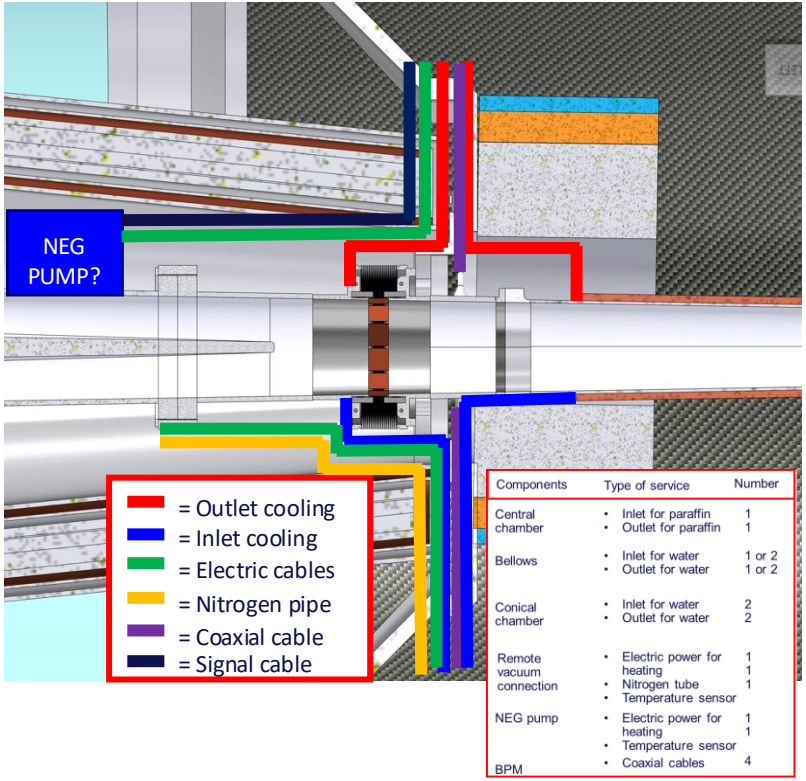
Support tube material
1mm CF + 8mm HC + 1mm CF





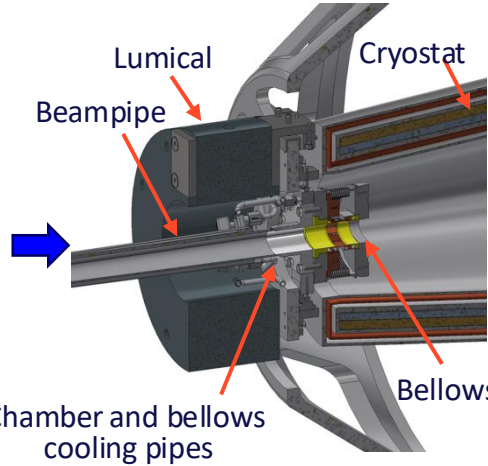
Services integration challenges

There are two problematic areas for the services integration.

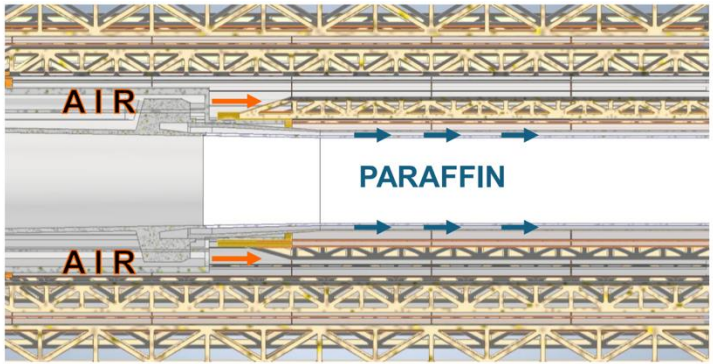


Components	Type of service	Number
Central chamber	• Inlet for paraffin • Outlet for paraffin	1 1
Bellows	• Inlet for water • Outlet for water	1 or 2 1 or 2
Conical chamber	• Inlet for water • Outlet for water	2 2
Remote vacuum connection	• Electric power for heating • Nitrogen tube • Temperature sensor	1 1 1
NEG pump	• Electric power for heating • Temperature sensor	1 1
BPM	• Coaxial cables	4

1. Interface with the cryomagnetic system.



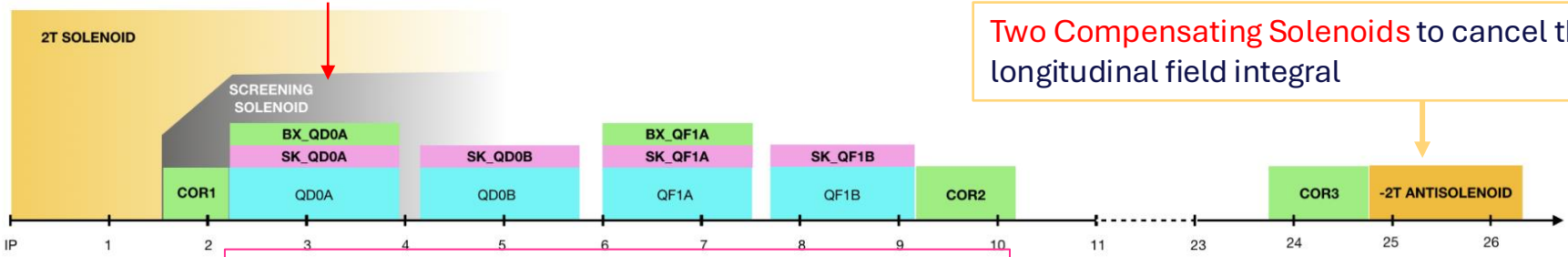
2. Interface between the vacuum chamber and the vertex detector.



Non-local Solenoid Compensation Scheme

To counteract the **beam rotation and deflection** that would be caused by the simultaneous effects of the **detector magnetic field of 2 T and the crossing angle**, a **compensating solenoid** is needed to **cancel out the longitudinal magnetic field integral along the z axis** from the last focusing quadrupole to the IP.

A Screening Solenoid shields the Final Focus Quads



Two Compensating Solenoids to cancel the longitudinal field integral

skew quadrupolar components in the FFQs align the magnet axis to the rotated reference frame of the beam

https://doi.org/10.1016/j.nima.2025.171135

correctors right after the beam pipe separation and around the FFQs compensate the orbit distortion generated by the horizontal crossing angle in the detector field

Detector solenoid field

Baseline detector solenoid field 2 T – physics requirement up to 3T

(Positive) impact of increased B field on Detectors:

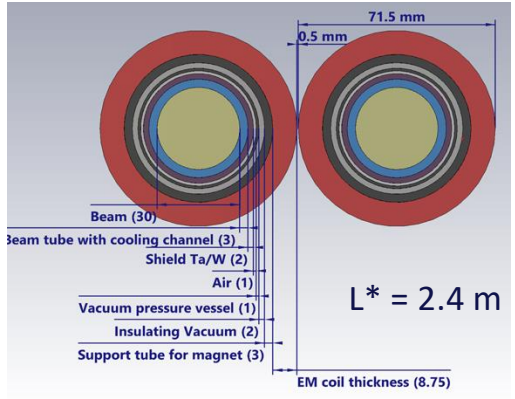
- Reduces IPC backgrounds (50% less from 2 to 3 T)
- Shrinks the dimensions (and cost!) of the detectors
- Improve detector performance (with the same radial dimensions)

(Negative) Impact on Collider:

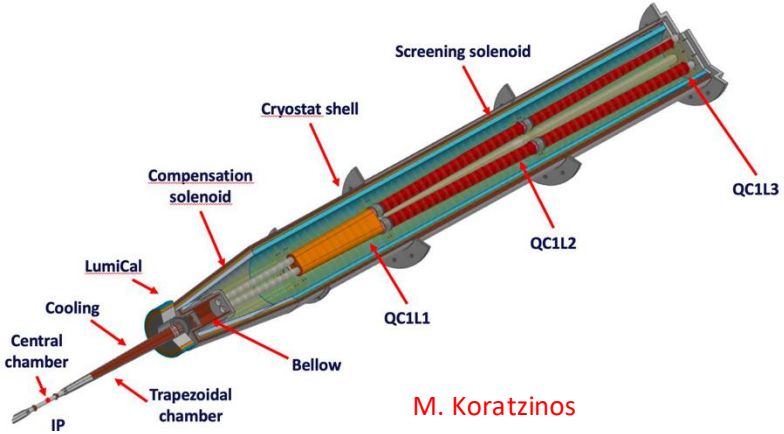
- Increases emittance → reduces the luminosity
- Needs a higher compensation → cryostat needs to be placed closer to IP (also affecting LumiCal backgrounds)
- Needs an stronger anti-solenoid field

Superconducting Final Focus Quadrupoles

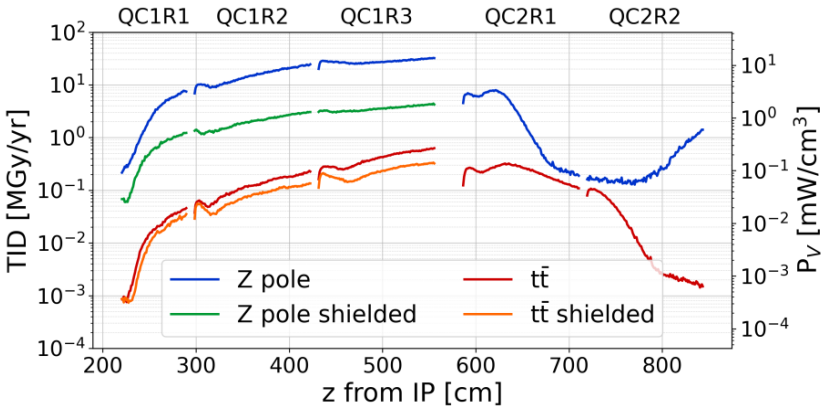
- **Provide nanometric beams ($\sigma_y^* = 41\ nm$) with 100 T/m gradient**
  - SC technology using He-II
  - Need to operate with the detector solenoid field shielded → screening solenoid
- **Cryostat manufacturing issues:**
  - Restricted space: maximum aperture 100 mrad ~24 cm radial extension
  - T=1.9 K requires thermal multilayers insulation
  - Tungsten shielding due to radiative Bhabha energy deposition
  - Few tens of tons magnetic field forces
  - Minimisation of vibrations (<15 nm)



V. Teotia, B. Parker, A. Ciarma, J. Seeman

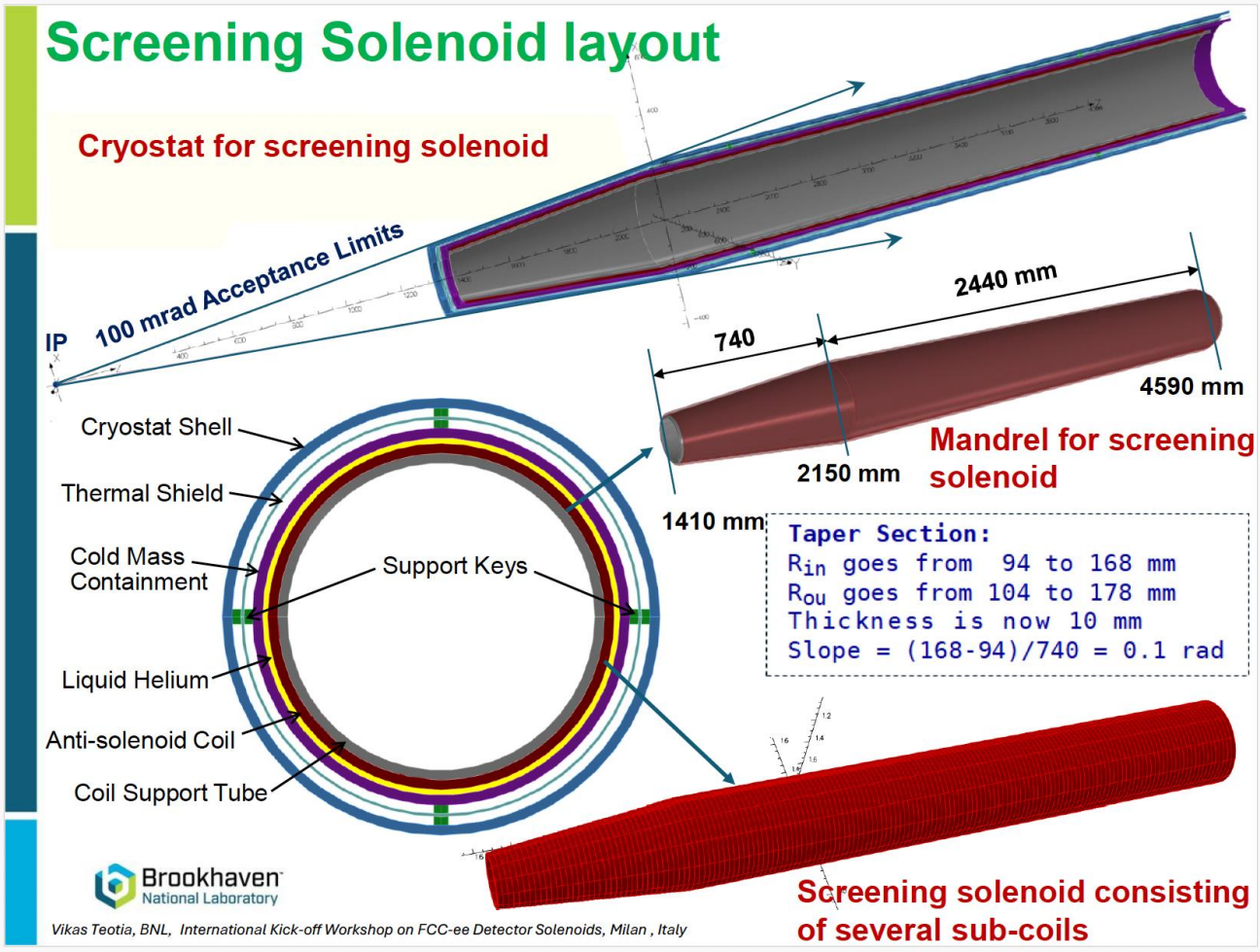


M. Koratzinos



Power deposition in FFQs SC coils from radiative Bhabhas

Courtesy Alessandro Frasca



Courtesy V. Teotia

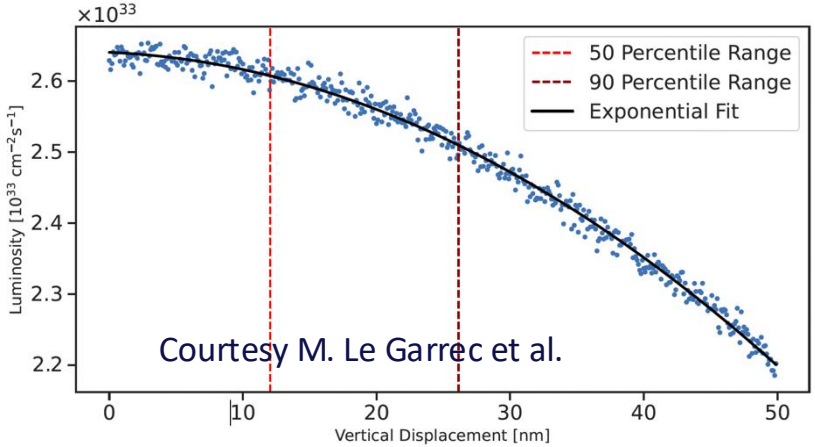
Optimisation ongoing

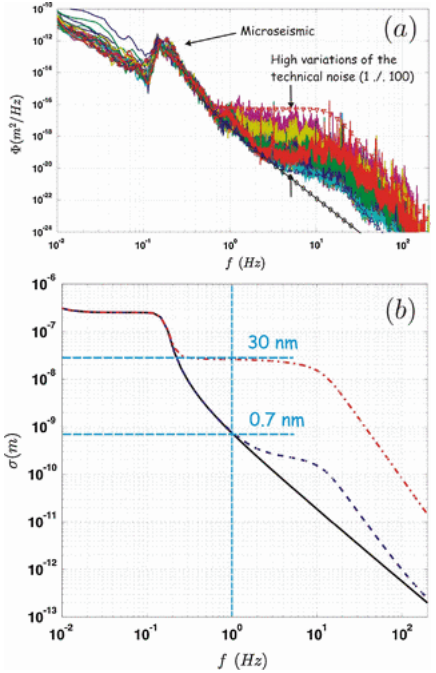
Sensitivity to vibrations

High sensitivity to ground motion vibrations due to the nanometric size of the beam.

RMS vertical displacement tolerances of FFQ around 10-15 nm

Need active damping systems



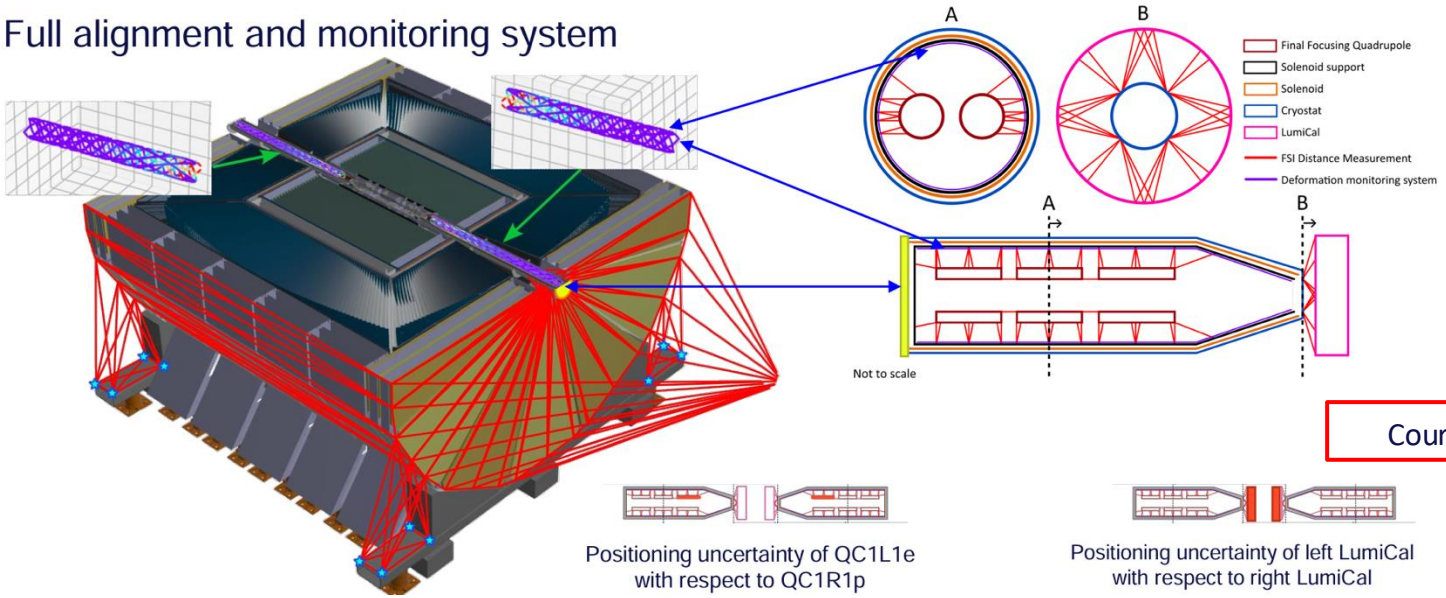


S. Collette et al
https://doi.org/10.1103/PhysRevSTAB.13.072801

Monitoring

Usage of In-Line Multiplexed and Distributed Frequency Scanning Interferometry (IMD-FSI) to monitor sections of optical fibres firmly installed on the inner surface of the screening solenoid support.

At the end of each fibre used in the deformation monitoring system, a mirror is installed to redirect the laser beam toward the centre of the assembly, targeting the final focusing quadrupoles, the BPMs, LumiCals, as currently done for HL-LHC MDI.



Courtesy L. Watrelot

EPJ Techn Instrum **12**, 4 (2025). https://doi.org/10.1140/epjti/s40485-025-00117-3

Beam-induced Backgrounds sources at FCC-ee

Synchronous with the interaction

Luminosity backgrounds

Beamstrahlung: photons and spent beam

Incoherent e^+e^- Pair Creation (IPC) ← dominant use GuineaPig

Coherent e^+e^- Pair Creation

$\gamma\gamma$ to hadrons

Radiative Bhabha $e^+e^- \rightarrow e^+e^-\gamma$ BBBREM (benchmarked at LEP)

Beam-beam

Mostly can be mitigated with collimators & shielding, except for those produced just in the IR.

Single Beam effects

Beam halo losses

Synchrotron Radiation BDSIM

Beam-gas

Thermal photons

Touschek

Injection backgrounds

A collimation insertion intercepts most the beam losses.

Tertiary collimators upstream MDI area protect the experiments.

Residual losses tracked into detectors for occupancy and data rates.

Incoherent Pairs Creation

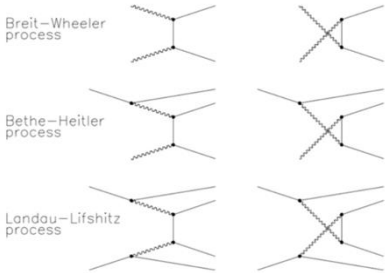
Secondary e+e- pairs produced during bunch crossing via the interaction of beamstrahlung photons with real or virtual photons.

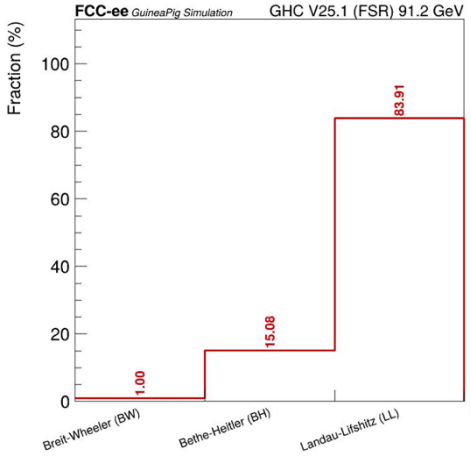
$\gamma + \gamma \rightarrow e^- + e^+$ Breit-Wheeler

$\gamma + e^{\pm} \rightarrow e^{\pm} + e^- + e^+$ Bethe-Heitler $\gamma + \gamma^* \rightarrow e^- + e^+$

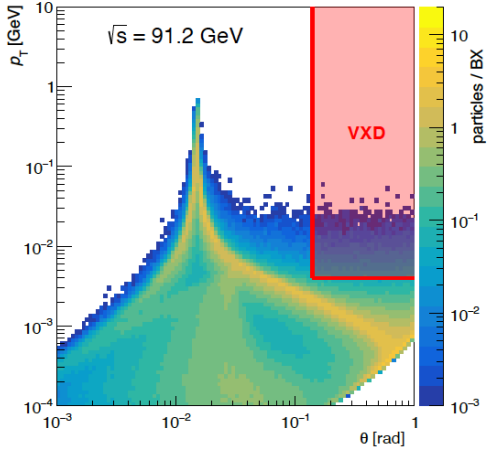
$e + e \rightarrow e + e + e^- + e^+$ Landau-Lifshitz $\gamma^* + \gamma^* \rightarrow e^- + e^+$

dominant



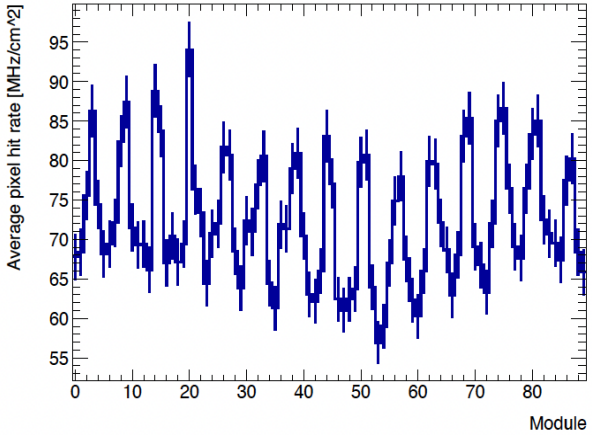


Lot of low p_T (few MeV) particles hitting the detectors directly or backscattering

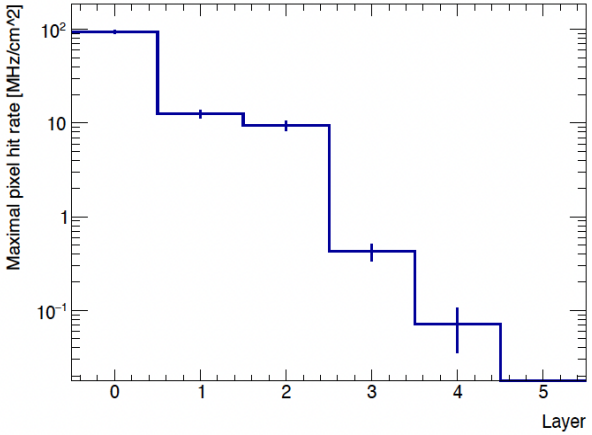


Dominant effect in the vertex detector background

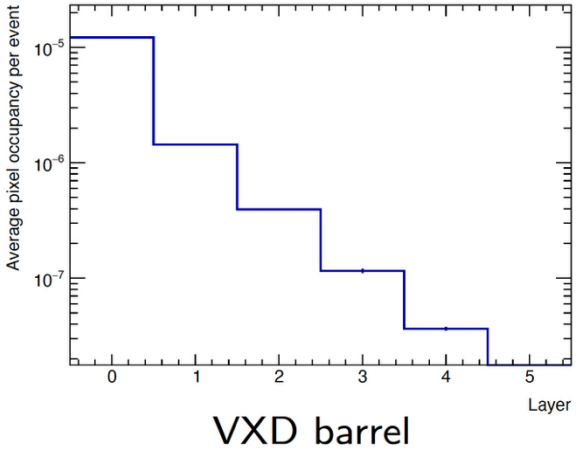
Effect on vertex detector



VXD barrel first layer



VXD barrel



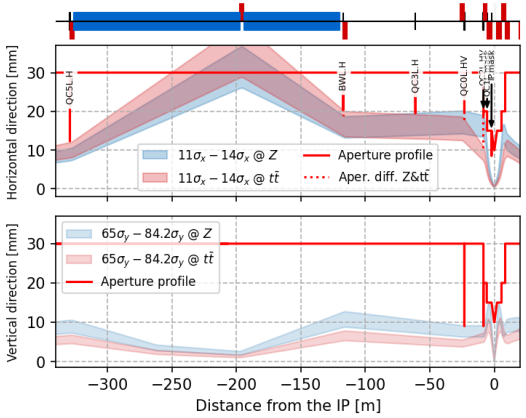
Hit rates ~100 MHz/cm^2

Occupancies < 10^{-5} per BX

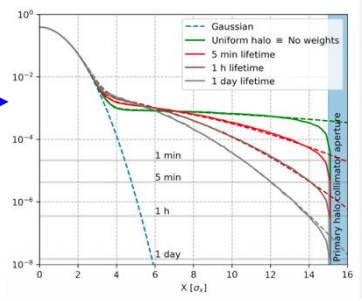
see G. Nigrelli talk

Synchrotron Radiation (SR) backgrounds

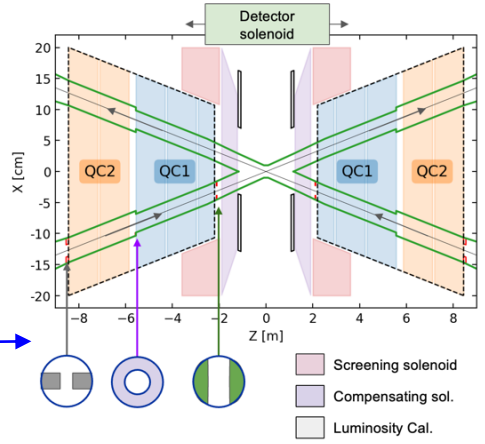
bulk of SR produced upstream the IR is stopped by collimators



- Simulations with BDSIM (GEANT4 toolkit)
- SR evaluated for
  - beam core with non-zero closed orbits for considering optics imperfections
  - transverse beam tails, pessimistic weighted halo model used:



- SR produced in the IR by IR quads and solenoids:
  - bulk of SR is collinear with the beam and will hit the beam pipe at the first dipole after the IP → no direct hits in the detectors
  - Transverse tails in the fringing field of the final quads produce SR that may hit the detector: masks at the exit of QC1 and QC2 – additional mask at ~1.3 meters



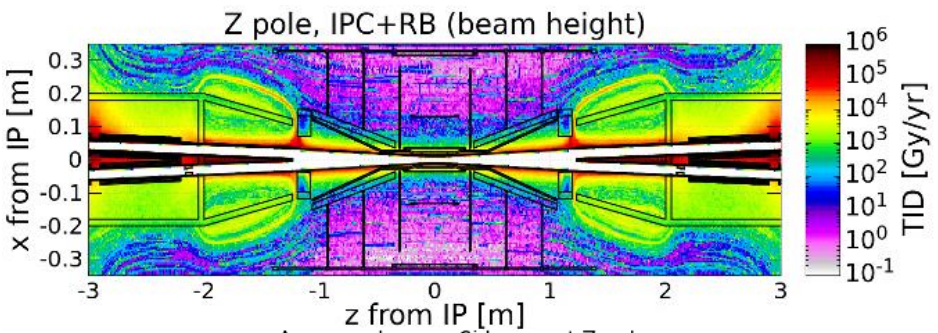
1 operational year = 10^7 s

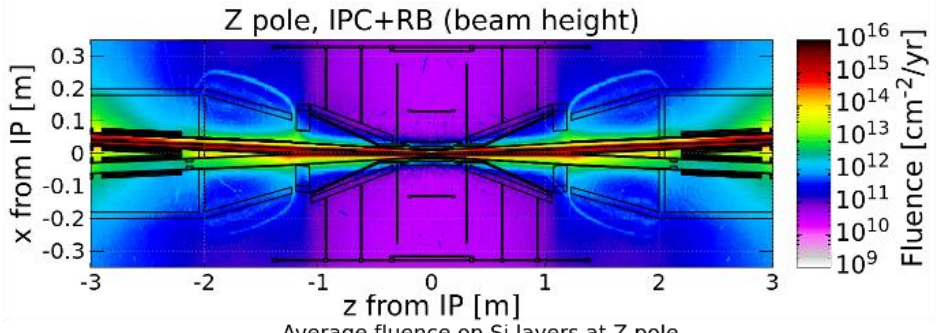
FCC-ee Vertex detector radiation levels

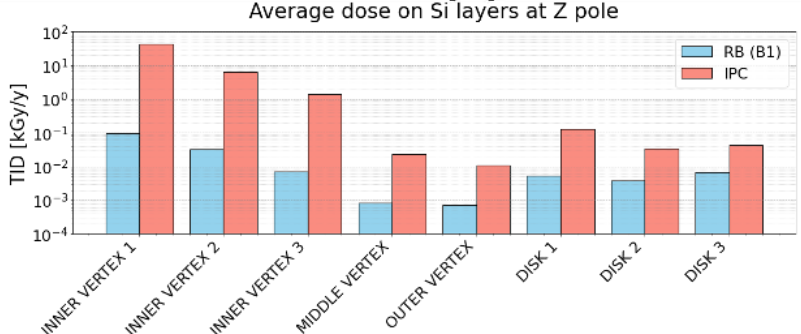
IPC: incoherent Pairs Creation
RB: radiative Bhabha

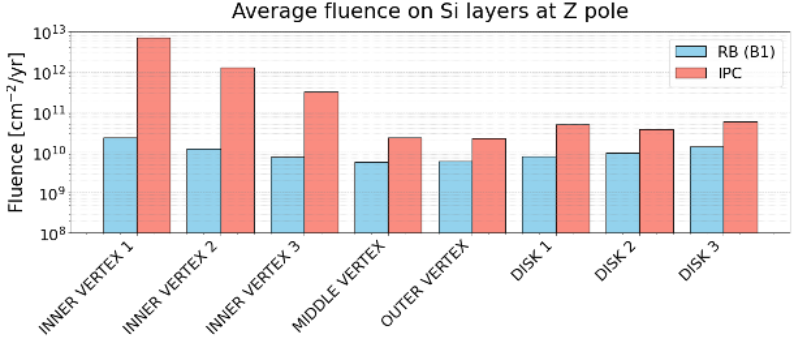
Radiation damage is quantified in TID and fluence

- **TID Total Ionising Dose** : ionising energy per unit mass (mostly affecting electronic circuits behaviour)
- **Cumulative silicon 1 MeV-neutron equivalent fluence** is obtained by weighting the fluence of different particles and energies with a damage function relative to the effect of a 1 MeV neutron in silicon.









Summary

The MDI of the FCC-ee is the crucial part of the project allowing to achieve the highest luminosity, while guaranteing the largest detector acceptance, minimising the machine induced backgrounds, and stable beam operations.

References:

Boscolo, M., Palla, F., Ammirabile, G. *et al*. Status of the FCC-ee interaction region design. *EPJ Techn Instrum* **12**, 4 (2025). https://doi.org/10.1140/epjti/s40485-025-00117-3

Boscolo, M., Palla, F., Bosi, F. *et al*. Mechanical model for the FCC-ee interaction region. *EPJ Techn Instrum* **10**, 16 (2023). https://doi.org/10.1140/epjti/s40485-023-00103-7

Benedikt, M., Zimmermann, F., Auchmann, B. *et al*. Future Circular Collider Feasibility Study Report. *Eur. Phys. J. C* **85**, 1468 (2025). https://doi.org/10.1140/epjc/s10052-025-15077-x