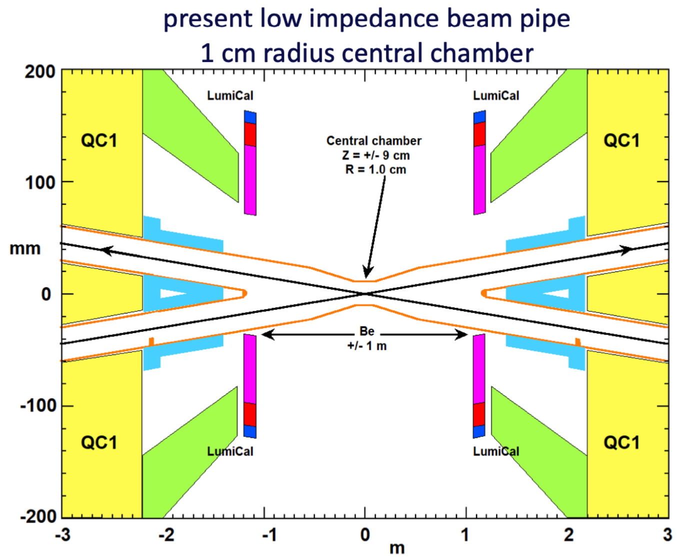
FCC-ee MDI STUDY PROGRESS UPDATE

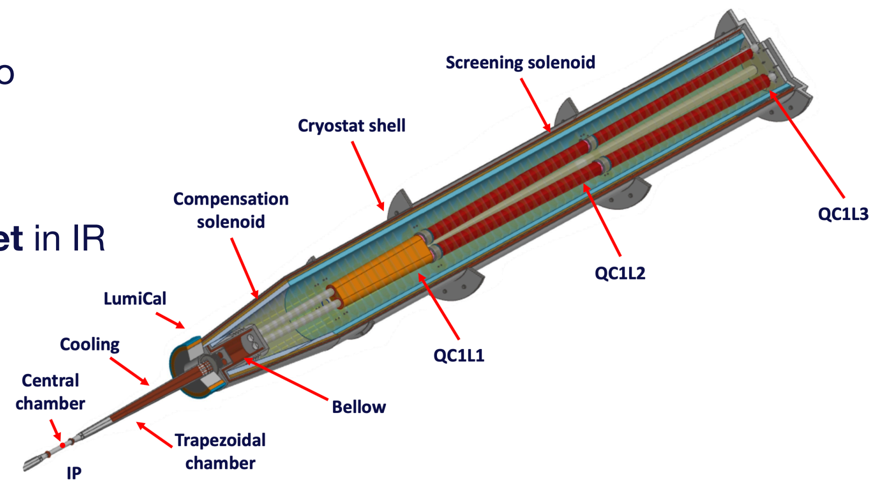
A. Ciarma
on behalf of the FCC-ee MDI group

FCC-ee Interaction Region and Machine Detector Interface

- Luminosity of O(10^{36} $cm^{-2}s^{-1}$) achieved via **crab waist scheme**
- Large Piwinski angle $\phi = \frac{\sigma_z}{\sigma_x}\frac{\theta}{2}$ requires **compact IR** and limits **detector solenoid field**

  ➡ $L^* = 2.2m \qquad B_{det} = 2T$
- **Common IR design** for all 4 working points
- Detector angular acceptance $100mrad$, beam pipe separation at $\sim 1m$
- First Final Focus Quadrupole **inside the detector**, requires **screening solenoid** to shield from detector magnet
- Solenoid compensation achieved locally via **-5T compensation solenoid**
- Low angle Bhabha luminosity monitor **LumiCal** requires **very low material budget** in IR vacuum chamber





FCC-ee MDI activities

IR Mechanical Model

- engineered design of beam pipe, cooling system and support
- heat load distribution from wakefield and SR
- integration in the MDI region and assembly strategy of LumiCal and vertex detector

Background Simulations

- estimation of beam losses in the MDI region and halo collimation scheme
- development of SR maskings
- tracking of unwanted particles in the detector for occupancy calculation

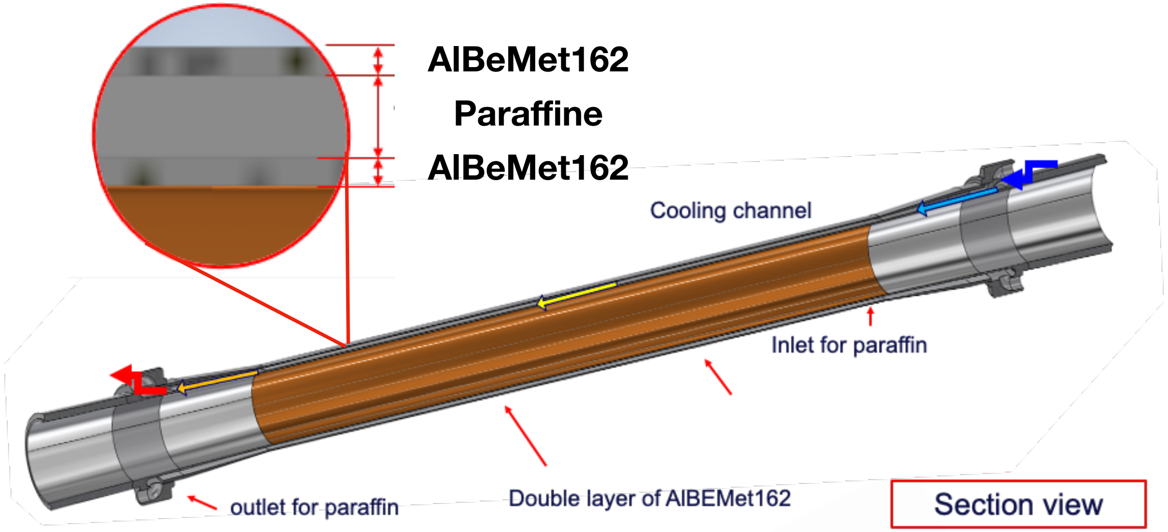
Beamstrahlung Photon Dump

- characterization of beamstrahlung radiation and first FLUKA studies on dump
- integration of extraction line with civil engineering of downstream tunnel and magnet aperture design

Non-local Solenoid Compensation Scheme

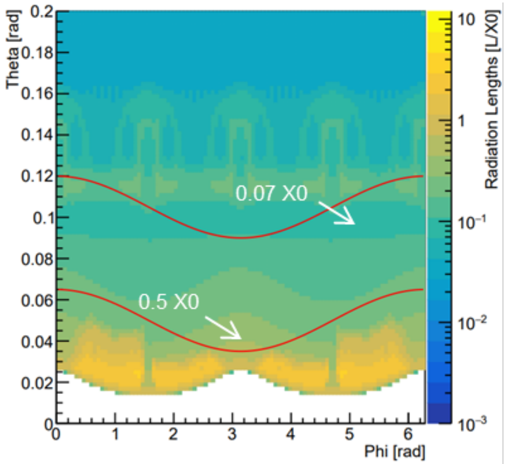
- first studies on alternative solenoid compensation scheme without the -5T compensating solenoid in IR

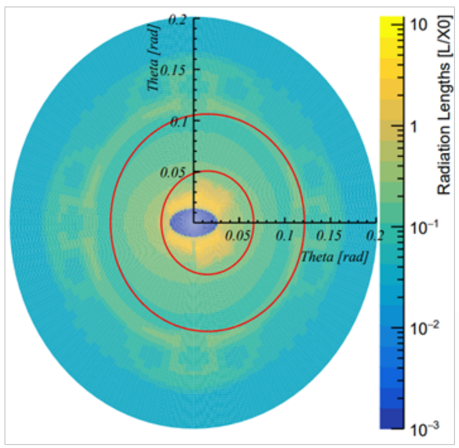
IR beam pipe



Central Chamber

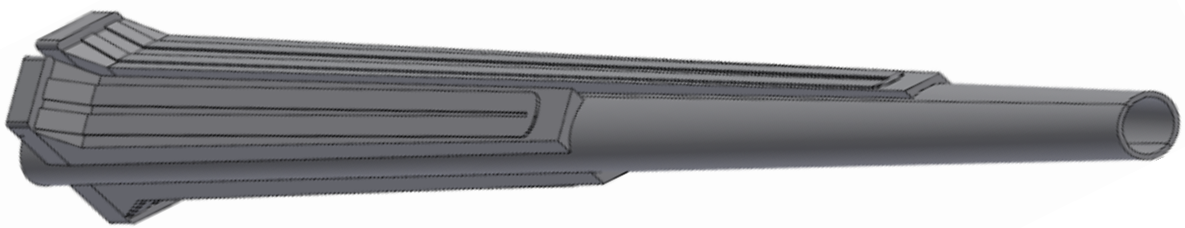
- Extending ±90mm from the IP
- Double layered **AlBeMet162** pipe
  - 1mm **Paraffine cooling**
- Geometry studied to integrate central chamber with vertex detector



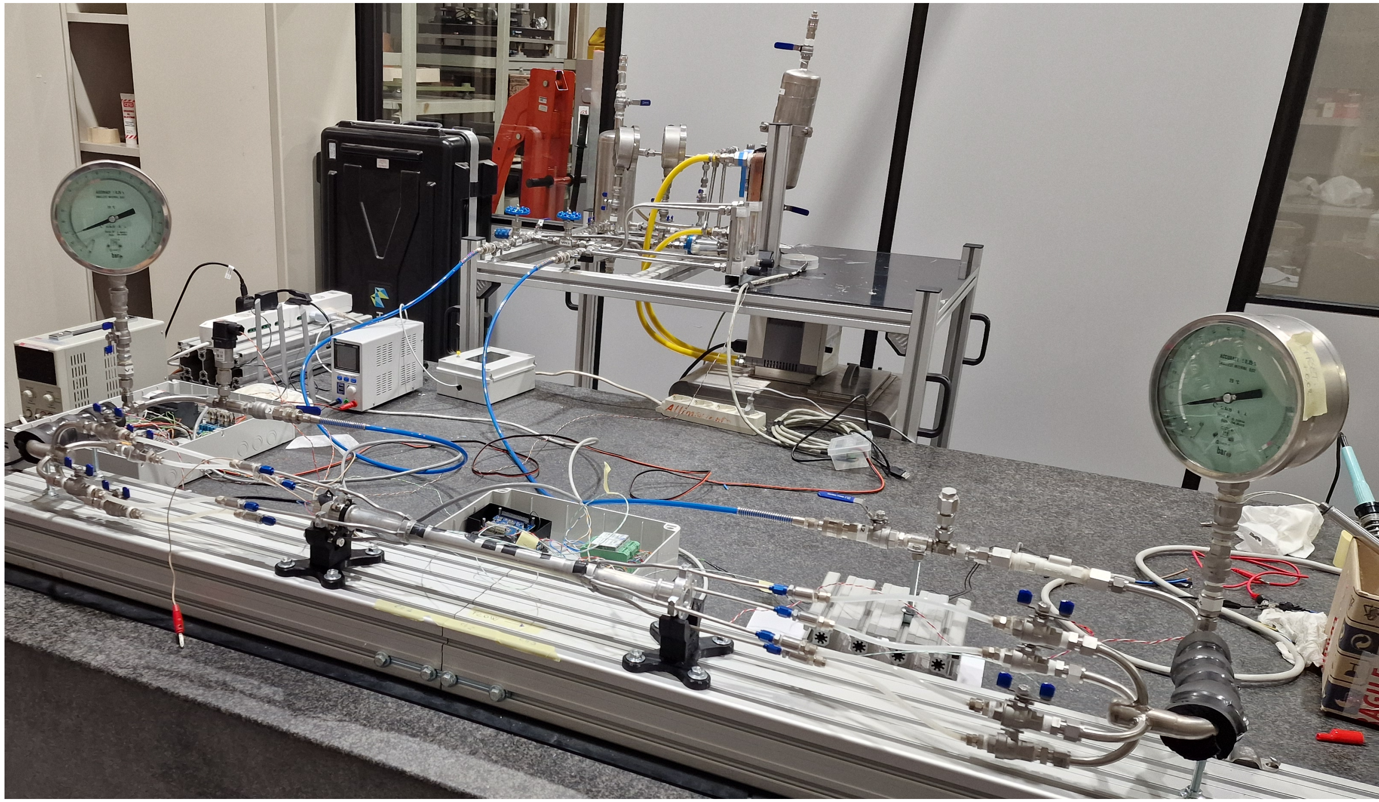


Elliptoconical Chamber

- Two AlBeMet162 chambers from 90mm to 190mm
- Assembled using **Electron-Beam Welding.**
- **Asymmetric water cooling** manifolds to **minimise material budget** in the LumiCal angular acceptance.



FCC-ee IR Mockup @INFN-LNF



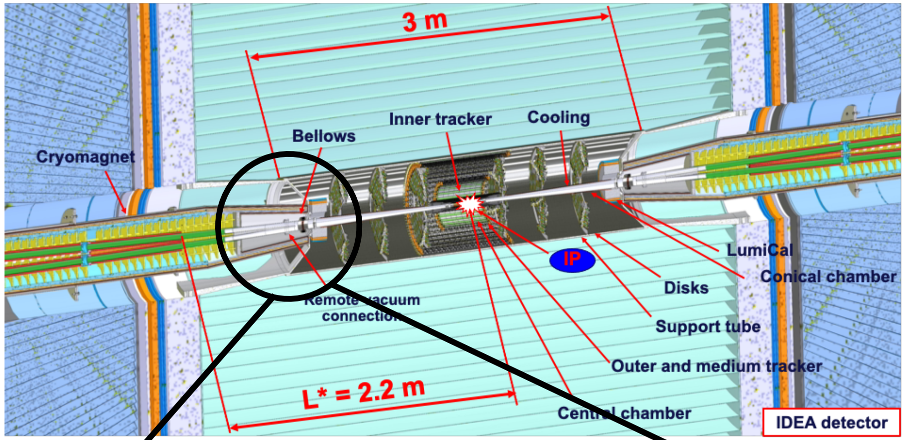
- 1:1 Aluminium model of the Central Chamber (double layered)
- Hydraulic characterization of the cooling manifolds
- Thermal tests of the cooling system
  - exp. power loads 54W (CST)
  - PT1000 sensors
- Elliptoconical chambers in final stage of manifacture
- VXD integration tests with INFN-Pisa

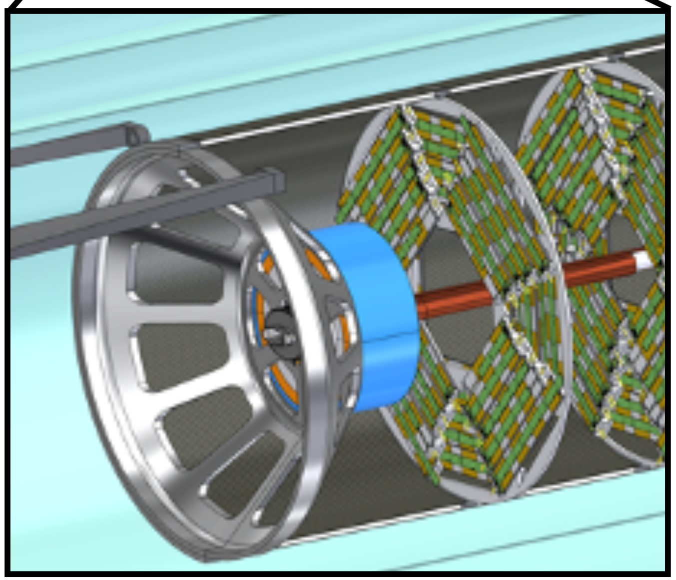
Support Tube for Vertex Detector and LumiCal Integration

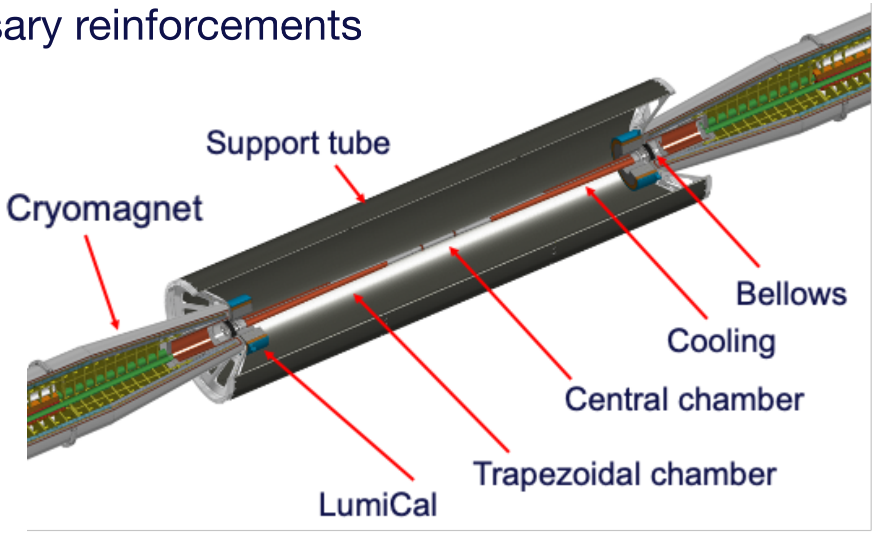
Carbon Fibre support tube + Aluminum endcaps for IR integration

- **Cantilevered support** for the beam pipe
- Ease **assembly procedure** for thin-walled central chamber
- Provide support for LumiCal and Vertex Detector

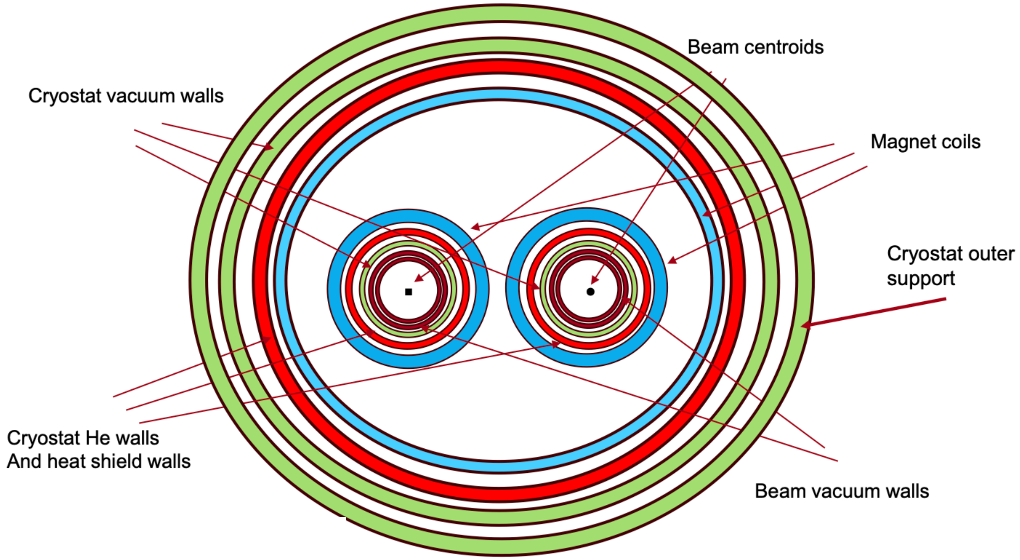
ANSYS structural analysis performed to optimise thickness and necessary reinforcements







Cryostats for Final Focus

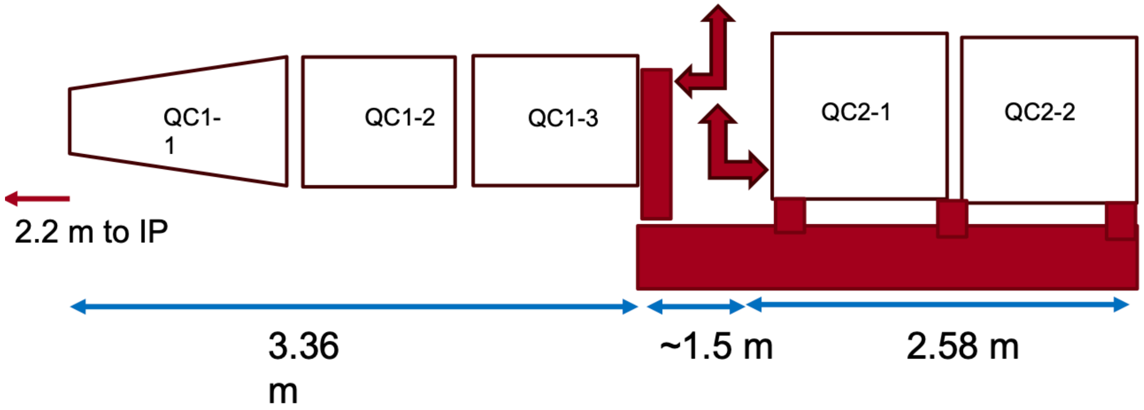


Main challenges for Final Focus cryostat design:

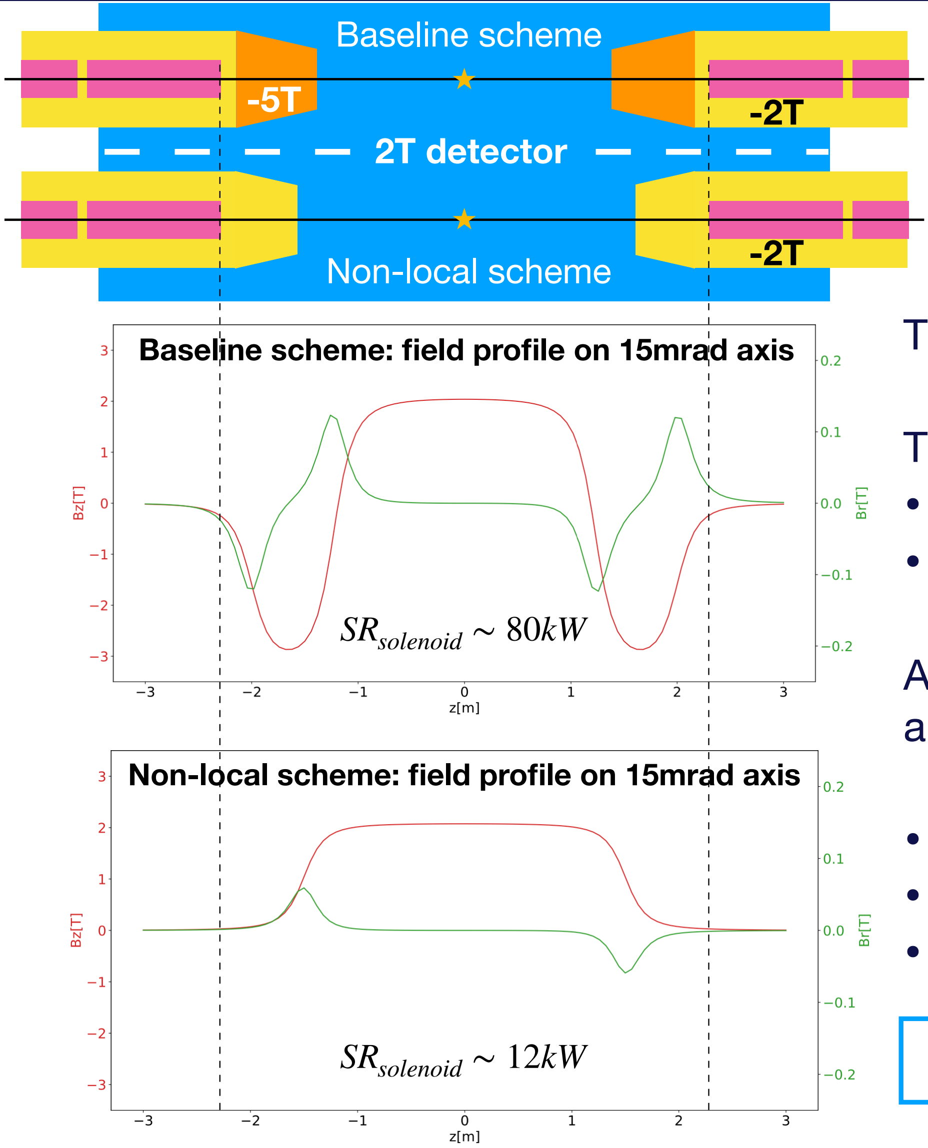
- Tight space inside the detector
- **Common He space** for antisolenoids and superconductive Final Focus Quadrupoles
- Thermal insulation for **warm beam pipe**
- SuperKEKB experience -> reserve some space for additional **shielding material** inside cryostat

Proposal to have two **separate cryostats** for QC1 and QC2 on the same raft.

- Reduced stress on cantilevered support
- Required space between the two FF quads



Coupling Correction Scheme at FCC-ee



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

The current correction scheme uses:

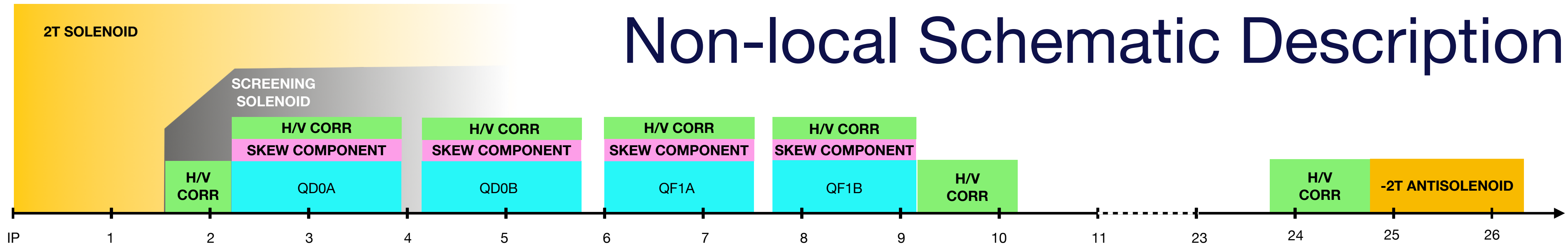
- **-5T compensating solenoids** to cancel the magnetic field integral
- **-2T screening solenoids** to shield the **FFQs** from the detector field

A **non-local correction scheme** proposed by P. Raimondi would allow to move the **compensating solenoids** outside the IR.

- relaxed mechanical constraints in the IR
- technical R&D of a -5T compact magnet
- **Synchrotron Radiation** from B-field transition region (~80kW).

IPAC proceeding: A. Ciarma, M. Boscolo, H. Burkhardt, P. Raimondi, “Alternative solenoid compensation scheme for the FCC-ee interaction region” - 10.18429/JACoW-IPAC2024-TUPC68

Non-local Schematic Description



- The Screening Solenoid starts at **1.23m from IP** and cancels the detector field in the FFQs region
  - may be **conical or cylindrical** according to detector angular acceptance and magnet radius
  - **starting point** can be varied to accomodate mechanical constraints
  - outer part will be **tapered** to match main solenoid fringe fields
- The antisolenoid moved outside the IR (before the first dipole) to cancel $\int B_z ds = 6.25\,Tm$ => **longer, weaker magnets**
- Skew components winded around the FFQs correct coupling due to beam rotation under Bs $K_{1s} = K_1 \ sin(2\theta) \sim 0.02 K_1$
- **H/V correctors** are used to close the orbit and dispersion bumps due to tilted solenoid Bx
  - y-axis bump O(100um), Dy bump O(150mm) closed before the antisolenoid
  - Orbit correctors are **needed regardless of correction scheme**, these are not additional elements
- Possibility to have **3T detector**: proportional increase of bumps, still manageable with weak correctors and skew

Sources of Background in the MDI area

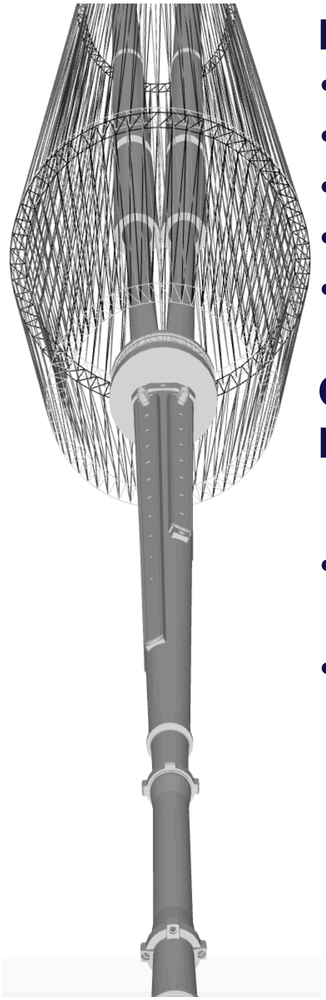
Luminosity backgrounds

- **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:

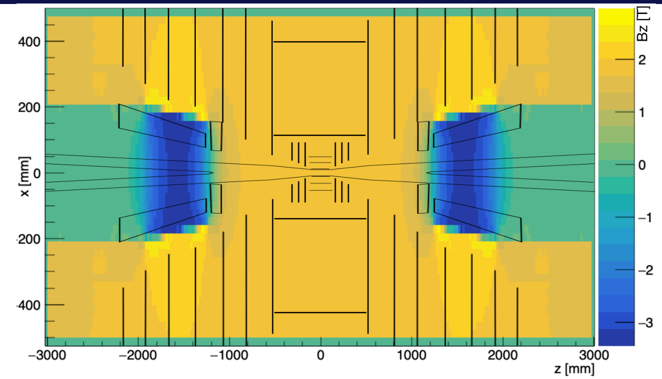
- **Beam halo losses:** high rate of beam losses in the IR coming from halo (transverse or longitudinal) being diffused by the collimators after lifetime drop
- **Synchrotron Radiation:** photons escaping the tip of the upstream SR mask at large angles
- **Beam-gas** (elastic, inelastic), Compton scattering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

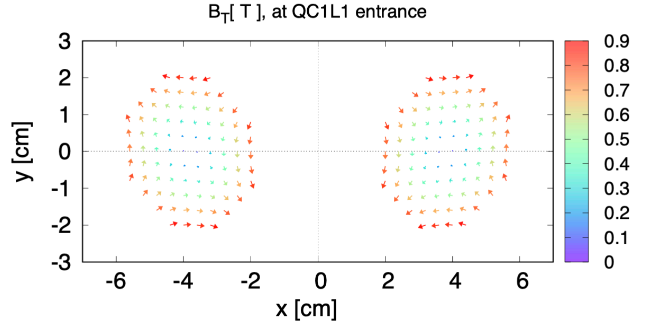
Key4hep MDI modelization



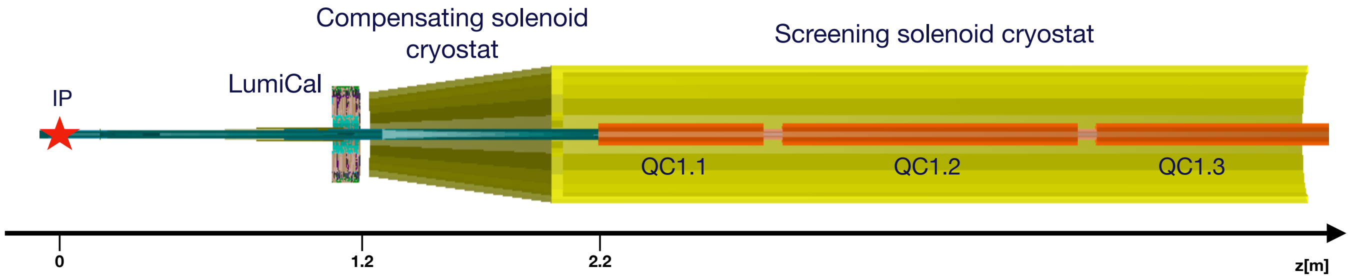
Engineered CAD model of IR beam pipe imported in **Key4hep.**
- Double-layered central section for paraffine cooling
- **Cooling manifolds** for ellipto-conical chambers implemented
- Bellows
- Beam pipe **separation region**
- Tungsten **SR masks** after final focus

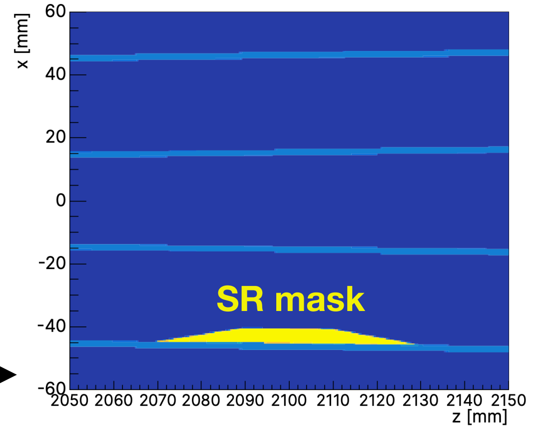
Compensating and Screening solenoid cryostats
Final Focus Quadrupoles simple equivalent material model



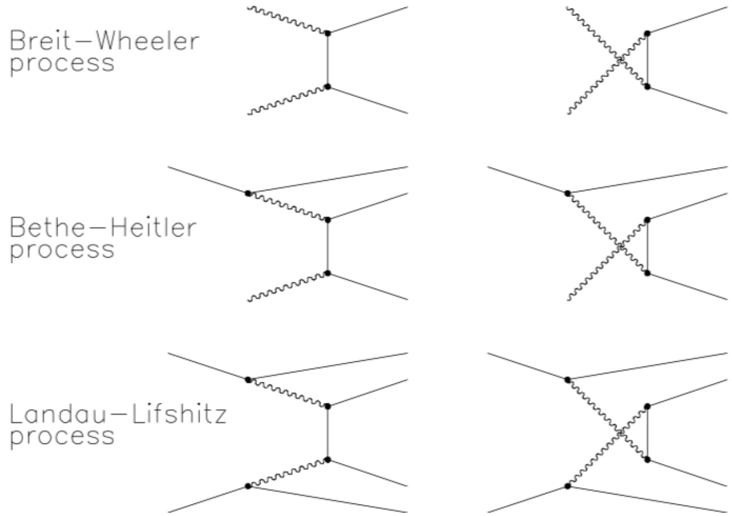


- Field coming from the **anti-solenoids** (screening-S, compensating-S) imported via **field map** to account for fringe effects
- Implementation of **FF quadrupole fields** in the Key4hep geometry





Incoherent Pairs Creation (IPC)

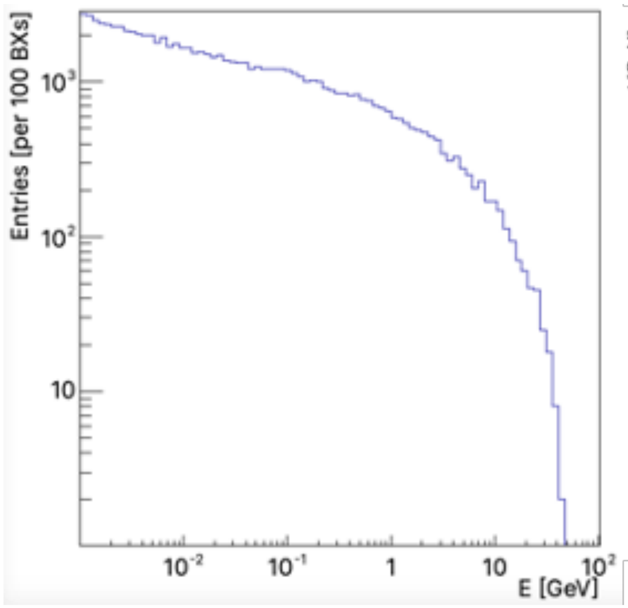


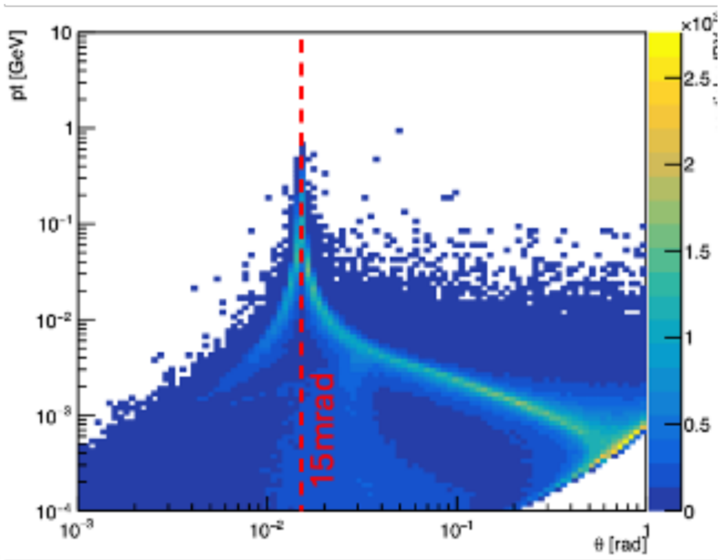
This process has been simulated using the generator **GuineaPig++.**

First occupancy calculations @Z-pole performed for CLD vertex/tracker, IDEA vertex/DC, and ALLEGRO ECal (see A. Ciarma FCCWeek24) show low background levels or possible background suppression strategies.

Beam parameters for V23 (06/05/2023)

β_x, β_y $[mm]$	110/0.7
σ_x, σ_y $[\mu m]$	8.837/0.031
σ_z $[\mu m]$	12700
N_e $[10^{11}]$	15.1
N_{IPC} $per\ BX$	~900



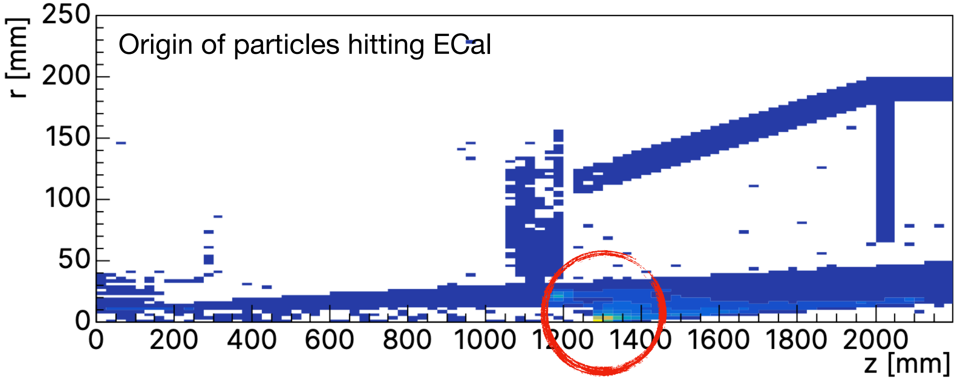


Number and kinematics of IPCs change with the evolution of the beam parameters!

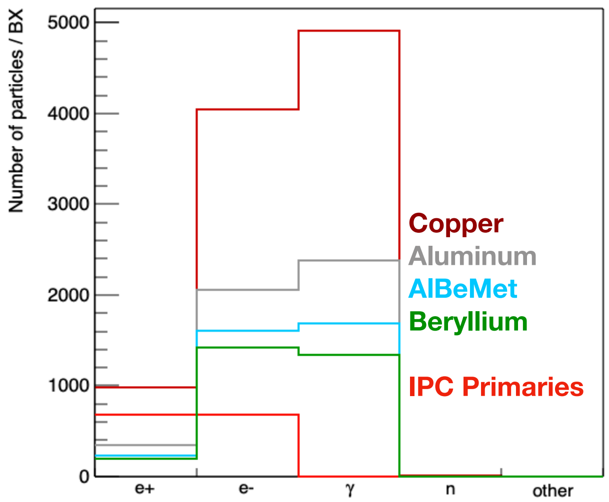
Secondaries from MDI elements

A large contribution of backgrounds in the IDEA DC and ALLEGRO ECAL comes from **secondaries** generated by low-Pt particles hitting the **beam pipe separation region** (currently made of **Copper**).

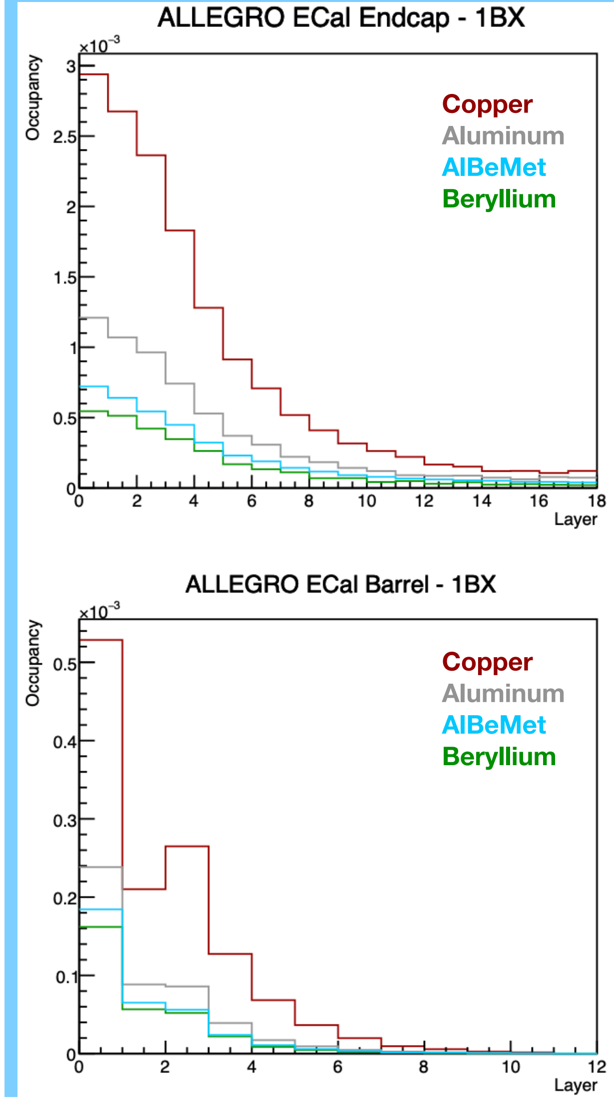
Without changing the geometry, the use of **lighter materials** reduces the amount of secondaries produced and therefore also the occupancy.



	Be	AlBeMet	Al	Cu
Secondaries per BX	3'000	3'500	4'800	10'000
X0 [cm]	35.28	16.67	8.897	1.436



Example: ECal occupancy



Radiative Bhabha: beam losses in IR

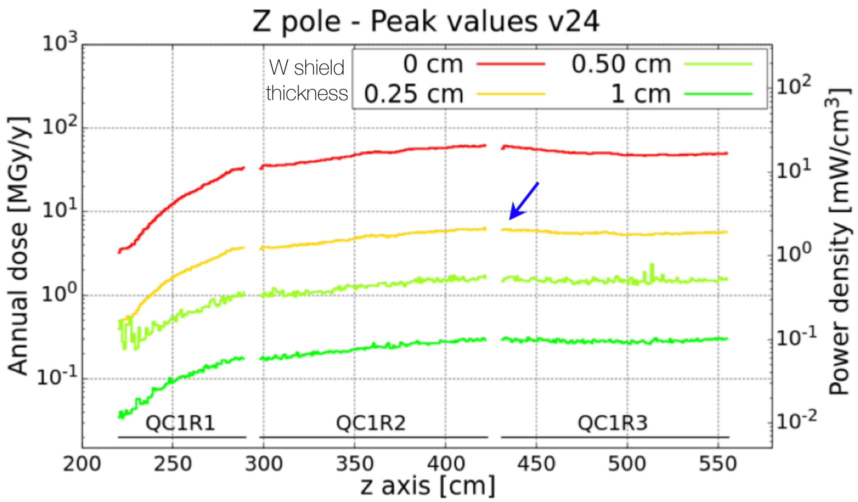
During bunch crossing beam particles can **lose energy** via photon emission, and exit the lattice **energy acceptance**.

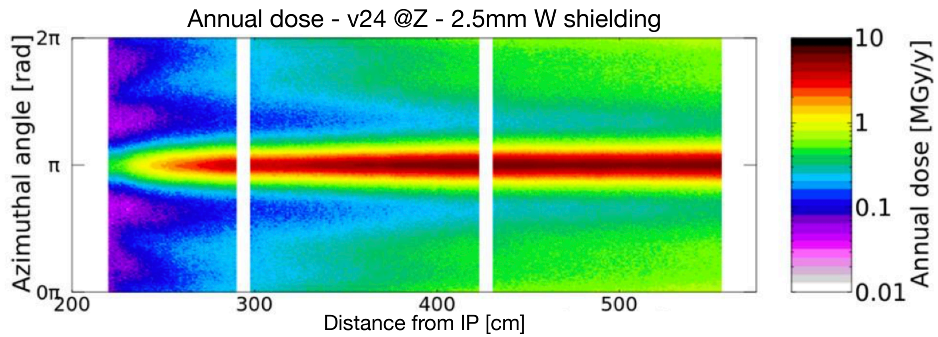
Particles produced using **BBBrem** and **GuineaPig++**.

Off-energy particles are tracked downstream to estimate the **power deposited** on the SC final focus quadrupoles.

FLUKA simulations show that a **thin tungsten shielding** between the magnets and the pipe efficiently reduces the total dose below O(10MGy/y).

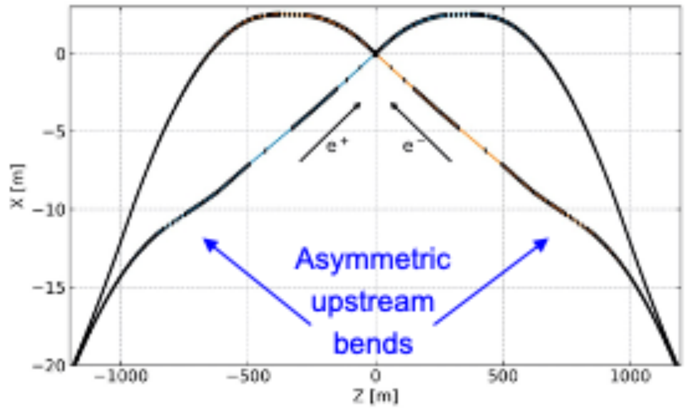
Integration of this shielding is an important part of the magnets final design.





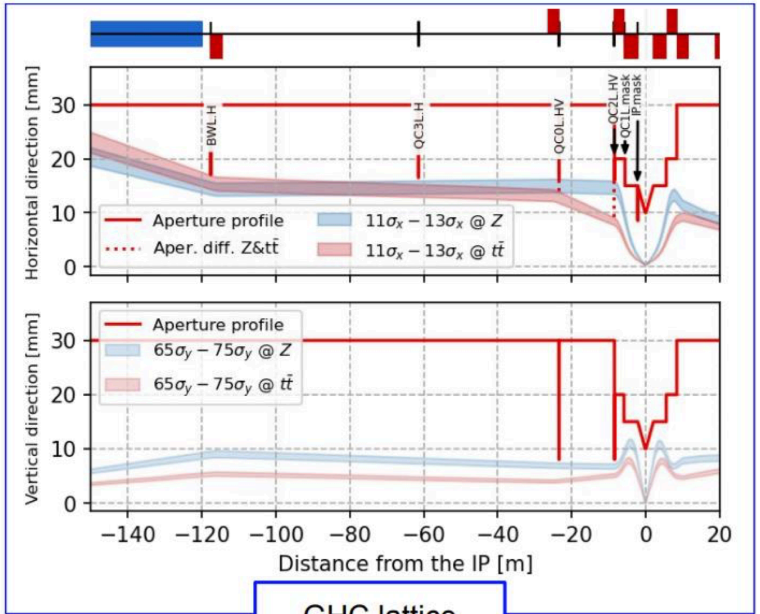
BBBREM – Monte Carlo simulation of radiative Bhabha scattering in the very forward direction, R. Kleiss, H. Burkhardt

Synchrotron Radiation



SR is the **main driver** for FCC-ee MDI and lattice design

- **Asymmetric bend** to mitigate SR coming from upstream magnets
- Characterization of the radiation using **G4 based tool BDSim**
- Tungsten **SR collimators and masks** to protect the IR



GHC lattice

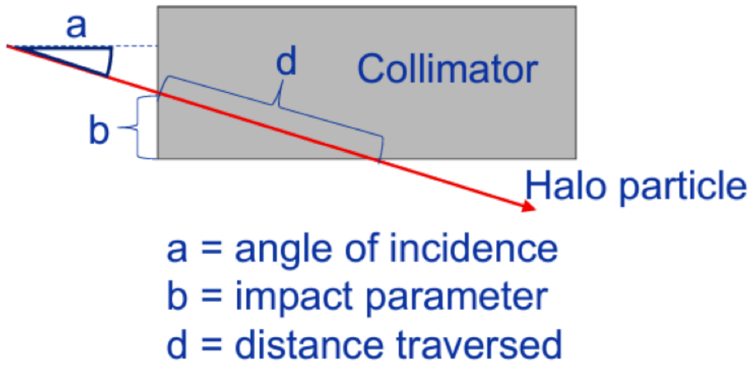
SR Background coming from the **beam core** particles is **shielded** thanks to the **tungsten masks**. Other contributions currently under study are:

- **beam halo** particles
- top-up **injection**

Characterization of background is essential for **dedicated shielding** design.

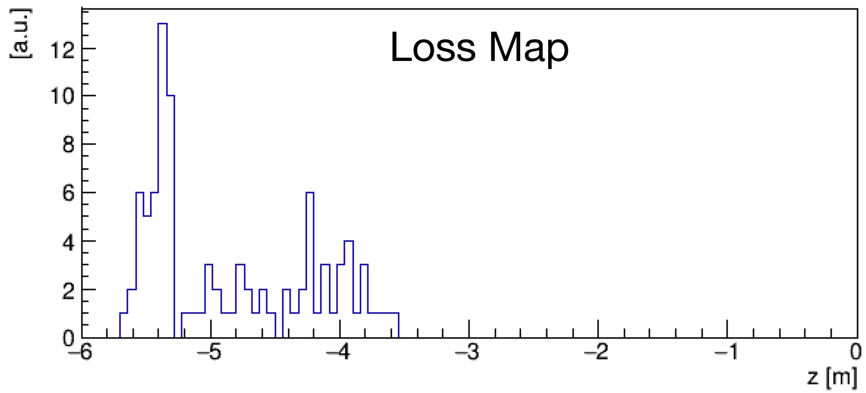
First tracking in key4hep ongoing for **occupancy calculation**.

Generic Halo Losses in the IR



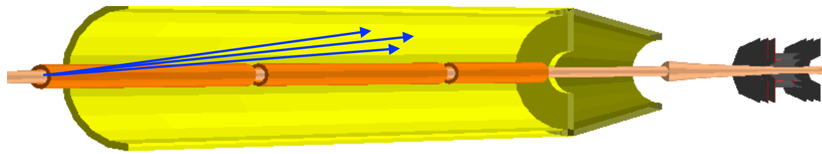
Following **beam lifetime reduction** due to a slow process, beam halo particles can be **lost in the MDI region** following the interaction with the **main collimators**.

This study is independent on the loss process, particles are generated hitting the collimator with a given **impact parameter range** and tracked for 500 turns into the full lattice.



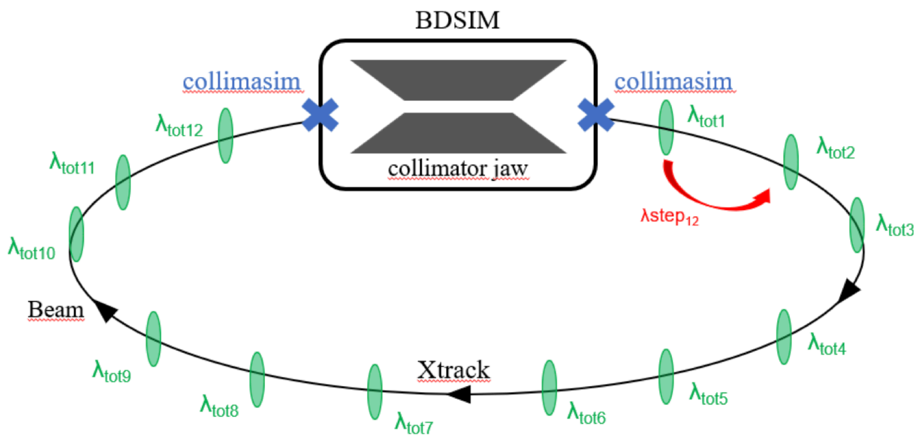
Tracking performed using **X-Suite**, interfacing with **BDSIM** for the collimator interaction.

Particles hitting the beam pipe in the MDI region need to be tracked using **FLUKA / key4hep** to study the production of secondaries and the **induced backgrounds** in the detector.



➡ optimization of collimation scheme and shielding design

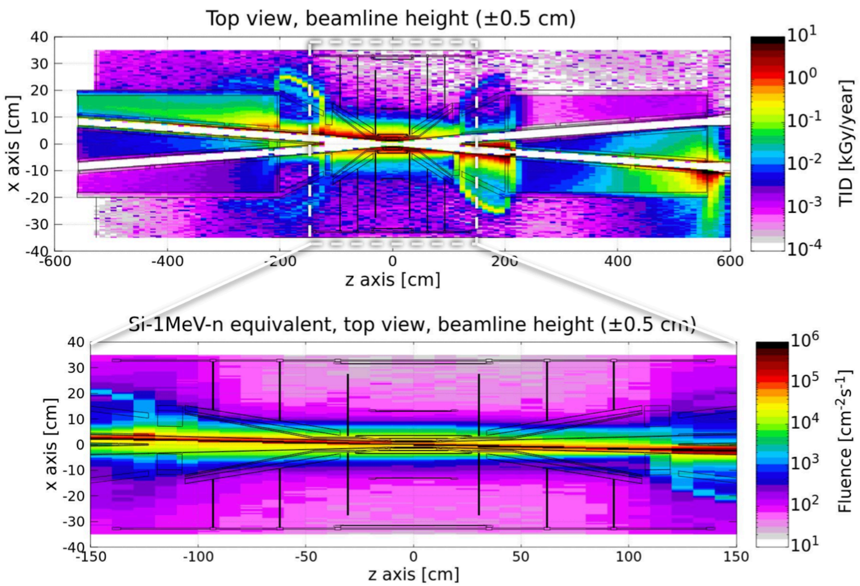
Beam-gas Losses from multi-turn



First multi-turn tracking in **X-Suite** using **beam-gas elements** based on lattice pressure profile.

Dominant contribution: **inelastic beam-gas** (Bremsstrahlung)

First loss maps produced, tracking in key4hep will follow.

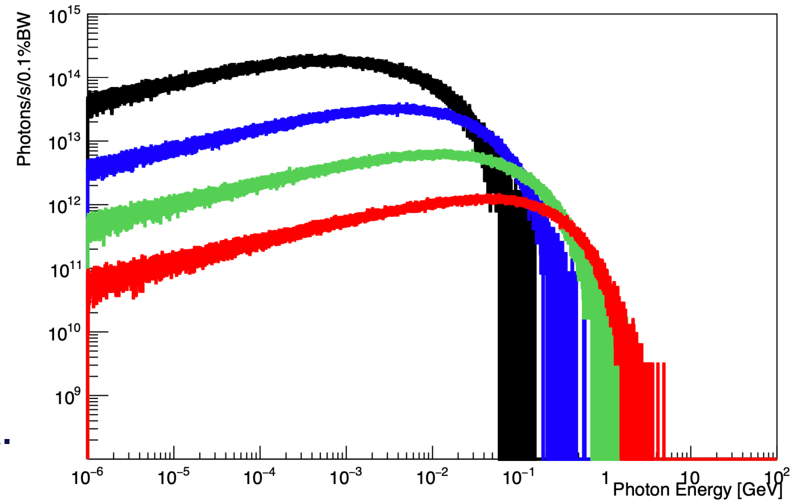


Beam-gas Losses in IR

Local beam-gas losses in the IR studied also with FLUKA.

- Geometry includes both beam lines, SR masks and collimators, MDI elements, IDEA detector.
- particles generated from 500m upstream the IP
- first loss maps for e^- and photons
- Total Ionizing Dose below kGy/year

Beamstrahlung radiation

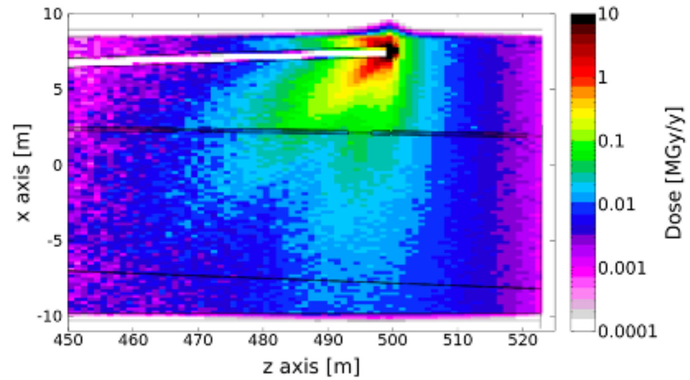


Extremely intense radiation **O(100kW)** produced by the deflection of a beam under the EM field of the other at the IP. The photons are emitted **collinear to the beam** with an angle proportional to the beam-beam kick.

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

A **dedicated extraction line** collects the intense radiation to a photon beam dump. The downstream **magnets** need to be **redesigned** to allow the passage of the extraction line.

Integration with the tunnel show that a possible location of the beamstrahlung dump is **500m from the IP**. First FLUKA studies to determine **power absorption** in the dump and tunnel ongoing.



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

Summary

Significant progress on all key aspects of the FCC-ee MDI design:

- Engineered model of the low impedance beam pipe
- Cylindrical support tube for assembly and vertex detector and LumiCal integration
- Development of primary collimators to mitigate IR beam losses
- Synchrotron Radiation masks
- Detector background estimation
- Beamstrahlung photon dump
- Non-local solenoid compensation scheme