FCC-ee MDI STATUS

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

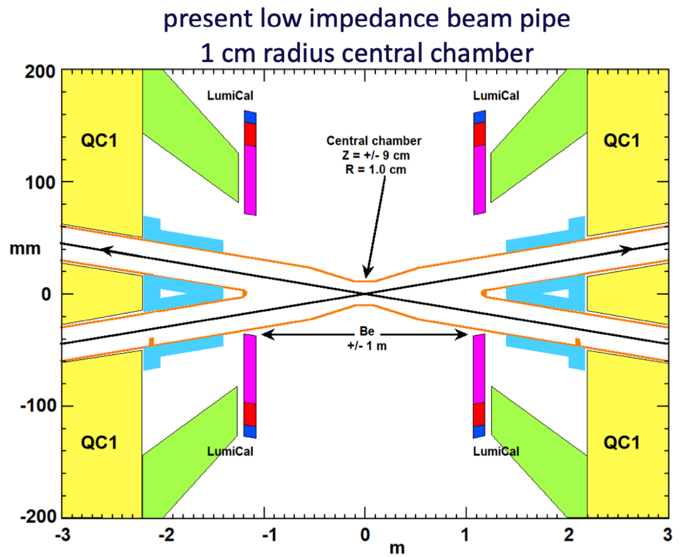
This project is supported from the European Union's Horizon 2020 research and innovation programme under grant agreement No 951754.

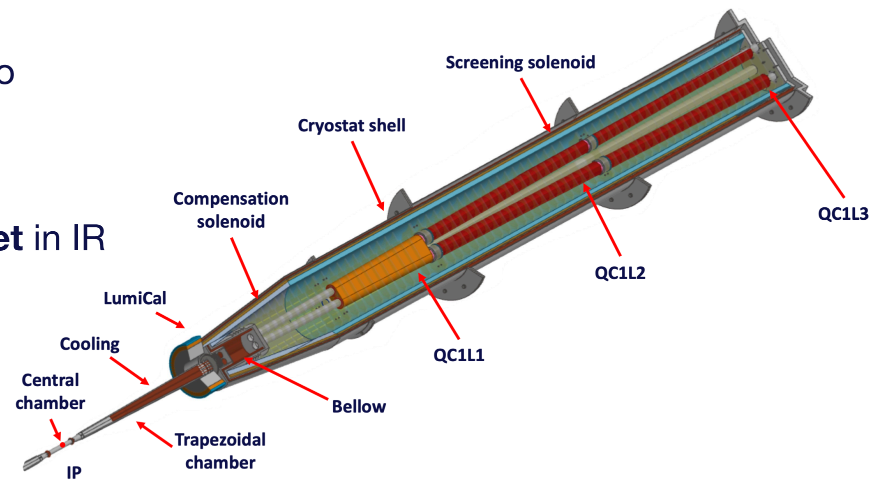
FCC-ee Interaction Region and Machine Detector Interface

- 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**

  ➡ $L^* = 2.2m \quad B_{det} = 2T$

- **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

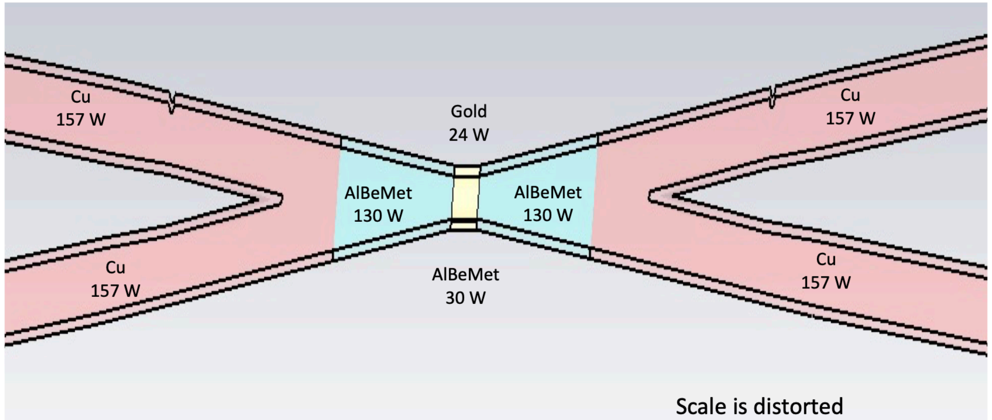
- estimation of beam losses in the MDI region and halo collimation scheme
- development of SR maskings
- tracking of unwanted particles in the detector for occupancy calculation

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

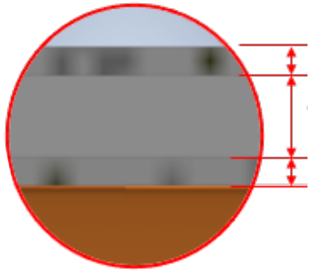
- first studies on alternative solenoid compensation scheme without the -5T compensating solenoid in IR

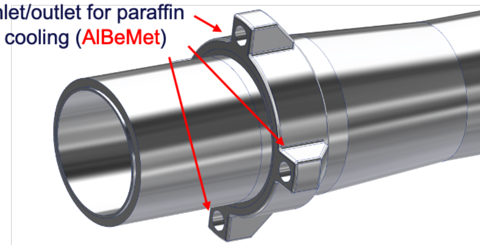


Low impedance beam pipe

Beam pipe design optimized for low impedance using CST wakefield evaluations.

Heat load estimates used in ANSYS simulations for cooling system dimensioning and structural analysis.





Central Chamber

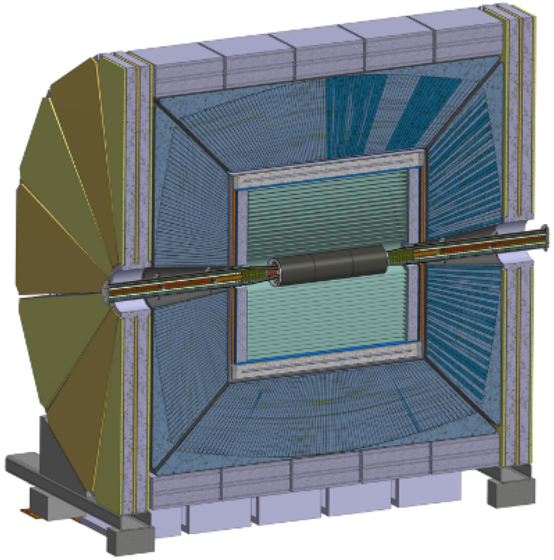
- Extending ±90mm from the IP
- Double AlBeMet162 layer to contain Paraffine cooling
- Geometry studied to integrate central chamber with vertex detector

Ellipto-conical Chamber

- Two AlBeMet162 chambers assembled using Electron-Beam Welding
- Cooling channels for water recirculation machined over the chamber
- Asymmetric cooling manifolds to follow 50 mrad LumiCal acceptance

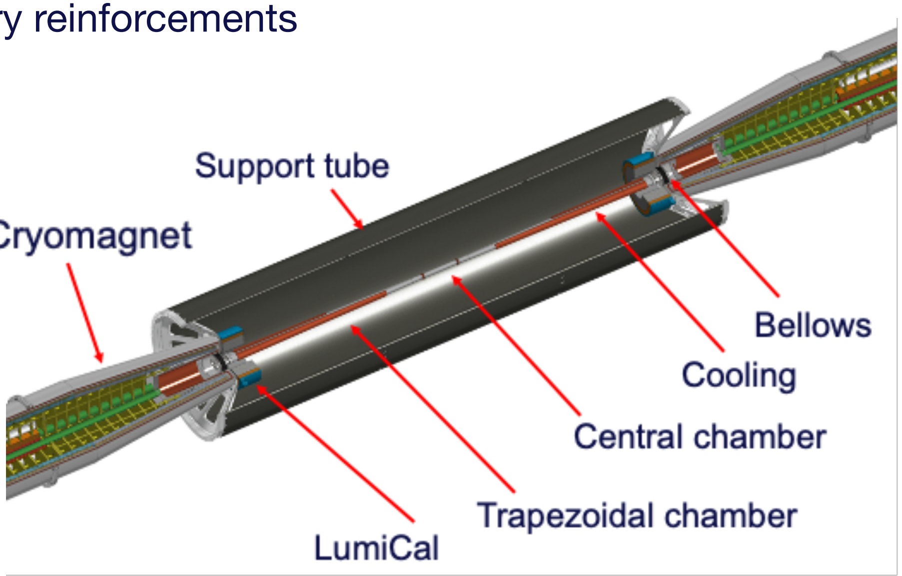
Ref. A. Novokhatski, F. Fransesini, et al. “Estimated heat load and proposed cooling system in the FCC-ee IR beam pipe”, IPAC23

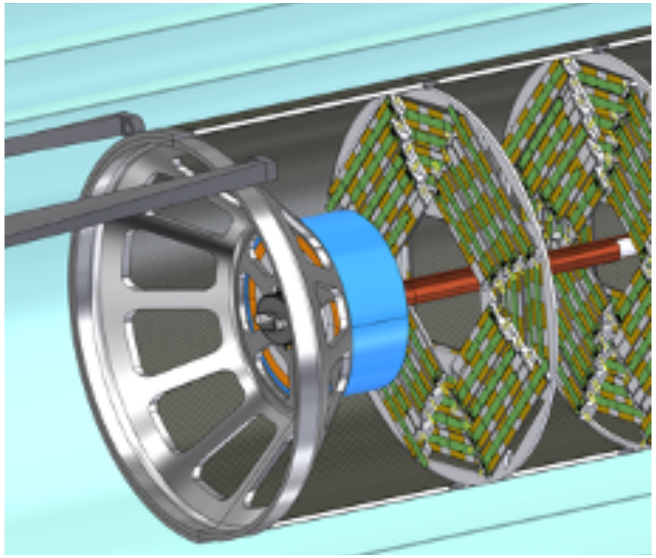
Support Tube for Vertex Detector and LumiCal Integration



- 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





Sources of Background in the MDI area

Luminosity backgrounds

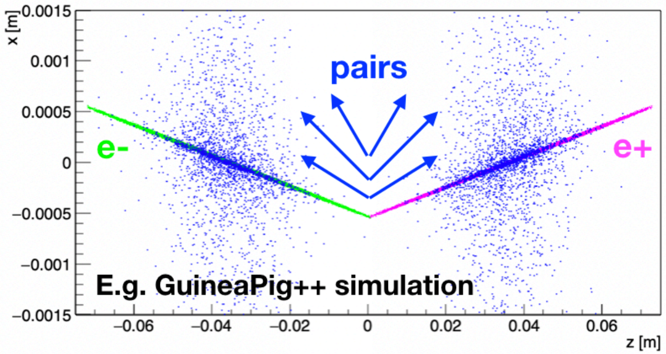
- **Incoherent Pairs Creation (IPC)**: Secondary e^-e^+ pairs produced via the interaction of the beamstrahlung photons with real or virtual photons during bunch crossing.
- **Radiative Bhabha:** beam particles which lose energy at bunch crossing and exit the dynamic aperture

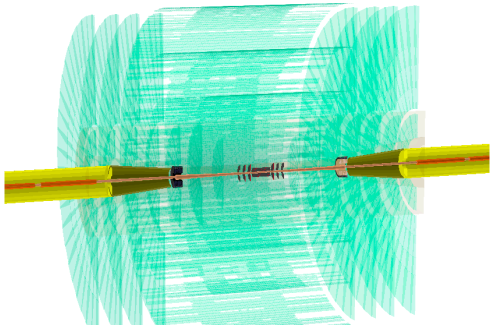
Single beam induced backgrounds:

- **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

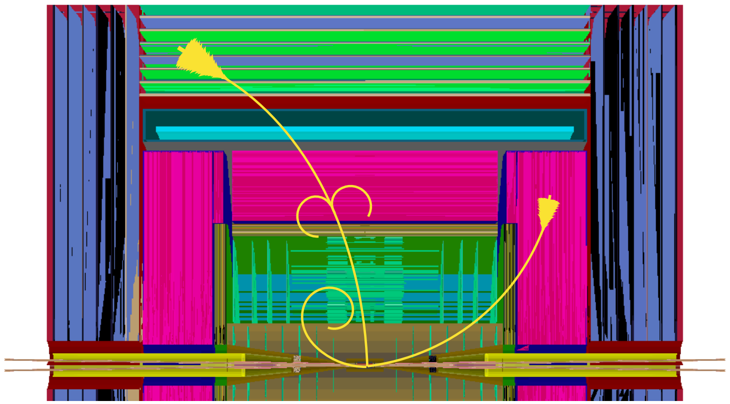
Primaries produced by **external generators** (GuineaPig++, BDSim, Xtrack, …)



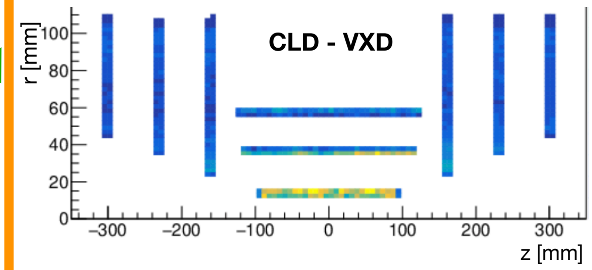


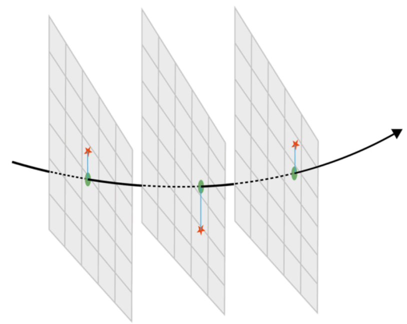
Detector and MDI geometry description in **DD4hep:** public common git repo

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



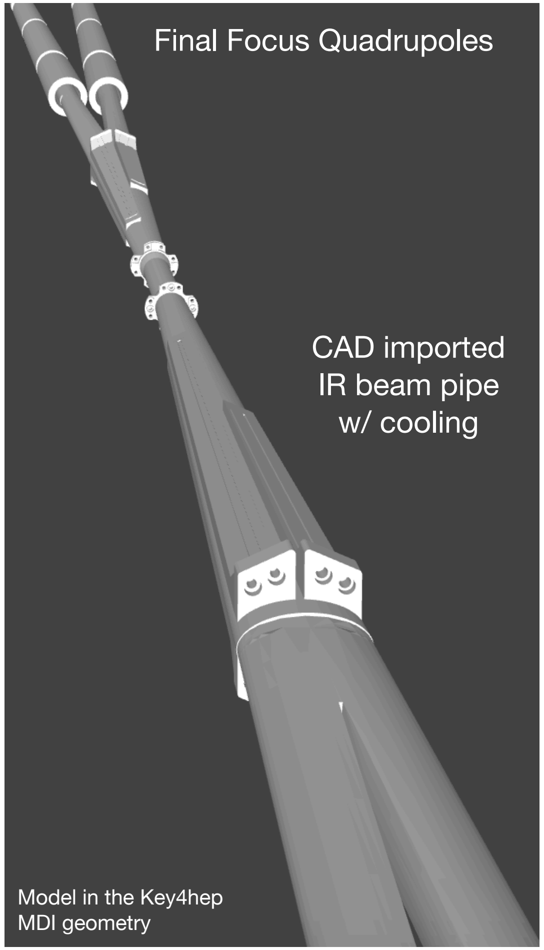
Hits collected for analysis and occupancy determination





Signal **reconstruction**

Key4hep MDI modelization



Engineered CAD model of AlBeMet162 beam pipe imported in **Key4hep**.

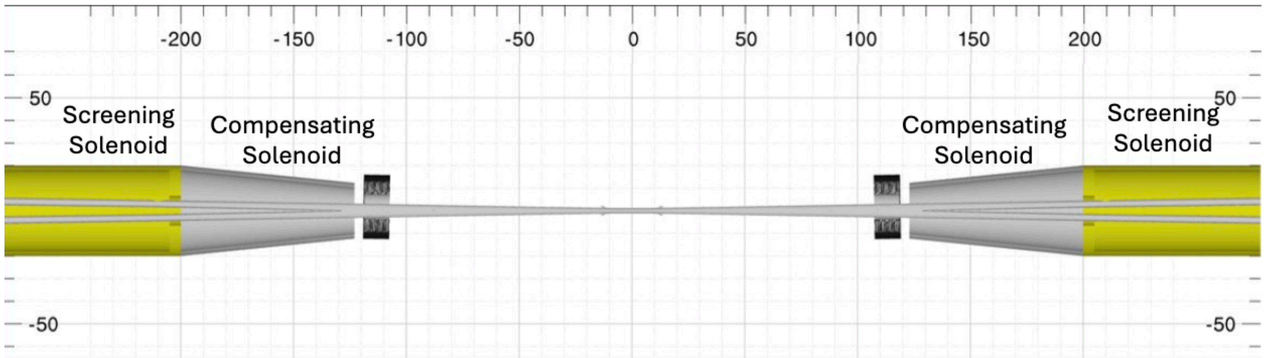
- Double-layered central section for paraffine cooling
- **Cooling manifolds** for ellipto-conical chambers implemented
- Beam pipe **separation region** profile congruent to impedance studies

Compensating and Screening solenoid cryostats

Final Focus Quadrupoles simple equivalent material model

Future upgrades:

- realistic **bellows** to be placed before beam pipe separation, currently under development
- IR carbon fiber **support tube**

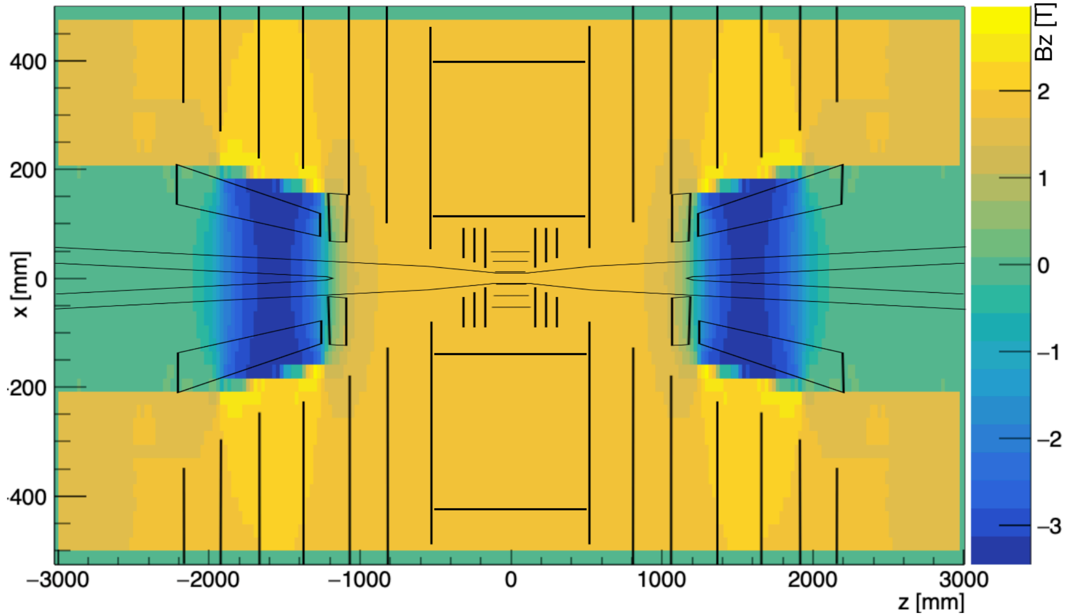


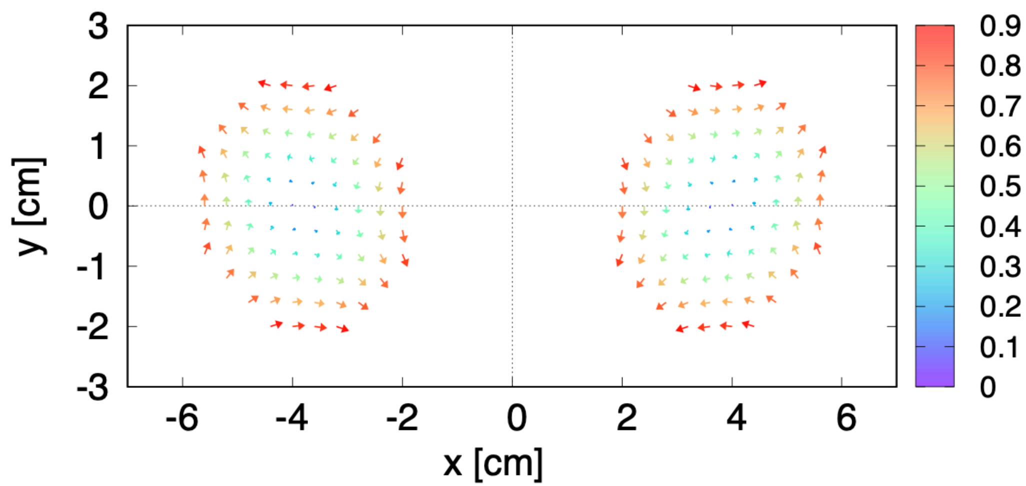
Magnetic Fields in the IR

In addition to the 2T solenoidal field of the experiment, allow for correct tracking of charged background particles, in particular those generated in the separated beam pipe region of the MDI area.

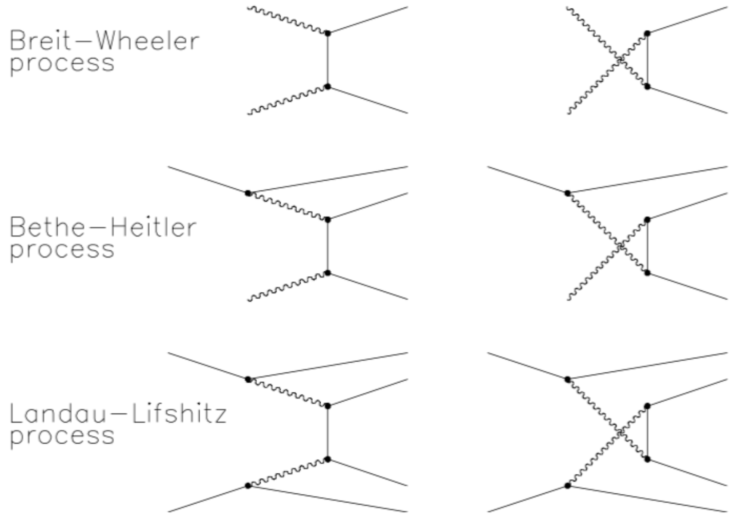
- Field coming from the **anti-solenoids** (screening-S, compensating-S) imported via **field map** to account for fringe effects

- Implementation of **FF quadrupole fields** in the Key4hep geometry

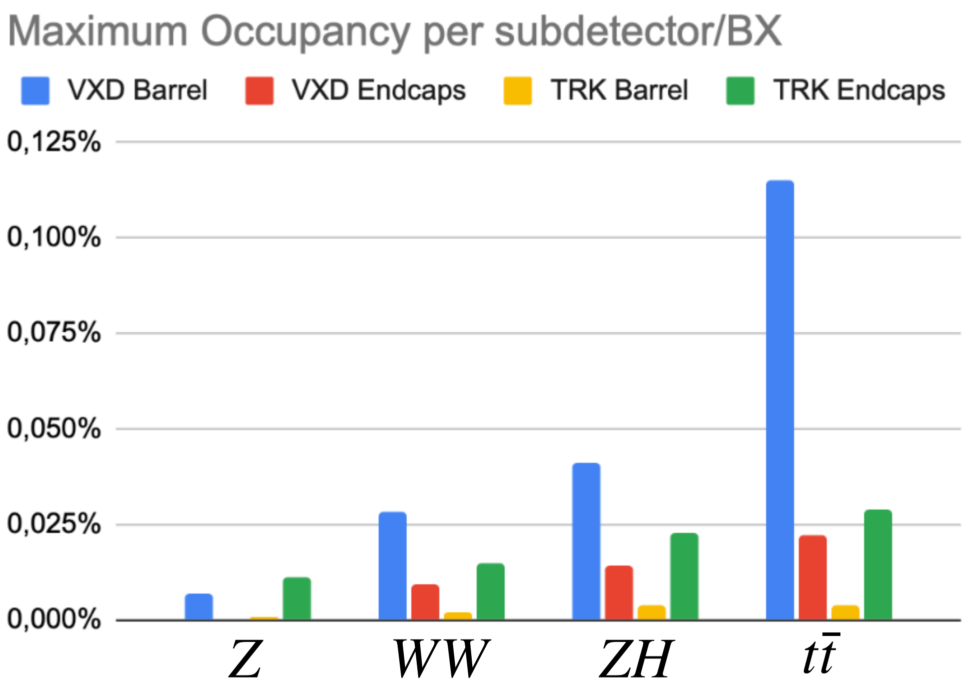




Incoherent Pairs Creation (IPC)



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



Well understood background in the CLD detector:

- higher production + kinematics: detector acceptance more populated at **high energies**
- Occupancy **below 1%** at all working points
- **Readout time** could be concerning at Z-pole due to high rep. rate ($\Delta t_{RO} = 10\mu s \rightarrow Occ^{VXD}_{max} = 2 \sim 3\,\%$)

CDR studies: average occupancy in IDEA DC 1-3%. These studies will be reproduced in Key4hep.

Radiative Bhabha: beam losses

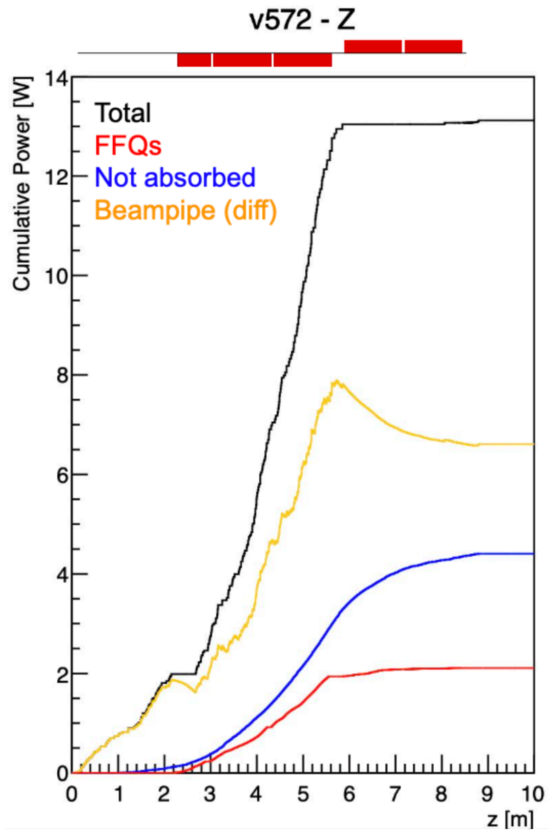
During bunch crossing beam particles can lose energy via photon emission, and exit the lattice energy acceptance.

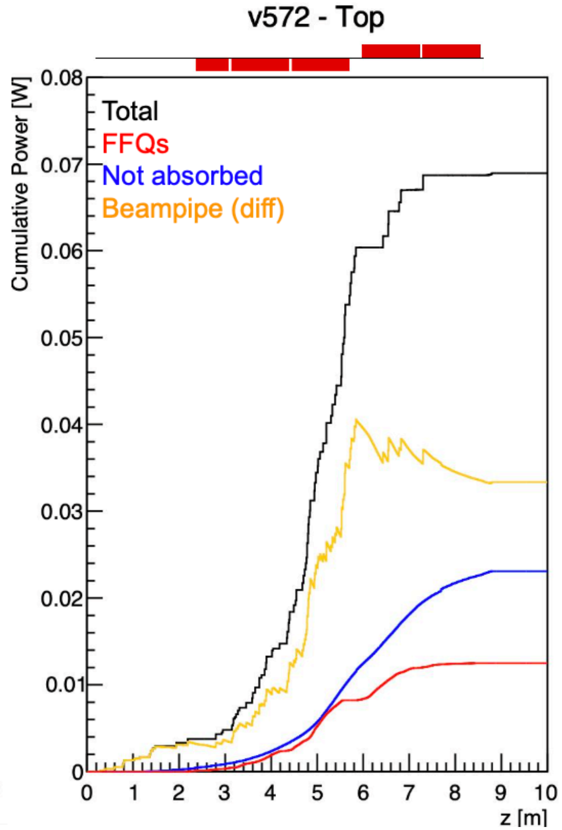
Particles produced using BBBrem[1] and GuineaPig++.

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

A benchmark with BDSIM showed good agreement.

Thermal shieldings to protect the FFQs under study.





	QC1R1	QC1R2	QC1R3	QC2R1	QC2R2	**Total**
Z	0.2 W	0.7 W	1.05 W	0.15 W	0.05 W	**2.15 W**
TOP	0.3 mW	2.0 mW	5.9 mW	3.8 mW	0.5 mW	**12.5 mW**

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

Beam Losses in the IR due to Failure Scenarios

Following **unexpected beam lifetime reduction,** a large number of particles can be **lost in the MDI region** following the interaction with the **main collimators**.

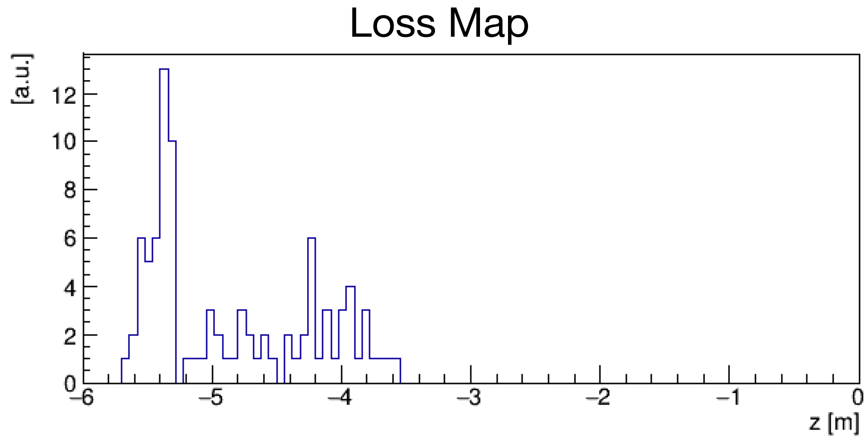
Loss maps produced with **X-Track**, occupancy with **key4hep**.

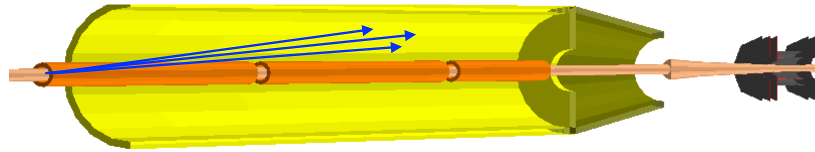
Losses located **few meters upstream** IP at all working points, both from horizontal and off-momentum collimators.

Particles will traverse the **final focus quadrupoles** and the antisolenoid **cryostat** before getting to the **innermost subdetectors**.

All this material can be source of large **secondary showers**, which are the cause of high occupancies O(1~10%)

Shieldings design and **collimator optimization** are ongoing to mitigate this effect.





	Losses/s (10^9)	Highest occupancy
	tt-threshold	
IPA	0.15	6% (ITE)
IPD	0.11	4% (ITE)
IPG	0.10	3% (ITE)
IPJ	0.16	9% (ITE)
	Z-pole	
IPA	0.26	0.02% (ITE)
IPD	0.14	< 0.01% (ITE)
IPG	0.12	< 0.01% (ITE)
IPJ	0.39	0.11% (ITE)

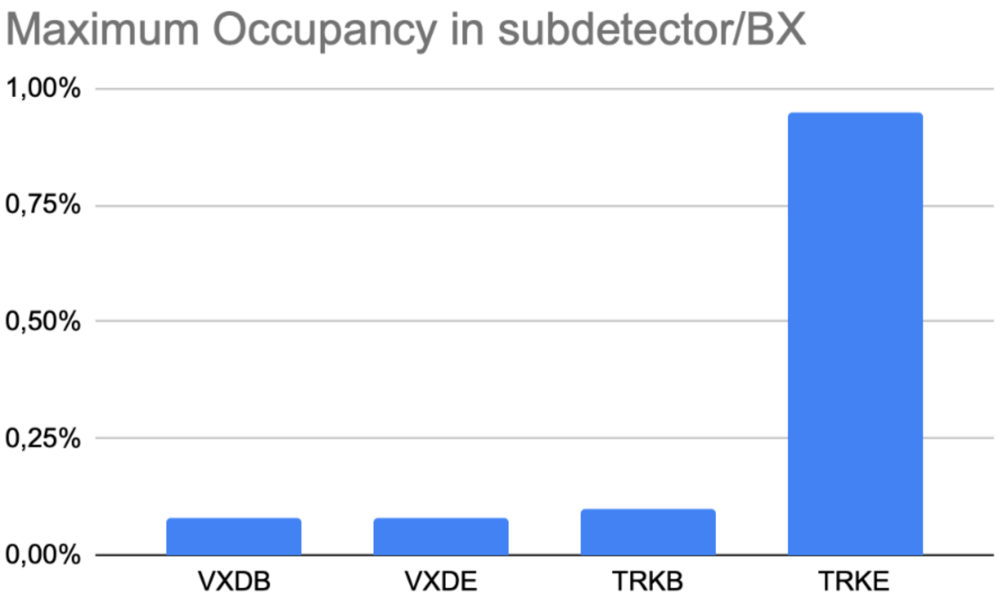
Background from SR photons

Background coming from photons **diffused at large angle** from the tip of the upstream SR mask.

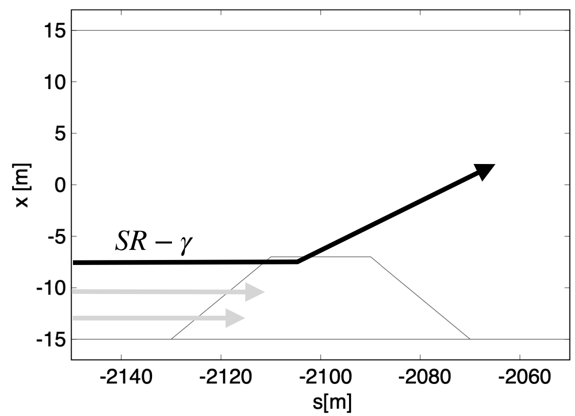
Recent **reprisal of CDR studies** shows that maximum occupancy can get up to **1% only in tracker endcaps** (close to the beam pipe).

Work to replicate this study for current beam parameters is **ongoing**.

Next steps: study secondaries produced at the SR masks (e.g. muons) which may induce backgrounds



($t\bar{t}$ threshold - CDR beam parameters
CLD detector - NO shieldings)

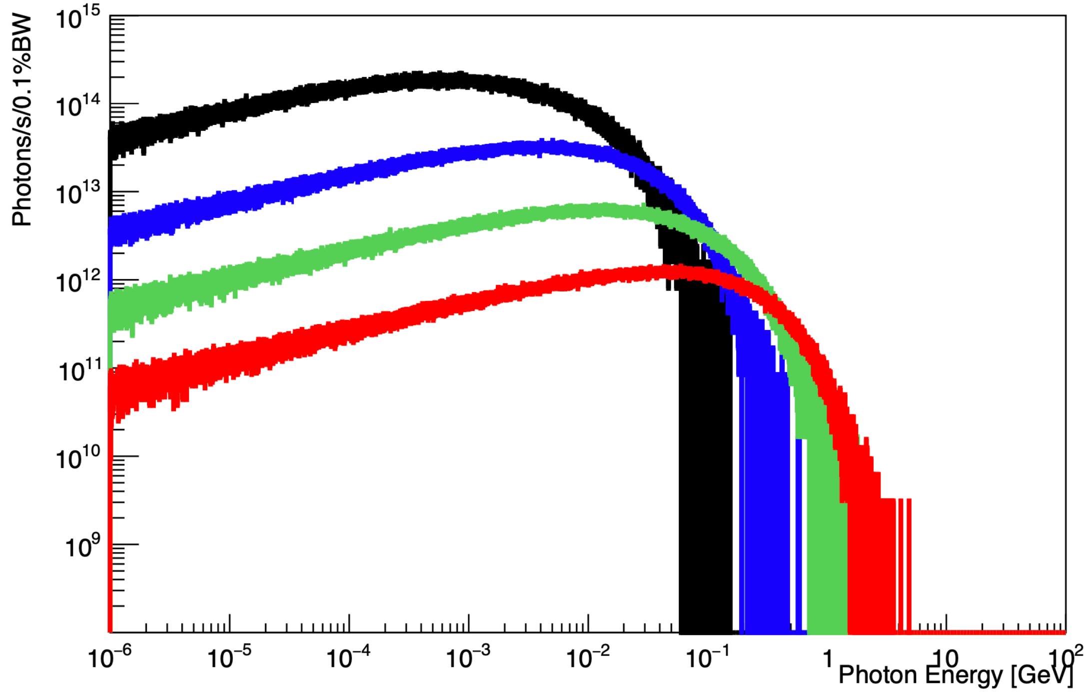


Beamstrahlung radiation Characterisation

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 **hits the beam pipe** at the end of the first downstream dipole.

The generator for the beamstrahlung radiation is **GuineaPig++**



	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

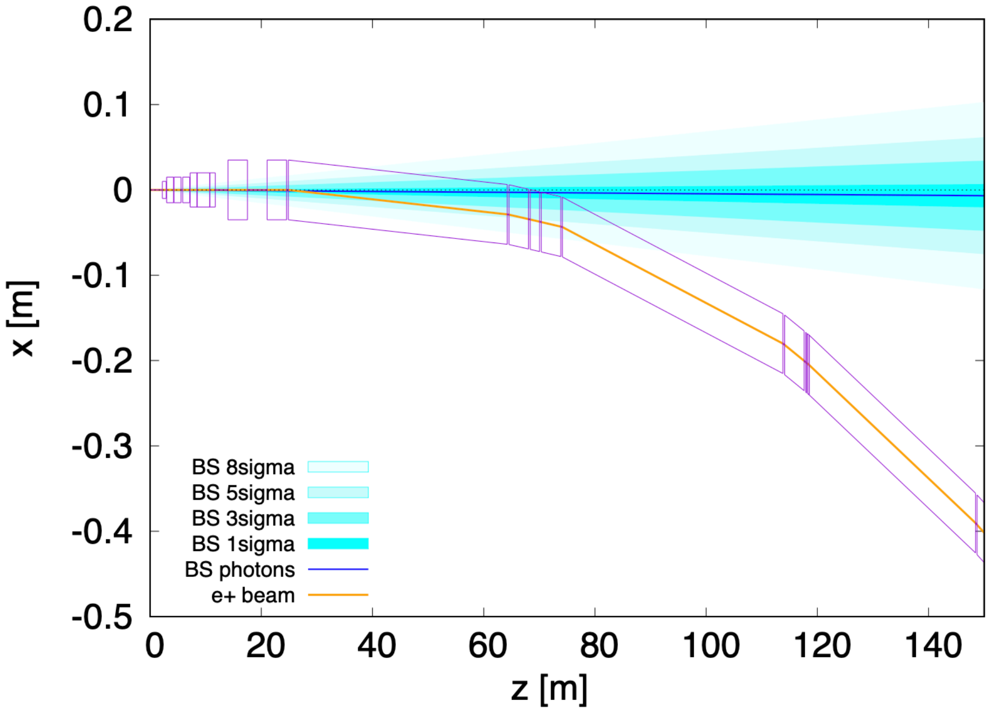
Beamstrahlung extraction line and beam dump

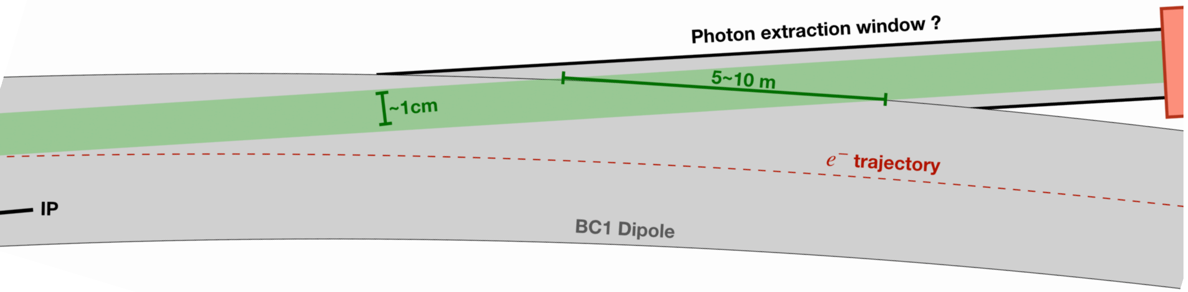
A **dedicated extraction line** is used to collect the intense radiation produced at the IP.

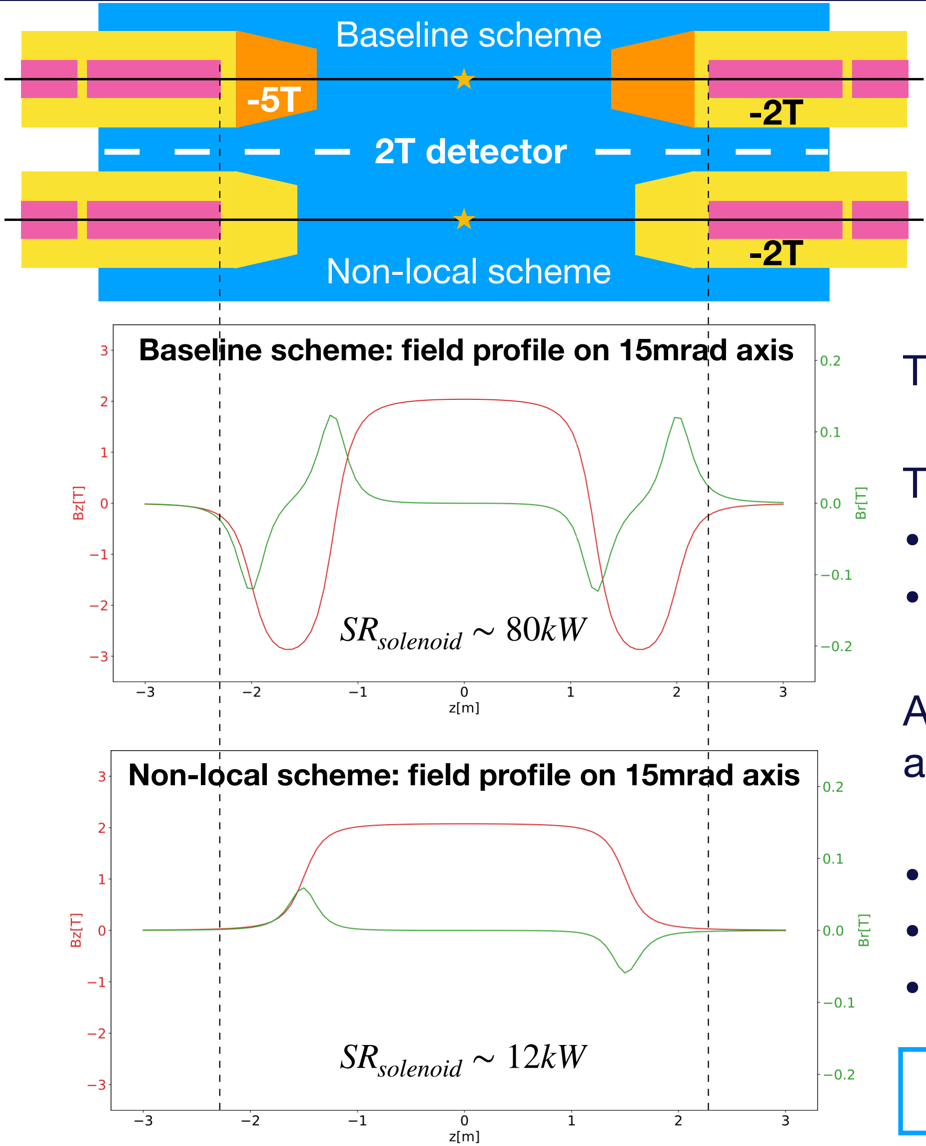
The downstream **magnets** need to be **redesigned** to allow the passage of the extraction line.

Integration with the tunnel show that a possible location of the beamstrahlung dump is **500m from the IP**.

First studies using Fluka to determine **power absorption** in the dump and potential damages to main ring electronics are ongoing.







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).

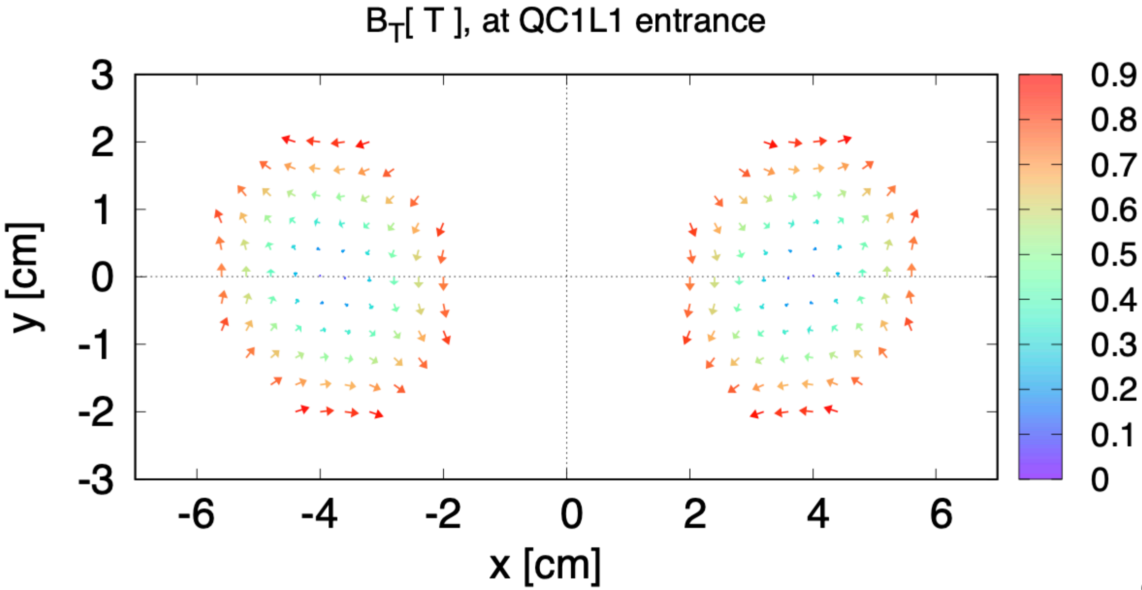
IPAC proceeding: A. Ciarma, M. Boscolo, H. Burkhardt, P. Raimondi, "Alternative solenoid compensation scheme for the FCC-ee interaction region" - 10.18429/JACoW-IPAC2024-TUPC68

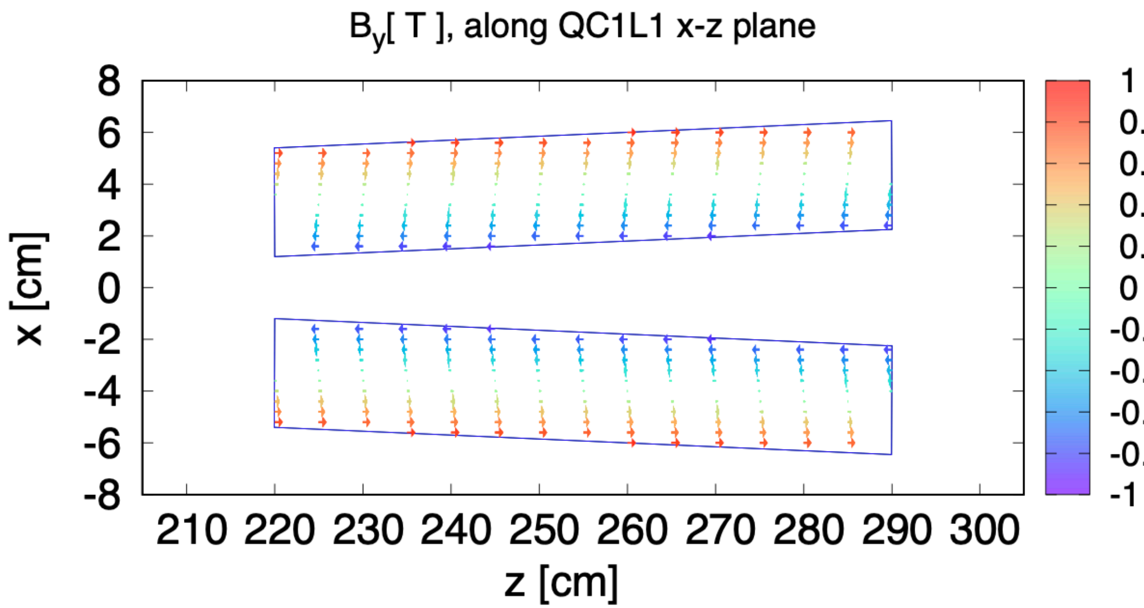
Summary

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
- Alternative solenoid compensation scheme

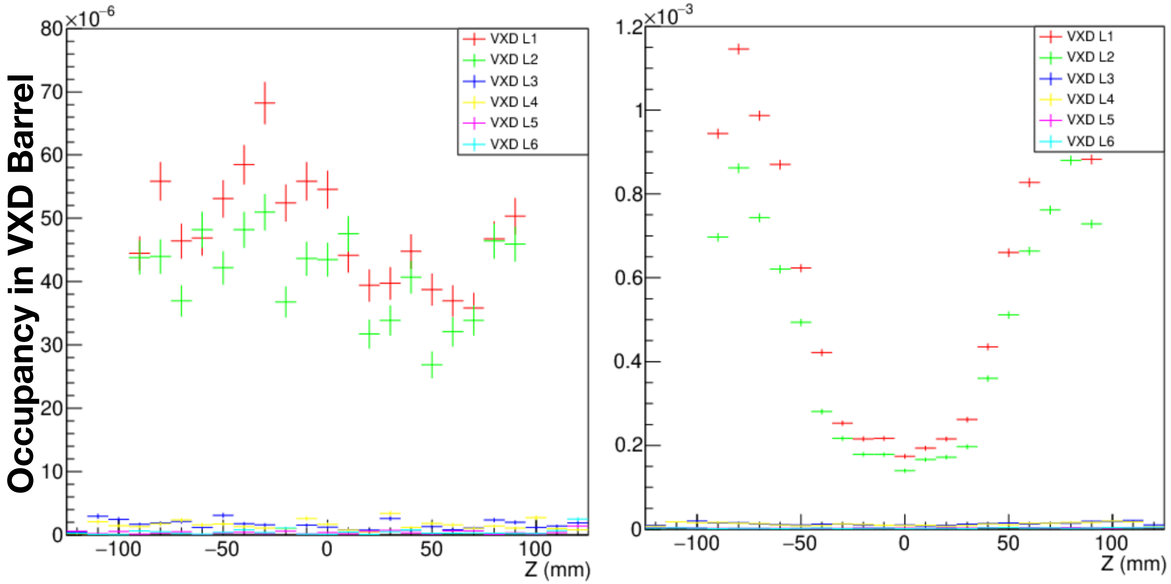
BACKUPS


B_T[T], at QC1L1 entrance
y [cm]
x [cm]
3
2
1
0
-1
-2
-3
-6
-4
-2
0
2
4
6
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0


B_y[T], along QC1L1 x-z plane
x [cm]
z [cm]
8
6
4
2
0
-2
-4
-6
-8
210
220
230
240
250
260
270
280
290
300
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1

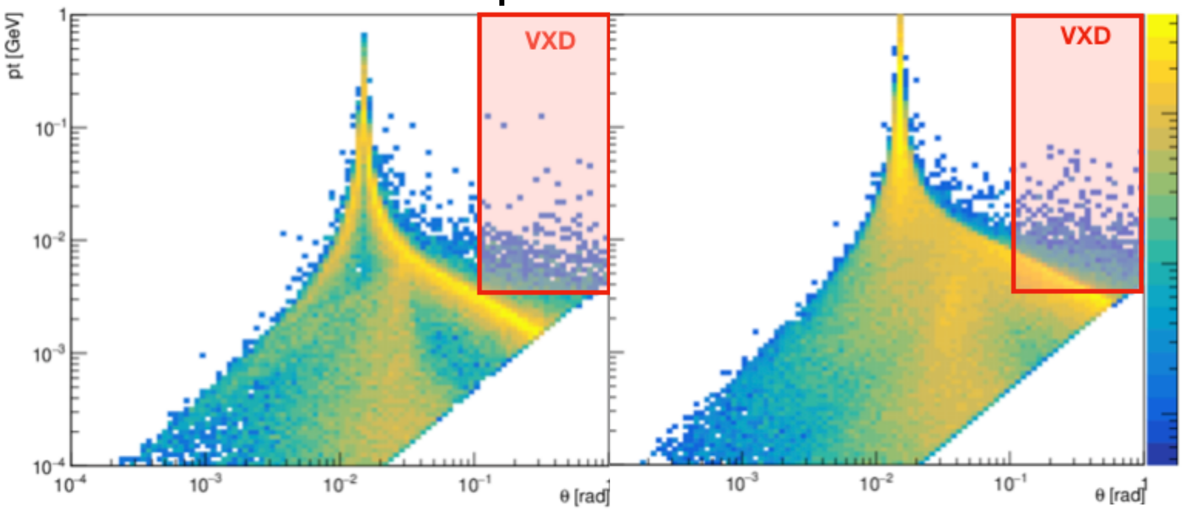
Z Top

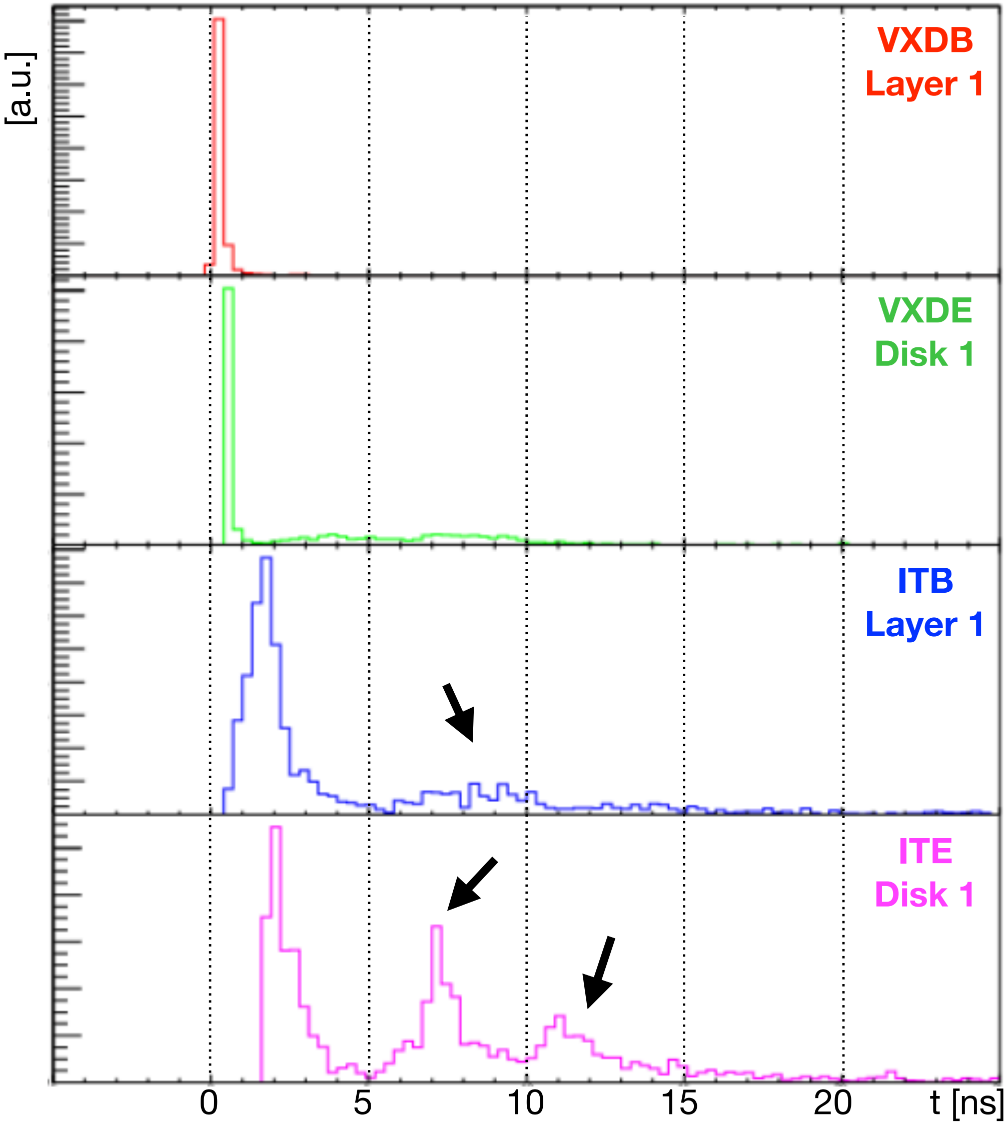
Considering a (very conservative) $10\mu s$ window, the occupancies will remain below the 1% everywhere **except for the VXD barrel** at the **Z.** While the pile-up of the detectors has not been defined yet, it is important to **overlay this background** to physics event to verify the **reconstruction efficiency.**



	Z	WW	ZH	Top
Bunch spacing [ns]	30	345	1225	7598
Max VXD occ. 1us	2.33e-3	0.81e-3	0.047e-3	0.18e-3
Max VXD occ.10us	23.3e-3	8.12e-3	3.34e-3	1.51e-3
Max TRK occ. 1us	3.66e-3	0.43e-3	0.12e-3	0.13e-3
Max TRK occ.10us	36.6e-3	4.35e-3	1.88e-3	0.38e-6

IPC production kinematics



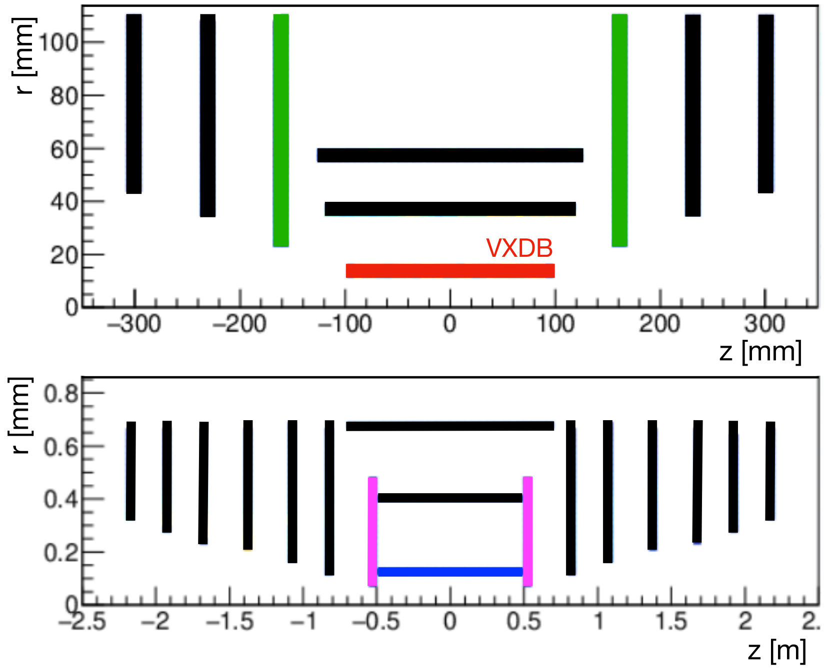


Incoherent Pairs Creation (IPC)

Timing information might be used to suppress this background.

Non negligible contribution from **backscattering** - in particular for the Inner Tracker (IT).

During reconstruction this signal could be rejected offline, further reducing the (already low) effect of this background.



Arrival time at detector, consistent with expectations:

VXDB L1: 0.05~0.3 ns

VXDE D1: 0.5~0.6 ns

ITB L1: 0.3~1.7 ns

ITE D1: 1.7~2.5 ns

Radiative Bhabha photons Characterisation

The radiation emitted in Bhabha events at the IP consists in **very hard photons** emitted collinear to the **beam direction**, so it will hit the beam pipe in the same location of the beamstrahlung photons, but with much **lower intensity**.

The RB photons energy spectrum endpoint is the nominal energy of the e+/e- beams, and have been generated using **BBBrem** (courtesy of H. Burkhardt)

Dedicated tracking of the **very off-energy e+/e-** after the emission should be performed in order to assess the **beam losses** due to this effect.