BACKGROUND CALCULATIONS IN THE FCC-EE

A. Ciarma, M. Boscolo

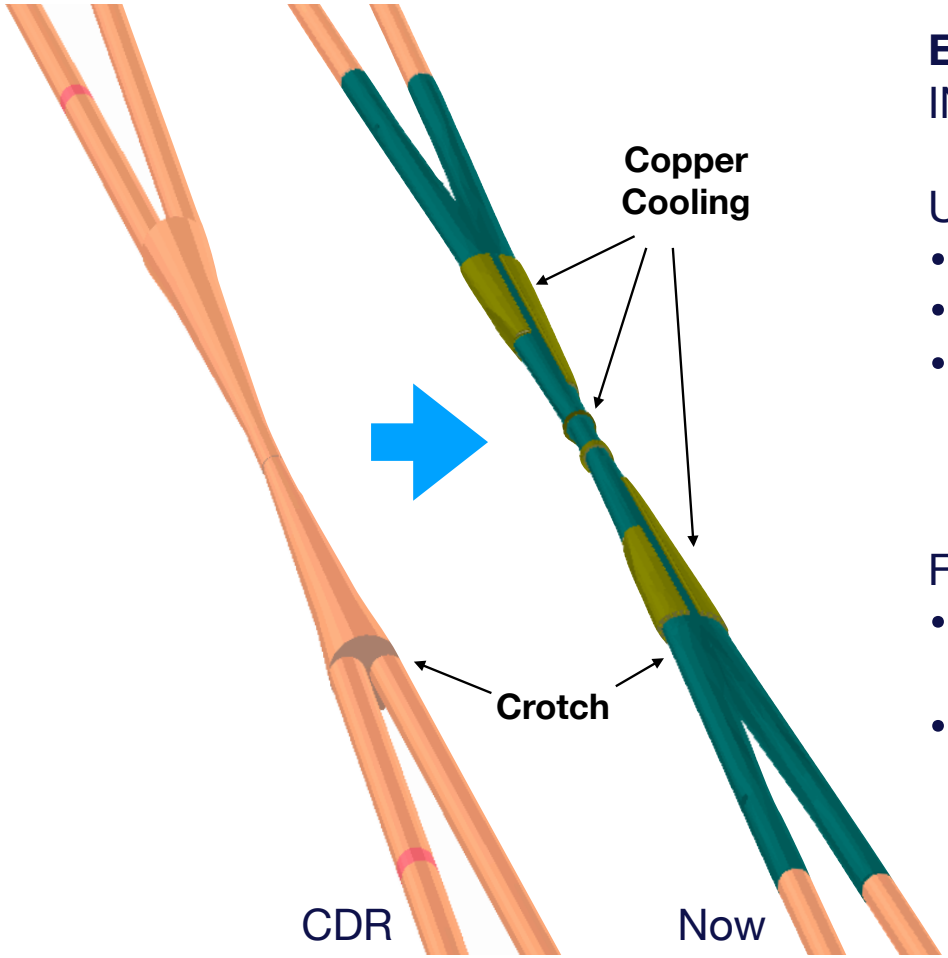
This project is supported from the European Union's Horizon 2020 research and innovation programme under grant agreement No 951754.

FUTURE CIRCULAR COLLIDER Innovation Study

Outline

- Overview of the MDI area modelling upgrades
- Sources of background: status and next steps
- Summary

Improving the MDI model: beam pipe



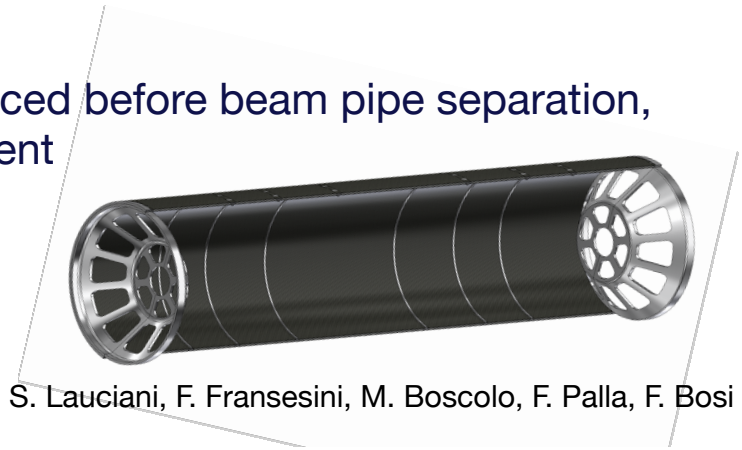
Engineered CAD model of AlBeMet162 beam pipe developed by INFN-LNF (many thanks to F. Fransesini) imported in **Key4hep**.

Upgrades respect to old model:

- Double-layered central section for paraffine cooling
- **Copper cooling** sections implemented
- Improved modelling of the beam pipe **separation region** (crotch), congruent to impedance studies

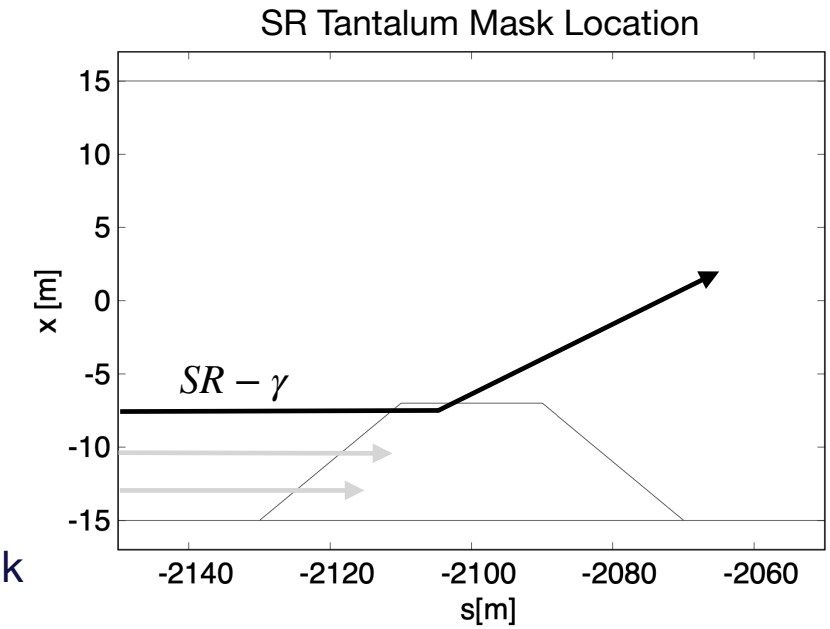
Future upgrades:

- realistic **bellows** to be placed before beam pipe separation, currently under development
- IR **support tube** proposal (see talks by F. Fransesini and F. Palla)



S. Lauciani, F. Fransesini, M. Boscolo, F. Palla, F. Bosi

SR Mask and Shieldings



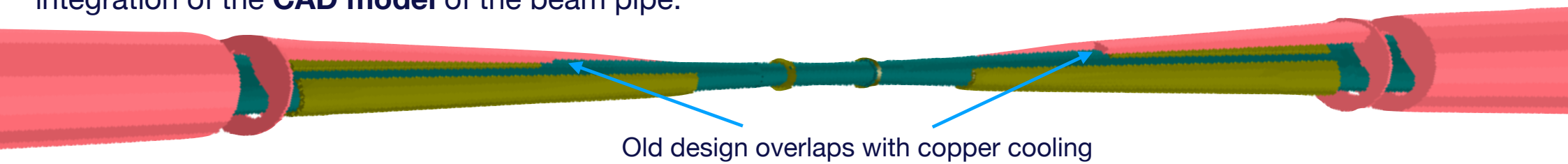
Horizontal masks located 2.1m upstream the IP are used to intercept SR photons coming from the **last bend**.

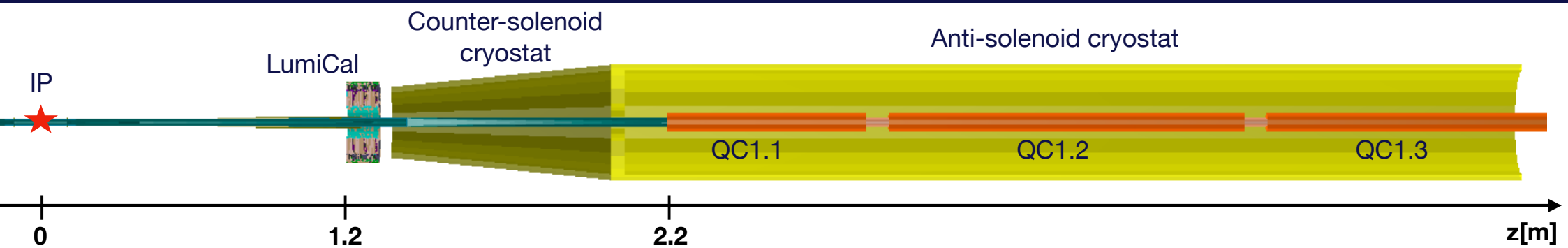
Current description is an **Tantalum mask** reaching **7mm** from the beam pipe center.

SR photons may be **diffused at large angle** from the tip of the mask and be the source of background in the detector.

During CDR, ~200kg **Tungsten shielding** to protect the experiment from these photons has been designed.

The possibility to **eliminate** or **redesign** this shielding is under evaluation, also considering the recent integration of the **CAD model** of the beam pipe.



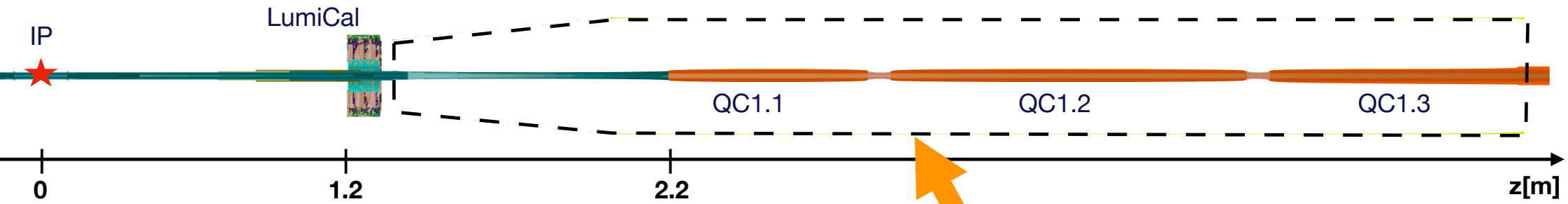


Other IR Elements

Currently present in the Key4hep description:

- Simple **quadrupole** geometry for power deposition studies
- **LumiCal** detailed description
- Cryostats for antisolenoids: **hollow shell** with 2cm thick walls

A more detailed description of the anti-solenoid **cryostats** and **support structures** for the various subdetectors is necessary for a better estimate of the **secondary showers** which can be produced by background particles in that region (e.g. from beam losses in the FF quads).



Other IR Elements

Currently present in the Key4hep description:

- Simple **quadrupole** geometry for power deposition studies
- **LumiCal** detailed description
- Cryostats for antisolenoids: **hollow shell** with 2cm thick walls

Novel Coupling Correction Scheme: use tilt/skew quadrupoles, removes needs for anti-solenoids at the IP.

First studies - coupling correction down to ~2%

Poster session for more details

A. Ciarma, M. Boscolo, H. Burkardt, M. Hofer, K. Oide, P. Raimondi

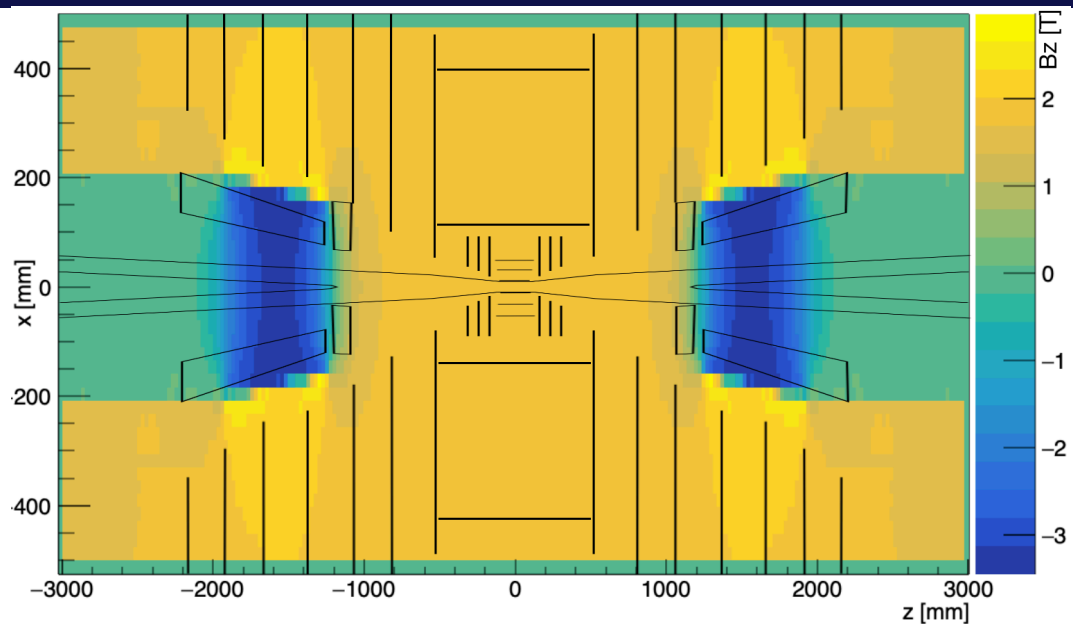
A more detailed description of the anti-solenoid **cryostats** and **support structures** for the various subdetectors is necessary for a better estimate of the **secondary showers** which can be produced by background particles in that region (e.g. from beam losses in the FF quads).

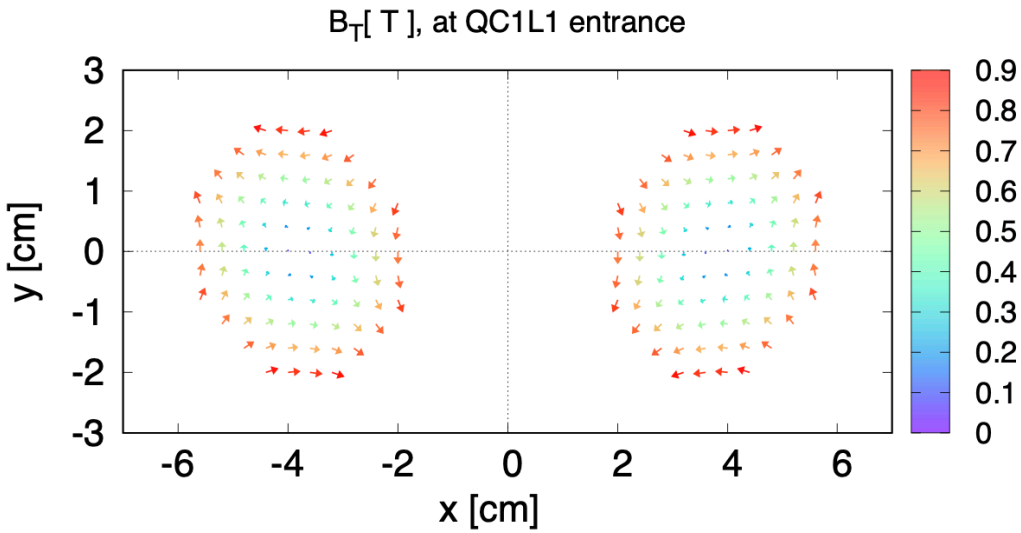
Magnetic Fields in the IR

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 under progress



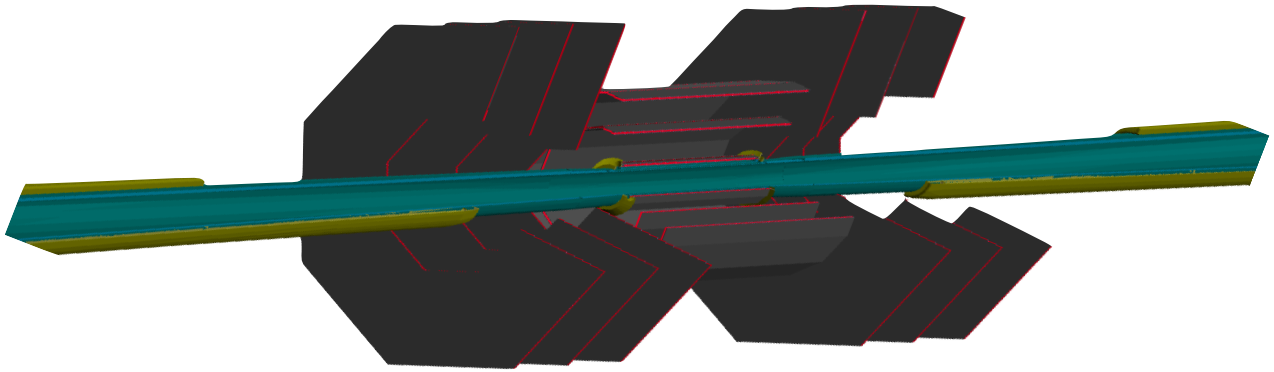


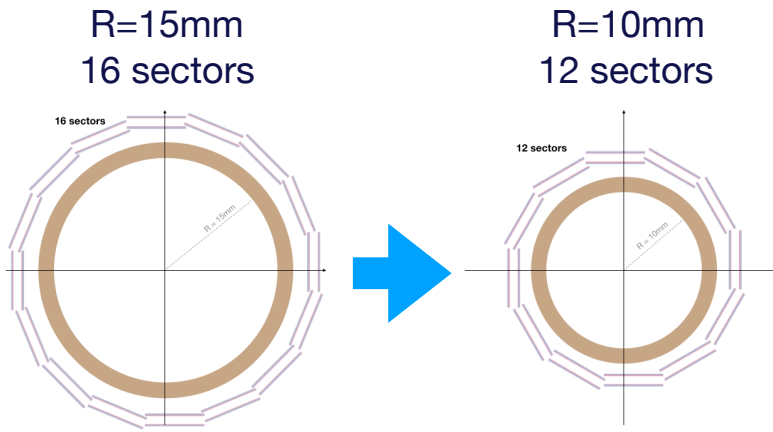
CLD Detector: Vertex Detector

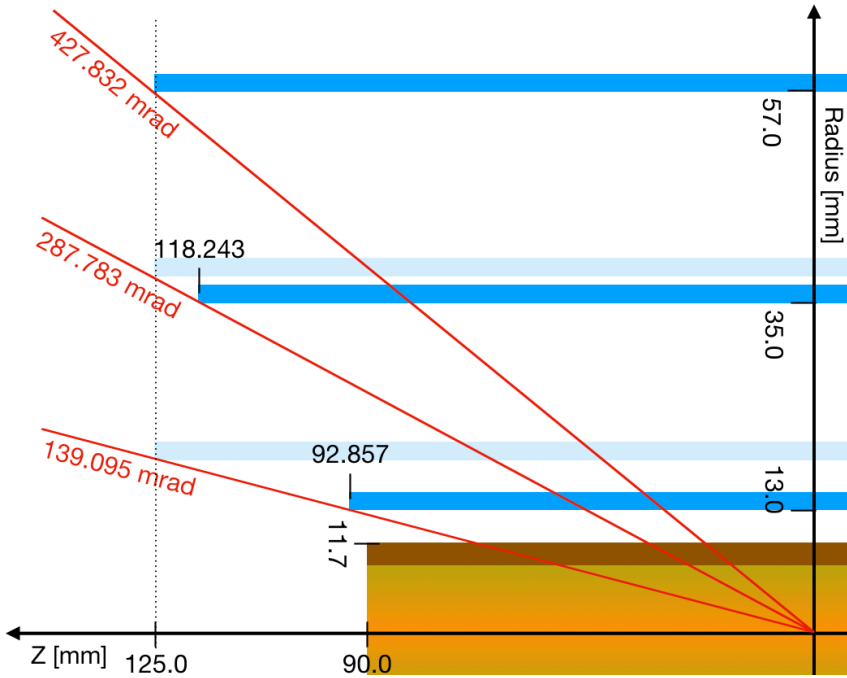
Difference since CDR: smaller beam pipe central chamber.

Vertex Detector adaptation:
- Reduced number of sectors in innermost barrel layer
- Modified barrel layers to keep same angular acceptance

Only **support layers** for Si-pixels inbetween double layers







Sources of Background in the MDI area

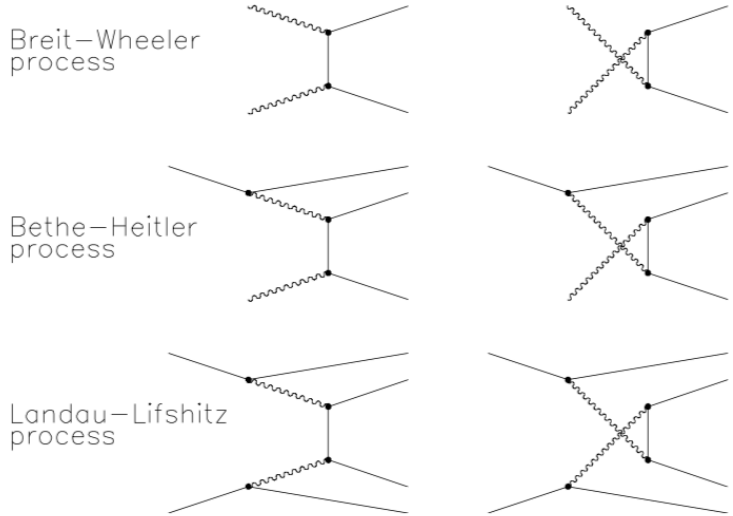
Luminosity backgrounds

- **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

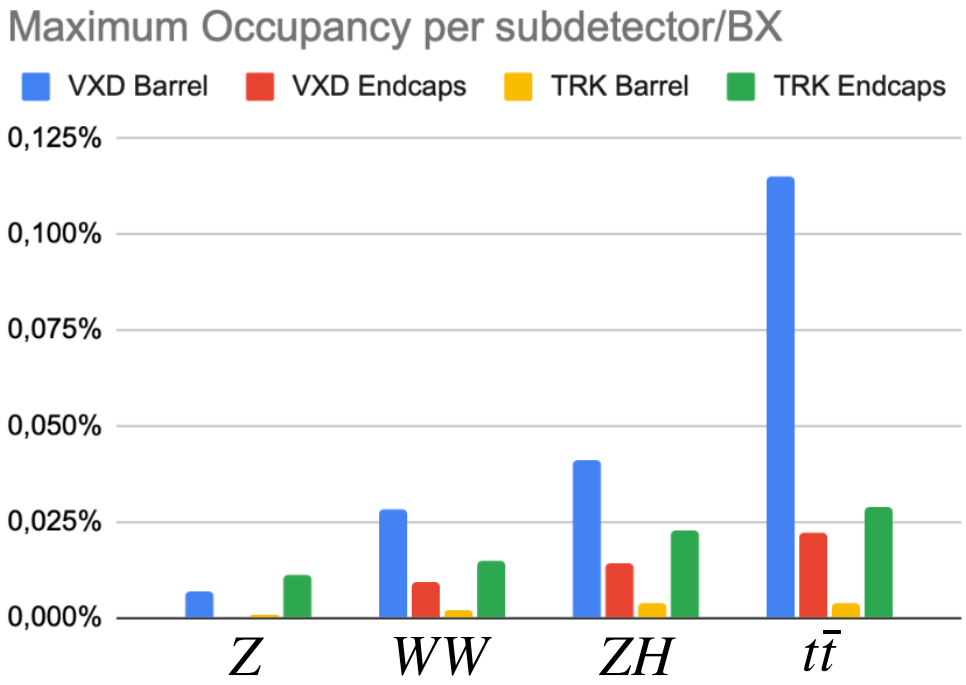
Single beam induced backgrounds:

- **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

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 ($\Delta t_{RO} = 10\mu s \rightarrow Occ_{max}^{VXD} = 2 \sim 3\,\%$)

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

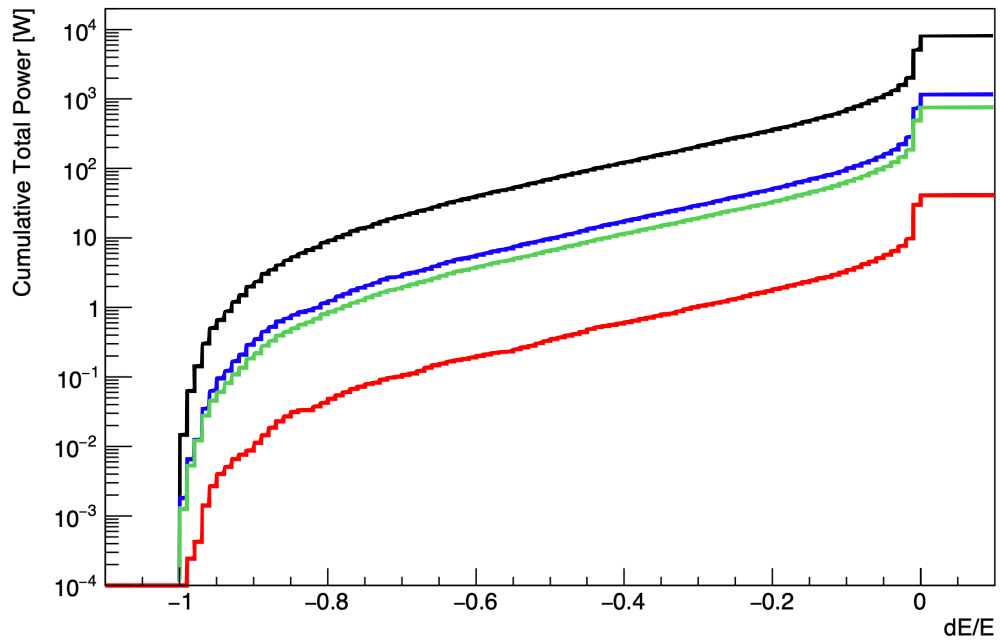
Radiative Bhabha: beam losses

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

Particles produced using BBBrem and GuineaPig++.

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

- **Energy loss <10-20%:** tracking in the FCC-ee lattice to produce loss maps, then verify backgrounds due to losses in MDI region
- **Energy loss >20%:** tracking directly in Key4hep with magnetic field of the final focus quads, background and power deposition study



Energy Radiated [dE/E]		>2%	>10%	>50%
Power Carried by spent beam [W]	**Z**	1500	650	70
	WW	200	100	10
	ZH	150	60	6
	tt	8	3	0.3

Beam Losses in the IR due to Failure Scenarios

Thanks to A. Abramov for the primary particles.

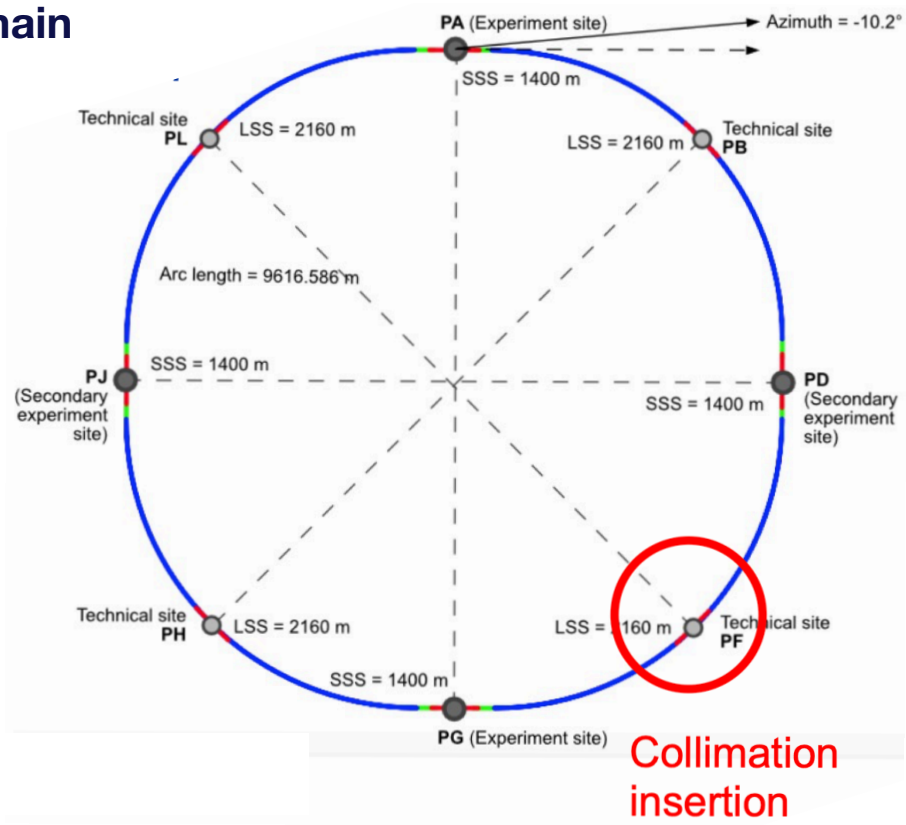
Following **unexpected beam lifetime reduction,** a large number of particles can be **lost in the MDI region** following the interaction with the **main collimators** (PF).

Background studied for lifetime losses due to:

- transverse halo (primary collimators)
- energy loss (off-momentum collimators)

Simulation flow to track these particles from the source location through detectors (X-Track, Key4hep) has been set and used to produce **preliminary occupancy results**.

4IP lattice v529



Beam Losses in the IR due to Failure Scenarios

Thanks to A. Abramov for the primary particles.

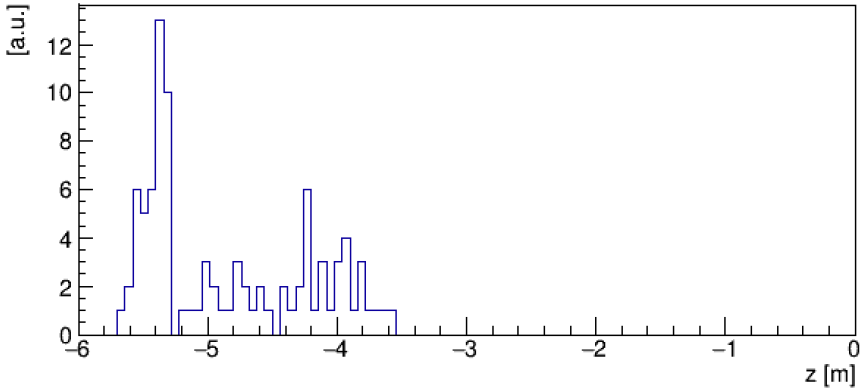
Losses located **few meters upstream** IP at all working points, both from horizontal and off-momentum collimators.

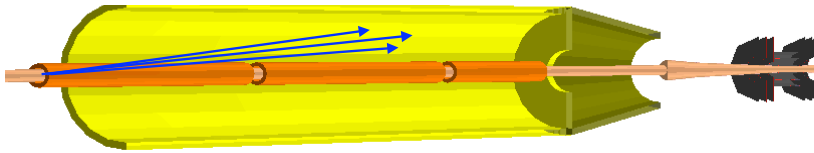
Particles will traverse the **final focus quadrupoles** and the antisolenoid **cryostat** before getting to the **innermost subdetectors**.

All this material can be source of large **secondary showers**. Already with the current simple IR model, high occupancies O(1~10%) have been observed in the CLD tracker endcaps at the $t\bar{t}$ energy, while is very small at the Z-pole.

An improved description of the MDI region (in particular the anti-solenoid cryostats) will give **more realistic estimates** for the background.

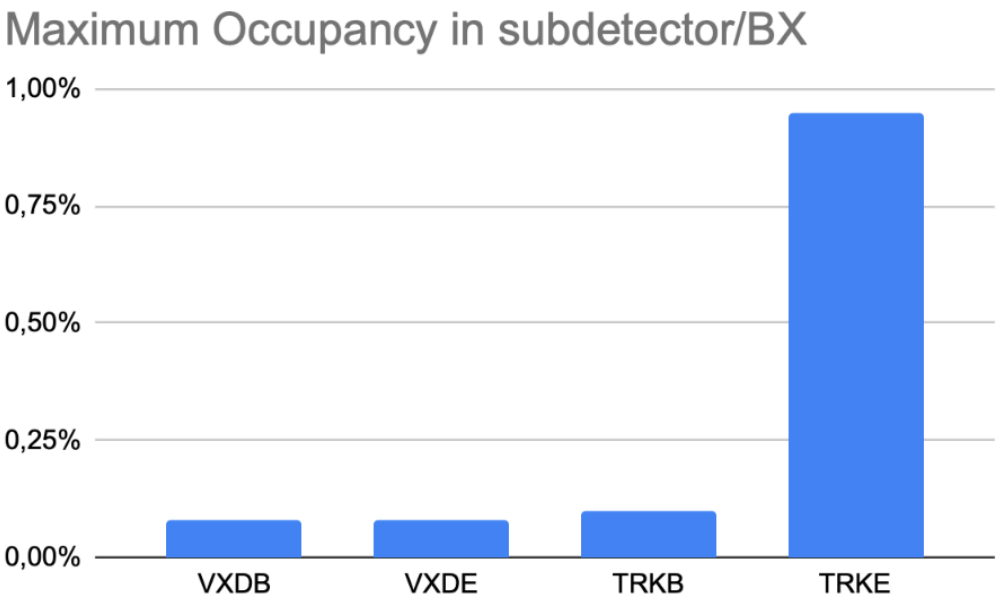
Loss Map





	Losses/s (10^9)	Highest occupancy
	tt-threshold	
IPA	0.15	5.73% (ITE)
IPD	0.11	3.99% (ITE)
IPG	0.10	3.16% (ITE)
IPJ	0.16	8.88% (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



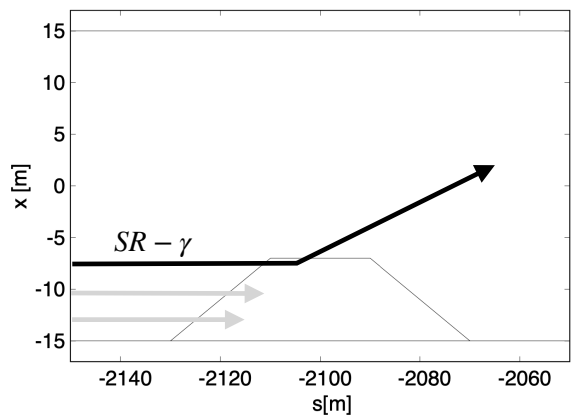
($t\bar{t}$ threshold - CDR beam parameters
CLD detector - NO shieldings)

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

Recent reprisal of CDR studies shows that, **without the tungsten shieldings**, 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 (many thanks to K. André).

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



Summary

- Upgrades to the Key4hep modelization of the MDI region since CDR presented
  - realistic model of the IR beam pipe with cooling sections
  - magnetic field of anti-solenoids and final focus quadrupoles (ongoing)
  - first layer of CLD vertex detector adapted to new central chamber

- Luminosity backgrounds (IPC) below safety limits in CLD. Similar expectation for IDEA.

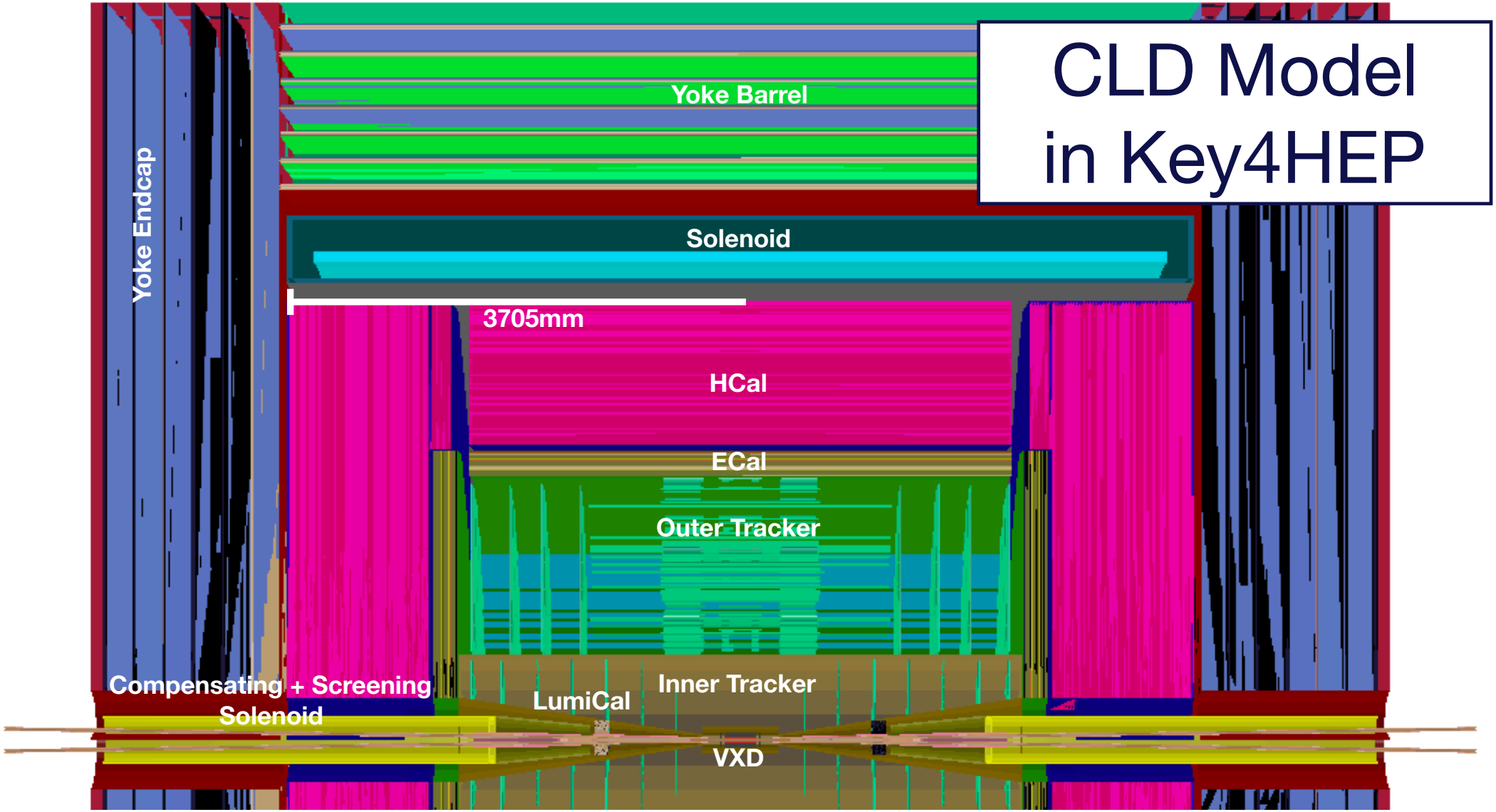
- Beam losses induced backgrounds suggests high occupancy in tracker endcaps. Detailed description of the cryostat will provide more realistic results

- Power deposited in the SC final focus quads due to beam losses show little risk of instantaneous quenching.

- Estimates on the induced background due to SR suggest that present tungsten shieldings may be removed or reduced.

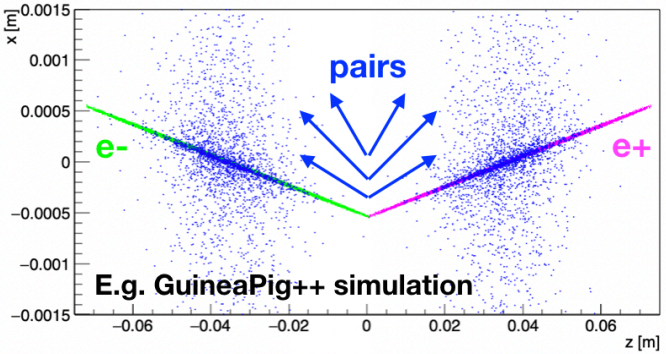
BACKUPS

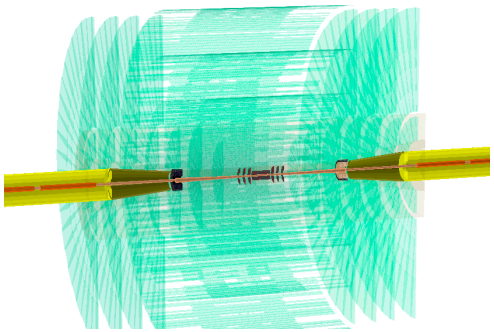
CLD Model in Key4HEP



Background assessment: workflow with Key4hep

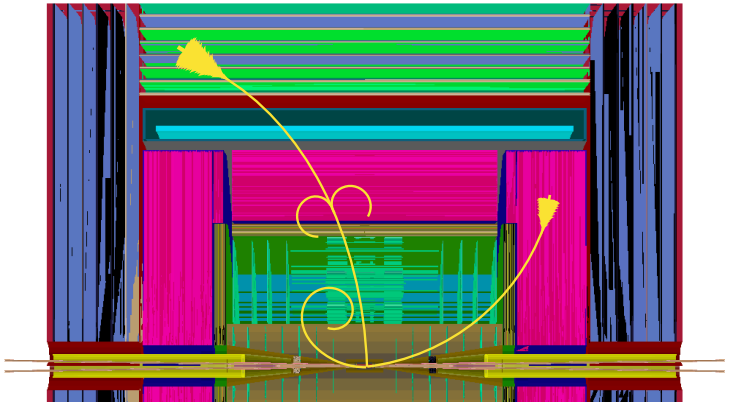
Primaries produced by **external generators** (GuineaPig++, BDSim, Xtrack, …)



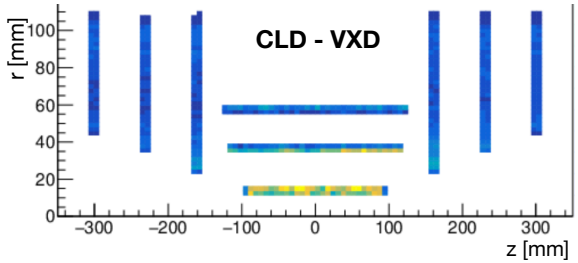


Detector and MDI geometry description in **DD4hep:** public common git repo, CLD fully implemented, IDEA ongoing

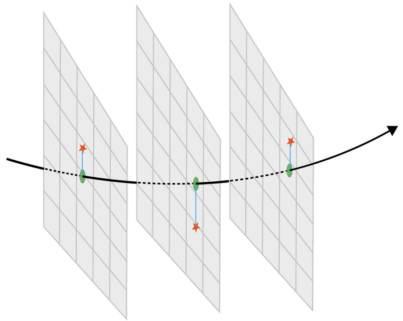
Tracking particles in the detector performed by **turnkey software Key4hep** - Geant4 physics libraries, DD4hep implementation, magnetic field map, …



Hits collected for analysis and occupancy determination



$$occupancy = hits/mm^2/BX \cdot size_{sensor} \cdot size_{cluster} \cdot safety$$

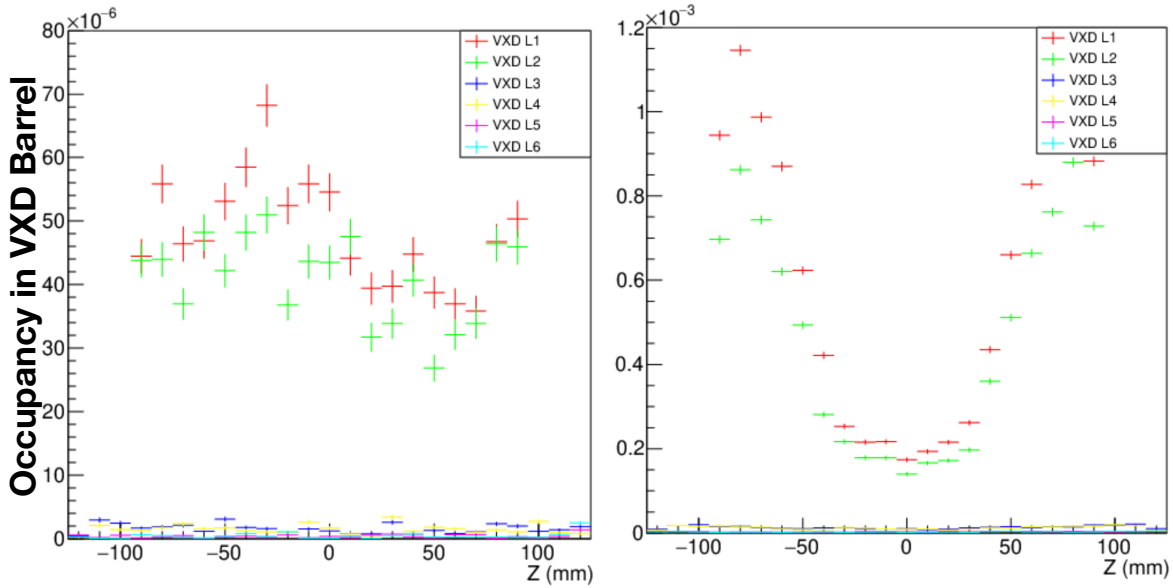


Signal **reconstruction**

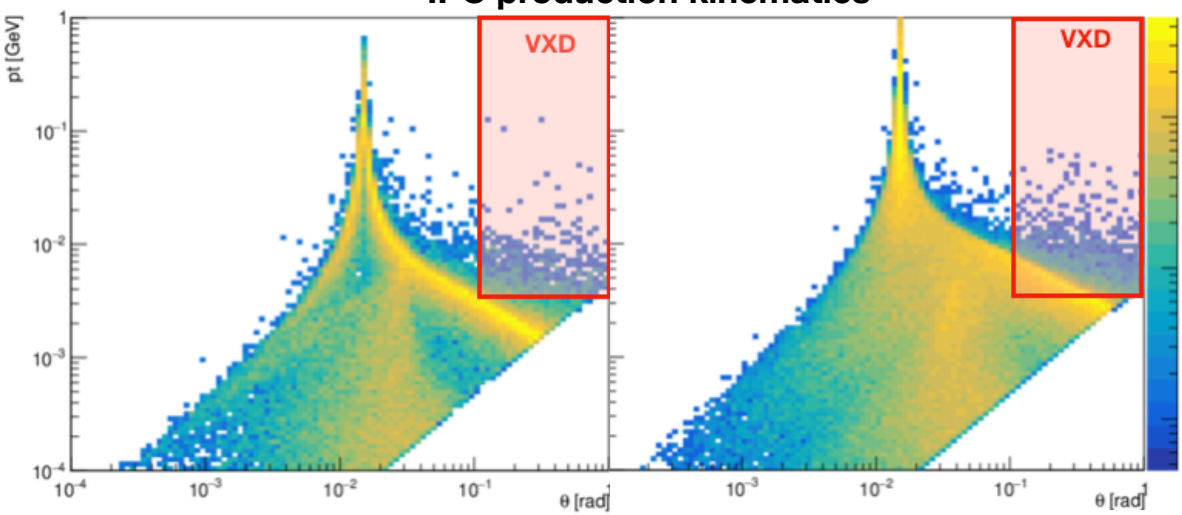
Considering a (very conservative) $10\mu s$ window, the occupancies will remain below the 1% everywhere **except for the VXD barrel** at the **Z**. While the pile-up of the detectors has not been defined yet, it is important to **overlay this background** to physics event to verify the **reconstruction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

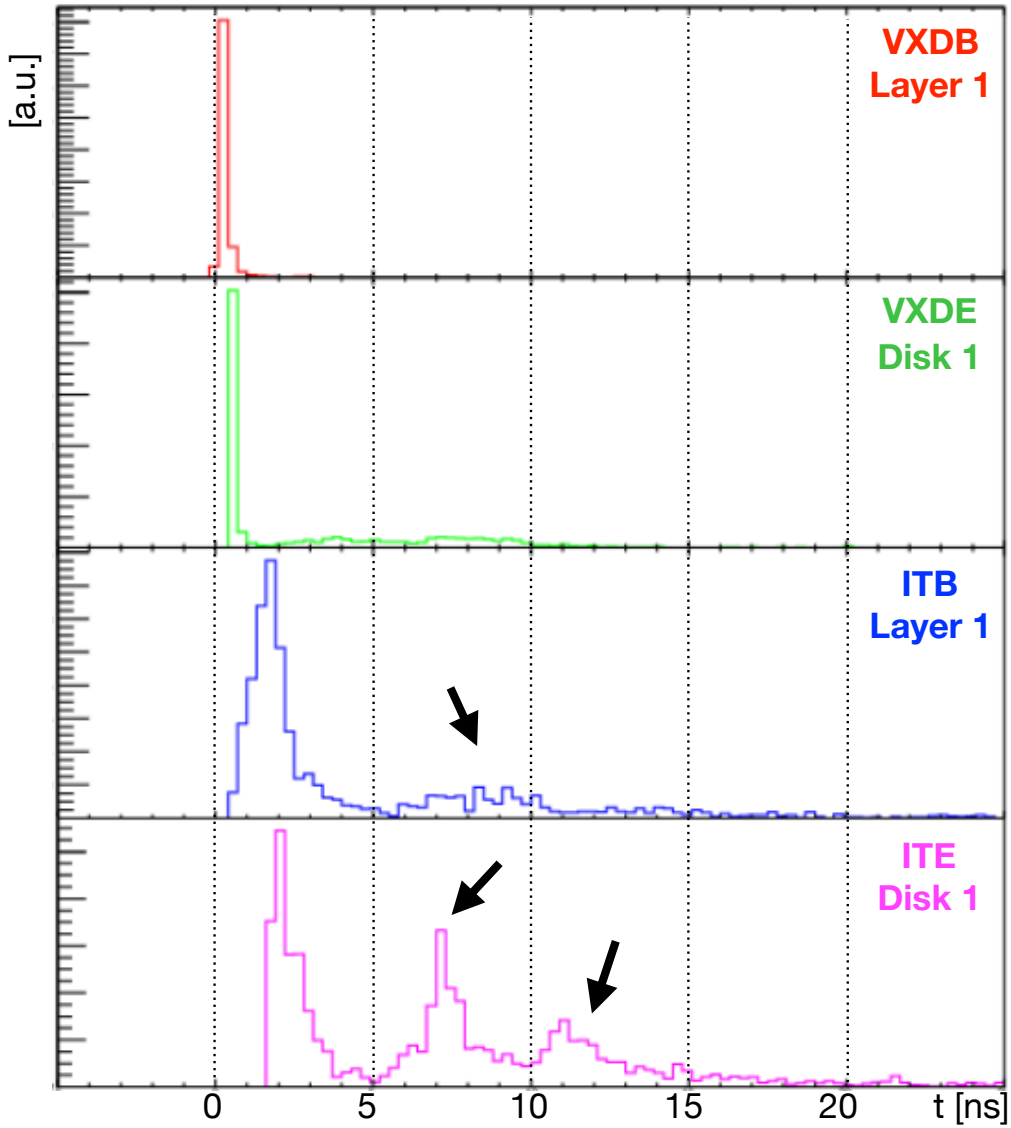
	Z	WW	ZH	Top
Bunch spacing [ns]	30	345	1225	7598
Max VXD occ. 1us	2.33e-3	0.81e-3	0.047e-3	0.18e-3
Max VXD occ.10us	23.3e-3	8.12e-3	3.34e-3	1.51e-3
Max TRK occ. 1us	3.66e-3	0.43e-3	0.12e-3	0.13e-3
Max TRK occ.10us	36.6e-3	4.35e-3	1.88e-3	0.38e-6

Z **Top**



IPC production kinematics



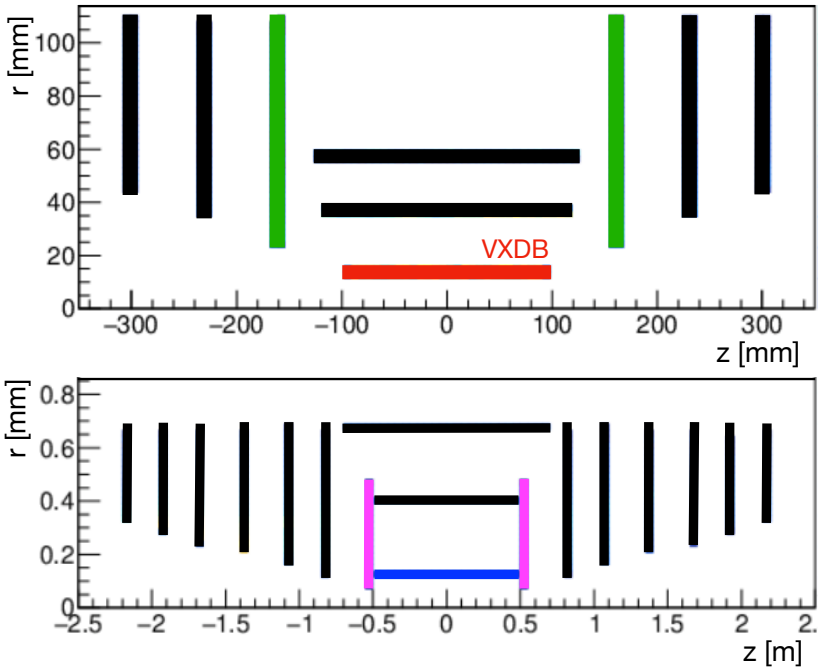


Incoherent Pairs Creation (IPC)

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.



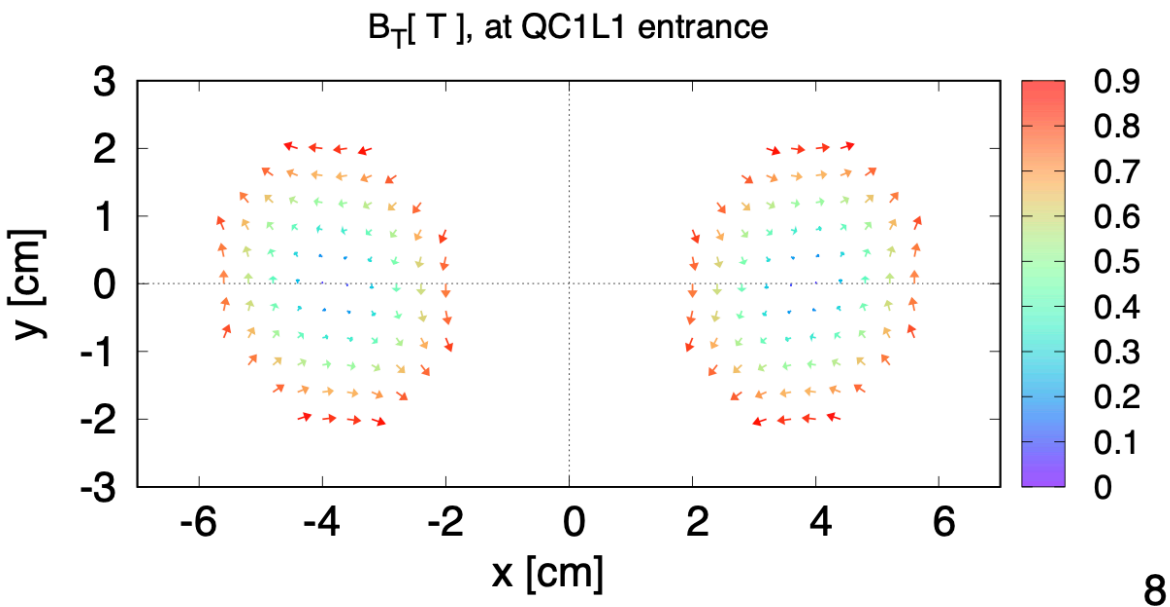
Arrival time at detector, consistent with expectations:

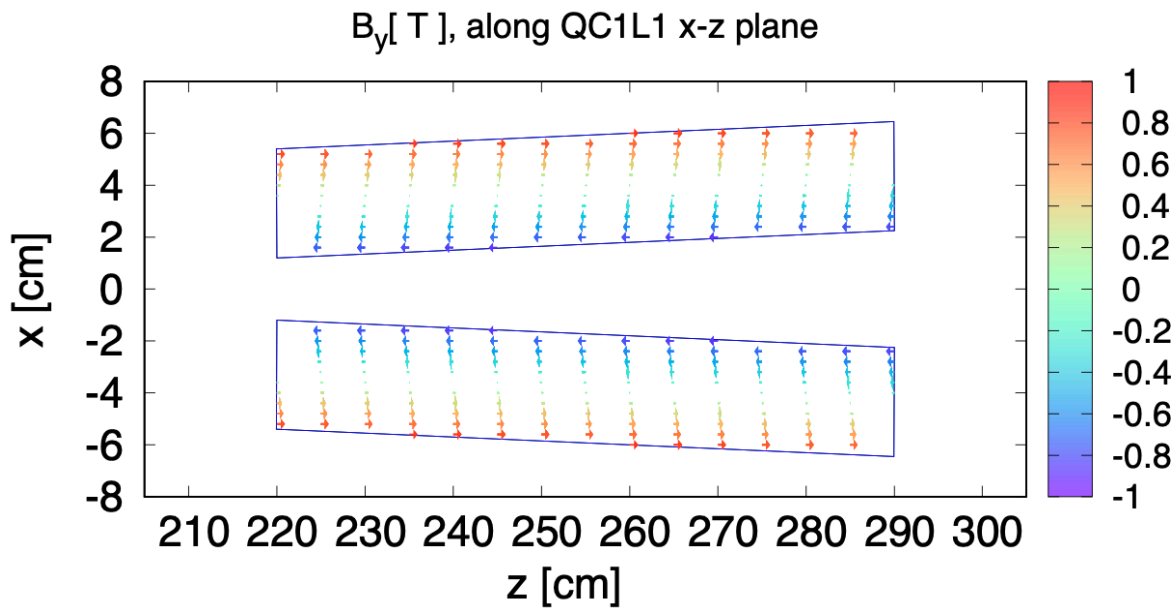
VXDB L1: 0.05~0.3 ns

VXDE D1: 0.5~0.6 ns

ITB L1: 0.3~1.7 ns

ITE D1: 1.7~2.5 ns


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

Failure scenarios: Power deposited in QC1

$t\bar{t}$—threshold, losses due to horizontal primary collimator

	IPA	IPD	IPG	IPJ
Losses per second (10^9)	0.15	0.11	0.10	0.16
QC1 hottest spot (W/cm3 in a 2mm3 bin)	0.035	0.026	0.013	0.025
Total power in QC1 (W)	1.77	1.34	1.09	1.92

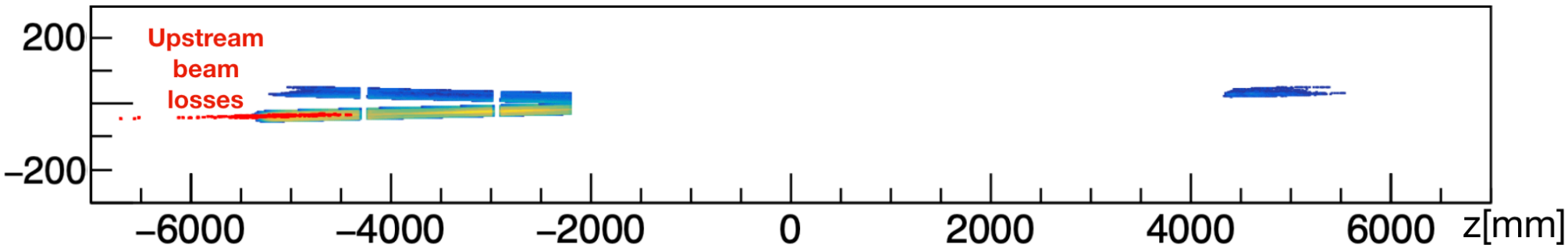
Z-pole, losses due to horizontal primary collimator

	IPA	IPD	IPG	IPJ
Losses per second (10^9)	0.26	0.14	0.12	0.39
QC1 hottest spot (W/cm3 in a 2mm3 bin)	0.011	0.004	0.003	0.016
Total power in QC1 (W)	0.72	0.32	0.18	1.15

The **deposited power** due to the beam losses in failure scenarios on the SC QC1 elements has been studied.

Losses coming from the **horizontal primary collimator** show **small values** of power density and total power deposited.

Preliminary analysis of losses coming from the off-momentum collimators suggest the possibility of higher power. Further studies on this are ongoing.

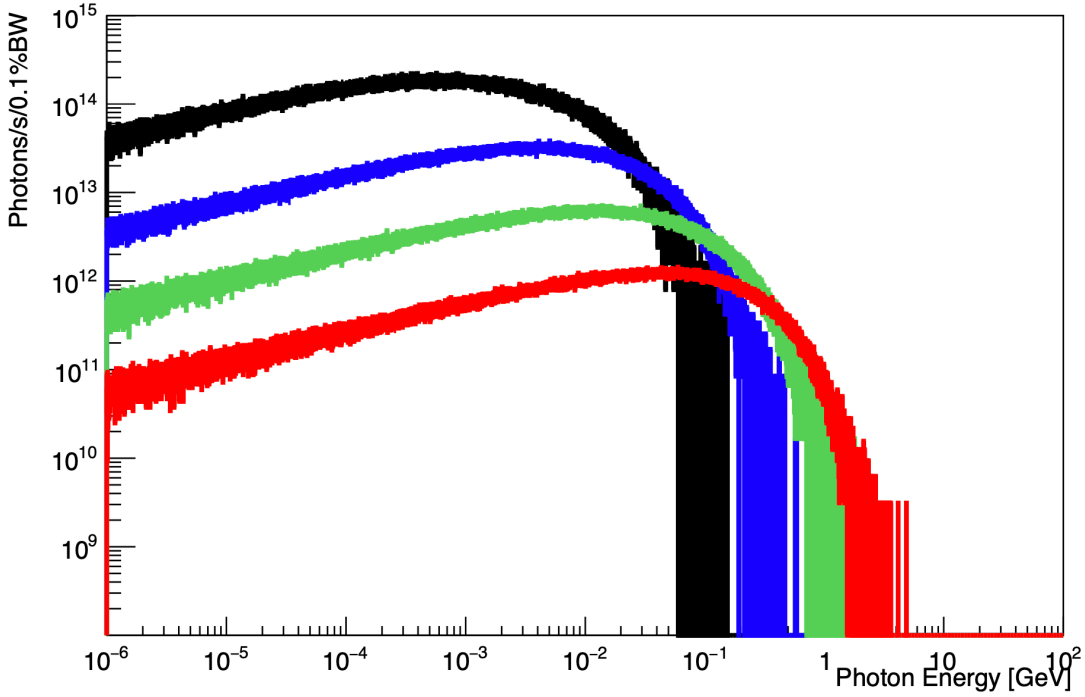


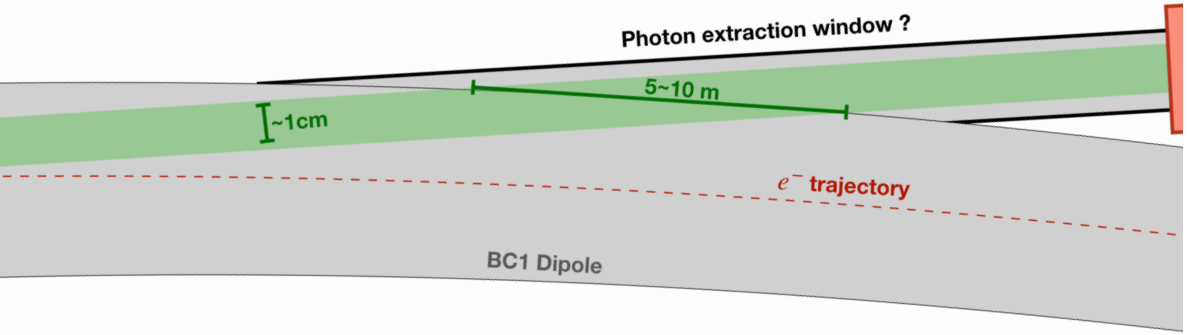
Beamstrahlung radiation Characterisation

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++**

The design of a **dedicated extraction line** and **beam dump** for tl beamstrahlung photons is currently in progress, exploring tunnel integration, magnets design, cooling system, and different materi for the beam dump.





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

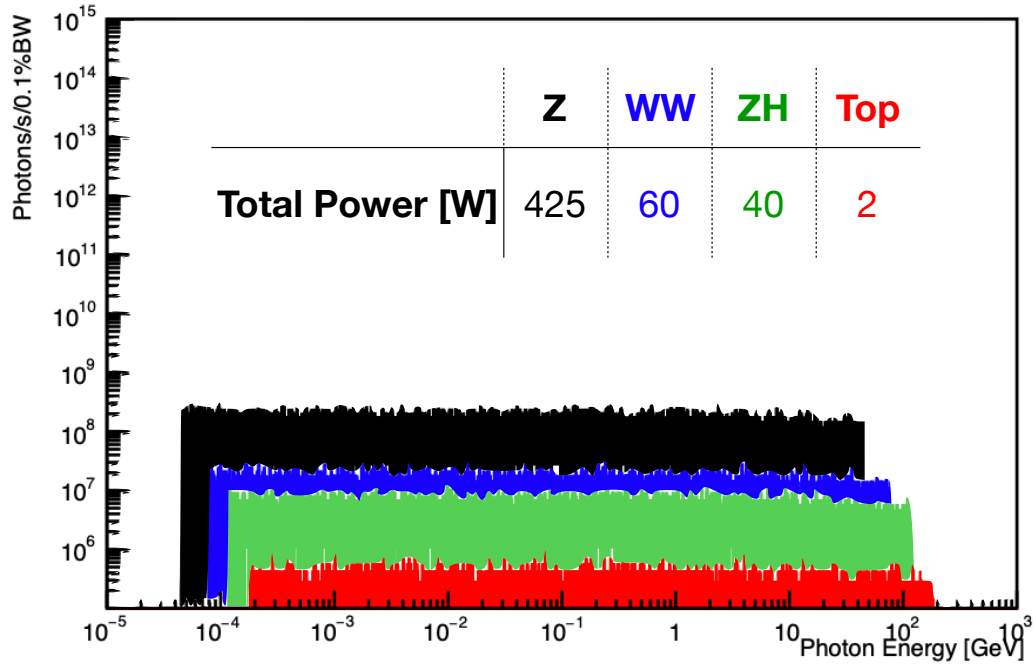
New Values for latest beam parameters
See Poster Session

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)

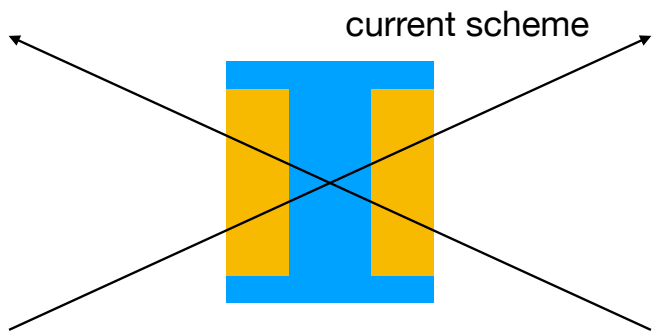
Dedicated tracking of the **very off-energy e+/e-** after the emission should be performed in order to assess the **beam losses** due to this effect.



Coupling Correction Scheme at FCC-ee

The **2T solenoids** induce coupling in the FCCee lattice. A **novel correction scheme** proposed by P. Raimondi would allow to remove the **compensating** and **screening solenoids**. This would be very **beneficial in terms of available space**.

This scheme has been tested on the HFD lattice, but this approach can in principle be applied also to the current lattice baseline.

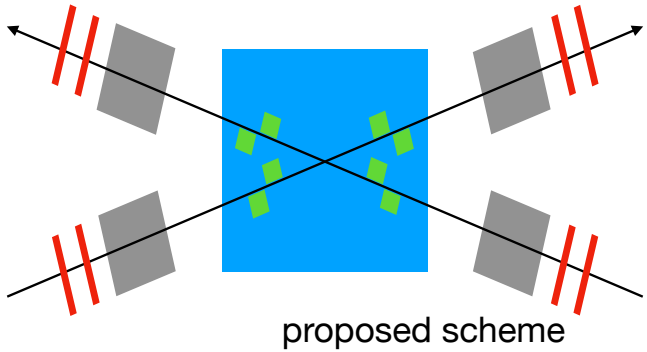


Coupling correction is achieved by:

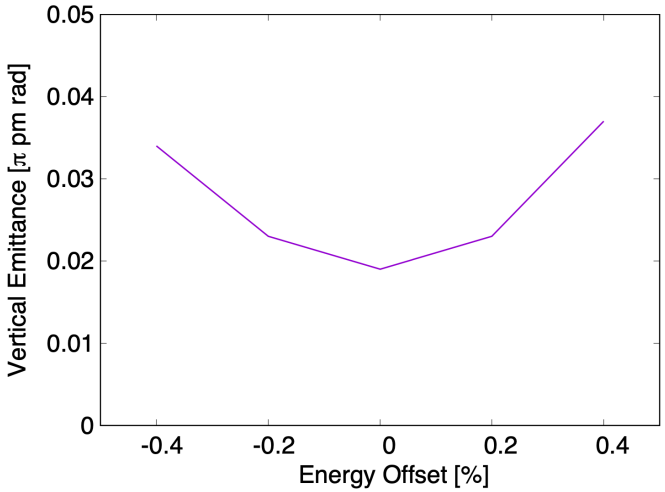
- a tilt of the **Final Focus quadrupoles**
- skew correctors at the **SDY1** and **SDY2** sextupoles (about ±200m and ±400m from the IP)
- alternated sign of the experiment's field at the IPs

Two **anti-solenoids** must be introduced for **polarization**

- Located at **±25.2m from IP**, midway in the ~30m drift after QF1B
- These solenoids are **on-axis** and **far from the IR**



Correction scheme performances



Fit with a 2nd order polynomial:
y = 0.01891429 + 0.003*x + 0.1035714*x^2

The introduction of the 4 solenoids in the lattice causes the vertical emittance to grow up to $\epsilon_y = 48[\pi\, pm\, rad]$.

The effect of **alternating the sign** of the solenoids reduces the coupling contribution of a factor 4, down to $\epsilon_y = 12[\pi\, pm\, rad]$.

Applying the corrections and rematching, we obtained:

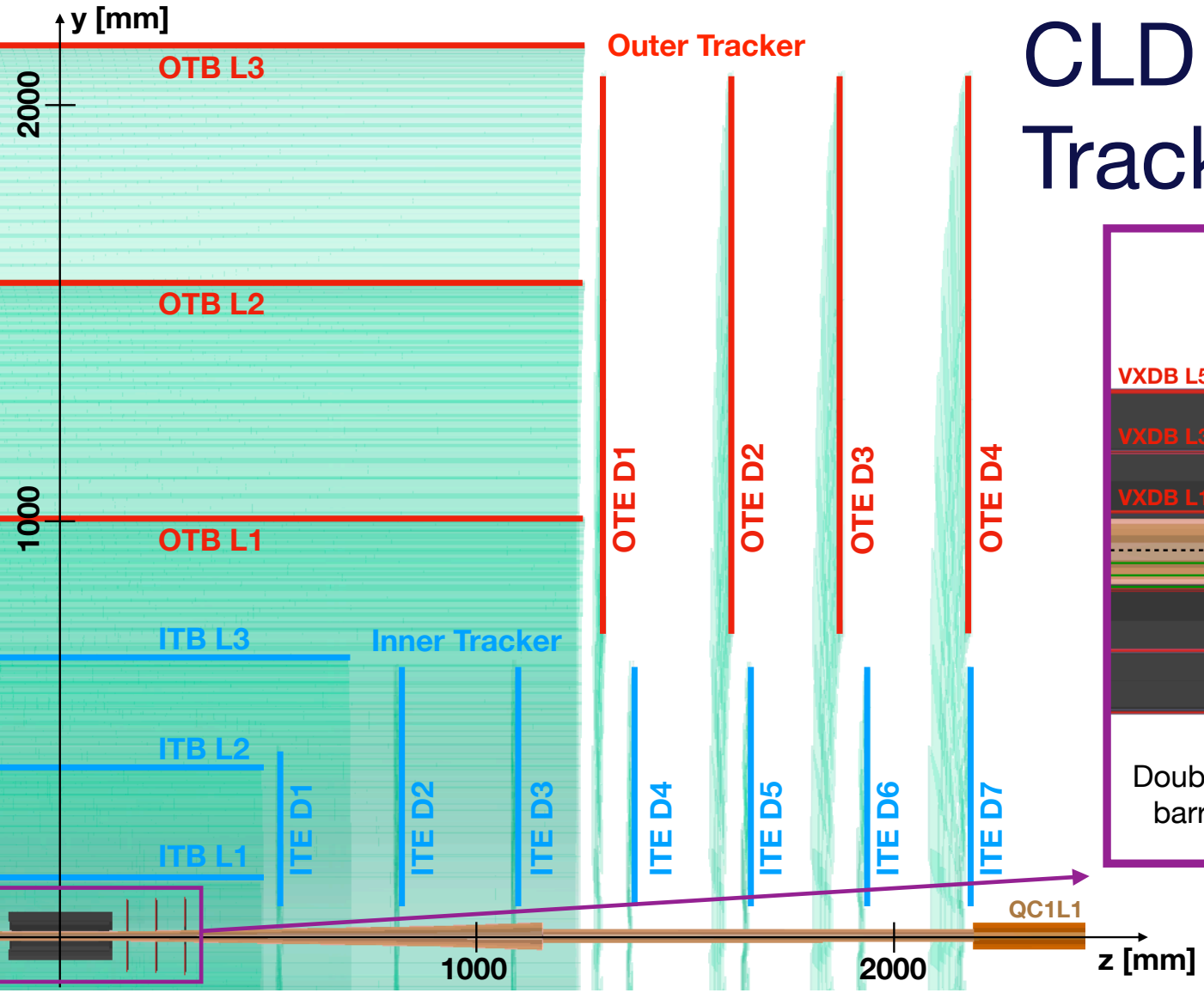
$$\theta_{QD0A,L} = +\,2.075\ [mrad]$$
$$\theta_{QF0,L} = -\,3.145\ [mrad]$$
$$K_{SQY} = -\,0.003 \cdot 10^{-3}\ [m^{-2}]$$

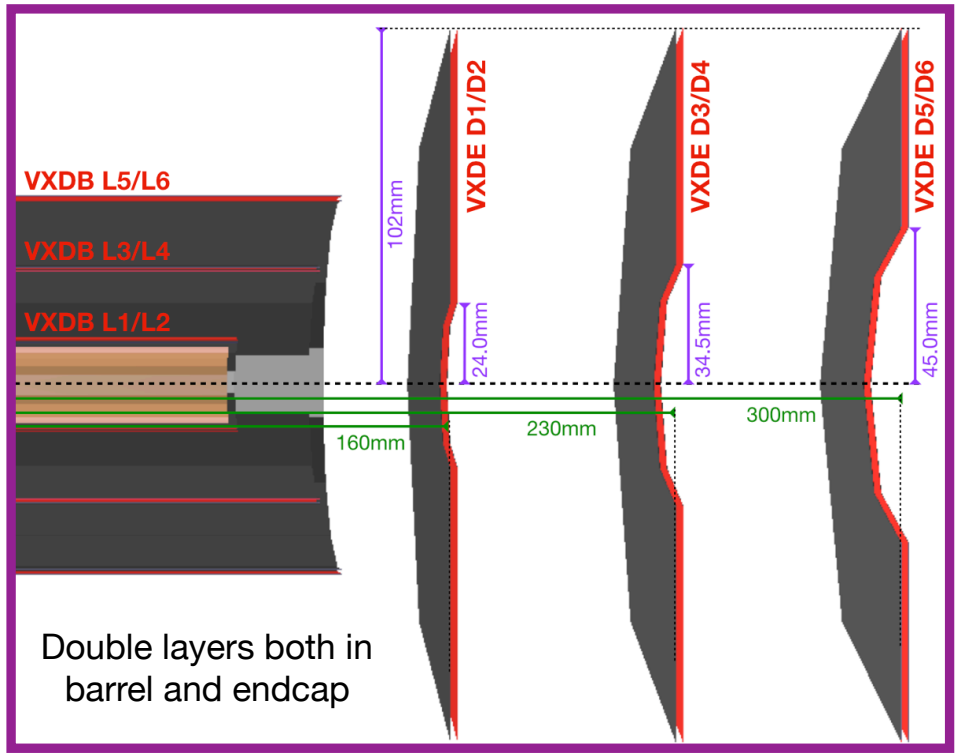
$$\epsilon_{y,c} = 0.0187\ [\pi\ pm\ rad]$$
$$\beta_x = 0.214\ m \qquad \beta_y = 0.796\ mm$$
$$Q_x = 0.325 \qquad Q_y = 0.294$$

The final contribution to vertical emittance value is **only few percents of the nominal one** $\epsilon_y = 1\ [\pi\ pm\ rad]$.

Next steps include the optimization of the match and DA studies.

CLD Subdetectors: Trackers and Vertex





Vertex Detector