# STATUS AND PERSPECTIVES FOR FCC-EE DETECTOR BACKGROUND STUDIES

Andrea Ciarma
M. Boscolo, P. Raimondi, F. Fransesini, A. Abramov, K. André, M. Hofer

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

# Background studies at FCC-ee

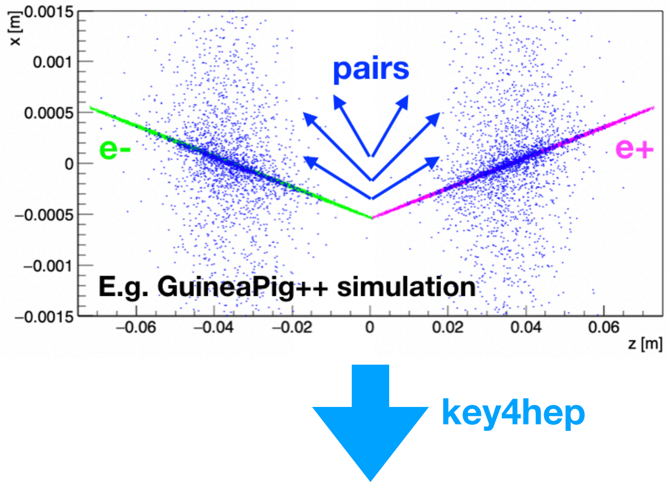
The study of the beam induced backgrounds is crucial for:

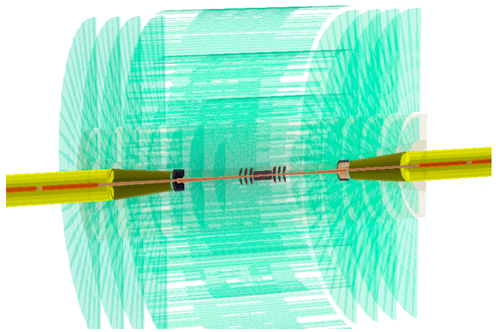
- assessing **sustainability by the detectors**
- designing **shieldings** and **solutions** to mitigate the effect of unwanted particles in the crowded **Machine-Detector Interface** area.

Tracking in the detector performed by **turnkey software Key4hep** (Geant4 physics libraries, DD4hep implementation, magnetic fields, … )

Backgrounds have been estimated only for the **CLD detector**.
As other detector concepts geometries will be added to the key4hep environment, such studies will be replicated.

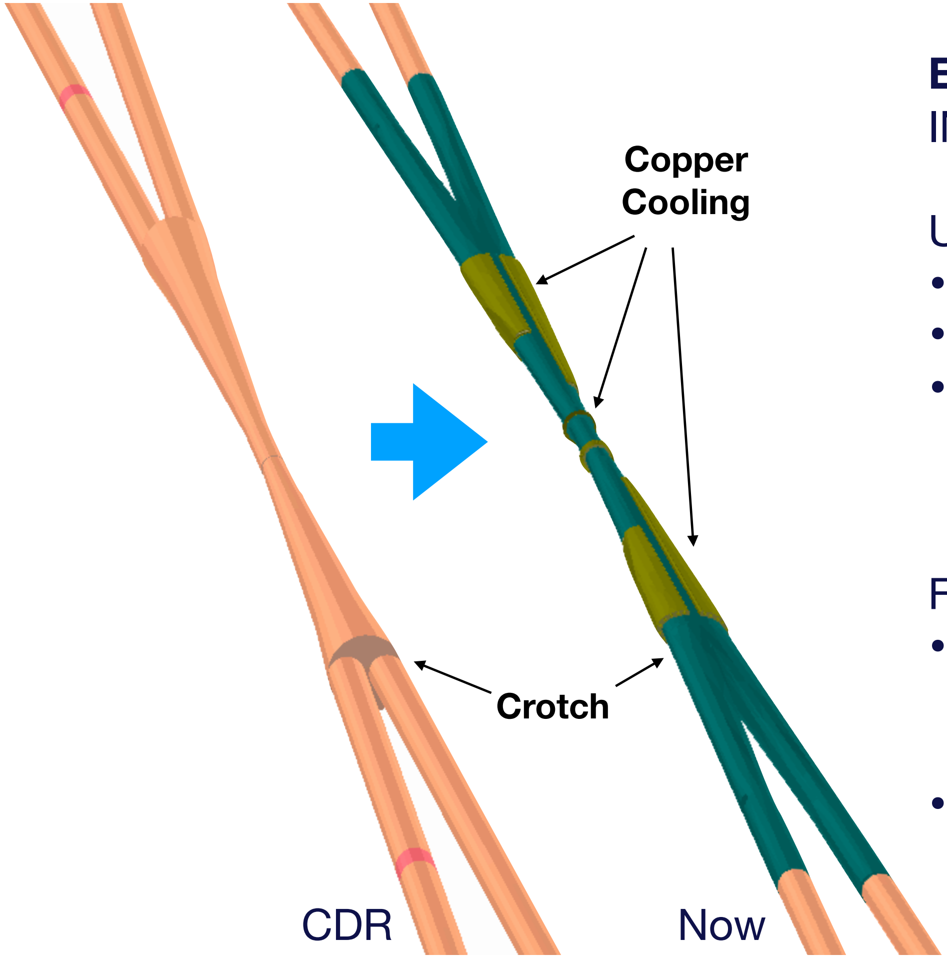
Primaries produced by **external generators** (GuineaPig++, BDSim, Xtrack, …)



Detector and MDI geometry description in **DD4hep:**
CLD fully implemented, IDEA ongoing

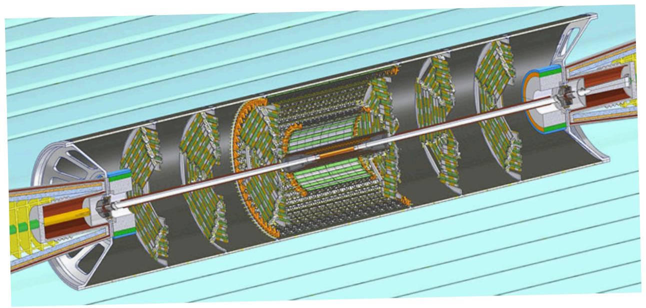
# Beam pipe description in the MDI model



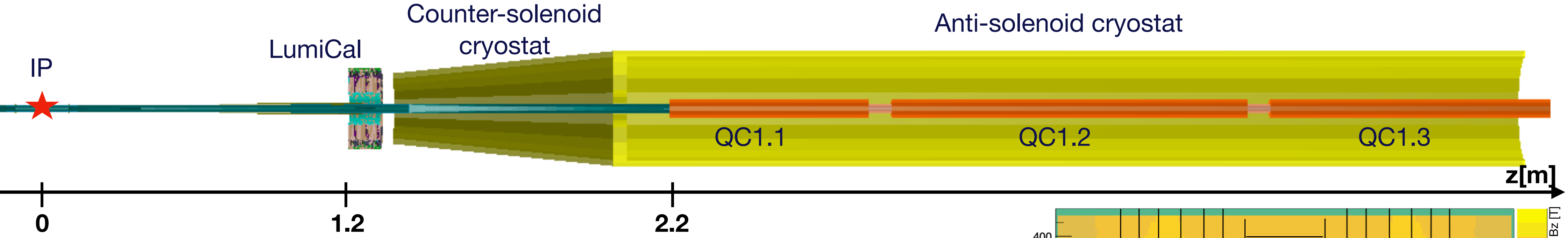

**Engineered CAD model** of AlBeMet162 beam pipe developed by INFN-LNF (many thanks to F. Fransesini) imported in **Key4hep**.

Upgrades respect to CDR 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

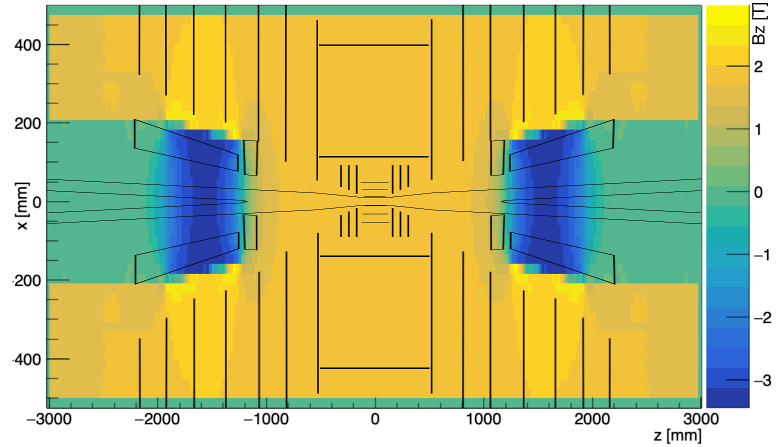
Future upgrades:
- realistic **bellows** to be placed before beam pipe separation, currently under development
- IR **support tube** proposal

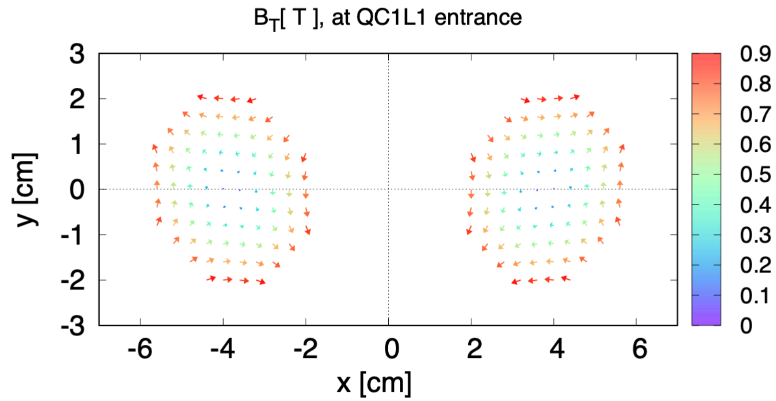


M. Boscolo *et al.* Mechanical model for the FCC-ee interaction region. *EPJ Techn Instrum* **10**, 16 (2023)




# Elements in the MDI region




Currently present in the Key4hep description:

- Simple geometry models for the **Final Focus Quadrupoles** (FFQs) including their **magnetic fields**
- **LumiCal** detailed description
- Cryostats for antisolenoids: **hollow shell** with 2cm thick walls
- Field coming from the **anti-solenoids** (counter-S, compensating-S) imported via **field map** to account for fringe effects

# Sources of Background in the MDI area

## Luminosity backgrounds

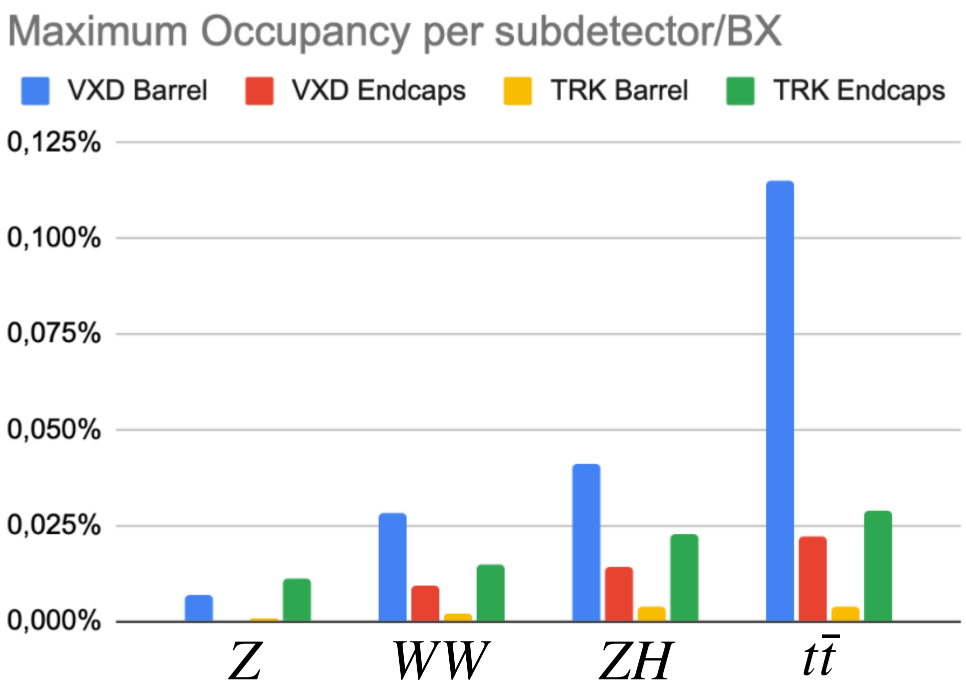
- **Incoherent Pairs Creation (IPC)**: Secondary $e^-e^+$ pairs produced via the interaction of the beamstrahlung photons with real or virtual photons during bunch crossing.
- **Radiative Bhabha:** beam particles which lose energy at bunch crossing and exit the dynamic aperture

## 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++** and tracked in the CLD using **key4hep.**




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.

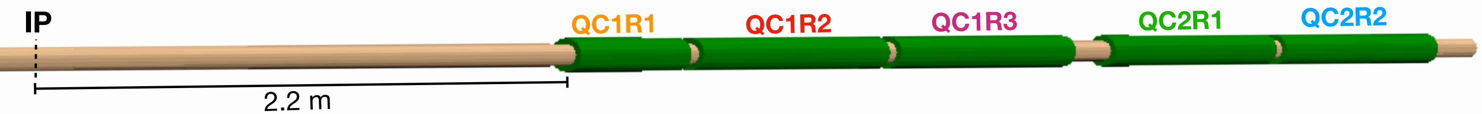
# Radiative Bhabha: beam losses

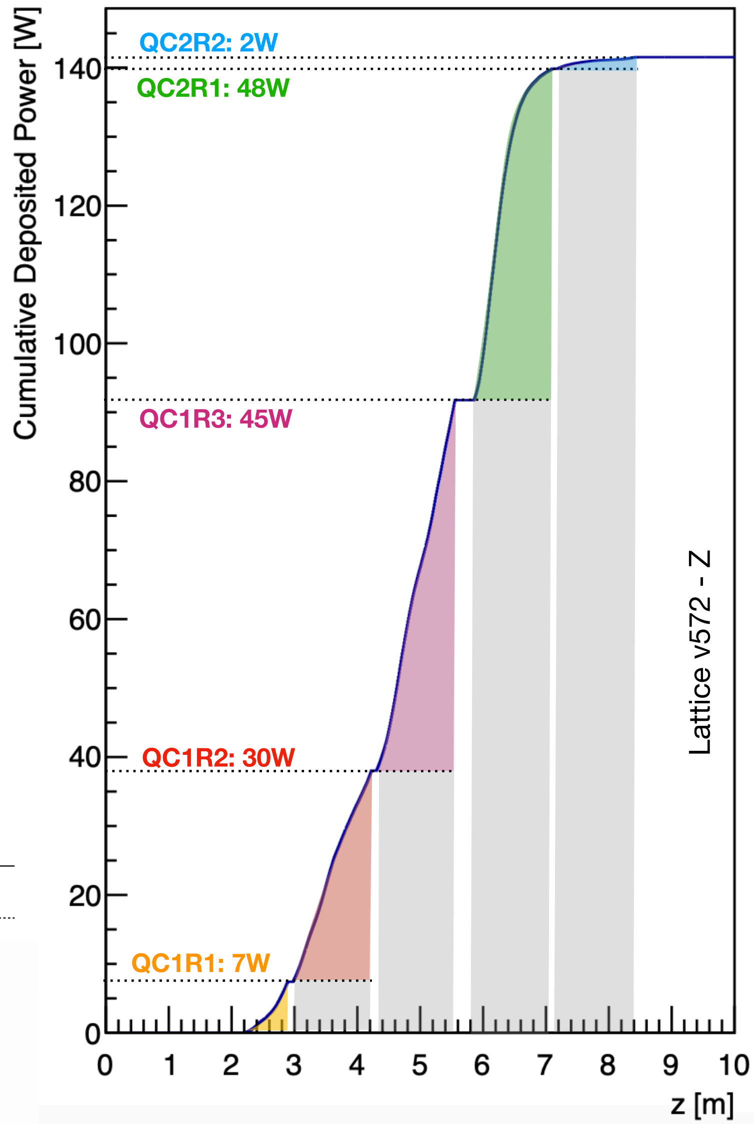
During bunch crossing, beam particles can **lose energy** via photon emission, and **exit the lattice acceptance** already at the first quadrupoles.

Particles produced using **BBBrem** and **GuineaPig++** are tracked through the beam pipe to study the **power deposition** on the downstream SC final focus quadrupoles QC1 and QC2.

This values are critical for the **design of the cryostat** and shieldings.

| | QC1R1 | QC1R2 | QC1R3 | QC2R1 | QC2R2 | Total |
|---|---|---|---|---|---|---|
| **Z-pole** | 7W | 30W | 45W | 48W | 2W | 142W |
| **tt-threshold** | 5W | 10W | 42W | 65W | 20W | 140W |



# 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).

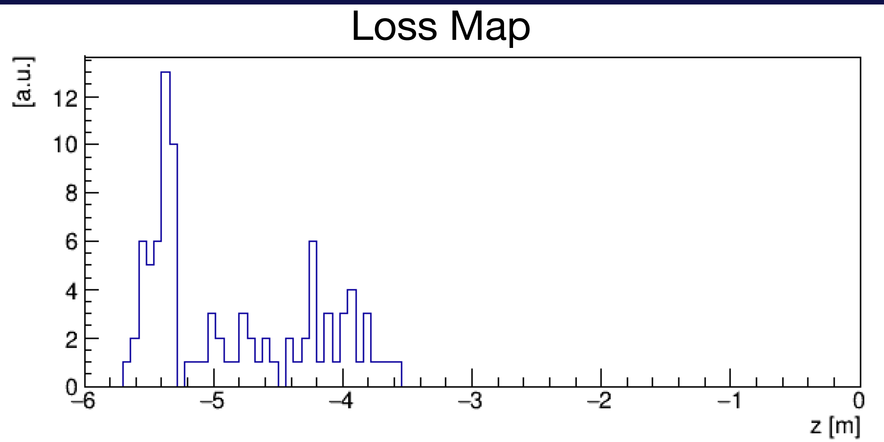
Background studied for lifetime losses due to:

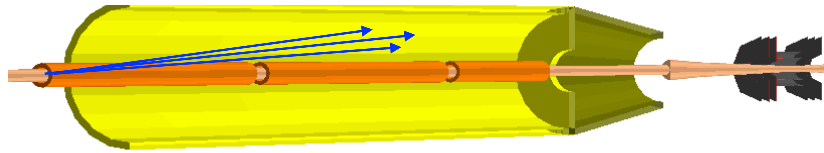
- **transverse halo** (primary collimators)
- **energy loss** (off-momentum collimators)

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

**High occupancies** O(1~10%) observed in the CLD tracker endcaps at the $t\bar{t}$ energy, while very small at the Z-pole.

**Optimization studies on the collimators** in progress to mitigate this effect



| | 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) |

# Failure scenarios: Power deposited in QC1

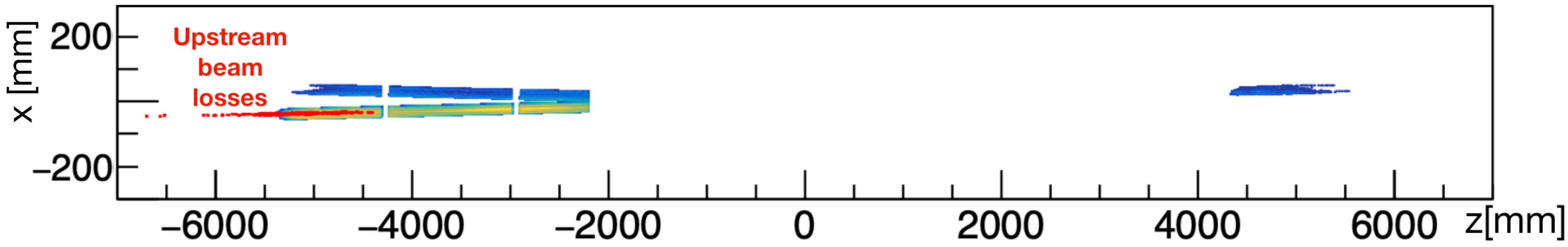
$t\bar{t}-$threshold, losses due to horizontal primary collimator

| | 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

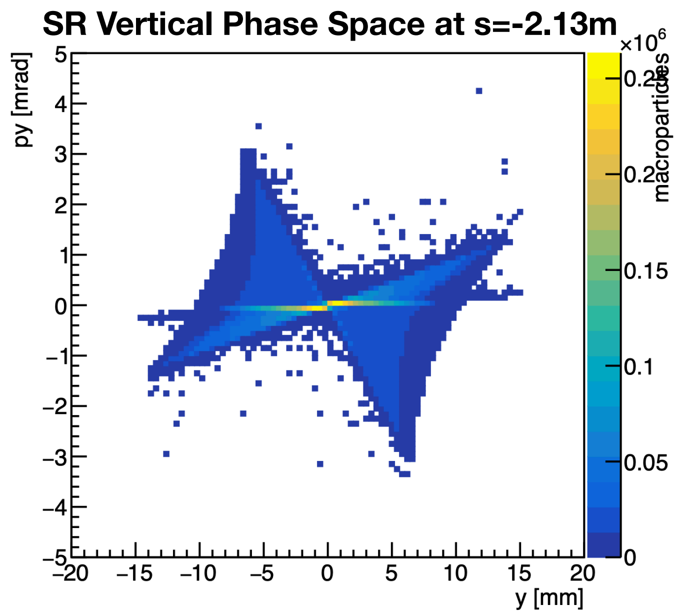
| | IPA | IPD | IPG | IPJ |
|---|---|---|---|---|
| **Losses per second (10^9)** | 0.26 | 0.14 | 0.12 | 0.39 |
| **QC1 hottest spot (W/cm3 in a 2mm3 bin)** | 0.011 | 0.004 | 0.003 | 0.016 |
| **Total power in QC1 (W)** | 0.72 | 0.32 | 0.18 | 1.15 |

- **horizontal primary collimator:** power density and total power deposited show **small values**.
- **off-momentum collimators:** preliminary analysis suggest the possibility of **high power**. Further studies on this are ongoing.



# Background from SR photons

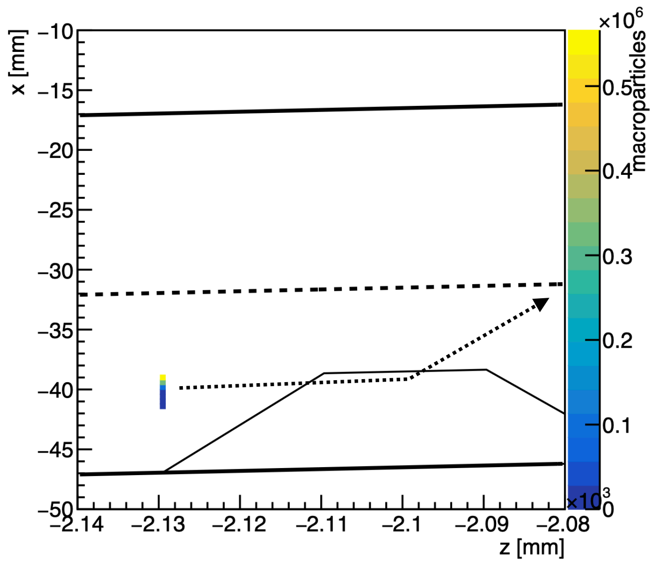
Thanks to K. Andrè for the primary particles.




- **SR from beam halo**

Induced background from a $10\sigma \sim 60\sigma$ halo (approx. 90% of the aperture) is below the occupancy safety limits $O(1\%)$ if the tail population is under 0.001% of the total.

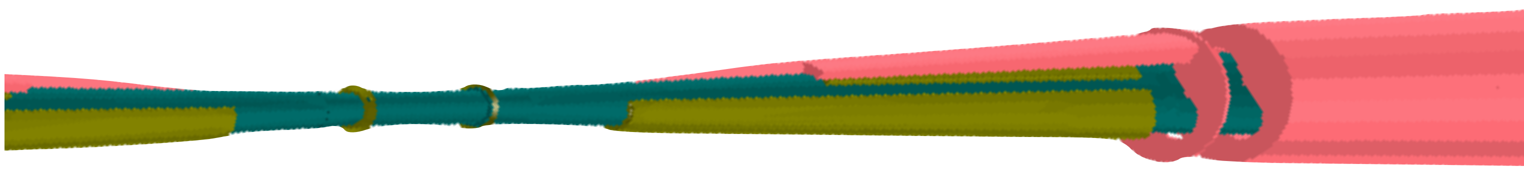
Other halo shapes need to be investigated to devise mitigation strategies.




- **SR photons scattered off mask tip**

Considering the same beam halo and a beam population of 0.1%, occupancy due to these photons is ~1% only in the tracker endcaps, and much lower in the others.

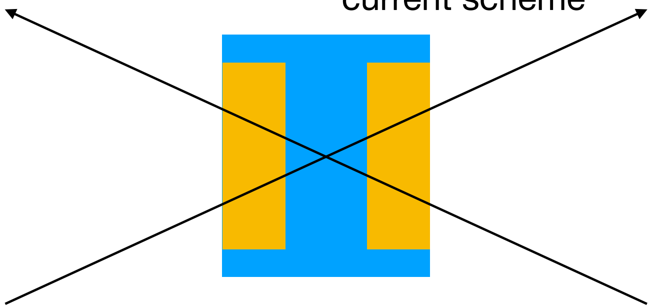
This suggests that the Tungsten Shieldings introduced during CDR may be reduced or removed.



# 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 scheme would be **very beneficial in terms of available space in the MDI area.**

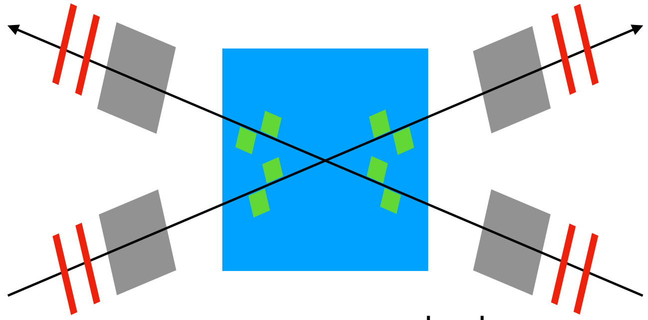



Coupling correction is achieved by:

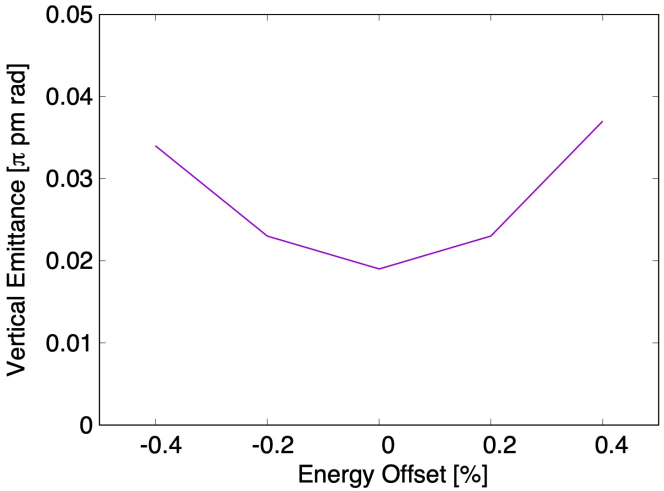
- a tilt of the **Final Focus quadrupoles**
- skew correctors at the **SDY1** and **SDY2** sextupoles (about ±200m and ±400m from the IP)
- alternated sign of the experiment's field at the IPs

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.

# Summary

- Key4hep **modelization of the MDI region** and **upgrades** since the CDR presented
  - realistic model of the IR beam pipe with cooling sections
  - magnetic field of anti-solenoids and final focus quadrupoles

- 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**.

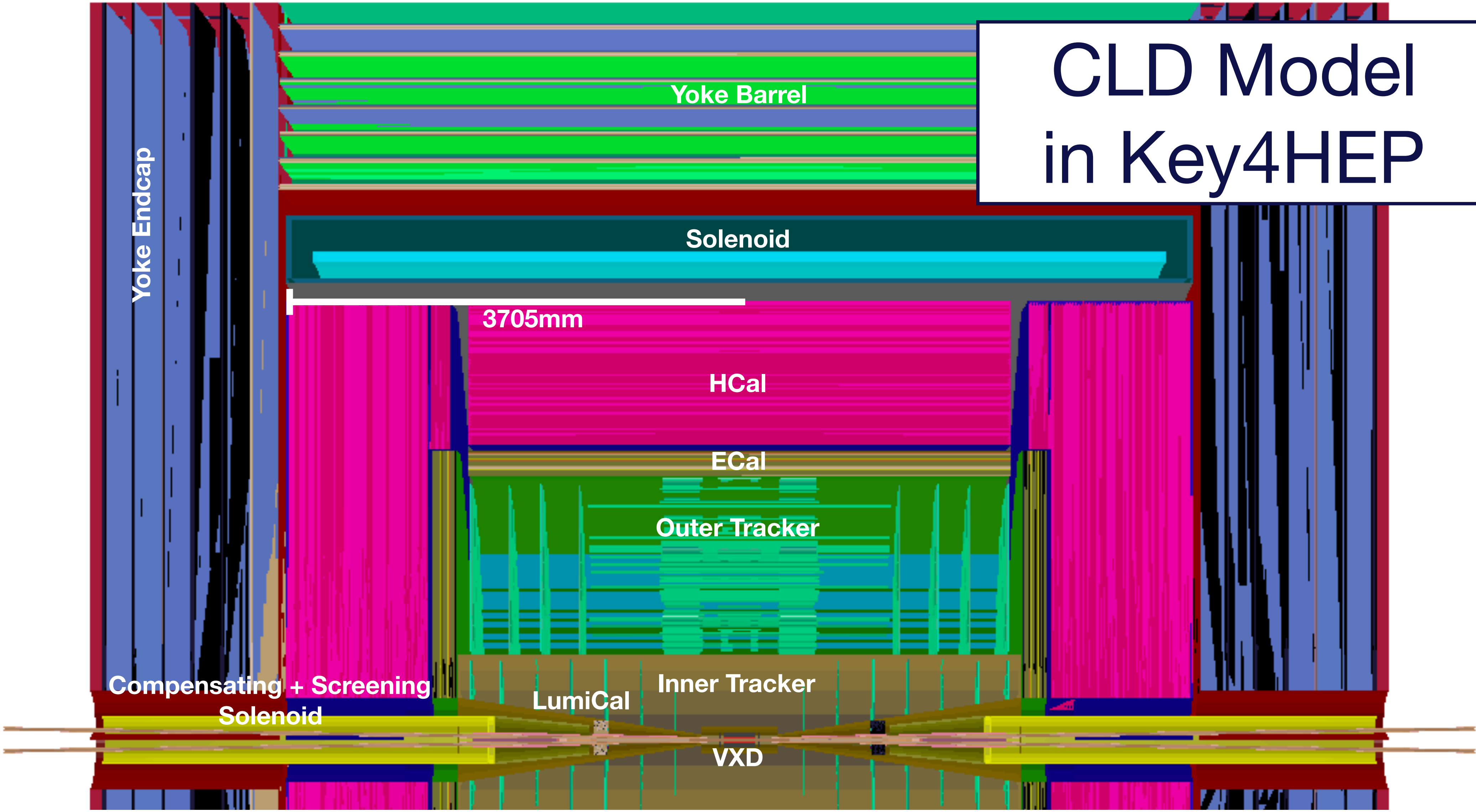
- Power deposited in the SC final focus quads due to beam losses show little risk of instantaneous quenching.

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

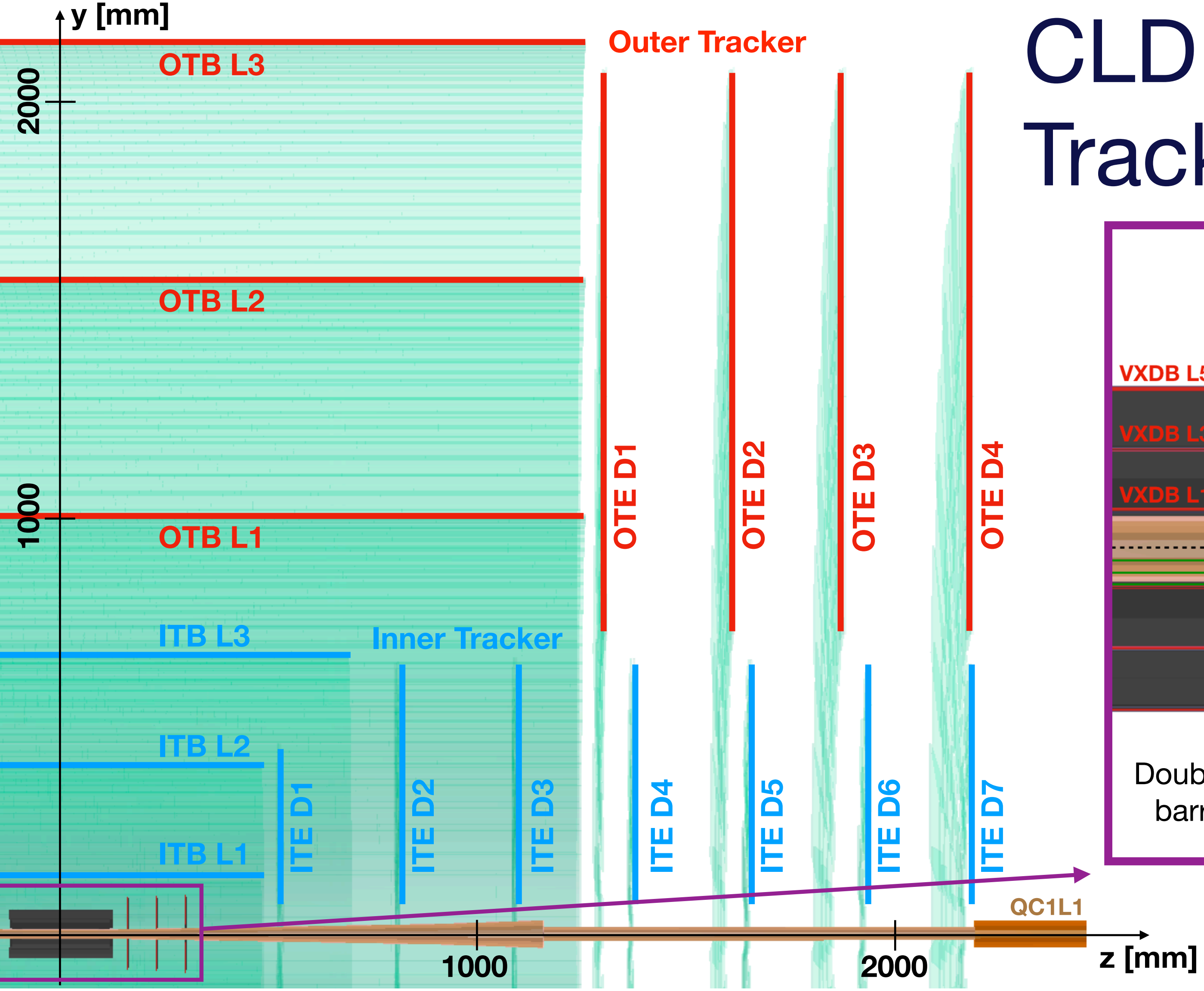
- **Radiative Bhabha particles** hit SC final focus quadrupoles, depositing ~150W

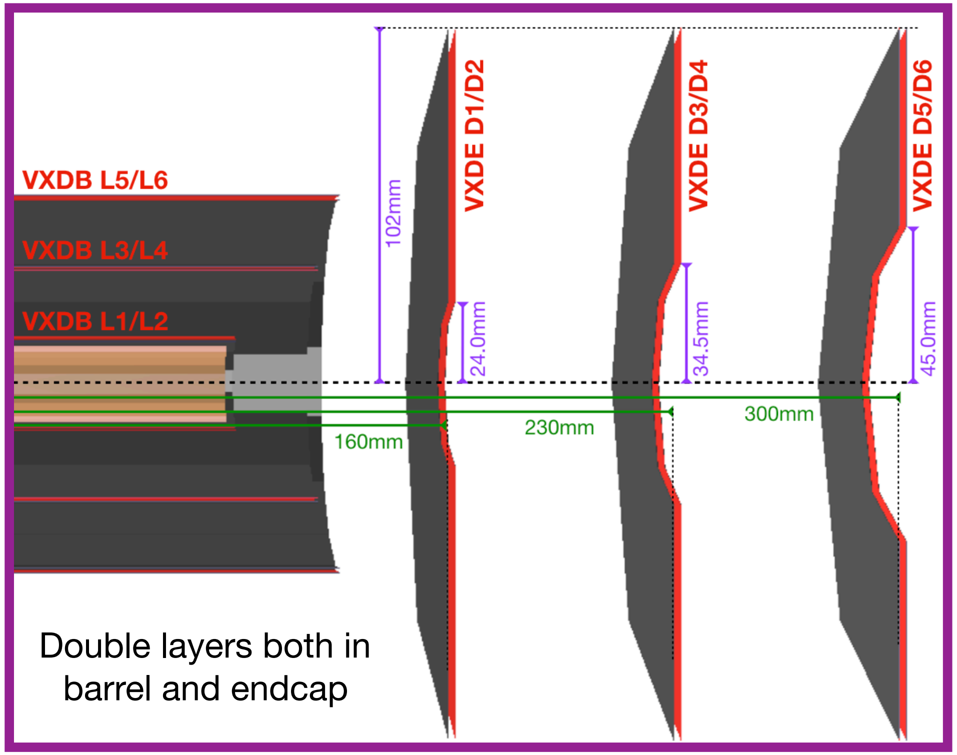
# BACKUPS

# CLD Model in Key4HEP



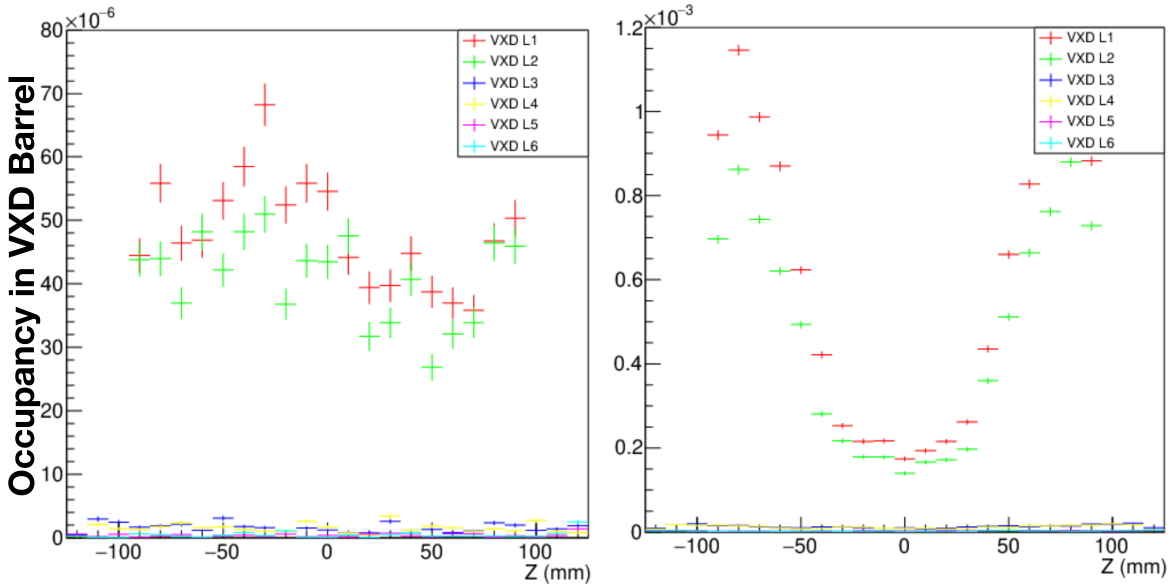
# CLD Subdetectors: Trackers and Vertex




Vertex Detector

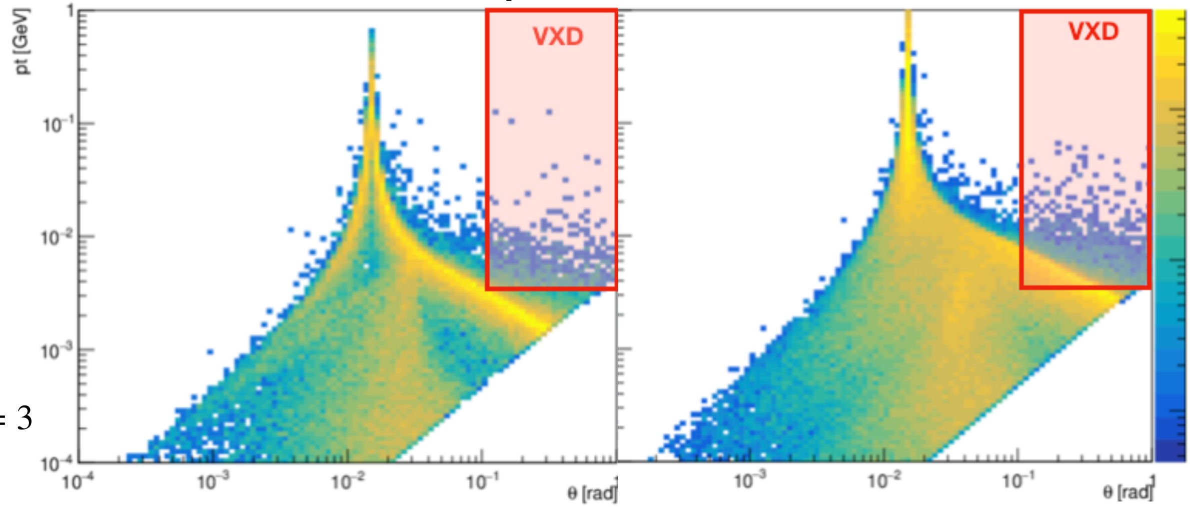
Z Top




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.**

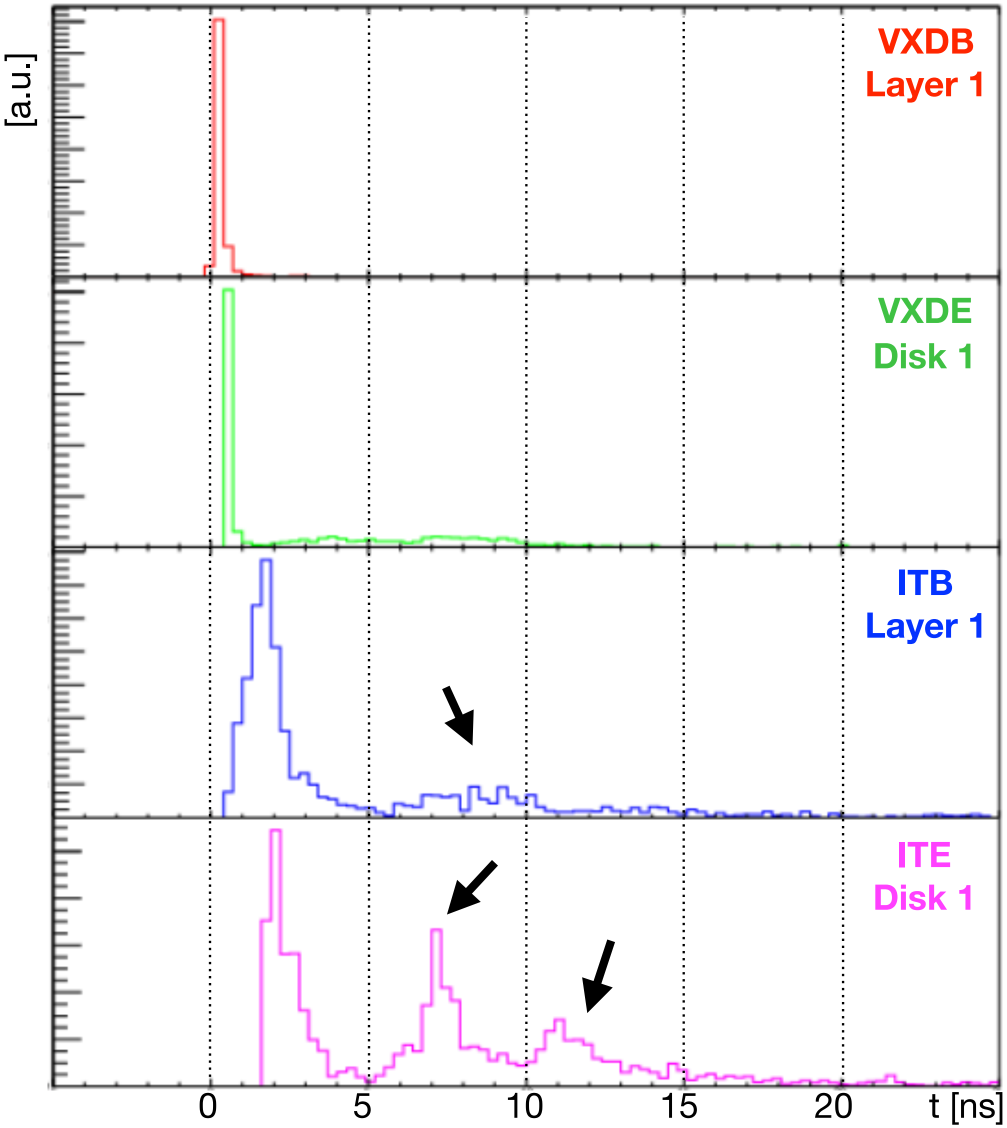
| | Z | WW | ZH | Top |
|---|---|---|---|---|
| **Bunch spacing [ns]** | 30 | 345 | 1225 | 7598 |
| **Max VXD occ. 1us** | 2.33e-3 | 0.81e-3 | 0.047e-3 | 0.18e-3 |
| **Max VXD occ.10us** | 23.3e-3 | 8.12e-3 | 3.34e-3 | 1.51e-3 |
| **Max TRK occ. 1us** | 3.66e-3 | 0.43e-3 | 0.12e-3 | 0.13e-3 |
| **Max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

**IPC production kinematics**




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

$$size_{sensor} = \begin{matrix} 25\mu m \times 25\mu m \ (pixel) \\ 1mm \times 0.05mm \ (strip) \end{matrix} \quad size_{cluster} = \begin{matrix} 5 \ (pixel) \\ 2.5 \ (strip) \end{matrix} \quad safety = 3$$

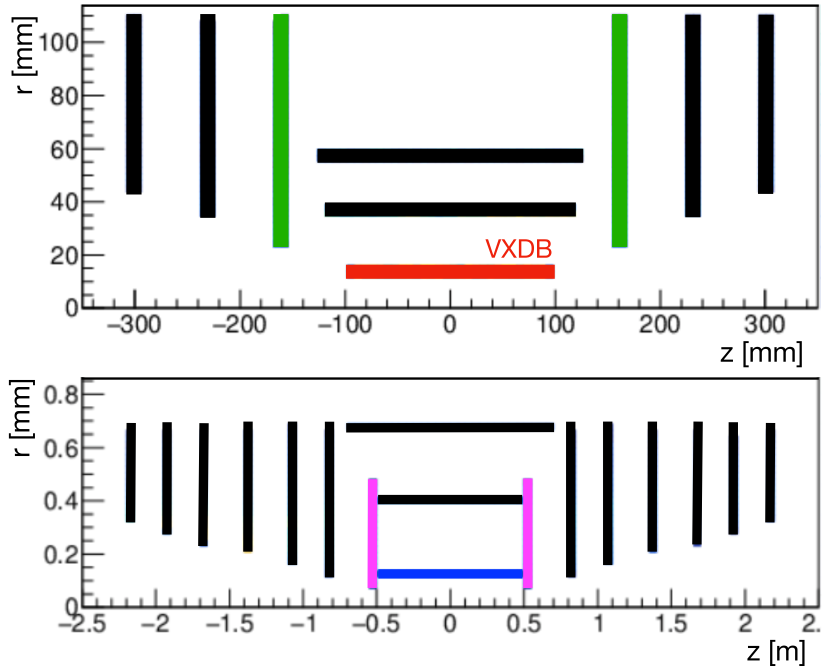



# Incoherent Pairs Creation (IPC)

**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:

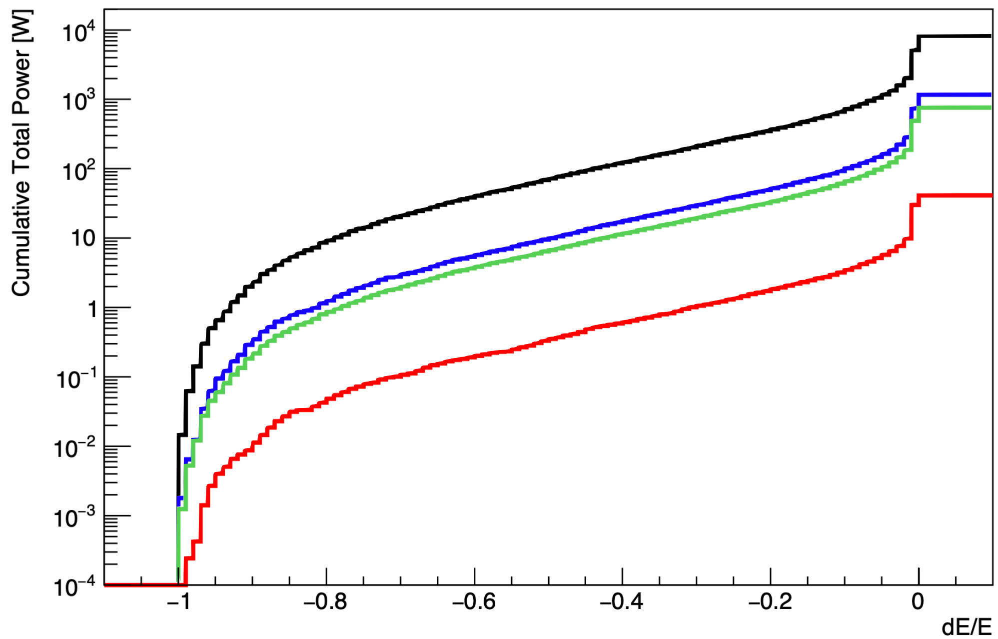
VXDB L1: 0.05~0.3 ns

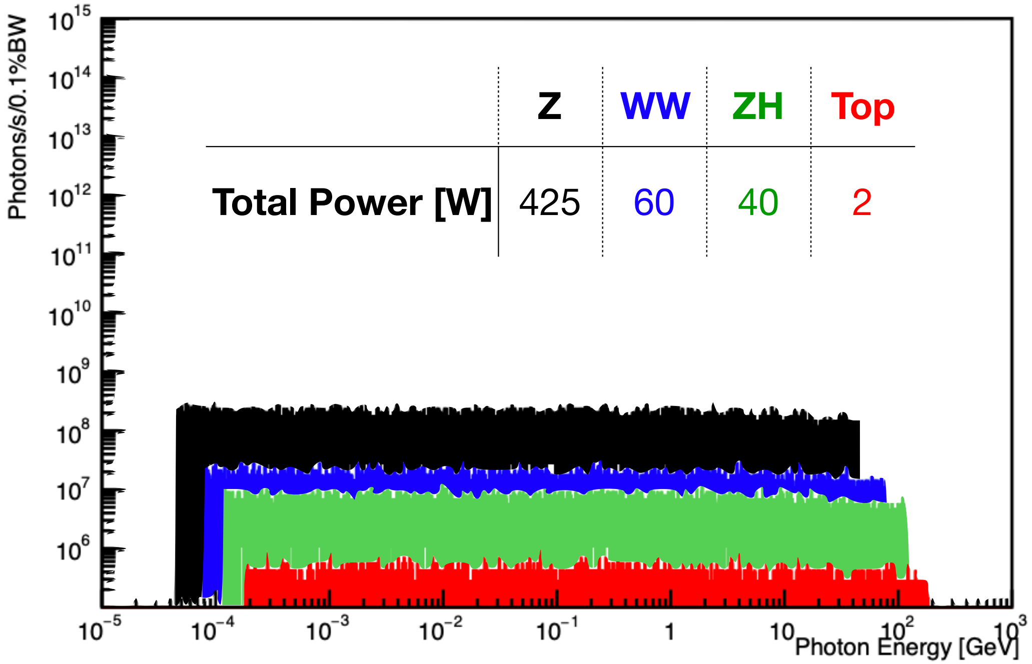
VXDE D1: 0.5~0.6 ns

ITB L1: 0.3~1.7 ns

ITE D1: 1.7~2.5 ns

# Radiative Bhabha: photons and spent beam



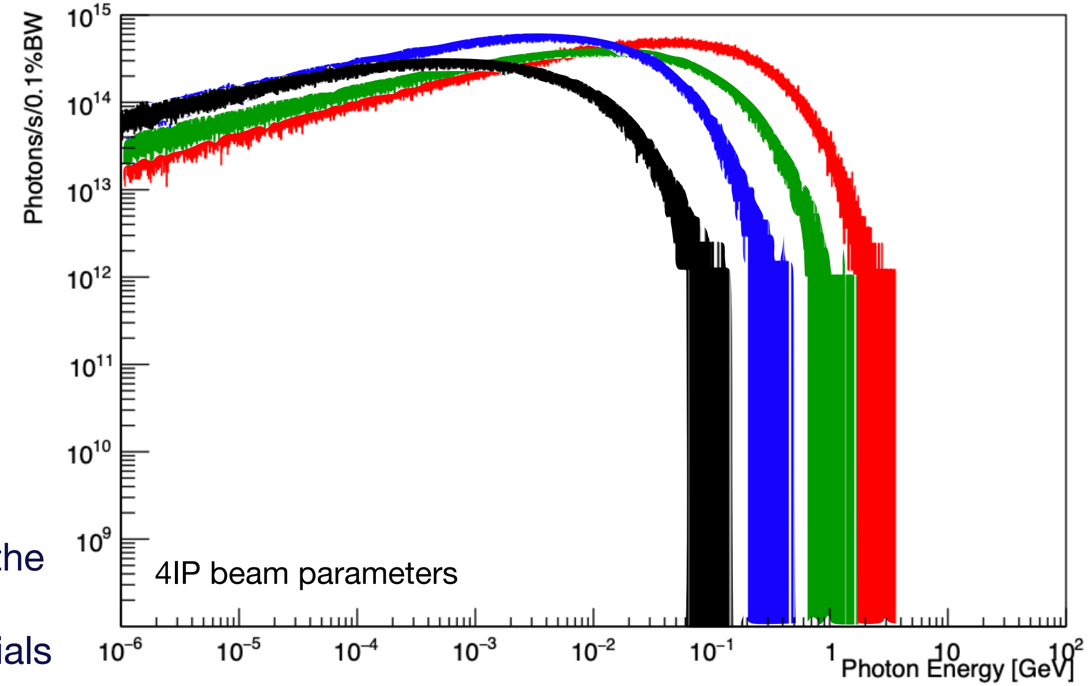

| Energy Radiated [dE/E] | | >2% | >10% | >50% |
|---|---|---|---|---|
| Power Carried by spent beam [W] | Z | 1500 | 650 | 70 |
| | WW | 200 | 100 | 10 |
| | ZH | 150 | 60 | 6 |
| | tt | 8 | 3 | 0.3 |

# Beamstrahlung radiation Characterisation

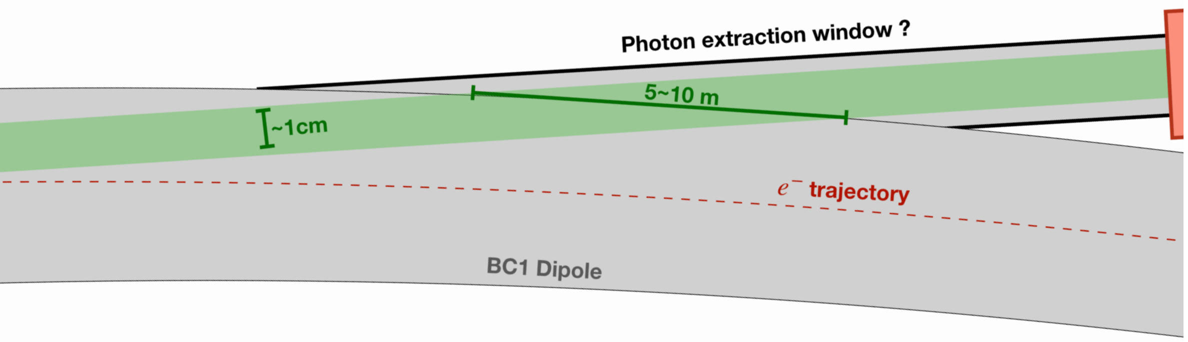
The photons are emitted **collinear to the beam** with an angle proportional to the beam-beam kick. This radiation is extremely intense **O(100kW)** and **hits the beam pipe** at the end of the first downstream dipole.

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

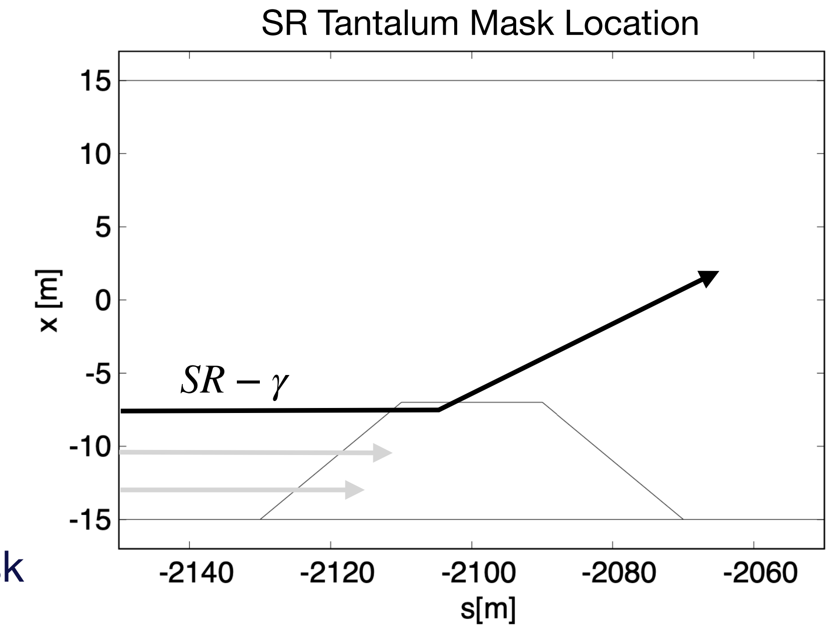
The design of a **dedicated extraction line** and **beam dump** for the beamstrahlung photons is currently in progress, exploring tunnel integration, magnets design, cooling system, and different materials for the beam dump.




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



# 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.