MACHINE INDUCED BACKGROUNDS IN THE FCC-ee MDI REGION AND BEAMSTRAHLUNG RADIATION

Andrea Ciarma

Thanks to: E. Perez, D. Shatilov, F. Fransesini, A. Abramov, K. Andrè, M. Boscolo

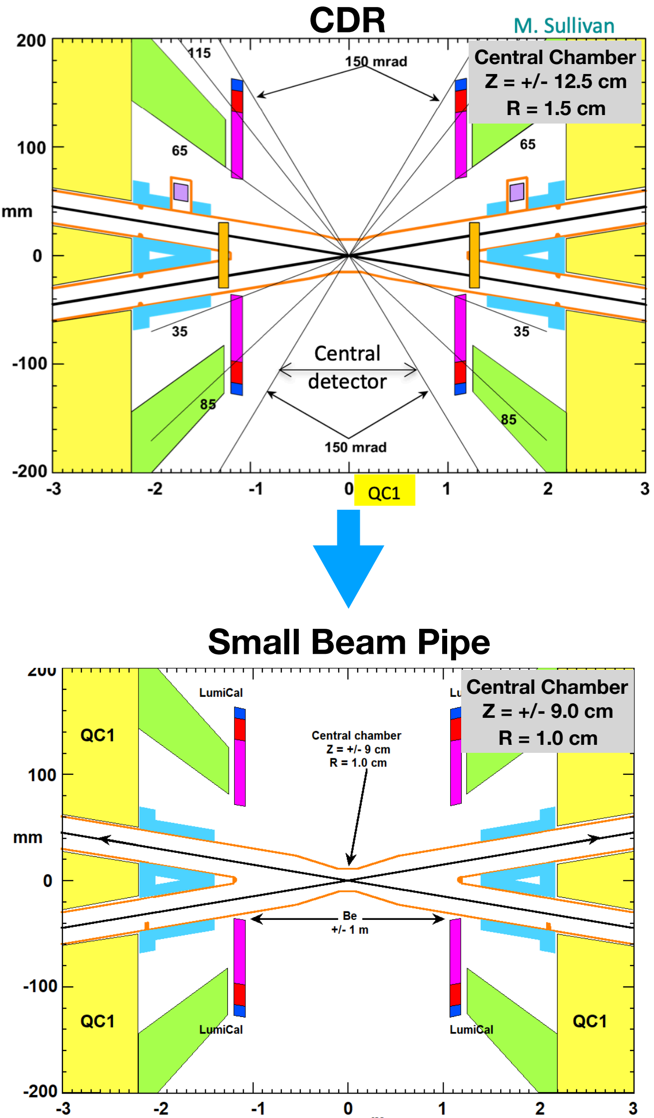
FCC-ee MDI background studies

Machine induced background studies were performed for the CDR and included the beam losses in the IR, pairs production and the development of Synchrotron Radiation masks and shieldings.

After the design of the **10mm radius beam pipe**, the new **4IP lattice** and the migration to the **turnkey software Key4HEP**, it is necessary to repeat and extend these studies.

- The evaluation of the VXD/TRK occupancy due to **Incoherent Pair Creation (IPC)**
- Tracking of **beam losses** in the CLD detector and MDI region during failure scenarios
- First study of **Synchrotron Radiation** induced occupancy
- Characterization of the **beamstrahlung radiation** produced at the IP

The tracking of the background particles in the **FCCSW model of the CLD detector** in order to estimate the related hit densities has been performed using the **turnkey software Key4HEP.**



M. Boscolo, M. Sullivan

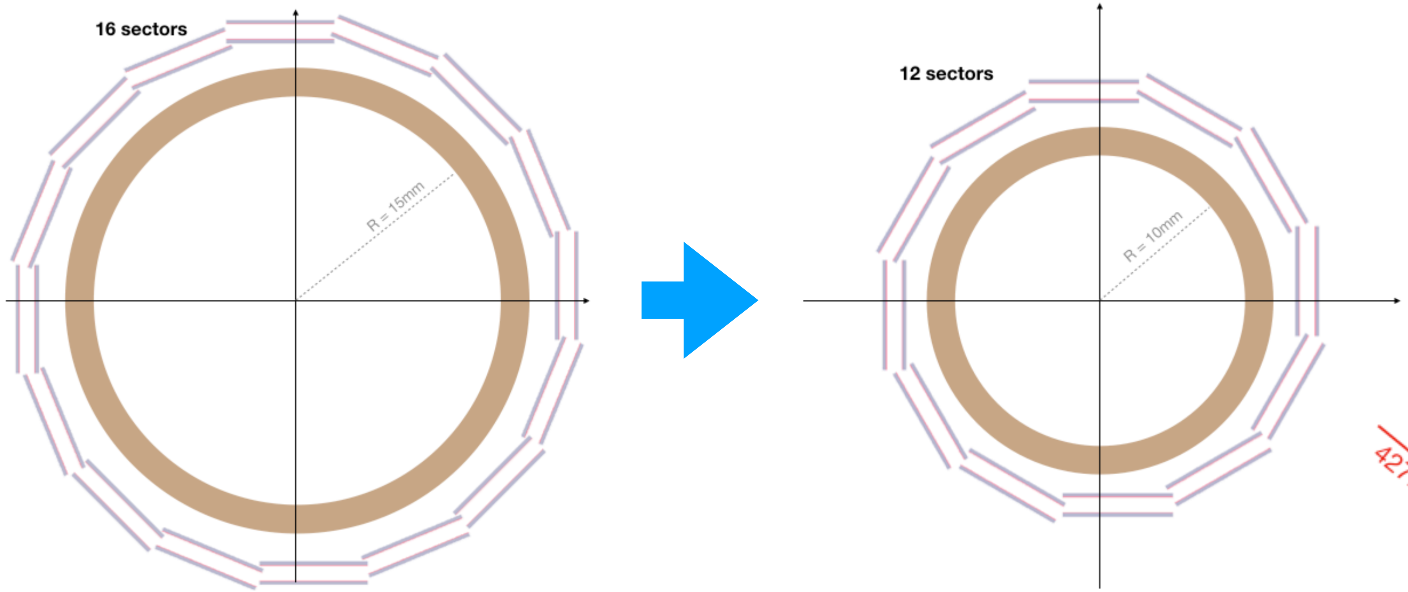
Updated CLD VXD for Small Beam Pipe

After the CDR, the design for the central chamber of the FCC-ee beam pipe has changed to a reduced radius of **R=10mm** and length of **L=18cm,** allowing to have the inner layer of the Vertex Detector Barrel **closer to the interaction point**.

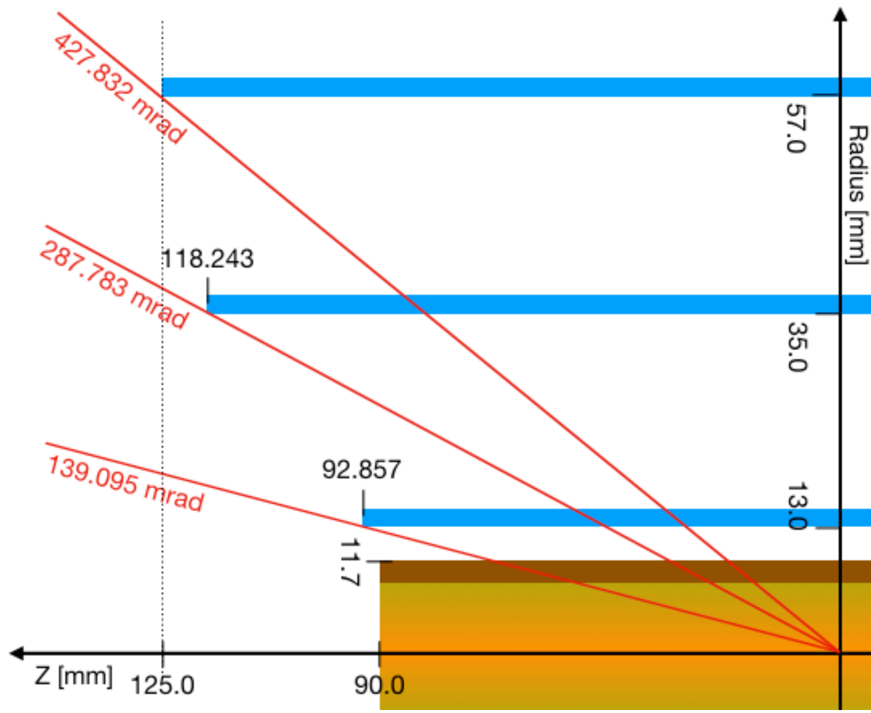
I have modified the **CLD VXD** in order to fit the new geometry of the MDI and studied the effect of several **beam induced backgrounds** in this new version. The main constraints for the modifications have been:

- keeping the **staves width** fixed
- don't change the **angular acceptance** of the layers

A re-design of the **IDEA** Vertex Detector is currently **work in progress**, and the same studies will be repeated once ready.



Keeping the **same distance** between the external surface of the beam pipe and the begin of the first ladder, and also the **same stave width**, I have reduced the **number of sectors to 12** (from 16) in order to avoid overlaps.



Also the **second layer** has been moved closer to the IP in order to have it **midway** between the two outermost layers.

The **length** of the first and second layer has therefore been changed in order to maintain the **same angular acceptance** of the original design.

Incoherent Pairs Creation (IPC)

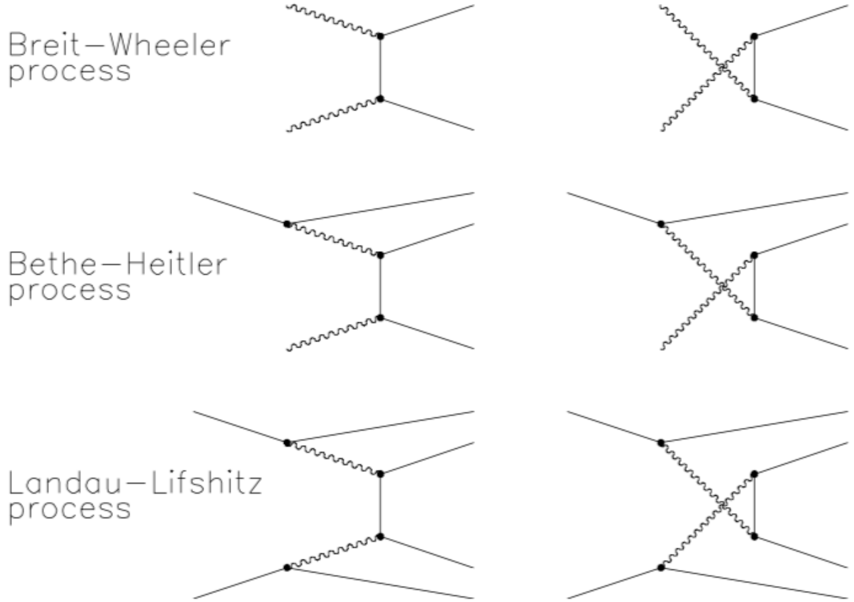
Secondary e^-e^+ pairs can be produced via the interaction of the beamstrahlung photons with real or virtual photons emitted by each particle of the beam during bunch crossing.

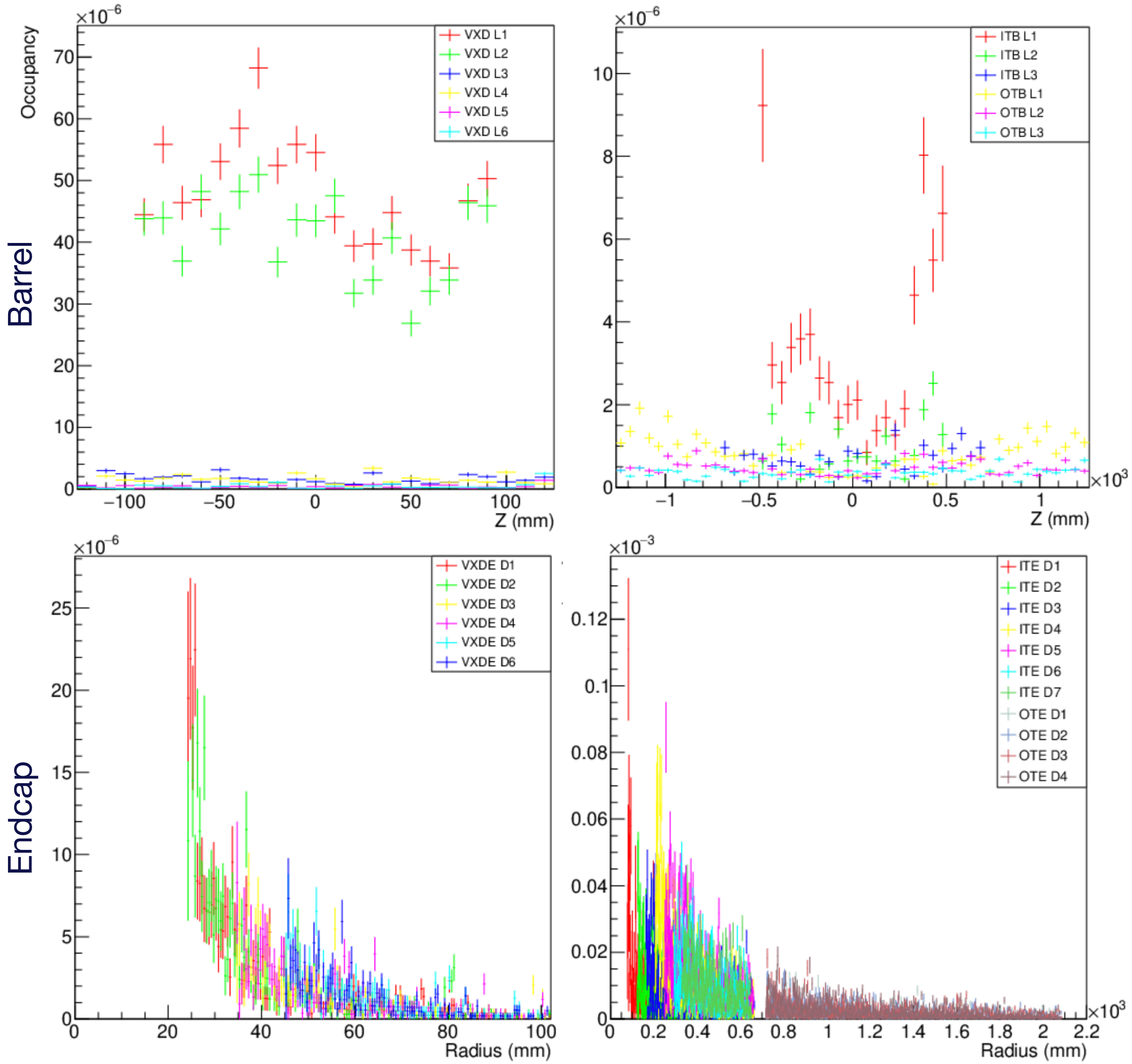
Previous studies with the old R=15mm central beam pipe showed that the induced occupancy was well below 1%, but it is important to check the increase due to the now closer VXD.

This process has been simulated using the generator **GuineaPig++** and tracking in the CLD detector using **Key4HEP.** The beam parameters for the latest 4IP lattice ($\beta_x^* = 0.10\,m$) have been considered at the four working energies.

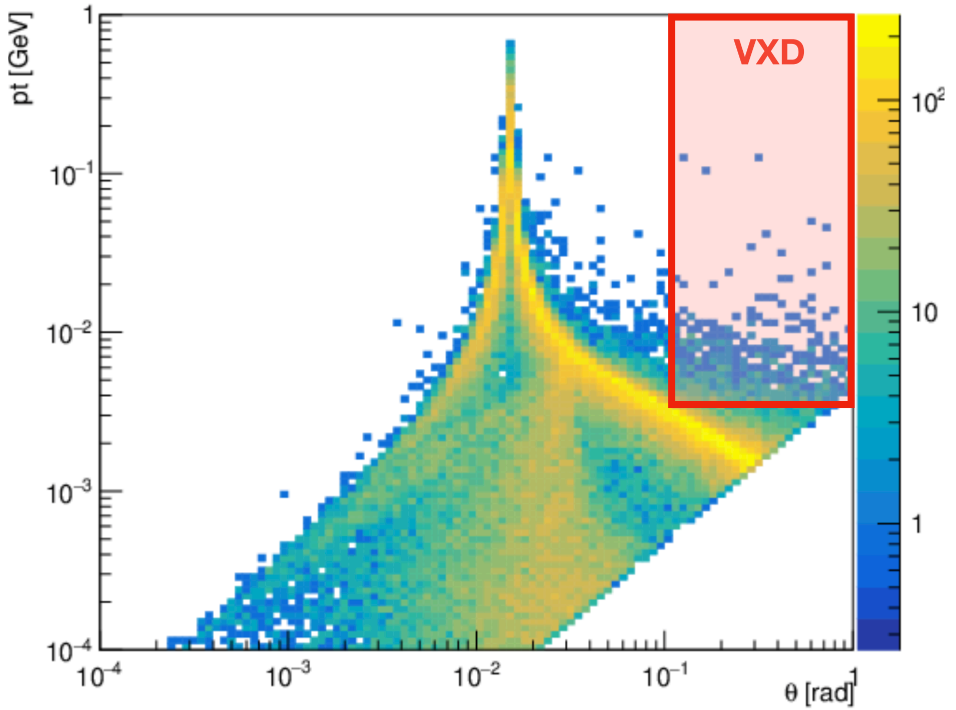
$$occupancy = hits/mm^2/BX \cdot size_{sensor} \cdot size_{cluster} \cdot safety$$

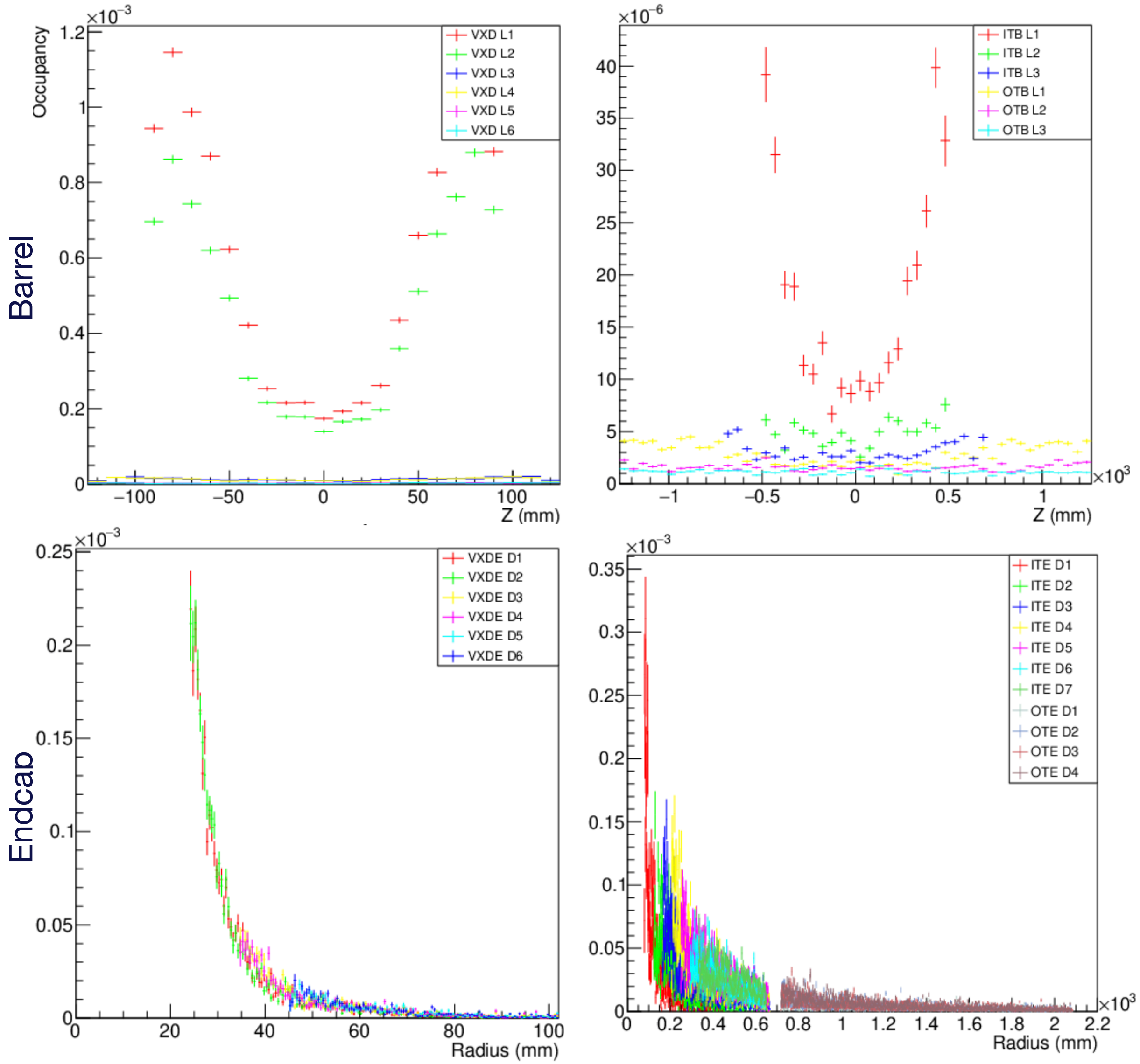
$$size_{sensor} = \begin{matrix} 25\mu m \times 25\mu m \ (pixel) \\ 1mm \times 0.05mm \ (strip) \end{matrix} \qquad size_{cluster} = \begin{matrix} 5 \ (pixel) \\ 2.5 \ (strip) \end{matrix} \qquad safety = 3$$





	Z	WW	ZH	Top
Pairs/BX	1300	1800	2700	3300
Max occup. VXDB	70e-6	280e-6	410e-6	1150e-6
Max occup. VXDE	22.5e-6	95e-6	140e-6	220e-6
Max occup. TRKB	9e-6	20e-6	38e-6	40e-6
Max occup. TRKE	110e-6	150e-6	230e-6	290e-6





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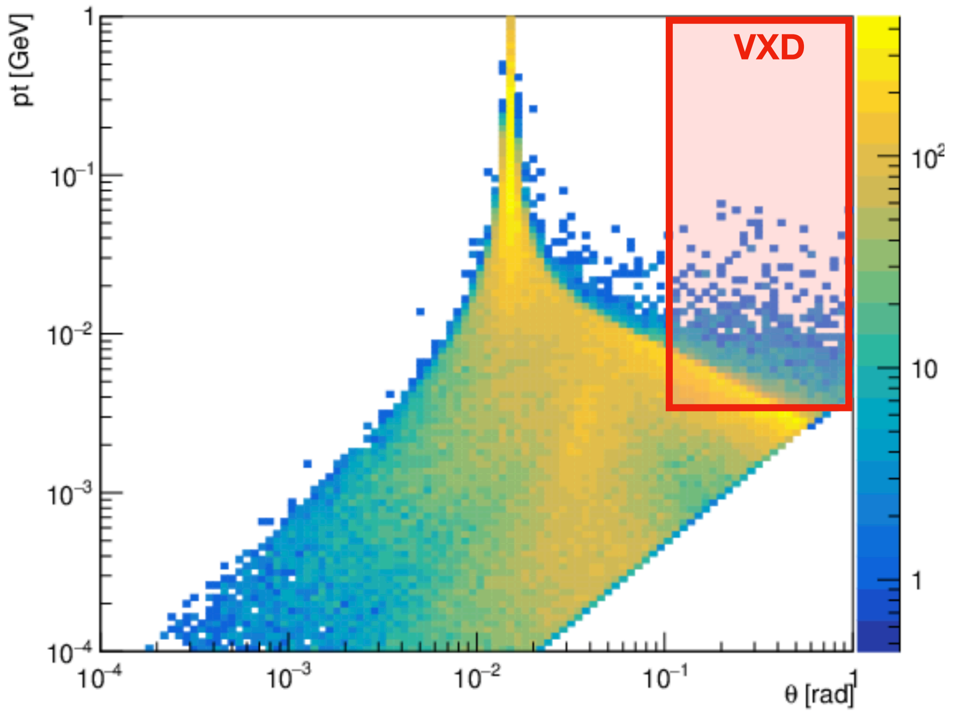
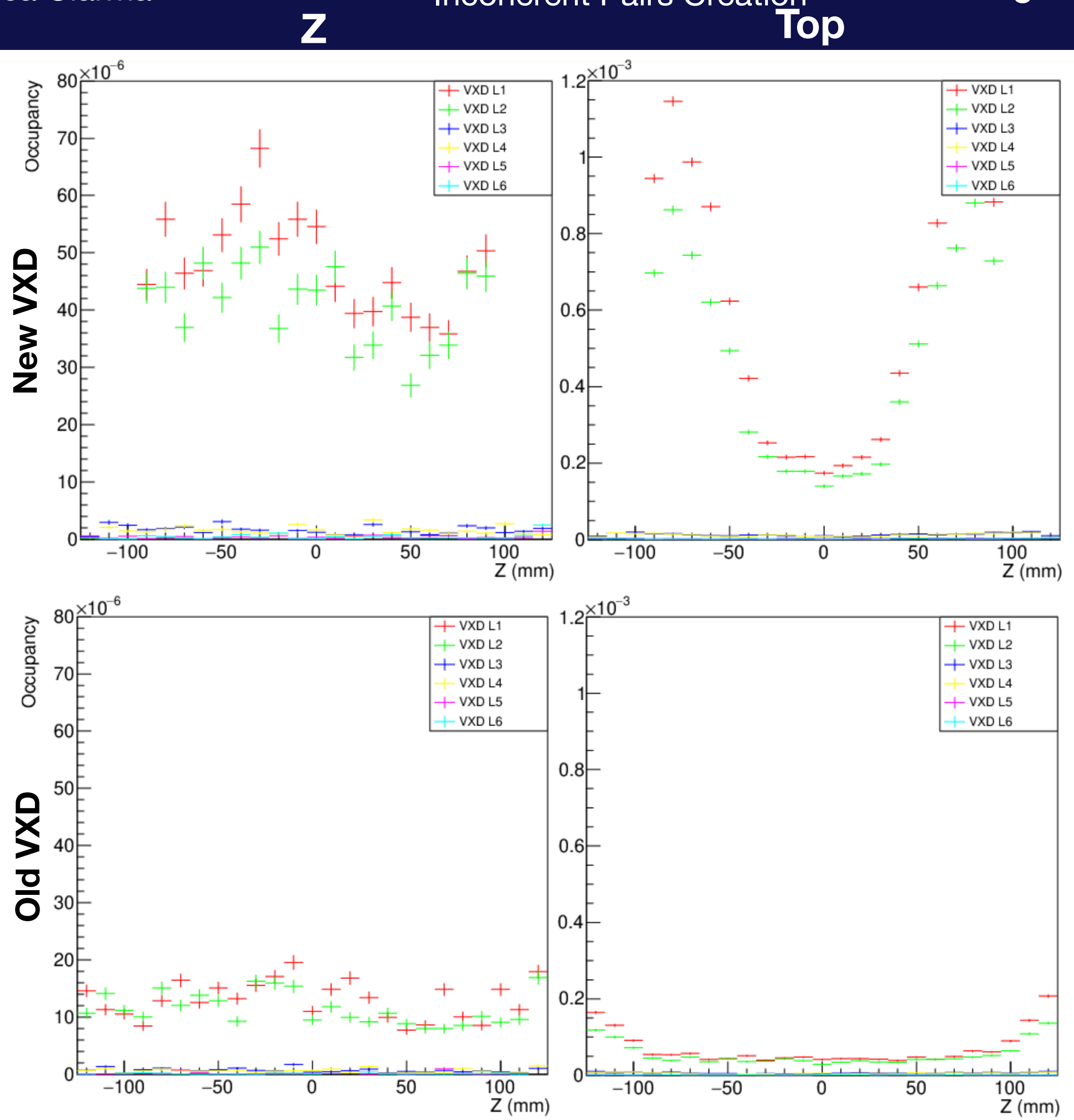


Preliminary studies on the occupancy due to the IPCs (generated with GuineaPig++ using the latest 4IP lattice beam parameters) show an increase of a **factor ~5** in particular in the **innermost layers** of the VXD barrel.

According to the electronics **readout time**, the sensors may integrate over more BXs.

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



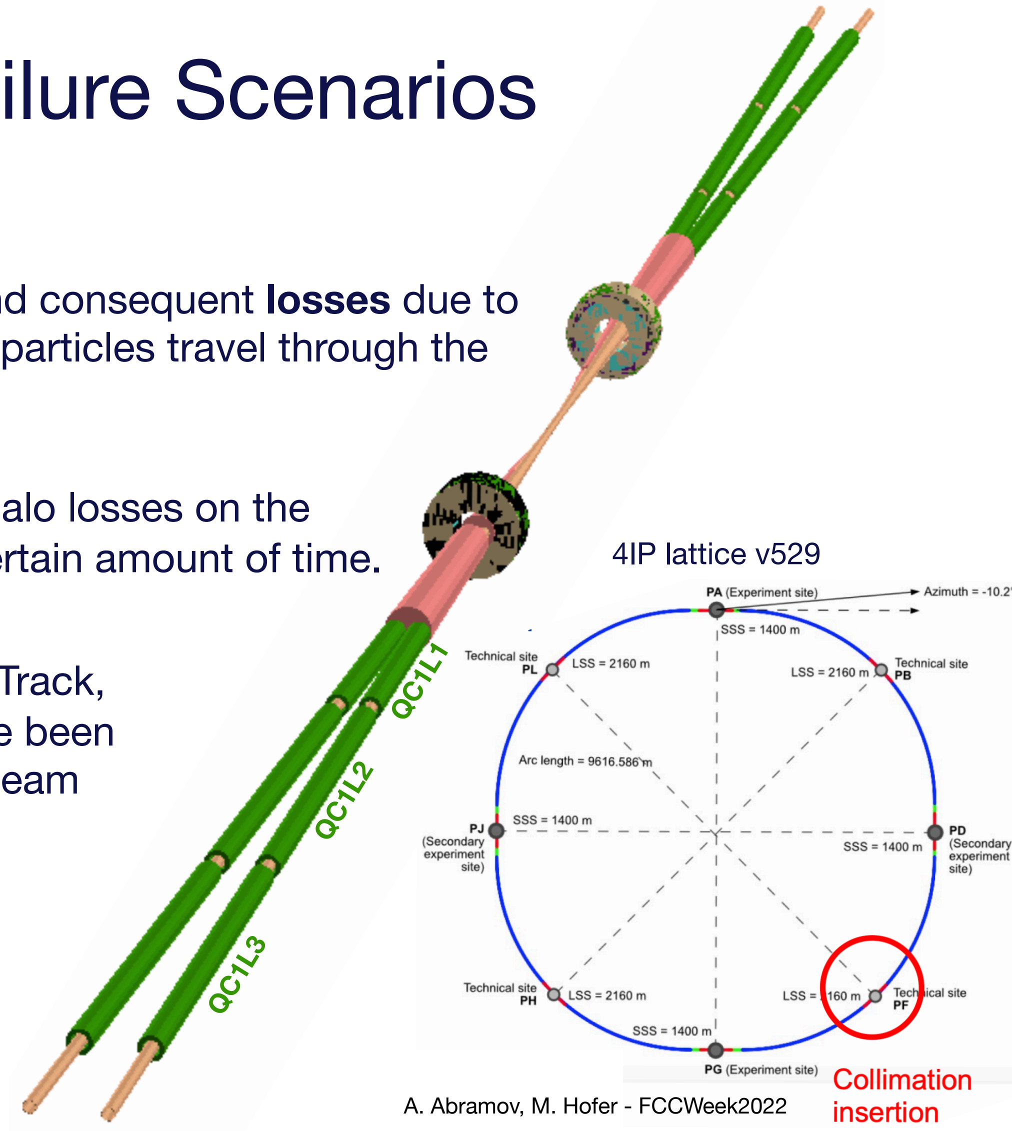
Beam Losses in the IR due to Failure Scenarios

Thanks to A. Abramov for the primary particles.

Several effects can lead to an increase of the beam emittance and consequent **losses** due to these particles impacting on the **main collimator.** The deflected particles travel through the machine and a fraction will hit the beam pipe in the **MDI region.**

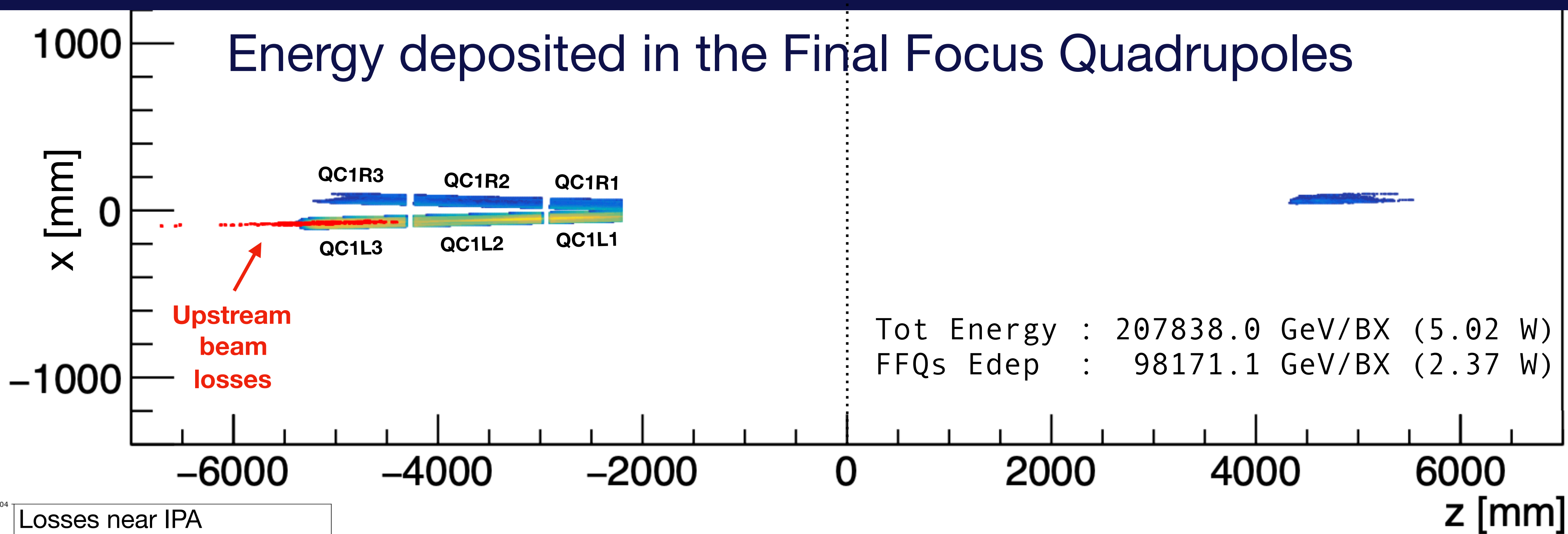
The considered scenario is a **drop of the beam lifetime** due to halo losses on the primary collimator (located in PF) **to 5 minutes**, tolerated for a certain amount of time.

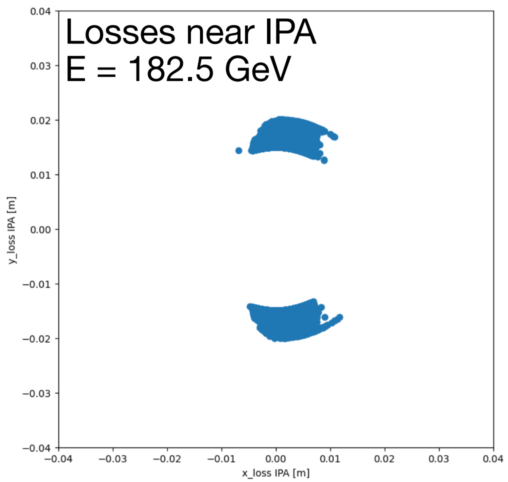
A **182.5GeV beam** has been tracked in the latest lattice using X-Track, and particles hitting the beam pipe in the **±7m from the IPA** have been tracked in the **CLD model of Key4HEP,** adapted for the 20mm beam pipe and the three elements of QC1.



A. Abramov, M. Hofer - FCCWeek2022

Energy deposited in the Final Focus Quadrupoles





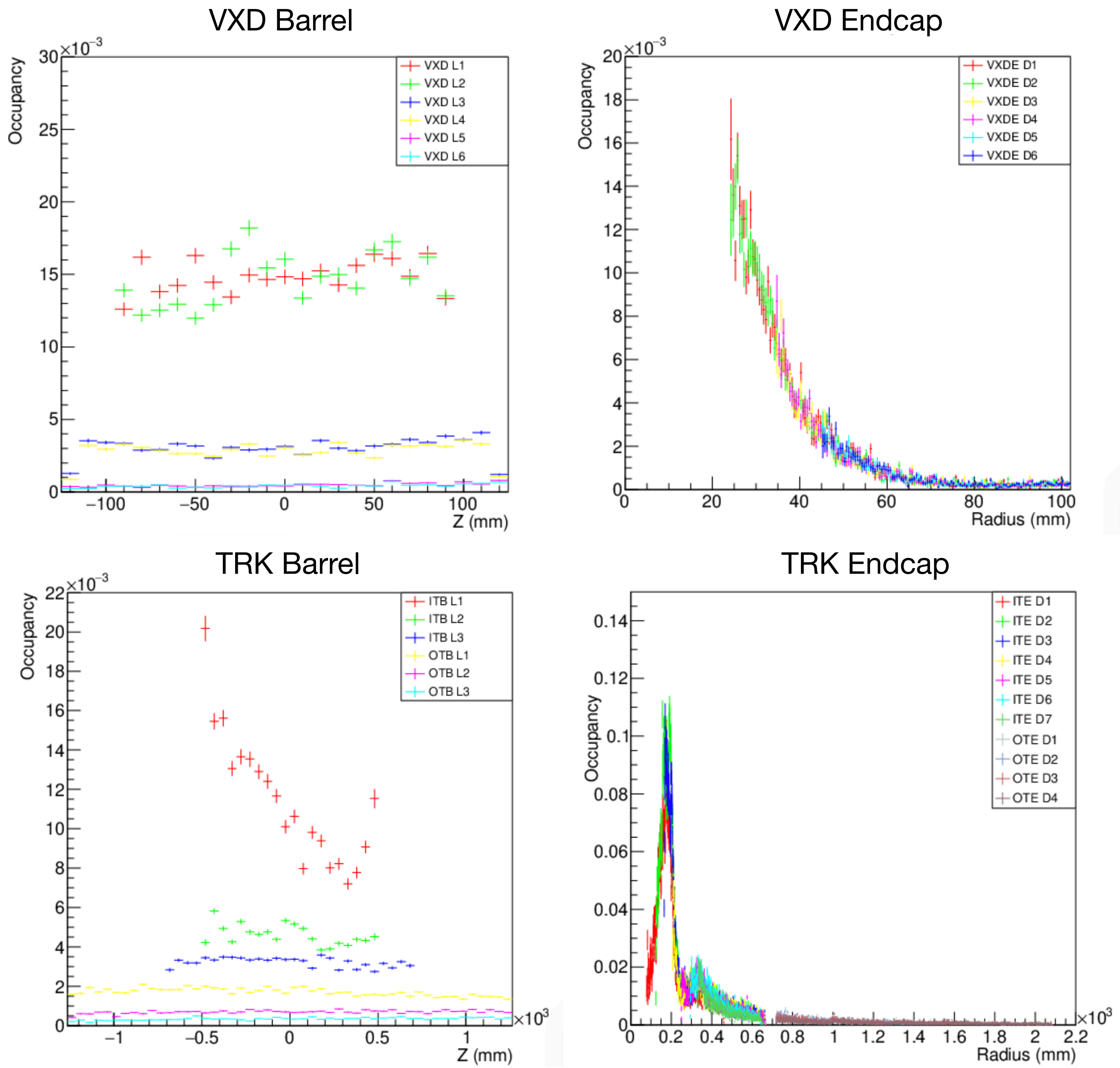
The beam losses happen **in correspondence of QC1**, so I modified the model of these elements to make them sensitive. From the tracking, most of the energy will be deposited in the **upstream quadrupoles**, for a total power of **2.37 W** continuous for the duration of the failure.

From preliminary calculations this should be well **below the quench limit** of the quadrupoles. Upcoming studies on this include other working point (in particular **Z**) and other effects (i.e. losses due to bhabhas).

Single Beam Induced Occupancy

The particle from the beam hitting the beam pipe will produce a **shower of secondaries**, causing the occupancy to rise up to **several percent points**, in particular in the IT.

This background level is higher than the rule-of-thumb value of 1%, therefore either some **mitigation strategies** should be applied, or this failure scenario is **not suited** for sustaining data acquisition.



```
TaShield_BH2        :  V = 3.595e-05 [m^3]    ->    0.69 [kg]
TaShield_AH         :  V = 7.756e-03 [m^3]    ->  149.69 [kg]
TaShieldTopPart     :  V = 1.235e-03 [m^3]    ->   23.83 [kg]
TaShieldTopPart2    :  V = 6.852e-05 [m^3]    ->    1.32 [kg]
TaShieldFiller1     :  V = 1.273e-04 [m^3]    ->    2.46 [kg]
TaShieldFiller2     :  V = 1.238e-04 [m^3]    ->    2.39 [kg]
-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-
Total               :  V = 9.346e-03 [m^3]    ->  180.39 [kg]

         QC1L1      :  V = 1.282e-03 [m^3]    ->    4.32 [kg]
         QC1L2      :  V = 2.289e-03 [m^3]    ->    7.71 [kg]
         QC1L3      :  V = 2.289e-03 [m^3]    ->    7.71 [kg]
```

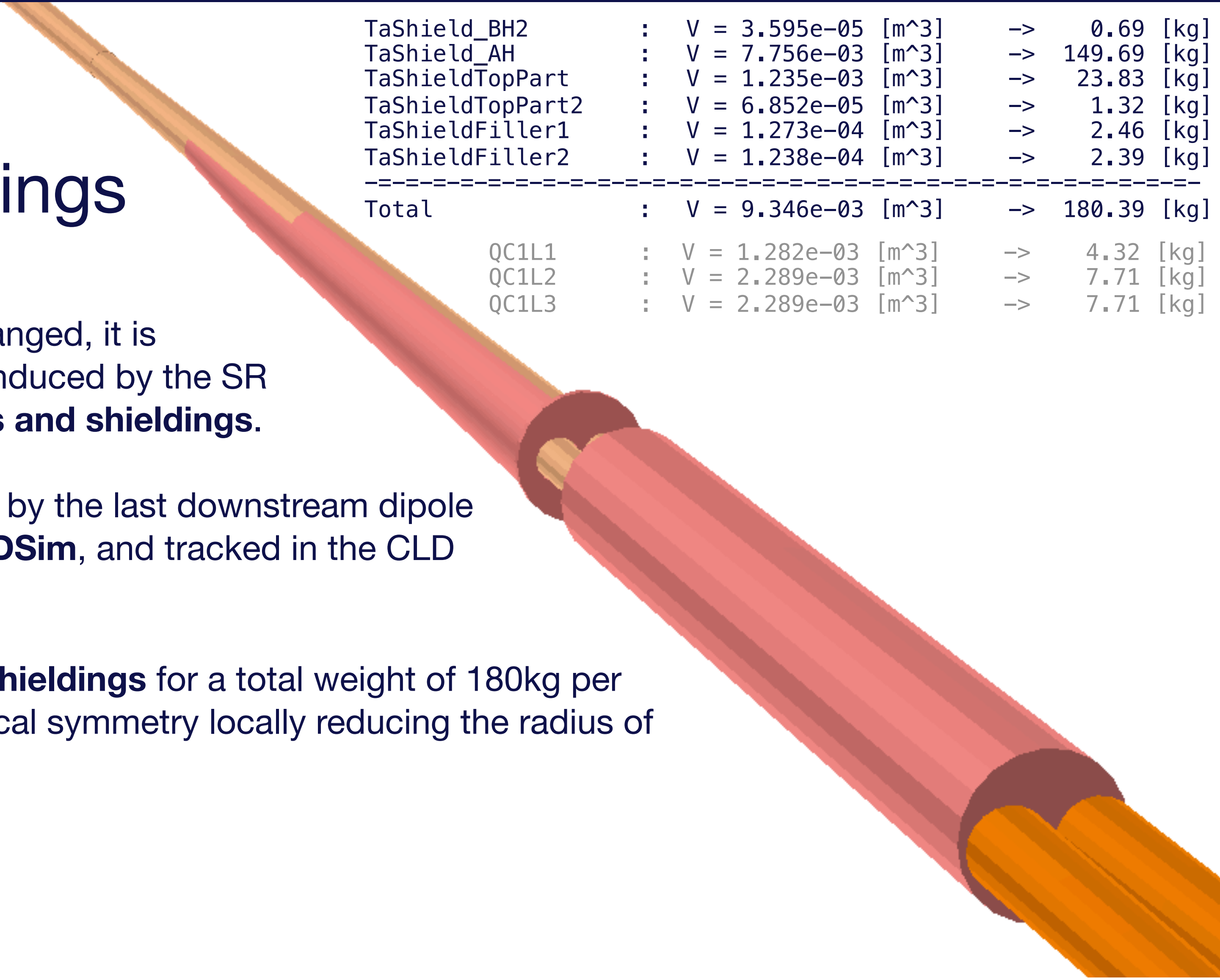
SR Mask and Shieldings

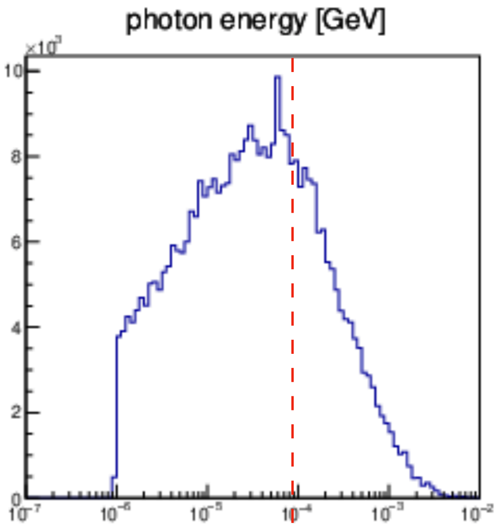
Thanks to K. André for the primary particles.

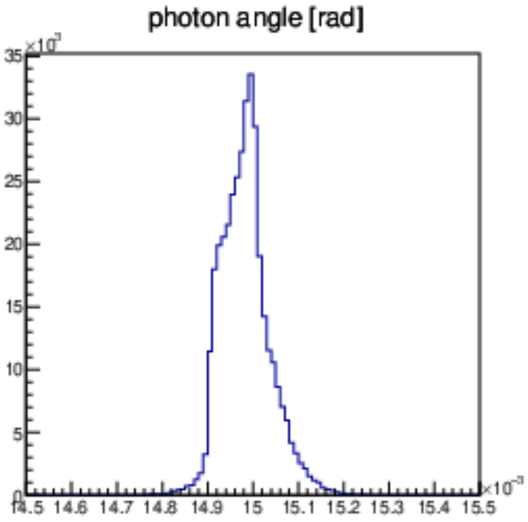
As the lattice and the beam pipe has changed, it is necessary to redefine the **background** induced by the SR and the features of the dedicated **masks and shieldings**.

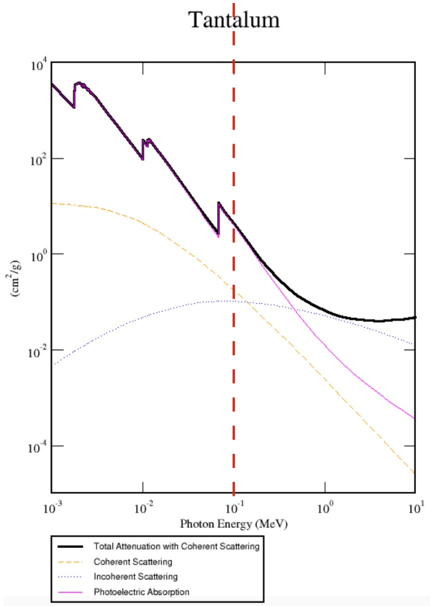
Synchrotron radiation photons produced by the last downstream dipole (no FFQs for now) are produced using **BDSim**, and tracked in the CLD detector model using Key4HEP.

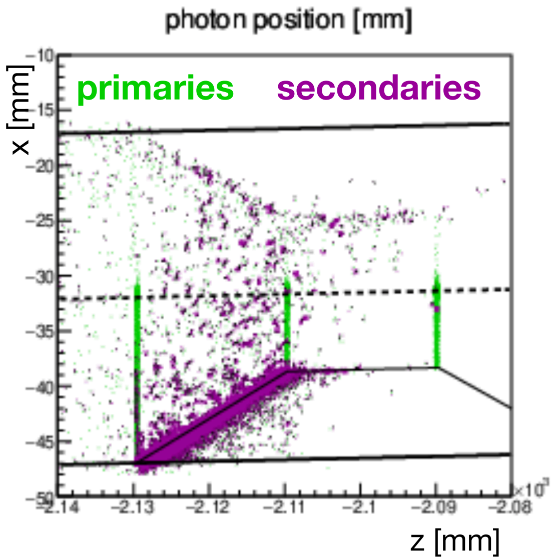
The implemented model has **Tungsten shieldings** for a total weight of 180kg per side, and a **Tantalum mask** with cylindrical symmetry locally reducing the radius of the beam pipe to 7mm.





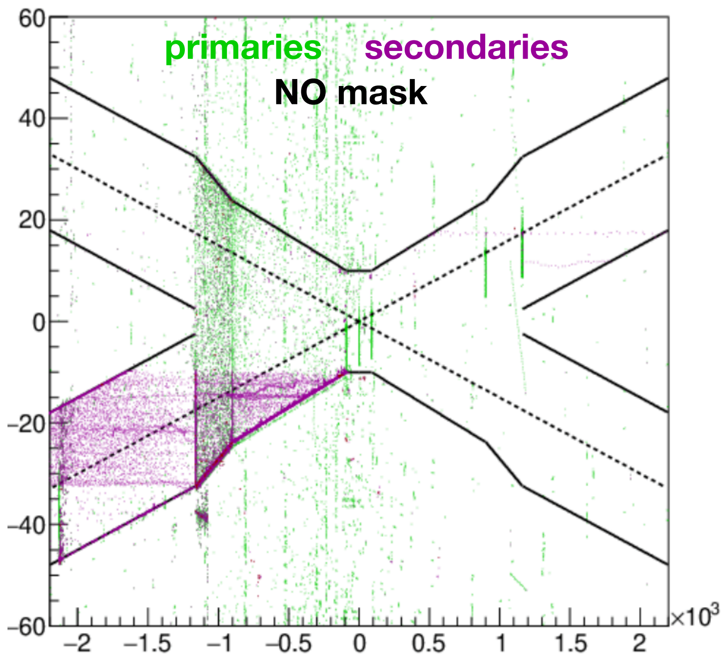


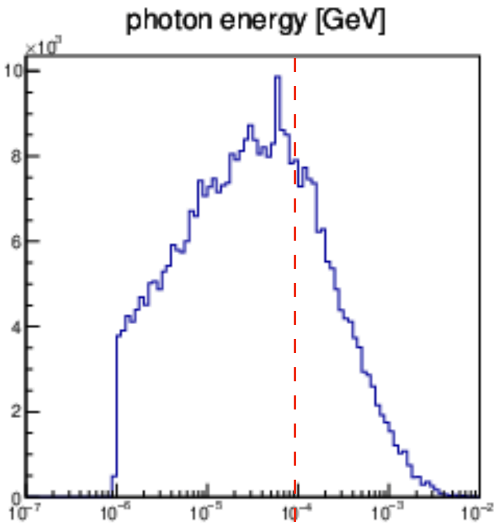


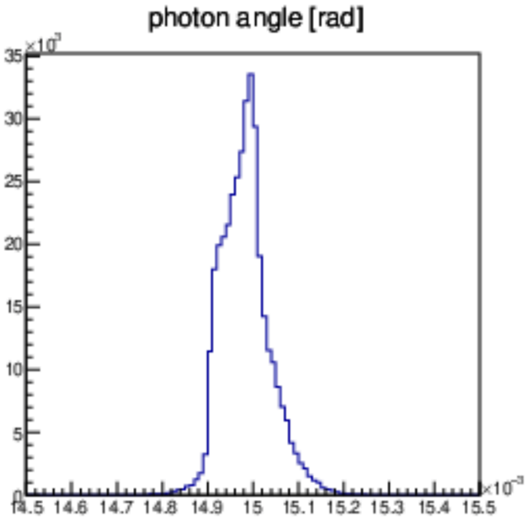


Due to the critical energy of **~100keV** the interaction of these photons with the tantalum mask is dominated by **photoelectric effect.**

From this **preliminary study**, most of the secondaries impacting on the mask are **absorbed or deflected by the mask itself.**







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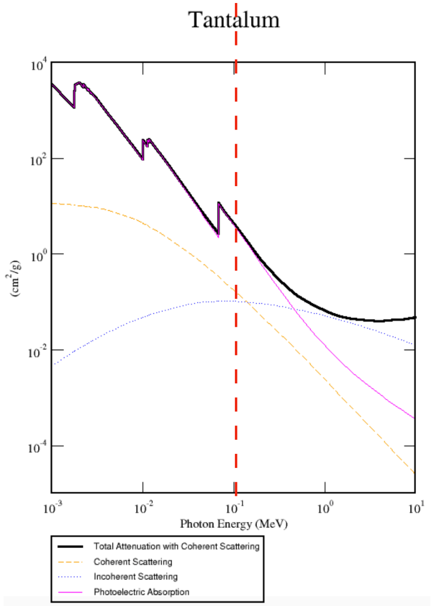
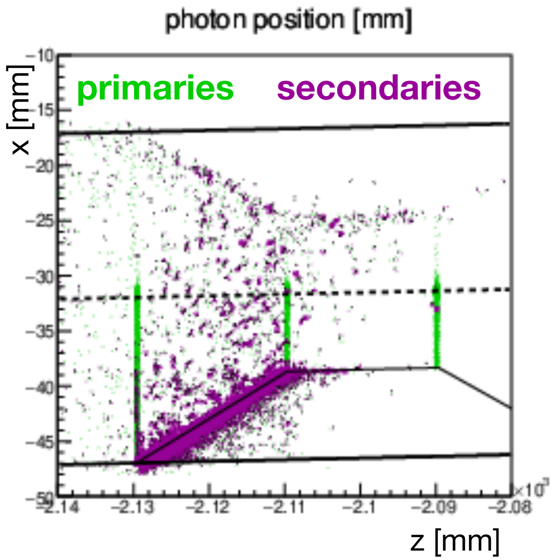
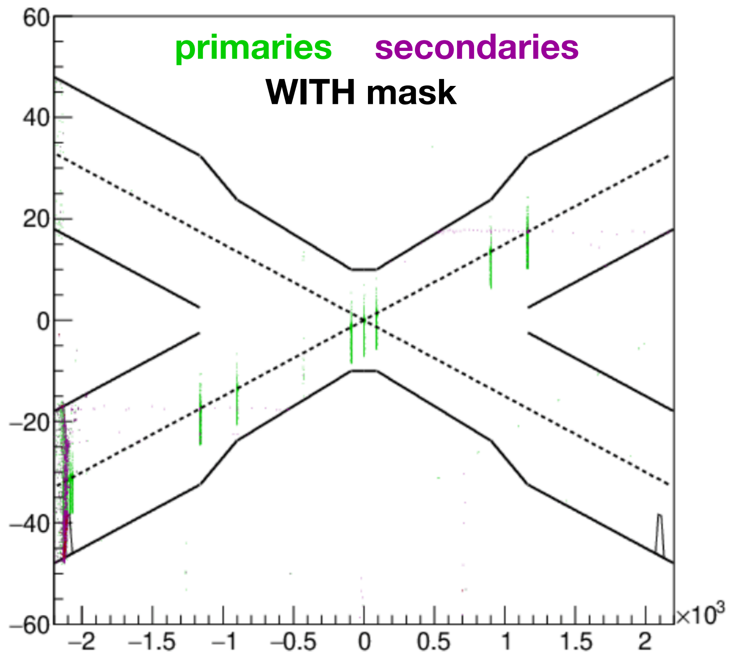




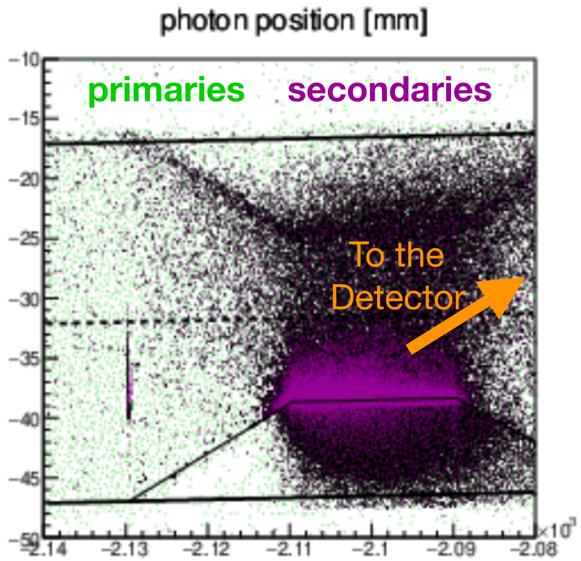


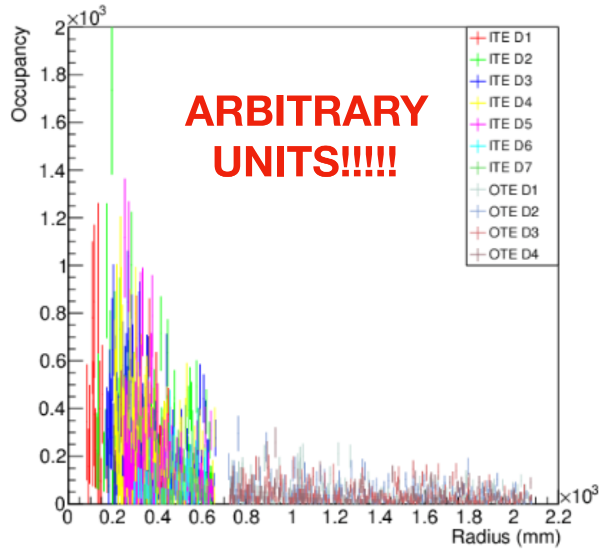
Special attention should be given to the photons which will impact **the tip of the mask**, as they are the main source of potential background in the detector.

As a **first approach** I simulated a monochromatic pointlike 1MeV photon beam impinging 50um from the edge of the mask, showing a large number of hits in the detectors, in particular in the **tracker endcaps.**

More detailed studies (using key4HEP, ddsim, Geant4) are currently in progress in order to understand better the **nature** and **features of the secondary particles** produced.

At the moment, the interaction of the particles with the material of the mask is left to Geant4, but the use of a **dedicated tool** to produce the scattered particles is of course still a valid an option.





Beamstrahlung radiation Characterisation

Beamstrahlung is a **dominant process** for the lifetime at FCCee due to the small beam size and high population.

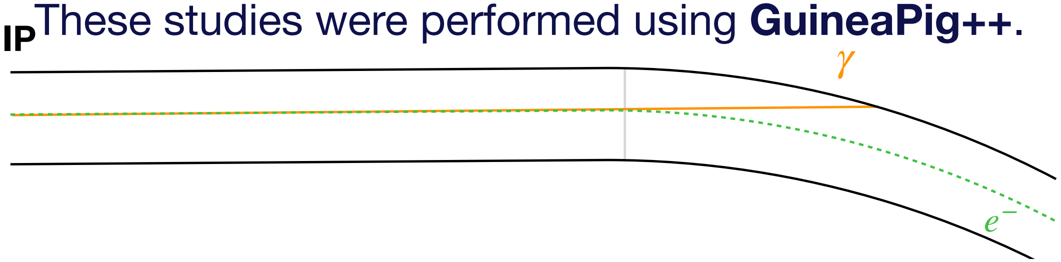
$$\Upsilon \sim \frac{5}{6}\frac{r_e^2 \gamma N_e}{\alpha \sigma_z (\sigma_x + \sigma_y)}$$

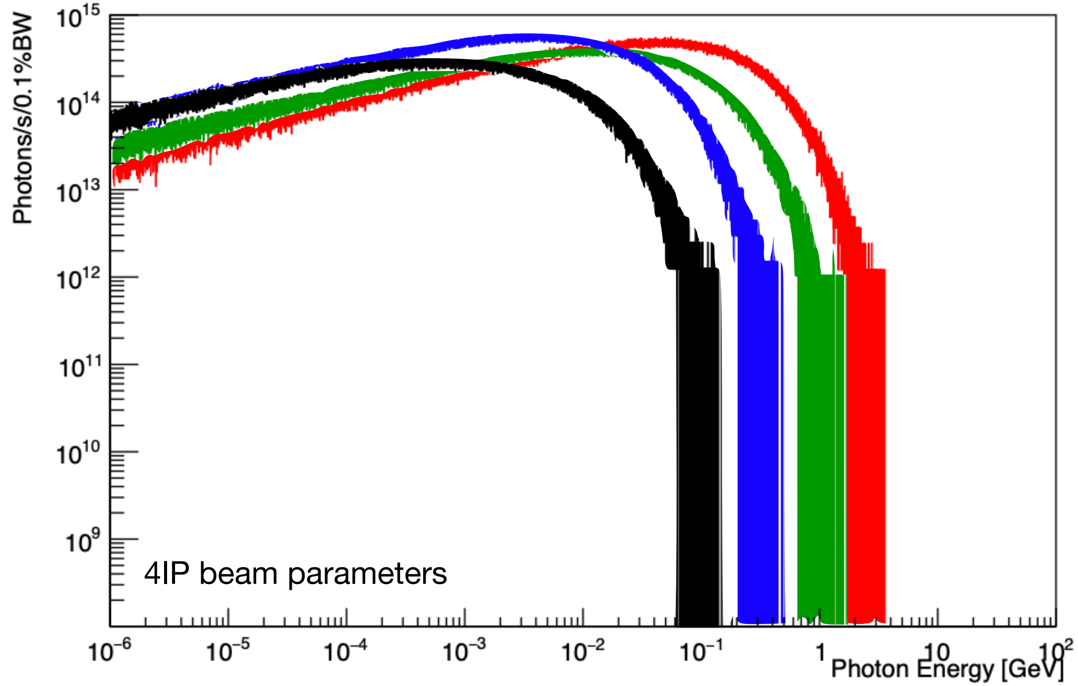
$$< E_\gamma > \sim E \times 0.462 \Upsilon$$

$$n_\gamma \sim 2.54 \left[\frac{\alpha^2 \sigma_z}{r_e \gamma}\Upsilon\right] \frac{1}{[1+\Upsilon^{2/3}]^{1/2}}$$

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.

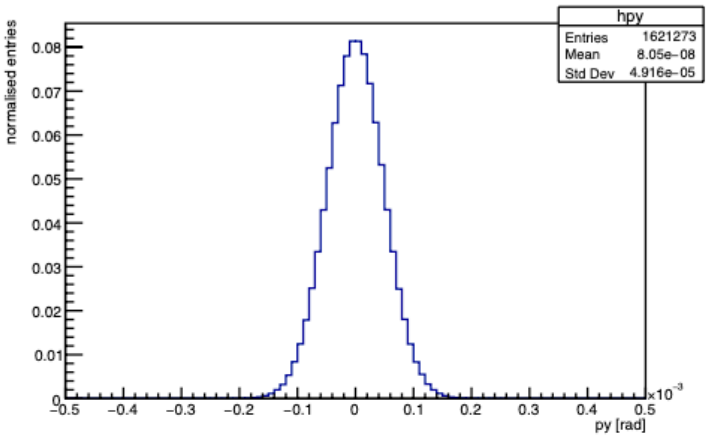
These studies were performed using **GuineaPig++**.

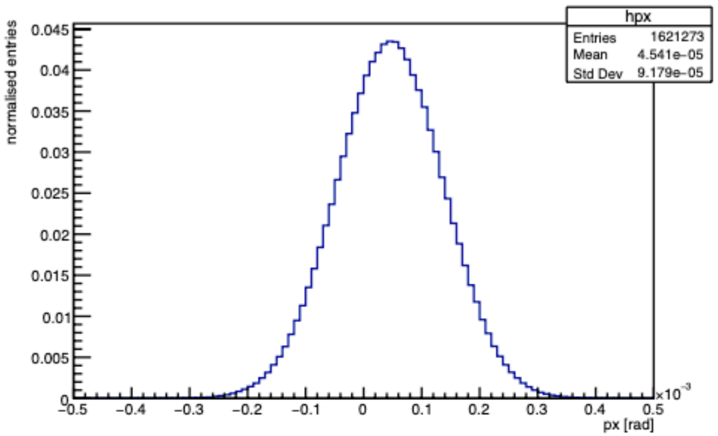


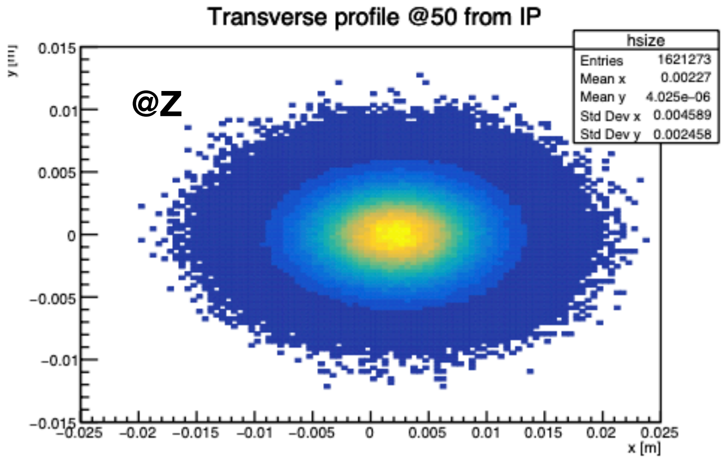


	Total Power [kW]	Mean Energy [MeV]
Z	370	1.7
WW	236	7.2
ZH	147	22.9
Top	77	62.3

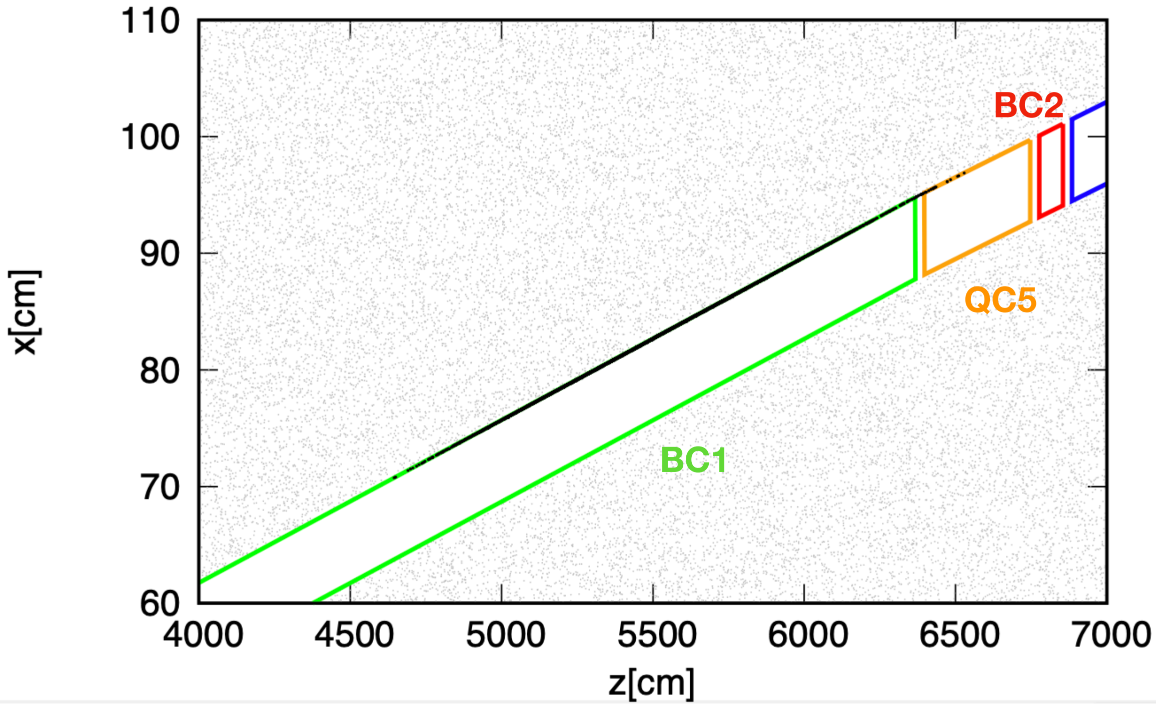
Photons are emitted in a **very narrow cone** ($\propto 1/\gamma$) in the direction of the particle which produced them. As the beam divergence is $O(10 \sim 100 \mu rad)$, the **transverse spot size** at few hundred meters from the IP will remain in the order of $O(cm^2)$

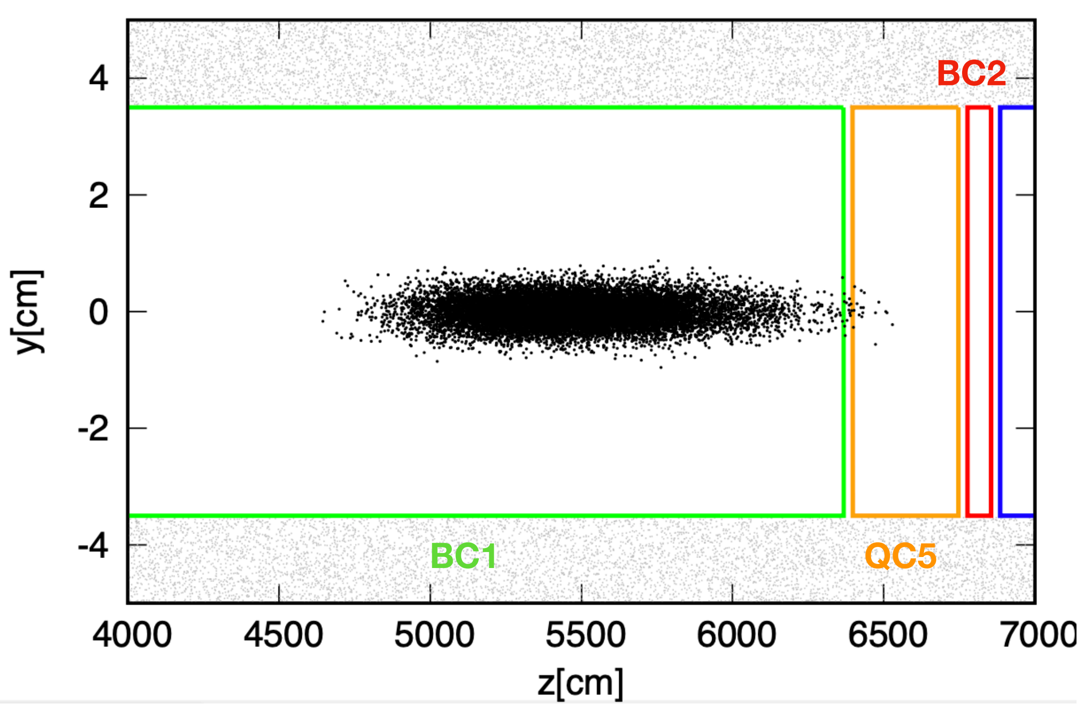






	$\sigma_{px}(\gamma)$ $[\mu rad]$	$\sigma_{py}(\gamma)$ $[\mu rad]$	$\sigma_{px}(e^-)$ $[\mu rad]$	$\sigma_{py}(e^-)$ $[\mu rad]$	$\sigma_x(\gamma)$ $[mm]$ @ $50m$	$\sigma_y(\gamma)$ $[mm]$ @ $50m$
Z	91.8	49.2	84.3	42.1	4.59	2.46
WW	110	73.0	103.4	65.7	5.50	3.65
ZH	51.7	41.3	46.2	35.9	2.58	2.06
Top	44.6	50.3	38.6	43.2	2.23	2.51



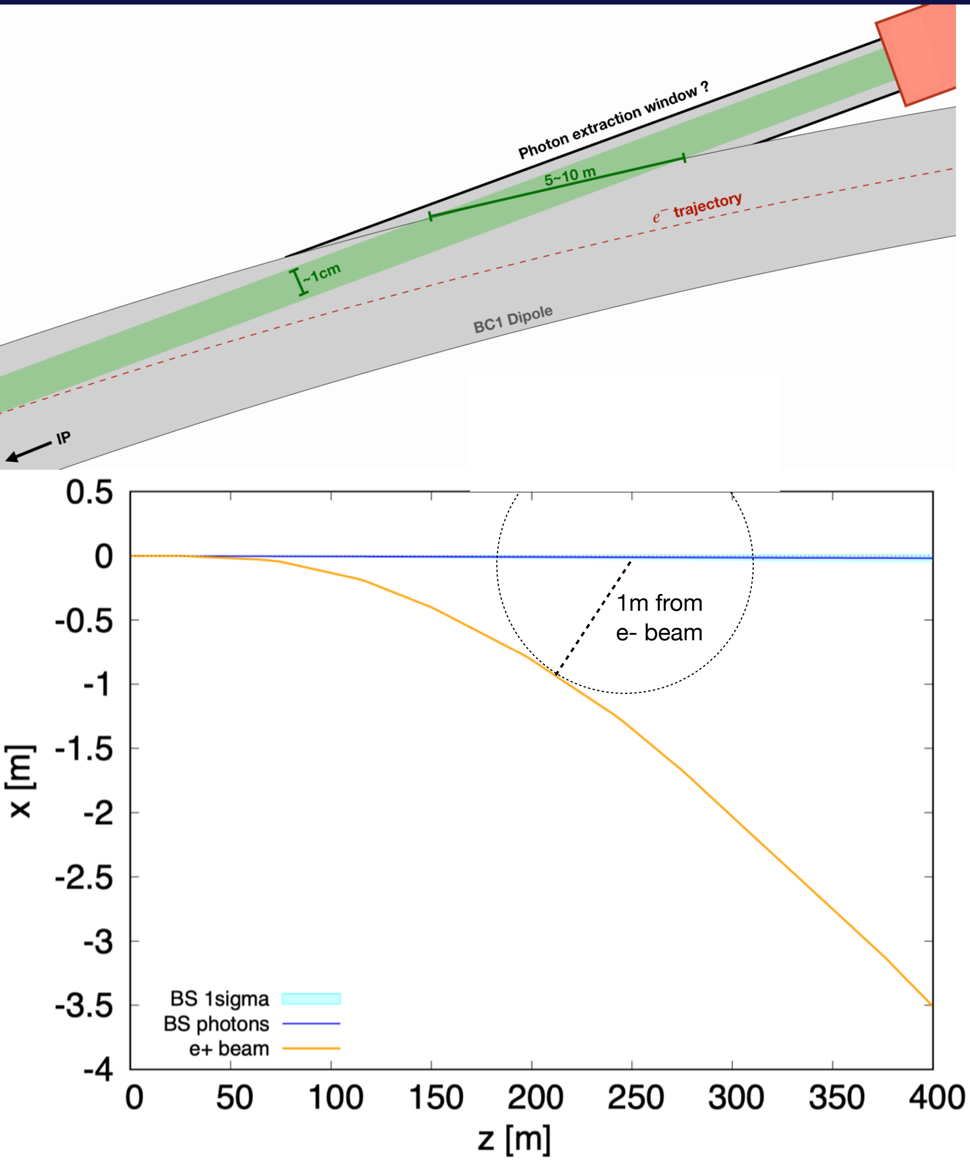


BS photons @Z tracking in the GDML description of lattice 217 - 2IPs. Photons hit the pipe mostly in **BC1**.

Drift spaces between elements in this part of the lattice is 30cm

No tracking performed yet on the latest lattice v530 - 4IPs (no GDML description available), but small changes are expected:

- BC1 ends at s=64.25m instead of s=63.70
- bending angle might be slightly different - to be checked



Beam dump for Beamstrahlung photons

Due to the very high power $O(100kW)$ it is necessary to have a **beam dump** for the beamstrahlung photons.

Several constraints like the long **extraction line** window, the **distance** of the dump from the beam pipe, and the **placement into the cavern** are all currently under study .

Also the possibility to have an **instrumented beam dump** to measure properties of the colliding beams at the IP is under investigation.

Conclusions and Next Steps

- The **Vertex Detector Barrel** for CLD has been adapted to the **R=10mm** central beam pipe

- **IPC induced occupancy** in the CLD VXD is **below the 1%** also for the now closer VXD Barrel

- Tracking of the **beam losses:**
  - occupancy @ttbar up to 10%, mitigation strategies should be investigated
  - repeat the study for different **failure scenarios** and **beam parameters**
  - the energy deposited in the **FFQs** is well below the SC material quench limit

- Preliminary study of the **SR masks and shieldings** efficiency started, and will focus on the photons hitting the tip of the mask, as they can be scattered and produce background in the detector

- **Beamstrahlung** radiation can reach up to **>300kW** with a divergence of $O(10 \sim 100 \mu rad)$
  - photons will hit the beam pipe at the **first downstream dipole** (~60m from IP)
  - a dedicated **beam dump** must be designed to absorb all this power
  - possibility to have an **instrumented beam dump** is also under investigation

- Up Next: repeat occupancy studies for the **IDEA** detector, extend to the other **working points** (in particular Z!)

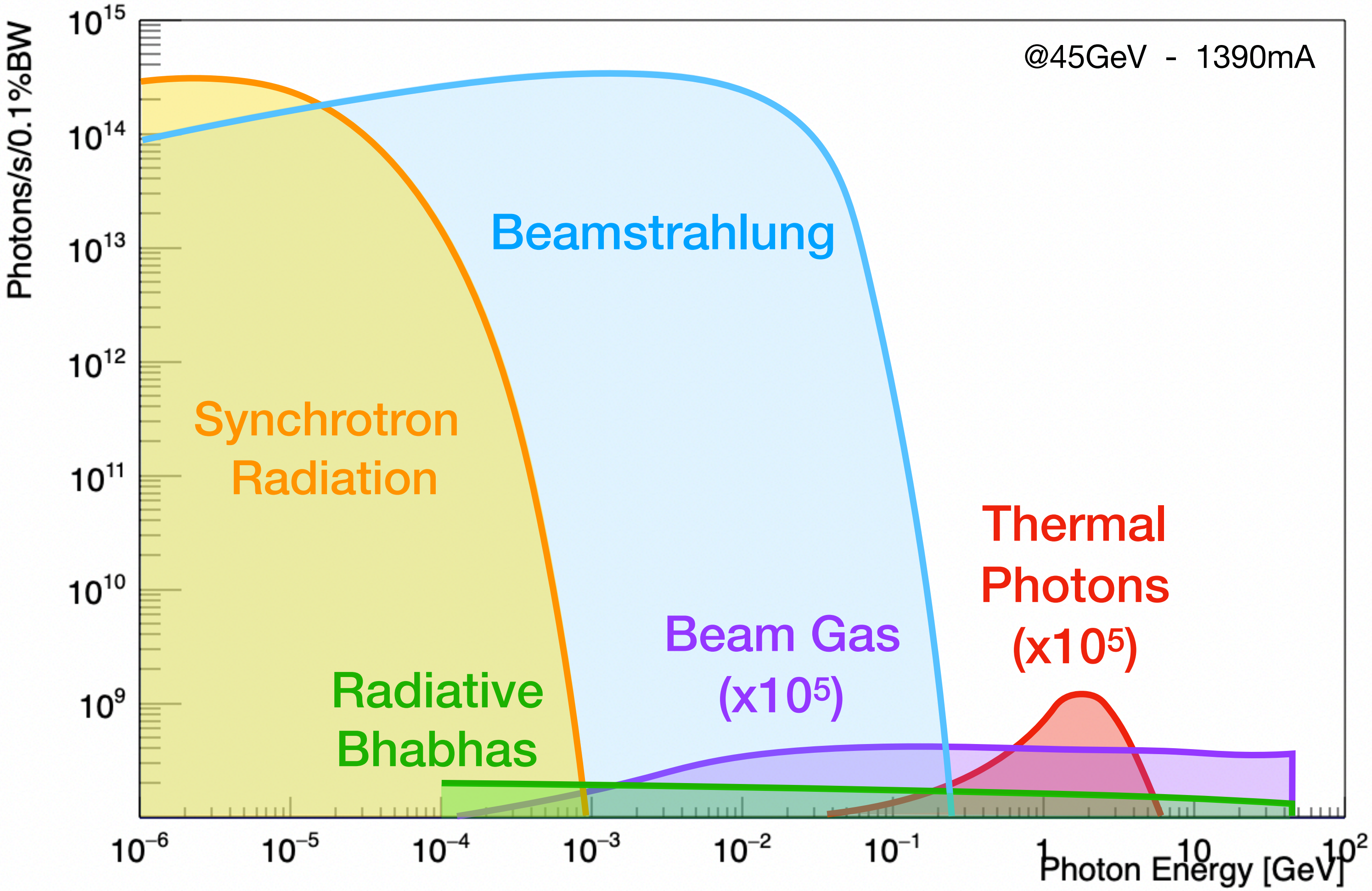
THANK YOU FOR YOUR ATTENTION

BACK-UPS

		CDR parameters				4IP PA31-1.0 (mar '22)			
[GeV]	**E**	45,6	80	120	182,5	45,6	80	120	182,5
[m.rad]	**emitt_x**	2,70E-10	8,40E-10	6,30E-10	1,46E-09	7,10E-10	2,16E-09	6,40E-10	1,49E-09
[m.rad]	**emitt_y**	1,00E-12	1,70E-12	1,30E-12	2,90E-12	1,42E-12	4,32E-12	1,29E-12	2,98E-12
[m]	**beta_x**	0,15	0,2	0,3	1	0,1	0,2	0,3	1
[m]	**beta_y**	0,0008	0,001	0,001	0,0016	0,0008	0,001	0,001	0,0016
[m]	**sigma_x**	6,364E-06	1,296E-05	1,375E-05	3,821E-05	8,426E-06	2,078E-05	1,386E-05	3,860E-05
[m]	**sigma_y**	2,828E-08	4,123E-08	3,606E-08	6,812E-08	3,370E-08	6,573E-08	3,592E-08	6,905E-08
[rad]	**sigma_px**	4,243E-05	6,481E-05	4,583E-05	3,821E-05	8,426E-05	1,039E-04	4,619E-05	3,860E-05
[rad]	**sigma_py**	3,536E-05	4,123E-05	3,606E-05	4,257E-05	4,213E-05	6,573E-05	3,592E-05	4,316E-05
[m]	**sigma_z**	1,21E-02	6,00E-03	5,30E-03	2,54E-03	1,54E-02	8,01E-03	6,00E-03	2,80E-03
[1]	**Ne**	1,70E+11	1,50E+11	1,80E+11	2,30E+11	2,43E+11	2,91E+11	2,04E+11	2,37E+11
[1]	**nbunch**	16640	2000	328	48	10000	880	248	40

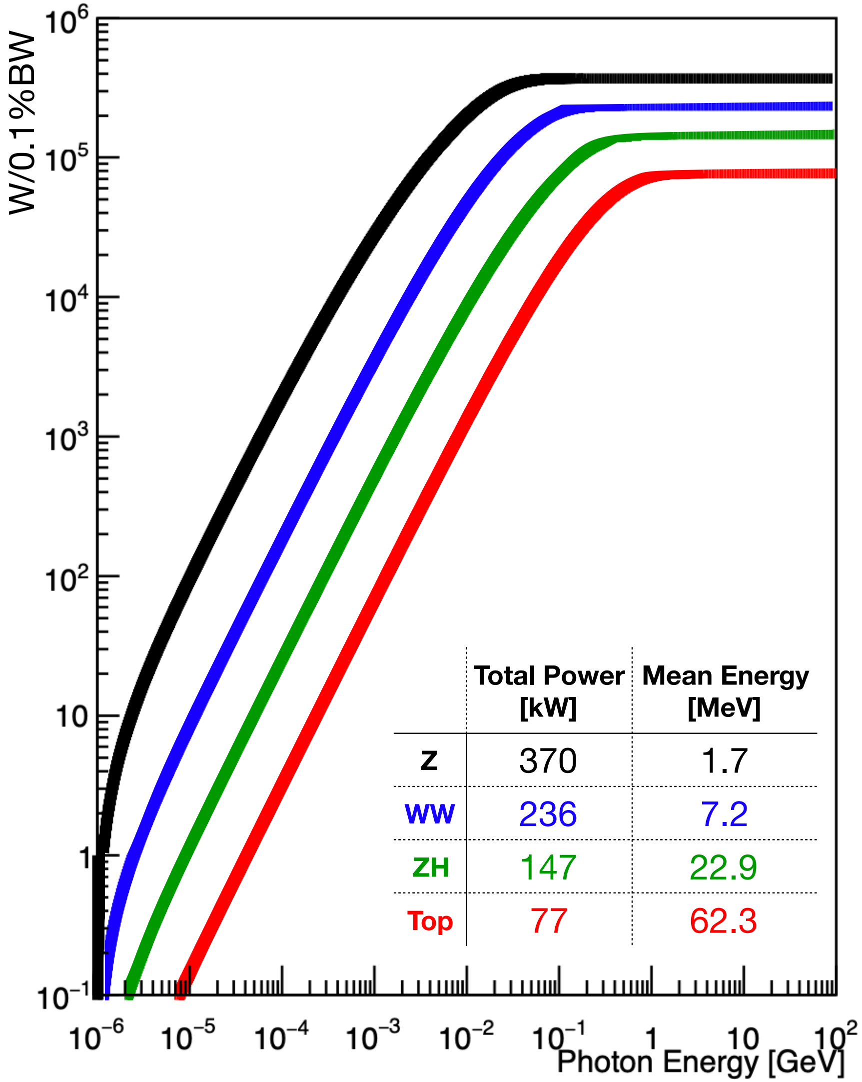
4IP lattice - see K. Oide https://indico.cern.ch/event/1118299/

Sources of radiation collinear to the beam axis

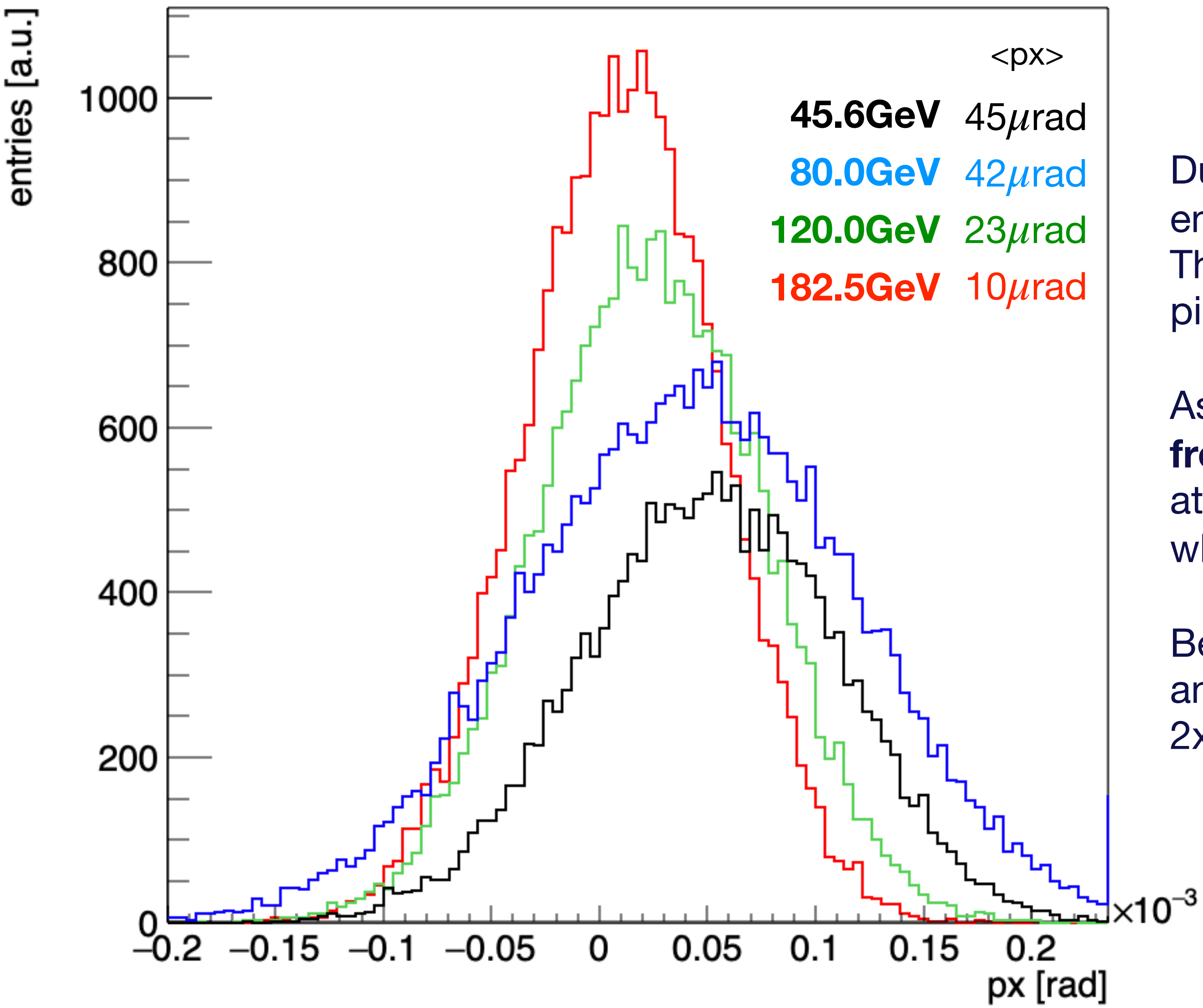


Other than beamstrahlung, there are **other sources of radiation** which can hit the beam pipe at the same downstream spot.

The comparison of the photon flux for the different sources shows that **beamstrahlung** is by far the most intense source by several orders of magnitude.



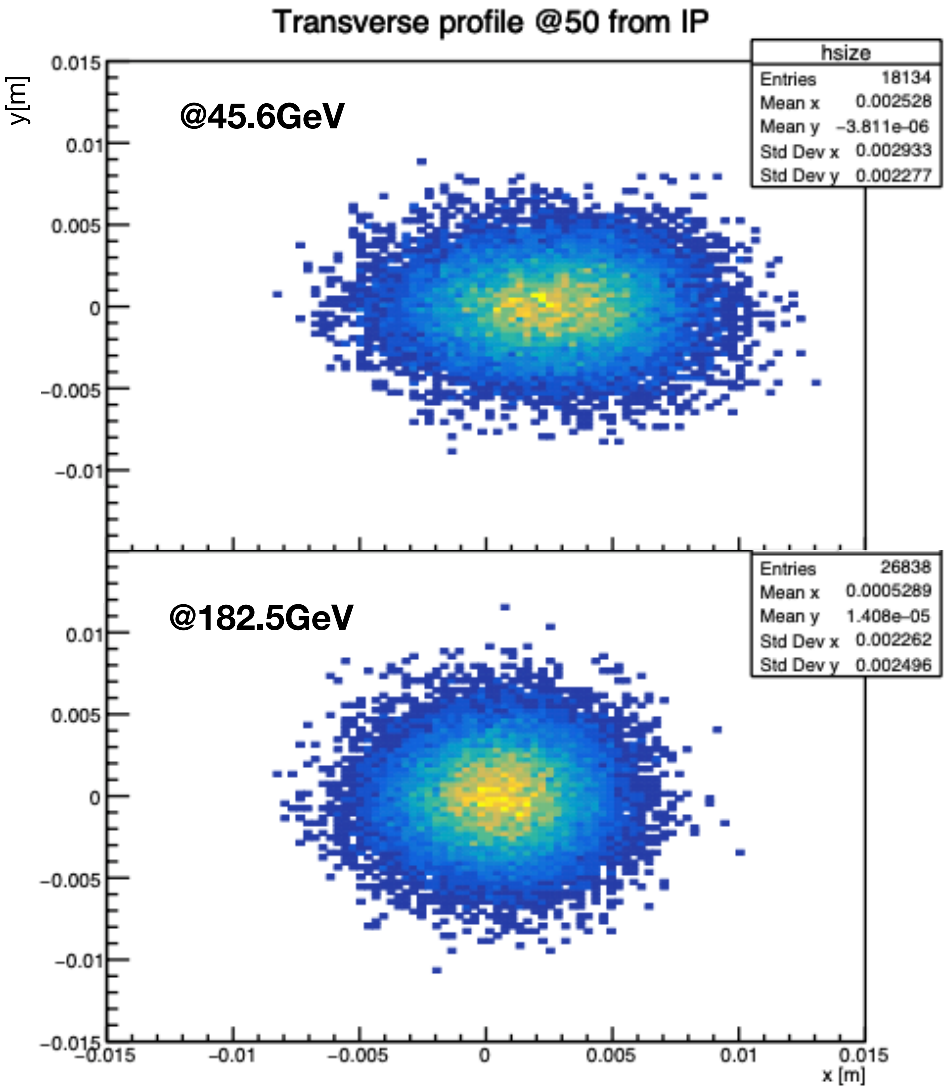
	Total Power [kW]	Mean Energy [MeV]
Z	370	1.7
WW	236	7.2
ZH	147	22.9
Top	77	62.3



Due to the **different magnetic rigidity**, less energetic particles will receive a stronger kick. This means that the photon beam will hit the pipe in different positions.

As an example, on a transverse plane **@50m from the IP**, the photon distribution produced at the Z will be centered 2mm further than what happens at the ttbar energy.

Being the spot sizes of the order of 1x1cm^2 anyway, all the spots are well contained in a 2x2cm^2 region.



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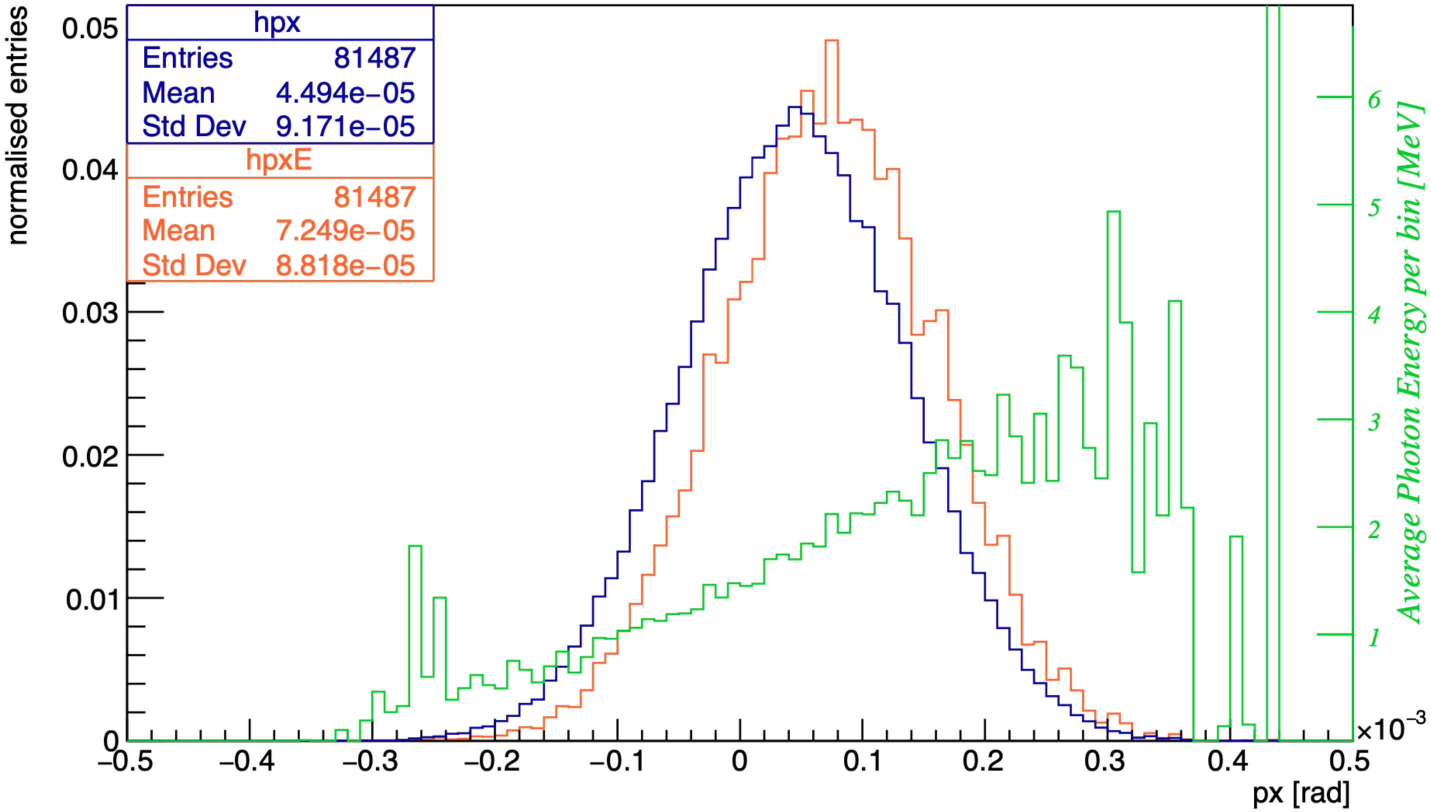
Being the spot sizes of the order of $1x1cm^2$ anyway, all the spots are well contained in a $2x2cm^2$ region.

Please note that the **power peak is slightly shifted** w.r.t. the flux peak. This because the photon energy is directly proportional to the intensity of the beam-beam kick (and therefore the photon horizontal momentum).

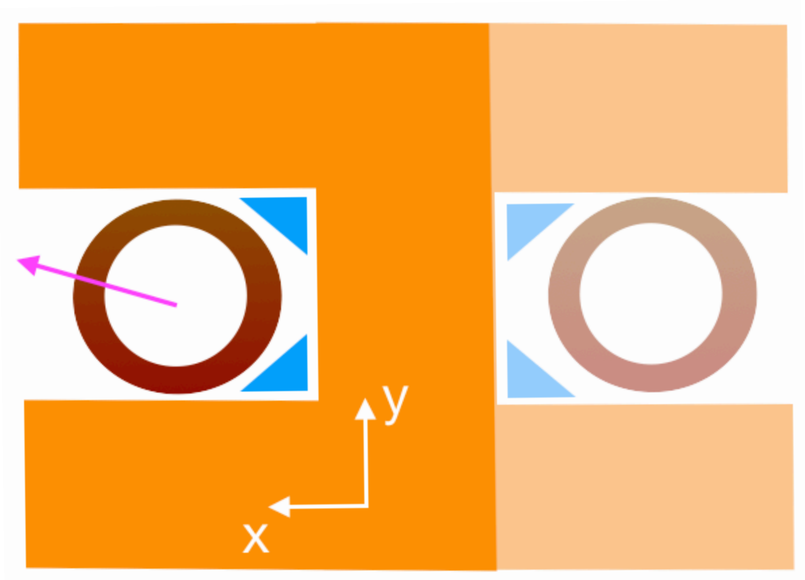
This shift means that the position of the power peak will be shifted of **O(mm) at O(100m)** from the IP



Thanks a lot to D. Shatilov for the extremely useful discussions

The yoke of the dipoles and quadrupoles has a “flipped-H” shape that does not go in the way of the BS radiation, in particular for the dipoles.

Could this be exploited for the photon extraction line?



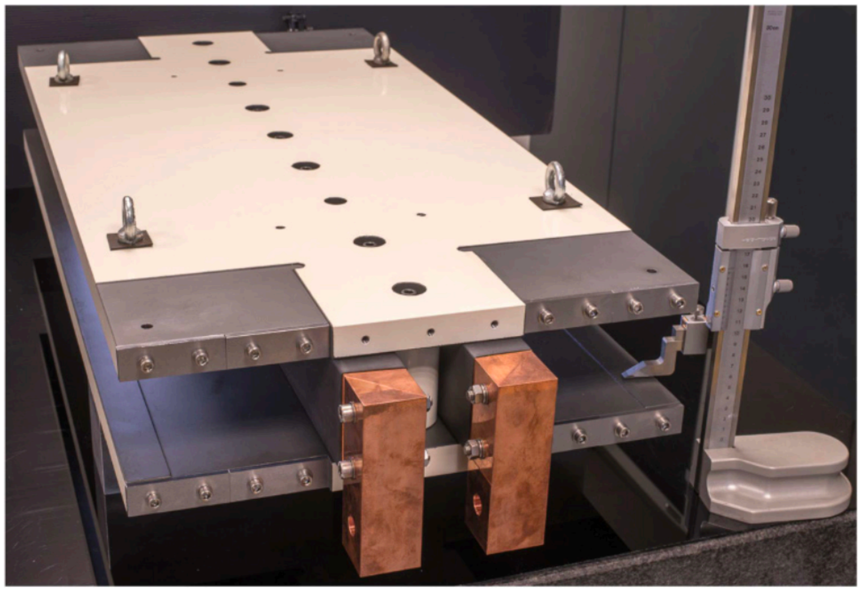


Fig. 3.2. One of the ca. 1 m long model dipole magnets manufactured at CERN.

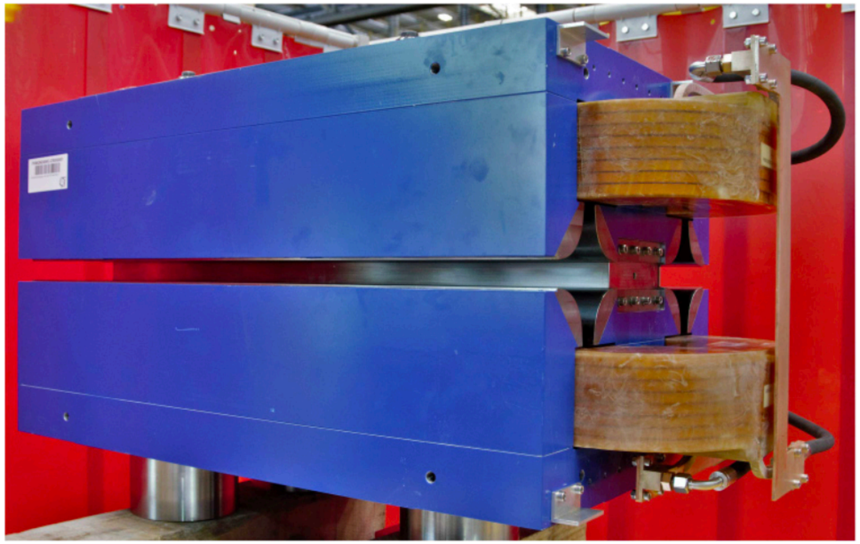
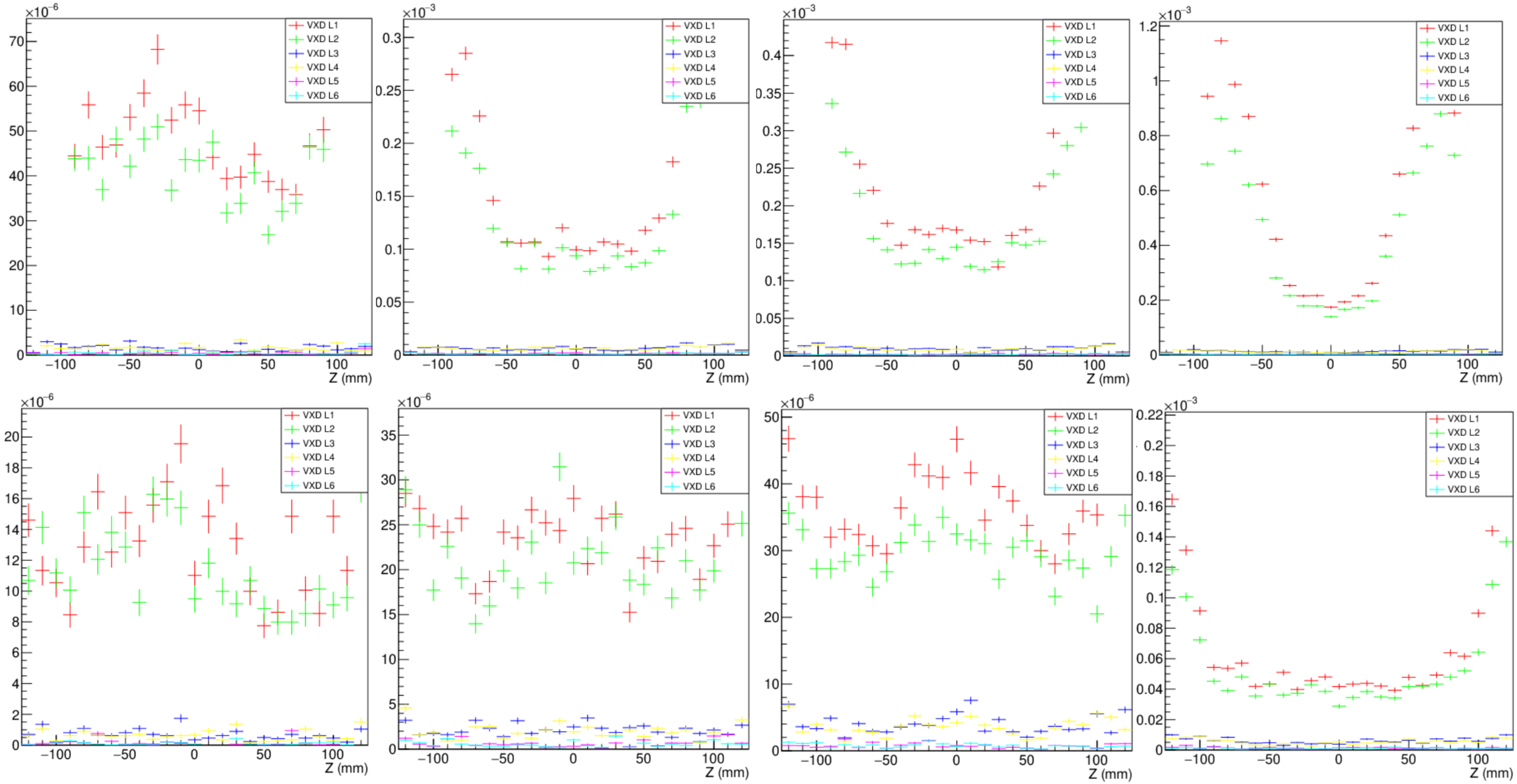


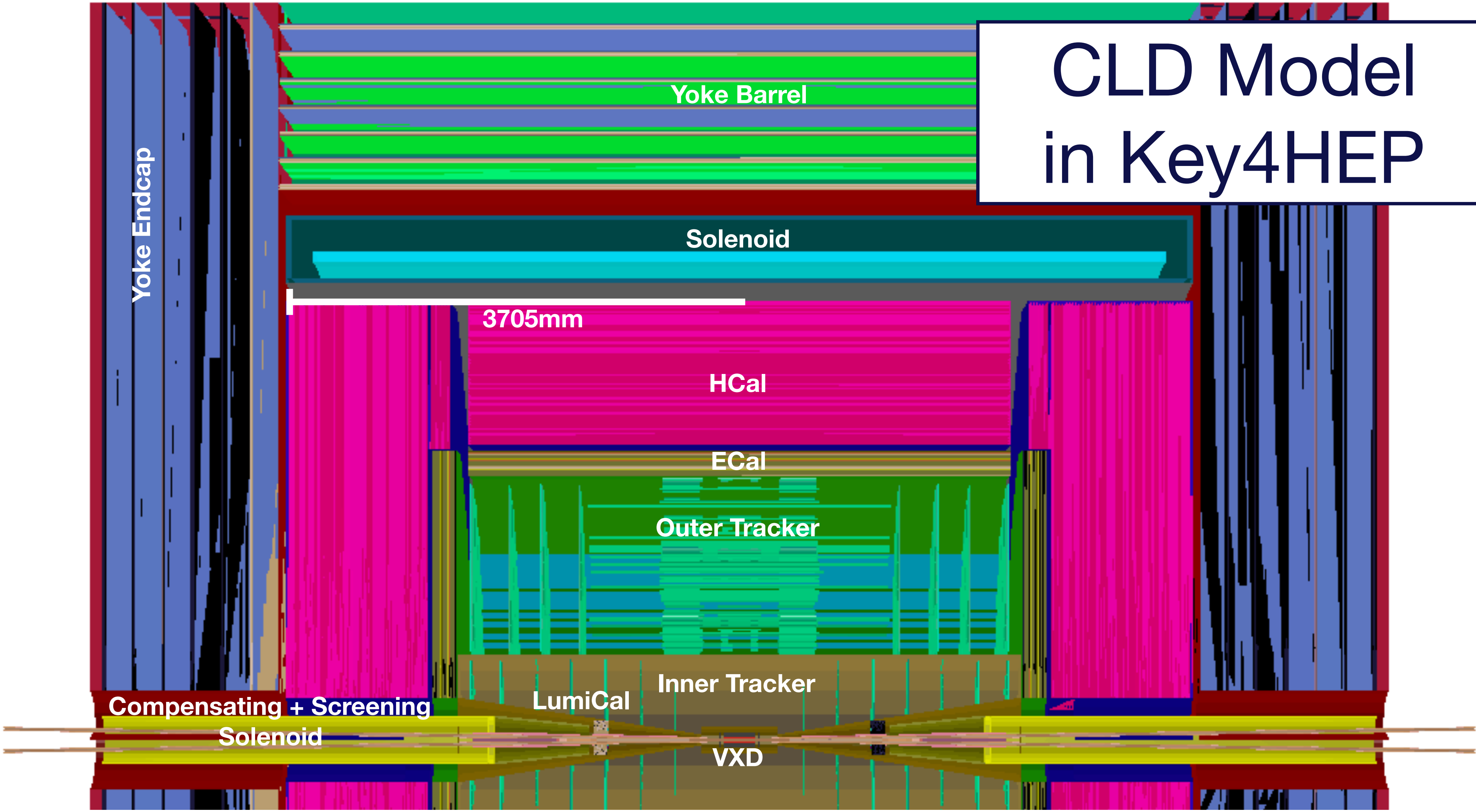
Fig. 3.5. Picture of a 1 m long quadrupole prototype magnet for the FCC-ee.

Z WW ZH Top

New VXD

Old VXD





CLD Model in Key4HEP