DETECTOR BACKGROUNDS IMPACT

Andrea Ciarma

Many thanks to: A. Abramov, K. Andrè, M. Boscolo, E. Perez

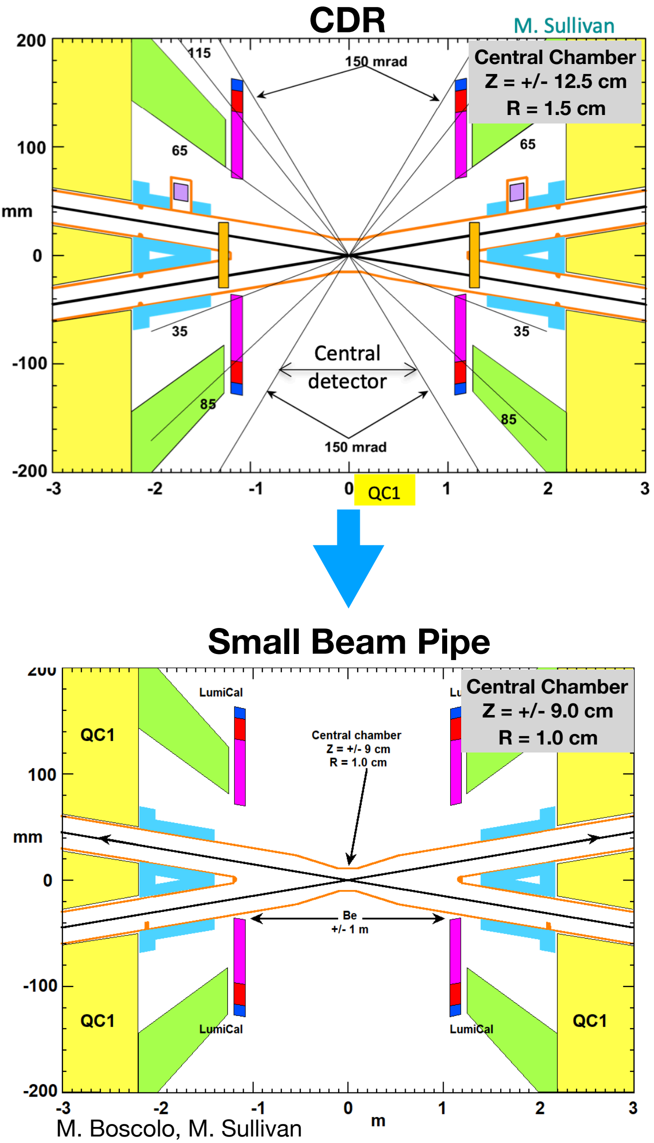
FCC-ee MDI background studies

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** and **radiative Bhabha photons** 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.**



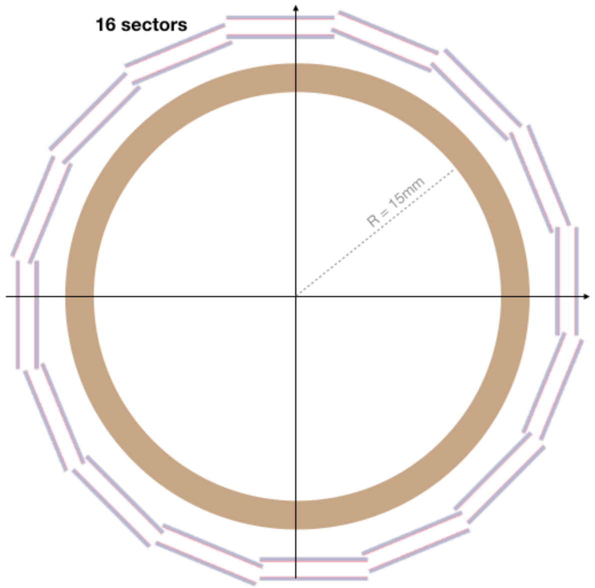
Updated CLD VXD for Small Beam Pipe

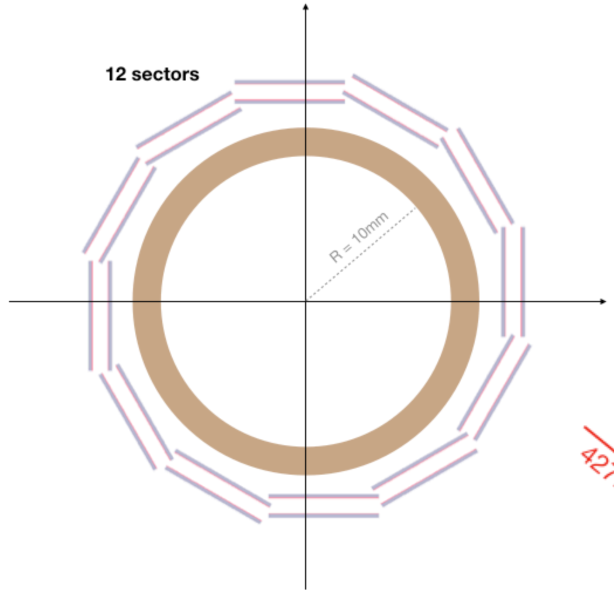
After the CDR, the design for the central chamber of the FCC-ee beam pipe has changed to a reduced radius of **R=10mm** and length of **L=18cm,** allowing to have the inner layer of the Vertex Detector Barrel **closer to the interaction point**.

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:

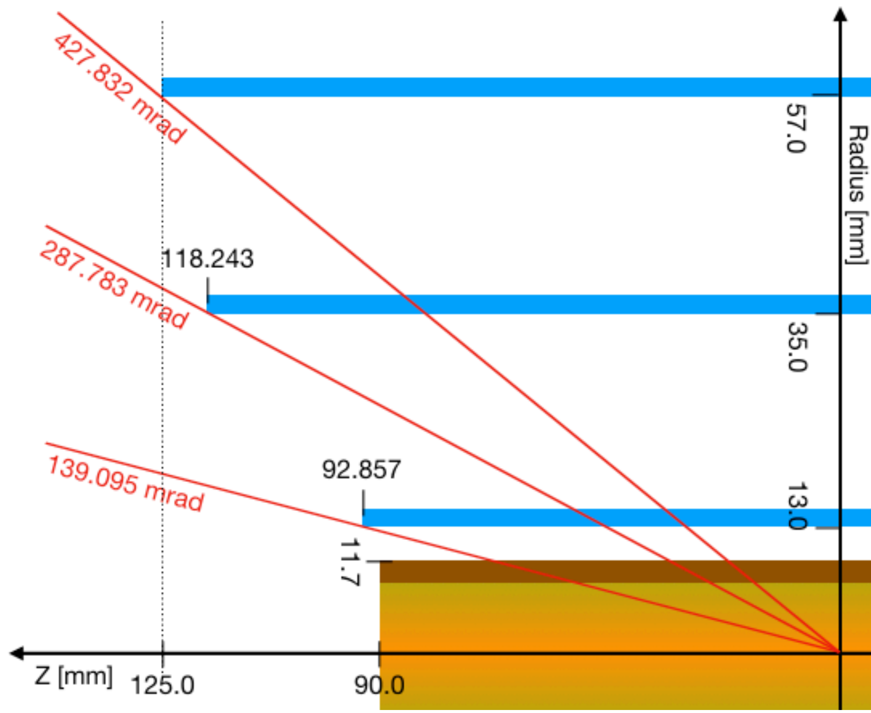
- keeping the **staves width** fixed
- don't change the **angular acceptance** of the layers

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)

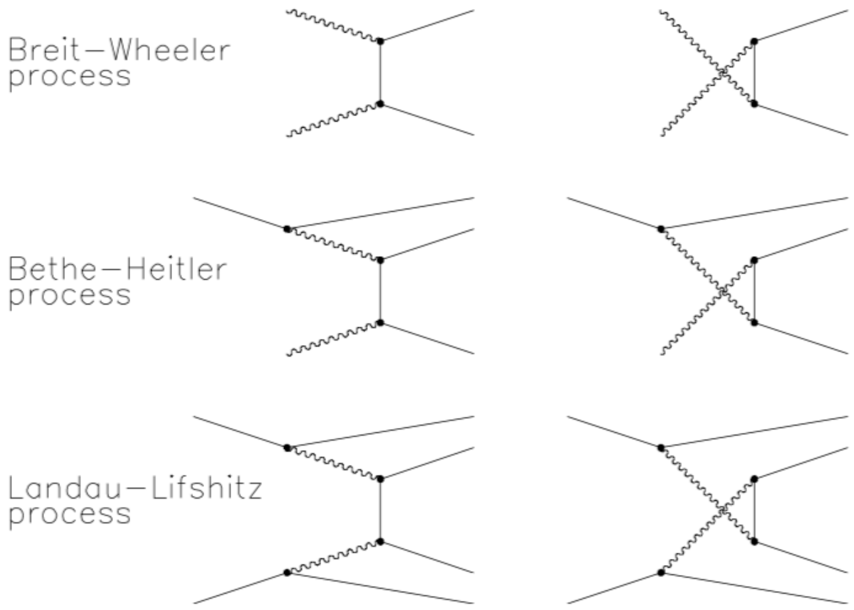
Secondary e^-e^+ pairs can be produced via the interaction of the beamstrahlung photons with real or virtual photons emitted by each particle of the beam during bunch crossing.

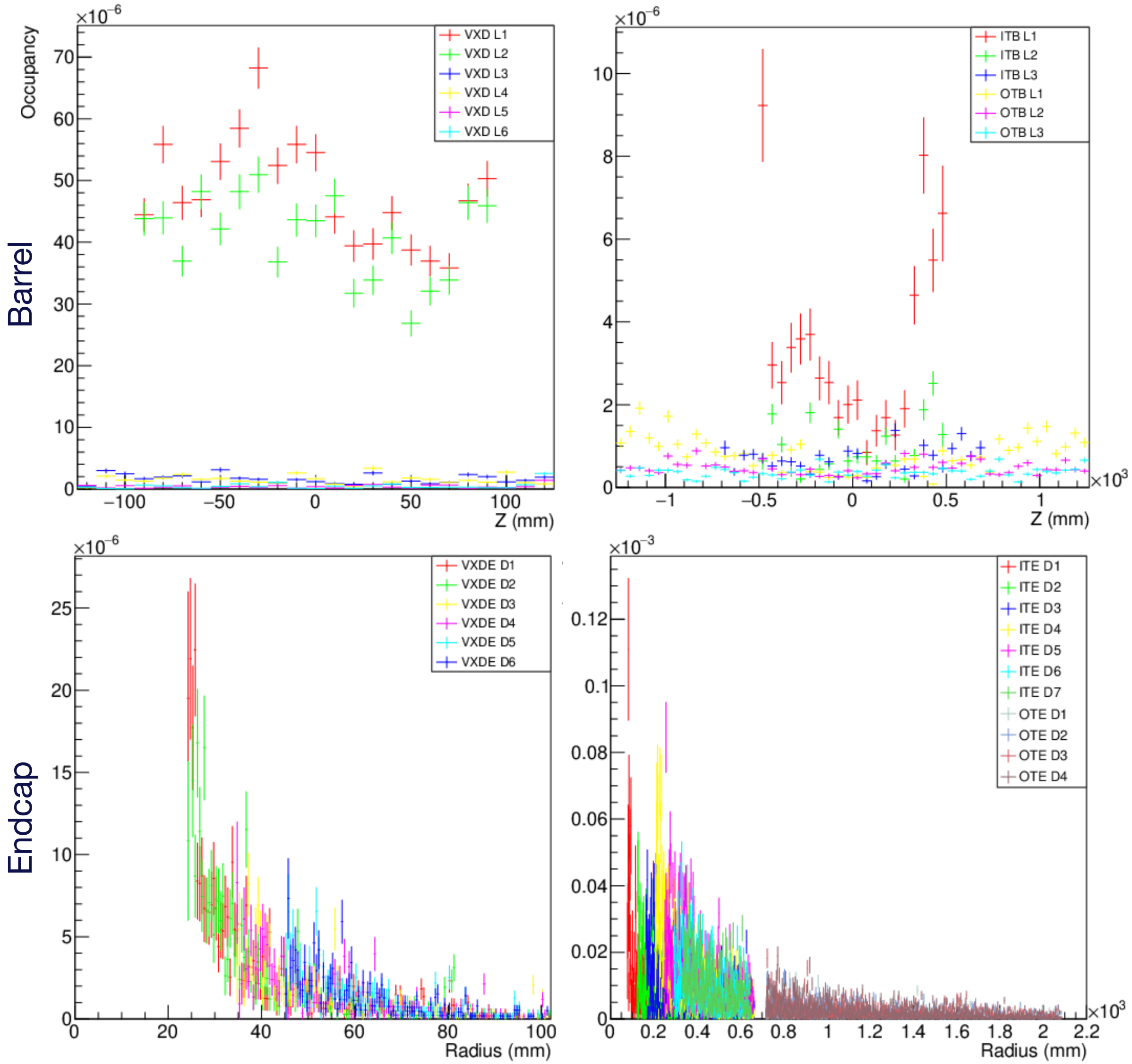
Previous studies with the old R=15mm central beam pipe showed that the induced occupancy was well below 1%, but it is important to check the increase due to the now **closer VXD**.

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.

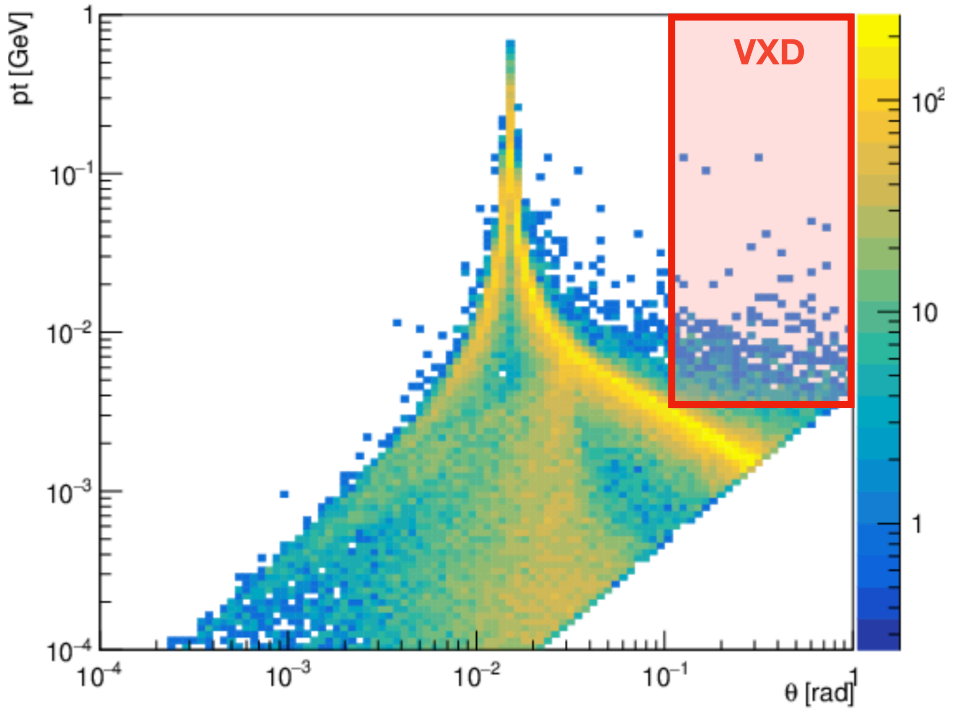
$$occupancy = hits/mm^2/BX \cdot size_{sensor} \cdot size_{cluster} \cdot safety$$

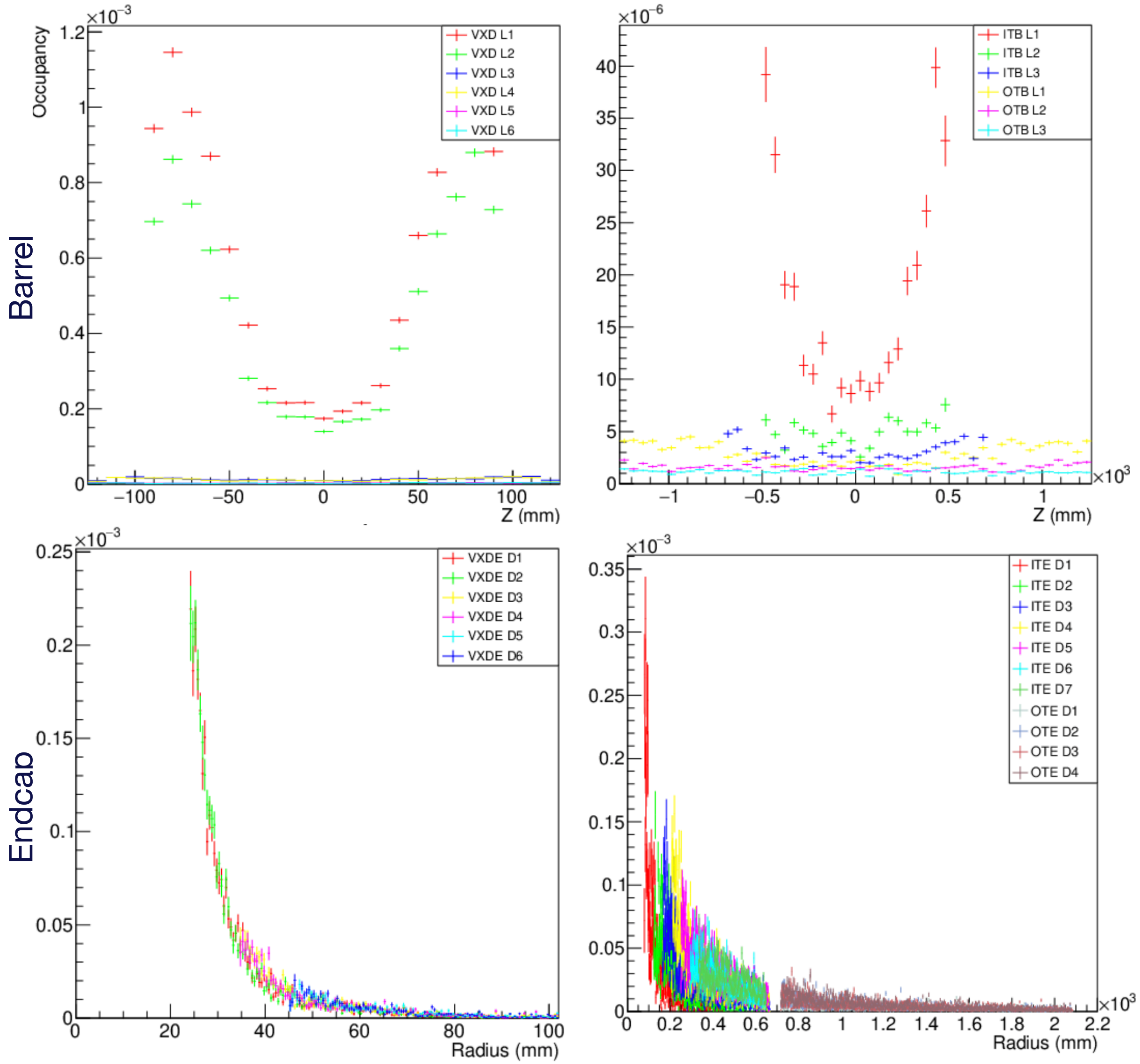
$$size_{sensor} = \begin{matrix} 25\mu m \times 25\mu m \ (pixel) \\ 1mm \times 0.05mm \ (strip) \end{matrix} \qquad size_{cluster} = \begin{matrix} 5 \ (pixel) \\ 2.5 \ (strip) \end{matrix} \qquad safety = 3$$





	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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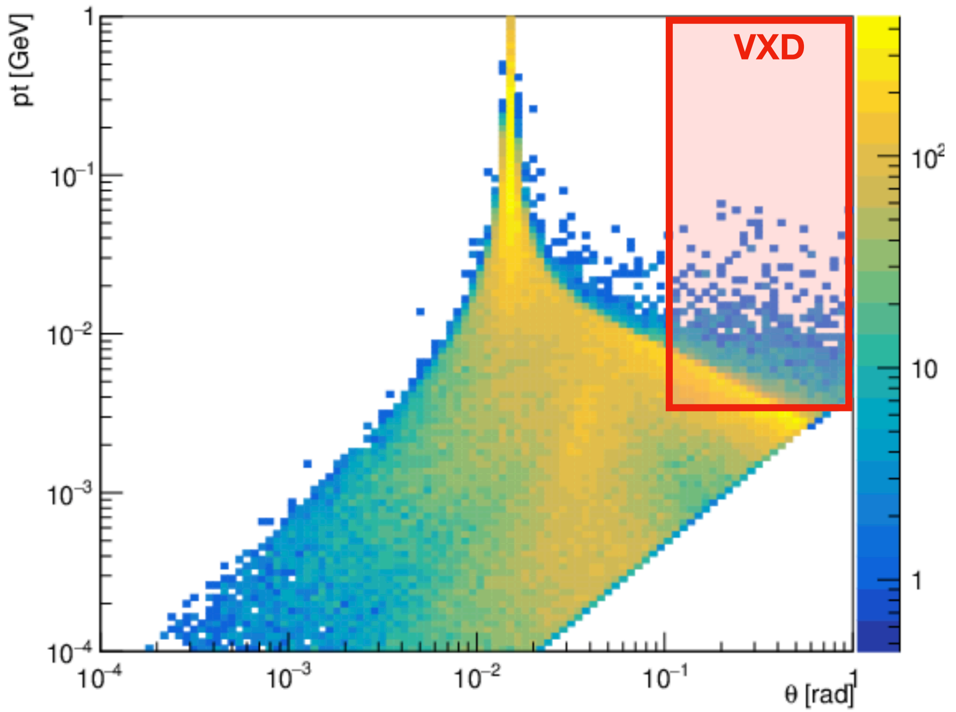
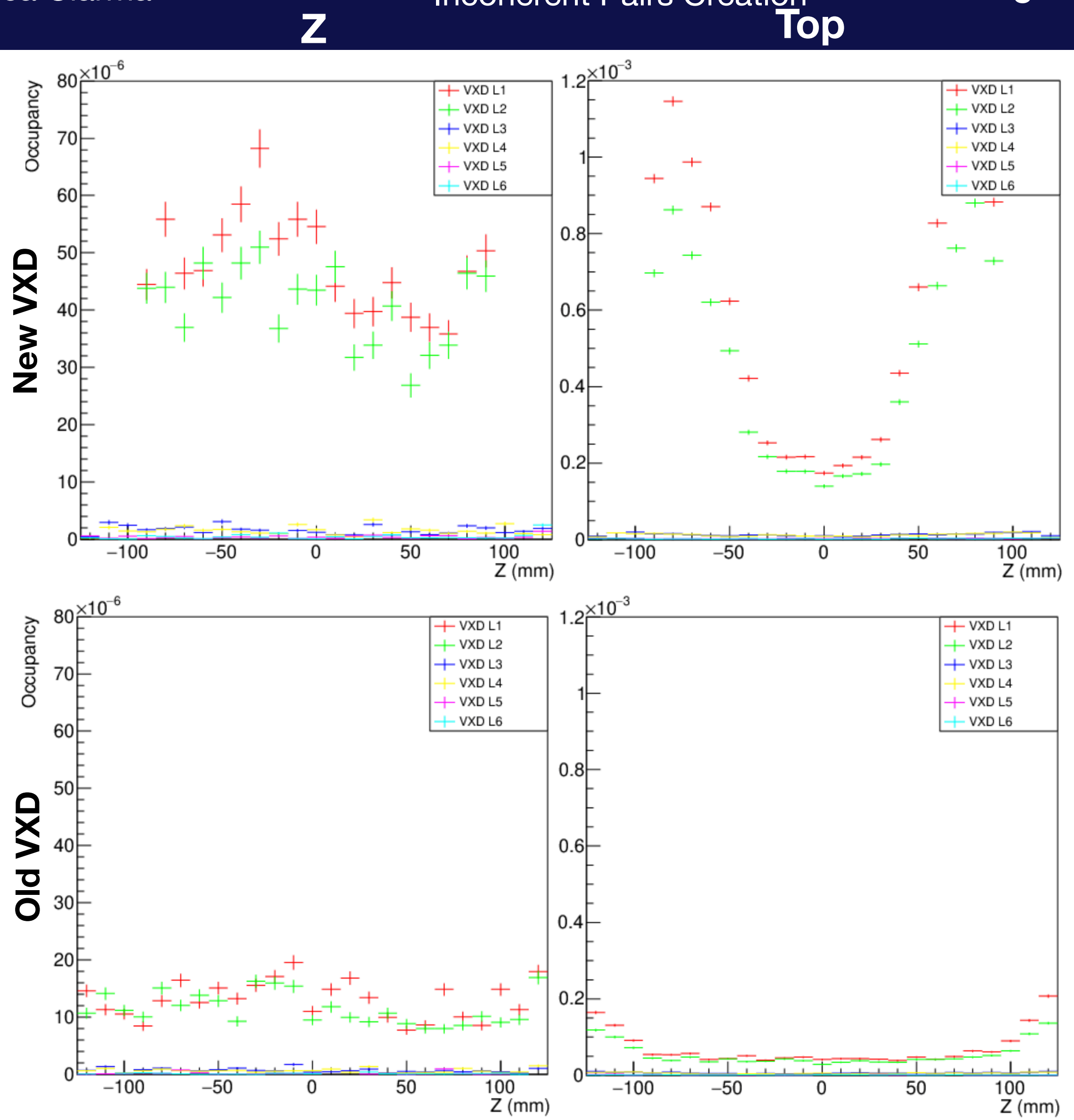


Preliminary studies on the occupancy due to the IPCs (generated with GuineaPig++ using the latest 4IP lattice beam parameters) show an increase of a **factor ~5** in particular in the **innermost layers** of the VXD barrel.

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



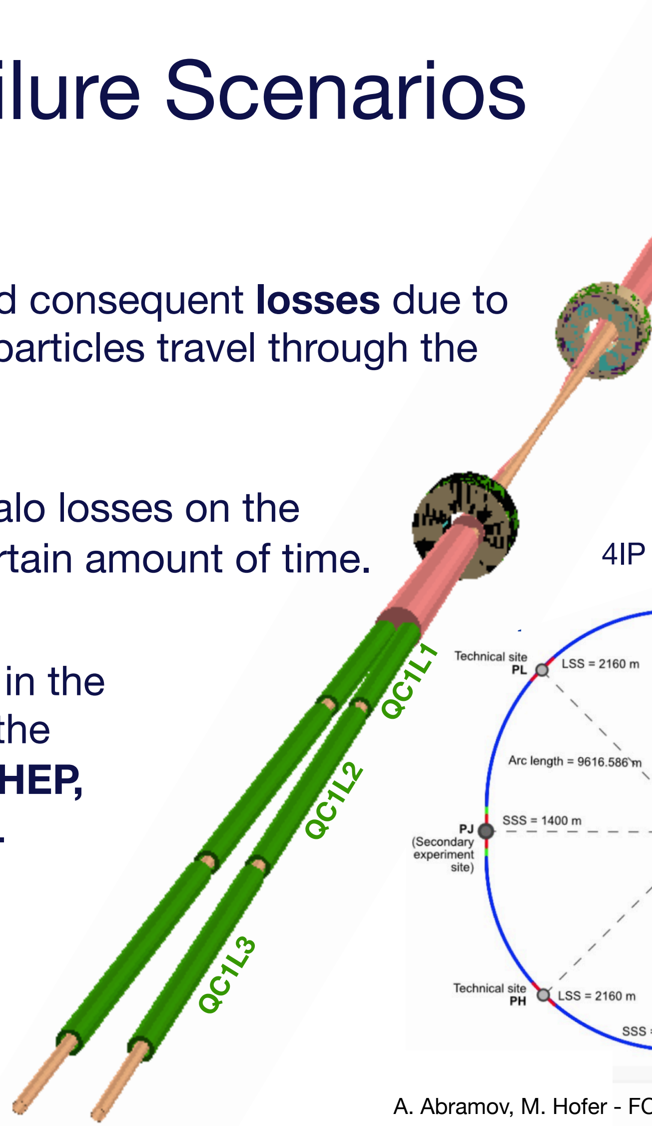
Beam Losses in the IR due to Failure Scenarios

Thanks to A. Abramov for the primary particles.

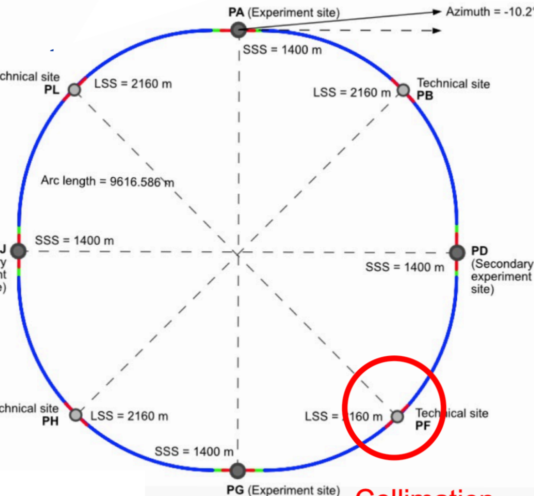
Several effects can lead to an increase of the beam emittance and consequent **losses** due to these particles impacting on the **main collimator.** The deflected particles travel through the machine and a fraction will hit the beam pipe in the **MDI region.**

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.

Particle tracking at both **Z** and **Top** energies has been performed in the lattice v529 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.



4IP lattice v529



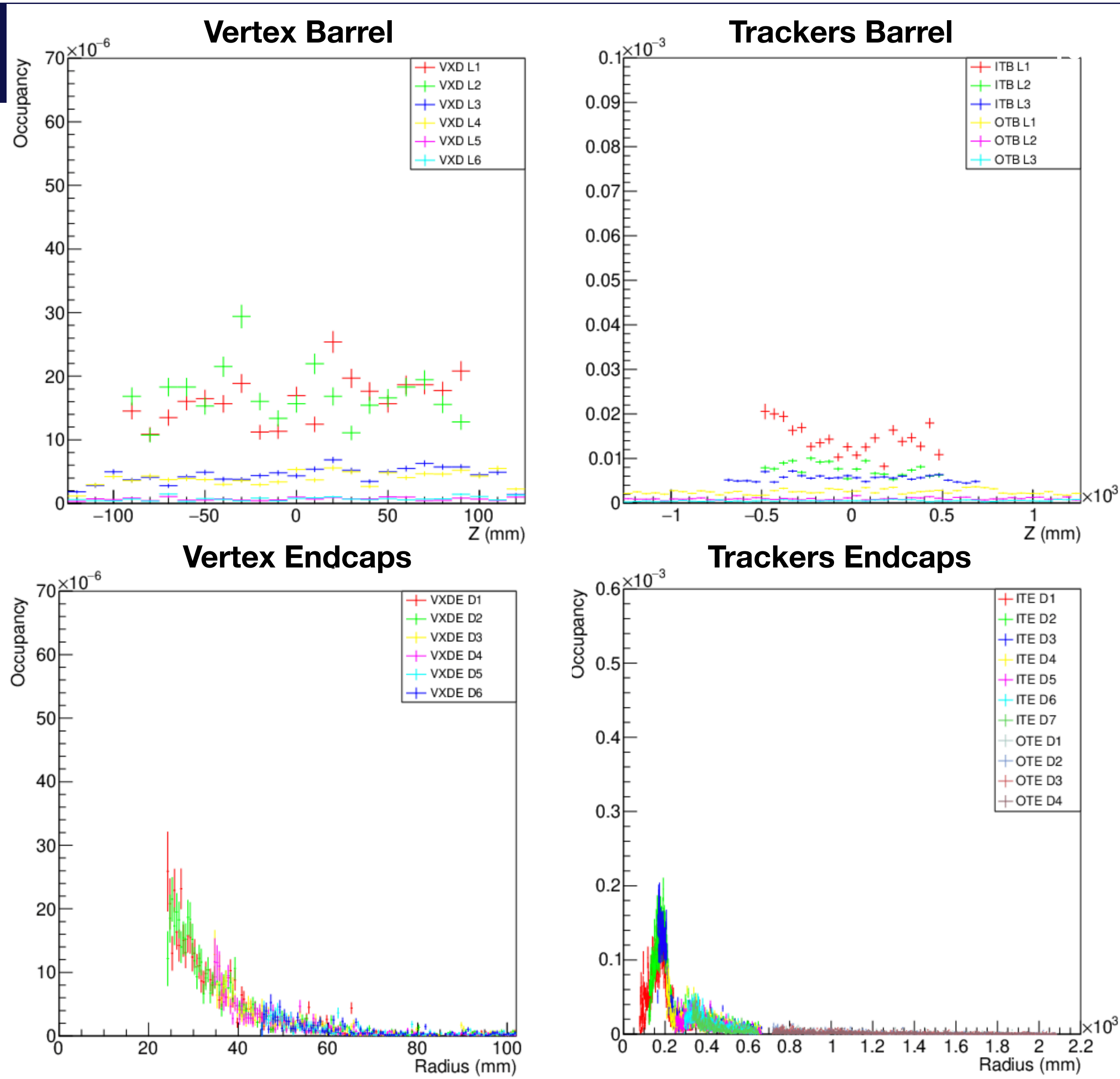
A. Abramov, M. Hofer - FCCWeek2022

Background @Z

As the losses happen few meters upstream the IP, the most interested detectors will be the **tracker endcaps**.

For the Z working point, the maximum occupancy registered is **well below the 1%** in all the subtedectors

	Losses per second	Highest occupancy
IPA	2.6244e+08	0.0195329% (ITE)
IPD	1.4418e+08	0.0087721% (ITE)
IPG	1.1826e+08	0.0056981% (ITE)
IPJ	3.8556e+08	0.112514 % (ITE)



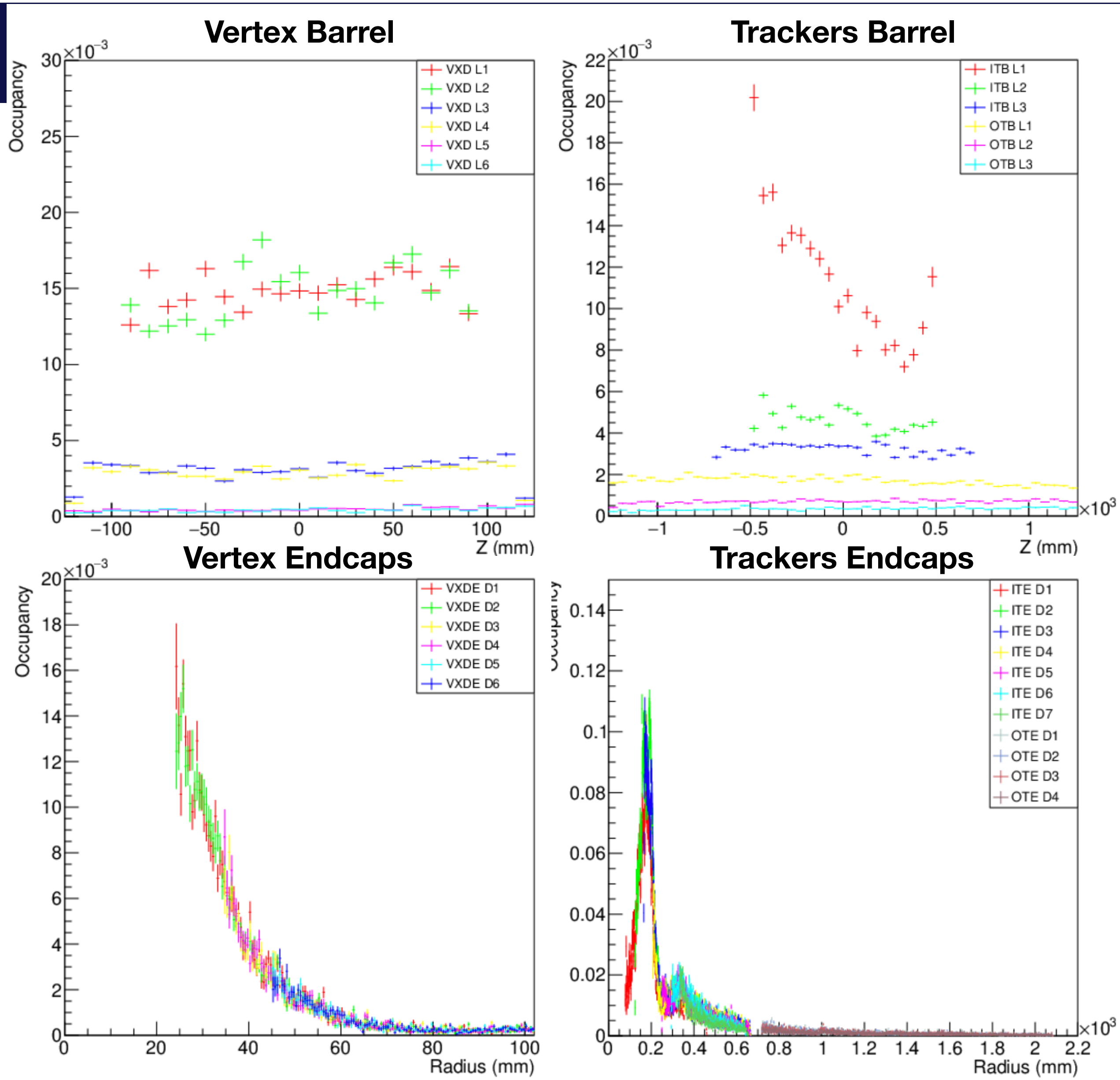
Occupancy at IPA for Z working point

Background @Top

At the Top working point the induced background can reach up to **several percent.**

Mitigation strategies should be investigated, or **relax the failure scenario** for this working point.

	Losses per second	Highest occupancy
IPA	1.5087e+08	10.9499 % (ITE)
IPD	1.0935e+08	- - sim running - -
IPG	1.0475e+08	- - sim running - -
IPJ	1.5882e+08	- - sim running - -

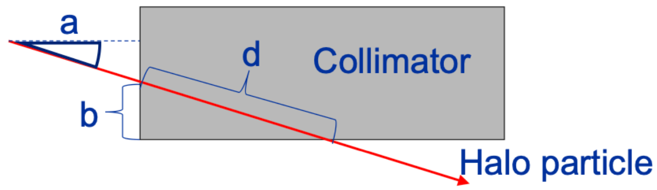


Occupancy at IPA for Top working point

```
Analyzing data from:  Top/IPA_withFFQs
Losses per second:        1.50871e+08
Losses per BX:            1146.29

Peak Occupancy per subdetector
VXDB L1 : 0.0164436 <--
VXDB L2 : 0.0182013 <--
VXDB L3 : 0.0040952
VXDB L4 : 0.00356512
VXDB L5 : 0.000796863
VXDB L6 : 0.000727065

VXDE D1 : 0.0161797 <--
VXDE D2 : 0.0151973 <--
VXDE D3 : 0.0080375
VXDE D4 : 0.00870192
VXDE D5 : 0.00294447
VXDE D6 : 0.00338048

ITB  L1 : 0.0201798 <--
ITB  L2 : 0.0058277
ITB  L3 : 0.00358624
OTB  L1 : 0.00210244
OTB  L2 : 0.000851902
OTB  L3 : 0.000506378

ITE  D1 : 0.101362  <--
ITE  D2 : 0.109499  <--
ITE  D3 : 0.106734  <--
ITE  D4 : 0.0474876 <--
ITE  D5 : 0.0218968 <--
ITE  D6 : 0.0228048 <--
ITE  D7 : 0.0214494 <--
OTE  D1 : 0.00563045
OTE  D2 : 0.00476161
OTE  D3 : 0.00384045
OTE  D4 : 0.0034092
```

```
Analyzing data from:  Top/IPA_withFFQs_tilted
Losses per second:        233840
Losses per BX:            1.77668

Peak Occupancy per subdetector
VXDB L1 : 6.31432e-06
VXDB L2 : 6.41617e-06
VXDB L3 : 1.13422e-06
VXDB L4 : 1.41051e-06
VXDB L5 : 4.28223e-07
VXDB L6 : 4.82314e-07

VXDE D1 : 5.42214e-06
VXDE D2 : 7.11655e-06
VXDE D3 : 3.07851e-06
VXDE D4 : 1.90435e-06
VXDE D5 : 2.16176e-06
VXDE D6 : 9.60784e-07

ITB  L1 : 2.50344e-05
ITB  L2 : 7.96835e-06
ITB  L3 : 5.69615e-06
OTB  L1 : 2.77005e-06
OTB  L2 : 1.10529e-06
OTB  L3 : 6.56041e-07

ITE  D1 : 0.00013083
ITE  D2 : 0.000164948
ITE  D3 : 0.000159211
ITE  D4 : 7.60651e-05
ITE  D5 : 3.44661e-05
ITE  D6 : 3.411e-05
ITE  D7 : 3.64456e-05
OTE  D1 : 6.73677e-06
OTE  D2 : 7.23761e-06
OTE  D3 : 7.18661e-06
OTE  D4 : 6.06501e-06
```

*A.Abramov



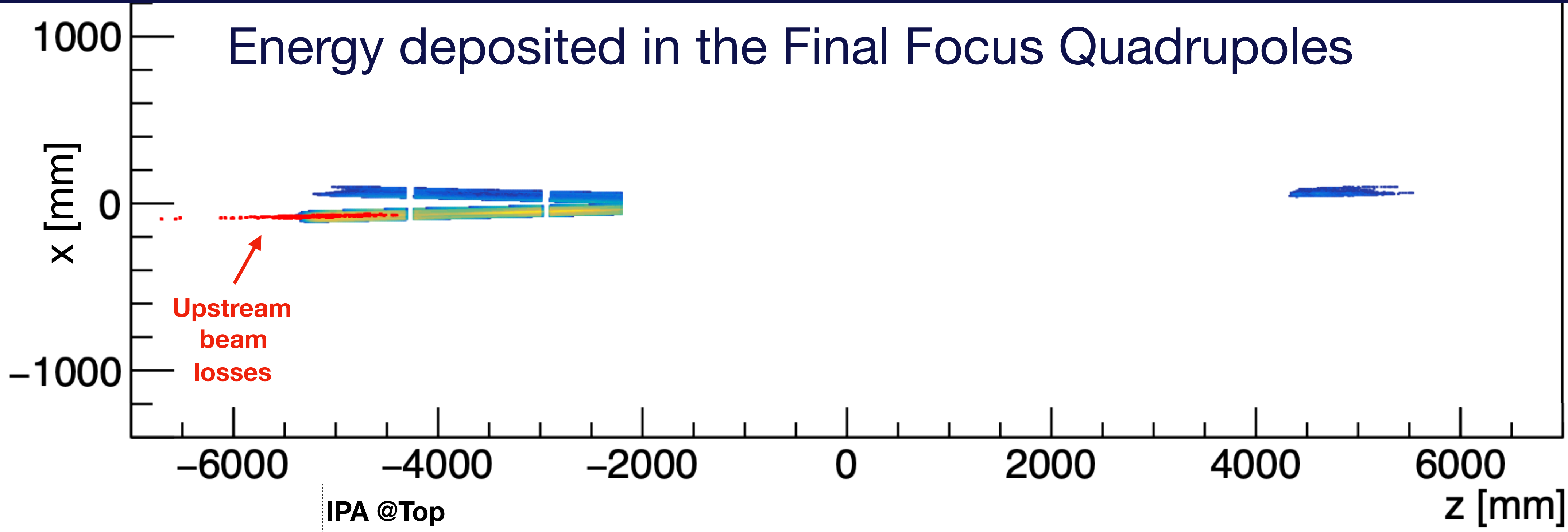
a = angle of incidence
b = impact parameter
d = distance traversed

A first **proposal** on how to mitigate this very high background is to use **tilted collimators** (G. Broggi - 19/10). The use of such elements could allow to **reduce the beam losses** of a factor **10^3** under the same failure scenario.

Please note that this is still a proposal, and the feasibility of this solution is yet to be studied.

Other possible solutions could include **adding shielding material** (e.g. internal to the cryostat), or simply relax the failure scenario in which it is still possible to keep the detectors running at this working point.

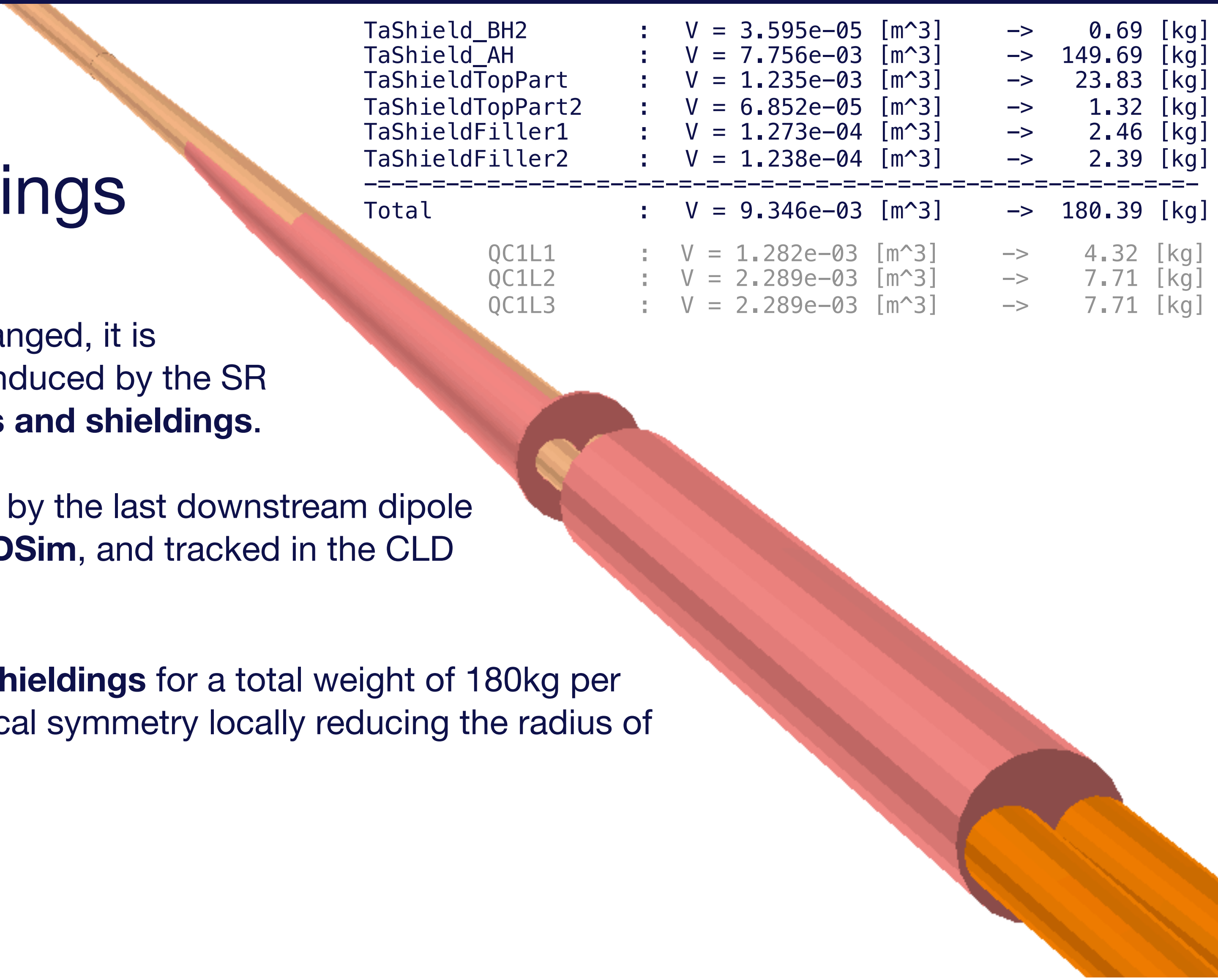
Energy deposited in the Final Focus Quadrupoles



	IPA @Top
Losses per second	1.5087e+08
Tot Power Dep. [W]	2.015
Max Power Dep. Density [W/cm3]	0.035
Max Instant Energy Dep. [GeV/BX/cm3]	1700
Avg Power Dep. Density [W/cm3]	0.00067

Evaluation of the **power deposited in the QC1 elements** due to beam losses in the considered failure scenario has been performed only -for now- at IPA at Top working point.

Preliminary estimates for the QC1 quench limits consider **instantaneous losses** lower than 10^4 GeV/BX/0.15mm3, and **continuous average power** limit of ~3mW/cm3. The simulation results are well below these safety limits.



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]

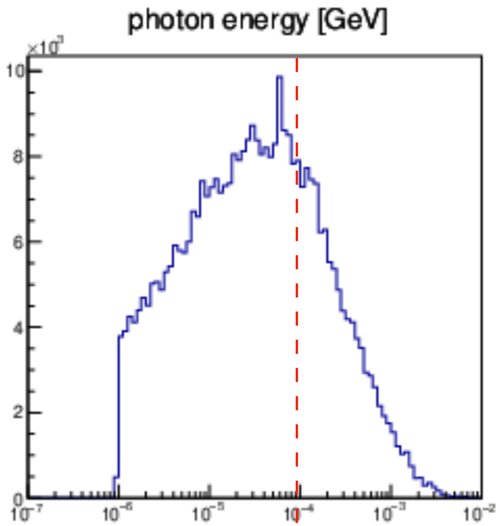
SR Mask and Shieldings

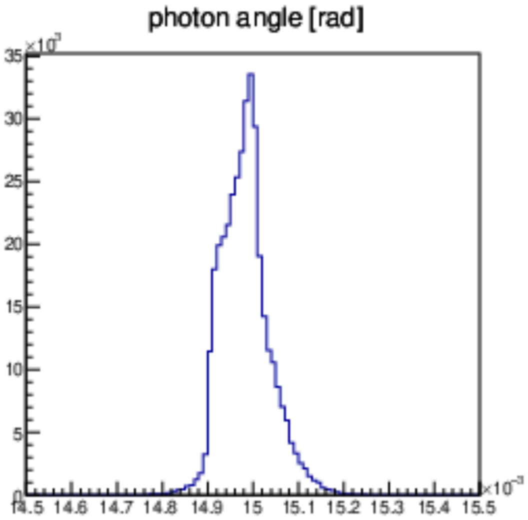
Thanks to K. André for the primary particles.

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.

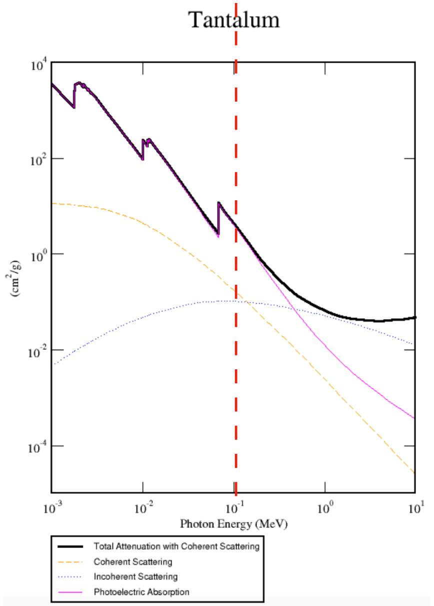
The implemented model has **Tungsten shieldings** for a total weight of 180kg per side, and a **Tantalum mask** with cylindrical symmetry locally reducing the radius of the beam pipe to 7mm.

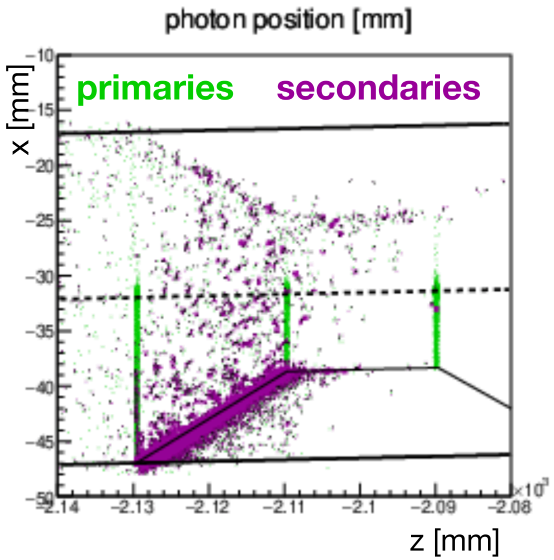


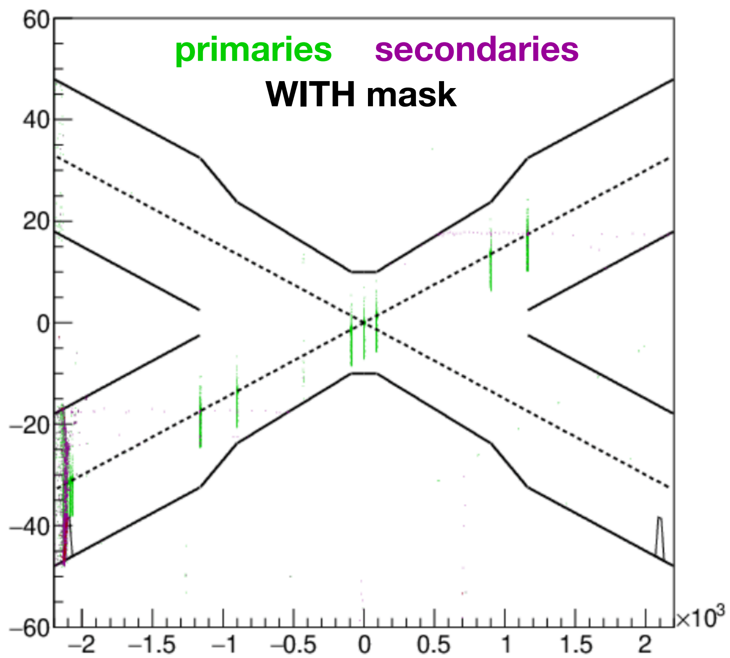


Due to the critical energy of **~100keV** the interaction of these photons with the tantalum mask is dominated by **photoelectric effect.**

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





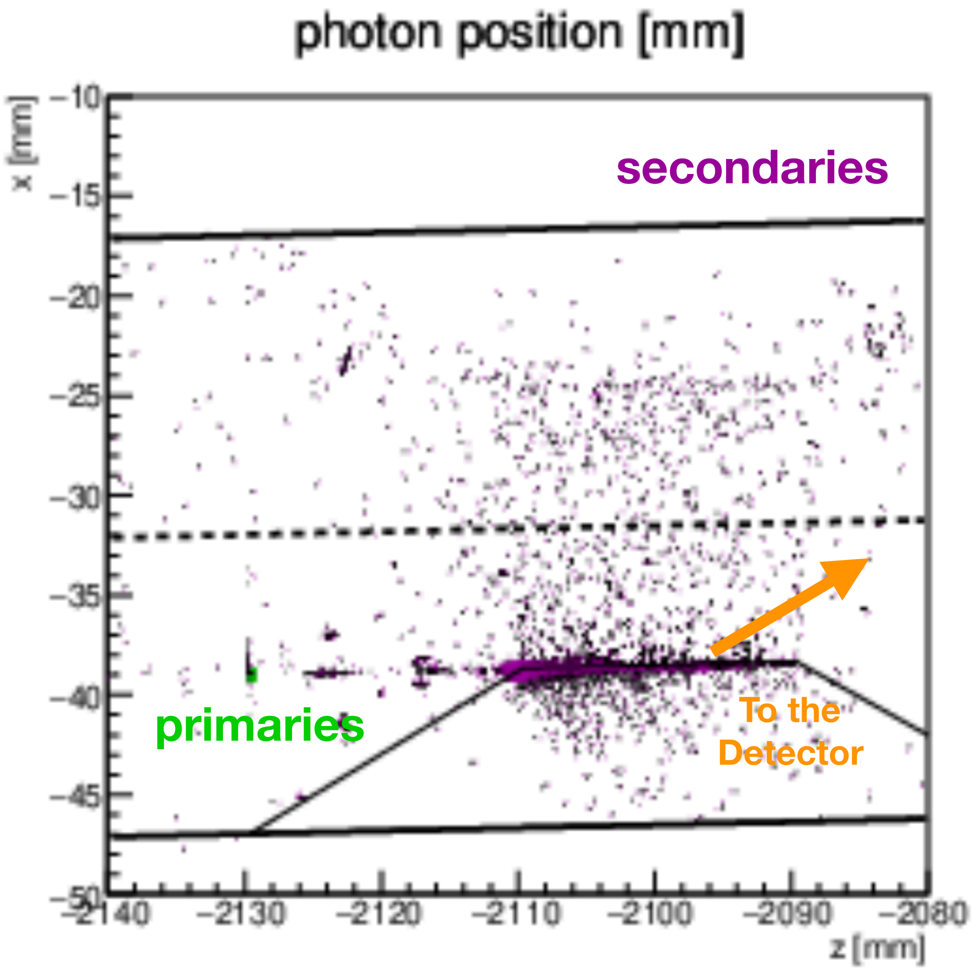


Special attention should be given to the photons which will impact **the tip of the mask**, as they are the main source of potential background in the detector.

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**.

The SR photons produced at the Top working point by a gaussian beam and **interacting with the tip of the mask** (-6.9mm < x < -7.2mm) have been tracked in Key4HEP, but the **statistic is too low** to produce useful results, even tracking the same macro-particles more times in the detector.

	$N_{macro}(e^-)$	$N_{macro}(\gamma)$	$N_{macro}(\gamma)^{TIP}$
Gaussian	1M	1.12M	5.5k
4-10 sigma ring	100k	390k	500
14-15 sigma H	100k	284k	439
49-50 sigma V	100k	273k	266



— Work In Progress —

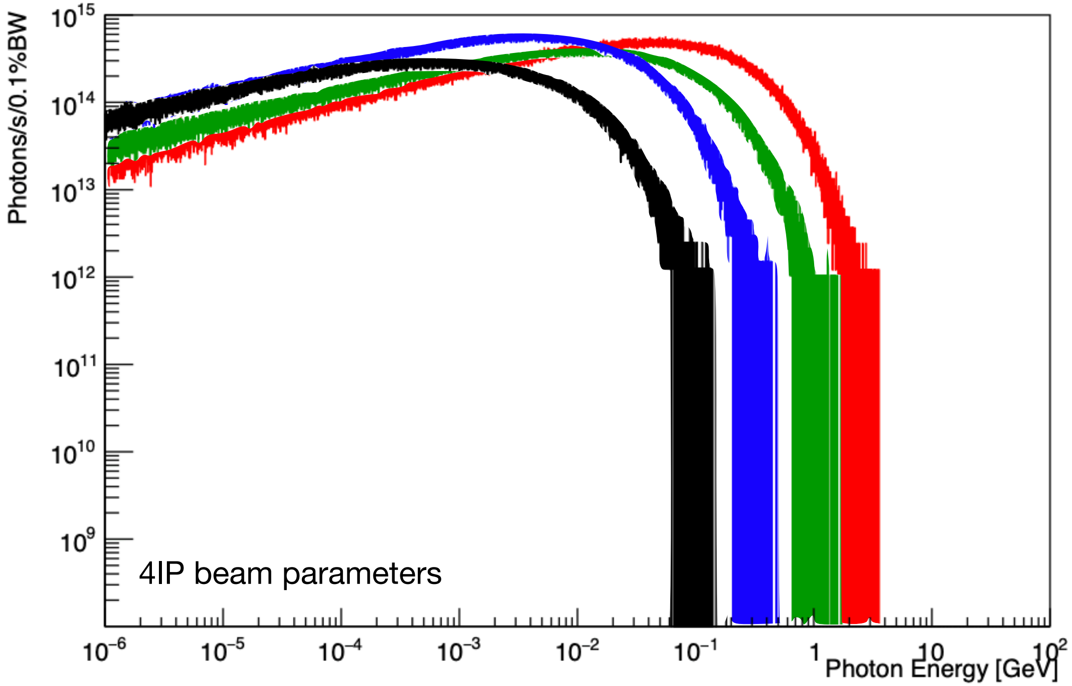
Beamstrahlung radiation Characterisation

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

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

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

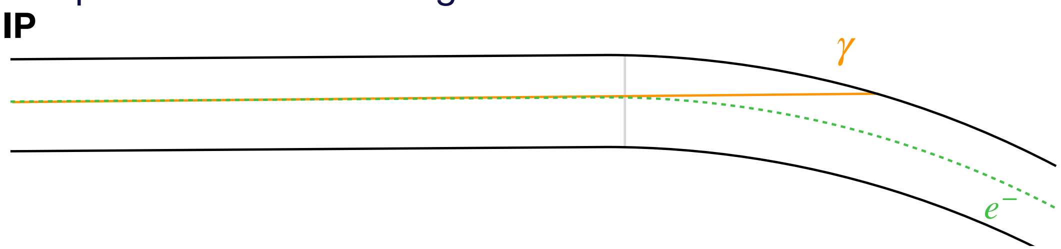
$$n_\gamma \sim 2.54\left[\frac{\alpha^2\sigma_z}{r_e\gamma}\Upsilon\right]\frac{1}{[1+\Upsilon^{2/3}]^{1/2}}$$



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.

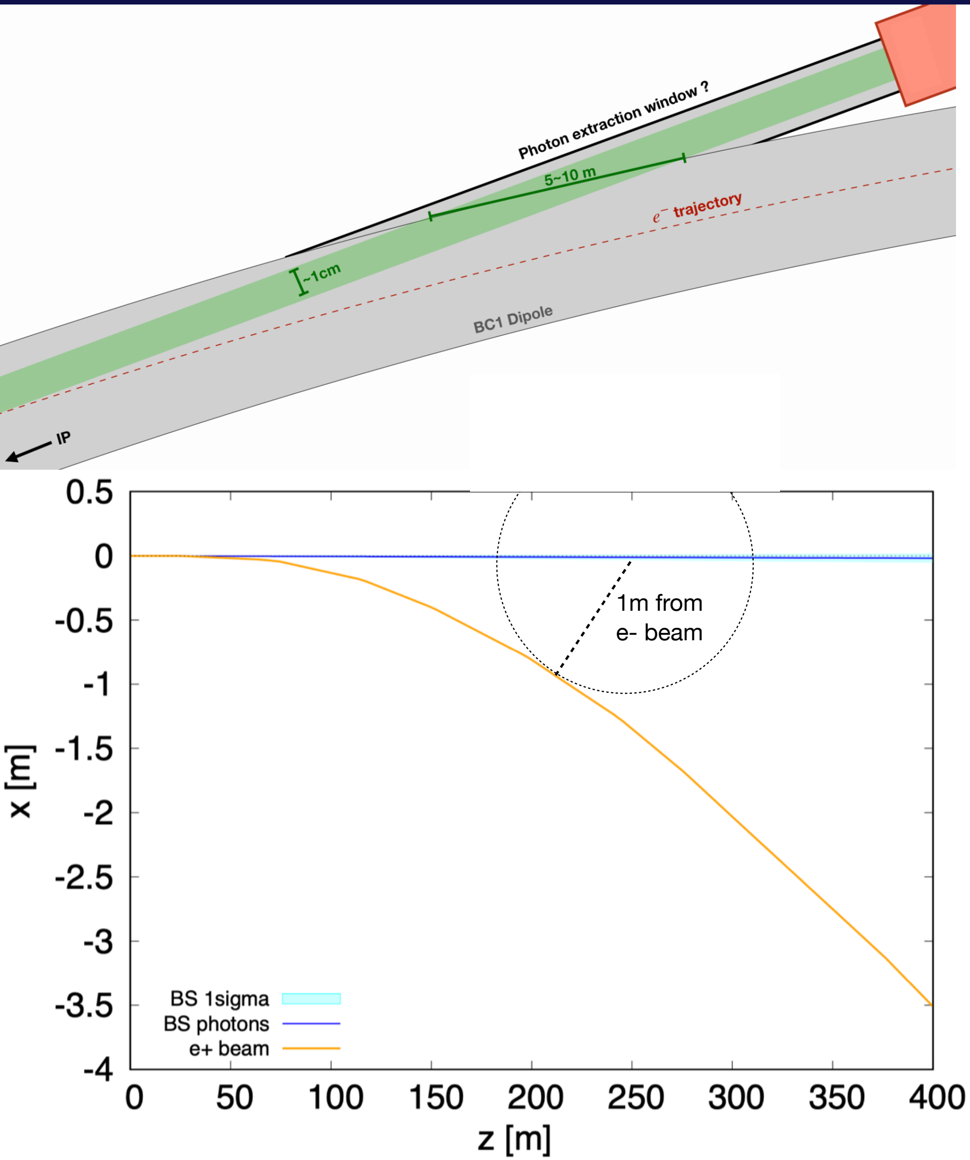
These studies were performed using **GuineaPig++**.

Paper on Beamstrahlung Radiation Characterisation at FCCee planned



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

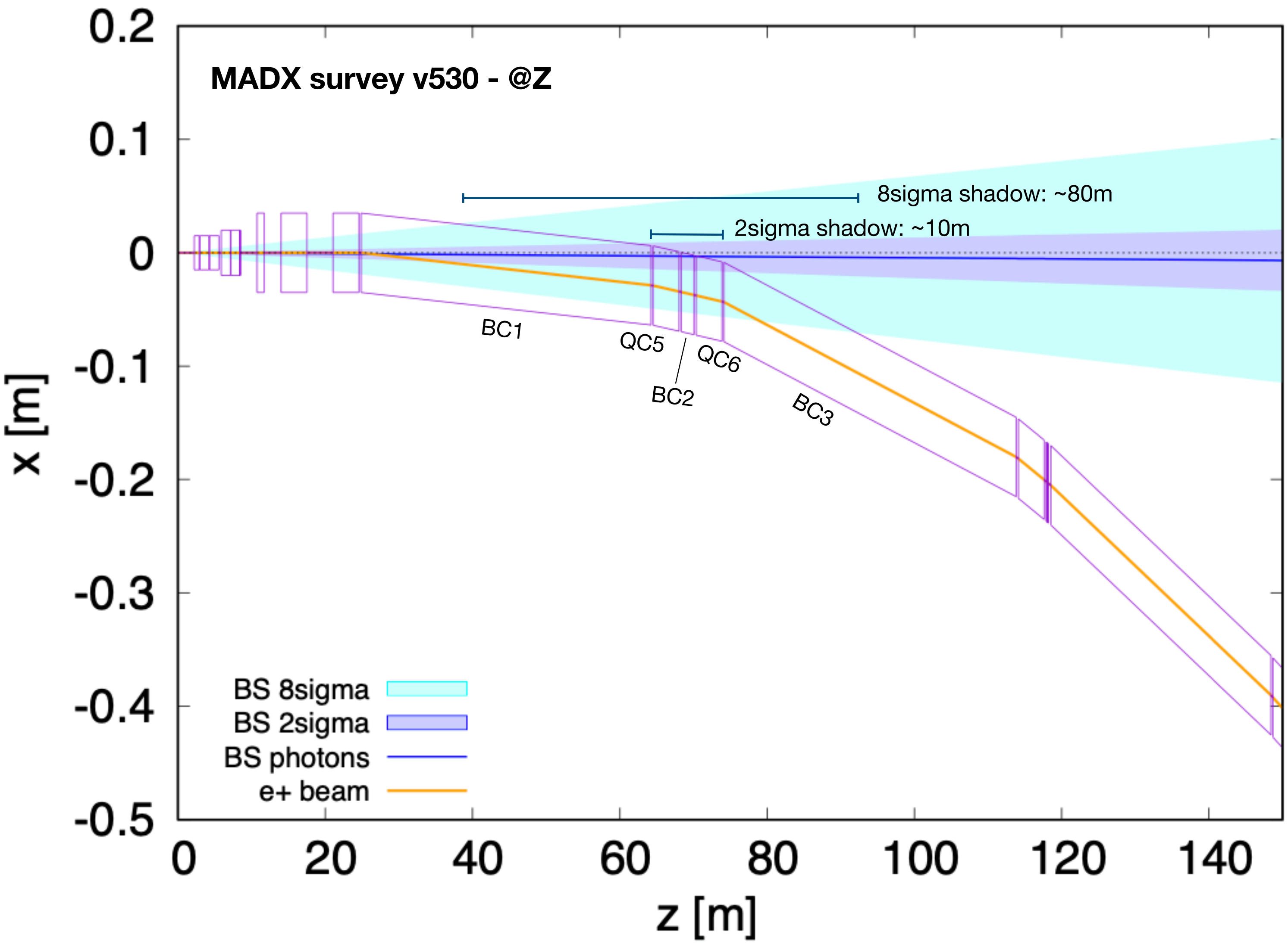
Beam dump for Beamstrahlung photons



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 (A. Perillo-Marcone, 27/10; A. Lechner, 27/10; Fani Valchkova-Georgieva, 27/10)

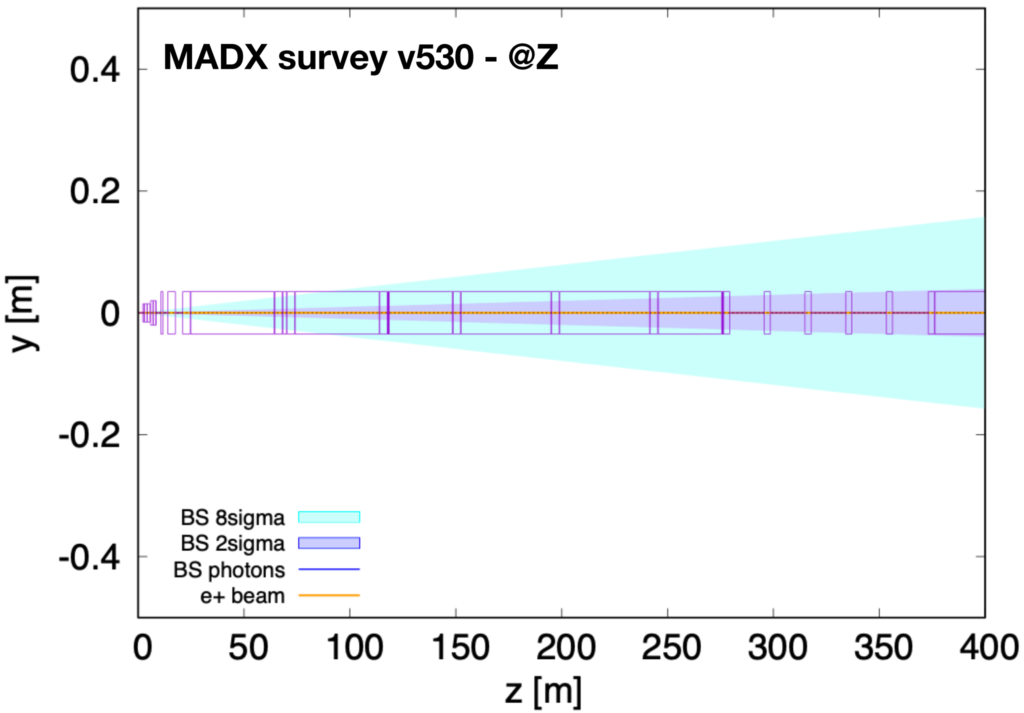
Also the possibility to have an **instrumented beam dump** to measure properties of the colliding beams at the IP is under investigation.

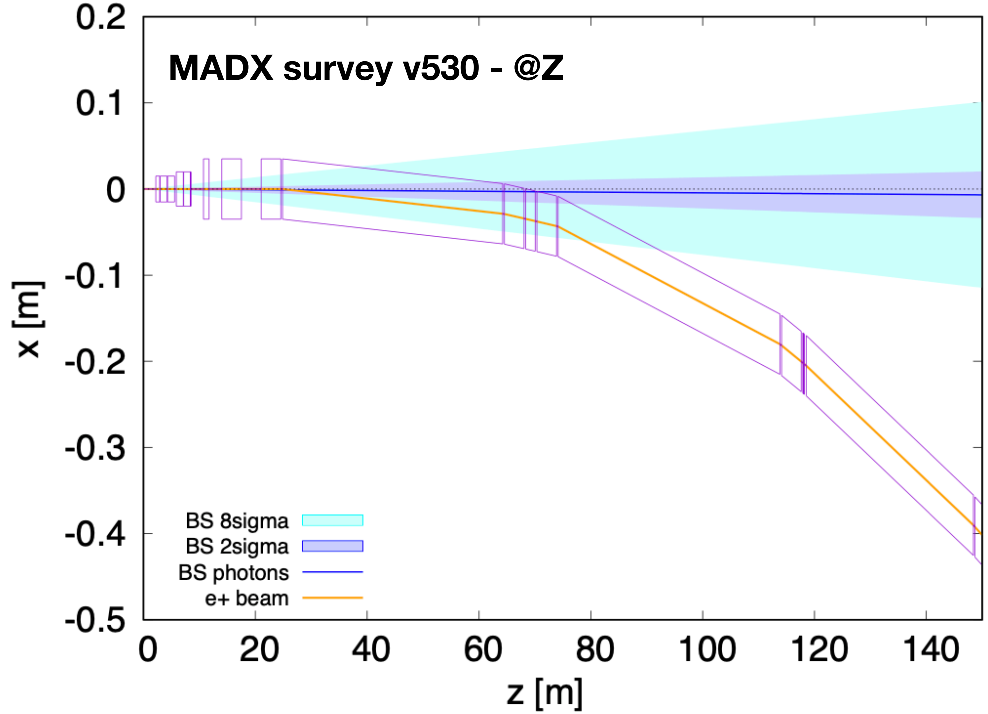


Comparison of the beamstrahlung photon distribution against the **MADX survey** for lattice **v530** show that the hits are localized in the “QC5-BC2-QC6” area - in agreement with the SR photons tracking in BDSIM (K. André 19/10).

This is further w.r.t. lattice v217 as BC1 is now a bit weaker.

The **size of the shadow** on the pipe wall depends on the amount of radiation which is necessary to collect with the extraction line, and it is **10 meters at just 2 sigmas**.





	$\sigma_{px}(\gamma)\ [\mu rad]$	$\sigma_{py}(\gamma)\ [\mu rad]$	$\sigma_{px}(e^-)\ [\mu rad]$	$\sigma_{py}(e^-)\ [\mu rad]$	$\sigma_x(\gamma)\ [mm]\ @\ 50m$	$\sigma_y(\gamma)\ [mm]\ @\ 50m$
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

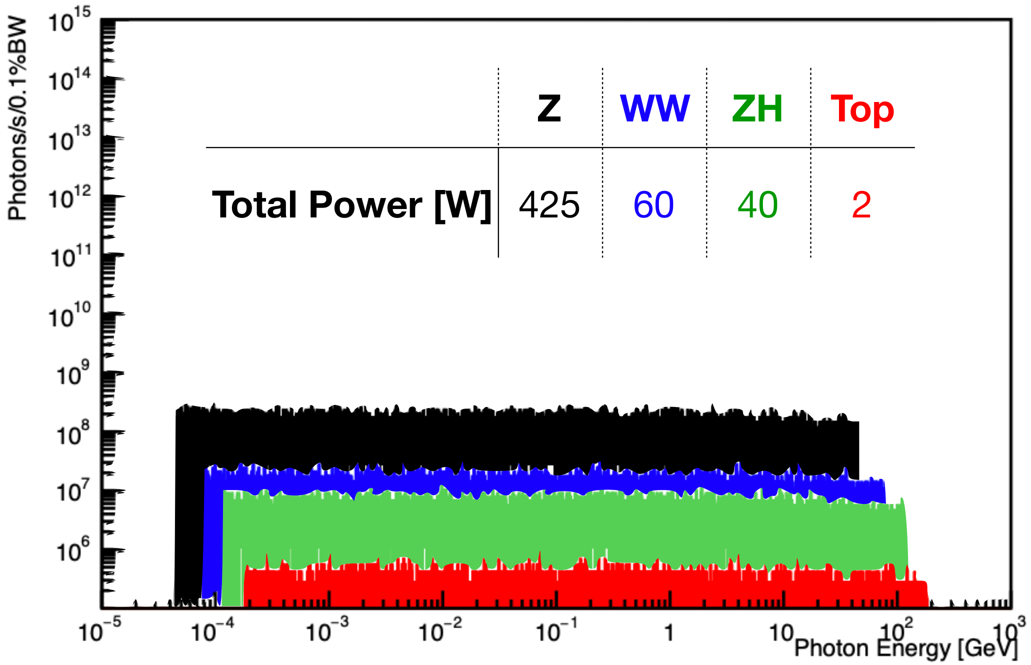
Radiative Bhabha photons Characterisation

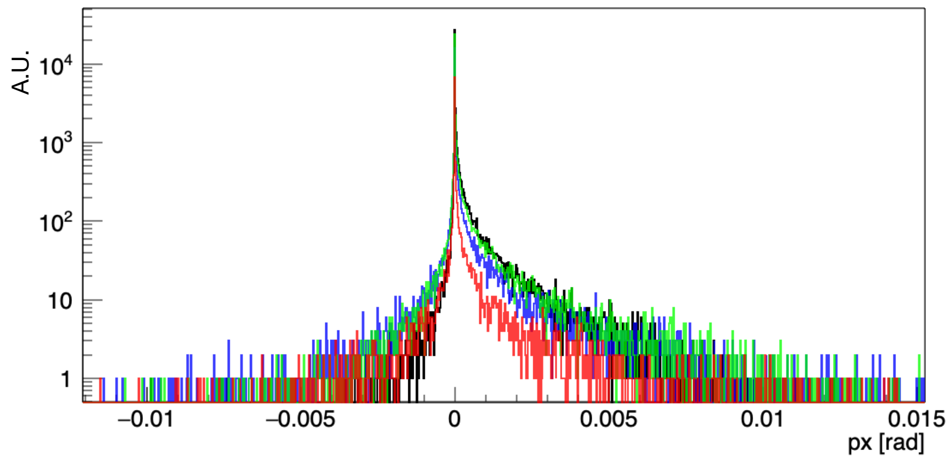
The radiation emitted in Bhabha events at the IP consists in **very hard photons** emitted collinear to the **beam direction**, so it will hit the beam pipe in the same location of the beamstrahlung photons, but with much **lower intensity**.

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.

Considerations on the possibility to have a **selective beam dump** will be discussed by A. Di Domenico on Thursday 27/01





Summary

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

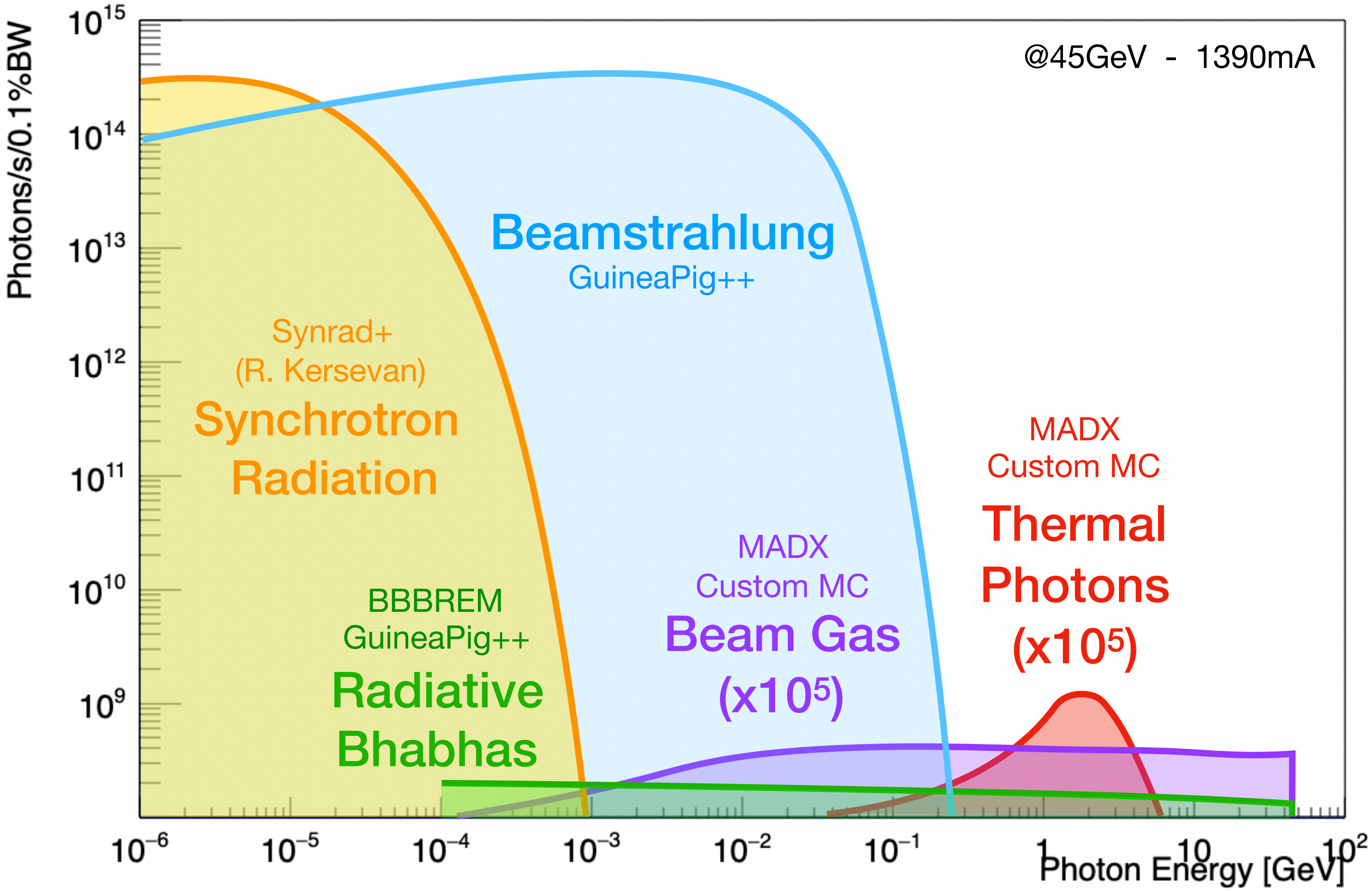
- **IPC induced occupancy** in the CLD VXD is **below the 1%** also for the now closer VXD Barrel

- Tracking of the **beam losses:**
  - occupancy @ttbar up to 10%, **mitigation strategies** should be investigated
  - occupancy @Z well below 1% despite higher current
  - repeat the study for different **failure scenarios**
  - 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.
  - Increase **statistics** and improve tails modeling

- **Beamstrahlung** radiation can reach up to **>300kW** with a divergence of $O(10 \sim 100\mu rad)$
  - photons will hit the beam pipe at about **70m from IP**, with a shadow of $O(10m)$ on the pipe walls
  - a dedicated **beam dump** must be designed to absorb all this power
  - possibility to have an **instrumented beam dump** is also under investigation

Signals vs Background sources



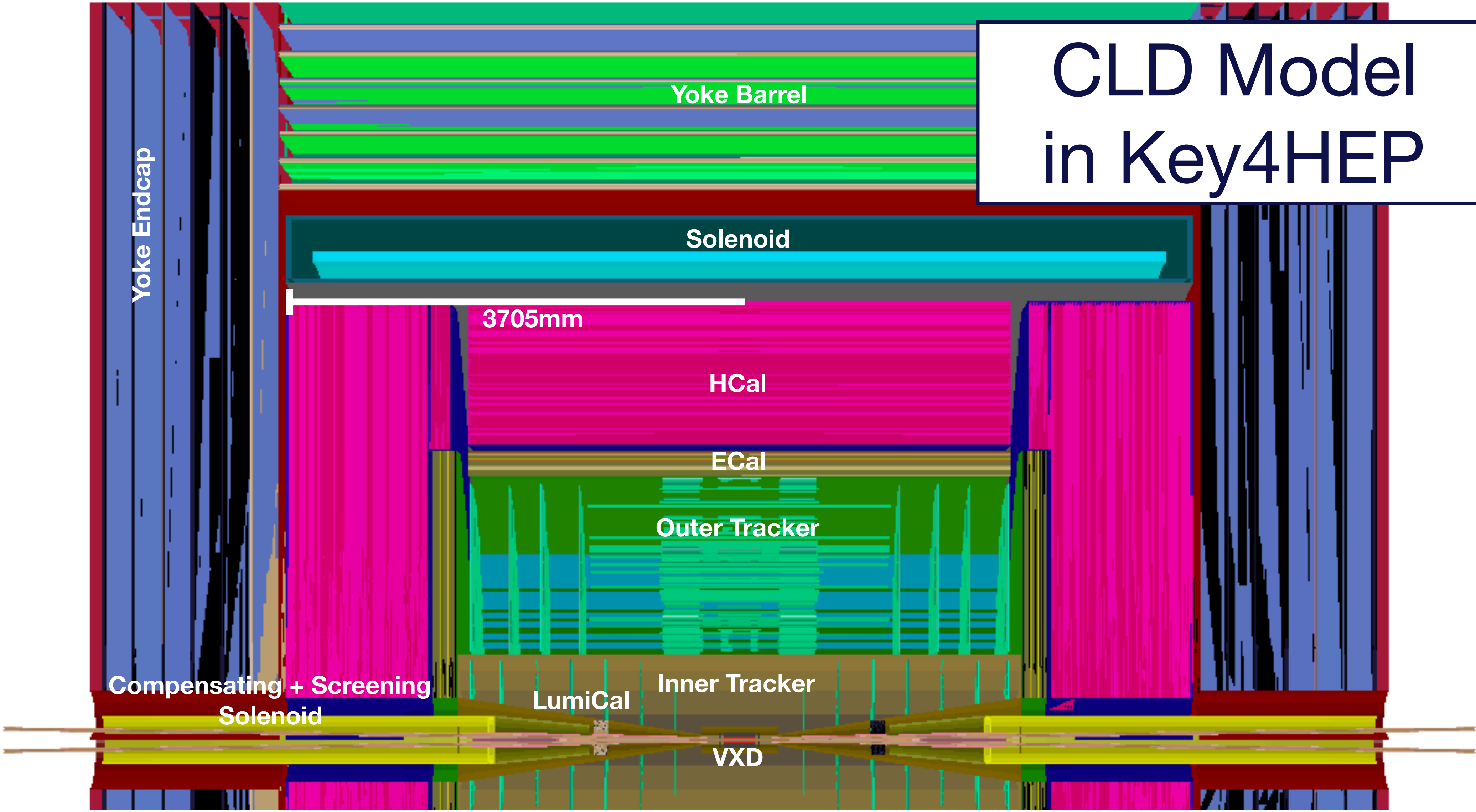
The comparison of the photon flux for the different sources shows that **beamstrahlung** might be a viable signal in the **multi-MeV range**, as its spectrum extends further compared to the synchrotron radiation.

In the **multi-GeV range** instead, **radiative bhabhas** might be detectable, as the flux coming from the backgrounds (i.e. beamgas and thermal photons) is several order of magnitudes smaller.

The dominant contribution to the total power comes from the **beamstrahlung**:

	FCCee_Z	FCCee_Top
Total BS power	$386.9[kW]$	$88.5[kW]$

CLD Model in Key4HEP



		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/

IPC - smaller beam pipe

A **smaller beam pipe** with radius $R = 10\,mm$ is currently under study. This will allow to have the first layer of the VXD **closer to the IP** and possibly improve the tagging efficiency.

Anyway this will also mean that more IPC particles will enter the VXD as its acceptance increases.

Previous studies estimated a x2 occupancy increase (negligible), but **dedicated simulations** using the smaller beam pipe and closer VXD are up next.