BEAM INDUCED BACKGROUNDS AT FCC-ee

Andrea Ciarma

Many thanks to: A. Abramov, K. Andrè, M. Boscolo, G. Ganis, 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** and relative **vertex detector** update, 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)**
- Characterization of the **beamstrahlung radiation** and **radiative Bhabha photons**
- Tracking of **beam losses** in the CLD detector and MDI region during failure scenarios
- **Synchrotron Radiation** induced occupancy and effect of the tungsten shieldings

→ A. Ciarma MDI Workshop 2022 24/10/2022

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.**

(more in: A. Ciarma - MDI Workshop 2022 - 24/10/2022)

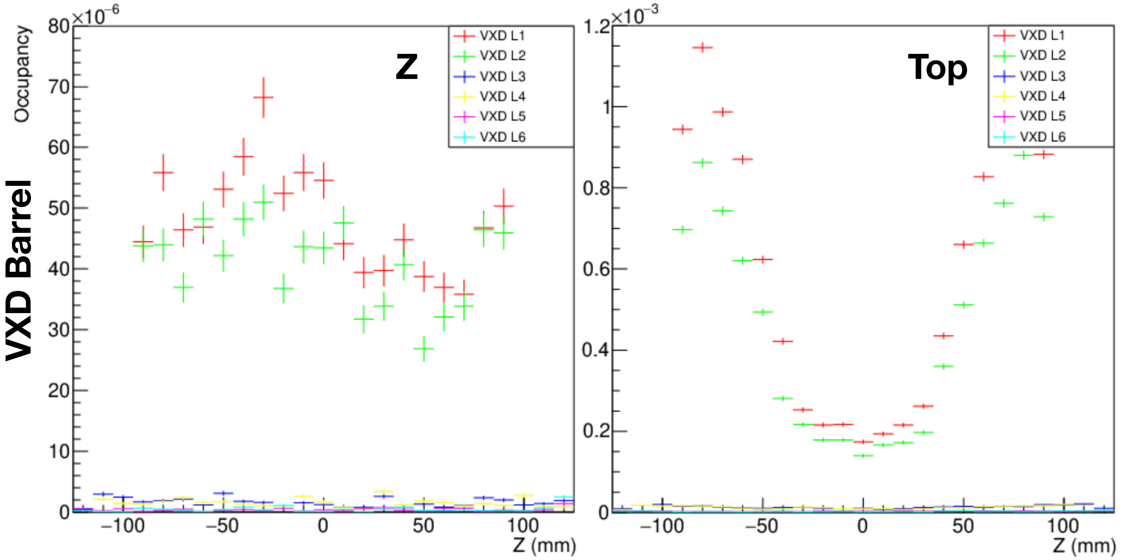
Incoherent Pairs Creation (IPC)

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.

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.

Induced **occupancy is well below the 1%** in every subdetector. This is true even considering a (very conservative) $10\mu s$ readout window - with the exception of the VXDB @Z. Next steps require the **overlay of this background** to physics event to verify the **reconstruction efficiency.**

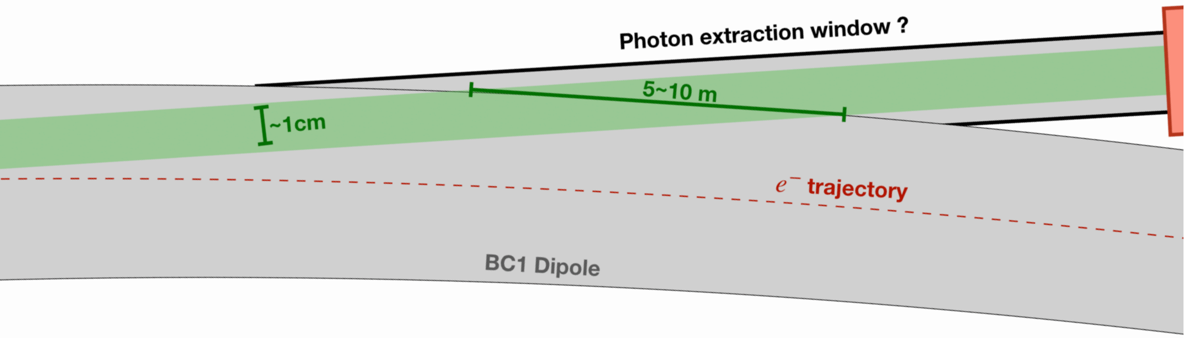
	Z	WW	ZH	Top
Pairs/BX	1300	1800	2700	3300
Max occup. VXDB	70e-6	280e-6	410e-6	1150e-6
Max occup. VXDE	22.5e-6	95e-6	140e-6	220e-6
Max occup. TRKB	9e-6	20e-6	38e-6	40e-6
Max occup. TRKE	110e-6	150e-6	230e-6	290e-6



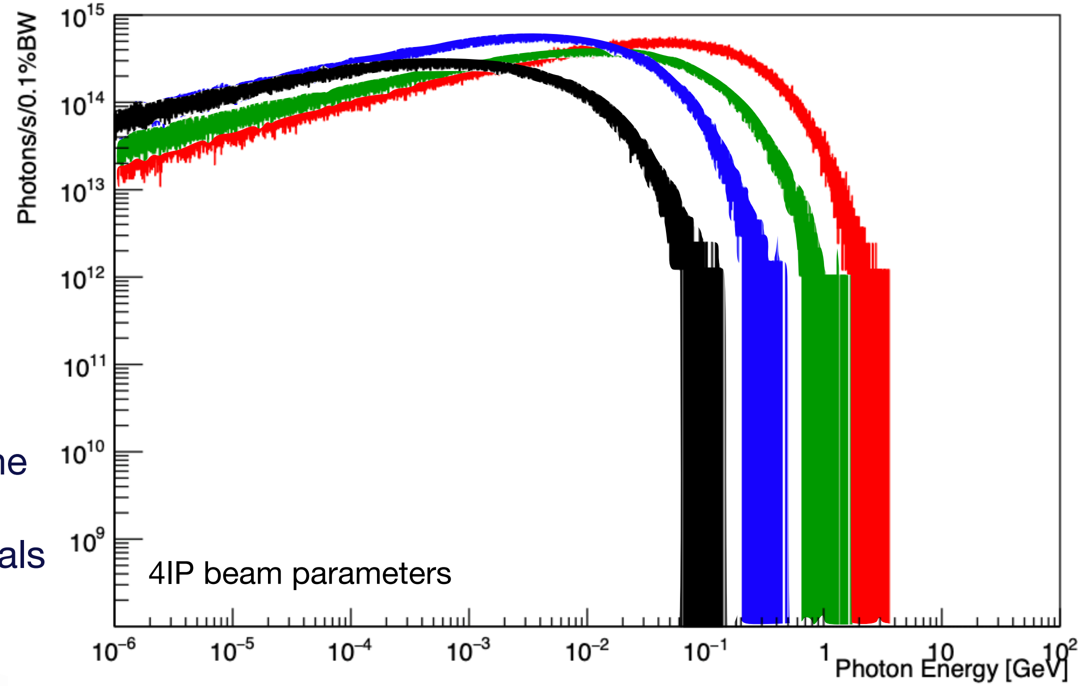
Beamstrahlung radiation Characterisation

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 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.



(more in: A. Ciarma - MDI Workshop 2022 - 24/10/2022)



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

Beam Losses in the IR due to Failure Scenarios

Thanks to A. Abramov for the primary particles. (Talk 07/12)

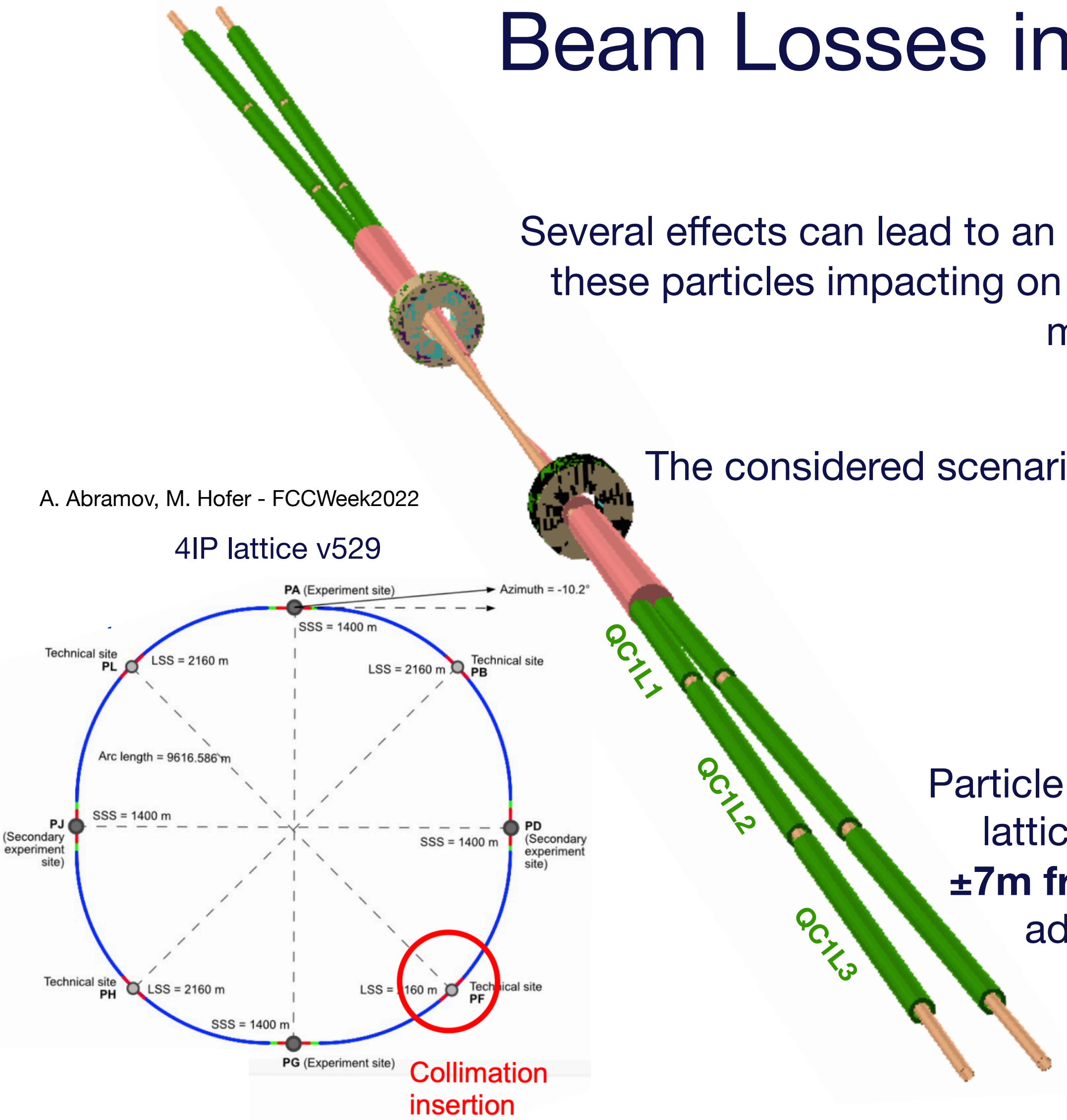
Several effects can lead to an increase of the beam emittance and consequent **losses** due to these particles impacting on the **main collimator.** The deflected particles travel through the machine and a fraction will hit the beam pipe in the **MDI region.**

The considered scenarios consist in a **drop of the beam lifetime to 5 minutes** due to:

- Halo losses on the Horizontal Primary Collimator
- Off-momentum collimators
- Off-momentum collimators + betatron oscillations

A. Abramov, M. Hofer - FCCWeek2022

4IP lattice v529



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.

The results shown next are for a single beam.

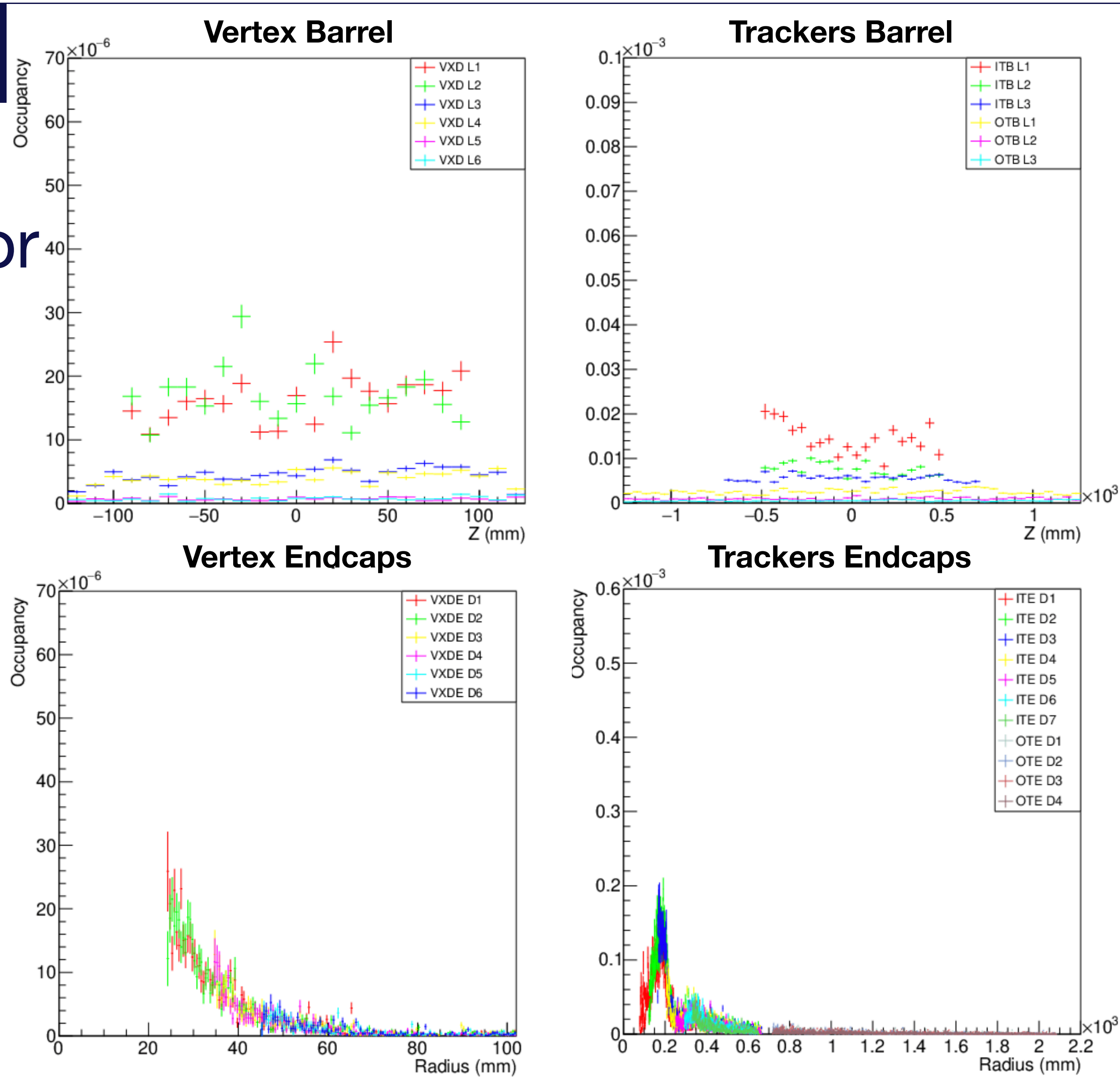
Background @Z
Horizontal Primary collimator

Beam losses coming from the **halo particles** intercepted by the horizontal primary collimator.

The losses happen few meters upstream the IP, so 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 (10^9)	Highest occupancy
IPA	0.26	0.02% (ITE)
IPD	0.14	< 0.01% (ITE)
IPG	0.12	< 0.01% (ITE)
IPJ	0.39	0.11% (ITE)



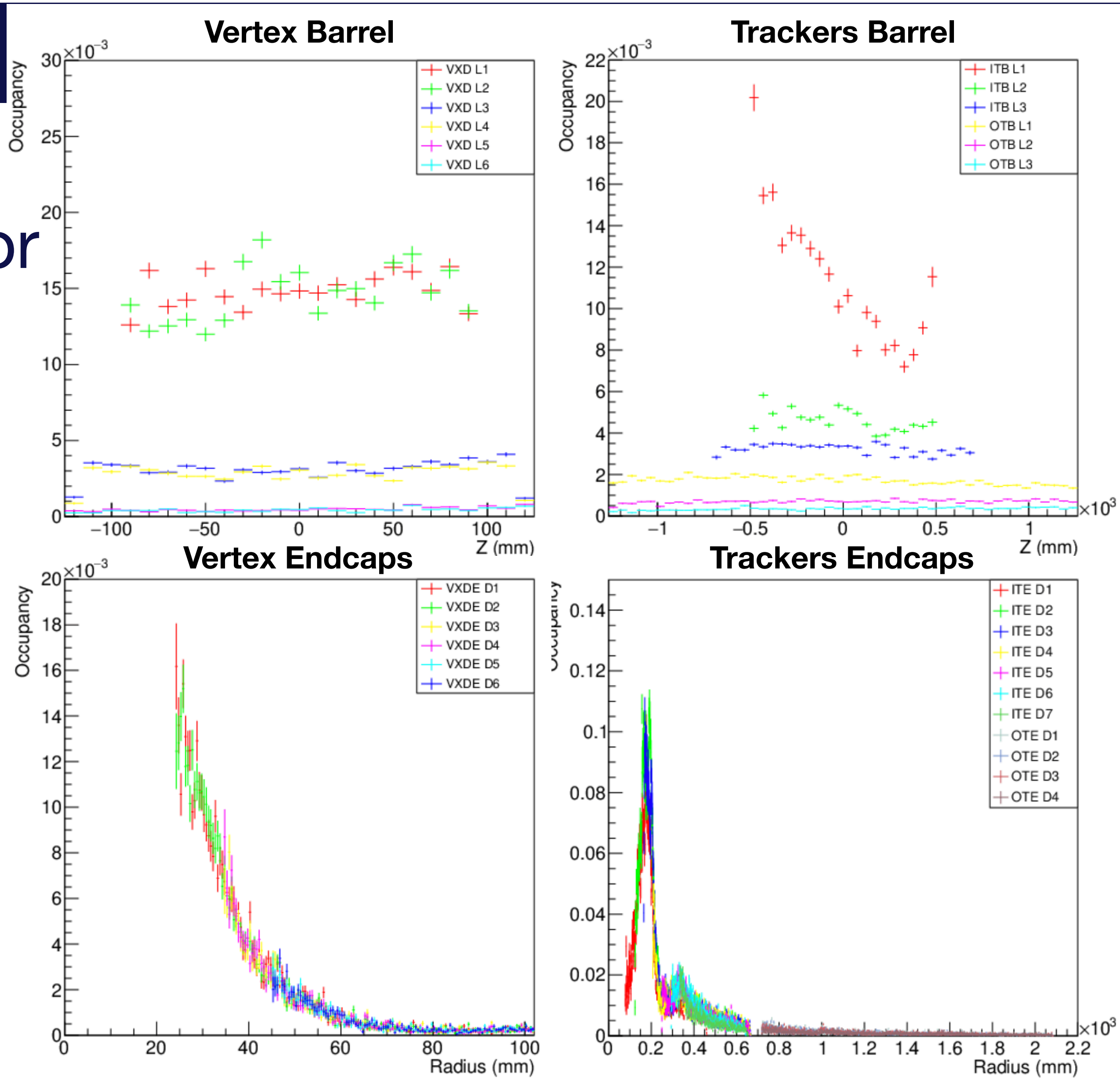
Occupancy at IPA for Z working point

Background @Top Horizontal Primary collimator

Going to the Top working point, the **induced background increases** a lot, reaching **several percents** in the inner tracker endcap, but also in the innermost layers of the other subdetectors.

This is due to the fact that, despite the losses per second are of the same order, the **number of bunches** is much lower now (40 vs 10'000), therefore the occupancy increases. A secondary factor is due to the particles **higher energy**.

	Losses per second (10^9)	Highest occupancy
IPA	0.15	10.95% (ITE)
IPD	0.11	7.78% (ITE)
IPG	0.10	6.41% (ITE)
IPJ	0.16	12.62% (ITE)



Occupancy at IPA for Top working point

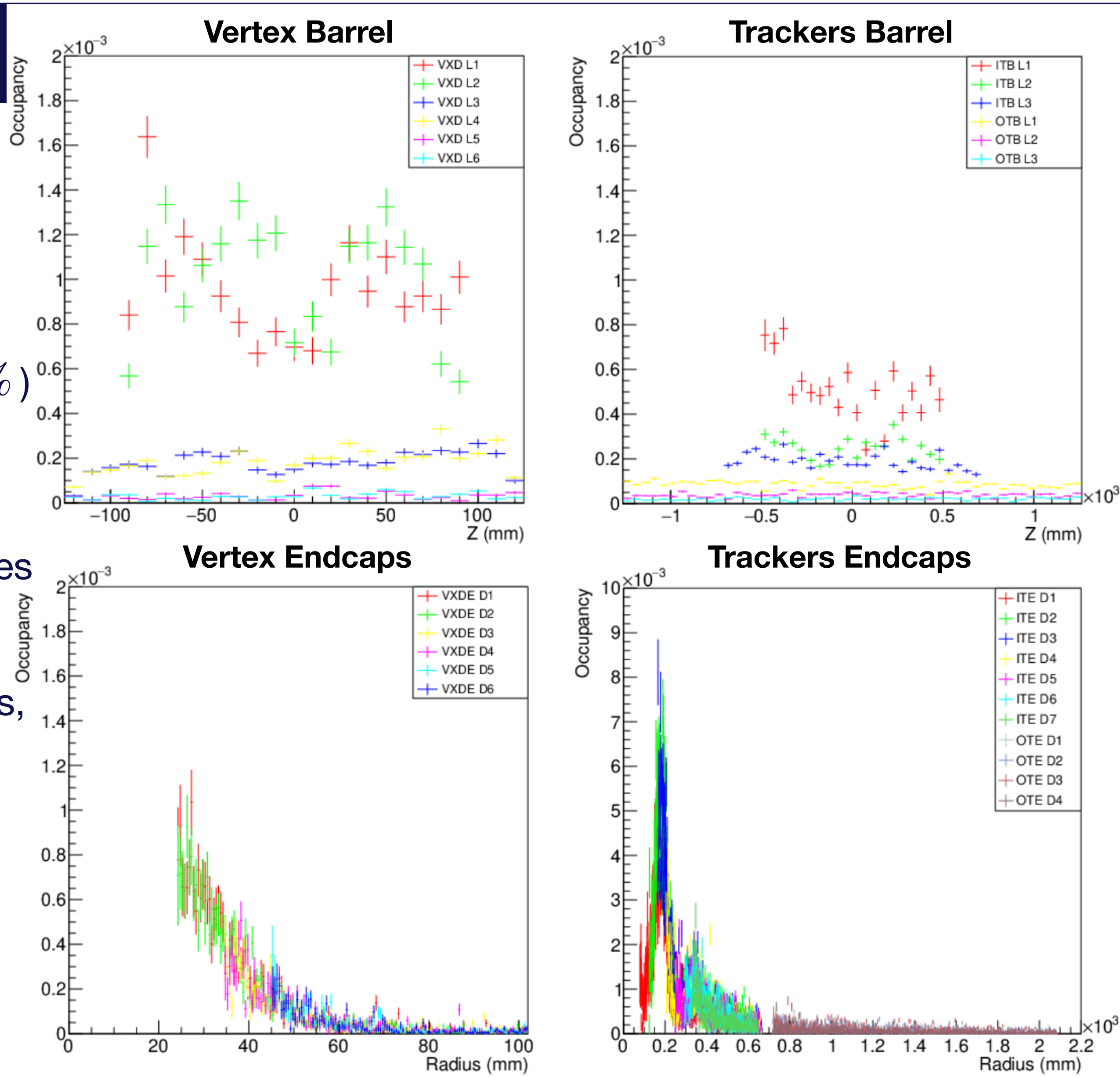
Background @Z
Off-momentum collimator
Momentum Offset

Pencil beam, $1\mu m$ impact par. ($\Delta p/p = +1.58\,\%$)

The loss map shows ah **higher loss rate at IPG**. This is expected due to the position of the collimators and distribution of the incident particles

For this scenario, the maximum occupancy registered is **below the 1%** in all the subtedectors, with only the ITE at IPG being close to this reference value.

	Losses per second (10^9)	Highest occupancy
IPA	1.66	0.12% (ITE)
IPD	0.38	0.04% (ITE)
IPG	12.21	0.81% (ITE)
IPJ	2.41	0.18% (ITE)



Occupancy at IPG for Z working point

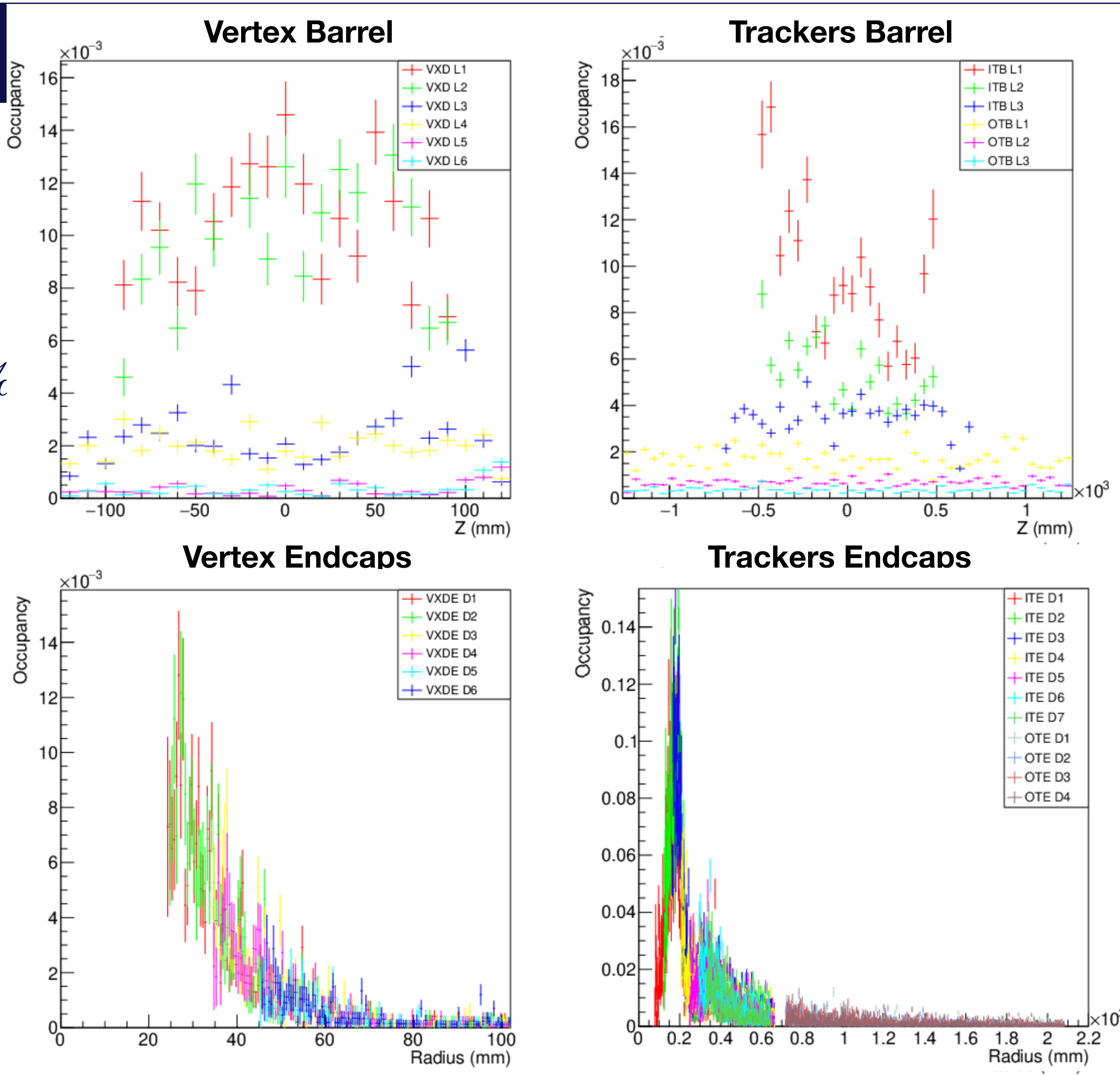
Background @Z Off-momentum collimator Momentum Offset

Pencil beam, $1\mu m$ impact par. ($\Delta p/p = -1.58\,\%$

For negative offset, **IPG** shows extremely high backgrounds in **all of the subdetectors**.

Negligible effects on IPJ, and **no losses at all** in IPA and IPD.

	Losses per second (10^9)	Highest occupancy
IPA	————	————
IPD	————	————
IPG	251.81	15.23% (ITE)
IPJ	0.04	< 0.01% (ITE)



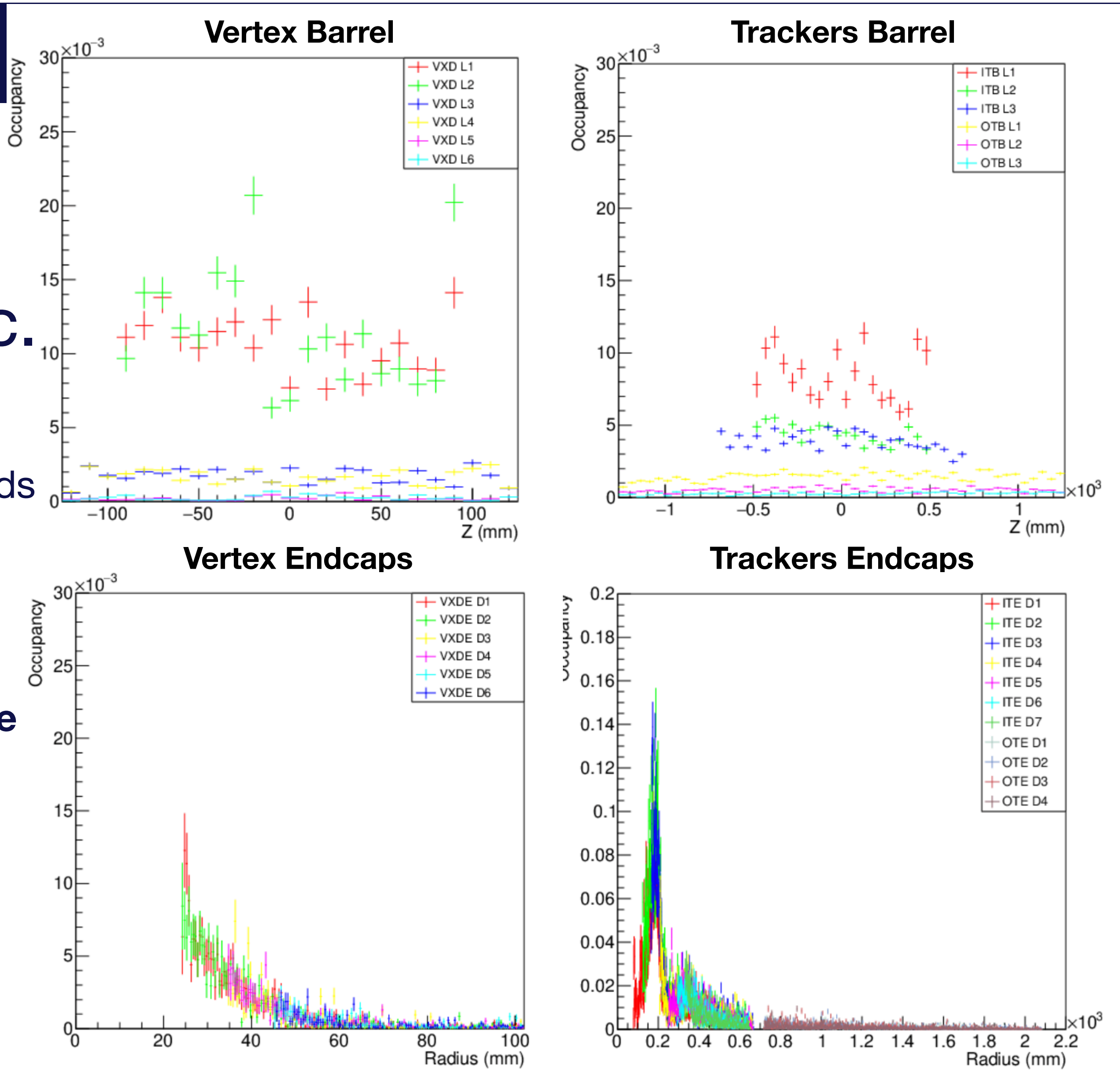
Occupancy at IPG for Z working point

Background @Z
Off-momentum collimator
Mom. Offset + Betatron Osc.

Adding **betatron oscillations** reduces the momentum offset to hit the collimator at the $1\mu m$ impact parameter ($\Delta p/p = -0.98\,\%$). It also leads to a **larger incidence angle**, meaning a shorter distance travelled in the collimator and **worse performance**.

In this scenario the occupancy at IPG is **above the 1%** not only in ITE but also in the **other subdetectors**.

	Losses per second (10^9)	Highest occupancy
IPA	0.15	< 0.01% (ITE)
IPD	0.24	0.01% (ITE)
IPG	182.10	14.54% (ITE)
IPJ	37.24	2.86% (ITE)



Occupancy at IPG for Z 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
```

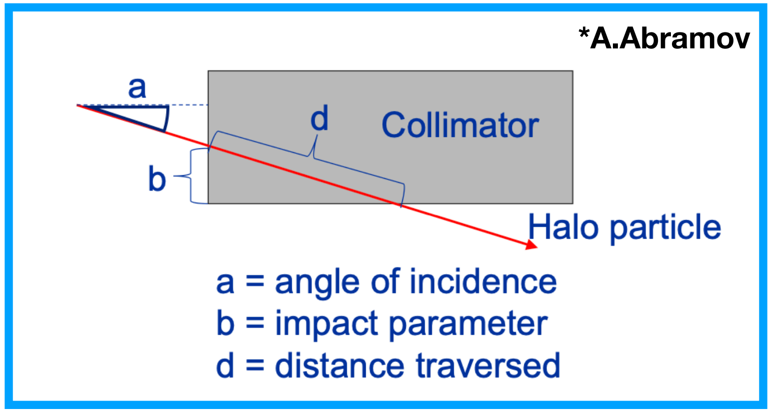
```
Analyzing data from:  Top/IPA_withFFQs_tilted
Losses per second:        233840
Losses per BX:            1.77668

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 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.

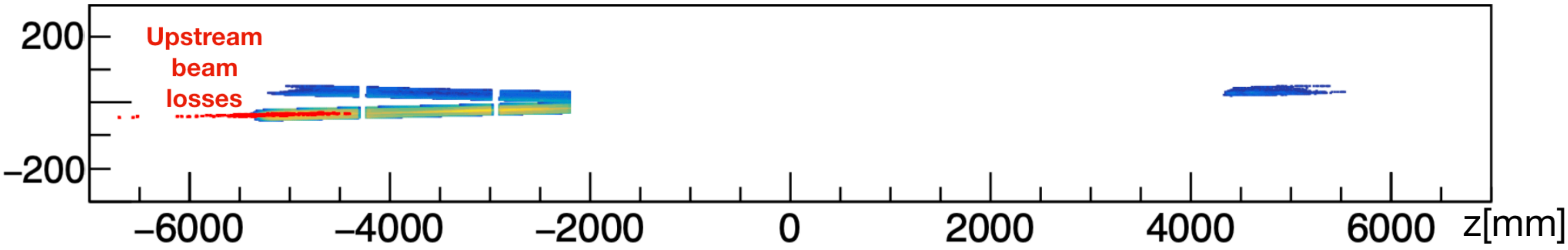
Power deposited in QC1

	Z: hor. primary collimator	TT: hor. primary collimator	Z: off-mom. collimator (dp/p>0)	Z: off-mom. collimator (dp/p<0)	Z: off-mom. collimator & beta. osc.
	Total power in QC1 (W)				
IPA	0.72	2.01	4.07	– – –	0.35
IPD	0.32	1.52	1.01	– – –	0.44
IPG	0.18	1.25	28.69	630.52	512.43
IPJ	1.15	1.92	6.75	0.045	102.52
	QC1 hottest spot (GeV in a 0.5mm² x 2mm bin)				
IPA	0.004	3.167	0.028	– – –	0.003
IPD	0.001	2.361	0.007	– – –	0.002
IPG	0.001	1.174	0.133	2.023	1.714
IPJ	0.006	2.267	0.019	0.001	0.590

A **simple model** (cylindrical homogeneous equivalent material) of the QC1 elements has been installed in the MDI description to study the **deposited power** due to the beam losses.

Supposing a **cooling capacity** of the cryogenic system of **~10W** we see that halo losses do not set a problem, while the **off-momentum** particles can reach several hundreds of W.

First calculations on the **Minimum Quench Energy** show that for 2mm long segments of a cable cross-section of 0.5mm² is $MQE \sim 10^5 GeV$. Using this binning one can see that the local energy peaks are **well below** this threshold in any scenario.



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

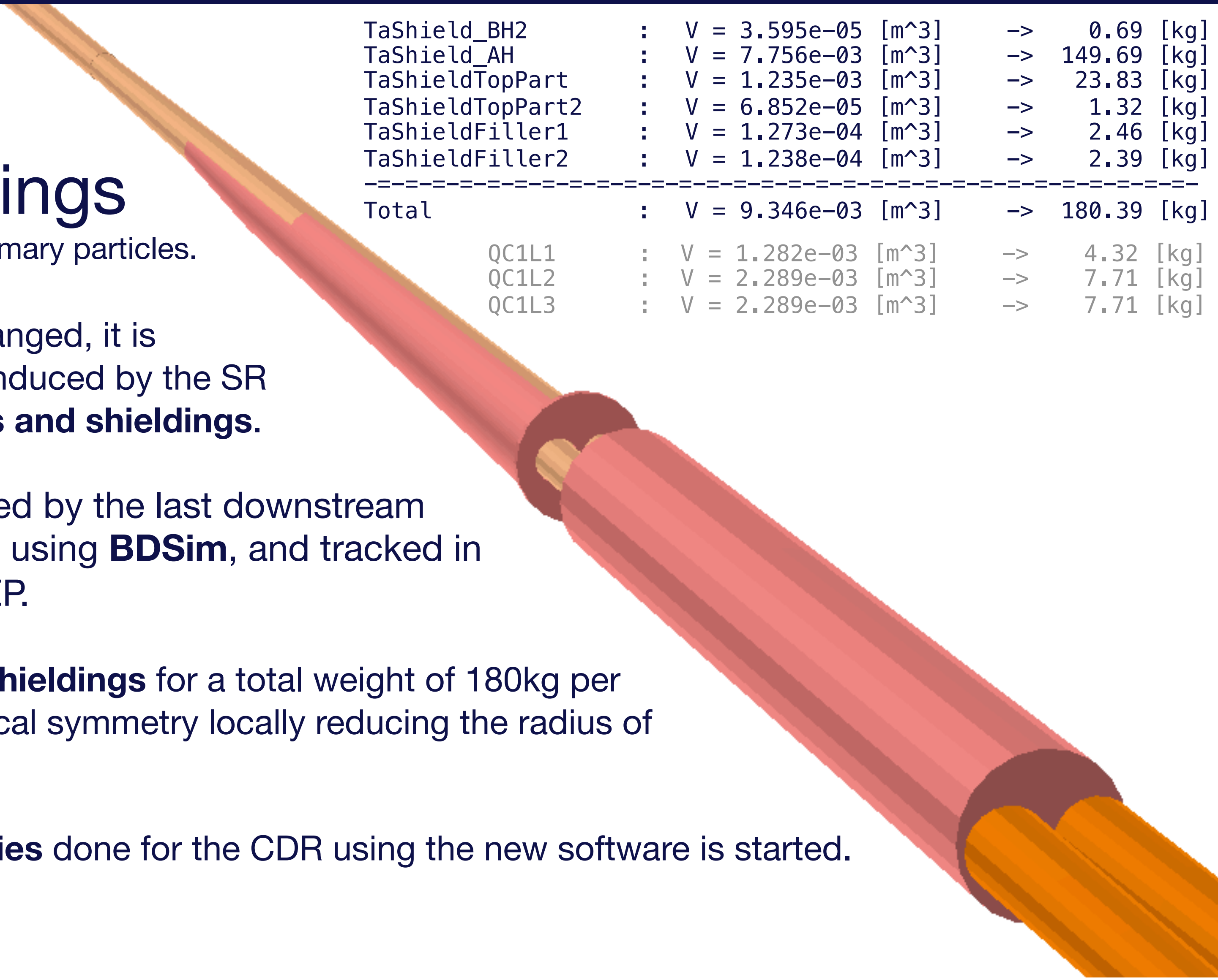
Thanks to K. André and M. Sullivan for the primary particles.

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.

Also the process of **replicating the studies** done for the CDR using the new software is started.



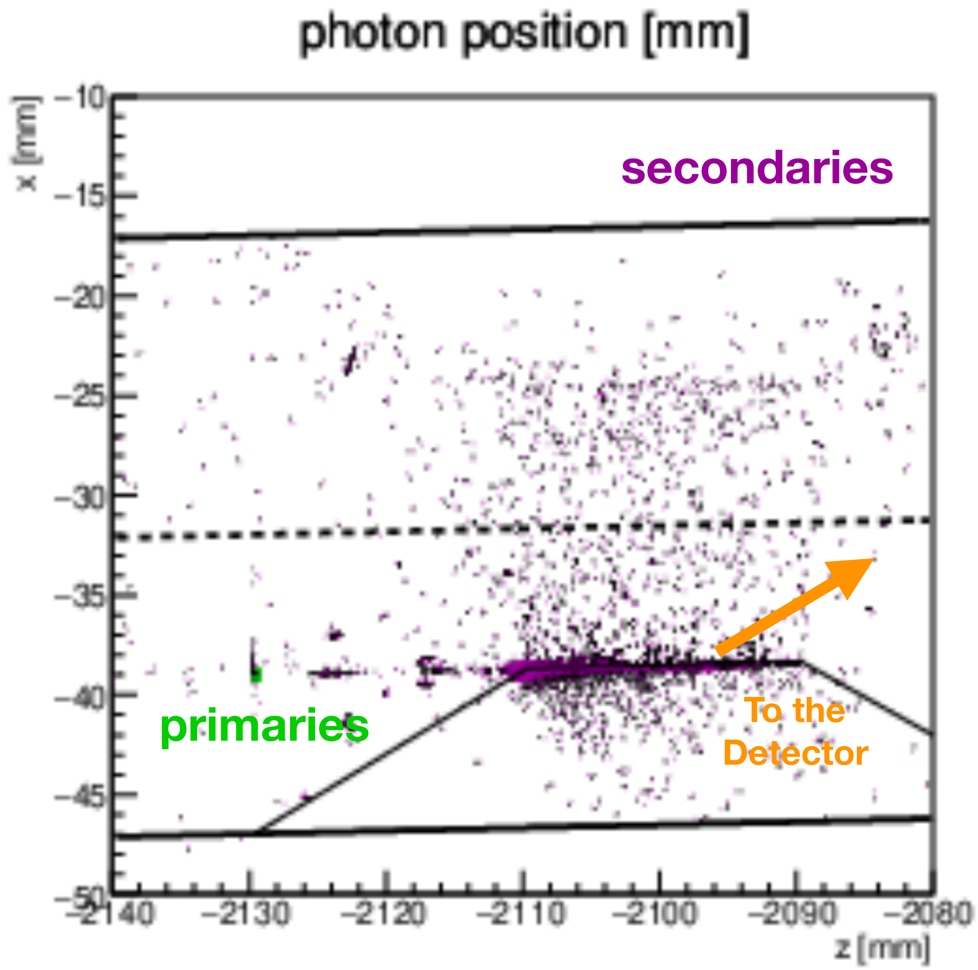
Special attention should be given to the photons which will impact **the tip of the mask**, as they are the main source of potential background in the detector.

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.

A **larger sample** for the 4-10sigmas ring has just been produced (see K. Andrè 08/12) and the study of the induced background is currently **ongoing**.

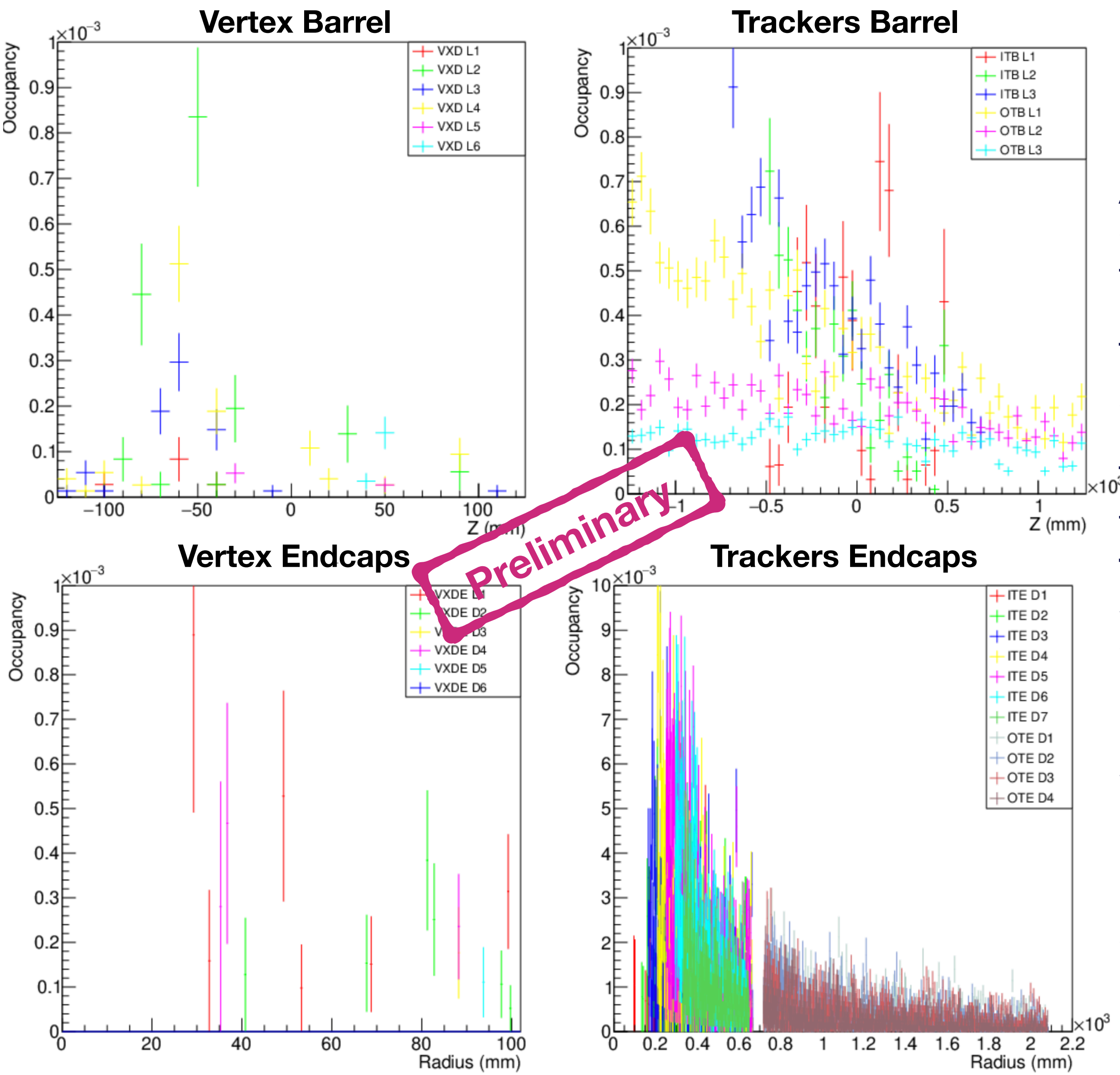
The contribution of **non-gaussian tails** is expected to be non negligible (e.g. SuperKEKB), and is currently **under investigation**.

	$N_{macro}(e^-)$	$N_{macro}(\gamma)$	$N_{macro}(\gamma)^{TIP}$
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 —

2IP @Top - no shieldings



2IP beam parameters - Top - no shielding

A **preliminary** study to **replicate** the work previously done for the CDR has been performed by repeating the tracking in **Key4HEP**, for the **CLD** detector.

The comparison with the old results on hit density shows an **overall good agreement** (see next slide).

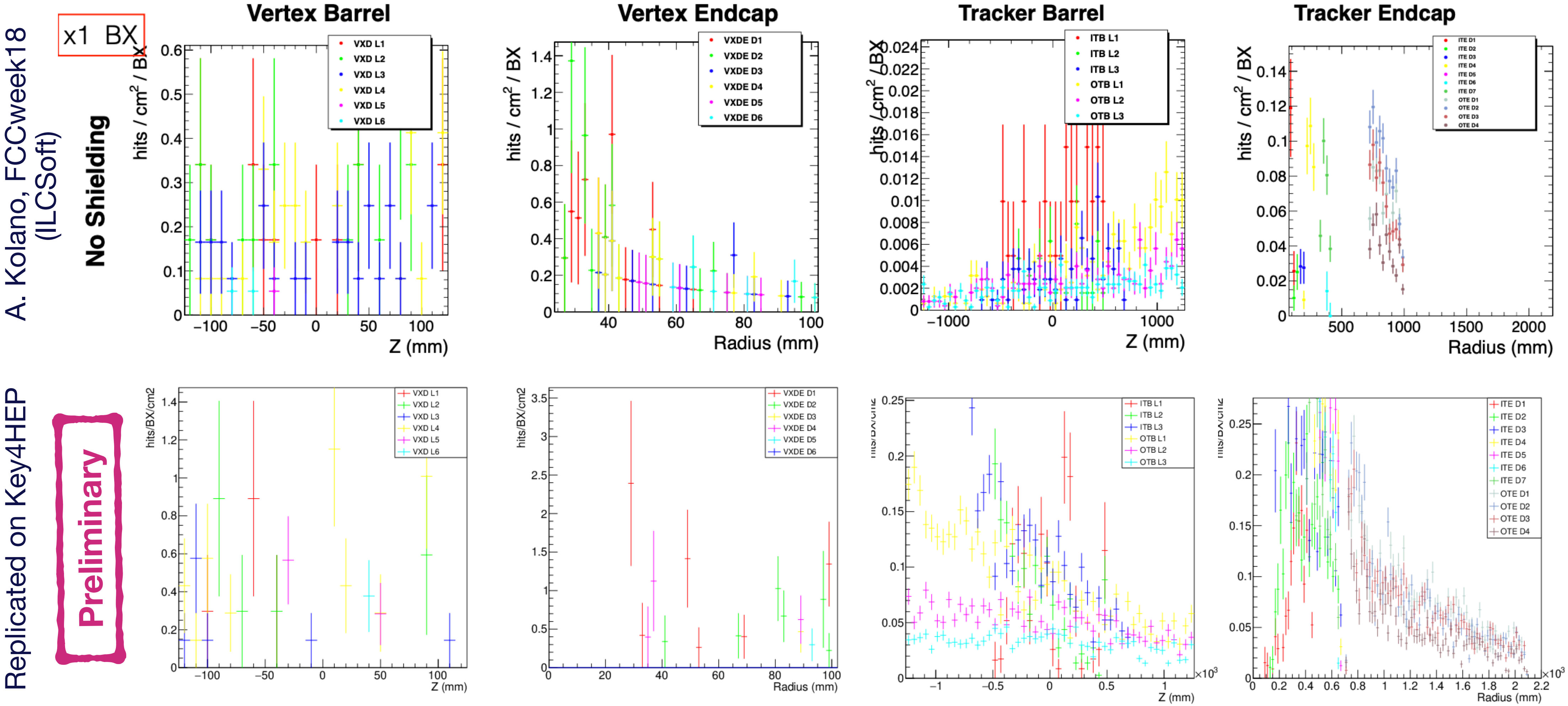
The **occupancy** induced by the SR photons scattered by the tip of the mask is **below the 0.1%**, except for the **tracker endcaps** where this value can reach **up to 1%**, so this might require some attention, in particular considering the **electronics readout time**.

For **drift chambers** instead, due to the limited z segmentation the effect could be much higher.

Please note that these results are **preliminary**, as the input file used is not exactly the same used in the past, and other small differences are **under investigation**.

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

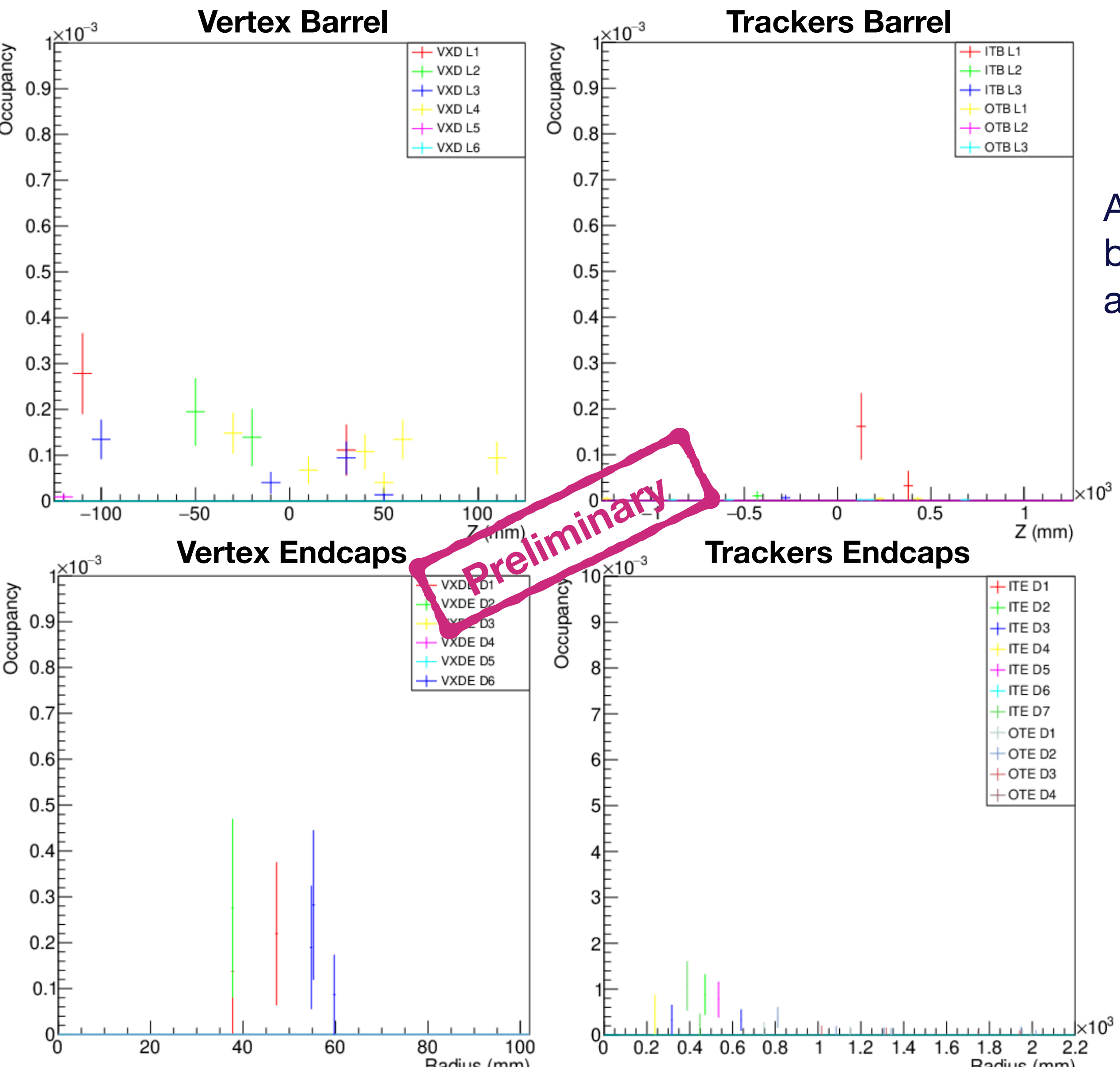
$$size_{sensor} = \frac{25\mu m \times 25\mu m\ (pixel)}{1mm \times 0.05mm\ (strip)} \qquad size_{cluster} = \frac{5\ (pixel)}{2.5\ (strip)} \qquad safety = 3$$



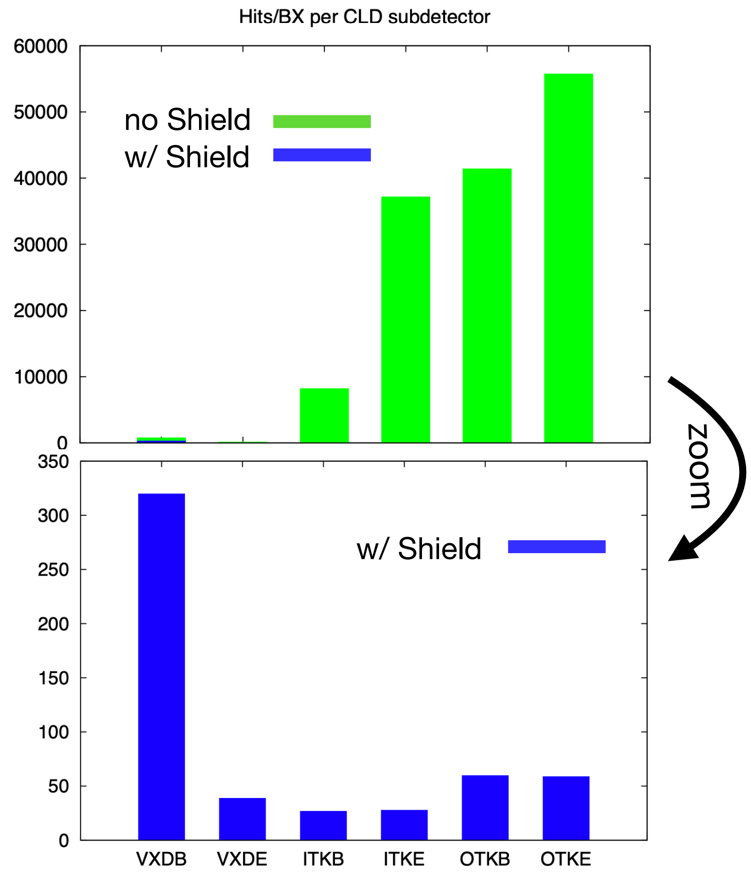
The **comparison of the hit density** in the subdetectors show that, while new results are a bit higher, an **overall good agreement** is found - except for the tracker barrel where a ~x10 factor is found. Small differences can be addressed to different SW, lower statistics, not exactly the same input file, variations in the geometry description, …

2IP @Top - with shieldings

Adding the **Tungsten shieldings** of course reduces by a lot the background in particular in the trackers, and with a smaller effect on the vertex detector.



2IP beam parameters - Top - w/ shielding



Summary

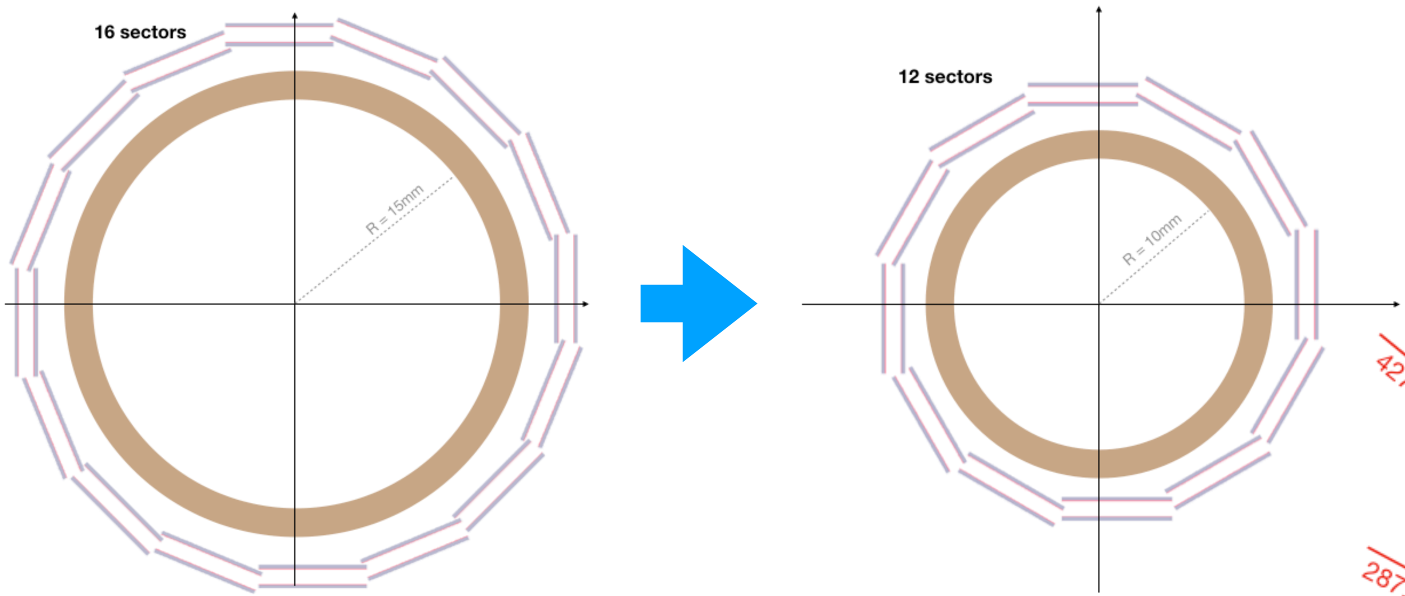
- Tracking of the **beam losses:**
  - occupancy from **horizontal primary collimator** is well below 1% @Z, but it can reach **up to 10% @Top**, so **mitigation strategies** should be investigated
  - first tracking of the losses due to the **off-momentum collimator** show that these losses are almost completely **localised in IPG** (after the coll. section in PF), in particular for negative dp/p, leading to high background levels.
  - adding **betatron oscillations** reduced the momentum offset required to hit the collimator, further increasing the occupancy
  - despite the high losses, the instantaneous energy deposited on QC1 is well **below the Minimum Quenching Energy**. On the other hand **total power** can reach up to several 100W, which may be too high for the cooling system to deal with —> is a **shielding** necessary/possible?

- 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 (work in progress)
  - preliminary study to **replicate** the CDR studies showed that without the shielding the occupancy is below 1% in almost all subdetectors for **CLD** (Silicon).
  - Effect in a **Drift Chamber** (lower z segmentation) might be much higher —> repeat this study once the implementation of the detector will be available

		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

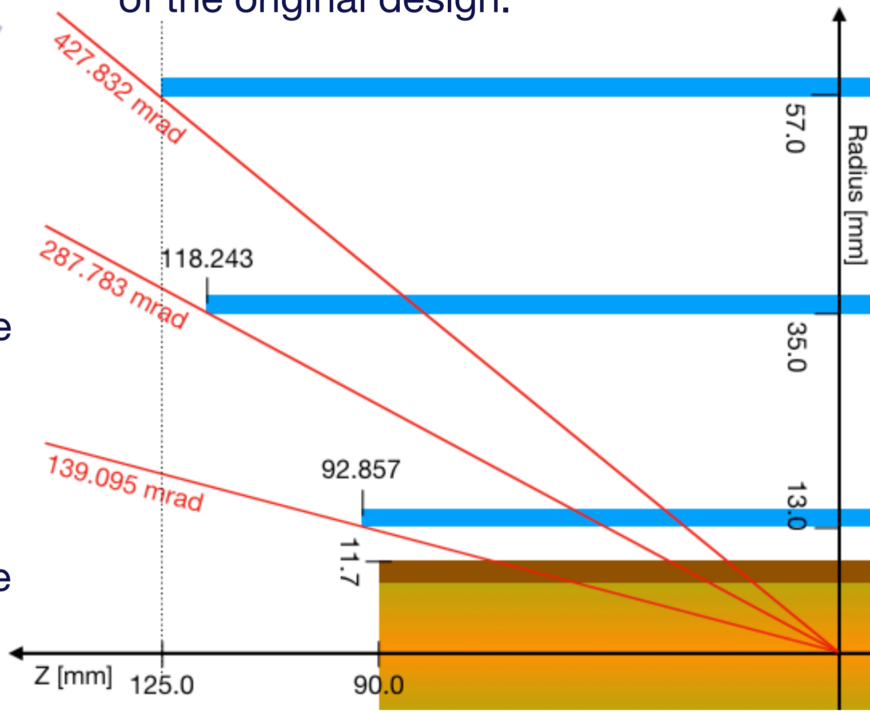
4IP lattice - see K. Oide https://indico.cern.ch/event/1118299/

Updated CLD VXD for Small Beam Pipe



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.



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**.

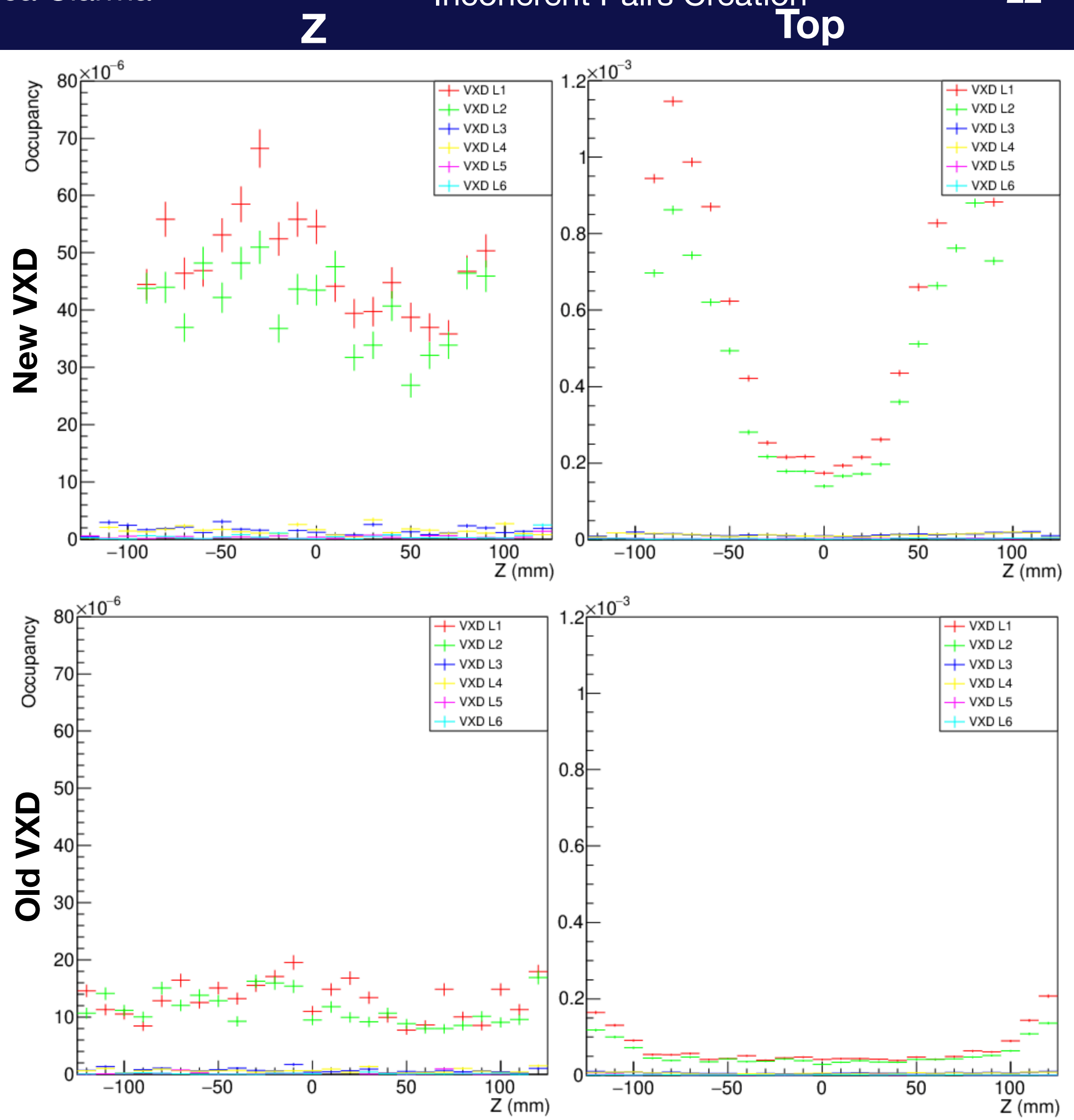
Keeping the **same distance** between the external surface of the beam pipe and the begin of the first ladder, and also the **same stave width**, I have reduced the **number of sectors to 12** (from 16) in order to avoid overlaps.

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



Failure Scenario Beam Losses Induced Background Recap

	Z: horizontal primary collimator	TT: horizontal primary collimator	Z: off-mom. collimator	Z: off-mom. collimator + betatron osc.
	Losses per second (10^9)			
IPA	0.26	0.15	1.66	0.15
IPD	0.14	0.11	0.38	0.24
IPG	0.12	0.10	12.21	182.10
IPJ	0.39	0.16	2.41	37.24
	Highest occupancy			
IPA	0.02% (ITE)	10.95% (ITE)	0.12% (ITE)	< 0.01% (ITE)
IPD	< 0.01% (ITE)	7.78% (ITE)	0.04% (ITE)	0.01% (ITE)
IPG	< 0.01% (ITE)	6.41% (ITE)	0.81% (ITE)	14.54% (ITE)
IPJ	0.03% (ITE)	12.62% (ITE)	0.18% (ITE)	2.86% (ITE)
	QC1 hottest spot (W/cm3 in a 2mm3 bin)			
IPA	0.011	0.035	0.078	0.007
IPD	0.004	0.026	0.021	0.005
IPG	0.003	0.013	0.371	4.767
IPJ	0.016	0.025	0.054	1.637
	Total power in QC1 (W)			
IPA	0.72	2.01	4.07	0.35
IPD	0.32	1.52	1.01	0.44
IPG	0.18	1.25	28.69	512.43
IPJ	1.15	1.92	6.75	102.52

Minimum quench energy MQE

M. Koratzinos

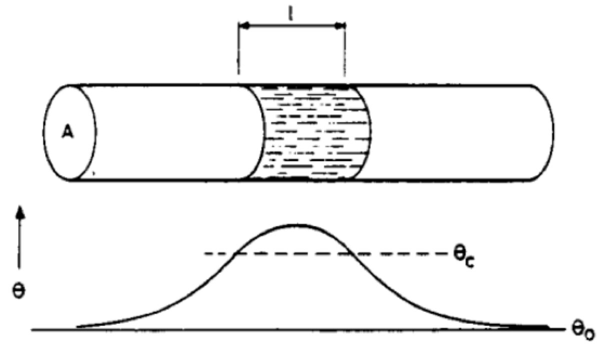


Fig. 20 A minimum propagating zone

NbTi at 4.2K and 2T typical values

critical current density	$J_c = 6 \times 10^9$ A m^{-2}
density	$\gamma = 6.2 \times 10^3$ kg m^{-3}
specific heat	$C = 0.89$ J kg^{-1}
critical temperature	$\theta_c = 8.6$ K

$$\mathrm{MQE} = Al\gamma\ C(\theta_c - \theta_o) = A\gamma\ C(\theta_c - \theta_o)^{3/2} \frac{(1-\lambda)}{\lambda J} \left\{ \frac{2k}{\rho} \right\}^{1/2}$$

$$l \approx \left\{ \frac{2k(1-\lambda)^2.(\theta_c - \theta_o)}{\lambda^2 J^2 \rho} \right\}^{1/2}$$

λ superconductor fraction = 0.3
k thermal conductivity
ρ resistivity
J current density = 7×10^8 A m^{-2}

In our case where margin is 2.5K, 0.825mm diam. cable, length is small (~200μm)

This is about 10TeV of instantaneous energy deposited in an area 300 μm X 0.5mm^2

Somebody needs to check my calculations, but is this number too big/too small?

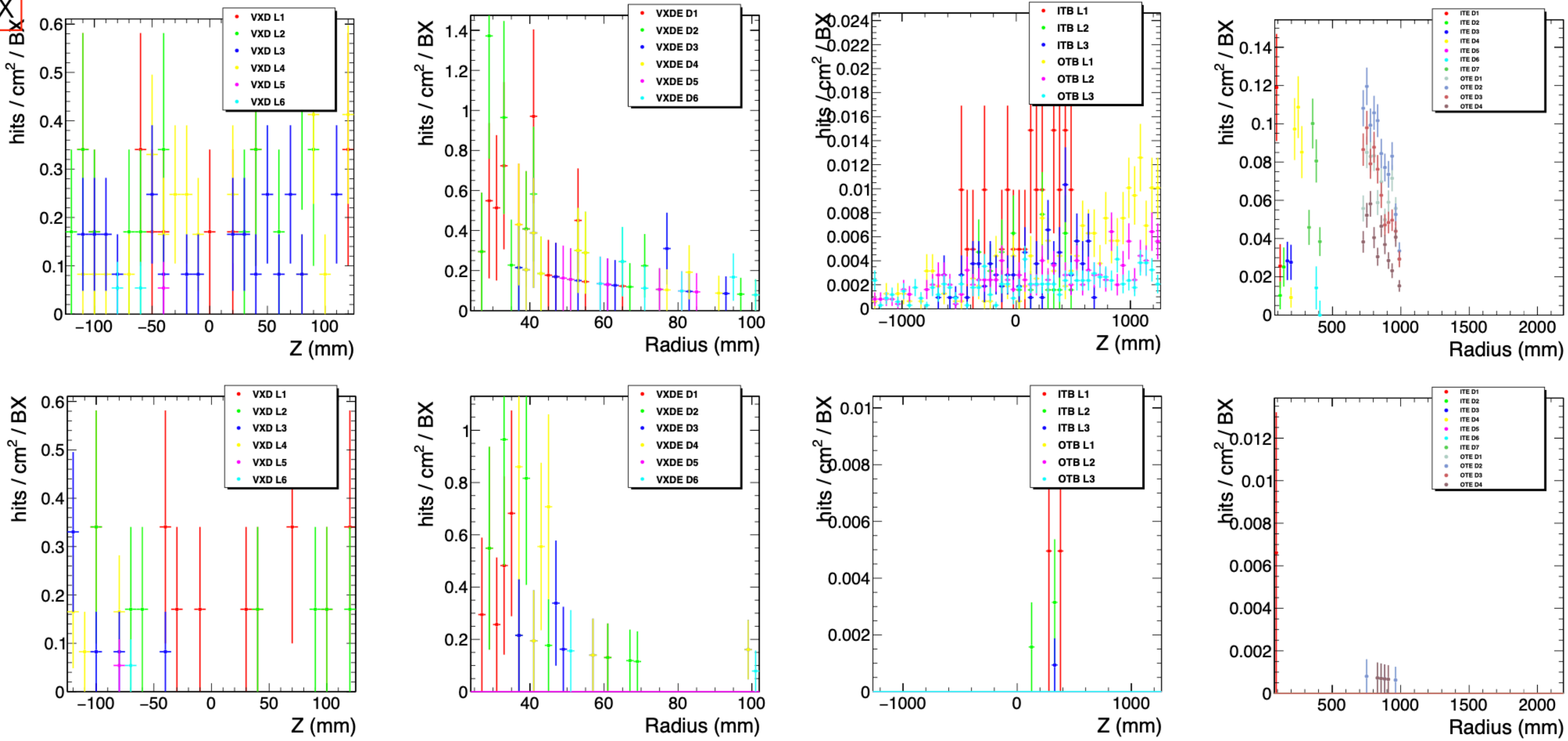
Hit density/cm2 in the Vertex and Inner Tracker Detectors

x1 BX

Vertex Barrel | Vertex Endcap | Tracker Barrel | Tracker Endcap

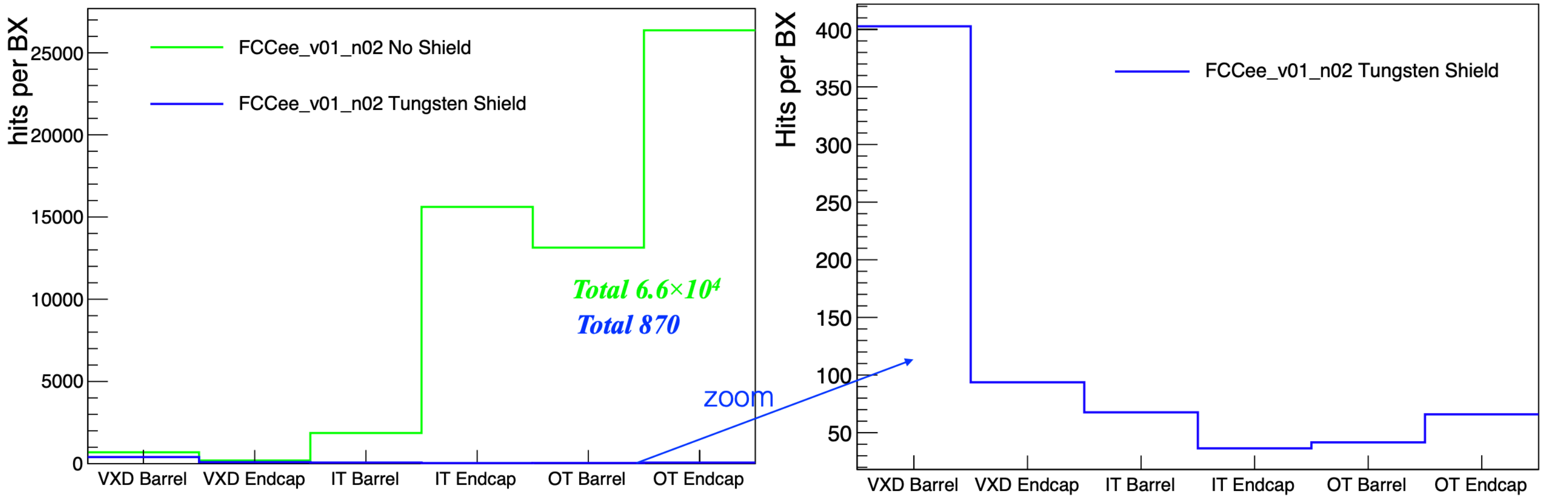
No Shielding

Shielding



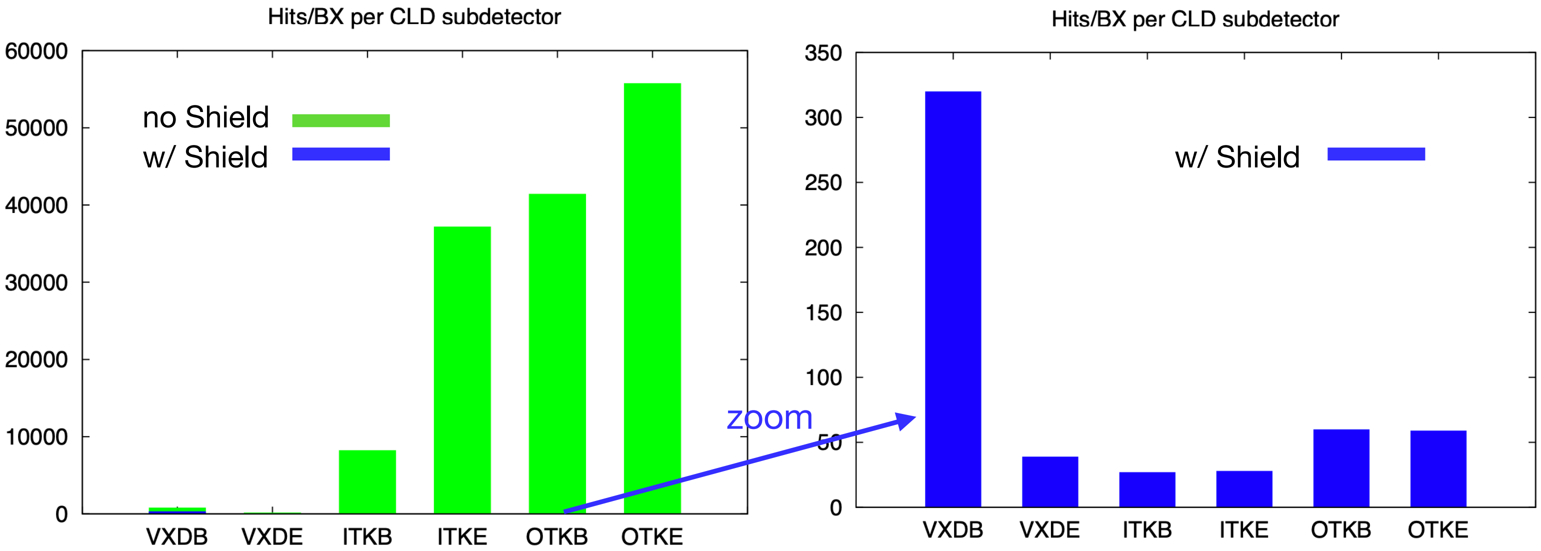
Total SR for two beams forward scattered from the last mask tip at 2.12 m from the IP

A. Kolano, FCCweek18 (ILCSoft)

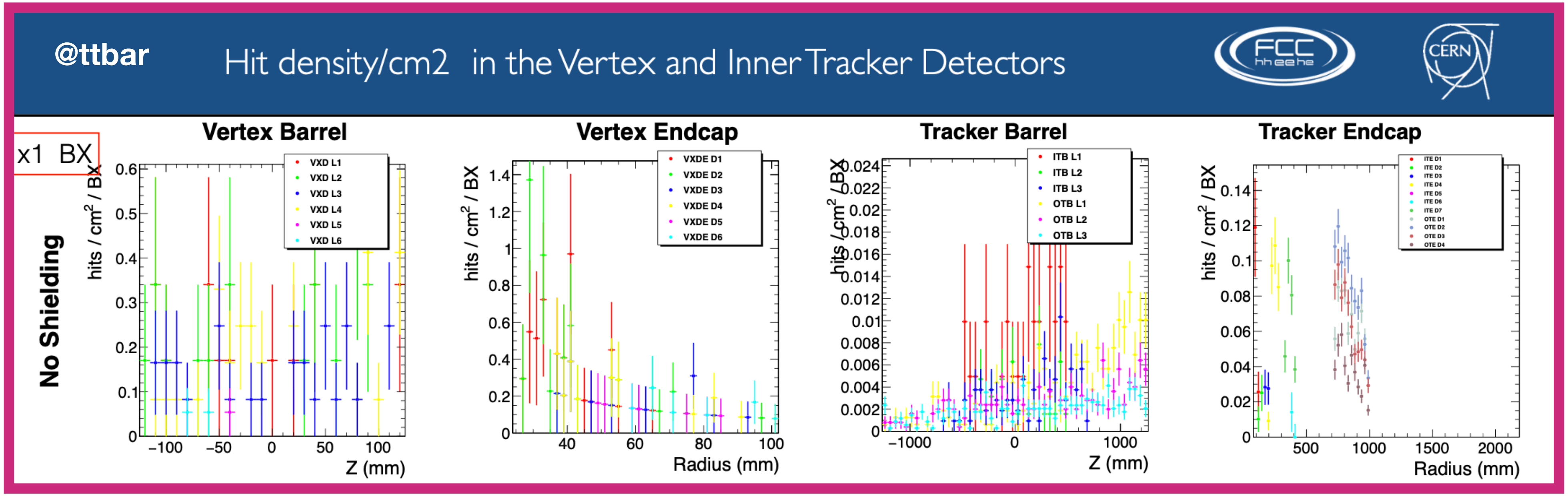


Replicated on Key4HEP

Preliminary



From FCCweek 2018

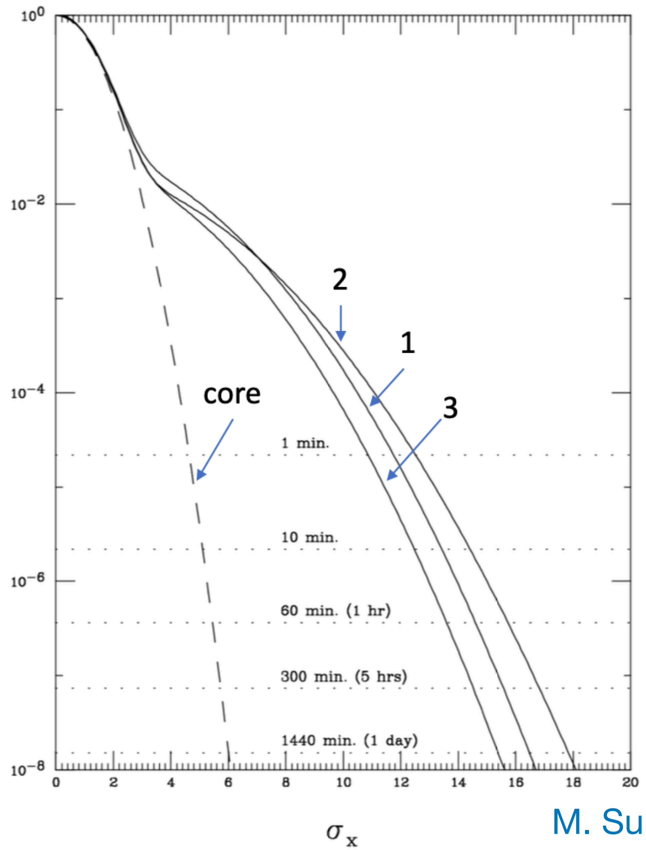


Consideration on previous results:

The conversion from hit density to occupancy is a factor O($10^{-4} \sim 10^{-3}$). As the maximum hit density is O(1~0.1), the max occupancy would be <<1% everywhere. Is the shielding necessary for CLD? Could it be added only @Top? Occupancy in Drift Chamber will likely be much higher…

$$occupancy = hits/cm^2/BX \cdot size_{sensor}[cm^2] \cdot size_{cluster} \cdot safety \simeq hits/cm^2/BX \cdot \begin{matrix} 1 \times 10^{-4}\ (VXD\ pixel) \\ 5 \times 10^{-3}\ (TRK\ strip) \end{matrix}$$

$$size_{sensor} = \begin{matrix} 25\mu m \times 25\mu m\ (pixel) \\ 1mm \times 0.05mm\ (strip) \end{matrix} = \begin{matrix} 6.25 \times 10^{-6}\ cm^2\ (pixel) \\ 5 \times 10^{-4}\ cm^2\ (strip) \end{matrix} \qquad size_{cluster} = \begin{matrix} 5\ (pixel) \\ 2.5\ (strip) \end{matrix} \qquad safety = 3$$

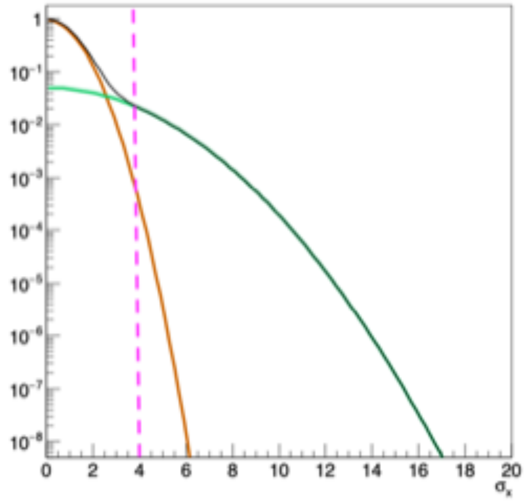


Tail distributions that can generate the background level seen in the superKEKB pixel detector (PXD) during early running.

They also approximately agree with the measured beam lifetime.

The one-day lifetime is derived by Matt Sands, "The Physics of Electron Storage Rings an Introduction", 1970, SLAC-121

M. Sullivan - eeFACT2022



Good parameters to simulate non-gaussian tails in FCCee?