STATUS AND PERSPECTIVES FOR FCC-EE DETECTOR BACKGROUND STUDIES

Andrea Ciarma

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

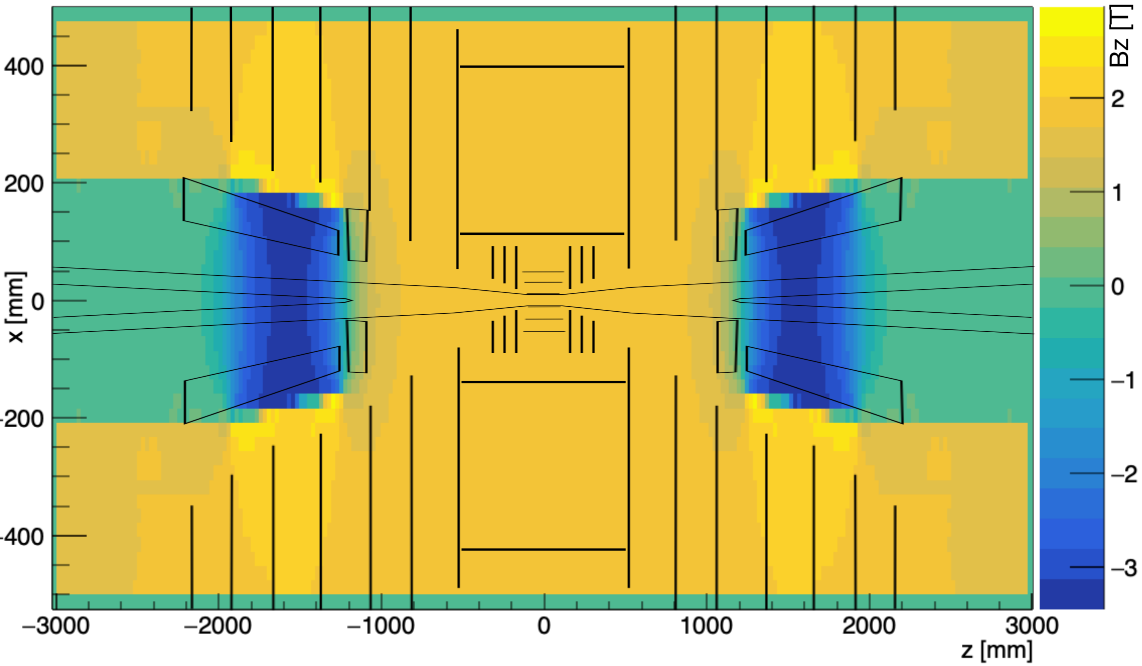
FCC-ee MDI background studies

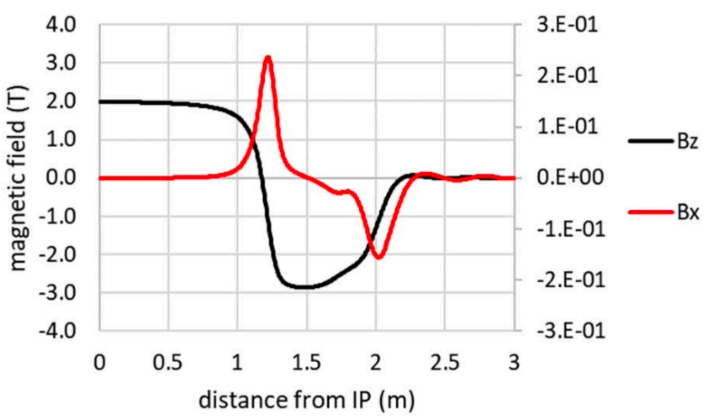
Beam induced background in the **CLD detector** using the **10mm radius central chamber**, relative **vertex detector** update and **4IP lattice** beam parameters, have been presented in past workshops (FCCIS - 12/2022, FCCee MDI - 10/2022).

After the update in the **magnetic field description** in the detector model - now coming from a **field map** - I replicated the following studies to have more realistic results:

- 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
- **Synchrotron Radiation** induced occupancy and effect of the tungsten shieldings

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.**





Magnetic Field in the Detector Area

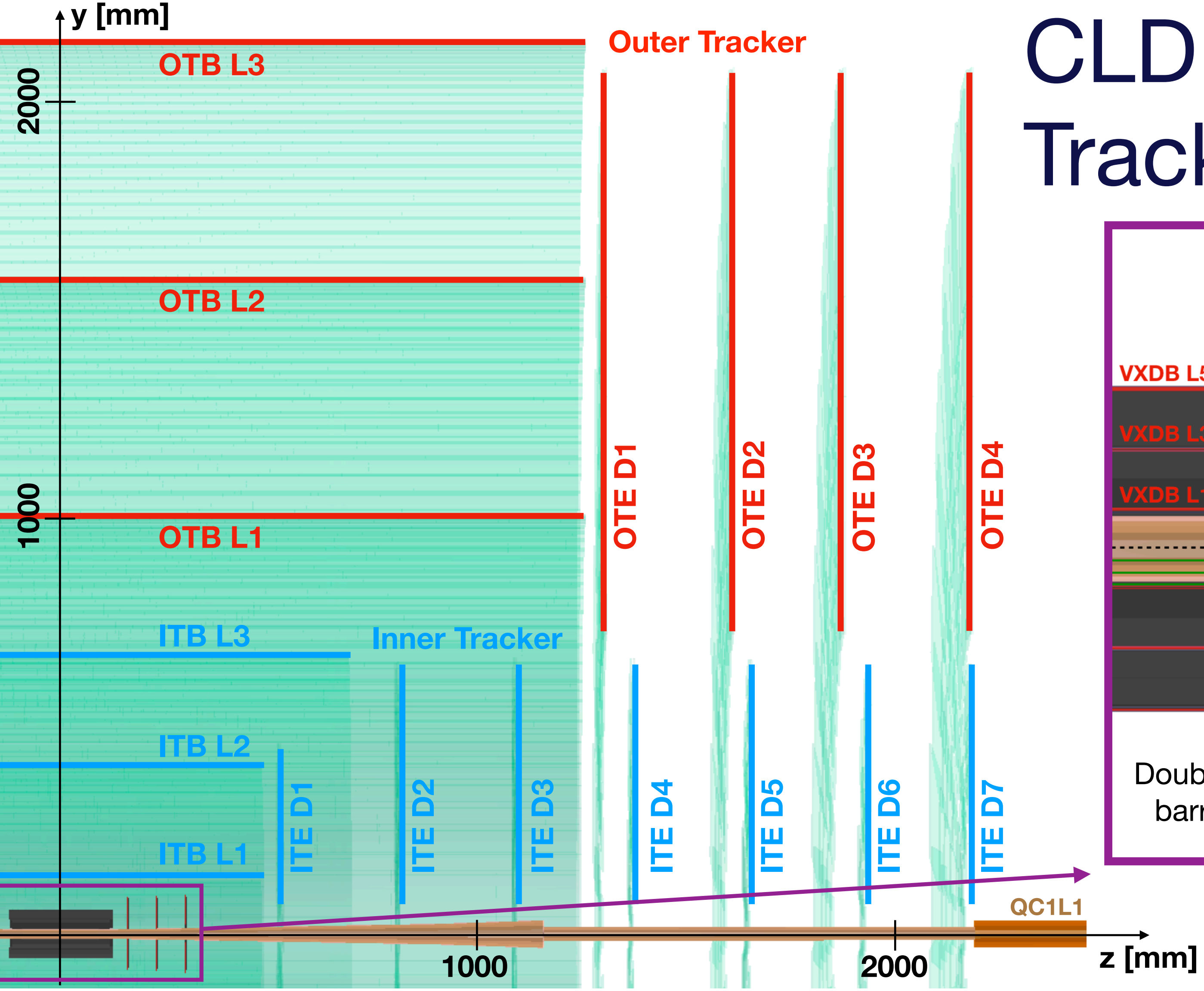
Improved description of the magnetic field in the detector, thanks to the possibility to **import field map** in key4hep geometry.

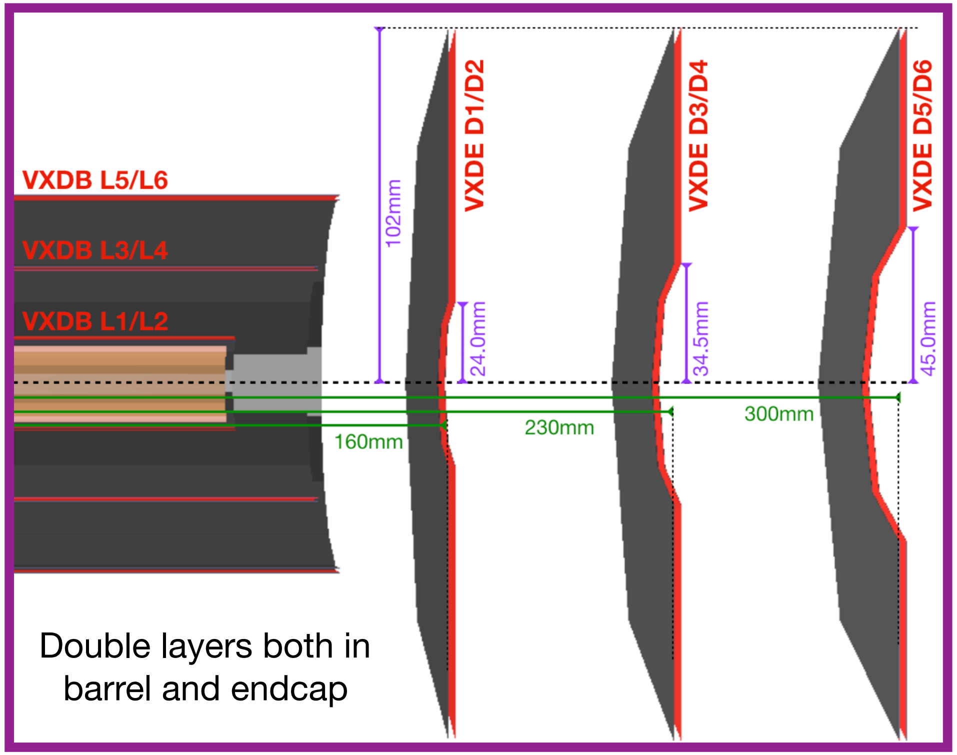
Screening and **compensating** solenoids contribution now introduced in addition to the 2T of the main solenoid.

Repeat background studies and compare with previous results:

- no difference expected for IP produced particles
- significant effect expected for particles produced upstream (e.g. beam losses)

CLD Subdetectors: Trackers and Vertex





Vertex Detector

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

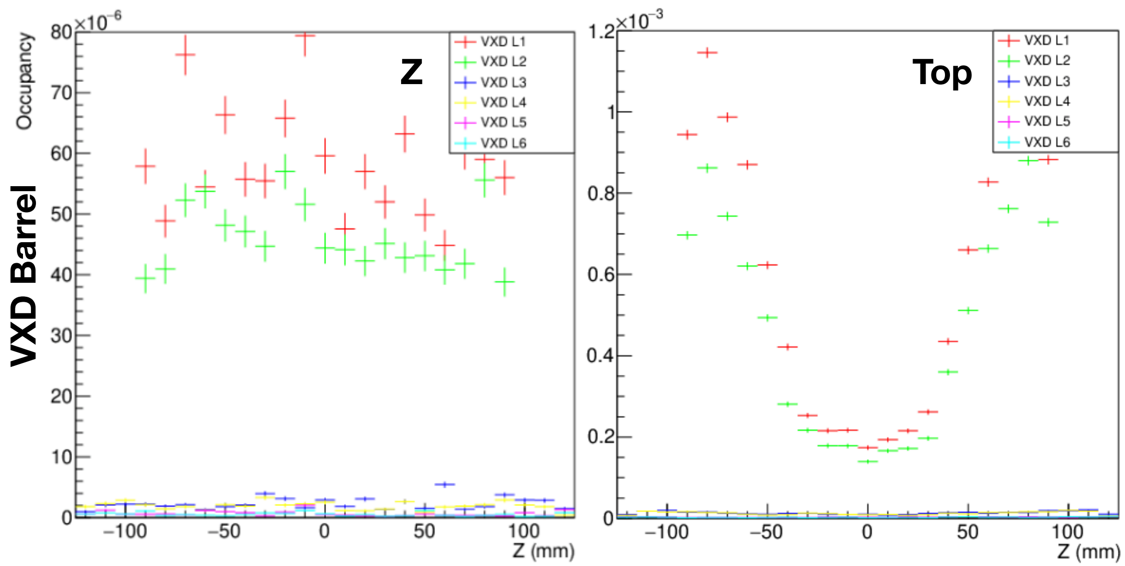
Incoherent Pairs Creation

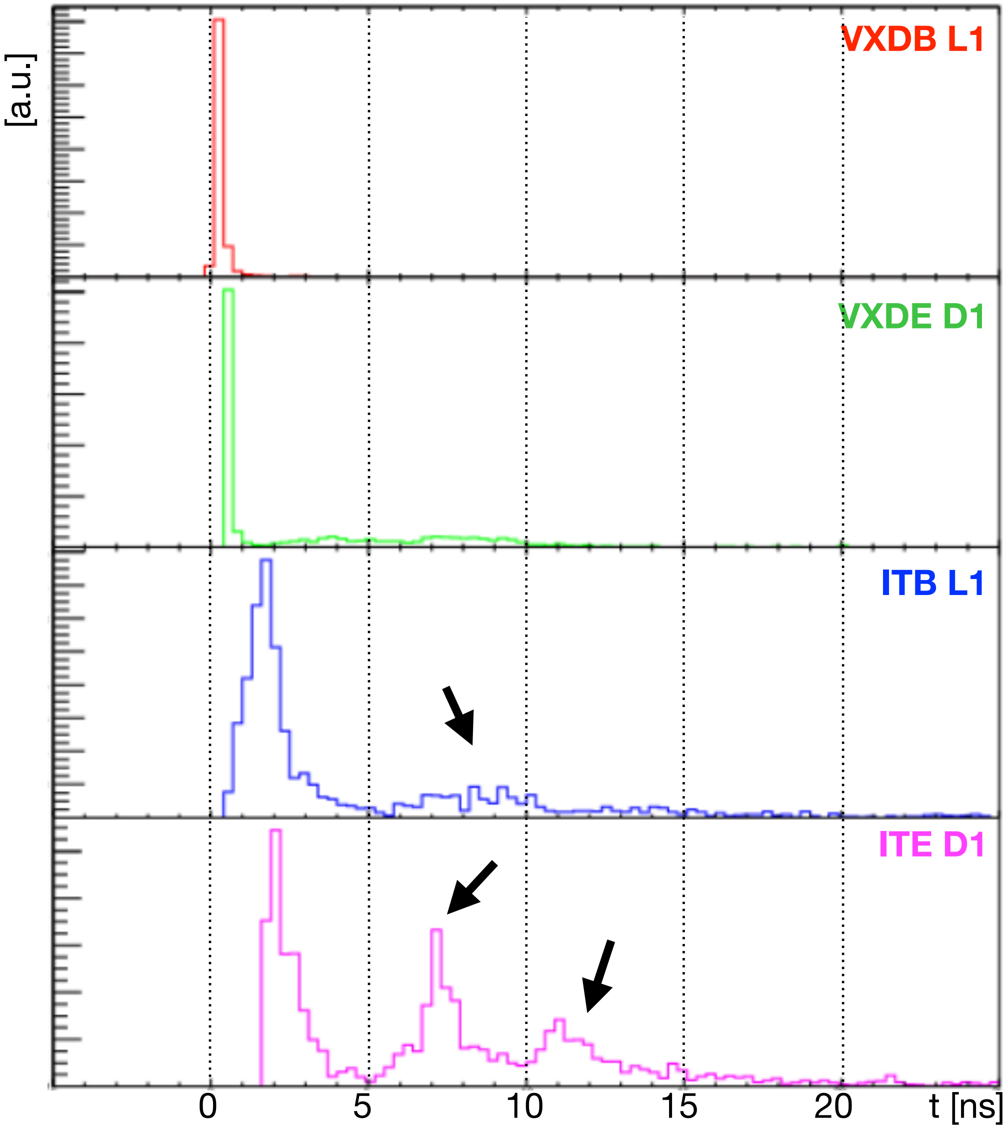
	Z	WW	ZH	Top
Pairs/BX	1300	1800	2700	3300
Max occup. VXDB	80e-6	280e-6	410e-6	1150e-6
Max occup. VXDE	25e-6	95e-6	140e-6	220e-6
Max occup. TRKB	8e-6	20e-6	38e-6	40e-6
Max occup. TRKE	100e-6	150e-6	230e-6	290e-6

As expected, the introduction of the anti-solenoids in the model had **no noticeable effect** in the induced background, as the particles are produced at IP and only traverse regions with 2T field.

The induced occupancy is still **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.

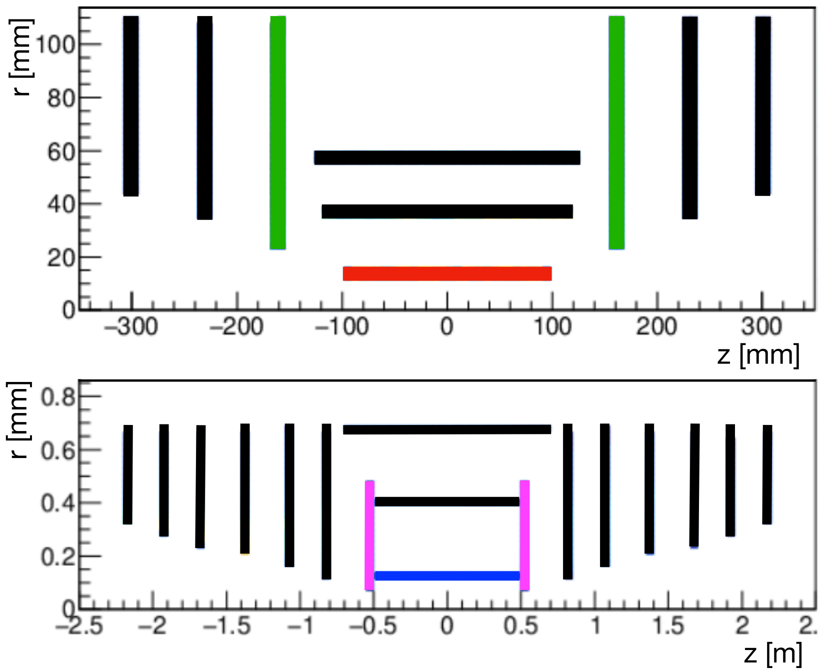
Next steps require the **overlay of this background** to physics event to verify the **reconstruction efficiency.**





From the study of the **signal time** we can see that, while most of the particles hit the detector directly, there is a contribution from **backscattering** - in particular for the IT.

For the reconstruction this signals could be rejected offline, further reducing the (already low) effect of this background.



Approx. expected
Time from IP
to detector:

VXBD 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

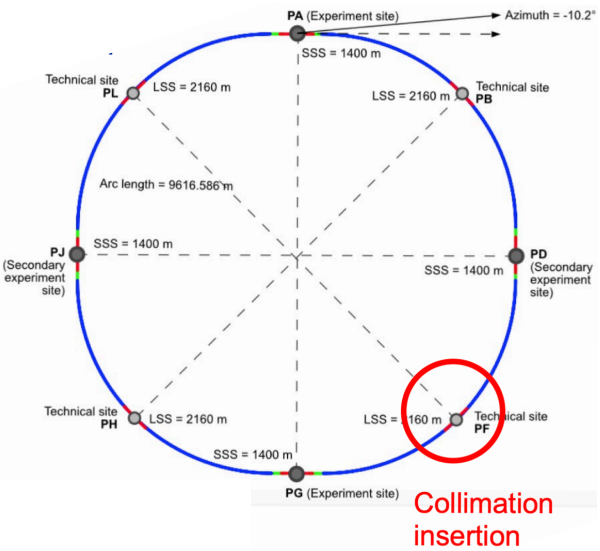
Beam Losses in the IR due to Failure Scenarios

Thanks to A. Abramov for the primary particles.

Previous studies (see my talk @ FCCIS Workshop 07/12/2022) on the induced background in the event of a **drop of the beam lifetime to 5 minutes** showed very high occupancies - up to **O(10%)**! - both from halo losses on the **Horizontal Primary Collimator** and the **off-momentum collimators**.

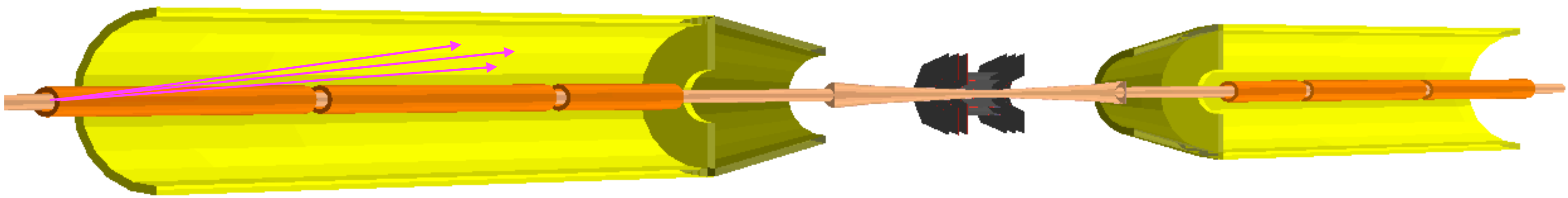
A. Abramov, M. Hofer - FCCWeek2022

4IP lattice v529



Collimation insertion

As the losses happen on the beam pipe **few meters upstream**, particles which will make it to the trackers will need to pass through the **screening** and **correcting solenoids** region. It is therefore important to replicate these studies using the realistic field map in place of the plain 2T field.

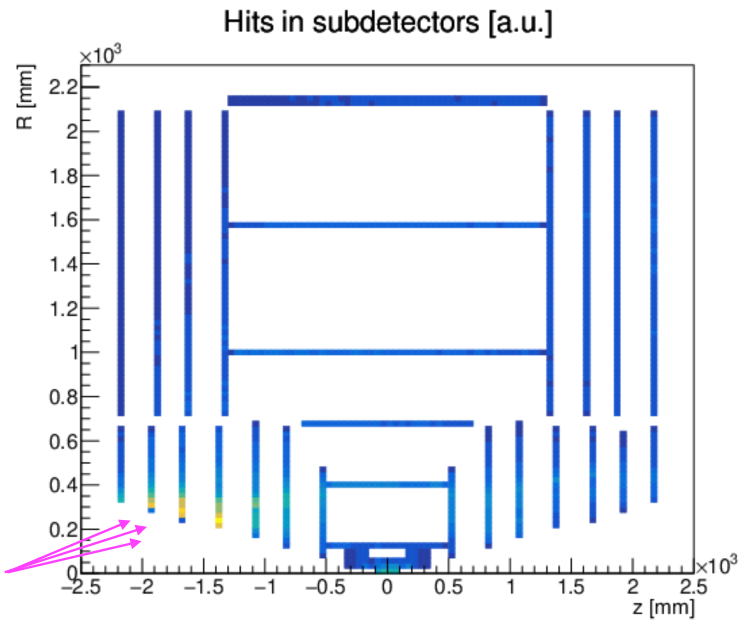


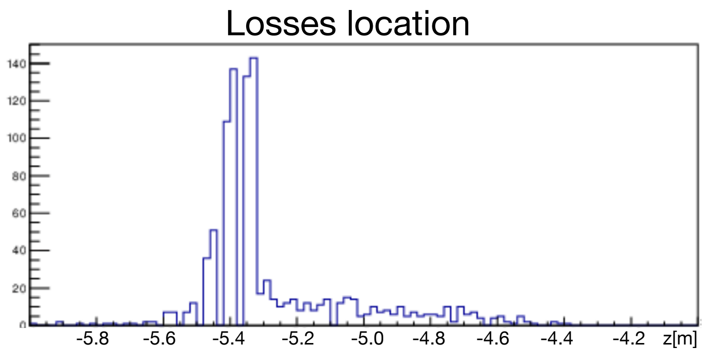
The results shown next are for a single beam.

Background @Top: Horizontal Primary collimator

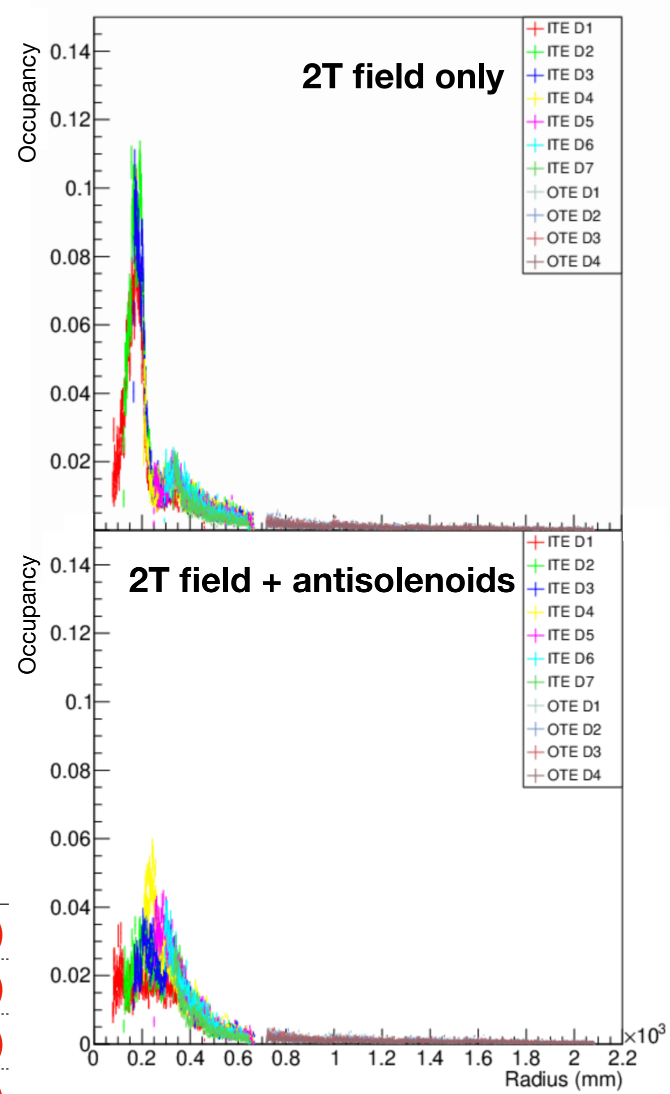
Compared to the simple 2T case, we can notice a **background reduction of a factor 2**, showing the peak on the IT endcap disks toward the losses location.

This is likely due to the lower amount of material traversed, causing fewer secondaries, or to the better confinement of lower energy particles.





	Losses per second	Highest occupancy	w/out anti-solenoids
IPA	0.15	5.73% (ITE)	10.95% (ITE)
IPD	0.11	3.99% (ITE)	7.78% (ITE)
IPG	0.10	3.16% (ITE)	6.41% (ITE)
IPJ	0.16	8.88% (ITE)	12.62% (ITE)



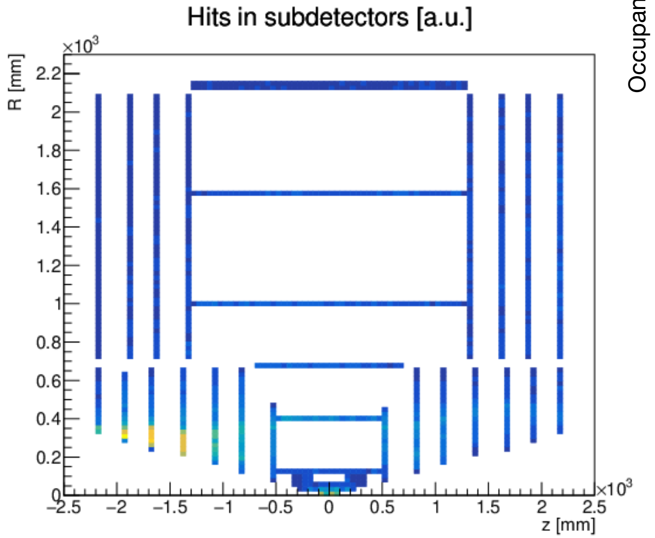
Background @Z Off-momentum collimator Negative Momentum Offset

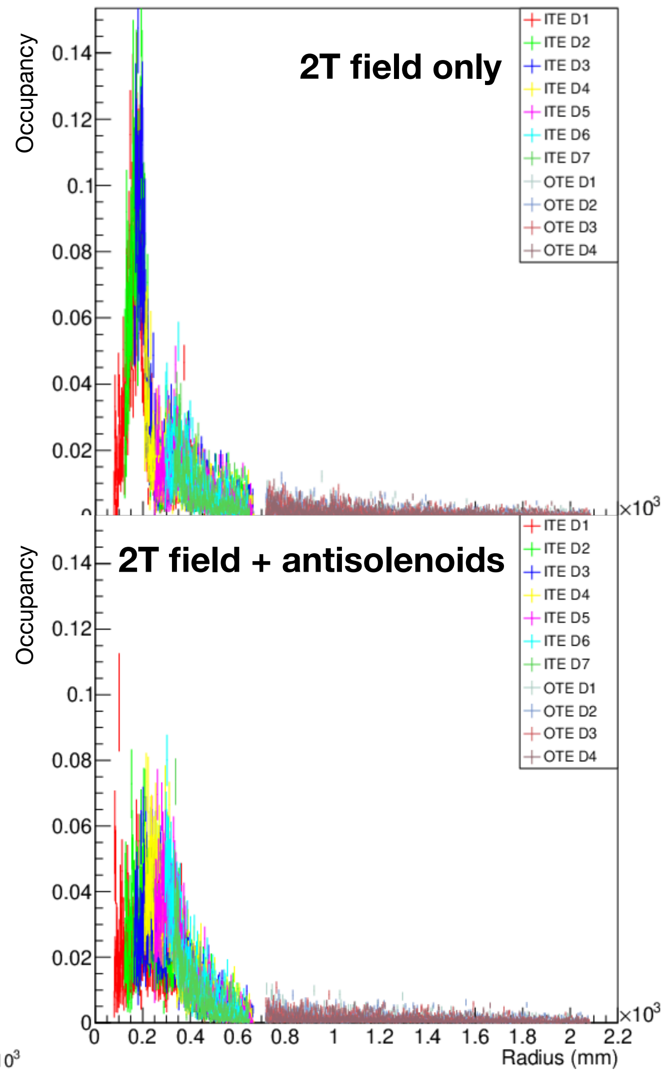
Pencil beam, $1\mu m$ impact par. ($\Delta p/p = -1.58\,\%$)

For negative offset, **IPG** showed extremely high backgrounds in **all of the subdetectors**, up to 15%, while negligible effects on IPJ and **no losses at all** in IPA and IPD.

Also in this case, with the antisolenoids the background is reduced of a factor 2, with the peak on the IT endcaps toward the losses location.

Similar results also are found including **betatron oscillations** to the momentum offset.





Failure Scenario Beam Losses: Induced Background Recap and Power in FFQs

	TT: horizontal primary collimator	Z: off-mom. collimator	Z: off-mom. collimator + betatron osc.
	Losses per second (10^9)		
IPA	0.15	1.66	0.15
IPD	0.11	0.38	0.24
IPG	0.10	12.21	182.10
IPJ	0.16	2.41	37.24
	Highest occupancy		
IPA	5.73% (ITE)	0.06% (ITE)	–––
IPD	3.98% (ITE)	0.04% (ITE)	–––
IPG	3.16% (ITE)	0.41% (ITE)	8.45% (ITE)
IPJ	8.88% (ITE)	0.09% (ITE)	1.60% (ITE)
	QC1 hottest spot (W/cm3 in a 2mm3 bin)		
IPA	0.035	0.077	–––
IPD	0.026	0.005	–––
IPG	0.013	0.278	4.311
IPJ	0.025	0.053	1.669
	Total power in QC1 (W)		
IPA	1.77	3.42	–––
IPD	1.34	0.35	–––
IPG	1.09	24.22	442.86
IPJ	1.92	5.88	96.10

Despite the induced **background** has now reduced of about a **factor 2 in every scenario**, the **power** deposited on the **final focus** quadrupoles does now show the same trend, remaining almost at the **same values** of previous studies.

This is expected as the quadrupoles are the first material the particles traverse after hitting the beam pipe, so the effect of the field is not evident yet.

SR Mask and Shieldings

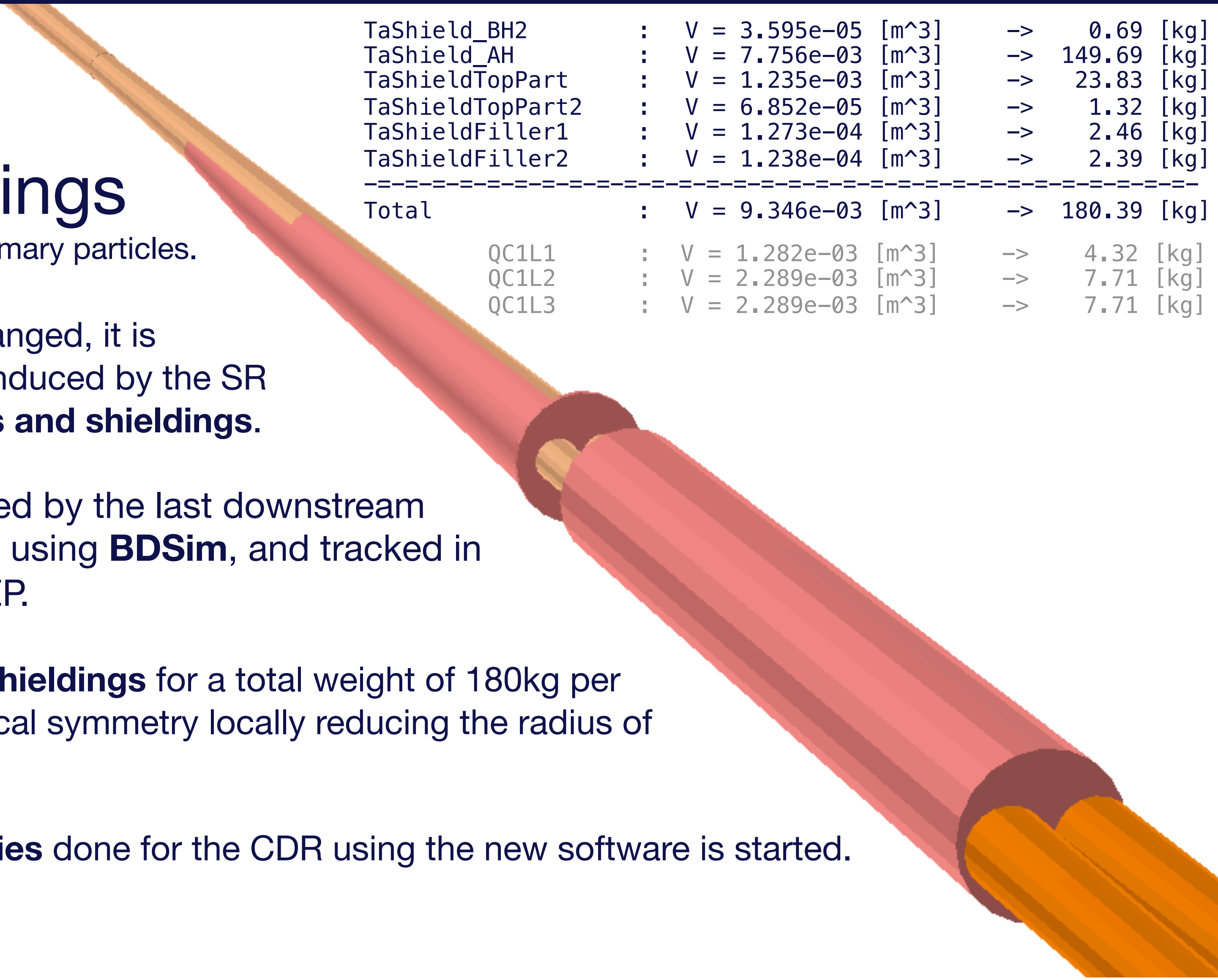
Thanks to K. André and M. Sullivan for the primary particles.

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.



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]

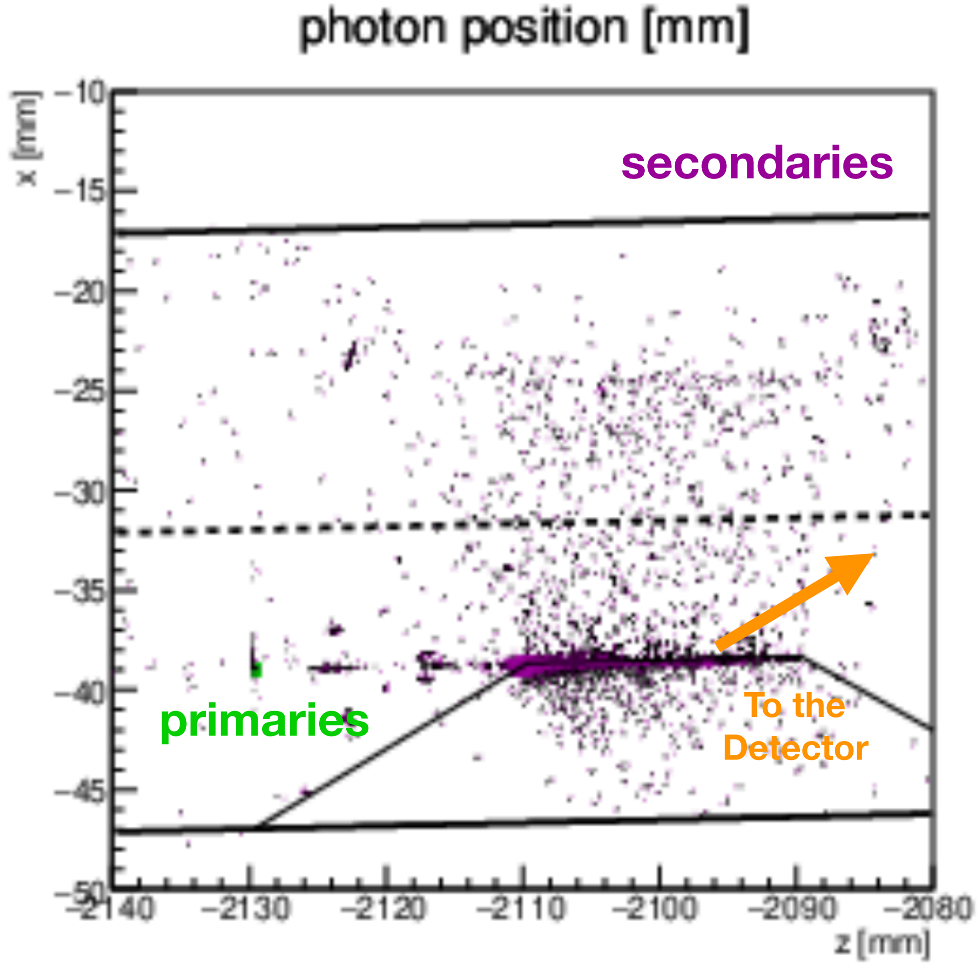
Special attention should be given to the photons which will impact **the tip of the mask**, as they are the main source of potential background in the detector.

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.

Despite a **larger sample** for the 4-10sigmas ring have been produced, the statistics does not suffice yet, so the study of the induced background is currently **ongoing.**

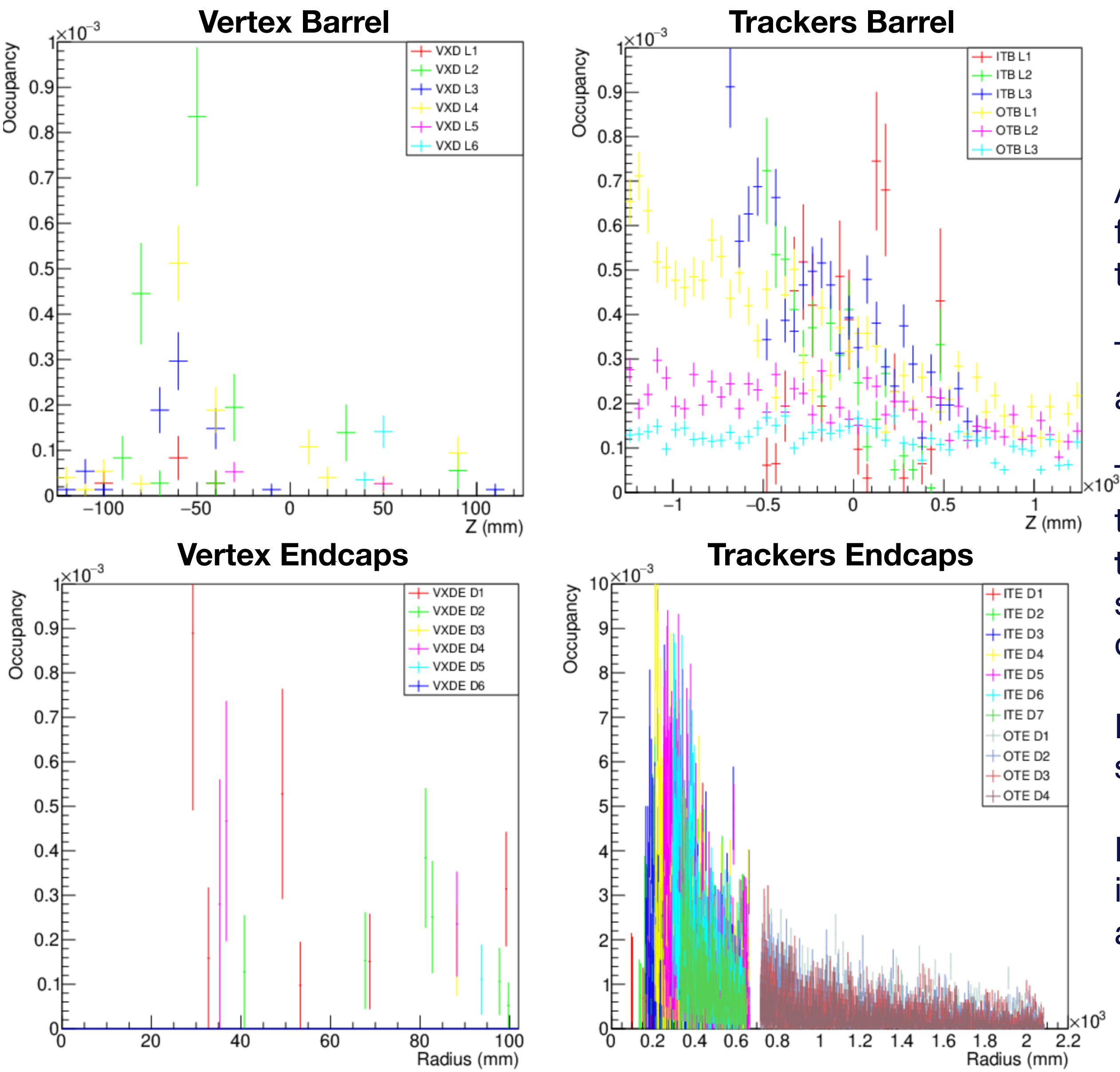
The contribution of **non-gaussian tails** is expected to be non negligible (e.g. SuperKEKB), and is currently **under investigation.**

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

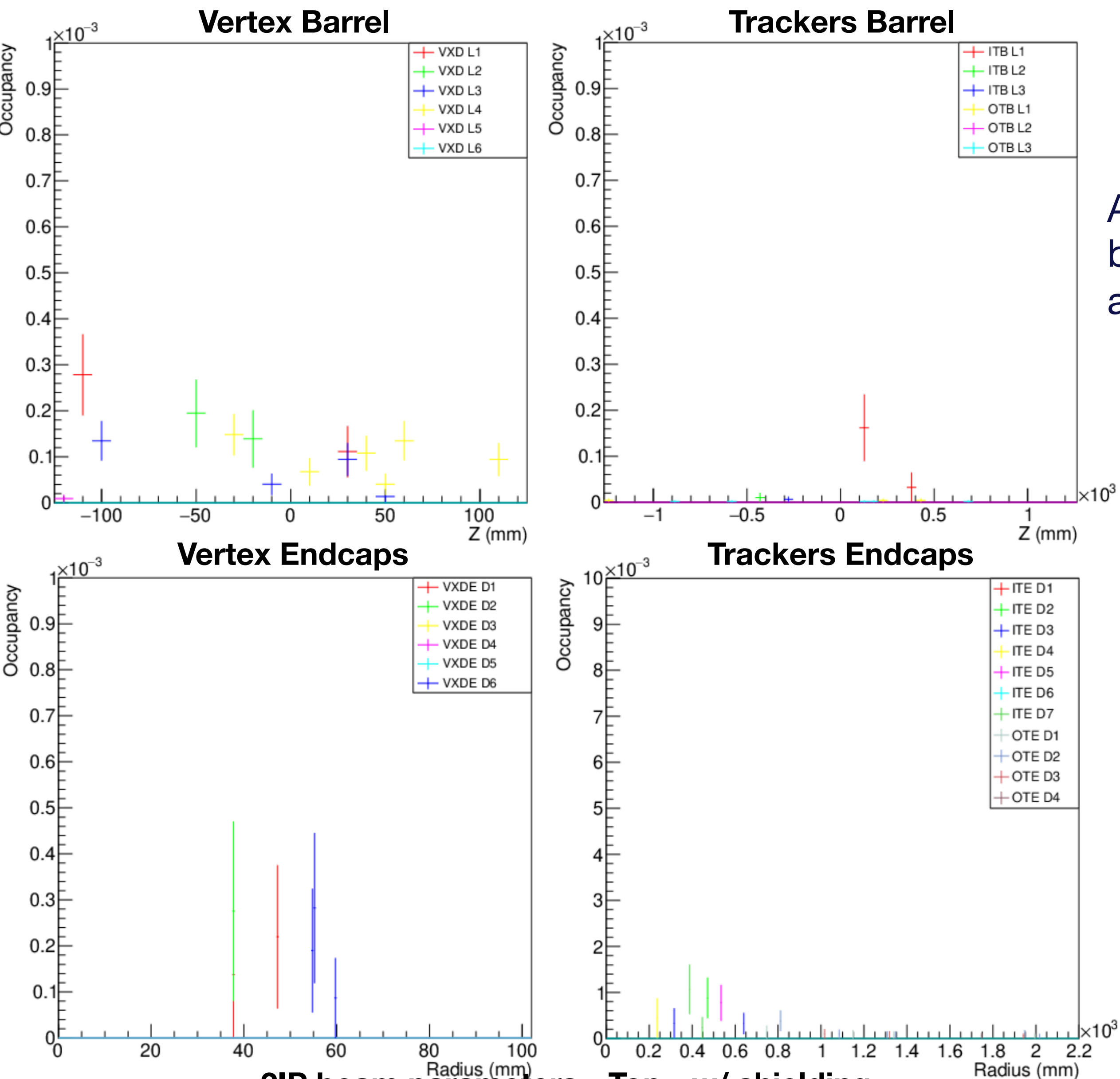
Please note that these results are **preliminary**, as the input file used is not exactly the same used in the past, and other small differences are **under investigation**.

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

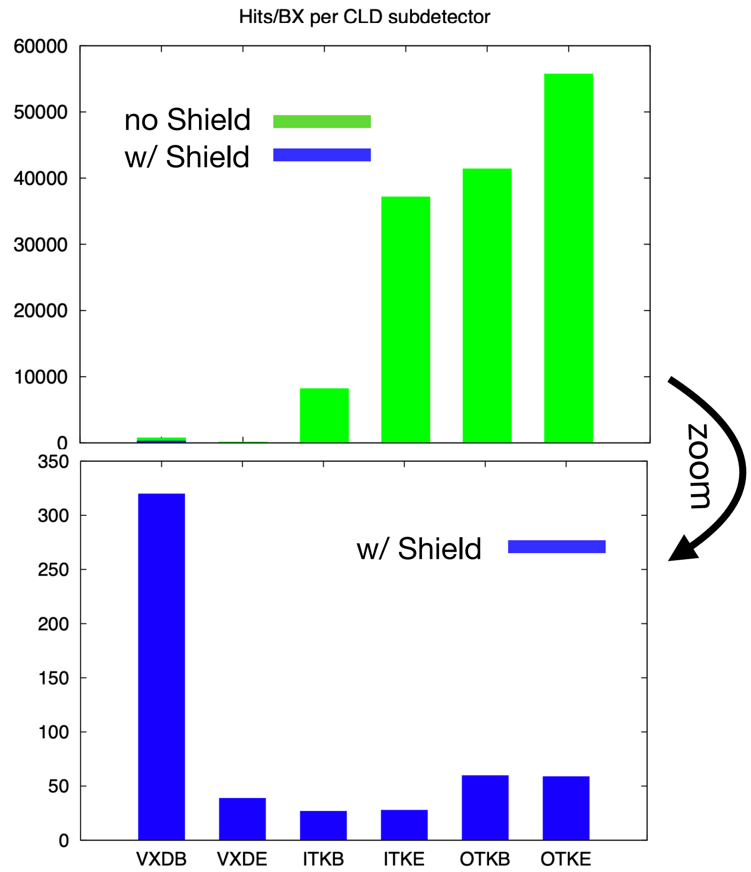
$$size_{sensor} = \begin{matrix} 25\mu m \times 25\mu m \ (pixel) \\ 1mm \times 0.05mm \ (strip) \end{matrix} \qquad size_{cluster} = \begin{matrix} 5 \ (pixel) \\ 2.5 \ (strip) \end{matrix} \qquad safety = 3$$

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

- Repeated backgrounds tracking for realistic **field map** implementation for **screening** and **compensating solenoid**.
  - No noticeable effect for **IPC** backgrounds, as produced at the IP
  - **Factor 2 reduction** w.r.t. previous studies for **beam losses backgrounds** in failure scenario, but with occupancies still **above the 1%** safety limit. No variation on power deposited in FFQs.
  - 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.
  - **further** increase **statistics** to account for **tip-scattered** photons (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).
  - study started on SR due to **top-up injection**

		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/

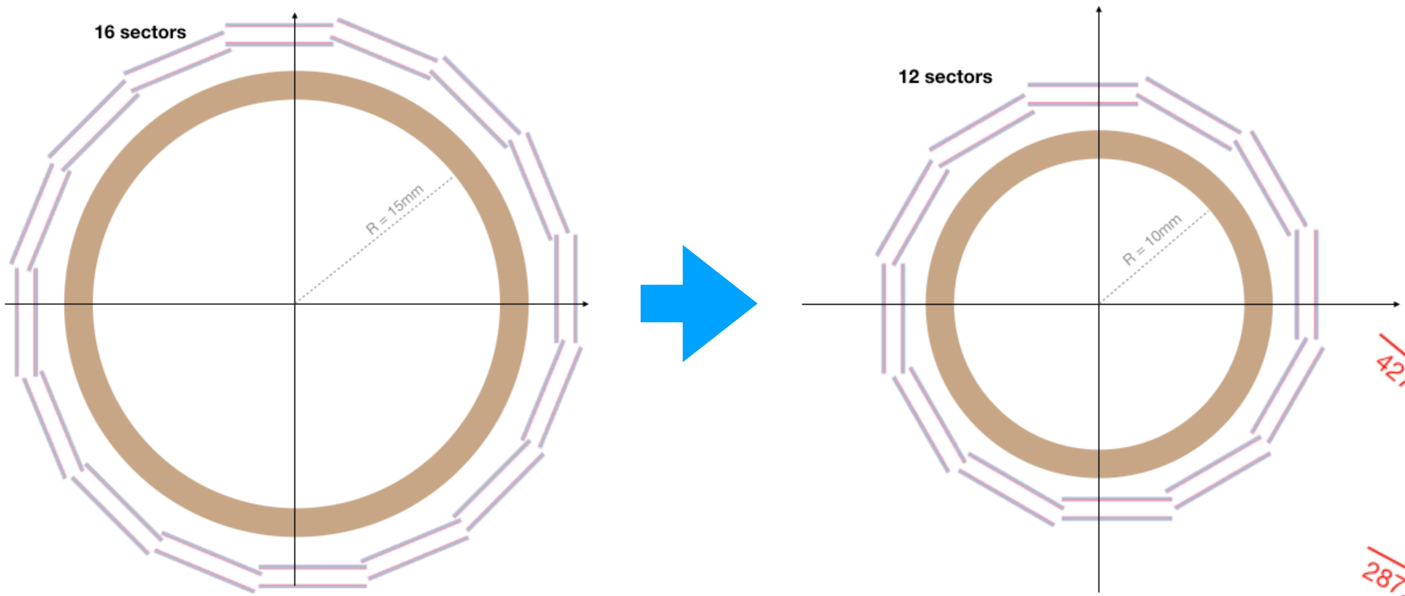
Table 3.4. Solenoids and compensation scheme parameters, given for one side (positive z).

	Start position (m)	Length (m)	Outer diameter (mm)	Current (A – turns)
Detector solenoid	0	3.6	400	3900 A – 1000
Screening solenoid	2.0	3.6	400	3900 A – 1000
Compensation solenoid	1.23	0.77	246–398 (tapered)	10600 A – 300

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

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

Updated CLD VXD for Small Beam Pipe

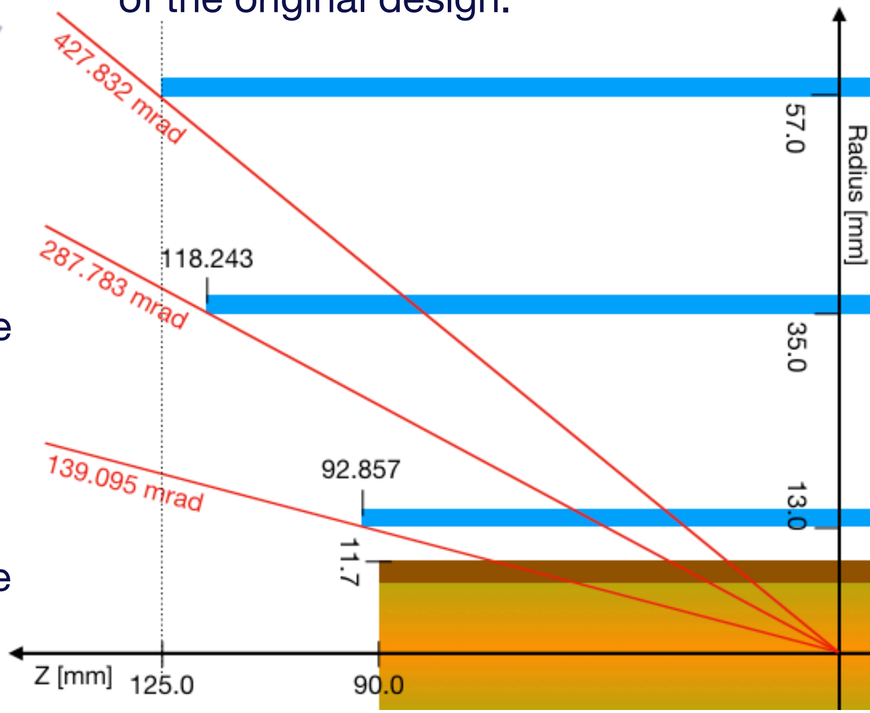


After the CDR, the design for the central chamber of the FCC-ee beam pipe has changed to a reduced radius of **R=10mm** and length of **L=18cm,** allowing to have the inner layer of the Vertex Detector Barrel **closer to the interaction point**.

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.

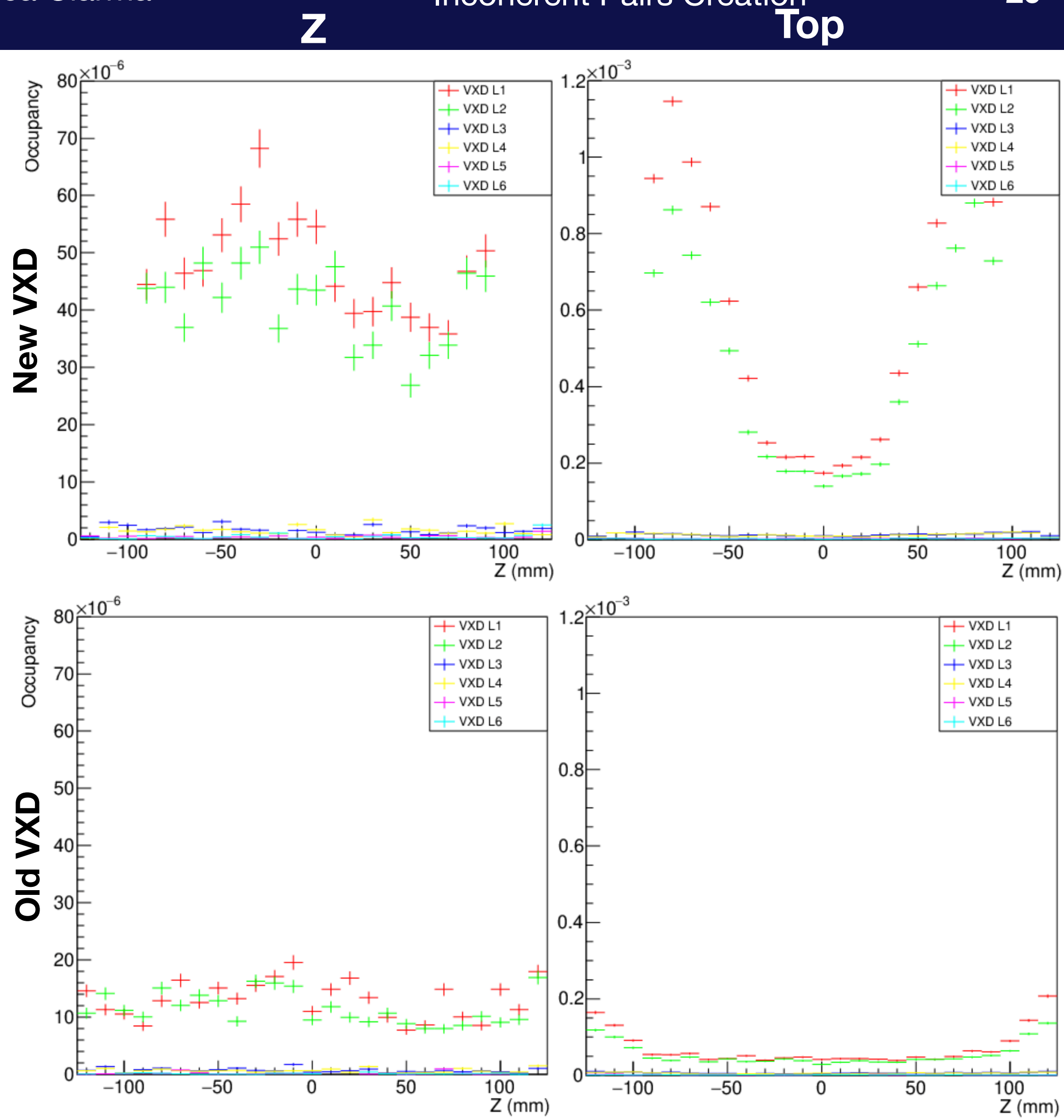


Preliminary studies on the occupancy due to the IPCs (generated with GuineaPig++ using the latest 4IP lattice beam parameters) show an increase of a **factor ~5** in particular in the **innermost layers** of the VXD barrel.

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

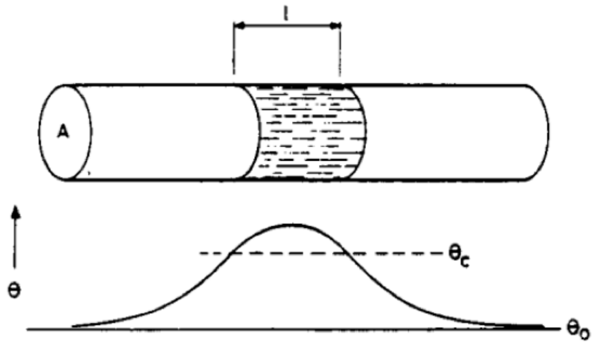


Fig. 20 A minimum propagating zone

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)

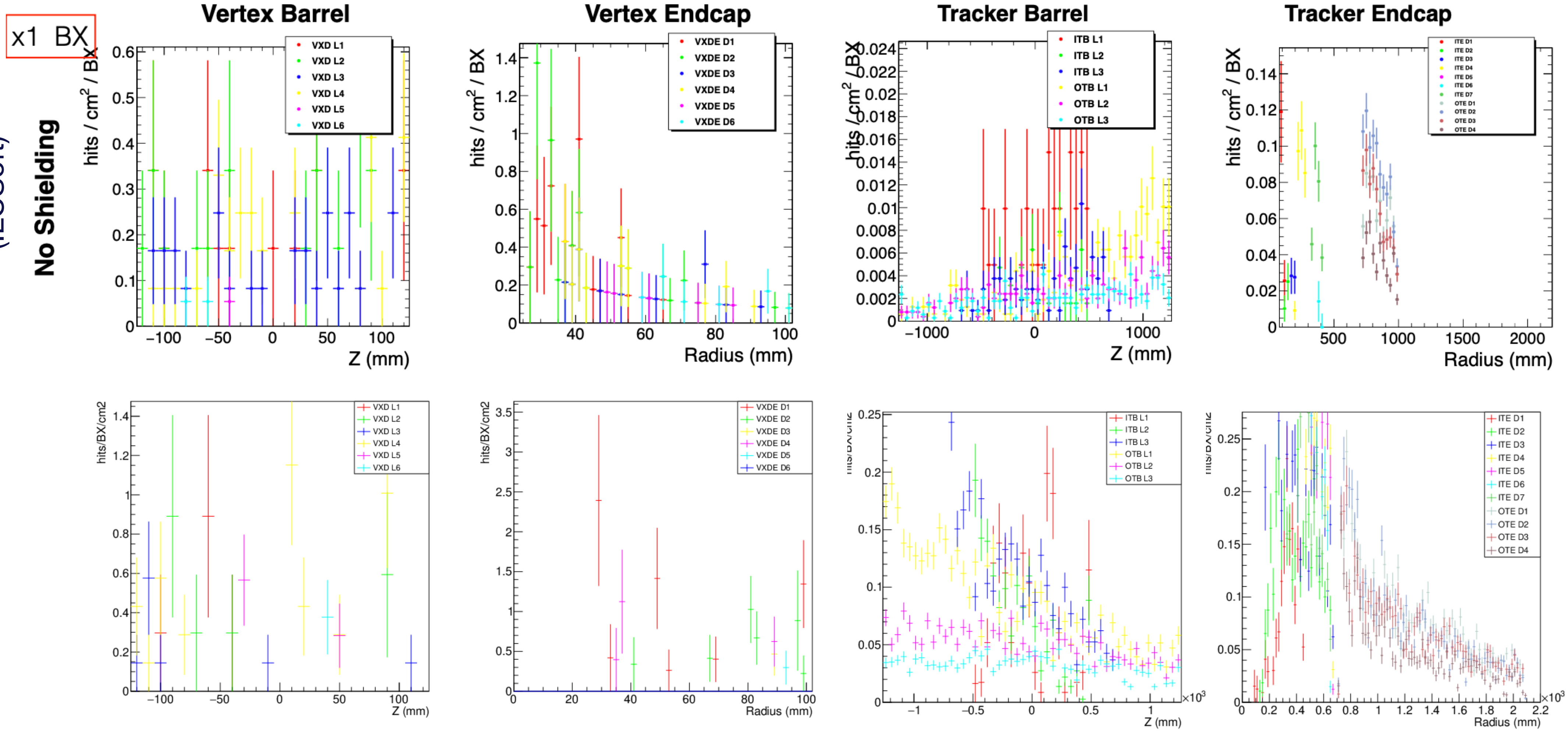
This is about 10TeV of instantaneous energy deposited in an area 300 µm X 0.5mm^2

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

A. Kolano, FCCweek18 (ILCSoft)

No Shielding

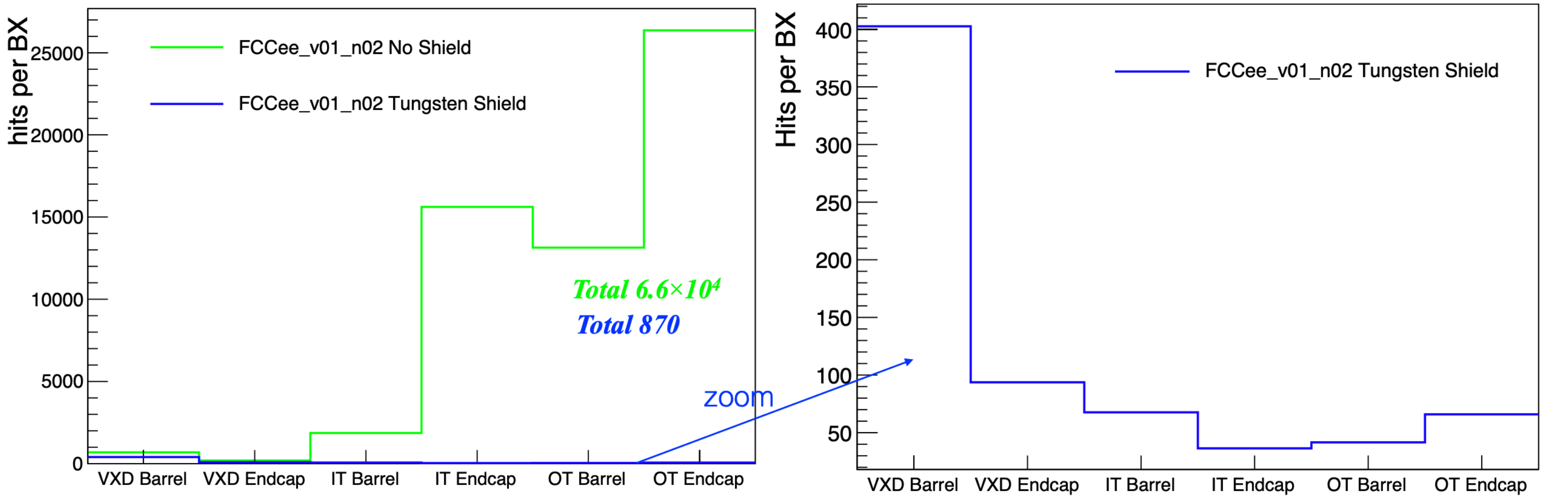
Replicated on Key4HEP



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, …

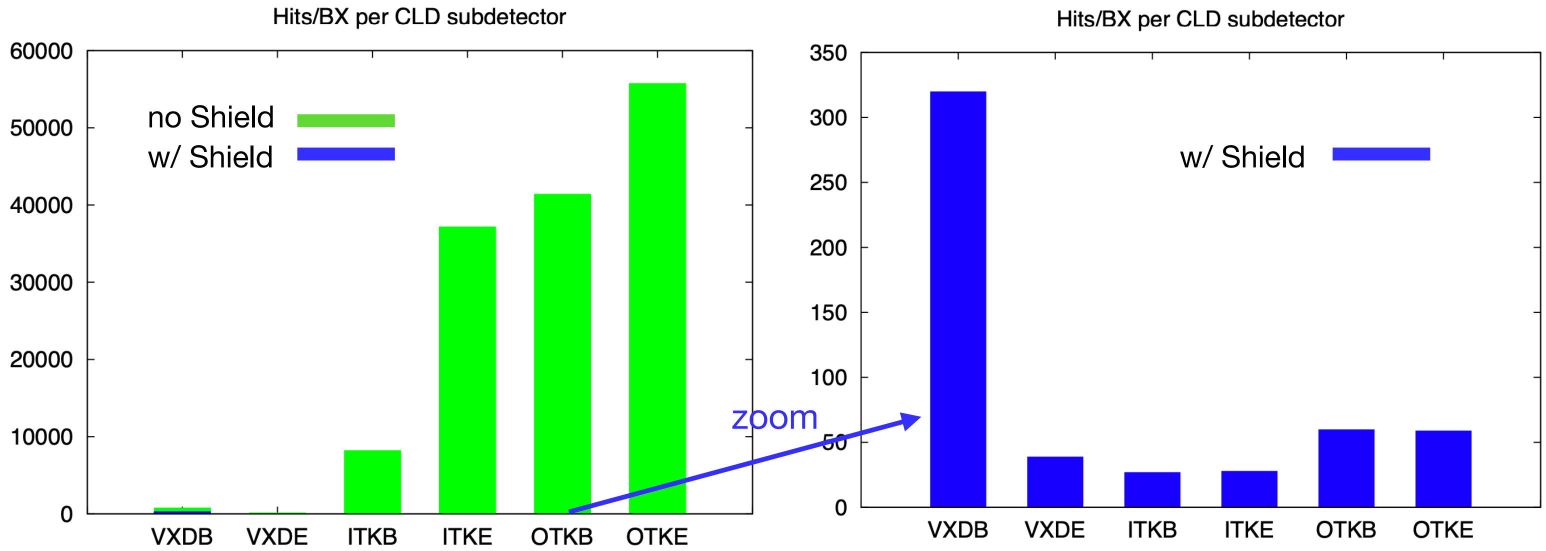
Total SR for two beams forward scattered from the last mask tip at 2.12 m from the IP

A. Kolano, FCCweek18 (ILCSoft)



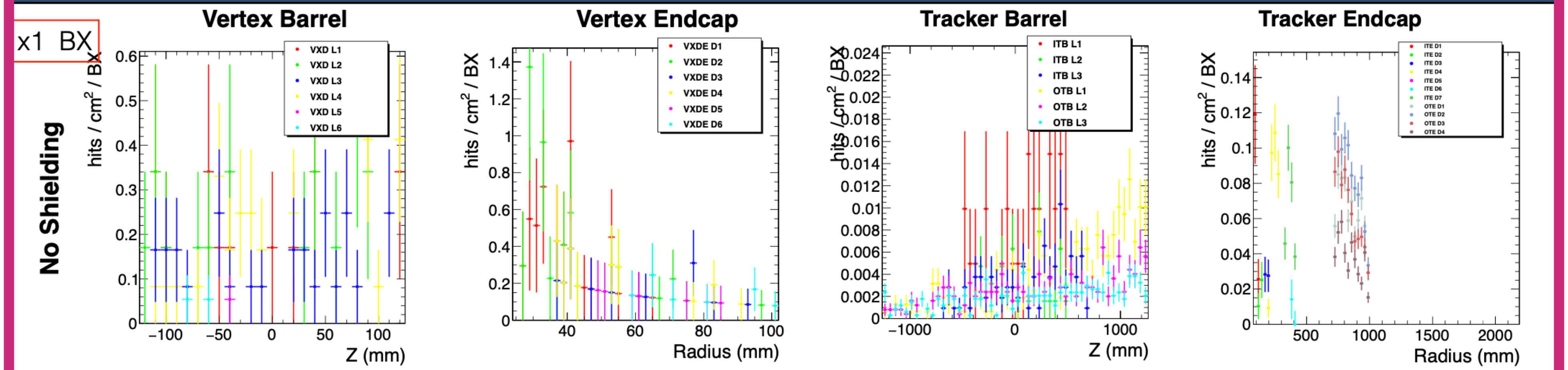
Replicated on Key4HEP

Preliminary



From FCCweek 2018

@ttbar Hit density/cm2 in the Vertex and Inner Tracker Detectors

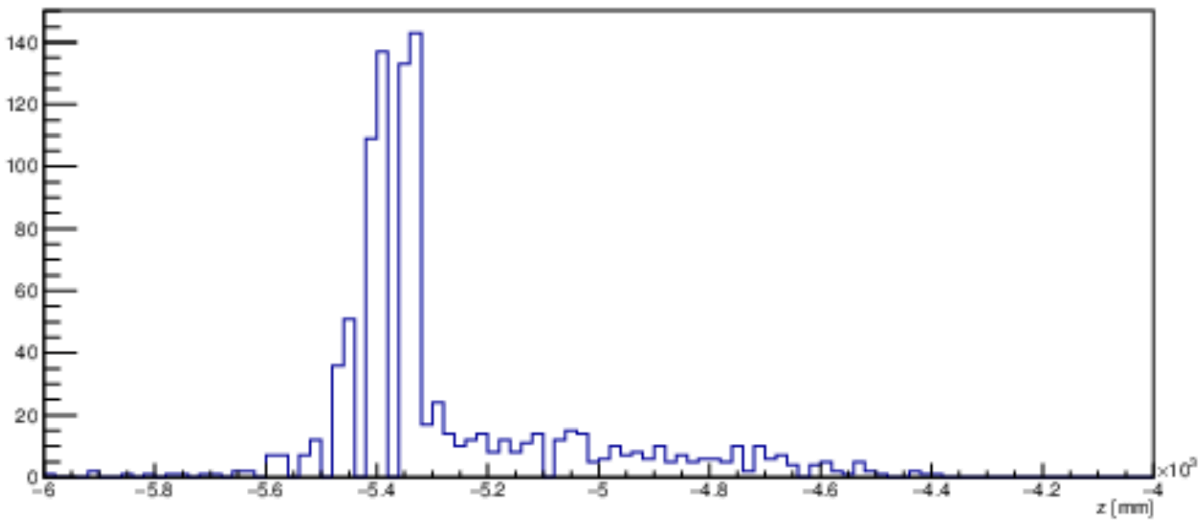


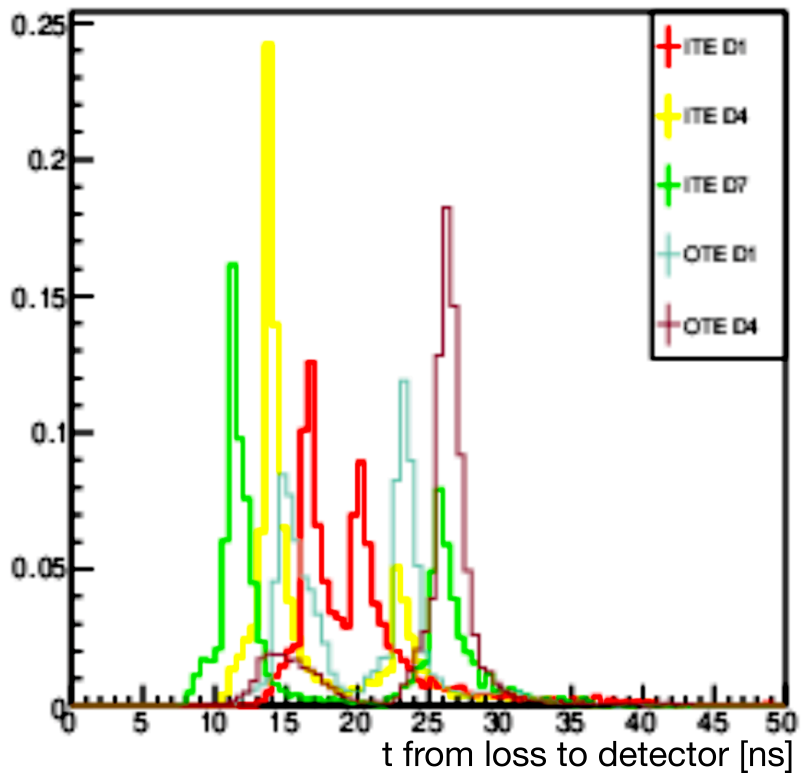
Consideration on previous results:

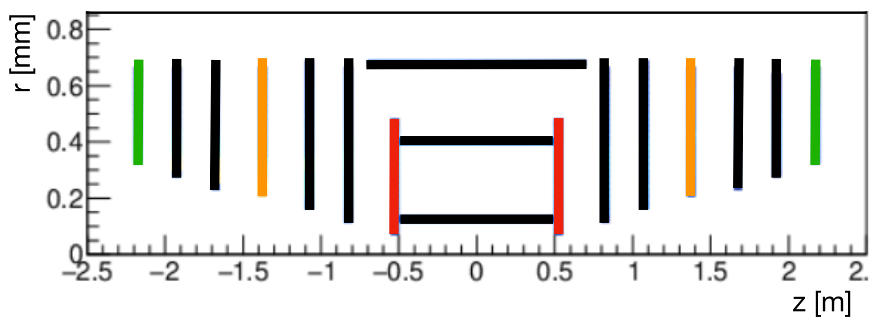
The conversion from hit density to occupancy is a factor O($10^{-4} \sim 10^{-3}$). As the maximum hit density is O(1~0.1), the max occupancy would be <<1% everywhere. Is the shielding necessary for CLD? Could it be added only @Top? Occupancy in Drift Chamber will likely be much higher…

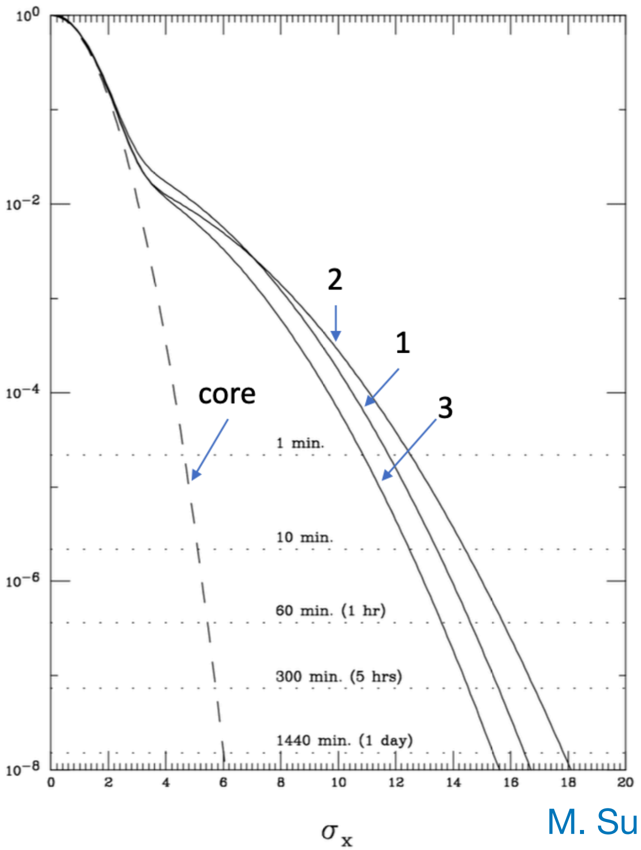
$$occupancy = hits/cm^2/BX \cdot size_{sensor}[cm^2] \cdot size_{cluster} \cdot safety \simeq hits/cm^2/BX \cdot \begin{matrix} 1 \times 10^{-4}\ (VXD\ pixel) \\ 5 \times 10^{-3}\ (TRK\ strip) \end{matrix}$$

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


140
120
100
80
60
40
20
0
−6
−5.8
−5.6
−5.4
−5.2
−5
−4.8
−4.6
−4.4
−4.2
−4
×10³
z [mm]


ITE D1
ITE D4
ITE D7
OTE D1
OTE D4
0.25
0.2
0.15
0.1
0.05
0
0 5 10 15 20 25 30 35 40 45 50
t from loss to detector [ns]


r [mm]
0.8
0.6
0.4
0.2
0
−2.5 −2 −1.5 −1 −0.5 0 0.5 1 1.5 2 2.
z [m]

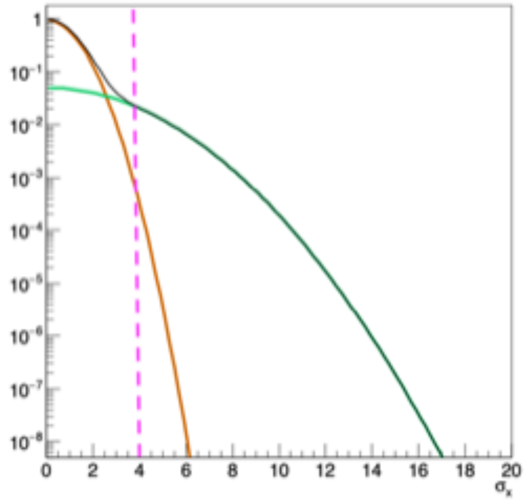


Tail distributions that can generate the background level seen in the superKEKB pixel detector (PXD) during early running.

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?