Mitigation of synchrotron radiation from IR

Anna M. Kolano (CERN)
on behalf of FCCee MDI group

Content

IR layout:

- Interaction region and masks
- Detailed shielding in iLCSoft/Geant 4
- CLD detector model

Input synchrotron radiation (SR) from bends and quads:

- SR figures
- SR Models (M. Sullivan and M. Lückhof)
- Quadrupole and dipole contribution
- Forward scattered SR

Simulation results of the SR Background:

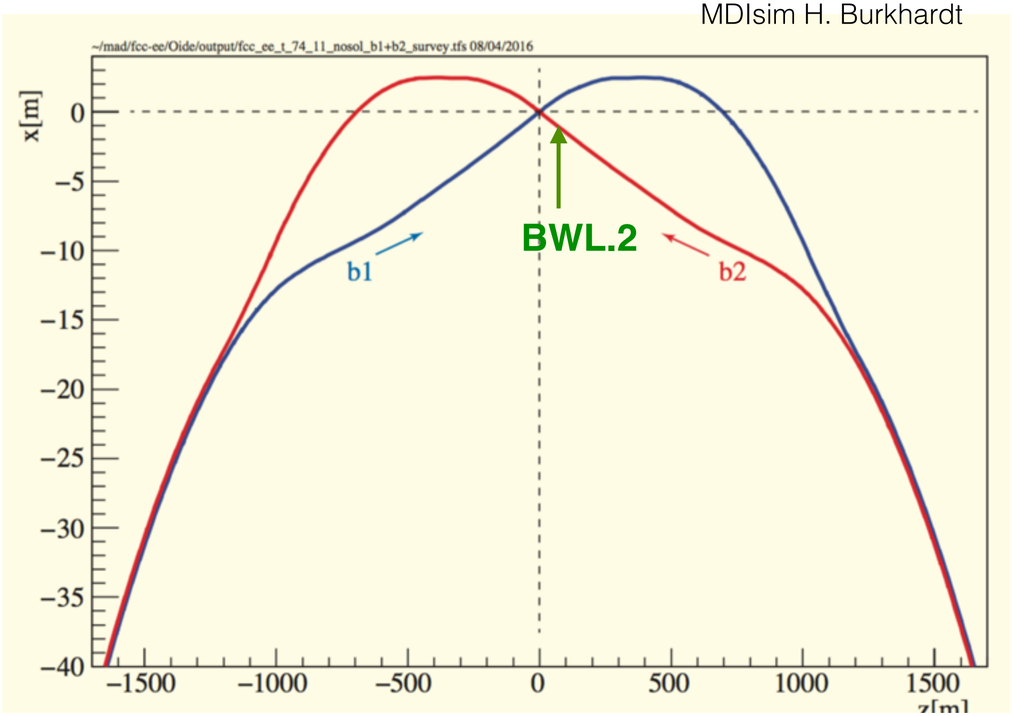
- Hit density in the CLD detector
- Occupancies per sub-detector

Summary

Synchrotron Radiation at the IP

- Total SR power kept at 100 MW
- Critical bend radiation of order of 100 keV @ the Top energy
- Series of Masks along last 100 m protect the IP from direct SR
- Some SR scatter off the mask tip and showers towards the IP
- A shielding scheme has been developed to mitigate this effect
- Several groups work on different aspects of this problem:
  - (a) IR and mask design, SR estimates with SYNC_B
    (M. Sullivan (SLAC))
  - (b) MDIsim and Geant 4 model of last 100 m from the IP
    (M. Lückhof, H. Burkhardt (CERN))
  - (c) SR effect on the CLD detector using iLCSoft
    (A. Kolano (CERN))
  - (d) Synch-Rad model, Saw-tooth masking scheme
    (R. Kersevan (CERN))

MDIsim H. Burkhardt



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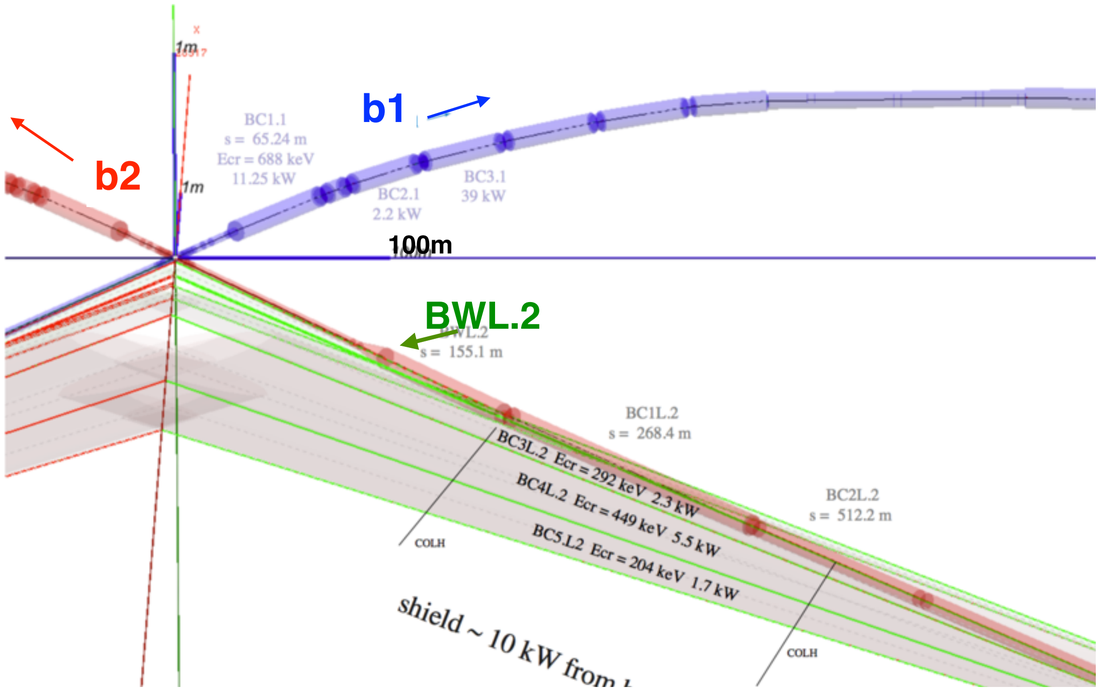
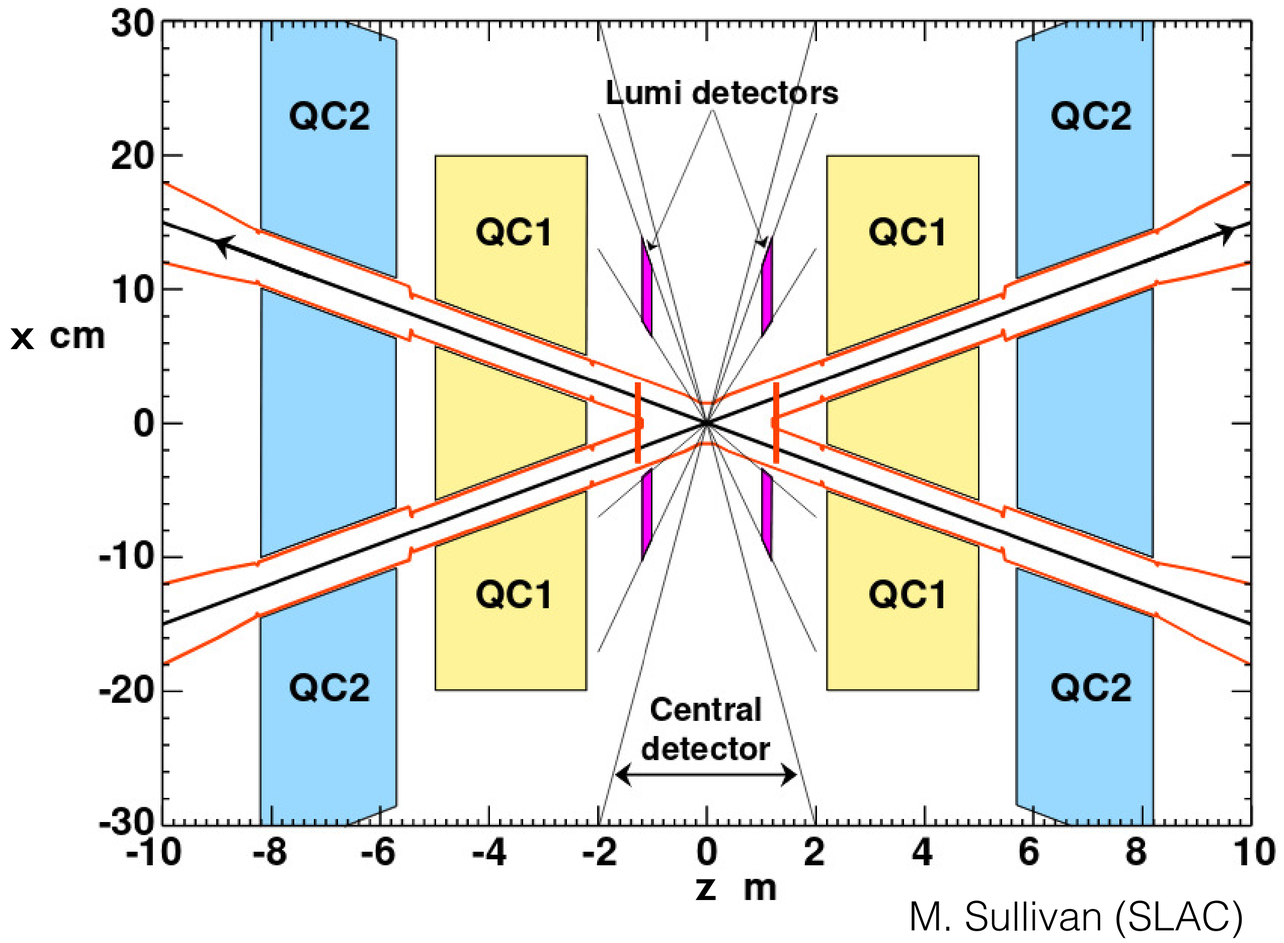


Interaction Region layout



M. Sullivan (SLAC)

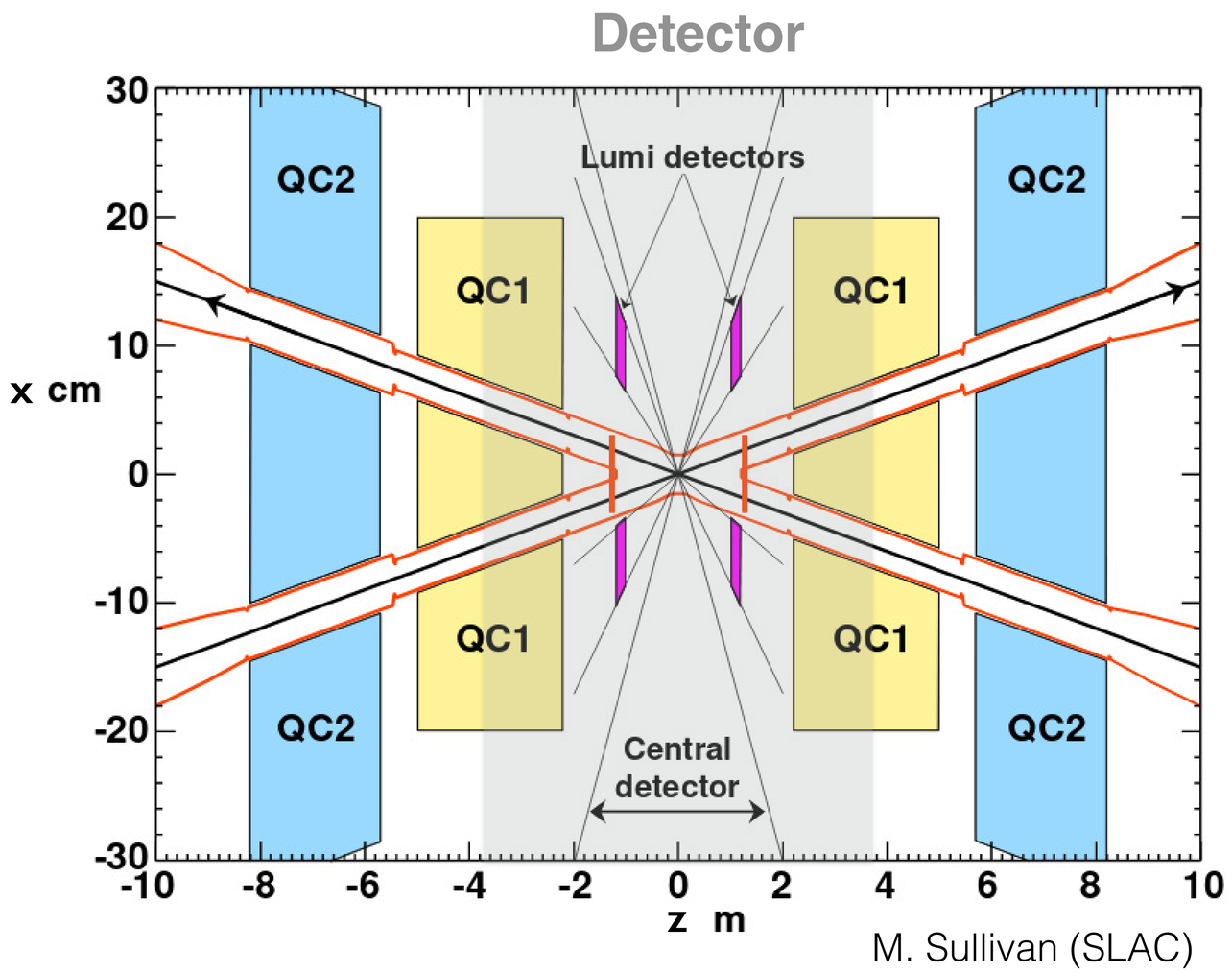
Beam Pipe:

- Central Beam Bipe (CBP) has 15 mm radius
- Out/Incoming beam pipe of 15 mm radius extends to QC1 quadrupole
- From second mask the beam pipe size increases to 20 mm diameter inside QC2
- Outside of QC2 beam pipe has 30 mm radius

Tungsten Masks:

- 12 mm radius at 2.1 m and 5.44 m from the IP
- 18 mm radius at 8.27 m

Interaction Region layout



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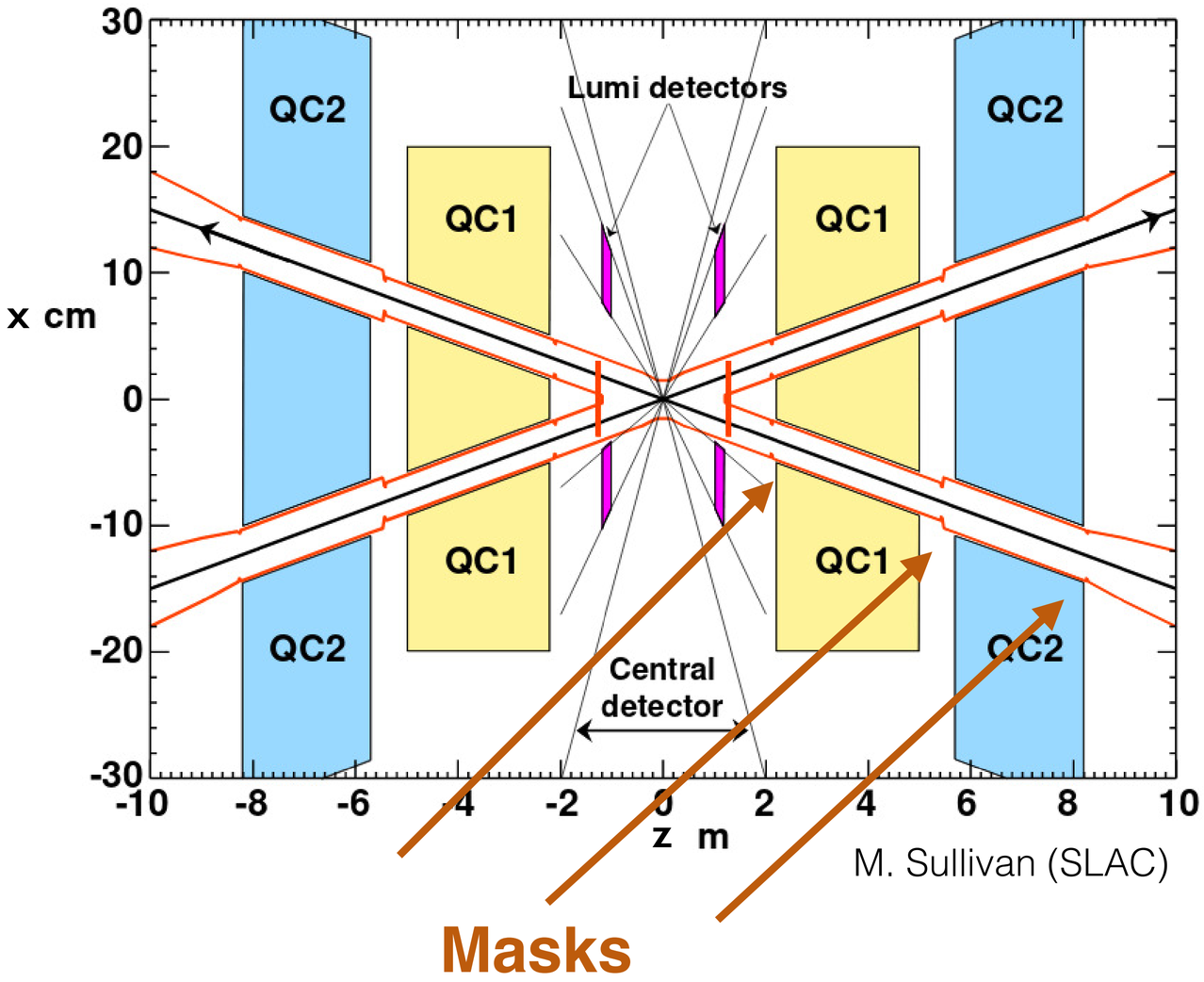

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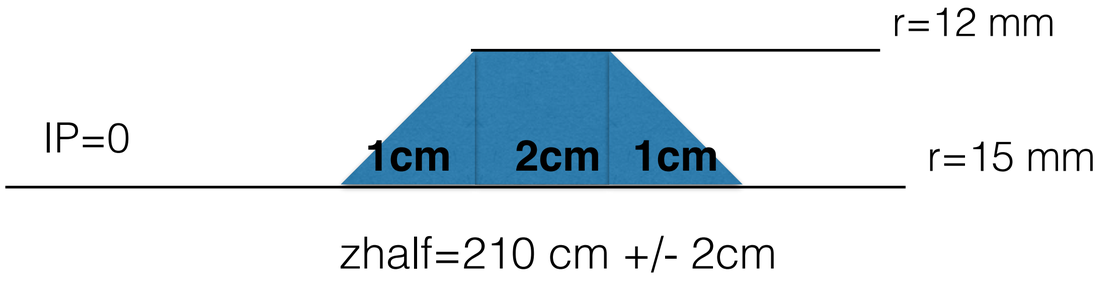
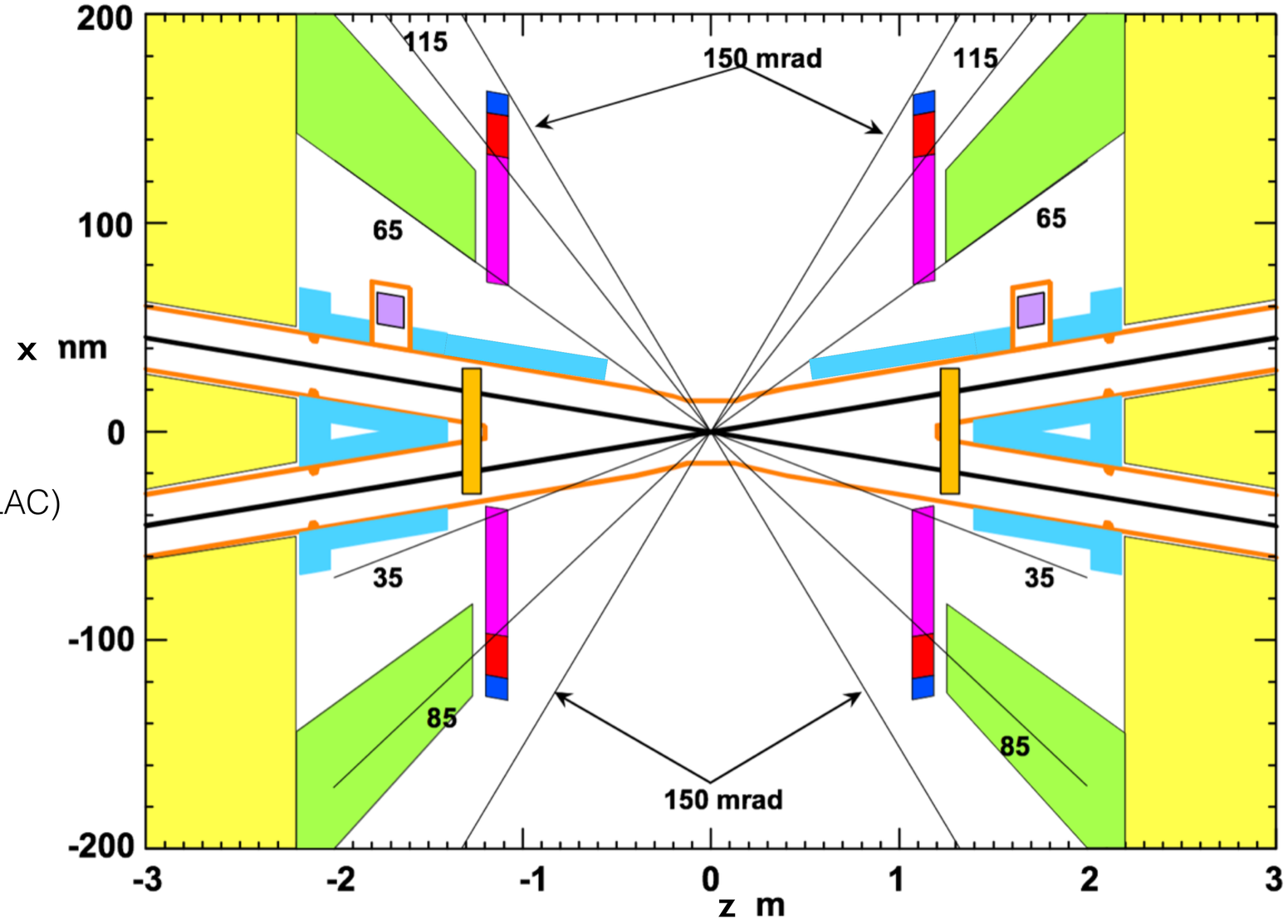


Interaction Region layout

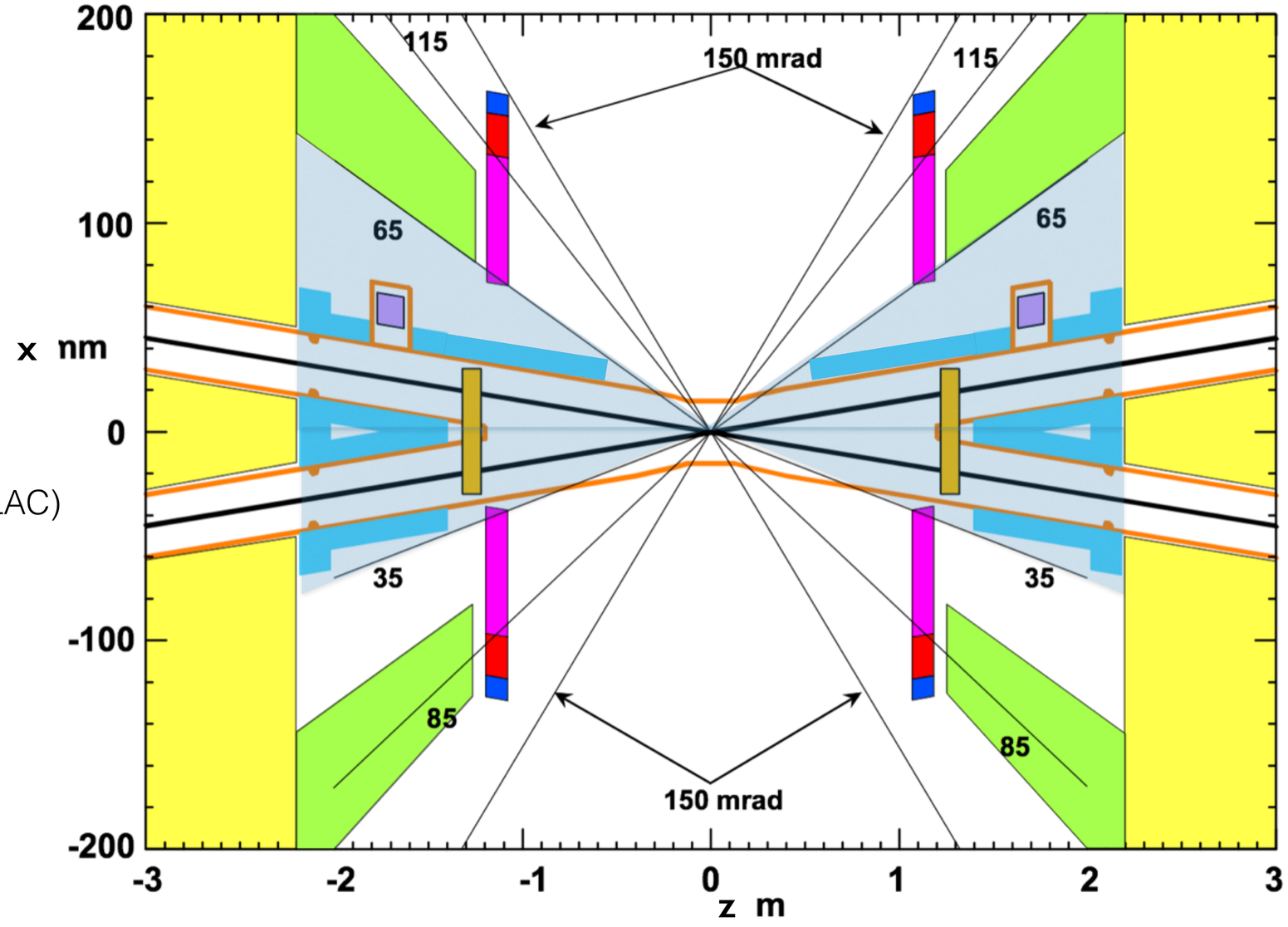
M. Sullivan (SLAC)



- Compensating solenoid
- LumiCal
- LumiCal electronics
- LumiCal cables
- Neg Pumps
- Tungsten shield
- Beam pipe
- HOM absorbers
- QC1 final focus

Interaction Region layout

M. Sullivan (SLAC)



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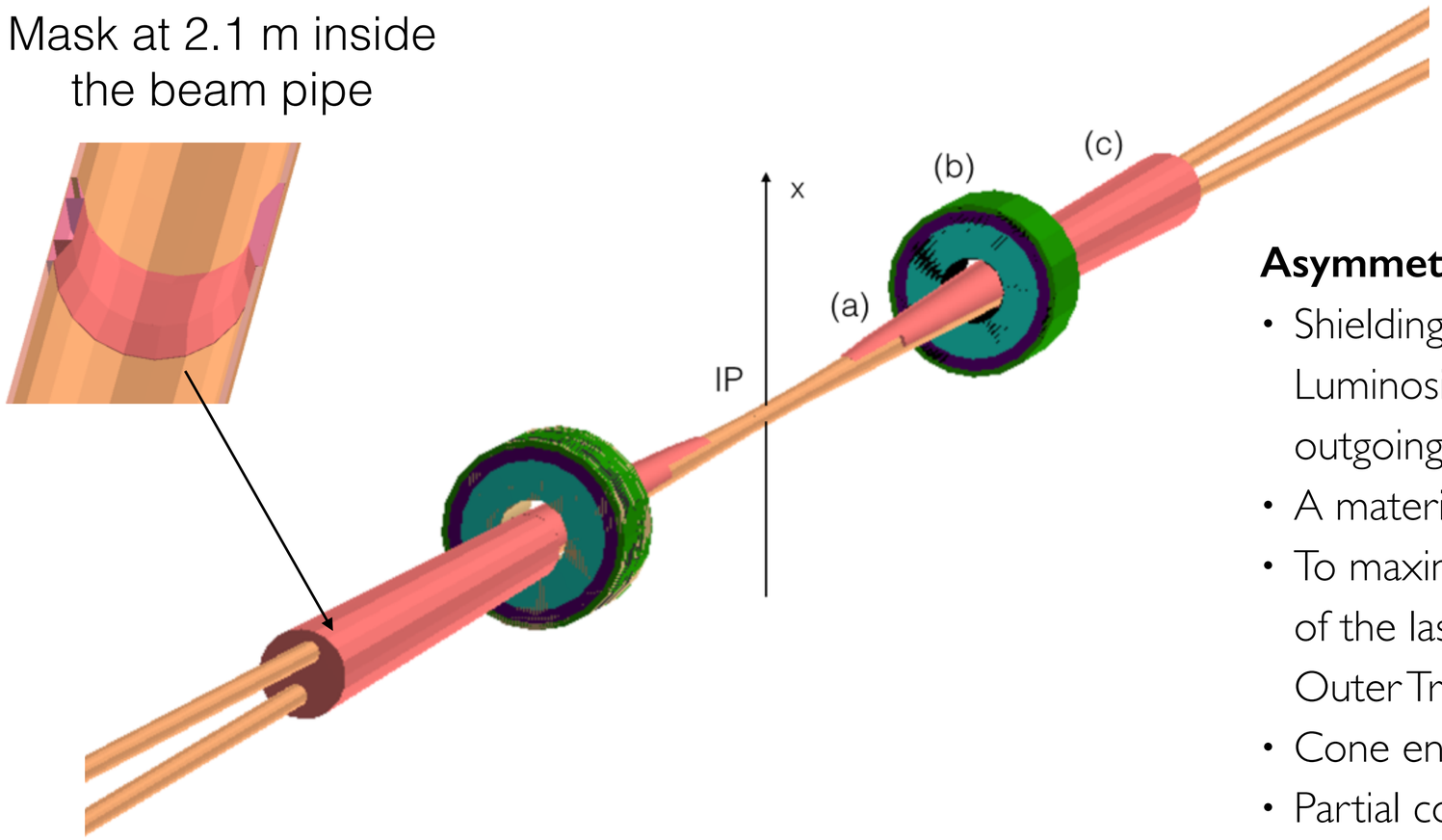
- Beam pipe
- HOM absorbers
- QC1 final focus
- “Free” space

Proposed Tungsten Shielding

Mask at 2.1 m inside the beam pipe

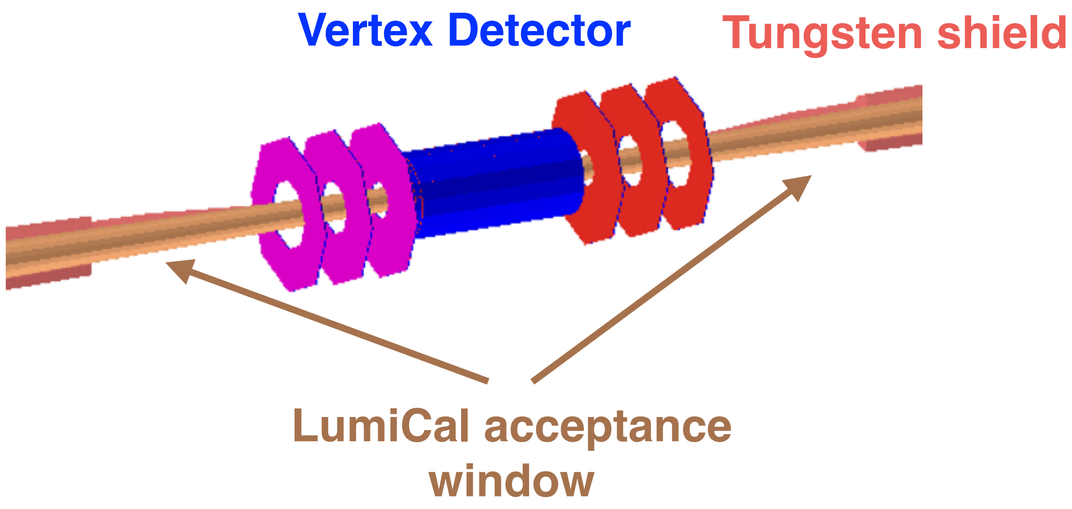


Asymmetric Tungsten Shielding:

- Shielding thickness and position constrained by the Luminosity Calorimeter acceptance centred along the outgoing beam pipe
- A material-free zone within a cone of 50 to 100 mrad
- To maximise given space, full tungsten cone covering the area of the last mask at 2.12 m from the IP protects the Inner/ Outer Tracker endcaps from SR scattering at large angles
- Cone ends at the back of the Luminosity Calorimeter
- Partial cones fill the remaining space, from the LumiCal towards the IP to protect the vertex detector

(a) Partial Tungsten Shield (z= 370-600 mm 68° cone and 600 mm to 1190 mm half-cone, 1-15mm thick)
(b) Luminosity Calorimeter
(c) Full Tungsten cone (z =1190 to 2199 mm, 15 mm thick)

Proposed Tungsten Shielding



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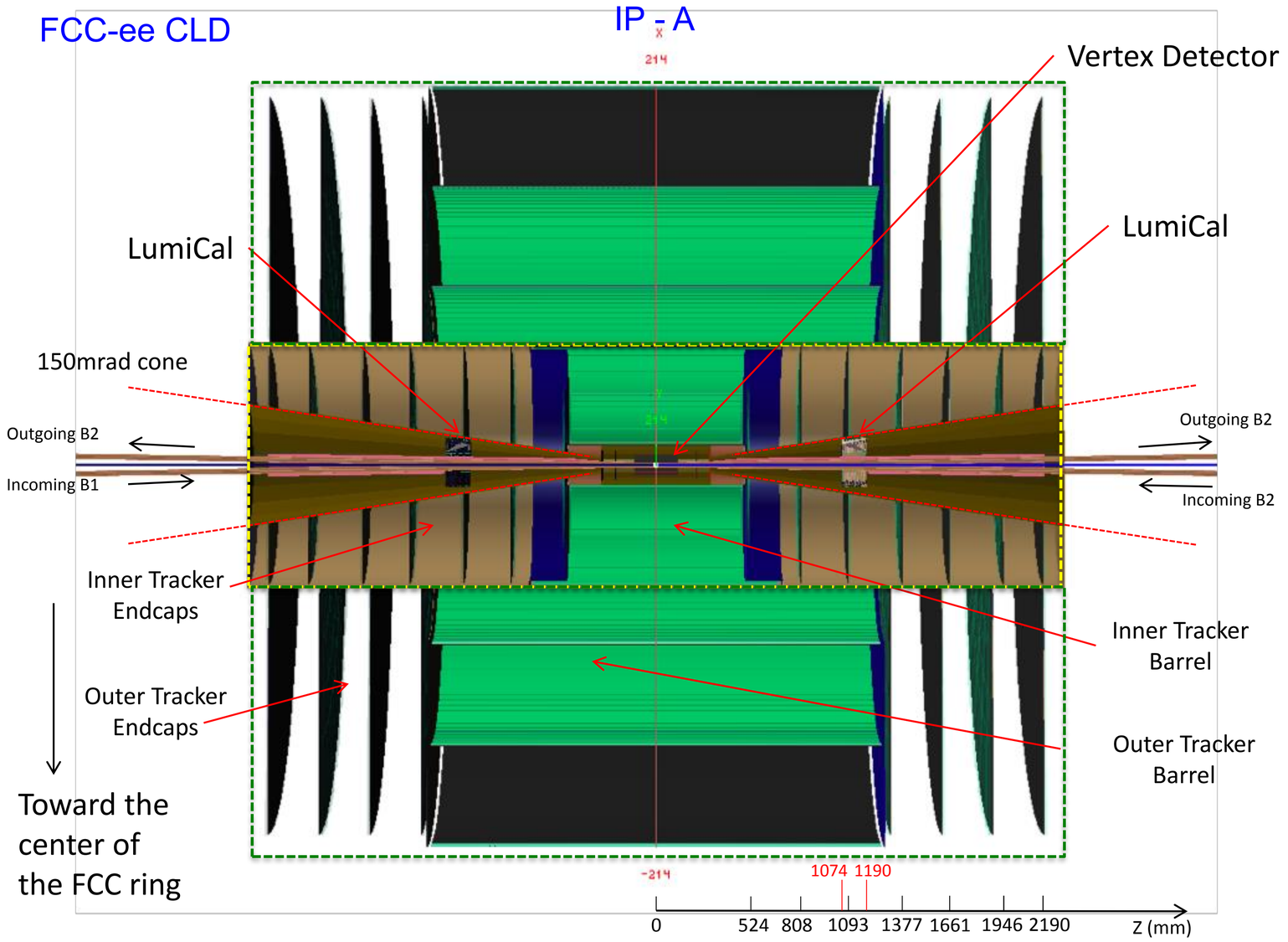
CLD Detector Design



More details about CLD detector
Oleksandr Viazlo's talk:
"CLD Detector Model overview"

Synchrotron Radiation estimates

Table 4: *Upstream dipoles. Beam energy E_b 182.5 GeV*

Magnet	S [m]	L [m]	Angle [mrad]	E_c [keV]	$n_\gamma/e^\pm$	Power [kW]	n_{tot}	$<E_\gamma>$ [keV]
BWL.2	214.2	114	-0.7879	93.2	2.96	0.456	8.3e11	28.7
BC1L.2	293.1	74.83	-0.4935	88.9	1.86	0.273	5.2e11	27.4
BC2L.2	549.2	61.99	1.038	226	3.91	1.46	1.09e12	69.5
BC3L.2	604.8	51.45	-2.182	572	8.21	7.75	2.3e12	176
BC4L.2	660.3	51.45	-2.179	571	8.2	7.73	2.29e12	176
BC5L.2	726.4	61.99	0.2015	43.8	0.758	0.0549	2.12e11	13.5
BL1.2	900.5	24	2.598	1.46e3	9.77	23.6	2.74e12	449
BL2.2	914.7	11.74	0.71	815	2.67	3.6	7.48e11	251
BL3.2	920.3	3.208	-0.2331	980	0.877	1.42	2.46e11	302
BL4.2	932.9	10.22	-1.133	1.5e3	4.26	10.5	1.19e12	460
B1.1256	965.2	24.44	2.234	1.23e3	8.4	17.1	2.35e12	380
B1.1255	993.2	24.44	2.234	1.23e3	8.4	17.1	2.35e12	380
B1.1254	1021	24.44	2.234	1.23e3	8.4	17.1	2.35e12	380
B1S.1152	1046	21.84	1.996	1.23e3	7.51	15.3	2.1e12	380
B1S.1151	1074	21.84	1.996	1.23e3	7.51	15.3	2.1e12	380
B1L.492	1104	23.54	2.152	1.23e3	8.09	16.5	2.27e12	380
B1L.491	1132	23.54	2.152	1.23e3	8.09	16.5	2.27e12	380
B1.1253	1161	24.44	2.234	1.23e3	8.4	17.1	2.35e12	380
B1S.1150	1186	21.84	1.996	1.23e3	7.51	15.3	2.1e12	380
B1S.1149	1214	21.84	1.996	1.23e3	7.51	15.3	2.1e12	380

Table 5: *Upstream quadrupoles. Beam energy E_b 182.5 GeV*

Magnet	S [m]	L [m]	E_c [keV]	n_γ	B_x [T]	B_y [T]	Power [keV]	σ_x	σ_y	Angle [mrad]
QC1L1.2	3.4	1.2	368	0.1232	-0.00819	-0.0145	0.0749	0.147	0.083	0.0328
QC1L2.2	4.48	1	517.7	0.1444	-0.00869	-0.0217	0.124	0.224	0.0897	0.0384
QC1L3.2	5.56	1	776.9	0.2167	-0.0081	-0.0341	0.278	0.342	0.0811	0.0576
QC2L1.2	7.11	1.25	553.1	0.1929	0.0029	0.0248	0.176	0.525	0.0613	0.0513
QC2L2.2	8.44	1.25	1013	0.3534	0.00426	0.0455	0.592	0.59	0.0552	0.0939
QC3L.2	97.01	3.5	22.61	0.02208	-9.95e-05	-0.00102	0.000825	0.665	0.0651	0.00587
QC4L.2	218	3.5	62.32	0.06085	2.07e-05	0.00281	0.00627	1.49	0.011	0.0162
QC5L.2	296.9	3.5	43.15	0.04214	-4e-05	-0.00195	0.003	0.795	0.0163	0.0112
QC6L.2	378.8	3.5	40.6	0.03964	4.85e-05	0.00183	0.00266	0.973	0.0257	0.0105
QC7L.2	486.4	3.5	13.34	0.01303	-0.000195	-0.00057	0.000287	0.193	0.066	0.00346
QY2L.4	553	3.5	46.2	0.04512	7.08e-05	0.00208	0.00344	0.515	0.0175	0.012
QY1L.2	608.6	3.5	28.06	0.0274	-1.9e-05	-0.00127	0.00127	0.291	0.00436	0.00728
QY2L.3	664.1	3.5	52.08	0.05086	7.69e-05	0.00235	0.00438	0.581	0.019	0.0135
QB1.2	730.4	3.1	24.17	0.0209	-0.000349	-0.00103	0.000835	0.194	0.0655	0.00556
QB2.2	765	3.1	53.82	0.04655	0.000189	0.00242	0.00414	0.393	0.0306	0.0124
QB3.2	801.1	3.1	12.11	0.01048	-5.81e-05	-0.000544	0.00021	0.259	0.0276	0.00279
QB4.2	826.2	3.1	41.74	0.0361	0.000126	0.00188	0.00249	0.289	0.0194	0.0096
QB5.2	851.2	3.1	27.01	0.02336	-0.000167	-0.00121	0.00104	0.181	0.025	0.0121
QB6.2	876.2	3.1	64.35	0.05565	9.75e-05	0.0029	0.00592	0.337	0.0113	0.0148

M. Lückhof (CERN)

With bunch population of 3.35×10^{11} there is roughly 1.3×10^{12} SR photons generated per BX/beam along the last 100 m from the IP

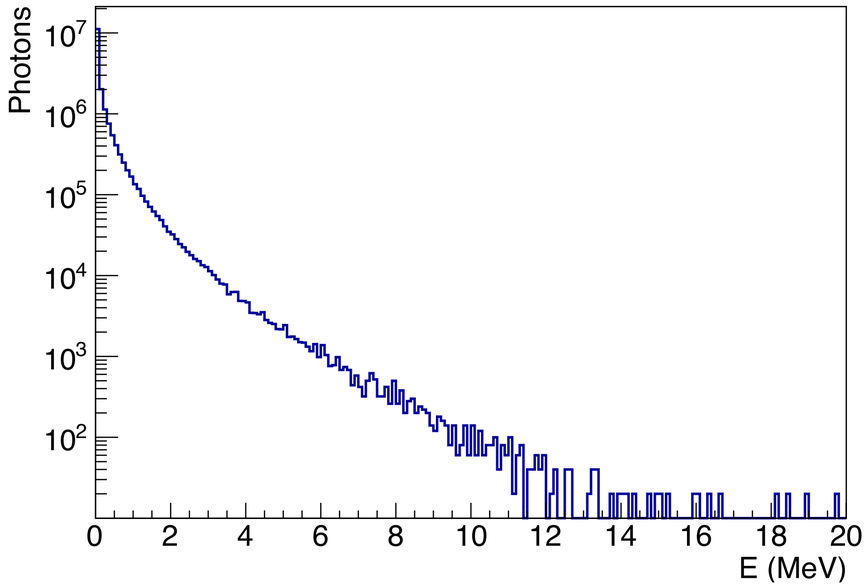
SR input files for Detector Background simulations

- Files too large to track Full SR in montecarlo codes for parameter studies—> need "tricks"
- Most of SR doesn't exit the beam pipe and goes straight through the IP towards the arc
- Masks stop the SR that would go into the detector
- Forward scattered SR of the last mask tip is at most relevance in the background study
- SR from SYNC_B and MDIsim/Geant4 (work in progress)

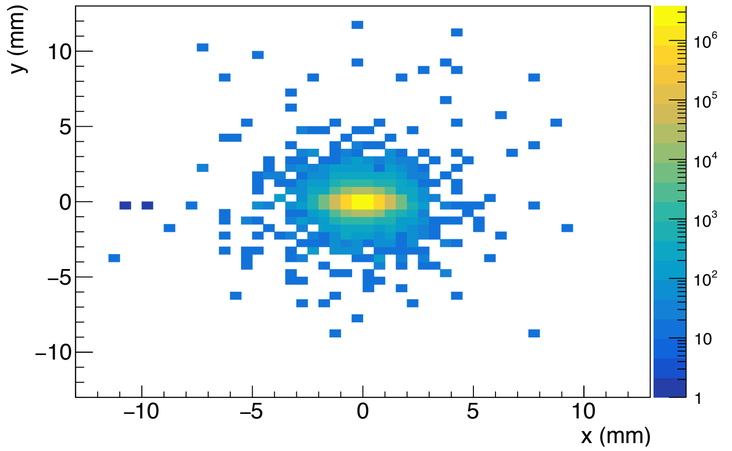
Contribution from all quads @ IP

MDIsim/G4 preliminary

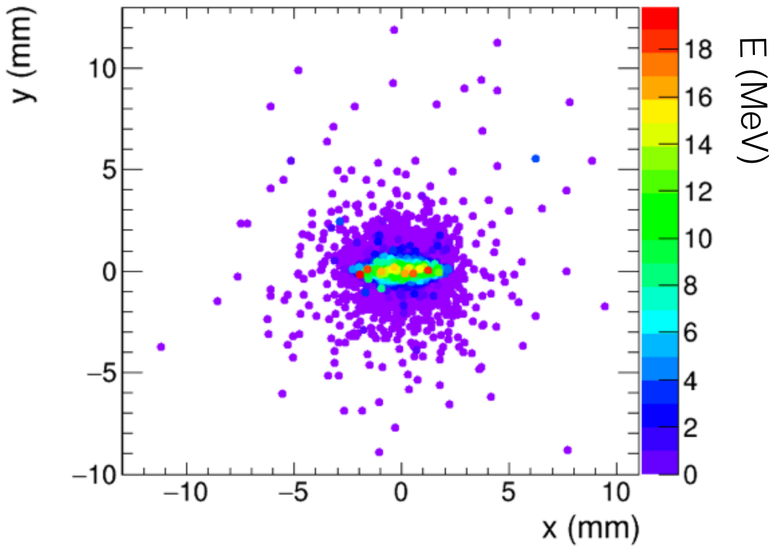
Input Photon Energy



Photon density @IP x-y



Energy distribution @IP x-y



- All SR from Quads is within the BP
- Statistics is still too low, however it already gives an idea
- Any beam fluctuation could send photons from Quads towards the detector

SR from all quads.
Input SR= full SR at 2m from IP
10^6 primaries

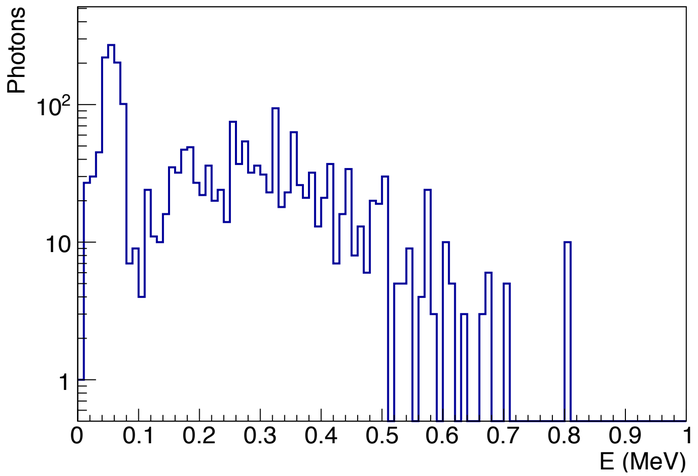
narrow beam of photons < 12 mm in x-y

M. Lückhof

SR contribution (bend)

MDIsim/G4 preliminary

Input Photon Energy



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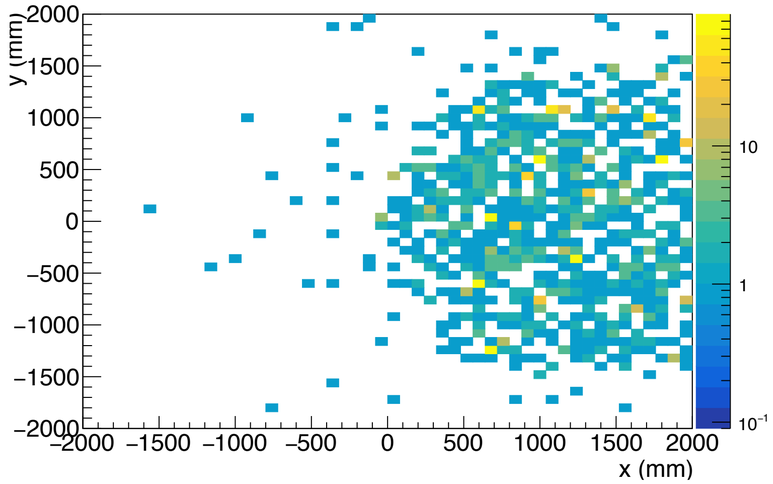

@ z=0 m

SR from BWL2. Input SR= only photons covering face of the mask @ 2.1 m from IP

Development of the MDIsim/Geant 4 model of the last 100 m from the IP is still ongoing, therefore the data presented is only a small fraction of the BX

M. Lückhof

SR contribution (bend)

FWDS SYNC_B /BX MDIsim/G4 preliminary

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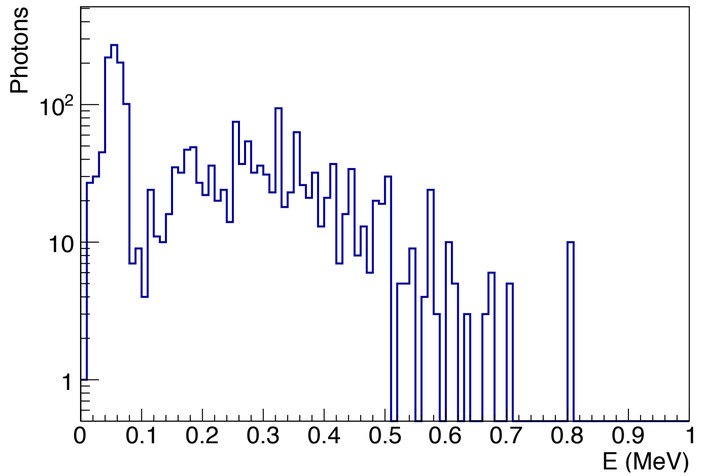

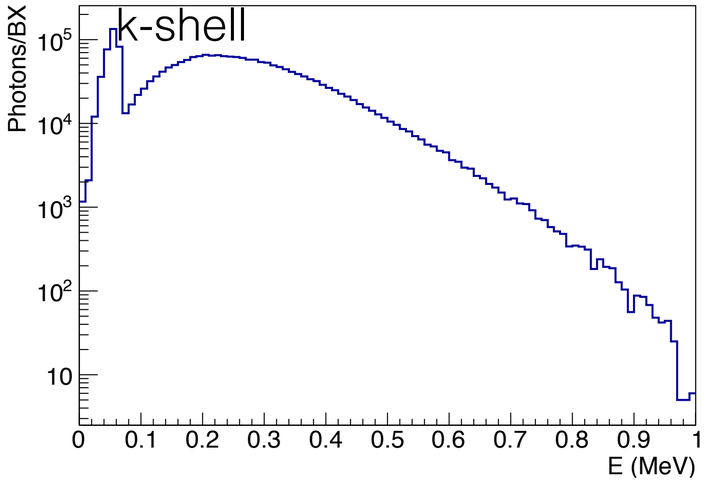

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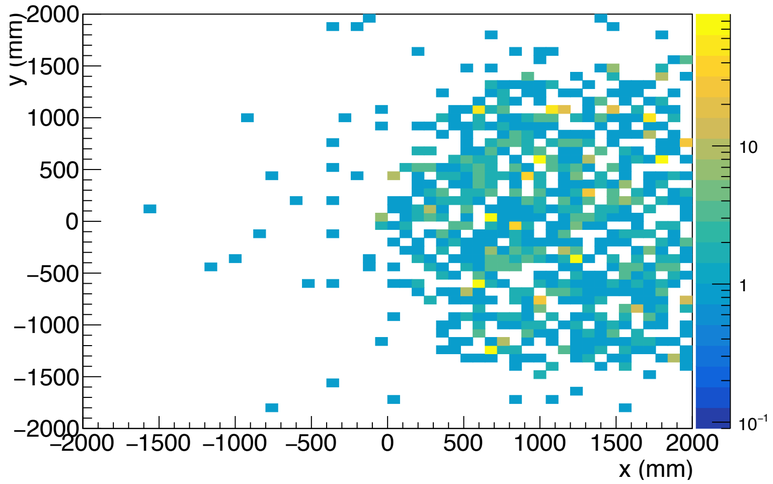

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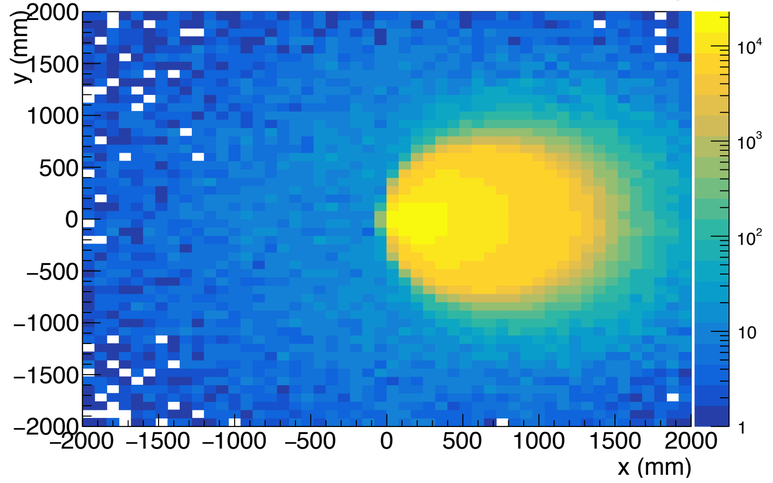


SR from BWL2. Input SR= only photons covering face of the mask @ 2.1 m from IP

For more details Poster Session: 363. Transporting synchrotron radiation from the last bend to the interaction region at FCC-ee with GEANT (Marian Lückhof)

SR contribution (bend)

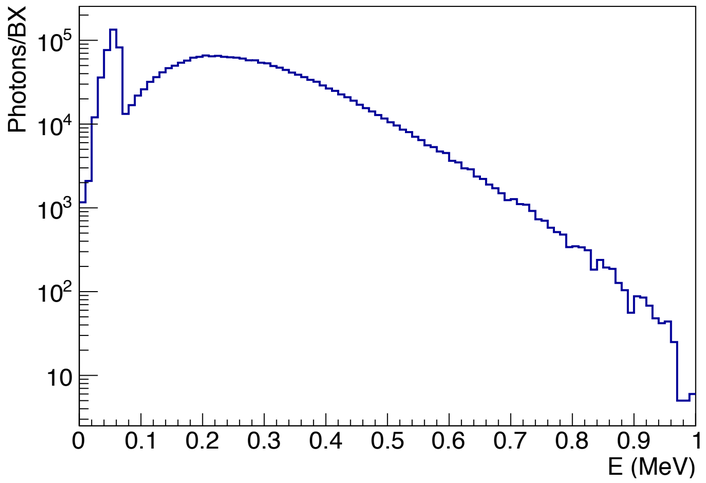
Forward Scattered SR (no shielding) per beam:

- Scattered at large angles
- Average photon energy of 200 keV
- Some forward scattered photons up to 1 MeV
- Photons scatter from the bottom mask towards positive-x
- Most of detector hits in the x > 0 area

SR from BWL2.
Input SR= only photons scattering off the mask tip @ 2.1 m from IP

FWDS SYNC_B /BX

Input Photon Energy



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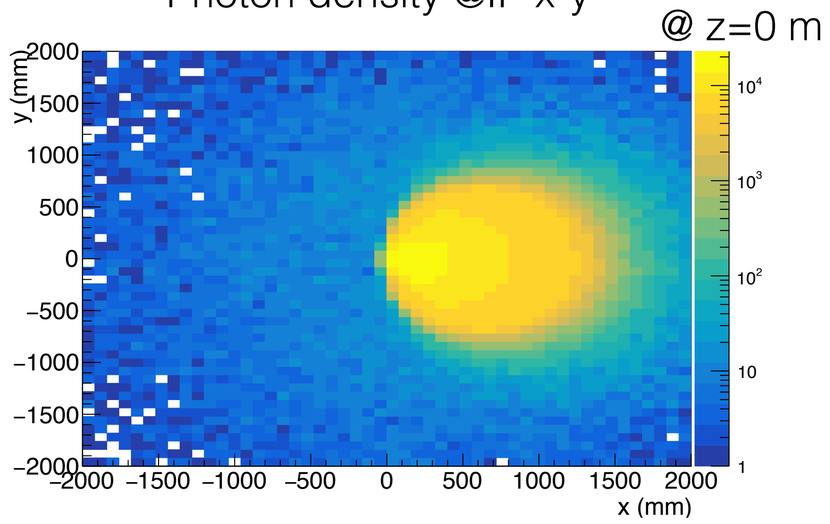


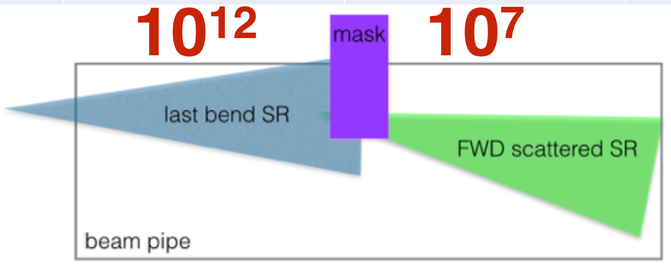
Synchrotron Radiation estimates

M. Sullivan (SLAC)

Beam energy (GeV)	Soft bend critical energy (keV)	Incident photon rate/ xing (>1 keV)	Generated photons	Ratio Inc/Gen	Generatedscattered photons	Actual scatter rate/xing	Hits in the detector rate/ xing
182.5	*100*	*2.41×10^{9}*	*5×10^{8}*	*4.82*	*1637608*	*7.9×10^{6}*	*3.3×10^{4} (435*)*
125	*35.0*	*7×10^{8}*	*5×10^{9}*	*0.1396*	*1837339*	*2.6×10^{5}*	*39*
80	*9.56*	*2.79×10^{7}*	*2×10^{10}*	*1.4×10^{-3}*	*799455*	*1119*	*0†*
45.6	*1.77*	*2.26×10^{7}*	*5×10^{10}*	*4.5×10^{-4}*	*73685*	*33.3*	*0‡*

*with shield
† Over 1400 xings
‡ Over 45000 xings

- No photons directly hit the central beam pipe



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*with shield
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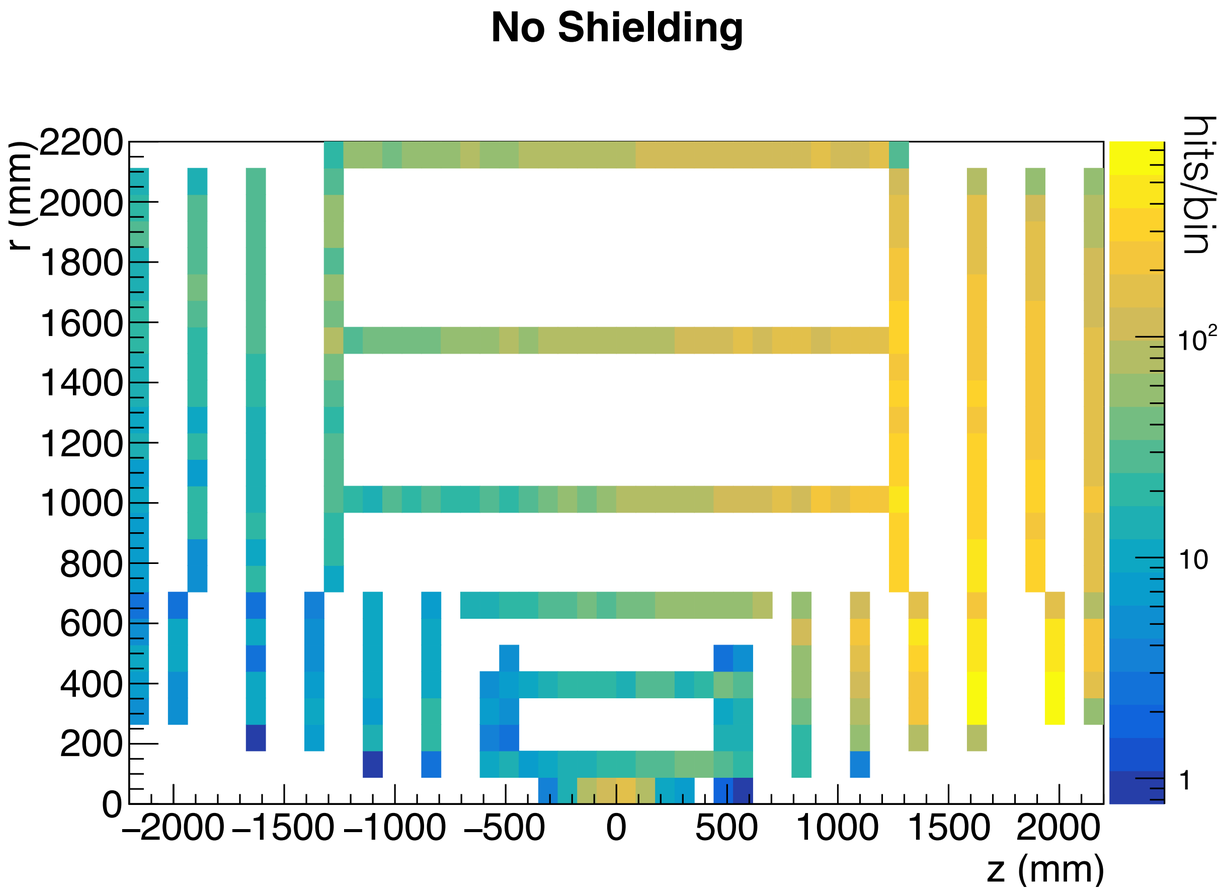
SR input files for Detector Background simulations:

- @ top **7.9×10^{6} /beam/BX** Forward scattered towards the detector
- Numbers per beam per mask
- Back scatter rate x2, however if warm bore magnets are used there is no need for upstream mask

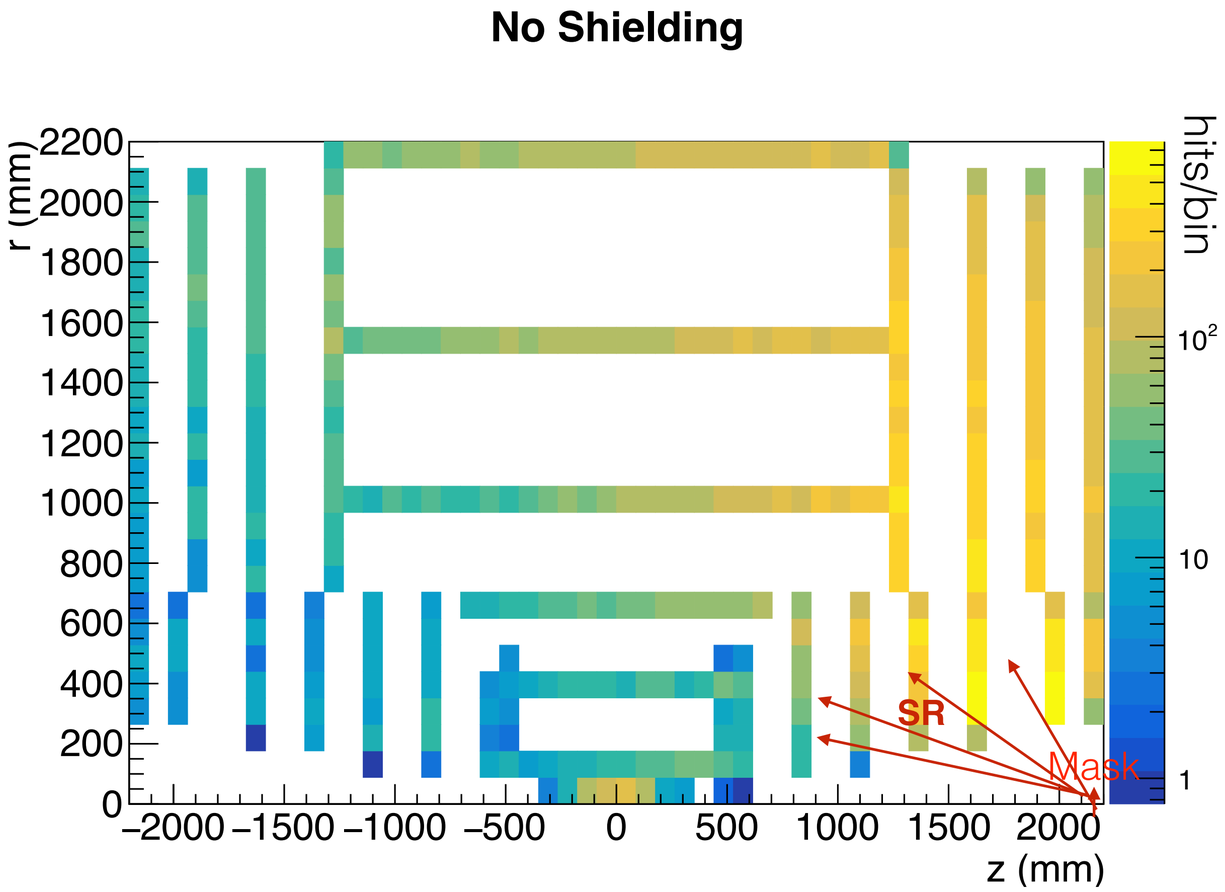
Hit distribution in the CLD detector



- 1 beam
- Forward scattered SR from z=212 cm towards IP
- Asymmetric hit distribution
- Mostly showers at Inner/Outer Tracker Endcaps and Barrel at large angles
- Few hundred photon-induced hits in the Vertex Detector

Detector hit-> Sensitive layer hit above a threshold

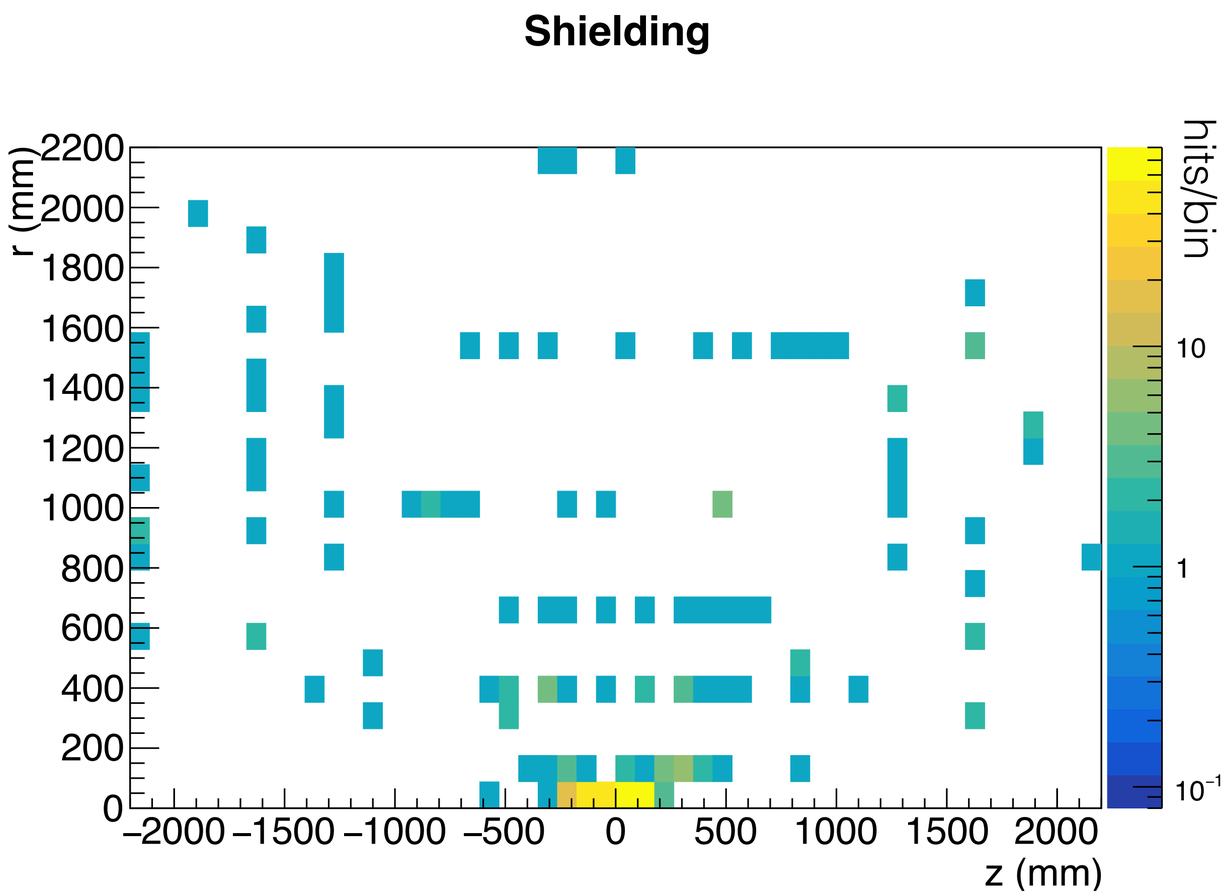
Hit distribution in the CLD detector



- 1 beam
- Forward scattered SR from z=212 cm towards IP
- Asymmetric hit distribution
- Mostly showers at Inner/Outer Tracker Endcaps and Barrel at large angles
- Few hundred photon-induced hits in the Vertex Detector

Detector hit-> Sensitive layer hit above a threshold

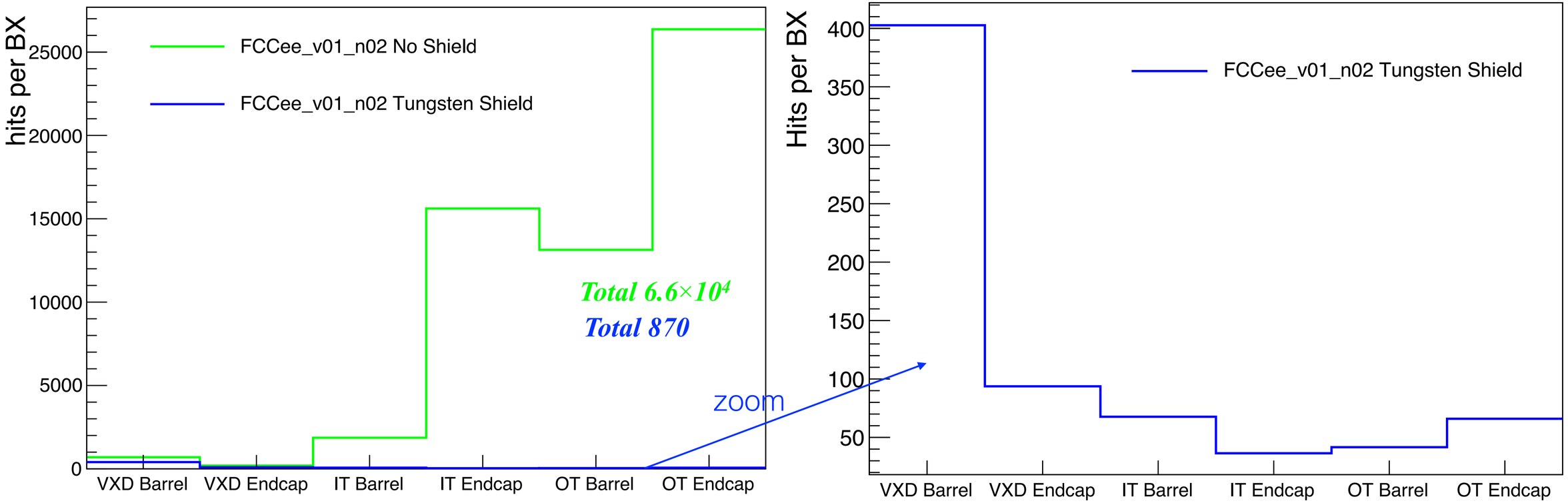
Hit distribution in the CLD detector



- 435 photon-induced hits in scattered around the detector per beam
- SR at Small angles (<2°) reaches the Vertex Detector
- Cannot be shielded within the Detector (LumiCal window and Vertex Detector)
- There is around 1500 FWDS/BX photons incident on the Central Beampipe per beam
- Low occupancies —> not an issue

Hit density in sub detectors

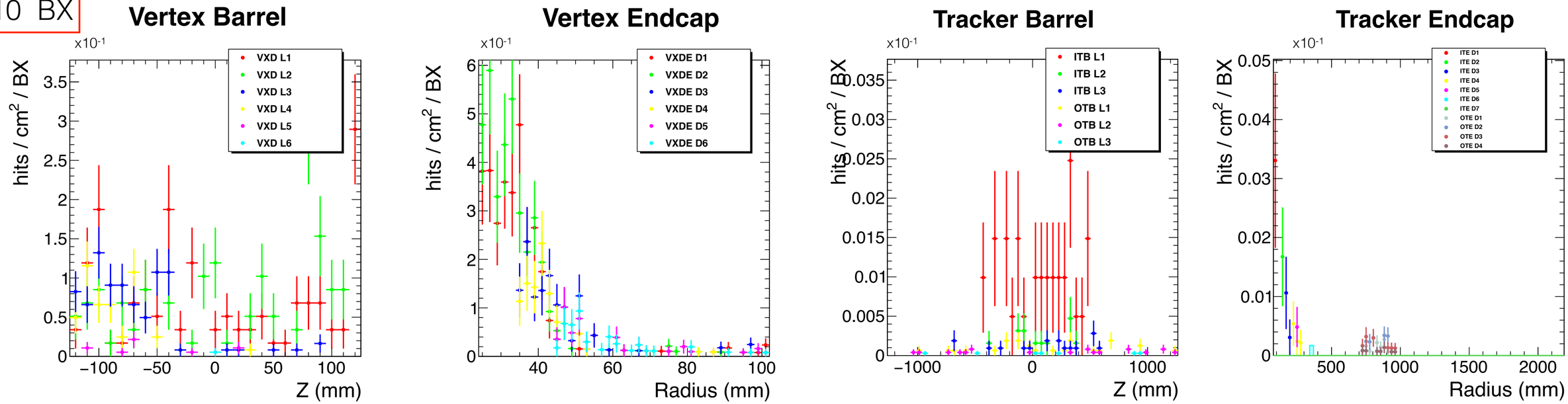
Total SR for two beams forward scattered from the last mask tip at 2.12 m from the IP



Hit density/cm2 in the Vertex and Inner Tracker Detectors

x10 BX

With Shielding



Maximum Occupancy of order of **10^{-4}/cm^2/BX** in the vertex detector.

Assuming x3 safety factor x5 multiplication factor and x2 to account for most hits being on the positive-x side of the detector .

- 0.6 x 10^{-4} /cm^2/BX in Vertex Barrel L1-2
- 1.1 x 10^{-4} /cm^2/BX in Vertex Endcap D2
- 0.4 x 10^{-4} /cm^2/BX in Inner Tracker Barrel L1
- 0.5 x 10^{-4} /cm^2/BX in Inner Tracker D1
- 3 x 10^{-6} /cm^2/BX in Outer Tracker Barrel L1
- 5.3 x 10^{-6} /cm^2/BX in Outer Tracker D2

Vertex Detector
25 μm x 25 μm pixel size

I/O Tracker
1 mm x 0.05 mm strip size

Conclusions and Future outlooks

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- SR backgrounds appear to be manageable with shielding and collimation at the Top energy
- At Z, W and H operating points the background from SR seems also manageable (for ideal conditions)
- Main contribution to the background is from the last bend (BWL)
- Maximum occupancies of order of $10^{-4}/cm^2/BX$
- Preliminary look at Quadrupole SR radiation shows that it will pass the IP, however any beam fluctuation could send energetic photons towards the detector volume

Future outlook:

- More statistics
- Incorporate CLD detector into the MDIsim work for full MC simulations from the last bend
- Consider other solutions such as saw-tooth masks

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Many thanks to colleagues from the FCCee MDI, Accelerator and Detector Groups and to Mike Sullivan from SLAC

Bakc-up slides

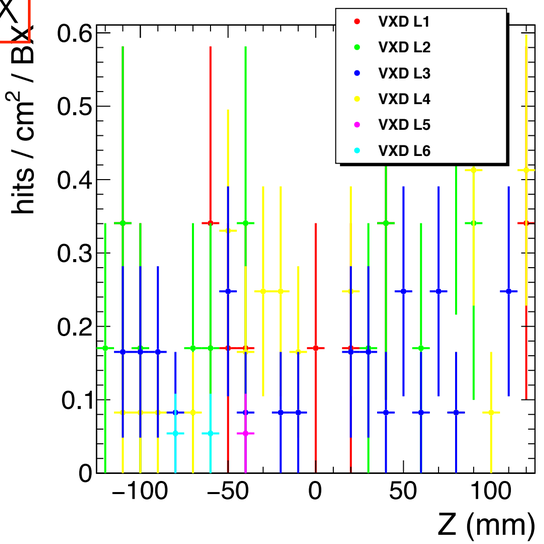
Hit density/cm2 in the Vertex and Inner Tracker Detectors

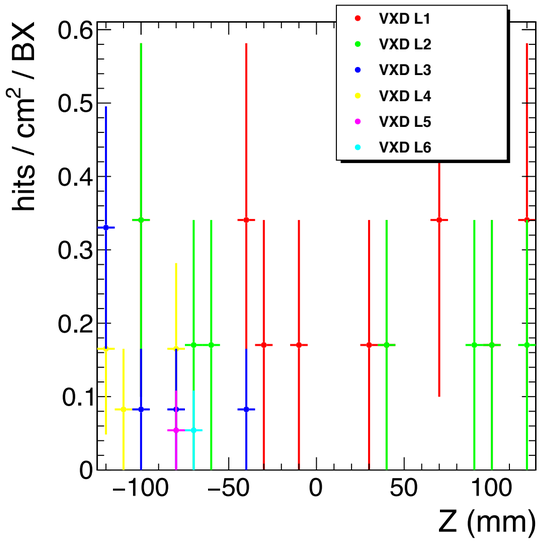
x1 BX

No Shielding

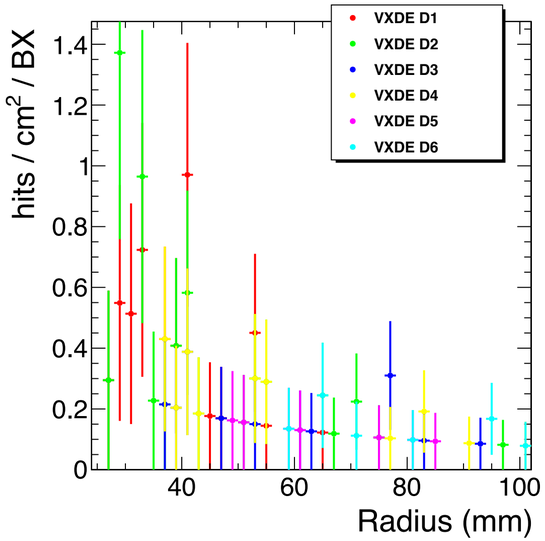
Shielding

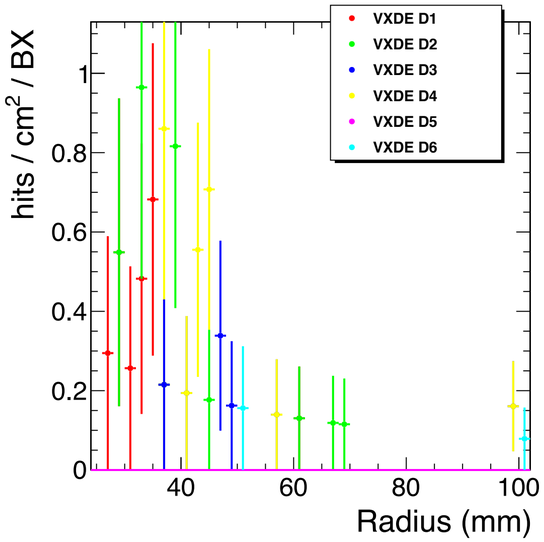
Vertex Barrel



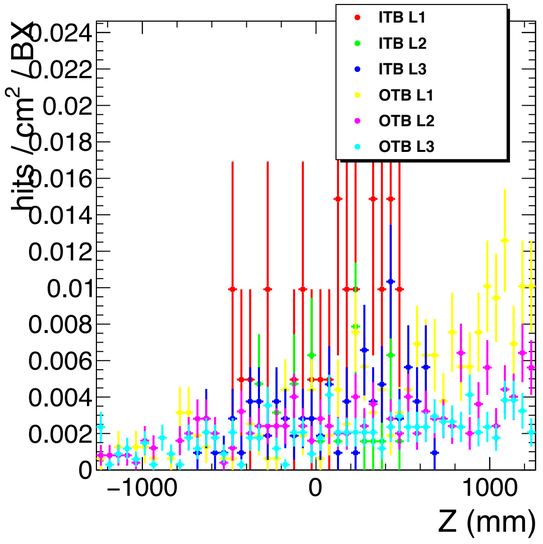


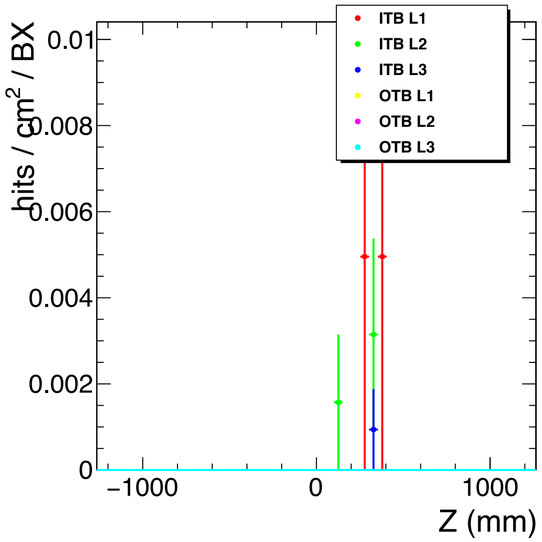
Vertex Endcap



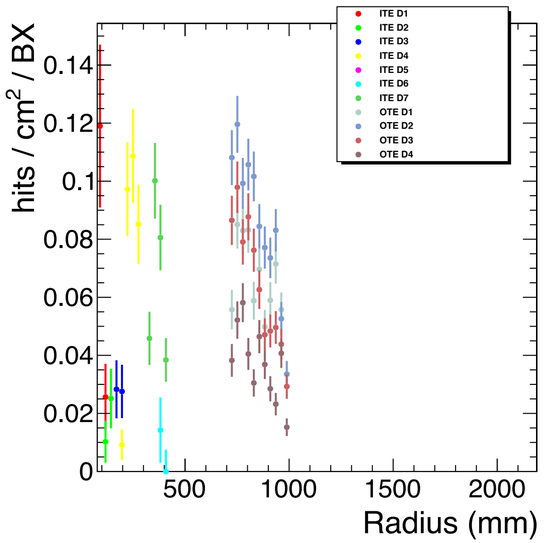


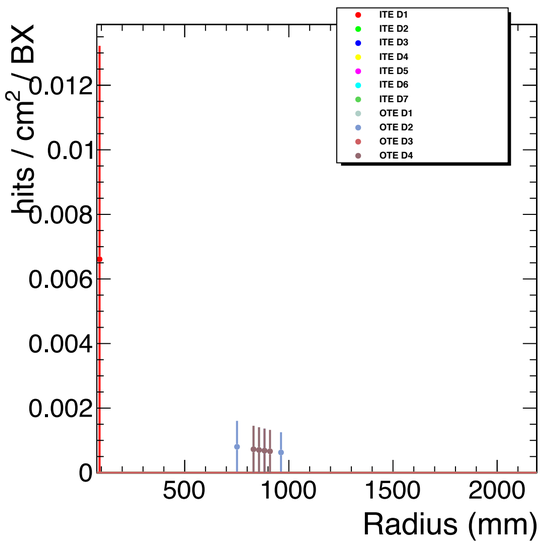
Tracker Barrel





Tracker Endcap





Hit Density distribution in the CLD detector

Shielding