Detector Simulation of Beam induced background

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on behalf of the MDI Group

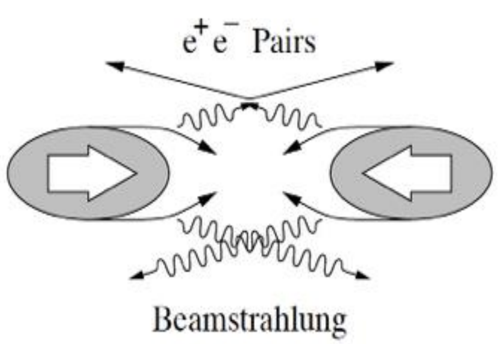
Outline

- Introduction
  - Induced backgrounds
  - Interaction region layout
  - Background estimators
- Results of background estimation
  - Pair production
  - Off-energy beam particles
- Summary

Operation Mode	Higgs (240 GeV)	W (160 GeV)	Z (91 GeV)
Particles/bunch N_e $[10^{10}]$	15	12	8
Bunch Number	242	1524	12000
Horizontal beam size $\sigma_x[\mu\text{m}]$	20.9	13.9	6.0
Vertical beam size $\sigma_y[\mu\text{m}]$	0.06	0.049	0.078
Energy spread [%]	0.134	0.098	0.080
$\mathscr{L}$ $[10^{34}\text{cm}^{-2}\text{s}^{-1}]$	3	10	17

Introduction

- Beam induced background at CEPC
  - Pairs production from beamstralung photon emitted from the beam particles
    - Dominated by the electron pair
    - Muon pairs and hadrons production are suppressed
  - Beam particles with fraction of energy loss greater than acceptance(beam lost particles)
    - Beam-gas scattering
    - Beam-thermal photon scattering
    - Bhabha scattering
- Radiation damage on the silicon tracker
- Lower the tracking efficiency

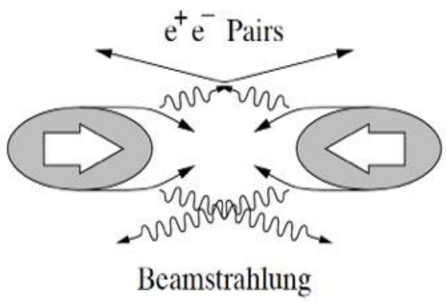


Detector Simulation

- Generation of background
  - Guinea-pig++
    - Pairs production
    - Beamstralung photons
  - SAD
    - Beam Lost particles

- Production of electron pairs
- Tracking of electron pairs
  - Deflection by the EM field of beam
  - Until beam sperate from each other completely
- Longer bunch of CEPC (millimeter level)
  - Produced electron pairs can reach to the region far away the IP
  - Effect of external the magnetic field and interaction with the beam pip need to be considered
  - Guinea-pig is develop for Linear collider (micrometer level)
- Modification of the Guinea-pig
  - Include the magnetic field from the solenoid
  - Stop tracking of electrons before hitting the beam pipe

- Mokka
  - A full simulation tool based on Geant4 and realistic description of detector (base line of CDR)
  - Record the steps of primary and secondary particles
    - Particle type, step length, momentum, position…



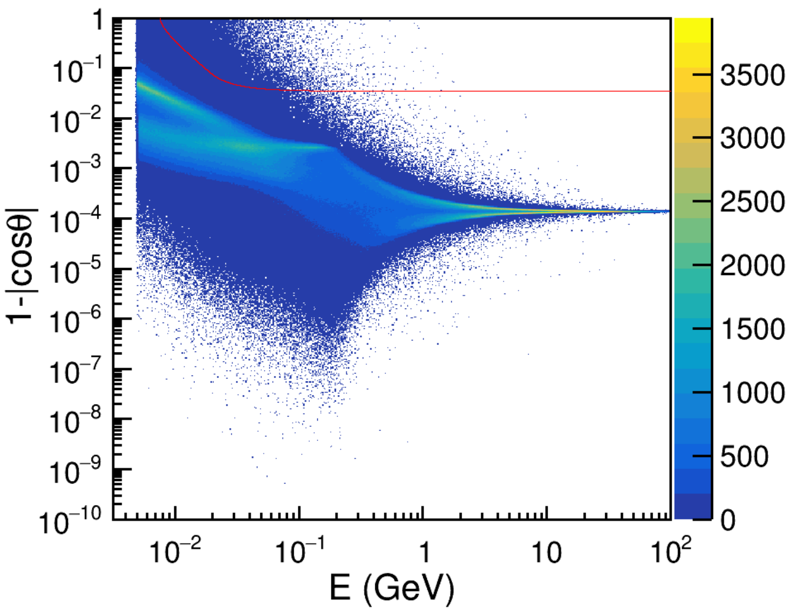
Estimation of background

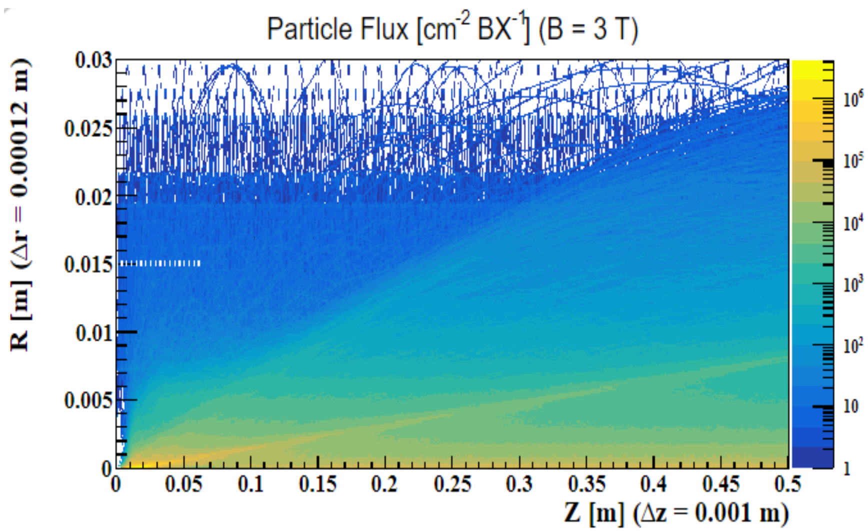
- Background estimators
  - Hit density: $\frac{Number\ of\ hits}{area}\ [hits/BX]$
    - Detector occupancy
  - TID: Total Ionizing dose Dose= $\frac{E_{deposited}}{M_{detector}} = \Sigma_i \frac{dE^i}{dx}_{Si} \frac{L_i}{\Delta M}\ [\mathrm{kRad}/year]$
    - Total energy deposited by the ionizing process in a unit volume
    - Surface damage of silicon devices
      - arXiv:1502.00289
  - 1 MeV equivalent neutron fluence
    - energy deposited by non-ionizing process in a unit volume: $\frac{dE_{non}}{dx\ \rho} \frac{L}{V}$
    - $NIEL(1\ MeV, neutron) \times \frac{NIEL(E_k, type)}{NIEL(1\ MeV, neutron)} Fluence$
    - Bulk damage of silicon devices
      - arXiv:1502.00289

A safety factor of 10 is always applied

Background from the Pairs production

- Pairs produced in beam-beam interaction
  - With the Generator GUINEA-PIG++
  - Low energy and in the very forward region

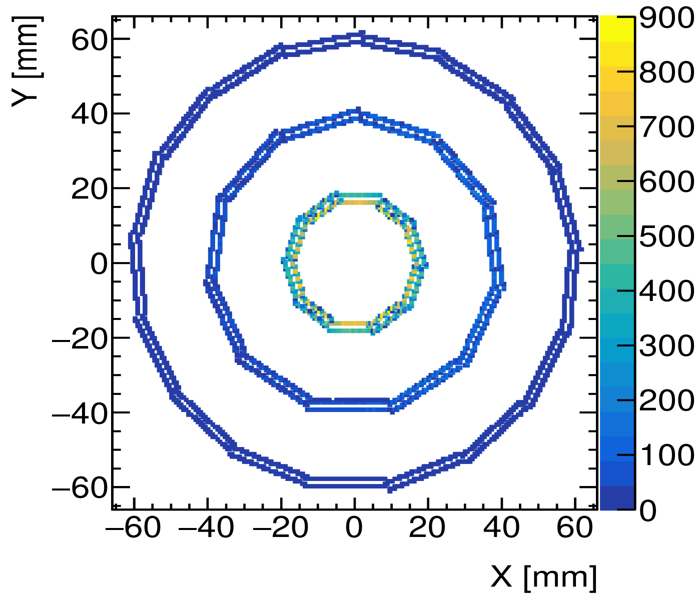




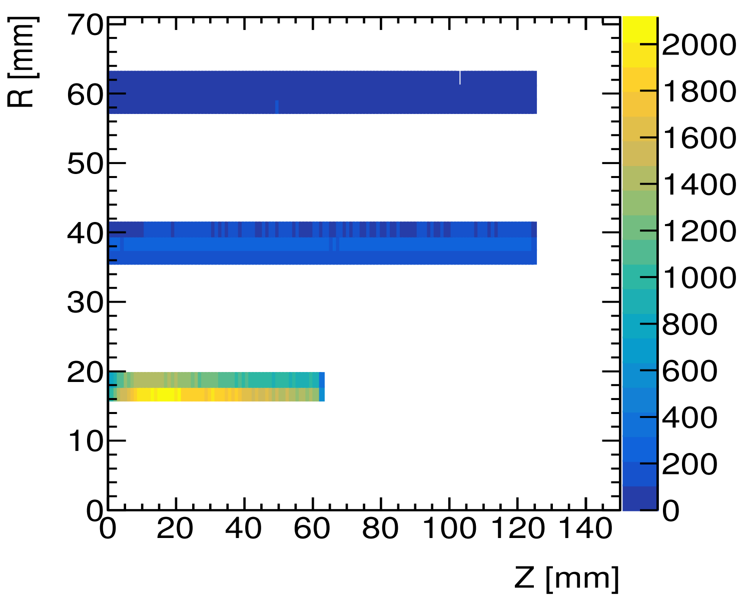
Without interaction

Pair Production

- Hit map of vertex detector at the Higgs mode



Nearly uniform in the transverse view



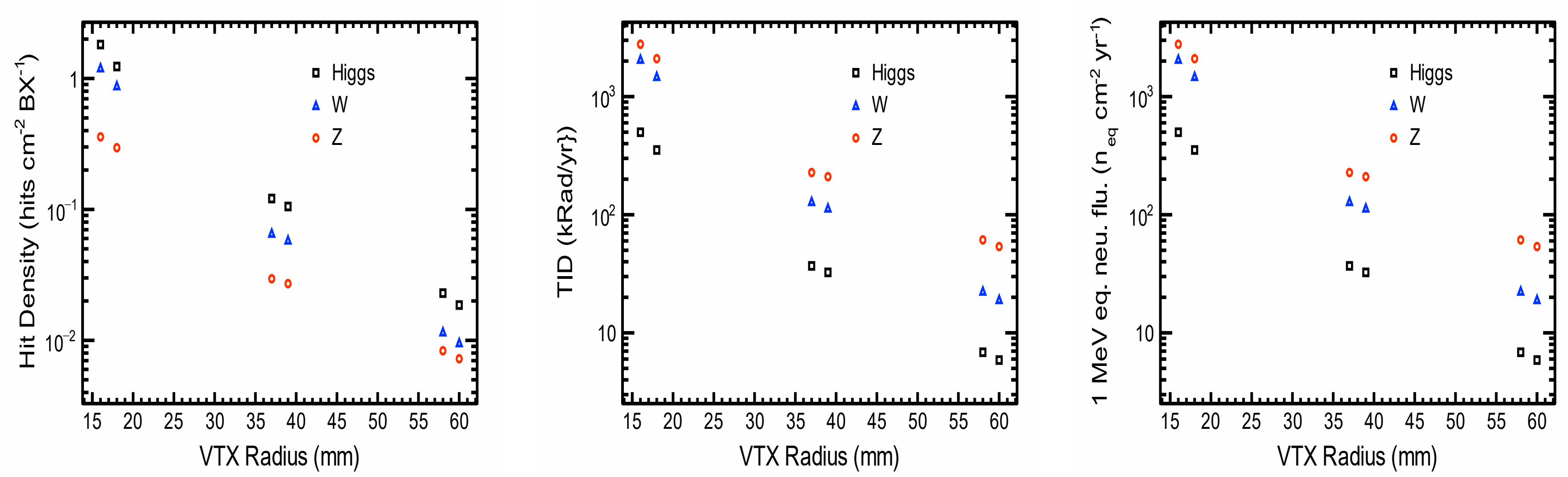
More dense in central of first layer

Pair Production

- Results of pair production in the vertex detector
  - BKG decrease rapidly with increasing radius

Table 1: Background from the pair production at different layers of VTX

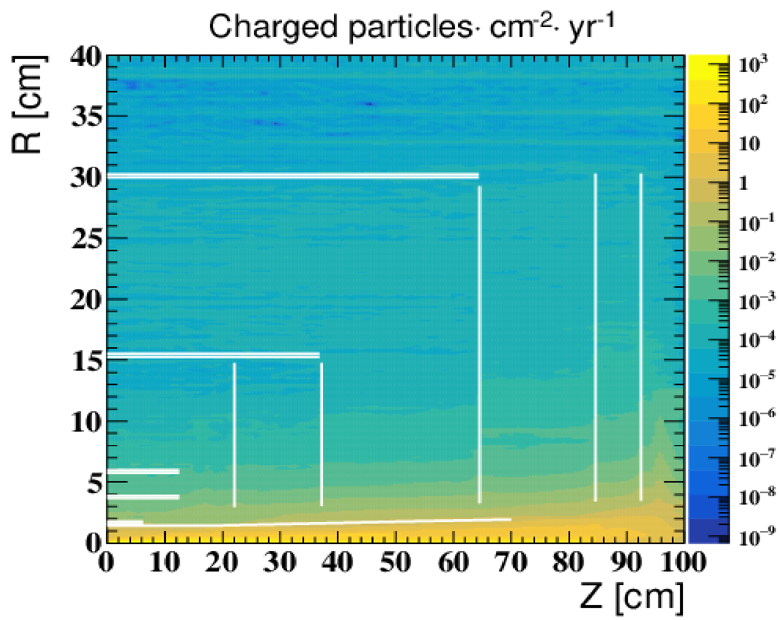
Layer	Hit Density $[cm^{-2}BX^{-1}]$			TID [kRad/yr]			1 MeV Equ. Neu. Fluence $[n_{eq} \times 10^{12} cm^{-2} yr^{-1}]$		
	Higgs	W	Z	Higgs	W	Z	Higgs	W	Z
1	1.81	1.21	0.36	499.44	2077.84	5551.37	0.97	3.82	10.64
2	1.23	0.88	0.29	353.3	1486.86	4188.47	0.68	2.75	7.76
3	0.12	0.07	0.03	36.89	129.83	455.15	0.07	0.26	0.87
4	0.11	0.06	0.03	31.52	114.26	419.84	0.07	0.24	0.78
5	0.02	0.01	0.01	6.85	22.63	122.46	0.02	0.076	0.27
6	0.01	0.01	0.01	5.89	19.20	107.54	0.02	0.065	0.24

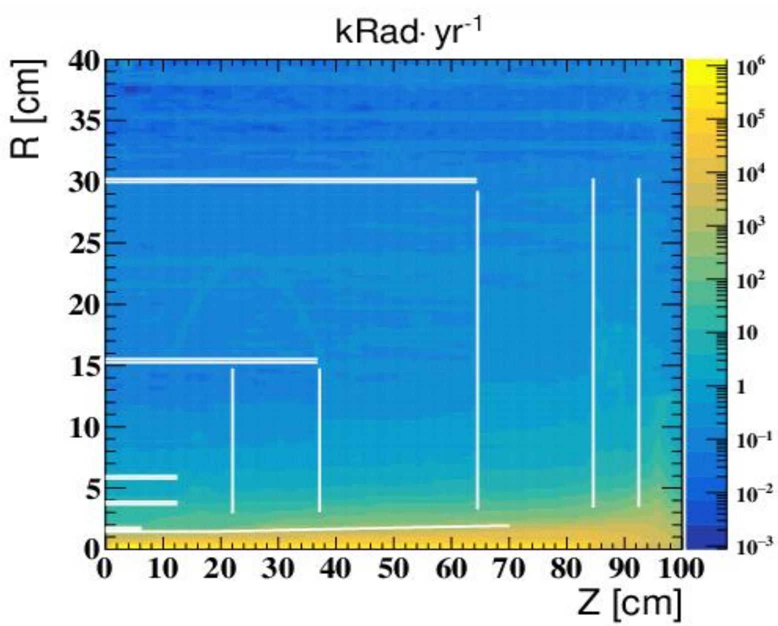


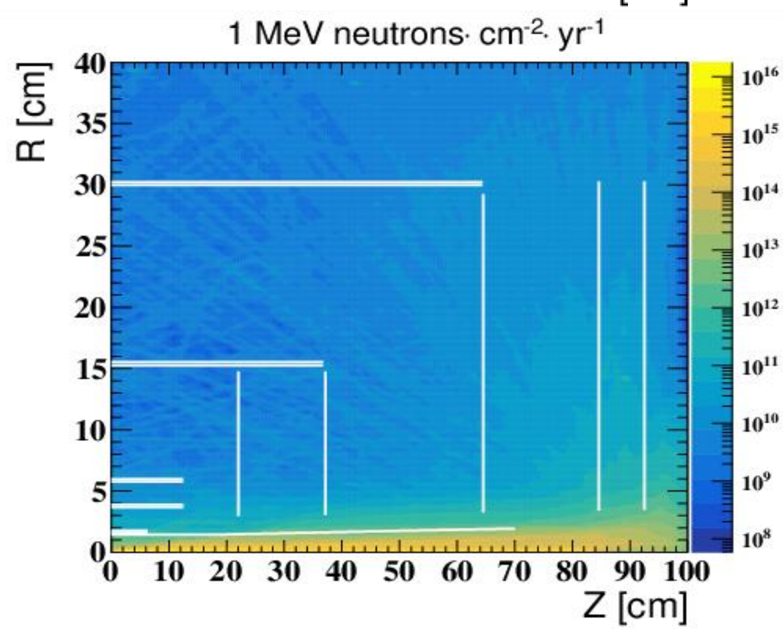
Higgs (240 GeV), W (160 GeV) and Z (91 GeV)

Radiation map tracker region

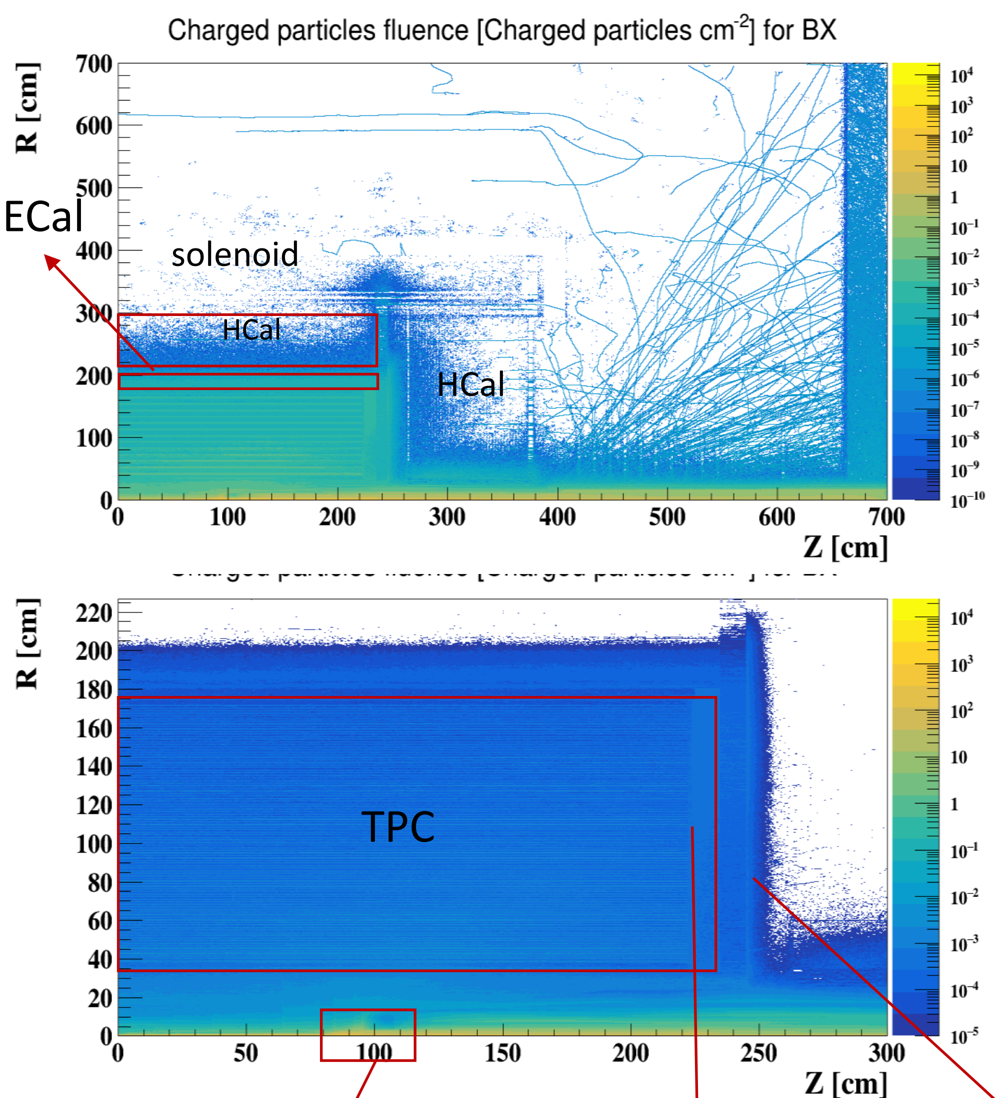
- Higgs mode
  - Most particles are confined in the beam pip
  - Backscattering particles are produced in the region $z \in [90, 100]$
    - LumiCal
    - Transition from single pipe to double pipe







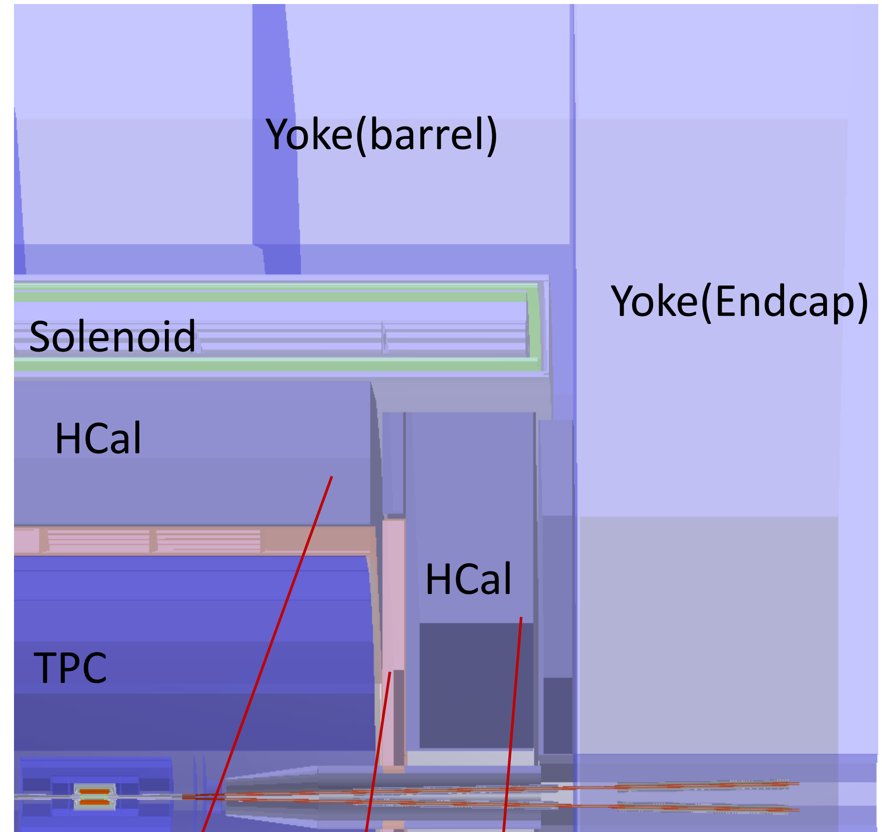
Charge particles fluence(Z2T)



LumiCal

TPC endplate

EMC endcap



⇩ 400 cm

End cap ring

EMC

Yoke plugin

Beamstrahlung photon for 2T mode

- Polar angles of most particles are very small
  - Exit the detector with beam
- Energy is low but the number of photons is huge
  - Number of photons per BX: $n_\gamma \times 2 \times N_{elec} = 2.82 \times 10^{11}$
  - Energy deposited per second per beam: 469.5 kW

$$\Upsilon \approx \frac{5}{6}\frac{r_e^2 \gamma N}{\alpha \sigma_s (\sigma_x^* + \sigma_y^*)}$$

$$n_\gamma \approx 2.54 \left[\frac{\alpha \sigma_s}{\bar{\lambda}_c \gamma} \frac{\Upsilon}{(1+\Upsilon^{2/3})^{1/2}}\right]$$

$$\delta_B \approx 1.24 \left[\frac{\alpha \sigma_s}{\bar{\lambda}_c \gamma} \frac{\Upsilon^2}{\left(1+(1.5\Upsilon)^{\frac{2}{3}}\right)^2}\right]$$

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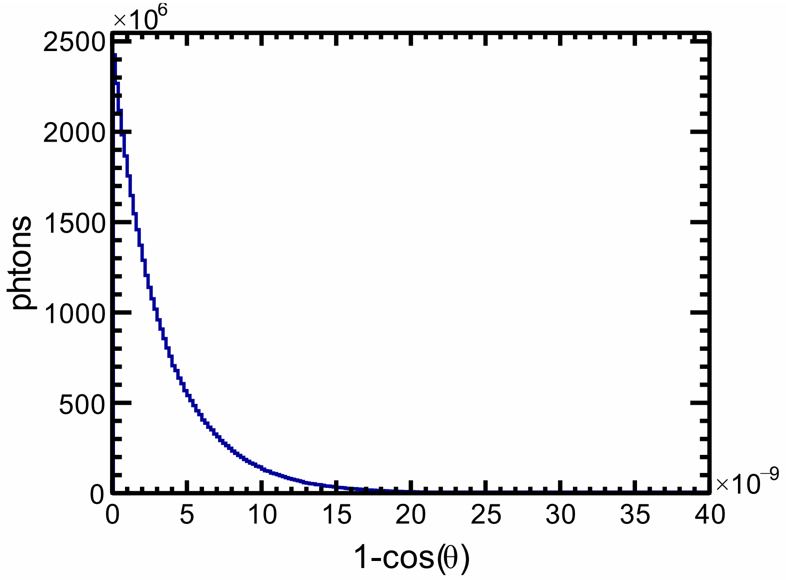
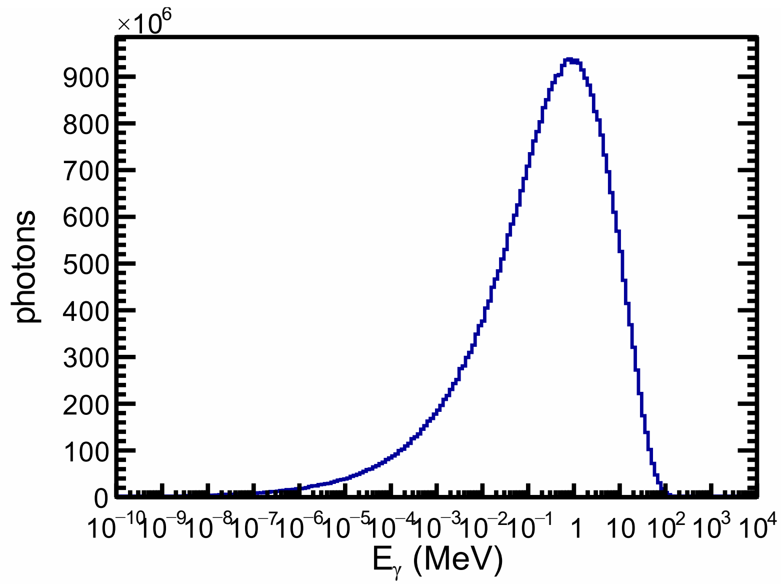
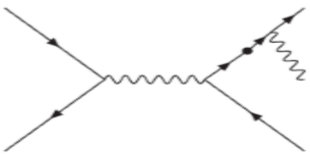
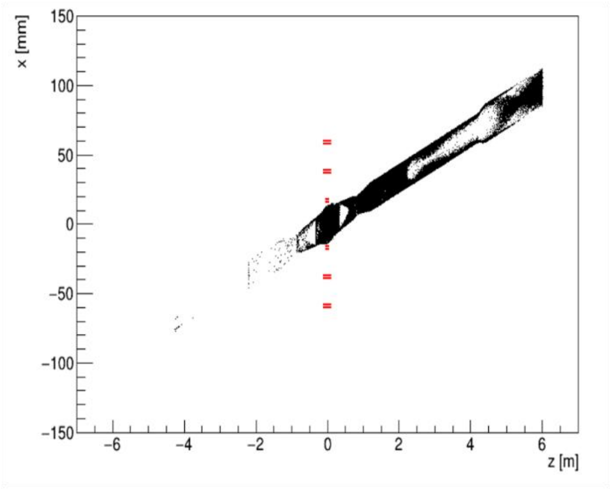


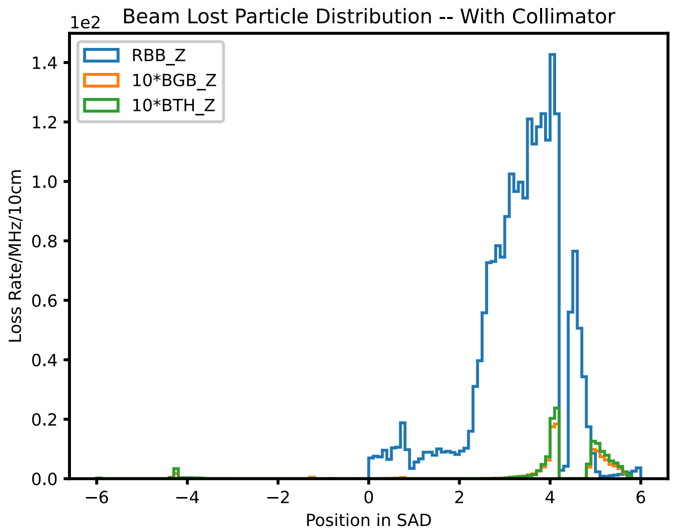


Generated beam lost particles

- Beam particles lose energy in scattering processes
  - Radiative Bhabha scattering
    - Negligible
  - Beam thermal photon
  - Beam-gas scattering







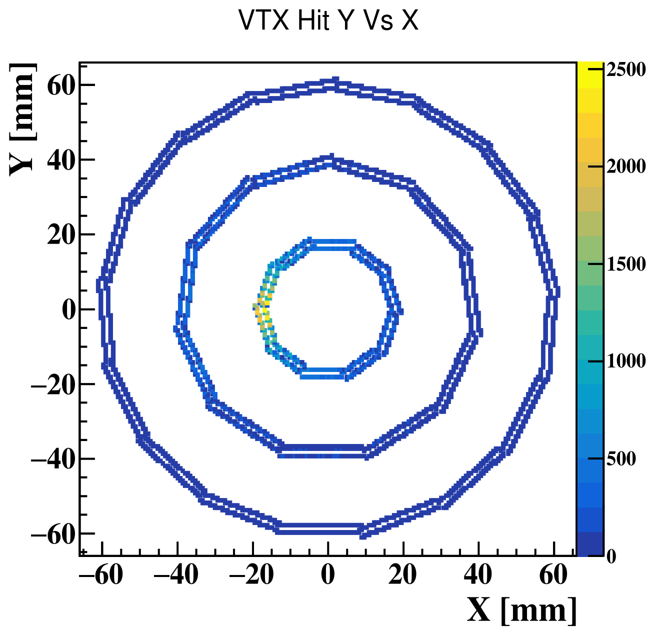
Beam direction

From Haoyu Shi

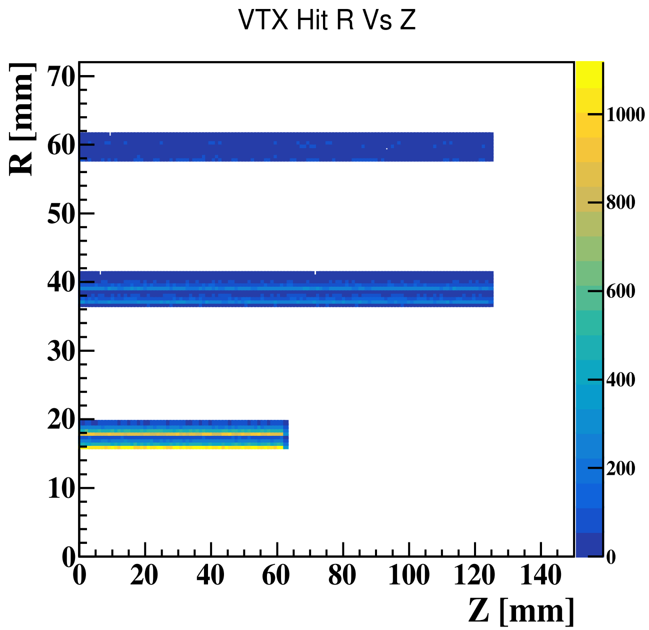
- Initial Position in z axis where the beam lost particles hit the beam pip
  - Can enter the detector
  - With the collimator in the upstream

Off-energy Particles

- Hit map of vertex detector
  - From beam gas scattering for Higgs mode



More hits in –X side



More uniform in the z axis compared to pair production

Results

- Beam lost particles
  - Beam-Gas scattering

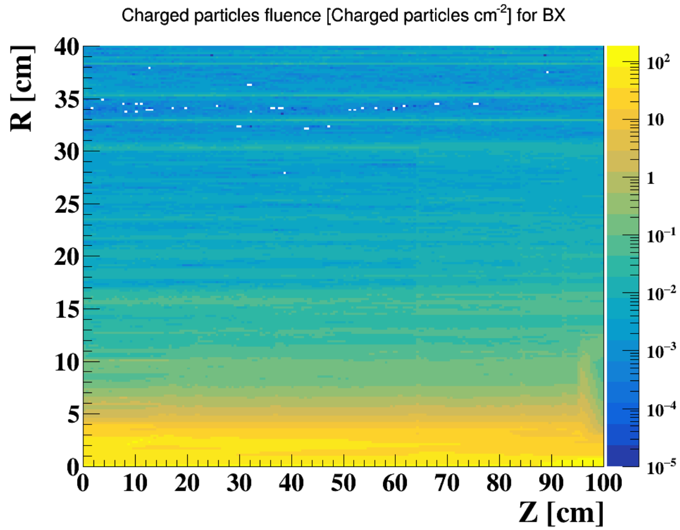
Layer	Hit Density $[cm^{-2}BX^{-1}]$			TID [kRad/yr]			1 MeV Equ. Neu. Fluence $[n_{eq} \times 10^{12}cm^{-2}yr^{-1}]$		
	Higgs	W	Z	Higgs	W	Z	Higgs	W	Z
1	0.33	0.35	0.14	390.20	1327.68	4061.53	1.04	3.62	11.00
2	0.42	0.47	0.17	452.52	1448.68	4159.80	1.16	3.67	10.78
3	0.13	0.14	0.09	124.96	433.04	1969.53	0.33	1.14	4.91
4	0.11	0.13	0.08	104.58	353.01	1664.31	0.29	0.96	4.41
5	0.01	0.01	0.01	12.49	44.34	361.85	0.04	0.14	1.12
6	0.02	0.02	0.01	11.19	42.60	329.28	0.03	0.14	0.98

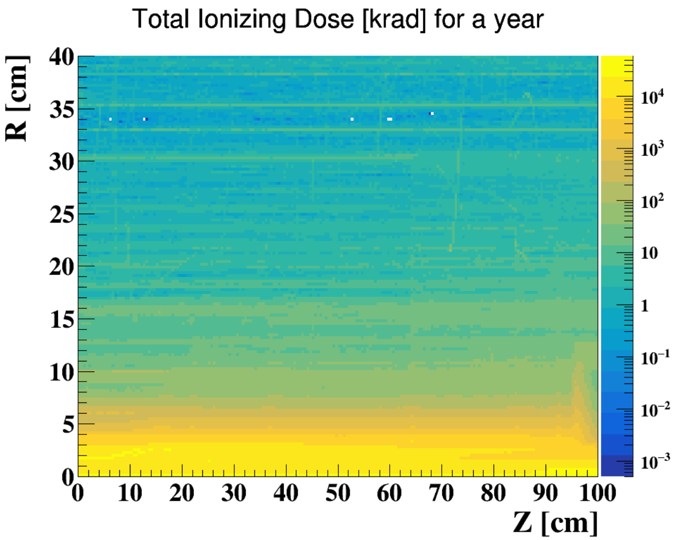
  - Beam-thermal scattering

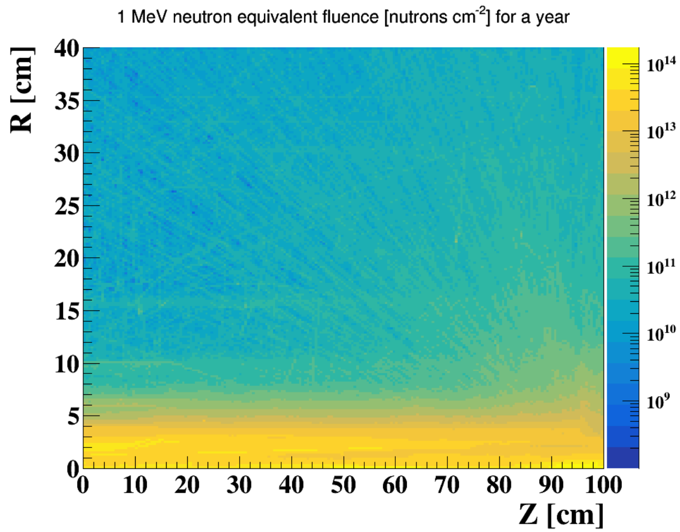
Layer	Hit Density $[cm^{-2}BX^{-1}]$			TID [kRad/yr]			1 MeV Equ. Neu. Fluence $[n_{eq} \times 10^{12}cm^{-2}yr^{-1}]$		
	Higgs	W	Z	Higgs	W	Z	Higgs	W	Z
1	0.13	0.07	0.03	72.33	253.01	770.06	1.95	6.87	19.16
2	0.15	0.08	0.03	77.67	247.86	786.21	1.99	6.85	20.01
3	0.05	0.03	0.02	25.94	83.46	368.76	0.74	2.27	9.79
4	0.06	0.03	0.02	21.25	74.93	334.04	0.56	2.08	8.95
5	0.01	0.01	0.01	3.41	9.94	92.67	0.11	0.31	2.98
6	0.01	0.01	0.01	2.83	11.83	73.73	0.09	0.56	2.19

Radiation map in the track region

- From the Beam-Gas scattering
  - for the Higgs mode
- Fluence is flat along the Z axis
  - Secondary scattering particles
  - Backscattering

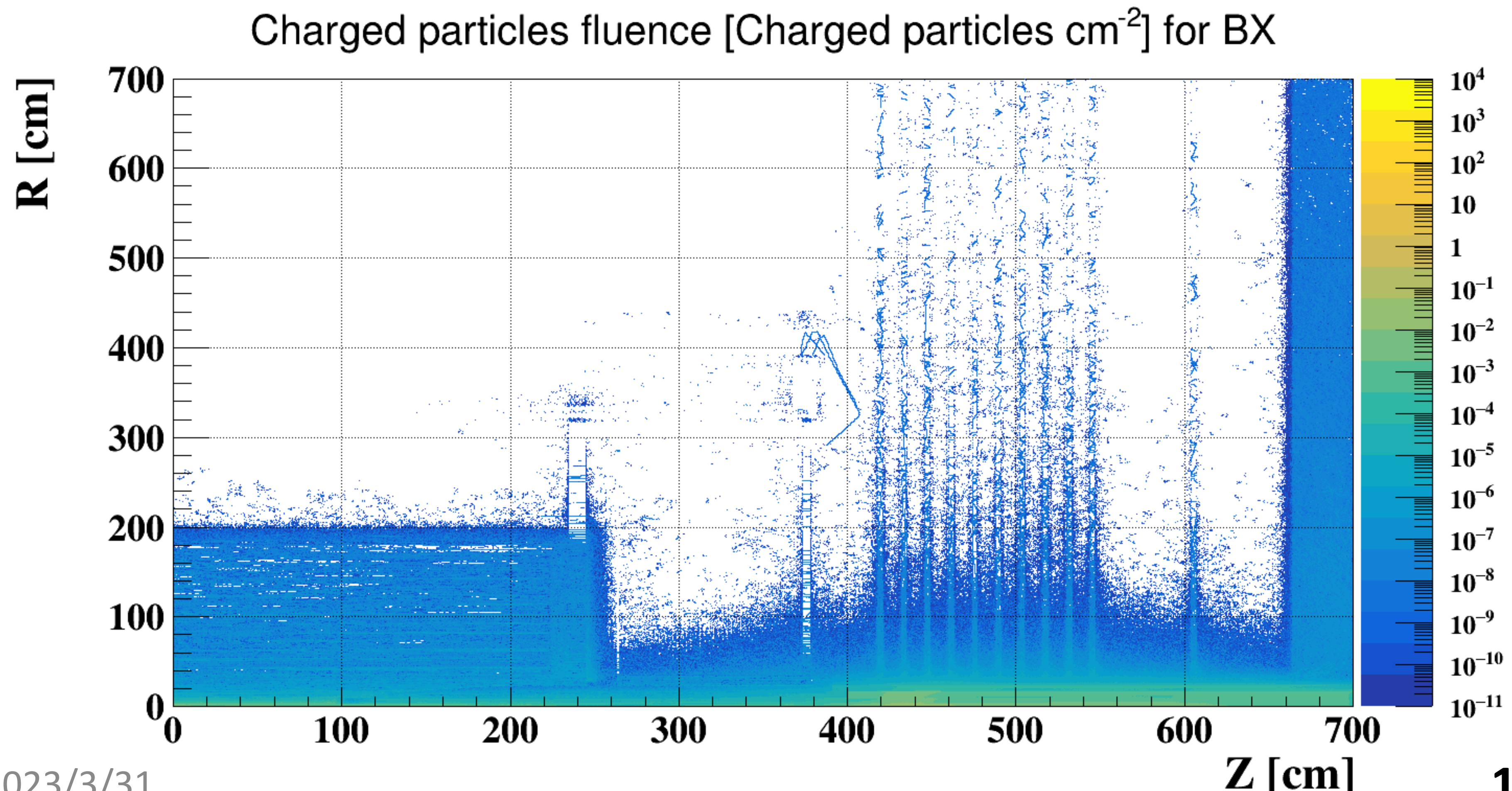






Radiation map in the track region

- From the Beam-Gas scattering
  - for the Z mode



Summary

- Pair production && beam lost particles
  - BKG at fist layer of vertex detector (dominated by the pairs production)

	H (240)	W (160)	Z (91)
Hit Density [hits/cm^2·BX]	2.3	1.7	0.63
TID [MRad/year]	0.93	3.65	10.47
1 MeV equ. Neu. Flu. [10^{12} n_{eq}/cm2·year]	2.2	8.1	23.6

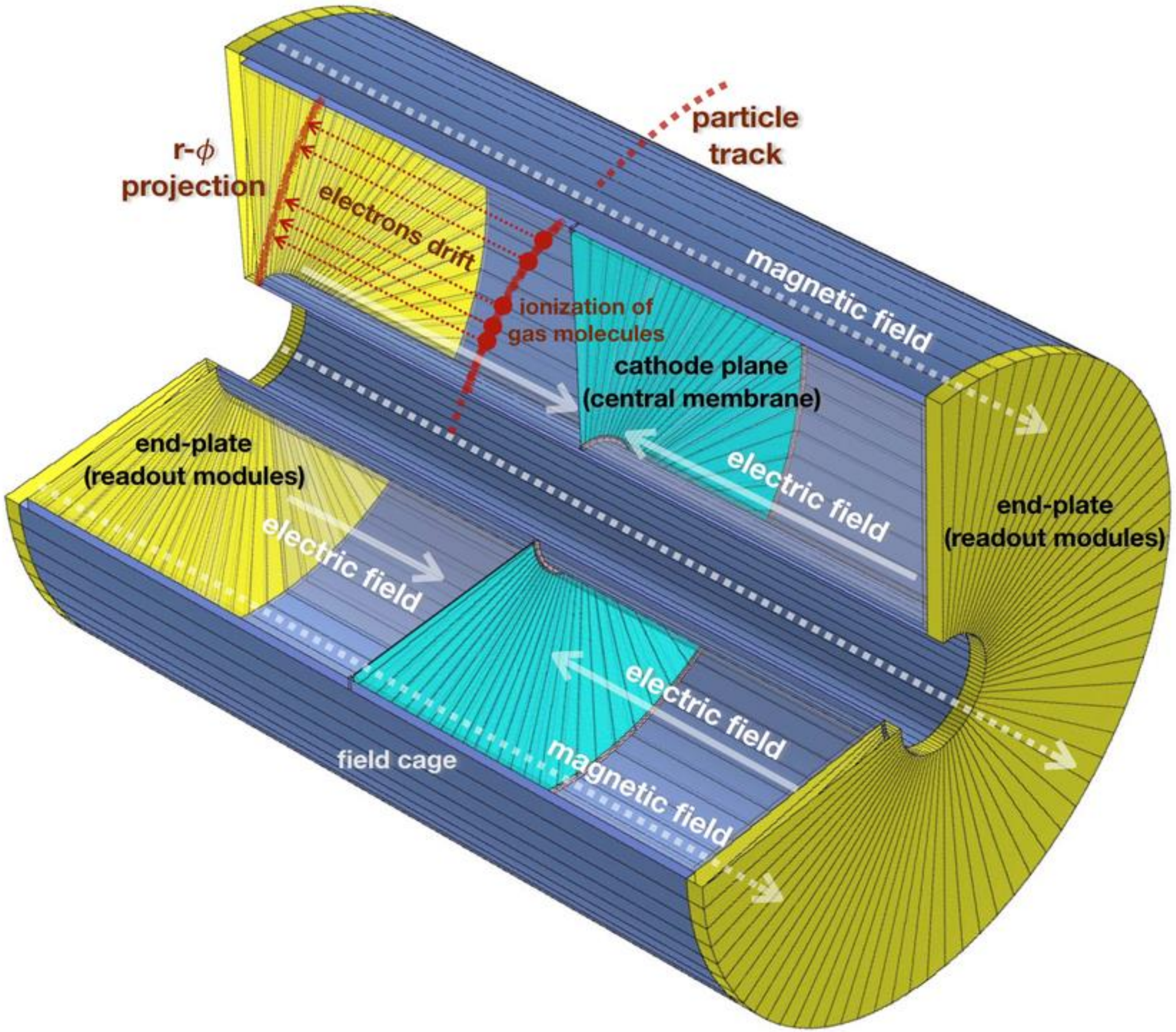
  - Large backscattering particles are produced in the region before LumiCal and transition from signal pipe to double pipe
  - For the TDR, the TID and 1 MeV equ. Neu. Flu. can increase by a factor 50 according to the luminosity
- Beamstrahlung photons
  - move along with beam
    - Without entering the detector
  - Photon energy is low but photon number is huge: 2.82×10^{11} per BX
  - Power for the beamstrahlung photons:469.5 kW per beam
    - Can be deposited in the downstream

Next to do

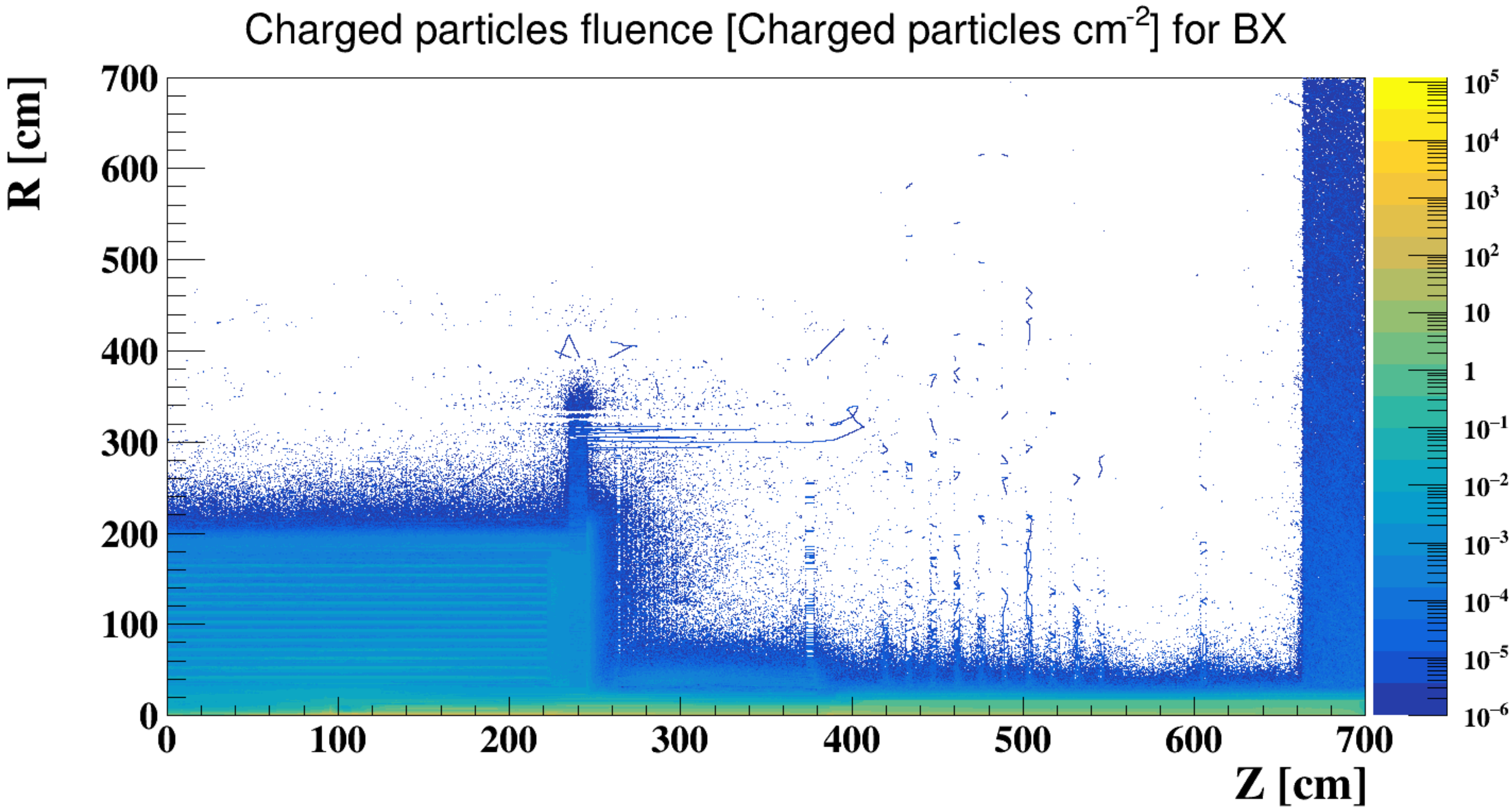
- Next to do
  - Extend background estimation to other sub detector
  - Stop recording the steps which don't enter the detectors
    - Speed up the simulation
    - Save the space
  - Complete simulation for the TDR

Backup

TPC

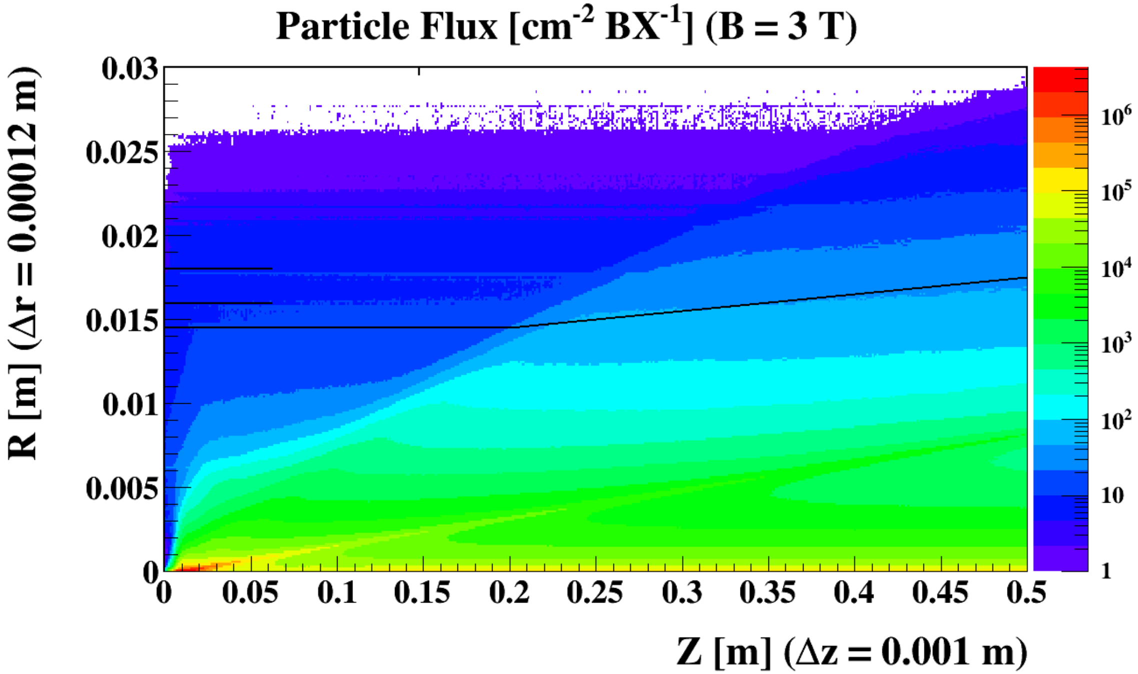

particle
track
r-ϕ
projection
electrons drift
ionization of
gas molecules
magnetic field
cathode plane
(central membrane)
end-plate
(readout modules)
electric field
electric field
end-plate
(readout modules)
electric field
field cage
magnetic field

Pair production

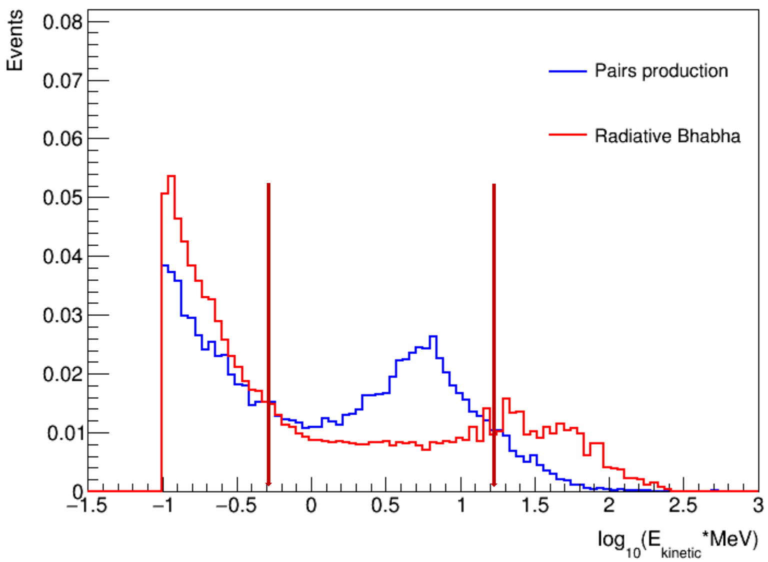


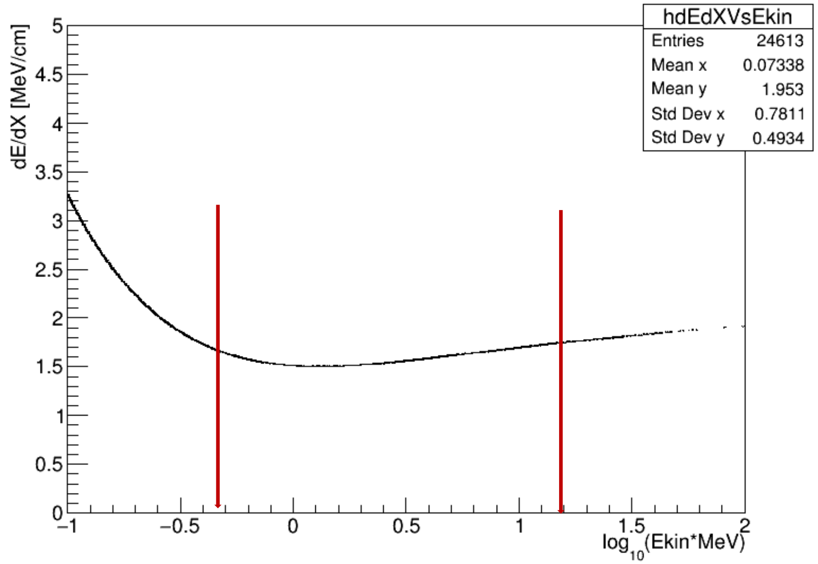
Pair Production

- Primary electrons flux without interaction



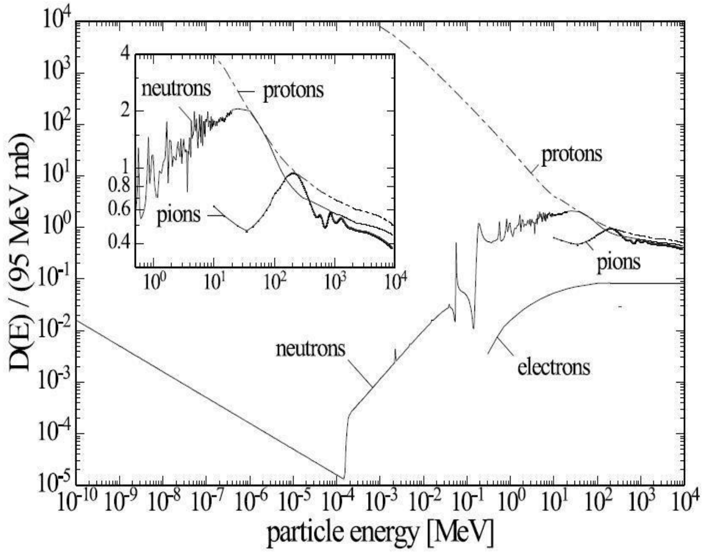
dE/dX and Energy Spectrum





In incoherent pair production, an electron-positron pair is produced via the interaction between two incoming photons, which can be real and/or virtual. There are three incoherent processes, including: the Breit-Wheeler process $\gamma\gamma \rightarrow e^+e^-$, in which both photons are real; the Bethe-Heitler process $e\gamma \rightarrow ee^+e^-$, in which one photon is real and the other is virtual; and the Landau-Lifshitz process $ee \rightarrow eee^+e^-$, in which both photons are virtual. The approximate cross sections of the three processes can be calculated with the formulae in Refs. [8, 12, 13]. In each bunch crossing at CEPC, there will be roughly 44, 327 and 1322 electron-positron pairs produced from the Breit-Wheeler process, the Bethe-Heitler process and the Landau-Lifshitz process, respectively.

Displacement damage



NIEL