# Beam Induced Background at CEPC

Wei Xu（IHEP）

on behalf of the MDI Group

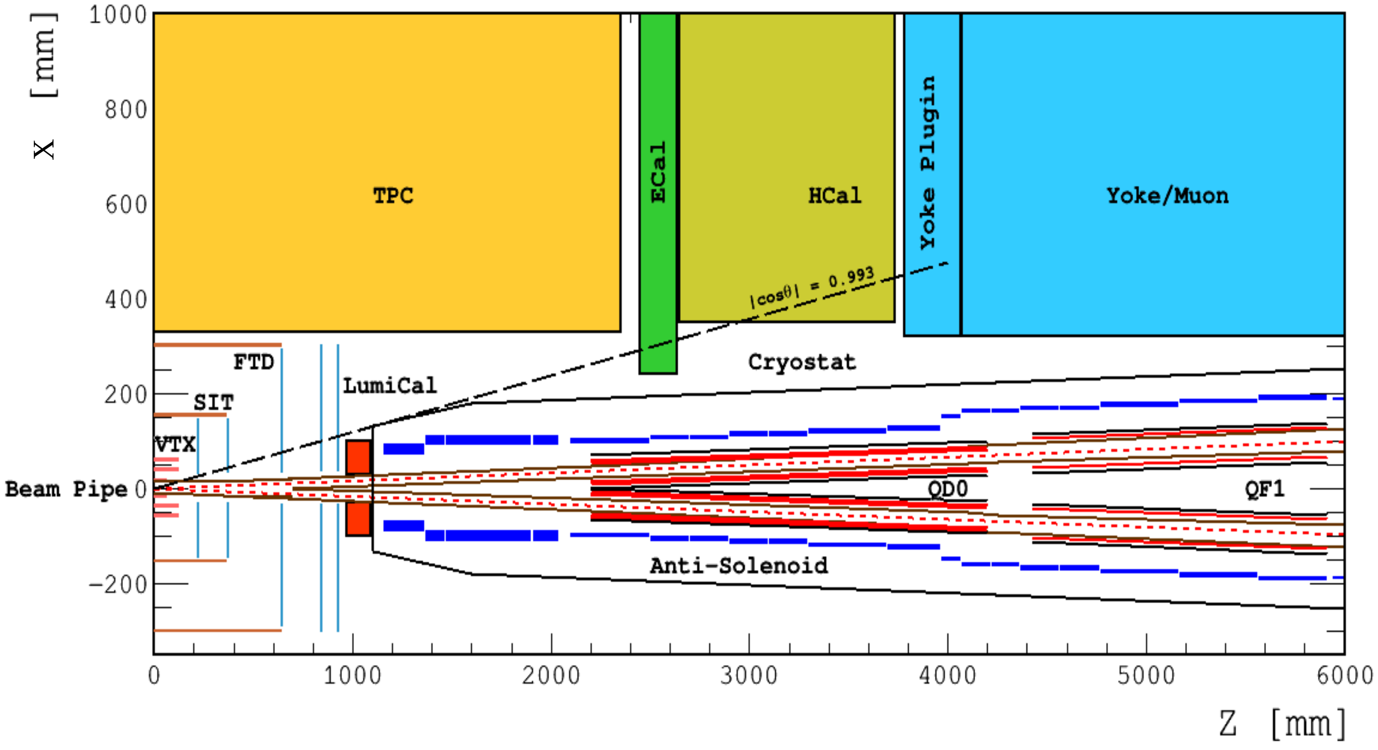
# Outline

- Introduction
  - Interaction region layout
  - Background estimators
- Results of background estimation
  - Pair production
  - Off-energy beam particles
  - Synchrotron radiation
- Conclusion

| | ***Higgs*** | ***W*** | ***Z*** |
|---|---|---|---|
| Number of IPs | 2 | | |
| Energy (GeV) | 120 | 80 | 45.5 |
| Circumference (km) | 100 | | |
| Half crossing angle (mrad) | 16.5 | | |
| $N_e$/bunch ($10^{10}$) | 15 | 15 | 8.0 |
| Bunch number | 242 | 1220 | 12000 |
| $\beta_{IP}$ x/y (m) | 0.36/0.0015 | | 0.2/0.0015 |
| Transverse $\sigma_{IP}$ (um) | 20.9/0.068 | 13.9/0.049 | 5.9/0.078 |
| Bunch length $\sigma_z$ (mm) | 3.26 | 6.53 | 8.5 |
| $L_{max}$/IP ($10^{34}cm^{-2}s^{-1}$) | 2.93 | 11.5 | 16.6 |

# Introduction

- Interaction region is designed for the double ring with crossing angle of $33\ mrad$
  - The vertex detector is sub detector closest to Interaction Point



# Introduction

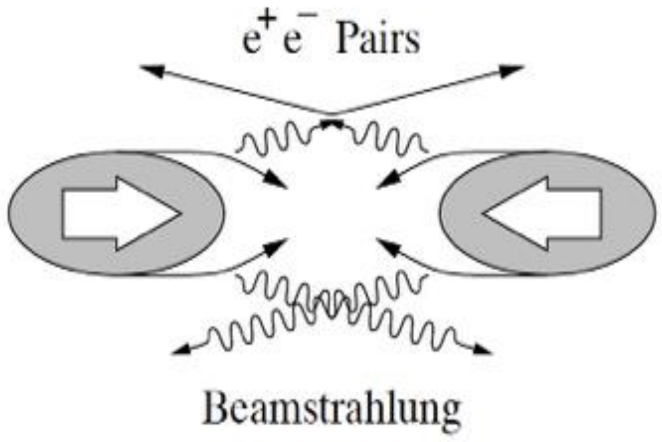
- Background estimators
  - Hit density = $\frac{Number\ of\ hits}{area}\ [hits/BX]$
    - Detector occupancy
  - TID: Total Ionizing Dose= $\frac{E_{deposited}}{M_{detector}}\ [\mathrm{kRad}/year]$
    - Surface damage of silicon devices
  - Displacement damage dose
    - $NIEL \times Fluence = \frac{dE_{non}}{dx\ \rho}\frac{L}{V}$, NIEL abbreviation of Non Ionizing Energy loss
    - $NIEL(1\ MeV, neutron) \times \frac{NIEL(E_k, type)}{NIEL(1\ MeV, neutron)} Fluence$

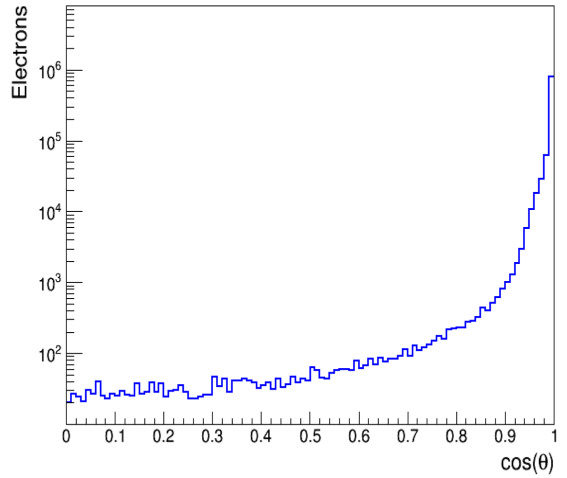
      1 MeV neutron equivalent fluence
    - Bulk damage of silicon devices

A safety factor of 10 is always applied

# Pair production

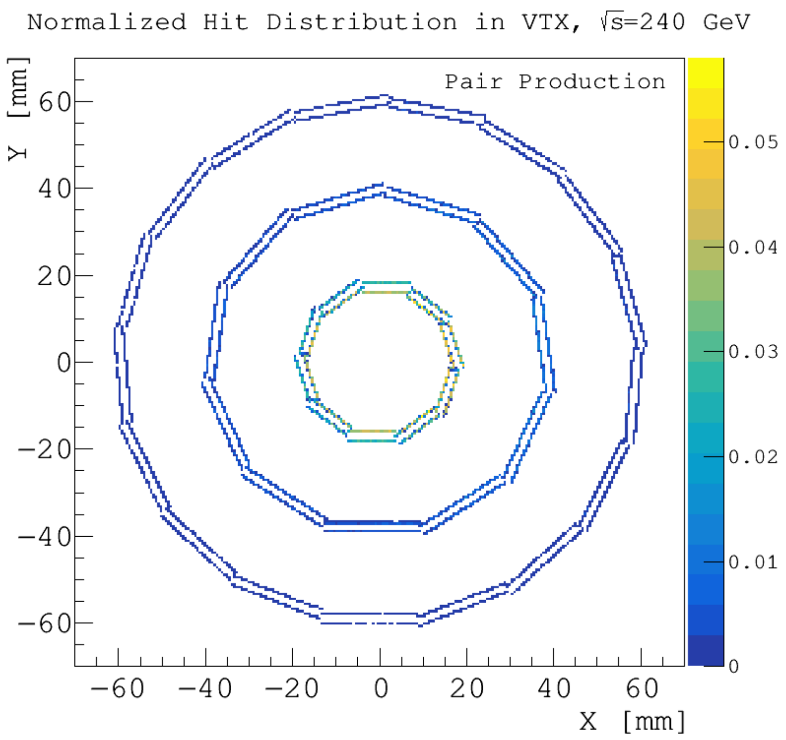
- Pair production in beam-beam interaction
  - Charged particles attracted by the opposite beam can emit photons (beamstrahlung), followed by electron-positron pair production
    - Most electrons/positrons are produced with low energies and in the very forward region, and can be confined within the beam pipe with a strong detector solenoid
  - GUINEA-PIG++ is used to simulate the pairs production process and pairs generated by GUINEA-PIG++ are fed to Mokka to perform a detector simulation



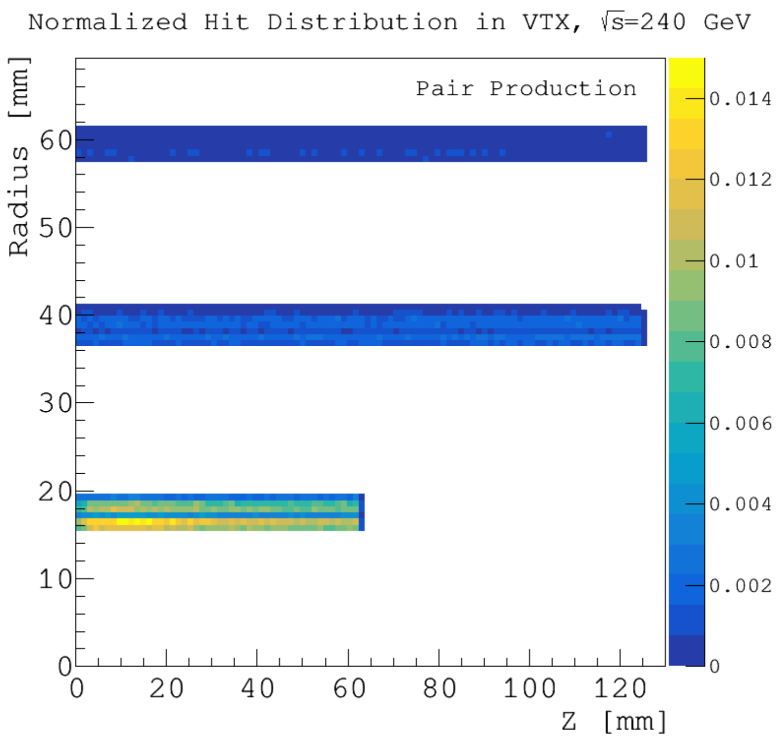



# Pair Production

- Hit map of vertex detector



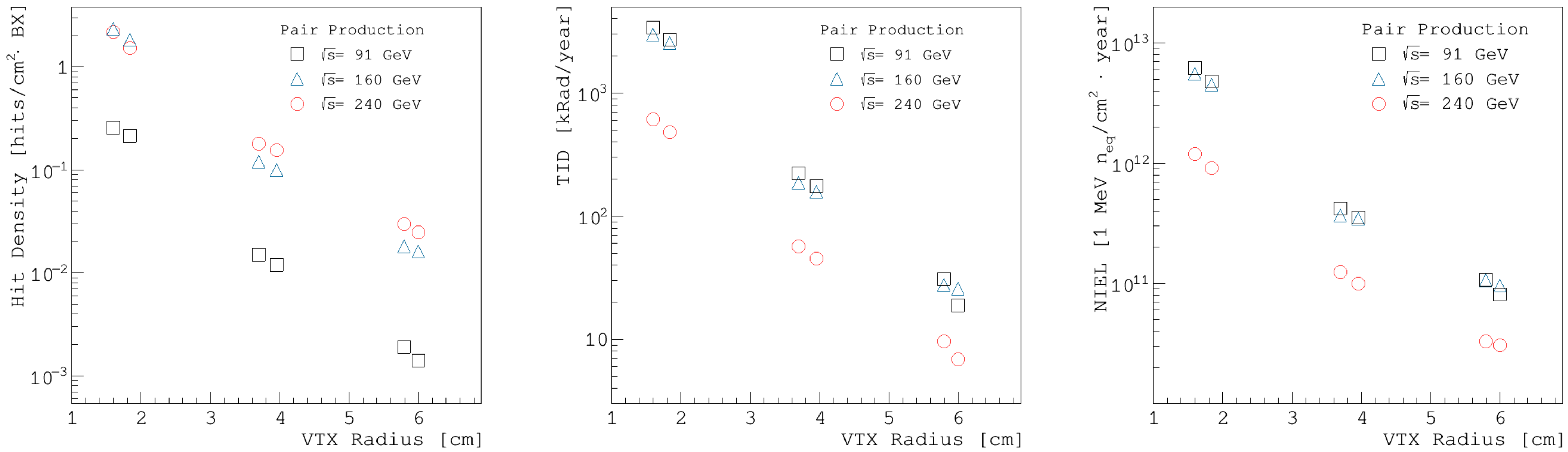

Nearly uniform in the transverse view




More dense in central of first layer

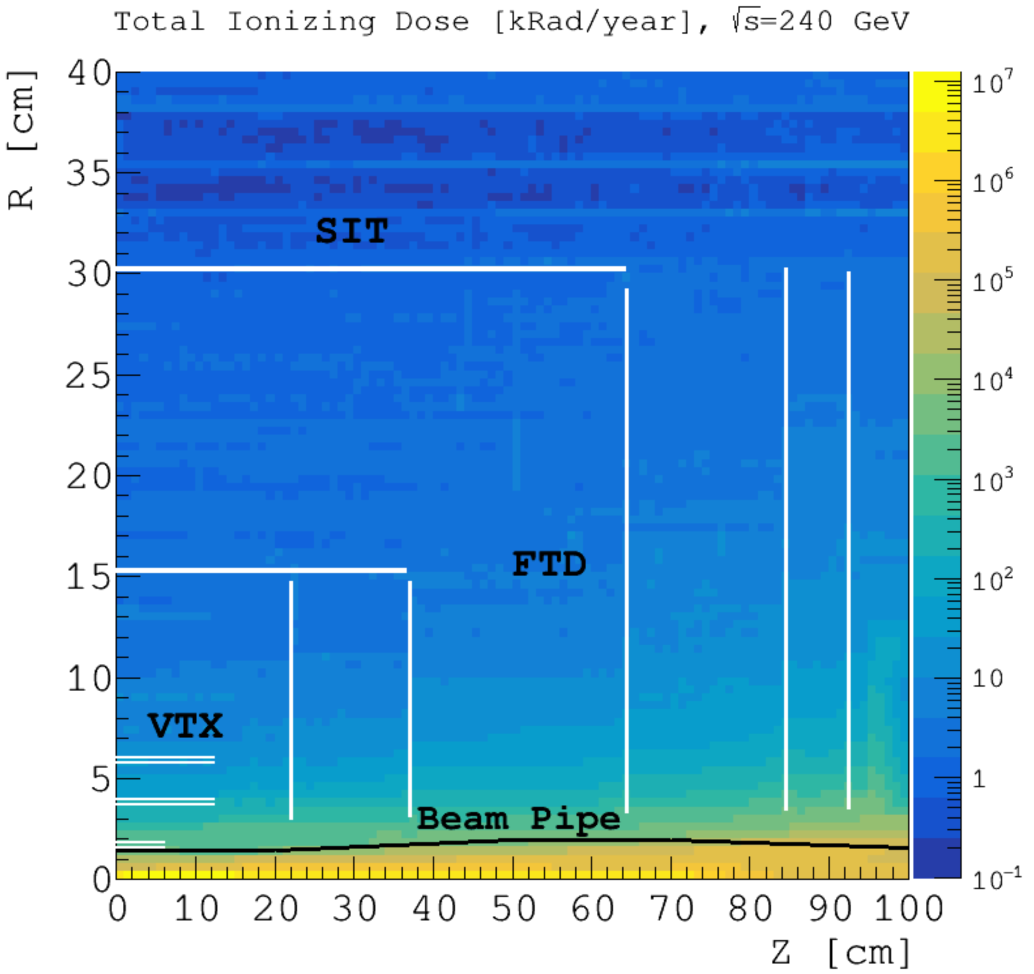
# Results

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

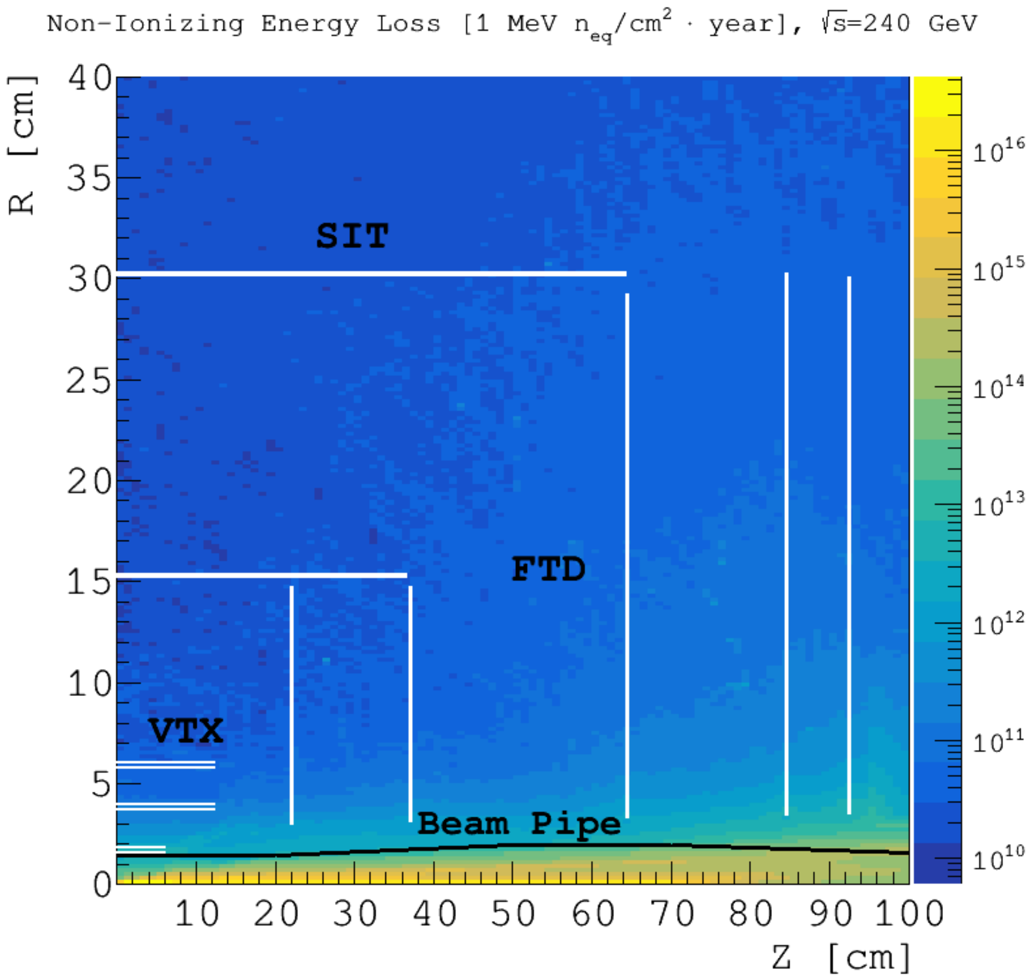



Higgs (240 GeV), W (160 GeV) and Z (91 GeV)

# TID and NIEL



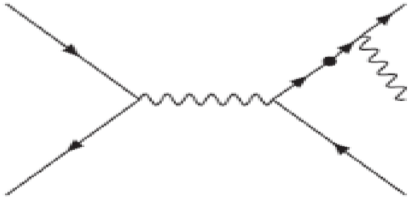
Total Ionizing Dose [kRad/year], √s=240 GeV
R [cm]
Z [cm]
SIT
FTD
VTX
Beam Pipe

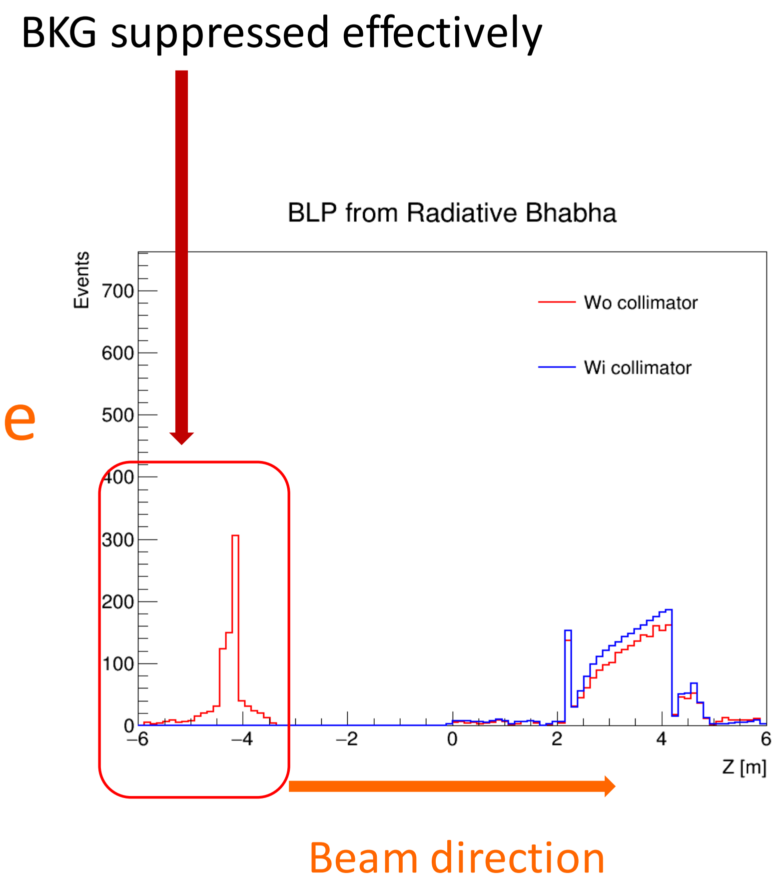
Non-Ionizing Energy Loss [1 MeV n_eq/cm² · year], √s=240 GeV
R [cm]
Z [cm]
SIT
FTD
VTX
Beam Pipe

# Off-energy Beam Particles

- Beam particles lose energy in scattering processes
  - Radiative Bhabha
  - Beam-gas scattering

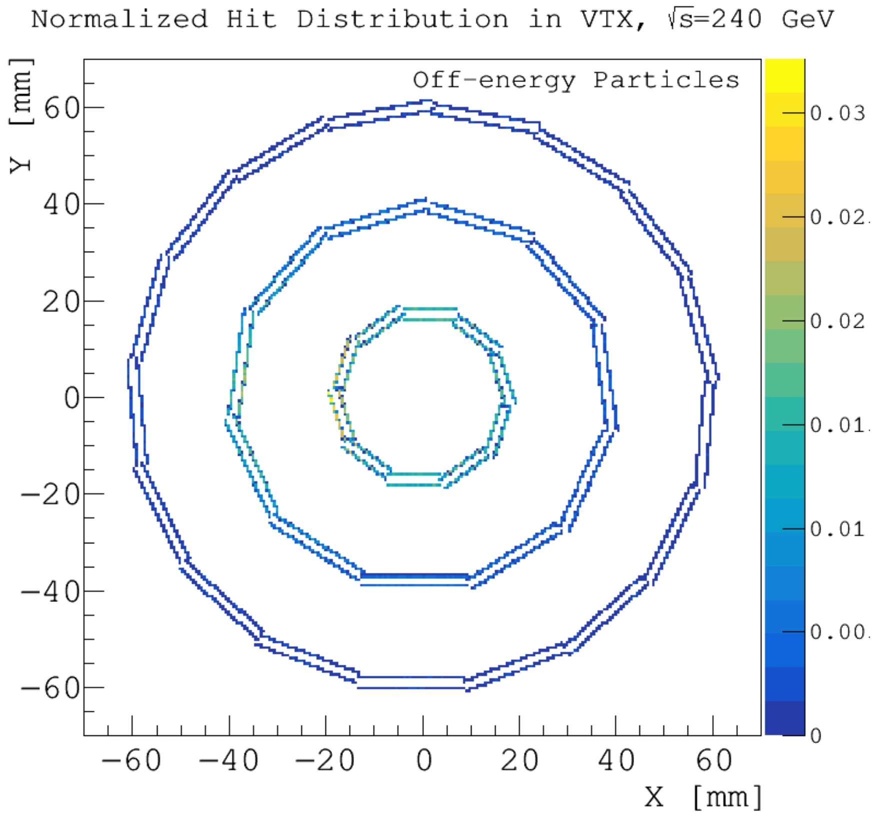


- Beam particles, losing energy larger than 1.5%, are kicked off their orbit and some of them can enter the detector
  - Collimators, placed in the arch region of upstream, are applied to suppress the BKG

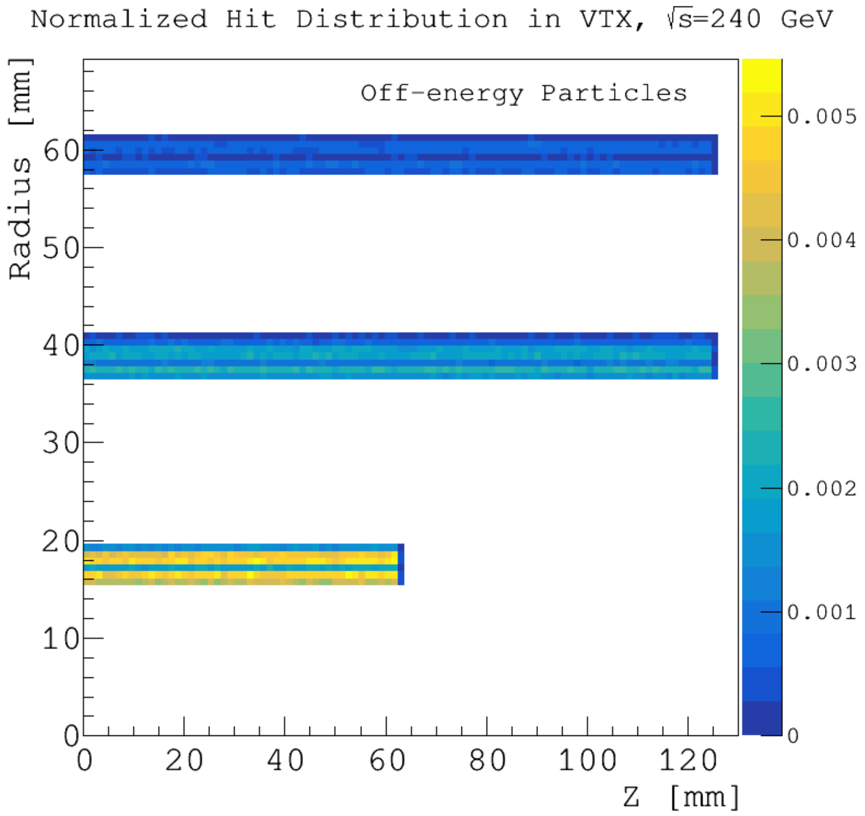


# Off-energy Particles

- Hit map of vertex detector(applying collimators)



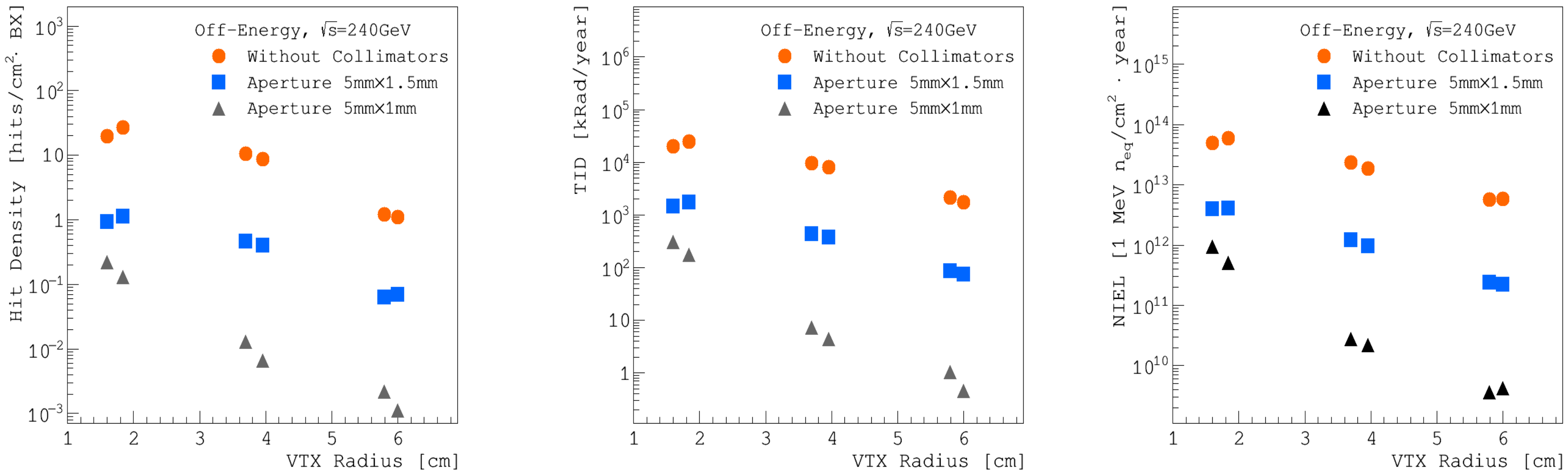

More hits in –X side




More uniform in the z axis compared to pair production

# Results

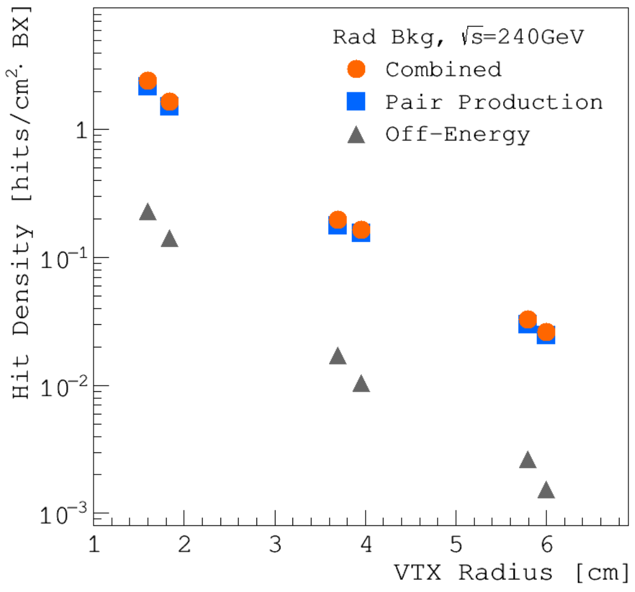
- Off-energy beam particles
  - BKG can be suppressed much by collimators



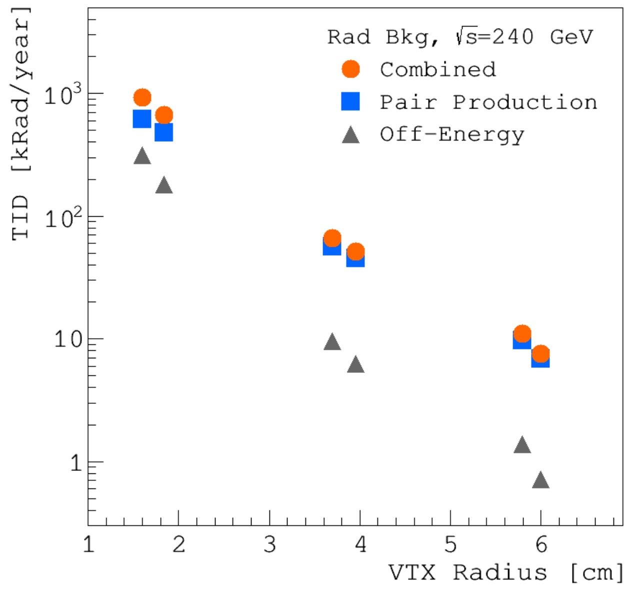
# Combination of BKG.

- Pair production is the main contribution of BKG.

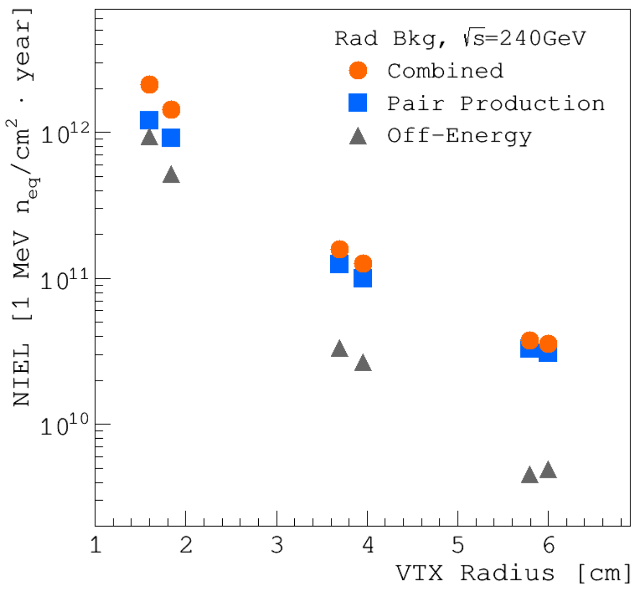
2.4 hits/cm$^2$ per bunch crossing




~ 1 MRad per year




~$2\times10^{12}$ 1MeV $n_{eq}$/cm$^2$ per year

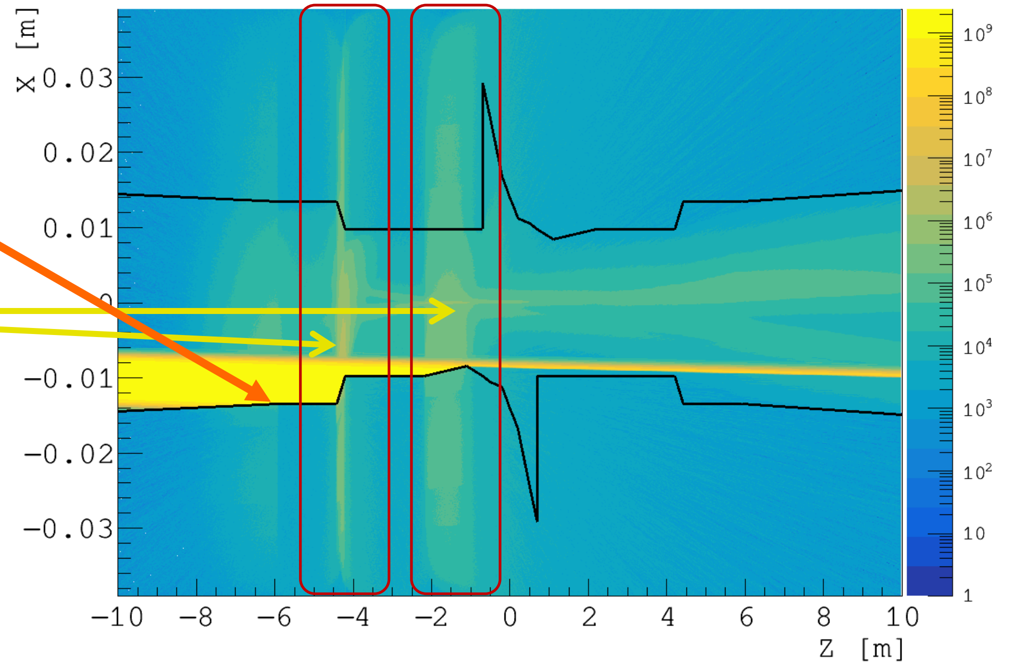


# Synchrotron Radiation

- Bunches emit synchrotron photons while passing through dipole and quadruple
- BDSIM is used in:
  - Bunches transport
  - Synchrotron photons generation/transport
  - Recording the particles hitting the central beryllium beam pipe

- Most of photons enter interaction region caused by dipole
- Synchrotron photons can be scattered into detector due to the interaction with beam pipe
- ~40000 photons hit the central beam pipe per bunch

Tips are introduced to collimate these photons.

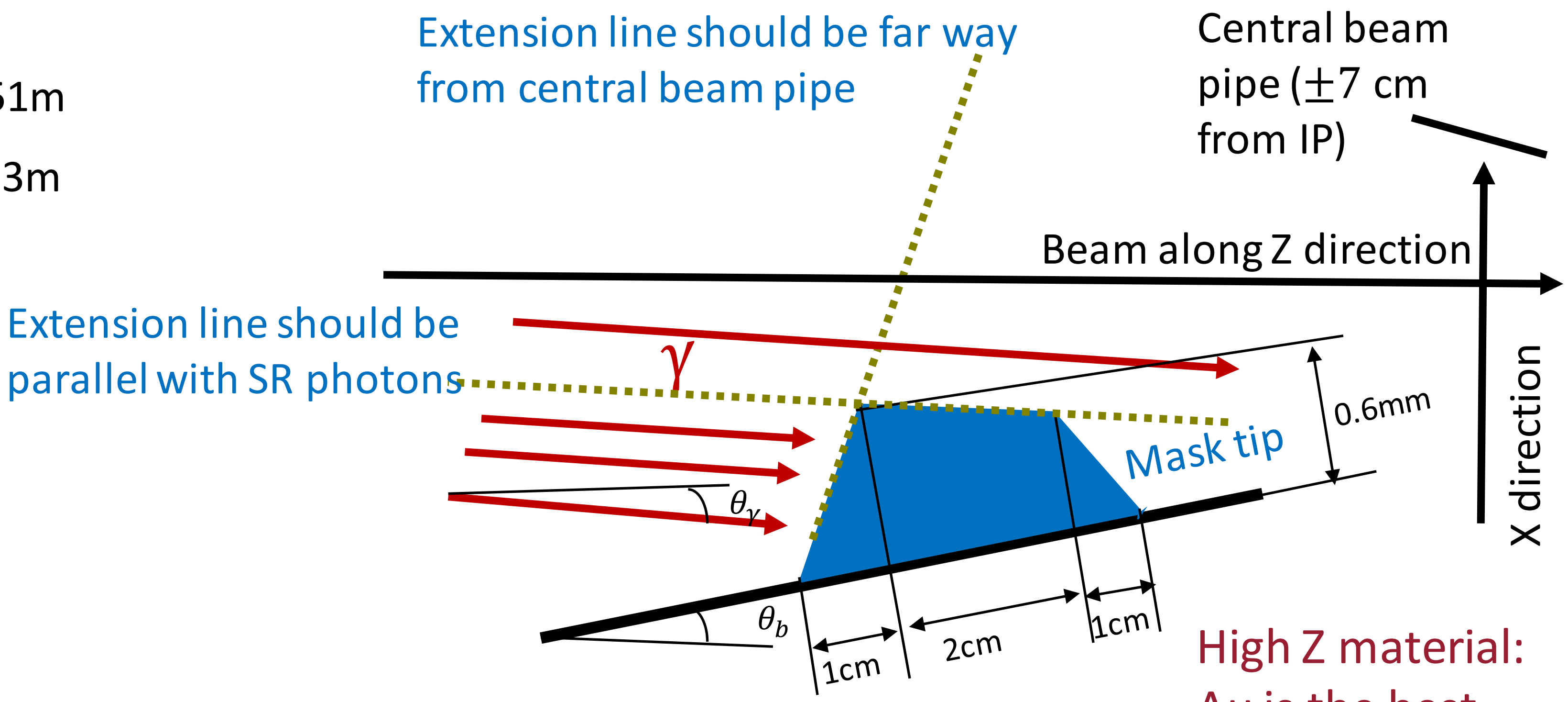


# Mask tips design

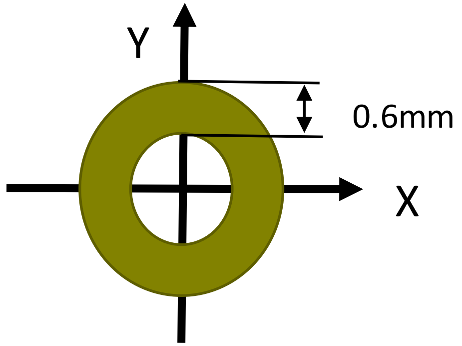
$\theta_b$= 1.17 mrad

$\theta_\gamma = -127 \pm 7\ \mu$rad at Z=-1.51m

$\theta_\gamma = -130 \pm 8\ \mu$rad at Z=-1.93m



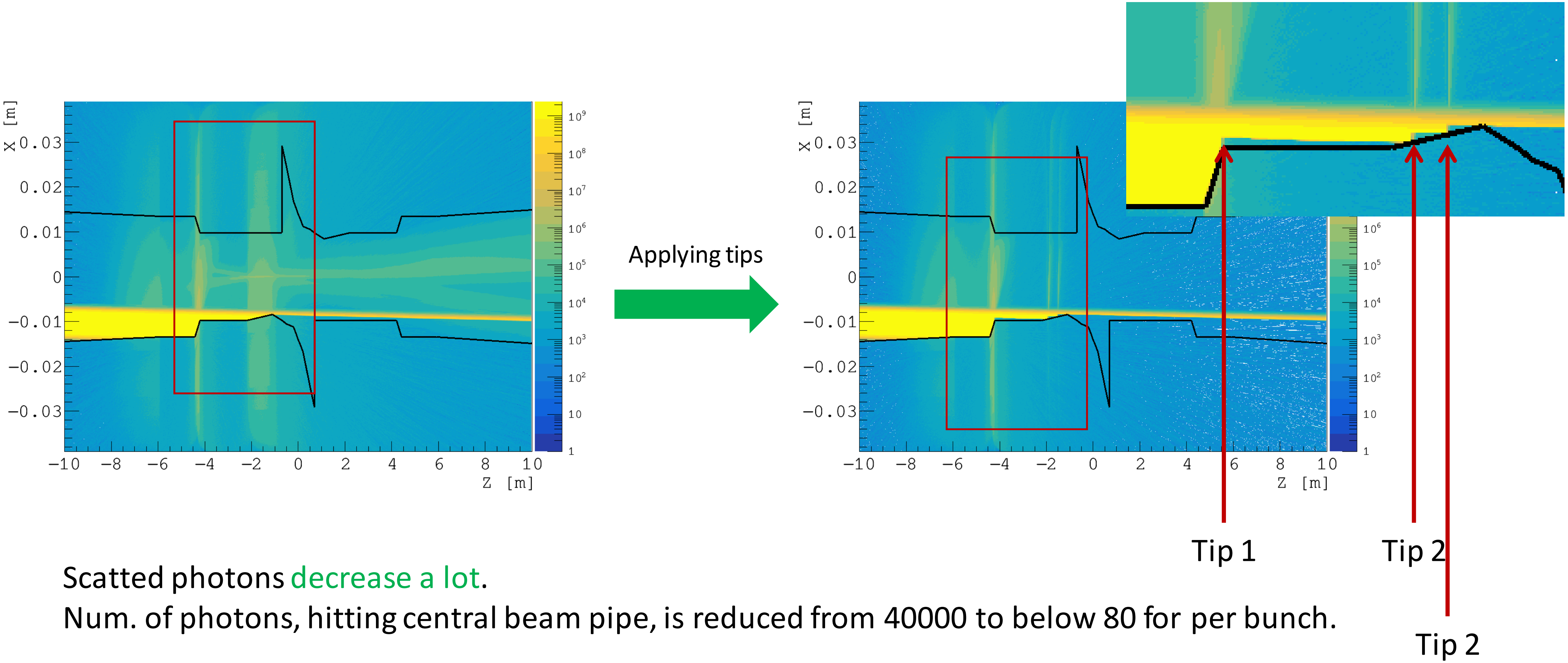

High Z material: Au is the best.




Mask tip at X-Y plane: a ring

# With Collimation

- 3 tips are placed at 1.51, 1.93 and 4.2 m to IP along beam pipe




Scatted photons decrease a lot.

Num. of photons, hitting central beam pipe, is reduced from 40000 to below 80 for per bunch.

# Conclusion

- Pair production && off-energy beam particles

  - BKG at fist layer of vertex detector

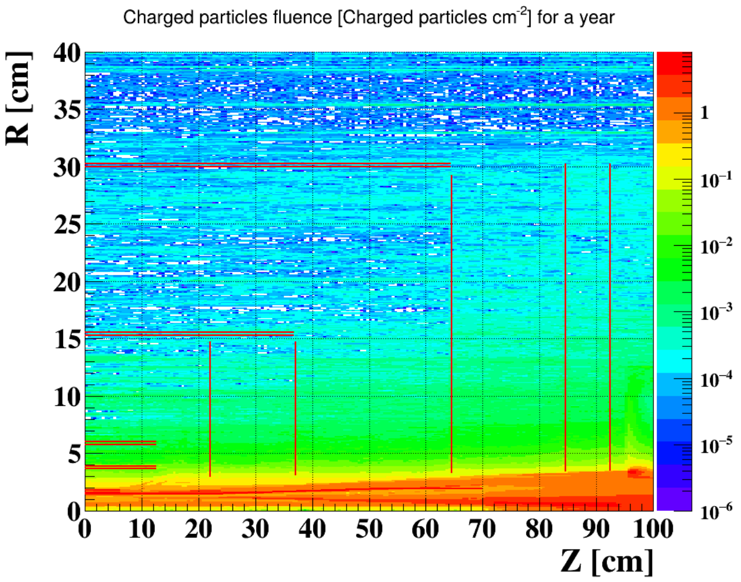
| | H (240) | W (160) | Z (91) |
|---|---|---|---|
| Hit Density [hits/cm$^2$·BX] | 2.4 | 2.3 | 0.25 |
| TID [MRad/year] | 0.93 | 2.9 | 3.4 |
| NIEL [$10^{12}$ 1MeV $n_{eq}$/cm2·year] | 2.1 | 5.5 | 6.2 |

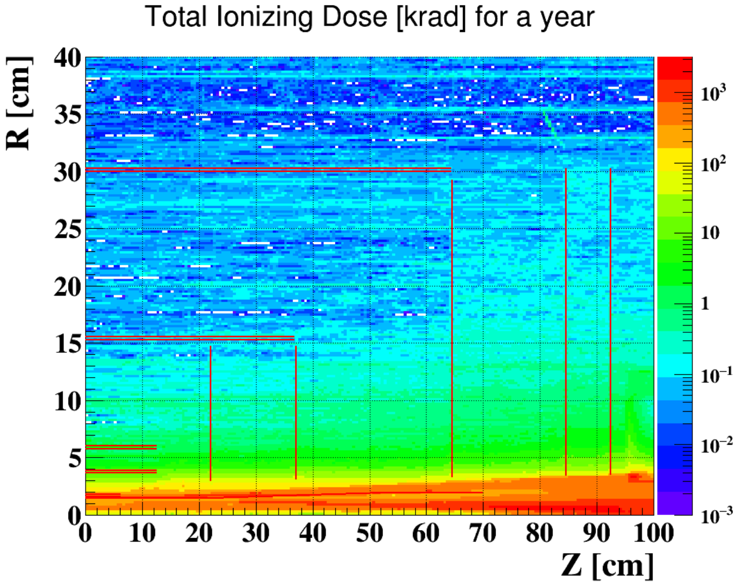
- Synchrotron radiation
  - After applying 3 tips, BKG from synchrotron radiation is suppressed effectively by three orders of magnitude

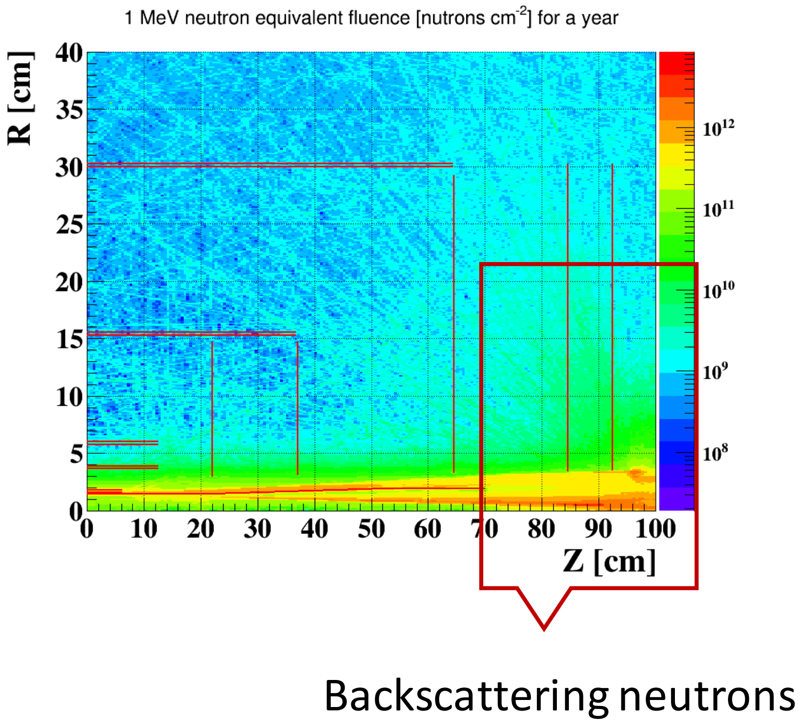
# Backup

# Estimation of BKG from  Lost Particles

- Result for Beam Lost Particles from Radiative Bhabha(Higgs mode) applied collimators

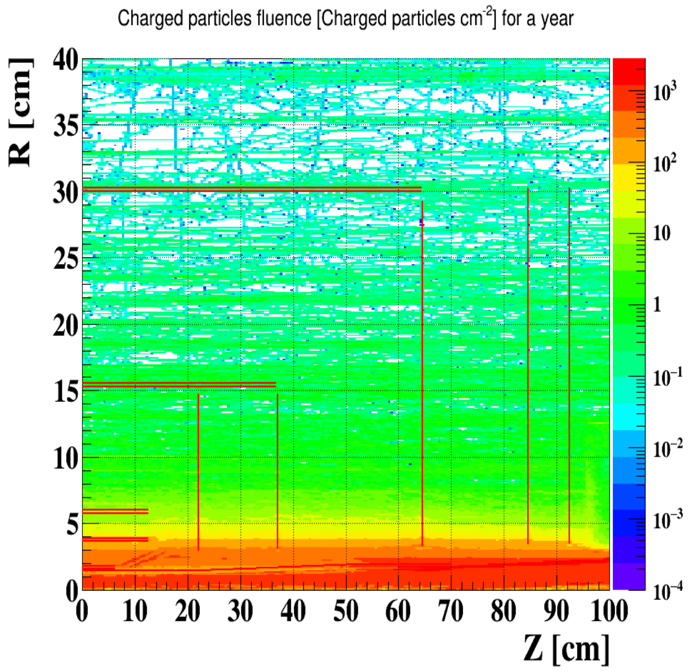


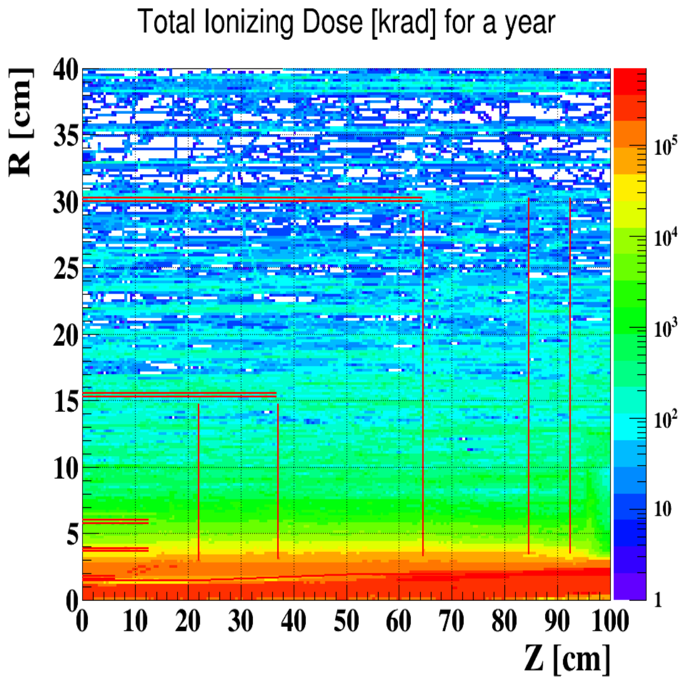



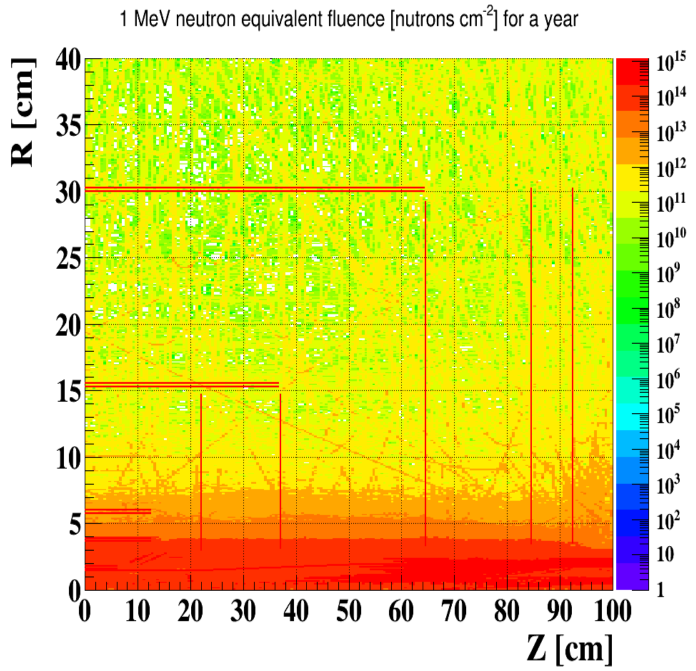



# Estimation of BKG from Lost Particles

- Result for Beam Lost Particles from Radiative Bhabha(Higgs mode) without collimators

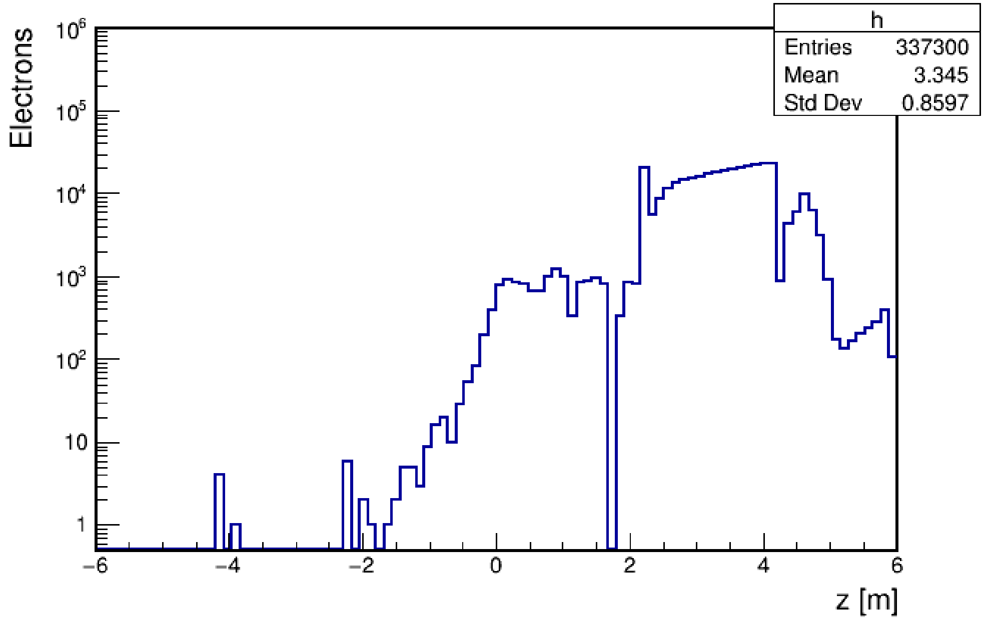


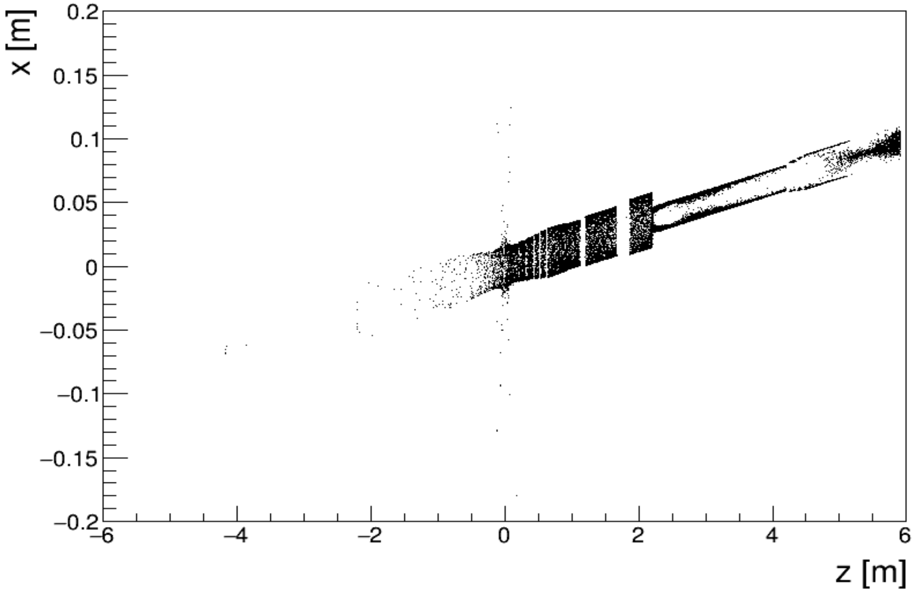



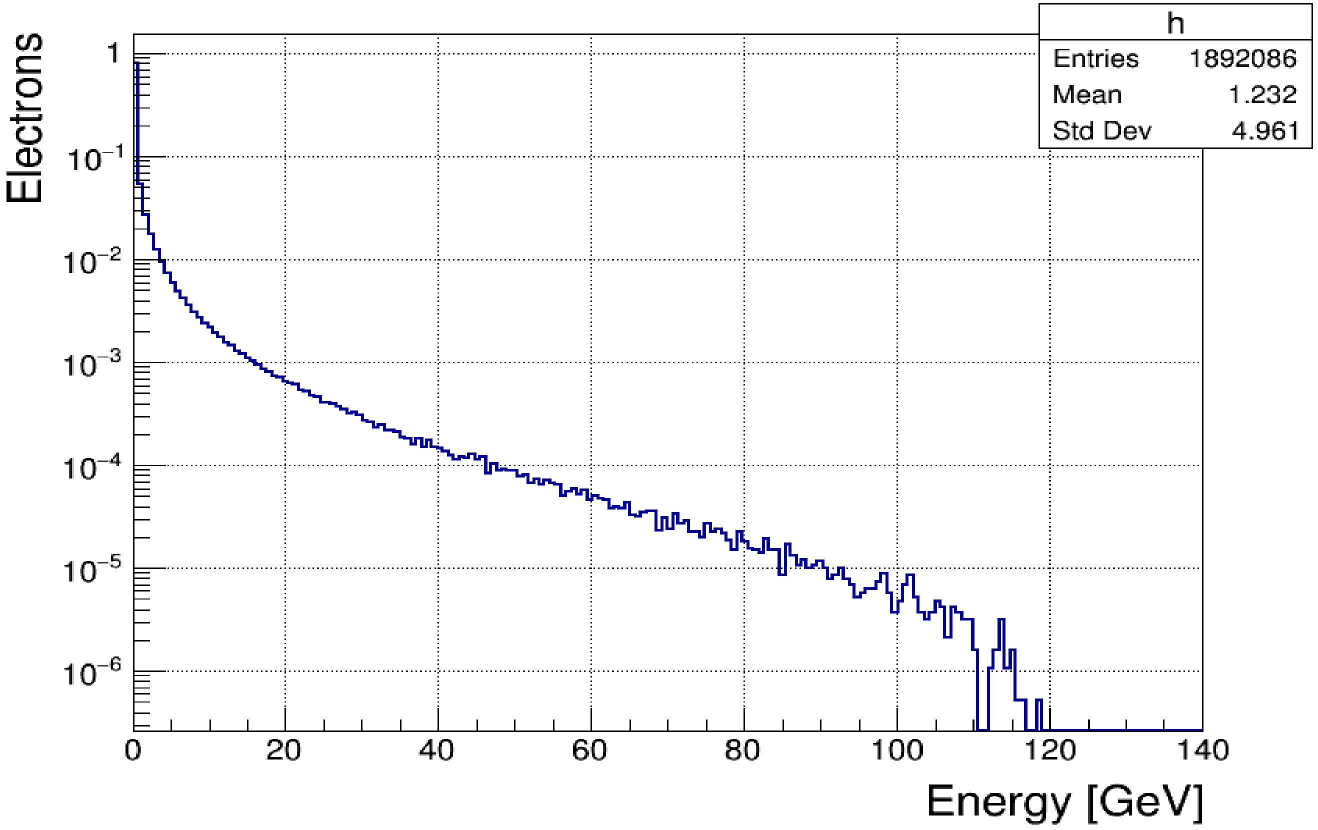
# Lost Position for Radiative Bhabha

- Using collimator [5mm, 1mm]



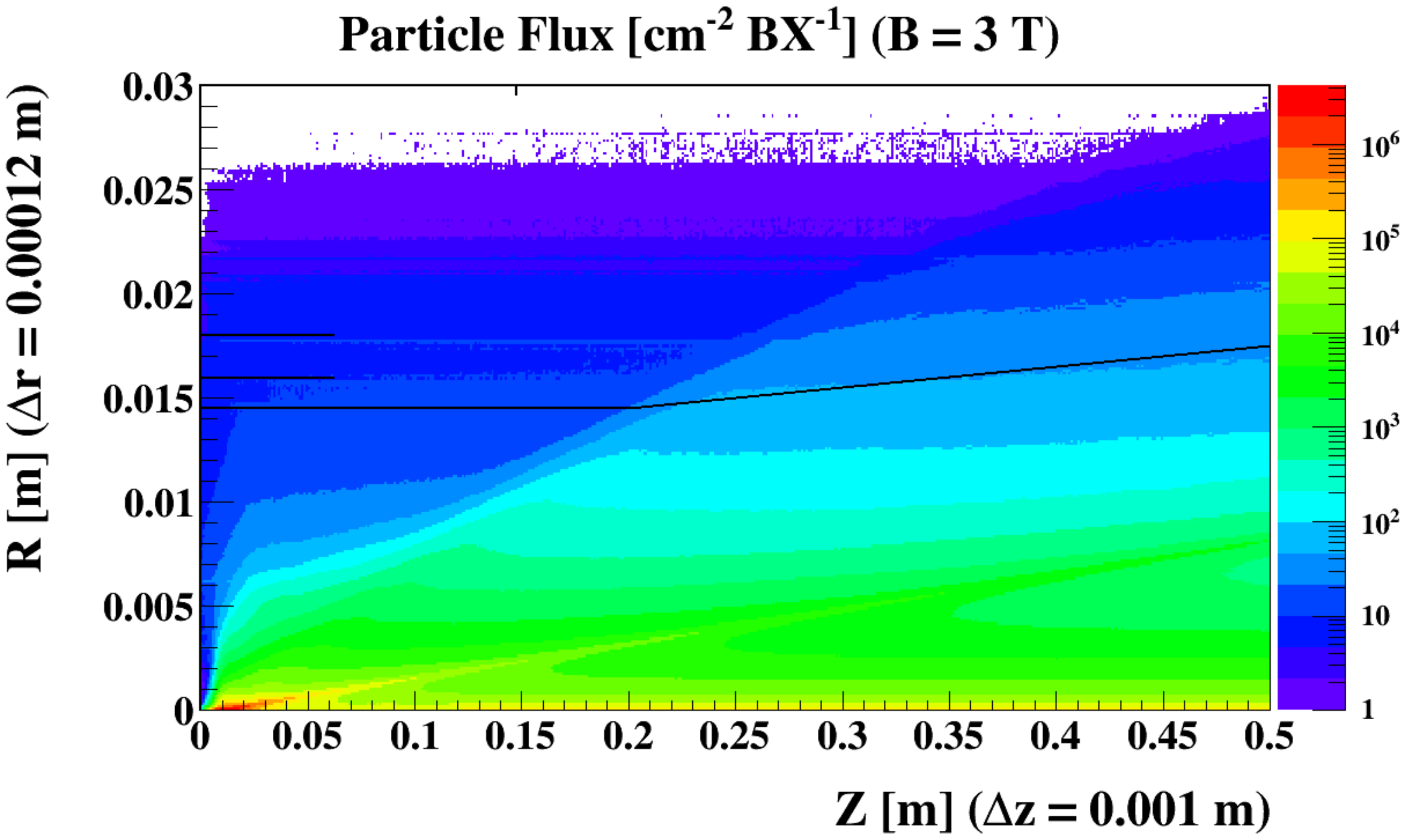
# Energy spectrum of pair production



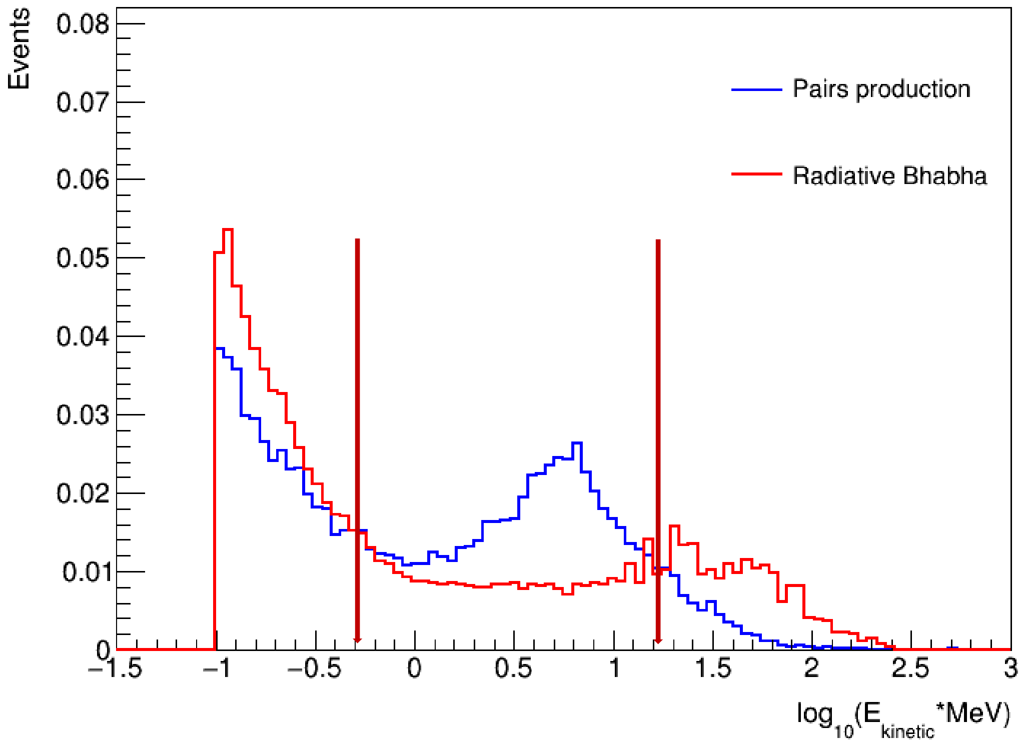

84.35 %

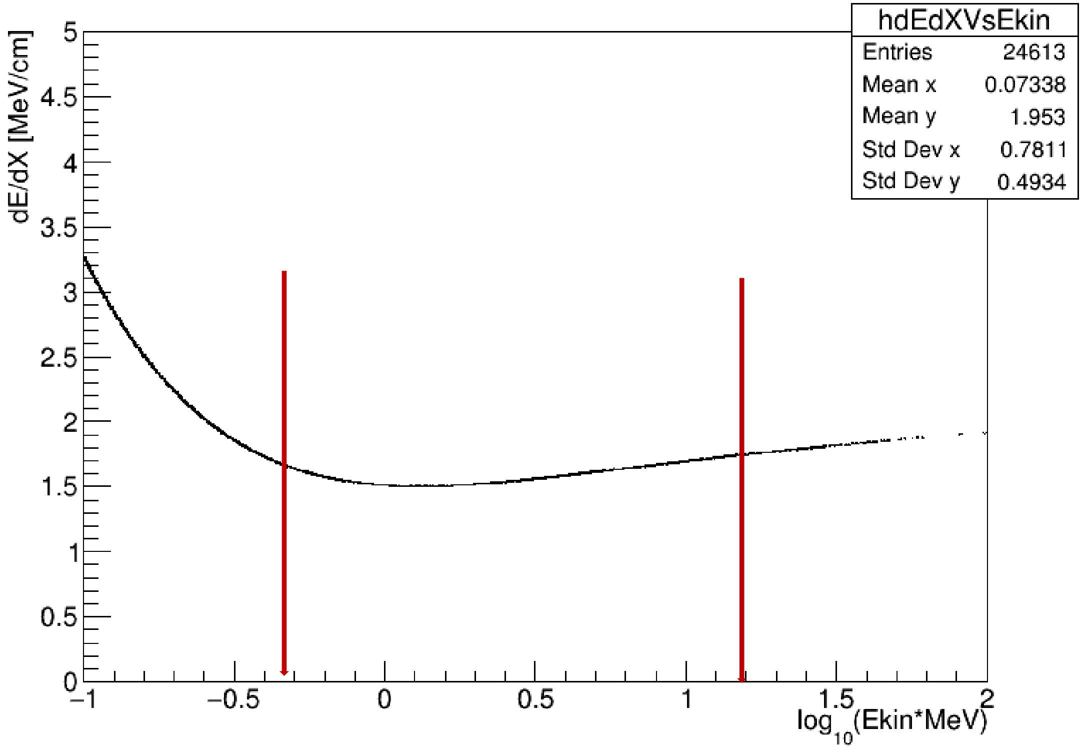
# Pair Production

- Primary electrons flux without interaction



# $dE/dX$ and Energy Spectrum



# Displacement damage

physical quantities

## Non Ionising Energy Loss (NIEL)

**BULK DAMAGE is proportional to total kinetic energy (K.E.) into DISPLACING atoms (silicon)**

- damage $\propto$ Kinetic Energy gone to DISPLACEMENT
- damage scales with particle fluence $\phi$

**displacement damage dose (DDD)** $= \frac{\text{KERMA}}{\text{mass}} \propto \phi$

KERMA $\equiv$ K.E. imparted by radiation into displacement
total Kinetic Energy Released in MAtter (silicon)

$$\text{DDD} = \frac{\text{KERMA}}{\text{mass}} = \text{NIEL} \times \phi$$

units: NIEL(MeV-cm$^2$/mg) = NIEL(keV-cm$^2$/g) $\times$ 10$^3$

KERMA (keV) = NIEL(keV-cm$^2$/g) $\times$ $\phi$(cm$^{-2}$) $\times$ mass(g)

**KERMA (MeV) = NIEL(MeV-cm$^2$/mg) $\times$ $\phi$(cm$^{-2}$) $\times$ mass(g) $\times$ 10$^3$**

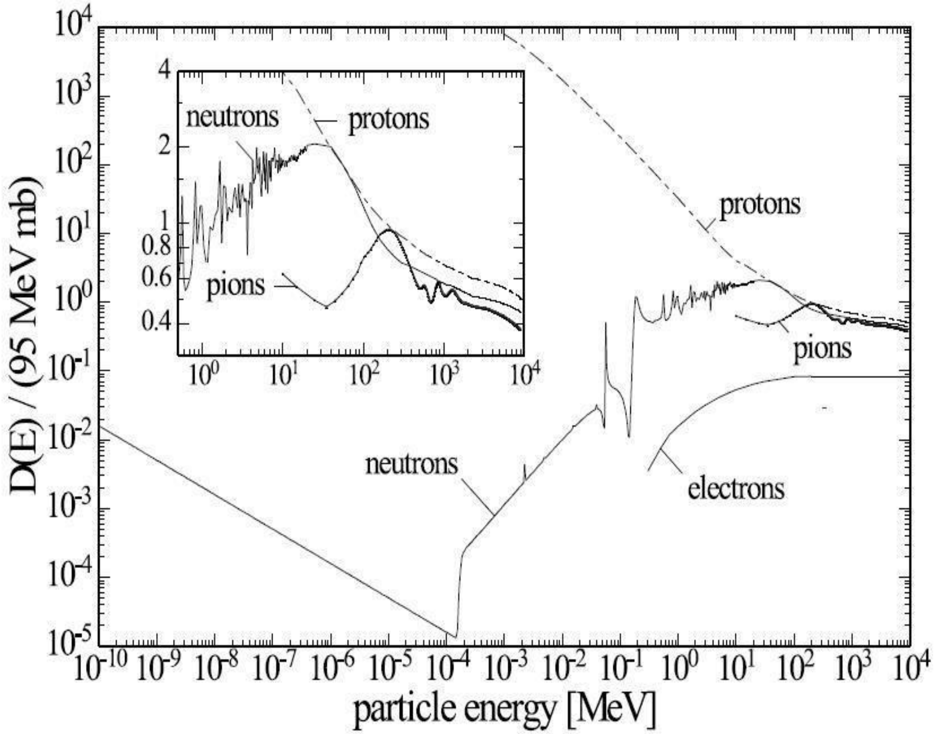
$$DDD = \frac{KERMA}{\text{mass}}$$

$$= \frac{dE_{non}}{dx}\frac{L}{\text{mass}}$$

$$= \frac{dE_{non}}{dx\,\rho}\frac{L}{V}$$

$$= NIEL \times \Phi$$

# Displacement damage




NIEL

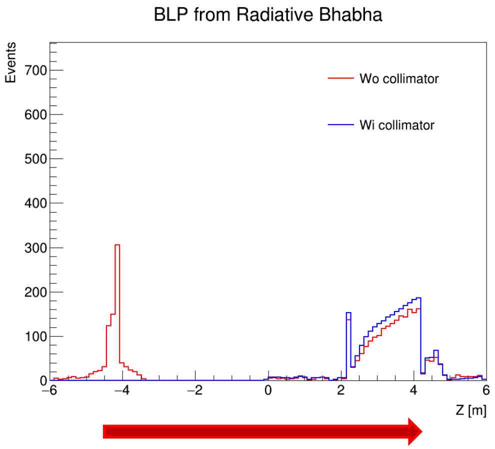
# Pairs production

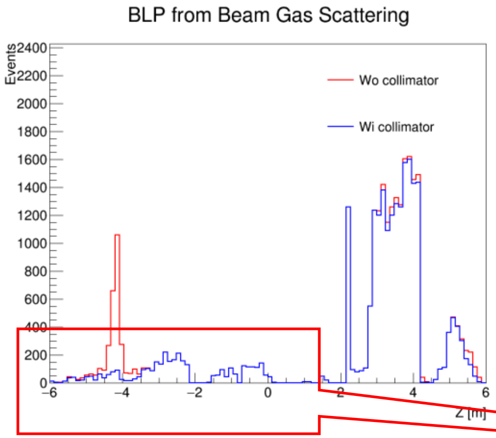
- Background source for vertex detector
  - Layer 1
    - Primary particles Ratio:77.9241%
    - Beam pipe wall( conic, Cu) Ratio:5.30339%
    - Beam pipe wall( conic, before QD0, Fe) Ratio:3.79821%
    - Foam Space( SiC, sandwiched between two layer of VTX ) Ratio:2.92411%
    - VXD Ratio:2.38319%
    - Beam pipe wall( Cylindrical, Cu, z:50~70cm) Ratio:1.54829%
    - Flex Cable Ratio:1.52085%
    - Lumical Ratio:0.84666%
  - Layer 3
    - Primary particles Ratio:47.7716%
    - Beam pipe wall( conic, before QD0, Fe) Ratio:14.2433%
    - Beam pipe wall( Cylindrical, Cu, z:50~70cm) Ratio:10.3714%
    - Lumical Ratio:8.96936%
    - Foam Space( SiC, sandwiched between two layer of VTX ) Ratio:3.96472%
    - VXD Ratio:2.98979%
    - Beam pipe wall( conic, before QD0, Fe) Ratio:2.65552%
    - Flex Cable Ratio:2.32126%
    - Beam pipe wall( conic, before QD0, Fe) Ratio:1.88487%
    - Tube Flange Ratio:0.909935%

- 
  - Layer 1
    - Primary particles Ratio:43.6701%
    - Lumical Ratio:12.0412%
    - Beam pipe wall( Cylindrical, Cu, z:50~70cm) Ratio:9.60825%
    - Beam pipe wall( conic, before QD0, Fe) Ratio:6.68041%
    - Foam Spacer Ratio:4.74227%
    - VXD Ratio:4%
    - Flex Cable Ratio:3.6701%
    - Metal Traces Ratio:3.58763%
    - beam pipe (Cu, conic z:20~50)Ratio:2.96907%
    - End plate of VXD shell Ratio:1.73196%
    - Tube Flange Ratio:1.27835%
    - FTD Ratio:1.07216%
    - FTD Petal Support Ratio:0.989691%

# Estimation of BKG from Lost Particles

- Result for Beam Lost Particles from Beam Gas Scattering(W) ;
- Much large cross section compared to RBB
  - Cross section of Beam Gas Scattering : $6.392 \times 10^{-28}\ m^2$
  - Cross section of Radiative Bhabha :$1.628 \times 10^{-29}\ m^2$
- Only collimator design for Radiative Bhabha applied;




Beam direction

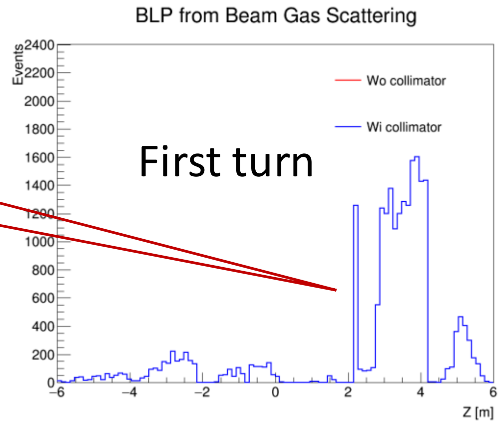
| Layer | Charged particles passing through VXD ($cm^{-2}BX^{-1}$) | TID ($kRad\ yr^{-1}$) |
|---|---|---|
| 1 | 31774 | 7.10314e+07 |
| 2 | 29934.8 | 6.61845e+07 |
| 3 | 3453.12 | 8.0779e+06 |
| 4 | 2923.65 | 7.08519e+06 |
| 5 | 566.16 | 1.27771e+06 |
| 6 | 550.369 | 1.26349e+06 |

Too heavy to accept!

Need collimator to eliminate.

# Beam Lost Particles from Beam Gas Scattering(W)

There is no difference between using and not using collimator because in the first turn the lost electron would not see the collimator.



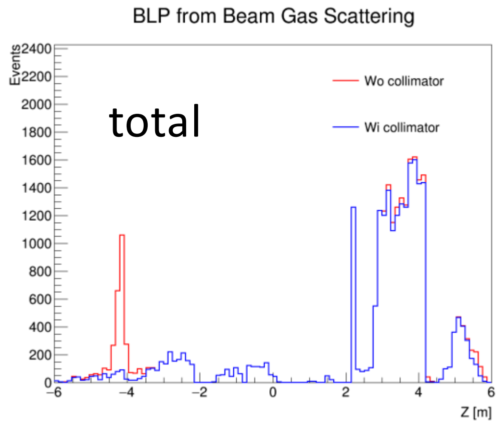

Background is too heavy to accept

| Layer | Charged particles passing through VXD ($cm^{-2}BX^{-1}$) | TID ($kRad\ yr^{-1}$) |
|---|---|---|
| 1 | 34260.1 | 7.64383e+07 |
| 2 | 32580.8 | 7.19559e+07 |
| 3 | 3959.89 | 9.22268e+06 |
| 4 | 3343.98 | 8.07252e+06 |
| 5 | 659.302 | 1.4876e+06 |
| 6 | 642.338 | 1.48764e+06 |

Table 1: without using collimator

| Layer | Charged particles passing through VXD ($cm^{-2}BX^{-1}$) | TID ($kRad\ yr^{-1}$) |
|---|---|---|
| 1 | 31774 | 7.10314e+07 |
| 2 | 29934.8 | 6.61845e+07 |
| 3 | 3453.12 | 8.0779e+06 |
| 4 | 2923.65 | 7.08519e+06 |
| 5 | 566.16 | 1.27771e+06 |
| 6 | 550.369 | 1.26349e+06 |

Table 2:collimator designed for RBB applied




- Cross section: $6.392 \times 10^{-28}\ m^2$(RBB:$1.628 \times 10^{-28}\ m^2$,BTH: $6.397 \times 10^{-28}\ m^2$)
- Lost electrons per BX: $\frac{L \cdot \sigma}{f} = 200980.570, L = 11.5 \times 10^{34} cm^{-2} s^{-1}, f = \frac{c}{n_{bunch\,number} / C_{circumference}}$
- Number of electrons Lost in IR wi. Collimator : 25604.618
- Number of electrons Lost in IR wo. collimator : 22511.044