Beam Induced Background at CEPC

Wei Xu（IHEP）

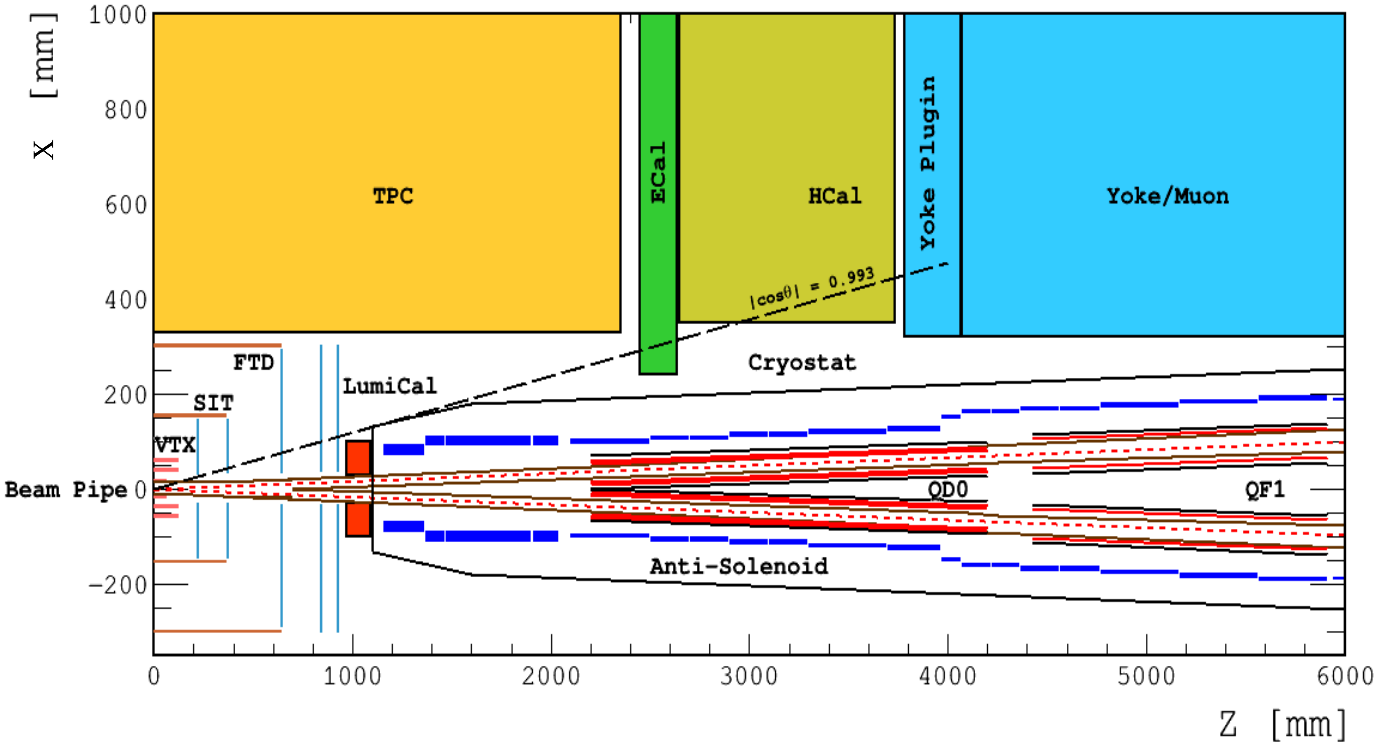
on behalf of the MDI Group

Outline

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

Interaction Region

- designed for the double ring with a crossing angle of 33 $mrad$
  - The vertex detector is the sub detector closest to the beams
    - Suffers the background most



Estimators

- 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
    - $NIEL(1\ MeV, neutron) \times \frac{NIEL(E_k, type)}{NIEL(1\ MeV, neutron)} Fluence$

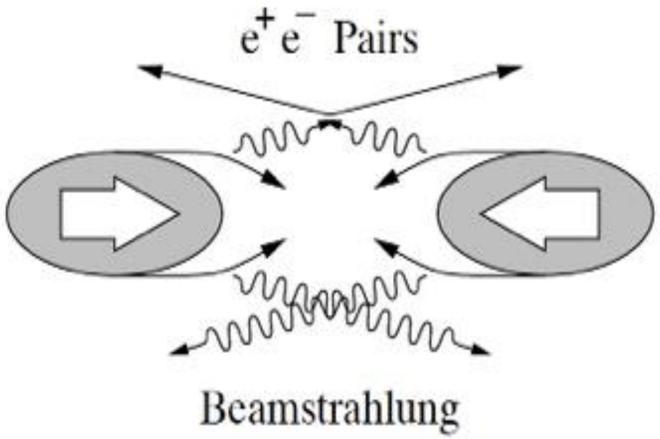
      1 MeV equivalent neutron fluence

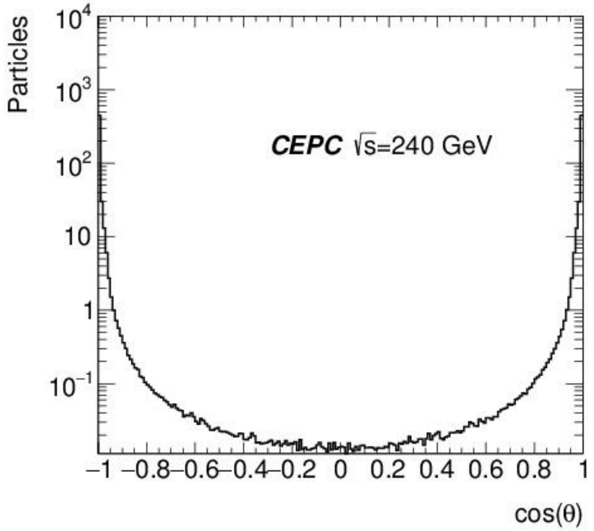
    - Bulk damage of silicon devices

A safety factor of 10 is always applied

Pair production

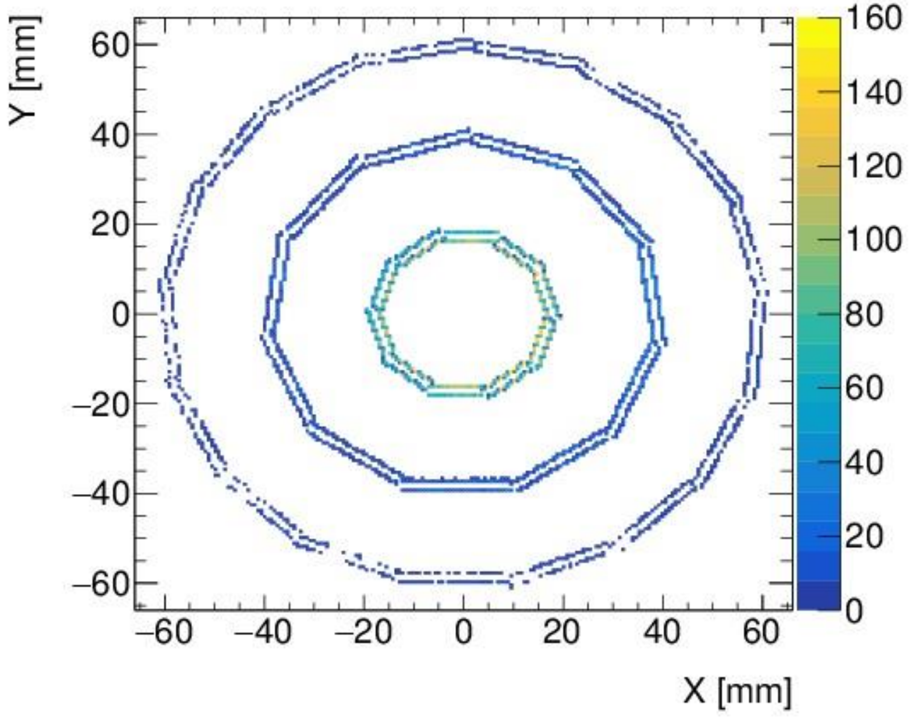
- Pair production in beam-beam interaction
  - Charged particles attracted by the opposite beam can emit photons (beamstrahlung), followed by electron-positron pair production
    - Most electrons/positrons are produced with low energies and in the very forward region, and can be confined within the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



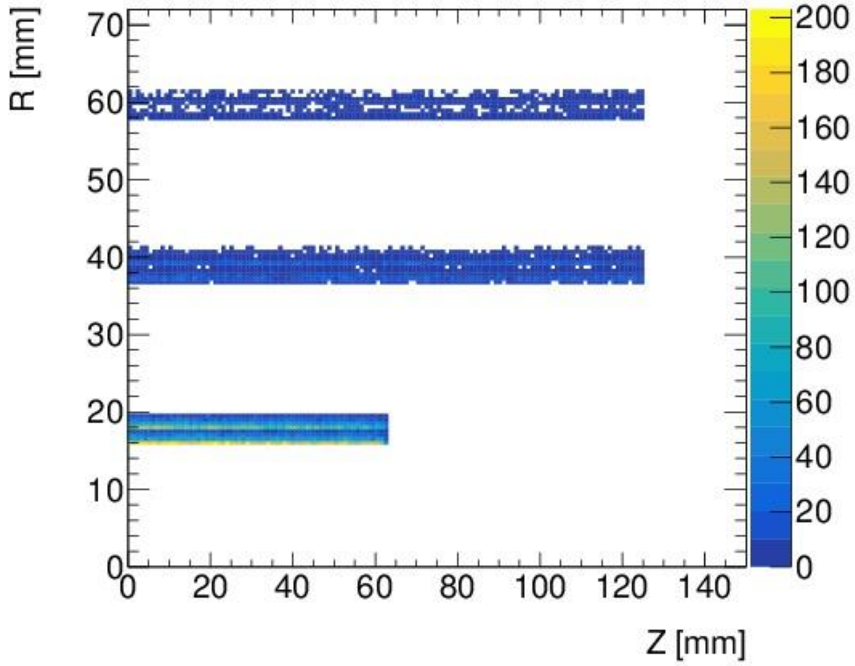


Pair Production

- Hits map of vertex detector



Nearly uniform in the transverse view



More dense in central of first layer

Results

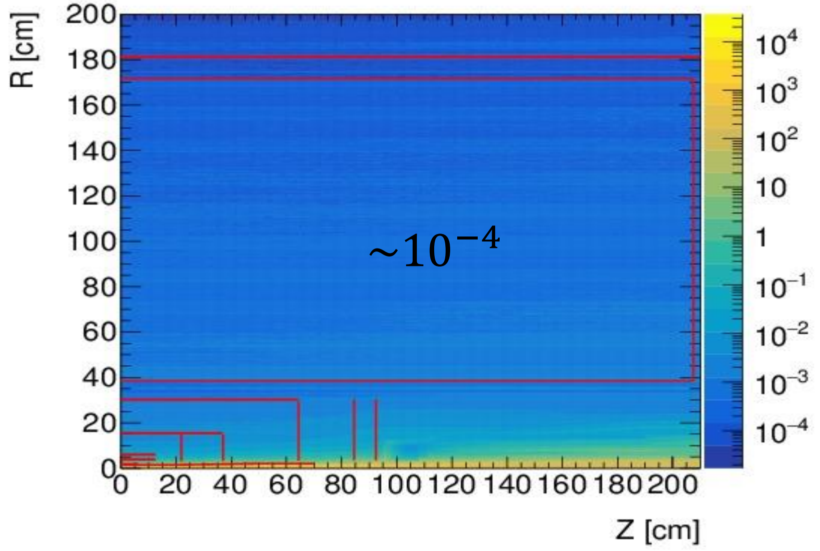
- Results of pair production in the vertex detector
  - BKG decrease rapidly with increasing radius

Layer	Hit Density $[cm^{-2}BX^{-1}]$	TID [kRad/yr]	1 MeV Equ. Neu. Fluence $[n_{eq}cm^{-2}yr^{-1}]$
1	2.26	591.14	1.11×10^{12}
2	1.70	472.12	8.66×10^{11}
3	0.14	42.63	9.08×10^{10}
4	0.11	35.62	8.09×10^{10}
5	0.02	6.15	2.57×10^{10}
6	0.01	5.37	2.41×10^{10}

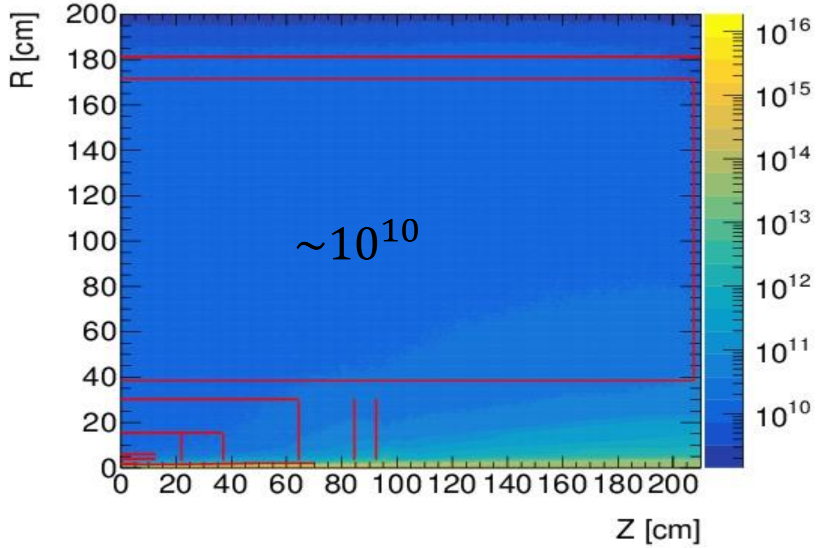
Radiation Map(Pair production, Higgs)

- Most particles are confined in beam pipe
- Background level decreases fast with increasing of radium
- Backscattered neutrons

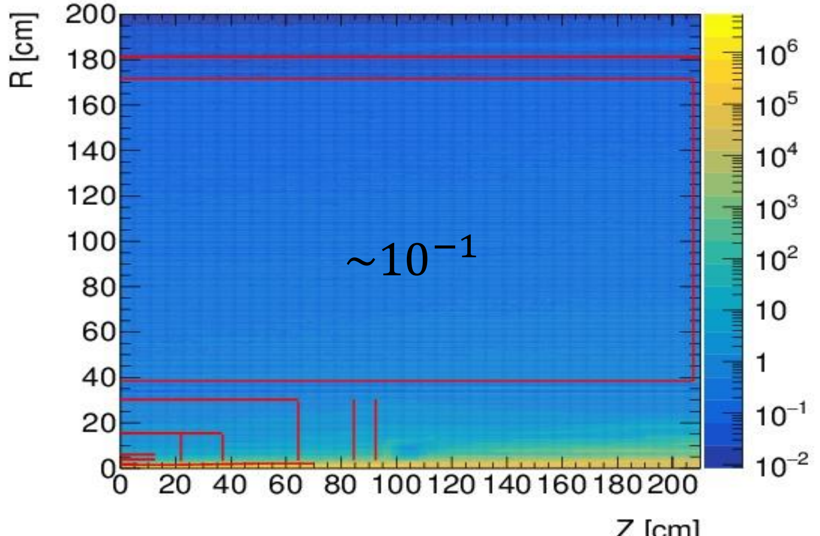
Charged particles fluence $[BX^{-1} \cdot cm^{-2}]$



1 MeV equivalent neutron fluence
$[1MeV\ n_{eq} \cdot cm^{-2} \cdot year^{-1}]$

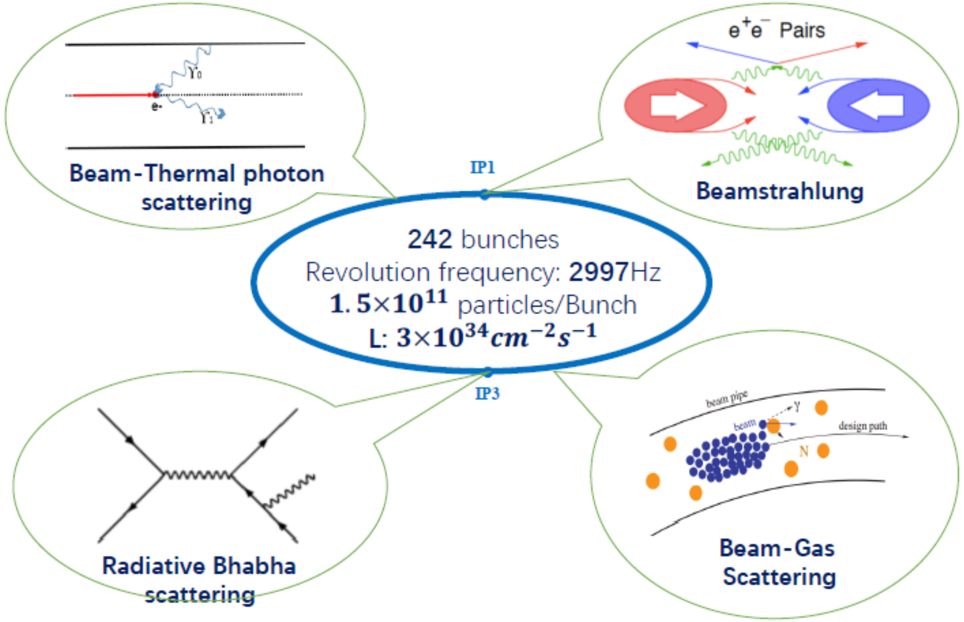


TID $[kRad \cdot yr^{-1}]$



Off-energy Beam Particles

- Beam particles lose energy in scattering processes
  - Beamstrahlung(BS, negligible with collimators)
  - Radiative Bhabha(RBB)
  - Beam-thermal photon scattering(BTH)
  - Beam-gas scattering(BGS)



- Beam particles, fraction of energy loss larger than 1.5%, are kicked off their orbit and some of them can enter the detector
  - Tracking of the off-energy particles is simulated by the SAD
  - Particles hitting beam pipe in the IR are output to Mokka perform a detector simulation

Beam lifetime

- $\frac{1}{\tau} \propto Background\ Ratio$

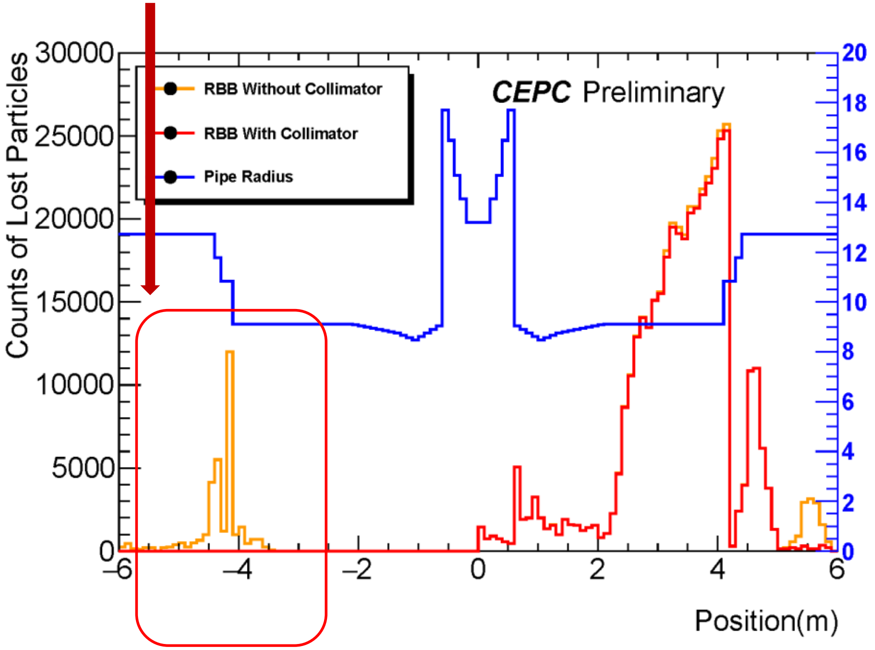
Effects	Beam Lifetime	Others
Quantum Effect	>1000h	
Touschek Effect	>1000h	
Beam Gas Comlomb Scattering	>400h	Residual Gas CO, $10^{-7}Pa$
Beam Gas Bremsstrahlung Scattering	63.8h	Residual Gas CO, $10^{-7}Pa$
Beam Thermal Photon Scattering	50.7h	
Radiative Bhabha Scattering	74min	
Beamstrahlung	80min	

Application of Collimators

Haoyu Shi

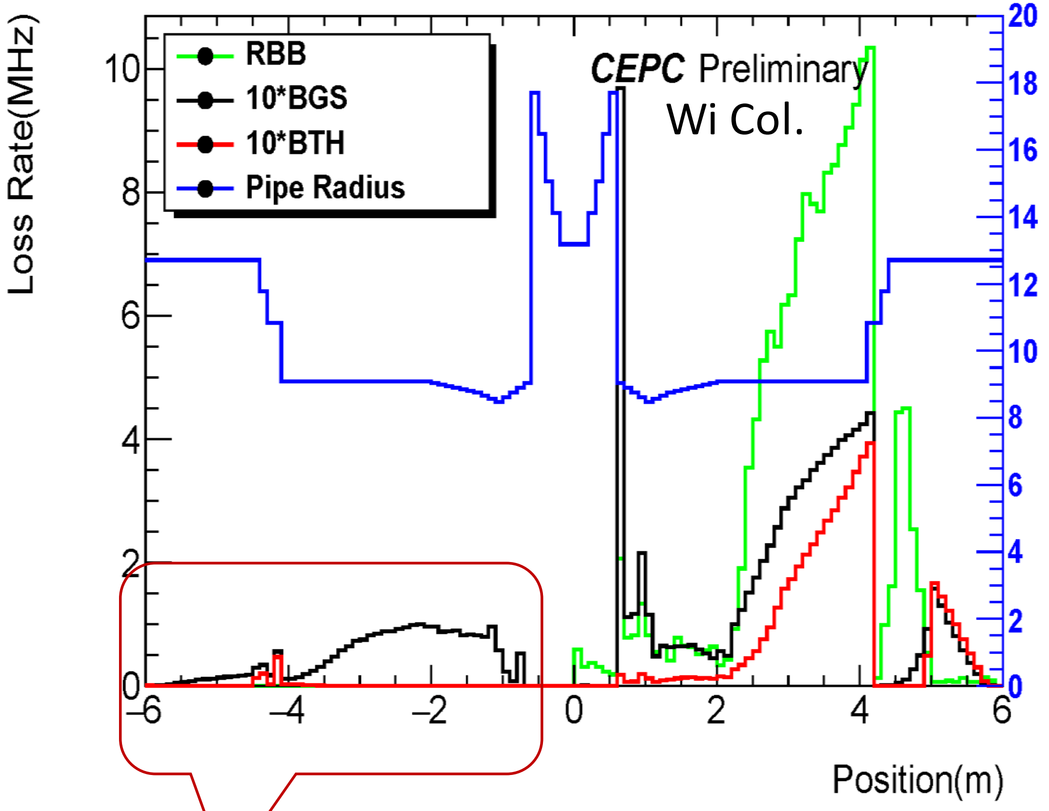
- Collimators, placed in the arch region of upstream, are applied to suppress the BKG

BKG suppressed effectively



Beam direction

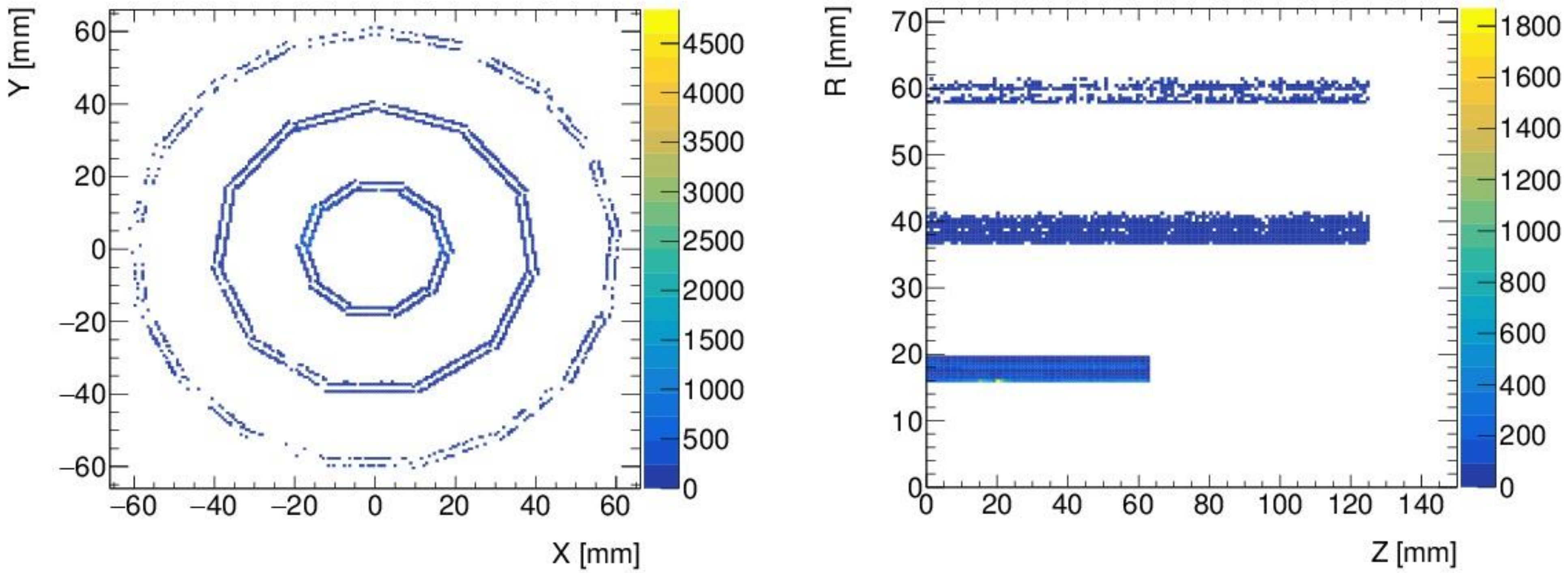
Beam direction



- BGS and BTH
- Produced between the collimator and IP
  - Enter the detector without passing through the collimators
- Can enter the detector cause heavy background
  - VXD is at the front of them

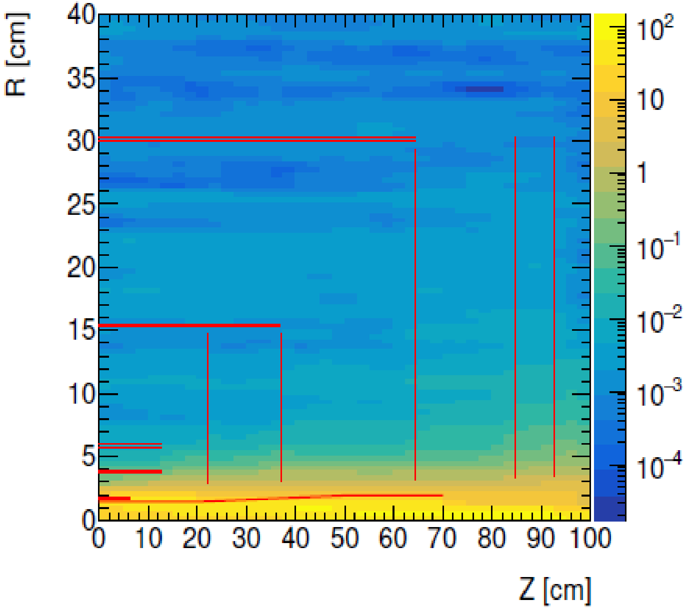
Off-energy Particles(Radiative Bhabha)

- Hits map of vertex detector(with collimators)

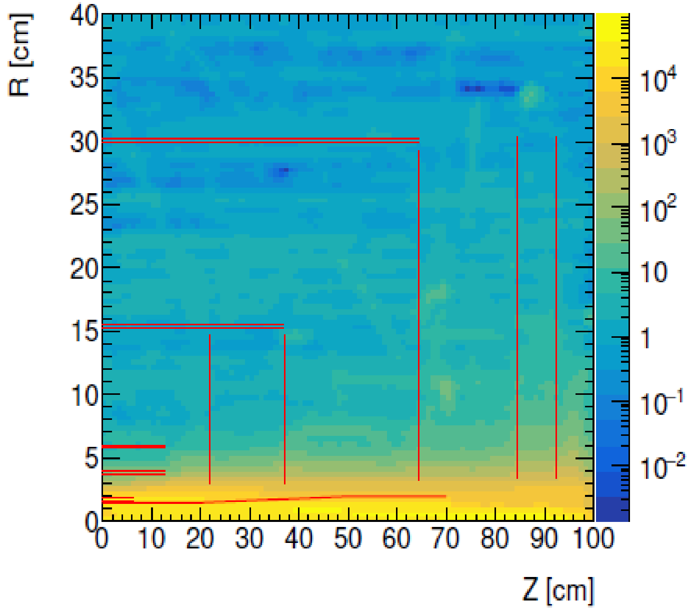


Radiation Map(Radiative Bhabha)

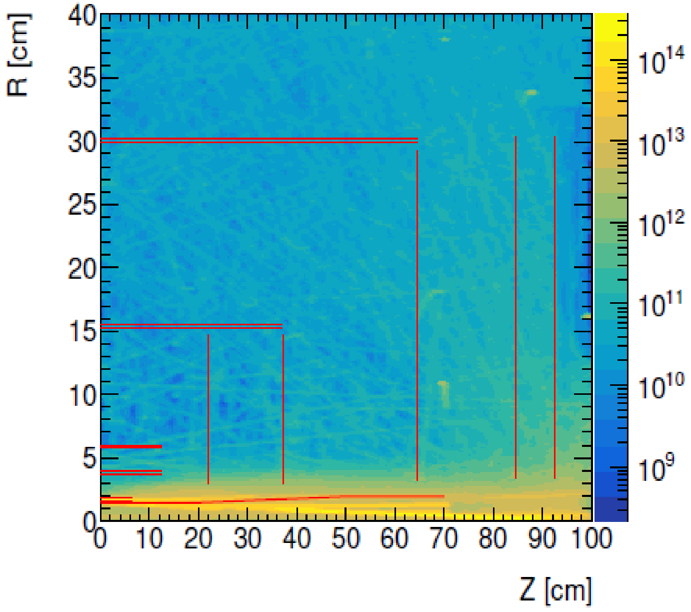
- Confined in the beam pipe mostly
- Hot region is around the beam pipe
- Backscattered neutrons



Charged particles fluence $[BX^{-1} \cdot cm^{-2}]$



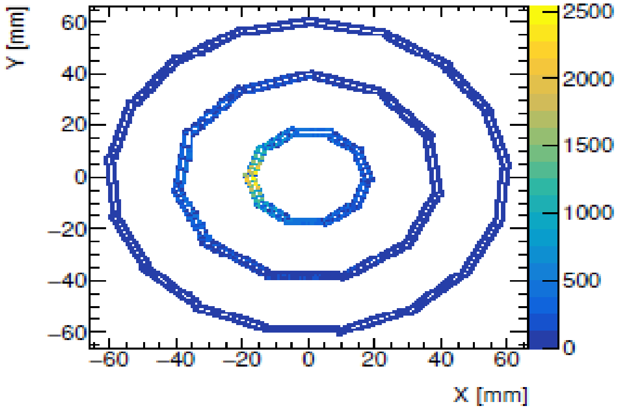
TID $[kRad \cdot yr^{-1}]$



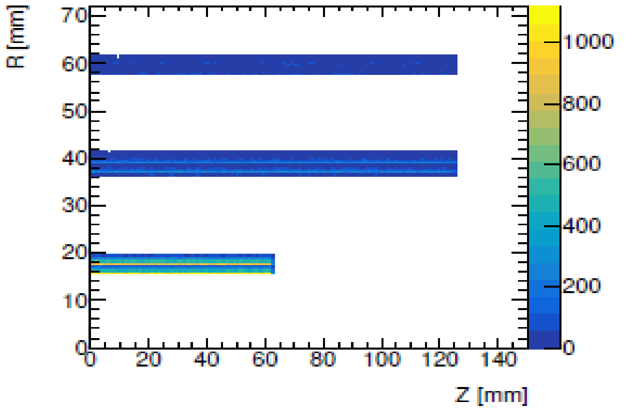
1 MeV equivalent neutron fluence $[kRad \cdot yr^{-1}]$

Off-energy Particles(BGS and BTH)

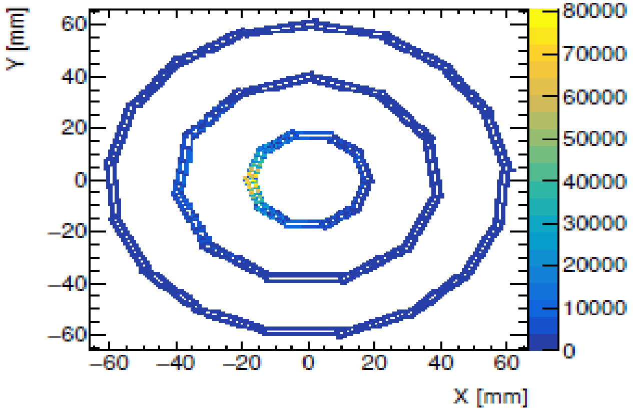
- Hit map of vertex detector(with collimators)
  - More hits in –x direction
    - Crossing angle



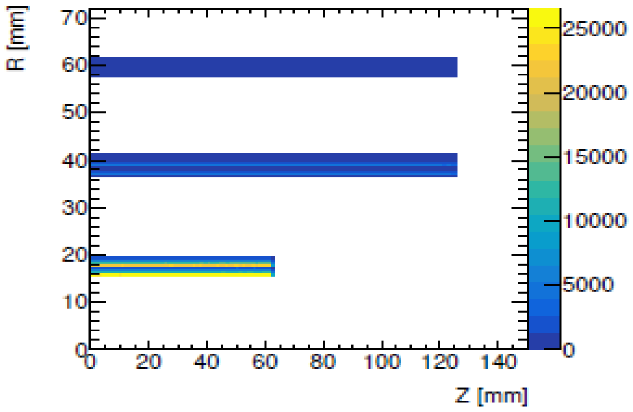
(a) X-Y plane (Beam-thermal photon Scattering)



(b) R-Z plane (Beam-thermal photon Scattering)



(c) X-Y plane (Beam-Gas Scattering)



(d) R-Z plane (Beam-Gas Scattering)

Results

- Results of off-energy particles in the first layer of vertex detector(background from beamstrahlung is negligible)

	Hit Density [hits/cm^2·BX]	TID [MRad/year]	NIEL [10^{12} 1MeV n_{eq}/cm2·year]
RBB	0.93	1.2	4.08
BTH	2.31	2.3	5.48
BGS(10^{-8} Pa)	36.84	3.99	96.5

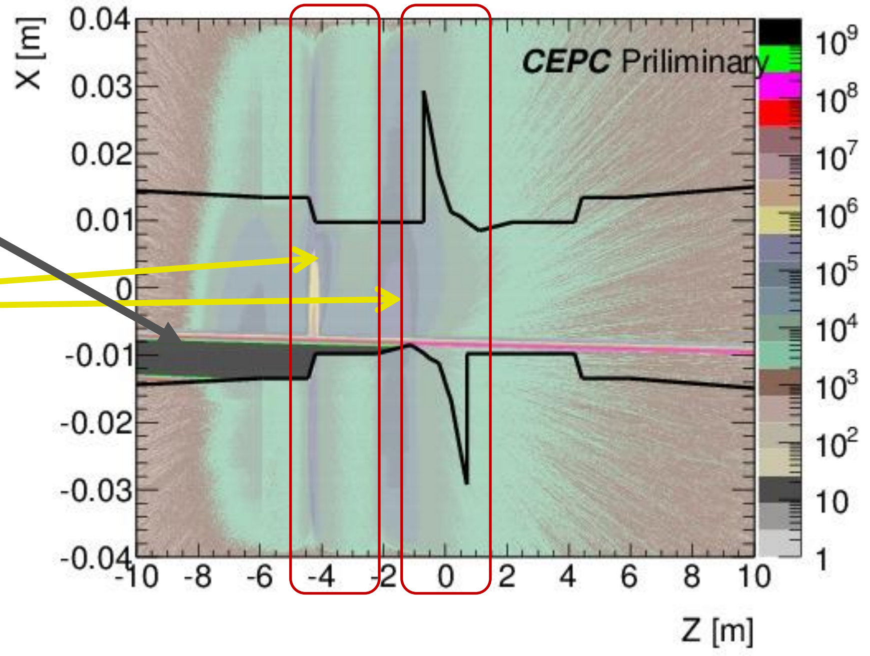
New shielding need to be designed.

Synchrotron Radiation

Ke Li

- 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
- $\sim 8 \times 10^4$ photons hit the central beam pipe per bunch



Tips are introduced to shielding these photons.

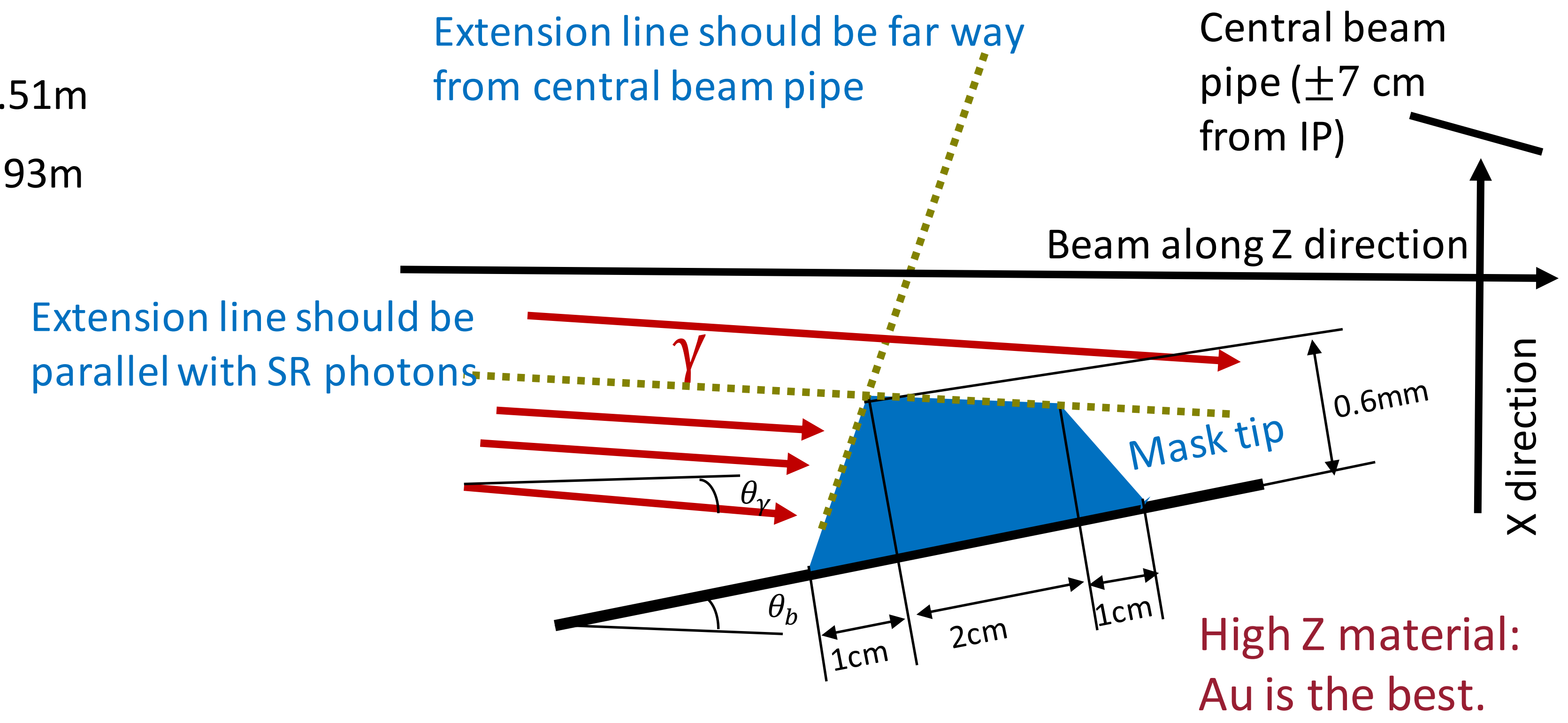
Mask tips design

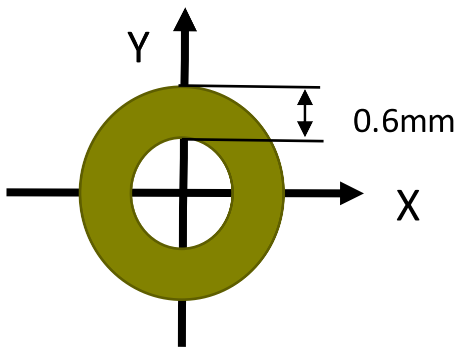
Ke Li

θ_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



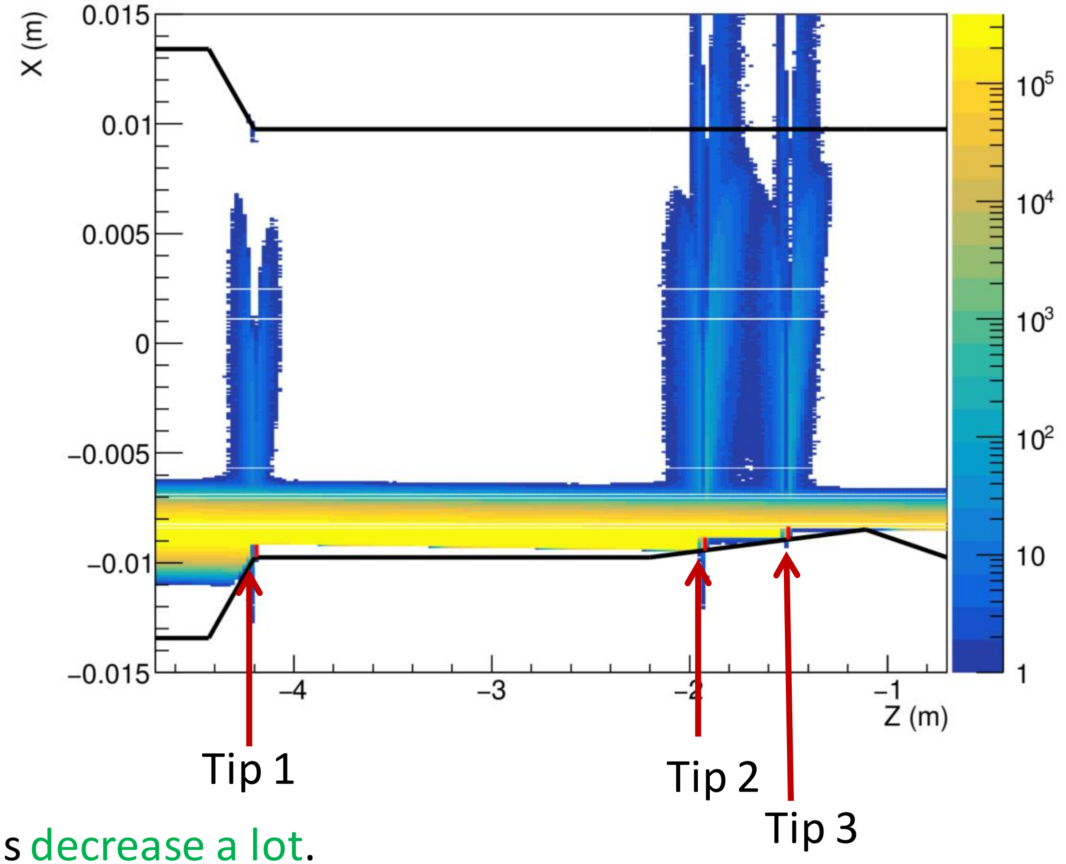


Mask tip at X-Y plane: a ring

With Tips

By Ke Li

- 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 8×10^4 to 233 for per bunch of single beam.

Summary

- Pair production && off-energy beam particles
  - BKG at fist layer of vertex detector (Z is negligible)

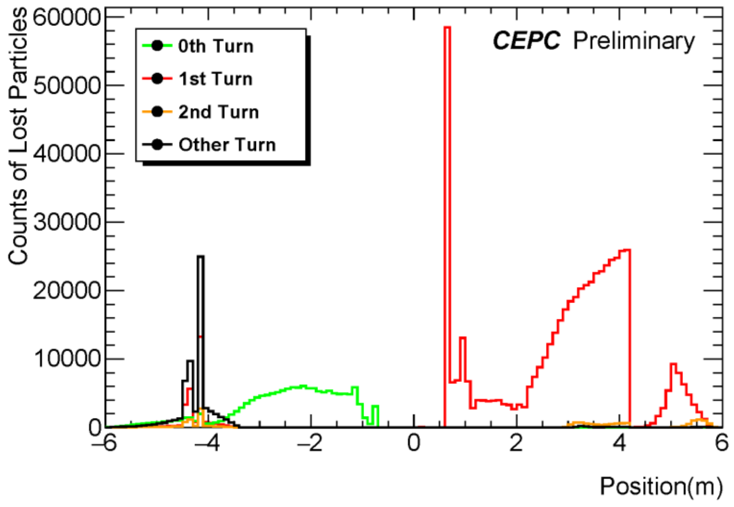
	Pairs Production (240)	Off-energy particles
Hit Density [hits/cm^2·BX]	2.4	~38
TID [MRad/year]	0.59	~6
NIEL [10^{12} 1MeV n_{eq}/cm2·year]	1.1	~19

  - Off-energy particles
    - RBB and Beamstrahlung: suppressed effectively(produced at IP)
    - BTH and BGS: extremely heavy(produced around the ring)
      - new shield, lattice optimization, higher vacuum …
- Synchrotron radiation
  - After applying the 3 tips, BKG from synchrotron radiation is suppressed effectively by two orders of magnitude

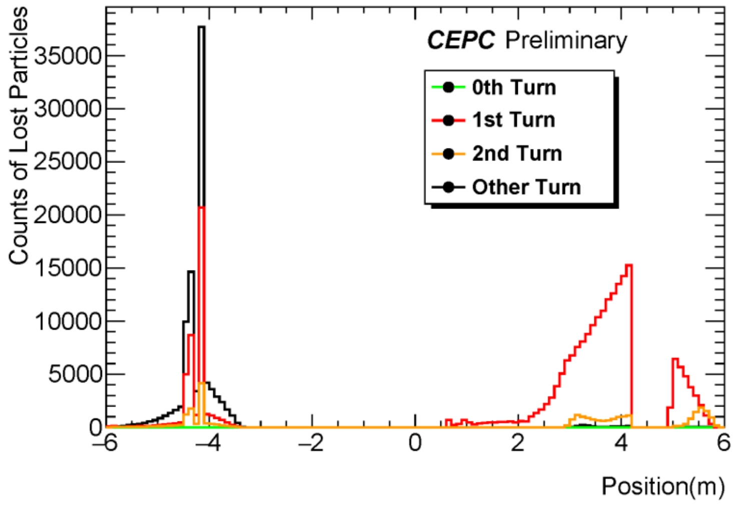
Backup

The Lost Distribution of BGS and BTH

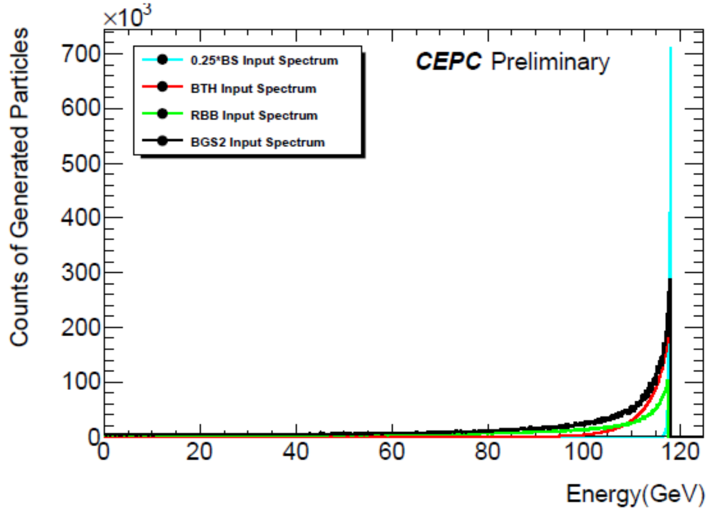
BGS



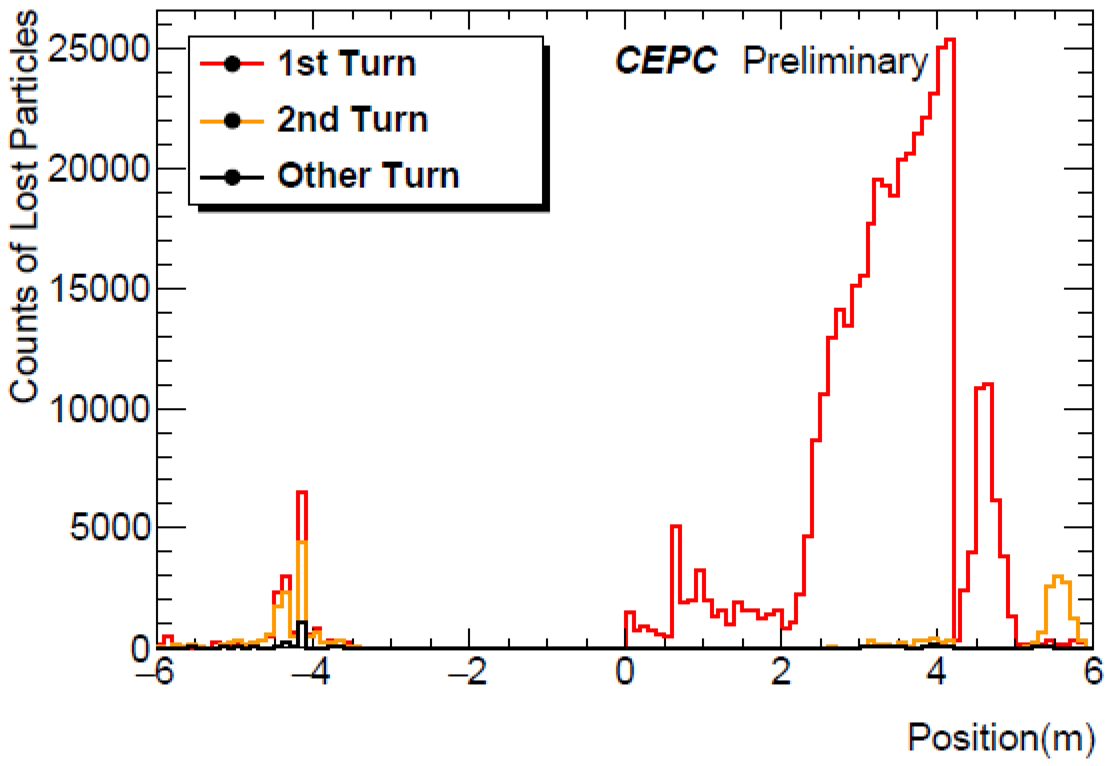
BTH

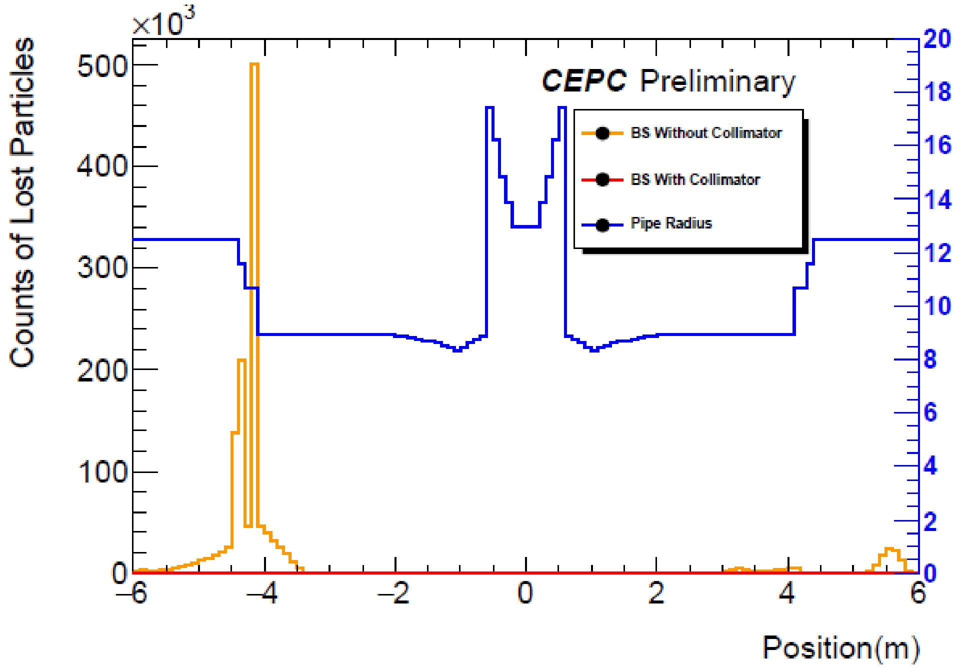


Energy Spectrum

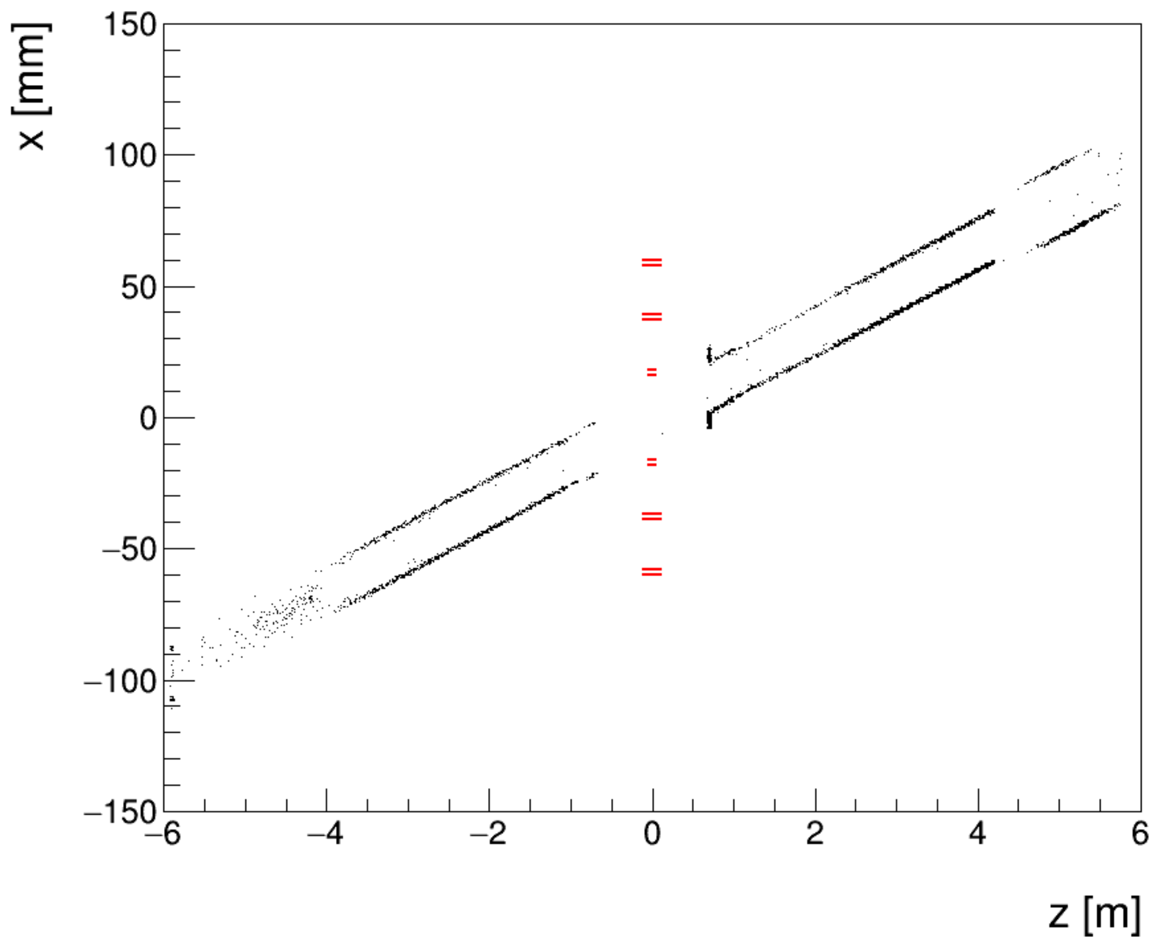


The Lost Distribution of Radiative Bhabha Scattering



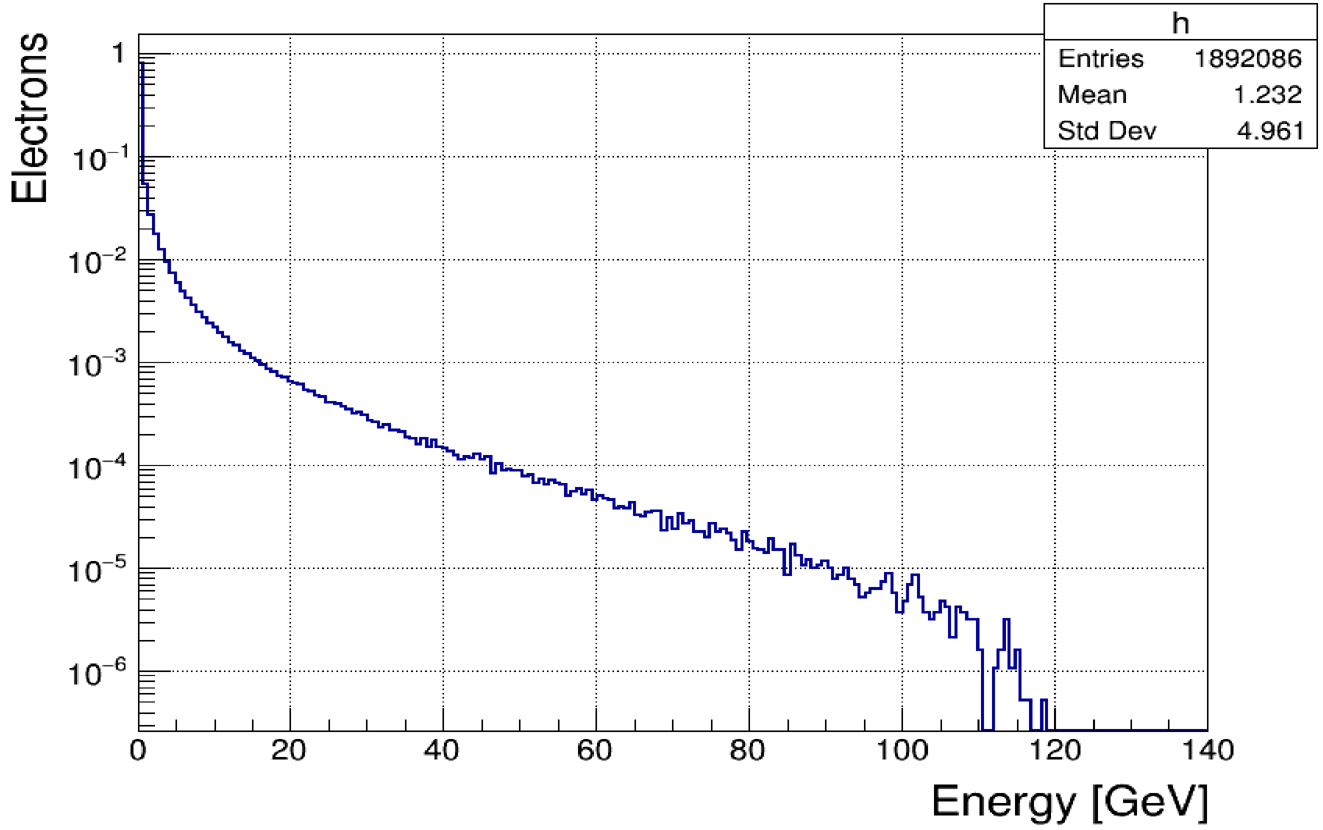


Beam-gas scattering



Beam direction

Energy spectrum of pair production



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 ϕ

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

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) $\times$ ϕ(cm^{-2}) $\times$ mass(g)

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

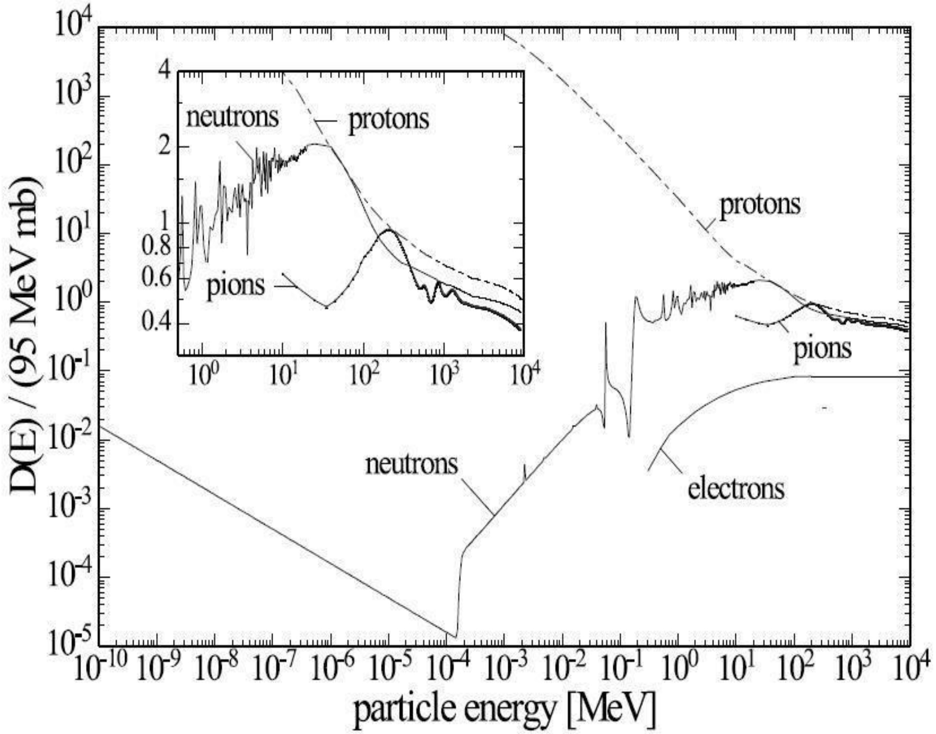
$$DDD = \frac{KERMA}{\text{mass}}$$

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

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

$$= NIEL \times \Phi$$

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%

Position of Collimators

Name	Position	Distance to IP/m
APTX.1	D1I.1897	2139.06
APTX.2	D1I.1894	2208.63
APTX.3	D1O.10	1832.52
APTX.4	D1O.14	1901.09

Generators and Tools

- Off energy particles were generated by several generators, and tracking by SAD in accelerators when necessary. Detector simulation was done by Mokka(Geant4).

Background Type	Generators
Beamstrahlung	PyBS/Guinea-Pig++
Radiative Bhabha	bbbrem/PyRBB
Beam Gas Scattering(inelastic)	PyBGS2
Beam Thermal Photon	PyBTH

Beam life time of BGS

Circulating electrons scatter elastically with nuclei of residual gas molecules. The electrons get lost from the beam if the resulting amplitude of the betatron motion exceeds the vacuum chamber aperture. The beam lifetime due to this effect is called elastic scattering lifetime and is given by

$$\tau^{-1} \propto P\, Z^2\, \beta < \beta > d_m^{-2}$$

where P= pressure, Z= atomic number, β = beta function, and d_m= minimum aperture of the vacuum chamber. Circulating electrons also scatter in-elastically

Machine parameters

	Higgs	*Z(2T)*	*Z(3T)*
Number of IPs	2		
Energy (GeV)	120	45.5	
Circumference (km)	100		
Half crossing angle (mrad)	16.5		
N_e/bunch (10^{10})	15	8.0	
Bunch number	242	12000	
β_{IP} x/y (m)	0.36/0.0015	0.2/0.0015	
Transverse σ_{IP} (um)	20.9/0.068	5.1/0.034	5.1/0.054
Bunch length σ_z (mm)	3.26	8.5	
L_{max}/IP ($10^{34}cm^{-2}s^{-1}$)	2.93	16.6	