Radiation Backgrounds for Future High Energy Electron Positron Colliders

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On behalf of the CEPC Study Group

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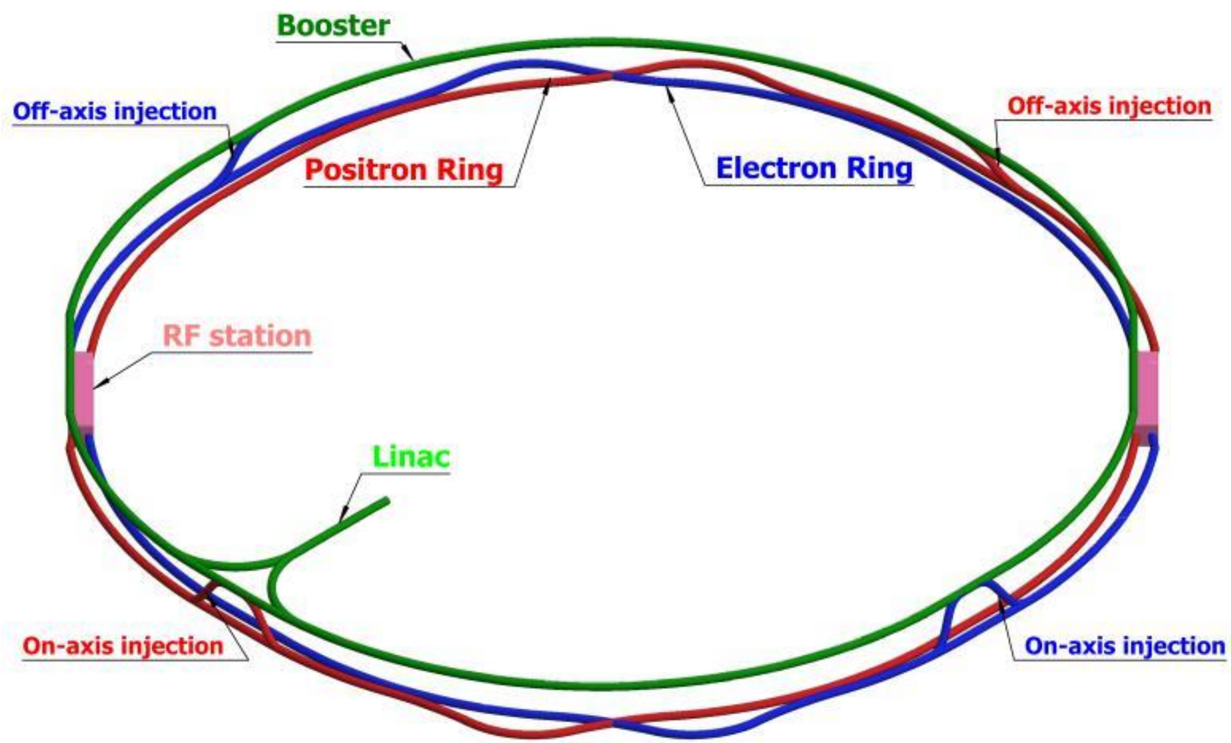
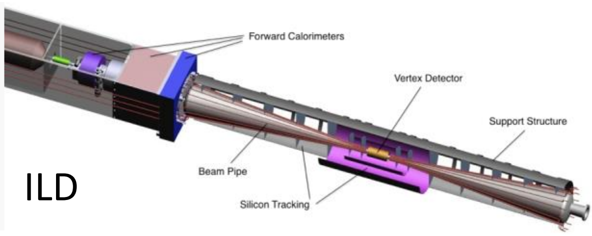
Outline

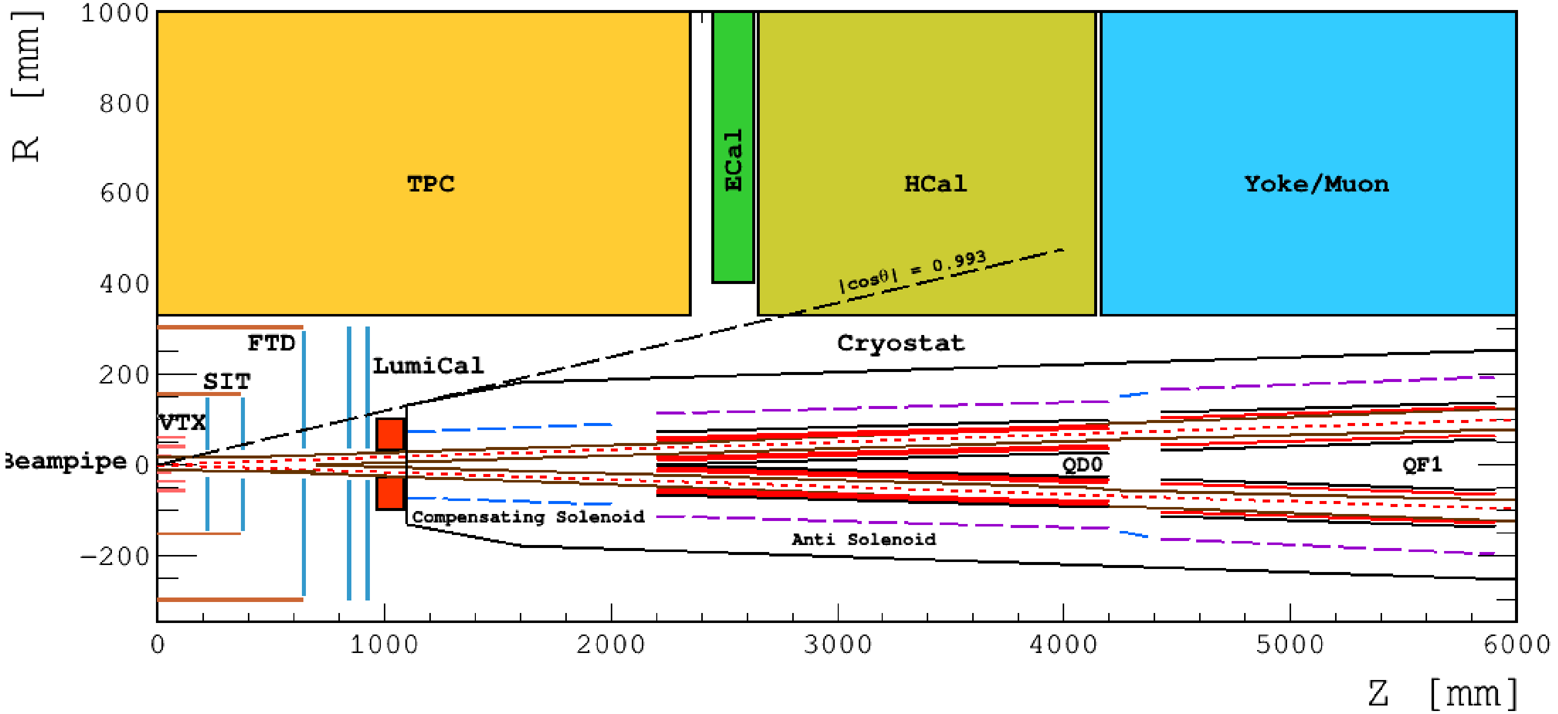
- Interaction Region Layout
- Radiation Backgrounds
- Summary



Interaction Region



- **Preliminary layout of the interaction region**: extremely limited space for several critical components → *trade-offs*
- Optimizations required in the forward region and installation scheme to be developed → *toward a more realistic design*



Radiation Backgrounds

- Important inputs in to detector (+machine) designs, e.g. detector occupancy, radiation tolerance …

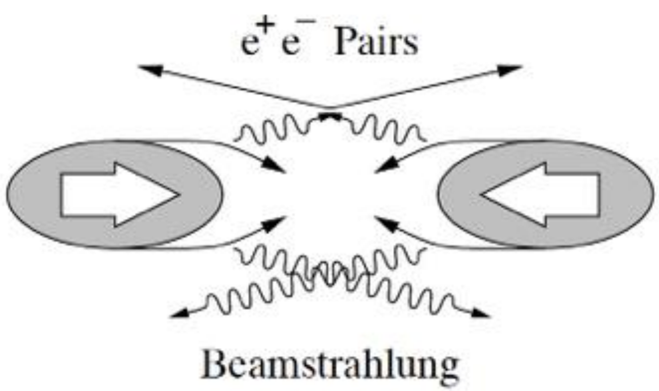
- Have investigated the most important sources of radiation backgrounds, including
  - *Pair production*
  - *Beam lost/off-energy particles*
  - *Synchrotron radiation*
  - *… Extending into other less critical sources*

Machine Parameters

	Higgs	W	Z（3T）	Z（2T）
Number of IPs	2			
Beam energy (GeV)	120	80	45.5	
Circumference (km)	100			
Synchrotron radiation loss/turn (GeV)	1.73	0.34	0.036	
Crossing angle at IP (mrad)	16.5×2			
Piwinski angle	2.58	7.0	23.8	
Number of particles/bunch N_e (10^{10})	15.0	12.0	8.0	
Bunch number	242	1524	12000 (10% gap)	
Bunch spacing (ns)	680	210	25	
Beam current (mA)	17.4	87.9	461.0	
Synchrotron radiation power (MW)	30	30	16.5	
Bending radius (km)	10.7			
Momentum compaction (10^{-5})	1.11			
β function at IP β_x^* / β_y^* (m)	0.36/0.0015	0.36/0.0015	0.2/0.0015	0.2/0.001
Emittance x/y (nm)	1.21/0.0031	0.54/0.0016	0.18/0.004	0.18/0.0016
Beam size at IP s_x /s_y (μm)	20.9/0.068	13.9/0.049	6.0/0.078	6.0/0.04
Beam-beam parameters ξ_x /ξ_y	0.031/0.109	0.013/0.106	0.004/0.056	0.004/0.072
RF voltage V_{RF} (GV)	2.17	0.47	0.10	
RF frequency f_{RF} (MHz)	650			
Harmonic number	216816			
Natural bunch length s_z (mm)	2.72	2.98	2.42	
Bunch length s_z (mm)	3.26	5.9	8.5	
Damping time t_x/t_y/t_E (ms)	46.5/46.5/23.5	156.4/156.4/74.5	849.5/849.5/425.0	
Natural Chromaticity	-493/-1544	-493/-1544	-520/-1544	-520/-3067
Betatron tune ν_x/ν_y/ν_s	363.10 / 365.22 / 0.065			
HOM power/cavity(2cell) (kw)	0.54	0.75	1.94	
Natural energy spread (%)	0.1	0.066	0.038	
Energy acceptance requirement (%)	1.35	0.40	0.23	
Energy acceptance by RF (%)	2.06	1.47	1.70	
Photon number due to beamstrahlung	0.29	0.35	0.55	
Lifetime _simulation (min)	100			
Lifetime (hour)	0.67	1.4	4.0	2.1
F (hour glass)	0.89	0.94	0.99	
Luminosity/IP L ($10^{34}cm^{-2}s^{-1}$)	2.93	10.1	16.6	32.1

Pair Production

- Estimated as the most important background at Linear Colliders, *not an issue for lower energy/luminosity machines*
- Charged particles attracted by the opposite beam emit photons (**beamstrahlung**), followed by electron-positron pair production (*dominate contributions from the incoherent 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;

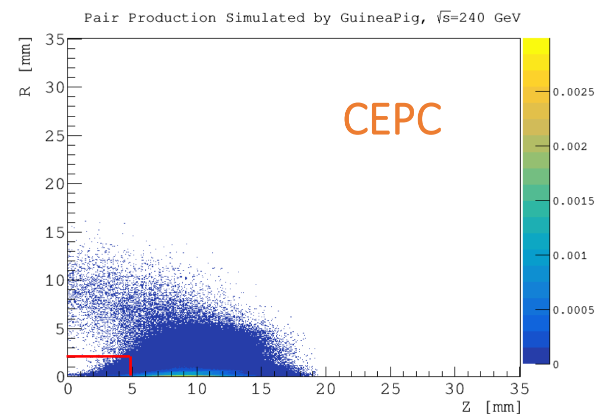
However, a non-negligible amount of particles can hit the detector → **radiation backgrounds**

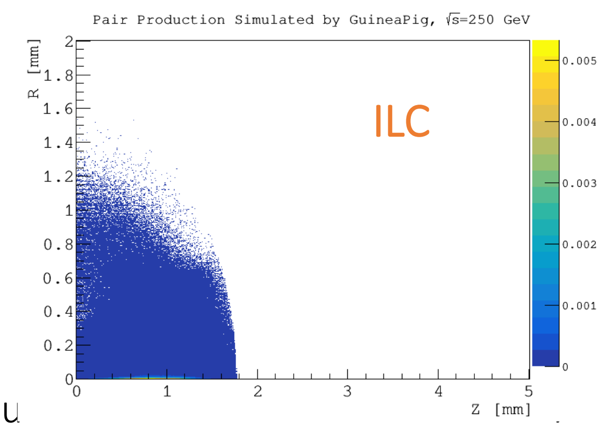
Hadronic backgrounds much less critical

Event Generation

- Pair production process simulated with the GuineaPig program and the output fed into Geant4 detector simulation
- *Long* time for colliding bunches to cross each other (e.g. Higgs operation with bunch length ~3.6 mm)
- Caveat: charged particles travelling over certain distance without seeing the solenoidal field, which unfortunately introduces bias to the hit positions

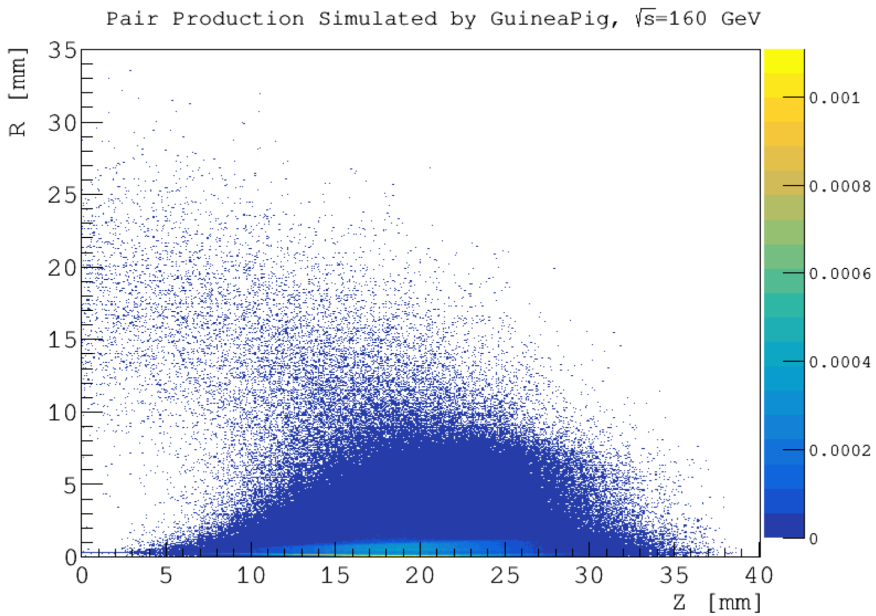
→ To implement external field in the GuineaPig, feature request sent to the author (to be followed up)

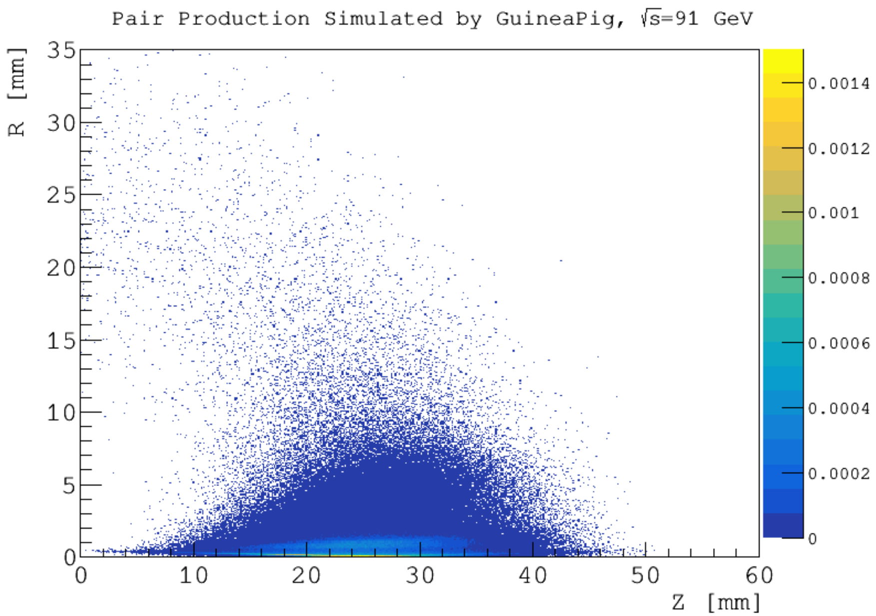




Pair Production @ W/Z

- More prominent at W/Z because of event longer bunch sizes and charged particles traveling over even longer distances

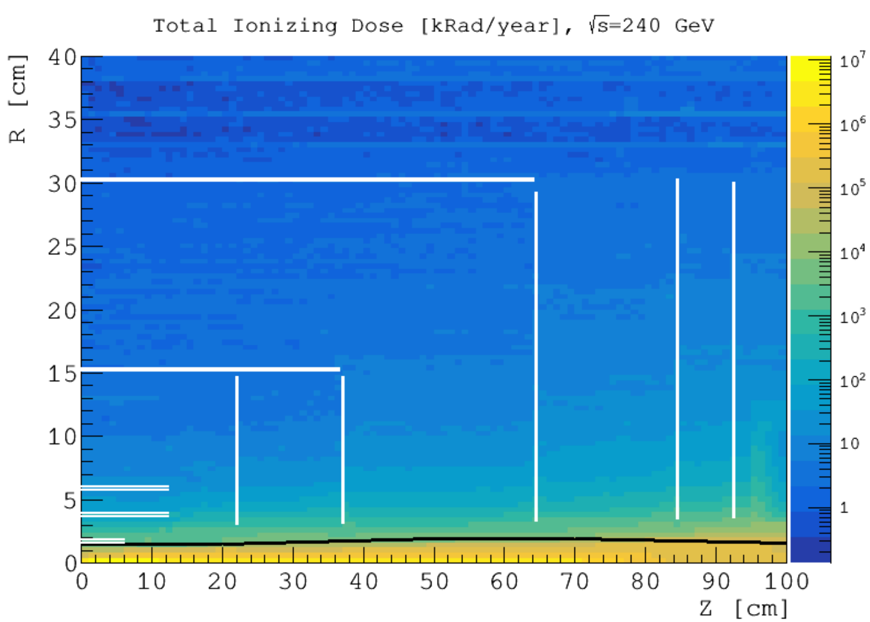


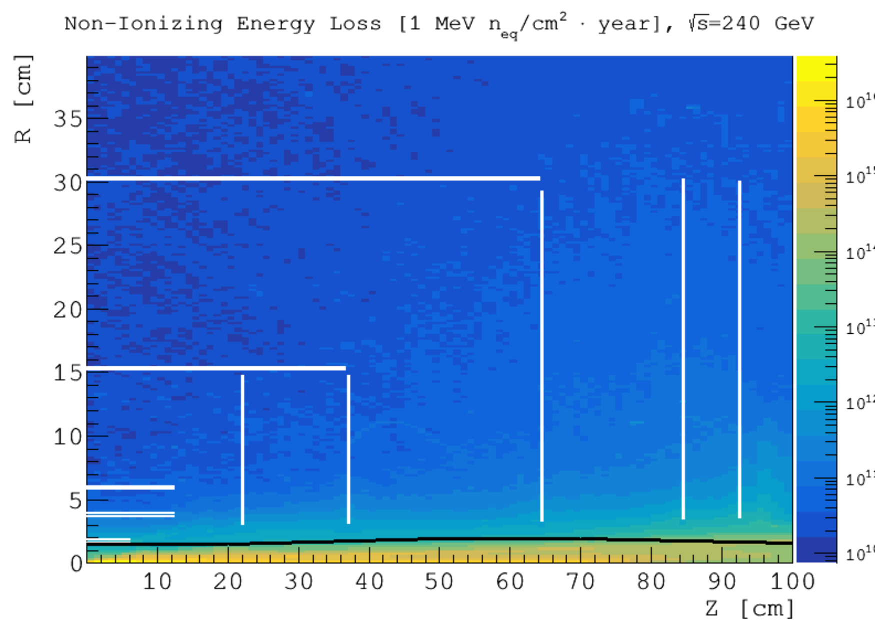


Radiation Background Levels

S. Bai, W. Xu and X. Wang

- Using hit density, total ionizing dose (TID) and non-ionizing energy loss (NIEL) to quantify the radiation background levels
- Adopted the calculation method used for the ATLAS background estimation (ATL-GEN-2005-001), safety factor of ×10 applied

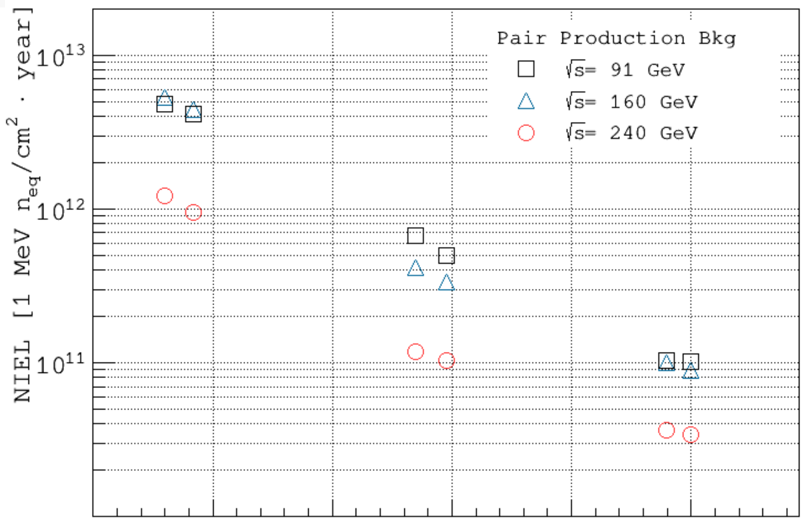




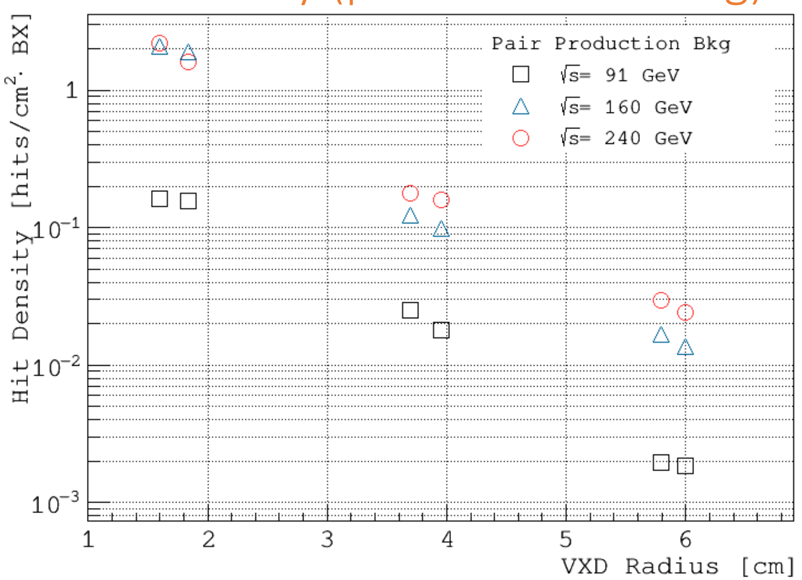
Higgs, W and Z

- Hit density, TID and NIEL at the 1st VXD layer (r = 1.6 cm) for operation at different energies
- Bunch spacing: *680 (H)/210 (W)/25 (Z) ns*

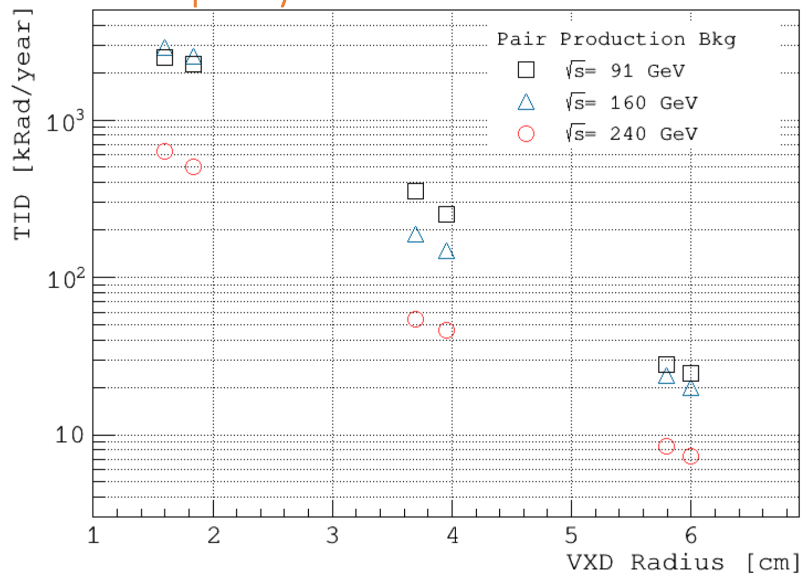
NIEL per year



Hit density (per bunch crossing)



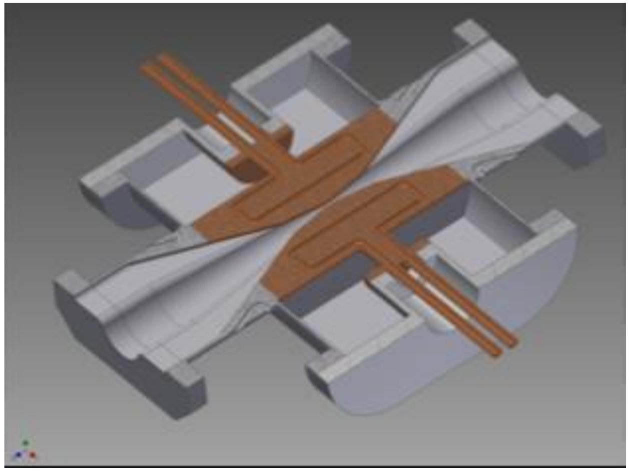
TID per year



Beam Lost Particles

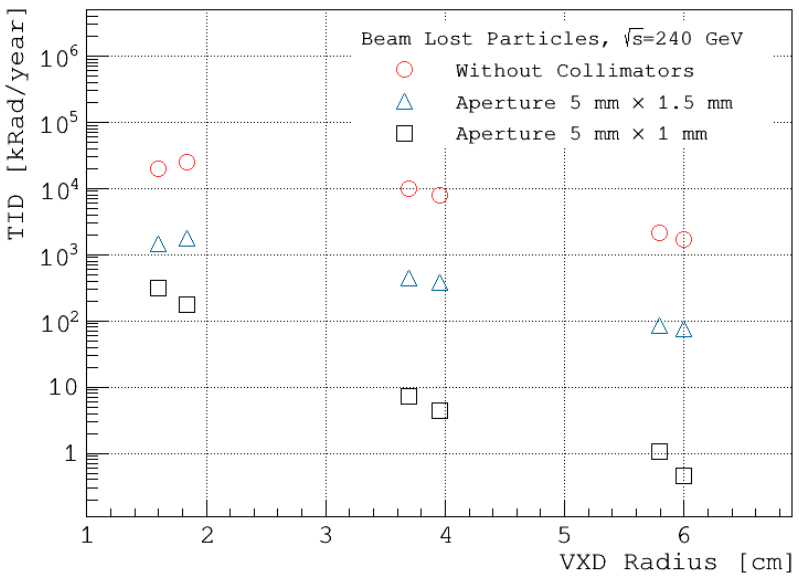
- Beam particles losing energies (radiative Bhabha scattering, beam-gas interaction, beam-gas interaction, etc.) larger than acceptance kicked off their orbit → lost in the interaction region
- Two sets of collimators placed upstream to stop off-energy beam particles, sufficiently away from the beam clearance area (aperture size subject to optimization)

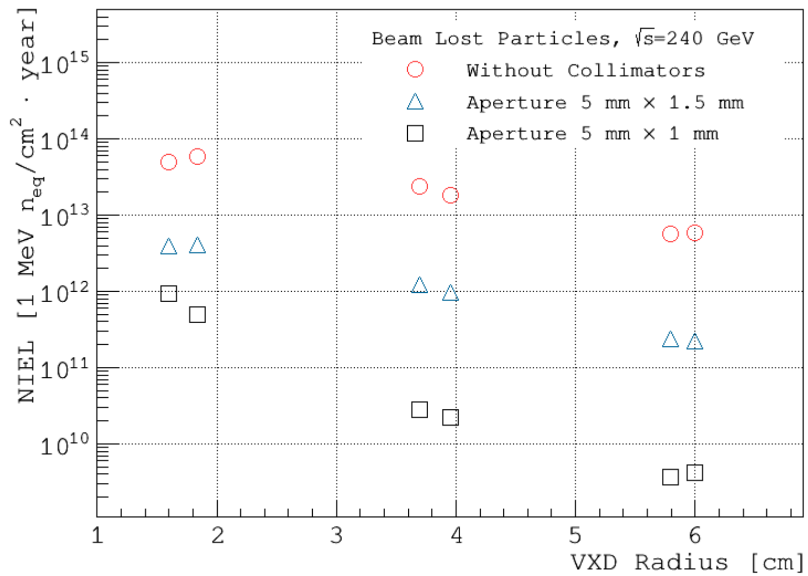
What shape?
SuperKEKB Type (PEP-II as reference)



Effectiveness of Collimators

- Suppression of detector backgrounds, close to a factor of 100 in reduction → remaining backgrounds smaller than that from pair production and there is room for further tuning

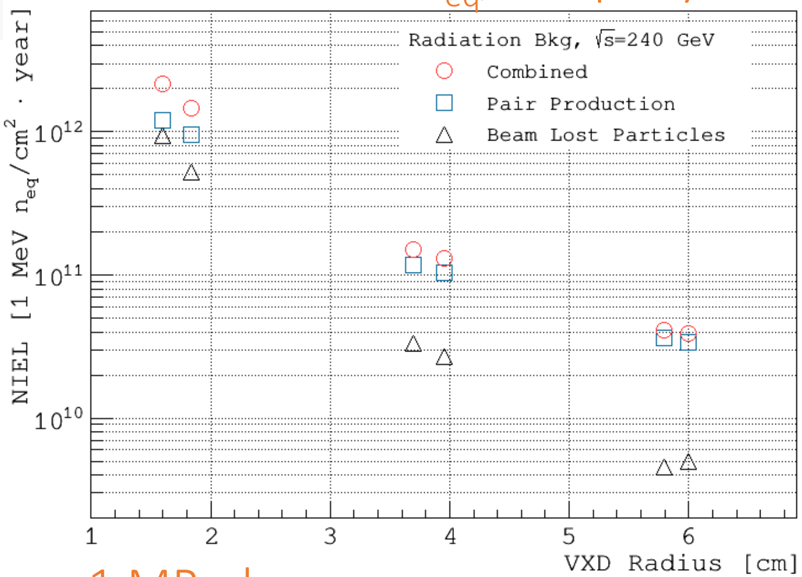




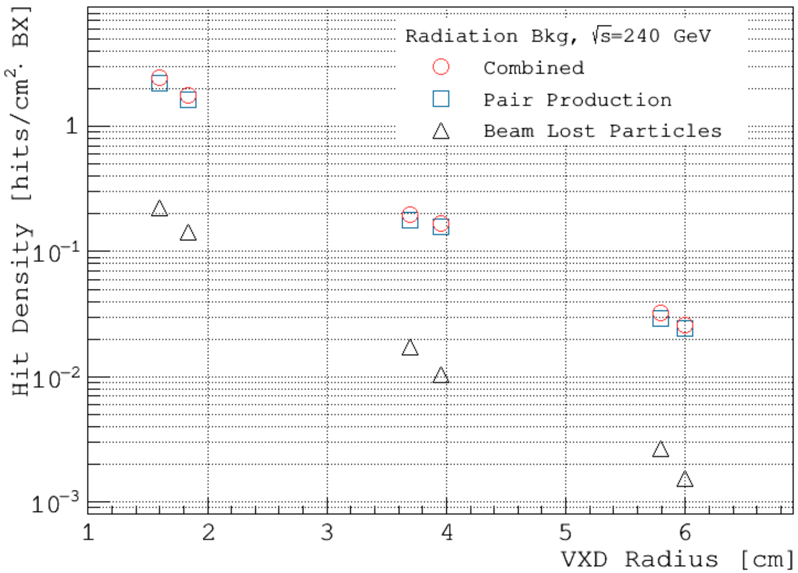
Combined Backgrounds

- Radiation backgrounds from pair production, radiative Bhabha scattering + beamstrahlung
- Most significant contributions from the pair production

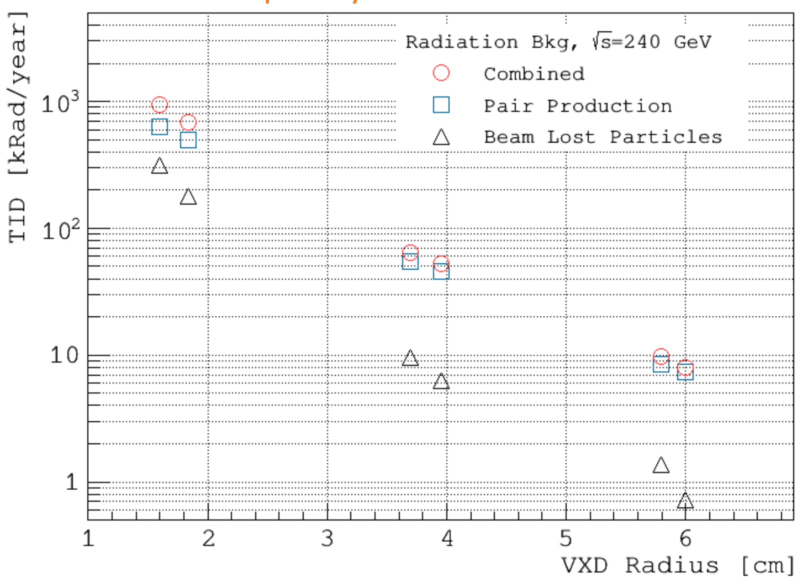
2×10^{12} 1MeV n_{eq}/cm^2 per year



2.5 hits/cm^2 per bunch crossing



1 MRad per year

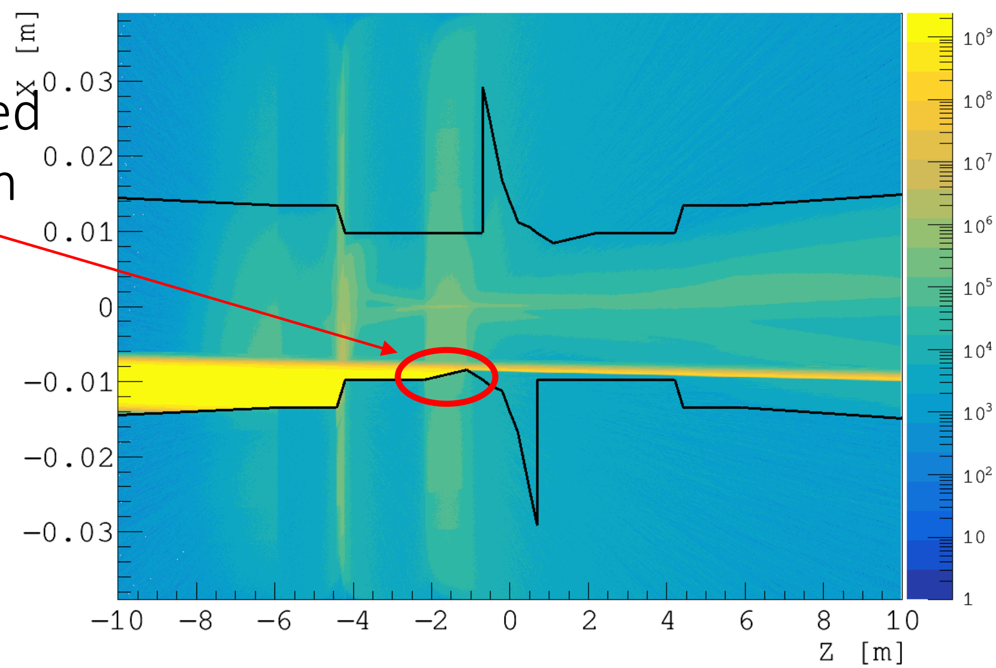


Synchrotron Radiation

K. Li & M. Sullivan (SLAC)

- Beam particles bent by magnets (last bending dipole, focusing quadrupoles) emit SR photons → important at circular machines
- BDSim to transport beam (core + halo) from the last dipole to the interaction region and record the particles hitting the central beryllium beam pipe

Large amount of photons scattered by the beam pipe surface between [1, 2 m] into the central region



Collimators made with high-*Z* material must be introduced to block those SR photons.

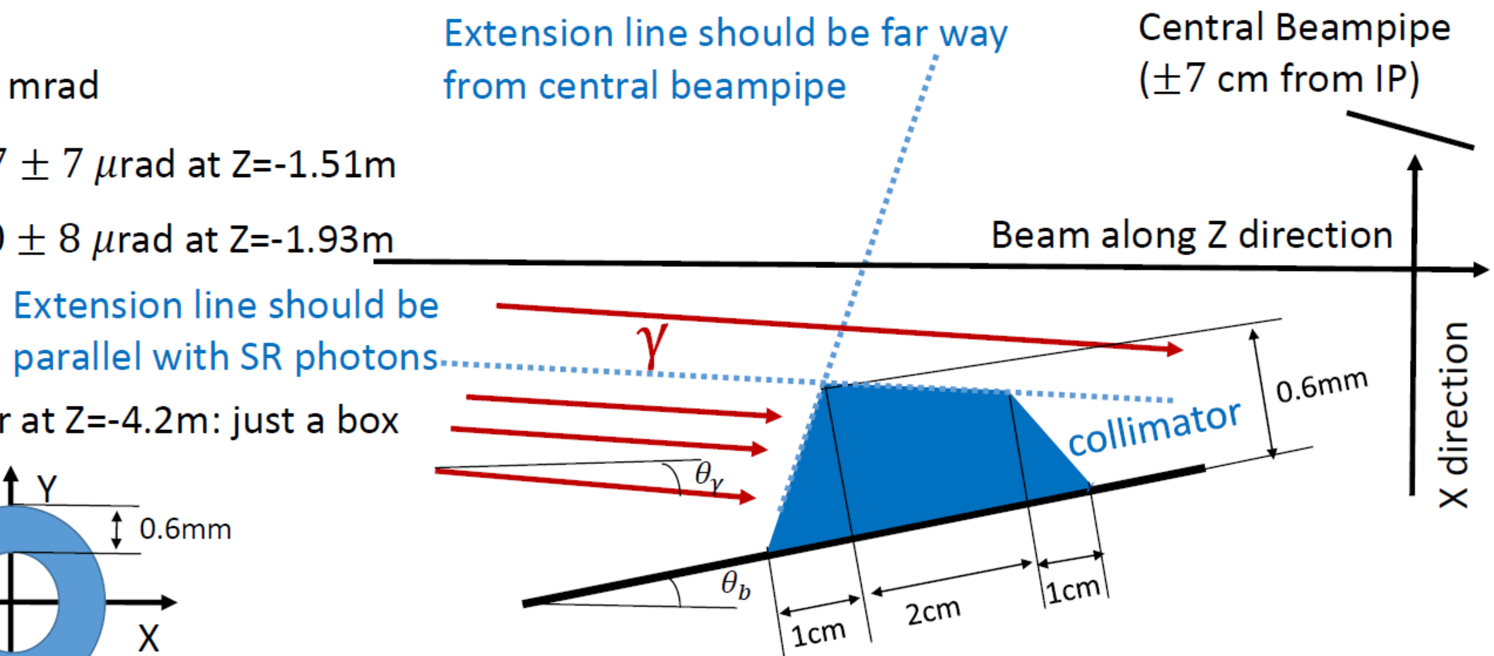
Mask Tips

Collimator shape

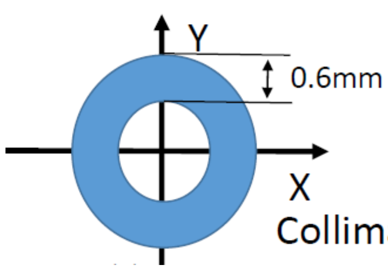
θ_b = 1.17 mrad

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

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



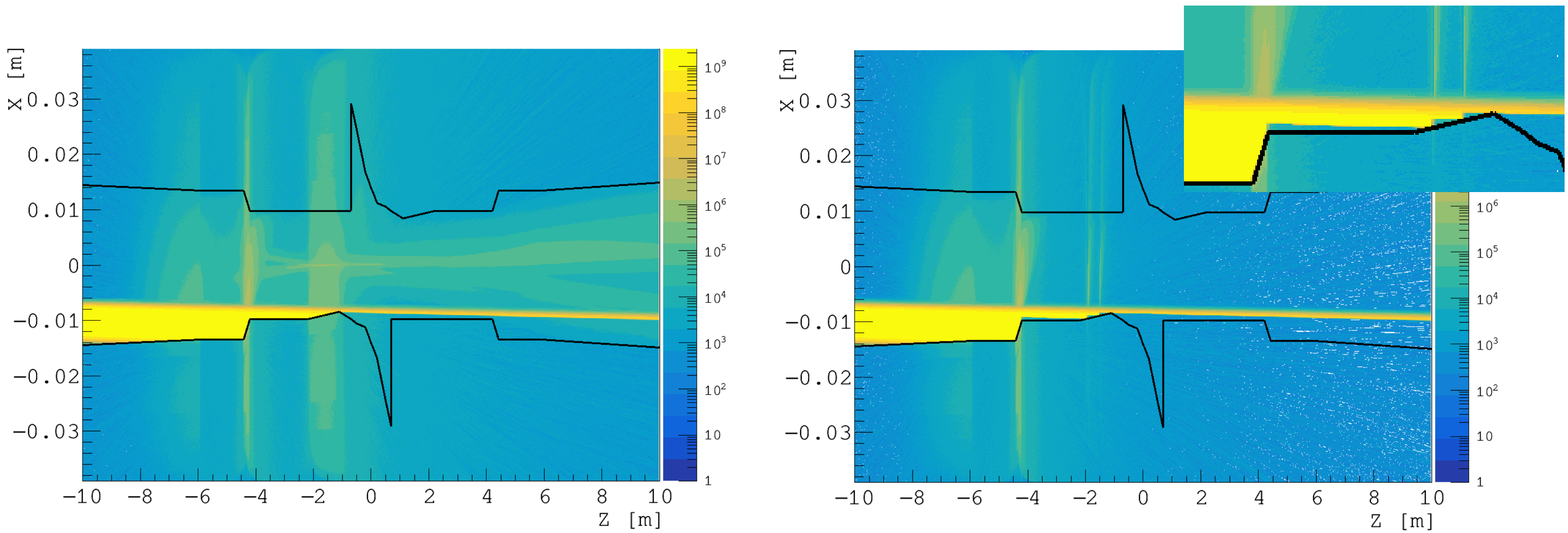
Collimator at Z=-4.2m: just a box



Collimator at X-Y plane: a ring

With Collimation

- Three masks at 1.51, 1.93 and 4.2 m along the beam pipe to the IP to block SR photons → shielding to the central beam pipe



- Number of photons per bunch hitting the central beam pipe dropping from 40, 000 to 80; power deposition reduced considerably

Summary

- Preliminary interaction region design that requires further optimization

- Investigated the main radiation backgrounds that are important for detector design (pair production to be re-visited shortly); more sources of backgrounds to be included
  - Hit density: 2.5 hits/cm^2 per bunch crossing
  - TID: 1 MRad per year
  - NIEL: 2×10^{12} 1MeV n_{eq}/cm^2 per year