Detector Beam Background Simulations for CEPC

Hongbo Zhu, Qinglei Xiu, Xinchou Lou (IHEP)

On behalf of the CEPC study group

ICFA Advanced Beam Dynamics Workshop: Higgs Factory (HF2014)

9-12 October 2014, Beijing

Outline

- Overview of different backgrounds
- Beam-induced backgrounds
- Backgrounds in the CEPC detector
- Summary and outlook

Overview of Different Backgrounds

- Different sources of backgrounds must be carefully evaluated
  - Constraints on the Interaction Region (IR) layout
  - Impacts on detector performance (and technology choice)

Physics Performance

Beam-induced background:

- Beamstrahlung
- Pair production
- Hadronic background
- Radiative Bhabha events
- …

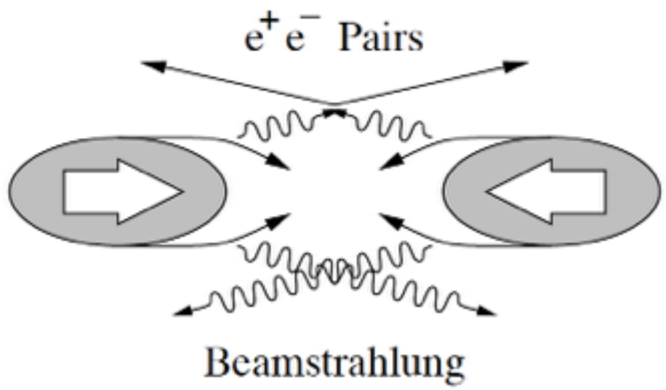
Topics of this presentation

Machine-induced background:

- Synchrotron radiation
- Beam-gas interactions
- Beam-halo muons
- Beam loss
- …

To be minimized by careful design

Beam-Beam Interaction



- The two bunches of opposite-charge attract each other at the interaction point (IP), the so-called “Pinch Effect”
  - Smaller bunch cross section → luminosity gain
  - Particles with trajectories bent, emit radiation (similar to synchrotron radiation) → beamstrahlung

- Main beam-induced backgrounds
  - Beamstrahlung, electron-positron pair production, YY→ hadrons

Simulation with GIUNEA-PIG

- Generator of Unwanted Interactions of Numerical Experiment Analysis – Program Interfaced to GEANT → widely used for TESLA, ILC and CLIC beam background studies
- GIUNEA-PIG simulation includes pinch effect, beamstrahlung, pair production, hadronic background and radiative Bhabha scattering (partially).
- Results to be cross-checked with other simulation tools

Input Machine Parameters

- Input CEPC machine parameters into GUINEA-PIG; ILC250 listed for comparison

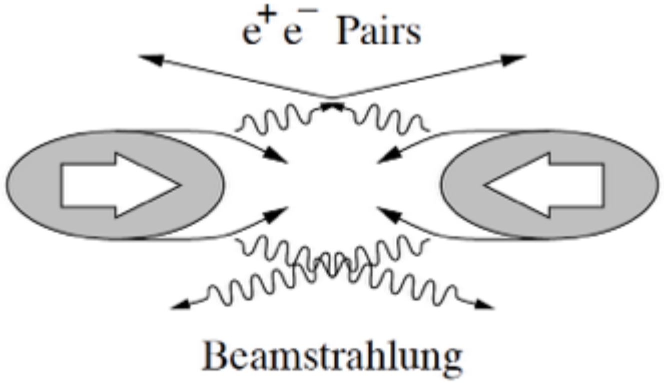
Machine Parameters	CEPC	ILC250
E_{cm} [GeV]	240	250
Particles per bunch	3.7×10^{11}	2.0×10^{10}
Beam size σ_x/σ_y [nm]	73700/160	729/7.7
Beam size σ_z [μm]	2260	300
Emittance $\varepsilon_x/\varepsilon_y$ [mm · mrad]	1595/4.8	10/0.035

$$\delta \propto \frac{\gamma}{E\sigma_z}\left(\frac{N}{\sigma_x+\sigma_y}\right)^2$$

$$\Upsilon \propto \frac{N\gamma}{\sigma_z(\sigma_x+\sigma_y)}$$

Promising smaller average relative energy loss and less beamstrahlung for CEPC

Background: Beamstrahlung

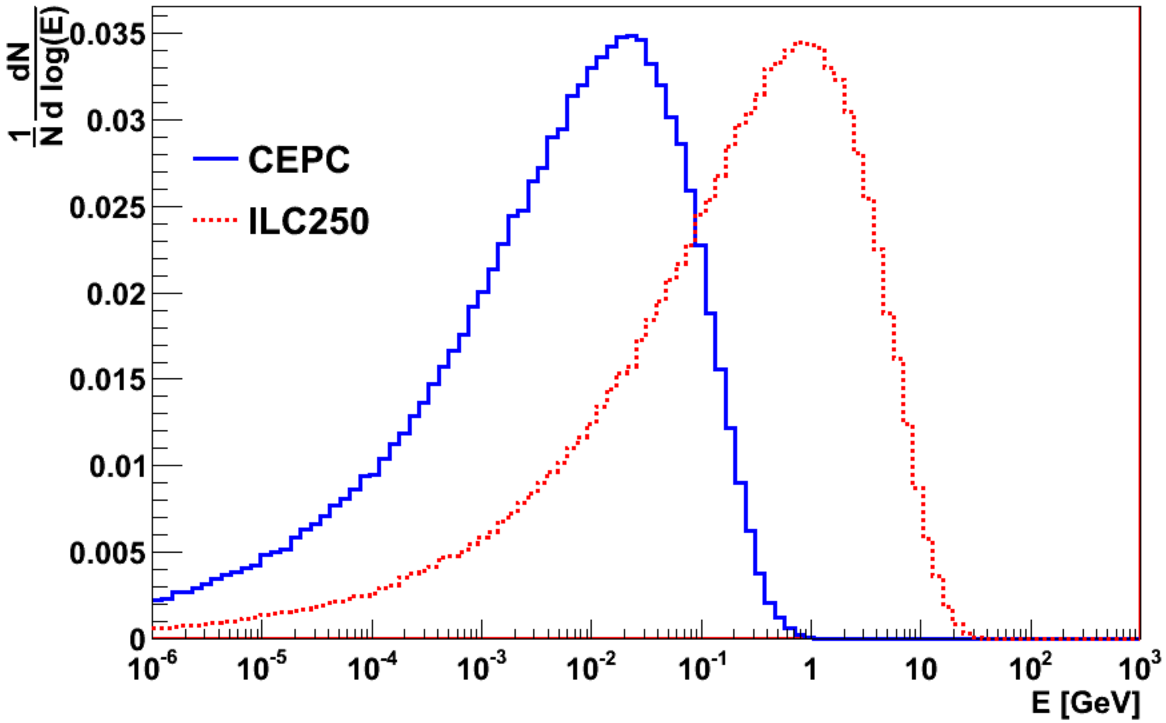


- Particles travelling on curved trajectories emit radiation; similar to synchrotron radiation but called "beamstrahlung"; collimated in a small cone along the beam axis.

- Beamstrahlung can cause significant problems for the collider (power dissipation) and direct hit on detector components must be avoided → careful design of the collimation system.

- Can be used to monitor luminosity (not proportional though)

Energy Loss

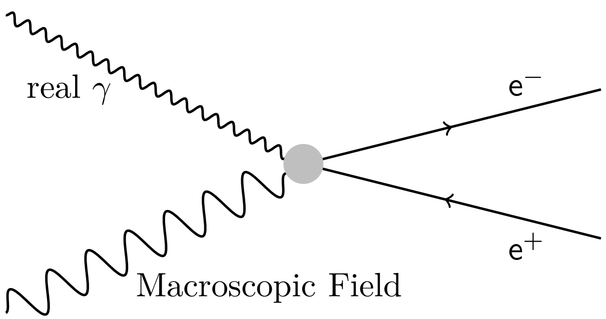


$$\delta \propto \frac{\gamma}{E\sigma_z}\left(\frac{N}{\sigma_x+\sigma_y}\right)^2$$

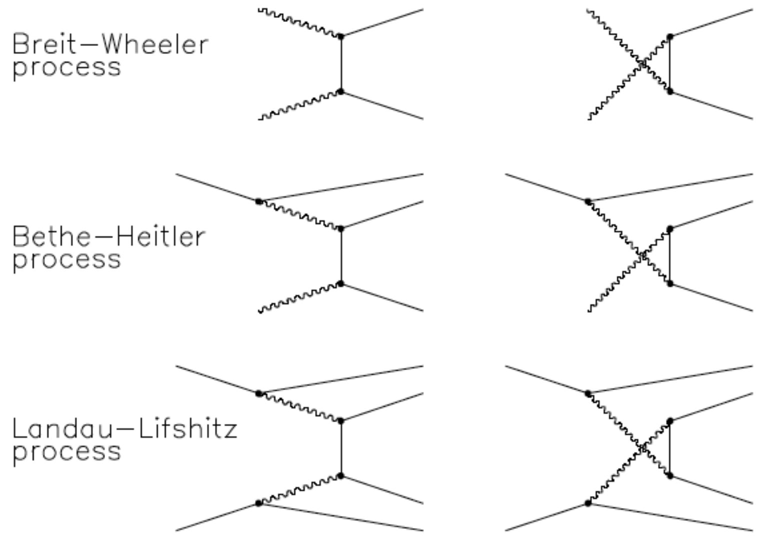
- Radiation photon energy spectrum peaks at lower energy for CEPC → lower relative energy loss as predicted

Background: Pair Production

- Coherent and incoherent electron-positron pair production; the most important background for detectors
  - **Coherent**: real photons (e.g. beamstrahlung) interaction with the coherent field of the out-coming bunch → in small angle
  - **Incoherent**: real/virtual photon interactions, including the Breit-Wheeler, Bether-Heitler and Landau-Lifschitz processes.



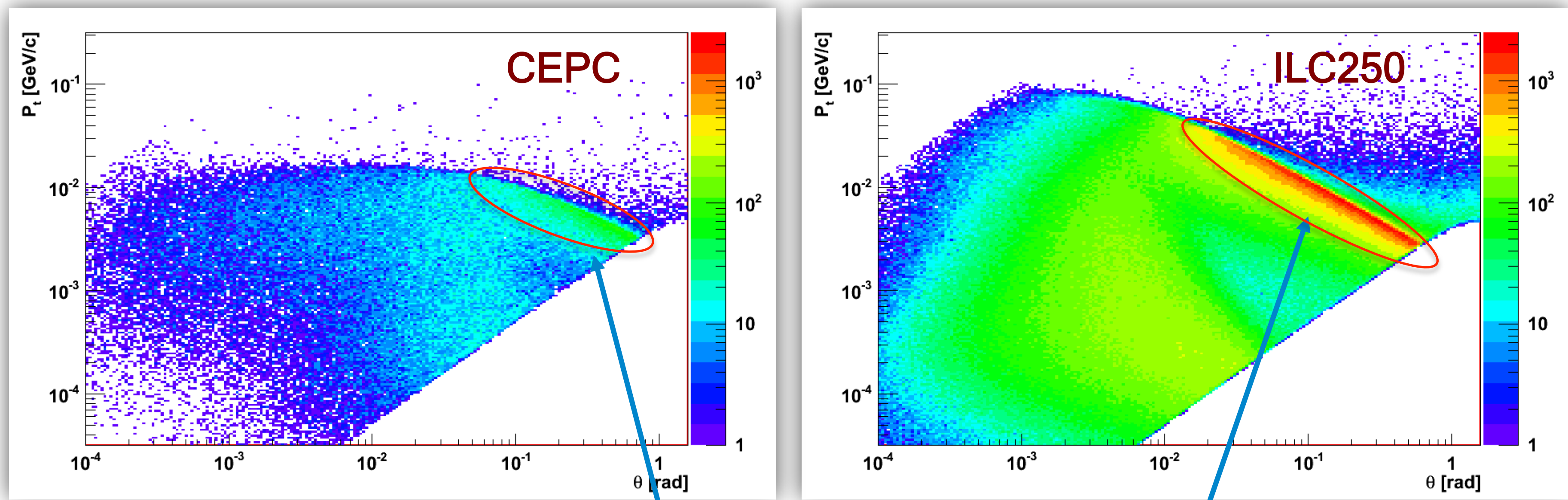
Coherent pair production



Incoherent pair production

Pair Production

- Transverse momentum of pairs vs. polar angle (integrated over 50 BX for better visualization)
- Significantly less background from pair production for CEPC, in particular in the detector coverage area

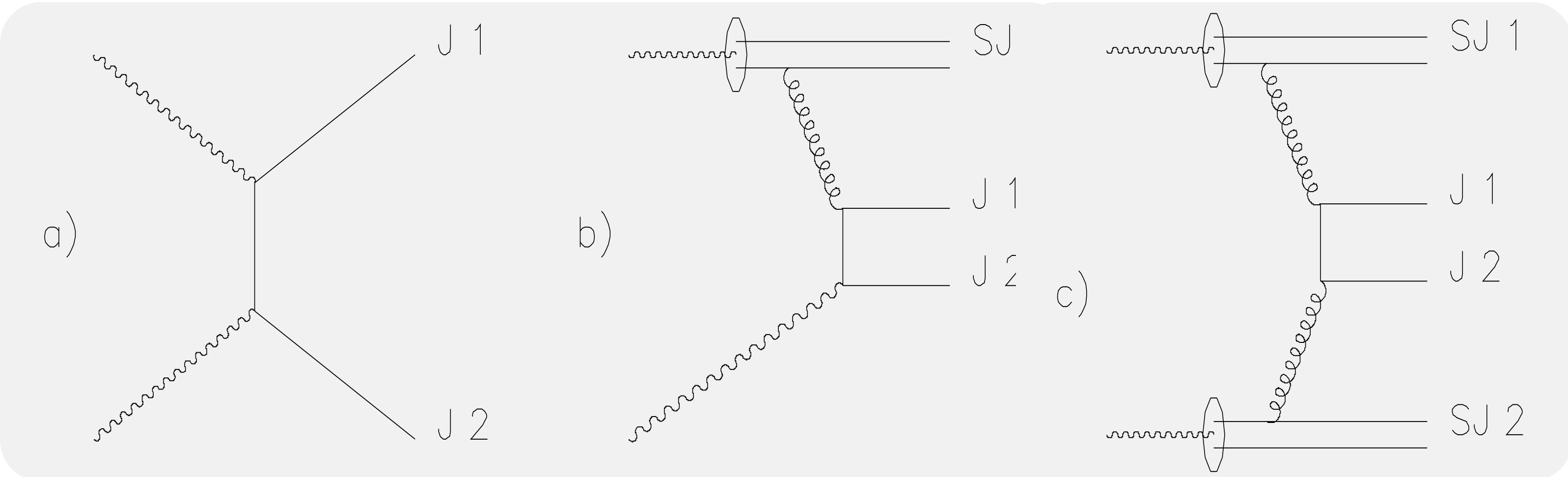


Vertex detector must be kept away from those particles.

Background: γγ→Hadrons

- Interaction of photons can also produce quark pairs (hadronic background); but cross-section much smaller compared to that of the dominant electron-positron pair production.

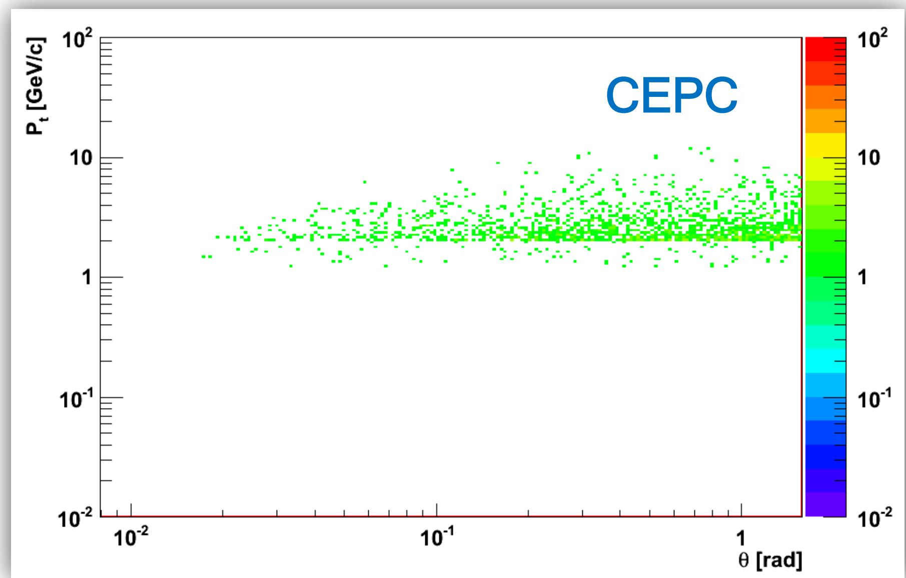
- Most events with very small transverse momenta and angles; but a small fraction of hard events called "mini-jets" can be problematic for calorimeters

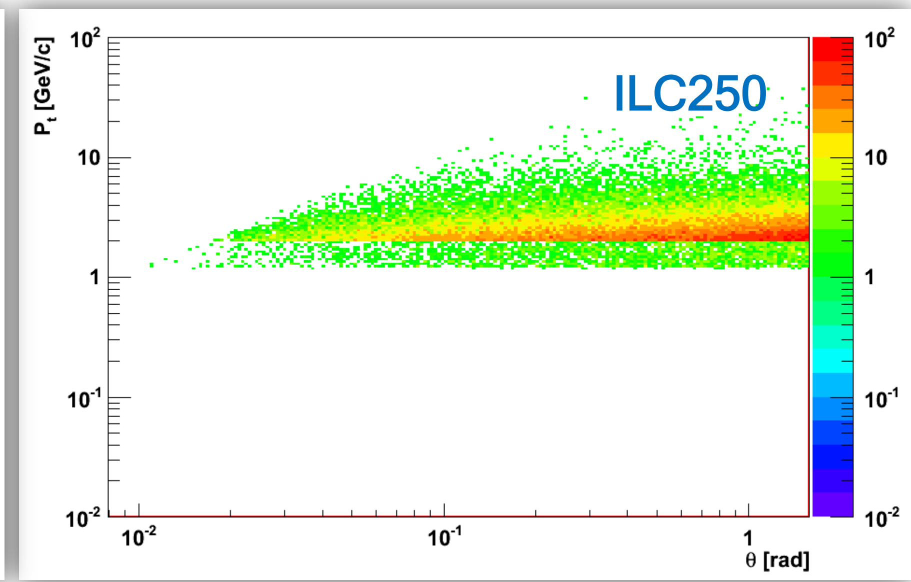


Hadronic Background

$$\gamma\gamma \rightarrow \text{hadrons}$$

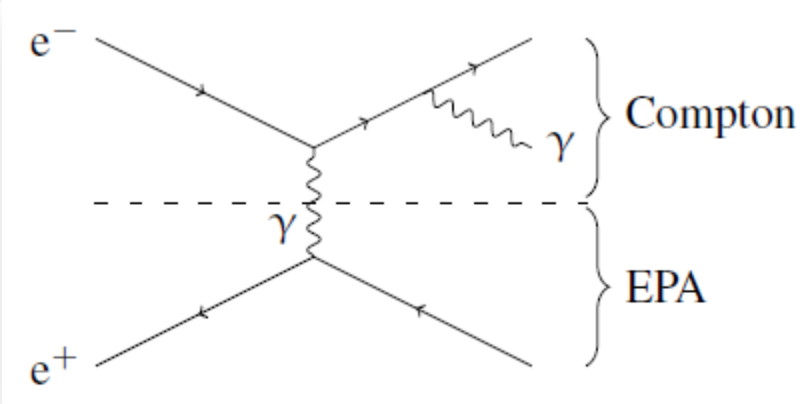
- Much smaller cross-section compared to the pair-production; artificially inflated by 10^5 to increase statistics





- Less hadronic background for CEPC thanks to the less beamstrahlung; exact impacts on calorimeters to be evaluated

Background: Radiative Bhabha Events



Implementation in GUINEA-PIG

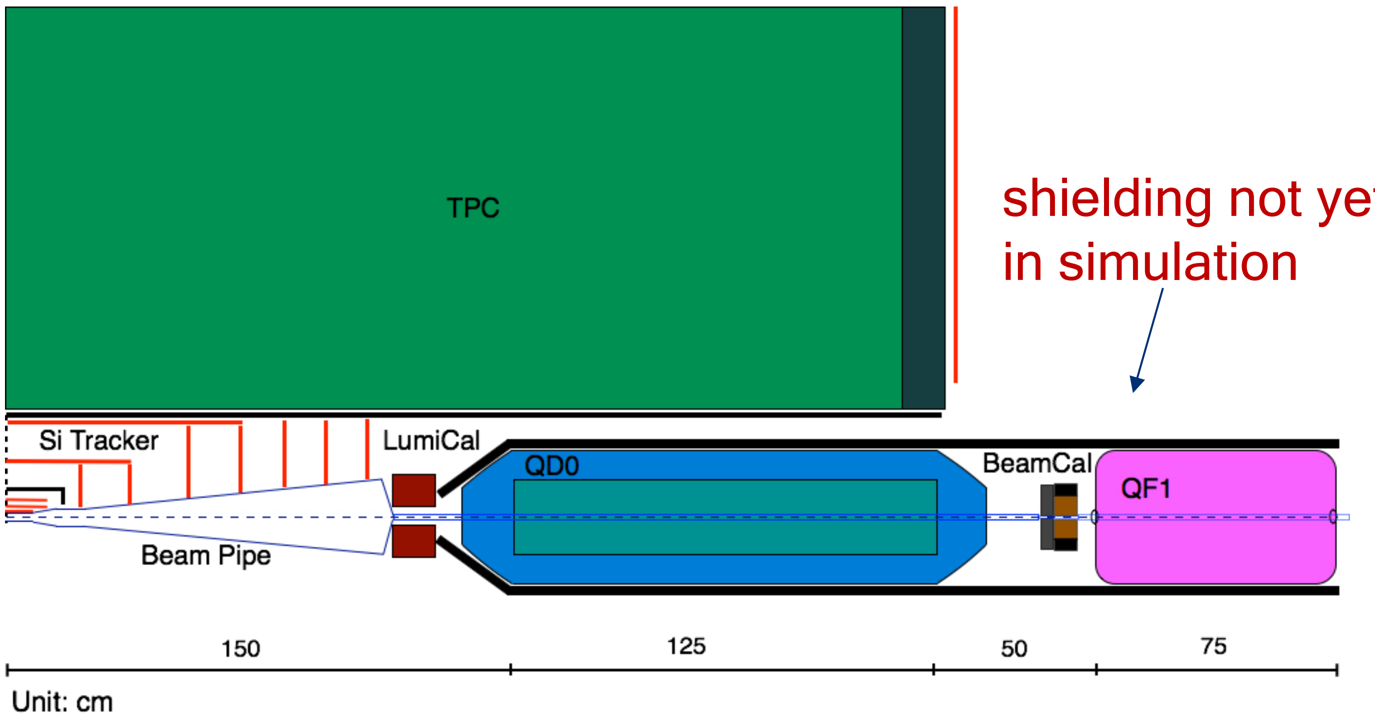
- Large cross-section, especially at small scattering angles and low center-of-mass energy.
- In GUINEA-PIG, Bhabha scattering events with small momentum transfer $Q^2 \sim p_T^2 < m_e^2$ are generated; to be fully studied with other generators, e.g. BHWIDE and WHIZARD.
- Small angle events for precise measurement of luminosity with appropriate instrumentation in the forward region

Interaction Region Layout

- ILD-like detector with re-designed IR layout to cope with the rather small L* = 1.5

Si tracker layout being optimized

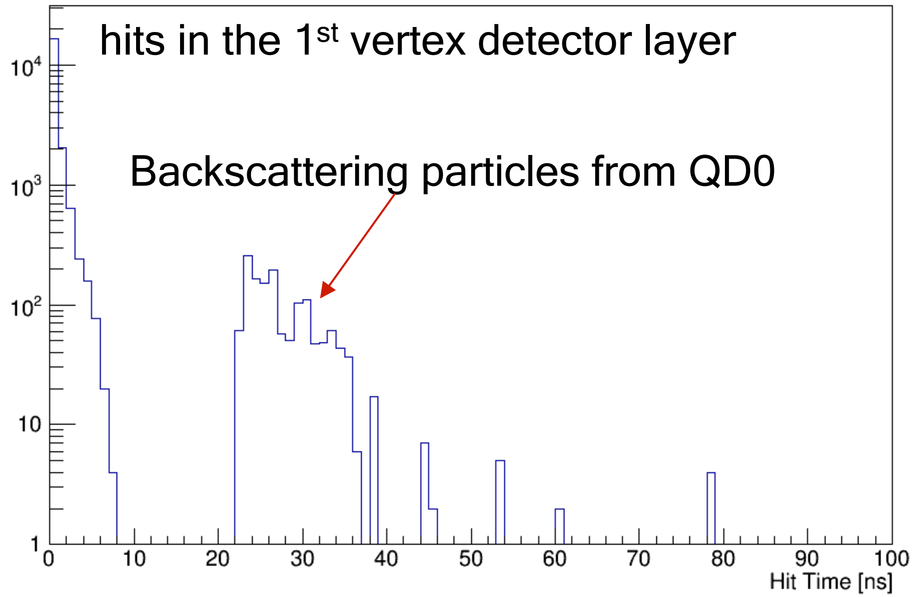
shielding not yet in simulation



- Detector simulation with the software framework of Mokka

Backscattering Particles

- background particles directly produced at IP + backscattering particles, which should be minimized as much as possible by careful detector design.



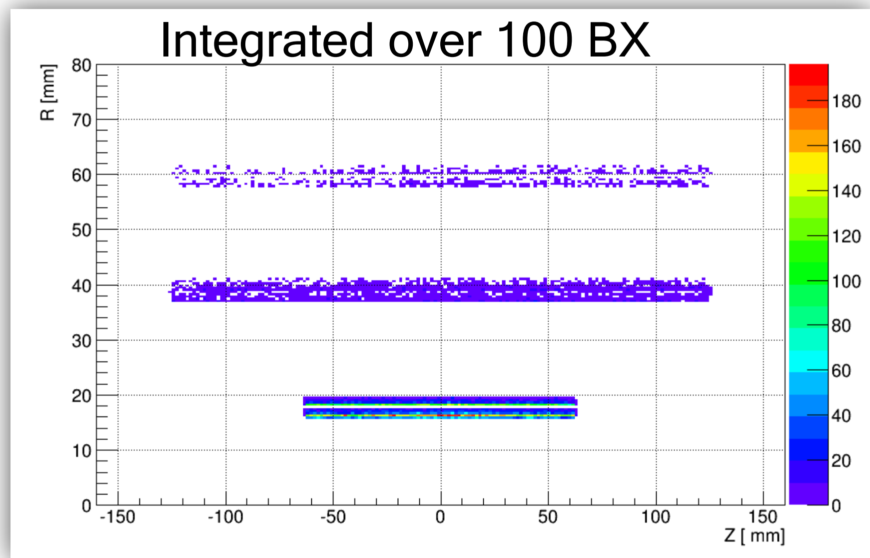
- Even more backscattering particles expected after changing the beam pipe radius from 6 cm to1.6 cm surrounded by QD0 → careful shielding required

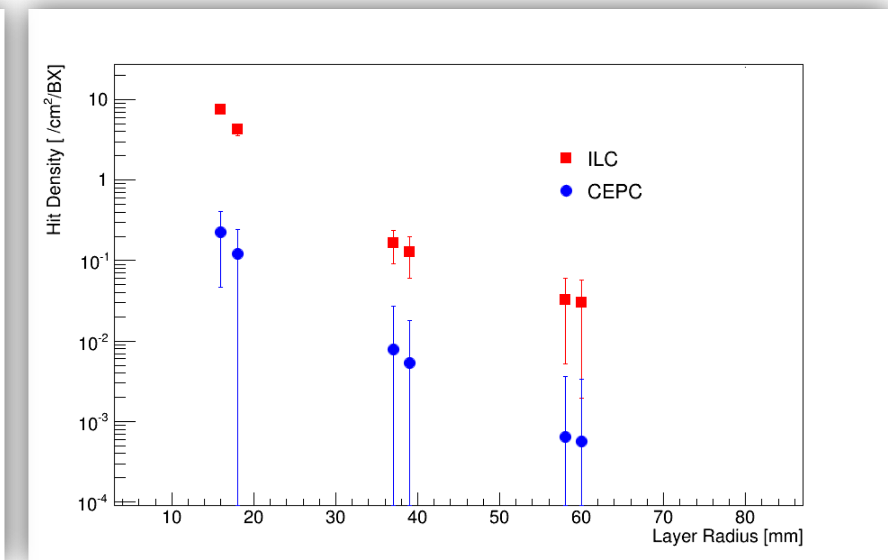
Hit Density

- The Vertex Detector placed closest to the interaction point, hence most vulnerable to radiation background
  - Radiation damage, detector occupancy, double-hit probability …

Hit Density on the 1st layer:

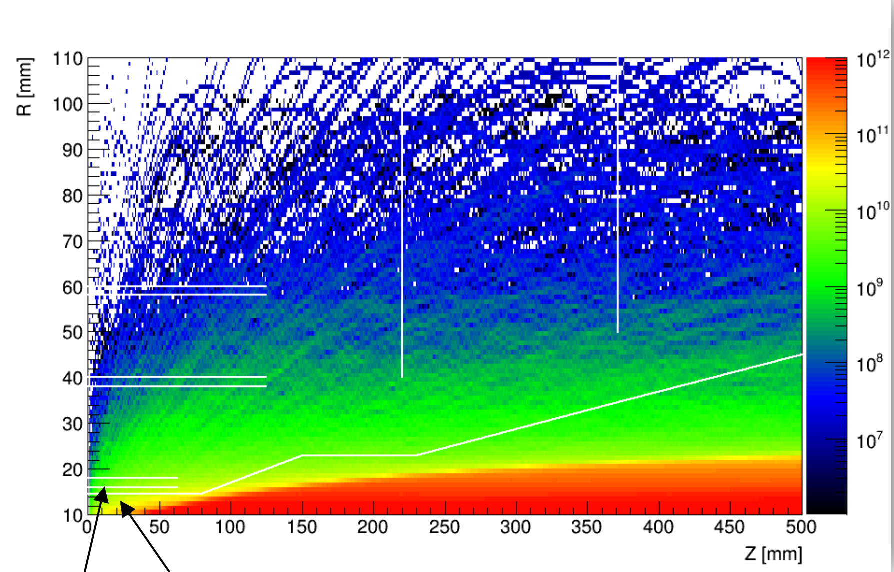
~0.2/cm^2/BX (CEPC) and 8/cm^2/BX (ILC250)

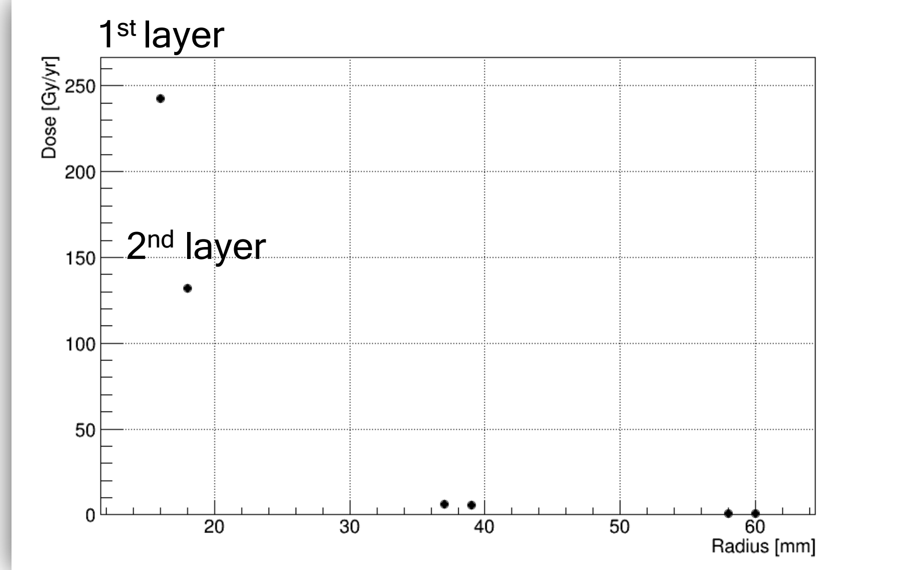




Radiation Levels

- Radiation damage, both Total Ionizing Dose (TID) and Nonionizing Energy Loss (NIEL), most critical for the Vertex Detector →rad. hard detector technology & detector layout





Beam pipe radius r=14 mm

1st VTX layer r=16 mm

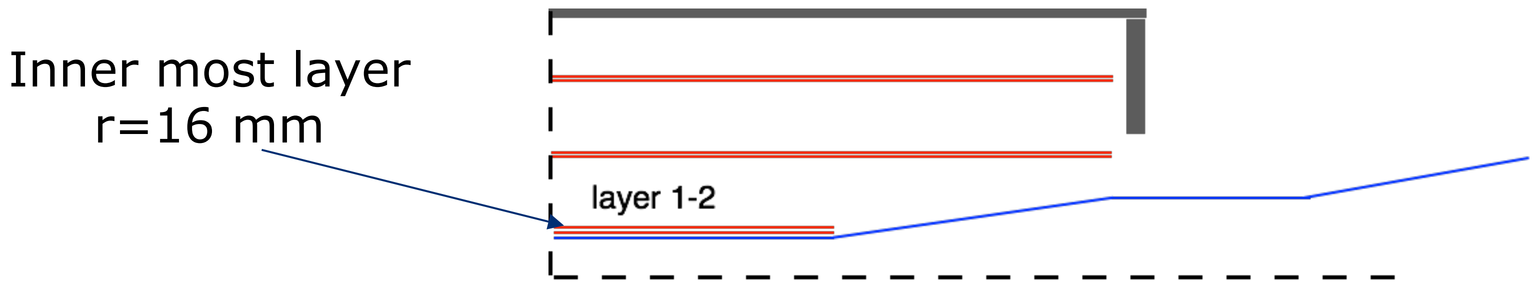
Preliminary results (1st layer):

NIEL: ~5×10^{10} n_{eq}/cm^2/year

TID: 50 kRad/year (safety factor of 2)

Closer to the Interaction Point

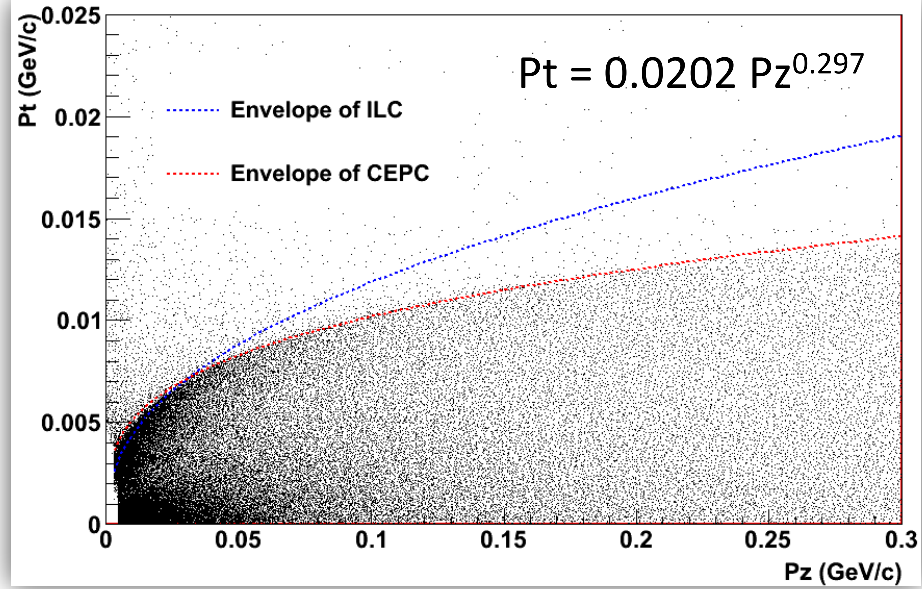
- Reduced extrapolation error from the 1st pixel layer to IP → improved impact parameter resolution → better heavy flavor tagging → Higgs branching ratio measurements

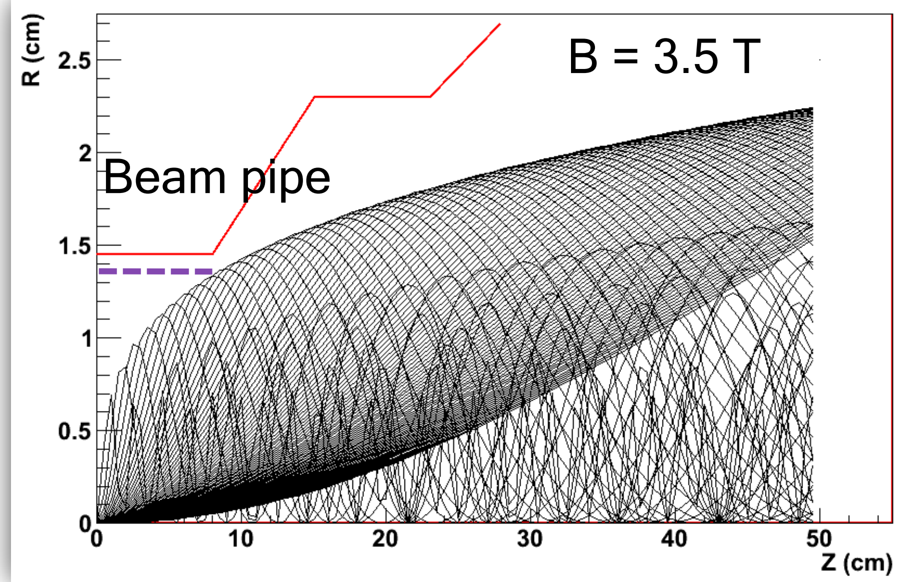


- Limiting factors on shorter distance
  - Large enough to allow SR photon to leave the detector through the quadrupole aperture (SR damage or additional collimation)
  - Away from the pair-edge of beam induced-background (particle shower, radiation damage) → *next slides*

Pair-Edge

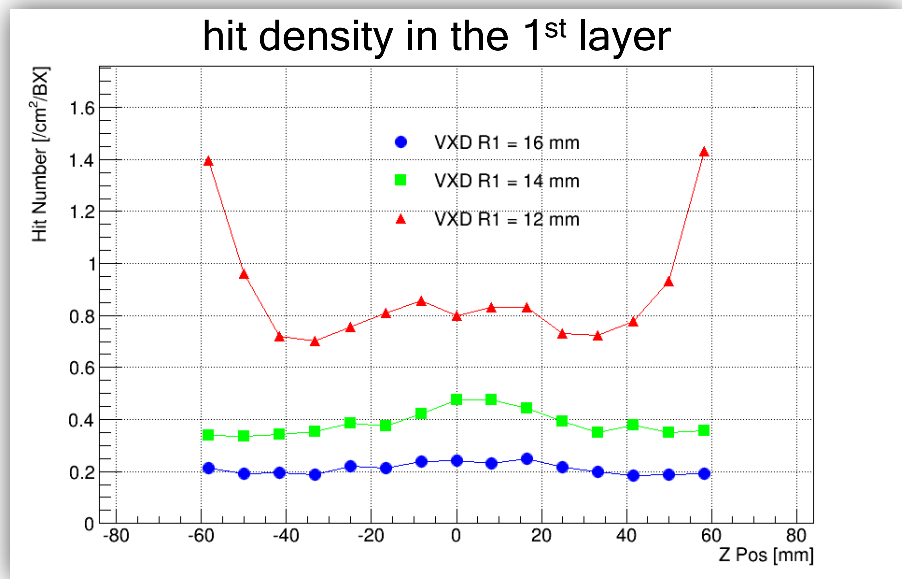
- Pairs develop a sharp edge and the beam pipe must be placed outside the edge.
- Translate the analytical function to helices in the RZ plane, taking into account the crossing angle and solenoid field.

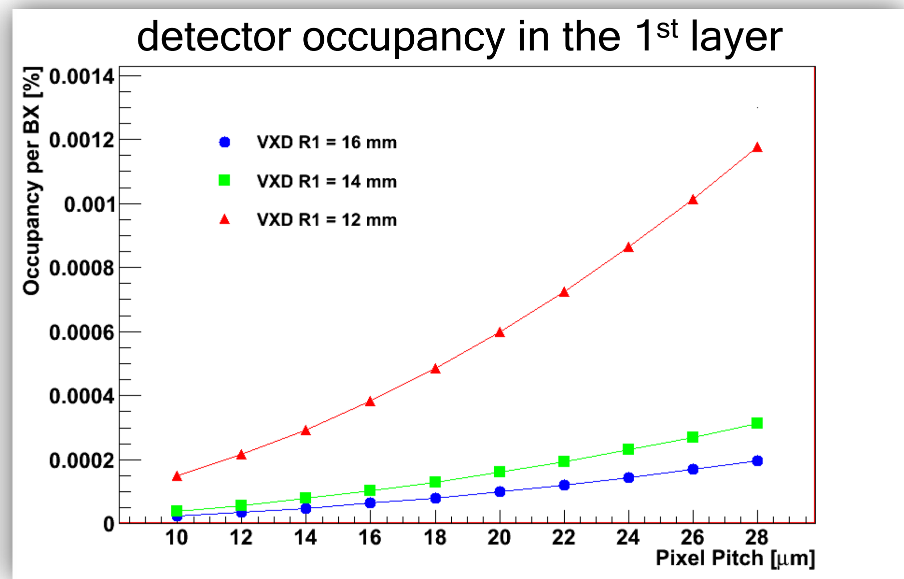




- Feasible to place the beam pipe closer by ~1 cm; more aggressive with shorter ladder and/or stronger solenoid field

Cross-checks





- Hit density increases moderately if placing the 1st layer closer by 1cm (corresponding to R1=15 mm, not plotted directly)
- Detector occupancy should be still acceptable even after accumulating over 20 BX (i.e. slow readout time of >60 µs)
- Higher sensor spatial resolution to truly benefit from a shorter distance to IP (concluded from geometry optimization studies)

Summary and Outlook

- Beam-induced background have to be carefully estimated with Monte Carlo simulation.

- Preliminary results obtained with GUINEA-PIG simulation as well as detector simulation have been presented.

- More careful studies are required to achieve better understanding of the detector background and provide guidance for detector layout optimization.

Thanks for your attention!