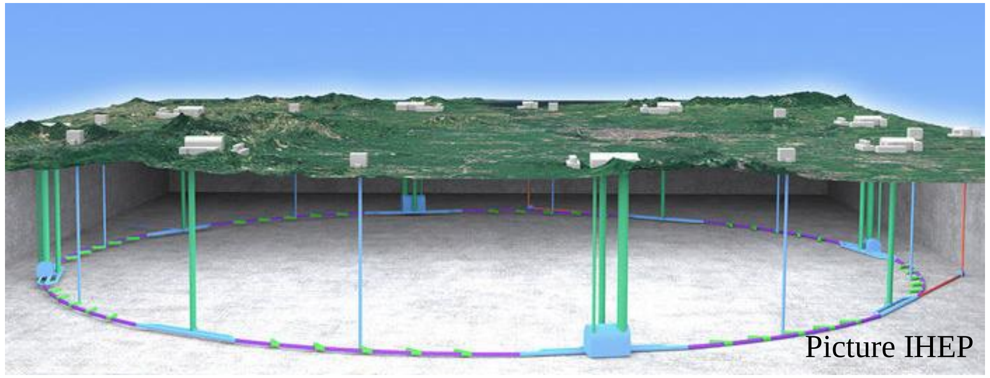
Pixel TPC for CEPC



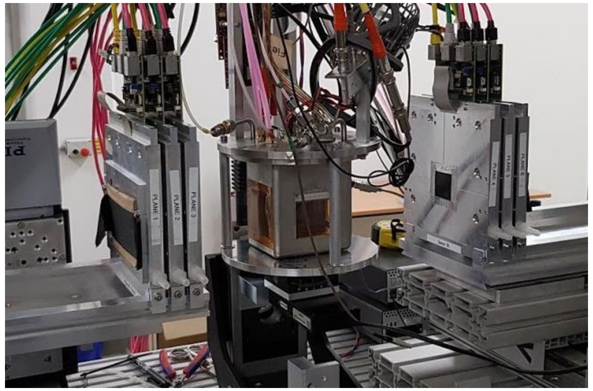
- LCWS 2019 Sendai:
  For one of the CEPC experiments there is interest in a pixel TPC
  Discussed with Huirong Qi
  https://agenda.linearcollider.org/event/8217/contributions/44627/
- CEPC workshop Beijing:
  Kees Ligtenberg https://indico.ihep.ac.cn/event/9960
- In this LCTPC workshop
  Huirong Qi presented the CEPC plans

CEPC Pixel TPC: introduction

- At a circular collider CEPC there is place for different experiments, one of them could use a TPC as the main tracker
- Why is a pixel TPC a serious and realistic option?
  - For Higgs and top running no problem for all TPC read out technologies
  - For W running probably no issue either
  - Running at the Z with high luminosities and high rates is however problematic for current micromegas and pad technologies. Tracks will overlap in the read-out plane and the occupancy at low radii will become too high
- Running at the Z with a pixel TPC?
  - Large potential in terms of rate capabilities
  - Pattern recognition profits from high granularity of 55x55 μm^2 pixels
- Will go through different aspects of CEPC Z running
  - Rates and occupancies
  - Distortions in a pixel TPC from primaries and Ion Back Flow
    - Could one apply a gating device to reduce IBF?

CEPC Pixel TPC: Z running

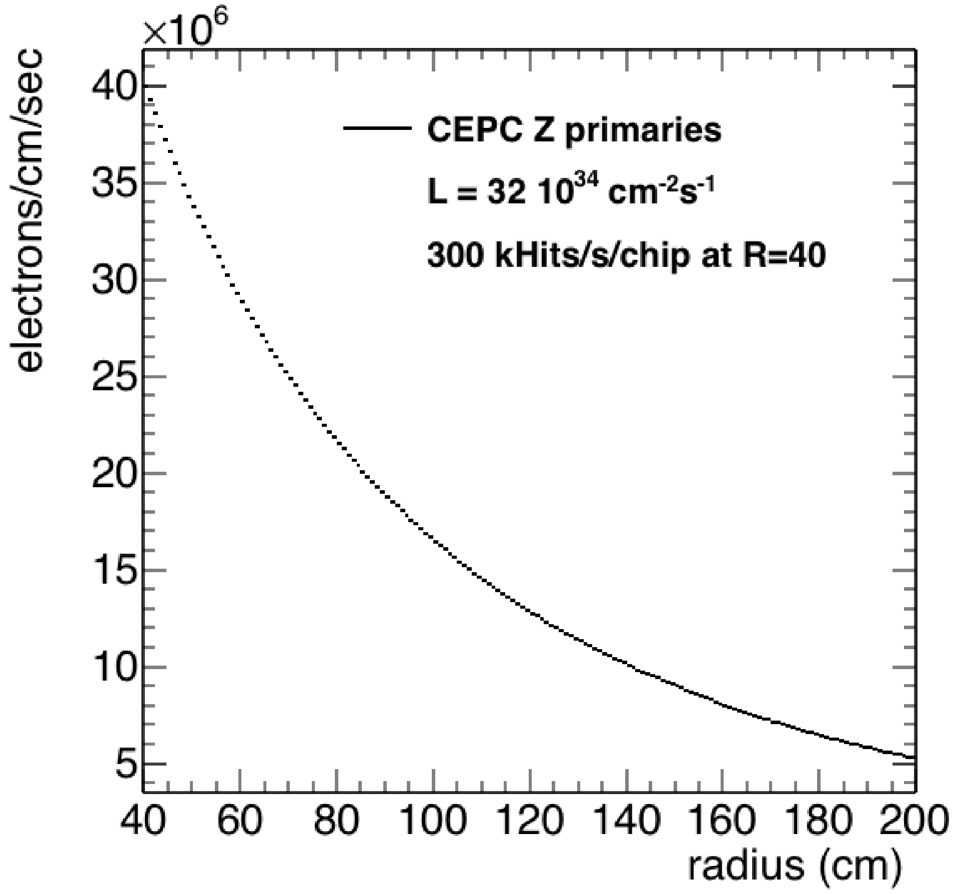
- The conditions for CEPC running
  - High(est) luminosity CEPC L = 32-50 (17-32) 10^{34} $cm^{-2}s^{-1}$ at 2 T from CDR.
    - CEPC Ring length 100 km with 12 000 bunches and a hadronic Z rate of 10-15 (5-10) k Hz (cross section 32 nb). Beam structure rather continuous 25 ns spacing.
    - Note that this Luminosity gives about 60-120 (30-60) G Zs per running year
  - Time between Z interactions 120-60 (200-100) μs
  - TPC drift takes 30 μs
  - So events are separated in the TPC



- High rate capabilities of the GridPix pixel chip TPX3
  - Bonn test beam was 5 kHz electrons for a quad
  - Link speed 80 Mbps per chip (256x256x 55 x 55 μm^2)
  - Test beam 2018 1.3M hits/s per chip could be read out
  - In 2019 the link speed doubled to 2.6M hits/s per 1.42x1.42 cm^2.

CEPC Pixel TPC rates

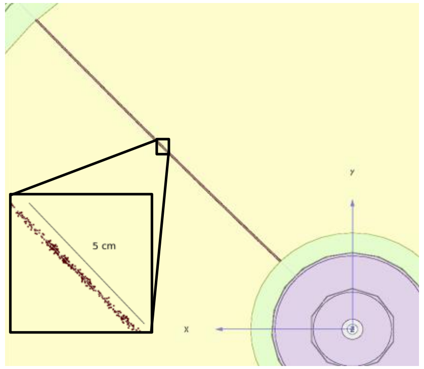
- Rates primary electrons in a Pixel TPC



- Using a simple simulation program the primary Z hit rate in the pixel TPC is calculated as a function of the radius.
- The rate amount to 300 k hits/s/chip at a radius of 40 cm.
- This is a rate the current quad and read out can easily handle.
- The test beam showed we can handle up to 2.6M hits/s per chip (1.42x1.42 cm^2). So about a factor 10 higher than what is needed.
- Occupancy rate 40/s (256*256 pixels)
  - With 0.1 ms read out< 0.004 (10kHz)

CEPC Pixel TPC: Z running

- Summary of Z rates @ L = 32 10^{34} $cm^{-2}s^{-1}$ and occupancies
  - Data is produced at a large rate of 300 k hits/s/chip (at R=40 cm)
  - In the test beam it has been demonstrated that the TPX3 can handle a rate that is a factor 10 higher
  - Occupancies are less than 1% at low radii
  - One needs to design a DAQ system to collect all data



- Pattern recognition will be no problem
  - The occupancies in the pixel plane are low. The time between the Z interactions is large 120 μs. The time will be measured by each pixel. The resolution is dominated by longitudinal diffusion. It amounts to less than about 20 nsec. Different Z events can be easily separated in time.

CEPC Pixel TPC backgrounds and distortions

- Important to estimate the charge in the TPC as it can cause distortions
  - Physics events like Zs
  - Other backgrounds γγ background and incoherent pairs from beam-beam interactions that produce hits
    - At ILC beam-beam effects are dominant over the physics interactions.
    - However TLEP and FCCee studies show that e.g. γγ background are very small at the Z. Also the incoherent pair production (backup slides) is several orders smaller than at the ILC.
    - As Adrian Vogel (DESY-thesis-08-036) in his thesis showed the detector - machine design is important to reduce the number of back scattered photons. See plot below.

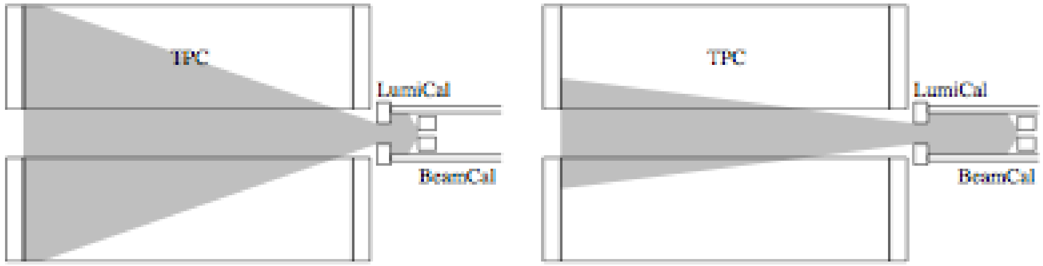


Figure 7.32: A larger distance between LumiCal and BeamCal reduces the backscattering of photons into the TPC.

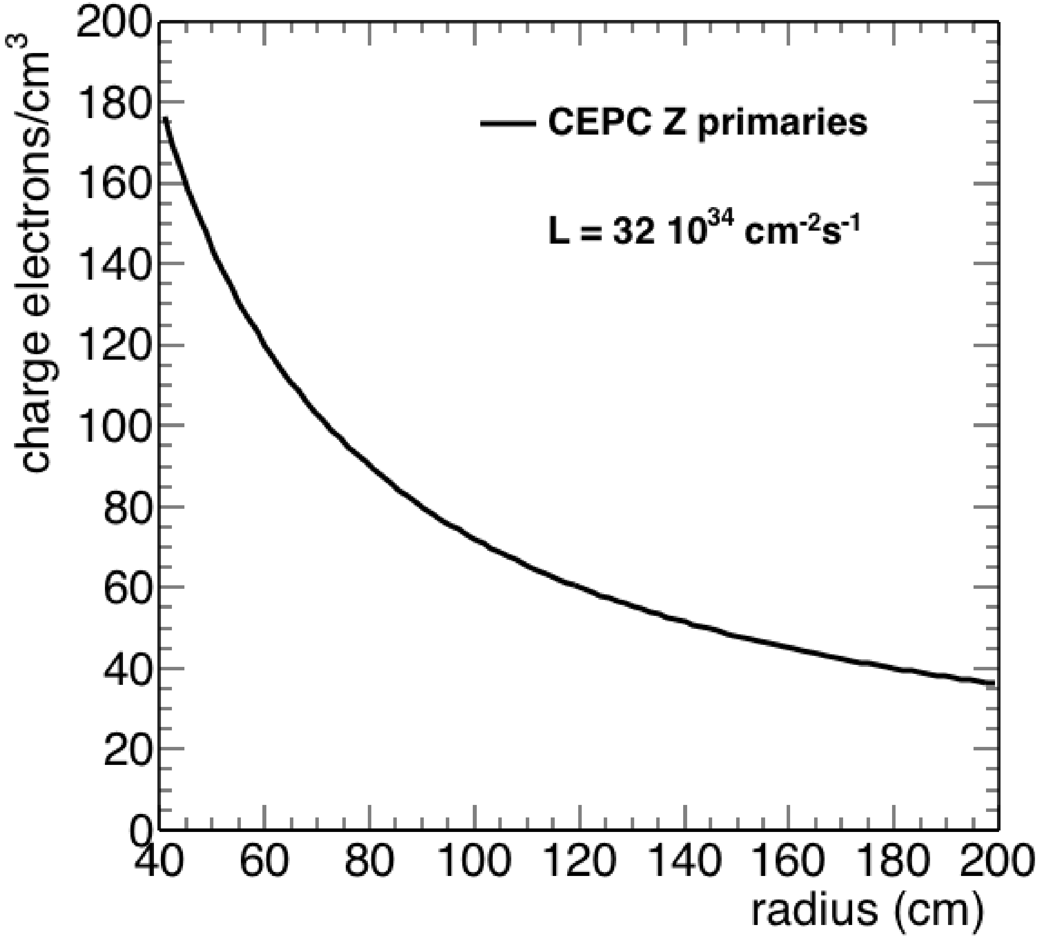
CEPC Pixel TPC: distortions from Zs

- Rate estimates for primary electrons and charge and distortions from primary ions due to Zs (back of the envelop)

  - Assume that the ions stay 0-300 ms before reaching the mid plane of the TPC. With a rate of 10-15 kHz one will accumulate 3000 - 4500 Zs; This gives 30 tracks producing 10^4 primary electrons and ions. TPC volume: Inner radius 40 cm; outer 180 cm; 400 cm length; so volume 3.8 10^7 cm^3. Charge density = 9-13 10^8/3.8 10^7 cm^3 = 23-34 e/cm^3. This is smaller than the charge at the ILC for 3000 bunches from beam-beam background (slide 9).
  - Here the studies were performed assuming no Ion Back Flow. Ions are produced in the gas amplification stage. A fraction of them will flow back into the TPC drift volume. For a Gridpix detector this is O(0.1%). A precise measurement will be performed in 2020.

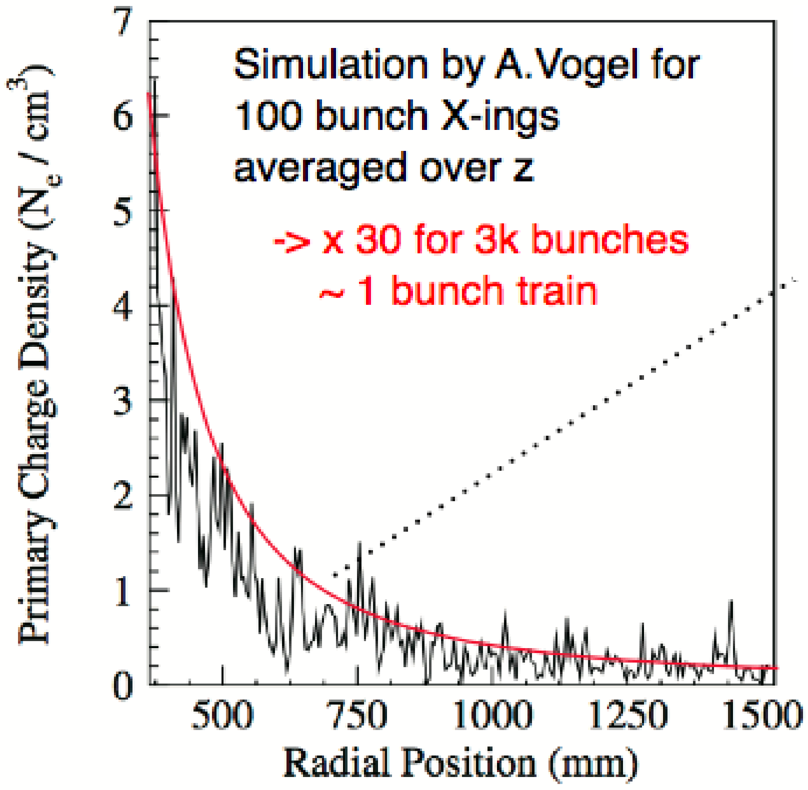
CEPC Pixel TPC charge and distortions

- Charge from primary ions due to Zs (back of the envelop)



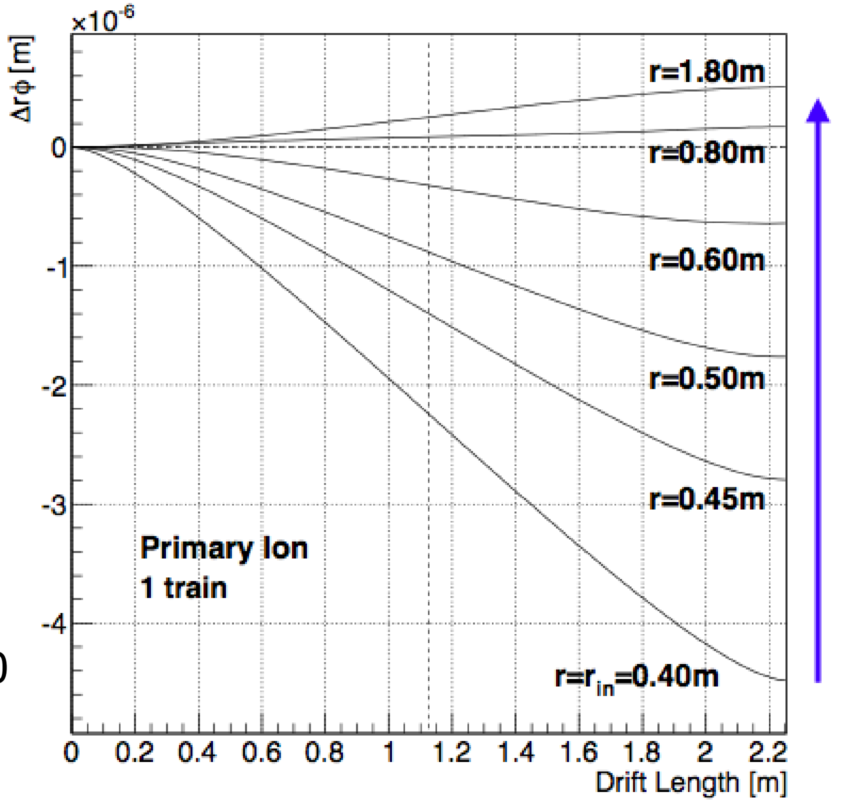
- At ILC this accumulated charge in the TPC bkg leads to distortions of max 5 µm. See next slide for details. Here no ion back flow IBF=0 is used.
- The CEPC study presented by Huirong Qi (backup) gives a larger number of up to 80 µm with IBF=5 and a lower luminosity.
- The distortions will depend on the IBF number of the device. With IBF = 1.5 (gas gain 1500 and IBF fraction 0.1%), the distortions are maximally 13 µm.

ILC beam-beam primary ions in TPC



Fit by D.Arai

$$\bar{\rho}_r(r) = 1.6 \times \frac{1}{4(r-0.2)^2} \times 30 \times 10^{-13} \quad [\mathrm{C/m^3}]$$

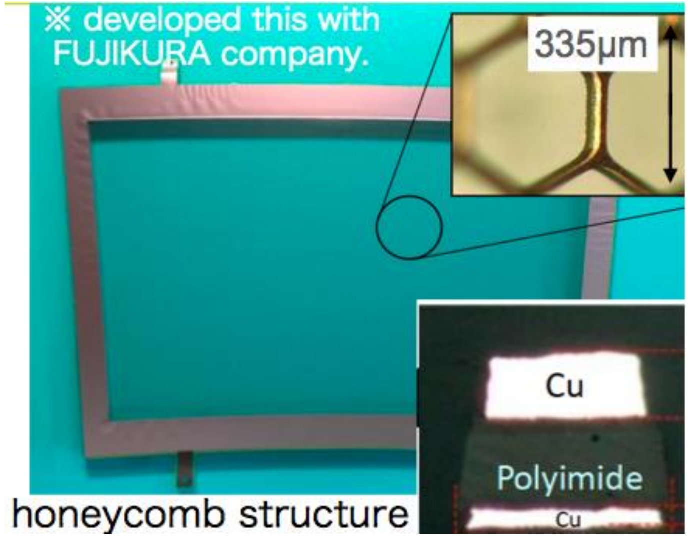


So deformations for a primary charge distribution (x 30) are less than 5 μm

Studies from Keisuke Fuji https://agenda.linearcollider.org/event/5504/contributions/24543/attachments/20144/31818/PositiveIonEffects-kf.pdf)

CEPC Pixel TPC gating

- Possible CEPC triggered gating scheme
  - Time between Z collisions is 120 μs. So one can think of gating
  - Make a GEM gating device a la ILD (see picture) but now at 1-5 mm above the grid
  - Gating in a triggered mode;
    - if a hadronic Z interaction in TPC start gating "stop the ions".
  - Gate length of e.g. 30-60 μs would stop the ions in Z triggered mode
    - the price is dead time, reduced efficiency
    - Trade off between IBF reduction 0 and efficiency 100%
  - This might work and will reduce IBF and distortions
- NB: ILC gating can exploit bunch structure: Gate opens 50 μs before the first bunch and closes 50 μs after last bunch. Close time between bunches 200 ms. Device 1 cm above grid.



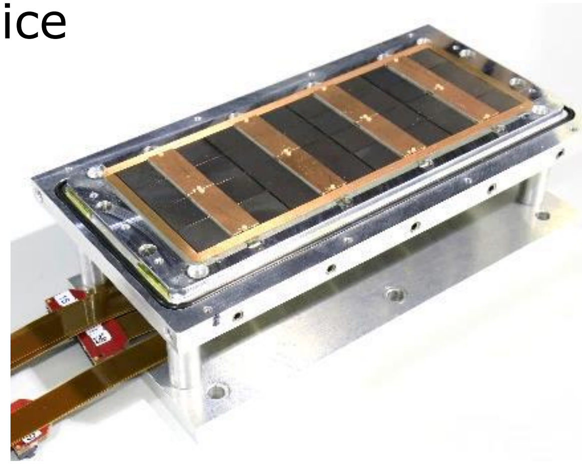
Yumi Aoki @ LCWS2019

CEPC Pixel TPC NO gating

- Depending on the IBF, the distortions could also be measured and corrected for
- Due to the large Z data set it will be possible to correct for the distortions in a timely manner. Suppose one has distortions that correspond to IBF = 15 (applying a safety factor 10). The maximum deviation will be 130 μm at small radii. It is realistic to assume that one can measure this number with a precision of 13 μm (factor 10) using the vertex detector.
- This means that one can reach the precision requirements of the ILD TPC: the systematics in the bending plane will be less than 10-20 μm
- NB for the W and Higgs runs it is important to install and use a gating device

CEPC Pixel TPC Summary

- A pixel TPC can handle the large data rates during CEPC Z running. The pixel occupancies are low and the pattern recognition will have no problem to separate events and find the tracks.
- Estimates have been presented for deformations coming from charges from primary Z events and Ion Back Flow. The maximum at small radius is 13-130 μm (safety factor 10).
  - The IBF can be reduced by applying a triggered gating device
  - With and without gating, the deformations can be corrected for and controlled at a level of the tracking requirements of the ILD TPC; systematics in bending plane: less than 10-20 μm
  - For the W and Higgs runs it is important to apply a gating device
- A pixel TPC is a realistic option at the CEPC and provides:
  - High precision tracking in the transverse and longitudinal planes
  - dE/dx by electron and cluster counting
  - Excellent two track resolution
  - Digital readout that can deal with high rates



backup

Physics requirements

- TPC limitations for Z
  - Ions back flow in chamber
  - Calibration and alignment
  - Low power consumption FEE ASIC chip

Huirong Qi

	ALICE TPC	CEPC TPC
Maximum readout rate	>50kHz@pp	w.o BG?
Gating to reduce ions	No Gating	No Gating
Continuous readout	No trigger	Trigger?
IBF control	Build-in	Build-in
IBF*Gain	<10	<5
Calibration system	Laser	NEED

Compare with ALICE TPC and CEPC TPC

CEPC CDR

Lumi.	Higgs	W	Z	Z(2T)
$\times 10^{34}$	2.93	11.5	16.6	32.1

Luminosities exceeded those in the preCDR

- double ring baseline design (30MW/beam)
- switchable between H and Z/W w/o hardware change (magnet switch)
- use half SRF for Z and W
- can be optimized for Z with 2T detector

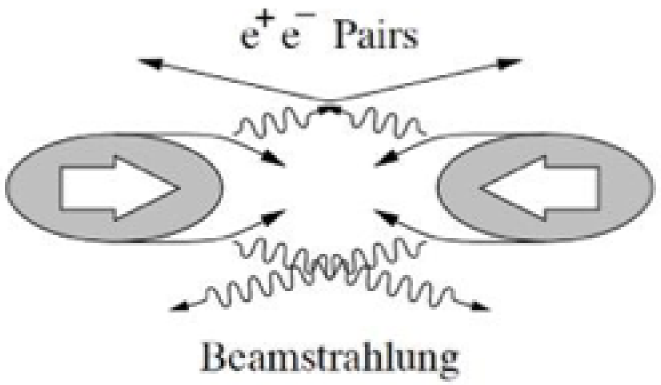
backup

BEAMSTRAHLUNG & PAIR PRODUCTION

CEPC Oxford

https://indico.cern.ch/event/783429/contributions/3379893/attachments/1830789/2998159/CEPC_Backgrounds_Oxford_Zhu.pdf

- 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*)



Simulated with GUINEAPIG with external field implemented

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 electrons/positrons can hit the detector → radiation backgrounds

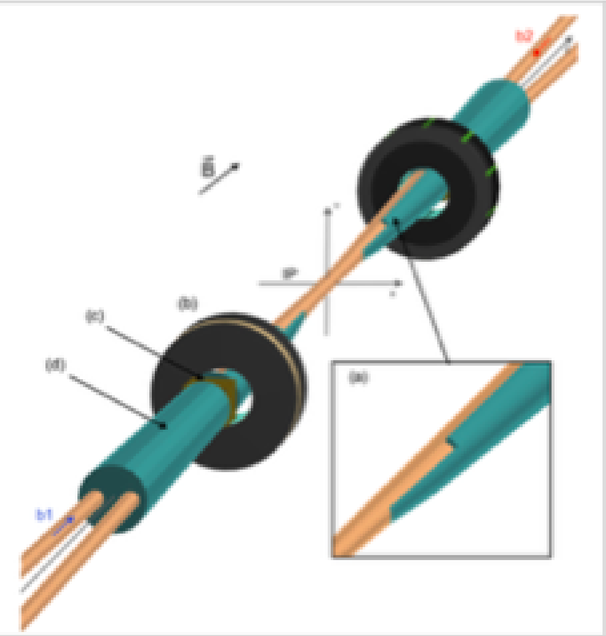
Hadronic backgrounds much less critical

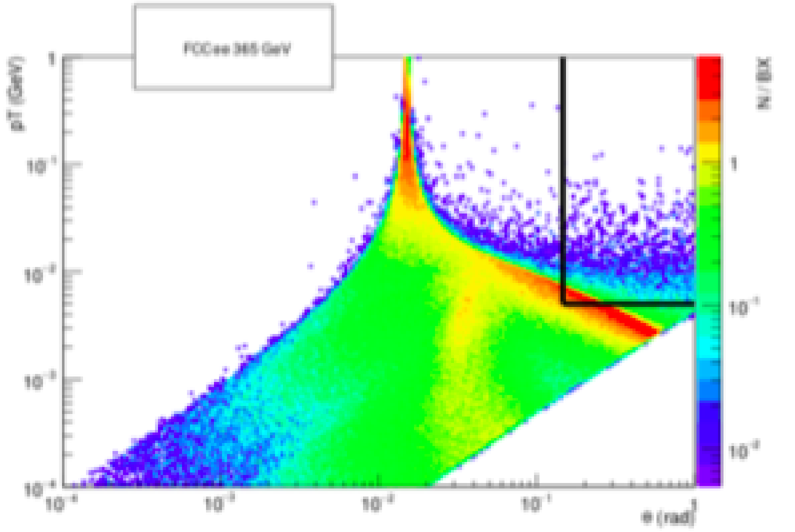
Vertex Detector Beam Backgrounds

Main beam backgrounds: synchrotron radiation, incoherent $\gamma\gamma \to e^+e^-$ pairs, $\gamma\gamma \to$ hadrons

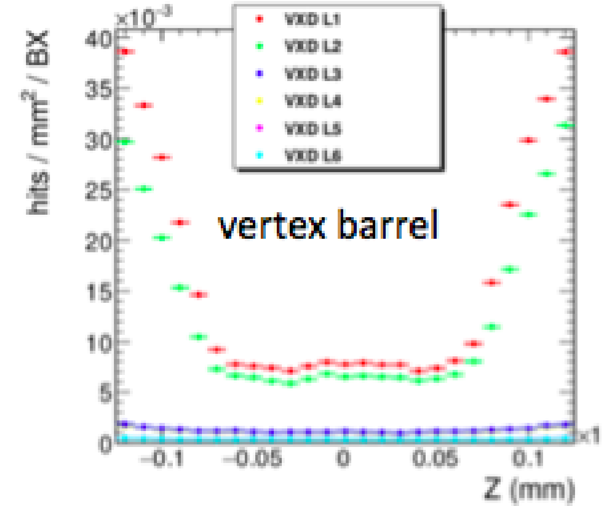
Backgrounds negligible everywhere except at $\sqrt{s}$ = 365 GeV:

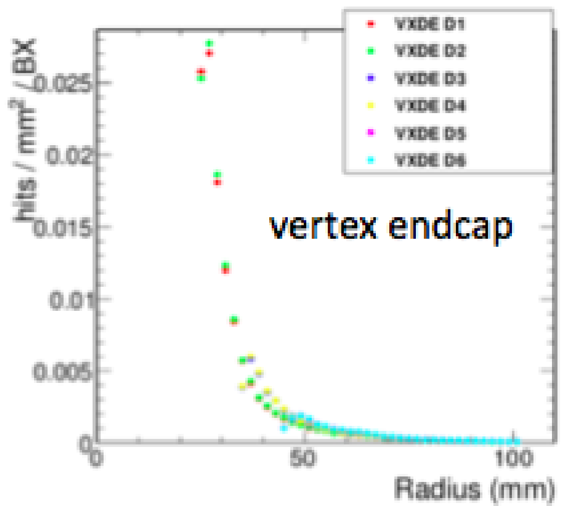
- ⇒ synchrotron radiation (SR)
  - ⇒ 7×10^4 hits / BX in the vertex detector
  - ⇒ reduced to 350 hits / BX with beam pipe shielding
- ⇒ incoherent pair creation (IPC)
  - ⇒ 1100 hits / BX in the vertex detector
- ⇒ $\gamma\gamma \to$ hadrons
  - ⇒ negligible





e^+e^- produced with E>5 MeV





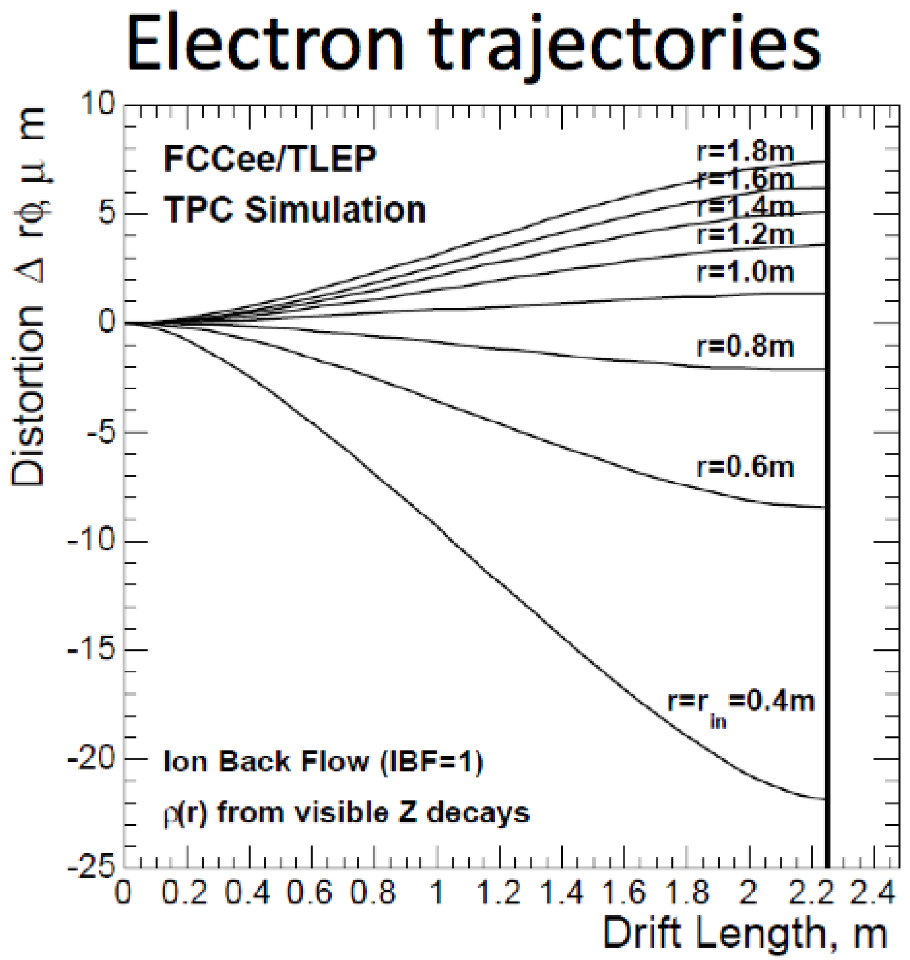
@91 GeV: max $10^{-5} \times$ 50BX < 10^{-3}

Studies for CLD detector
Expect similar results for IDEA

backup

Pixel TPC for TLEP/FCCee

- Distortions from primary ion from Zs have been performed by Schwemling for a TPC at TLEP/FCCee https://indico.cern.ch/event/467955/



- Note here the Z rate is 16 kHz so similar to CEPC at 50 10^{34} $cm^{-2}s^{-1}$.
- Studies are more detailed – use Pythia plus distortion program from Keisuke Fuji- than a back of envelop calculation.
- NB IBF is not zero but put to 1.
- The number of ions/cm is not 100 but only 40. So a bit low.

backup

Huirong Qi

This is based on physics events

No beam-beam

Deviations due to primary ions should be factor 5 smaller

In my calculations
L = 32-50 10^{34} $cm^{-2}s^{-1}$
at 2 T.

Simulation of deviation with IBF (k=Gain×IBF) @CEPC

here L = 17 10^{34} $cm^{-2}s^{-1}$