CEPC Pixel Time Projection Chamber

- LCWS 2019 Sendai: for one of the CEPC experiments there is interest in a pixel TPC
- CEPC workshop Beijing; Kees Ligtenberg https://indico.ihep.ac.cn/event/9960
- Discussed with Huirong Qi (https://agenda.linearcollider.org/event/8217/contributions/44627/)
  - In his talk presented issues with a TPC running at the Z (next slide)
    - Higgs running no problem for TPC
    - For high Lumi Z run distortions due to Ion Back Flow
    - As ALICE one can run without gating (reducing the IBF of the GEMs)
    - Ion Back Flow measurements IBF with a MM show Gain*IBF = 5

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

CEPC Pixel TPC

- What is the situation for a pixel TPC?
  - Large potential in terms of rate capabilities
  - Pattern recognition high granularity works in high Z rate
  - Question what is the IBF for our GridPix? O(0.1%) We will measure it.
- Can we apply gating in Z collisions?
  - High(est) luminosity CEPC L = 32-50 (17-32) 10^{34} $cm^{-2}s^{-1}$ at 2 T.
    - CEPC Ring length 50 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 14 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; gating is possible

CEPC Pixel TPC

- High rate capabilities of the GidPix 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)
  - Testbeam 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.

- Possible CEPC gating scheme for physics events
  - Make a GEM gating device a la ILD but now at 1-5 mm above the grid
  - Gating in a triggered mode;
    - if a hadronic Z interaction in TPC start gating
  - Gate length of 30-60 μs would stop the ions in Z triggered mode
    - the price is dead time, reduced efficiency;
    - One will start "leveling" if gate time = 20 μs -> efficiency 66-85%
  - Needs thinking but might work and reduce IBF and (therefore) 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.

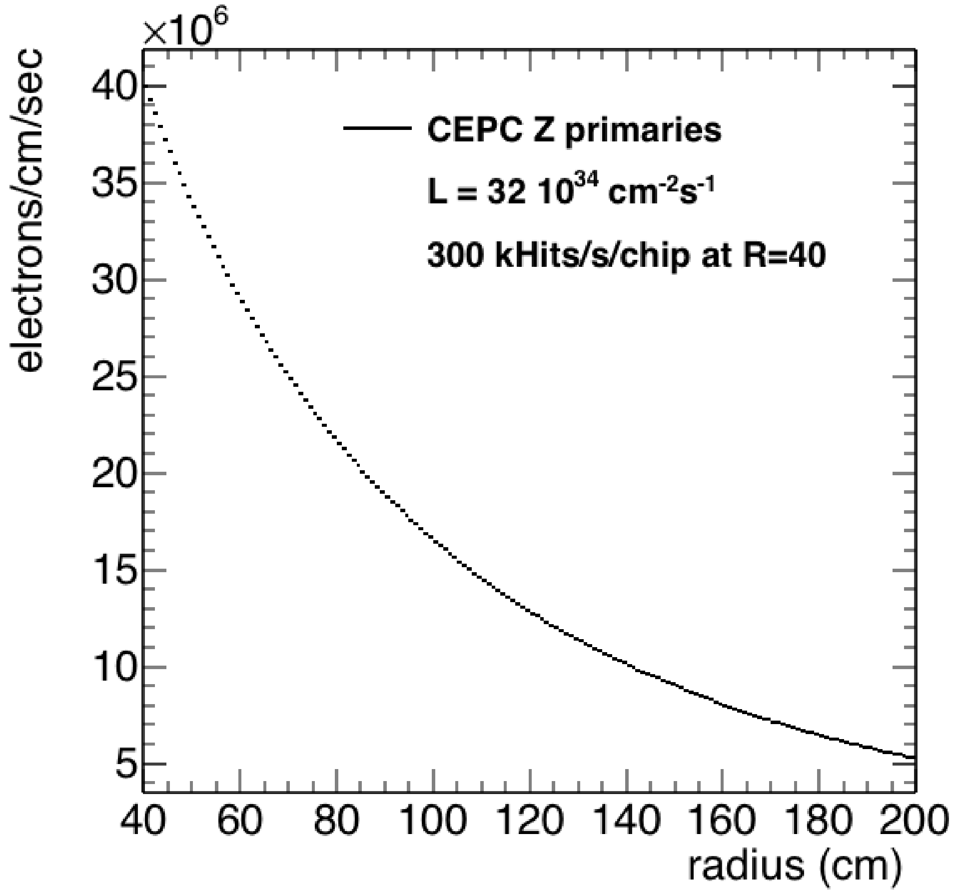
CEPC Pixel TPC

- Important to estimate the charge in the TPC as it causes distortions.
  - Physics events like Zs
  - Other backgrounds γγ background and incoherent pairs from beam-beam interactions that produce hits

- 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 7).

CEPC Pixel TPC rates

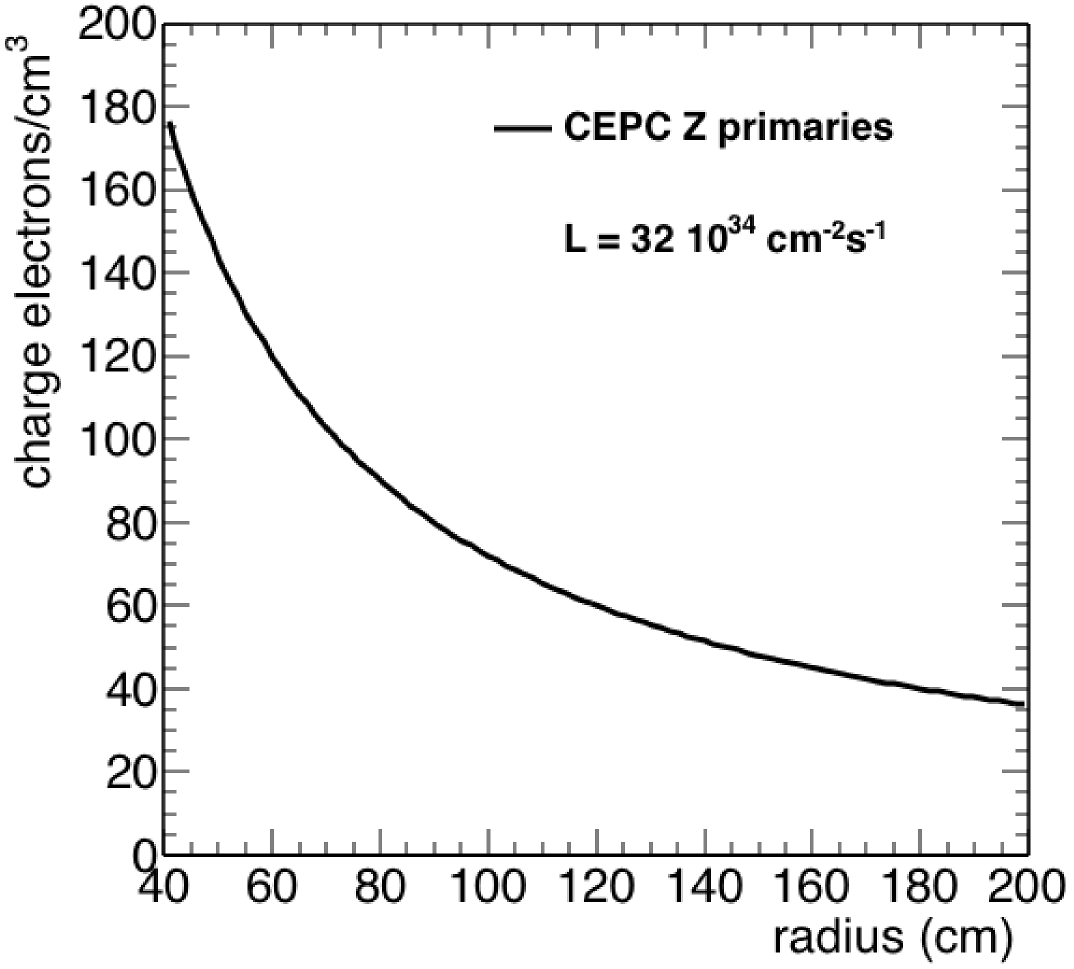
- Rates primary electrons in a Pixel TPC (back of the envelop)



- Using a 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 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)

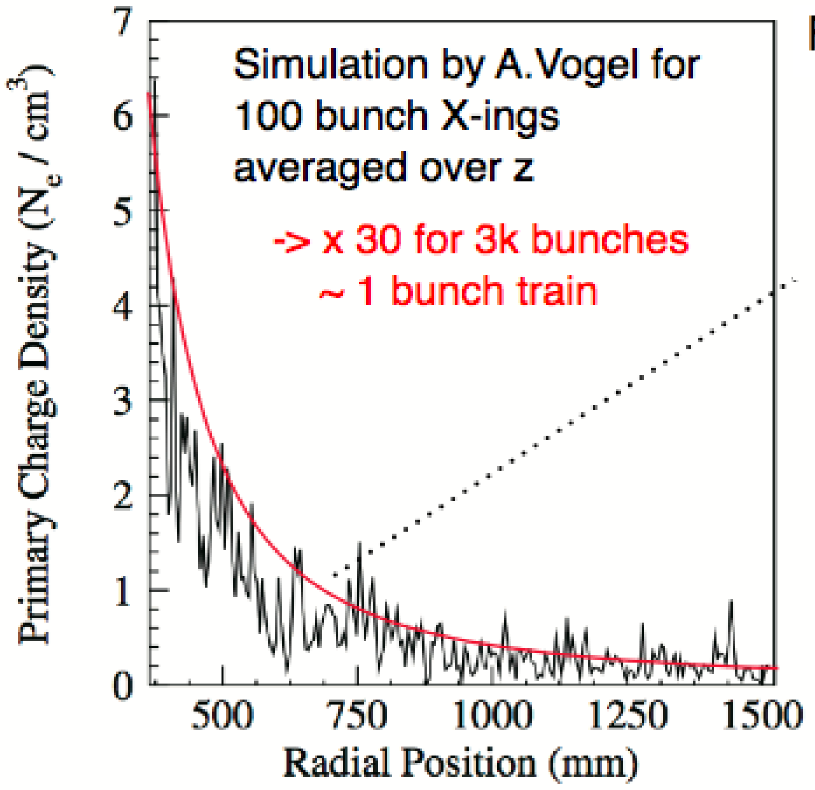
CEPC Pixel TPC charge

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



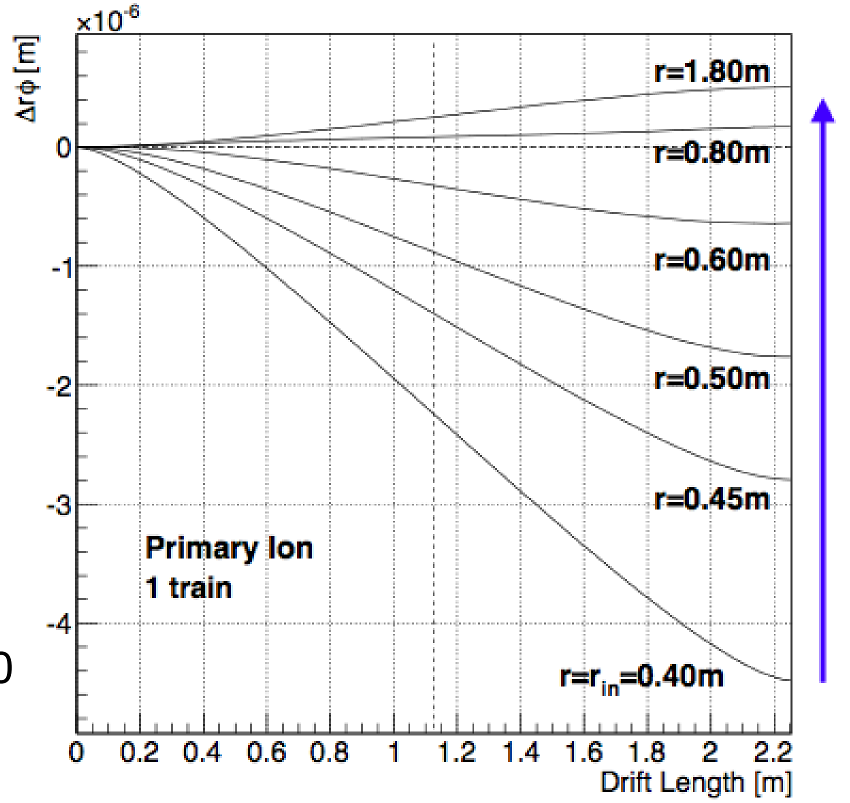
- At ILC this accumulated charge in the TPC bkg leads to distortions of max 5 μm. See next slide for details. Here no ion back flow IBF=0 is used.
- The CEPC study by presented by Huirong Qi (backup) gives a larger number of up to 80 μm with IBF=5 and a lower luminosity.
- So assuming that the IBF for Zs can be gated (IBF < 1) with the proposed trigger scheme these distortions are rather small.

ILC beam-beam primary ions in TPC



Fit by D.Arai

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

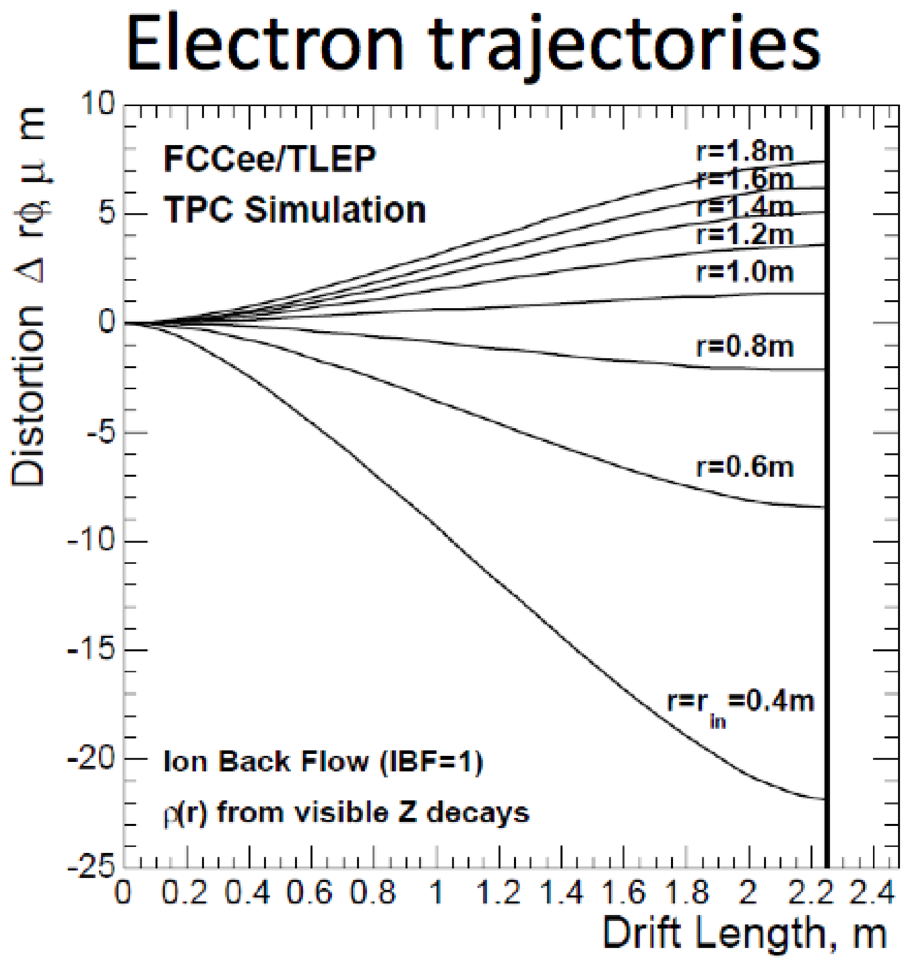


So deformations for a primary charge distribution (x 30) are less than 5 μm

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

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 lowish.

CEPC backgrounds Pixel TPC

- What is the charge of the other backgrounds in the TPC?
  - At ILC beam-beam effects from primary ions 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.

DESY-thesis-08-036

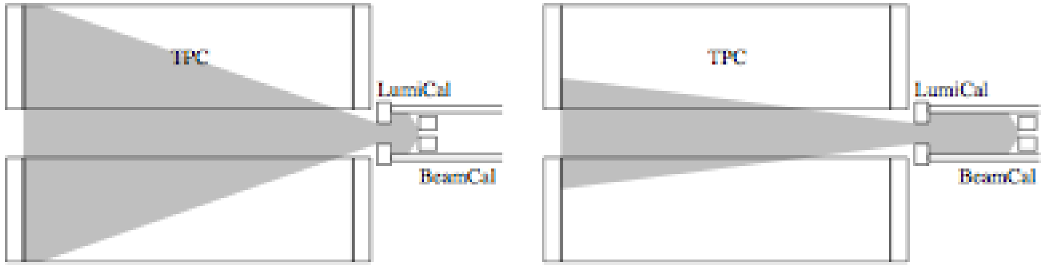


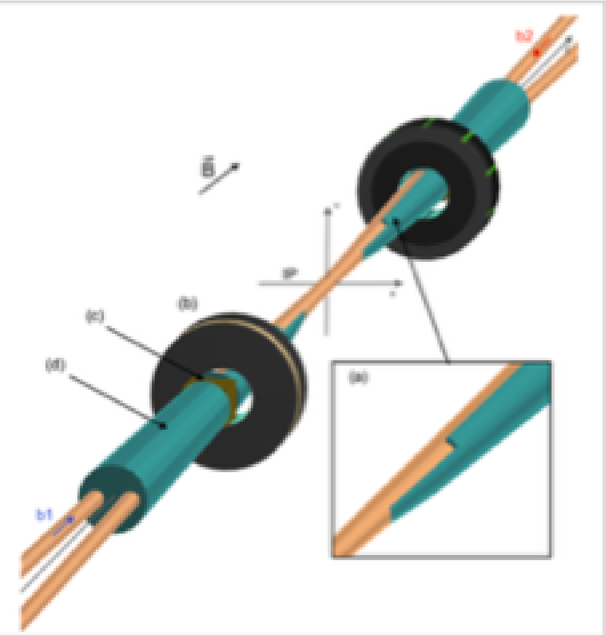
Figure 7.32: A larger distance between LumiCal and BeamCal reduces the backscattering of photons into the TPC.

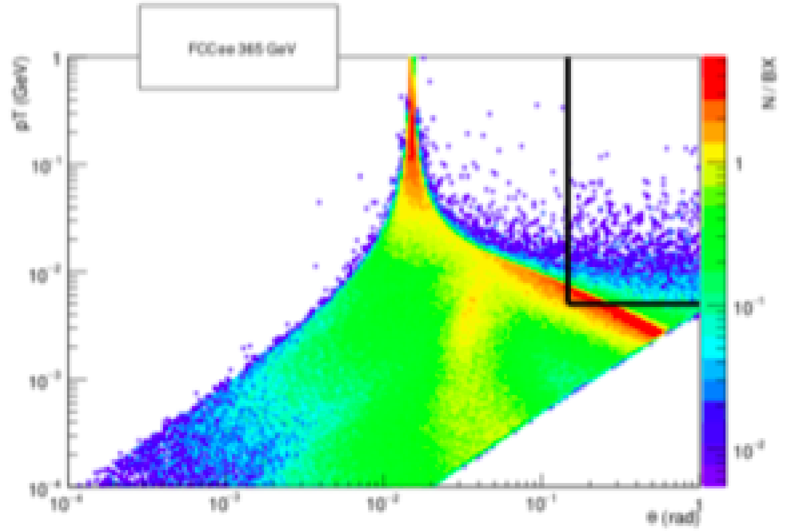
Vertex Detector Beam Backgrounds

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

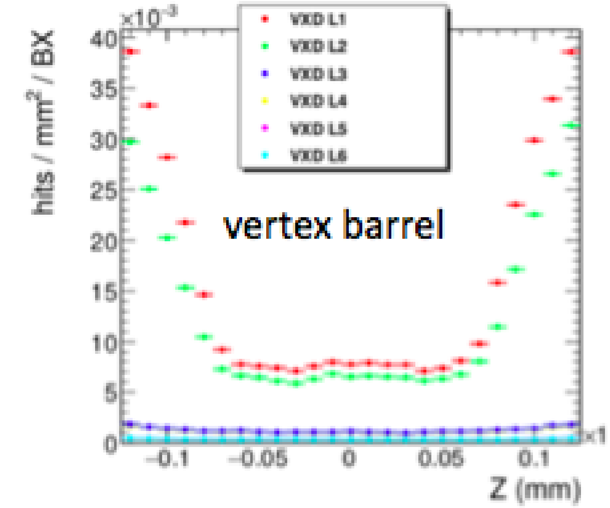
Backgrounds negligible everywhere except at $\sqrt{s}$ = 365 GeV:

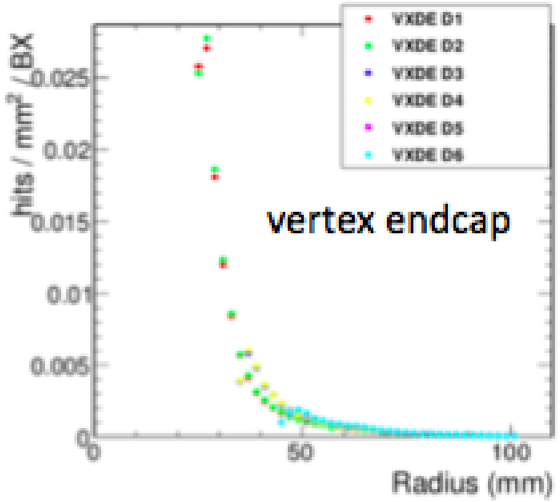
- ⇒ synchrotron radiation (SR)
  - ⇒ 7×10^4 hits / BX in the vertex detector
  - ⇒ reduced to 350 hits / BX with beam pipe shielding
- ⇒ incoherent pair creation (IPC)
  - ⇒ 1100 hits / BX in the vertex detector
- ⇒ $\gamma\gamma \to$ hadrons
  - ⇒ negligible





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





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

Studies for CLD detector
Expect similar results for IDEA

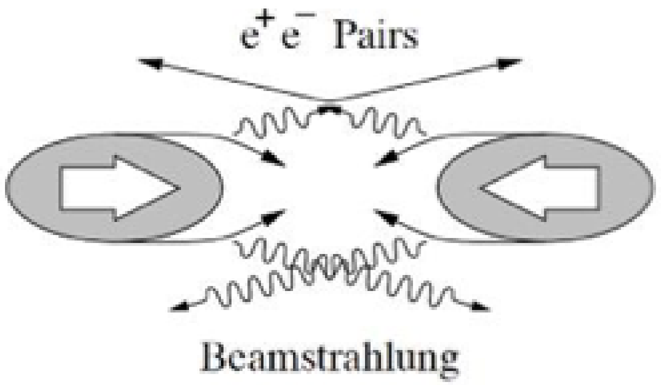
backup

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

backup

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

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

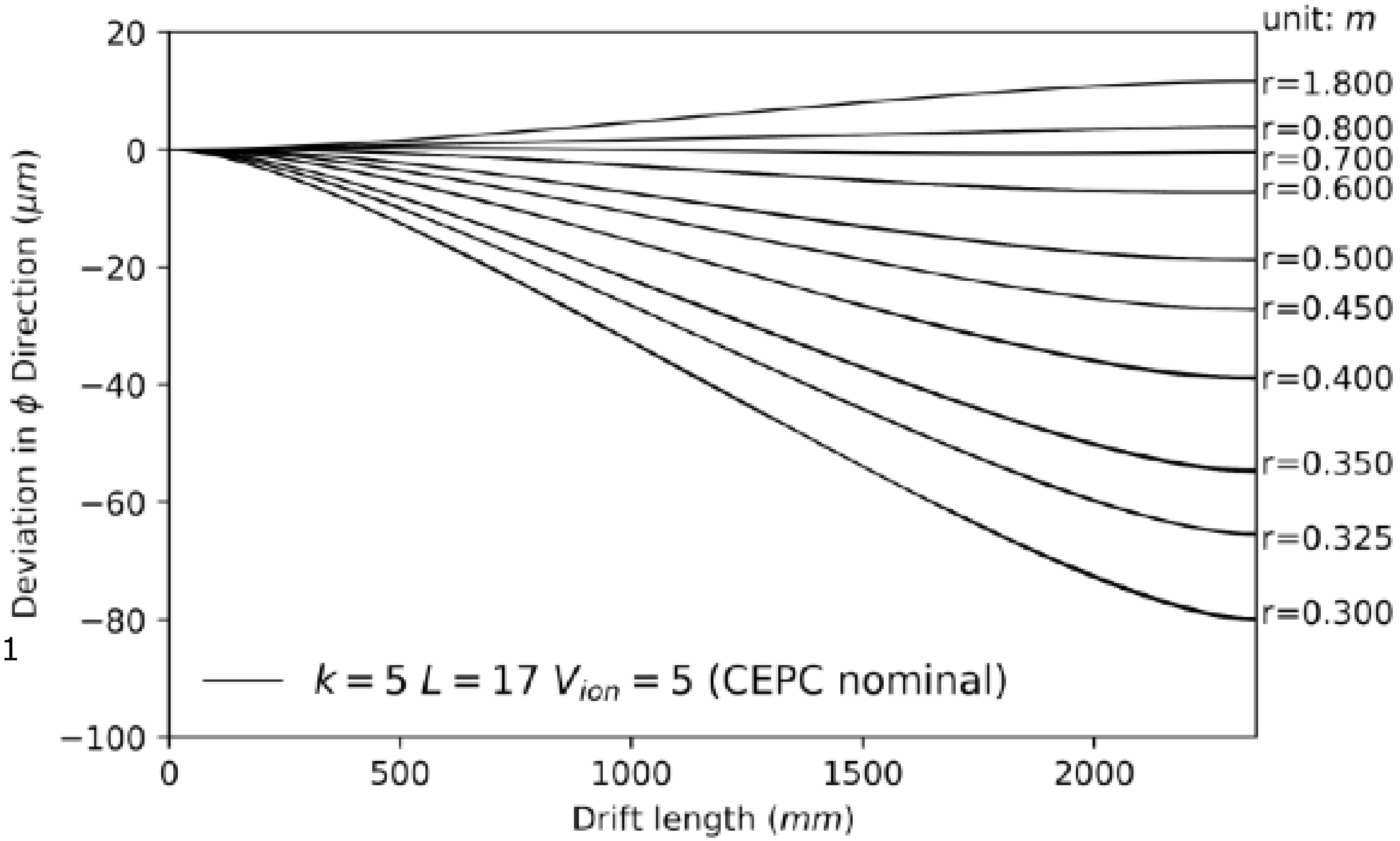
Huirong Qi

This is based on physics events

No beam-beam

Deviations due to primary ions should be factor 5 smaller

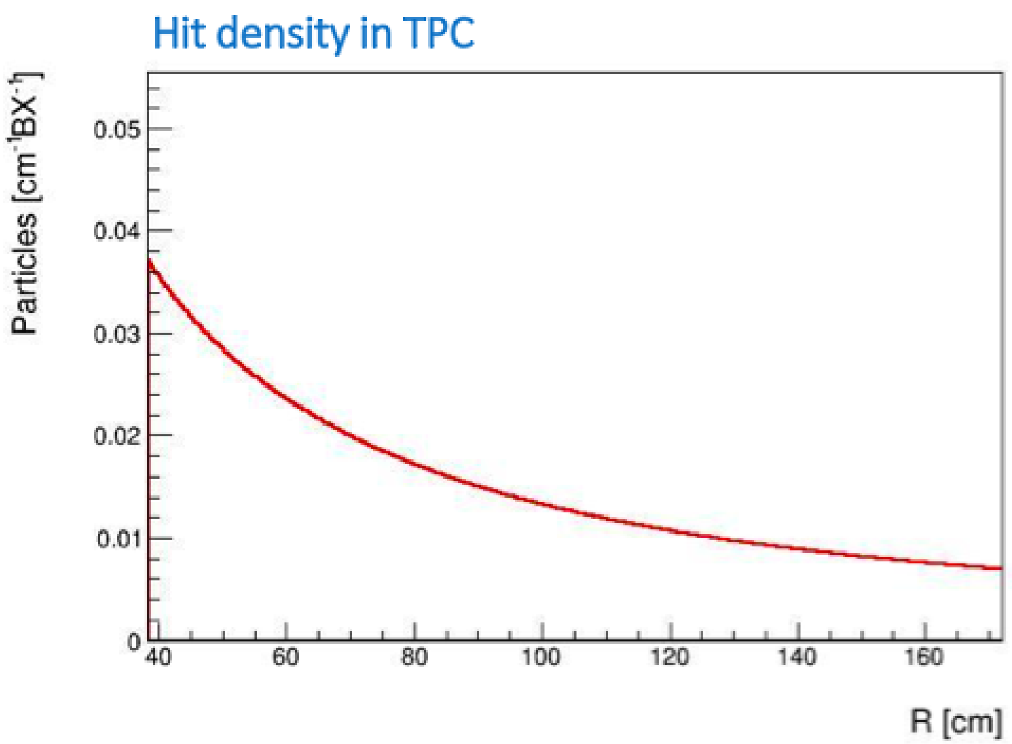
In my calculations
L = 32-50 10^{34} $cm^{-2}s^{-1}$
at 2 T.



backup

CEPC Pixel TPC CEPC Oxford

Extending to Other Subdetectors



SIT/SET, LumiCal → larger background samples to see detailed distributions

What is the energy (Z pole, 250 GeV) ?

What is the type of background?

What is a hit/particle in the TPC?

Maybe we can calculate the charge (Radius) from this distribution.

This is 8 10^{-5} particles/cm^2/BX (R=40) (assume z TPC 2*220 cm).