

FCC workshop  
Krakow, January 22-27, 2023

# TPC operability at circular colliders

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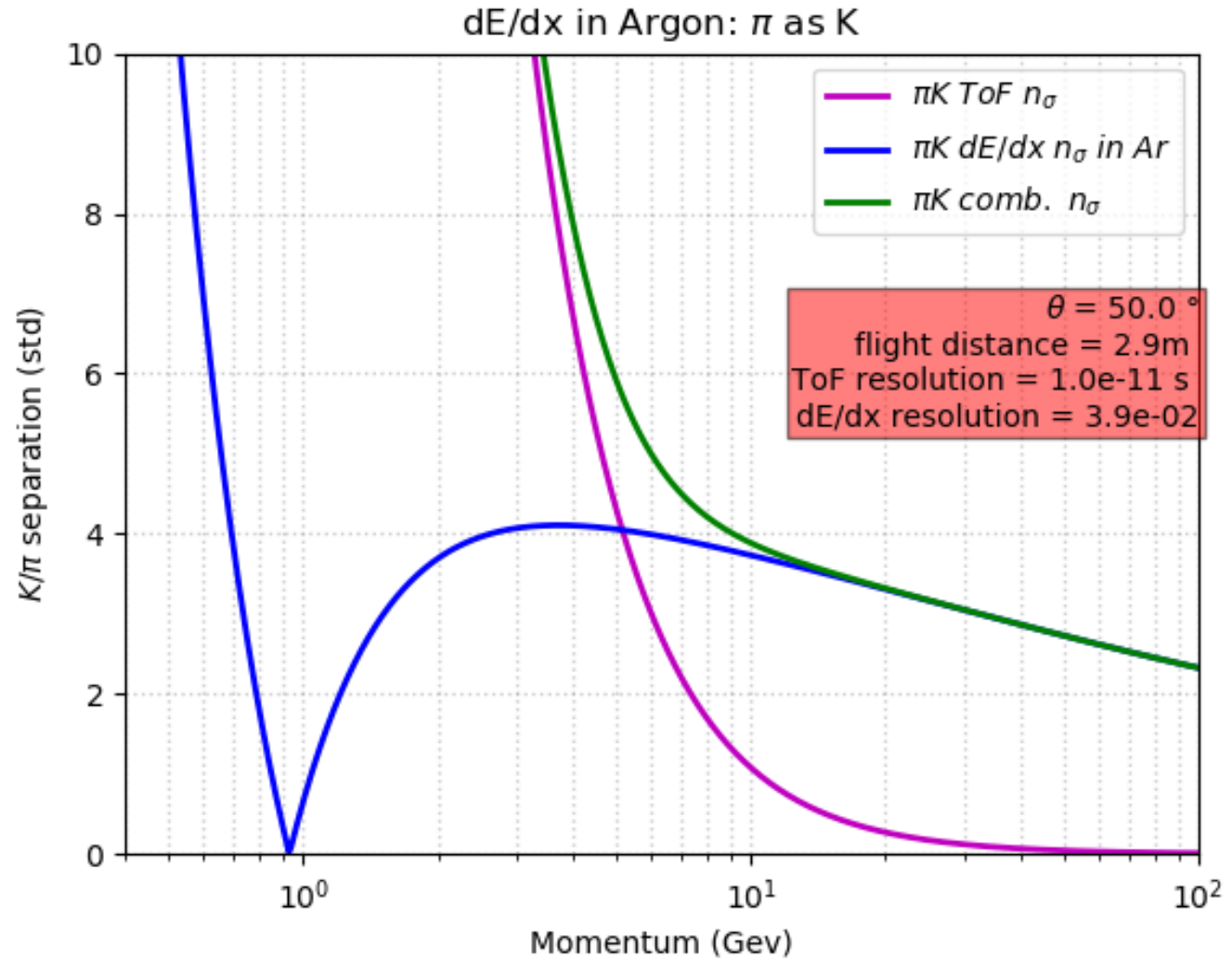
Thanks to contribution from LCTPC colleagues. Special thanks to K. Fujii, S. Ganjour, D. Jeans, P. Kluit

# Tracking at an EW/Higgs/top factory

- At the Z pole and beyond, particle ID is an essential ingredient, for tagging and studies of Heavy Flavours (together with an excellent vertex detection)
- A TPC ideally combines  $dE/dx$  measurement and low material budget, allowing a continuous measurement of the tracks. A strong magnetic field aligned with the TPC drift field limits diffusion and allows charged track momentum measurement.
- Together with silicon (vertex) detectors, it allows the excellent performance in resolution needed to extract the Z recoil peak to tag Higgses in a model-independent and unbiased way
- TPC is the main tracker for the ILD detector concept. At ILC, it profits from a beam time structure allowing power switching and gating. ILD is considering adapting the concept in case a circular collider is built first.

# SEPARATION POWER

dE/dx and TOF (10 ps) Combined

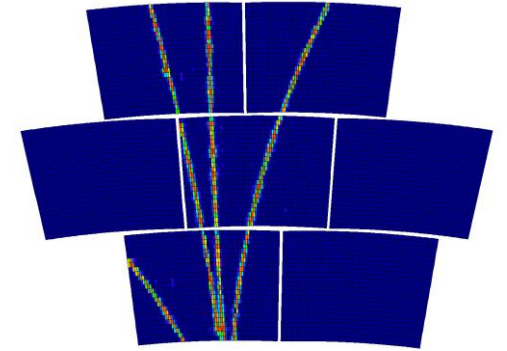


R. Aleksan

# TPC R&D

The TPC R&D is carried out within the LCTPC collaboration (spokesperson Jochen Kaminski). There are 3 main options for the readout : Micromegas with a resistive anode (ERAM), GEM, and Gridpix.

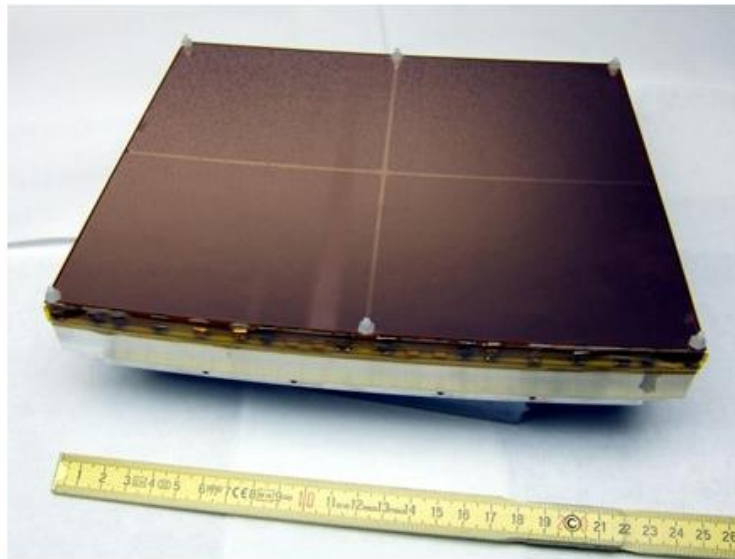
Beside this dedicated R&D, lessons are learned from experiments in progress, using TPCs with similar techniques issued from e+e- collider studies : **ALICE** at LHC (GEMs), **T2K/ND280** at J-PARC (resistive Micromegas)



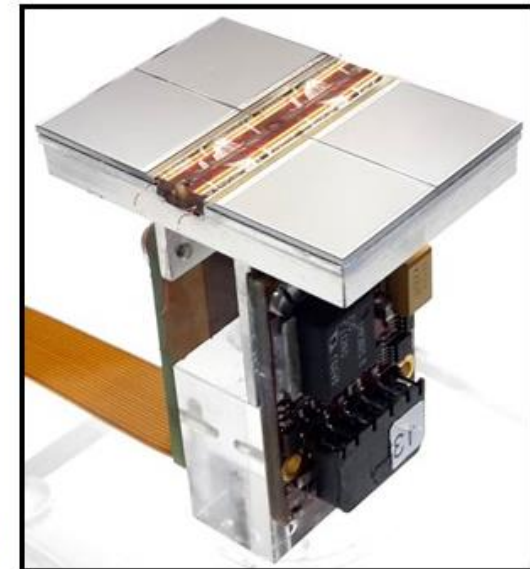
Micromegas



GEM



Gridpix

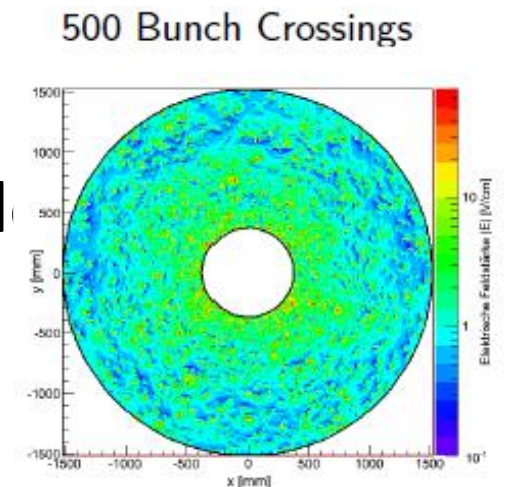


# Gas choice

- Base gas :
  - Ar for largest ionization : 97 e-ion pairs in ~35-40 clusters
  - He for well-separated clusters easing  $dN/dx$  (but cannot set field to the maximum drift velocity over 2 m)
- Additional gases
  - Isobutane : quencher, cuts UVs to avoid avalanche propagation
  - $CF_4$  : increases electron drift velocity and reduces diffusion in magnetic field by a factor of ~10 at 3.5 T and ~5 at 2T.
  - Low e attachment (keep  $O_2$  and  $H_2O$  below ~10 ppm to drift over 2m) velocity)
- T2K gas Ar:CF4:Isobutane 95:3:2 satisfies all requirements for a TPC
- Note that the optimal gas is not the same for cluster counting (He) and for space resolution (large  $\omega\tau$  for low diffusion: 'fast gas')

# Distortions from positive ions

- Ions drifting in the gas are very slow (typically a few m/s)
- **Primary ions** from ionization in the gas (from event tracks or from machine background) or **secondary ions** created during amplification and back-flowing in the drift region, drift very slowly, producing space charge which distorts the trajectories of the electrons drifting from the tracks by creating a component transverse to the drift field
- This effect is common to all the amplification devices
- Calculated in 2011 by D. Arai and K. Fujii
- 2022-2023 : New calculation in progress, adapt to Z pol (K. Fujii, D. Jeans, S. Ganjour, Mingrui Zhao...)



Simulation by M. Killenberg (2009)

# Calculation of the distortions (K. Fujii)

The ion charge density creates a potential at each point  $\boldsymbol{x}$  of the field cage volume :

$$\Delta\phi_{\text{ion}}(\boldsymbol{x}) = -4\pi \rho_{\text{ion}}(\boldsymbol{x})$$

From which one derives the transverse field (with I, K modified Bessel functions)

$$E_r(r, z) = -8\pi \sum_{n=1}^{\infty} \frac{\sin(\beta_n z)}{I_0(\beta_n a)K_0(\beta_n b) - I_0(\beta_n b)K_0(\beta_n a)} \left[ [K_0(\beta_n b)I_1(\beta r) + I_0(\beta_n b)K_1(\beta_n r)] \int_a^r dr' \frac{K_0(\beta_n a)I_0(\beta r') - I_0(\beta_n a)K_0(\beta_n r')}{K_0(\beta_n r')I_1(\beta_n r') + K_1(\beta_n r')I_0(\beta_n r')} \int_0^L \frac{dz'}{L} \sin(\beta_n z') \rho_{\text{ion}}(r', z') + [K_0(\beta_n a)I_1(\beta r) + I_0(\beta_n a)K_1(\beta_n r)] \int_r^b dr' \frac{K_0(\beta_n b)I_0(\beta r') - I_0(\beta_n b)K_0(\beta_n r')}{K_0(\beta_n r')I_1(\beta_n r') + K_1(\beta_n r')I_0(\beta_n r')} \int_0^L \frac{dz'}{L} \sin(\beta_n z') \rho_{\text{ion}}(r', z') \right]$$

$$\beta_n = n\pi/L$$

In practice one needs  $\sim n=500$  first terms

# Calculation of the distortions II (K. Fujii)

The Langevin equation gives the modification of the drift velocity :

$$\langle \mathbf{v} \rangle = \left( \frac{\tau}{1 + (\omega\tau)^2} \right) \left[ 1 + (\omega\tau) \hat{\mathbf{B}} \times + (\omega\tau)^2 \hat{\mathbf{B}} \hat{\mathbf{B}} \cdot \right] \frac{e}{m} \mathbf{E}$$

$$\Delta \langle \mathbf{v} \rangle = \frac{e}{m} \left( \frac{\tau}{1 + (\omega\tau)^2} \right) \left[ (1 + (\omega\tau)^2) \Delta \mathbf{E}_{\parallel} + \mathbf{E}_{\perp} - (\omega\tau) \mathbf{E}_{\perp} \times \hat{\mathbf{B}} \right]$$

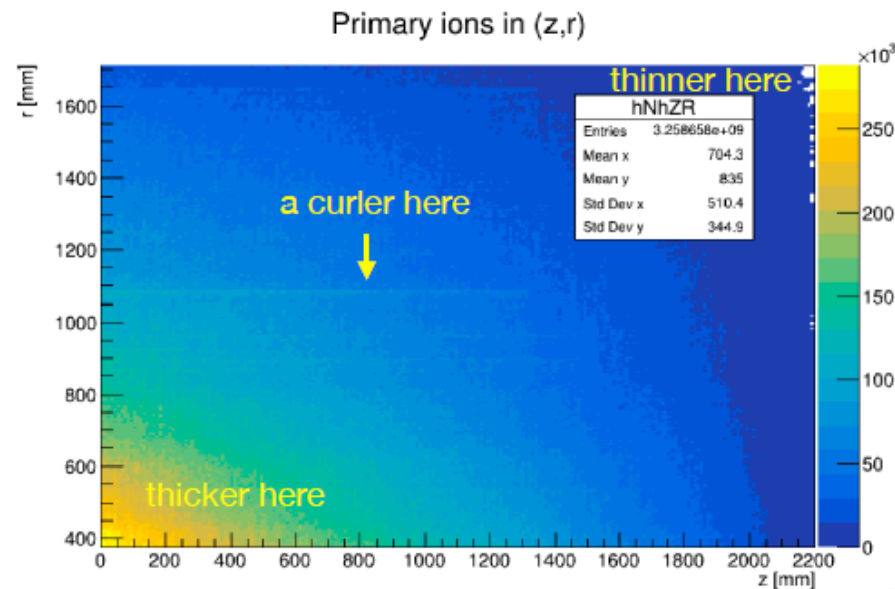
$$\begin{aligned} \langle \Delta \mathbf{x} \rangle &= \sum_{i=1}^n \frac{\Delta \langle \mathbf{v} \rangle_i}{\langle v_{\parallel} \rangle_i} \delta l_i \\ &\simeq \sum_{i=1}^n \delta l_i \left[ -\frac{\Delta \mathbf{E}_{\parallel i}}{E_0} - \left( \frac{1}{1 + (\omega\tau)^2} \right) \frac{\mathbf{E}_{\perp i}}{E_0} + \left( \frac{\omega\tau}{1 + (\omega\tau)^2} \right) \frac{\mathbf{E}_{\perp i} \times \hat{\mathbf{B}}}{E_0} \right] \end{aligned}$$



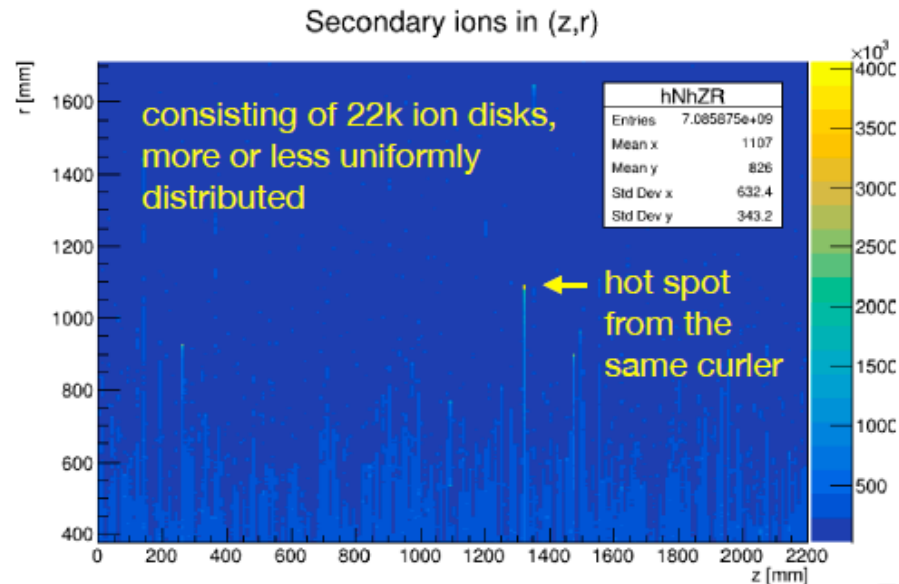
# Positive ion density at the Z peak

- From hadronic Z decays (Tox MC by K.Fujii, full simulation by Daniel Jeans)
- 60 KHz of Z decays : 26 000 ion disks created in the amplification pile-up in the 0.44 s of flushing time of the ions (assuming 5 m/s ion drift velocity)

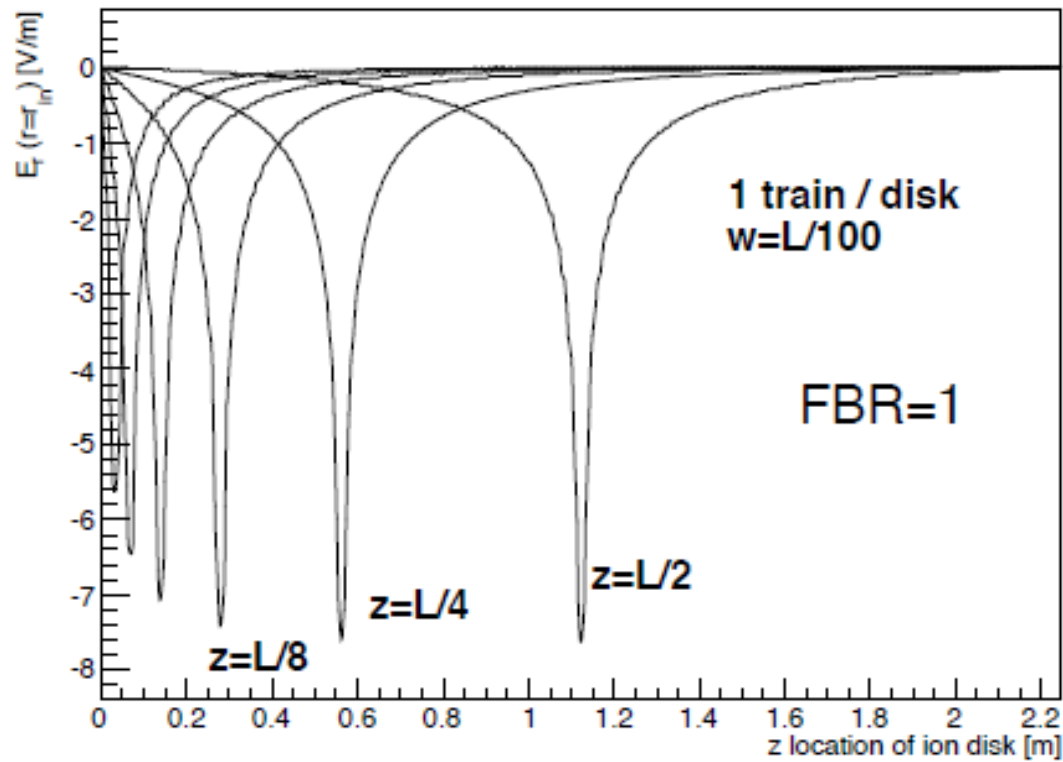
## Primary Ions



## Ion Back Flow



$E_r(r=r_{in}, z)$  for different disk locations in “z”



Case of FCC or CEPC at Z pole :  
almost continuous set of disks.

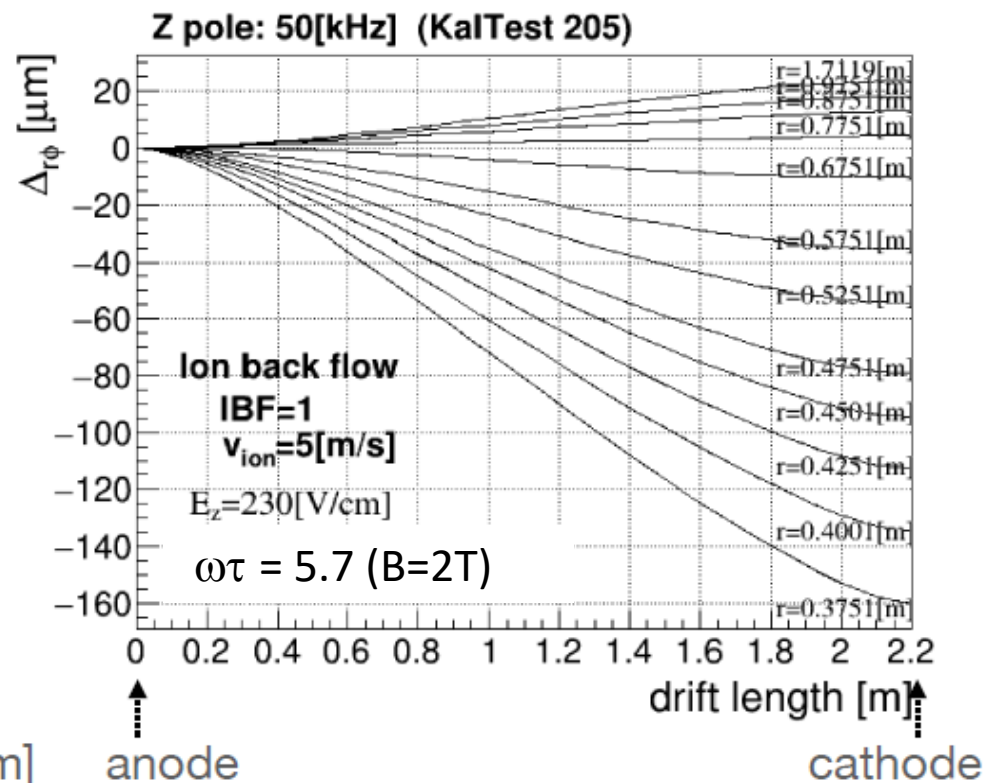
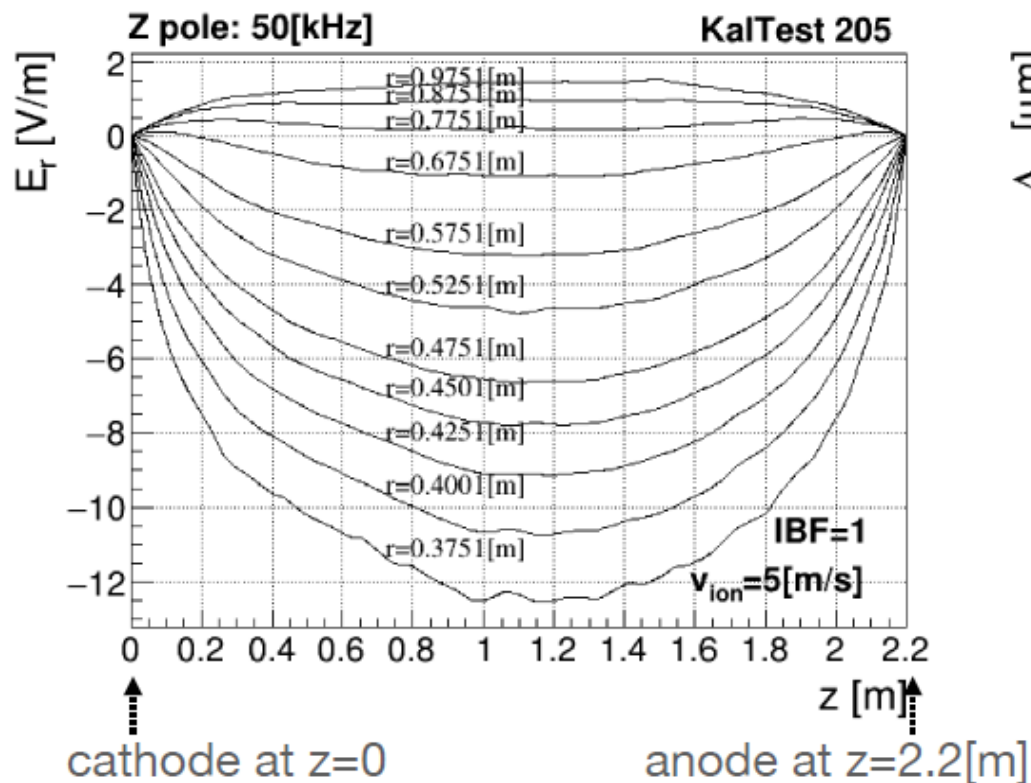
<https://agenda.linearcollider.org/event/5504/contributions/24543/attachments/20144/31818/PositiveionEffects-kf.pdf>

Z pole run: hadronic Z event rate: **50 [kHz]** (toy MC using pythia8)

$v_{ion} = 5$  [m/s]

**IBF = 1**

K. Fujii



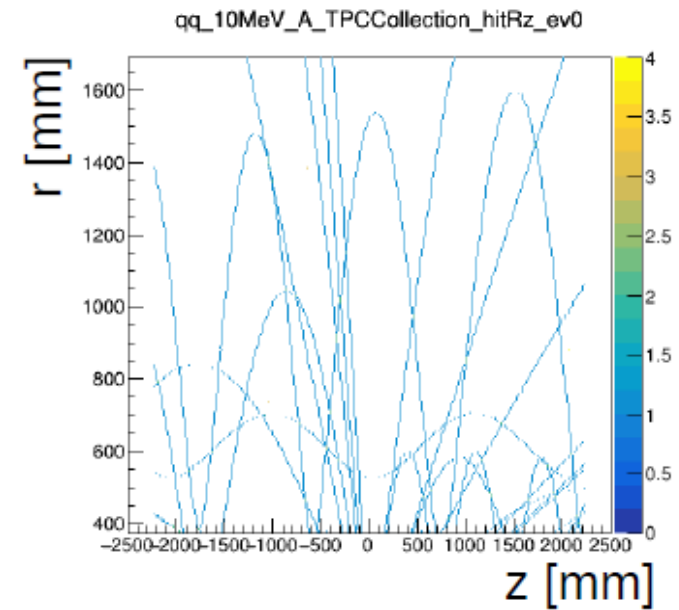
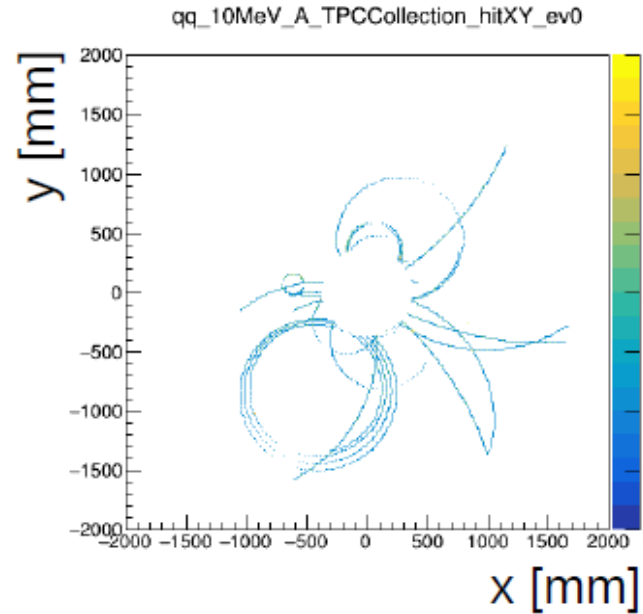
bin size:  $(\Delta z, \Delta r)=(1$ [cm],  $0.5$ [cm])

**Glitches correspond to hot spots in  $\rho_{ion}$ , which seem to be averaged out in  $\Delta r_\phi$**

**Maximum distortion  $\sim 160$  [ $\mu\text{m}$ ] at the innermost region for hadronic Z rate of 50 [kHz]**

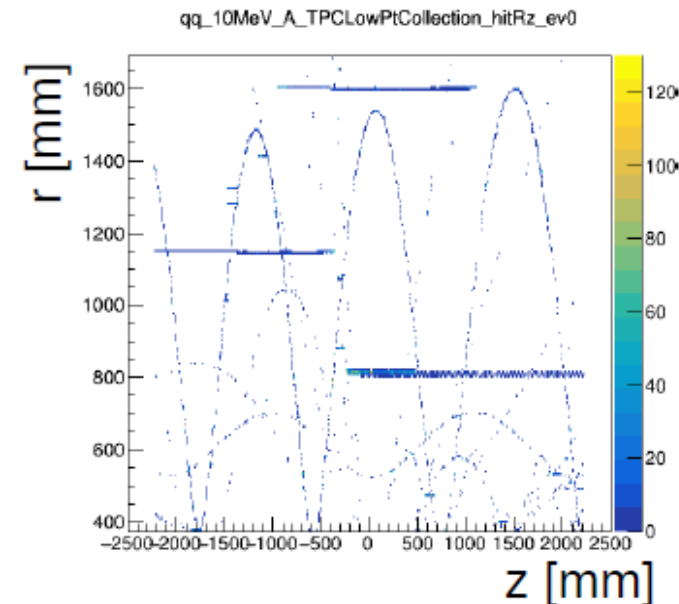
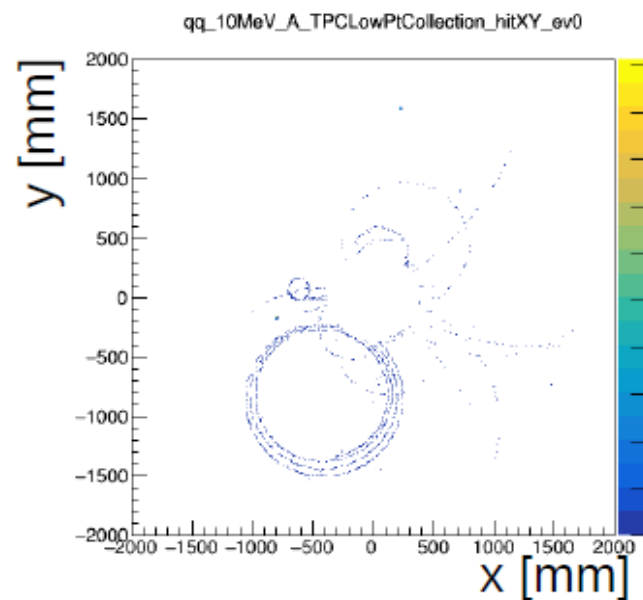
# one event

hits associated to track with  
 $p_T > 10$  MeV  
“high  $p_T$ ”



$p_T < 10$  MeV  
“low  $p_T$ ”

typically delta-rays along main tracks  
some long micro-curlers



D. Jeans

Resulting distortions at Z pole for IBF=5  $\sim 800 \mu\text{m}$  (preliminary)  
( $330 \mu\text{m}$  if IBF can be fully suppressed...)

Can it be corrected for?

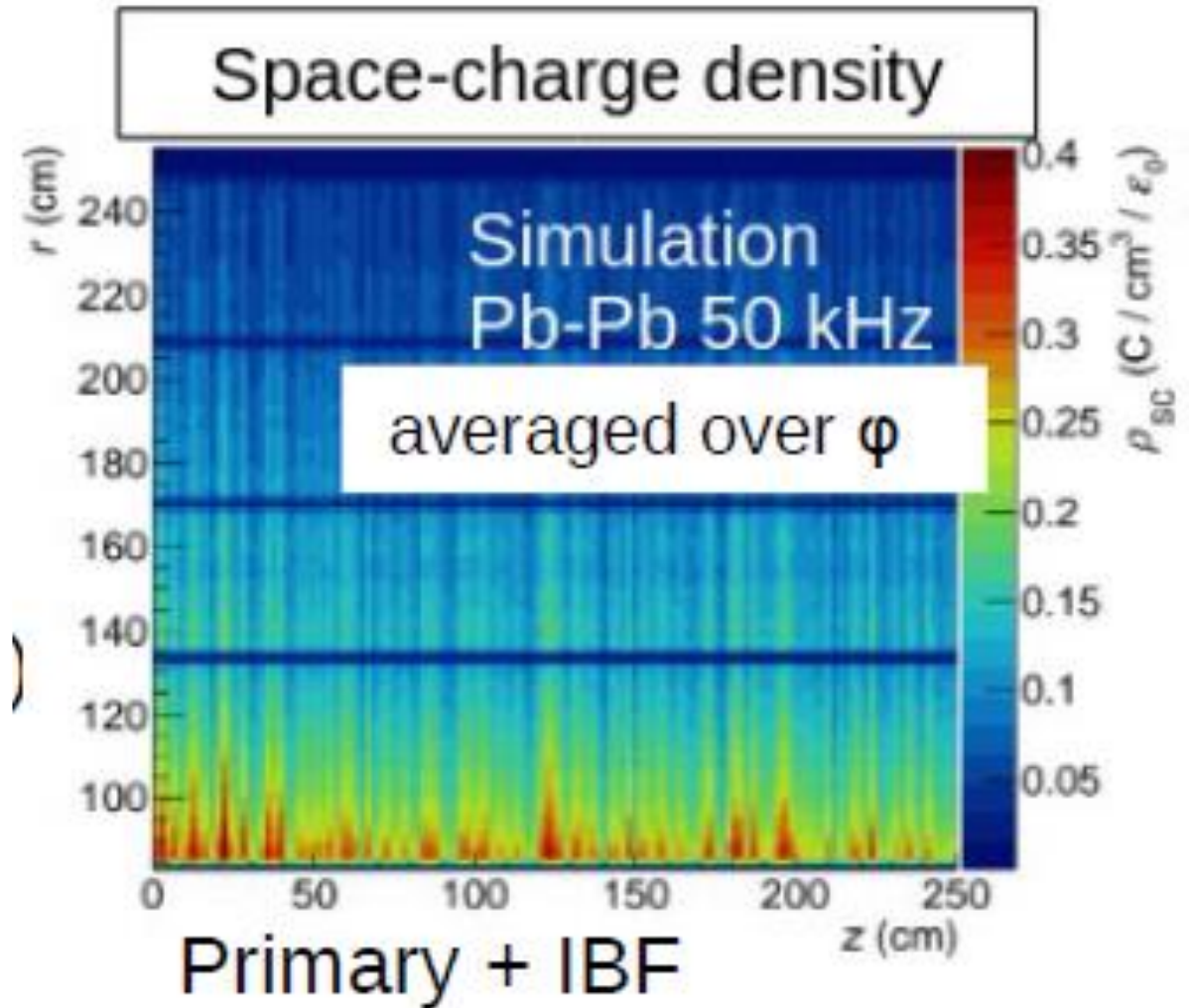
Only on average, or the charge must be locally measured. This is difficult, as the micro-curlers saturate the amplifiers.

Maybe only way, in Gridpix, using the segmented mesh of the chips : monitor the mesh current of each chip.

Similar situation in ALICE at Run3. IBF~1%, gain=2000.  
200 ms ion drift

50 kHz lead-lead collisions.  
-> the ions of 10 000 collisions pile-up in a TPC length.

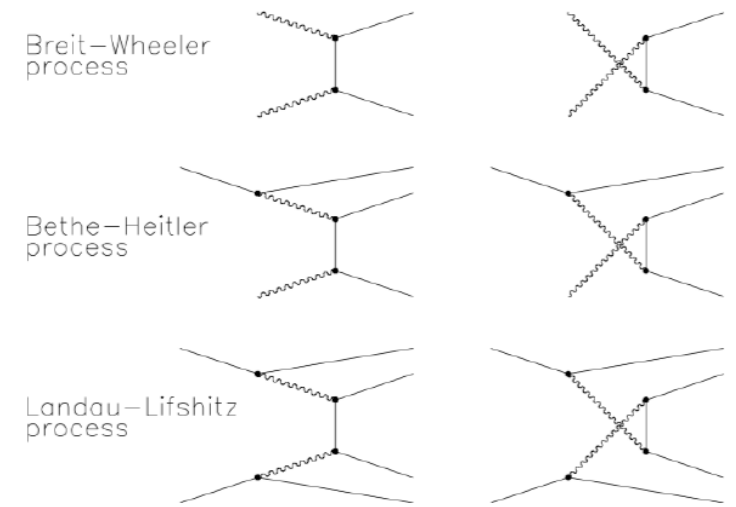
Space-charge density cause distortions up to several cm,  
varying with instantaneous luminosity and fluctuating.  
Measurement of the space charge (from integrated  
currents) necessary.



ALICE, [Jens Wiechula](#), LCTPC collaboration  
meeting, Jan 18, 2023.

# Pair production background

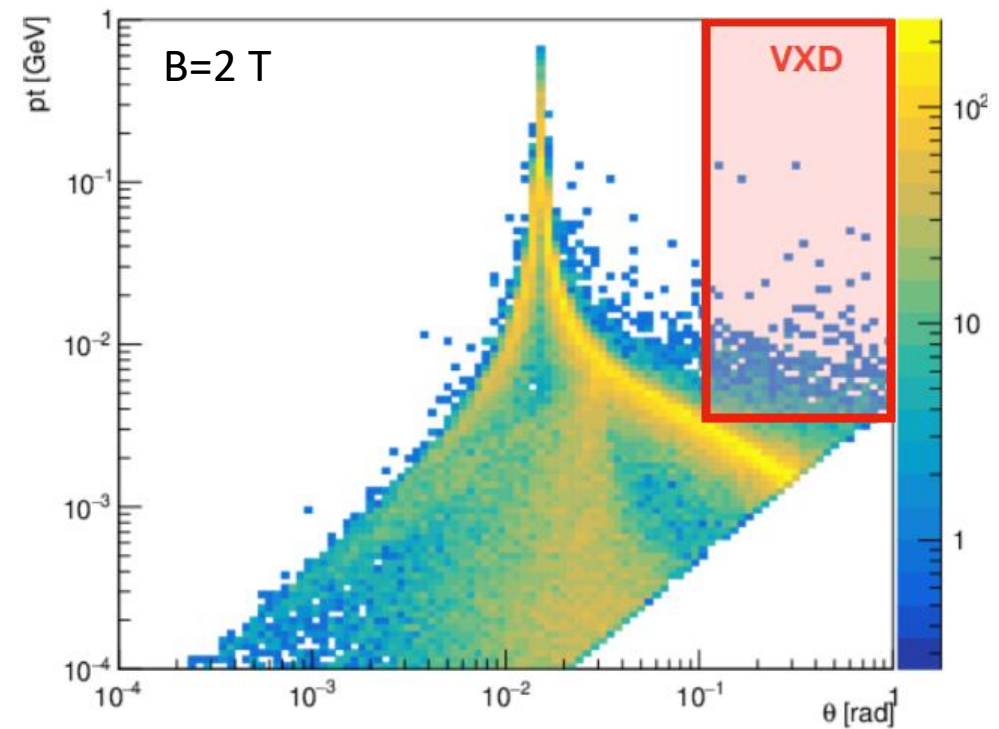
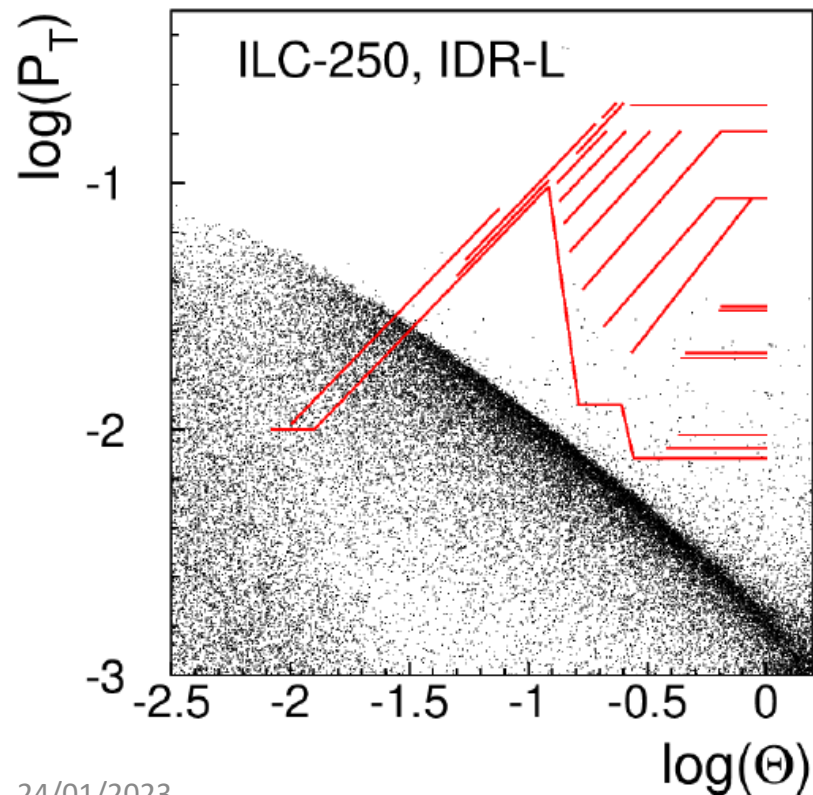
Studied with GUINEA-PIG MC (ILC, D. Schulte 2003, A. Vogel 2007)  
and GUINEA PIG++ (FCC, E. Perez 2019, A. Ciarma 2022)



ILC 250 GeV

B=3.5 T

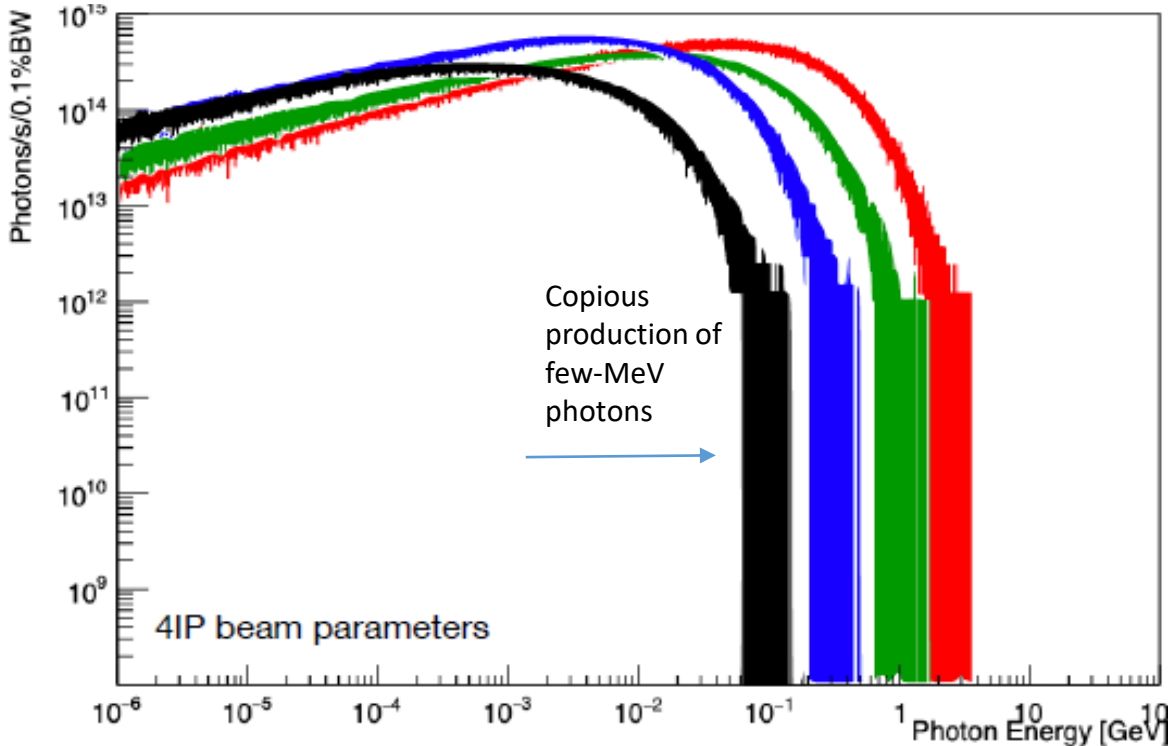
FCC 91.2 GeV



# Beamstrahlung photons at FCC

Enormous power radiated and copious photon production with energy of a few MeV: will produce e+e- pairs in the TPC gas if not extracted

Also beam-gas background is being assessed



	Total Power [kW]	Mean Energy [MeV]
<b>Z</b>	370	1.7
<b>WW</b>	236	7.2
<b>ZH</b>	147	22.9
<b>Top</b>	77	62.3



# SUMMARY

- Running a TPC @ Z pole @  $2 \cdot 10^{36} \text{ cm}^{-2} \text{ s}^{-1}$  is not trivial
- 65 kHz of Z decays means 1 decay every 1.2 mm on average
- The positive ions of 22 000 Zs will accumulate in the TPC volume before drifting out, causing distortion of several 100  $\mu\text{m}$  at least
- The ion backflow has to be suppressed drastically
- A continuous DAQ and tracking will be necessary, with real-time corrections for space point distortions
- The experience from ALICE at LHC (50 kHz of Pb-Pb collisions) will be crucial
- Control of beam-induced BGs will be crucial, not only at the Z but also at HZ.