Recent progress in TPC R&D

- Work in progress along the lines discussed at the ECFA workshop at DESY on adapting to FCC or CEPC conditions.

K. Fujii, D. Jeans and S. Ganjour are re-visiting the distortion estimates

New background calculations at the Z are in progress

  - See my presentation at the France-Italy FCC workshop in Lyon.
  - Watch the next FCC workshop in January in Cracow

- Particle ID is best done by combining dE/dx and time-of-flight
- Synergies with other TPCs have to be exploited. ALICE GEM-TPC is about to start taking data and T2K is half-way characterizing and constructing elements. BELLE 2 experience is also worth exploiting.

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.

TPC R&D

- All the R&D is carried out within the LCTPC collaboration (spokesperson Jochen Kaminski)
- France is mainly involved in the Micromegas pad readout option
- There are also GEM pad options (Germany and Japan) and Micromegas pixels (digital readout, Nikhef and Bonn, and formerly Saclay and Freiburg). All the options are tested at the DESY beam test facility, using a large field cage, common gas system, cosmic-ray and beam trigger, power supplies
- Beside this dedicated R&D, lessons are learnt 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)

Gas choice has to be revisited

- Base gas :
  - Ar for largest ionization : 97 e-ion pairs in ~35-40 clusters
  - He for well-separated clusters (but cannot set field to the maximum drift velocity)

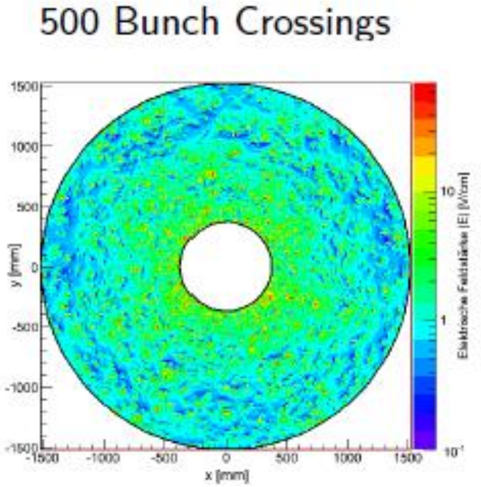
- Additional gases
  - Isobutane : quencher, cuts UVs to avoid avalanche propagation, but sensitive to neutrons
  - CF4 : increases electron drift velocity and reduces diffusion in magnetic field by a factor of ~10 at 3.5 T and ~5 at 2T.
  - Low e attachment (keep O_2 and H_2O below ~10 ppm to drift over 2m) velocity)

- T2K gas Ar:CF4:Isobutane 95:3:2 satisfies all requirements for a TPC, but CF4 might be forbidden in future. Recirculating should be sufficient.

Distortions from positive ions

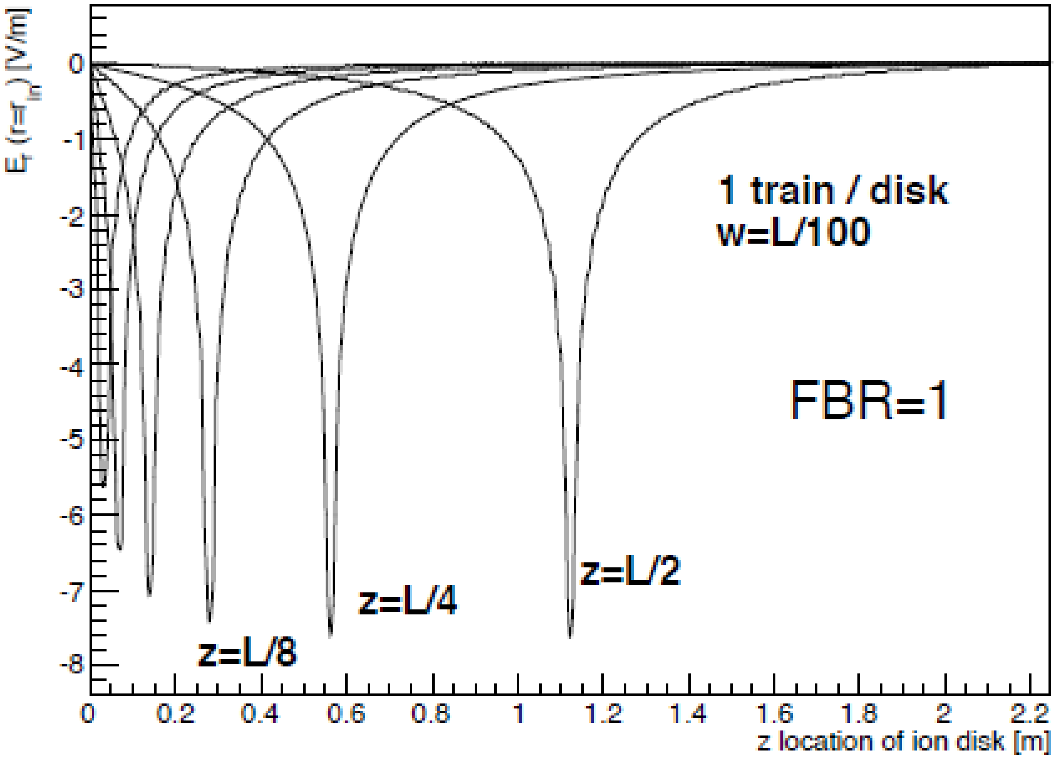
- Ions drifting in the gas are very slow (typically a few m/s)
- Primary ions from ionization in the gas (from event track of from machine background) or secondary ions from the amplification back-flowing in the drift region, drift very slowly, producing space charge which distorts the trajectories of the electrons drifting from the tracks by creating a transverse component to the drift field
- Calculated in 2011 by D. Arai and K. Fujii :
- 2022 : New calculation in progress, adapt to Z pole

(K. Fujii, S. Ganjour, Mingrui Zhao…)



Simulation by M. Killenberg (2009)

Er(r=rin, z) for different disk locations in “z”



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

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

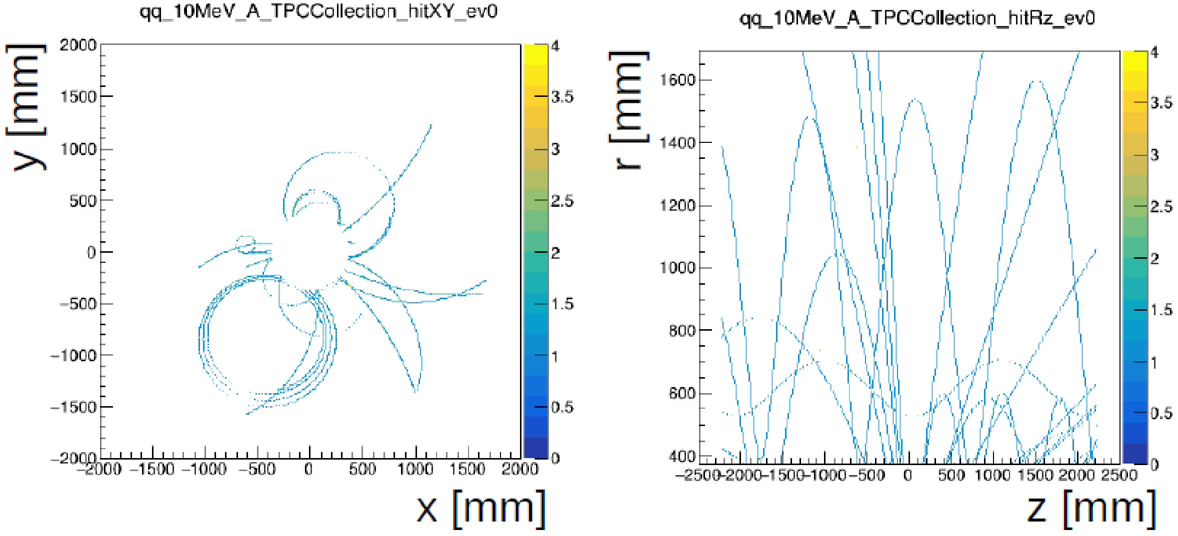
Daniel Jeans studied primary ion density from Z events

Presented one week ago in Software meeting

one event

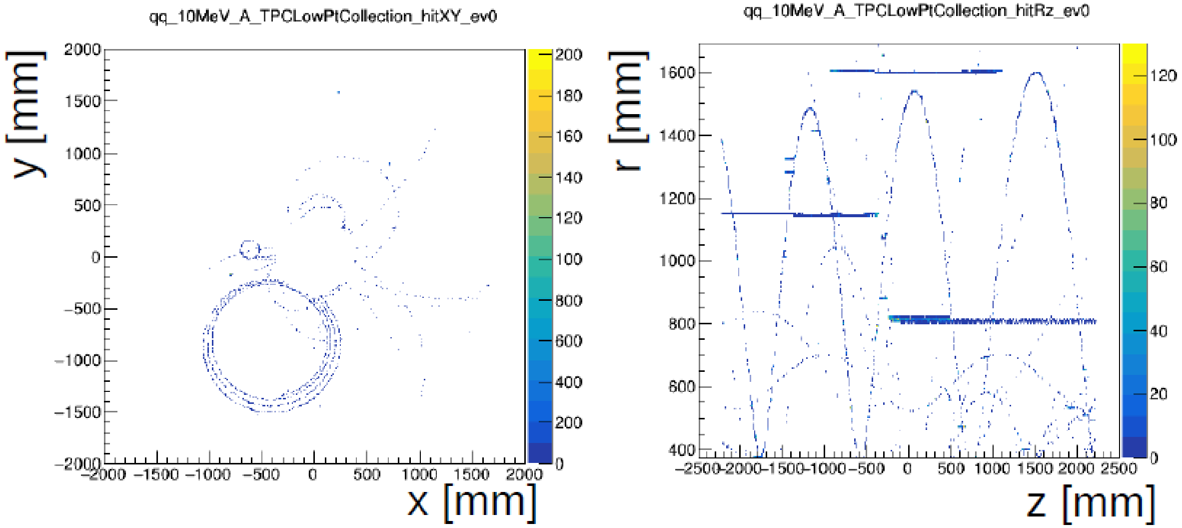
ILD detector but B=2T
Keep low-pT tracks, but only from Z (no machine background)

hits associated to track with
pT > 10 MeV
“high pT”

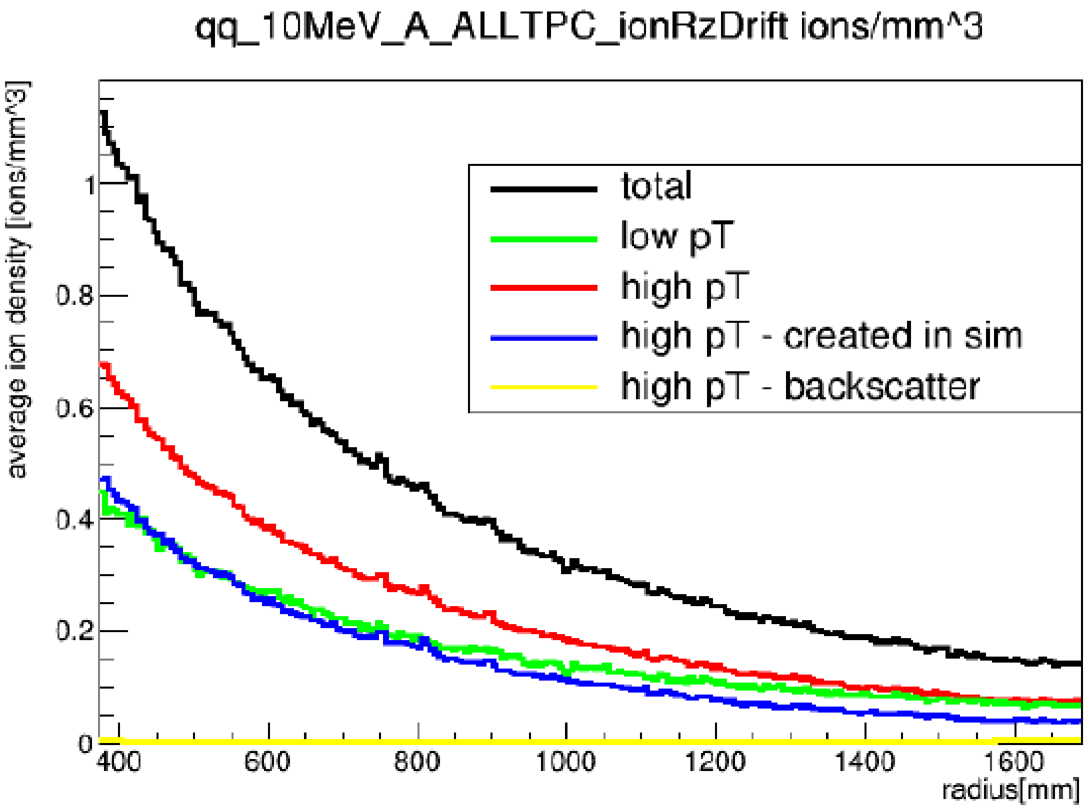


pT < 10 MeV
“low pT”

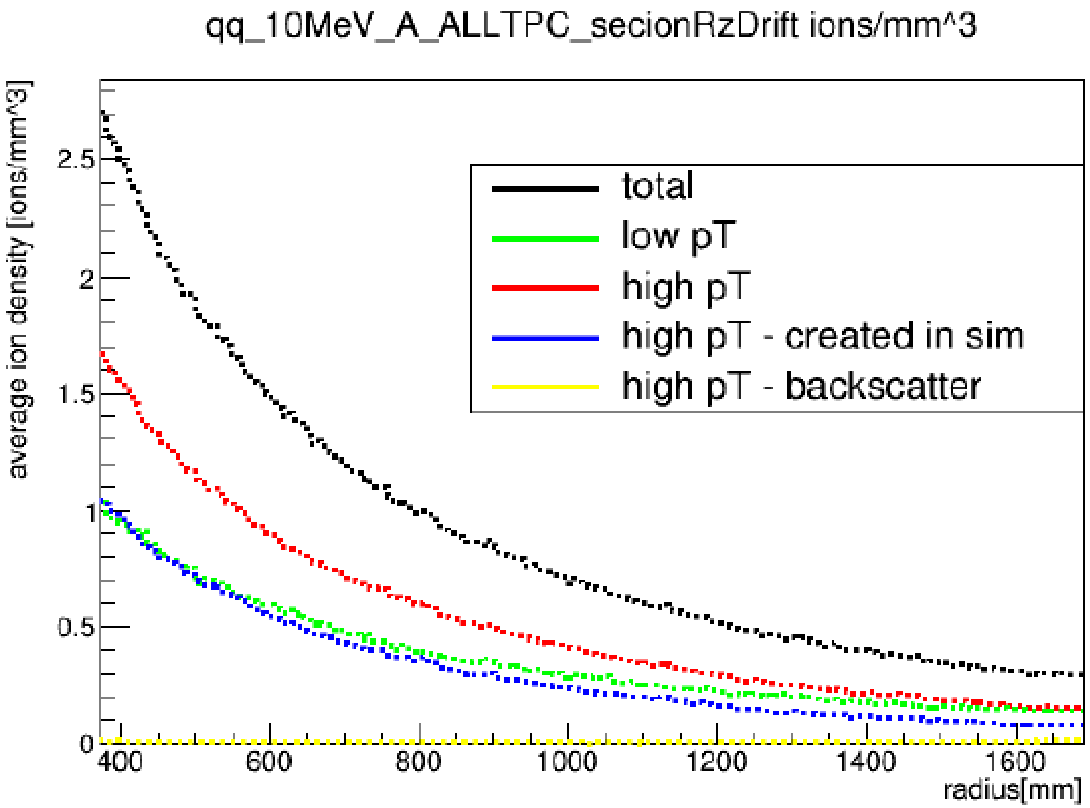
typically delta-rays along main tracks
some long micro-curlers



primary ions



back-flowing ions (IBF=1)

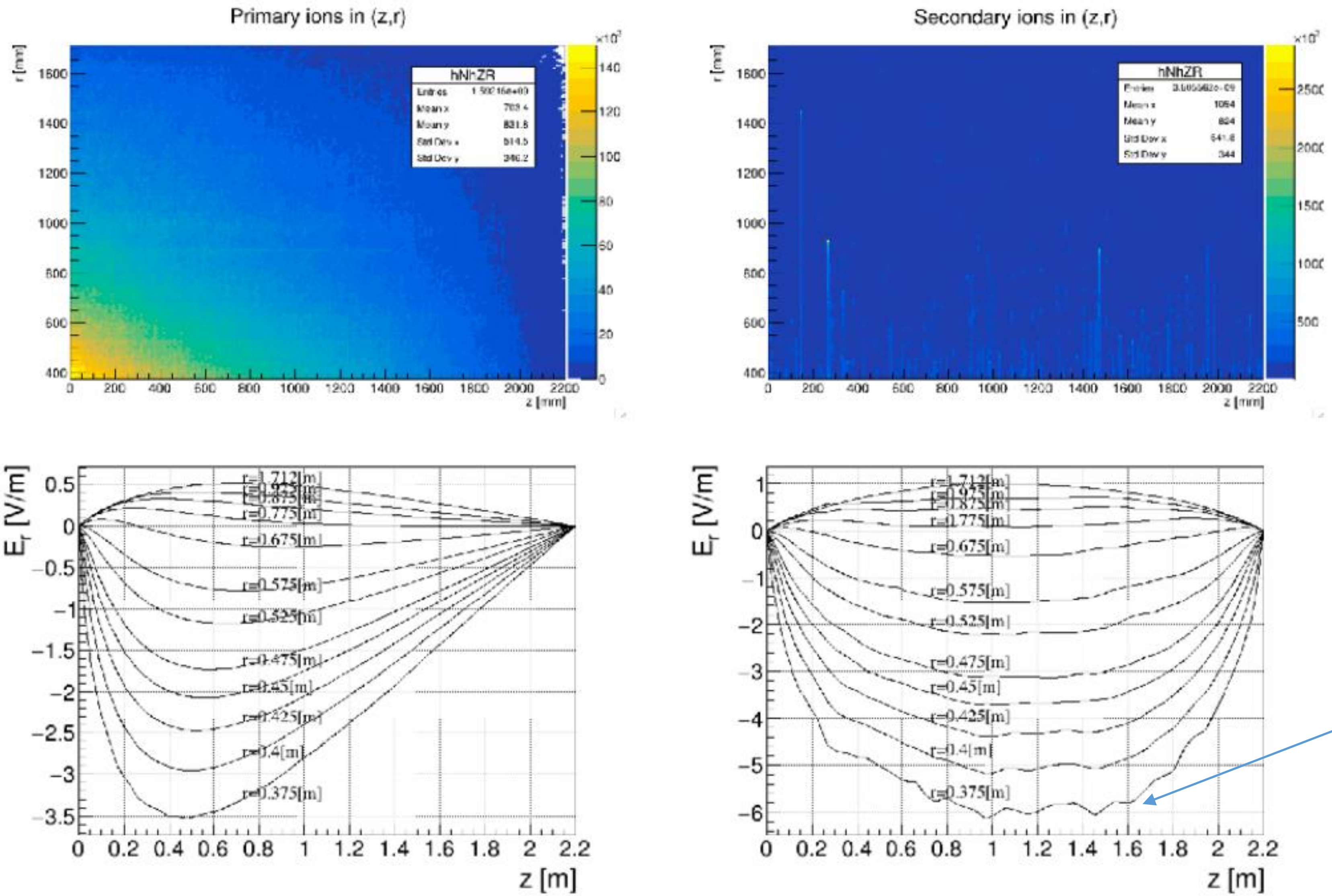


D. Jeans

more important contribution

Positive Ion back flow (11k Z pole events)

Corresponds to 1 ion drift time



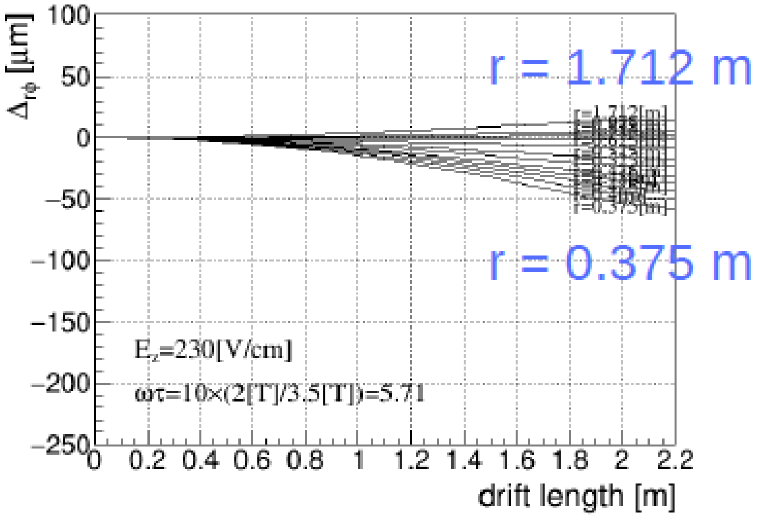
Fluctuations of charge density due to curlers

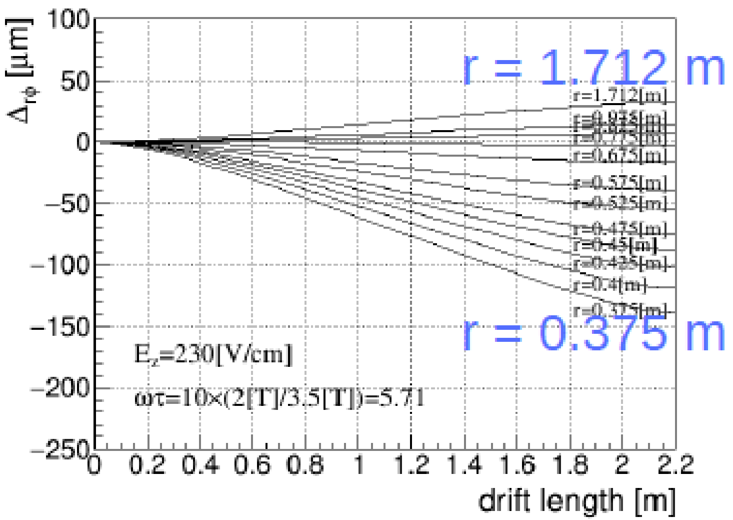
K. Fujii, preliminary

primary

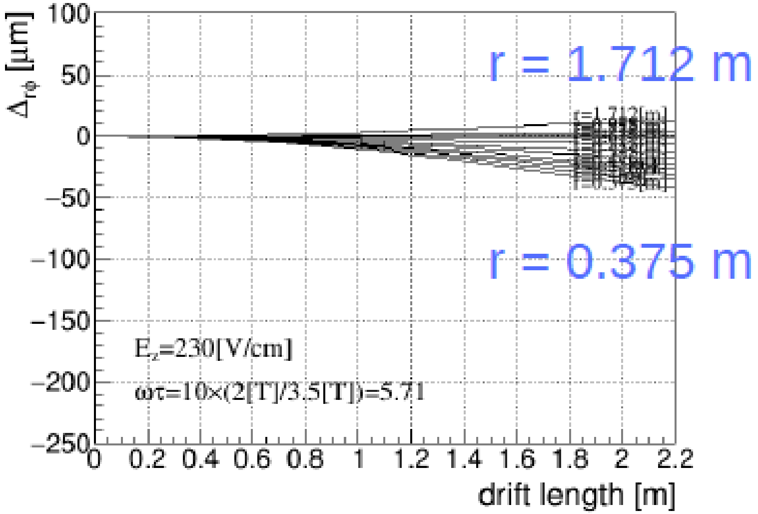
secondary IBF=1

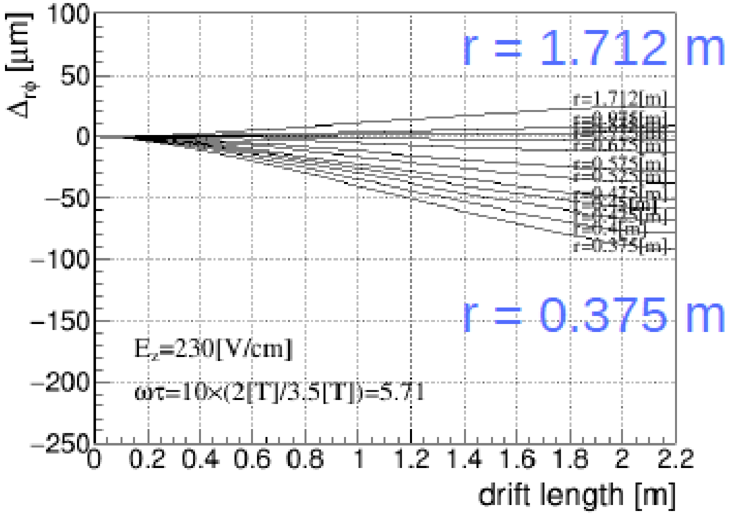
high pT

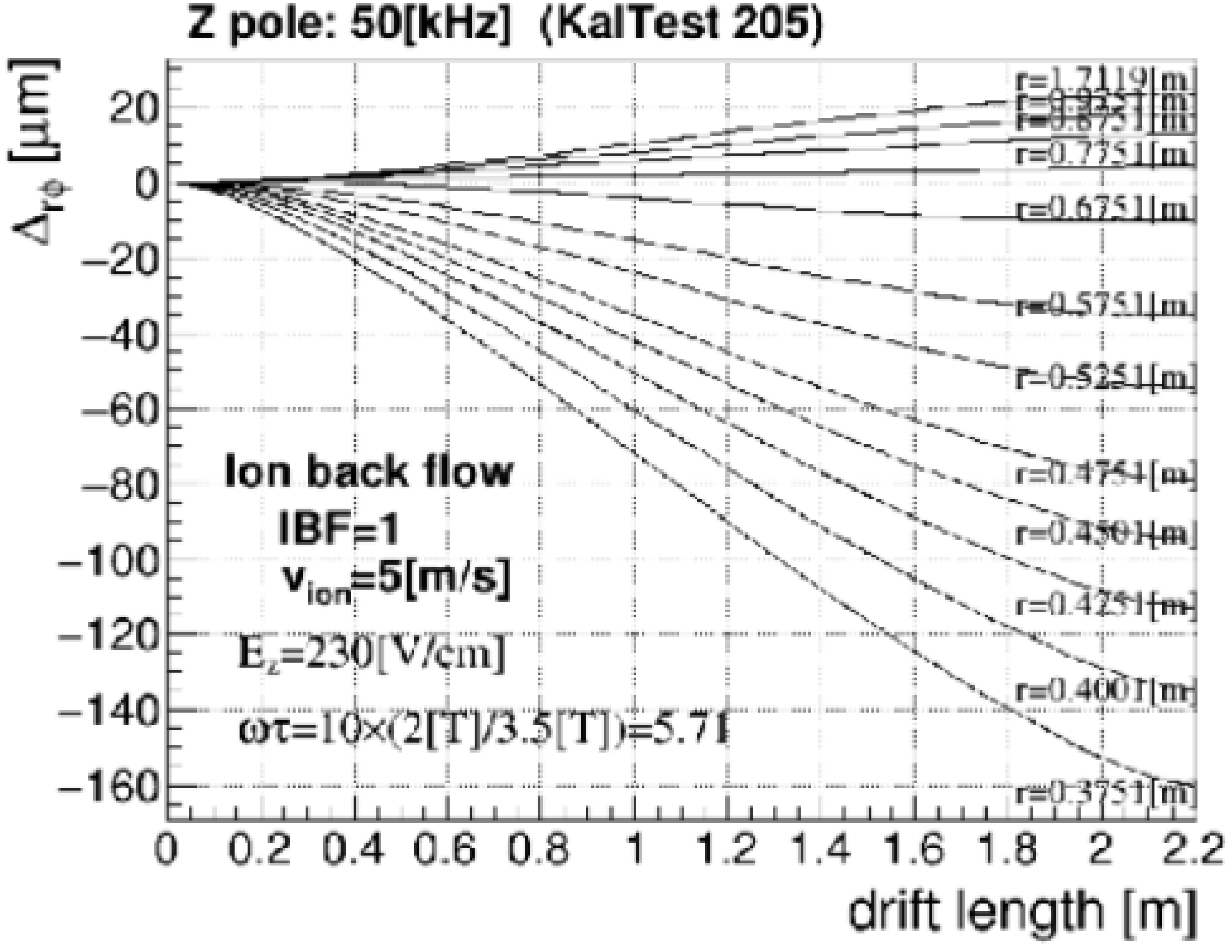




low pT







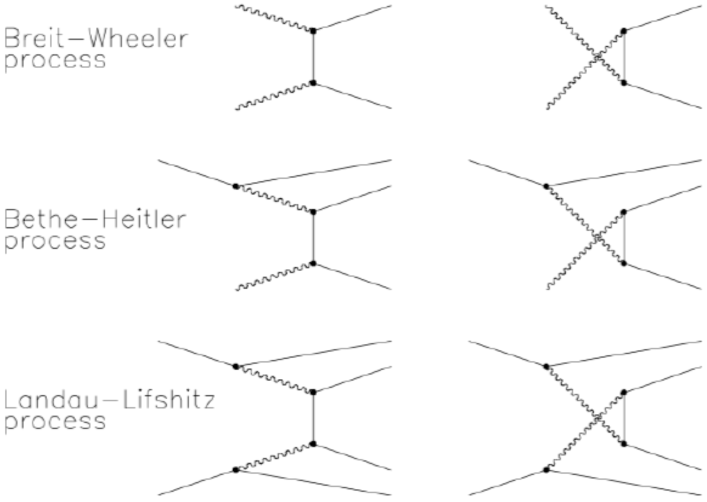
Resulting maximum distortions at Z pole for IBF=5 :
~1200 μm (preliminary, does not include beam-induced background)
(100 μm if IBF can be fully suppressed…)

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.

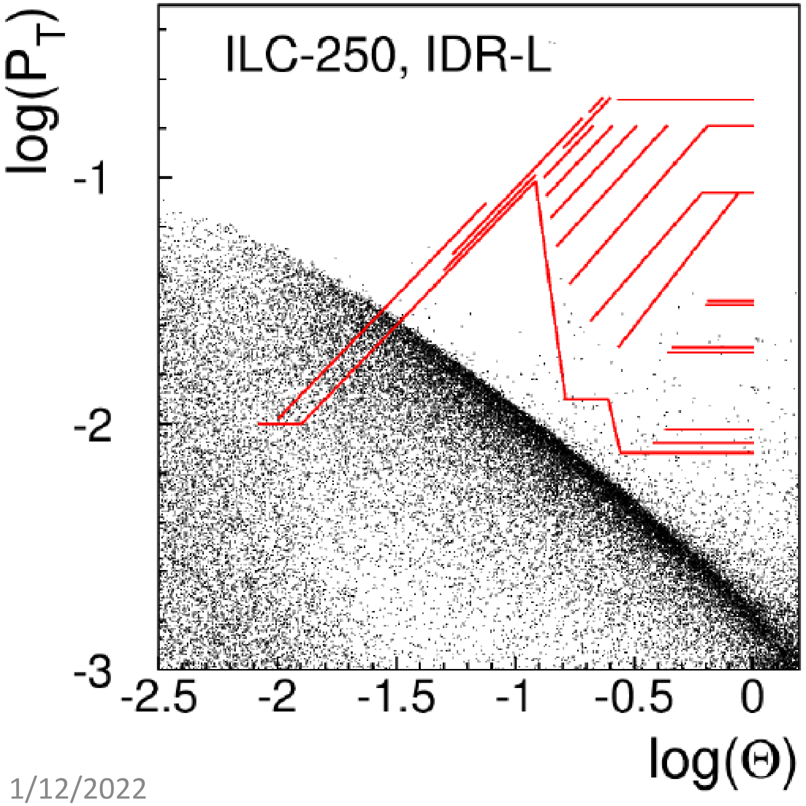
Pair production background

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

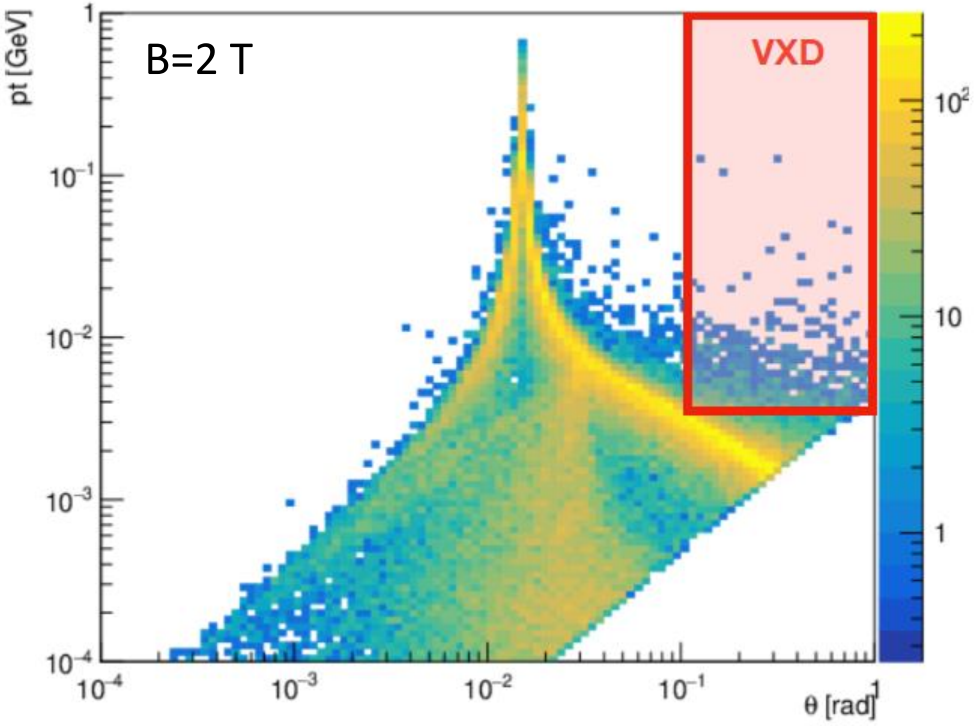


ILC 250 GeV

B=3.5 T

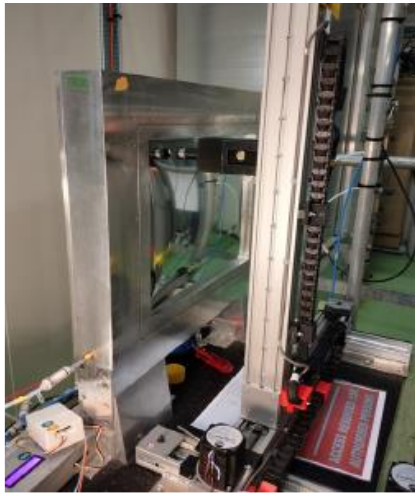


FCC 91.2 GeV

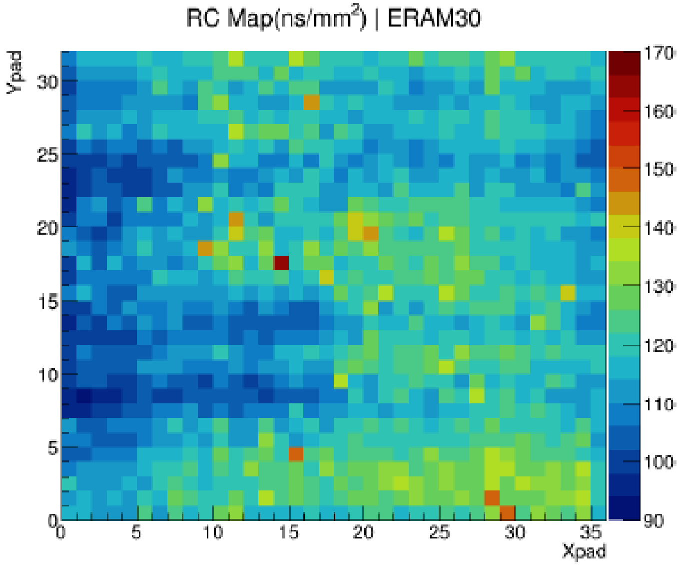


Charge spreading studies in T2K

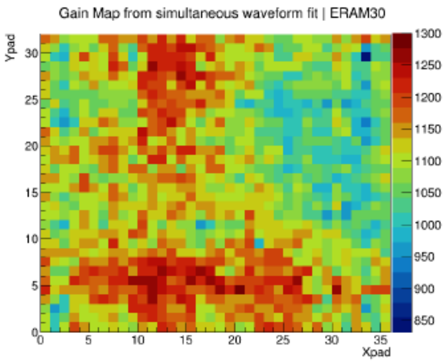
Waveforms of a pad and its neighbours are simultaneously fitted to extract RC and amplitude. This allows to determine RC maps and gain maps for each ERAM module (Encapsulated Resistive Anode Micromegas)



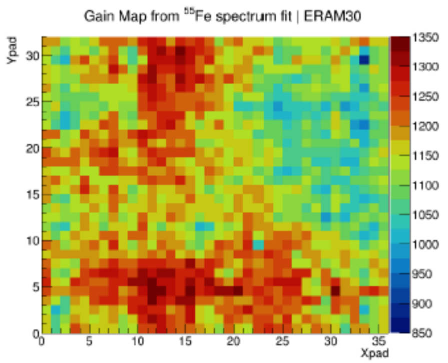
X-ray test bench



RC map of ERAM30

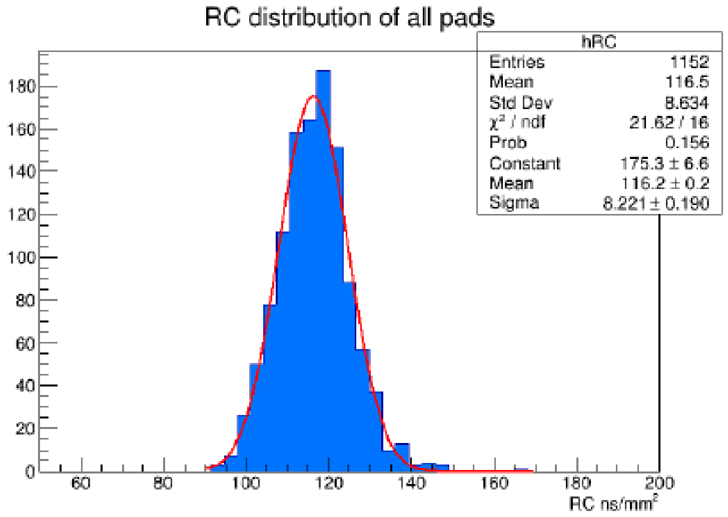


Gain map from simultaneous fit method



Gain map from waveform sum method

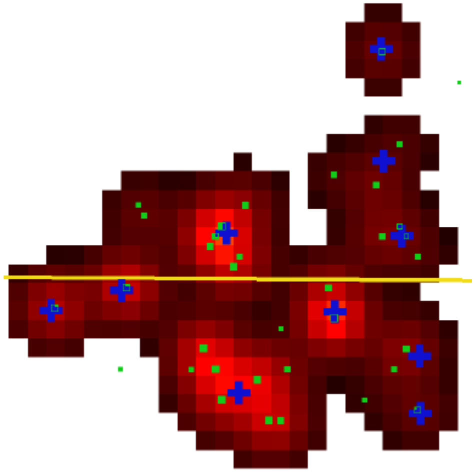
RC$_{mean}$ = 116.2 ns/mm^2



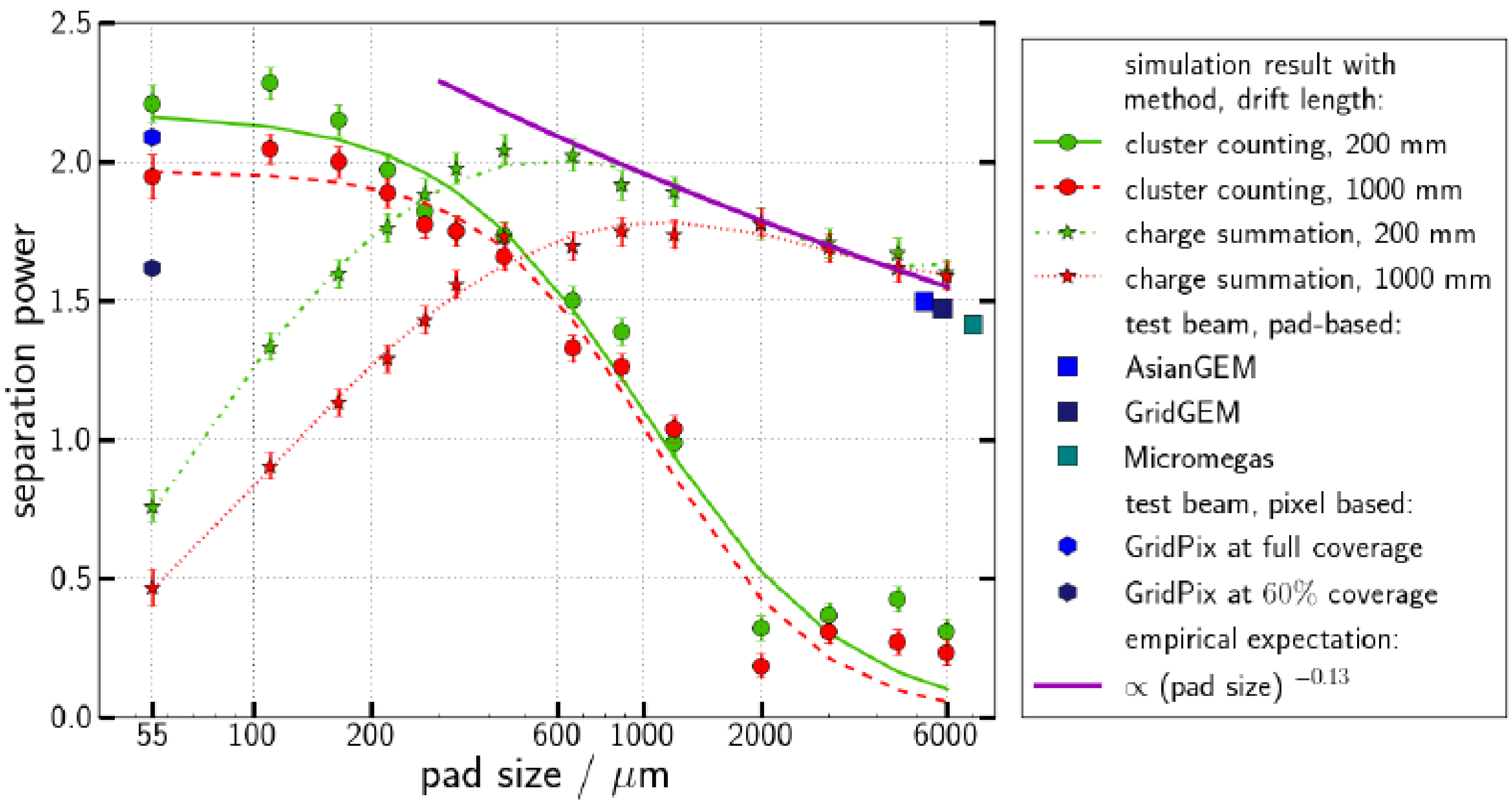
RC distribution of ERAM30

S. Joshi, S. Hassani, J.-F. Laporte

Pad size : from pixel (digital TPC) to pad



Y. Aoki *et al* 2022 *JINST* **17** P11027



Pixel TPC

Pad TPC

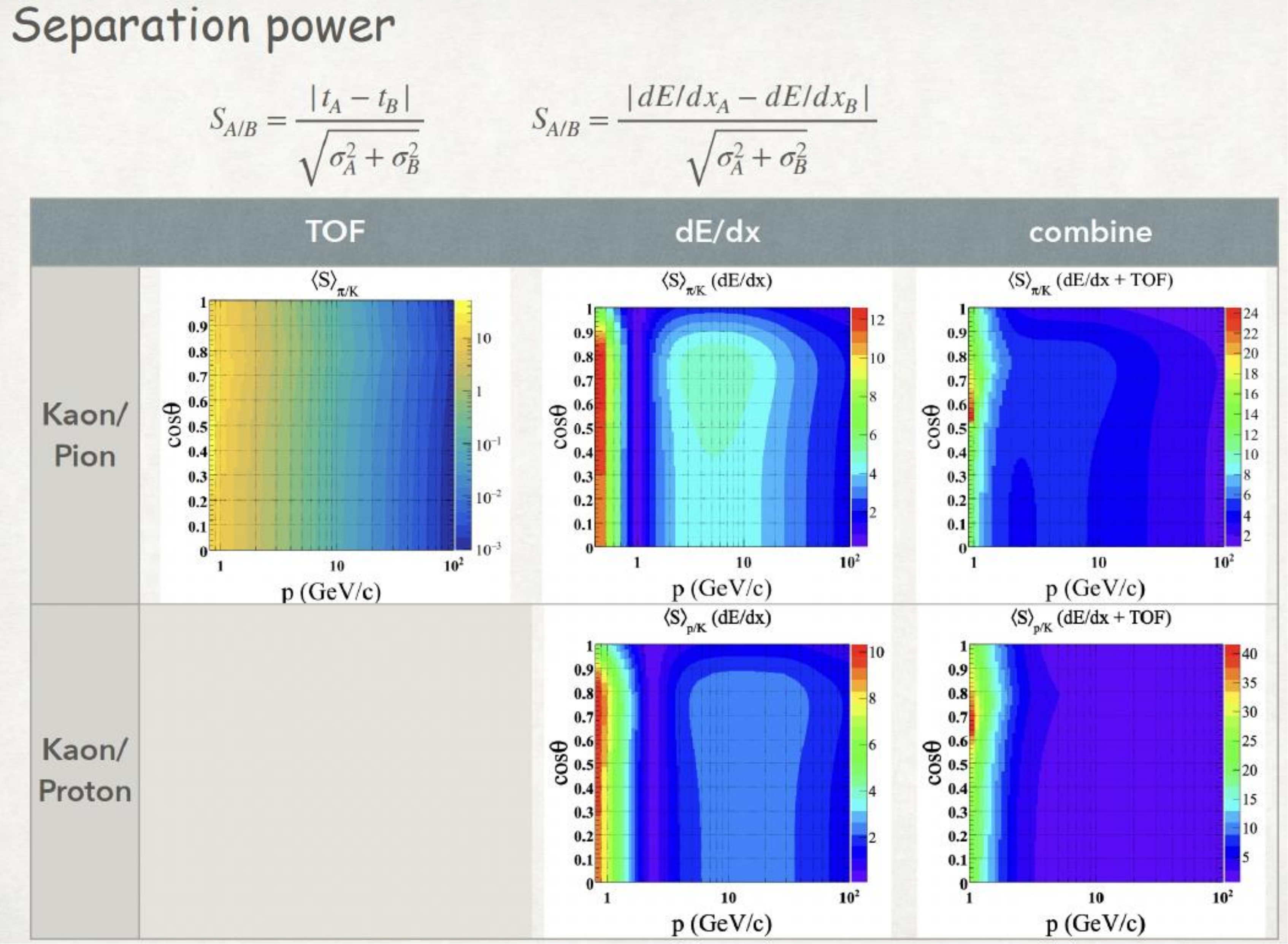
Uli Einhaus

Use of Time-of-flight for PId

10 ps resolution can be envisaged from Si envelope and could provide pi-K separation at up to 20 GeV/c.

(here plots for 50ps)

See also Bohdan Dudar (ILD software and analysis meeting, 11/2022)



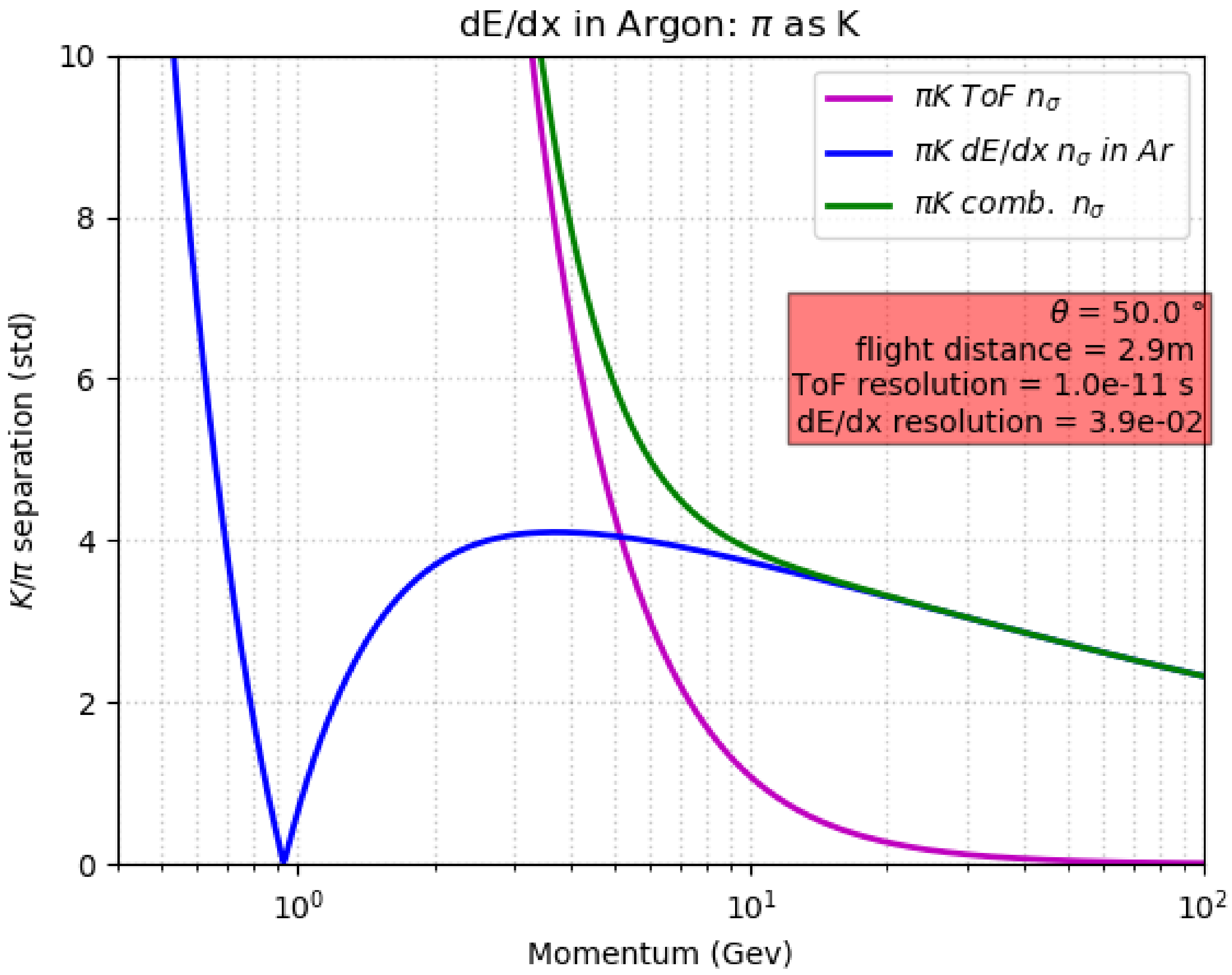
Separation power

$$S_{A/B} = \frac{|t_A - t_B|}{\sqrt{\sigma_A^2 + \sigma_B^2}} \qquad S_{A/B} = \frac{|dE/dx_A - dE/dx_B|}{\sqrt{\sigma_A^2 + \sigma_B^2}}$$

	TOF	dE/dx	combine
Kaon/ Pion	$\langle S \rangle_{\pi/K}$	$\langle S \rangle_{\pi/K}$ (dE/dx)	$\langle S \rangle_{\pi/K}$ (dE/dx + TOF)
Kaon/ Proton		$\langle S \rangle_{p/K}$ (dE/dx)	$\langle S \rangle_{p/K}$ (dE/dx + TOF)

Manqi Ruan
ILD meeting
10/2022

SEPARATION POWER
Combined



R. Aleksan

Conclusion

- The use of a TPC at circular colliders requires new R&D work
    - Recent and ongoing studies show that running a TPC at the Z pole and at the 2 10^{36} $cm^{-2}s^{-1}$ luminosity is difficult because of positive ions creating distortions.
    - Real-time and localized ionization measurement might prove necessary for correcting for distortions
    - Ultimate ion backflow suppression is essential
    - Power consumption can be source of a problem if power pulsing not possible :cooling
    - Machine background studies need to be revisited at all energies
    - Gas choice has to be revisited and several options have to be considered
    - Including precise timing in the tracking might be very helpful at moderate momentum
    - The limitation of the magnetic field at 2T (required for high luminosity) is not good for momentum resolution (plays on sagitta and diffusion)
- It is very difficult to optimize a detector both for EW-heavy flavour physics and for HZ and ttbar physics.
- My personal opinion is that it is essential to recognize the complementarity between a circular collider from the Z pole to HZ and a linear collider at the higher energies : HZ to ttbar and above.