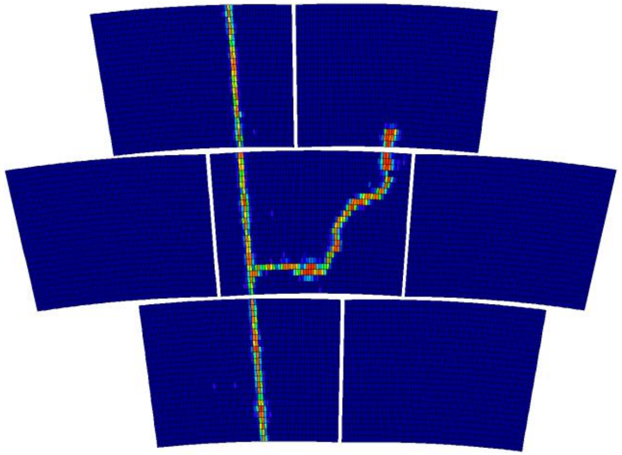
FCC France-Italy workshop
Lyon, November 21-23, 2022

TPC R&D and Particle Identification

Paul Colas (CEA/Irfu Université Paris Saclay)



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

Tracking at an EW/Higgs/top factory

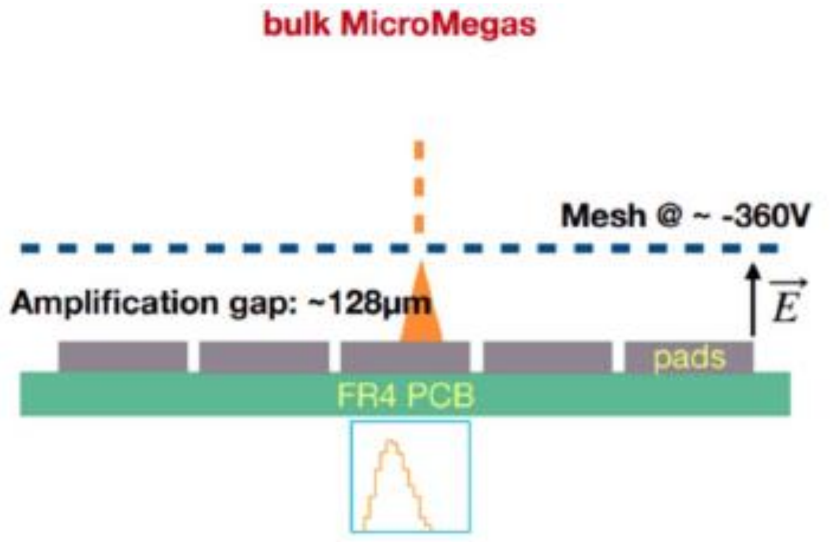
- At the Z pole and beyond, particle ID is an essential ingredient, for tagging and studies of Heavy Flavours (together with an excellent vertex detection)
- A TPC ideally combines dE/dx measurement and low material budget, allowing a continuous measurement of the tracks. A strong magnetic field aligned 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.

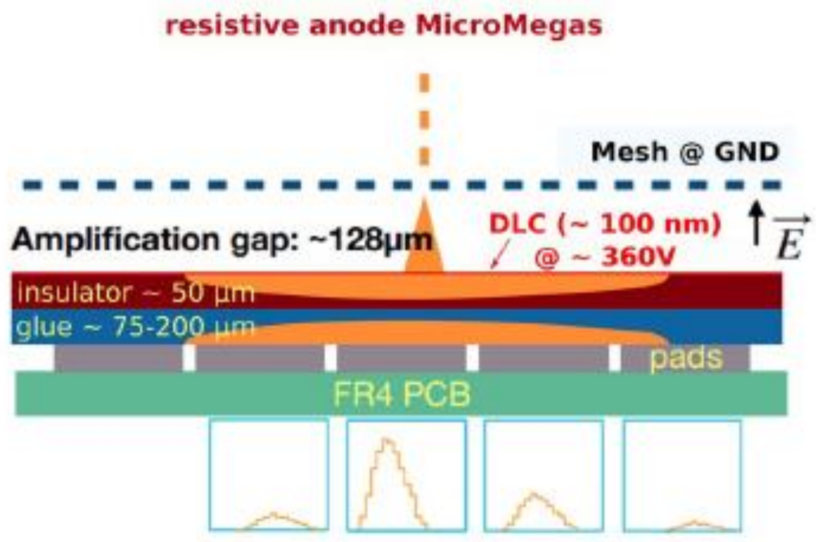
TPC R&D

- 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)

ERAM

Encapsulated resistive anode Micromegas

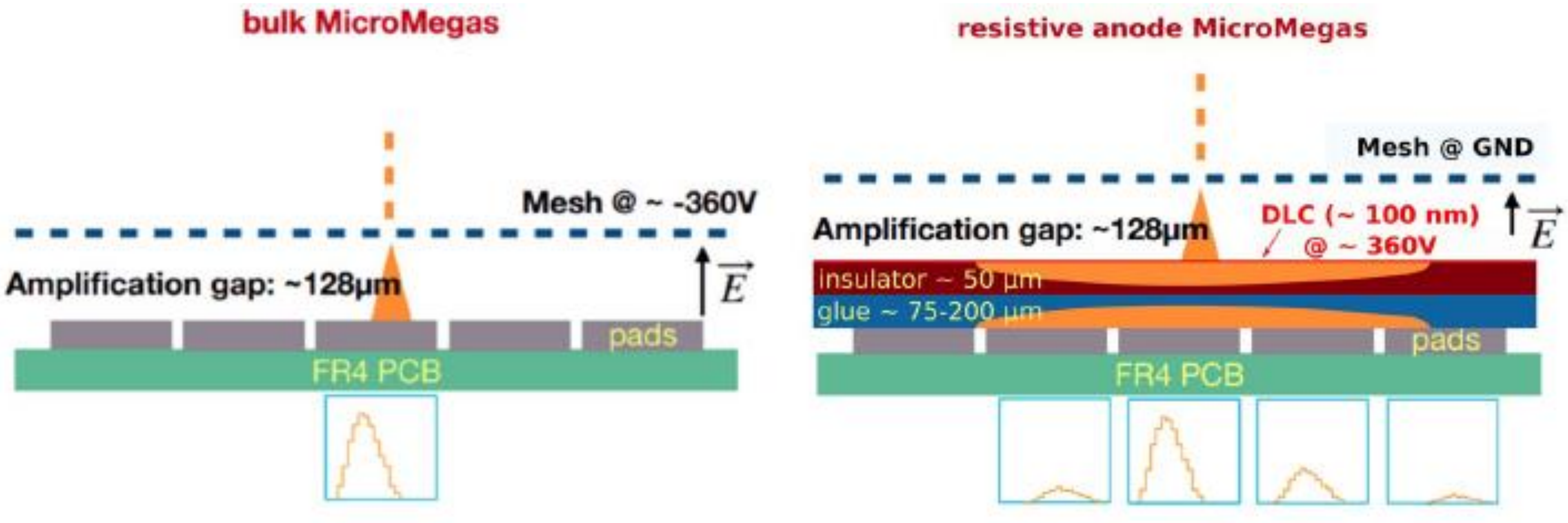




Acts as a continuous resistive-capacitive network characterized by an RC charge diffusion constant.
R : surface resistance (DLC coating), C : capacitance per unit surface.

ERAM

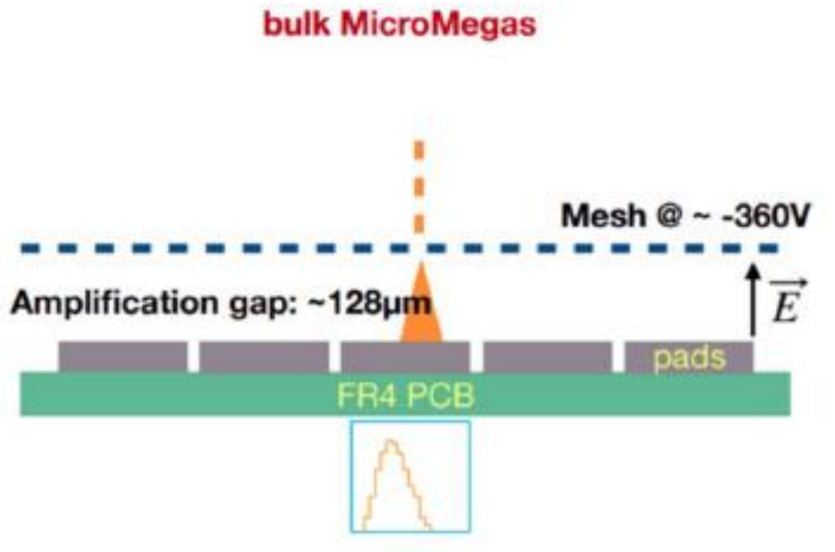
Encapsulated resistive anode Micromegas

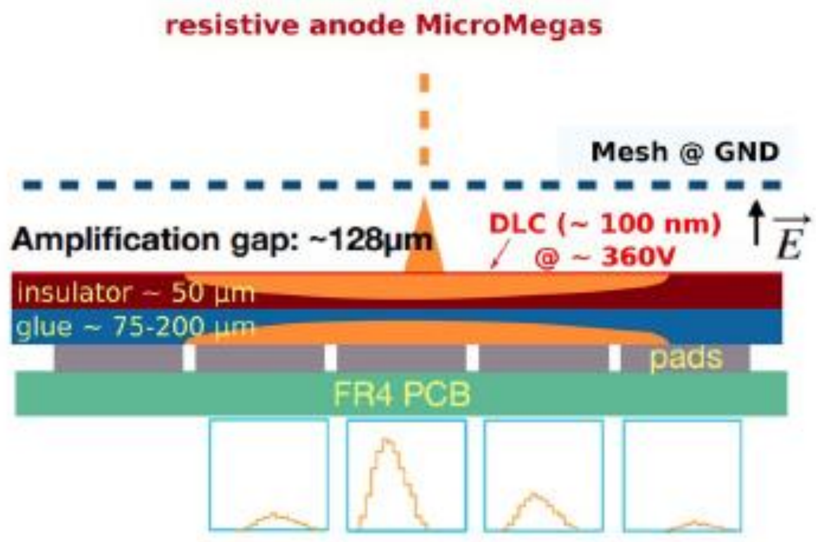


Advantages :
- Improves the resolution without increasing the number of readout channels
- Stabilizes Micromegas by damping the sparks
- Protects the electronics
- Allows tunning the gain module by module while keeping the anode equipotential.

ERAM

Encapsulated resistive anode Micromegas

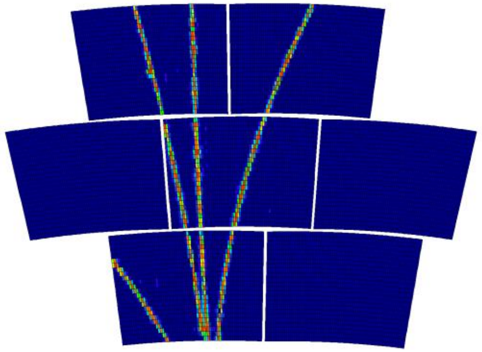


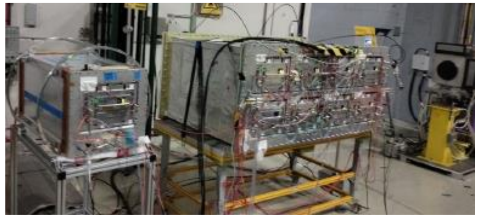


Invented for ILD TPC
Adopted and developped by T2K

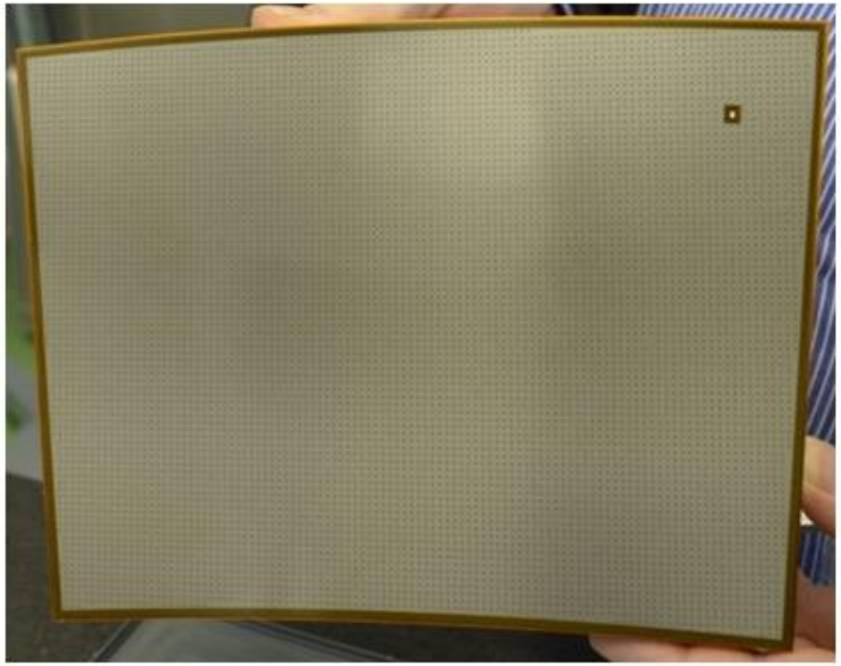
TPC R&D

Beam tests at DESY and at CERN
Cosmic tests at Saclay

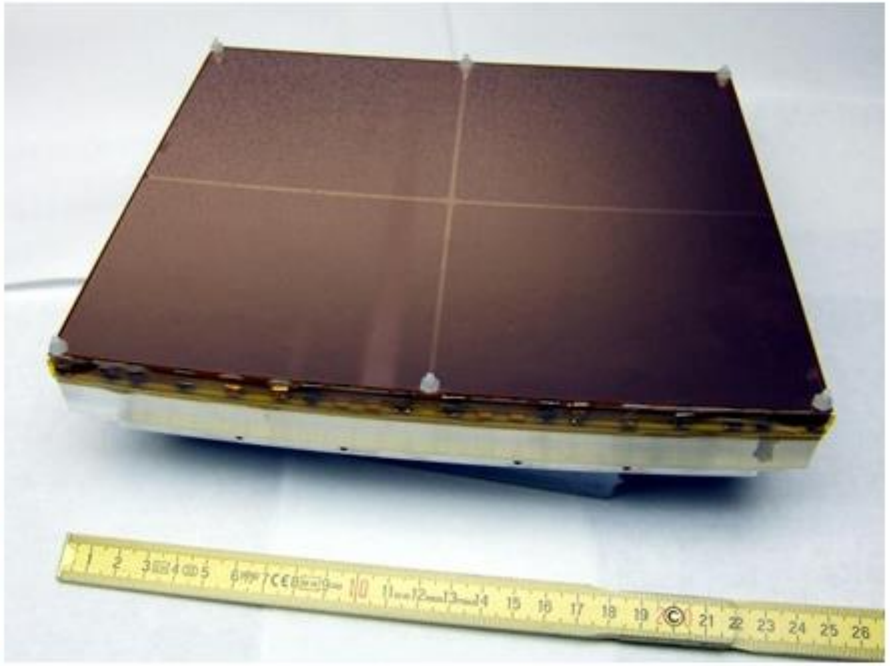




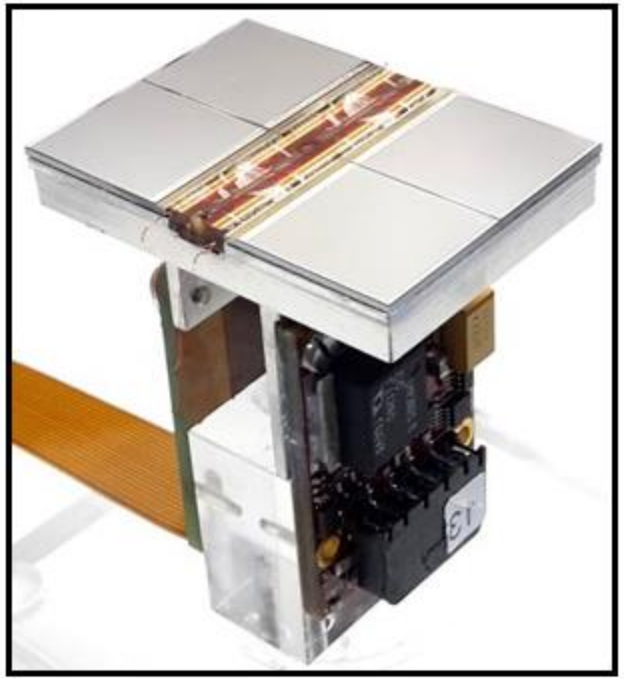
Micromegas



GEM



Gridpix



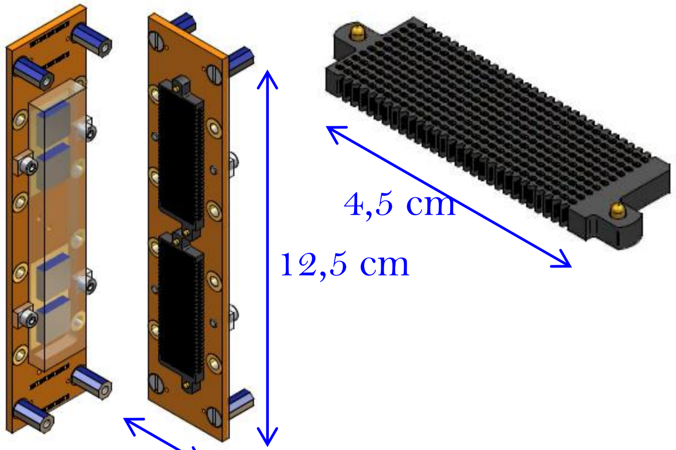
Integrated electronics for LCTPC 7-module project

- Remove packaging and protection diodes
- Wire –bond AFTER chips
- Use 2 × 300 pins connector

FEC

25 cm

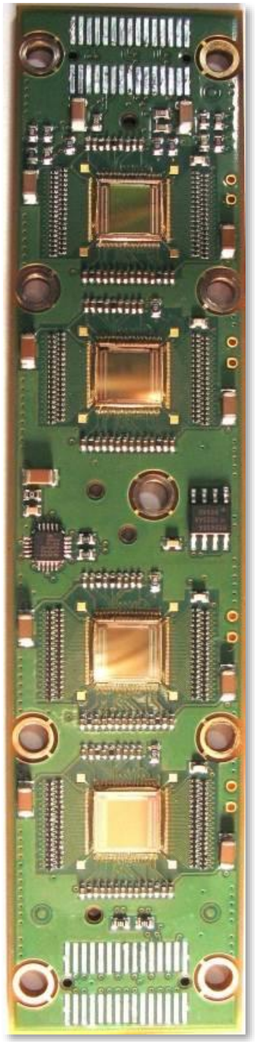
14 cm



12,5 cm

4,5 cm

2,8 cm

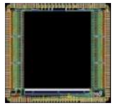


3,5 cm

Chip

3,5 cm

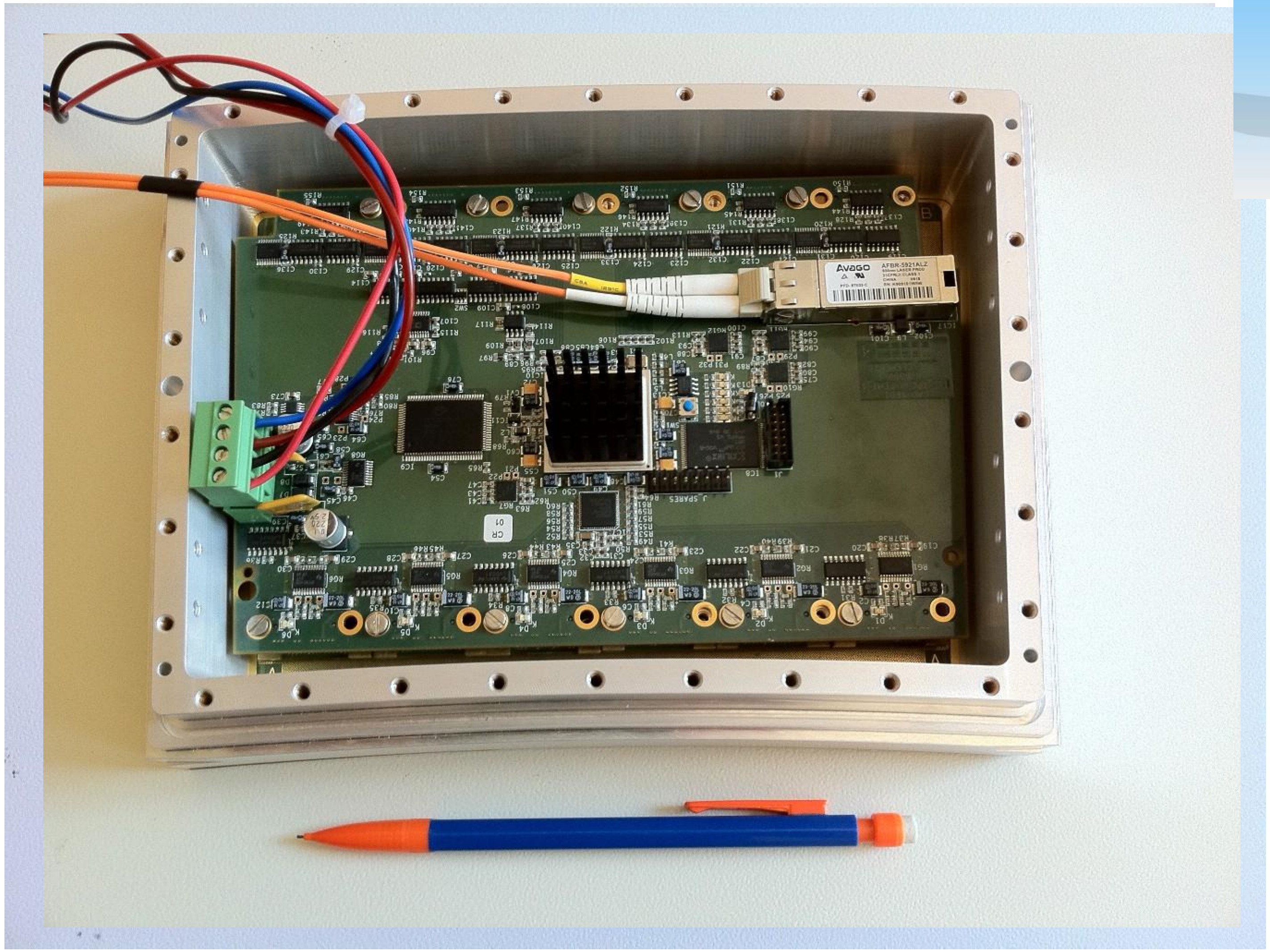
0,78 cm

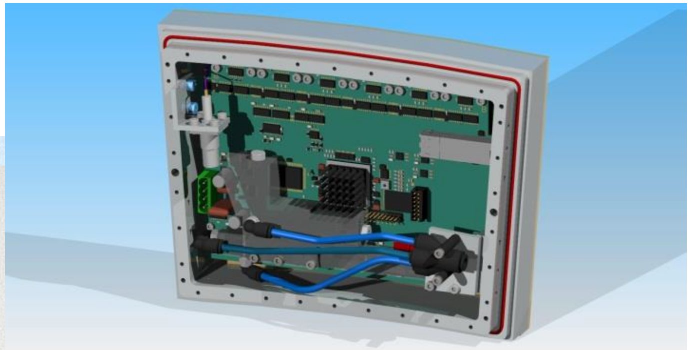


0,74 cm

The resistive foil protects against sparks

The goal of < 25% X0 is attained





Cooling with 2-phase CO_2 at 50-60 bar added in 2014. Aluminum 3D-printed Cooling plate tested in 2021

-test of full integration

-test of quasi industrial production, with characterization and qality procedures

Gas choice

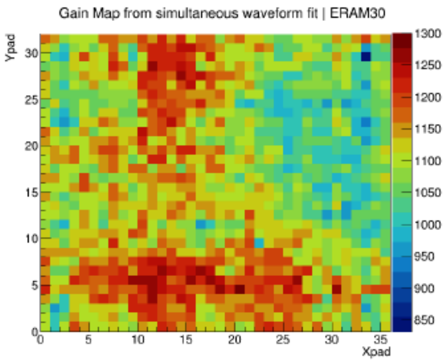
- Base gas :
  - Ar for largest ionization : 97 e-ion pairs in ~35-40 clusters
  - He for well-separated clusters (but cannot set field to the maximum drift velocity)

- Additional gases
  - Isobutane : quencher, cuts UVs to avoid avalanche propagation
  - 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)

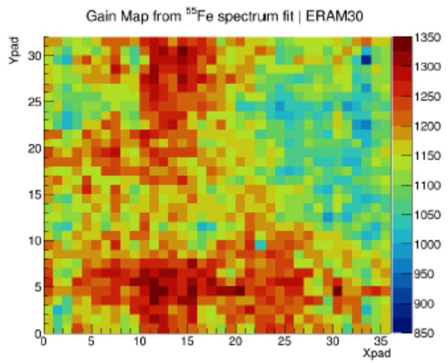
- T2K gas Ar:CF4:Isobutane 95:3:2 satisfies all requirements for a TPC

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)

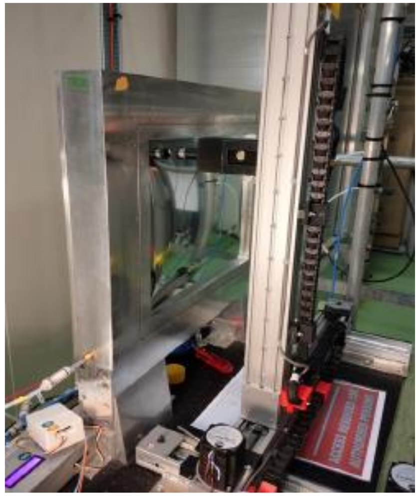


Gain map from simultaneous fit method

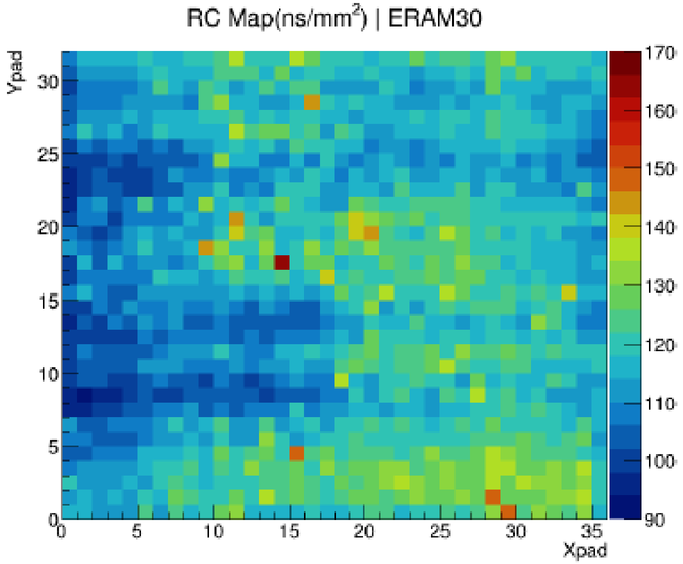


Gain map from waveform sum method

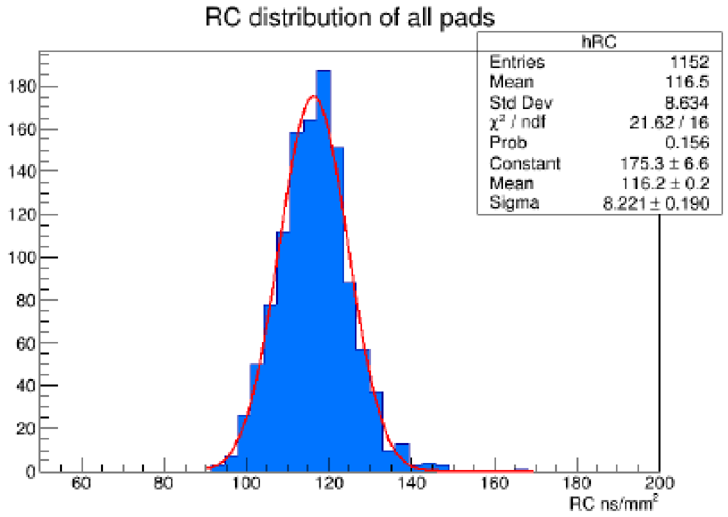
RC_{mean} = 116.2 ns/mm²



X-ray test bench



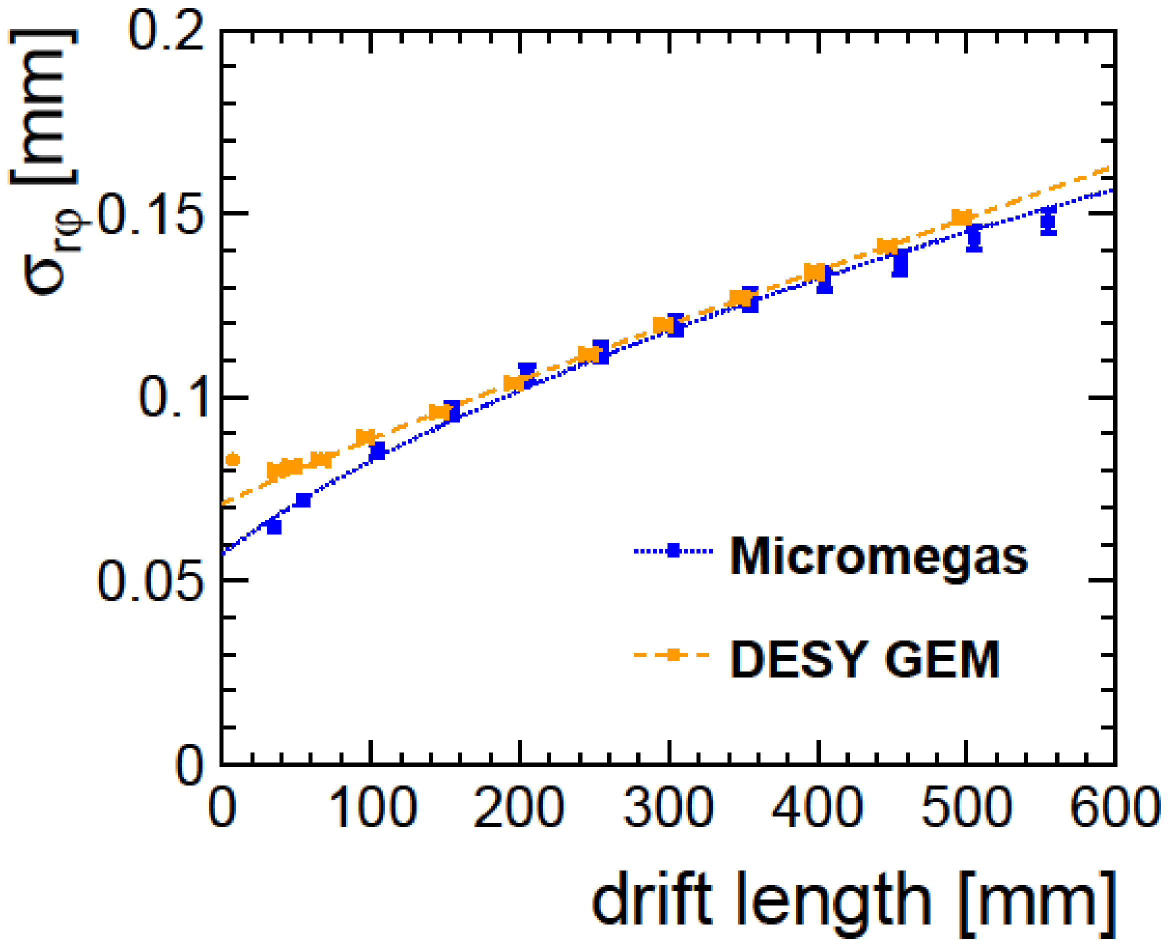
RC map of ERAM30



RC distribution of ERAM30

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

rϕ resolution

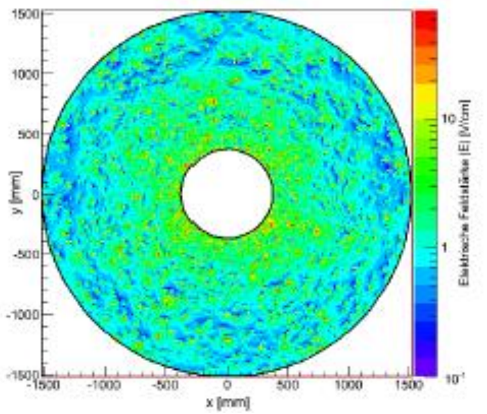


Distortions from positive ions

- 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

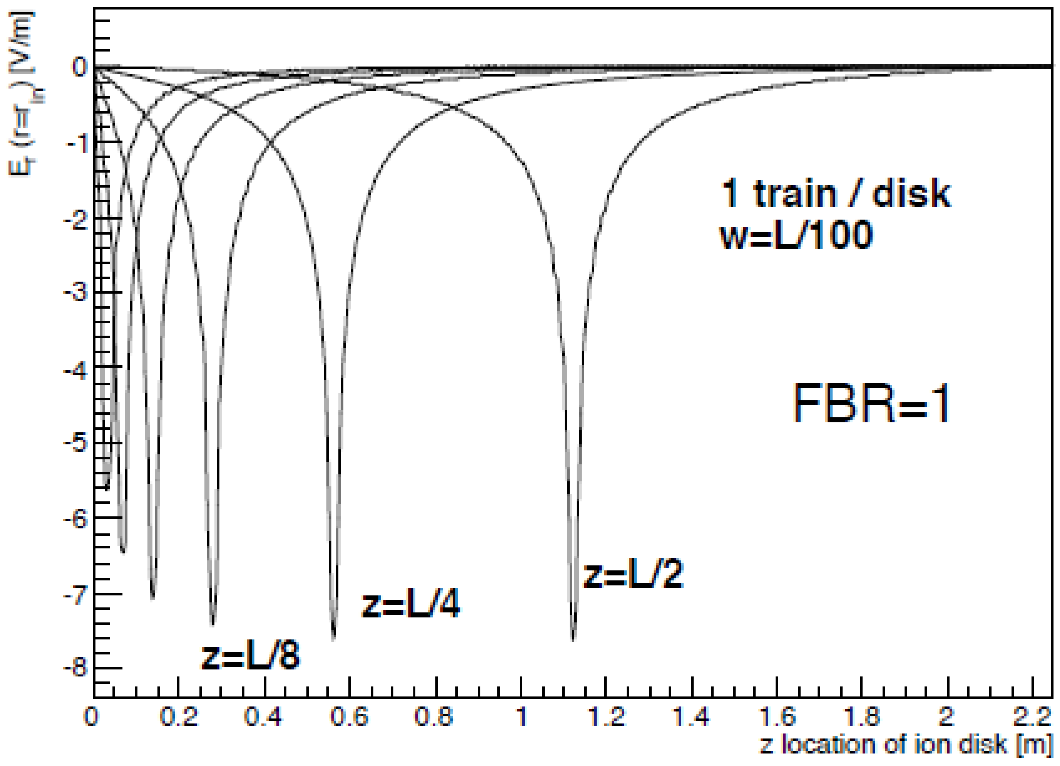
(K. Fujii, S. Ganjour, Mingrui Zhao…)

500 Bunch Crossings



Simulation by M. Killenberg (2009)

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

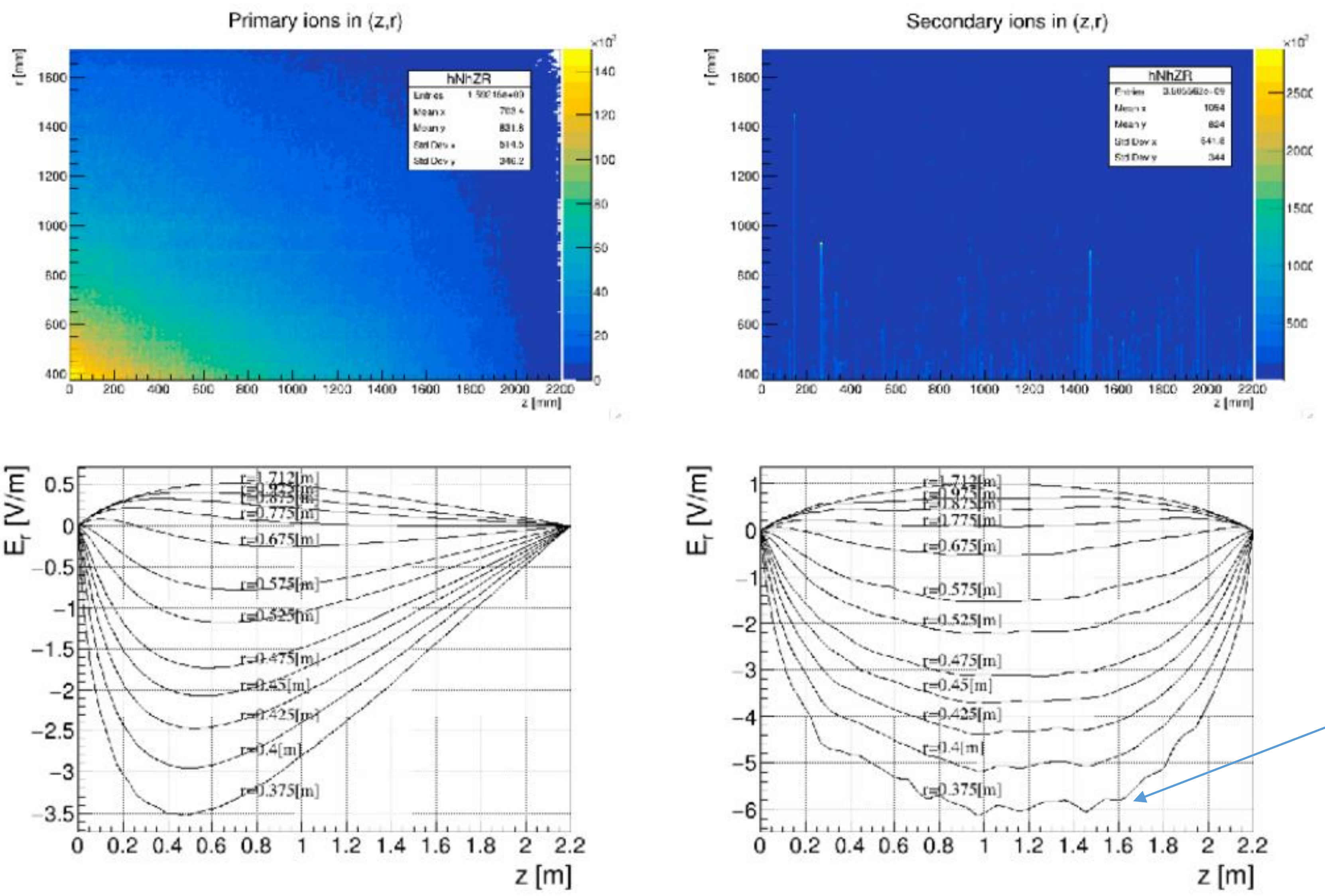


Case of FFC or CEPC at Z pole : almost continuous set of disks.

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

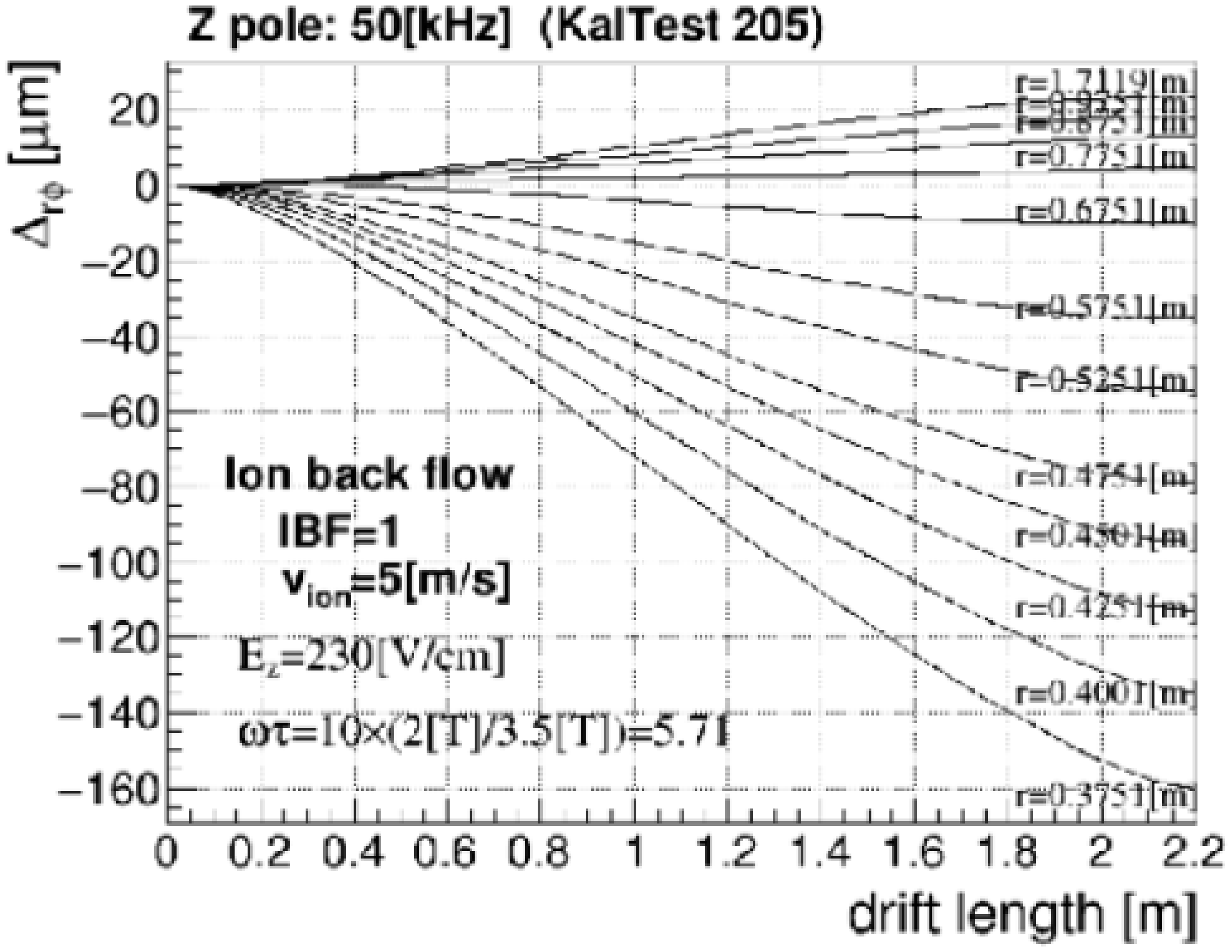
Positive Ion back flow (11k Z pole events)

Corresponds to 1 ion drift time



Fluctuations of charge density due to curlers

K. Fujii, preliminary



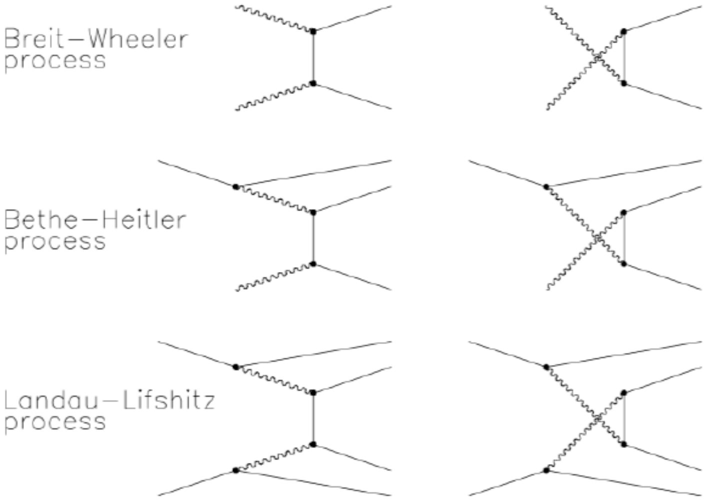
Resulting distortions at Z pole for IBF=5 :
~800 µm (preliminary)
(160 µm if IBF can be fully suppressed…)

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.

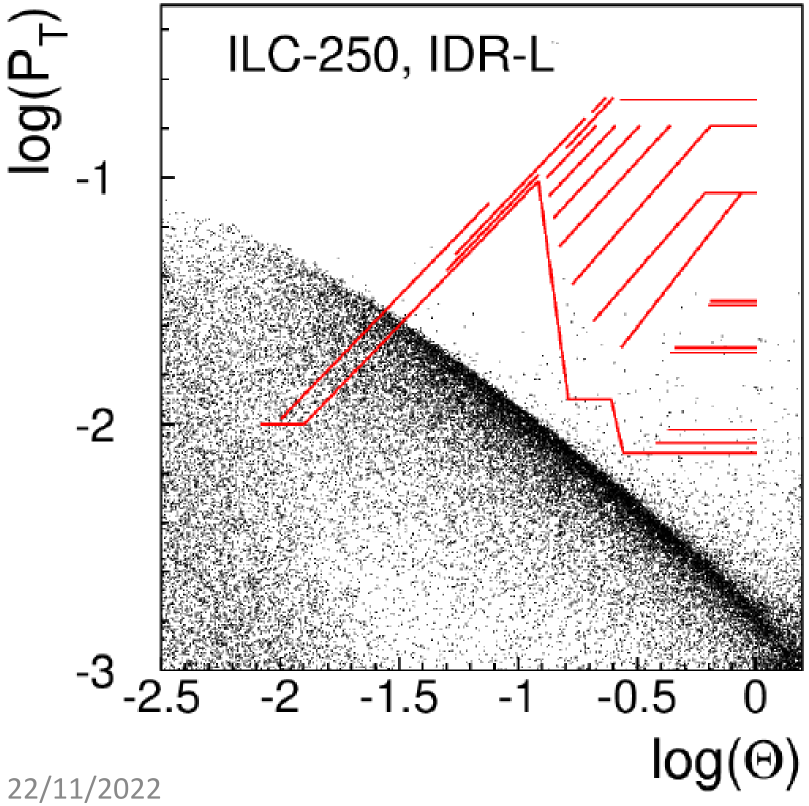
Pair production background

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

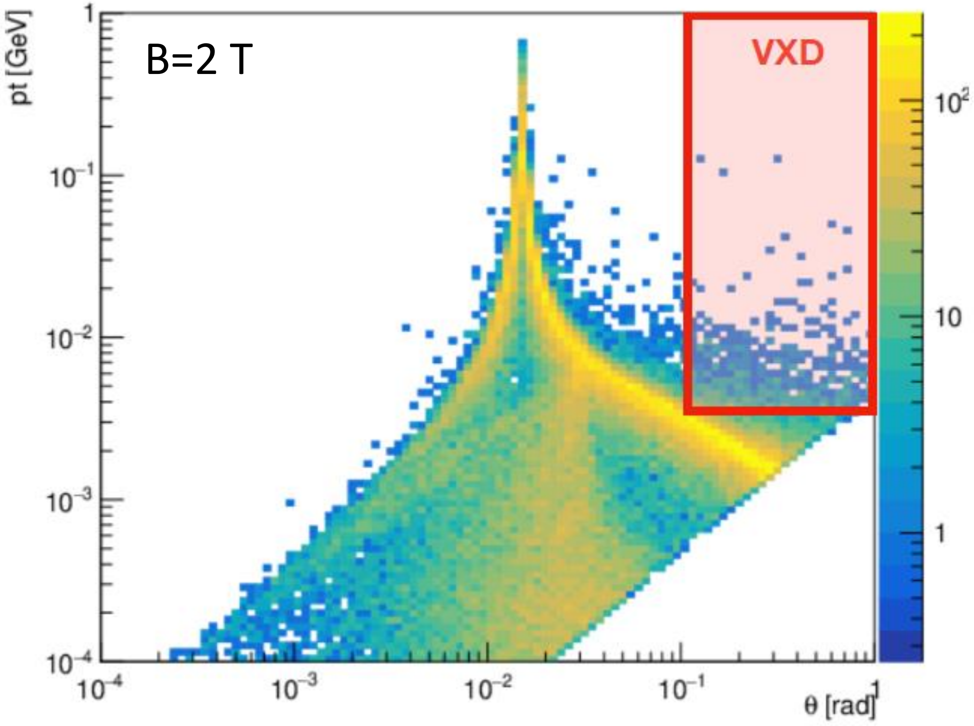


ILC 250 GeV

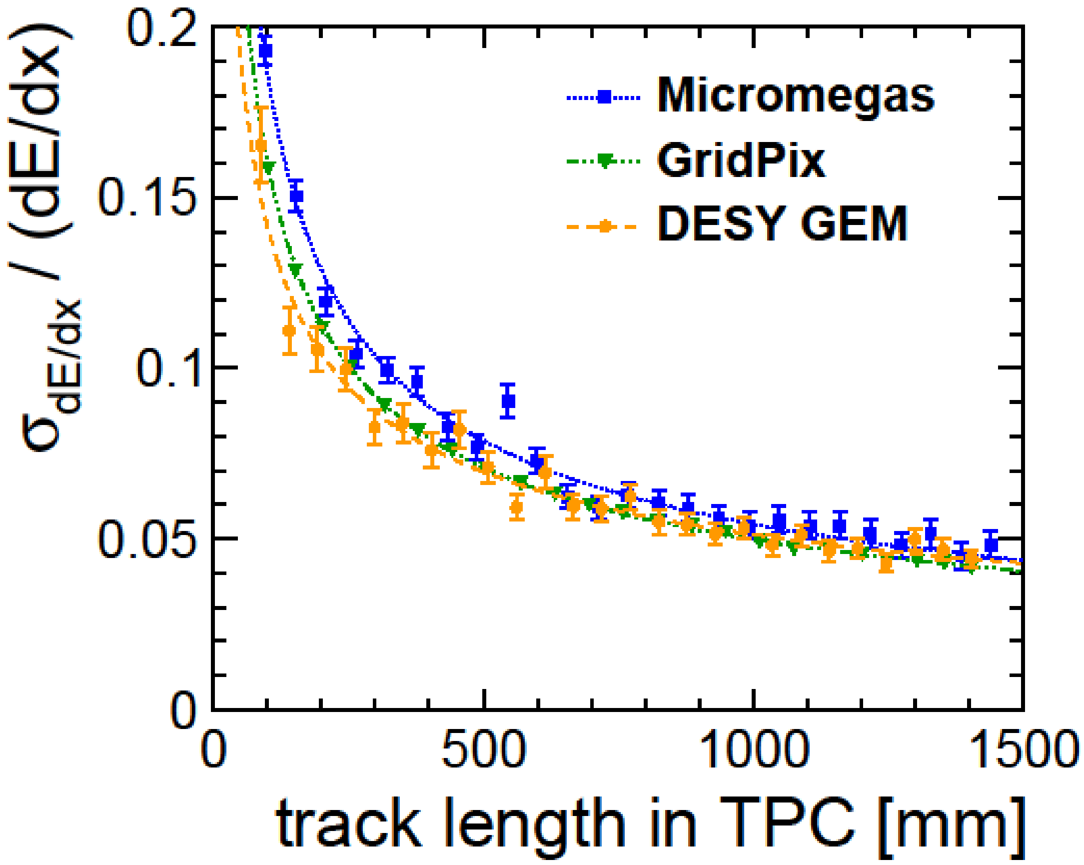
B=3.5 T



FCC 91.2 GeV

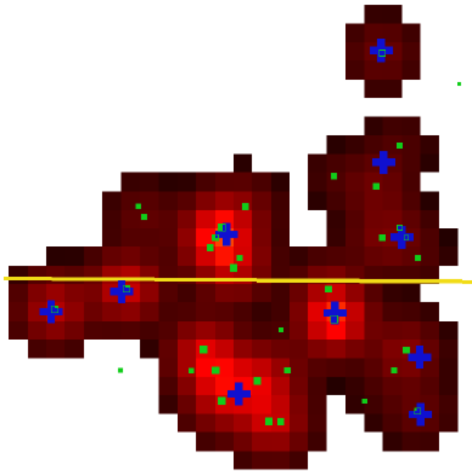


Particle identification

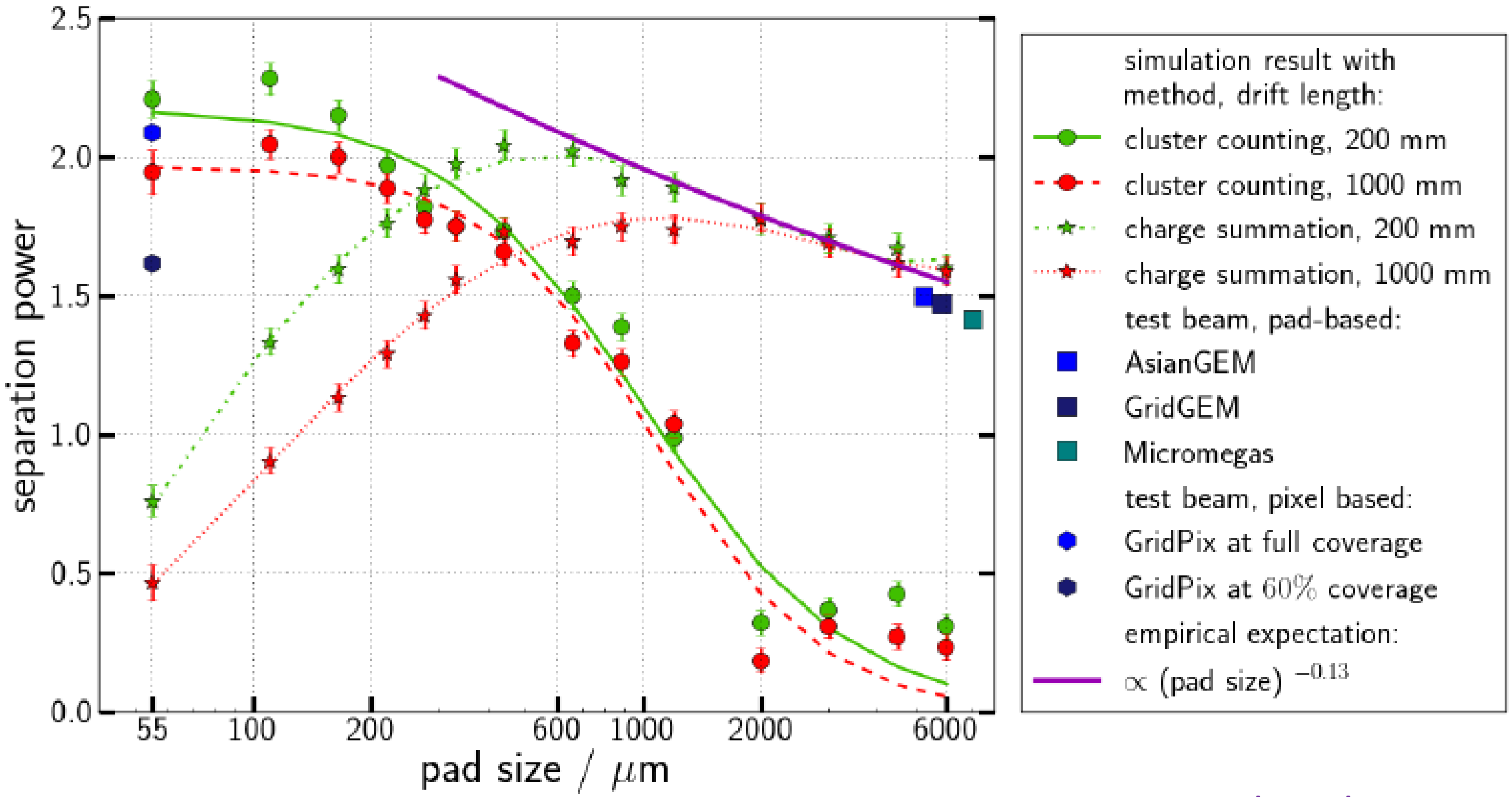


Results from beam tests

Pad size : from pixel (digital TPC) to pad



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



Pixel TPC

Pad TPC

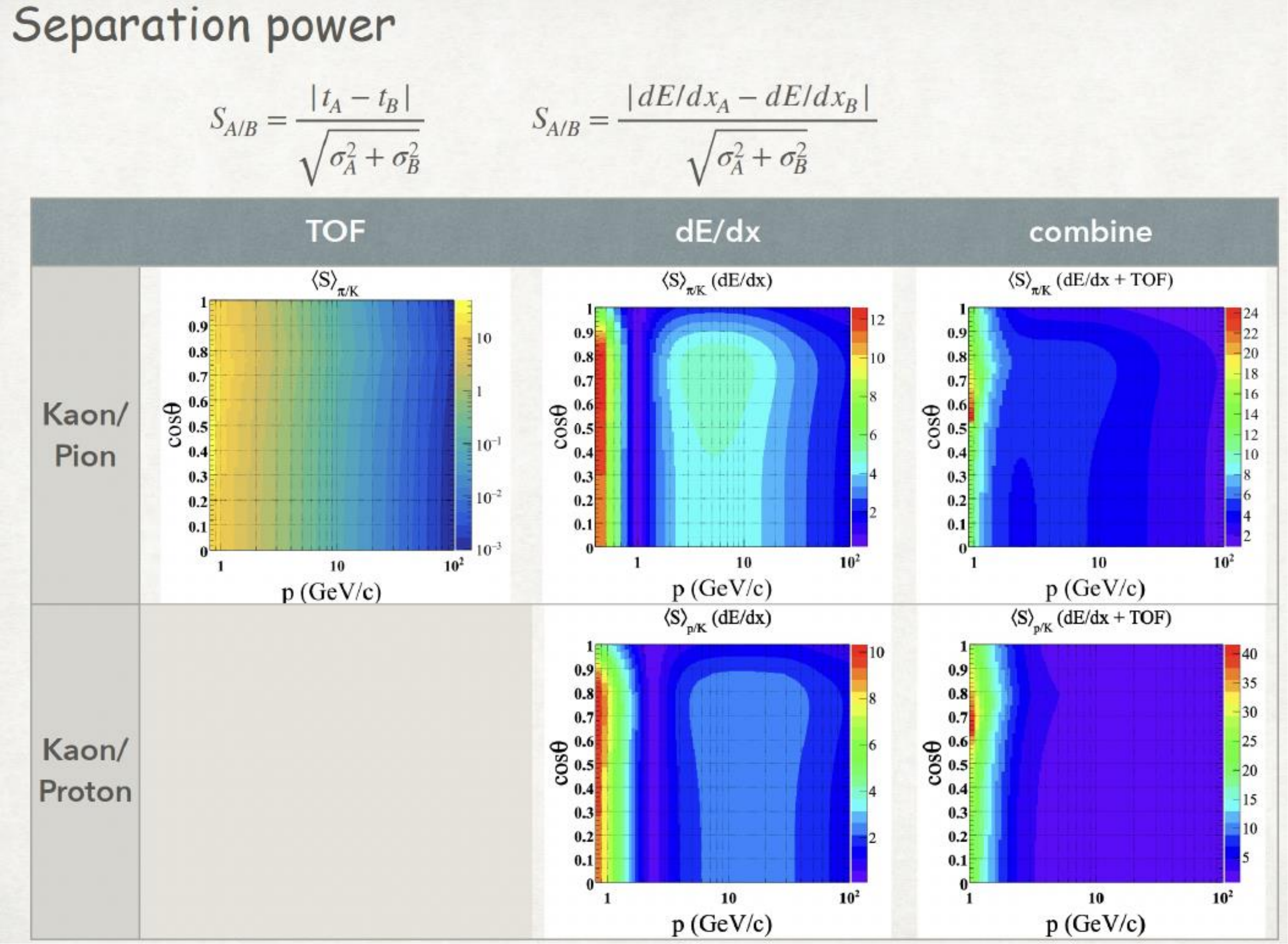
Uli Einhaus

Use of Time-of-flight for PId

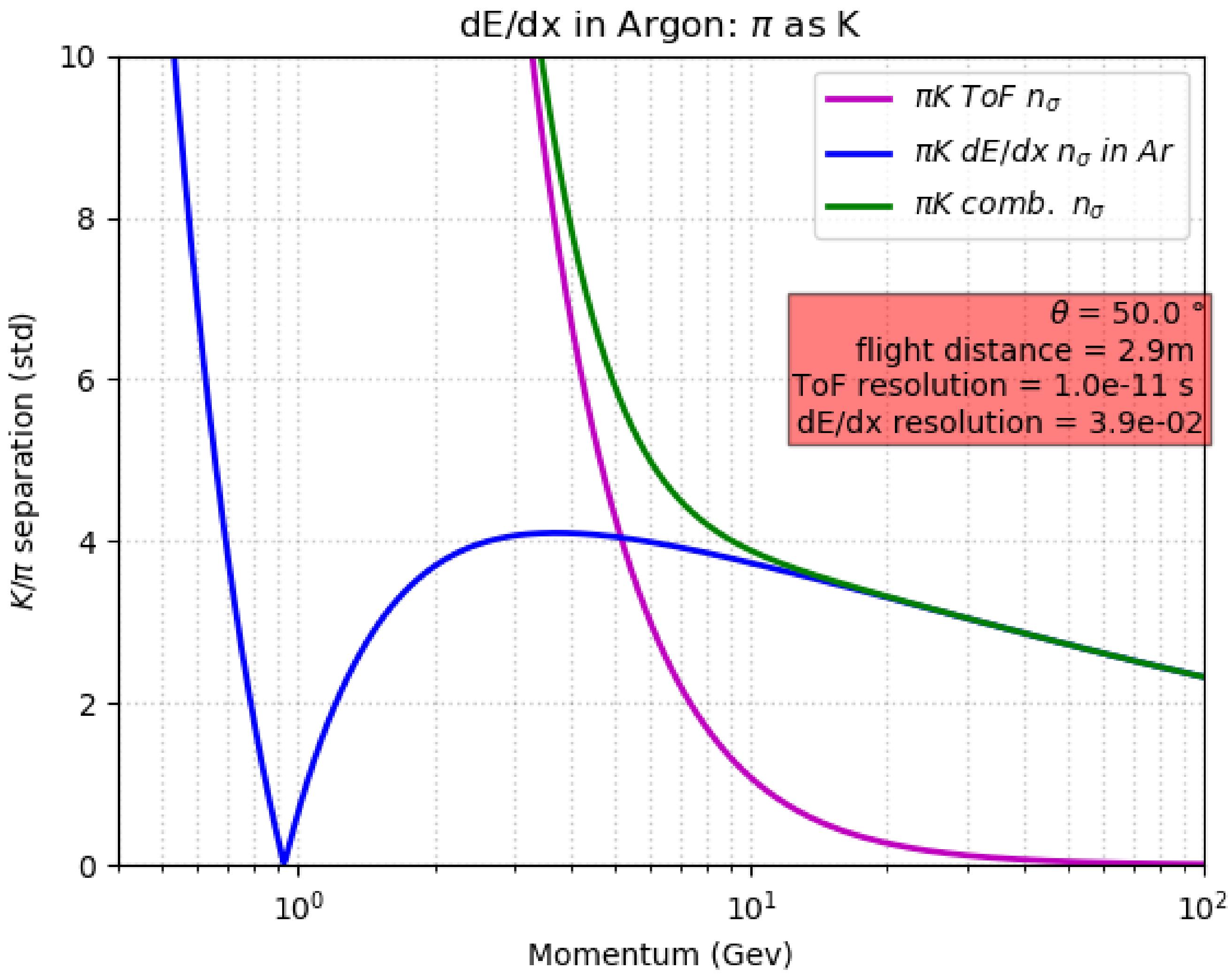
10 ps resolution can be envisaged from Si envelope and could provide pi-K separation at up to 20 GeV/c.

(here plots for 50ps)

Manqi Ruan
ILD meeting
10/2022



SEPARATION POWER
Combined



R. Aleksan

Conclusion

- The R&D for a TPC at an e+e- factory evolves since 1996
- 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.
- Machine background studies need to be revisited

- My personnal conclusion is that it is very difficult to optimize a detector both for EW-heavy flavour physics and for HZ and ttbar physics