Update results of TPC prototype and PID with High granularity dE/dx

Huirong Qi

ZhiYang Yuan, Yiming Cai, Yue Chang, Jian Zhang, Zhi Deng, Yulan Li, Hui Gong, Wei Liu

Institute of High Energy Physics, CAS

Tsinghua University

CEPC Det.&Phy., June, 9, 2021

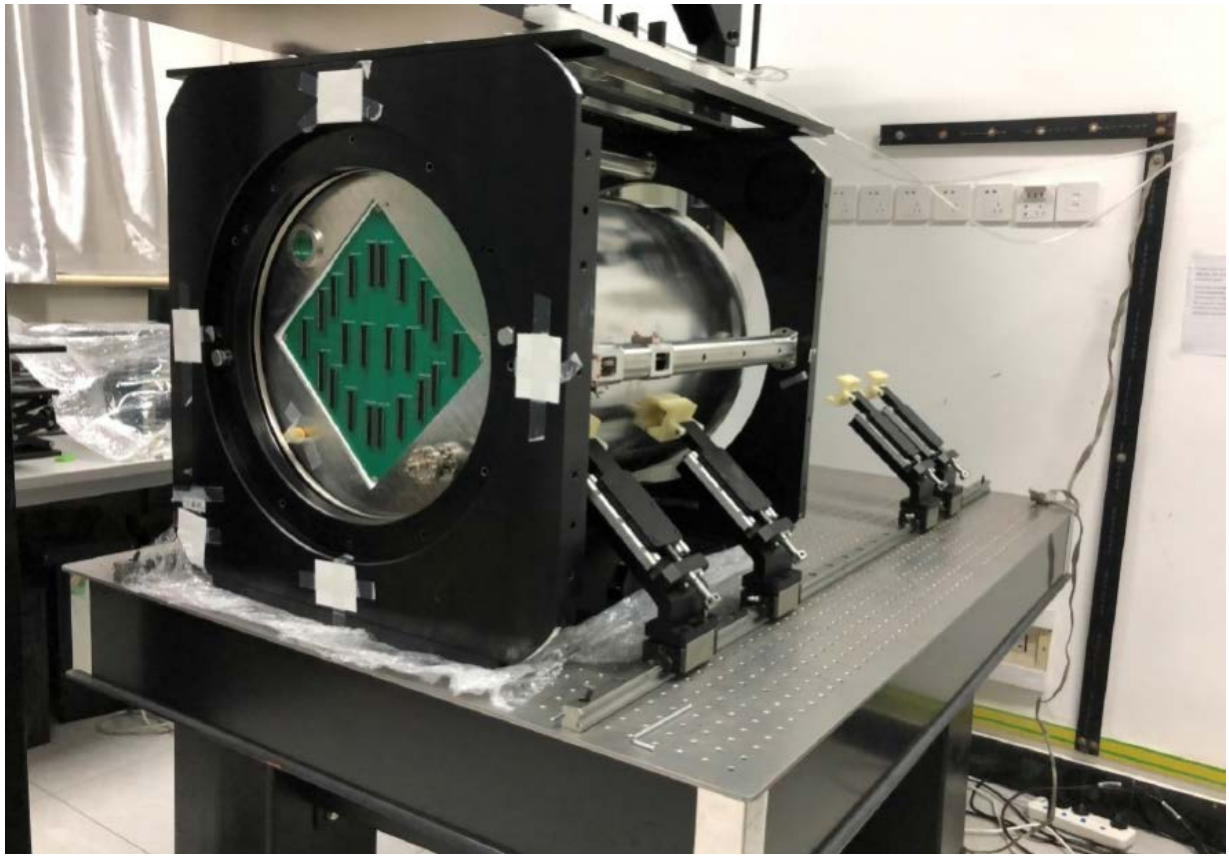
Outline

- TPC prototype
- PID with High Granularity dE/dx

- TPC prototype

Achievements and prospects

- Detector prototype was done and studied in 2021
- Commissioning:
  Huirong Qi, Zhiyang Yuan, Yiming Cai, Yue Chang, Jiang Zhang, Yulan Li, Zhi Deng
- Data taking: the same, plus: Hongyu Zhang, Ye Wu
- Compared with some previous LCTPC R&D, update results of the drift velocity , the spatial resolution and FEE electronics were observed

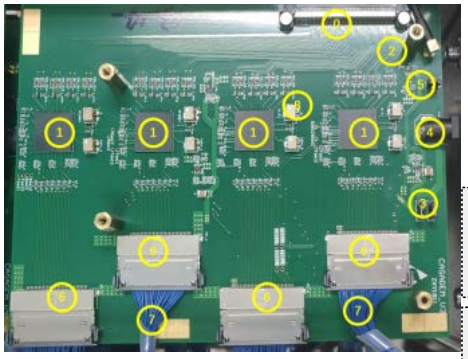


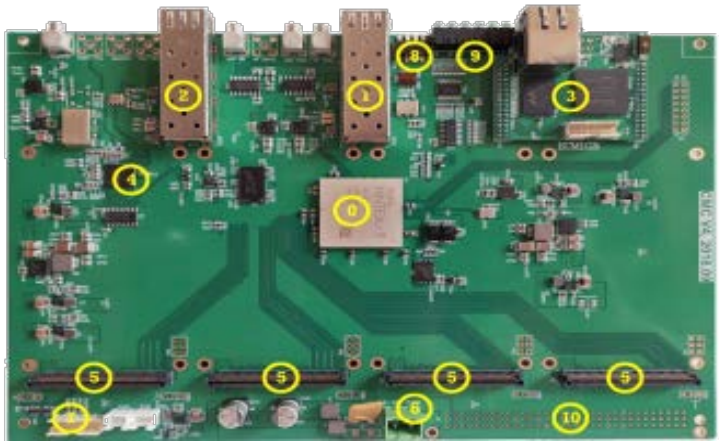
TPC prototype in the lab

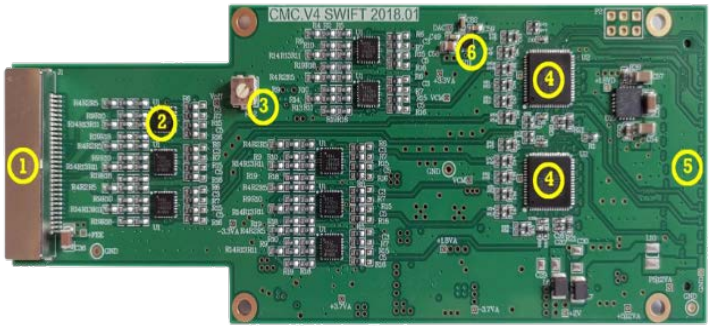
Electronic and DAQ

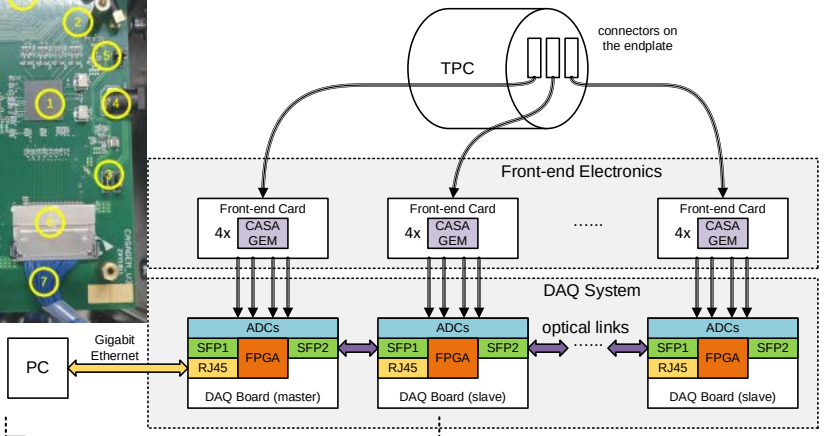
Electronics for TPC

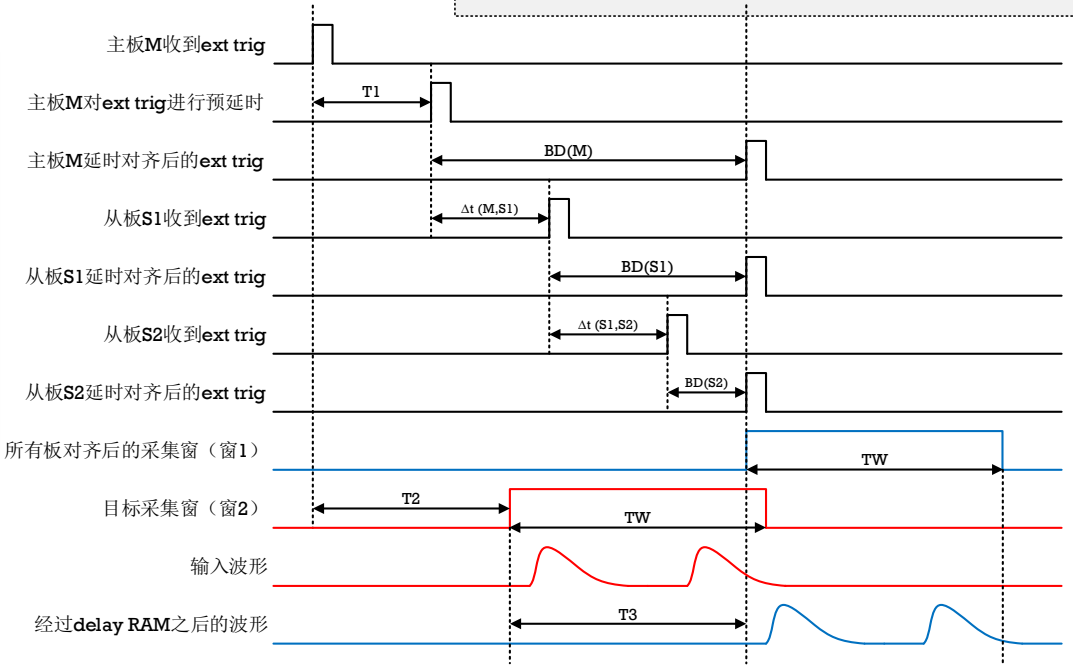
- FEE electronics with self-calibration(update)
- Zero compression
- Waveform reconstruction











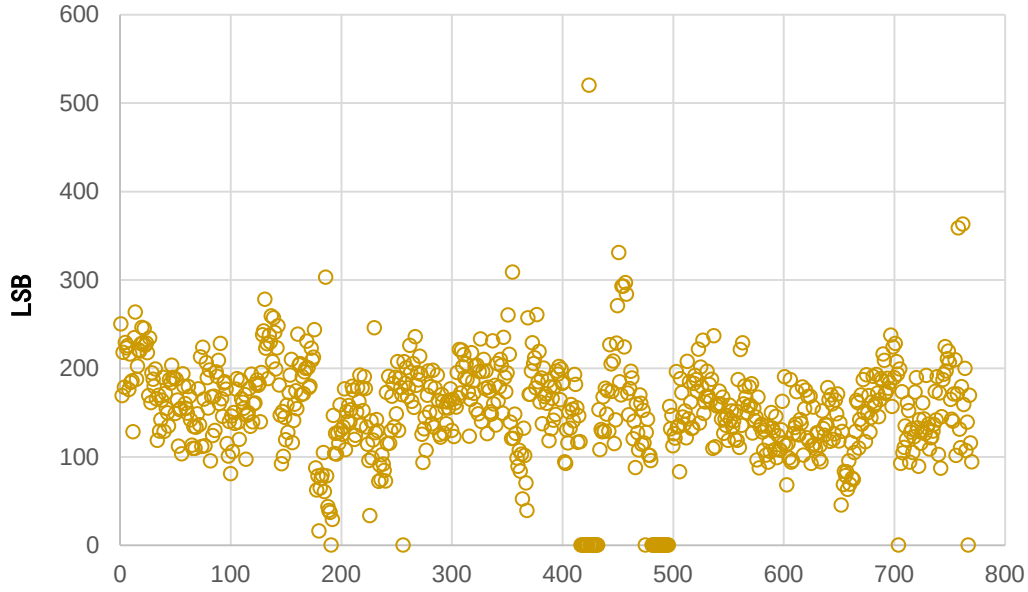
$$T_{relative3} = T_3 - T_{ext} + T_{B1/B2} + T_{B2/B3}$$

$$T_3 = T_{3gravity} - T_{delay} + T_{int}$$

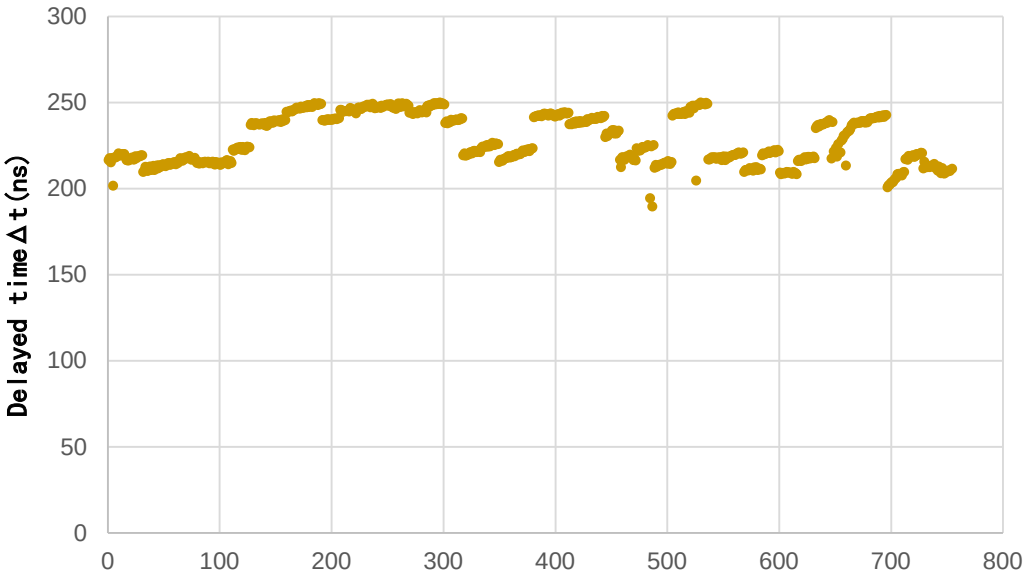
Electronic calibration

Electronics for TPC

- Study of the baseline calibration of FEE with 1280 channels
  - Here listed of 768 channels
  - FEE gain of 20mV/fC
  - FEE shape time of 120ns
- Study of the delayed time of FEE with 1280 channels
  - Here listed of 768 channels
  - Connected with the detector and HV ON
  - HV of the filed cage ON



Baseline calibration of FEE

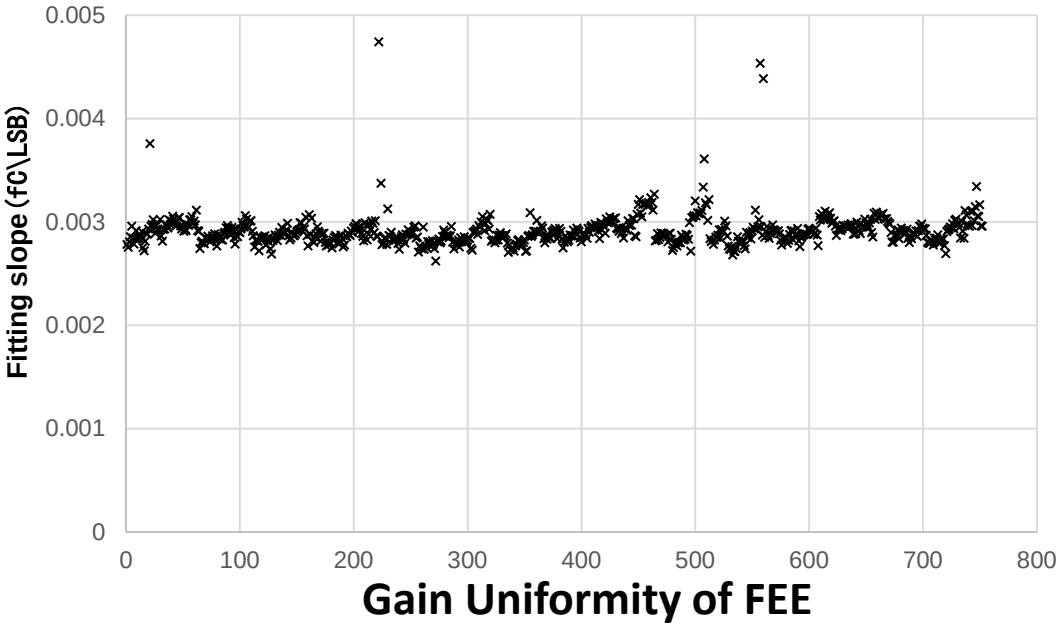


Uniformity of the delayed time

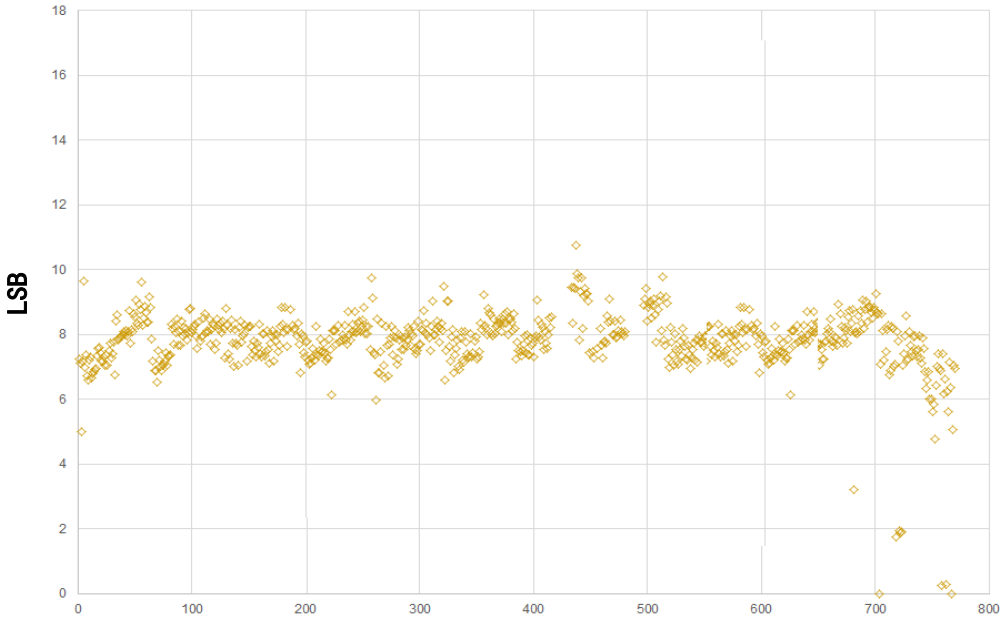
Electronic calibration

Electronics for TPC

- Study of the gain uniformity of FEE with 1280 channels
  - Here listed of 768 channels
  - FEE gain of 20mV/fC
  - FEE shape time of 120ns
- Study of the noise of FEE with 1280 channels
  - Here listed of 768 channels
  - Connected with the detector and HV ON
  - HV of the filed cage ON
  - Without the baseline



Gain Uniformity of FEE

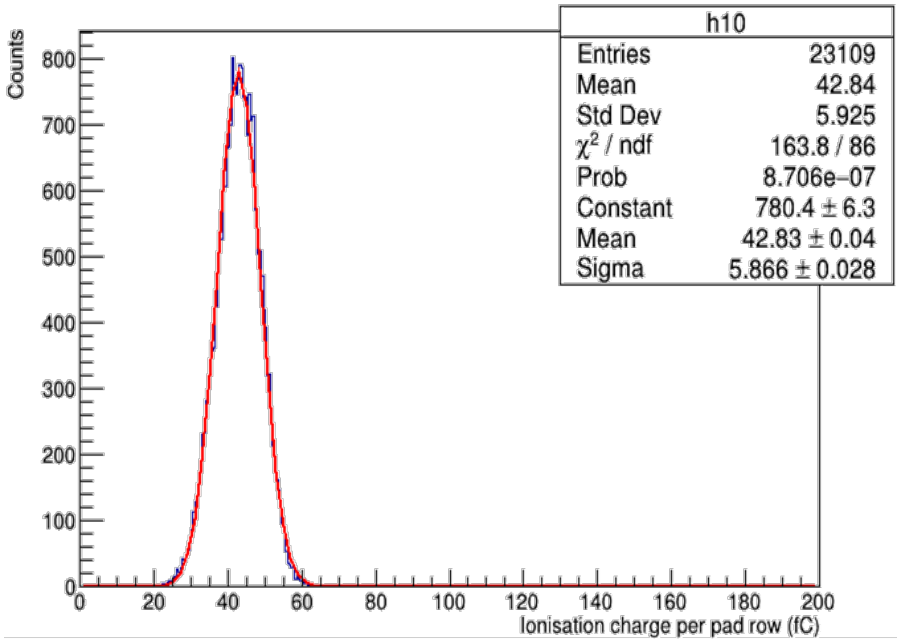


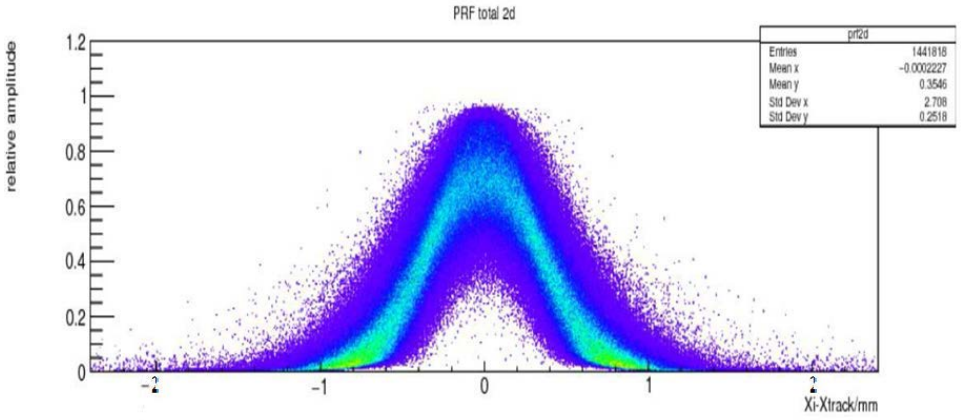
Noise of FEE with HV connection

Update results with the calibration

Electronics for TPC

- Pad size: 1mm*6mm





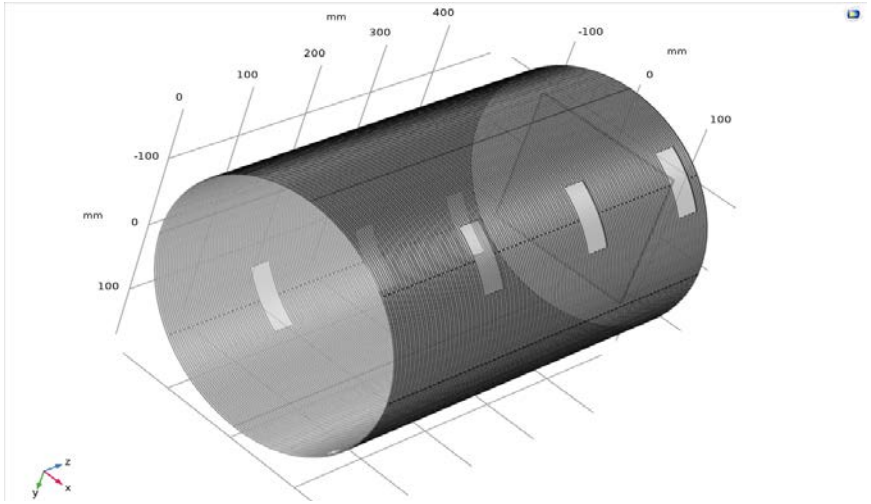
Ionization charge per pad and the PRF profile of all pad rows

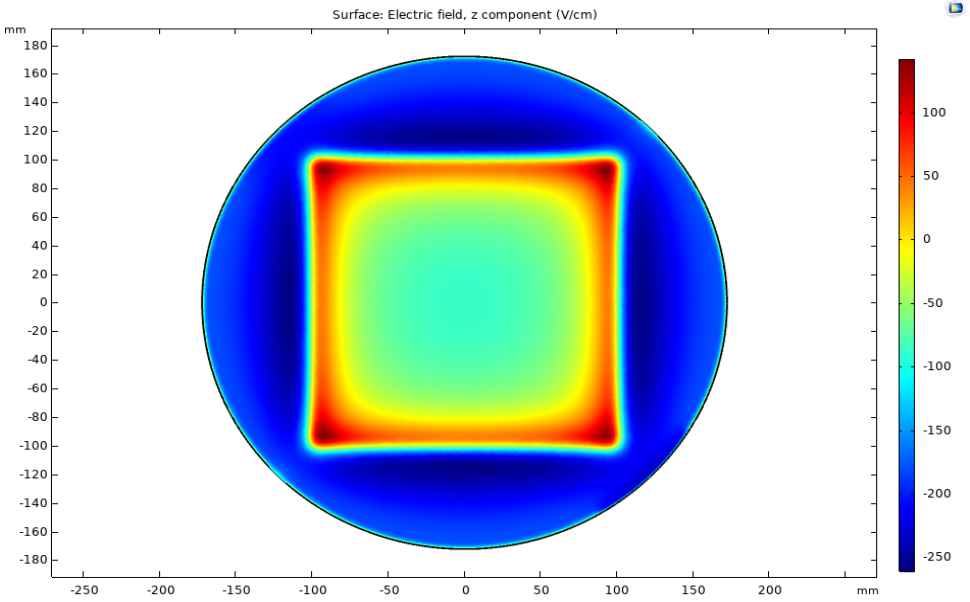
Update results with the calibration

On going of the analysis

- Electric field calibration
- Drift time calibration
- Using Comsol and ANSYS
- Finised:
  - TPC modeling
  - Finite element segmentation

- Zhiyang Yuan and Chang Yue

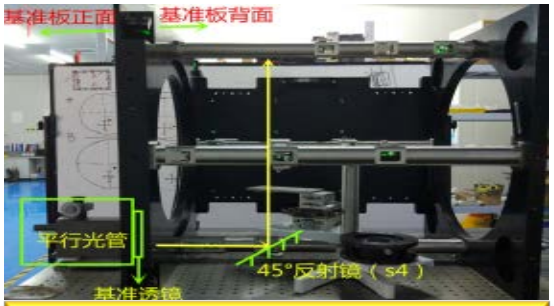




TPC modeling and electric field analysis

- **PID with High Granularity dE/dx**

Motivation for the pixelised TPC



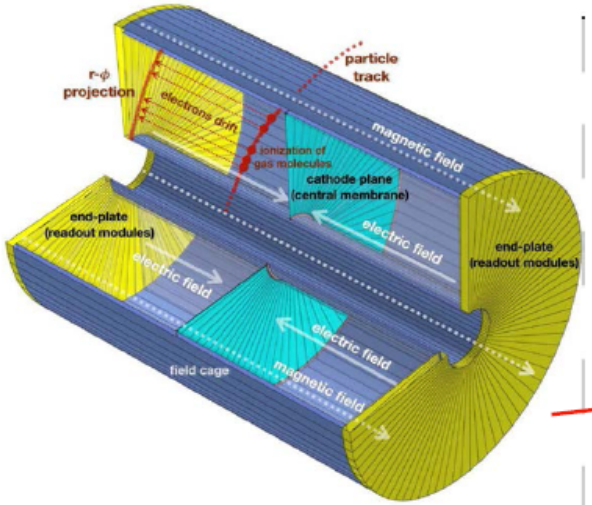
Pad TPC Prototype
at IHEP 2015-2020

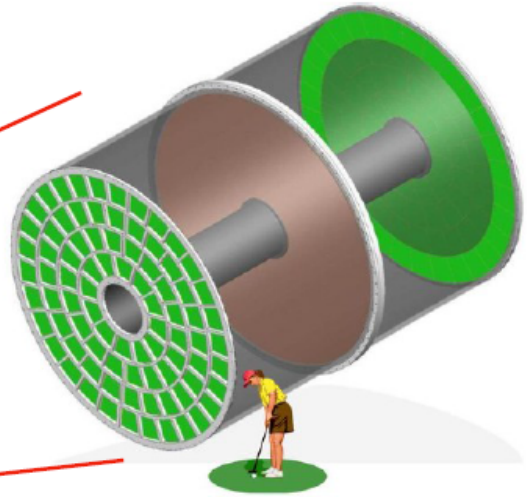
R&D

- Improved dE/dx by cluster counting
- Improved measurement for the low angle tracks
- Improved double track separation
- Much reduced hodoscope effect
  - Near to the endplate
  - Decreased the spatial resolution
- Lower occupancy in the high rate environments
- Fully digital readout

TPC detector concept

Central tracker of CDR concept





Detects reactions of charged particles in 3-dim as tracks

Role of TPC

charged particle

Track measurement

Measure passing points along trajectory

↪ Directions of track

Momentum measurement

Measure the bend of tracks in B-Field

↪ Momentum of charged particle

Particle Identification (PID)

TPC detector concept

Particle identification

Charged particle pass ->detect as track

main charged particle on the detector

- **π**
- **K**
- **e**
- **μ**

from the direction of bending by a B-Field

charge can be identified

↓ **particle type**

dE/dx:Energy loss per unit length

Bethe-Bloch formula

$$\left\langle -\frac{dE}{dx} \right\rangle = Kz^2 \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2m_e c^2 \beta^2 \gamma^2 W_{max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2} \right]$$

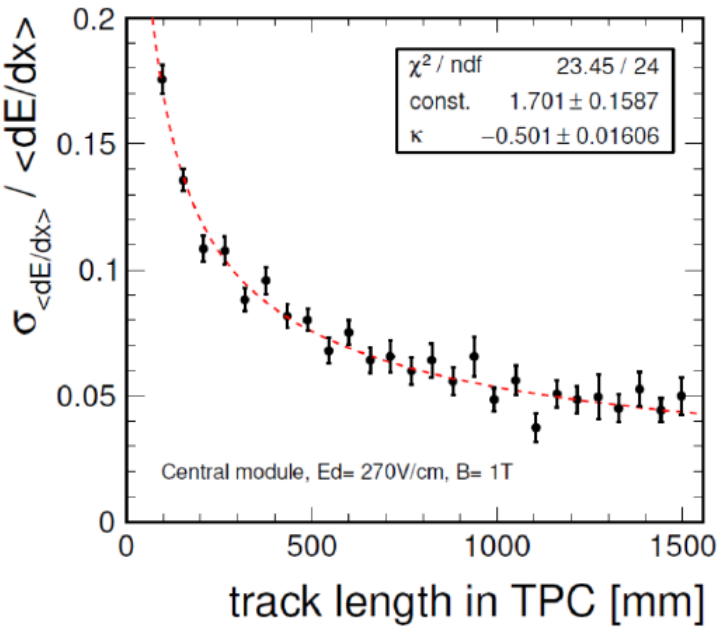
the value of <dE/dx> depends on particle species at a given momentum

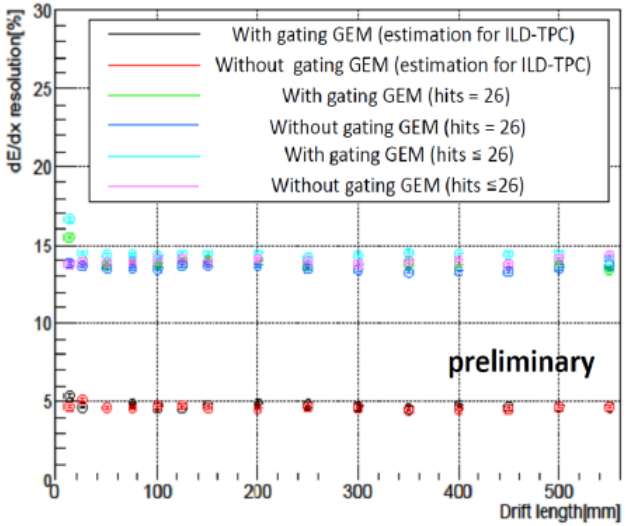
→particle type can be identified

Pad TPC

Beam test results@5GeV/1T/Pad TPC

Jochen@ILD meeting

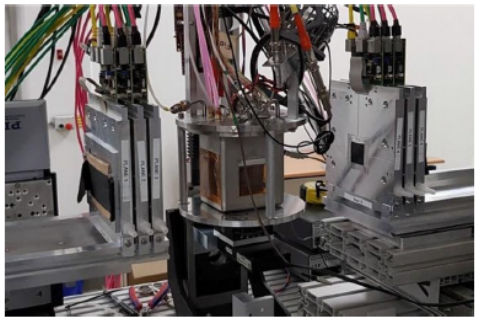




e average of dE/dx resolution expected from the ILD-TPC is 4.70 ± 0.02% (4.61±0.02%)
:h (without) the gating GEM.

- dE/dx resolution extrapolated to ILD
- Pad-based systems, beam test @DESY II test beam facility:
  - 4.7 % (GEMs) **https://arxiv.org/abs/2006.08562, paper in preparation**
  - 4.6 % (GEMs) **https://arxiv.org/abs/1801.04499**
  - 5.0 % (Micromegas) **https://agenda.linearcollider.org/event/7826/contributions/41602/**

Pixel TPC



- Transformed to dE/dx resolution extrapolated to ILD
- GridPix, beam test at ELSA test beam @Uni Bonn
- 3.5 % by method 1: electron counting per 20-pixel intervals, 90 % truncated sum
- 3.4 % by method 2: cluster counting, by applying a weight w_i to every recorded electron, depending on the distance d_i to its sucessor; w_i extracted from simulation

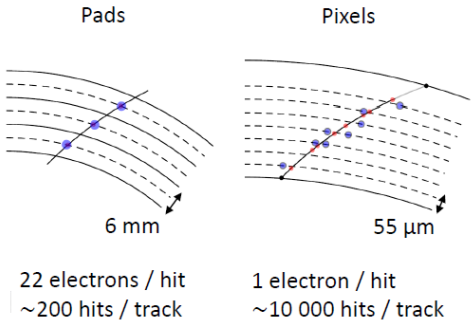
$$\mu' = \frac{1}{N_{\text{hits}}} \sum_{i=0}^{N_{\text{hits}}} w(d_i) d_i,$$

- 3.26 % combined
  (numbers revised since publication of proceedings)

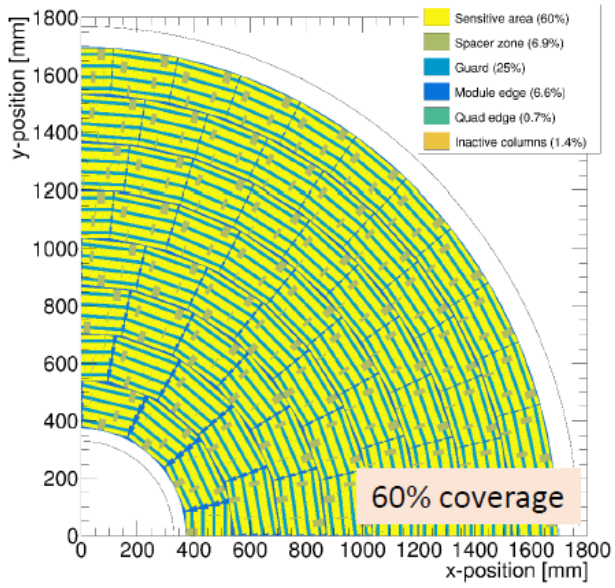
https://arxiv.org/abs/1902.01987

Simulation of TPC with pixel readout (NIKHEF)

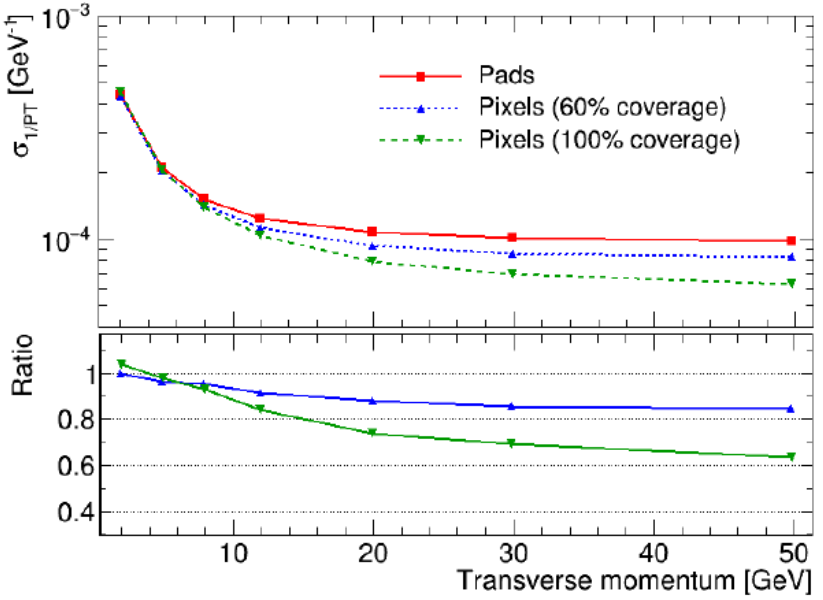
- To study the performance of a large pixelized TPC, the pixel readout was implemented in the full ILD DD4HEP (Geant4) simulation
- Changed the existing TPC pad readout to a pixel readout
- Adapted Kalman filter track reconstruction to pixels
- From full simulation, momentum resolution can be determined
- Momentum resolution is ~15% better (with realistic 60% coverage)



Realistic tiling with quad module

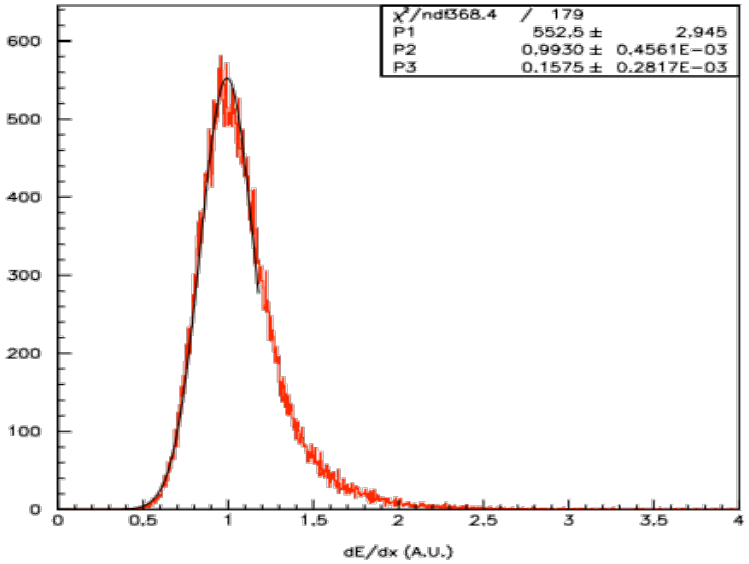


Momentum resolution of the TPC for a simulated muon

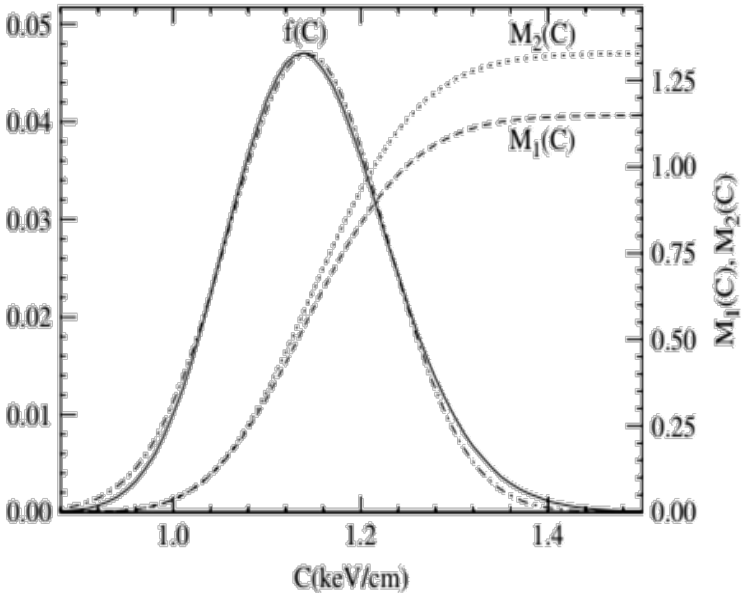


dE/dx of Laser TPC

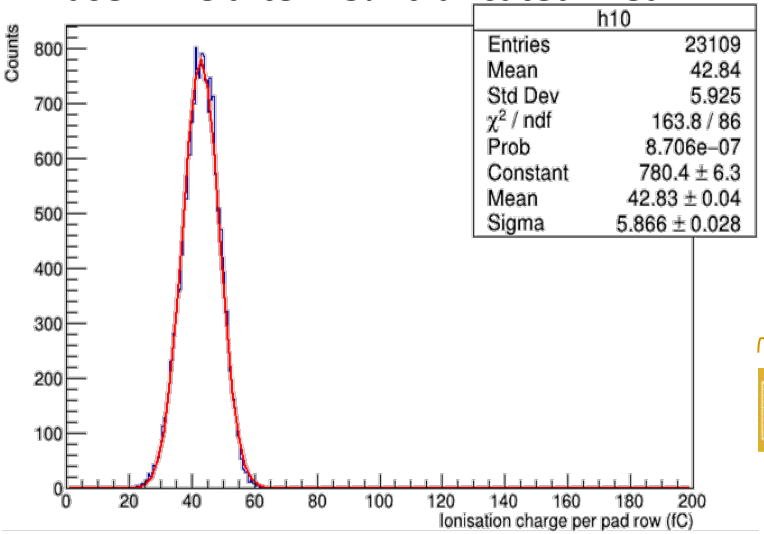
HARP TPC dE/dx average over 6 sector



STAR TPC dE/dx after 70% truncated mean



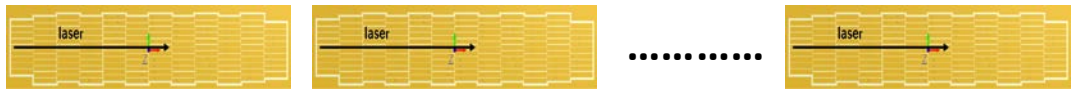
Laser TPC after 75% truncated mean



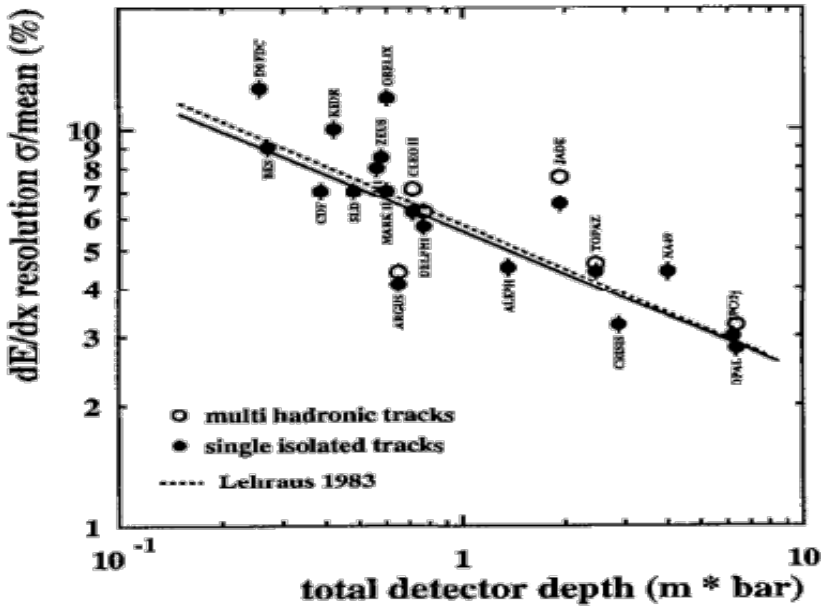
$$\text{separation power} = \frac{dE/dx(A) - dE/dx(B)}{\sigma(dE/dx)_{A.B}}$$

- Truncated average method

- Defined dE/dx $\dfrac{\langle dE/dx \rangle}{\sigma(dE/dx)}$



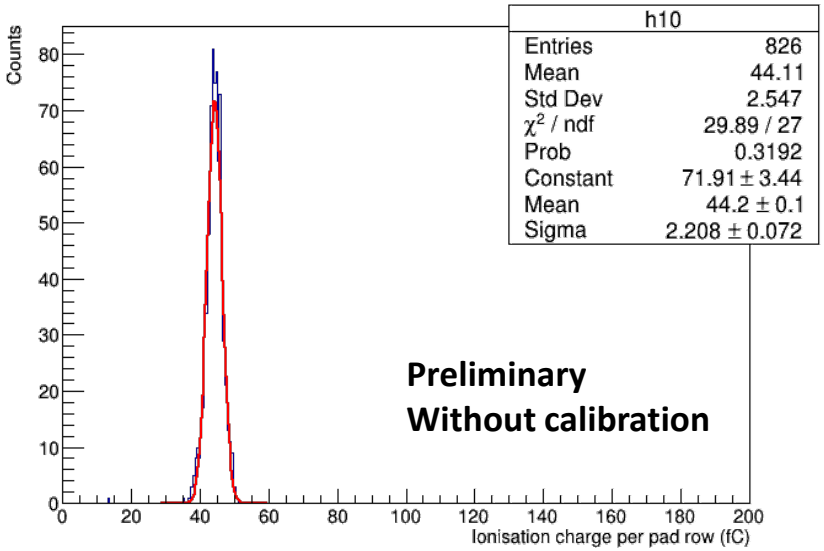
dE/dx of Laser TPC to simulate full size



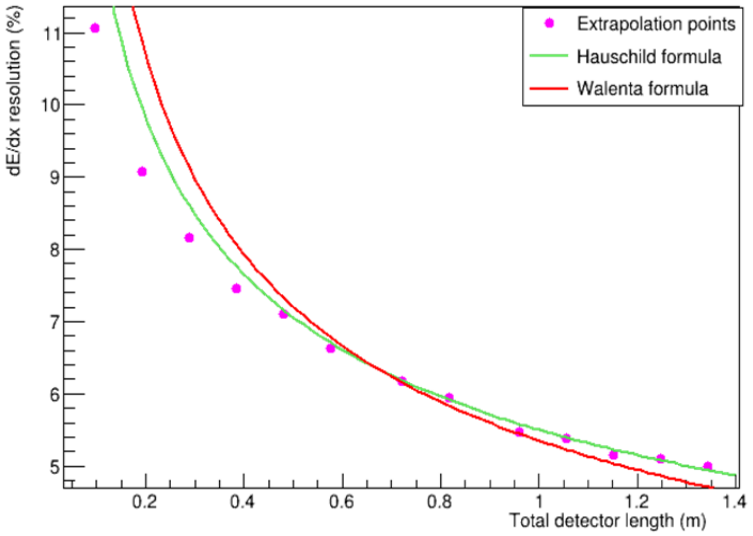
Hauschild's formula $\frac{\sigma(dE/dx)}{dE/dx} = 5.5 \times L^{-0.36}$ (%)

Walenta's formula $\frac{\sigma(dE/dx)}{dE/dx} = 5.57 \cdot L^{-0.30}$ (%)

-Simulation of the full size CEPC TPC



CEPC TPC dE/dx

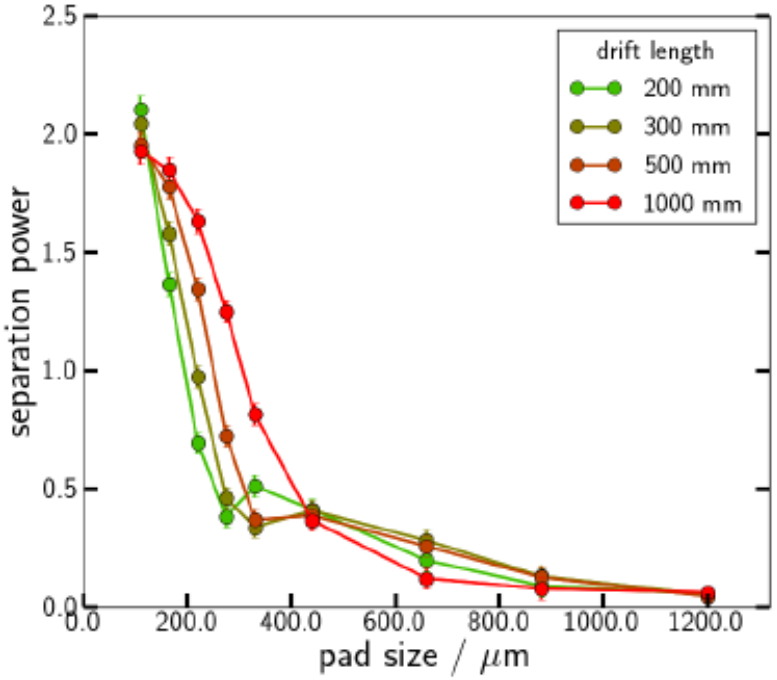


Pad size

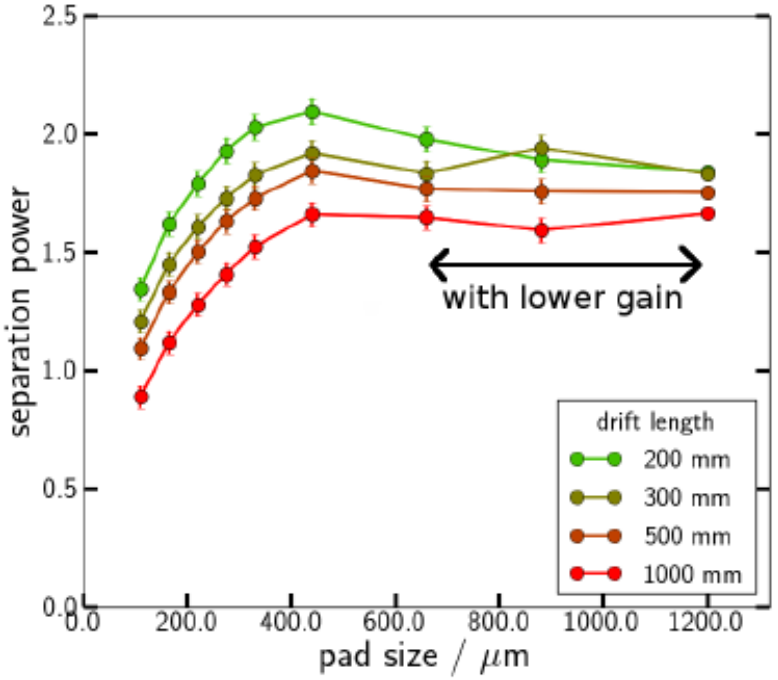
Simulation shows: the higher the granularity, the better the performance.

Cluster counting kicks in at the pixel level O(200μm).

arXiv:1902.05519v1



(a) Cluster counting.



(b) Charge summation.

Simulation of separation power between pions and kaons depending on pad size (LCTPC meeting 2021.6)

Summary

- Some update results of TPC prototype have been studies, the prototype is working well
- PID can contribute to high level reconstruction and a large number of physics analyses, the high granularity method was ready to study in the next steps with more international collaboration using the existing TPC prototype.
- More analysis on going
  - Calibration of E
  - Graduates: Yuan Zhiyang and Chang Yue

Thanks for your attention.