Status of high spatial resolution pad and pixelated TPC technology R&D for CEPC

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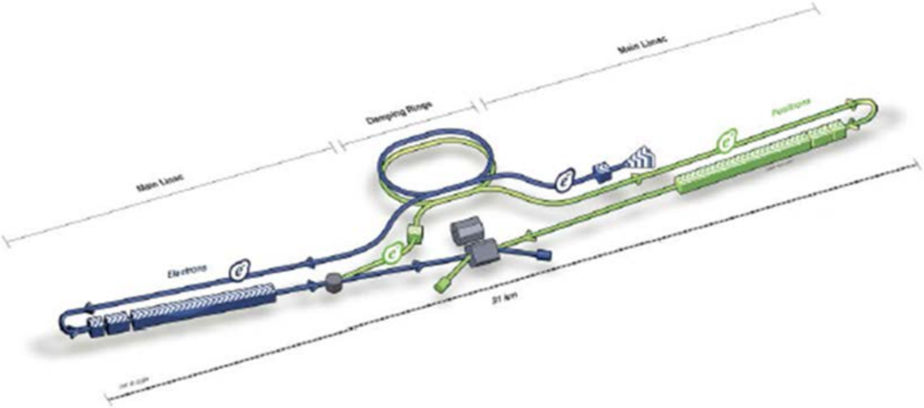
Content

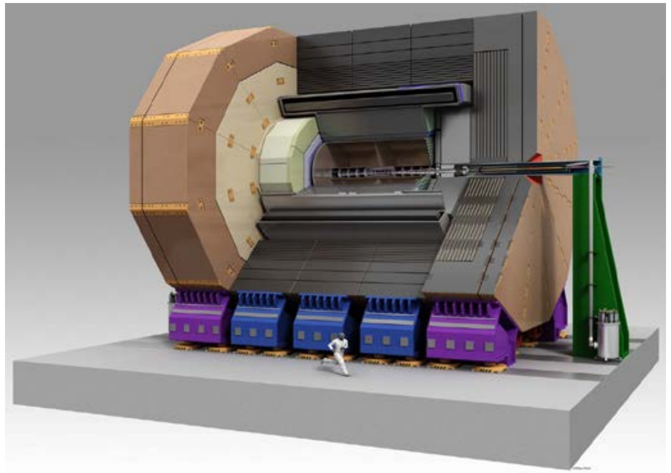
- **TPC detector for e+e- colliders**
- **High spatial resolution pad readout TPC**
- **Pixelated readout TPC R&D**
- **Summary**

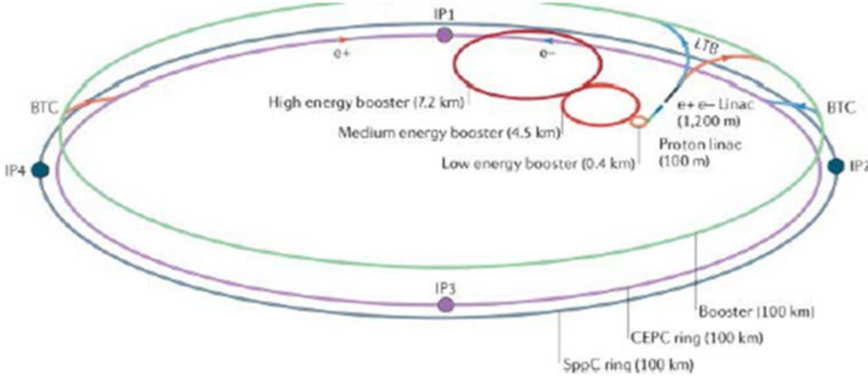
TPC technology for the future e+e- colliders

- A TPC is the main tracking detector for **some candidate experiments at future e+e- colliders**
  - ILD at ILC and the baseline detector concept of CEPC
- TPC technology can be of interest for other future e+e- colliders

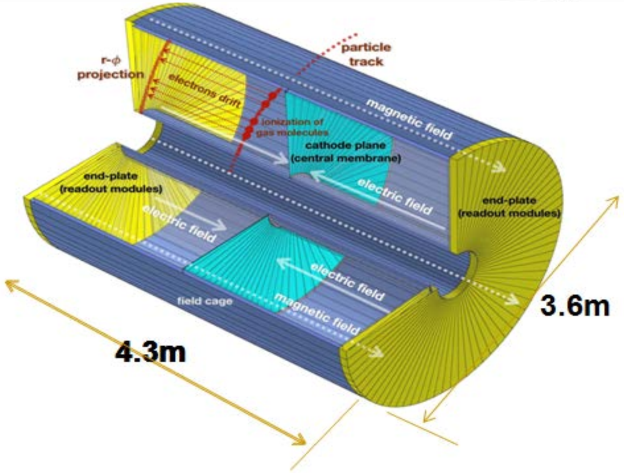


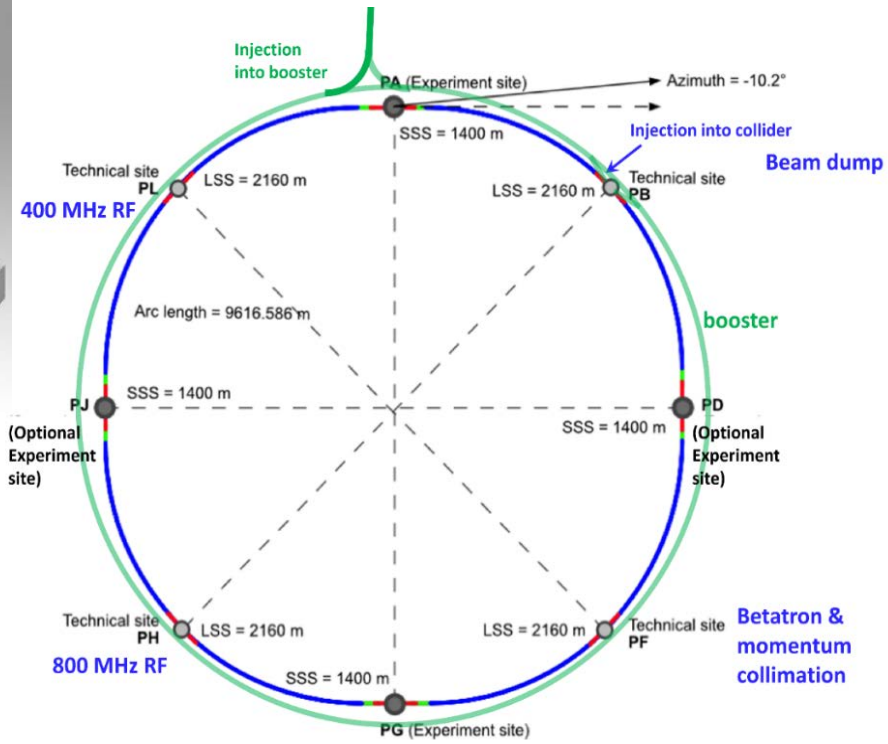
International Linear Collider (ILC)





Circular Electron Positron Collider (CEPC)



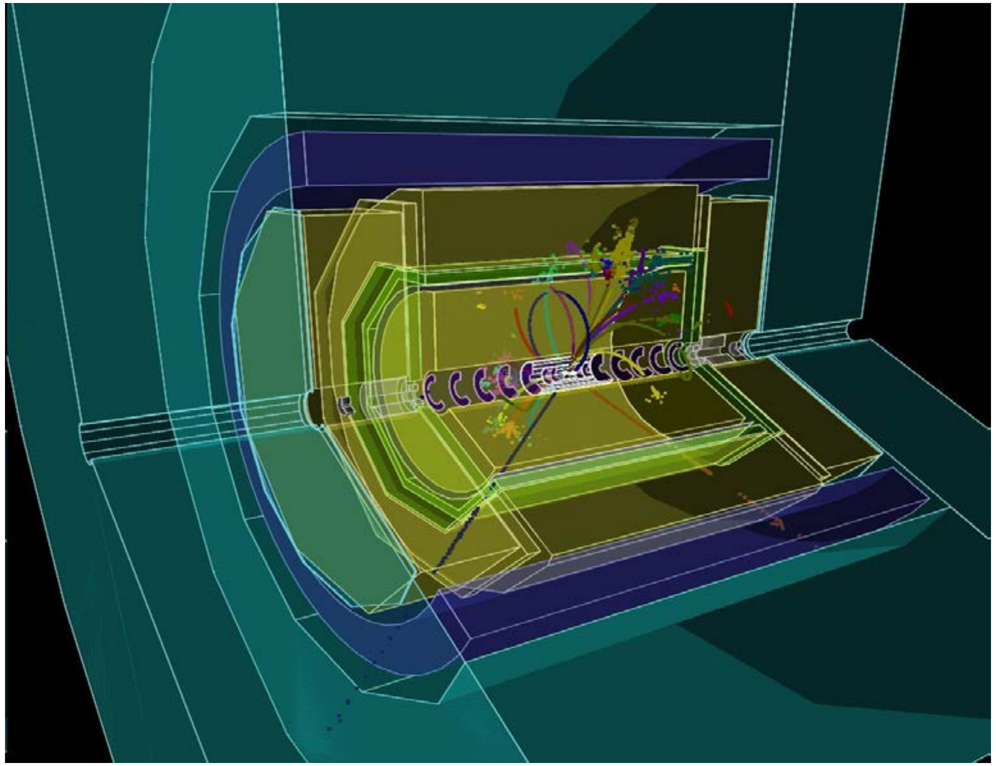


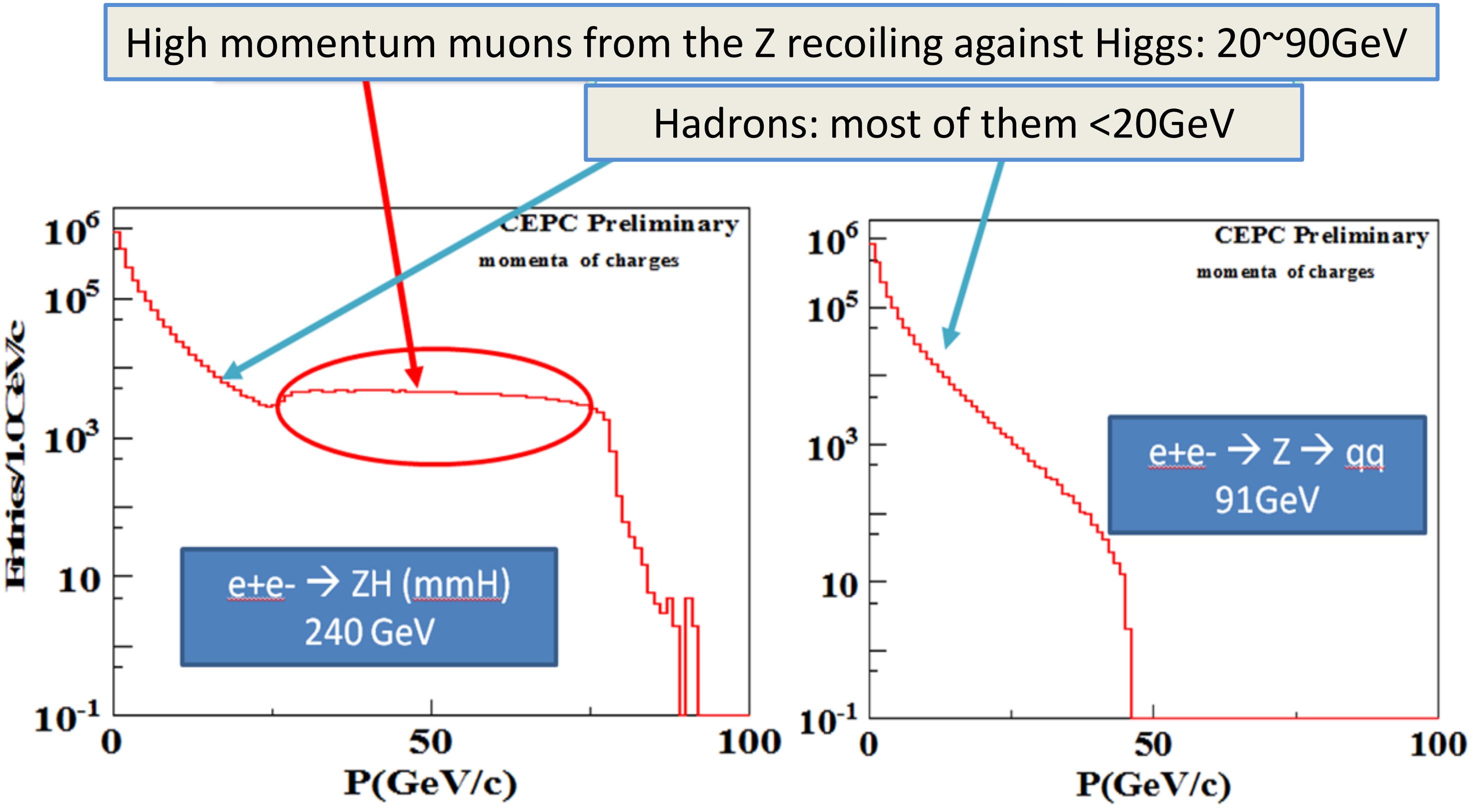
Future Circular Collider (FCC-ee)

https://arxiv.org/abs/2203.06520

TPC requiremetns from e+e- Higgs/EW/Top factories

- TPC can provide hundreds of hits (for track finding) with high spatial resolution compatible with PFA design (**very low material** in chamber)
    - $\sigma_{1/pt}$ ~10^{-4} $(GeV/c)^{-1}$ with TPC alone and σ_{point}<100μm in rϕ
- **Provide dE/dx and dN/dx with a resolution** <4%
    - Essential for Flavor physics @ Z run
    - Beneficial for jet at higher energy



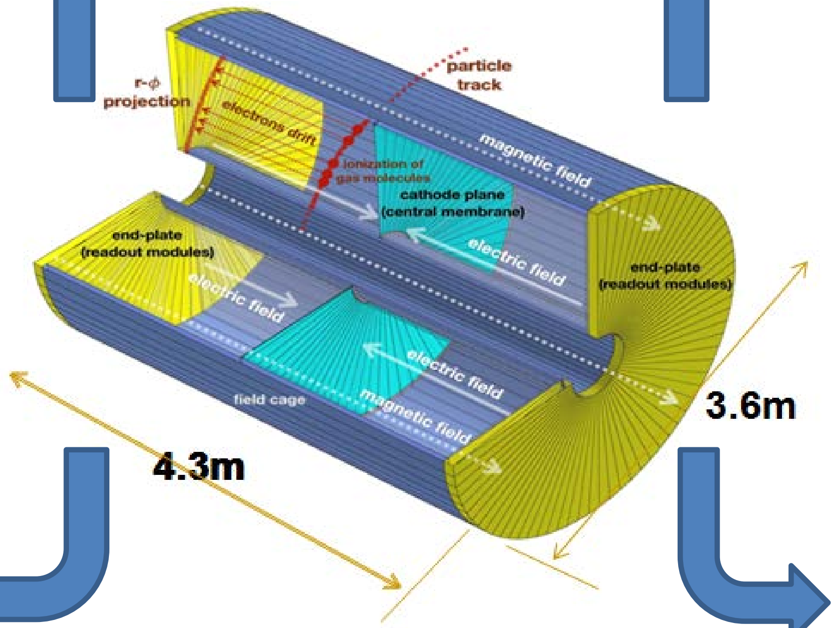


Key issues of TPC technology for e+e- collider

TPC track detector for e+e- collider

Pad readout TPC
- To meet Higgs physics
- 1mm×6mm of Pad
- TPC module
- TPC prototype with UV laser

Pixelated readout TPC
- To meet Z physics
- ~500µm of Pad
- TPC prototype with UV laser track
- dN/dx+dE/dx study

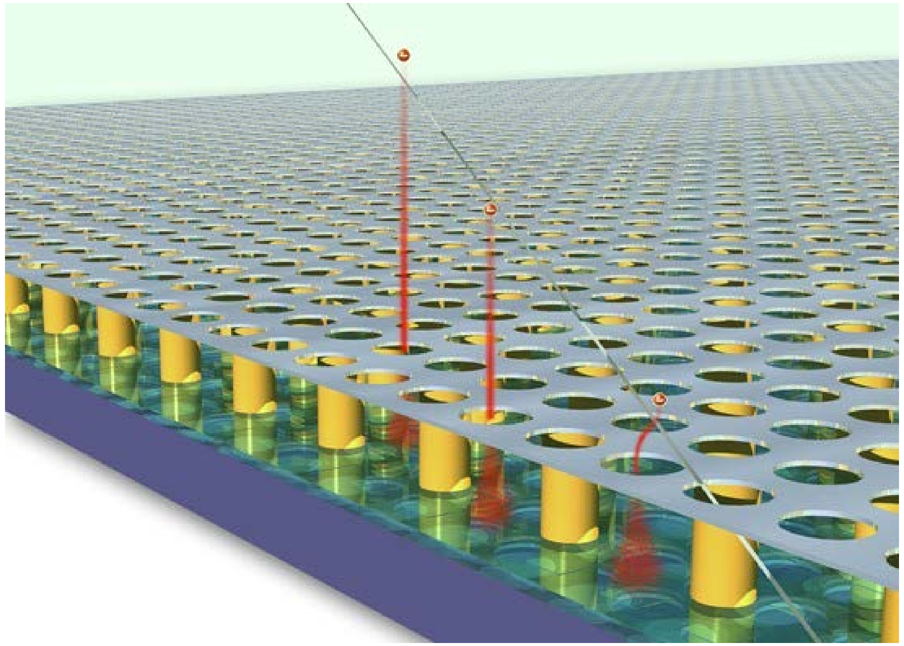


Ion back flow study
- Simulation of Ion Backflow
- Test the UV light created the ions by photoelectric effect
- Experimental study

PID performance Study
- Simulation of the ionization cluster in space
- PID studies of the different readout TPC prototype
- Experimental study

Pad and pixelated readout TPC technology for CEPC

- TPC as the main tracker detector to satisfy the physics requirements :
  - For Higgs, W and top running, **no problem** for all TPC readout technologies.
- For high luminosity **(2×10^{36})** Z running
  - Pixelated readout TPC is a good option at **high luminosity** on the circular e+e- collider
  - Pixelated readout TPC is a realistic option to provide
    - High spatial resolution **under 2T or 3T magnetic field**
    - Better momentum resolution
    - High-rate operation (MHz/cm^2)
    - dE/dx and Cluster counting (**in space**)
    - Excellent two tracks separation



Standard charge collection:

Pads (1 mm × 6 mm)/ long strips

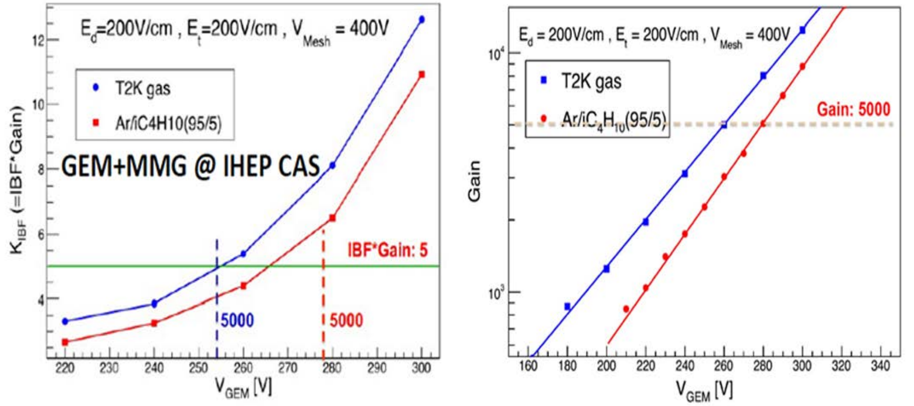
Pixelated readout:

Bump bond pads are used as charge collection pads.

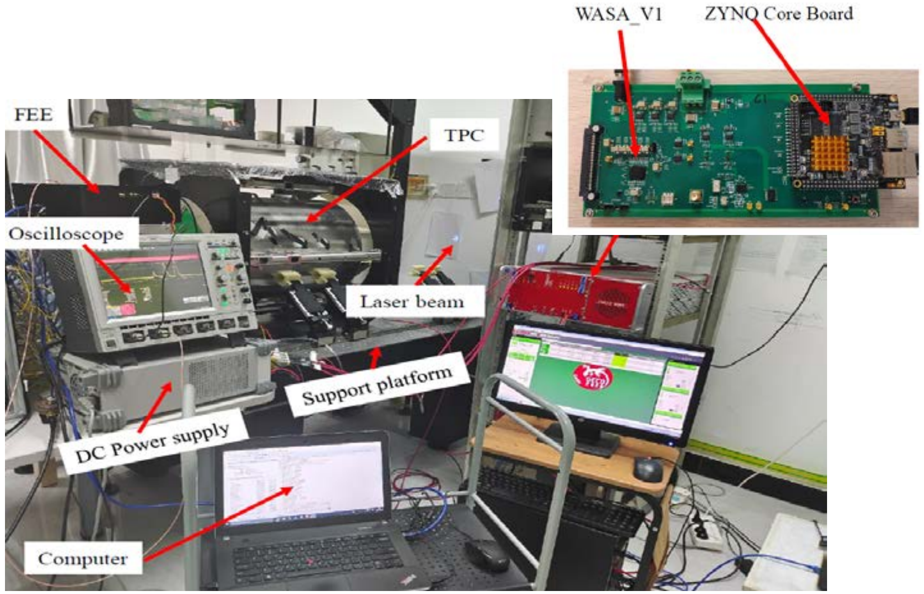
55µm × 55 µm or larger

CEPC TPC detector R&D

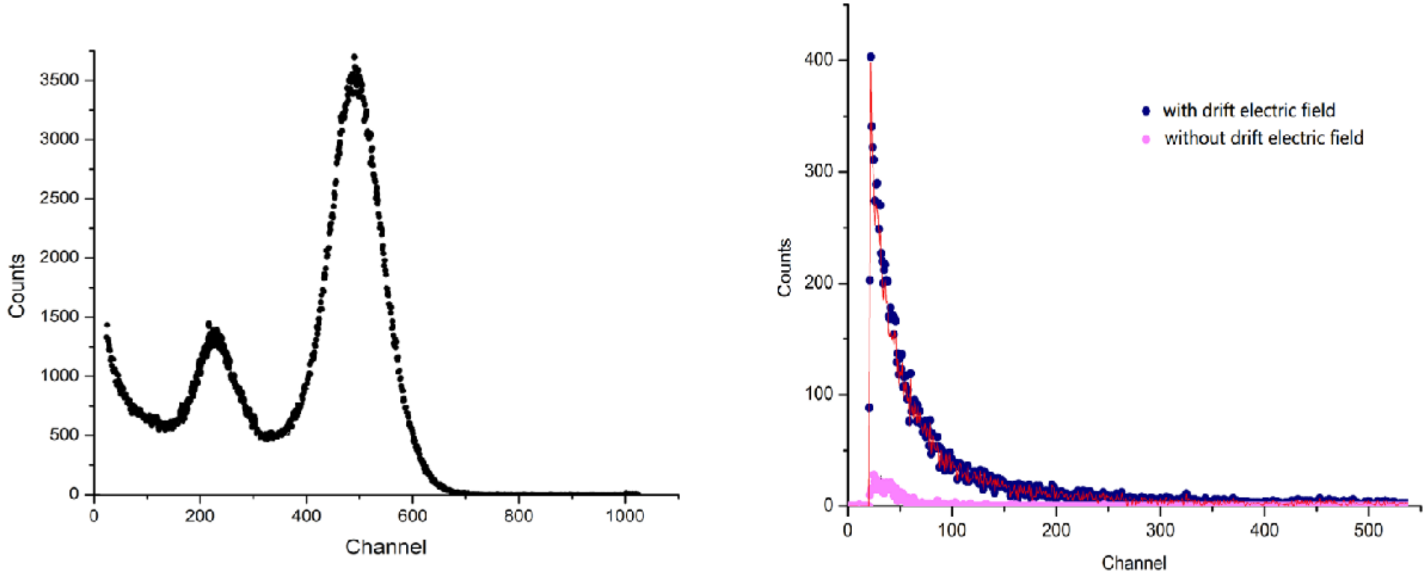
- CEPC TPC detector prototyping roadmap:
  - From TPC module to TPC prototype R&D for beam test
  - Low power consumption FEE ASIC (**reach <5mW/ch** including ADC)
- Achievement by far:
  - Supression ions hybrid GEM+Micromegas module
    - IBF×Gain **~1 at Gain=2000** validation with GEM/MM readout
  - Spatial resolution of $\sigma_{r\varphi}\leq 100\ \mu m$ by TPC prototype
  - dE/dx for PID: <4% (as expected for CEPC baseline detector concept)



GEM+Micromegas module R&D



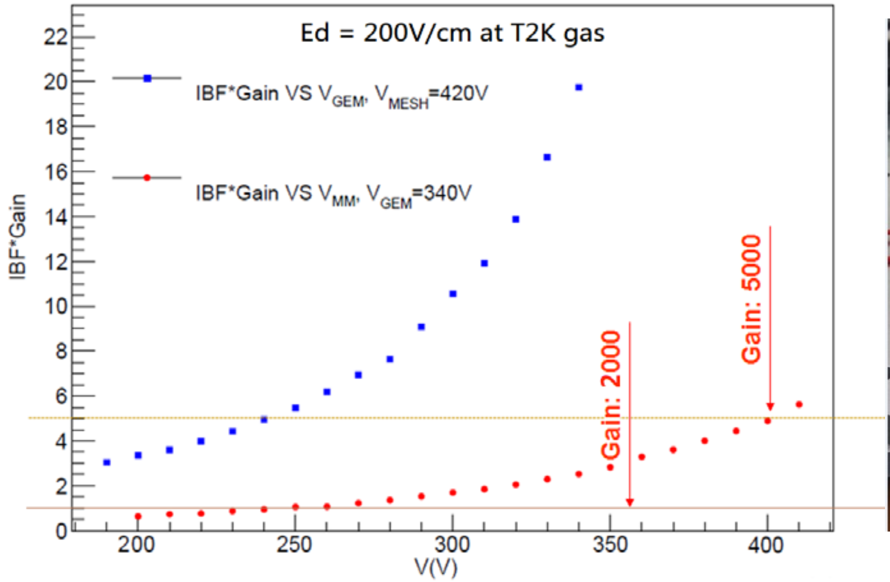
Low power consumption readout

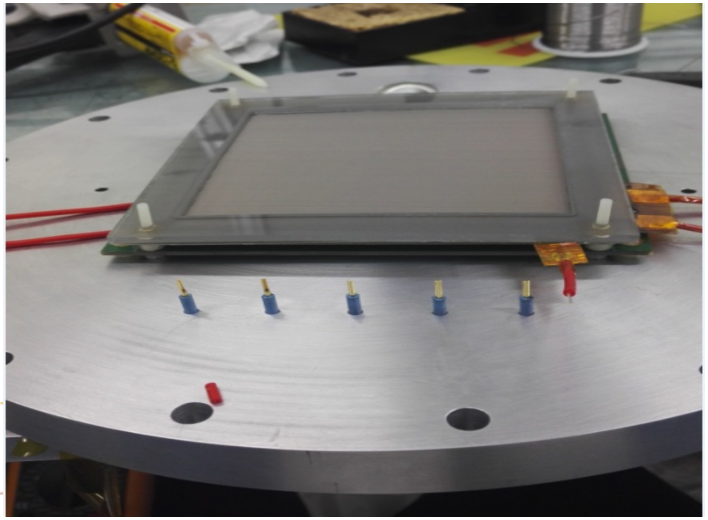


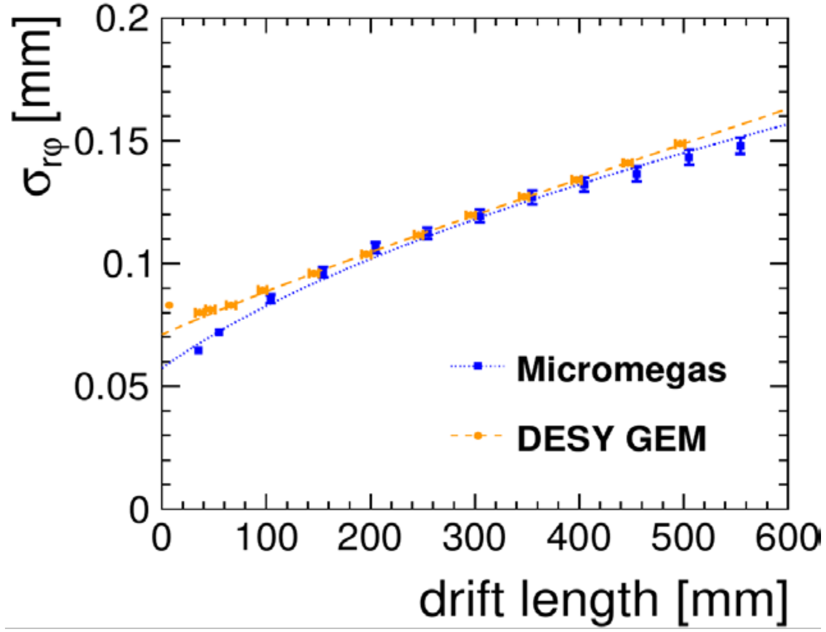
^{55}Fe X-ray spectrum profile(Left) and cosmic ray spectrum(Right)

#1 Pad TPC technology – Detector Module

- For CEPC
  - Combined Micromegas + GEM readout has been developed, which promises a **lower ion backflow** (IBF) at CEPC TPC group without gating option.
    - IBF×Gain ~ 1 at total gain of 2000 (primary ionization level)
- For LCTPC
  - GEM and Micromegas groups have finished analysis of test beam data with previous set of detector modules
    - Both technologies show **very similar performance**.

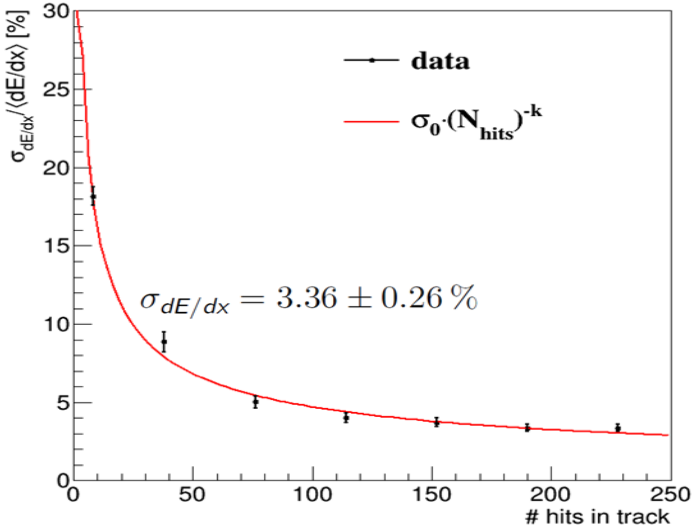


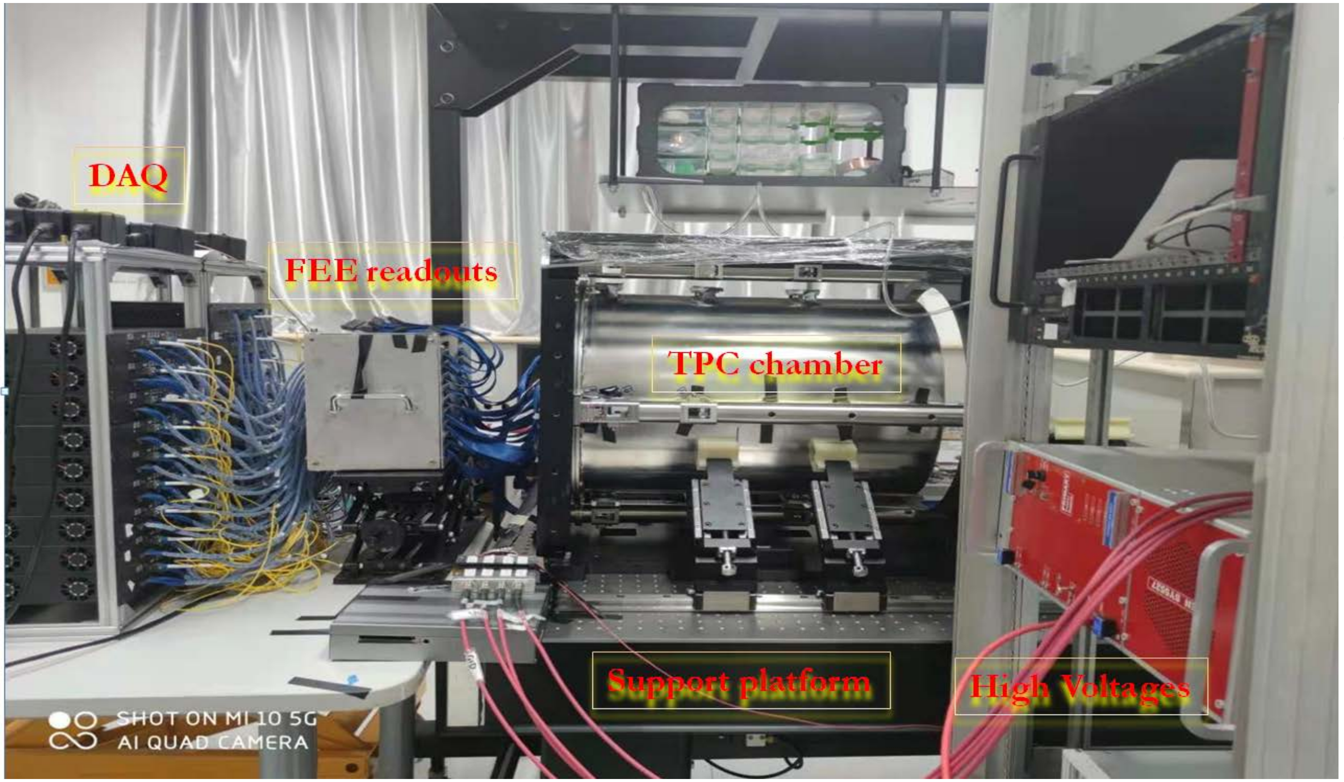


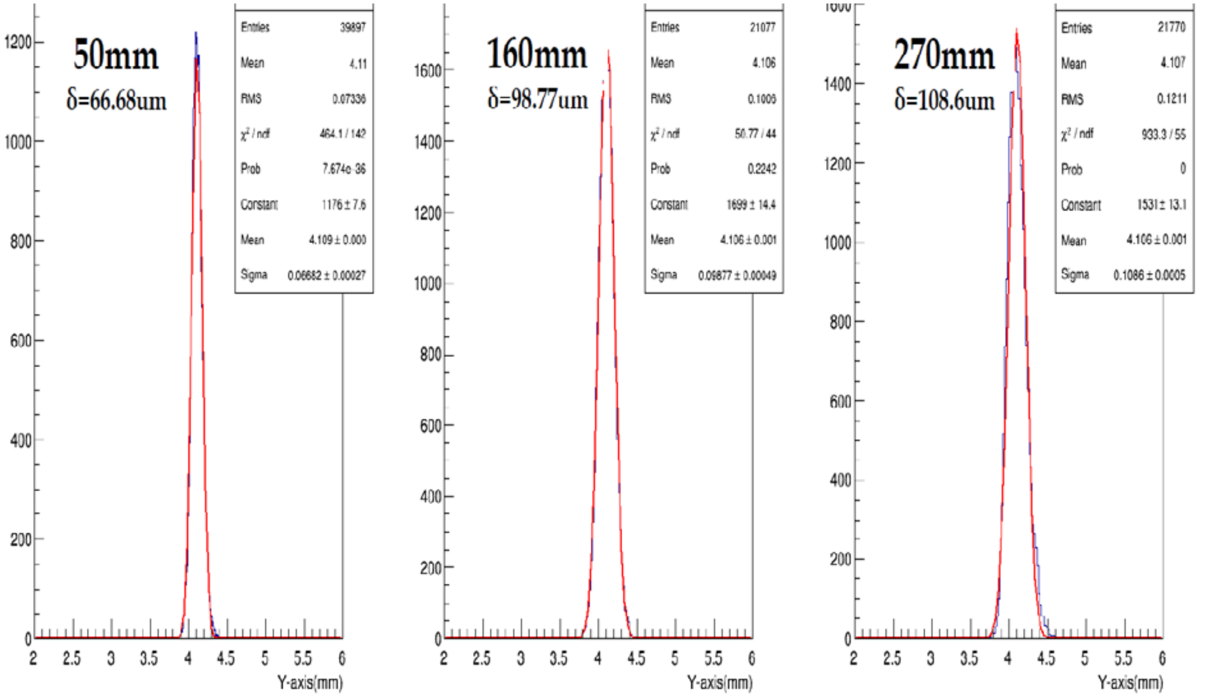


#2 TPC prototype with 266nm UV laser tracks

- The TPC prototype integrated 266nm UV laser tracks has successfully developed.
- Analysis of UV laser signal, the spatial resolution, dE/dx resolution
  - Spatial resolution can be less than **100 μm along the drift length** of TPC prototype
  - Pseudo-tracks with 220 layers (**same as the actual size of CEPC baseline detector concept**) and dE/dx is about 3.4 ± 0.3%





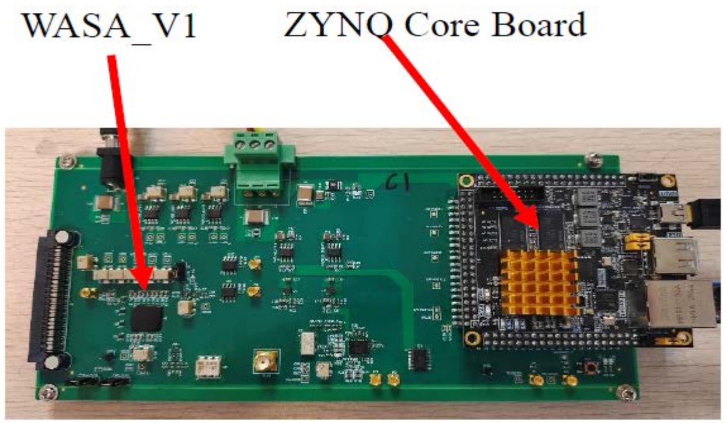


https://doi.org/10.1016/j.nima.2022.167241

#3 Low power consumption readout ASIC R&D

See Zhi Deng's talk today

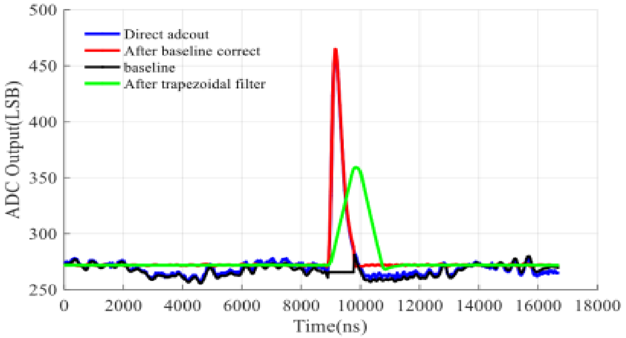
- WASA V1 has been developed: 16 channel AFE+ADC+LVDS data output
- Total power consumption with ADC function: ~2.4 mW/ch
- Tested with TPC detector using 128 channels at IHEP

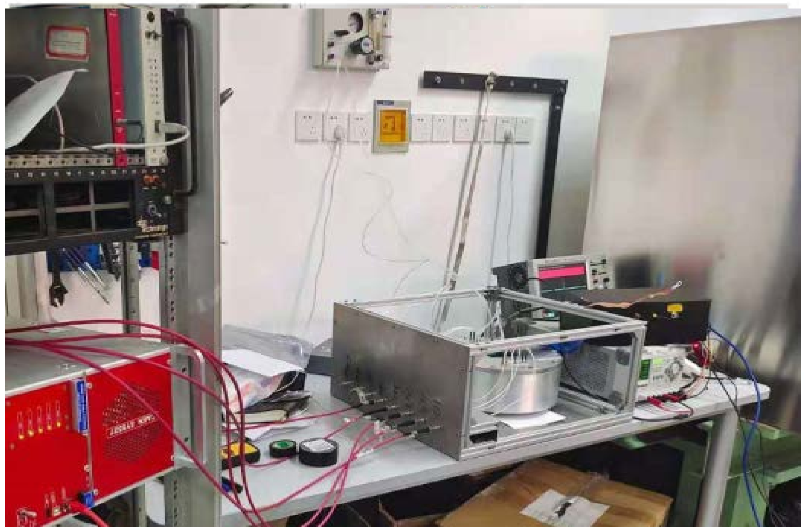


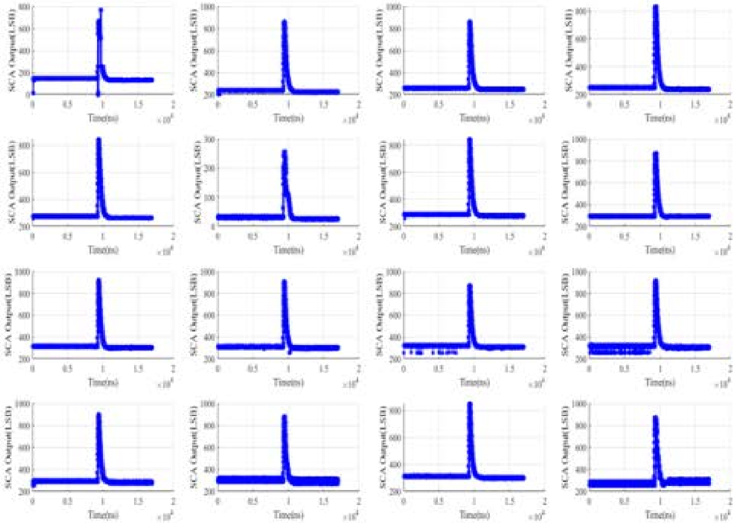
^{55}Fe testing

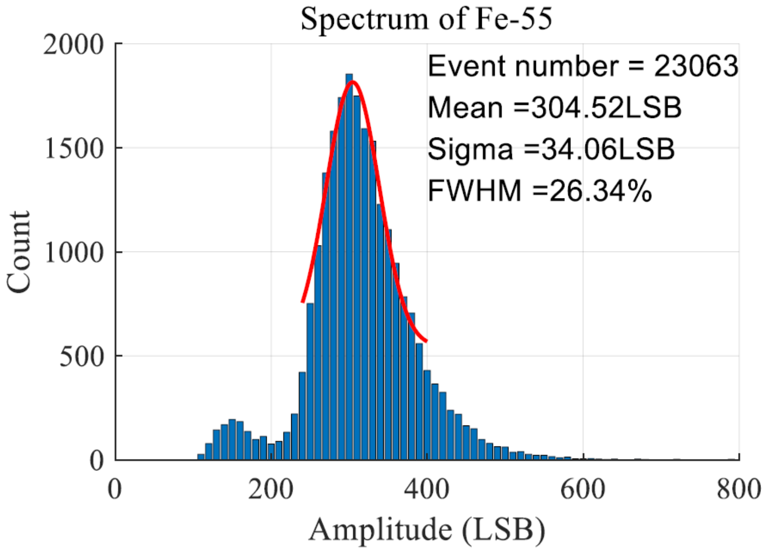
Testing parameters:

- GEMs detector: 280V-310 V
- E_{drift}: ≤280 V/cm
- Operation gases: $Ar/CF_4/iC_4H_{10}$ 95/3/2 (T2K)
- Radioactive source: ^{55}Fe@ 1mCi
- Successfully commissioned and collected signals using DAQ









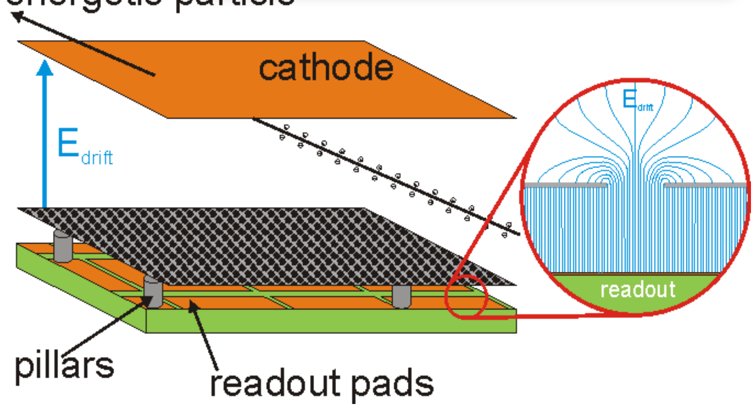
https://doi.org/10.1088/1748-0221/15/05/P05005

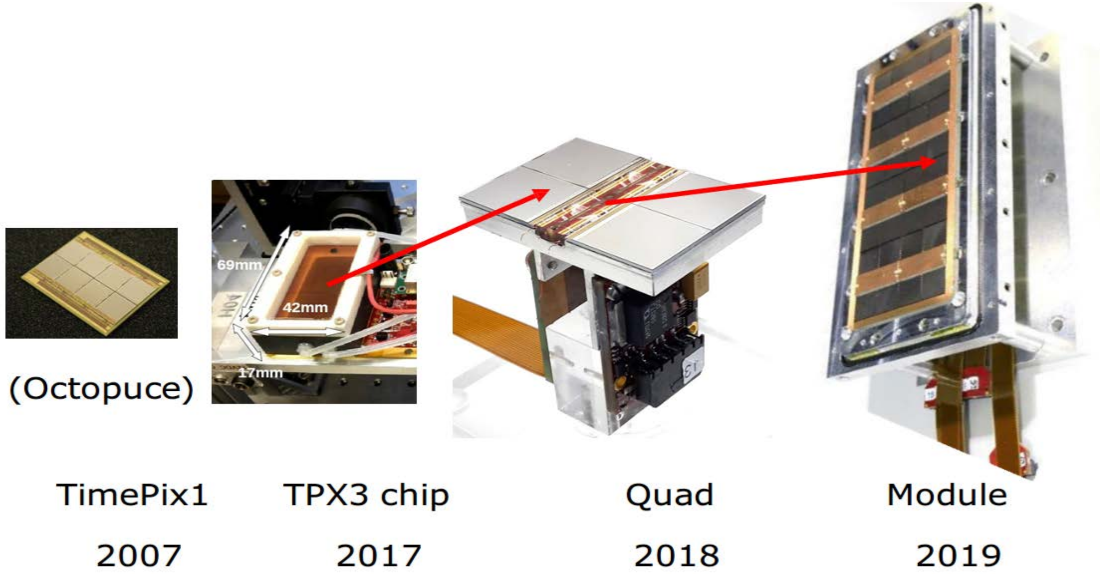
- Towards pixelated readout TPC technology

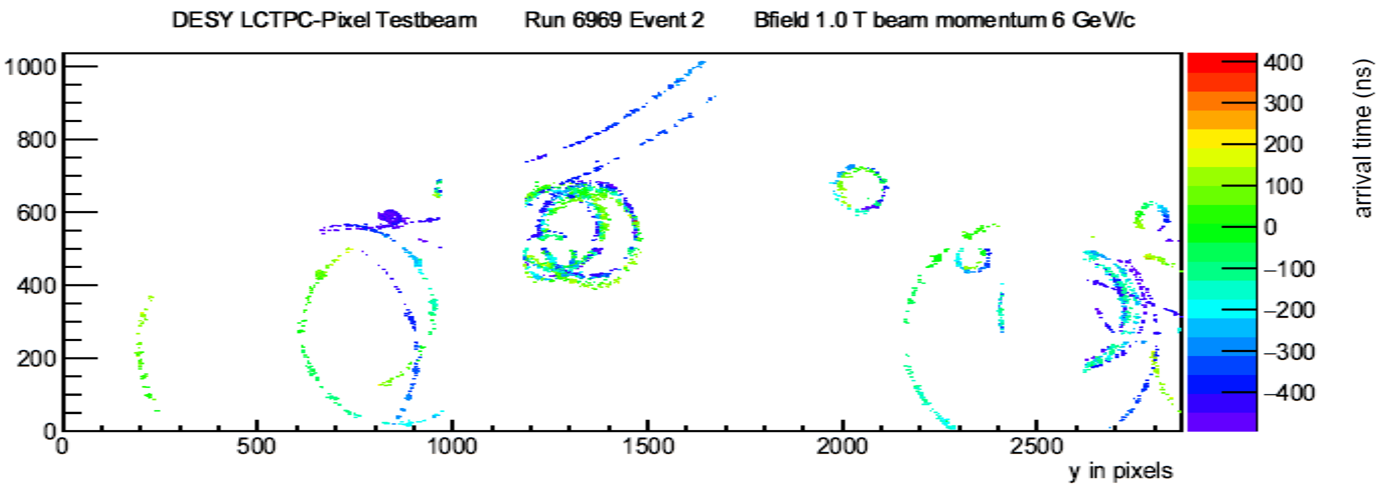
Pixelated TPC technology - Timepix3-based GridPix

- GridPix detector have moved from Timepix to Timepix3 ASICs. Tests with single and quad devices have been successfully done.
- A module **with 32 GridPixes has been constructed** and was in a test beam in B=1.0T at DESY in June 2021.
- Very high detection efficiency results in **excellent tracking and dE/dx performance.** Timepix4 development is ongoing.
- Ion back flow of the module has been measured and can be further reduced by applying a double grid and the resistivity of the protection layer.

See Peter's talk today







DESY testbeam in June 2021

https://arxiv.org/abs/1902.01987

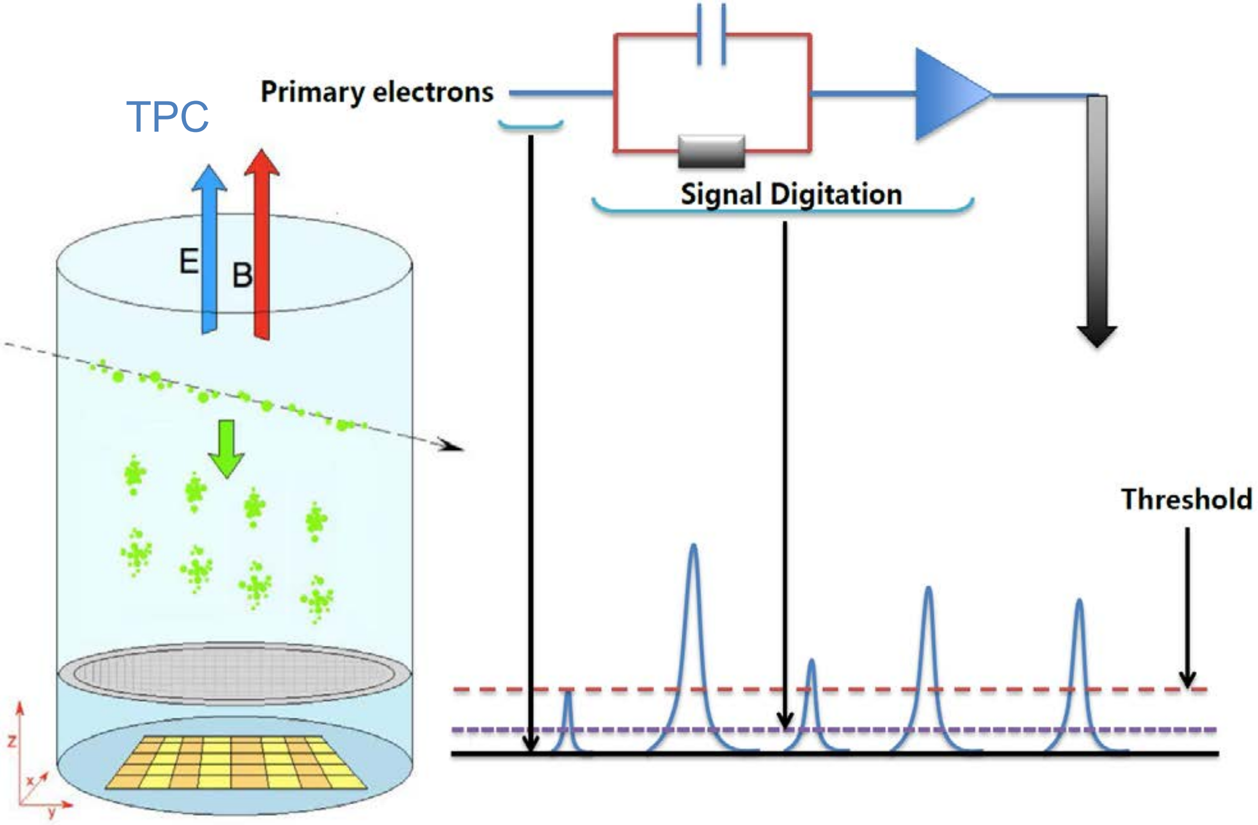
Identify the clusters to achieve dN/dx and Occupancy

See Yue Chang's talk today

dN/dx cluster counting

- Challenging for the **low power consumption** electronics (>40mV/fC needed at 2000 of gas gain)
- Pixelated readout
  - → **high granularity readout in endplate**
  - → the reasonable pixilation reveals the underlying cluster structure in 3D chamber

- Occupancy of the pixelated TPC
  - Occupancy is very **key issue** at the high rate or high luminosity
  - Smaller pad/pixel size
    → **smaller occupancy**
  - To be addressed by R&D
    → A detailed simulation would be necessary to determine the scaling factor
    → Simulation ongoing at IHEP



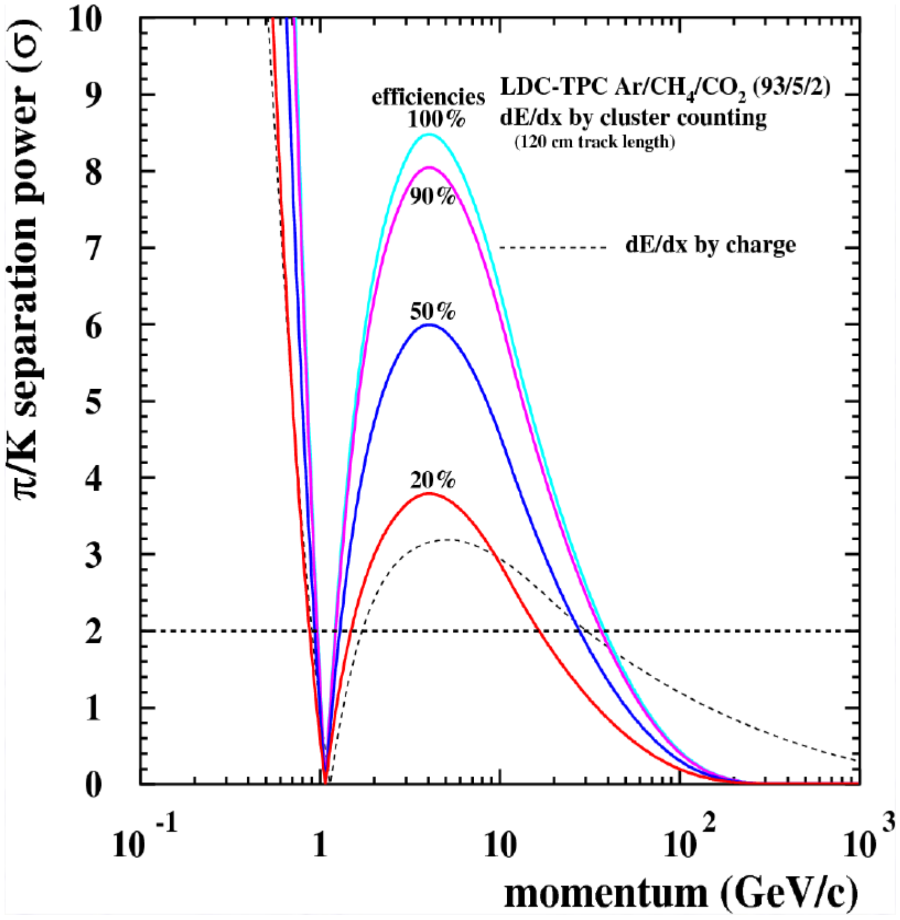
High granularity for improved PID in TPC

- For **traditional dE/dx detection**, the charge summation is performed using the center-of-gravity method.
- In most experimental study from small to large TPC
    - L: track length
    - N: number of readout rows
    - Constant L and changing granularity G = N/L

$$\frac{\sigma_{dE/dx}}{\langle \mu_{dE/dx} \rangle} \propto L^{-0.45} G^{-0.13}$$

- If pad size is at the level of cluster distances of primary ionization
    - i.e. ~ **300-500 μm in Ar-based**
    - Cluster counting becomes effective
- PID improvement
    - The potential of **better resolution by at least a factor 2**
    - Novel method studied by several R&D groups for the TPC

  for the e+e- collider



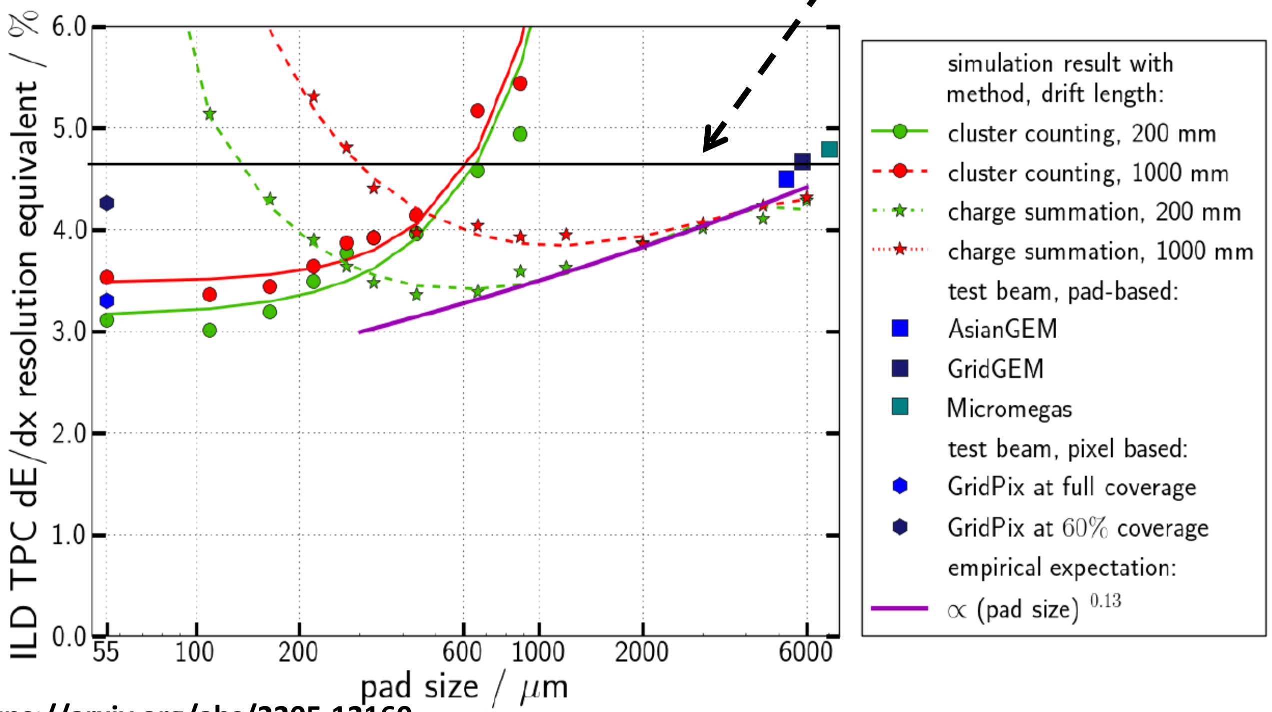
Hauschildt
http://ific.uv.es/~ilc/ECFA-GDE2006/0

High granularity for improved PID in TPC

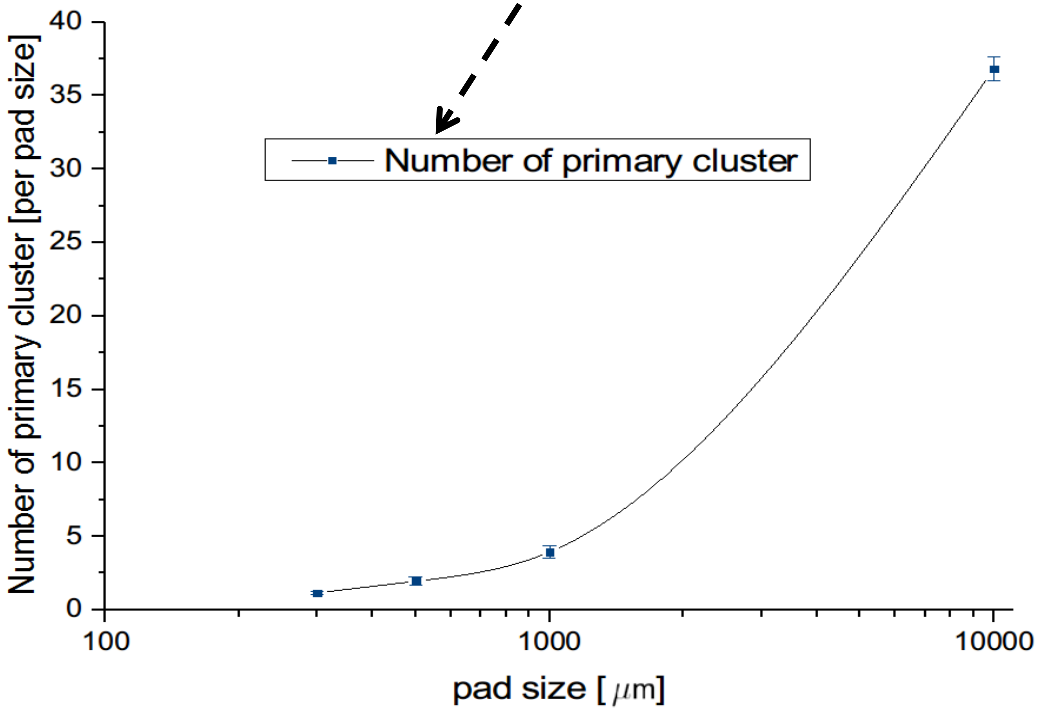
- Current full ILD reconstruction: 6mm pads → **~4.8% dE/dx resolution**
- 6mm → 1mm: 15% improved resolution via the charge summation (dE/dx)
- 6mm → 0.1mm: 30% improved resolution via the cluster counting (dN/dx)
  - Pad size of about 300μm can record **~1 primary cluster along track length** at T2K gas
  - High **readout granularity** VS the primary cluster size optimization

All studies ongoing

current resolution in the full ILD reco assuming 6 mm pads



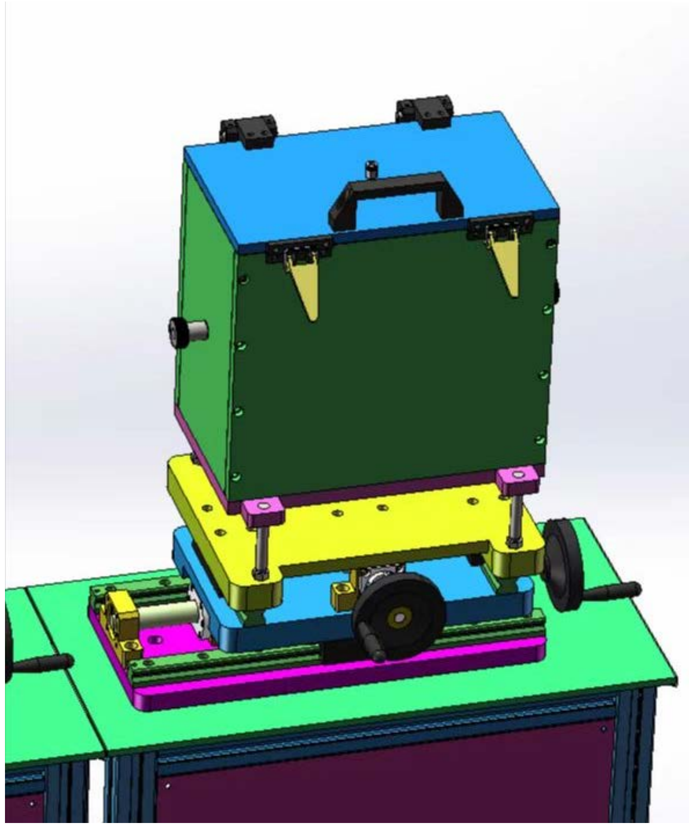
Simulation of the primary cluster along the drift length



https://arxiv.org/abs/2205.12160

New TPC prototype design and optimization (v0 -> v1)

- Study some new parameters complemented previous circular TPC
- Cascaded TPC detectors to test dE/dx and IBF distortion
- Plan： Single TPC detector to test **under 1.0T beam test in DESY in 2023**
- New FEE ASIC chip wafer production **will received in November**.(500um pixelated readout based)



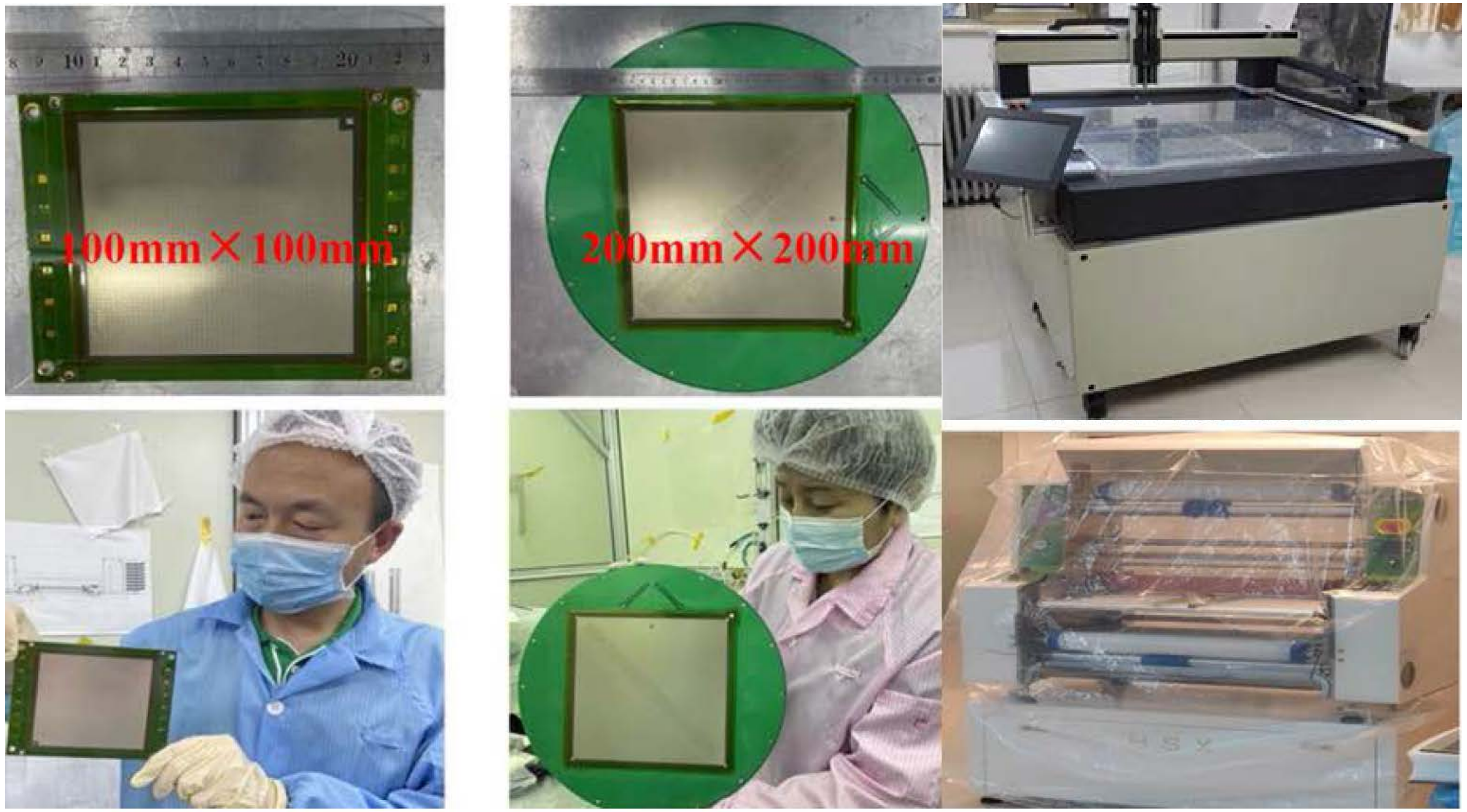
Bump bond pixelated readout with Micromegas detector	Module size	To be addressed by R&D
• **≥300 μm×300 μm** • Developed the readout chip by Deng Zhi (Tsinghua) • Developed the Micromegas detector sensor at IHEP • Development of the new module and prototype	1-2 cm^2	• Research on pixelated readout technology realization • Optimization of cluster profile and pad size • Study of the 'dN_{cl}+dx'
	100 cm^2	• Study the distortion using UV laser tracks and UV lamp to create ions disk • In-situ calibration with UV Laser system • Study of the '$dE/dx+dN_{cl}/dx$'

Highlights of CEPC TPC technology R&D

- Pad readout towards pixelated readout TPC to increased PID with dN/dx
- Massive production and assemble MPGD lab has been setup at IHEP
- Very active internal CEPC TPC R&D roadmap
- Active international collaboration with LCTPC and RD51

Publications by TPC group:

https://doi.org/10.1016/j.nima.2022.167241
https://doi.org/10.1109/NSS/MIC44867.2021.9875566
https://doi.org/10.1088/1748-0221/15/09/C09065
https://doi.org/10.1088/1748-0221/15/05/P05005
https://dx.doi.org/10.1142/S0217751X20410146
https://doi.org/10.1088/1674-1137/41/5/056003
https://doi.org/10.1088/1748-0221/15/02/T02001



CEPC-TPC regular meeting	11 events
Laser-TPC	124 events
Public conference	12 events
Neutron TPC	1 event
CMOS Tracker	79 events
Drift Chamber	11 events
Pixelated TPC R&D	32 events

https://indico.ihepa.ac.cn
Regular meetings

Summary

- In CEPC TPC study group, TPC detector using the pad towarding pixelated readouts have been developed for the future e+e- colliders.
- Many simulations are still necessary to understand the detailed requirements of the pixelated detector (e.g. number of ADC bits, pixel readout sizes, occupancy, ion backflow, etc.), but also new ideas are welcome.
- R&D plan focus on the Pixelated TPC readout & prototype, optimization to the local configuration (for dN/dx, power consumption, …) and global geometry optimization (inner Radius, etc)
- Synergies with CEPC/LCTPC/FCCee/EIC/T2K/ALICE allow us to continue R&D and ongoing, we learn from their experiences.

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- National Natural Science Foundation of China (Grant NO.: 11775242)
- National Natural Science Foundation of China (Grant NO.: 11675197)
- Some good inputs from LCTPC collaboration

Many thanks!