Status of TPC detector R&D for the circular e+e- collider

Huirong Qi, Yue Chang
Hongliang Dai, Jian Zhang, Zhi Deng, Chunxu Yu, Wei Liu,
Hui Gong, Hongyu Zhang, Hongliang Dai, Yulan Li, Manqi Ruan,
Gang Li, Linghui Wu, Xin She

Nankai University
Institute of High Energy Physics, CAS
Tsinghua University

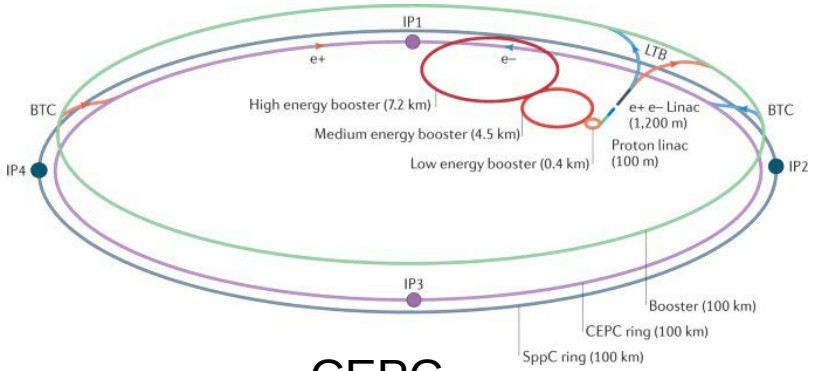
ICHEP 2022 XLI, 6-13, July, Bologna, Italy

Content

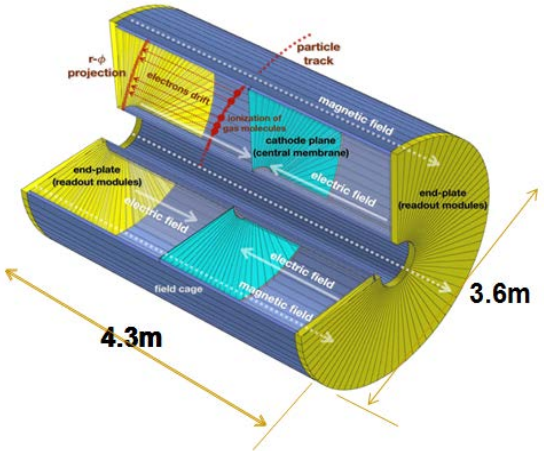
- **Motivation**
- **TPC technology R&D**
- **Feasibility of pixelated readout**
- **Prototype R&D plan**
- **Summary**

TPC detector@ Future e+e- Colliders

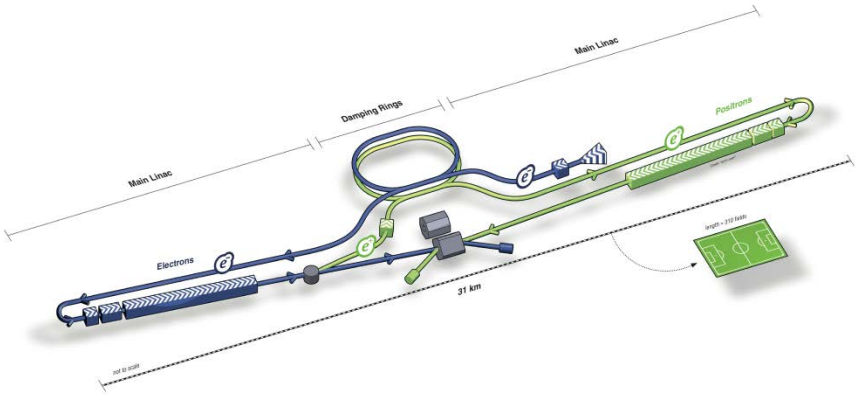
- TPC detector acts the key role at the future e+e- Colliders
- Some advantages of TPC detector
  - Operation under 3 T magnetic field
  - Large number of 3D space points
  - Very low material budget



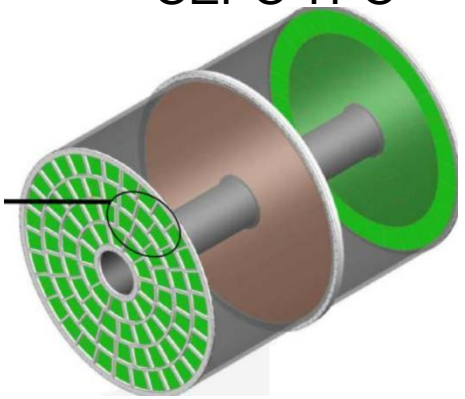
CEPC



CEPC TPC



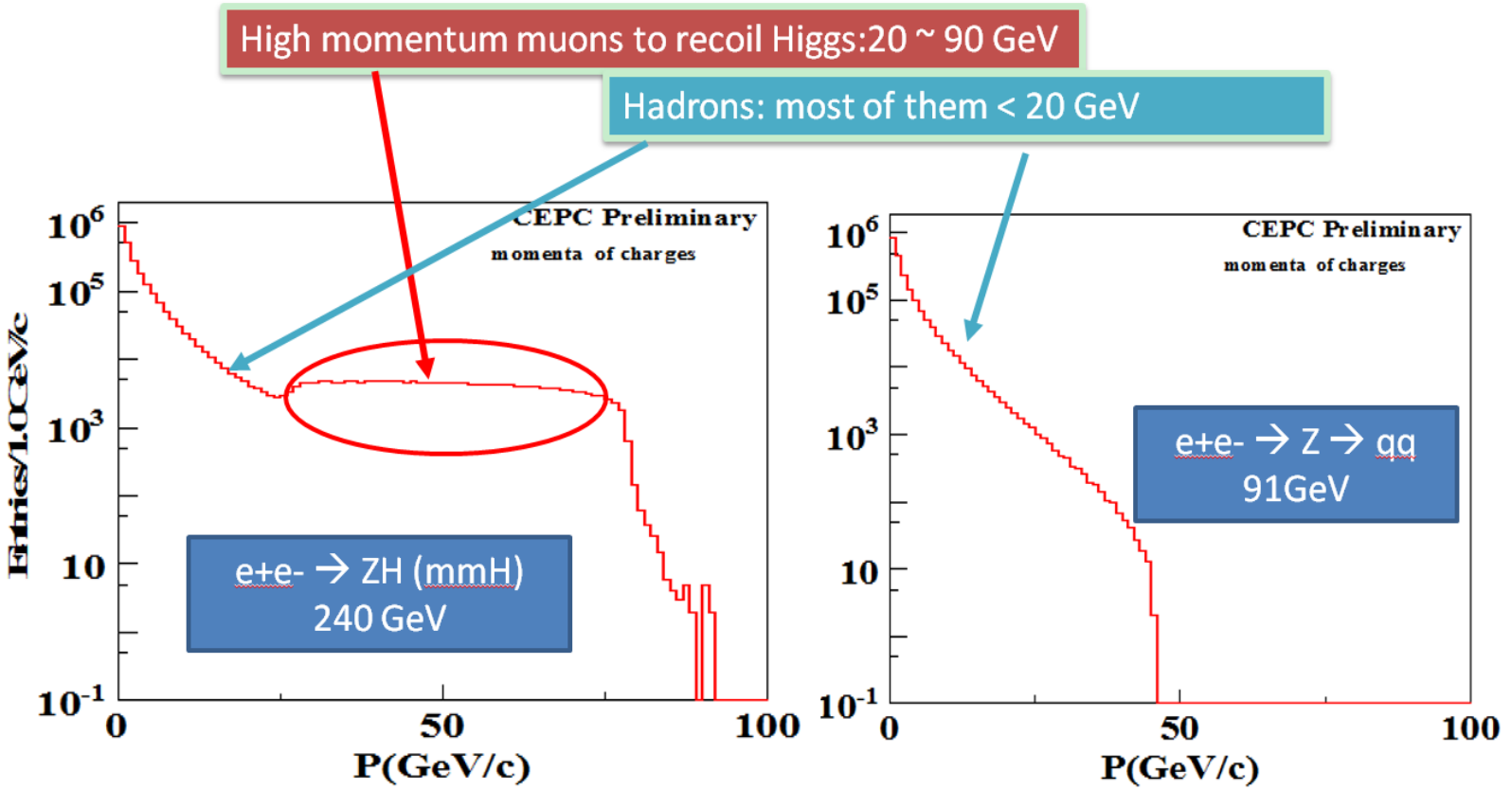
ILC



ILD TPC

Physics requirements

- Provide decent #Hits (for track finding) with high spatial resolution compatible with PFA design (low material)
  - dP/p ~ 0.1%
- Provide dE/dx + dN/dx <3%
  - Essential for Flavor @ Z pole
  - Beneficial for jet & differential at higher energy

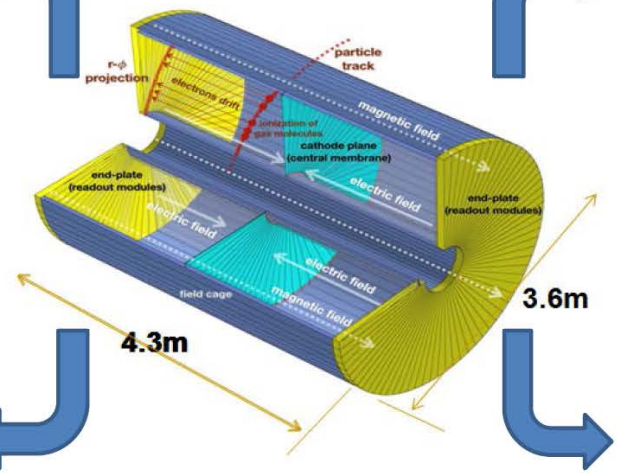


Motivation: Challenges of TPC

- **Pad readout TPC** operational at modest Lumi @ Higgs, with 3 T B-field or higher.
- **Pixelated readout TPC** operational at high Lumi (2×10^{36}) @ Z & 2 T B-Field
  - CEPC @ Z pole with 50 MW: 1.92×10^{36}
  - FCC ee @ Z pole 2.3×10^{36}

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

TPC track technology for e+e- collider



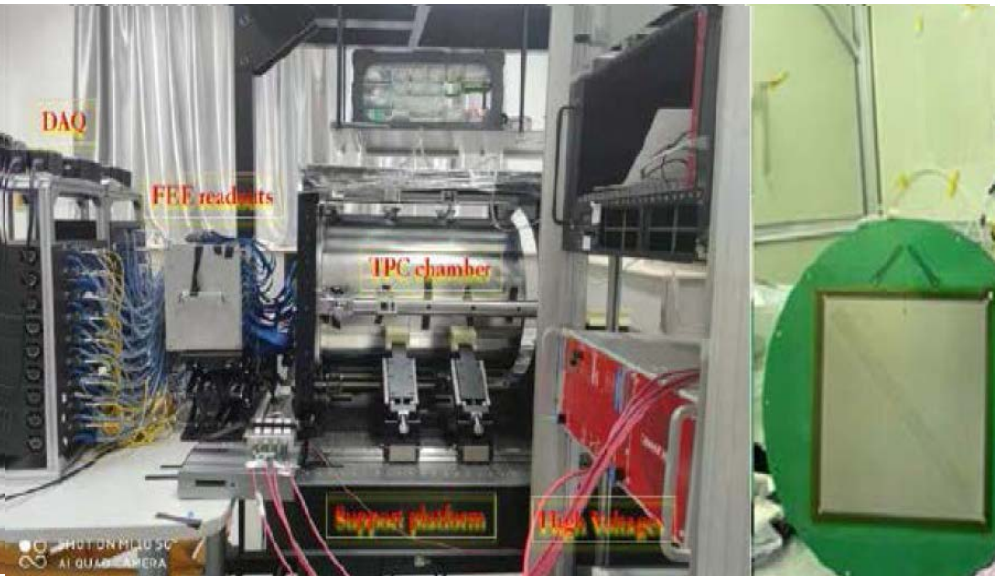
Pixelated readout TPC
- To meet Z physics
- ~500μm of Pad
- TPC prototype with UV laser track
- dN/dx+dE/dx study

Ion back flow study
- Simulation of Ion Back flow
- Testing the UV light created the ion disk 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

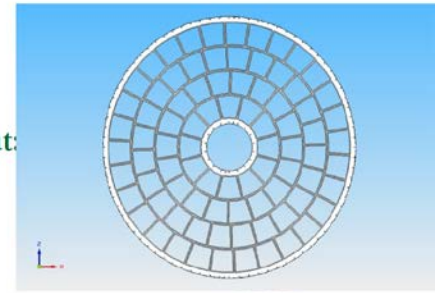
Pad TPC technology

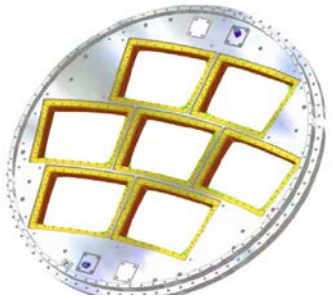
- At a circular collider CEPC there is place for different experiments, one of the detector concept could use a TPC as the main tracker.
- For Higgs, W and top running **no problem** for all TPC read out technologies.
- Laser TPC prototype has been successfully developed **in last 6 years** at IHEP.



Pad TPC for collider

- Active area: $2\times10m^2$
- One option for endplate readout:
  - GEM or Micromegas
  - 1×6 mm² pads
  - 10^6 Pads
  - 84 modules
  - Module size: $200\times170mm^2$
  - Readout: Super ALTRO
  - CO_2 cooling





Pixelated TPC technology

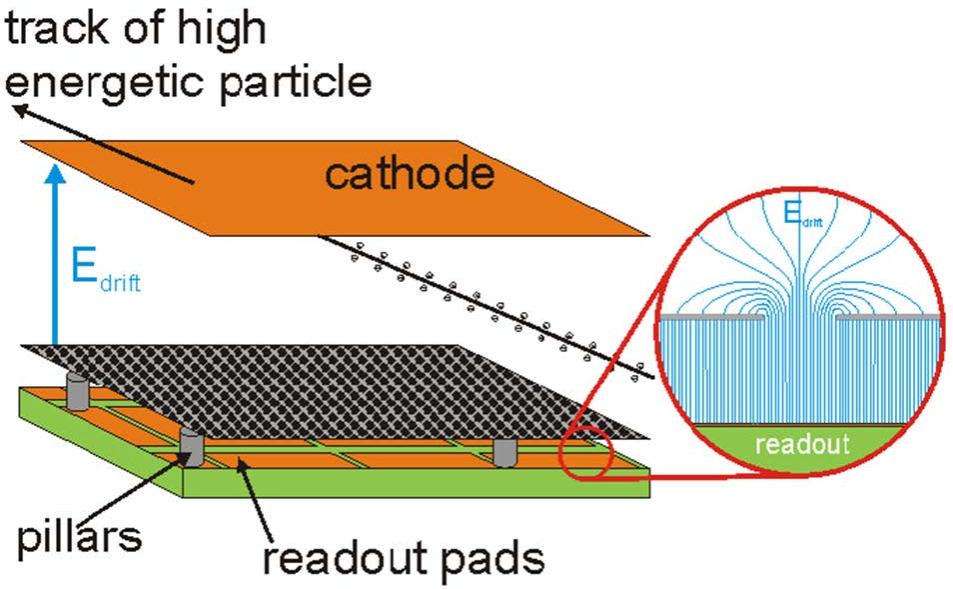
- A pixelated TPC is a good option to provide realistic physics requirements and can work at high luminosity (2×10^{36}) on CEPC.
- Pixelated → better resolution → low gain(<2000) → less distortion
- Pixelated readout TPC is a realistic option to provide at CEPC
  - Can deal with high rates (MHz/cm^2)
  - High spatial resolution → better momentum resolution
  - dE/dx + Cluster counting (In space)
  - Excellent two tracks separation

Standard charge collection:

Pads (1 mm×6 mm)/ long strips

Instead:

Bump bond pads are used as charge collection pads.

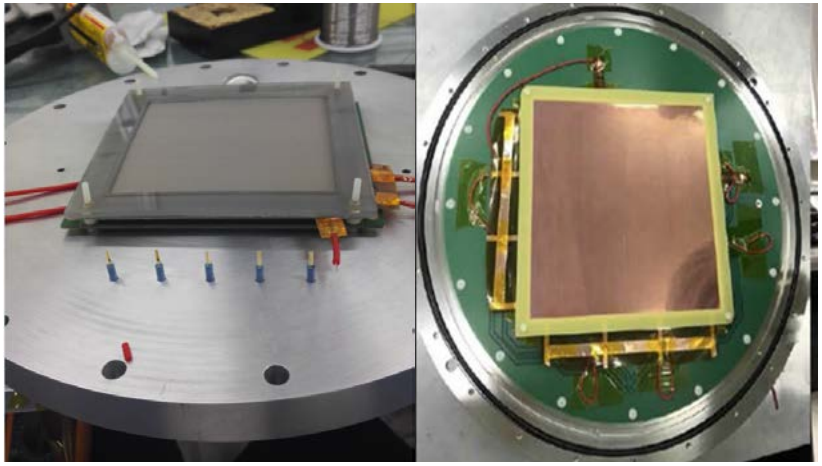


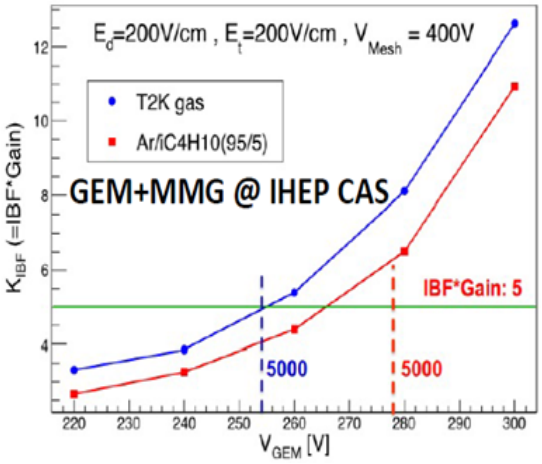
- **Status of TPC detector R&D at IHEP**

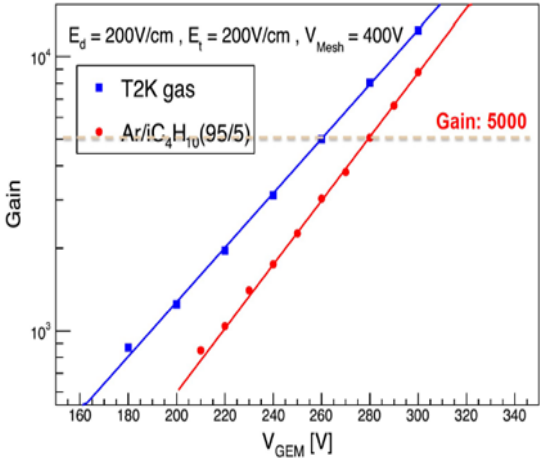
    1. **TPC detector module with the ions suppression**
    2. **Status of TPC prototype using UV laser**
    3. **Low power consumption readout**

#1. TPC detector module R&D

- Studies have been done using the different active area of the hybrid TPC detector modules
  - Active area: from 50 mm×50 mm to 200 mm×200 mm
  - Tested under the different mixture gases
- Validated IBF×Gain using the TPC detector module
  - IBF×Gain ≤ 5@Gain/5000
  - Gas gain<2000, IBF×Gain ≤ 1 using MPGD as readout



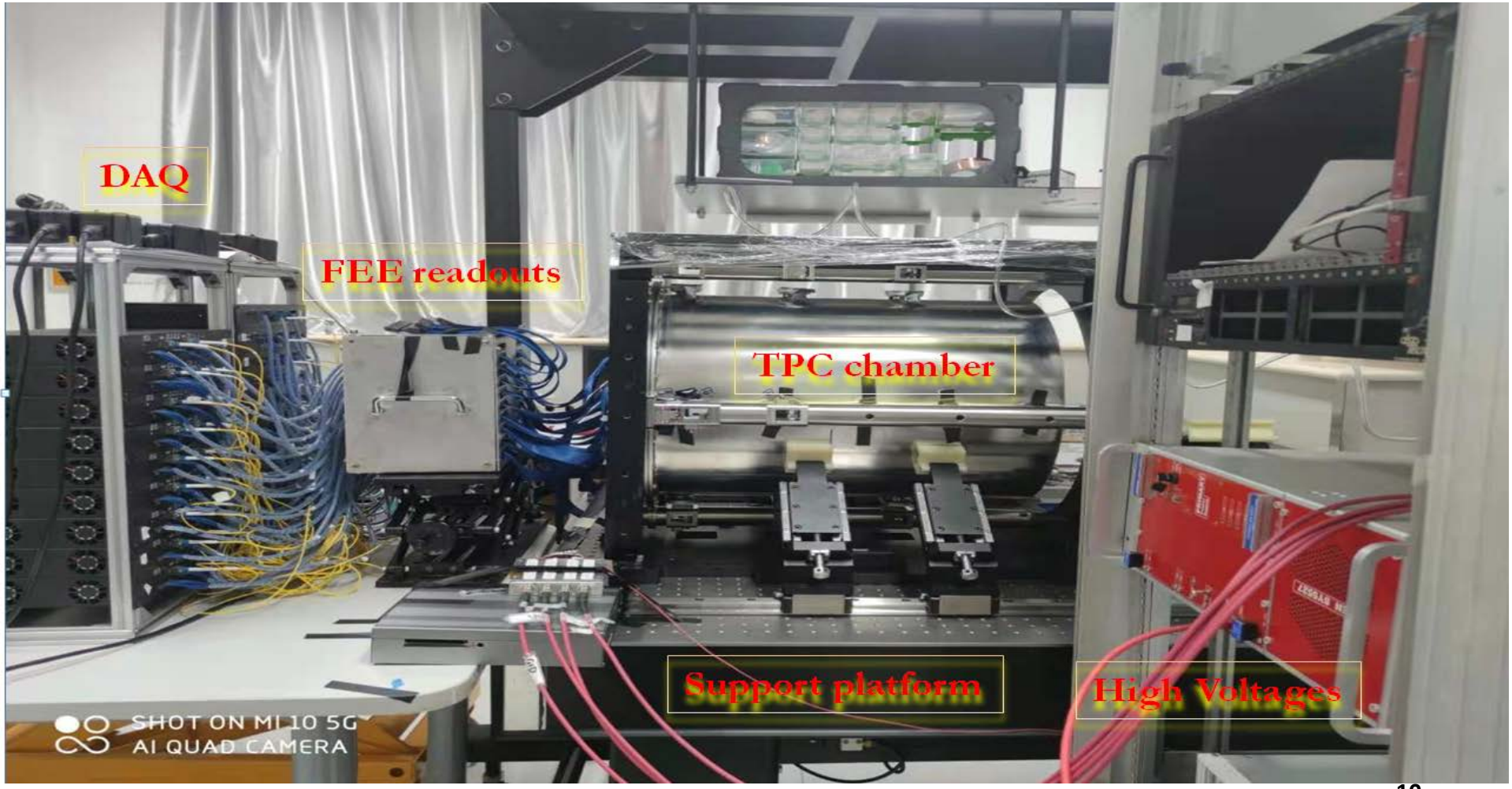




Results of different sizes of the hybrid TPC detector modules

#2. TPC prototype R&D

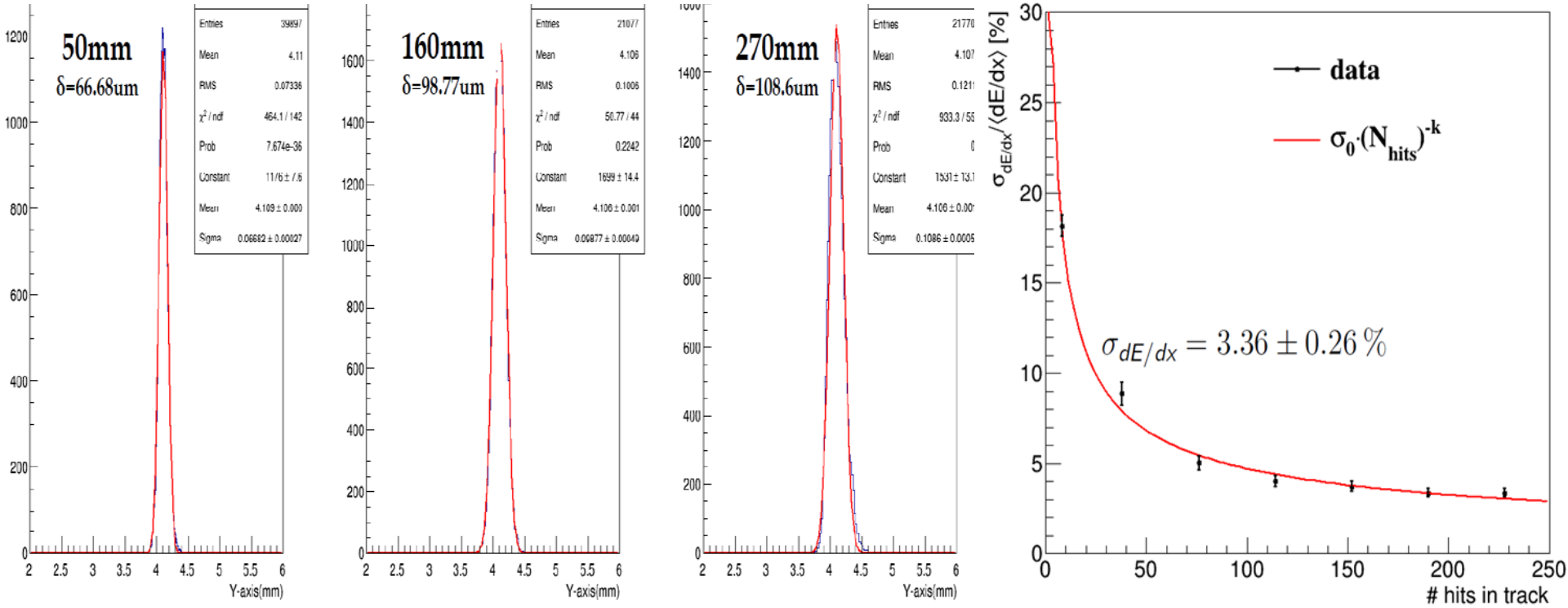
- Successfully to develop the TPC prototype integrated 42 UV laser tracks
- Spatial resolution, dE/dx resolution achieved with the pseudo-tracks (**DONE**)



TPC prototype R&D using 266nm UV laser tracks

#3. TPC prototype R&D

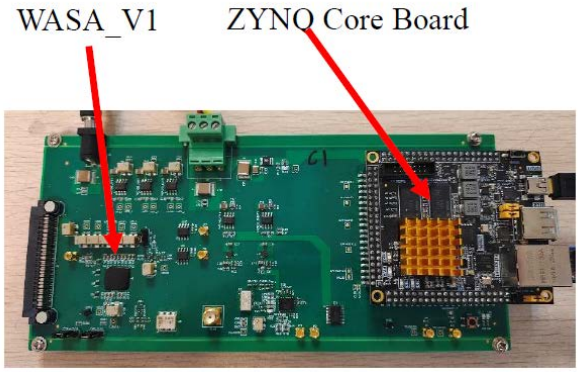
- Spatial resolution can reach to about 100 μm along the drift length of the TPC prototype and it can meet the physics requirement of CEPC
- Pseudo-tracks with 220 layers (same as the actual size of CEPC detector concept) and dE/dx can reach to 3.36 ± 0.26%



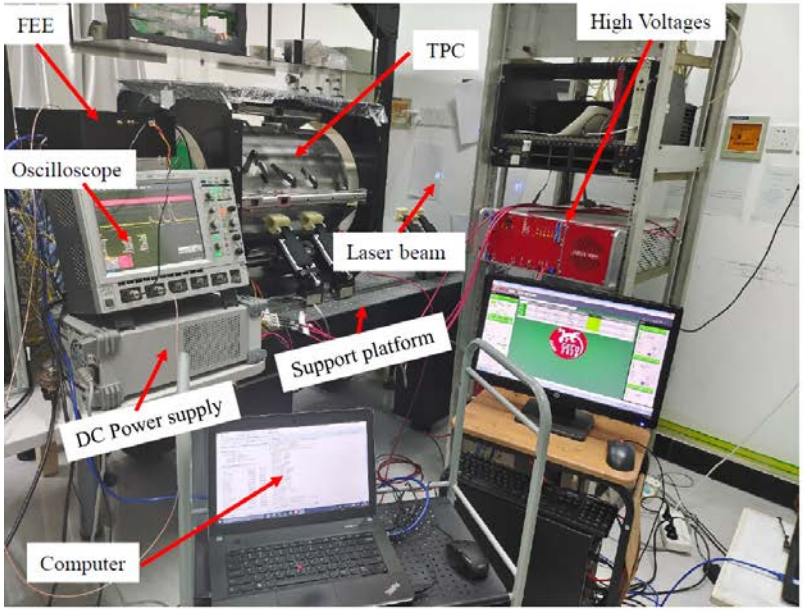
Results of the spatial resolution and dE/dx

#4. Low power consumption readout

- WASA V1 has been developed: 16 channel AFE+ADC+LVDS data output
- Total power consumption with ADC function: ~2.4 mW/ch
  - AFE in 1.4 mW/ch and ADC in 1 mW/ch
- Tested with TPC detector using 64 channels at IHEP
  - All channels collected the energy spectrum of ^{55}Fe

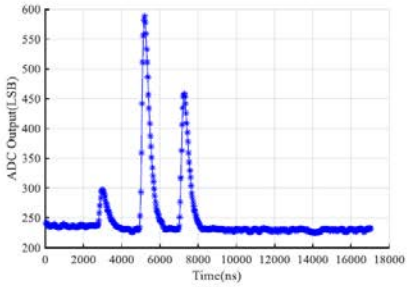


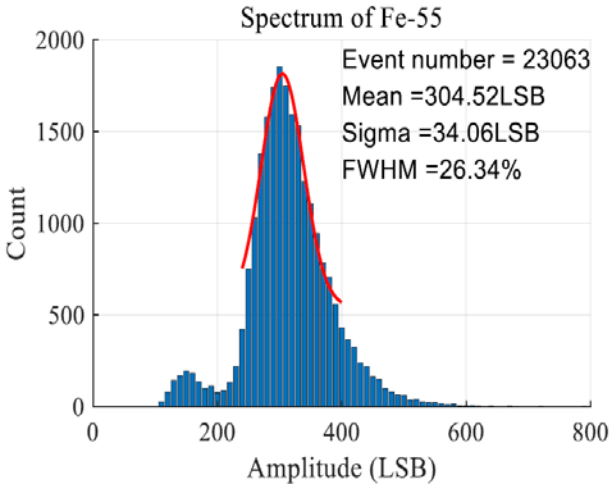
Test Results: Laser Tracks



TPC Work Conditions:

- GEM: 280 V
- Drift Field: 9000 V/50 cm = 180 V/cm
- Gas: Ar/CF_4/iC_4H_{10} 95/3/2 (T2K)
- Laser: 7.2 mJ @20 Hz
- Sampling Rate: 30 MS/s



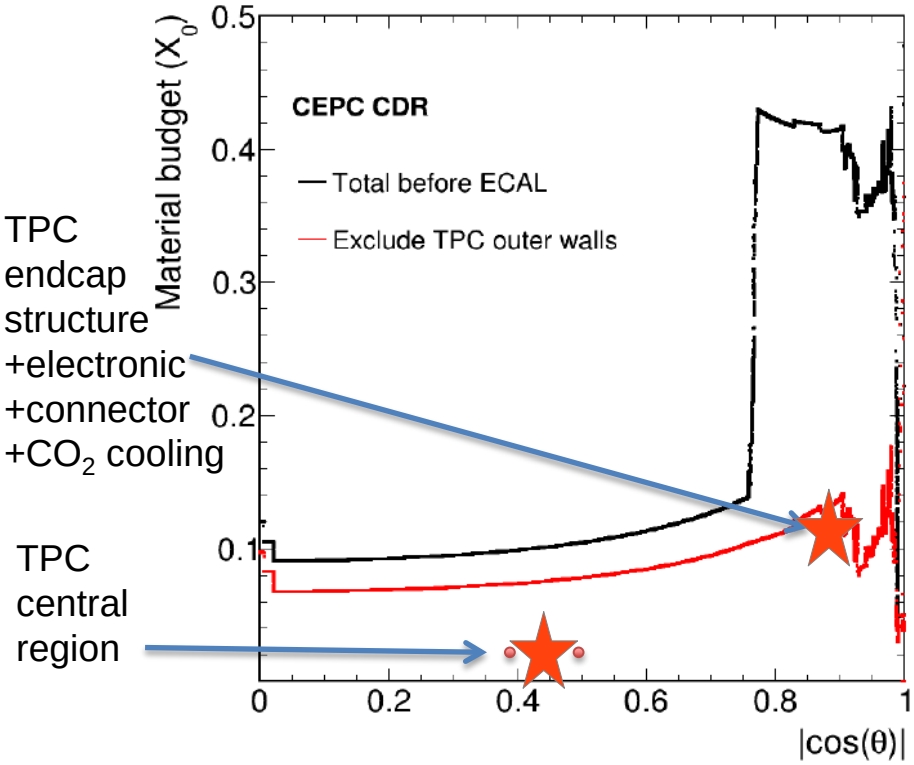


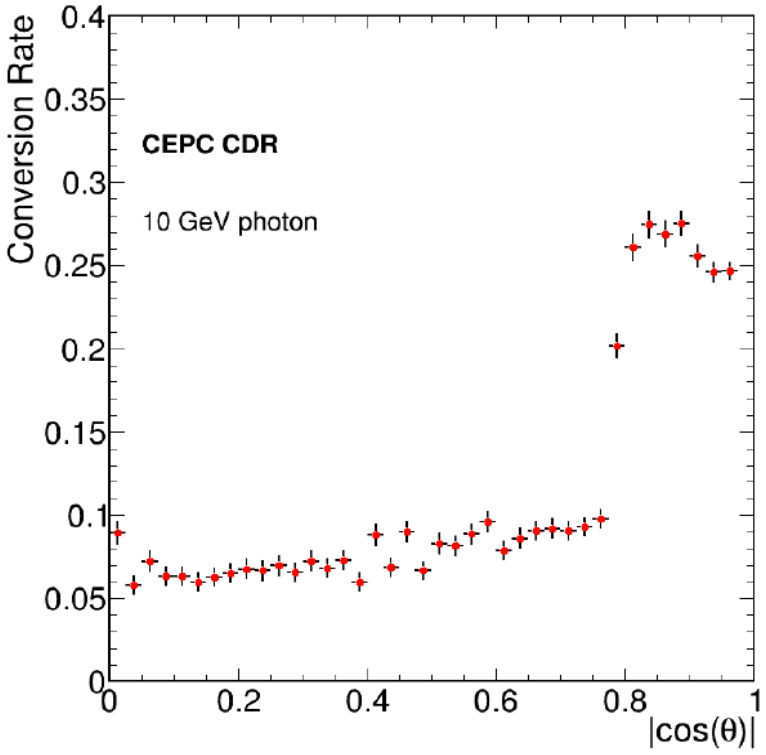
- **Feasibility of pixelated readout TPC**

    1. **Material budget of endplate/barrel**
    2. **Ions affect and distortion**
    3. **Occupancy**
    4. **Running at 2 Tesla**

#1. Material budget of endplate/barrel (OK)

- Typical requirement: ~ 0.1 X_0 at Barrel.
- At CDR setup (Pad TPC): conservative implementation of material budget
  - 0.1 X_0 at Barrel, 0.4 X_0 at endplate (sufficient for any readout with cooling)
  - Sizeable effects on detector performance, but tolerable
    - Observed on Photon conversion, PFA, …
- Pixelated readout TPC can reduce the material from CDR setup





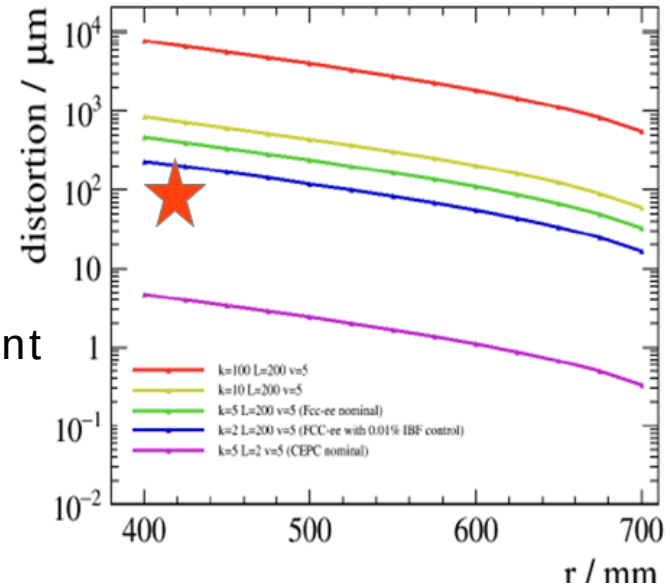
#2. Ions affect and distortion

- Distortion: proportional to event rate, ion back flow and gain. Largest distortion occurs at the inner region
- Analysis (cite#1) shows that at
  - IBF×Gain ~ 1
  - Lumi ~ 2 × 10^{36}
  - Hit from Physics event only
  - Distortion ~ 100 μm ~ pixelated size
    - Might limit spatial/momentum measurement
- Open question: to be addressed by R&D
  - Correction by at least 1 order of magnitude?

    ==> future simulation studies...
  - In-situ calibration with Laser system/Z-> μ μ event (cite#2)

    ==> laser system test ... collaborative studies with LCTPC
  - Contribution from other sources, especially at Z pole

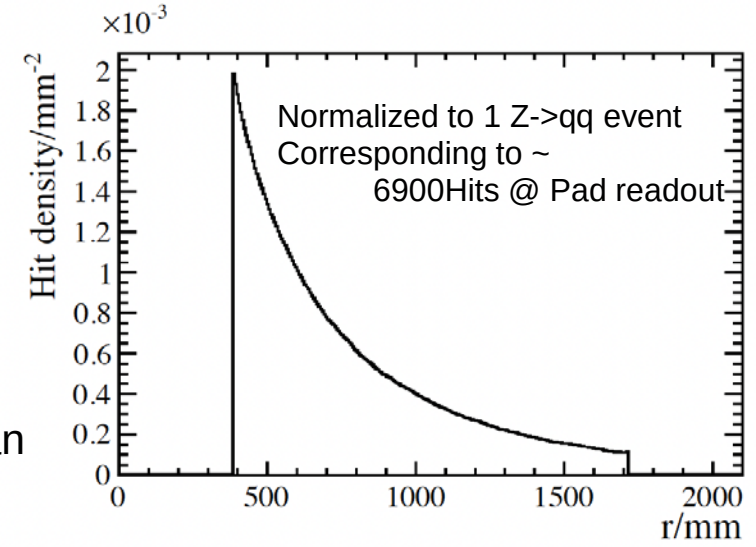
    ==> MDI, Beam background



- Cite#1 https://doi.org/10.1088/1748-0221/12/07/P07005
- Cite#2 Correcting for Distortions due to Ionization

#3. Occupancy (Safe)

- Low voxel occupancy : 1×10^{-5} to 1×10^{-6}(cite#3)
- At 2×10^{36} with Physics event only, even bunch distribution(cite#4).
  - Pad readout (1 mm×6 mm), inner most occupancy 1×10^{-4}
  - Pixelated readout (55 μm ×55 μm), much **LOWER** inner most occupancy ~ 1×10^{-6}
- Pixelated readout can easily handle a high hits rate at Z pole.
  - The test beam showed GridPix TPC prototype can handle up to 2.6M hits/s per chip (cite#5).
- Reconstruction algorithm with high Pile Up need to be developed.

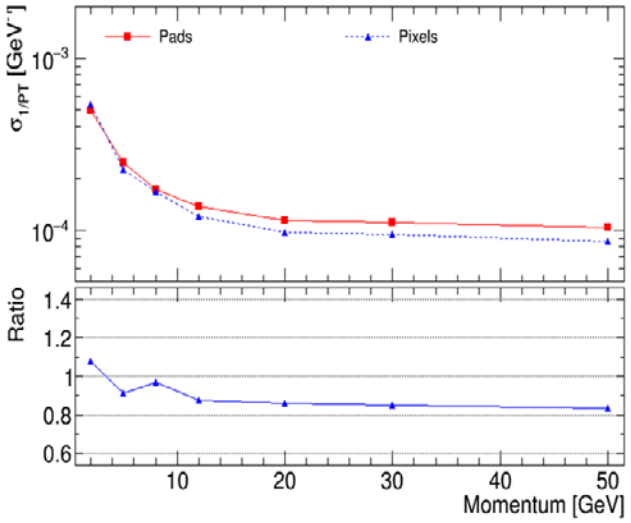


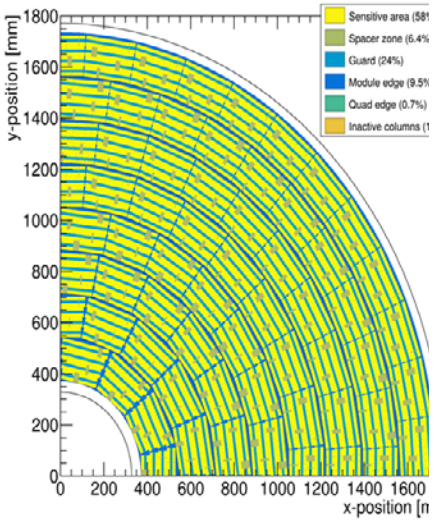
Marlin TPC software package

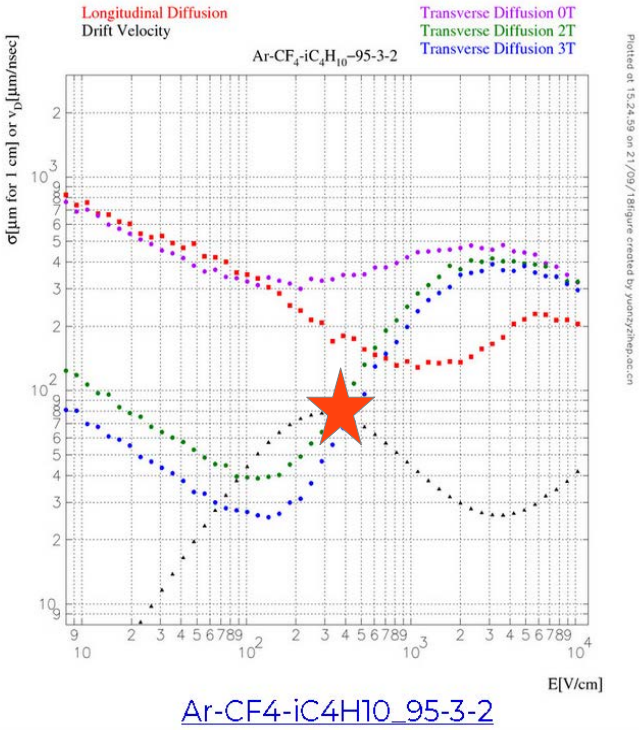
- Cite#3 Occupancy in the CLIC
- Cite#4 https://doi.org/10.1088/1748-0221/12/07/P07005
- Cite#5 GridPix detectors

#4. Running at 2 Tesla

- TPC can work well at the 2 T B-field **without any E×B effect**.
- Momentum resolution is better (>20%) compared with the pad readout technology at the same geometry (cite#5).
  - Pixelated technology: ~10,000hits/track; Pad: 220hits/track
  - Transverse diffusion constant is same level at 2 T & 3 T
- Open question: to be addressed by R&D
  - **Optimized TPC geometry** at 2 T B-field
  - Beam induced background at 2 T B-field







Ar-CF4-iC4H10_95-3-2

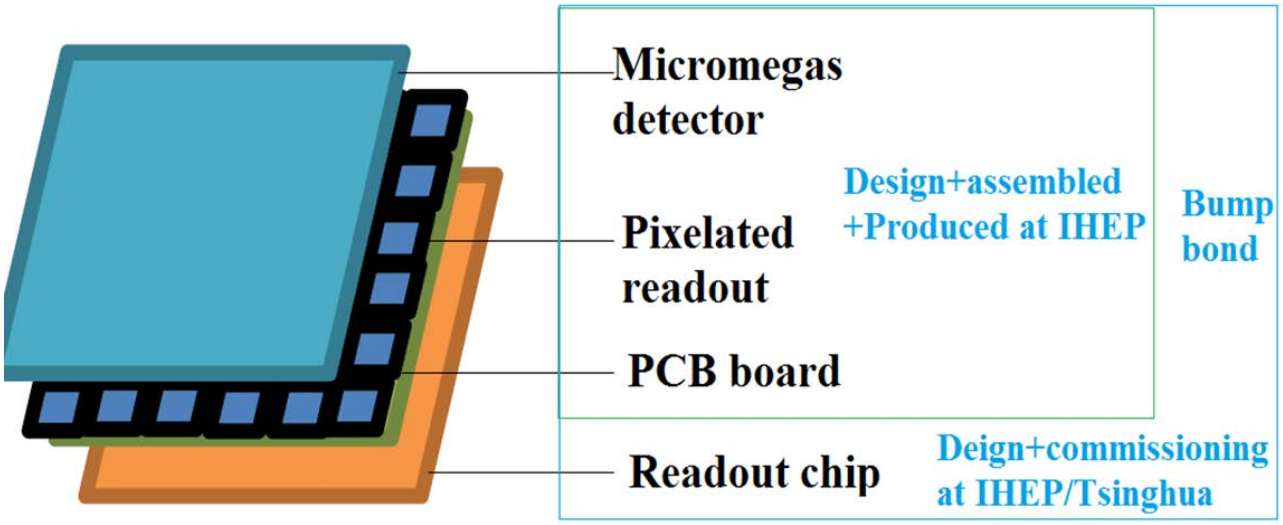
Prototype R&D plan

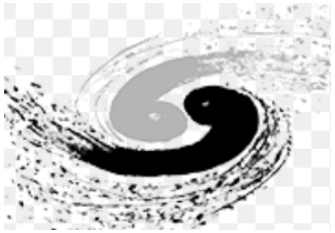
- **Advantage and realized R&D**
  - **Improved dE/dx**
  - **Optimization of cluster/pixel size**

Prototype plan at IHEP

- **Realization of pixelated technology collaborated with Tsinghua**

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 '$dE/dx+dN_{cl}/dx$'

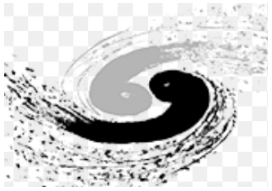




Tsinghua University
University

Prototype plan at LCTPC Collaboration

- **Realization of pixelated technology using GridPix chip collaborated Bonn**
  - **110 μm×110 μm and smaller**
  - Design the different readout pixelated size
  - Bonn University to produce the new prototype
  - Collaborated to study using UV laser tracks

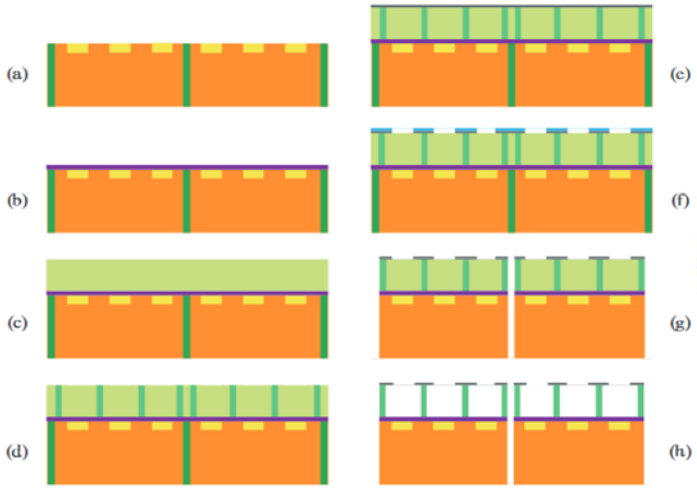


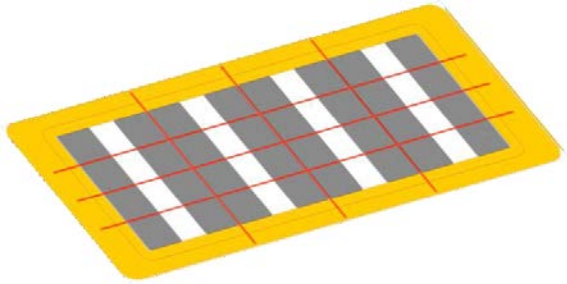
University of Bonn

University

Production of GridPixes

a) Cleaning
b) Deposition of Protection layer
c) SU-8 covering
d) Exposure with mask
e) Aluminium layer is deposited
f) Another layer of photoresist is applied, exposer with a mask creates a hole pattern, and the holes are chemically etched
g) The wafer is diced
h) The unexposed SU-8 is resolved





Summary

- Pad readout TPC can operate @ CEPC W/Higgs operation, with 3 T B-field or higher.
  - Spatial resolution can reach to about 100 μm along the drift length of the TPC prototype and it can meet the physics requirement of CEPC.
  - A laser TPC prototype has been successfully developed and studied at IHEP in the last 6 years. Ionback flow can be reduced to 1 level at gain 2000.
- High Lumi operation (2×10^{36}) @ Z with 2 T B-Field is challenge for gaseous.
  - Pixelated readout TPC is promising, compared to Pad readout.
  - Material budget, construction cost, power & cooling, Occupancy is OK.
  - Lower Ion backflow at low gain (to be addressed by R&D).
  - Potential for dN/dx, essential for PID.
- 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)
- Collaborated with LCTPC international group, and any cooperation is welcome

Many Thanks