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

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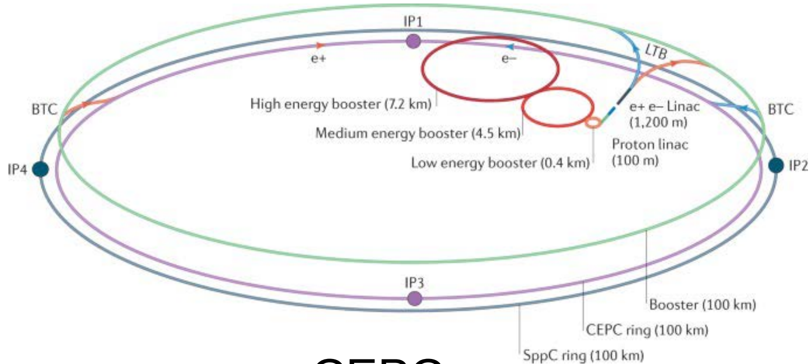
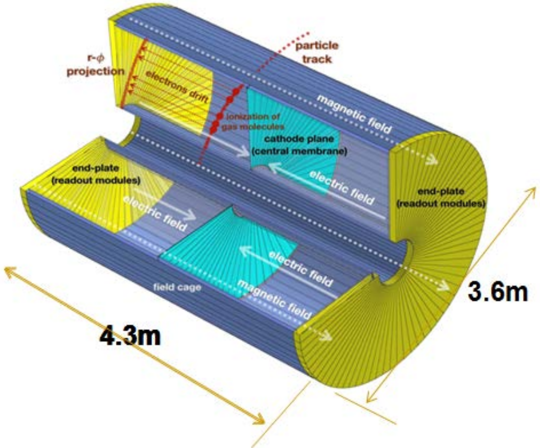
- **TPC technology R&D**
- **Feasibility of pixelated readout**
- **Prototype R&D plan**
- **Summary**

TPC detector@ Future e+e- Colliders

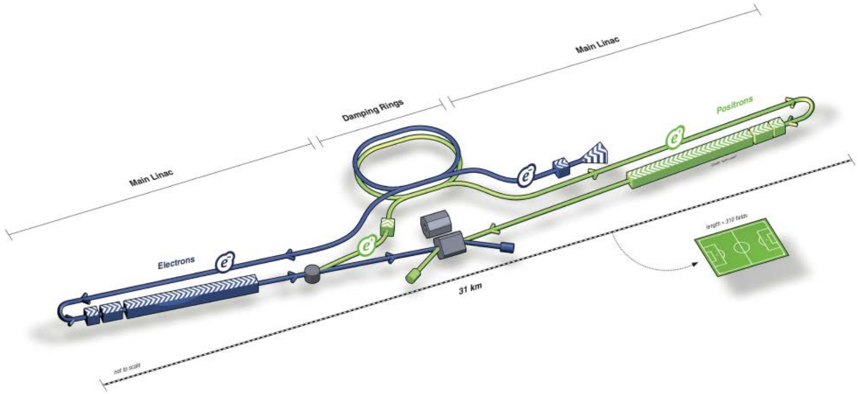
- TPC detector acts the key role at the future e+e- Colliders
- Some advantages of TPC detector
  - Operation under **3 T magnetic field**
  - Large number of **3D** space points
  - **Very low material** budget



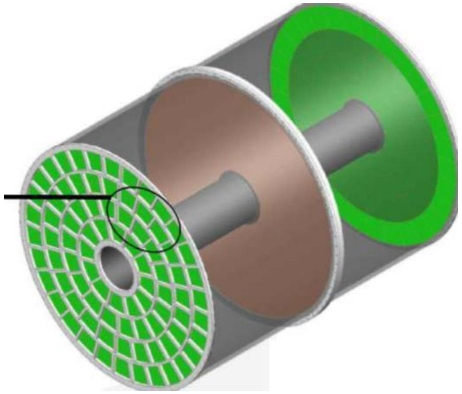
CEPC



CEPC TPC



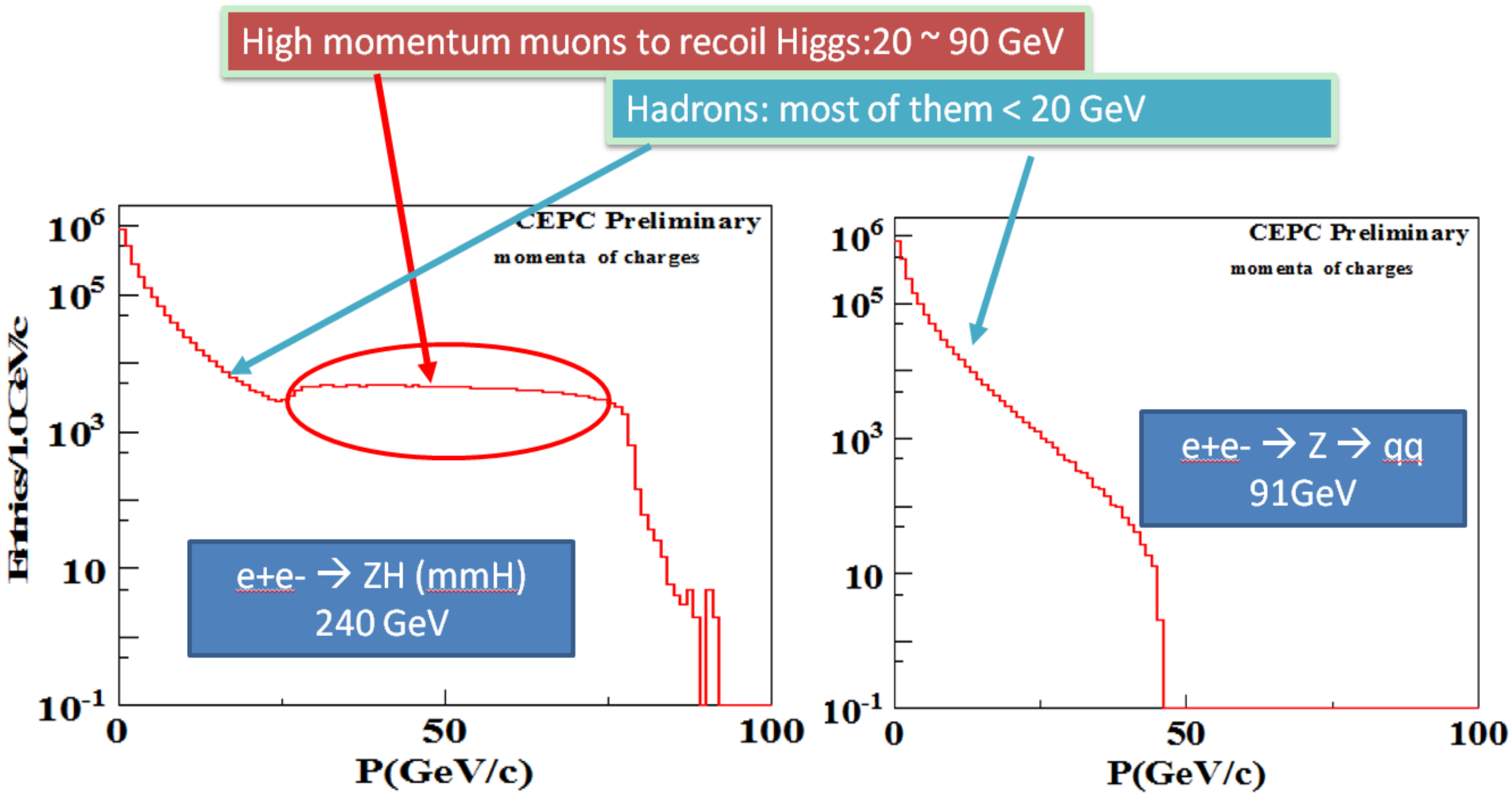
ILC



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

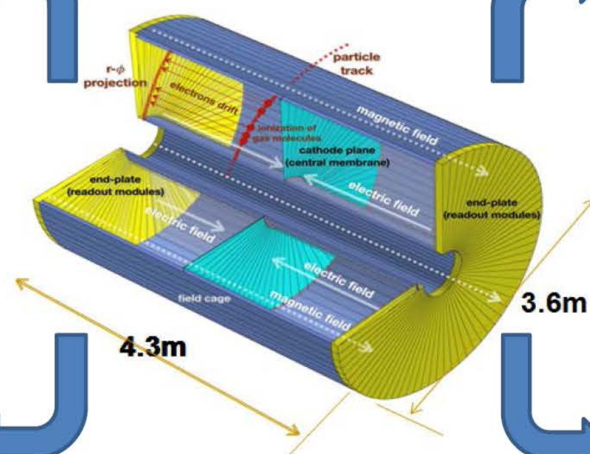


Motivation: Challenges of TPC

- **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

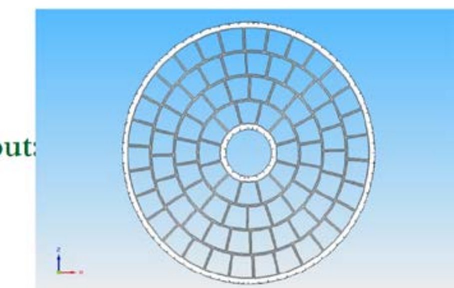
PID performance study
- Simulation of the ionization cluster in space
- PID studies of the different readout TPC prototype
- Experimental study

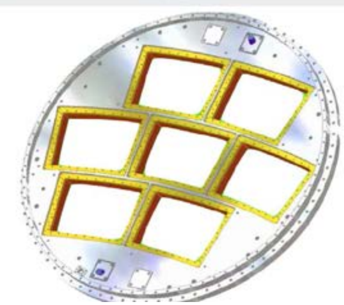
Pad TPC technology for CEPC

- 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: $2 \times 10m^2$
- One option for endplate readout:
  - GEM or Micromegas
  - 1×6 mm^2 pads
  - 10^6 Pads
  - 84 modules
  - Module size: $200 \times 170mm^2$
  - Readout: Super ALTRO
  - CO_2 cooling





Pixelated TPC technology for CEPC

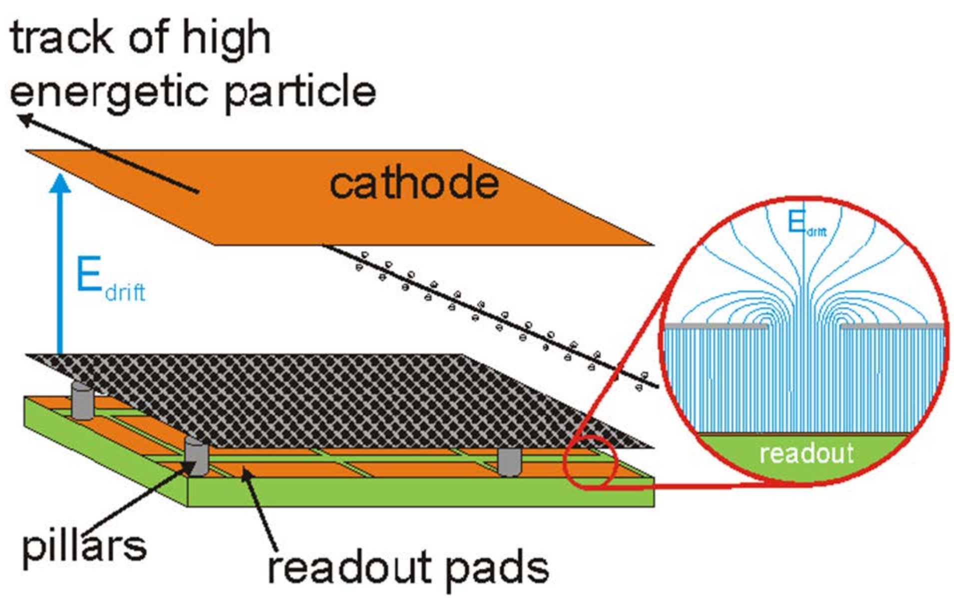
- A pixelated TPC is a good option to provide realistic physics requirements and can work **at high luminosity** (2×10^{36}) on CEPC.
- Pixelated → better resolution → low gain(<2000) → less distortion
- Pixelated readout TPC is a realistic option to provide at CEPC
  - Can deal with high rates (MHz/cm^2)
  - 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.



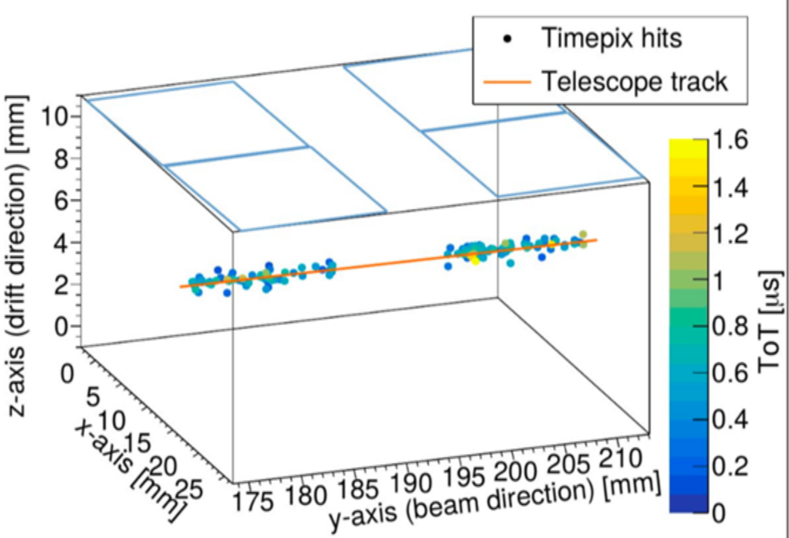
How to identify the clusters and achieve dN/dx

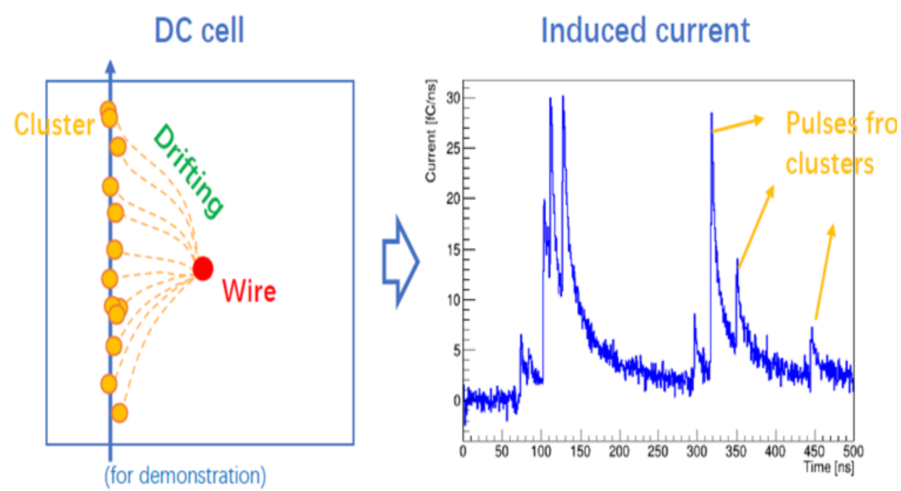
In Space - TPC

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

In Time - Wire Chamber

- Challenging of the fast-shaping electronics (~ ns needed)
- De-couple the charge collection from the cluster counting altogether
- → optical, with ~(sub)ns continuous readout sensors



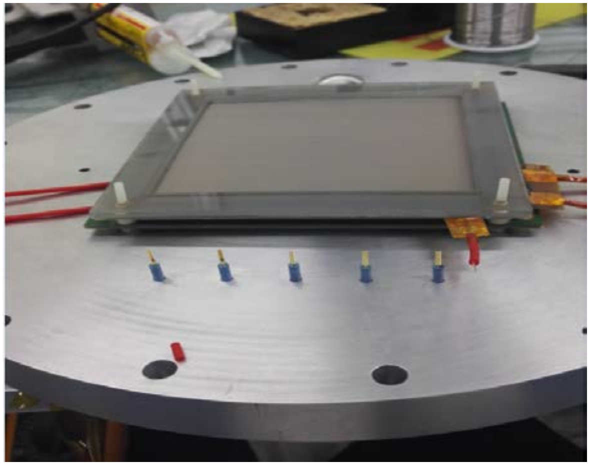


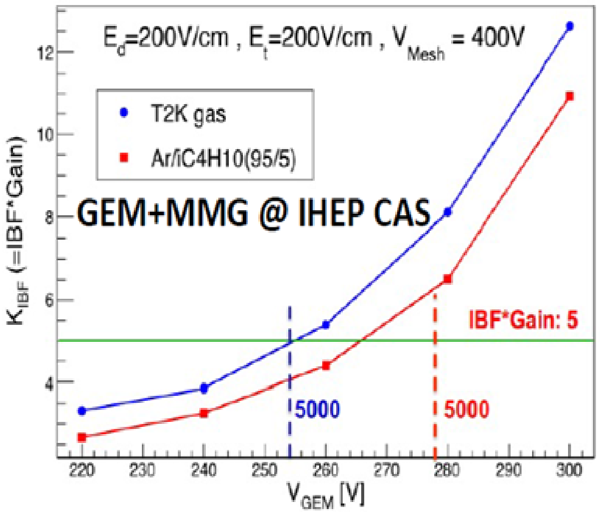
- **Status of TPC detector R&D at IHEP**

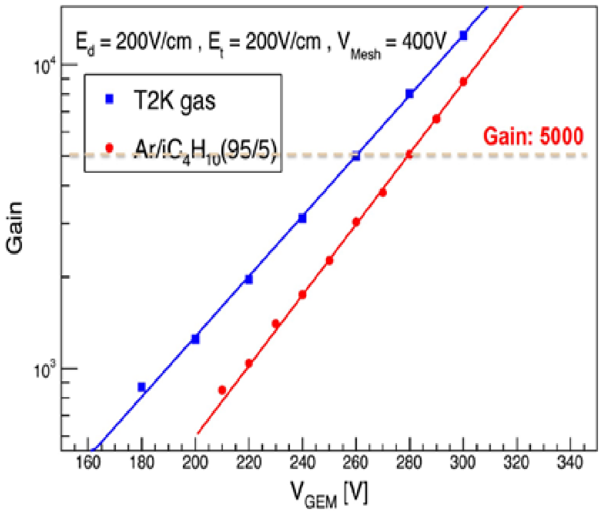
    1. **TPC detector module with the ions suppression**
    2. **Status of TPC prototype using UV laser**
    3. **Low power consumption readout**

#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



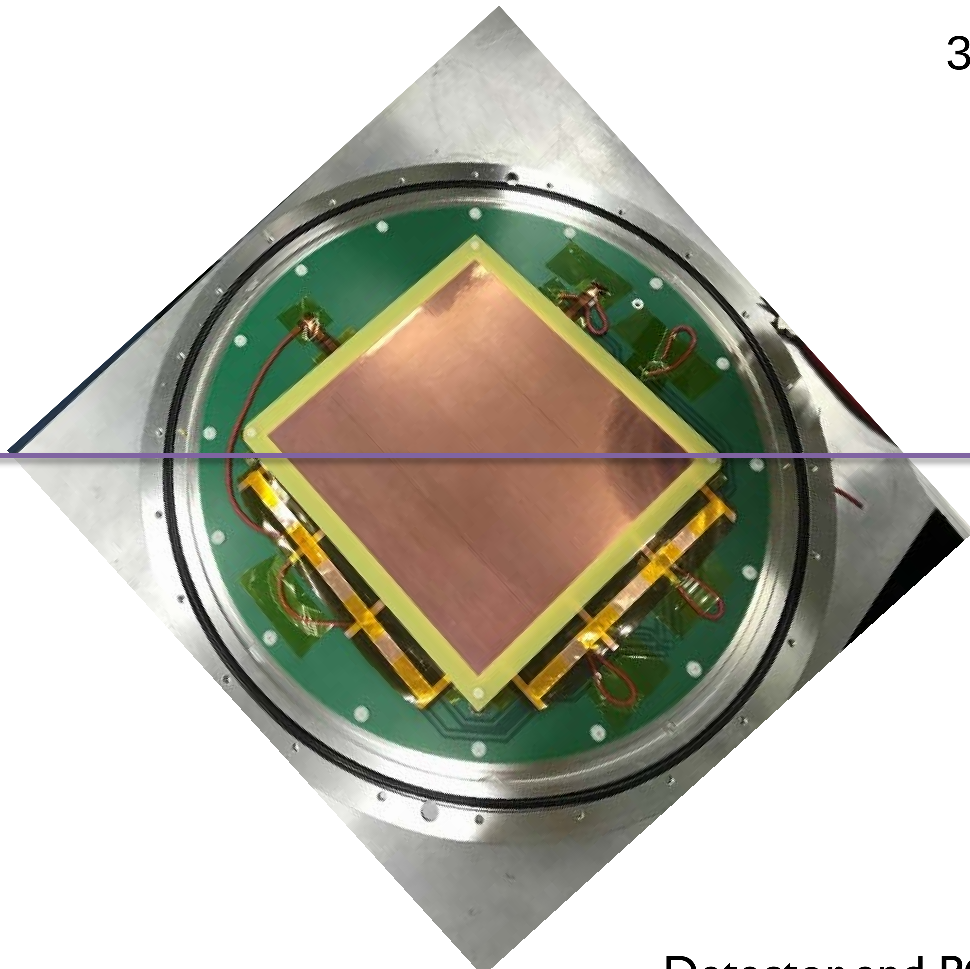




Results of different sizes of the hybrid TPC detector modules

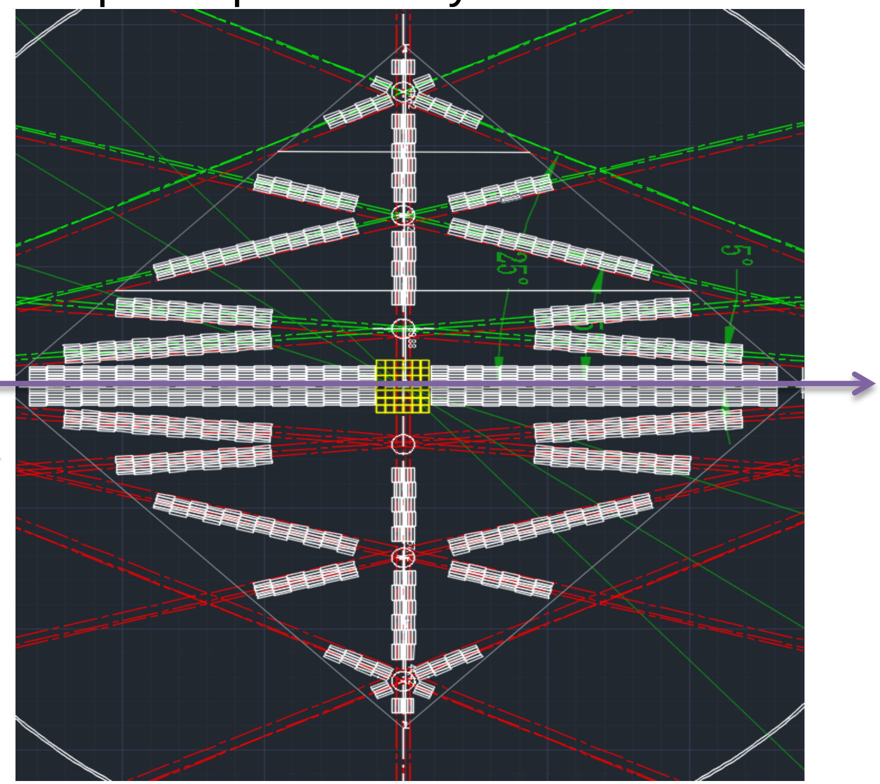
#2. TPC readout R&D

- Designed TPC readout pads to cover the specific the UV laser
- To study the PID using **266nm UV laser track** (Ø0.85mm)



Pad size: 1mm × 6mm

38 hit points per track by UV laser



Detector and PCB readout board

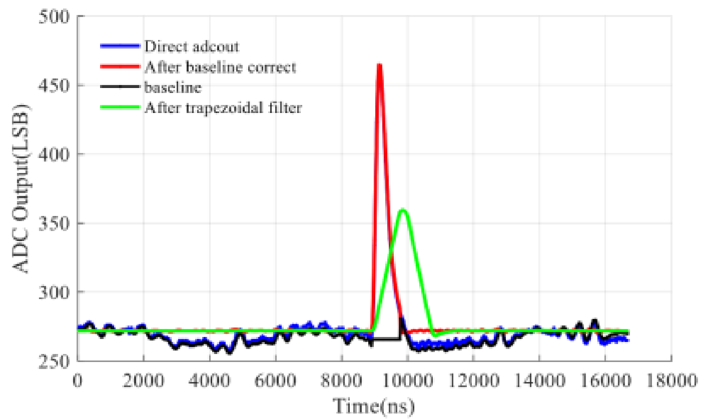
#3. Electronics commission testing

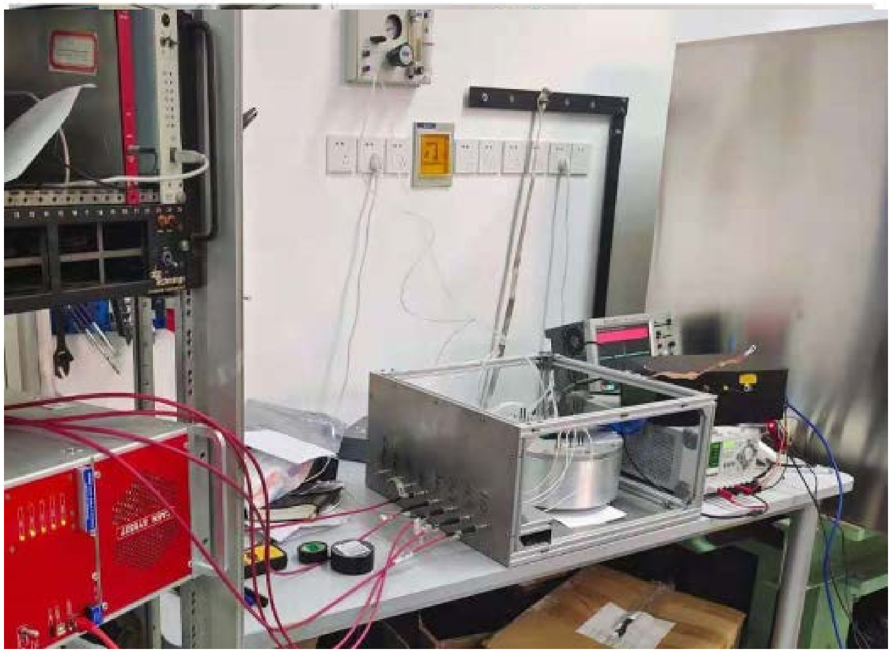
- Successfully testing and collected signals using the electronics

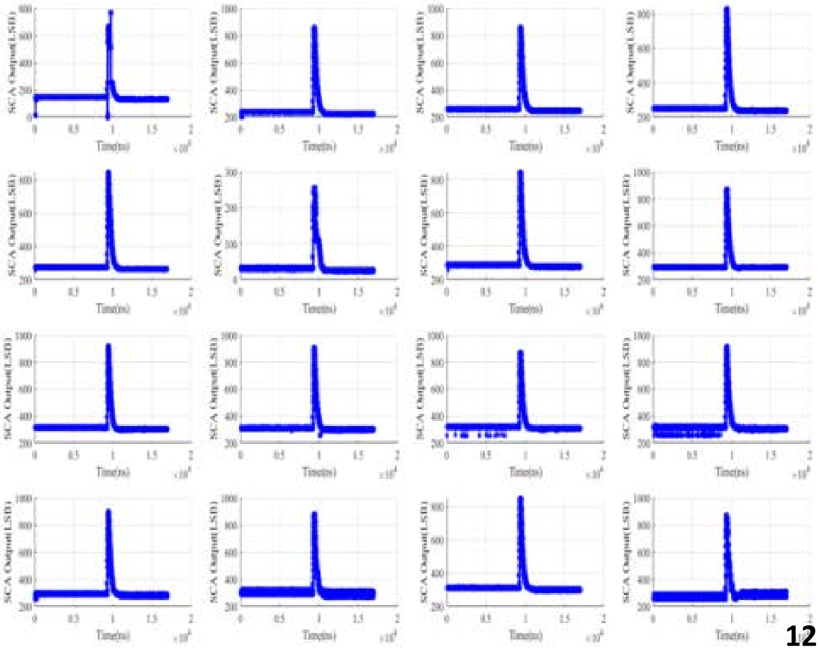
^{55}Fe testing

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**





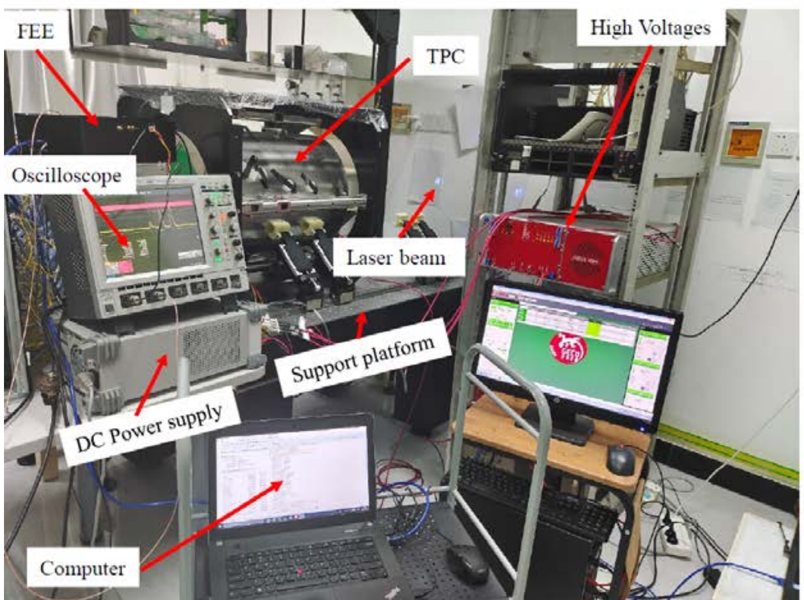


Transient output waveform @30 MS/s

#4. Low power consumption readout

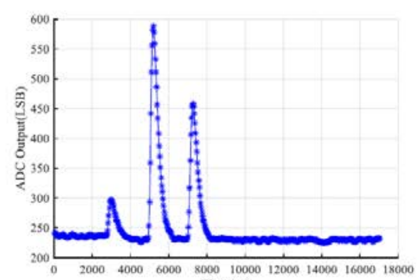
- WASA V1 has been developed: 16 channel AFE+ADC+LVDS data output
- Total power consumption with ADC function: **~2.4 mW/ch**
  - AFE in 1.4 mW/ch and ADC in 1 mW/ch
- Tested with TPC detector using 64 channels at IHEP
  - All channels collected the energy spectrum of ^{55}Fe

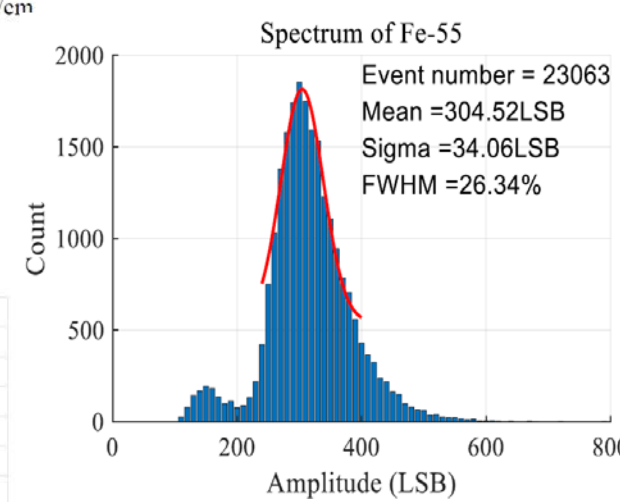
Test Results: Laser Tracks



TPC Work Conditions:

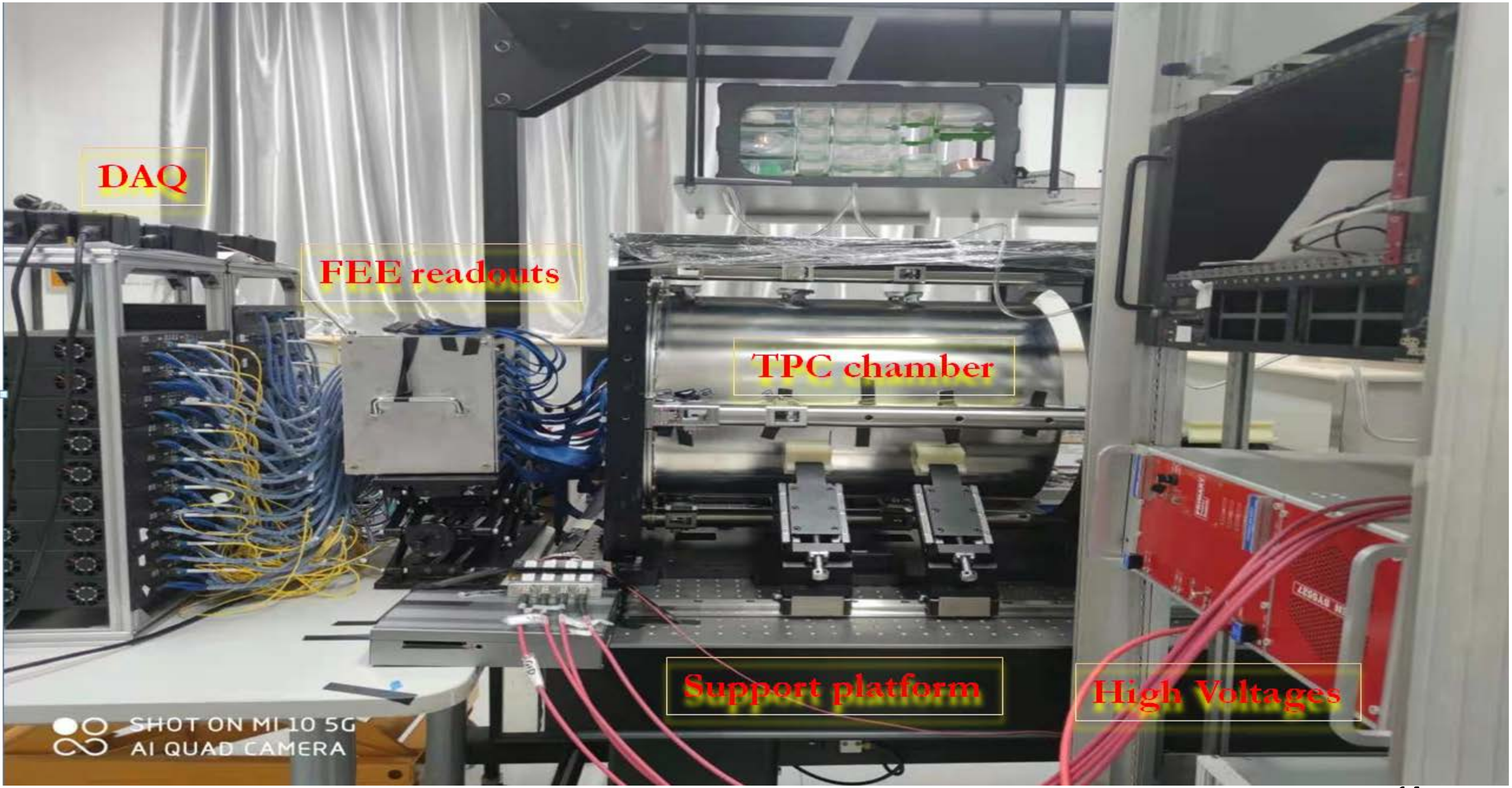
- GEM: 280 V
- Drift Field: 9000 V/50 cm = 180 V/cm
- Gas: Ar/CF_4/iC_4H_{10} 95/3/2 (T2K)
- Laser: 7.2 mJ @20 Hz
- Sampling Rate: 30 MS/s





#5. TPC prototype R&D

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

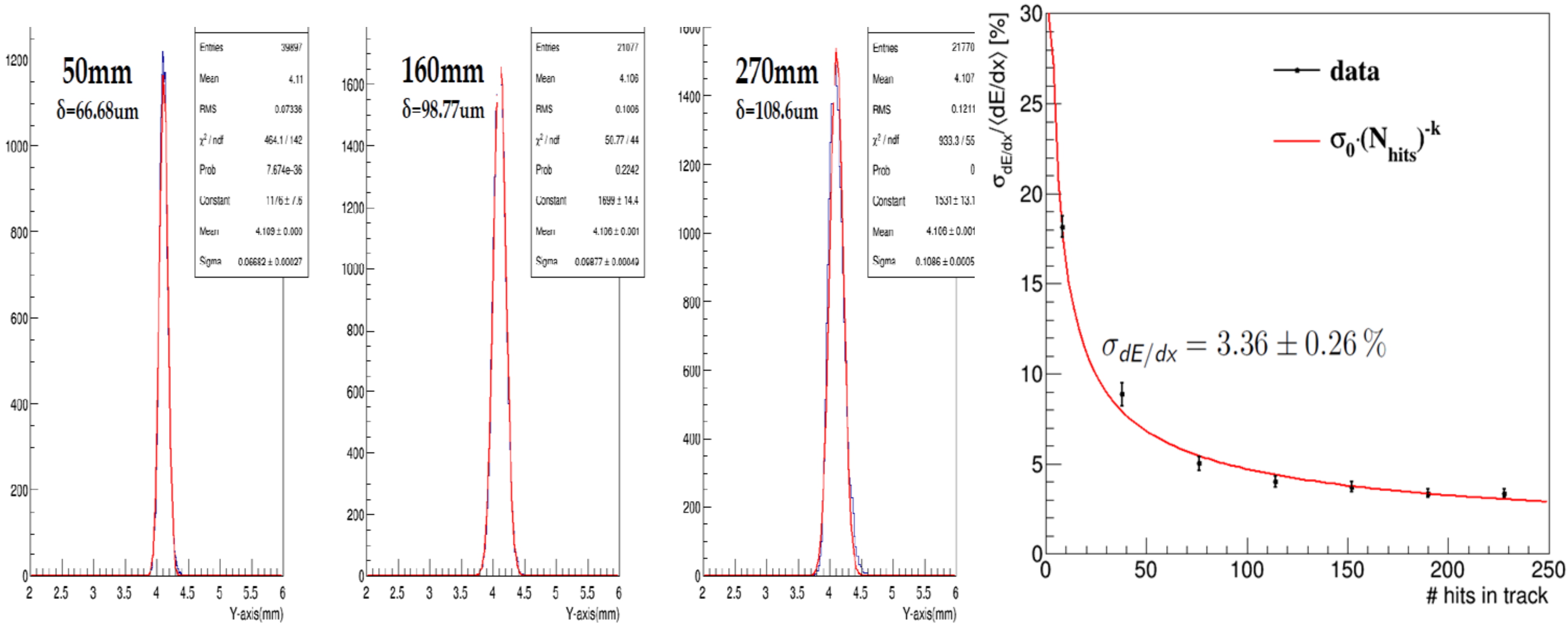


TPC prototype R&D using 266nm UV laser tracks

#6. Spatial resolution and dE/dx

- 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 $3.36 \pm 0.26\%$

[Updated publication: https://doi.org/10.1016/j.nima.2022.167241](https://doi.org/10.1016/j.nima.2022.167241)

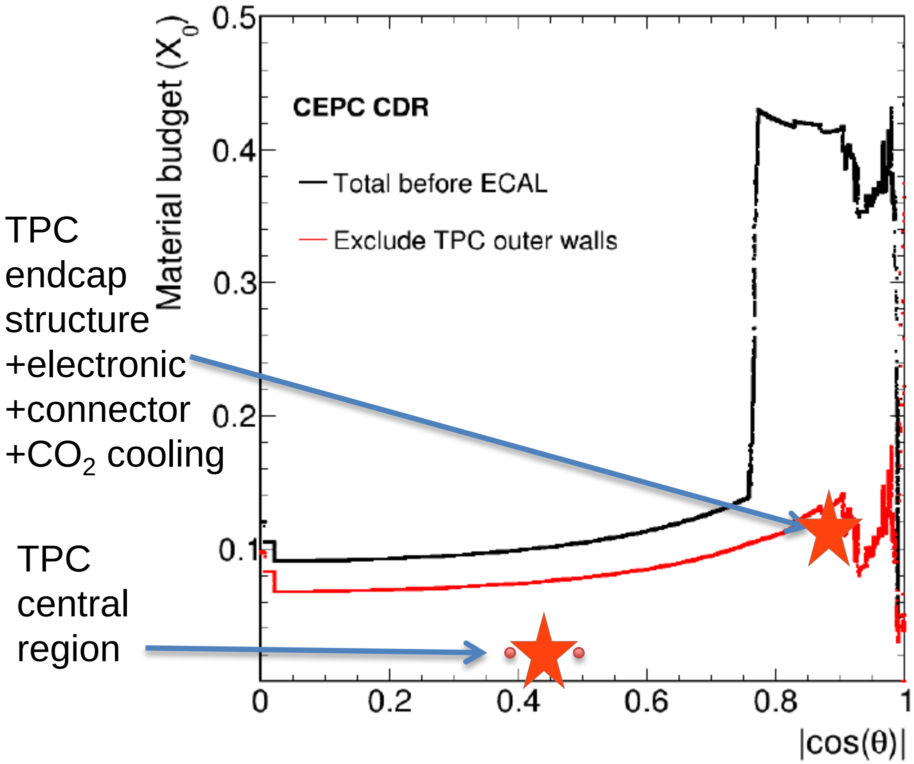


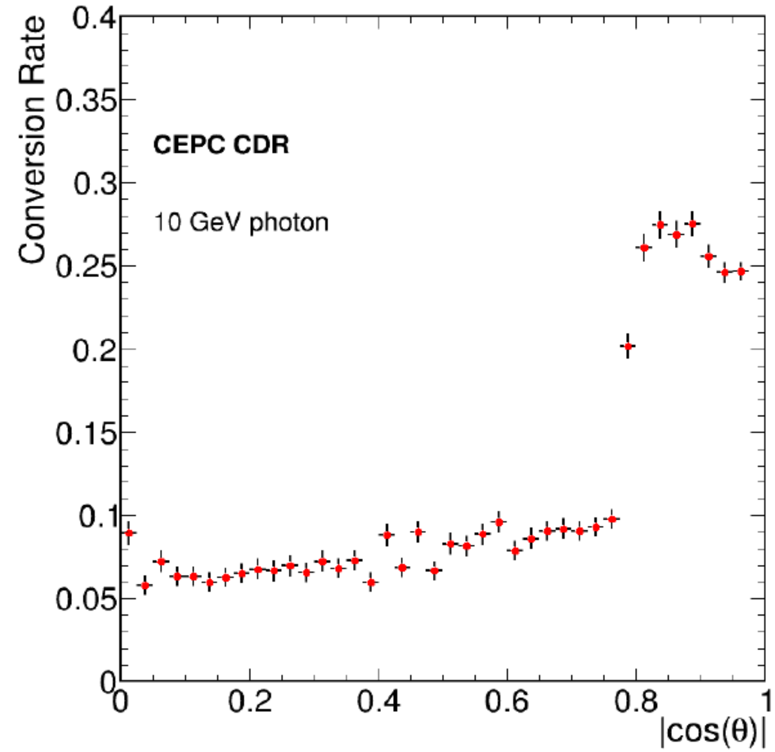
Results of the spatial resolution and dE/dx

- **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)

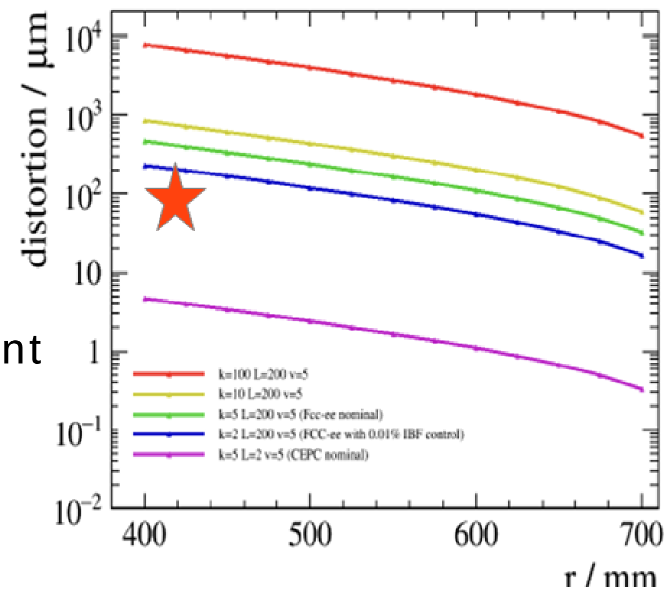
- Typical requirement: **~ 0.1 X_0 at Barrel**.
- At CDR setup (Pad TPC): conservative implementation of material budget
  - 0.1 X_0 at Barrel, 0.4 X_0 at endplate (sufficient for any readout with cooling)
  - Sizeable effects on detector performance, but tolerable
    - Observed on Photon conversion,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

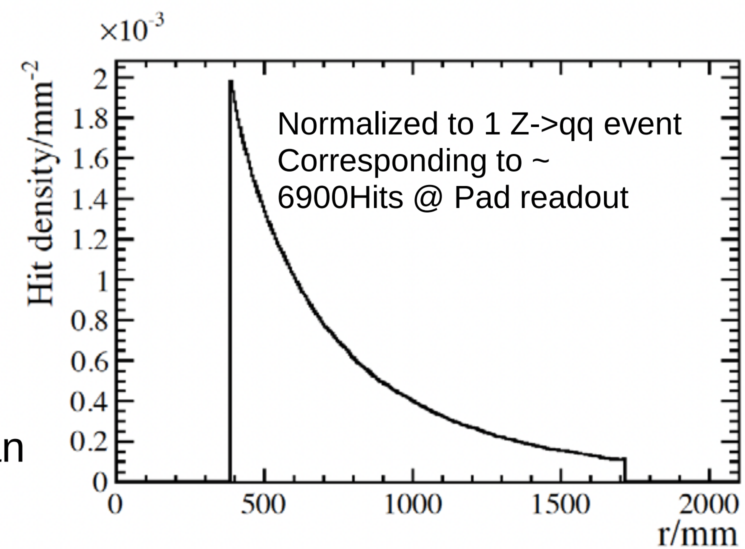
    ==> laser system test … collaborative studies with LCTPC
  - Contribution from other sources, **especially at Z pole**

    ==> 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.

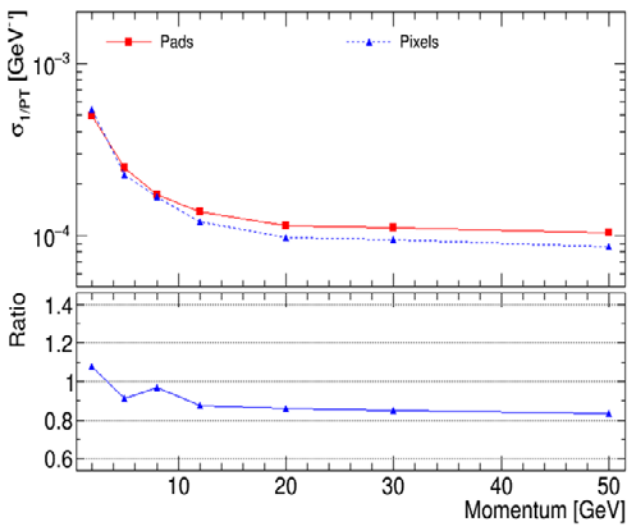


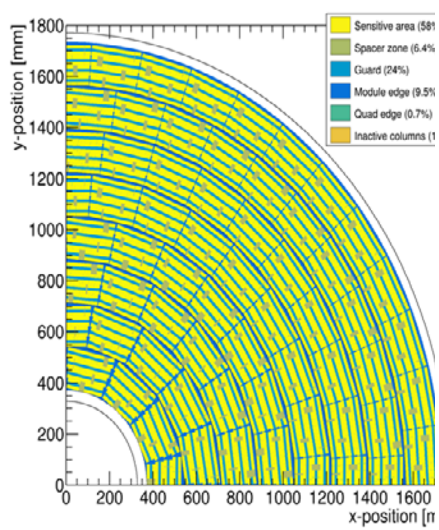
→ **Marlin TPC software package**

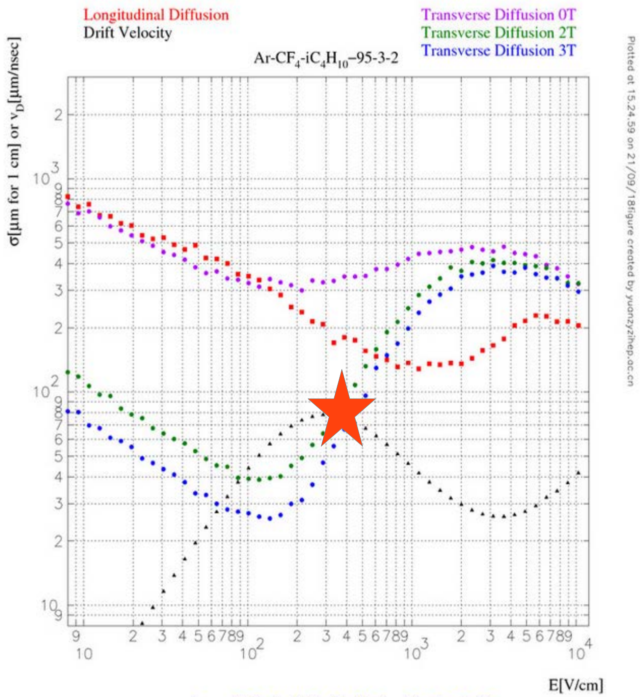
- Cite#3 Occupancy in the CLIC
- Cite#4 https://doi.org/10.1088/1748-0221/12/07/P07005
- Cite#5 GridPix detectors

#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: **~10,000 hits/track; Pad: 220 hits/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







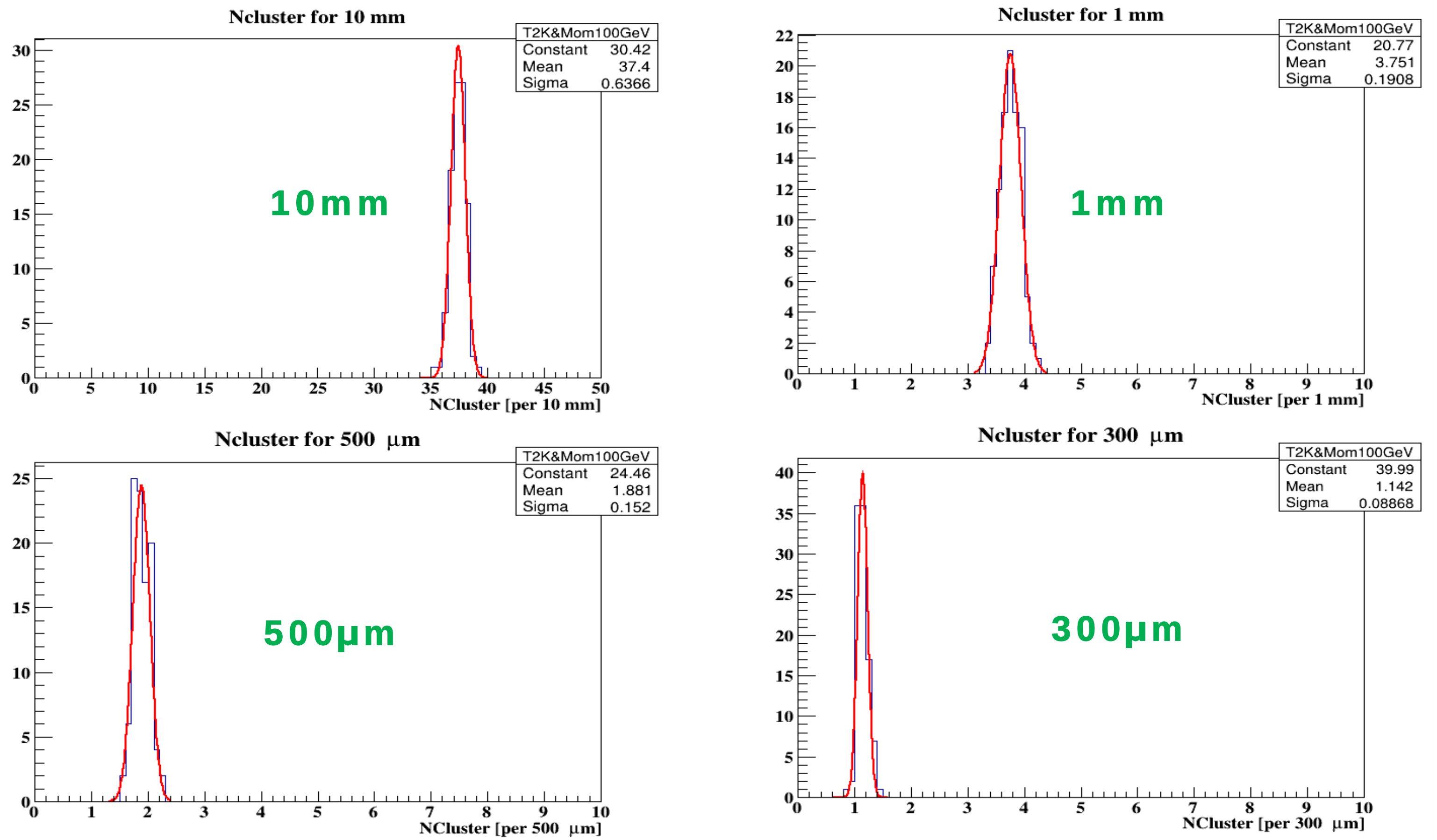
Ar-CF4-iC4H10_95-3-2

New prototype R&D plan

- **Pixelated simulation and realized R&D**
  - **Simulation of the primary cluster**
  - **Optimization of cluster/pixel size**

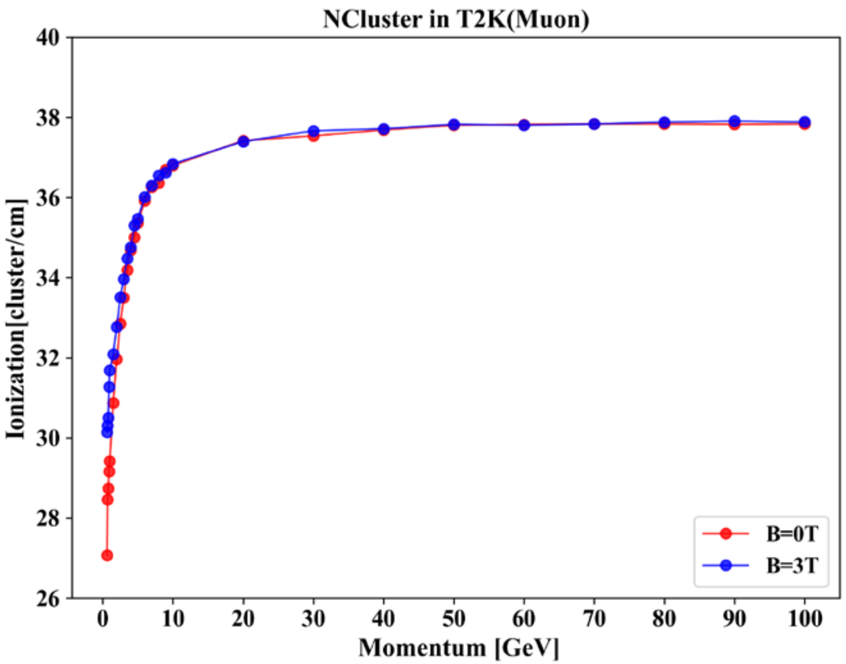
Simulation of the primary cluster at T2K

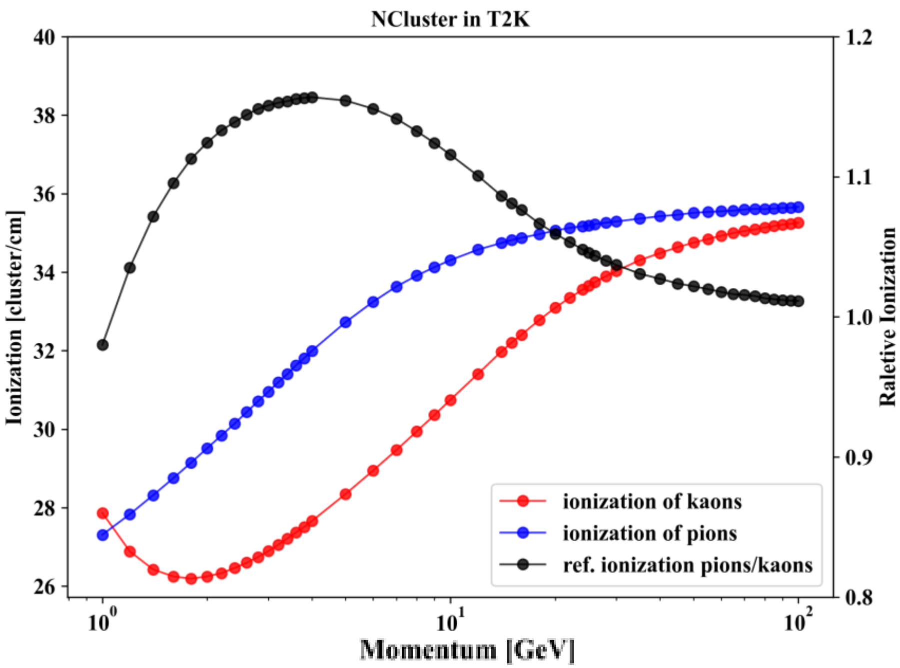
- Simulation: Running 10000 events using Garfiled++
- Simulation result show that the **primary cluster profile** along the drift length
- For **300um-500um**, the standard deviation of the primary cluster distribution can keep in the same level



Primary cluster profile at T2K - π/κ/μ

- Simulation of the particles: **Pion, Muon, Kion, 0.5GeV – 100GeV**
- Variation of $N_{cluster}$(cm) with the different momentum of the specific incident particle
- Comparing the $N_{cluster}$ of muon under different magnetic fields (0T and 3T)
- **Separation of pions and kaons** with the different momentum at T2K
  - Open question: to be addressed by R&D -> dN/dx -> High granularity readout





High granularity for improved PID in TPC

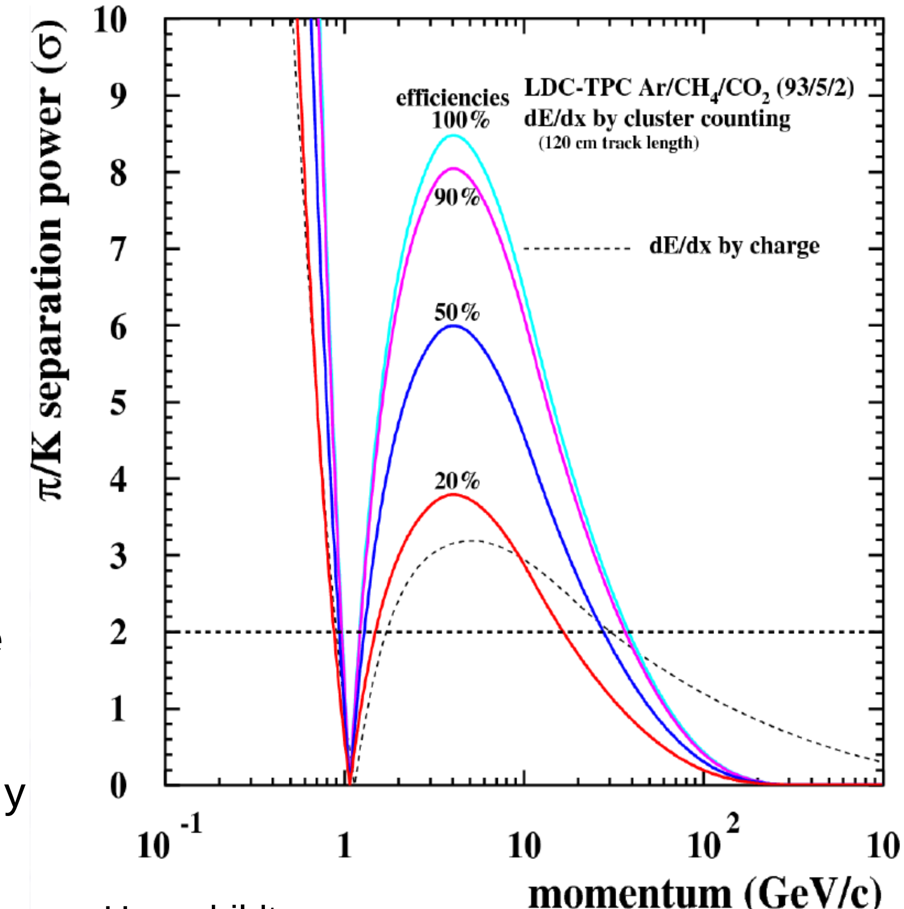
- For traditional dE/dx detection, the charge summation can be expected using the gravity method.

- In most experimental study from small to large TPC
  - L and N are correlated.
  - 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

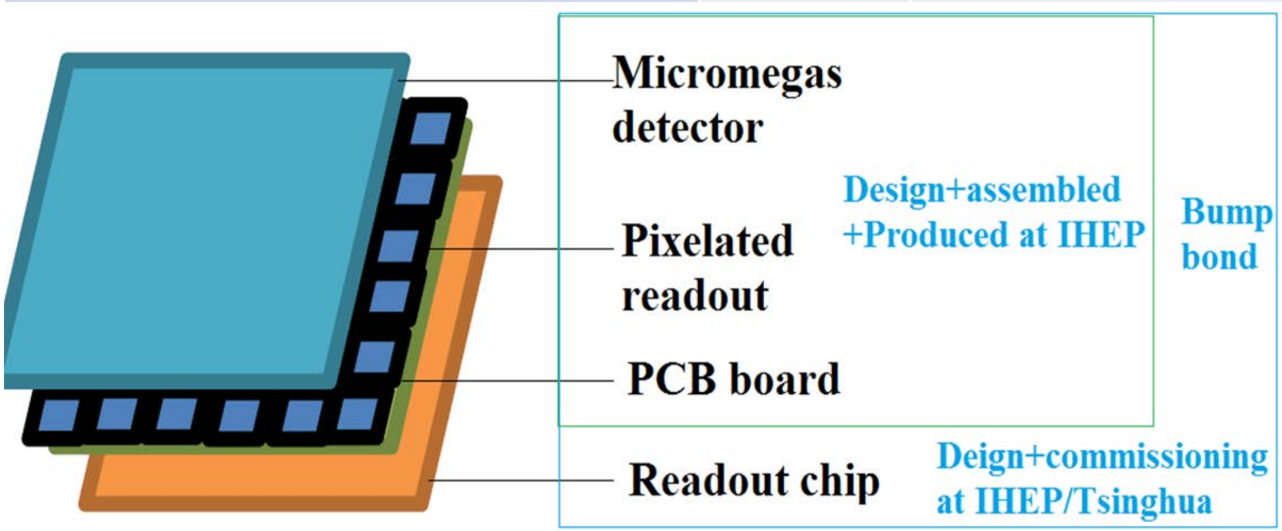


Hauschildt
http://ific.uv.es/~ilc/ECFA-GDE2006/0

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 Tsinghua University • Developed the Micromegas detector sensor at IHEP • Development of the new module and prototype in the end of 2022	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

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