Status of TPC detector R&D for CEPC

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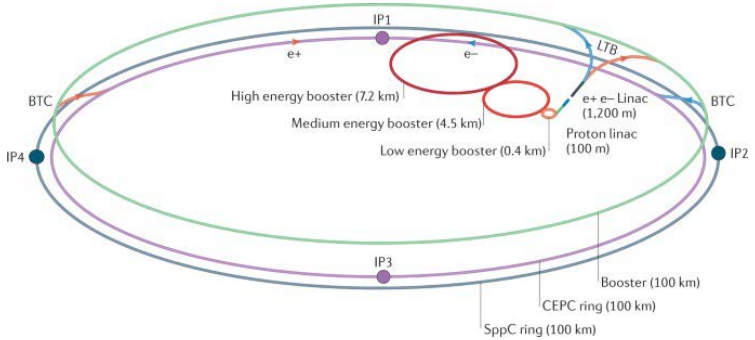
Content

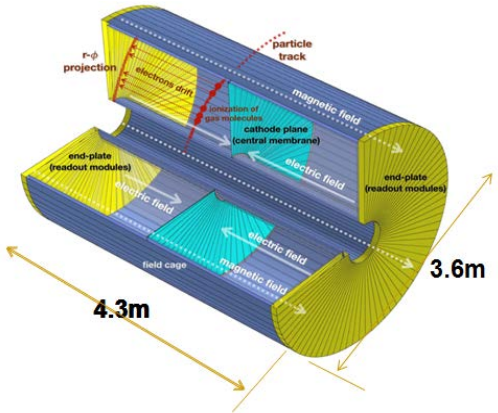
- **Motivation**
- **TPC technology R&D**
- **Feasibility of pixelated readout**
- **Prototype R&D plan**
- **Summary**

TPC detector@ Future e+e- Colliders

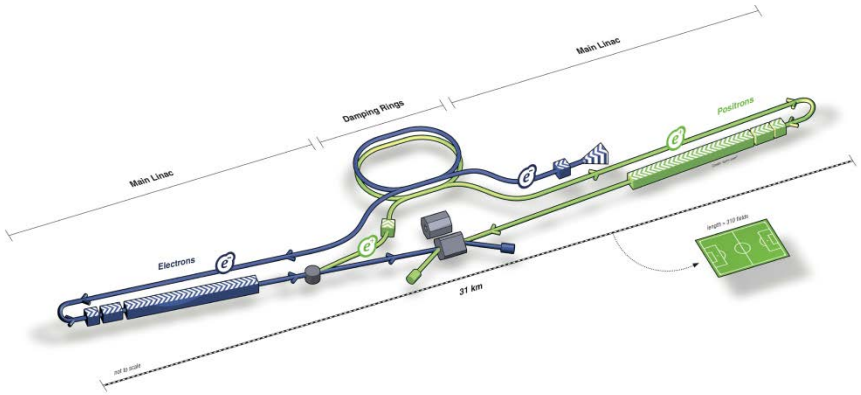
- TPC detector acts the key role at the future e+e- Colliders
- Some advantages of TPC detector
  - Operation under 3 Tesla magnetic field
  - Large number of 3D space points
  - Very low material budget



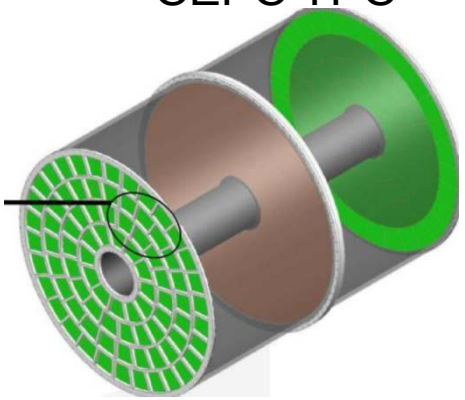
CEPC



CEPC TPC



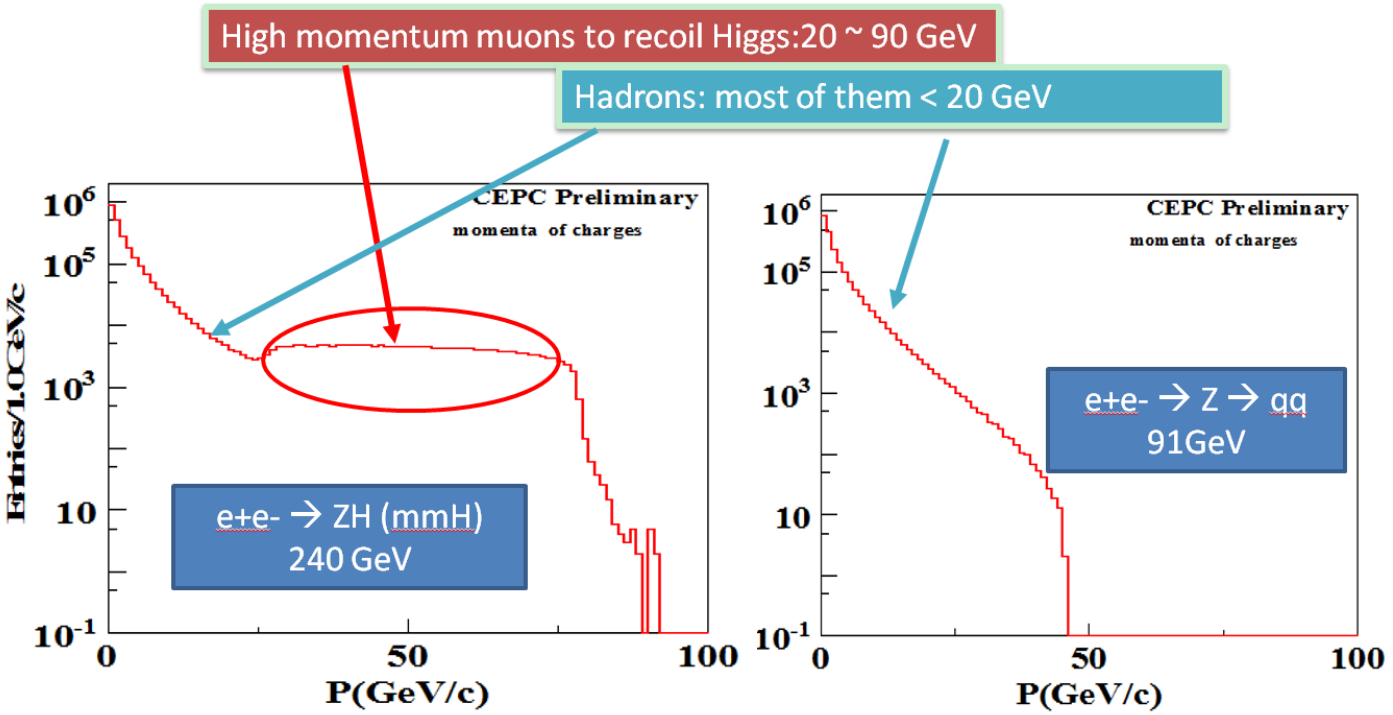
ILC



ILD TPC

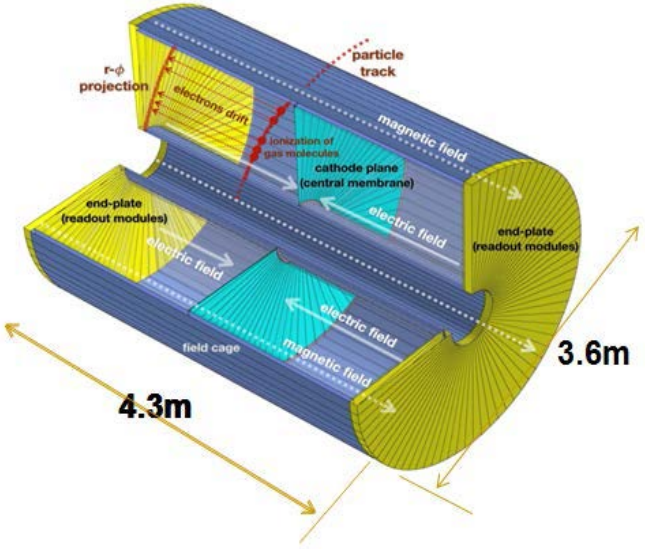
Physics requirements

- 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 ~ 2-3%
  - Essential for Flavor @ Z pole
  - Beneficial for jet & differential at higher energy



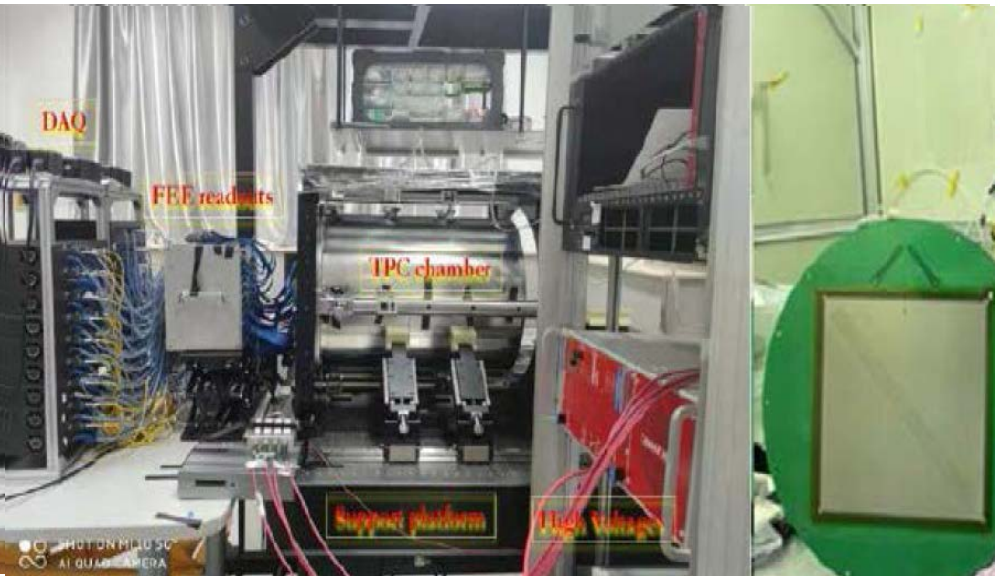
Motivation: Challenges of TPC

- **Pad readout TPC** operational at modest Lumi @ Higgs, with 3 T B-field or higher.
- **Pixelated readout TPC** operational at high Lumi (2 E36) @ Z & 2 T B-Field
  - CEPC @ Z pole with 50 MW: 1.92 E36
  - FCC ee @ Z pole 2.3 E36
- Challenges of TPC as main tracker
  - Ion distortion?
  - Material Budget? (Compatibility)
  - Total power & Readout?
  - #Hits & Intrinsic spatial resolution?



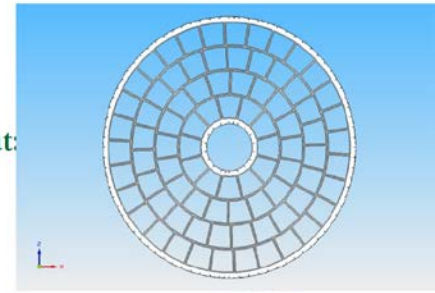
Pad TPC technology

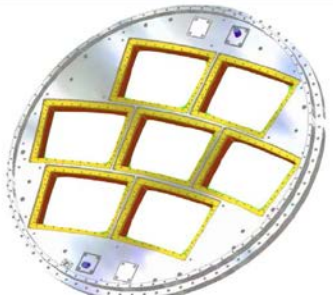
- At a circular collider CEPC there is place for different experiments, one of the detector concept could use a TPC as the main tracker.
- For Higgs, W and top running **no problem** for all TPC read out technologies.
- Laser TPC prototype has been successfully developed **in last 6 years** at IHEP.



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





Pixlated TPC technology

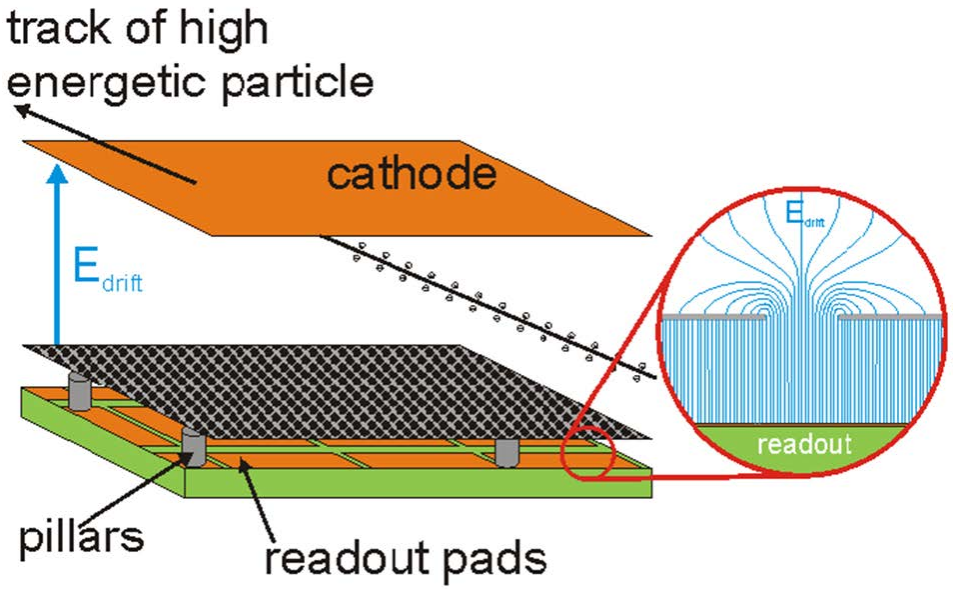
- A pixelated TPC is a good option to provide realistic physics requirements and can work at high luminosity (2 E36) on CEPC.
- Pixelated → better resolution → low gain(<2000) → less distortion
- Pixelated readout TPC is a realistic option to provide at CEPC
    - Can deal with high rates (MHz/cm^2)
    - High spatial resolution → better momentum resolution
    - dE/dx + Cluster counting (In space)
    - Excellent two tracks separation

Standard charge collection:

Pads (1mm×6mm)/ long strips

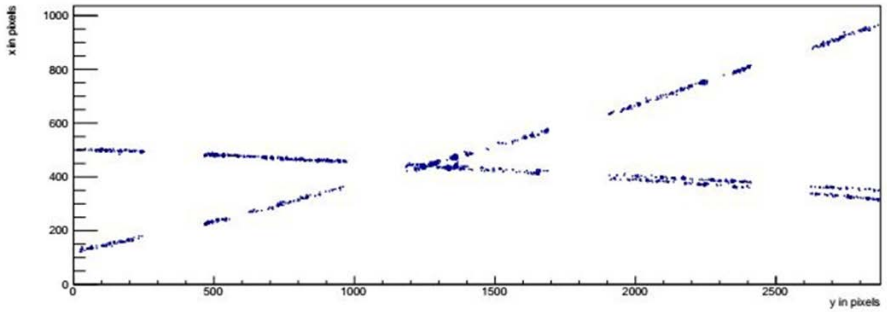
Instead:

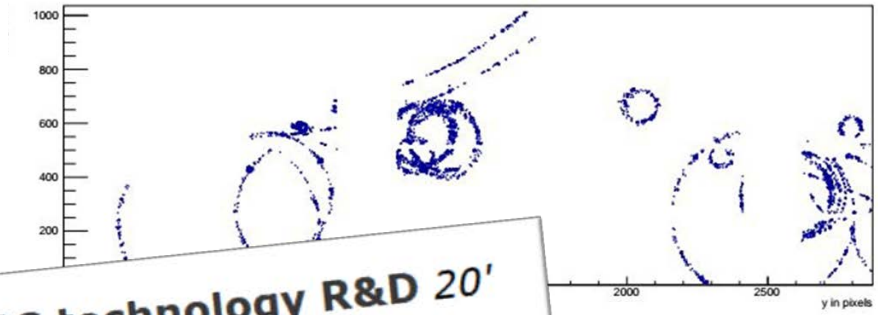
Bump bond pads are used as charge collection pads.



Highlight: Good spatial resolution

- **Good spatial resolution**
  - **Intrinsic resolution 100um → 16um**
- **Good track reconstruction**
- **Good momentum resolution**





$$\sigma_{r\phi}^{\text{pads}} = \sqrt{\sigma_{r\phi 0}^2 + \sigma_{\phi 0}^2 \sin^2(\phi_{\text{pad}}) + \frac{D_{r\phi}^2}{N_{\text{Eff}}} \sin(\theta_{\text{pad}}) \left(\frac{6\text{ mm}}{h_{\text{pad}}}\right) \left(\frac{2.0\text{ T}}{B}\right)^2 L}$$

$$\sigma_{r\phi}^{\text{pixels}} = \sqrt{\sigma_{r\phi 0}^2 + D_{r\phi}^2 \left(\frac{2.0\text{ T}}{B}\right)^2 L}$$

$$\sigma_z = \sqrt{\sigma_{z0}^2 + D_z^2 L}$$

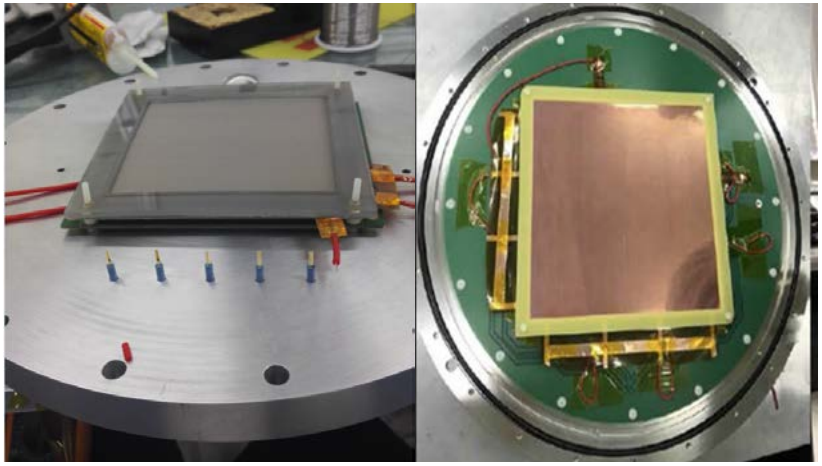
16:40 **Upate pixelated TPC technology R&D** *20'*
Speaker: Peter Kluit (N)

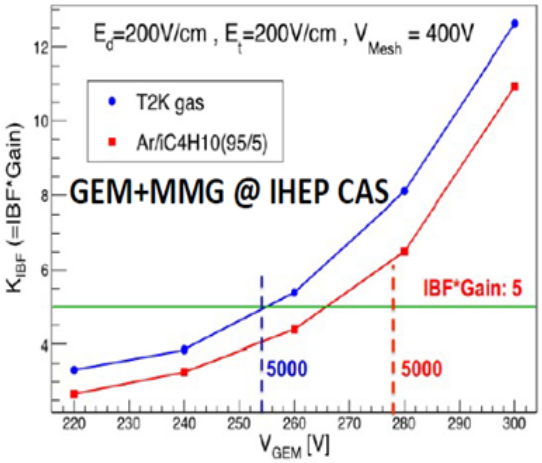
Intrinsic resolution	Pad TPC (1mm×6mm)	Pixel TPC (55um×55um)
$\sigma_{r\varphi 0}$	100um	16um
$\#\mathrm{Hits/track}$	~220	~28k
$Gain$	5000	2000

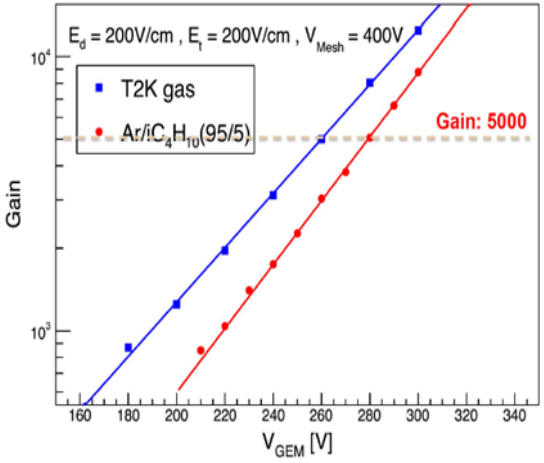
- **Status of TPC detector R&D at IHEP**
    1. **TPC detector module with the ions suppression**
    2. **Status of TPC prototype using UV laser**

#1. TPC detector module R&D

- Studies have been done using the different active area of the hybrid TPC detector modules
  - Active area: from 50mm×50mm to 200mm×200mm
  - 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



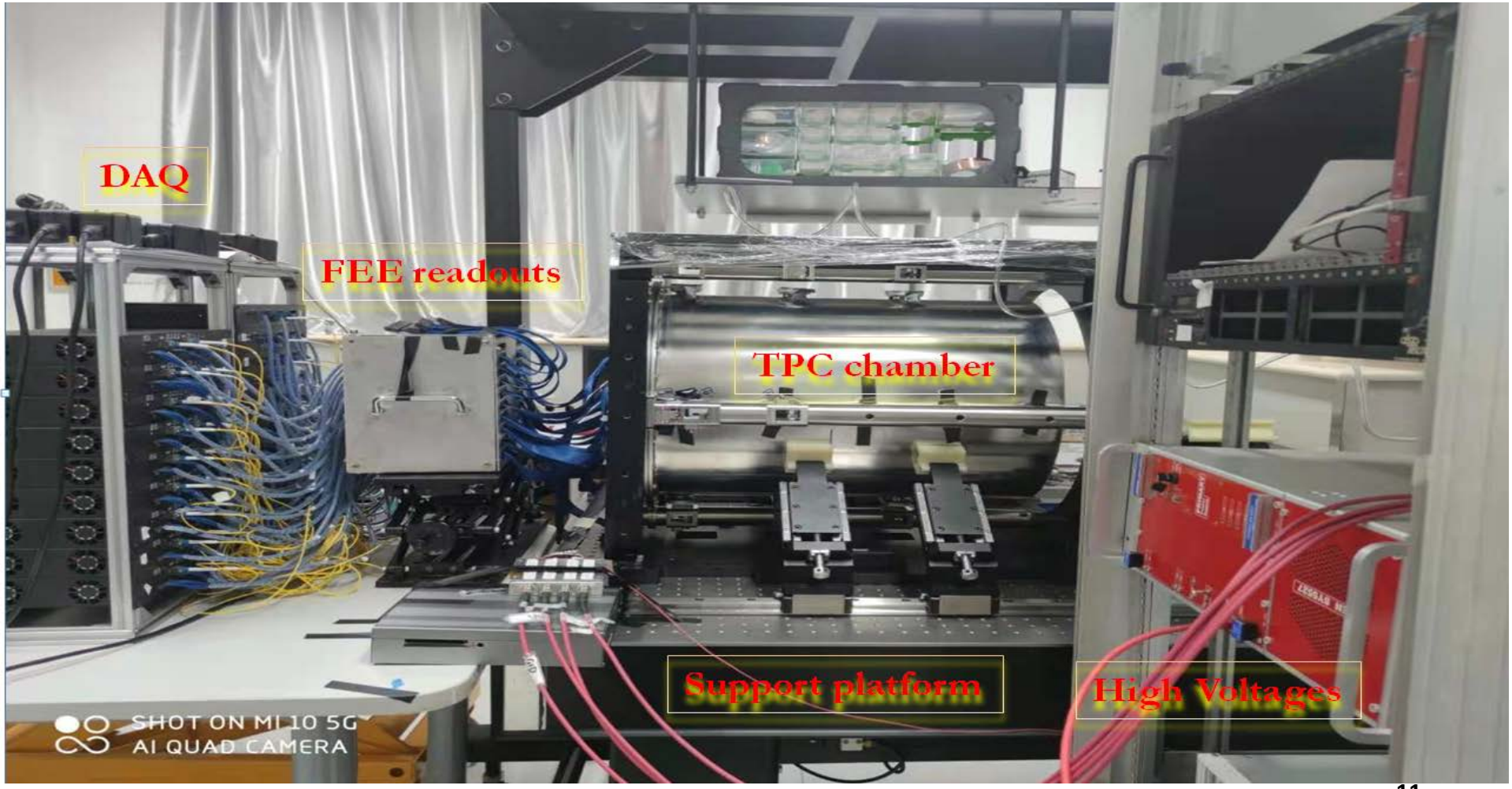




Results of different sizes of the hybrid TPC detector modules

#2. TPC prototype R&D

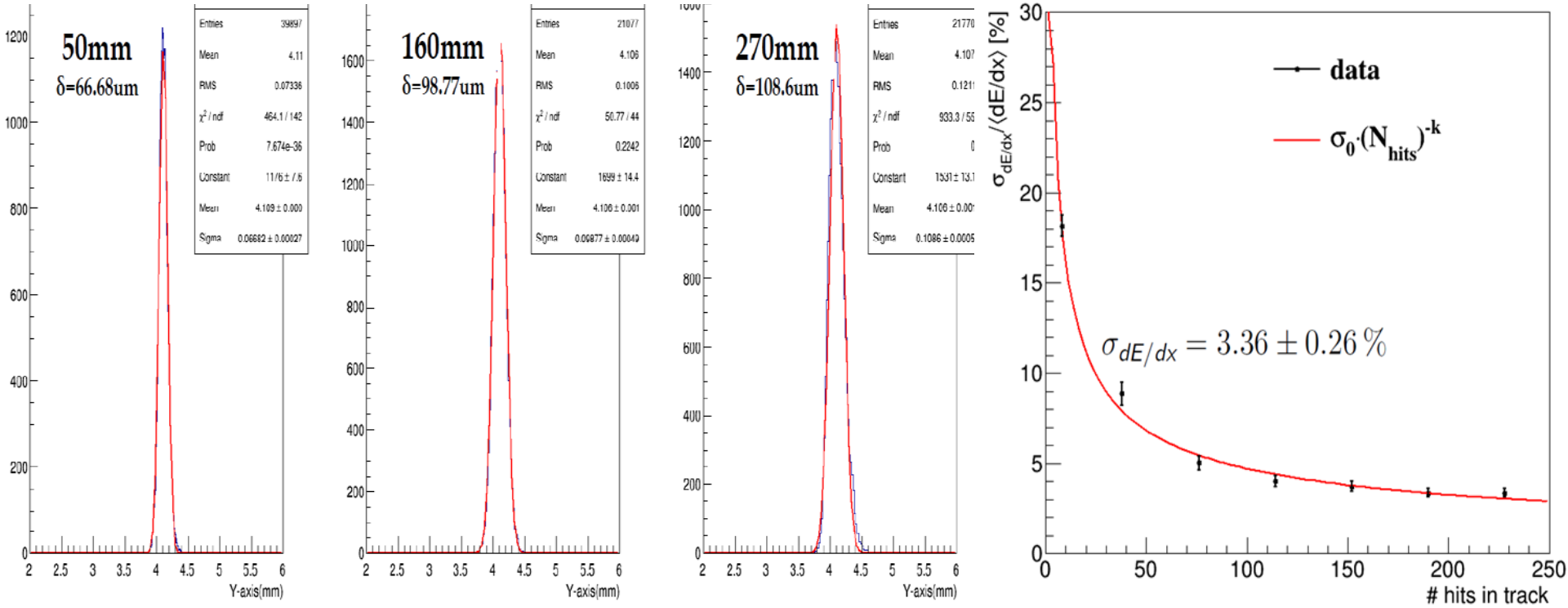
- Successfully to develop the TPC prototype integrated 42 UV laser tracks
- Spatial resolution, dE/dx resolution achieved with the pseudo-tracks (DONE)



TPC prototype R&D using 266nm UV laser tracks

#3. TPC prototype R&D

- Spatial resolution can reach to about 100um 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%

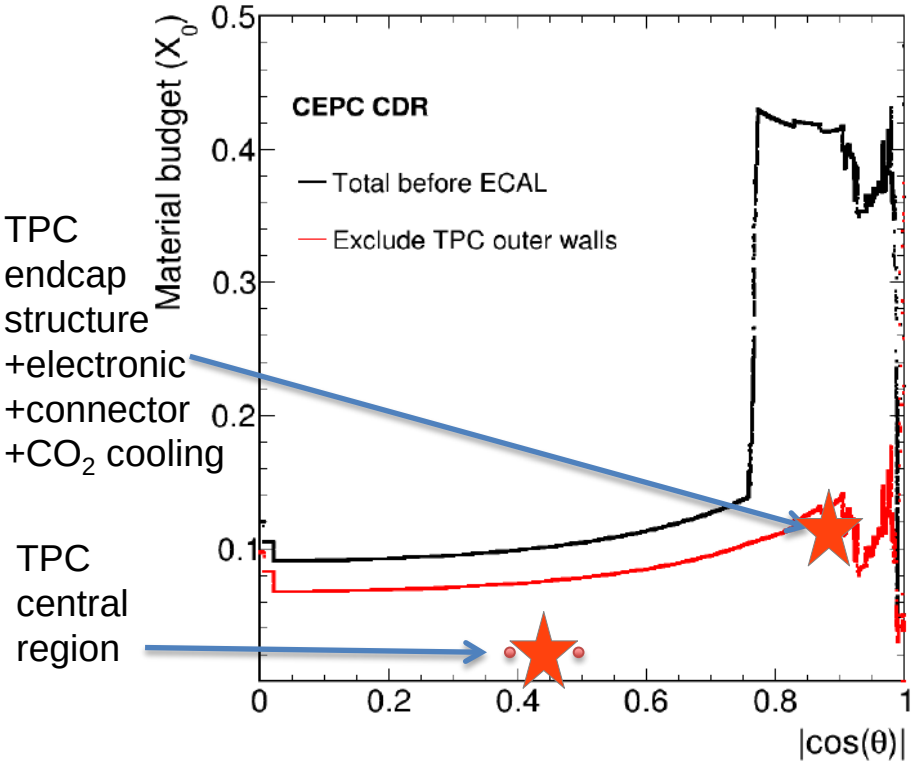


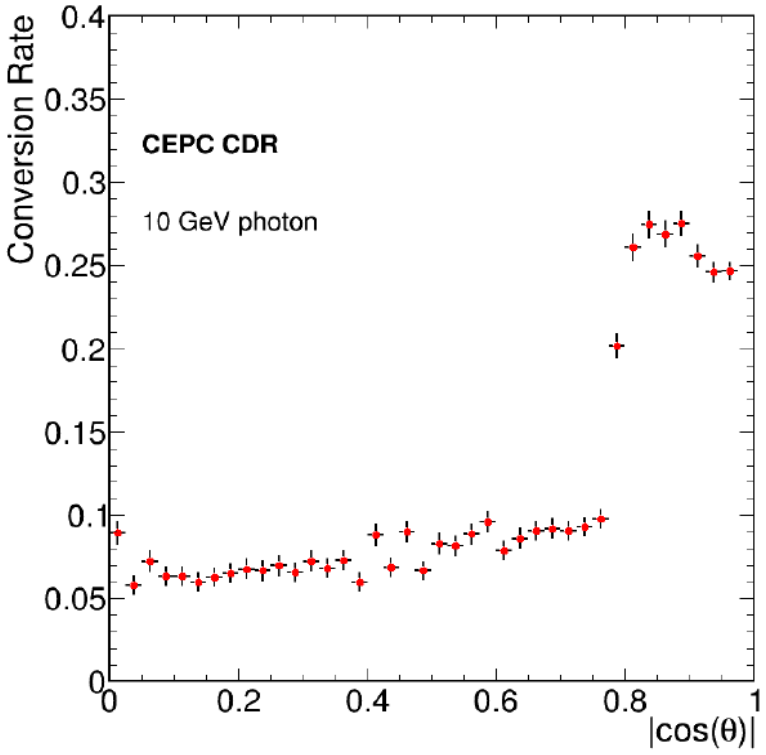
Results of the spatial resolution and dE/dx

- **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, 0.4X_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





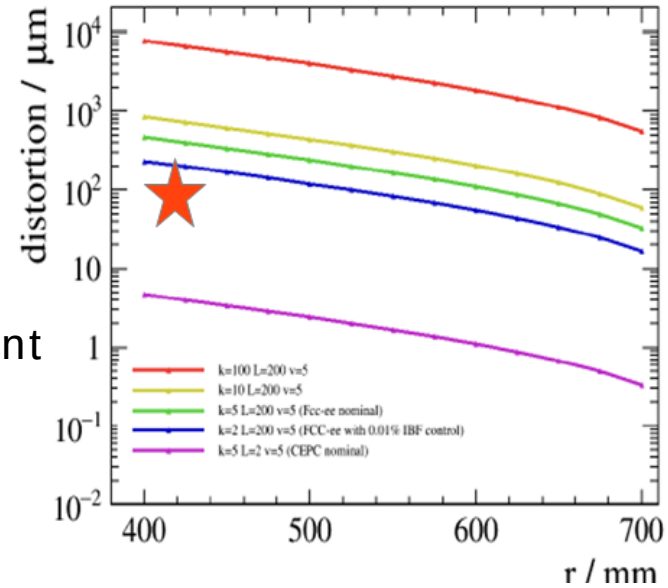
#2. Ions affect and distortion

- 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 ~ 2E36
  - Hit from Physics event only
  - Distortion ~ 100 micrometer ~ 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->mumu event (cite#2)

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

    ==> MDI, Beam background

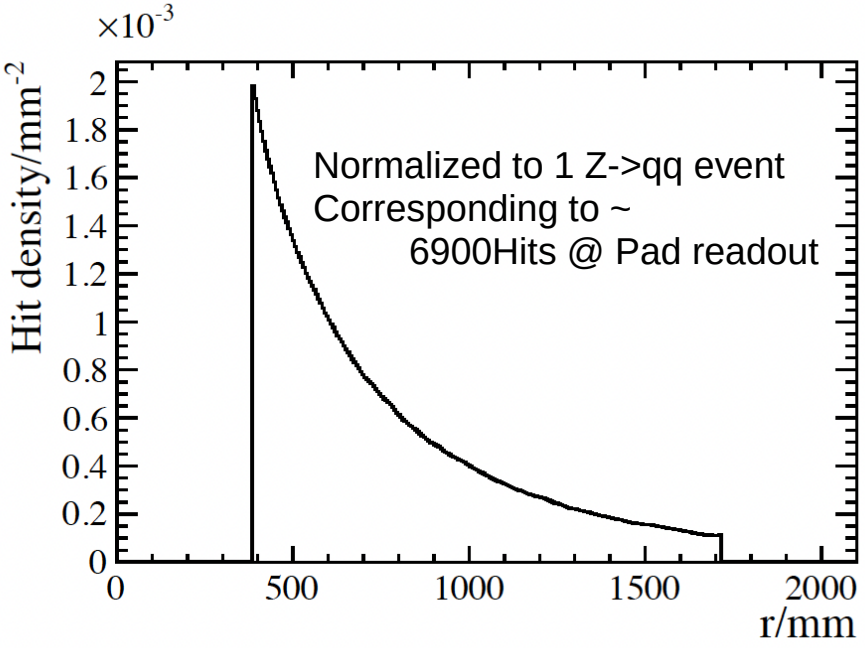


New strategy and task in LCTPC now

- 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 : 1E-5 to 1E-6 (cite#3)
- At 2 E36 with Physics event only, even bunch distribution(cite#4).
  - Pad readout (1mm×6mm), inner most occupancy 1 E-4
  - Pixelated readout (55um×55um), much **LOWER** inner most occupancy ~ 1 E-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.

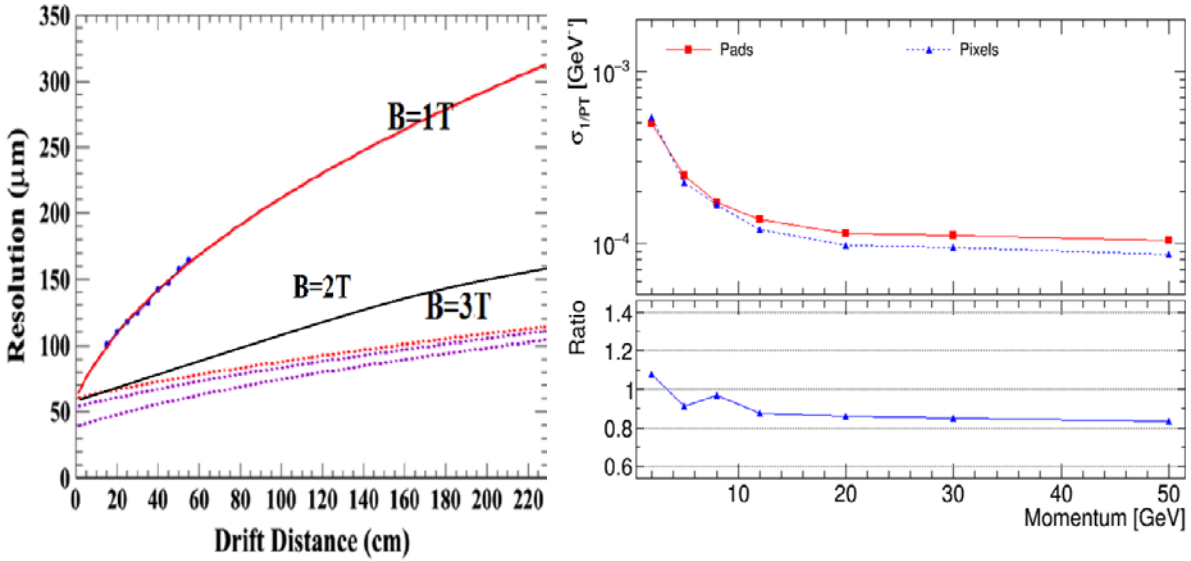


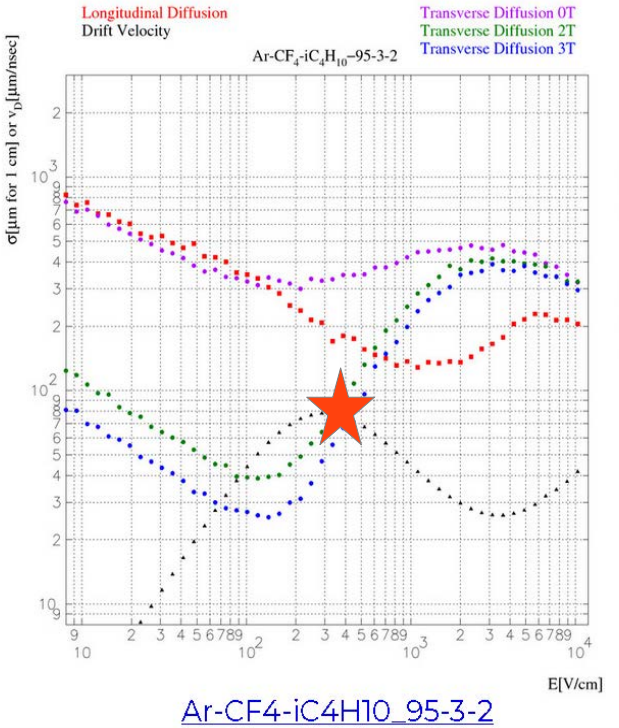
➡ **Marlin TPC software package**

- 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.
  - 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

- **Feasibility of pixelated readout TPC**
  - **Material budget of endplate/barrel √**
  - **Occupancy √**
  - **Running at 2 Tesla √**
  - **Ions affect and distortion √ (need more R&D)**

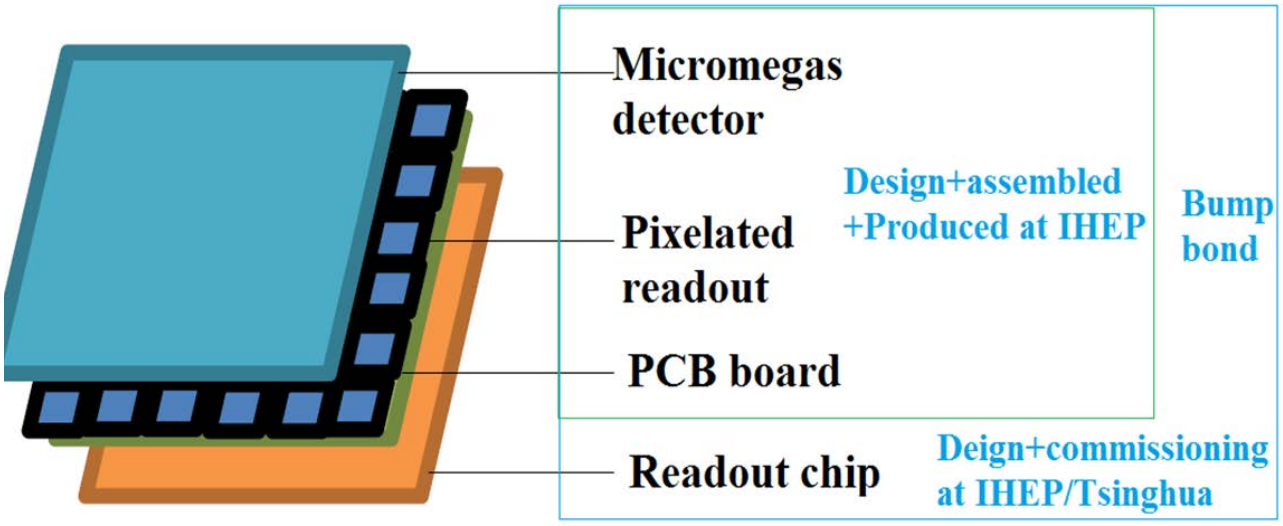
Prototype R&D plan

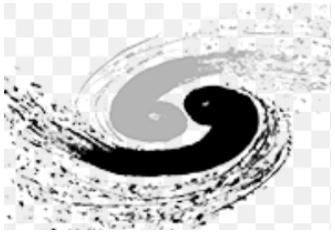
- **Advantage and realized R&D**
  - **Prototype R&D plan**
  - **Improved dE/dx**
  - **Optimization of cluster/pixel size**

Prototype plan #1

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

Bump bond pixelated readout with Micromegas detector	Module size	To be addressed by R&D
• ≥300um×300um • 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 '$dE/dx+dN_{cl}/dx$'

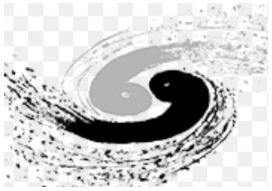




Tsinghua University
University

Prototype plan #2

- **Realization of pixelated technology using GridPix chip collaborated Bonn**
  - **110um×110um and smaller**
  - Design the different readout pixelated size
  - Collaborated with Bonn University to produce the new prototype (Peter, Jan and Jochen from Bonn)
  - Study using UV laser tracks

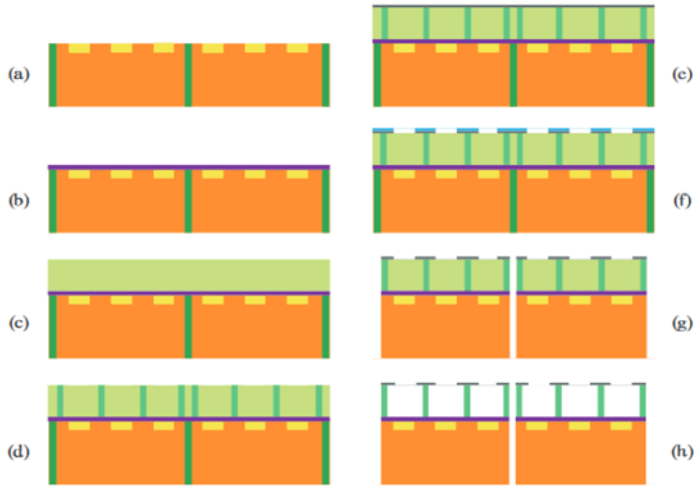


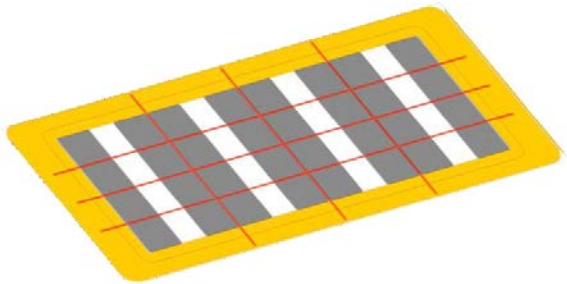
University of Bonn

University

Production of GridPixes

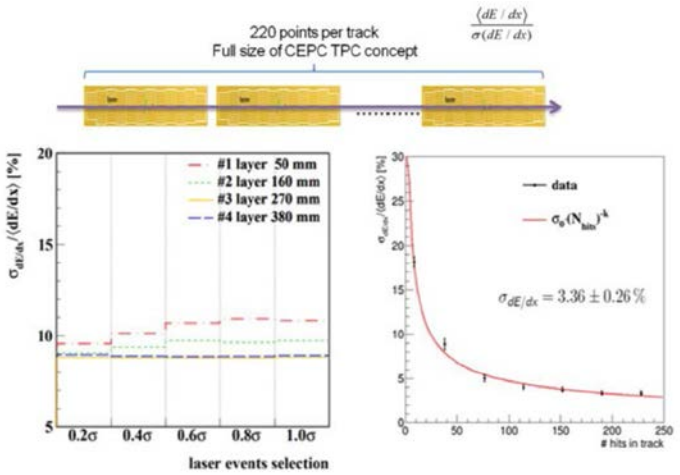
a) Cleaning
b) Deposition of Protection layer
c) SU-8 covering
d) Exposure with mask
e) Aluminium layer is deposited
f) Another layer of photoresist is applied, exposer with a mask creates a hole pattern, and the holes are chemically etched
g) The wafer is diced
h) The unexposed SU-8 is resolved



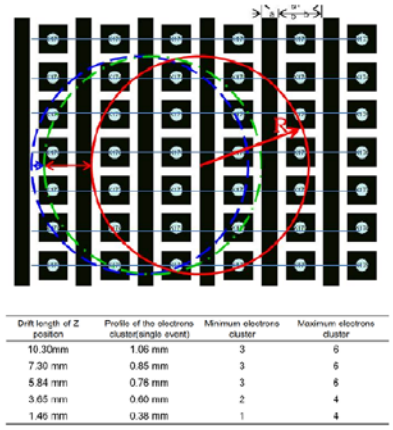


Study the cluster/pixel size

- **R&D plan will mainly focus on making pixelated TPC work**
- **Using the existing UV laser TPC prototype**
- **Some key issues R&D**
  - **– improve the laser track resolution and cluster size**
  - **– improved dE/dx to 2-3% level (TOA+TOT methods)**
    - Pixel size:(300μm or similar level size)
    - Micromegas + WASA ASIC Chips (Gain: 40mv/fC)
    - Almost without IBF (Gain< 2000)

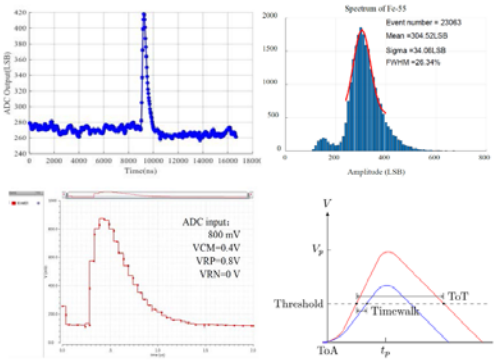


Resuls of the laser TPC prototype



Drift length of Z position	Profile of the electrons cluster(single event)	Minimum electrons cluster	Maximum electrons cluster
10.30mm	1.06 mm	3	6
7.30 mm	0.85 mm	3	6
5.84 mm	0.78 mm	3	6
3.65 mm	0.60 mm	2	4
1.46 mm	0.38 mm	1	4

Electron cluster profile



10bit TOT + 12bit TOA

dE/dx along drift length

dE/dx + dN_{cl}/dx

Summary

- Pad readout TPC can operate @ CEPC W/Higgs operation, with 3 T B-field or higher.
  - 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 E36) @ Z with 2 T B-Field is challenge for gaseous.
  - Material budget, construction cost, power & cooling, Occupancy is OK.
  - Further study is needed to better understand the Distortion (induced by ion charge) and beam background:
    - Geometry Optimization
    - Distortion correction & in-situ calibration
    - Beam background validation & simulation
- Pixelated readout TPC is promising, compared to Pad readout:
    - Much Lower Occupancy;
    - Lower Ion backflow;
    - High Precision;
    - 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)
- Good International/domestic Partners: LCTPC, CEA-Saclay, NIKHEF, Tsinghua…
  - And, any collaboration will be welcome

Many Thanks