Update results of TPC module and prototype for CEPC

Huirong Qi

ZhiYang Yuan, Yue Chang, Jian Zhang, Liwen Yu, Zhi Deng, Yulan Li, Hui Gong, Wei Liu

Institute of High Energy Physics, CAS

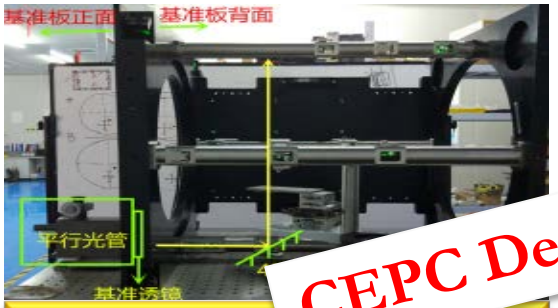
Tsinghua University

CEPC Day, August, 30, 2021

Outline

- Update of pixel TPC
- Analysis of prototype
- Status of collaboration
- Summary

Motivation for the pixelised TPC



Pad TPC Prototype
at IHEP 2015-2020

CEPC Det.&Phy., June, 7, 2021

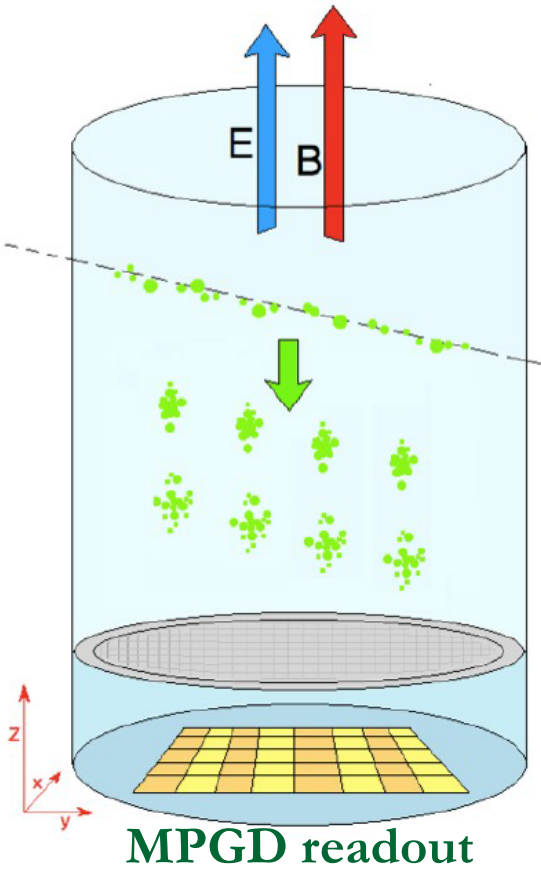
R&D

- 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 concept

Operating principle of TPC

electric field and magnetic field are applied in parallel in the TPC



MPGD readout

A charged particle ionizes the atoms of the gas mixture along its trajectory

The liberated electrons drift in the E-field towards the readout pad

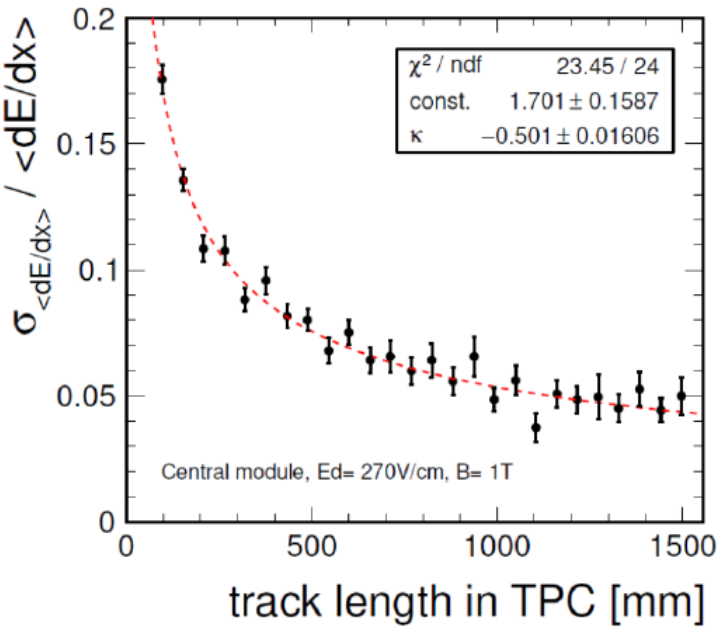
gas-amplified and read as signal
⇨ 2-dimensional (x,y) information

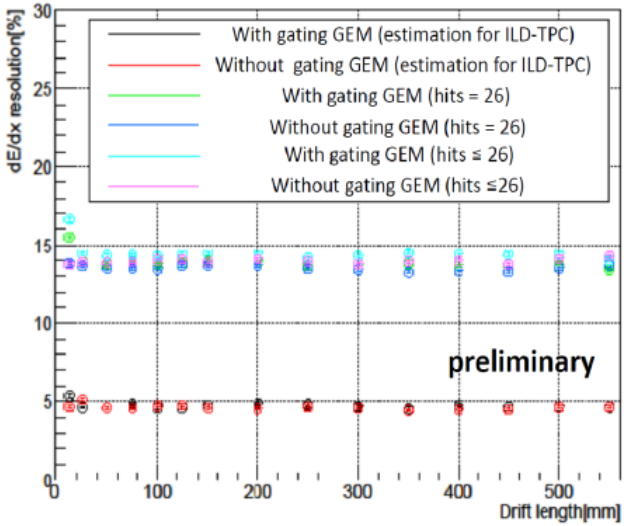
z component is obtained from drift time ⇨ 3-dimensional (x, y, z) information

Pad TPC

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

Jochen@ILD meeting

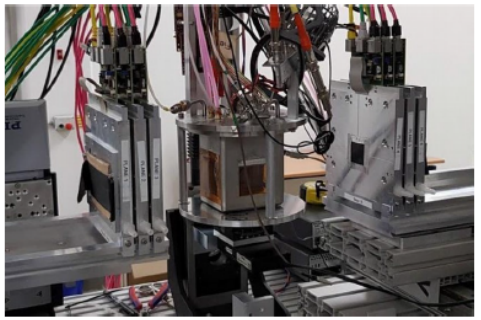




e average of dE/dx resolution expected from the ILD-TPC is 4.70 ± 0.02% (4.61±0.02%)
:h (without) the gating GEM.

- 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

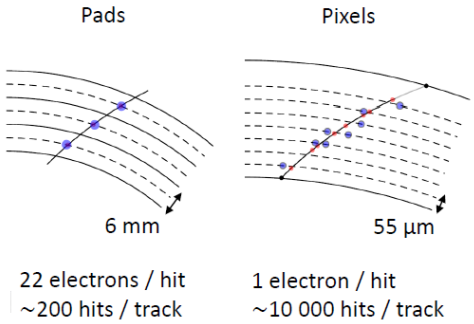
$$\mu' = \frac{1}{N_{\text{hits}}} \sum_{i=0}^{N_{\text{hits}}} w(d_i) d_i,$$

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

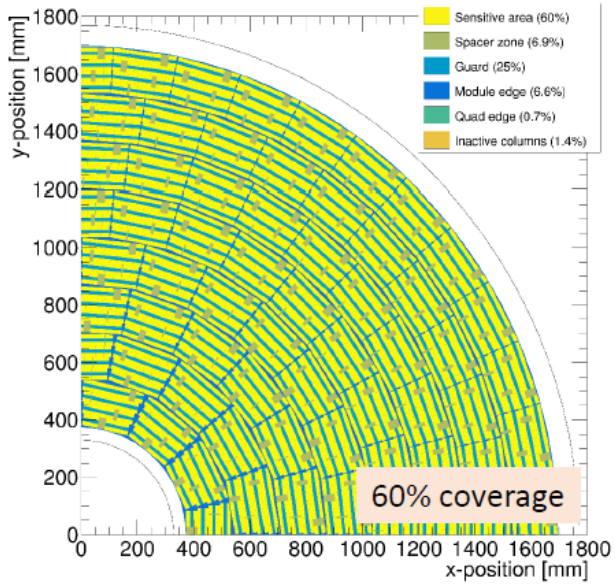
https://arxiv.org/abs/1902.01987

Simulation of TPC with pixel readout

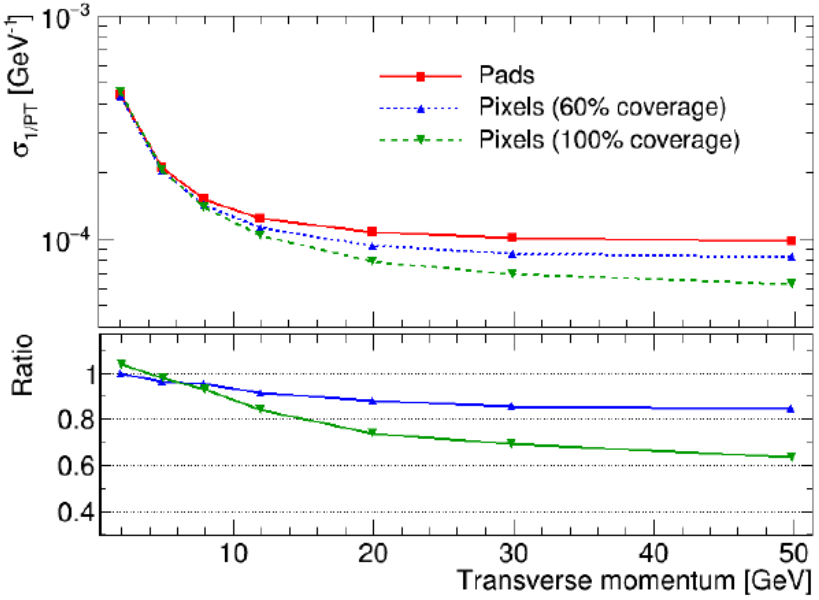
- To study the performance of a large pixelized TPC, the pixel readout was implemented in the full ILD DD4HEP (Geant4) simulation
- Changed the existing TPC pad readout to a pixel readout
- Adapted Kalman filter track reconstruction to pixels
- From full simulation, momentum resolution can be determined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



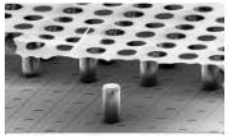
Realistic tiling with quad module



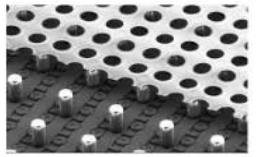
Momentum resolution of the TPC for a simulated muon

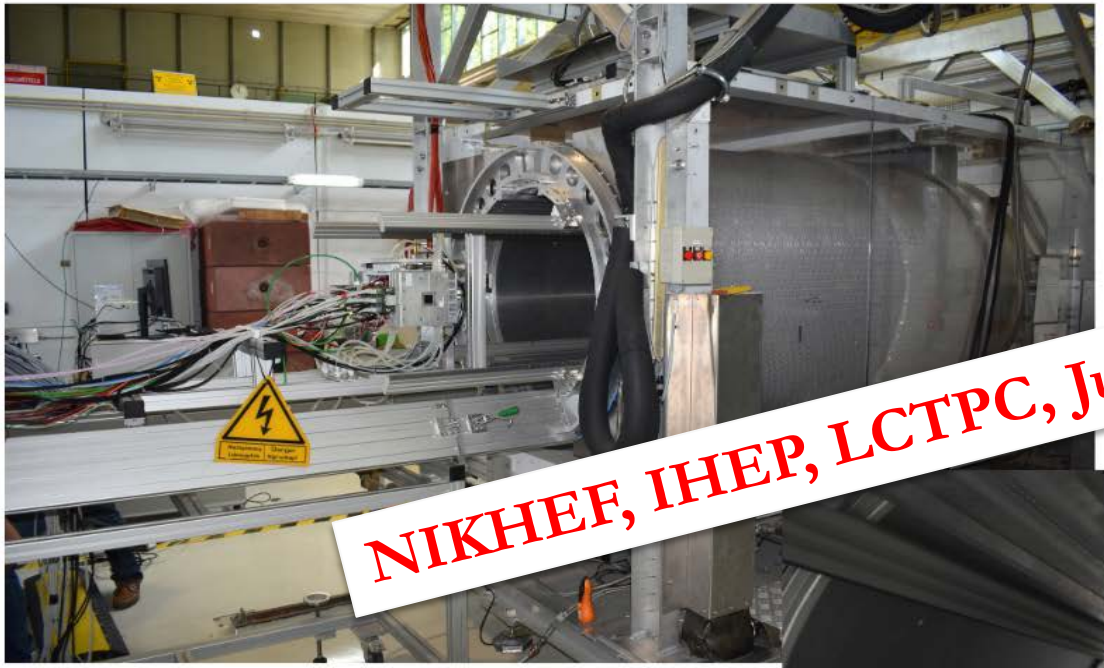


Beam test of the pixel TPC@LCTPC



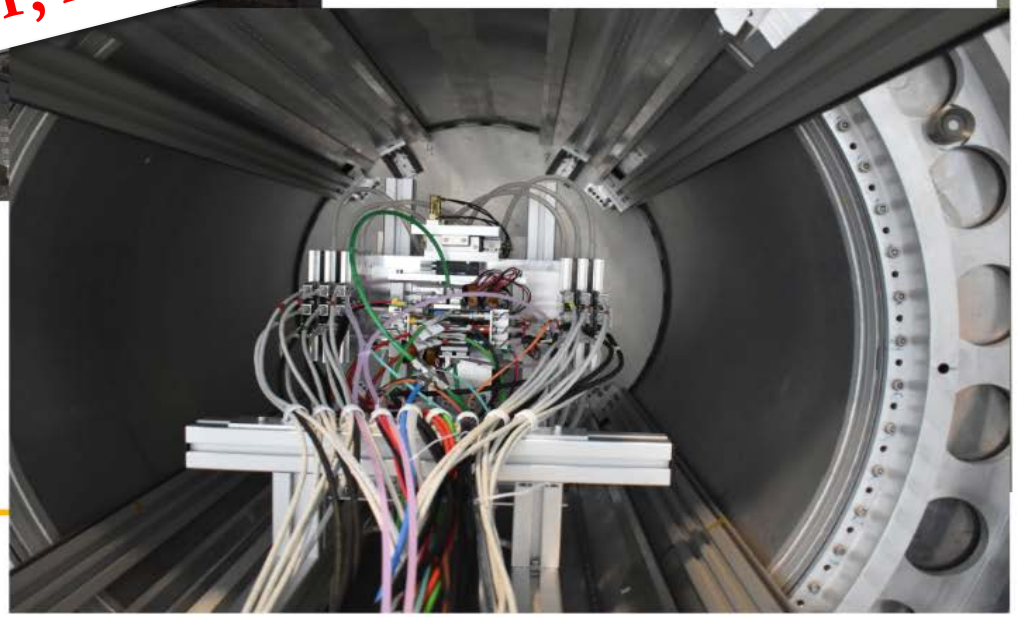
Setup in PCMAG





It was pushed into the magnet.

NIKHEF, IHEP, LCTPC, June, 28, 2021



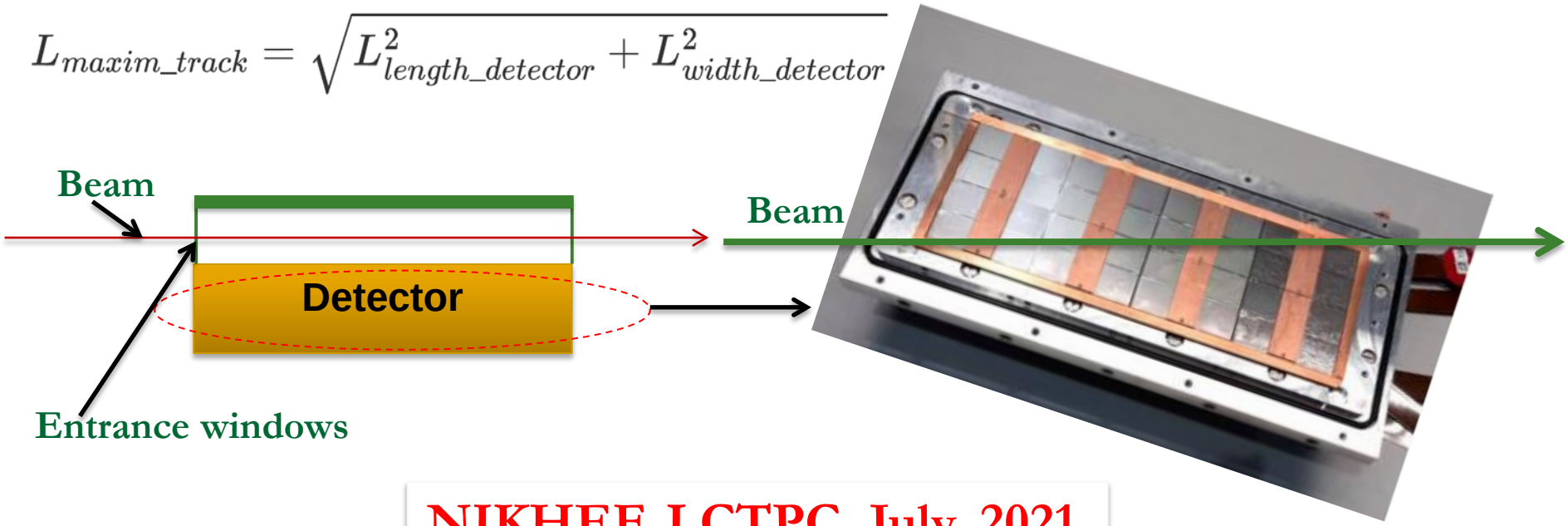
After some problems with HV lines, everything worked fine.

Started productive data taking on Sunday.

Pixel TPC@LCTPC

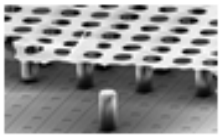
- 32 chip quad module in the gas envelop
- Entrance windows are 50μm kapton
- The setup at DESY includes a MIMOSA silicon telescope with 2×3 planes

$$L_{maxim\_track} = \sqrt{L^2_{length\_detector} + L^2_{width\_detector}}$$

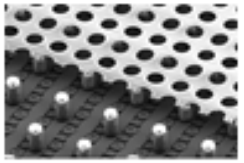


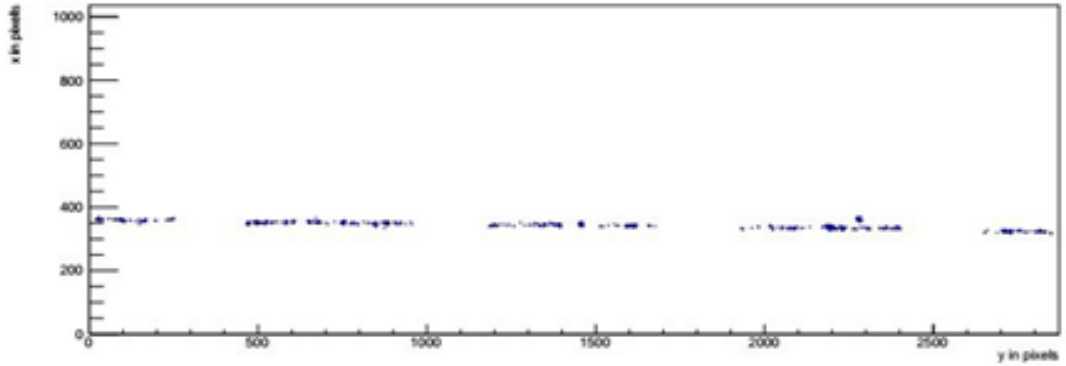
NIKHEF, LCTPC, July, 2021

Beam test of the pixel TPC

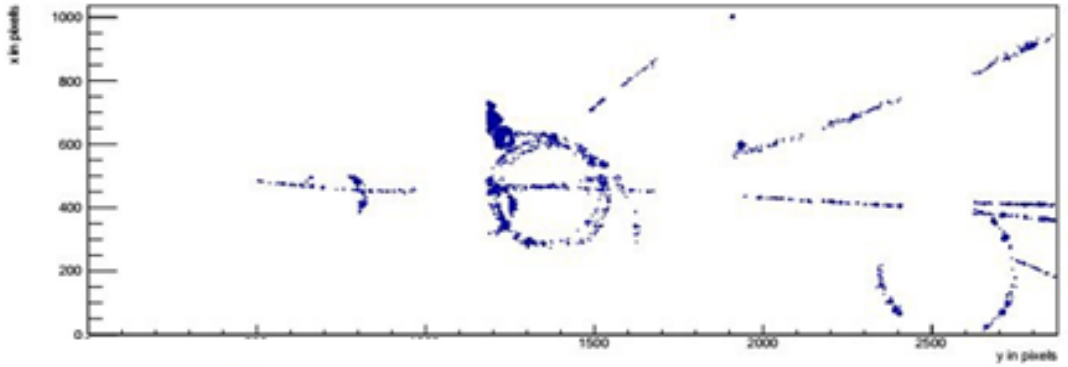


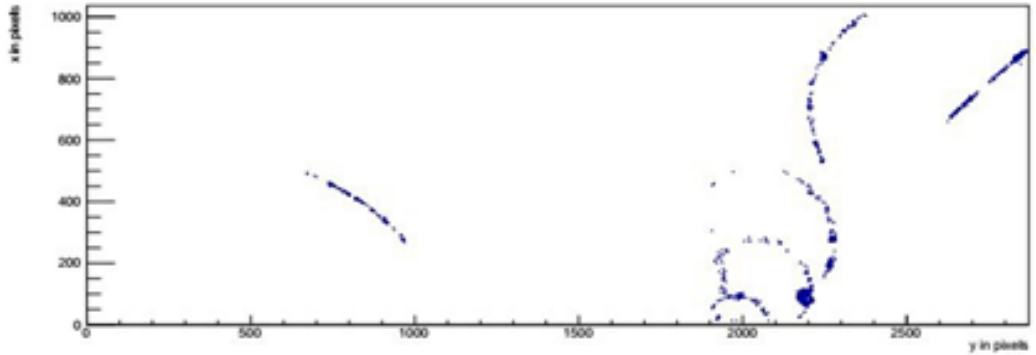
Event Pictures at B = 0.5 T



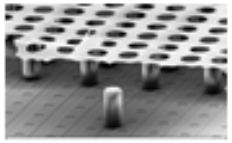


Tracks at
Drift d = 0.5-1.5 cm
Gain 2130
T2K gas
B =0.5 T
p = 6 GeV/c

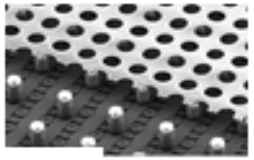


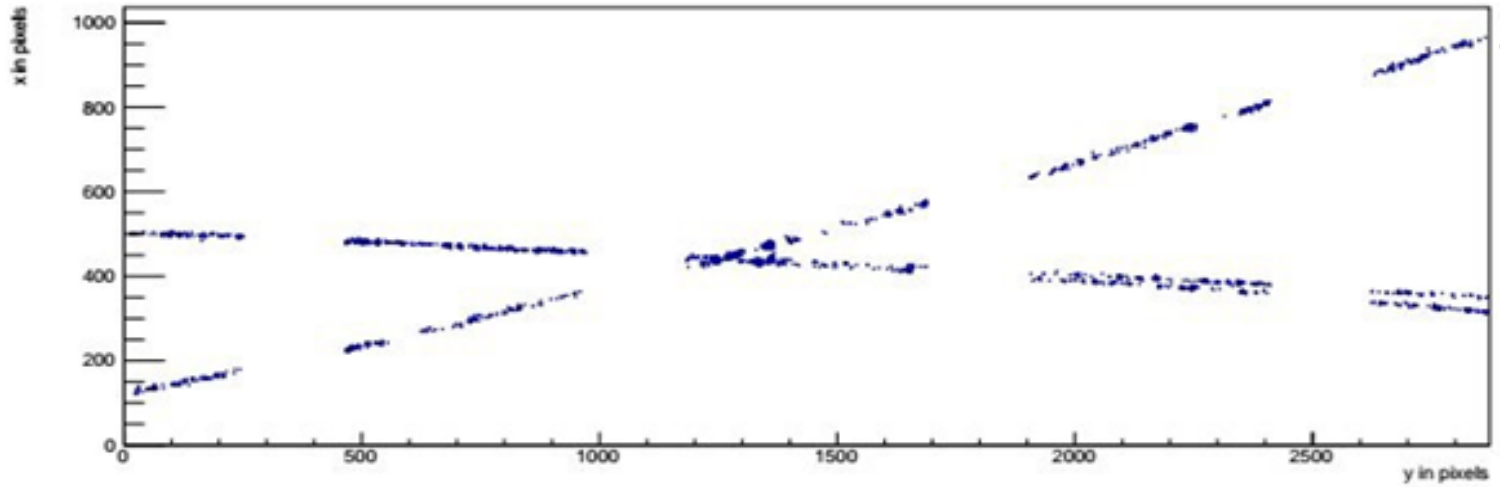


Beam test of the pixel TPC

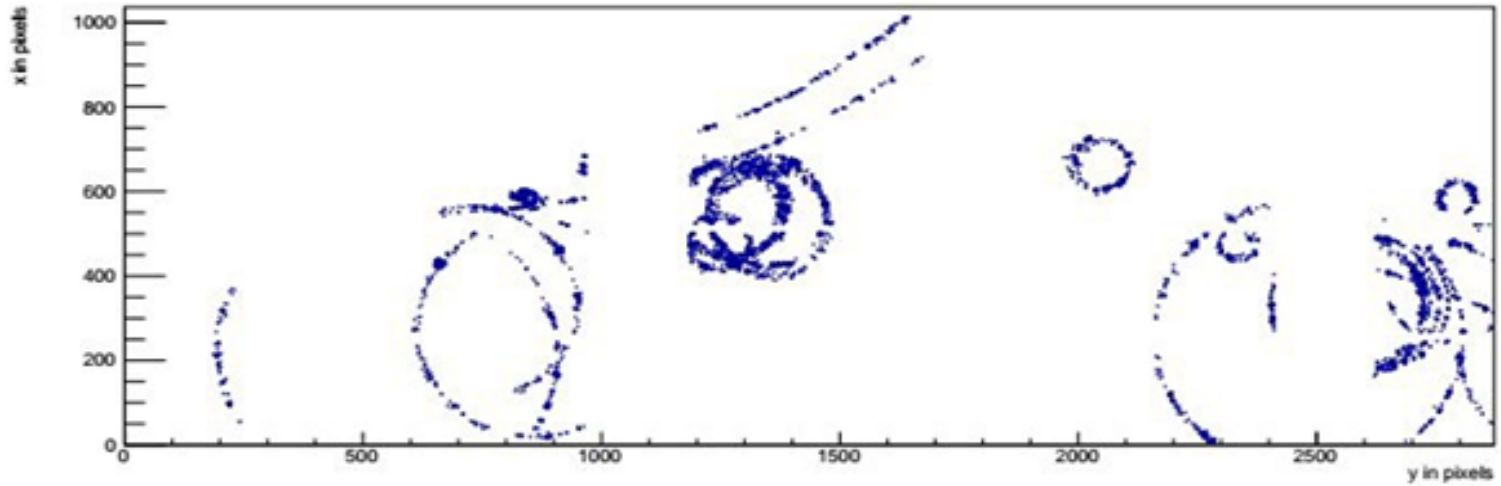


Event Pictures at B = 1 T



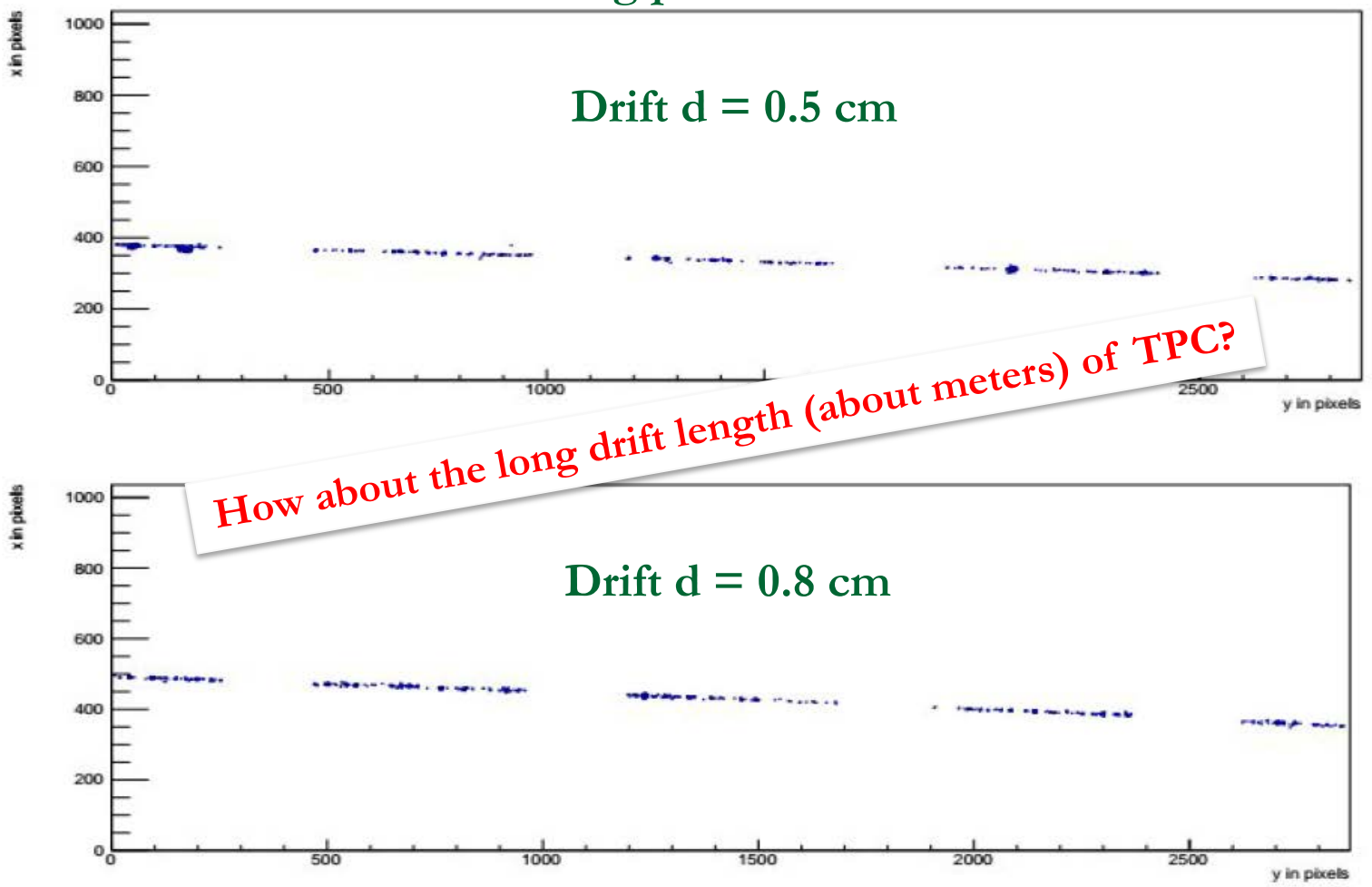


Tracks at
Drift d=1.5cm
Gain 2130
T2K gas
B =1.0T
p = 6 GeV/c



Beam test of the pixel TPC

Event Pictures using pixel readout at B = 1 T

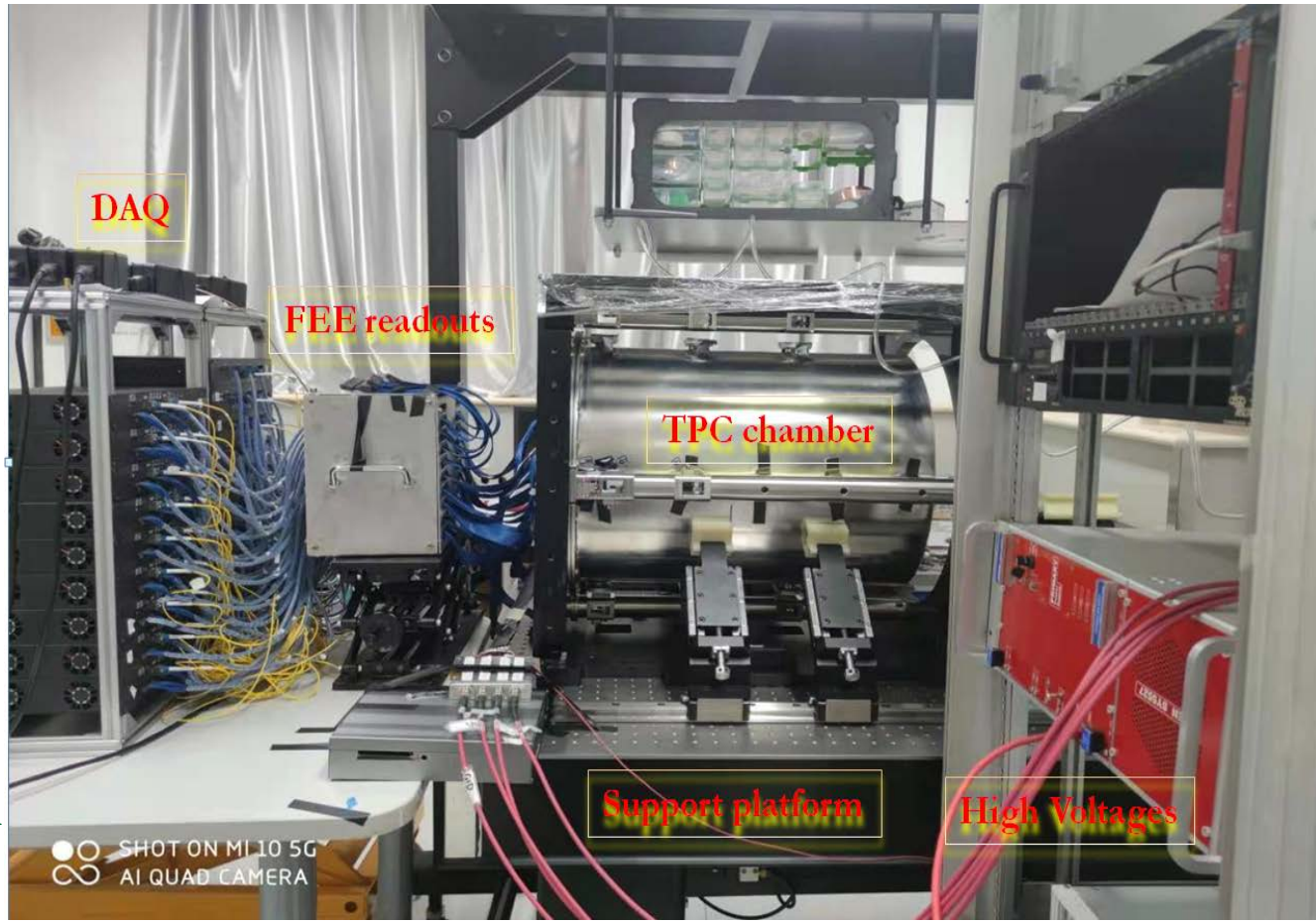


- Some interesting events reconstruction, which can either not be seen by pads or which are usually nor recorded
- Analyzing on going (dE/dx, Time walk correction…)

- TPC prototype and analysis

Status of TPC prototype

- Based on this prototype and analysis of the electrons cluster size at the readout pads
- Data taking and more analysis
- Commissioning:
  Huirong Qi, Zhiyang Yuan, Yiming Cai, Yue Chang, Jiang Zhang, Yulan Li, Zhi Deng

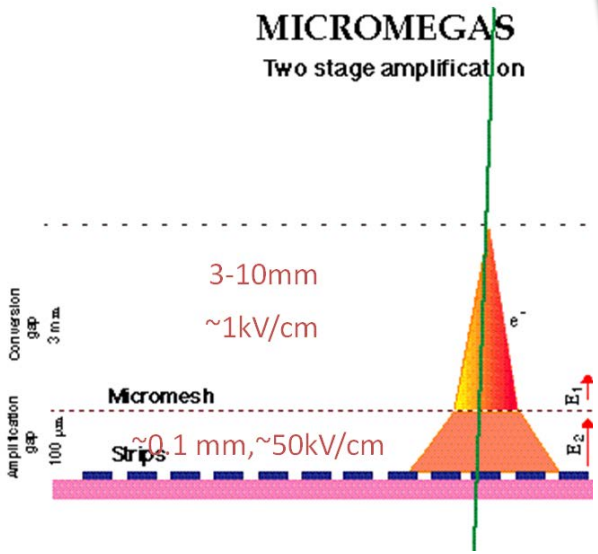


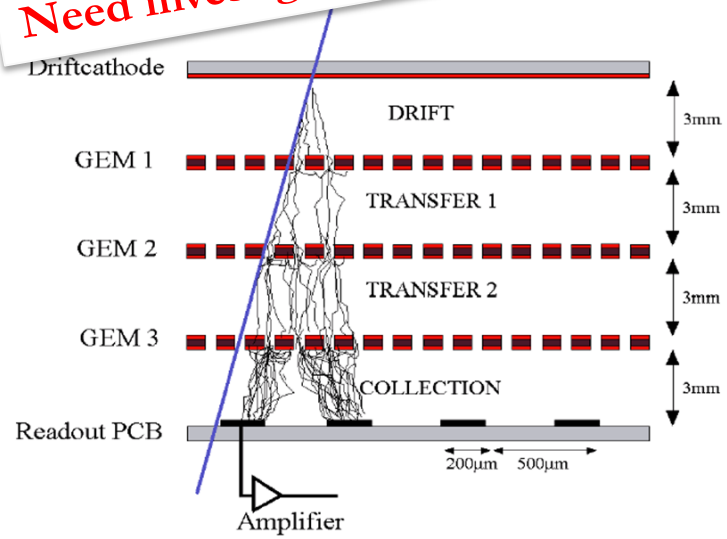
TPC prototype in the lab

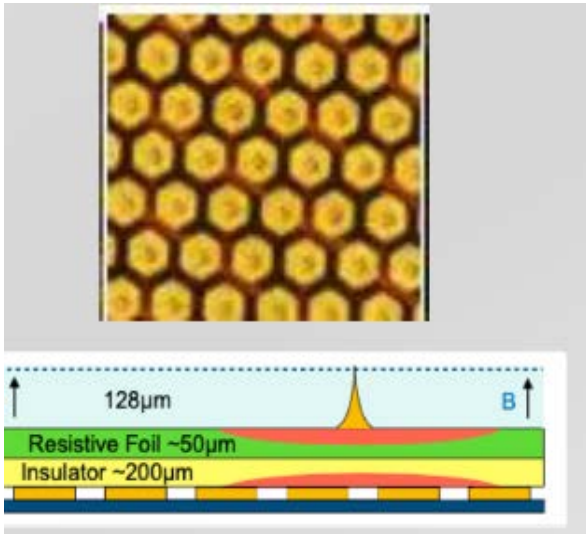
Electrons cluster profile to reach at the readout pad

- High magnetic field
  - Reduce the diffusion along the drift length
  - Cluster size limited to the pixel readout

Need investigation and analysis







Standard GEM and Micromegas

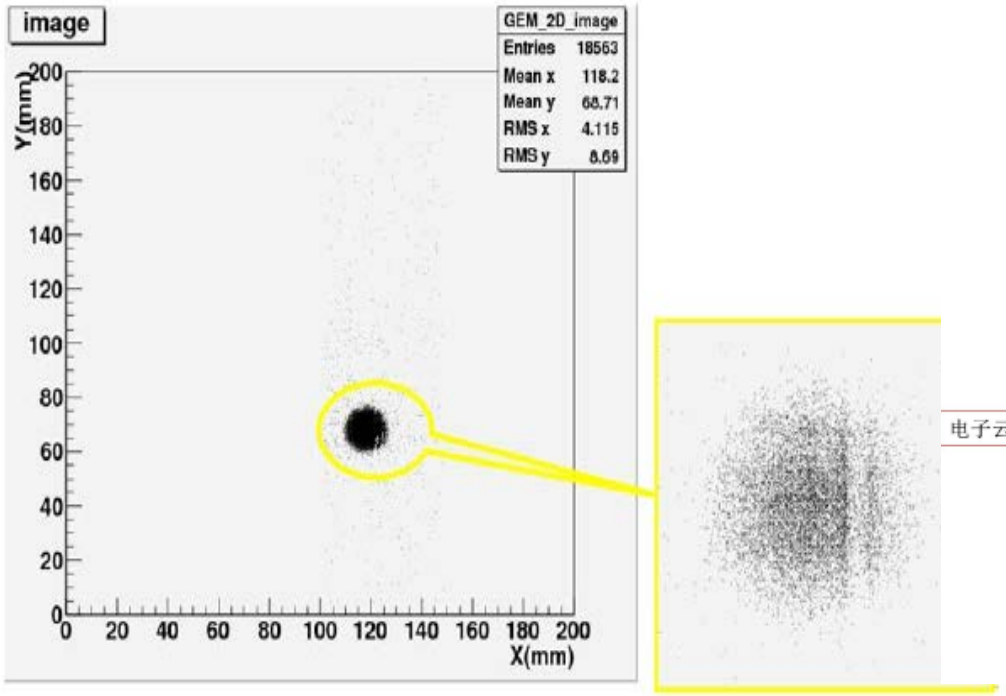
- Higher rate and position resolution
- Discharge near to readout pad

Standard resistive Micromegs

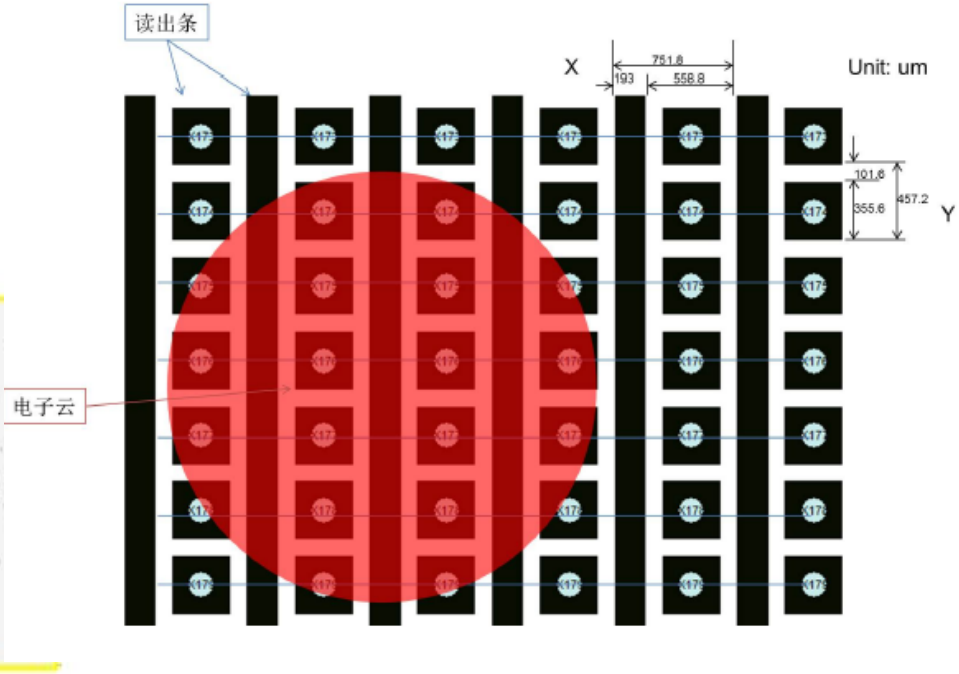
- Not reach to higher rate
- No Discharge near to readout pad

Our triple GEM's results (previous)

- 2D detector module of Triple GEMs in 2015
- Investigation of single event's electrons cluster at the readout pads
- Drift length: 14mm (only this parameter)



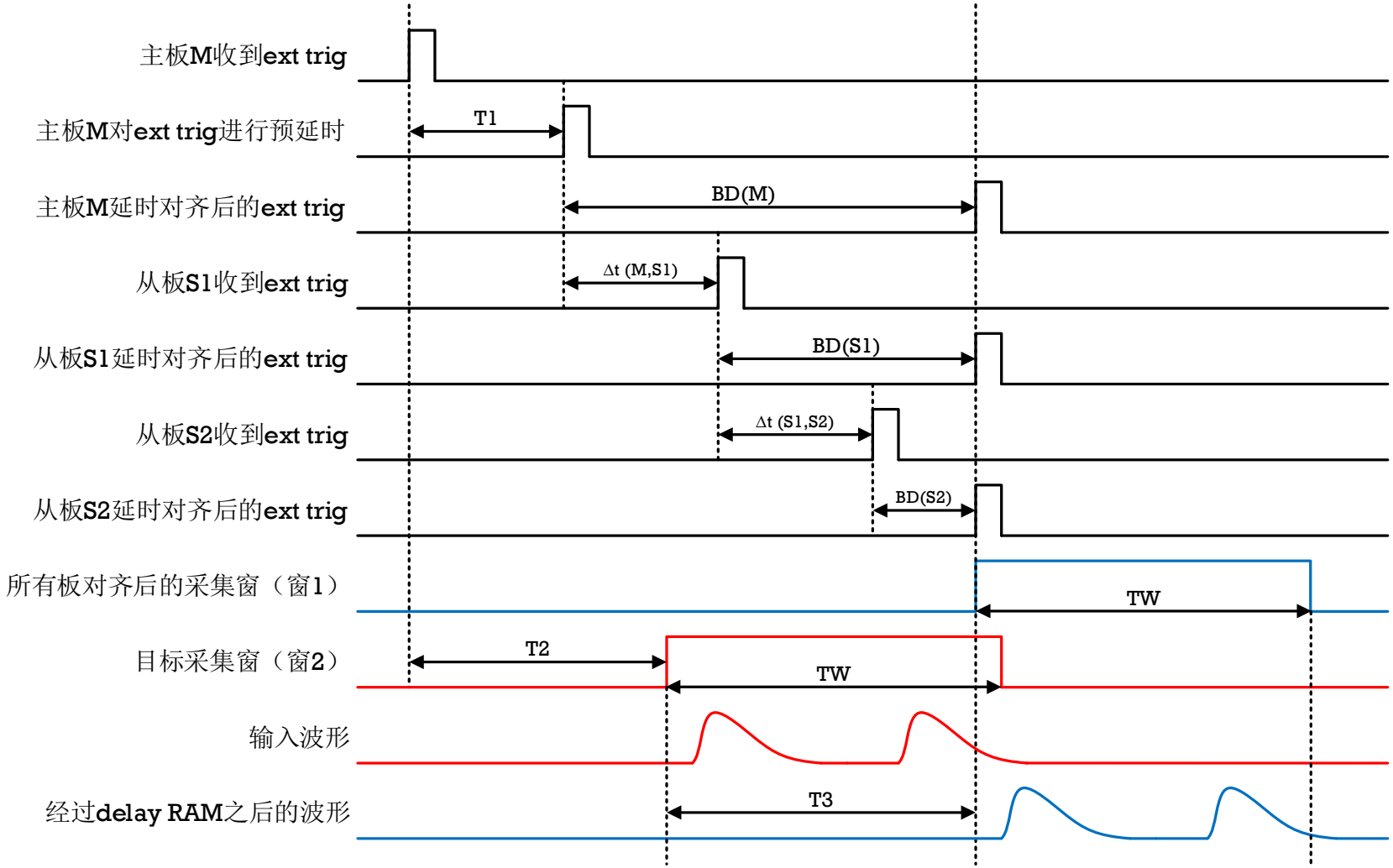
2D profile of ^{55}Fe
With Ø5.0mm collimator



2D profile of the electrons cluster size at the readout pads

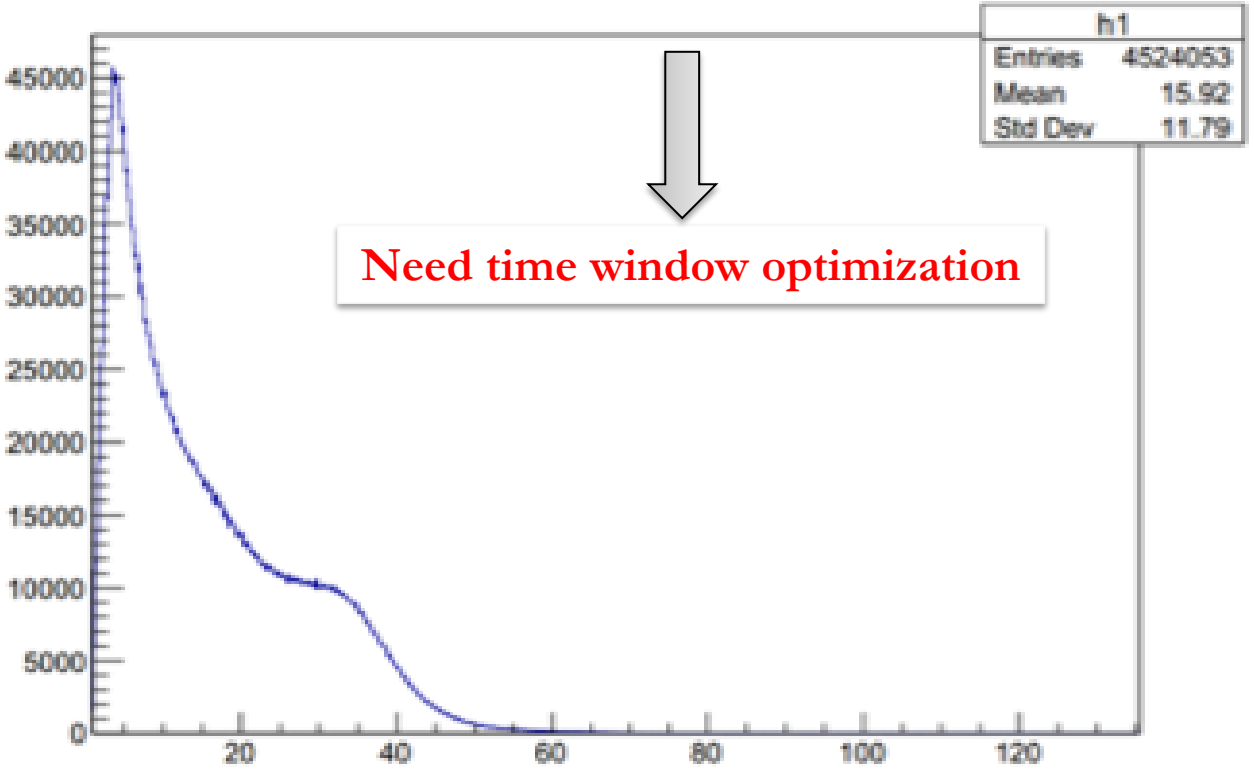
Calibration of ^{55}Fe

- Time window of self-trigger



Calibration of ^{55}Fe

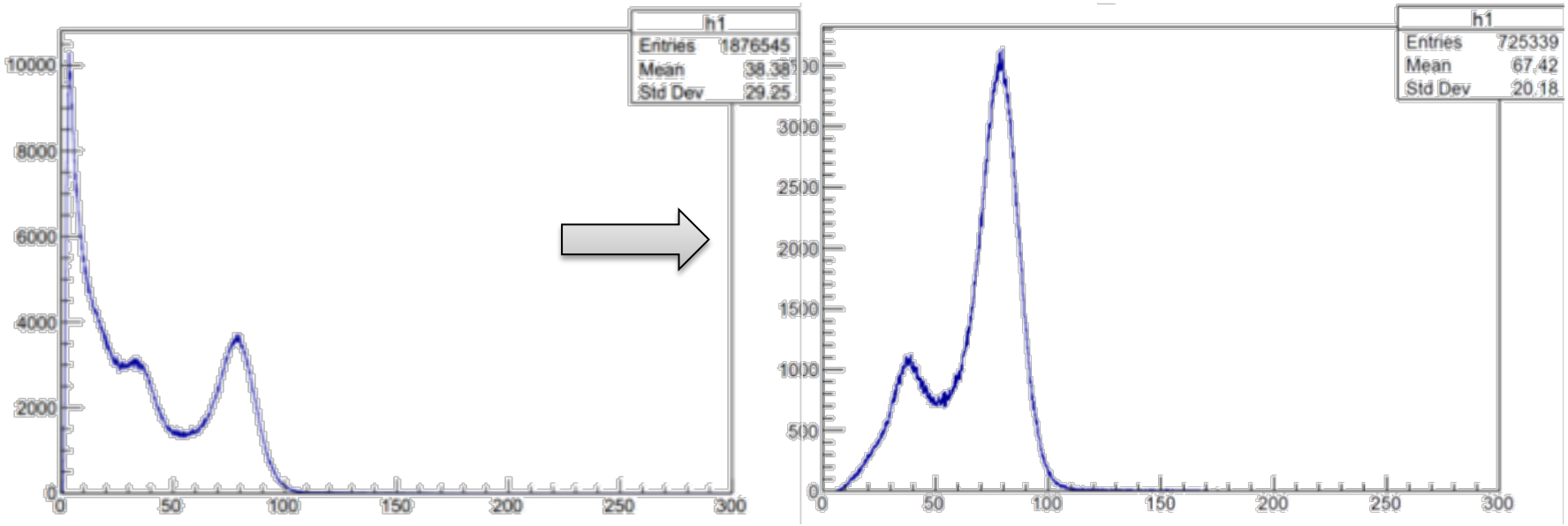
- Self-trigger of TPC prototype
  - Self-trigger principle: Just consideration of the pulse time @400MHz TDC
  - Shape time: 120ns (CR^2-RC^3, CASAGEM ASIC)
  - ^{55}Fe with Ø1.0mm collimator
  - Trigger rate(every pulse): ~34550Hz



Spectrum of ^{55}Fe using TPC prototype

Calibration of ^{55}Fe

- Self-trigger of TPC prototype
  - Optimization: different time window value
  - Confirmation: using ^{55}Fe energy spectrum
  - Optimization selection: eliminate incomplete or accidental coincidence event

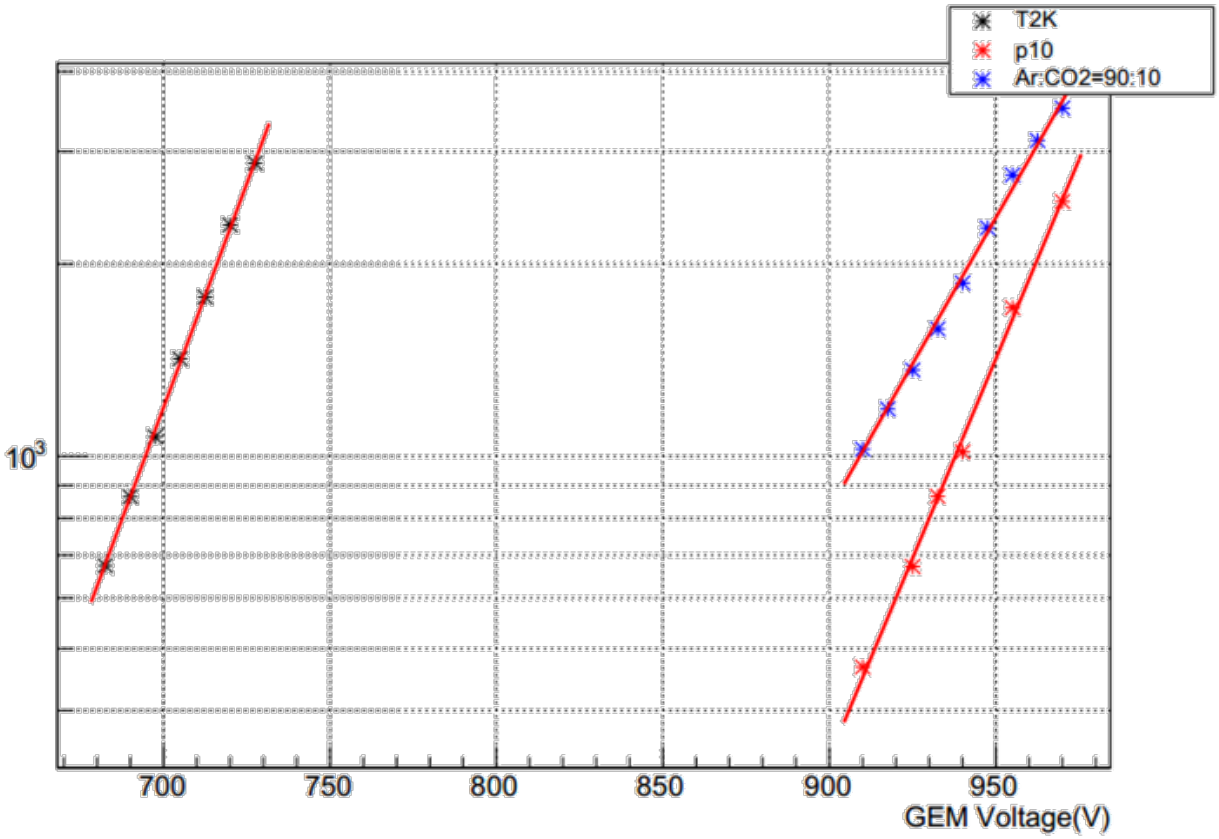


Spectrum of ^{55}Fe using TPC prototype

Calibration of ^{55}Fe

Confirmation with the previous results

- Self-trigger (or triggerless) of TPC prototype
  - Setting as the optimization time window
  - Operation mixture gases: T2K. P10, Ar/CO2=90/10



Gain of ^{55}Fe using TPC prototype

Calibration of ^{55}Fe

- Self-trigger (or triggerless) of TPC prototype at Gain=6000
  - Along the different drift length
  - Setting as the optimization time window
  - Some parameters of the electron cluster size

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	0.76 mm	3	6
3.65 mm	0.60 mm	2	4
1.46 mm	0.38 mm	1	4

- Next to do

  Scanned and analyzed of the different gain of the detector

- No conclusions
- But, the electrons cluster size can be investigated and analyzed using UV laser beam, even without the high magnetic field
- And, this parameter can measured using the smaller dipole magnetic(0.1T-3T) field with our TPC module
- This parameter is very important for TPC technology

Deviation of the electrons

- Electrons drifting along the drift length
  - Electromagnetic field (temperature, pressure, gases)
  - Fluctuation of gain (impact N_{eff})
  - Electronics (Shape time, amplifier, digitalized)
  - Diffusion: D_T, D_L

Langevin's formula for electronic directional drift

$$v = \mu |E| \frac{1}{1+\omega^2\tau^2}(\hat{E} + \omega\tau\left[\hat{E}\times\hat{B}\right] + \omega^2\tau^2(\hat{E}\cdot\hat{B})\hat{B})$$

No magnetic or the electric field is parallel to the magnetic field

$$v = \mu E$$

With magnetic and no parallel of E/B E×B effect

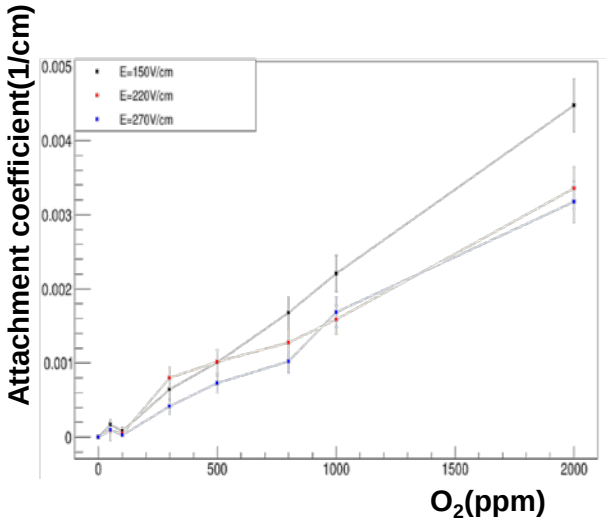
$$v_x = \frac{\mu}{1+(\omega\tau)^2}[E_x - \frac{\omega\tau}{|B|}(E_yB_z - E_zB_y) + \frac{(\omega\tau)^2}{|B|^2}(E_xB_x + E_yB_y + E_zB_z)B_x]$$

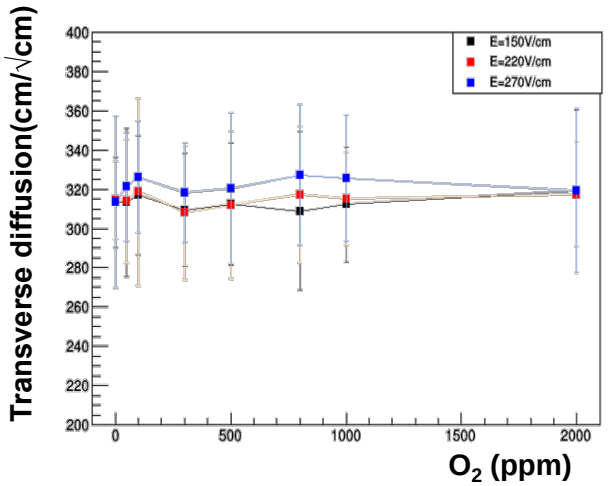
$$v_y = \frac{\mu}{1+(\omega\tau)^2}[E_y - \frac{\omega\tau}{|B|}(E_zB_x - E_xB_z) + \frac{(\omega\tau)^2}{|B|^2}(E_xB_x + E_yB_y + E_zB_z)B_y]$$

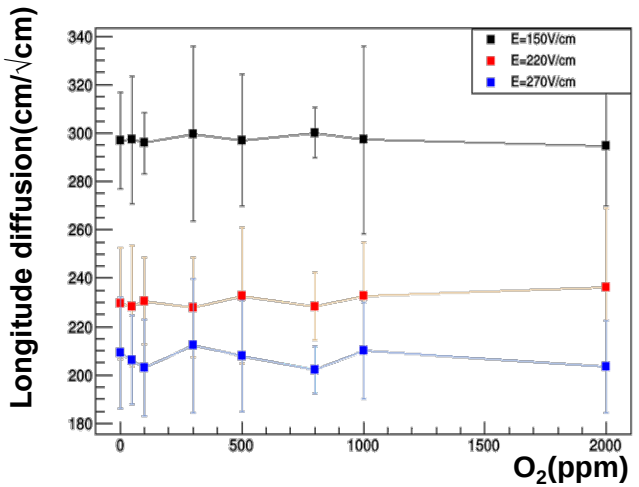
$$v_z = \frac{\mu}{1+(\omega\tau)^2}[E_z - \frac{\omega\tau}{|B|}(E_xB_y - E_yB_x) + \frac{(\omega\tau)^2}{|B|^2}(E_xB_x + E_yB_y + E_zB_z)B_z]$$

Deviation of the electrons

- Electrons drifting along the drift length
  - Gas impurities: Oxygen and water





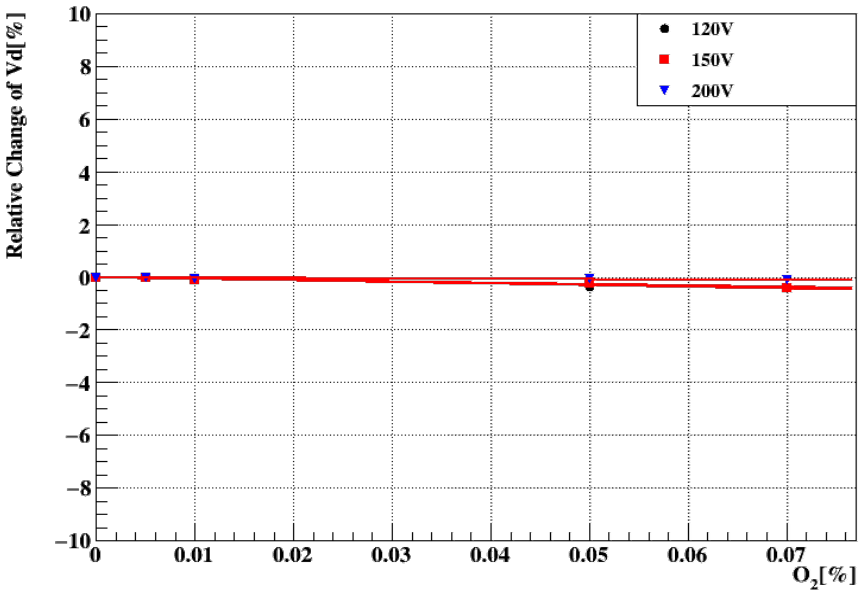


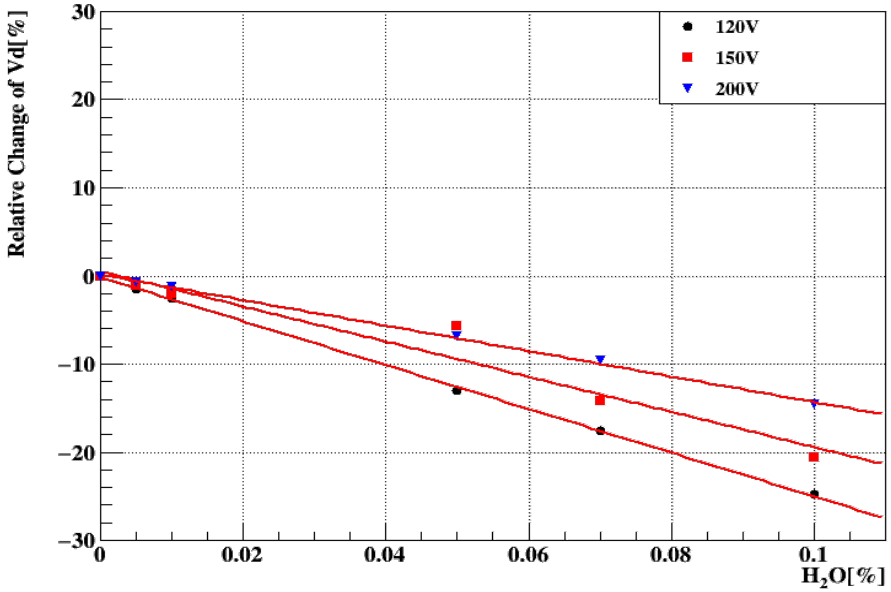
Deviation of the electrons

- Electrons drifting along the drift length
  - Gas impurities: Oxygen and water

$\frac{\partial v_d}{\partial C_{O_2}}$= -5.103 $\pm$ 0.606 [%/%]

$\frac{\partial v_d}{\partial C_{H2O}}$= -199.105 $\pm$ 22.728[%/%]





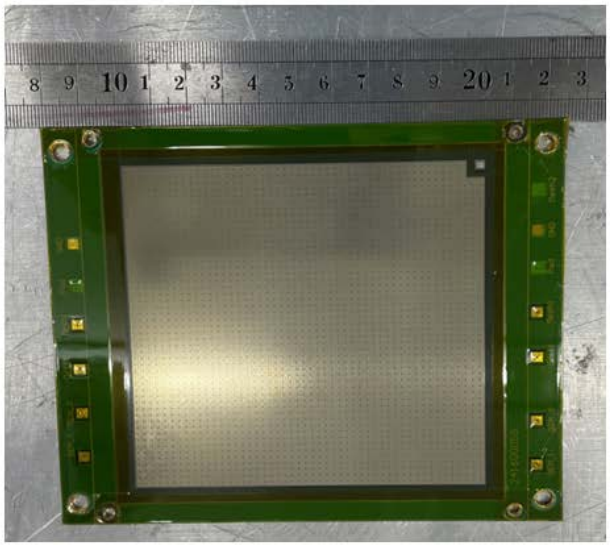
- Conclusion

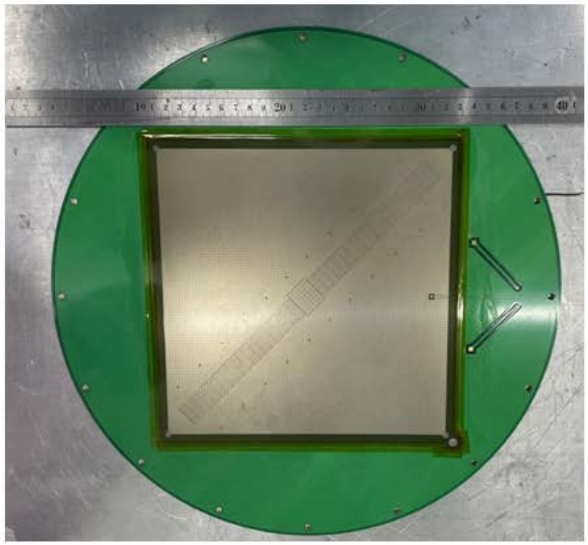
  The influence of the purity(ppm) of Oxygen and water can be ignored for the previous taking data from TPC prototype.

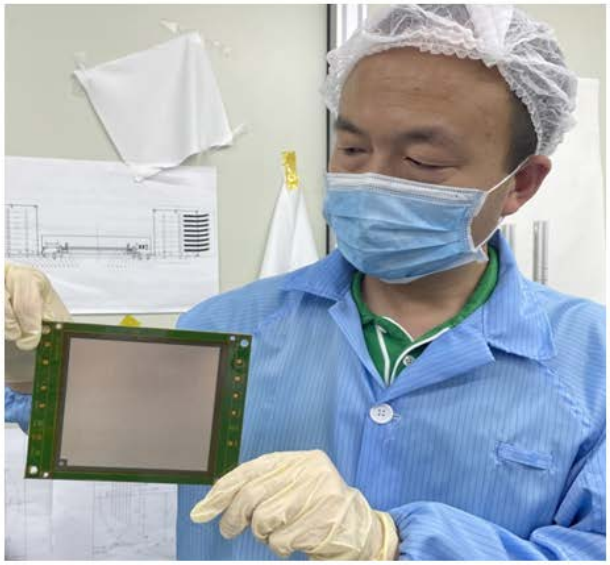
- Status of the collaboration

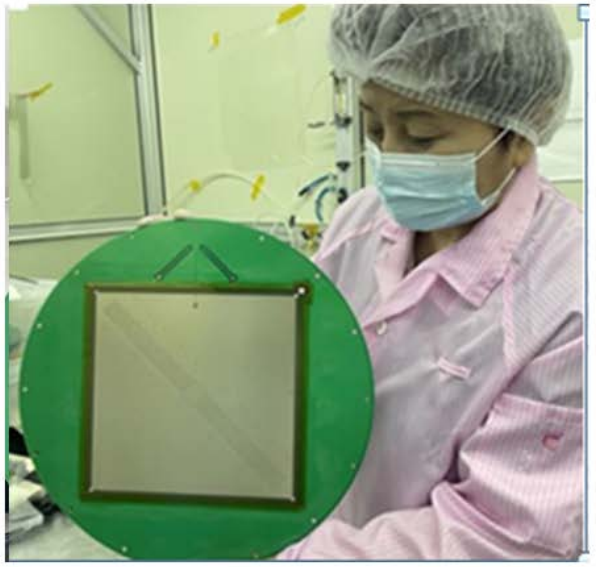
Start of mock up preparations in 2021

- Some samples of the Micromegas detector successfully were assembled in our lab
- The different active area of the detector could be prepared, and the maximum size could be more than 1000mm
- The preliminary gain test of the detector were fine







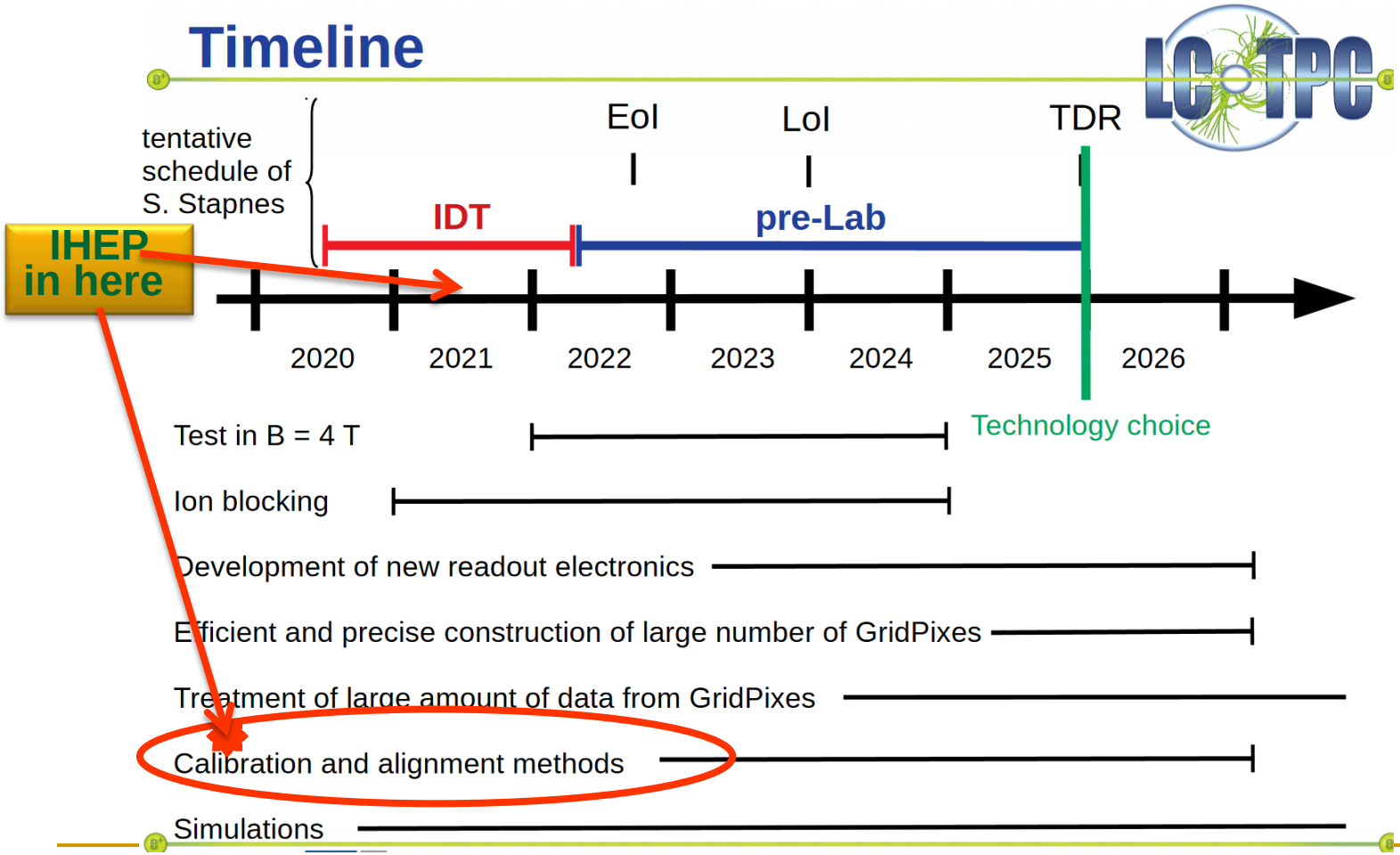


Plans

- The detector module will assembled and commissioned with the low power consumption ASIC chip.
- Deeply involved in the laser test using 266nm UV
  - dE/dx
  - Drift volecity
  - T/P monitor
- Mass production will be started in 2021
  - Bulk-micromegas devices all ready
  - Test and optimization for the non-boundary Micromegas
  - TPC module will be further studies
  - High rate and low IBF module for Z pole
- Some simulation will be collaborated with LCTPC's Marlin software group
  - Studies for CEPC TPC R&D
  - Studies with ILC pre-lab

Some contributions for TPC R&D in LCTPC

- Some contributions of the laser calibration studies from IHEP
- IHEP will involved in pre-lab as one member from 2021



Summary

- Some update information of the pixel TPC beam test in DESY.
- Some update results of the electrons cluster size are starting to investigate and some new plan are raised for this parameter.
- Some update simulation and analysis are given here.

Thanks for your attention.