A Time Projection Chamber for a Future Linear Collider

Status and plan of TPC technology R&D for e^+e^- collider at IHEP

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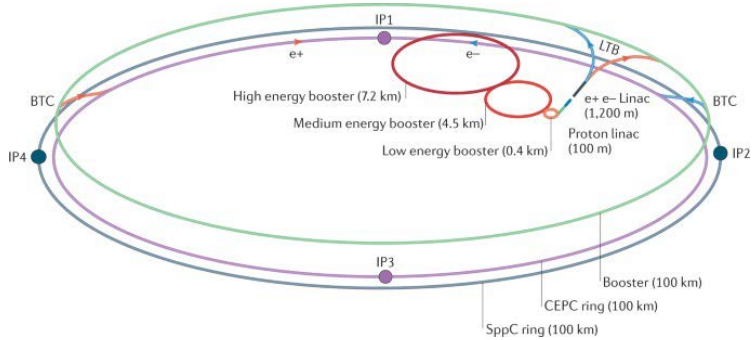
Outline

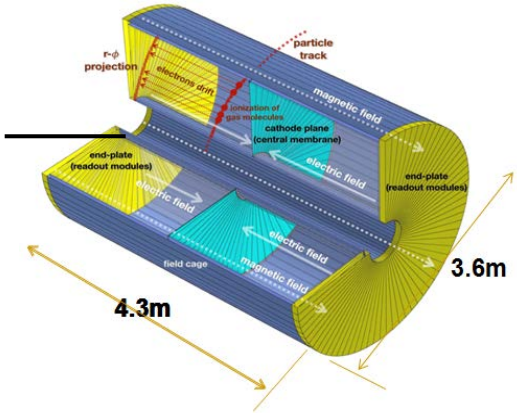
- Physics motivation
- TPC technology R&D
- Some related TPC R&D
- Summary

TPC technology challenge @ Future e^+e^- Colliders

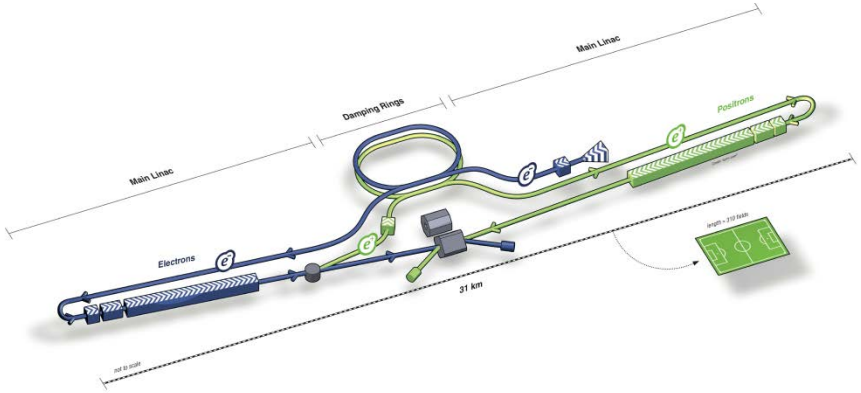
Beam parameters	ILC		CLIC			FCC-ee			CepC	
Energy(TeV)	0.25	0.5	0.38	1.5	3	0.091	0.24	0.36	0.091	0.24
Luminosity (x 10^{34} cm^{-2} s^{-1}) per IP	1.35	1.8	1.5	3.7	5.9	230	8.5	1.7	32	1.5
Bunch train frequency (Hz)	5		50							
Bunch separation (ns)	554		0.5			20	994	3000	25	680
Number of bunches / train - beam	1312		312	312		16640	393	48	12000	242



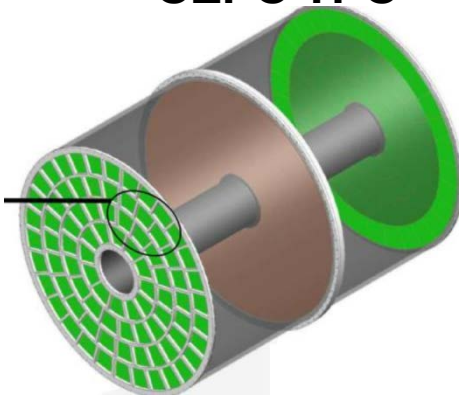
CEPC



CEPC TPC



ILC

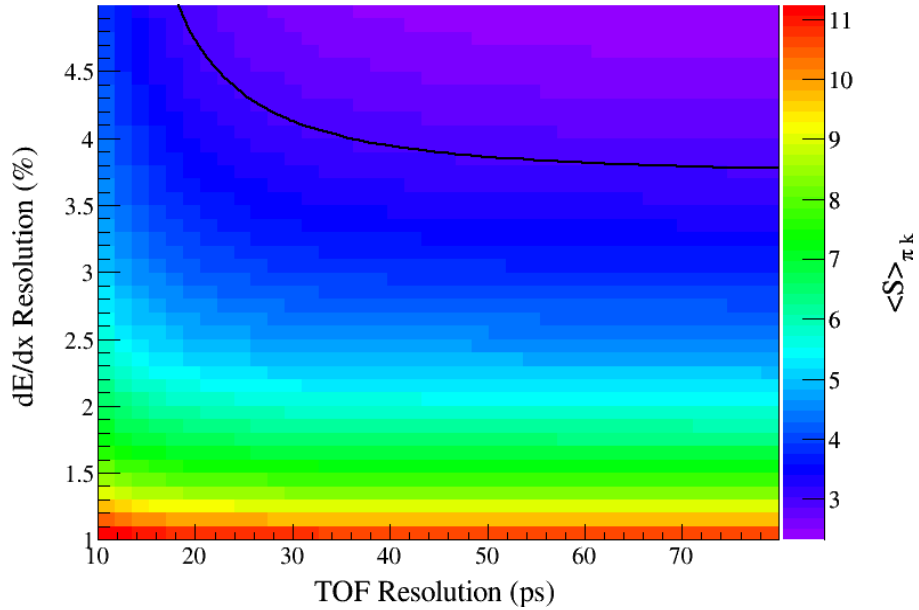


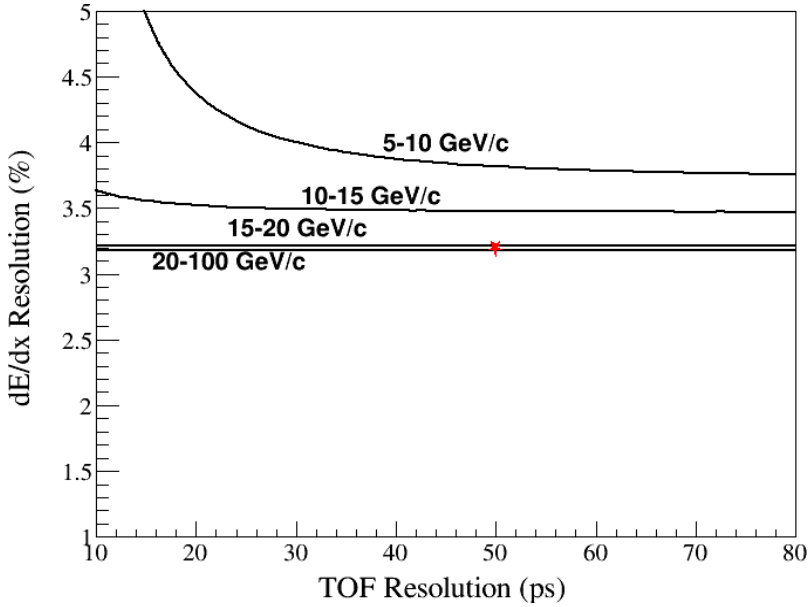
ILD TPC

Motivation of Particle identification (dE/dx)

Manqi and Zhiyang

- **Simulation results from CEPC**
- **Scan of the baseline detector concept performance**
  - **3.2% dE/dx resolution**
  - **50psTOF resolution**





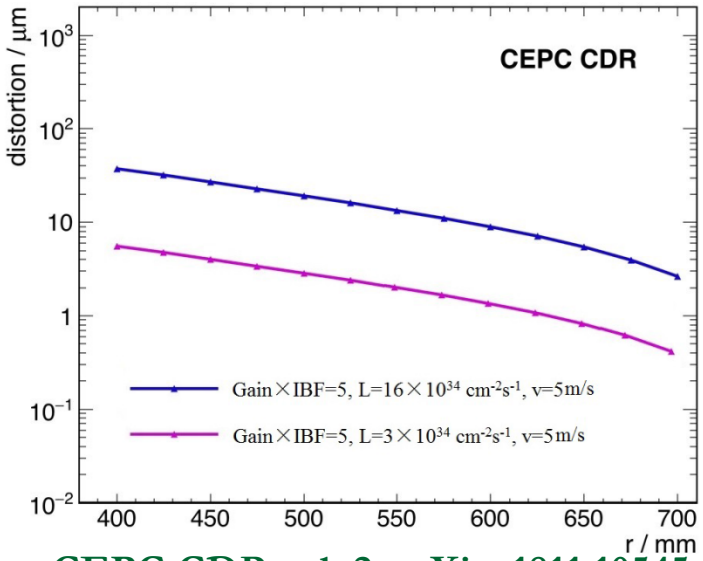
Status of TPC technology R&D

Goals:

- **Operate TPC at high luminosity ($\mathcal{L}$ = 32×1034 cm-2 s-1) at Z pole run (~10 kHz)**
- **No gating**
- **Maximal occupancy at TPC inner-most layer: ~10^{-5} (safe!)**
- **Rough estimations for primary ionisation⇒distortions < 10 μm (safe!)**
- **Total ions in chamber: Gain × IBF per primary ionization**
- **For Gain×IBF < 5 distortions < 40 μm(~50% of intrinsic resolution)**
- **UV laser mimic tracks without the beam to study the performance**

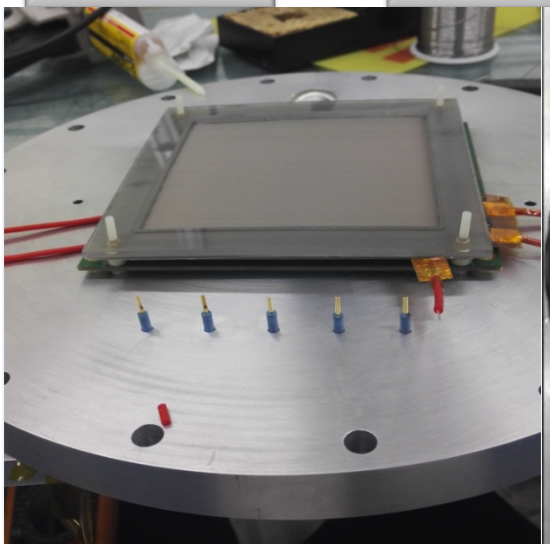
TPC detector module @IHEP

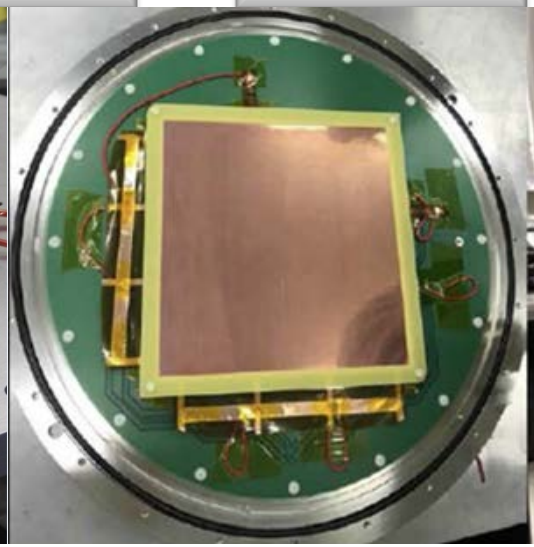
- Study with GEM-MM module
  - New assembled module
  - Active area: 100mm×100mm
  - X-tube ray and 55Fe source
  - Bulk-Micromegas assembled from Saclay
  - Standard GEM from CERN
  - Avalanche gap of MM:128μm
  - Transfer gap: 2mm
  - Drift length:2mm~200mm
  - pA current meter: Keithley 6517B
  - Current recording: Auto-record interface by LabView
  - Standard Mesh: 400LPI
  - High mesh: >508 LPI
  - Pixel option for the consideration



CEPC CDR vol. 2, arXiv: 1811.10545

50×50mm² 2015-2016 → 100×100mm² 2017-2018 → 200×200mm² 2019-2020

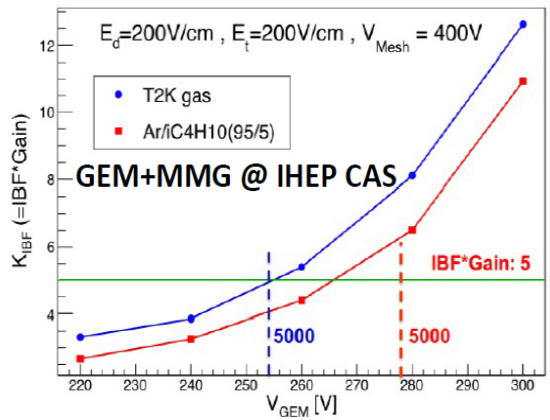


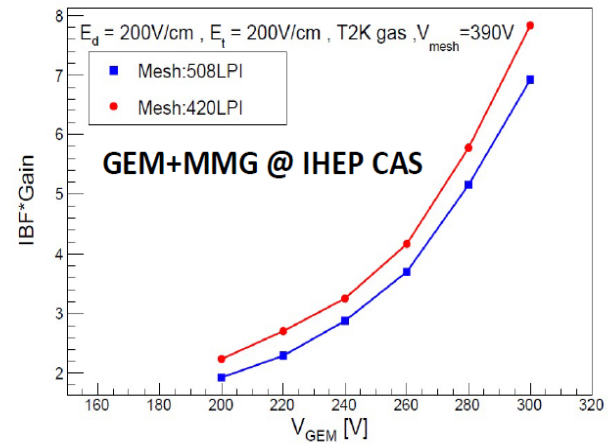


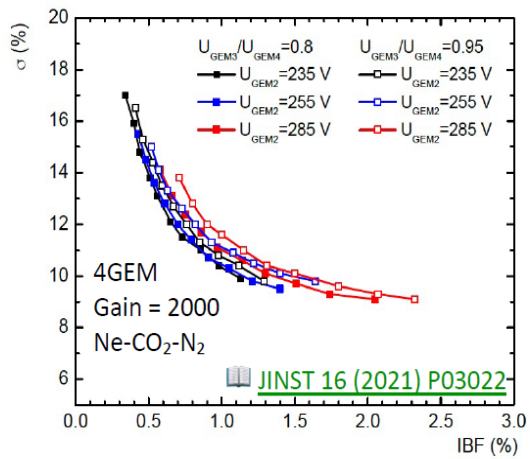
GEM-MM detector cathode

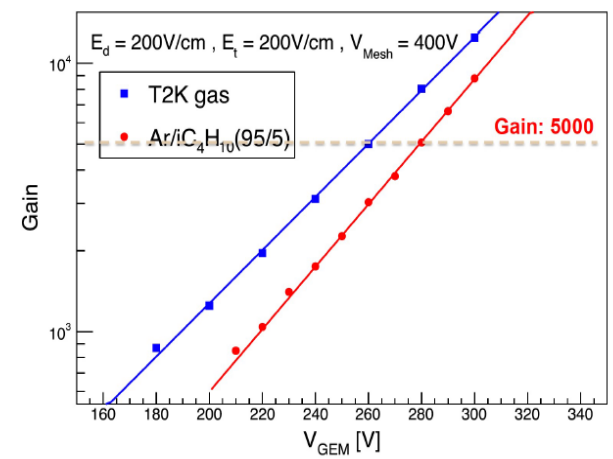
TPC detector module @IHEP

- Study with GEM-MM module
  - CEPC: keep IBF × Gain ≤ 5@Gain/5000
  - When MPGD gas gain<2000, IBF × Gain ≤ 1
  - Studies with hybrid GEM+MM detectors
  - sPHENIX R&D with 2GEM+MMG
  - USTC with DMM
- To be optimized:
  - Optimize IBF together with energy resolution/Gain
  - Gas mixture
  - Magnetic field (influence on IBF)
  - Distortion corrections









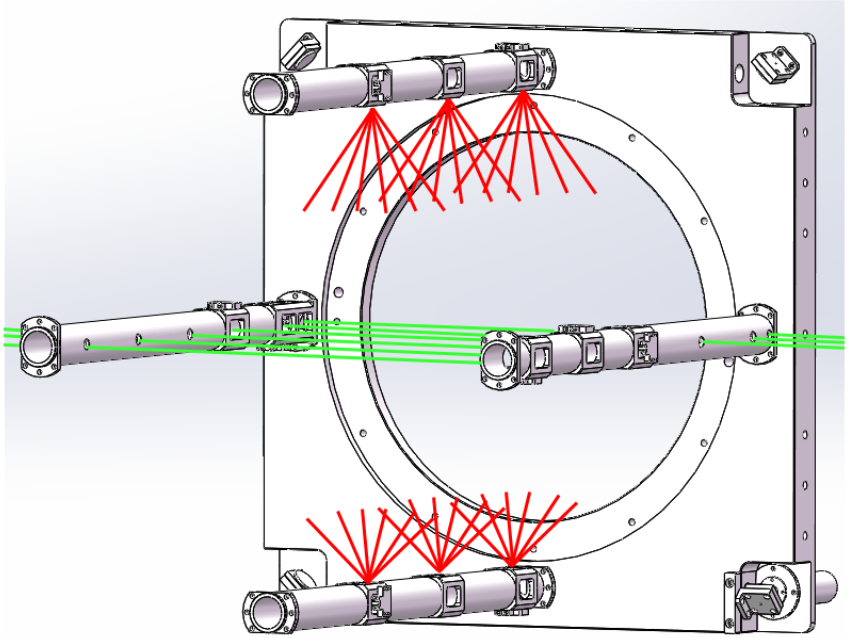
GEM-MM detector

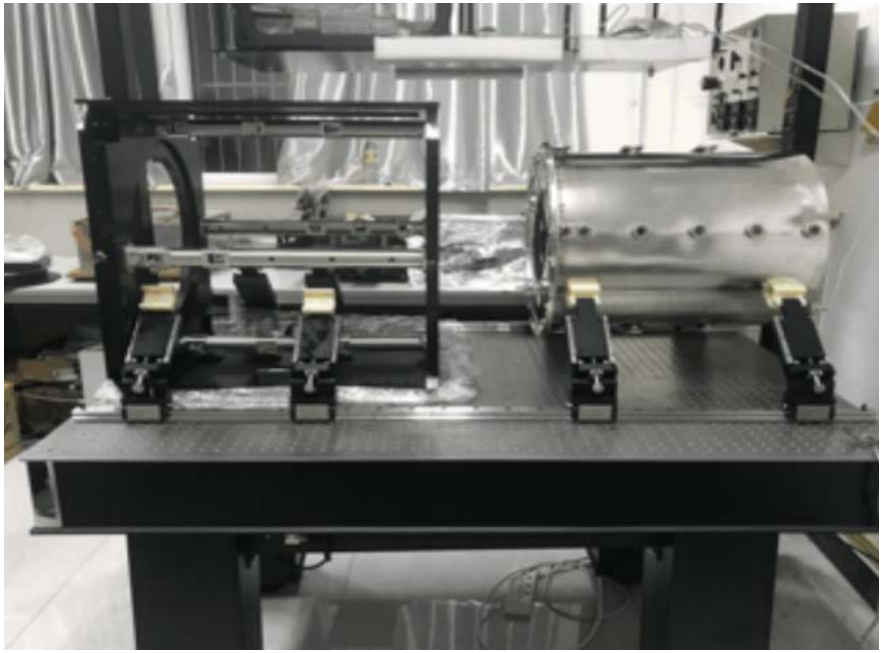
Ongoing: Amplification structure R&D

Pixel TPC (double mesh?)	Triple or double GEMs	Resistive Micromegas	GEM+ Micromegas	Double meshes Micromegas
IHEP, Nikehf	KEK, DESY	Saclay	IHEP	USTC 📖 NIM A 976 (2020) 164282 (also 📖 NIM A 623 (2010) 94)
Pad size: 55um-150um square	Pad size: 1mm×6mm	Pad size: 1mm×6mm	Pad size: 1mm×6mm	Pad size: 1mm×6mm (If resistive layer)
Advantage for TPC: Low gain: 2000 IBF×Gain: 1-2	Advantage for TPC: Gain: 5000-6000 IBF×Gain: <10	Advantage for TPC: Gain: 5000-6000 IBF×Gain: <10	Advantage for TPC: Gain:5000-6000 IBF×Gain: <5	Advantage for TPC: High gain: 10^4 Gain: 5000-6000 IBF×Gain: 1-2
Electrons cluster size for FEE: About Ø200um	Electrons cluster size for FEE: About Ø5mm	Electrons cluster size for FEE: About Ø8mm	Electrons cluster size for FEE: About Ø6mm	Electrons cluster size for FEE: About Ø8mm
Integrated FEE in readout board Detector Gain：2000	FEE gain: 20mV/fC Detector Gain：5000-6000	FEE gain: 20mV/fC Detector Gain：5000-6000	FEE gain: 20mV/fC Detector Gain：5000-6000	FEE gain: 20mV/fC Detector Gain：5000-6000

TPC prototype sketch

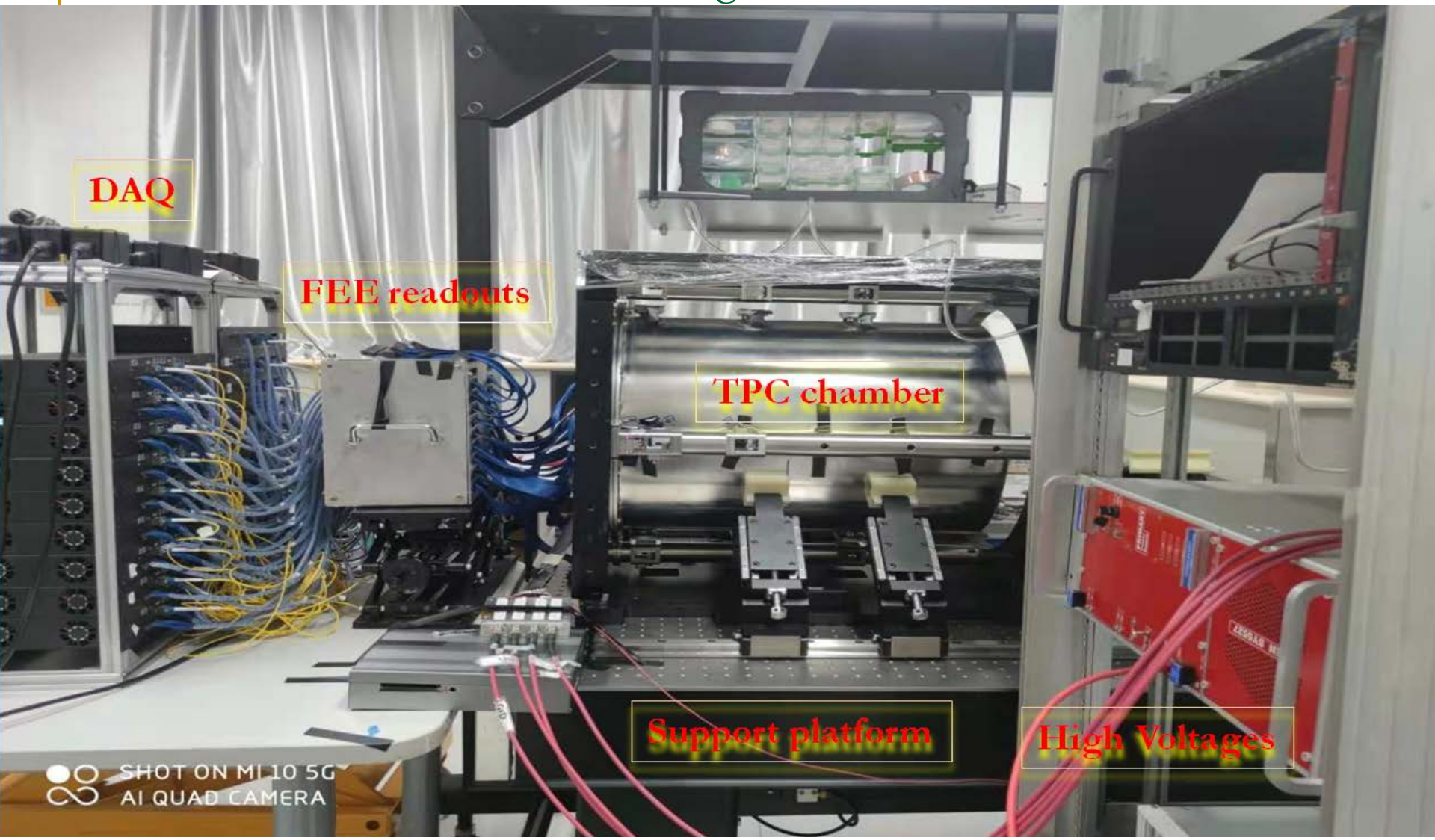
- Main parameters
  - Same test parameters in CEPC
    - Drift field=200V/cm
    - Relative gain: ≥2000
    - Readout pad(anode) is designed to 0V (Ground)
    - TPC detector system: Fieldcage+ Pads readout
    - Working mixture gas:
      - $Ar/CF_4/iC_4H_{10}$=95/3/2
      - Same purity
  - Specific prototype parameters
    - Drift length: ~500mm
    - Active area: 200mm^2
    - Integrated 266nm laser beam
    - MPGD detector as the readout
    - TPC cathode: -10kV
    - Readout Pads: 1280 channels





TPC prototype

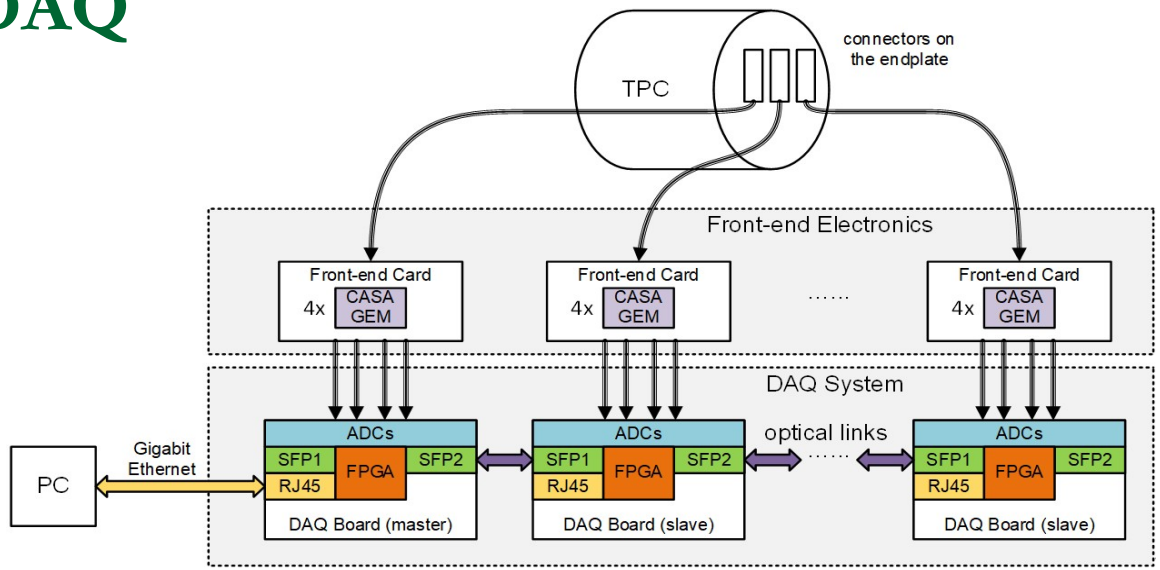
Commission: Chamber/Fieldcage/UV laser/Readout



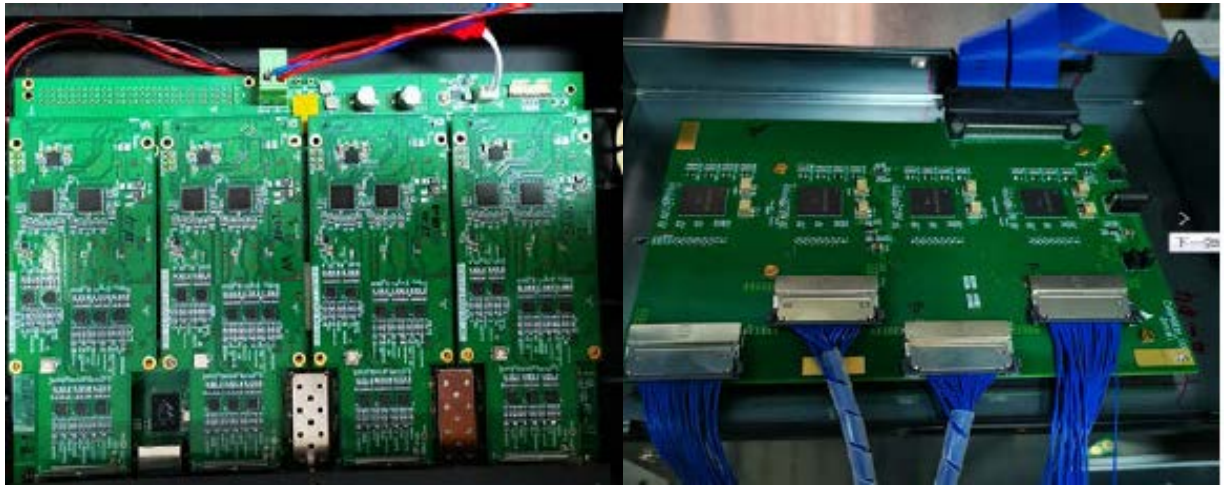
- Data taking and more analysis on going
- Commissioning: Huirong Qi, Zhiyang Yuan, Yue Chang, Yiming Cai, Yulan Li, Zhi Deng
- Data taking

Electronics and DAQ

- Amplifier and FEE
  - CASAGEM chip
  - 16Chs/chip
  - 4chips/Board
  - Gain: 20mV/fC
  - Shape time: 100ns



- DAQ
  - FPGA+ADC
  - 4 module/board
  - 64Chs/module
  - Sample: 40MHz
  - 1280chs



FEE Electronics and DAQ setup photos

Validation of UV laser with the mixture gases -Signal

The three operation gases for the detector compared with ILC DESY and KEK working gas

- T2K
- P10
- Ar/CO2=90/10

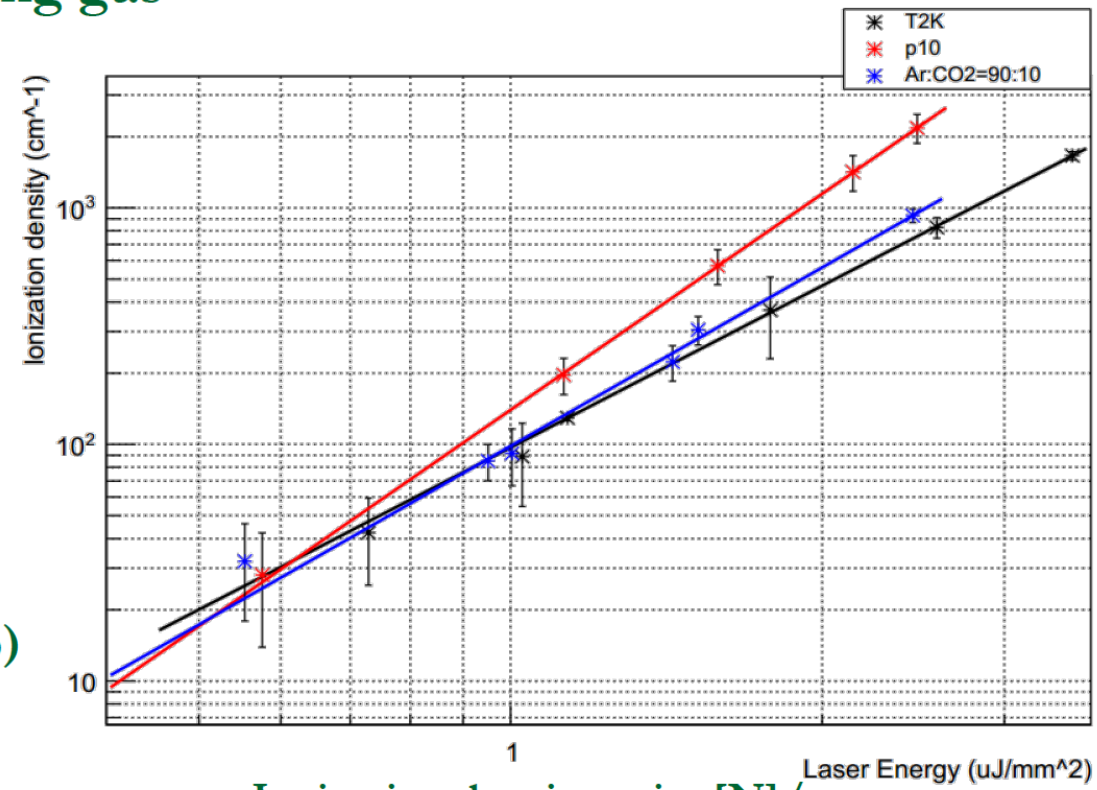
Gas purity

- Ar (99.999%)
- CO2 (99.999%)
- CH4 (99.999%)
- CF4 (99.999%)
- Isobutane (99.9%)

Ionization

- ~100 electrons/cm

at ~1uJ/mm^2

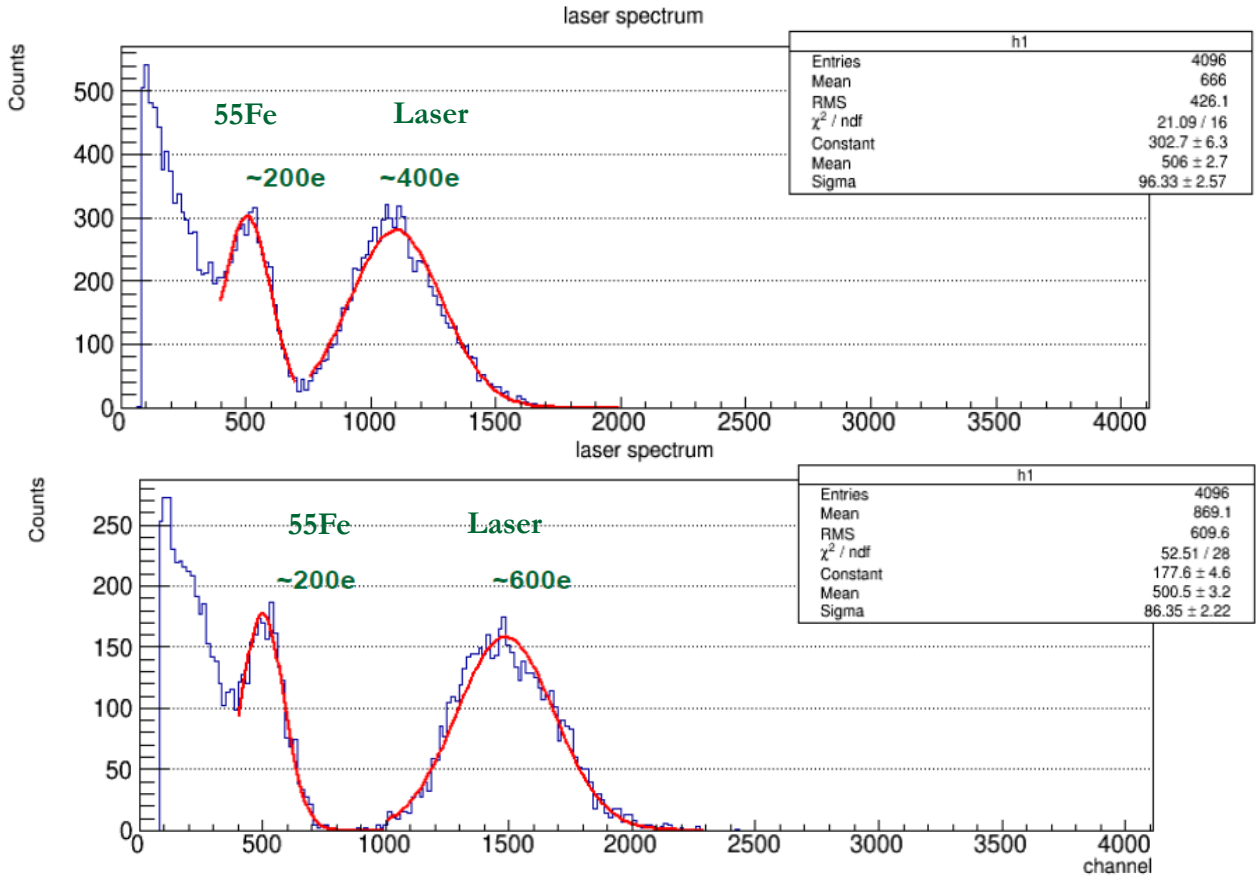


Ionization density unit: [N]/cm

(N is the primary electron number per 0.85mm^2)

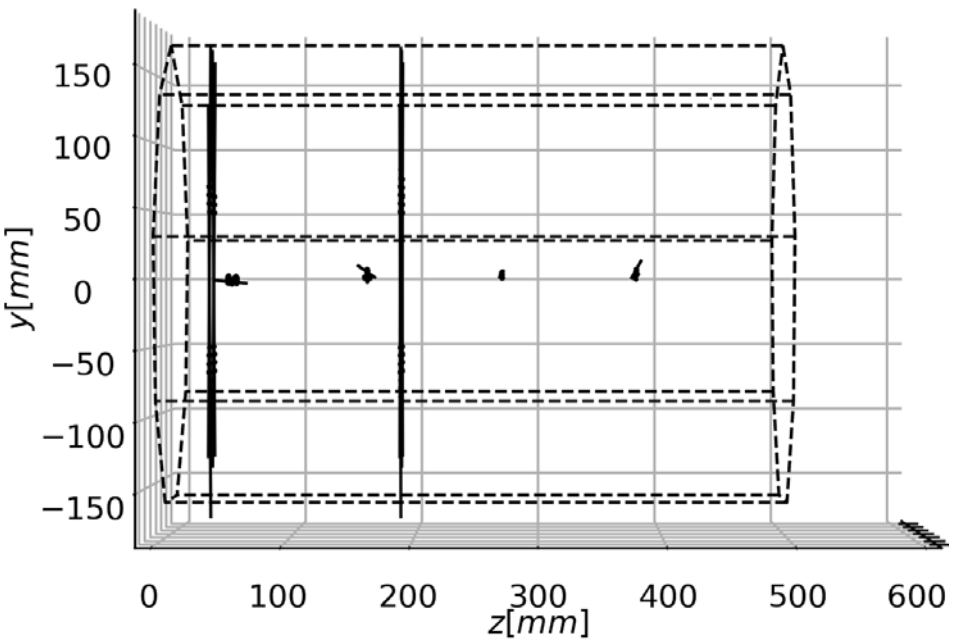
Pad size: 0.9mm×6.0mm

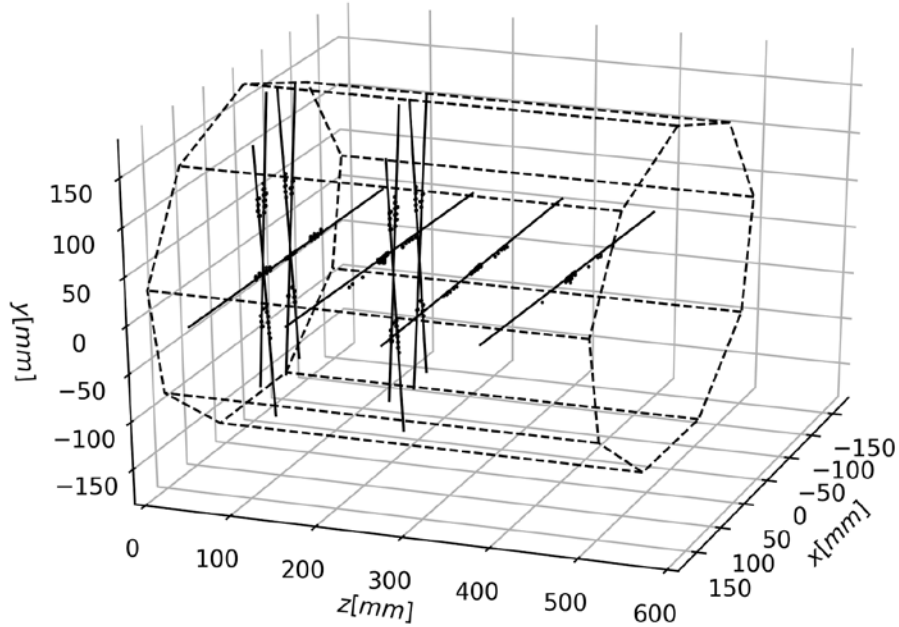
Validation of UV laser and ^{55}Fe -Energy



- Same test conditions under the same working gases and high voltage
- The ionization results indicate that the number for Ar:CO2(90:10)-gas and T2K-gas are similar for the ionization density.
- About the gas purity, the experiment shows all mixture gas of the purity of isobutane is 99.9% despite other gases are 99.999%.

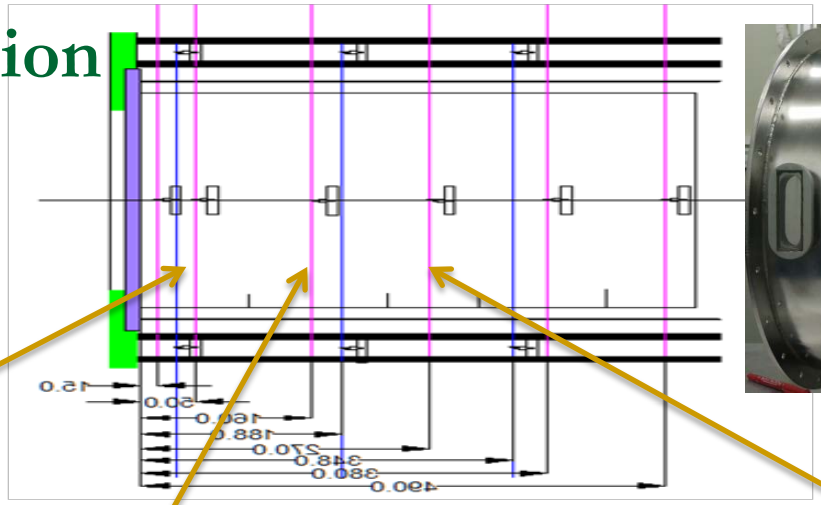
Validation of UV laser tracks@T2K gas

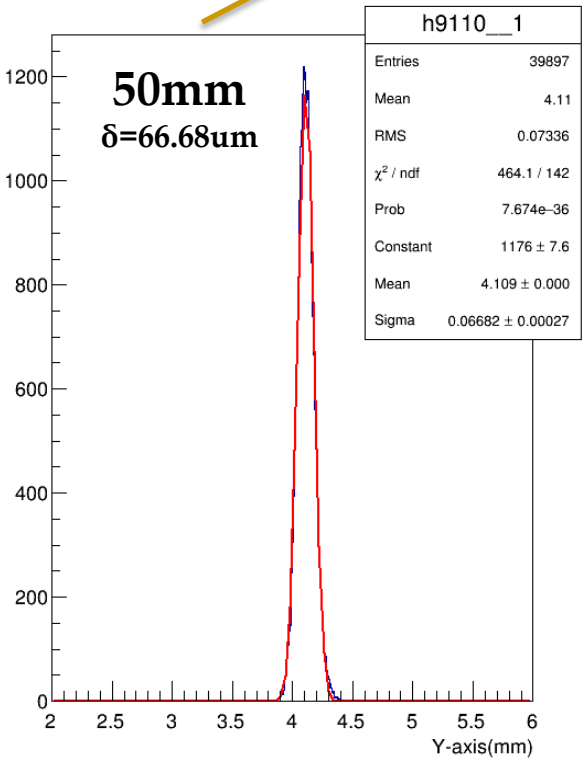


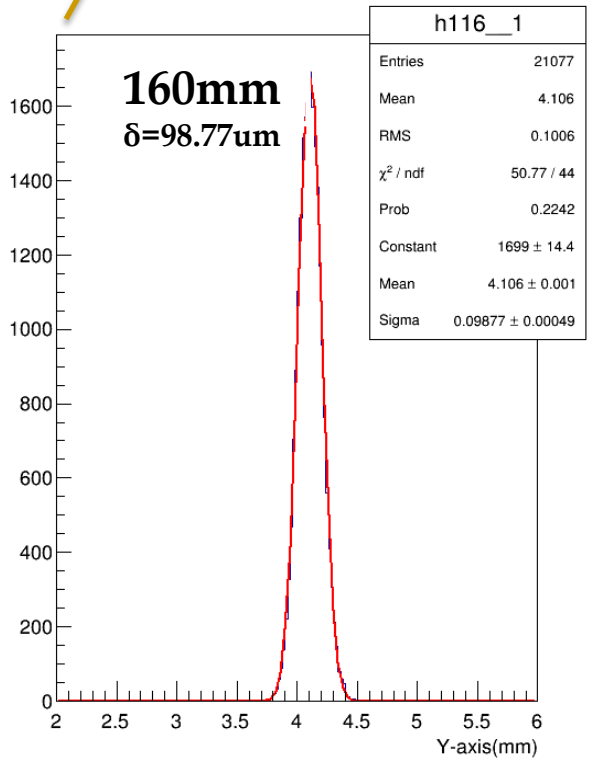


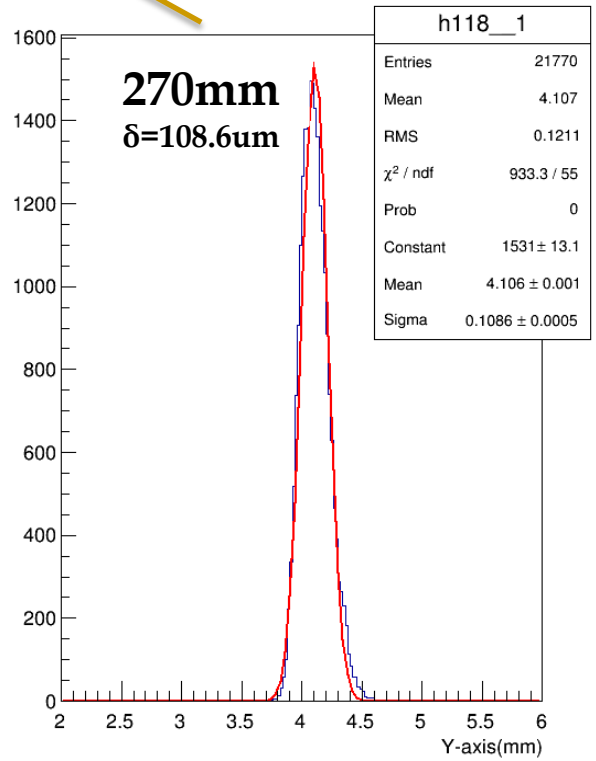
- Same of working gas@T2K, same of high voltage, same of test conditions
- Different of GEMs@ 320V
- Double GEMs without any discharge

Spatial resolution





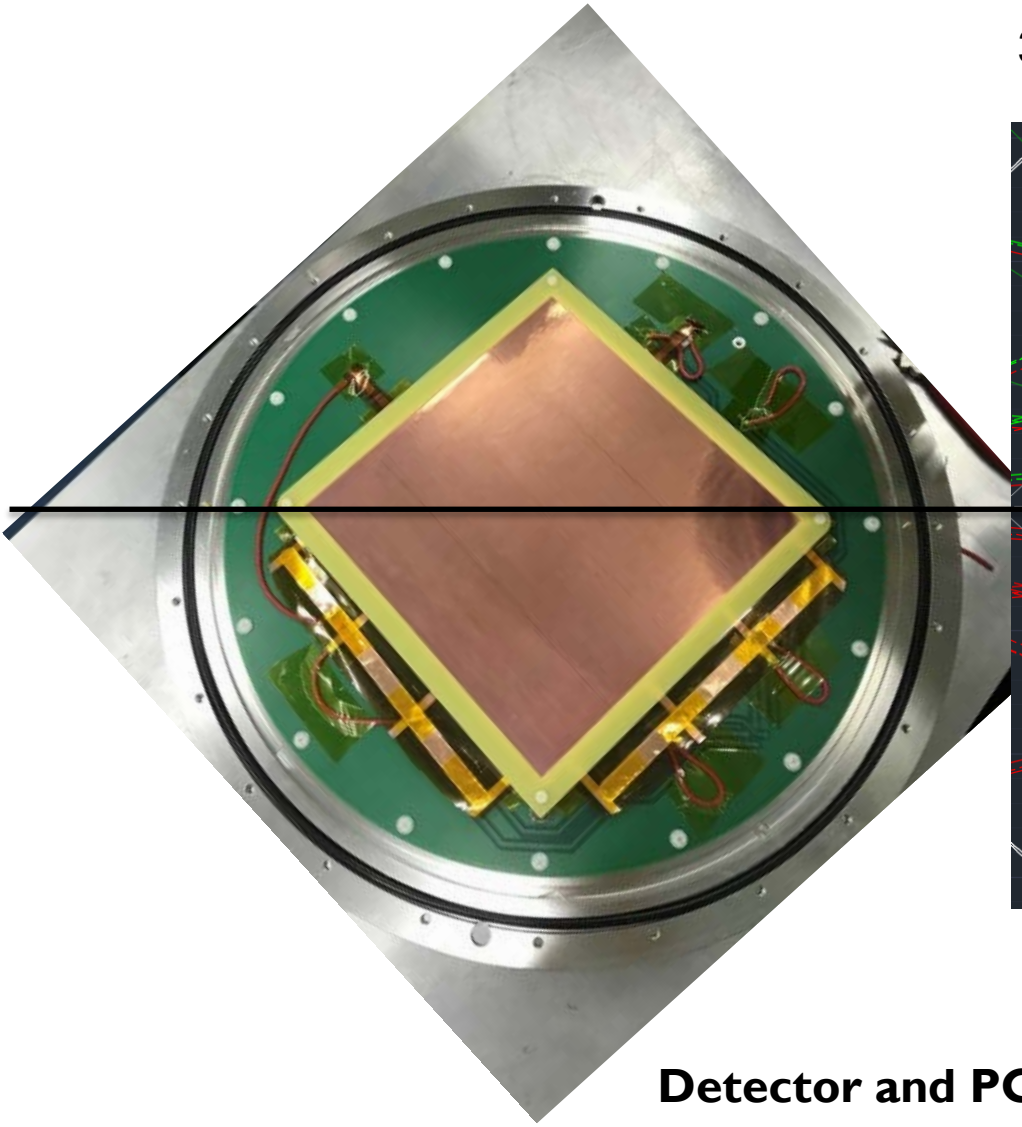


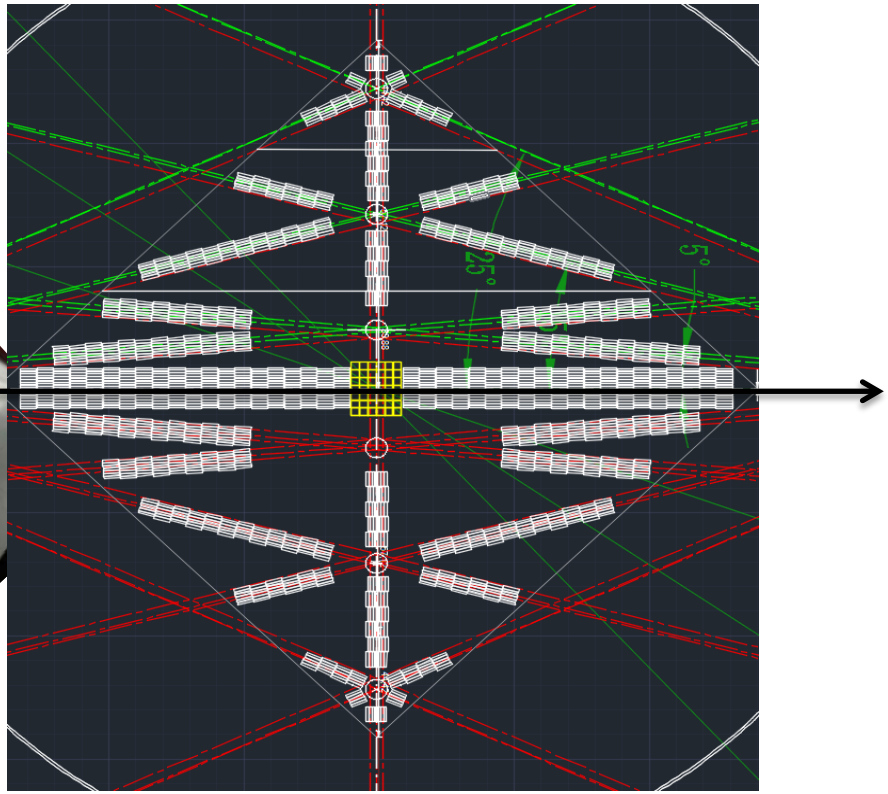


Space resolution at the different drift length

PID measurement using UV laser tracks

Pad size: 1mm × 6mm
38 hit points per track by UV laser



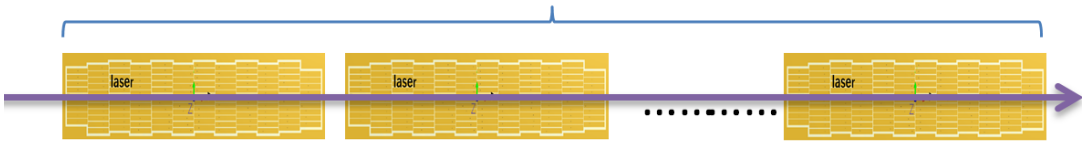


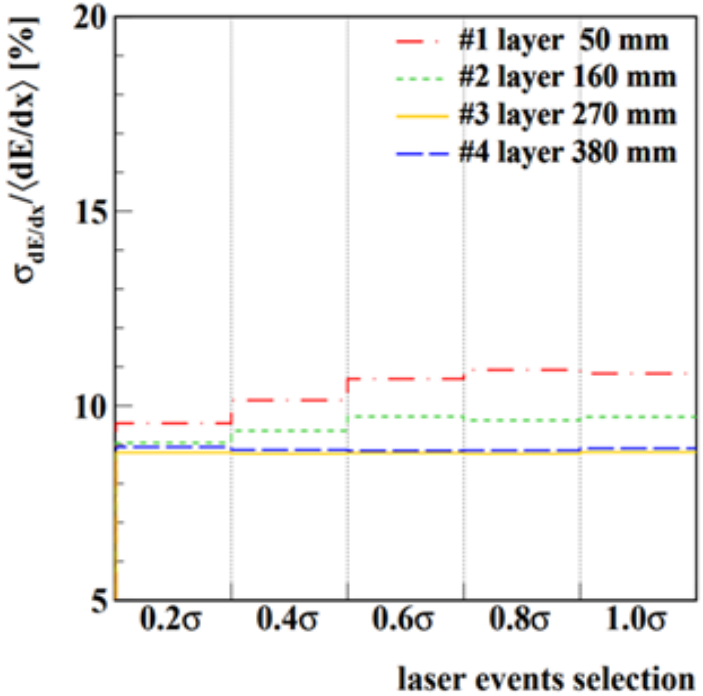
Detector and PCB readout board

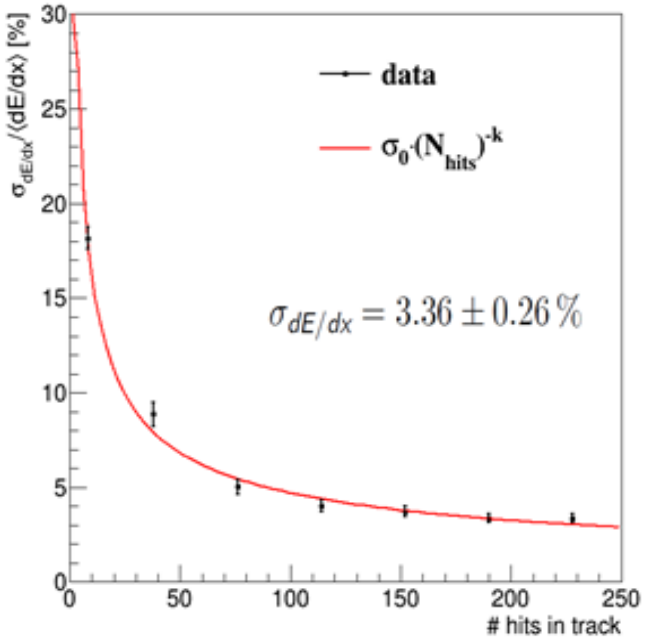
PID analysis using UV laser tracks

- dE/dx resolution achieved with pseudo-tracks of various lengths
- Comparison of simulation and experimental dE/dx
- Pseudo-tracks with 220 layers and dE/dx can reach to 3.36 ± 0.26%

$$\frac{\langle dE/dx \rangle}{\sigma(dE/dx)}$$







Some related TPC R&D

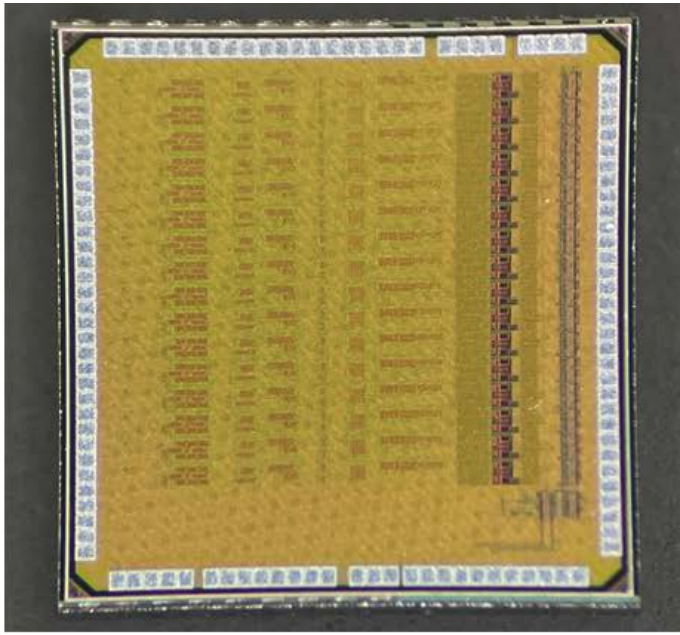
Goals:

- **Different size of TPC modules production**
- **Low power consumption FEE ASIC chip R&D**
- **Some other readout options for TPC prototype**
- **More collaboration**

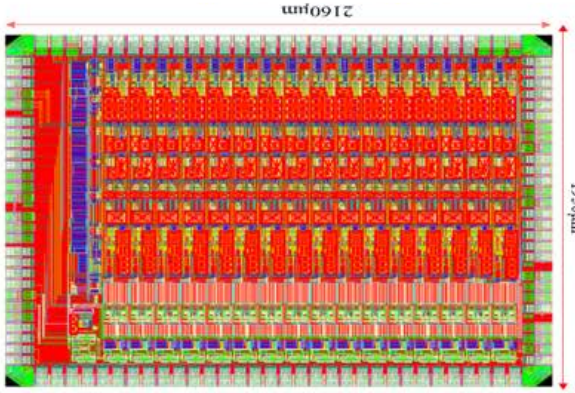
New electronics commissioning

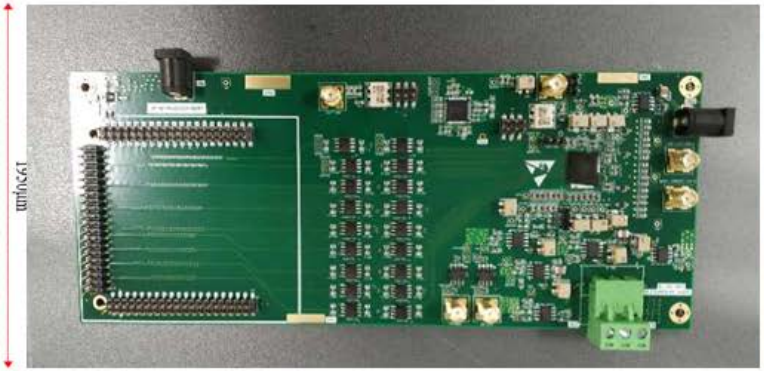
ASIC chip for TPC readout have been developed

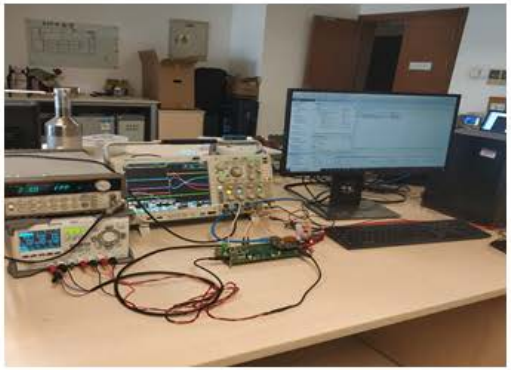
- The power consumption is 2.33 mW/channel
  - P_{AFE} = 1.43 mW/channel
  - P_{ADC} = 0.9 mW/channel @ 40M/s
- ENC =852e @Cm = 2pF, gain =10 mV/fC and can be reduced to 474e using digital trapezoidal filter



65nm ASIC芯片实物图







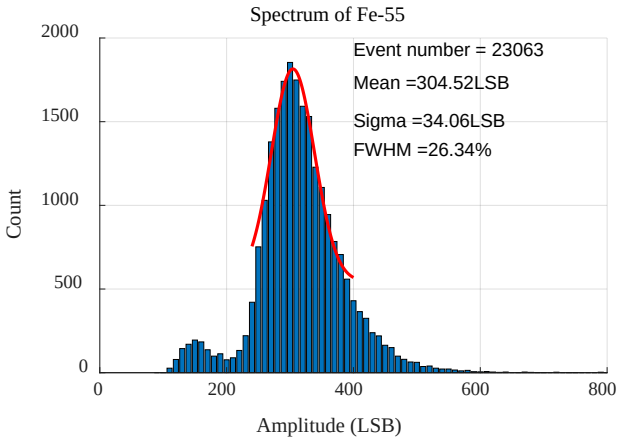
65nm ASIC芯片设计版图 及测试板实物图

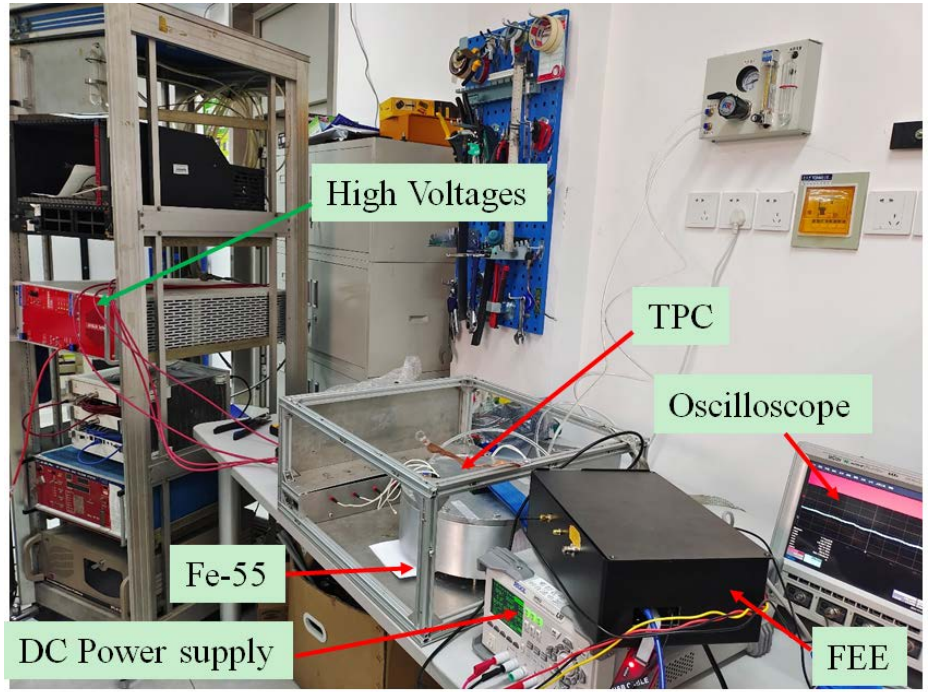
New electronics testing with the module

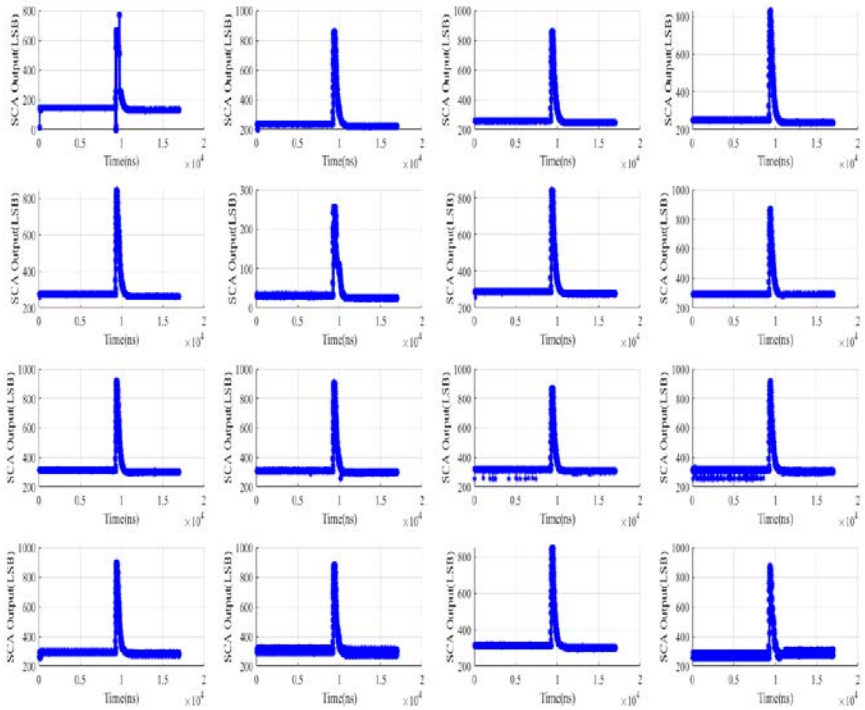
^{55}Fe testing

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**

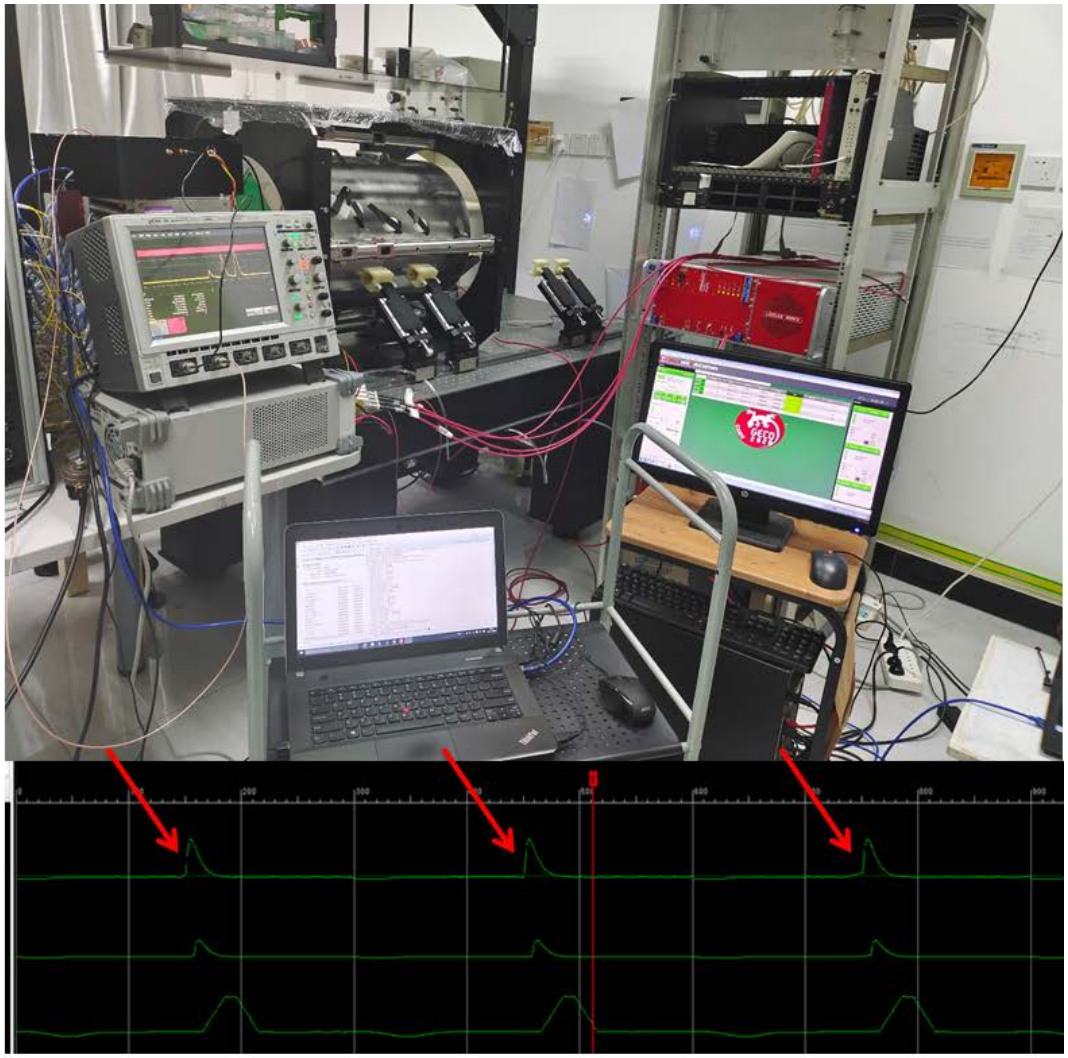






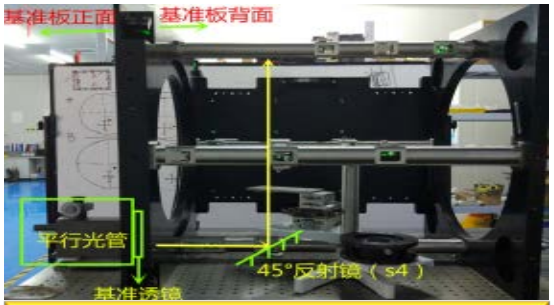
New electronics testing with the prototype

- Successfully realized the joint test of low-power ASIC chip and TPC prototype
- ASIC+TPC parameters
  - TPC:
    - GEM: 280 V
    - Drift length: 500mm
    - E drift: 180 V/cm
    - Gas: Ar/CF4/iC4H10 95/3/2 (T2K)
    - UV laser: 7.2 mJ @20 Hz
    - Laser tracks: 3 layers along drift length
  - Electronics:
    - Trigger by UV laseer
    - Gain: 20 mV/fC
    - Sample frequency: 30 MS/s



65nm ASIC + TPC prototype

Plan of the pixelated TPC technology



Pad TPC Prototype at IHEP 2015-2021

R&D

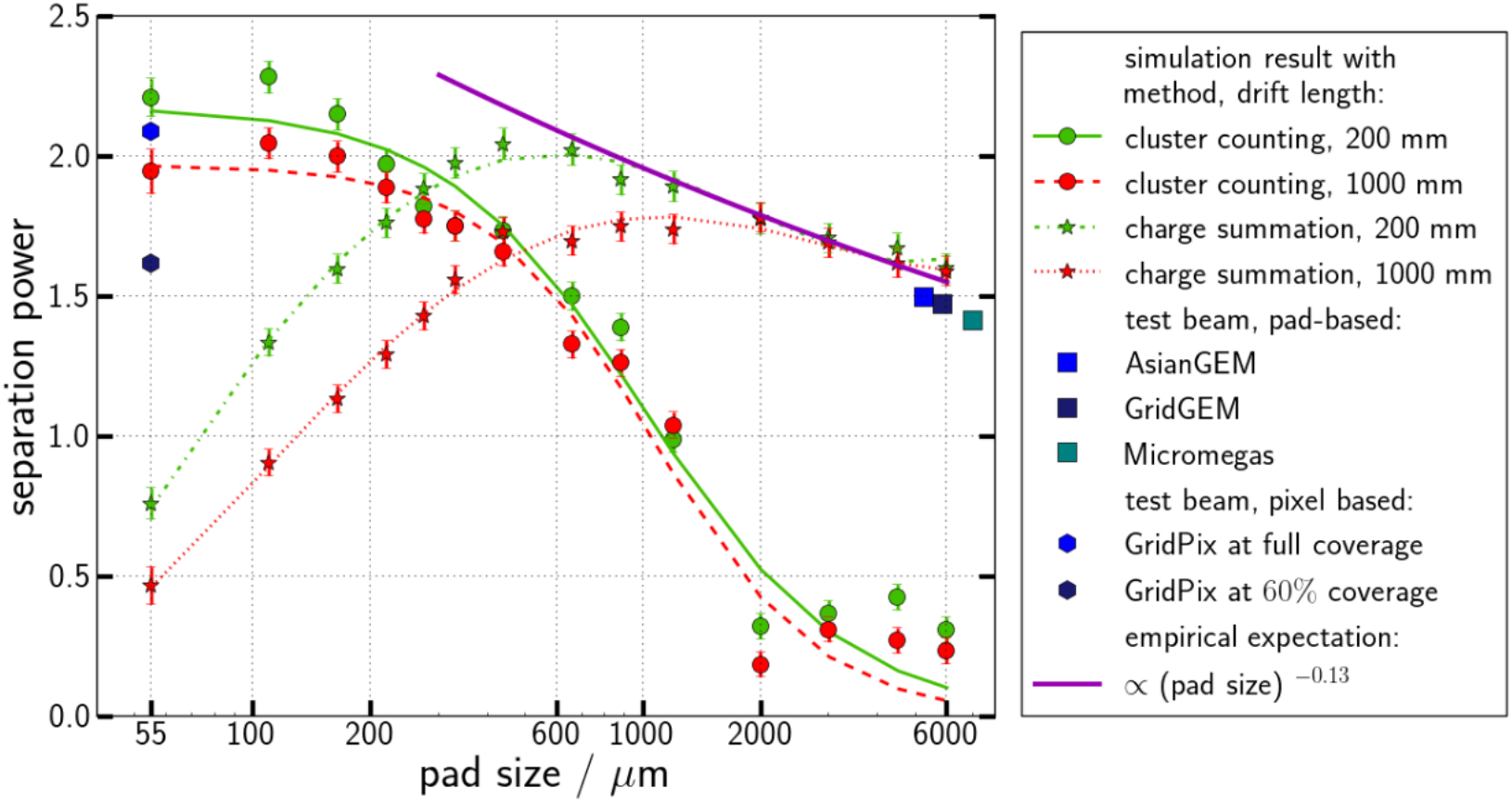
- Improved dE/dx by cluster counting
- Improved measurement for the low angle tracks
- Improved double track separation
- Much reduced hodoscope effect
  - Near to the endplate
  - Decreased the spatial resolution
- Lower occupancy in the high rate environments
- Fully digital readout

Translation between dE/dx and Separation Power

LCTPC Meeting 16.12.2021

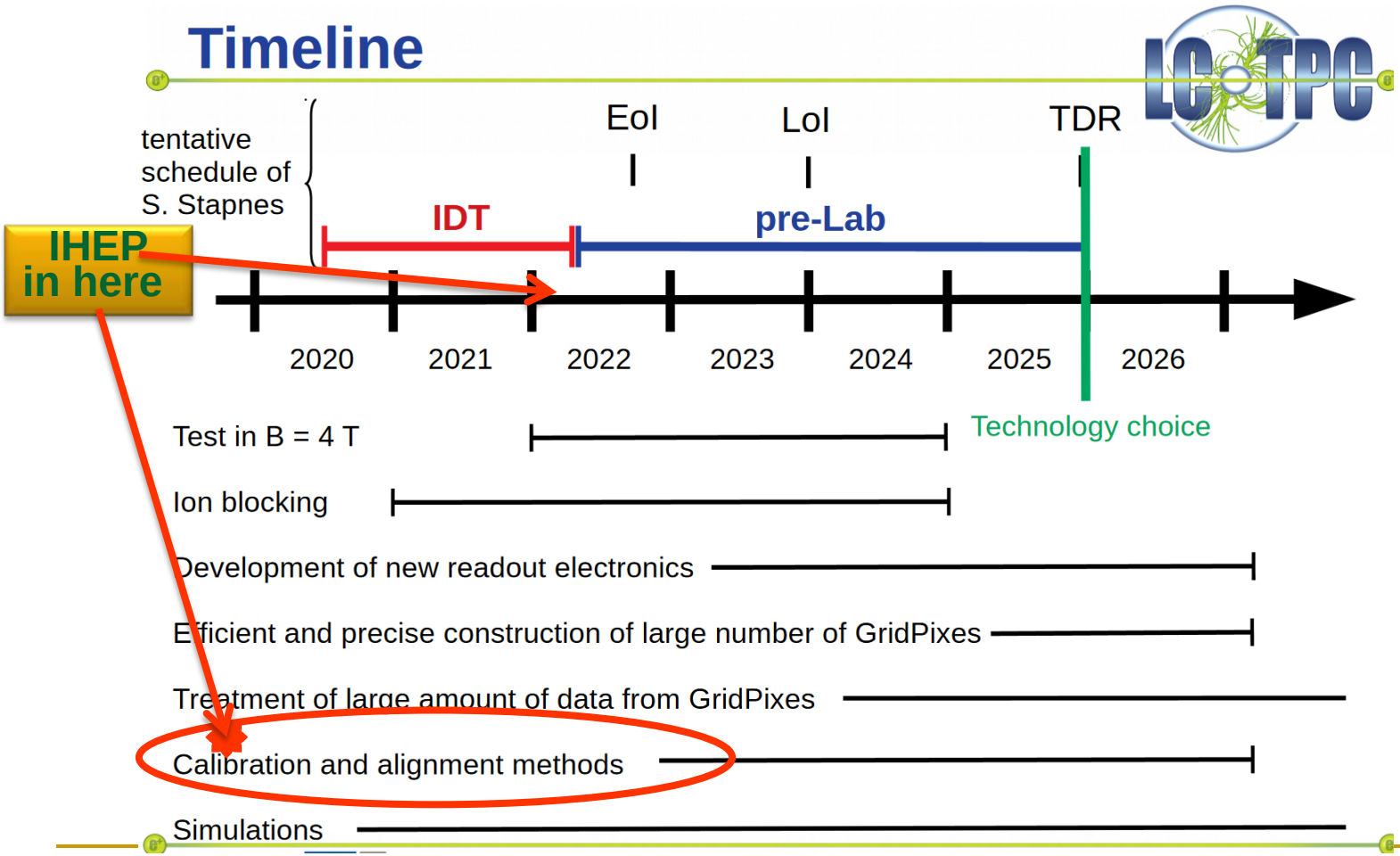
Uli Einhaus

Final Plot: Separation Power



Plan of TPC R&D for LCTPC

- Some contributions of the 266nm UV laser studies from IHEP
- IHEP will involved in pixelated TPC technology R&D



Summary

- **Some motivations of TPC detector for the circular collider at high luminosity listed.**
- **Some update results of TPC module have been studies, it can effectively reduce ions at the low gain without the space charge and the discharge.**
- **Some update results of TPC prototype have been studies, the prototype is working well, and the results indicated that 266nm UV laser beams will be very useful.**
- **Some plans of the TPC technology for e+e- collider in particle physics.**

Thanks for your attention.