Progress and planning of TPC technology R&D for CEPC

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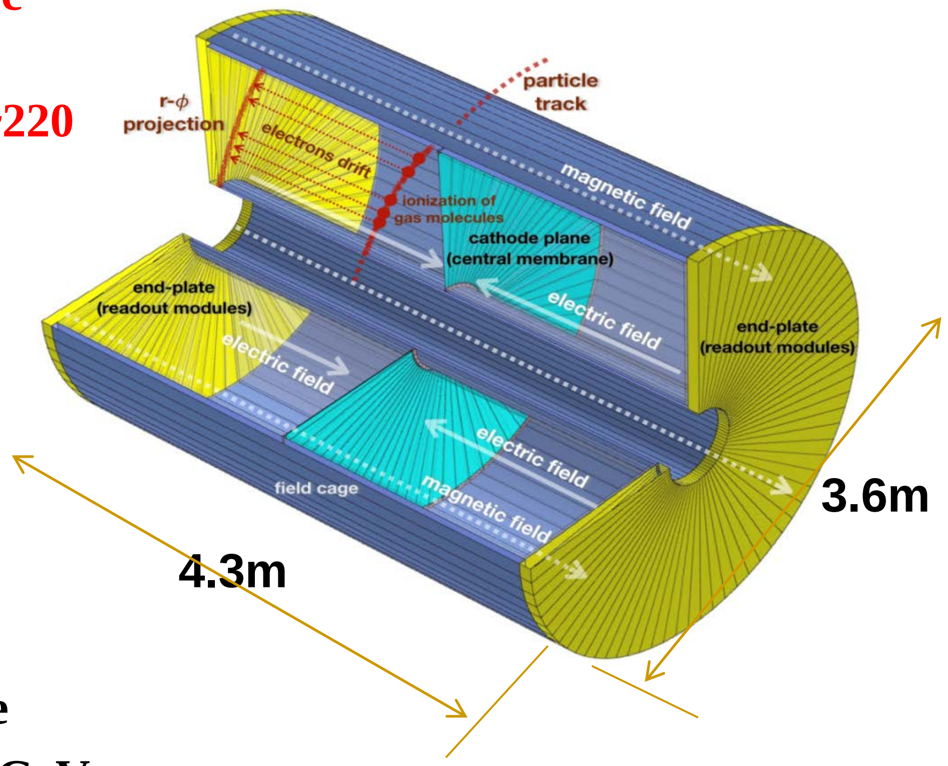
Outline

- Motivation
- TPC module R&D
- TPC prototype R&D
- Plan and summary

Overview of TPC concept

TPC detector concept:

- Under 2-3 Tesla magnetic field (Momentum resolution: ~10^{-4}/GeV/c with TPC standalone)
- Large number of 3D space points(~220 along the diameter)
- dE/dx resolution: <5%
- ~100 μm position resolution in rφ
  - ~60μm for zero drift, <100μm overall
  - Systematics precision (<20μm internal)
- TPC material budget
  - <$1X_0$ including outer field cage
- Tracker efficiency: >97% for pT>1GeV
- 2-hit resolution in rφ : ~2mm
- Module design: ~200mm×170mm
- Minimizes dead space between the modules: 1-2mm



TPC detector concept

Motivation of TPC

TPC critical R&D for Z

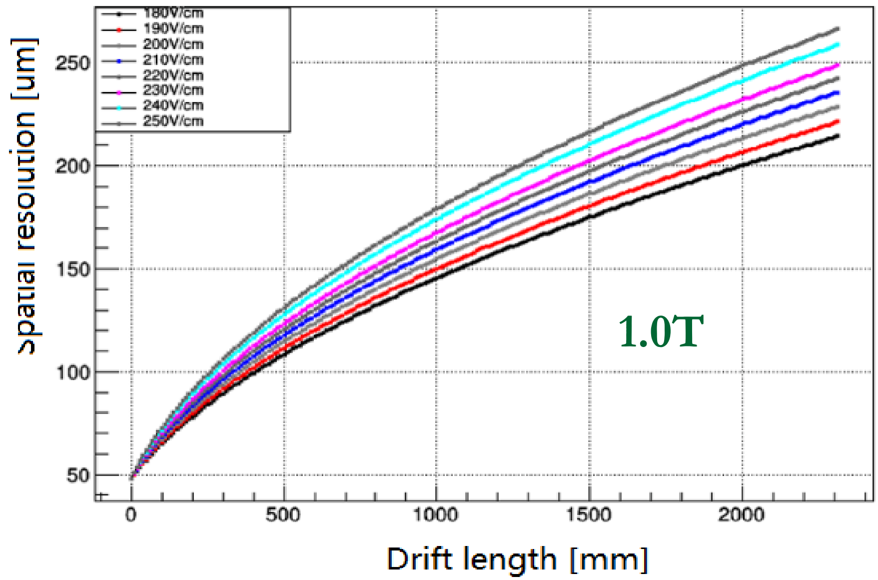
- TPC can provide large-volume high-precision 3D track measurement with stringent material budget
- In order to achieve the high spatial resolution (<100um in all drift length), small pads (e.g.1mmx6mm) are needed, resulting ~1million channels of readout electronics
- Need low power consumption readout electronics working at continuous mode
- Need effectively reduce ions

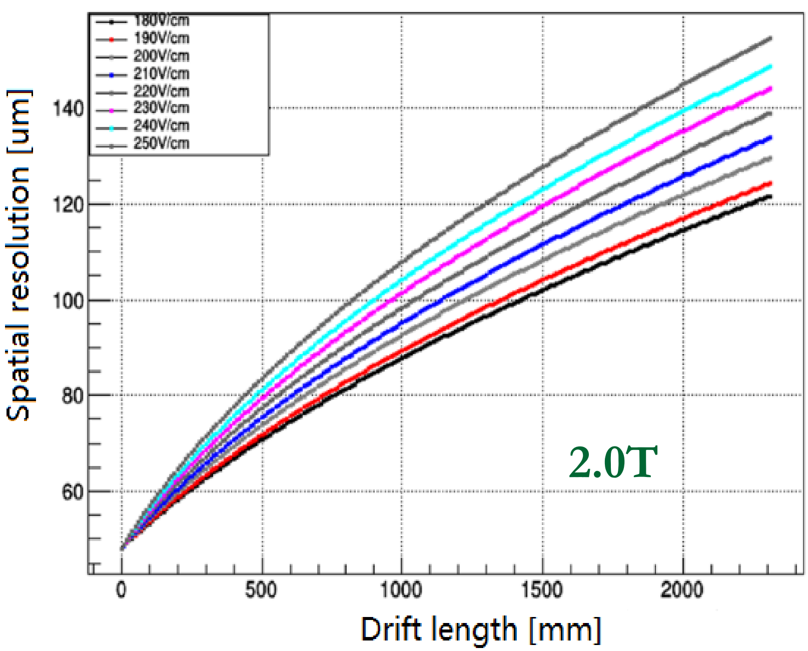
Momentum resolution (B=3.5T)	$\delta(^1/_{p_t} \approx \mathbf{10^{-4}/GeV/c})$
δ_{point} in $r\Phi$	<100 μm
δ_{point} in rz	0.4-1.4 mm
Inner radius	329 mm
Outer radius	1800 mm
Drift length	2350 mm
TPC material budget	$\approx 0.05X_0$ incl. field cage $< 0.25X_0$ for readout endcap
Pad pitch/no. padrows	≈ 1 mm × (4~10mm) /≈ 200
2-hit resolution	≈ 2 mm
Efficiency	>97% for TPC only ($p_t > 1GeV$) >99% all tracking ($p_t > 1GeV$)

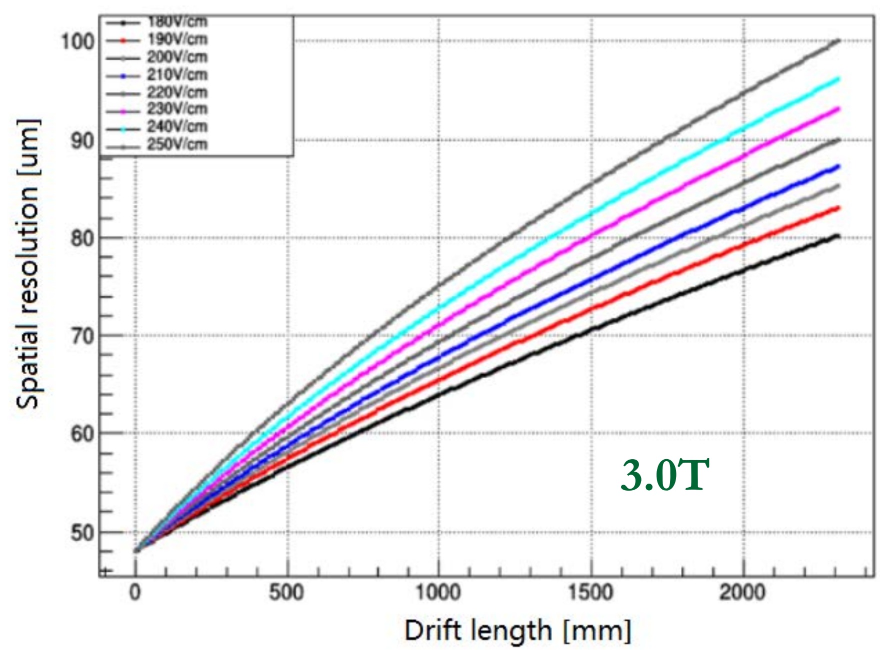
Spatial resolution VS magnetic field

$$\frac{\sigma_{p_\perp}}{p_\perp} = \sqrt{\left(\frac{\alpha'\sigma_x}{BL^2}\right)^2 \left(\frac{720}{N+4}\right) p_\perp^2 + \left(\frac{\alpha' C}{BL}\right)^2 \frac{10}{7}\left(\frac{X}{X_0}\right)}$$

measurements — multiple scattering





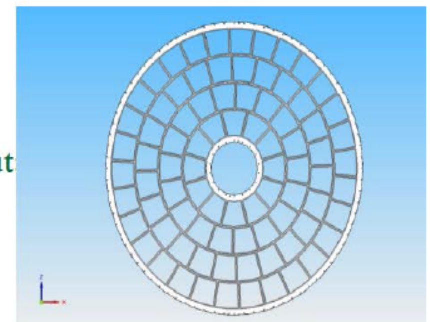


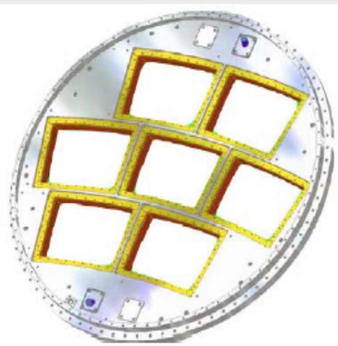
Overview of two readout options

Pad TPC and Pixel TPC

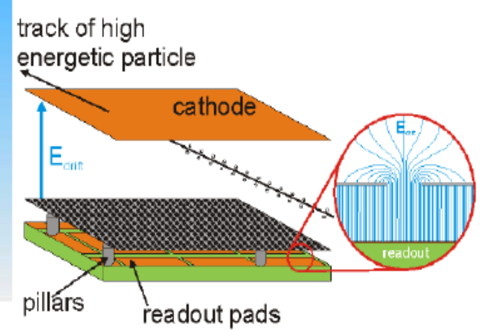
Pad TPC for collider

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





Pixel TPC for collider



For Collider @cost:
But to readout the TPC with GridPixes:
→100-120 chips/module
240 modules/endcap (10 m^2)
→50k-60k GridPixes
→ 10^9 pixel pads

Benefits of Pixel readout:

- Lower occupancy
  → 300 k Hits/s at small radii.
  → This gives < 12 single pixels hit/s.
  → With a read out speed of 0.1 msec (that matches a 10 kHz Z rate)
  → the occupancy is less than 0.0012
- Improved dE/dx
  → primary e- counting
  - Smaller pads/pixels could result in better resolution!
  - Gain <2000
  - Low IBF*Gain<2
  - CO_2 cooling

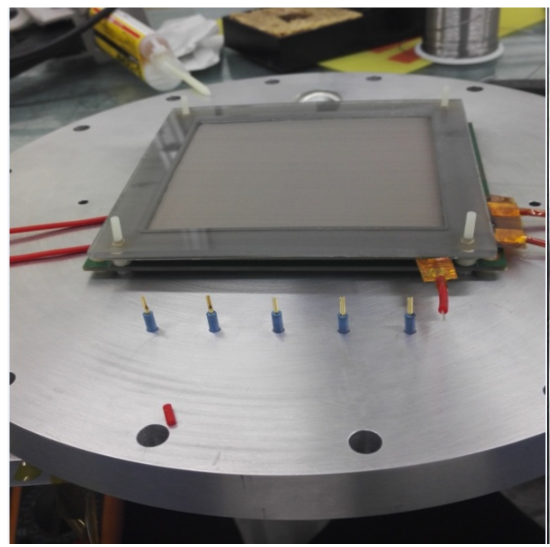
- **TPC module R&D**

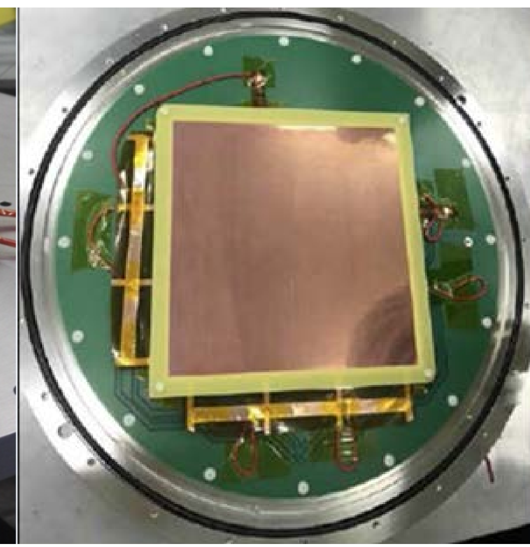
TPC detector module@ IHEP

- 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 in 2020

DOI: 10.1088/1748-0221/12/04/P0401 JINST，2017.4
DOI: 10.1088/1674-1137/41/5/056003， CPC,2016.11
DOI: 10.7498/aps.66.072901Acta Phys. Sin. 2017,7
DOI: 10.1142/S2010194518601217 (SCI) 2018
DOI: 10.1088/1748-0221/13/04/T04008 (SCI) 2018
DOI: 10.1007/978-981-13-1316-5_20 (SCI) 2018

50×50mm^2 2015-2016 → 100×100mm^2 2017-2018 → 200×200mm^2 2019-2020

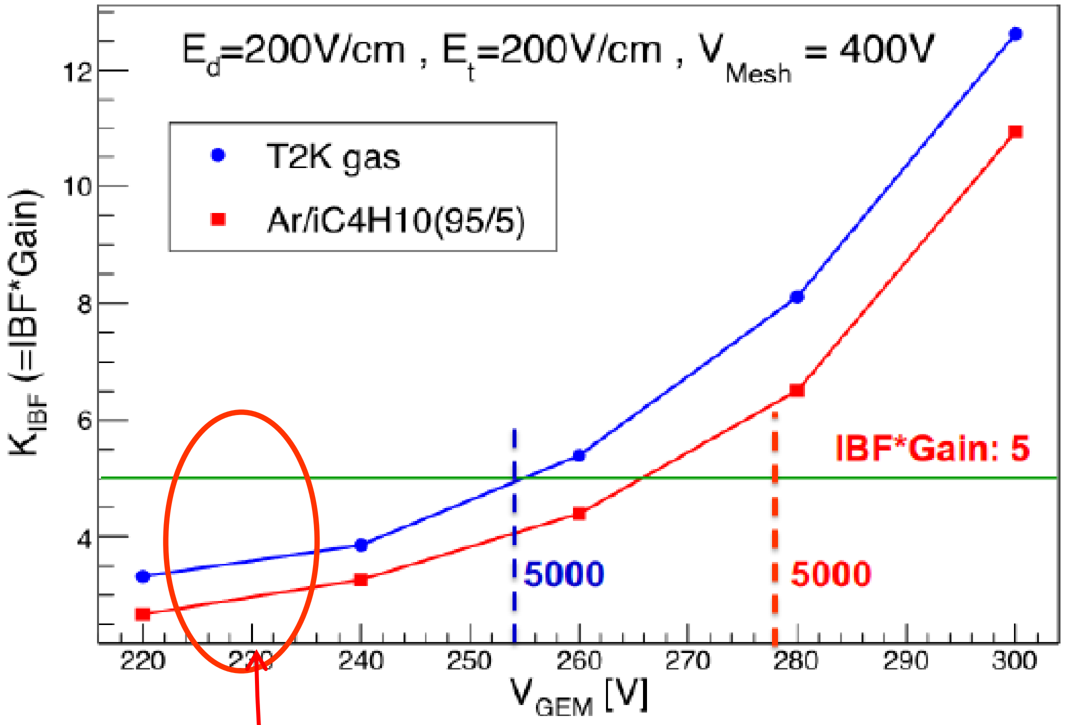




GEM-MM detector cathode

GEM+MM

Micronegas + GEM detector module @IHEP

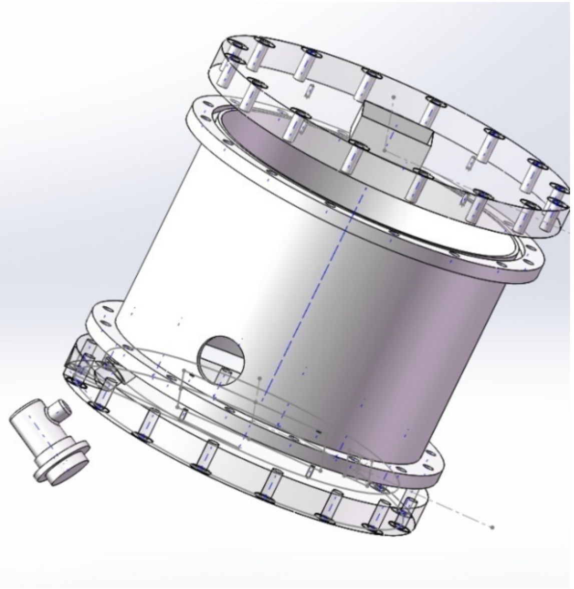


- IBF×Gain ratio can meet less than 2 at the lower gain under two mixture gases
- Lower gain and lower IBF ratio

UV test of the new module

- UV lamp measurement
  - New designed and assembled UV test chamber
  - Active area: 100mm×100mm
  - Deuterium lamp and aluminum film
  - Principle of photoelectric effect
  - Wave length: 160nm~400nm
  - Fused silica: 99% light trans.@266nm
  - Improve the field cage in drift length

Deuterium lamp
X2D2 lamp



UV test geometry with GEM-MM

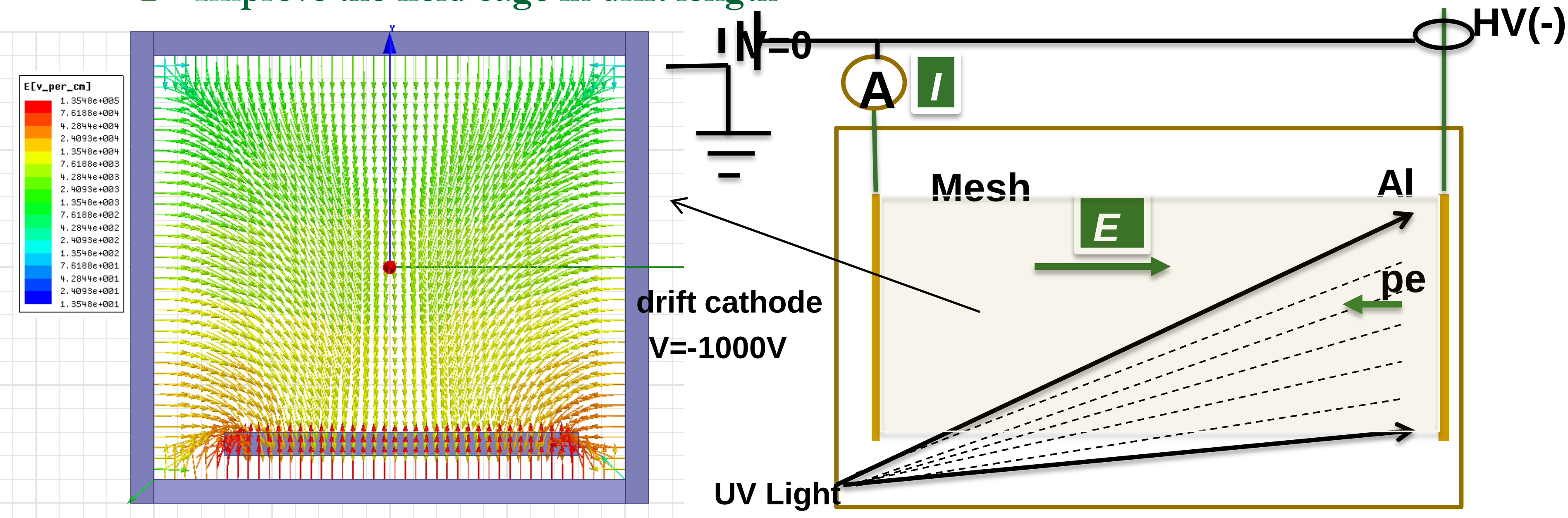
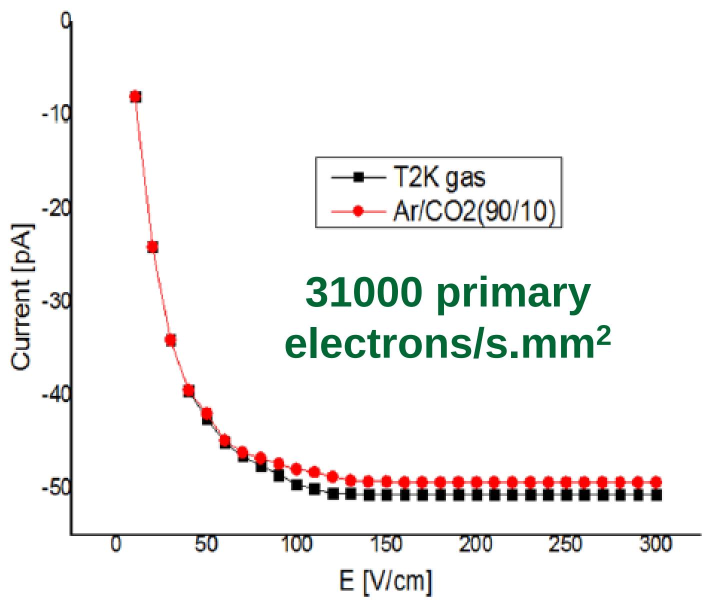


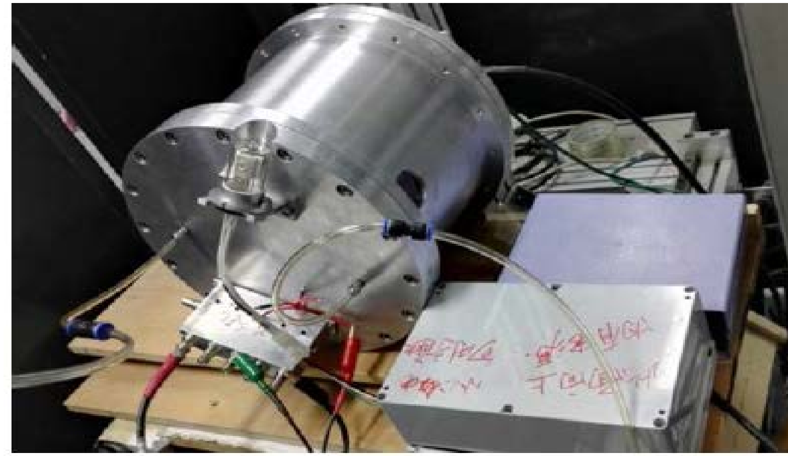
Diagram of the UV test with new module

IBF suppression R&D

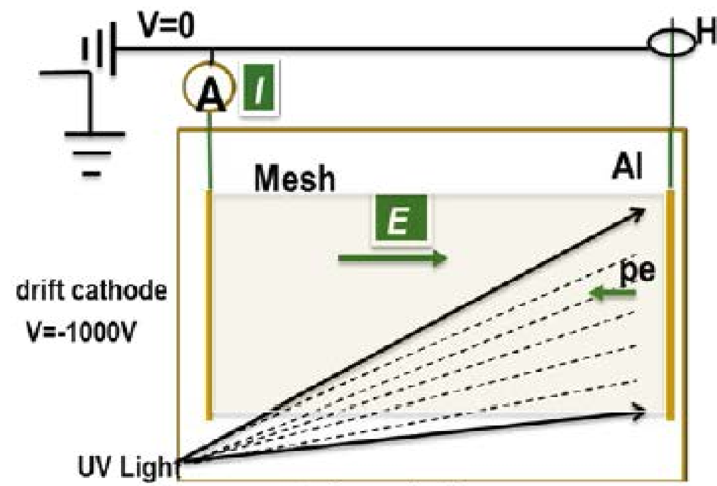
- UV lamp measurement
  - Added a new voltage controller
  - pA current meter from Keithley
  - First step test about the current in mesh
  - E_drift: 10~175V/cm
  - ~43pA@175V/cm
  - Stable current with UV light
  - ~200V/cm@T2K operation gas



MESH收集光电流随电压变化关系

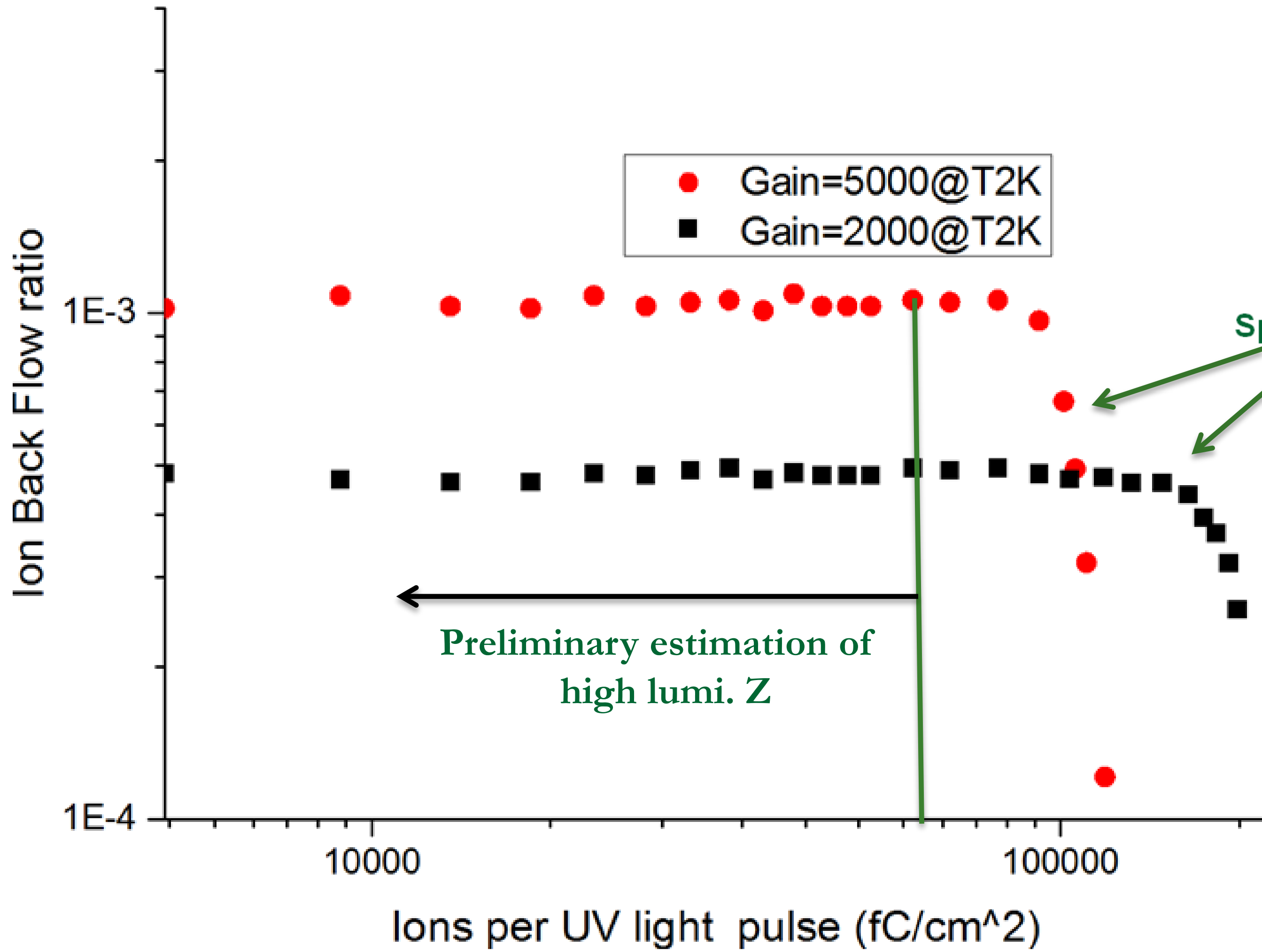


实验装置图



原理图

Space charge effect at the different gain



- Preliminary estimation of the high luminosity Z
- There are more safe factor when the detector will run at the lower gain (eg.2000-3000)

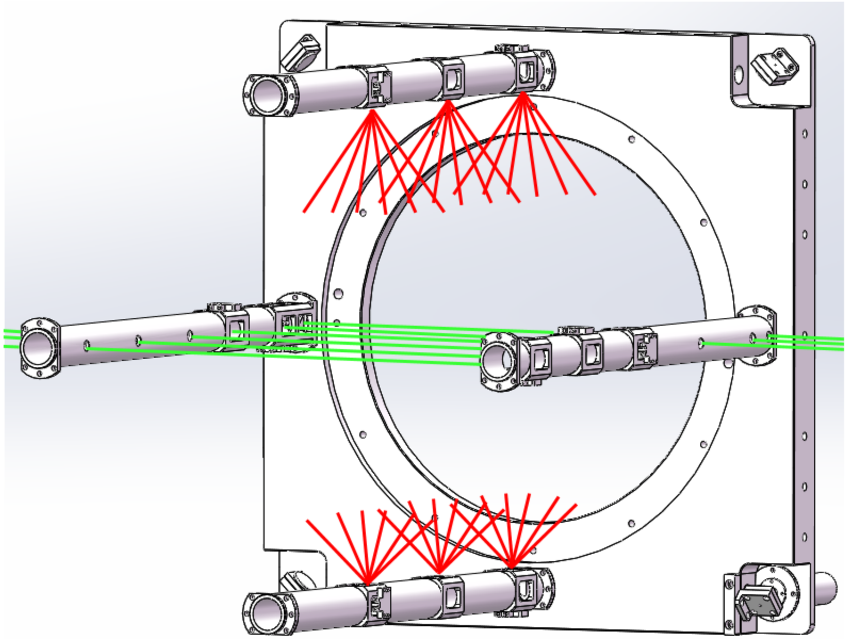
Different concepts with IBF suppression

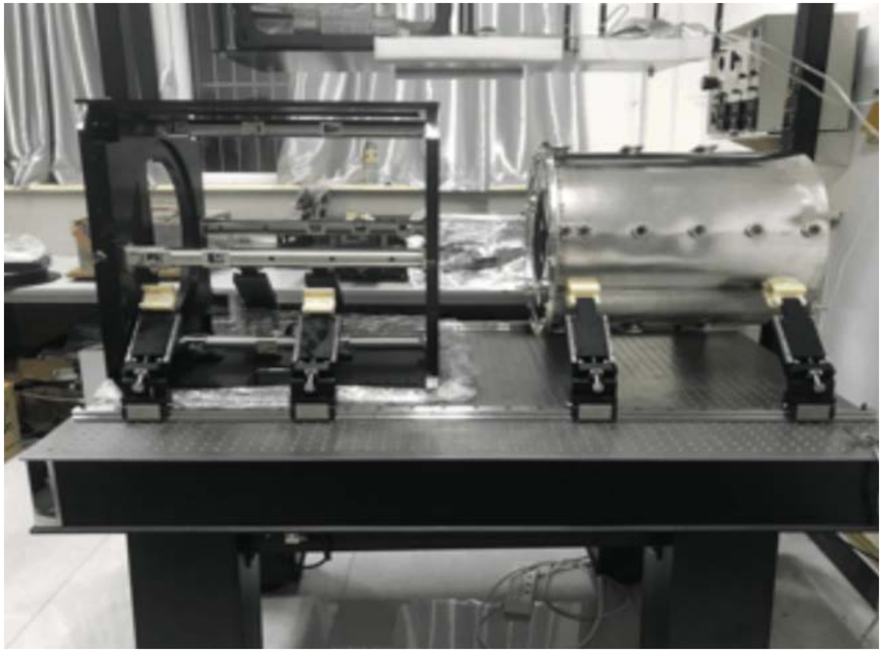
Pixel TPC with double meshes	Triple or double GEMs	Resistive Micromegas	GEM+ Micromegas	Double meshes Micromegas
IHEP, Nikehf	KEK, DESY	Saclay	IHEP	USTC
Pad size: 55um-150um square	Pad size: 1mm×6mm	Pad size: 1mm×6mm	Pad size: 1mm×6mm	Pad size: 1mm×6mm (If resistive layer)
Advantage for TPC: Low gain: 2000 IBF×Gain: -1	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 R&D**

TPC Prototype sketch

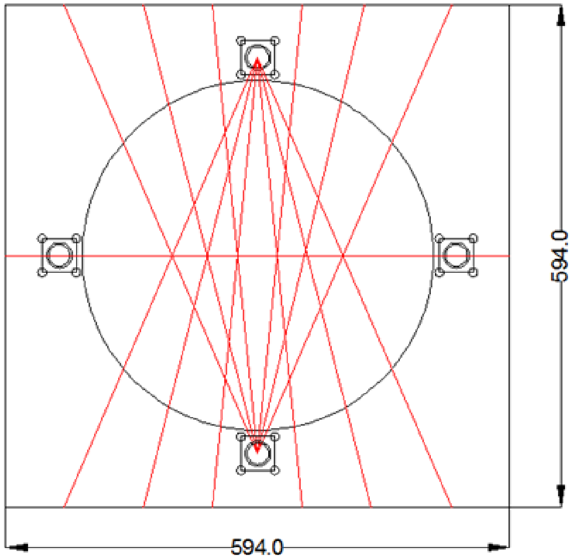
- Main parameters
  - Same test parameters in CEPC
    - Drift field=200V/cm
    - Relative gain: ≥2000
    - Readout pad(anode) is designed to 0V (Ground)
    - TPC detector system: Fieldcage+ Pads readout
    - Working mixture gas:
      - $Ar/CF_4/iC_4H_{10}$=95/3/2
      - Same purity
  - Specific 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



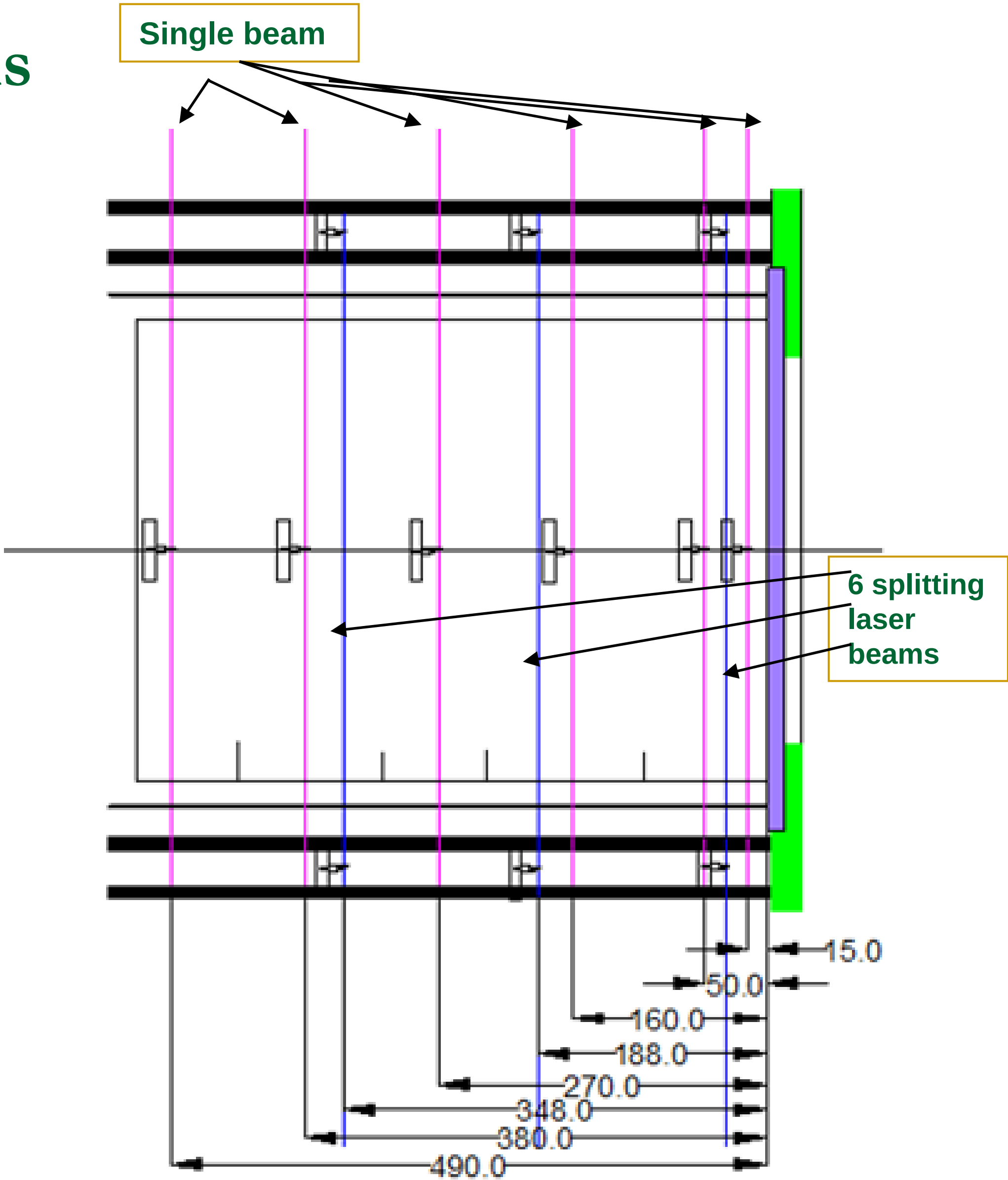


TPC prototype

Layout of UV laser beams



Laser map in X-Y direction



Laser map along drift length

Electronics and DAQ

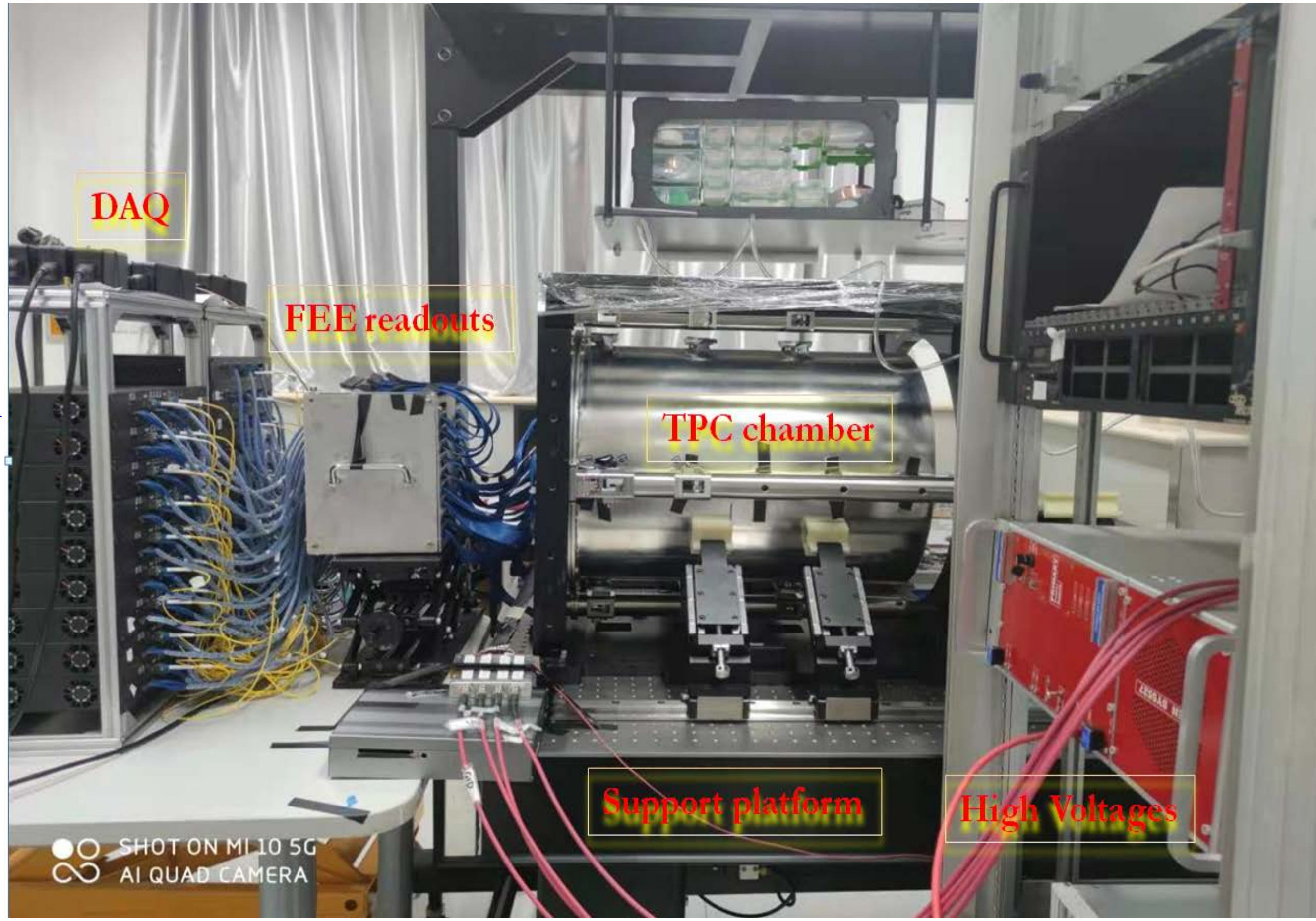
- Amplifier and FEE
  - CASAGEM chip
  - 16Chs/chip
  - 4chips/Board
  - Gain: 20mV/fC
  - Shape time: 20ns

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

FEE Electronics and DAQ setup photos

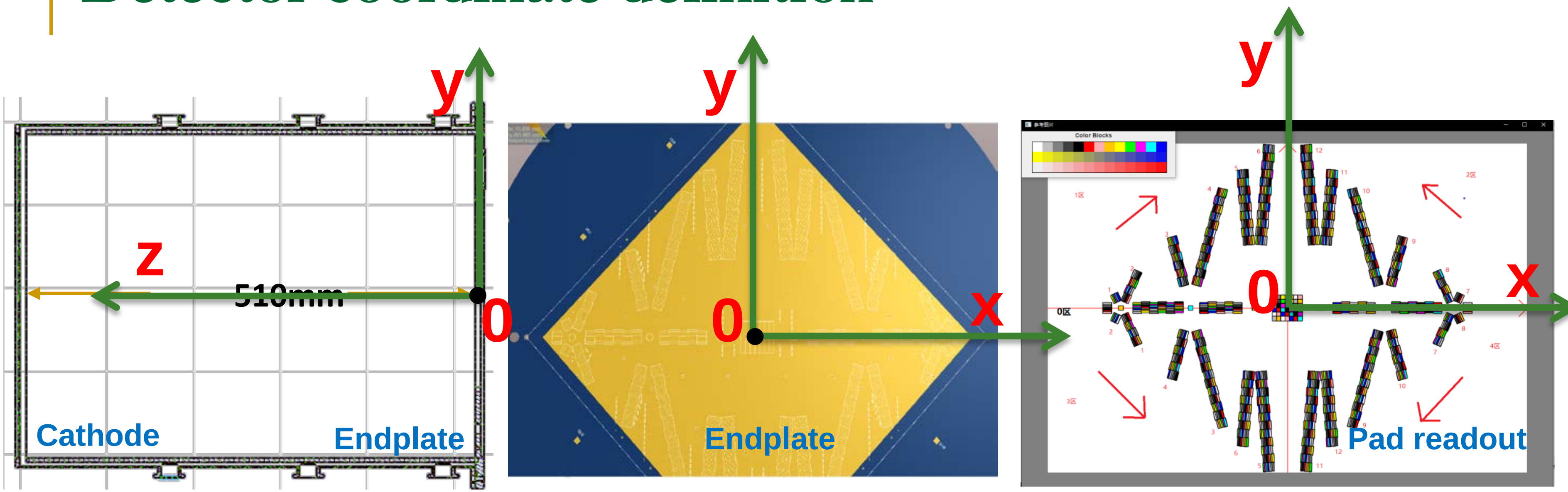
Status of TPC prototype

- Detector prototype was done and working well
- Commissioning: Huirong Qi, Zhiyang Yuan, Yiming Cai, Yue Chang, Jiang Zhang, Yulan Li, Zhi Deng
- Data taking: the same, plus: Hongyu Zhang, Ye Wu
- Data taking and more analysis on going



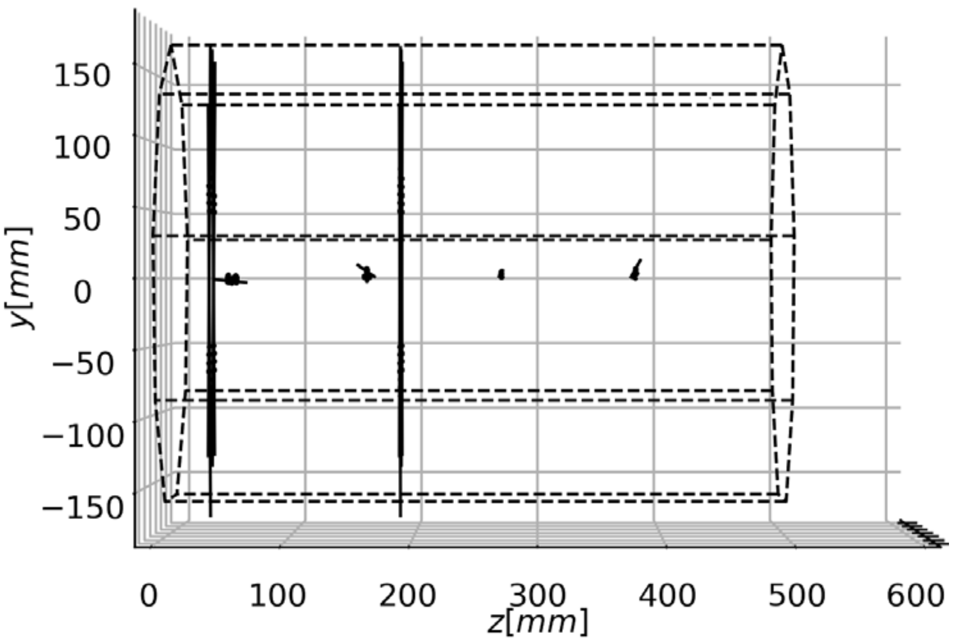
TPC prototype in the lab

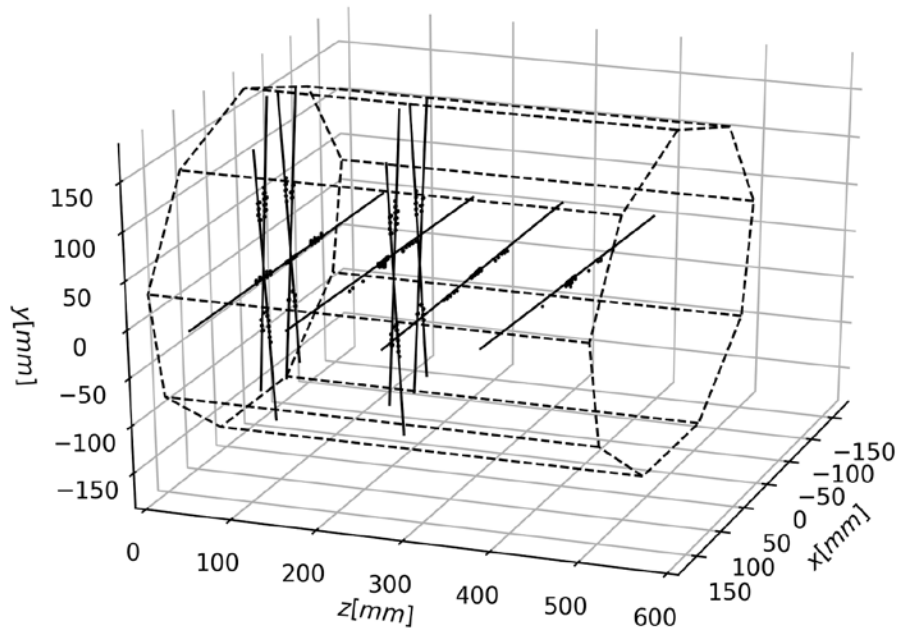
Detector coordinate definition



- The origin of the coordinate is set at the center of the endplate board.
- X and Y plan is set as the readout plane
- Z is set along the drift length from endplate to the cathode
- Z_0 plane is set at the first surface of the detector from cathode to endplate plane.
- The center of the pad is set as the pad's coordinate, and every pad has the specific x and y.

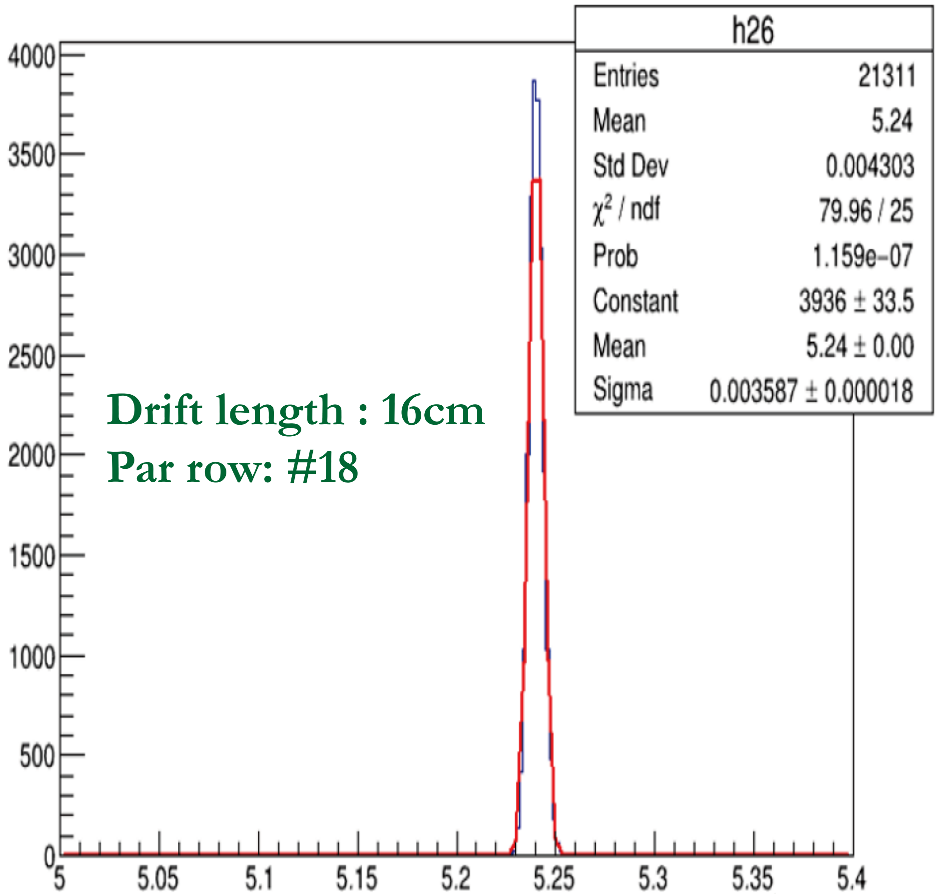
Laser tracks in chamber@T2K gas



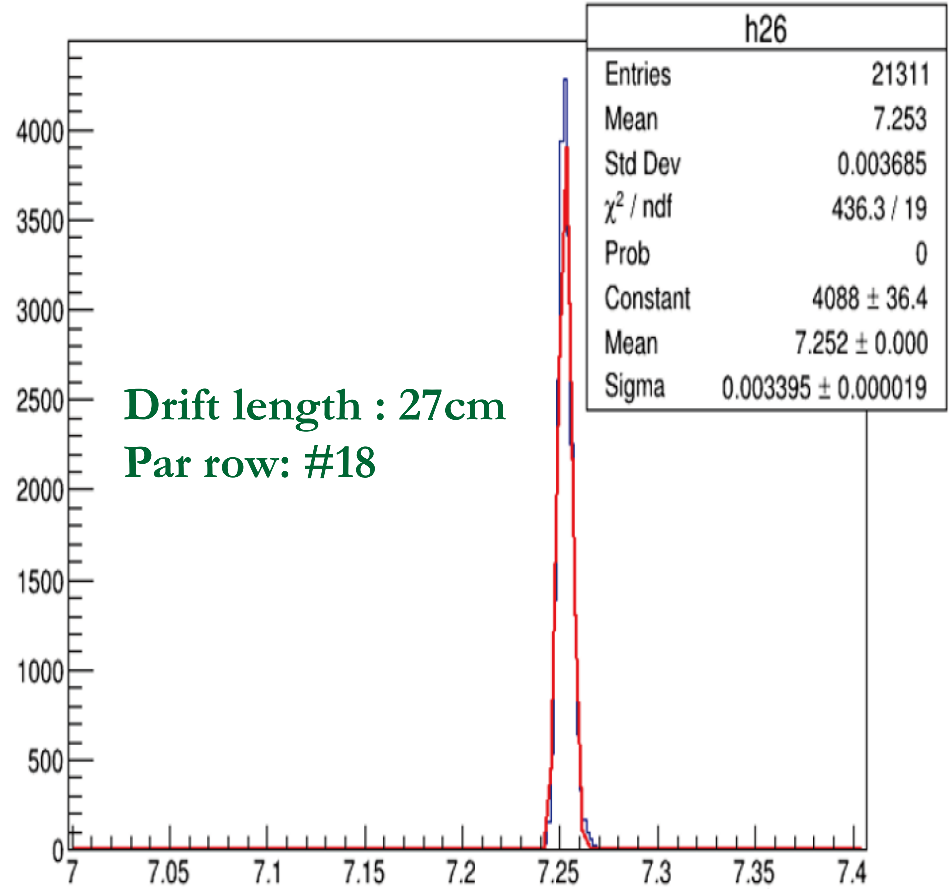


- Same of working gas@T2K, same of high voltage, same of test conditions
- Different of GEMs@ 320V
- Triple GEMs to double GEMs
- No discharge

Drift time @400MHz



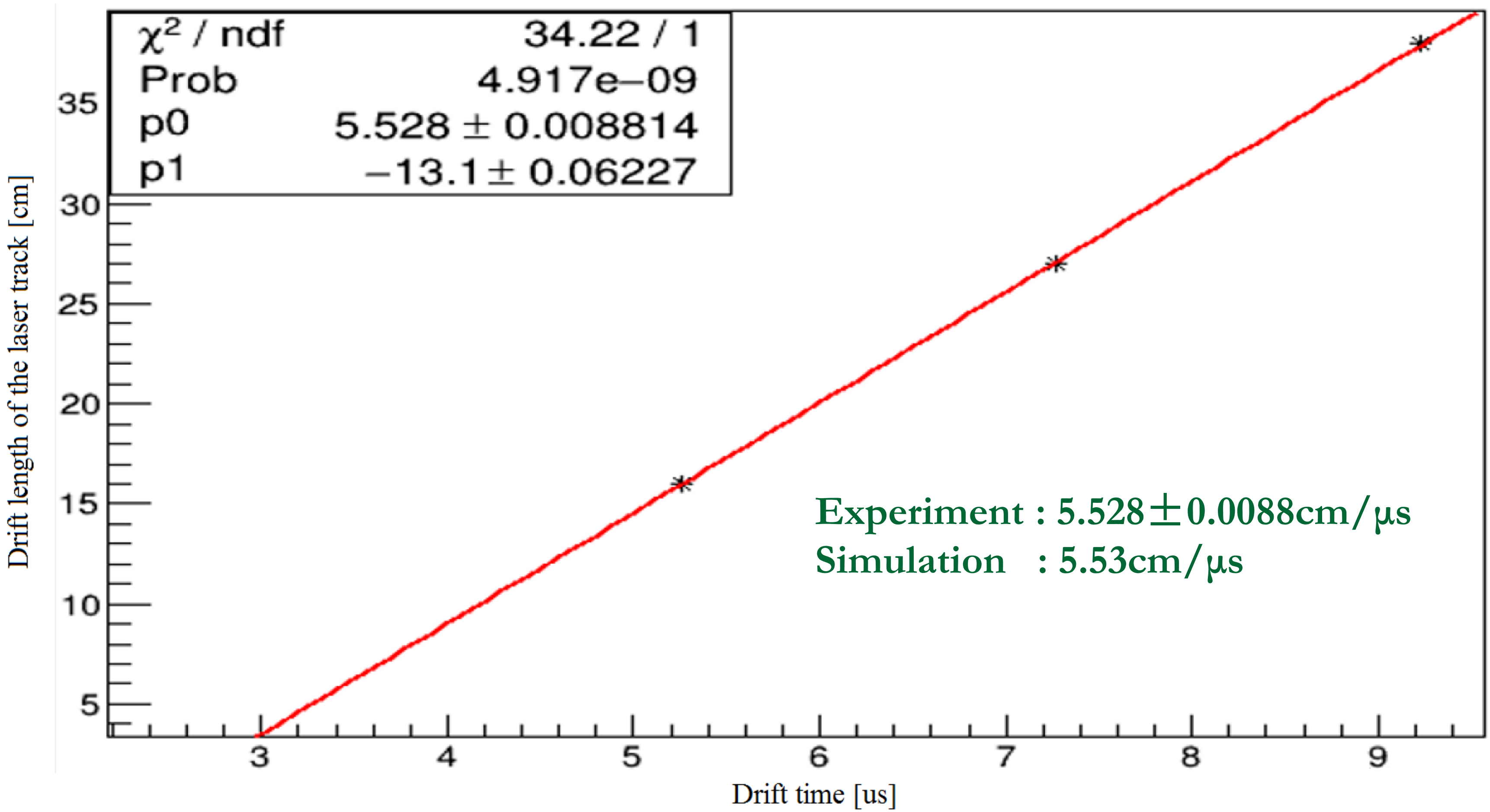
Drift time [µs]



Drift time [µs]

Drift time of the electron at 150V/cm in T2K

Drift velocity



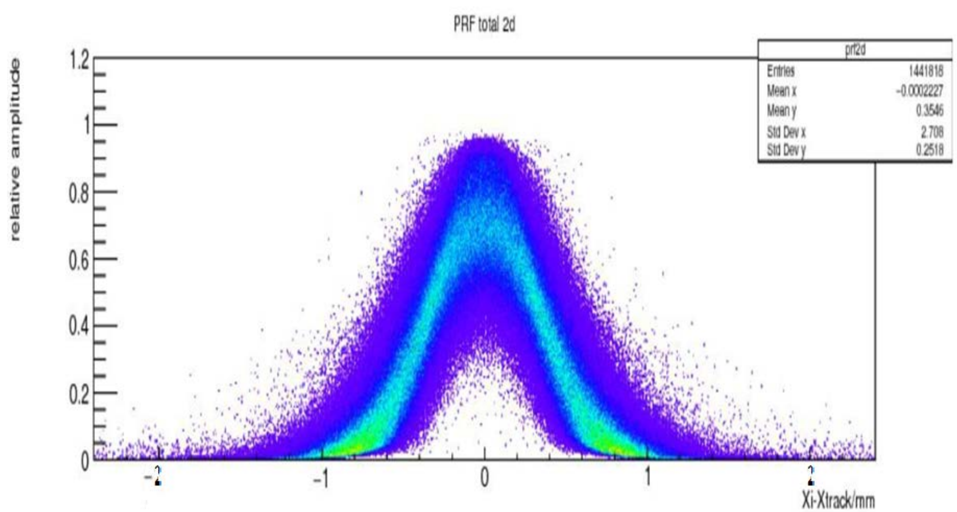
Drift velocity of the electron at 150V/cm in T2K

PRF analyzing of the spatial resolution (update)

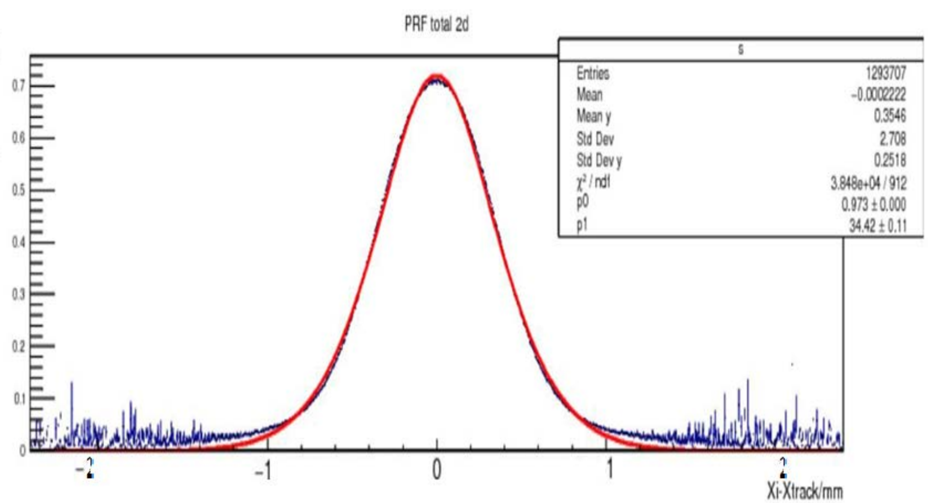
- **Pad Response Function** (PRF): a function used to describe the charge distribution and to determine the hit position via Pad

$$PRF(x, y, w) = \frac{e^{-4ln2(1-y)x^2/w^2}}{1 + 4y \cdot x^2/w^2}$$

  - x is the Pad's coordinate of the center of the corresponding Pad in x-aixs.
  - y is a factor to describe Lorentzian and the Gaussian function
  - w is the width of the Pad (in here, the Pad's width is 0.9 mm)



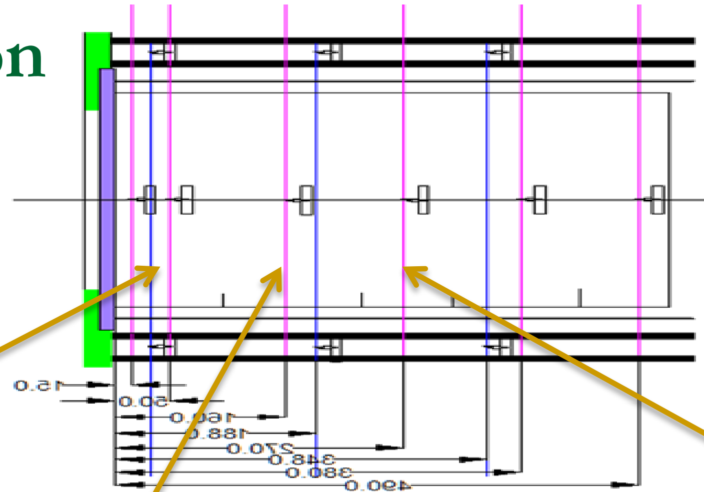
PRF total of all data

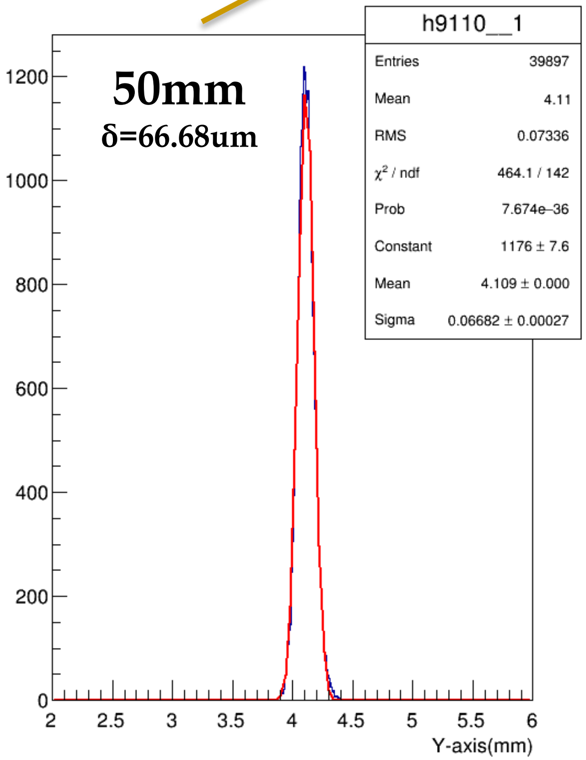


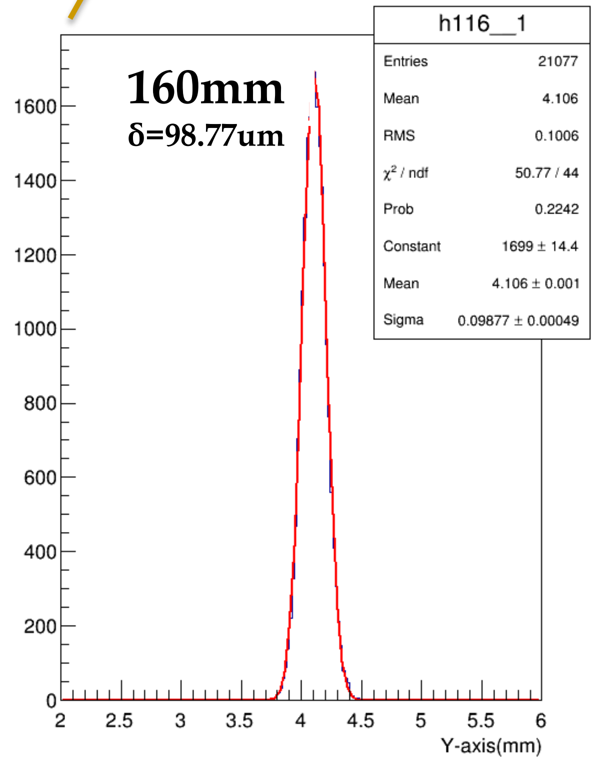
Profile of PRF from one pad row

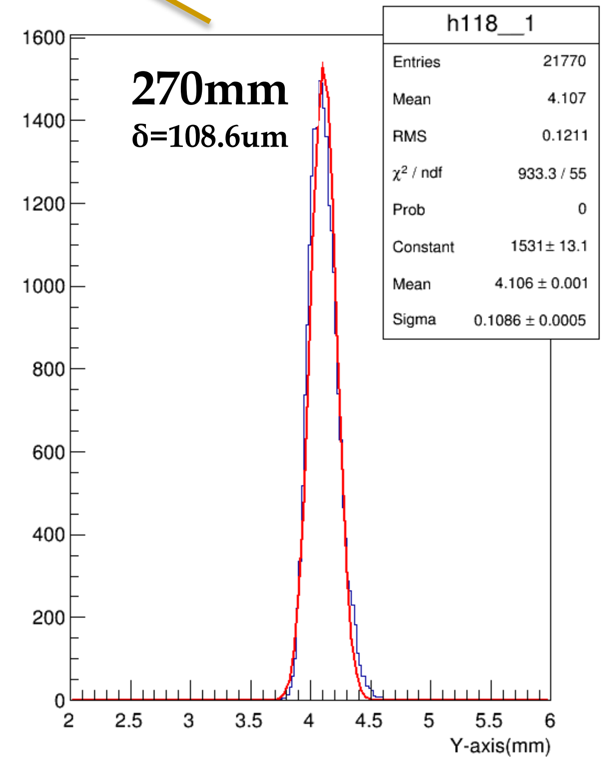
Space resolution

N_{eff} of UV laser in test: ~80



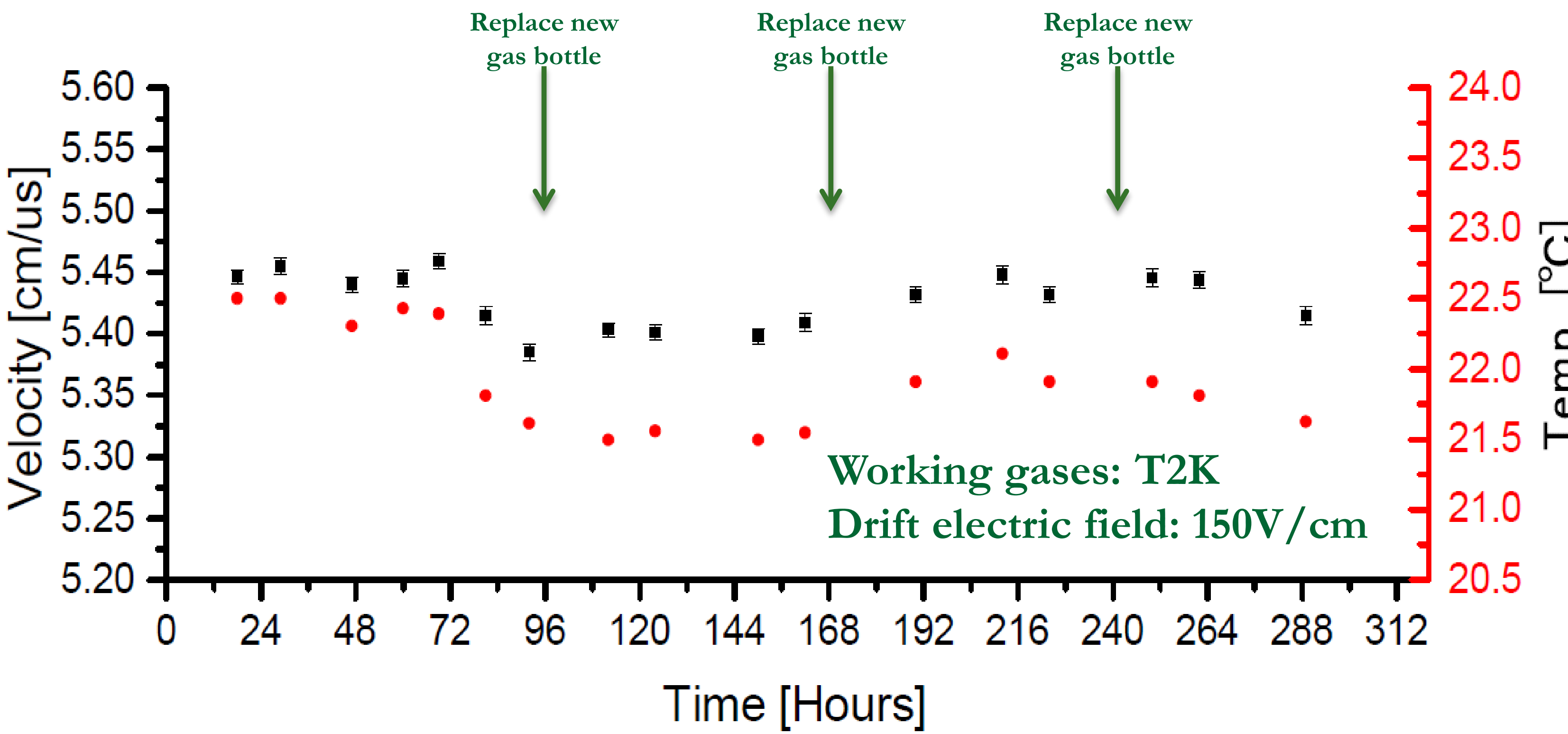






Space resolution at the different drift length

Drift velocity measurement



- Two weeks of continuous testing (Data of E_{drift}=220V/cm is still taking)
- Room temperature recorded
- Comparison of the drift velocity and the temperature
- Simulation of some influencing factors using Garfield/Gariflield++ software

Conclusion: 266nm UV laser can work well when it can be as the online monitor option.

Plan studies of TPC prototype

more studies are ongoing…

dE/dx

track distortion

gain uniformity

and …

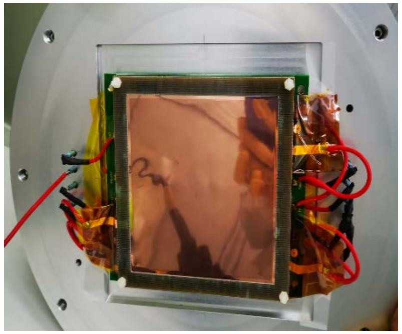
Current TPC readout ASICs

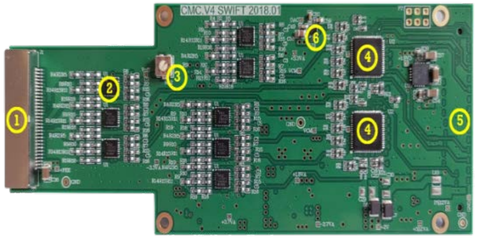
- Waveform sampling (8-10 bit, ~10MS/s) is required for TPC signal processing
- Direct ADC sampling is more preferable than SCA for high rate applications
- Lower power consumption → less cooling → less material

	PASA/ALTRO	AGET	Super-ALTRO	SAMPA
TPC	ALICE	T2K	ILC	ALICE upgrade
Pad size	4x7.5 mm^2	6.9x9.7 mm^2	1x6 mm^2	4x7.5 mm^2
Pad channels	5.7 x 10^5	1.25 x 10^5	1-2 x 10^6	5.7 x 10^5
Readout Chamber	MWPC	MicroMegas	GEM/MicroMegas	GEM
Gain	12 mV/fC	0.2-17 mV/fC	12-27 mV/fC	20/30 mV/fC
Shaper	$CR-(RC)^4$	$CR-(RC)^2$	$CR-(RC)^4$	$CR-(RC)^4$
Peaking time	200 ns	50 ns-1us	30-120 ns	80/160 ns
ENC	385 e	850 e @ 200ns	520 e	482 e @ 180ns
Waveform Sampler	ADC	SCA	ADC	ADC
Sampling frequency	10 MSPS	1-100 MSPS	40 MSPS	20 MSPS
Dynamic range	10 bit	12 bit(external)	10 bit	10 bit
Power consumption	32 mW/ch	<10 mW/ch	47.3 mW/ch	8 mW/ch
CMOS Process	250 nm	350 nm	130 nm	130 nm

New electronics commissioning

- A 16 channels low power consumption readout 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





Detector and ASIC

- Future studies
  - More ASIC evaluations: Higher sampling rate, more detailed noise test, test with detectors …
  - Low power digital filter and data compression in FPGA/ASIC
  - Commission of ASIC chip board and the detector to test in the laboratory

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 system will be very useful in the TPC prototype R&D.
- The detector module will assembled and commissioned with the low power consumption ASIC chip in this year.

Thanks for your attention.