Investigation of TPC prototype using 266nm UV laser tracks for CEPC

Huirong Qi

ZhiYang Yuan, Yiming Cai, Yue Chang, Jian Zhang, Zhi Deng
Yulan Li, Hui Gong, Wei Liu, Hongyu Zhang, Ye Wu

Institute of High Energy Physics, CAS

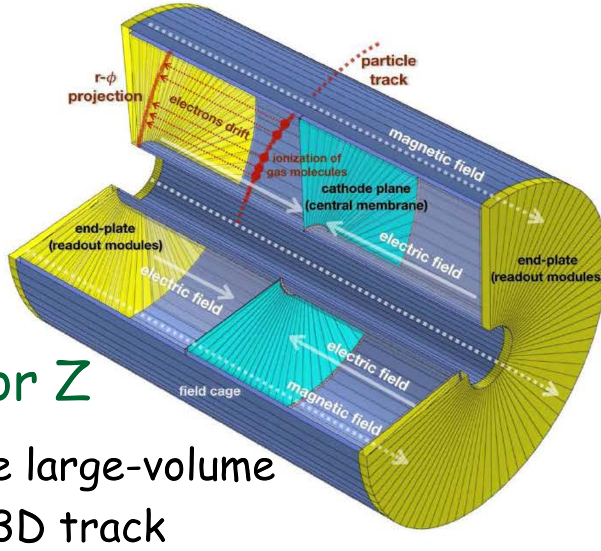
Tsinghua University

AFAD 2021, March, 17, 2021

Outline

- Motivation
- TPC module and readout
- TPC prototype R&D
- Summary

Motivation



Momentum resolution (B=3.5T)	$\delta(1/p_t \approx 10^{-4}/GeV/c)$
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 ($p_t > 1GeV$)

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

CEPC High Luminosity Parameters after CDR

	tt	*Higgs*	*W*	*Z*	
Number of IPs	2	2	2	2	
Energy (GeV)	180	120	80	45.5	
Circumference (km)	100	100	100	100	
SR loss/turn (GeV)	8.53	1.73	0.33	0.036	
Half crossing angle (mrad)	16.5	16.5	16.5	16.5	
Piwinski angle	1.16	4.87	9.12	24.9	
N_e/bunch (10^{10})	20.1	16.3	11.6	15.2	
Bunch number (bunch spacing)	37 (4.45μs)	214 (0.7us)	1588 (0.2μs)	3816 (86ns)	11498 (26ns)
Beam current (mA)	3.5	16.8	88.5	278.8	839.9
SR power /beam (MW)	**30**	**30**	**30**	**10**	**30**
Bending radius (km)	10.7	10.7	10.7	10.7	
Phase advance of arc cell	90°/90°	90°/90°	90°/90°	60°/60°	
Momentum compaction (10^{-5})	0.73	0.73	0.73	1.48	
β_{IP} x/y (m)	1.0/0.0027	0.33/0.001	0.33/0.001	0.15/0.001	
Emittance x/y (nm)	1.45/0.0047	0.68/0.0014	0.28/0.00084	0.27/0.00135	
Transverse σ_{IP} (um)	37.9/0.11	15.0/0.037	9.6/0.029	6.36/0.037	
ξ_x/ξ_y/IP	0.076/0.106	0.018/0.115	0.014/0.13	0.0046/0.131	
V_{RF} (GV)	9.52	2.27	0.47	0.1	
f_{RF} (MHz) (harmonic)	650 (216816)	650 (216816)	650 (216816)	650 (216816)	
Nature bunch length σ_z (mm)	2.23	2.25	2.4	2.75	
Bunch length σ_z (mm)	2.66	4.42	5.3	9.6	
HOM power/cavity (kw)	**0.45 (5cell)**	**0.48 (2cell)**	**0.79 (2cell)**	**2.0 (2cell)**	**3.02 (1cell)**
Energy spread (%)	0.17	0.19	0.11	0.12	
Energy acceptance requirement (DA) (%)	2.0	1.7	1.2	1.3	
Energy acceptance by RF (%)	2.61	2.5	1.82	1.48	
Lifetime (hour)	0.59	0.35	1.3	1.7	1.4
L_{max}/IP ($10^{34}cm^{-2}s^{-1}$)	**0.5**	**5.0**	**18.7**	**35.0**	**105.5**

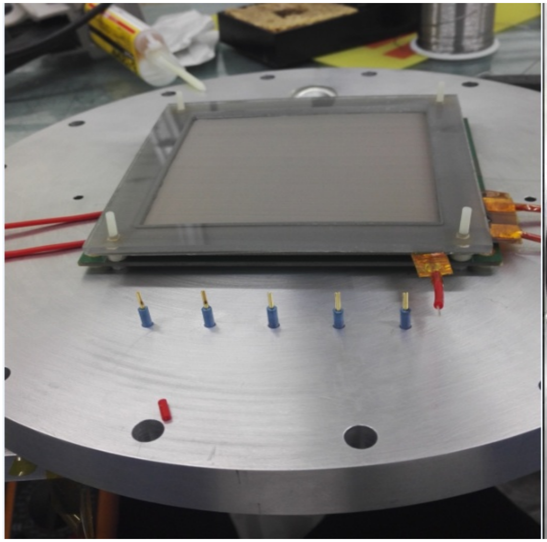
- **TPC module R&D**

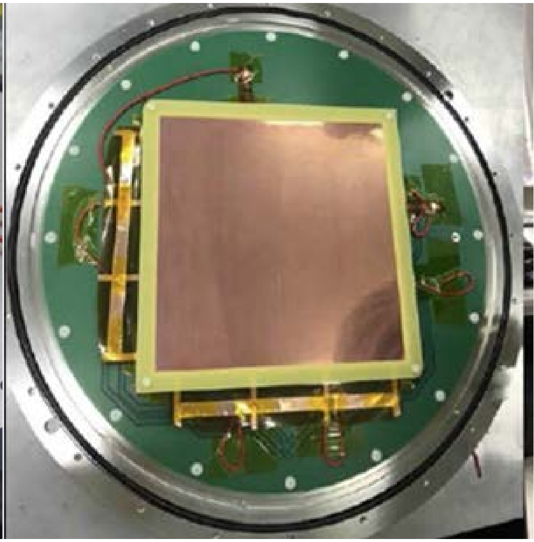
TPC detector module@ IHEP

- **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

$50\times50mm^2$ 2015-2016 → $100\times100mm^2$ 2017-2018 → $200\times200mm^2$ 2019-2020

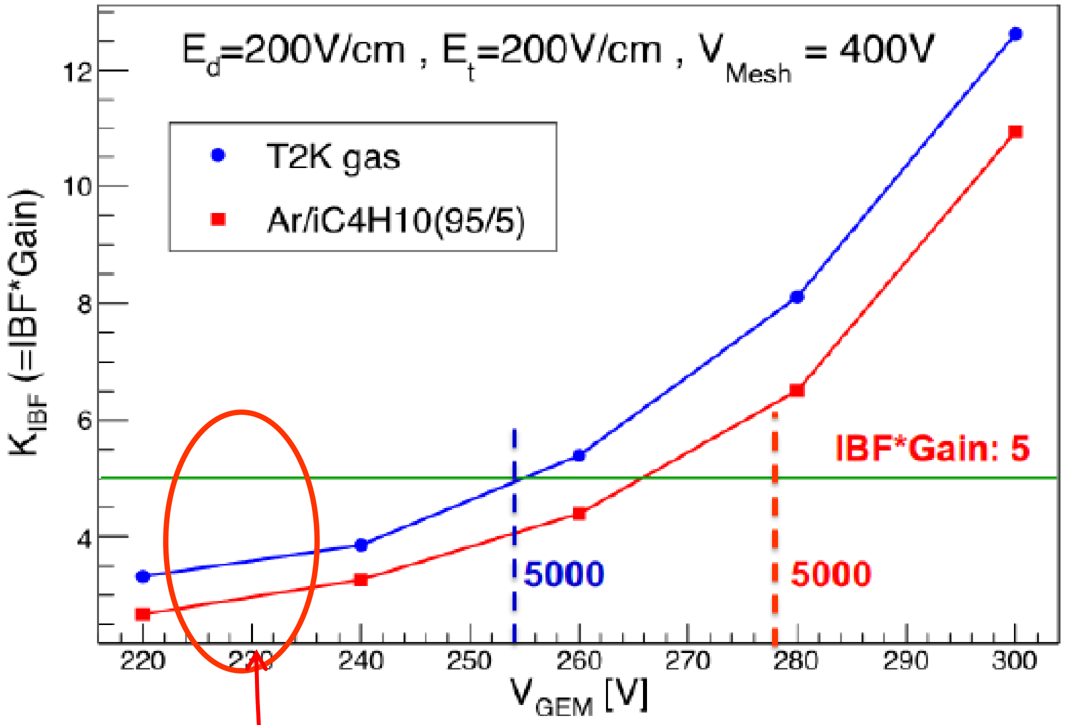




GEM-MM detector cathode

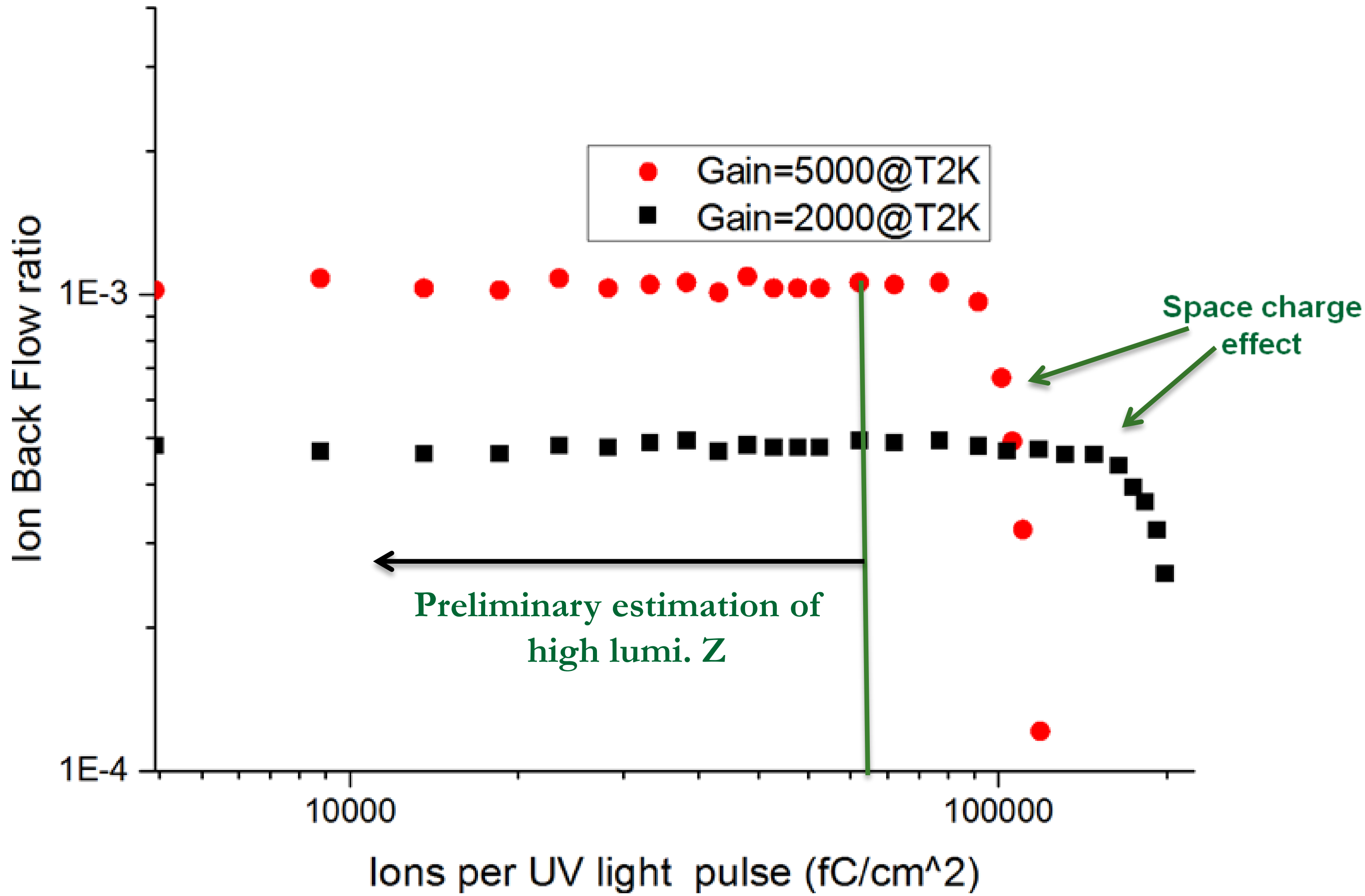
GEM+MM

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

Space charge effect at the different gain

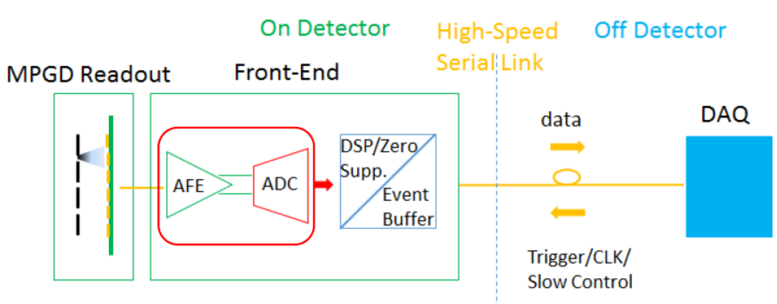


- Preliminary estimation of the high luminosity Z
- There are more safe factor when the detector will run at the lower gain (eg.2000-3000)

Specifics of ASIC using 65nm

- In order to reduce the power consumption:
  - Using more advanced 65 nm CMOS process favoring digital logics
  - Reducing analog circuits:
    - CR-$(RC)^n$ →CR-RC, moving high order shaping to digital domain
    - ADC structure : pipeline → SAR (Successive Approximation Register)
- So far only the AFE and the ADC parts have been implemented

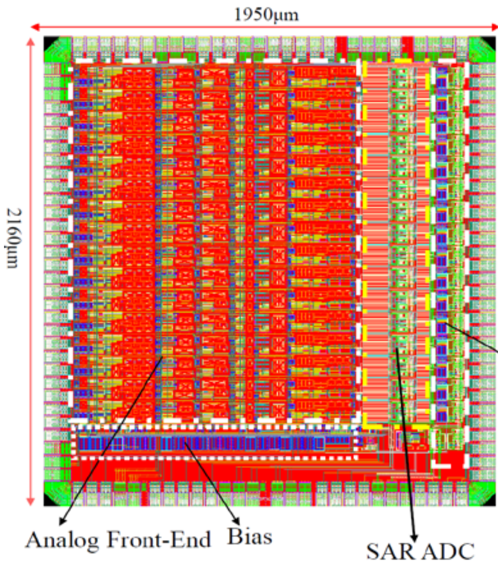
AFE(Analog Front-End)	
Signal Polarity	Negative
Detector Capacitance	5-20 pF
Shaper	CR-RC
Shaping Time	160 ns
ENC (Equivalent Noise Charge)	<500 e @ 10pF
Dynamic Range	120 fC max.
Gain	10-40 mV/fC
INL (Integrated Non-Linearity)	<1%
Crosstalk	<1%
Power Consumption (AFE)	<2.5 mW/ch



SAR-ADC	
Input Range	-0.6 V ~ 0.6 V diff.
Resolution	10 bit
Sampling Rate	40 MS/s
DNL	<0.6 LSB
INL	<0.6 LSB
SFDR @ 2MHz, 40MSPS	68 dBc
SINAD	57 dB
ENOB	>9.2 bit @ 2MHz
Power Consumption (ADC)	<2.5 mW/ch

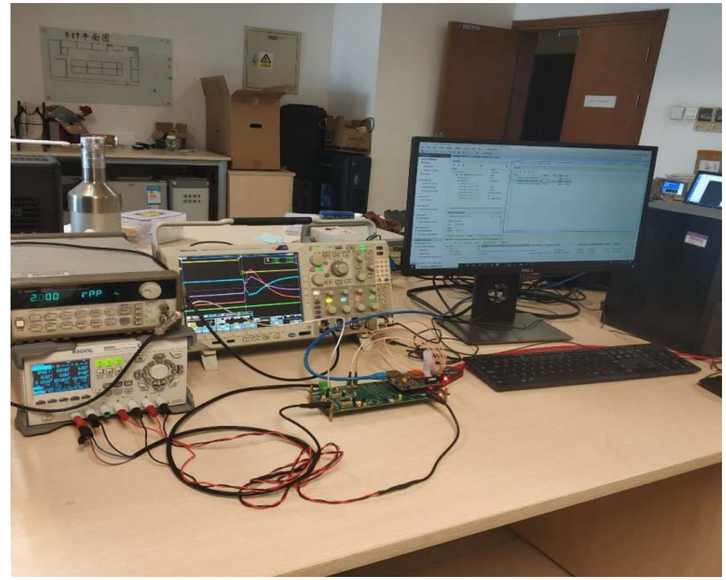
- AFE + waveform sampling ADC + direct output
- Process: TSMC 65nm LP
- Power supply: 1.2V

Tests of the ASIC chip

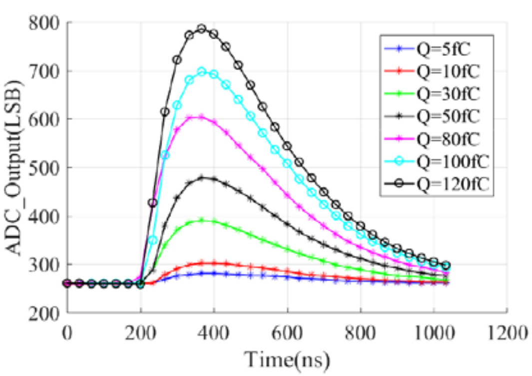


Layout of ASIC chip

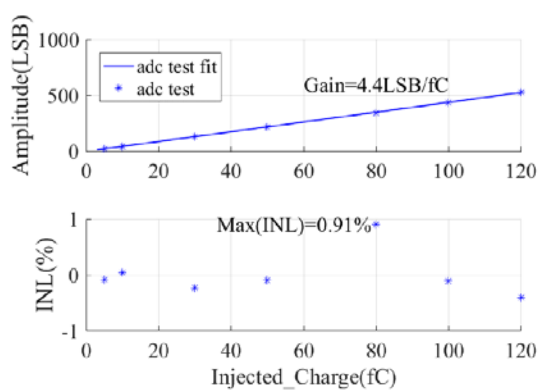
- A 16 channel low power readout ASIC for TPC readout have been developed
  - The power consumption is 2.33 mW/channel:
    - P_{AFE}=1.43 mW/channel
    - P_{ADC} = 0.9 mW/channel @ 40MS/s
  - ENC = 852 e @ Cin=2 pF, gain=10 mV/fC and can be reduced to 474 e using digital trapezoidal filter
  - The ASIC have been taped out in November, 2019 and is being evaluated



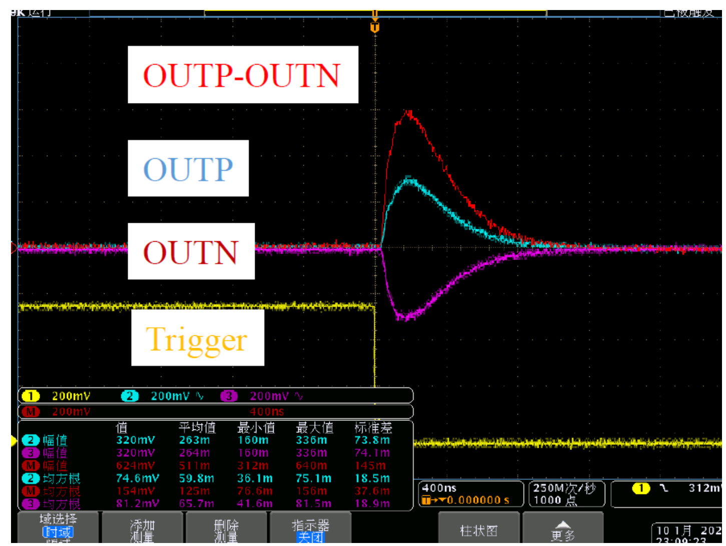
- Transient outputs



- The linearity @ gain = 10 mV/fC



Gain = 4.4 LSB/fC = 4.4 x 2.34 mV/fC = 10.3 mV/fC



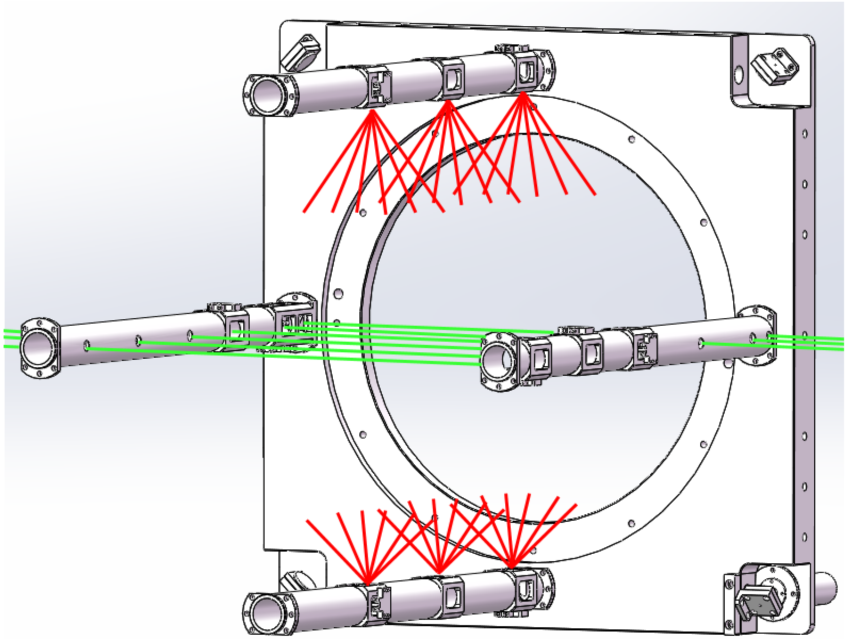
Test of the signals

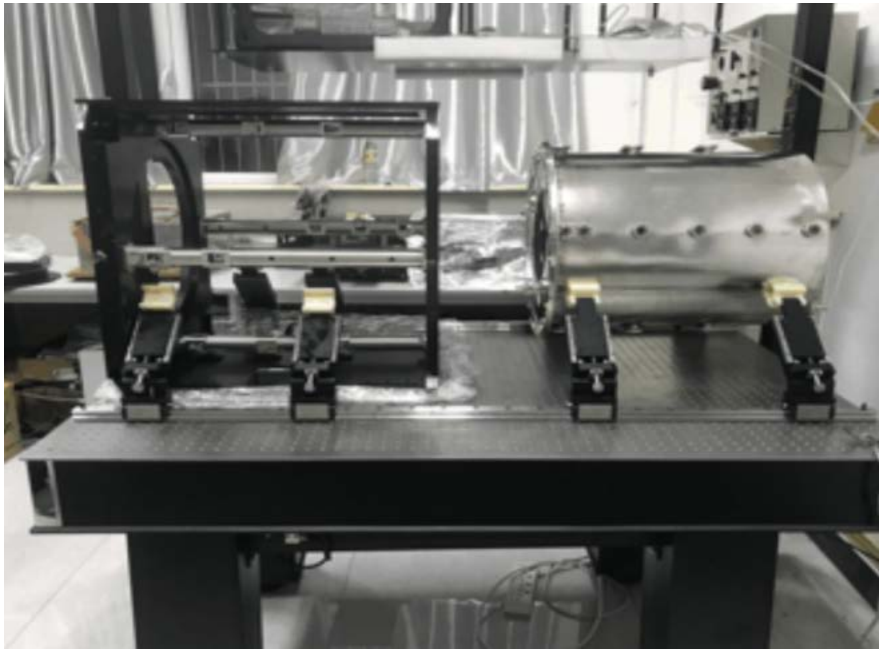
- **TPC prototype R&D**

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

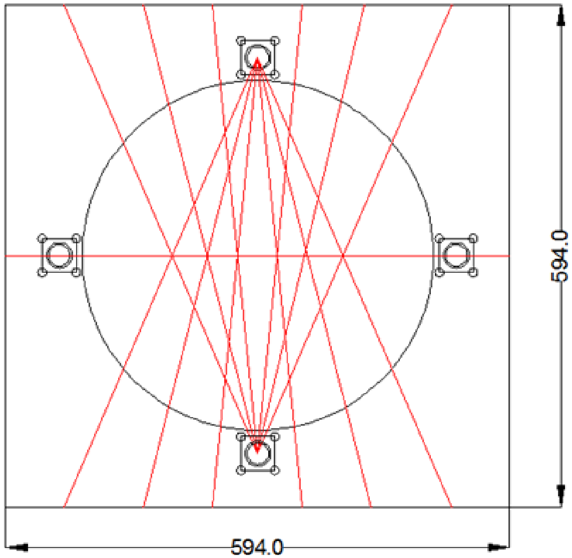
preliminary



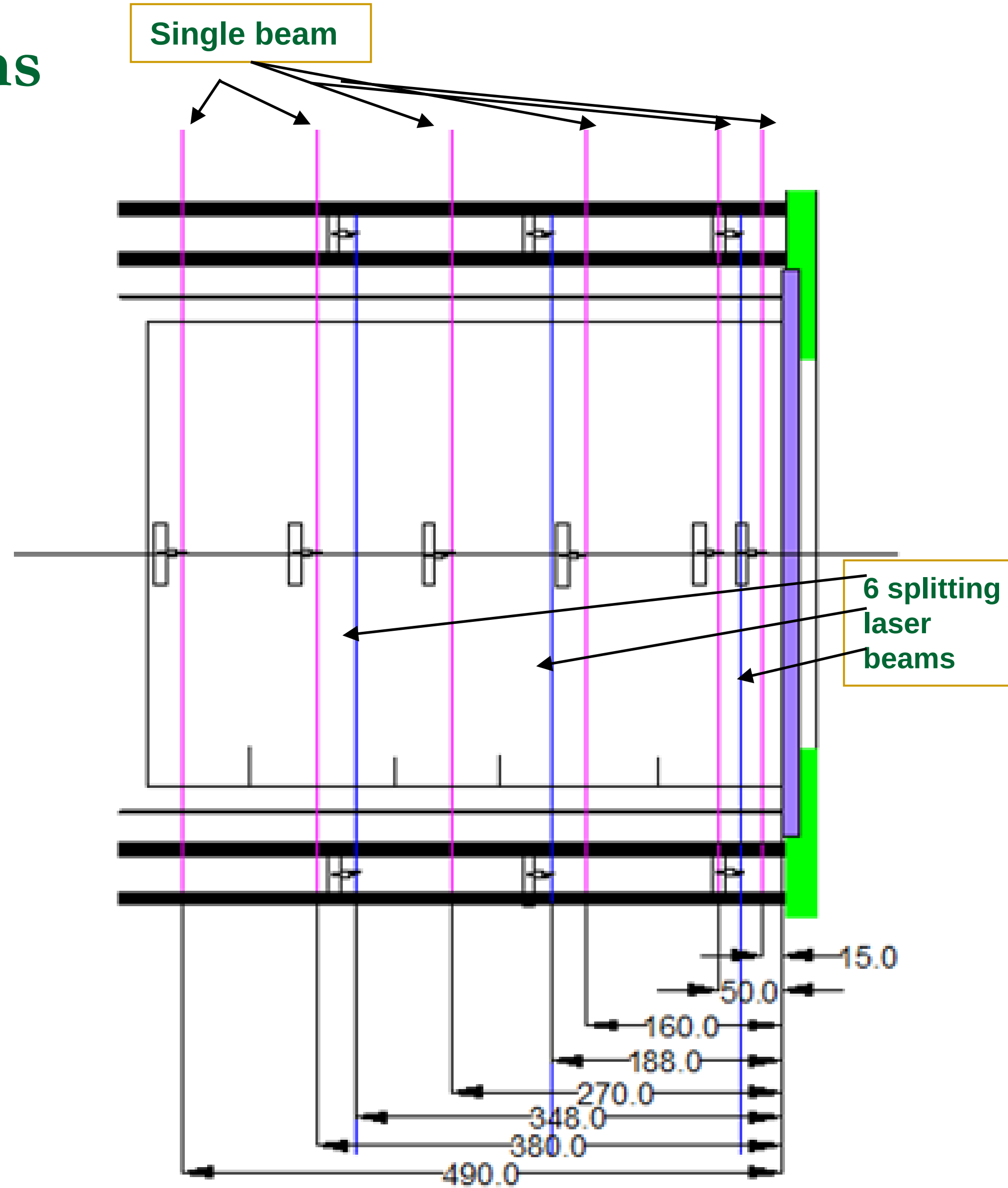


TPC prototype

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

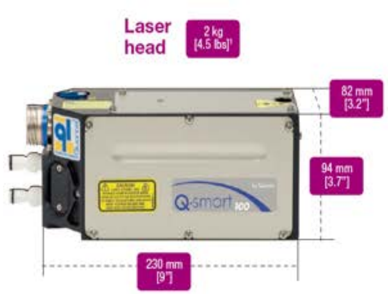
- DAQ
  - FPGA+ADC
  - 4 module/board
  - 64Chs/module
  - Sample: 40MHz
  - 1280chs

FEE Electronics and DAQ setup photos

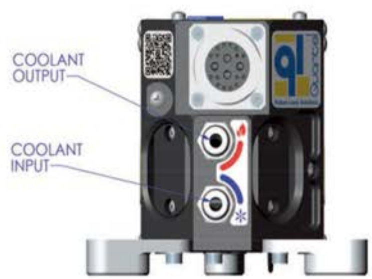
UV laser device

- Gaussian laser device
  - Nd-LAG UV laser
  - Wave length: 266nm
  - Quantel Q-smart Lasers
  - Frequency: 20Hz
  - Power: <20mJ/pulse
  - Trigger: BNC output

UV laser along the drift length



灯泵脉冲激光器头

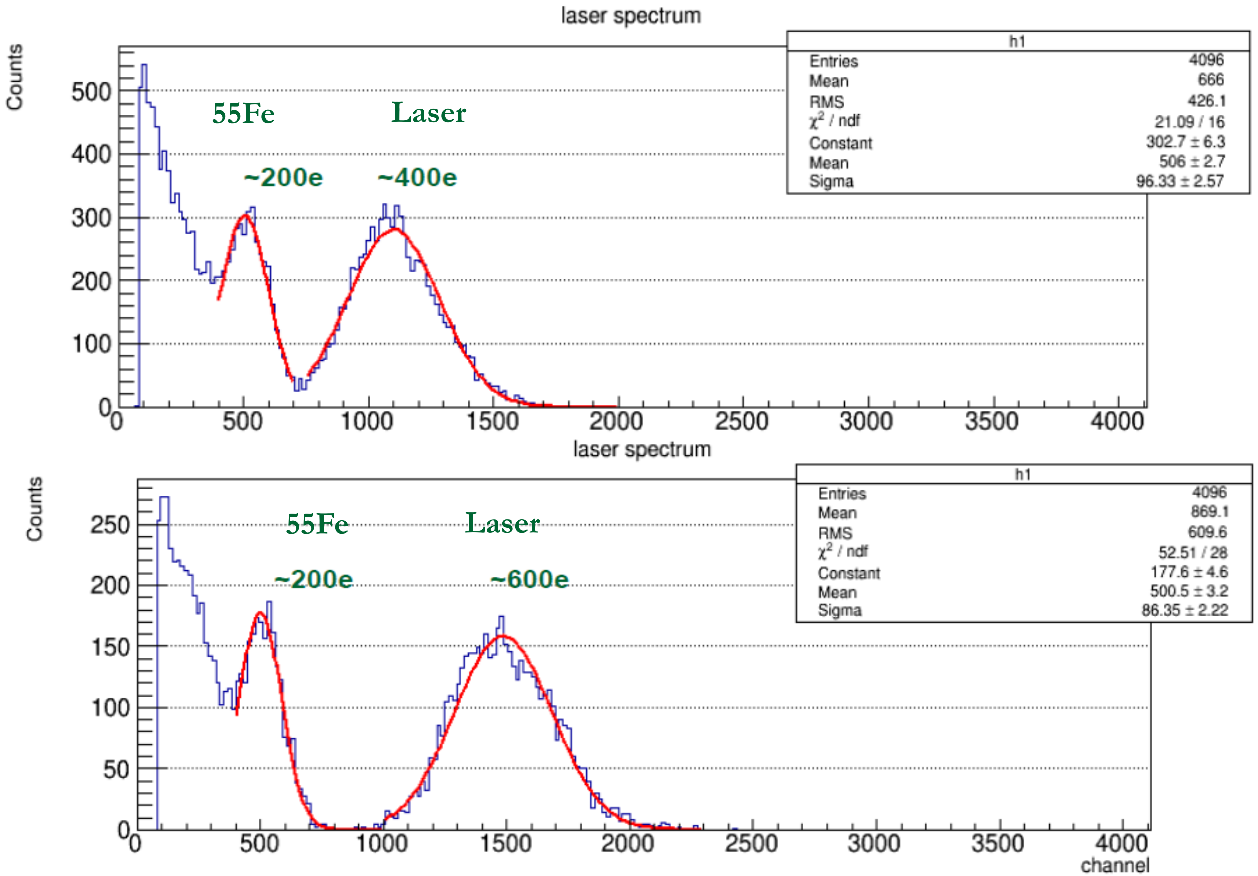


倍频模块

激光器电源

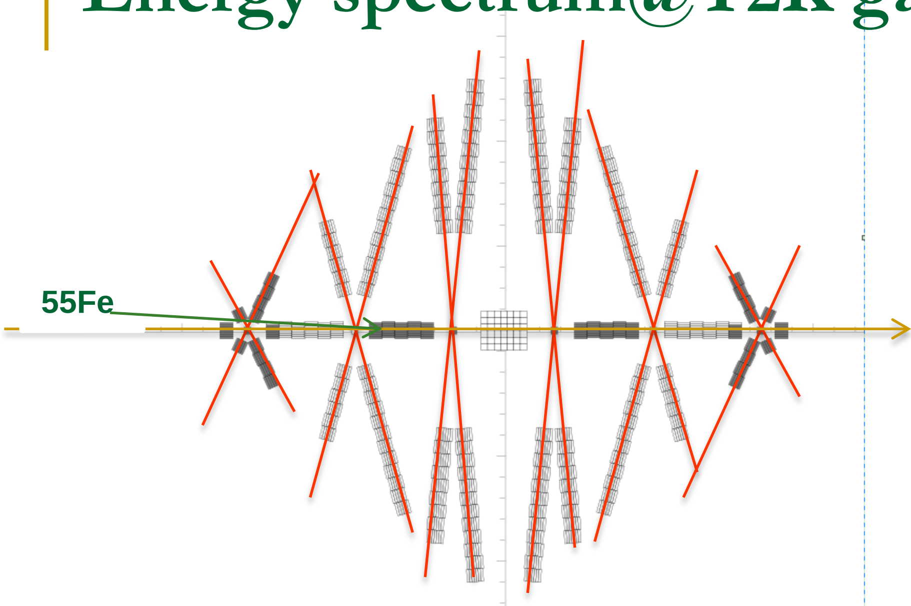
Parameters of the UV laser device

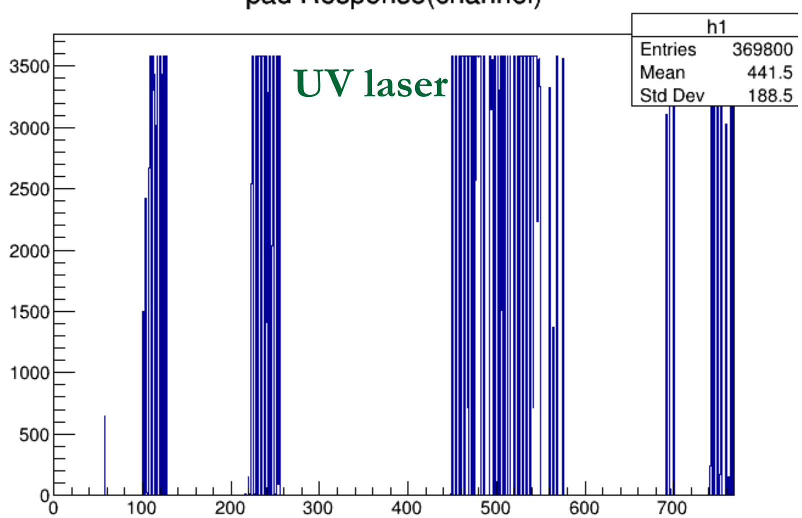
Comparison of UV laser and ^{55}Fe



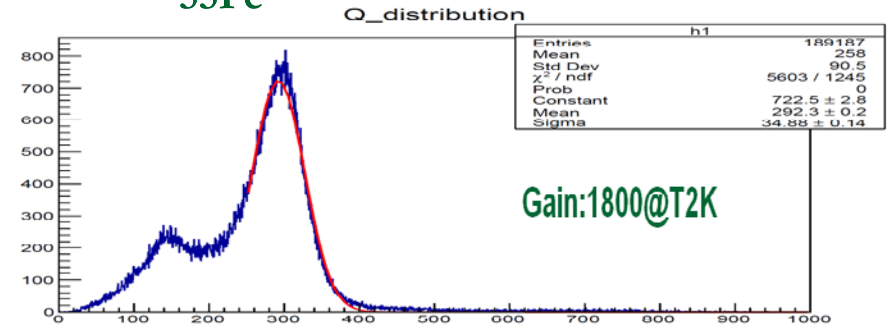
- Same test conditions under the same working gases and high voltage
- The ionization results indicate that the number for Ar:CO2(90:10)-gas and T2K-gas are similar for the ionization density.
- About the gas purity, the experiment shows all mixture gas of the purity of isobutane is 99.9% despite other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

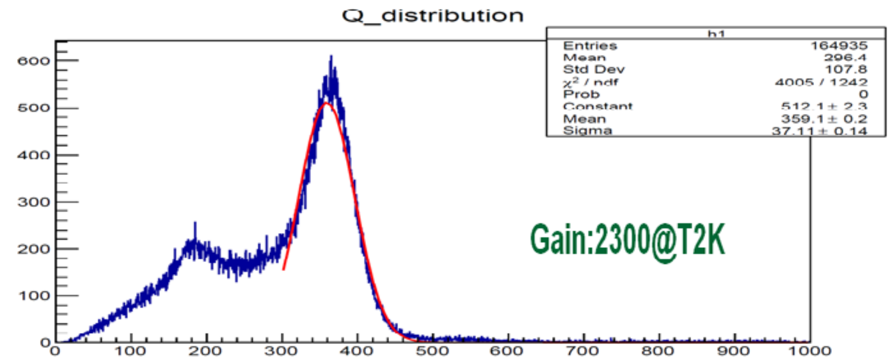
Energy spectrum@T2K gas

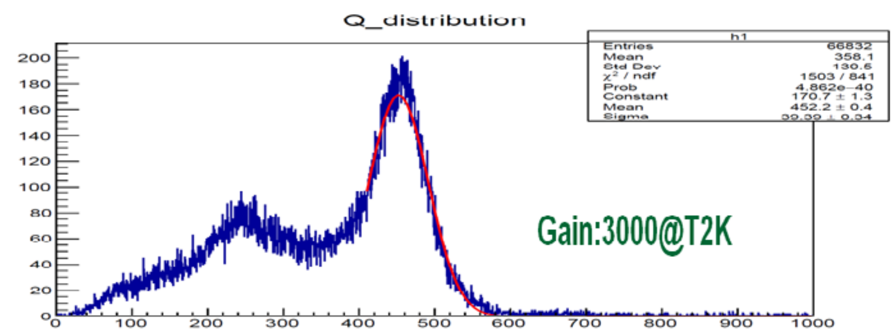




55Fe

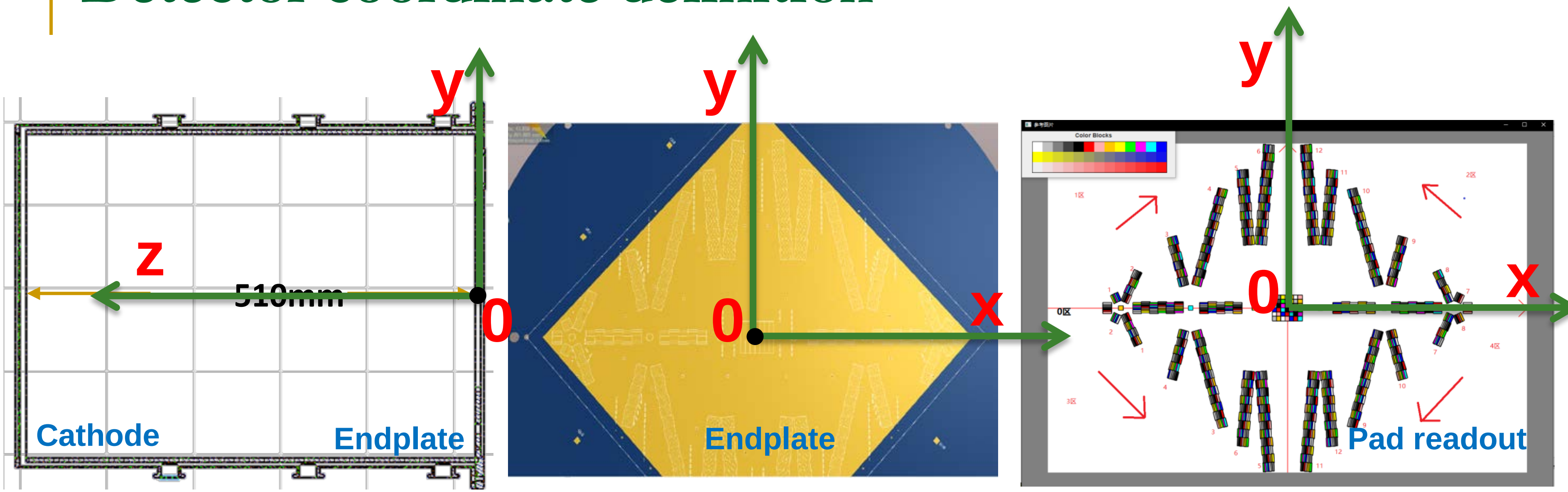






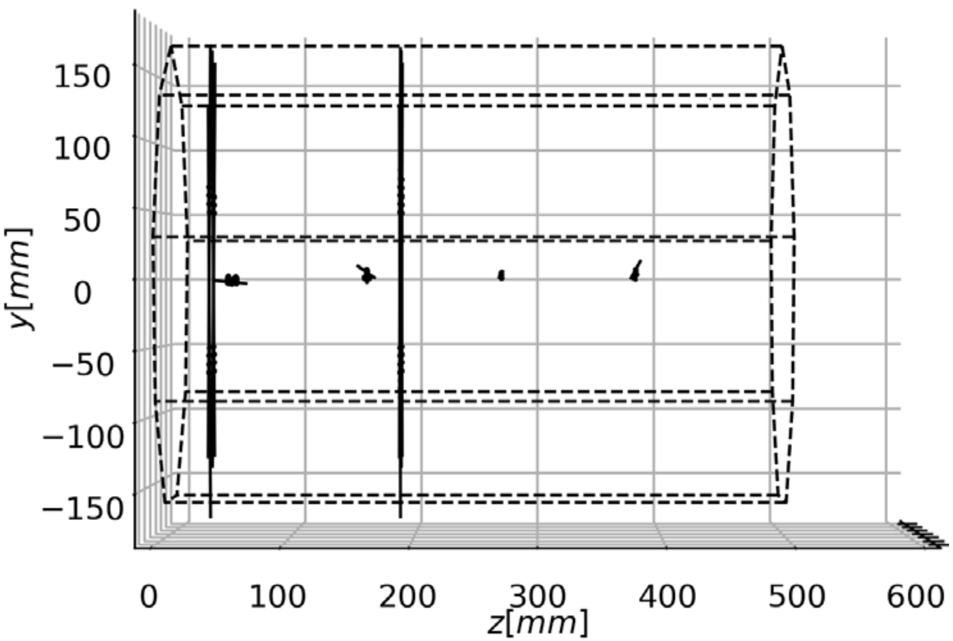
All pads response and energy spectrum @laser and 55Fe

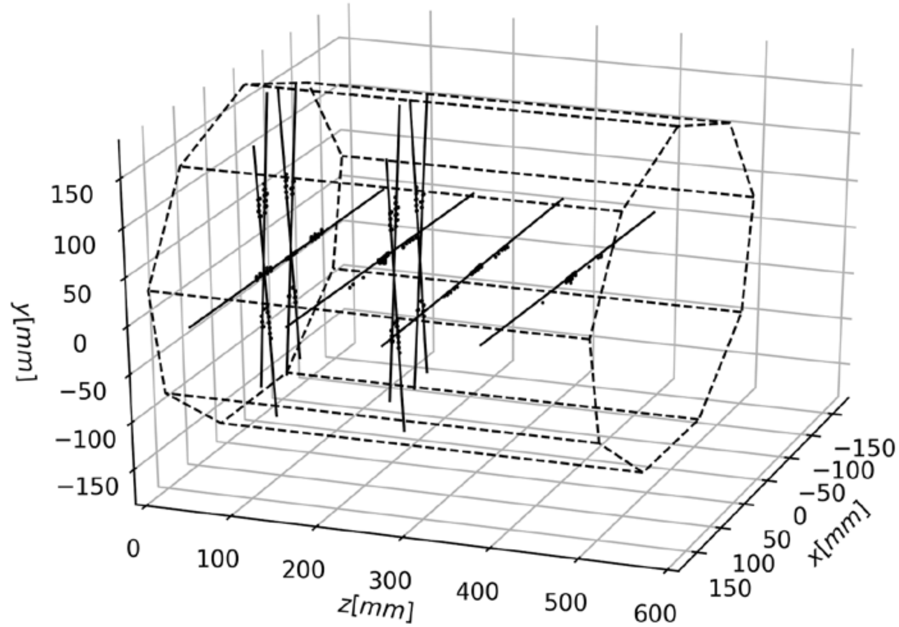
Detector coordinate definition



- 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 reconstruction@T2K gas

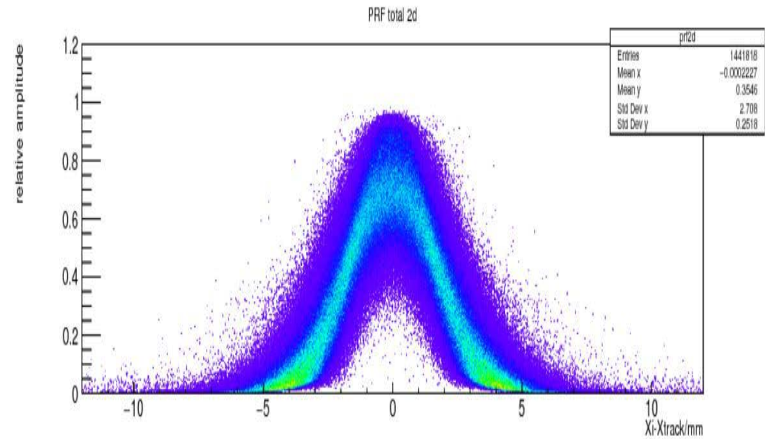


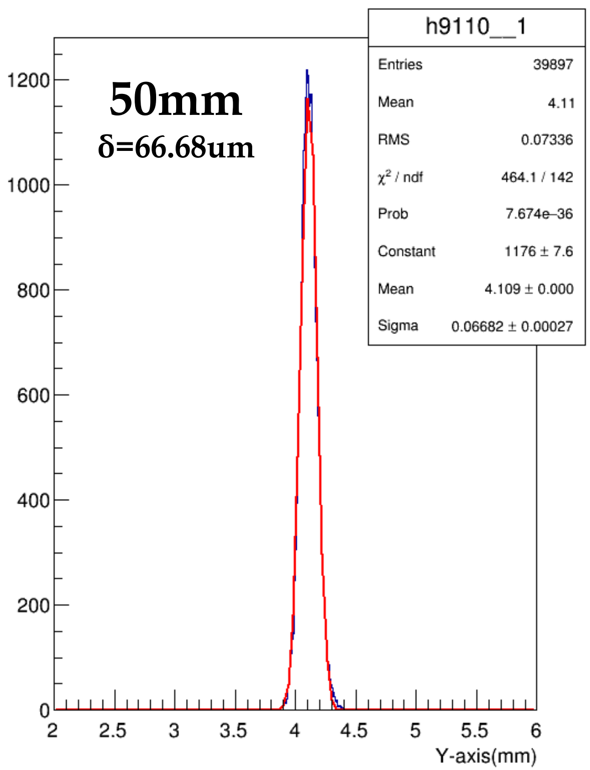


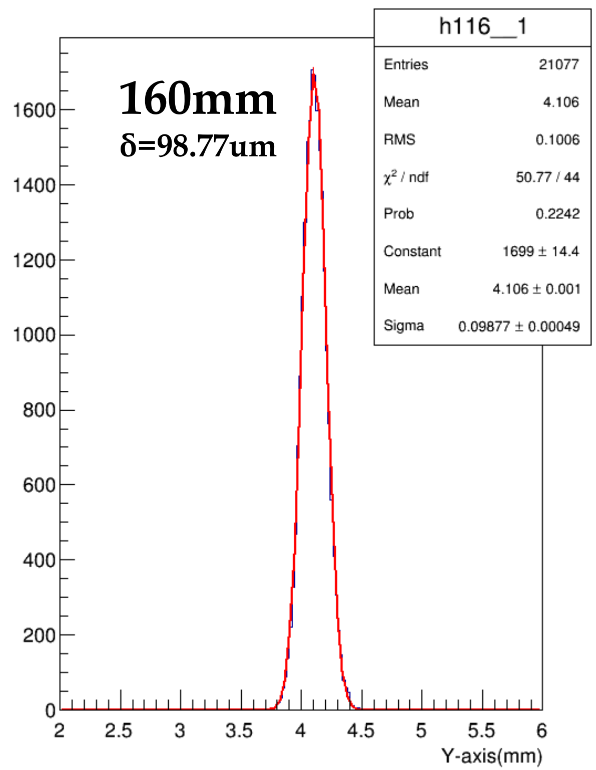
- Same of working gas@T2K, same of high voltage, same of test conditions
- Different of GEMs@ 320V
- No any discharge to damage the detector
- Conclusion
  - All of the triple GEMs, double GEMs and GEM+Micromegas could be as the readout option for TPC prototype
  - 2000 of gain is fine to study UV laser
  - The spatial resolution and the drift velocity could be analyzed

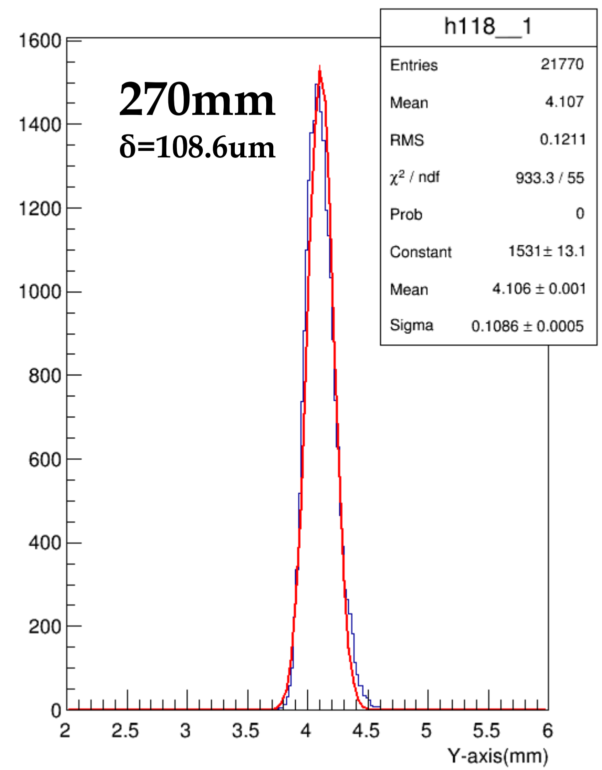
Space resolution

$$PRF(x,r,w) = \frac{\exp[-4\ln 2(1-r)x^2/w^2]}{1+4rx^2/w^2}$$



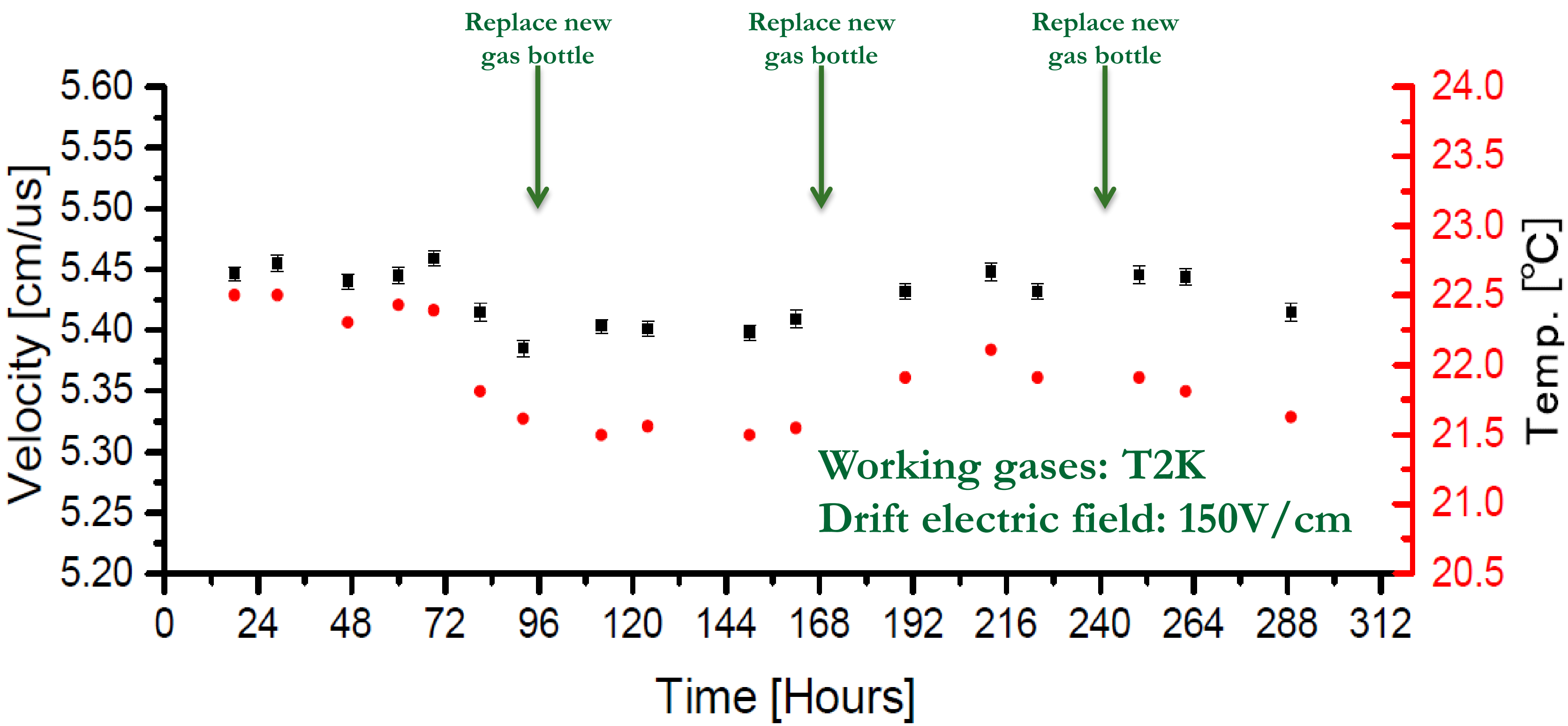






Left(drift length: 50mm) Right(drift length: 270mm)

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/Garifield++ software

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

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.**
- **266nm UV laser beams system will be very useful in the TPC R&D for the future circular collider.**
- **The detector module will assembled and commissioned with the low power consumption ASIC chip in 2021.**

Thanks for your attention.