Status and Prospects of TPC Module and Prototype at High Luminosity Z

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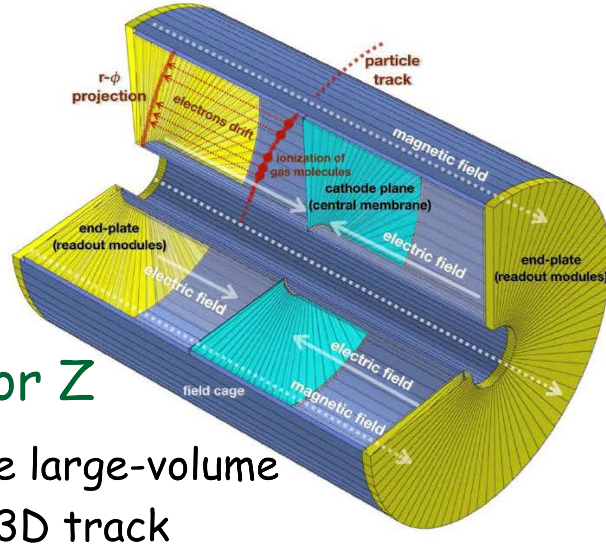
Outline

- Motivation
- TPC module R&D
- TPC prototype R&D
- FEE ASIC 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					
Momentum compaction (10^{-5})					
β_{IP} x/y (m)					
Emittance x/y (nm)					
Transverse σ_{IP} (um)					
ξ_x/ξ_y/IP					
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	
L_{max}/IP ($10^{34}cm^{-2}s^{-1}$)	0.5	5.0	18.7	35.0	105.5

#1: CEPC Status

Speaker: Jie GAO (Institute of High Energy Physics, Chinese Academy of Sciences)

CEPC Status and T...

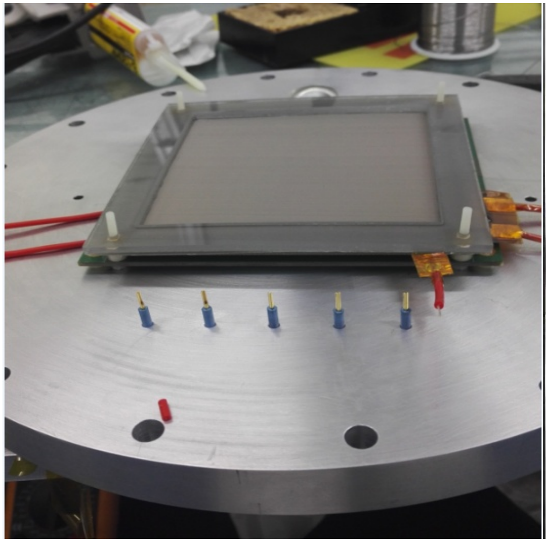
- **TPC module R&D**

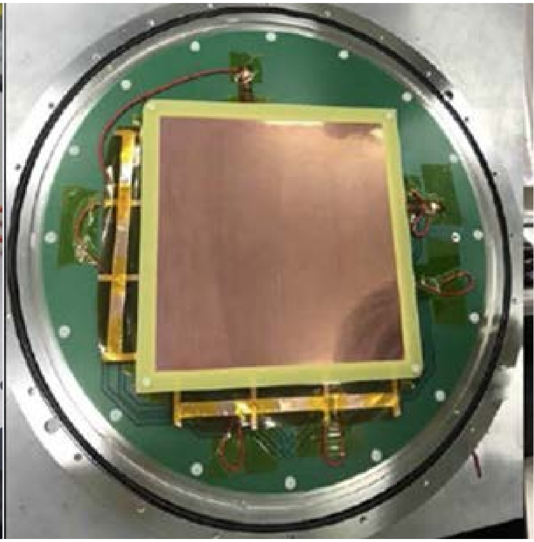
TPC detector module@ IHEP

- 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

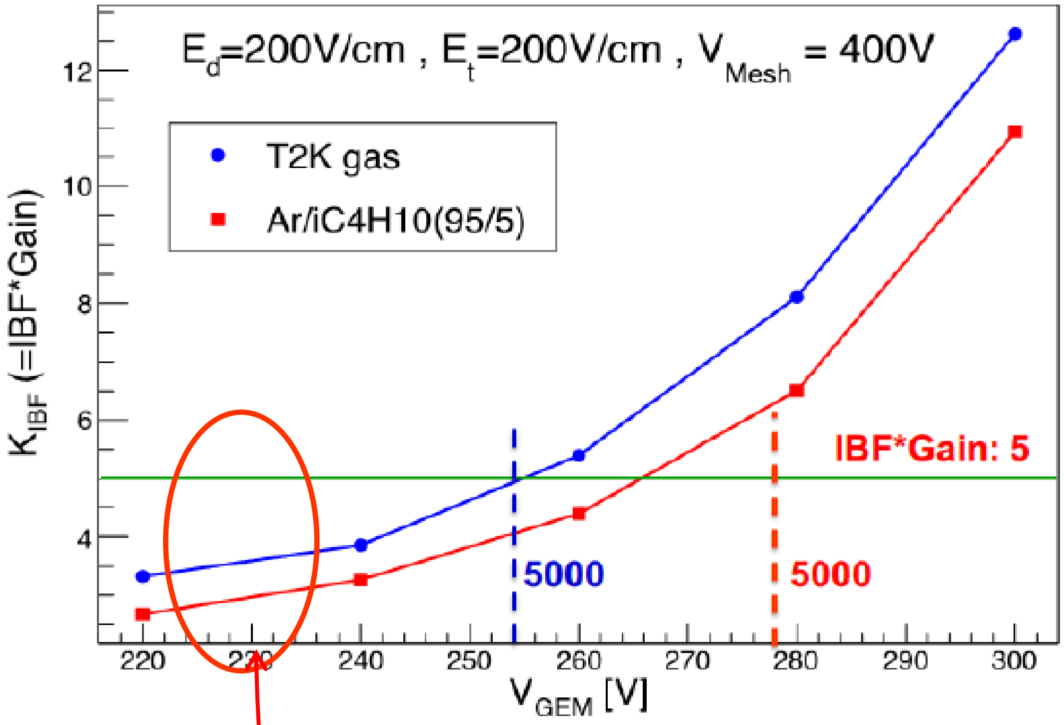




GEM-MM detector cathode

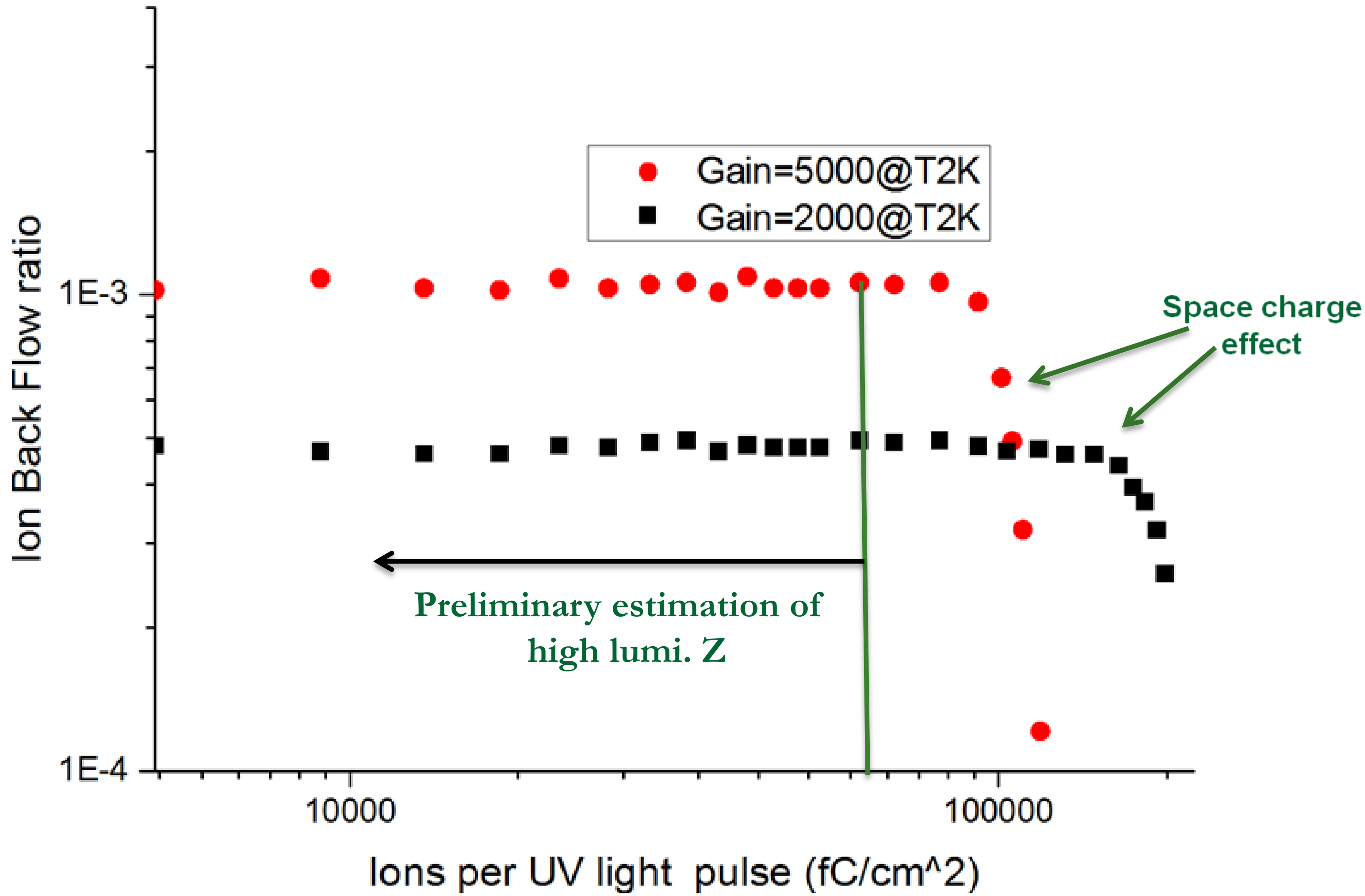
GEM+MM

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

Space charge effect at the different gain

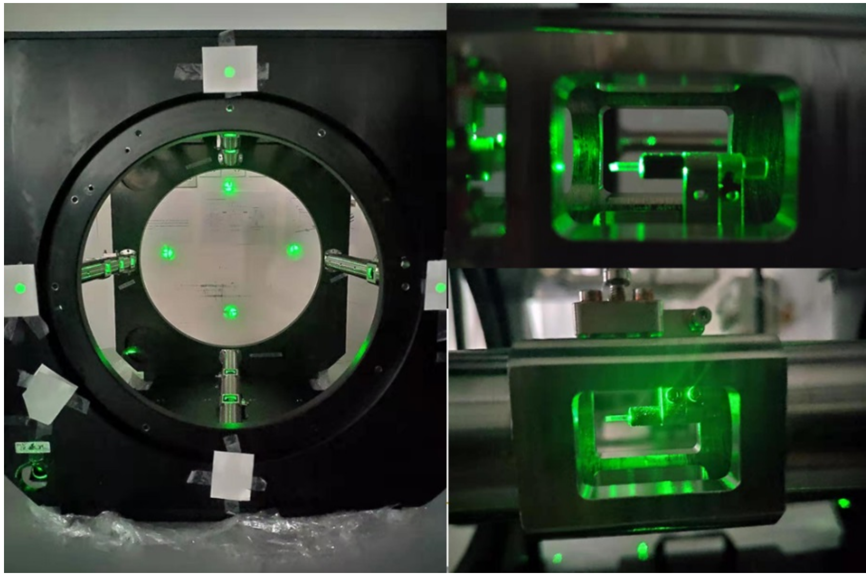


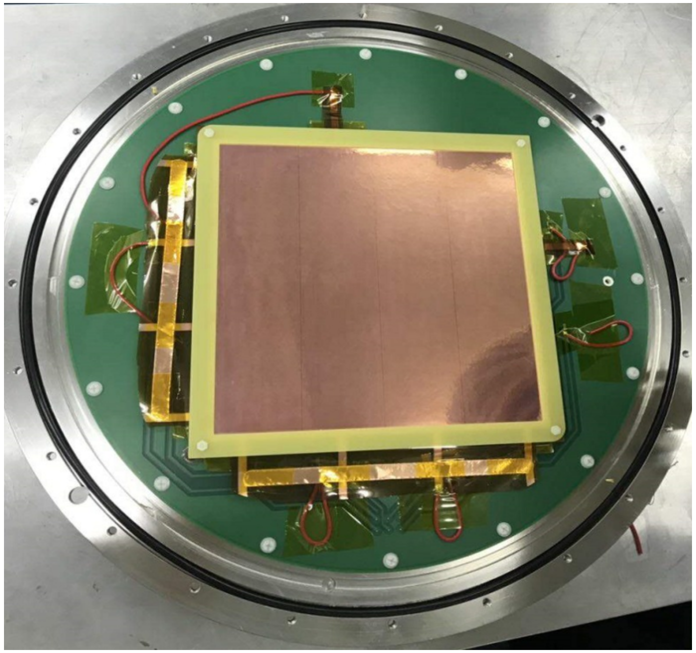
- Preliminary estimation of the high luminosity Z
- There are more safe factor when the detector will run at the lower gain (eg.2000-3000)

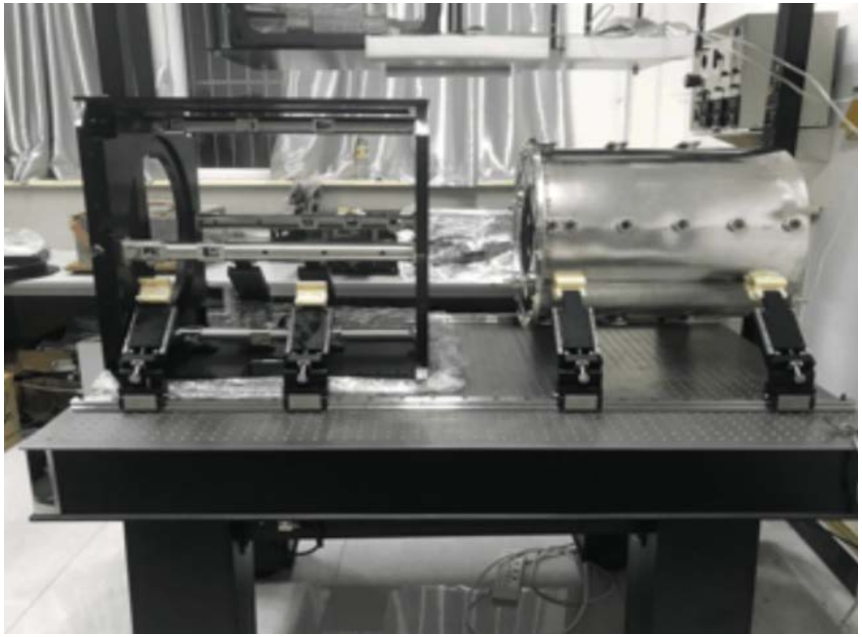
- **TPC prototype R&D**

TPC detector prototype

- Study of TPC prototype with 42 UV laser beams
- Main parameters
  - Drift length: ~500mm, Active area: 200mm^2
  - Integrated 266nm laser beam
  - GEMs/Micromegas as the readout







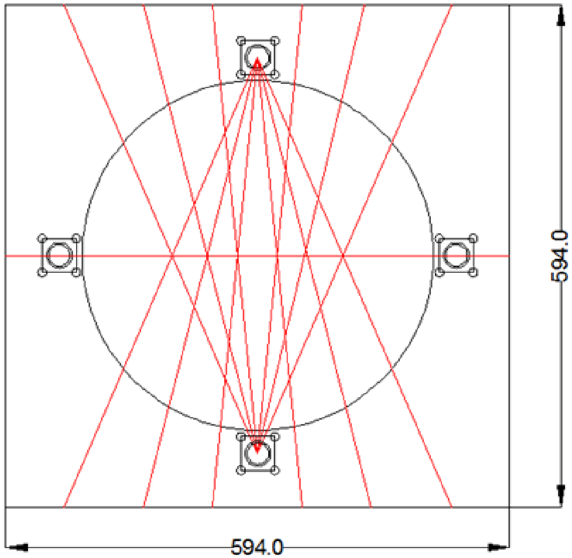
Electronics and DAQ

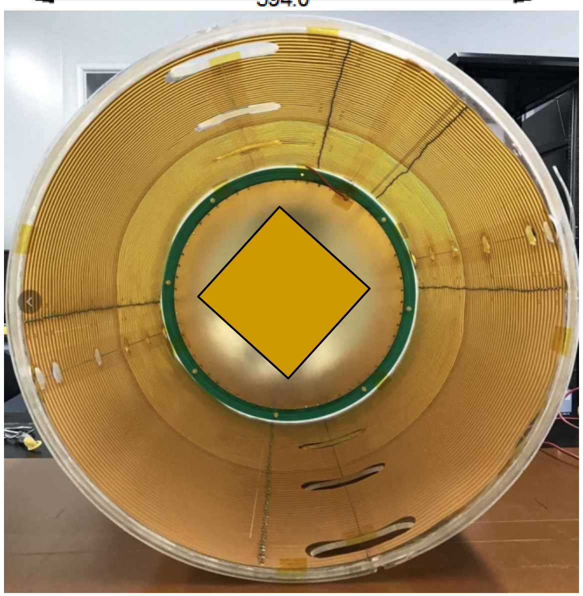
- Amplifier and FEE
  - CASAGEM chip
  - 16Chs/chip
  - 4chips/Board
  - Gain: 20mV/fC
  - Shape time: 20ns

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

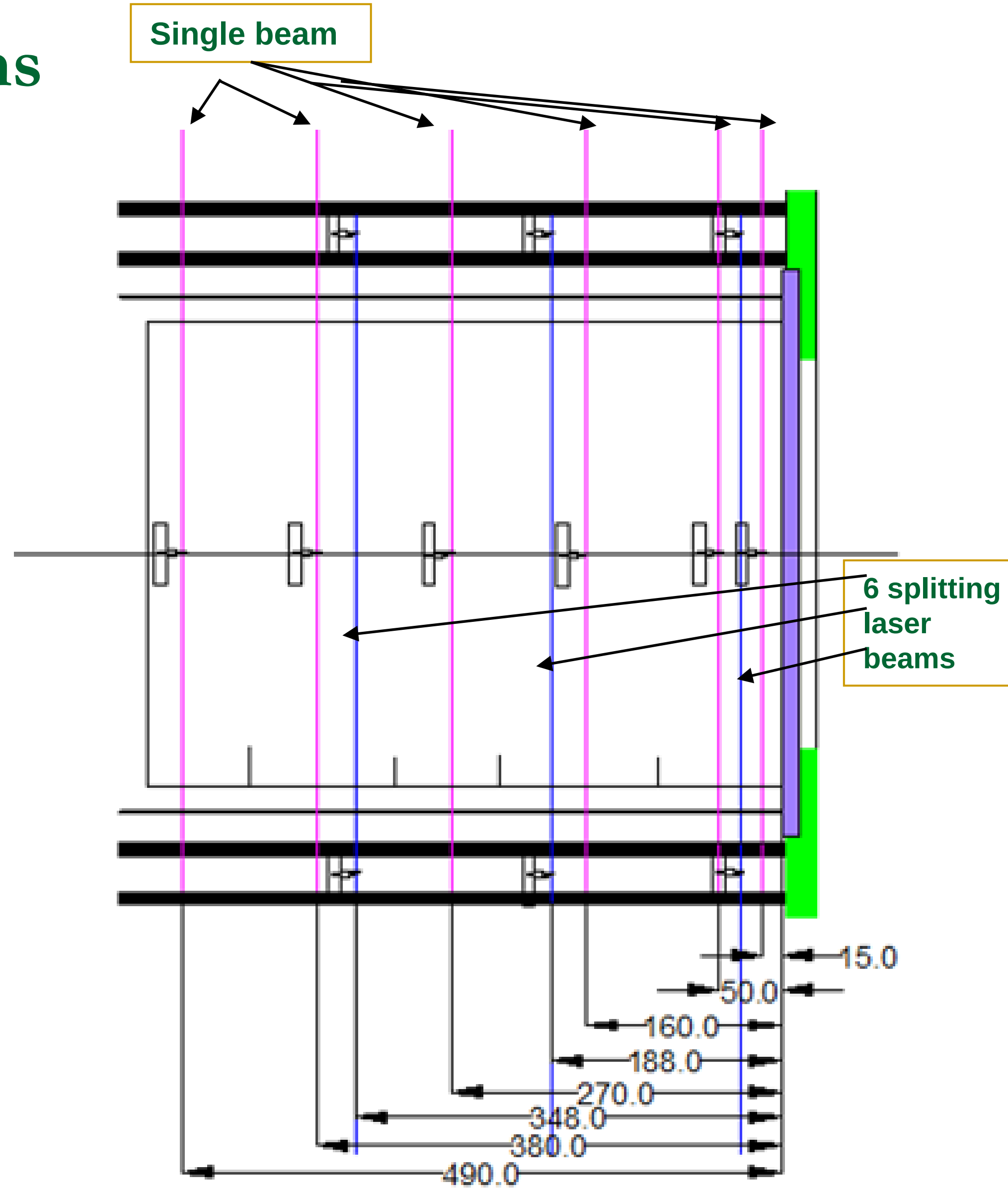
FEE Electronics and DAQ setup photos

Layout of UV laser beams



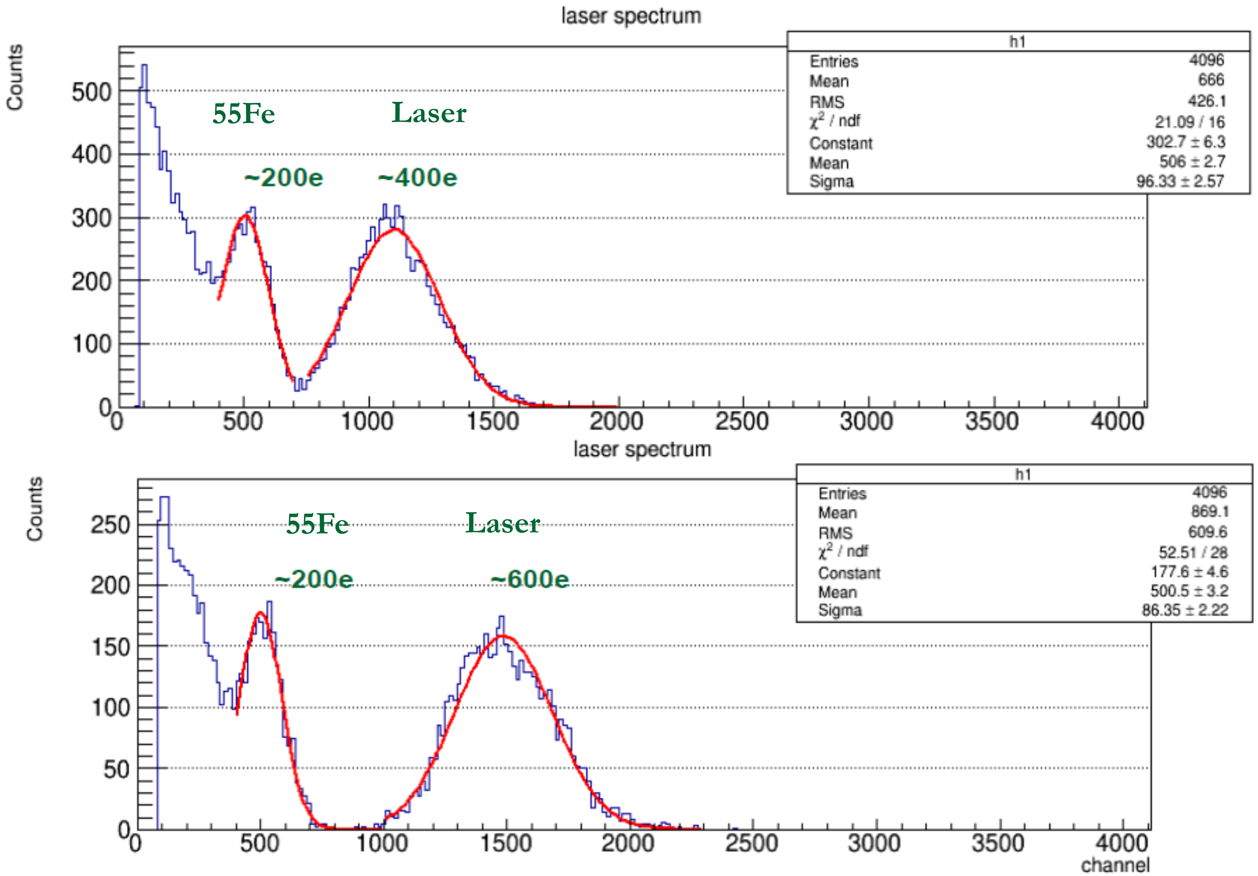


Laser map in X-Y direction



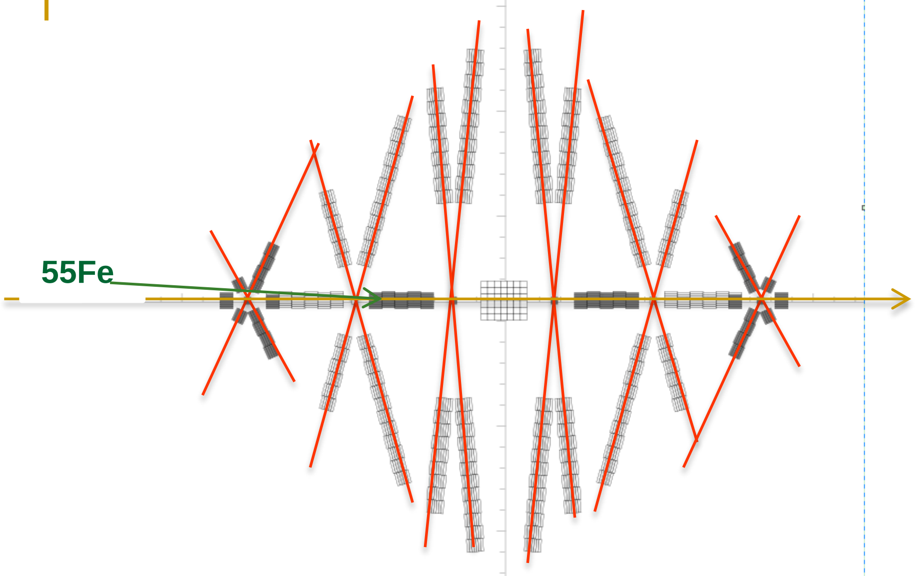
Laser map along drift length

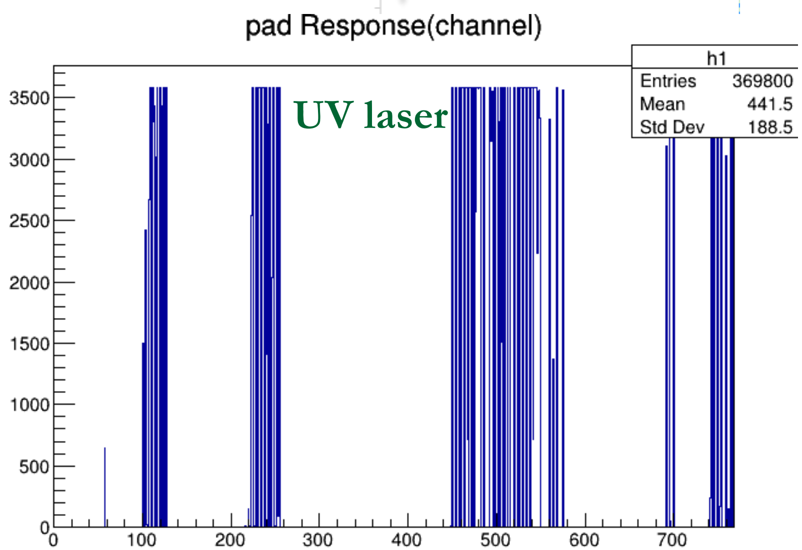
Comparison of UV laser and ^{55}Fe

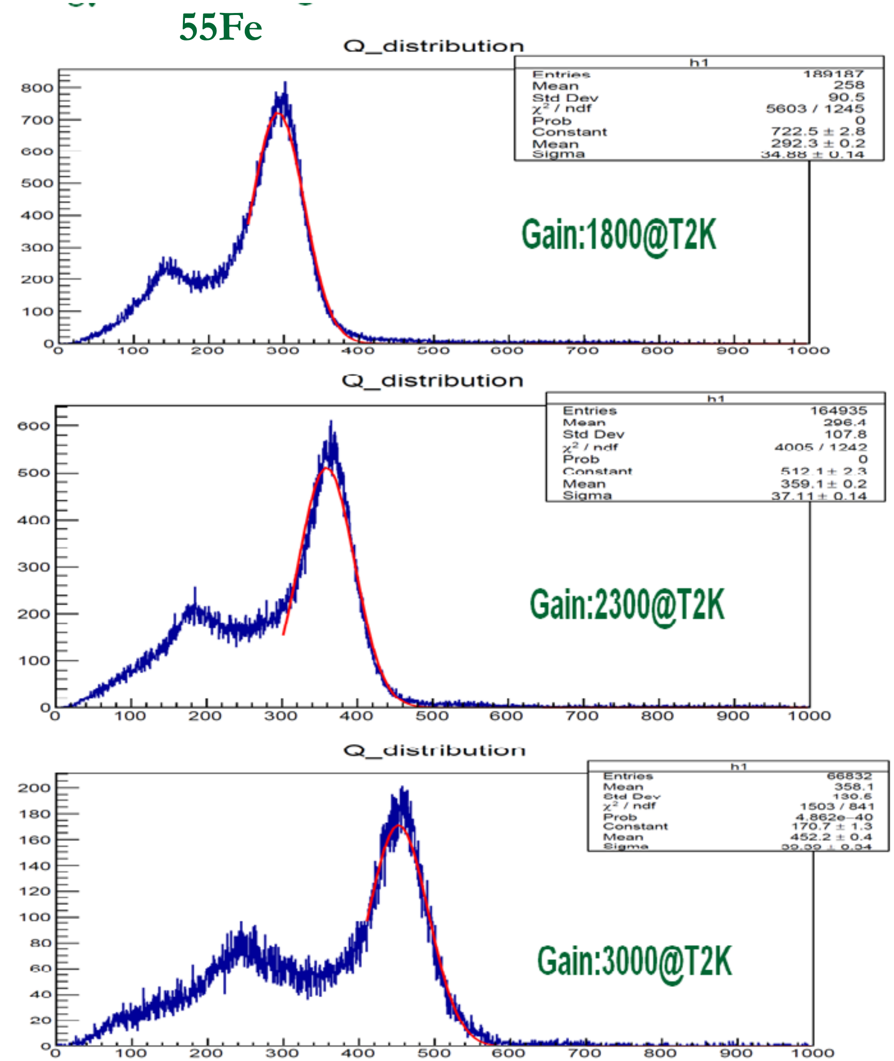


- Same test conditions under the same working gases and high voltage
- The ionization results indicate that the number for Ar:CO2(90:10)-gas and T2K-gas are similar for the ionization density.
- About the gas purity, the experiment shows all mixture gas of the purity of isobutane is 99.9% despite other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

Energy spectrum@T2K gas

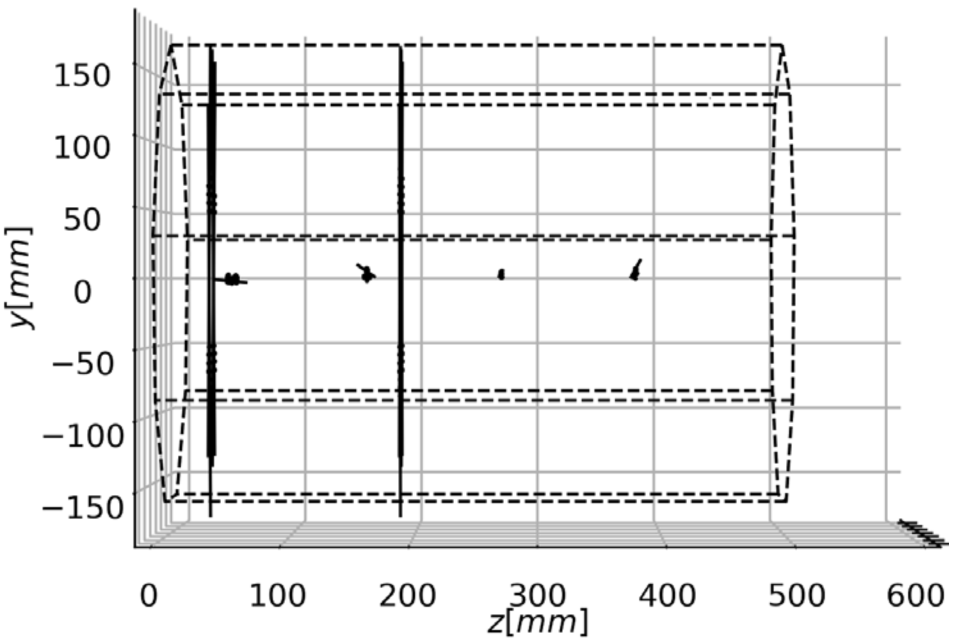


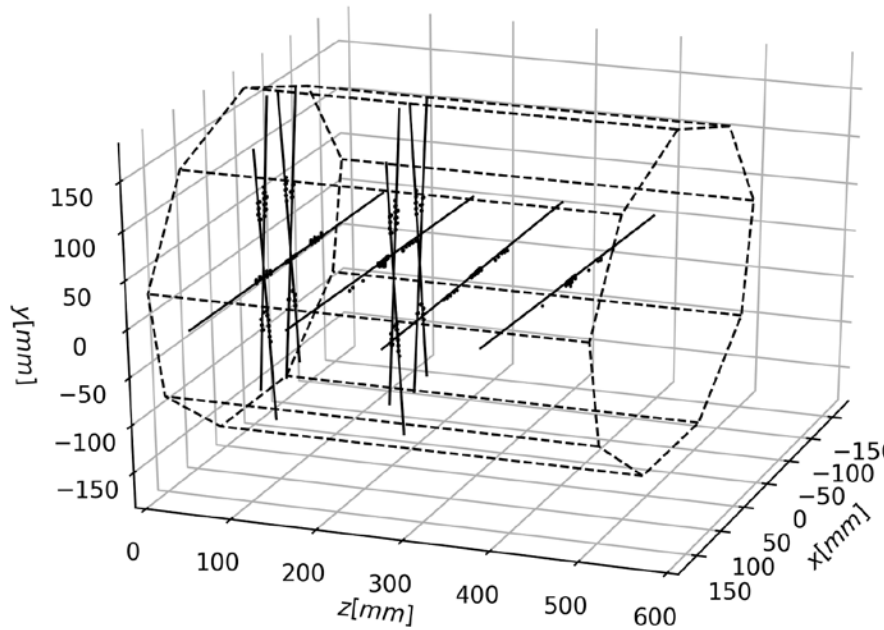




All pads response and energy spectrum @laser and 55Fe

Laser tracks in chamber@T2K gas

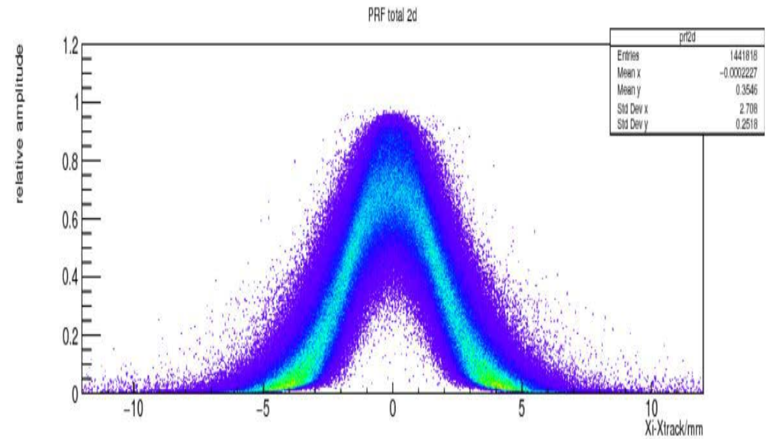


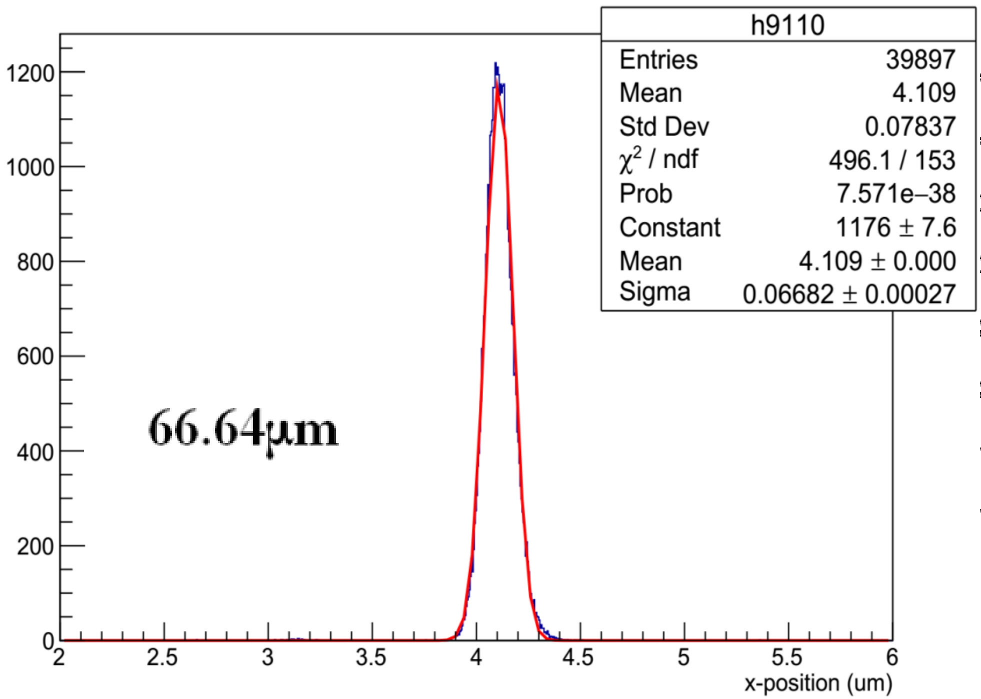


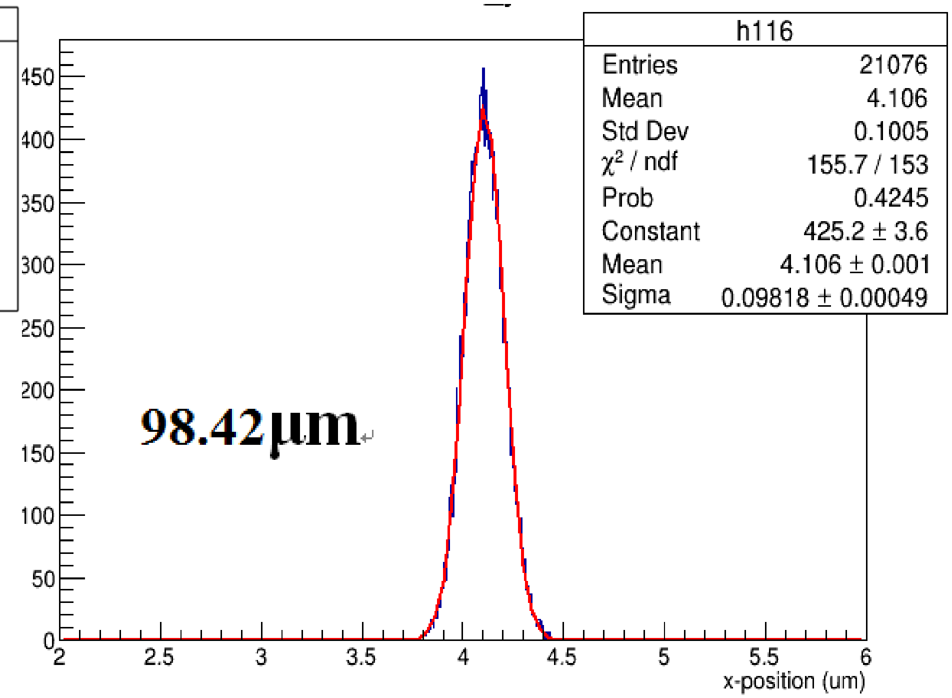
- Same of working gas@T2K, same of high voltage, same of test conditions
- Different of GEMs@ 320V
- Triple GEMs to double GEMs
- No discharge

Space resolution

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

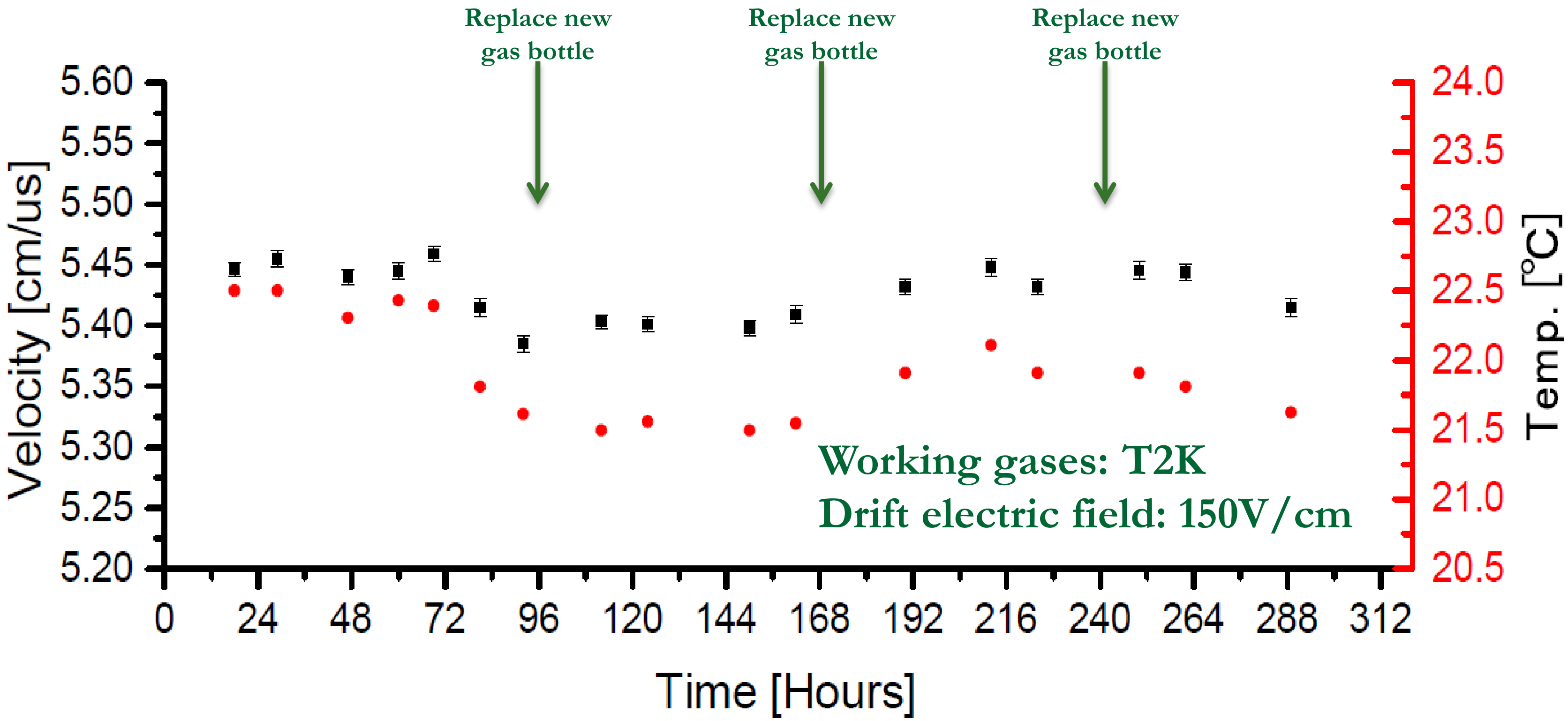






Space resolution at the different drift length
Left(drift length: 50mm) Right(drift length: 270mm)

Drift velocity measurement



- Two weeks of continuous testing
- Room temperature recorded
- Comparison of the drift velocity and the temperature
- 266nm UV laser can work well when it can be as the calibration and monitor

- **FEE ASIC chip R&D**

Current TPC readout ASICs

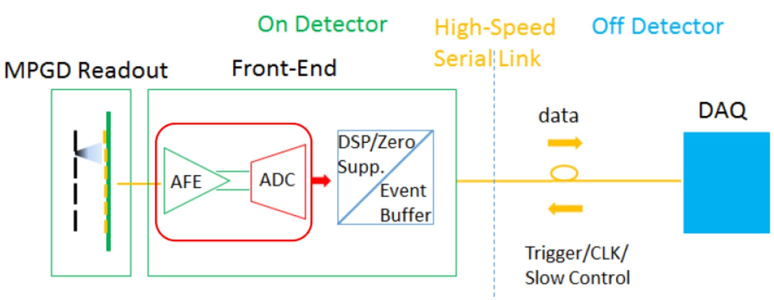
- Waveform sampling (8-10 bit, ~10MS/s) is required for TPC signal processing
- Direct ADC sampling is more preferable than SCA for high rate applications
- Lower power consumption → less cooling → less material

	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	5.7×10^5	1.25×10^5	$1\text{-}2 \times 10^6$	5.7×10^5
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	$CR\text{-}(RC)^4$	$CR\text{-}(RC)^2$	$CR\text{-}(RC)^4$	$CR\text{-}(RC)^4$
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

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

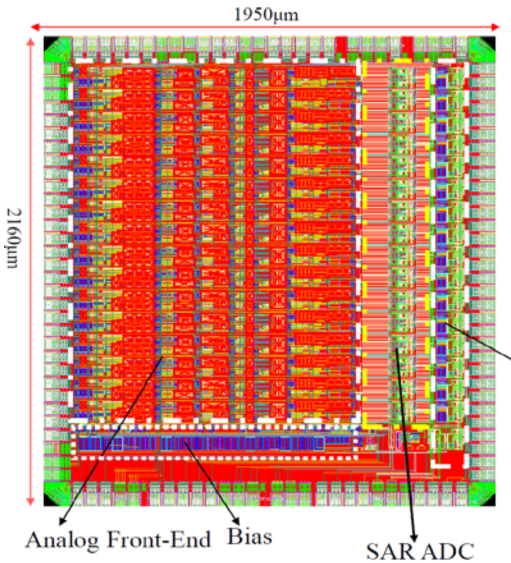
AFE(Analog Front-End)	
Signal Polarity	Negative
Detector Capacitance	5-20 pF
Shaper	CR-RC
Shaping Time	160 ns
ENC (Equivalent Noise Charge)	<500 e @ 10pF
Dynamic Range	120 fC max.
Gain	10-40 mV/fC
INL (Integrated Non-Linearity)	<1%
Crosstalk	<1%
Power Consumption (AFE)	<2.5 mW/ch



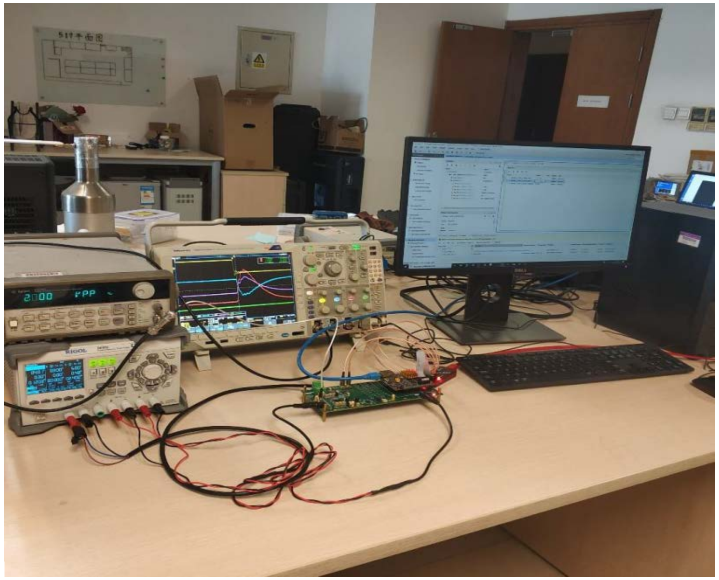
SAR-ADC	
Input Range	-0.6 V ~ 0.6 V diff.
Resolution	10 bit
Sampling Rate	40 MS/s
DNL	<0.6 LSB
INL	<0.6 LSB
SFDR @ 2MHz, 40MSPS	68 dBc
SINAD	57 dB
ENOB	>9.2 bit @ 2MHz
Power Consumption (ADC)	<2.5 mW/ch

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

Tests of the ASIC chip

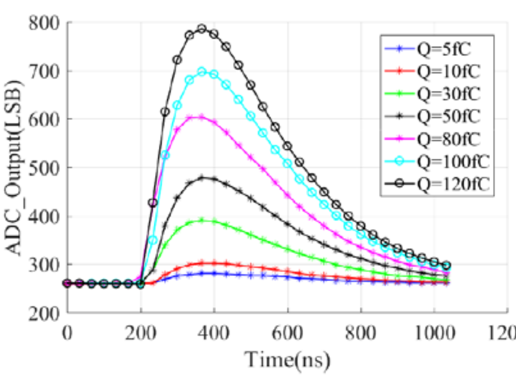


- The floor plan in layout：
  - The die size of 1950 μm x 2160 μm
  - Analog Front-End , SPI, SAR ADC, LVDS driver are supplied by separate power
- The ASIC have been taped out in November, 2019 and is being evaluated

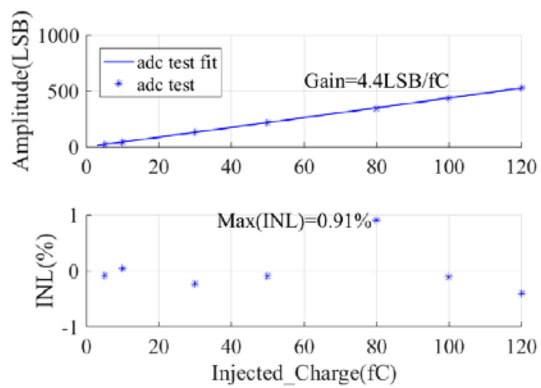


Layout of ASIC chip

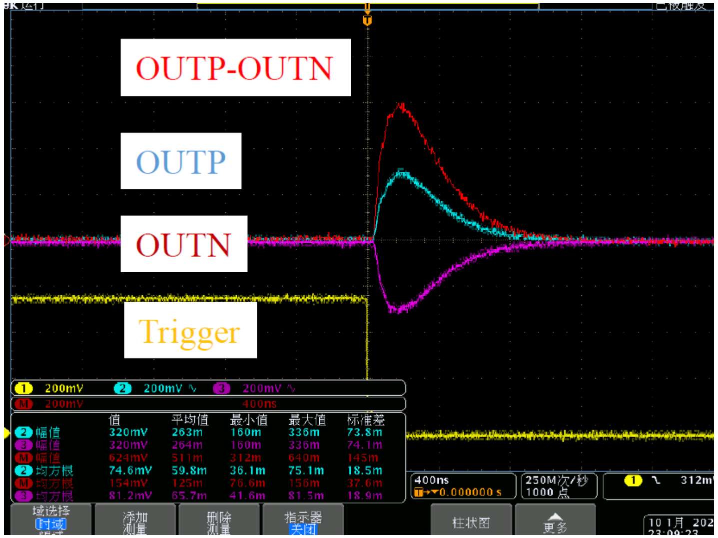
- Transient outputs



- 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

Results 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
- Future Plan
  - More ASIC evaluations: higher sampling rate, more detailed noise test, test with detectors…
  - Low power digital filter and data compression in FPGA/ASIC

Summary

- **Some motivations of TPC detector for the circular collider at high luminosity Z pole listed.**
- **Some update results of TPC module have been studies, it can effectively reduce ions at the low gain without the space charge and discharge.**
- **266nm UV laser beams system will be very useful in the TPC module and prototype R&D.**
- **The detector module will assembled and commissioned with the low power consumption ASIC chip in 2021.**

Thanks for your attention.