Status and progress of UV light in studying TPC detector for CEPC

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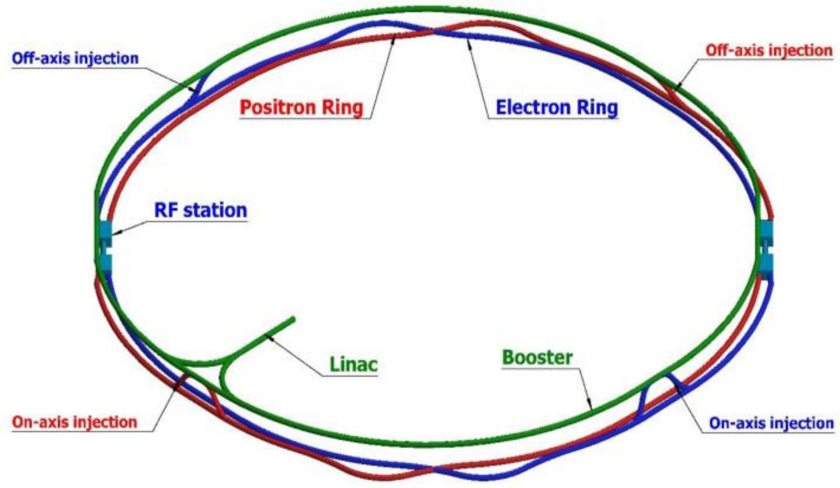
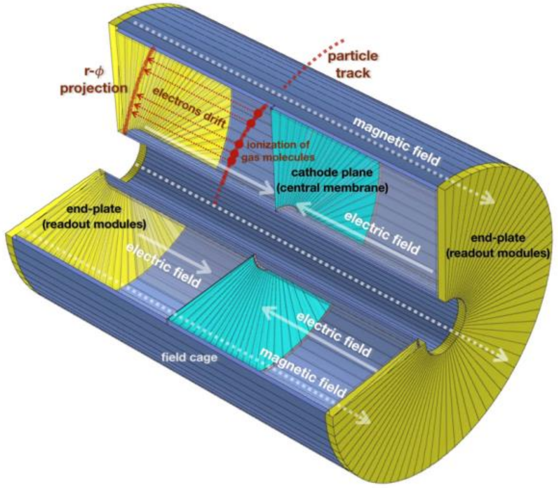
Content

- Motivation: TPC technology for future e+e- colliders
- Interaction Mechanism of UV light with TPC detectors
- UV light in studying TPC detectors
  - UV light mimic the space charge effect in TPC chamber
  - UV laser mimic the charged particle tracks
- Summary

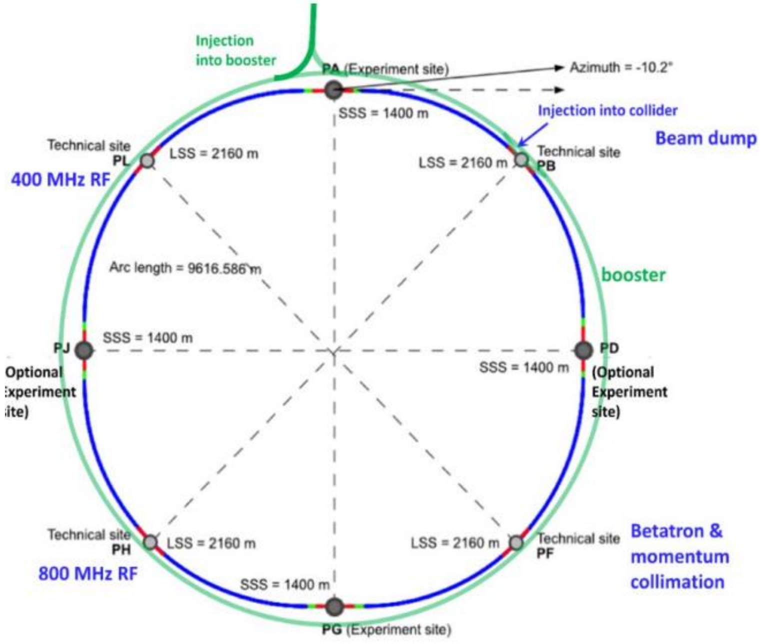
TPC technology for future e+e- collider

- Time Projection Chamber (TPC) is a candidate for the main tracker detector at some future e+e- colliders (CEPC, FCCee, ILC)
  - Very low material budget(~$0.1X_0$), hundreds of 3-D hits with high spatial resolution, Excellent pattern recognition capability
- Physics requirements for TPC detector at high luminosity (**$10^{36}cm^{-2}s^{-1}$**)
  - Spatial resolution ($\sigma_{r\varphi}<100\mu m$, $\sigma_z<500\mu m$)
  - Particle Identification ($Sp_{\pi K}>3\sigma$ from 5GeV/c to 20GeV/c)





Circular Electron Positron Collider (CEPC)



Future Circular Collider (FCCee)

https://arxiv.org/abs/1811.10545

https://arxiv.org/abs/2203.08310

Key issues of TPC technology at high luminosity

- The track distortion caused by **the space charge effect** is a critical issue to research
  - Massive electrons/ions in the TPC detector chamber @CEPC Z-pole run
  - Ion backflow suppression studies (hybrid readout module， graphene foil etc.)
  - Beam induced background investigation

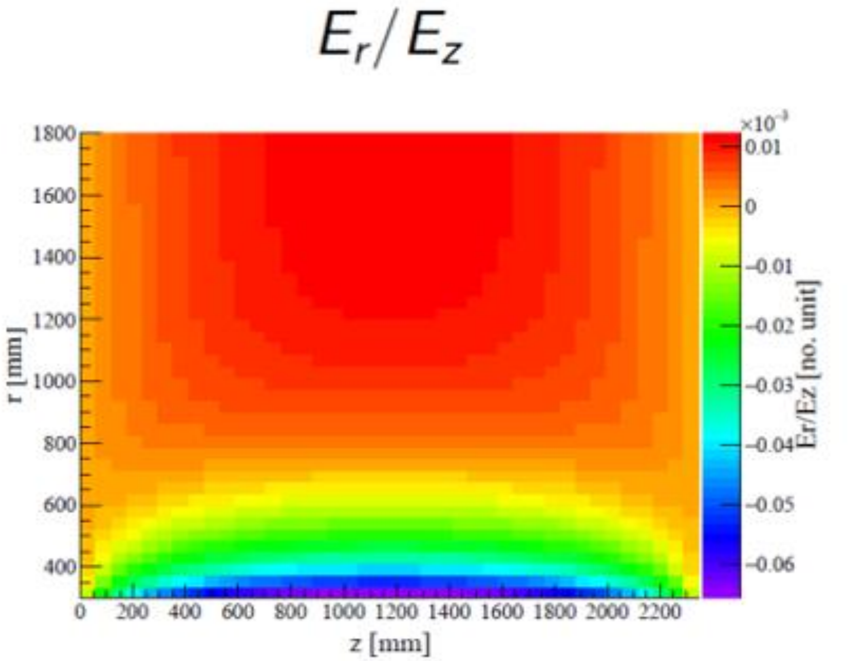
Ion suppression using graphene foil

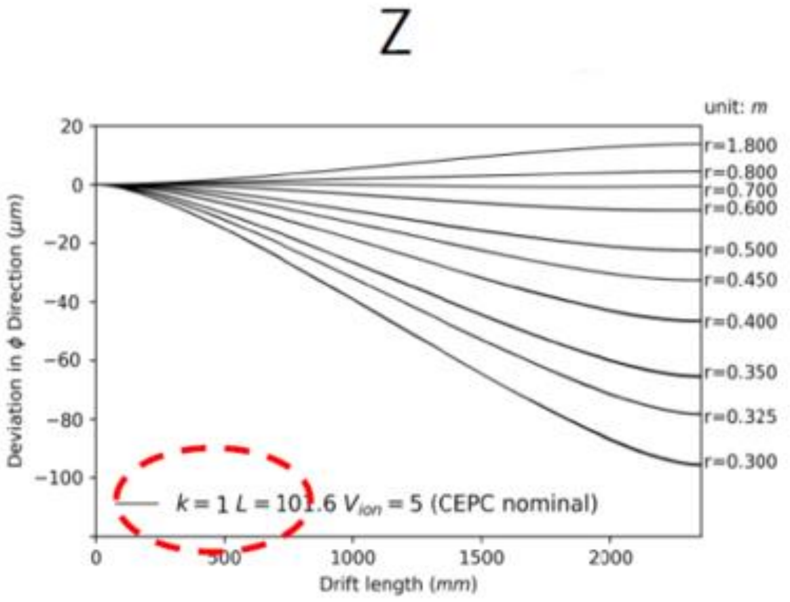
Oct 25, 2023, 10:15 AM
25m
CEPC Room 2 (GrandHotelNanjing)

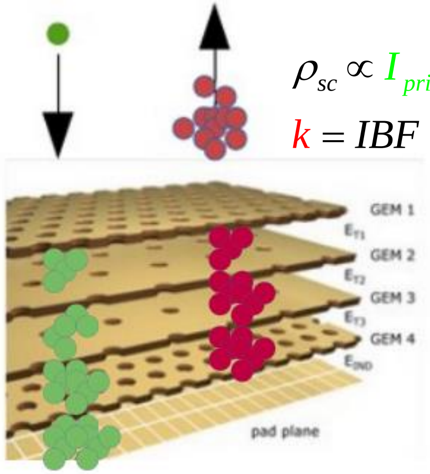
Speaker

chengguang zhu (Shandong Univ)

Dr Kang Jia (Shandong University)







$$\rho_{sc} \propto I_{prim} * k,$$
$$k = IBF \times Gain$$

The distribution of the the ratio of Er/Ez at CEPC Z-pole run (Left). The deviation in Φ direction as a function of drift length at different radius (Right)

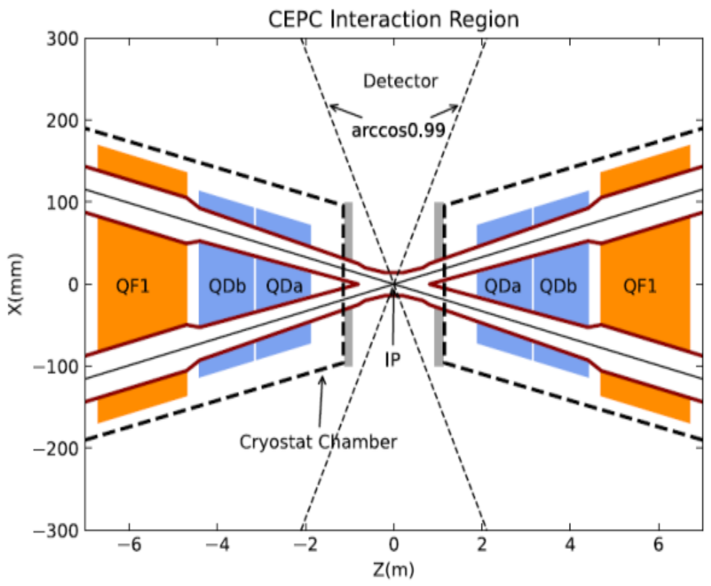
https://doi.org/10.1142/S0217751X2142015X

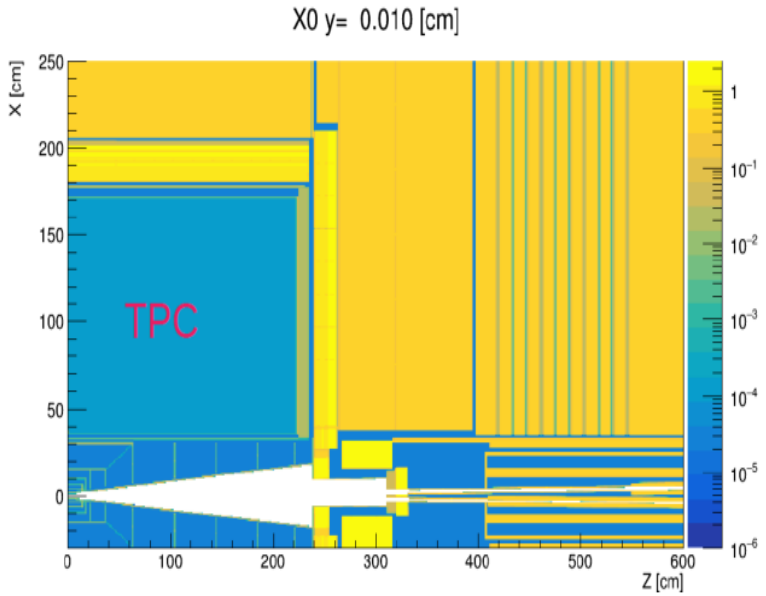
Full simulation data of the CEPC Z-pole

- All data from the full simulation of the Z-pole run at CEPC
  - IBF×Gain=1 , B=2T

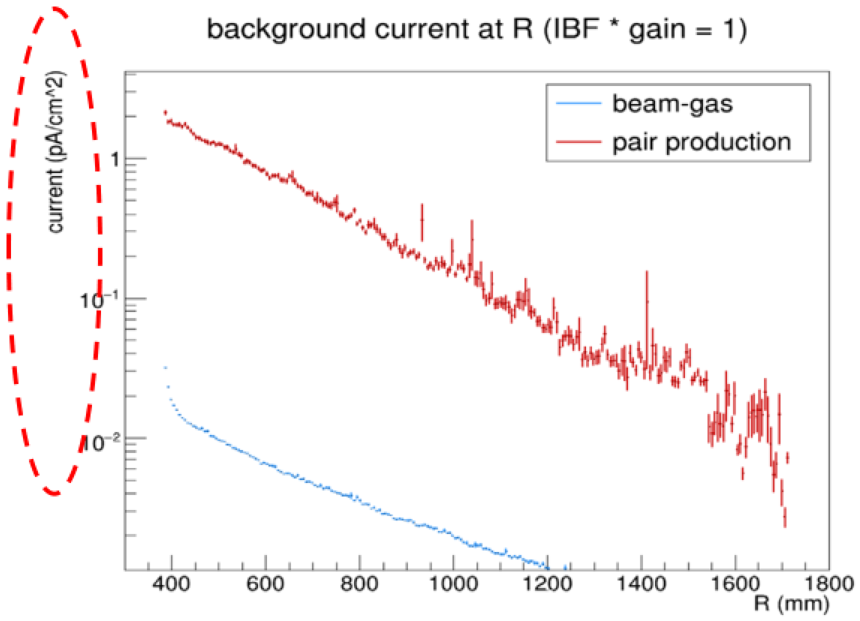
Based on CEPC software framework

- The current of the electrons in the TPC chamber can reach to **~pA/cm^2**
  - Beam-gas and pair-production effect have been consider to study
- To **investigate new methods** to mimic the space charge in the specific area to study the deviation





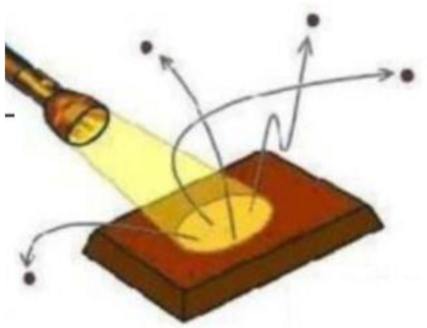
CEPC MDI region

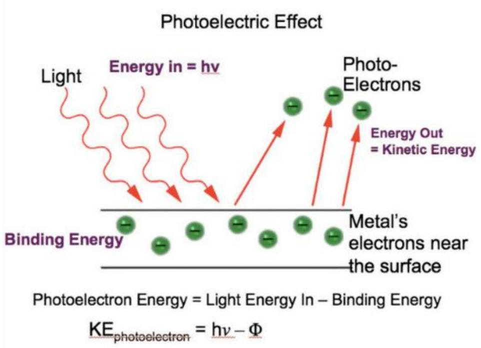


Current of the electrons in TPC chamber

Interaction mechanism of UV light with TPC detectors

- **UV photon: Photoelectric effect(<$10\mu J/cm^2$)**
  - The work function is below 4.66 eV for most metallic surfaces
  - Massive electrons will be emitted and create stable current





Work function of elements (eV)

Ag	4.26 – 4.74		Al	4.06 – 4.26	305.4-291.0nm
Au	5.10 – 5.47	243.1-226.7nm	B	~4.45	
Be	4.98		Bi	4.31	
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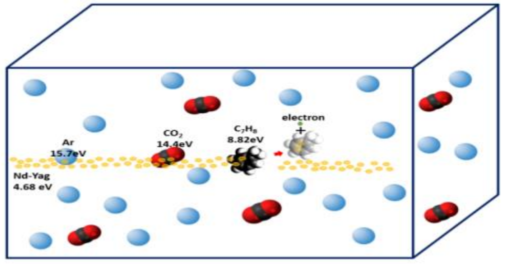
Co	5		Cr	4.5	
Cu	4.53 – 5.10	273.7-243.1nm	Eu	2.5	
Ga	4.32		Gd	2.90	

UV light to mimic the space charge effect

Studying the track distortion under high luminosity

- **UV laser: Two-photon ionization(>$10\mu J/cm^2$)**
  - Some organic impurities in the chamber can be ionized by absorbing two or more photon
  - Nd-Yag laser wavelength： 266nm (almost 4.66eV×2)
  - Imitating charged particle tracks, TPC performance study and calibration

Nd-Yag 266nm laser



$$n_i(T) = \frac{1}{2} n_0 \sigma_e \sigma_i^* N^2 T^2$$

N: photon flux
σ: transition cross section
n: ionization density
T: the width of the laser pulse

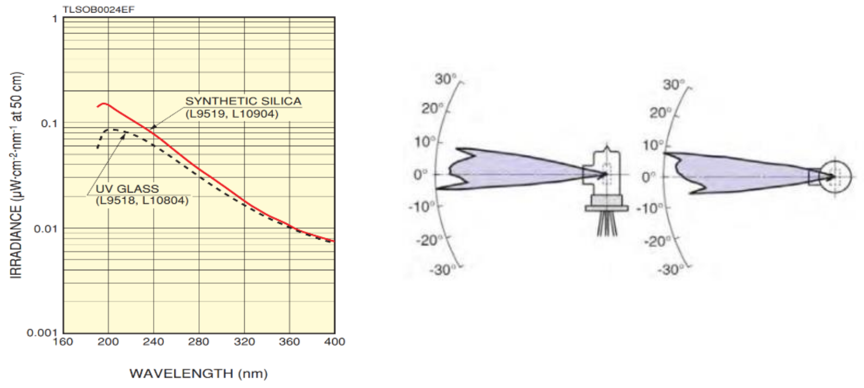
UV laser mimic the charged particle tracks

- **UV light mimic the space charge effect in TPC detector**

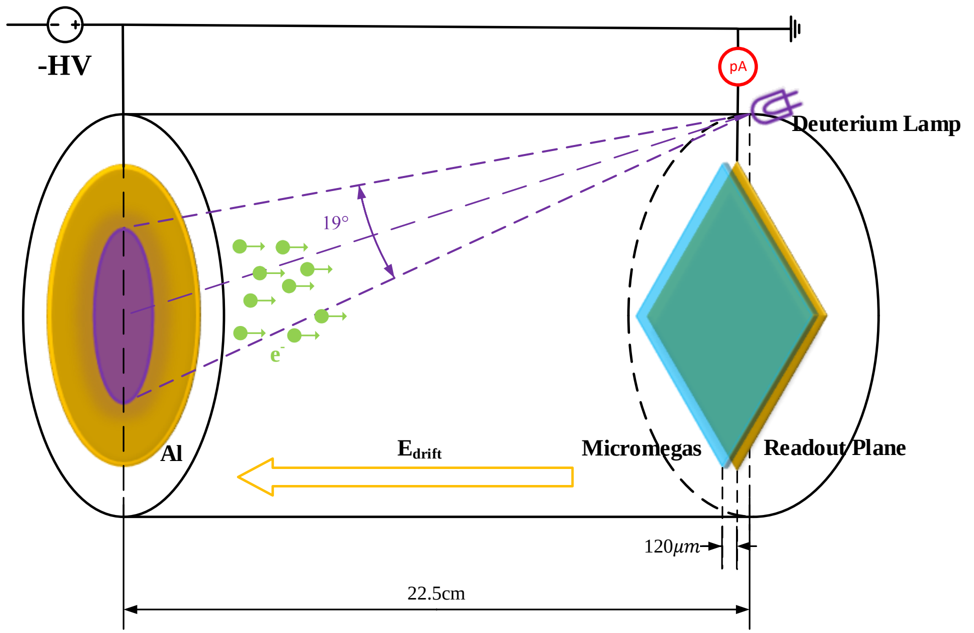
Experimental setup for generating massive electrons

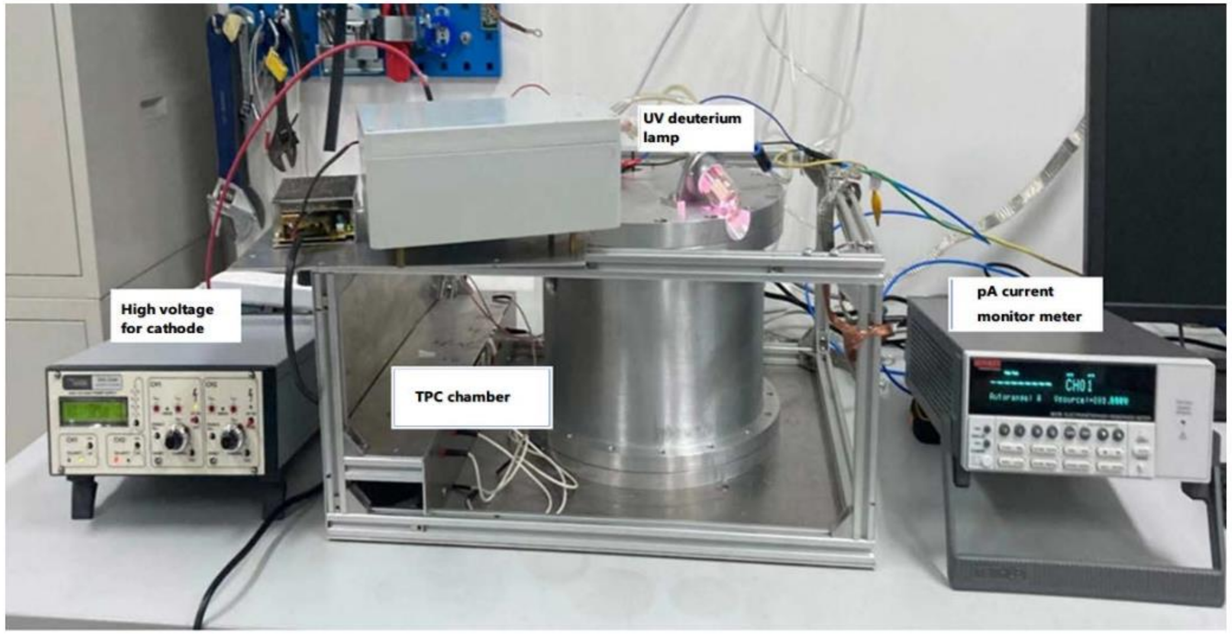
UV deuterium lamp create the massive electrons:

- Metal material: Aluminum with polished surface (600-2000 LPI)
- Work function W_0=4.08eV(cutoff wavelength:251nm)
- Spectral distribution of UV deuterium lamp:200nm-400nm



Spectral distribution and directivity

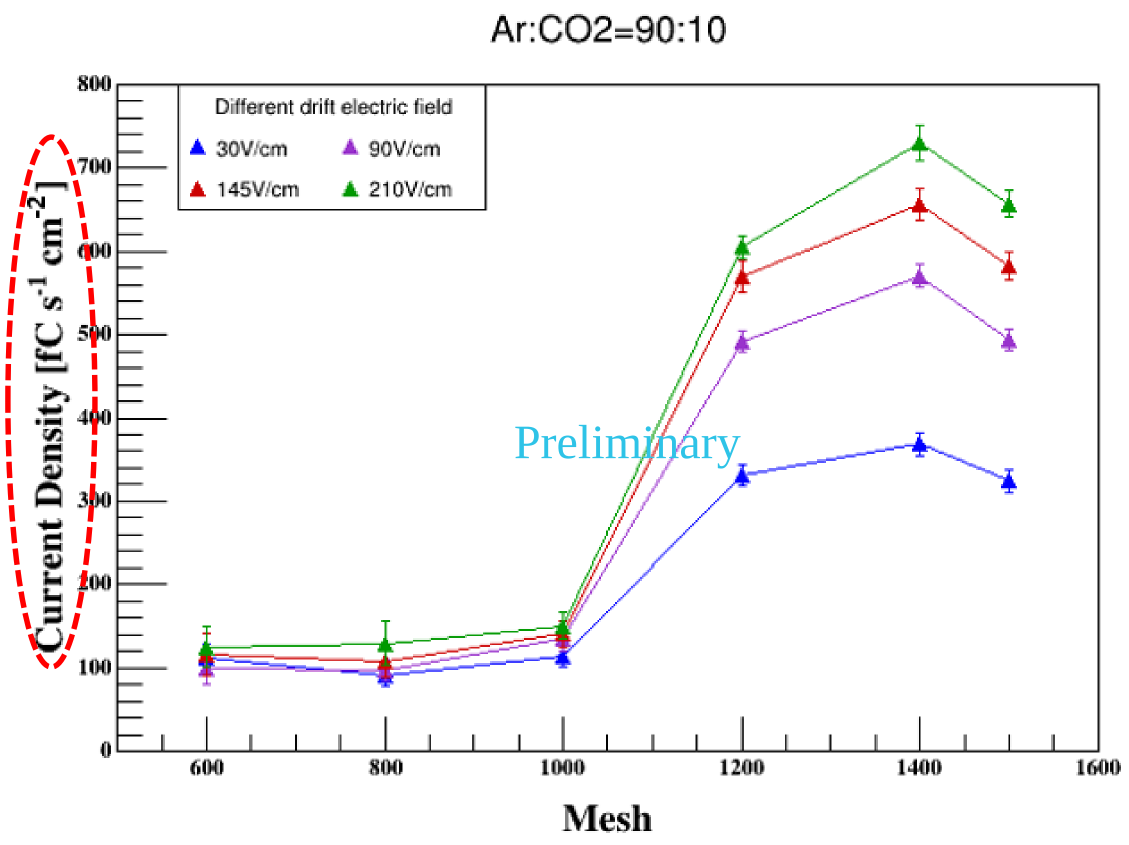


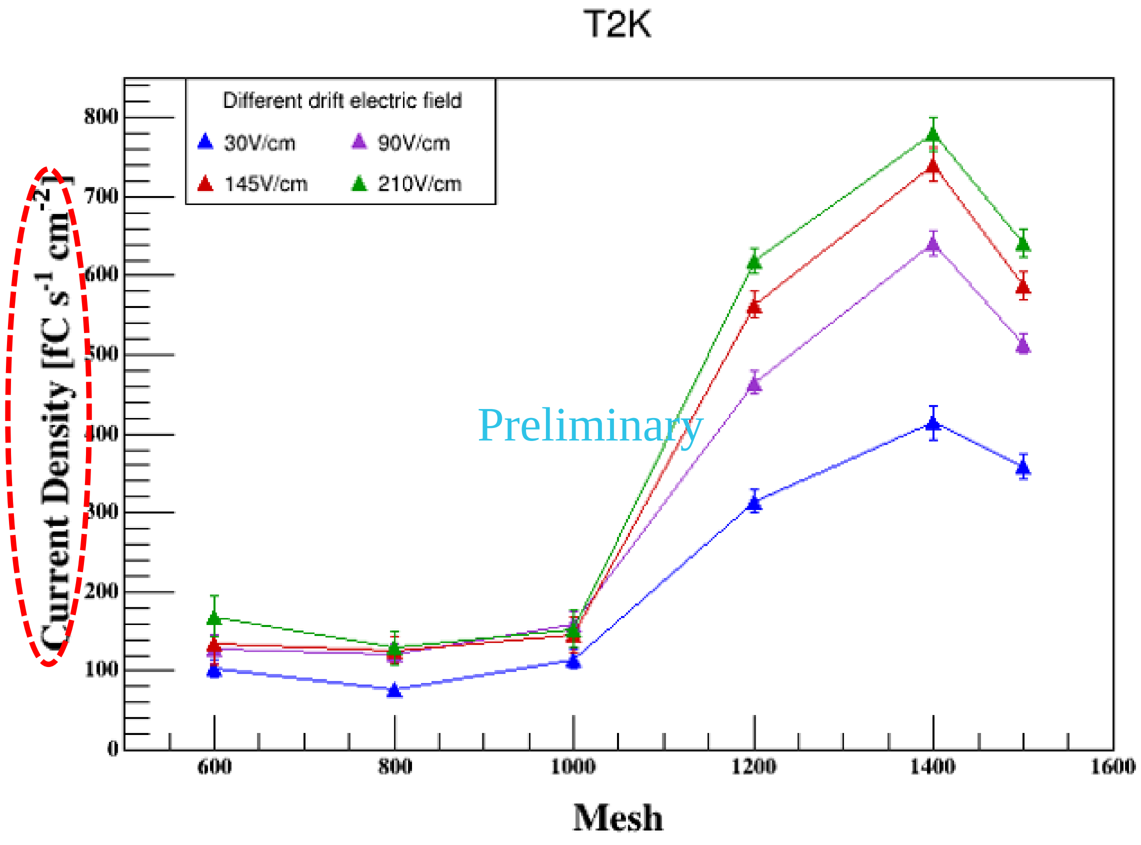


Concept and photo of the experimental study using UV deuterium lamp

Photocurrent measurement

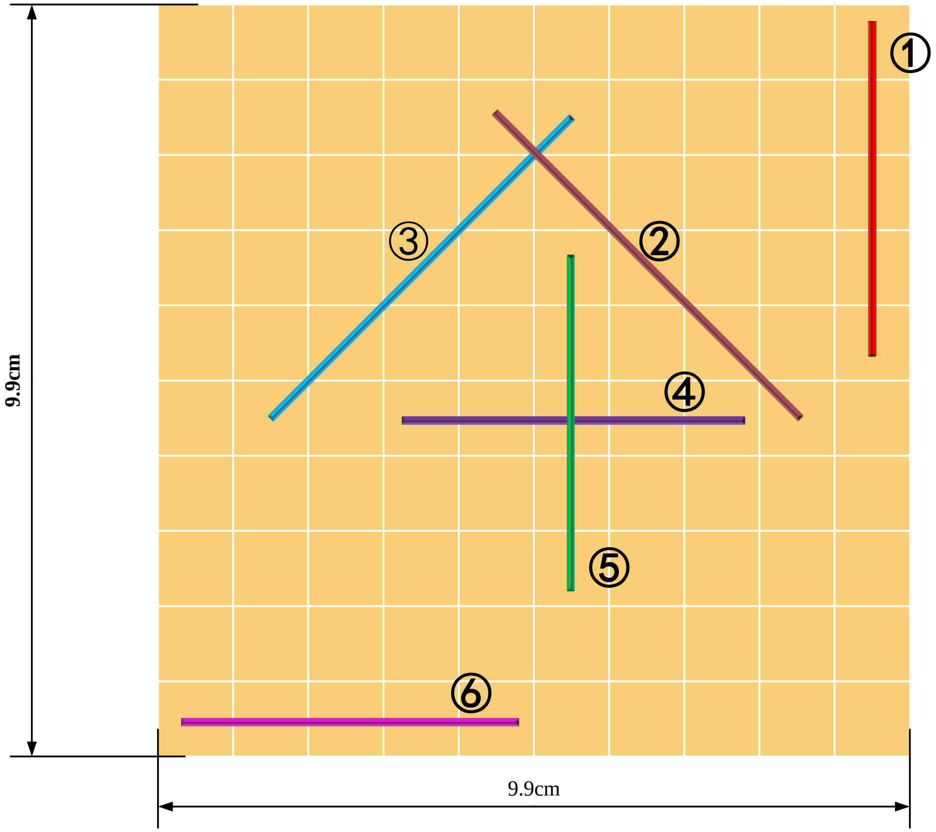
- Photocurrent is very stable in different LPI Aluminum's surfaces and electric field
- Detector has been studied under two kind of working gases（Ar/CO2=90/10,T2K）
- The maximum current density reach to **780 fA cm^{-2}** in T2K gas，**consistent with simulation results**

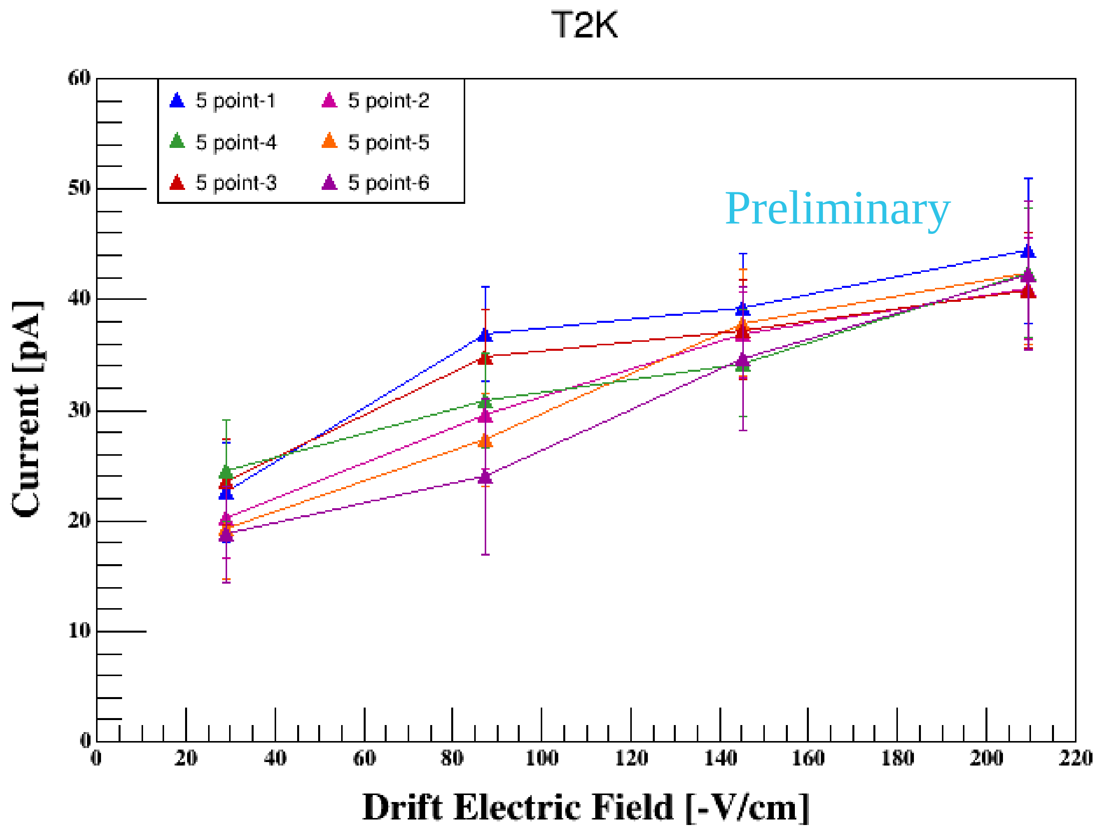




Photocurrent uniformity in the readout plane

- Analyzing uniformity by connecting pads in series at different locations and measuring current values
- Uniformity of current value at different positions ~96%

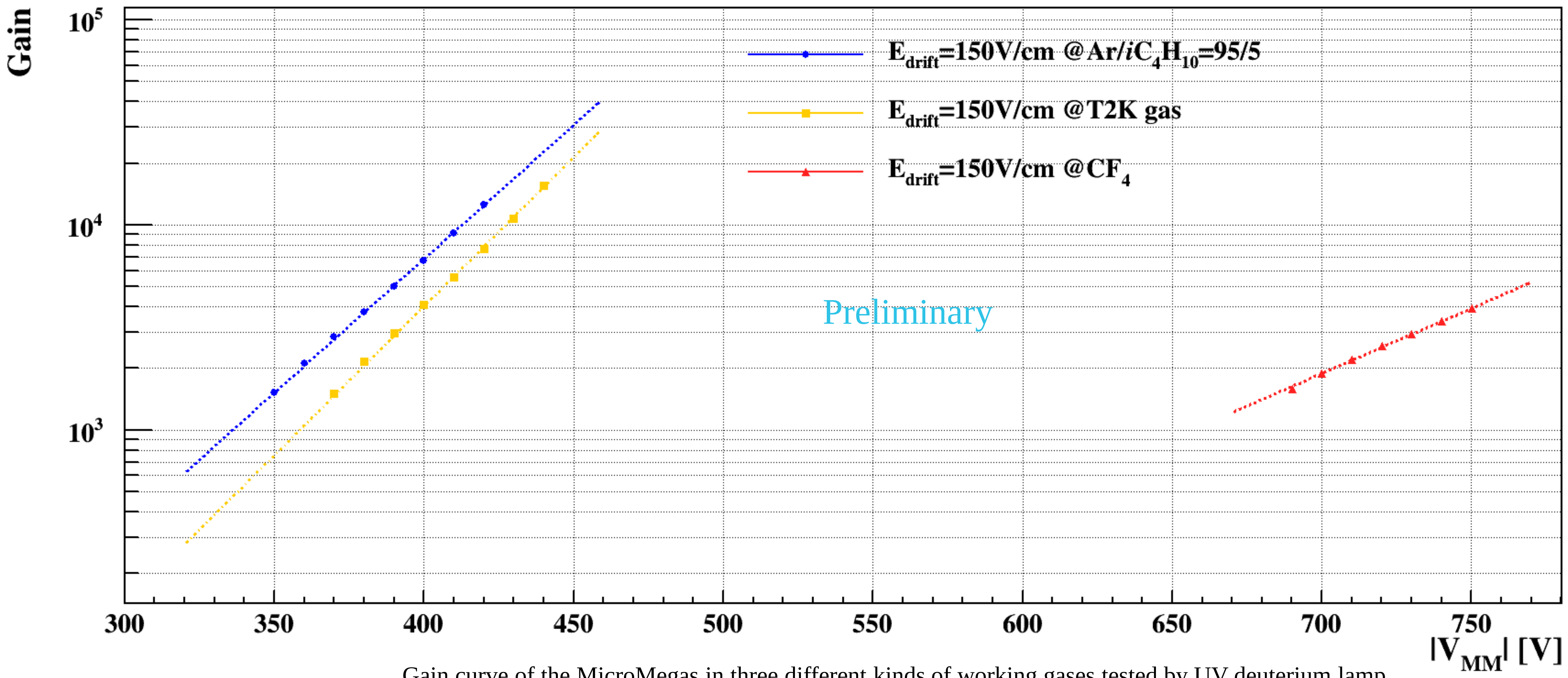




Schematic diagram of connecting pads in series at different locations and current measurement results

Photoelectron amplification using MPGDs

- Massive electrons caused by photoelectric effect are amplified by **MicroMegas**
- The novel method is feasible to study the Ion back flow, space charge, and track distortion at high luminosity Z-pole

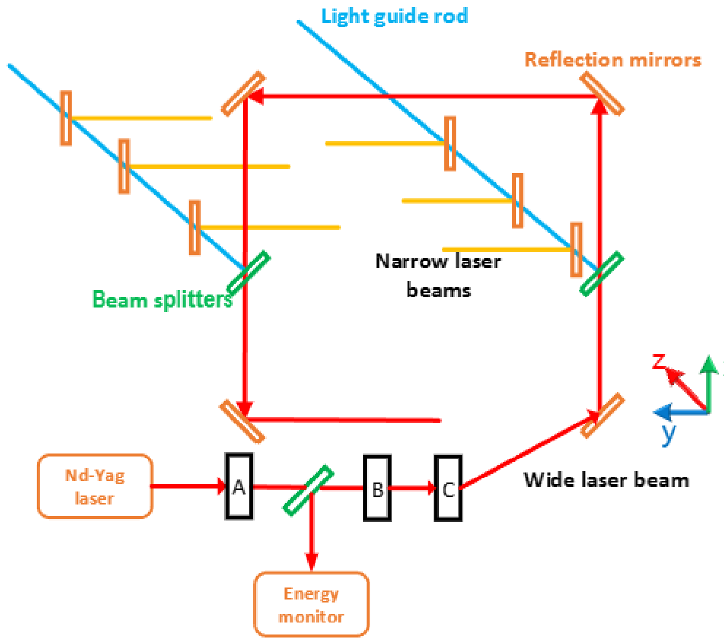


Gain curve of the MicroMegas in three different kinds of working gases tested by UV deuterium lamp

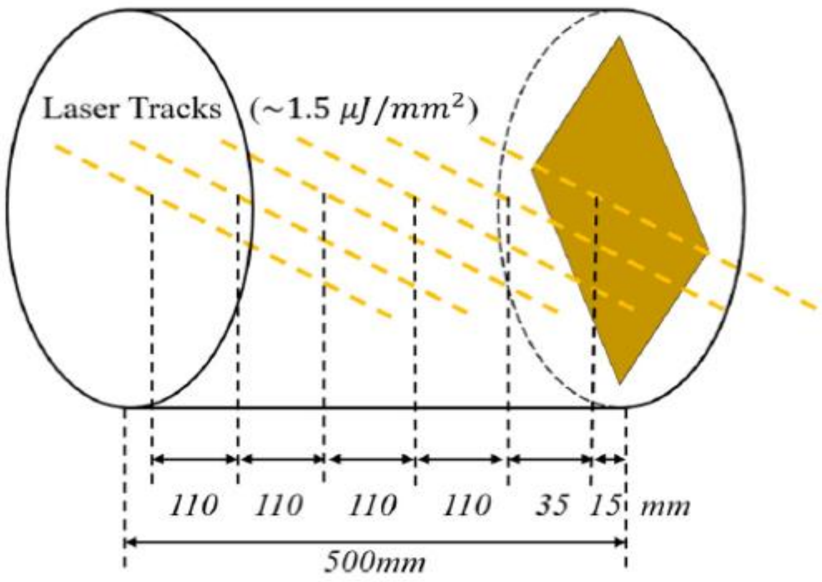
- **UV laser mimic the charged particle tracks**

TPC prototype integrated with laser tracks

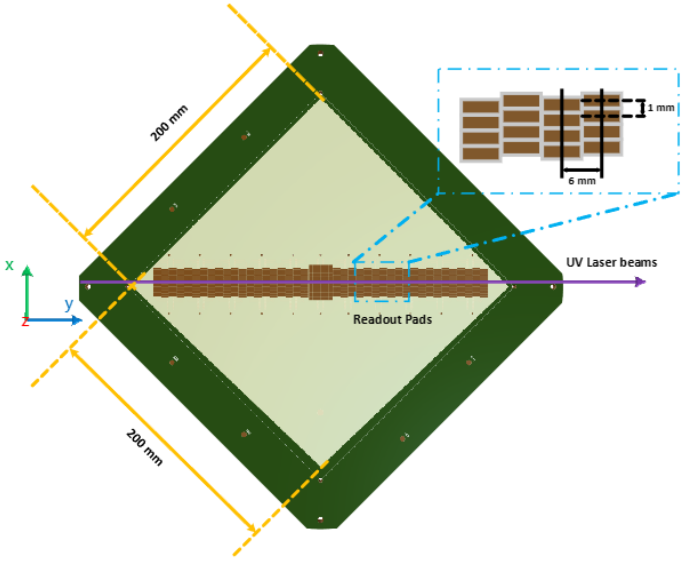
- 6 horizontal laser tracks is designed along the TPC prototype with drift length of 500 mm and a diameter of 380 mm
- The laser spot diameter is 0.8 mm, the energy density is about 1.5 μJ/mm^2
- The laser signal is read out through a double cascade GEM detector, 200mm×200mm effective area, gain~3000, using 1mm ×6mm pad size
- About 700 readout pads (with 15 pads in each column, staggered structure) arranged along the UV laser track



UV laser calibration system



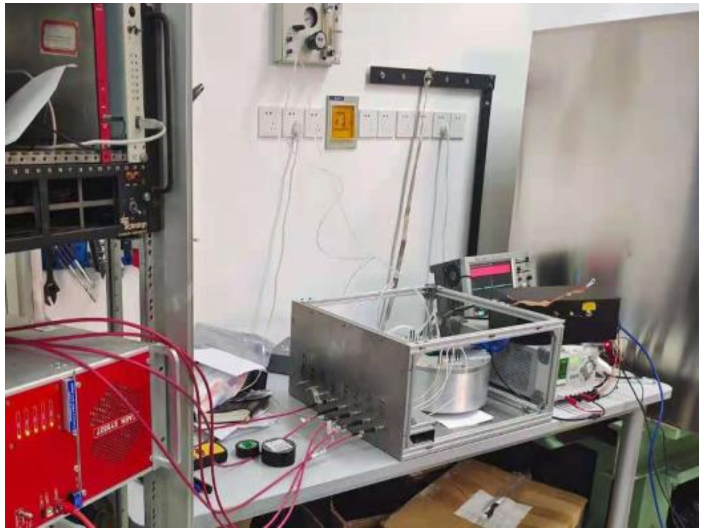
Laser tracks along the drift length

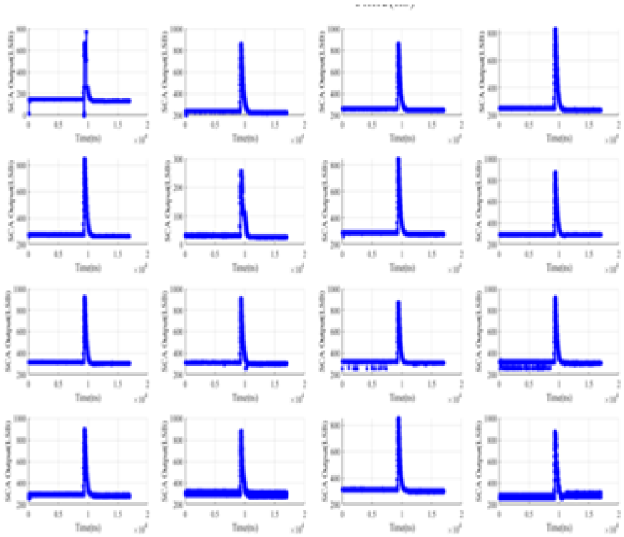


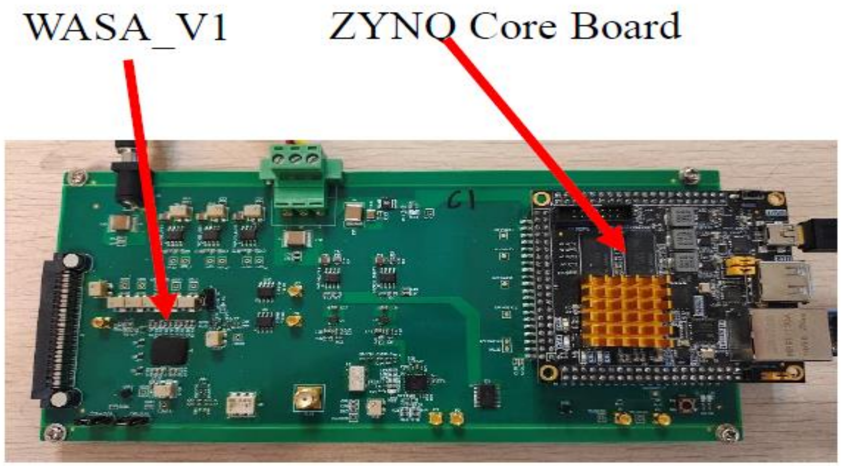
Readout pads arrangement

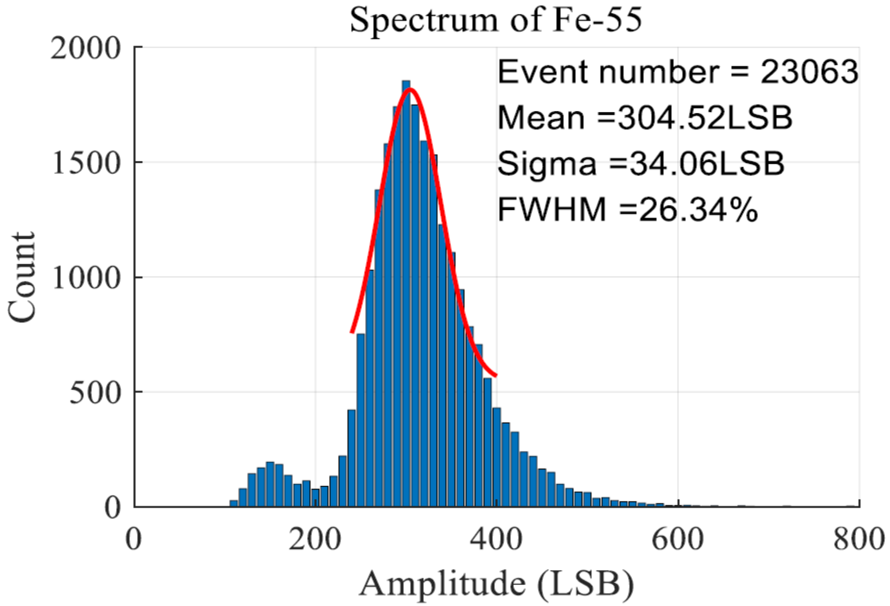
Low power consumption readout ASIC R&D

- WASA V1 has been developed: 16 channel AFE+ADC+LVDS data output
- Total power consumption with ADC function: ~2.4 mW/ch
- Tested with TPC detector using 128 channels at IHEP,CAS









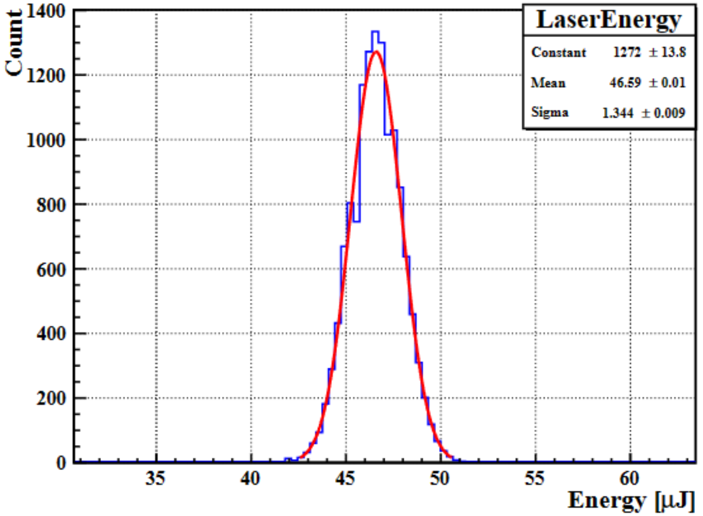
^{55}Fe testing parameters:

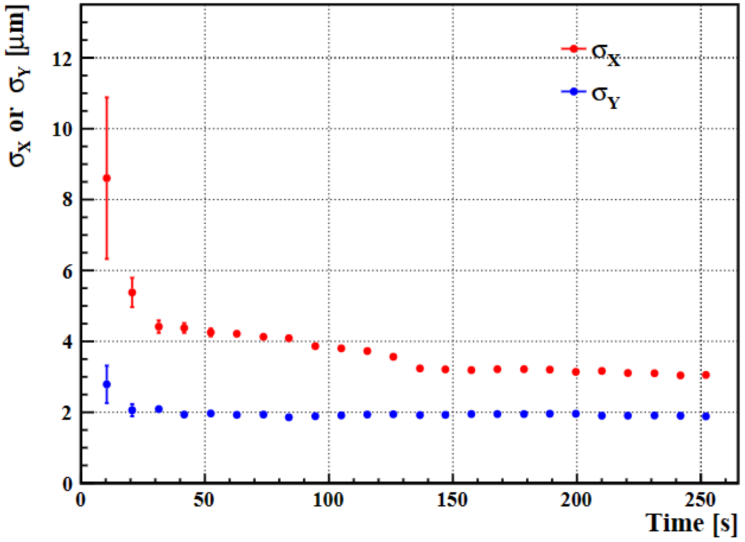
- GEMs detectors:280V-310V
- Edrift:<=280V/cm
- Working gas: T2K gas(Ar/CF4/iC4H10=95/3/2)
- Successfully commissioned and collected signals using DAQ

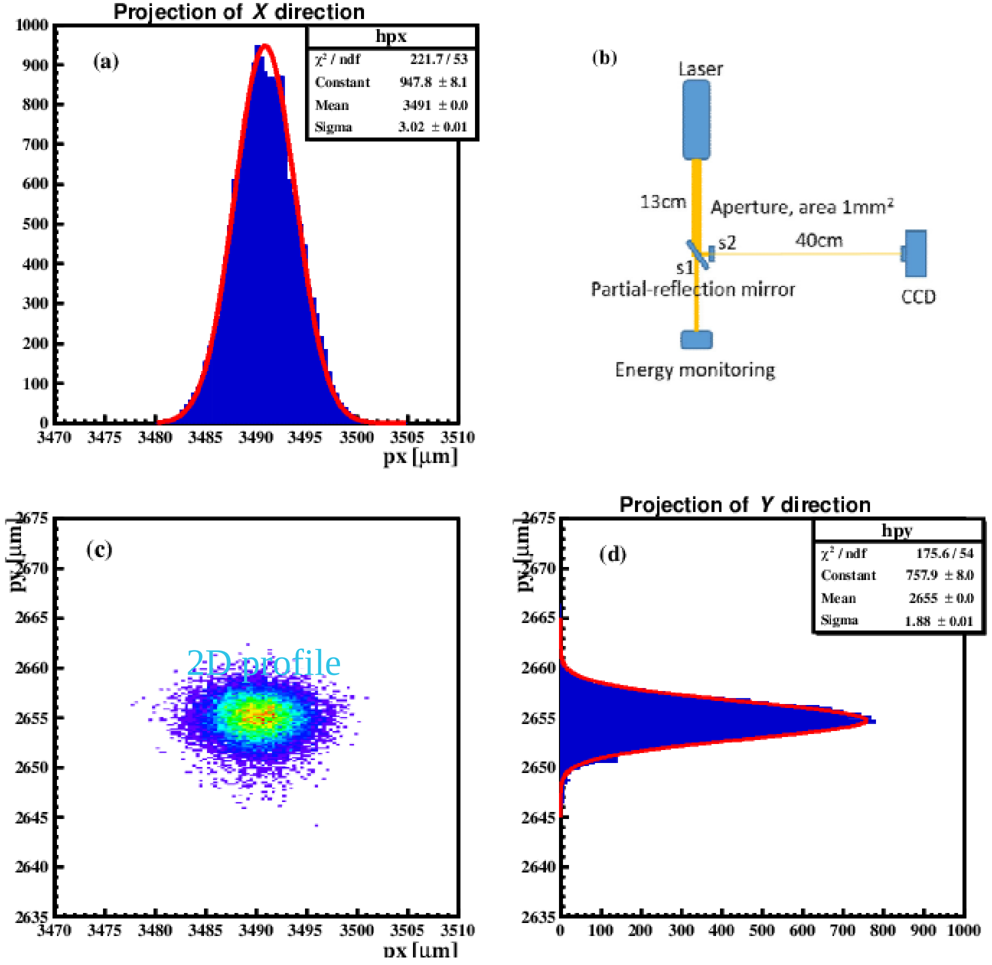
https://doi.org/10.1088/1748-0221/15/05/P05005

Stability of narrow laser beams

- **Nd-Yag laser parameters(**Q-smart 100 model **)**：
  - Output laser wavelength:266nm (1064nm->532nm->266nm)
  - Spot diameter:4.5mm with the divergence of ~0.5mrad
  - Ouput energy：20μJ/pulse-100mJ/pulse，repetition rate：20Hz
- **Nd-Yag UV laser’s stability can meet requirements**
  - Energy stability after warming up:<3%
  - Pointing stability:3.02μm @X,1.88μm @Y
  - The σ_{xy} stabilizes after a measurement time of more than 3 mins



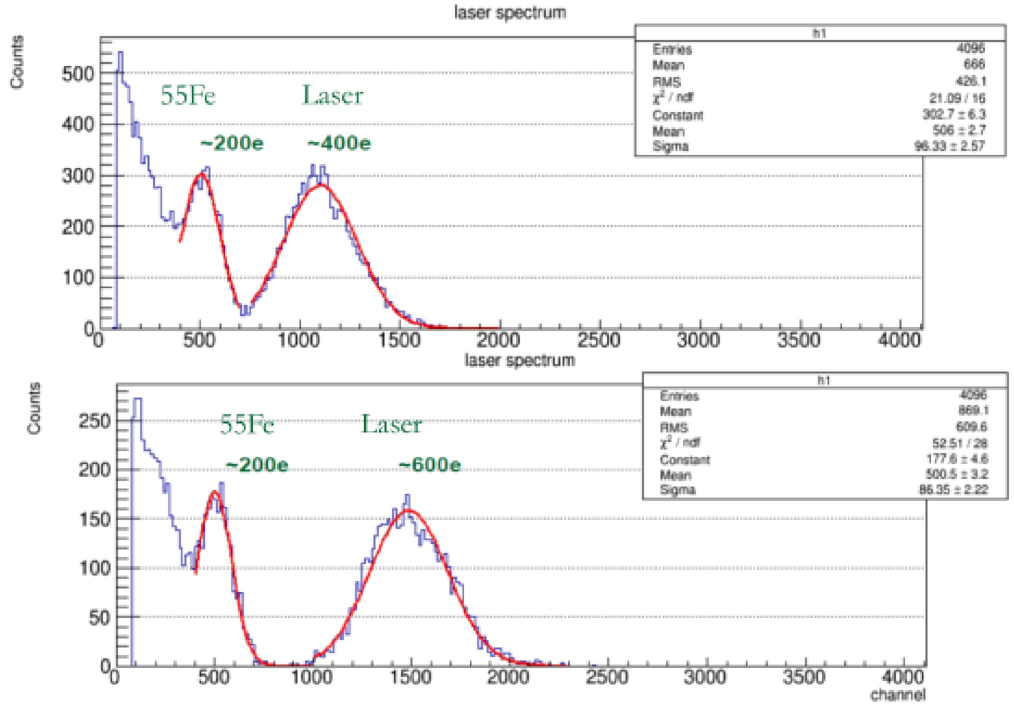




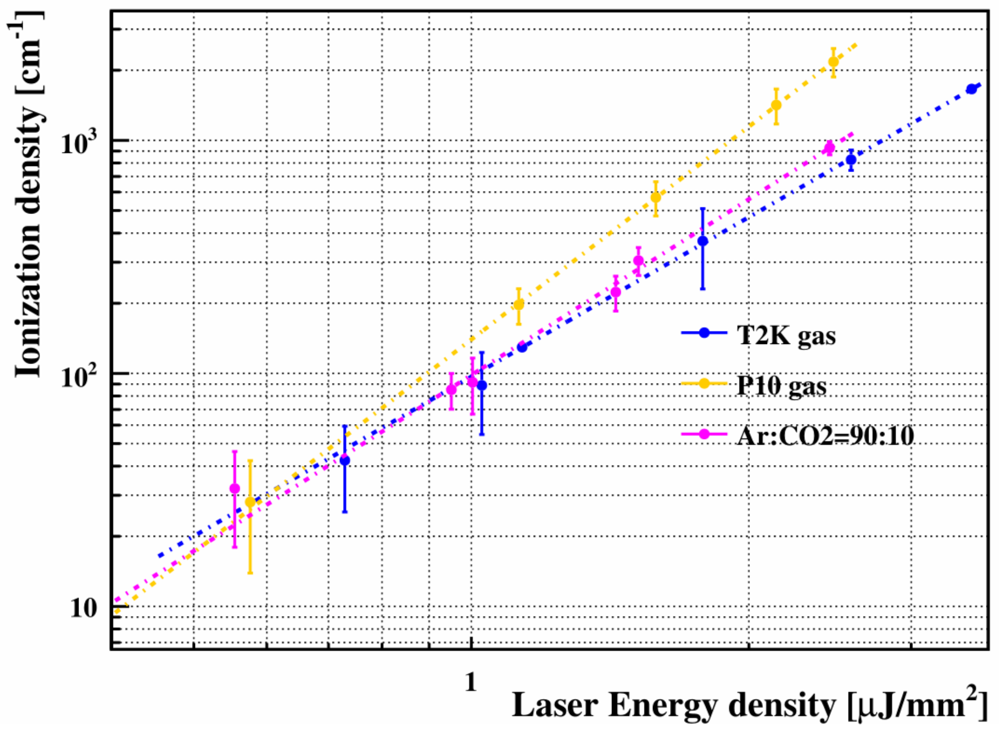
The pointing stability measurement result of the narrow laser beams

Study of 266nm UV laser beams ionization

- **Experimentally tested laser ionization spectra at different energies (Compare with ^{55}Fe source)**
- **Relation between the laser and its ionization density in three argon-based gases (T2K,P10,Ar/CO2=90/10) are obtained**
  - The laser ionization could be similar to 1-2 MIPs (100-200 electrons per centimeter) by optimizing the laser energy density
  - Important gas and energy selection reference for UV laser beams applications in TPC research



Different laser energy spectra vs ^{55}Fe



Laser ionization density curves in different argon-based gases

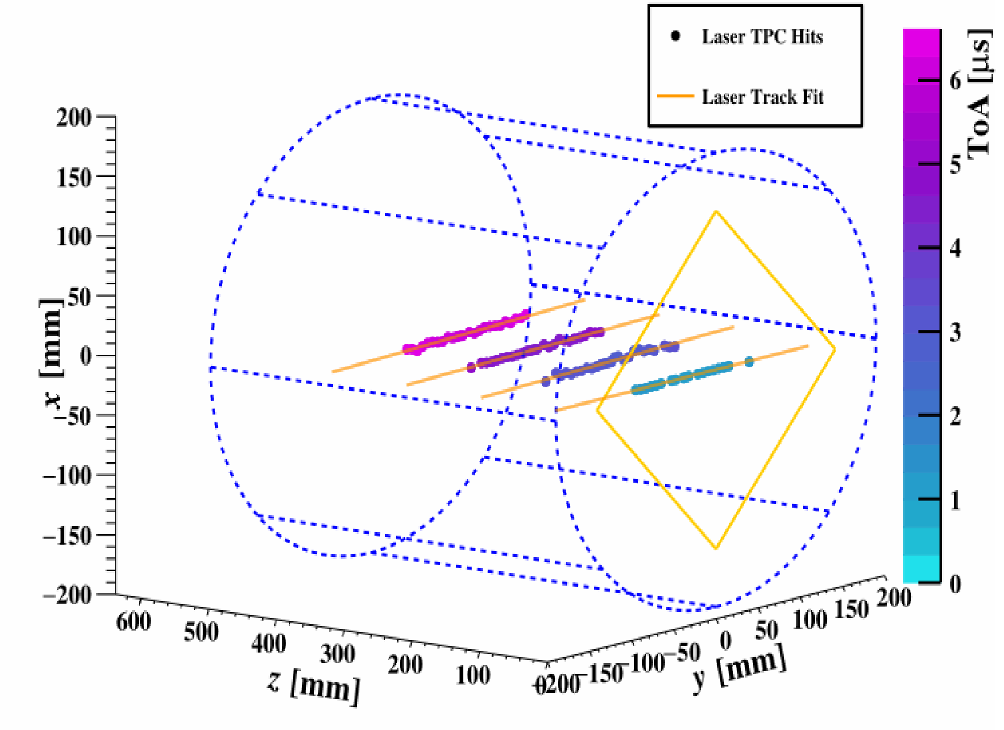
DOI 10.1088/1748-0221/15/02/T02001

Laser track reconstruction

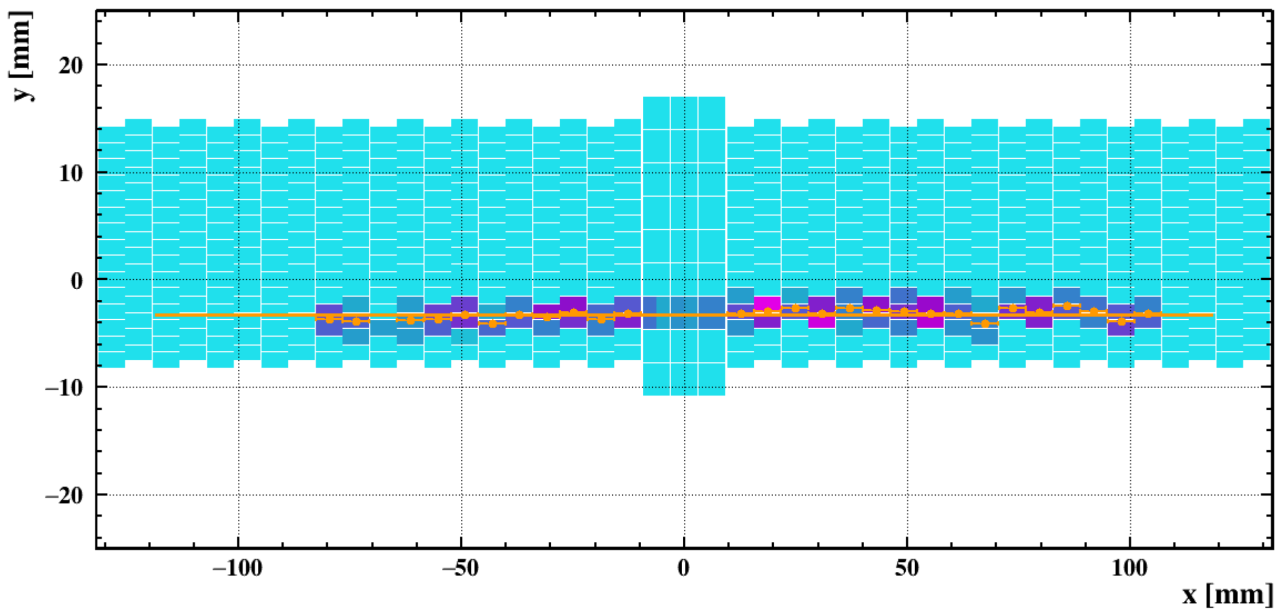
- Reconstruction Process：
  - I. Laser events selection
  - II. Hits reconstruction
  - III. TPC performance（σ_y， dE/dx， Drift Velocity etc.）
- Laser events display：

Table 1 Summary of the event selection cuts.

Laser energy monitor	Variation range	$E_{\mathrm{mean}} \pm \sigma$
TPC detector	Hit ToA	layer#1 $1.1 \sim 1.8\mu s$
		layer#2 $2.9 \sim 3.6\mu s$
		layer#3 $4.7 \sim 5.3\mu s$
		layer#4 $6.2 \sim 6.9\mu s$
	Trigger pad Number	≥ 2 for each column
Laser and detector	The laser control chassis triggers the energy monitor and DAQ system at the same time.	



3-D track reconstruction for the middle four laser tracks



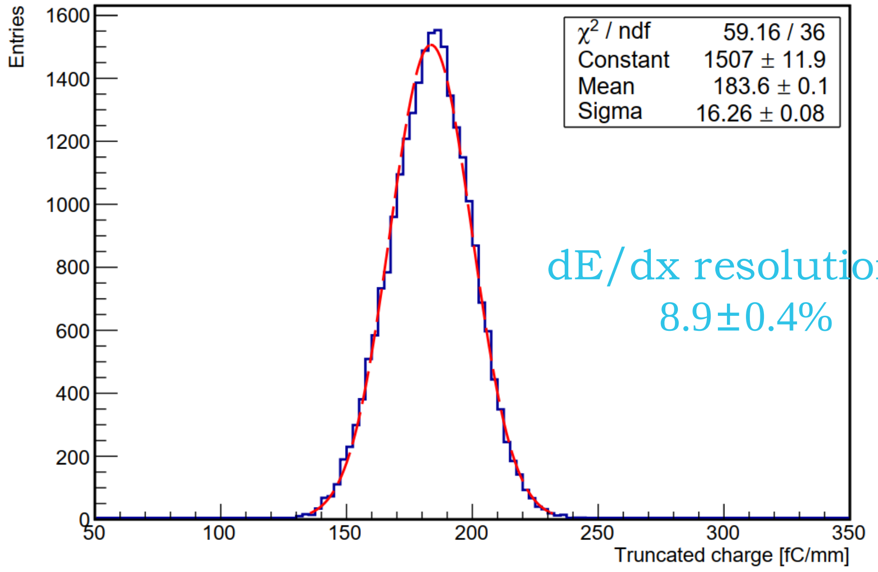
The projection in XY plane for the first layer

PRF method and truncated mean method

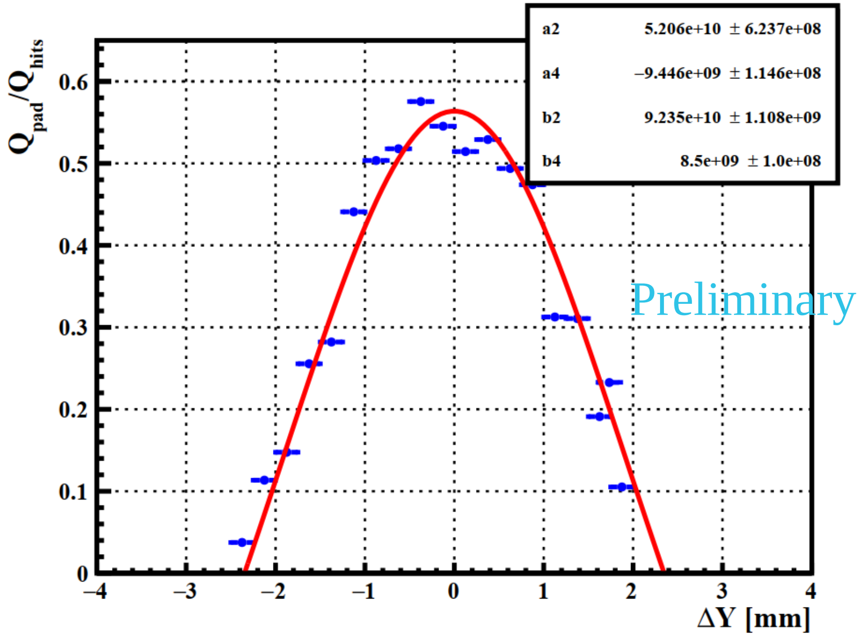
- **Determination of spatial resolution**：
  - PRF parameters: the ratio of two symmetric 4-th order polynoms
  - The spatial resolution is given by the width of residual of the track ($\Delta Y = Y_{track} - Y_{fit}$)
  - Minimize the chi2 between Q_{pad}/Q_{hit} and $PRF(y_{track}-y_{pad})$ to infer the position of the track
- **Determination of dE/dx resolution**：
  - Truncated-trimmed mean is utilized to suppress the Landau tail（Truncate-trim10%-1%）
  - Events with laser energy well above (below) the mean value are also excluded

$$\mathrm{PRF}(y,\Gamma,\Delta,a,b)=\frac{1+a_2x^2+a_4x^4}{1+b_2x^2+b_4x^4}$$

$$\chi^2=\sum_{\text{pads}}\left(\frac{Q_{\text{pad}}/Q_{\text{hit}}-PRF(y_{\text{track}}-y_{\text{pad}})}{\sigma_{Q_{\text{pad}}}/Q_{\text{hit}}}\right)^2$$



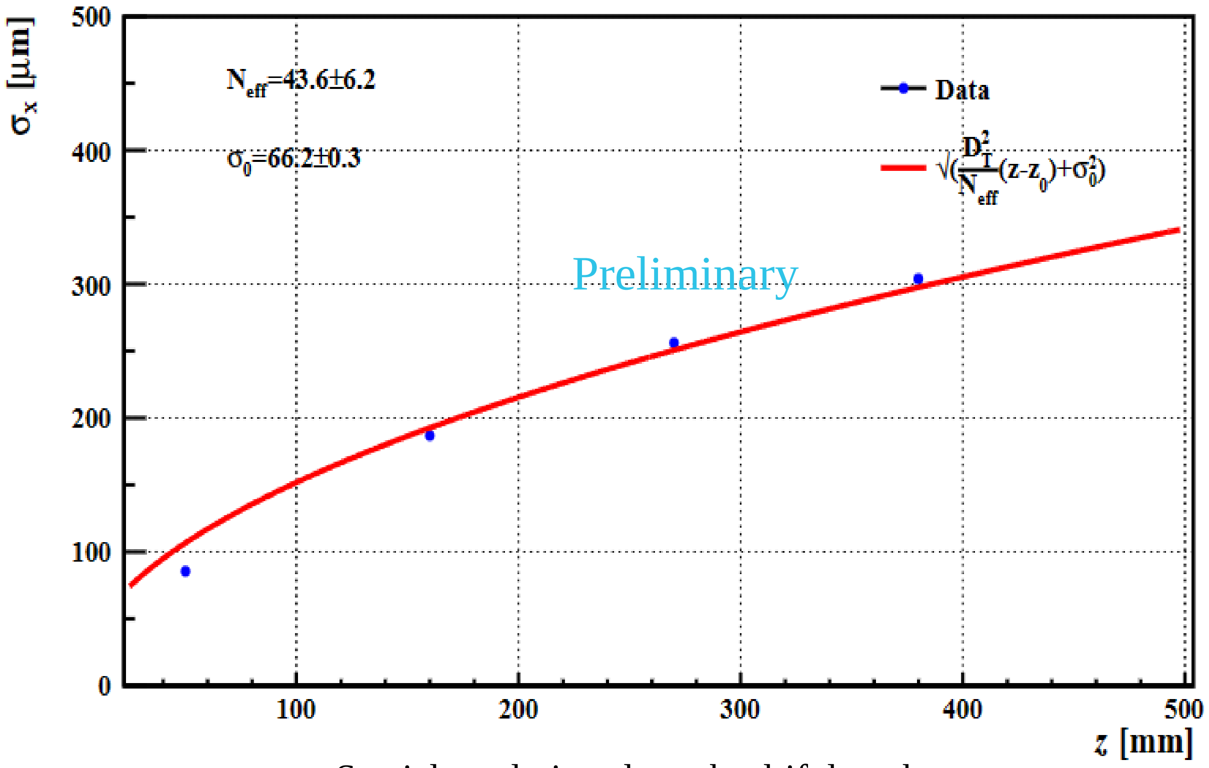
dE/dx distribution for single laser track, slight asymmetry



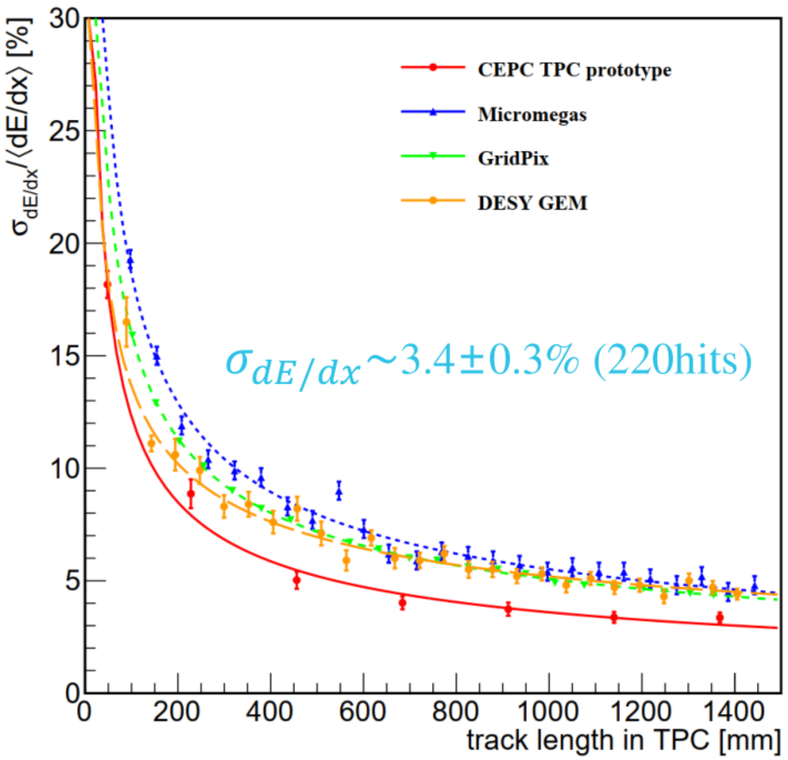
Pad Response Function fit

The performance of the TPC prototype

- The spatial resolution can be less than 100μm (@50mm drift length) without magnetic field
- The number of effective electrons N_{eff}~40 (*calibrated by* ^{55}Fe)
- Pseudo-tracks with N_{hit}=220 (same as the actual size of CEPC baseline detector concept) ,dE/dx is about 3.4±0.3%



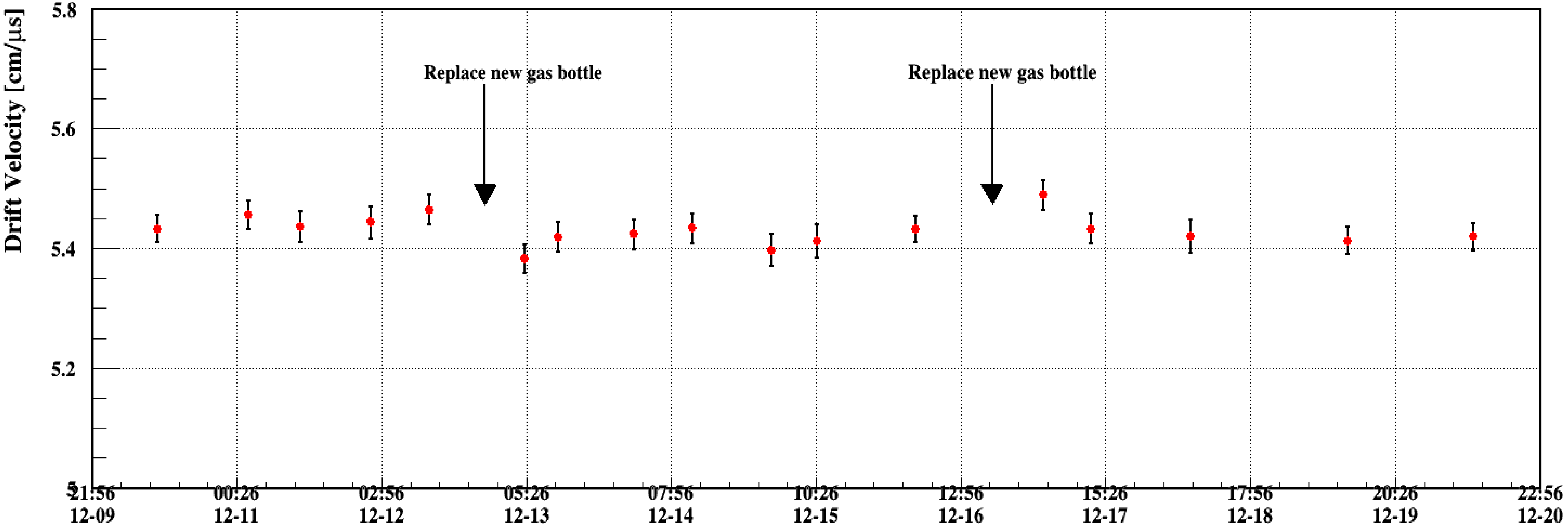
Spatial resolution along the drift length



dE/dx resolution as a function of track length

Drift velocity monitoring

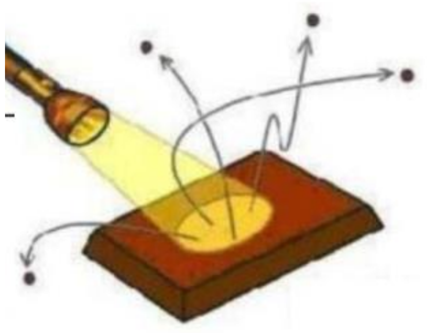
- The drift velocity of the TPC prototype can be monitored by using UV laser tracks
- The drift velocity can reach about 5.4 cm/μs in more than two weeks, and it's sensitive to the gas variation

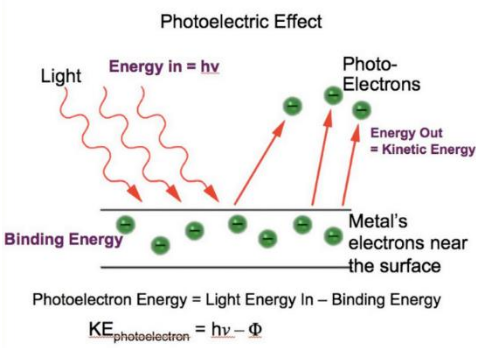


Monitoring the drift velocity of TPC detector over two weeks

Summary

- **UV photon: Photoelectric effect(<10μJ/cm^2)**
  - The work function is below 4.66 eV for most metallic surfaces
  - Massive electrons will be emitted and create stable current





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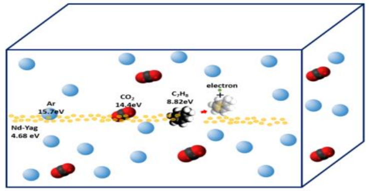
Ga	4.32		Gd	2.90	

- massive electrons had been generated uniformly in big area
- Maximum current density 780 fA cm^{-2} in T2K mixture gas
- Electrons created by photoelectric effect had been amplified by MPGDs successfully

- **UV laser: Two-photon ionization(>10μJ/cm^2)**
  - Some organic impurities in the chamber can be ionized by absorbing two or more photon
  - Nd-Yag laser wavelength：266nm (almost 4.66eV×2)
  - Imitating charged particle tracks, TPC performance study and calibration

Nd-Yag
266nm laser



- TPC prototype integrated with UV laser tracks was developed successfully
- Relation between the laser and its ionization density
- Spatial resolution <100μm @B=0T
- dE/dx resolution:3.4±0.3%（N_{hit}=220， ~2.4MIPs）

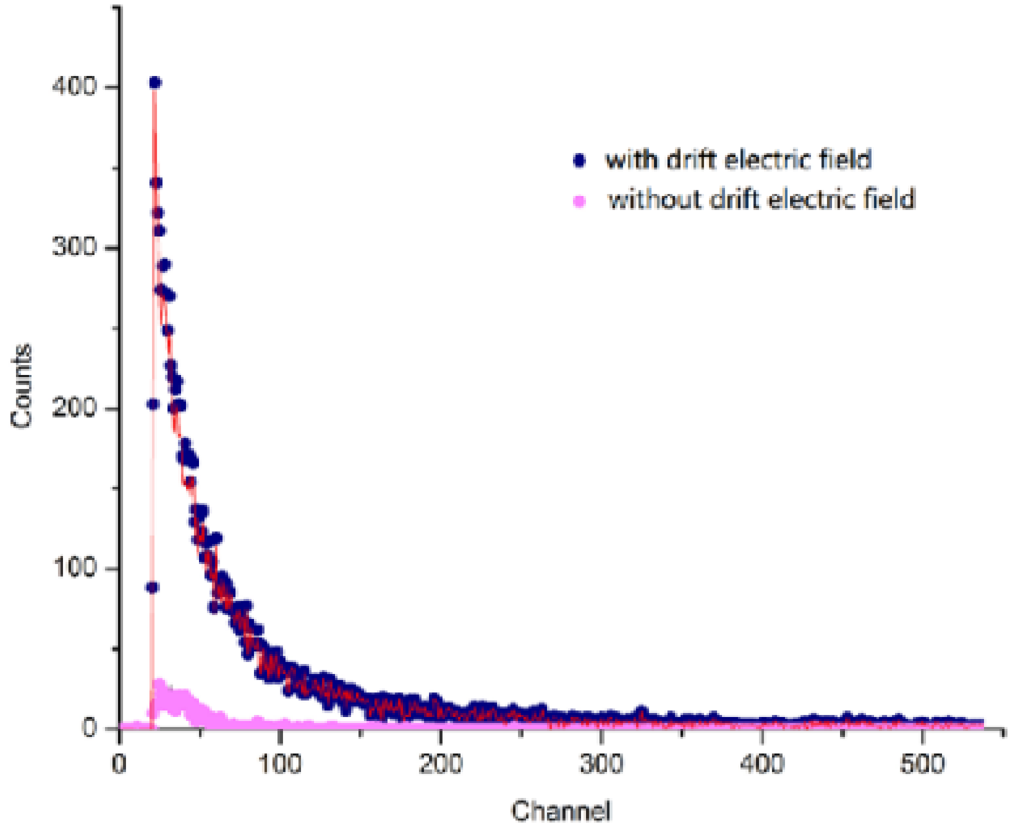
Future prospects

- UV light can mimic the space charge effect in TPC at CEPC Z-pole run, more detailed track distortion studies are ongoing based on photoelectric effect
- UV laser beams can be a useful tool to study TPC's performance in the laboratory, detailed track distortion correction studies are ongoing

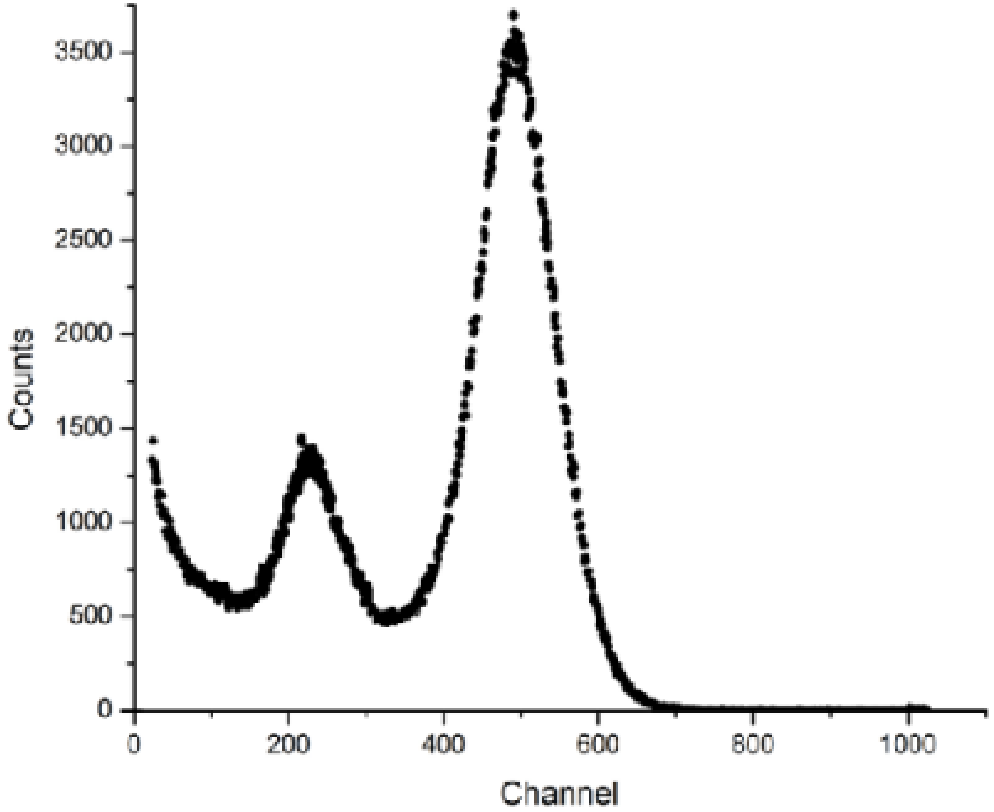
Thanks for listening

Spectra

- TPC prototype was checked after one year development
- Detector gain just shift 2% than one year before
- The Landau distribution of the cosmic ray's spectra and ^{55}Fe X-ray spectra was obtained



Cosmic ray spectra



^{55}Fe spectra