Development of TPC prototype integrated with UV laser tracks for CEPC

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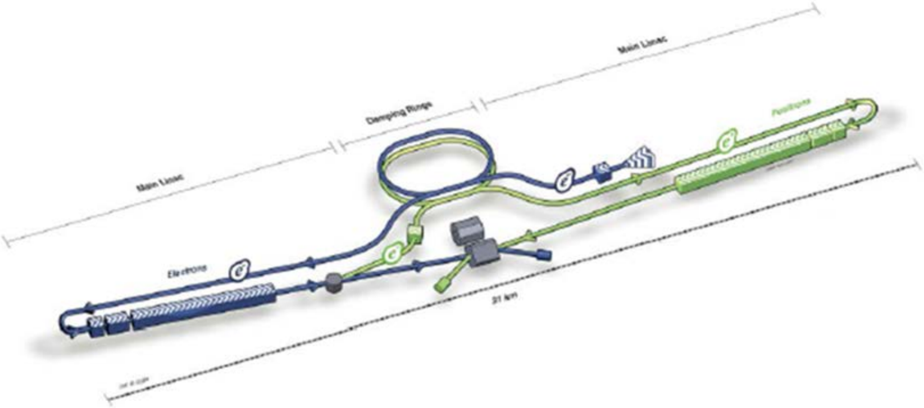
Content

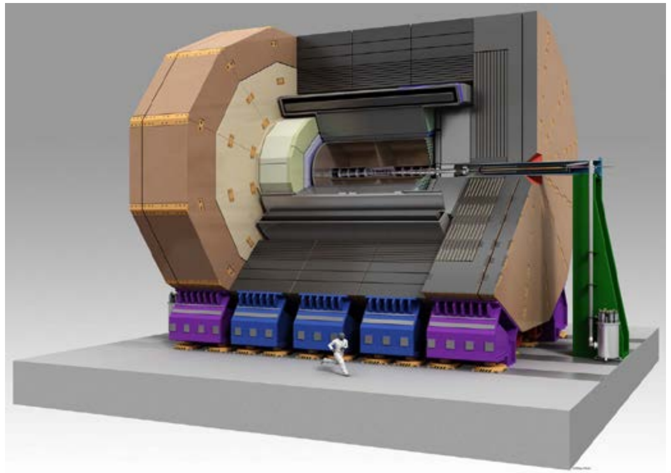
- **TPC detector for e+e- colliders**
- **UV light to study the tracks and massive electrons**
- **TPC prototype with integrated UV laser**
- **UV light create the massive primary electrons**
- **Summary**

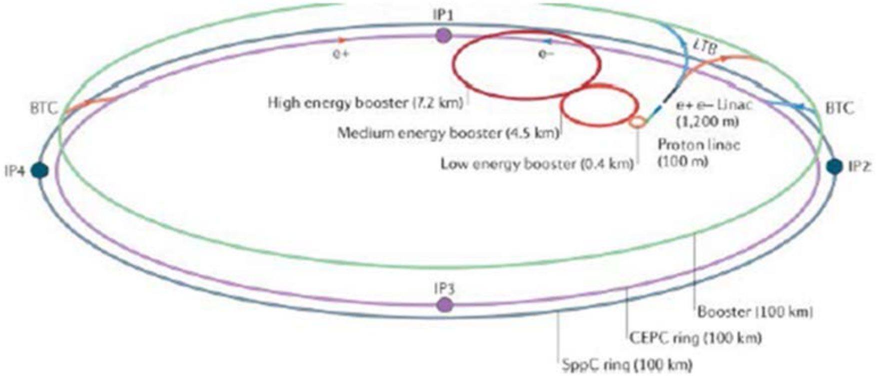
TPC technology for the future e+e- colliders

- A TPC is the main tracking detector for **some candidate experiments at future e+e- colliders**
  - ILD at ILC and the baseline detector concept of CEPC
- TPC technology can be of interest for other future e+e- colliders

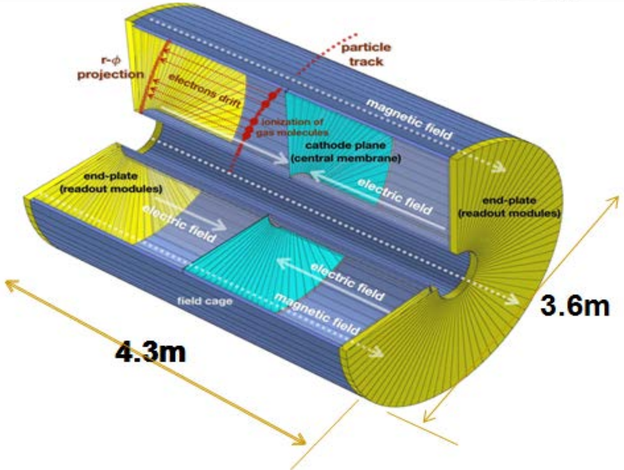


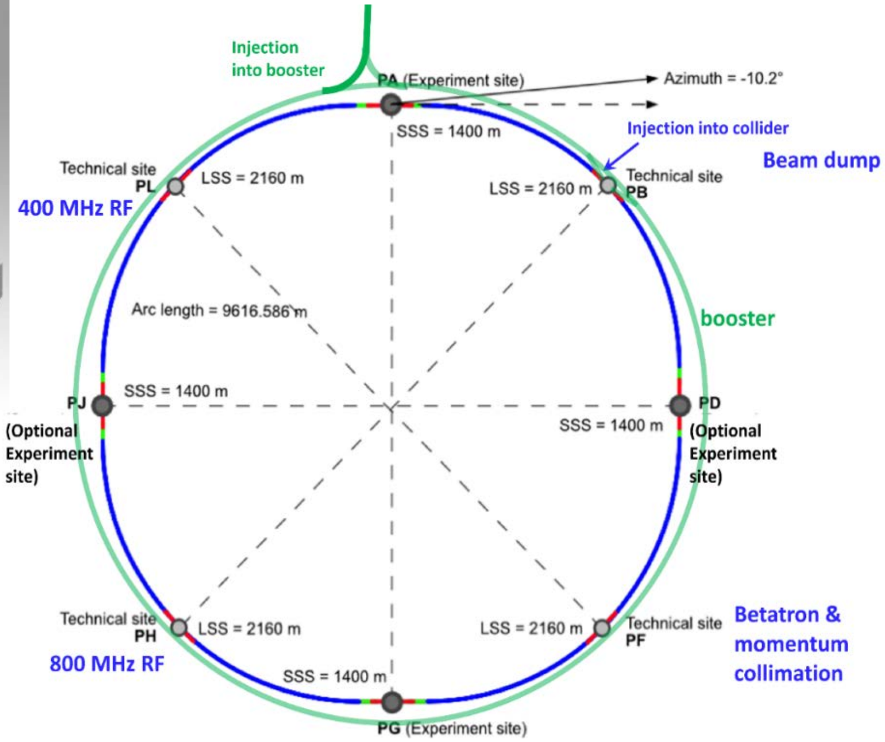
International Linear Collider (ILC)





Circular Electron Positron Collider (CEPC)



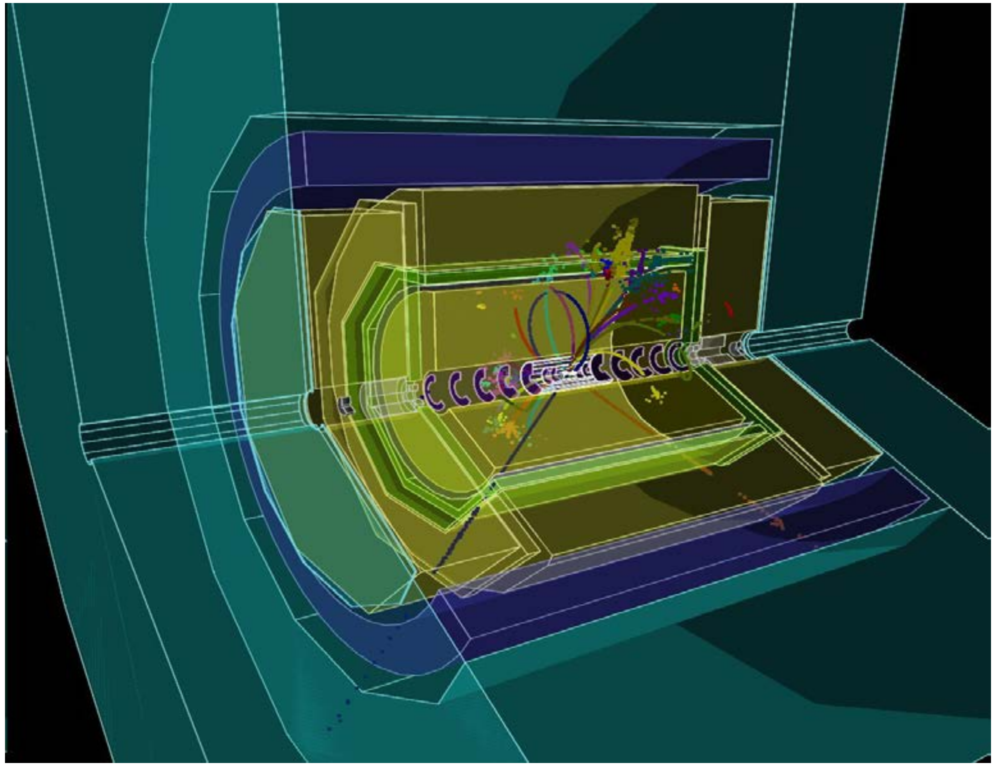


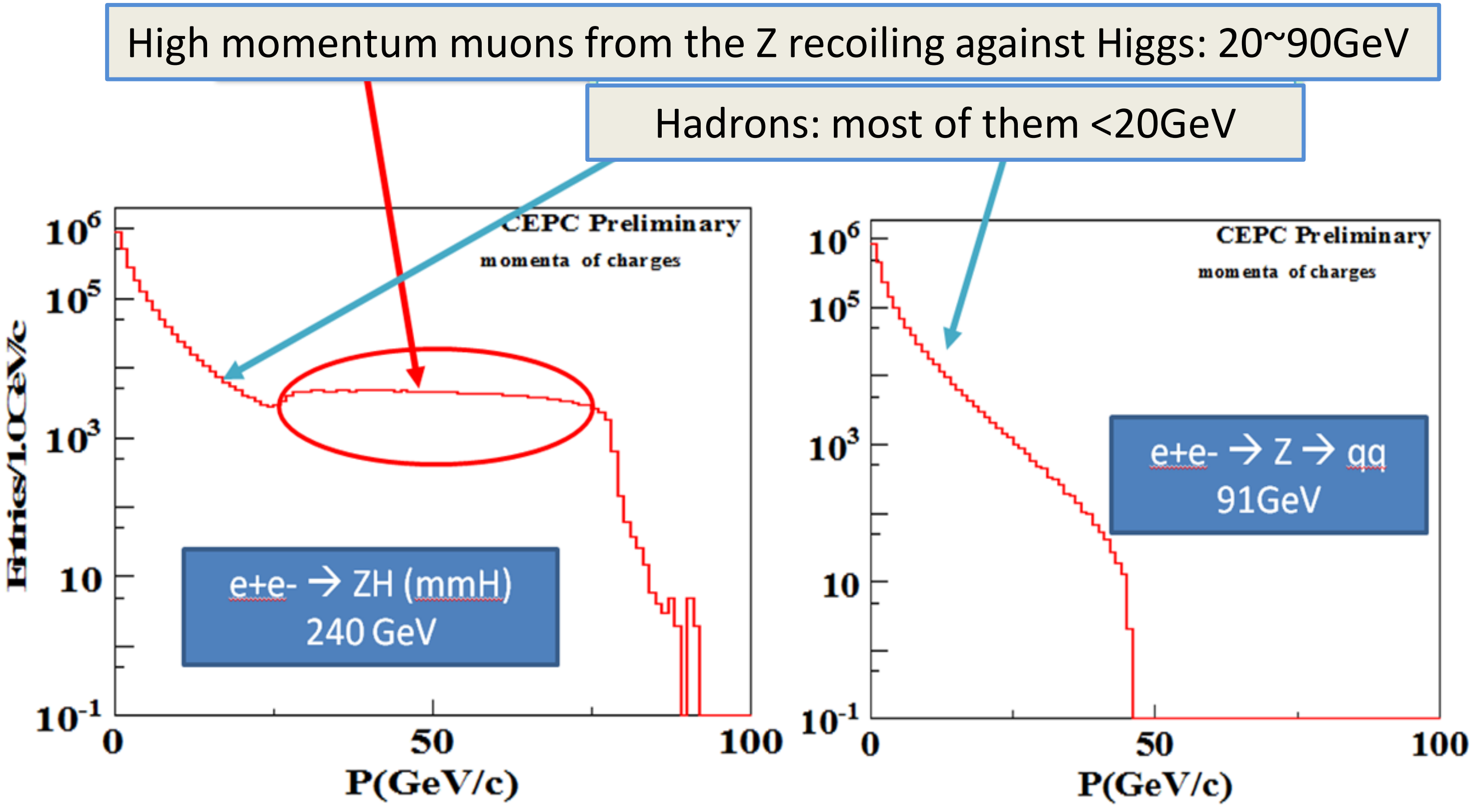
Future Circular Collider (FCC-ee)

https://arxiv.org/abs/2203.06520

TPC requiremetns from e+e- Higgs/EW/Top factories

- TPC can provide hundreds of hits (for track finding) with high spatial resolution compatible with PFA design (**very low material** in chamber)
  - $\sigma_{1/pt}$ ~10^{-4} $(GeV/c)^{-1}$ with TPC alone and σ_{point}<100μm in rϕ
- **Provide dE/dx and dN/dx with a resolution** <4%
  - Essential for Flavor physics @ Z run
  - Beneficial for jet at higher energy





Key issues of TPC technology for e+e- collider

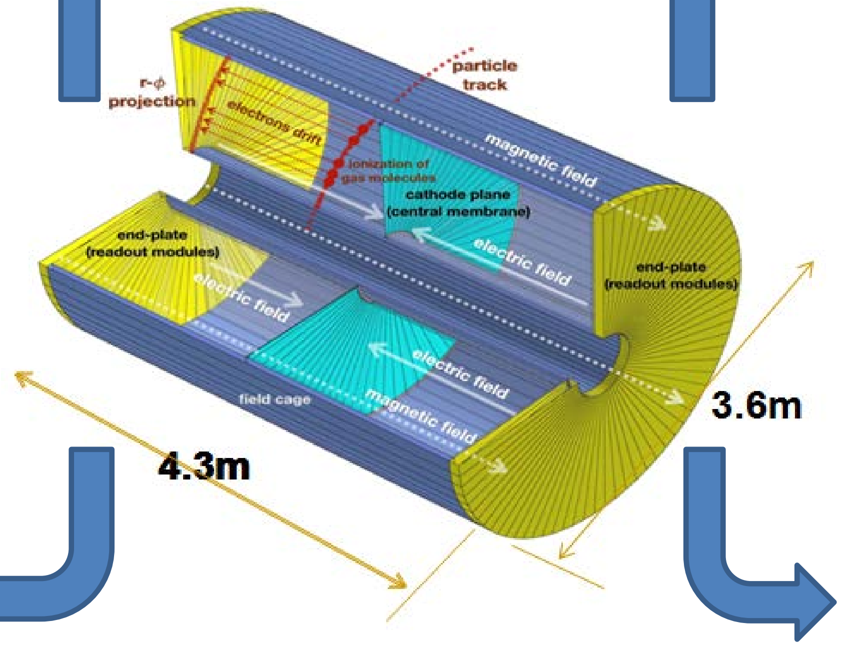
Pad readout TPC

- To meet Higgs physics
- 1mm×6mm of Pad
- TPC module
- TPC prototype with UV laser

TPC track detector for e+e- collider

Pixelated readout TPC

- To meet Z physics
- ~500µm of Pad
- TPC prototype with UV laser track
- dN/dx+dE/dx study



Ion back flow study

- Simulation of Ion Backflow
- Test the UV light created the ions by photoelectric effect
- Experimental study

PID performance Study

- Simulation of the ionization cluster in space
- PID studies of the different readout TPC prototype
- Experimental study

Need investigation of the electrons/ions density at CEPC

- Simulation results based on CEPC's parameters (**High luminosity at Z pole: 10^{36}**)
- CEPC or others detector will meet the **massive electrons/ions in the detector chamber**
- To investigate and create the stable electrons/ions in the specific area to study the deviation
- Positive ion feedback in Z physics **(gain ~2000, IBF ratio ~0.1%)**

Electric field analysis

$$\vec{\nabla}\cdot\vec{E} = \frac{\rho}{\varepsilon} \quad \longrightarrow$$

Cylindrical coordinates

$$\phi(r,\theta,z) = \sum_{m=-\infty,\infty} \phi_m(r,z)e^{im\theta},$$

$$\phi_m(r,z) = \int_{-\infty}^{\infty} \Phi_m(r,k)e^{ikz}dk,$$

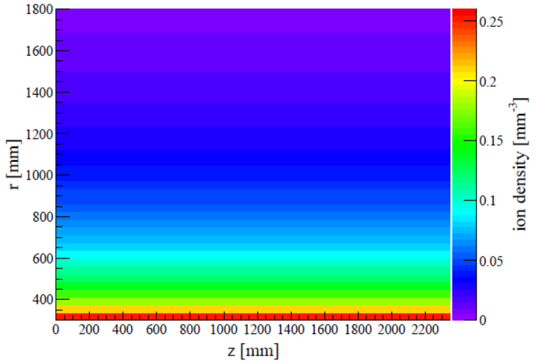
$$\Phi_m(r,k) = K_m(kr)\int_0^r R_m(r',k)\, I_m(kr')\, r'dr' + I_m(kr)\int_r^{\infty} R_m(r',k)\, K_m(kr')\, r'dr'$$

$$R_m(r',k) = \frac{1}{2\pi}\int_{-\infty}^{\infty} \rho_m(r',z')\, e^{-ikz'}dz'$$

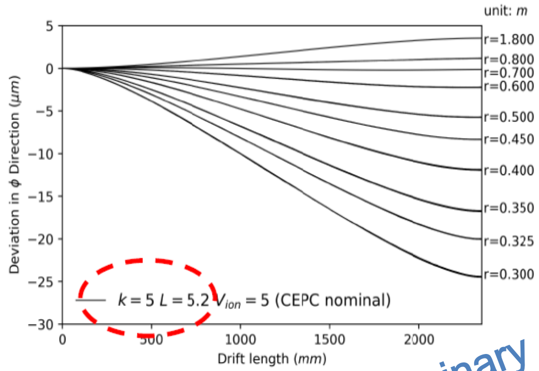
$$\rho_m(r',z') = \frac{1}{2\pi}\oint \frac{\rho(r',\theta',z')}{\epsilon_0} e^{-im\theta}d\theta'$$

Resnati F. Modelling of dynamic and transient behaviours of gaseous detectors[J]. 2017.

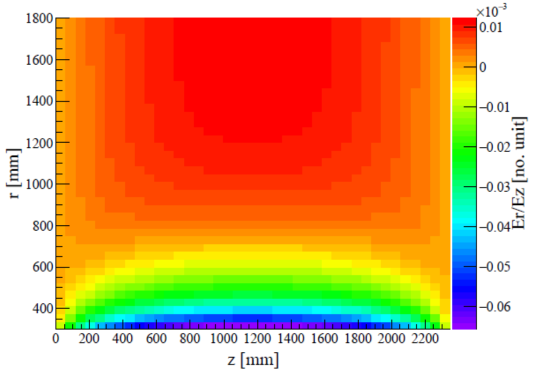
Ions density in chamber



Higgs

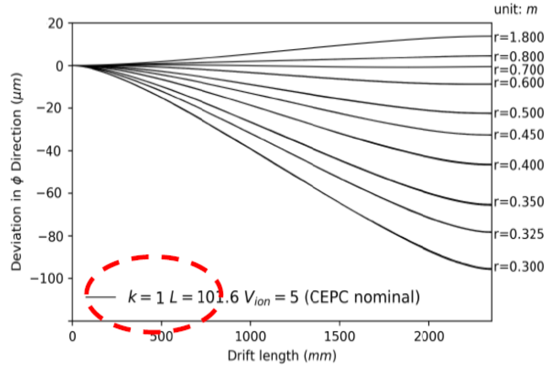


E_r/E_z



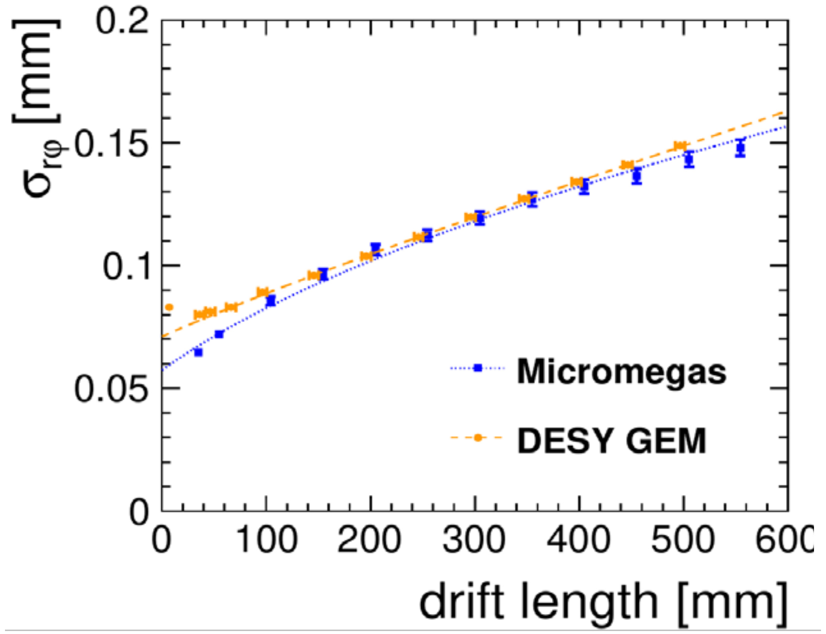
Z

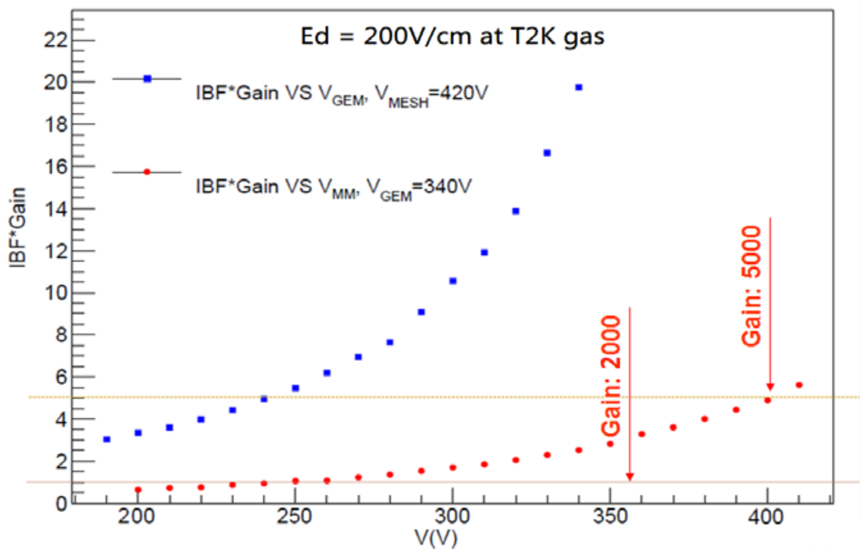
Preliminary

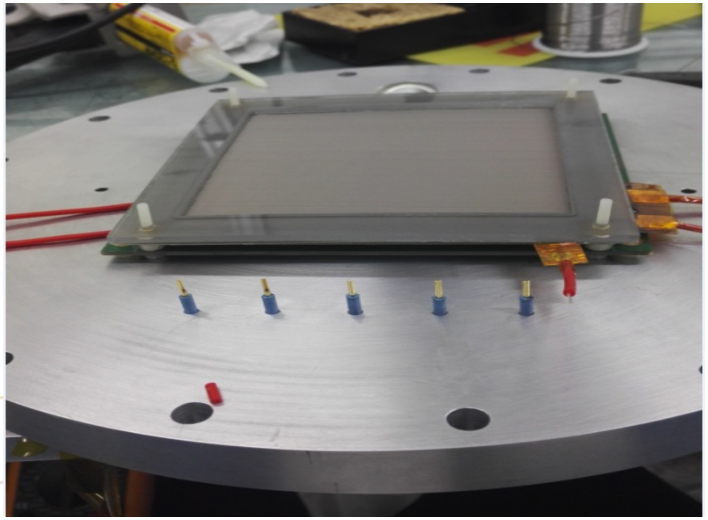


Pad TPC technology – Detector Module R&D

- **GEM and Micromegas** groups have finished analysis of test beam data with previous set of detector modules. Both technologies show **very similar performance**.
- LCTPC will implement improvements in a **new generation of modules** => **common modules**
  - Common readout electronics (sALTRO)
  - Only the gas amplification stage differs
- Combined Micromegas + GEM readout has been developed, which promises a **lower ion backflow** (IBF ratio and reasonable detector gain) at CEPC TPC group without gating.

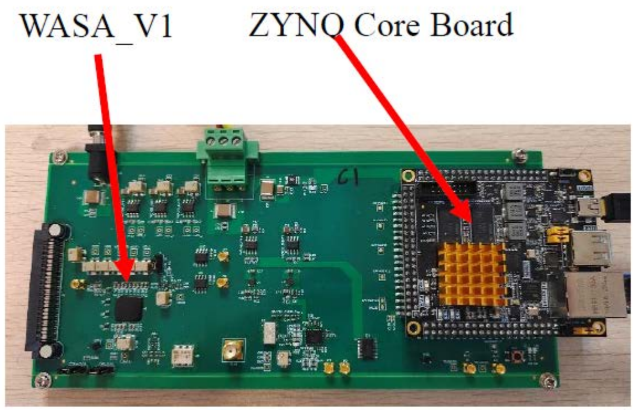


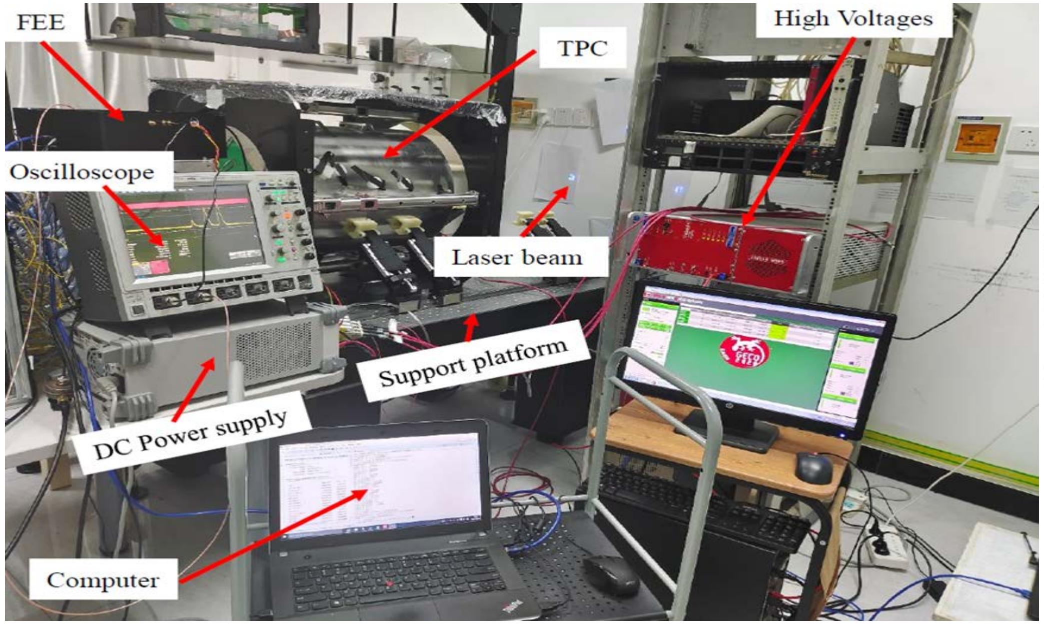




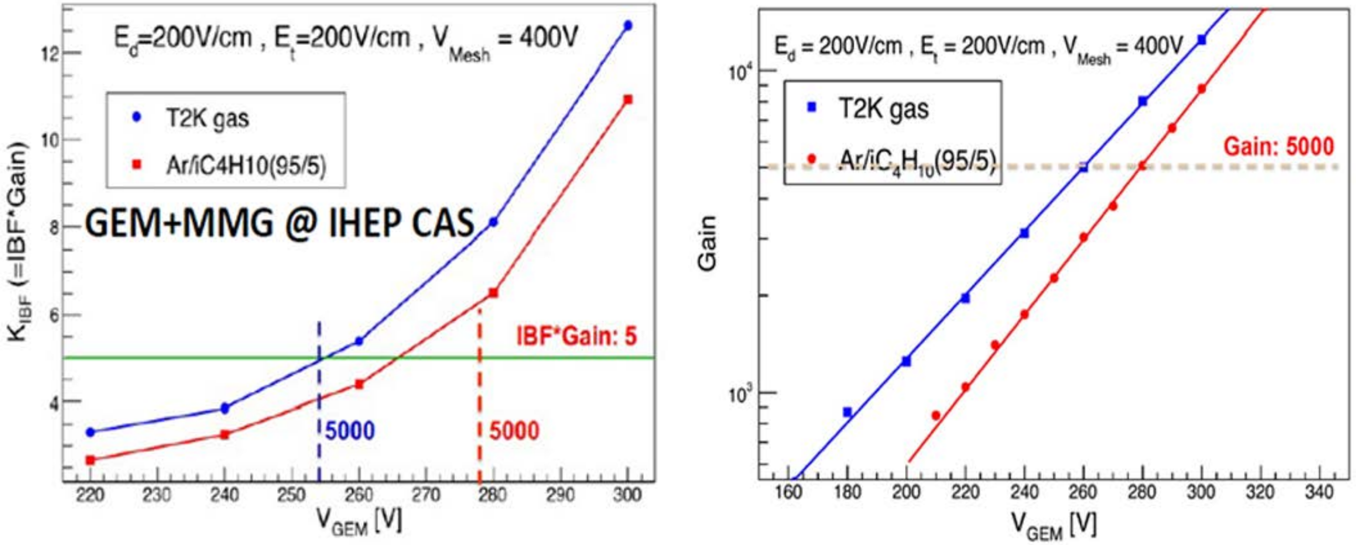
CEPC TPC detector prototyping roadmap

- From TPC module to TPC prototype R&D for beam test
  - Low power consumption FEE ASIC (**reach <5mW/ch** including ADC)
- Achievement by far:
  - Supression ions hybrid GEM+Micromegas module
    - IBF×Gain **~1 at Gain=2000** validation with GEM/MM readout
  - Spatial resolution of **$\sigma_{r\varphi}$≤100 μm** by TPC prototype
  - dE/dx for PID: <4% (as expected for CEPC baseline detector concept)





Low power consumption readout



GEM+Micromegas module R&D

- UV light to study the track and massive electrons

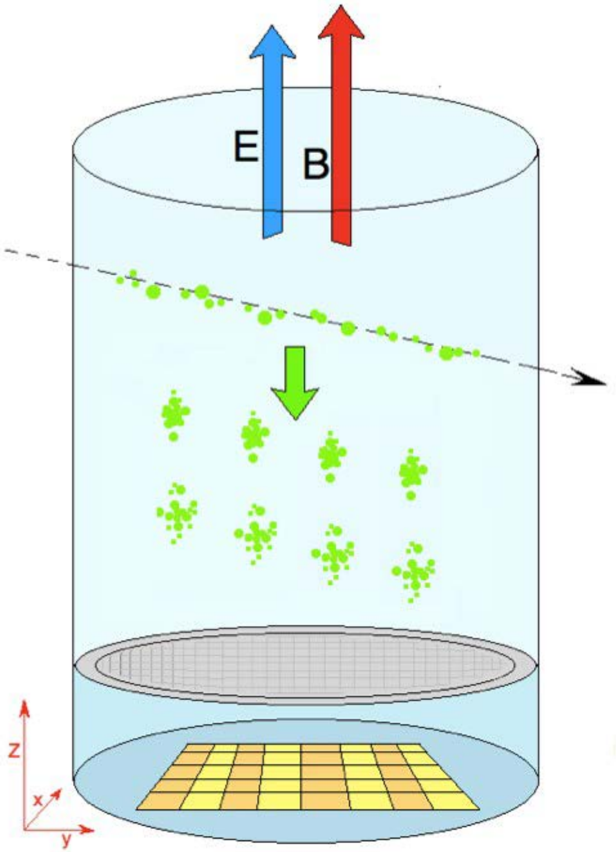
How to create stable tracks and massive electrons in the chamber?

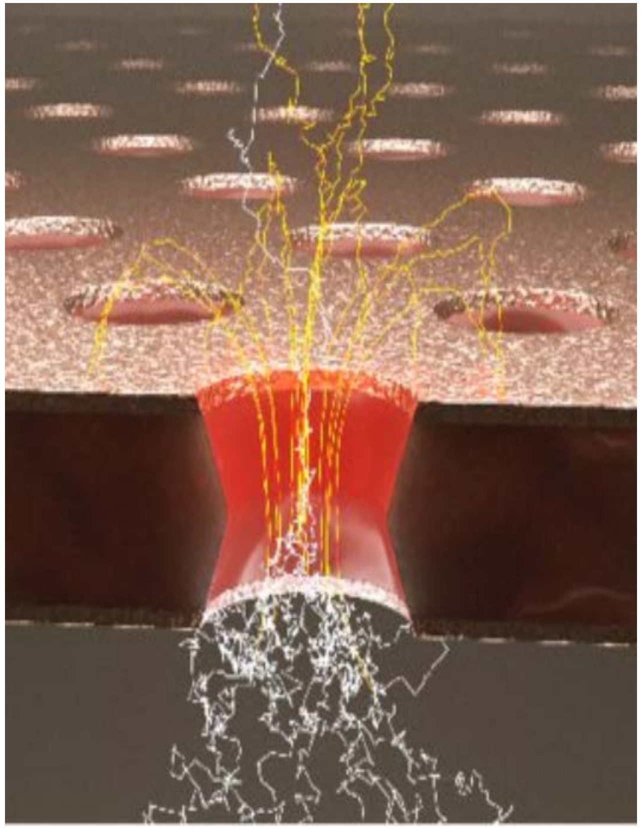
Indirect method to generate electrons

- ^{55}Fe source, X-ray tube, synchrotron radiation
- Electron beam
- MPGD detector multiplication method
- Discharge, Ions back flow on the small area

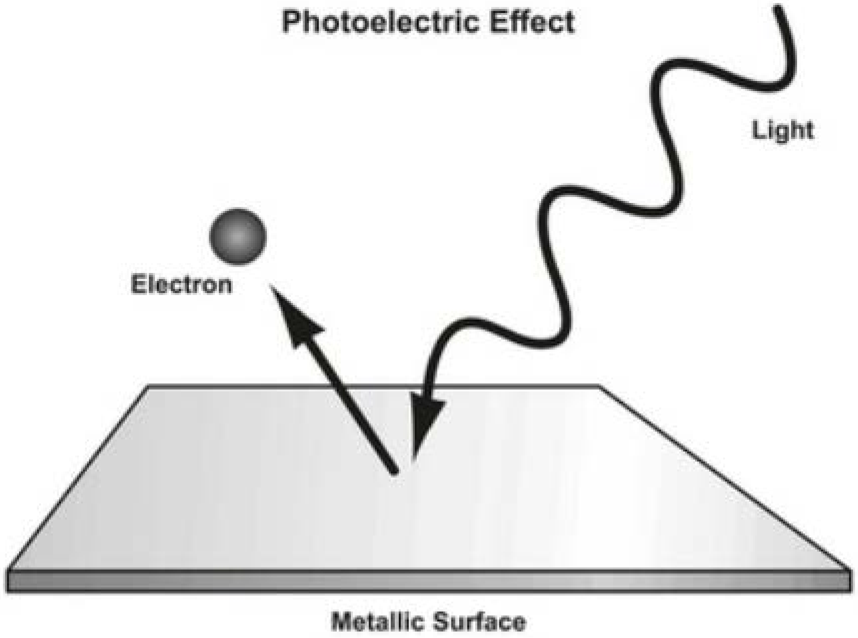
Direct method to generate primary electrons

- Created the massive electrons on big area
- **Photoelectric effect** method **(<10uJ/cm^2)**
- **Two-photon ionization** method **(>10uJ/cm^2)**





Indirect method



Direct method

UV laser: Two-photon ionization method (>10uJ/cm^2)

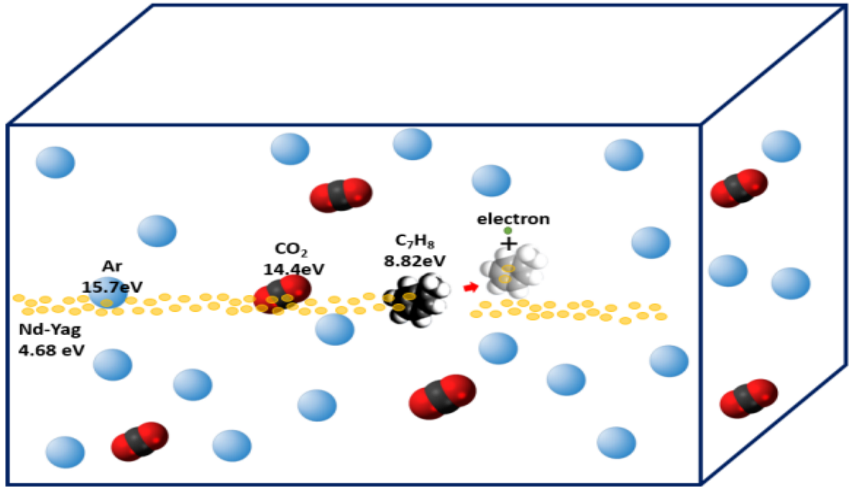
- Some gas can absorb the energy of 2 photons from UV laser and ionized
- Wavelength of UV laser: 266nm (almost: 4.66eV × 2)
- Threshold of the ionization energy: **>10uJ/cm^2 @MIP**

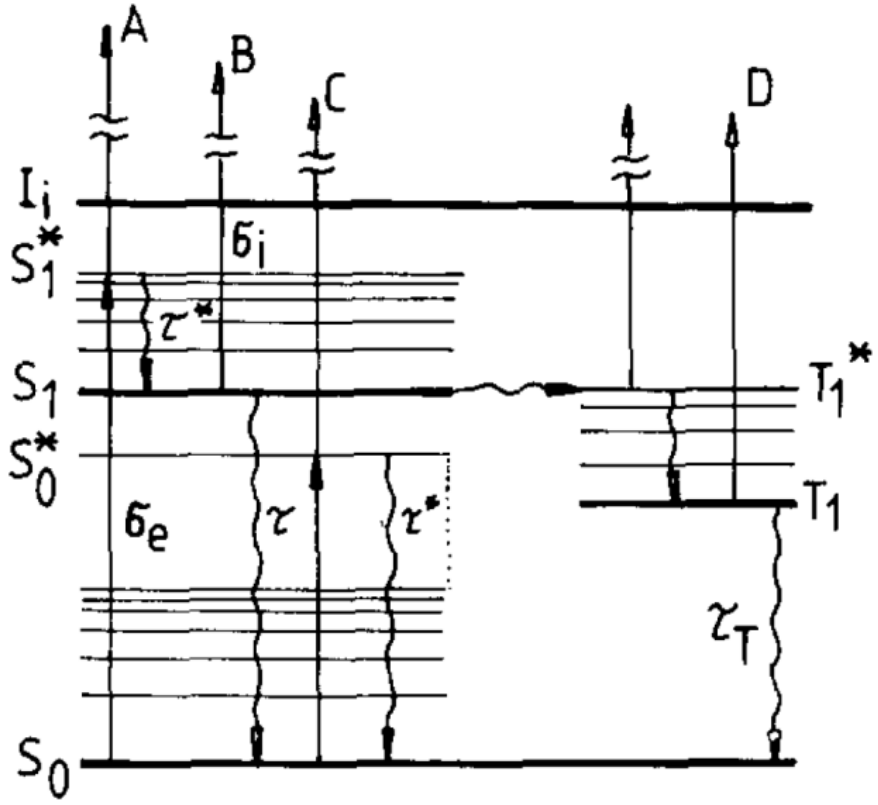
UV Laser TPC prototype R&D

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

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

Nd-Yag
266nm laser



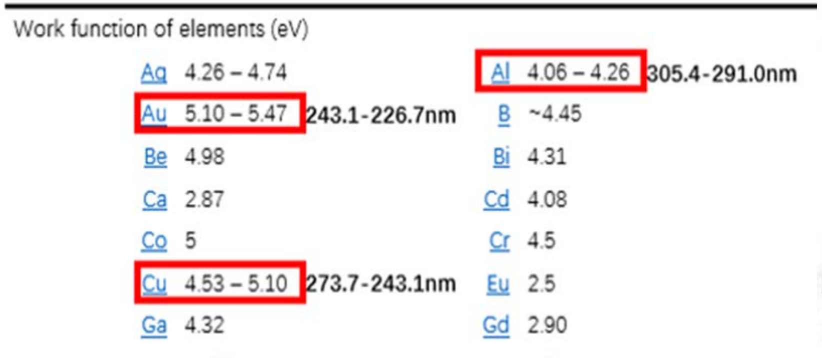


Possible transition channels by two-photon ionization of complex molecules

UV light: Photoelectric effect method (<10uJ/cm^2)

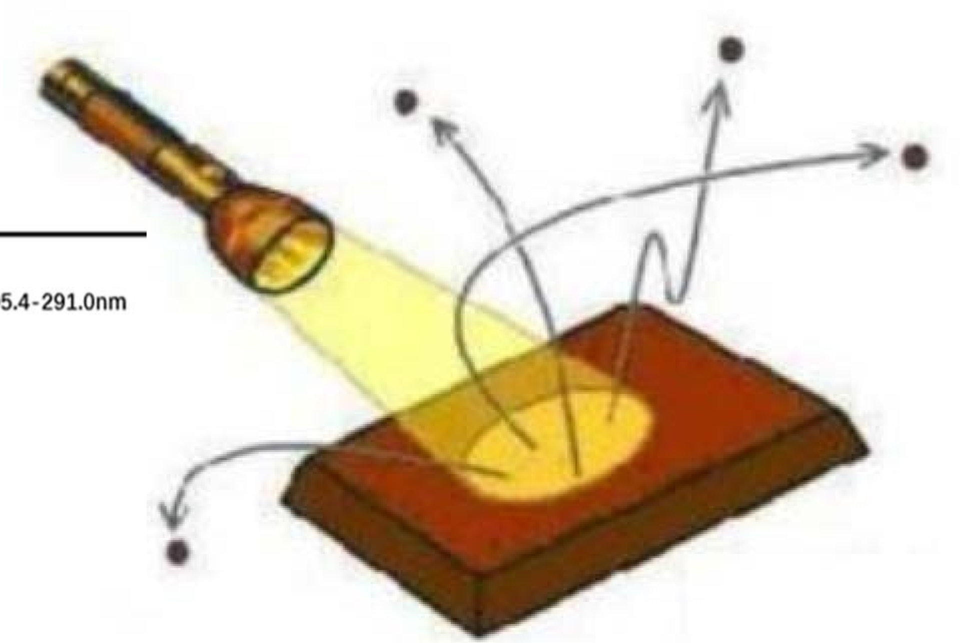
- Explanation of photoelectric effect by A.Einstein
- Each photon carries energy proportional to its frequency $E_\gamma = hf = hc/\lambda$
- One electron absorbs only one photon
- Energy of UV can less than 10uJ/cm^2
- **Stable current of photoelectric needed R&D**

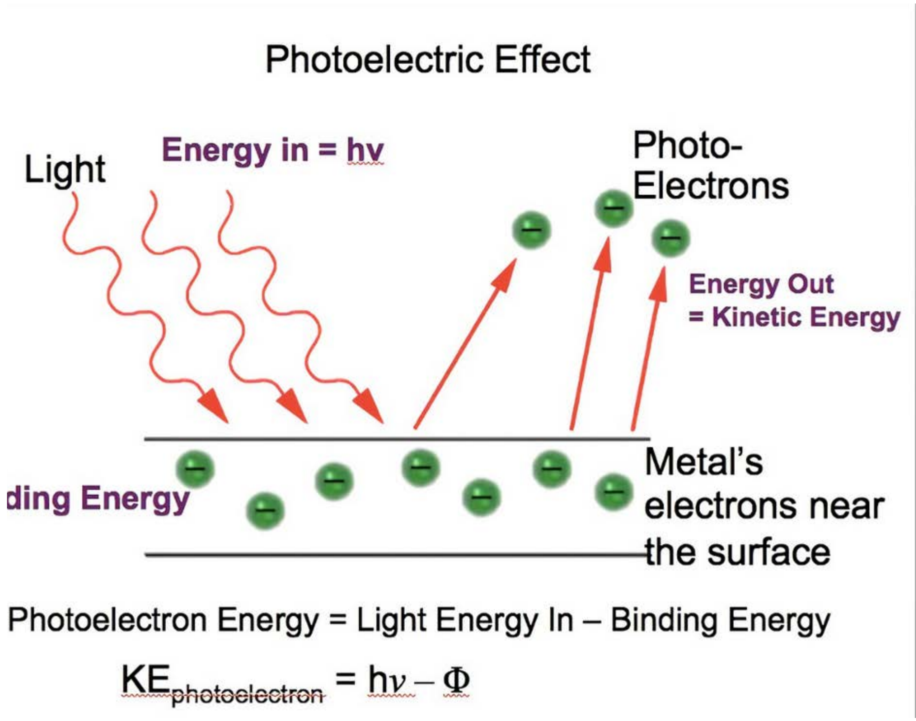
Massive electrons R&D
Without influence working gas



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	
Ca	2.87		Cd	4.08	
Co	5		Cr	4.5	
Cu	4.53 – 5.10	273.7-243.1nm	Eu	2.5	
Ga	4.32		Gd	2.90	

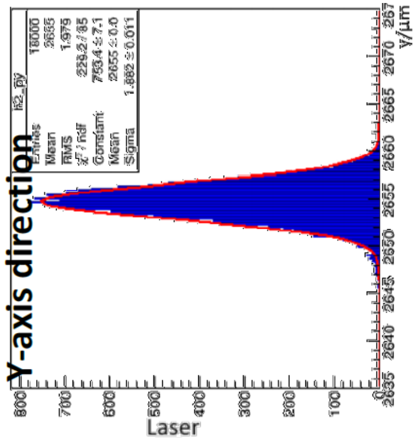


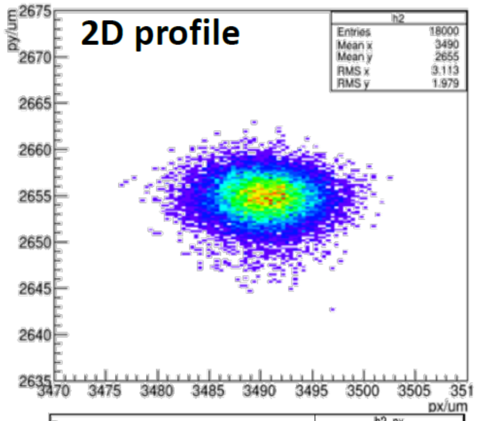


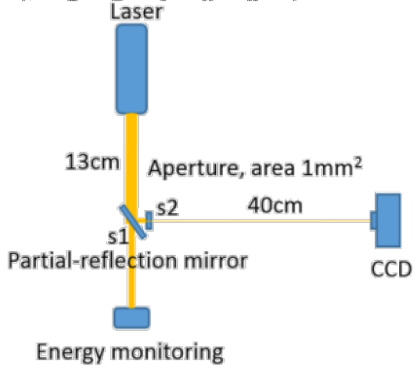
- TPC prototype with integrated UV laser

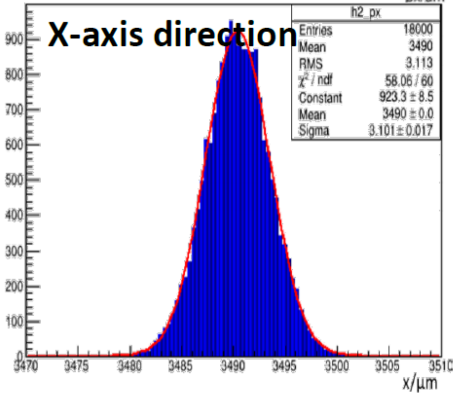
Stability studies of 266nm UV laser

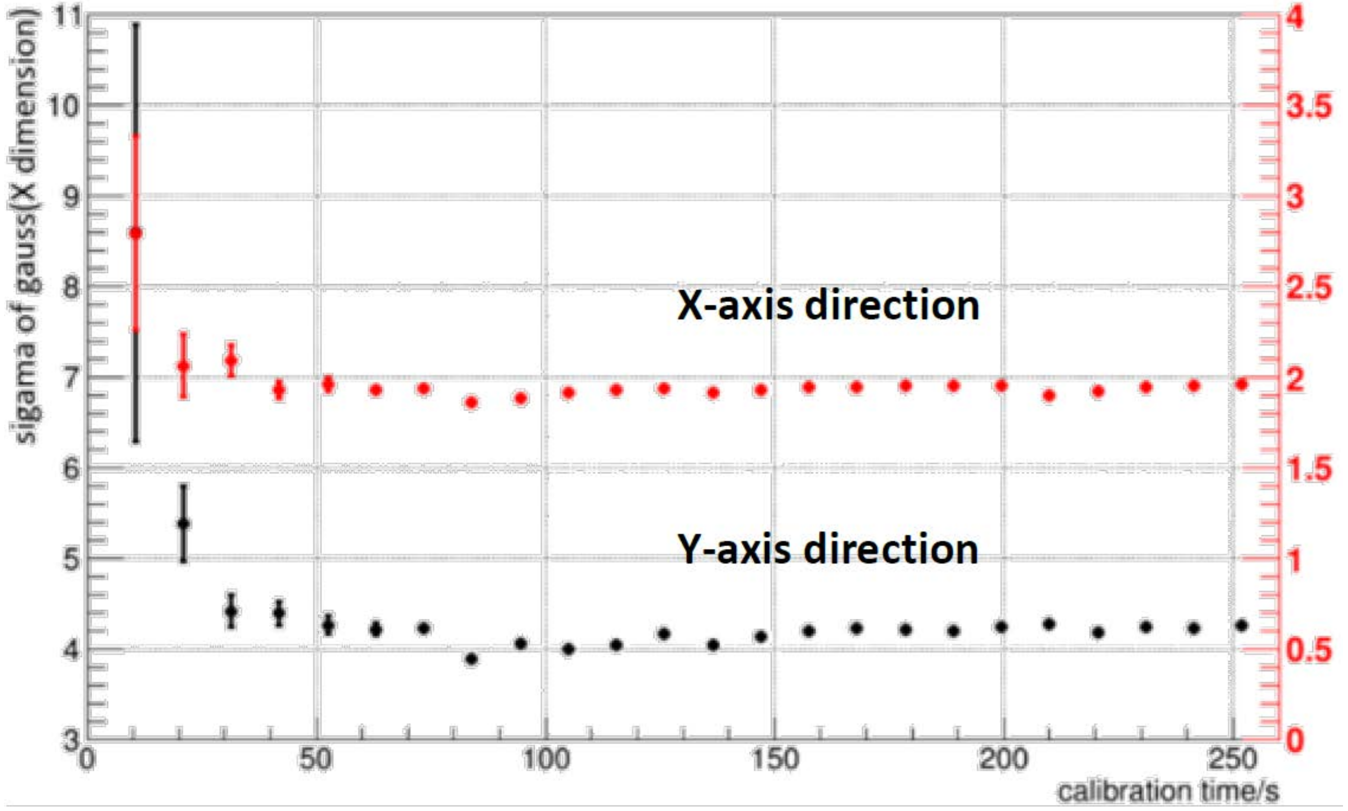
- **266nm** UV laser device: Q-smart 100 model Nd-YAG UV laser by Quantel
- Precision value of UV laser's stability **can meet TPC prototype's physical requirement**
  - 2D profile of UV laser track: **Gaussian distribution**
  - Stability of 2D profile's centering after warming up: **<3.2 μm**
  - Stability of the energy after warming up: **<2%**





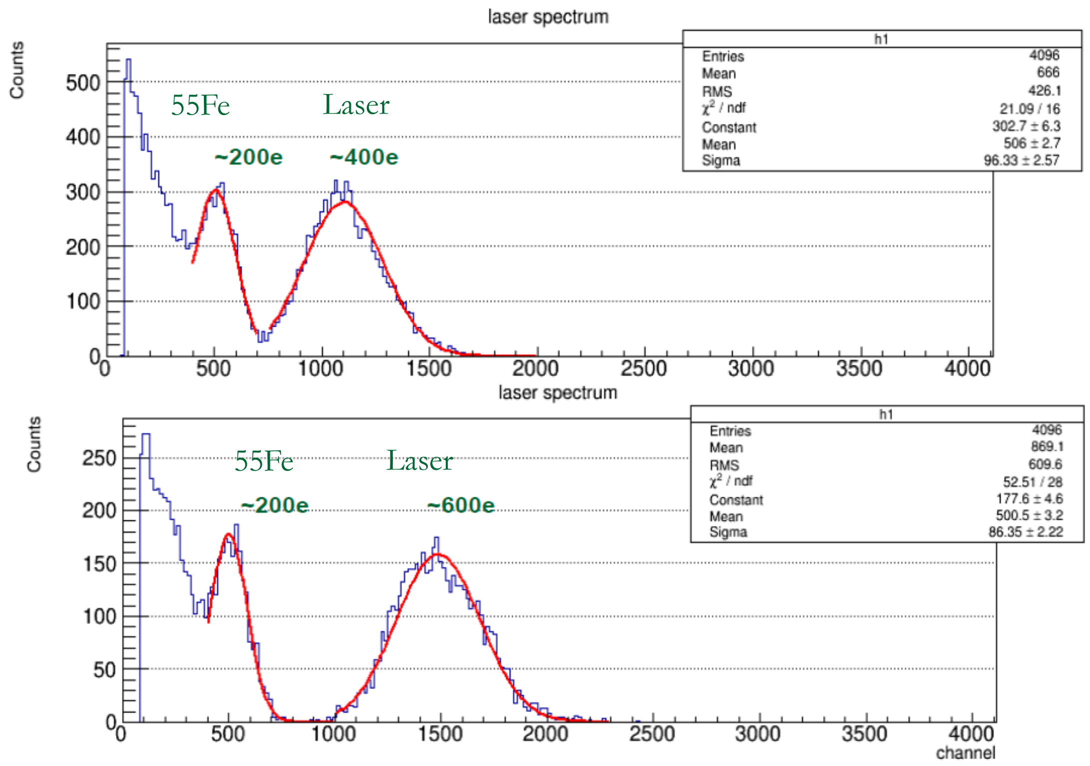




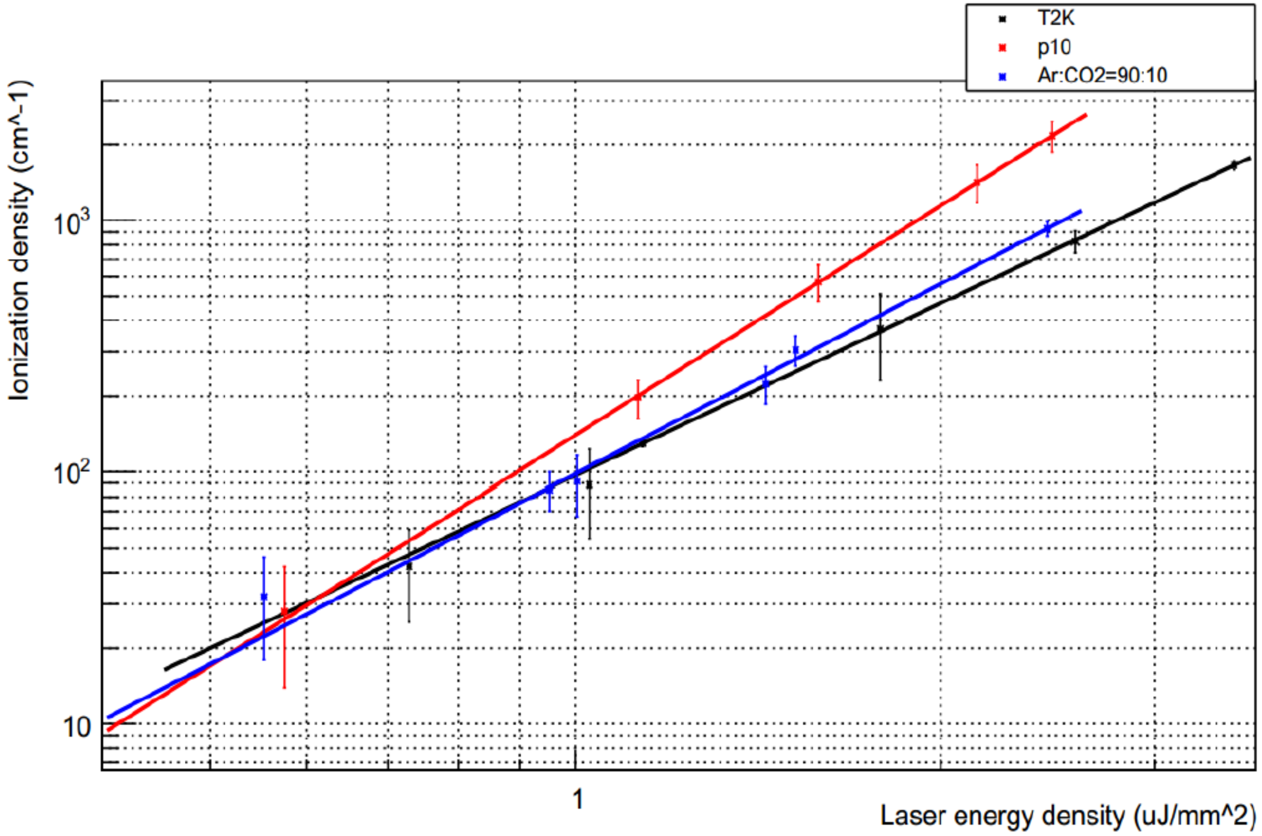


Study of 266nm UV laser ionization

- Relation between the laser and its ionization density in all three gases (T2K, P10, Ar/CO_2=90/10)
- The laser ionization density in P10 gas is higher than that in the other two mixture gases
- The laser ionization should be similar to **1-2 MIPs**, which can generate **100-200 electrons** per centimeter in an argon-based gas (**optimization of the laser energy density**)



Different laser energy VS ^{55}Fe

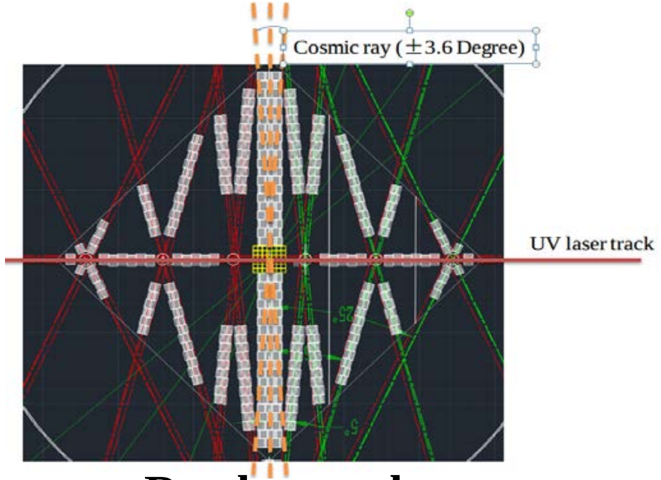


Laser ionization density in different gas mixtures.

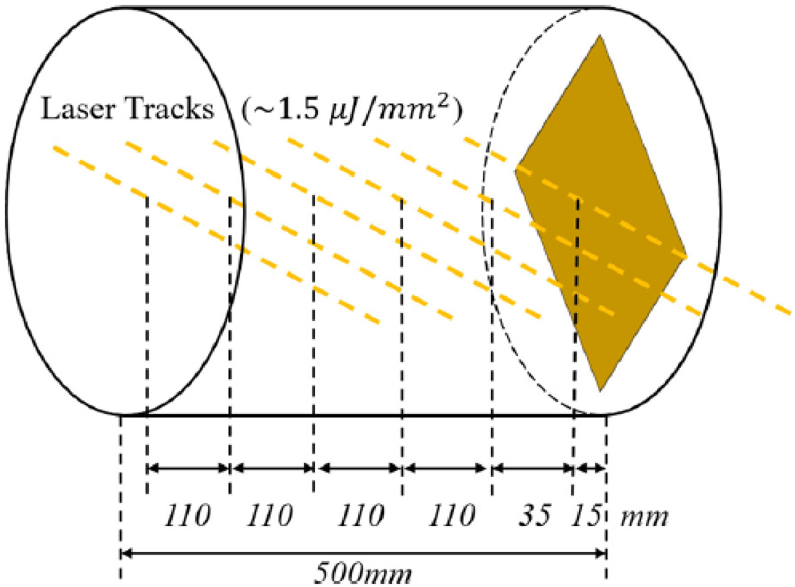
https://doi.org/10.1088/1748-0221/15/02/T02001

Design and commission of TPC prototype with 266nm UV laser tracks

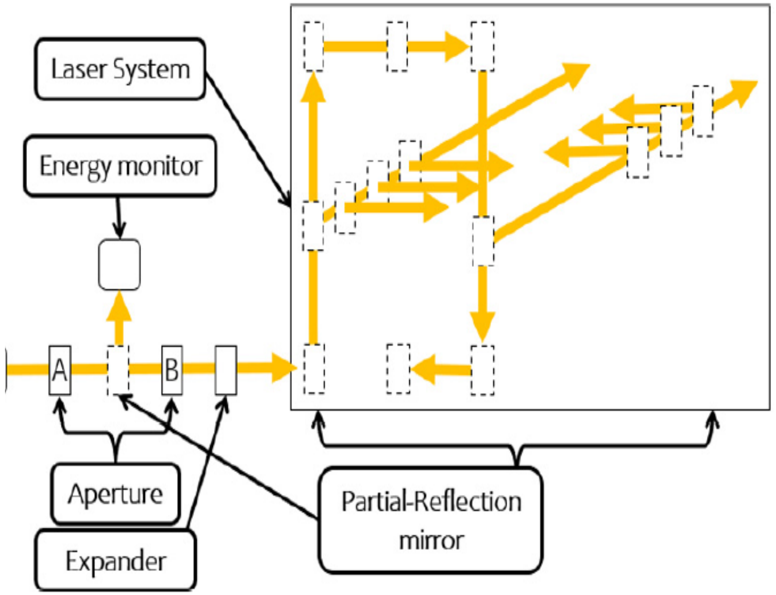
- TPC prototype with separately 6 horizontal laser tracks is designed along the drift length of 500 mm
- Effective area of 200mm×200 mm using **1mm×6mm pad readout size** to record charge on the ground plane (15 pads in each column)
- UV laser energy with a maximum output energy of **20 mJ/pulse** and a minimum energy of **50 μJ/pulse**
- Laser beam spot diameter: 0.8 mm



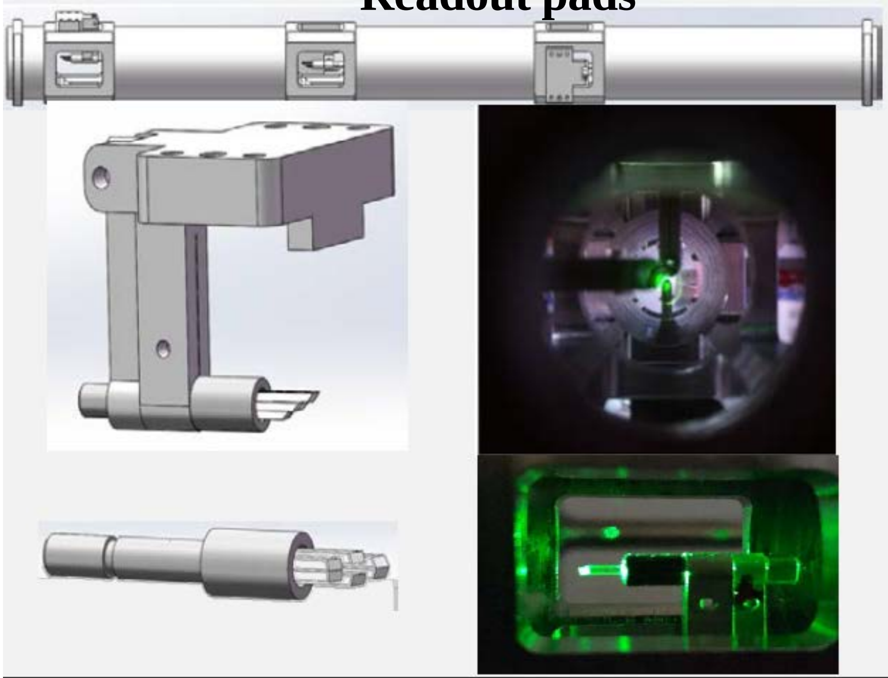
Readout pads



Laser tracks along the drift length



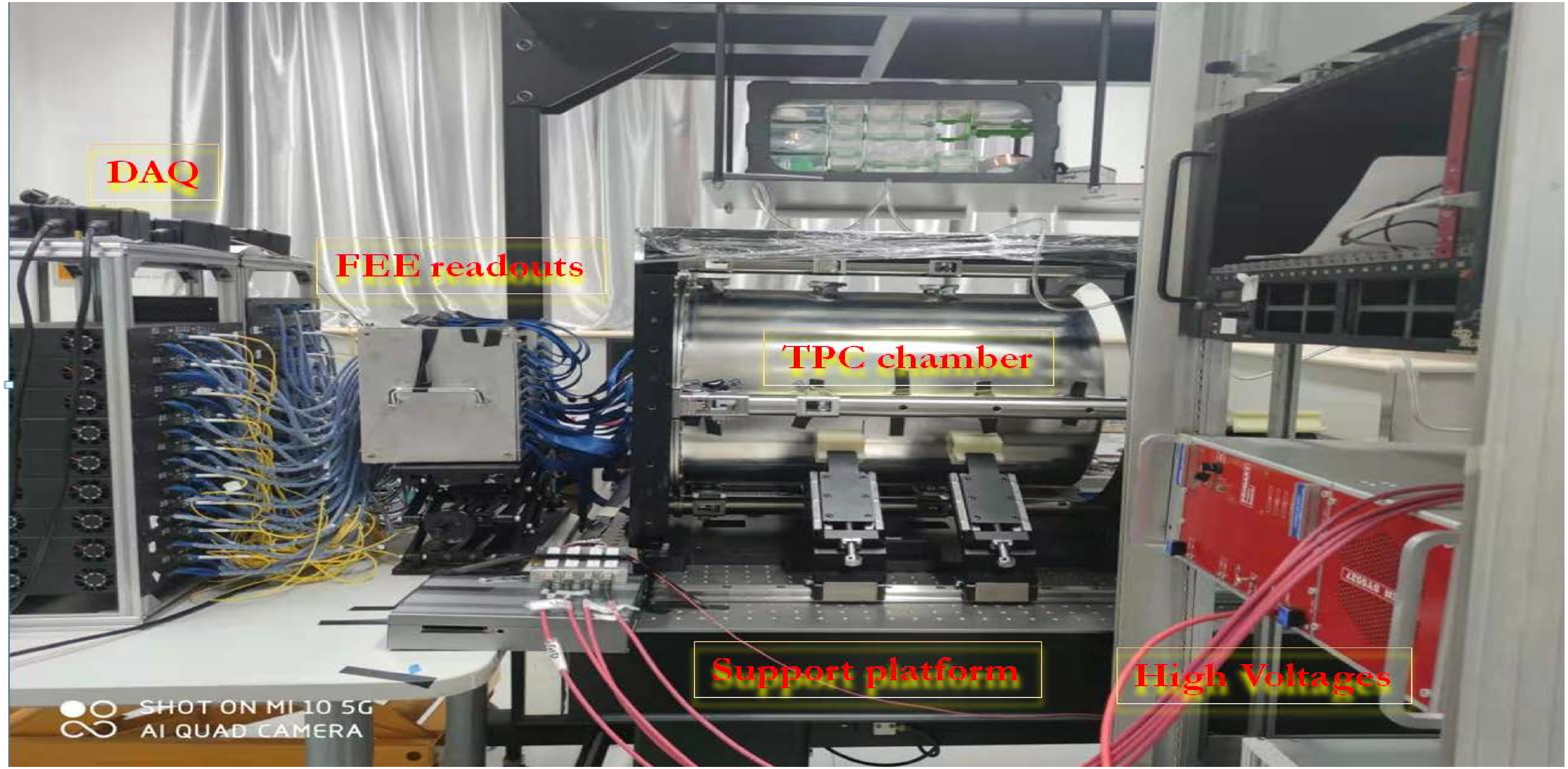
UV laser tracks mapping



UV laser mirror system

Development of TPC prototype

- Successfully to develop the TPC prototype integrated UV laser tracks at IHEP, CAS
- Experimental studies of the **spatial resolution, dE/dx resolution** achieved with the pseudo-tracks

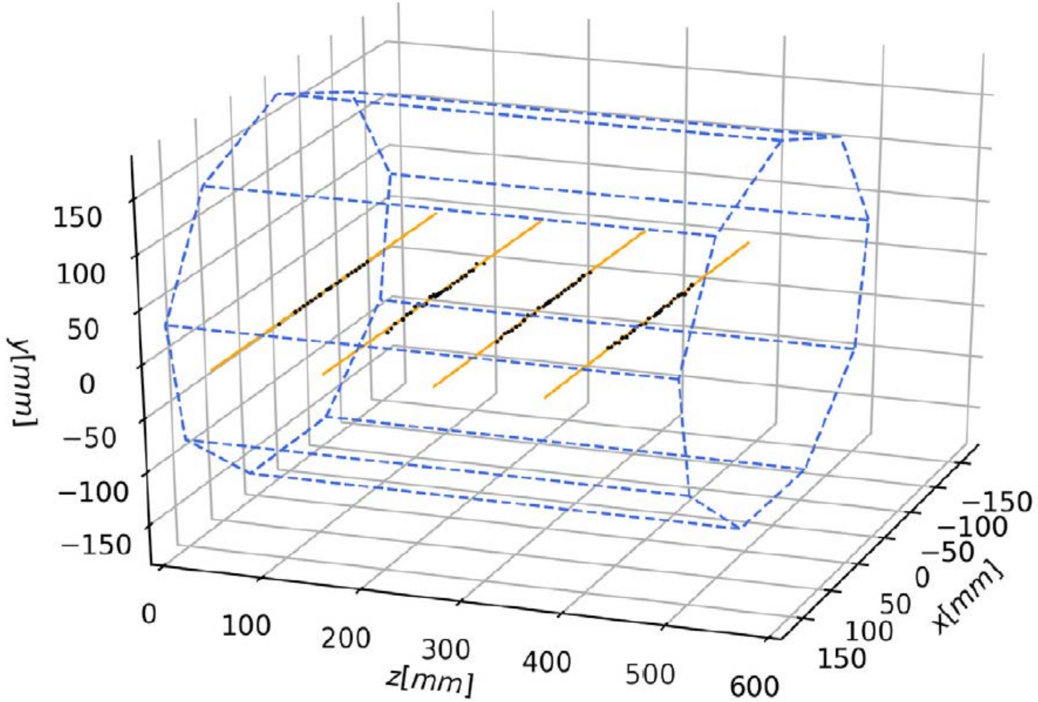


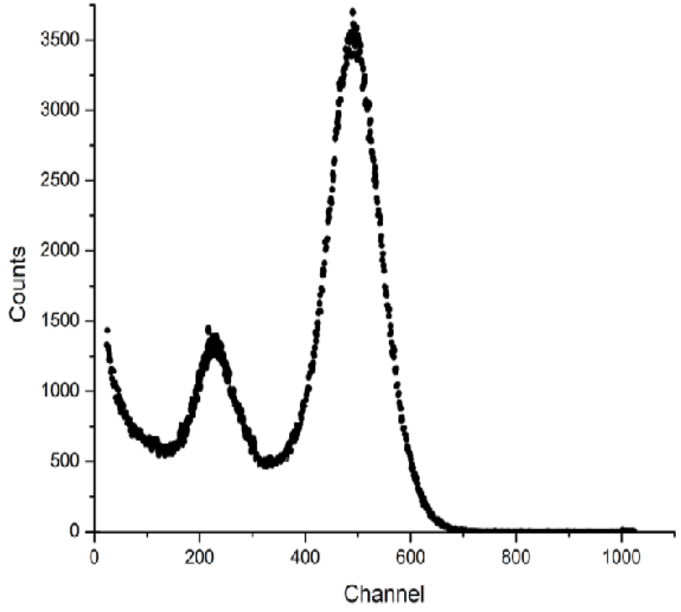
Reconstruction event and energy spectrum of ^{55}Fe/Cosmic ray

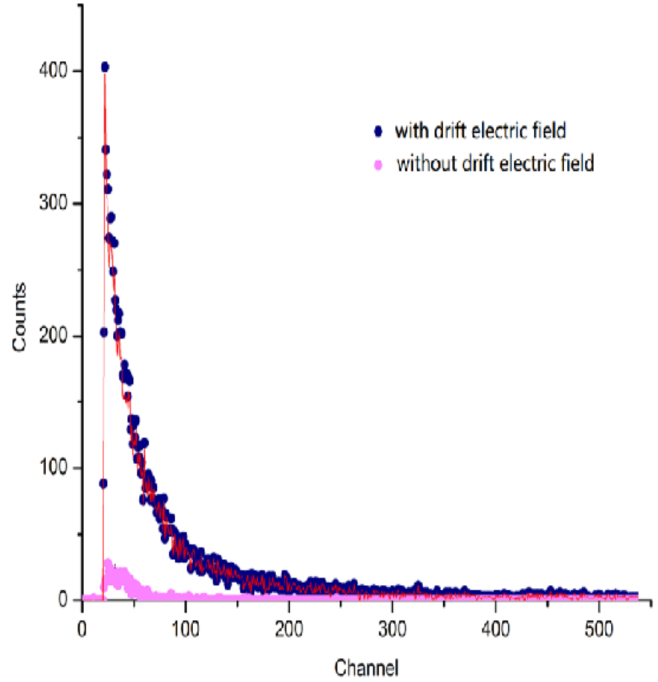
- TPC detector prototype can study the UV laser track, 55Fe radiation source and the cosmic ray.
- TPC prototype was checked after one year development
    - ^{55}Fe X-ray spectrum profile is very good
    - **Detector gain just shift 2% than one year before.**
- The Landau distribution of the cosmic ray's energy spectrum was successfully obtained.

Summary of the event selection cuts.

Laser energy monitor	Variation range	$E_{mean} \pm \sigma$
TPC detector	Hit ToA	layer#1 2.6 ~ 2.9 μs
		layer#2 5.7 ~ 6.0 μs
		layer#3 8.2 ~ 8.5 μs
		layer#4 10.5 ~ 11.0 μs
	Trigger pads	≥ 2 for each column
Laser and detector	The laser control chassis triggers the energy monitor and DAQ system at the same time.	



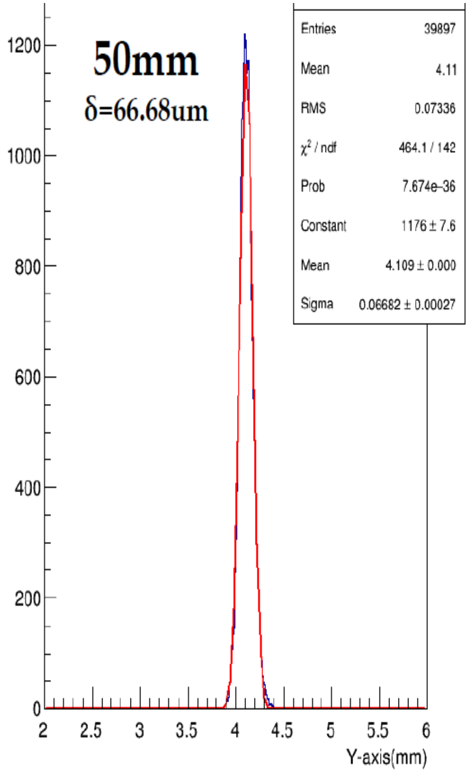


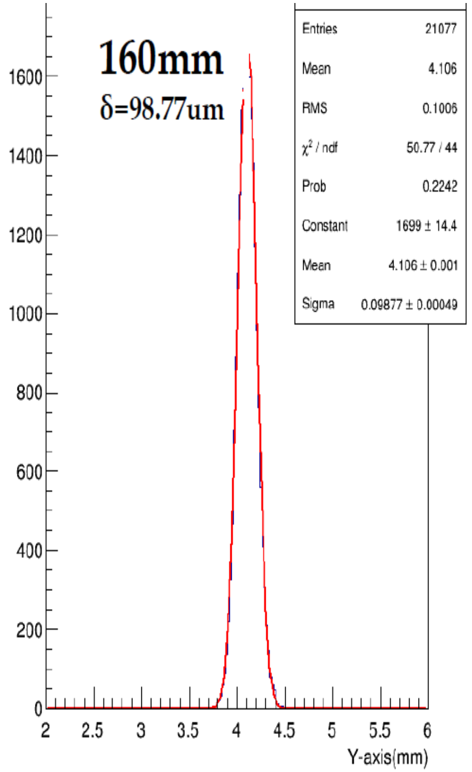


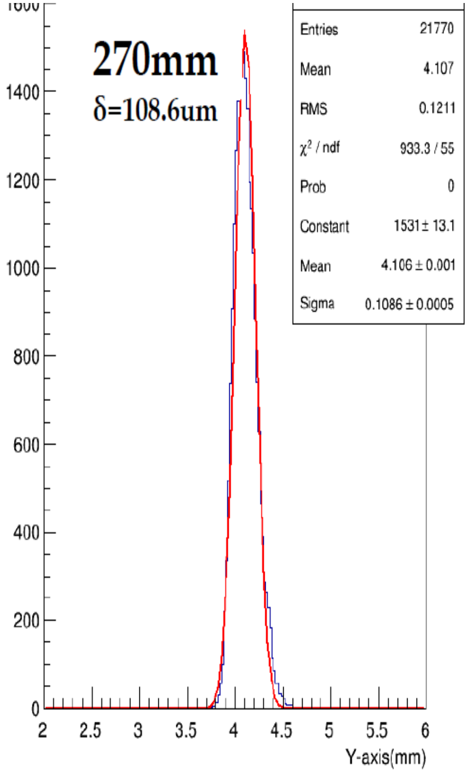
Reconstruction events and ^{55}Fe X-ray spectrum profile(middle) and cosmic ray spectrum(Right)

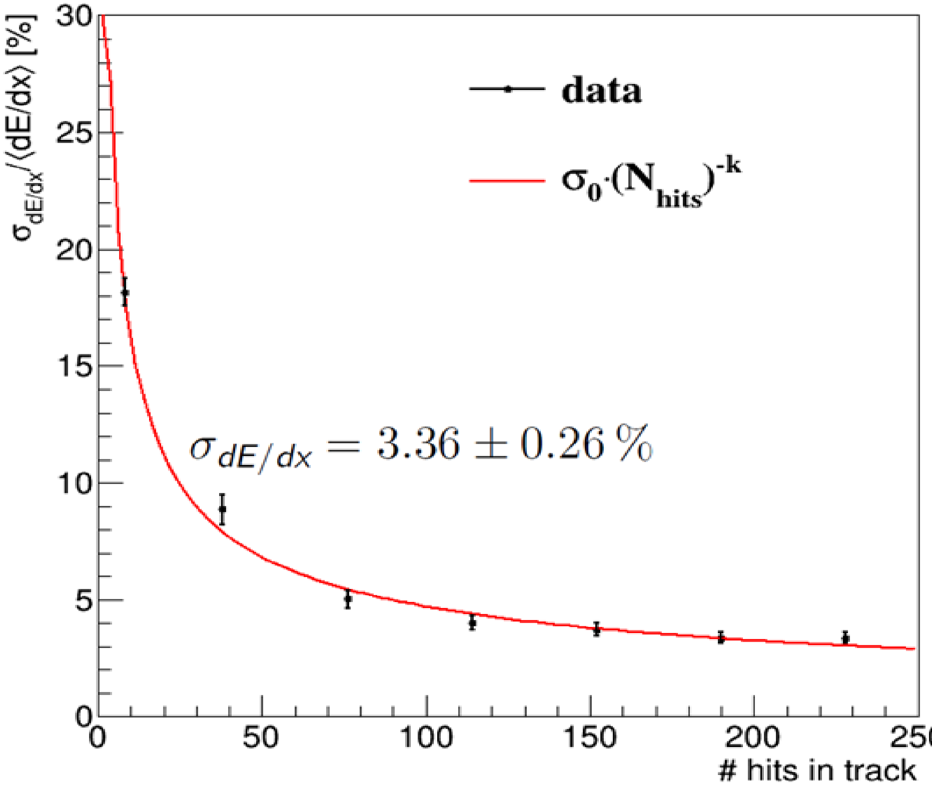
TPC prototype with 266nm UV laser tracks

- The TPC prototype integrated 266nm UV laser tracks has successfully developed.
- Analysis of UV laser signal, the spatial resolution, dE/dx resolution
  - Spatial resolution can be less than **100 μm along the drift length** of TPC prototype
  - Pseudo-tracks with 220 layers (**same as the actual size of CEPC baseline detector concept**) and dE/dx is about 3.4 ± 0.3%





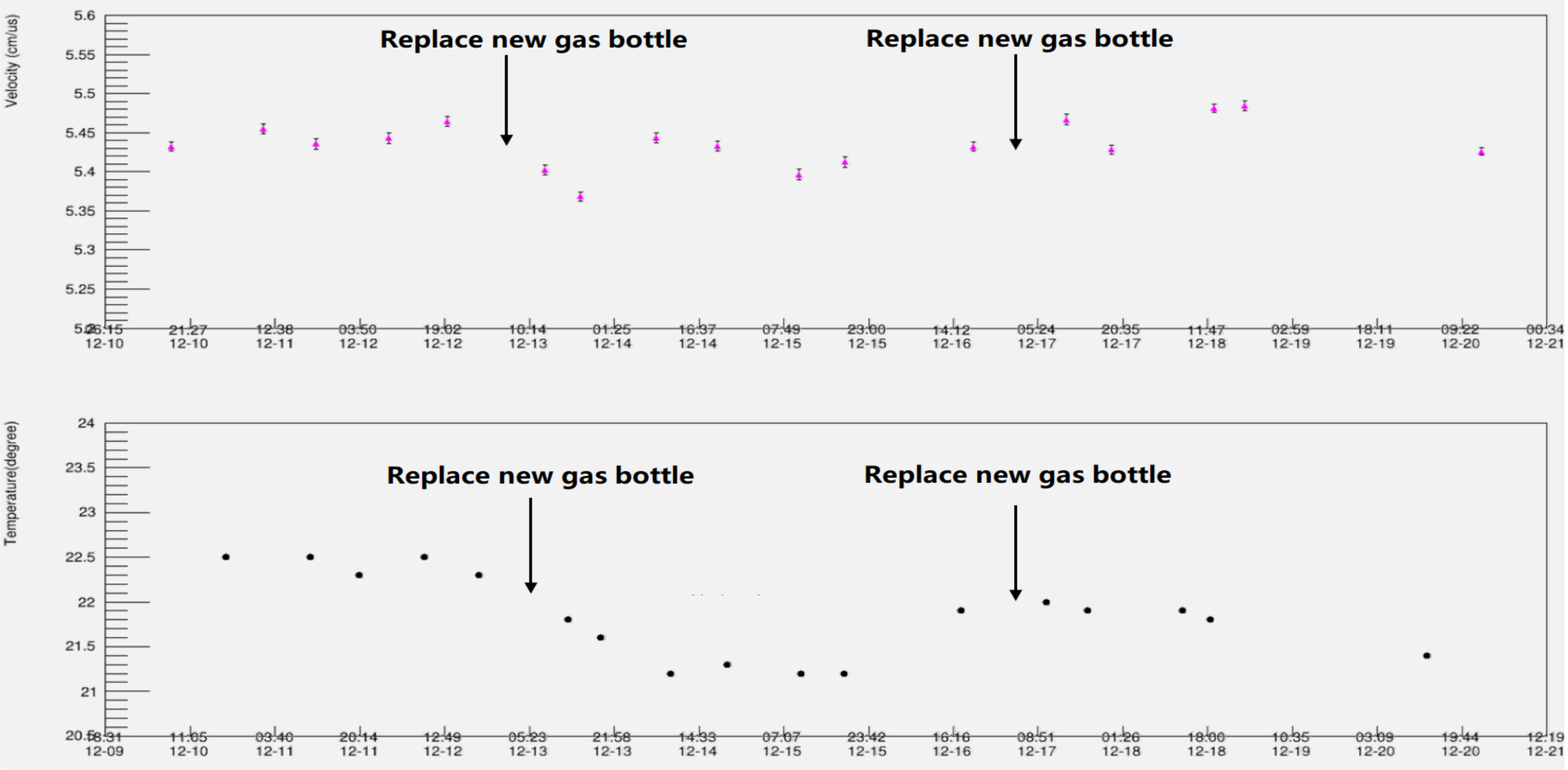




https://doi.org/10.1016/j.nima.2022.167241

Monitor the drift velocity using UV laser

- TPC prototype can monitor the drift velocity using UV laser tracks in two weeks.
- Recorded and compared the drift velocity and temperature (more studies ongoing)

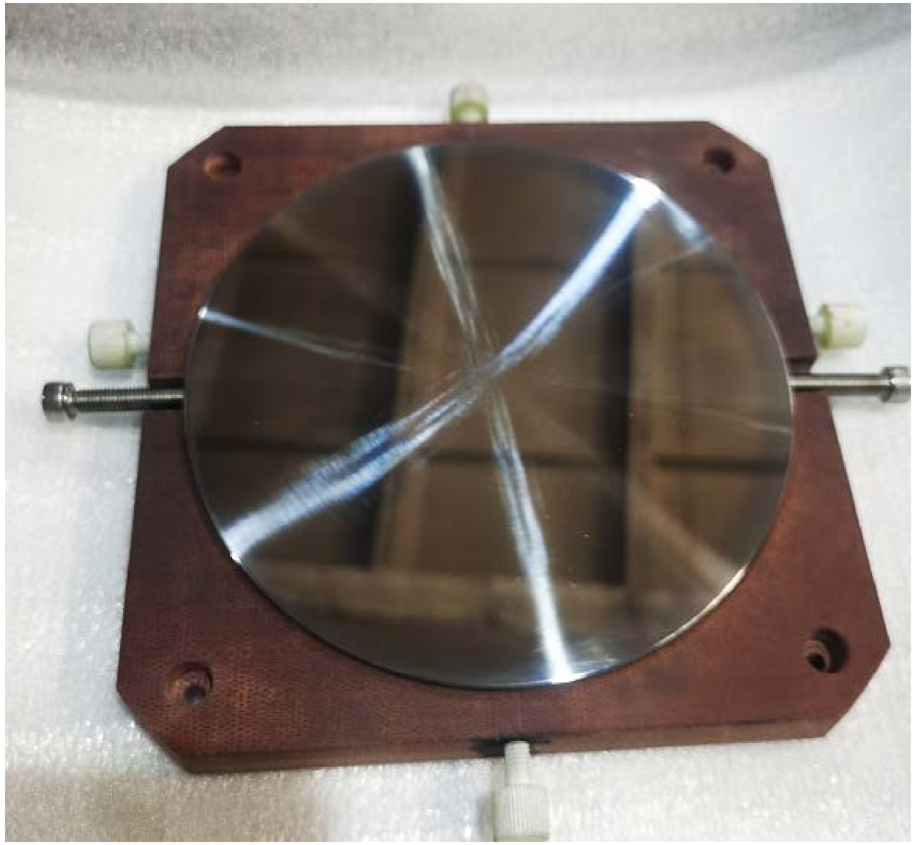


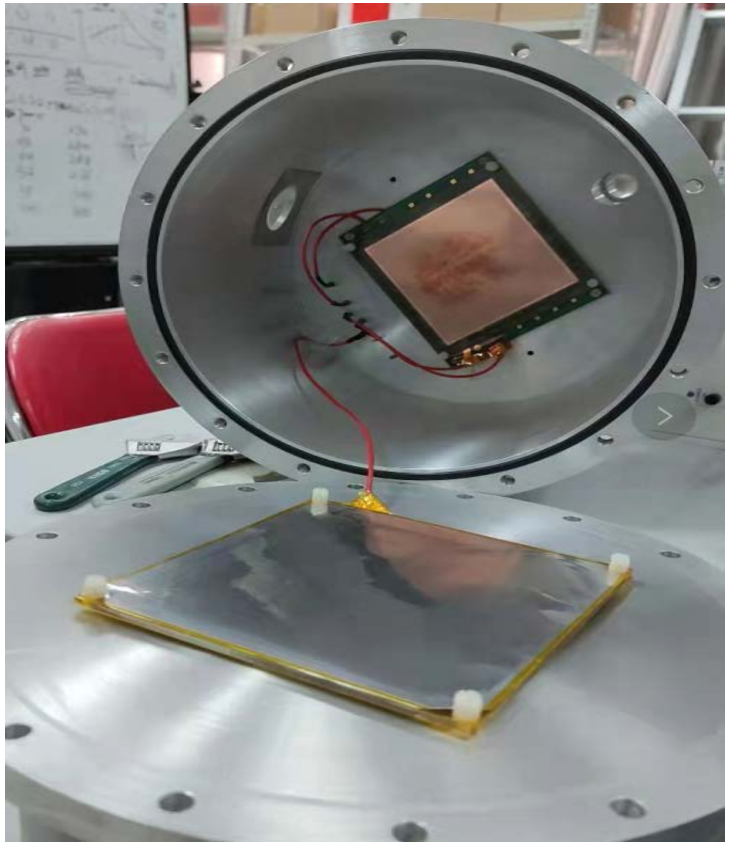
- UV light create the massive primary electrons in chamber

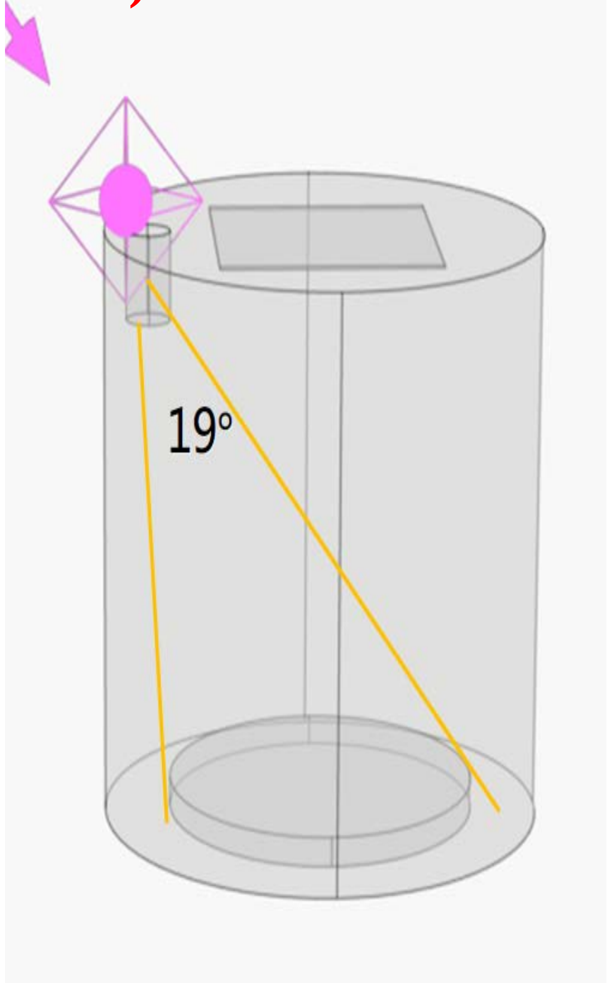
Testing the UV light created the massive electrons by photoelectric effect

UV light created the massive primary electrons

- Ions will fill in the drift chamber of TPC to mimic the ions distortion
- **Metal mesh polished Aluminum**: 600/800/1000/1200/1400/2000 (**LPI: Linear Pair)**
- Experimental testing of the current at record detector layers

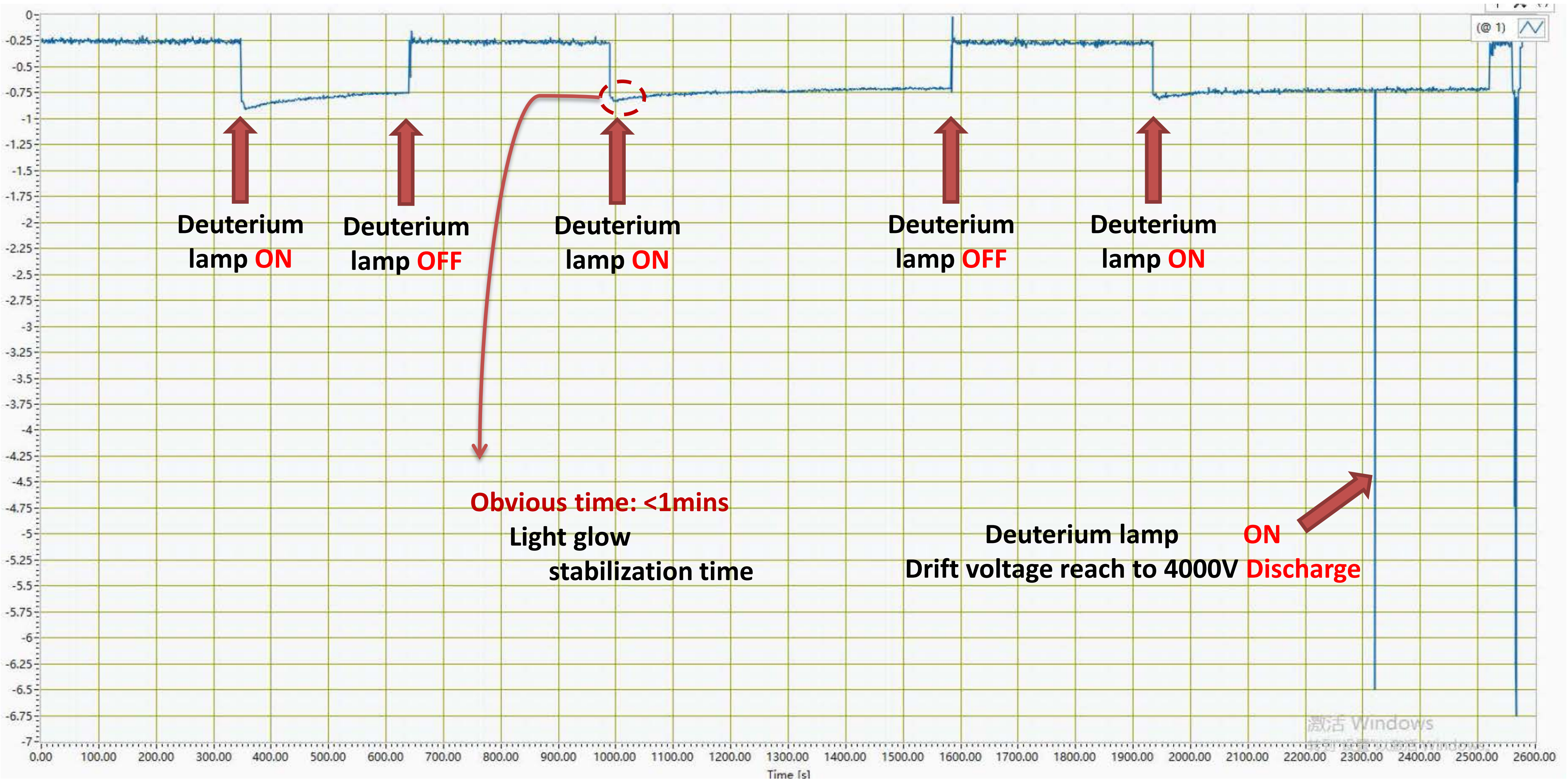






Testing the UV light created the massive electrons by photoelectric effect

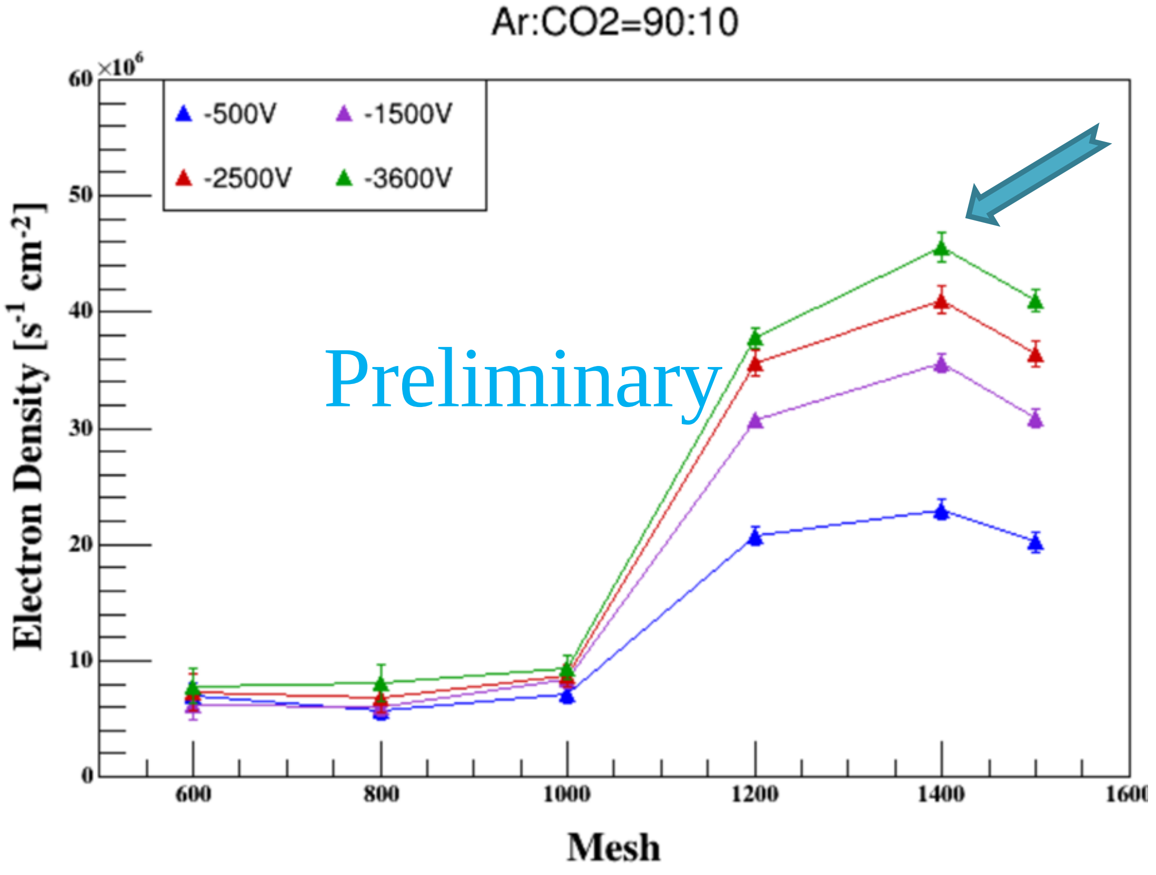
- Results of the experimental studies **: very good stable** current obtained

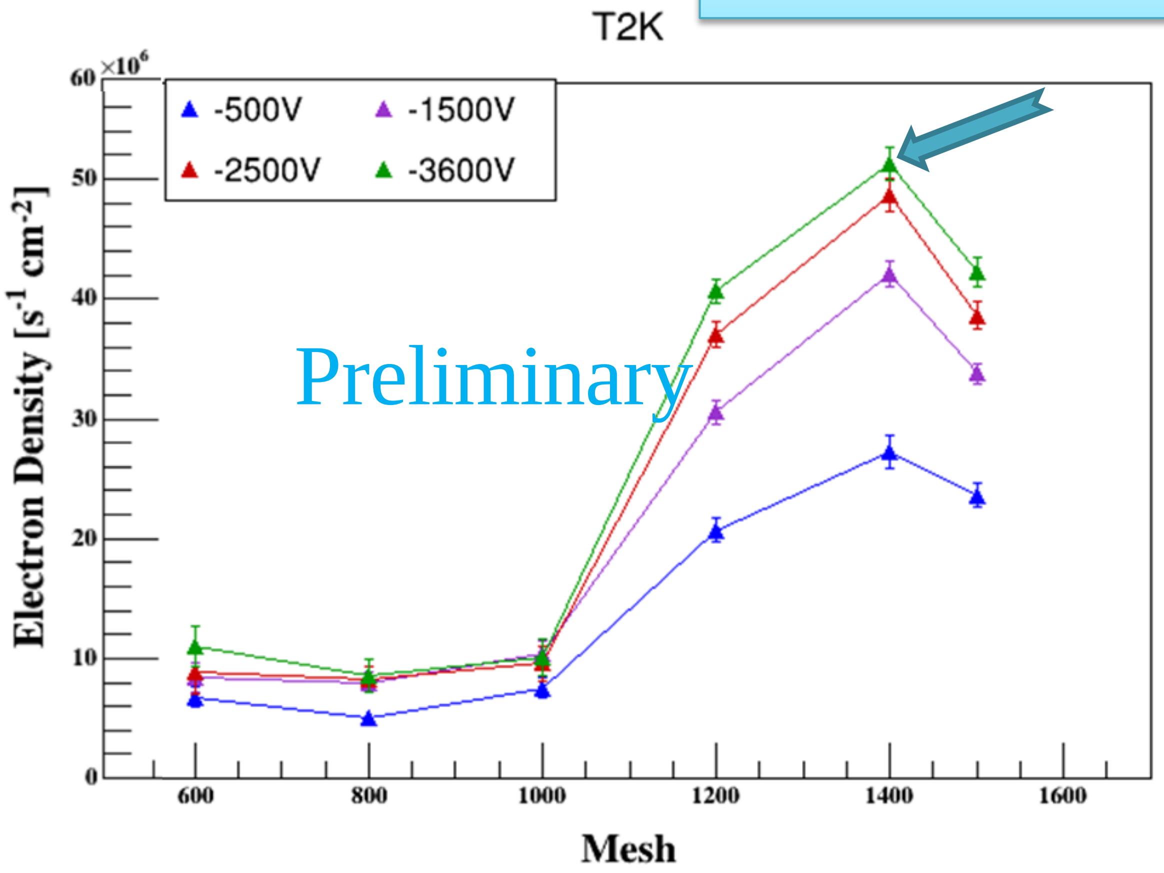


Testing the UV light created the massive electrons by photoelectric effect

- The different LPI Aluminum's surface tested the stable current
- The maximum current reached at 1400LPI Aluminum's surface (**Of course, Very stable**)
- Detector has been studied under the two different mixture gases
  - Very similar trends **from 30V/cm to 210V/cm (Electric field of drift)**

Study on going:
Deviation of the track





Summary

- In CEPC TPC study group, TPC detector prototype using the pad with integrated 266nm UV laser tracks have been developed for the future e+e- colliders.
- The detector module will assembled and commissioned with the low power consumption ASIC chip. 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. UV light can created the enough massive primary electrons in the chamber.
- Synergies with CEPC/LCTPC/FCCee/EIC/T2K/ALICE allow us to continue R&D and ongoing, we learn from their experiences.

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