Experimental study on primary electrons created by photoelectric effect and simulation of the ionization cluster

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Linghui Wu, Gang Li, Manqi Ruan and some good inputs from LCTPC

August 17, 2022

Content

- **Updated progress of TPC prototype**
- **Experimental studies on primary electrons**
- **Simulation of the ionization cluster**
- **Plan and summary**

Updated progress of TPC prototype – NIMA paper publication

- Paper of TPC prototype integrated with 266nm UV laser tracks has been published in NIMA this month
- One reviewer from ALICE TPC and another reviewer from STAR TPC
- Updated analyses of **the spatial resolution, gain uniformity and dE/dx will be done and released too**.

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Performance of TPC detector prototype integrated with UV laser tracks for the circular collider

Check for updates

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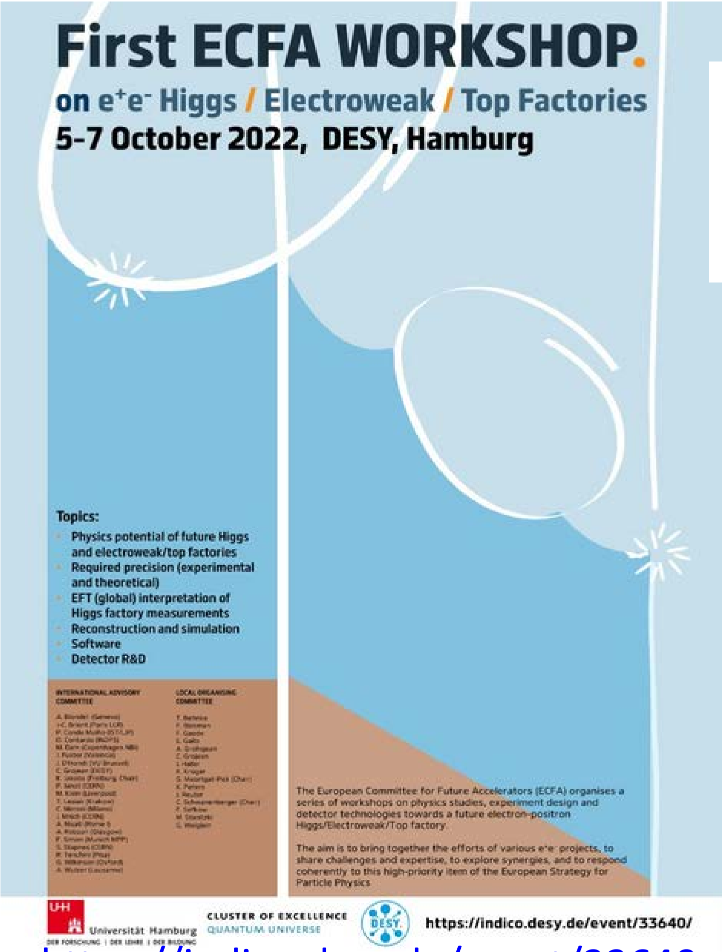
Updated progress of TPC prototype – Oral acceptance

- Two oral talk **have been acceptance**. (ECFA Workshop 2022 and IEEE 2022)
- **ECFA 2022 in Oct.:** High resolution pad and pixelated TPC R&D for future e+e- collider
- **IEEE 2022 in Nov.:** Potential R&D of TPC technology integrated with UV laser for e+e- collider

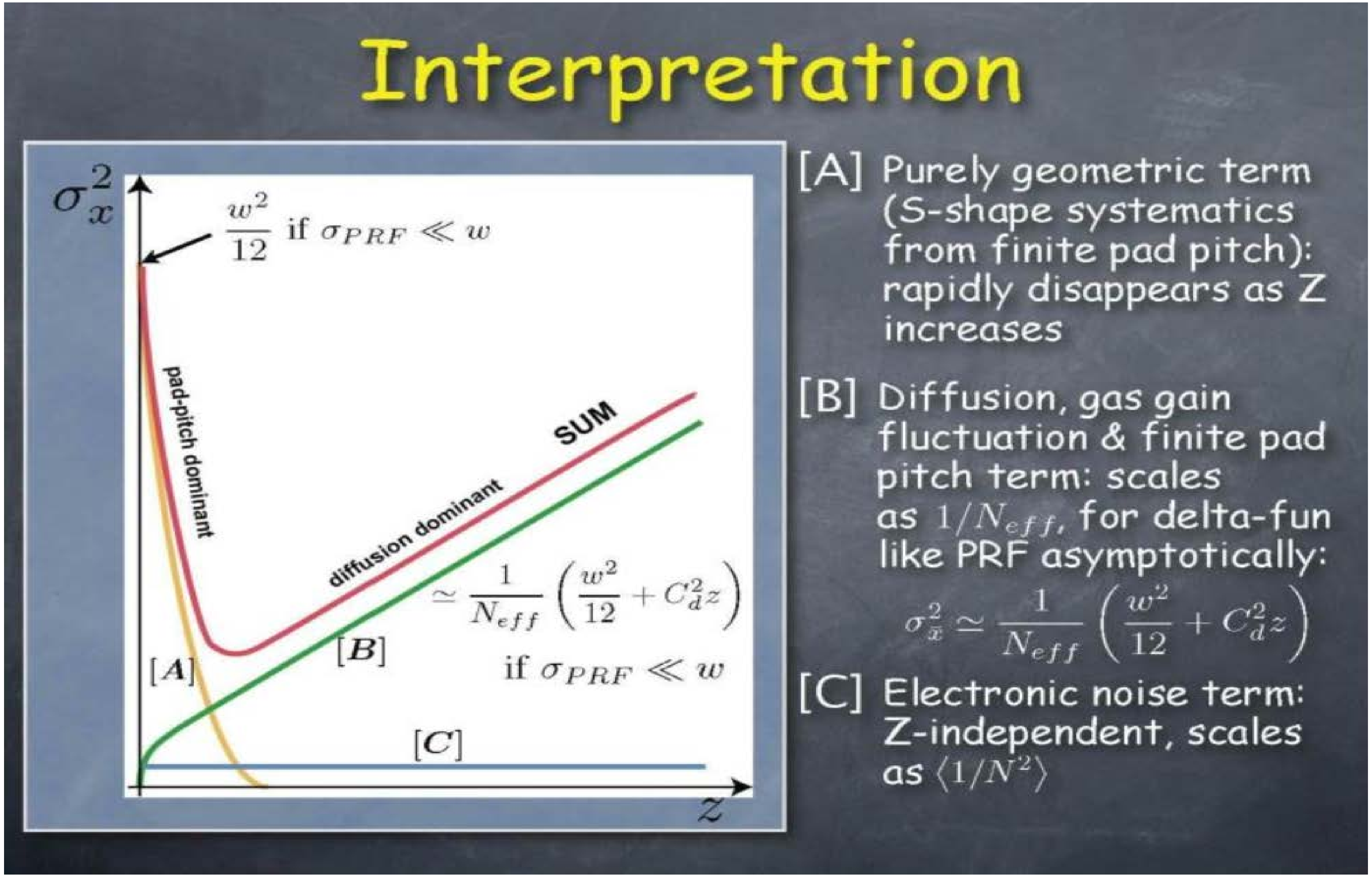


https://indico.desy.de/event/33640

https://eventclass.org/contxt_ieee2022/welcome/index

Updated progress of TPC prototype – Spatial resolution along drift length

- The spatial resolution along the drift length has been analyzed cooperated with LCTPC.
- **Prof. Fujii gave many warm helpings to our group in this summer.**
- Some good references
  - **IHEP laser TPC**
  - LCTPC LP TPC
  - Tsinghua GEM TPC
  - ALICE TPC
  - STAR TPC
  - …



- Experimental studies on ions

Primary electrons

- Experimental studies on ~~ions~~

Motivation: Need investigate the electrons/ions density at CEPC

- Simulation results by Zhiyang Yuan in his thesis based on CEPC's parameters
- To investigate and create the stable electrons/ions in the specific area
- CEPC or others detector with the massive electrons/ions

Electric field analysis

Cylindrical coordinates

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

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

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

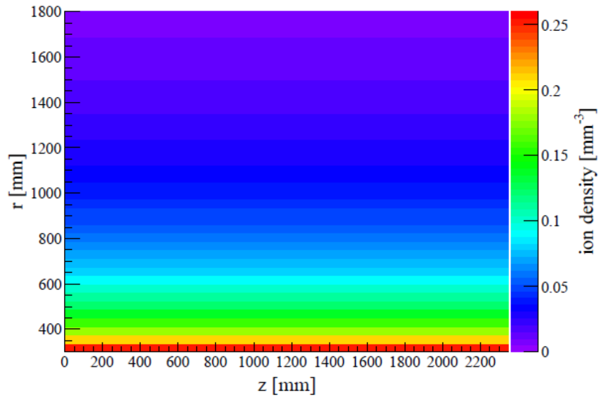
$$\Phi_m(r,k) = K_m(kr) \int_0^r R_m(r',k)\, I_m(kr')\, r' dr' + I_m(kr) \int_r^{\infty} R_m(r',k)\, K_m(kr')\, r' dr'$$

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

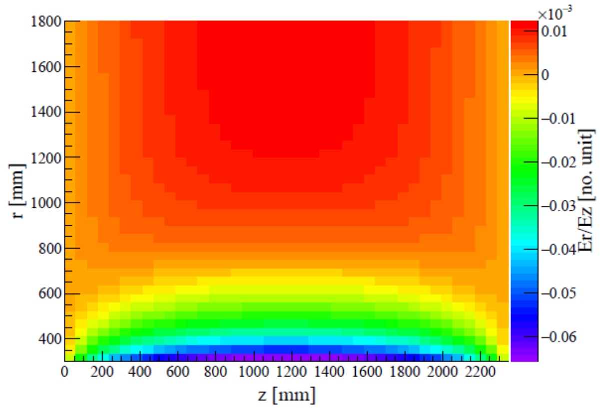
$$\rho_m(r',z') = \frac{1}{2\pi} \oint \frac{\rho(r',\theta',z')}{\epsilon_0} e^{-im\theta} d\theta'$$

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

Ions density in chamber



E_r/E_z



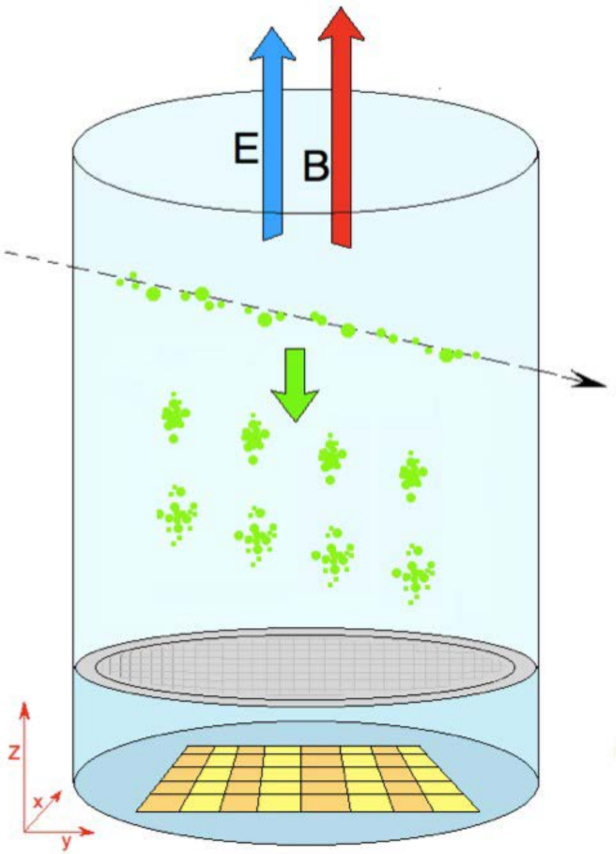
How to create stable massive electrons in the chamber?

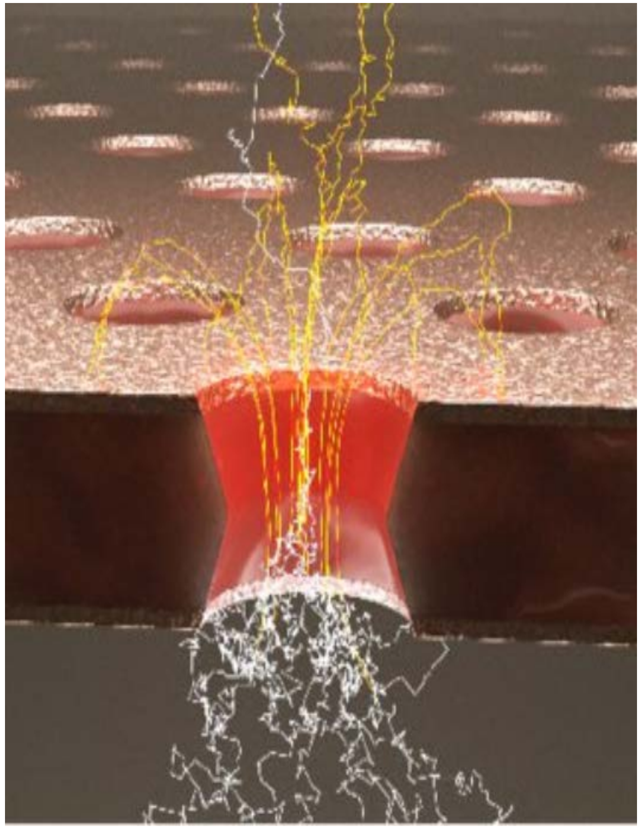
Indirect method to generate electrons

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

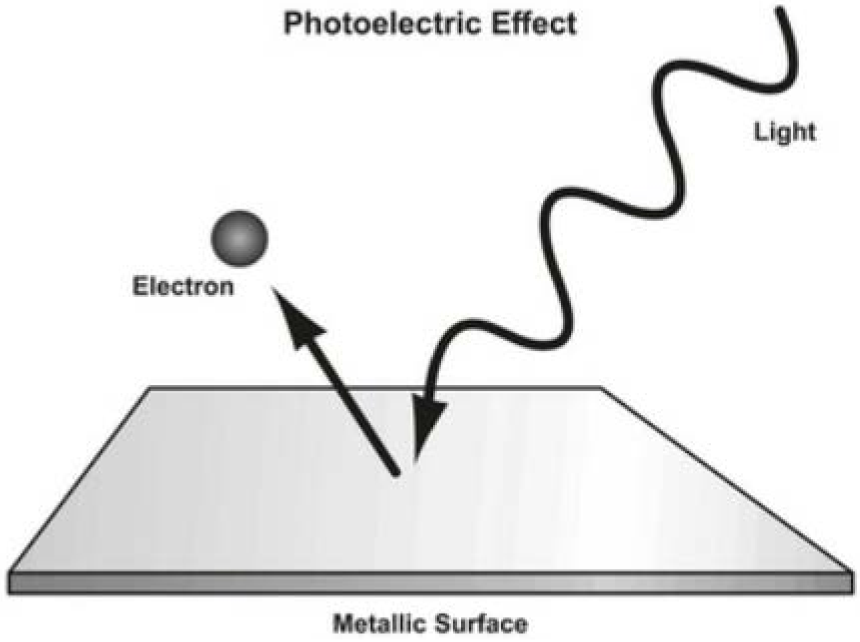
Direct method to generate electrons

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





Indirect method



Direct method

Two-photon ionization method (>10uJ/cm^2) - **Indirect method**

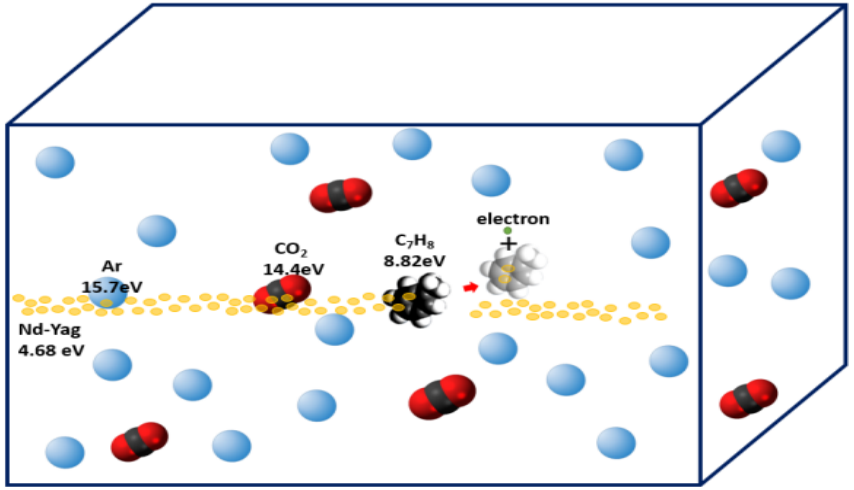
- Some gas can absorb the energy of 2 photons from UV laser and ionized
- Wavelength of UV laser: 266nm (almost: 4.66eV × 2)
- Threshold of the ionization energy: **>10uJ/cm^2 @MIP**

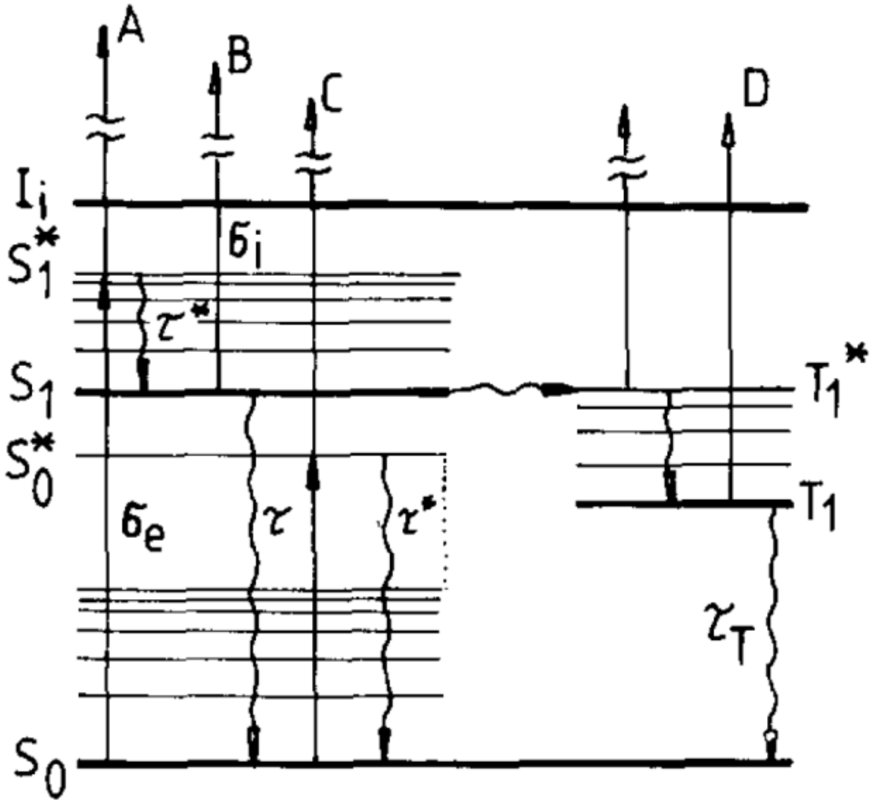
Laser TPC prototype R&D

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

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

Photoelectric effect method (<10uJ/cm^2) - **Direct method**

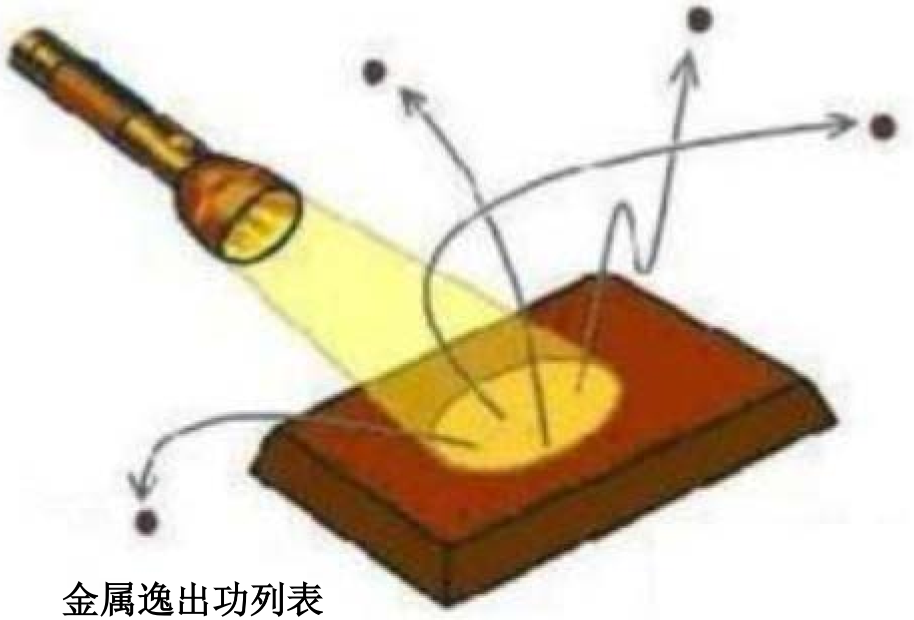
- Explanation of photoelectric effect by A.Einstein
- Each photon carries energy proportional to its frequency $E_\gamma=hf=hc/\lambda$
- One electron absorbs only one photon
- Energy of UV can less than 10uJ/cm^2
- **Stable current of photoelectric needed R&D**

Massive electrons R&D
Without influence working gas

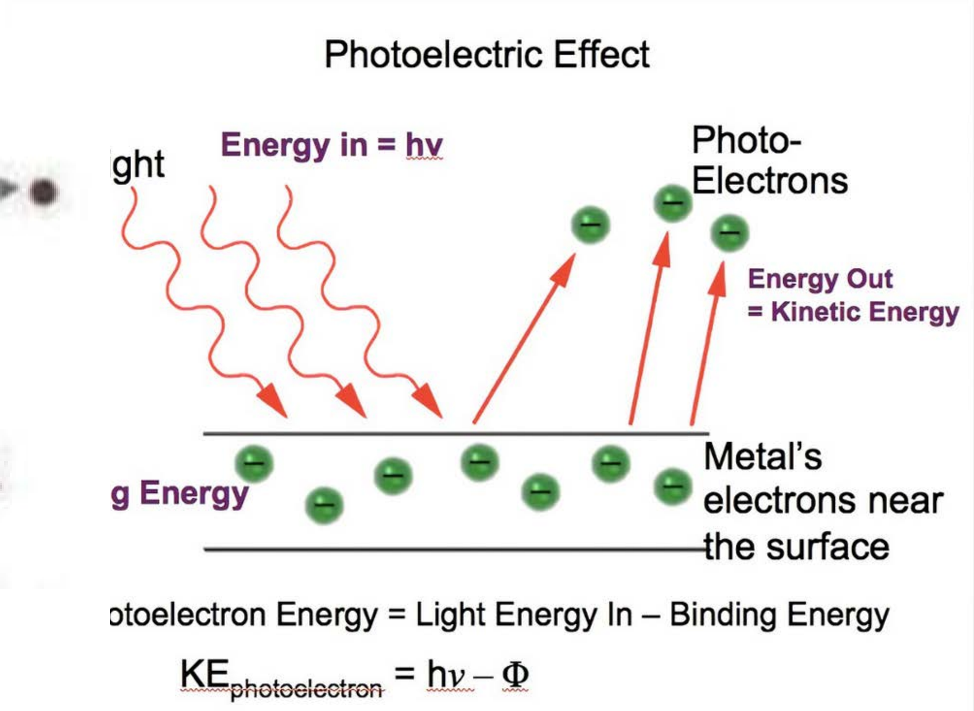
Work function of elements (eV)

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	

金属逸出功列表



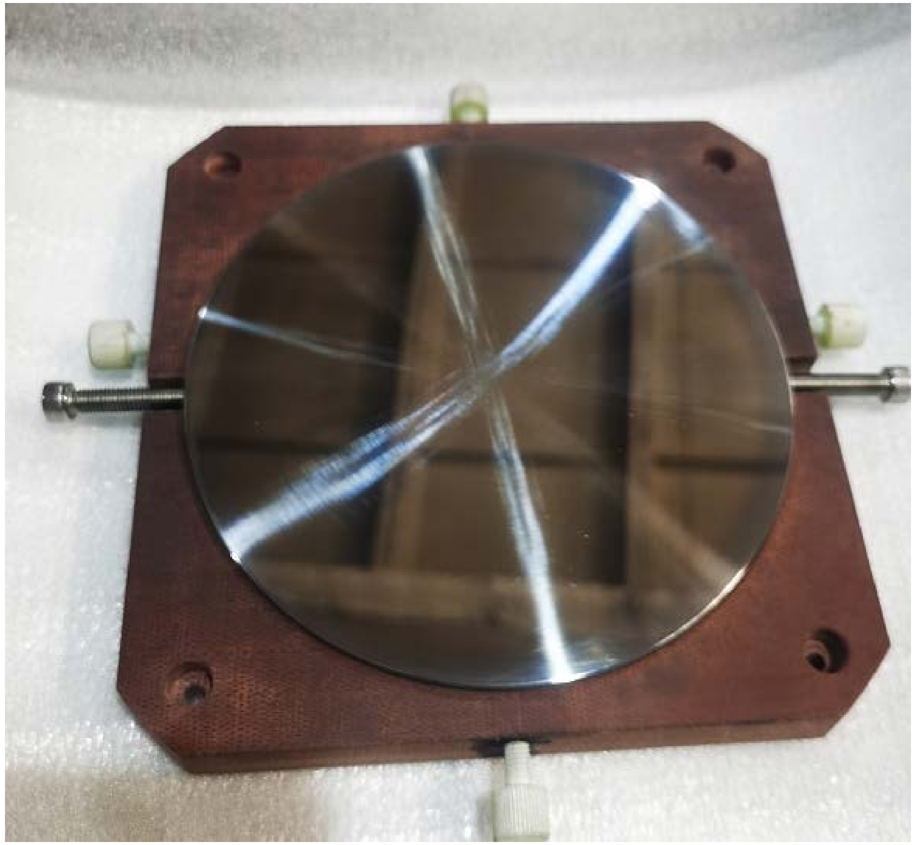
金属逸出功列表

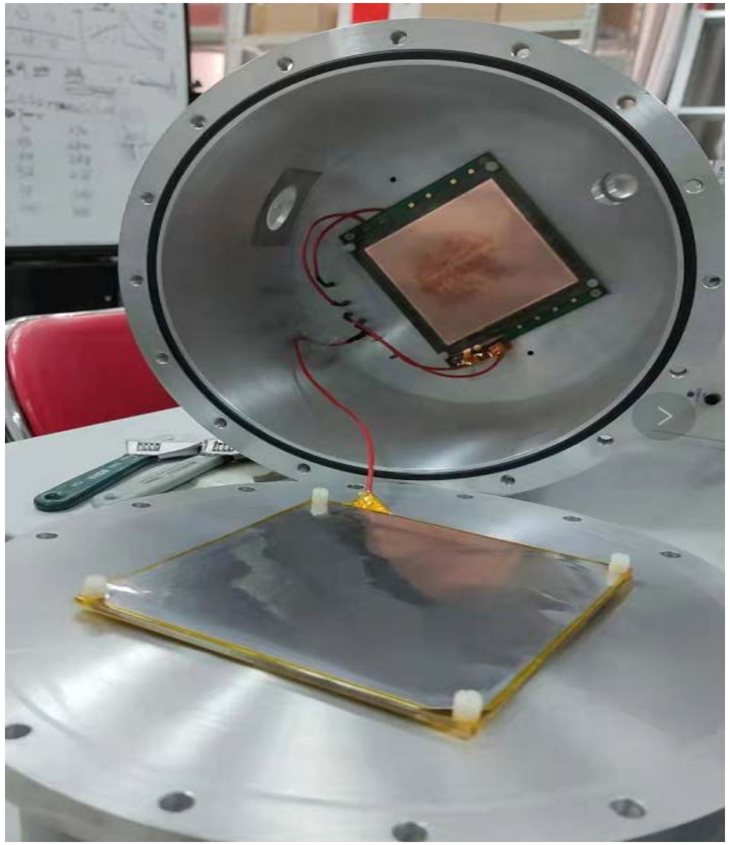


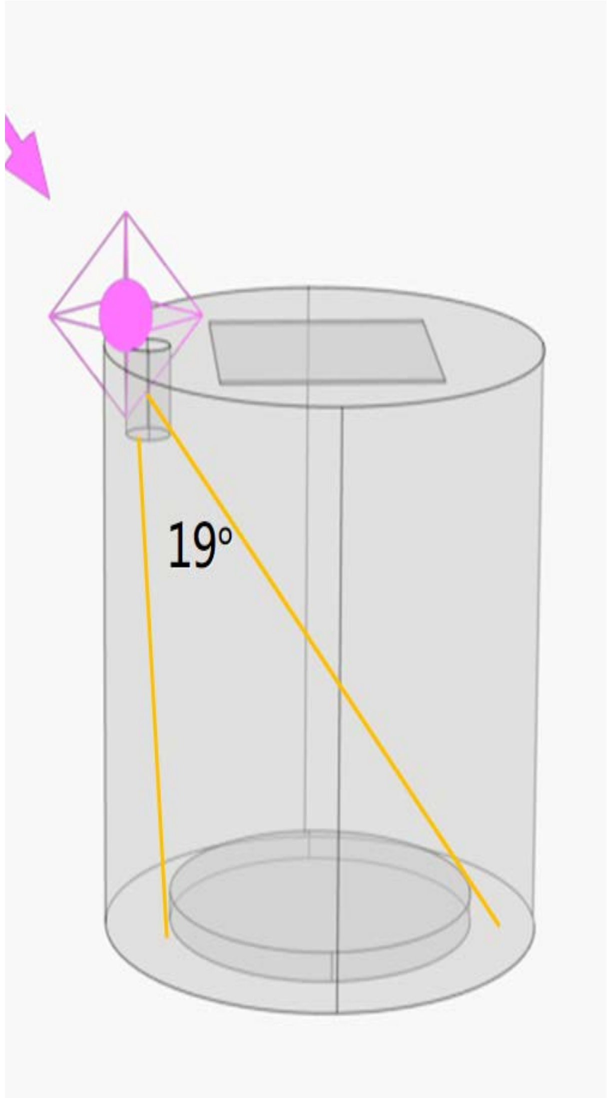
Testing the UV light created the massive electrons by photoelectric effect

UV light created the ion disk

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

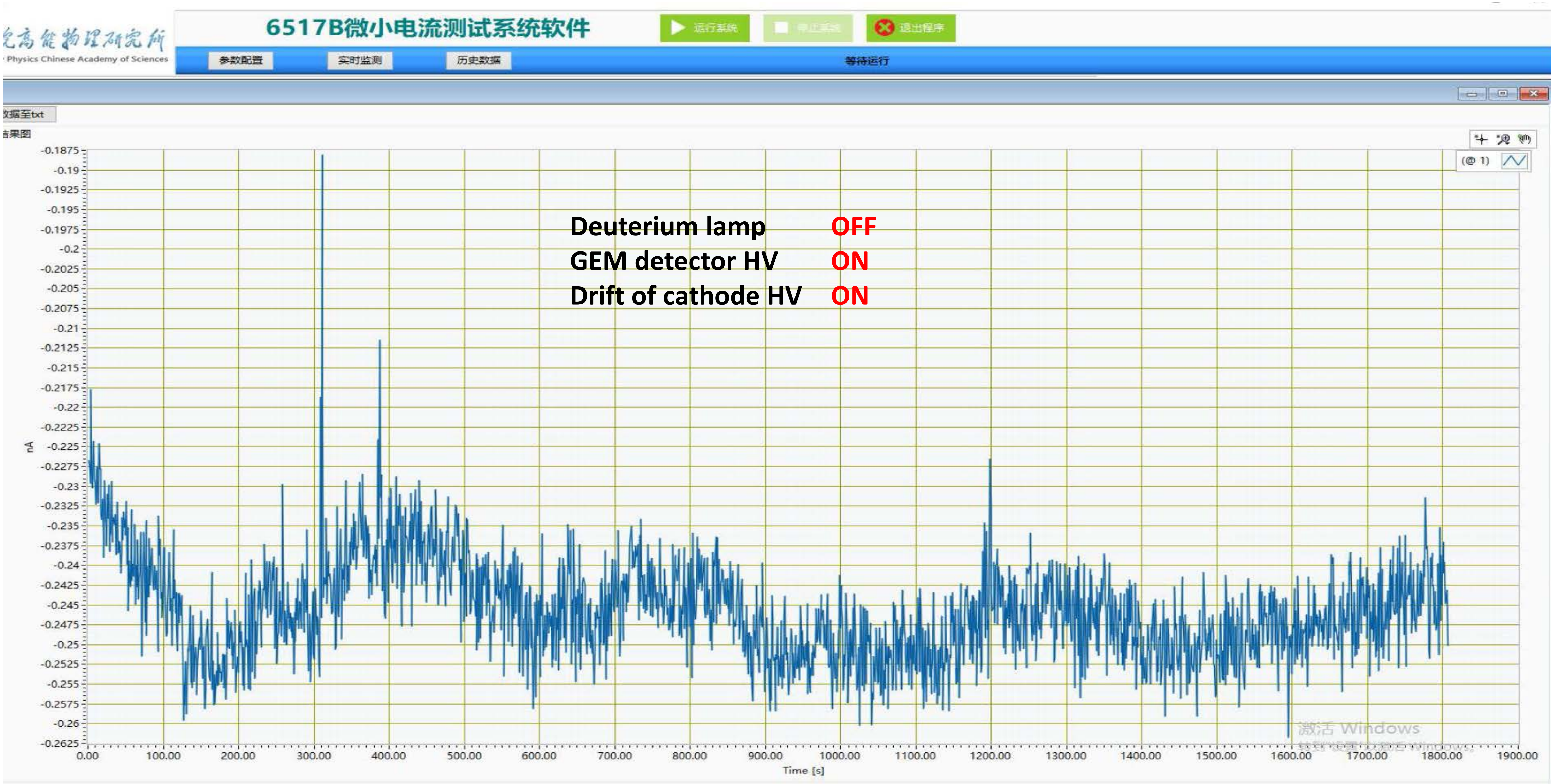






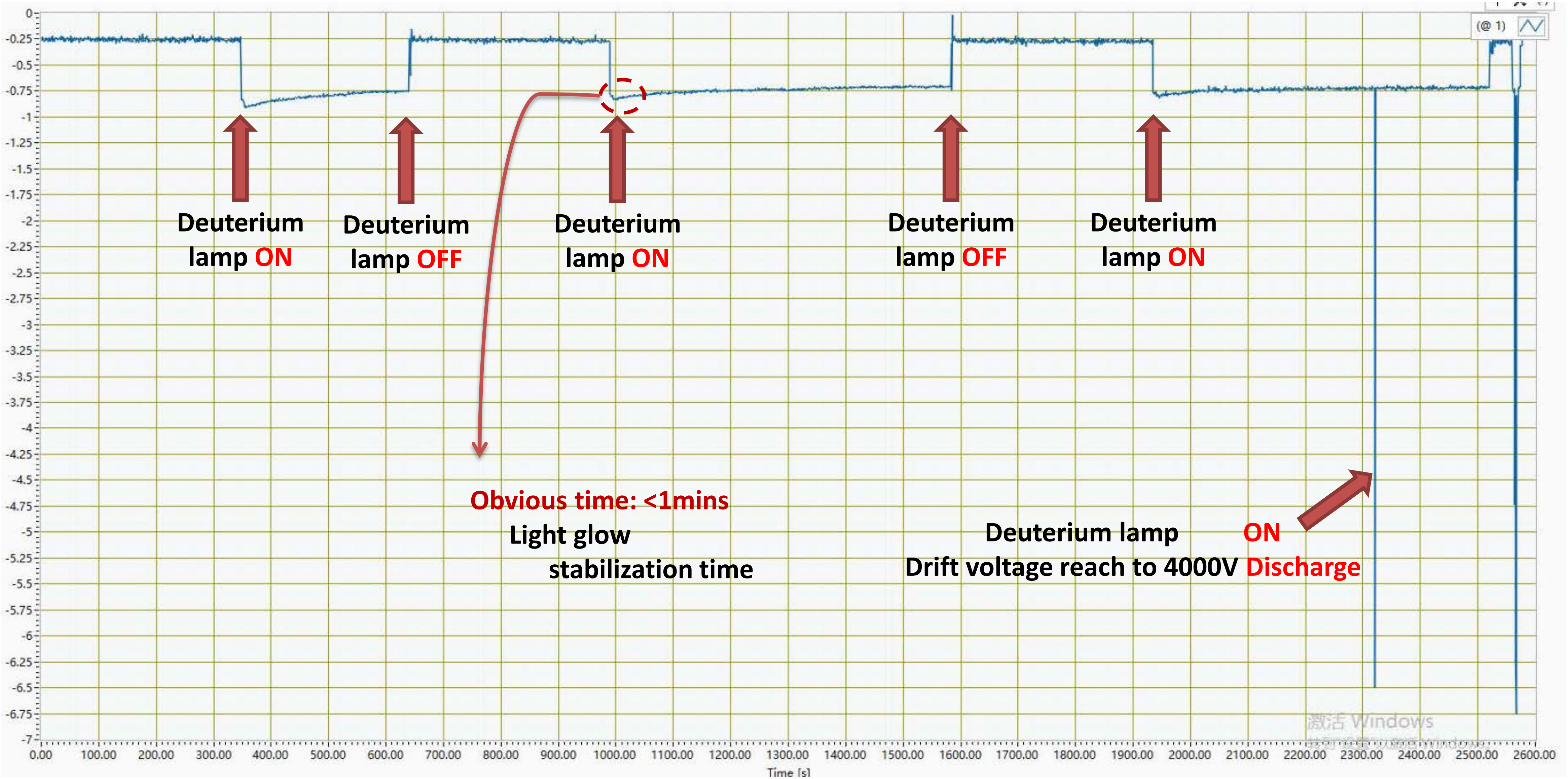
Testing the UV light created the massive electrons by photoelectric effect

- Current of the background noise (**pA current monitor**)



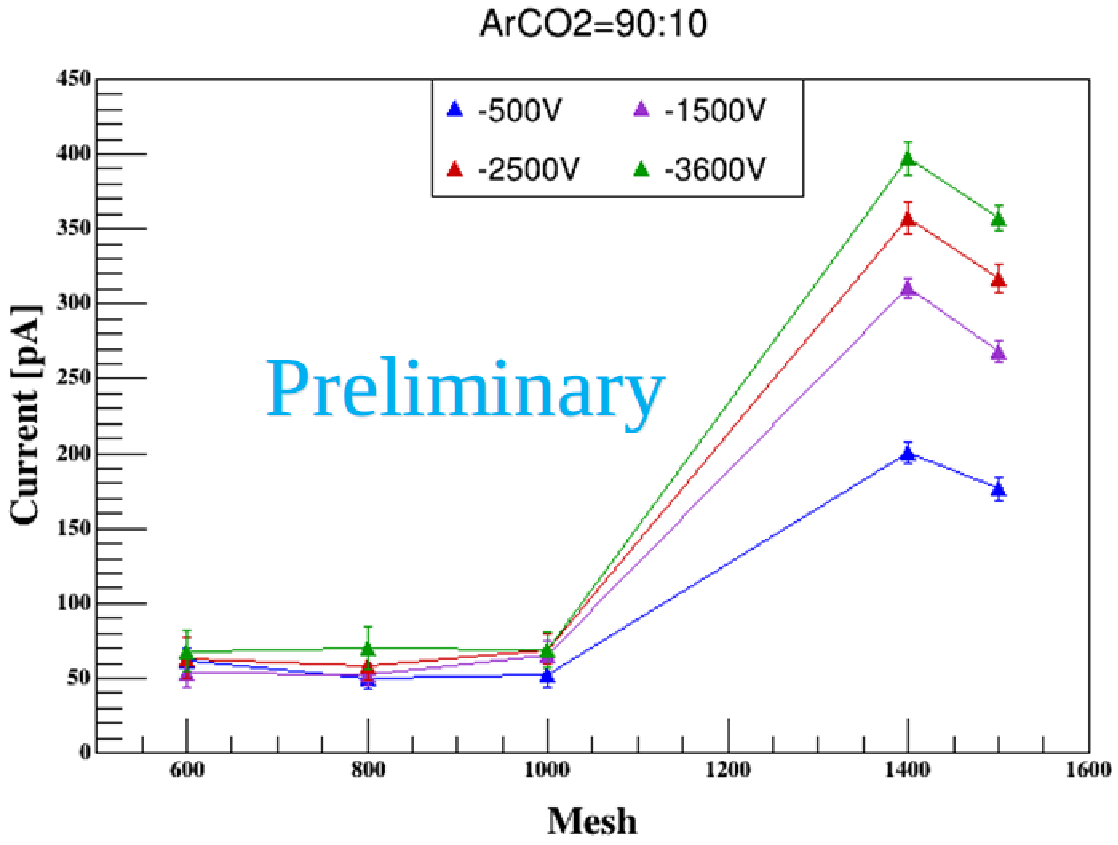
Testing the UV light created the massive electrons by photoelectric effect

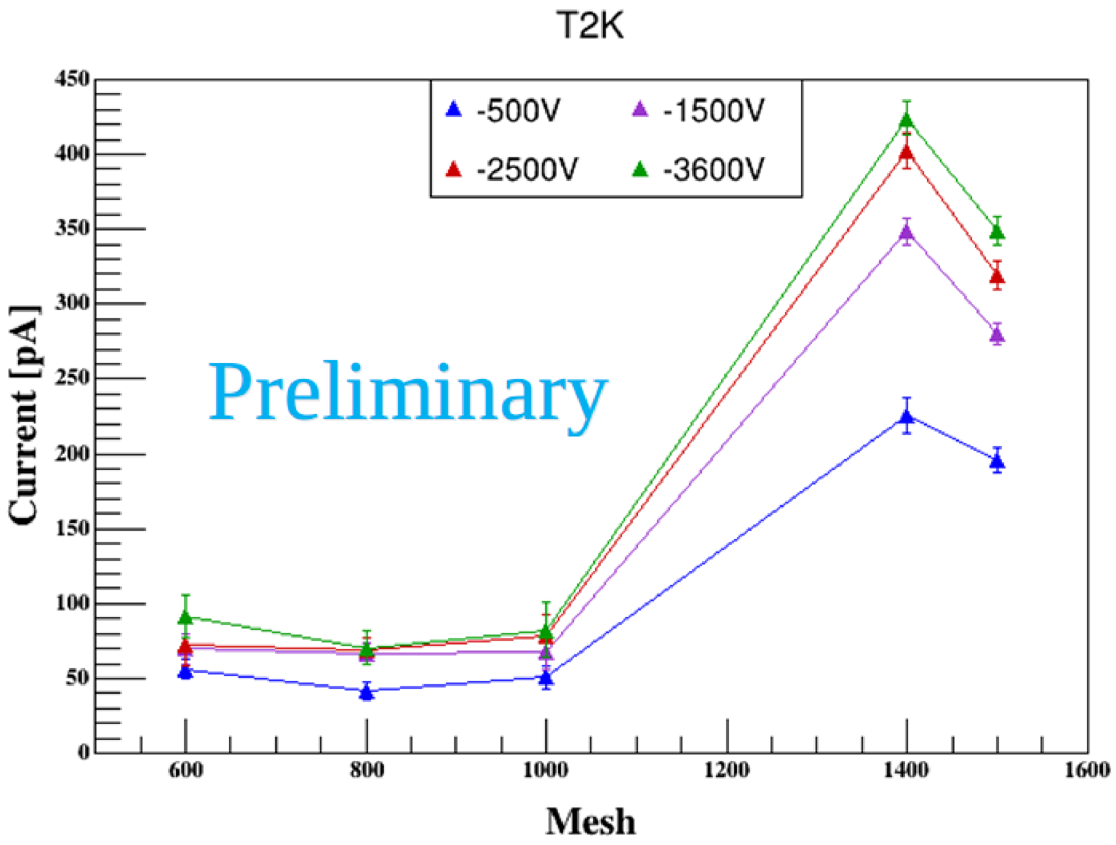
- Preliminary results**: very good stable** current obtained



Testing the UV light created the massive electrons by photoelectric effect

- The different LPI Aluminum's surface tested the different 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

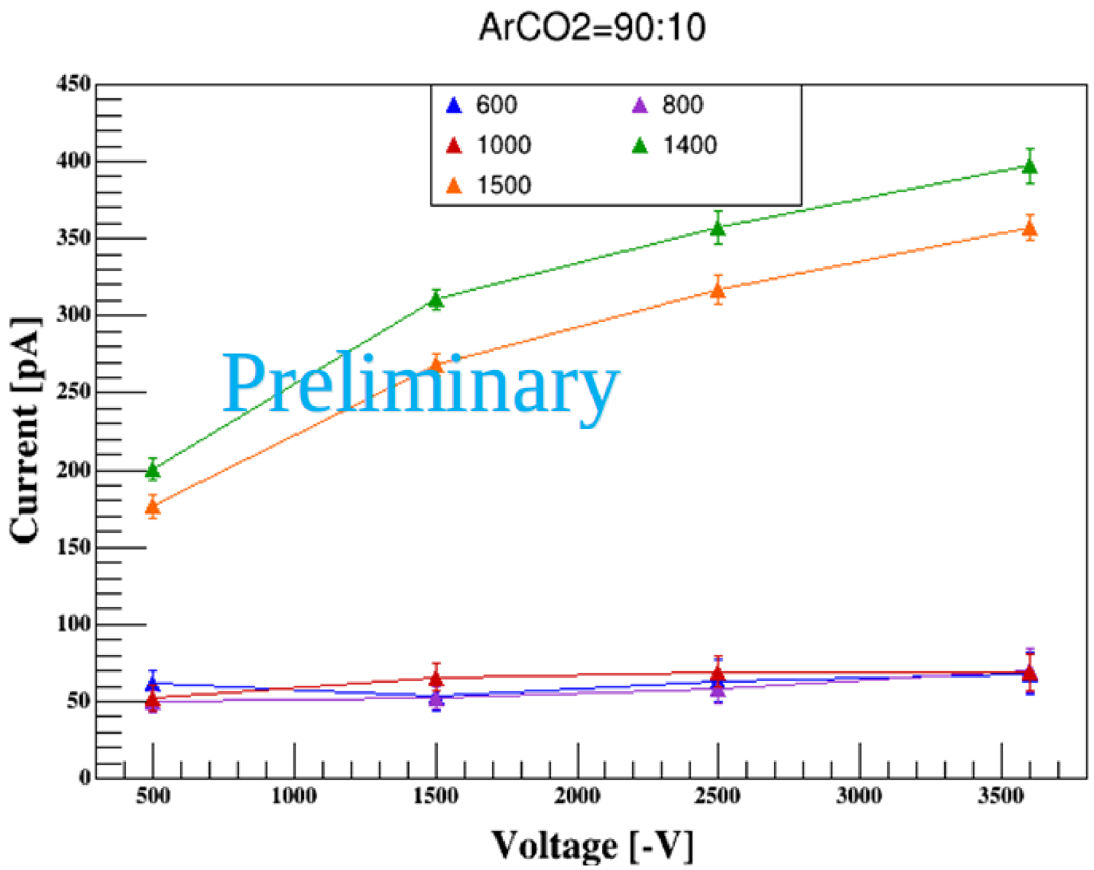


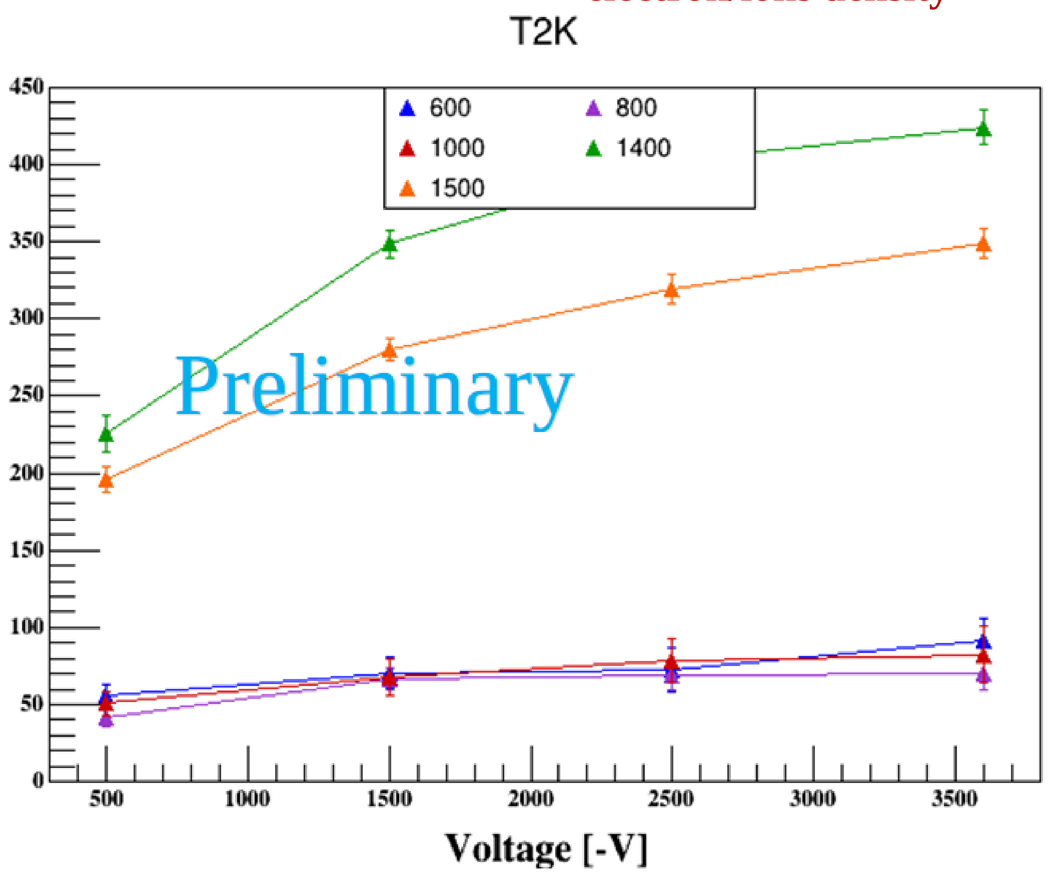


Testing the UV light created the massive electrons by photoelectric effect

- To meet the TPC prototype's drift electric filed (example: ~200V/cm at T2K)
- Scanning the different drift electric field (different voltage of cathode)
  - Verification of the same trend with the drift velocity by Garfield++
  - Verification of the two different mixture gases

Study ongoing:
Mimic the same level with CEPC electron/ions density

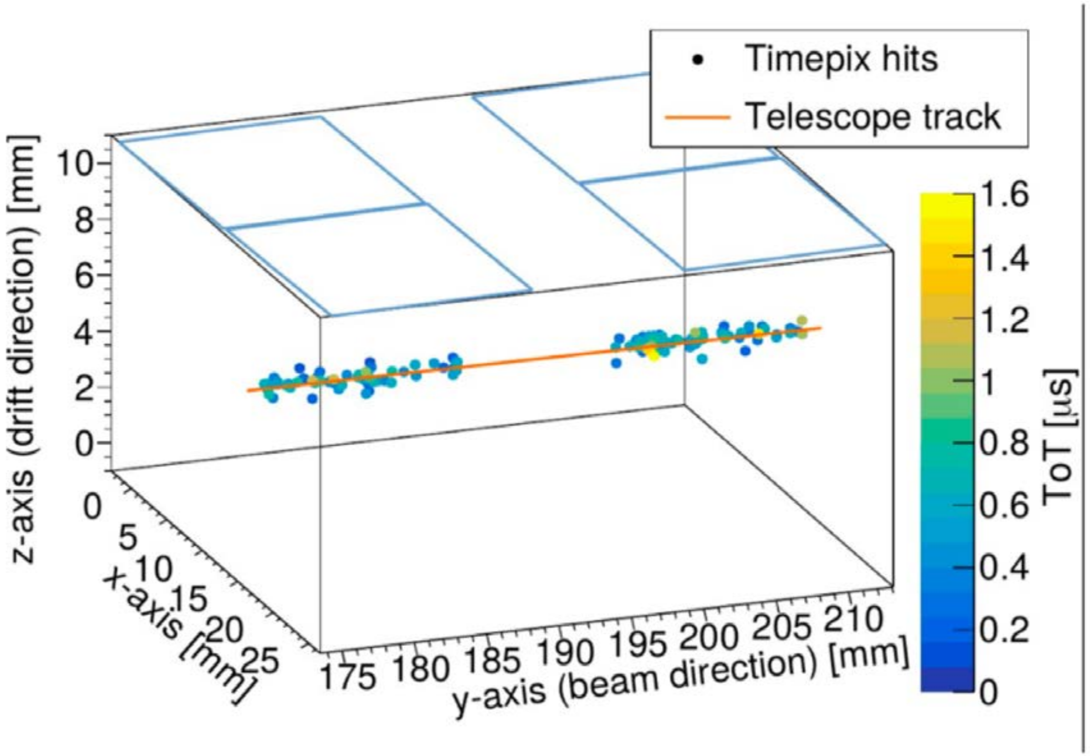




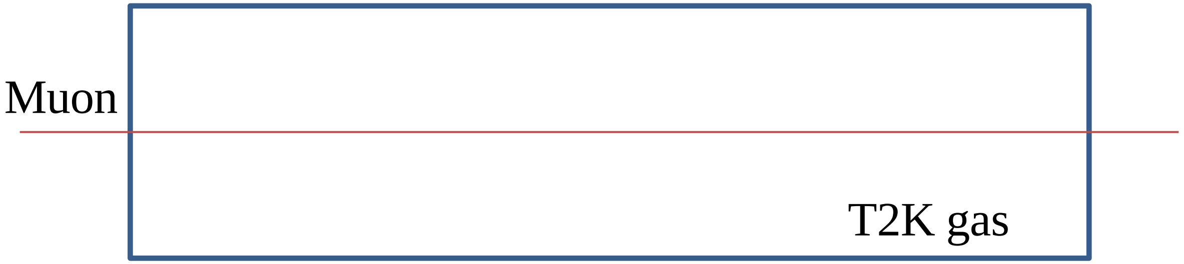
- Simulation of the ionization cluster in space

In Space

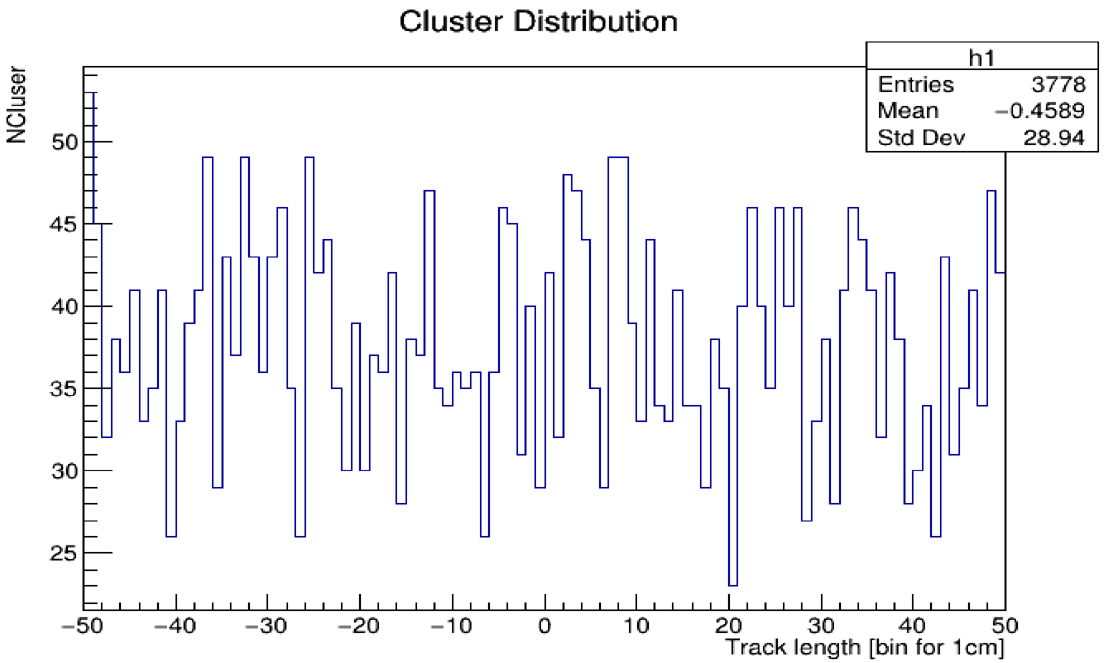
- Challenging of the low power consumption electronics (>40mV/fC needed at 2000 of gas gain)
- Pixelated readout
  → the reasonable pixilation reveals the underlying cluster structure in 3D chamber



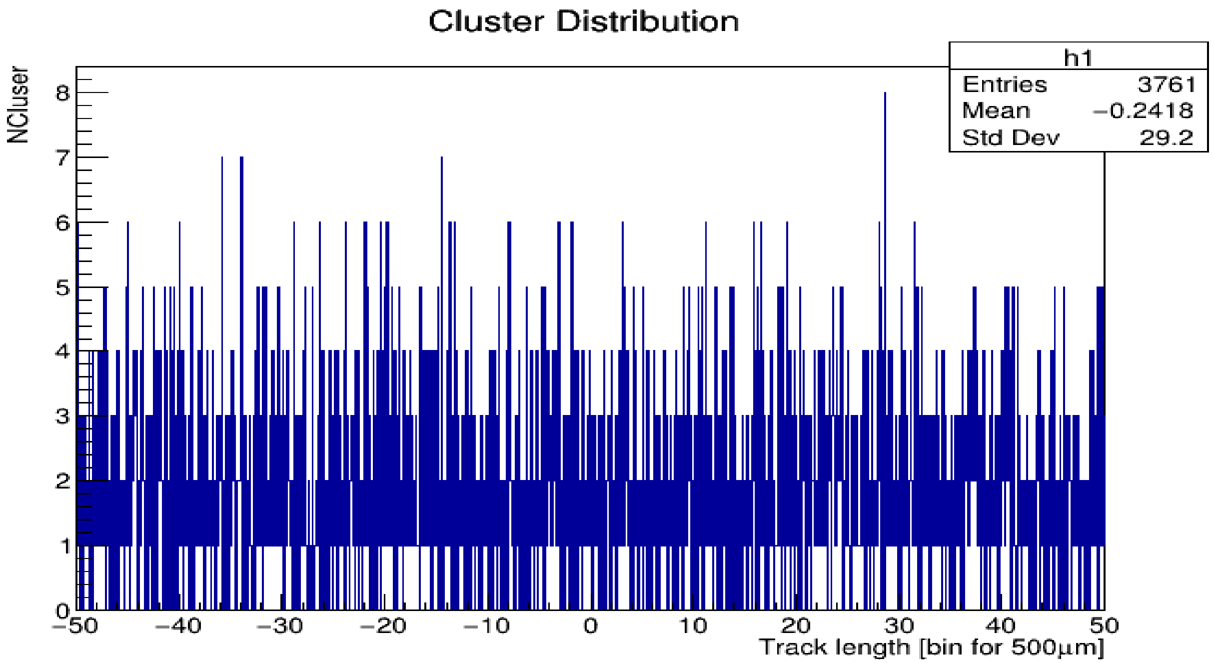
- Running 10000 events using Garfiled++
- Drift length: 1m, Incidence angle: 0^o
- Operation gas: **T2K gas @1atm**
- Particle: Muon@100GeV/c



- Simulation result show that the primary cluster profile along the drift length



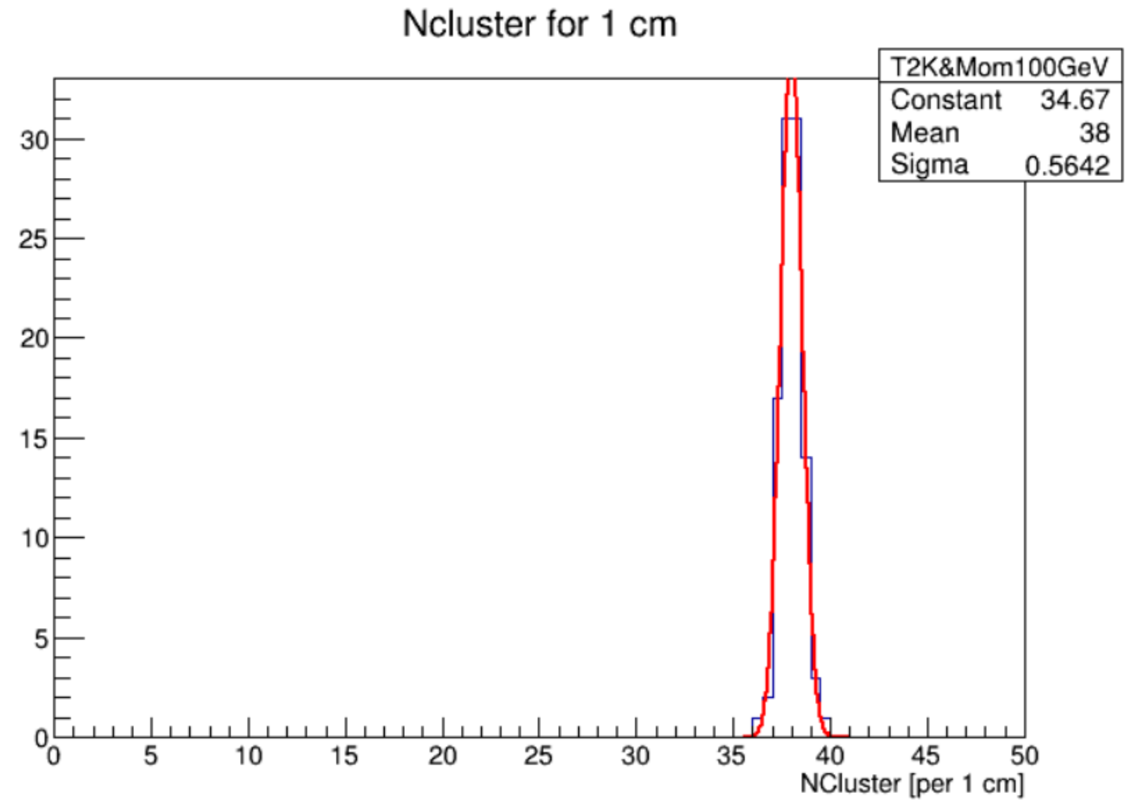
Bin: per 10mm



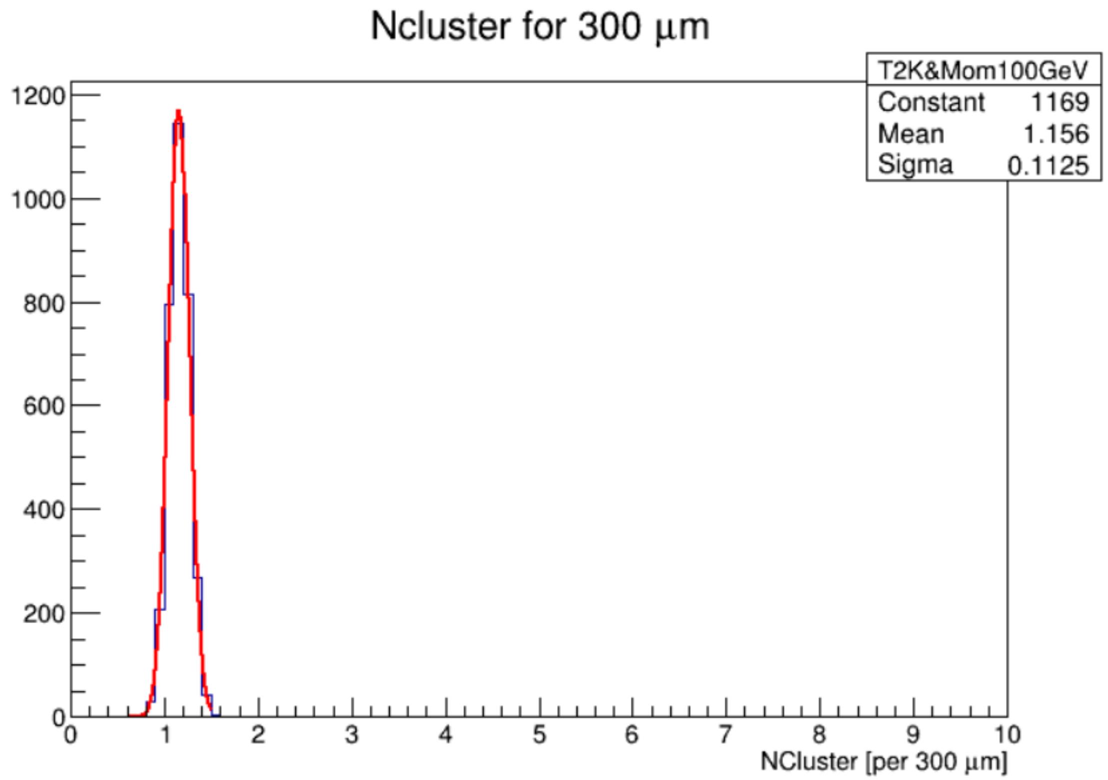
Bin: per 500um

Primary cluster profile using T2K gas

- Simulation result of the primary cluster using T2K gas
- Mean of N_cluster
    - Pressure: 1atmm, B: 0T, cosθ=0^o , Muon, E=100GeV/c



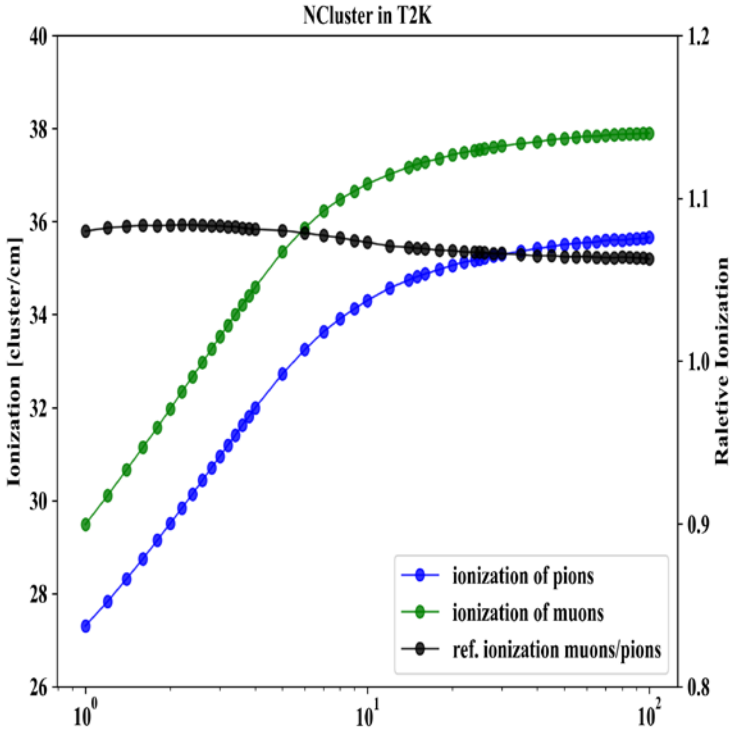
Bin: per 10mm



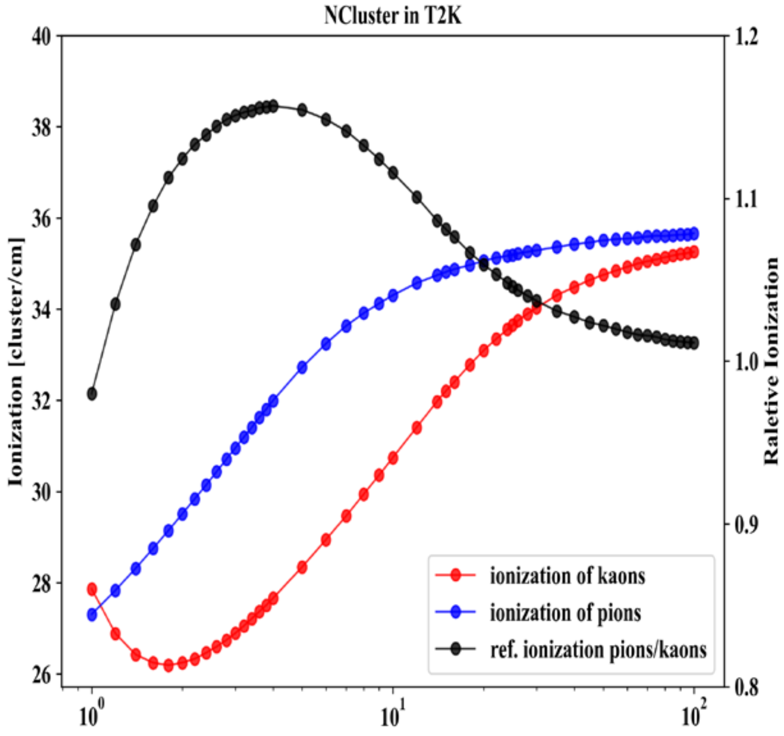
Bin: per 300um

Primary cluster profile using **T2K** gas – **π/κ/μ**

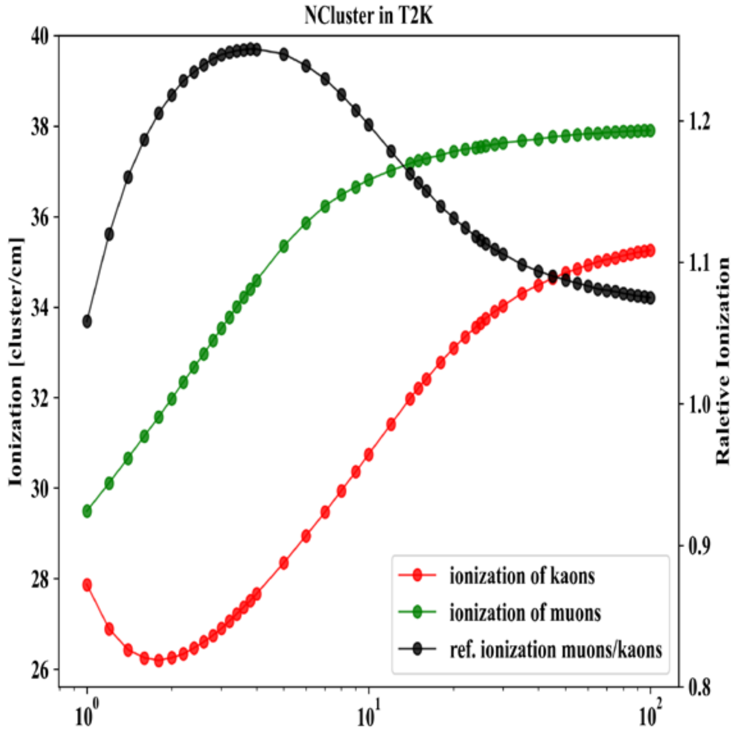
- Simulation result of the primary cluster using T2K gas
- Particles: Pion, Muon, Kion, 0.1GeV – 100GeV
- Variation of N_cluster(cm) with the different momentum of the specfic incident particle



Pion VS Muon



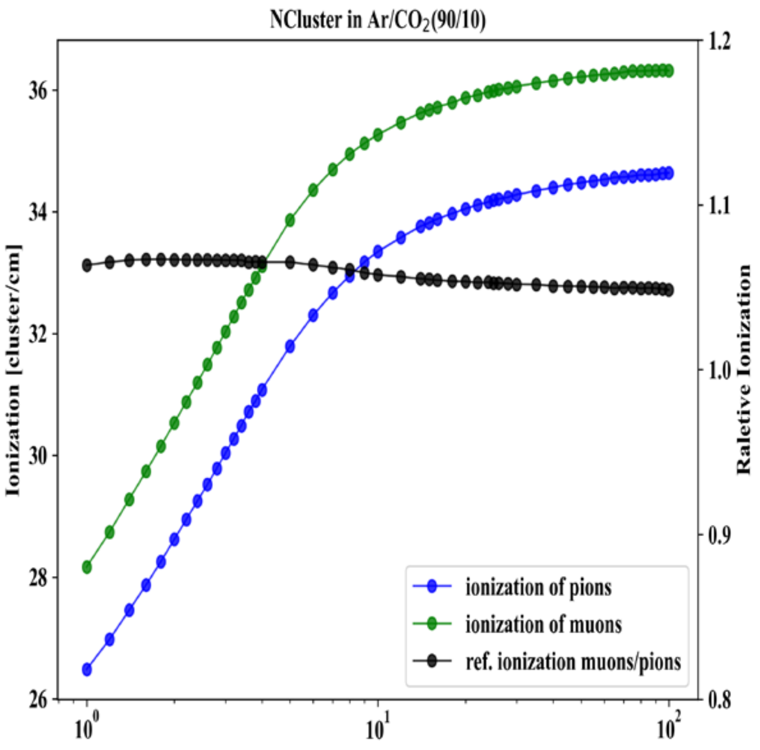
Kion VS Pion



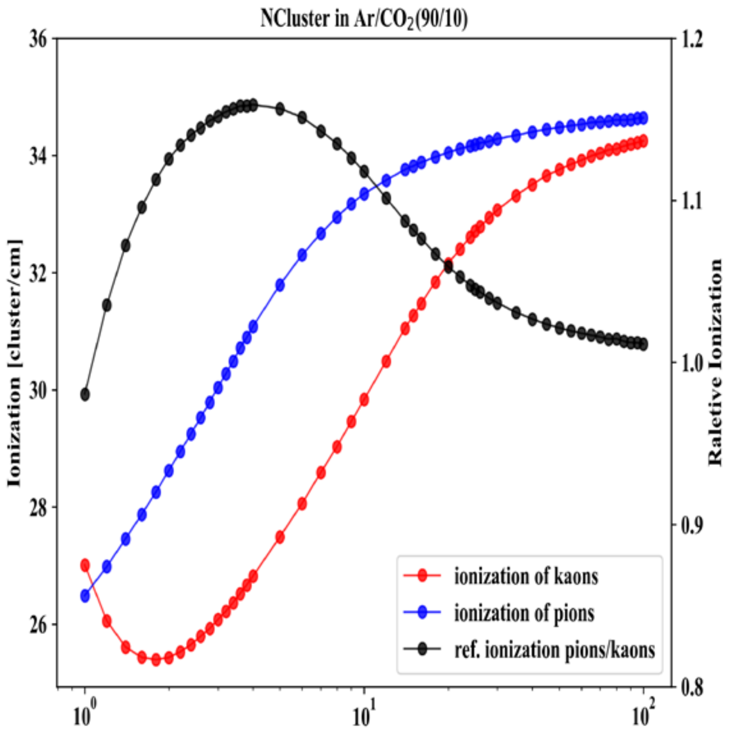
Kion VS Muon

Primary cluster profile using **Ar/CO_2=90/10** gas – **π/κ/μ**

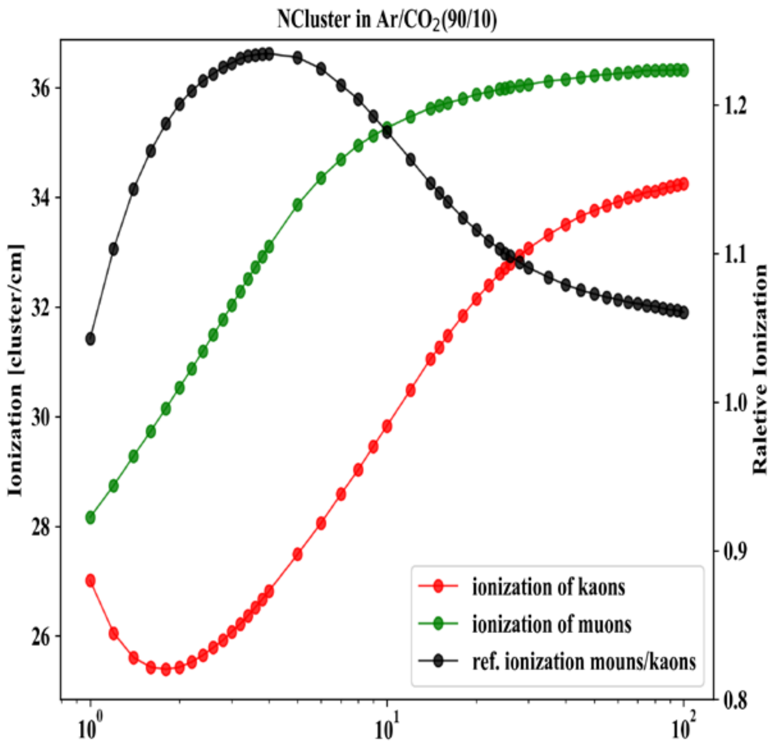
- Simulation result of the primary cluster using Ar/CO_2=90/10 gas
- Particles: Pion, Muon, Kion, 0.1GeV – 100GeV
- Variation of N_cluster(cm) with the different momentum of the specific incident particle



Pion VS Muon



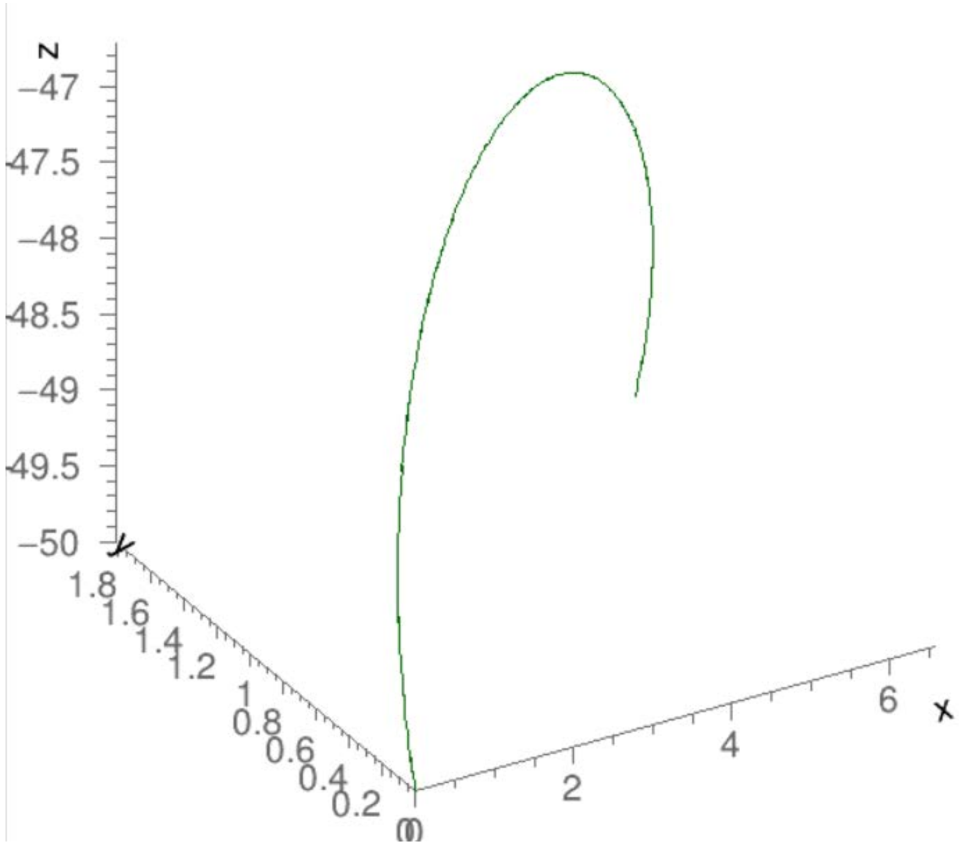
Kion VS Pion



Kion VS Muon

Primary cluster profile under E and B

- To study the N_cluster profile under E and B
- Particles: Muon , 0.1GeV – 100GeV
- Verification of the simulation code
  - Successfully create this module
  - Incidence angle: 10^{o}
  - B = 1.0T
  - Momentum = 0.1 GeV/c
  - Radius of curvature: 3.3cm
  - Validation of the results of the calculation and simulation
- Ongoing
  - Starting to investigate the primary cluster profile under the different **E and B**



Simulation conclusion and plan

- The codes successfully simulated the primary cluster using the different operation mixture gases, **the different particles** and the different electric/magnetic field.
- Simulation result show that the primary cluster profile along the drift length, and it **could meet** the pixelated readout TPC detector if the pad size will be kept in the rang of 300um – 500um.
- Simulation result show that the number of the primary cluster under the different gas pressure, and it **could be optimized and meet the requirements** of the pixelated readout TPC detector if the MPGD readout will run at the low gain.
- The simulation module has been integrated with the different **E and B**.

Summary

- TPC detector prototype was studied using the UV laser track, ^{55}Fe radiation source and the cosmic ray.
  - One paper published in NIMA based on laser TPC prototype
  - Two oral talk have been accepted by ECFA Workshop 2022 and IEEE 2022
- The simulation is starting to study the primary cluster using the different operation mixture gases, the different operation gas pressure and optimization.
- To meet high luminosity of Z pole run, the testing the UV light created the ion disk by photoelectric effect, and the experimental results show good to study.
  - Created the stable massive electrons **without influence** working gas
  - Mimic the same level with CEPC electron/ions density in TPC chamber

Many thanks!