Updated study of the primary electrons, cluster and TPC technology for e^+e^- collider

Huirong Qi

Yue Chang, Liwen Yu, Xin She, Jian Zhang , Zhiyang Yuan, Hongliang Dai, Jinxian Zhang

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

CEPC Day Meeting, September 20, 2022

Content

- **Motivation**
- **Studies on primary electrons and cluster**
- **Updated progress of TPC prototype**
- **Some contribution and information from LCTPC**
- **Summary**

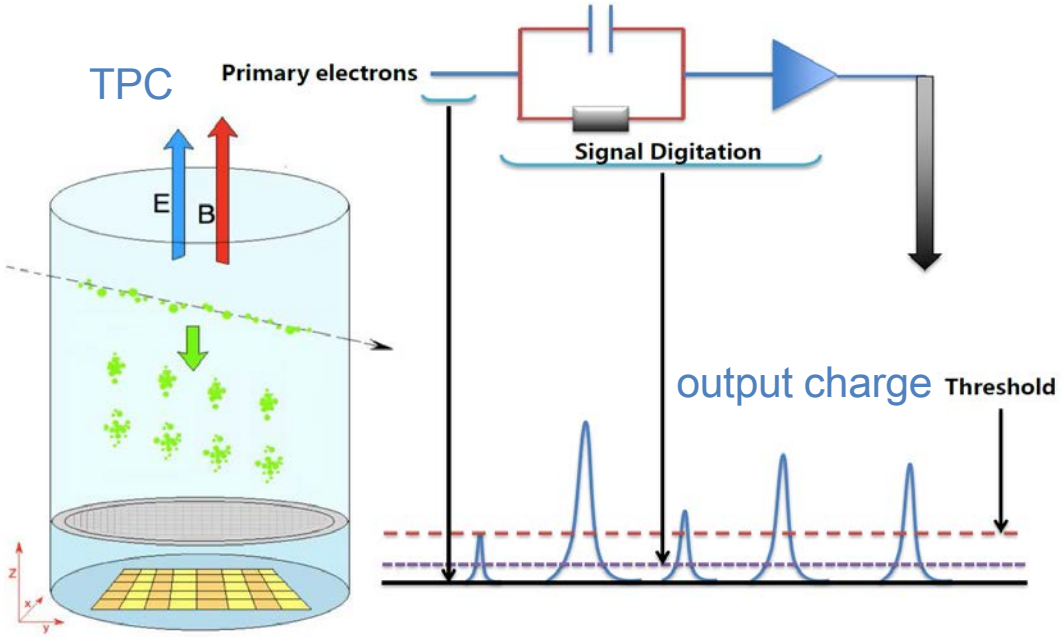
Motivation: identify the clusters and achieve dN/dx

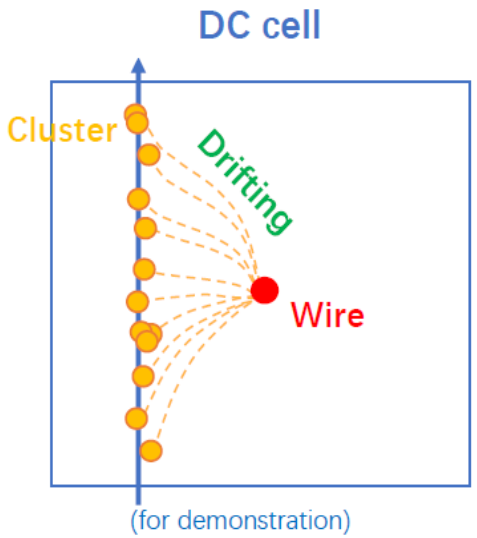
In Space

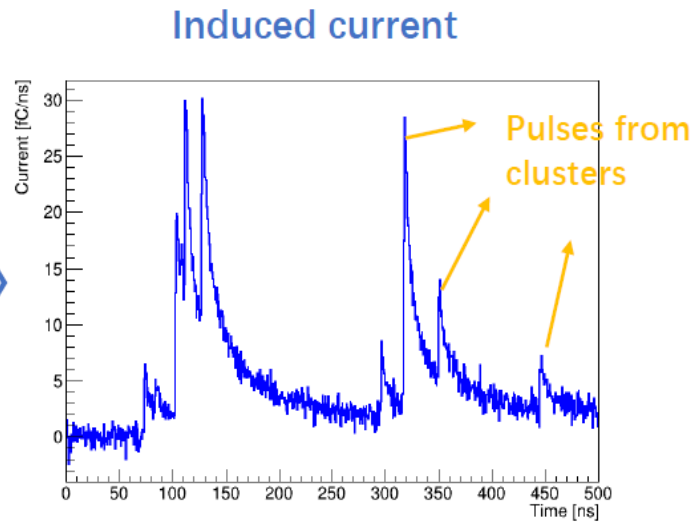
- Challenging of the **low power consumption** electronics (>40mV/fC needed at 2000 of gas gain)
- Pixelated readout - **high granularity**
- → the reasonable pixilation reveals the underlying cluster structure in 3D chamber

In Time

- Challenging of the **fast-shaping** electronics (~ ns needed)
- De-couple the charge collection from the cluster counting altogether
- → optical, with ~(sub)ns continuous readout sensors







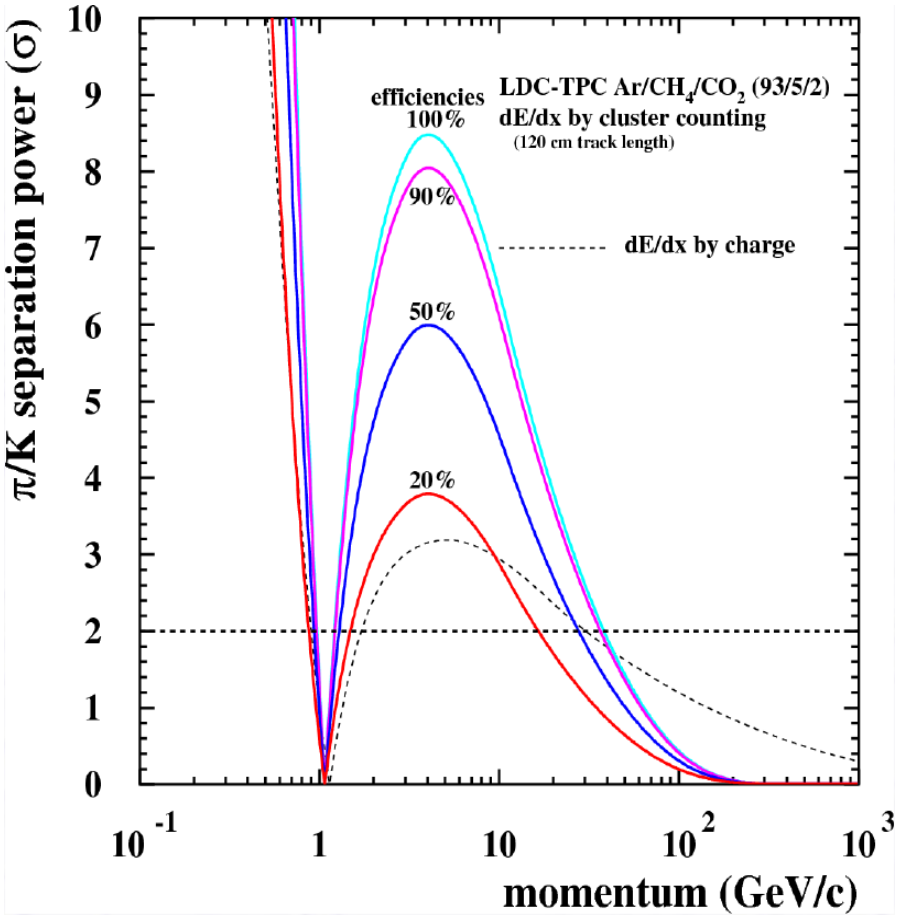
Motivation: High granularity for improved PID in TPC

- For traditional dE/dx detection, the charge summation can be expected using the gravity method.
- In most experimental study from small to large TPC
  - L and N are correlated.
  - Constant L and changing granularity G = N/L

$$\frac{\sigma_{dE/dx}}{\langle \mu_{dE/dx} \rangle} \propto L^{-0.45} G^{-0.13}$$

- If pad size is at the level of cluster distances of primary ionization
  - i.e. ~ **300-500 μm in Ar-based**
  - Cluster counting becomes effective

- PID improvement
  - The potential of **better resolution by at least a factor 2**
  - Novel method raised in some groups R&D for e+e- collider
    - IHEP significantly pushed



Hauschildt
http://ific.uv.es/~ilc/ECFA-GDE2006/0

- Studies on primary electrons and cluster
  - To create the massive primary electrons/ions
  - To simulate the primary cluster in space

- Experimental studies on ions

Firstly: Primary electrons

- Experimental studies on ions

Need investigate the electrons/ions density at CEPC

- Simulation results based on CEPC's parameters (PhD. thesis by Zhiyang Yuan)
- CEPC or others detector will face the massive electrons/ions
- To investigate and create **the stable electrons/ions** in the specific area

Electric field analysis

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

Cylindrical coordinates

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

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

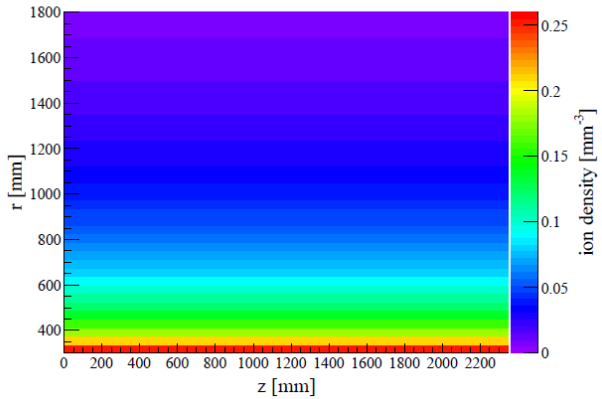
$$\Phi_m(r,k) = K_m(kr) \int_0^r R_m(r',k)\, I_m(kr')\, r' dr' + I_m(kr) \int_r^{\infty} R_m(r',k)\, K_m(kr')\, r' dr'$$

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

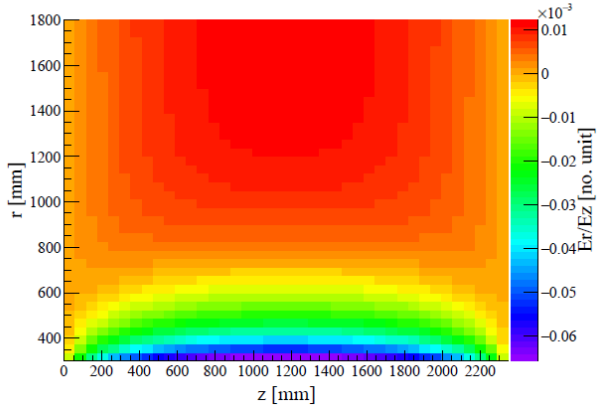
$$\rho_m(r',z') = \frac{1}{2\pi} \oint \frac{\rho(r',\theta',z')}{\epsilon_0} e^{-im\theta} d\theta'$$

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

Ions density in chamber



E_r / E_z



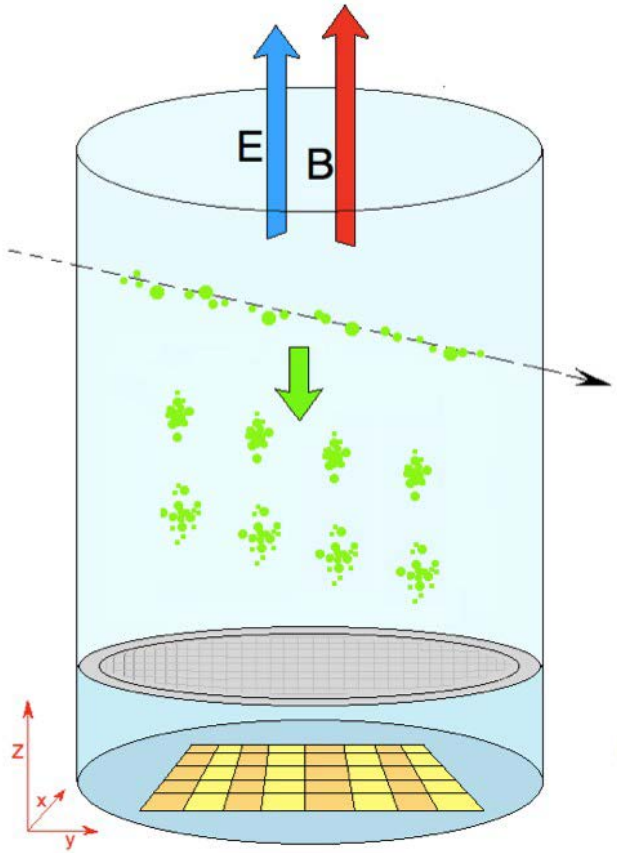
How to create stable massive electrons in the chamber?

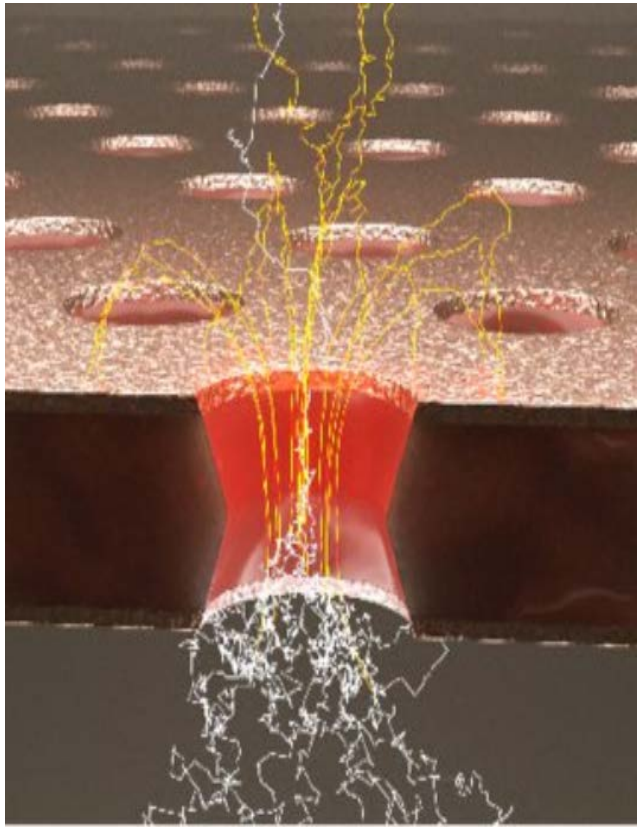
Indirect method to generate electrons

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

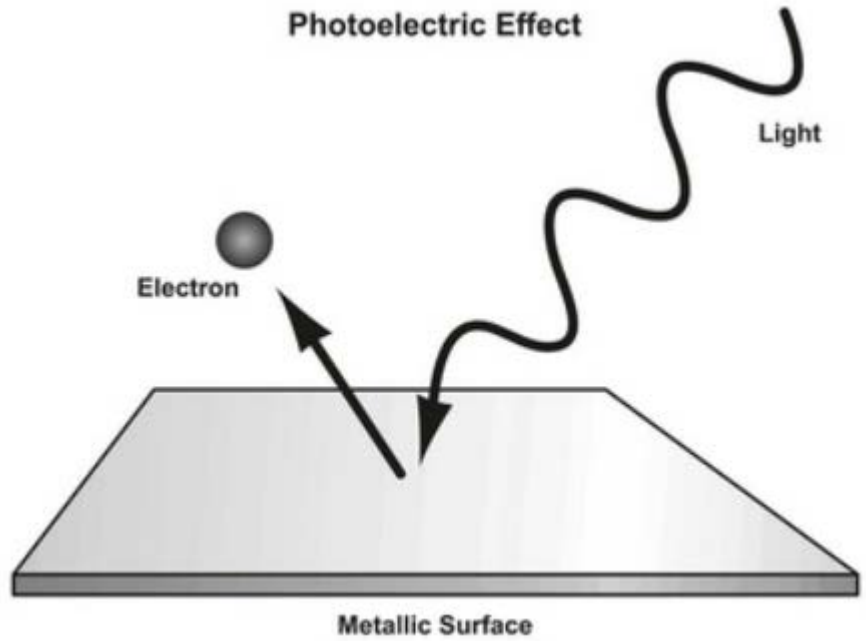
Direct method to generate electrons

- 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**

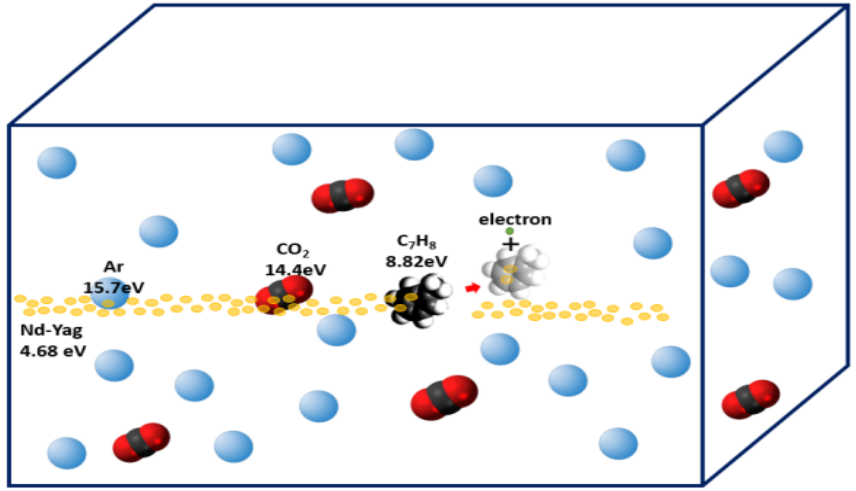
- Some gas can absorb the energy of 2 photons from UV laser and ionized
- Wavelength of UV laser: 266nm (almost: 4.66eV×2)
- Threshold of the ionization energy: **>10uJ/cm^2 @MIP**

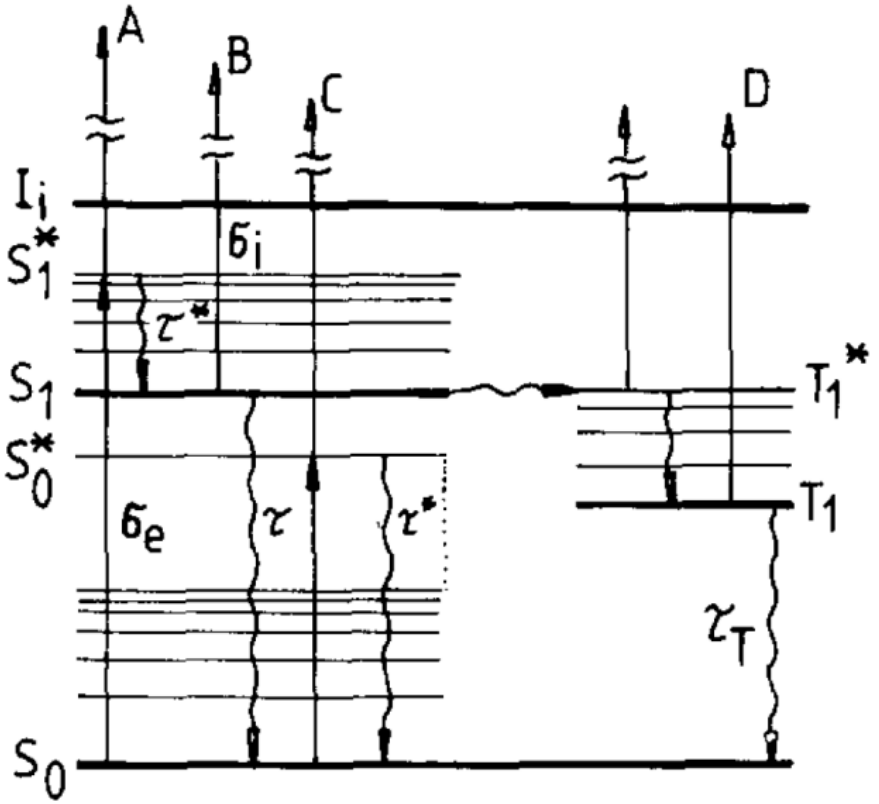
Laser TPC prototype R&D

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

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**

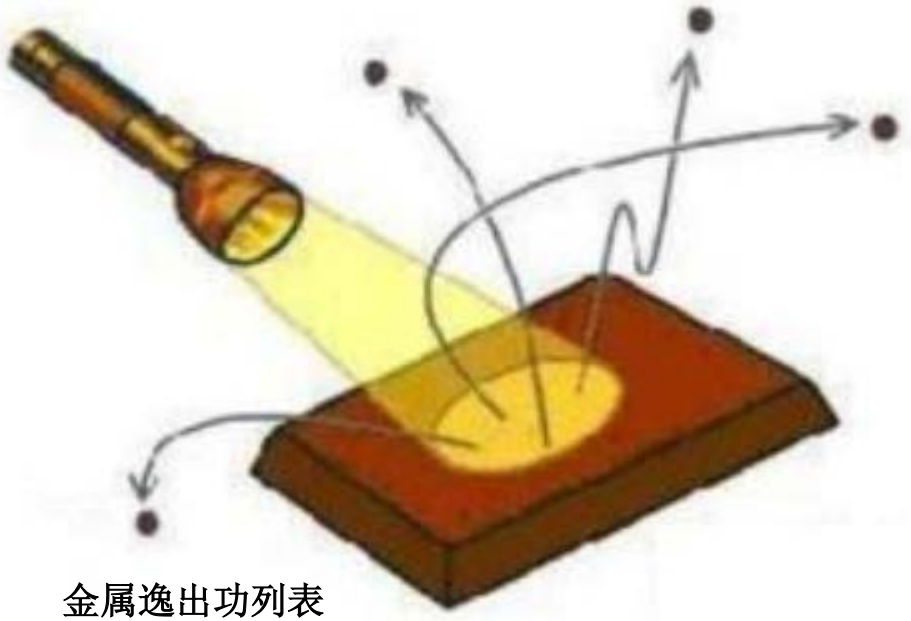
- Explanation of photoelectric effect by A.Einstein
- Each photon carries energy proportional to its frequency $E_\gamma = hf = hc/\lambda$
- One electron absorbs only one photon
- Energy of UV can less than 10uJ/cm^2
- **Stable current of photoelectric needed R&D**

Massive electrons R&D
Without influence working gas

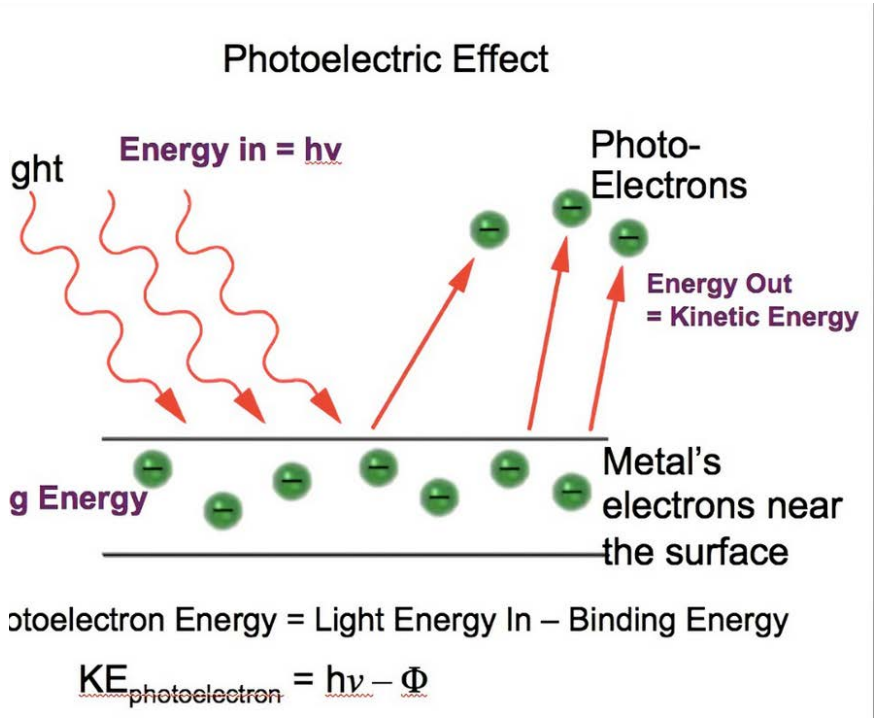
Work function of elements (eV)

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



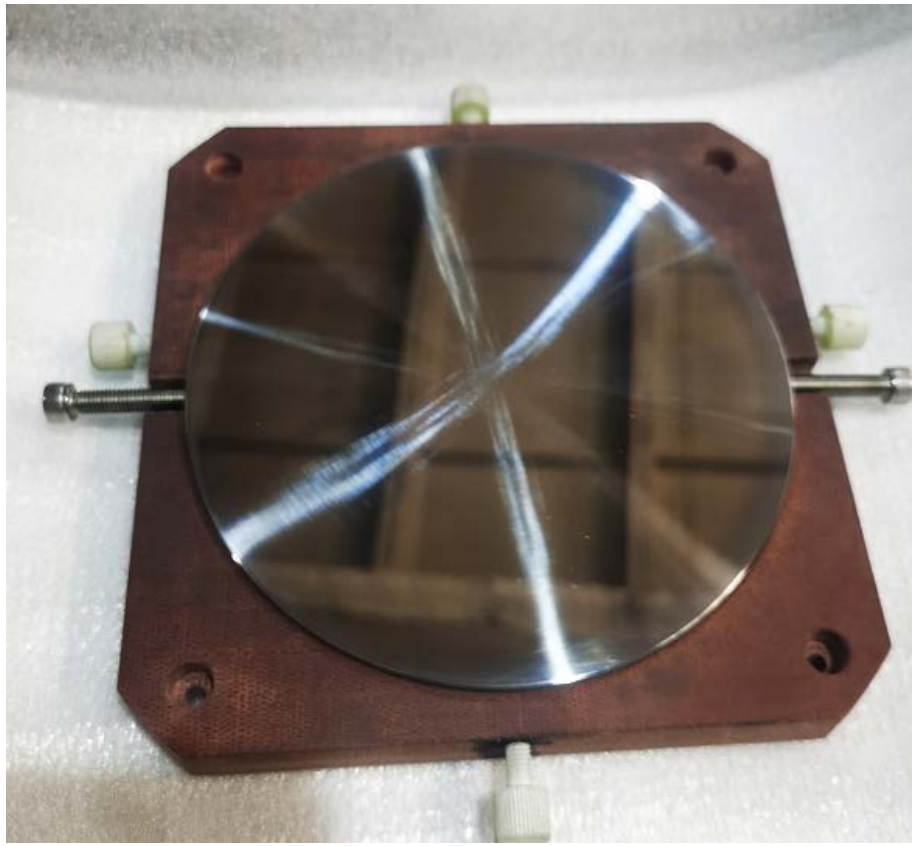
金属逸出功列表

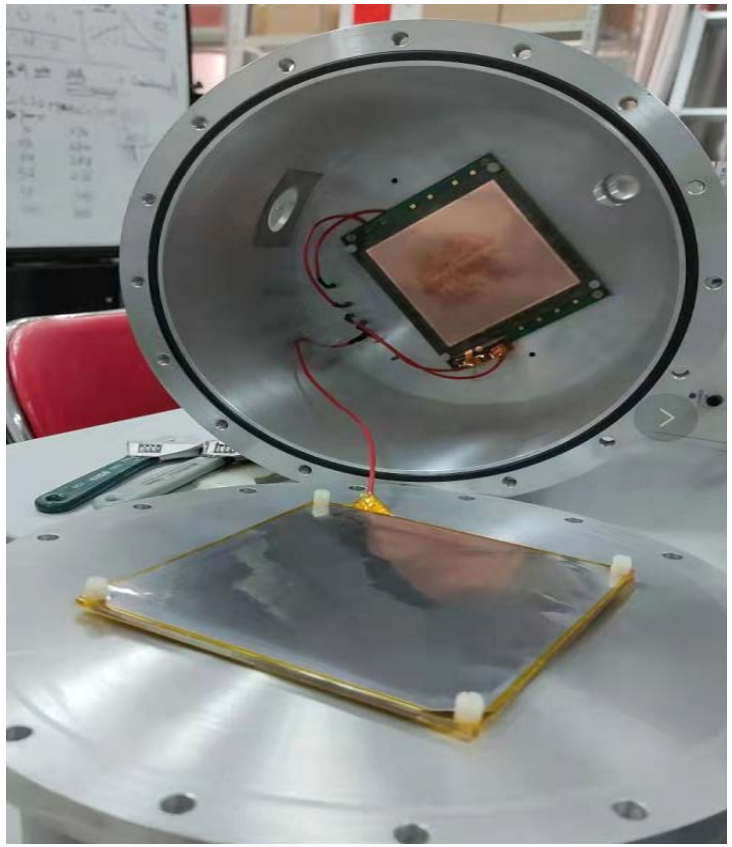


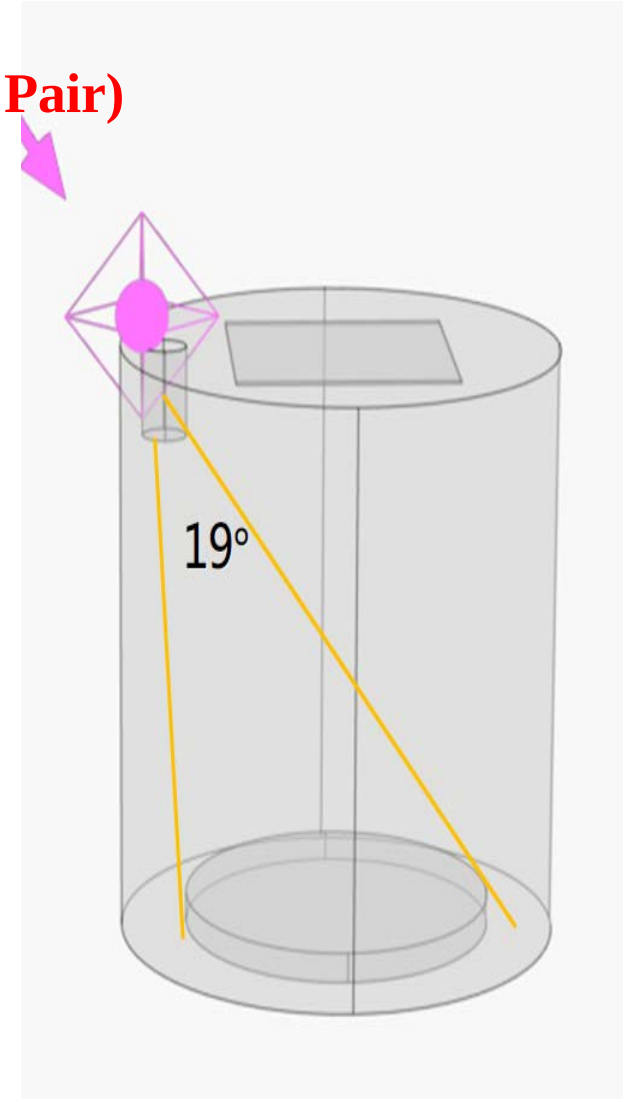
Testing the UV light created the massive electrons by photoelectric effect

UV light created the ion disk

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

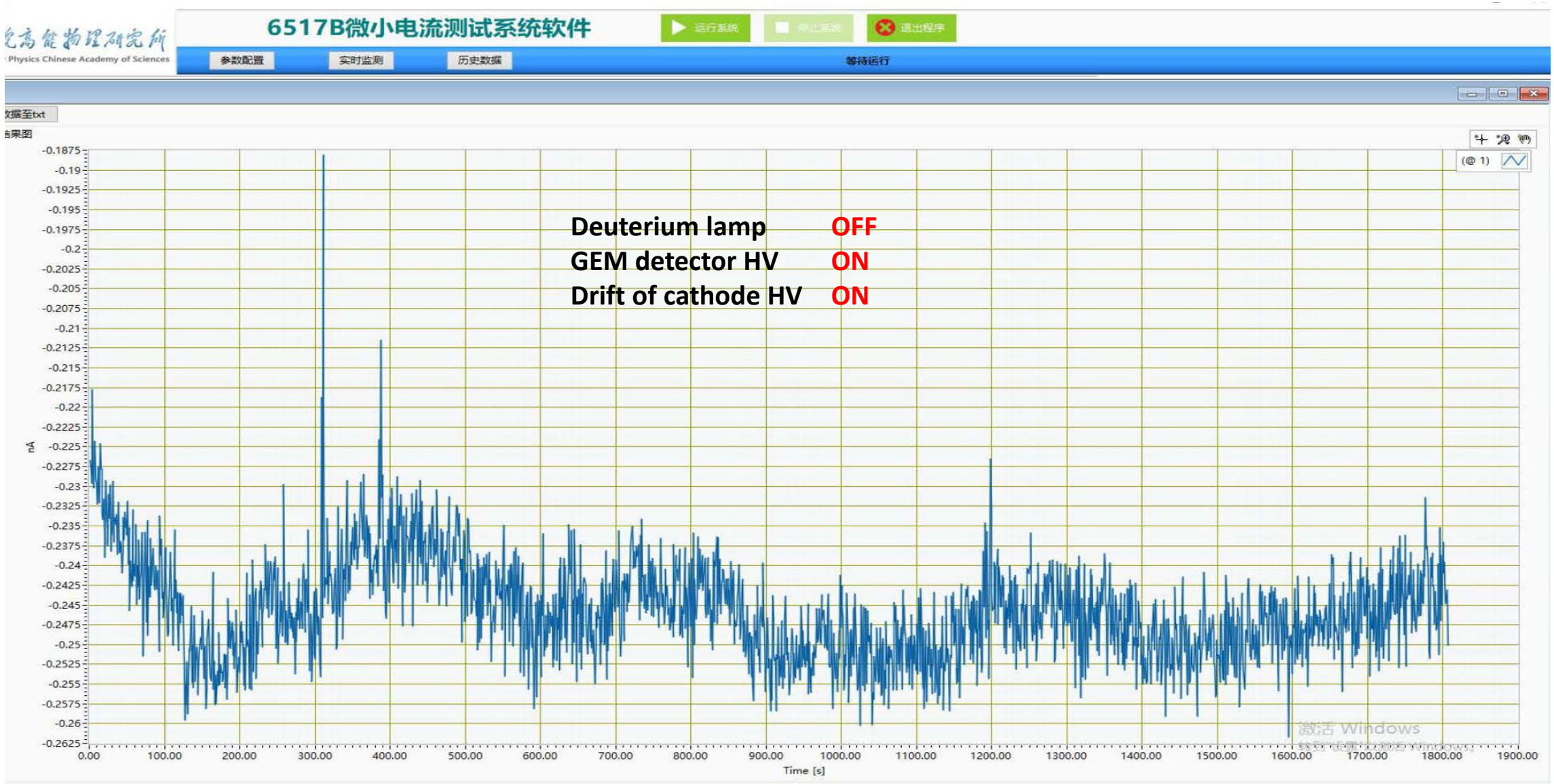






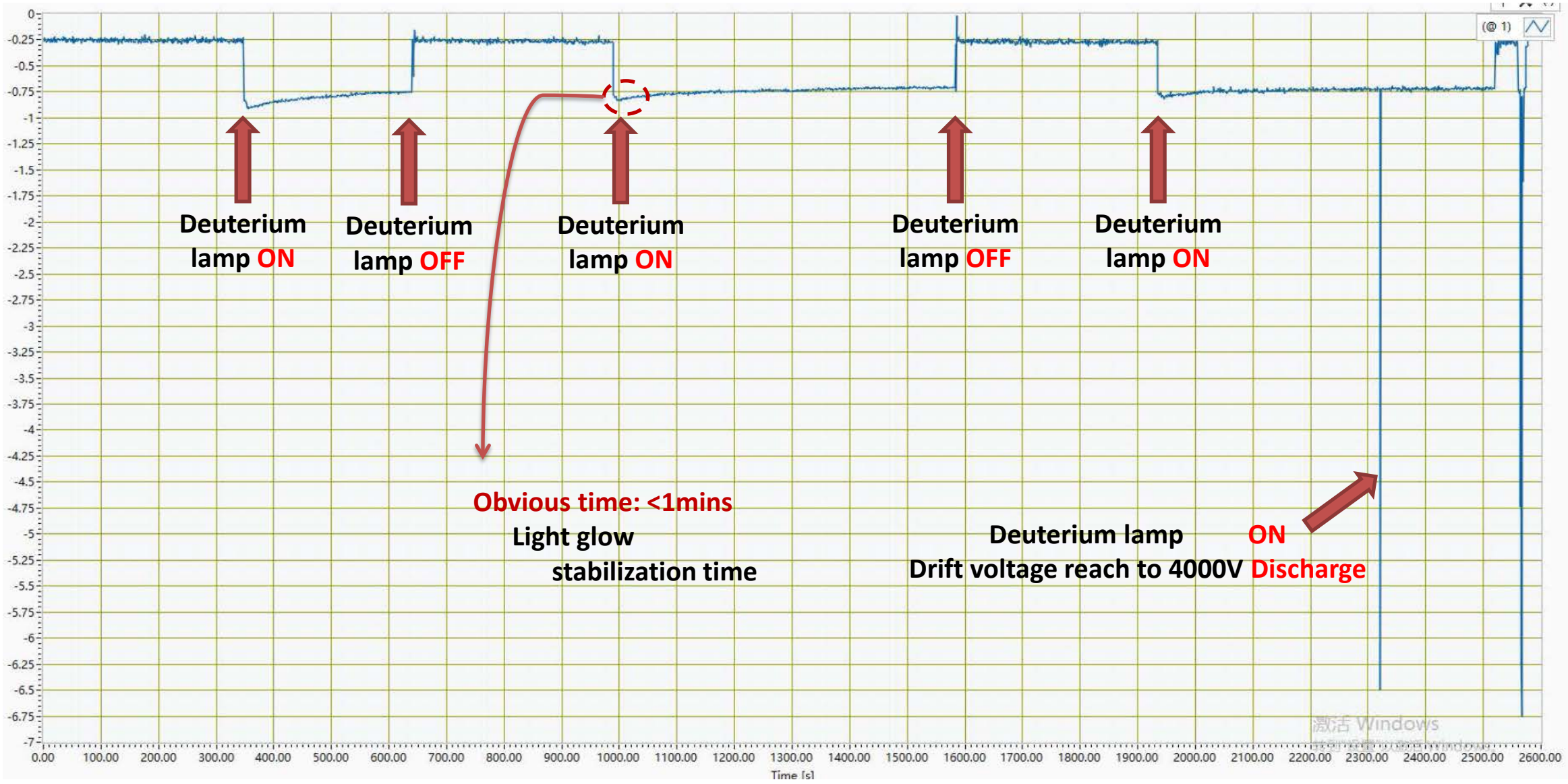
Testing the UV light created the massive electrons by photoelectric effect

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



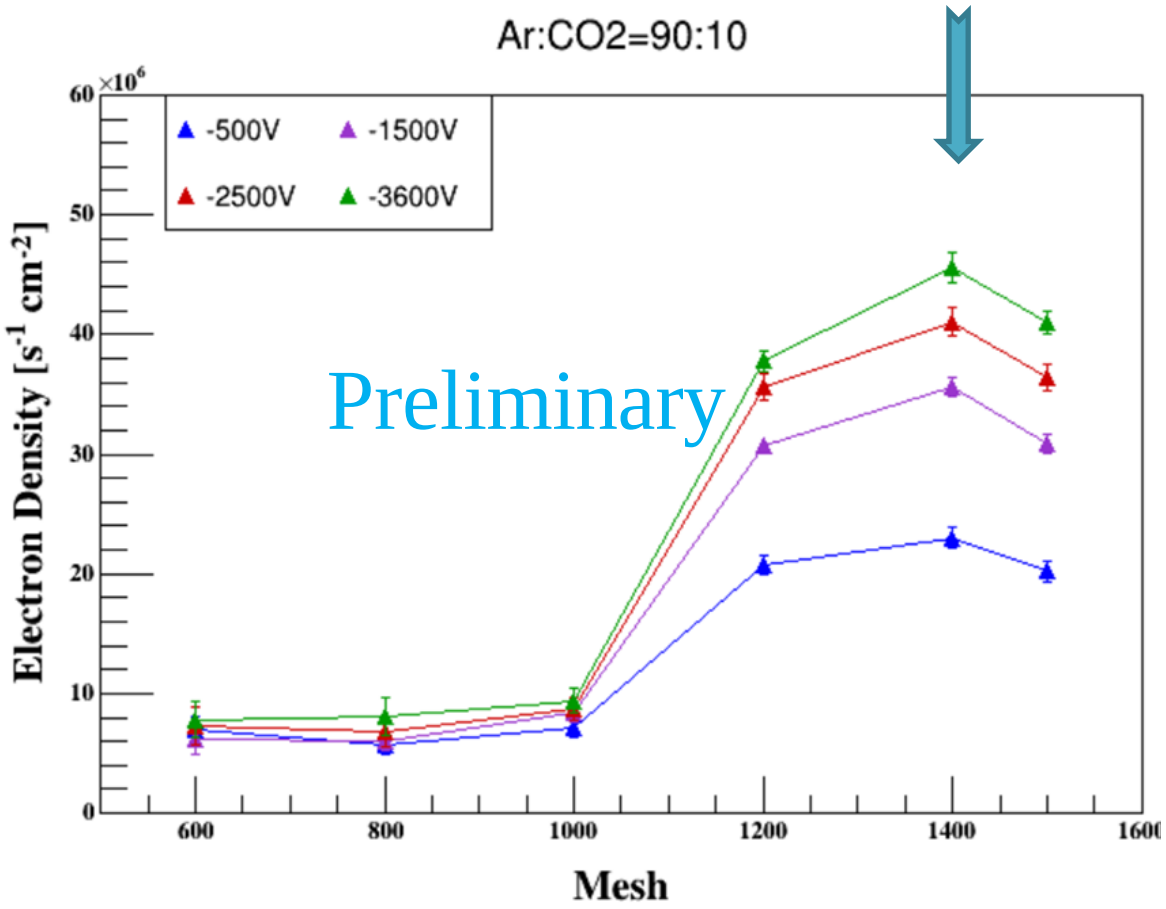
Testing the UV light created the massive electrons by photoelectric effect

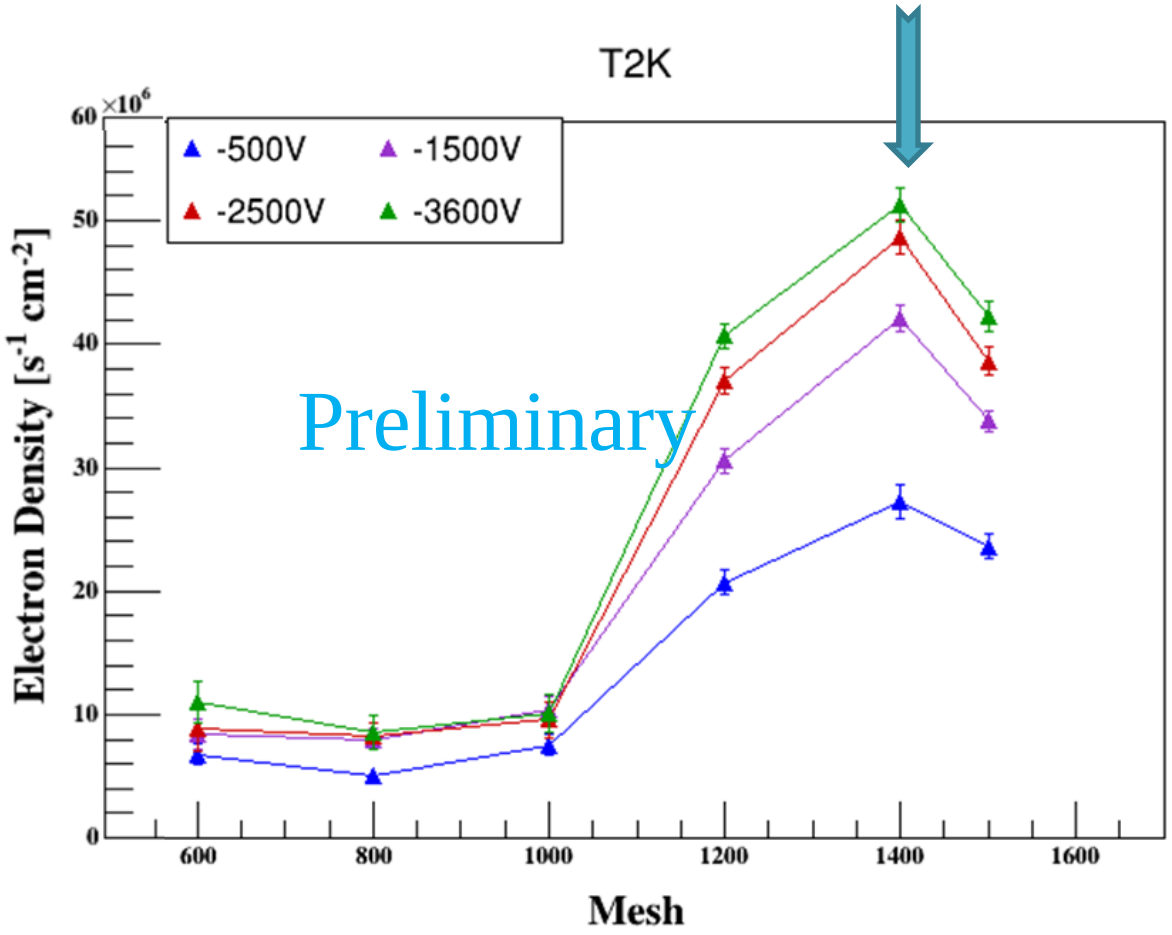
- Preliminary results**: very good stable** current obtained



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 **from 30V/cm to 210V/cm (Electric field of drift)**

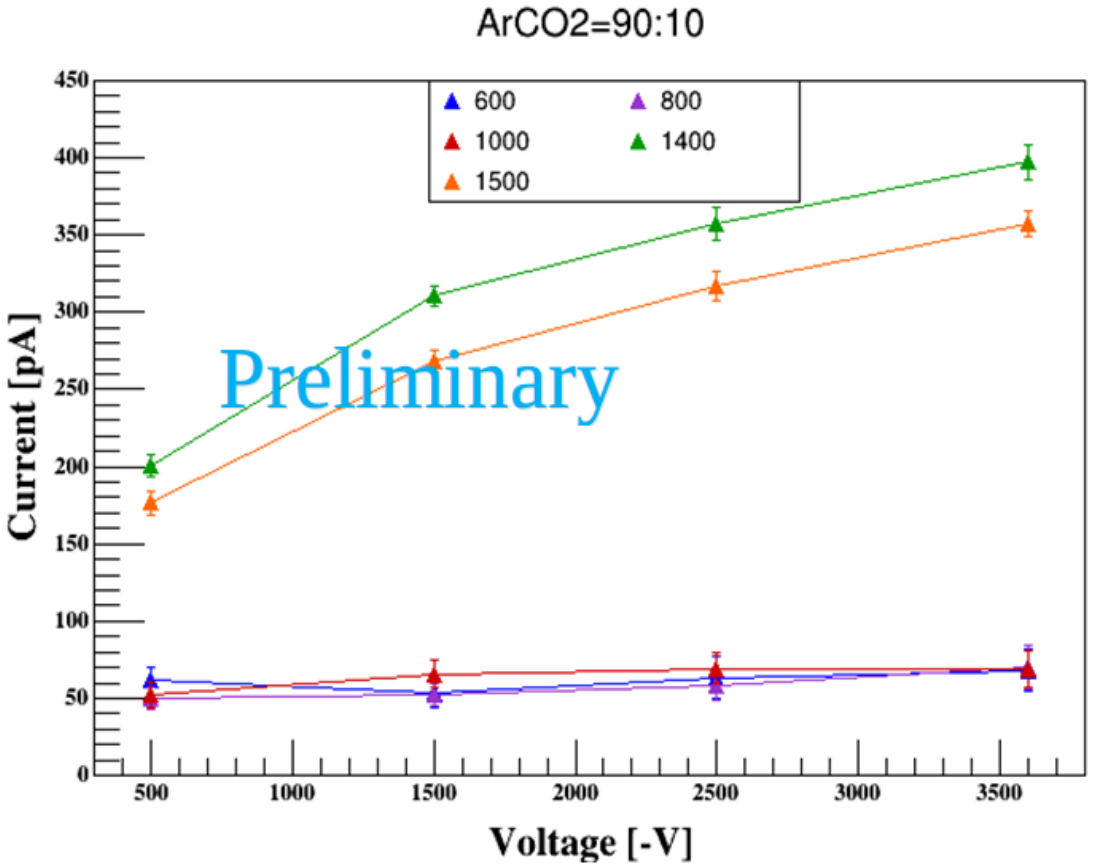


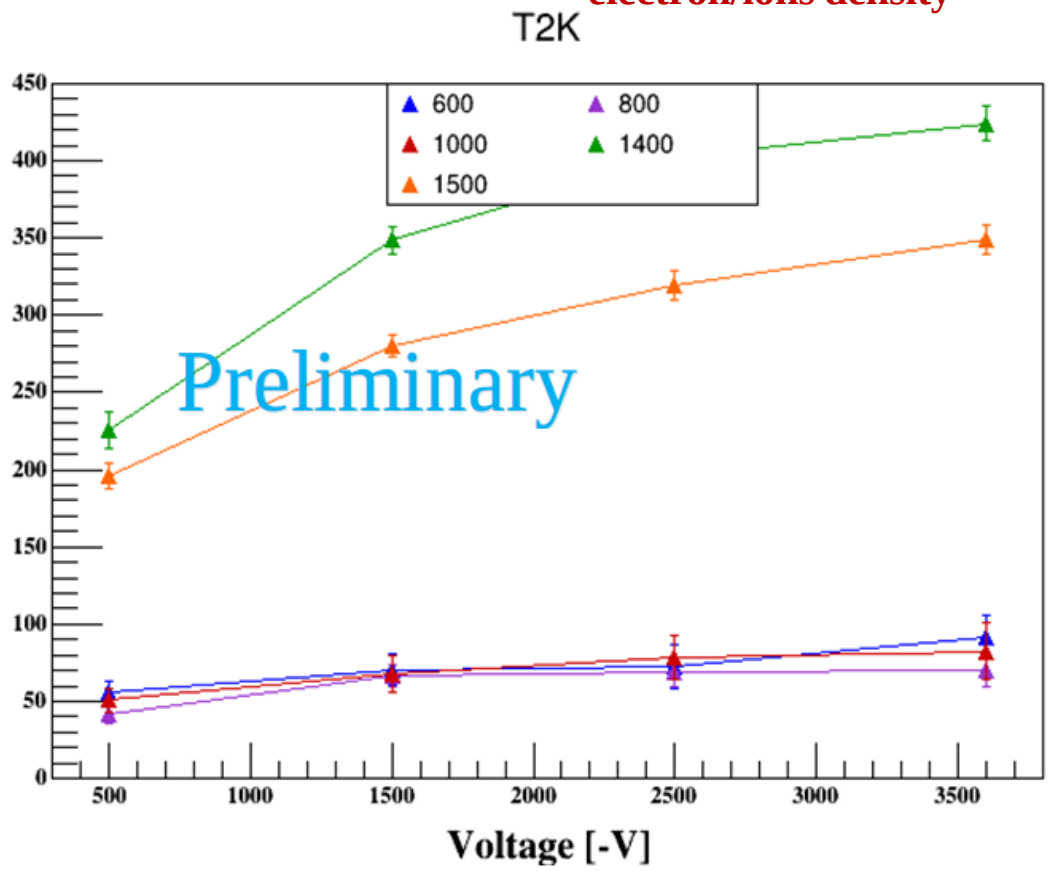


Testing the UV light created the massive electrons by photoelectric effect

- To meet the TPC prototype's drift electric filed (example: ~200V/cm at T2K)
- Scanning the different drift electric field (E_{drift} **from 30V/cm to 210V/cm**)
  - Validation of the same trend with the drift velocity by Garfield++
  - Validation of the two different mixture gases

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

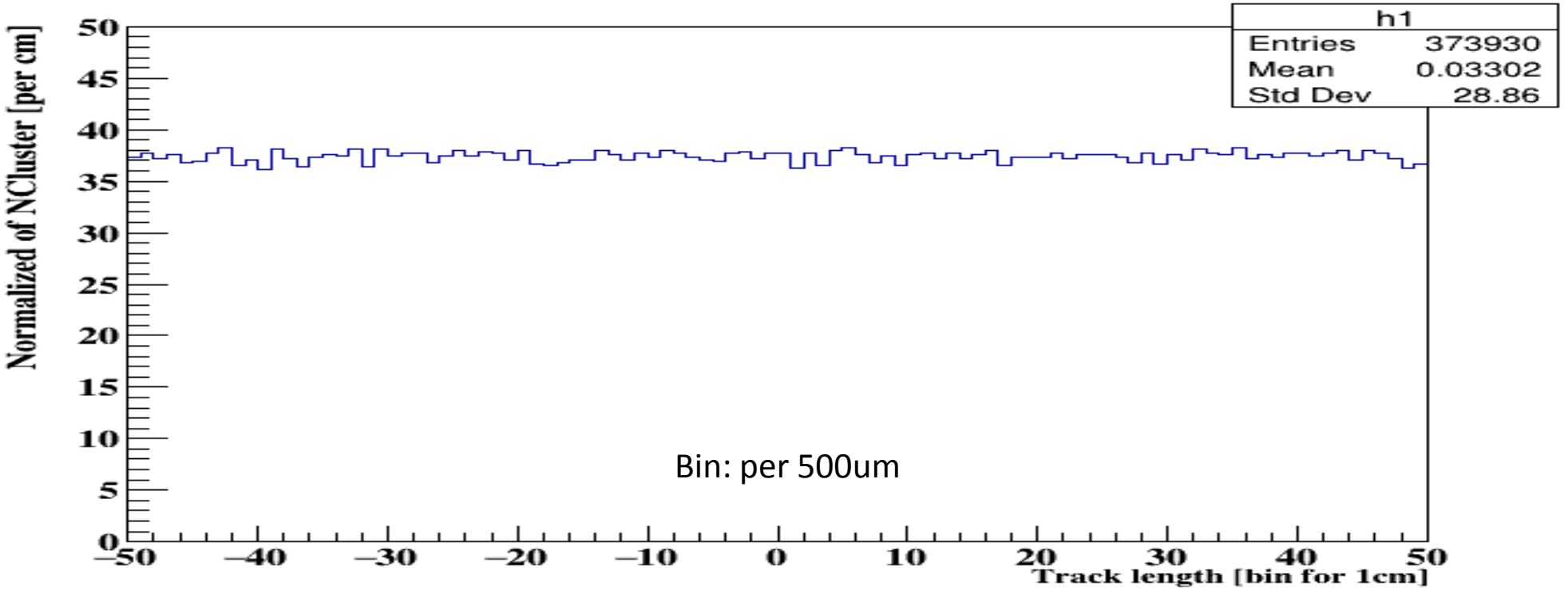




- Simulation of the ionization cluster in space

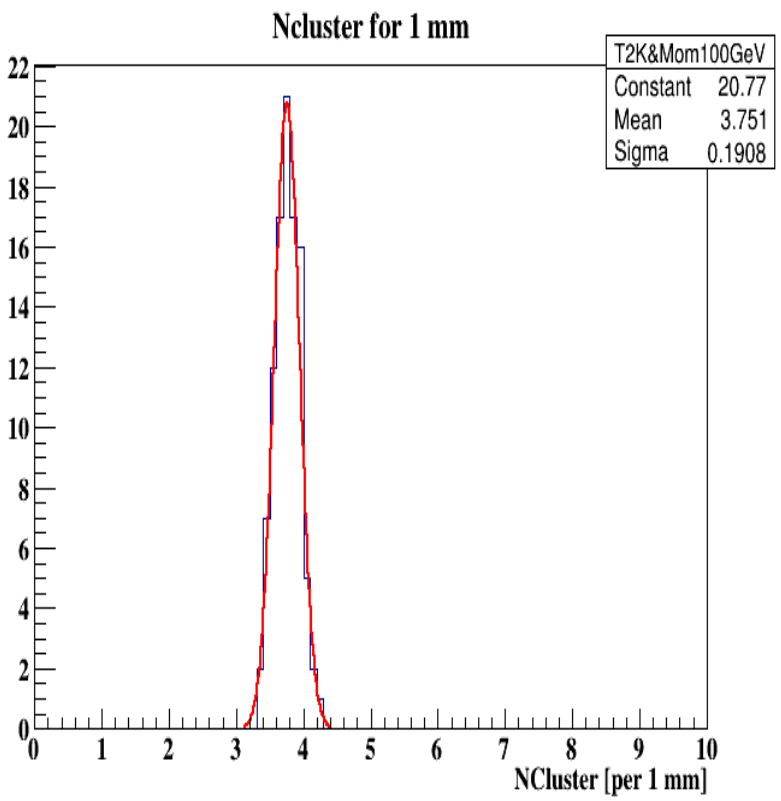
Primary cluster profile along the drift length

- Running 10000 events using Garfiled++
- Drift length: 1m, Incidence angle: 0^{o}
- Operation gas: **T2K gas @1atm**
- Particle: Muon@100GeV/c@1atm
- Simulation result show that the primary cluster profile along the drift length

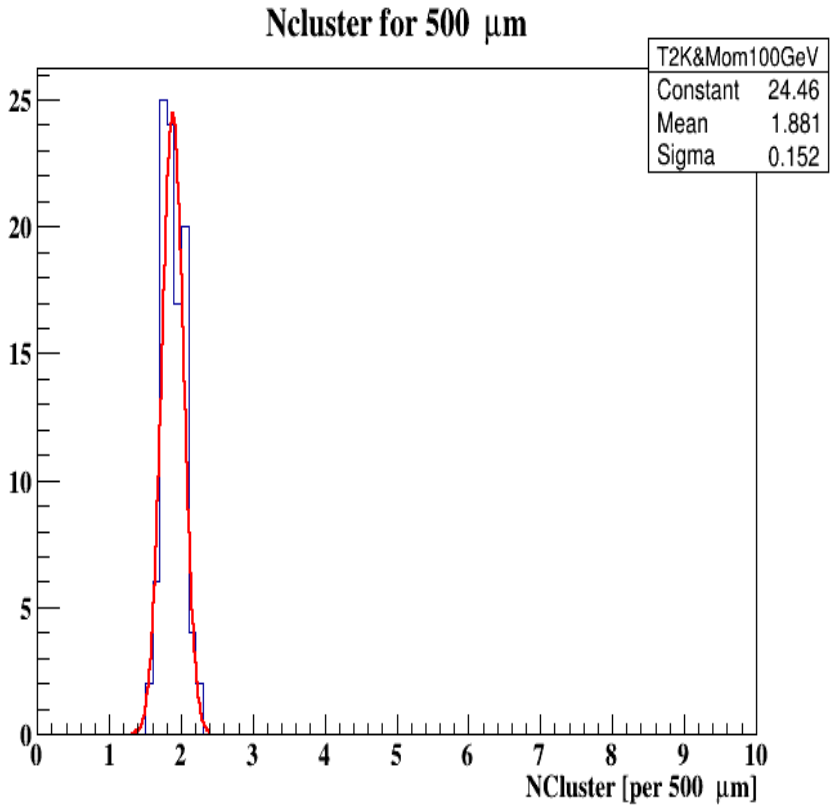


Primary cluster profile using T2K gas

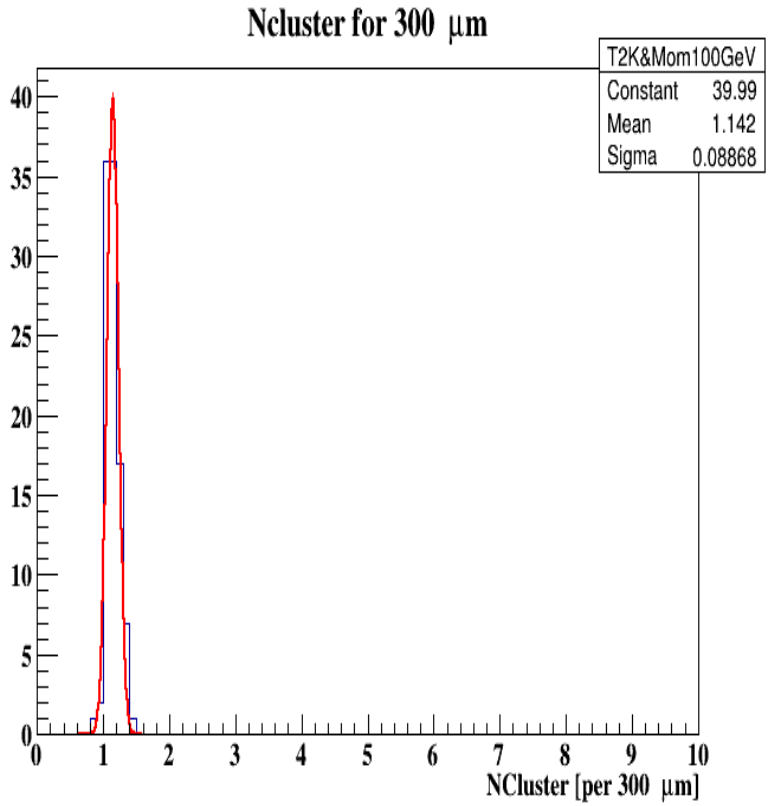
- Simulation result of the primary cluster using T2K gas
- Mean of N_cluster
  - Pressure: 1atmm, B: 0T, $\cos\theta=0^{o}$, μ particle, E=100GeV/c, E_{drift}=200V/cm



Bin: per 1mm



Bin: per 500um

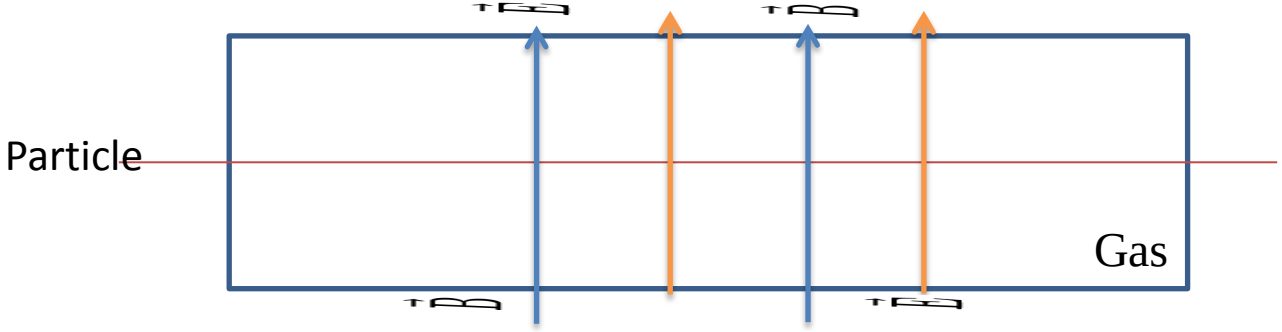


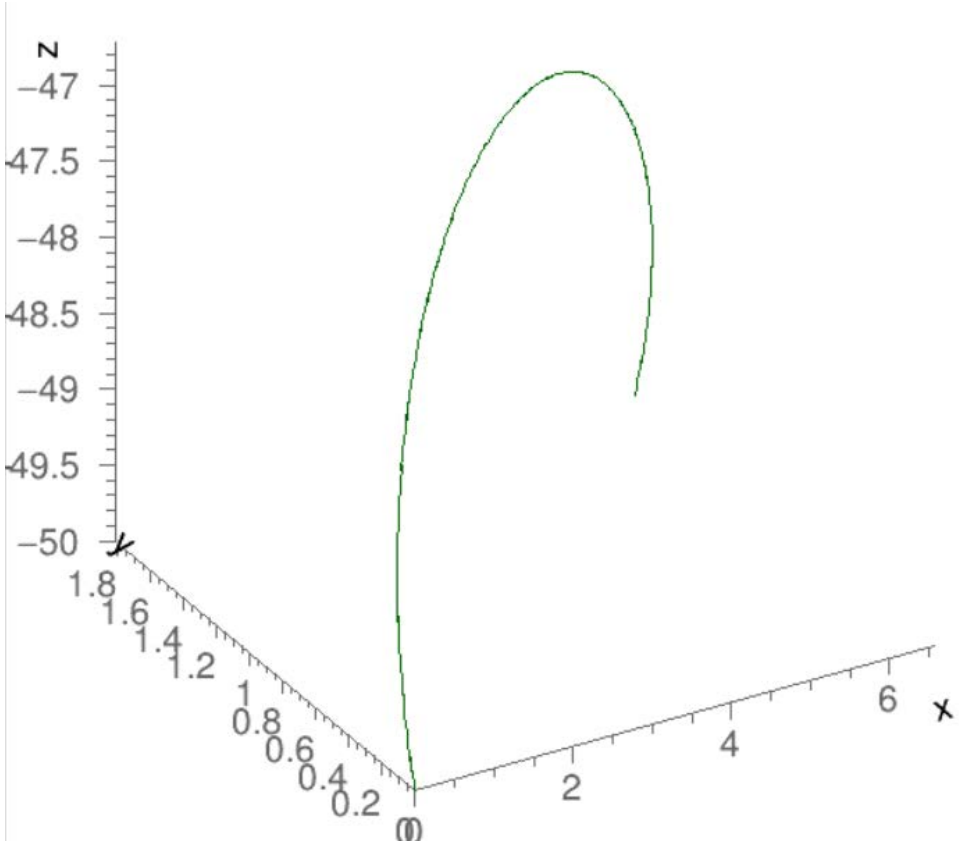
Bin: per 300um

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/2.0T/3.0T
  - Momentum = 0.1 GeV/c
  - Radius of curvature: 3.3cm
  - Validation of the results of the calculation and simulation

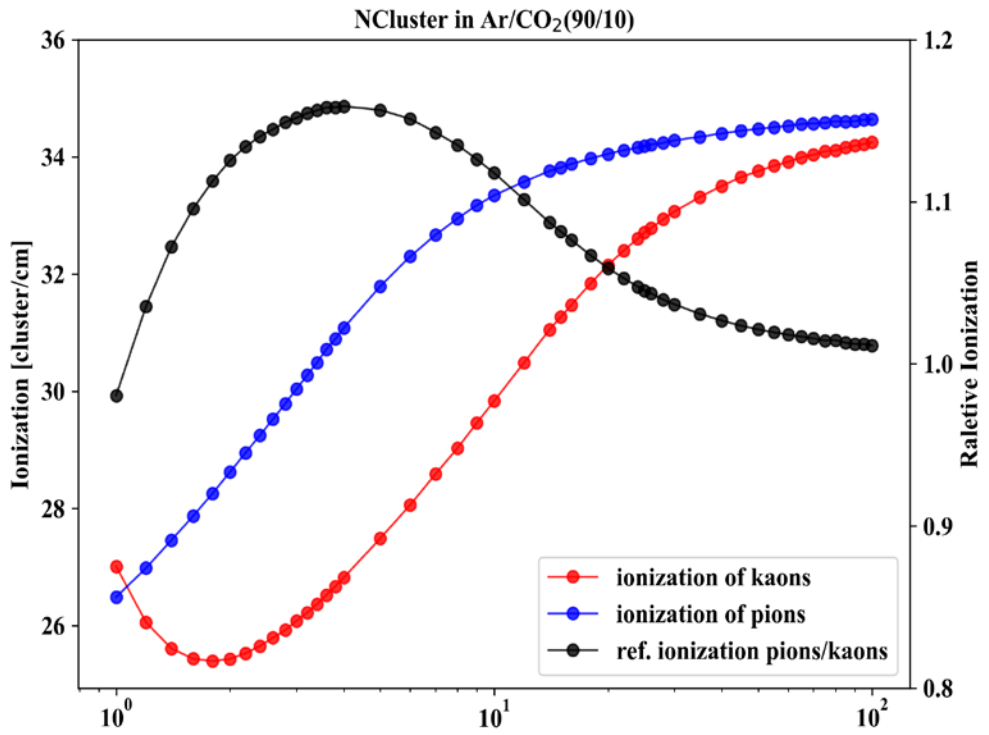
- Simulation ongoing
  - Starting to investigate the primary cluster profile under the different **E and B**



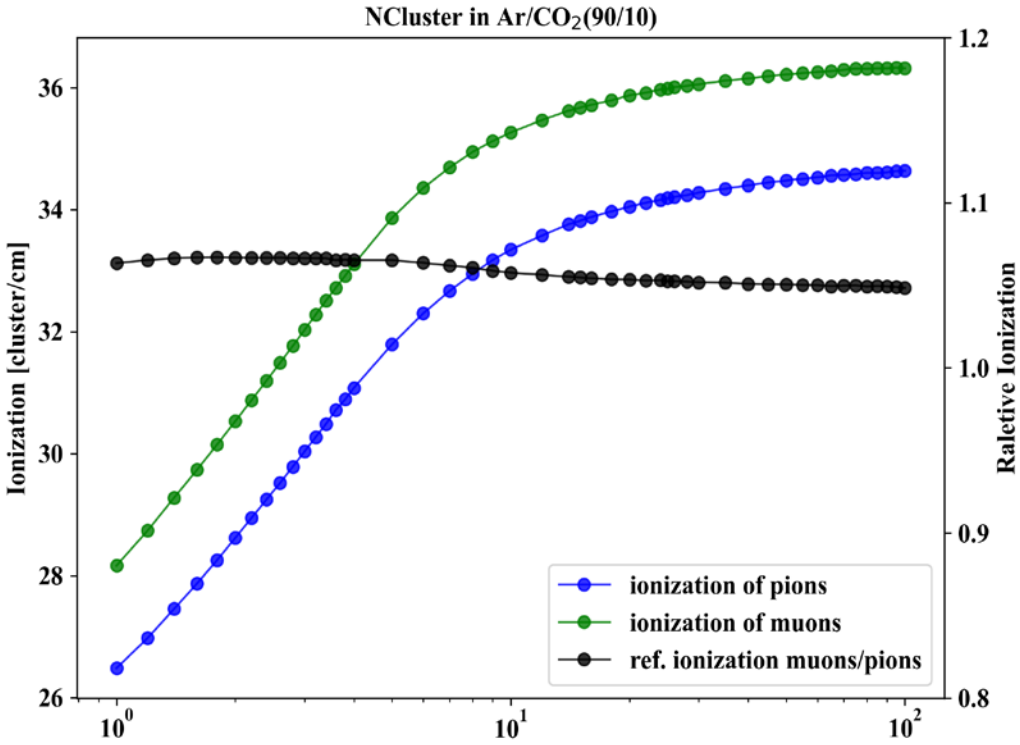


Primary cluster profile using Ar/CO_2=90/10 gas – π/κ/μ

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



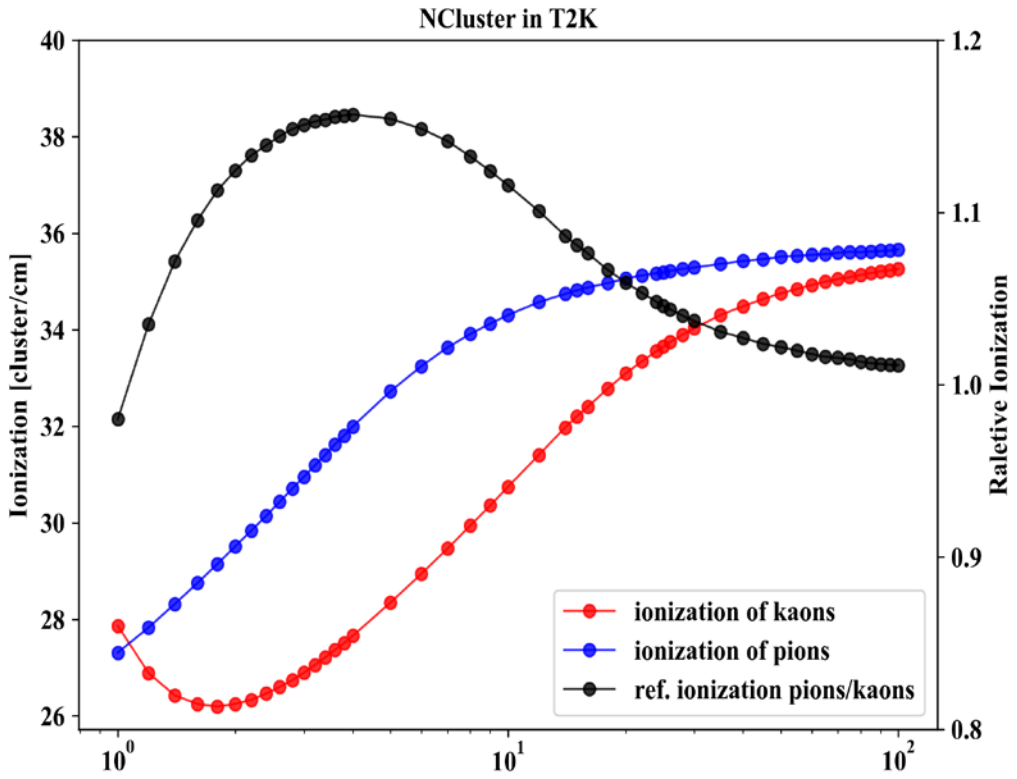
Kion VS Pion



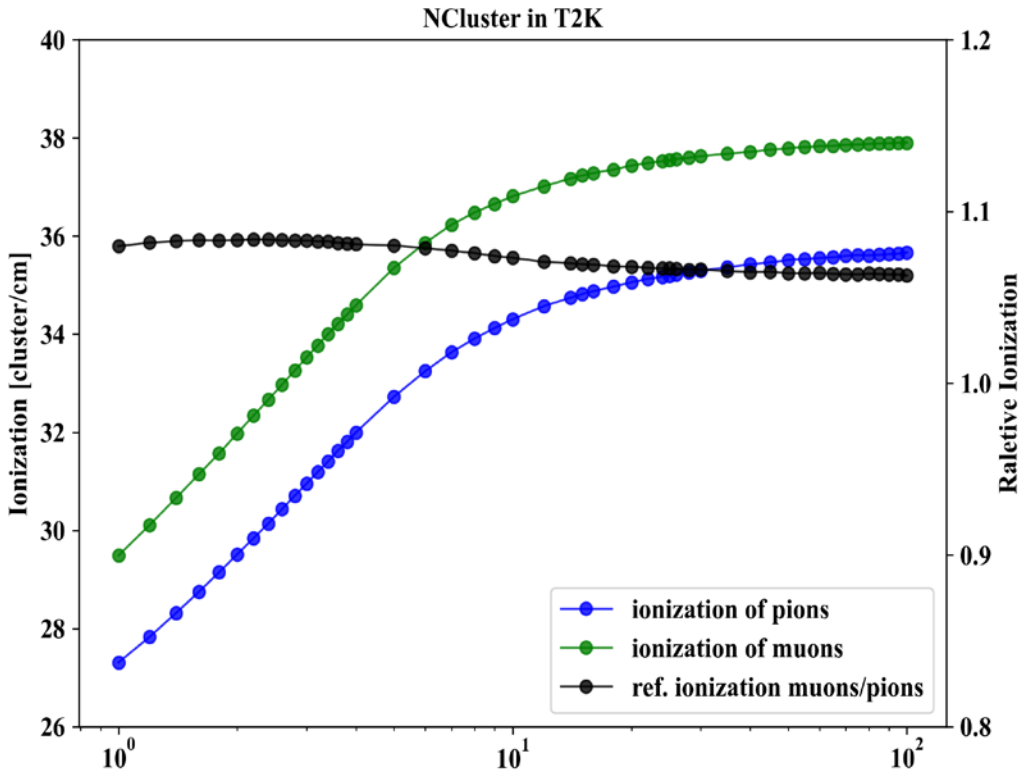
Pion VS Muon

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
- Comparing of $N_{cluster}$(cm) with the different momentum of the specific incident particle



Kion VS Pion



Pion VS Muon

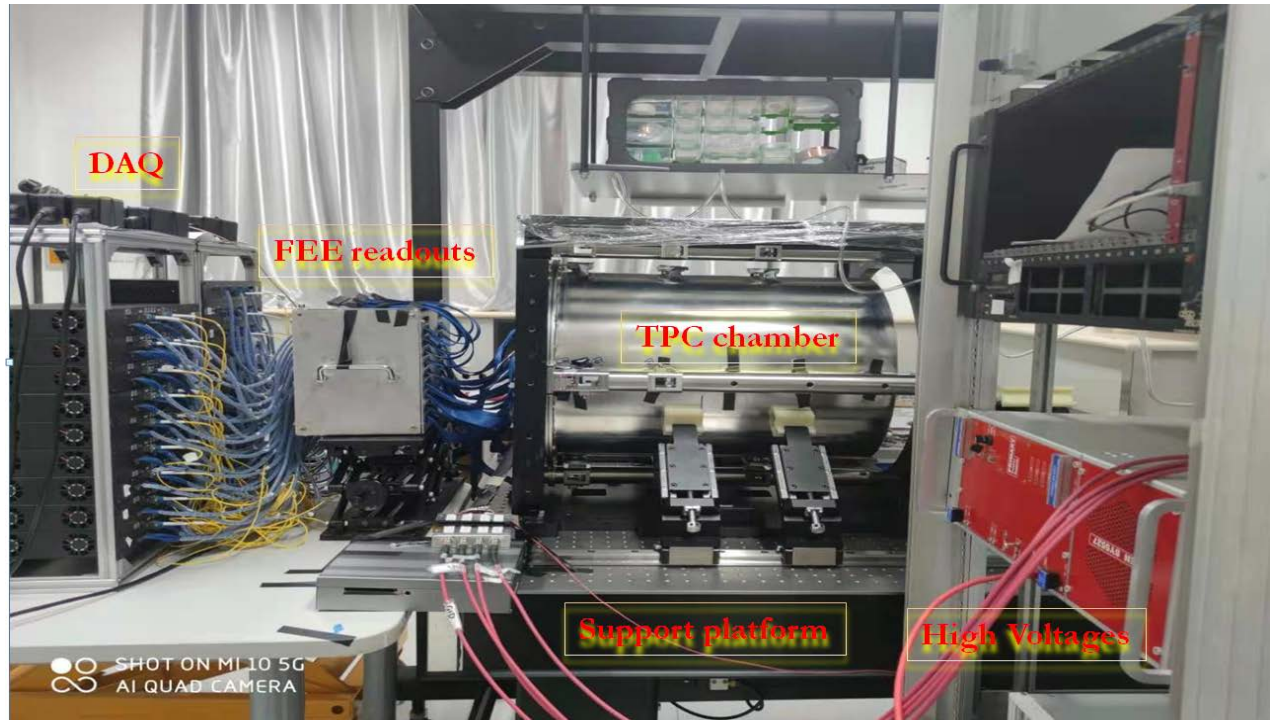
Simulation conclusion and plan

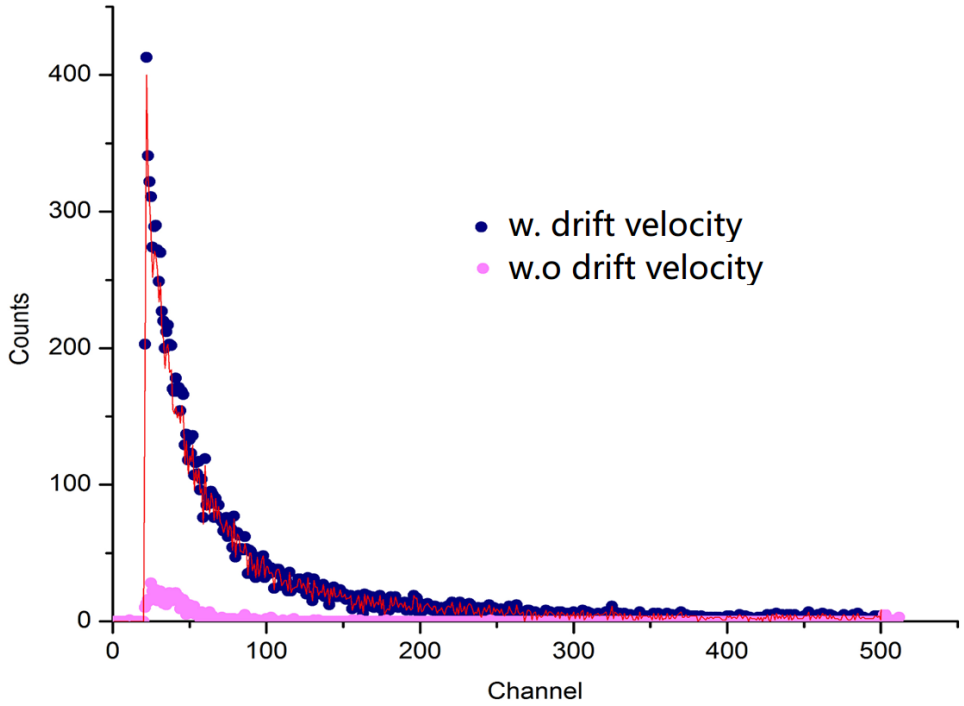
- The codes successfully simulated the primary cluster using the different operation mixture gases, **the different particles** and the different electric/magnetic field.
- Simulation result show that the primary cluster profile along the drift length, and it **could meet** the pixelated readout TPC detector if the pad size will be kept in the rang of 300μm – 500μm.
- 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**.

- Updated progress of TPC prototype
  - UV laser TPC prototype checked
  - Progress of pixelated TPC R&D

UV laser PC detector tested Cosmic ray

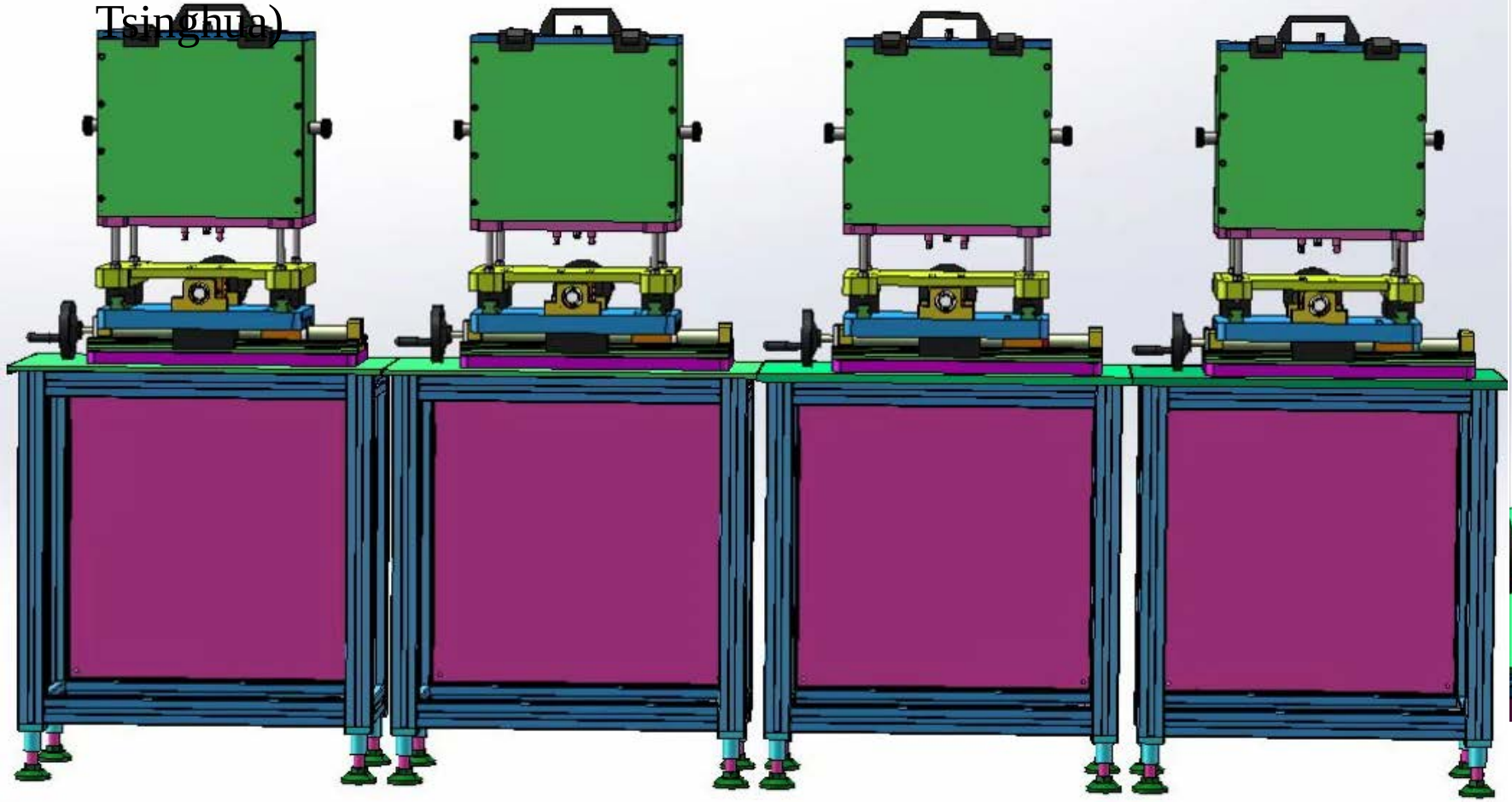
- UV laser TPC detector prototype can study using the cosmic ray.
  - Taken three months data
  - Trigger rate: 0.32Hz in ± 3.6 degree
- **Landau distribution** of the cosmic ray's energy spectrum was successfully obtained
- After 6 months, UV laser TPC detector prototype's gain just shift in ± 5% (**CHECKED**)

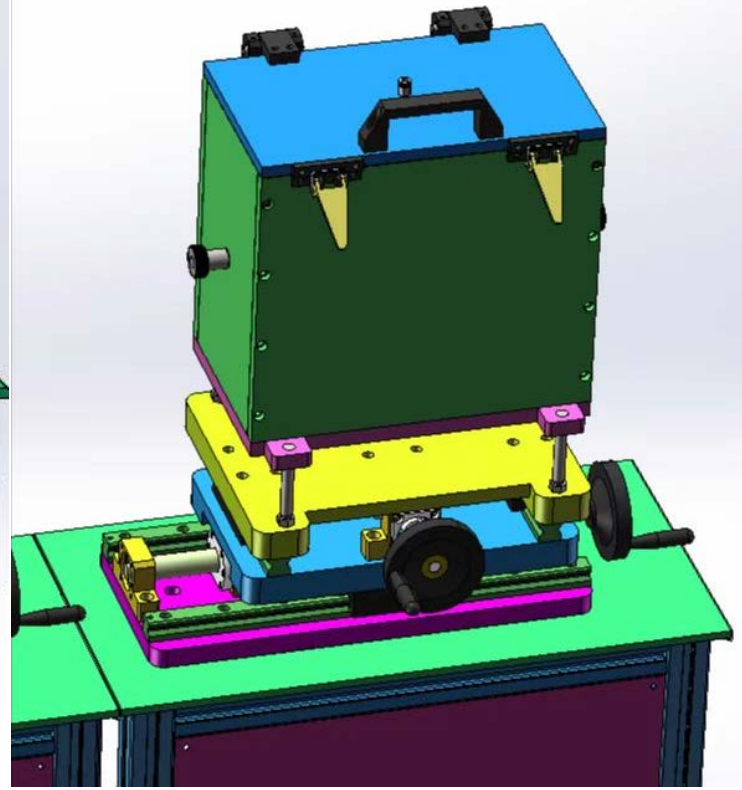




New TPC prototype design and optimization (v0 -> v1)

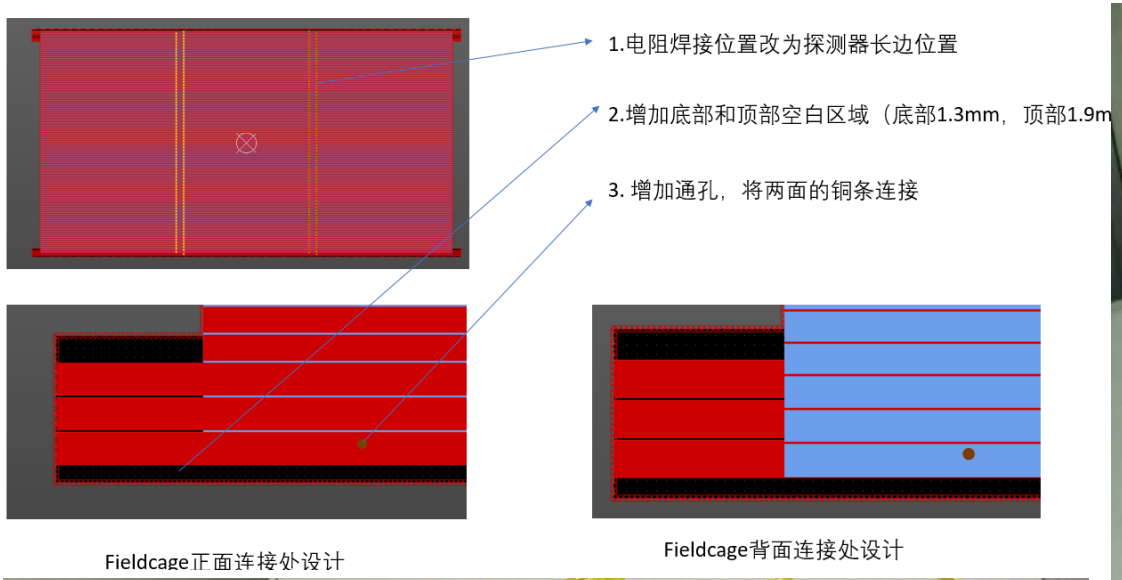
- Study some new parameters complemented previous circular TPC
- Cascaded TPC detectors to test dE/dx and IBF distortion
- Plan： Single TPC detector to test **under 1.0T beam test in DESY in 2023**
- New FEE ASIC chip wafer production **will received in October**.(500um pixelated based, Tsinghua)

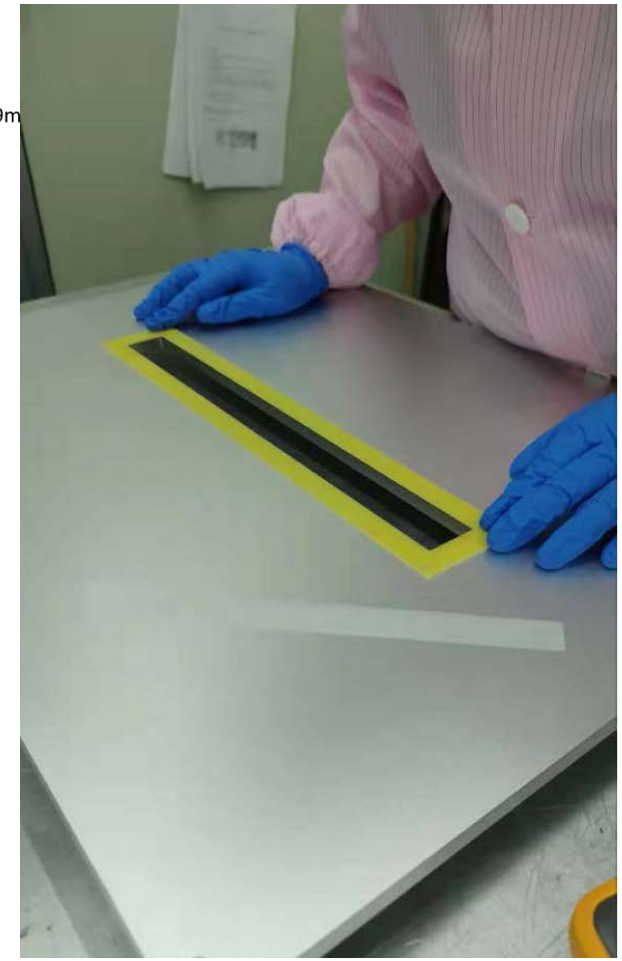


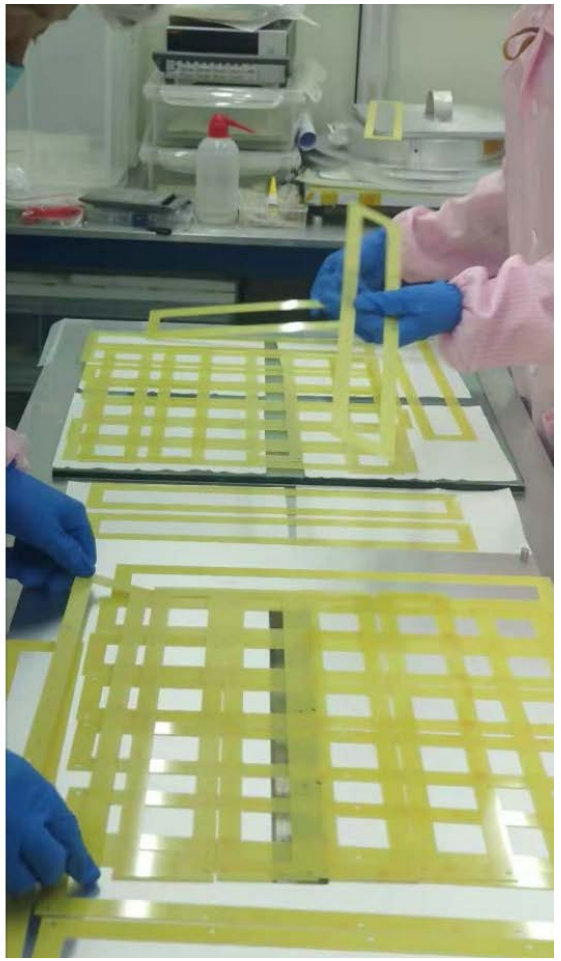


New TPC detector assembling starting in lab

- Some TPC detector design done and assembling starting
  - Field cage PCB design, readout PCB design and detector chamber design: **ALL Finalized in August**
  - Aluminum board, PCB frame and detector: **ALL Ready in September**
  - Detector production with frame: **assembling starting in September**







- Some contribution and information from LCTPC

NIMA paper publication

- Paper of TPC prototype integrated with 266nm UV laser tracks has been published in **NIMA in August**
- 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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journal homepage: www.elsevier.com/locate/nima

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

Z.Y. Yuan [c,b,a], H.R. Qi [a,b,c,*], Y. Chang [d], L.W. Yu [e], Y.M. Cai [g,f], H.Y. Zhang [a,b,c], J. Zhang [a,b,c], Q. Ouyang [a,b,c], Y.L. Li [f], Z. Deng [f], H. Gong [f]

[a] Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049, China
[b] State Key Laboratory of Particle Detection and Electronics, Beijing 100049, China
[c] University of Chinese Academy of Sciences, Beijing 100049, China
[d] Nankai University, Tianjin 300071, China
[e] Liaoning University, Liaoning 110036, China
[f] Department of Engineering Physics, Tsinghua University, Beijing 100084, China
[g] China Nuclear Engineering Consulting Co., Ltd, Beijing 100000, China

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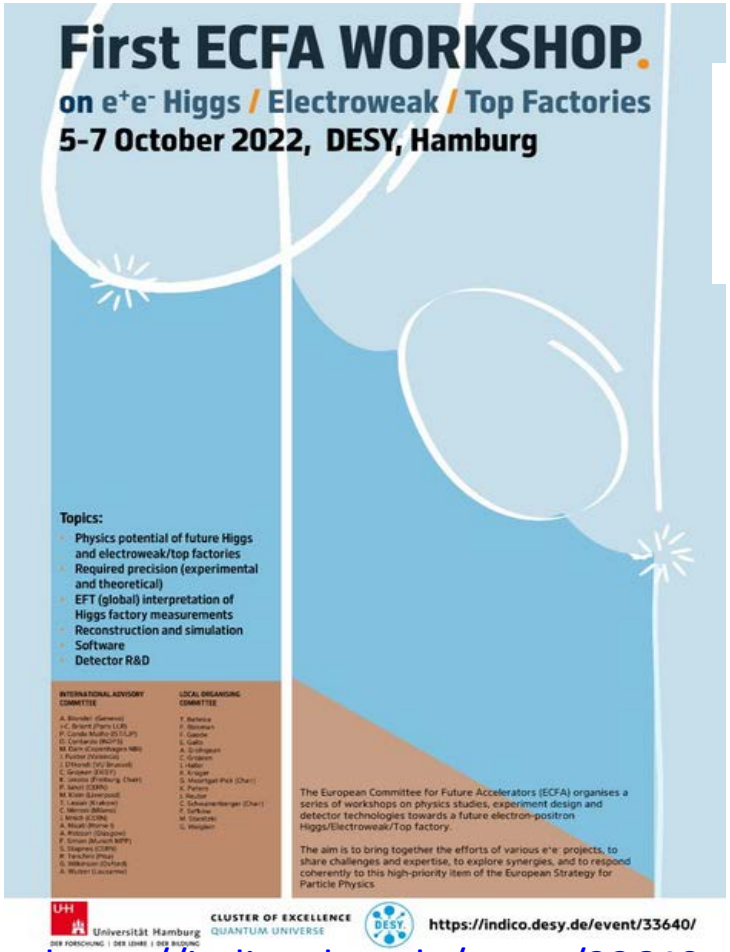
International conference – Oral acceptance

- 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

International conference – three Oral talks

- Three oral talk **in August and September**
  - ICHEP 2022
  - CHEP2022/ eeFACT2022

Status of TPC detector R&D for the circular e+e- collider

Huirong Qi, Yue Chang

Hongliang Dai, Jian Zhang, Zhi Deng, Chunxu Yu, Wei Liu, Hui Gong, Hongyu Zhang, Hongliang Dai, Yulan Li, Manqi Ruan, Gang Li, Linghui Wu, Xin She

Nankai University
Institute of High Energy Physics, CAS
Tsinghua University

ICHEP 2022 XLI, 6-13, July, Bologna, Italy

面向正负电子对撞机物理的时间投影室径迹探测技术（TPC）研究进展

祁辉荣，常悦，喻丽雯，佘信，原之洋，代洪亮，张建，章红宇
邓智，李玉兰，刘伟，阮曼奇，李刚，伍灵慧，陈元柏，喻纯旭

中国科学院高能物理研究所
清华大学 南开大学

中国物理学会高能物理分会第十一届全国会员代表大会，8月8-11，2022

Status of TPC detection technology R&D for the circular e+e- collider

Huirong Qi, Liwen Yu

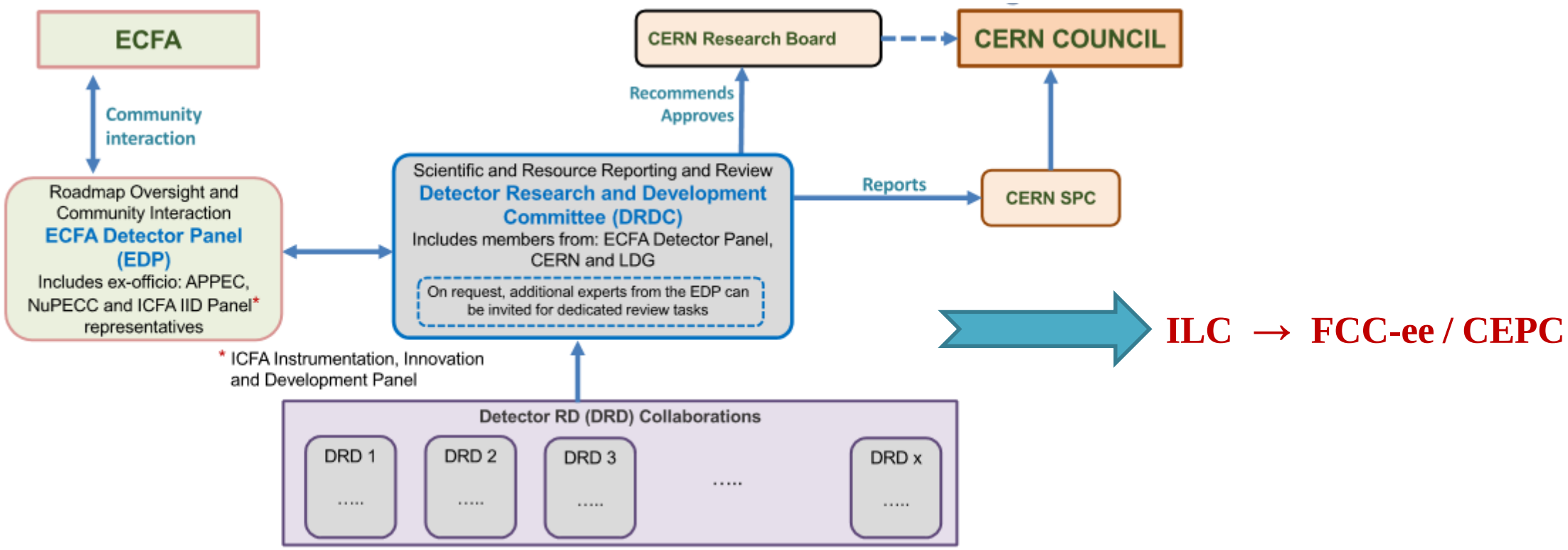
Yue Chang, Xin She, Jian Zhang, Hongliang Dai, Zhi Deng, Wei Liu, Yulan Li
Manqi Ruan, Gang Li, Linghui Wu and some inputs from LCTPC collaboration

Institute of High Energy Physics, CAS
Tsinghua University, Liaoning University

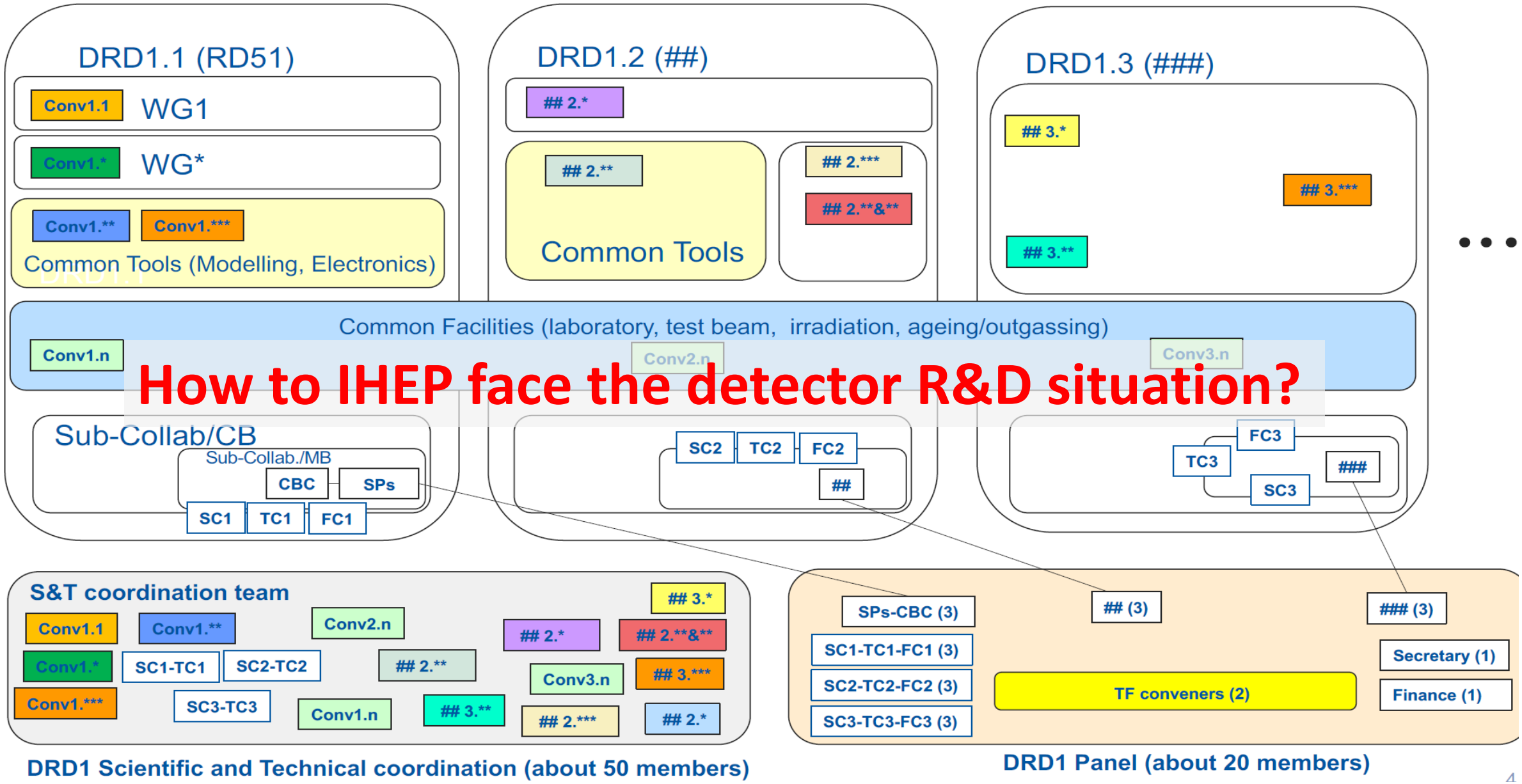
eeFACT2022, 12-16, September, Frascati, Italy

Some international collaboration information

- ECFA detector R&D roadmap & impact on the RD51 Collaboration, even ILD, LCTPC….
- ECFA Detector R&D panel is **forcing the formation of the new detector R&D collaborations**
  - DRDC1 to DRDC6
  - DRDs able to benefit from CERN recognition in dealings with Funding Agencies and corporations
  - **New DRD activities from Autumn of this year**
  - For example: RD51 should **run out at the end of 2023**



A potential “implementation” based on substructures



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!