# A novel method to study the primary track using TPC prototype with integrated UV laser


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## Introduction

In recent years, with the discovery of the Higgs boson at the Large Hadron Collider(LHC), the concept design of colliders have been continuously proposed in the international and domestic high-energy physics community,such as CEPC. As the main track detector, TPC( Time Projection Chamber) technology is an important experimental tracking device to need R&D. It can easily to meet the high spatial resolution at the Higgs running, and there are a massive electrons and ions in chamber when Z pole run.

In order to realize the 3D track reconstruction of charged particles, we use the 2-photon ionization effect of the UV laser in the gas to simulate the track of charged particles, and perform more optimized TPC performance testing and calibration. The track produced by laser ionization has the characteristics of minor ionization density fluctuations, good repeatability, good collimation, strong stability, and better spatial resolution in long-track and double-track measurements. It is easy to be controlled by a specially designed optical path.

## TPC prototype design

Innovatively, UV laser is used for the specific track reconstruction, performance measurement, and operating condition monitoring.Laser TPC prototype has been successfully developed in last 6 years at IHEP,CAS. In this poster, some performance and test results of the TPC prototype integrated with UV laser tracks were presented including $^{55}Fe$ 5.9keV X-ray spectrum, cosmic ray spectrum, the spatial resolution and dE/dx resolution.

**Basic principle:2-photon ionisation**

UV laser is used to produce ionization track in the impurity gas but unable to ionize the working gas. Because photon energy of standard UV laser is lower than typical chamber gases ionization energy. But some low percentage substances with ionization potential lower than 9.4eV/7.4eV make the 2-photon ionization possible.

**IBF experiment studies:**

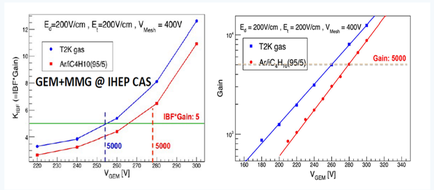


Figure 1: The IBF×Gain as a function of $V_{GEM}$(Left), and the Gain as a function of $V_{GEM}$(Right)

Studies have been done using the different active area of the hybrid TPC detector modules,A readout scheme of GEM+Micromegas can successfully suppress the positive ion feedback problem continuously( see in Figure 1). The experimental results show that the IBF ratio of GEM-MM can be reduced to 0.1% (Gain=5000), which promises a lower ion backflow at CEPC TPC group without gating.

**Prototype experiment studies:**

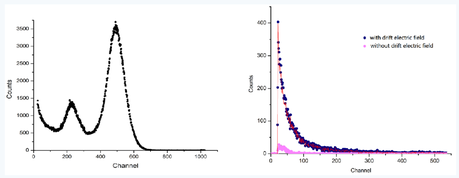


Figure 2: $^{55}Fe$ X-ray spectrum profile(Left) and cosmic ray spectrum(Right)

Using $^{55}Fe$ radiation source and cosmic ray to study the TPC detector prototype,T2K as the working gas, $^{55}Fe$ X-ray spectrum profile is very good and the Landau distribution of the cosmic ray's energy was successfully obtained( see in Figure 2).

## TPC prototype system

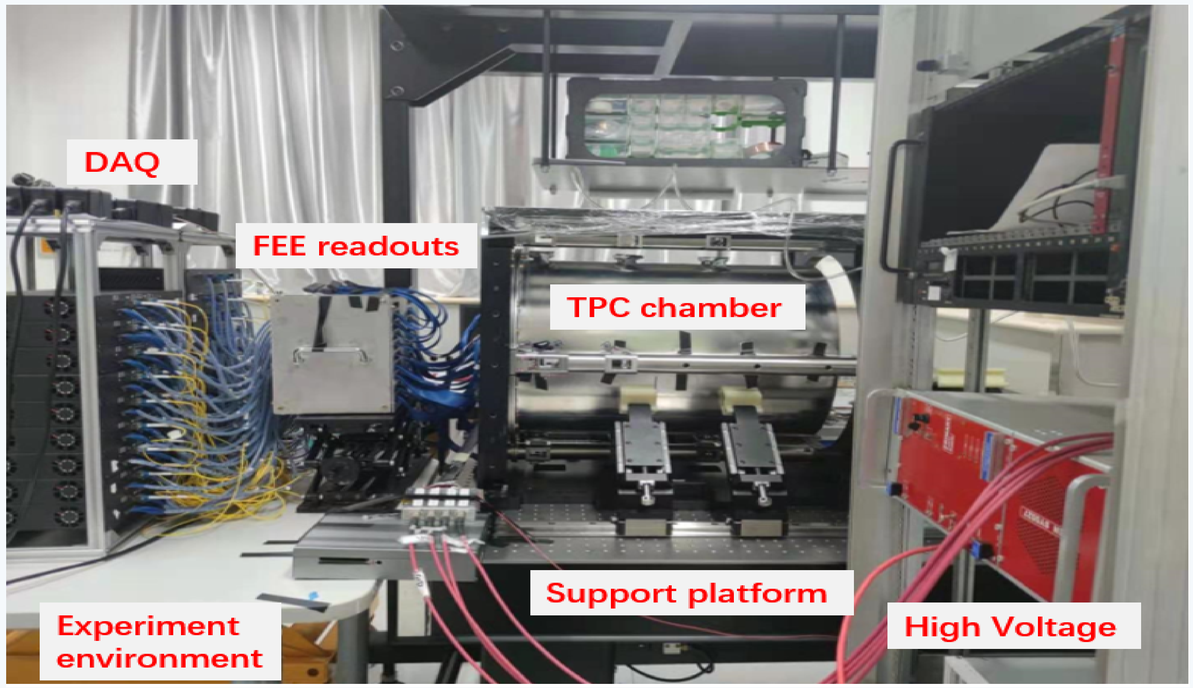


Figure 3: TPC prototype with integrated 266nm UV laser

The joint commission of the electronics and laser system of the prototype has been completed, and the laser signal has been successfully measured.
The performance of the detector is evaluated using filtered events with clean tracks. After optimizing and analyzing the laser track events, and finally determine the reconstructed track. Tracks are fitted using singular value decomposition(SVD). The spatial resolution and dE/dx resolution of the TPC prototype are determined by analyzing the reconstructed, clean laser track events.

## TPC performance: Spatial resolution

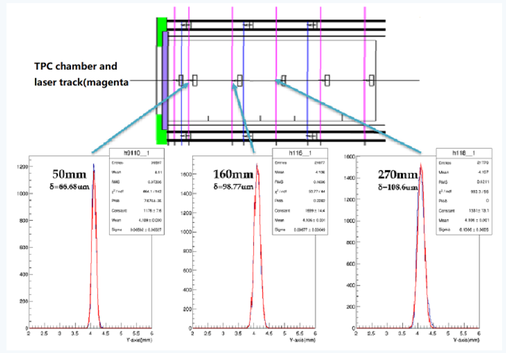


Figure 4: Spatial resolution at different drift length

As show in Figure 4, spatial resolution at drift length $z$=50mm,160mm and 270mm respectively are given. Spatial resolution can be less than 100 $\mu m$ along the drift length of TPC prototype.

For different drift length(Number of laser layers), the measured spatial resolution is fitted with formula to obtain the transverse diffusion coefficient $D_T$, The measured transverse diffusion coefficient $D_T$ is (310.7±7.6)$\mu s/\sqrt{cm}$ matches the expected value 312.7$\mu s/\sqrt{cm}$ from the simulation of Garfield++.

## TPC performance: dE/dx resolution

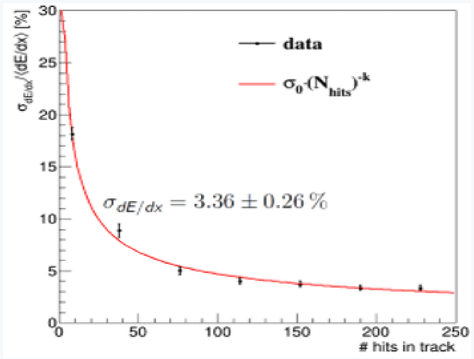


Figure 5: The dE/dx resolution versus the number of hits in a pseudo-track of various length

In TPC detector, the energy loss is one of the means of particle identification. The dE/dx resolution was required to be better than 5% in the CEPC CDR. It is determined to be (8.9±0.4)% for events with 38 hits in a track. In order to estimate the performance of a full-scale 220-rings CEPC TPC, extrapolation of the prototype measurements is required. Hits from multiple tracks in consecutive events are combined to form pseudo-tracks of arbitrary length, the result is shown in 5. This leads to an estimate for the resolution at 220 hits of $\sigma_{dE/dx} = 3.36 \pm 0.26\%$.

## Highlight of updated R&D

**Publications:**


[1]. Int J Mod Phys A, 2022 ,doi: 10.1142/S0217751X22460095
[2]. NIM-A, 2022, doi: 10.1016/j.nima.2022.167241
[3]. Int J Mod Phys A, 2021, doi: 10.1142/S0217751X2142015X
[4]. JINST, 2020, doi: 10.1088/1748-0221/15/09/C09065
[5]. JINST, 2020, doi: 10.1088/1748-0221/15/02/T02001
[6]. Int J Mod Phys A, 2020, doi: 10.1142/S0217751X20410146
[7]. JINST, 2020, doi: 10.1088/1748-0221/15/05/P05005
[8]. Int J Mod Phys A, 2019, doi: 10.1142/S0217751X19400165
[9]. ACTA PHYS SIN-CH ED, 2019, doi: 10.7498/aps.68.20181613


**PhD Thesis:**


[1]. Z.Y.Yuan, 2022, The analysis of particle identification capability for the time projection chamber and the experimental study of detector prototype
[2]. W.Liu, 2022, Development of A Low Power and High Integration Front-end Readout Electronics for TPC
[3]. Y.M.Cai, 2021, Investigation of UV laser application in Time Projection Chamber detecrtor
[4]. H.Y.Wang, 2019, Study of TPC with laser calibration system for future circular collider
[5]. Y.L.Zhang, 2017, Study on Continuous Ion Backflow Suppression Detector Module for Circular Collider


## Summary and Future plan

**Summary:**

A system including a TPC prototype with laser system, readout electronics with double GEM and the DAQ, was set up and tested. All results indicated that the TPC detector prototype can work well. This prototype can be used in the future lepton collider and will be a helpful device in the experiments. Spatial resolution and dE/dx resolution can meet the physics requirement of CEPC. It can operate at CEPC W/Higgs operation, with 3T B-filed or higher.

**Future:**

Further studies on the high precision resolution requirements are needed in the future electron–positron colliders, especially CEPC project. Higher luminosity operation($2 \times 10^{36} cm^2 s^{-1}$) at Z with 2T B-Field is a challenge for gaseous. Pixelated readout TPC is promising.

- Compared to Pad readout,the material budget, construction cost, power & cooling, Occupancy of pixelated readout is OK.
- A new type method for PID combining cluster counting(dN/dx) and charge summation(dE/dx) can achieve resolution performance better than 3%.

## References


[1]. https://doi.org/10.1051/epjconf/20147000062
[2]. https://doi.org/10.1016/j.nima.2009.12.011
[3]. https://doi.org/10.48550/arXiv.1811.10545
[4]. https://doi.org/10.1103/PhysRevD.90.075004
[5]. https://doi.org/10.48550/arXiv.1306.6329



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