中国科学院高能物理研究所
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INFN Istituto Nazionale di Fisica Nucleare

# Study of Primary Ionization Counting Method in Drift Chamber

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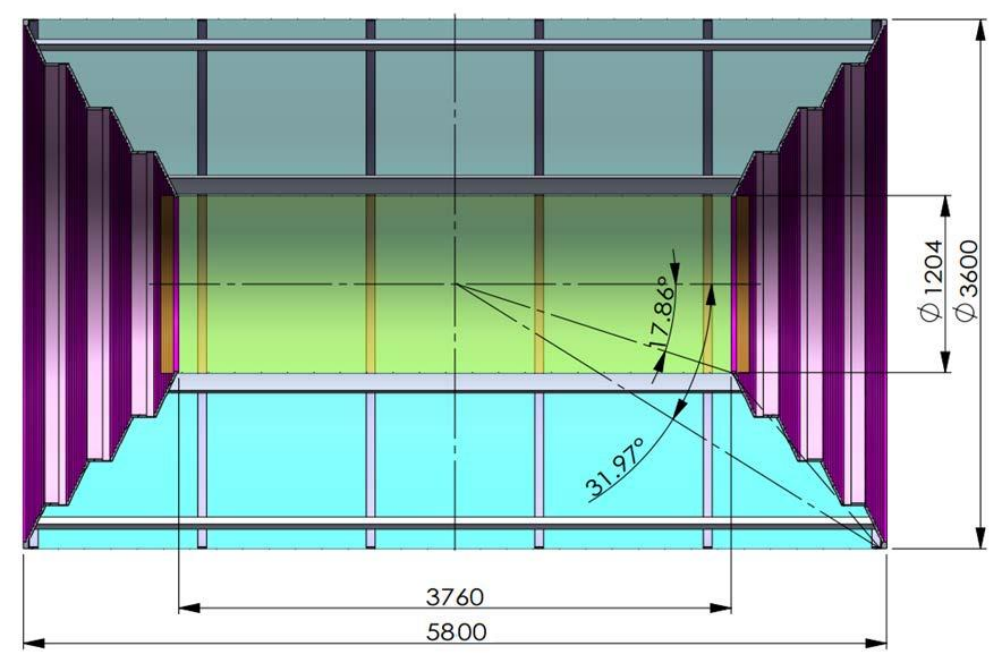
The 2025 International Workshop on the High Energy Circular Electron Positron Collider, Nov 6-10, Guangzhou

# Outline

1 Introduction of DC for CEPC
2 dN/dx Method in DC
3 Prototype System Design
4 Preliminary Tests
5 Summary and Future Plans

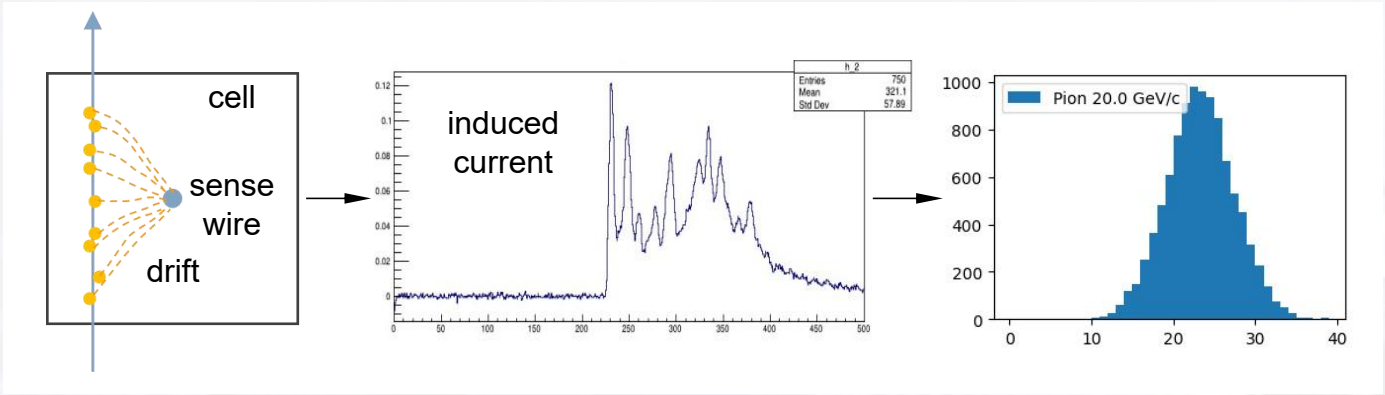
# CEPC drift chamber




- R extension: 600-1800 mm
- Length: 5800 mm
- Cell size: ~ 18 mm × 18 mm
- 64 wire layers and 26483 cells
- Ratio of field wires to sense wires: 3:1
- Gas mixture: $He/iC_4H_{10}$ = 90:10
- CF Frame structure: 8 longitudinal hollow beams + 8 annular hollow beams

- **Flavor physics and jet research at CEPC impose increasingly demanding requirements on Particle Identification (3 σ K/π separation power at 20 GeV/c)**
- **As an alternative gaseous detector，one of the critical optimization objectives for the drift chamber is PID**

# Primary Ionization Counting Method

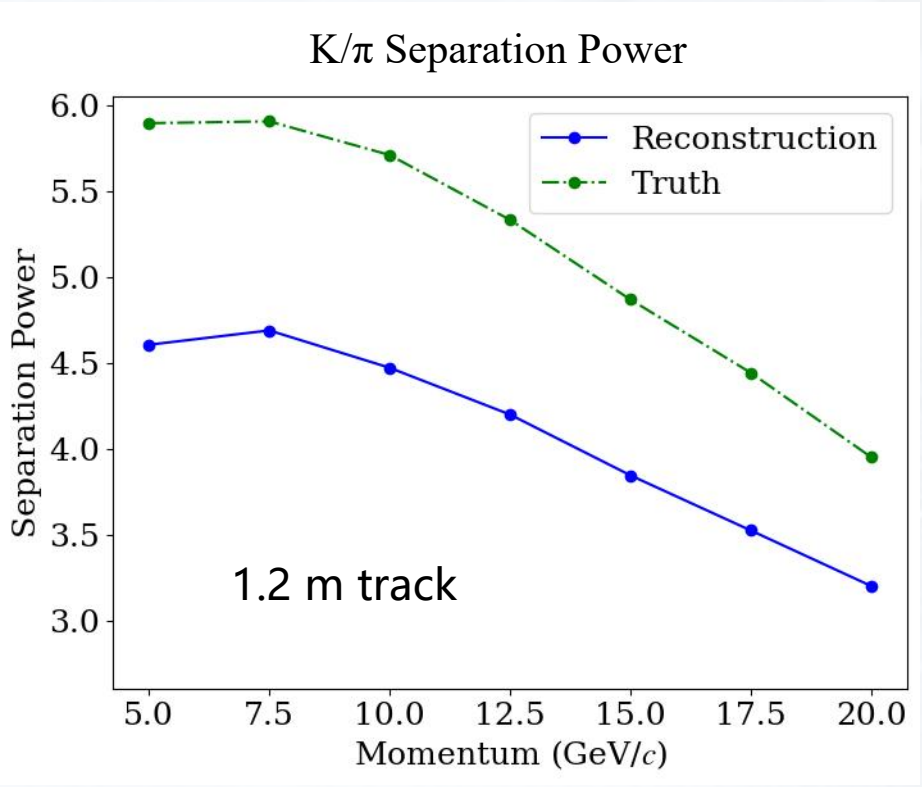



## dE/dx

- Landau distribution
- Truncated mean leads to loss of statistical data
- Particle identification is limited

## dN/dx

- Poisson distribution
- Smaller fluctuation
- In theory, resolution of dN/dx can be approximately twice that of dE/dx




**□ Simulations indicate that for 1.2 meter track, the dN/dx resolution is less than 3%, and the K/π separation power can reach 3.2 σ at 20 GeV/c**

# Key technology for DC with dN/dx measurement

## ➢ Challenges for waveform measurement

- Sufficient time interval between different ionization signals
- Reduce interference between different ionization clusters

→ ✓ Detector optimization includes cell size and gas

- Fast signal shaping speed and SNR

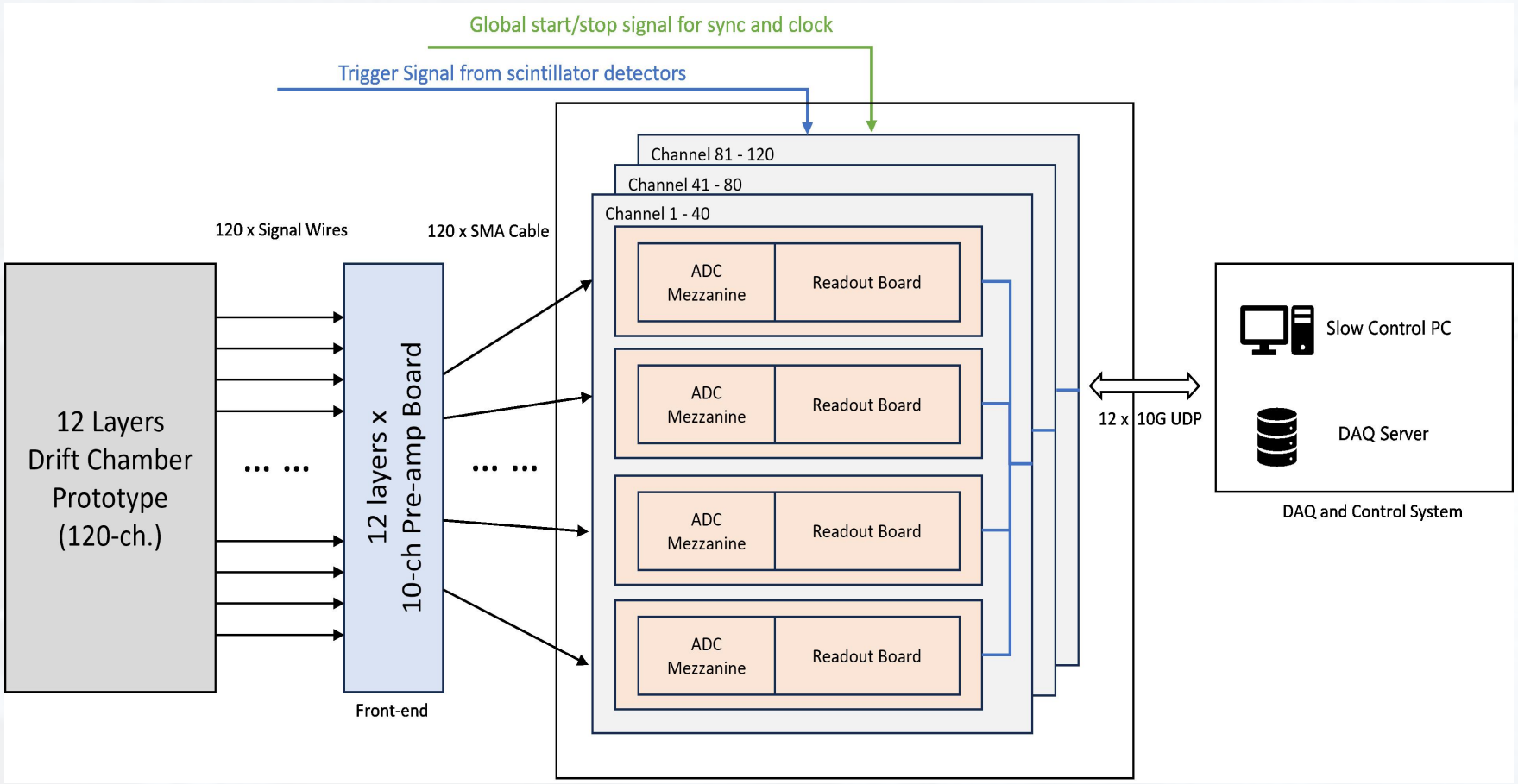
→ ✓ Fast and low noise electronics

## ➢ Challenges for reconstruction algorithm

- Process piled-up signals
- Identification of primary and secondary ionization signals
- Reduce noise impacts

→ ✓ Deep learning algorithm

# Motivations of the prototype system

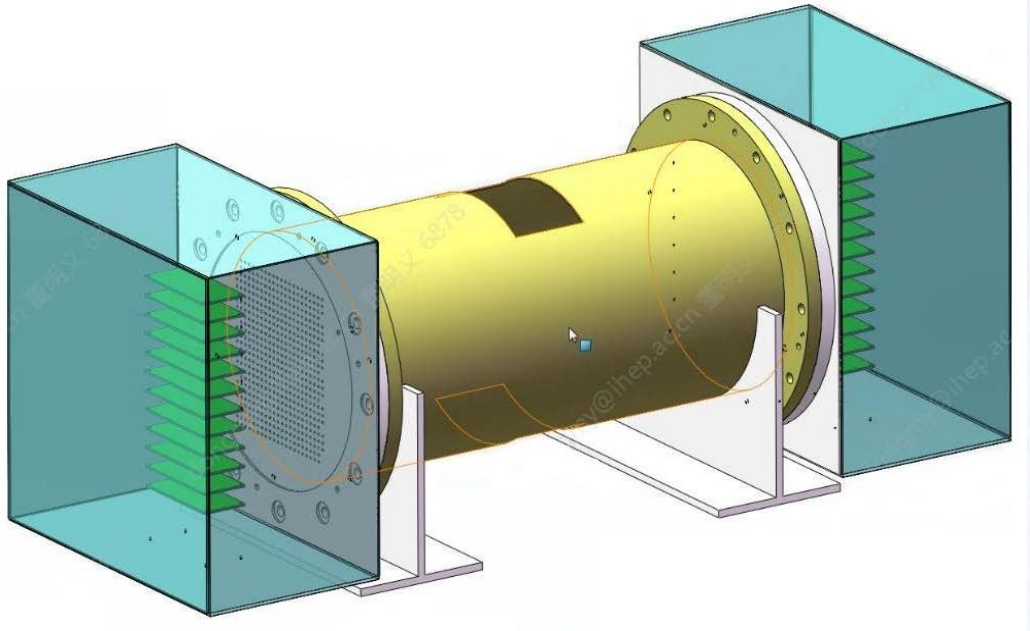


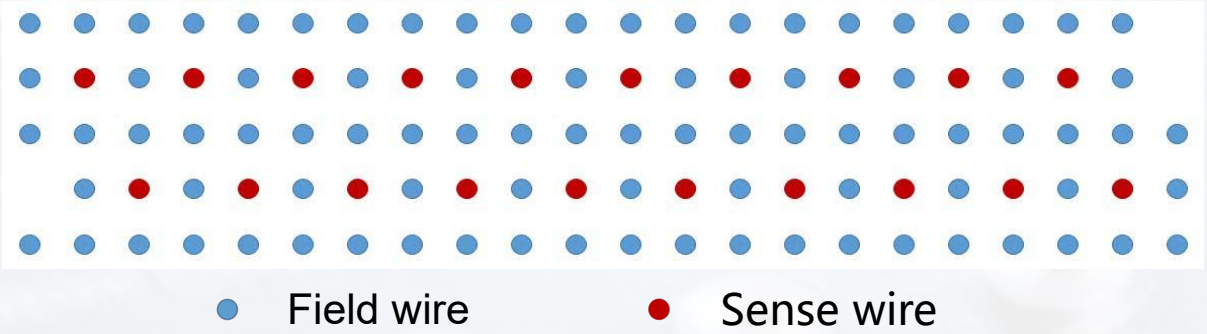

Block diagram of the prototype system

- Verify the detector simulation results
- Validate the performance of the self-developed electronics
- Test the reconstruction algorithm
- Deliver the results for the drift chamber dN/dx method

# Multi-layer DC protopyte

- A prototype was designed for dN/dx resolution study
- Details of the prototype:
  - 12 layers, 10 cells/layer, 120 cells
  - Cell size: 18 mm × 18 mm
  - Sense wire: 20 μm Au-plated tungsten
  - Field wire: 70 μm Aluminum
  - Length: 60 cm

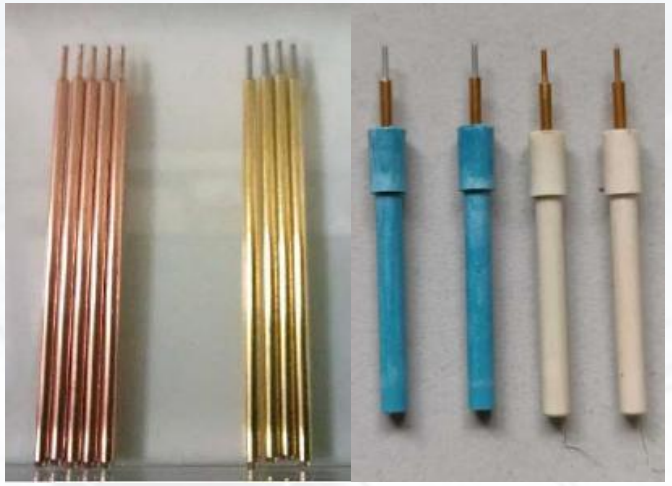




# Multi-layer DC protopyte

- Wiring, tension test, leakage current test and HV training
  - 120 sense wires tension: 11 g
  - 416 field wires tension: 19 g
  - Sag: 25 μm
  - Leakage current: < 1 nA

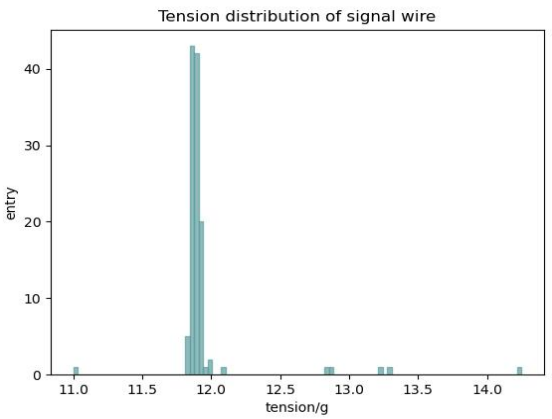
Wires



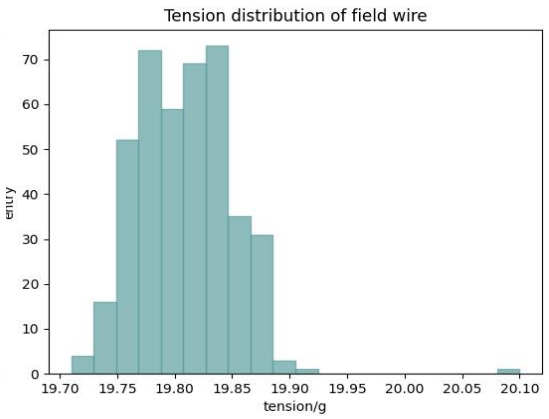
Feedthroughs

Wiring

HV training



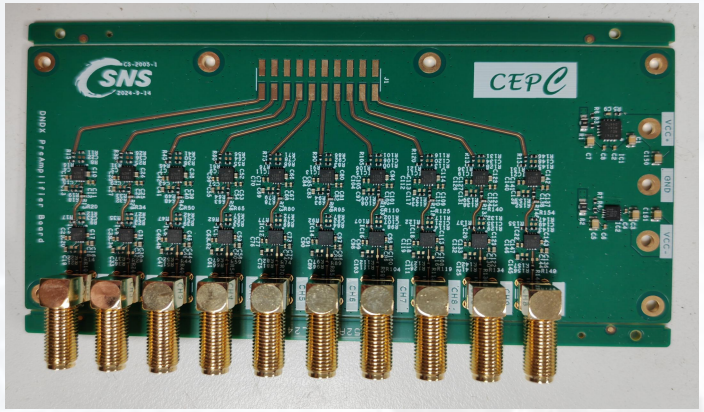

Tension distribution of SW



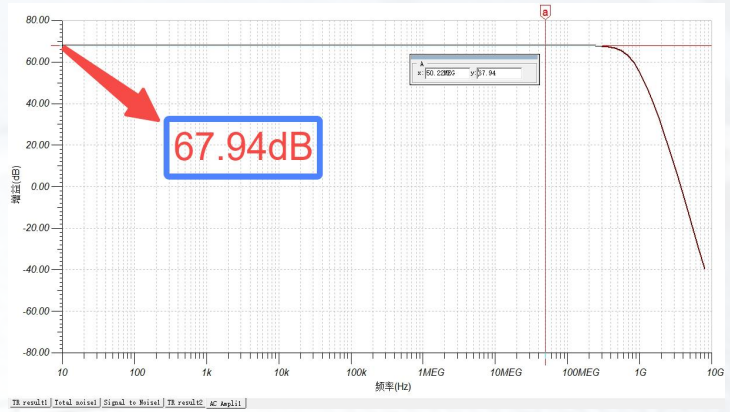

Tension distribution of FW

# Fast front-end current preamplifier

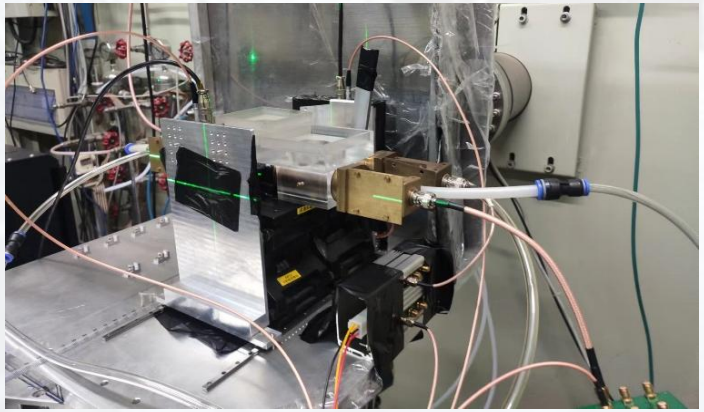
- Fast front-end current preamplifier circuit based on two-stage non-inverting LHM6629 amplifier configuration
- High gain, high bandwidth and low noise
  - Current gain: 67.94 dB
  - Bandwidth: 587.74MHz @-3dB
  - Baseline noise: 1.53 mVrms
- Beam test has been conducted for functional verification



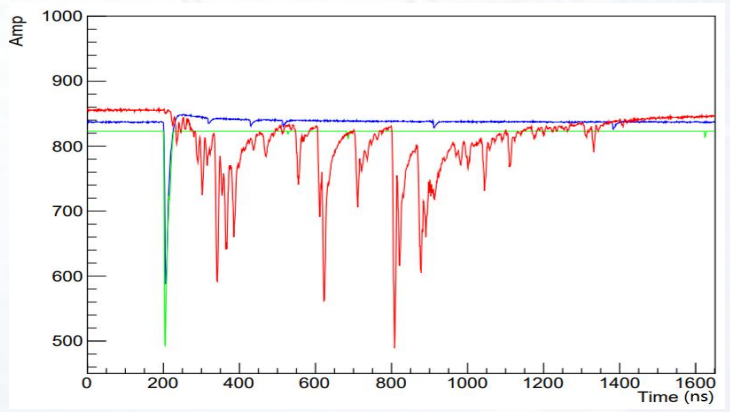

Fast front-end current preamplifier




Current gain simulation



Beam test



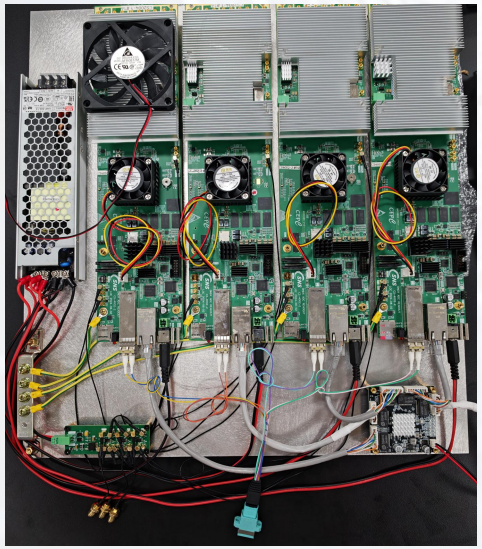

Drift tube signal

# Electronics for high-density waveform digitization


Digitization board

Front panel of the chassis

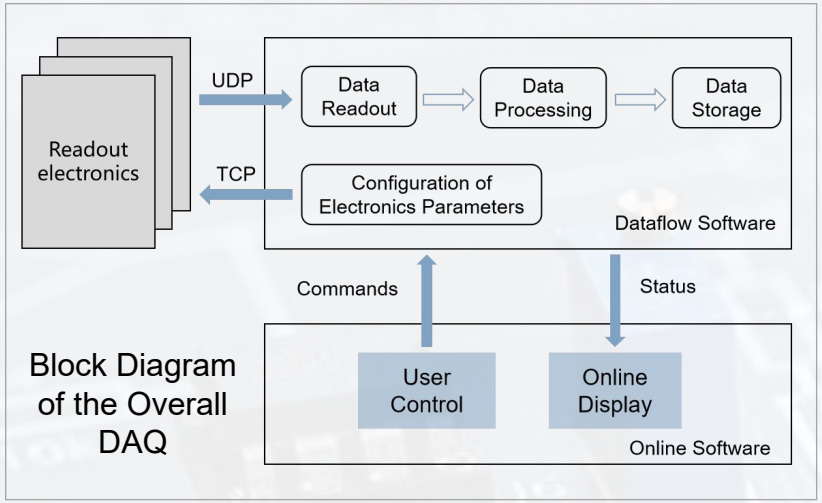
Rear panel of the chassis

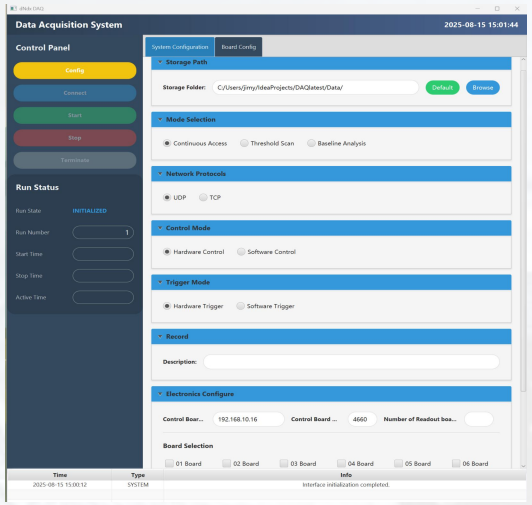


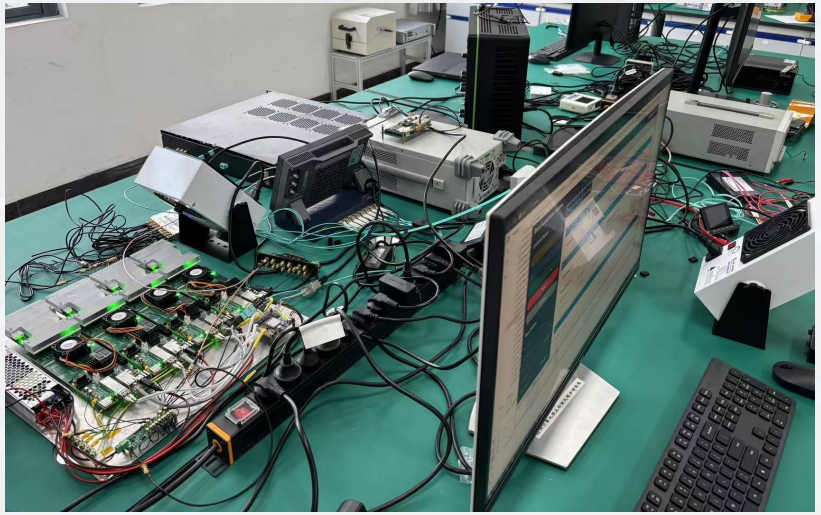
Internal layout of the 40 channels chassis

- ADC mezzanine board
  - 1.3 Gsps sampling rate, 14 bit resolution
  - Power consumption: 750 mW/channel
- FPGA readout board
  - Receive data streams from five AD9695 ADCs via twenty 13 Gbps JESD204B links
  - Provide data buffering, trigger processing, and data packaging functionalities
- 10 Gbps UDP link is utilized for data acquisition and slow control
- The chassis containing 40 digitization channels has been designed and manufactured

# Data acquisition software

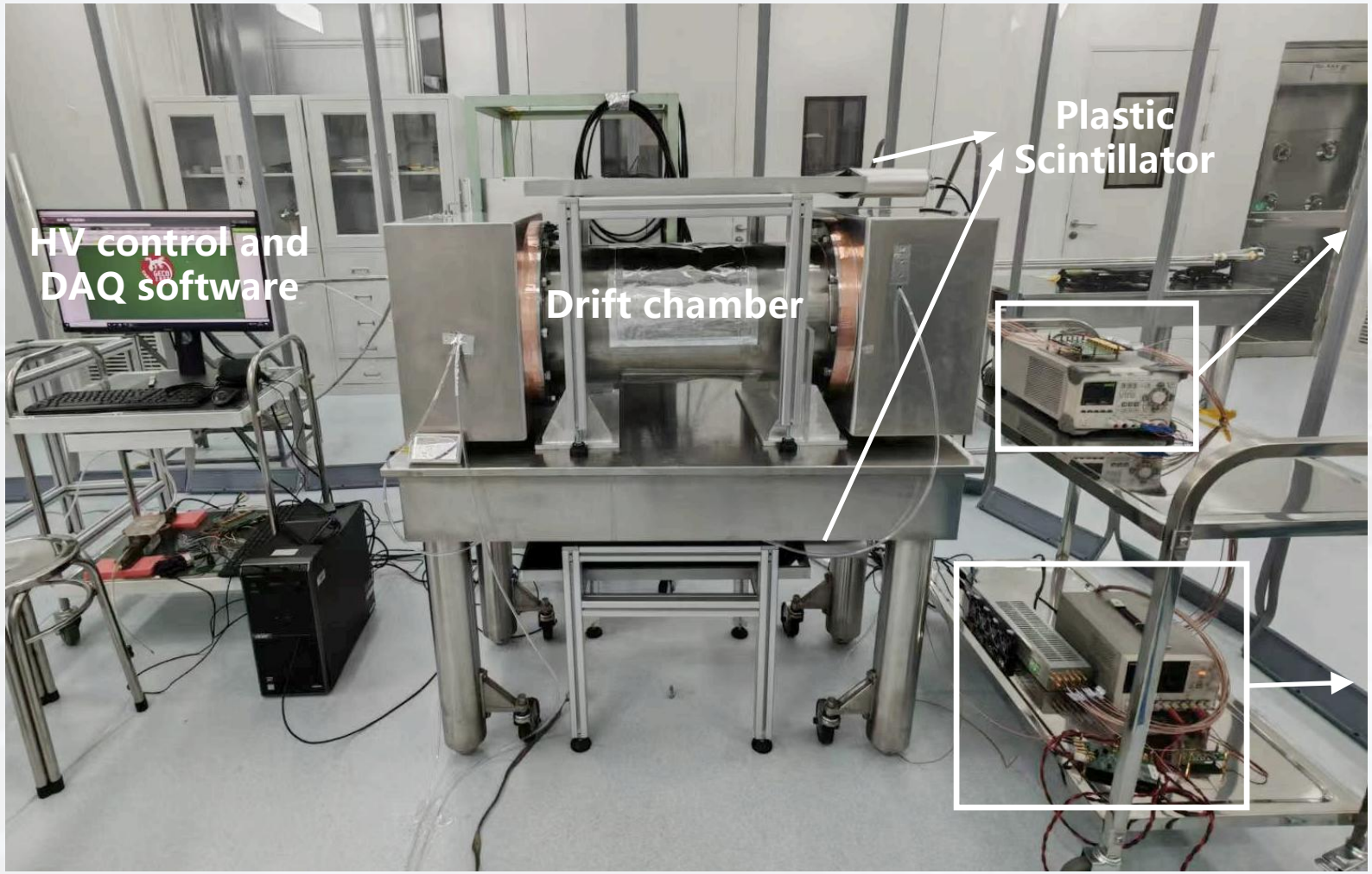


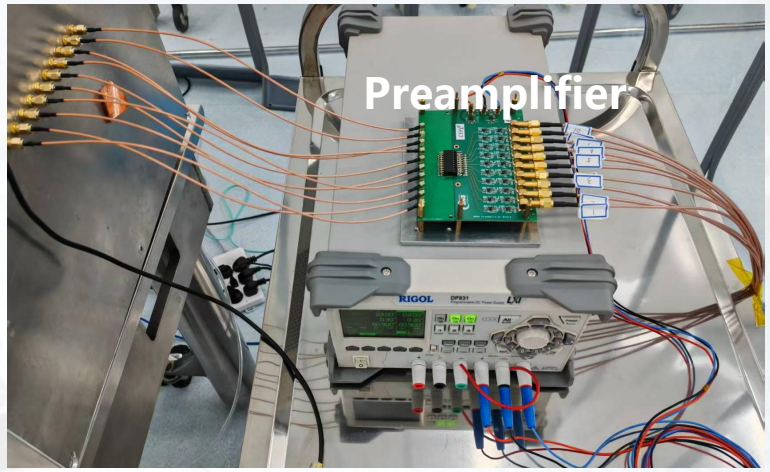



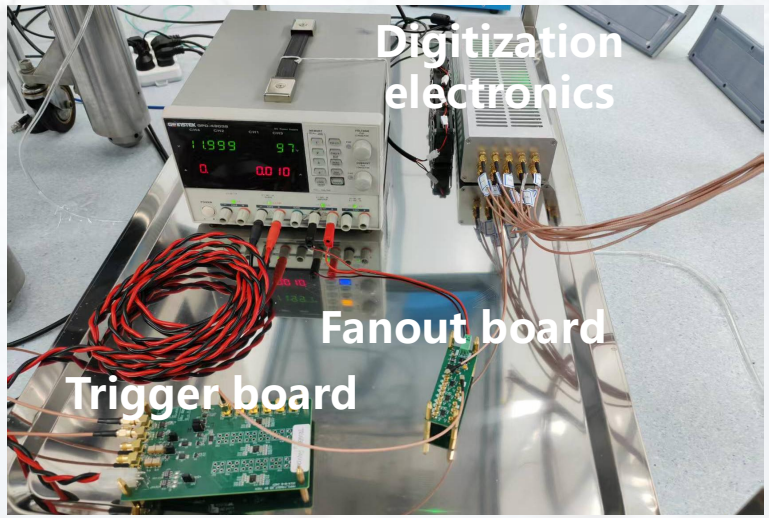



- Dataflow Software
  - Read out data from the electronics
  - Verify and parse the data format
  - Store data to disk and forward it to the online software
  - Configure parameters for the electronics
- Online Software
  - Provide user-layer services: command execution and information feedback
  - Transmit information to the dataflow software
  - Process data online

# Preliminary cosmic ray test

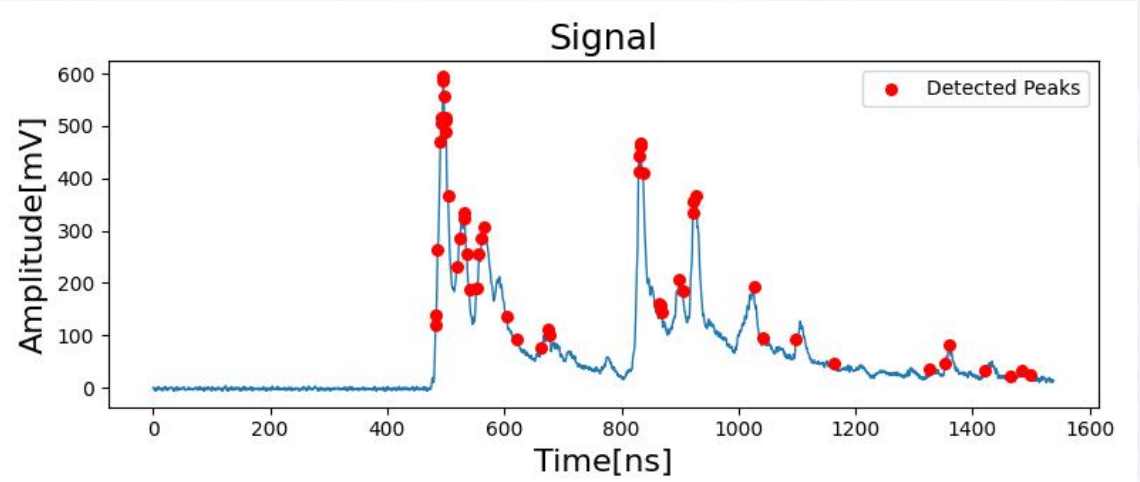


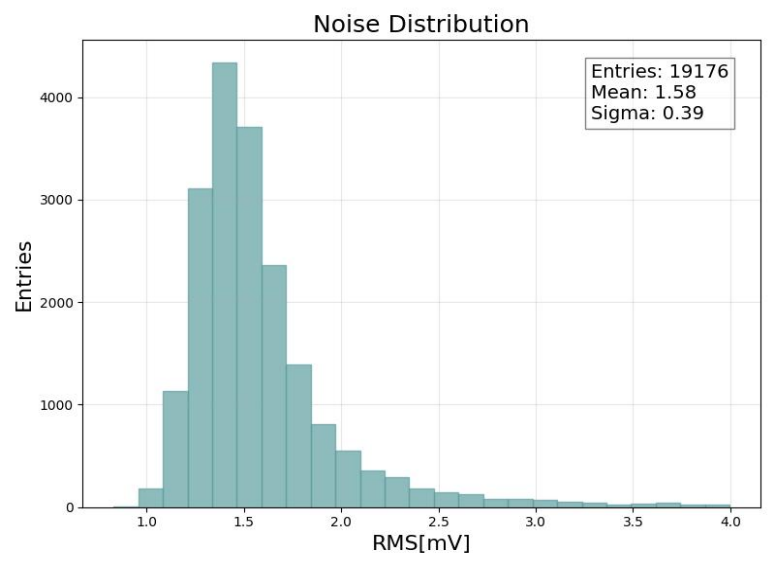



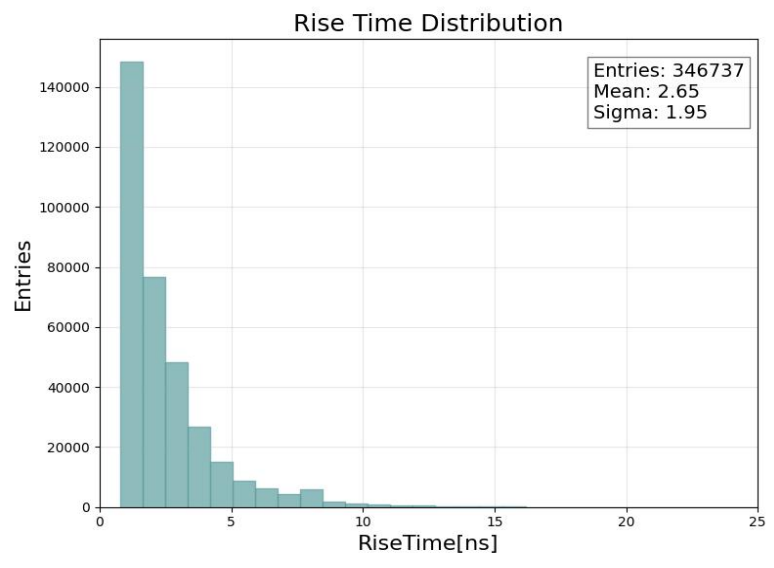



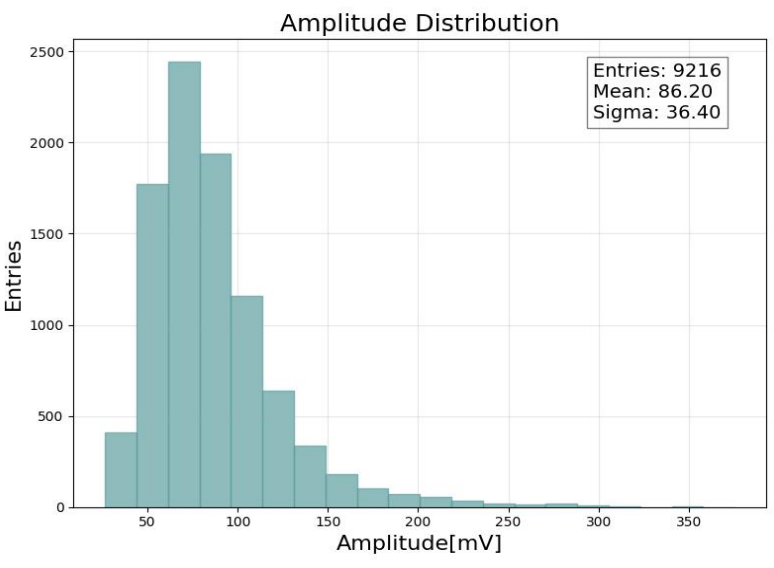
# Preliminary cosmic ray test

- Preliminary data analysis confirms that the system is operating correctly
  - Baseline noise: 1.58 mVrms
  - Risetime: 2.65 ns
  - Amplitude: 86.2 mV

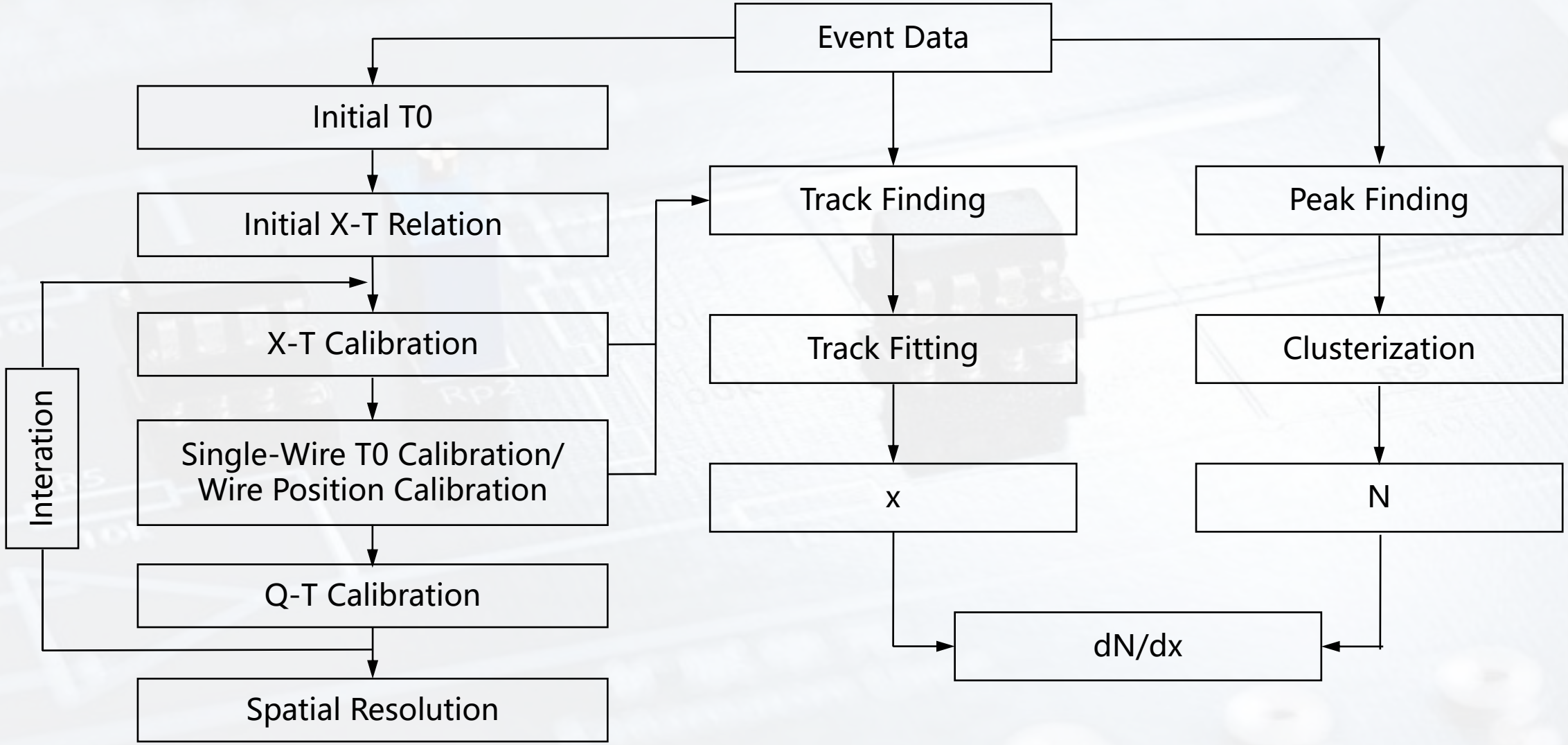


# Subsequent data analysis

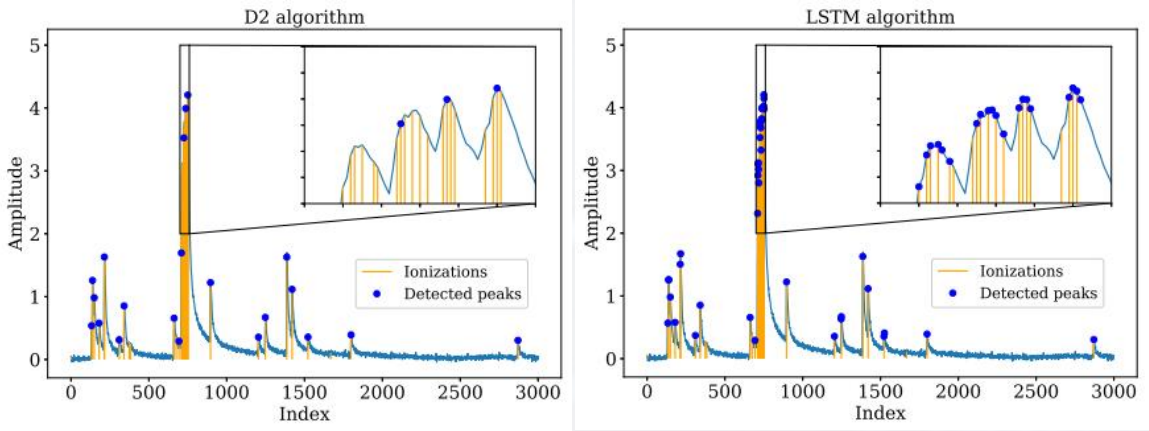


# Reconstruction algorithm

## Step 1

### ➢ Peak Finding

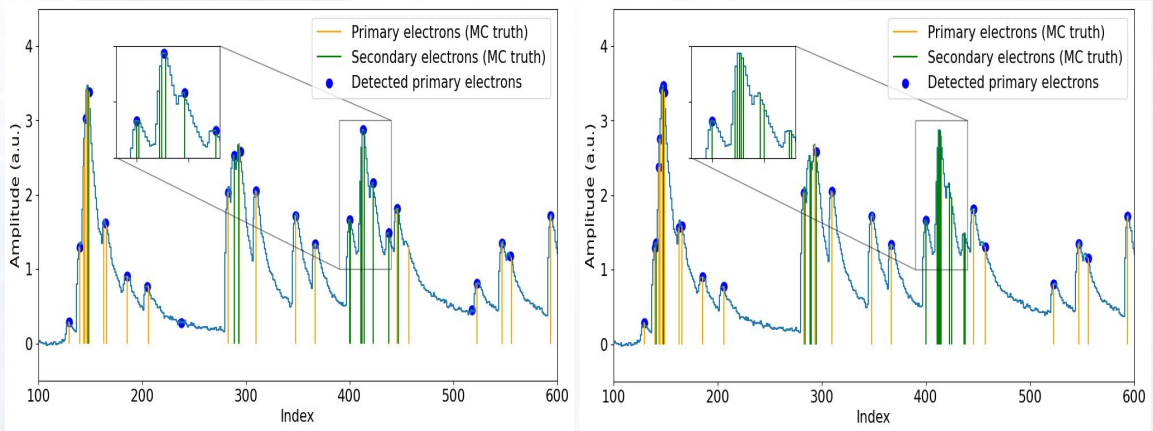
- Derivative algorithm
- Long Short-Term Memory (LSTM) based algorithm
- Domain adaptation based algorithm




## Step 2

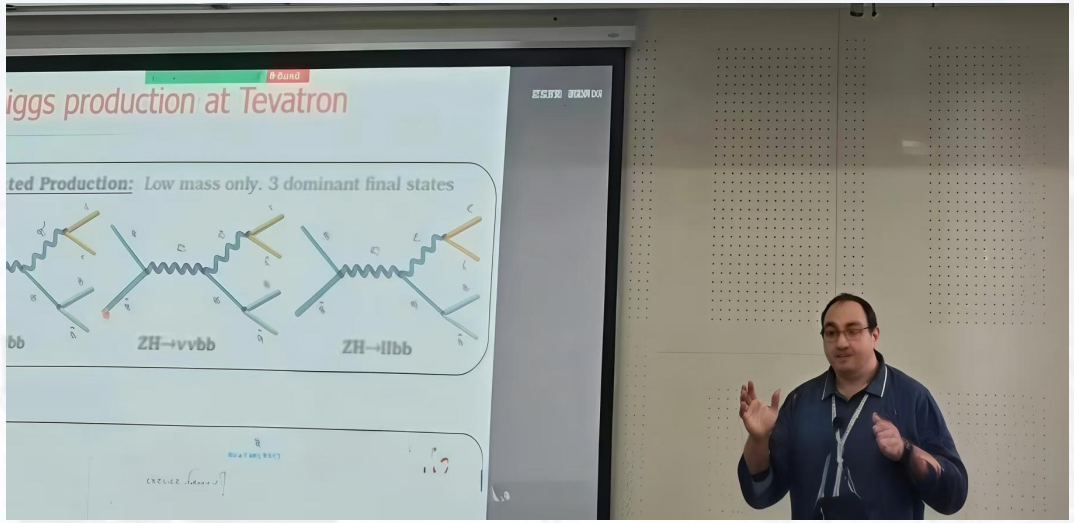
### ➢ Cluster Reconstruction

- Time Cut based algorithm
- Dynamic Graph CNN (DGCNN) based algorithm



# Collaboration with INFN (IDEA DC group)

- Close collaboration focusing on the dN/dx technique in drift chamber
  - Beam tests and data analysis
  - Deep learning reconstruction algorithm
  - Detector structure design for CEPC DC
  - Prototype tests
- Academic activities and discussion
- NSFC-MAECI joint research project application




Computational Physics

## Peak finding algorithm for cluster counting with domain adaptation ☆

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## Summary

- The drift chamber is a vital option for tracker. Utilizing the dN/dx method can significantly enhance its PID performance.
- A DC prototype test system has been constructed to allow for the experimental validation of the dN/dx method. Currently, the design and construction of the prototype, readout electronics, and DAQ system have been completed.
- The prototype system is currently under test. Preliminary data analysis confirms that the system is operating correctly.

## Future plans

- Cosmic ray test and dN/dx resolution analysis
- Beam test of the prototype system
- Optimization of deep learning algorithm

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# Thank you for your attention !

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