

Status of CEE Experiment

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(for CEE Collaboration)

Institute of Modern Physics

2025.10.16

The 2nd International Workshop on Physics at High Baryon Density (PHD2025)

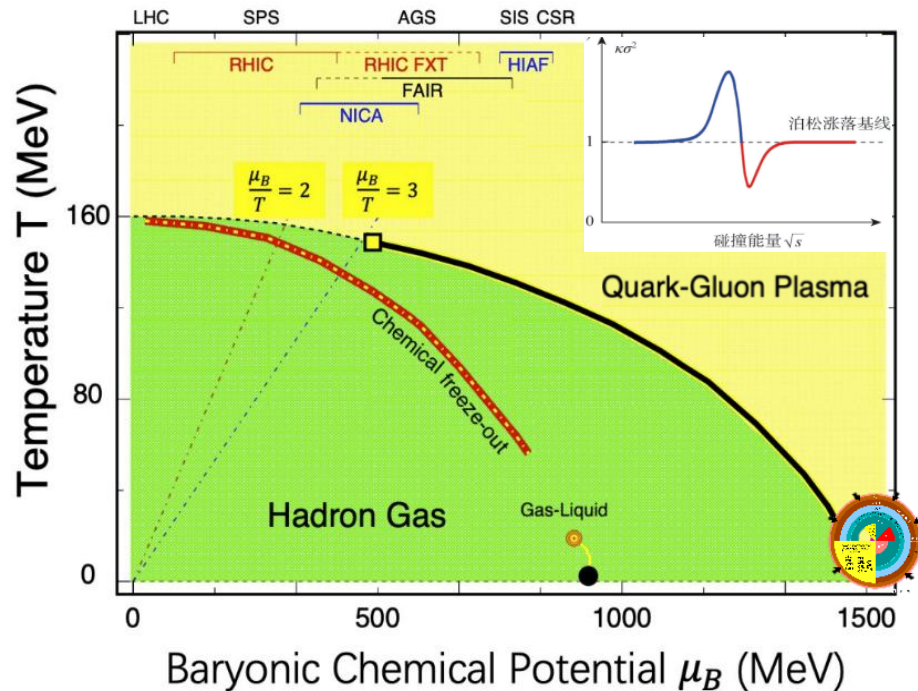


中国科学院
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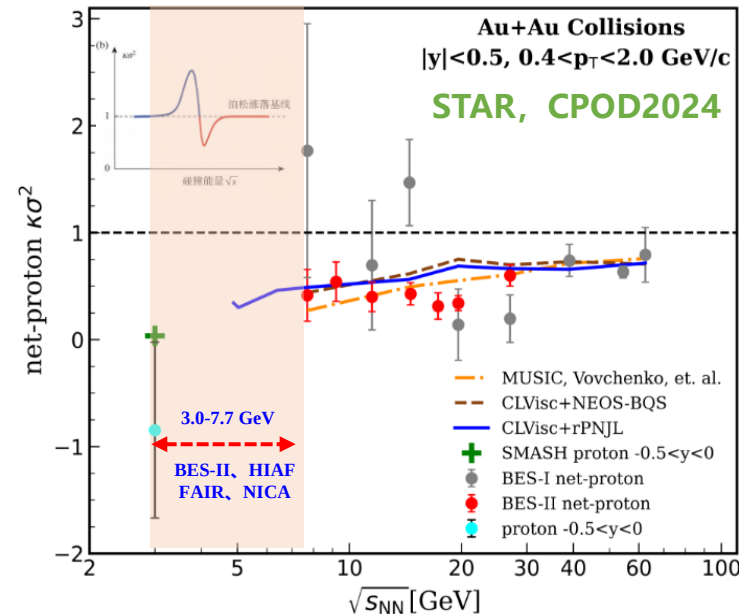
Outline

- Physics Motivation
- CEE Spectrometer and Construction Progress
- Simulation & Beam Test Results
- Summary

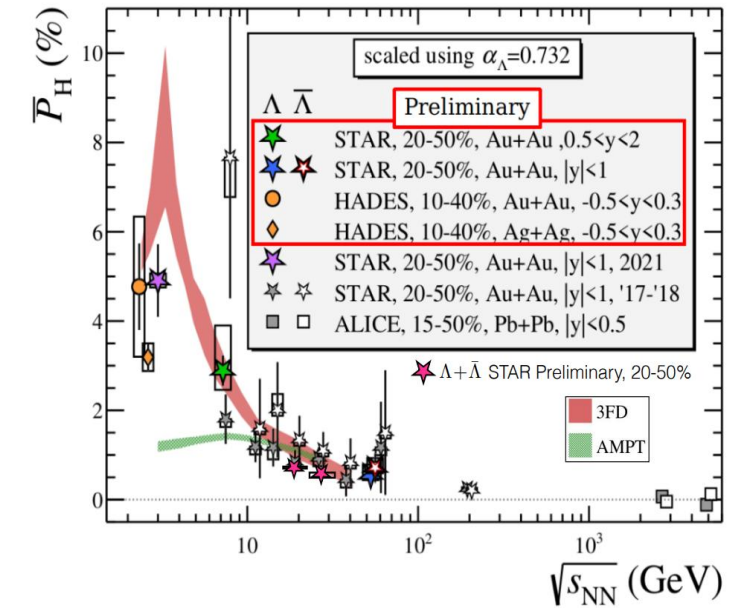
QCD Phase Diagram



PRL 135,142301(2025)



Quark Matter 2022



- Phase diagram at high baryon density: phase transition, critical point
- QCD matter properties at high baryon density

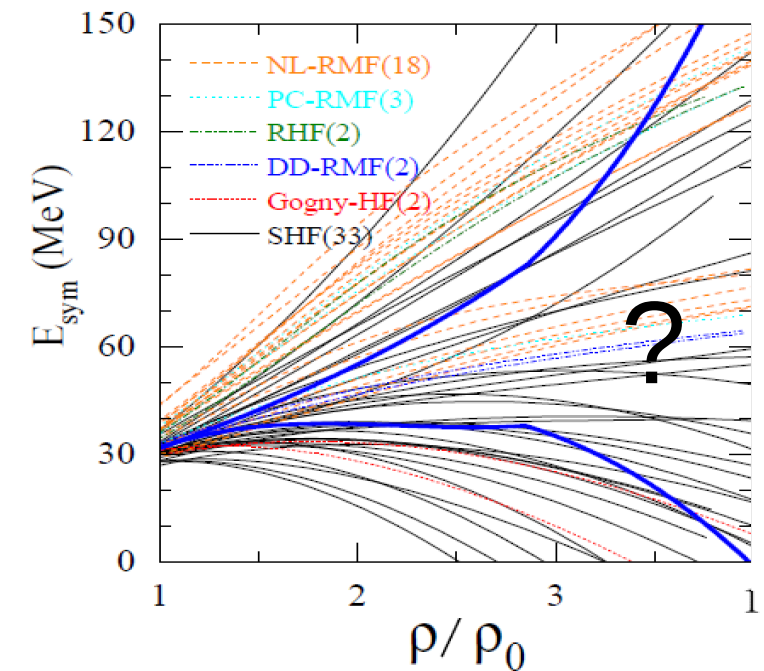
Nuclear Matter Equation of State (EoS)



$$E(\rho, \delta) = E_0(\rho) + \underbrace{E_{\text{sym}}(\rho)}_{\text{Symmetry Energy}} \delta^2 + \mathcal{O}(\delta^4), \quad \delta = \frac{N - P}{N + P}$$

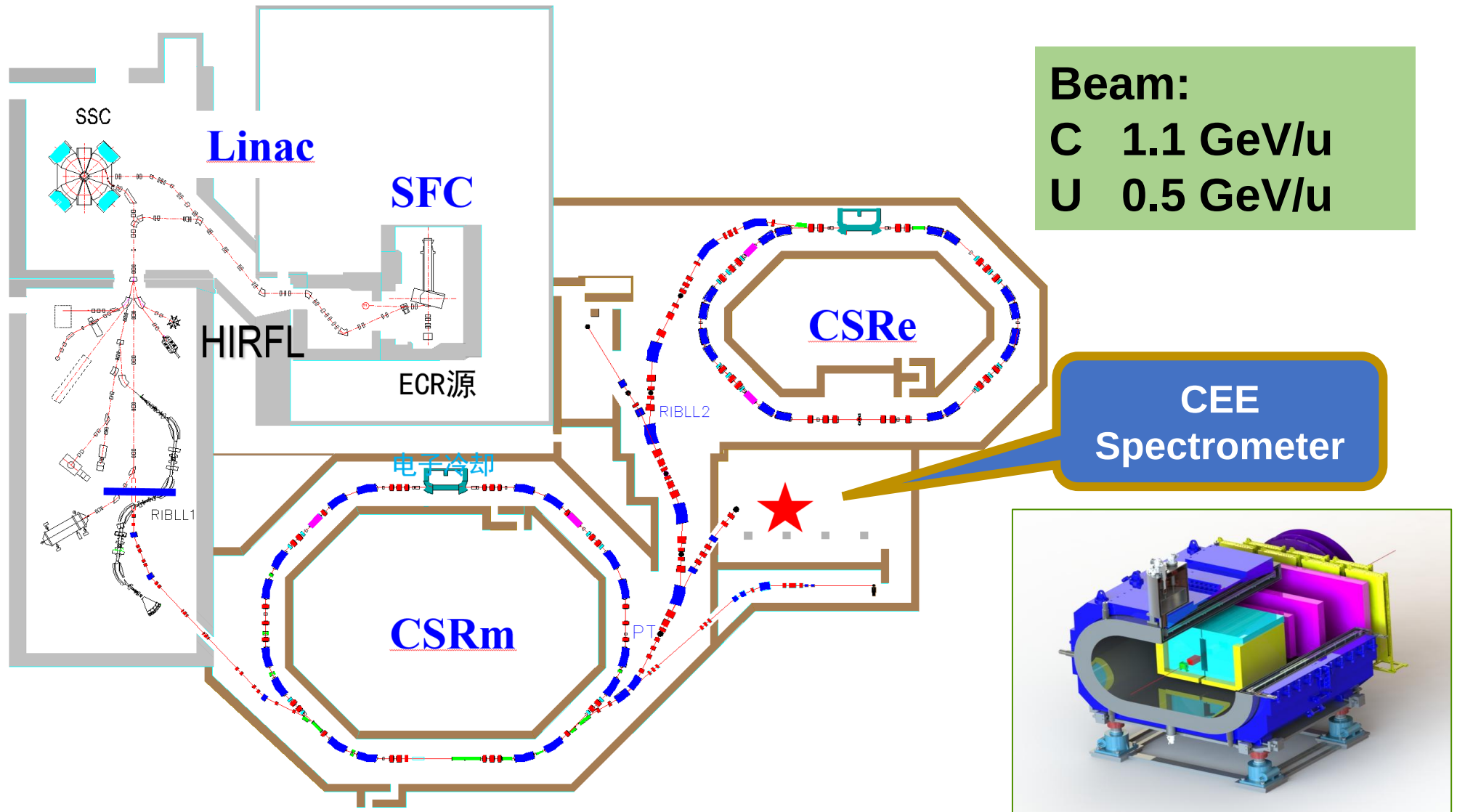
$$E_0(\rho) \approx E_0(\rho_0) + \frac{K_0}{2} \left(\frac{\rho - \rho_0}{3\rho_0} \right)^2 + \frac{J_0}{6} \left(\frac{\rho - \rho_0}{3\rho_0} \right)^3$$

$$E_{\text{sym}}(\rho) \approx E_{\text{sym}}(\rho_0) + L_{\text{sym}} \left(\frac{\rho - \rho_0}{3\rho_0} \right) + \frac{K_{\text{sym}}}{2} \left(\frac{\rho - \rho_0}{3\rho_0} \right)^2 + \frac{J_{\text{sym}}}{6} \left(\frac{\rho - \rho_0}{3\rho_0} \right)^3$$



B.A Li et al. Universe, 7, 182(2021)

Lanzhou Heavy Ion Research Facility (HIRFL-CSR)



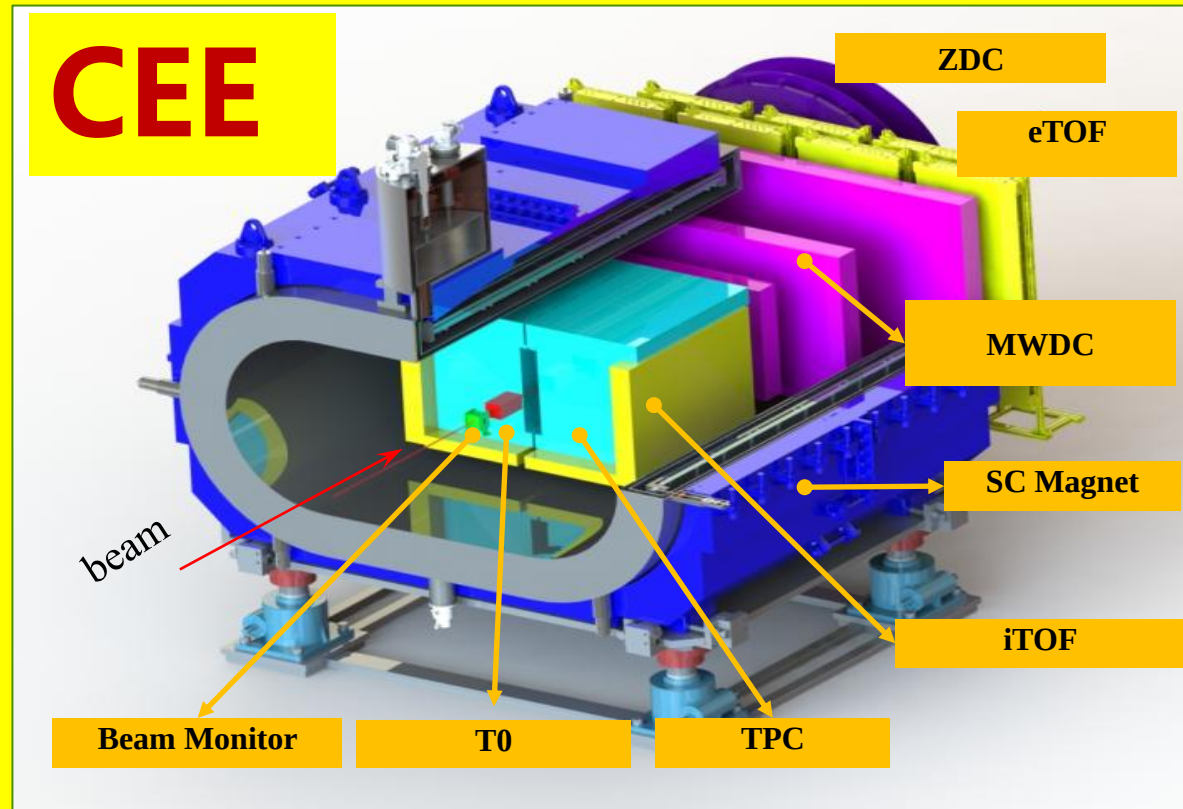
CEE: CSR External-target Experiment

CEE Spectrometer:

- 1) Super-conducting Dipole Magnet
- 2) Si-PIX Beam Monitor (BM)
- 3) Time Projection Chamber (TPC)
- 4) Multi-Wire Draft Chamber (MWDC)
- 5) T0/Inner TOF (iTOF)
- 6) External TOF (eTOF)
- 7) Zero Degree Counter (ZDC)
- 8) Data Acquisition system (DAQ)
- 9) Trigger system (Trigger)
- 10) Clock system (Clock)
- 11) Technical Support
- 12) Slow Control (SC)

Software: simulation and analysis

Supported by NSFC and CAS



Key performance goals

- $\Delta p/p$: $\sim 5\%$, $\Delta t/t$: $\leq 80\text{ps}$
- Max. Rate: 10 kHz
- Proton acceptance: $> 80\%$

CEE Collaboration

China:

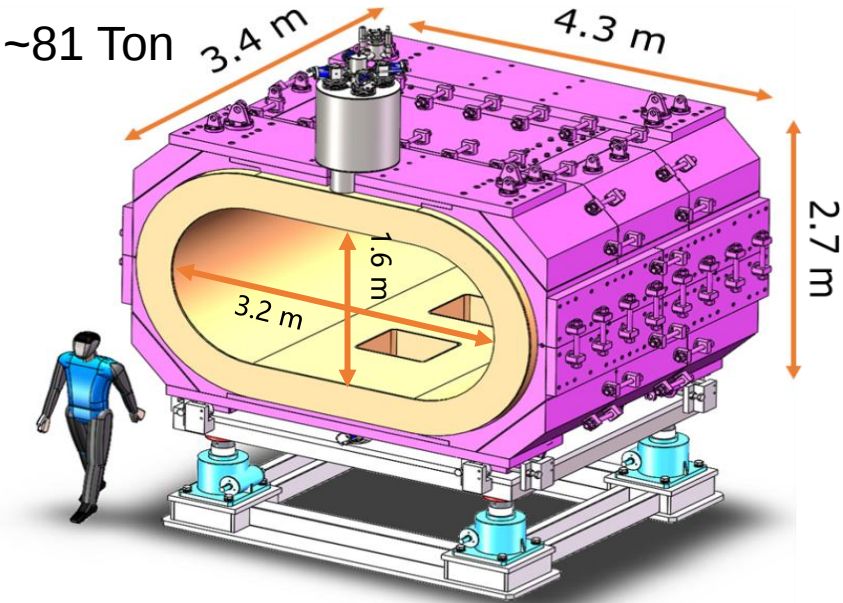
- Central China Normal University (CCNU)
- Fudan University (FDU)
- Institute of Modern Physics, CAS (IMP)
- Tsinghua University (THU)
- University of Science and Technology of China (USTC)
- Harbin Institute of Technology University (HIT)

Japan:

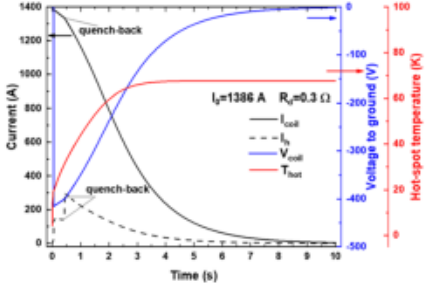
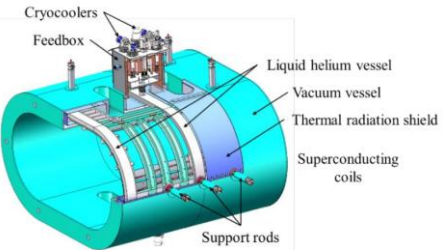
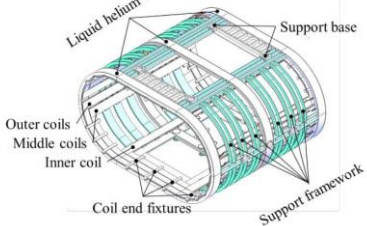
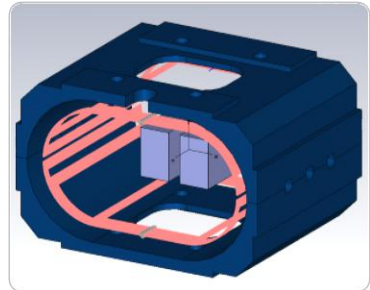
- Tsukuba University

Super-Conducting Dipole Magnet

Quantity	Performance
Central Field	0.5 T
Uniform range	$1200 \times 800 \times 900 \text{ mm}^3$
Uniformity	$\pm 2.5\%$
Current in operation	231 A



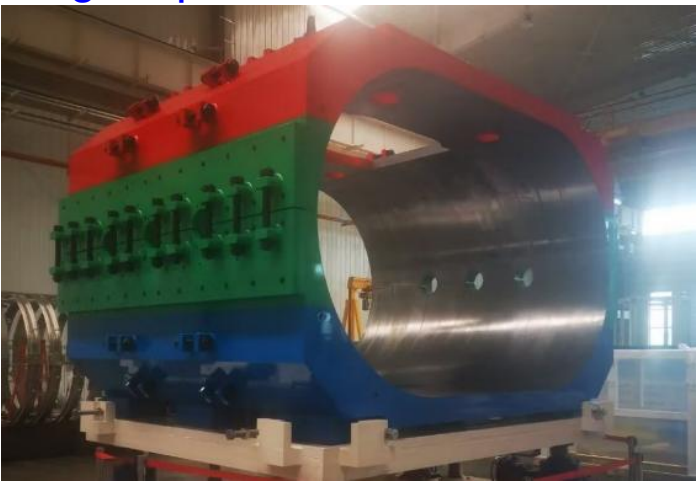
Magnet design



SC Magnet prototype



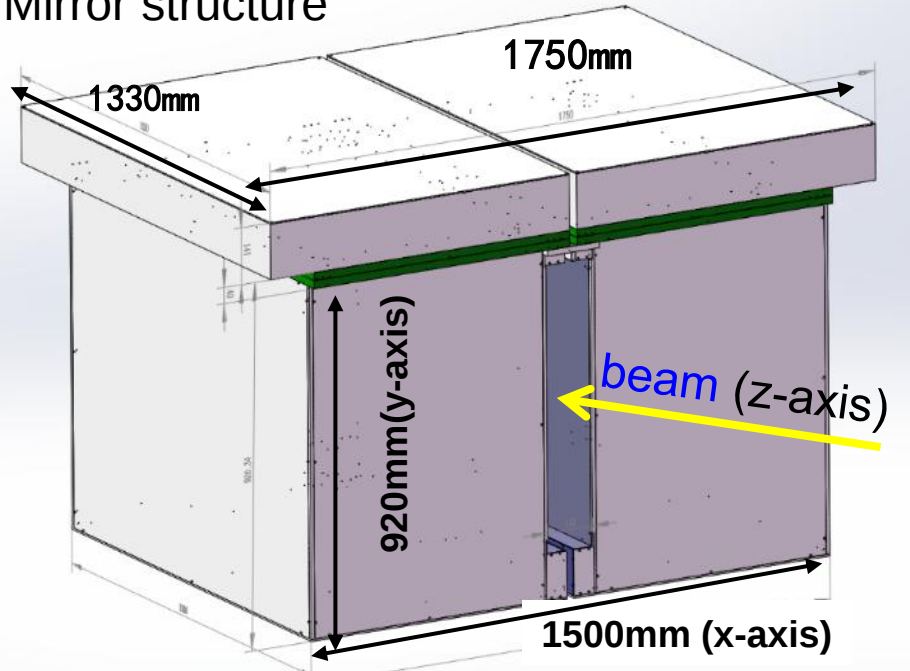
Magnet production



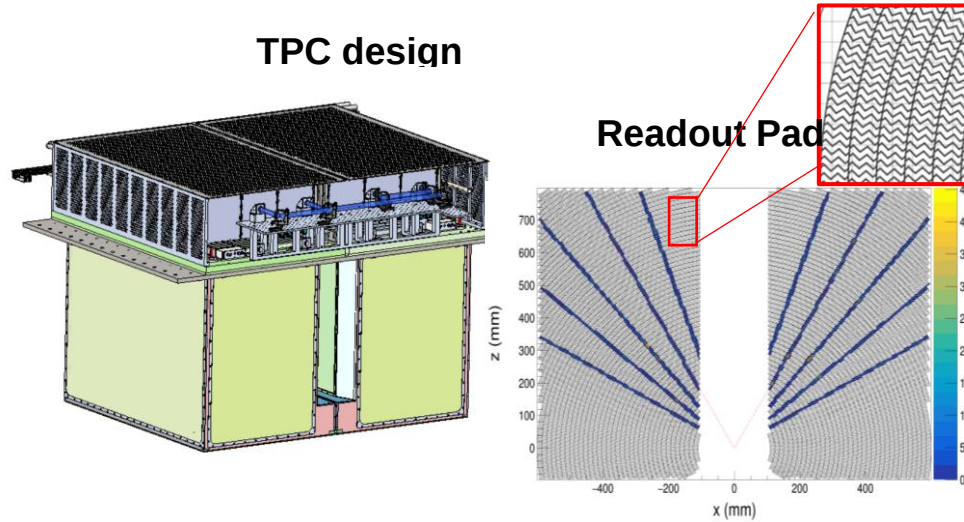
Time Projection Chamber

Quantity	Design index
Channels	15000
Volume	$2 \times 45 \times 80 \times 90 \text{ cm}^3$
σ_{xz}	500 μm
2-track separation	3 cm
Momentum resolution	5%

Mirror structure



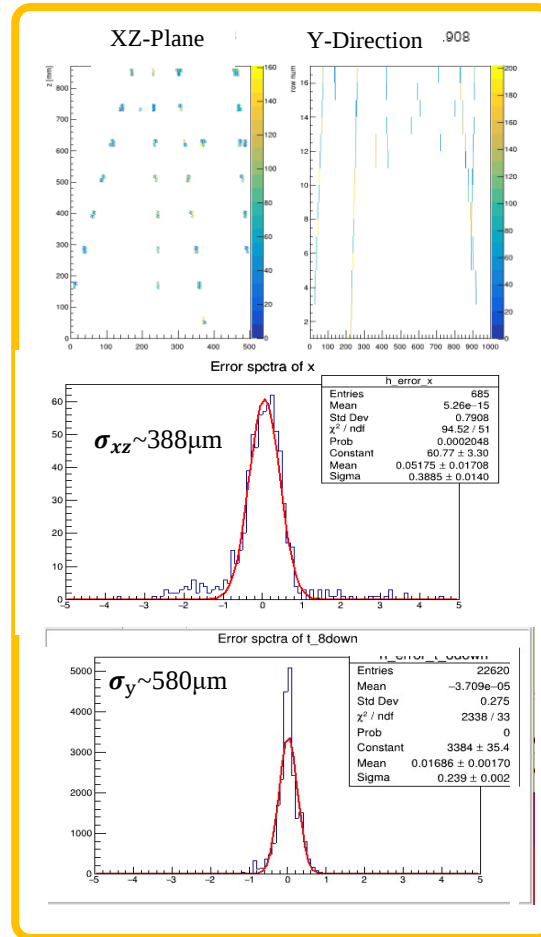
TPC design



TPC production



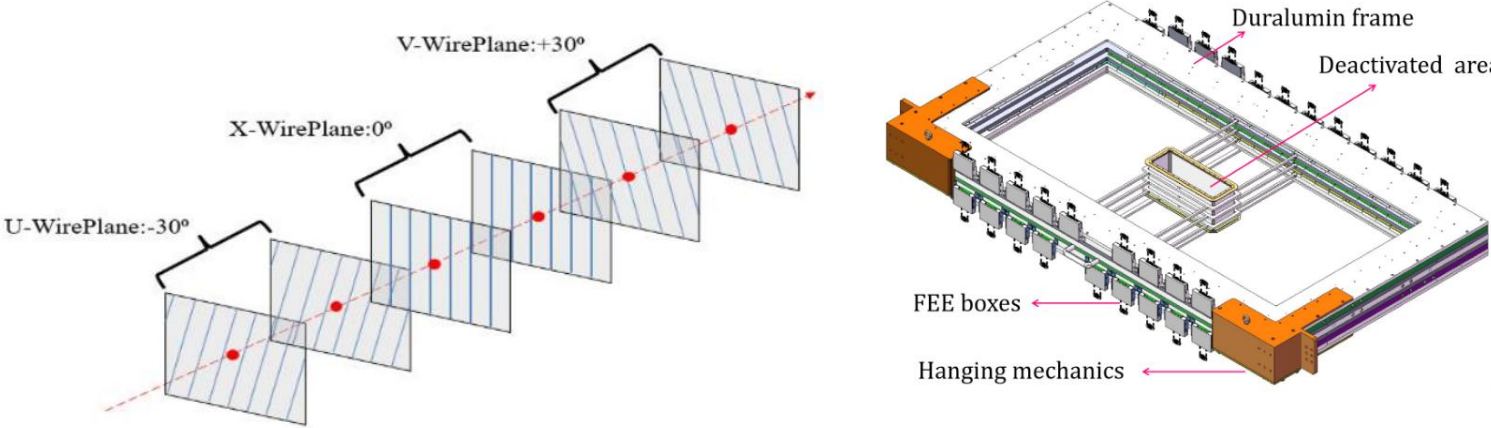
Beam Test Result



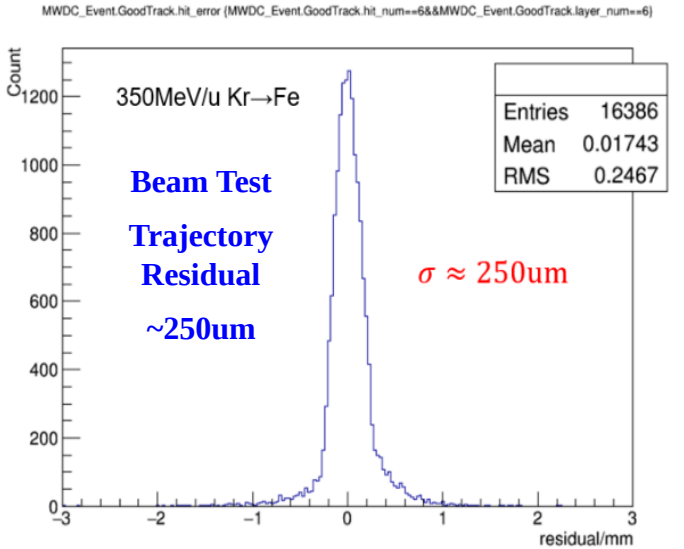
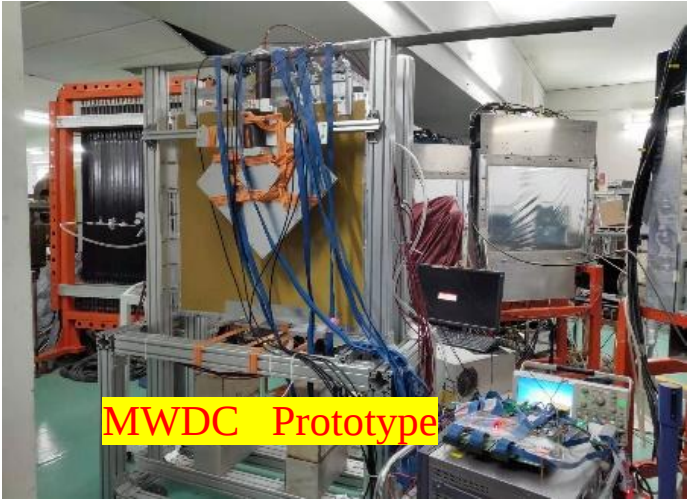
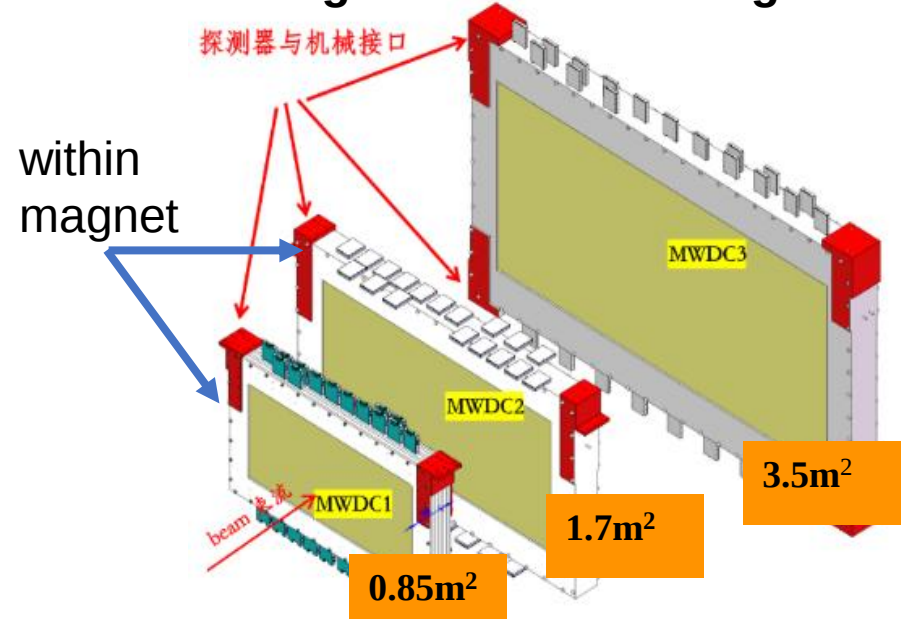
Multi Wire Drift Chamber

Quantity	Design index
Channels	~3200
Wire layer per module	X、X'、U、U'、V、V'
σ_{xz}	300 μm
Energy resolution	> 22%
Detection efficiency	> 98%
Momentum resolution	<5%

MWDC design



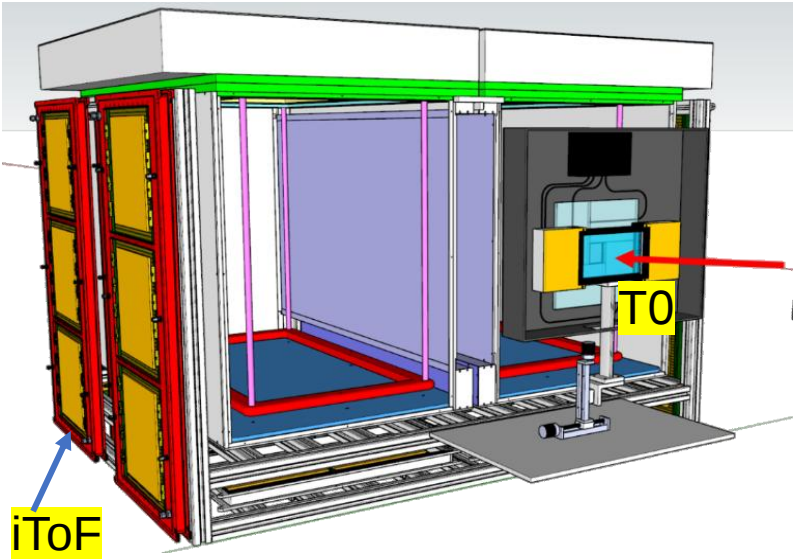
Tracking in the forward angle



T0/Inner ToF

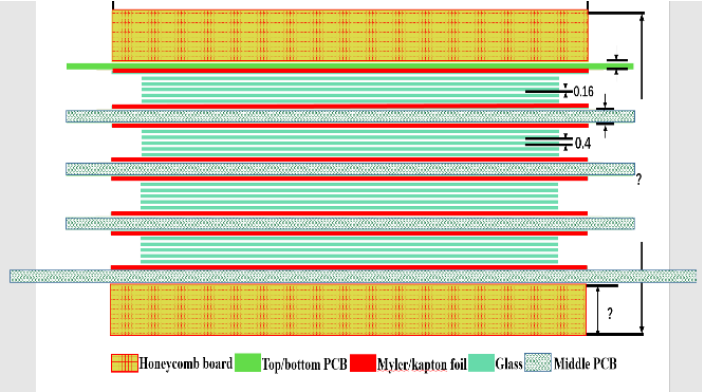
Particle identification and trigger

Quantity	Design index T0/iTOF
σ_T	50ps / 50 ps
Efficiency	>99% / >95%
Rate	1MHz / 10kHz

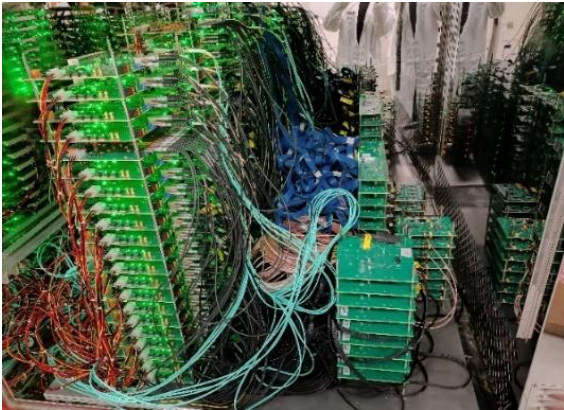


iToF : covers 3 sides of TPC

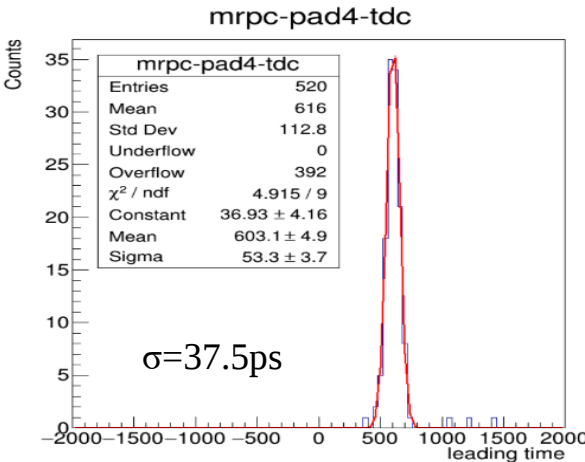
iTOF based MRPC Design



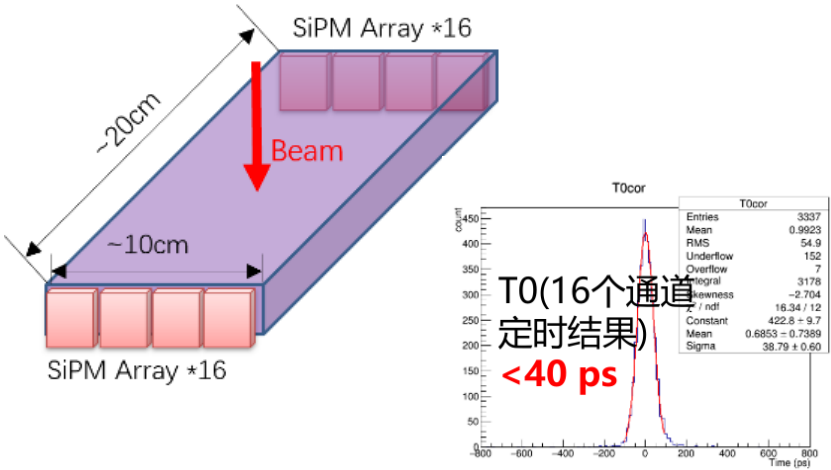
Electronics Maturity Test



Beam test results

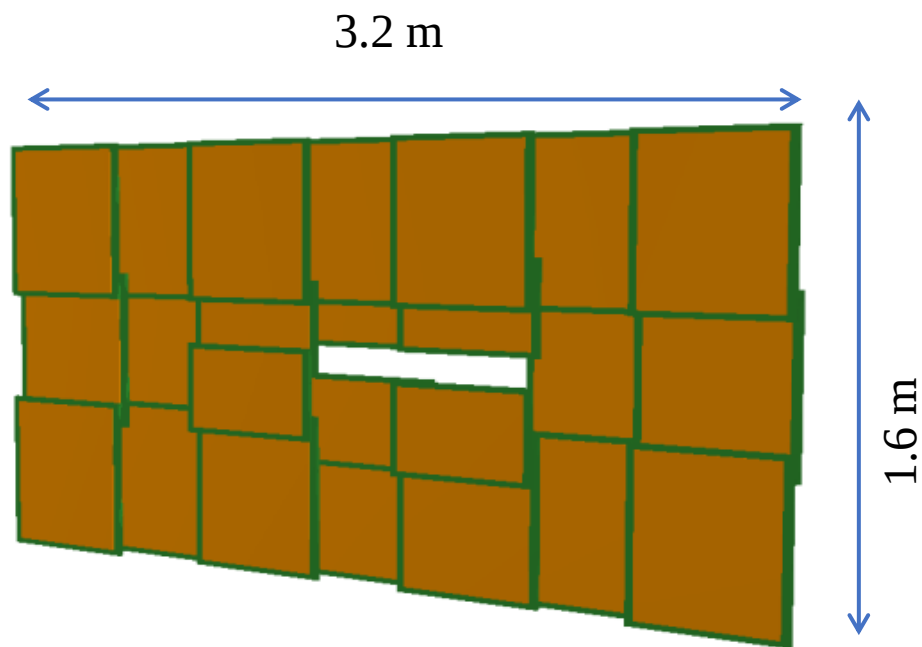


T0: Scintillator + SiPM



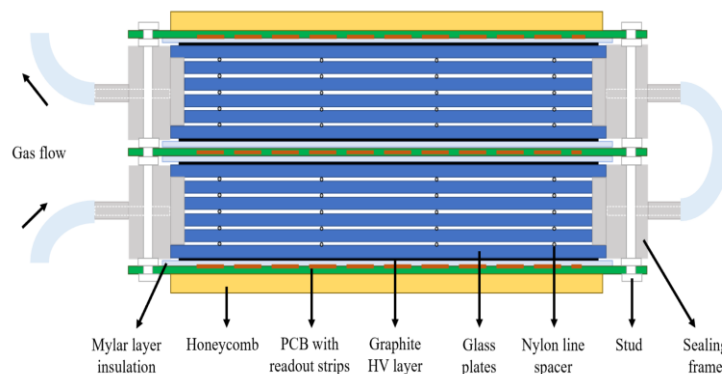
External ToF

Quantity	Design index
σ_T	60 ps
Efficiency	>95%
Rate	>10kHz

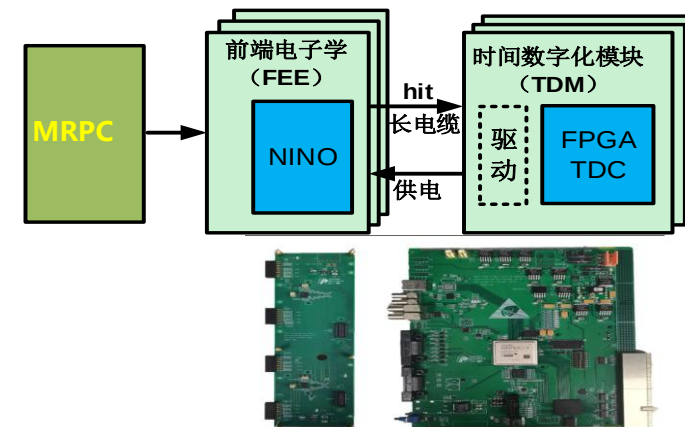


eToF : forward angle

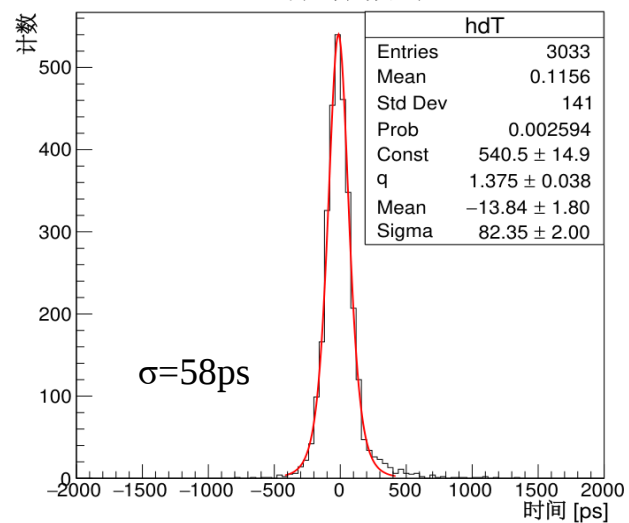
eTOF MRPC configuration



MRPC readout



Prototype time resolution

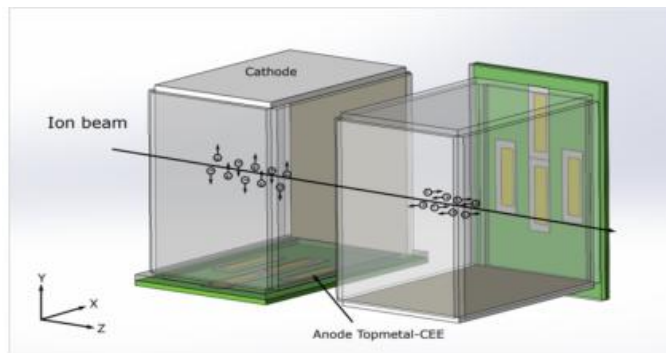


Massive Production

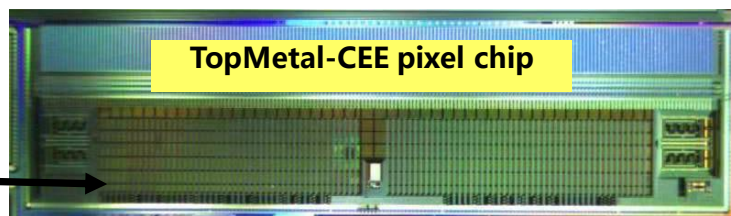
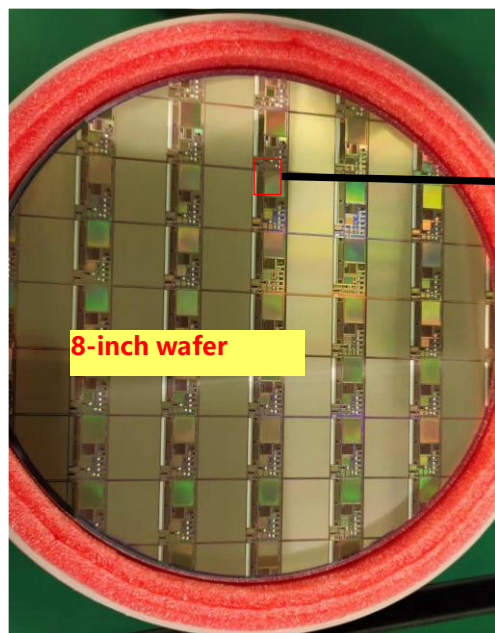
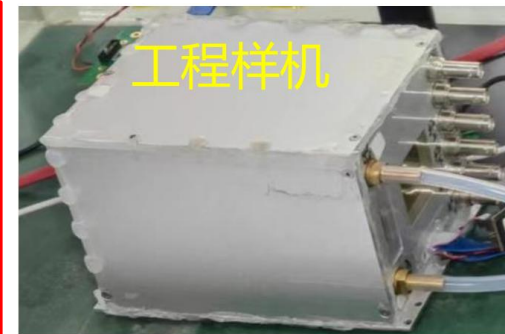
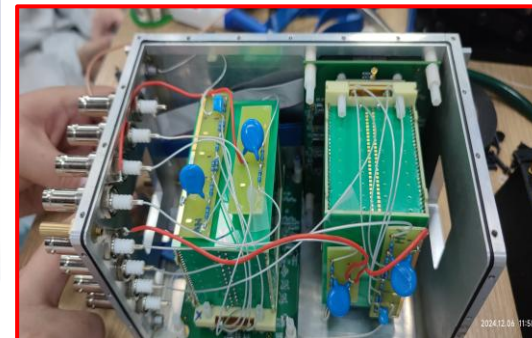


Beam Monitoring Detector

BM Parameters	Design index
Position resolution	50 μm
Time resolution	1 μs
Volume	10x10x12 cm^3

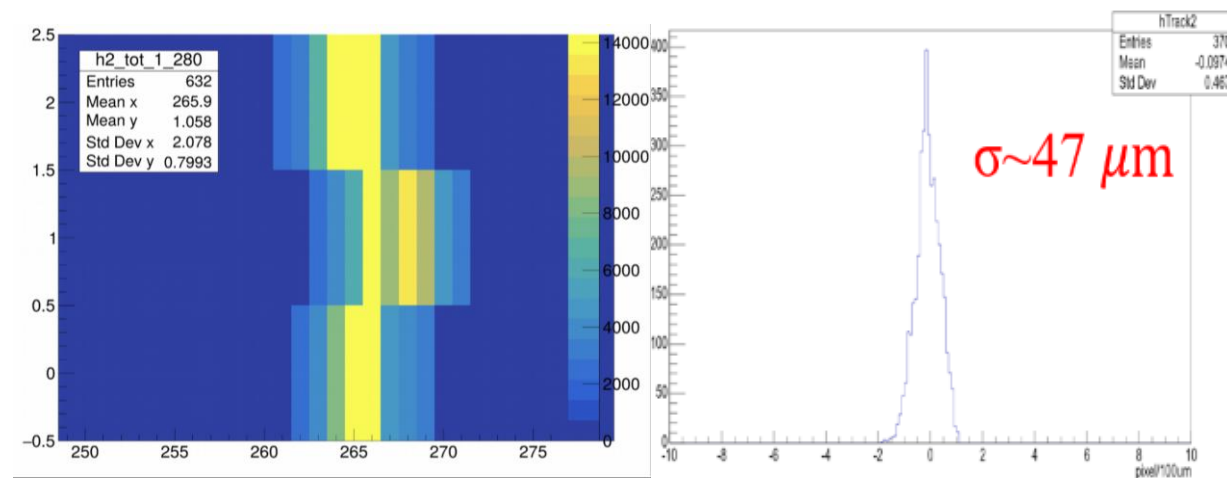


Prototype



- High spatial resolution
- High time resolution
- High radiation tolerance

Beam test result

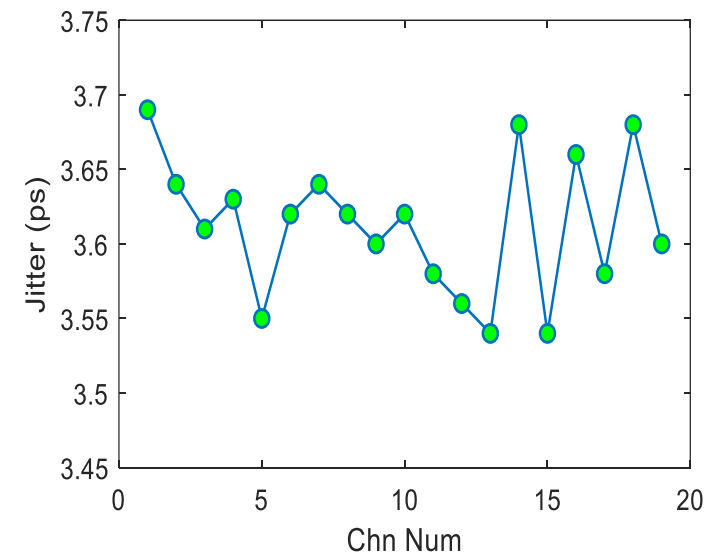
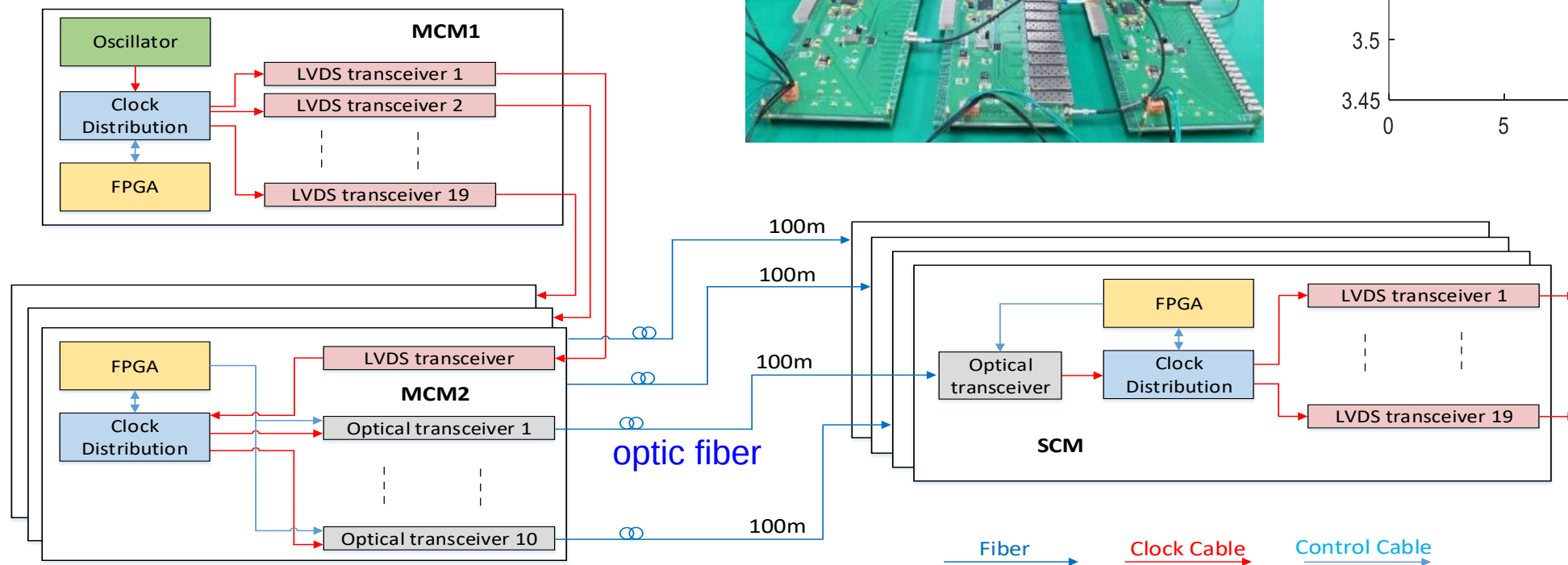


Clock System

Provides high-quality timing reference and ensures time synchronization

- Frequency: 40 MHz
- Period jitter: < 10 ps RMS

Clock system block diagram



Trigger System

Generates and distributes event selection signals

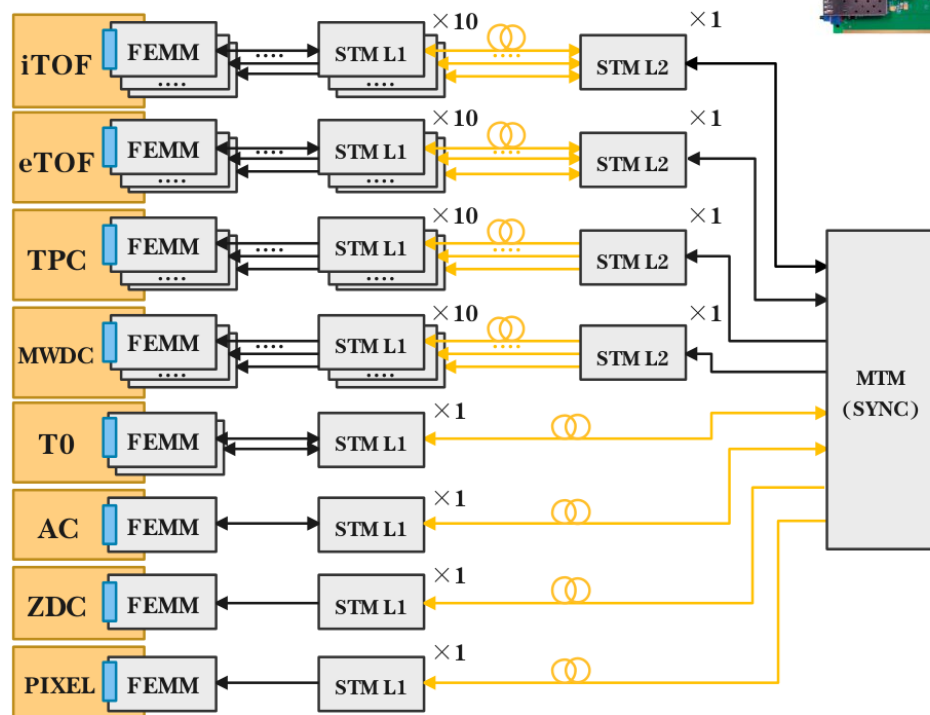
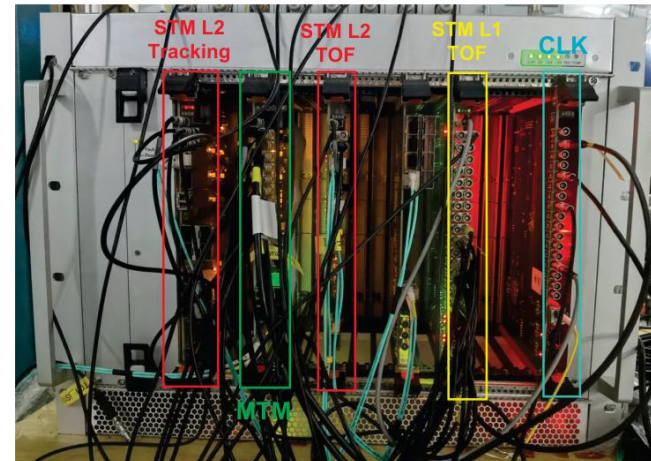
Working mode:

- Normal (data taking)
- Laser mode
- Pulse mode

Trigger Electronics



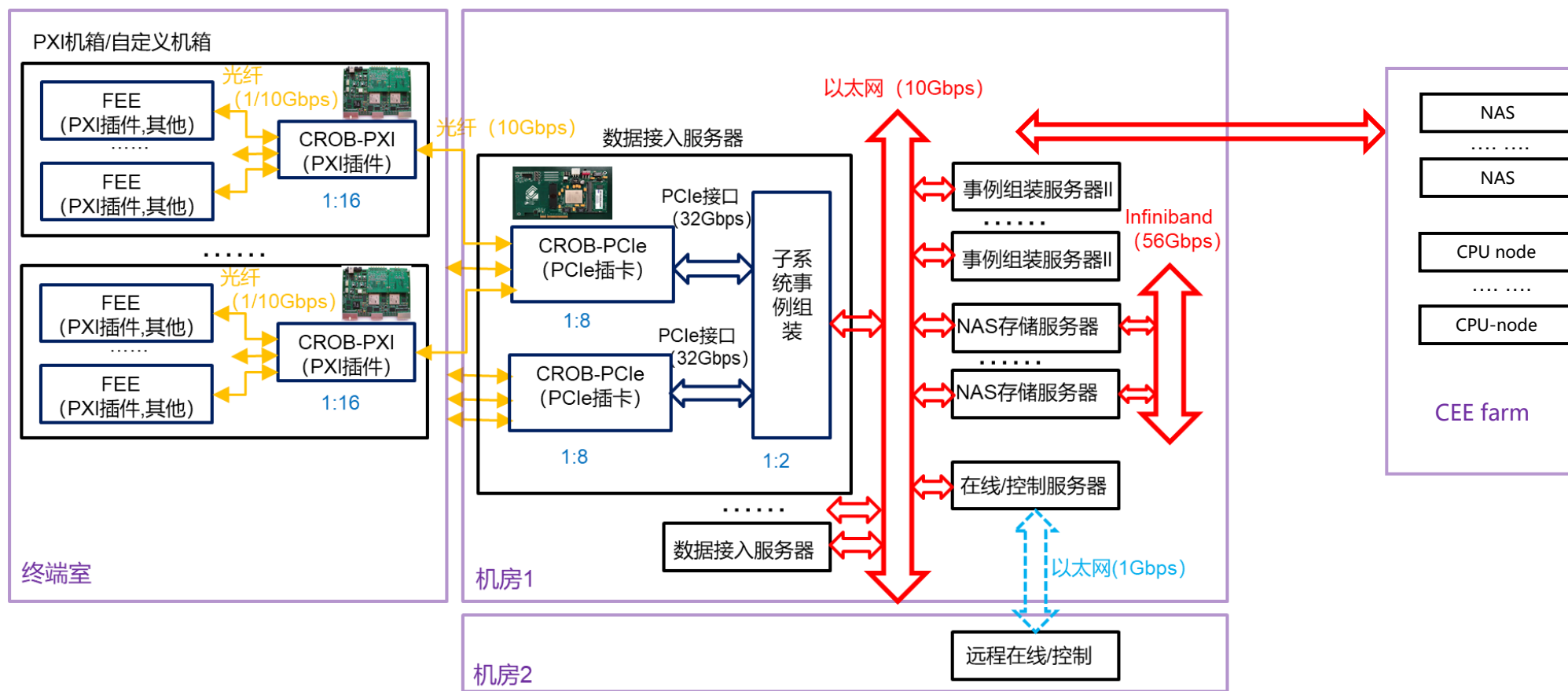
Beam test



Data Acquisition System (DAQ)

Collection, transmission, processing, assembly, and storage of scientific data

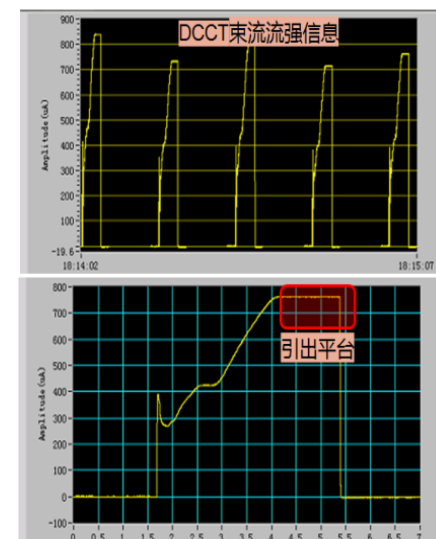
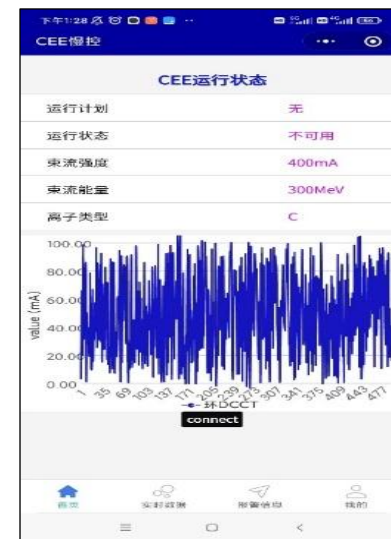
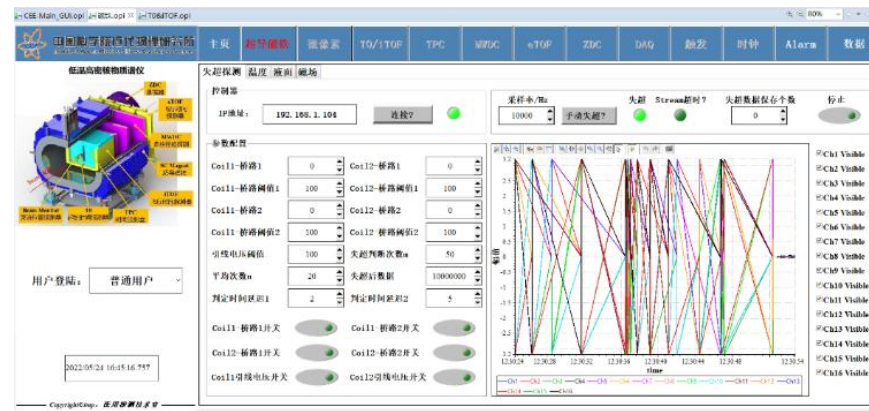
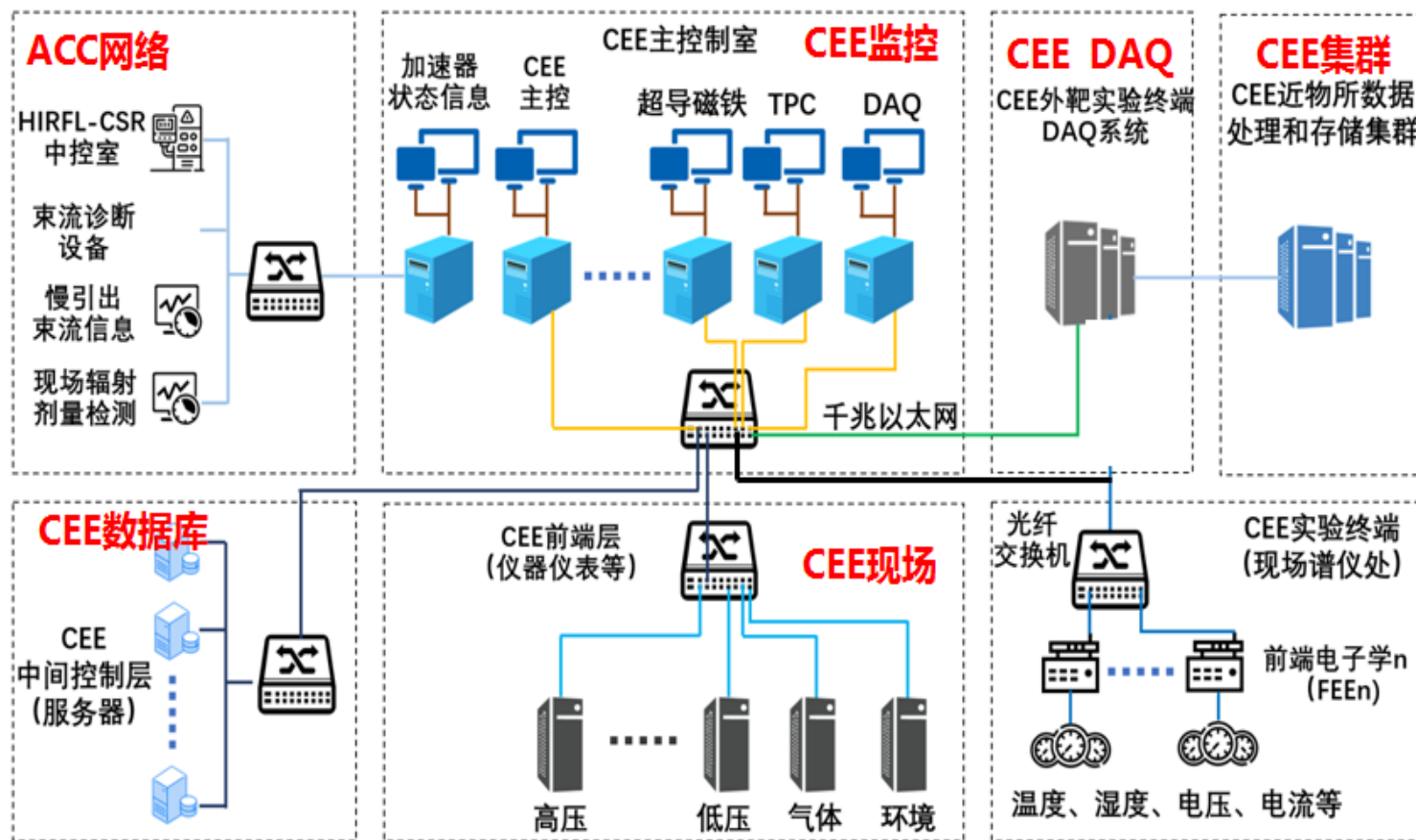
- Electronic channels: $\sim 22,000$
- Zero-suppressed data rate: ~ 4.4 Gbyte/s
- Event rate: ~ 10 kHz



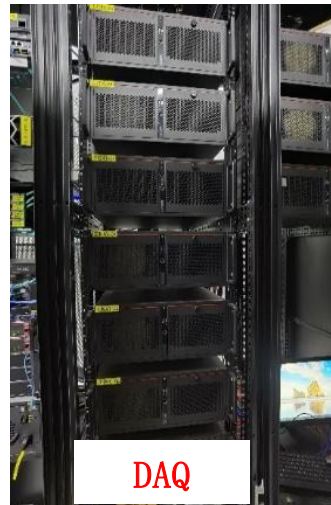
Slow Control

SC is based on the EPICS, preforms real-time monitoring of all detector parameters and operational status.

Experimental Physics and
Industrial Control System

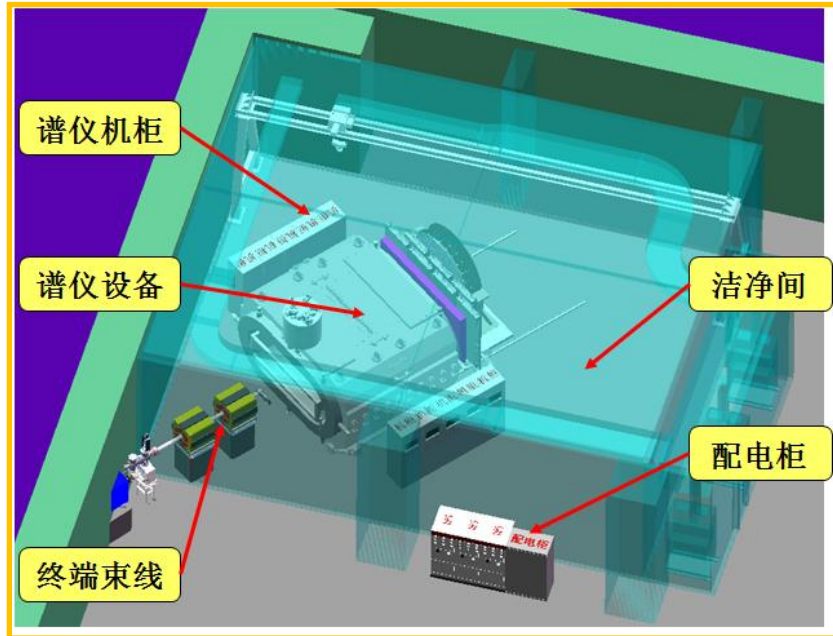


System Integration & Infrastructure



System Integration & Infrastructure

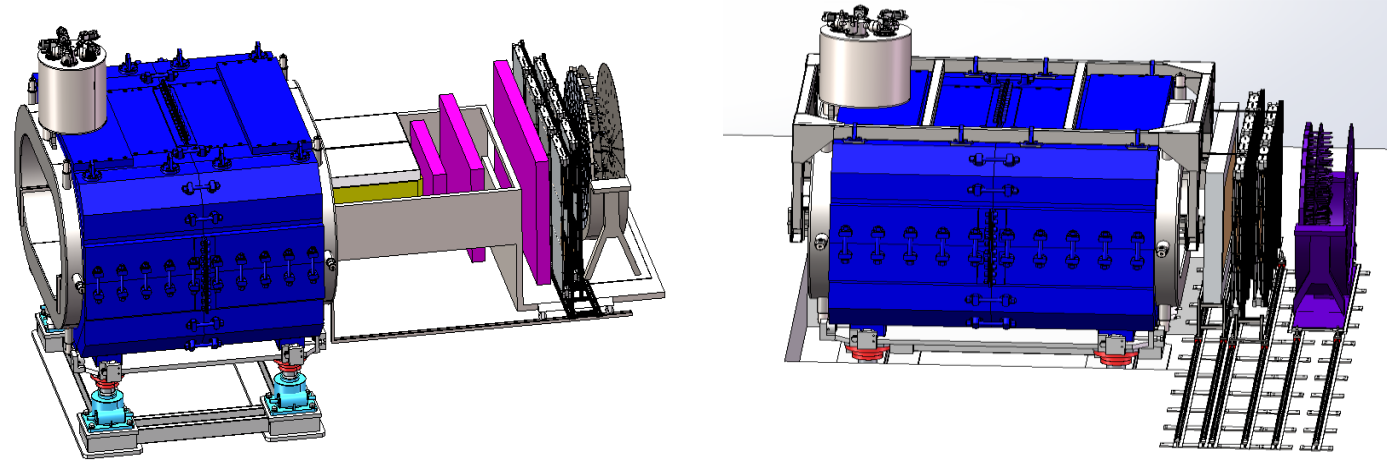
CEE Hall Layout



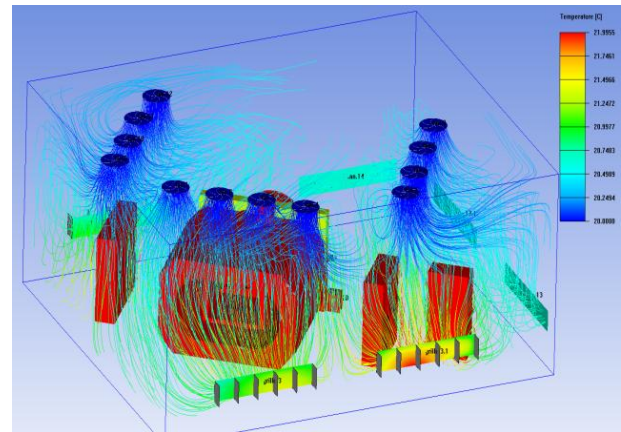
Other supporting:

- Accelerator upgrade (Done)
- Gas system (Done)
- Beam line optimization (Done)
- Background noise treatment (Done)
- Radiation control (Done)

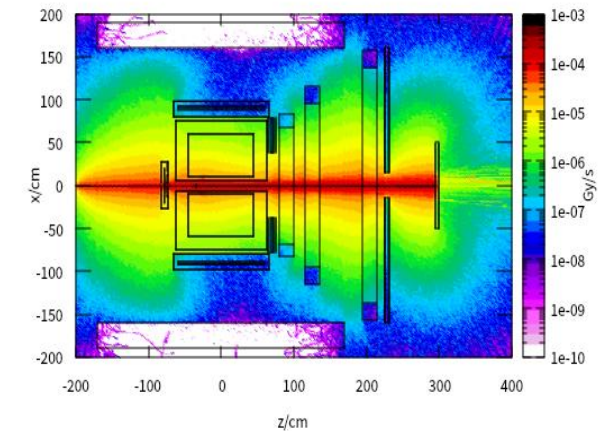
Sub-detectors installation



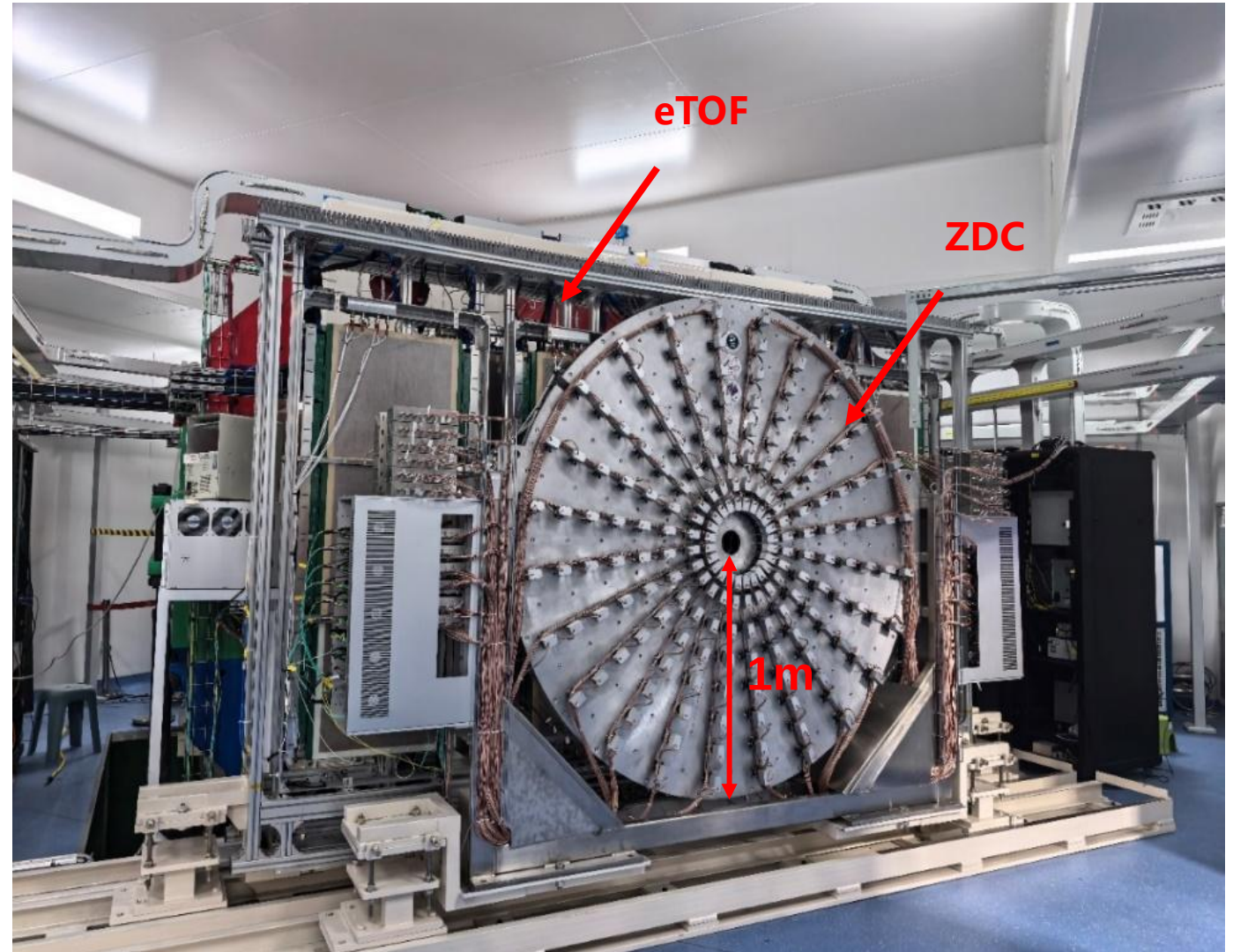
Heat simulation



Radiation dose simulation



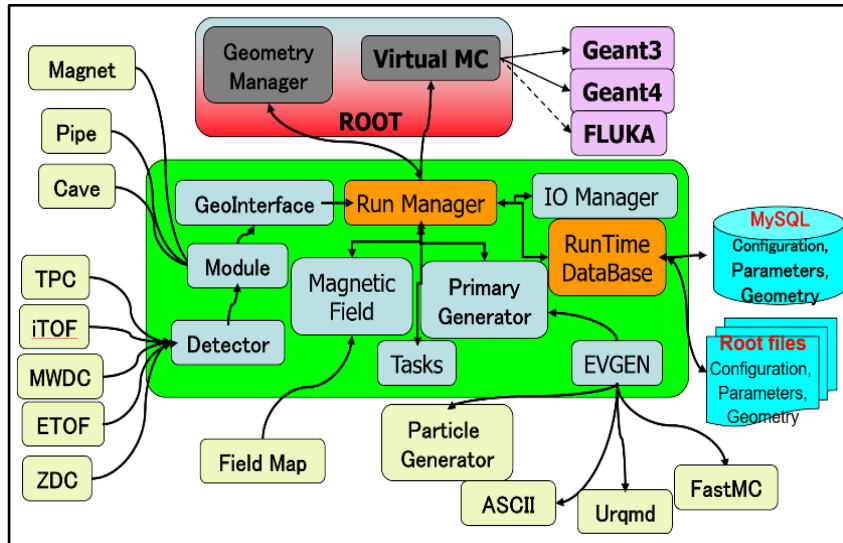
CEE Detector Without Magnet



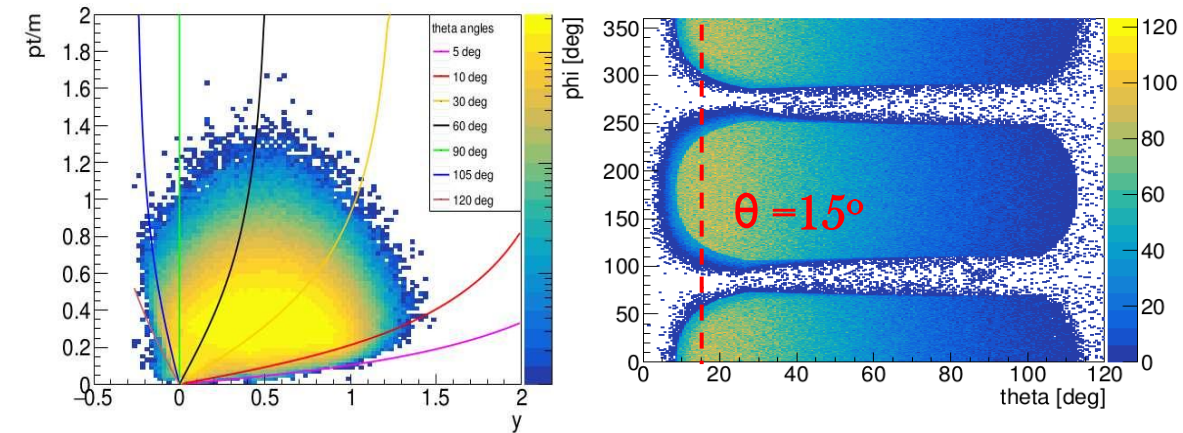
CeeROOT: CEE Simulation & Analysis Software

FairROOT Platform (<https://fairroot.gsi.de>)

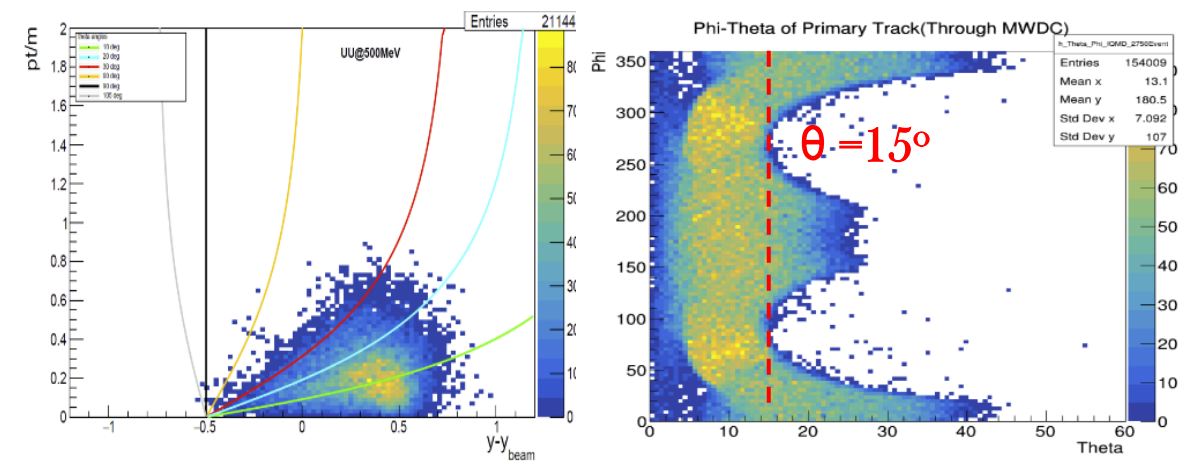
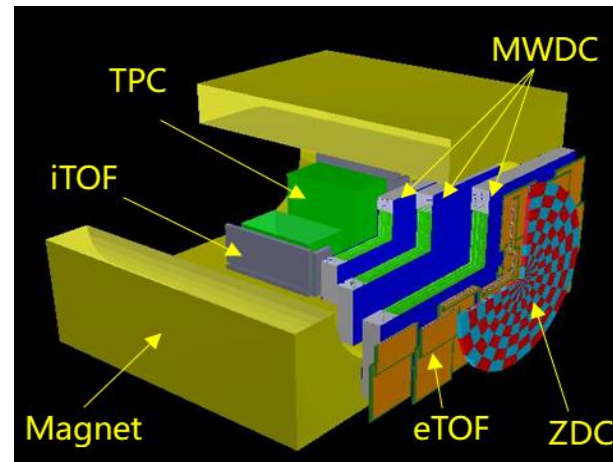
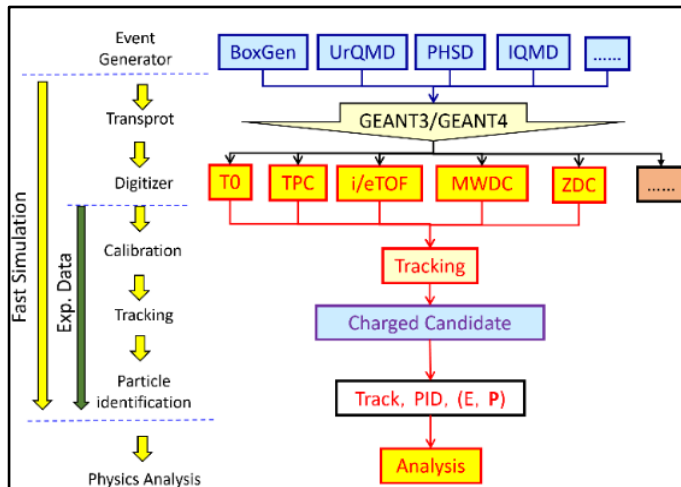
TPC acceptance



CeeROOT
Home page:
<https://gitee.com/C-EESM/CeeRoot>
(Open source)



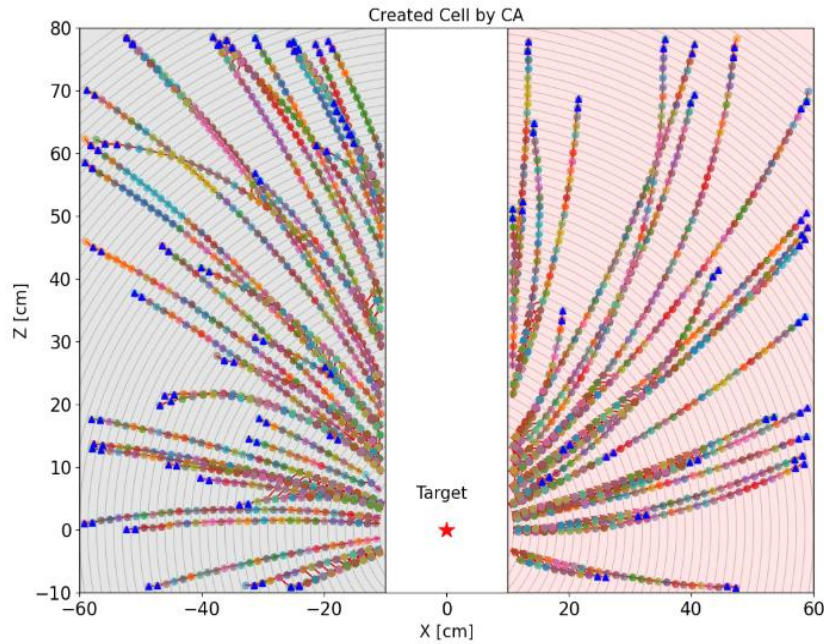
MWDC acceptance



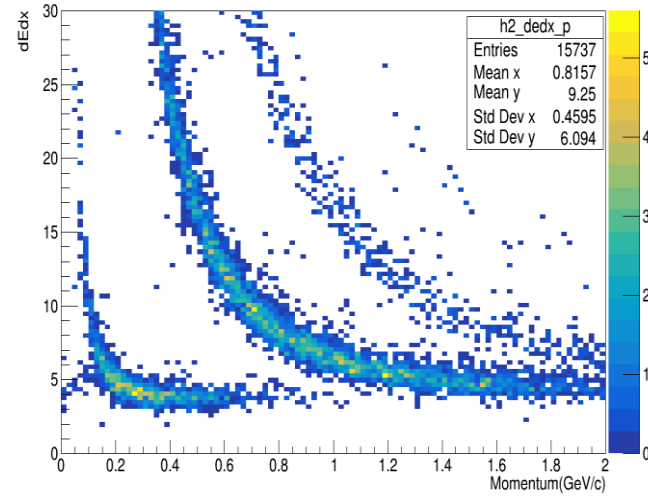
CEE Simulation

- Track finder
Cellular Automaton (CA)
- Track fitting
Kalman filter (Genfit)
- Vertex fitting: RAVE

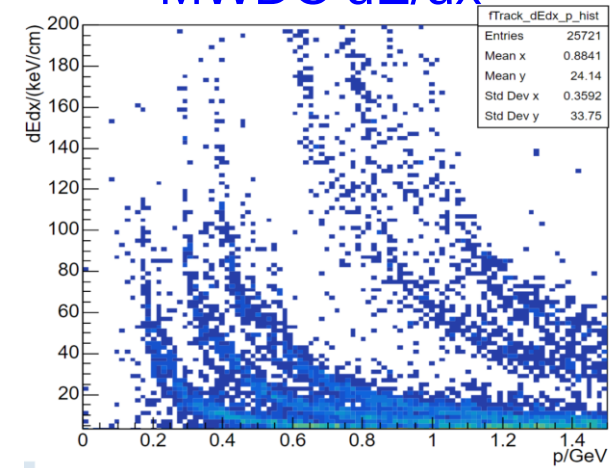
TPC tracking



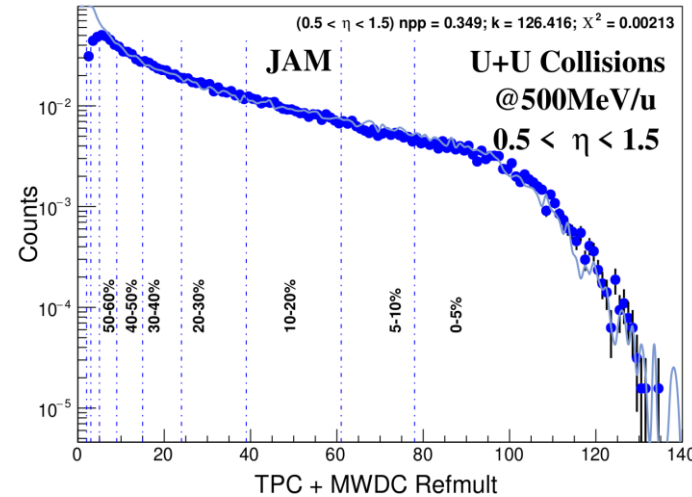
TPC dE/dx



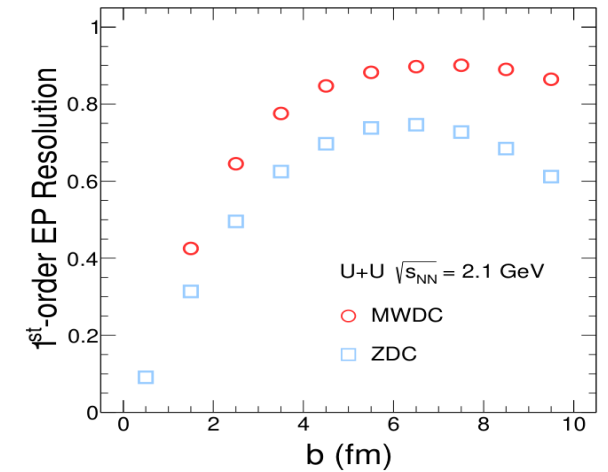
MWDC dE/dx



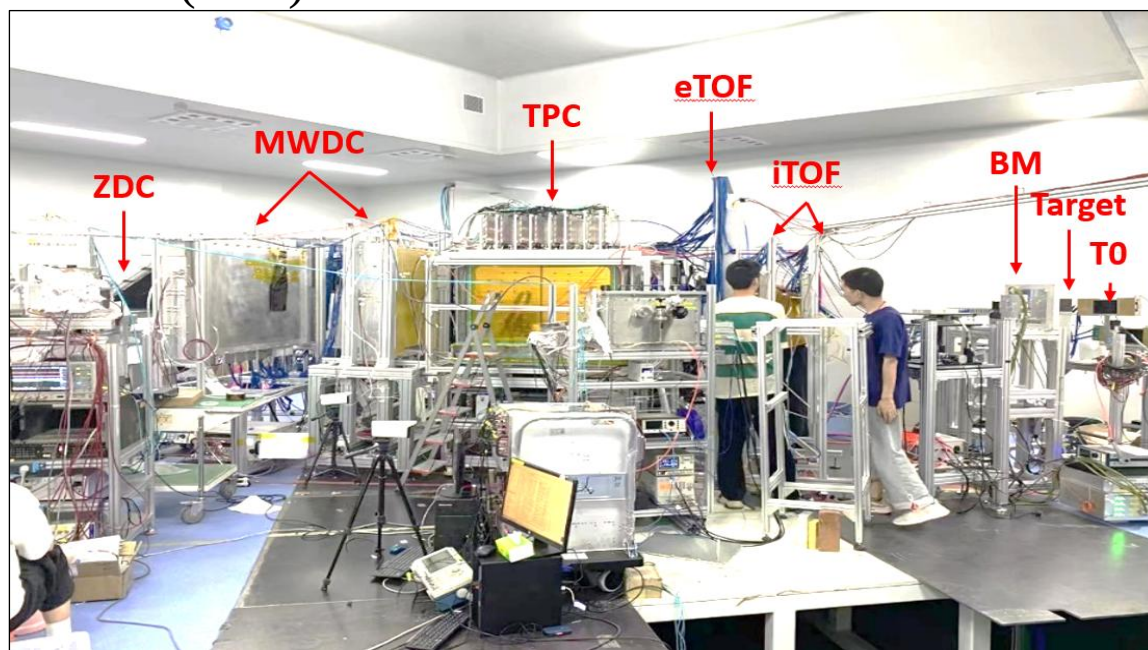
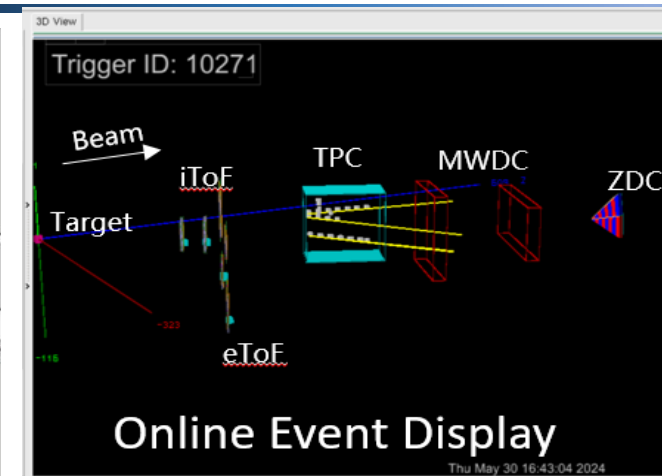
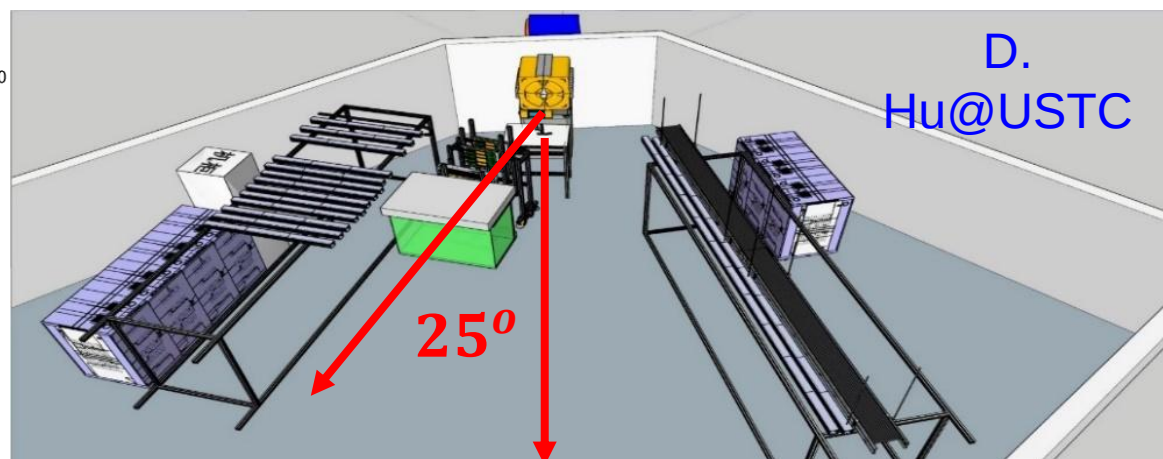
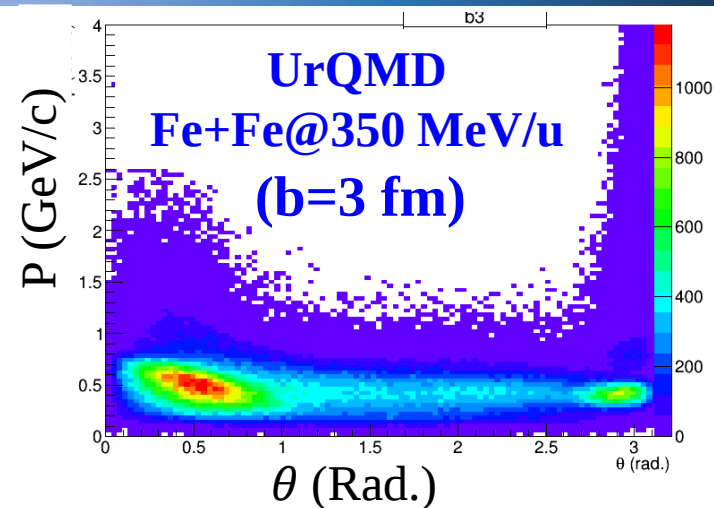
Centrality definition



Event plane resolution

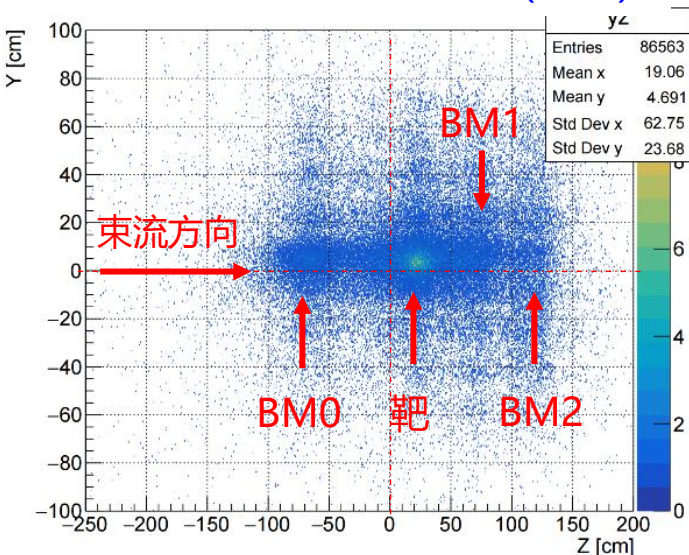


Beam Test: Fe+Fe@350 MeV/u (May 2024)

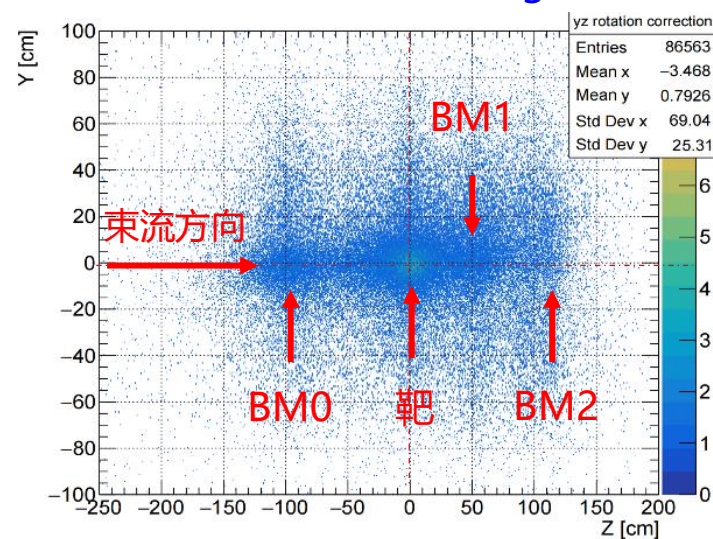


Vertex Reconstruction and Matching

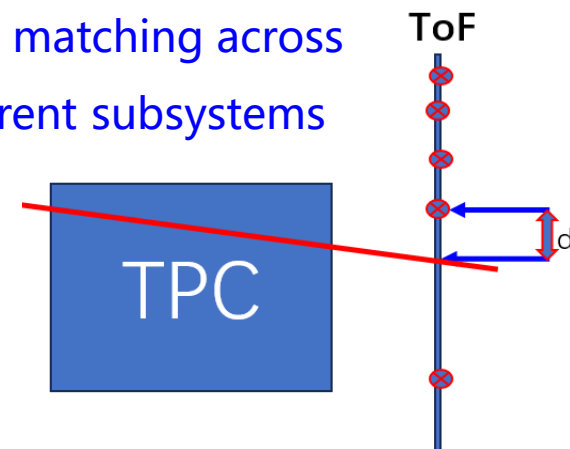
Vertex Reconstruction (X=0)



Vertex with TPC alignment



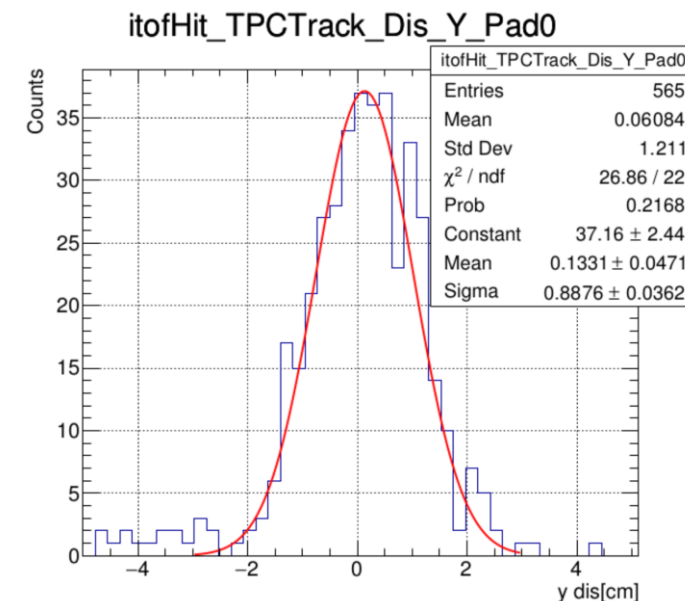
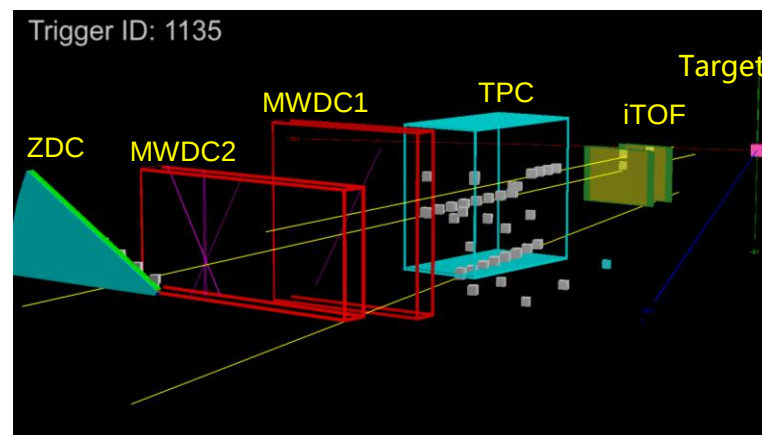
Data matching across different subsystems



Detectors on the beam line

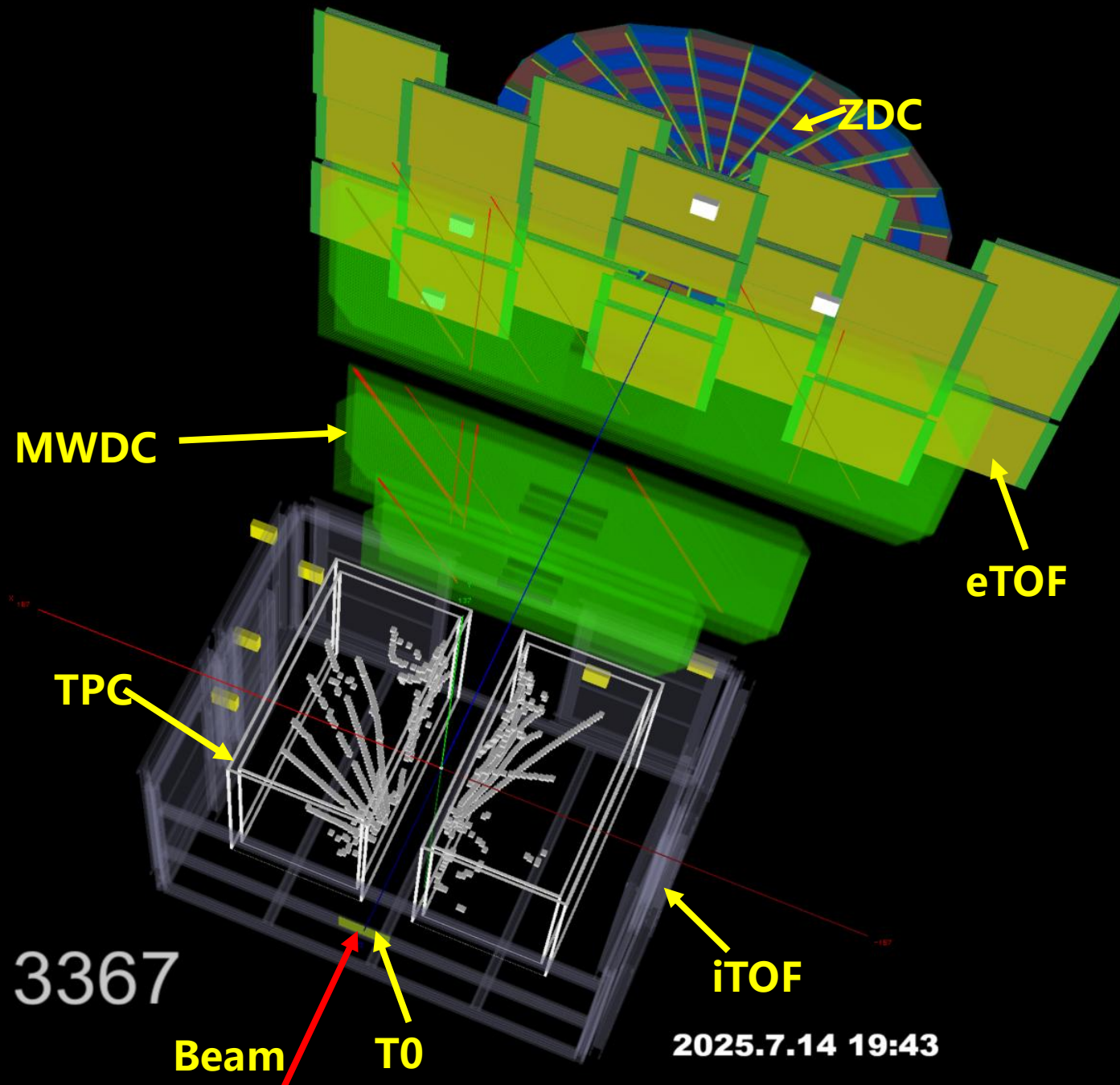


Detector Alignment



CEE

320 MeV/u Sn+Pb

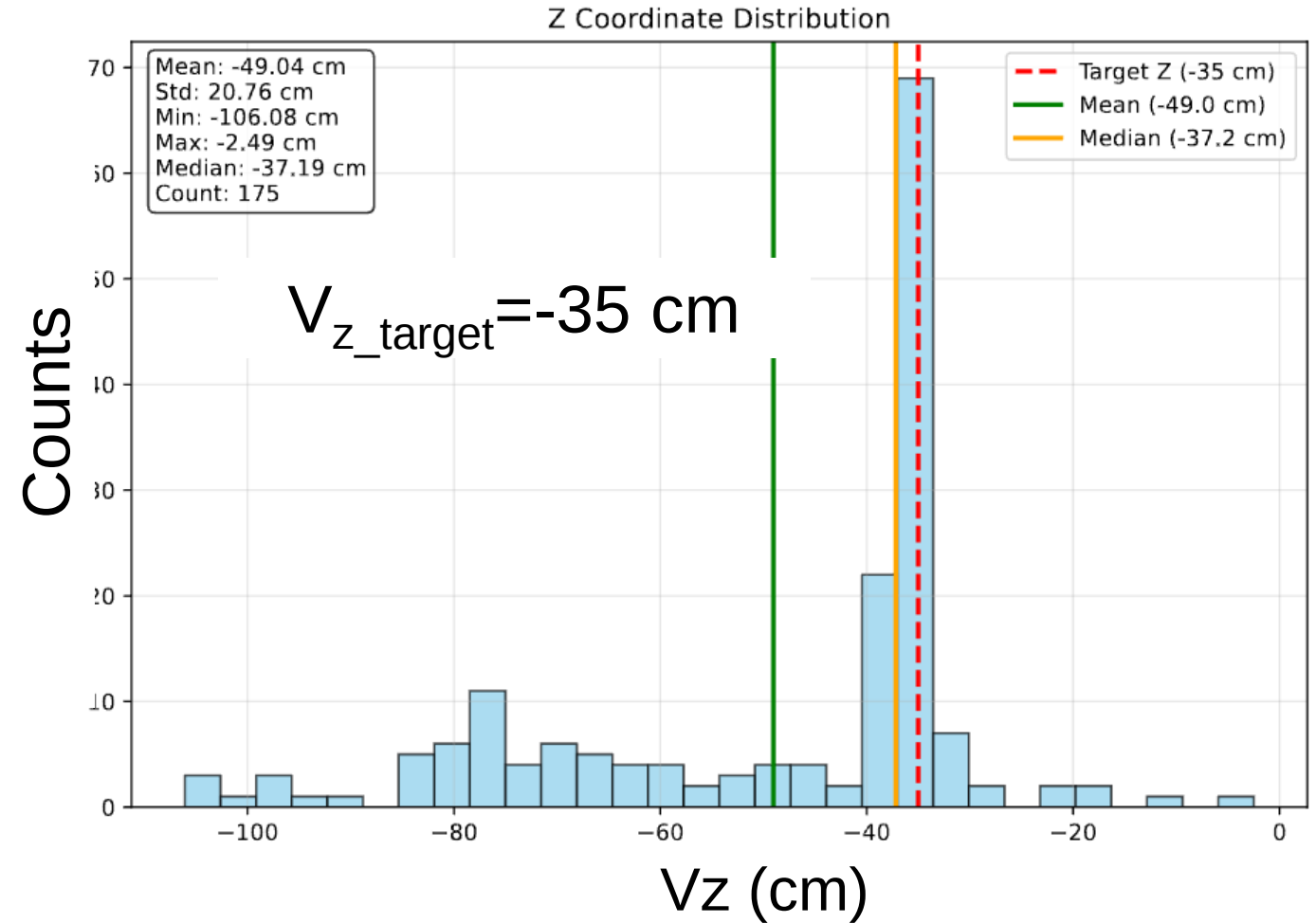
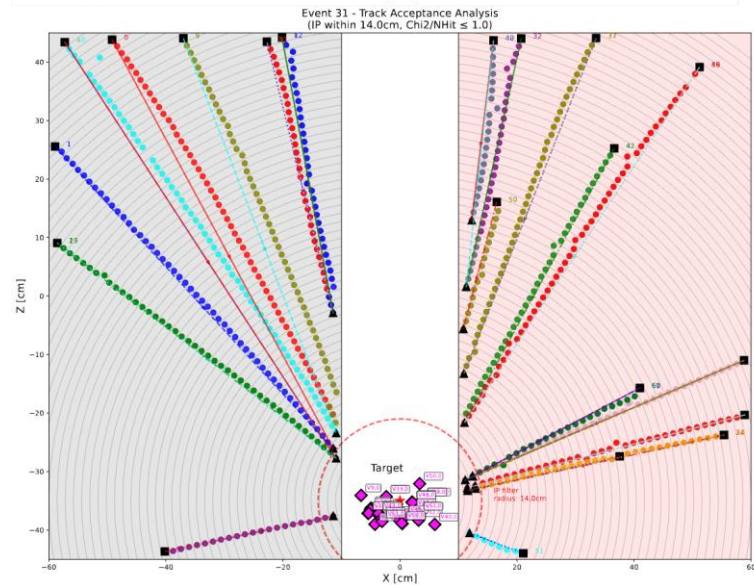
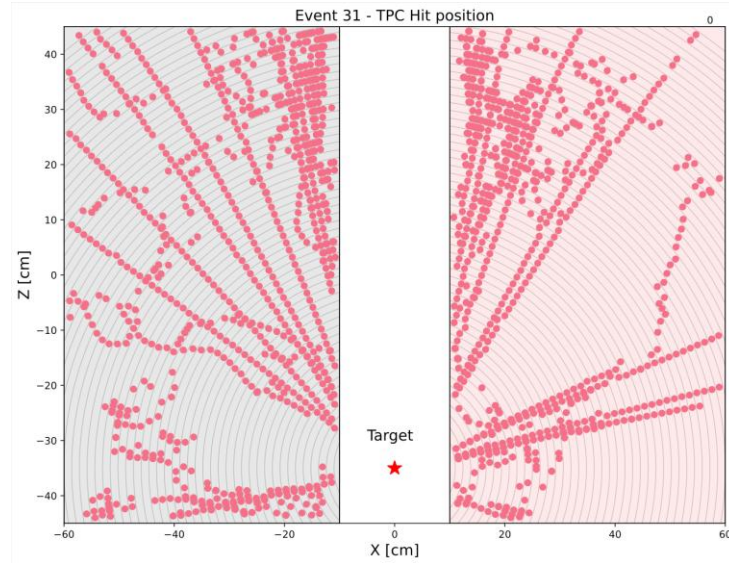


Trigger ID: 3367

2025.7.14 19:43

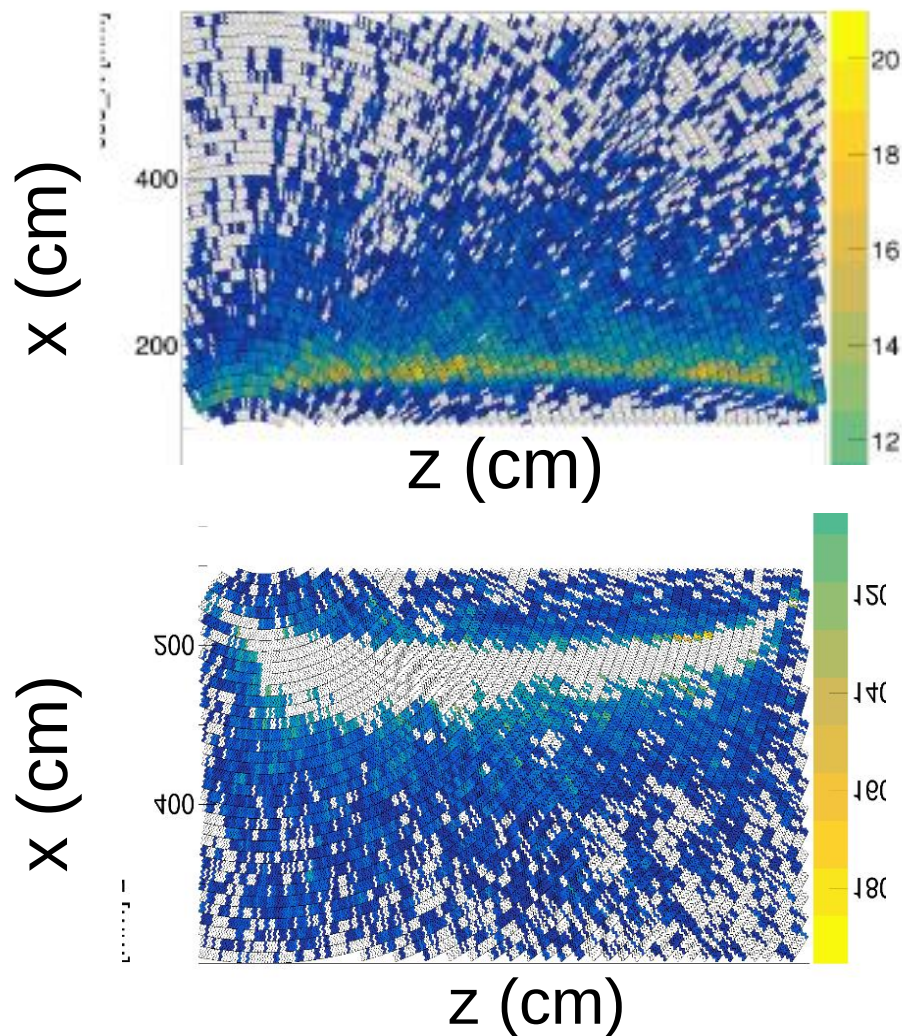
Vertex Fitting

320 MeV/u Sn+Pb

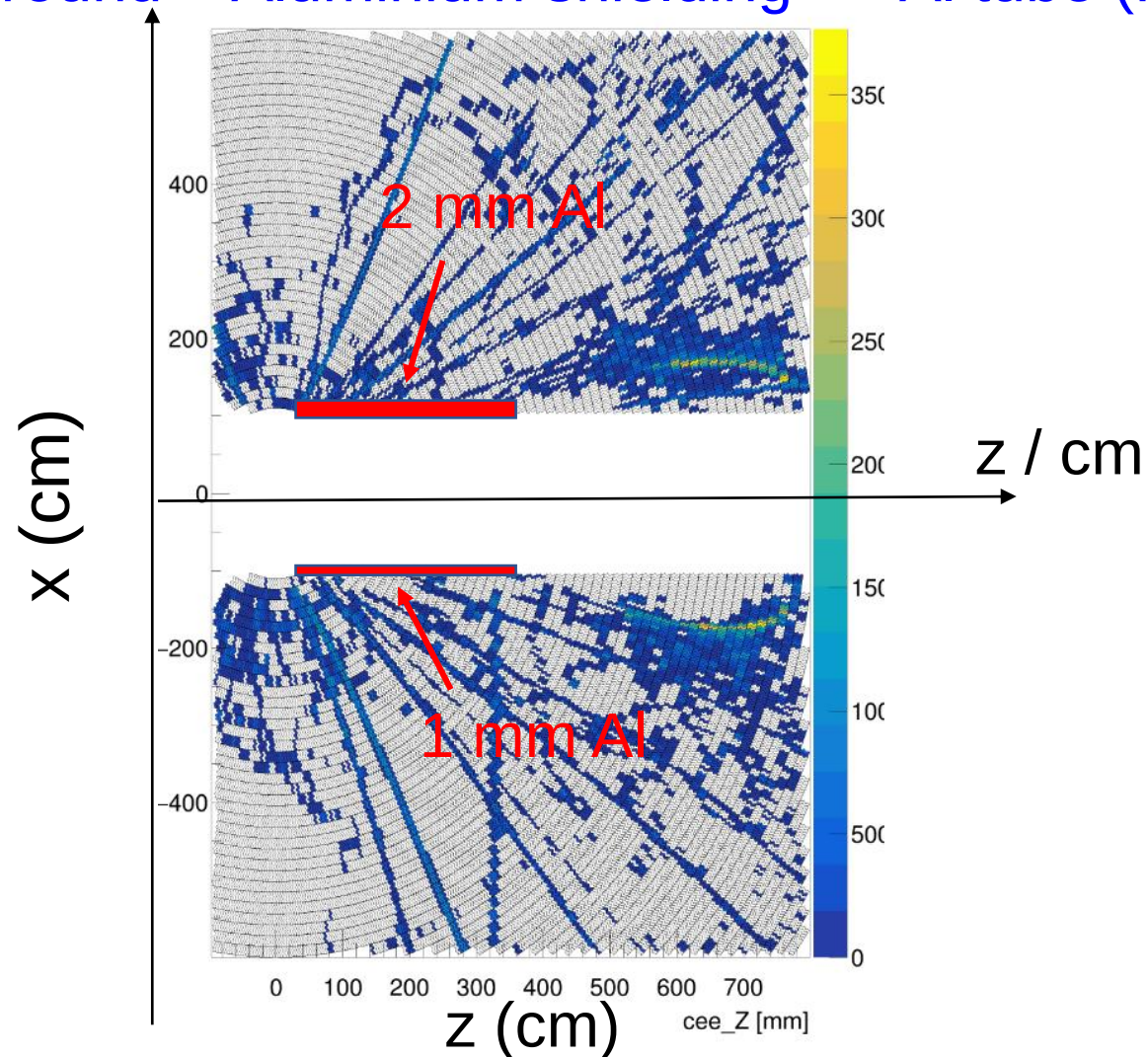


320 MeV/u $^{112}\text{Sn}+\text{Air}$ (July 2025)

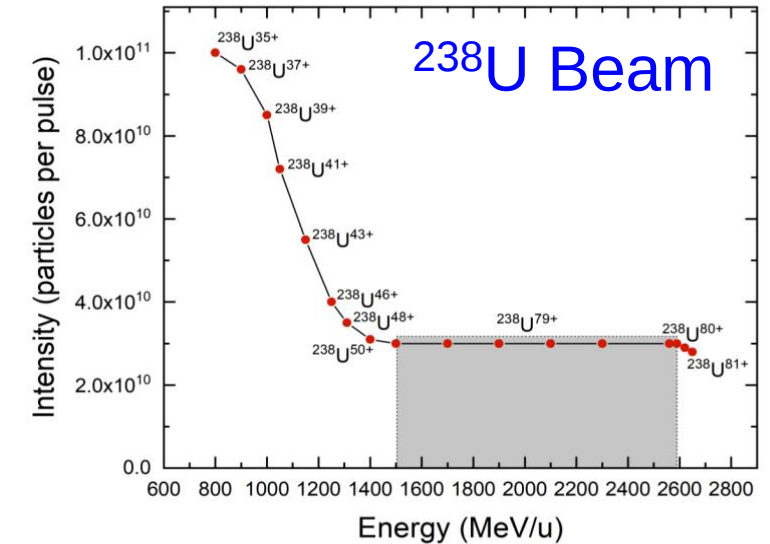
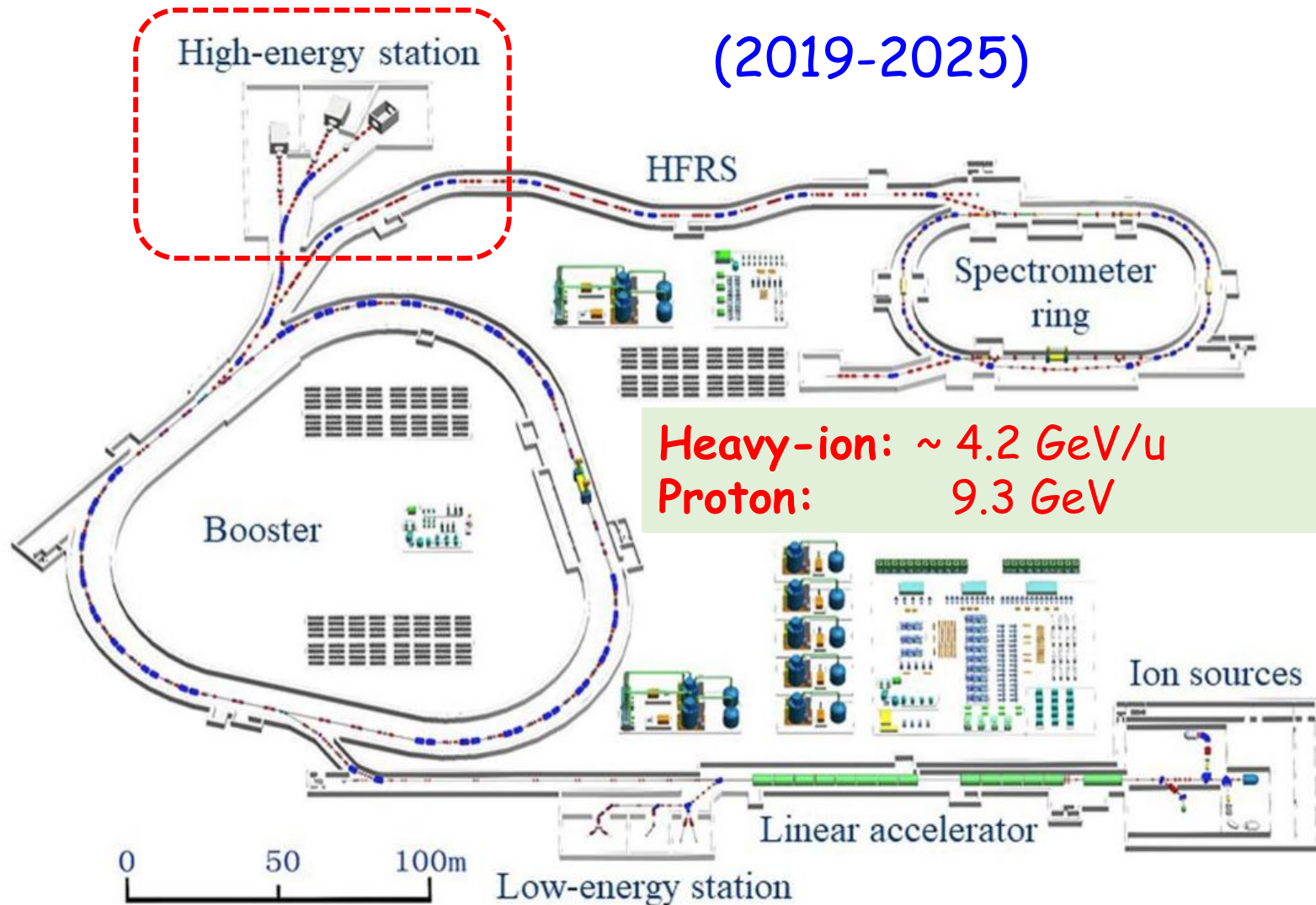
Background



Background + Aluminium shielding $\Rightarrow$ Al tube (He)



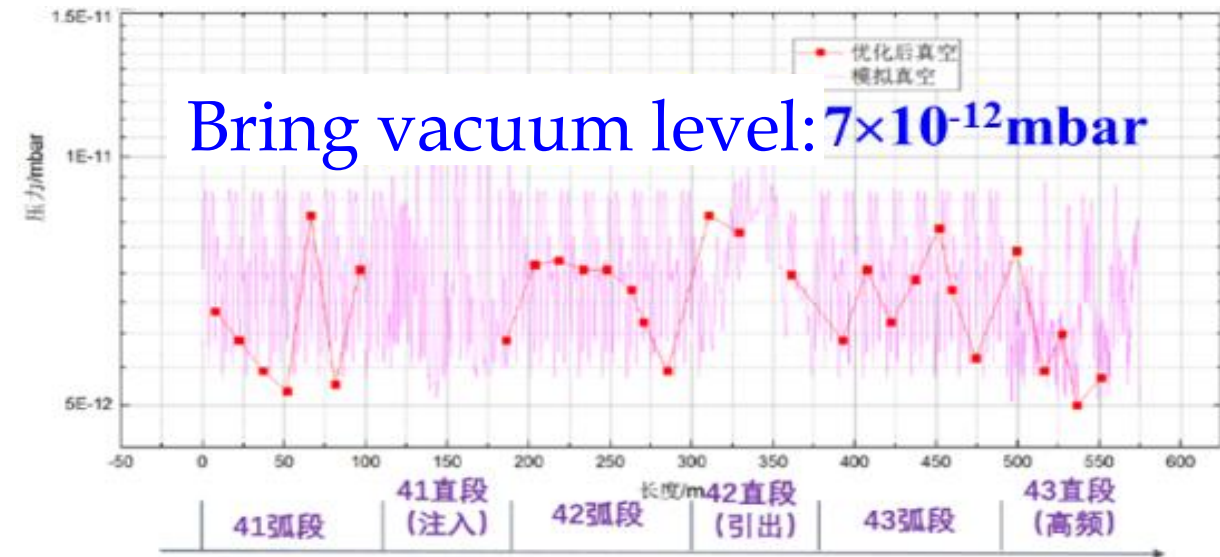
High Intensity heavy-ion Accelerator Facility (HIAF)



With pp/pA/AA at HIAF

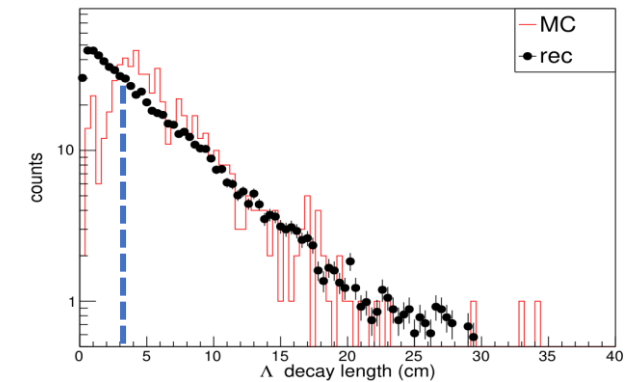
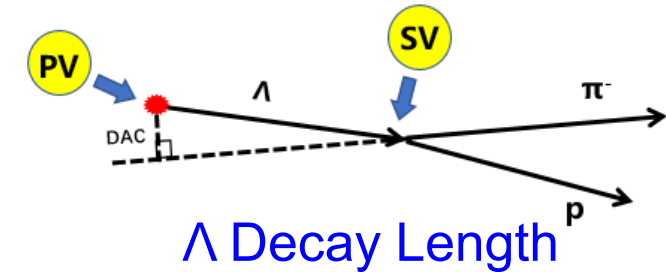
- Phase diagram
- EoS & neutron star
- Strangeness & hypernuclei
- In-medium effect of hadron
- Short range correlation
- ...

HIAF Construction Status

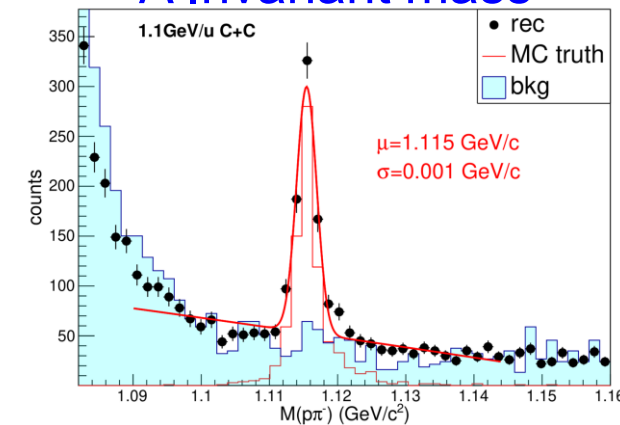


Summary

- ❑ CEE detection system installation was completed
- ❑ **First physics run: 1.1 GeV/u C+C/Au (no magnet) is scheduled in next month**
- ❑ CEE SC magnet needs 3~4 months
- ❑ CEE Spectrometer is expected to be in commissioning in 2026 with SC magnet (UU at 500 MeV/u)
- ❑ HIAF allows us to explore more physics at high-baryon density region



Λ Invariant mass





Thanks for your attention!