

The 16th Workshop on QCD Phase Transition and
Relativistic Heavy-Ion Physics (QPT 2025)

The Status of HIRFL-CSR External-target Experiment (CEE)

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Institute of Modern Physics, CAS

24-28, October 2025, Guilin

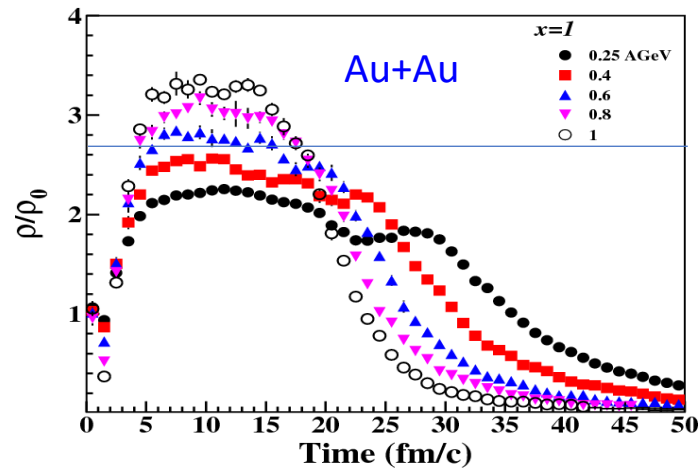
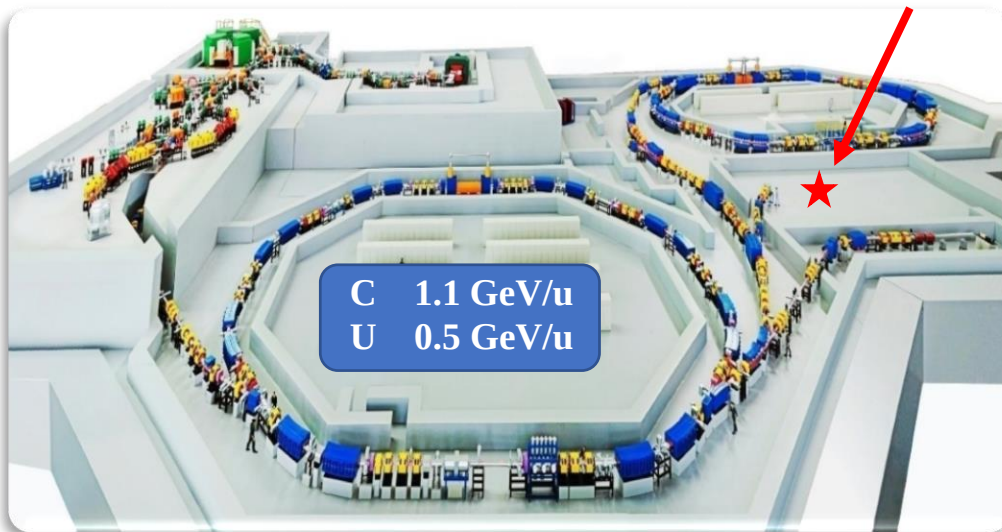
Outline

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

Heavy Ion Research Facility in Lanzhou- Cooling Storage Ring

HIRFL-CSR Complex

CEE



M. Zhang, ZGX et al., PRC 80 (2009) 034616

F. Fu ZGX et al, PLB 666 (2008) 359

Search for the QCD phase boundary/CEP at low temperature and high baryon density

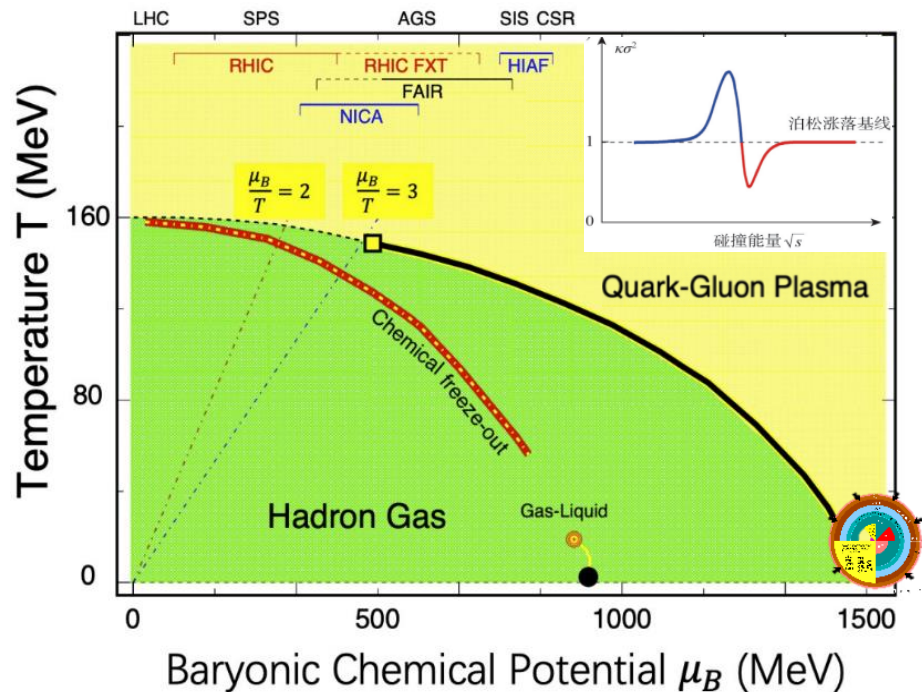
Nuclear equation of state at $\rho > 2\rho_0$ regime

Interplay with Neutron Star Physics

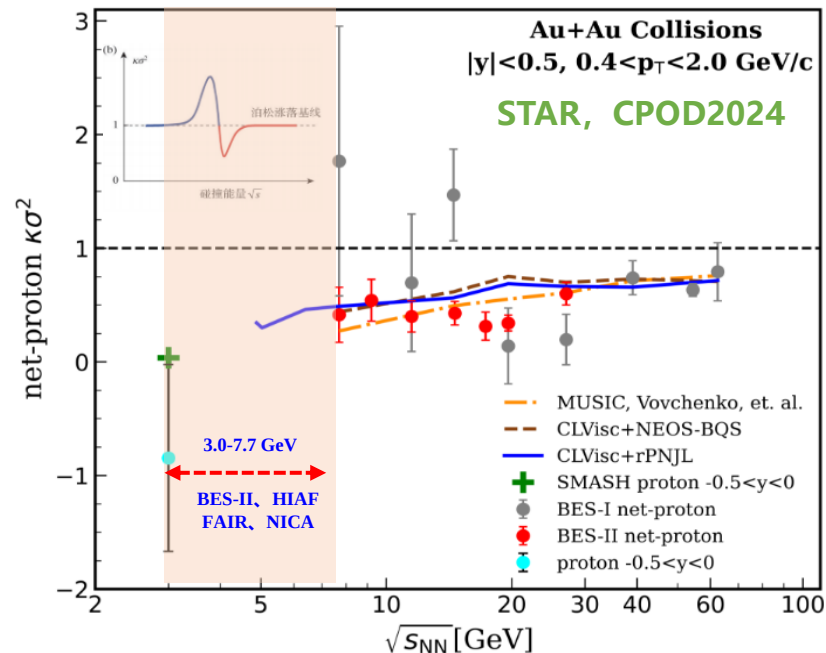
Sub-threshold production
Short range correlation

.....

QCD Phase Diagram



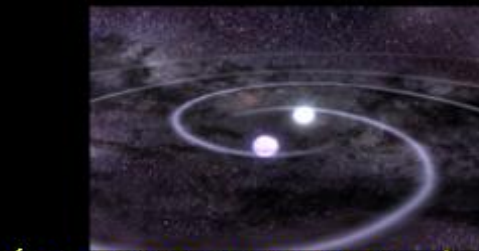
PRL 128, 202303 (2022)



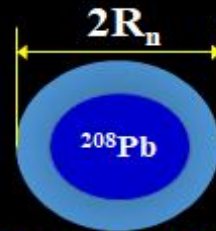
Nuclear Matter Equation of State (EoS)



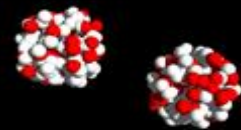
Neutron star



(Neutron Star and NS Merge)



(Static Properties of Nuclei)



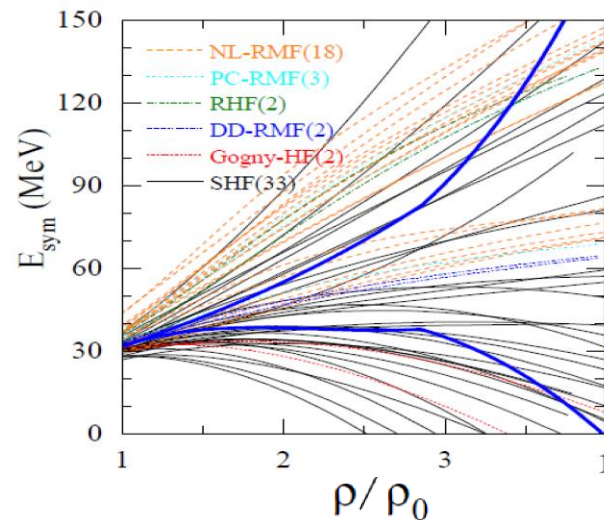
(Heavy Ion Collisions)

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

Symmetry Energy

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

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



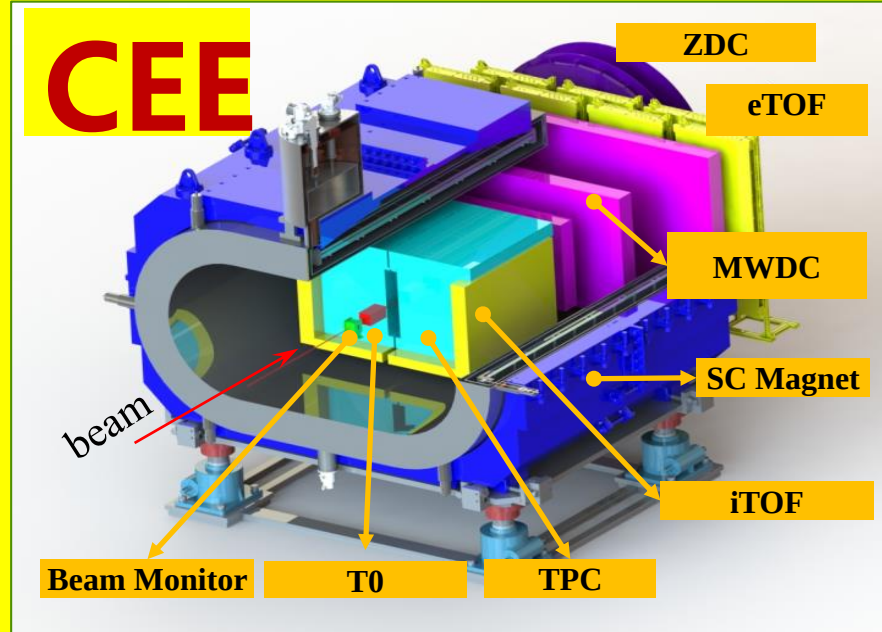
B.A Li et al. Universe, 7, 182(2021)

CEE Detection System

CEE Spectrometer:

- 1) Super-conducting Dipole Magnet
- 2) Si-PIX Beam Monitor (BM)
- 3) Time Projection Chamber (TPC)
- 4) T0/Inner TOF (iT0F)
- 5) External TOF (eTOF)
- 6) Multi-Wire Draft Chamber (MWDC)
- 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)
- 13) Software: simulation and analysis

Supported by NSFC and CAS



- $\Delta p/p: \leq 5\%, \Delta t/t: \leq 80\text{ps}$
- Max. Rate: 10 kHz
- Proton acceptance: $\sim 85\%$

CEE Collaboration

China:

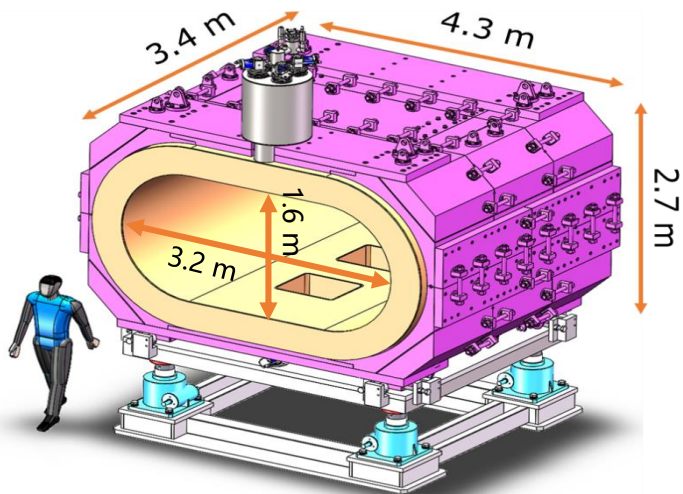
- Central China Normal University (CCNU)
- Fudan University (FDU)
- Institute of Modern Physics, CAS (IMP)
- Tsinghua University (THU)
- University of Science and Technology of China (USTC)
- Harbin Institute of Technology

Japan:

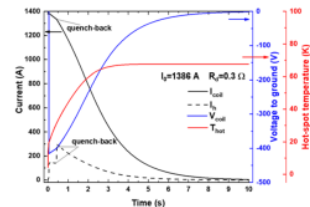
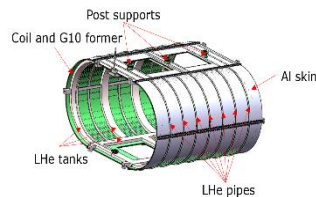
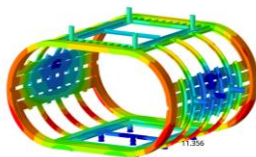
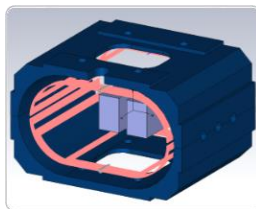
- Tsukuba University

Super-Conducting Dipole Magnet

Quantity	Performance
Central Field	0.5 T
Uniform range	1200×800×900 mm ³
Uniformity	±2.5%
Current in operation	231 A



Magnet design



SC Magnet prototype



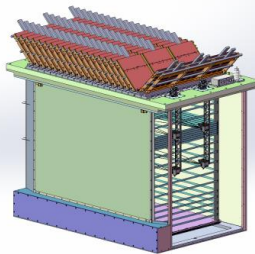
Magnet production



TPC development

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

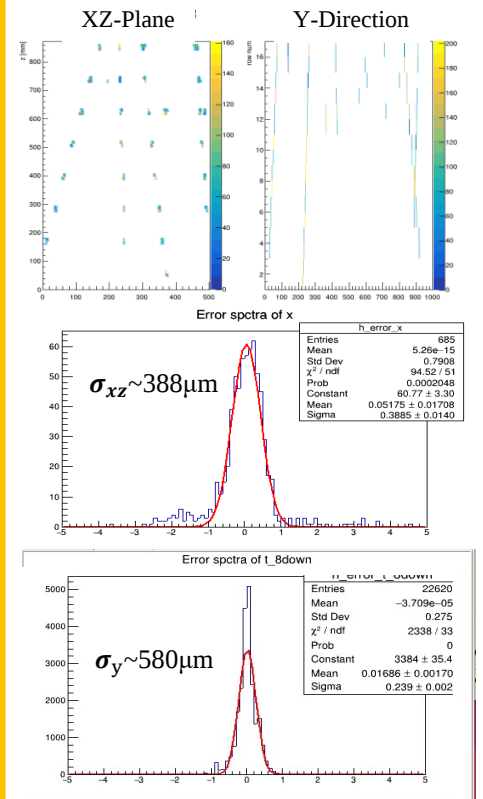
TPC design



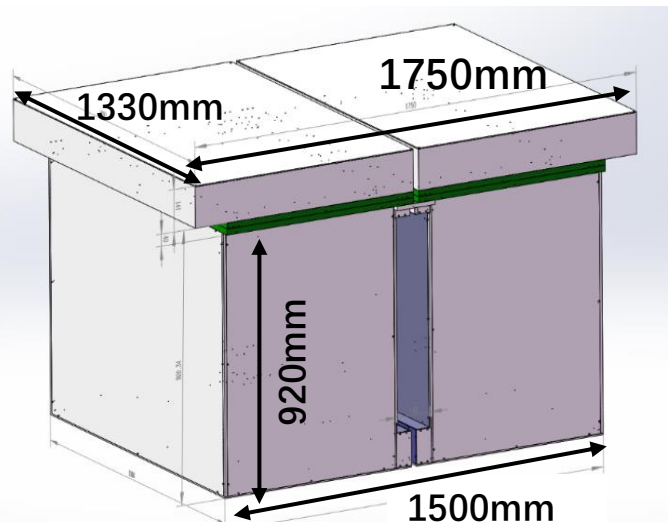
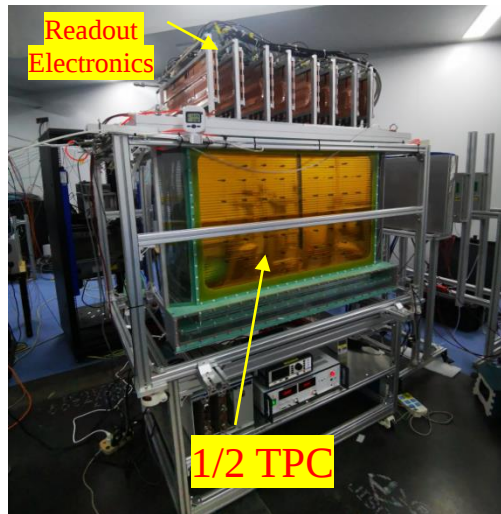
SAMPA-based readout



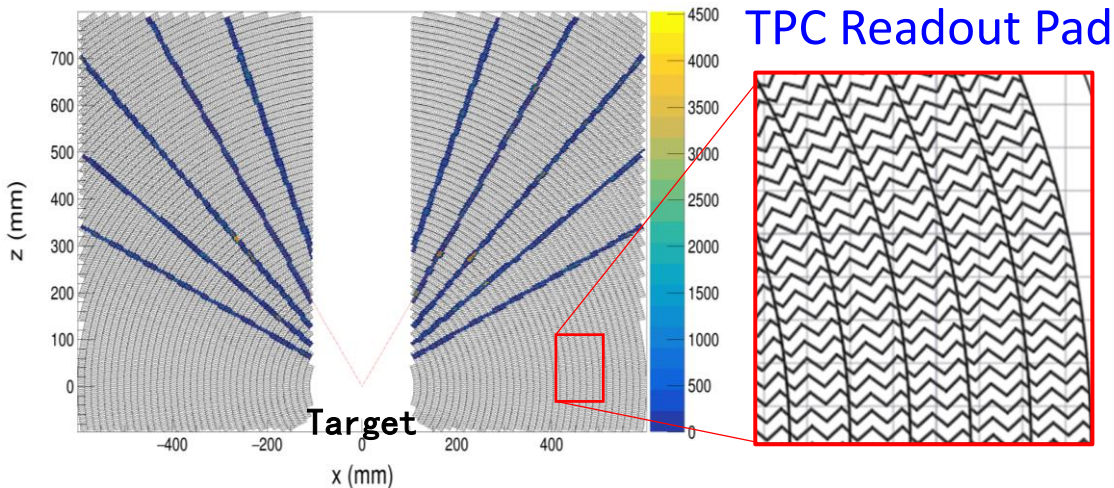
Beam Test Result



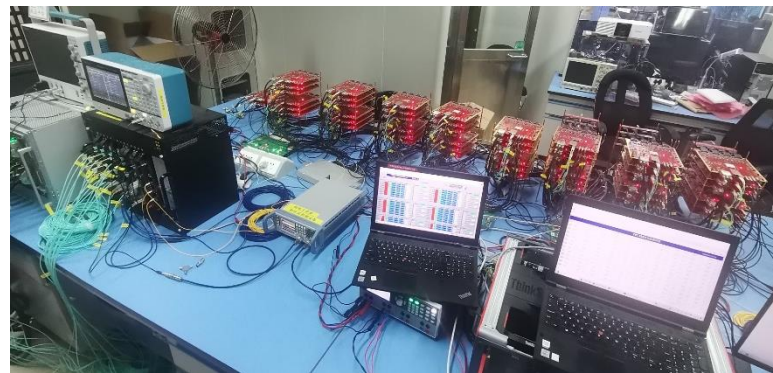
样机束流测试



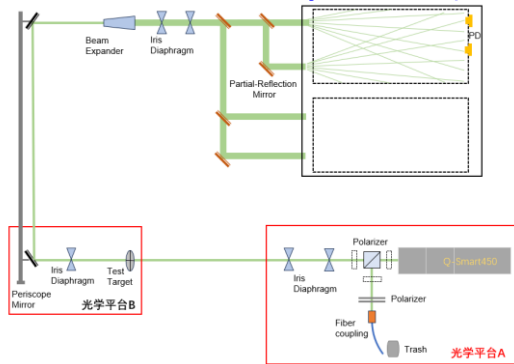
TPC Production



Electronics Stability Test



Laser system (14 beam $\times$ 3 layers)

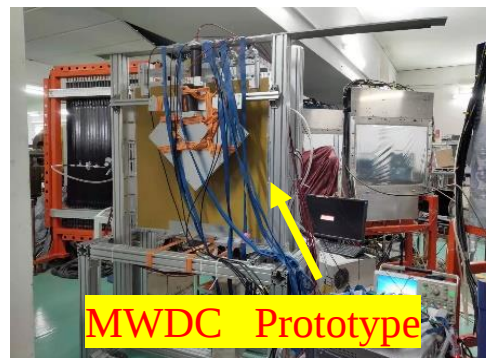


TPC Detectors

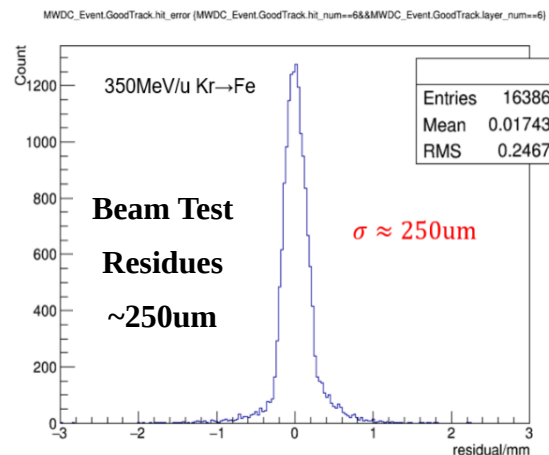
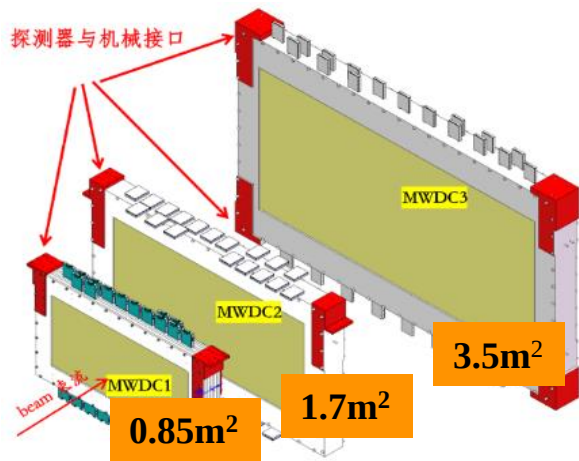
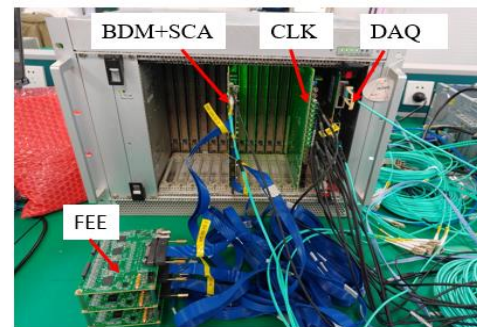


MWDC Development & Production

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%



Electronics Stability Test

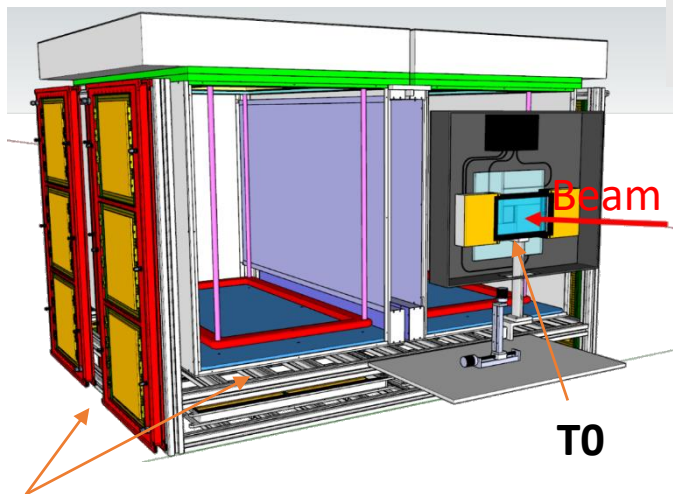


MWDC3 detector



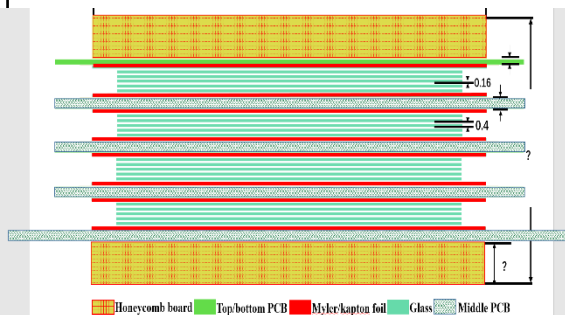
iTOF development & Production

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

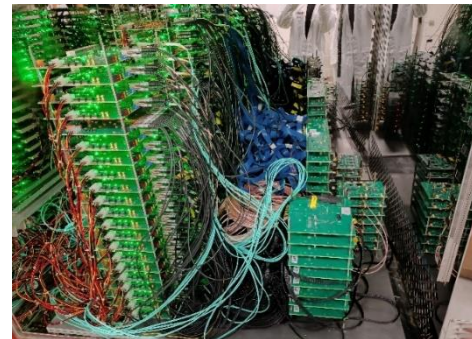


iTOF: covers 3 side of TPC

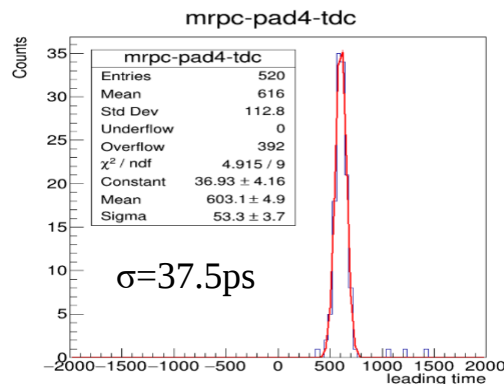
iTOF based MRPC Design



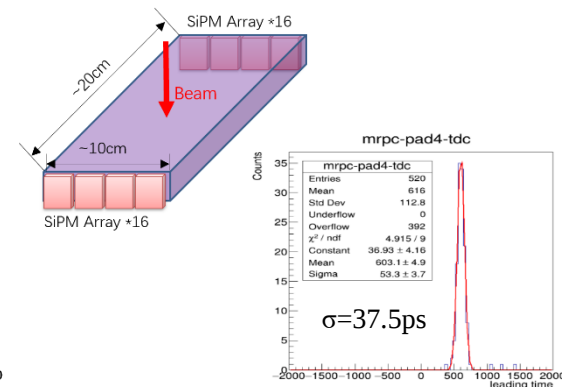
Electronics Stability Test



Beam test results

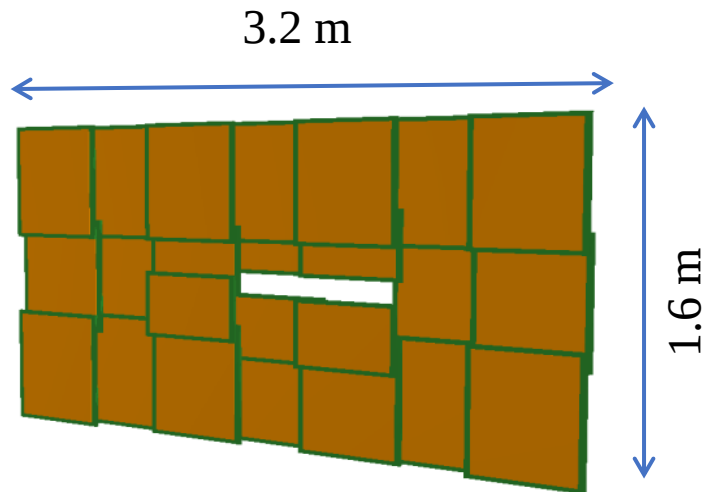


T0: Scintillator + SiPM

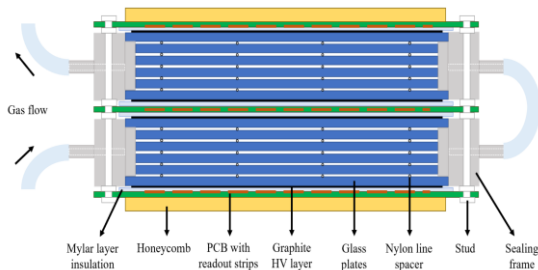


eTOF development

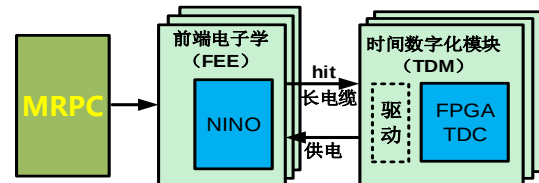
Quantity	Design index
σ_T	60 ps
Efficiency	>95%
Rate	>10kHz



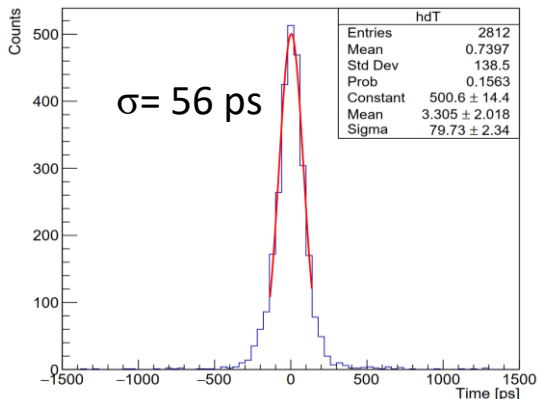
eTOF MRPC configuration



MRPC readout



Prototype time resolution



Massive Production



Zero Degree Counter (ZDC)

ZDC Parameters	Design index
Energy Resolution	< 15%
Detection Efficiency	> 95% (MIPs)

□ Event Plane

□ Centrality definition

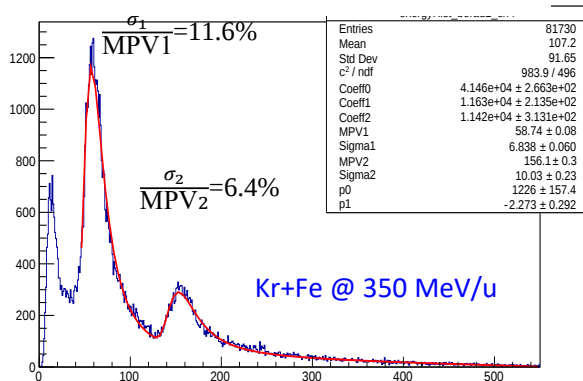
ZDC Prototype



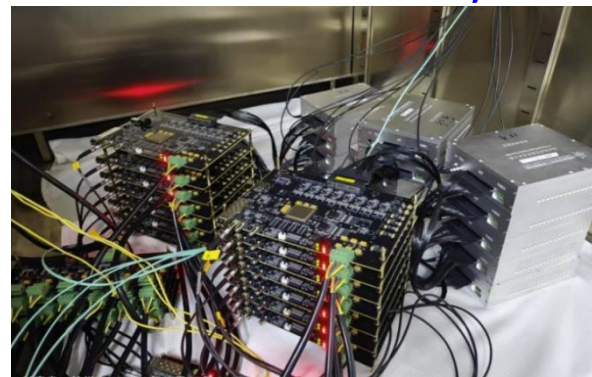
Massive Production



Beam test result



Electronics Stability Test

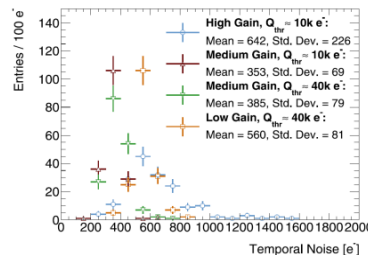
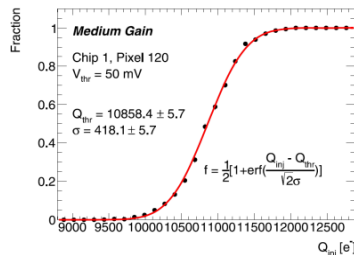
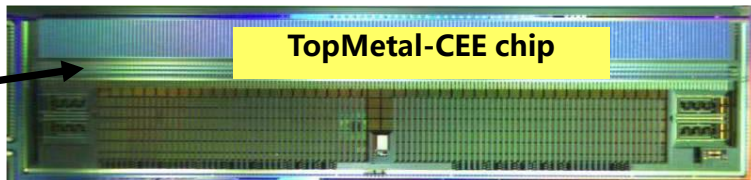
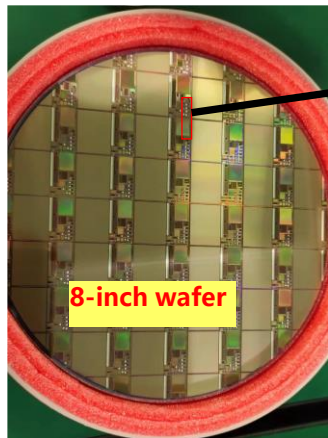
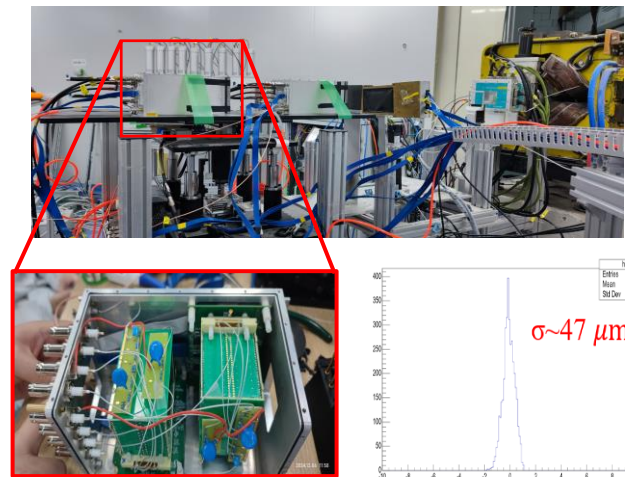
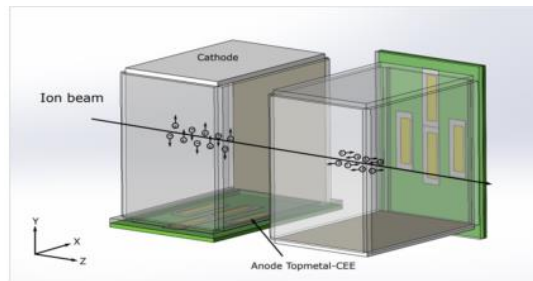


CCNU & Uni. Tsukuba

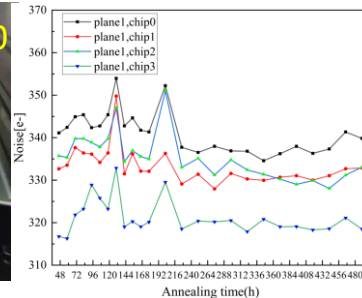
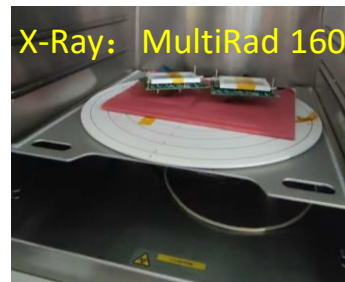
Beam Monitoring (BM) Detector

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

BM design



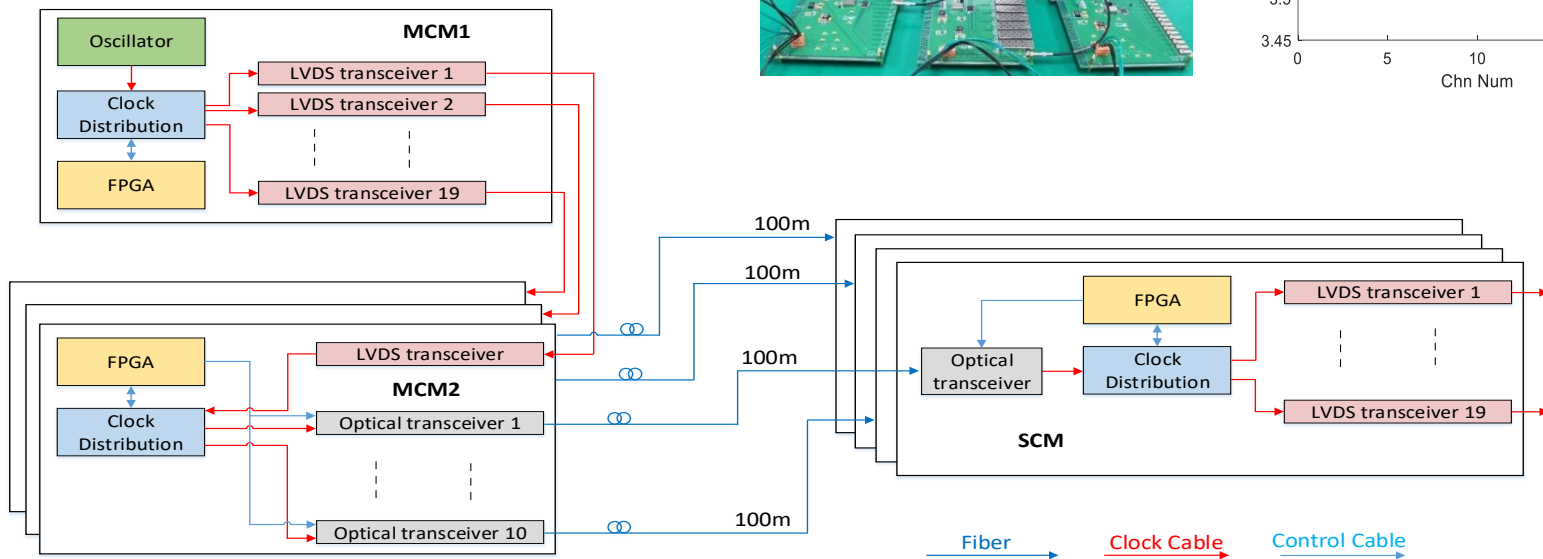
Electronics Stability Test



Clock System

- Frequency: 40 MHz
- Period jitter: < 10 ps RMS
- Fan-out channel: ~ 400
- Long distance transmission: ~ 10 m

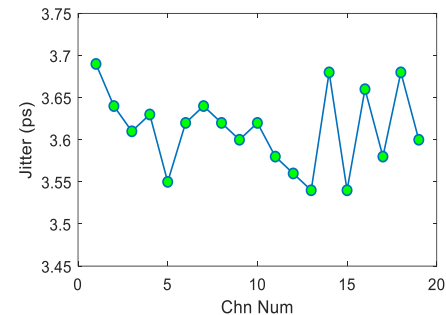
Clock system block diagram



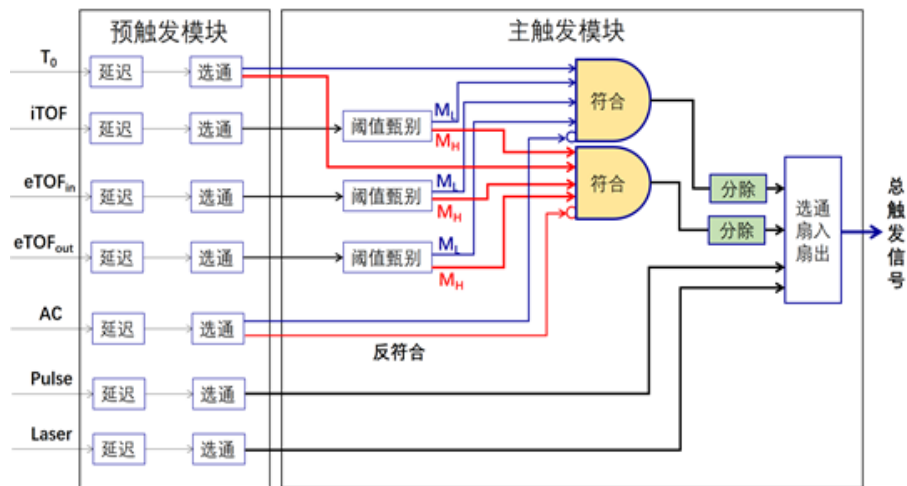
Test Setup



Test Result



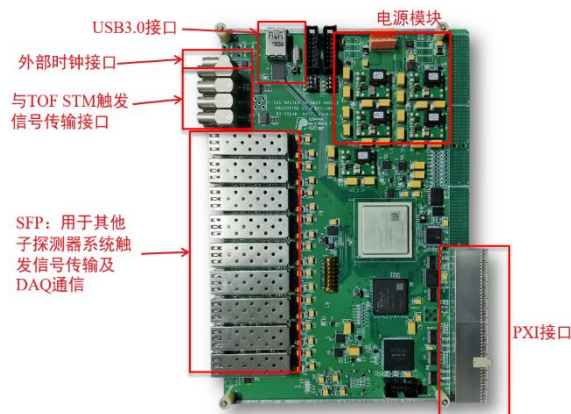
Trigger System (TS)



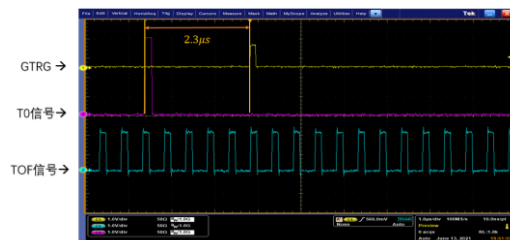
Working mode:

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

Lab test

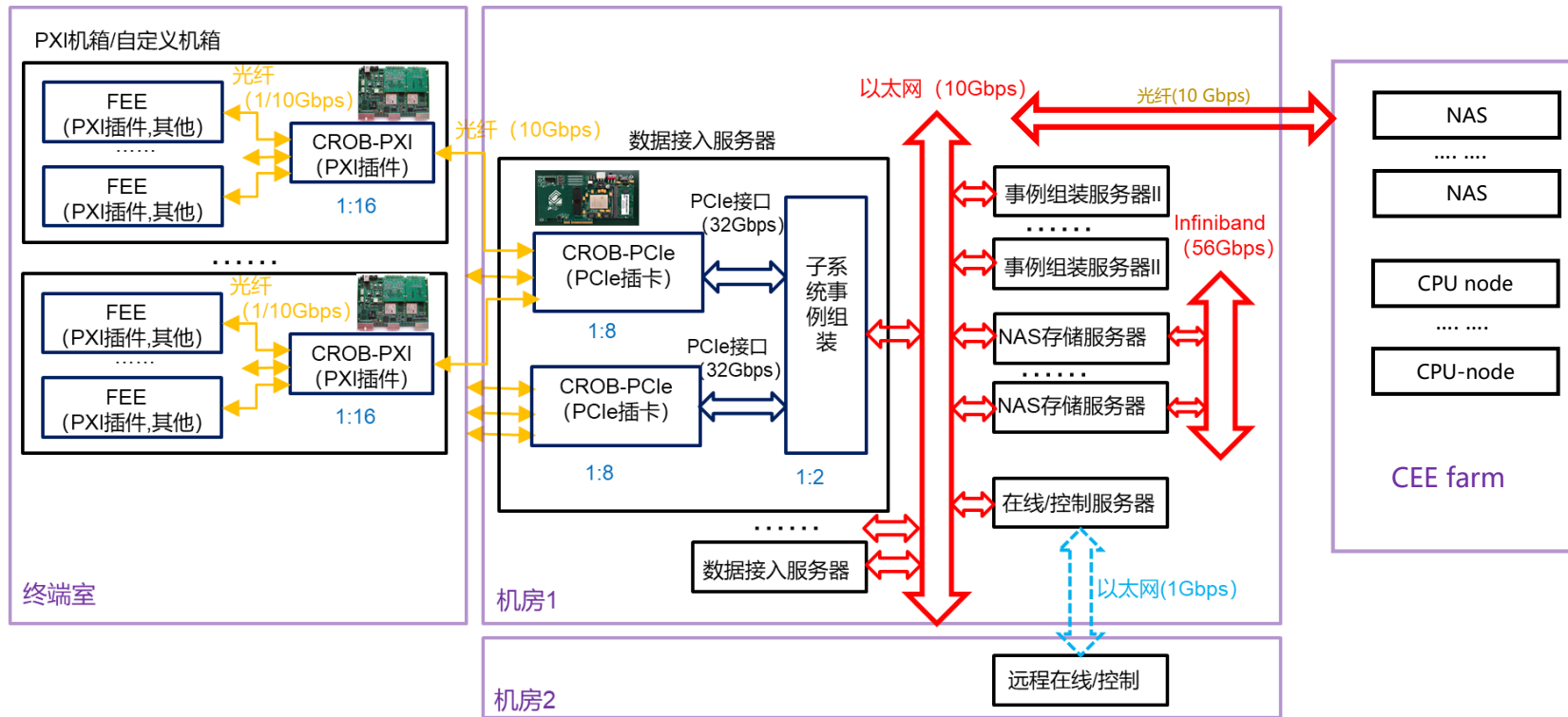


Trigger logic simulation

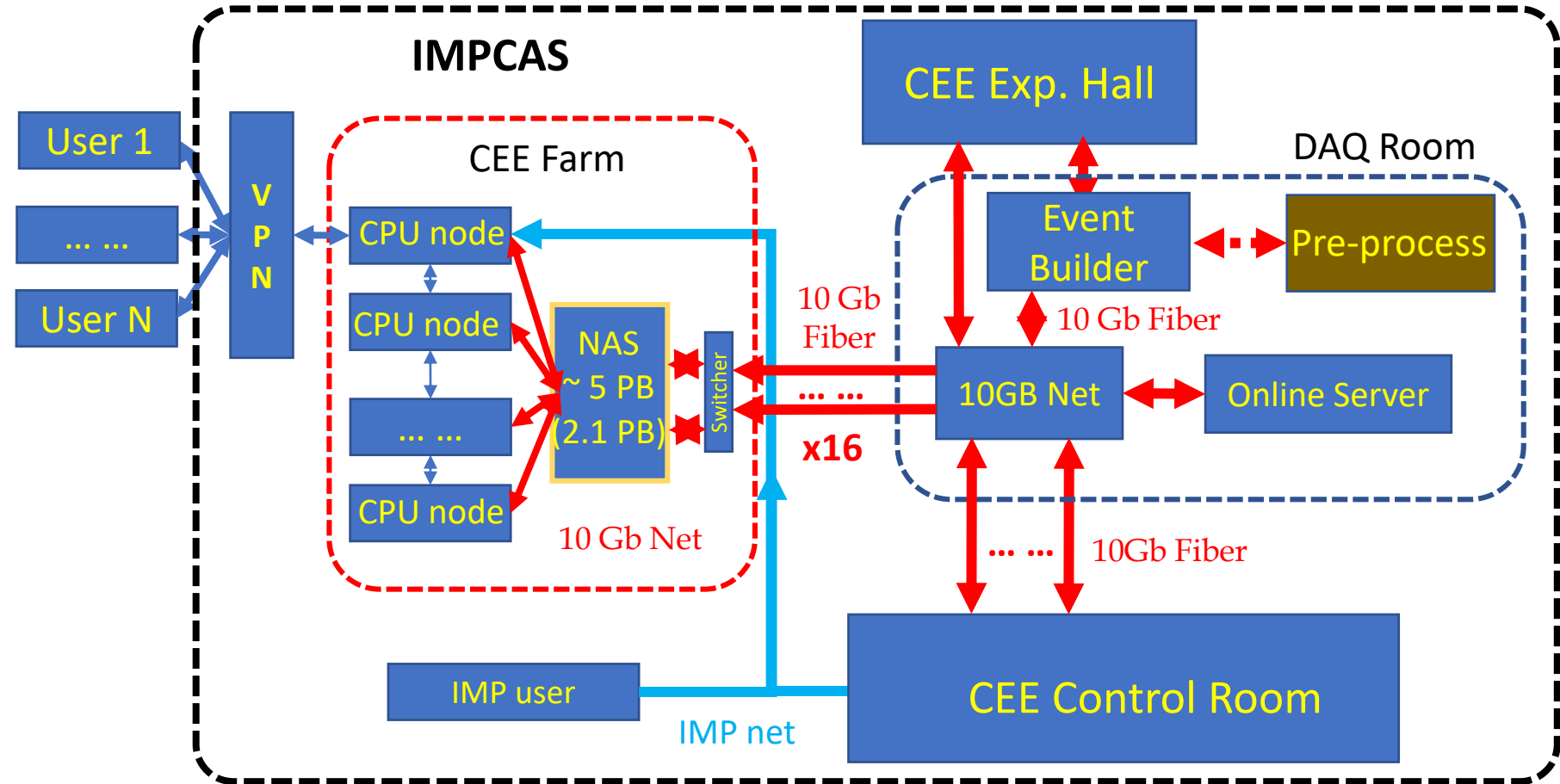


Data Acquisition System (DAQ)

Zero-suppressed data rate: ~ 4.4 Gbyte/s



Data flow and Computing

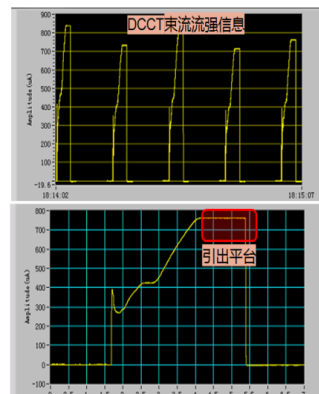
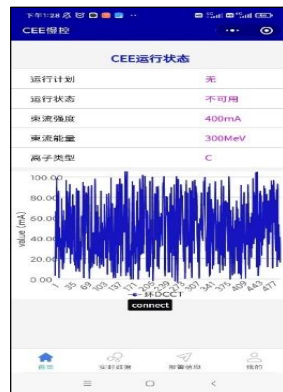
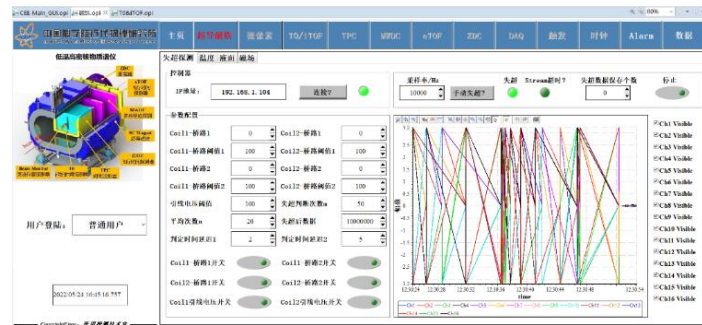
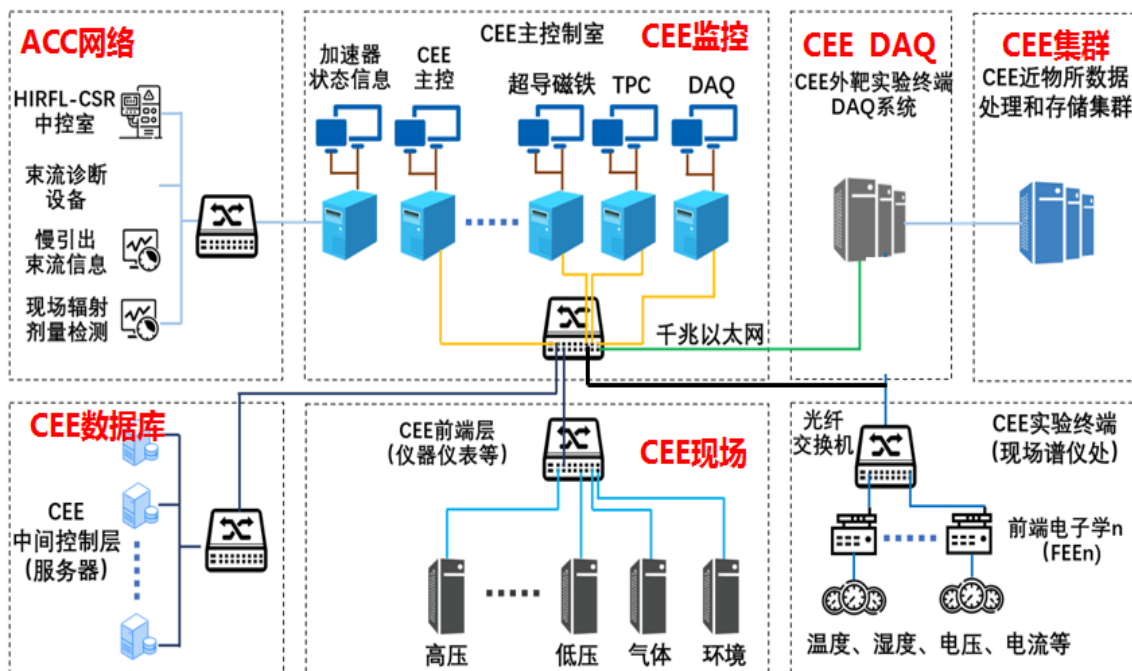


Slow Control (SC)

SC is based on the EPICS



Experimental Physics and
Industrial Control System

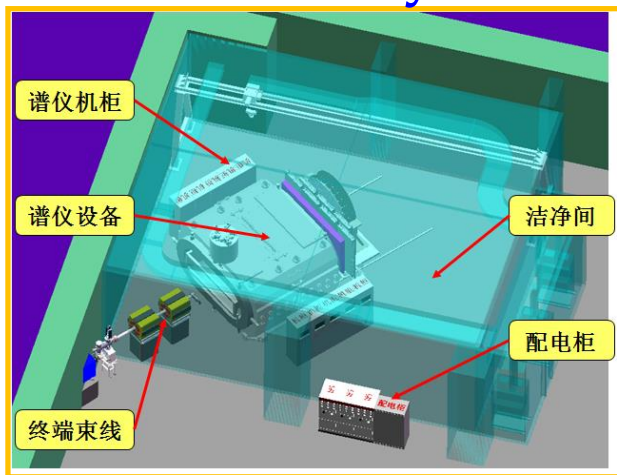


System Integration & Infrastructure

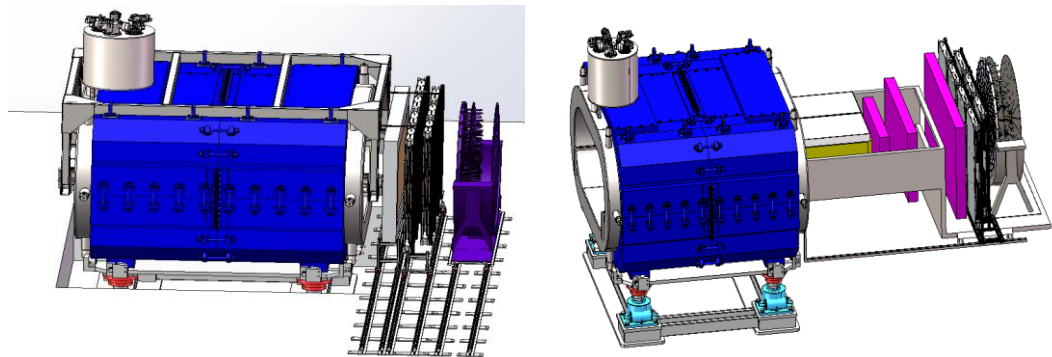


System Integration & Infrastructure

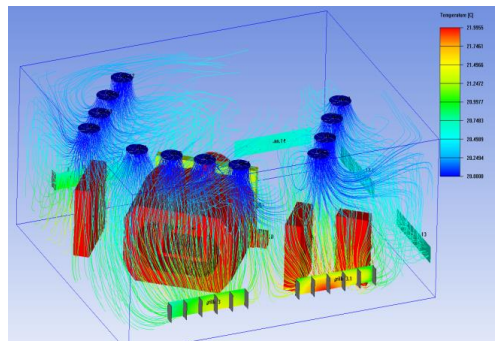
CEE Hall Layout



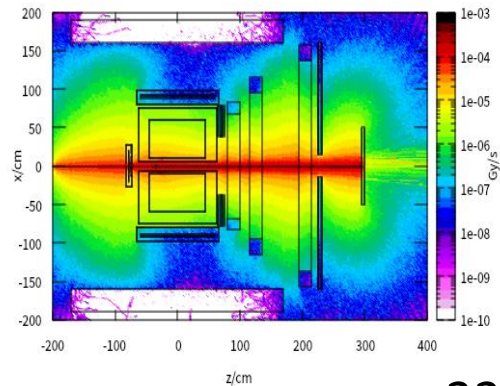
Assembly scheme



Heat simulation



Radiation dose simulation



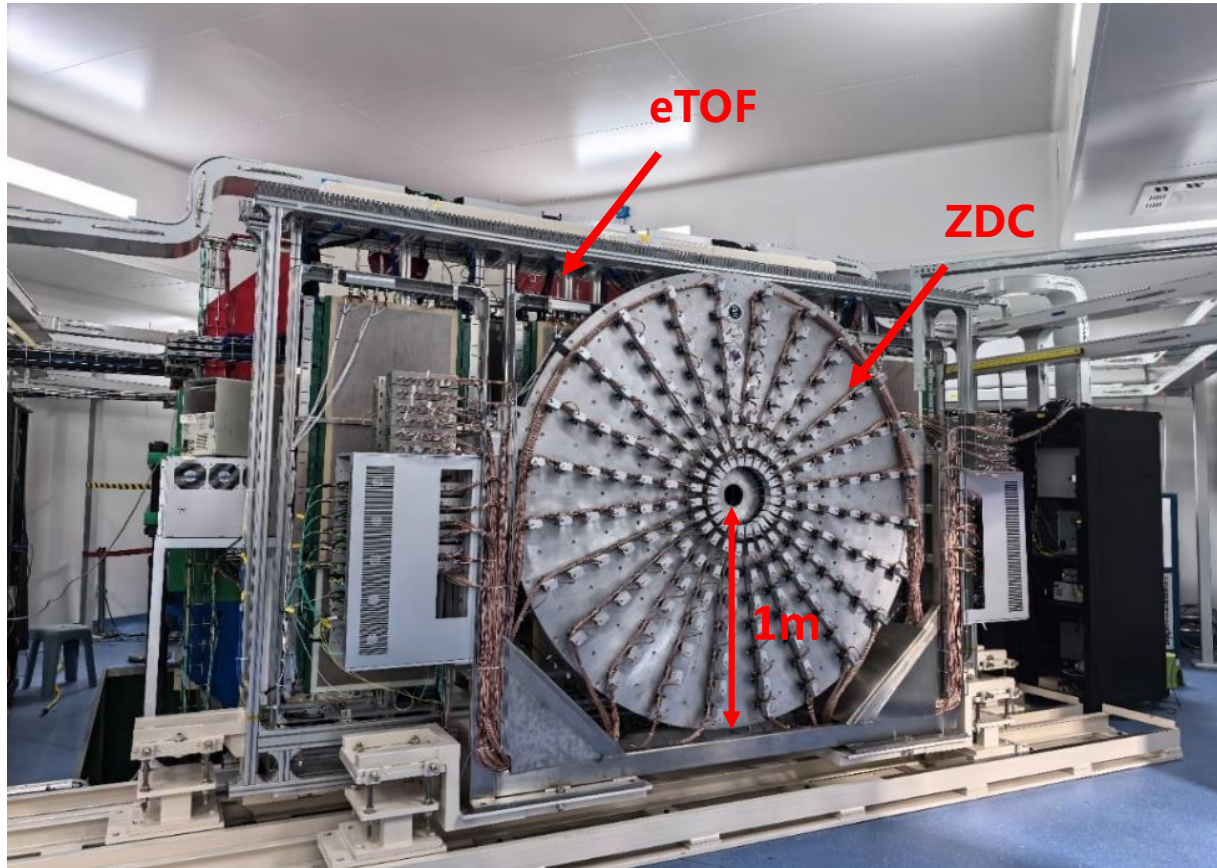
Others:

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

Detector System installation

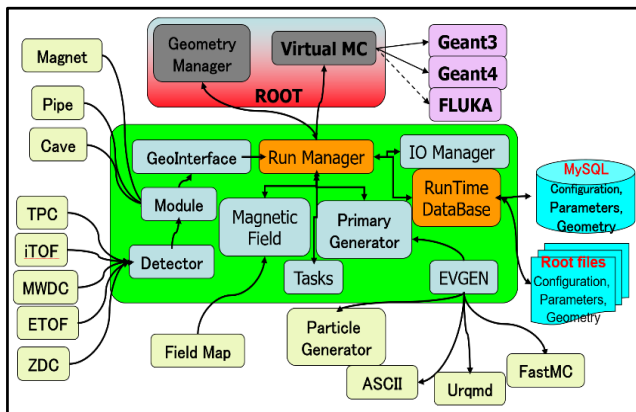


CEE detector without magnet



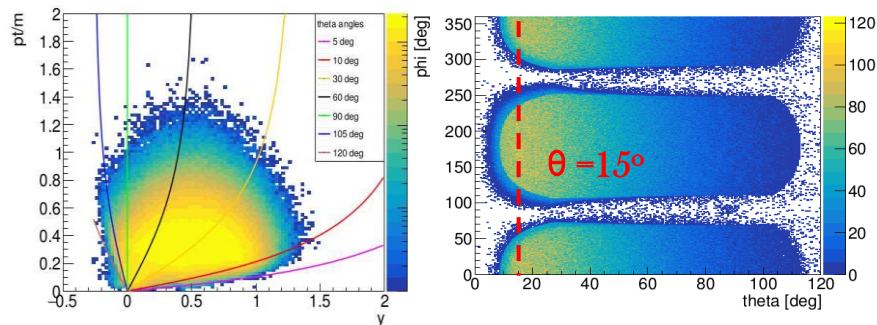
CeeROOT: CEE Simulation & Analysis Software

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

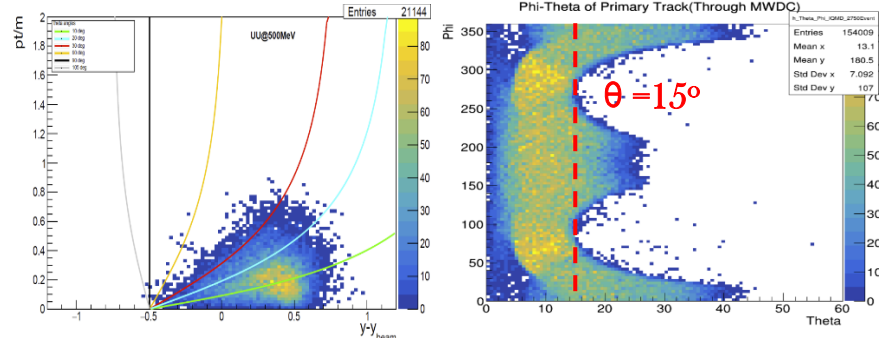
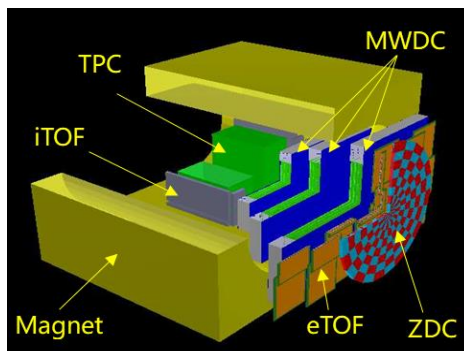
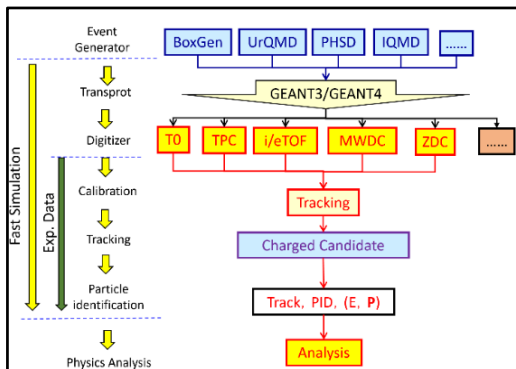


CeeROOT
Home page:
<https://gitee.com/CEESM/CeeRoot>
(Open source)

TPC acceptance

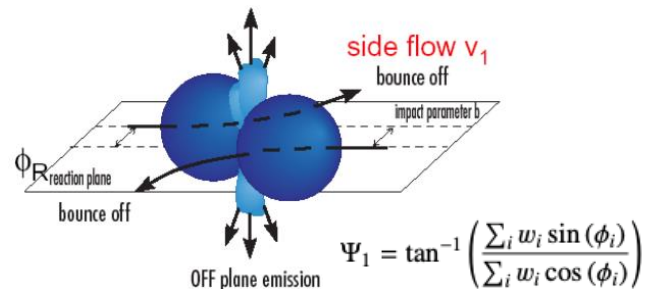
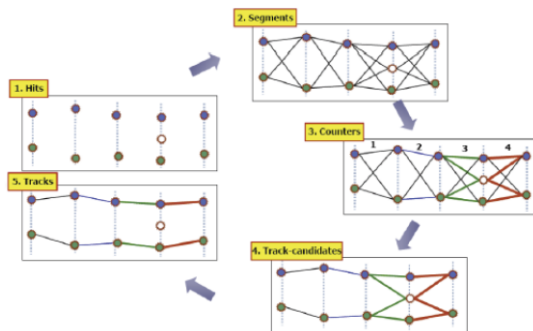


MWDC acceptance

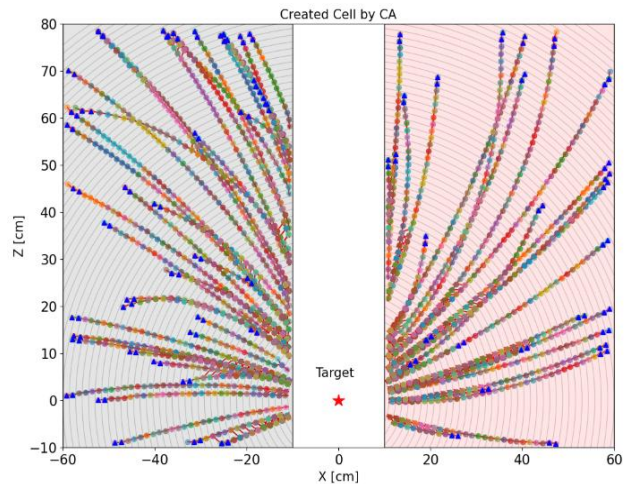


TPC tracking/Event plane reconstruction

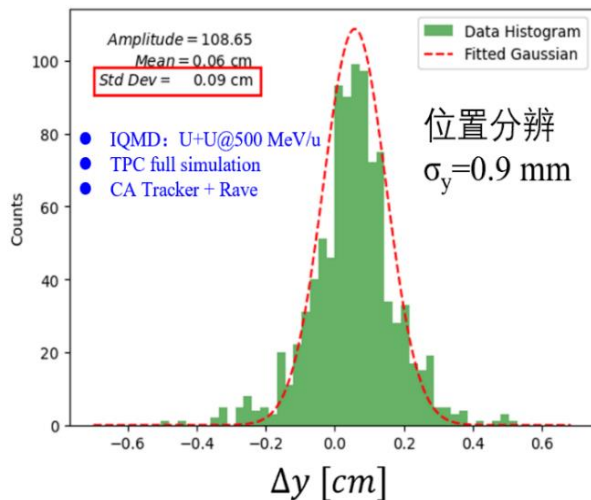
- Track finder
Cellular Automaton (CA)
- Track fitting
Kalman filter (Genfit)
- Vertex fitting: RAVE



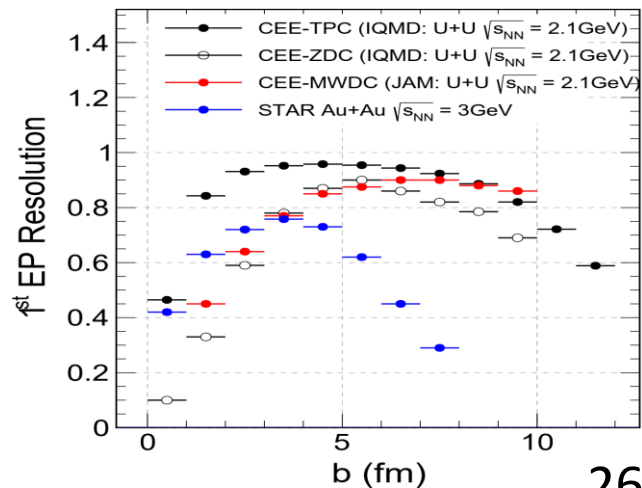
TPC tracking with IQMD event



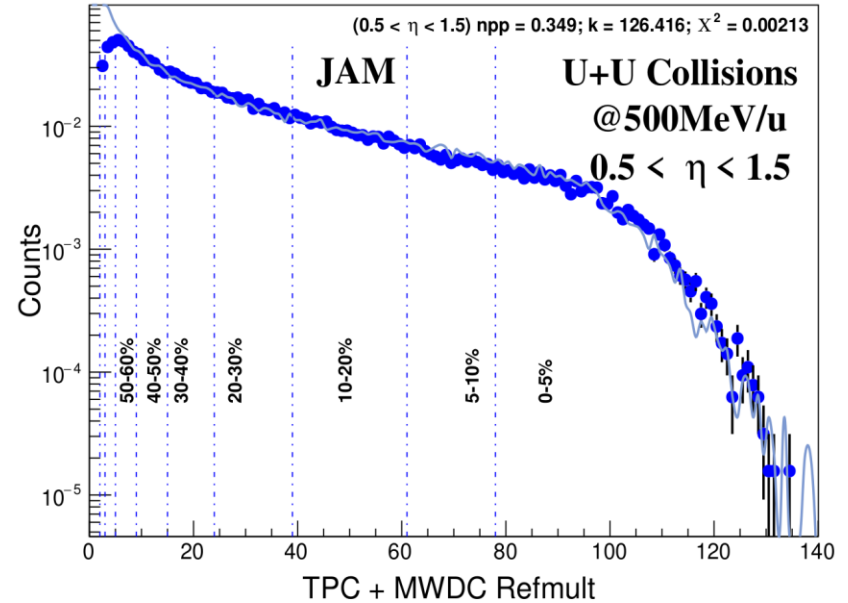
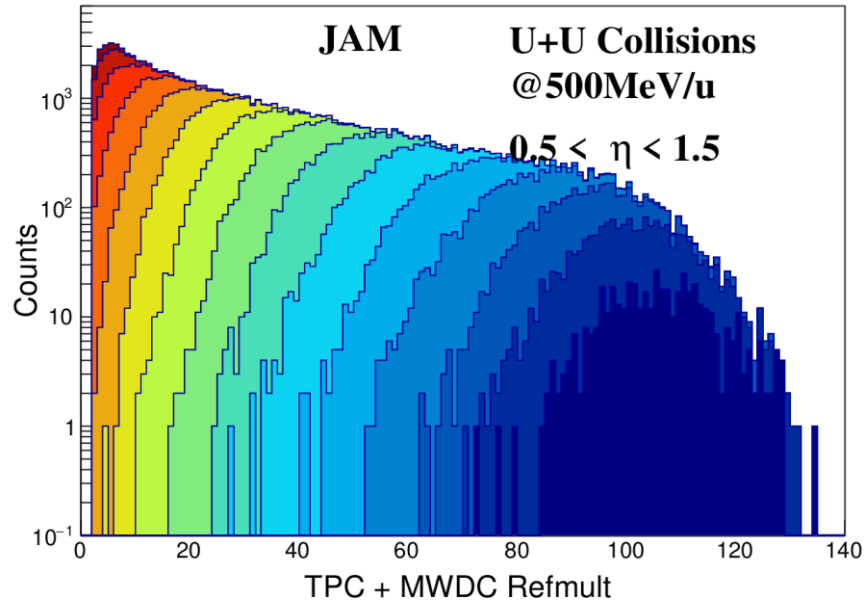
Vertex based TPC tracks



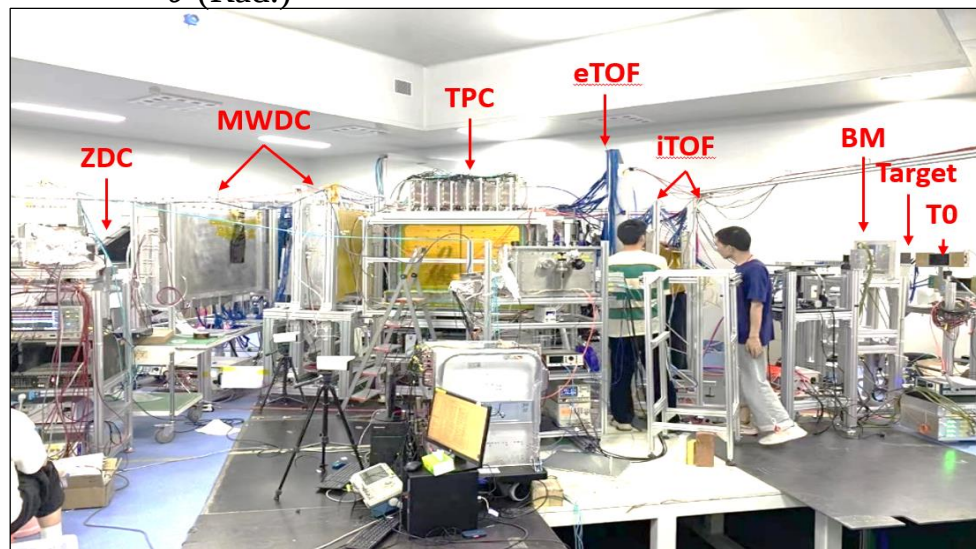
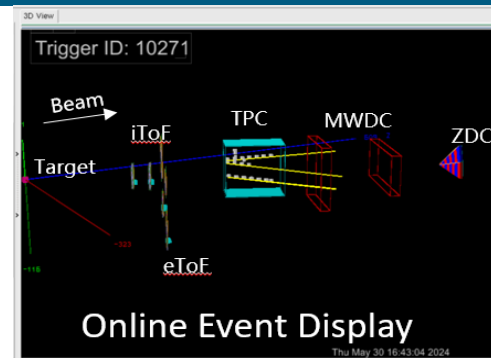
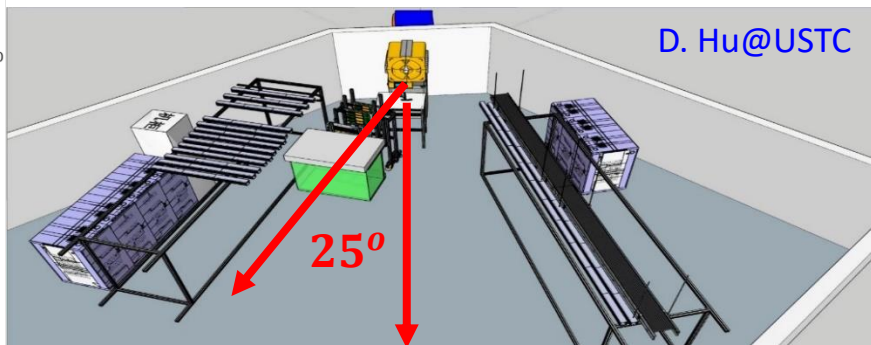
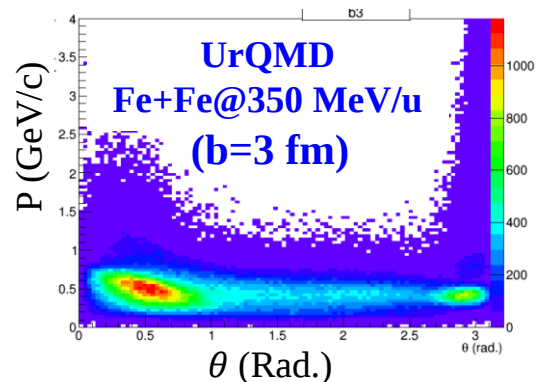
Event plane reconstruction



Centrality Definition



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



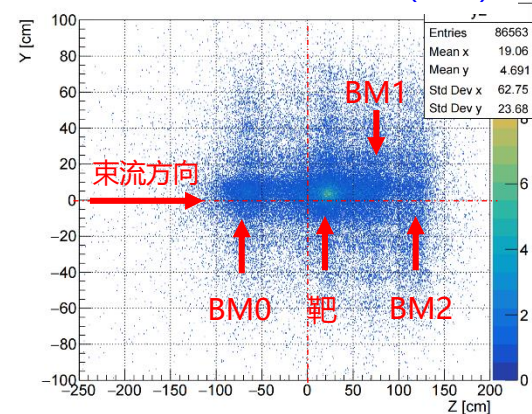
CEE谱仪第三次（模块级）束流联试

May, 2024

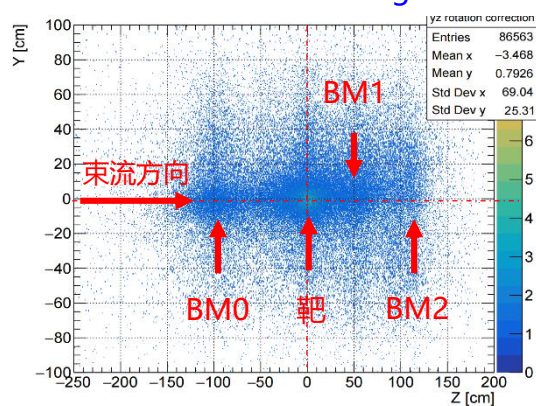


Vertex Reconstruction and Matching

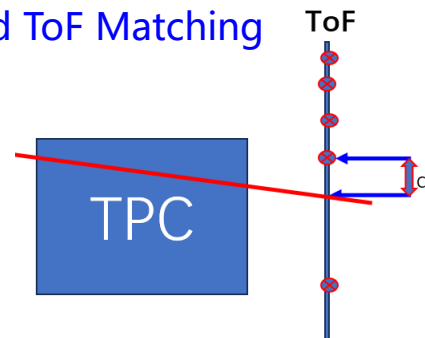
Vertex Reconstruction (X=0)



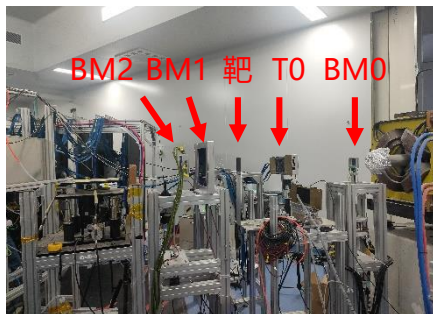
Vertex with TPC alignment



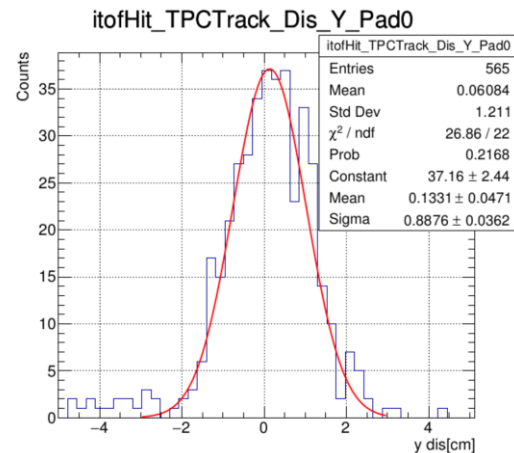
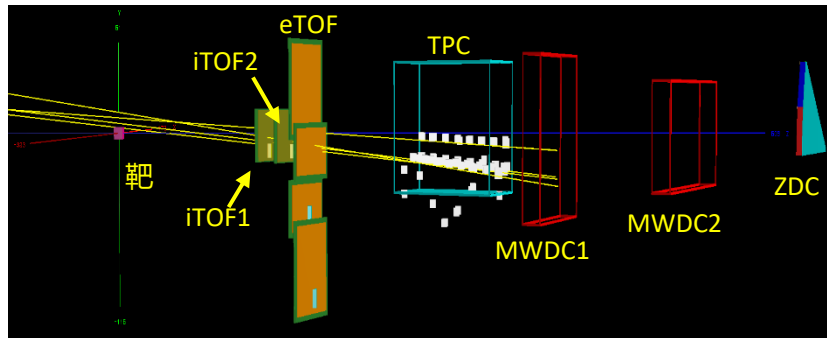
TPC and ToF Matching



Detectors on the beam line

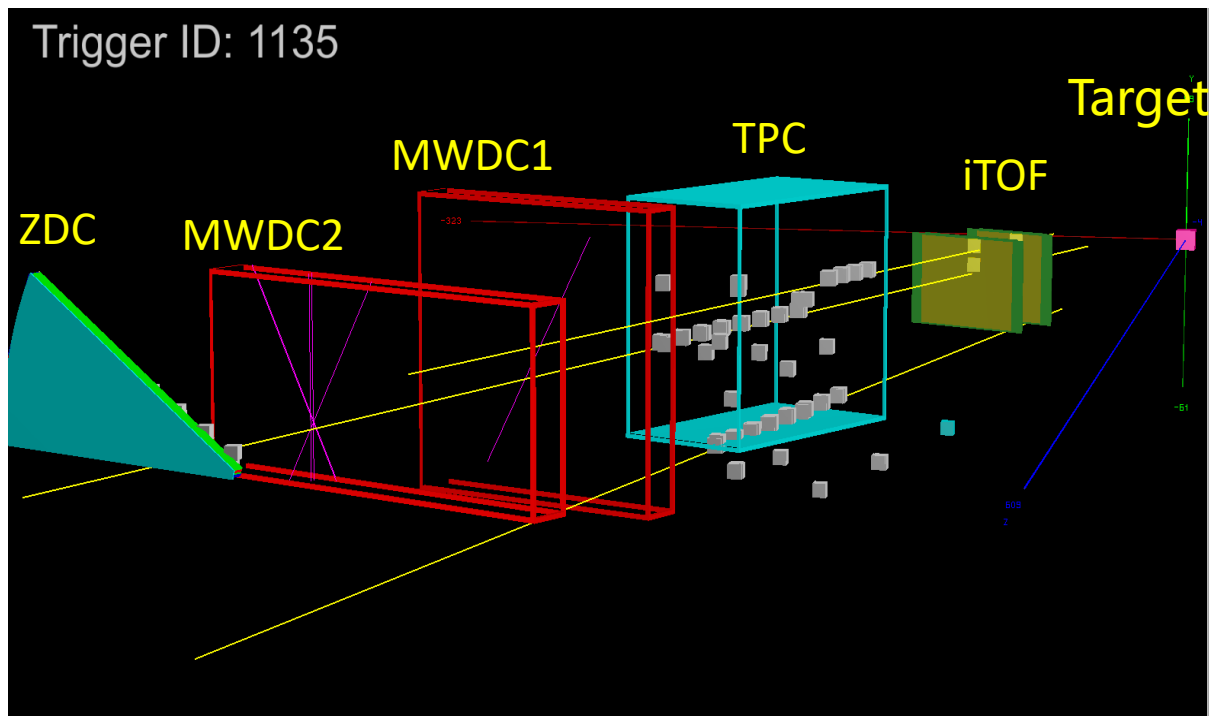


TPC and TOF matching event

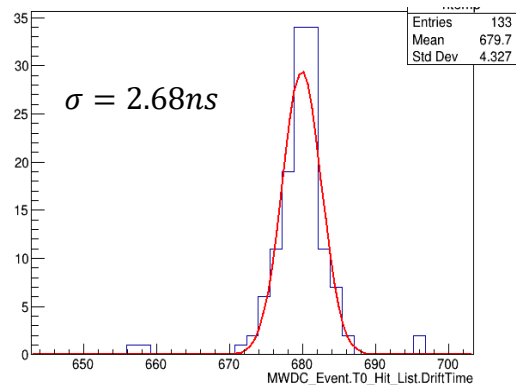


TPC-MWDC Matching

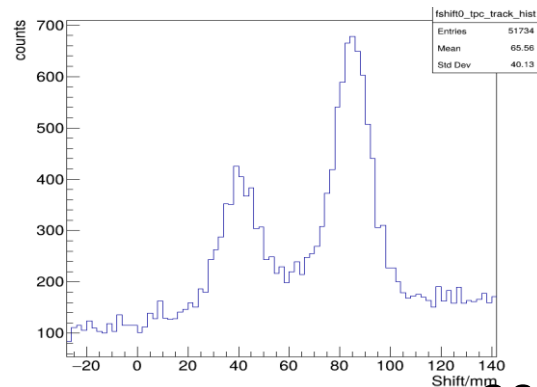
TPC-MWDC-TOF Matching



Scintillator-TOF time matching

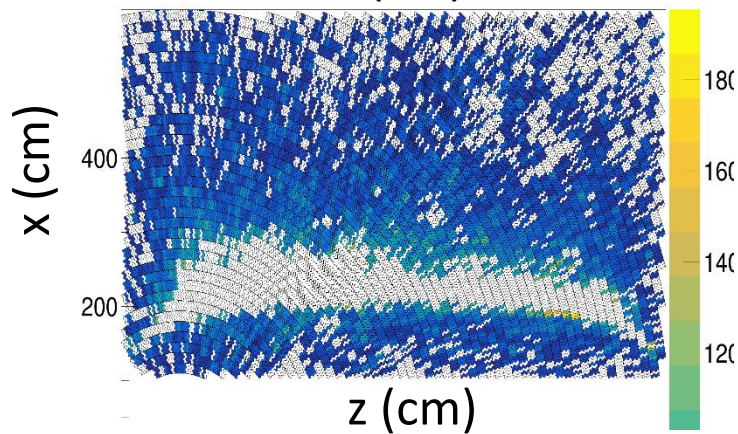
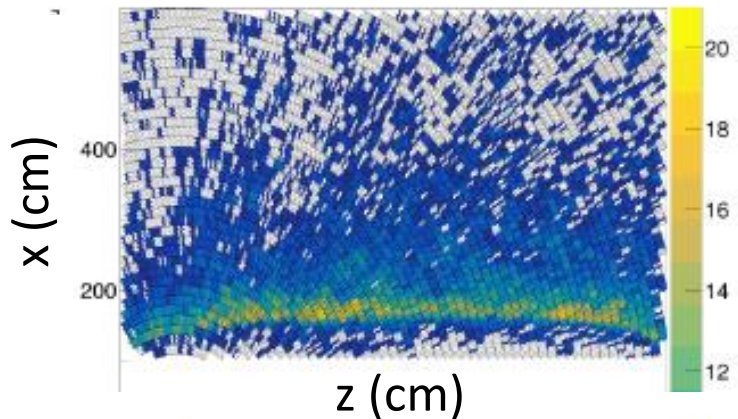


TPC and MWDC position matching

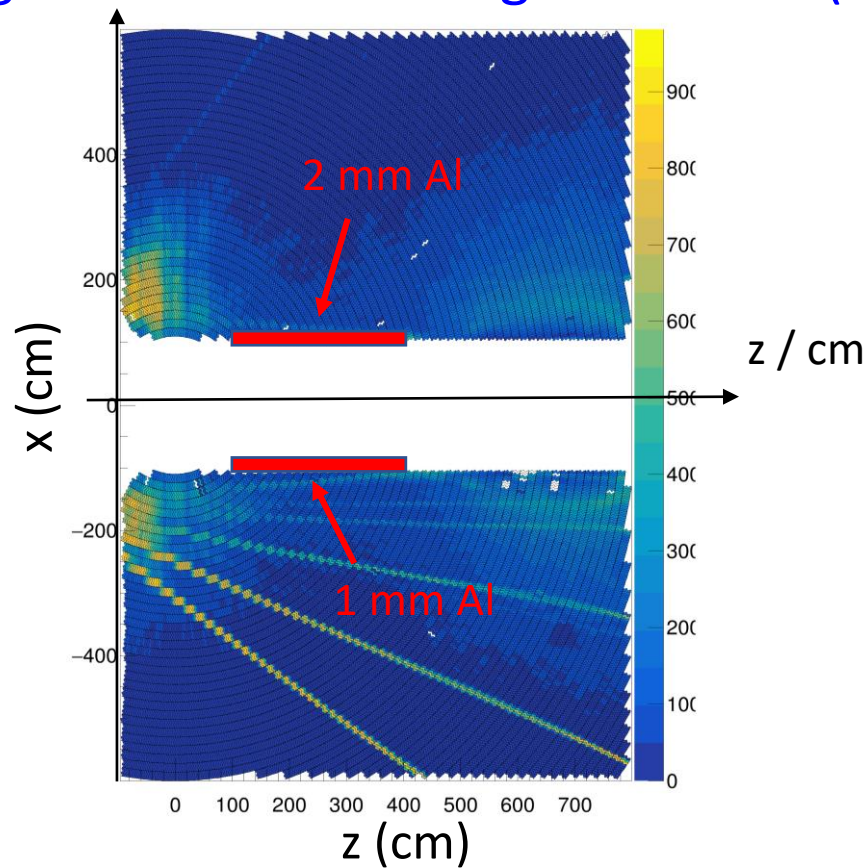


320 MeV/u ^{112}Sn +Air (14th, July 2025)

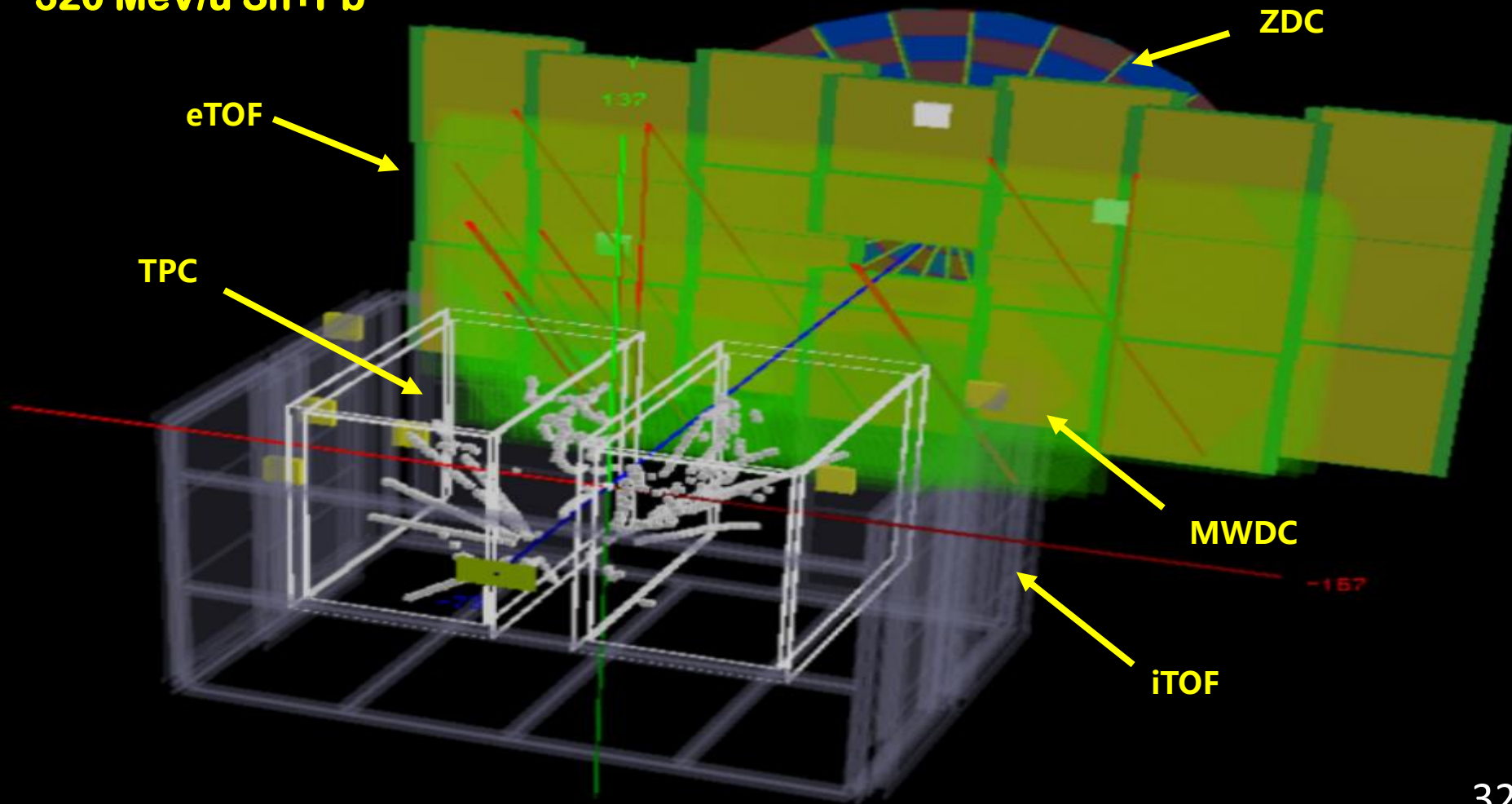
Background



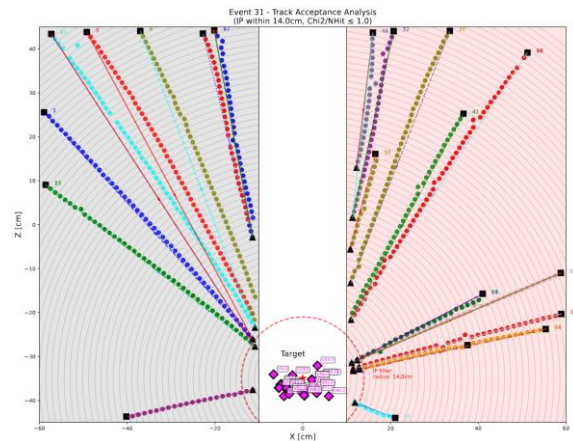
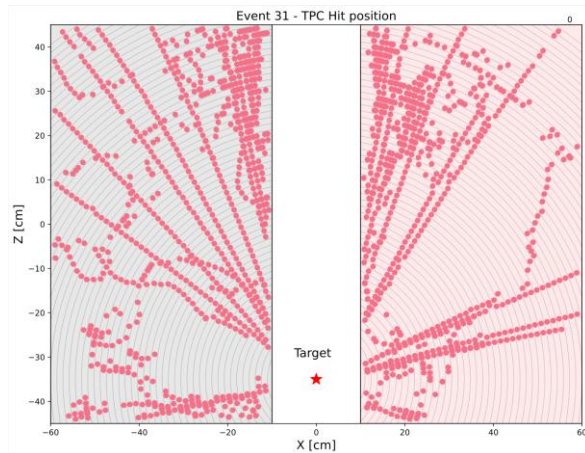
Background + Al shielding => Al tube (He)



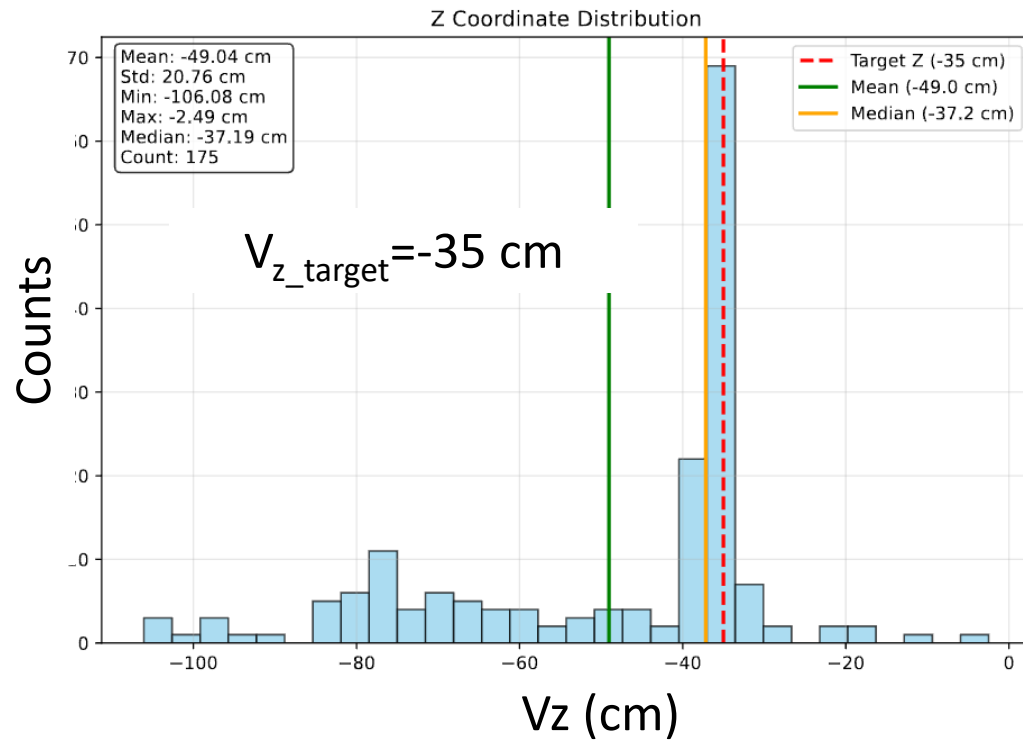
320 MeV/u Sn+Pb



Vertex fitting



320 MeV/u Sn+Pb

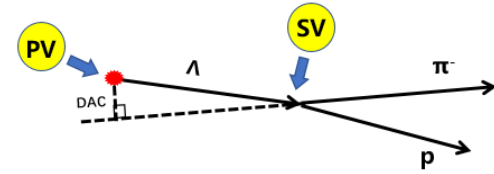


CEE Physics Program

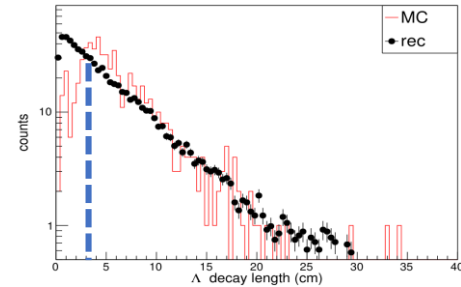
	Collision	Measurement	Physics
I	1.1 GeV/u C+C/ Au (No Magnetic field)	Pion ratios (rapidity, Pt, Centrality)	EoS
		Collectivity: p, d, t, ^3He , ^4He , Λ , K^0	EoS
		Rapidity Distribution: p, d, t, ^3He , ^4He , Λ , K^0	EoS
		Correlations: pion HBT; p-p, p-d, p-t, d-d	FIS
		Hyper-Nuclei Production: $^3_{\Lambda}\text{H}$, $^4_{\Lambda}\text{H}$	EoS & YN
		High moments of proton	PD
II	0.3-0.5 GeV/u U+U/ Au+Au	Pion ratios (rapidity, Pt, Centrality)	EoS
		Collectivity: p, d, t, ^3He , ^4He	EoS
		Rapidity Distribution: p, d, t, ^3He , ^4He	EoS
		Correlations: pion HBT; p-p, p-d, p-t, d-d	FIS
		High moments of proton	PD

Summary

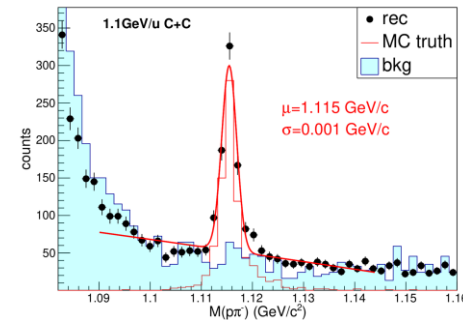
- CEE SC magnet still needs 2~3 months
- CEE detection system installation is completed
- CEE Spectrometer is expected to be in commissioning in 2026 with SC magnet
- 1.1 GeV/u C+C/Au (no magnet) is scheduled in 2025
- UU at 500 MeV/u Runs in 2026



Λ Decay Length



Λ Invariant mass

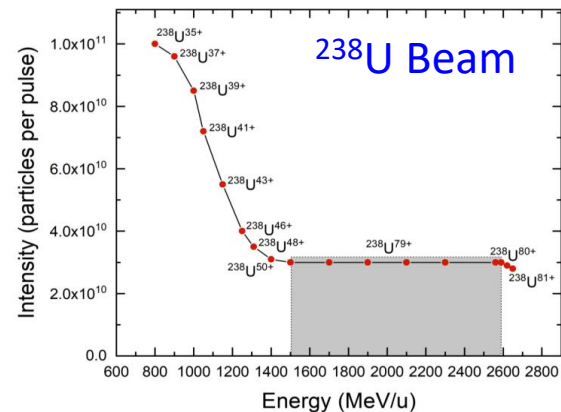
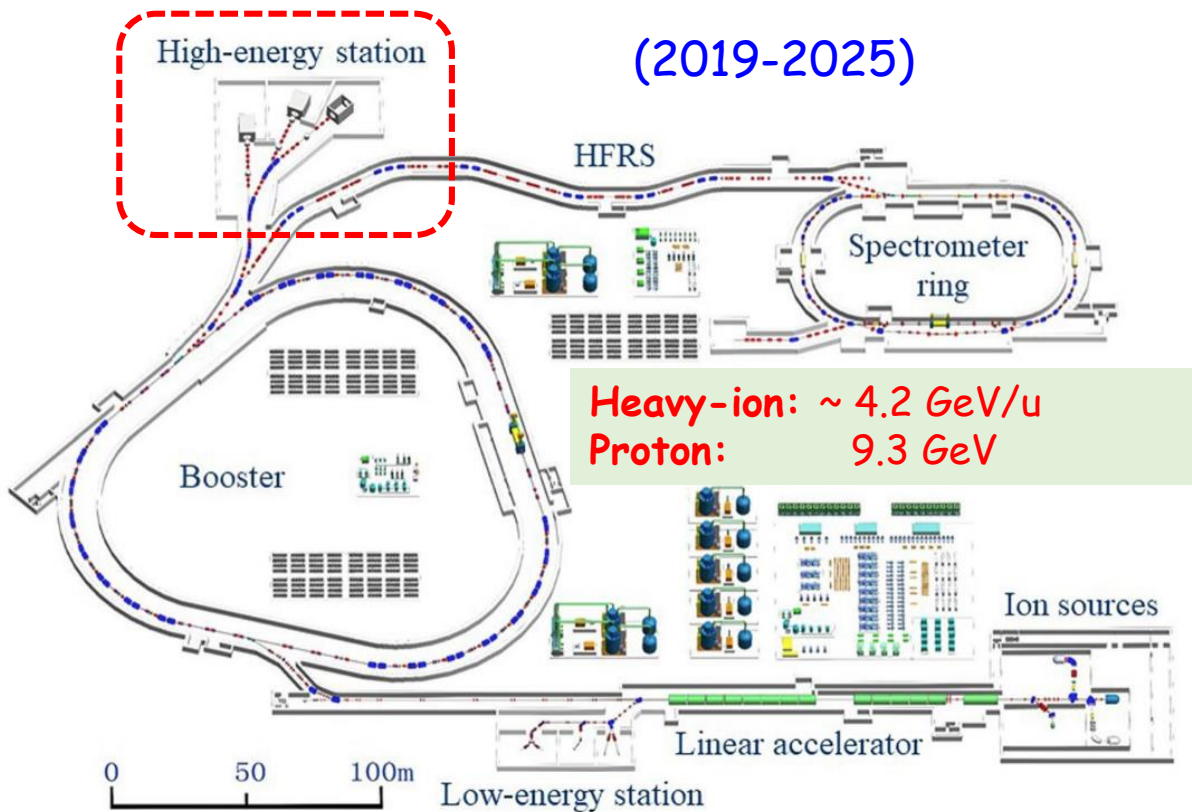




Thanks for your attention!

Backup

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
- ...