

极端条件下的QCD研讨会

Status of the CEE Experiment and Its Physics Program

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2026年八月19-20日, 烟台



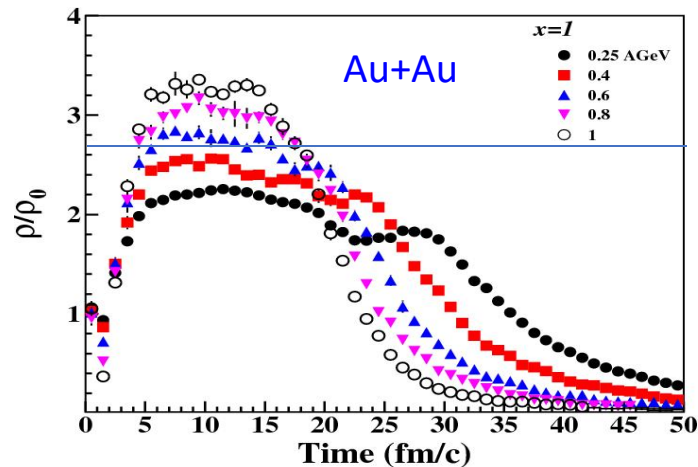
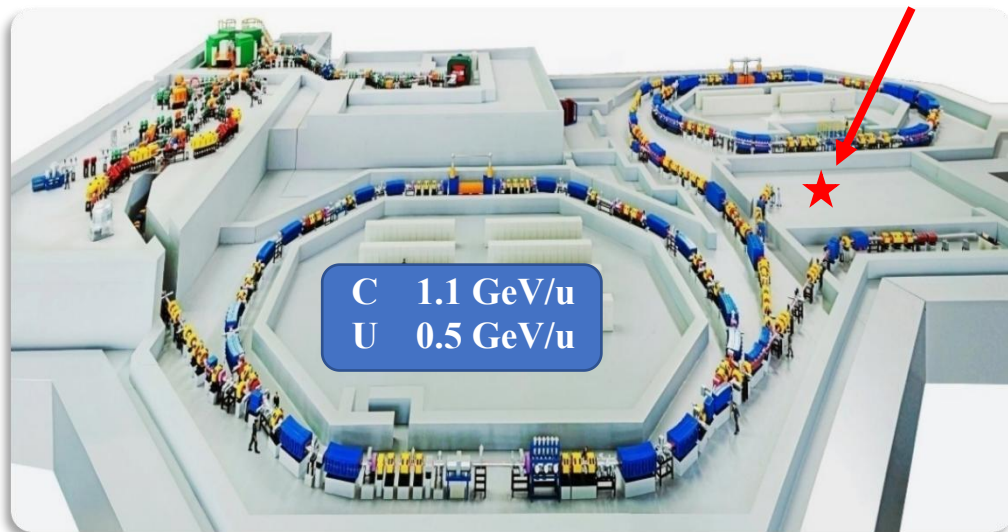
Outline

- Physics Motivation
- Status of CEE Detection System
- CEE Simulation & Analysis Software
- 1.1 GeV/u C+C/Pb Experiment Progress
- 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

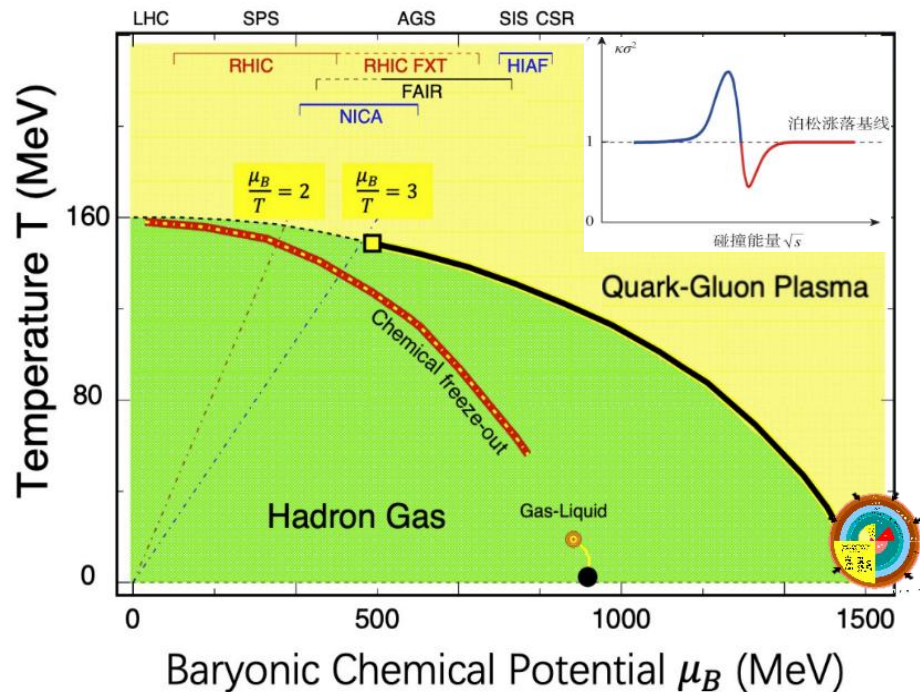
F. Fu ZGX et al, PLB 666 (2008) 359

QCD phase boundary/CEP
Liquid-Gas phase transition

Nuclear equation of state
at $\rho > 2\rho_0$ regime
Interplay with Neutron
Star Physics

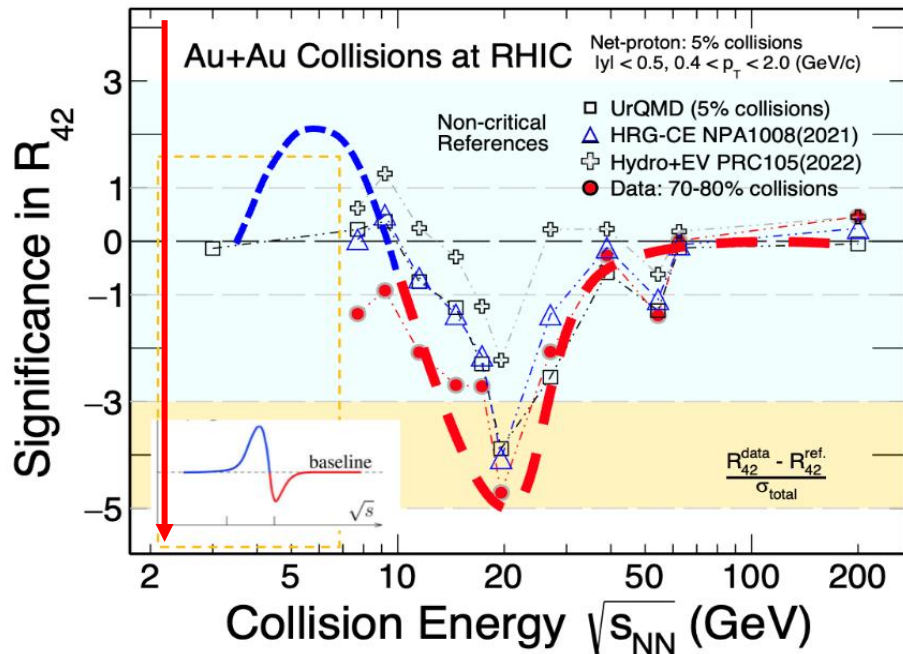
Sub-threshold production
Short range correlation
.....

QCD Phase Diagram



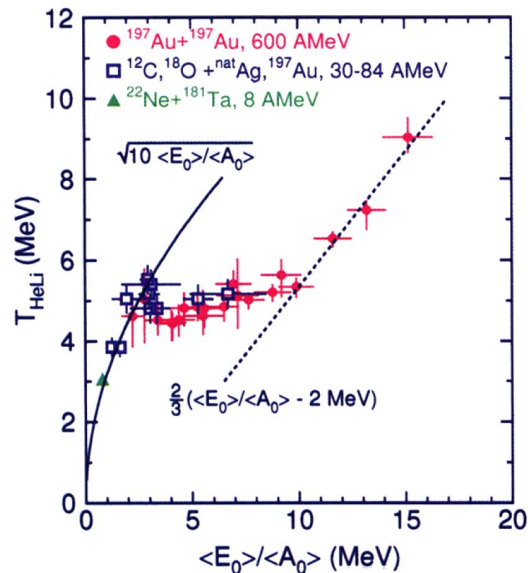
HIRFL-CSR

STAR: PRL 135, 142301 (2025)



Liquid-Gas Phase Transition

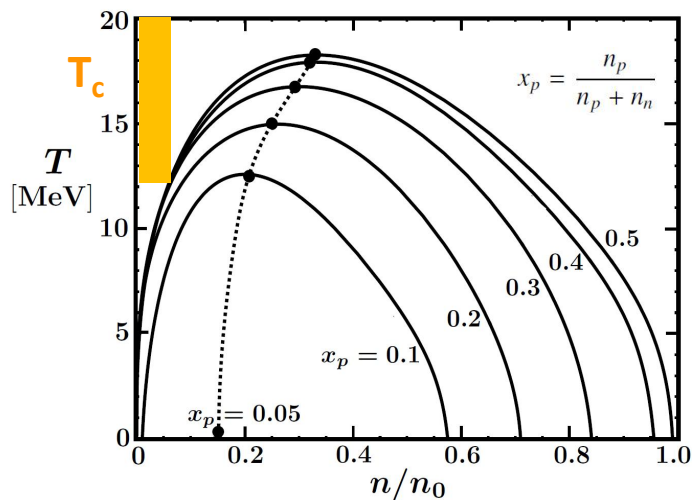
Caloric Curve



$$T_{\text{HeLi}} := 16 / \ln \left(2.18 \times \frac{Y_{6\text{Li}}/Y_{7\text{Li}}}{Y_{3\text{He}}/Y_{4\text{He}}} \right)$$

Pochodzalla, J., et al. ,PRL, 75,
1040 (1995)

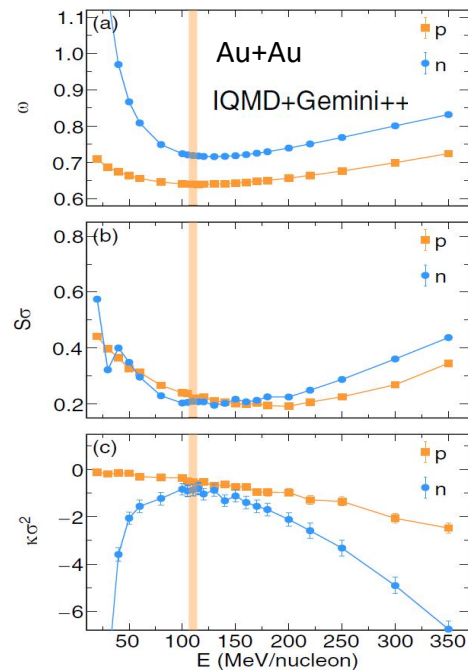
Chiral nucleon-meson model+FRG
(T_c, ρ_c)-Isospin asymmetry



Drews, M., and Weise, W, Prog. Part. Nucl.
Phys. 93 (2017) 69-107;

Kaiser, N. and Weise, W, arXiv: 2602.09916v1

$$\omega = \frac{\chi_2}{\chi_1}, \quad S\sigma = \frac{\chi_3}{\chi_2}, \quad \kappa\sigma^2 = \frac{\chi_4}{\chi_2}.$$



X.G. Deng et al.,
PRC 113, 064610 (2026)

Nuclear Matter Equation of State (EoS)

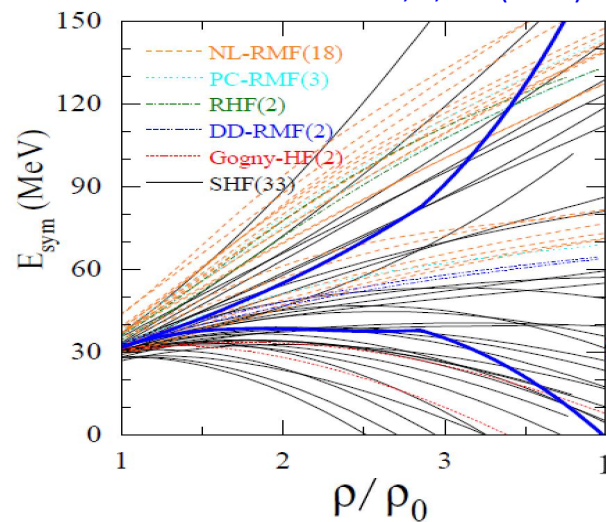
$$E(\rho, \delta) = E_0(\rho) + \underbrace{E_{\text{sym}}(\rho)}_{\text{Symmetry Energy}} \delta^2 + \mathcal{O}(\delta^4), \quad \delta = \frac{N - P}{N + P}$$

Symmetry Energy

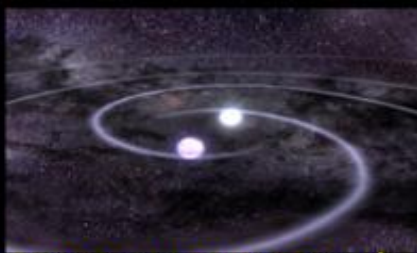
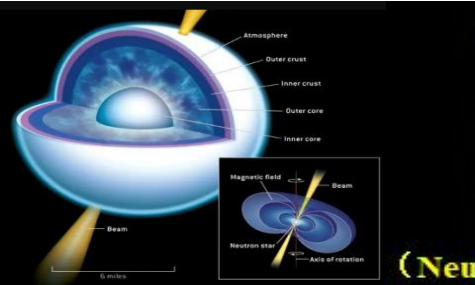
$$E_0(\rho) \approx E_0(\rho_0) + \frac{K_0}{2} \left(\frac{\rho - \rho_0}{3\rho_0} \right)^2 + \frac{J_0}{6} \left(\frac{\rho - \rho_0}{3\rho_0} \right)^3$$

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

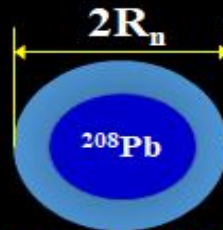
B.A Li et al. Universe, 7, 182(2021)



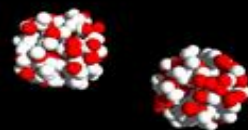
张亚鹏等,中高能重离子碰撞与核物质状态方程研究. 物理学报, 2025, 74(11): 112101



(Neutron Star and NS Merge)



(Static Properties of Nuclei)



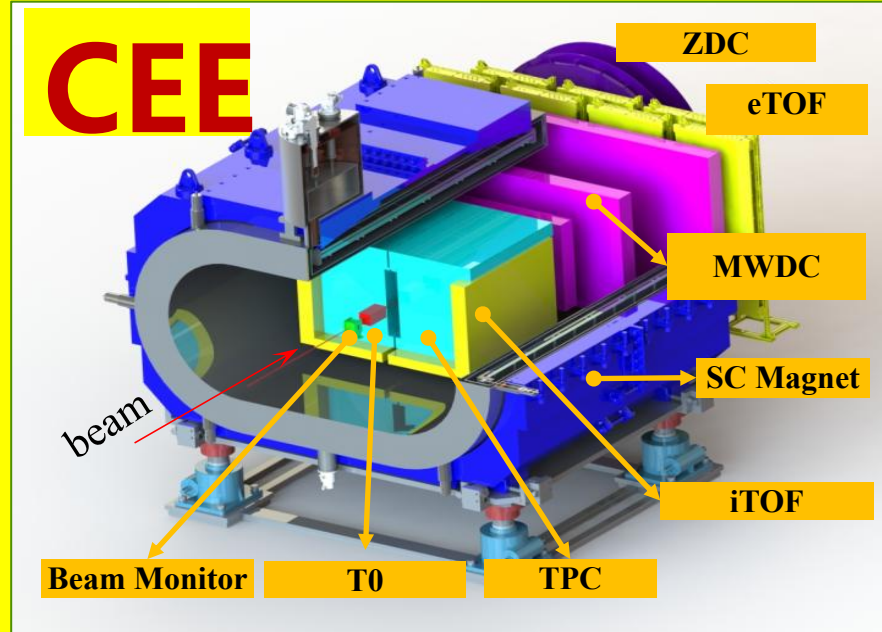
(Heavy Ion Collisions)

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



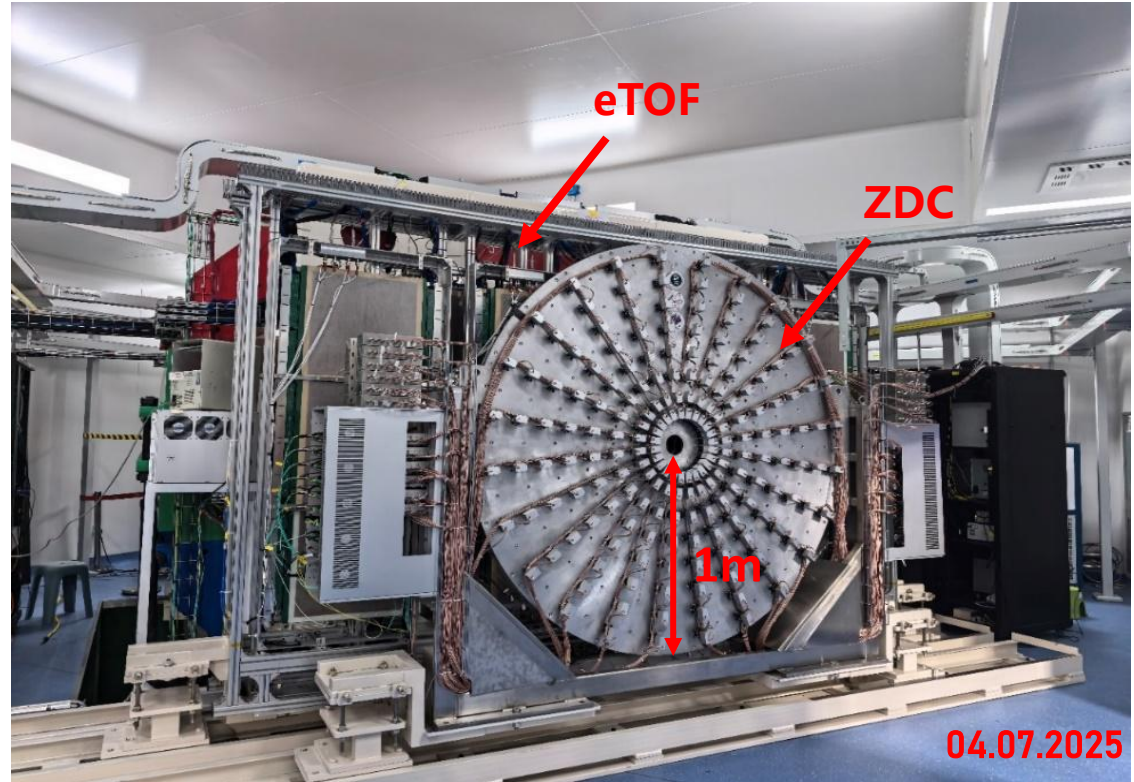
- $\Delta p/p: \leq 5\%, \Delta t/t: \leq 80\text{ps}$
- Max. Rate: 10 kHz
- Proton acceptance: $\sim 85\%$

CEE Detector Integration

TPC & itof installation



ZDC installation



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

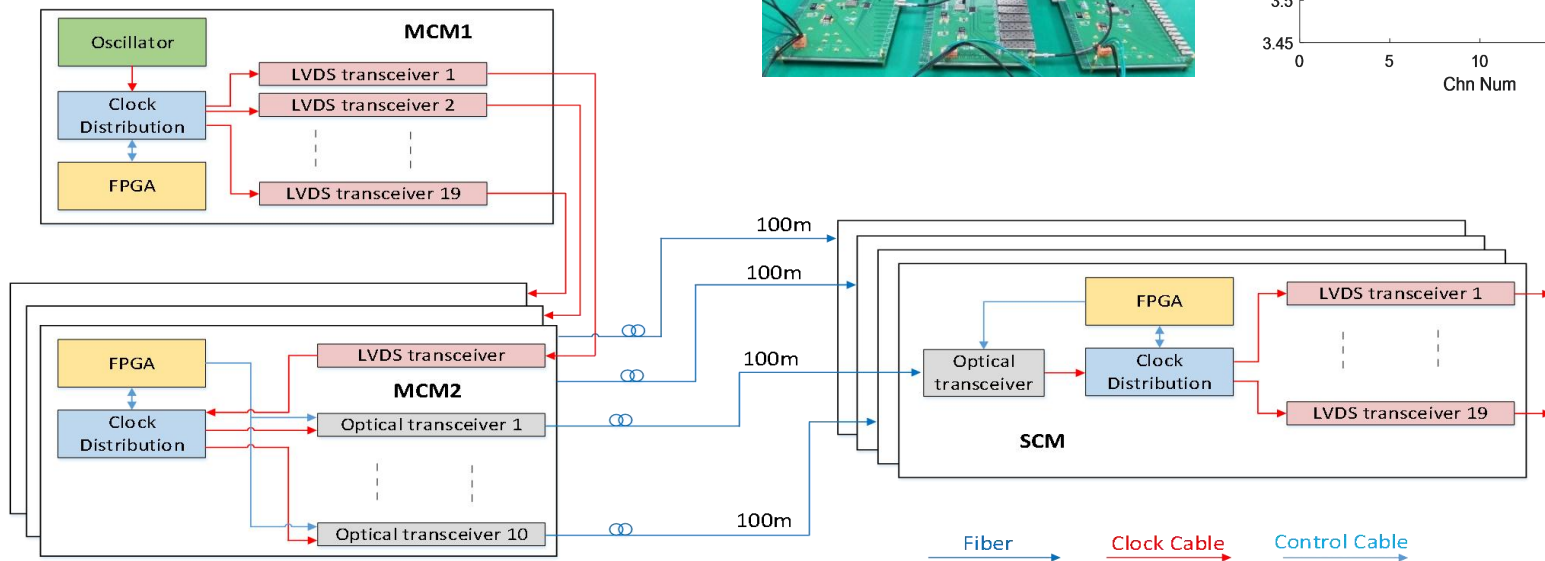
Japan:

- Tsukuba University

Clock System

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

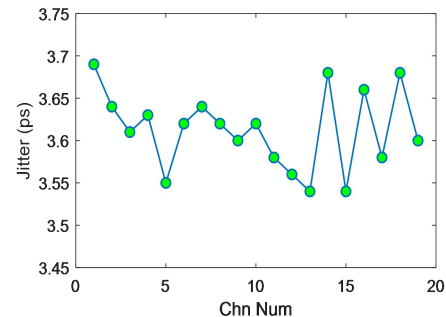
Clock system block diagram



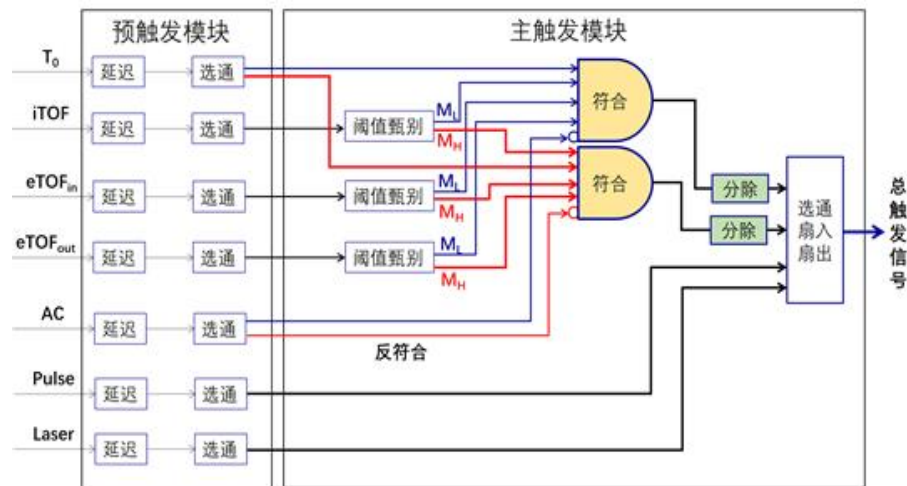
Test Setup



Test Result



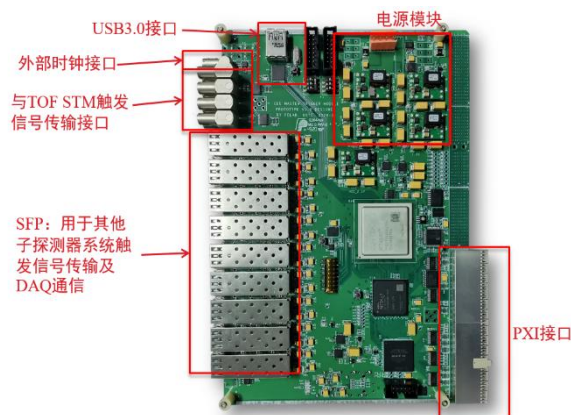
Trigger System (TS)



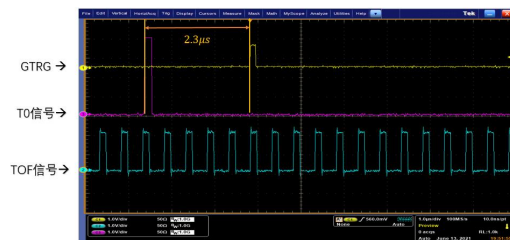
Working mode:

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

Lab test

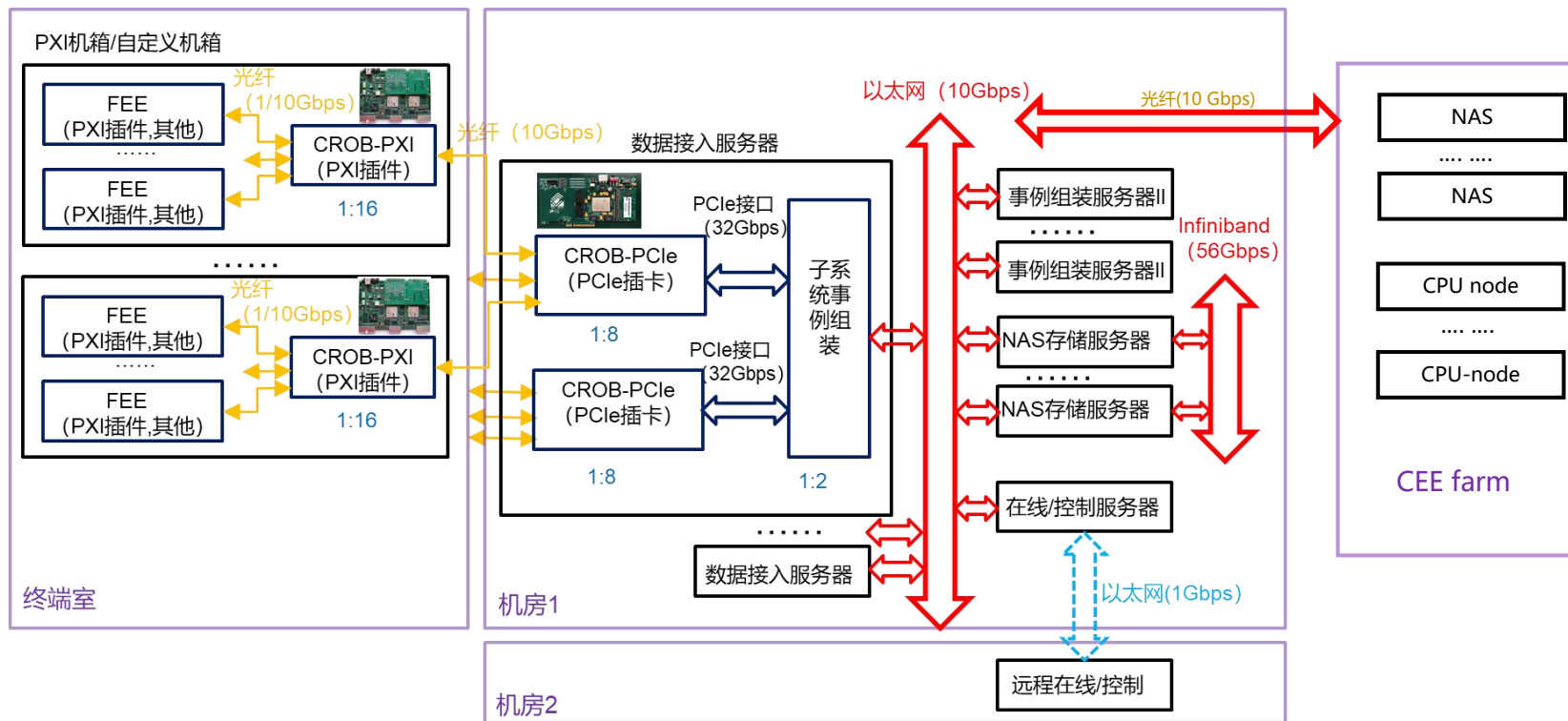


Trigger logic simulation



Data Acquisition System (DAQ)

Zero-suppressed data rate: ~ 4.4 Gbyte/s

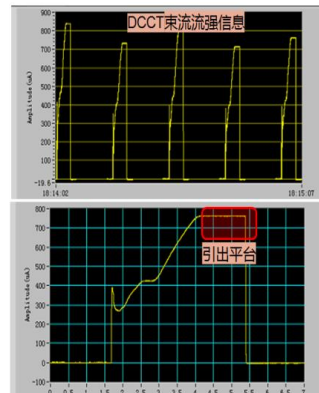
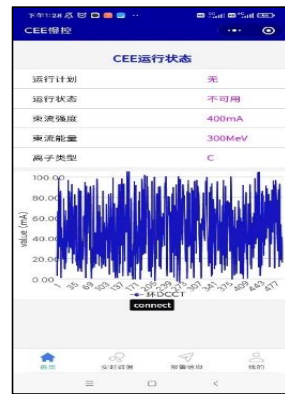
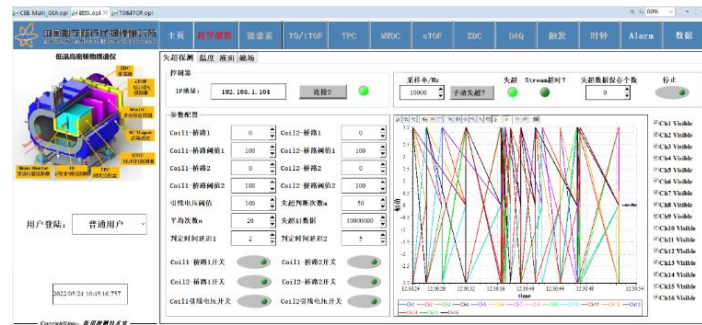
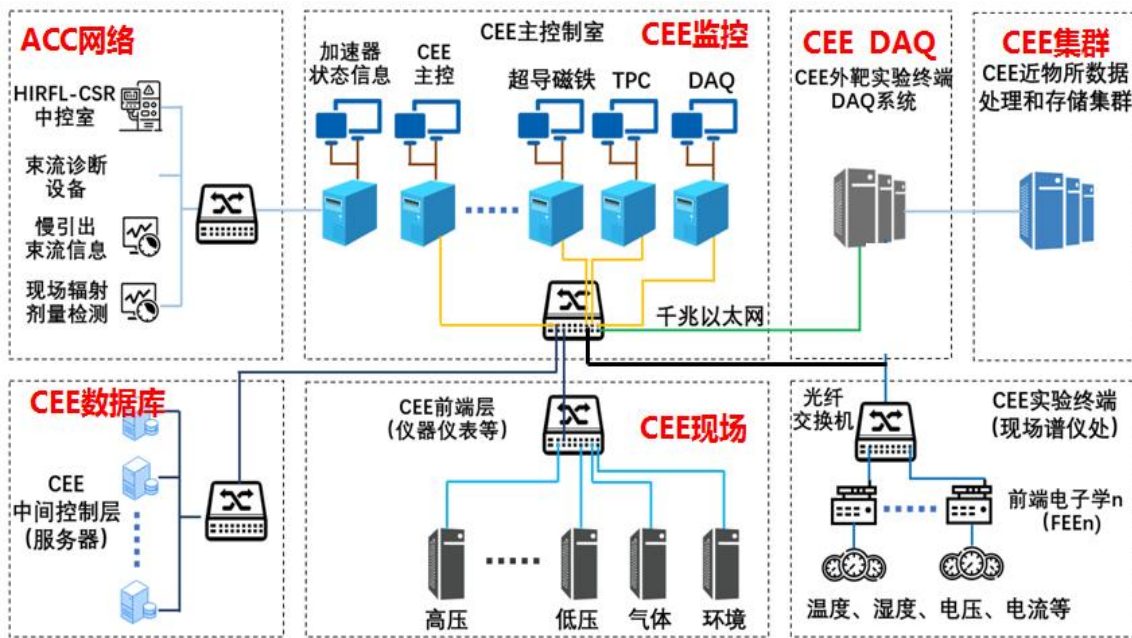


Slow Control (SC)

SC is based on the EPICS



Experimental Physics and
Industrial Control System



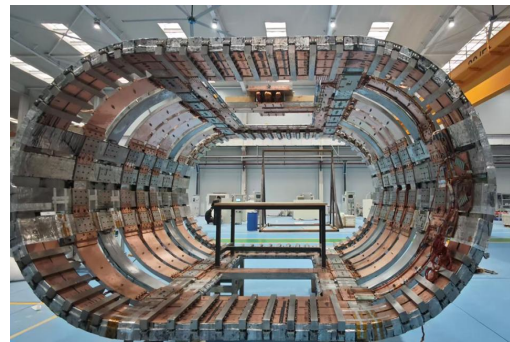
Super-Conducting Dipole Magnet

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

Magnet Yoke



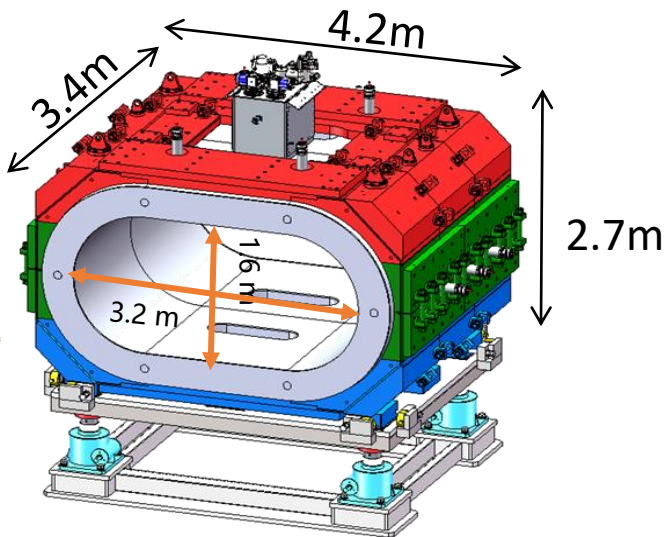
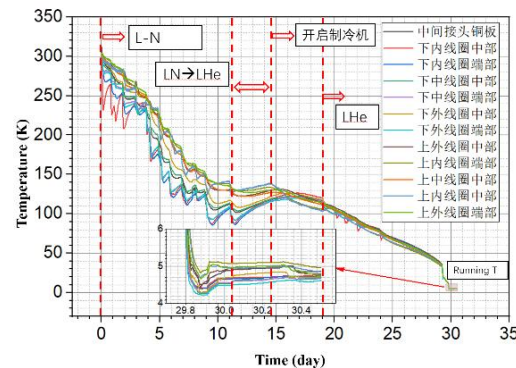
Coil & cooling pipe



Integrated Coil



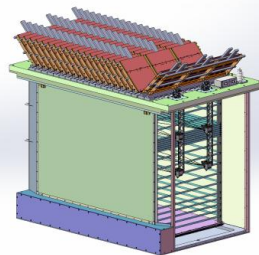
Cooling Down



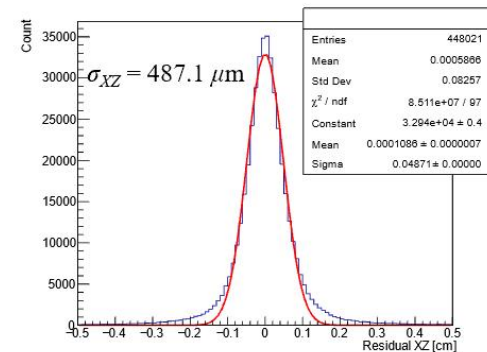
TPC Detector

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%

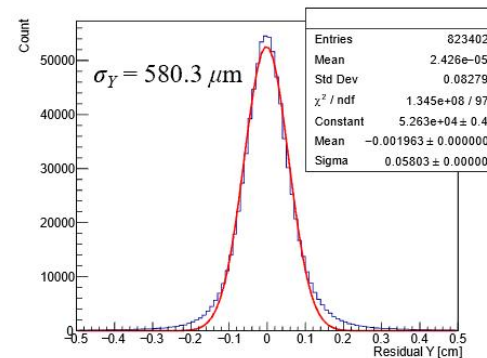
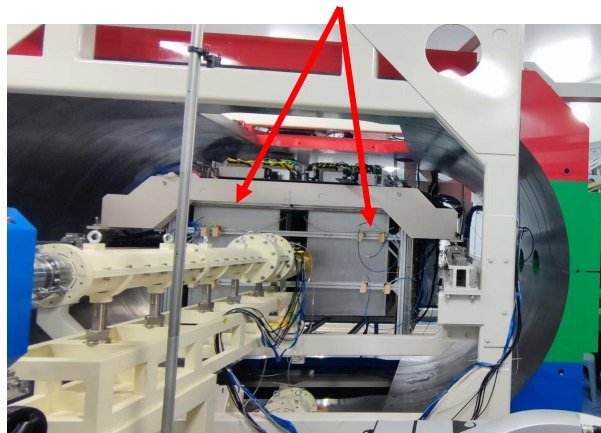
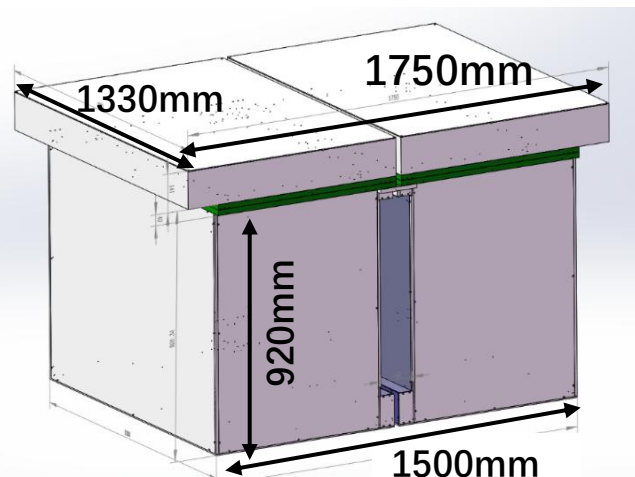
SAMPA-based readout



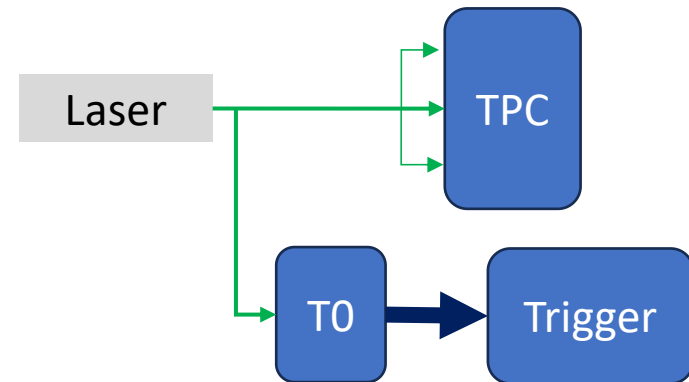
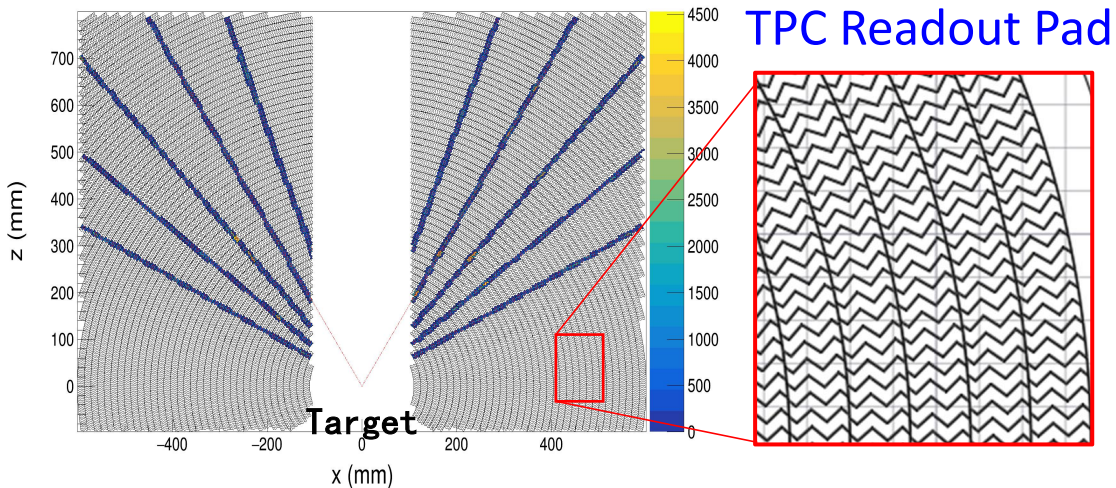
TPC track residual



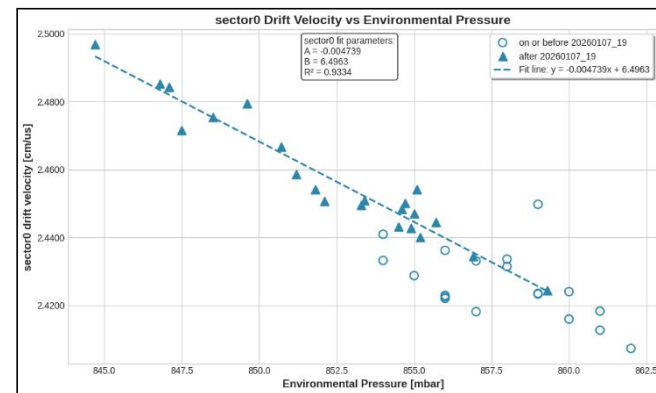
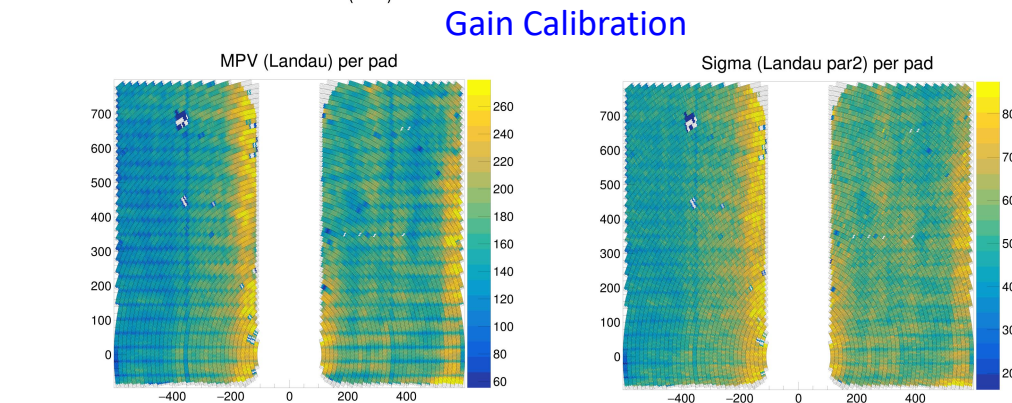
TPC



TPC Calibration

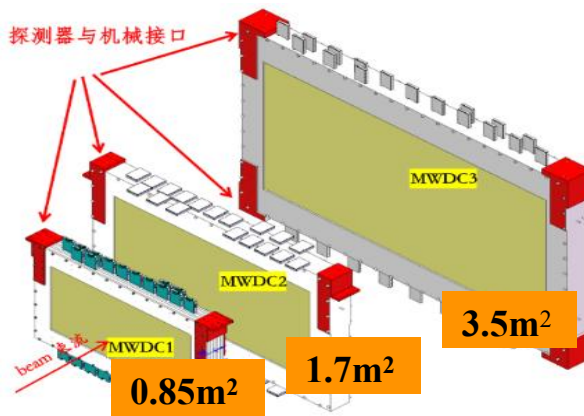


Drift Velocity vs Pressure

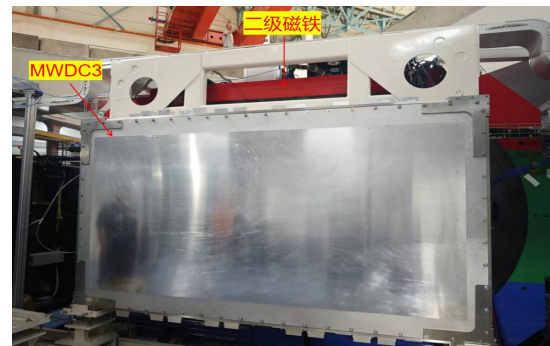


MWDC Detection Array

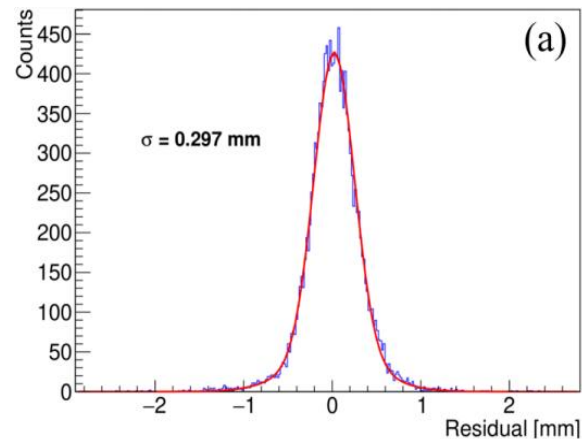
Quantity	Design index
Channels	~3200
Wire layer per module	X、X'、U、U'、V、V'
σ_{xz}	300 μm
Energy resolution	> 22%
Detection efficiency	> 98%
Momentum resolution	< 5%



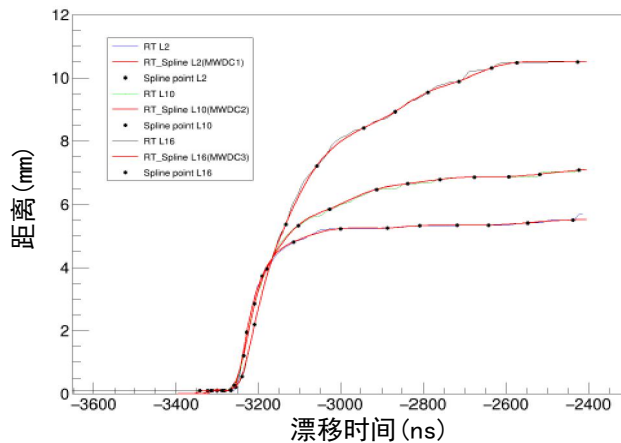
MWDC-3



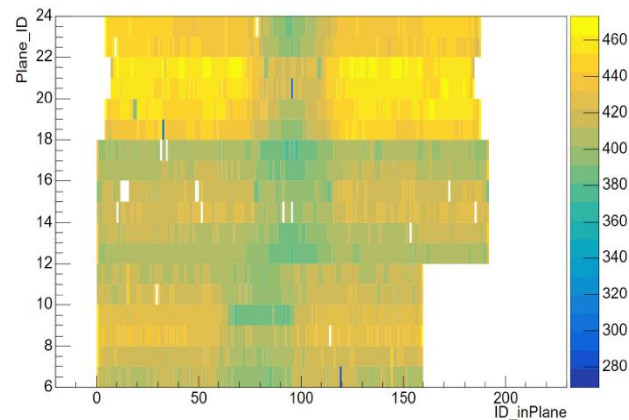
Track residual < 300 μm



Drift time-R



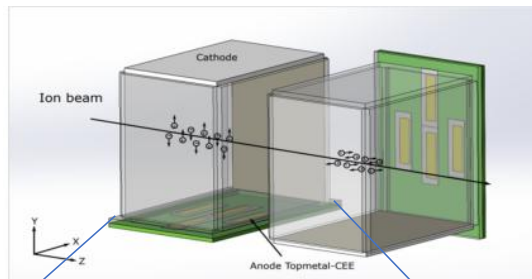
Gain Calibration



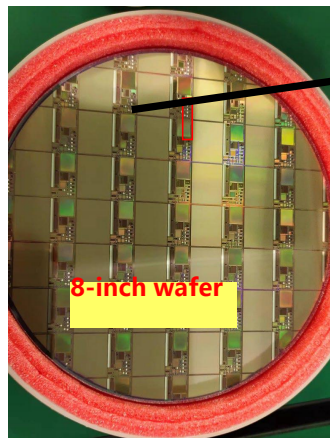
Beam Monitoring (BM) Detector

BM design

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

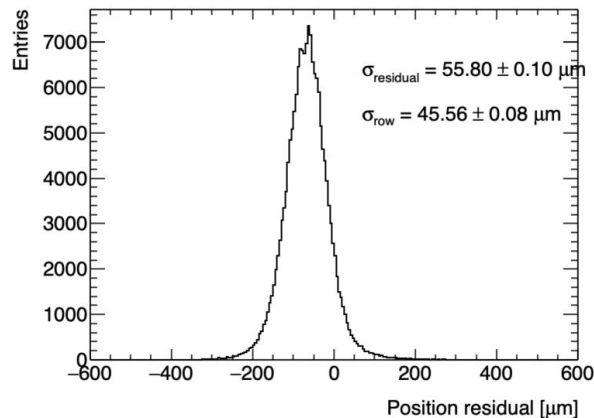


Topmetal-CEE chip



1.1 GeV/u的C束斑

X 方向位置分辨

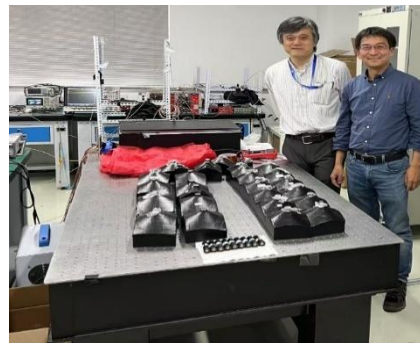


Zero Degree Counter (ZDC)

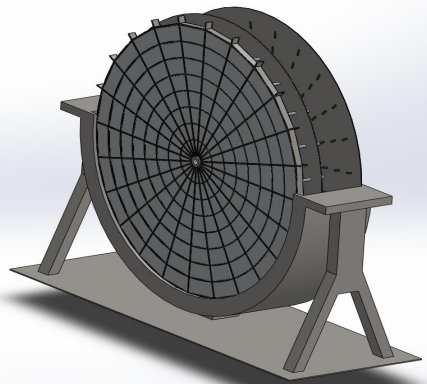
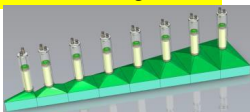
ZDC Parameters	Design index
Charge resolution	$\sim 15\% / Z=1-15$
Area	$5 < R < 100 \text{ cm}^2$

Function:

- ▣ Reaction Plane
- ▣ Centrality

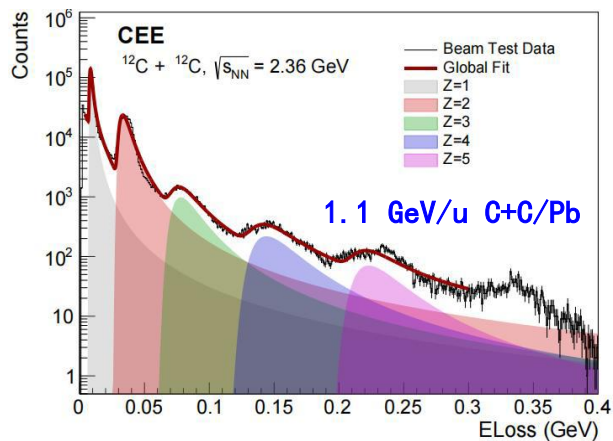


ZDC Geometry

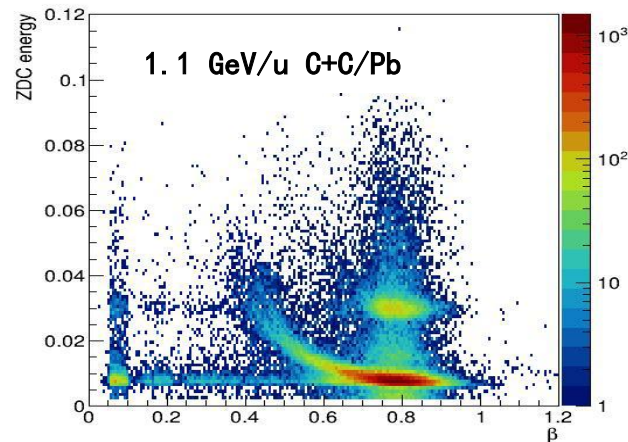


24 Sectors $\times$ 8 Rings

Charge Spectrum



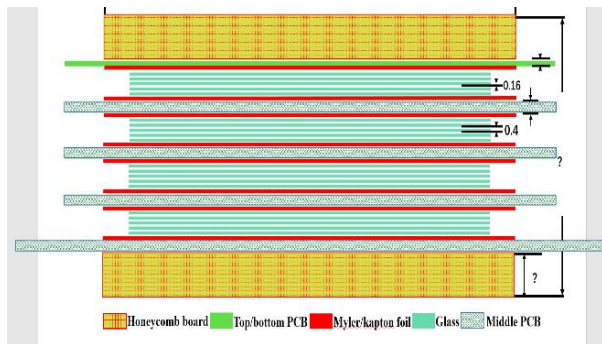
ZDC dE/dx Vs eTOF



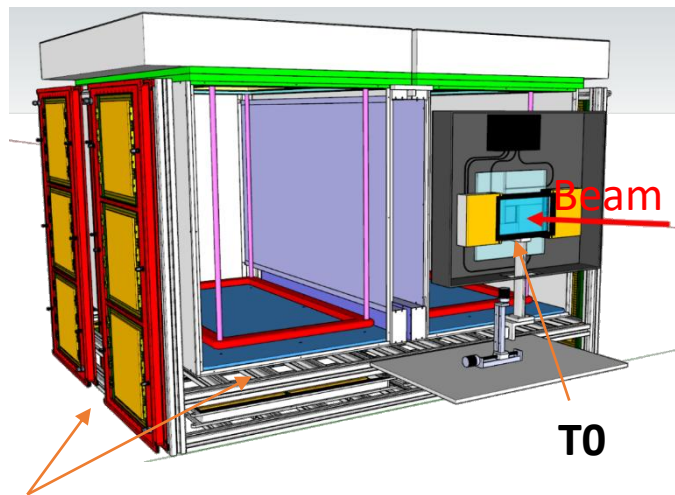
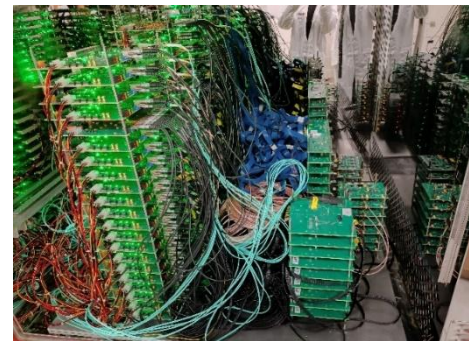
iTOF development & Production

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

iTOF-MRPC Design

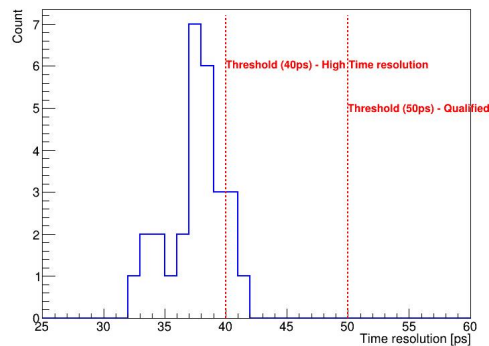


Electronics Stability Test

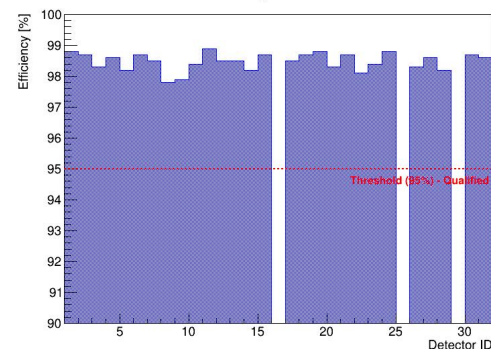


iTOF: covers 3 side of TPC

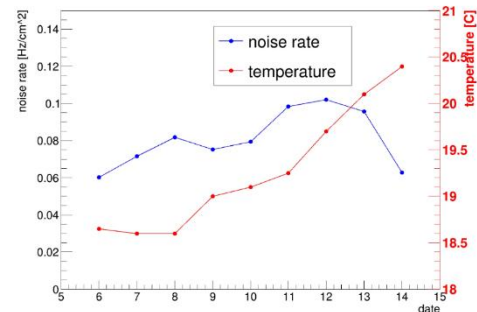
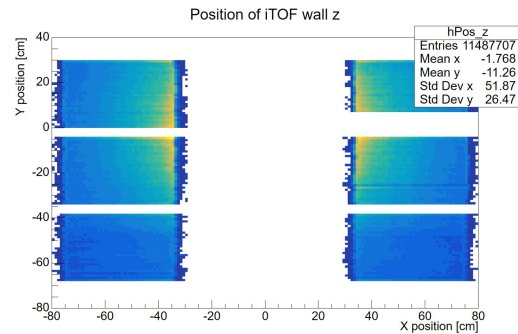
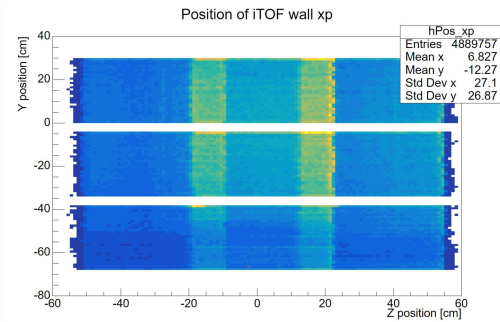
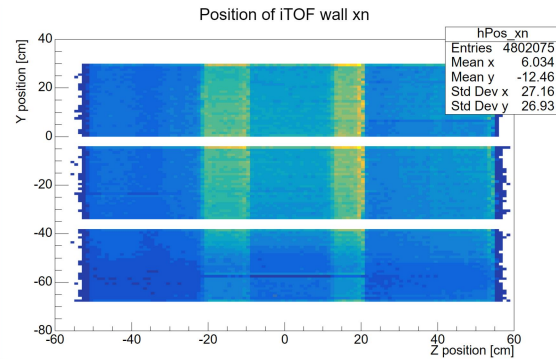
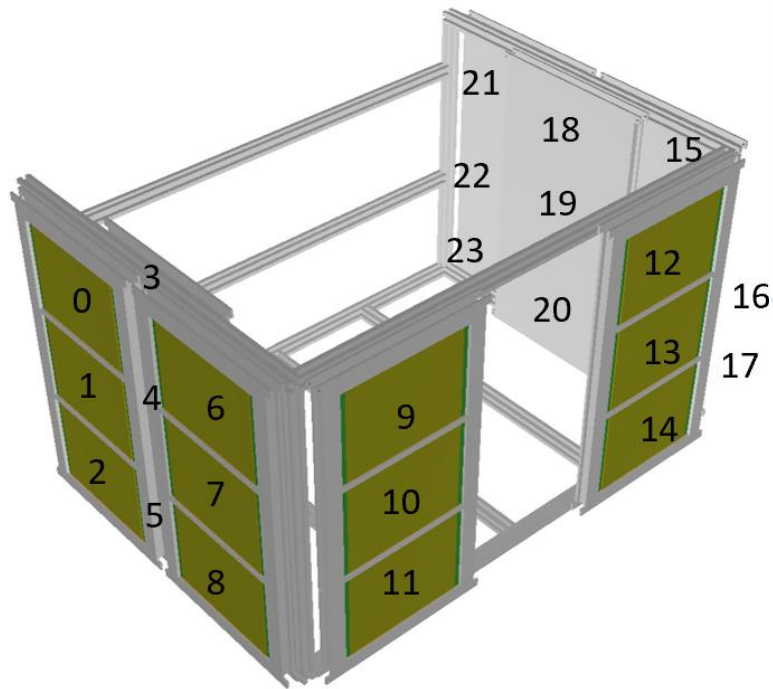
Time Resolution Distribution



Efficiency Distribution

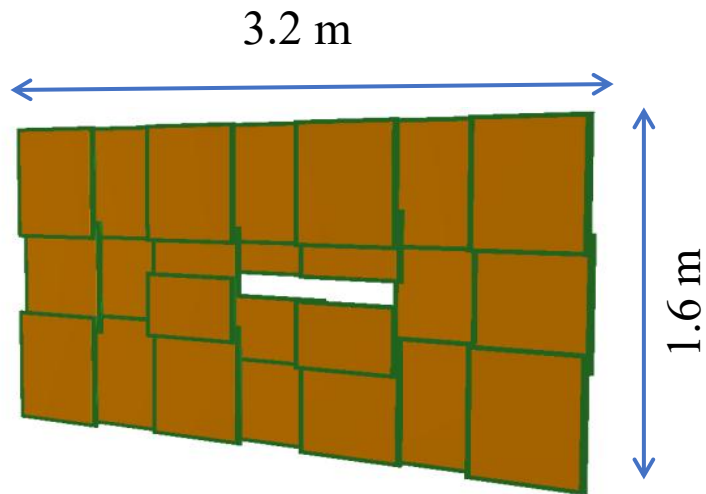


iTOF hit map in 1.1 GeV/u C+C/Pb

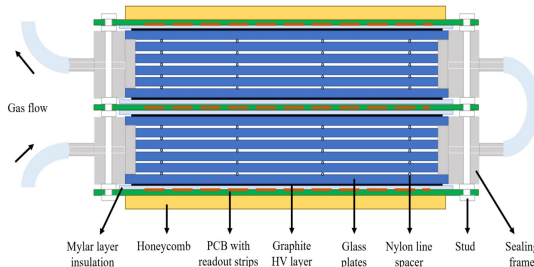


eTOF Runing Status

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



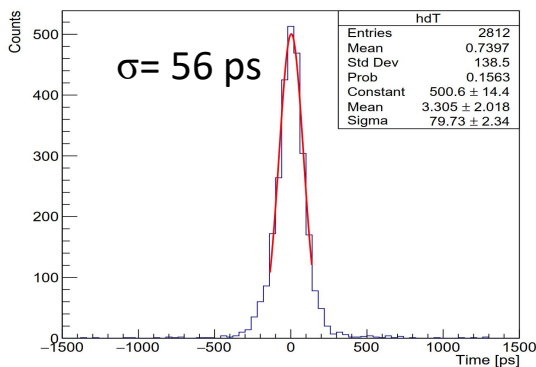
eTOF MRPC configuration



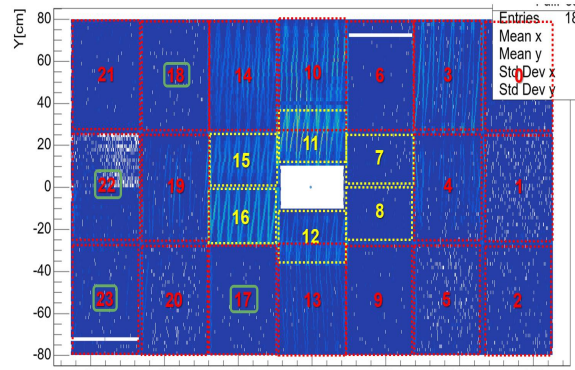
Module Installation



Prototype time resolution

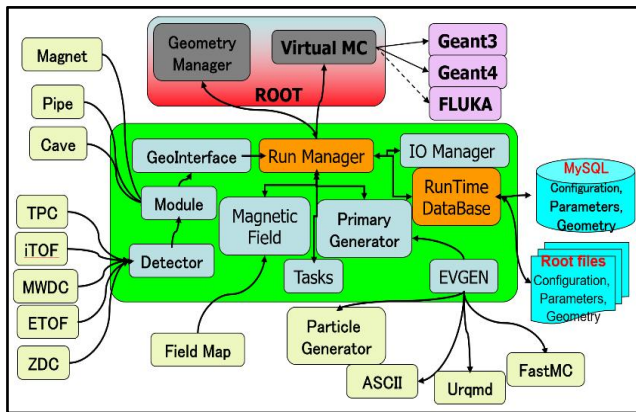


eTOF Hit Map



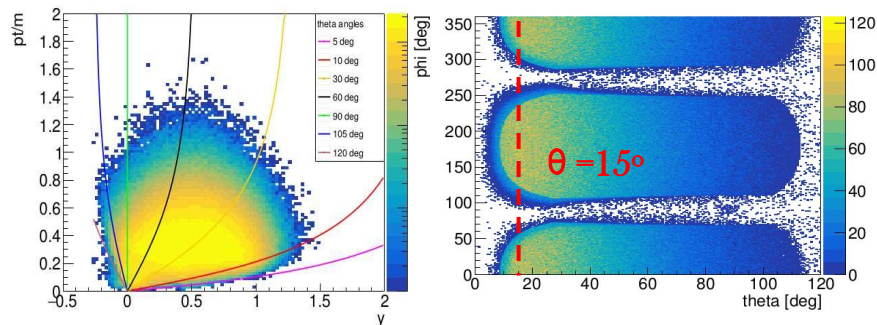
CeeROOT: CEE Simulation & Analysis Software

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

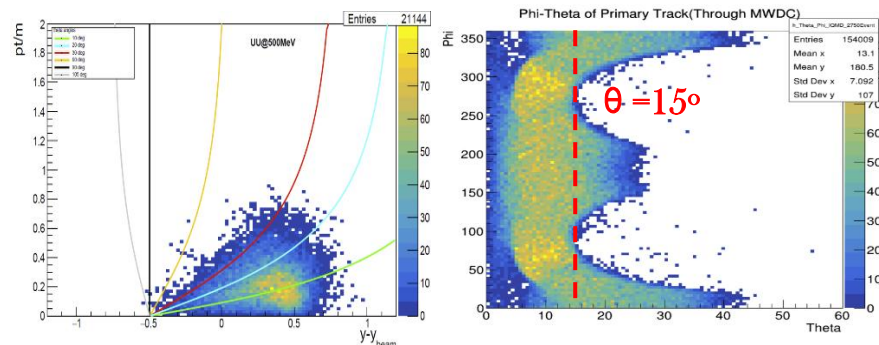
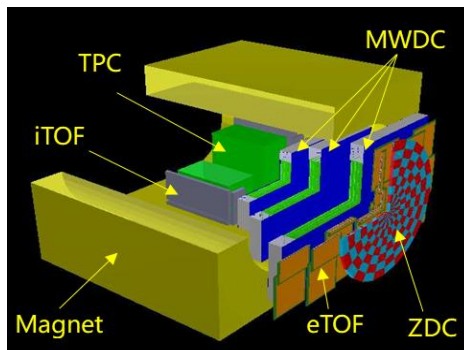
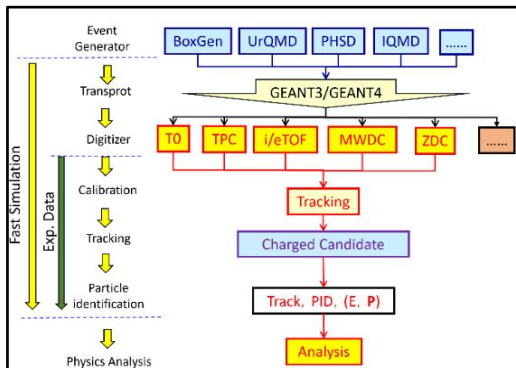


CeeROOT
Home page:
<https://gitee.com/CEESM/CeeRoot>
(Open source)

TPC acceptance

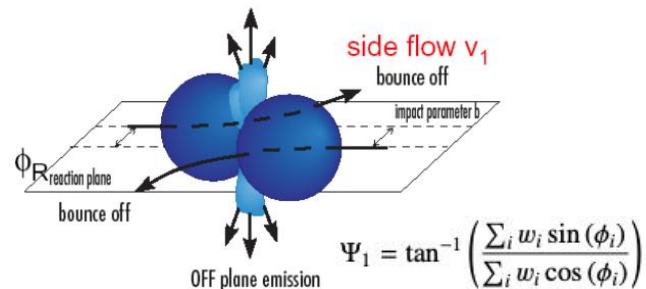
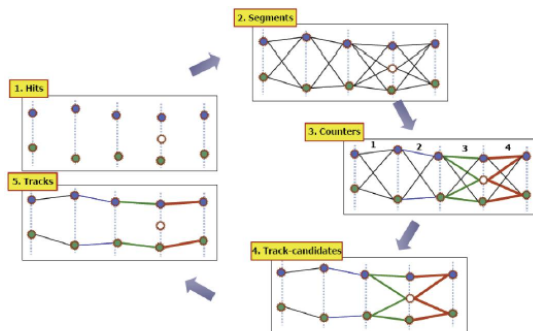


MWDC acceptance

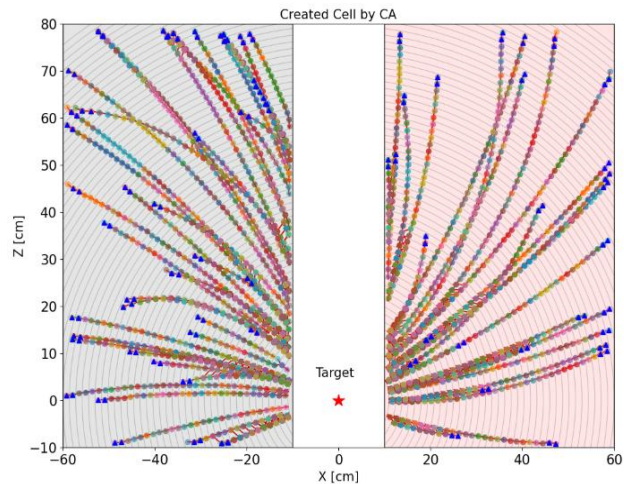


TPC Tracking/Event Plane Reconstruction

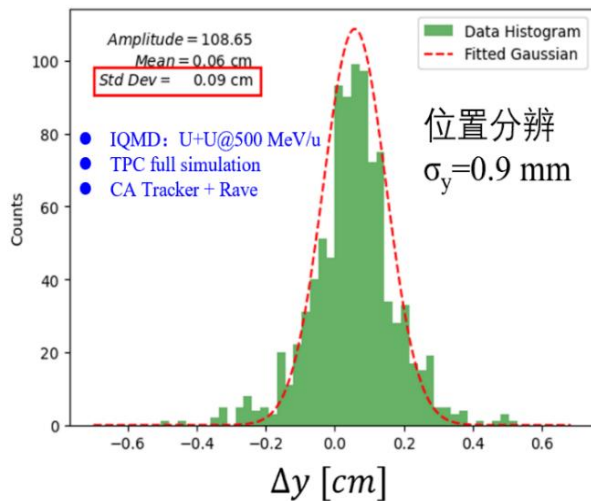
- Track finder
Cellular Automaton (CA)
- Track fitting
Kalman filter (Genfit)
- Vertex fitting: RAVE



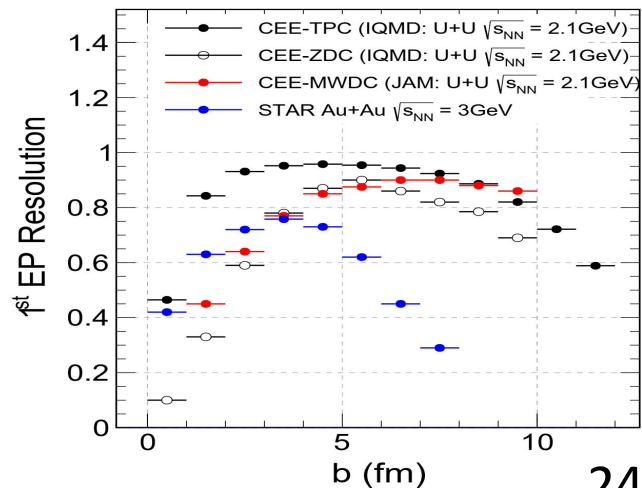
TPC tracking with IQMD event



Vertex based TPC tracks



Event plane reconstruction

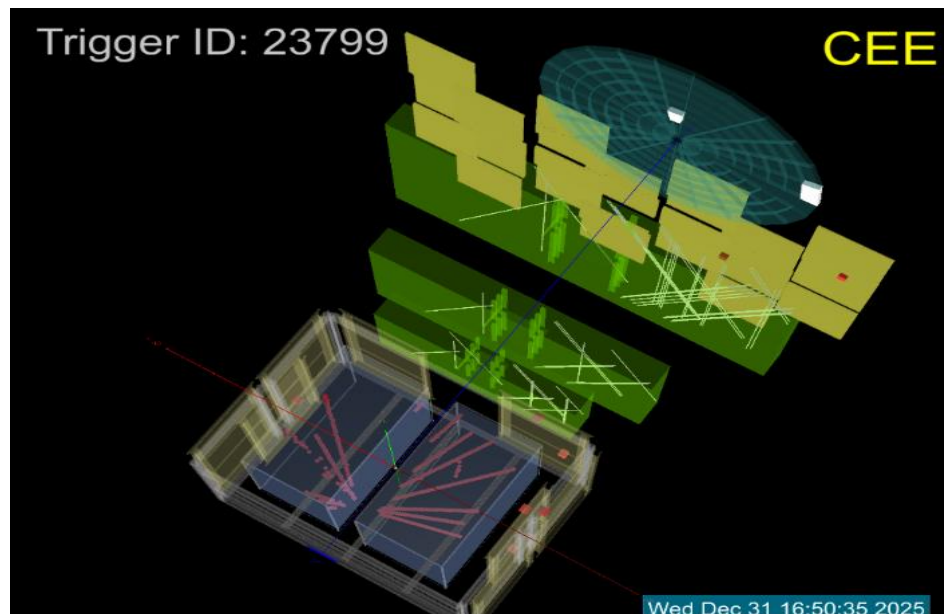
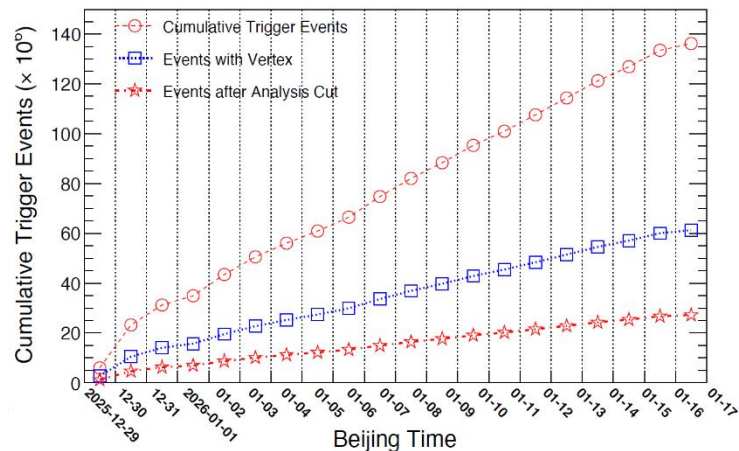
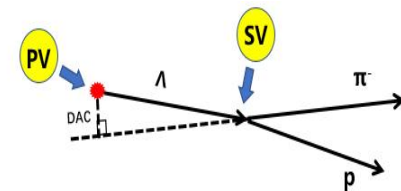


1.1 GeV/u C+C/Pb (No magnet)

Item	Remarks
Beam	1.1 GeV/u $^{12}\text{C}^{6+}$
Target	C-Pb-C-Pb (1cm space)
Beam Time	2025/12/29-2026/01/17
Recorded	1.36亿 (136M)

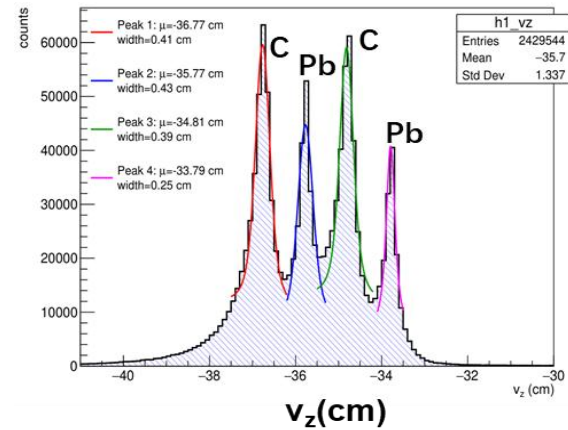
Goal :

- Test CEE detection system
- Sub-threshold Λ production

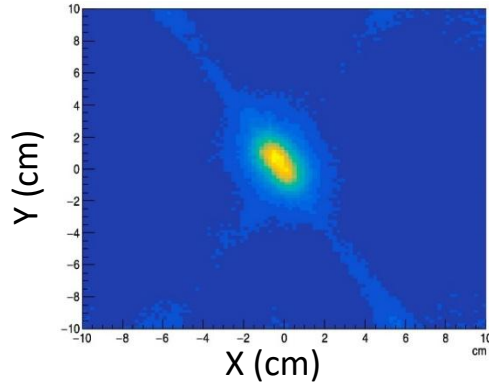


1.1 GeV/u C+C/Pb Analysis Progress

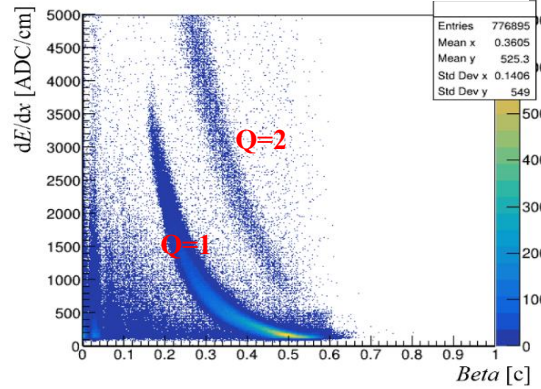
Vertex reconstruction



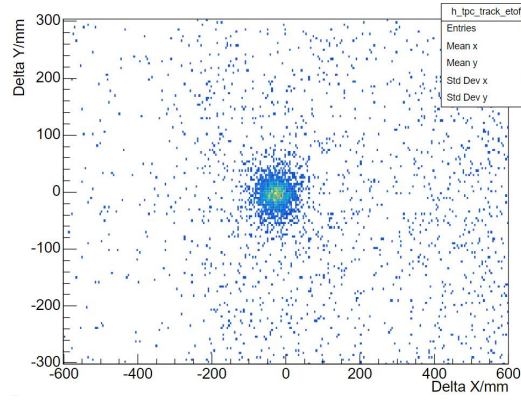
TPC and MWDC track matching



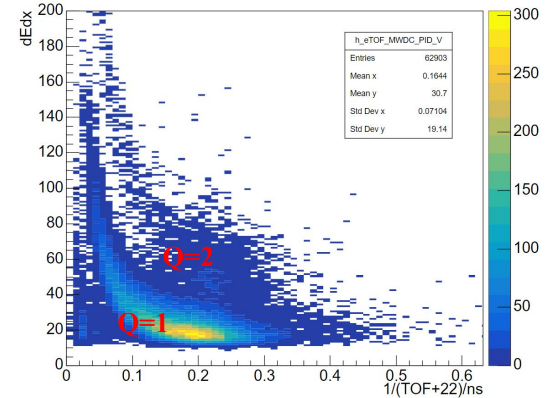
TPC dE/dx Vs iTOF



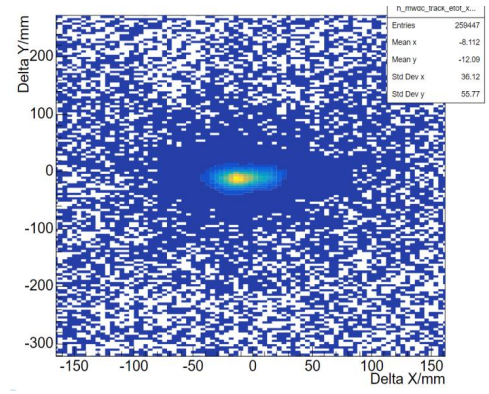
TPC and eTOF matching



MWDC dE/dx Vs eTOF

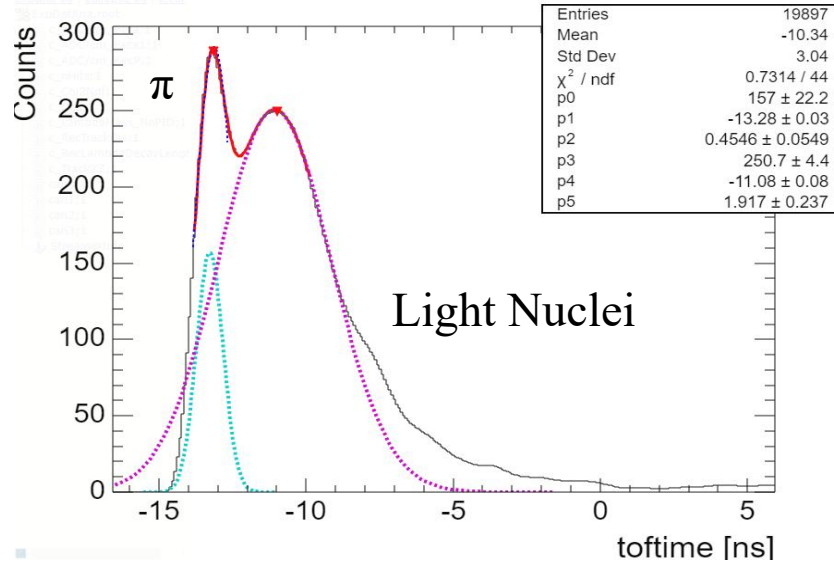


MWDC与eTOF matching

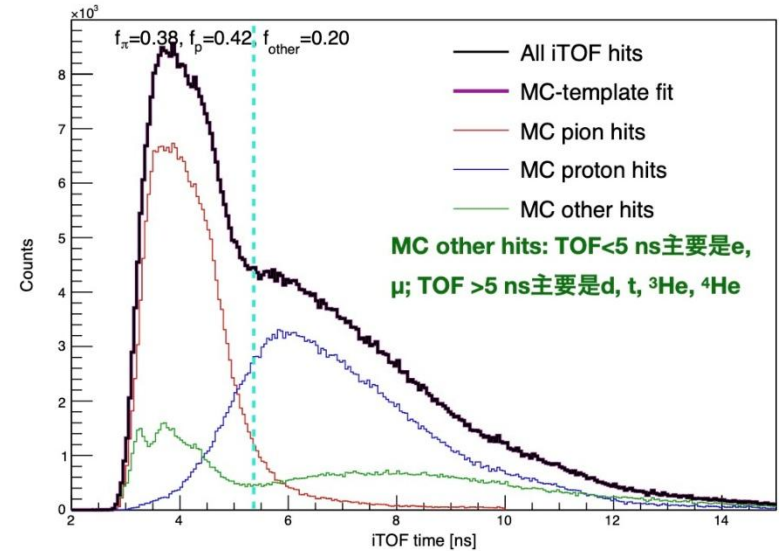


TOF Spectrum of iToF

1.1 GeV/u C+C/Pb



Simulation Data



CEE Physics Program

	Collision	Measurement	Physics
I	1.1 GeV/u C+C/Au	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 detection system works as expected; 1st round of calibration has been finished; 2nd round of data production is on going
- Λ and K^0 reconstruction and other analyses are ongoing
- CEE SC magnet will be installed in Q4 2026 and 1.1 GeV/u C+C/ Au
- Event Reconstructions algorithms (RP, Centrality, Efficiency) , simulation validation, BenoDST (like STAR PicoDST) are on going
- Beam energy scan (U-C beam, 0.3-1.1 GeV/u)



谢谢各位老师