The 4th Korea-China Workshop for Rare Isotope Physics

Progress of the HIRFL-CSR External-target Experiment (CEE)

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(for CEE collaboration)

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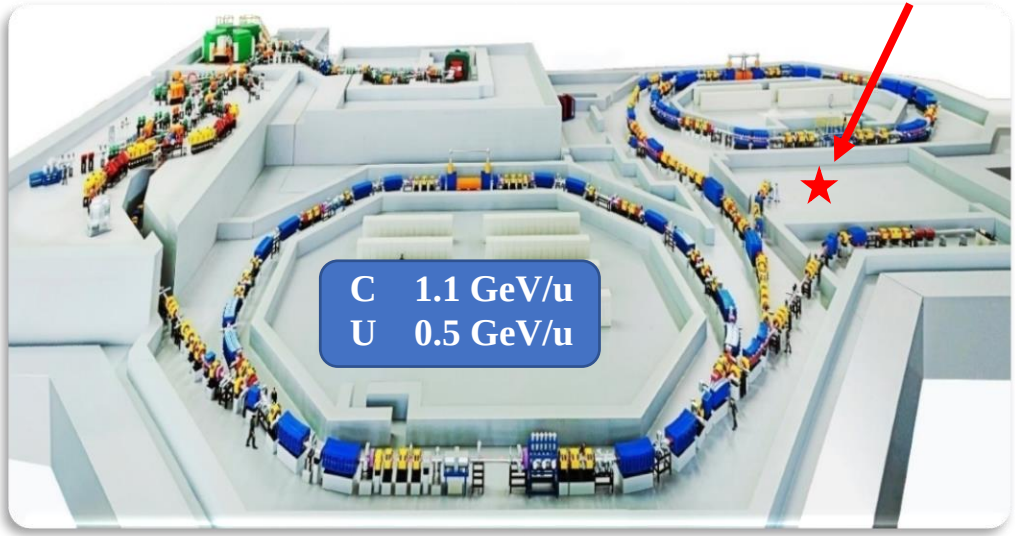
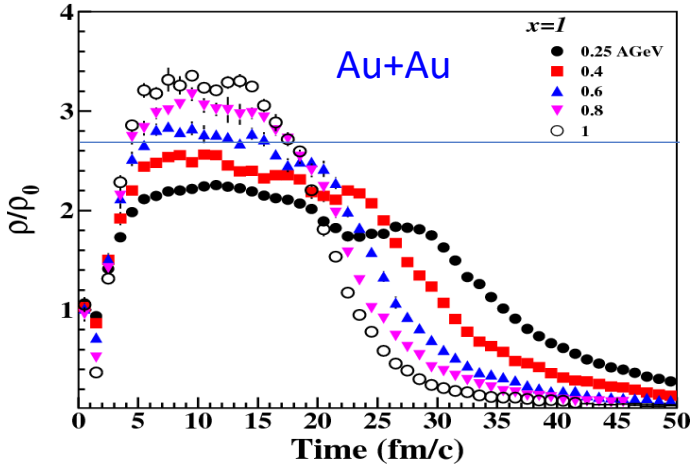
Outline

- Physics motivation
- CEE spectrometer and development progress
- Beam test and software
- CEE+ at HIAF
- Summary

Heavy Ion Research Facility in Lanzhou (HIRFL)

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

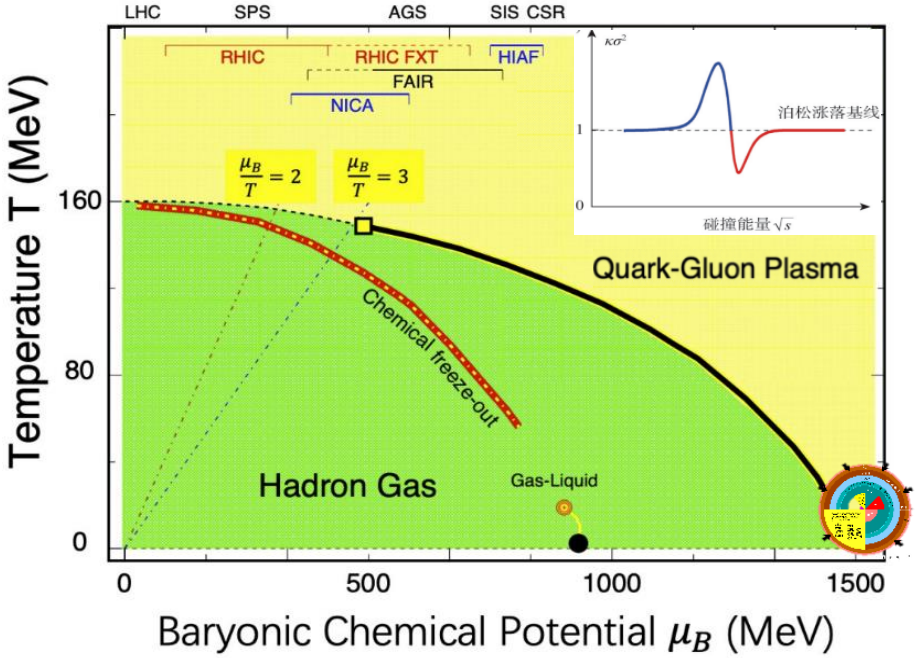
Interplay with Neutron Star Physics

Sub-threshold production

Short range correlation

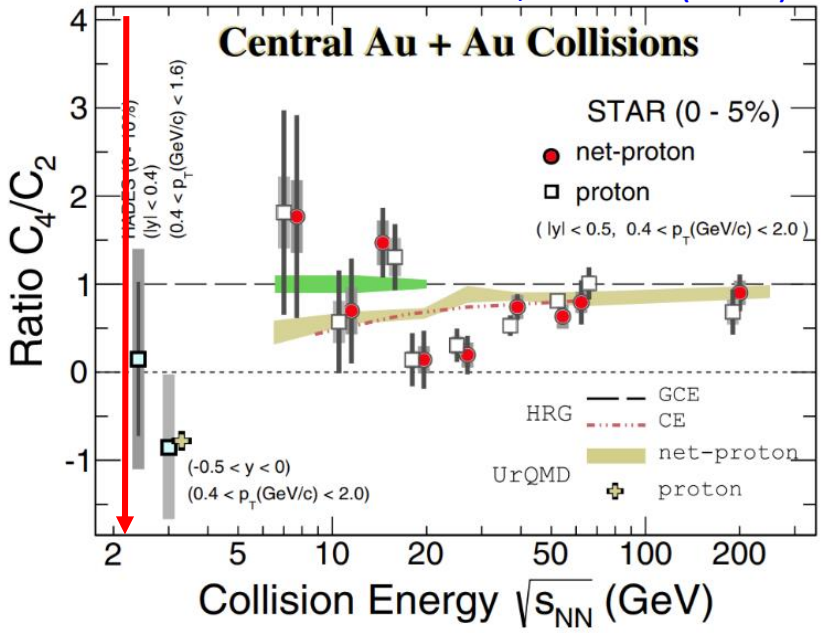
……

QCD Phase Diagram

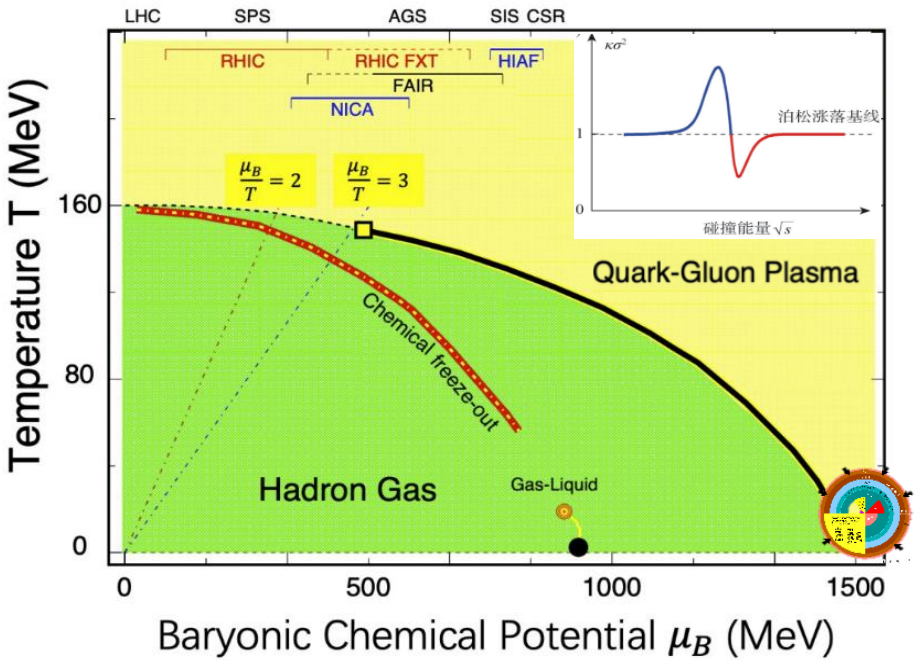


CEE@HIRFL

PRL 128, 202303 (2022)

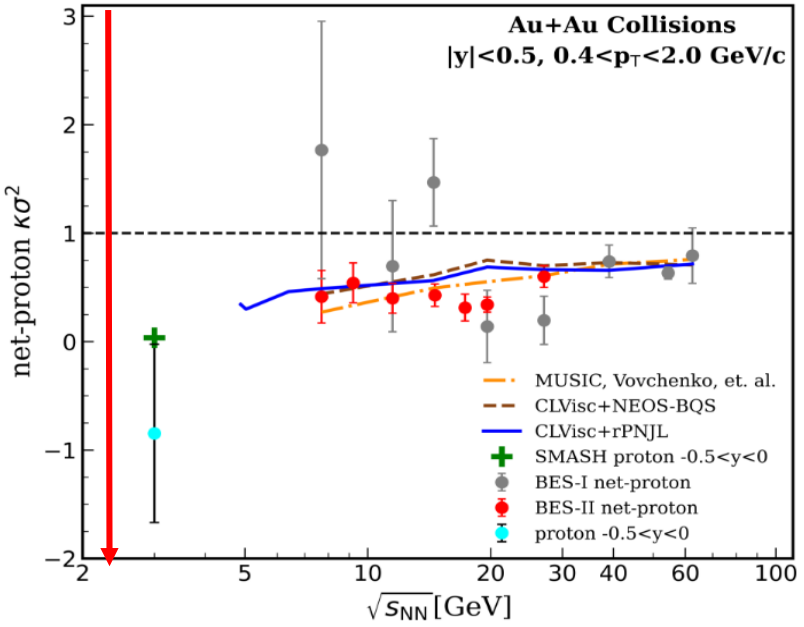


QCD Phase Diagram

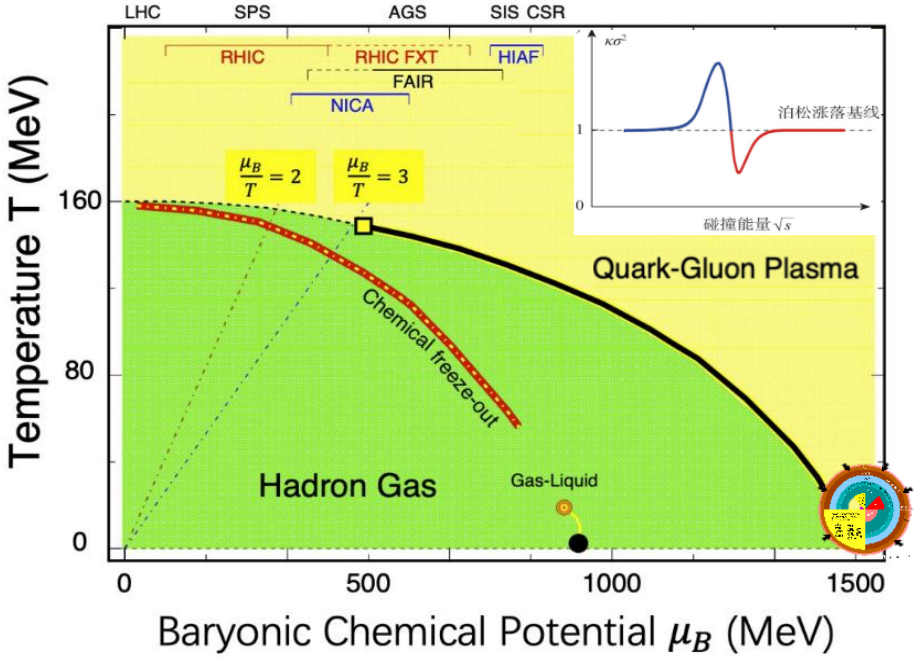


CEE@HIRFL

STAR：arXiv:2504.02531



QCD Phase Diagram



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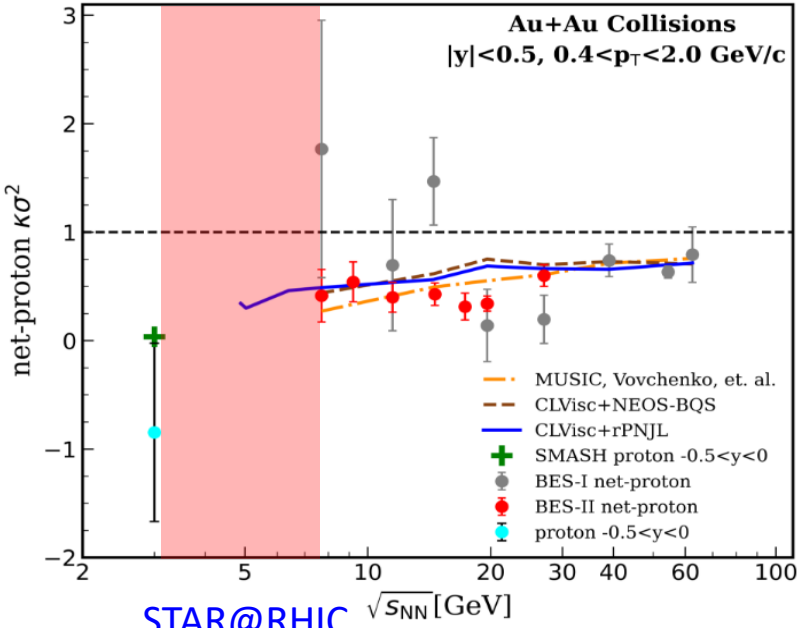


STAR@RHIC
CBM@FAIR
MPD@NICA
CEE+@HIAF

Nuclear EOS of Asymmetric Matter $E_{sym}(\rho)$

Nuclei: $B(Z,A) = B_v + B_s + B_c + B_a + B_p$

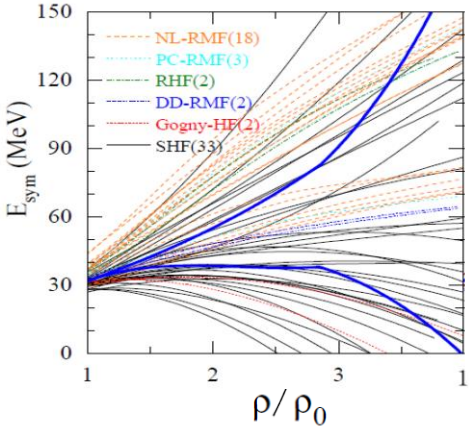
$$= a_v A - a_s A^{2/3} - a_c Z^2 A^{-1/3} - a_a (N-Z)^2 A^{-1} + a_v \delta A^{-1}$$

Nuclear matter

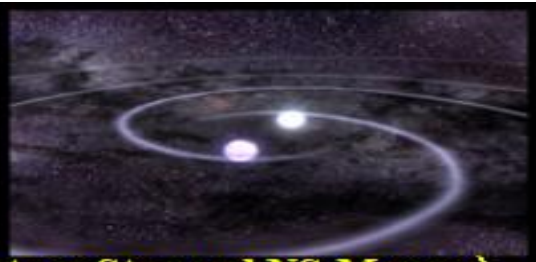
$$E(\rho,\delta) = E_0(\rho) + \delta^2 E_{sym}(\rho)$$

$$\delta = \frac{N-P}{N+P}$$

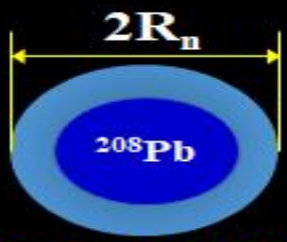
$$E_{sym}(\rho) = L\frac{\rho-\rho_0}{3\rho_0} + \frac{K_{\rm sym}}{2}\left(\frac{\rho-\rho_0}{3\rho_0}\right)^2 + \frac{J_{\rm sym}}{6}\left(\frac{\rho-\rho_0}{3\rho_0}\right)^3$$



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



(Neutron Star and NS Merge)



(Static Properties of Nuclei)

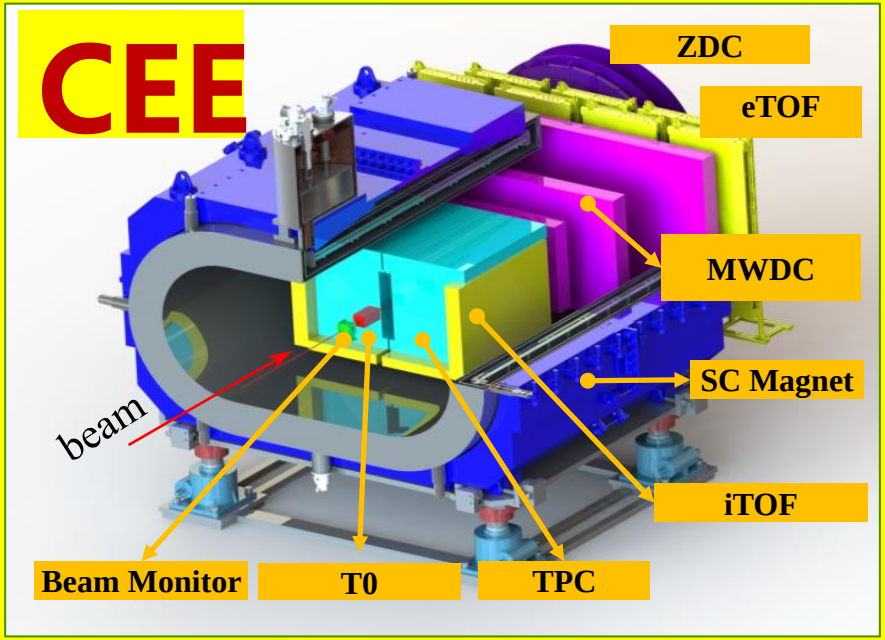
(Heavy Ion Collisions)

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 (iTOF)
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



- $\Delta p/p$: $\leq 5\%$, $\Delta t/t$: ≤ 80ps
- Max. Rate: 10 kHz
- Proton acceptance: ~ 85%

CEE Collaboration

China:

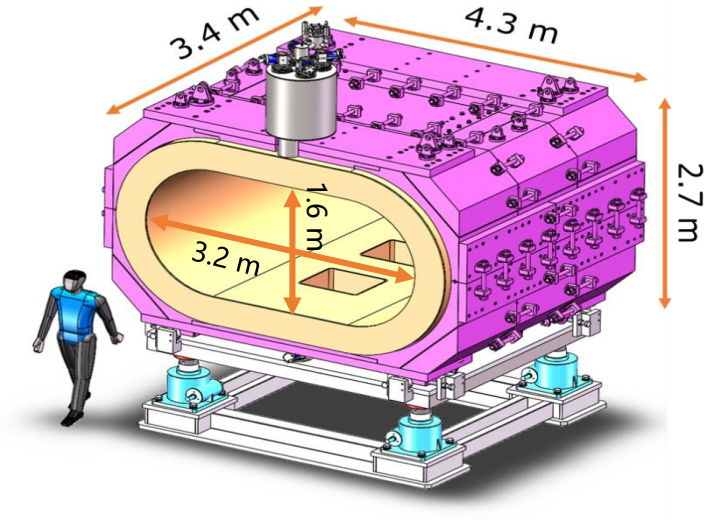
- Central China Normal University (CCNU)
- Fudan University (FDU)
- Institute of Modern Physics, CAS (IMP)
- Tsinghua University (THU)
- University of Science and Technology of China (USTC)

Japan:

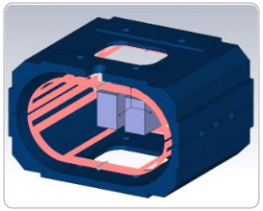
- Tsukuba University

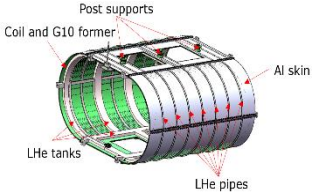
Super-Conducting Dipole Magnet

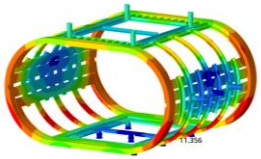
Quantity	Performance
Central Field	0.5 T
Uniform range	1200×800×900 mm^3
Uniformity	±2.5%
Current in operation	231 A

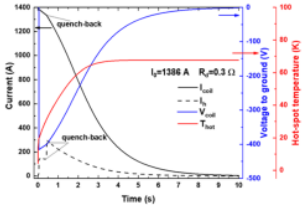


Magnet design



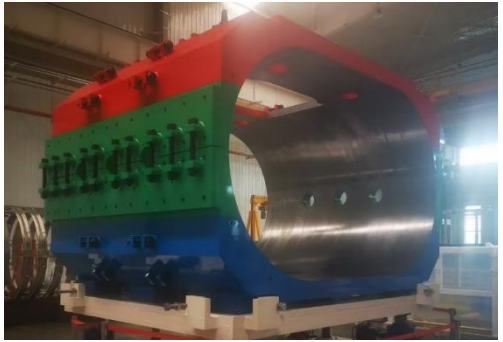






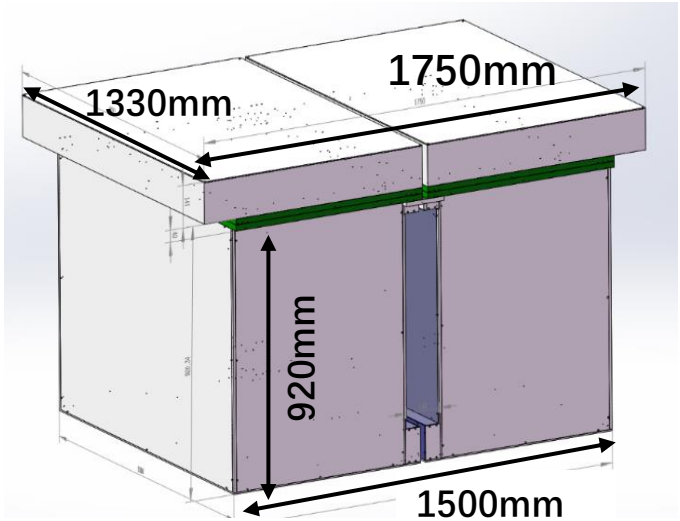
SC Magnet prototype

Magnet production

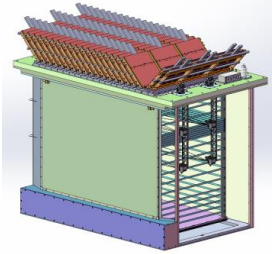


TPC development

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

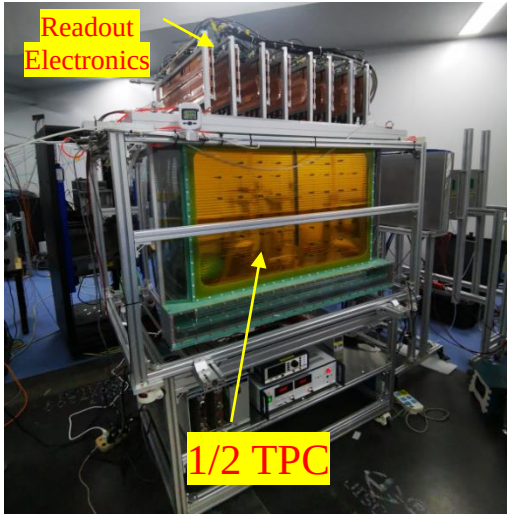


TPC design

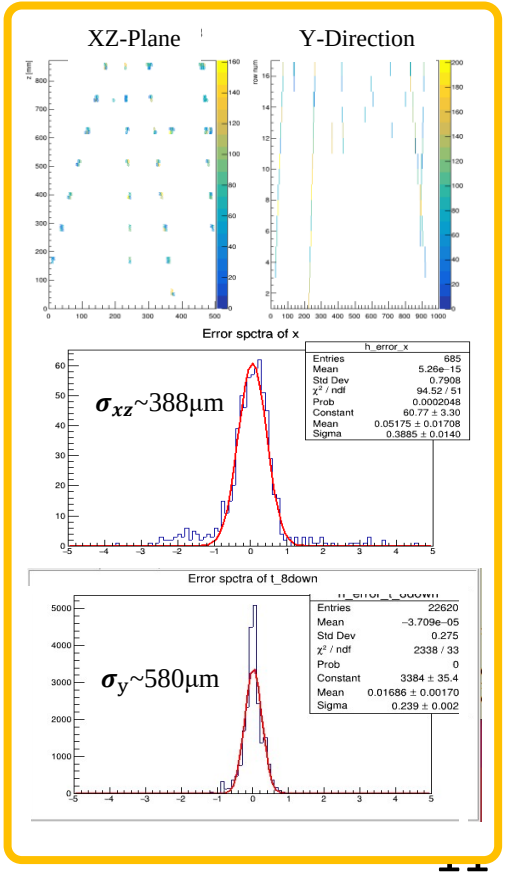


SAMPA-based readout

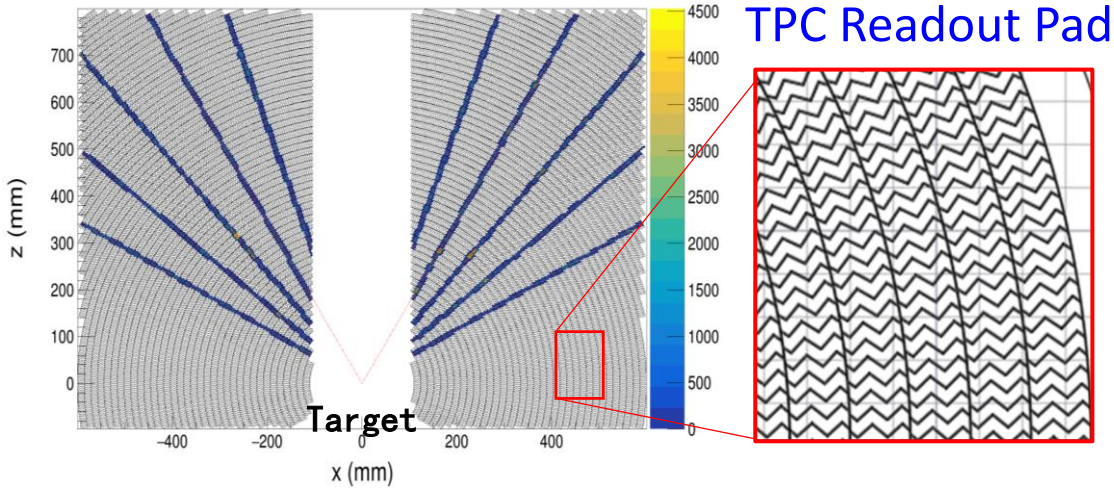
样机束流测试



Beam Test Result

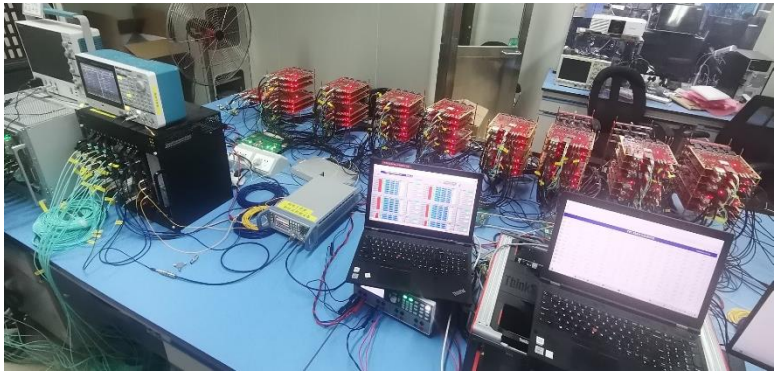


TPC Production

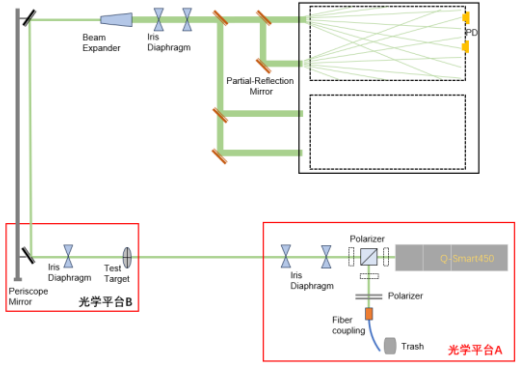


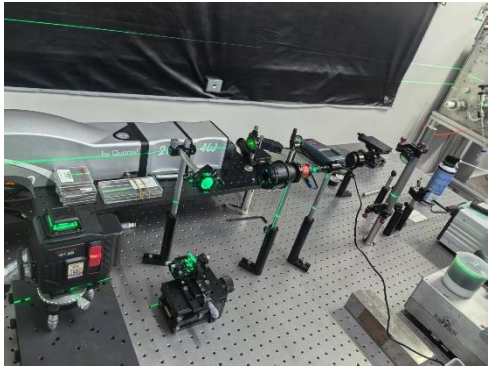
TPC Readout Pad

Electronics Maturity Test

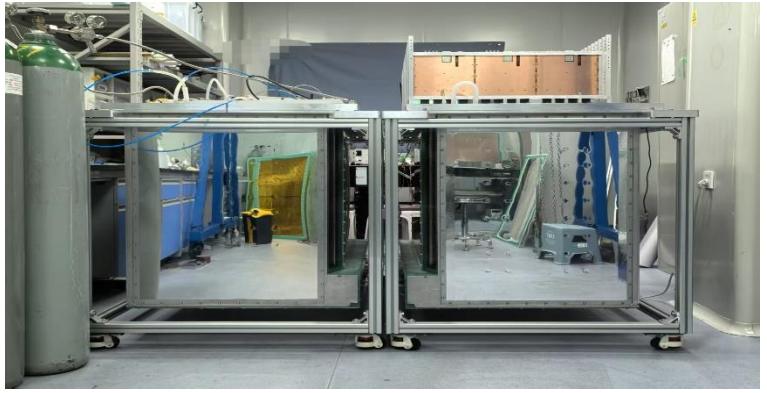


Laser system (14 beam × 3 layers)



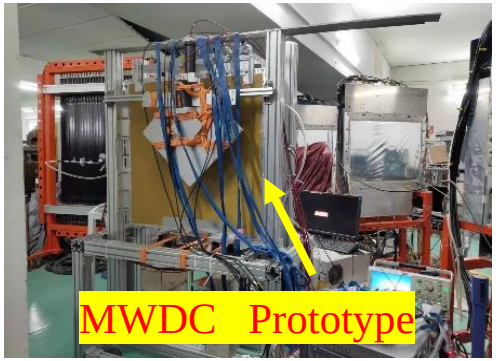


TPC Detectors

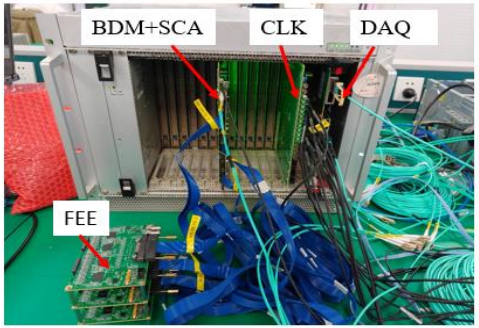


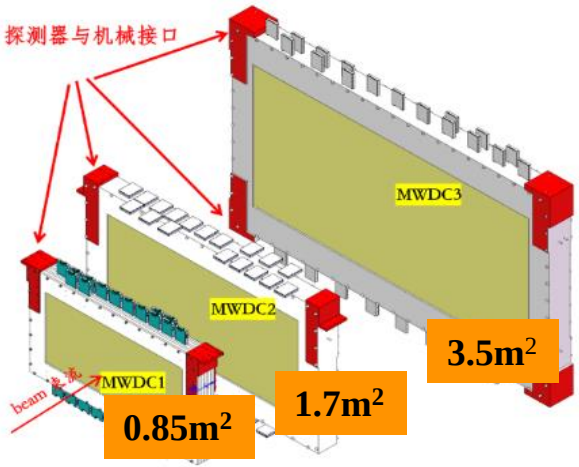
MWDC Development & Production

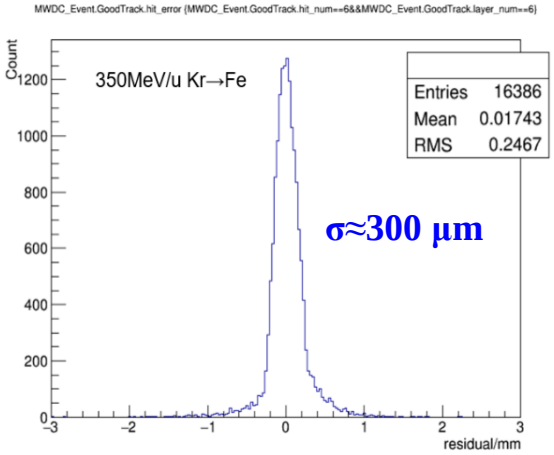
Quantity	Design index
Channels	~3200
Wire layer per module	X、X’ 、U、U’ 、V、V’
σ_{xz}	300 μm
Energy resolution	> 22%
Detection efficiency	> 98%
Momentum resolution	<5%



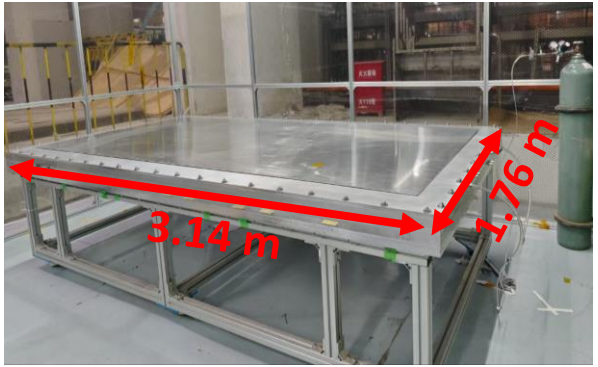
Electronics Maturity Test





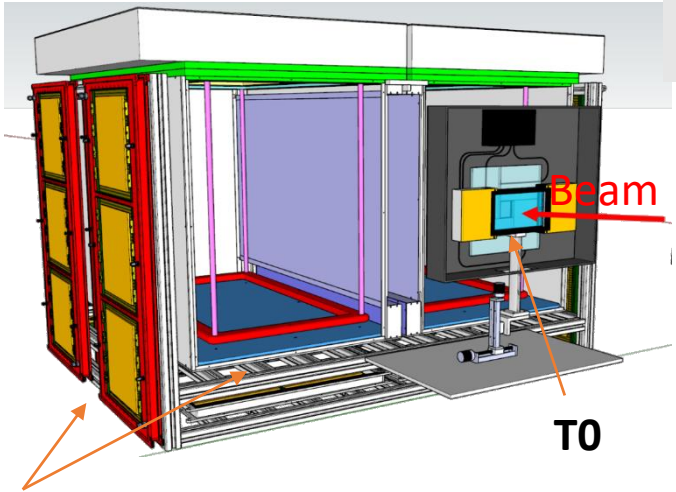


MWDC3 detector



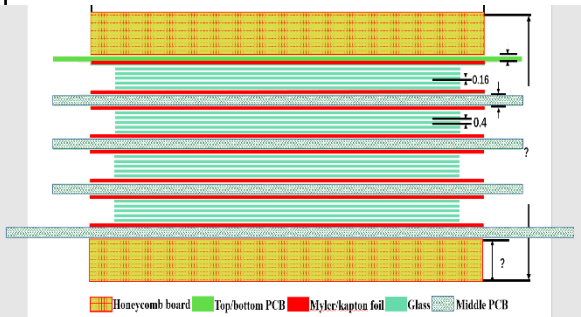
iTOF development & Production

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

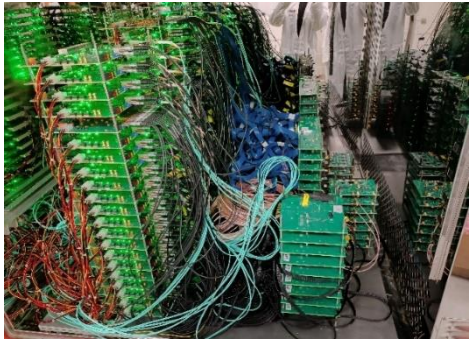


iTOF: covers 3 side of TPC

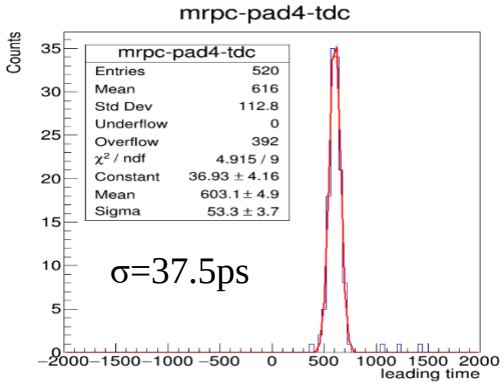
iTOF based MRPC Design



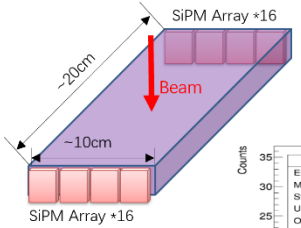
Electronics Maturity Test

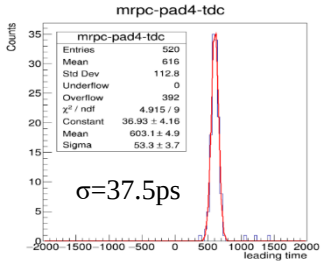


Beam test results



T0: Scintillator + SiPM

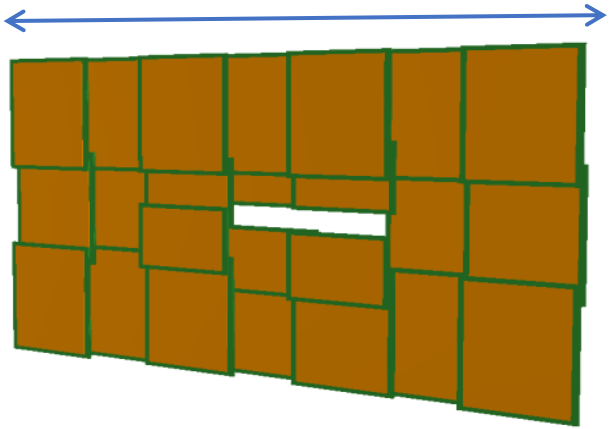




eTOF development

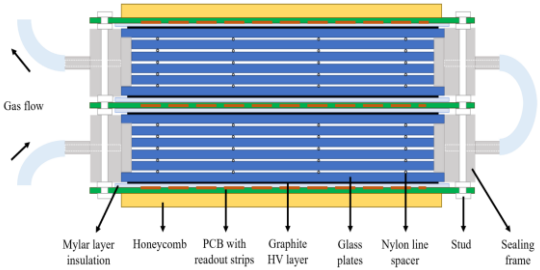
Quantity	Design index
σ_T	60 ps
Efficiency	>95%
Rate	>10kHz

3.2 m

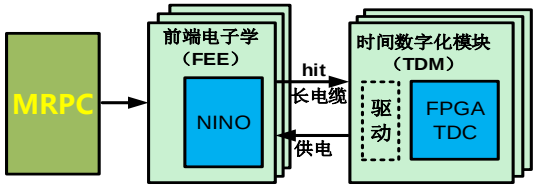


1.6 m

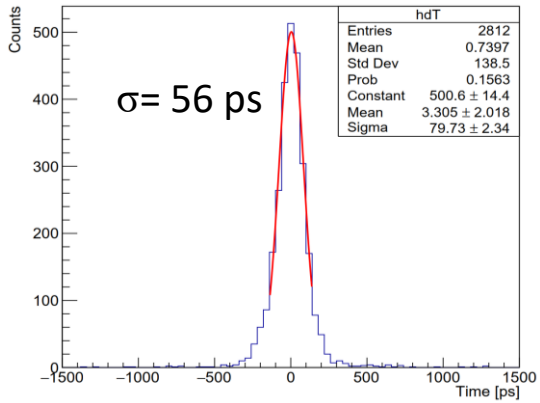
eTOF MRPC configuration



MRPC readout



Prototype time resolution



Massive Production

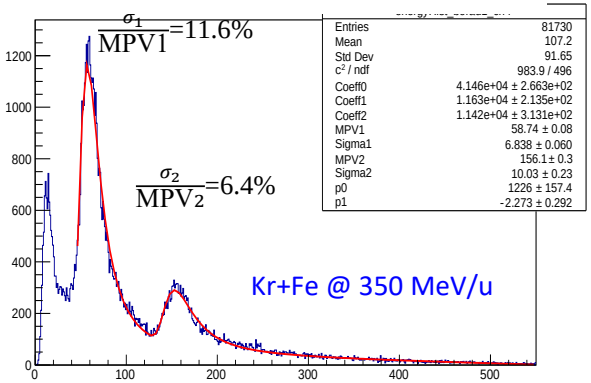
Zero Degree Counter (ZDC)

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

- Event Plane
- Centrality definition

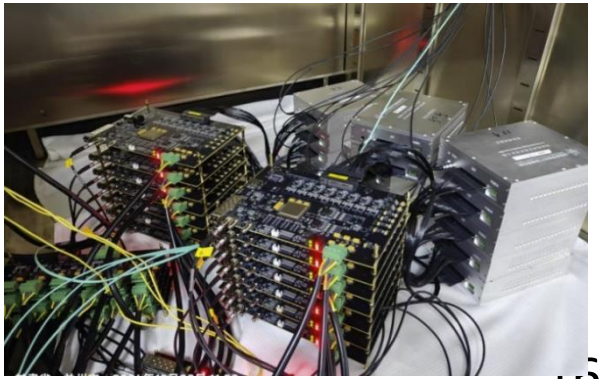
ZDC Prototype

Beam test result



Massive Production

Electronics Maturity Test

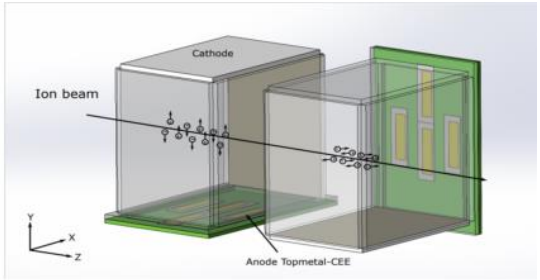


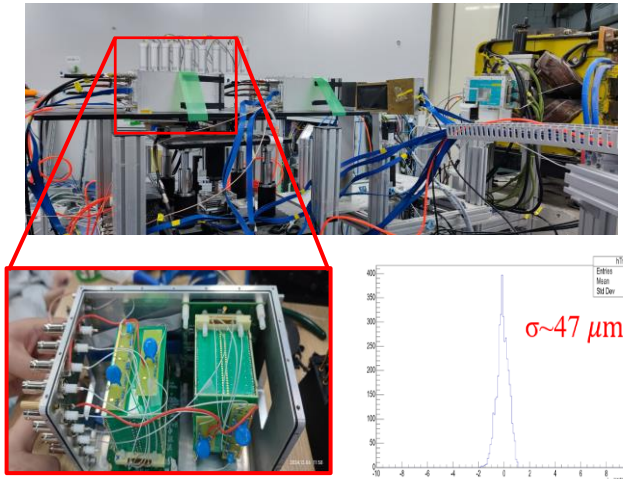
CCNU & Uni. Tsukuba

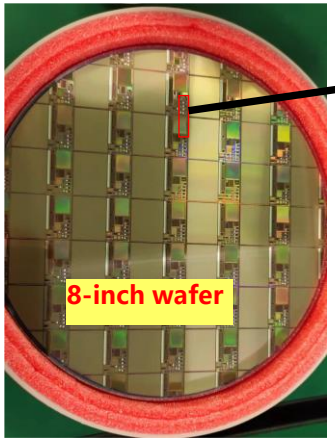
Beam Monitoring (BM) Detector

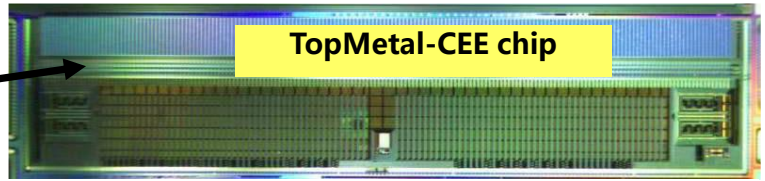
BM Parameters	Design index
Position resolution	50 μm
Time resolution	1 μs
Volume	10x10x12 cm³

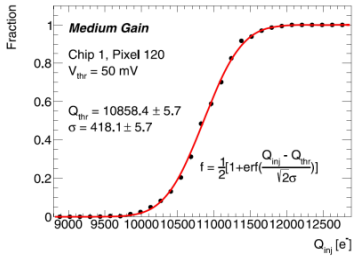
BM design

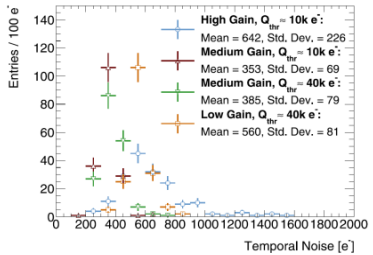




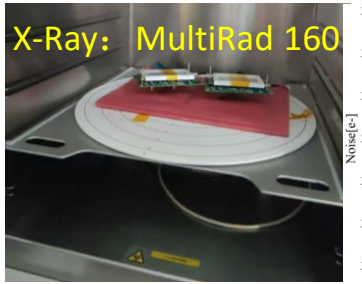


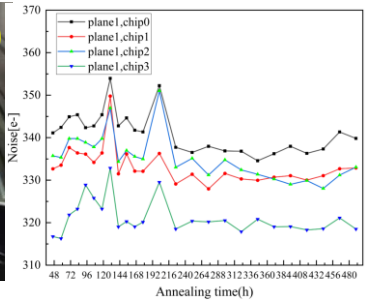






Electronics Maturity Test



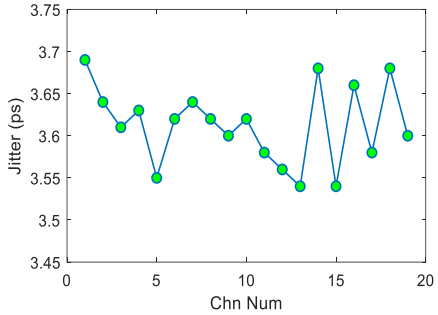


Clock System

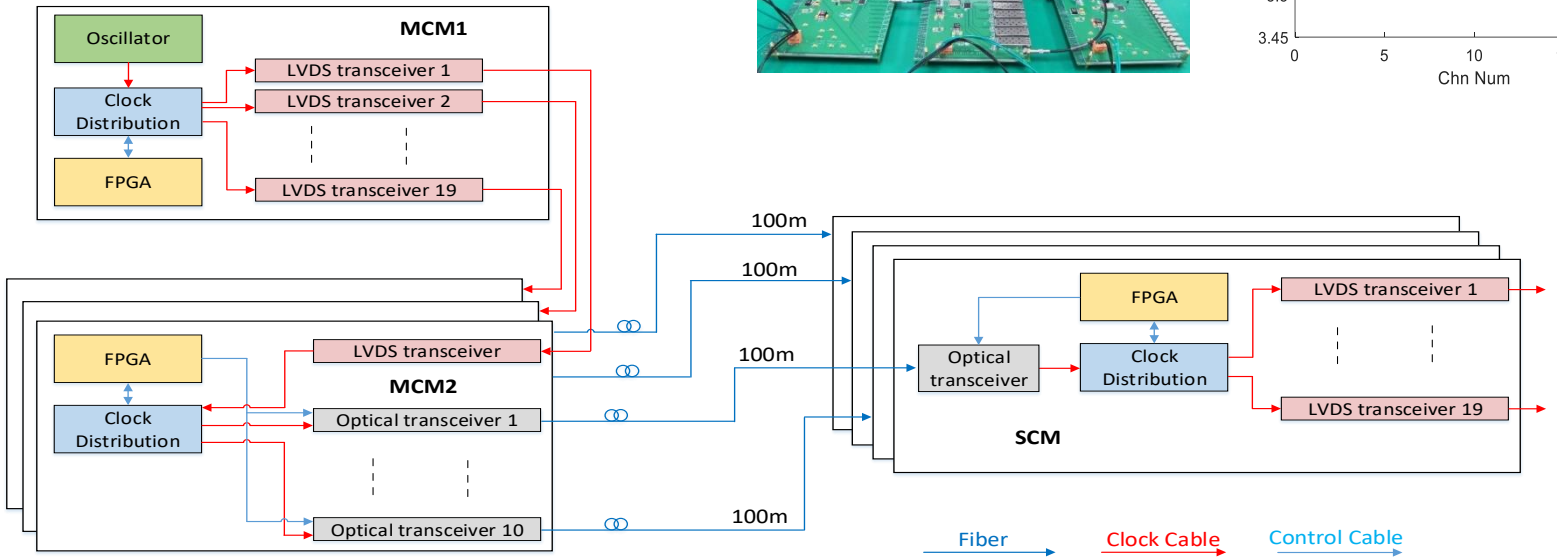
- Frequency: 40 MHz
- Period jitter： < 10 ps RMS
- Fan-out channel： ~ 400
- Long distance transmission： ~ 10 m

Test Setup

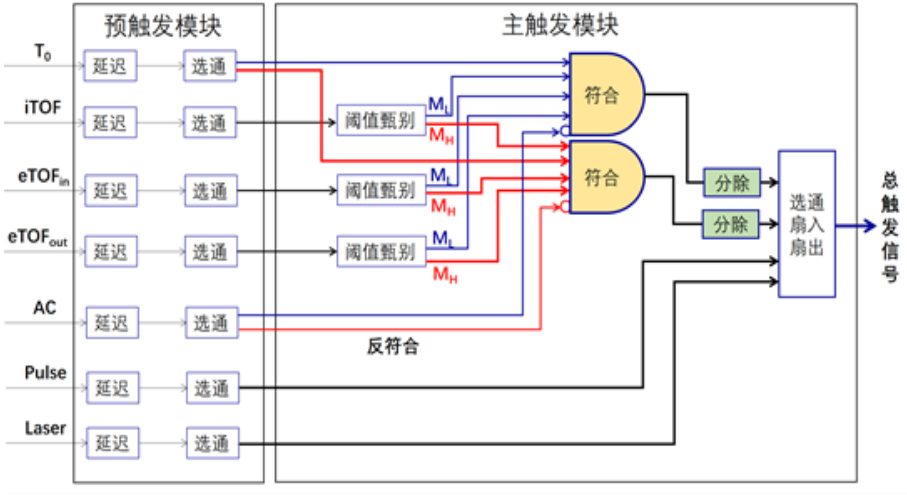
Test Result



Clock system block diagram

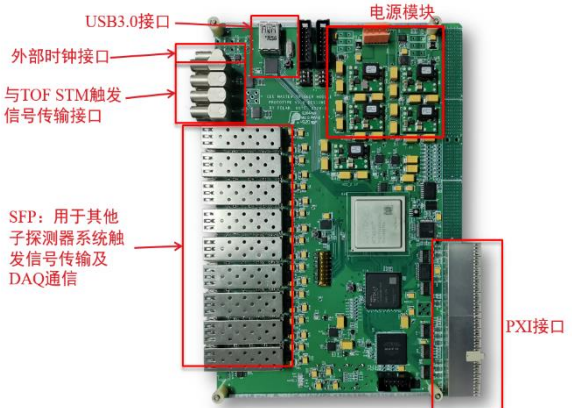


Trigger System (TS)

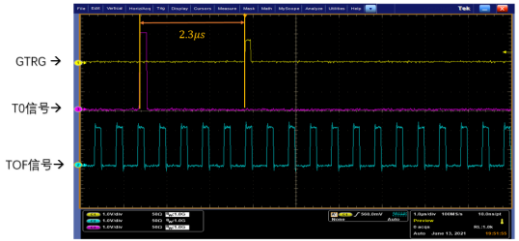


Working mode:

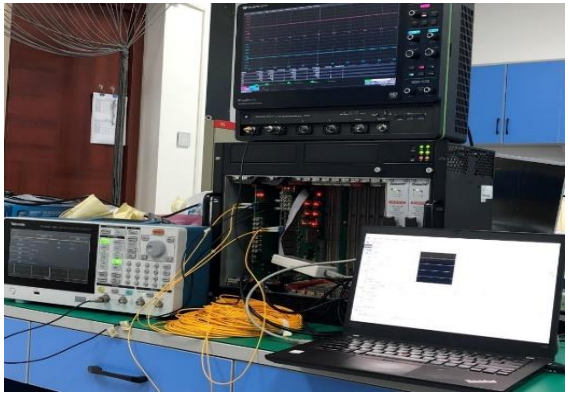
- Normal (data taking)
- Laser mode
- Pulse mode



Trigger logic simulation

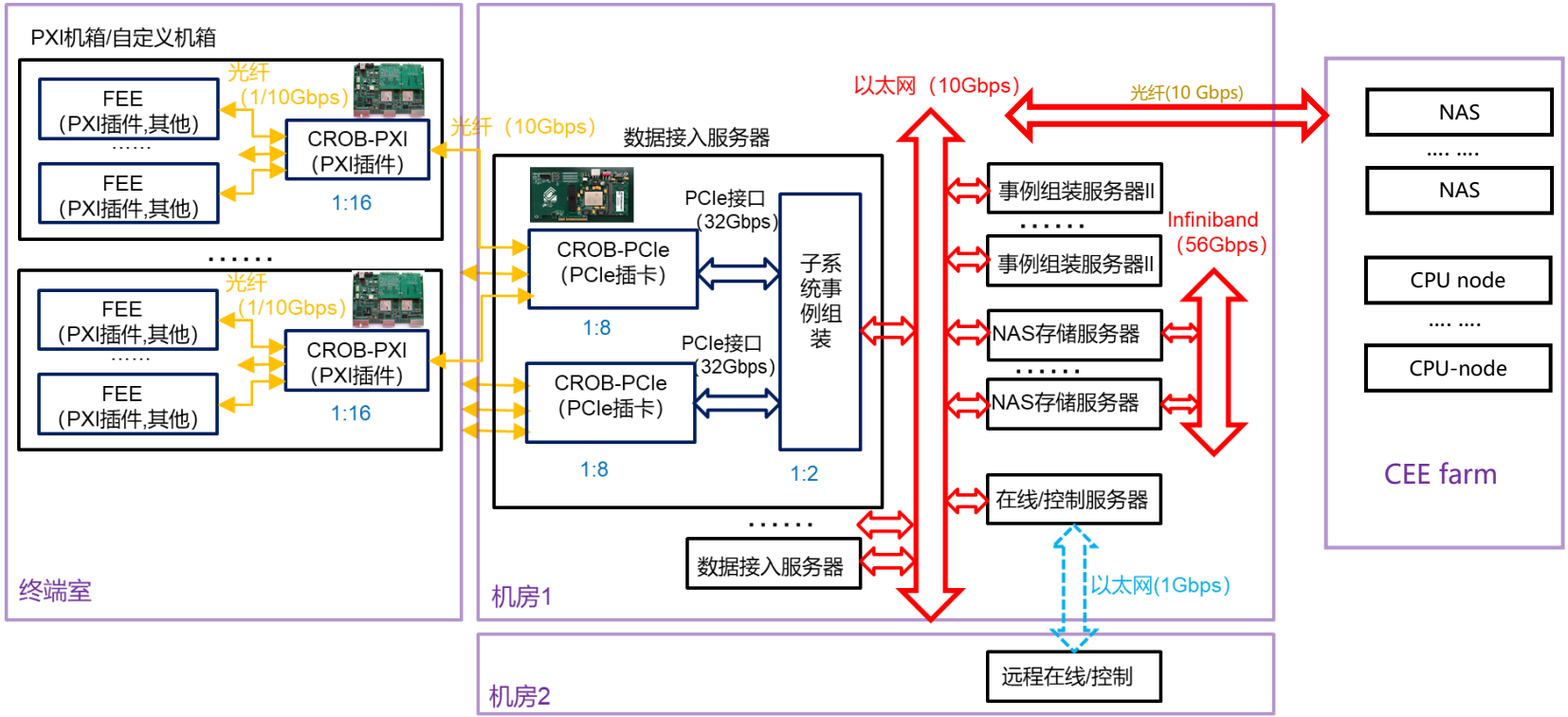


Lab test

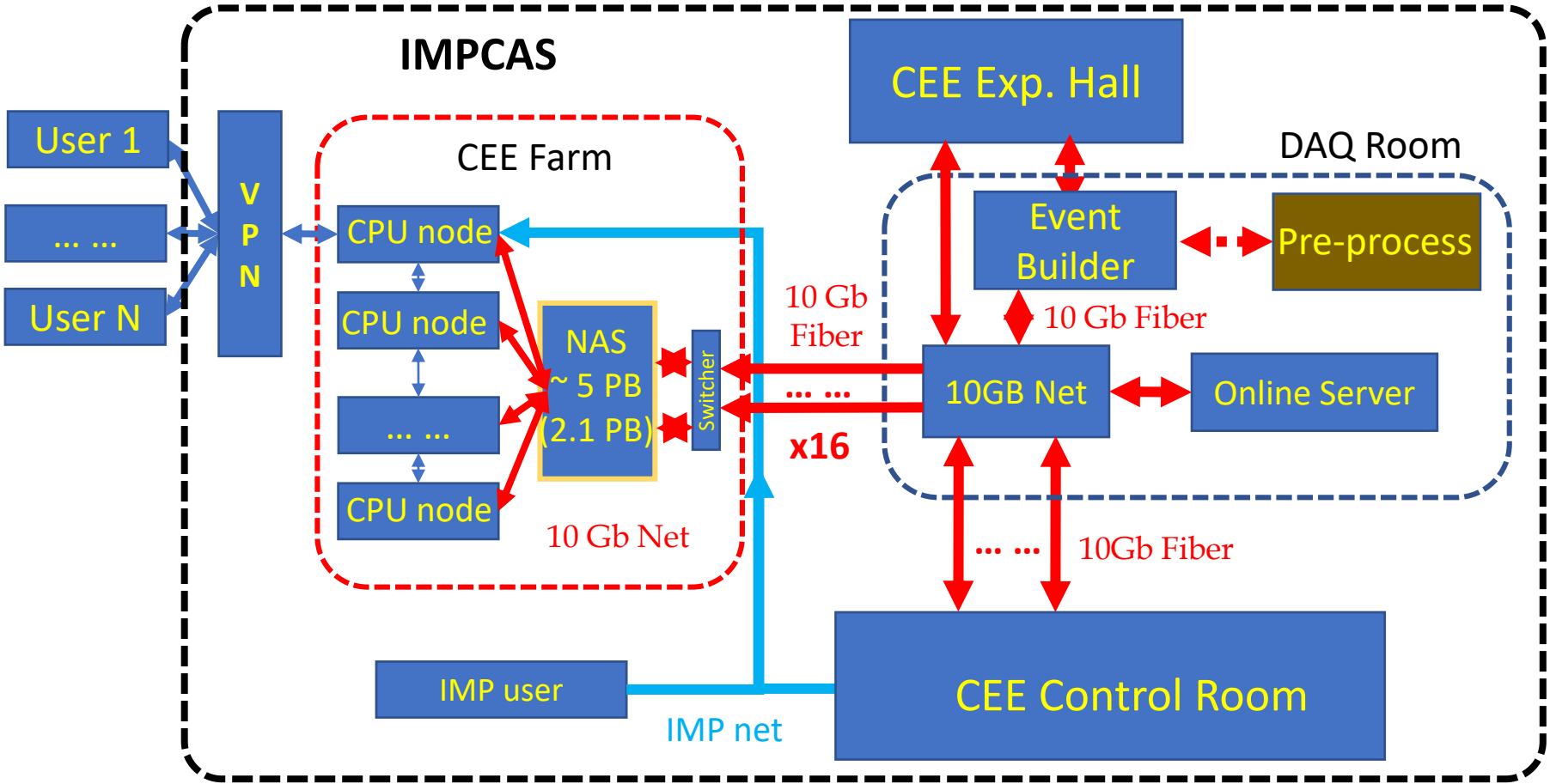


Data Acquisition System (DAQ)

Zero-suppressed data rate：~4.4 Gbyte/s



Data flow and Computing

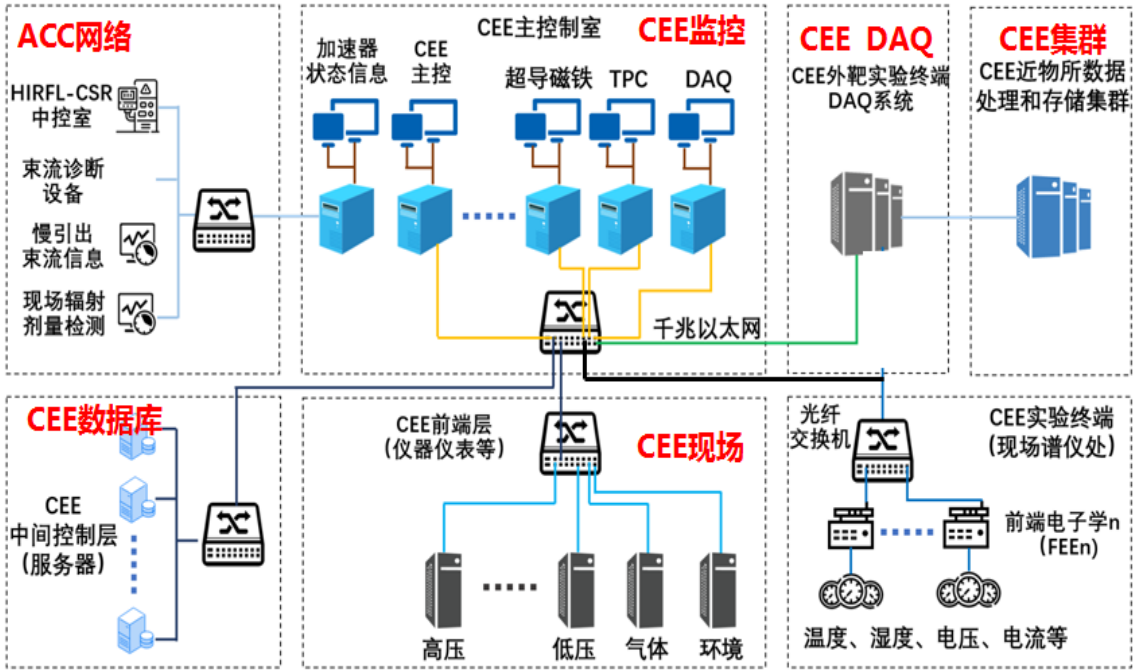


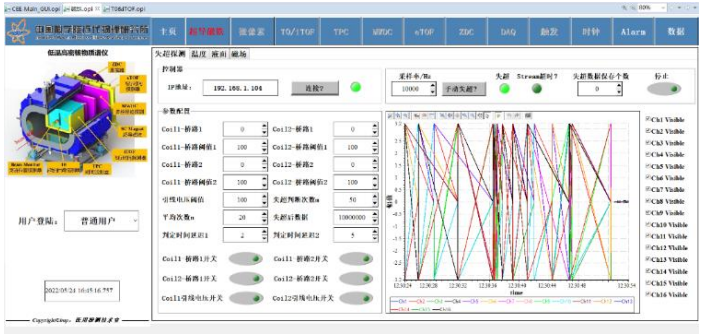
Slow Control (SC)

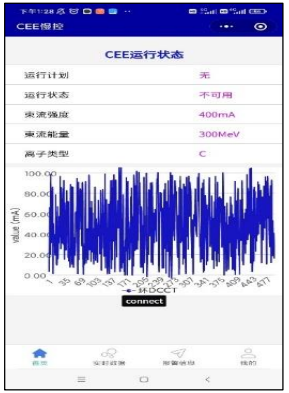
SC is based on the EPICS

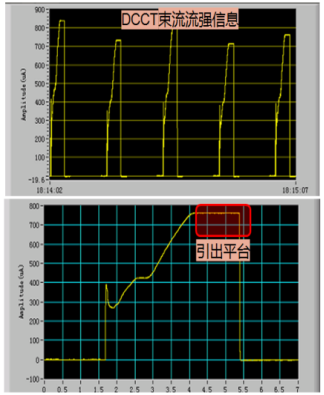
Argonne NATIONAL LABORATORY

Experimental Physics and Industrial Control System









System Integration & Infrastructure


Gas system


CEE Control Room


Ground treatment


Power system

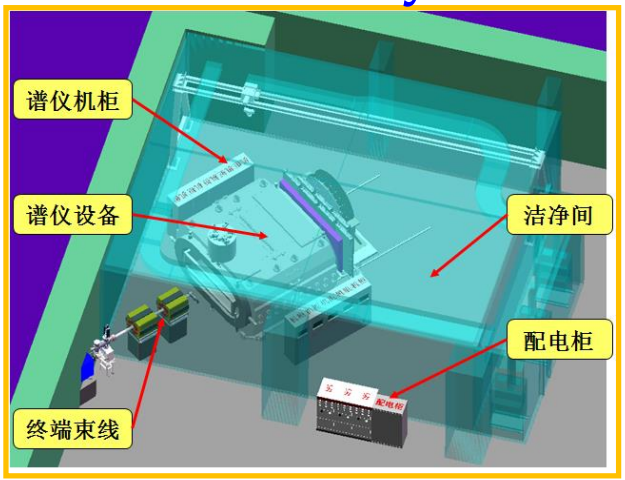

DAQ


Safety control

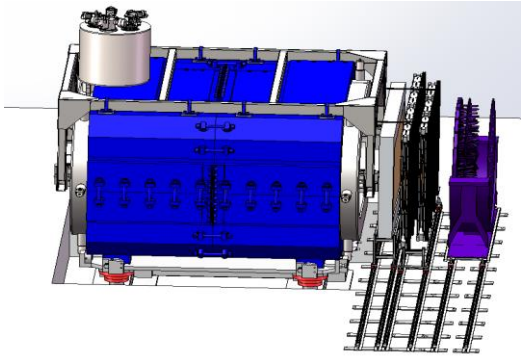

CEE Hall

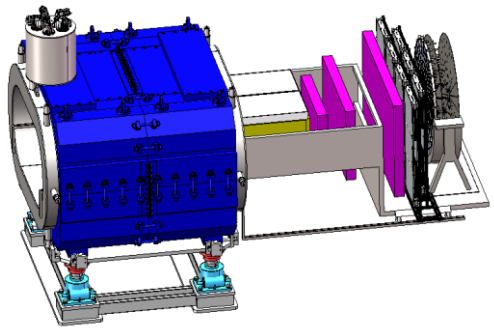
System Integration & Infrastructure

CEE Hall Layout

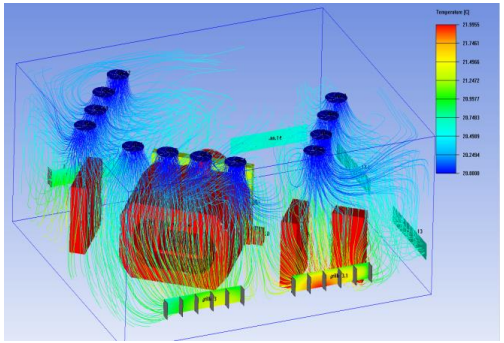


Assembly scheme

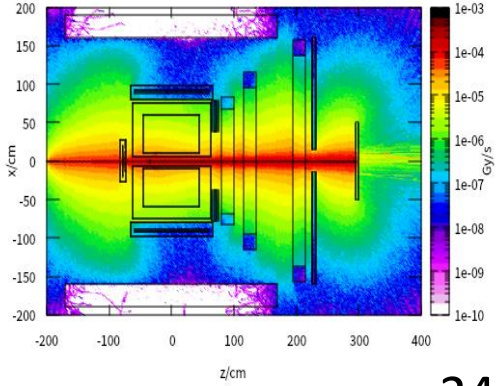




Heat simulation



Radiation dose simulation

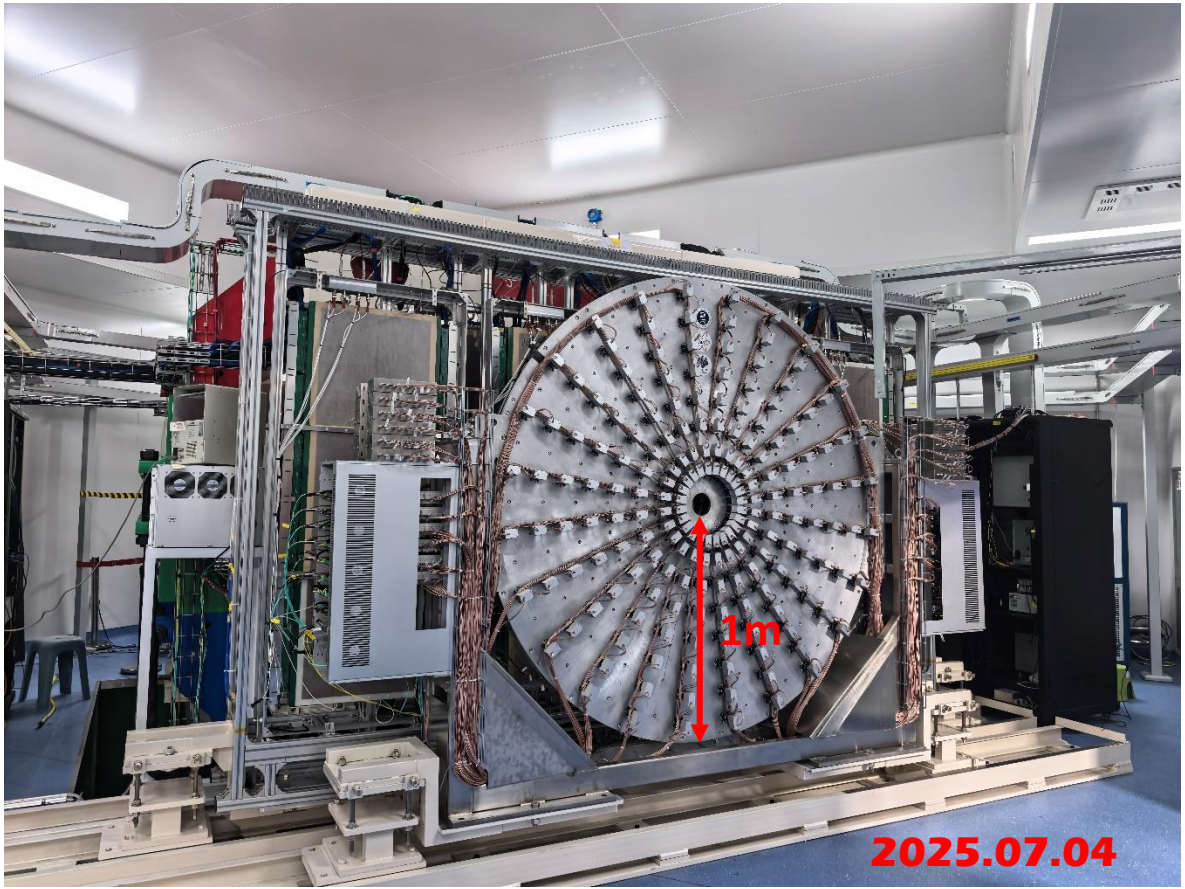


Others:

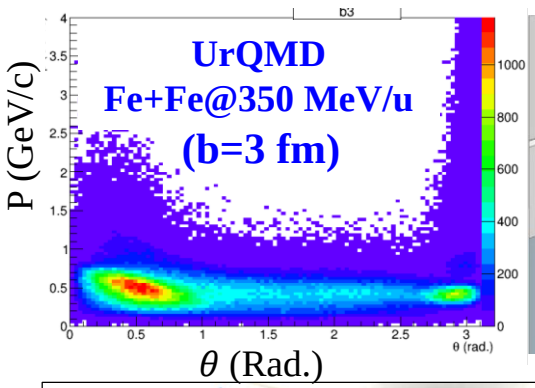
- Accelerator upgrade (in progress)
- Gas system (in progress)
- Beam line optimization (Done)
- Background noise treatment (Done)
- Radiation control (Done)

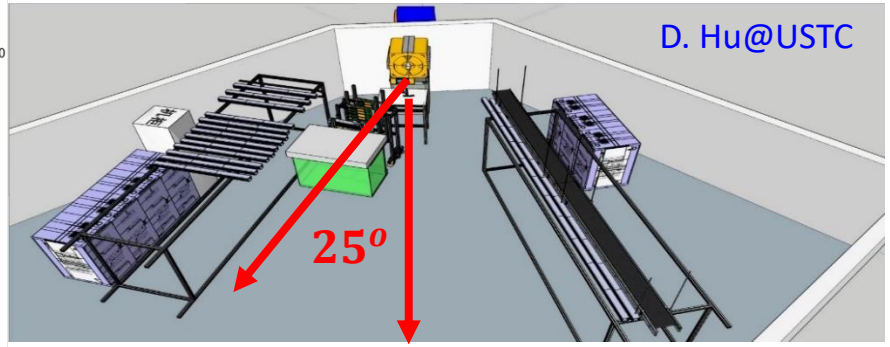
Detector System installation

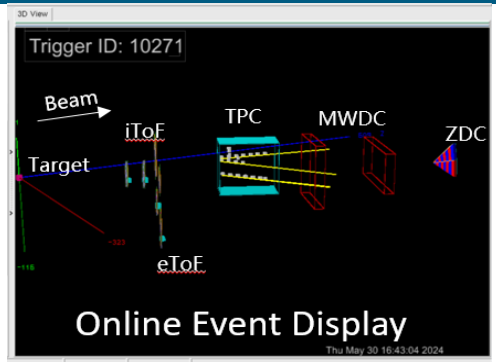
CEE detector without magnet

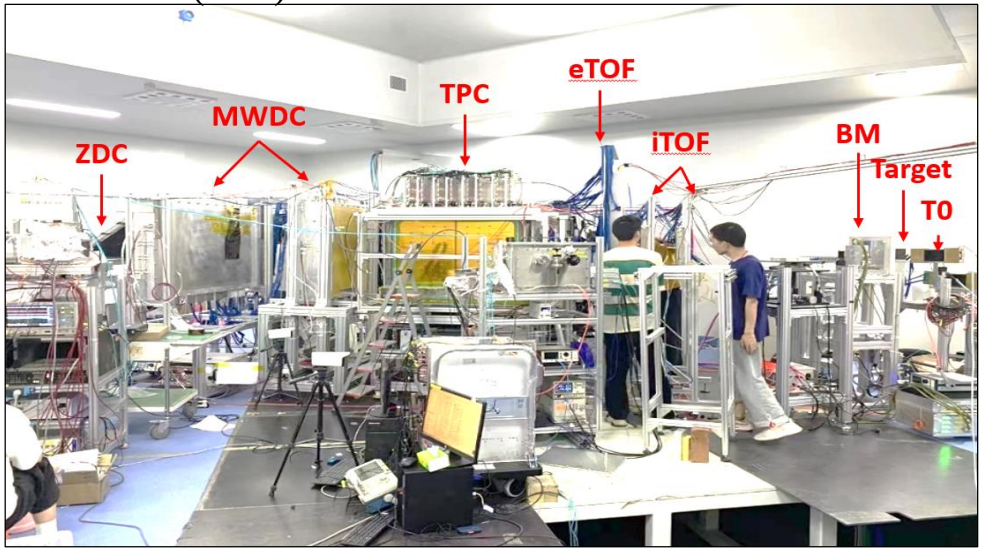


Beam Test in May 2024



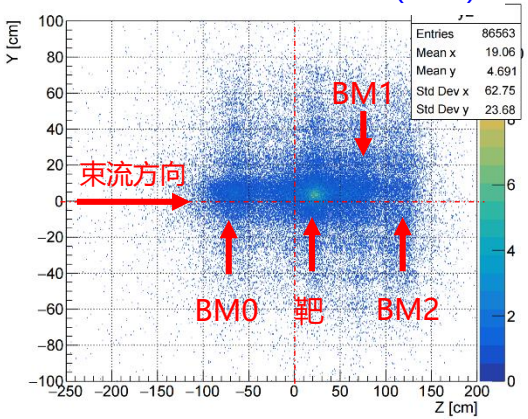




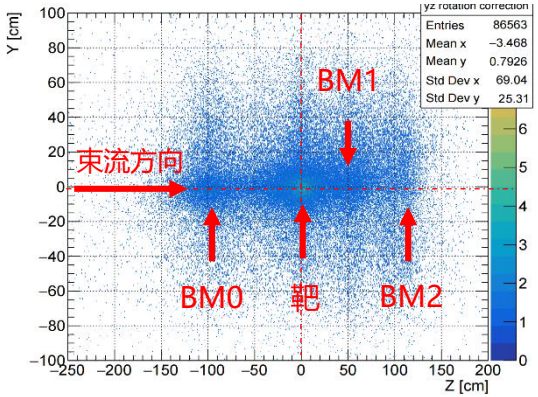


Vertex Reconstruction and Matching

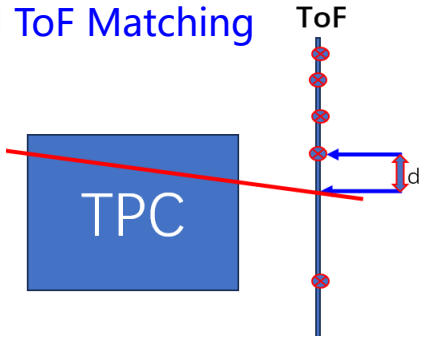
Vertex Reconstruction（X=0）



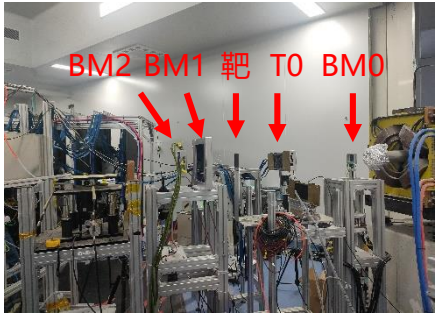
Vertex with TPC alignment



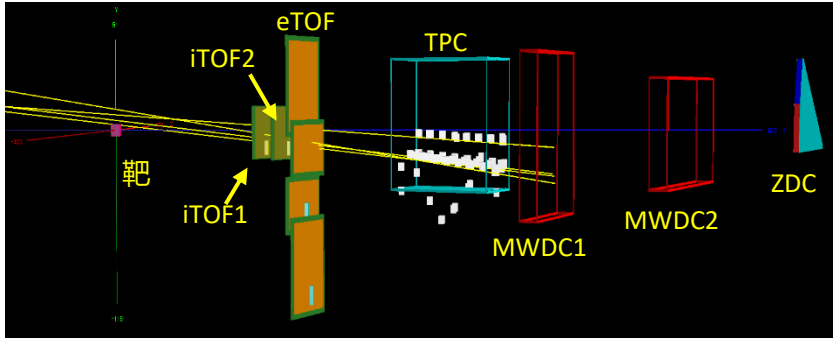
TPC and ToF Matching



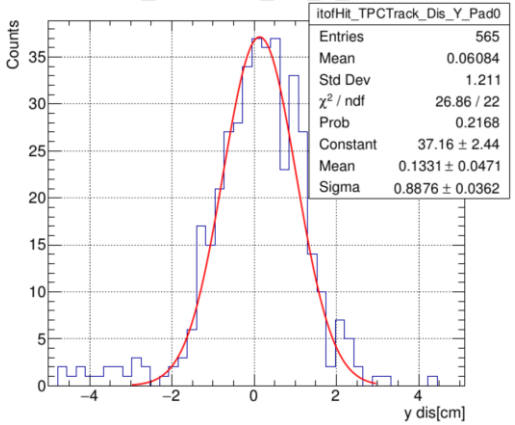
Detectors on the beam line



TPC and TOF matching event

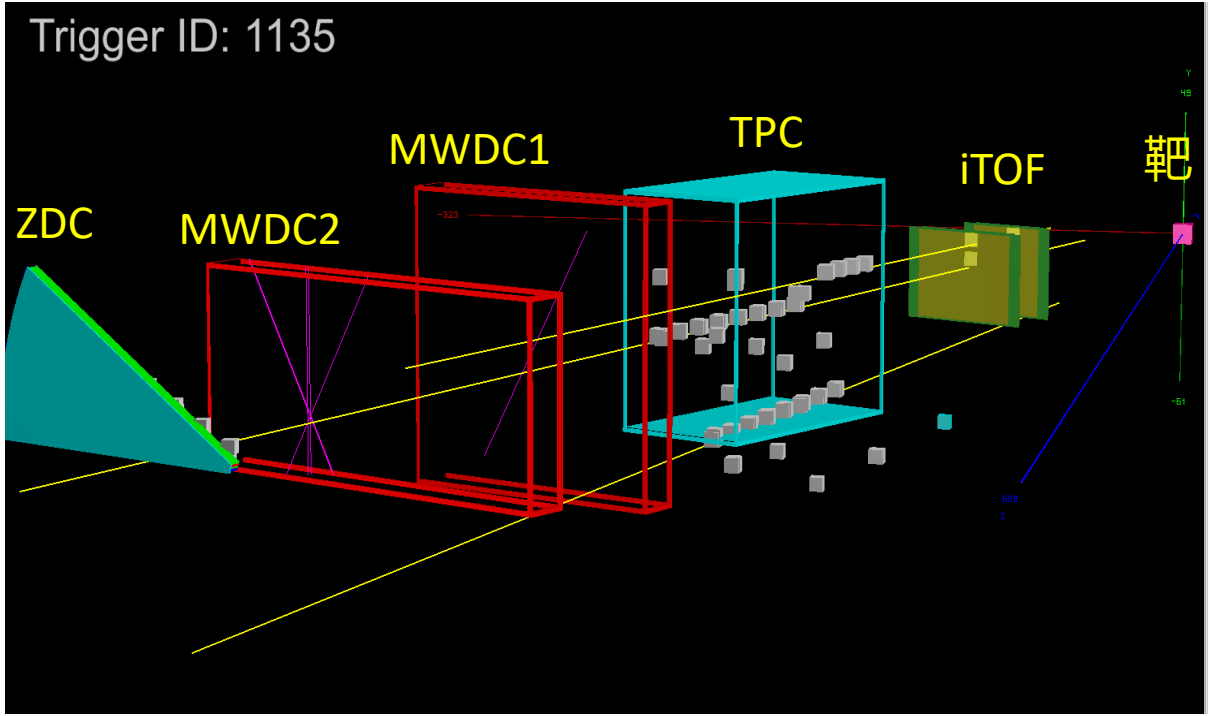


itofHit_TPCTrack_Dis_Y_Pad0

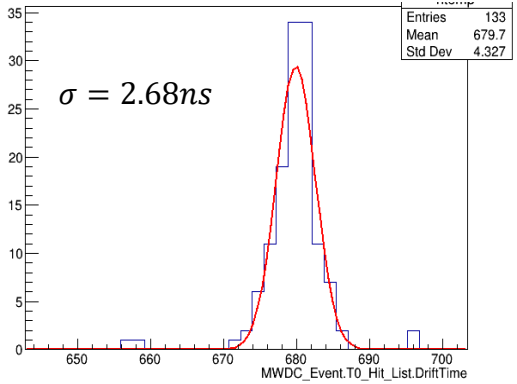


TPC-MWDC Matching

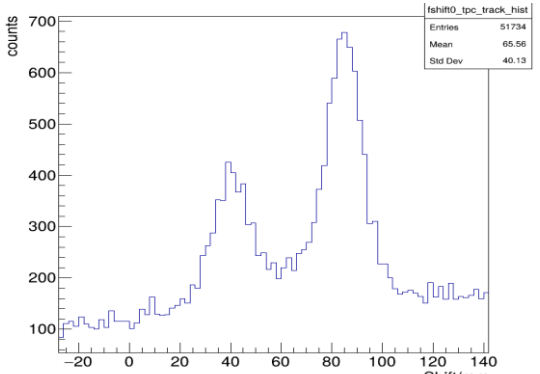
TPC-MWDC-TOF Matching



Scintillator-TOF time matching



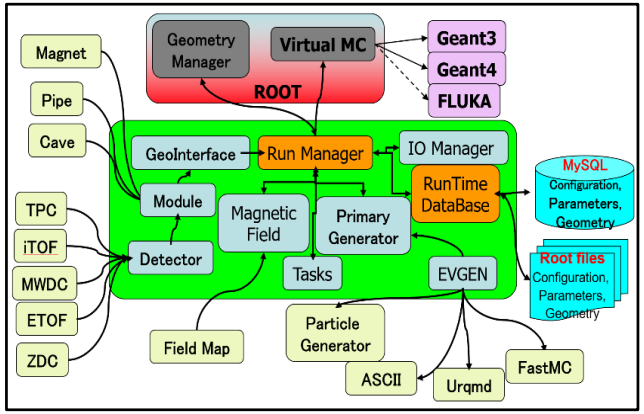
TPC and MWDC position matching



秦智

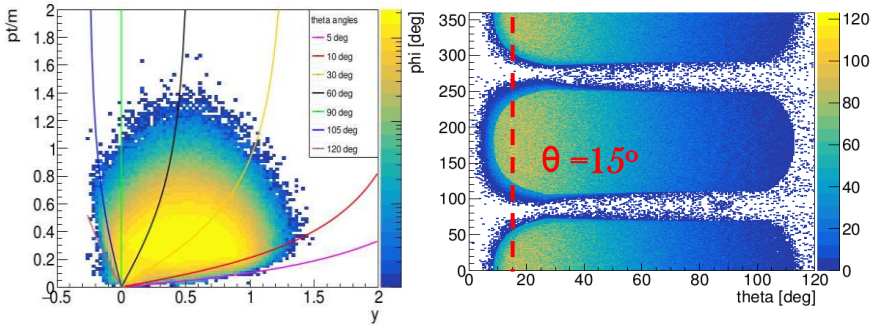
CeeROOT: CEE Simulation & Analysis Software

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

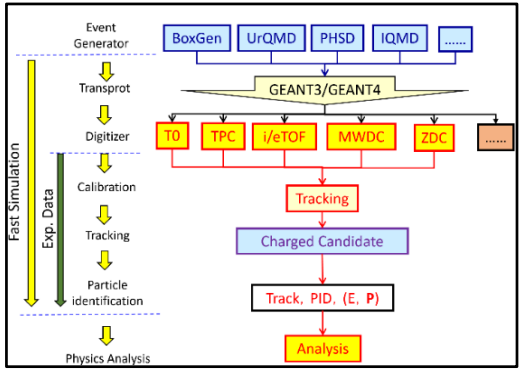


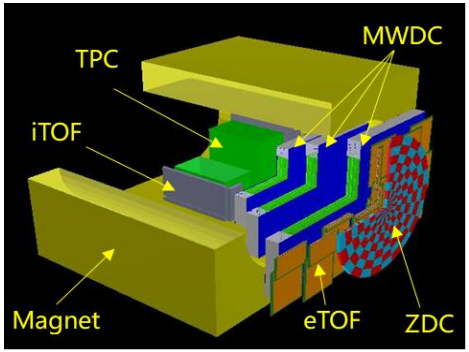
CeeROOT Home page: https://gitee.com/CEESM/CeeRoot (Open source)

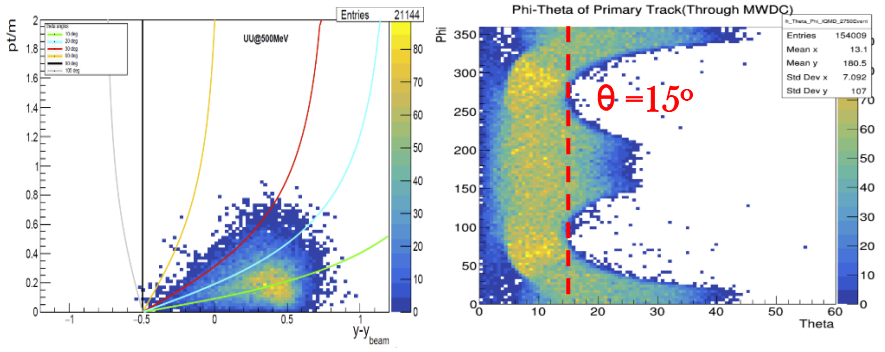
TPC acceptance



MWDC acceptance

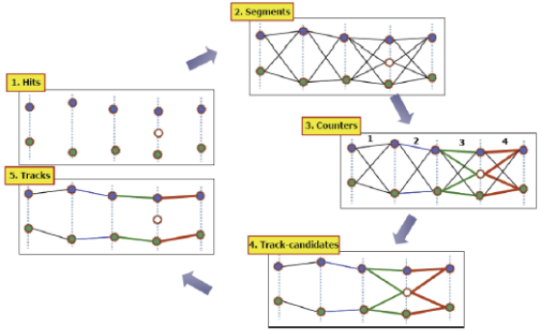


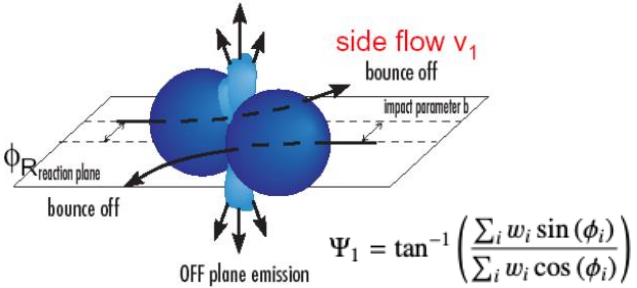




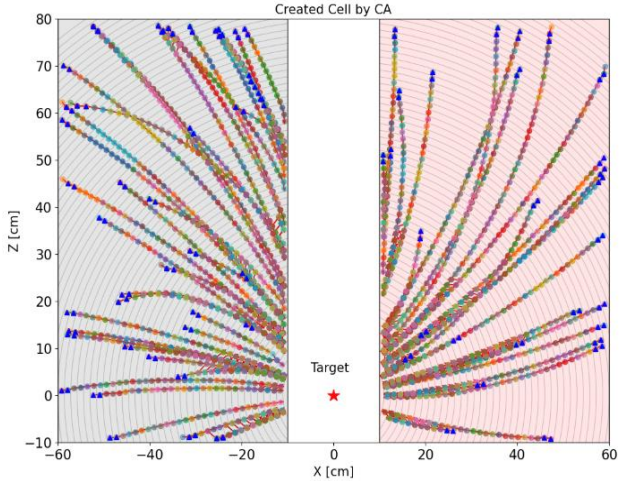
TPC tracking/Event plane reconstruction

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

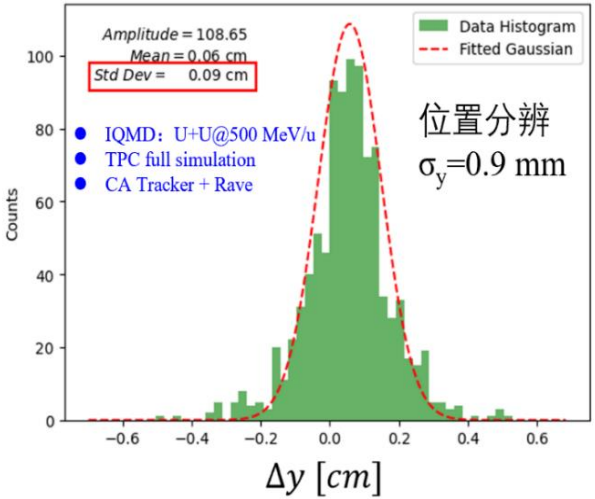




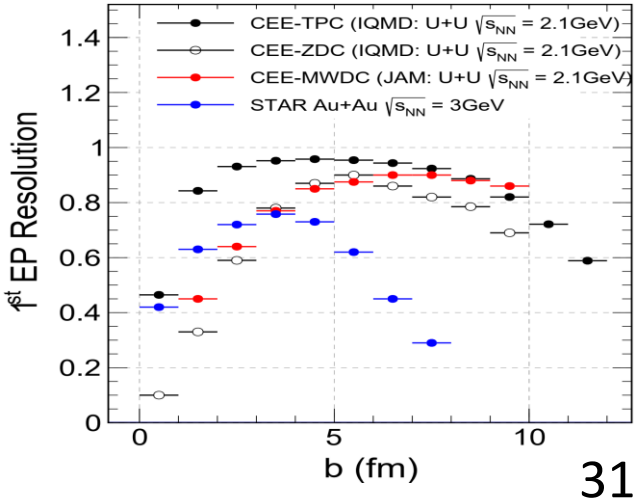
TPC tracking with IQMD event



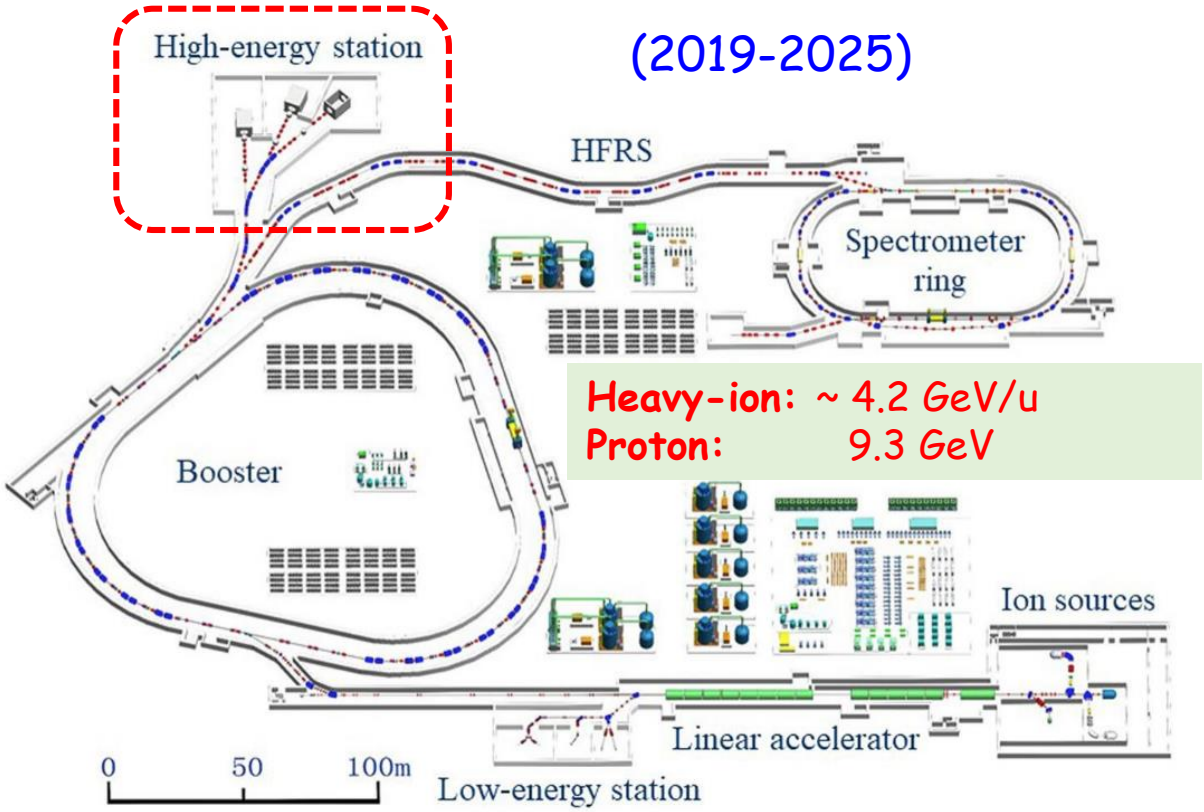
Vertex based TPC tracks



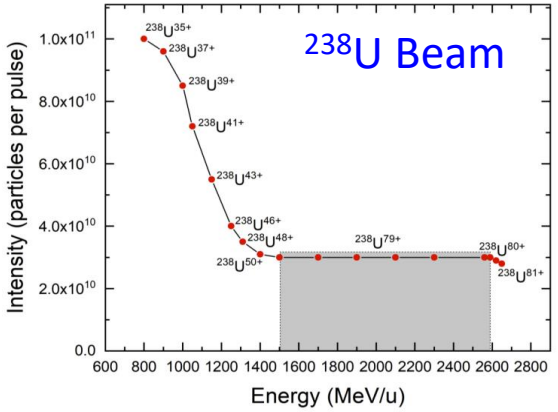
Event plane reconstruction



CEE+@HIAF



Zhou et al. AAPPS Bulletin (2022) 32

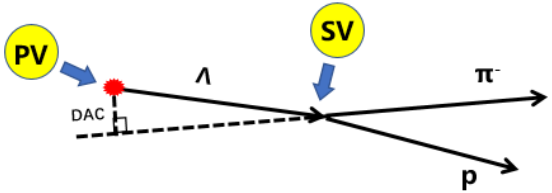


With pp/pA/AA at HIAF

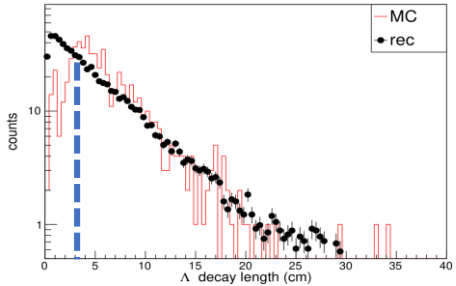
- Phase diagram
- EoS & neuron star
- Strangeness & hypernuclei
- In-medium effect of hadron
- Short range correlation
- …

Summary

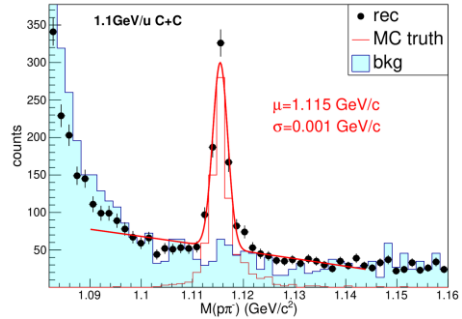
- CEE SC magnet still needs ~8-12 months delay
- CEE detection system installation is completed
- Test Run will be 10-14, July, 2025
- CEE Spectrometer is expected to be in commissioning in end of 2025 with SC magnet (UU at 500 MeV/u)
- HIAF allows us to explore more physics at high-baryon density region



Λ Decay Length



Λ Invariant mass



Thanks for your attention!