The 16th Workshop on QCD Phase Transition and Relativistic Heavy-Ion Physics
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Flow Simulation at 500 MeV/u U+U in the HIRFL-CSR External-target Experiment (CEE)

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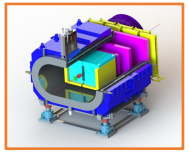
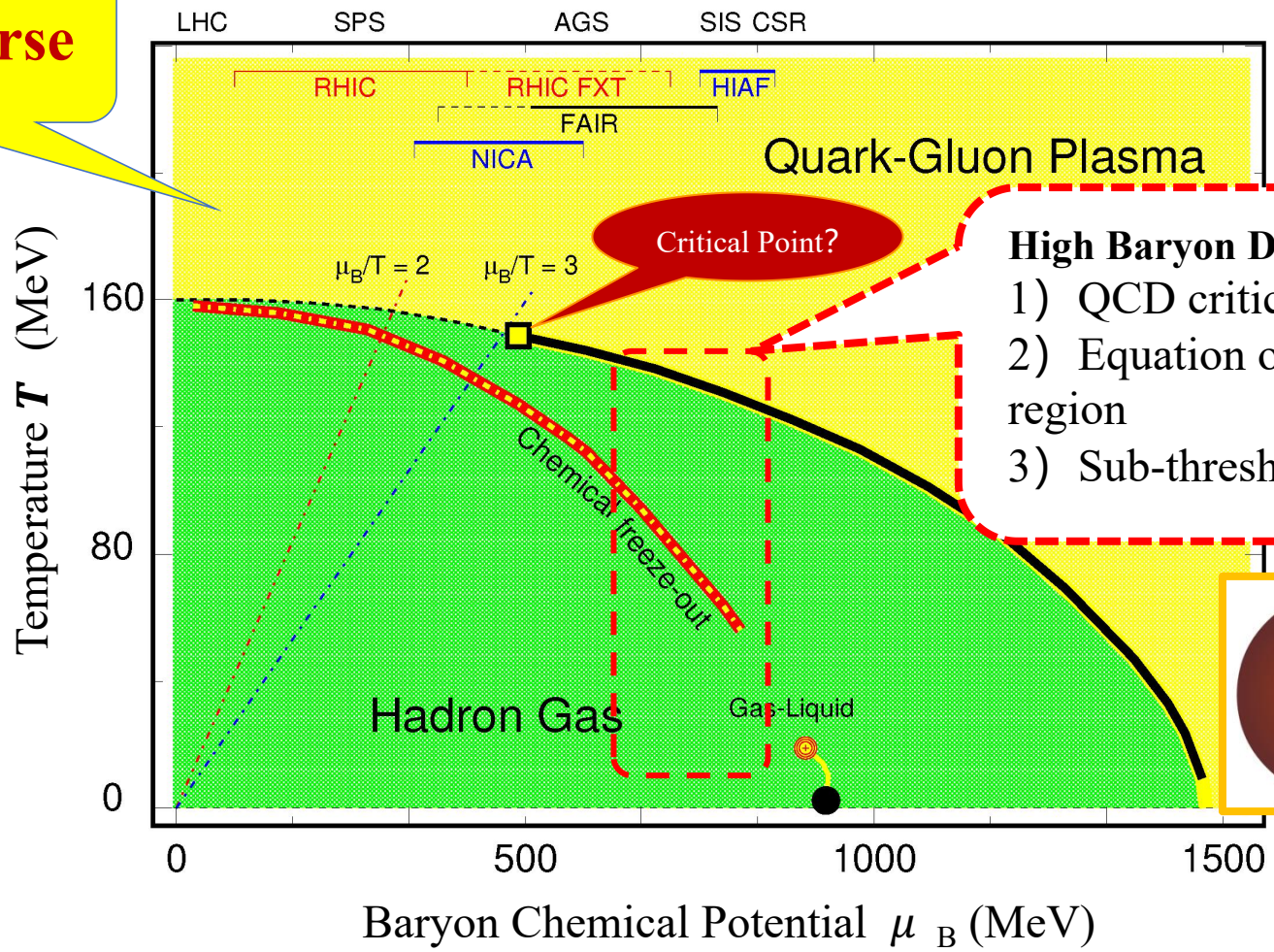
Outline



- Physics Motivation
- Studies of Directed Flow with Event Plane Method at CEE
- Flow Simulation of Light Nucleus at 500 MeV/u U+U in CEE
- Summary and Outlook

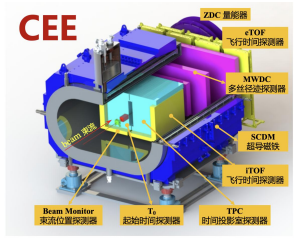
QCD Phase Diagram

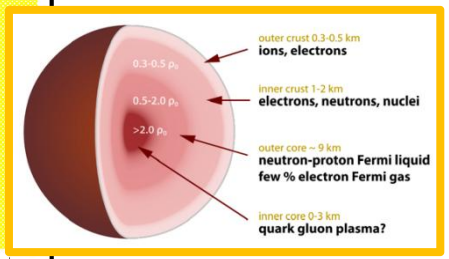
Early Universe



High Baryon Density Region:

1) QCD critical point
2) Equation of State at $\rho > 2\rho_0$ region
3) Sub-threshold production





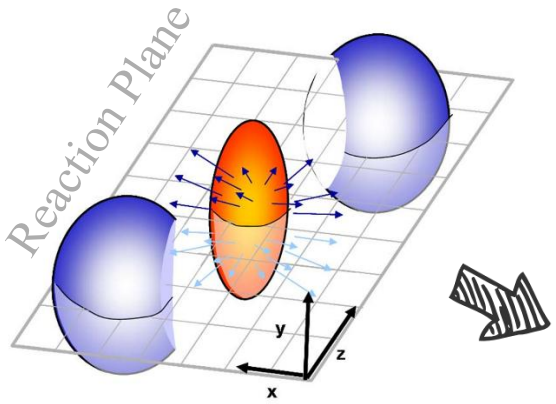
Collective Flow

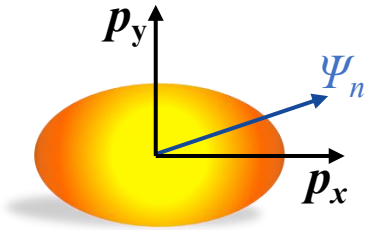
Anisotropic Flow

Initial spatial anisotropy

Pressure gradient

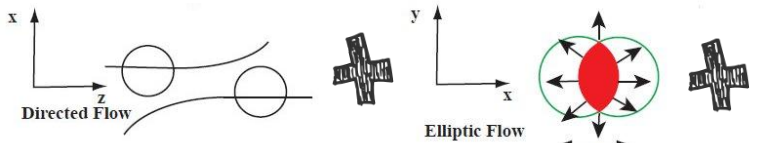
Momentum anisotropy

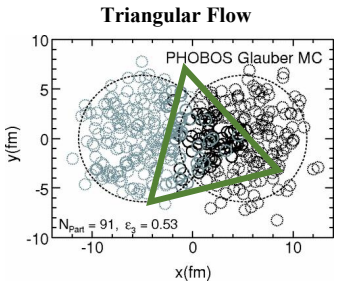




Arthur M. Poskanzer, S. A. Voloshin. Phys. Rev. C.**58,** 1671(1998).

$$E\frac{\mathrm{d}^3N}{\mathrm{d}p^3}=\frac{1}{2\pi}\frac{\mathrm{d}^2N}{p_T\mathrm{d}p_T\mathrm{d}y}\left(1+\sum_{n=1}^{\infty}2v_n\cos\left(n(\phi-\Psi_{RP})\right)\right)$$



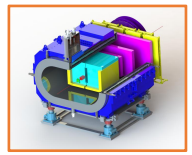


arXiv:0809.2949v2

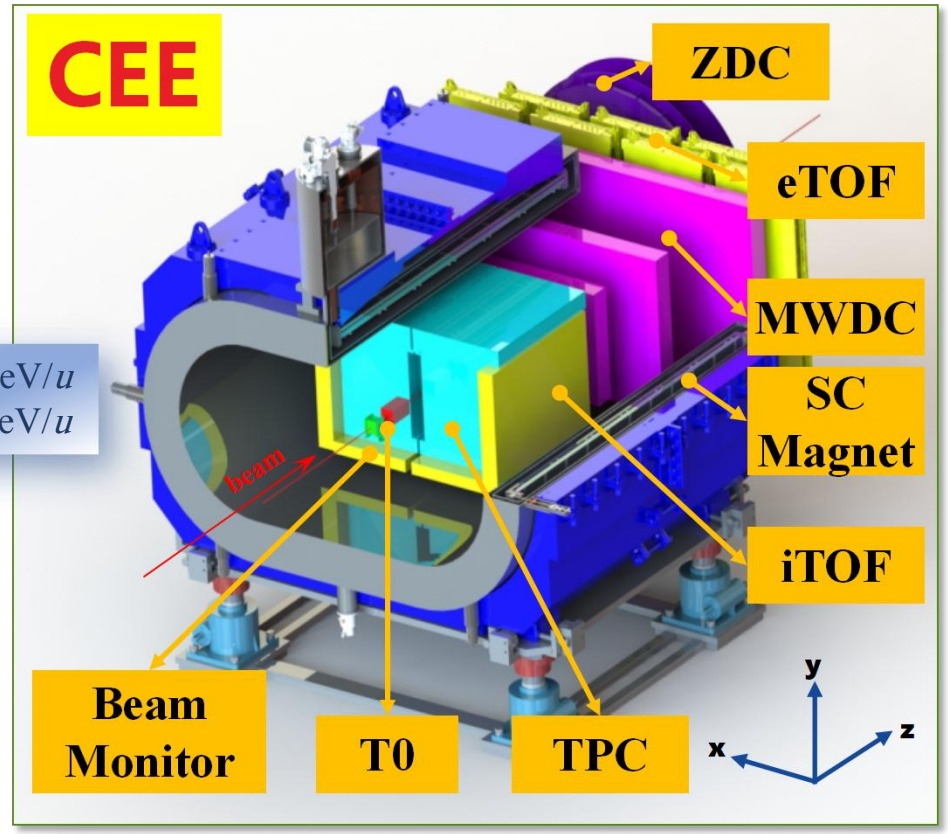
Phys.Rev.C81,054905 (2010)

- v_1: Collective sideward motion of particles
- v_2: Sensitive to initial eccentricity
- v_3: Initial geometry fluctuations

CEE Detector



Supported by NSFC and CAS



U	0.5	GeV/*u*
C	1.1	GeV/*u*

- Δp/p：≤ 5%, Δt/t：≤ 80ps
- Max. Rate： 10 kHz
- Proton acceptance: ~ 85%

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

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

Interplay with Neutron Star Physics

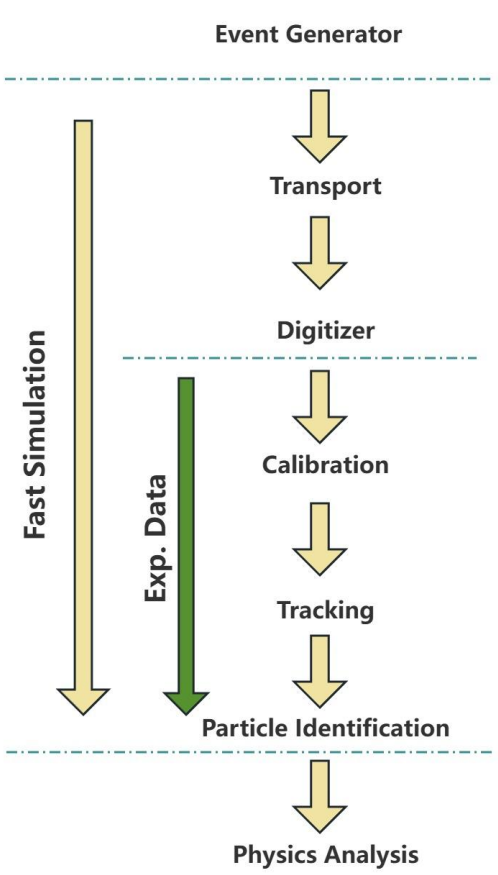
Sub-threshold production

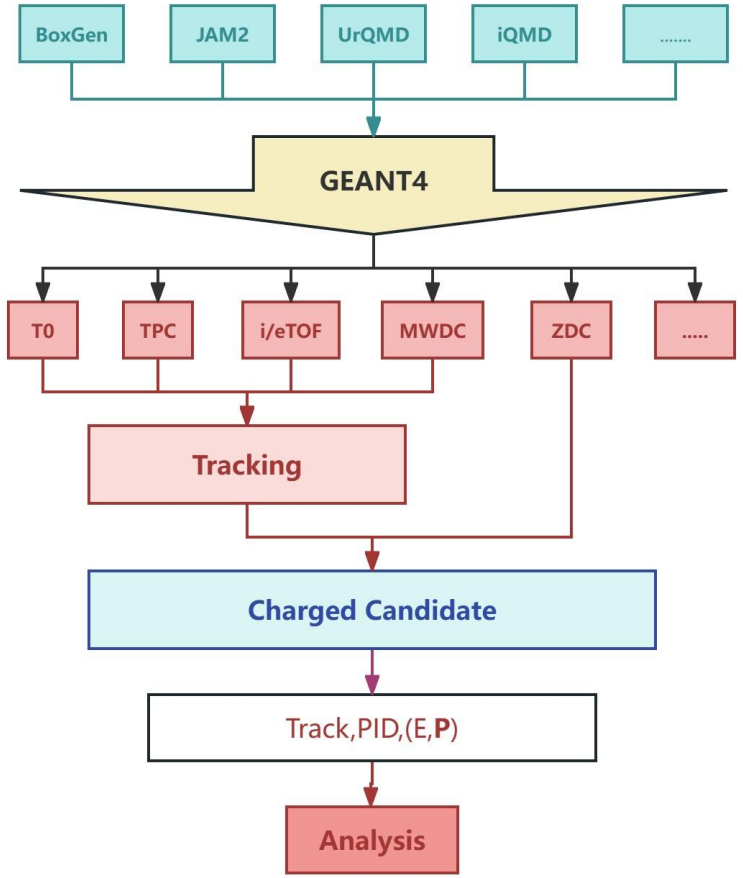
Short range correlation

……

CEE Detector Simulation

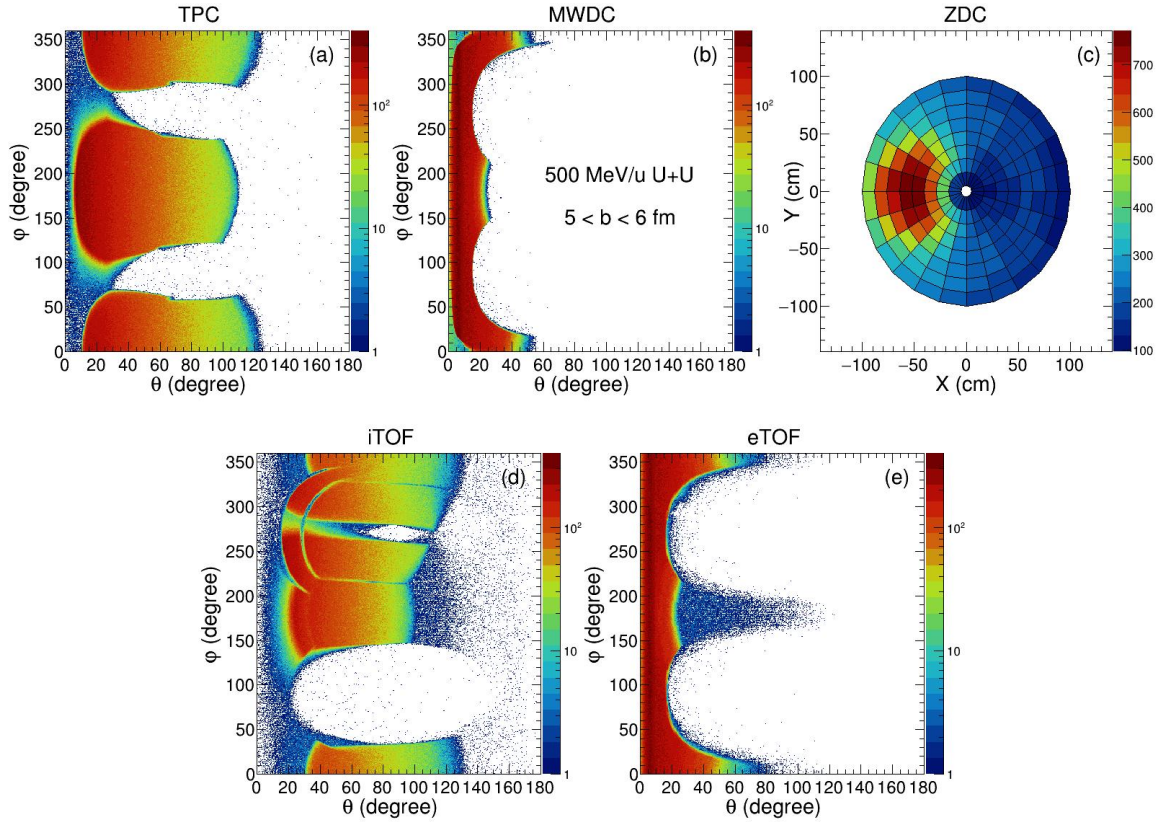
CEE Simulation





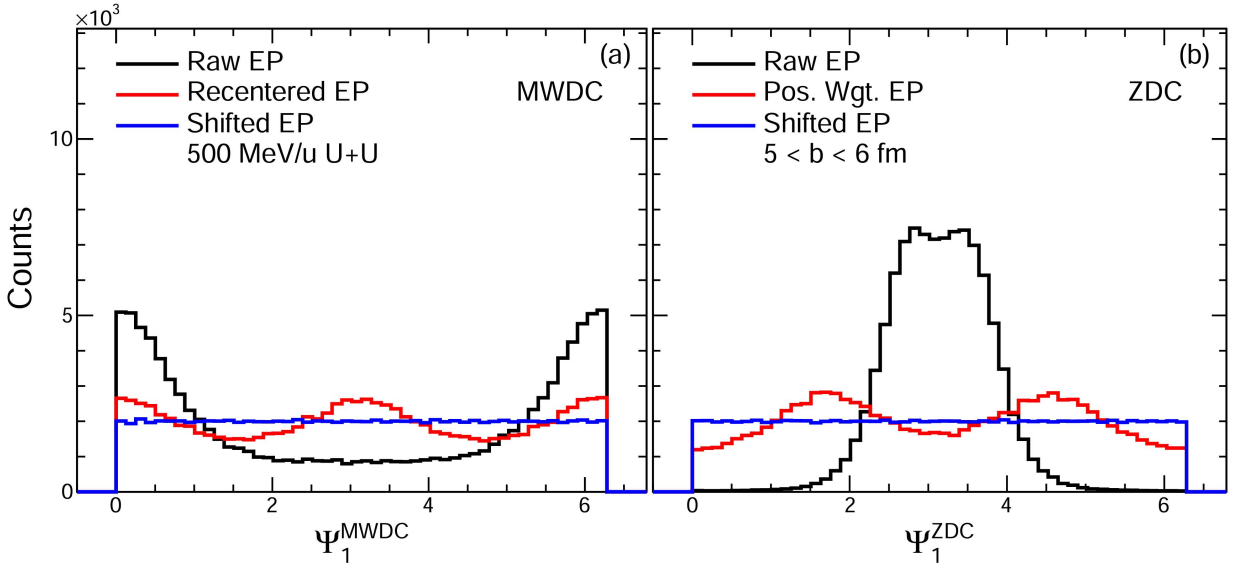
CEE Acceptance

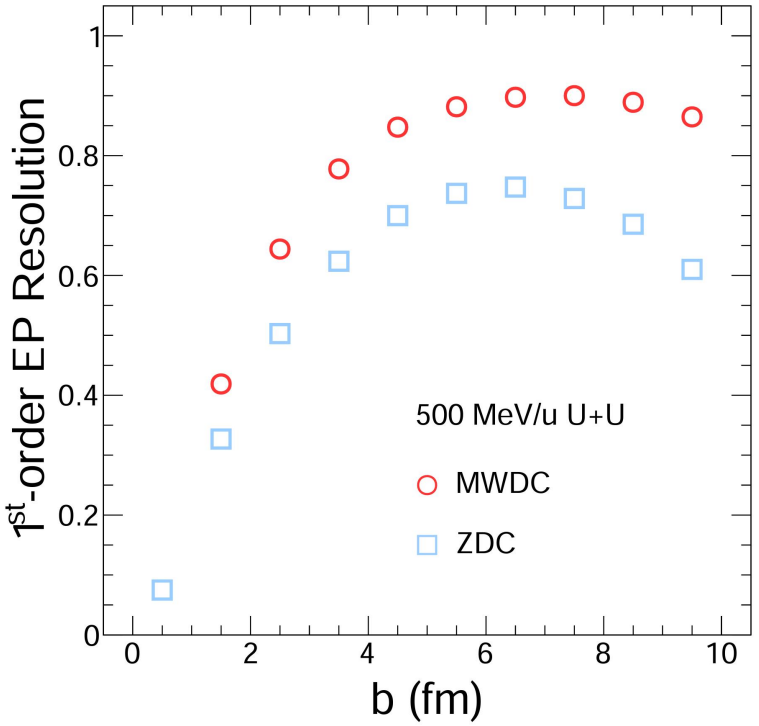
JAM2 + CEE FastSimulation



https://gitee.com/CEESM/CeeRoot

Event Plane Reconstruction





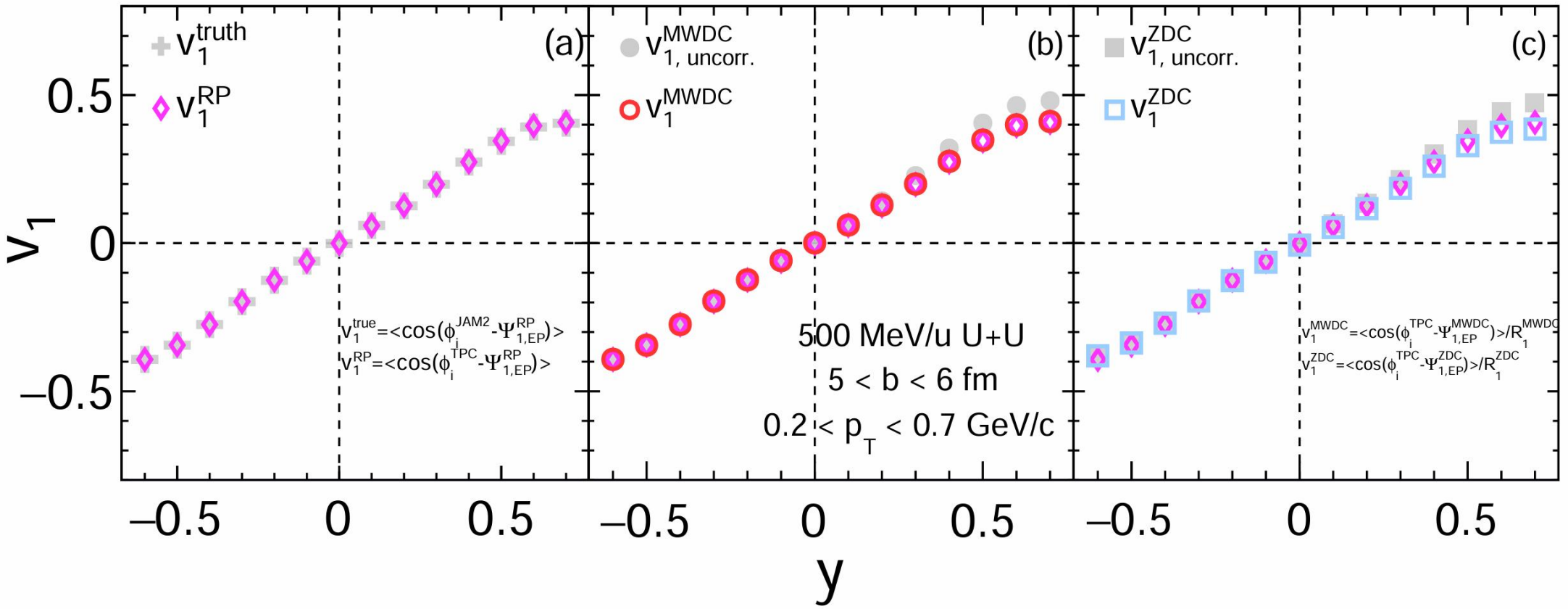
- EP reconstruction : Q vector method
- For MWDC: **Re-centering + shift calibration**
- For ZDC: **Position weighted + shift calibration**

$$\Psi_1 = \arctan\left(\frac{\sum \omega_i sin\,\varphi_i^{MWDC,ZDC}}{\sum \omega_i \cos\,\varphi_i^{MWDC,ZDC}}\right)$$

- Event plane resolution : two-sub events method

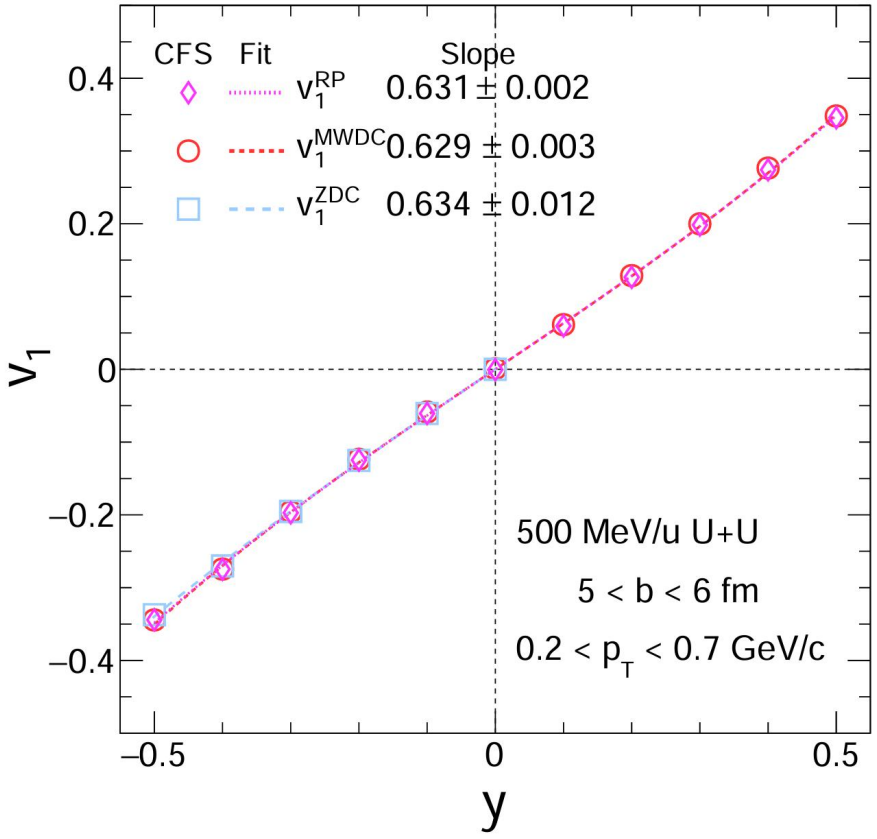
$$R_1 = \langle \cos[(\Psi_{RP} - \Psi_1)] \rangle$$

Directed Flow in CEE



- **Validity of standard event plane method in the CEE experiment**
- **Flow signal measured by CEE detector is reliable**

Directed Flow in CEE



Optimal kinematic regions

For MWDC

- removing self-correlation effect and momentum conservation effect

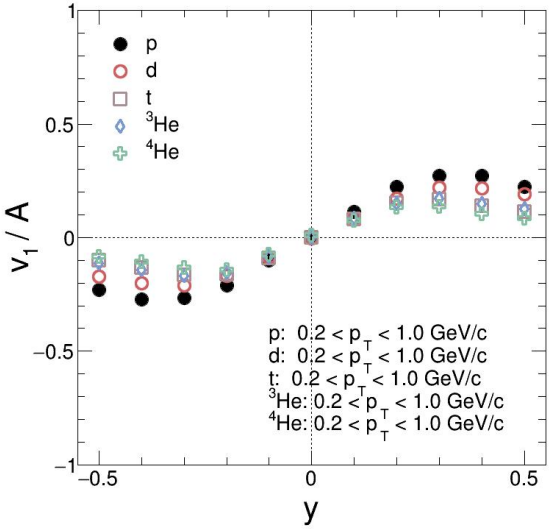
For ZDC

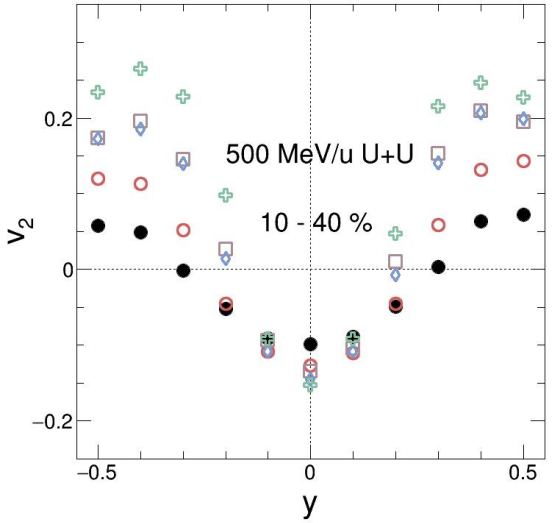
- used the backward protons in TPC ($-0.5 < y < 0$)

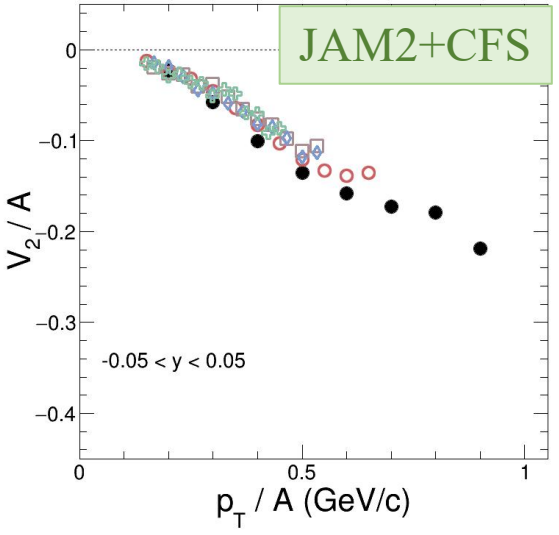
Light Nucleus Flow Simulation

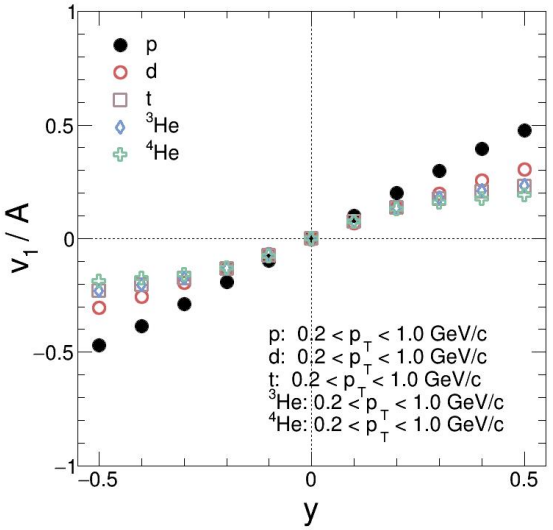
› **Distinct distributions between JAM2 and IQMD**

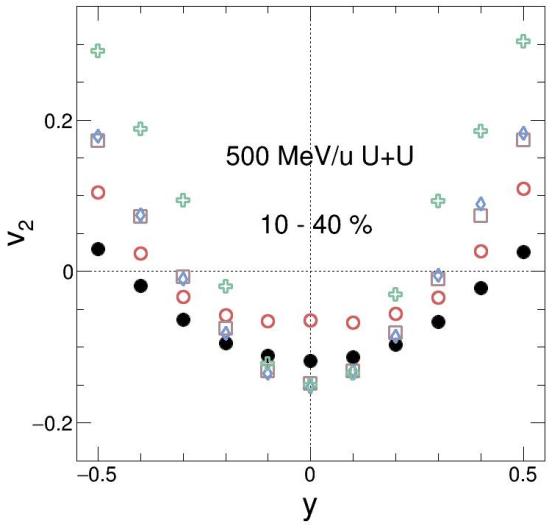
› **Nuclear number scale of directed flow and elliptic flow**

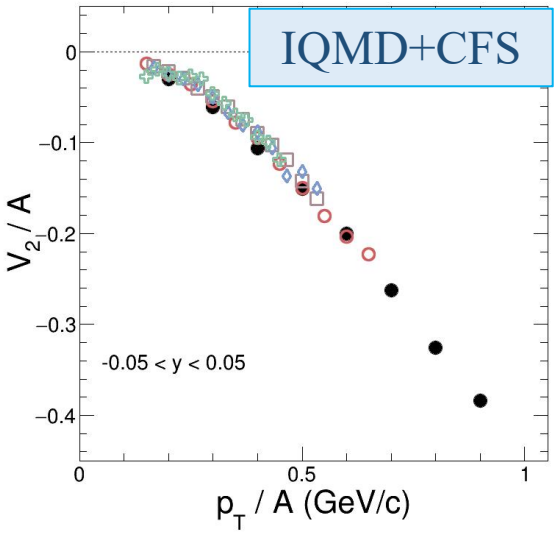




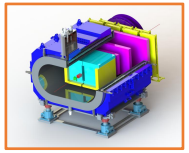






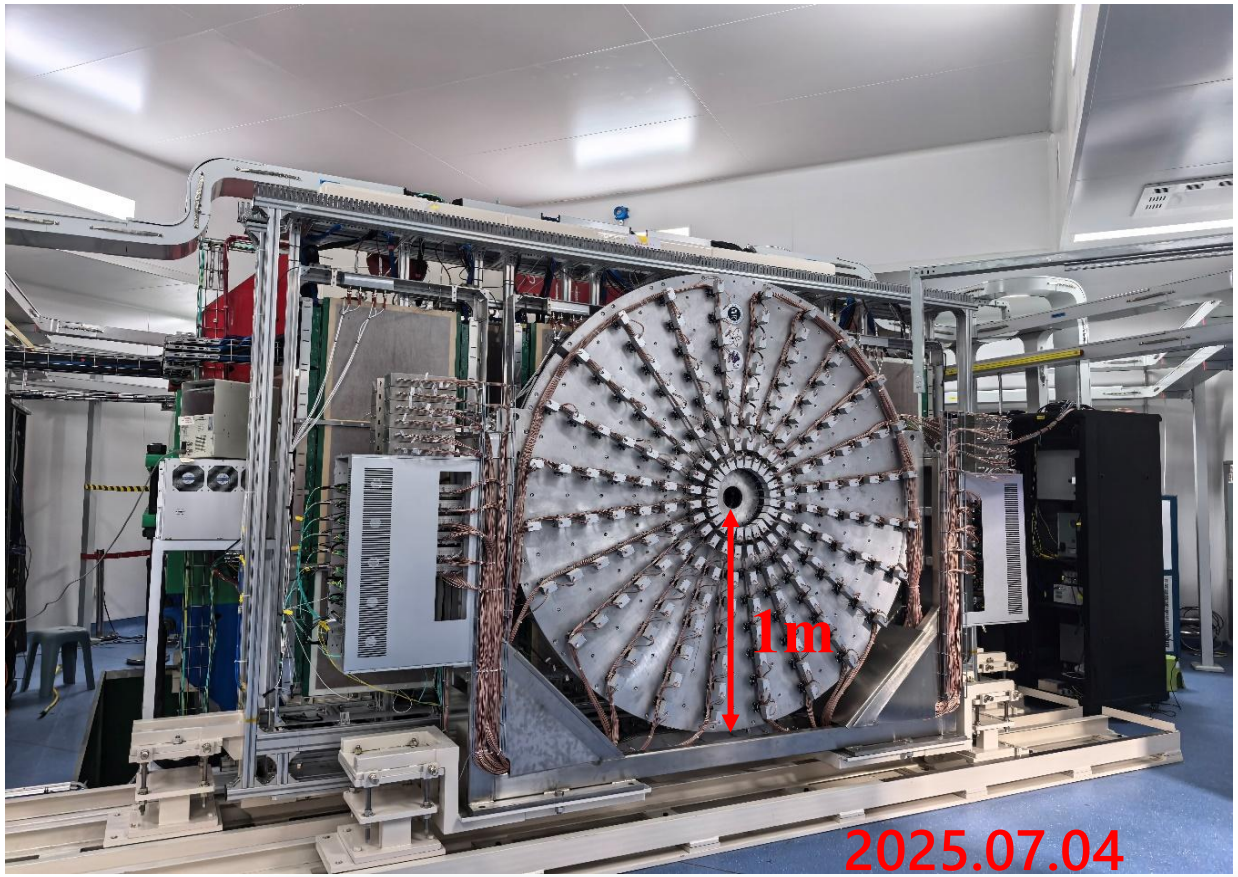


Summary



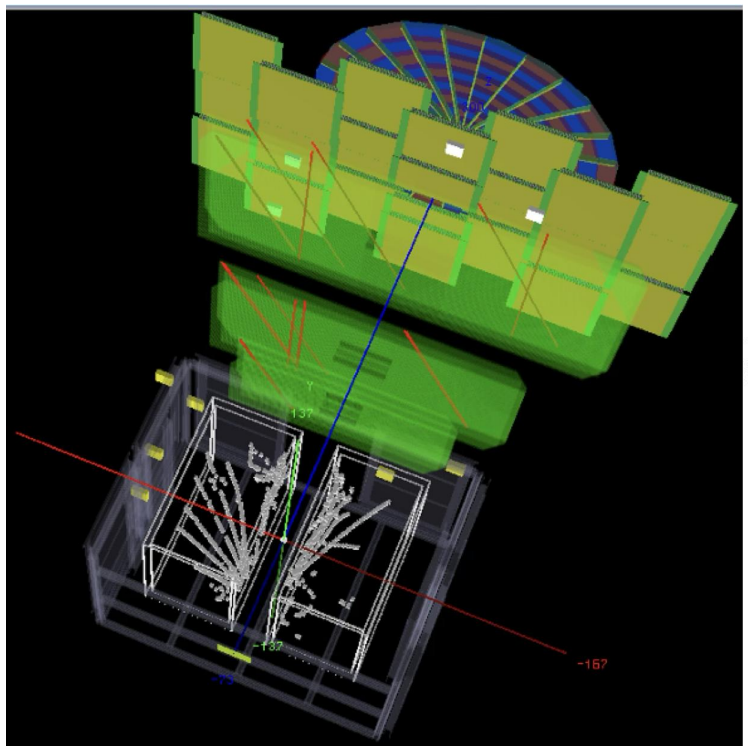
- Validated the effectiveness of the standard event plane method in the CEE experiment
- Proposed optimal kinematic regions for proton directed flow measurement w.r.t. MWDC and ZDC in the CEE experiment
- Light nucleus flows in CEE experiments will aid understanding of the production mechanism of light nuclei in the high baryon density region

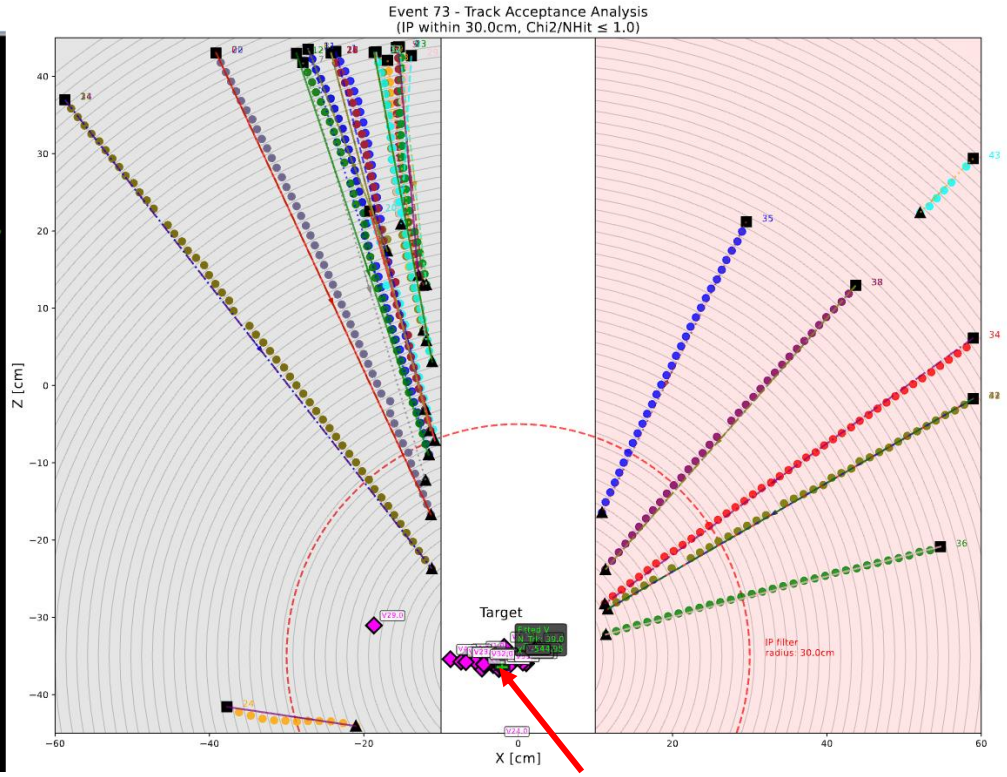
CEE Detector Without Magnet

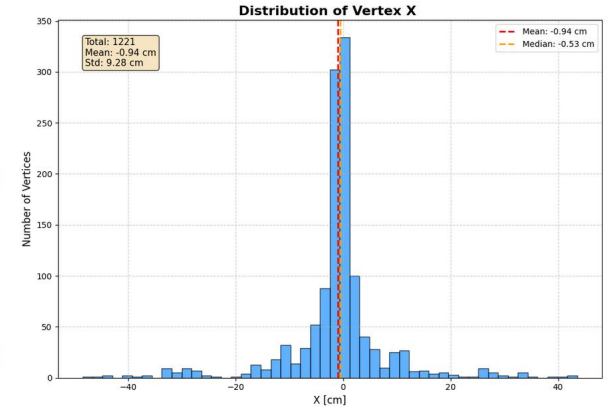


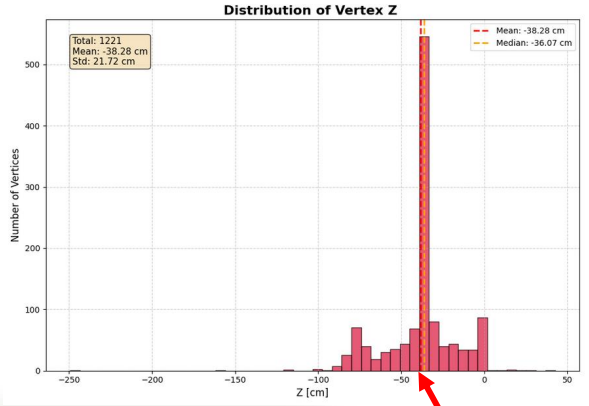
- CEE installation completed on 2025.07.04
- Final test beam experiment completed on 2025.07.15

Test Beam: 320 MeV/u Sn+Pb @ CEE







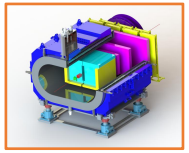


Reconstructed Vertex

Target

- All sub-detectors were commissioned on time and ready to take data
- Promissing tracking and vertex reconstruction performance

Outlook



- CEE is scheduled to run 1.1 GeV/u C+C by the end of the year

- Focus on Λ sub-threshold production

Thanks for your attention!