sPHENIX FLOW MEASUREMENTS

PROSPECTS AND HIGHLIGHTS

Ejiro Umaka, Brookhaven National Lab
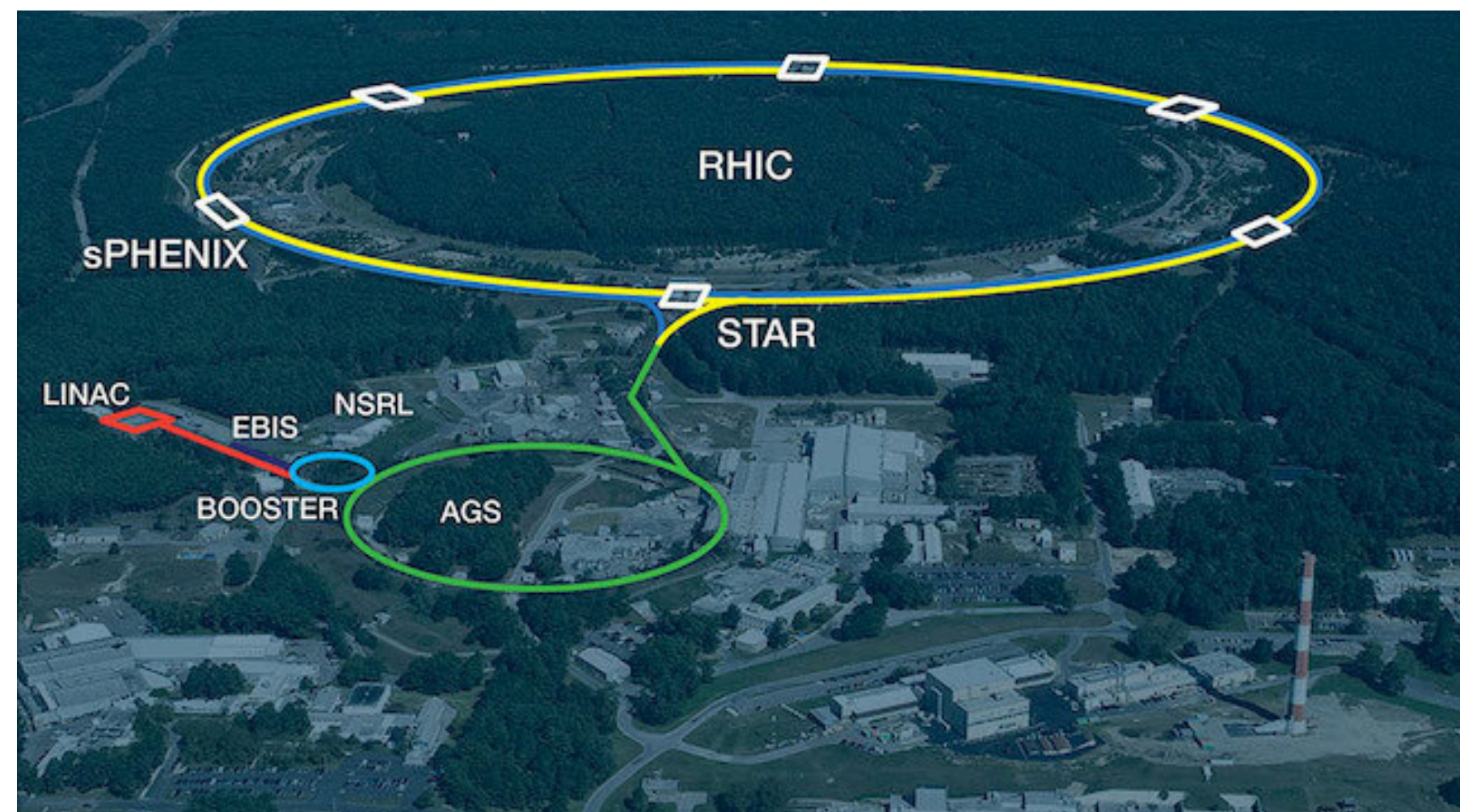**2024 RHIC/AGS Annual Users' Meeting**
11 June, 2024

Brookhaven
National Laboratory
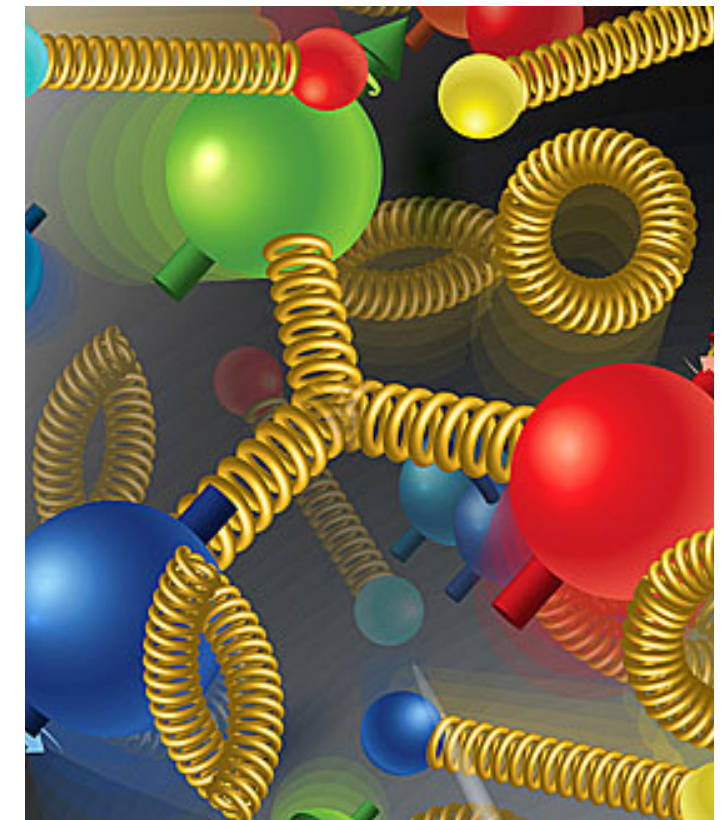
- Installation completed on May 2023
- First collisions in the brand new detector occurred on May 18, 2023
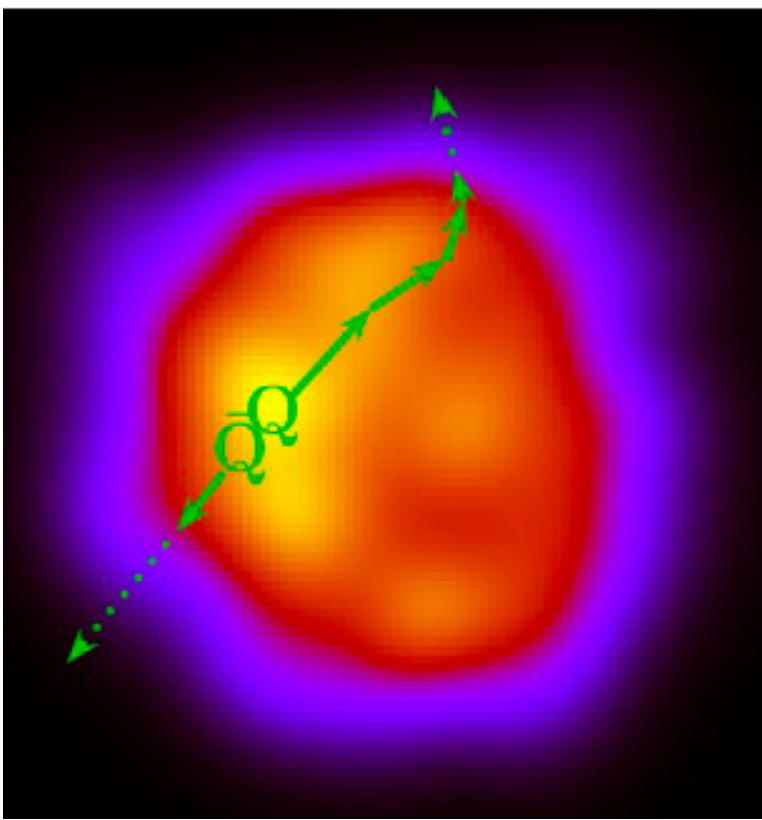- See first performance plots showcasing sPHENIX journey through commissioning

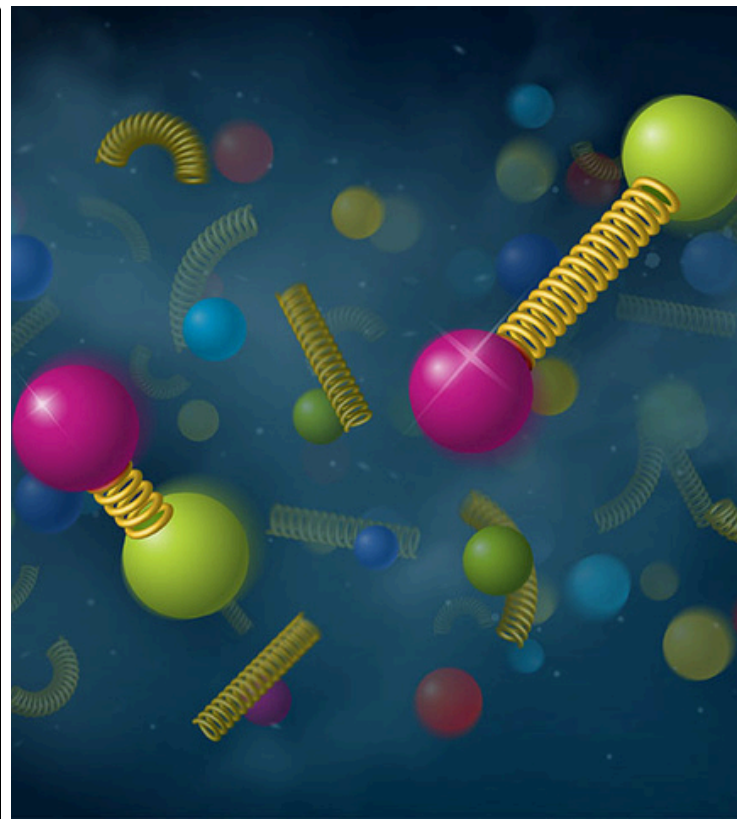- Wide array of physics topics at sPHENIX from hard probes to "softer" physics, plus spin physics!
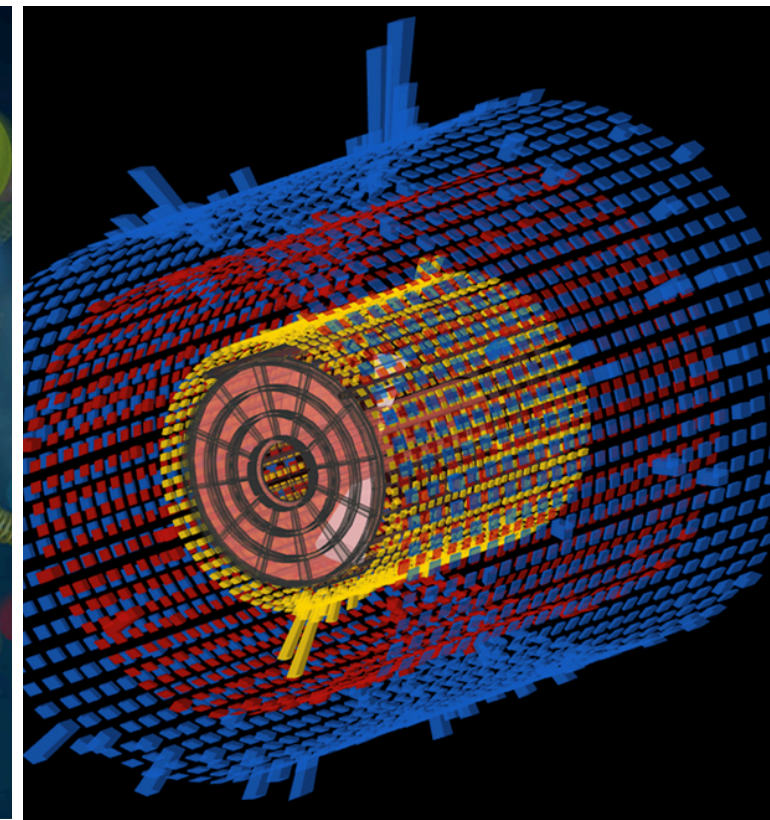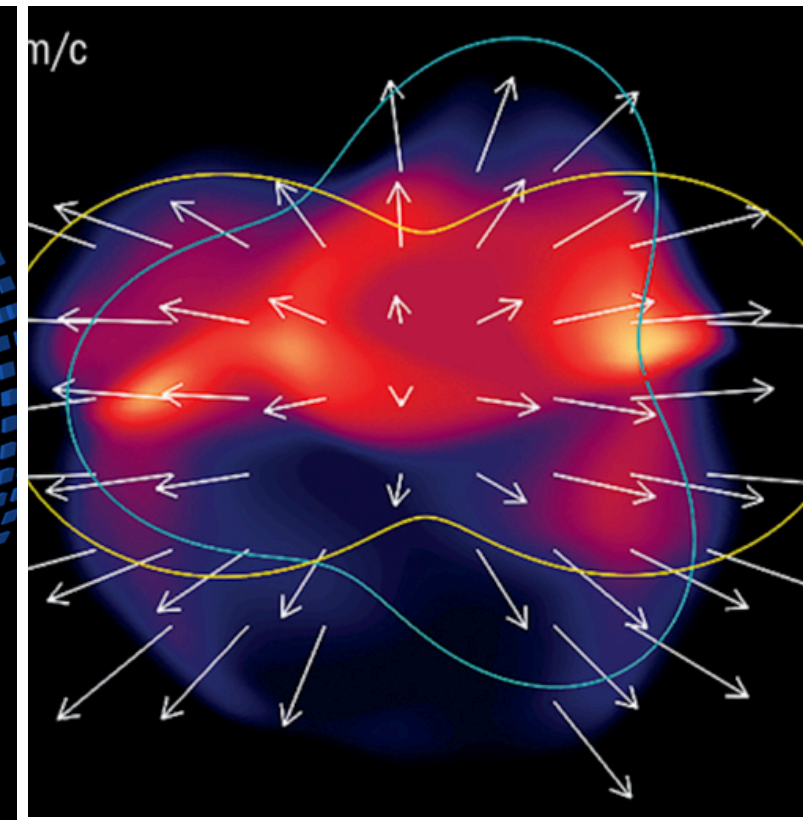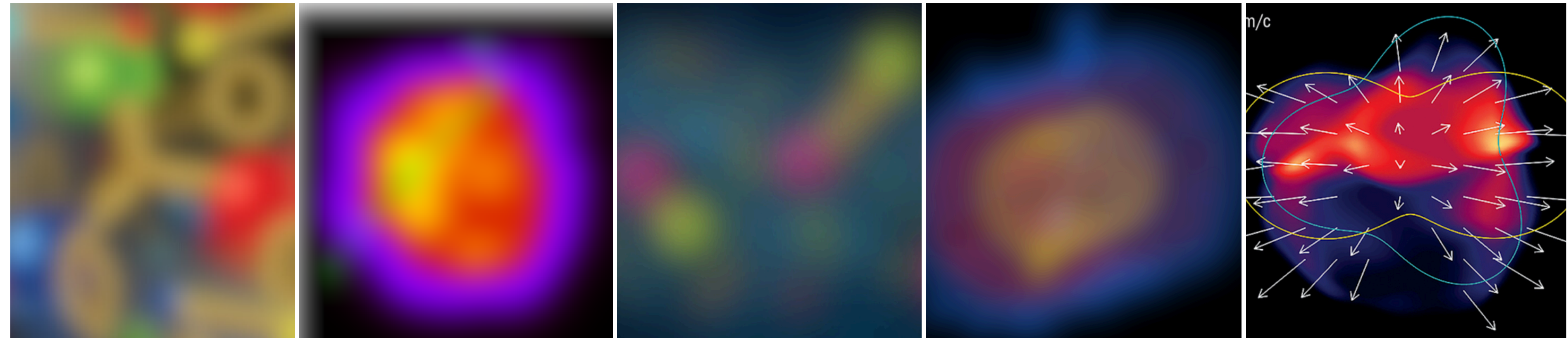
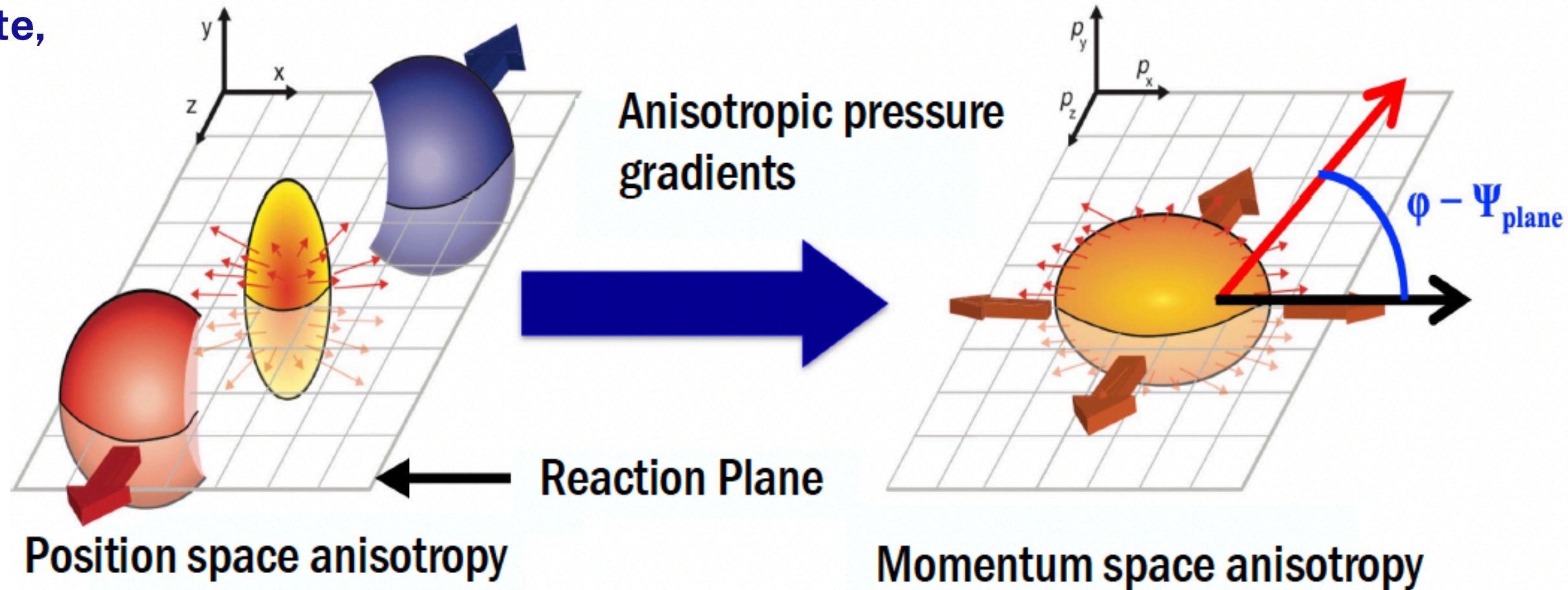| Cold QCD | Heavy flavor | Quarkonia | Jets | Collectivity |

- Wide array of physics topics at sPHENIX from hard probes to "softer" physics, plus spin physics!

- This talk will focus on flow related measurements at sPHENIX

Collectivity

In the initial state, for mid-central collisions, the shape of the overlap region is elliptical

Anisotropic pressure gradients

Stronger pressure gradients and expansion in-plane. Particles are boosted in-plane more than out-of-plane

$\phi - \Psi_{plane}$

Reaction Plane

Position space anisotropy

Momentum space anisotropy

- **Anisotropic flow/collective behavior:** correlations with respect to the event plane.

    Encapsulates the systems response to azimuthally asymmetric conditions in the initial state.

- Can be described by Fourier expansion of the azimuthal distribution of produced particles

$$N(\phi) = N_0\{1 + 2v_1 cos(\phi - \Psi) + 2v_2 cos[2(\phi - \Psi)] + ...\}$$
$$v_n = \langle cos[n(\phi - \Psi)]\rangle$$

- The event flow vector Q_n is a 2D vector in the transverse plane:

$$Q_{n,x} = \sum_i w_i \cos(n\phi_i) = \mathbf{Q}_n \cos(n\Psi_n),$$

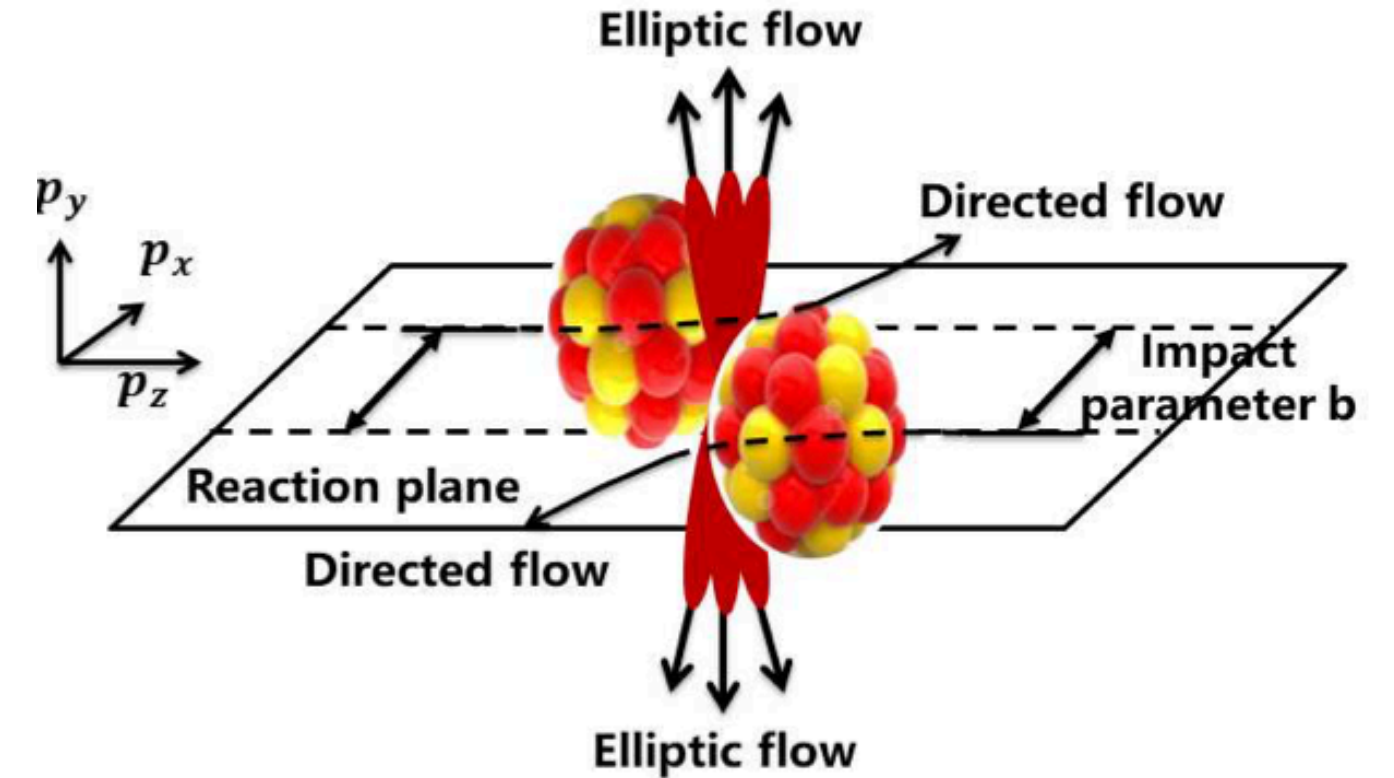$$Q_{n,y} = \sum_i w_i \sin(n\phi_i) = \mathbf{Q}_n \sin(n\Psi_n),$$

- The event plane and observed v_n:

$$\Psi_n = \arctan2(Q_{n,y}, Q_{n,x})/n,$$

$$v_n^{\text{obs}}(p_T, y) = \langle \cos[n(\phi_i - \Psi_n)] \rangle$$

- The event plane resolution and final flow coefficients:

$$\mathscr{R}_n = \langle \cos[n(\Psi_n - \Psi_{\text{RP}})] \rangle \qquad v_n = \frac{v_n^{\text{obs}}}{\mathscr{R}_n}$$

- Whereas, the scalar product method uses the magnitude of the flow vector as weights

$$\langle Q_n^a Q_n^{b\,*} \rangle = \langle v_n^2 M^a M^b \rangle$$

$$v_n(\eta, p_t) = \frac{\langle Q_n u_{n,i}^*(\eta, p_t) \rangle}{2\sqrt{\langle Q_n^a Q_n^{b\,*} \rangle}}$$

arXiv:0809.2949 [nucl-ex]

- Tracking subsystems:
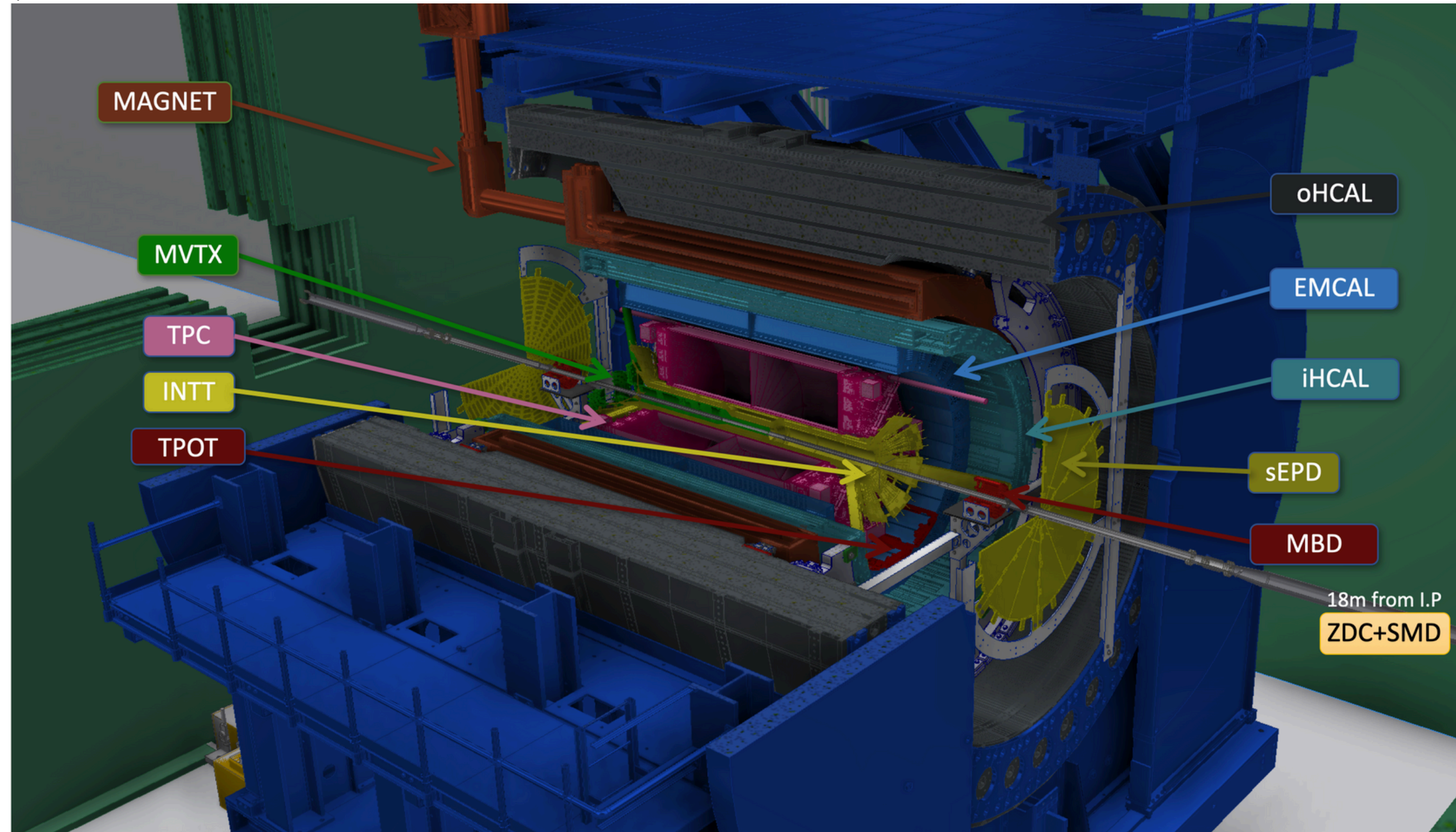   - MVTX, INTT, TPC, TPOT
- Calorimeters:
    - EMCAL, HCAL
- 1.4T magnet

$$|\eta| \leqslant 1.1$$

- Forward subsystems used for centrality and event plane measurements:
    - **sEPD**
    - **MBD**
    - **ZDC/SMD**

- Tracking detectors:
  - MVTX, INTT, TPC, TPOT
- Calorimeters:
  - EMCAL, HCAL
- 1.4T magnet
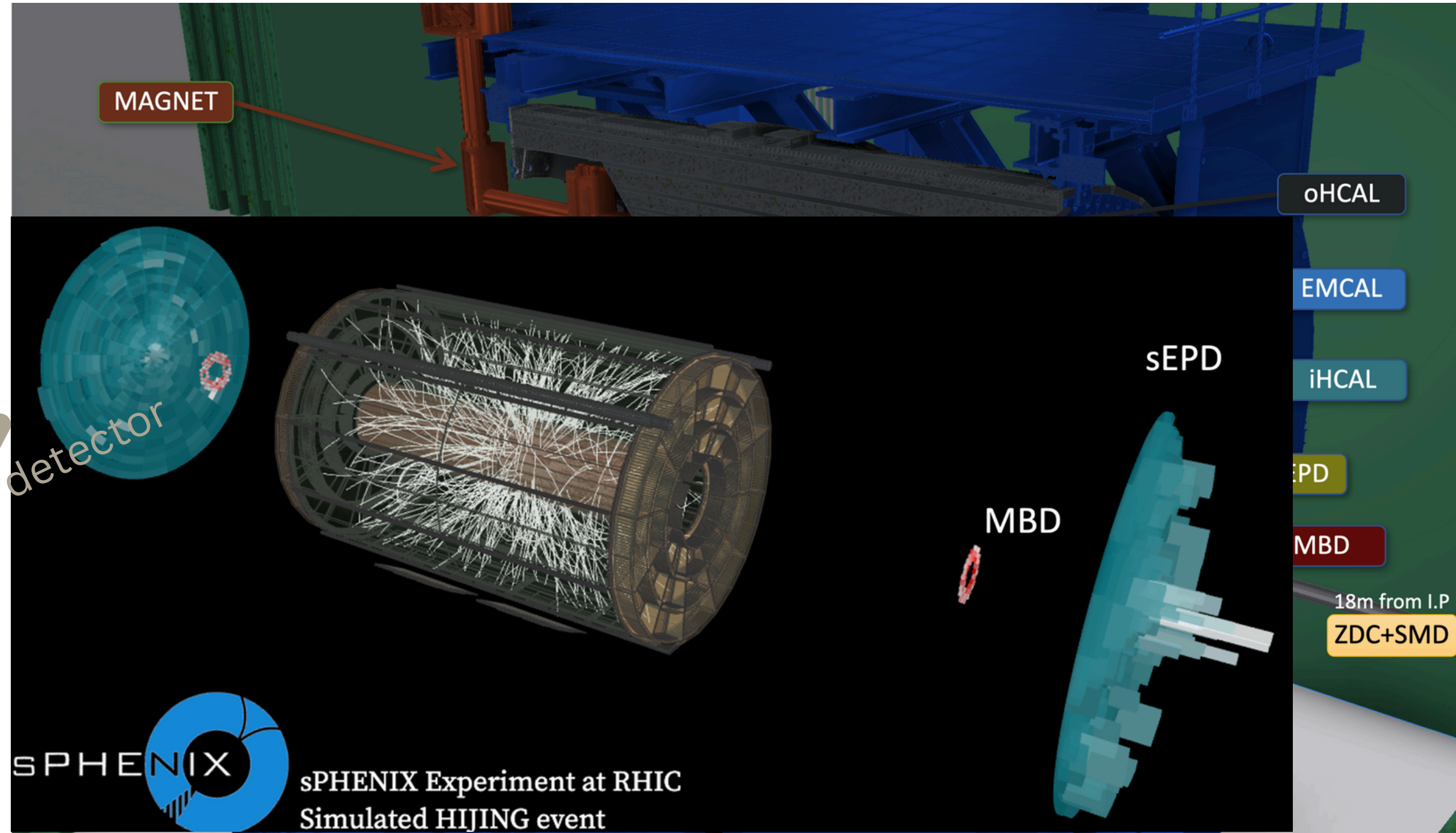- Forward detectors used for centrality and event plane measurements:
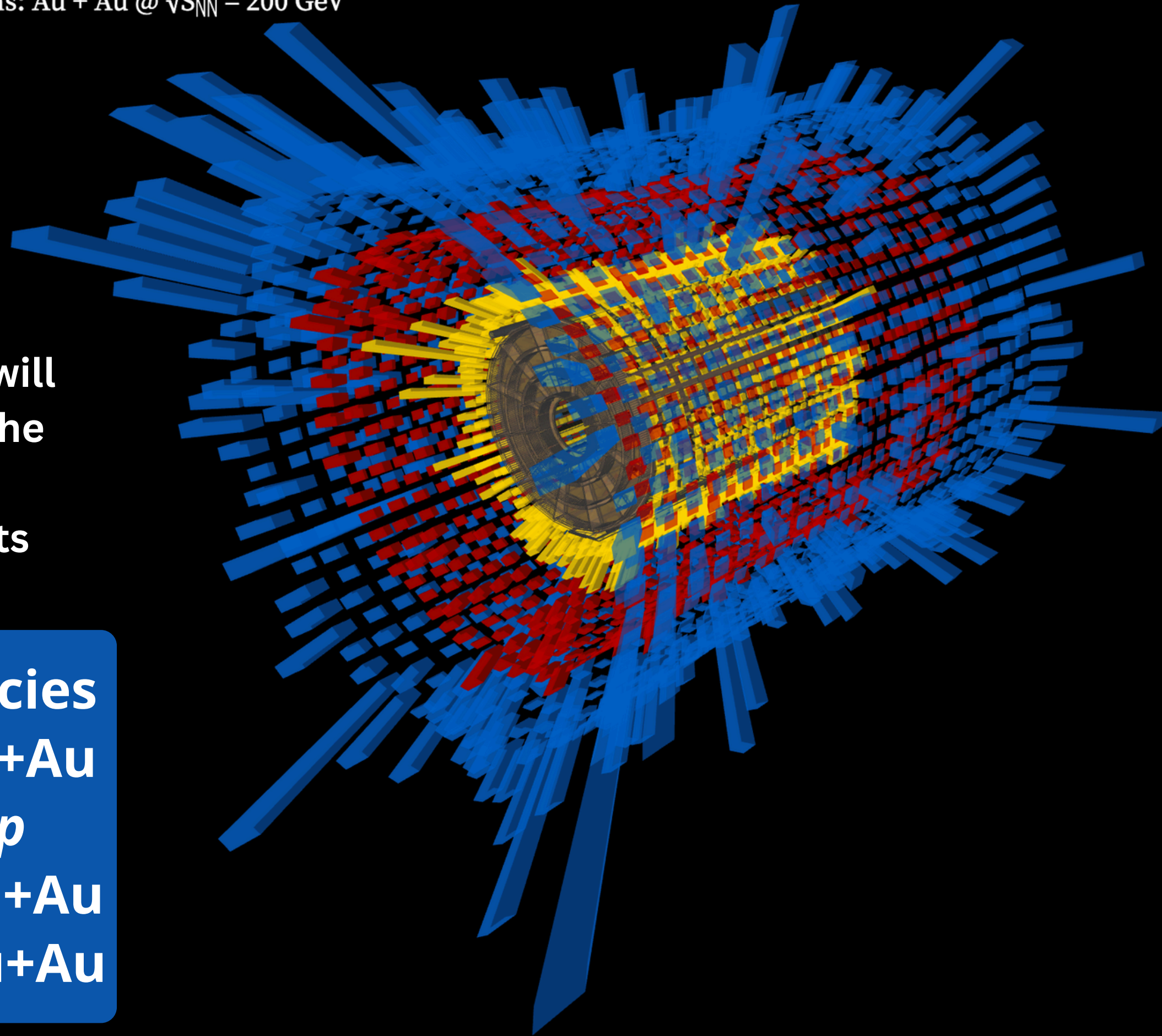 - **sEPD**
  - **MBD**
  - **ZDC/SMD**

dedicated event plane detector

MAGNET

oHCAL

EMCAL

iHCAL

sEPD

MBD

EPD

MBD

18m from I.P

ZDC+SMD

sPHENIX Experiment at RHIC
Simulated HIJING event

sPHENIX Experiment at RHIC
Data recorded: 2023-07-16 00:54:00 EST
Run / Event: 21707 / 3194
Collisions: Au + Au @ $\sqrt{S_{NN}} = 200$ GeV

sPHENIX is currently in the commissioning phase. This talk will focus on the commissioning of the subsystems used for flow measurements and recent results with the commissioning data.

Year	Cryo-weeks	Species
2023	11.5	Au+Au
2024	25	p+p
		Au+Au
2025	28	Au+Au

sPHENIX Event Plane Detector
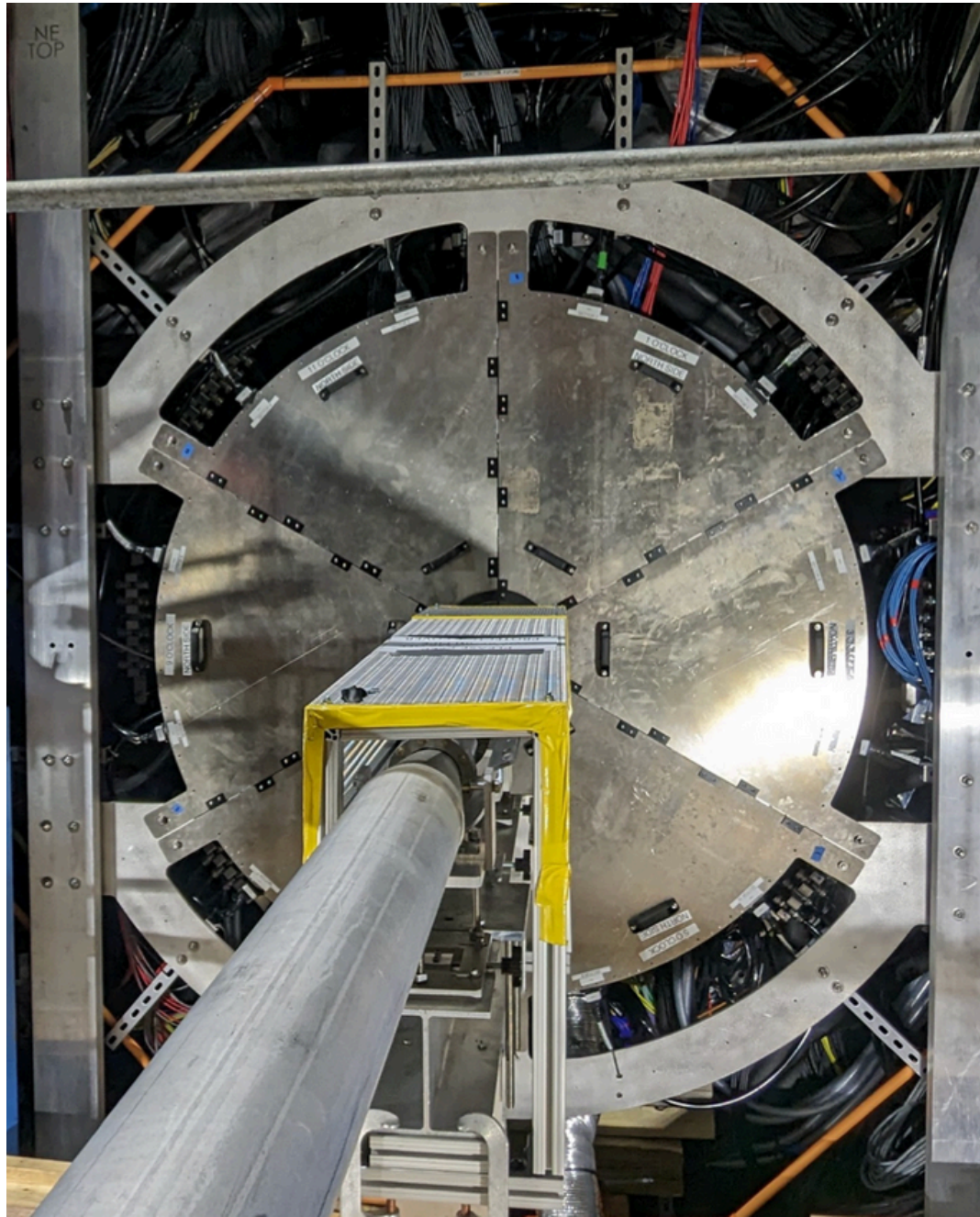
1.2 cm thick plastic scintillators with embedded WLS fibers. 2.0 ≤ |eta| ≤ 4.9

MIP peaks in Au+Au

Commissioning in p+p
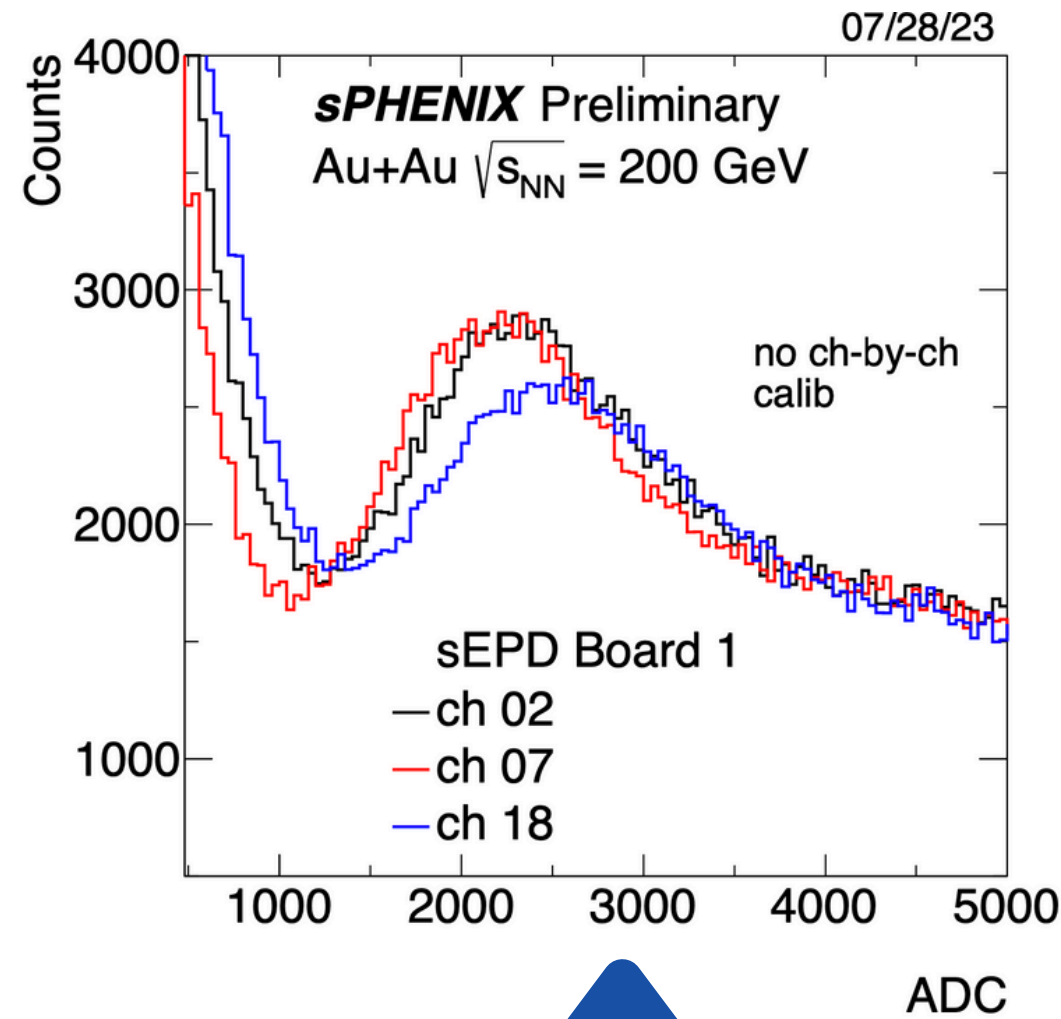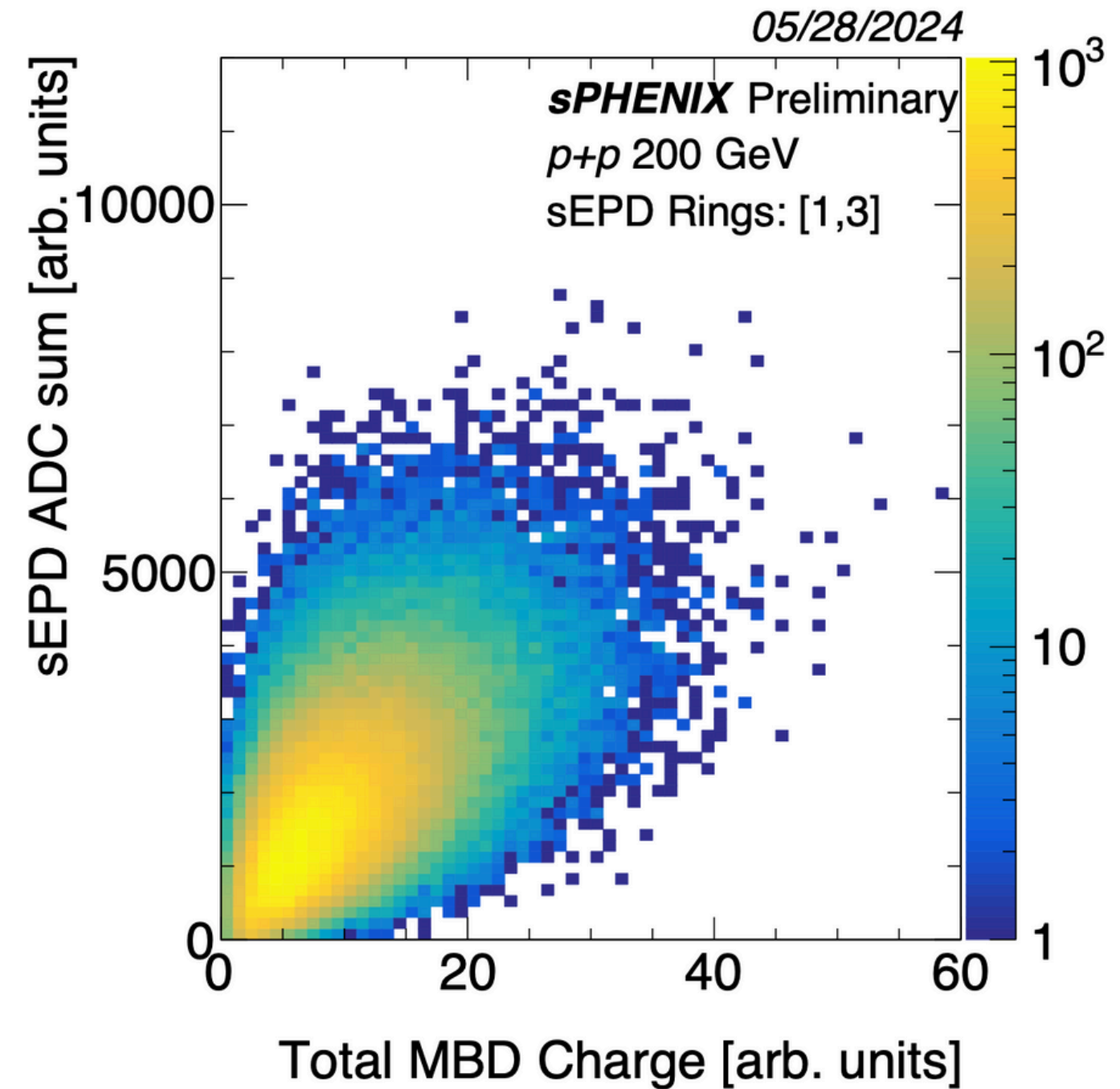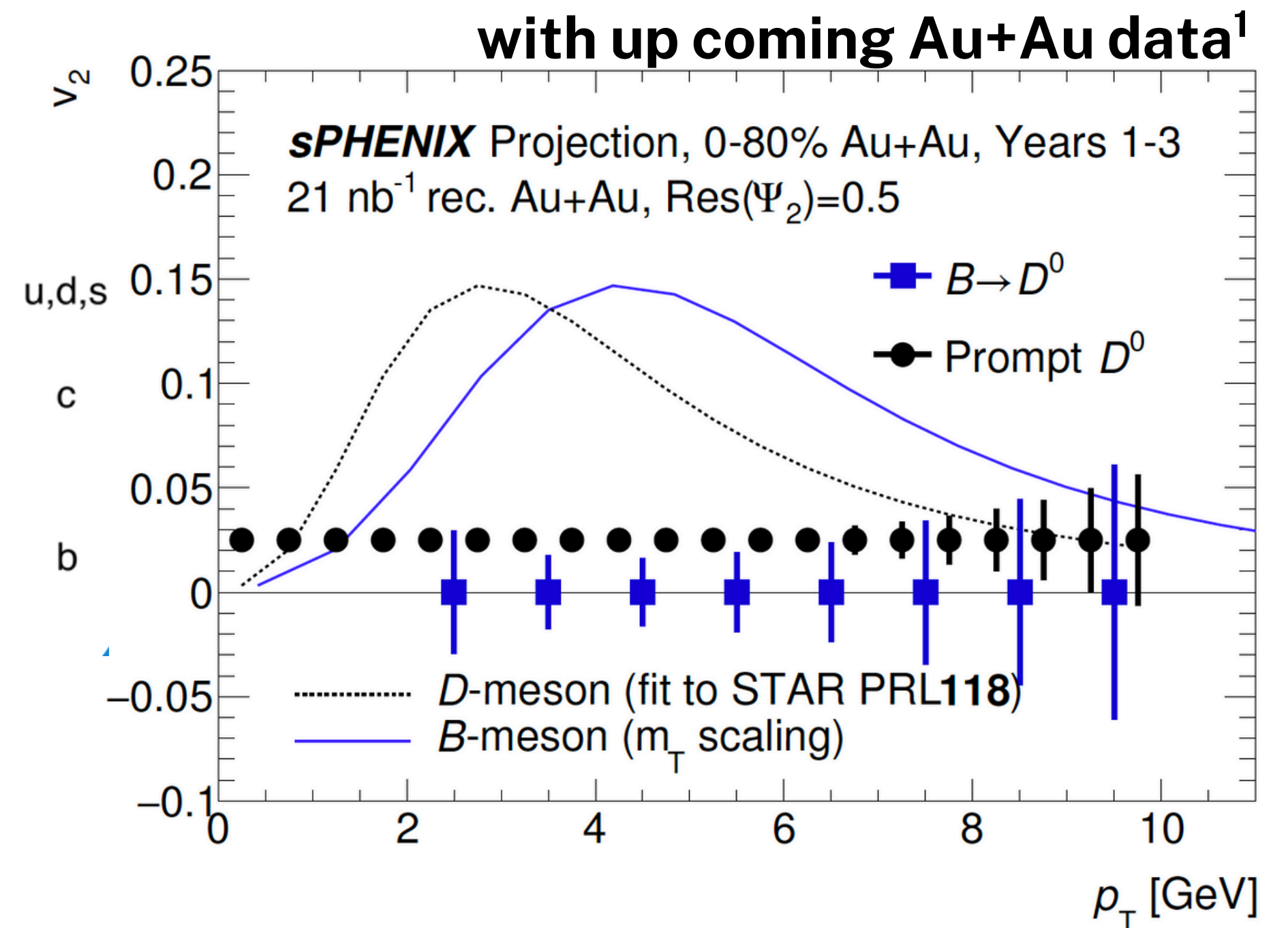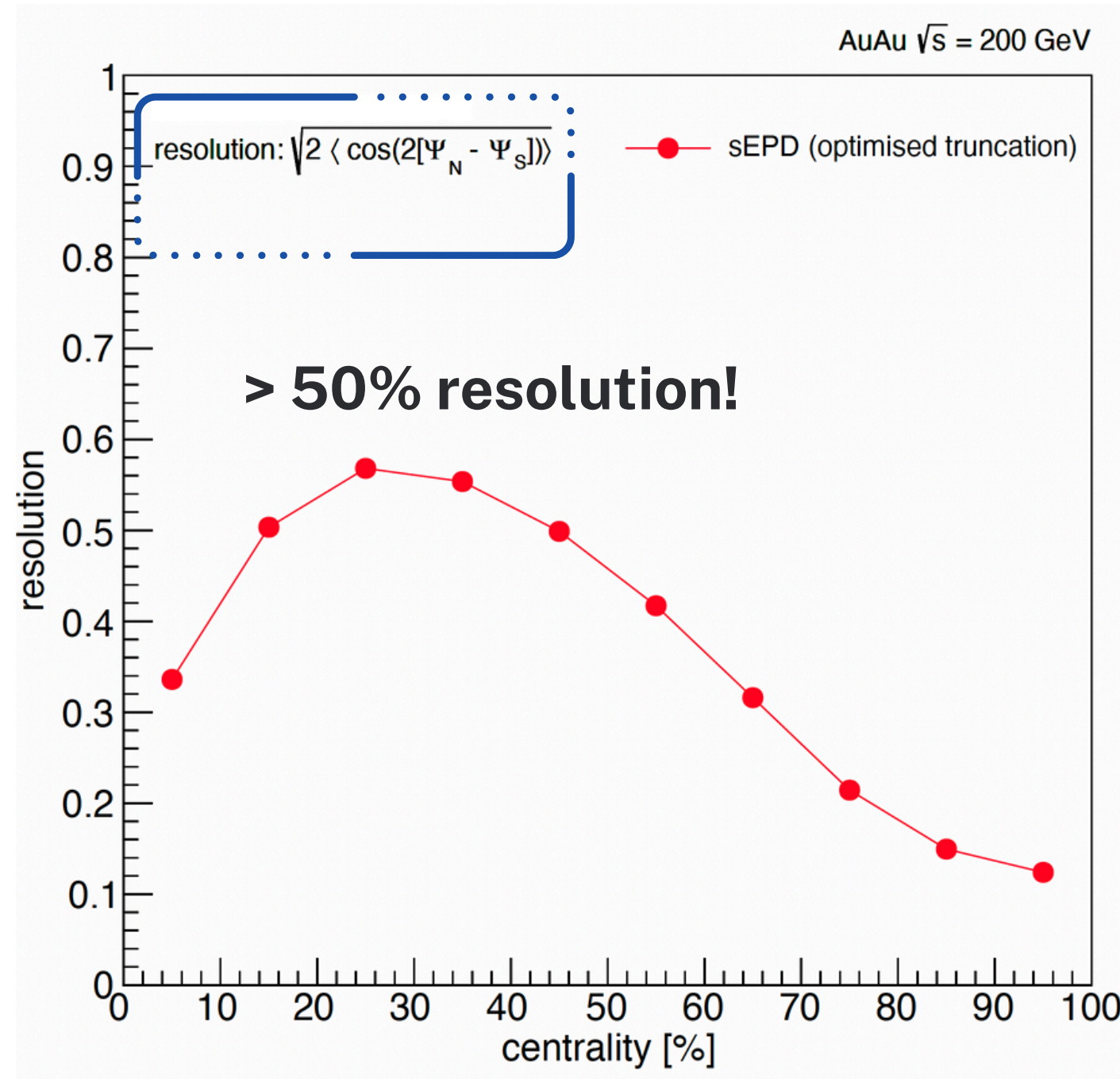
Projection for D^0 v_2 in Au+Au (right) with the expected event plane resolution of the sEPD in simulations (top)

D^0 v_2 will allow for the study of heavy flavor collectivity in the quark gluon plasma

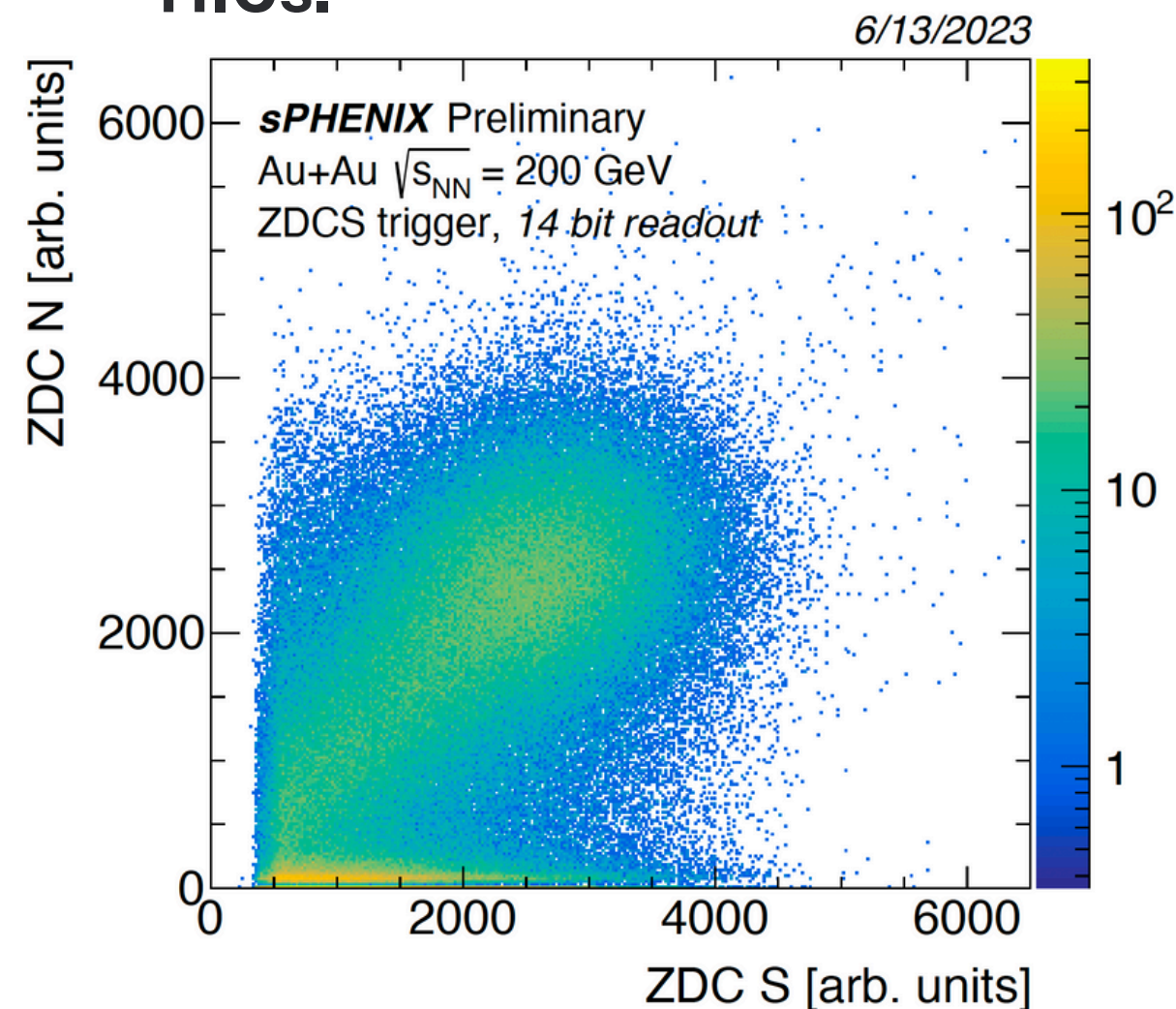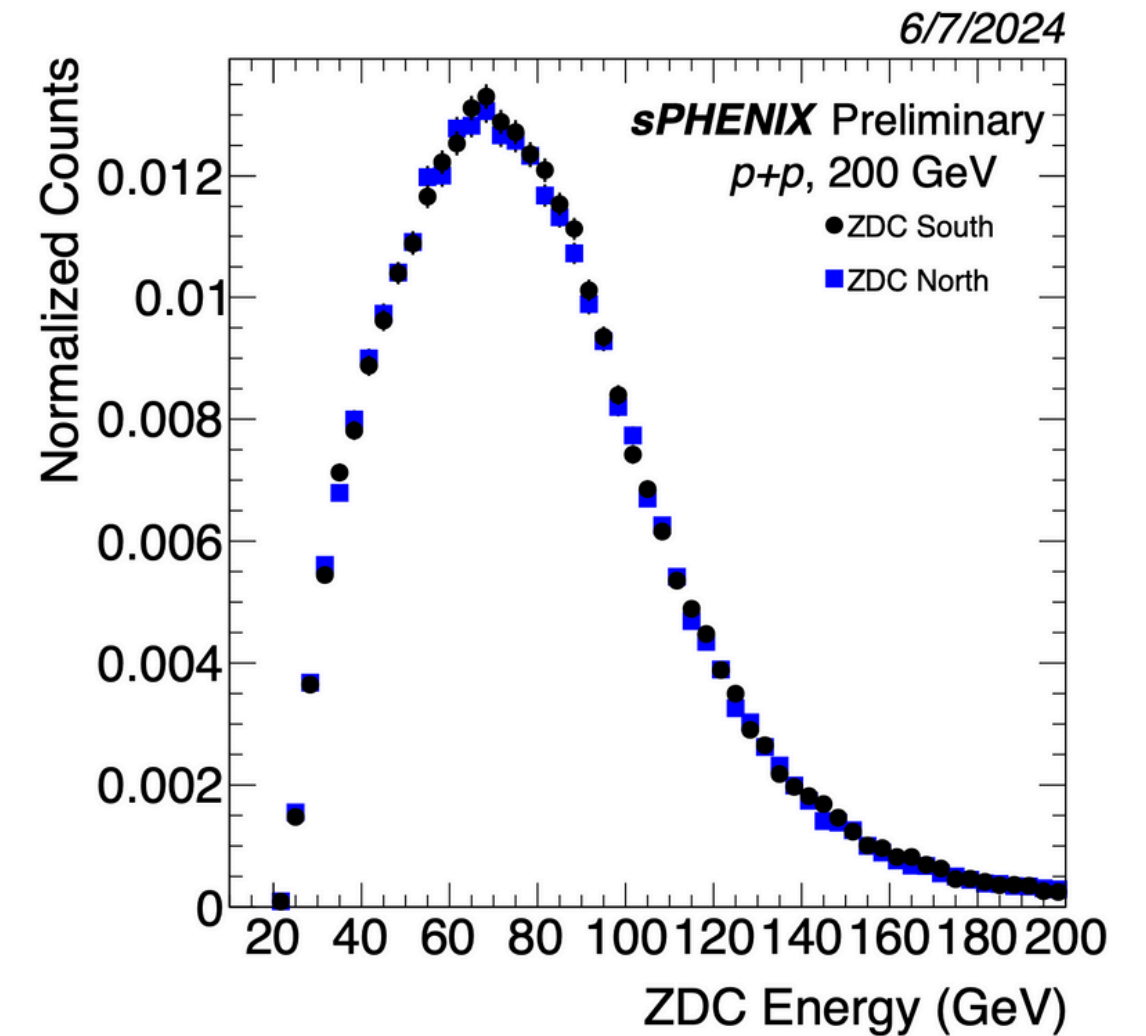1. Statistical error bars may be larger than depicted

Zero degree calorimeter and shower max detector

The ZDC is made out of 3 tungsten-fiber modules located symmetrically at z = +/- 18m. The SMD is located between the first and second ZDC module and has 2 layers of scintillator strips, which provides (x,y) positions for where the neutrons hit the ZDC. The ZDC/SMD system provides measurement of direct flow of neutrons in HICs.

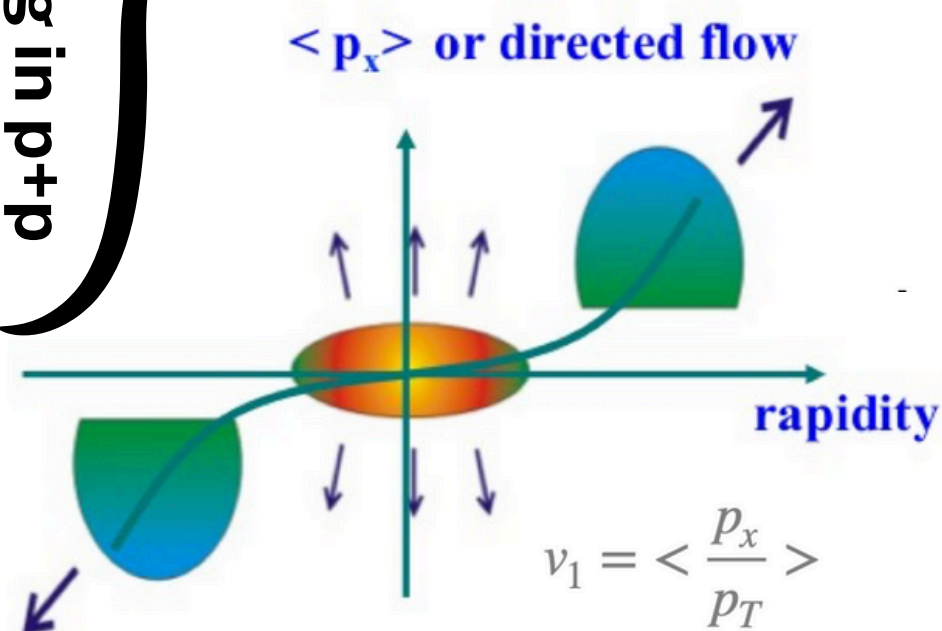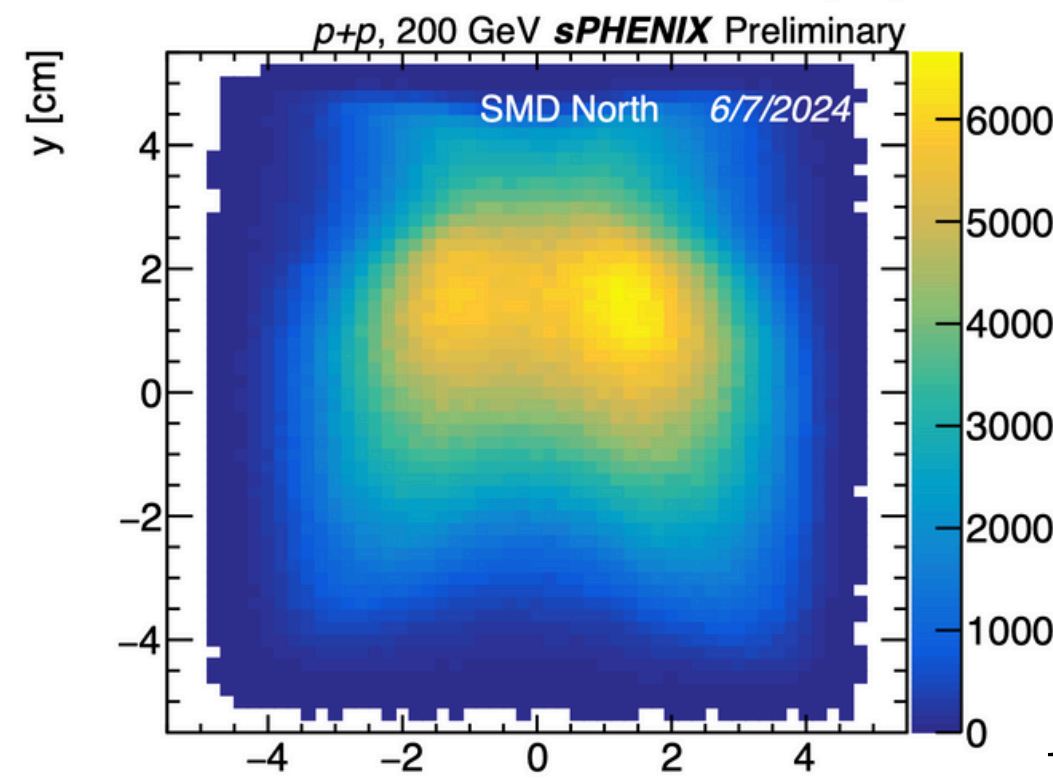

ZDC ADC N-S correlation in Au+Au
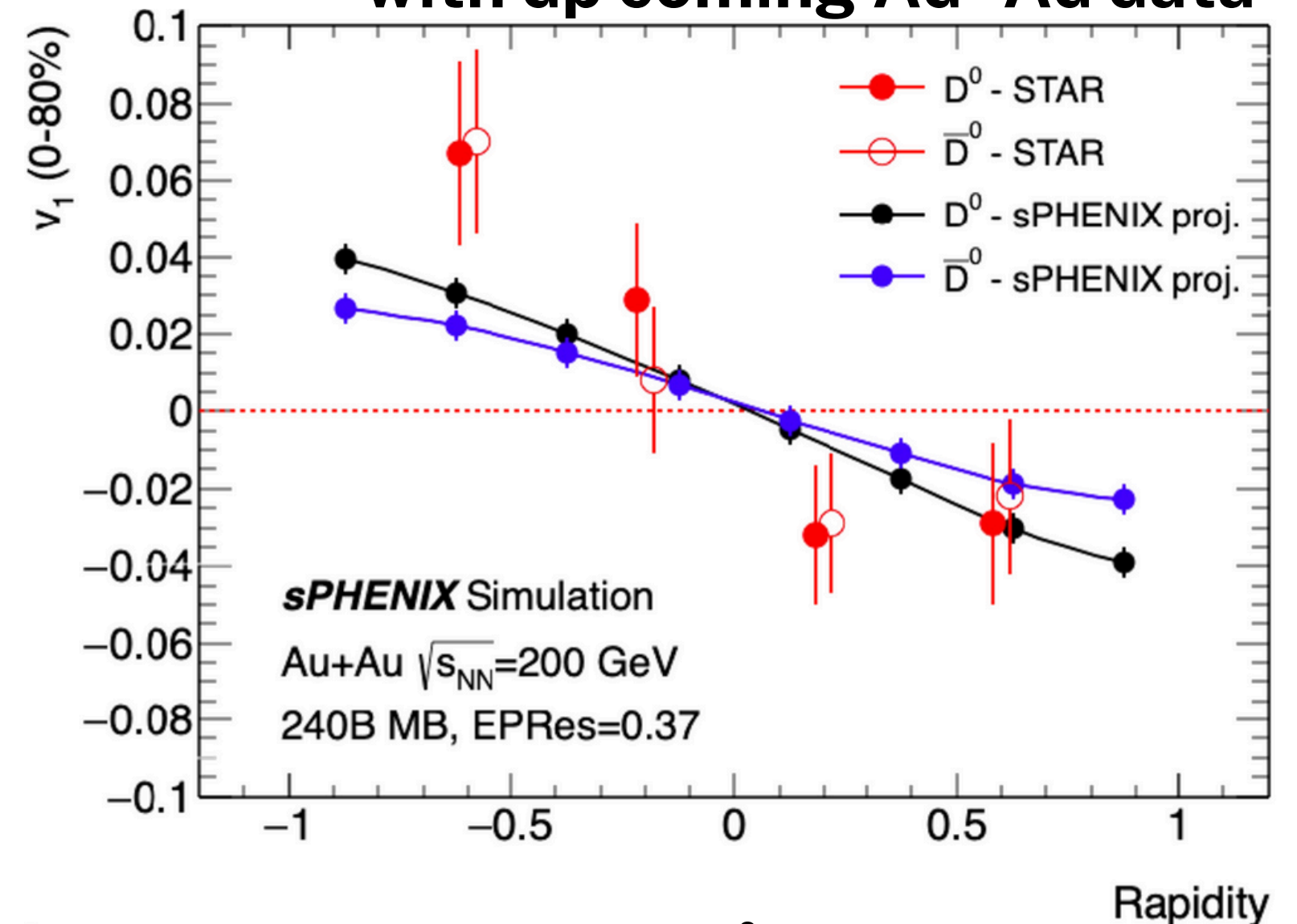

ZDC calibrated energy in p+p

with up coming Au+Au data[1]
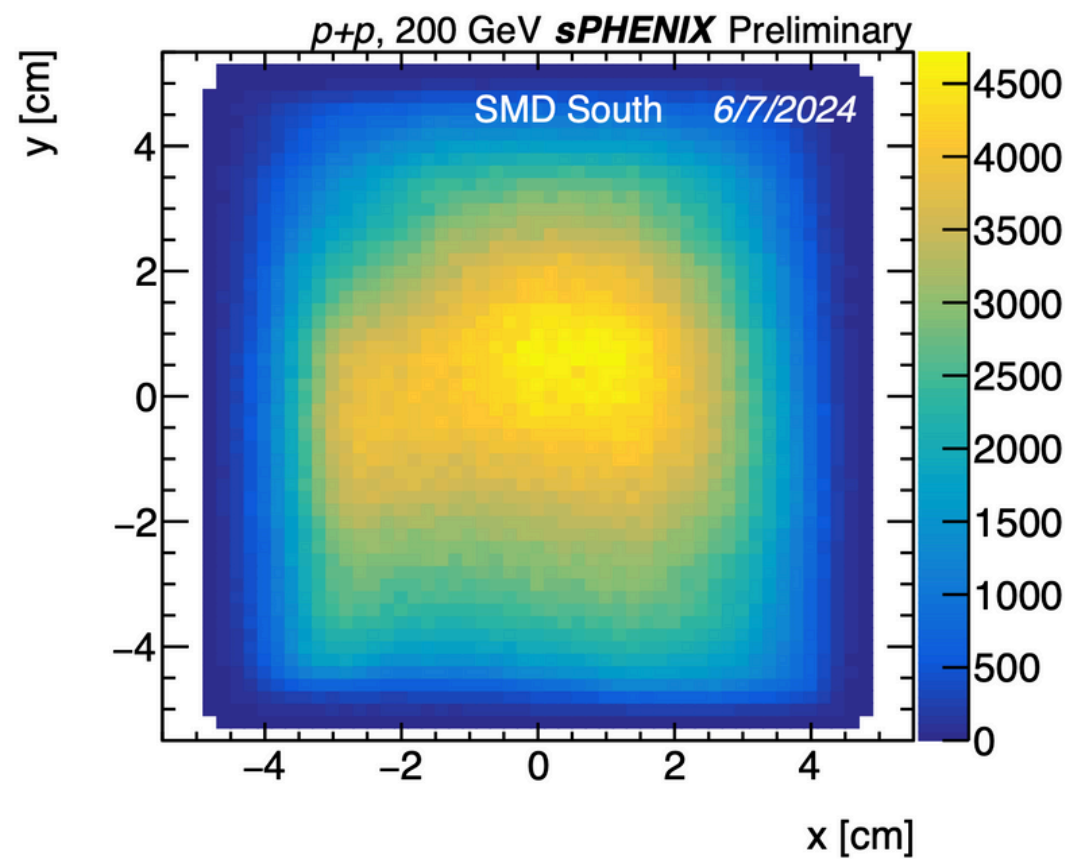
Commissioning in p+p

Neutron hit (x,y) profiles as seen in the SMD

$v_1 = <\frac{p_x}{p_T}>$

Non-zero direct flow of D^0 meson and split between particle and anti-particle expected as a function of rapidity. Precision measurement at sPHENIX enabled by higher statistics and secondary vertex reconstruction with the MVTX
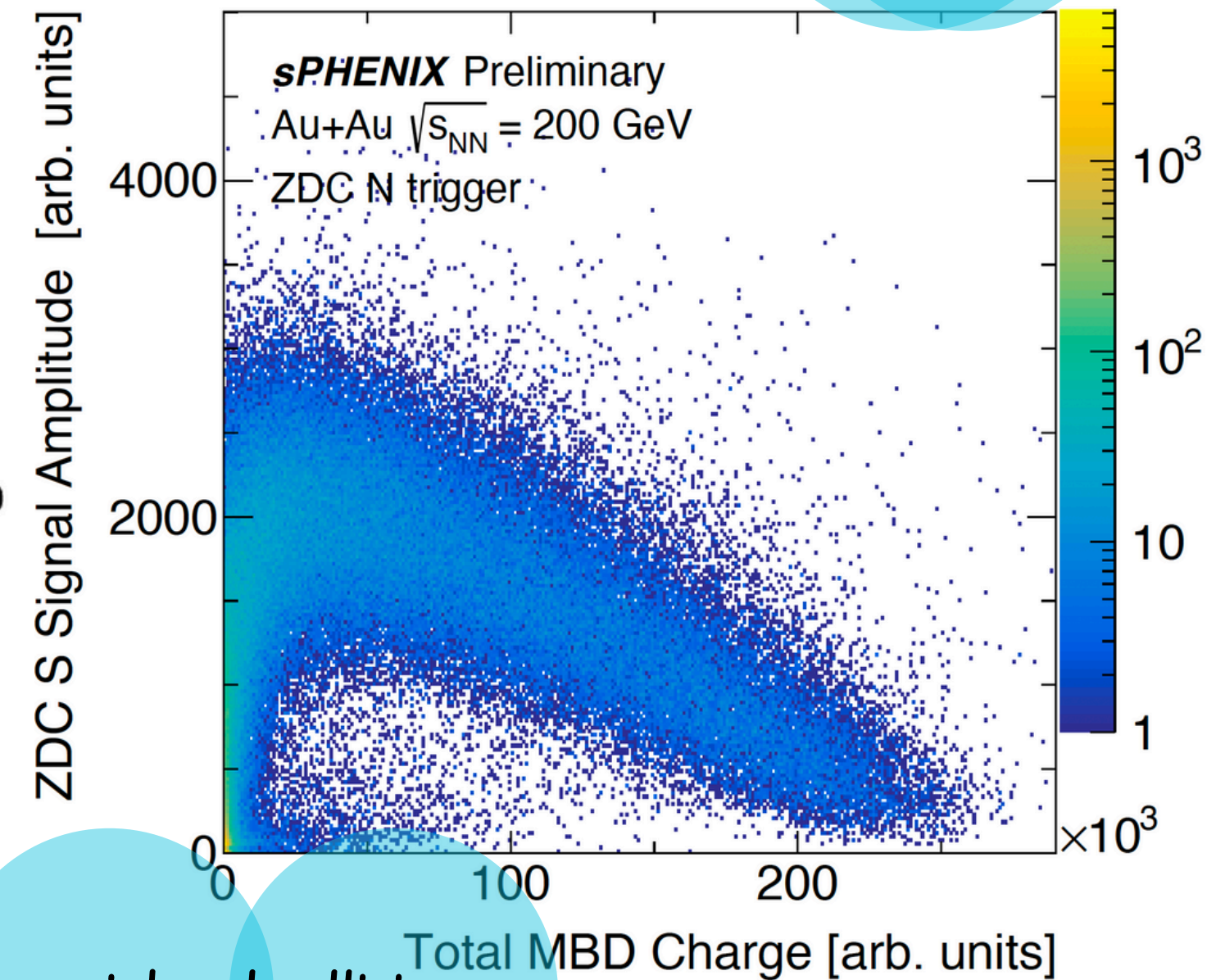
1. Statistical error bars may be larger than depicted

The Miniumum Bias Detector
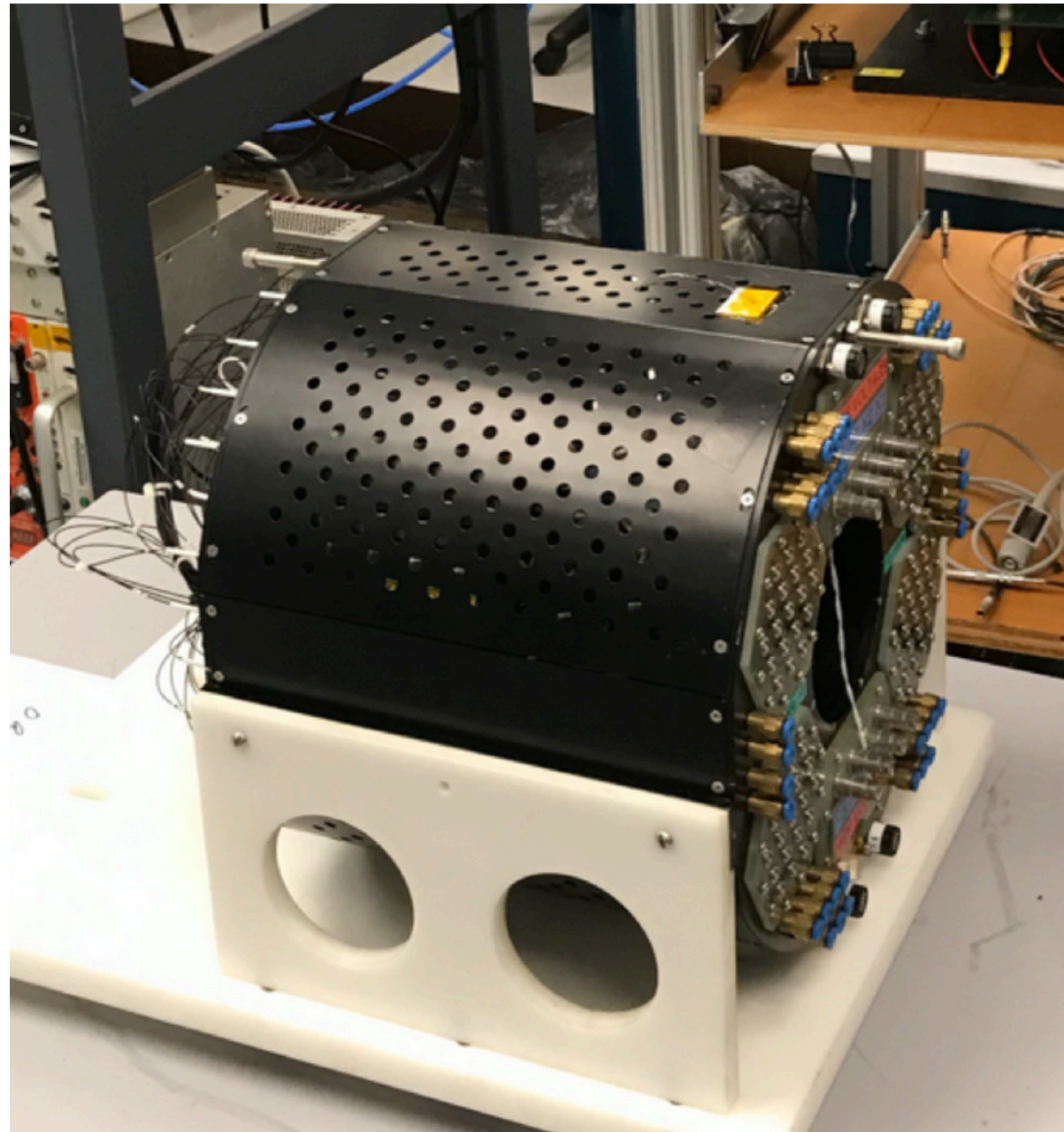
3 cm thick quartz radiator on mesh
dynode PMT. 3.51 ≤ |eta| ≤ 4.61
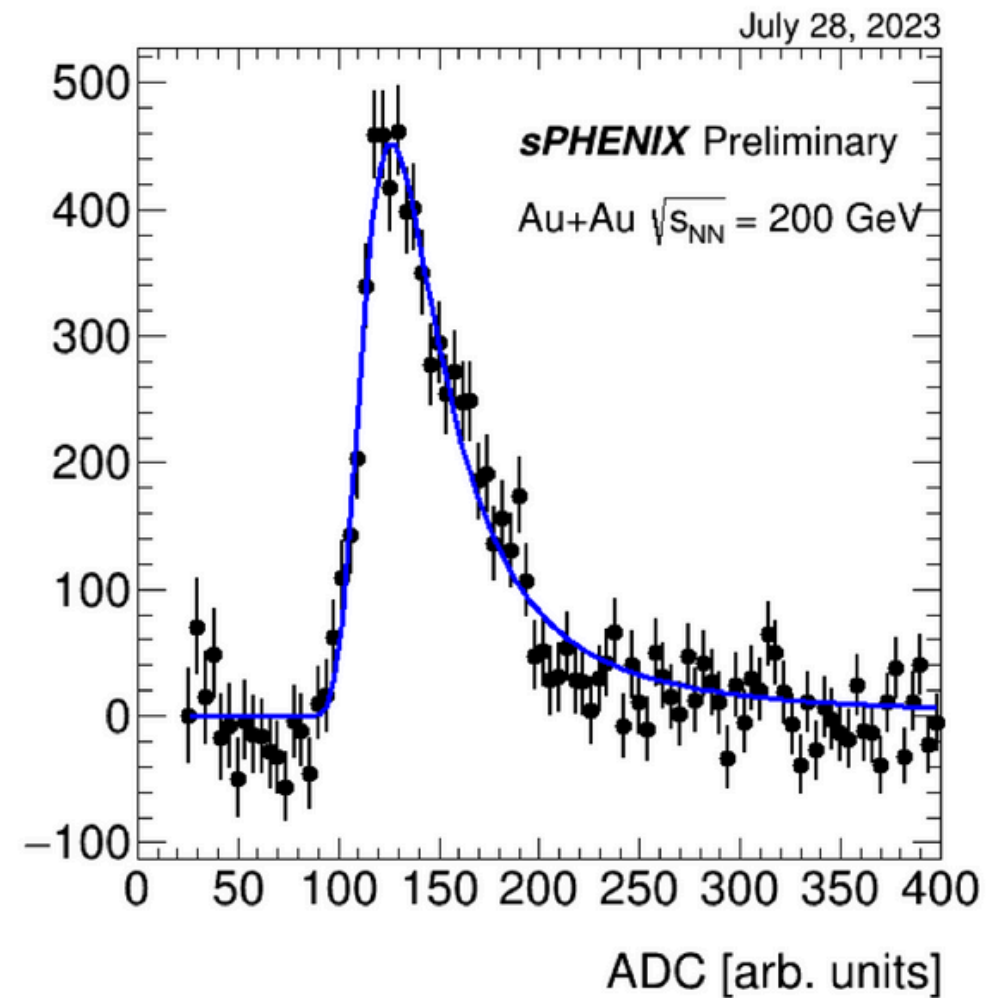
MIP peak
in Au+Au
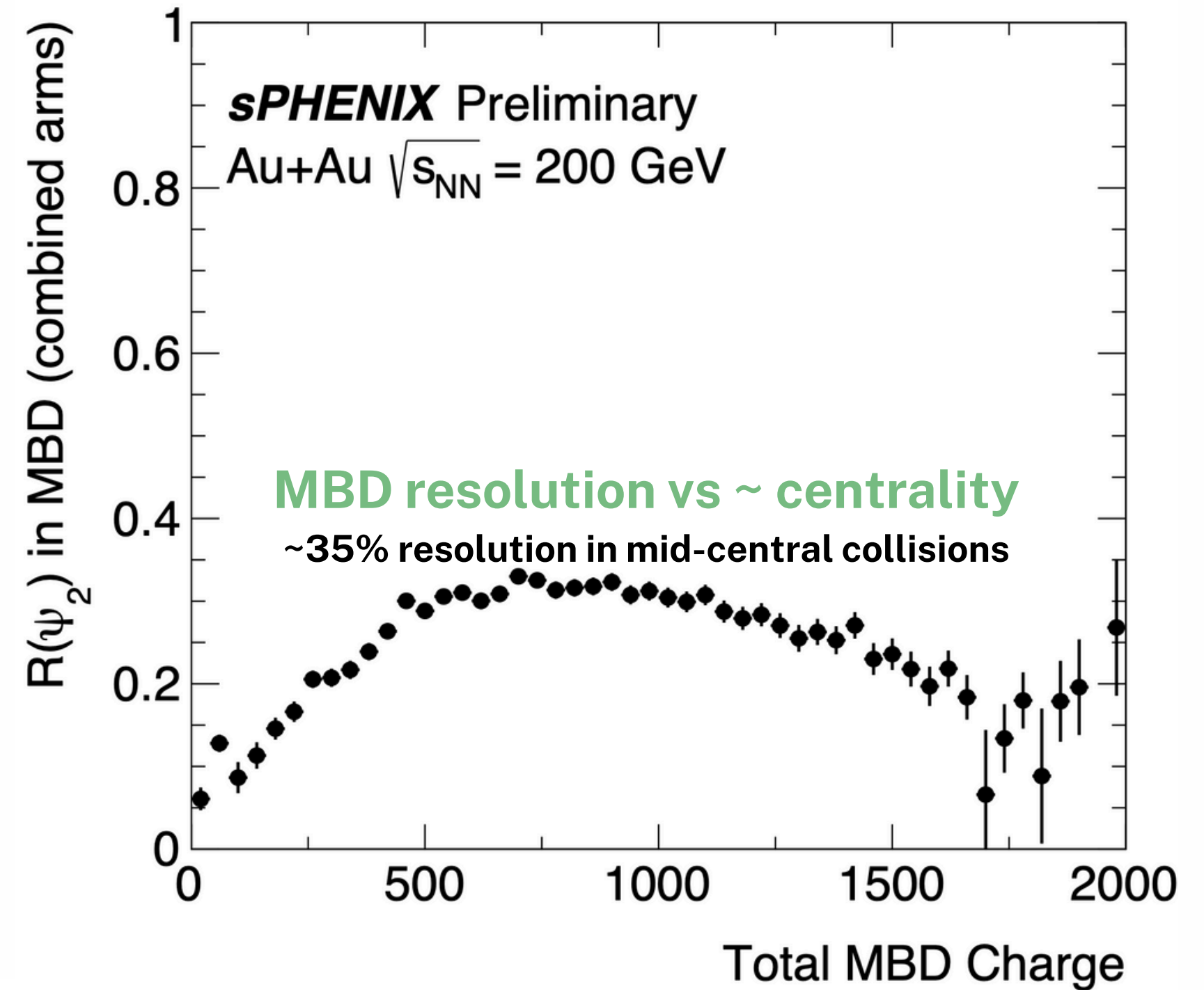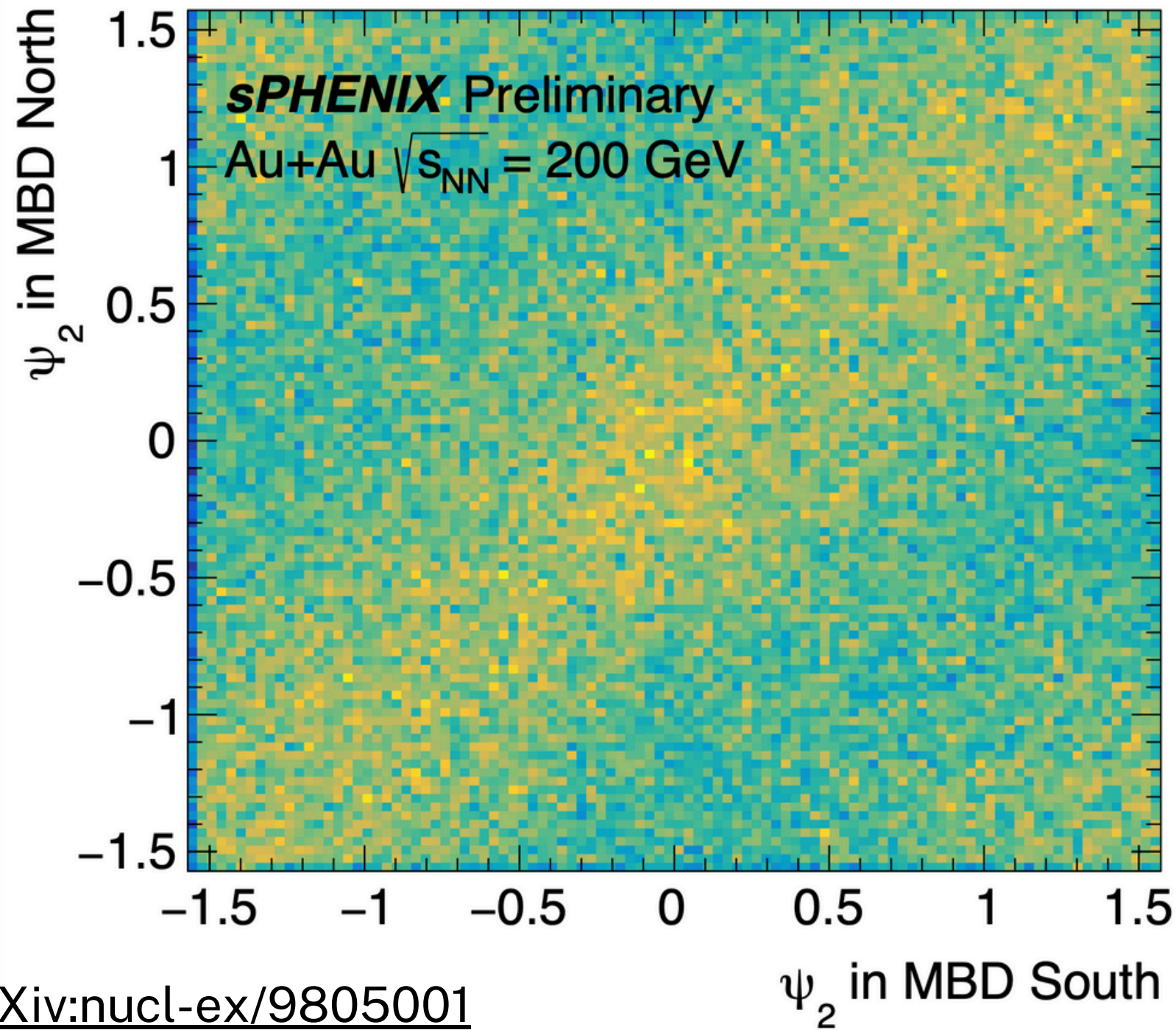
arXiv:nucl-ex/9805001

$$n\Delta\Psi_n = \sum_{i=1}^{i_{max}} \frac{2}{i}(-\langle\sin(in\Psi_n)\rangle\cos(in\Psi_n) + \langle\cos(in\Psi_n)\rangle\sin(in\Psi_n)).$$
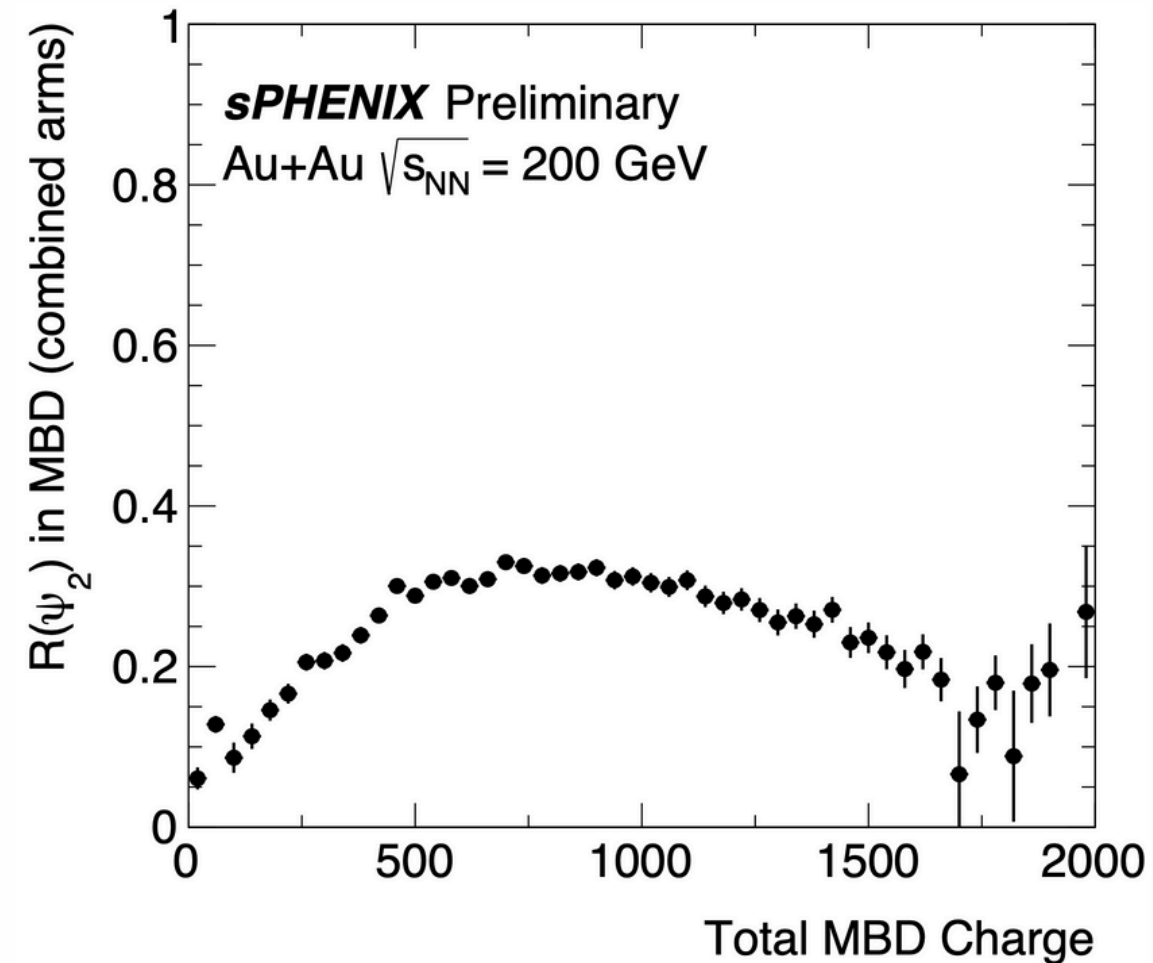

MBD resolution vs ~ centrality

~35% resolution in mid-central collisions

With Au+Au commissiong data

Number of clusters in INTT
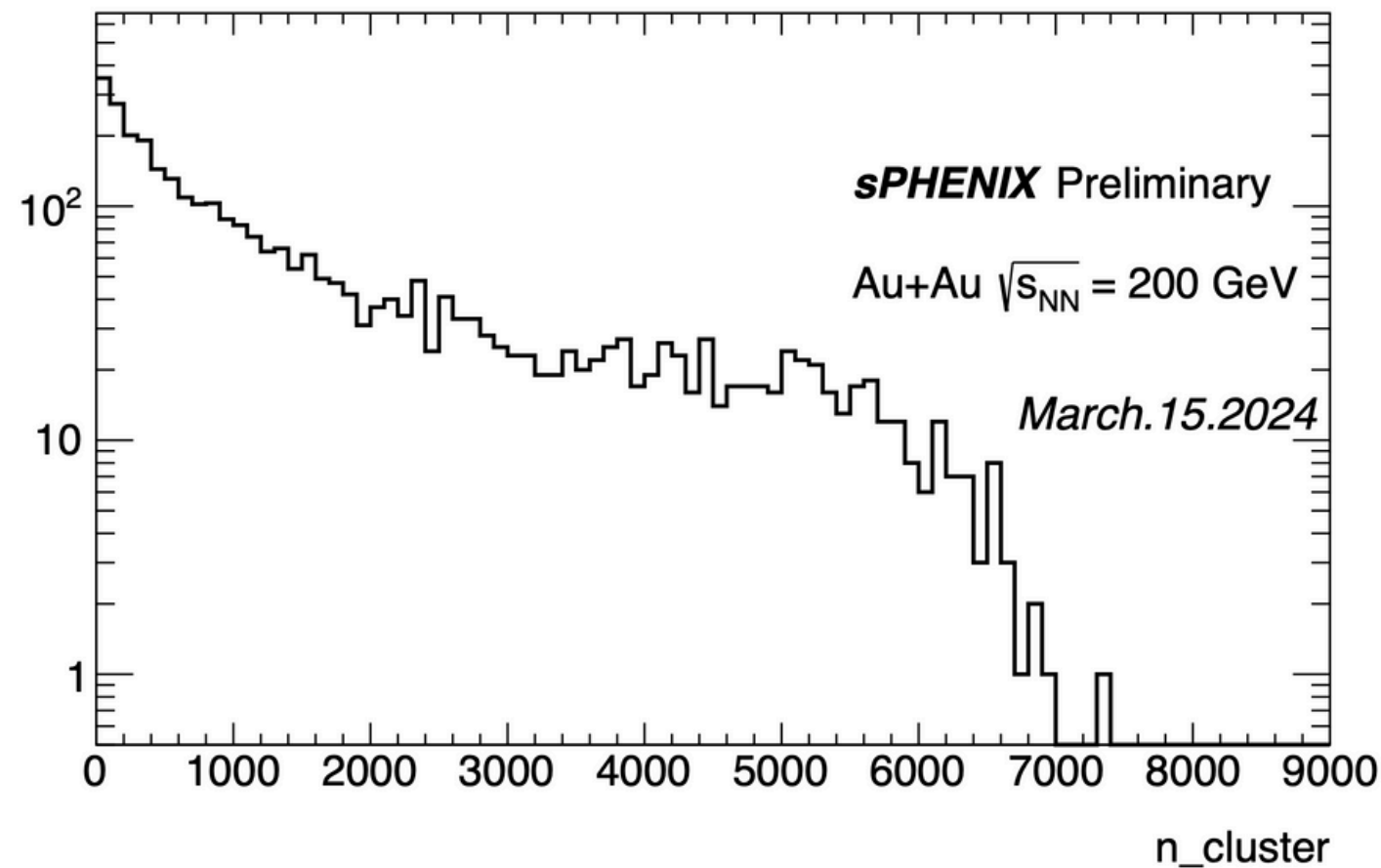
With Au+Au commissiong data

MBD Event plane resolution

Intermediate Silicon Strip Tracker

sPHENIX standard candle
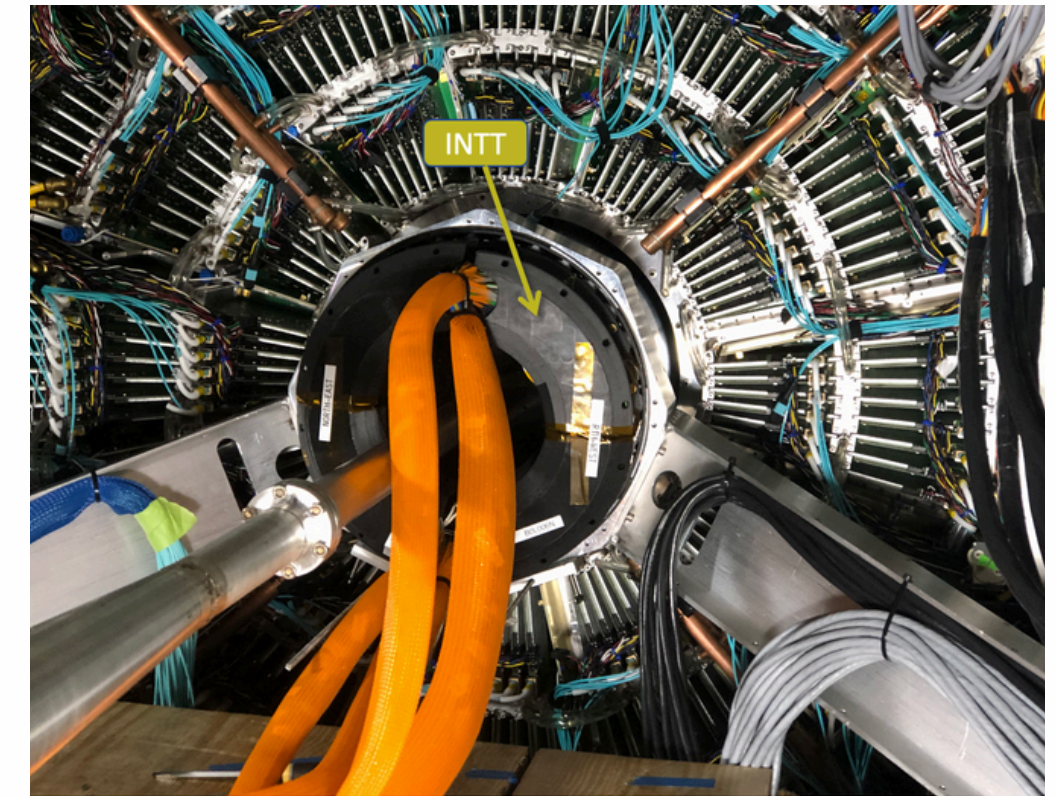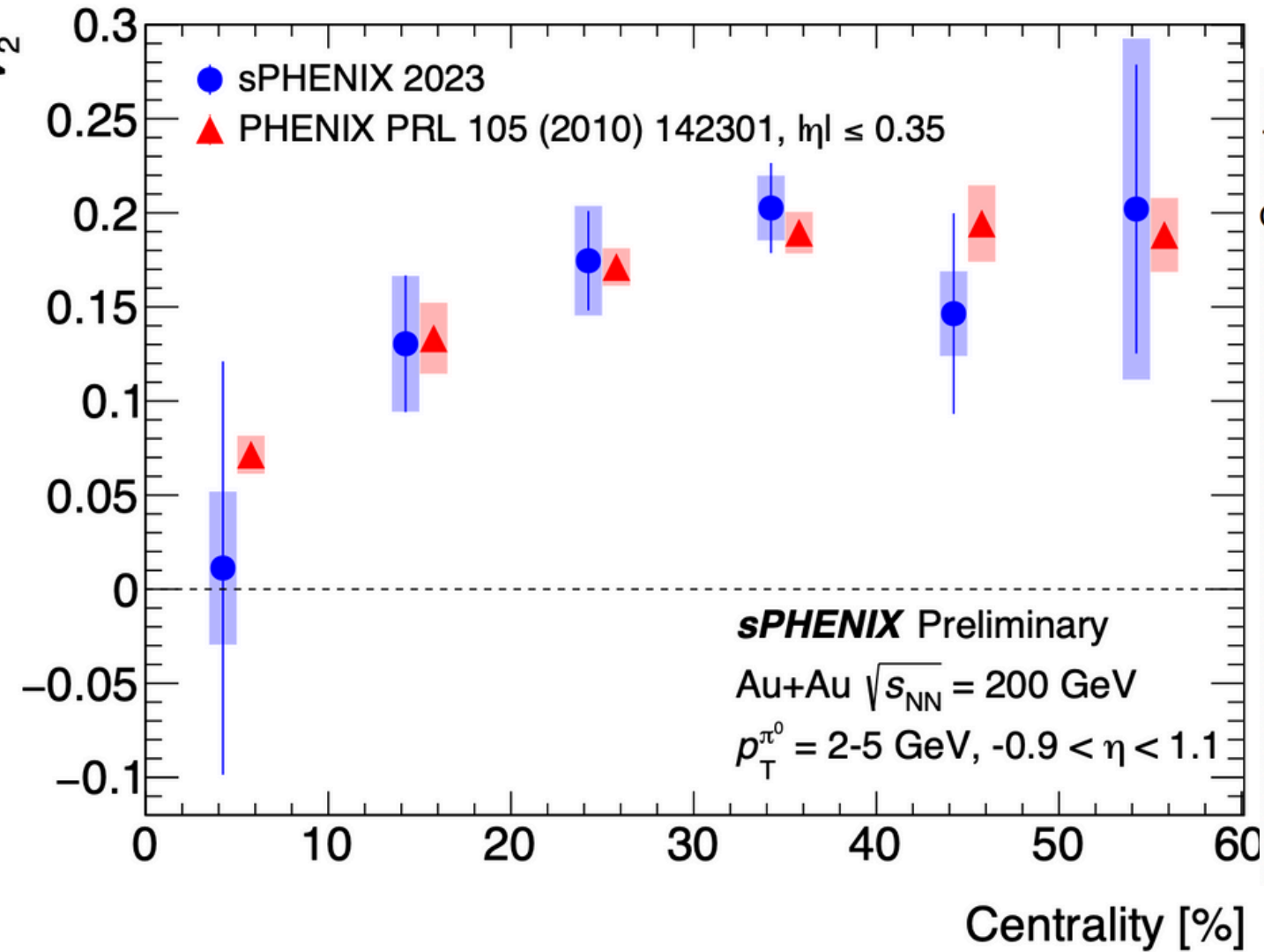
Charged hadron v_2 (WIP)

- INTT clusters in phi correlated with MBD psi_2 using the event plane method (ongoing analysis)
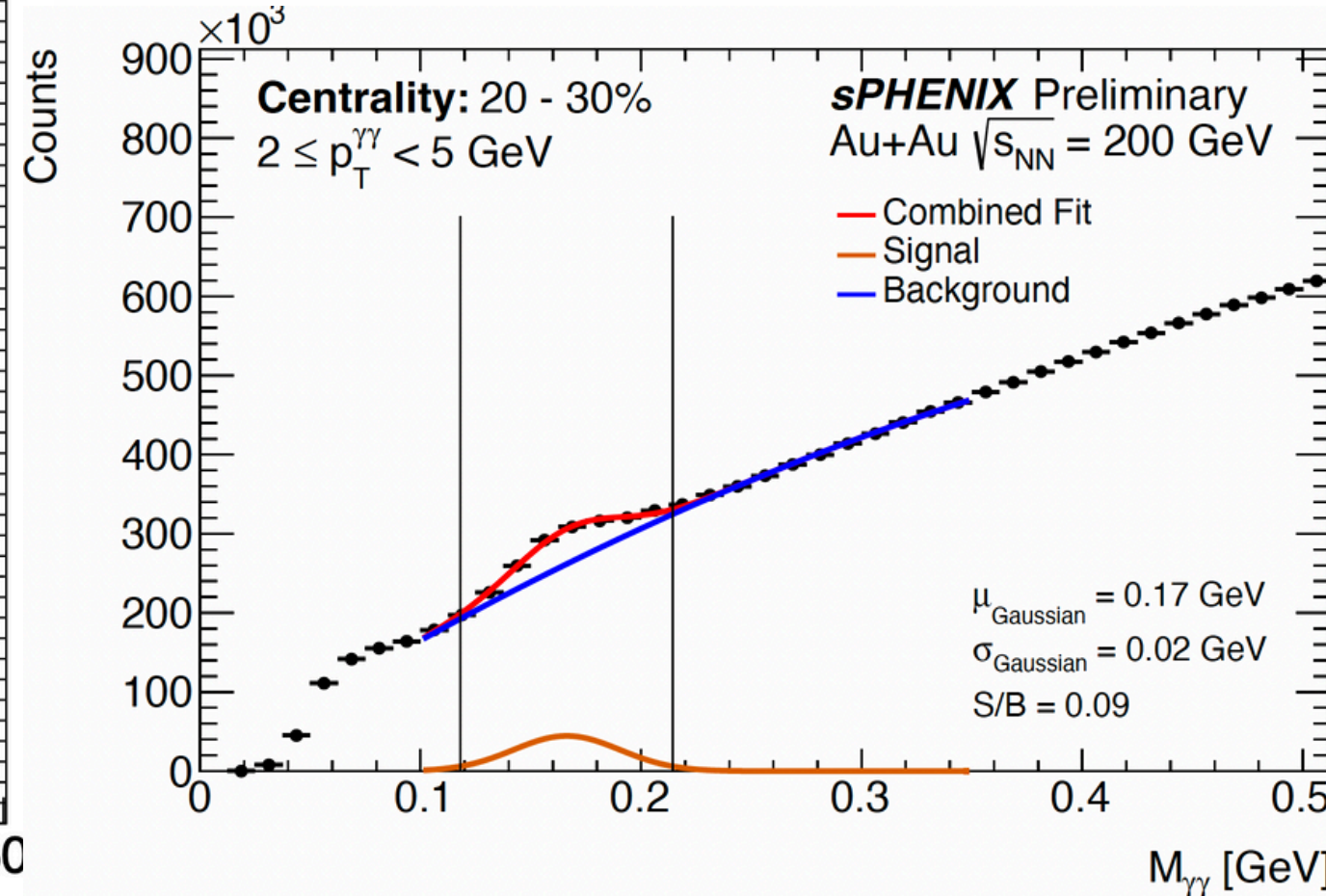- Repeat of the PHENIX analysis, but new for sPHENIX as part of commissioning both subsystems
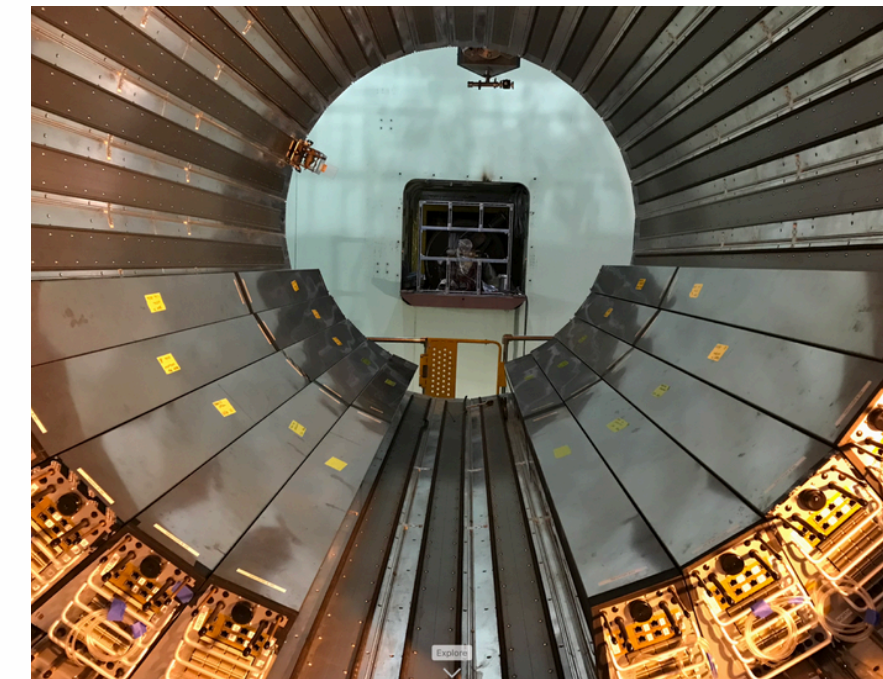
sPH-CONF-BULK-2024-01

Neutral pion elliptic flow

di-photon mass

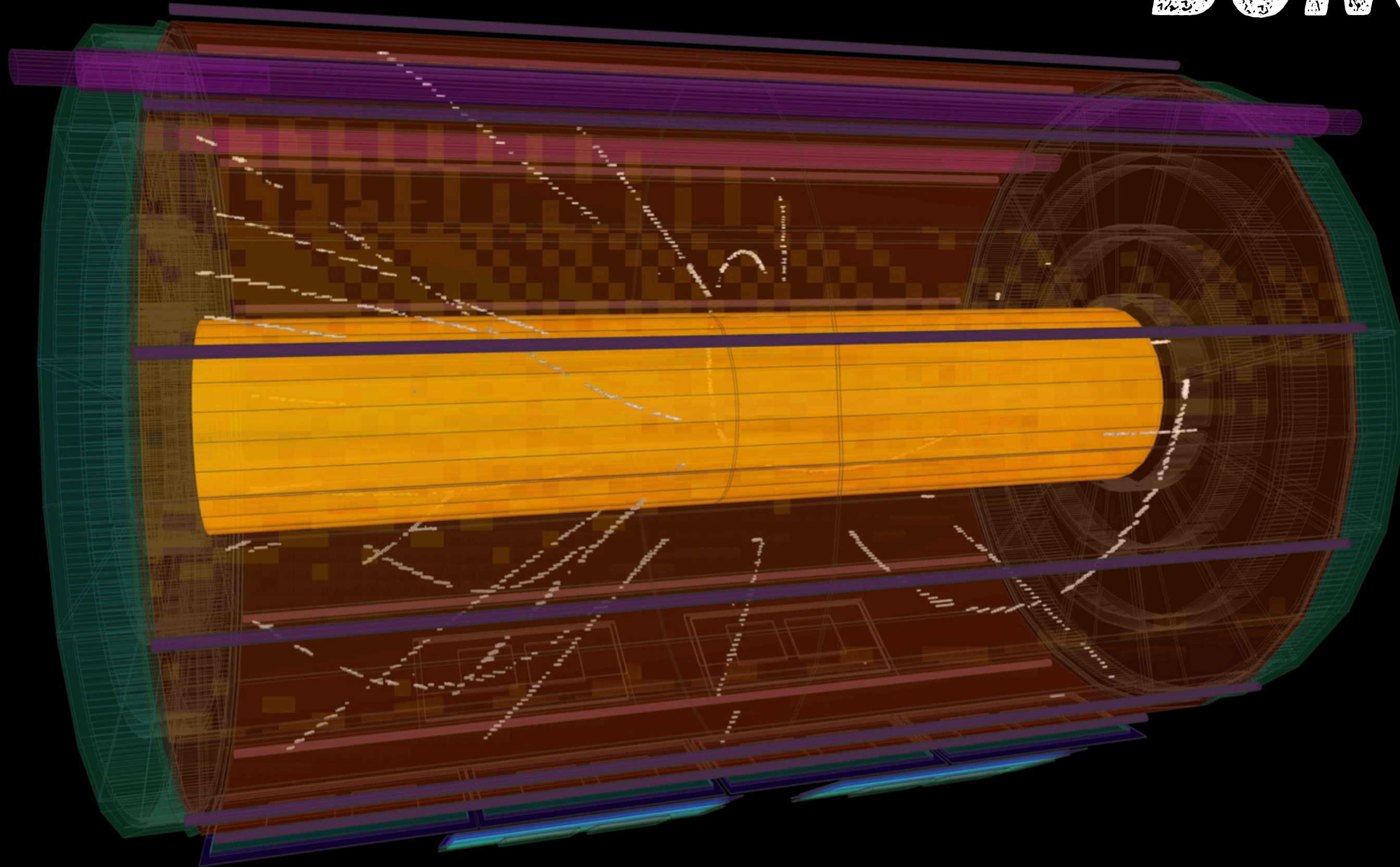**EMCAL sectors**

Neutral pion v_2 (completed)

- di-photon clusters reconstructed with EMCAL
- PiO v_2 extracted with scalar product method. MBD north/south treated as 2 subevents.
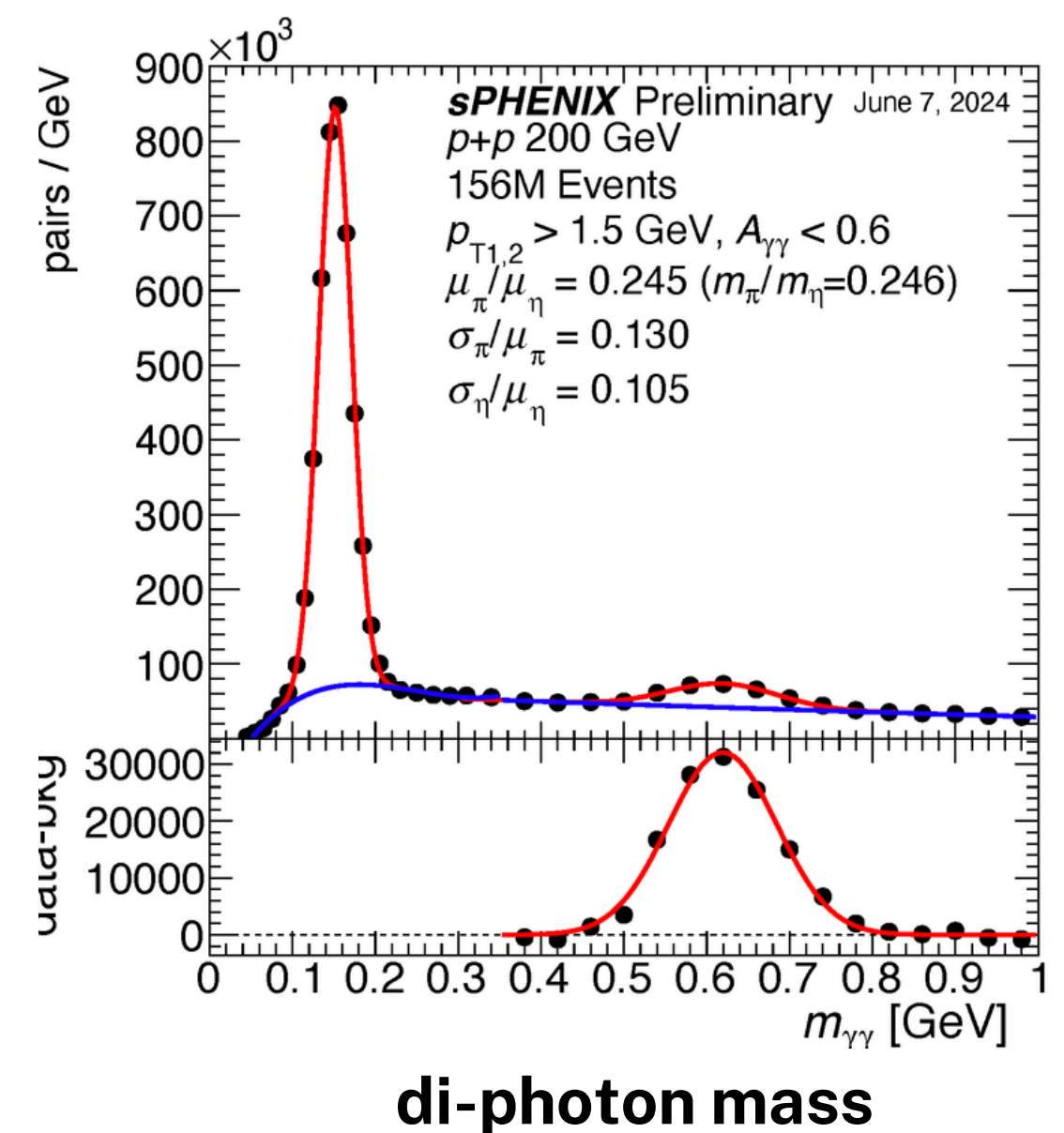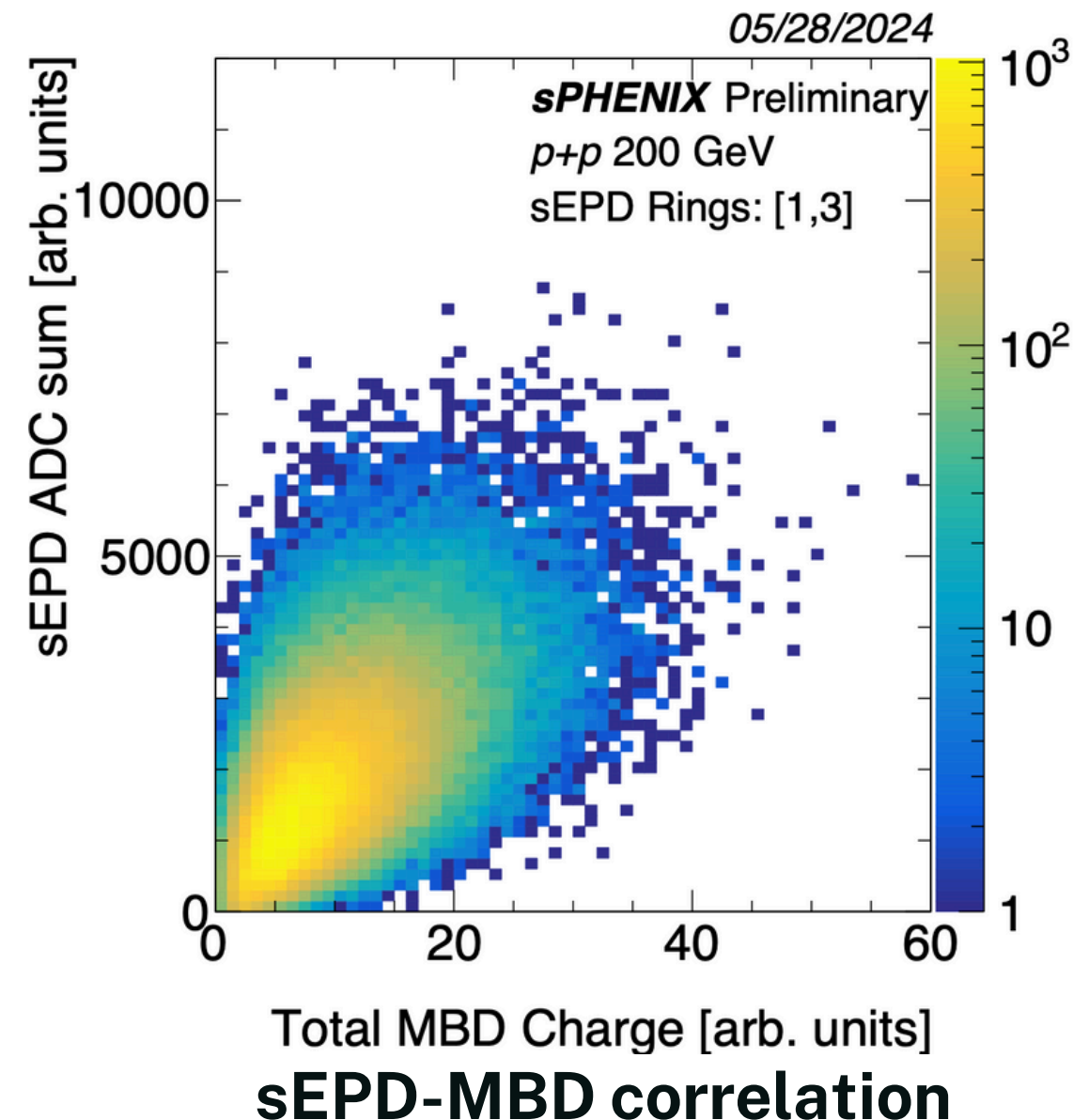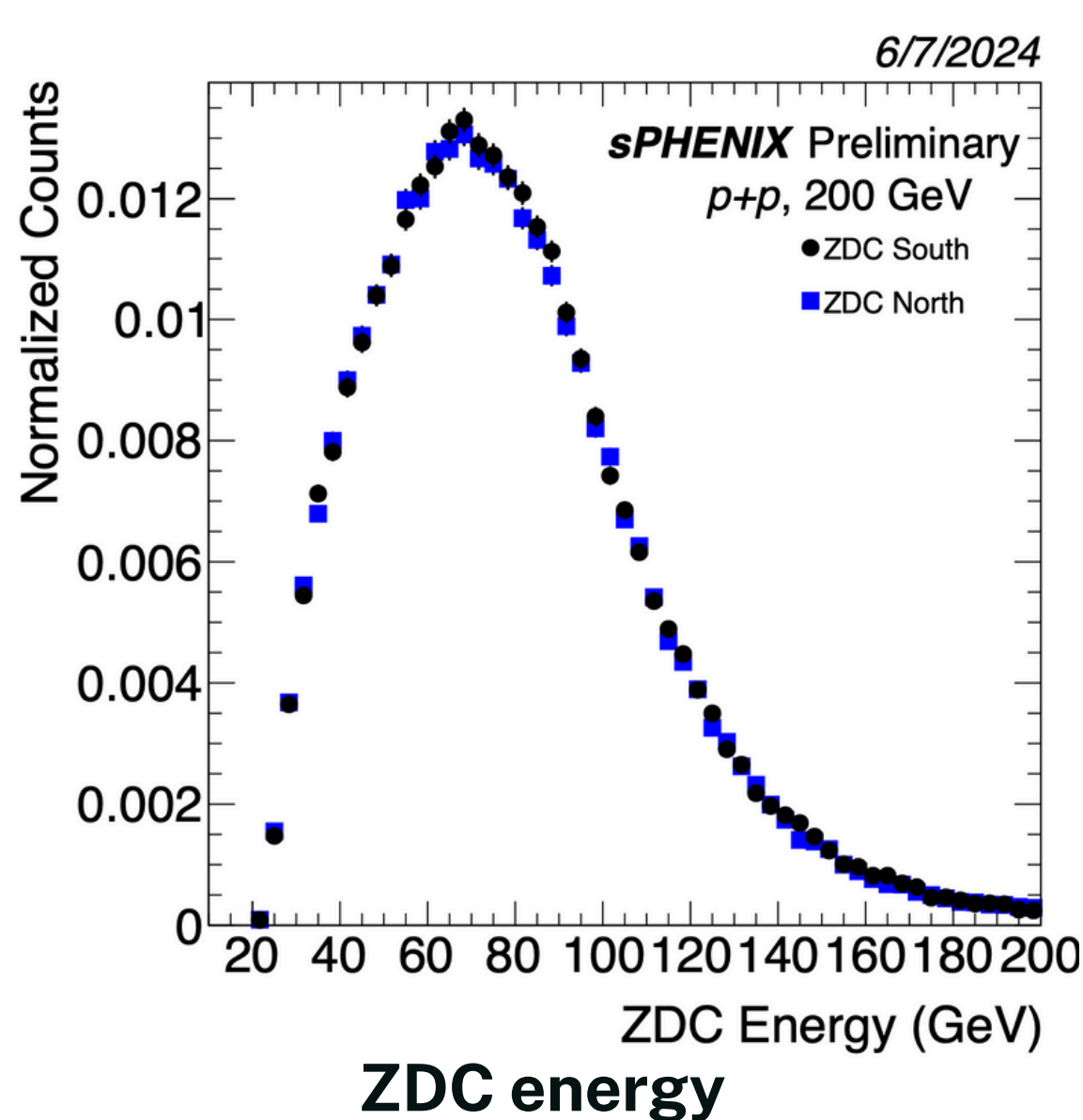- New sPHENIX results as afunction of centrality is in good agreement with the previous PHENIX results (in red)

BONUS

- sPHENIX subsystem commissioning in p+p collisions is making good progress
- High statistics Au+Au physics data expected after p+p running
- Stay tuned for new flow measurements from sPHENIX!

ZDC energy

sEPD-MBD correlation

di-photon mass

Thank you!

QUESTIONS?

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