Workshop Report: Flow & Vorticity

Niseem Magdy Abdelrahman
The University of Tennessee, Knoxville
niseemm@gmail.com
Inspire-hep: 1305036
ORCID: 0000-0002-6458-6552

Yu Hu
Lawrence Berkeley National Laboratory
yuhu@lbl.gov

Supported in part by the
U.S. DEPARTMENT OF ENERGY | Office of Science

Thanks for all participants

Talks

Introduction

Final Particle

- Momentum anisotropy
- Charge separation
- Angular momentum

Hydro-response

Medium properties

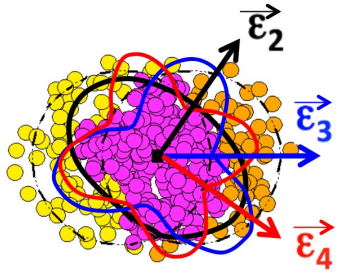
✓ $\frac{\eta}{s}, \frac{\zeta}{s}, \ldots.$

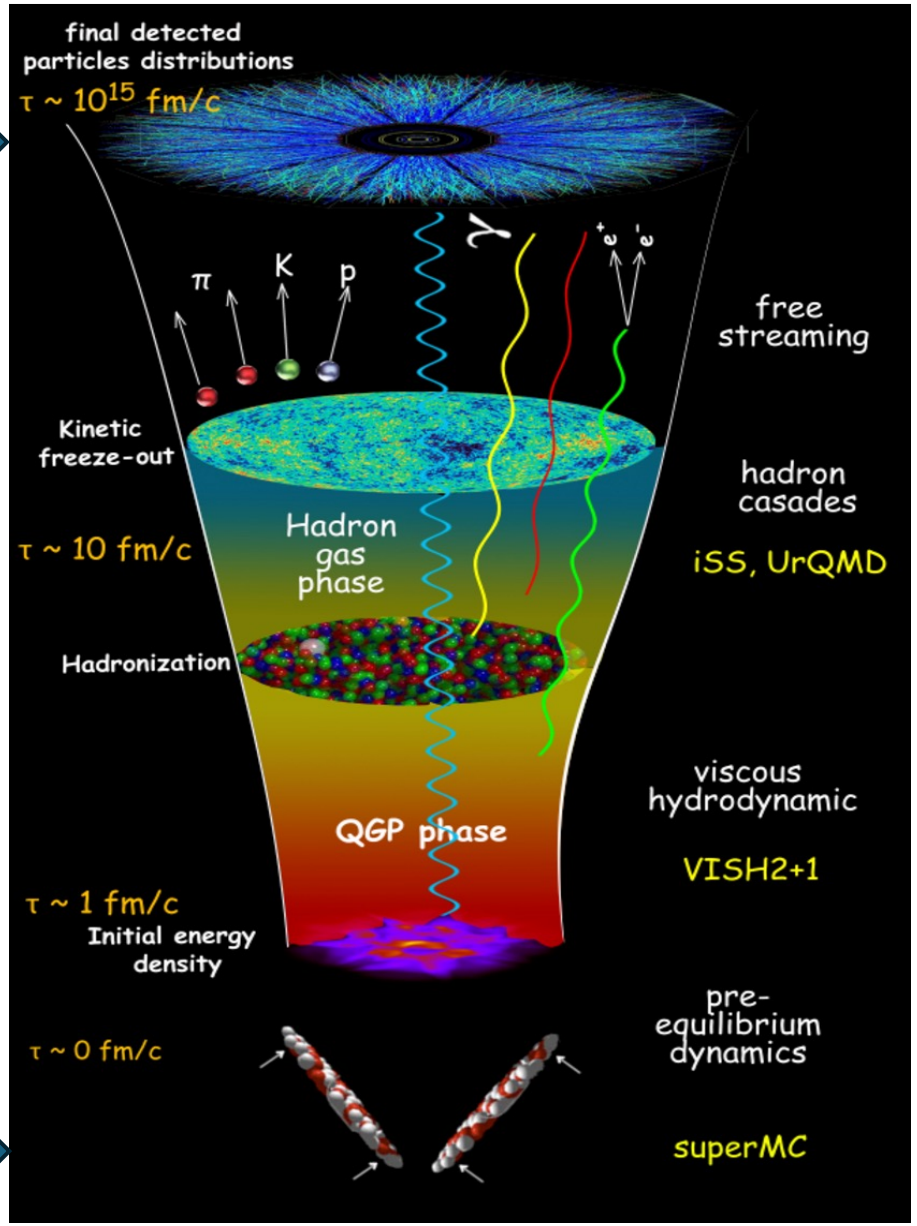
✓ μ_5

Space-time dynamics

Initial state

- Initial shape and structure
- Shape correlations and fluctuations
- Initial magnetic field





Chun Shen
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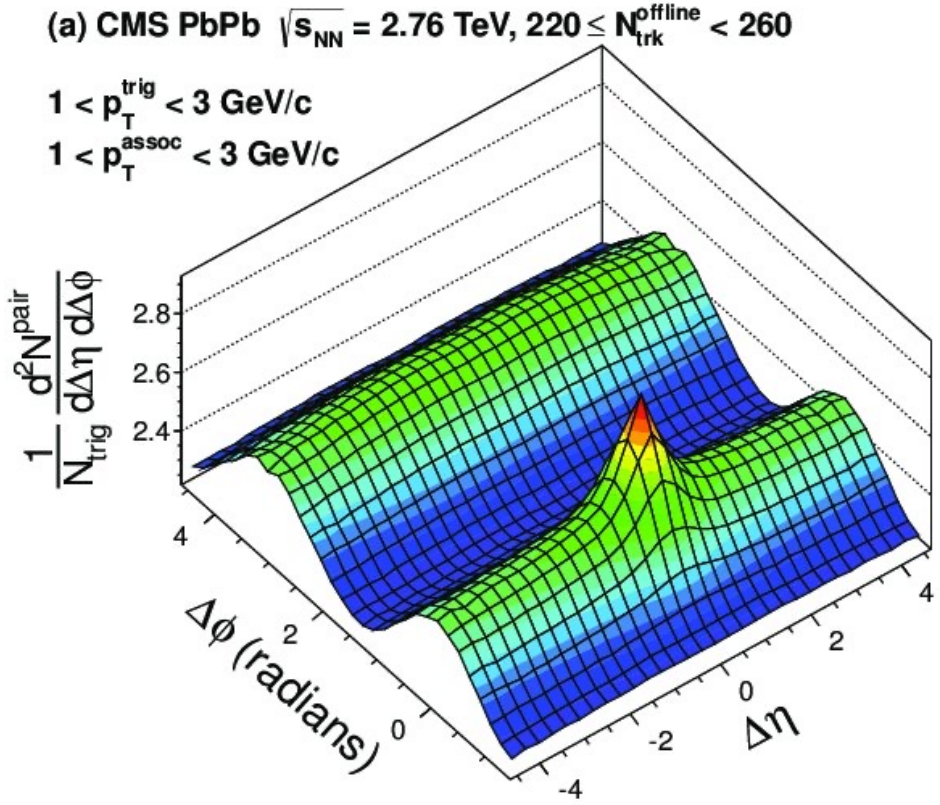
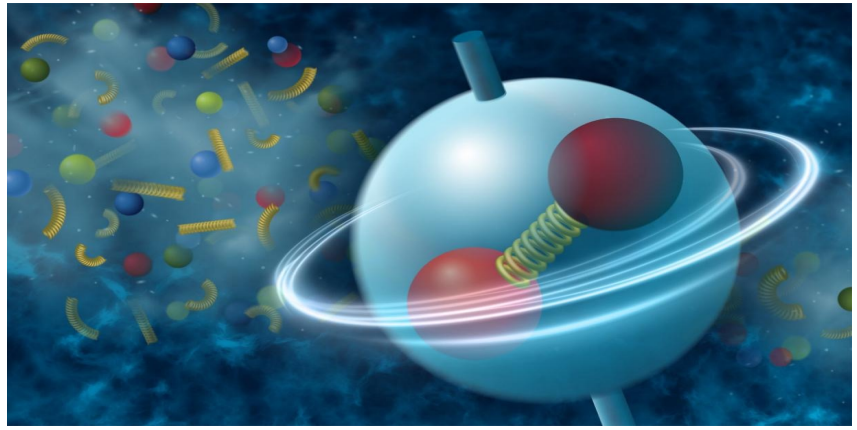
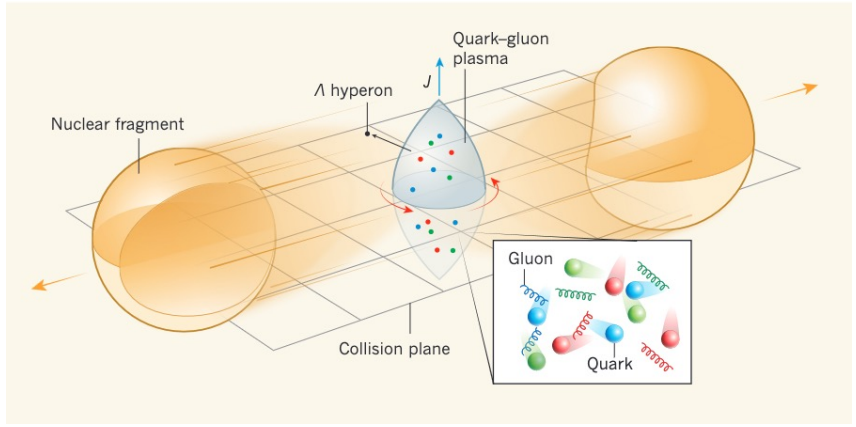
Introduction



Physics Letters B B724(4):213-240
The CMS Collaboration



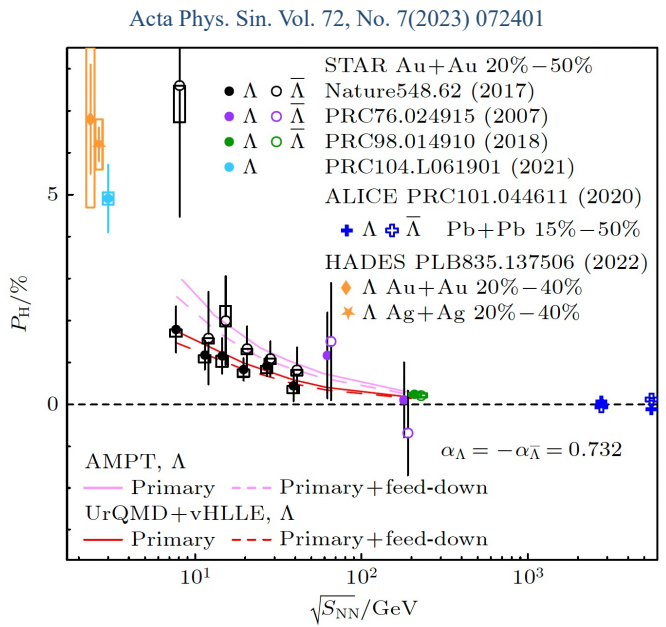
The phi meson in the quark-gluon plasma.
(Image from Brookhaven National Laboratory)

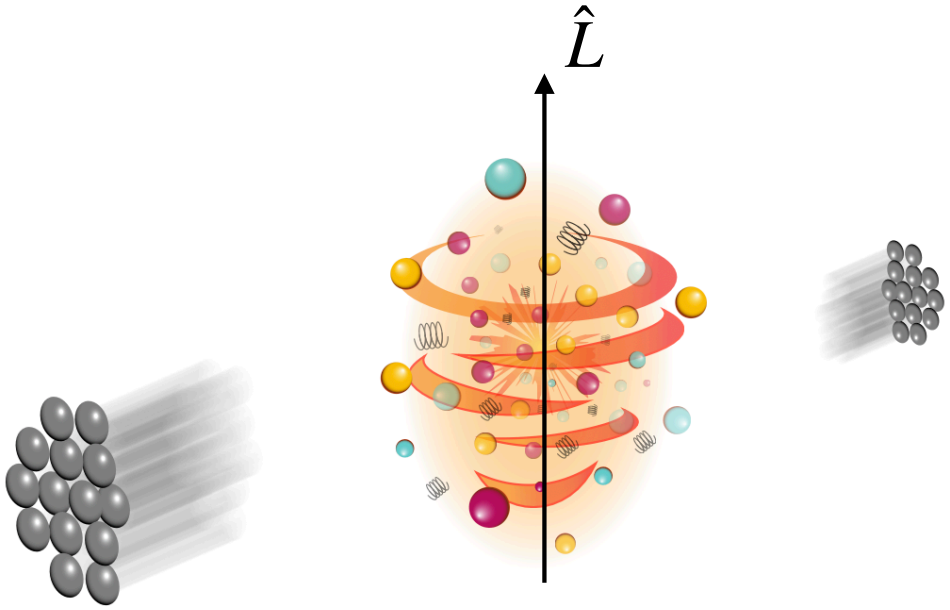


Measuring the rotation of the quark–gluon plasma.

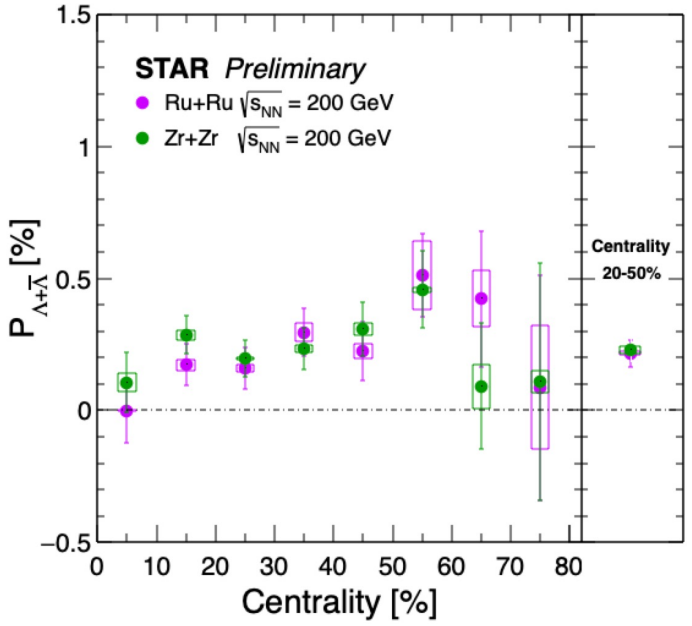
Polarization and Spin Alignment

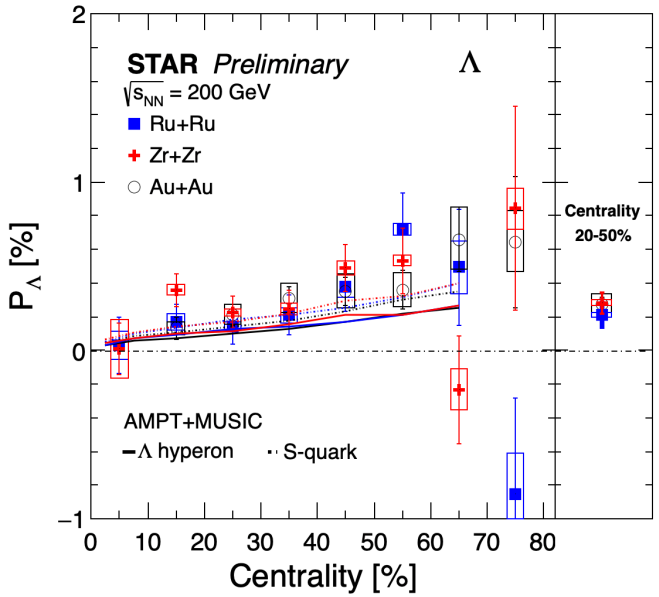
Beam energy and system size dependence of Λ global polarization

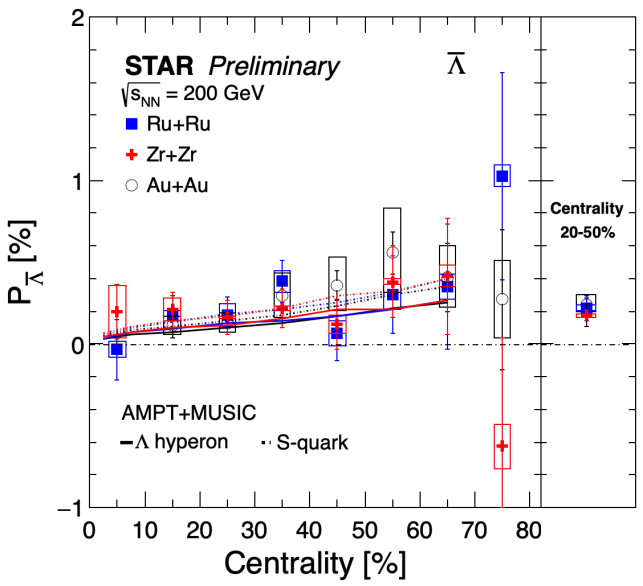




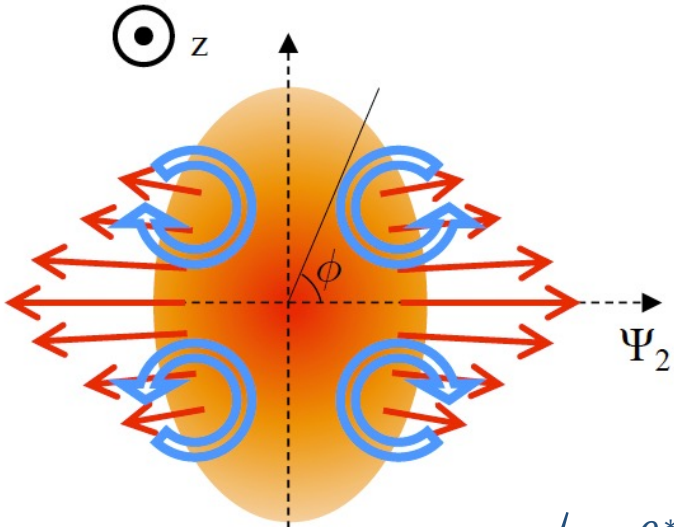
Xingrui Gou
Shandong University
11 June 2024



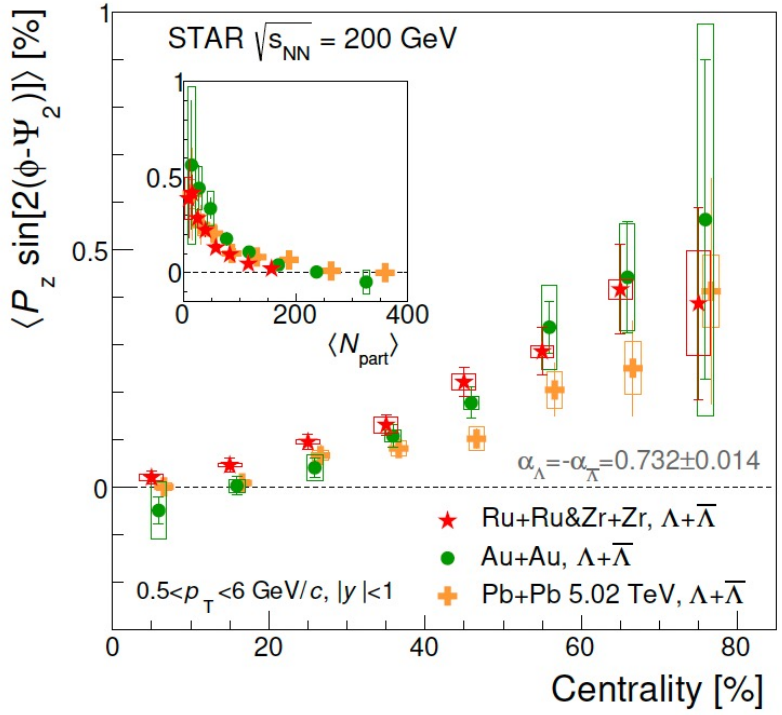


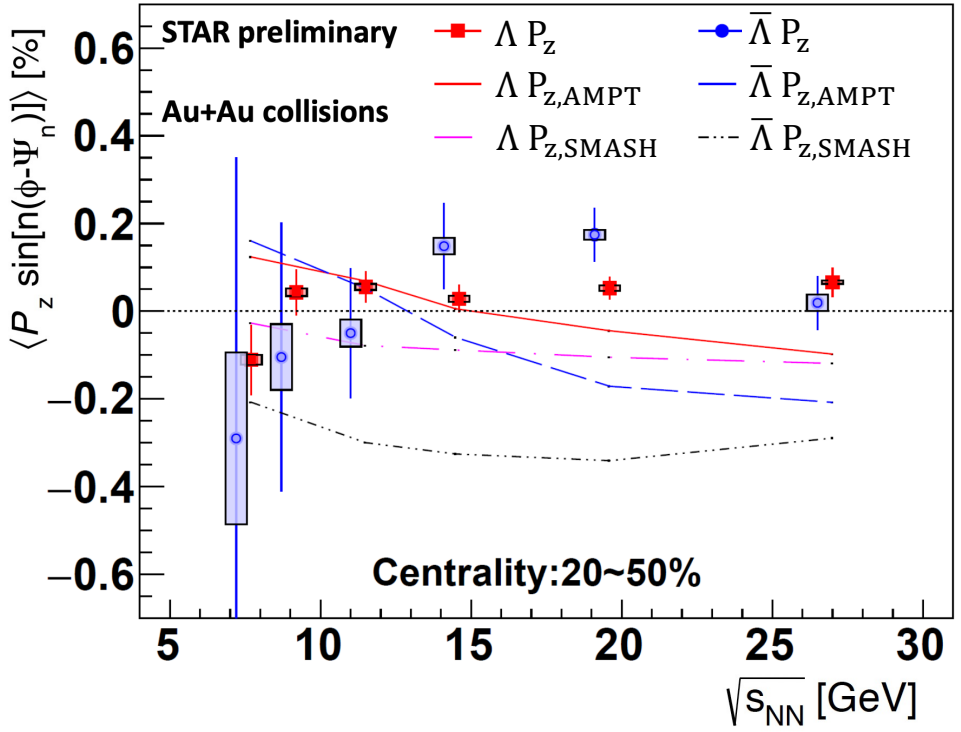


Local vorticity:
Beam energy and system size dependence of P_z



STAR, PRL 131, 202301 (2023)





Xingrui Gou
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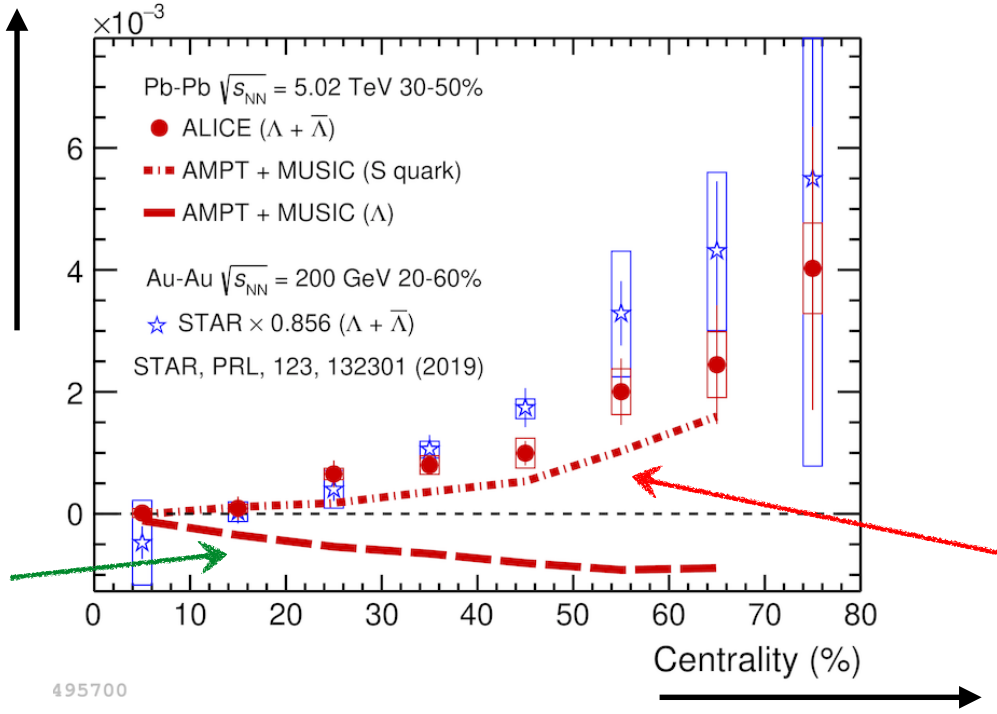
Model: X. Wu et al.,
PRC 105 (2022) 064909

$P_{2,z}$: Coefficient of $\sin(2\phi)$ modulation

LHC results from ALICE collaboration PRL 22



Suppressing shear effect

Including shear effect

Stronger shear stress

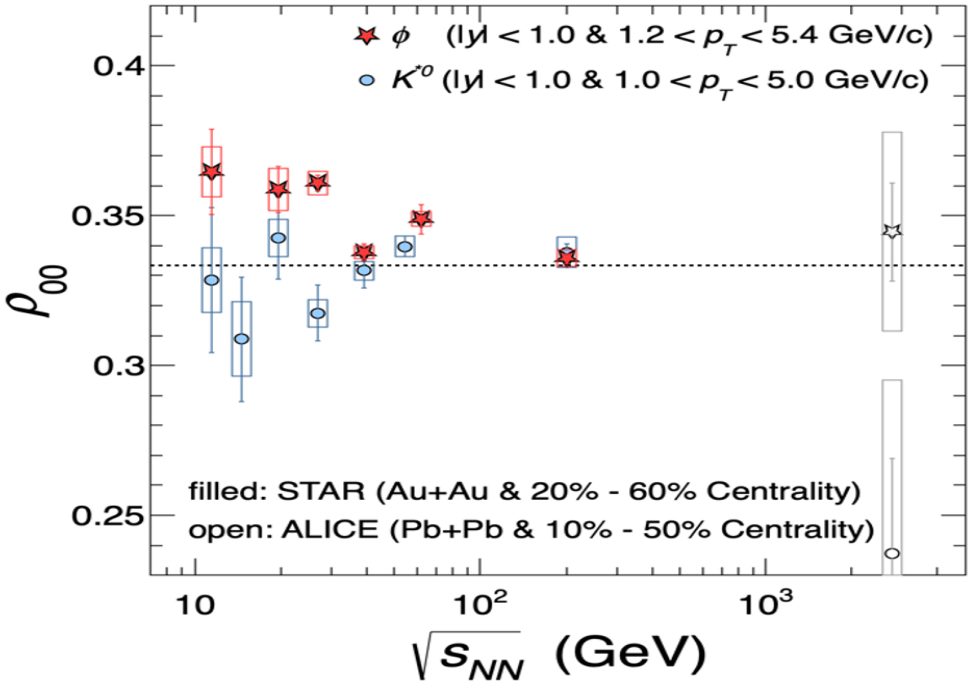
Yi Yin
Institute of Modern Physic, CAS

11 June 2024

- Tantalizing evidence for SIP: data can no be understood without including shear effects. More efforts are needed to claim discovery

Shear effects on other spin observables: STAR PRL 23

STAR, Nature 614, 244 (2023)



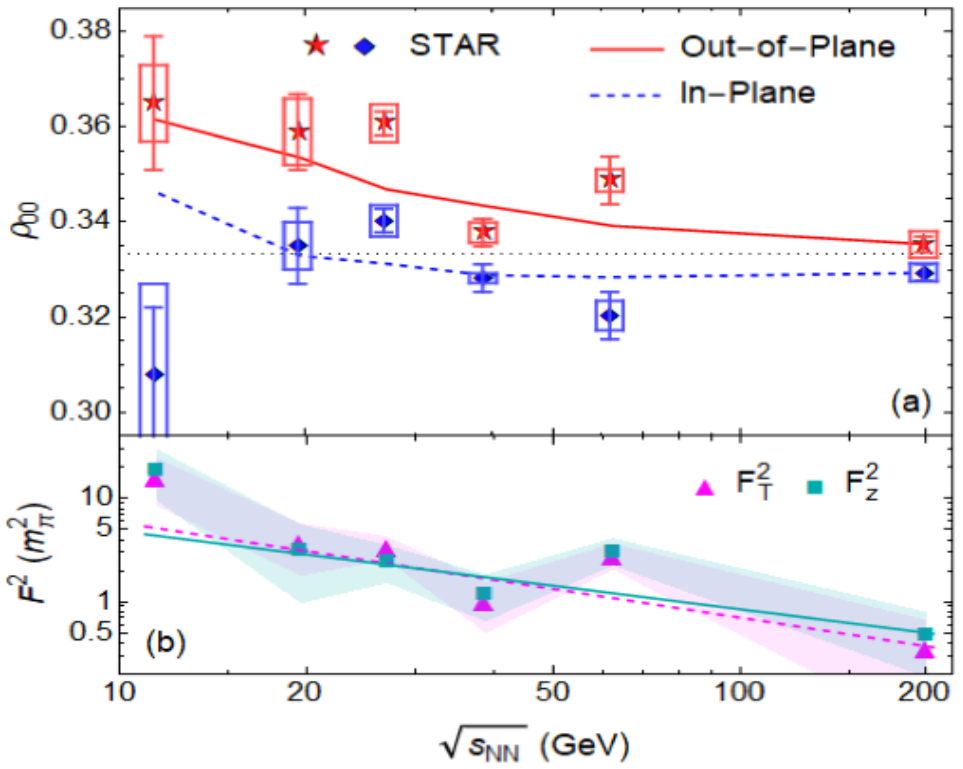
1)ϕ-meson is significantly above 1/3 below 62 GeV (the ρ_{00} was expected to be ρ_{00} - 1/3 ~ -10^{-4} from Λ results).

2)K* is almost consistent with 1/3

3)Averaged over 62 GeV and below:

•0.3541 ± 0.0017 (stat.) ± 0.0018 (sys.) for ϕ (~ 8 sigma from 1/3)
•0.3356 ± 0.0034 (stat.) ± 0.0043 (sys.) for K* (~ 1 sigma from 1/3)

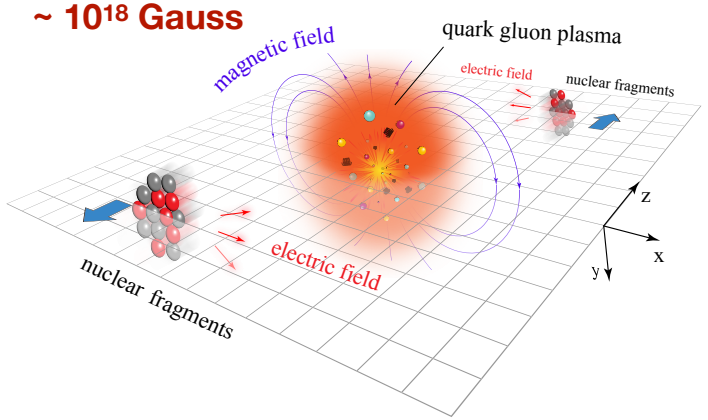
Diyu Shen
Fudan University
11 June 2024

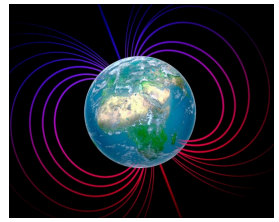


The local correlation or fluctuation of ϕ fields is the dominant mechanism for the observed ϕ-meson ρ_{00}.

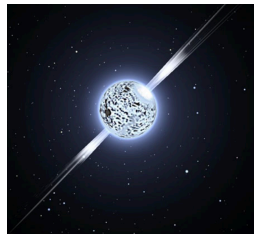
Yi Yin
Institute of Modern Physic, CAS
11 June 2024

The EM-field in HIC: Evolution



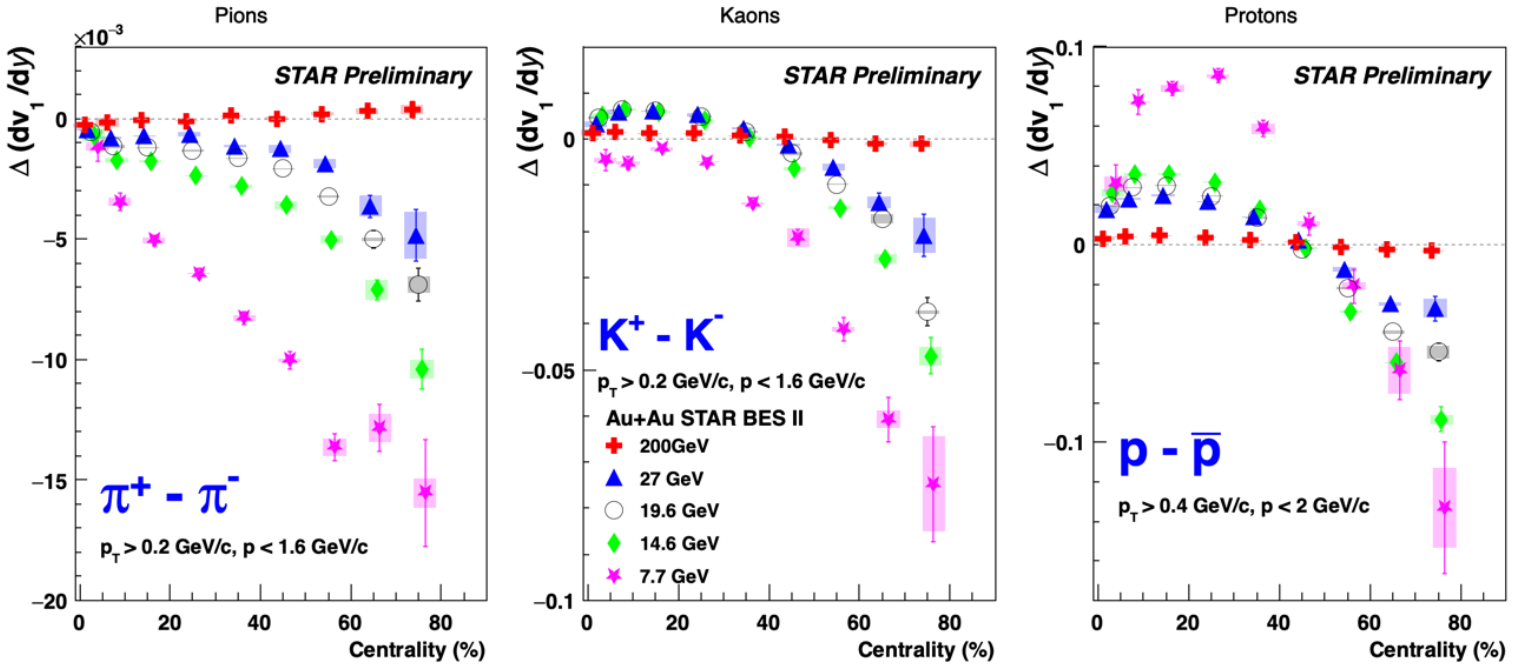


Earth ~ 0.5 Gauss



Neutron Star: ~ 10^{14} Gauss

- An ultra-strong magnetic field along -y, on the order of 10^{18} Gauss, can be generated.



Diyu Shen
Fudan University
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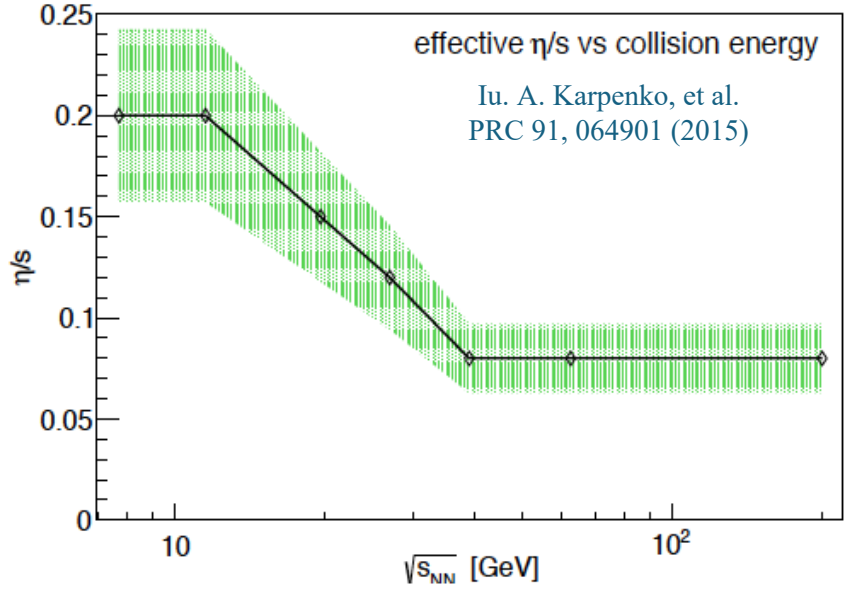
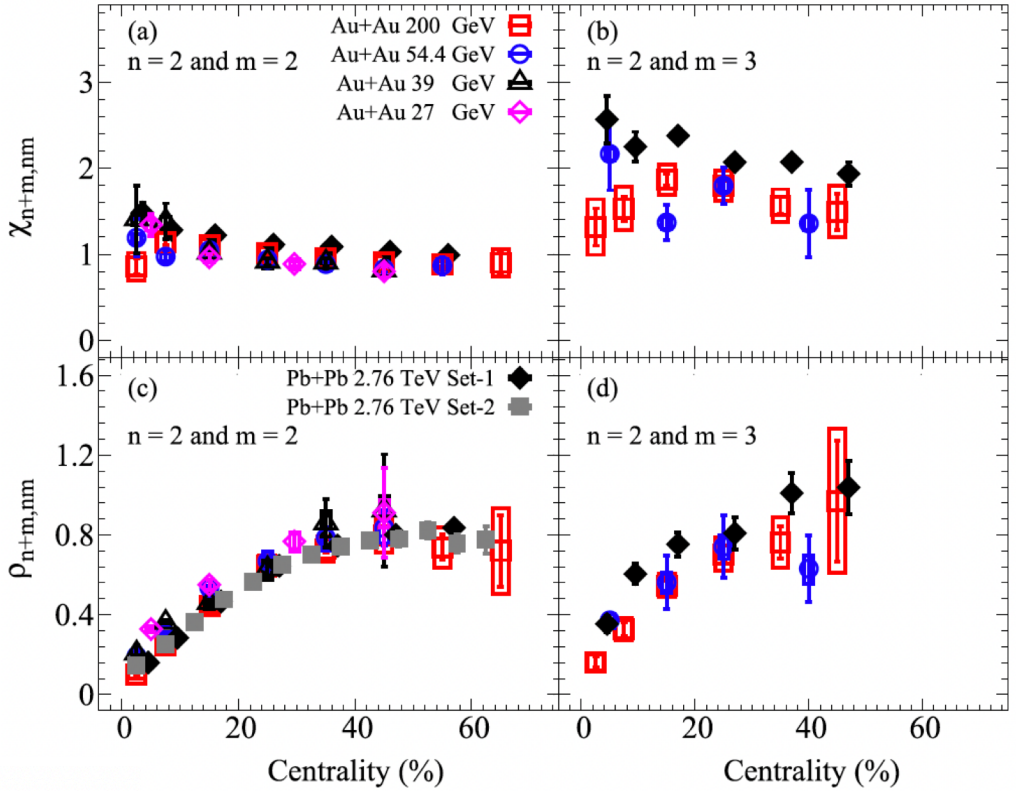
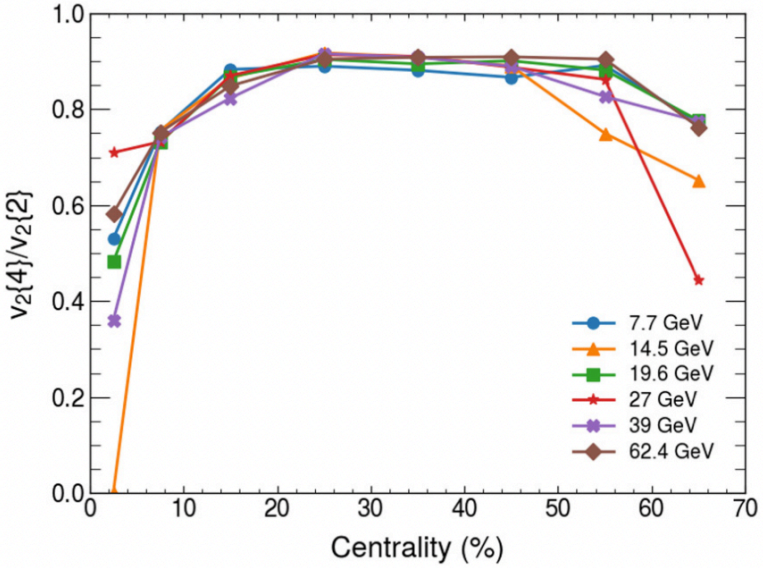
Understanding the QGP properties

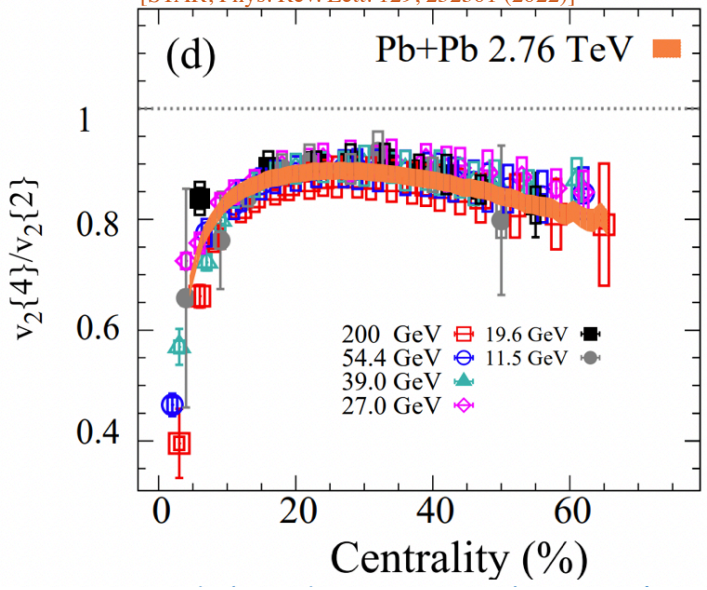
Beam energy scan measurements







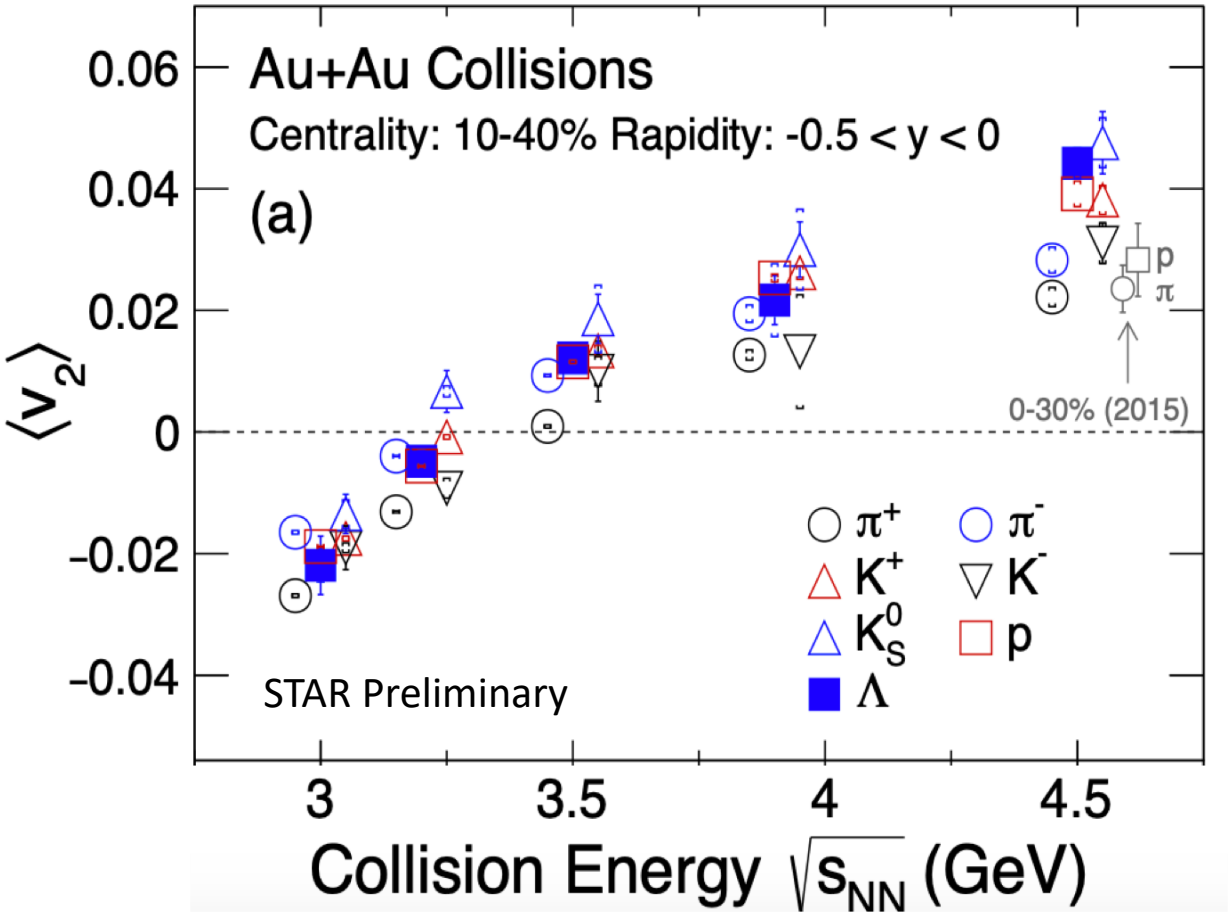
[STAR, Phys. Rev. Lett. 129, 252301 (2022)]

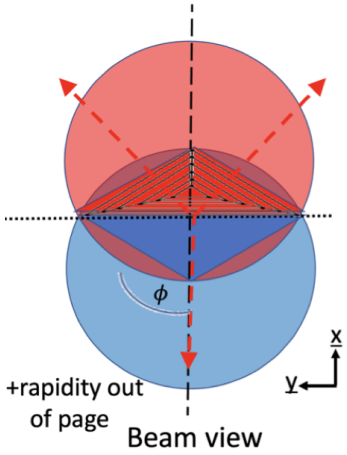


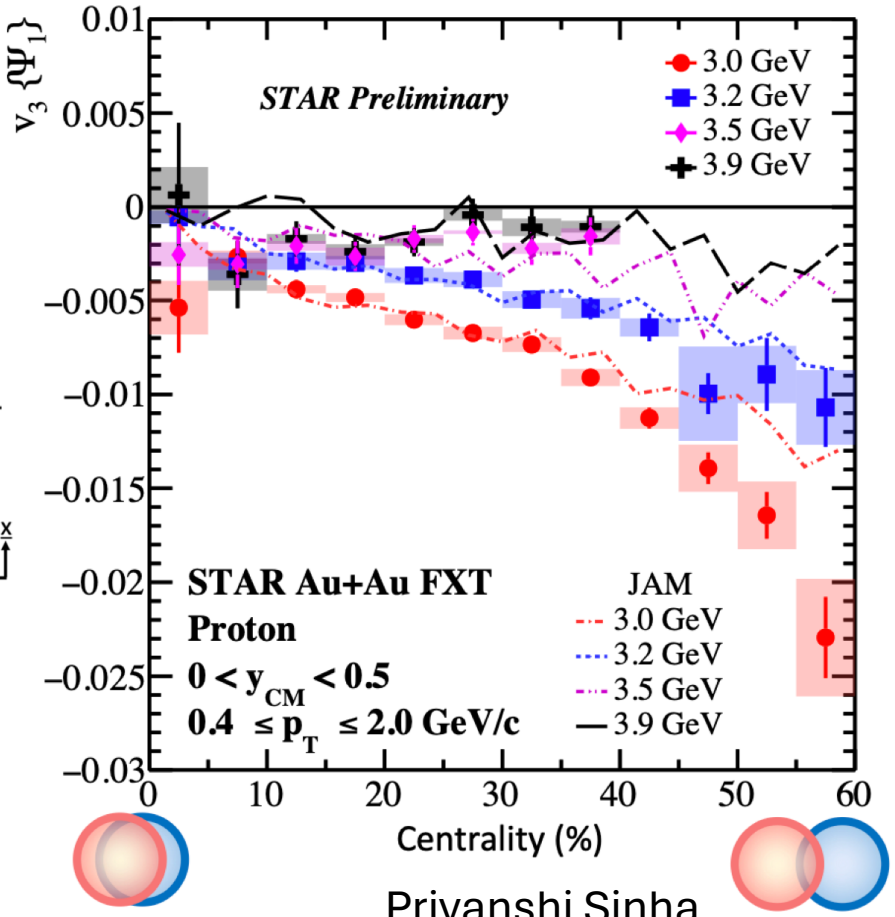
Priyanshi Sinha
IISER Tirupati
11 June 2024

Xiang-Yu Wu
McGill University
11 June, 2024

Beam energy scan measurements

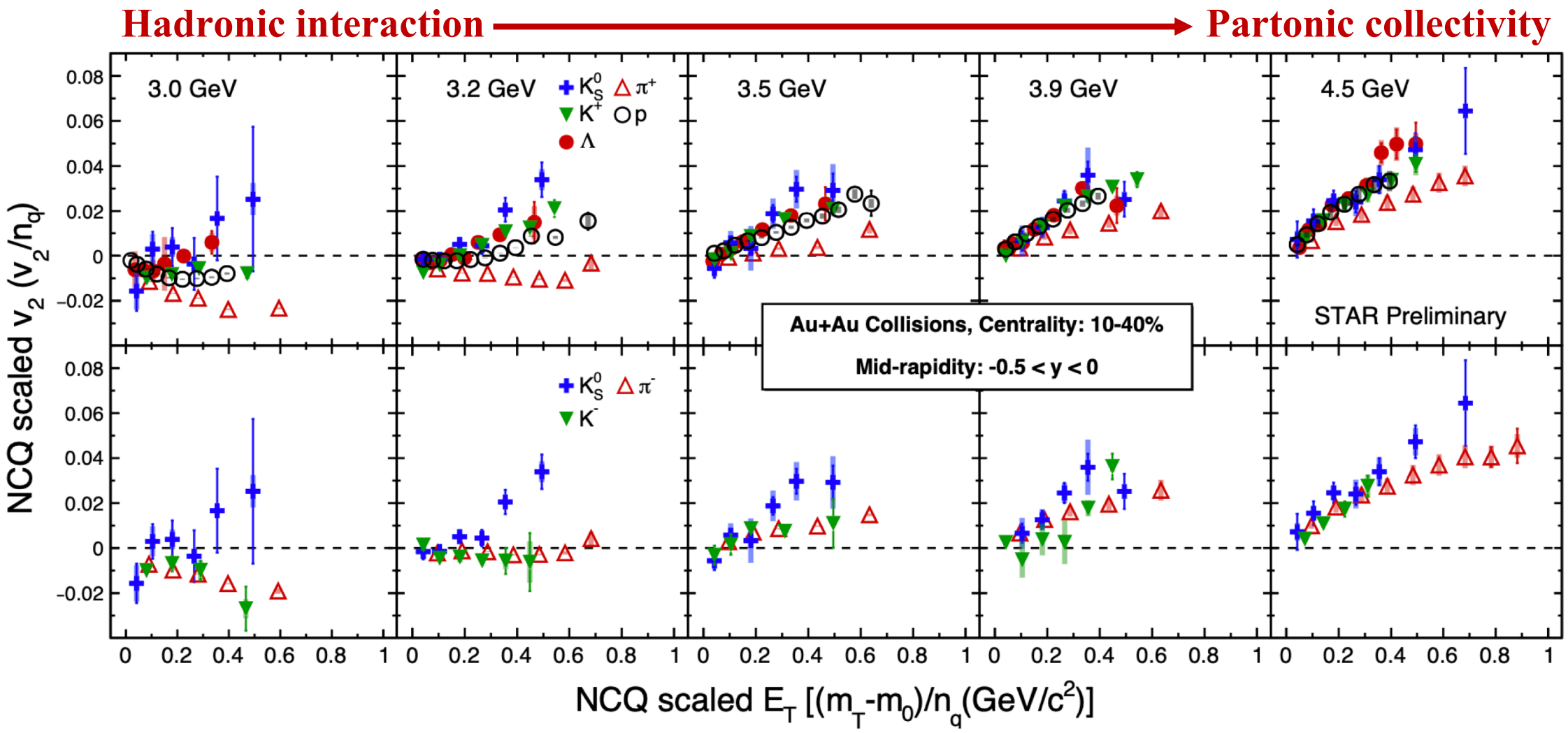




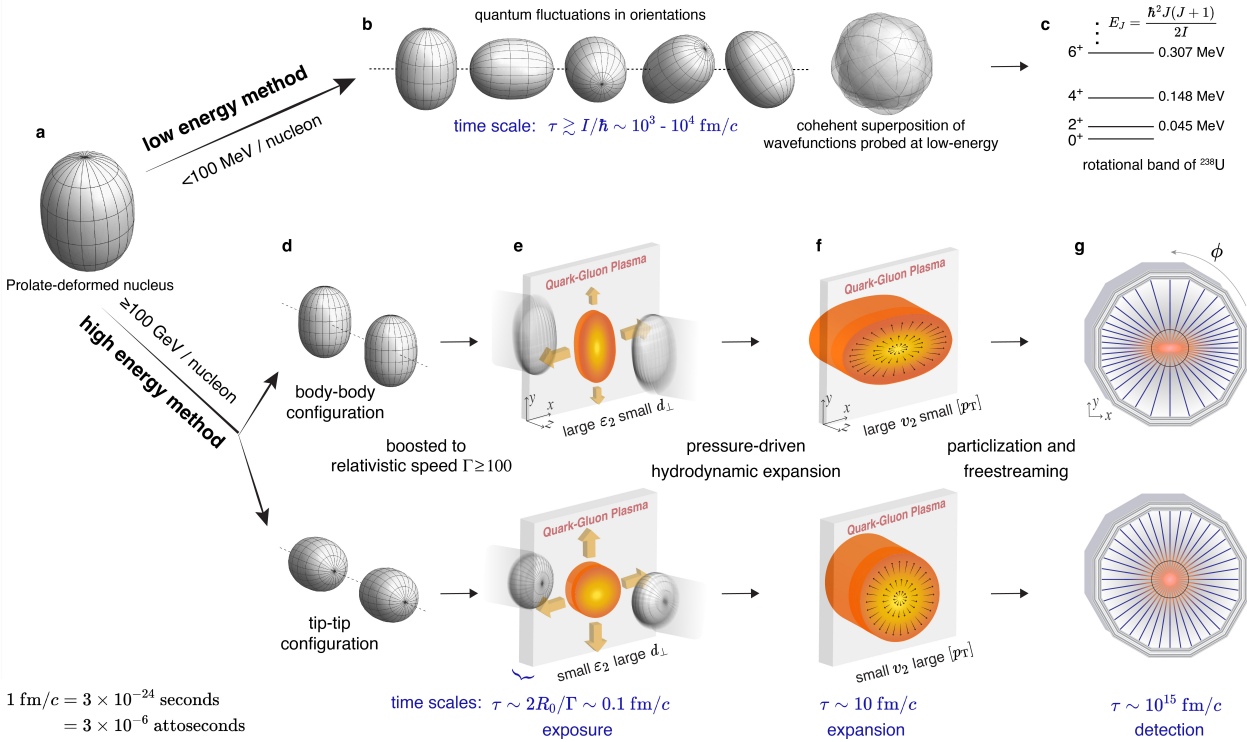


Priyanshi Sinha
IISER Tirupati
11 June, 2024

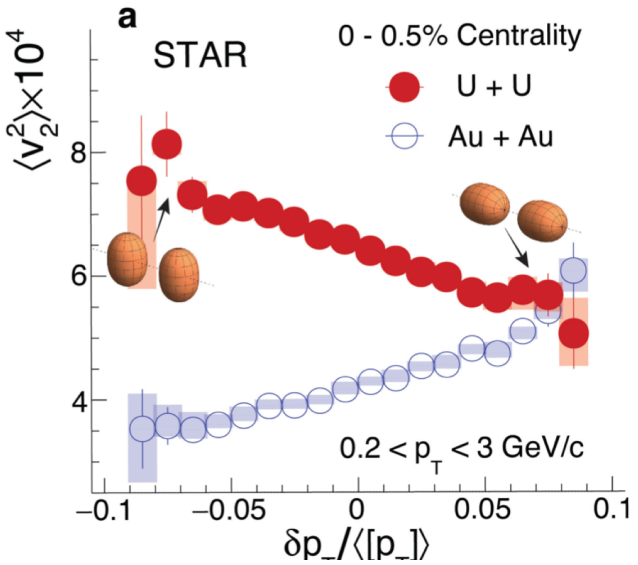
Beam energy scan measurements

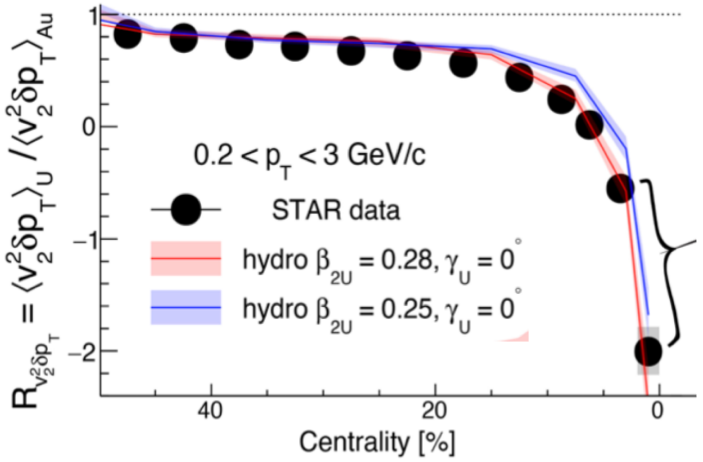


Initial state shape and structure

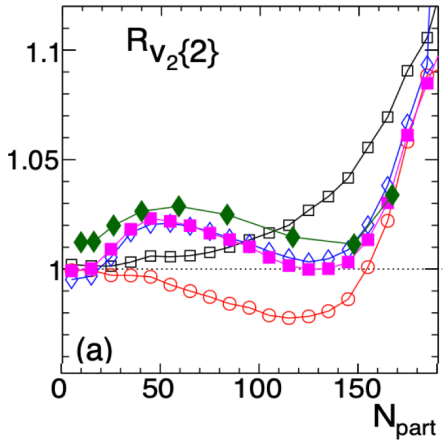


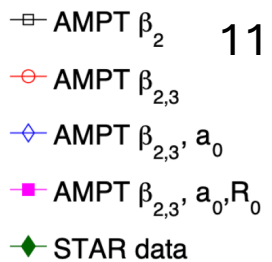
STAR Collaboration, e-Print: 2401.06625





$\beta_2^U = 0.286 \pm 0.025$





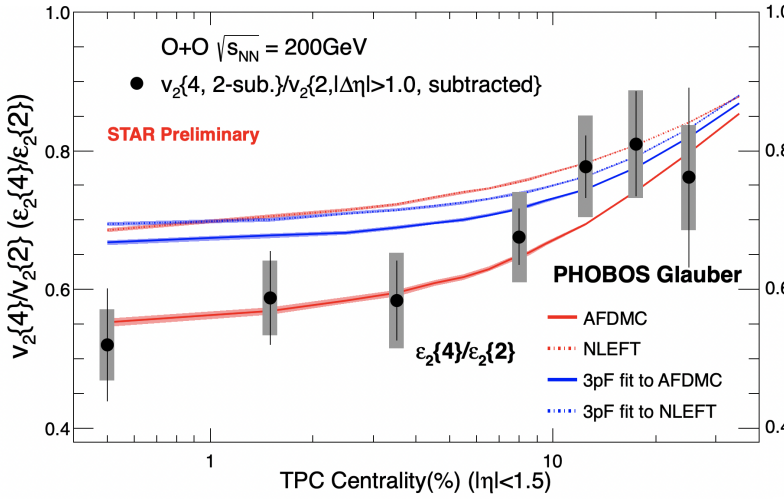
$\beta_2^{Ru} = 0.16 \pm 0.02$ $\beta_3^{Zr} = 0.20 \pm 0.02$

Priyanshi Sinha
IISER Tirupati
11 June, 2024

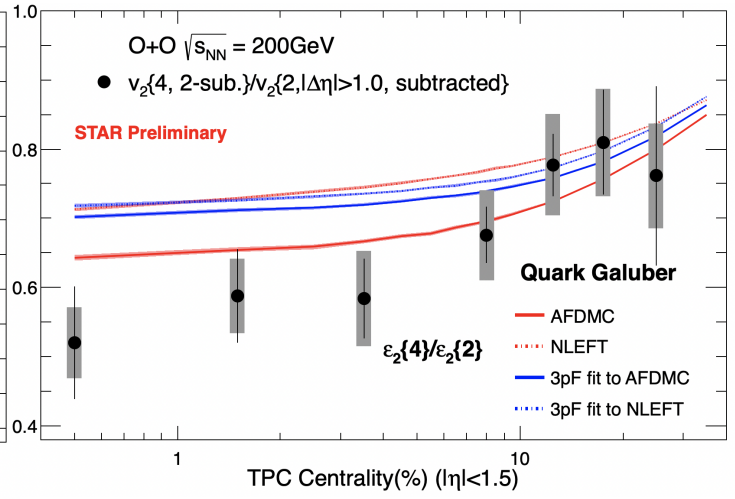
Flow Fluctuation

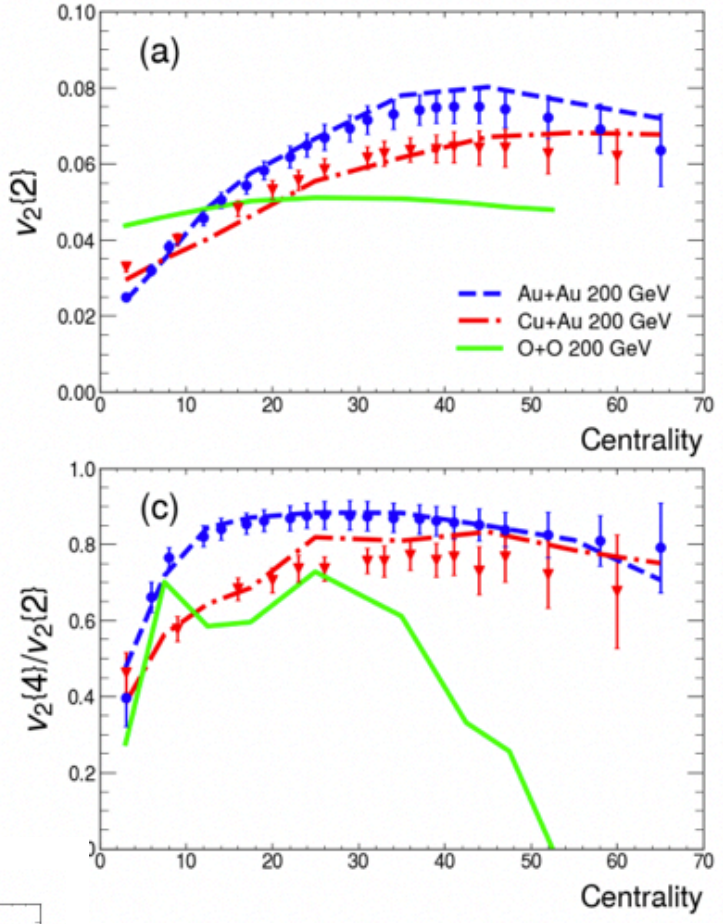
Zhengxi Yan
Stony Brook University
11 June, 2024

Default Glauber

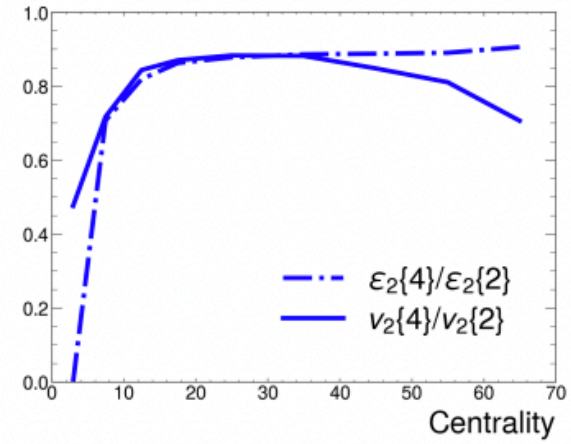


Gaussian field around quarks

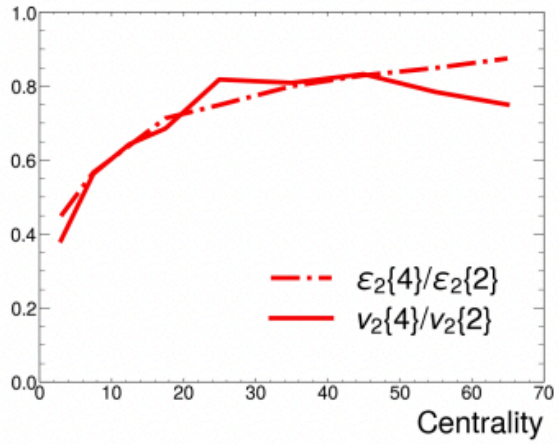




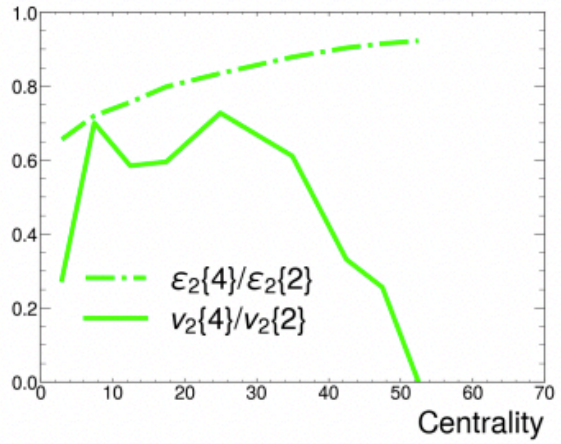
Au+Au@200 GeV



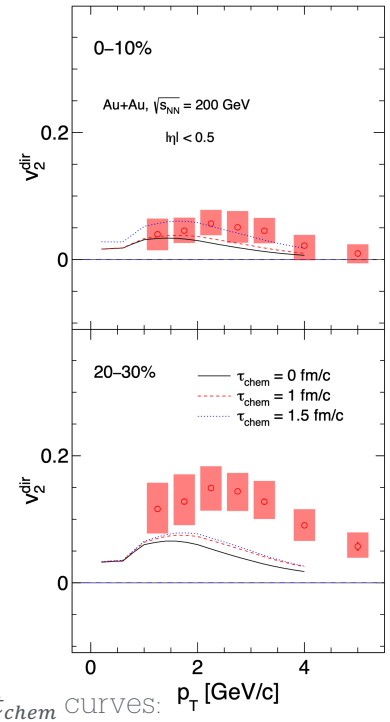
Cu+Au@200 GeV

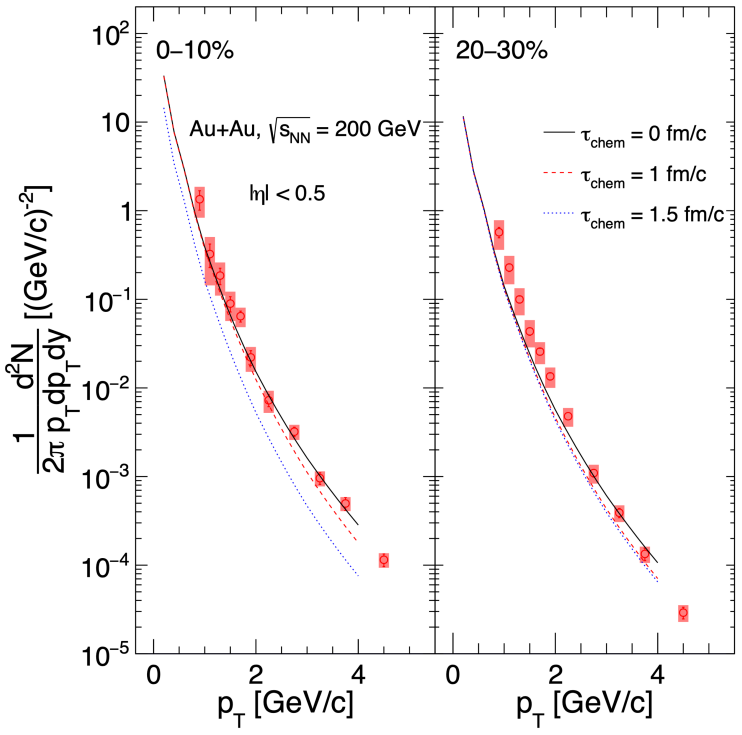


O+O@200 GeV

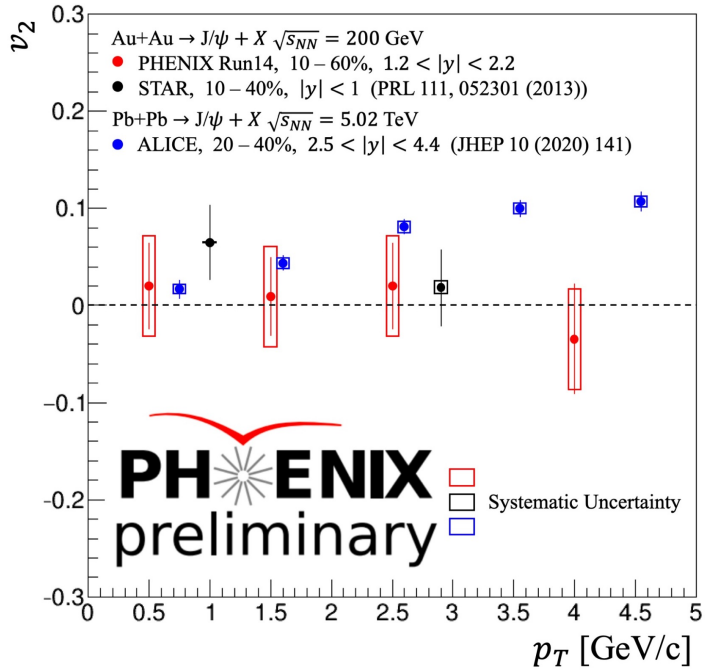


Xiang-Yu Wu
McGill University
11 June, 2024



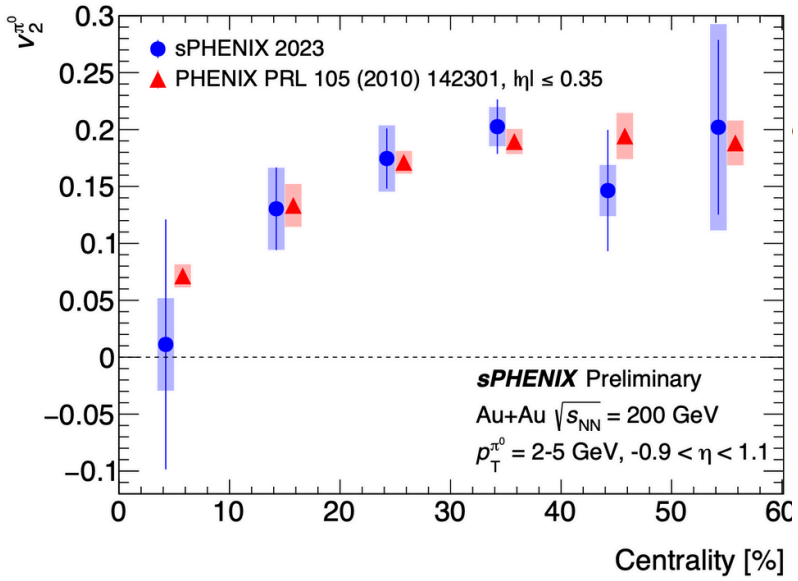


t_{chem} curves:
PRC 106, 014909 (2022)



- PHENIX J/ψ v_2 at forward rapidity is consistent with 0
- Forward and mid-rapidity results at RHIC are consistent, but the uncertainties are large
- The ALICE nonzero result is different from our measurement
- Not enough energy at RHIC for J/ψ regeneration to become noticeable?

Neutral pion elliptic flow



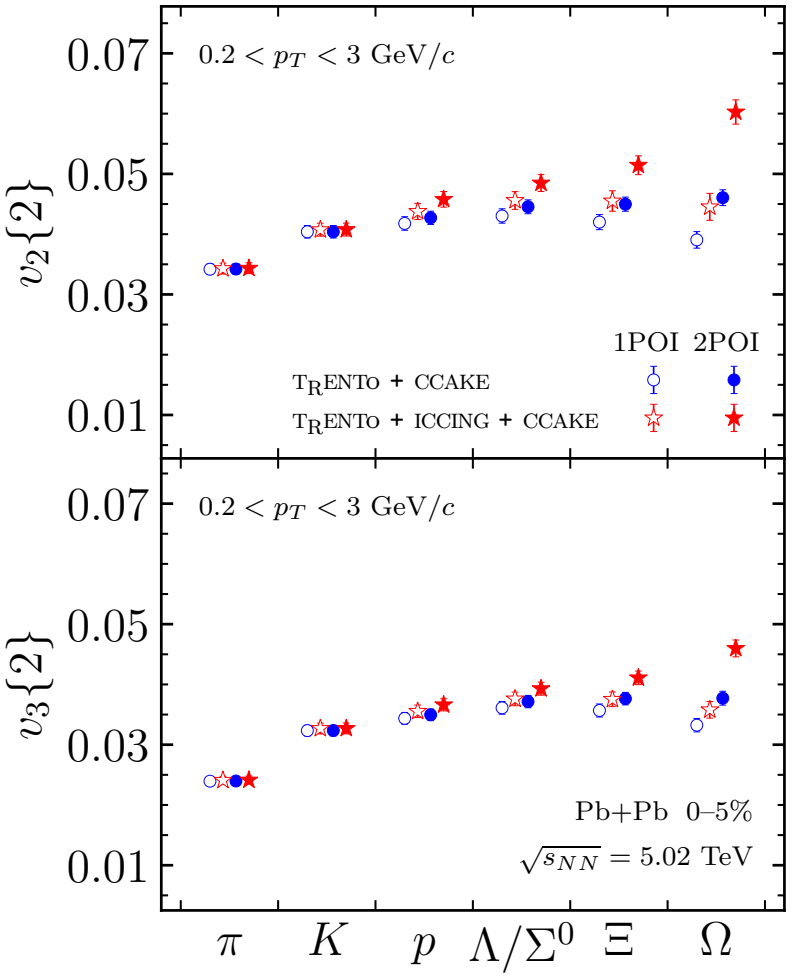
Ejiro Umaka
Brookhaven National Lab
11 June, 2024

Yuri Mitrankov
Stony Brook University
11 June 2024

Signals from BSQ fluctuations in flow

Jordi Salinas San Martín
Illinois at Urbana-Champaign
11 June, 2024

C. Plumberg, JSSM et al. (2024) 2405.09648



Q. What other influence do BSQ fluctuations have on flow?

- 1POI and 2POI method is used for identified particle flow coefficients

$$v_n^{\mathrm{1POI}}\{2\} = \frac{\langle v_n v_n' \cos n(\Psi_n - \Psi_n')\rangle}{v_n\{2\}}$$

A. Holtermann et al. (2023, 2024) 2307.16796, 2402.03512

- If the event plane angles are not aligned, 1POI gets suppressed

$$v_n^{\mathrm{2POI}}\{2\} = \sqrt{\langle (v_n'')^2 \rangle}$$

- 2POI is not suppressed, even if event plane angles are fully misaligned

- BSQ charge fluctuations lead to an enhancement of 2POI flow for (multi-)strange baryons
- LHC updates will bring the statistics necessary to contrast with experiment

Collectivity in small collision systems

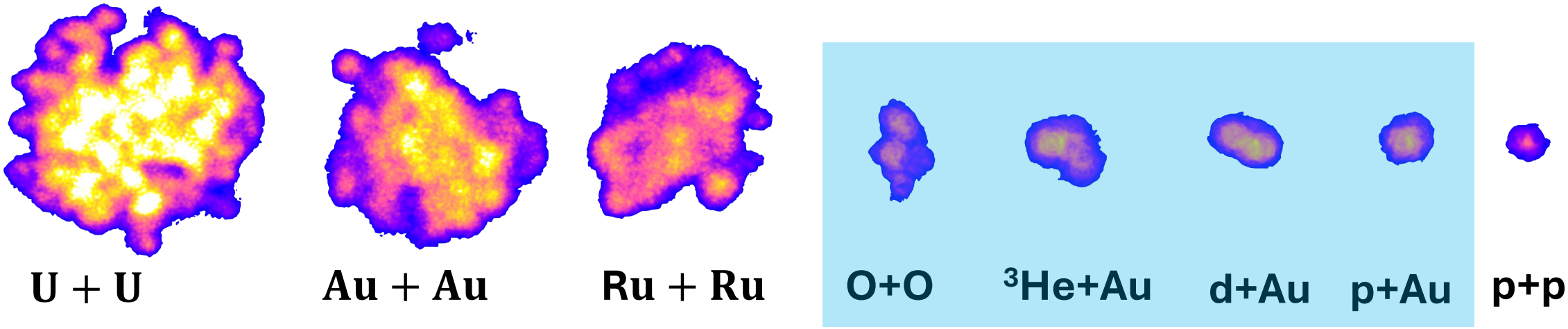
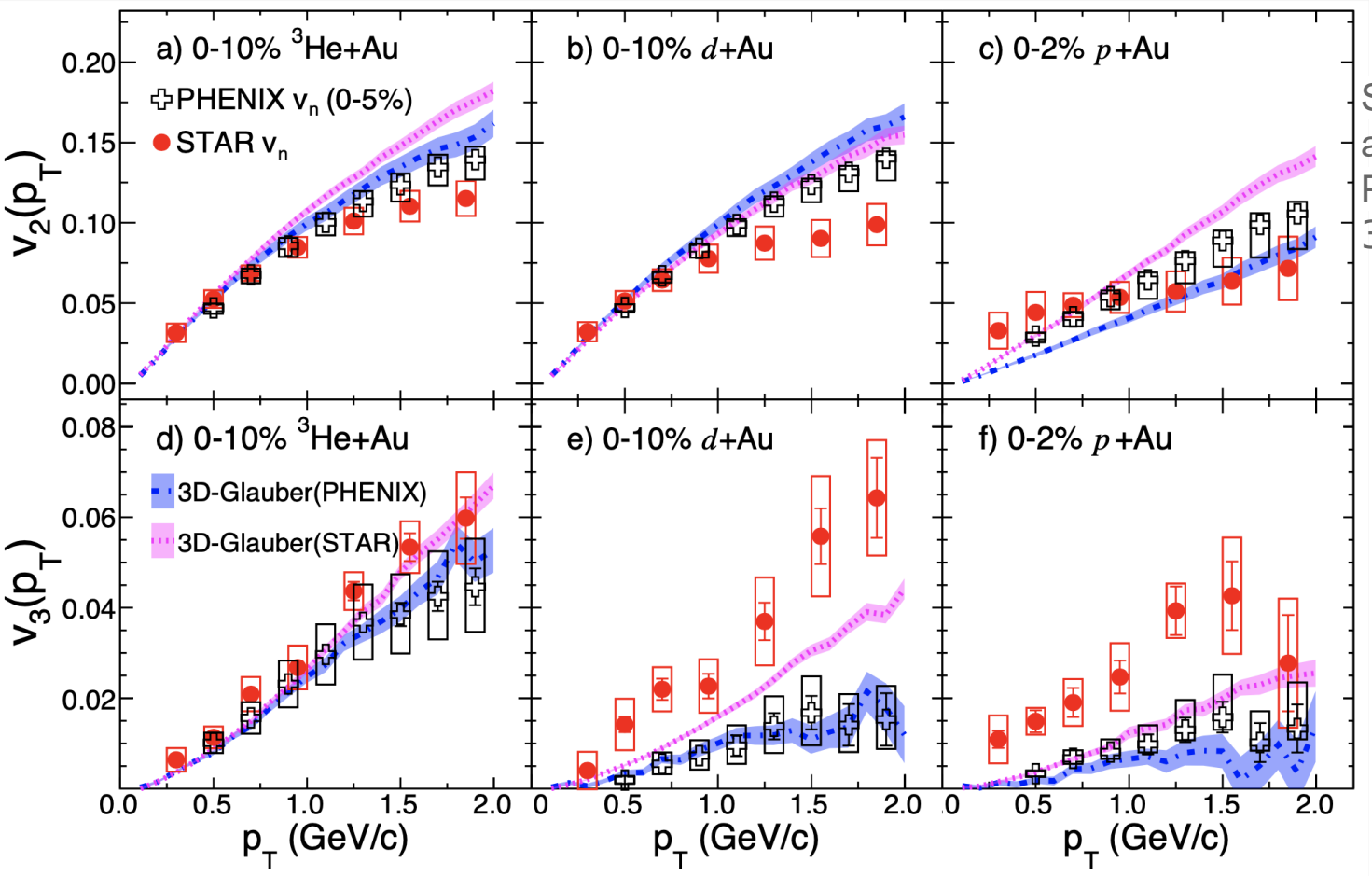


fig: Chun Shen QM19

Collectivity in small collision systems



STAR: PRL 130, 242301
arXiv:2312.07464
PHENIX: Nature Phys. 15, 214
3D-Glauber: PRC 107, 014904

Large difference in v_3 for STAR and PHENIX in data and models.

STAR use mid-rapidity: $|\eta| < 0.9$

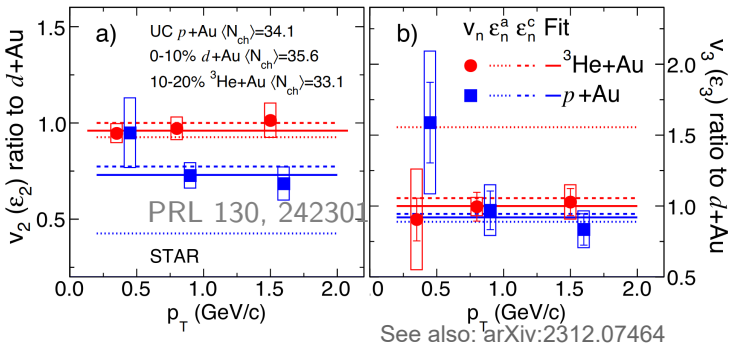
PHENIX use mid-forward rapidity: $|\eta| < 0.35$ to $-3.0(3.9) < \eta < -1(-3.1)$

$\rightarrow$ Due to decorrrelation?

Collectivity in small collision systems

Zhengxi Yan
Stony Brook University
11 June, 2024

Previous STAR result

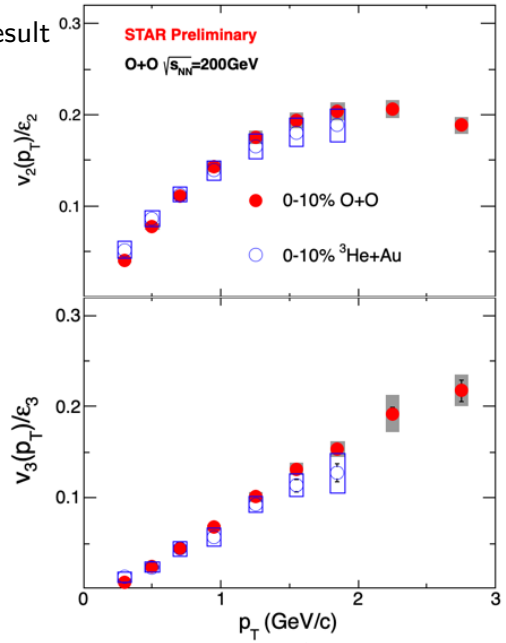


See also: arXiv:2312.07464

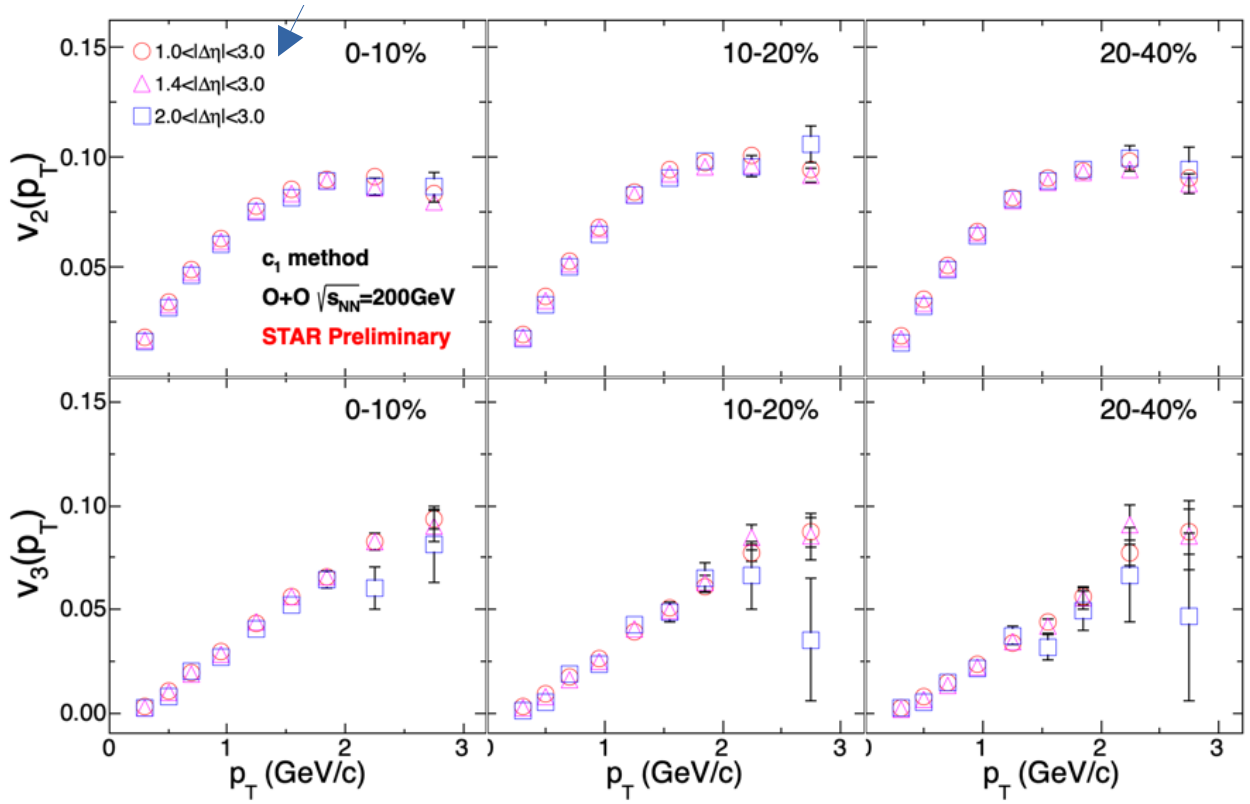
Model c → Gaussian field around quarks

Compare v_n ratio in data and ε_n ratio in model

O+O result

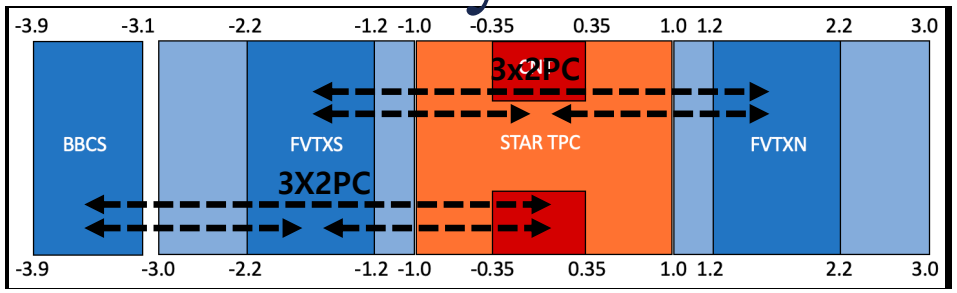


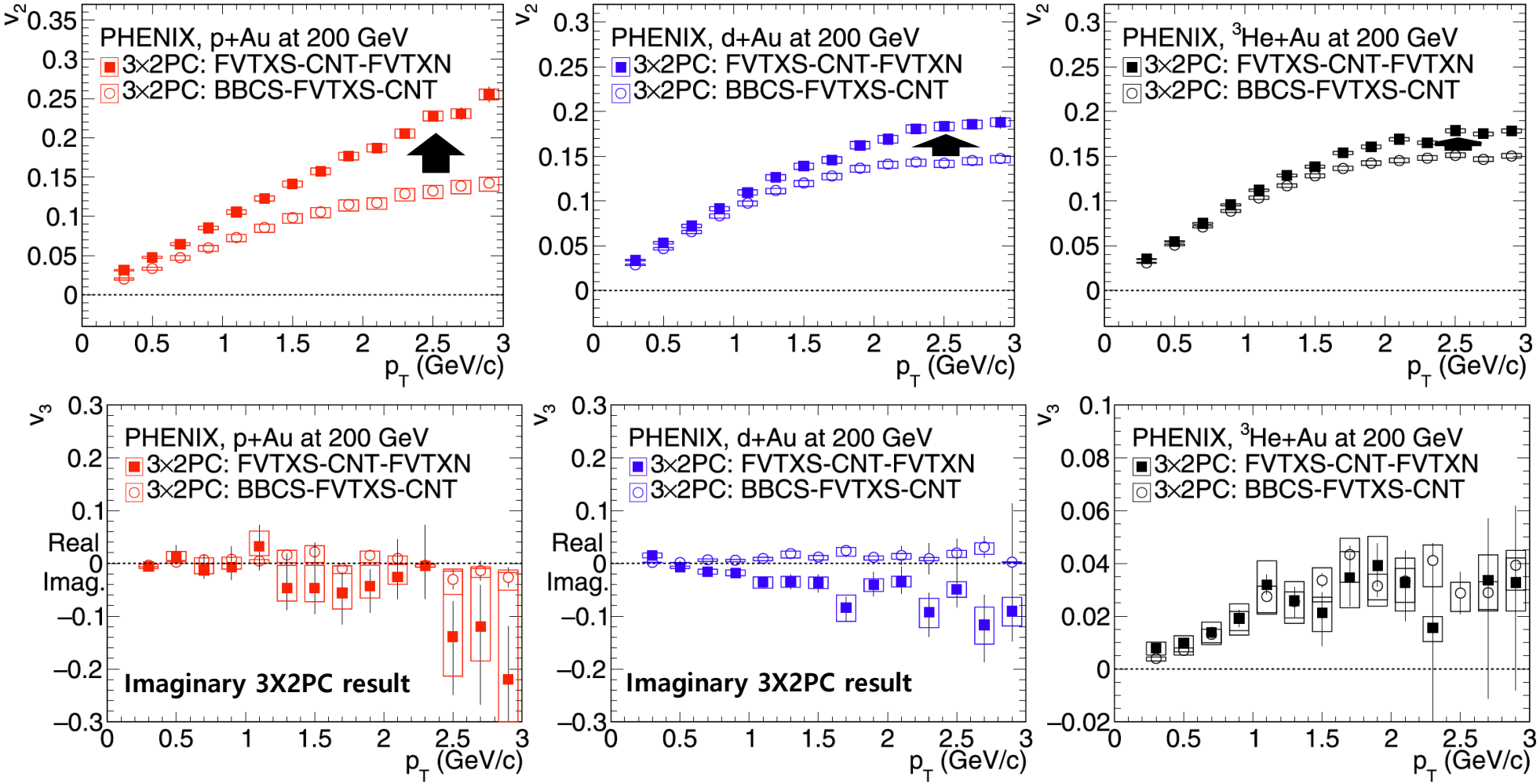
- ε_n with quark Glauber
- Same v_n/ε_n scaling to ^{3}He+Au.



Collectivity in small collision systems

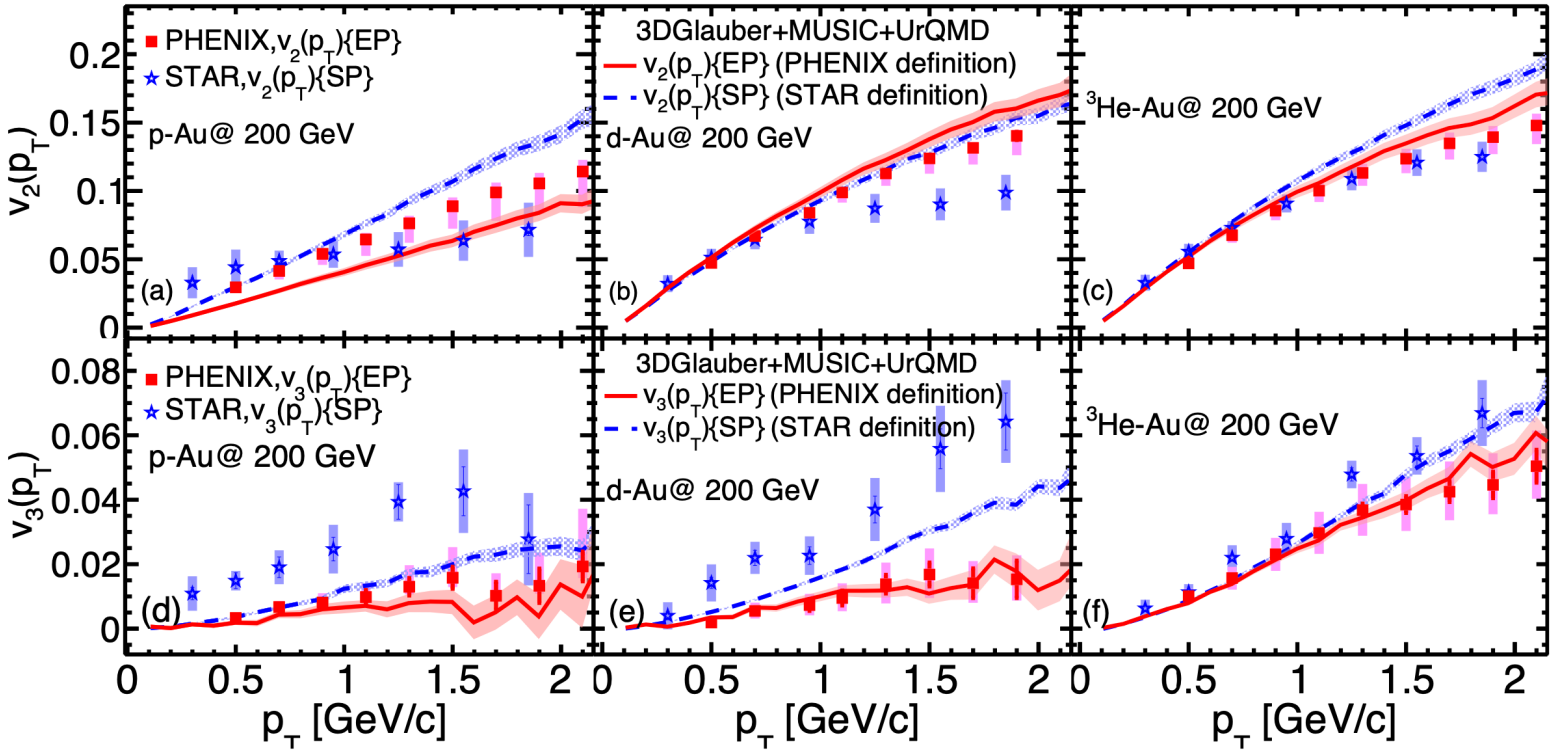
Sanghoon Lim
Pusan National University
11 June, 2024





Collectivity in small collision systems

Wenbin Zhao
Lawrence Berkeley National Laboratory University of California, Berkeley
11 June, 2024



PHENIX η range:
$[-3.9, -3.1]\ v.s.\ [-0.35, 0.35]$
$[-3.0, -1.0]\ v.s.\ [-0.35, 0.35]$;

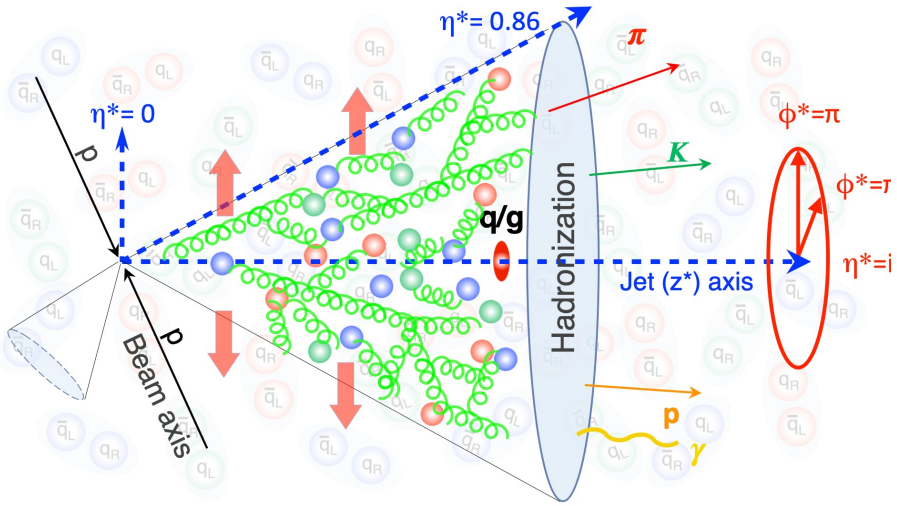
STAR η range:
$[-0.9, 0.9]$ and $|\Delta\eta| > 1.0$

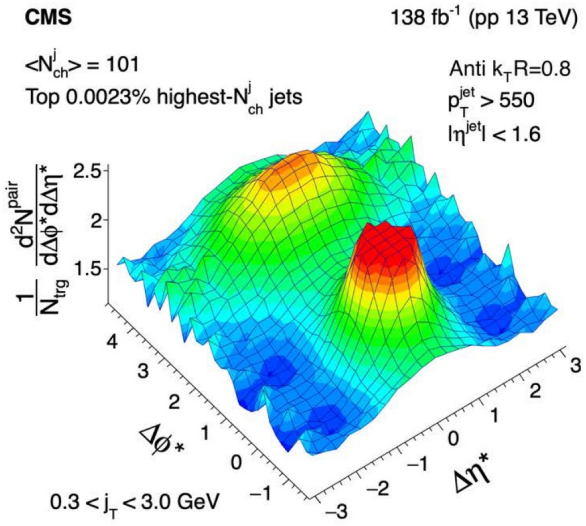
W. Zhao, S. Ryu, C. Shen and B. Schenke Phys. Rev. C 107, 014904 (2023).

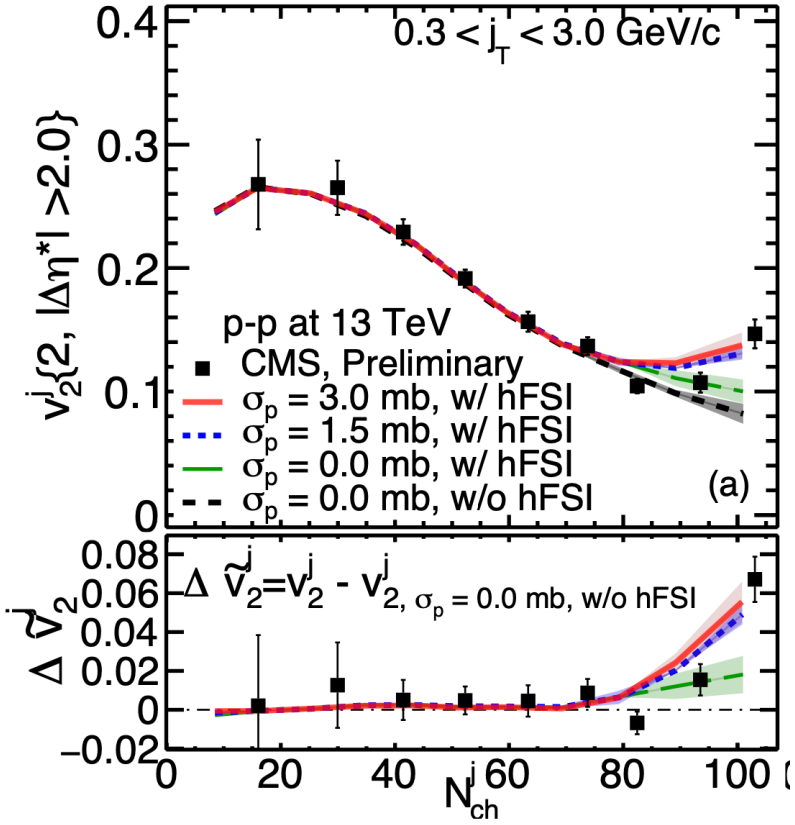
- Using the PHENIX definition, our 3D hybrid model reproduces the $\boldsymbol{v_2(p_T)}$ and $\boldsymbol{v_3(p_T)}$ for all three systems.
- The 3D hybrid model gives larger $\boldsymbol{v_3(p_T)}$ with the STAR definition in (p, d)+Au collisions than those from PHENIX.
- The longitudinal decorrelation explains 50% difference between PHENIX and STAR $\boldsymbol{v_3}$ measurements.

Collectivity in small collision systems

"Collectivity" inside the high multiplicity jet in p-p





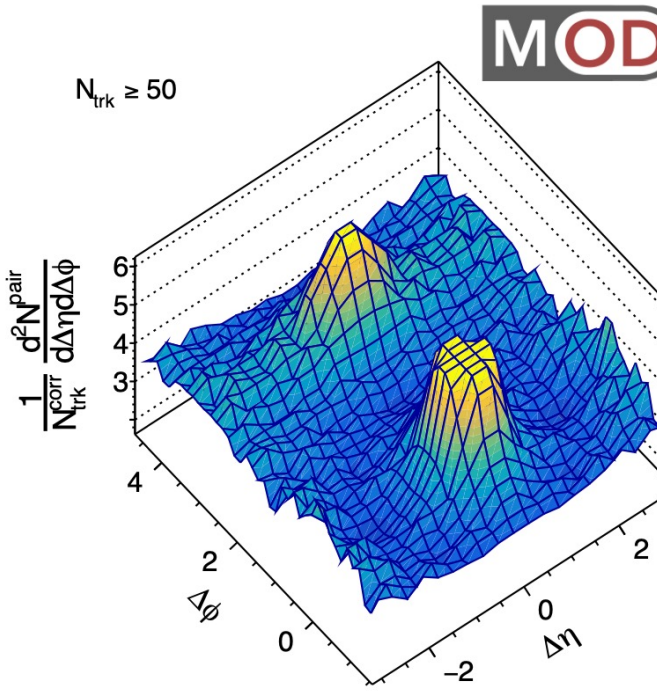


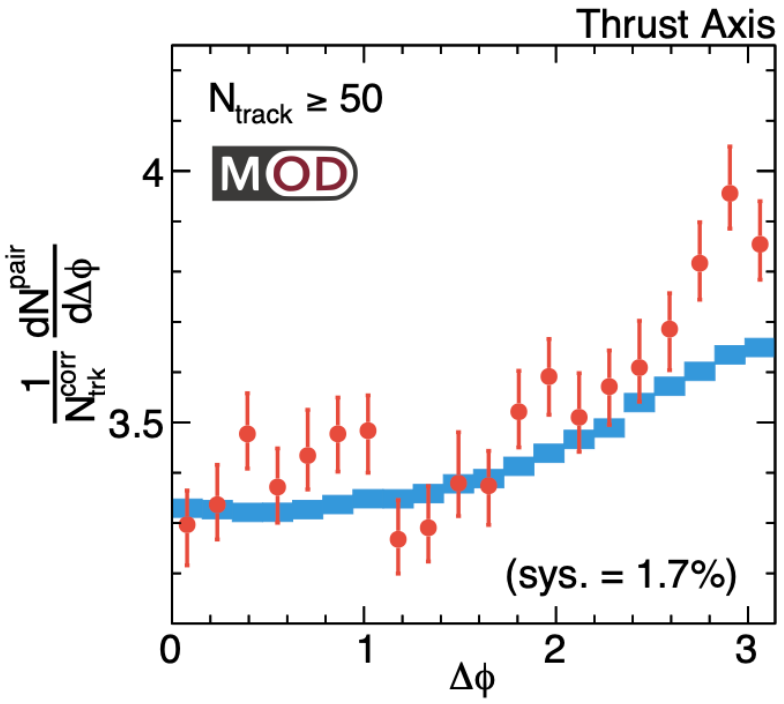
CMS, [arXiv:2312.17103 [hep-ex]].
W. Zhao, Zi-Wei Lin and Xin-Nian Wang [arXiv:2401.13137].

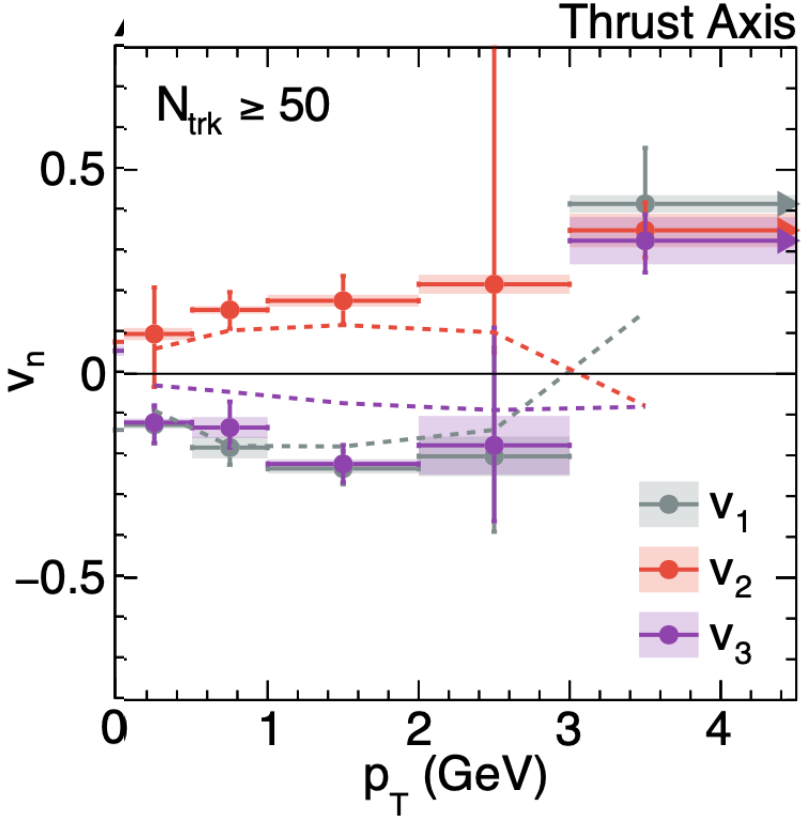
- "Collectivity" features inside high multiplicity jets in p-p.
- Final state interaction enhances the v_2 inside high multiplicity jet in p-p. QGP droplet?

Collectivity in small collision systems

"Collectivity" in high multiplicity e^+e^-







ALEPH, [arXiv:2312.05084 [hep-ex]].

- Pythia8 without long range correlations underestimates the v_2 at high multiplicity e^+e^-.
- Smallest QGP droplet?

Thank You