极端核物质前沿研讨会

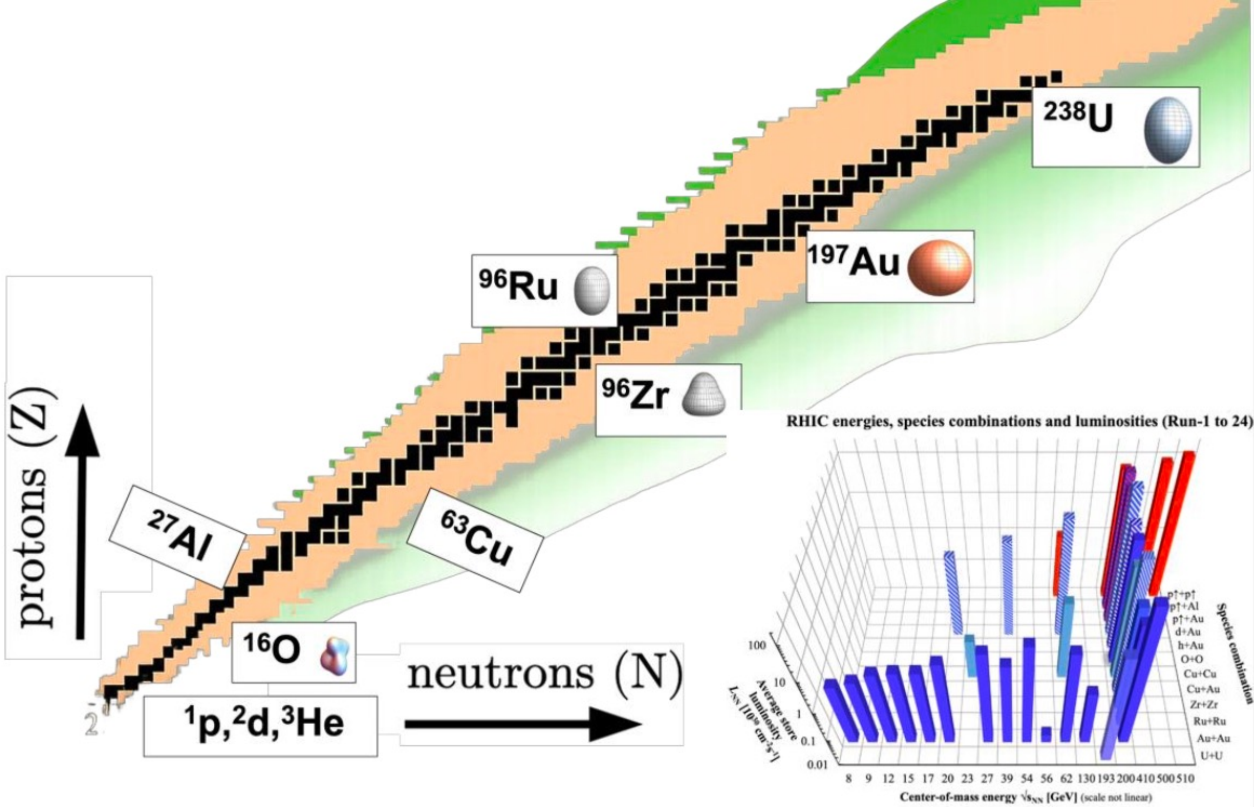
重离子碰撞中径向流与平均横动量高阶涨落的实验研究

张春健

复旦大学

宜昌，2026年4月24-28日

Outline



❑ Imaging nuclear structure in heavy ion physics

- Nuclear deformation in ^{238}U, ^{96}Ru/^{96}Zr

  STAR, *Rep. Prog. Phys. 88,108601 (2025)*

- Cluster pattern in ^{16}O

  STAR, *arXiv: 2510.19645*

❑ New measurements of radial flow and its fluctuations: system-size and energy dependence

- Second-order fluctuation (Radial flow) in ^{197}Au and ^{16}O

  STAR, *arXiv: 2604.06434*

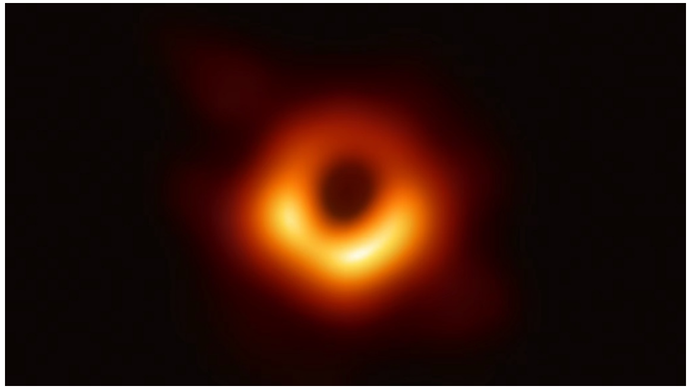
- High-order fluctuations

Nuclear deformation in ^{238}U, $^{96}Ru/^{96}Zr$

STAR, *Rep. Prog. Phys. 88,108601 (2025)*

Analogy to the snapshot imaging technique

First-ever image of a black hole



MRI CT image

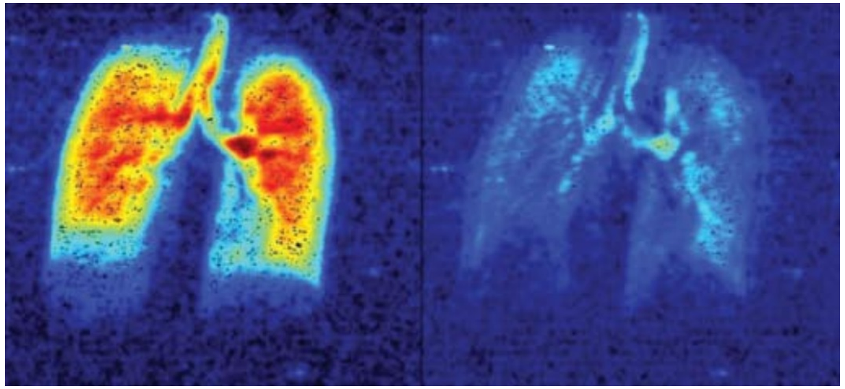
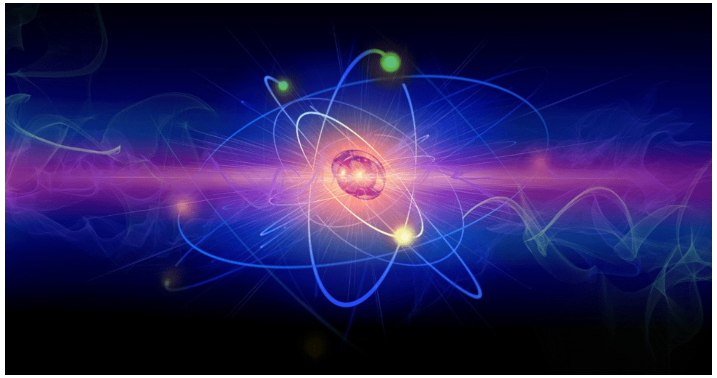


Image of electrons at attosecond

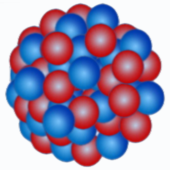


Astronomical scale → **Microscopic scale**

J. Jia et al., *Nucl. Sci. Tech. 35, 220 (2024), G. Giacalone, EPJA 59, 297 (2023), T. Duguet et al., PRL 135, 182301 (2025)* W. Ke, *2509.09549, …*

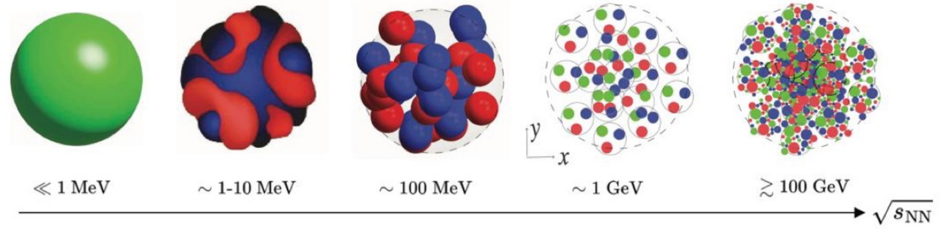
Emergent seeing shape directly require access to instantaneous nucleon distributions

$\Psi\left(\mathbf{r}_1, \mathbf{r}_2 \ldots\right)$



Will see all DOFs longer than exposure timescale:

nucleons, hadrons, quark, gluons, gluon saturations



Yoctosecond scale

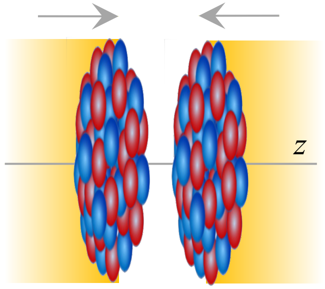
$$1\text{fm}/c = 3 \times 10^{-24}\text{ seconds} = 3 \times 10^{-6}\text{ attoseconds} = 3\text{ yoctoseconds}$$

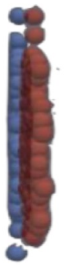
A new, complementary, and independent of low-energy experiments

Imaging by smashing method

Take a snapshot | Evolution | Measurement

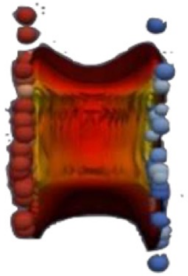
Nuclei collisions $T_{\mu\nu}(\tau=0)$ | $\partial_\mu T^{\mu\nu}=0$, EOS, viscosity… | $T_{\mu\nu}(\tau=\infty)$





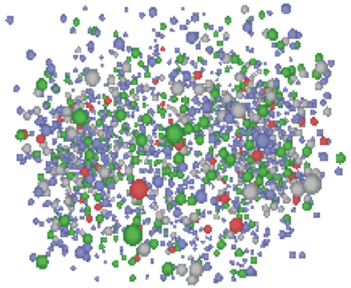
$\tau \sim 2R_0/\Gamma \sim 0.1\text{fm}/c$
exposure

Pressure-driven expansion of
Quark-gluon plasma (QGP)



$\tau \sim 10\text{fm}/c$
expansion

free-streaming



$\tau \sim 10^{15}\text{fm}/c$
detection

J. Jia et al., *Nucl. Sci. Tech. 35, 220 (2024)*

$$\rho(r,\theta,\phi)=\frac{\rho_0}{1+e^{(r-R(\theta,\phi))/a_0}}$$

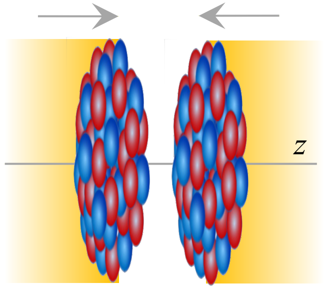
- $\beta_2 \rightarrow$ quadrupole deformation
- $\beta_3 \rightarrow$ octupole deformation
- $\gamma \rightarrow$ triaxiality
- $a_0 \rightarrow$ surface diffuseness
- $R_0 \rightarrow$ nuclear size

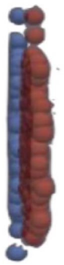
ab initio theory/shell model/DFT

Imaging by smashing method

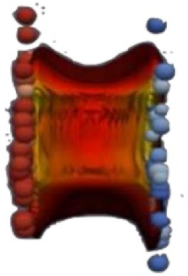
Take a snapshot — Evolution — Measurement

Nuclei collisions $T_{\mu\nu}(\tau=0)$ — $\partial_\mu T^{\mu\nu}=0$, EOS, viscosity… — $T_{\mu\nu}(\tau=\infty)$

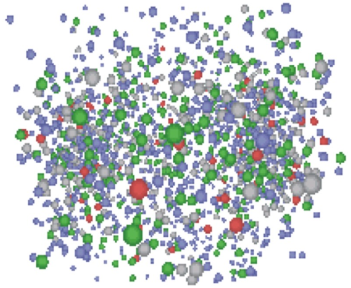




Pressure-driven expansion of Quark-gluon plasma (QGP)



free-streaming



$\tau\sim 2R_0/\Gamma\sim 0.1\mathrm{fm}/c$ exposure

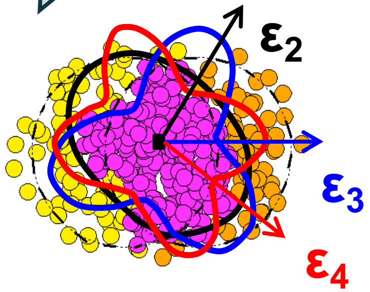
$\tau\sim 10\mathrm{fm}/c$ expansion

$\tau\sim 10^{15}\mathrm{fm}/c$ detection

$$\rho(r,\theta,\phi)=\frac{\rho_0}{1+e^{(r-R(\theta,\phi))/a_0}}$$

- β_2 → quadrupole deformation
- β_3 → octupole deformation
- γ → triaxiality
- a_0 → surface diffuseness
- R_0 → nuclear size

ab initio theory/shell model/DFT



size & shape

J. Jia et al., *Nucl. Sci. Tech. 35, 220 (2024)*

$R_\perp^2\propto\langle r_\perp^2\rangle$

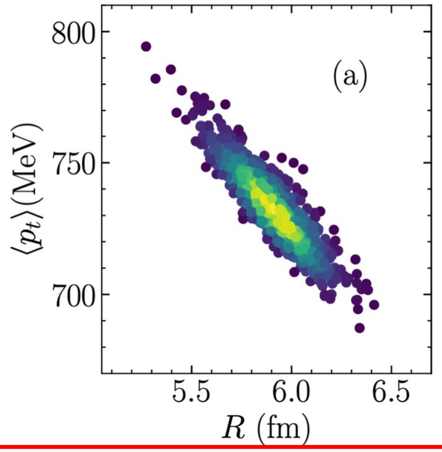
$\mathcal{E}_n\propto\langle r_\perp^n e^{in\phi}\rangle$

R_0 a_0 β_n

Observables $\frac{d^2N}{d\phi dp_T}=N(p_T)\left(\sum_n V_n e^{-in\phi}\right)$

linear responses:

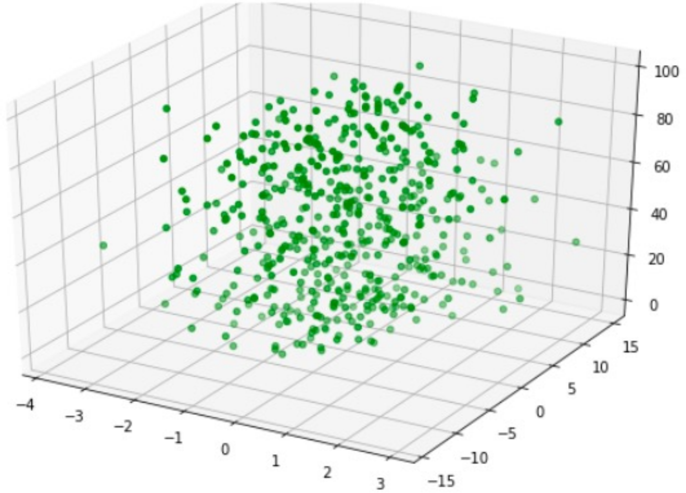
$$\frac{\delta[p_T]}{[p_T]}\propto-\frac{\delta R_\perp}{R_\perp}$$



Key: 1) fast snapshot, 2) linear response, 3) large multiplicity for many-body correlation

Mean transverse momentum fluctuations

$f\left(p_{x1}, p_{y1}, p_{z1}, p_{x2}, p_{y2}, p_{z2} \ldots\right)$



Event-by-event temperature fluctuations

J. Jia, S. Huang, C. Zhang, *PRC 105 , 014906 (2022)*

S. Bhatta, C. Zhang, J. Jia, *PRC106, L031901 (2022)*

C. Zhang, A. Behera, S. Bhatta, J. Jia, *PLB 822, 136702 (2021)*

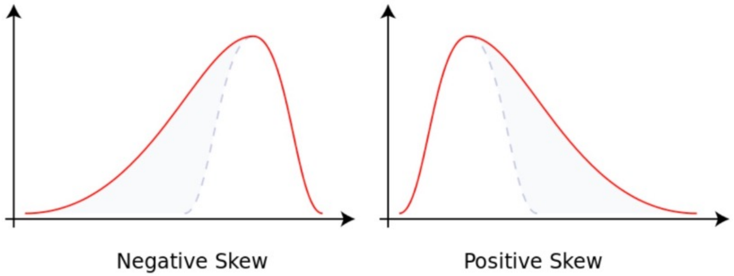
Mean: $$\langle\langle p_{\mathrm{t}}\rangle\rangle = \frac{\sum_{k=1}^{N_{\text{events}}} \langle p_{\mathrm{t}}\rangle_k}{N_{\text{events}}} \quad \text{where} \quad \langle p_{\mathrm{t}}\rangle_k = \frac{\sum_{i=1}^{N_k} p_{\mathrm{t},i}}{N_k}$$

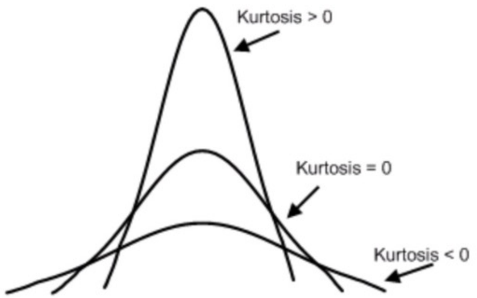
Variance: $$\left\langle\left(\delta p_T\right)^2\right\rangle = \frac{\sum_i \sum_{j\neq i} \omega_i \omega_j \left(p_{T,i} - \langle[p_T]\rangle\right)\left(p_{T,j} - \langle[p_T]\rangle\right)}{\sum_i \sum_{j\neq i} \omega_i \omega_j},$$

Skewness: $$\left\langle\left(\delta p_T\right)^3\right\rangle = \frac{\sum_{i,j\neq i,k\neq j\neq i} \omega_i \omega_j \omega_k \left(p_{T,i} - \langle[p_T]\rangle\right)\left(p_{T,j} - \langle[p_T]\rangle\right)\left(\left(p_{T,k} - \langle[p_T]\rangle\right)\right)}{\sum_{i,j\neq i,k\neq j\neq i} \omega_i \omega_j \omega_k},$$

Kurtosis: $$\left\langle\left(\delta p_T\right)^4\right\rangle = \frac{\sum_{i,j\neq i,k\neq j\neq i,l\neq k\neq j\neq i} \omega_i \omega_j \omega_k \omega_l \left(p_{T,i} - \langle[p_T]\rangle\right)\left(p_{T,j} - \langle[p_T]\rangle\right)\left(\left(p_{T,k} - \langle[p_T]\rangle\right)\right)\left(p_{T,l} - \langle[p_T]\rangle\right)}{\sum_{i,j\neq i,k\neq j\neq i,l\neq k\neq j\neq i} \omega_i \omega_j \omega_k \omega_l}$$

Related to the entropy of the initial source presumably deposited early
in the collision before thermalization and interactions with QGP

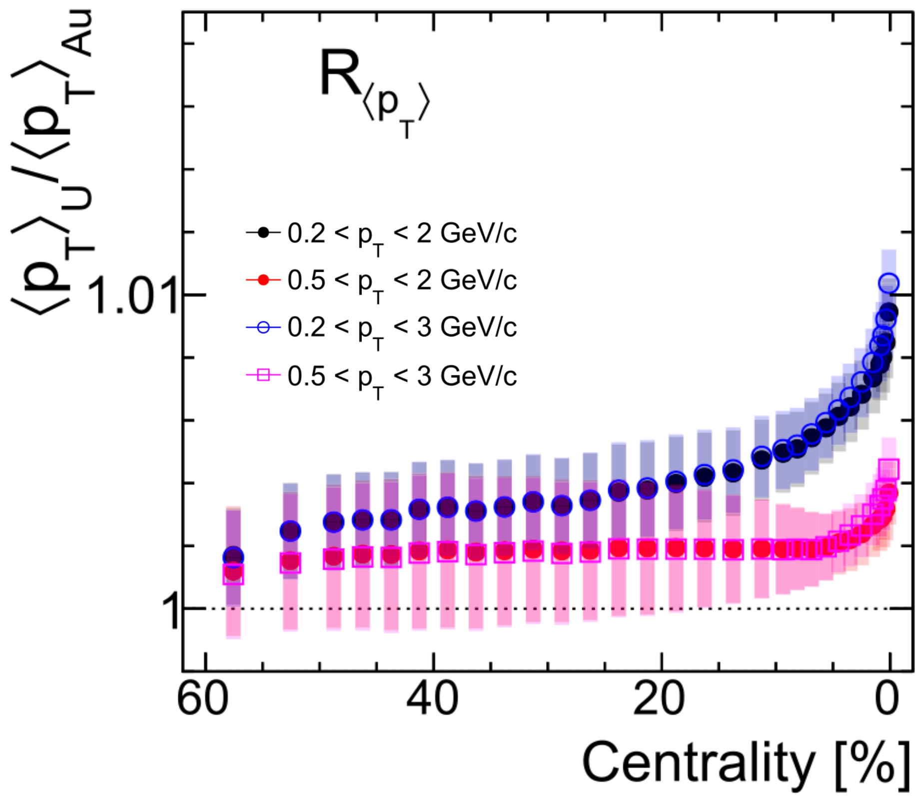


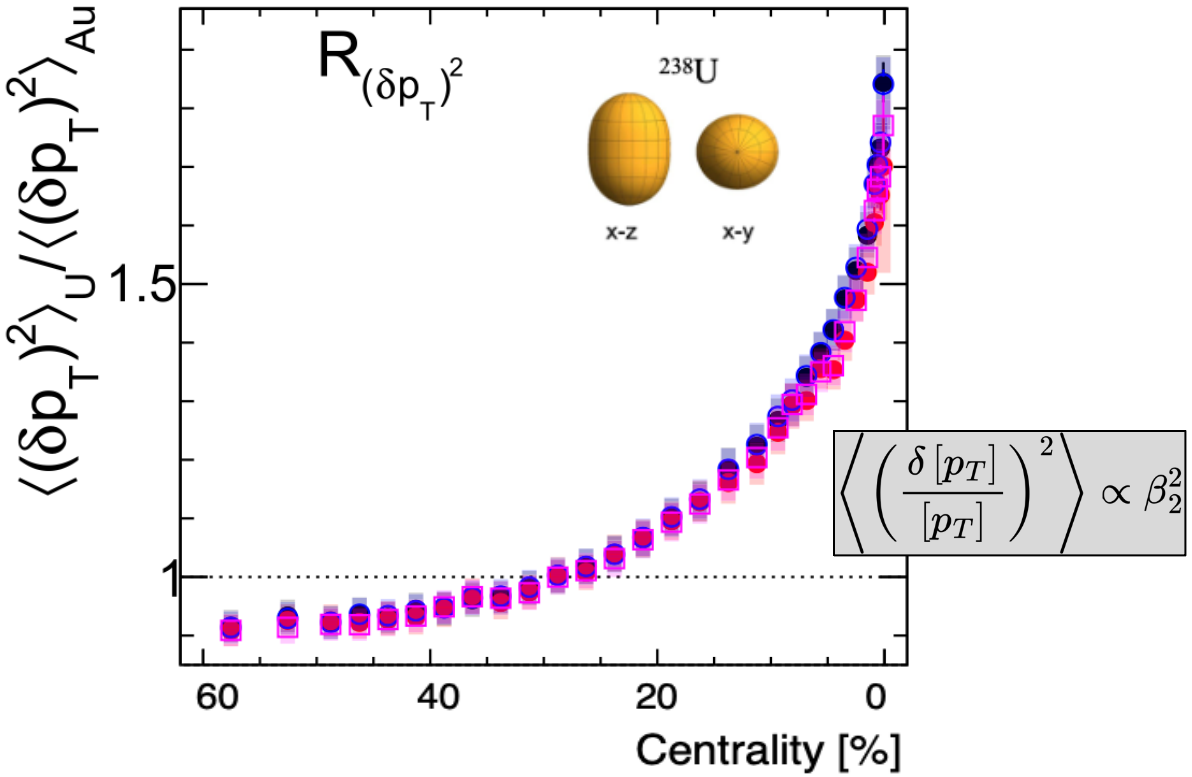


S. Gavin, *PRL 92, 162301 (2004)*

Size fluctuation sensitive to nuclear deformation

STAR, *Rep. Prog. Phys. 88,108601 (2025)*





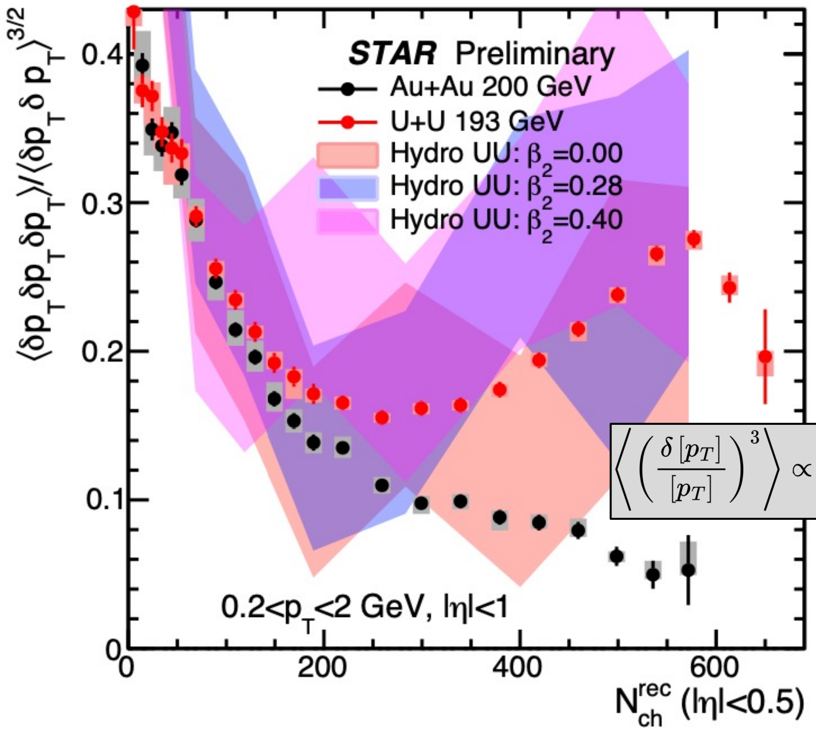
large enhancement in mean and variance ⟶ size fluctuations enhanced

A good probe to image nuclear deformation.

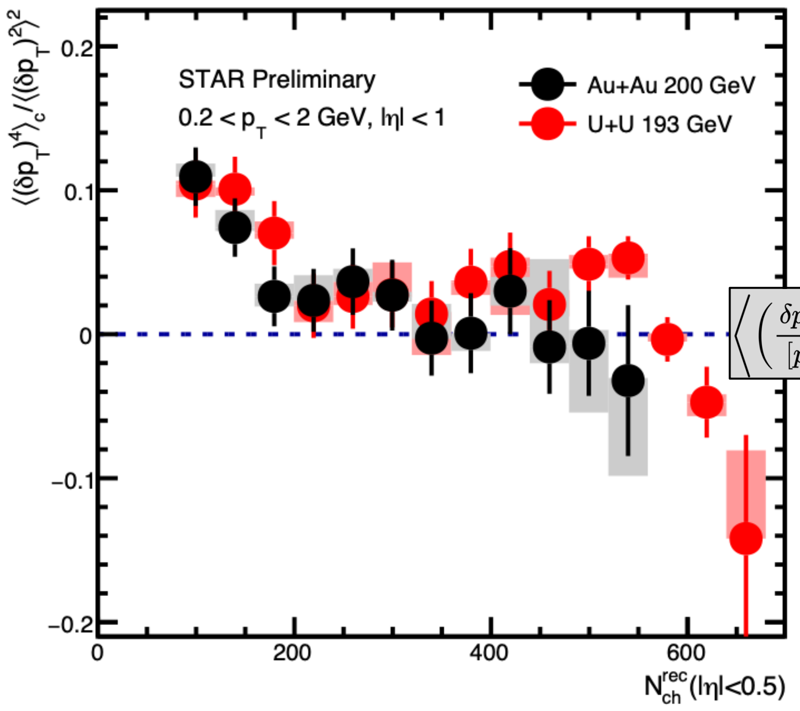
ALICE, *PLB 850, 138541 (2024);* ATLAS, *PRL 133, 252301 (2024);* G. Giacalone, J. Jia, C. Zhang, *PRL 127, 242301 (2021)*

Size fluctuation sensitive to nuclear deformation

C. Zhang (STAR), *IJMPE 32, 2341001 (2023)*



$$\left\langle \left(\frac{\delta [p_T]}{[p_T]} \right)^3 \right\rangle \propto \cos(3\gamma)\beta_2^3$$



$$\left\langle \left(\frac{\delta p_T}{[p_T]} \right)^4 \right\rangle - 3 \left\langle \left(\frac{\delta p_T}{[p_T]} \right)^2 \right\rangle^2 \propto -\beta_2^4$$

Independence source model: following $1/N_s^{n-1}$ within power-law decrease in high-order

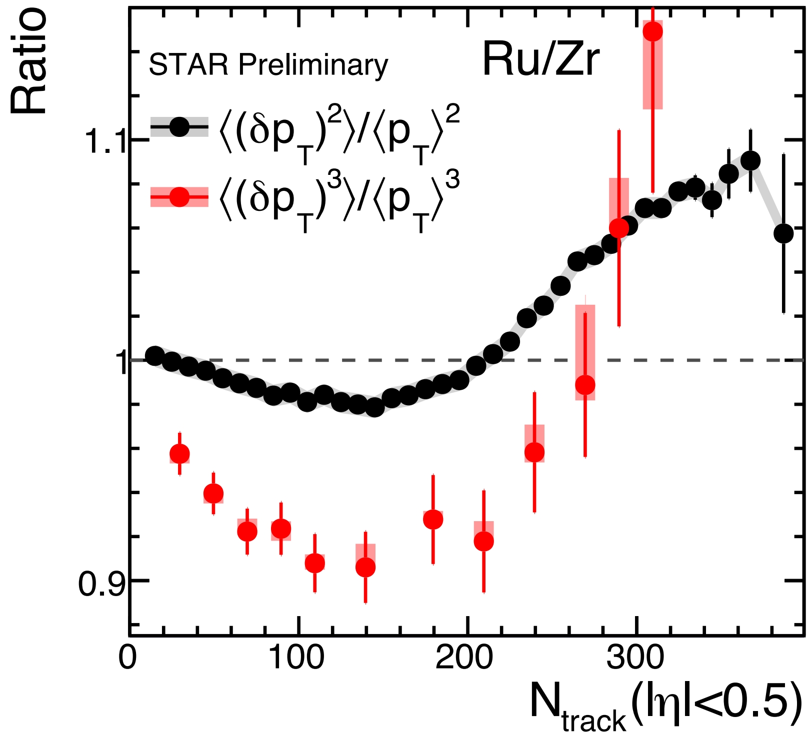
M. Cody et. al., *Phys. Rev. C 107, (2023)*

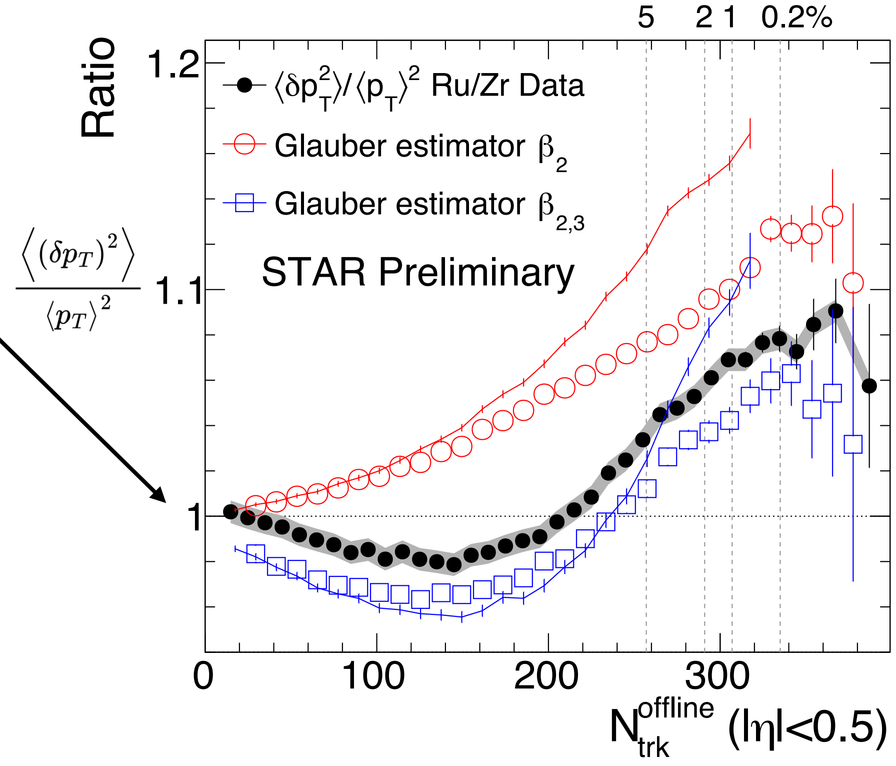
Size fluctuations enhanced: large enhancement in skewness and **sign-change** in kurtosis

confirmed by hydro, but statistics hungry.

ALICE, *PLB 850, 138541 (2024);* ATLAS, *PRL 133, 252301 (2024);* G. Giacalone, J. Jia, C. Zhang, *PRL 127, 242301 (2021)*

Size fluctuation sensitive to nuclear deformation





$$\left\langle \left(\frac{\delta [p_T]}{[p_T]} \right)^2 \right\rangle \propto \beta_2^2$$

$$\left\langle \left(\frac{\delta [p_T]}{[p_T]} \right)^3 \right\rangle \propto \cos(3\gamma)\beta_2^3$$

$$\frac{\langle \delta p_T^2 \rangle_{\mathrm{Ru}}}{\langle \delta p_T^2 \rangle_{\mathrm{Zr}}} \approx 1 + \frac{b_0}{a_0}\left(\beta_{2,\mathrm{Ru}}^2 - \beta_{2,\mathrm{Zr}}^2\right) - \frac{b_{0,3}}{a_0}\beta_{3,\mathrm{Zr}}^2$$

Cancelation expected in non-central collisions

C. Zhang, J. Jia, *PRL 128, 022301 (2022)*

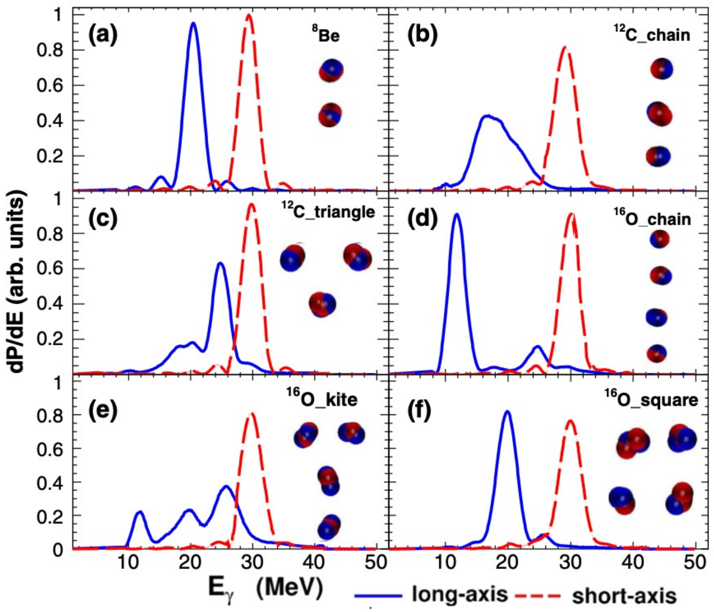
indicate octupole deformation: large enhancement in skewness and sign-change in kurtosis

Cluster pattern in ^{16}O

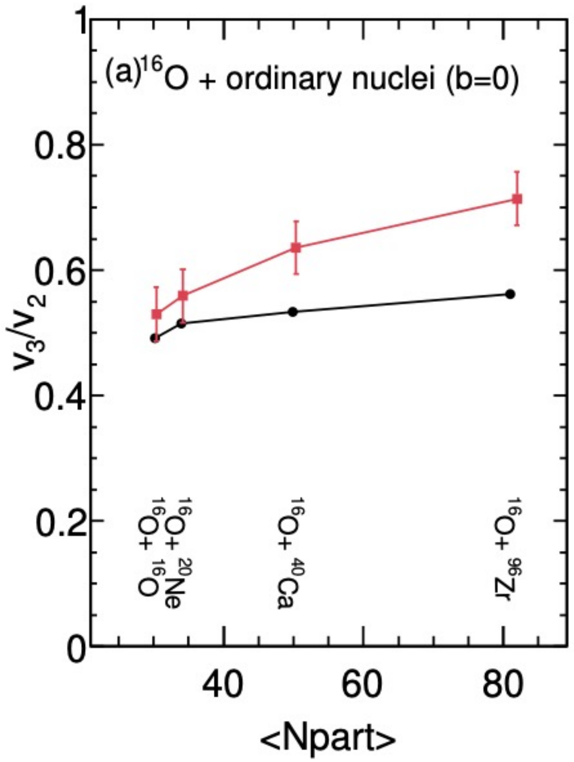
STAR, *arXiv: 2604.06434*

Pioneer theory instructions of the nucleonic clustering

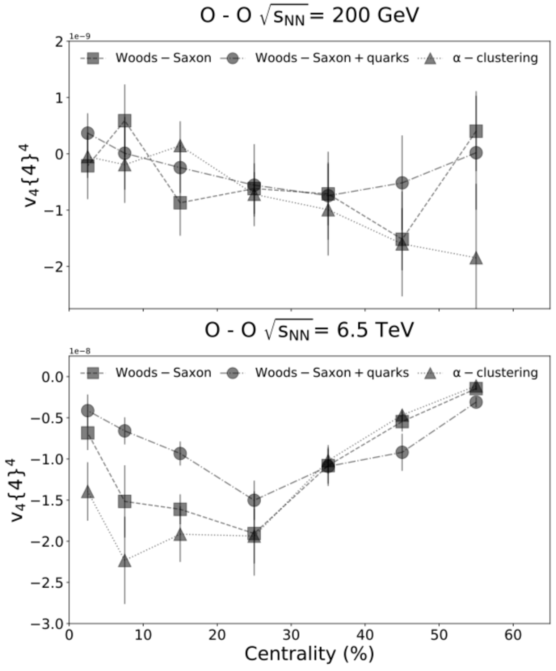
"Double magic number" in $^{16}_{8}O$ nuclei, possible alpha cluster in low-energy studies.



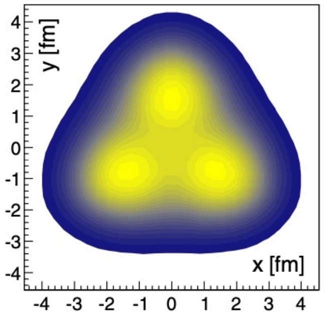
W. He, Y.-G. Ma et al., *PRL 113, 032605 (2014)*

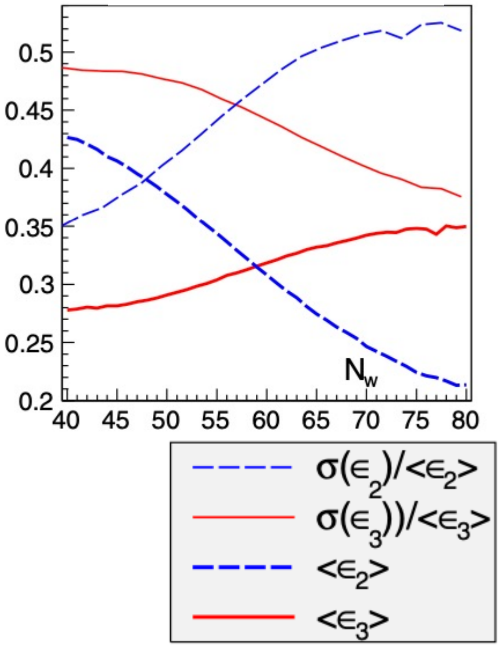


Y.-G. Ma and S. Zhang, *Handbook of Nuclear Physics,* 2206.08218



Nicholas et al., *PRC 104, L041901 (2021)*





W. Broniowski, E. Arriola, *PRL 112, 112501 (2014)*

- ^{16}O nucleus could have different intrinsic topological structures.
- The initial configurations straightforwardly affect the final state observables in high energies.

Nucleon-nucleon correlations in quantum many-body system

Possible cluster in ground-state $^{16}_{8}O$ nuclei in low energy

***1) Woods-Saxon:** without many-body nuclear correlation*

2) Nuclear Lattice Effective Field theory (NLEFT):
model with many-nucleon correlation including α clusters

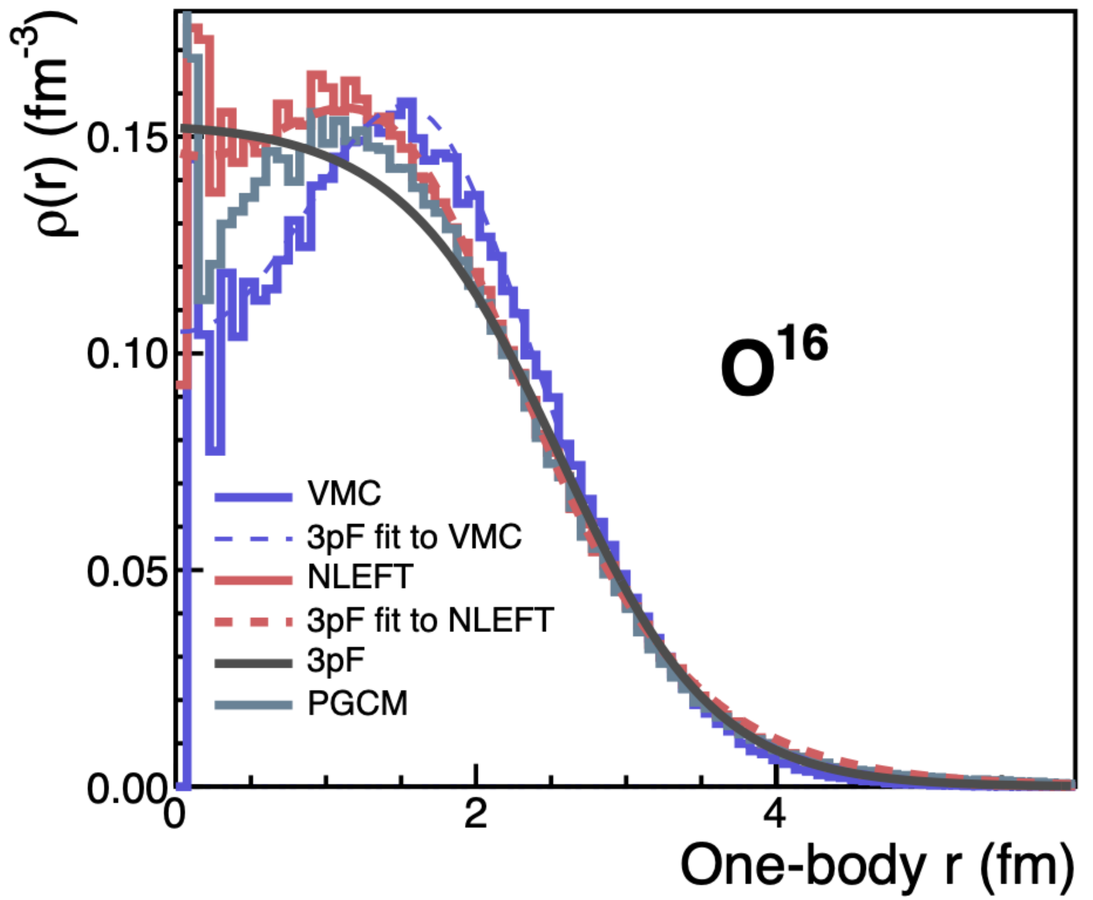
Lu et al., *PLB 797, 134863 (2019)*
M. Freer et al., *Rev. Mod. Phys. 90, 035004 (2018)*
S. Elhatisari et al., *Nature 630, 59 (2024)*

3) Variational auxiliary field diffusion Monte Carlo (VMC):
MC solution of Schrödinger eq. from the time evolution of trial wave function.

A. Lonardoni et al., *PRC 97, 044318 (2018)*
J. Carlson and R. Schiavilla, *Rev. Mod. Phys. 70, 743 (1998)*

4) ab-initio Projected Generator Coordinate Method (PGCM):
Wave function from variational calculation (as in density functional theory)

Frosini et al., *EPJA 58, 62 (2022); EPJA 58, 63 (2022); EPJA 58, 64 (2022)*

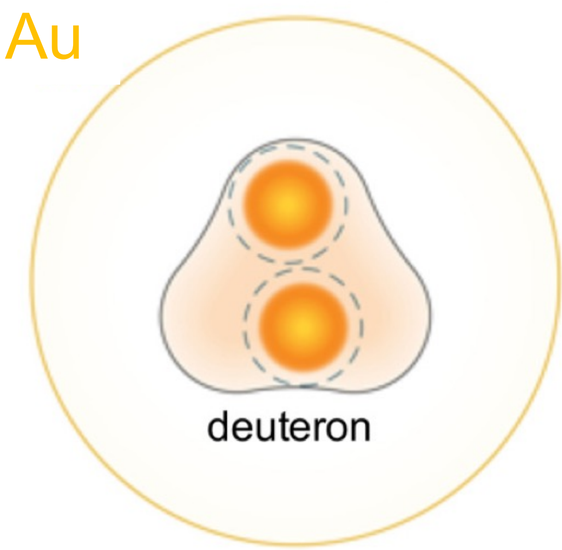


C. Zhang, J. Chen, G. Giacalone, S. Huang, J. Jia, Y.-G. Ma, *PLB 862, 139322 (2025)*

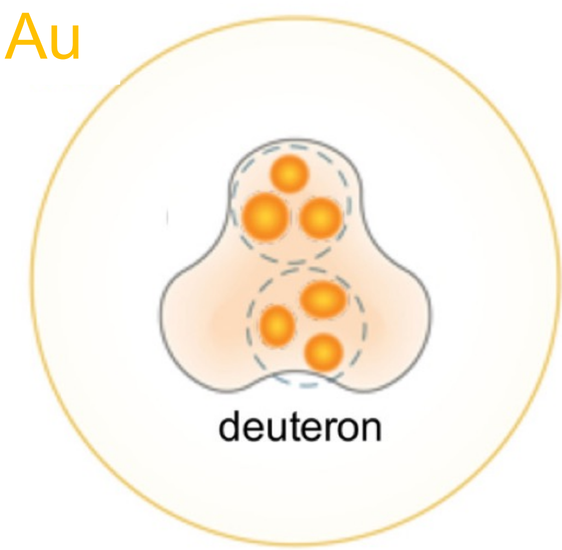
5) Some other micro models…

Nucleon/sub-nucleon fluctuation vs. nucleon-nucleon correlations

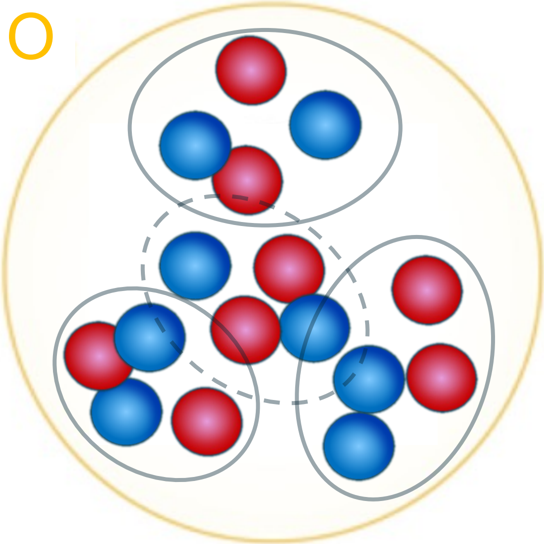
Nucleon fluctuation

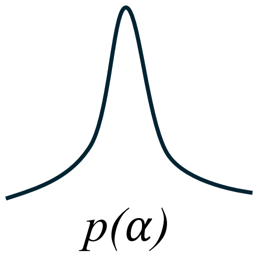


subnucleon fluctuation



NN correlation (cluster pattern)





ab initio calculations

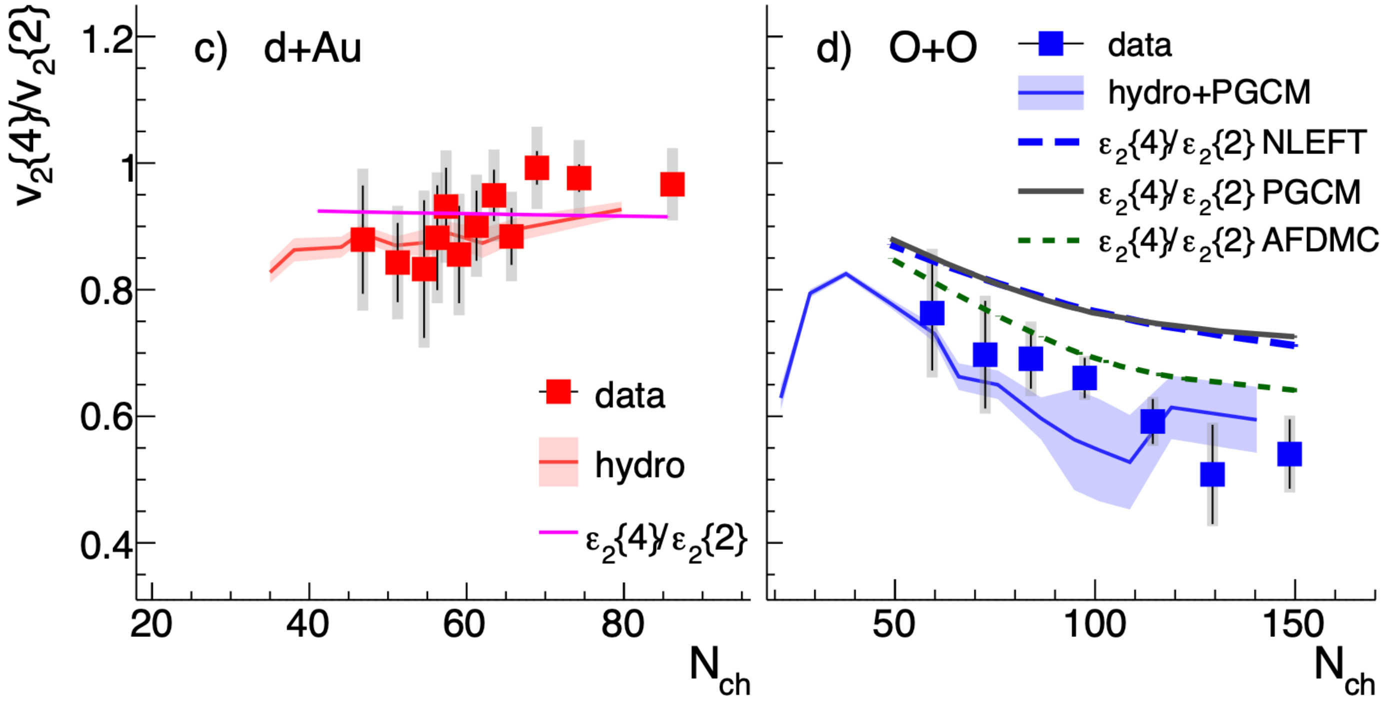
Y.-G. Ma, S. Zhang, *Handbook of Nuclear Physics (2022)*
C. Zhang, J. Chen, G. Giacalone, S. Huang, J. Jia, Y.-G. Ma, *PLB 862, 139322 (2025)*
S. Huang, J. Jia, C. Zhang, *PLB 870, 139926 (2025)*
X. Zhao, G. Ma. Y. Zhou, Z. Lin and C. Zhang, *PLB 874, 140254 (2026)*
P. Li, B. Zhou, G.-L. Ma, *PRL 136, 082302 (2026)*
S. Jahan, Roch, C. Shen, *PRC 113, 024919 (2026)*
Y. Wang, S. Zhao, B. Cao, H. Xu and H. Song, *PRC 109, L051904 (2024)*
H. Wang, S. Li, J. Xu, Z. Ren, *PLB 866, 139516 (2025)*
J. Hu, H. Xu, X. Wang, S. Pu, *2507.01493*
...

STAR, *PRL 130, 242301 (2023)*
STAR, *PRC 110, 064902 (2024)*

d+Au collision, 200 GeV ⟷ Nearly same N_{ch} ⟷ O+O collision, 200 GeV

Benchmarking geometric tomography of ^{16}O nucleus

STAR, *2510.19645*



S. Jahan, Roch, C. Shen, *PRC 113, 024919 (2026)* *NLEFT from* D. Lee, *PGCM from* B. Bally, T. Duguet

$\varepsilon_2\{4\}/\varepsilon_2\{2\}$ from three models:

AFDMC vs. EFT/PGCM has a visible difference.

Nucleon-nucleon correlations impact initial-state fluctuations.

Y.-G. Ma, S. Zhang, *Handbook of Nuclear Physics (2022)*
C. Zhang et al., *PLB 862, 139322 (2025)*
G. Giacalone, B. Bally, et al., *PRL 135, 012302 (2025)*
G. Giacalone, W. Zhao et al., *PRL 134, 082301 (2025)*
P. Li, B. Zhou, G.-L. Ma, *PRL 136, 082302 (2026)*

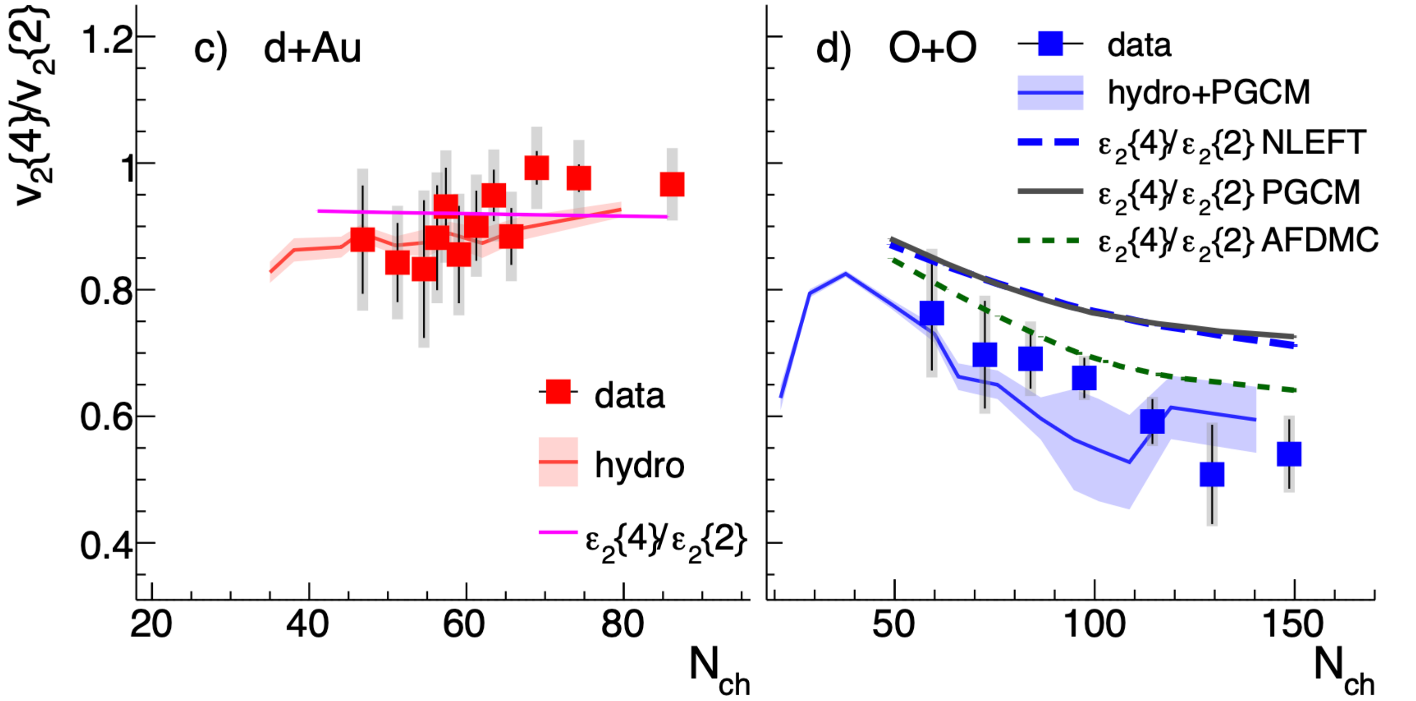
Small fluctuation in d+Au **large fluctuation in O+O**

$$\frac{v_2^{dAu}\{4\}}{v_2^{dAu}\{2\}} \approx \frac{\varepsilon_2^{dAu}\{4\}}{\varepsilon_2^{dAu}\{2\}} \approx 0.9 \qquad \frac{v_2^{OO}\{4\}}{v_2^{OO}\{2\}} \approx \frac{\varepsilon_2^{OO}\{4\}}{\varepsilon_2^{OO}\{2\}} \sim 0.6$$

d+Au is flat; Large enhancement in O+O with continuous decrease

Benchmarking geometric tomography of ^{16}O nucleus

STAR, *2510.19645*



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Small fluctuation in d+Au **large fluctuation in O+O**

$$\frac{v_2^{dAu}\{4\}}{v_2^{dAu}\{2\}} \approx \frac{\varepsilon_2^{dAu}\{4\}}{\varepsilon_2^{dAu}\{2\}} \approx 0.9 \qquad \frac{v_2^{OO}\{4\}}{v_2^{OO}\{2\}} \approx \frac{\varepsilon_2^{OO}\{4\}}{\varepsilon_2^{OO}\{2\}} \sim 0.6$$

$\varepsilon_2\{4\}/\varepsilon_2\{2\}$ from three models:

AFDMC vs. EFT/PGCM has a visible difference.

Nucleon-nucleon correlations impact initial-state fluctuations.

Y.-G. Ma, S. Zhang, *Handbook of Nuclear Physics (2022)*
C. Zhang et al., *PLB 862, 139322 (2025)*
G. Giacalone, B. Bally, et al., *PRL 135, 012302 (2025)*
G. Giacalone, W. Zhao et al., *PRL 134, 082301 (2025)*
P. Li, B. Zhou, G.-L. Ma, *PRL 136, 082302 (2026)*

The interplay between nucleon/sub-nucleon fluctuation and many-nucleon correlation.

STAR, *PRL 130, 242301 (2023)*
S. Huang, J. Jia, C. Zhang, *PLB 870, 139926 (2025)*

Geometric scan elucidates nuclear tomography and strong nuclear force?

New 2025-2026 dataset: ~10 X High multiplicity

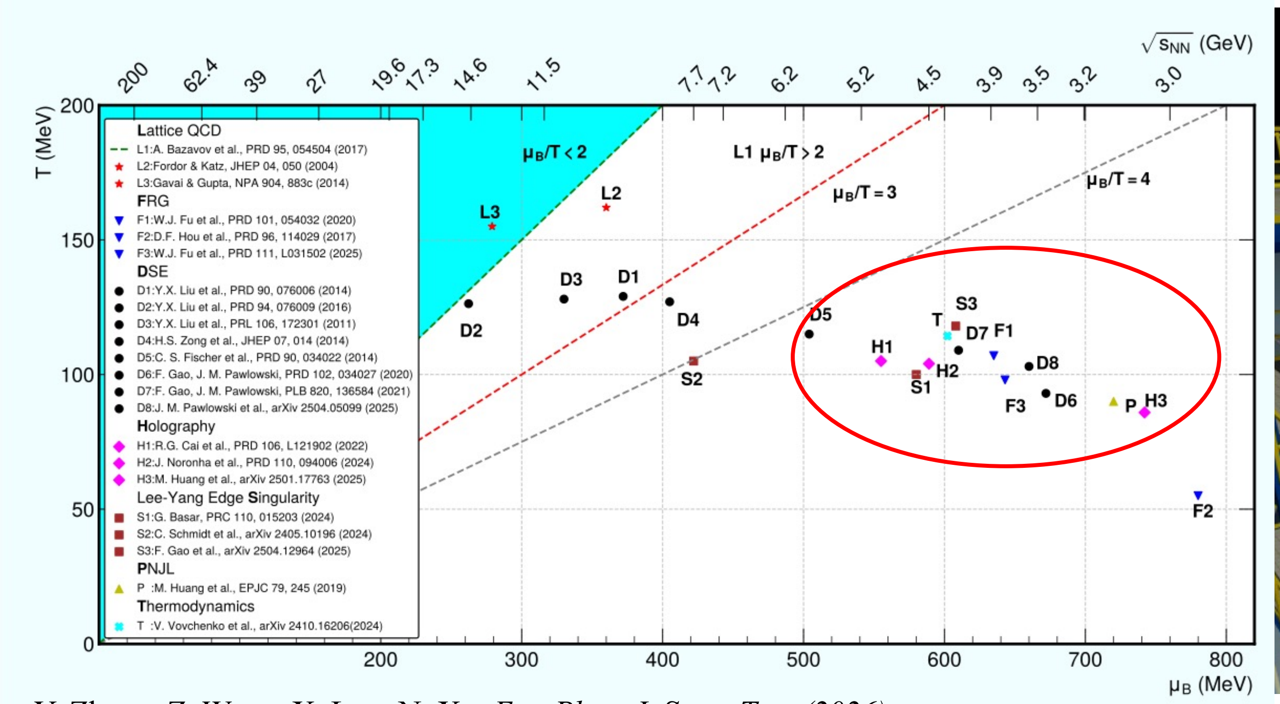
d+Au is flat; Large enhancement in O+O with continuous decrease

See Xianglei Zhu's talk

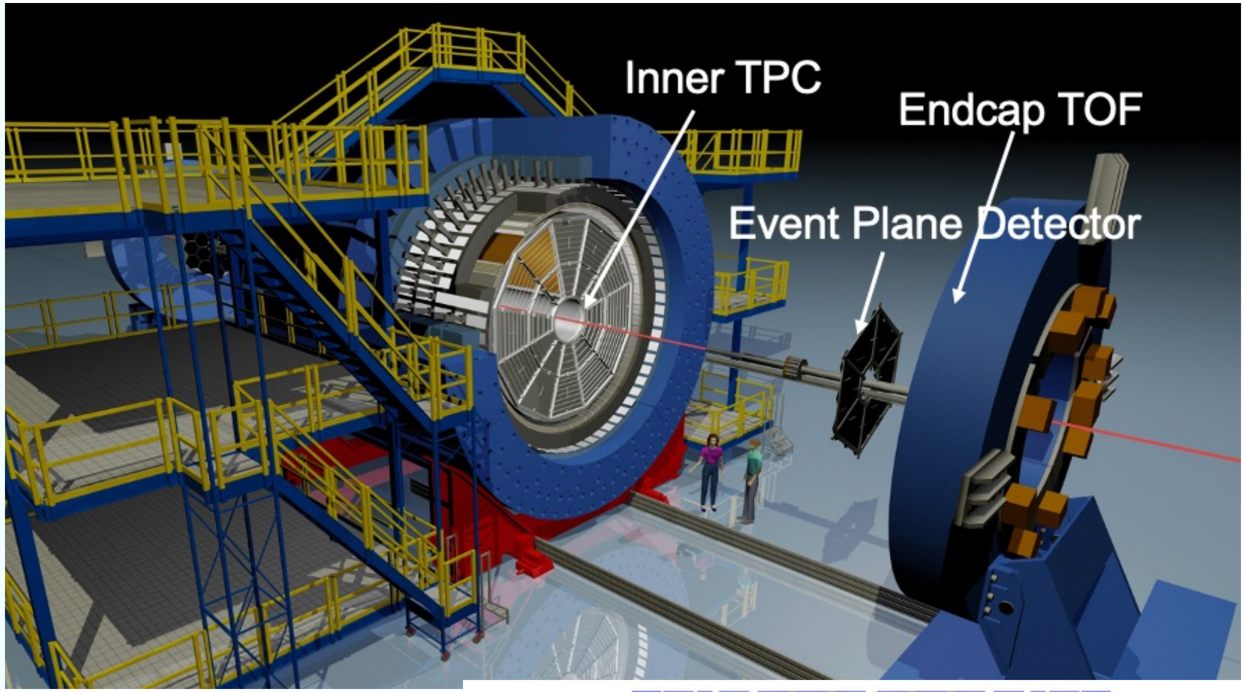
New measurements of radial flow and its fluctuations: system-size and energy dependence

STAR, *arXiv: 2604.06434*

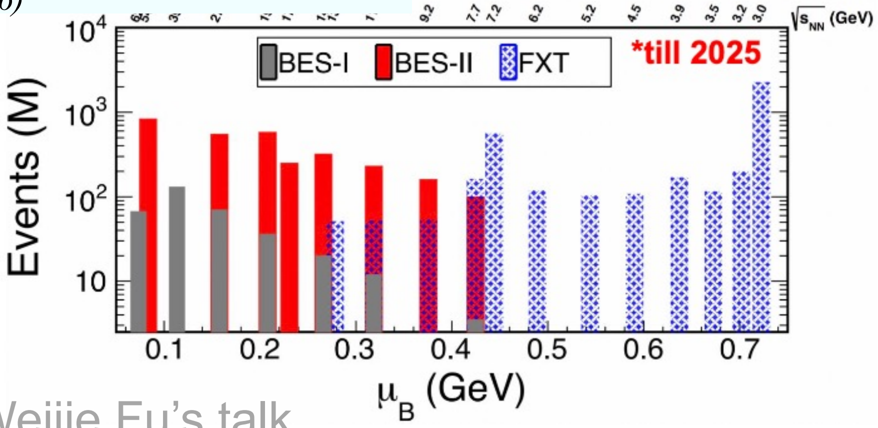
The BES-II Upgrades and fixed-target (FXT) mode

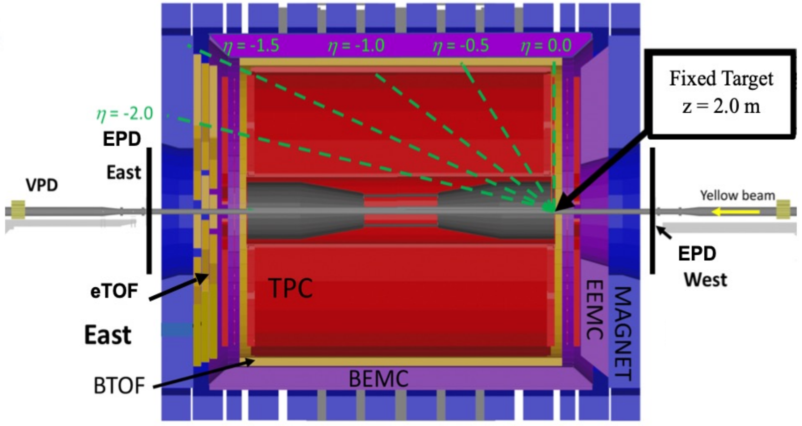


Y. Zhang, Z. Wang, X. Luo, N. Xu, *Eur. Phys. J. Spec. Top. (2026)*



a strong convergence of predicted points within the 3–6 GeV energy range





Also see Xiaofeng Luo, Gaoqing Cao, Weijie Fu's talk

Large datasets with iTPC upgrade ~10 X BES-I

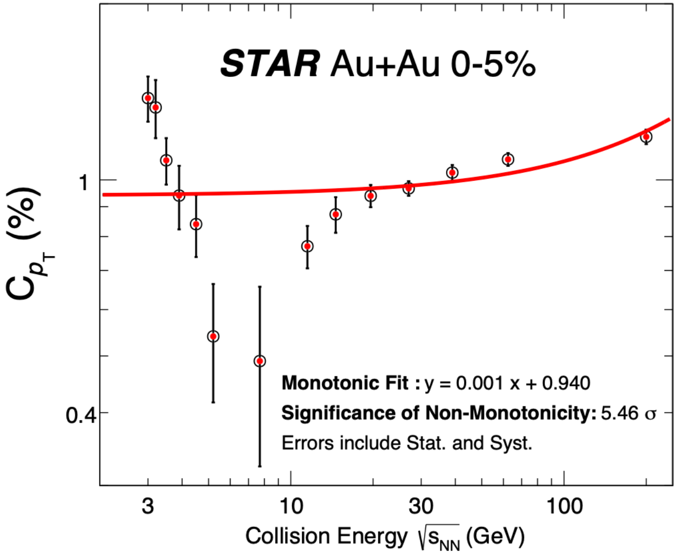
Mid-rapidity for 3.0 GeV is y = 1.049

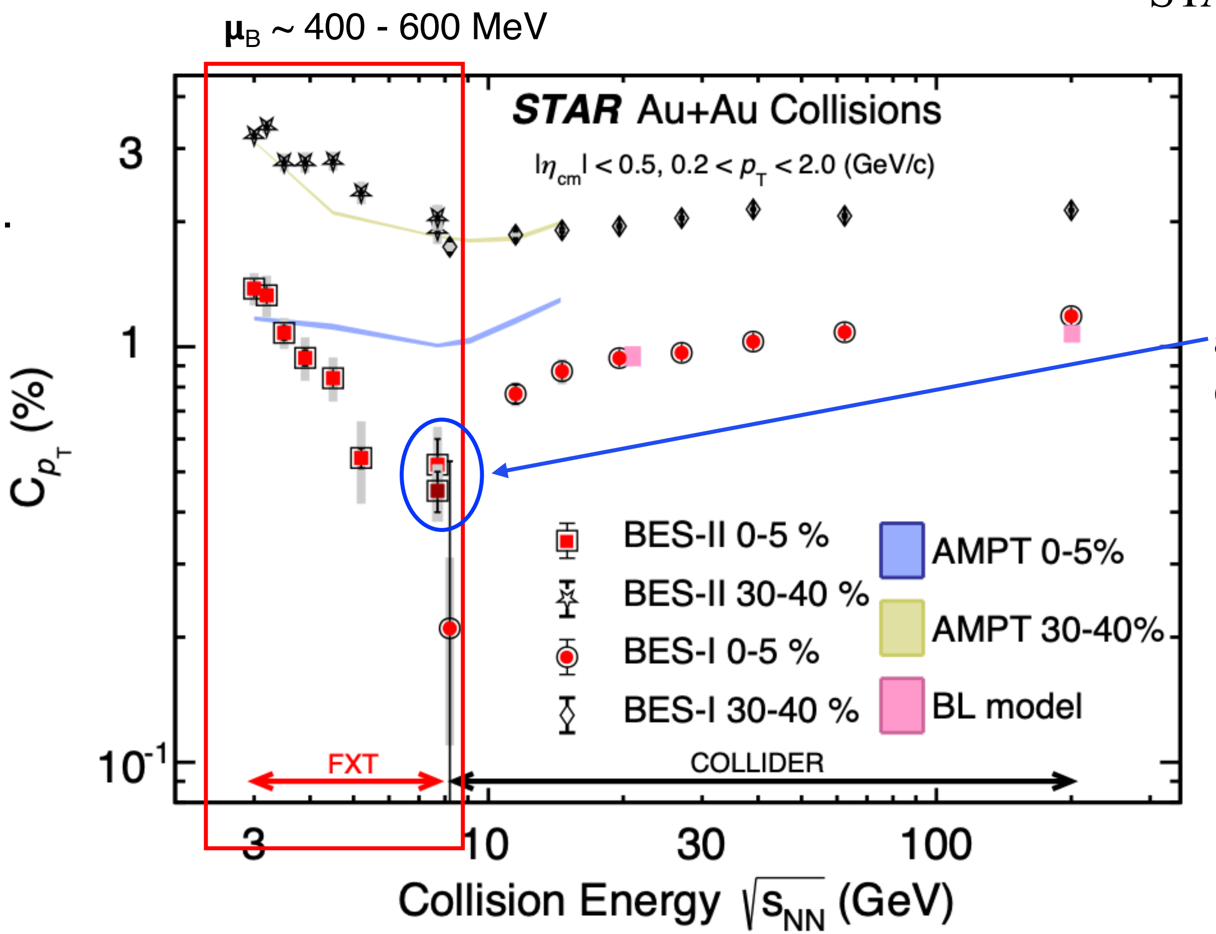
Correlator $\sqrt{\Delta p_{T,i}\Delta p_{T,j}}/\langle\langle p_T\rangle\rangle$ vs collision energy in FXT mode

STAR, *arXiv: 2604.06434*

BES-II results show a **significant non-monotonic behavior** in 0–5% central collisions, but not in 30–40%.

STAR 0-5 %	**~5.5 σ**
AMPT 0-5 %	**~1.4 σ**
STAR 30-40 %	**~2 σ**





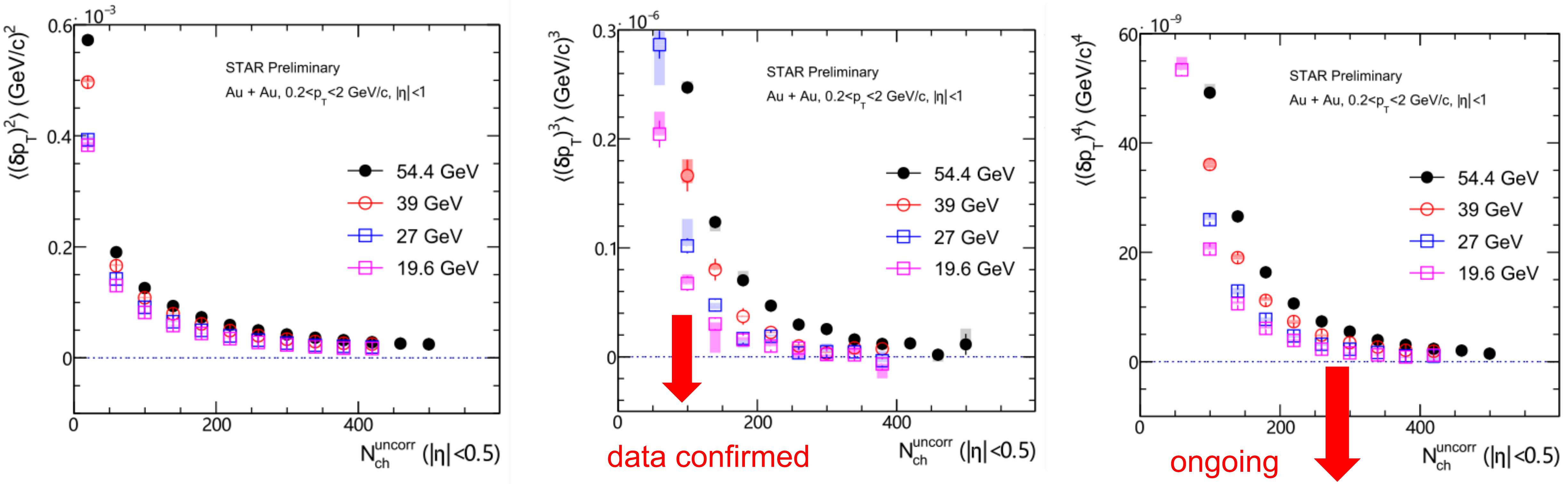
No acceptance effect: at 7.7 GeV, BES-II is consistent with BES-I.

Useful for constraining EoS and understanding the phase diagram.

Boltzmann–Langevin model: S. Gavin et. al., *Phys. Rev. C 95, (2017)*

AMPT: L. Zhang, J. Chen, C. Zhang, *PRC 111, 024911 (2025)*

Correlator $\langle(\delta p_T)^n\rangle$ vs centrality in collider mode



Efficiency-uncorrected N_{ch}

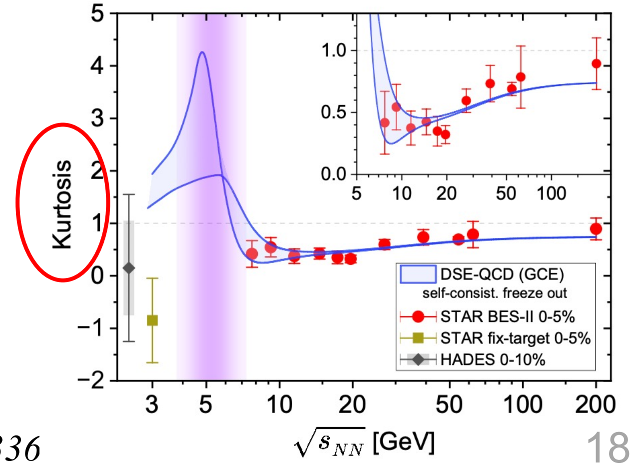
J. Chen, W. Fu, S. Yin, C. Zhang, *arXiv:2504.06886*

Also see Weijie Fu's talk

- Values of correlators of variance, skewness and kurtosis increase towards peripheral collisions.

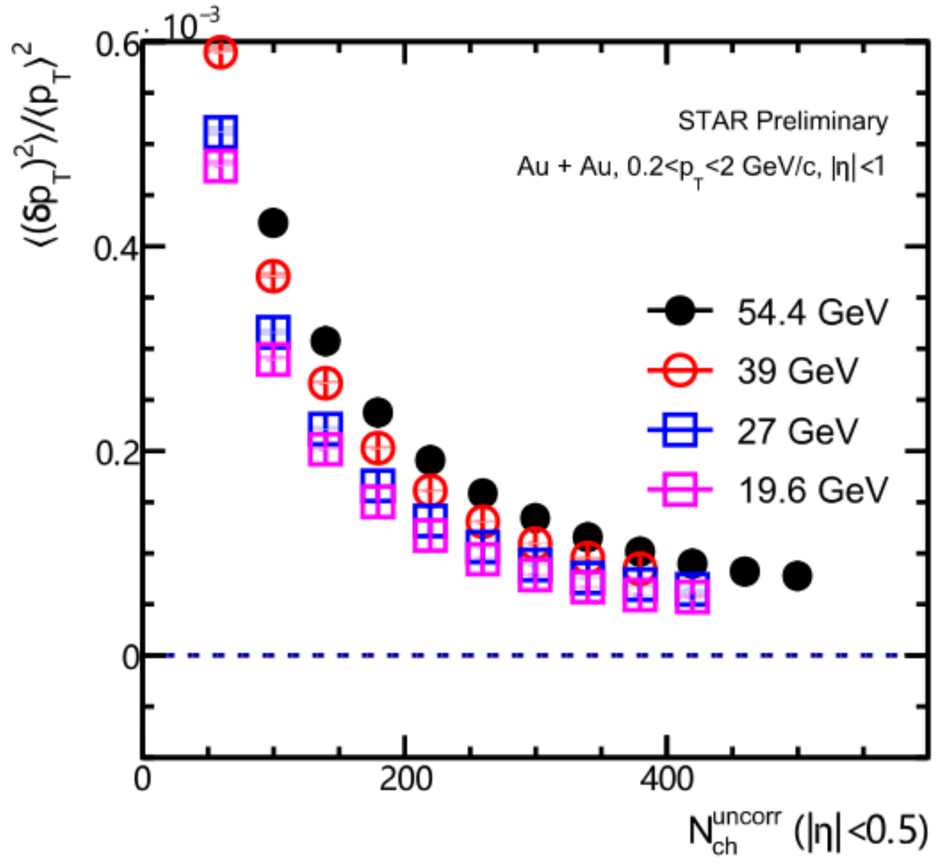
- Slight energy dependence is observed.

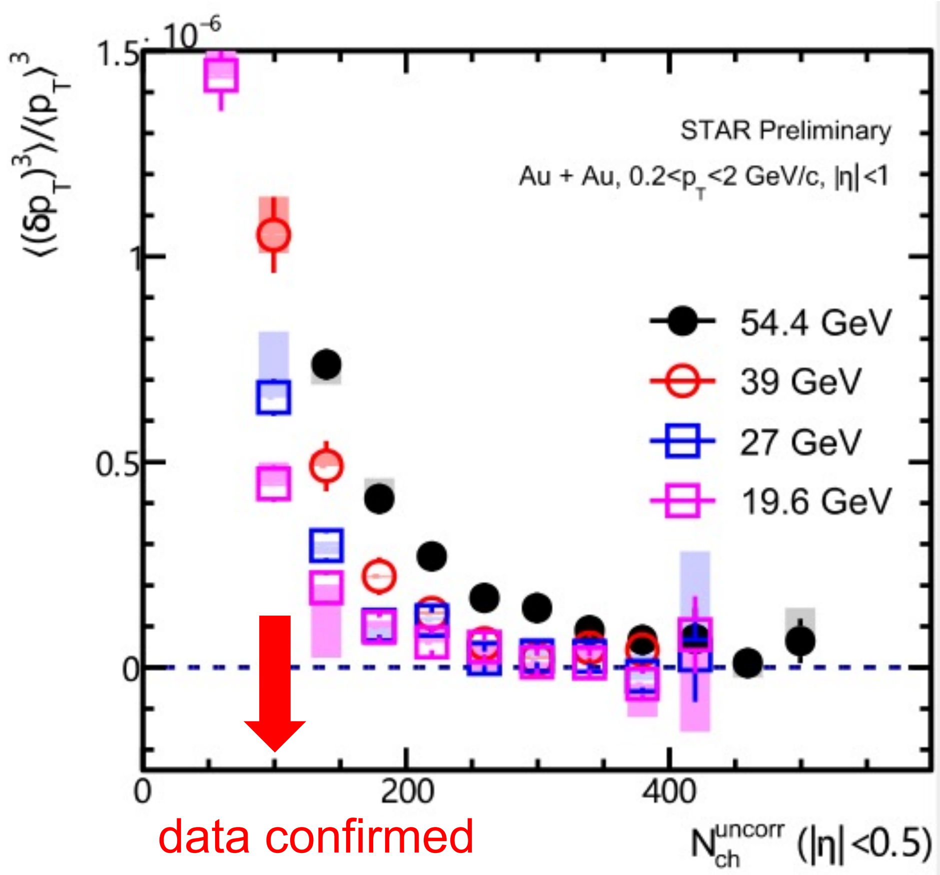
Analog: Interesting to study such energy dependence



Y. Lu, C.S. Fischer, F. Gao, Y.X. Liu, J.M. Pawlowski, *arXiv:2603.09336*

Correlator $\langle(\delta p_T)^n\rangle$ vs centrality in collider mode





J. Chen, W. Fu, S. Yin, C. Zhang, *arXiv:2504.06886*

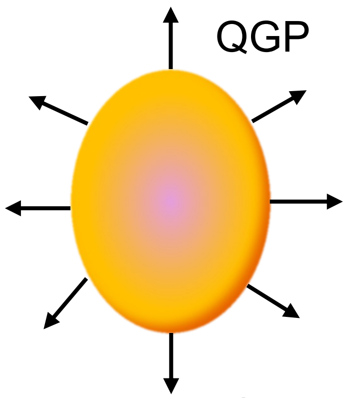
- With increasing charge-multiplicity, the normalized correlators of variance and skewness decrease in magnitudes.

- Energy dependence that increases towards peripheral collisions are observed.

Further understand initial conditions and EbE fluctuations across different collision energies.

New measurement: radial flow $v_0(p_T)$

Radial expansion: the n=0 modulation

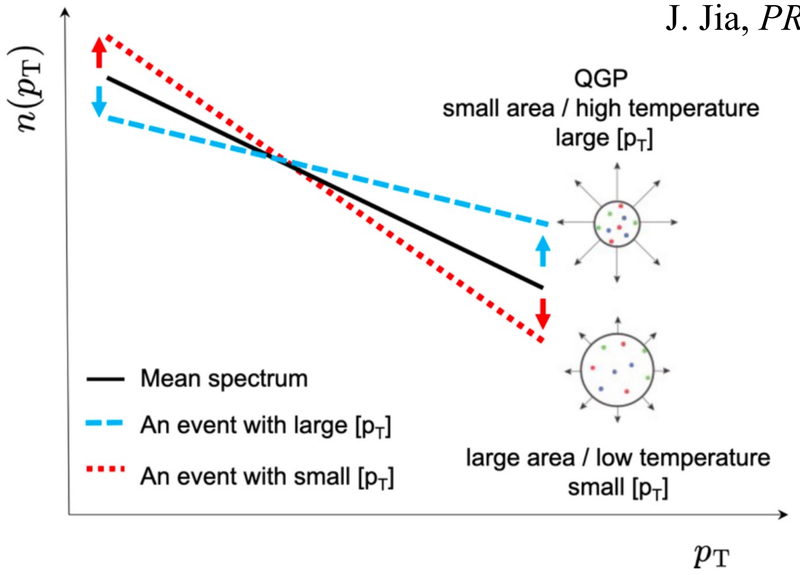


Response to size fluctuations

$$\delta p_T / \langle [p_T] \rangle \approx -\delta R / \langle R \rangle$$

ζ/s and EoS sensitive

J. Jia, *PRL 136, 112301 (2026)*



Spectra slope quantified by $[p_T]$ in each event:
Fluctuation in $[p_T]$ →Fluctuation in spectra.

Calculated within a reference range, p_T-independent.

$$v_0(p_T) = \frac{\langle \delta n(p_T) \delta [p_T] \rangle}{\langle n(p_T) \rangle \langle [p_T] \rangle} \times \frac{1}{v_{0,\mathrm{int}}}$$

$$v_{0,\mathrm{int}} \equiv \frac{\sqrt{\langle (\delta [p_T])^2 \rangle}}{\langle [p_T] \rangle}$$

Quantify the correlation induced by radial flow using
covariance between $n(p_T)$ and $[p_T]$: $\langle \delta n(p_T) \delta [p_T] \rangle$

Pearson Correlations between local possiblity of particle yield and reference mean p_T from spectra

Remove influence from global fluctuations

B. Schenke, C. Shen, D. Teaney, *PRC 102, 034905 (2020)*
T. Parida, R. Samanta, J.Y. Ollitrault, *PLB 857, 138985 (2024)*
S. A. Jahan, H. Roch, C. Shen, *arXiv: 2507.11394*
L. Du, *2508.07184*
J. Zhu, X.-Y. Wu, G.-Y. Qin, *2602.04148*

Verify the signatures of radial flow, like for anisotropic flow (n≥1)

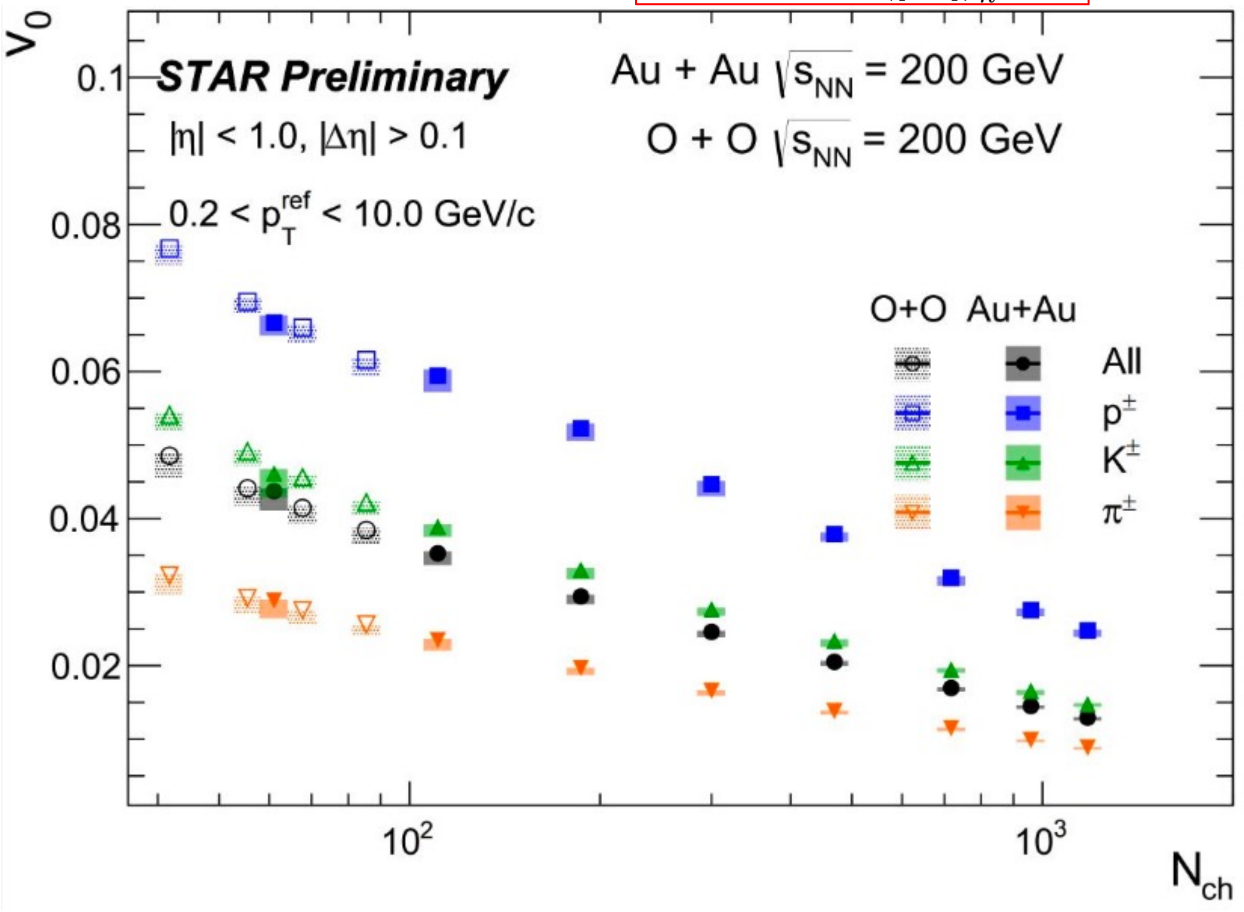
Also see Shusu Shi's talk

Integral p_T fluctuation v_0 at 200 GeV

- Measured for charged hadrons, protons, kaons and pions in O+O to Au+Au.
- larger fluctuation signals for heavier particles.
- v_0 follows an approximate power scaling

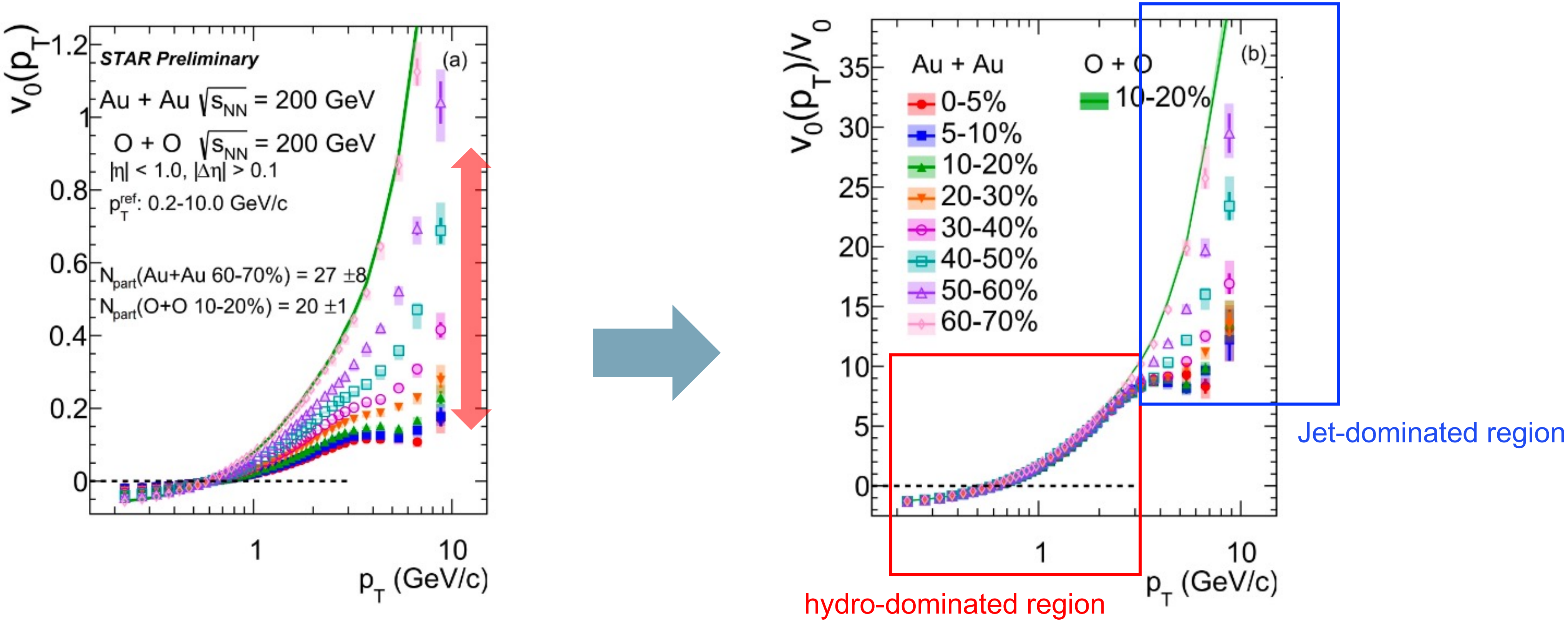
$$v_0 \sim 1/\sqrt{N_{ch}}$$

$$v_{0,\mathrm{PID}} = \frac{\langle \delta[p_\mathrm{T}]_\mathrm{PID} \delta[p_\mathrm{T}]_h \rangle}{\langle [p_\mathrm{T}] \rangle_h}$$



ATLAS, *PRL 136, 032301 (2026),* ALICE, *PRL 136, 032302 (2026)*

$v_0(p_T)$ in Au+Au and O+O at 200 GeV



Strong centrality-dependence: size-driven radial flow fluctuations

$$\frac{\delta[p_T]}{\langle[p_T]\rangle} = \kappa_0 \left(-\frac{\delta R}{R}\right)$$

$$v_0(p_T) = \kappa_0(p_T)\left(-\frac{\delta R}{R}\right)$$

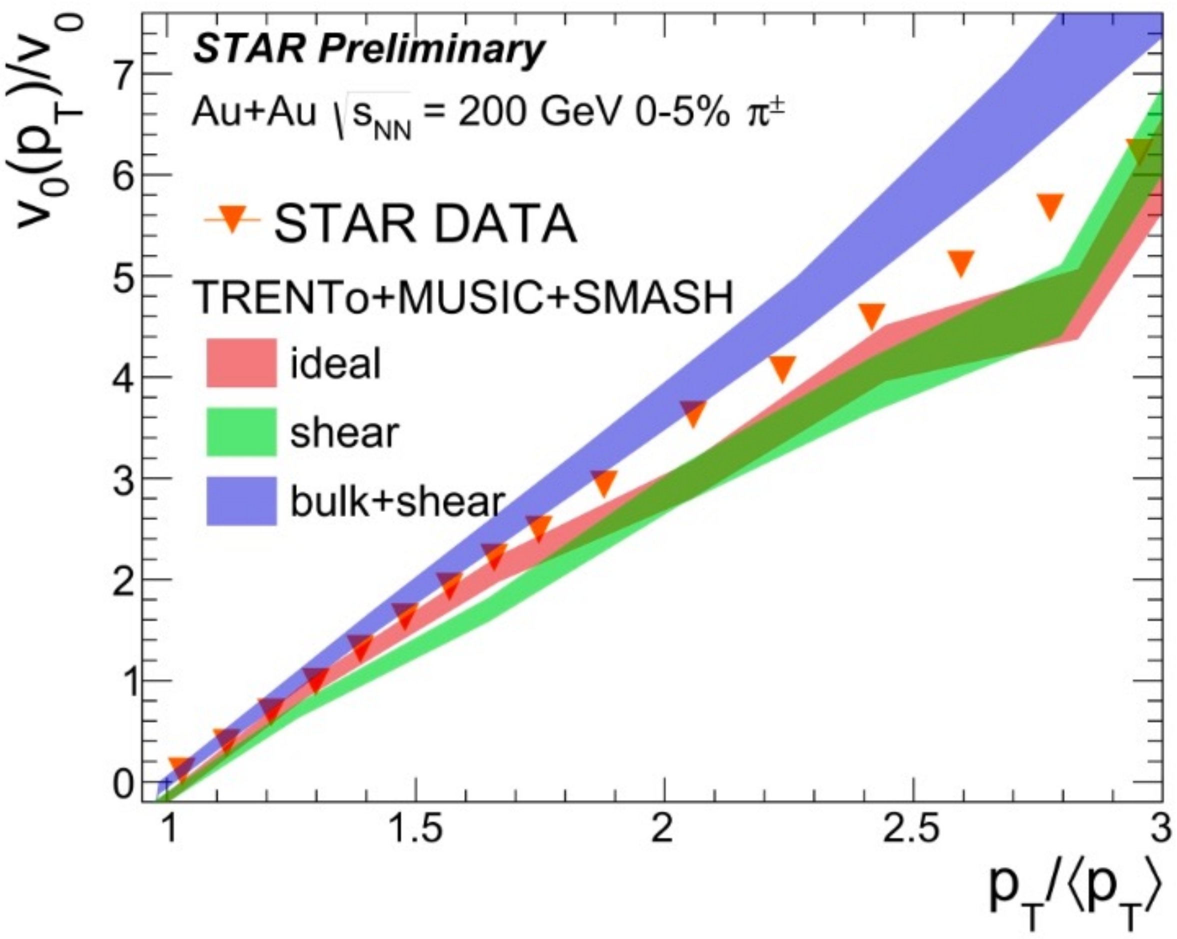
$$v_0 = \kappa_0 \left(-\frac{\delta R}{R}\right)$$

$$\frac{v_0(p_T)}{v_0} = \frac{\kappa_0(p_T)}{\kappa_0}$$

Access medium properties

Universal shape scaling across centrality and systems, except at high p_T

Access the bulk properties



$$\frac{v_0(p_{\mathrm{T}})}{v_0} = \frac{\kappa_0(p_T)}{\kappa_0}$$

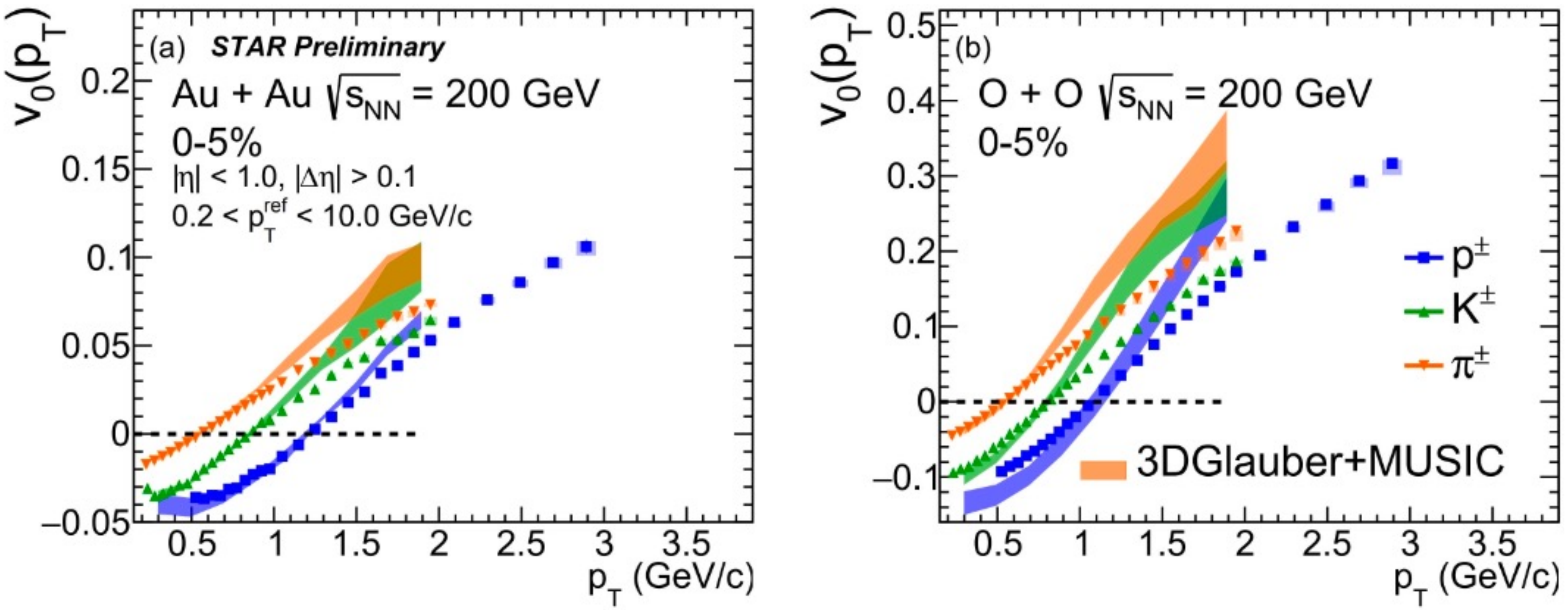
Access medium properties

providing a new approach to constrain bulk properties in hydrodynamic models.

Trento+MUSIC+Smash: L. Du, *arXiv.2508.07184*

Particle mass-ordering and model comparison

$$v_0(p_T) = \frac{\langle \delta n(p_T)\, \delta[p_T]_{p_T^{ref}} \rangle}{\langle \delta n(p_T) \rangle \left(\langle \delta [p_T] \rangle v_0 \right)_{p_T^{ref}}}$$

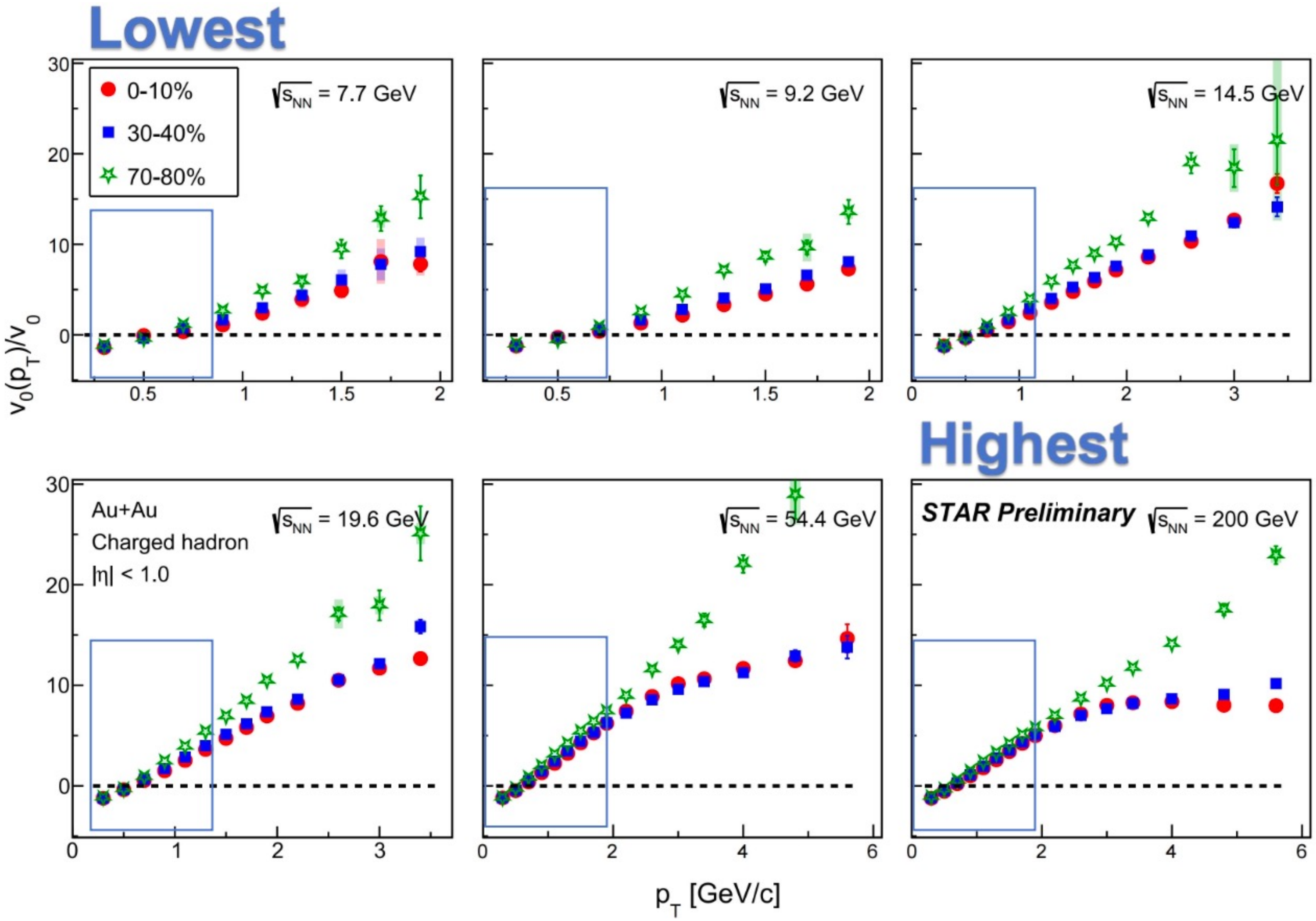


The stronger boost experienced by heavier particles gives rise to a clear mass ordering

3D-Glauber+MUSIC+UrQMD model also show clear mass ordering, but quantitative differences compared to data

3D-Glauber+MUSIC+UrQMD: S.A. Jahan, H. Roch, C. Shen, *PRC113, 024919 (2026)*

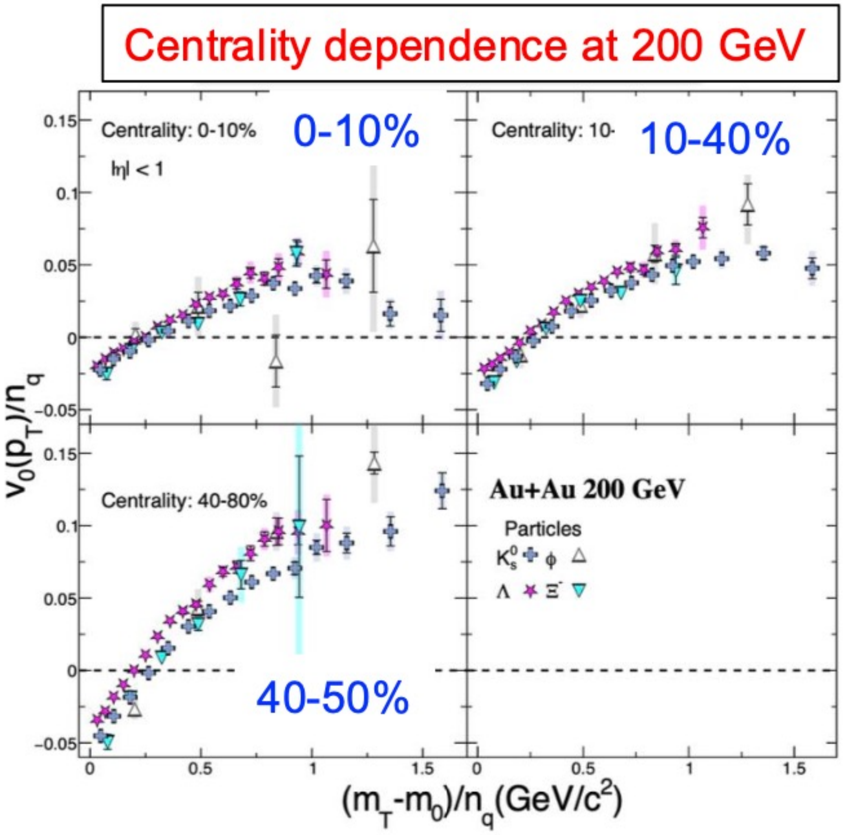
Energy-dependence of radial expansion

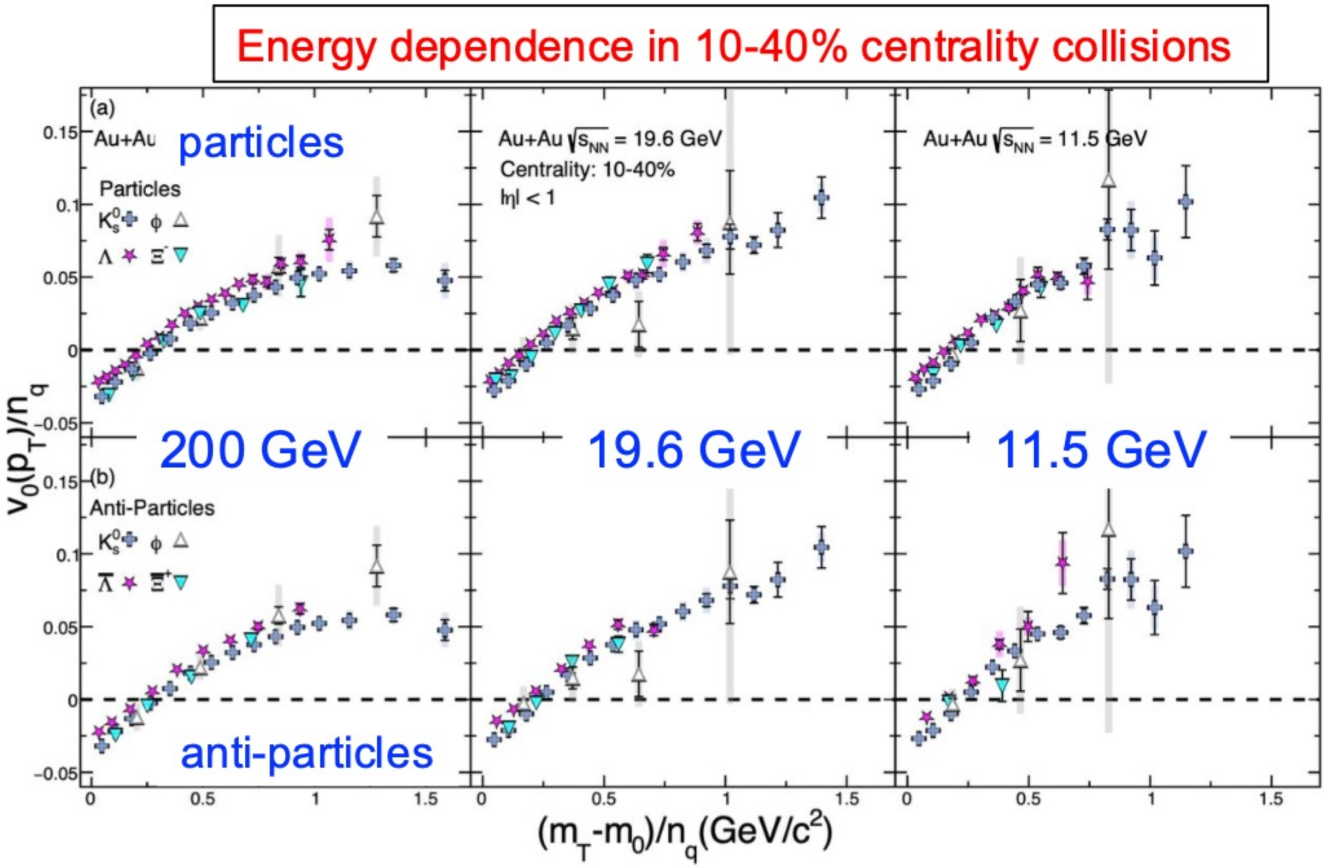


Structure persists down to lower energies: with response coefficients similar to those at higher energies.

Strange hadrons and its energy dependence

PID (strange meson and baryons) dependence allows a detailed test of NCQ scaling





deviation in more peripheral collisions

approximately hold in broad $\sqrt{S_{NN}}$ range

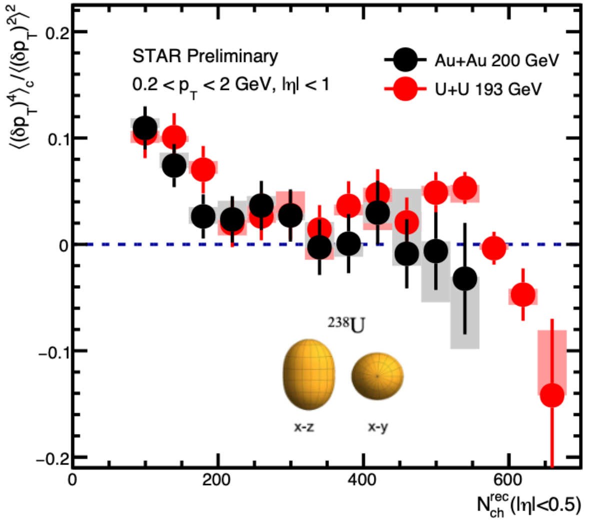
signal also change weakly with $\sqrt{S_{NN}}$ range

Also see Shusu Shi's talk

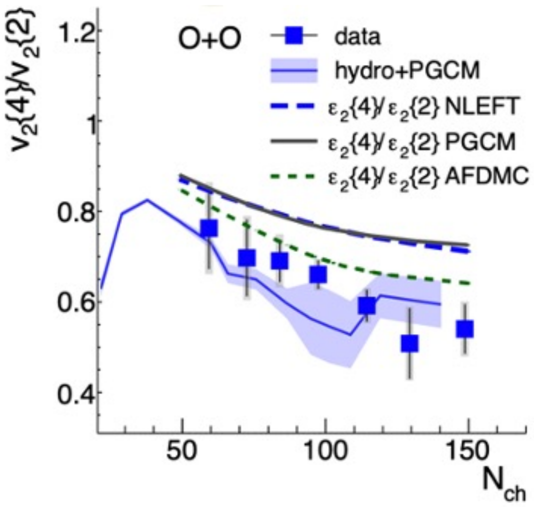
Conclusions and Outlooks

Data: nature of mean p_T fluctuations → **Theoretical model calculations/interpretations**

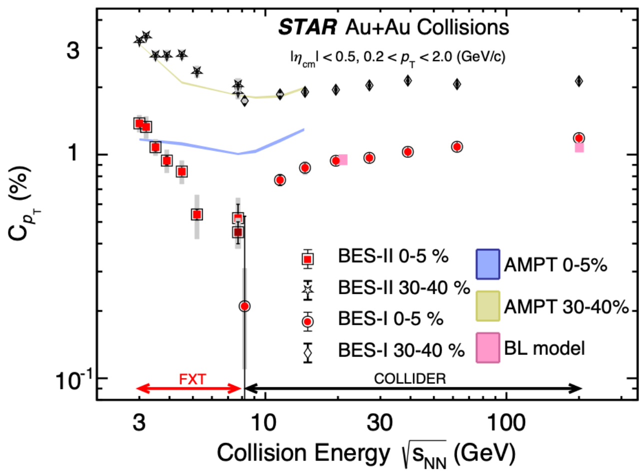
- **Negative kurtosis** in highly deformed ^{238}U indicates the nuclear structure effect.
- Light ion ^{16}O is a good connection to investigate **nucleon-nucleon correlations and cluster patterns**.
- Observation of **non-monotonic dependence** of second-order mean p_T fluctuations at high μ_B.
- $v_0(p_T)$ as a new approach to constrain bulk properties in energy-, system-size, and PID-dependences.



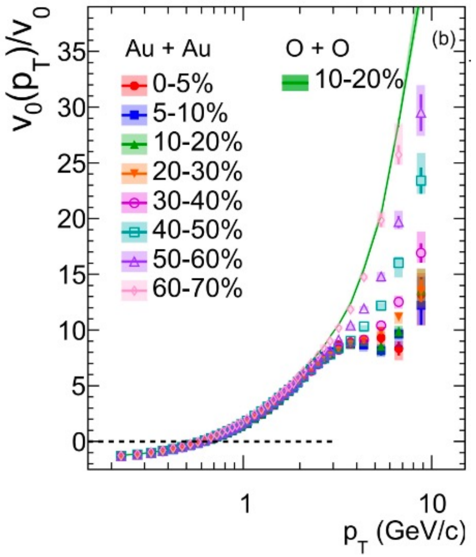
STAR, *Rep. Prog. Phys. 88,108601 (2025)*
High-order fluctuation is ongoing



STAR, *arXiv: 2510.19645*
Other observables are ongoing



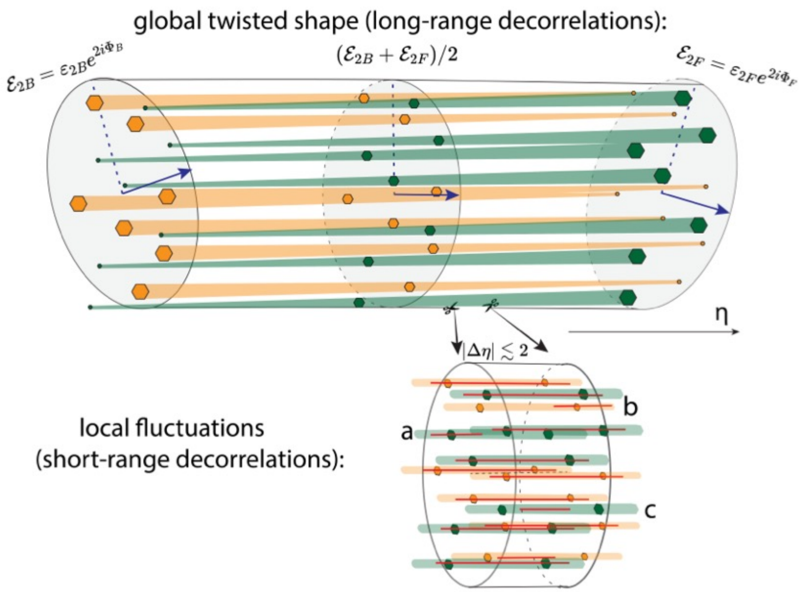
STAR, *arXiv: 2604.06434*
High-order is ongoing



First $v_0(p_T)$ measurement at RHIC

Conclusions and Outlooks

1) 3D QGP initial conditions

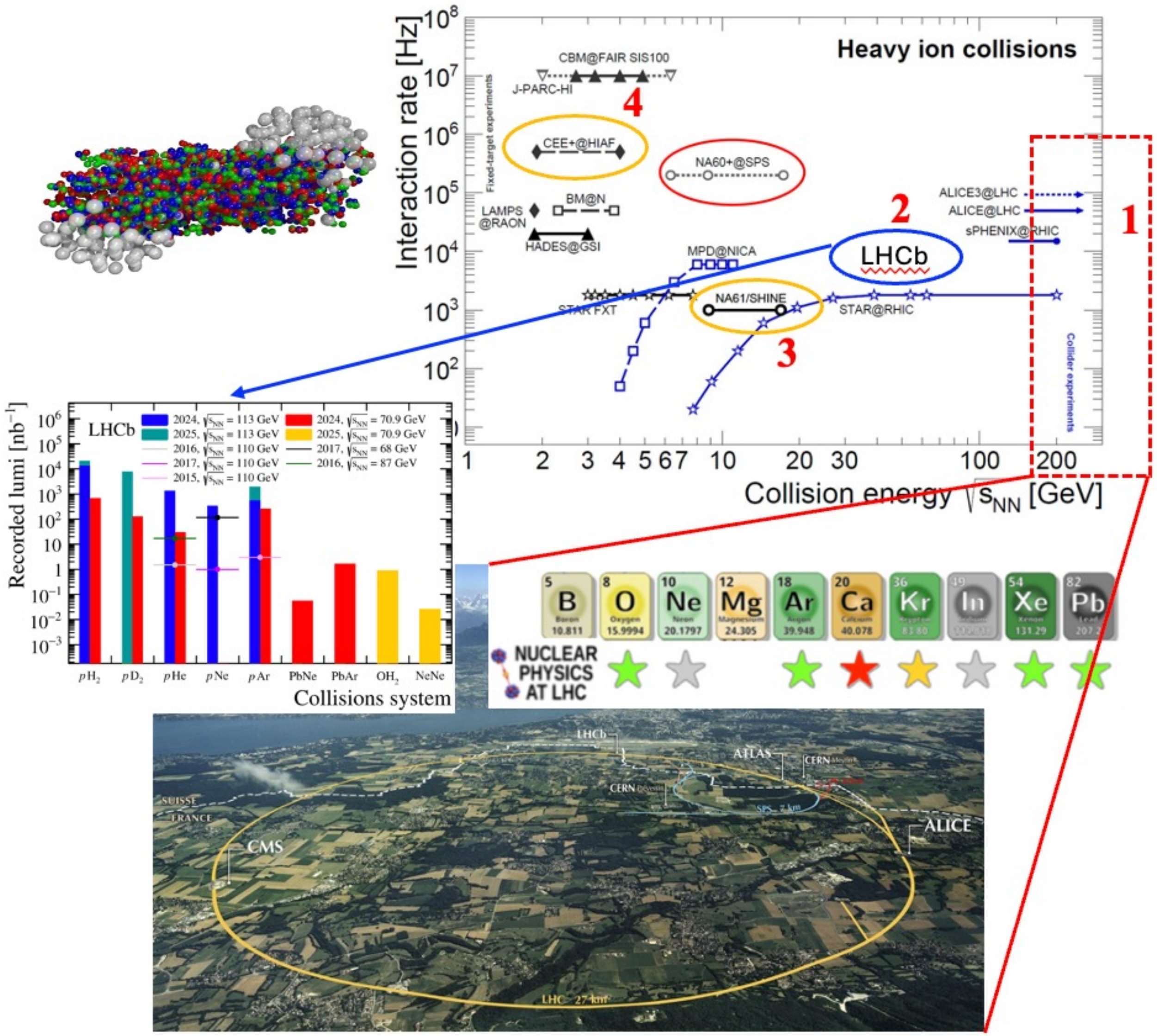


Decorrelation map:

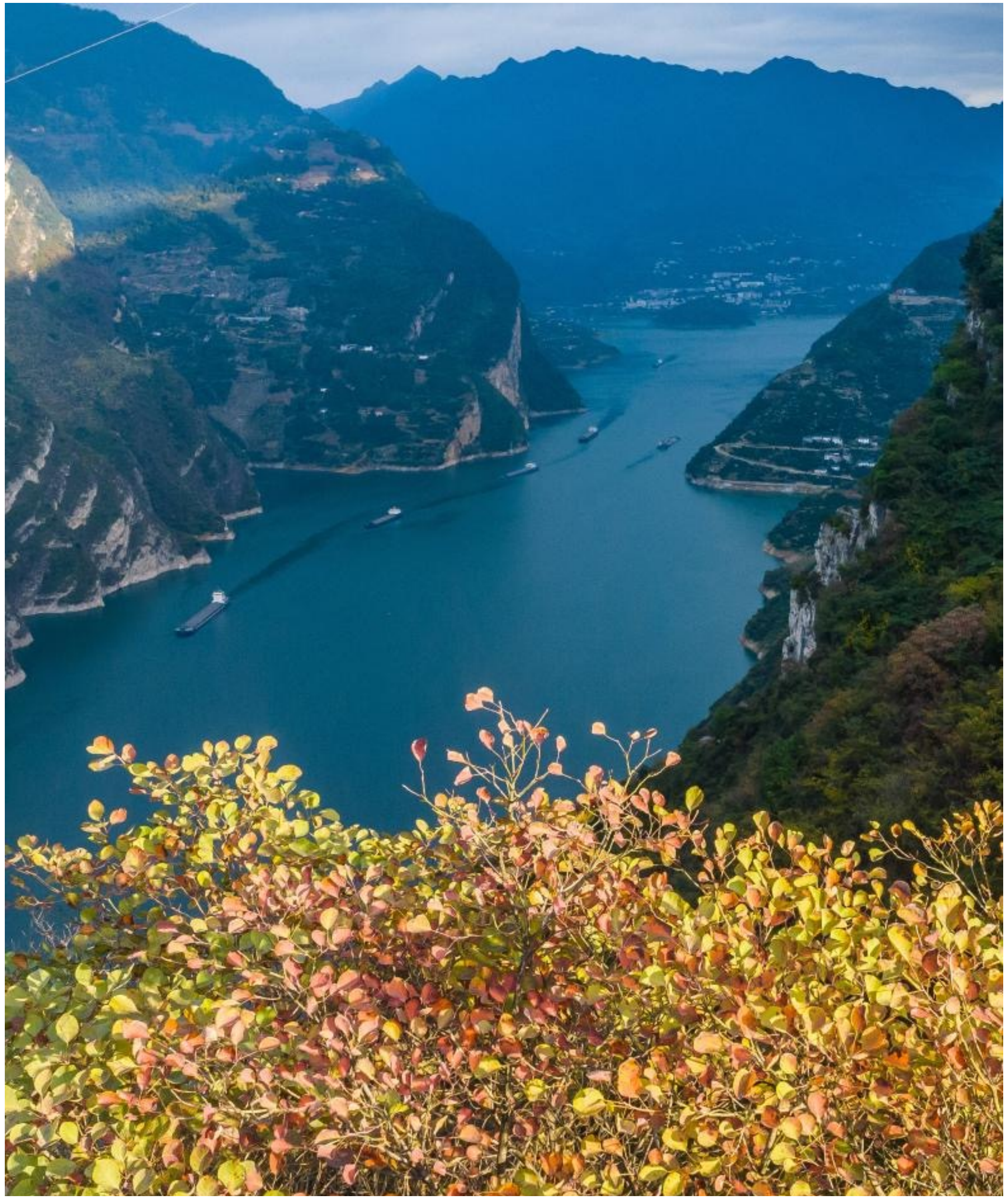
v_n decorrelations (deformation-induced component):
C. Zhang, S. Huang, J. Jia, *2405.08749*
J. Jia, S. Huang, C. Zhang, S. Bhatta, *2408.15006*

p_T decorrelations and EoS:
L. Liu, J. Chen, X.-G. Huang, J. Jia, C. Shen, C. Zhang, *2511.11094*
J. Zhu, X.-Y. Wu, G.-Y. Qin, *2602.04148*
S. Jahan, Roch, C. Shen, *PRC 113, 024919 (2026)*
…

2) Energy evolution, system scan in nuclear reaction



Acknowledgement

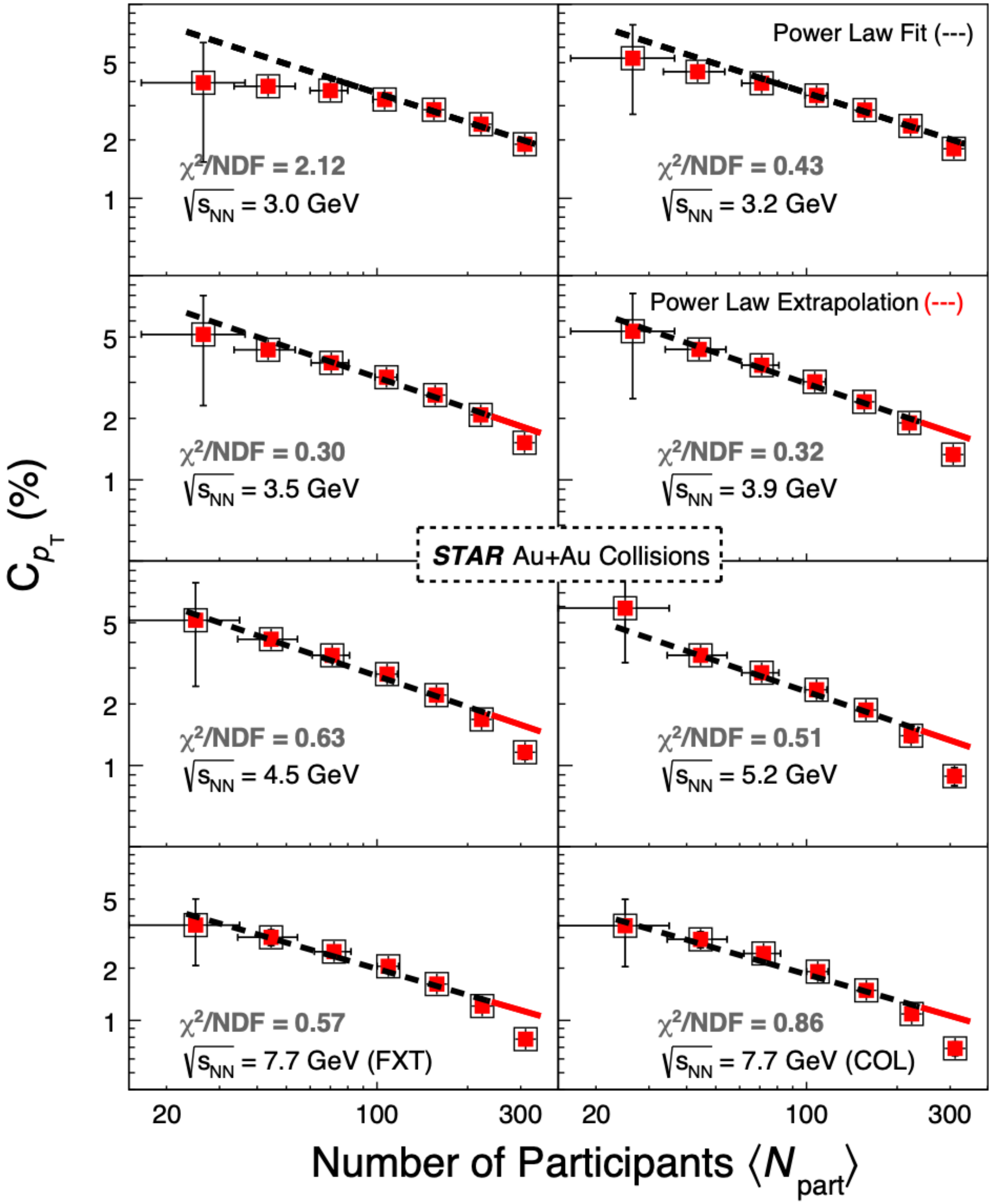


Thank you

Backup

Correlator $\sqrt{\Delta p_{T,i}\Delta p_{T,j}}/\langle\langle p_T\rangle\rangle$ vs centrality in FXT mode

STAR, *arXiv: 2604.06434*



- correlations larger in the peripheral collisions and decrease with centrality

- Measurements deviate from power law behavior, implying the centrality dependence does not follow a simple superposition scenario

- Independent of the collision mode: good agreement between measurements made at 7.7 GeV in FXT and collider modes.