Longitudinal De-correlation of Anisotropic Flow at RHIC-STAR

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For the STAR Collaboration

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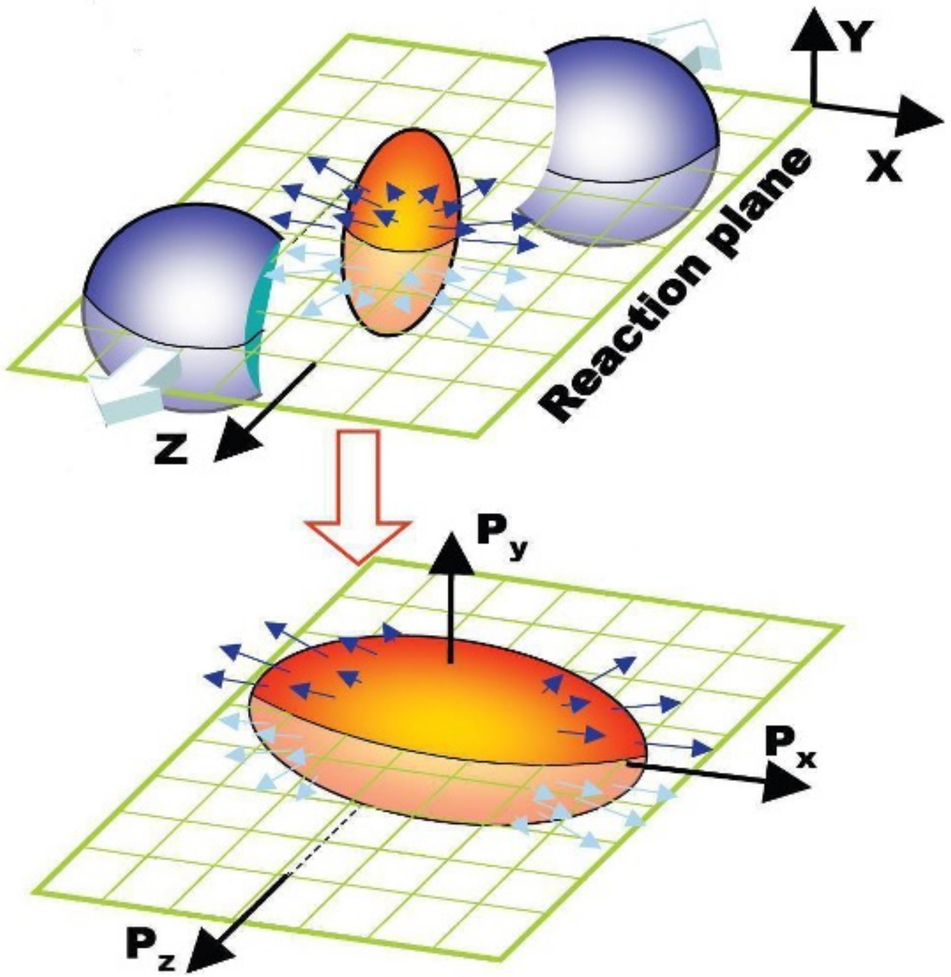
Supported in part by the U.S. DEPARTMENT OF ENERGY Office of Science

Anisotropic flow



$$\frac{dN}{d\phi} \propto 1 + 2\sum_{n=1} v_n cos\{n(\phi - \psi_n)\}$$

S. Voloshin, Y. Zhang
Z. Phys. C70: 665-672,1996

v_2: elliptic flow v_3: triangular flow

- Two-particle correlation method (2PC)

$$\frac{dN^{pair}}{d\phi} \propto 1 + 2\sum_{n=1} V_{n\Delta} cos(n\Delta\phi)$$

S. Wang et al.
Phys. Rev. C 44, 1091 (1991).

- Single particle flow:

$$V_{n\Delta} = v_n^a(p_T^a, \eta^a) v_n^b(p_T^b, \eta^b)$$

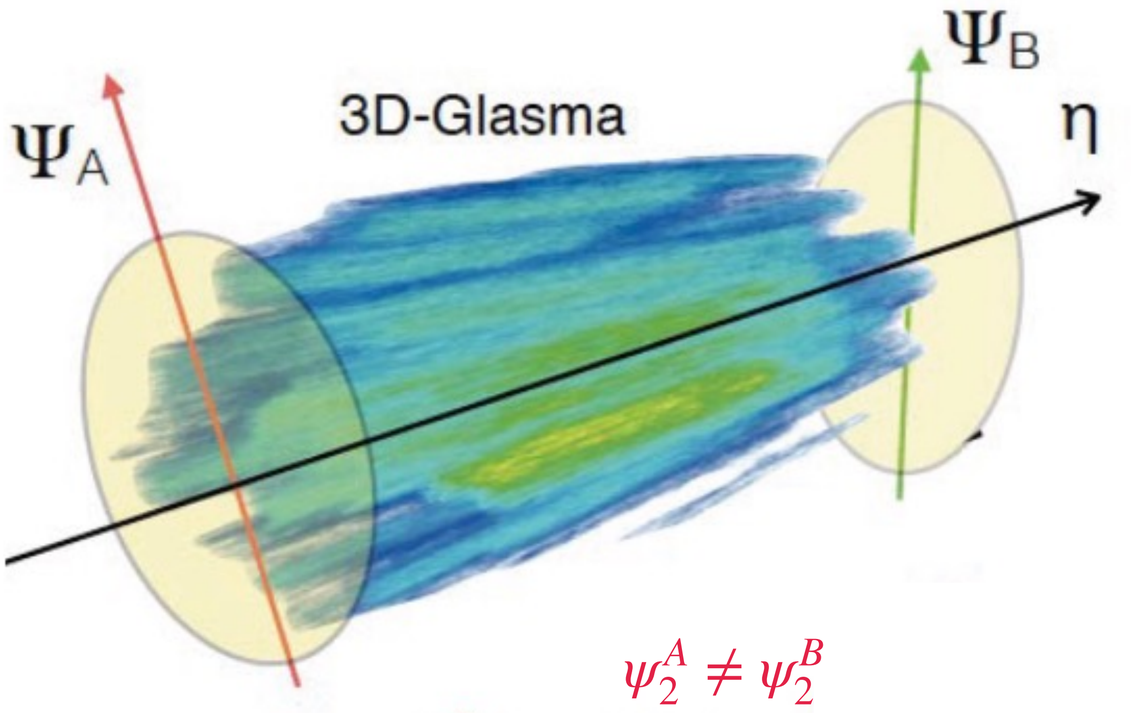
- Event-by-event fluctuation

$$V_{n\Delta} = v_n^a(p_T^a, \eta^a) v_n^b(p_T^b, \eta^b) e^{in(\psi_n^a - \psi_n^b)}$$

Fernando G. Gardim et al.
Phys. Rev. C. 87. 031901

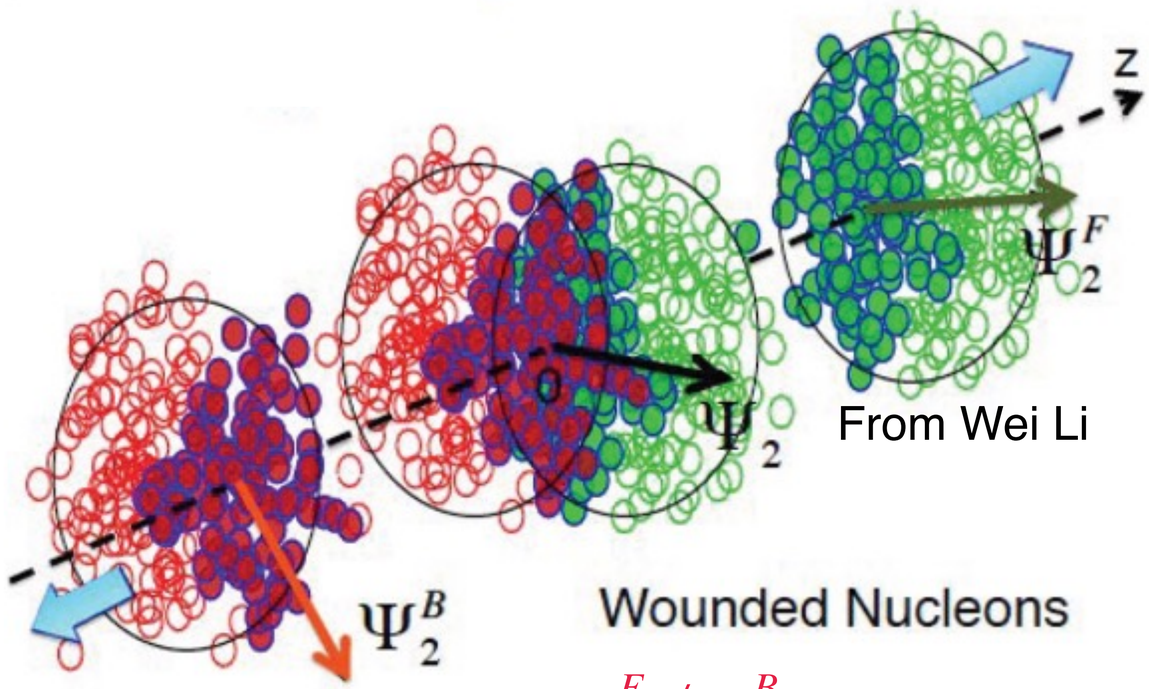
Piotr Bozek et al.
Phys. Rev. C. 83. 034911

Longitudinal de-correlation



$\psi_2^A \neq \psi_2^B$

Bjorn Schenke, Soren Schlichting
Phys. Rev. C 94 (2016) 4, 044907



$\psi_2^F \neq \psi_2^B$

Jiangyong Jia, Peng Huo
Phys. Rev. C 90 (2014) 034905

Measurement of de-correlation can probe 3D initial state and dynamical evolution of the QGP

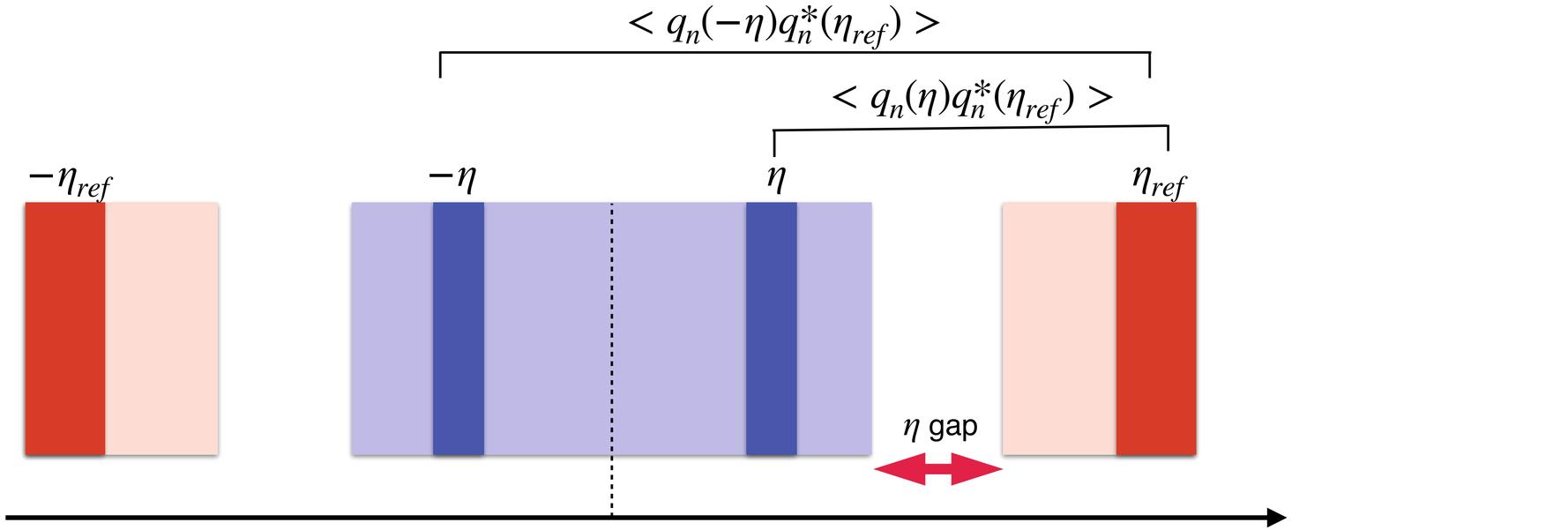
Measuring de-correlation

- The factorization ratio, r_n, is constructed to measure flow de-correlation

$$r_n(\eta) = \frac{< q_n(-\eta) q_n^*(\eta_{ref}) >}{< q_n(+\eta) q_n^*(\eta_{ref}) >} = \frac{< v_n(-\eta) v_n(\eta_{ref}) cos\{n[\psi_n(-\eta) - \psi_n(\eta_{ref})]\}) >}{< v_n(+\eta) v_n(\eta_{ref}) cos\{n[\psi_n(+\eta) - \psi_n(\eta_{ref})]\}) >}$$

CMS Collaboration
Phys. Rev. C 92 (2015) 034911

- The $r_n(\eta)$ measures relative fluctuation between $-\eta$ and $+\eta$



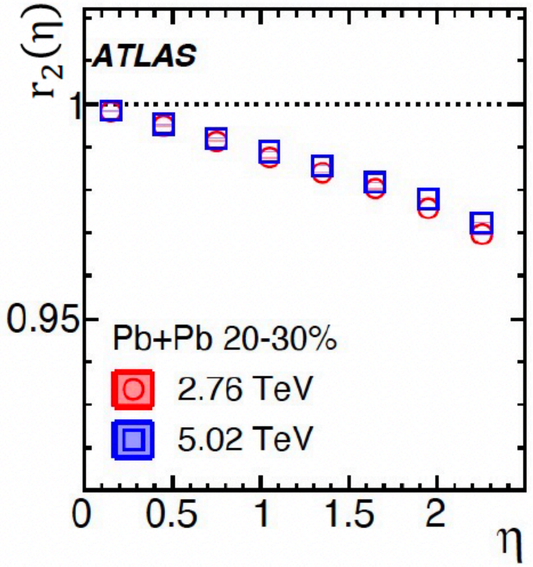
From Maowu Nie

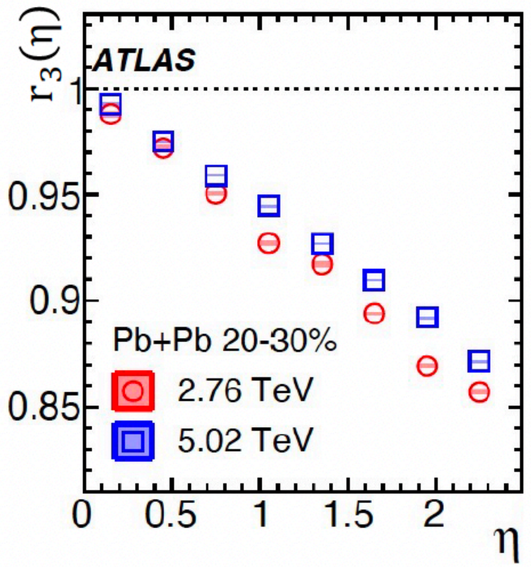
A large η gap can avoid short-range correlation

LHC results

- Energy dependence

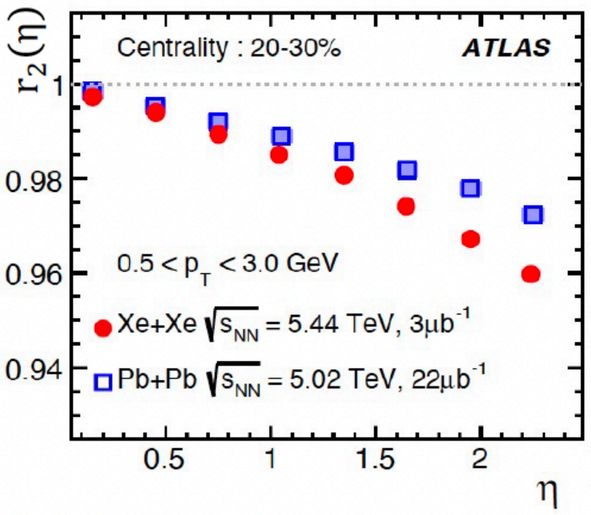
ATLAS Collaboration
Eur. Phys. J. C 78 (2018) 2, 142

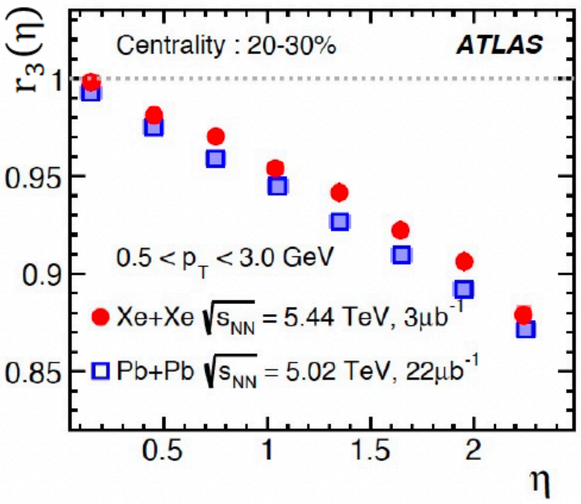




- System size dependence

ATLAS Collaboration
Phys. Rev. Lett. 126 (2021) 122301





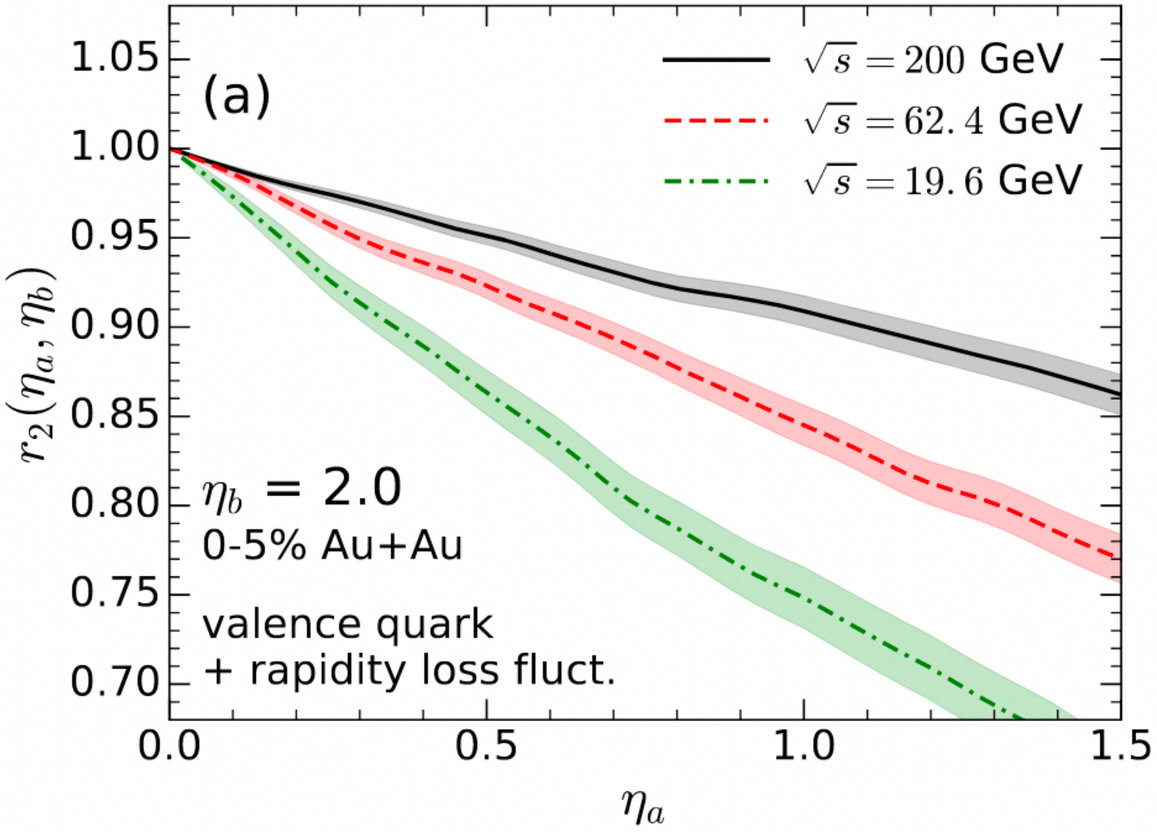
Indication of larger longitudinal de-correlation at lower energy

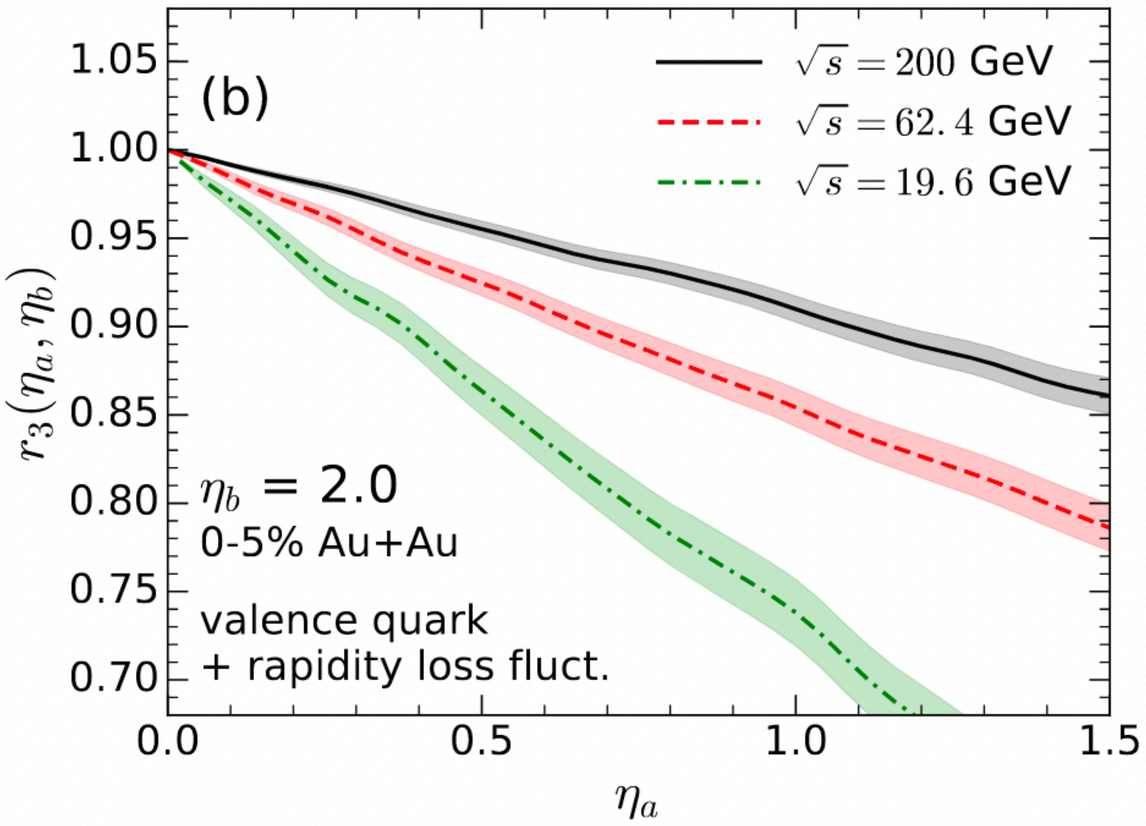
Smaller system size has larger longitudinal de-correlation

What about at RHIC? → Energy dependence: Beam Energy Scan

System size dependence: various species

Dynamical initial state model calculation

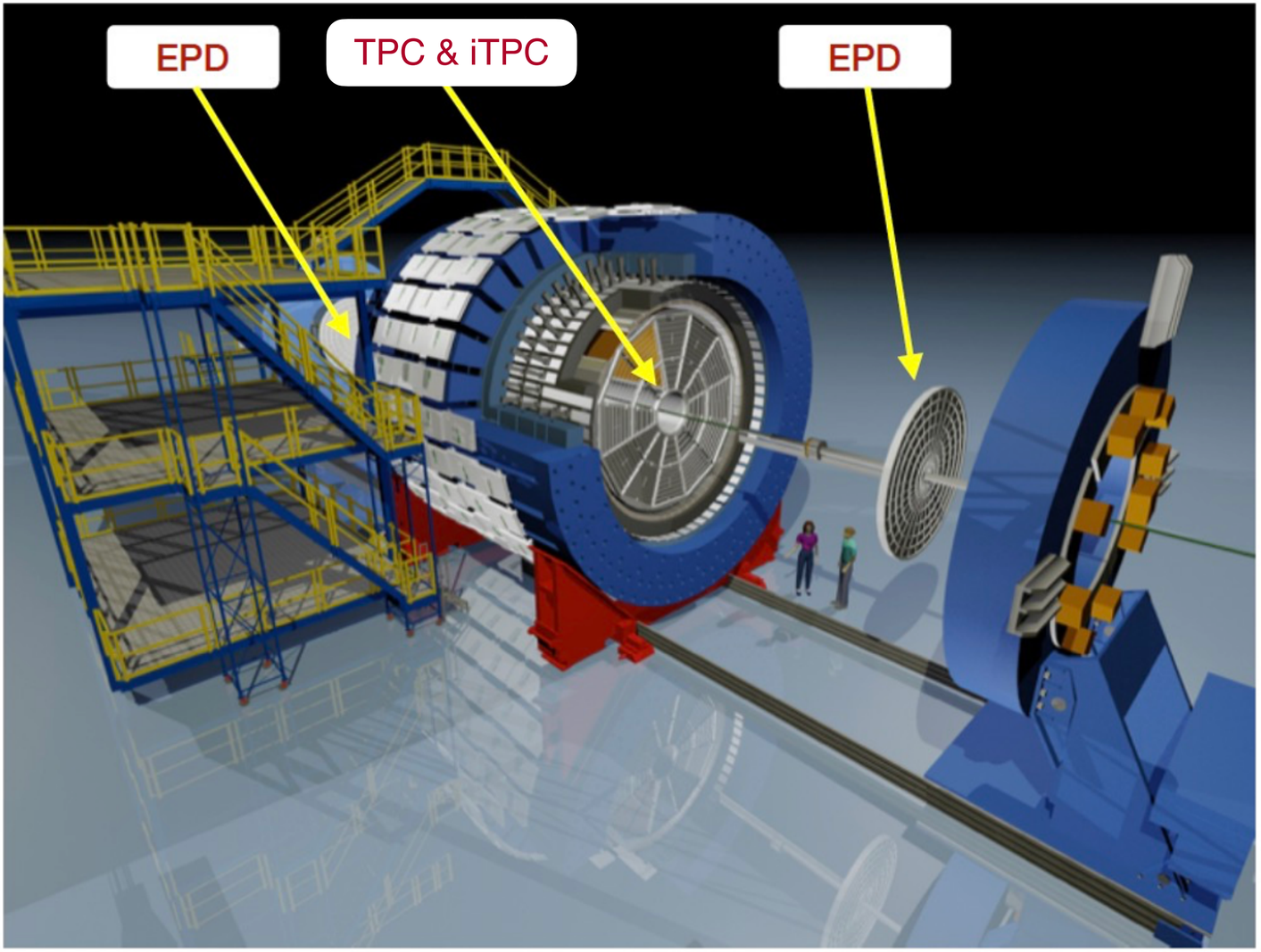




The de-correlation effect becomes stronger at lower collision energies

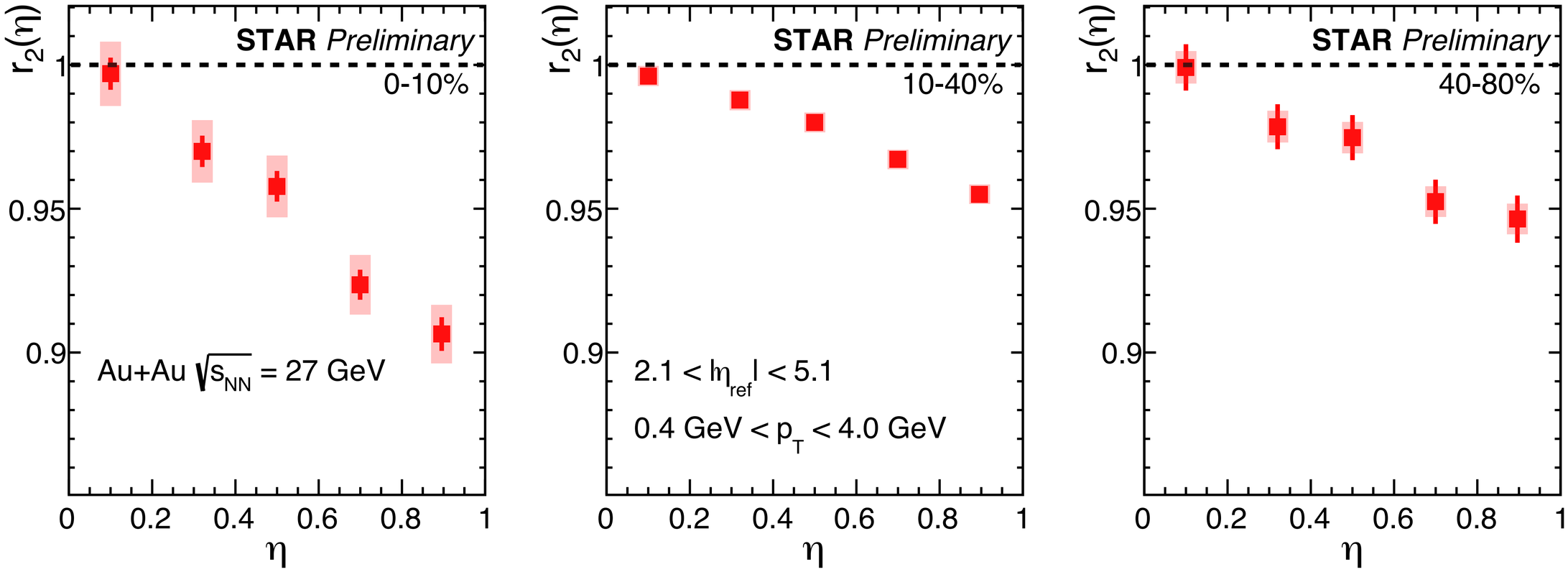
Chun Shen, Bjorn Schenke
Phys. Rev. C 97 (2018) 2, 024907

The STAR detector and datasets



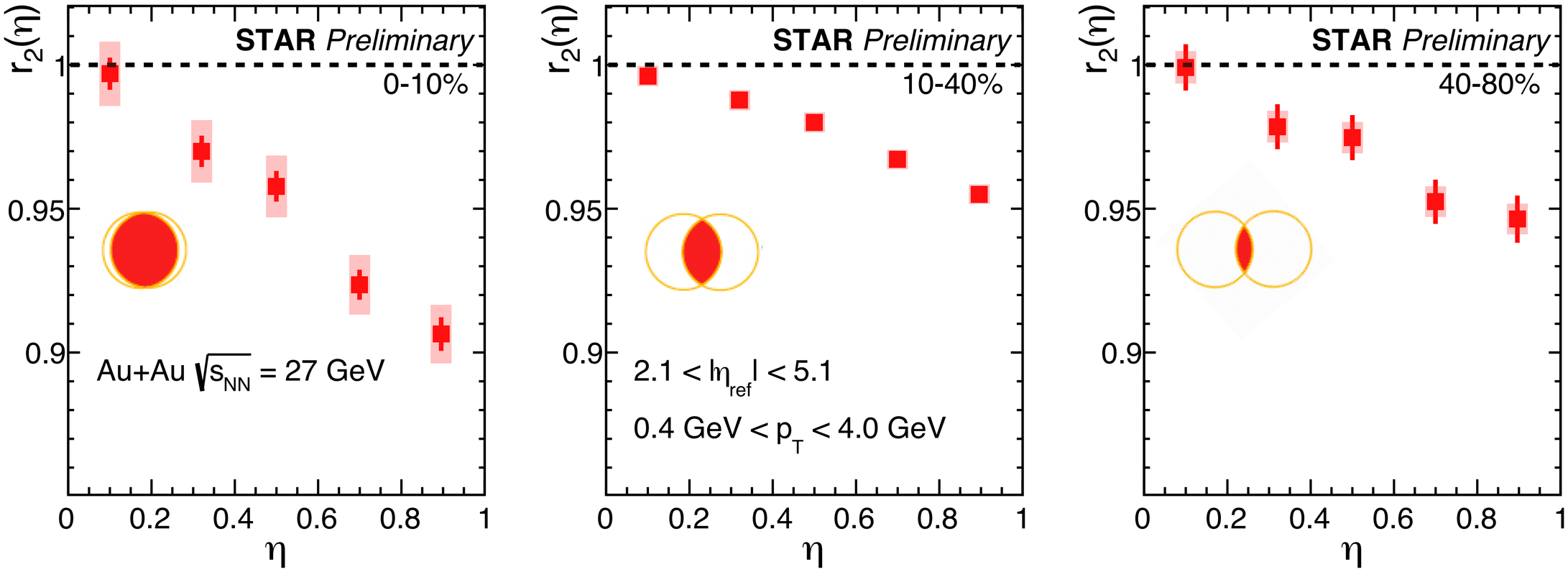
- Time Projection Chamber
  - Full azimuthal coverage
  - TPC: $|\eta| < 1.0$
  - iTPC: $|\eta| < 1.5$
- Event Plane Detector
  - Better event plane resolution
  - $2.1 < |\eta| < 5.1$
- Data
  - Zr+Zr/Ru+Ru collisions at 200 GeV
  - Au+Au collisions at 19.6, 27, 54.4 GeV

2nd order de-correlation in Au+Au at 27 GeV



Significant longitudinal de-correlation at RHIC energy

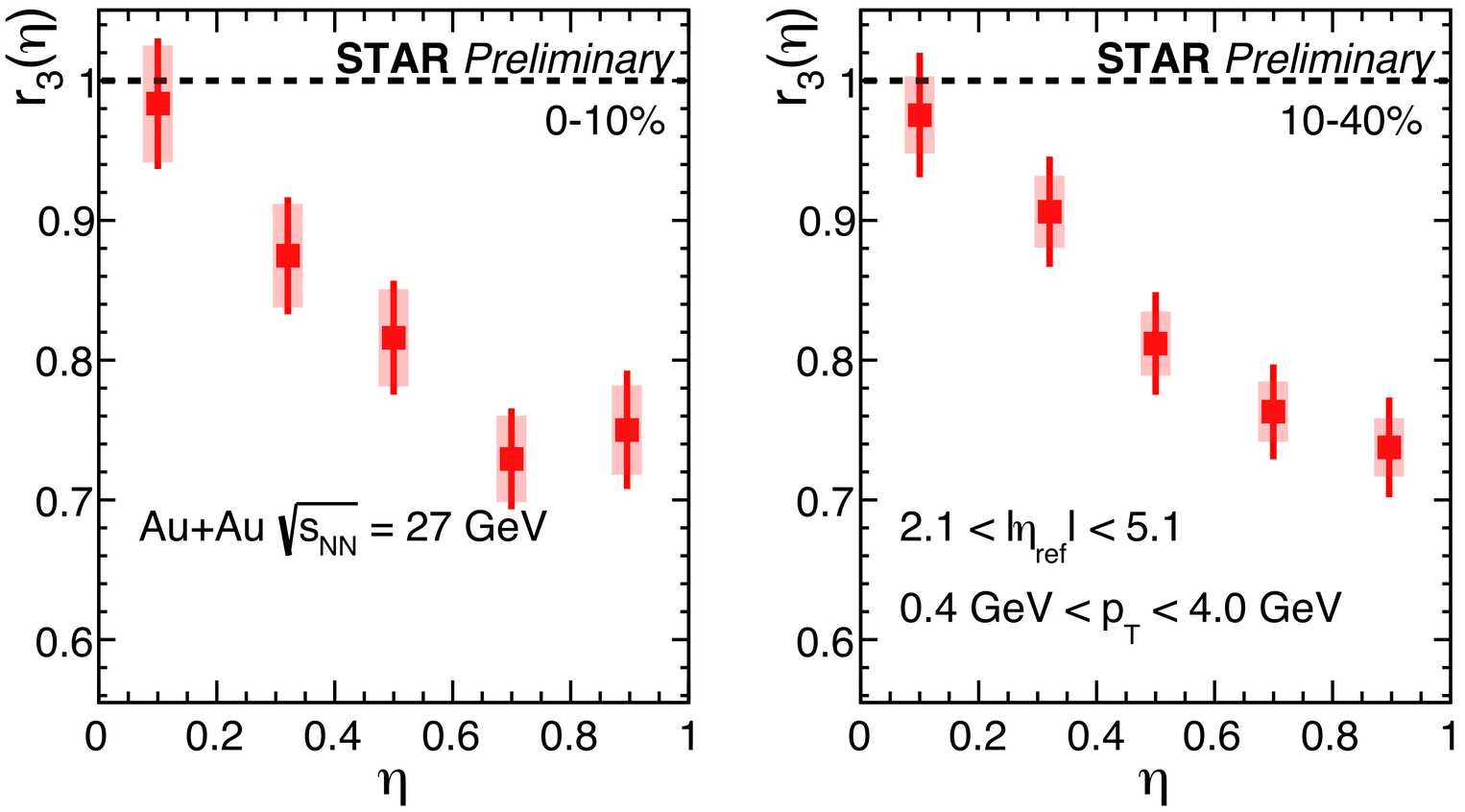
2nd order de-correlation in Au+Au at 27 GeV



Significant longitudinal de-correlation at RHIC energy

De-correlation is the strongest in central collisions

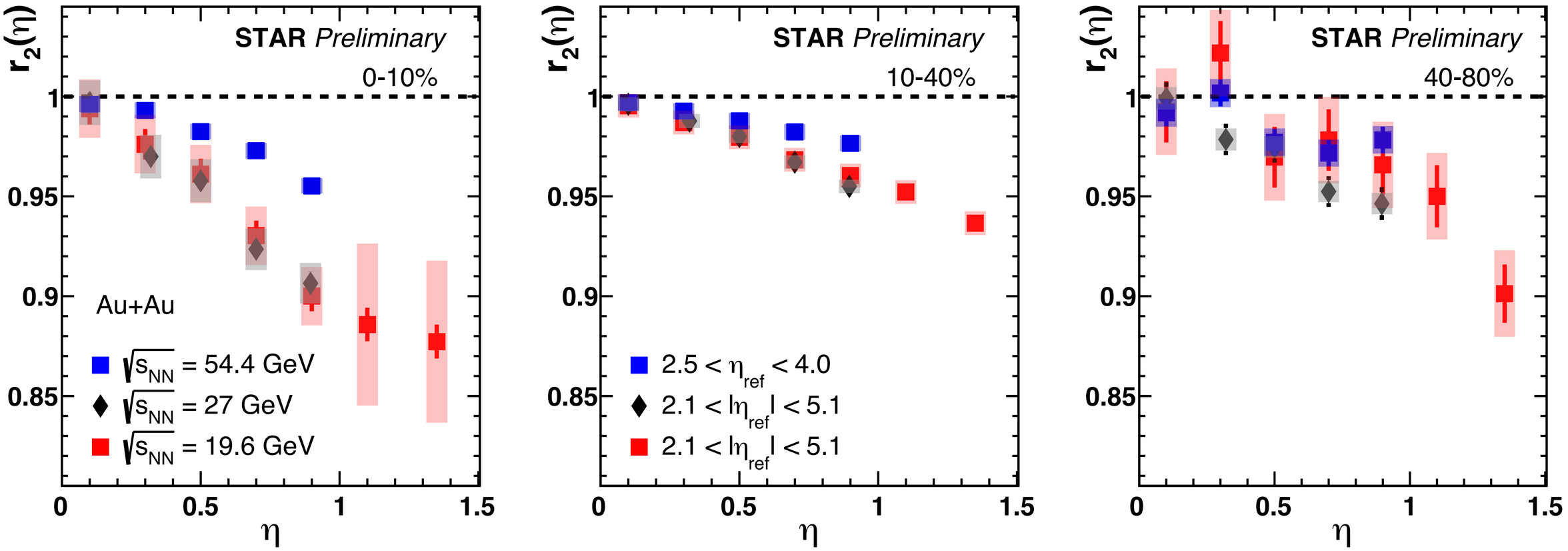
3rd order de-correlation in Au+Au at 27 GeV



No obvious centrality dependence

The 3rd order de-correlation is 2-3 times stronger than 2nd order

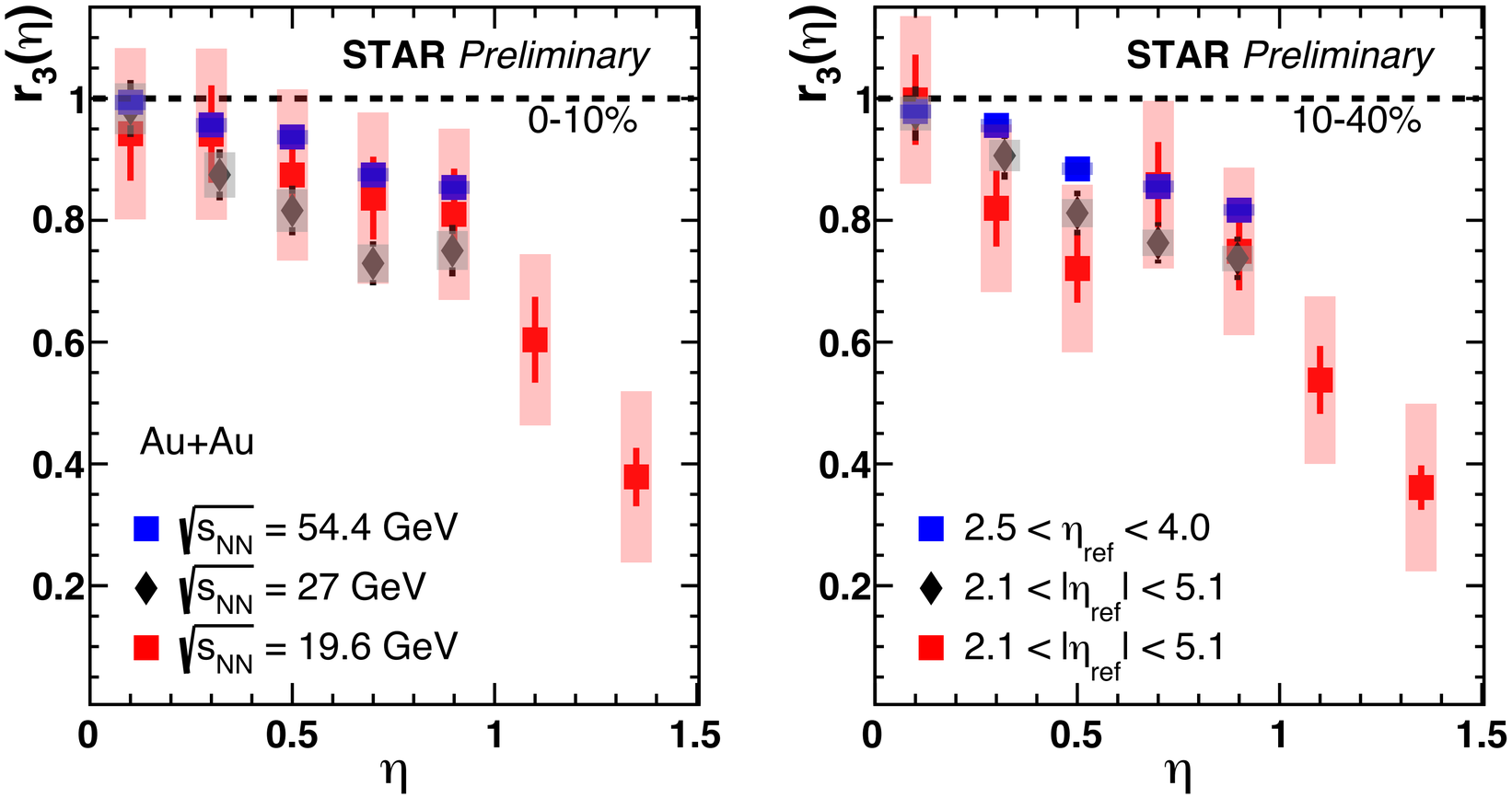
Collision energy dependence of r_2



Clear energy dependence between 54 GeV and 27 GeV

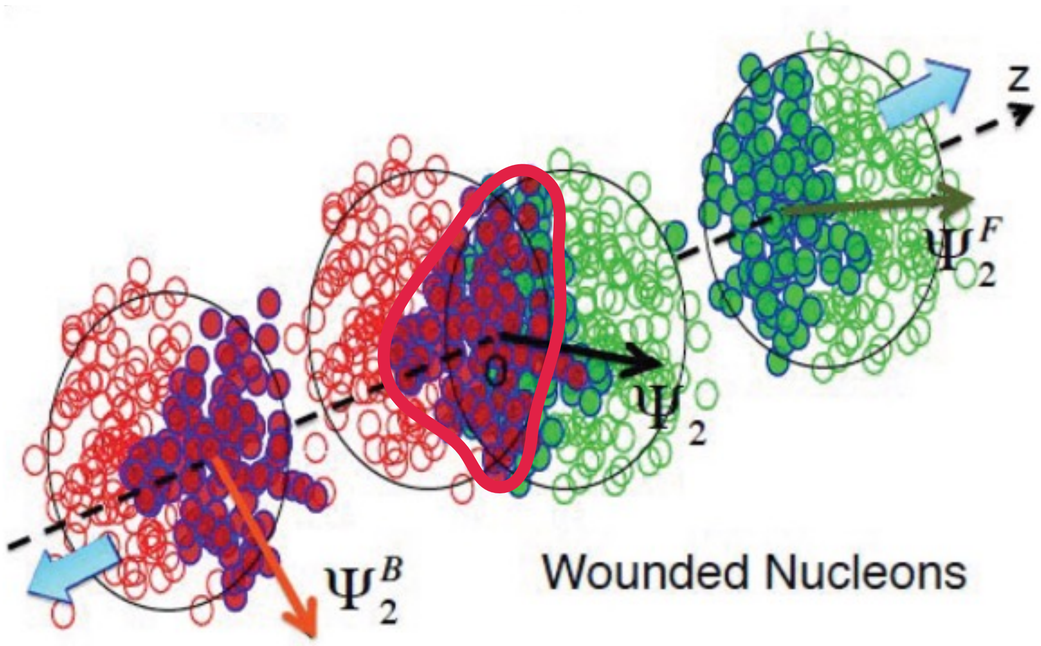
Hint of nonlinear energy dependence?

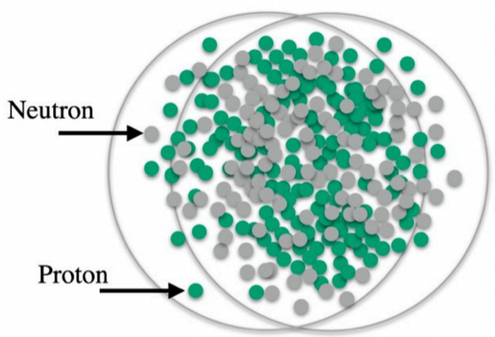
Collision energy dependence of r_3



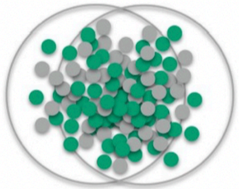
Clear energy dependence between 54 GeV and 27 GeV

System size dependence





$^{197}_{79}Au + ^{197}_{79}Au$

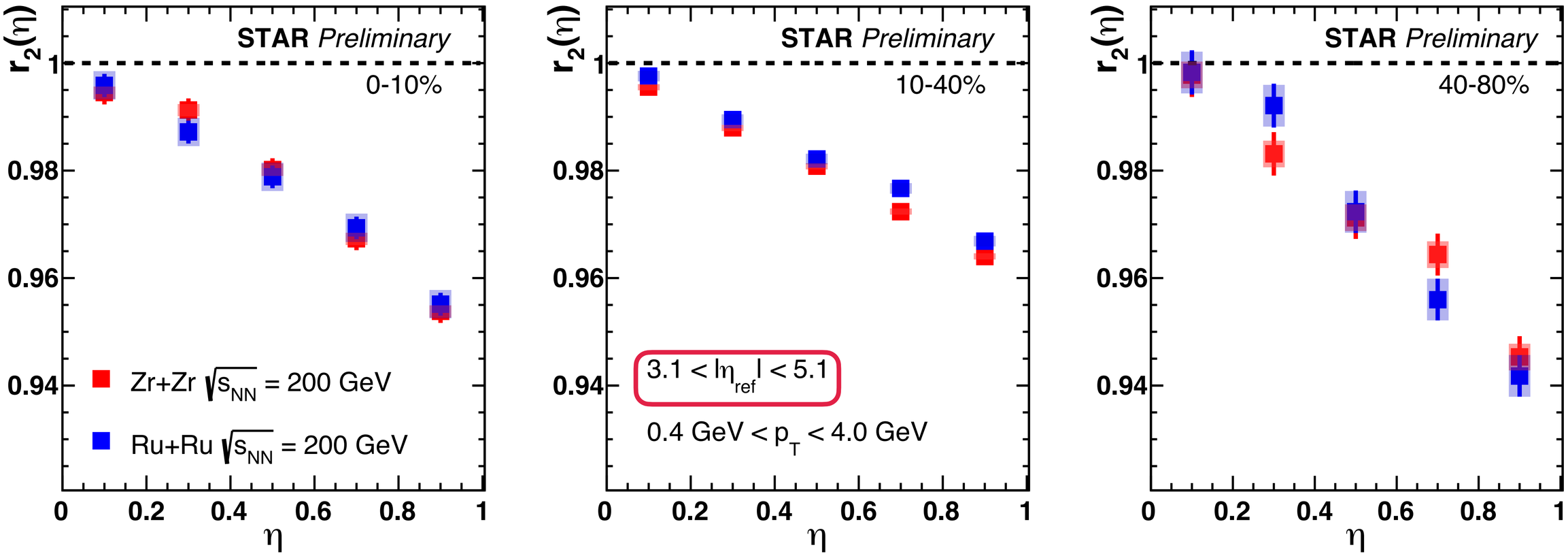


$^{96}_{40}Zr + ^{96}_{40}Zr$ / $^{96}_{44}Ru + ^{96}_{44}Ru$

Smaller initial size and shorter evolution time lead to larger different event plane between forward and backward directions

Longitudinal de-correlation in smaller collisions system is expected to be larger

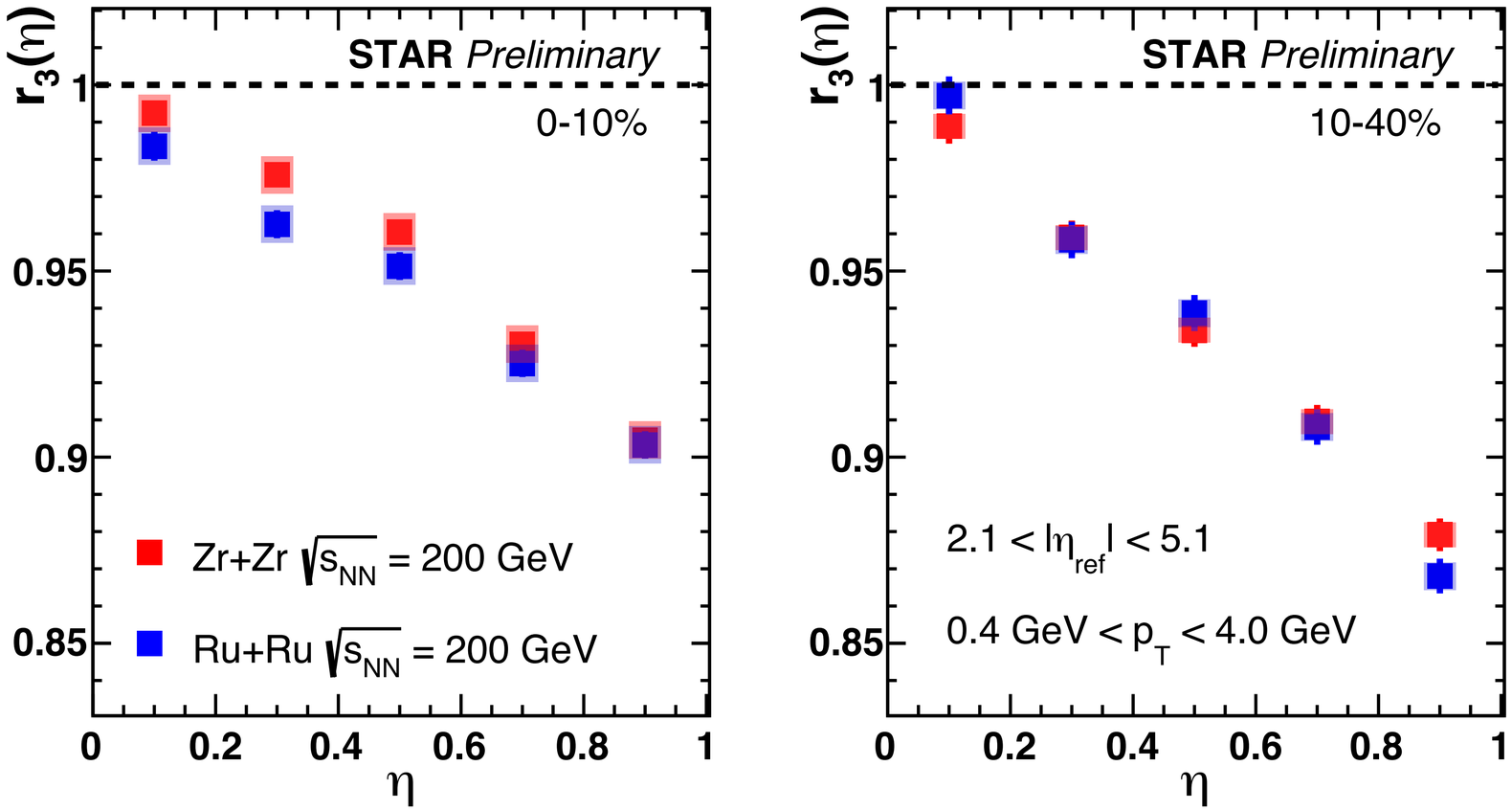
2nd order de-correlation in Zr+Zr/Ru+Ru



No obvious difference between Zr+Zr and Ru+Ru collisions within uncertainties

De-correlation is weakest in mid-central collisions

3rd order de-correlation in Zr+Zr/Ru+Ru

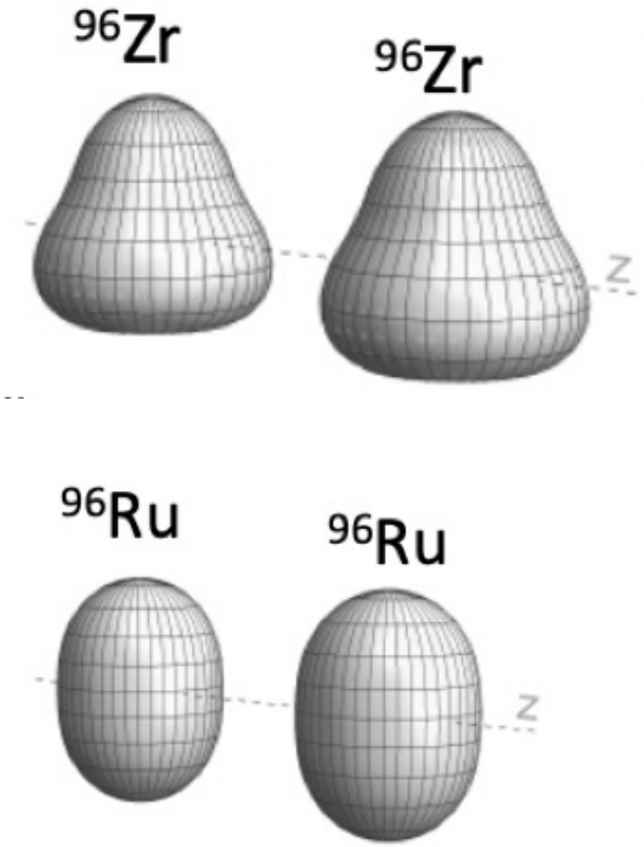


No obvious difference between Zr+Zr and Ru+Ru collisions within uncertainties

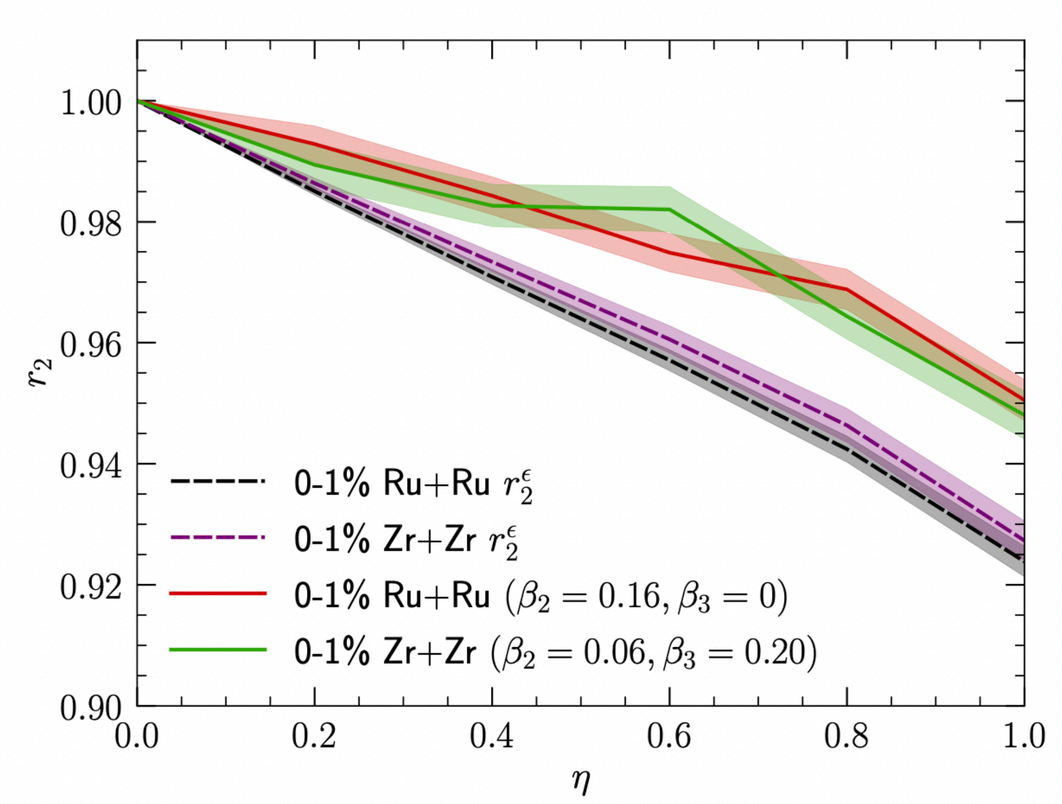
Indication of centrality dependence

The 3rd order de-correlation is 2-3 times stronger than 2nd order

Nuclear structure effect



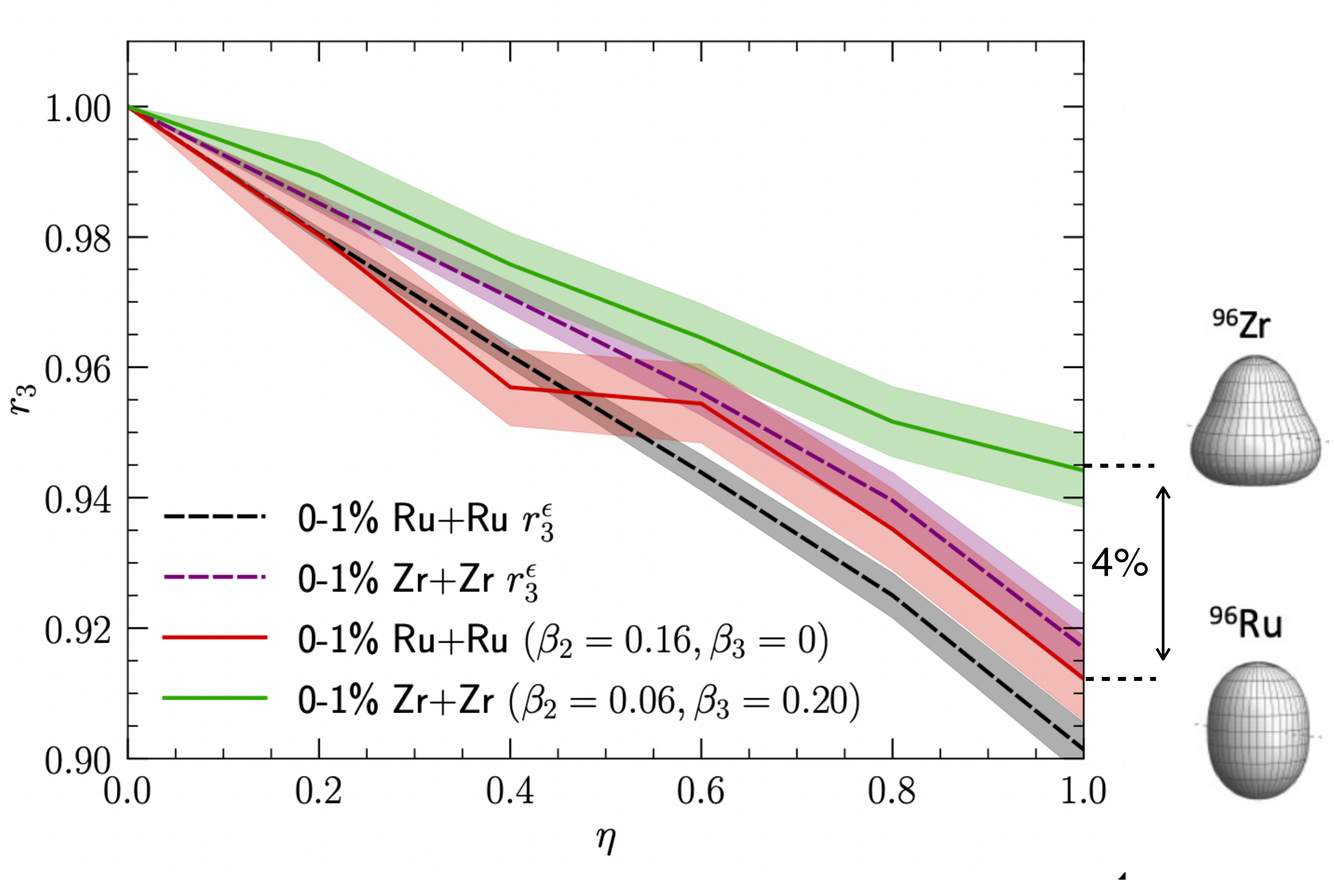
Chunjian Zhang and Jiangyong Jia
Phys. Rev. Lett. 128 (2022) 2, 022301

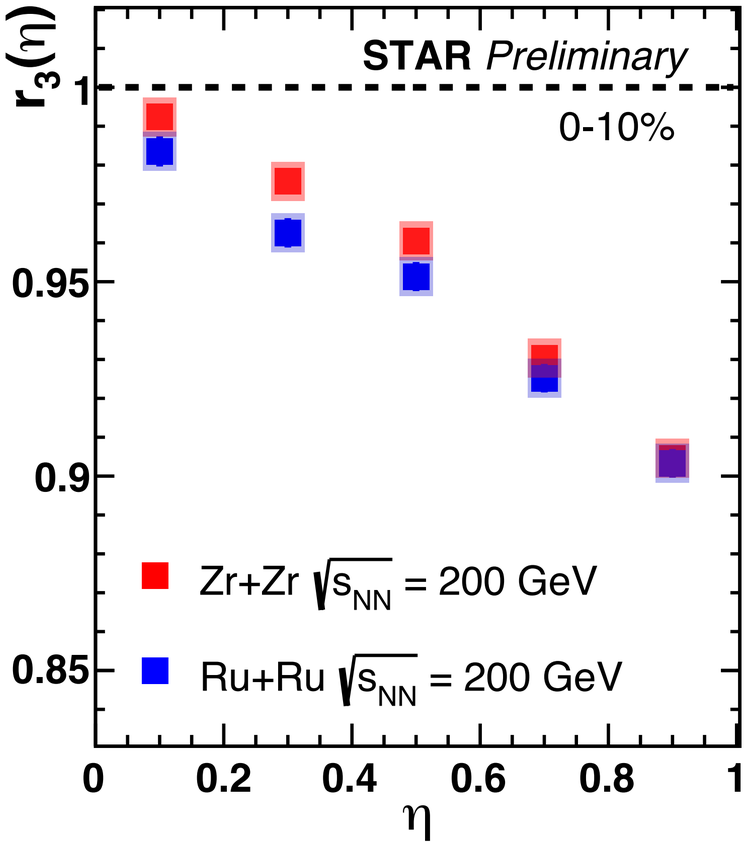


The β_2 has a very small influence in Zr+Zr and Ru+Ru collisions

From Chun Shen at the INT workshop: Intersection of nuclear structure and high-energy nuclear collisions

Nuclear structure effect



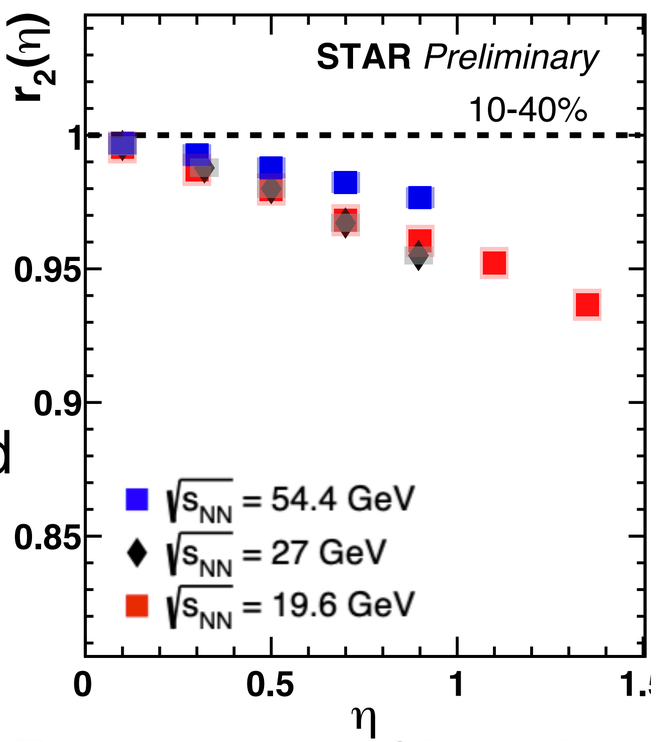


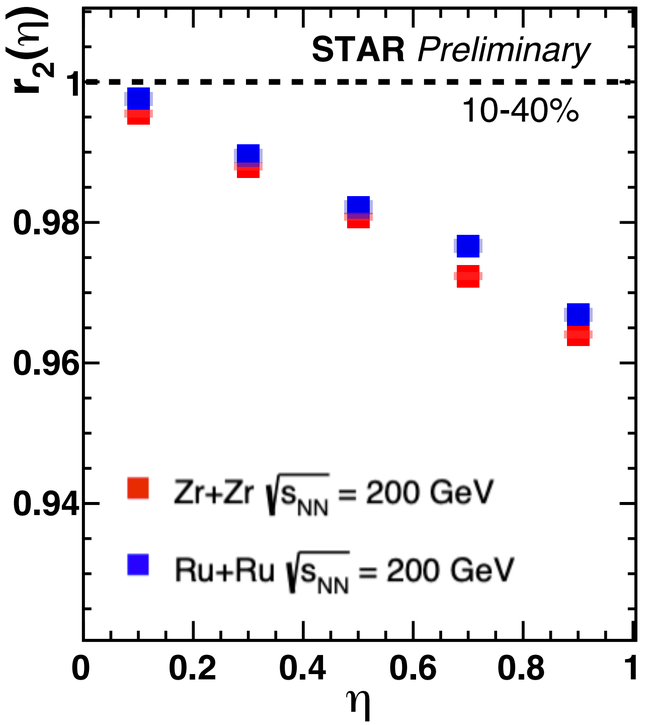
The non-zero β_3 in Zr+Zr collisions results in a smaller third order de-correlation than Ru+Ru collisions in very central collisions

From Chun Shen at the INT workshop: Intersection of nuclear structure and high-energy nuclear collisions

Summary

- Longitudinal de-correlation, $r_n(\eta)$ $(n = 2,3)$, in Au+Au collisions at 19.6, 27, 54.4 GeV and in Zr+Zr and Ru+Ru collisions at 200 GeV are measured
  - $r_2(\eta)$ shows centrality dependence
  - $r_3(\eta)$ shows weak centrality dependence
  - Lower collision energies show larger longitudinal de-correlation
  - No obvious difference between Zr+Zr and Ru+Ru collisions
    - Ultra central collision yet to explore





- The results provide new constraints on 3D structure of initial stages and dynamical evolution of the QGP in heavy-ion collisions

Outlook

- Using STAR BES-II data to study energy dependence precisely
- System size dependence: Au+Au, Zr+Zr/ Ru+Ru and O+O collisions

System	$\sqrt{s_{NN}}$ (GeV)	Events (10^6)	Year
Au+Au	54.4	1200	2017
Isobar	200	4000	2018
Au+Au	27	560	2018
Au+Au	19.6	538	2019
Au+Au	14.5	325	2019
Au+Au	11.5	230	2020
Au+Au	9.2	160	2020
Au+Au	7.7	100	2021
Au+Au	200	138	2019
O+O	200	400	2021
Au+Au	200	10000	2023

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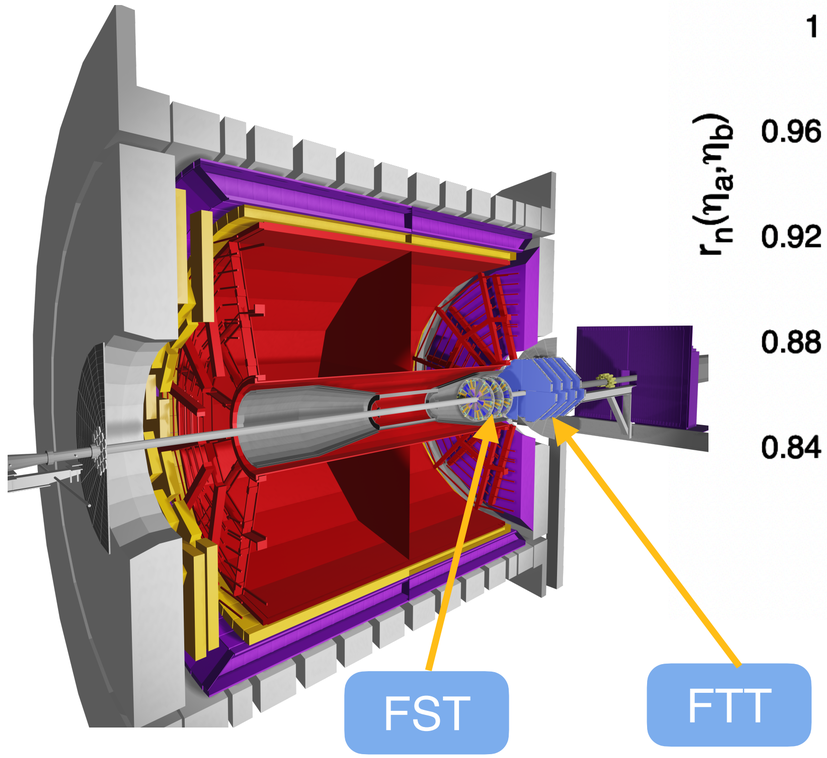
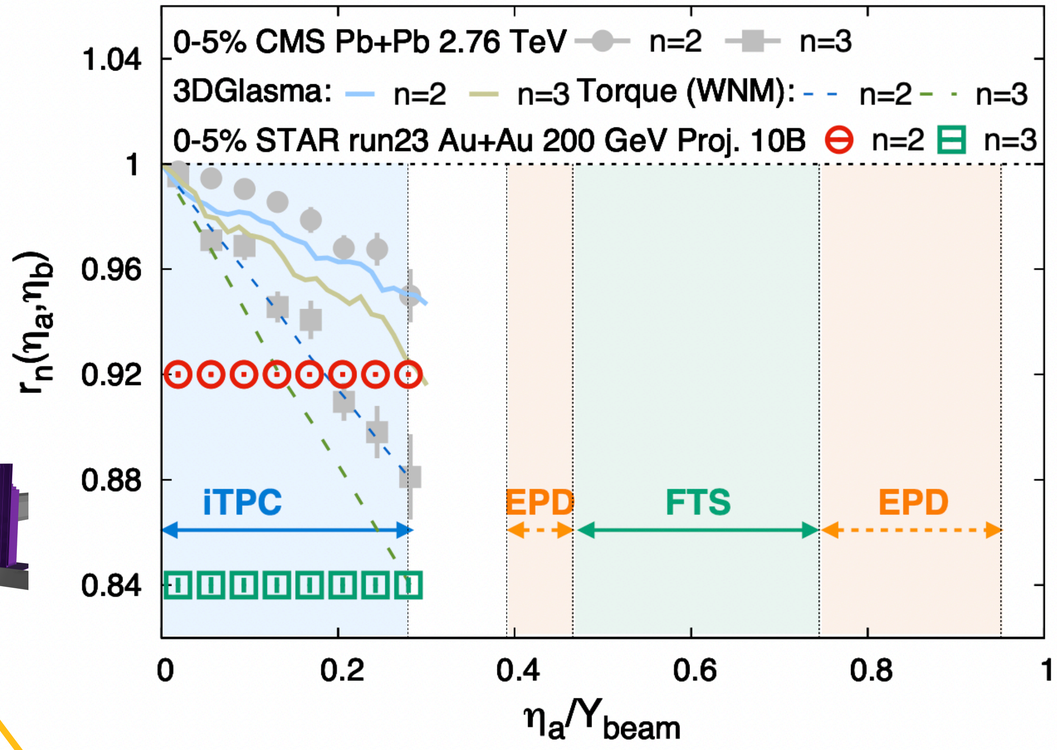
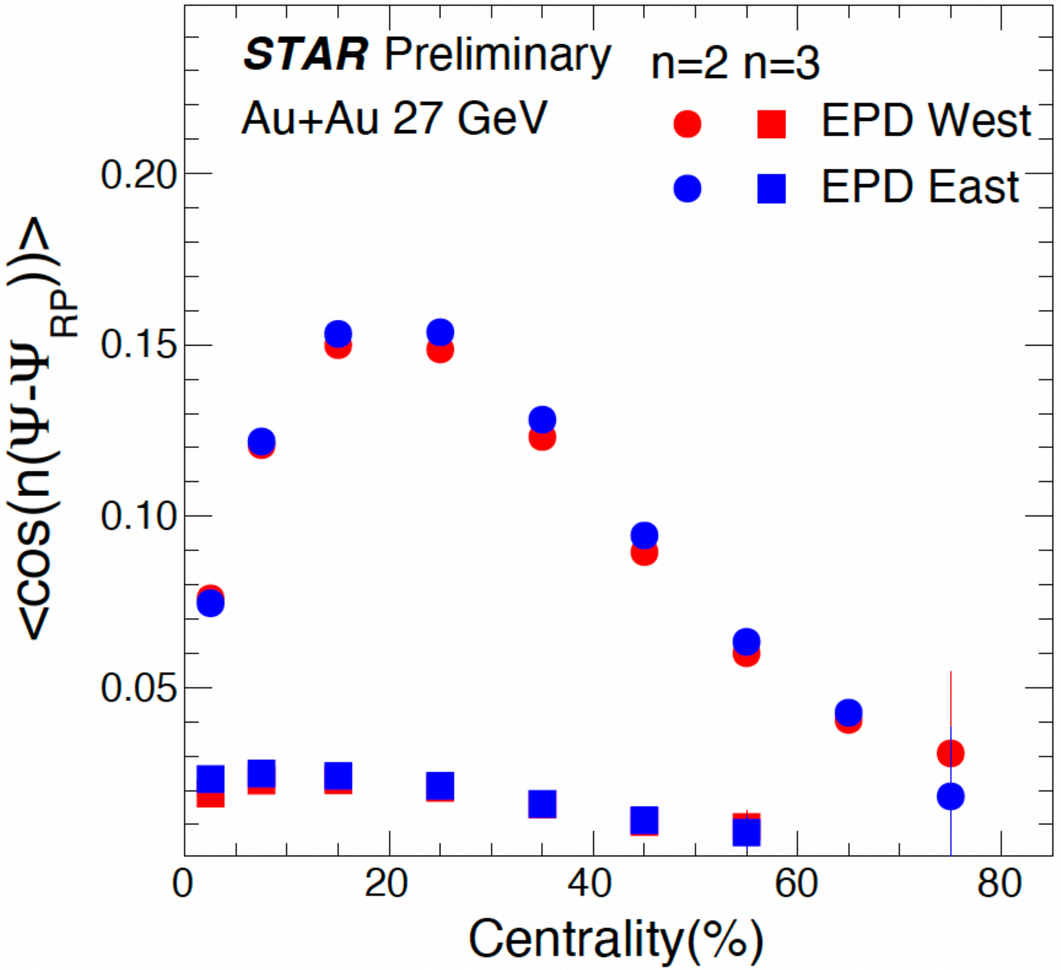


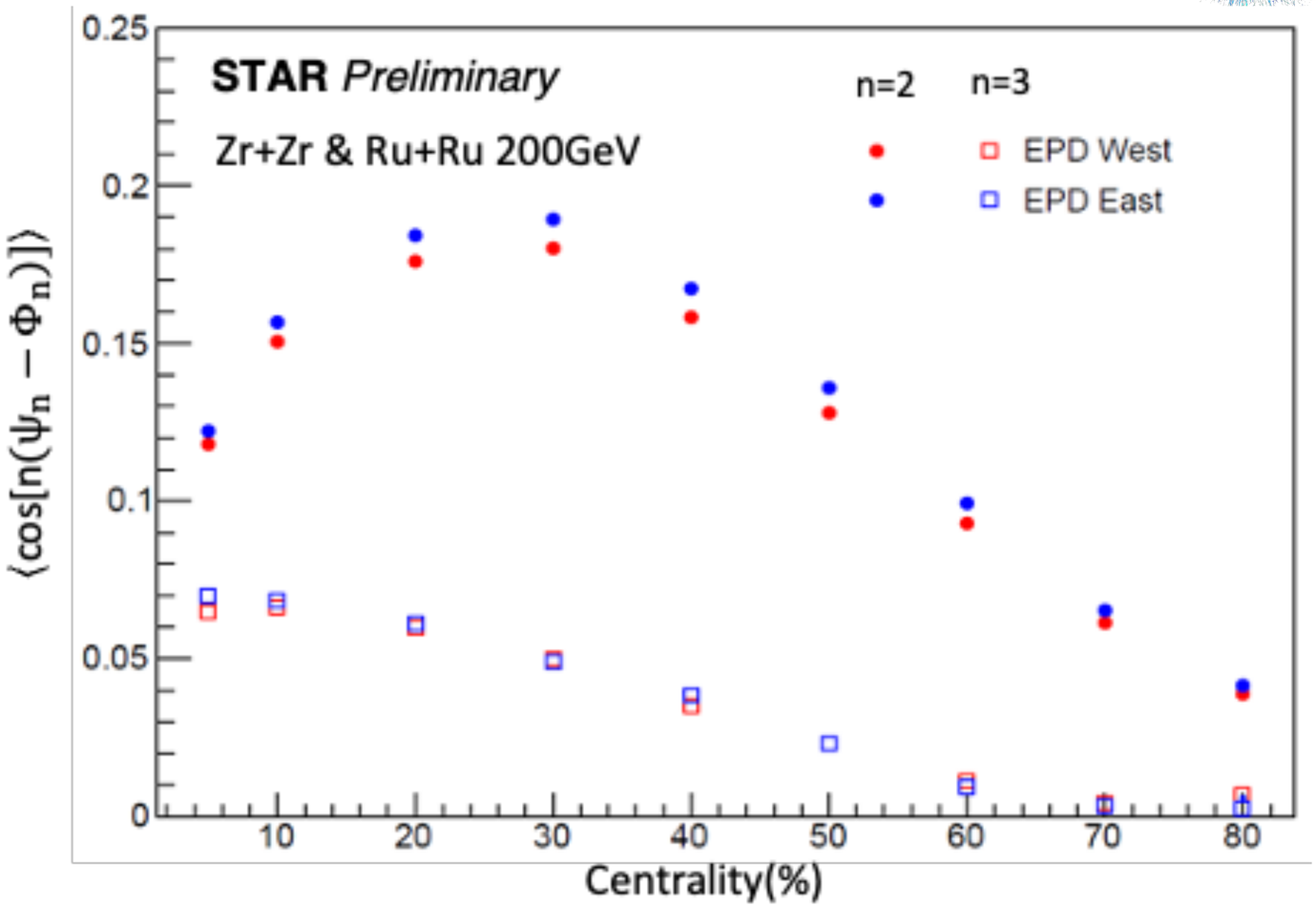
- Forward upgrade $(2.5 < \eta < 4.0)$: de-correlation in a larger η



Backup

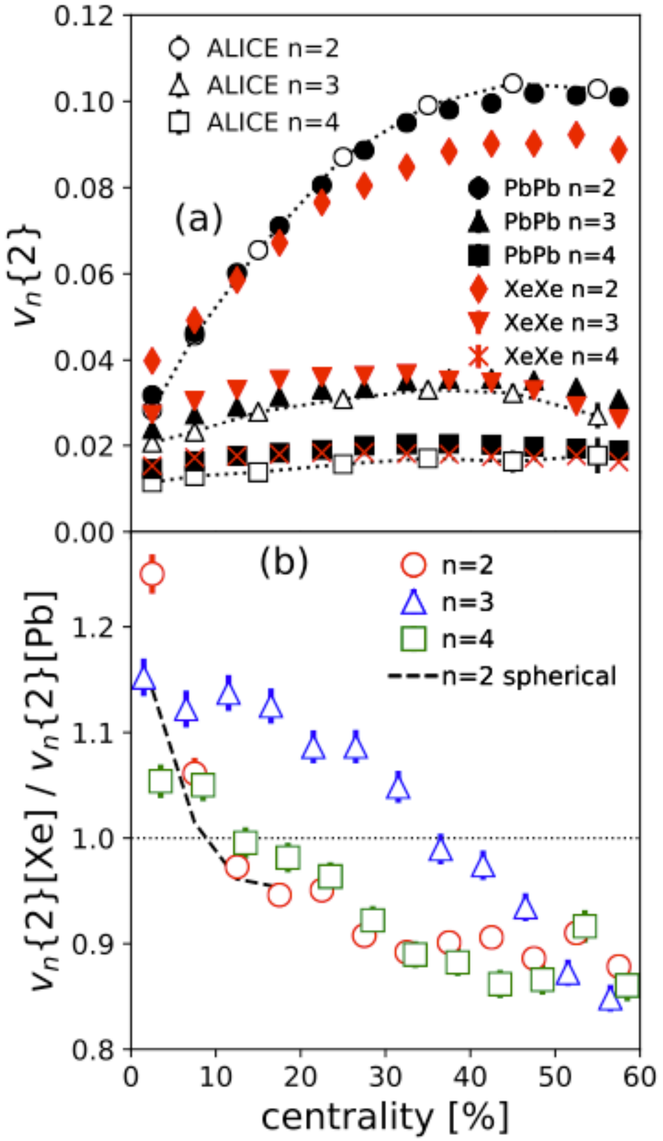
Resolution



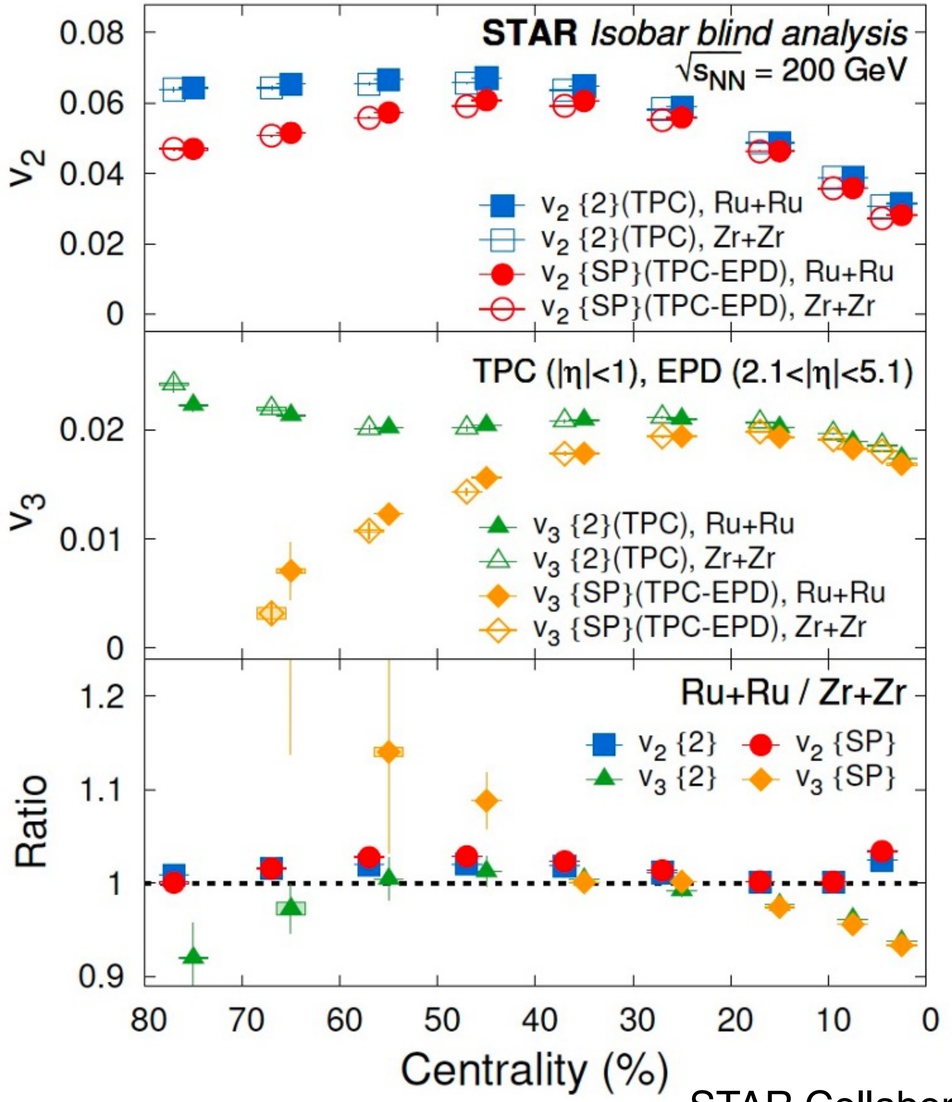


EPD shows consistent results for second and third order event plane resolutions

Anisotropic flow



Phys. Rev. C 97 (2018) 034904



STAR Collaboration
Phys. Rev. C 105 (2022) 014901