Probing initial and final state effects of heavy-ion collisions with STAR experiment

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For the STAR Collaboration

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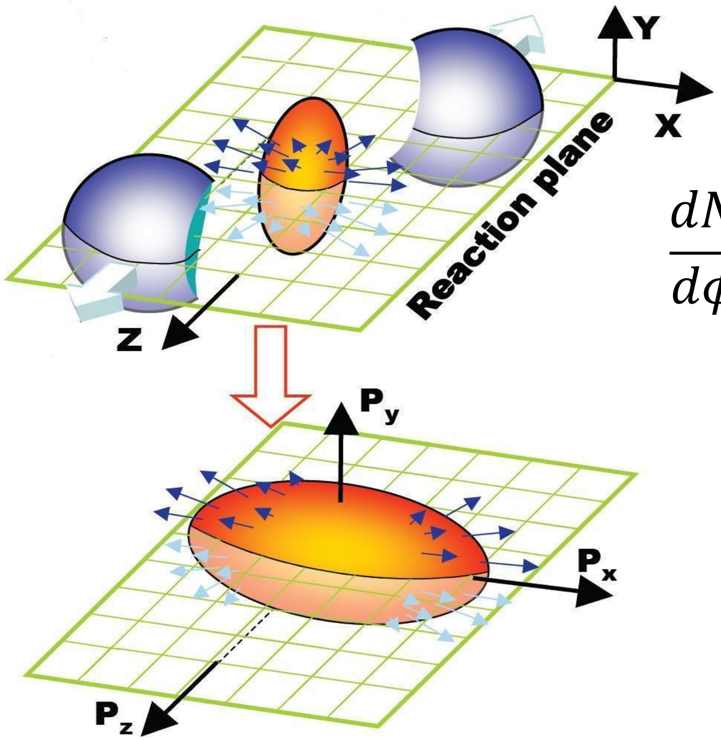
Supported in part by the

U.S. DEPARTMENT OF ENERGY | Office of Science

Longitudinal dynamics in heavy-ion collisions

➢ Anisotropic flow

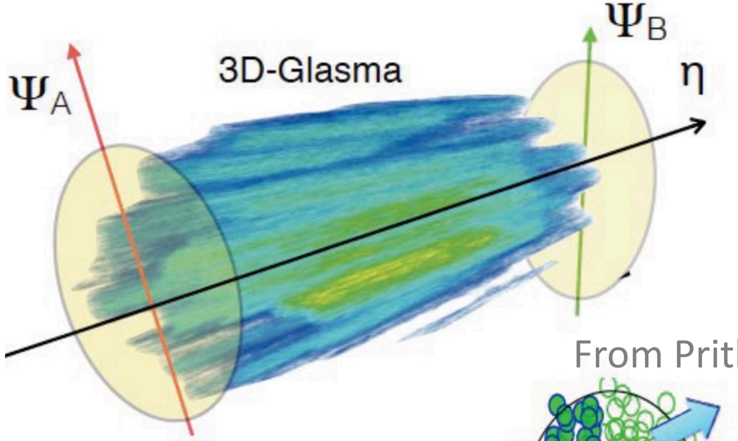


$$\frac{dN}{d\phi} \propto 1 + 2\sum_{n=1} v_n \cos(\phi - \psi_n)$$

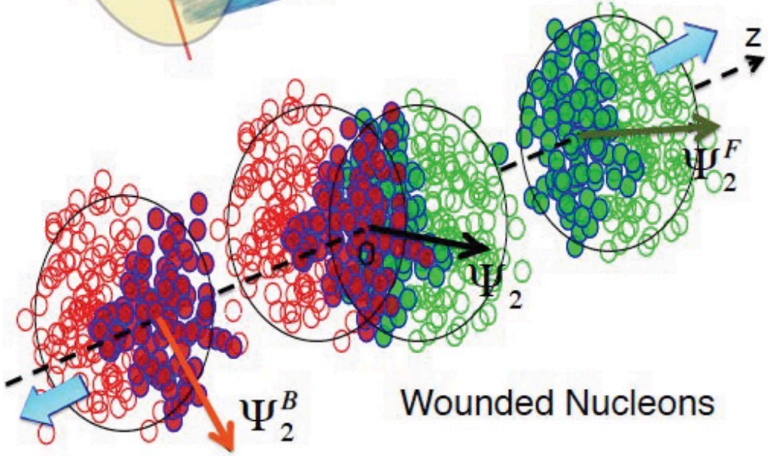
v_2: elliptic flow

v_3: triangular flow

➢ Longitudinal evolution



From Prithwish Tribedy



From Wei Li

The difference between forward and backward event planes probes longitudinal fluctuation

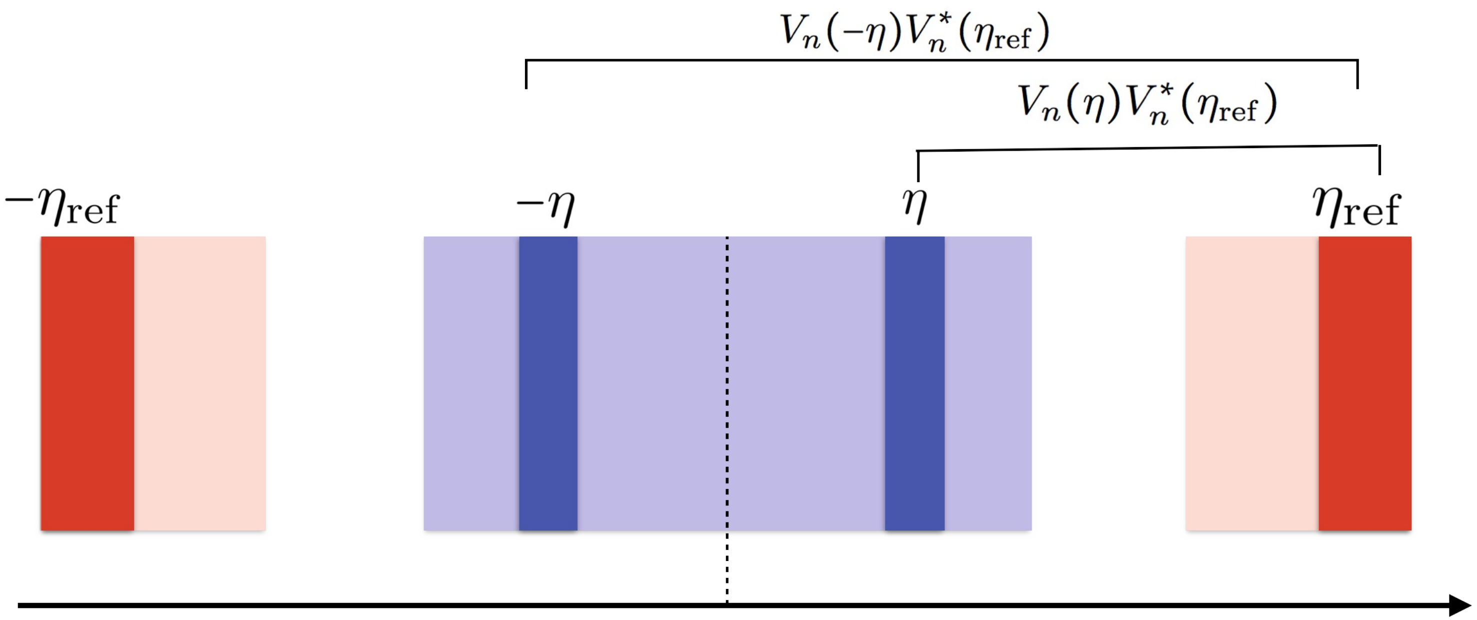
Flow decorrelation observables

- The ratio, r_n, is constructed as measurement of flow decorrelation

$$r_n(\eta) = \frac{\langle V_n(-\eta)V_n^*(\eta_{ref})\rangle}{\langle V_n(\eta)V_n^*(\eta_{ref})\rangle} = \frac{\langle v_n(-\eta)v_n(\eta_{ref})\cos\{n[\Psi_n(-\eta) - \Psi_n(\eta_{ref})]\}\rangle}{\langle v_n(\eta)v_n(\eta_{ref})\cos\{n[\Psi_n(\eta) - \Psi_n(\eta_{ref})]\}\rangle}$$

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

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

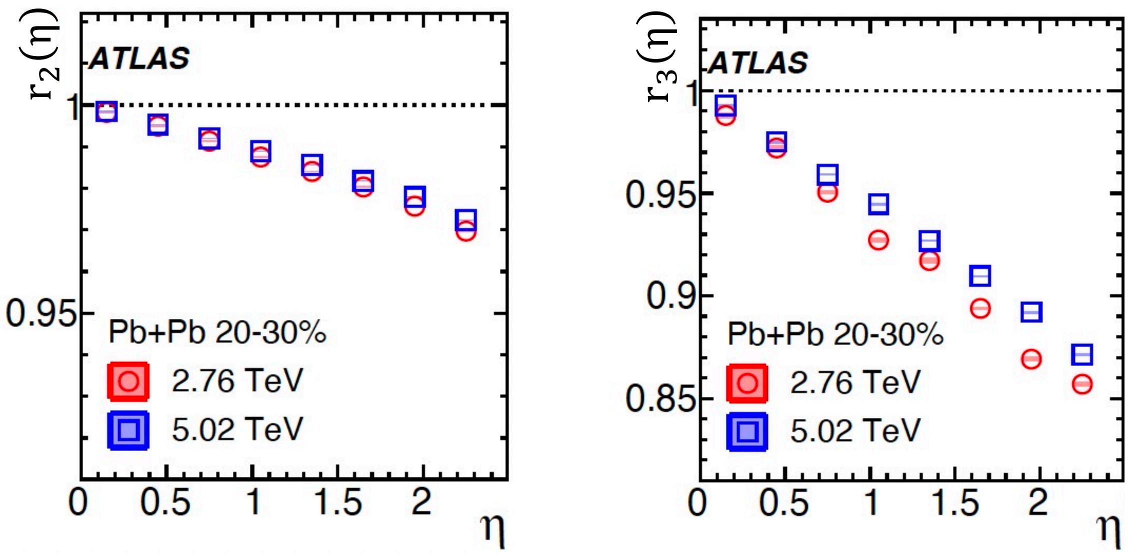


From Maowu Nie

Previous results at the LHC

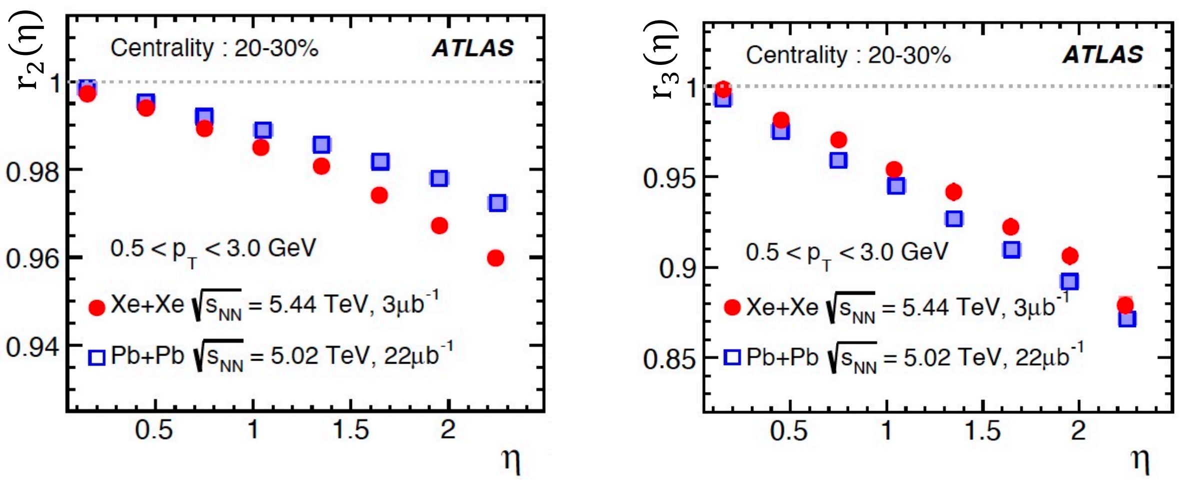
- Energy dependence

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



- System size dependence

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

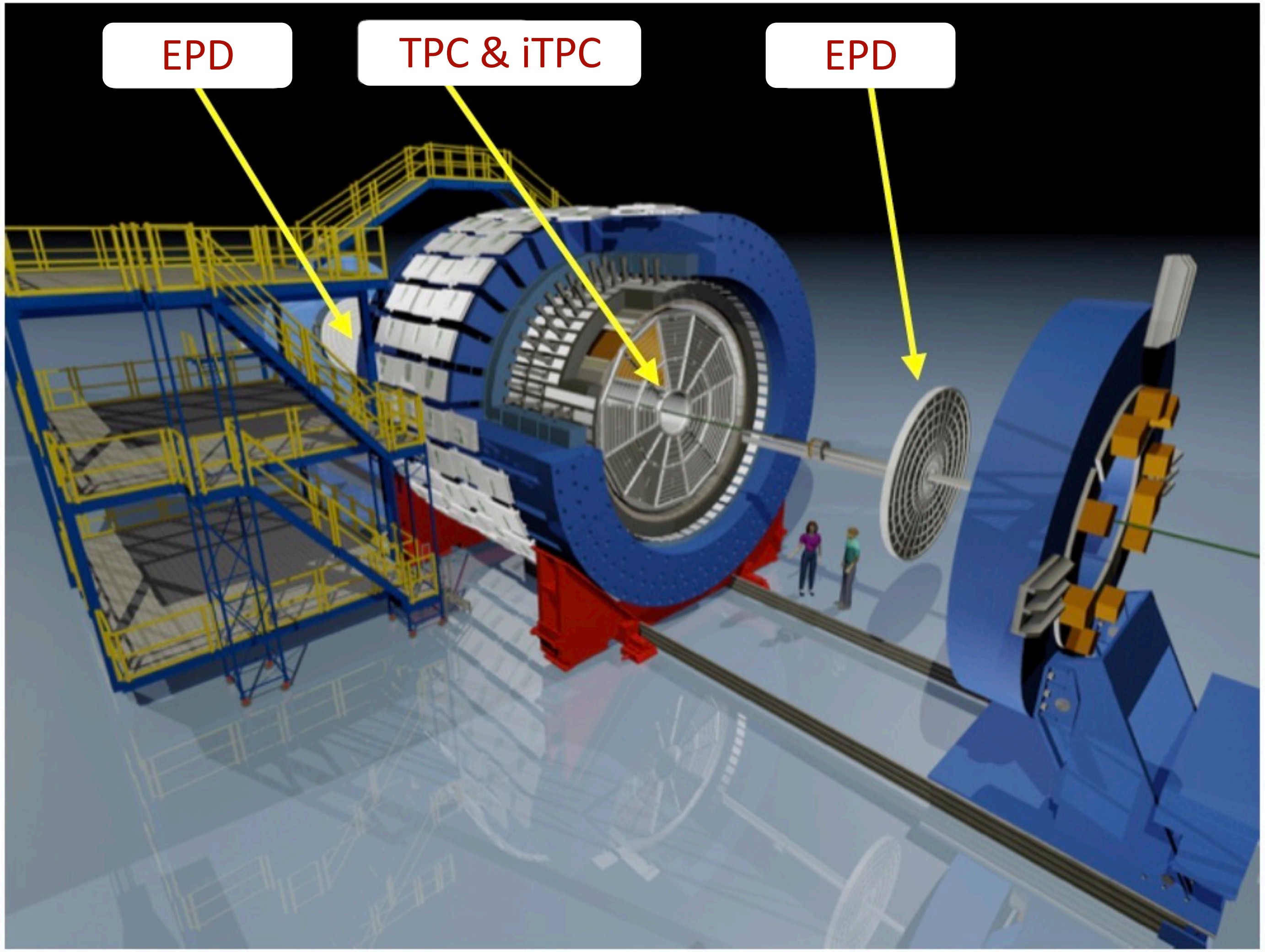


What about at RHIC ?

Energy dependence: Beam Energy Scan

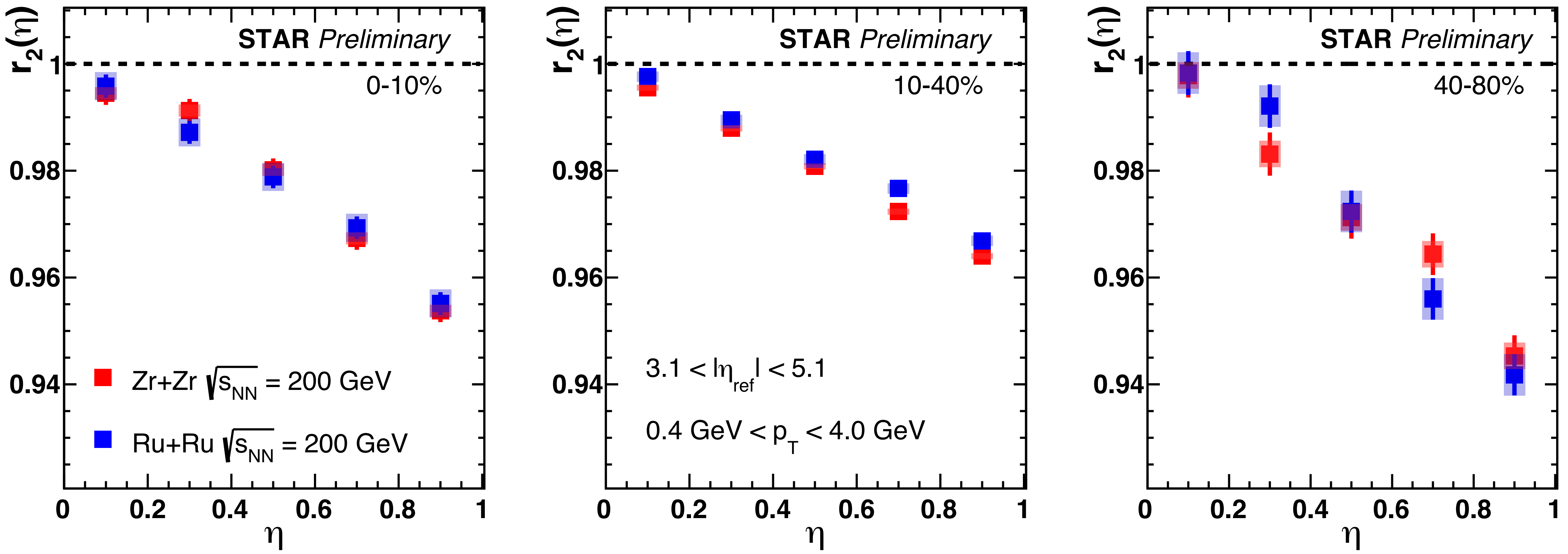
System size dependence: various collisions species

The STAR detector and datasets



- Time Projection Chamber
  - Full azimuthal coverage
  - TPC $|\eta| < 1.0$
  - iTPC $|\eta| < 1.5$
- Event Plane Detector
  - Event plane reconstruction
  - $2.1 < |\eta| < 5.1$
- Data
  - Zr+Zr & Ru+Ru collisions at 200 GeV
  - Au+Au collisions at 54.4 GeV
  - Au+Au collisions at 19.6 GeV

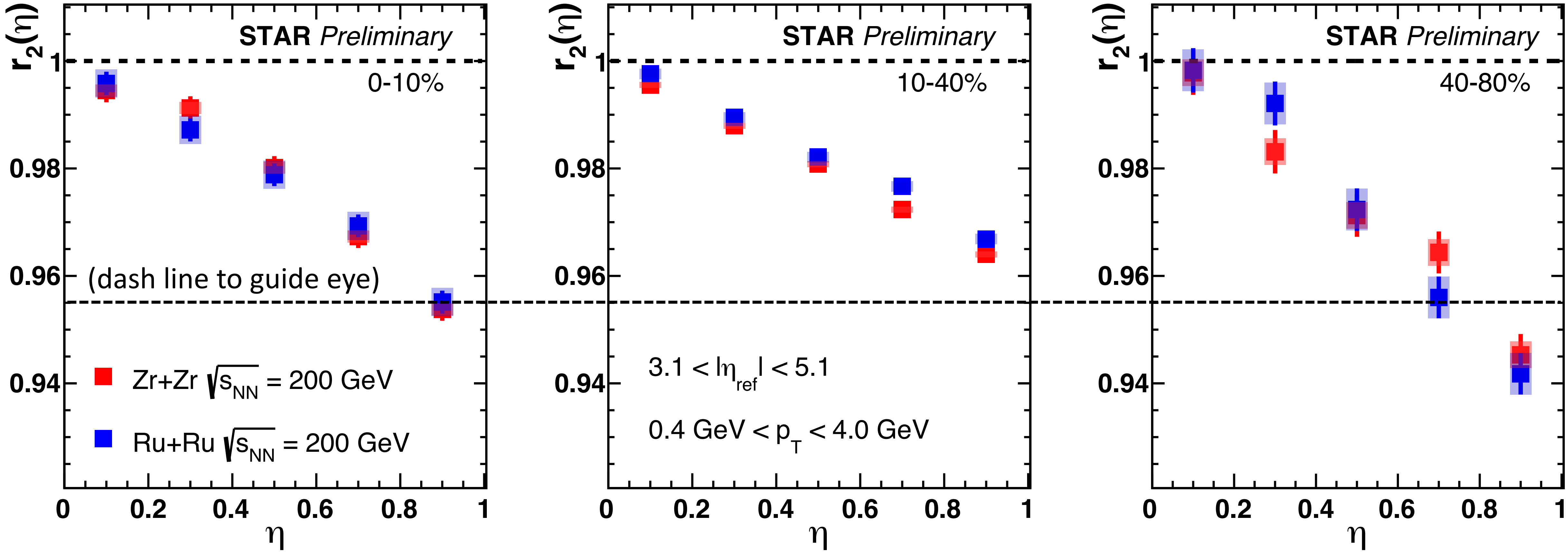
r_2 in Zr+Zr/Ru+Ru collisions



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

$$r_2(\eta) = \frac{\langle V_2(-\eta)V_2^*(\eta_{ref})\rangle}{\langle V_2(\eta)V_2^*(\eta_{ref})\rangle}$$

r_2 in Zr+Zr/Ru+Ru collisions

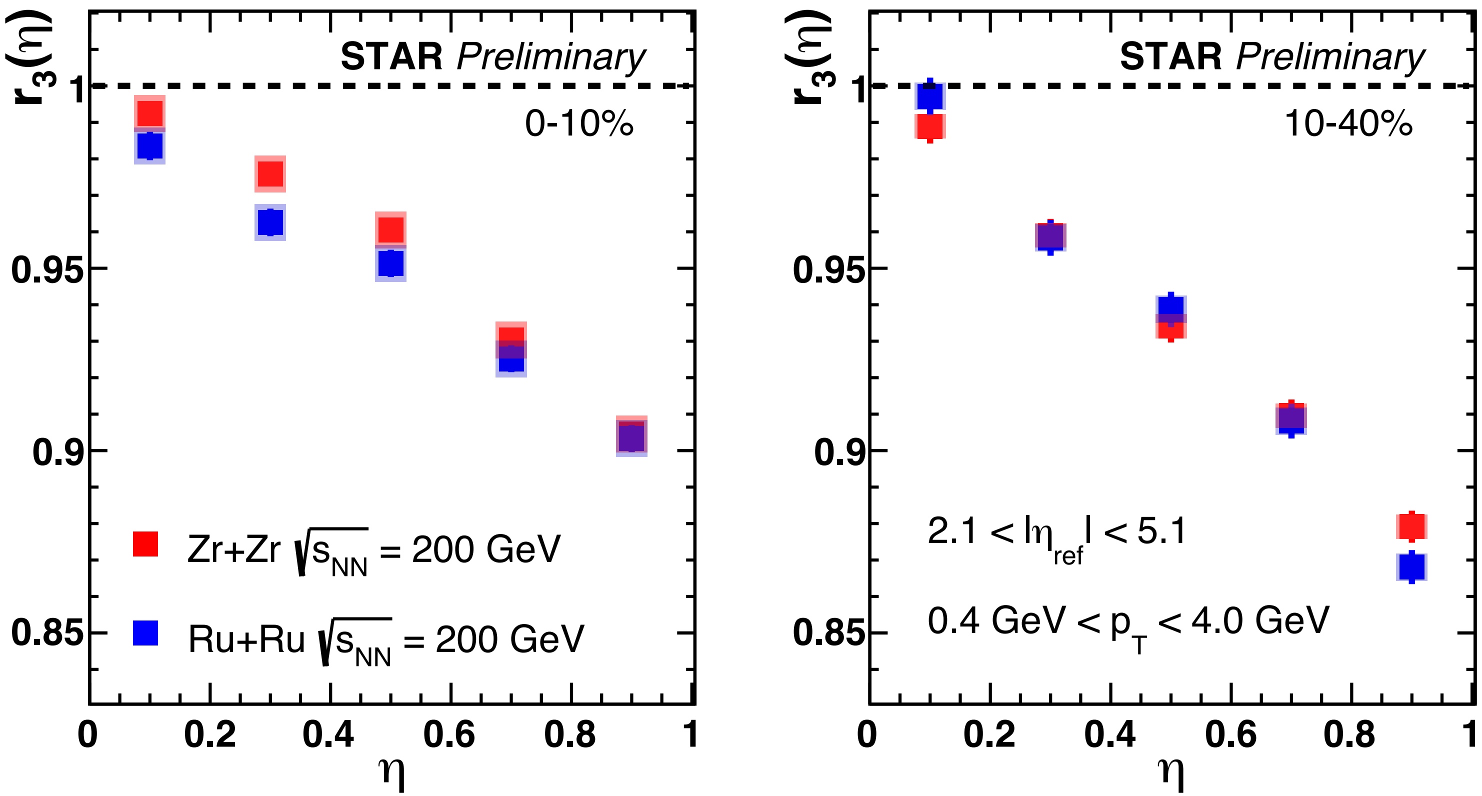


No obvious difference between Zr+Zr and Ru+Ru within uncertainties

Decorrelation is weakest in mid-central collisions

$$r_2(\eta) = \frac{\langle V_2(-\eta)V_2^*(\eta_{ref})\rangle}{\langle V_2(\eta)V_2^*(\eta_{ref})\rangle}$$

r_3 in Zr+Zr/Ru+Ru collisions

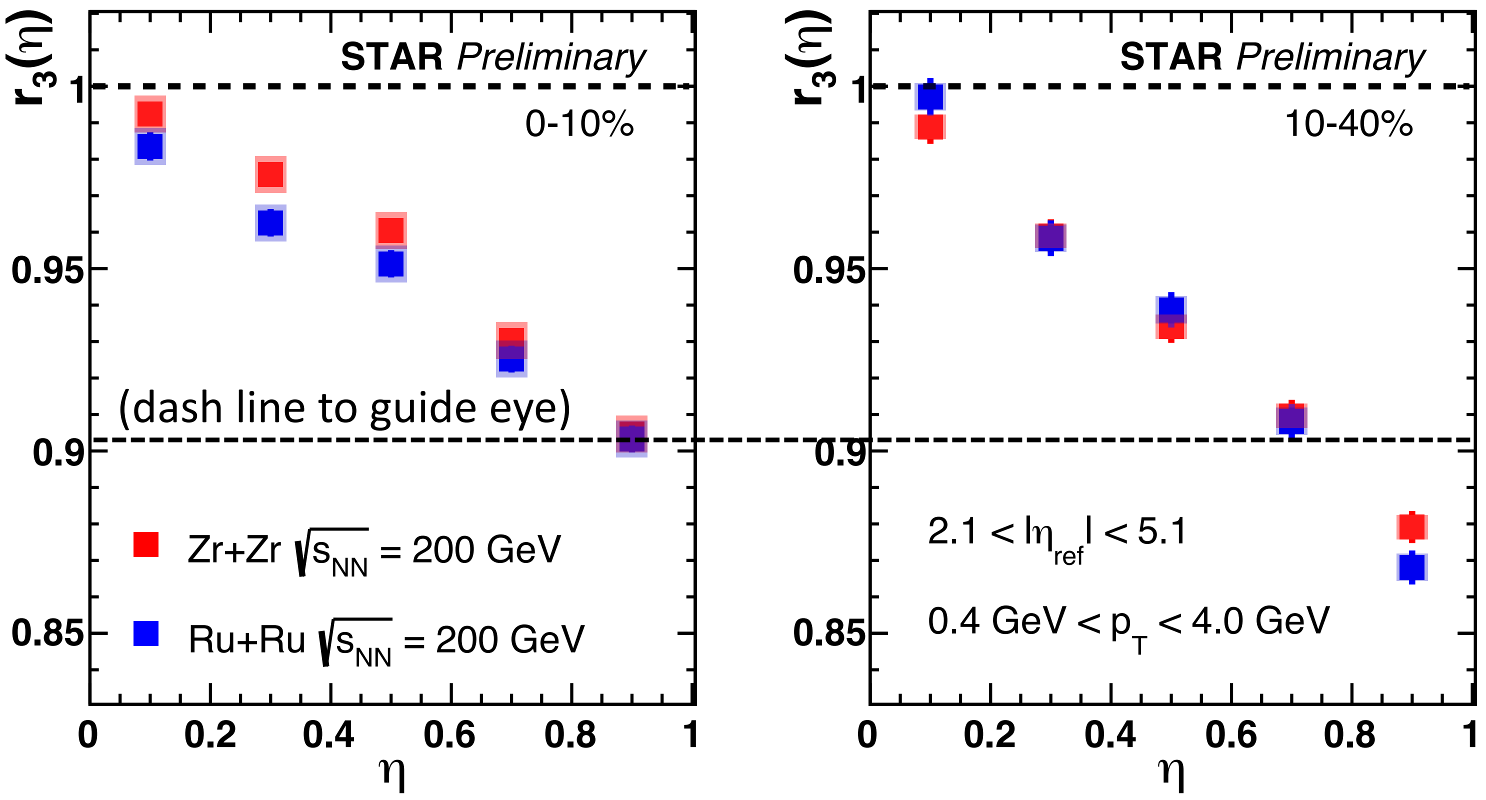


No obvious difference between Zr+Zr and Ru+Ru within uncertainties

The third order is 2-3 times stronger than second order

$$r_3(\eta) = \frac{\langle V_3(-\eta)V_3^*(\eta_{ref})\rangle}{\langle V_3(\eta)V_3^*(\eta_{ref})\rangle}$$

r_3 in Zr+Zr/Ru+Ru collisions



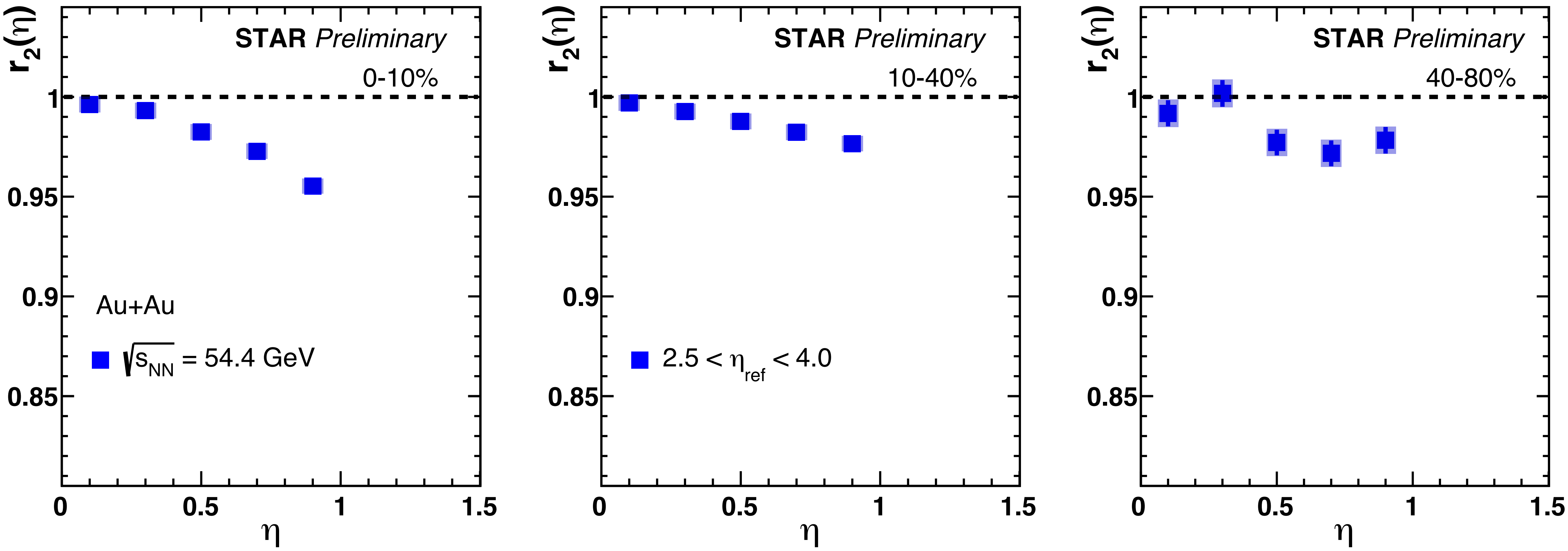
No obvious difference between Zr+Zr and Ru+Ru within uncertainties

Third order is 2-3 times stronger than second order

Indication of centrality dependence

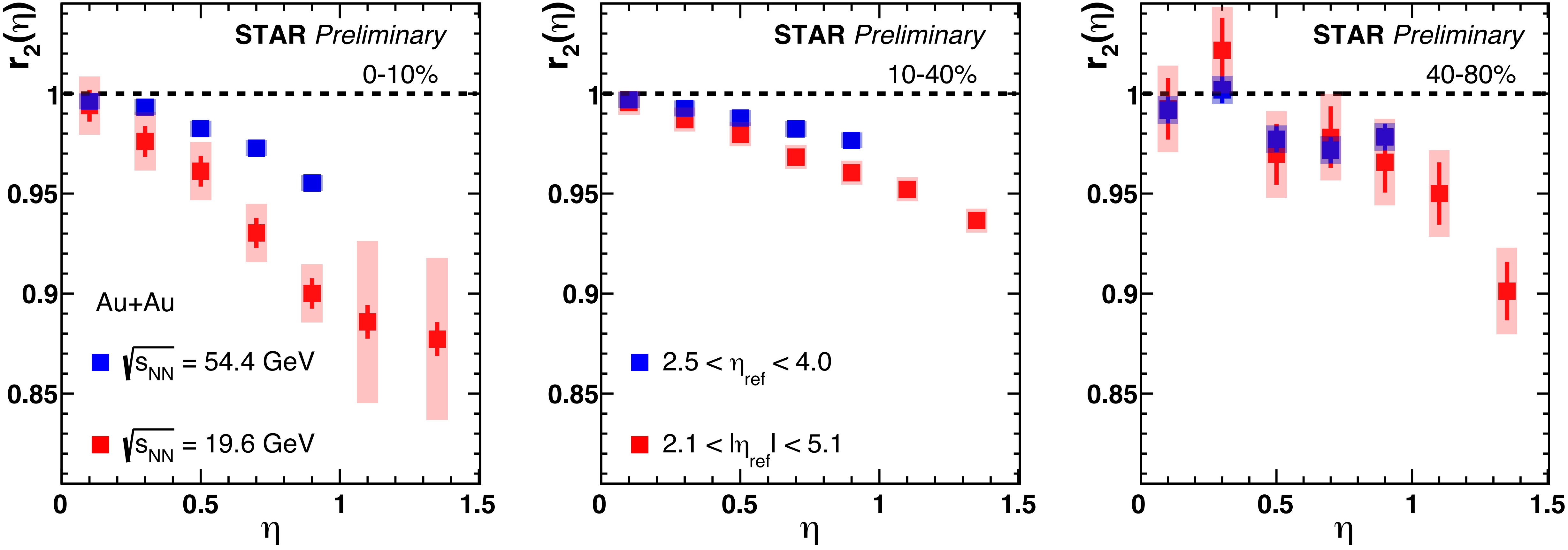
$$r_3(\eta) = \frac{\langle V_3(-\eta) V_3^*(\eta_{ref})\rangle}{\langle V_3(\eta) V_3^*(\eta_{ref})\rangle}$$

r_2 in Au+Au collisions at 54.4 GeV



$$r_2(\eta) = \frac{\langle V_2(-\eta) V_2^*(\eta_{ref})\rangle}{\langle V_2(\eta) V_2^*(\eta_{ref})\rangle}$$

Energy dependence of r_2



Lower energy has larger decorrelation because it becomes less boost-invariant

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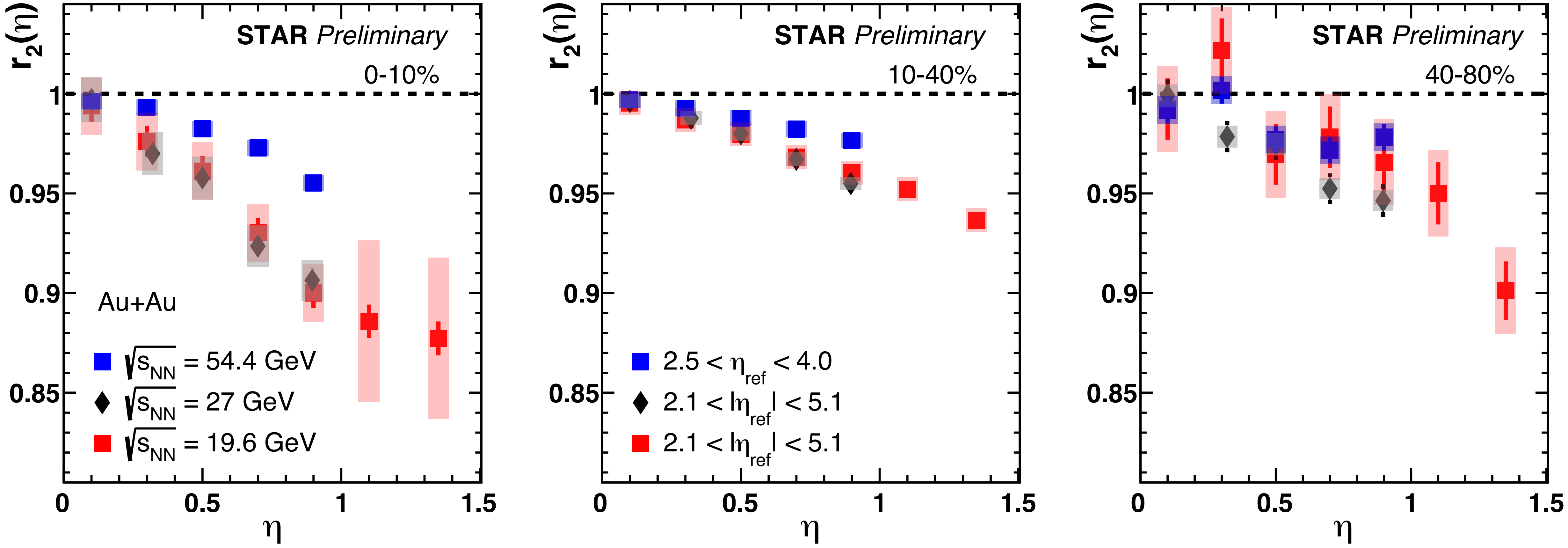
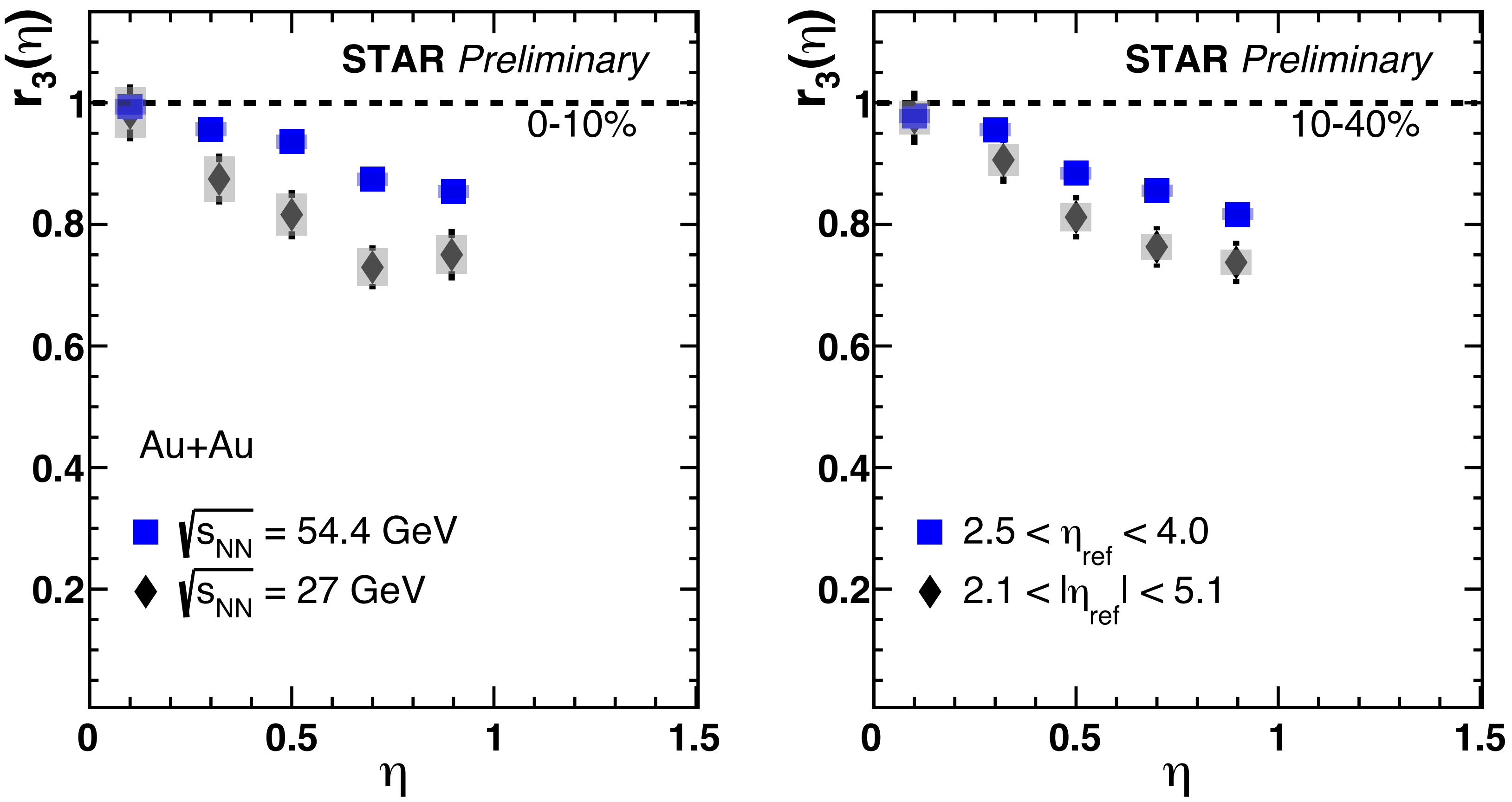
Energy dependence of r_2



Lower energy has larger decorrelation because it becomes less boost-invariant

No obvious difference between 27 GeV and 19 GeV because of their small different energy

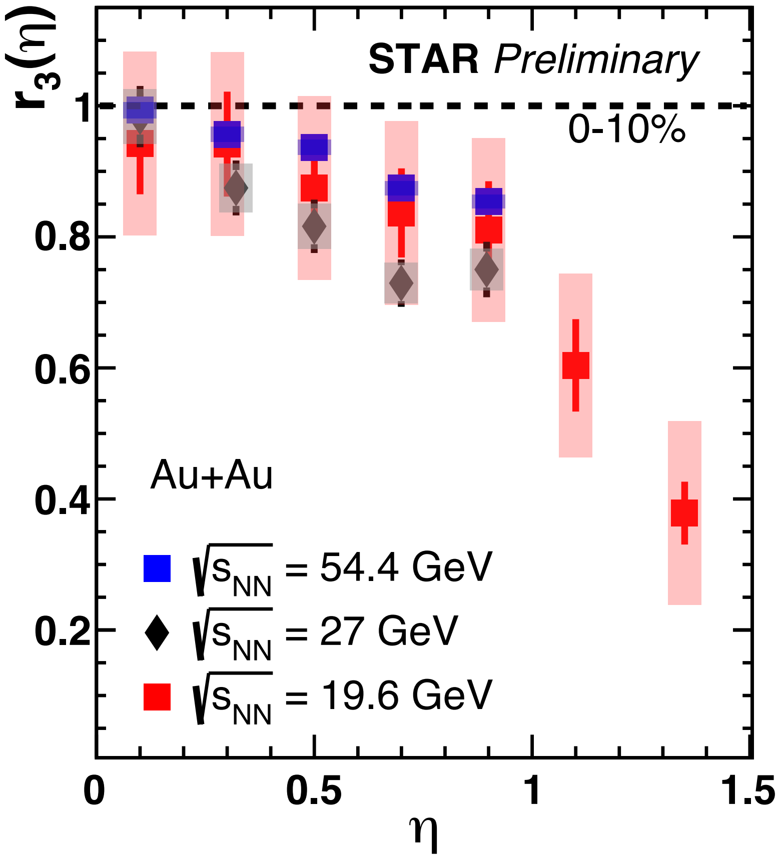
Energy dependence of r_3

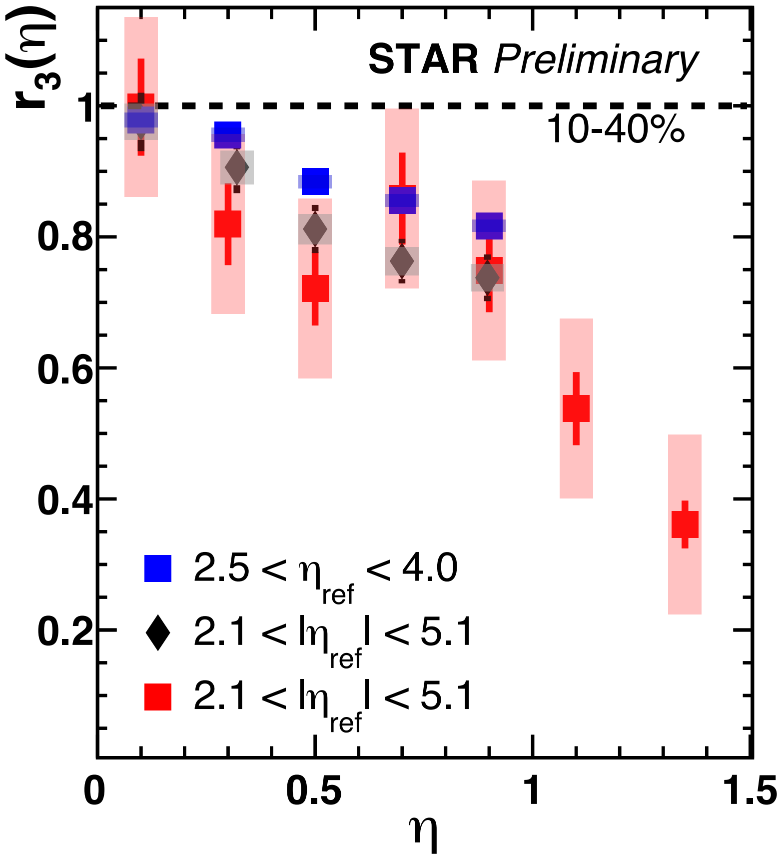


There is energy dependence between 54 GeV and 27 GeV because lower energy becomes less boost-invariant

$$r_3(\eta) = \frac{\langle V_3(-\eta)V_3^*(\eta_{ref})\rangle}{\langle V_3(\eta)V_3^*(\eta_{ref})\rangle}$$

Energy dependence of r_3





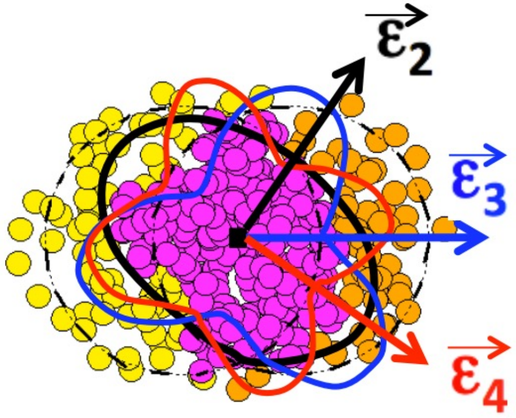
There is energy dependence between 54 GeV and 27 GeV because lower energy become less boost-invariant

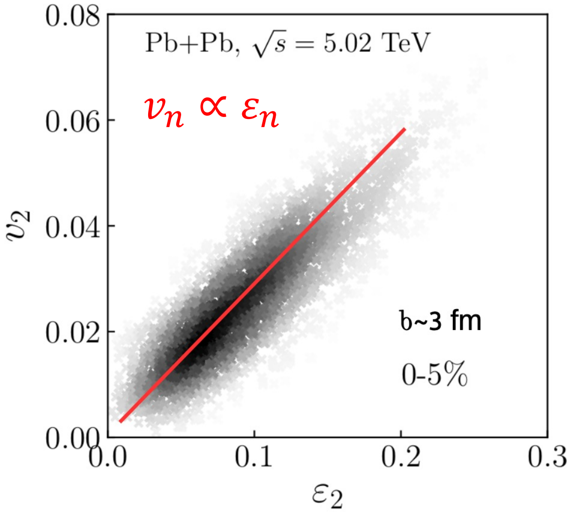
$$r_3(\eta) = \frac{\langle V_3(-\eta)V_3^*(\eta_{ref})\rangle}{\langle V_3(\eta)V_3^*(\eta_{ref})\rangle}$$

Transverse fluctuation

- shape → anisotropic flow

$$\mathrm{Var}(v_n^2)_{dyn} = v_n^4\{2\} - v_n^4\{4\}$$

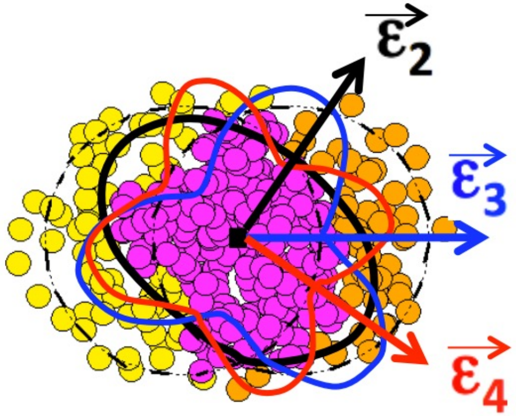


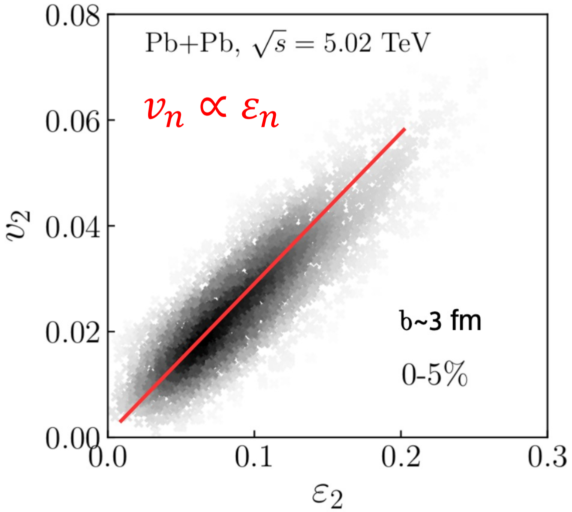


Transverse fluctuation

- shape → anisotropic flow

$$\mathrm{Var}(\mathrm{v_n^2})_{\mathrm{dyn}} = \mathrm{v_n^4\{2\}} - \mathrm{v_n^4\{4\}}$$

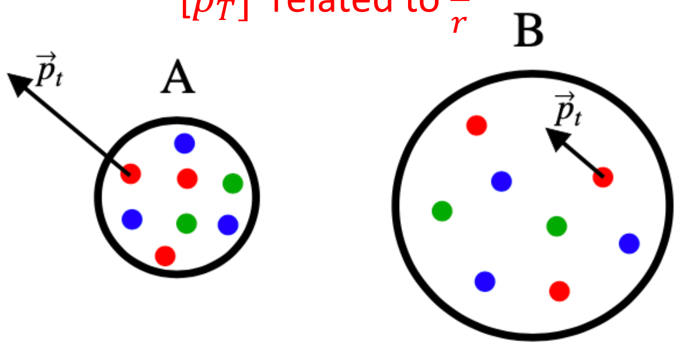




- size → radial flow

$$\mathrm{C_k} = \langle (p_{T,i} - \langle [p_T] \rangle)(p_{T,j} - \langle [p_T] \rangle) \rangle$$

$[p_T]$ related to $\frac{1}{r}$



From Arabinda Behera

Transverse fluctuation

- shape → anisotropic flow

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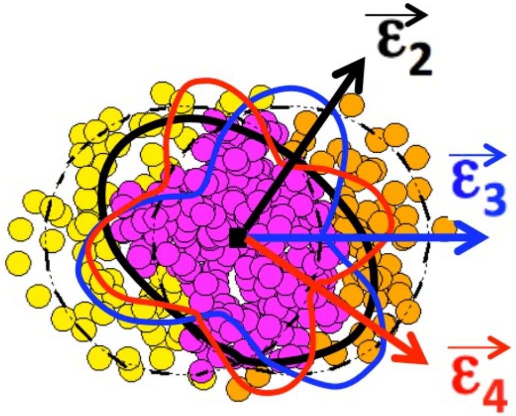

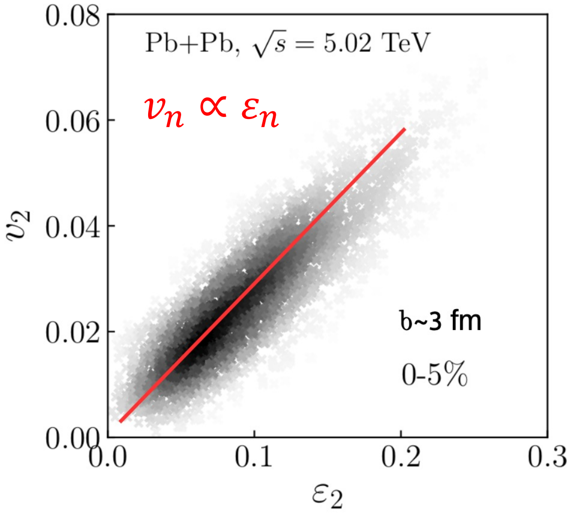

- size → radial flow

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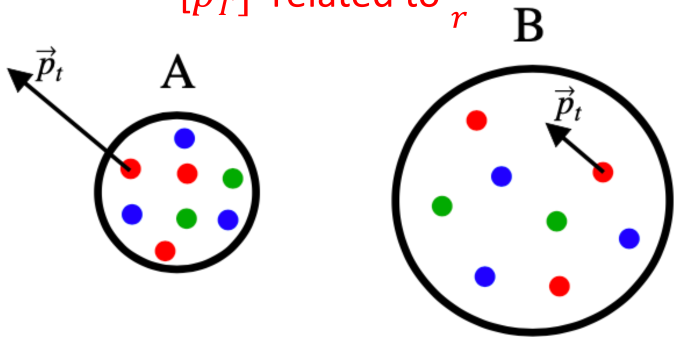


From Arabinda Behera

correlation between v_n^2 and average p_T

$$\mathrm{cov}(v_n^2, [p_T]) = \left\langle e^{in(\phi_i - \phi_j)}(p_{T,k} - \langle [p_T] \rangle) \right\rangle$$

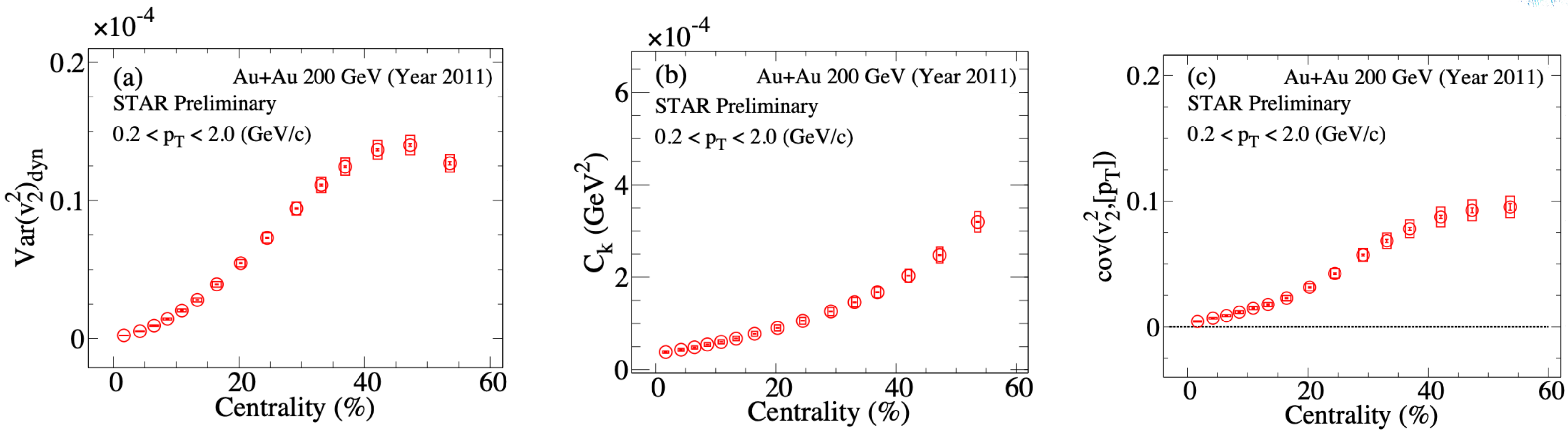
correlation between initial state shape and size →

Pearson coefficient：

$$\rho(v_n^2, [p_T]) = \frac{cov(v_n^2, [p_T])}{\sqrt{Var(v_n^2)_{dyn}\, C_{\{k\}}}}$$

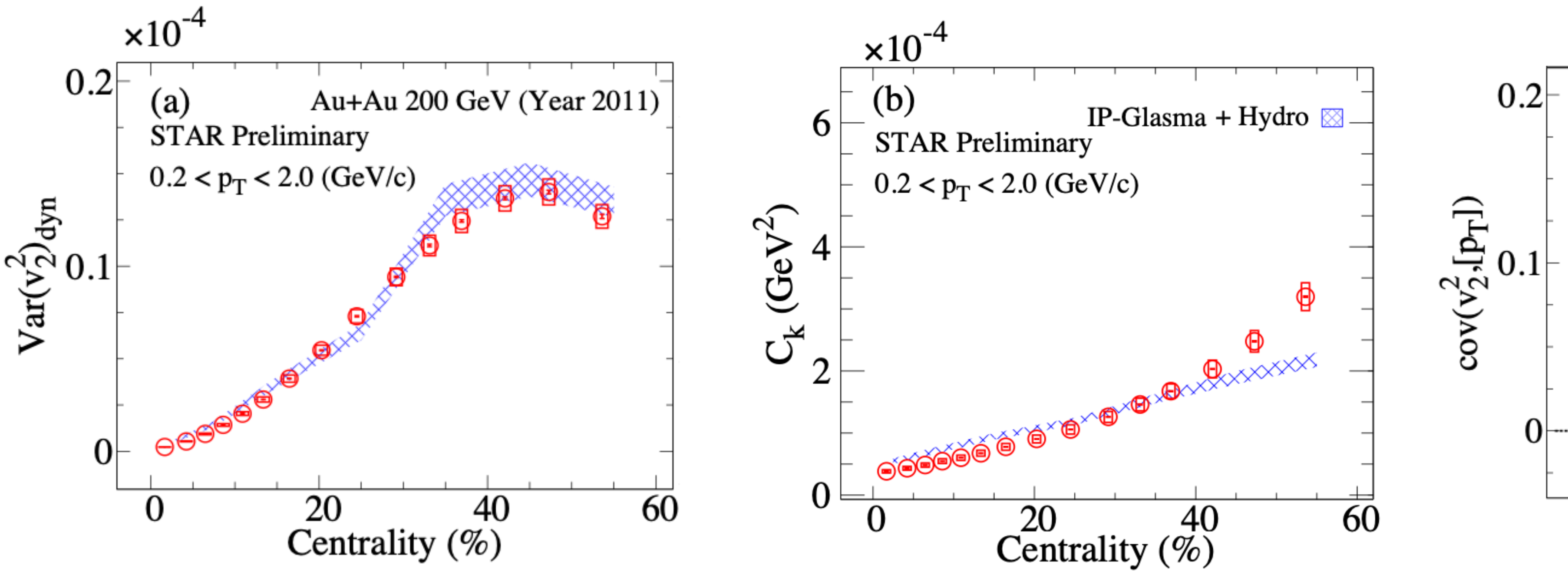
P. Bozek, Phys. Rev. C 93 (2016) 4, 044908
G. Giacalone, B.Schenke, C.Shen, Phys. Rev. Lett. 128 (2022) 4, 042301

$v_2^2 - [p_T]$ correlations



$\mathrm{Var}(v_2^2)_{\mathrm{dyn}}$ C_K and $\mathrm{cov}(v_2^2, [p_T])$ increase with centrality

$v_2^2 - [p_T]$ correlations



$\mathrm{Var}(v_2^2)_{\mathrm{dyn}}$ C_K and $\mathrm{cov}(v_2^2, [p_T])$ increase with centrality

IP-Glasma + Hydro :

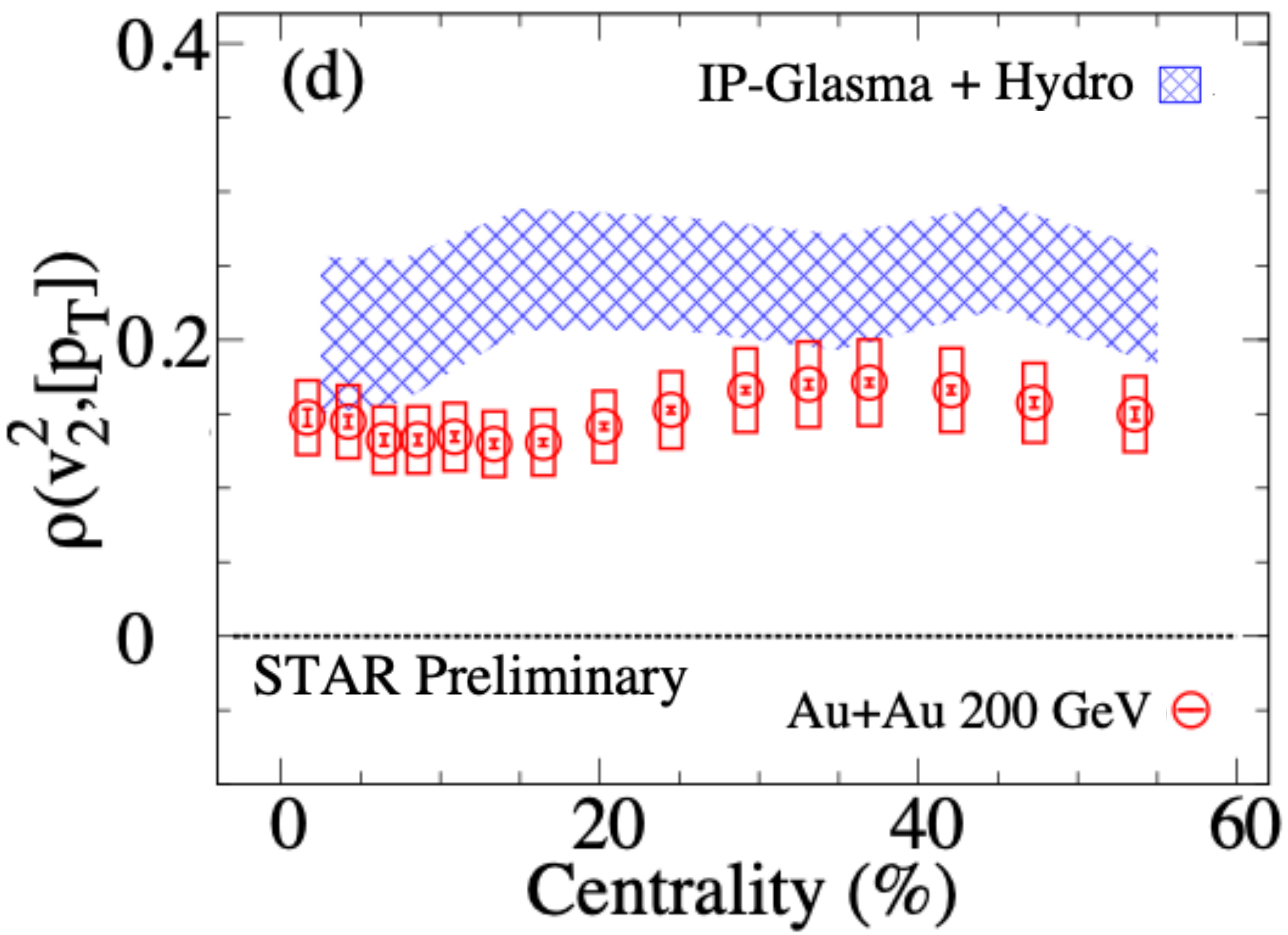
good agreement with $\mathrm{Var}(v_2^2)_{\mathrm{dyn}}$

good agreement with C_k from central to mid central

overestimates $\mathrm{cov}(v_2^2, [p_T])$

B.Schenke, C.Shen, and P.Tribedy, Phys. Rev. C 99 (2019) 4, 044908

$v_2^2 - [p_T]$ correlations



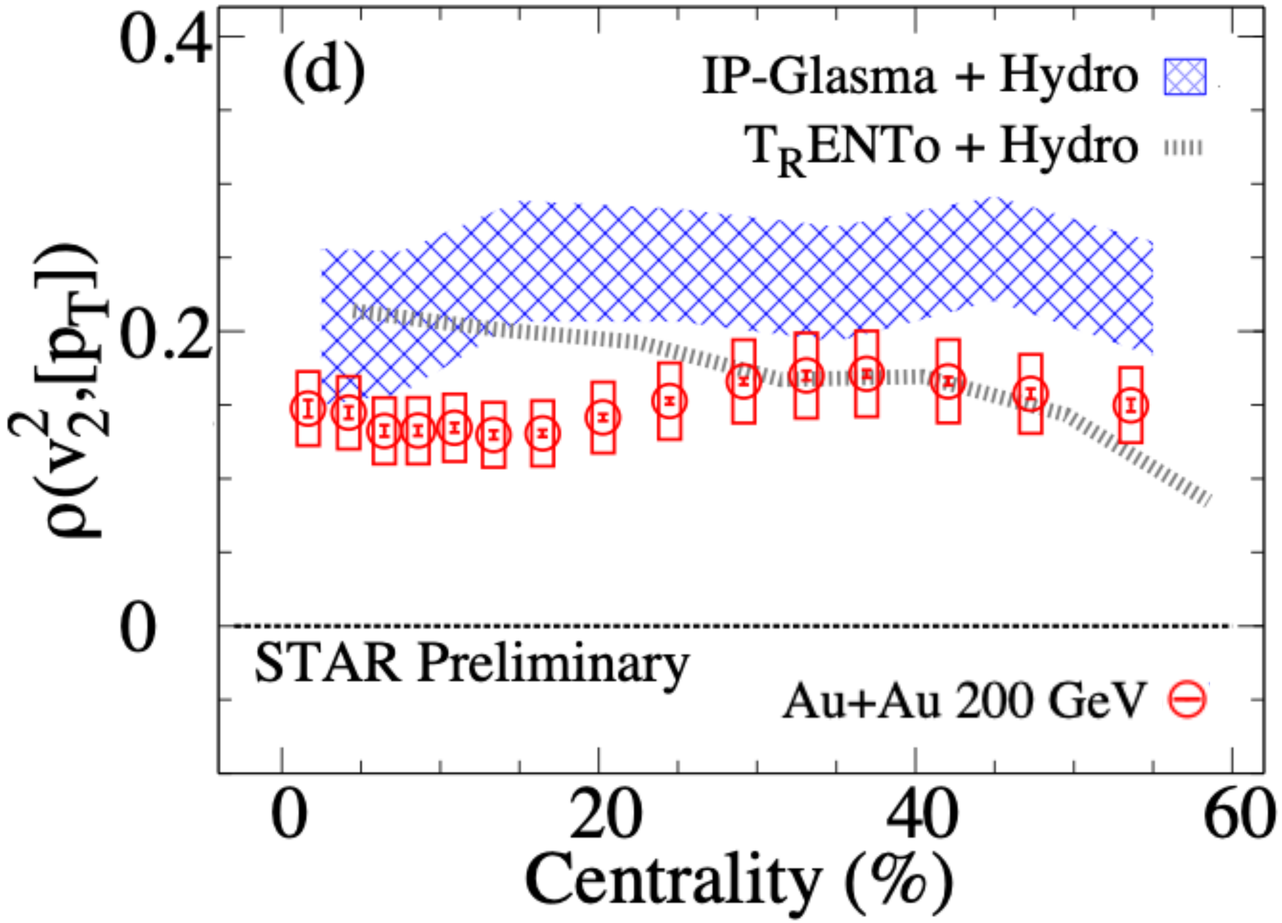
$$\rho(v_n^2,[p_T]) = \frac{cov(v_n^2,[p_T])}{\sqrt{Var(v_n^2)_{dyn}\, C_{\{k\}}}}$$

Pearson coefficient is sensitive to initial state

IP-Glasma overestimates $\rho(v_2^2,[p_T])$

B.Schenke, C.Shen, and P.Tribedy, Phys. Rev. C 99 (2019) 4, 044908

$v_2^2 - [p_T]$ correlations



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Pearson coefficient is sensitive to initial state

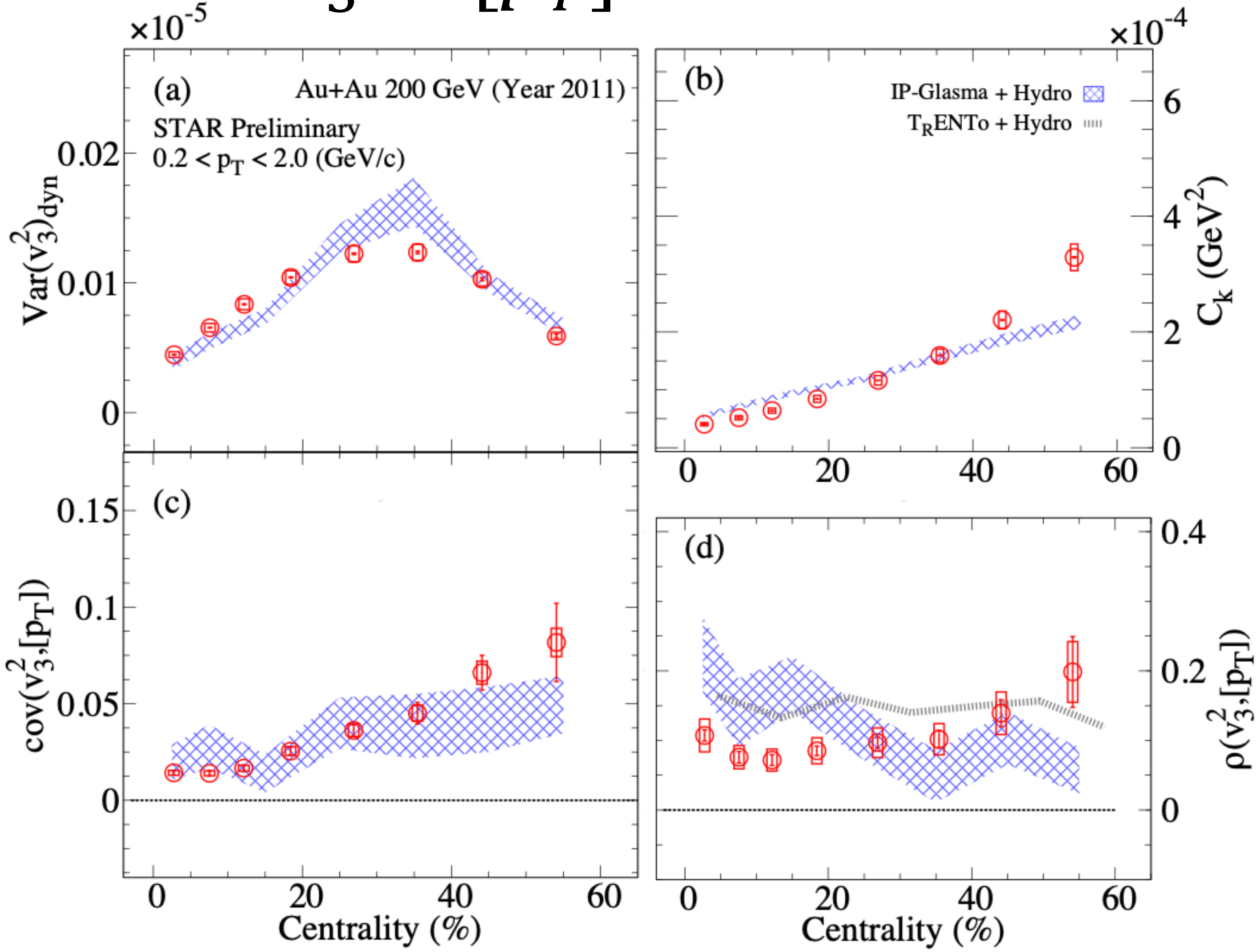
IP-Glasma overestimates $\rho(v_2^2,[p_T])$

TRENTO overestimates $\rho(v_2^2,[p_T])$ in central collisions

B.Schenke, C.Shen, and P.Tribedy,
Phys. Rev. C 99 (2019) 4, 044908
P. Alba, et al.,
Phys. Rev. C 98 (2018) 3, 034909

Poster: Chunjian Zhang, session 2 T01
Poster: Jiangyong Jia, session 2 T01

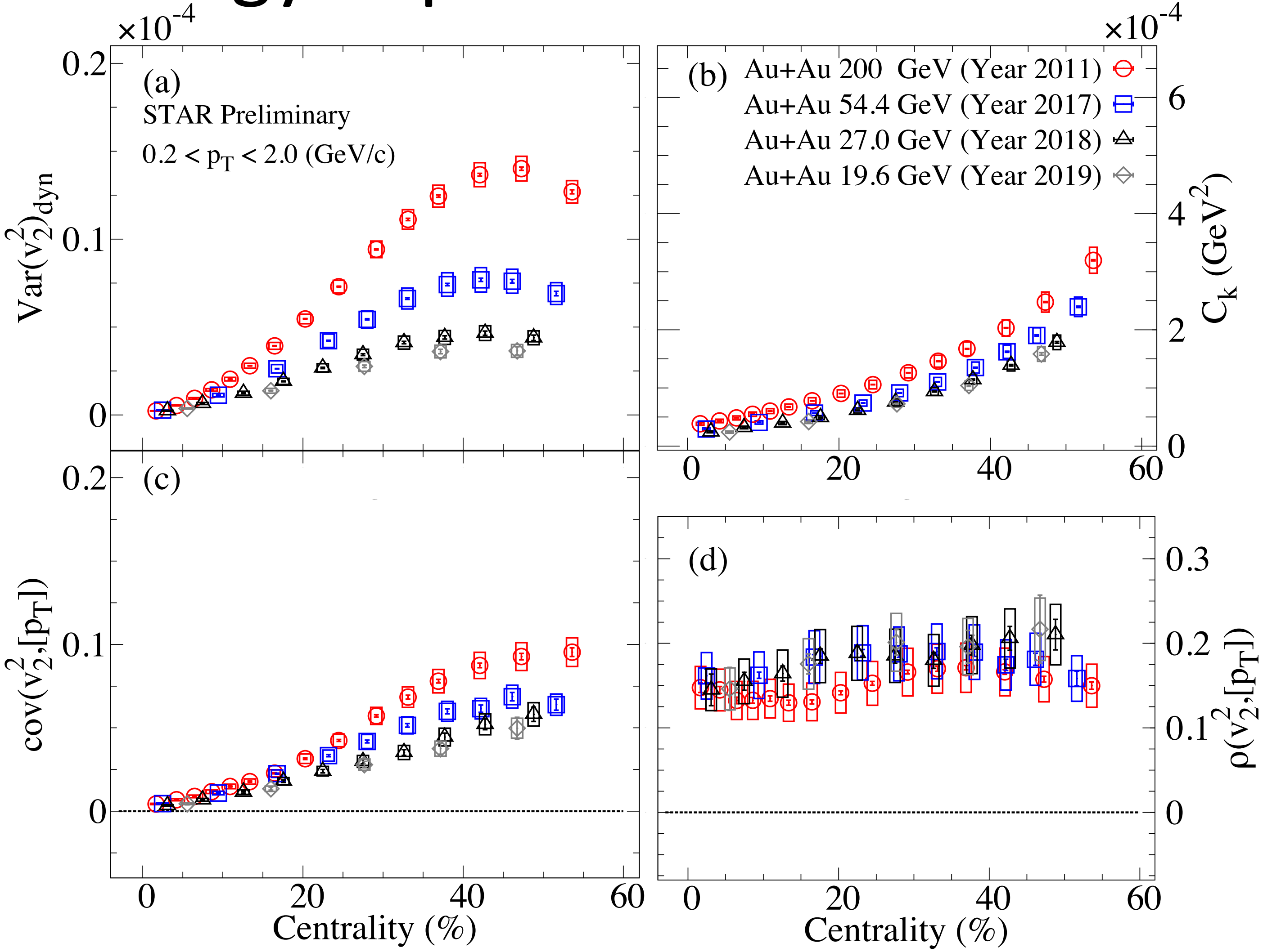
$v_3^2 - [p_T]$ correlations



IP-Glasma + Hydro shows a good agreement with $Var(v_3^2)_{dyn}$

IP-Glasma + Hydro shows an agreement with C_k and $cov(v_3^2, [p_T])$

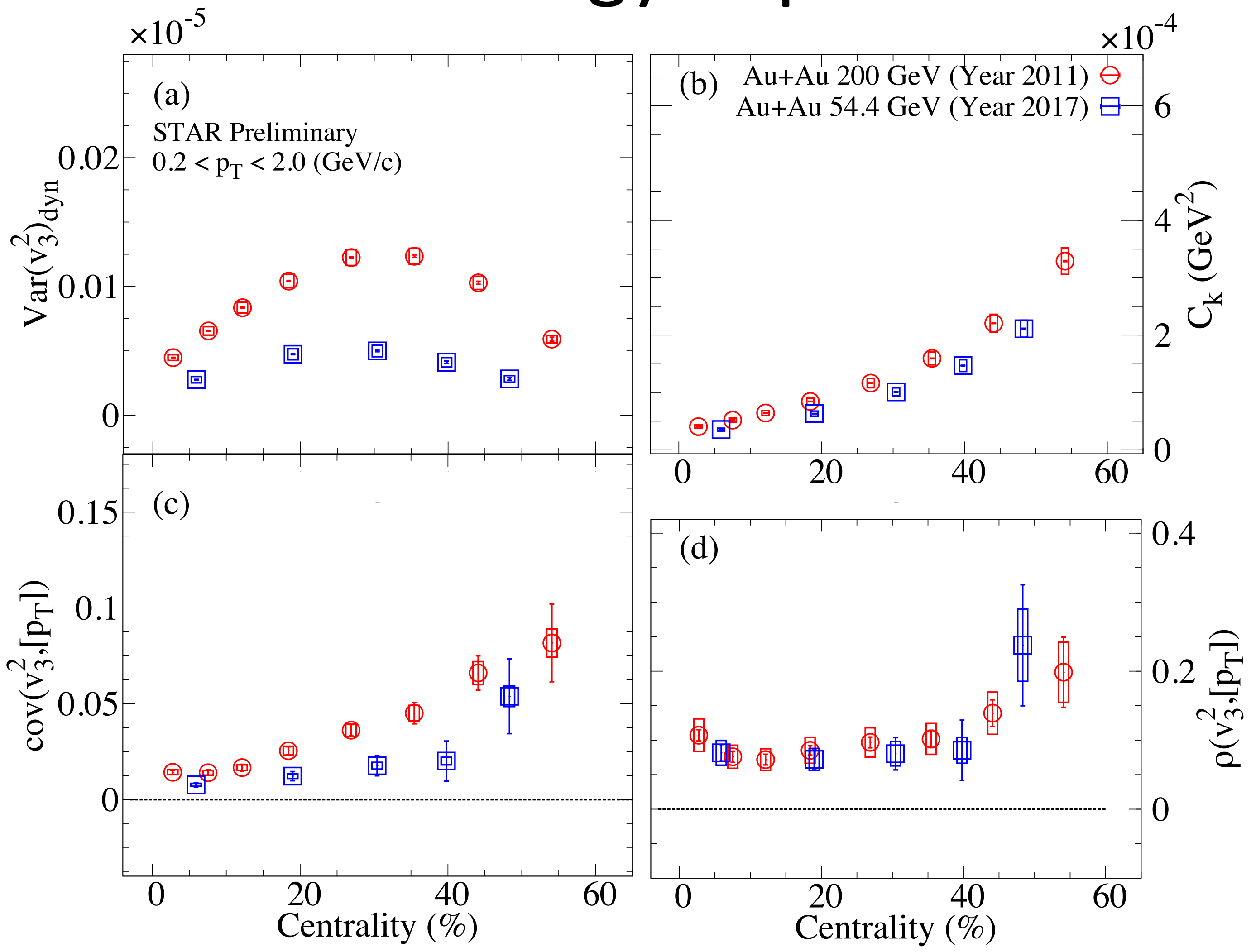
Beam energy dependence from 19.6 - 200 GeV



$Var(v_2^2)_{dyn}$, C_k and $cov(v_2^2, [p_T])$ decrease with beam energy

The Pearson coefficient, $\rho(v_2^2, [p_T])$, shows some hint of beam energy dependence

Beam energy dependence



$Var(v_3^2)_{dyn}$, C_k and $cov(v_3^2, [p_T])$ decrease with beam energy

The Pearson coefficient, $\rho(v_3^2, [p_T])$, shows weak beam energy dependence

Summary

Longitudinal flow decorrelation and $v_n^2 - p_T$ correlations measurements provide new constraints on initial conditions

- Longitudinal flow decorrelation:

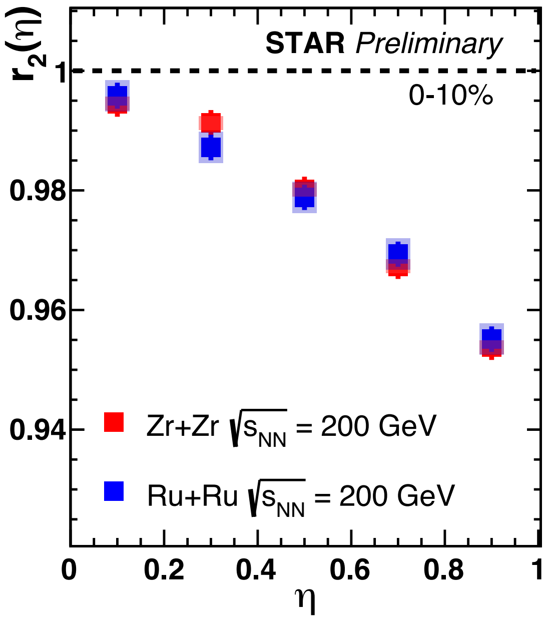
  $r_{2/3}$ shows centrality dependence

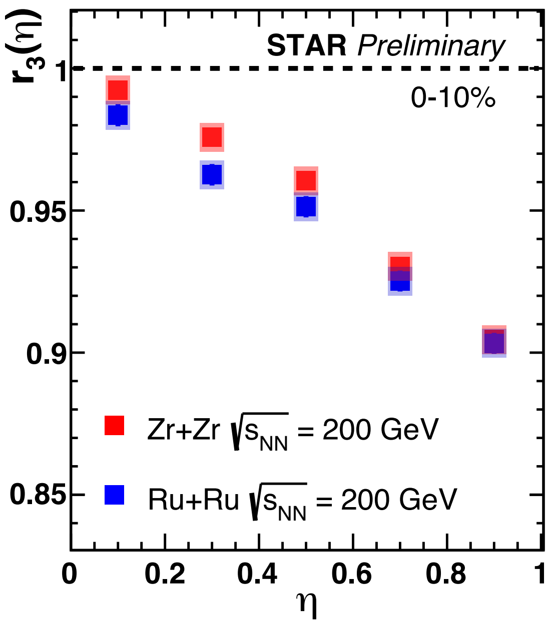
  $r_{2/3}$ shows energy dependence

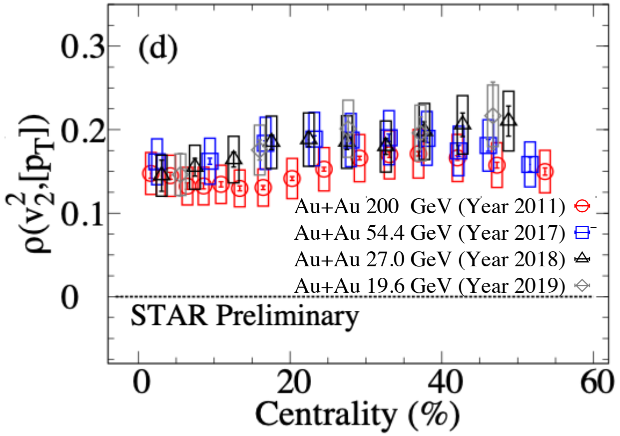
- Pearson coefficient:

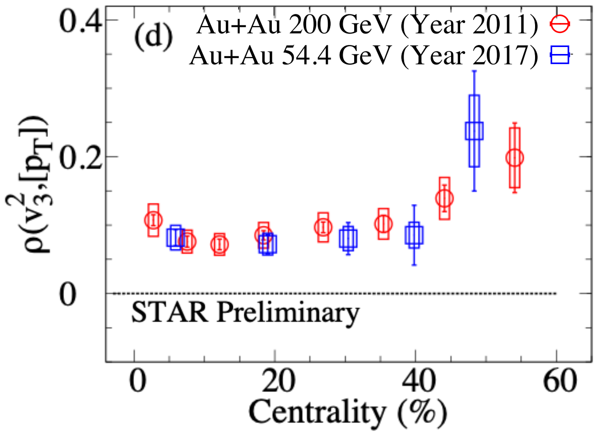
  $\rho(v_2^2, [p_T])$ shows hint of energy dependence

  $\rho(v_3^2, [p_T])$ shows weak energy dependence









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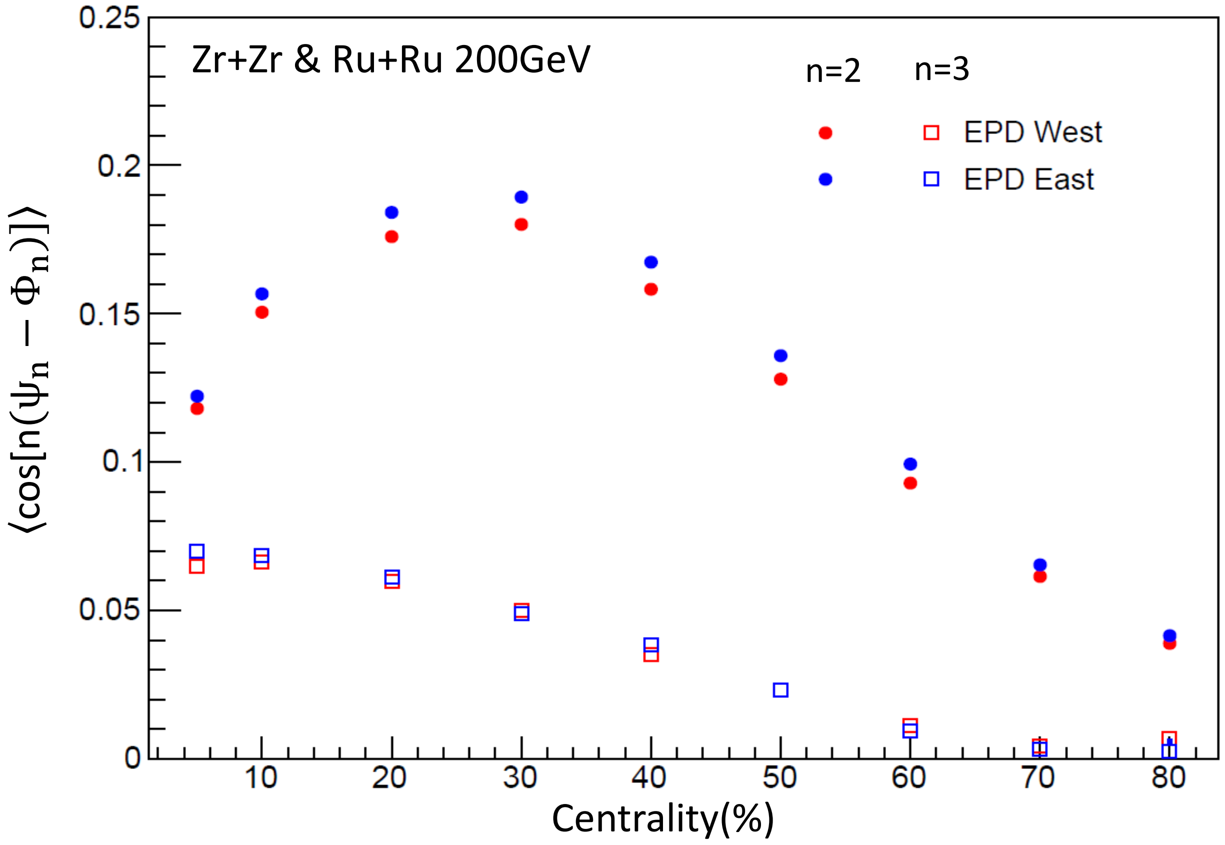
APRIL 4-10, 2022
KRAKÓW, POLAND

Thanks for your attention

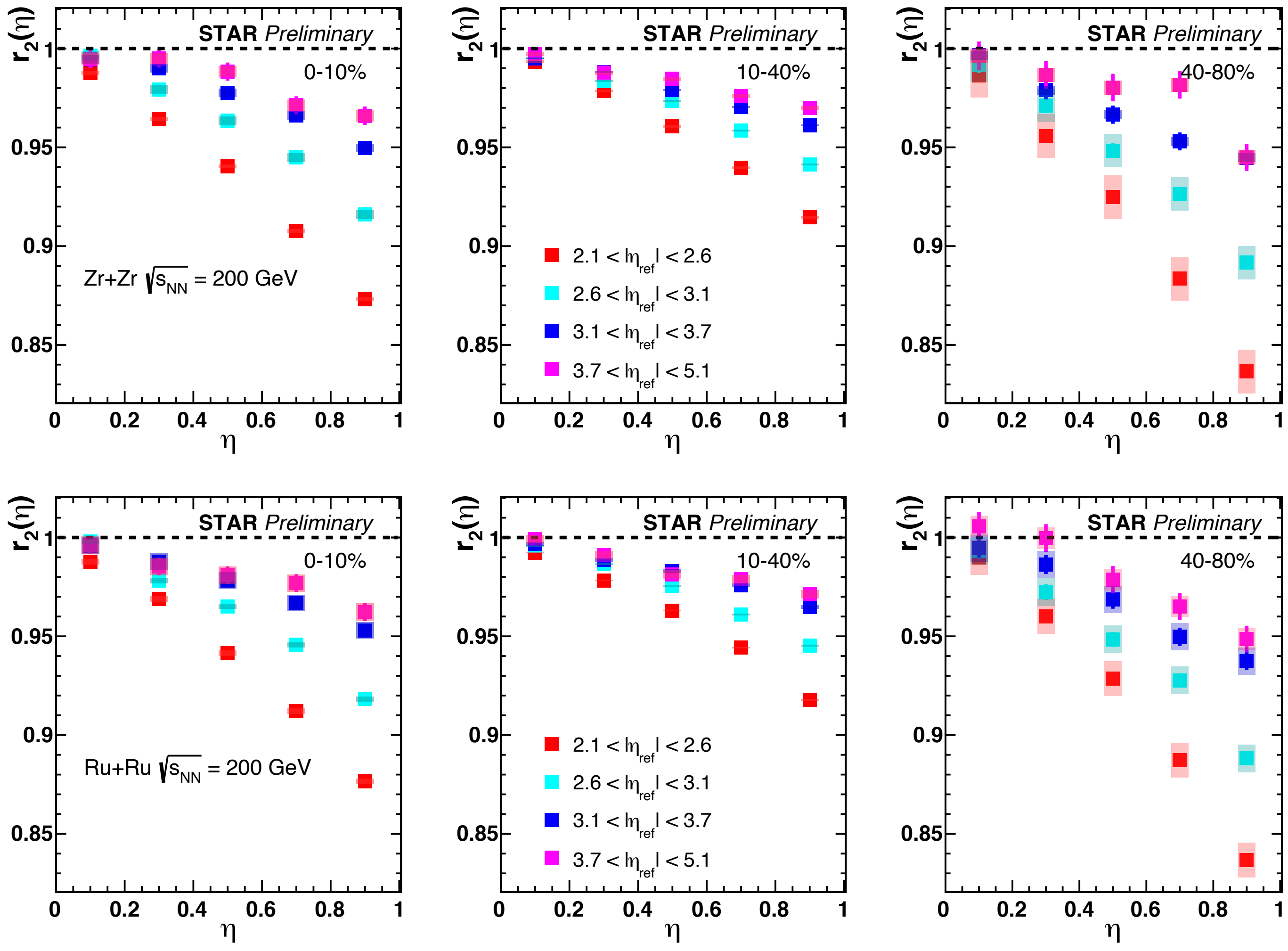
Back up

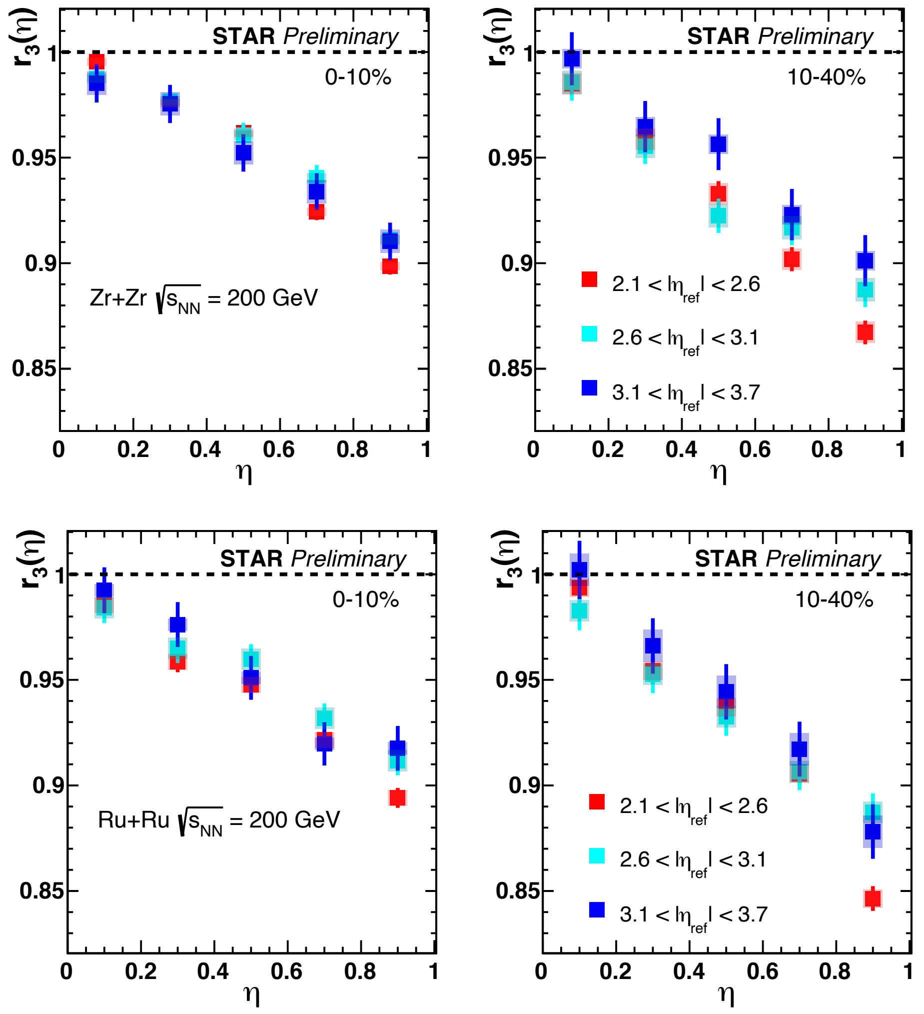
Resolution at Zr+Zr/Ru+Ru at 200GeV



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

η_{ref} dependence at Zr+Zr/Ru+Ru at 200GeV

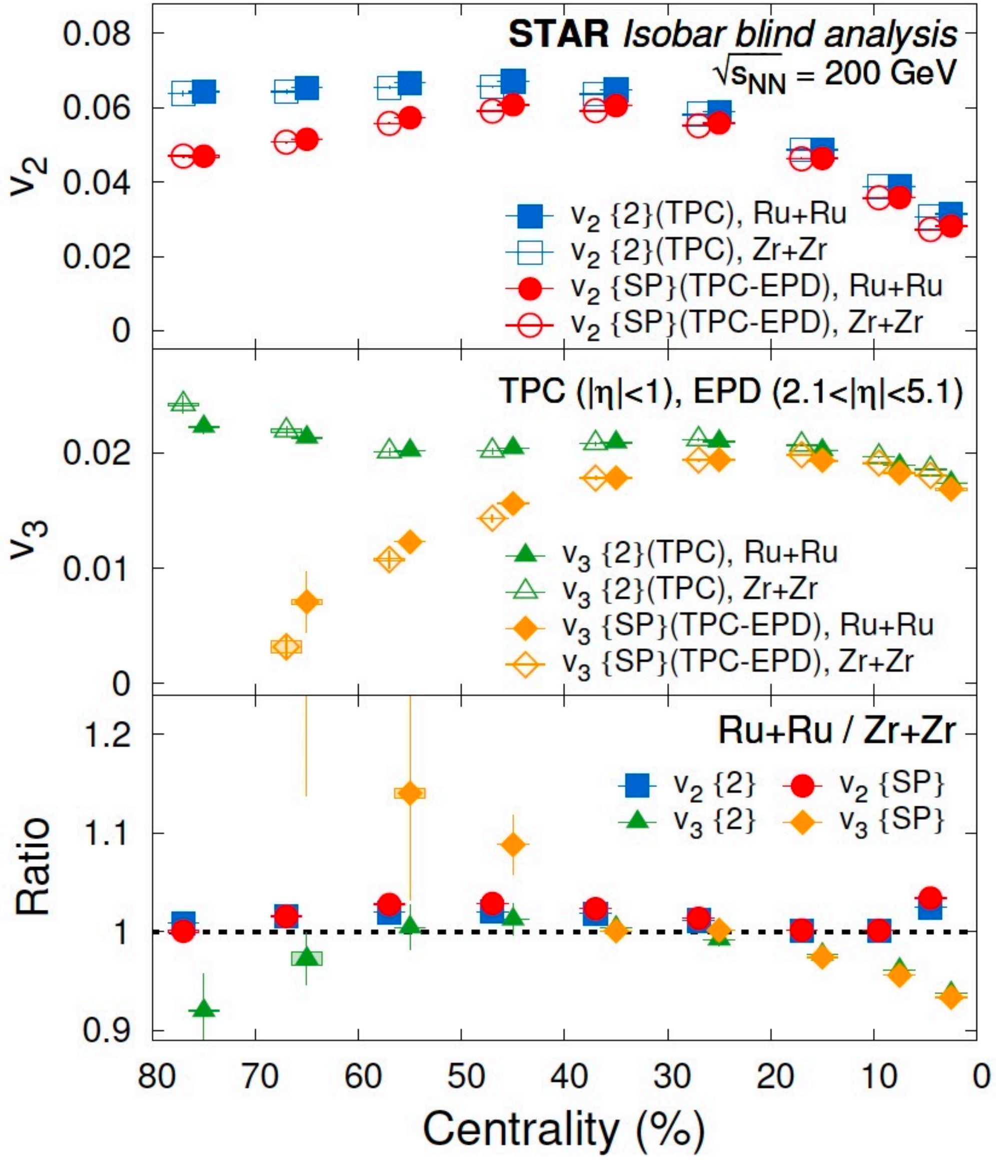




✓ Second order: η_{ref} dependence

✓ Third order: no η_{ref} dependence

Anisotropic flow at Zr+Zr/Ru+Ru at 200GeV



STAR Collaboration
Phys. Rev. C 105 (2022) 1, 014901