

Energy dependence of longitudinal flow decorrelation from STAR

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For the STAR collaboration

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In part funded by

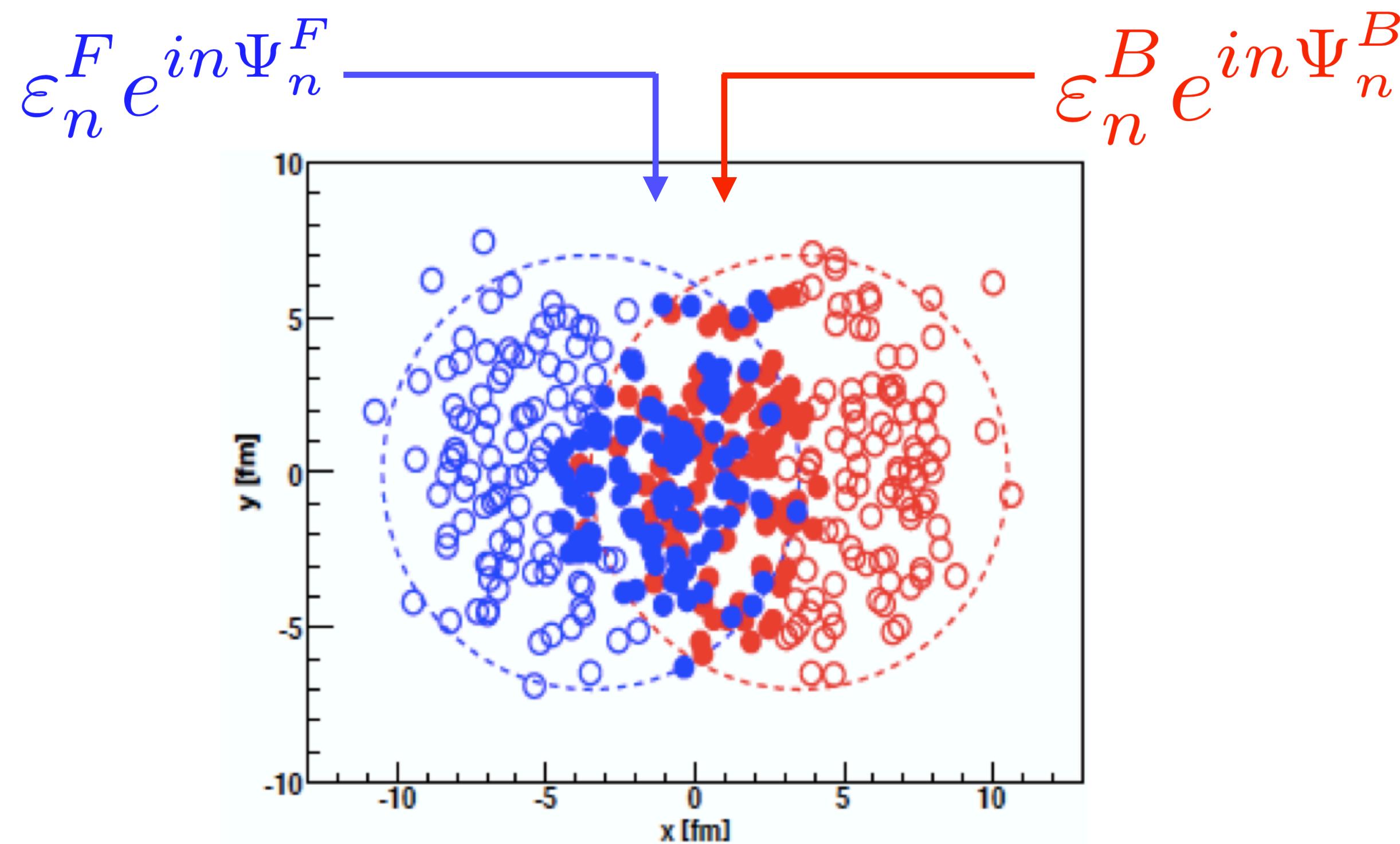


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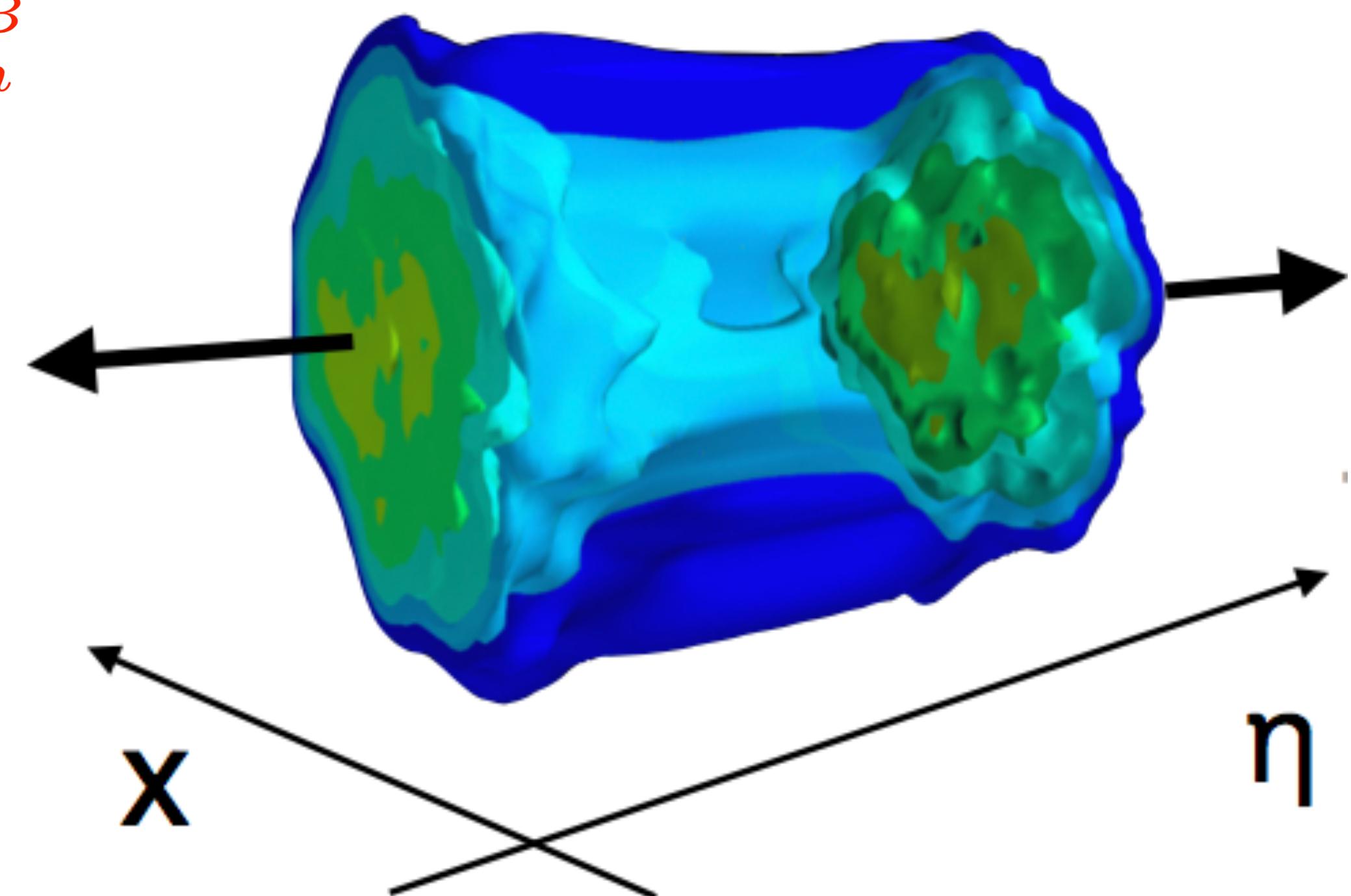
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Longitudinal dynamics in heavy-ion collisions

- ◆ Fluctuation of sources in two nuclei



- ◆ Evolution of the QGP in (3+1)D



- Longitudinal dynamics can provide the full space-time evolution of the fireball.

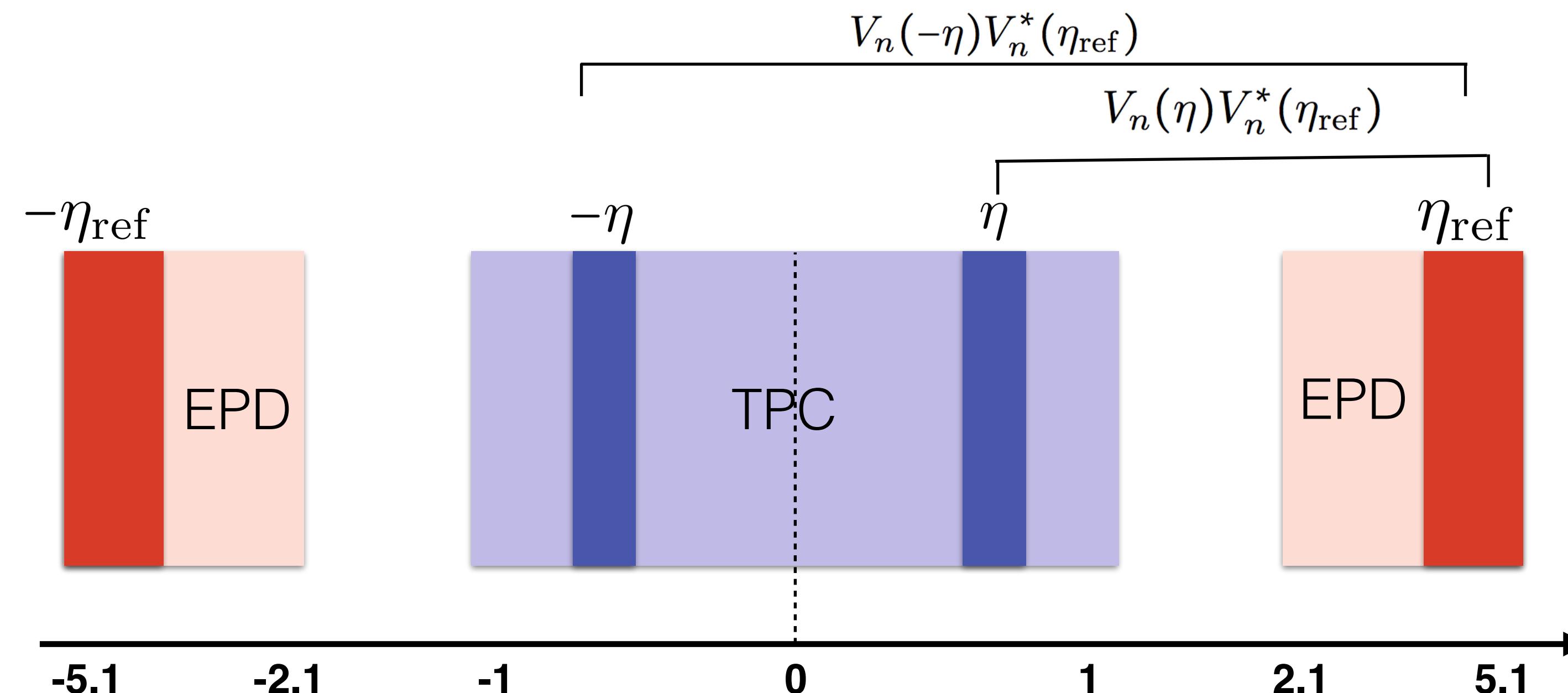
Flow decorrelation observables

- ♦ Factorization ratio, r_n , is constructed as a measure of the flow decorrelation

$$\begin{aligned} r_n(\eta) &= \frac{\langle V_n(-\eta) V_n^*(\eta_{\text{ref}}) \rangle}{\langle V_n(\eta) V_n^*(\eta_{\text{ref}}) \rangle} \\ &= \frac{\langle v_n(-\eta) v_n(\eta_{\text{ref}}) \cos n(\Psi_n(-\eta) - \Psi_n(\eta_{\text{ref}})) \rangle}{\langle v_n(\eta) v_n(\eta_{\text{ref}}) \cos n(\Psi_n(\eta) - \Psi_n(\eta_{\text{ref}})) \rangle} \end{aligned}$$

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

- ♦ r_n measures relative fluctuation between $v_n(-\eta)$ and $v_n(\eta)$

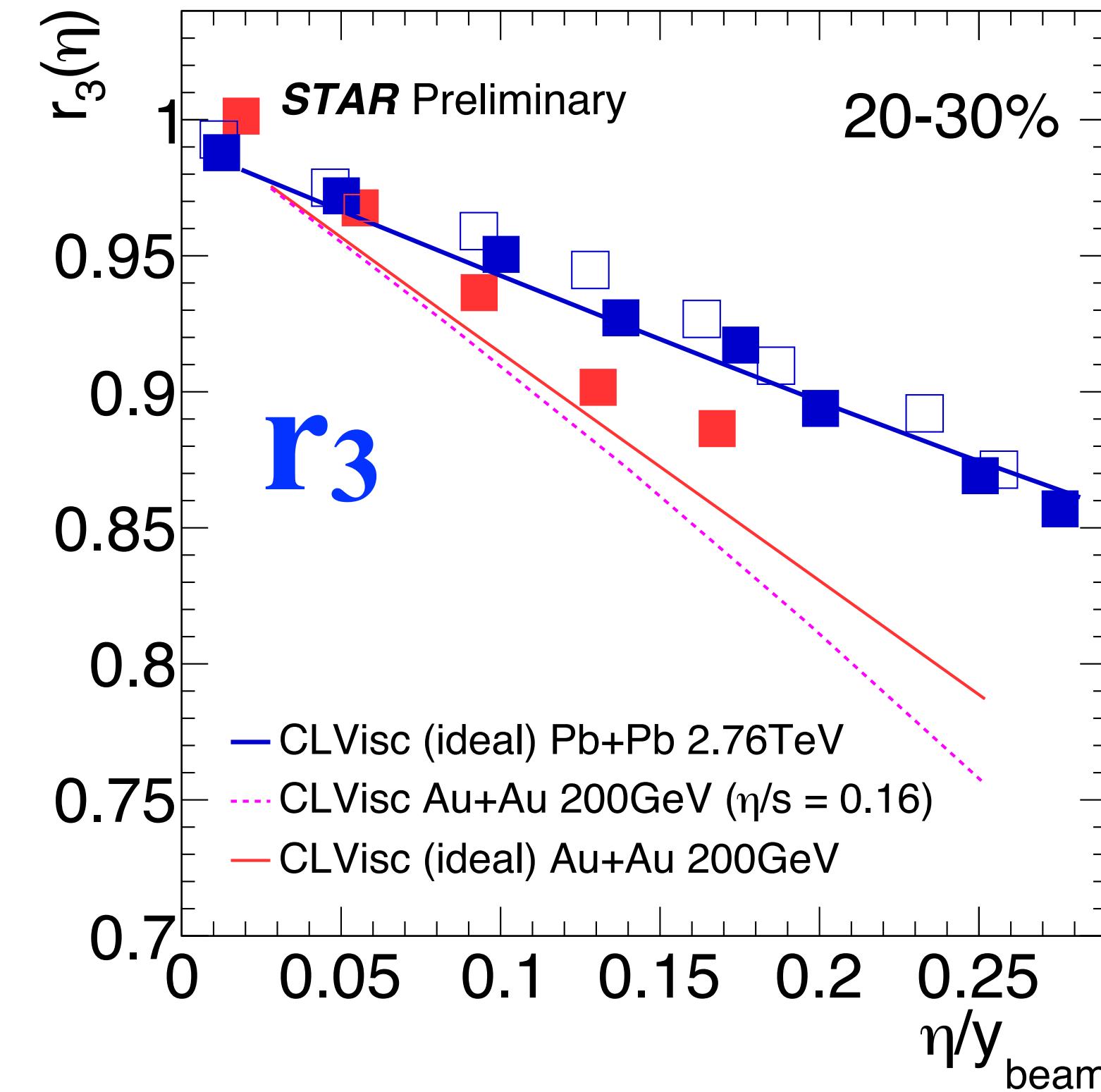
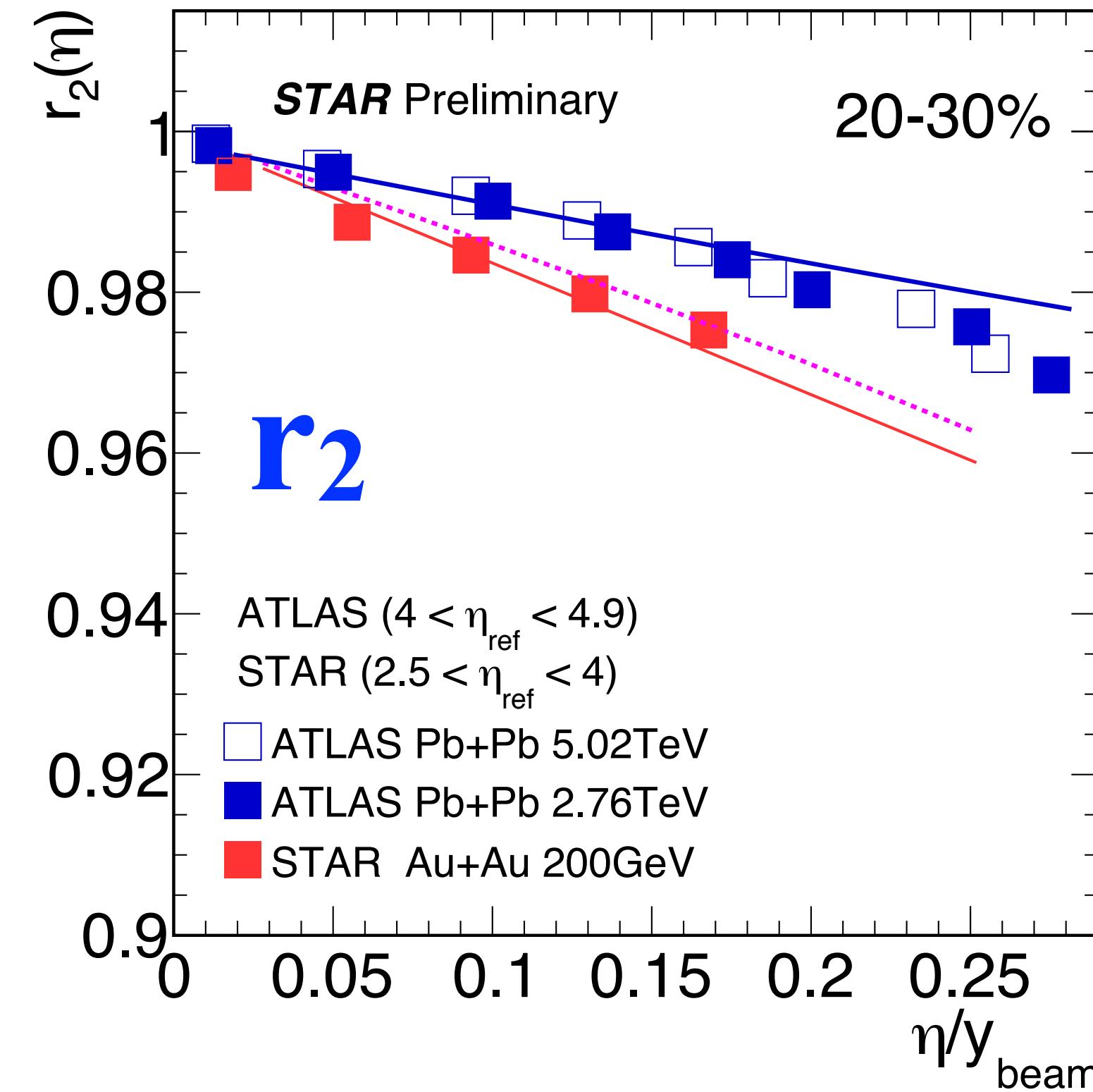


A large η gap is imposed to avoid short-range correlations.

Current results on longitudinal dynamics

- ◆ **Decorrelation results from RHIC and LHC energies**

QM2018, STAR Collaboration
 ATLAS Collaboration, Eur. Phys. J. C (2018) 78:142
 L. Pang et al, Eur. Phys. J. A 52 (2016) 97
 L. Pang et al, arXiv: 1802.04449



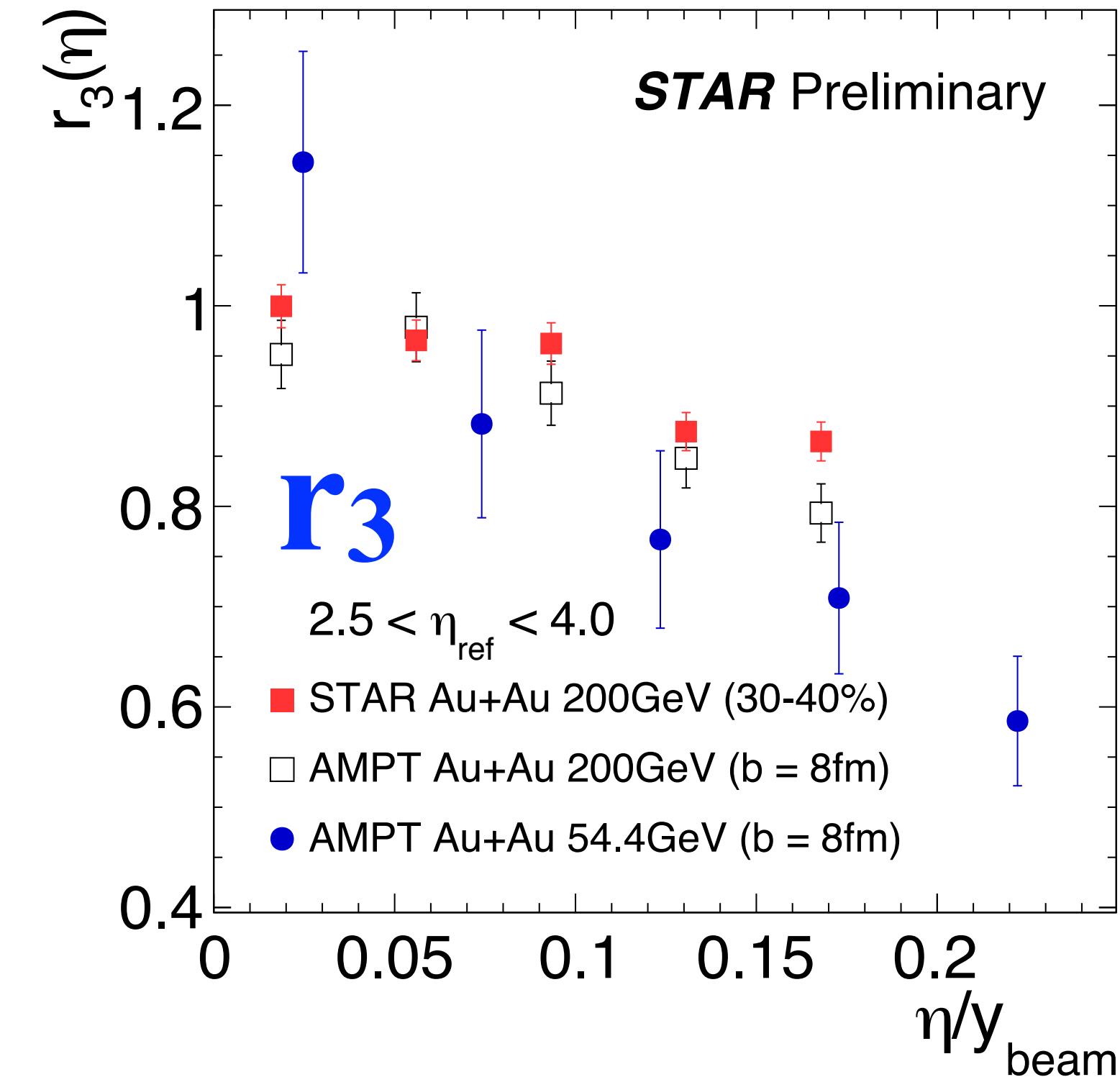
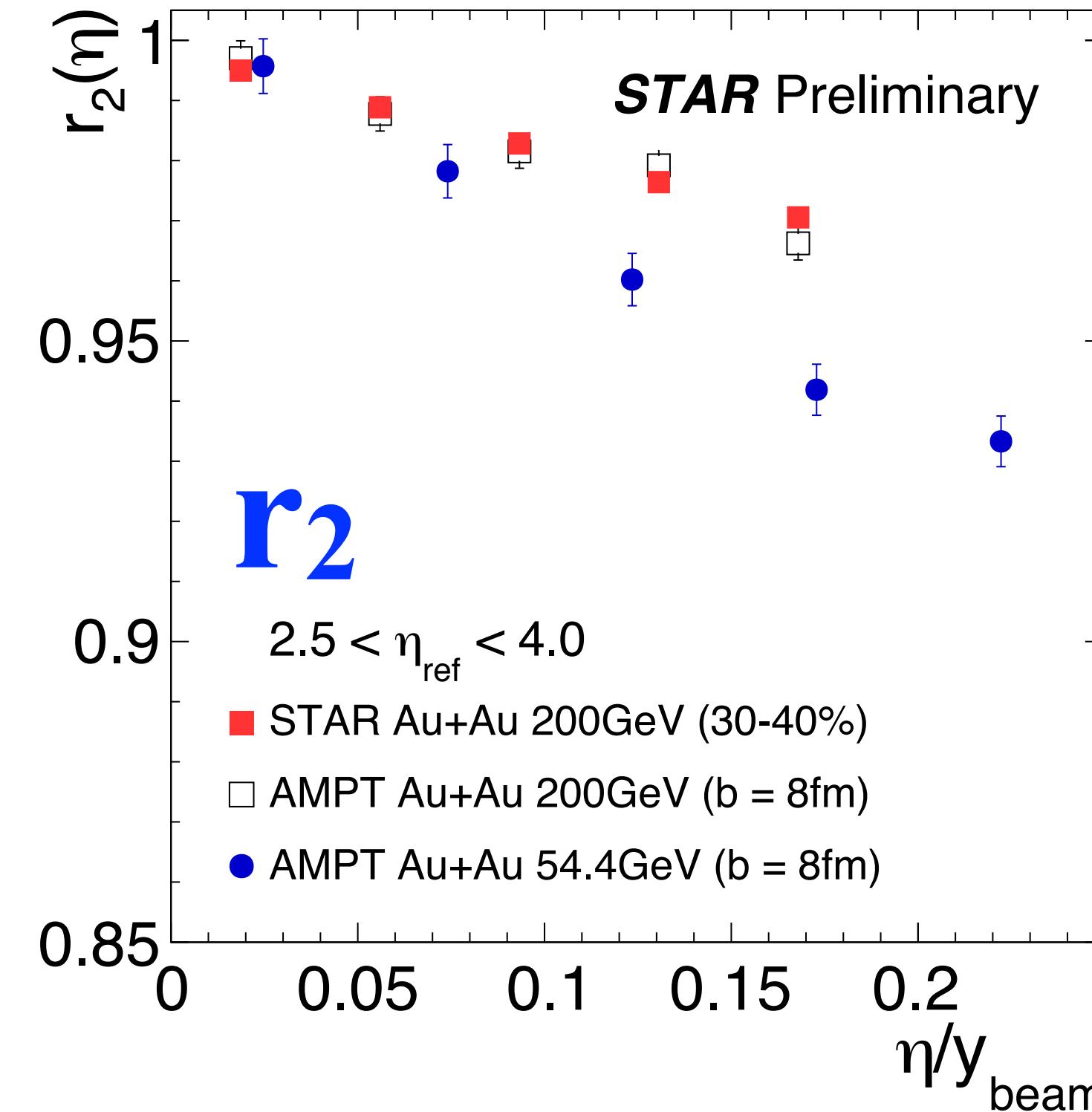
- Clear difference between RHIC and LHC energies.
- Hydrodynamic calculations cannot simultaneously describe RHIC and LHC data.

Expectation of decorrelation at lower $\sqrt{s_{\text{NN}}}$

- ♦ Decorrelation results from AMPT calculations

QM2018, STAR Collaboration

AMPT(with string melting) parton-parton $\sigma = 3\text{mb}$

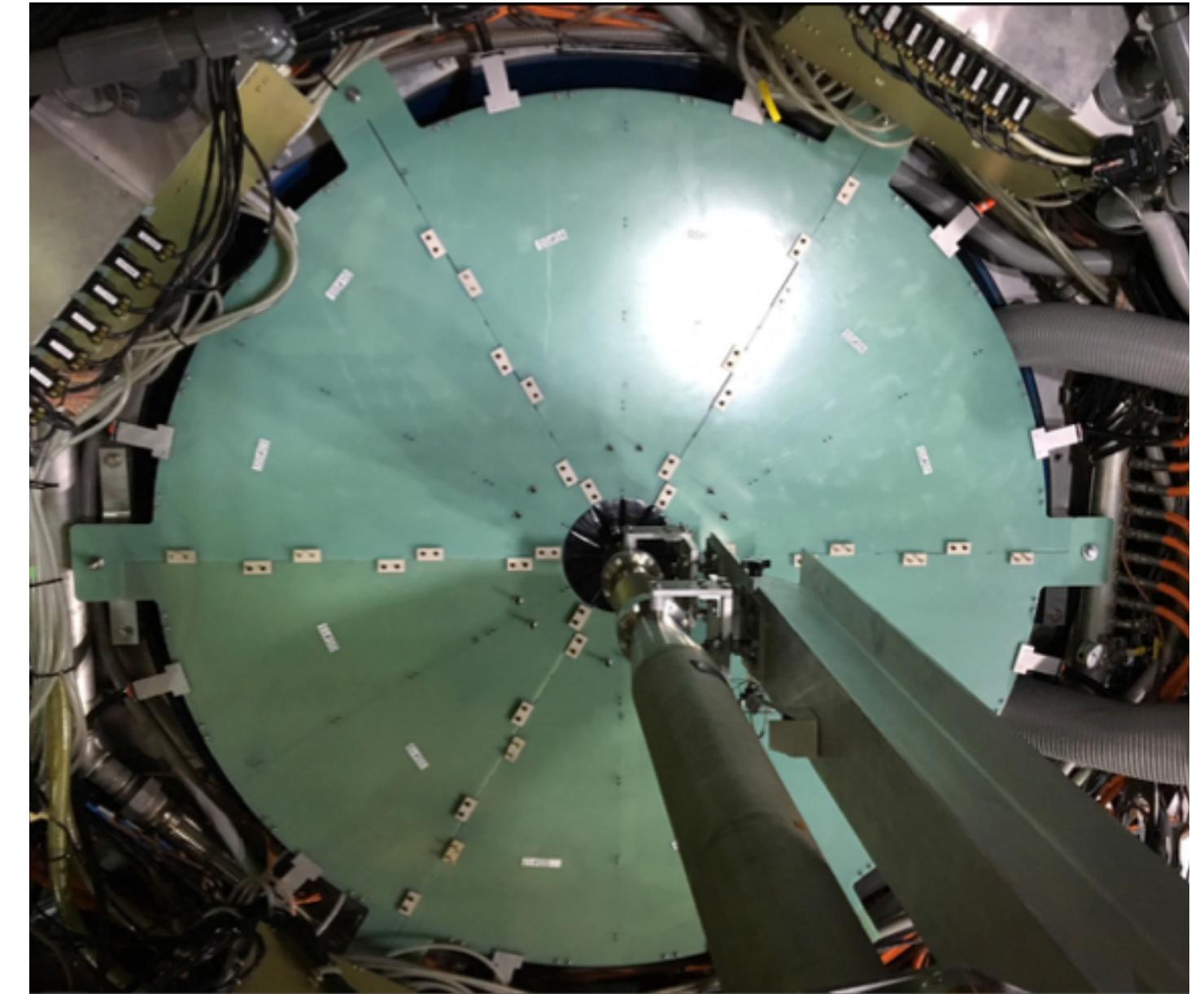
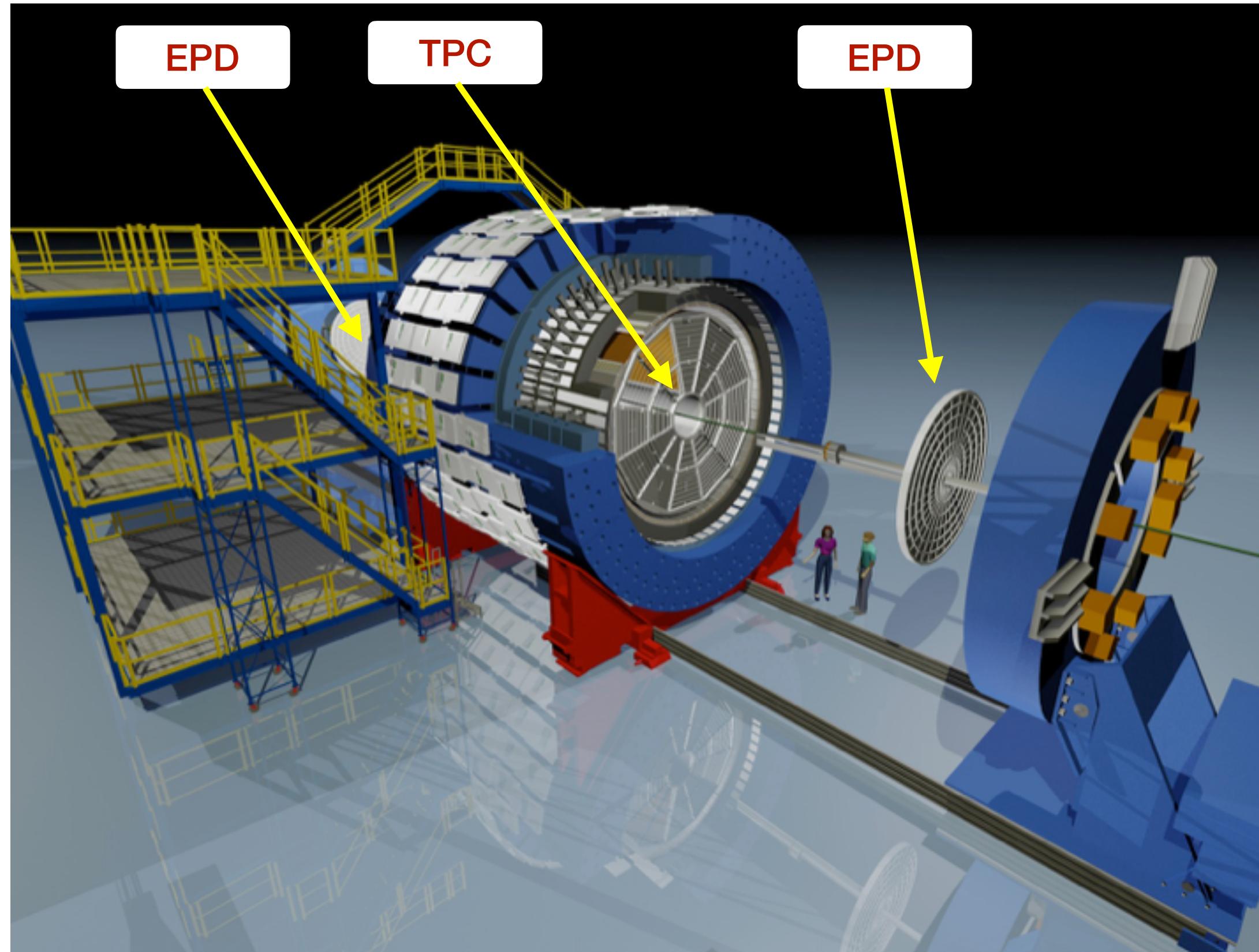


- Transport model also indicates stronger decorrelation at lower energy.
- Energy dependence needs to be measured at lower energies.
- New measurement at $\sqrt{s_{\text{NN}}} = 27\text{ GeV}$ is presented.

The STAR detectors

- ♦ A schematic diagram of the STAR detectors

Event Plane Detector

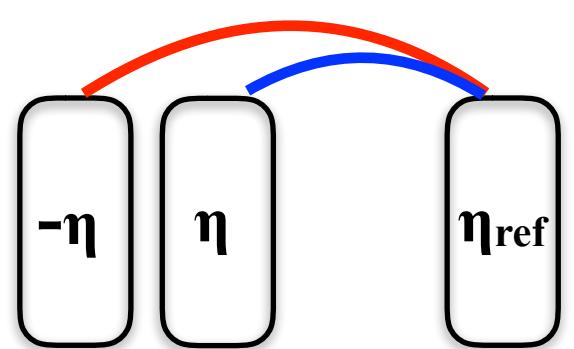
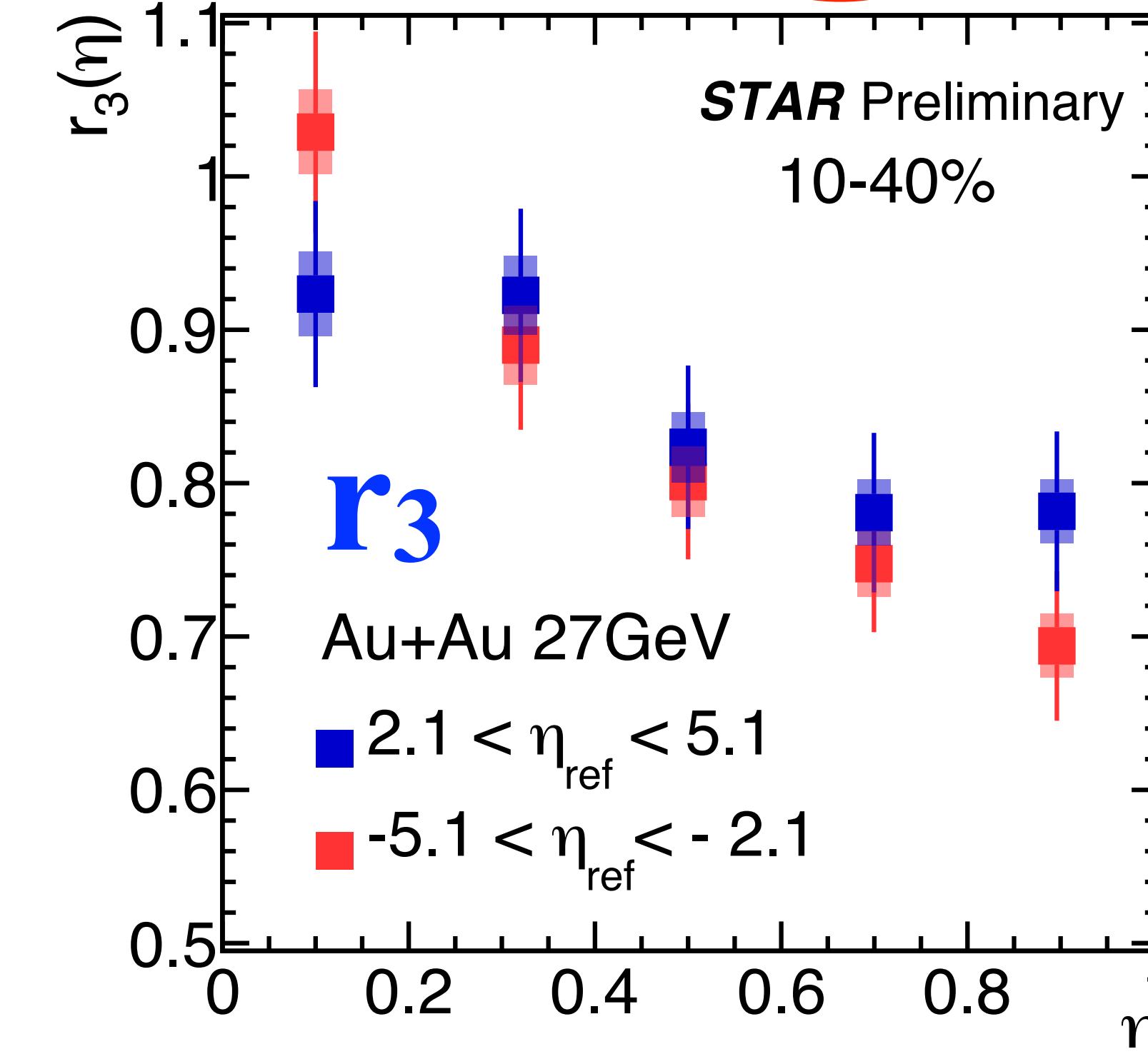
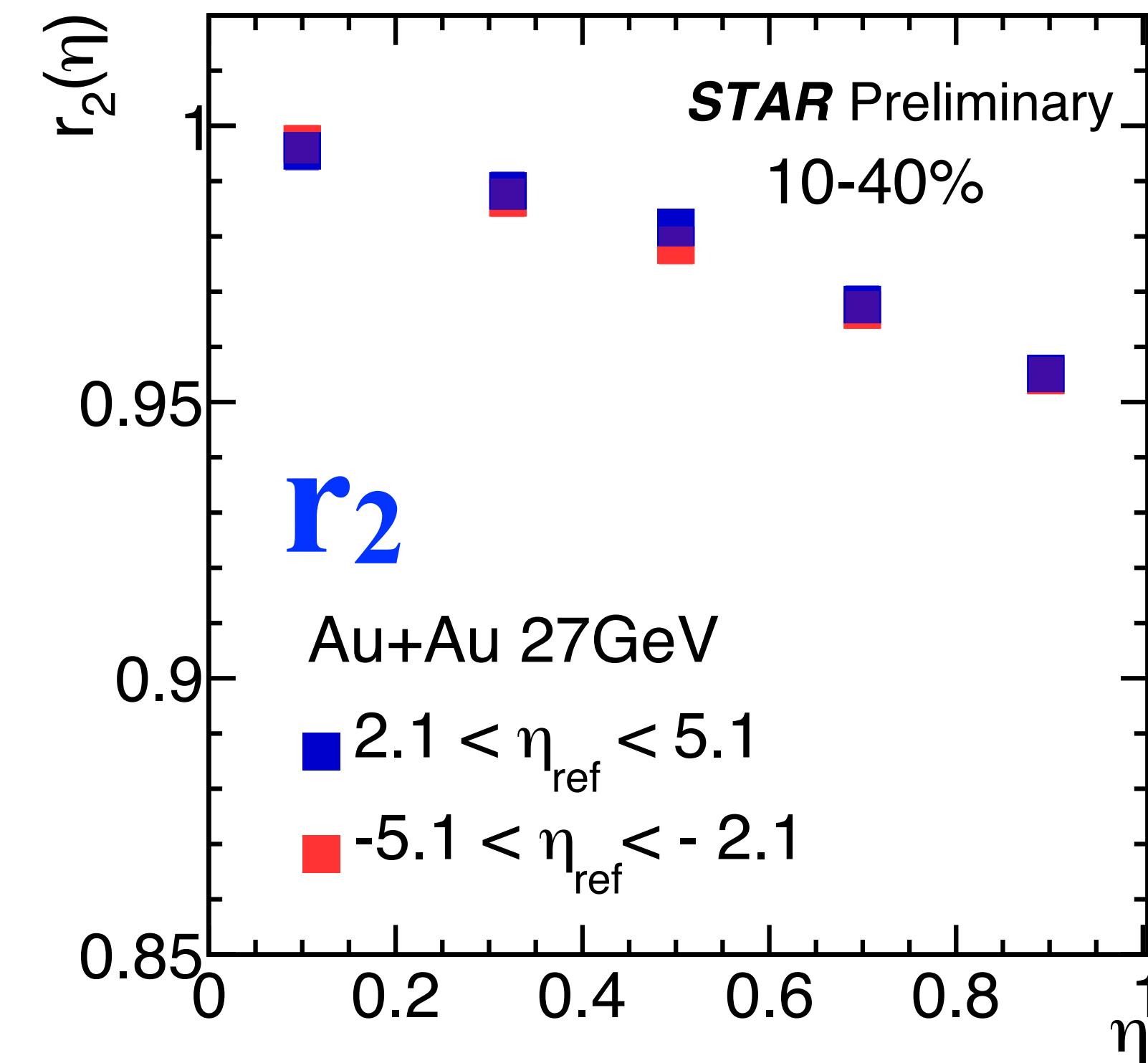


provides centrality definition
and event plane measurement at
forward region

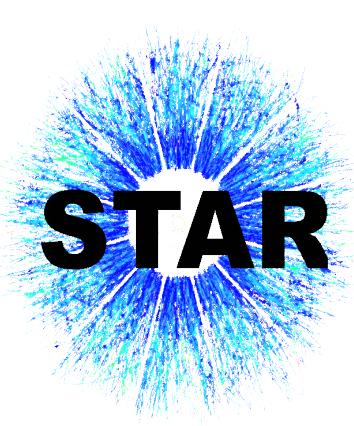
- TPC and EPD are used for this analysis, 2018 Au+Au 27 GeV data (~800M) is used.
- TPC acceptance : $-1 < \eta < 1$; EPD acceptance : $2.1 < |\eta| < 5.1$.

Decorrelation measurement at 27 GeV

◆ v_n decorrelation with η_{ref} and $-\eta_{\text{ref}}$

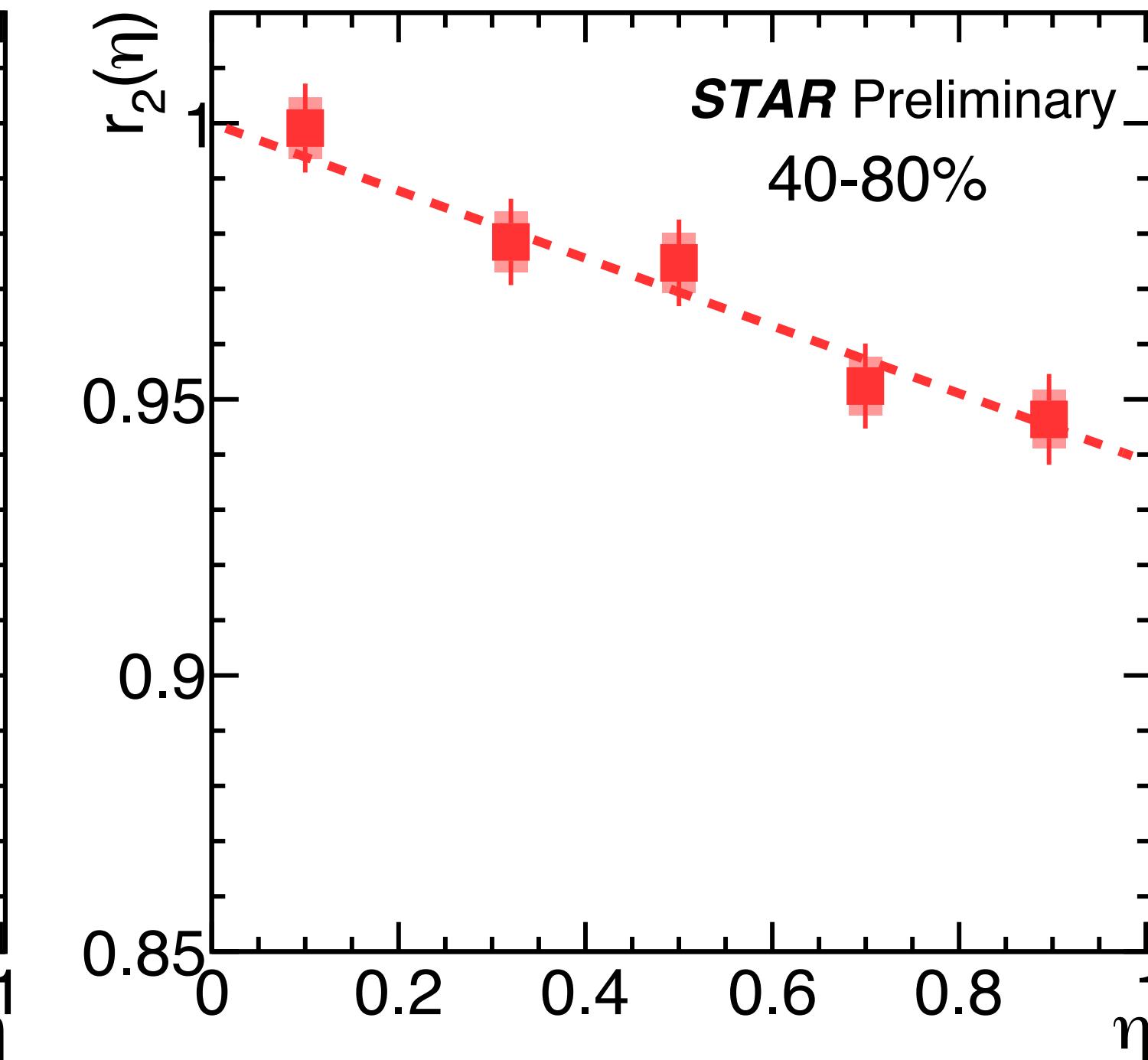
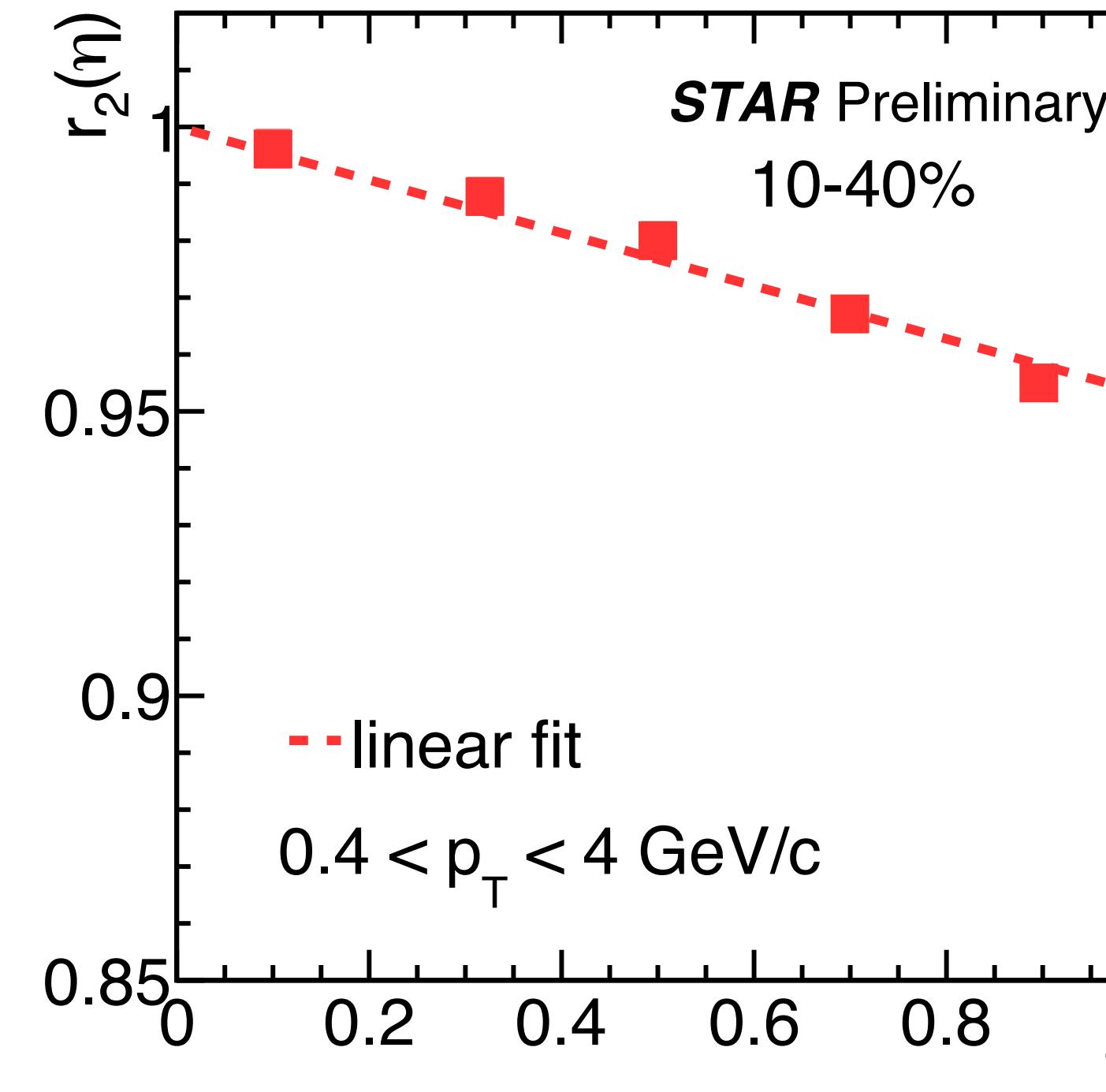
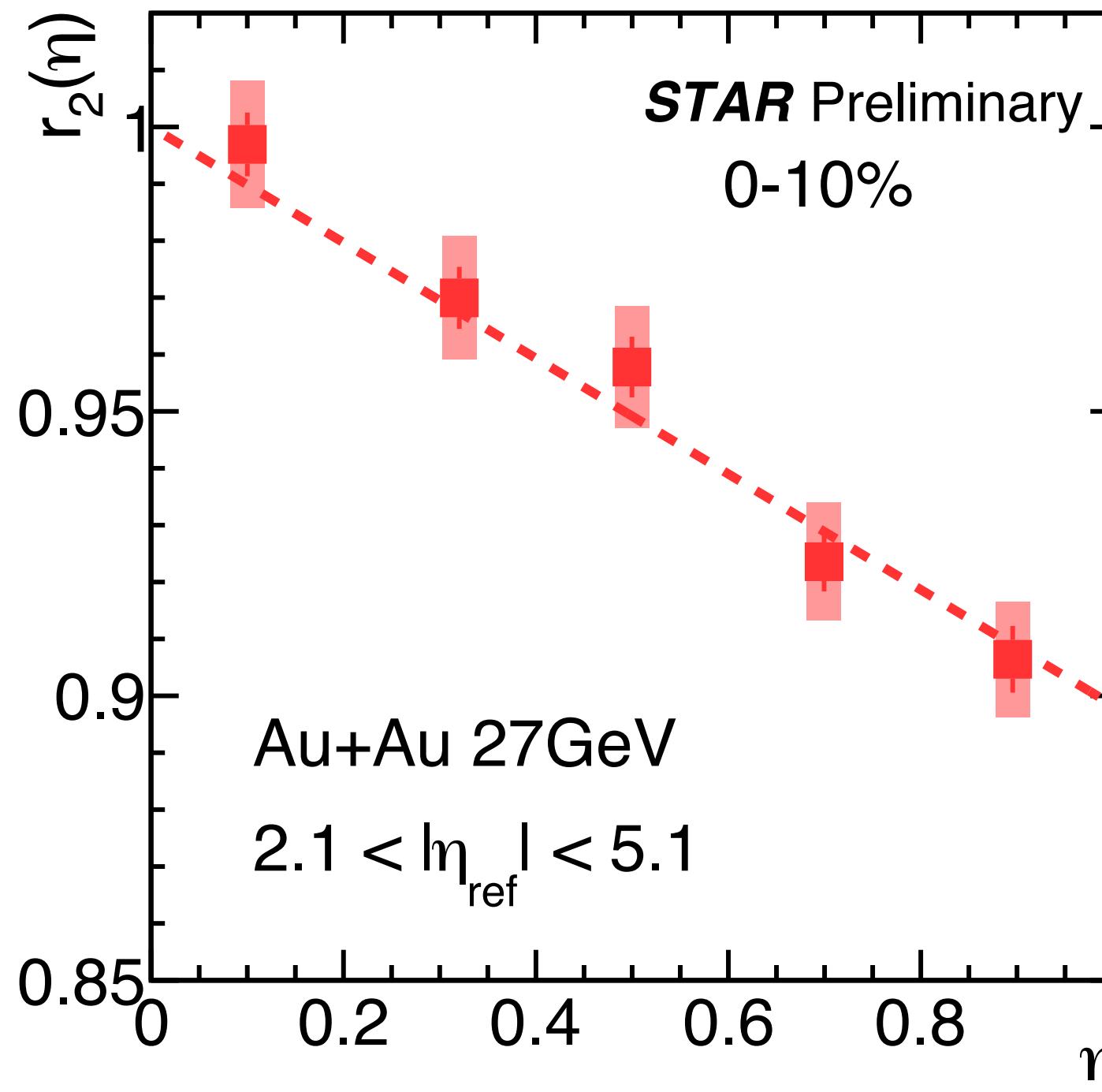
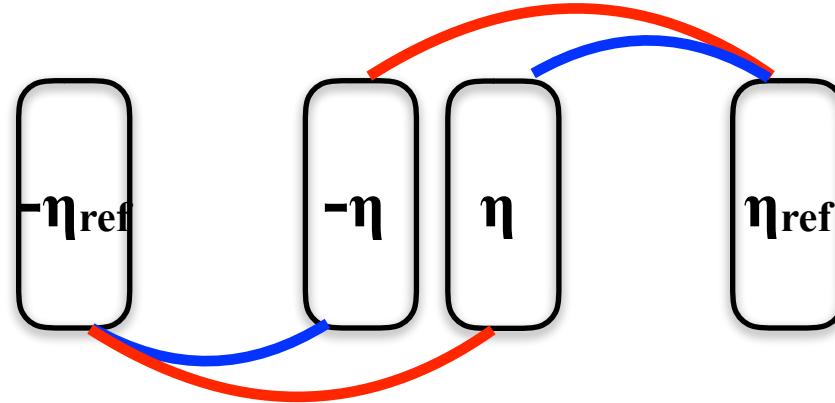


- Two sides of EPD provide sanity check for detector effects.
- Both r_2 and r_3 show consistent results for two sides of EPD.

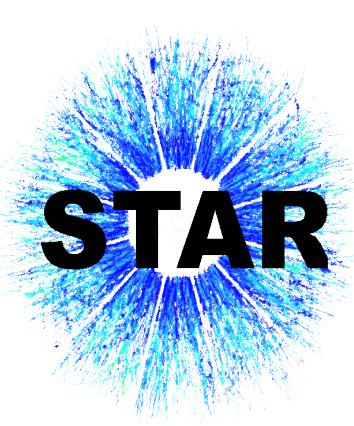


v2 decorrelation at 27 GeV

◆ Decorrelation of v2

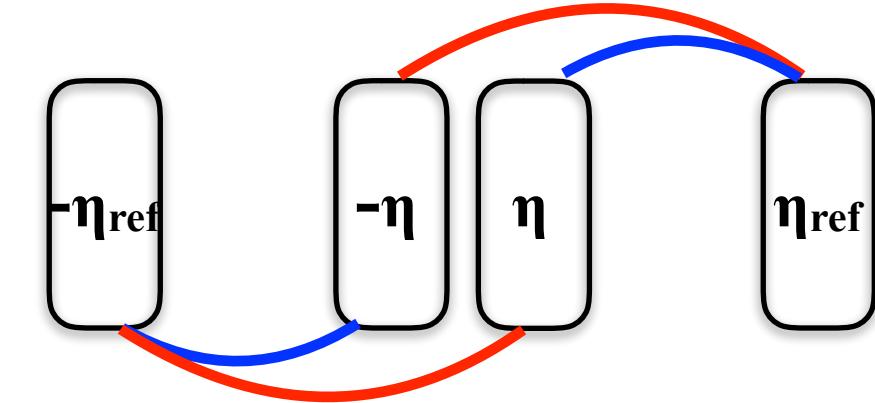
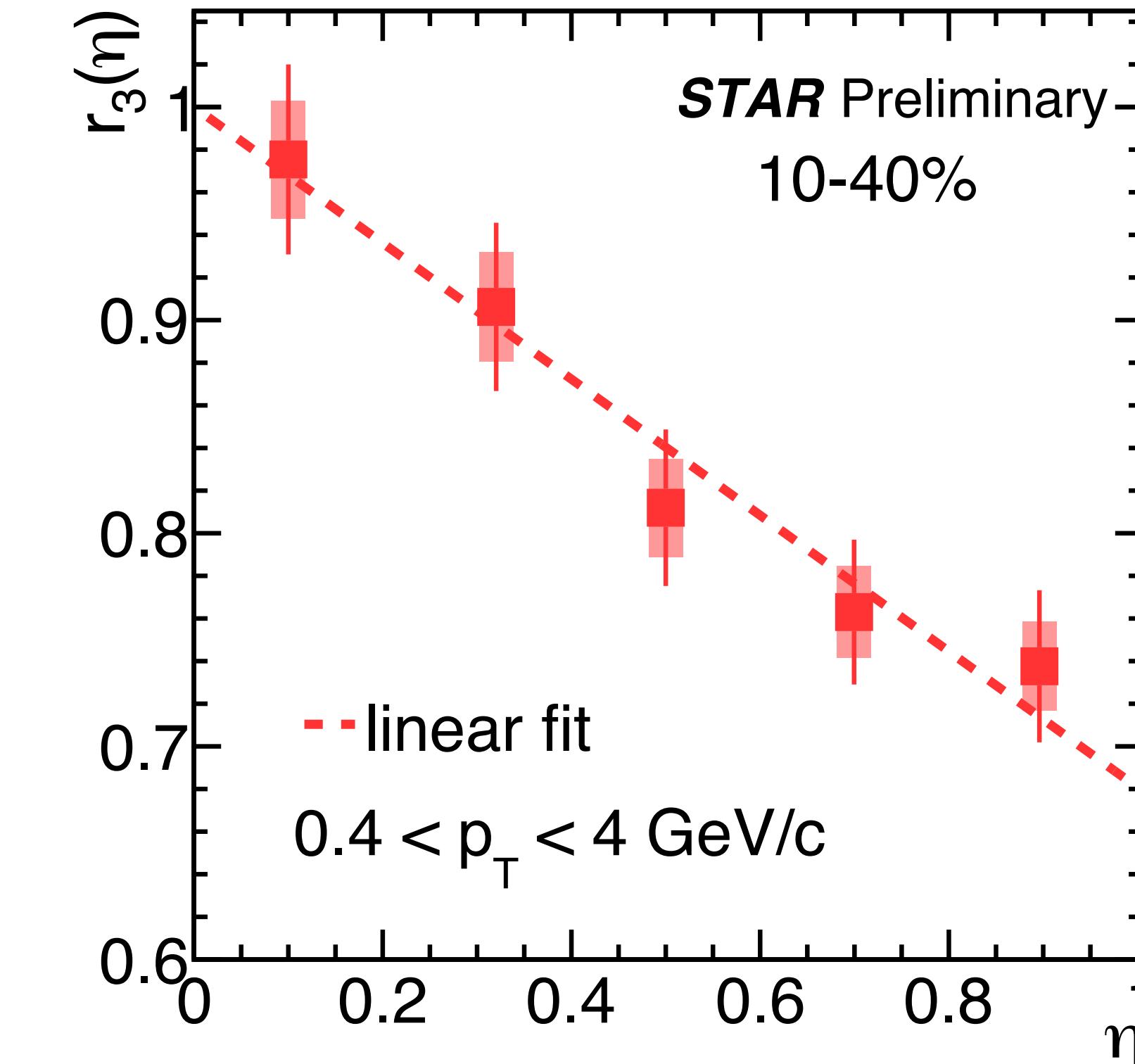
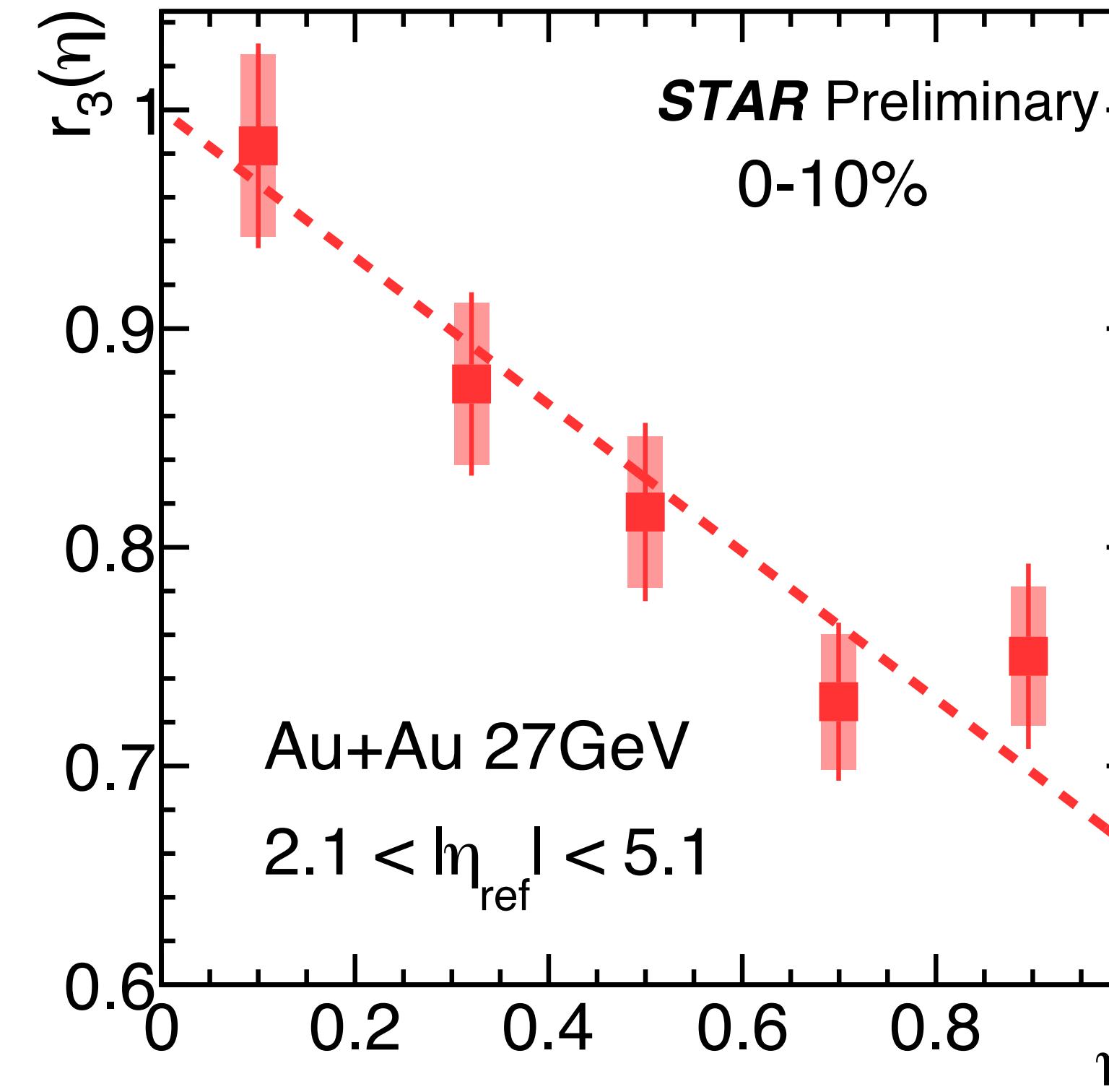


- $r_2(\eta)$ decreases linearly for the shown centralities.
- Decorrelation of v2 is the strongest in central collisions.



v3 decorrelation at 27 GeV

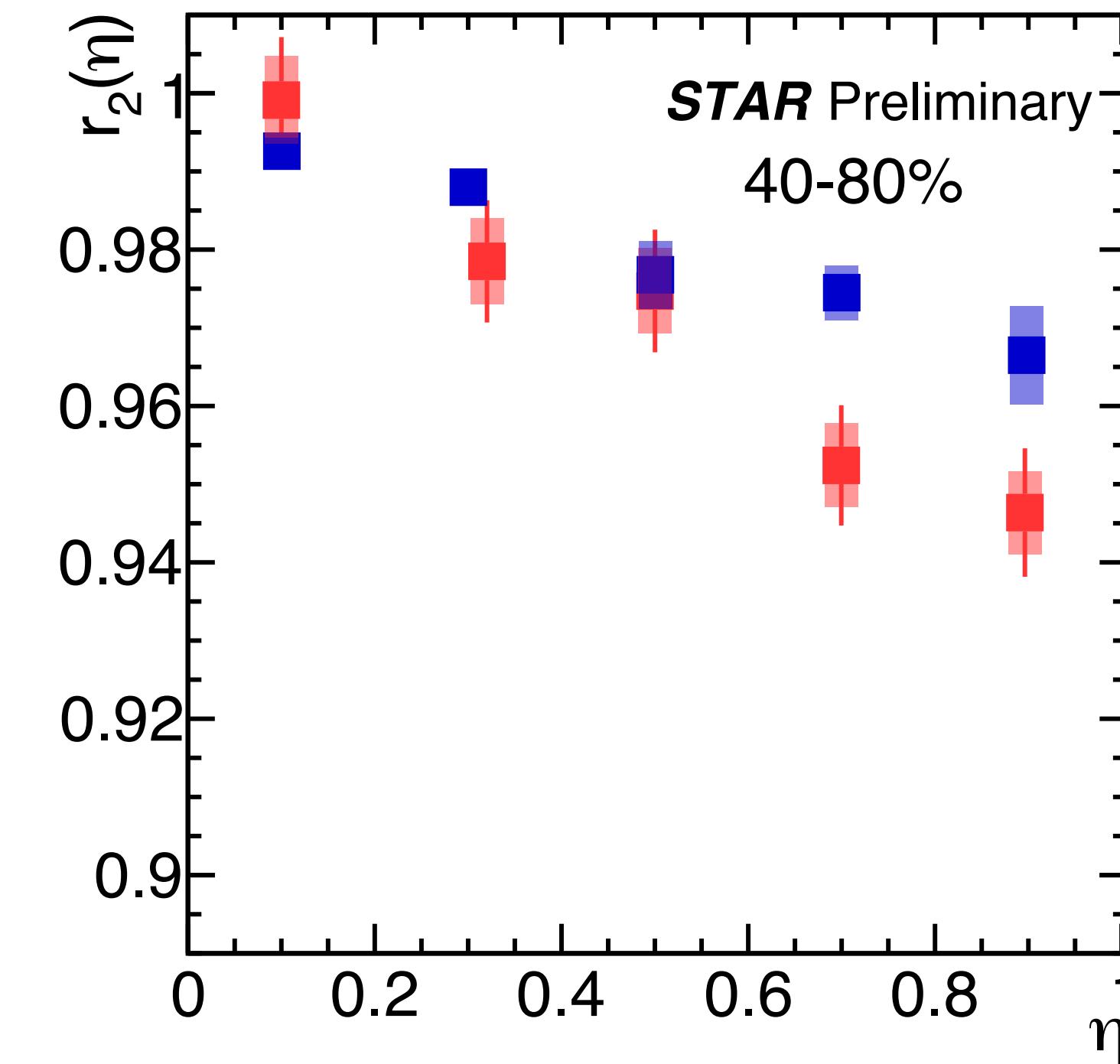
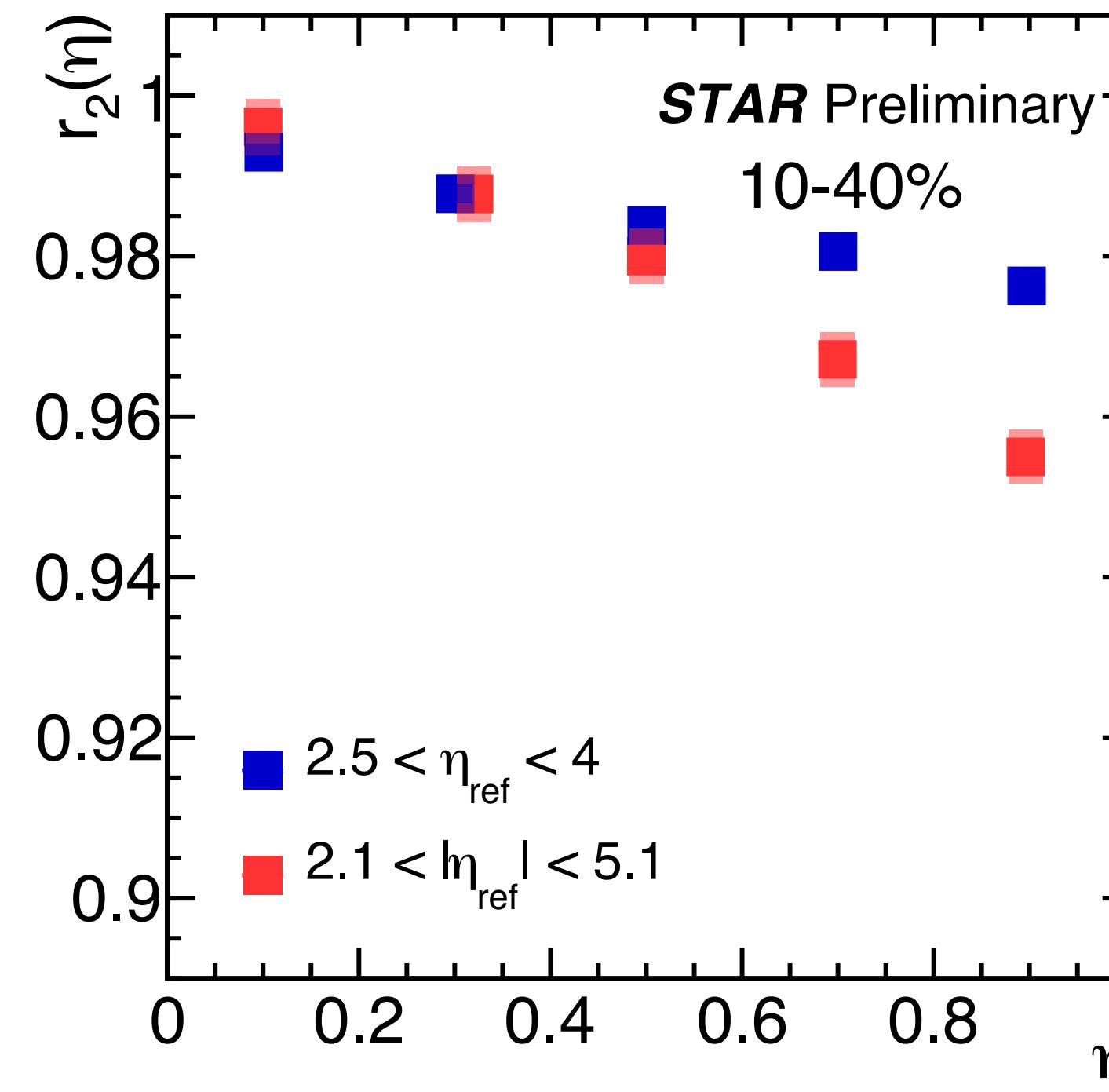
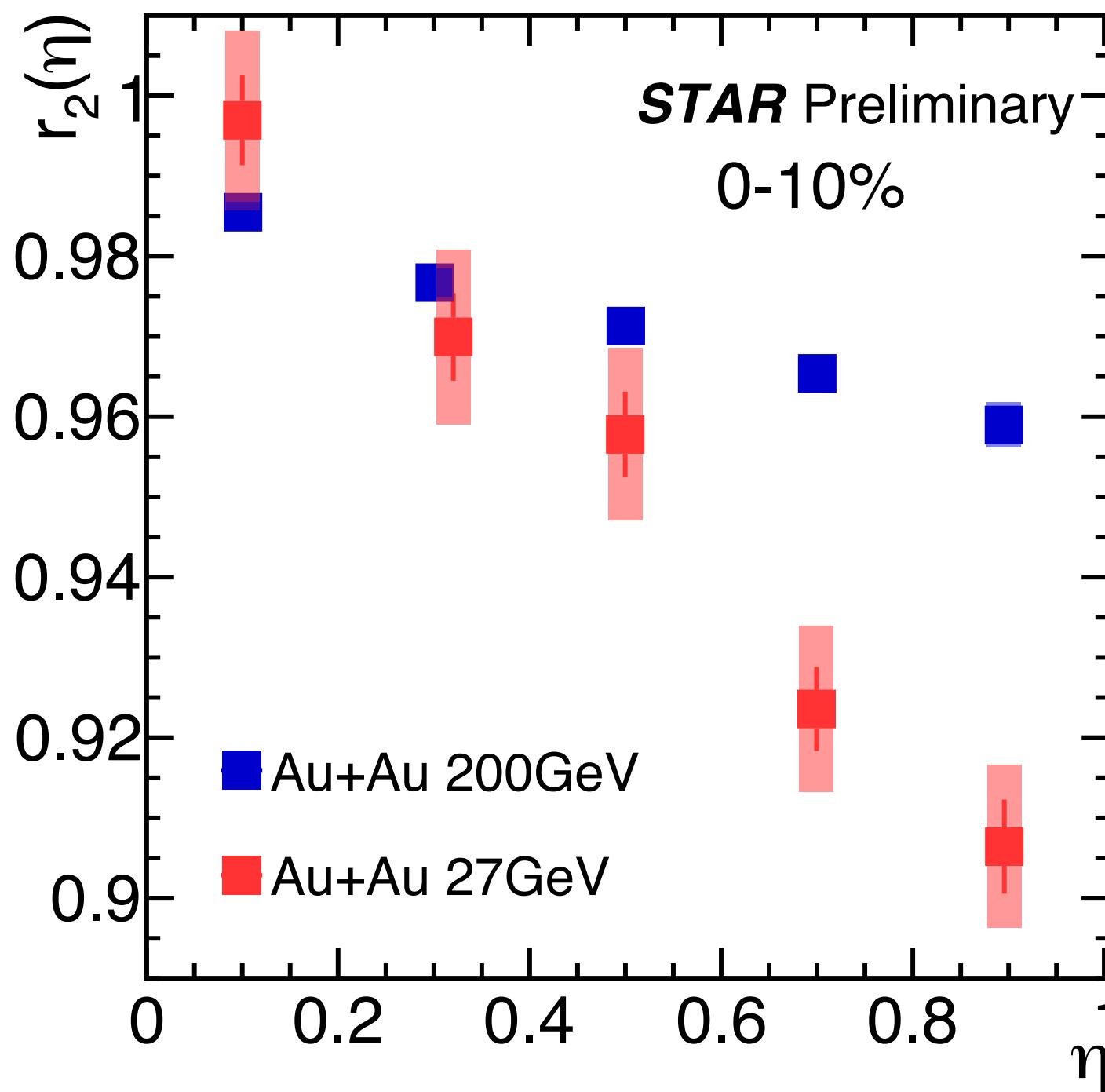
♦ Decorrelation of v3



- $r_3(\eta)$ decreases linearly for the shown centralities.
- v_3 decorrelation is as large as 30% and roughly centrality independent.

V2 decorrelation 27 vs 200 GeV

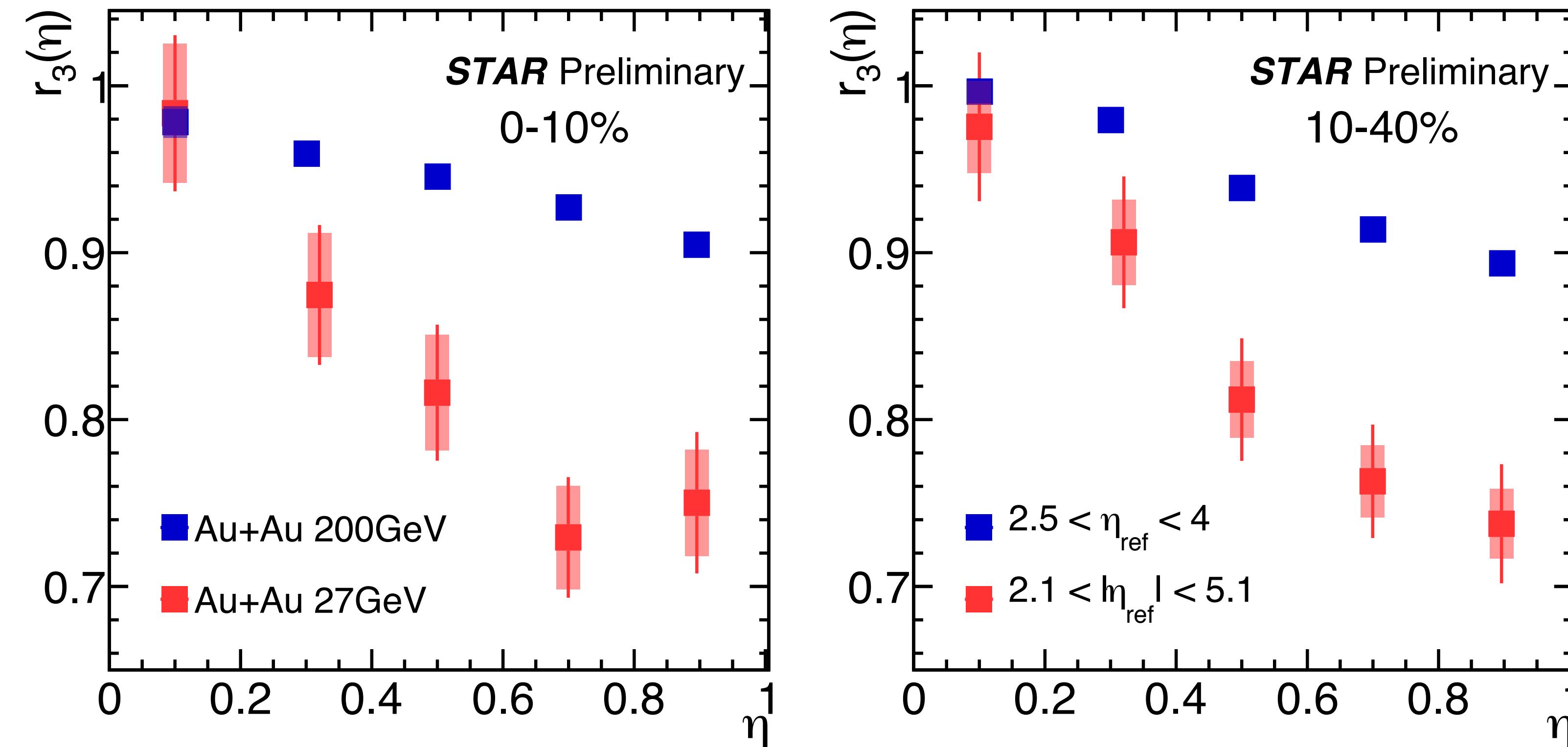
◆ r_2 comparison between 27 GeV and 200GeV



- Stronger v_2 decorrelation at 27 GeV is observed for all shown centralities.
- v_2 decorrelation at 27 GeV is ~2 times larger than at 200 GeV.

V3 decorrelation 27 vs 200 GeV

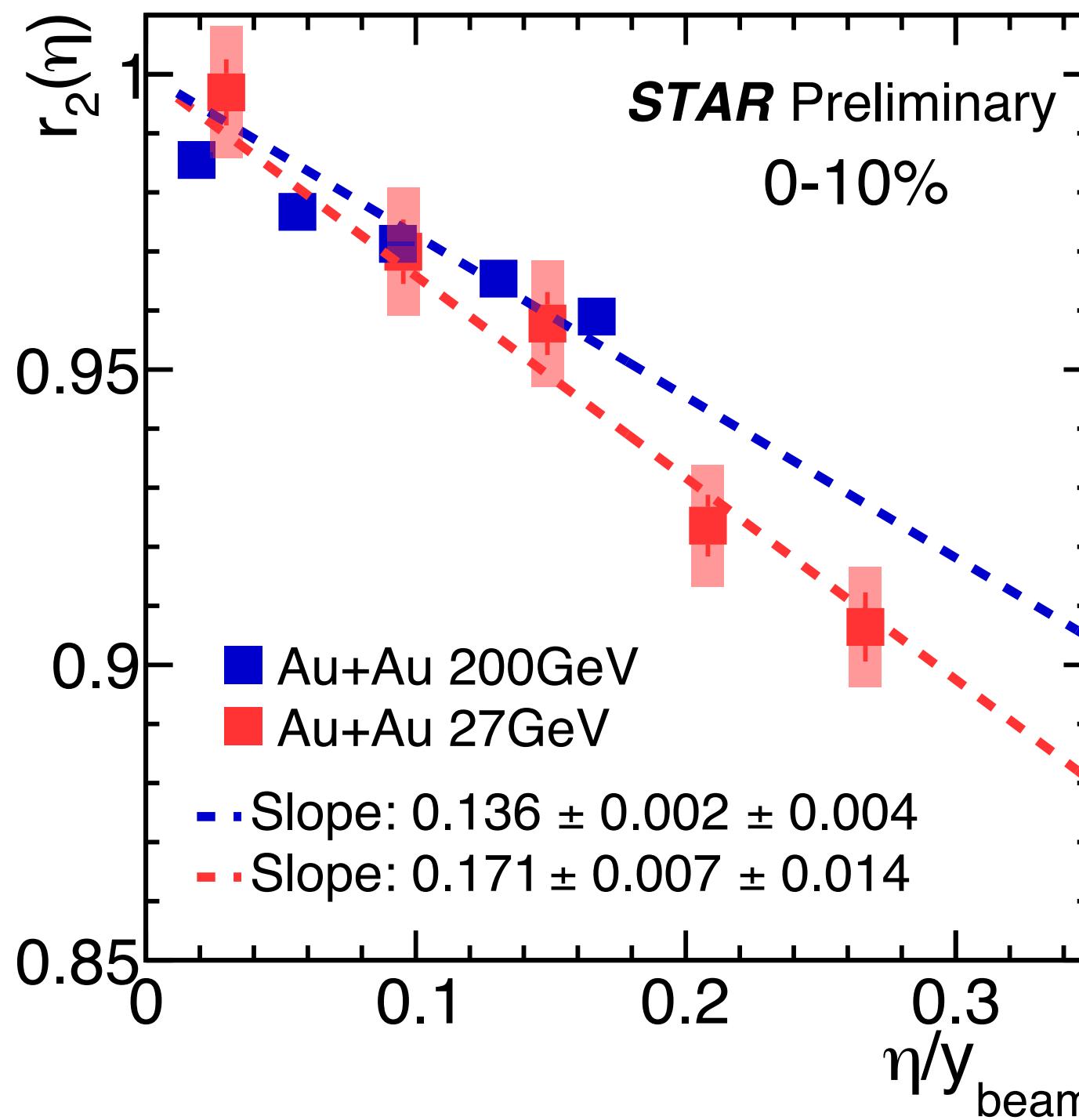
◆ r₃ comparison between 27GeV and 200GeV



- Stronger v₃ decorrelation at 27 GeV is observed for the two centralities.
- v₃ decorrelation at 27 GeV is ~3 times larger than at 200 GeV.

V2 decorrelation scaled by beam rapidity

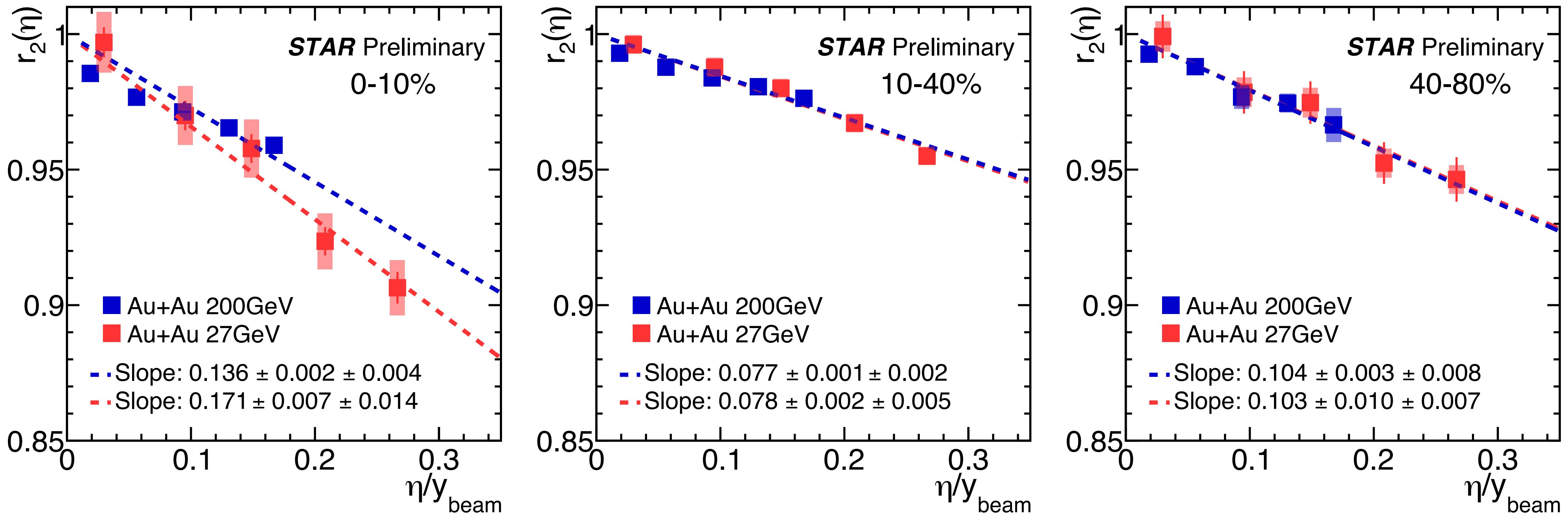
- ◆ r_2 comparison between 27 GeV and 200 GeV with rapidity normalization



- After y_{beam} normalization, r_2 shows:
 - 0-10% weak energy dependence;

V2 decorrelation scaled by beam rapidity

- ◆ r₂ comparison between 27 GeV and 200 GeV with rapidity normalization

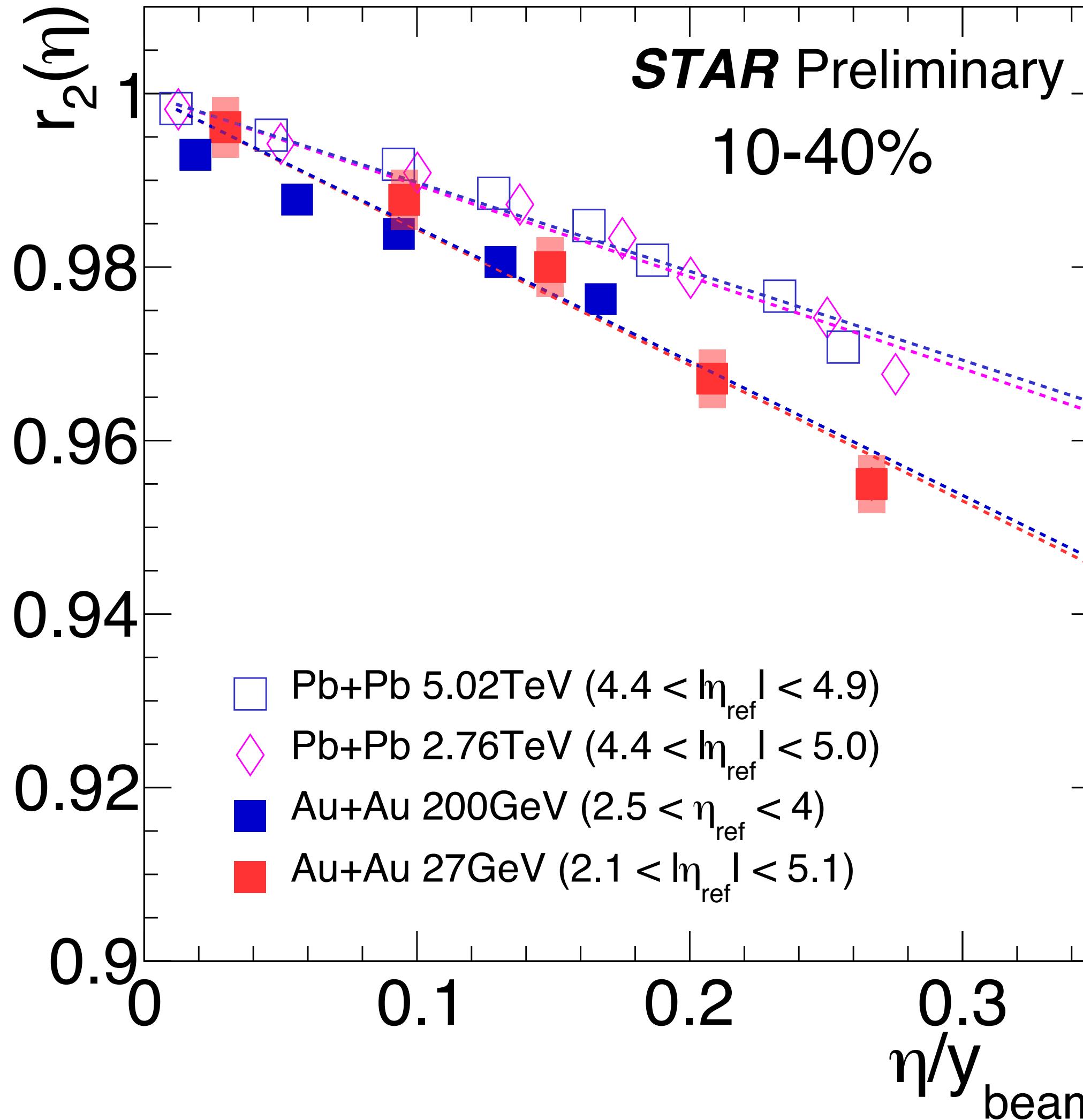


- After y_{beam} normalization, r_2 shows:
 - ▶ 0-10% weak energy dependence;
 - ▶ 10-40% & 40-80% no energy dependence.

r₂ comparison with LHC results

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

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



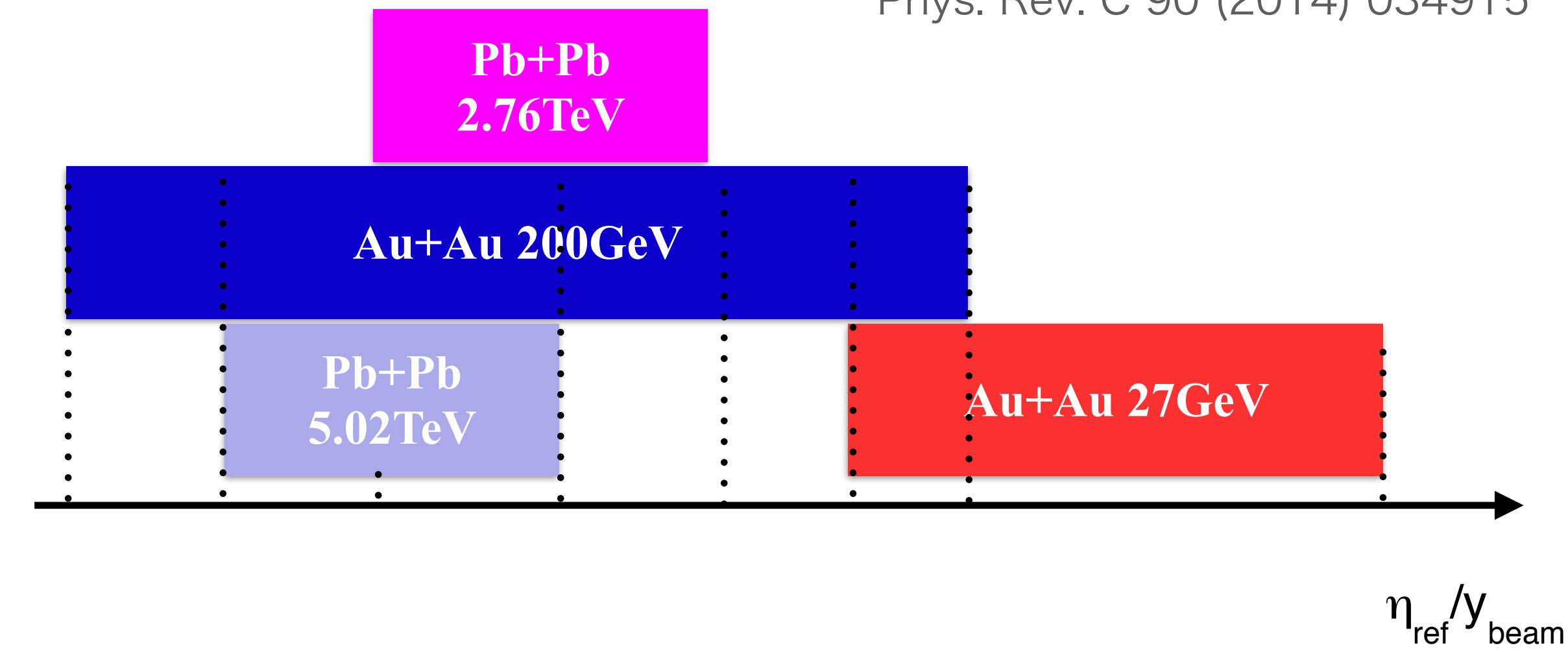
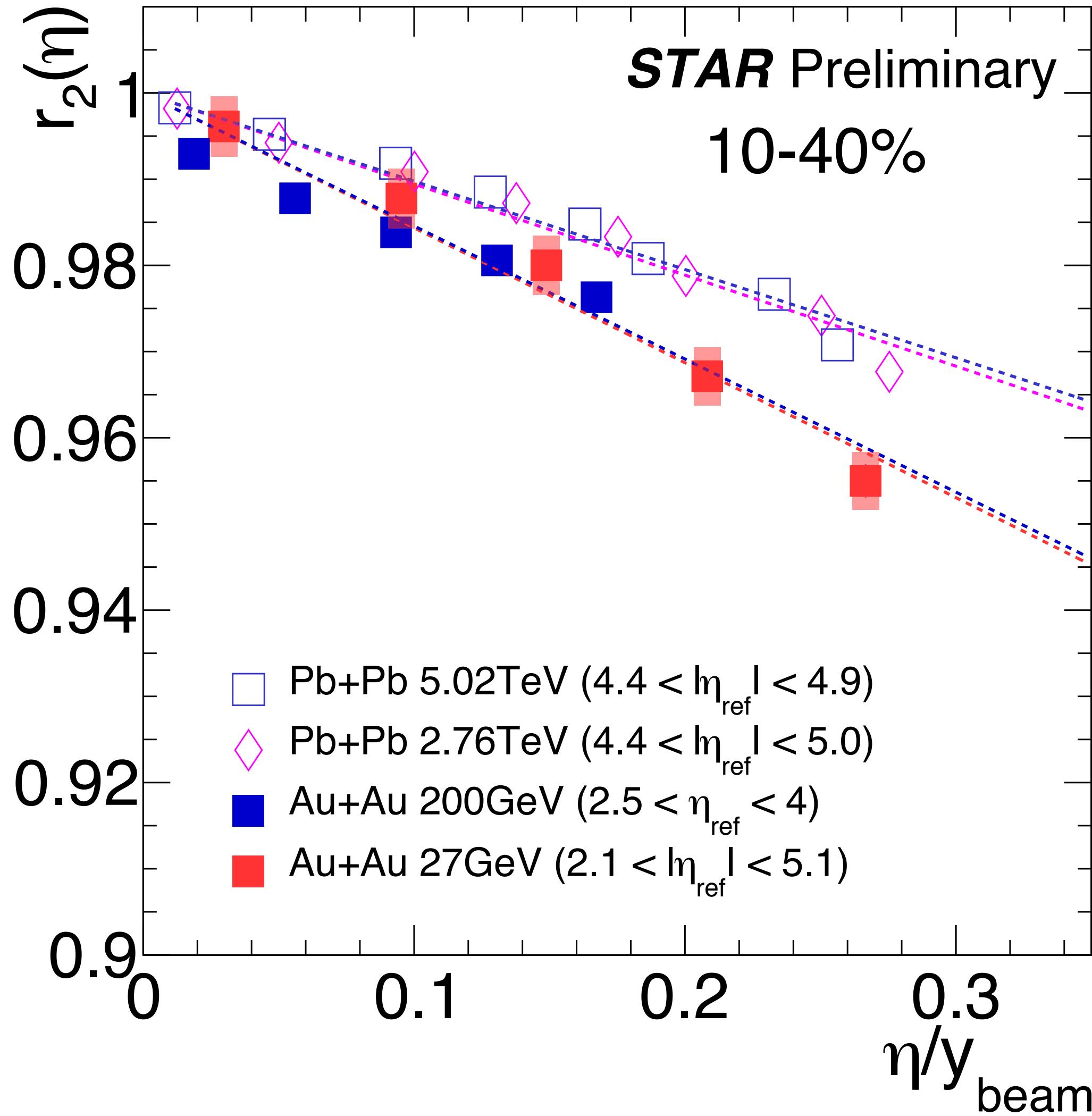
	Slope
Au+Au 27GeV	0.078 ± 0.002
Au+Au 200GeV	0.077 ± 0.001
Pb+Pb 2.76TeV	0.053 ± 0.001
Pb+Pb 5.02TeV	0.051 ± 0.001

- No clear energy dependence for both RHIC or LHC energies.

r₂ comparison with LHC results

CMS Collaboration, Phys. Rev. C 92 (2015) 034911
 ATLAS Collaboration, Eur. Phys. J. C (2018) 78:142

J. Jia, P. Huo,
 Phys. Rev. C 90 (2014) 034915

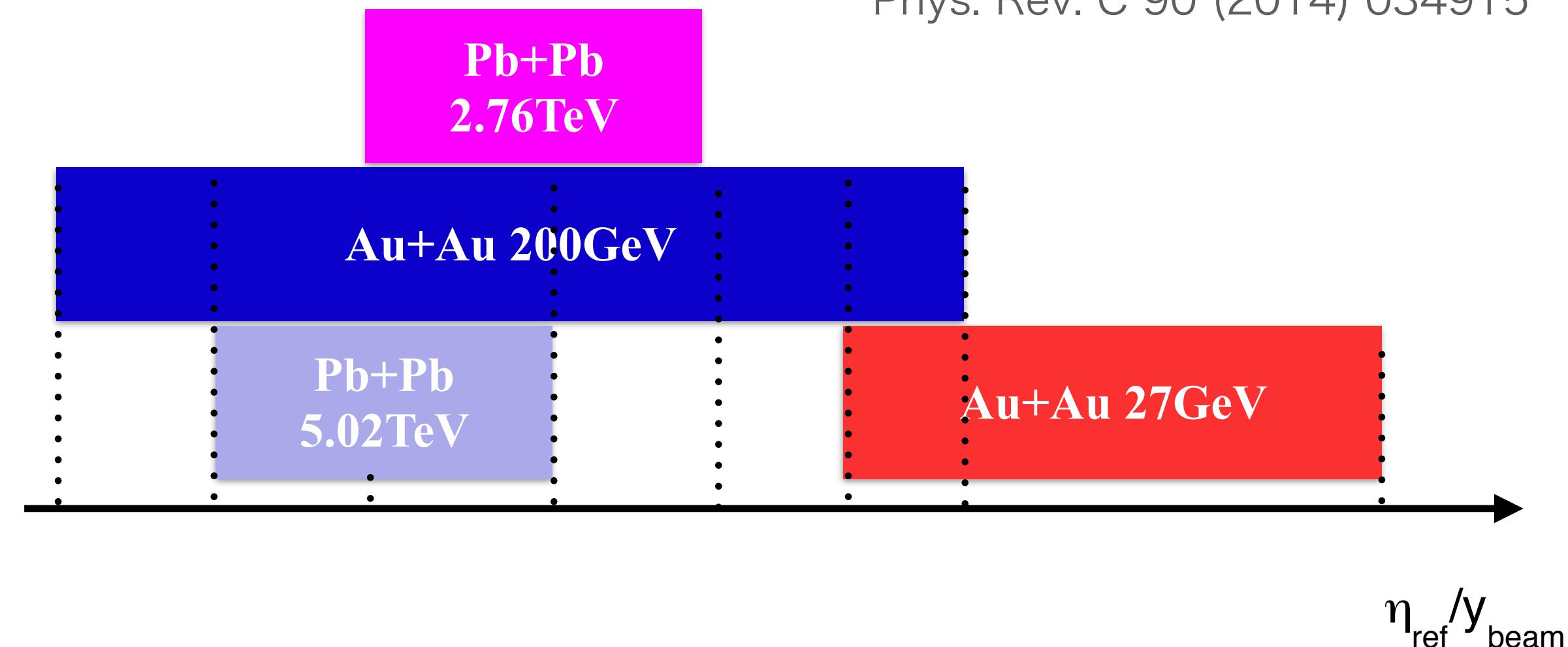
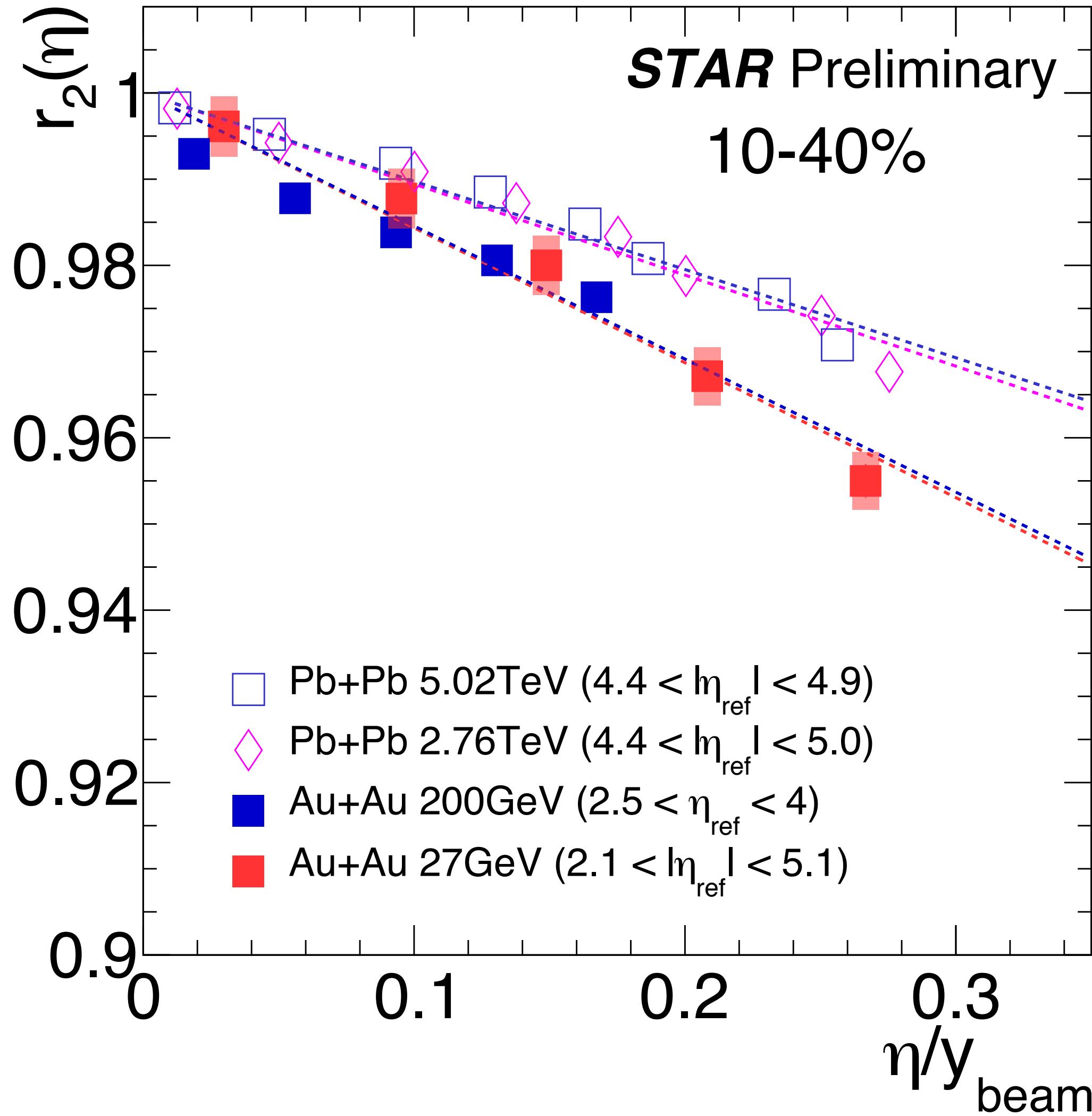


- No clear energy dependence for both RHIC or LHC energies.
- Potential non-linear behavior of decorrelation when reference is close to beam rapidity?

r₂ comparison with LHC results

CMS Collaboration, Phys. Rev. C 92 (2015) 034911
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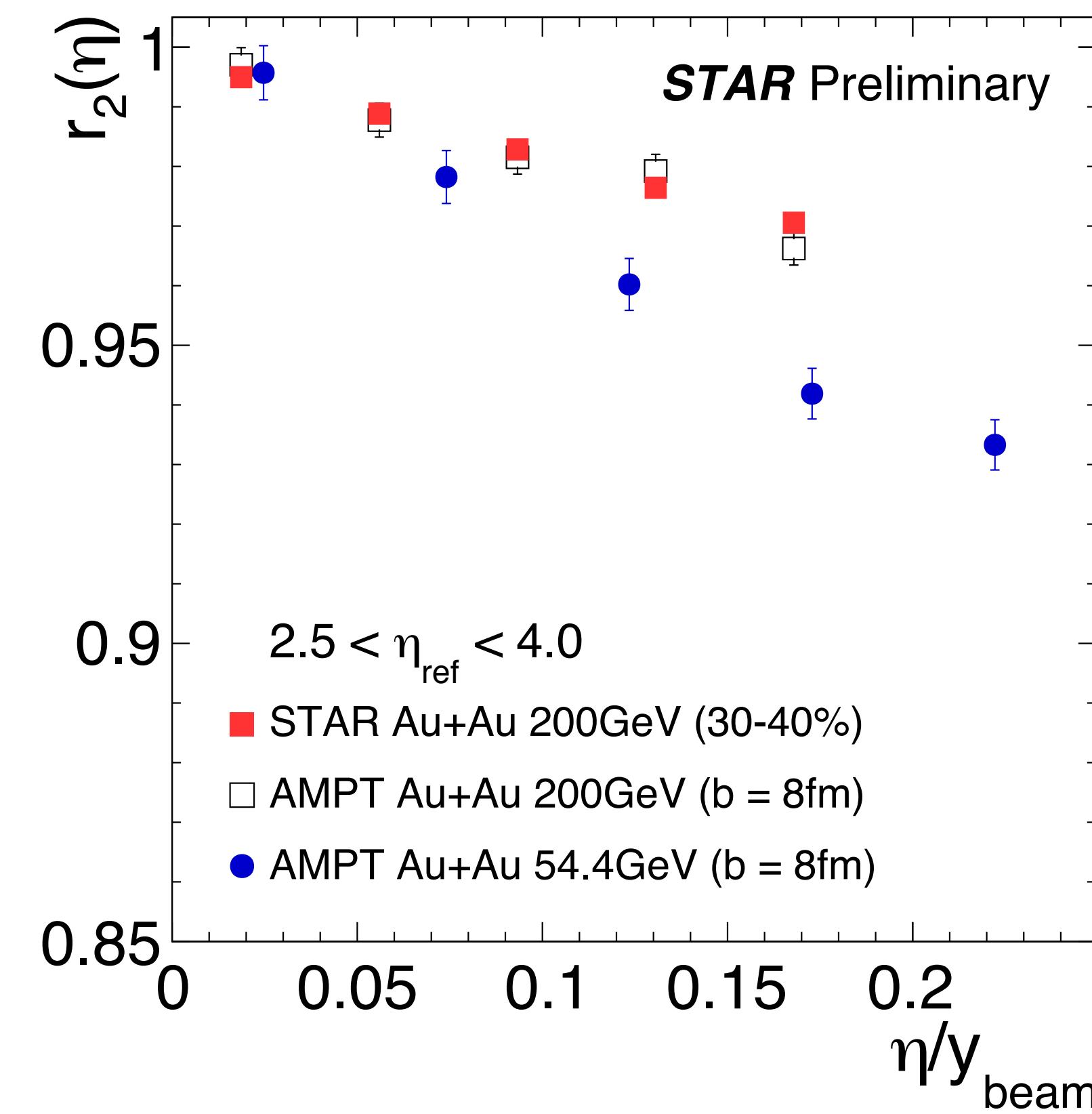
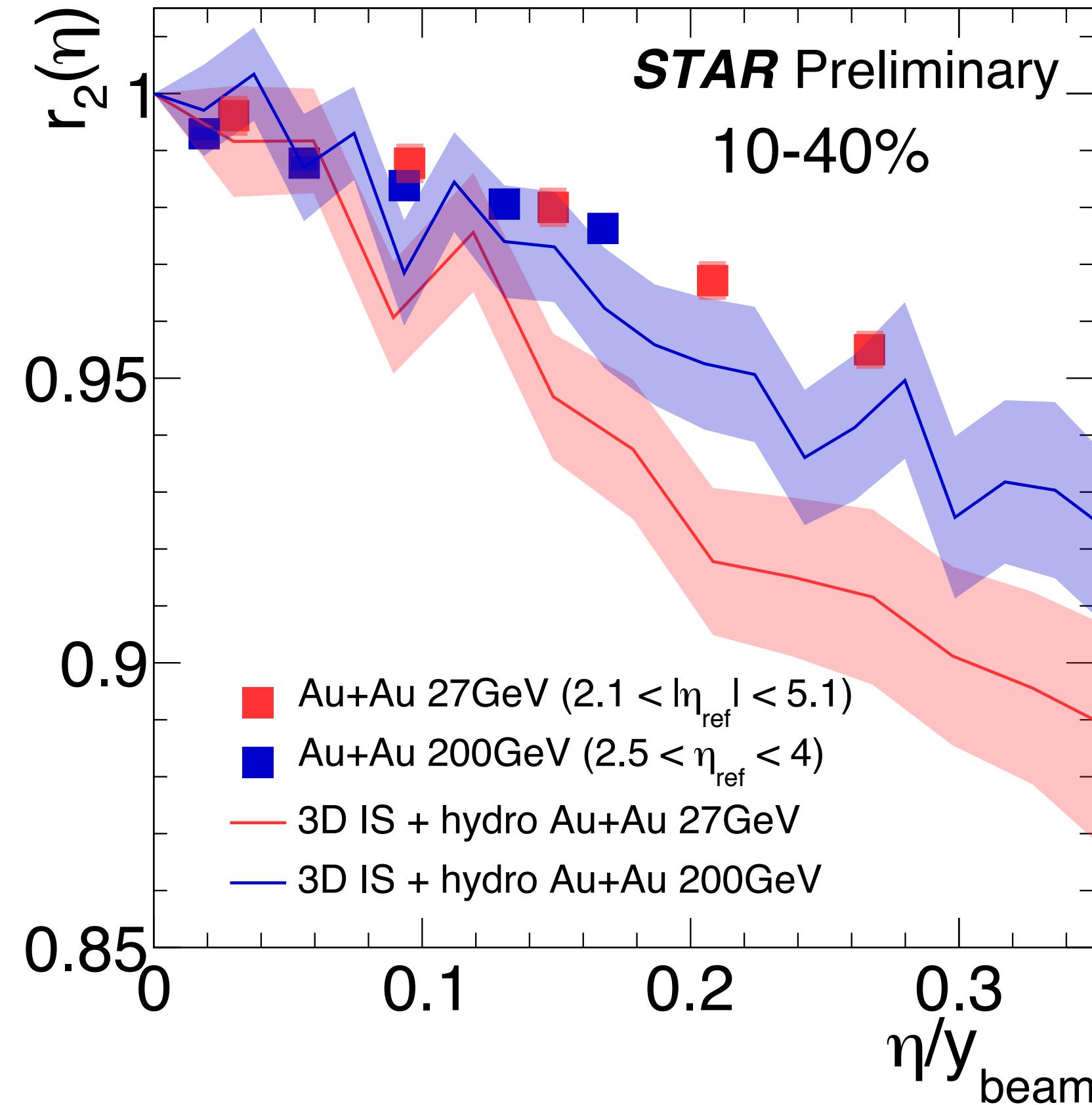
- No clear energy dependence for both RHIC or LHC energies.
- Potential non-linear behavior of decorrelation when reference is close to beam rapidity?
- Energy dependence can be further studied using BES-II data.

Zr+Zr/Ru+Ru vs Au+Au to further study system size dependence.

r₂ comparison with models study

- ◆ r₂ comparison with hydro and AMPT

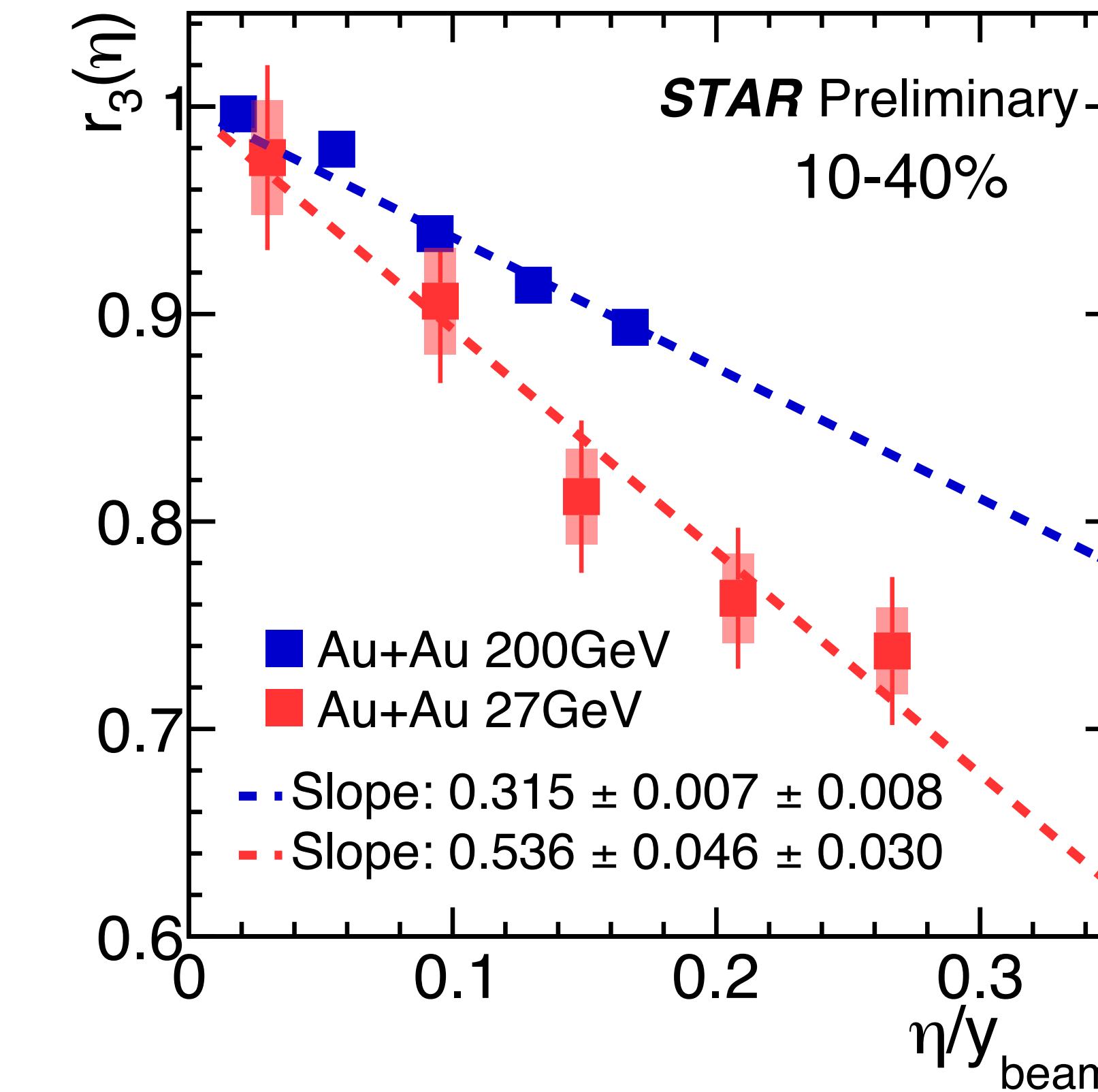
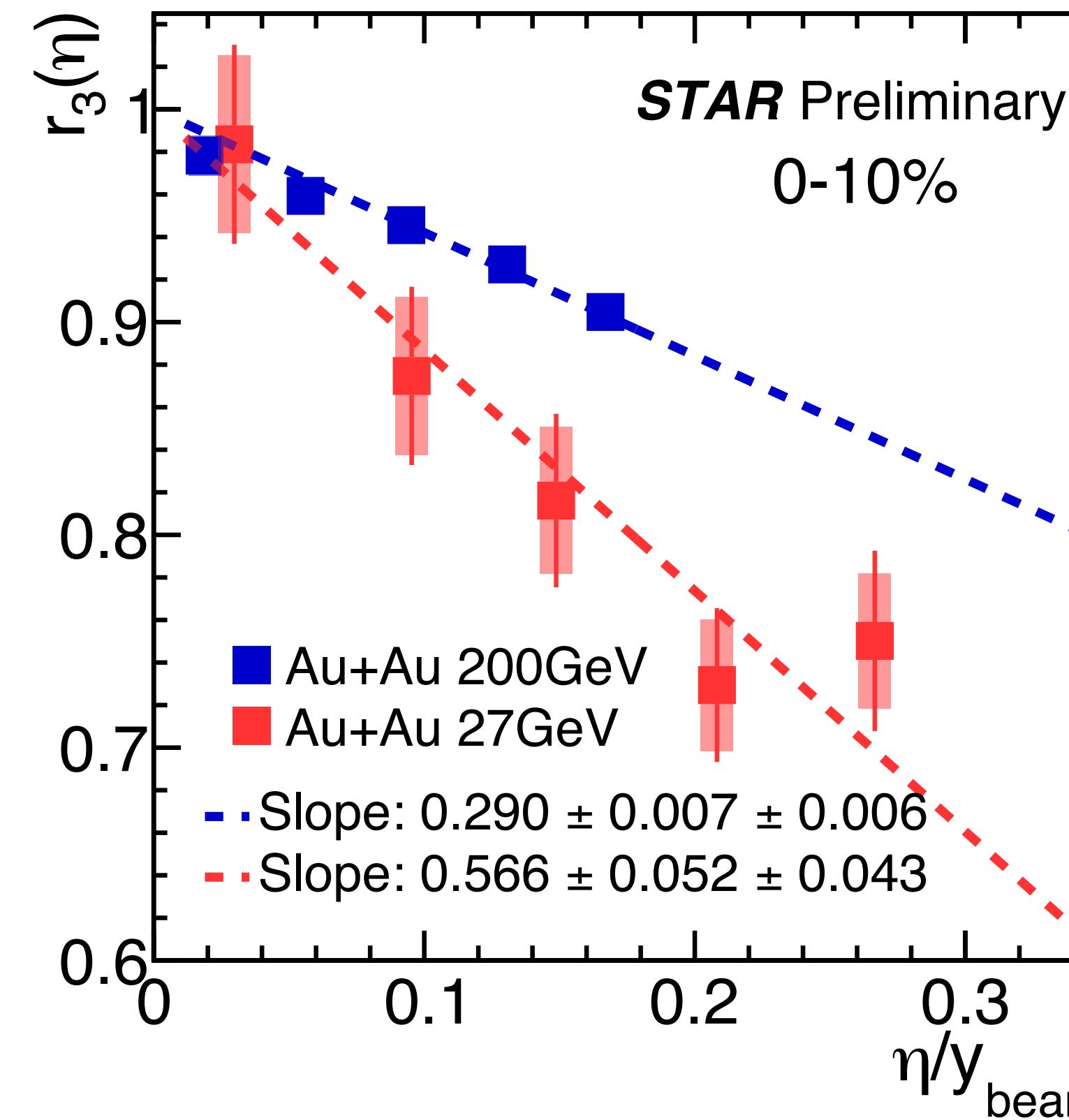
C. Shen, B. Schenke, Phys. Rev. C 97 (2018) 024907
 QM2018, STAR Collaboration



- Hydrodynamics and AMPT models predict stronger energy dependence than the data.

V3 decorrelation scaled by beam rapidity

- ◆ r_3 comparison between 27GeV and 200GeV with rapidity normalization

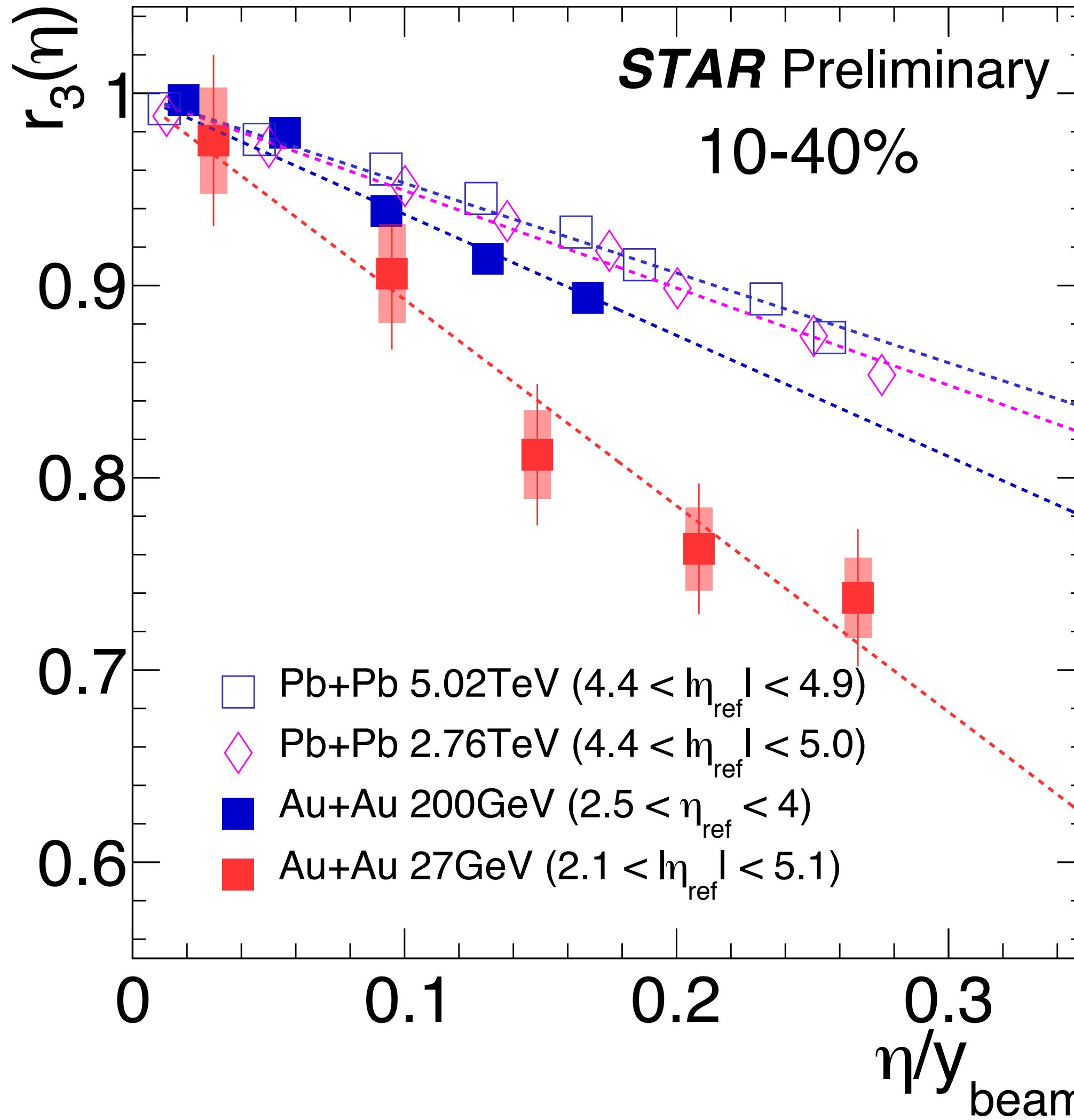


- Stronger v_3 decorrelation at 27 GeV after y_{beam} normalization.

r₃ comparison with LHC results

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

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

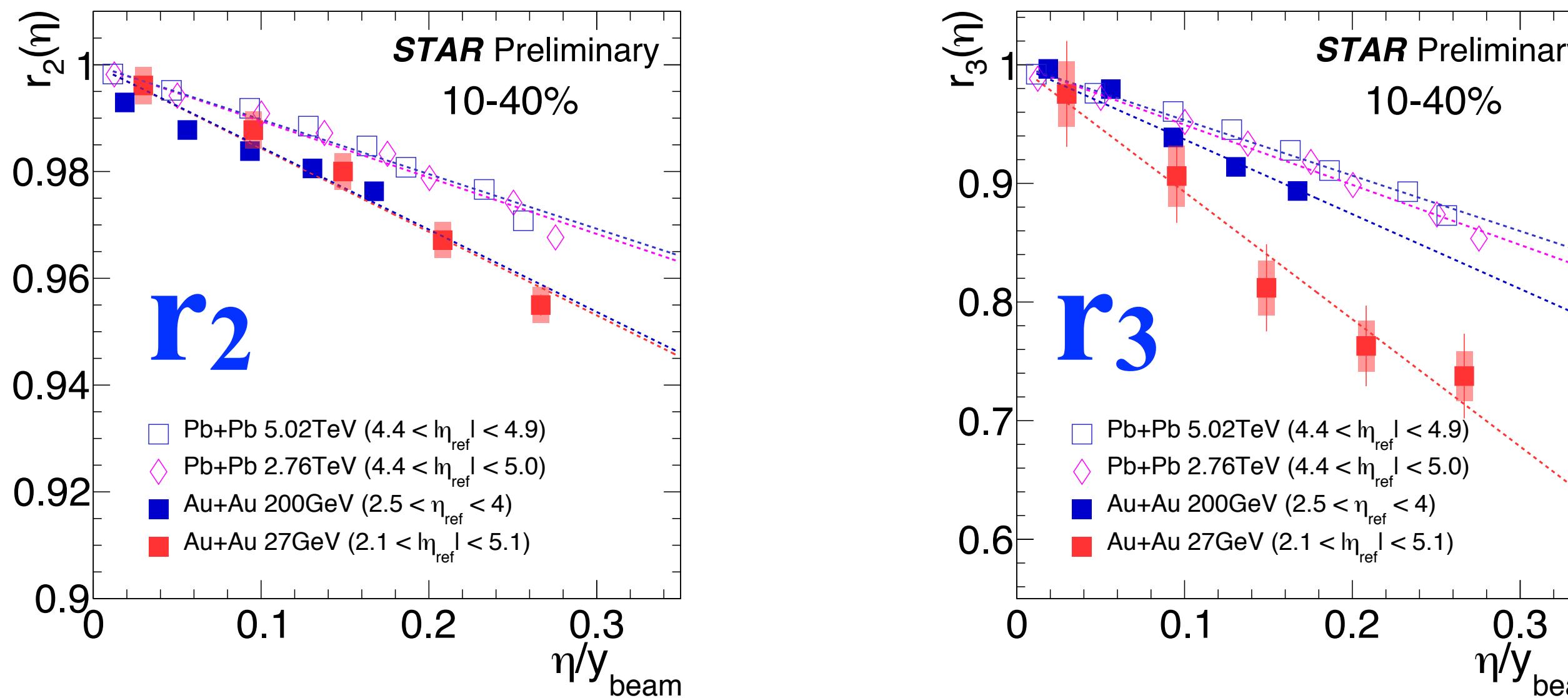


	Slope
Au+Au 27GeV	0.536 ± 0.046
Au+Au 200GeV	0.315 ± 0.007
Pb+Pb 2.76TeV	0.253 ± 0.002
Pb+Pb 5.02TeV	0.234 ± 0.001

- Clear energy dependence for r_3 at RHIC.
- r_3 provides unique constraints on fluctuation-driven longitudinal dynamics.

Summary & Outlook

- Longitudinal flow decorrelation measurements at 27 GeV at RHIC provide new constraints on longitudinal dynamics of heavy-ion collisions.
 - ▶ r_2 shows centrality dependence and no clear energy dependence after beam rapidity normalization.
 - ▶ r_3 shows weak centrality dependence but clear energy dependence after beam rapidity normalization.

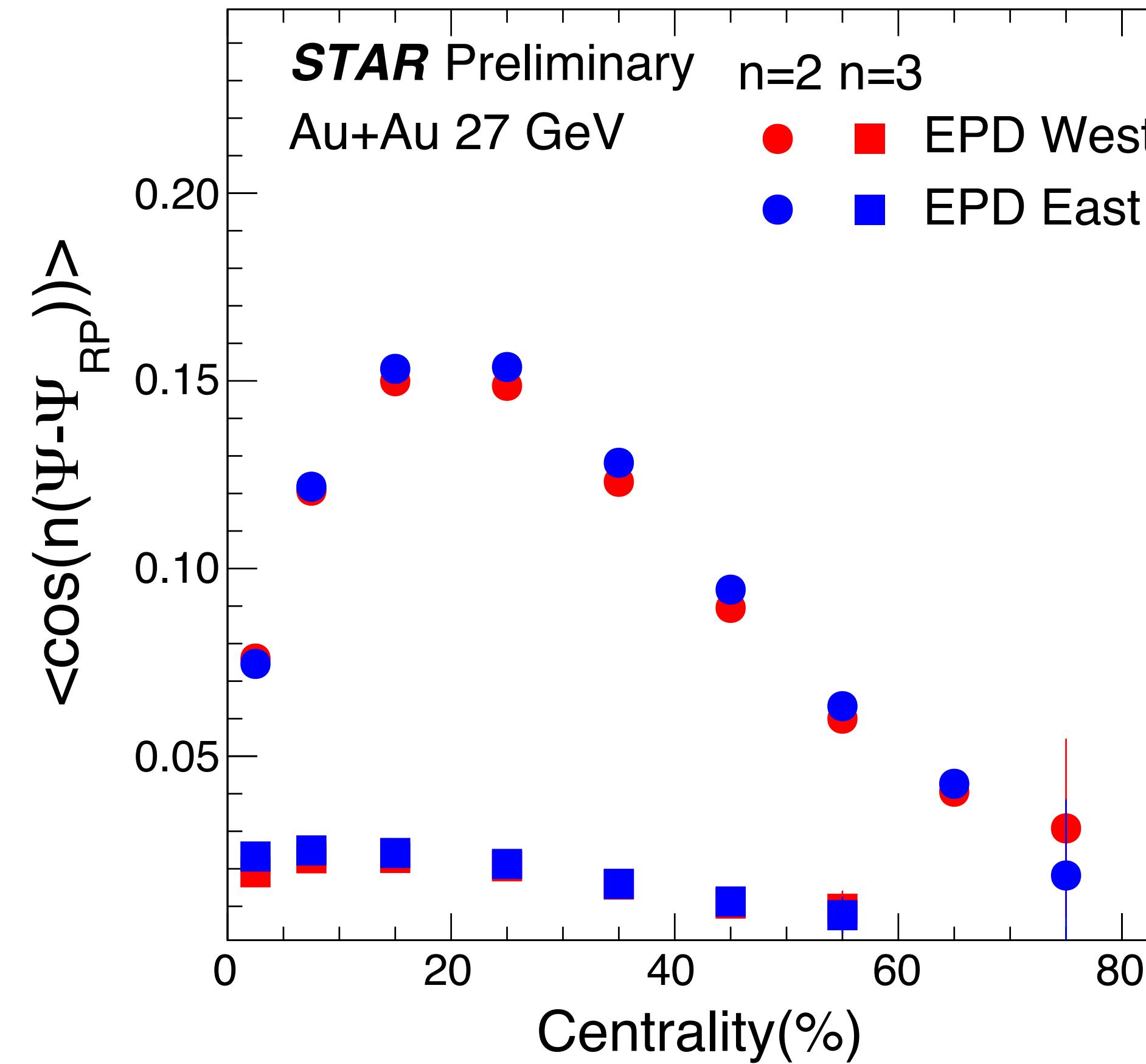


- Energy dependence can be further studied using STAR BES-II data.
- System size dependence: Zr+Zr/Ru+Ru vs Au+Au; small system scan (O+O vs Au+Au).

Backup

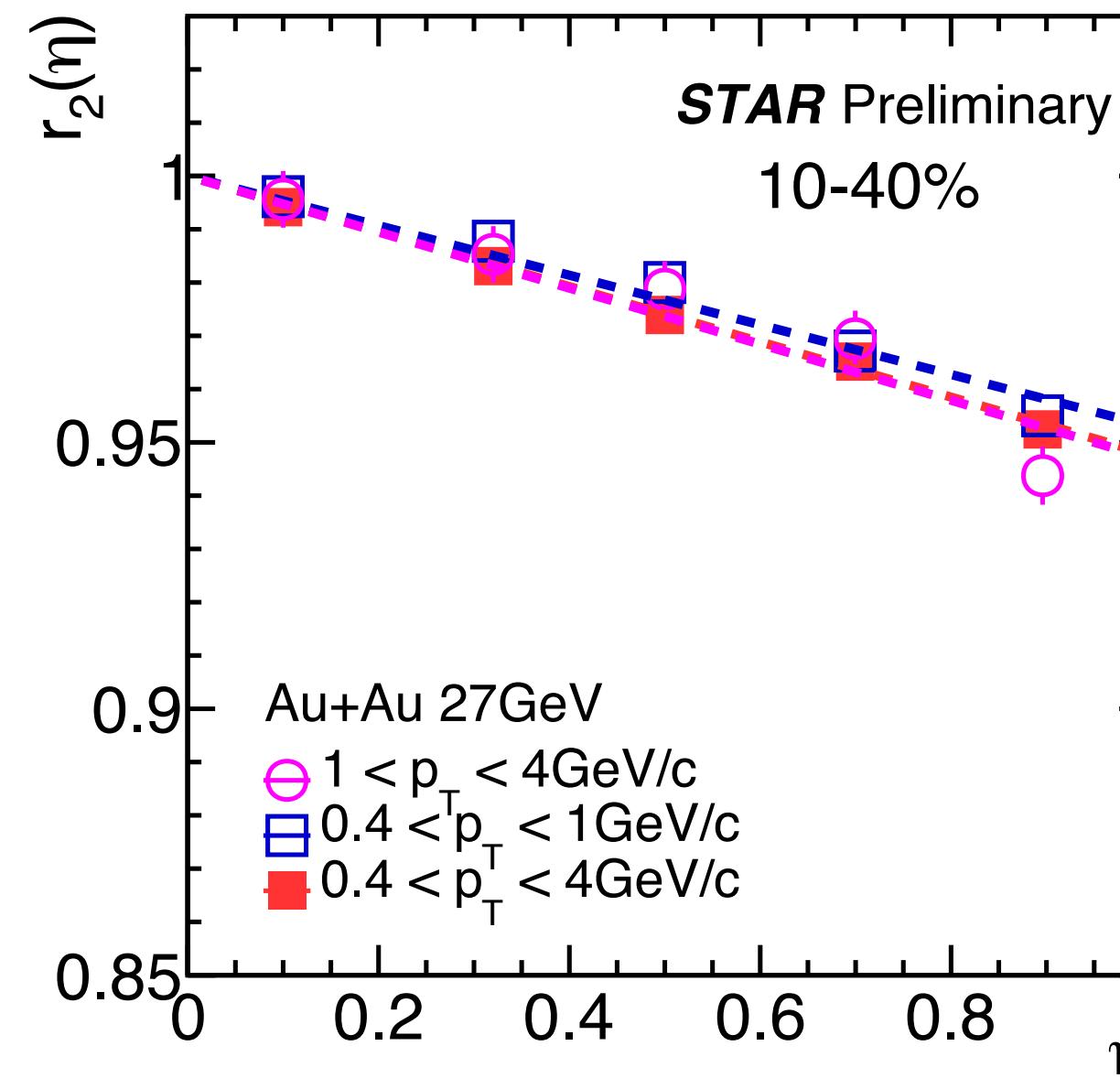
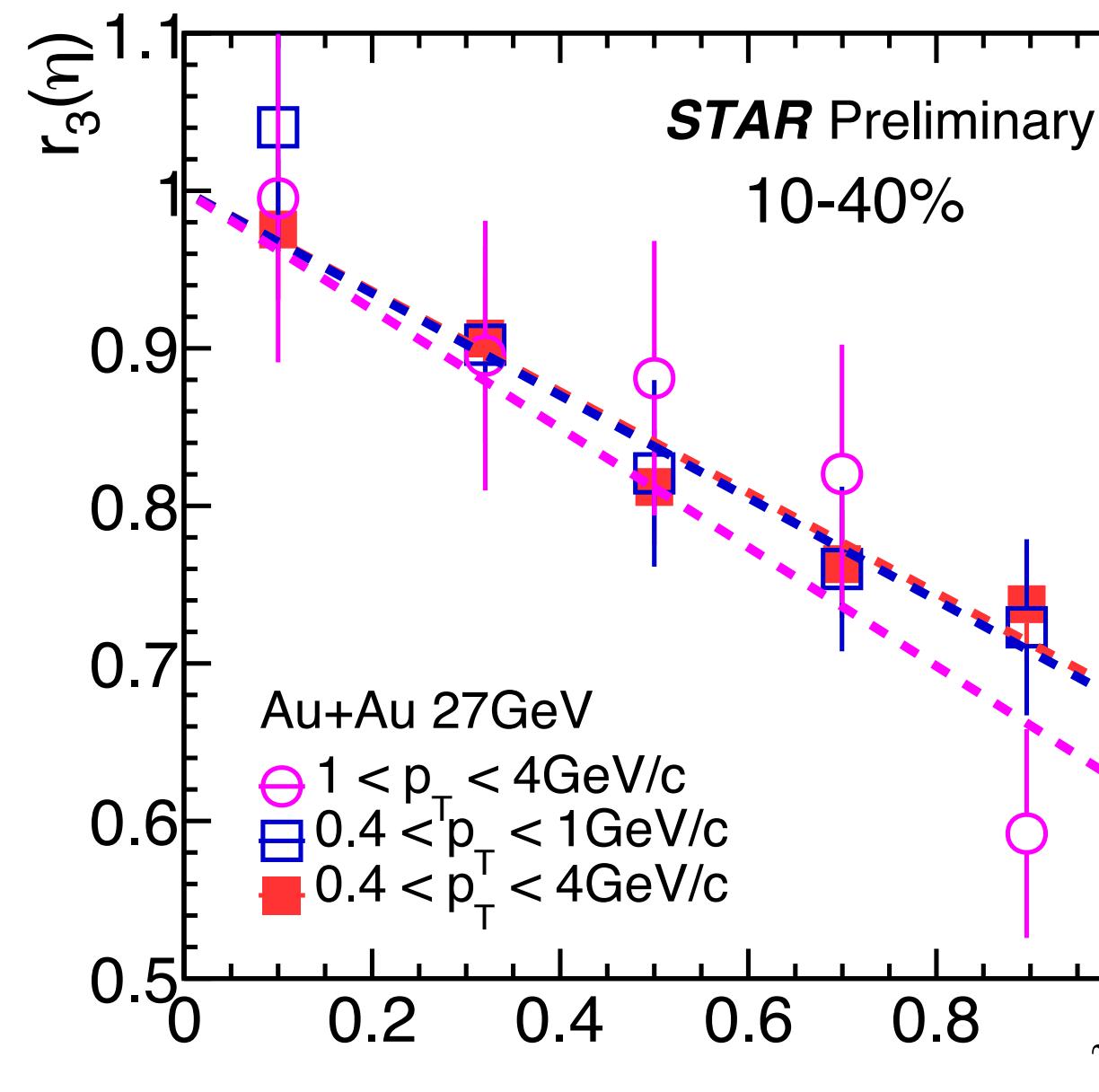
EPD as an event plane detector

- ◆ EPD event-plane resolution



- EPD shows consistent results for 2nd- and 3rd-order event plane resolutions.

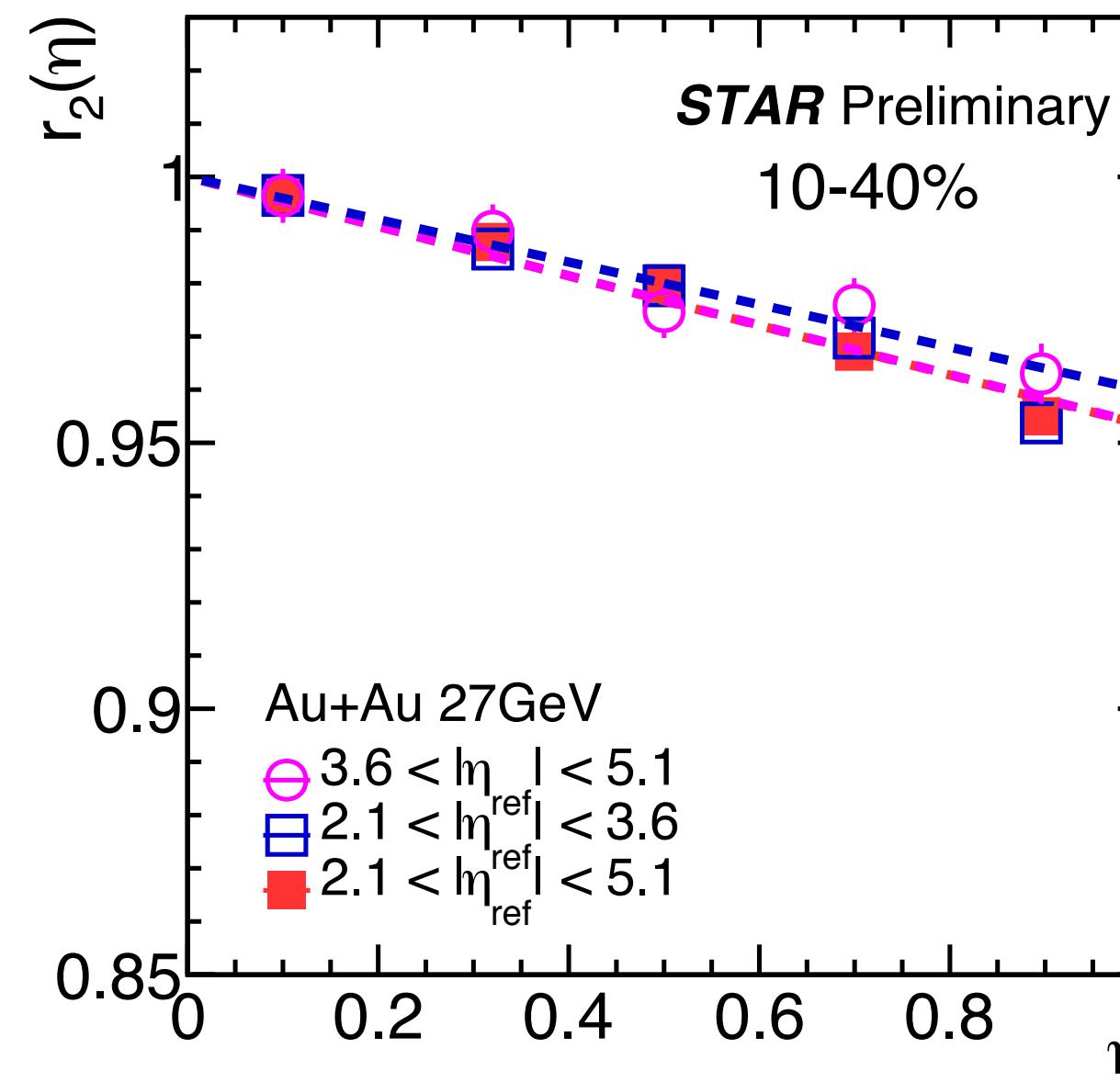
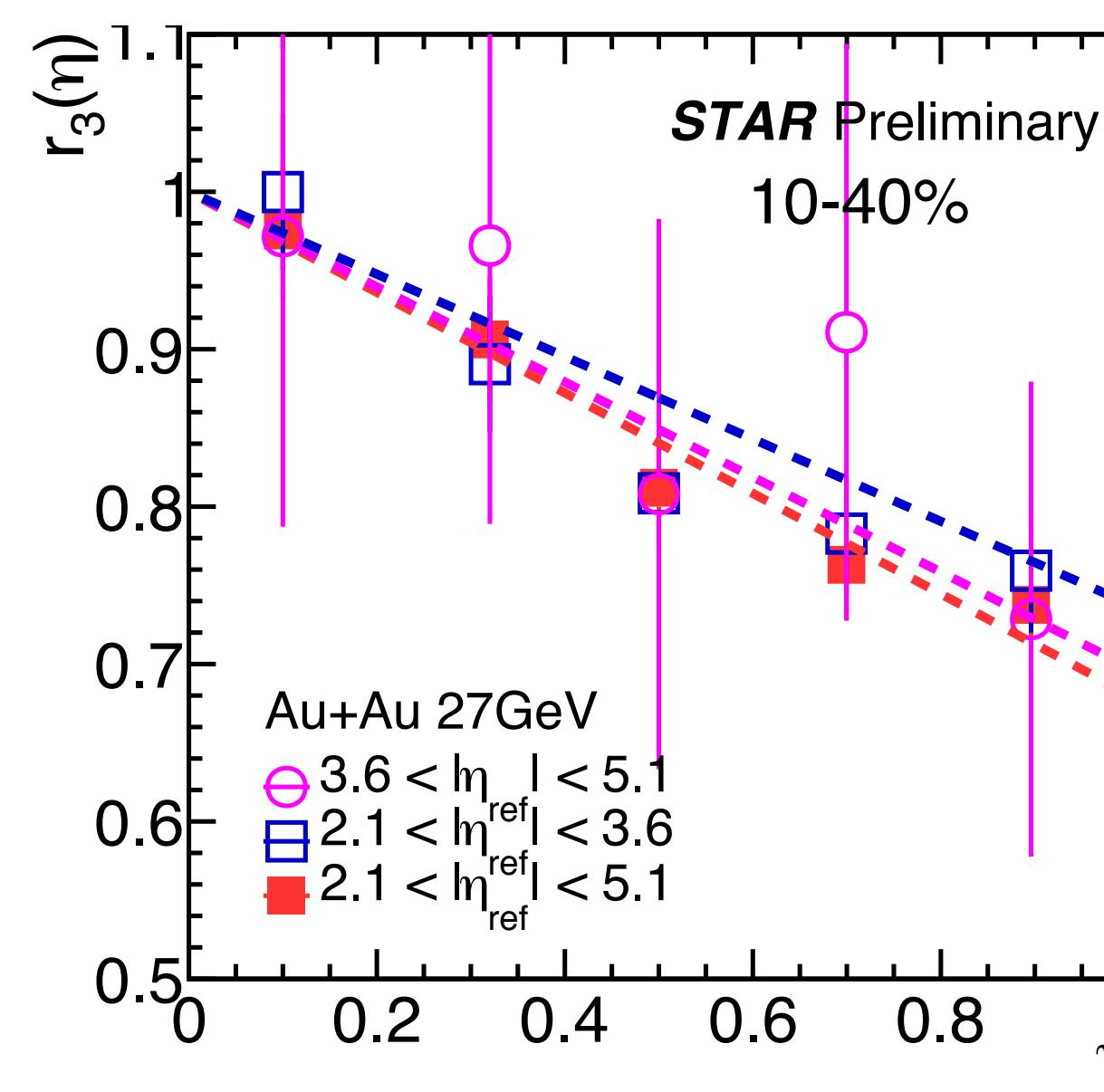
p_T dependence of r_n

 **r_2**  **r_3**

	r_2 slope	r_3 slope
$0.4 < p_T < 4 \text{ GeV}/c$	0.026 ± 0.001	0.160 ± 0.014
$0.4 < p_T < 1 \text{ GeV}/c$	0.023 ± 0.001	0.162 ± 0.022
$1 < p_T < 4 \text{ GeV}/c$	0.026 ± 0.002	0.189 ± 0.029

- Both r_2 and r_3 are weak p_T dependent.

η_{ref} dependence of r_n

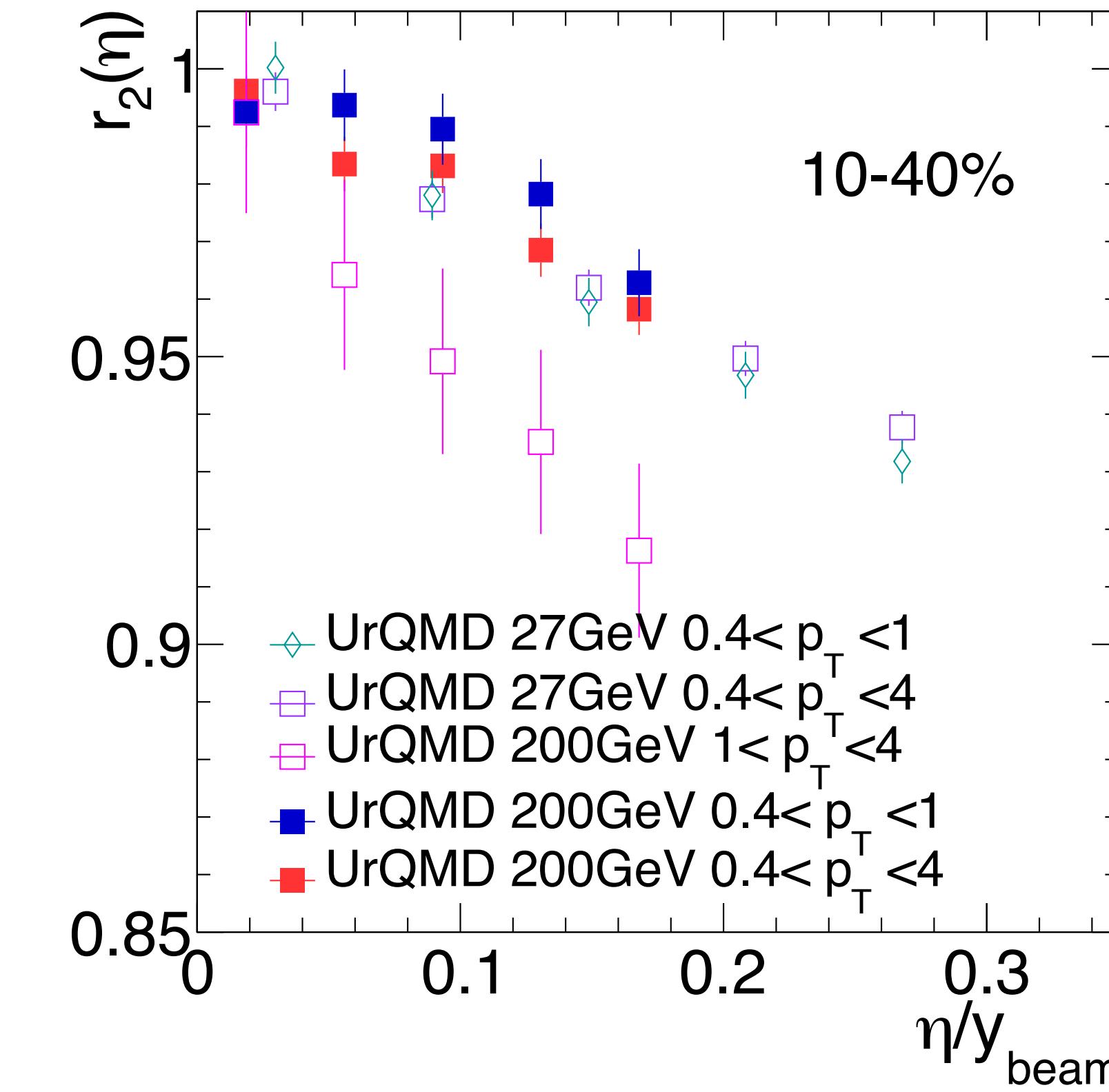
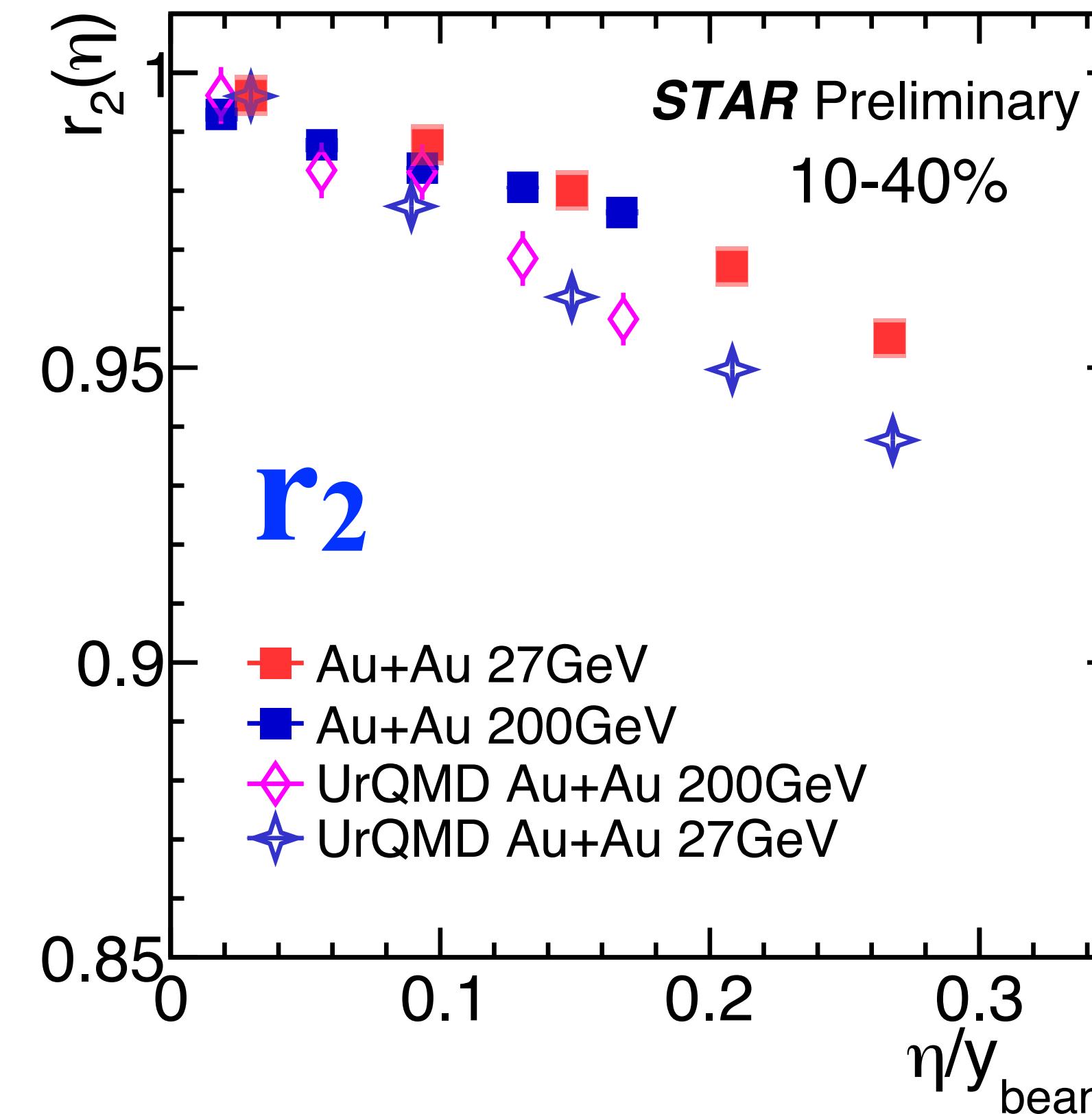
**r₂****r₃**

	r₂ slope	r₃ slope
$2.1 < \eta_{\text{ref}} < 3.6$	0.023 ± 0.001	0.131 ± 0.064
$3.6 < \eta_{\text{ref}} < 5.1$	0.026 ± 0.002	0.160 ± 0.014
$2.1 < \eta_{\text{ref}} < 5.1$	0.026 ± 0.001	0.160 ± 0.014

- Both r_2 and r_3 are weak η_{ref} dependent.

UrQMD decorrelation results

UrQMD calculations from Chuan Sun



- UrQMD overestimate the decoration effect, but capture the energy dependence feature.
- UrQMD calculations are strongly p_T dependent.