Energy dependence of longitudinal flow decorrelation from STAR

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For the STAR collaboration

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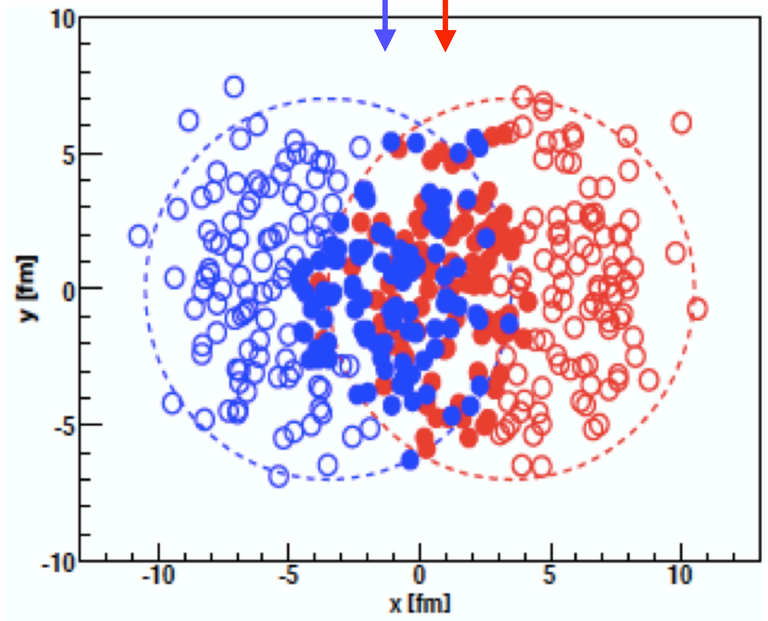
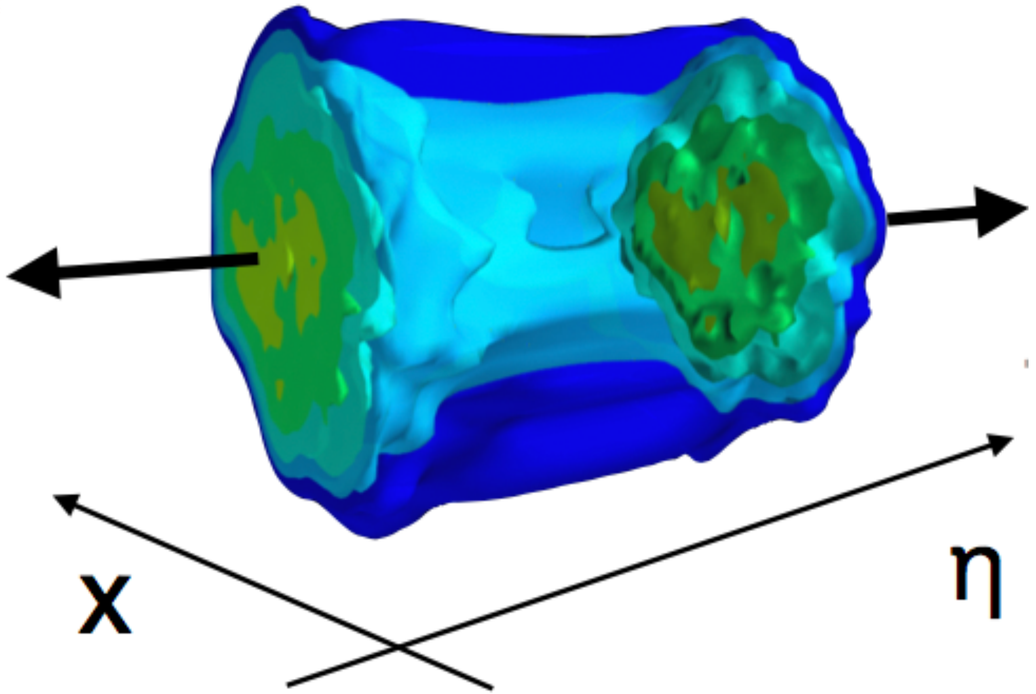
Longitudinal dynamics in heavy-ion collisions

- Fluctuation of sources in two nuclei

$\varepsilon_n^F e^{in\Psi_n^F}$ $\varepsilon_n^B e^{in\Psi_n^B}$



- Evolution of the QGP in (3+1)D



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

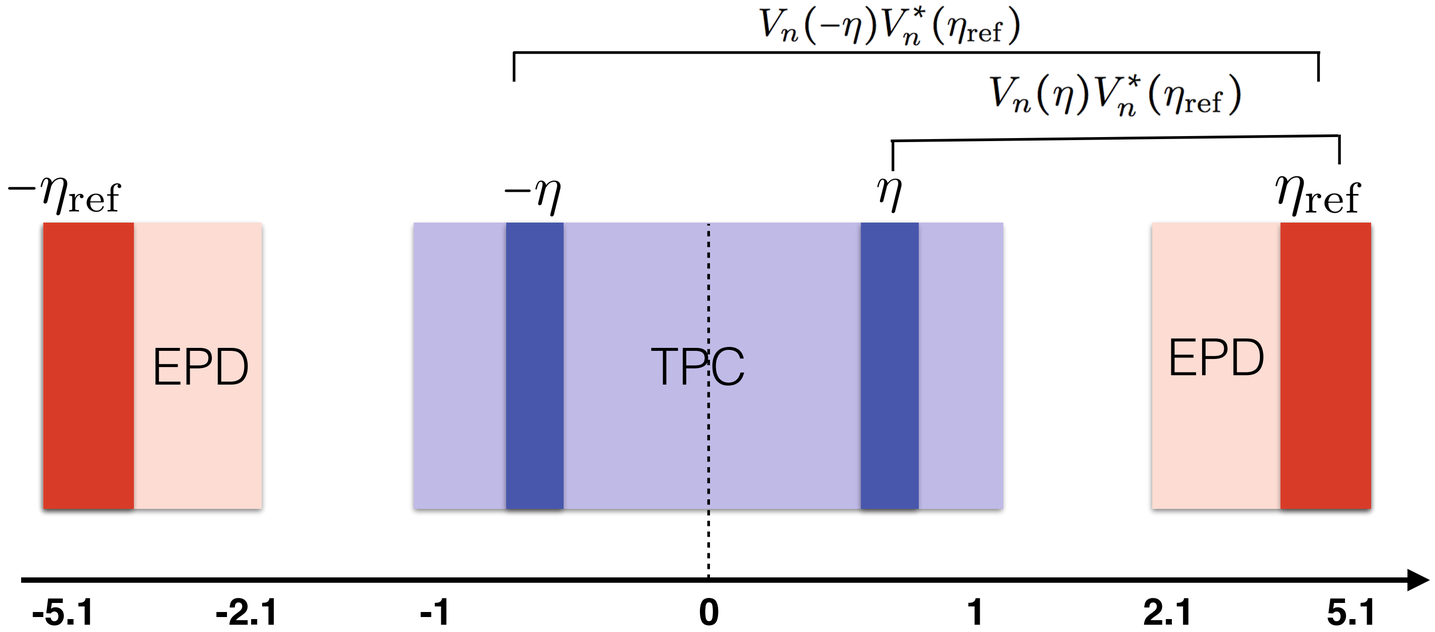
Flow decorrelation observables

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

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

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

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

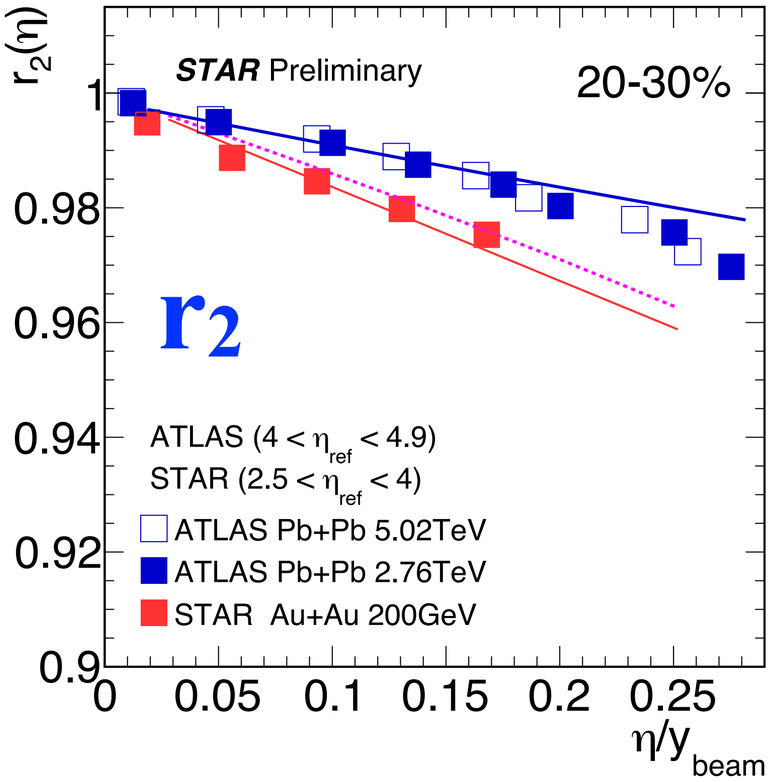


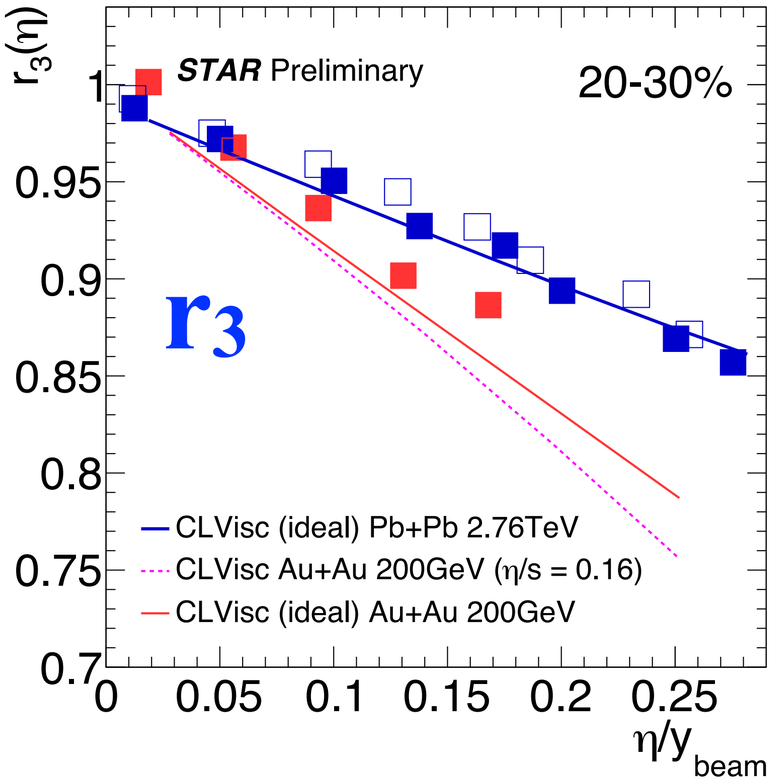
A large η gap is imposed to avoid short-range correlations.

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





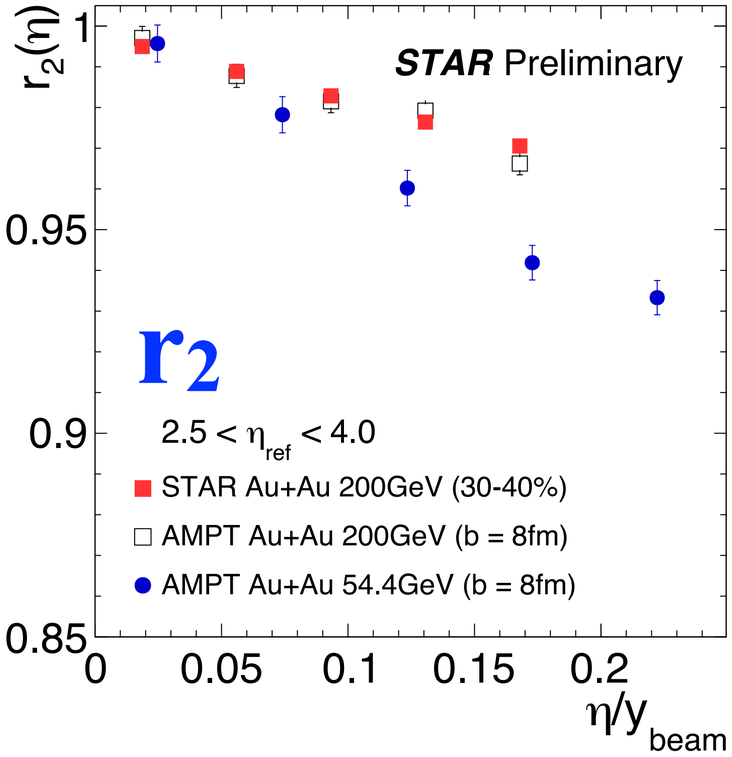
- Clear difference between RHIC and LHC energies.
- Hydrodynamic calculations cannot simultaneously describe RHIC and LHC data.

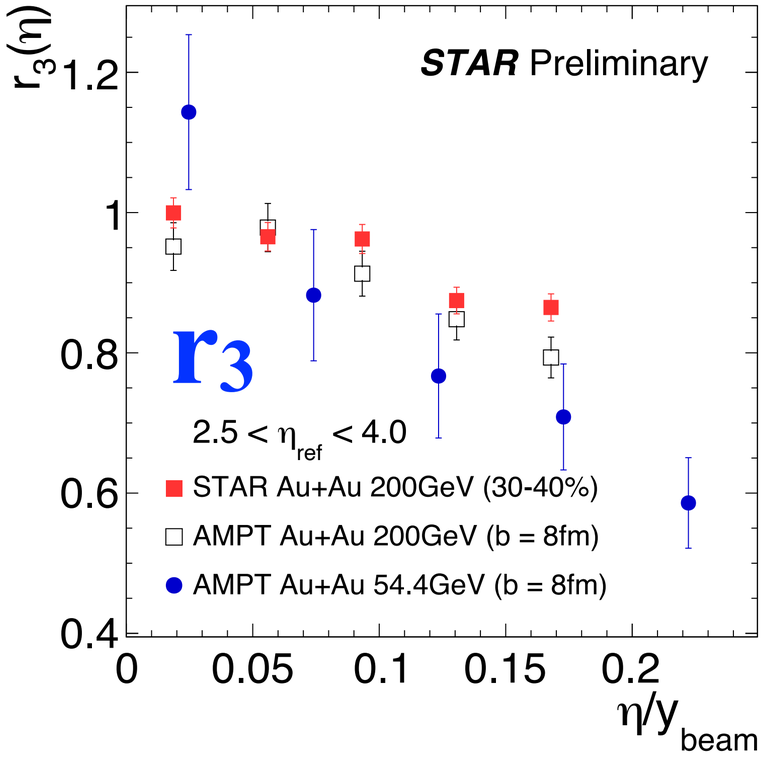
Expectation of decorrelation at lower $\sqrt{s_{NN}}$

- **Decorrelation results from AMPT calculations**

QM2018, STAR Collaboration

AMPT(with string melting) parton-parton σ=3mb

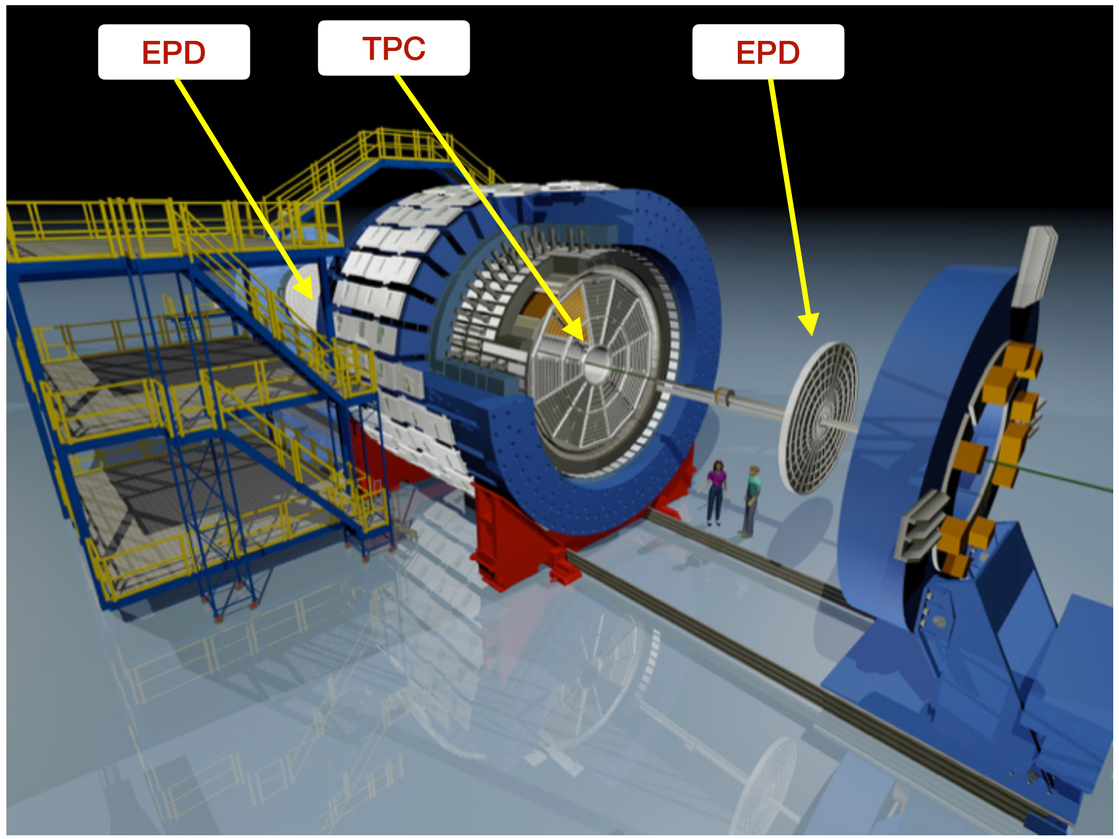




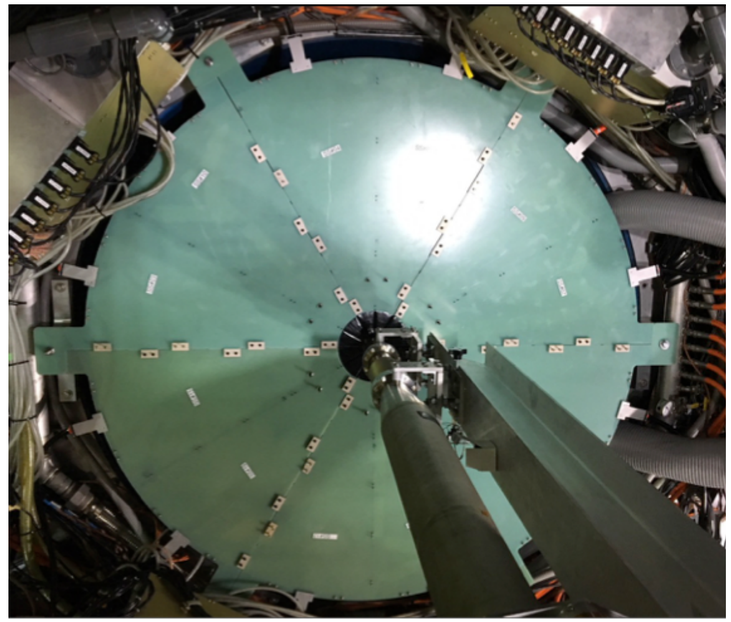
- **Transport model also indicates stronger decorrelation at lower energy.**
- **Energy dependence needs to be measured at lower energies.**
- **New measurement at $\sqrt{s_{NN}}$ = 27 GeV is presented.**

The STAR detectors

✦ A schematic diagram of the STAR detectors



Event Plane Detector

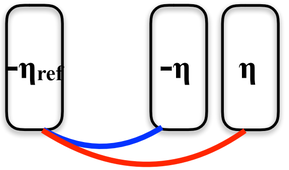


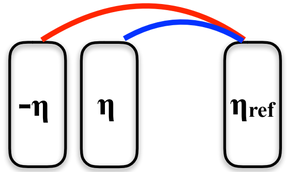
provides centrality definition
and event plane measurement at
forward region

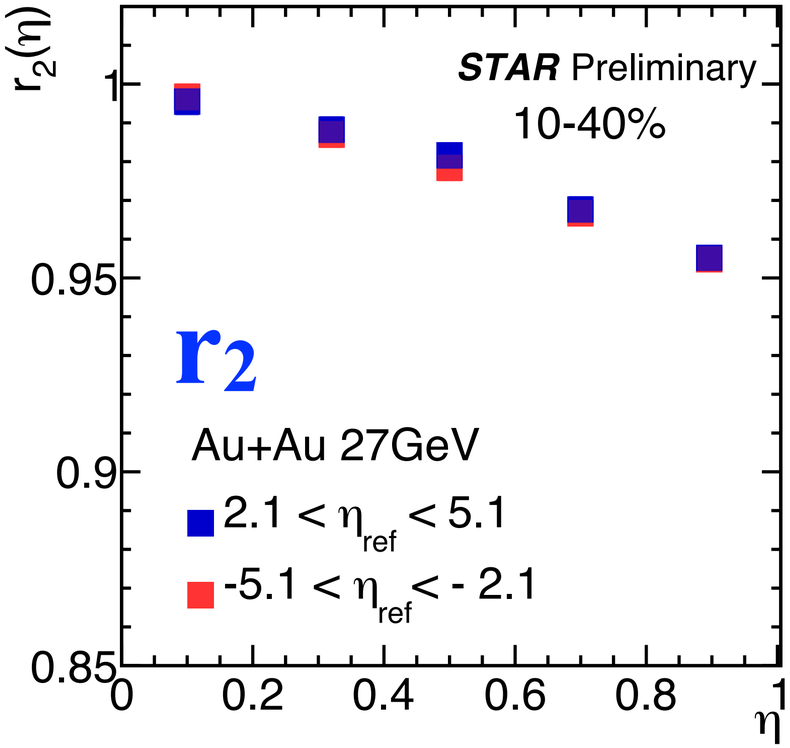
- **TPC and EPD are used for this analysis, 2018 Au+Au 27 GeV data (~800M) is used.**
- **TPC acceptance : $-1 < \eta < 1$; EPD acceptance : $2.1 < |\eta| < 5.1$.**

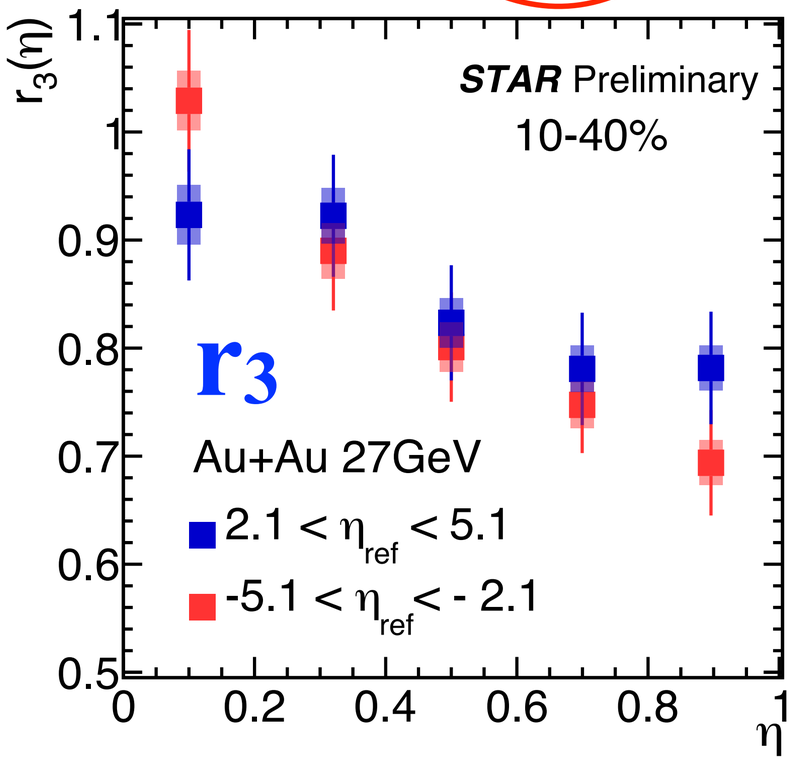
Decorrelation measurement at 27 GeV

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



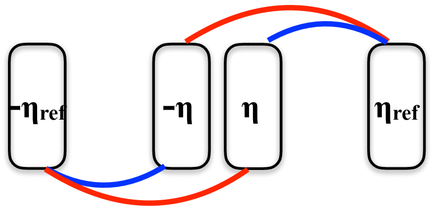




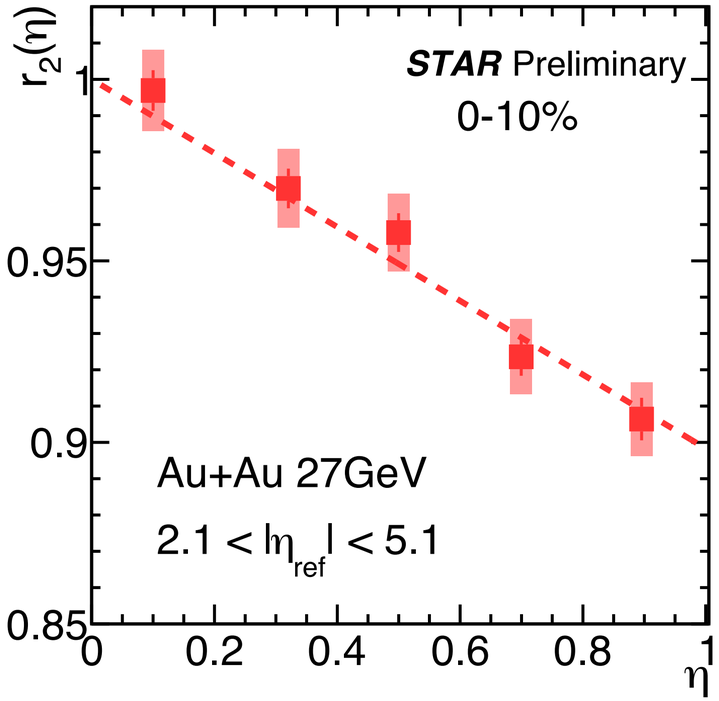


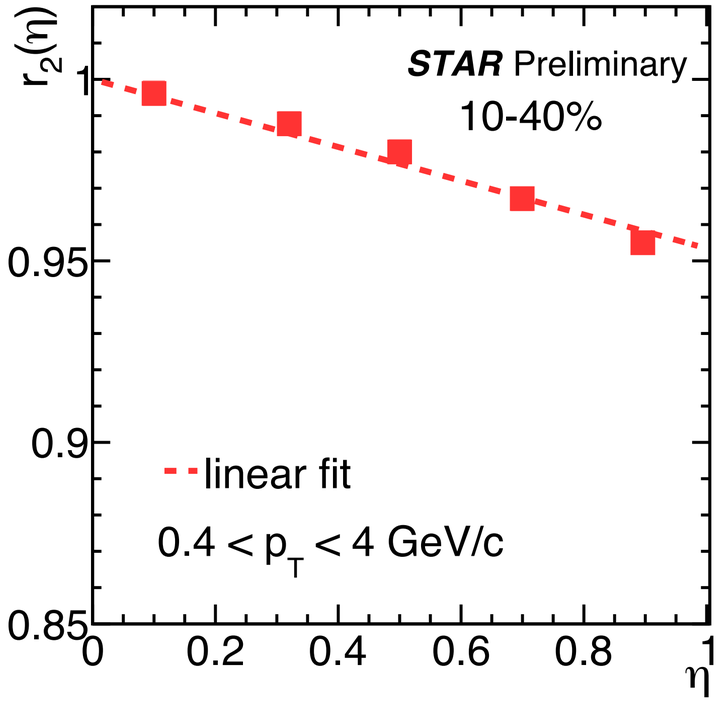
- Two sides of EPD provide sanity check for detector effects.
- Both r_2 and r_3 show consistent results for two sides of EPD.

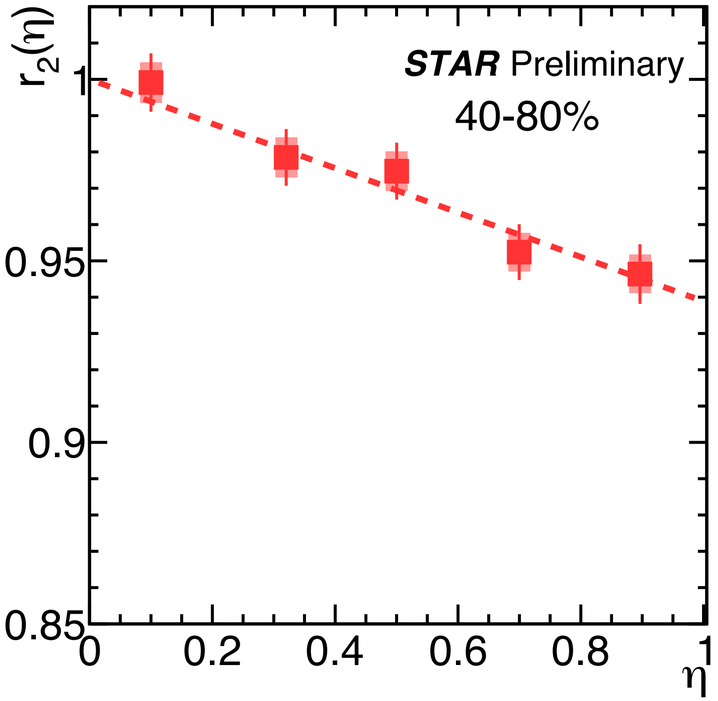
v_2 decorrelation at 27 GeV



✦ Decorrelation of v_2

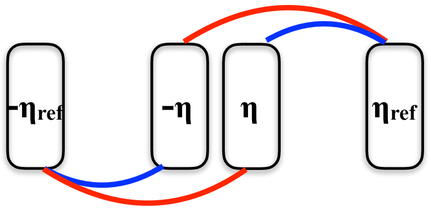




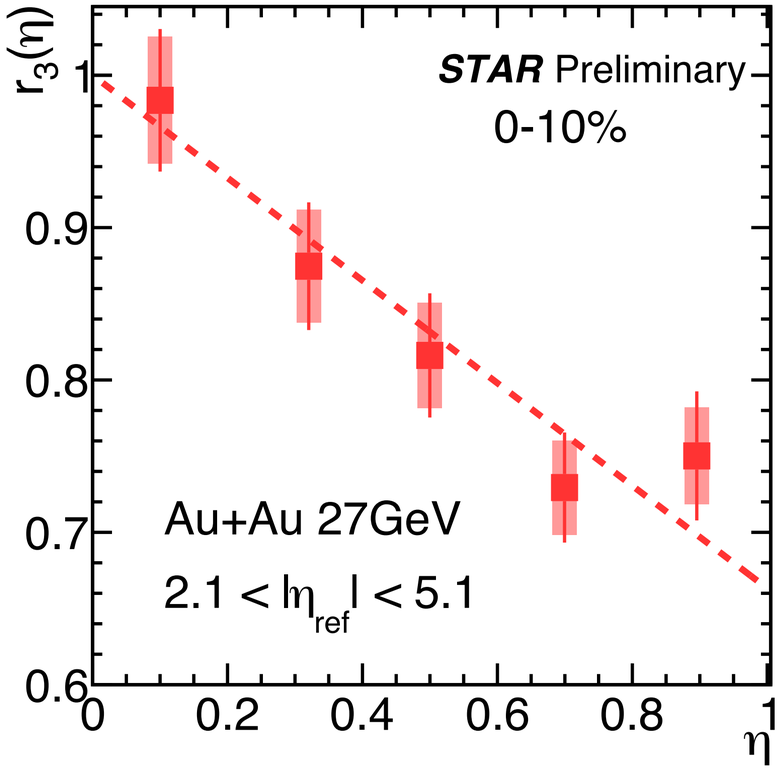


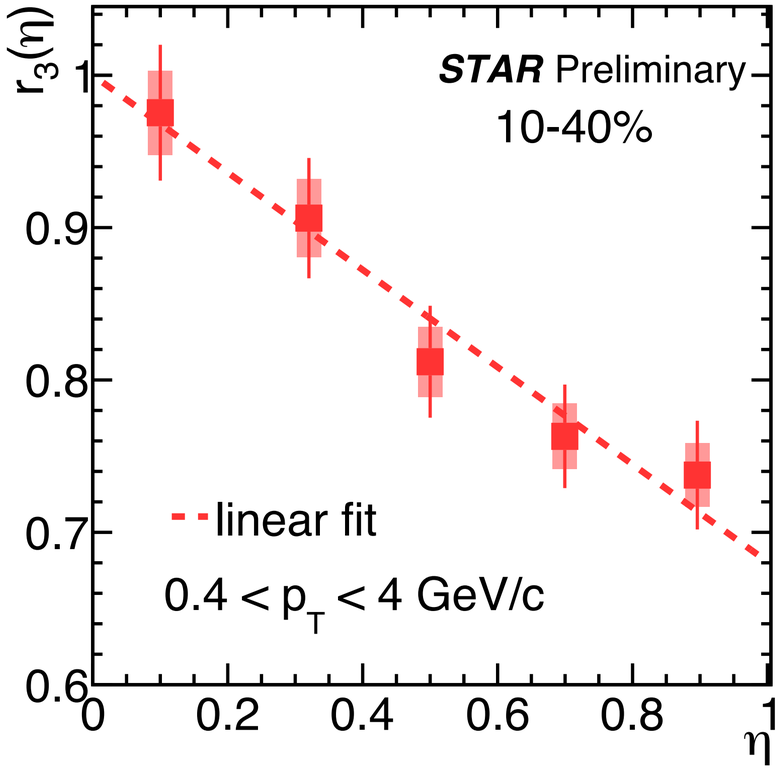
- $r_2(\eta)$ decreases linearly for the shown centralities.
- Decorrelation of v_2 is the strongest in central collisions.

v_3 decorrelation at 27 GeV



✦ Decorrelation of v_3

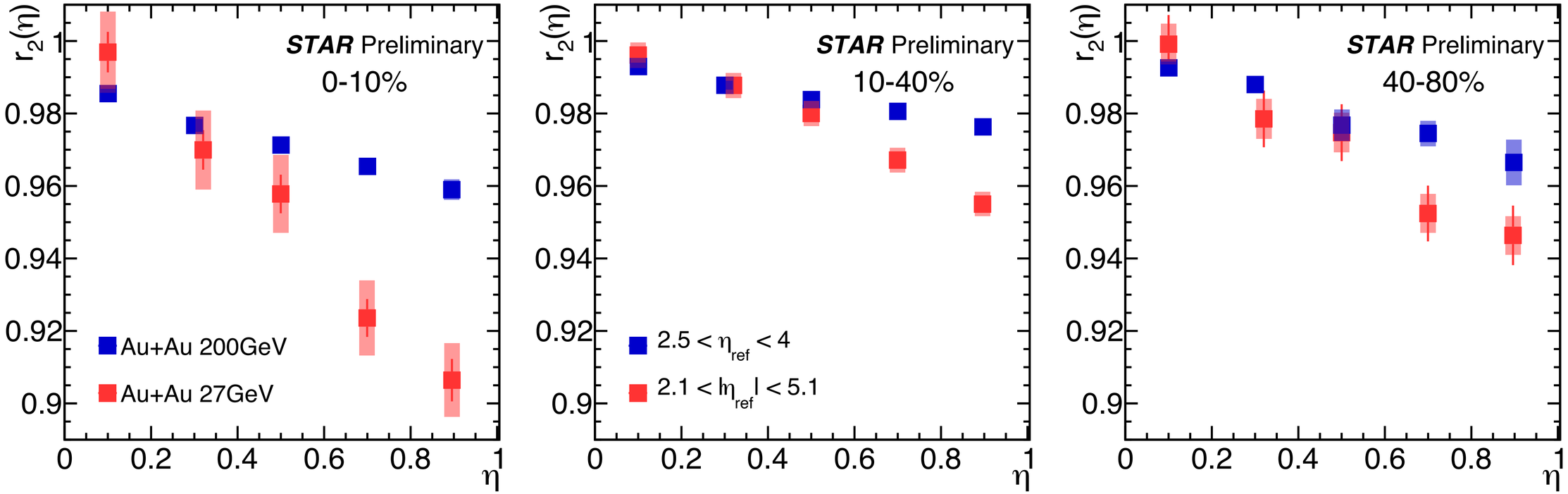




- $r_3(\eta)$ decreases linearly for the shown centralities.
- v_3 decorrelation is as large as 30% and roughly centrality independent.

v_2 decorrelation 27 vs 200 GeV

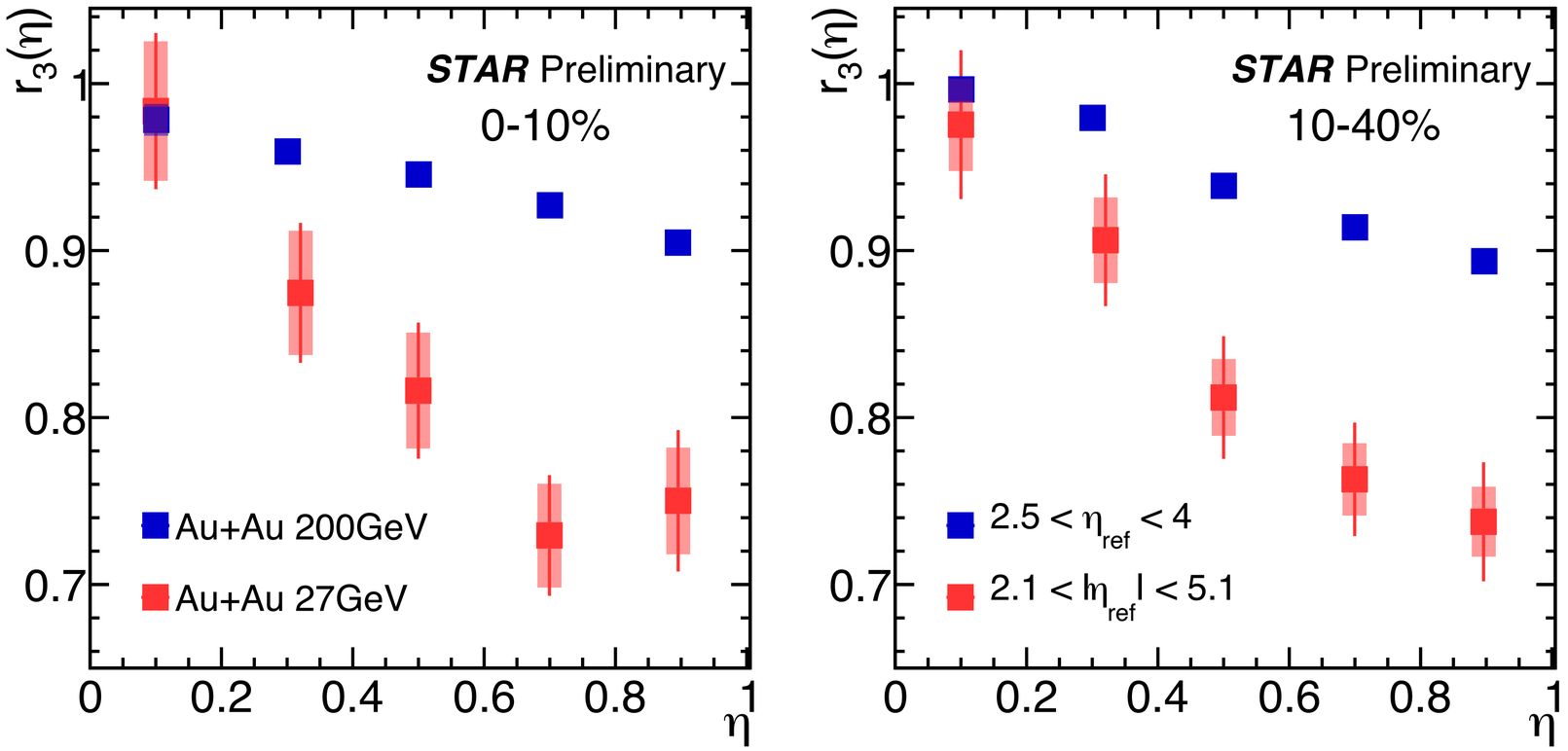
- r_2 comparison between 27 GeV and 200GeV



- 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.

v_3 decorrelation 27 vs 200 GeV

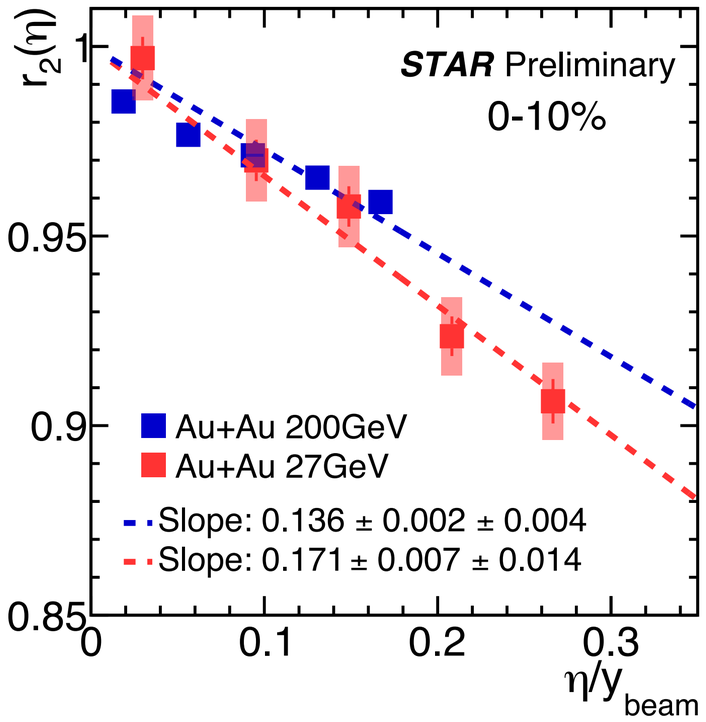
- r_3 comparison between 27GeV and 200GeV



- Stronger v_3 decorrelation at 27 GeV is observed for the two centralities.
- v_3 decorrelation at 27 GeV is ~3 times larger than at 200 GeV.

v_2 decorrelation scaled by beam rapidity

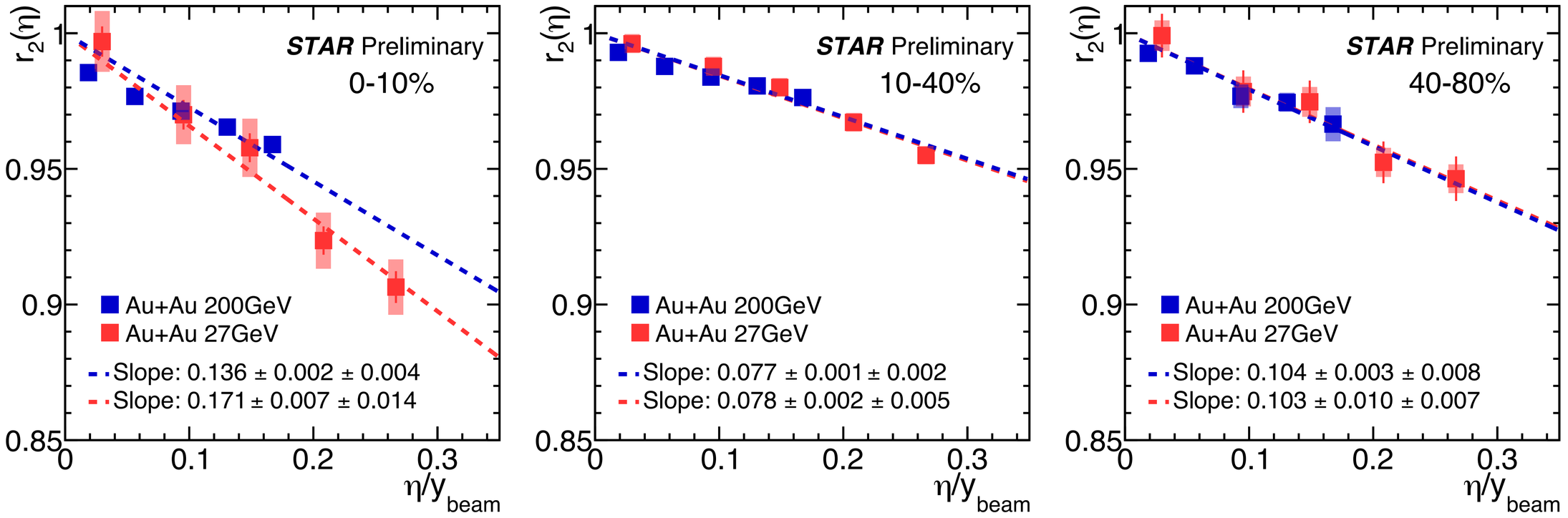
- r_2 comparison between 27 GeV and 200 GeV with rapidity normalization



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

v_2 decorrelation scaled by beam rapidity

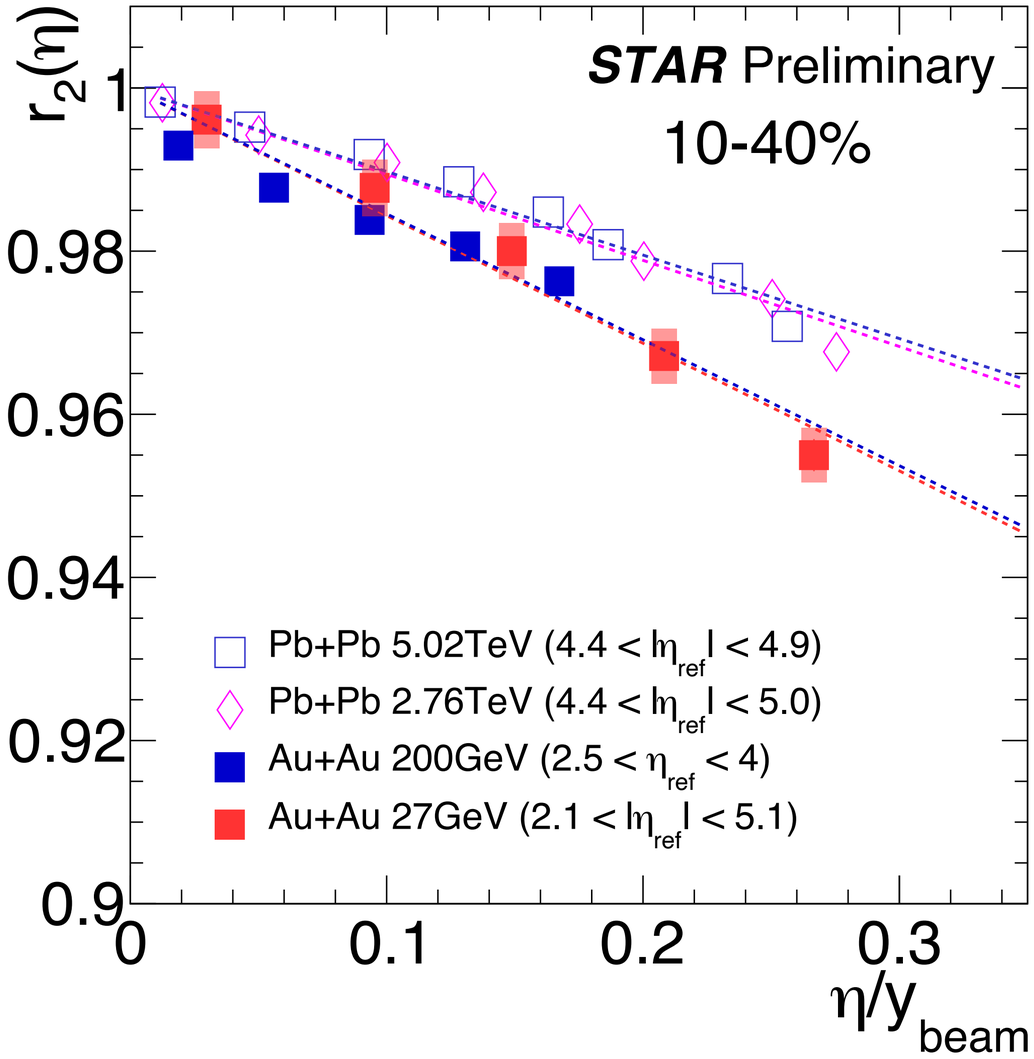
- r_2 comparison between 27 GeV and 200 GeV with rapidity normalization



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

r_2 comparison with LHC results

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

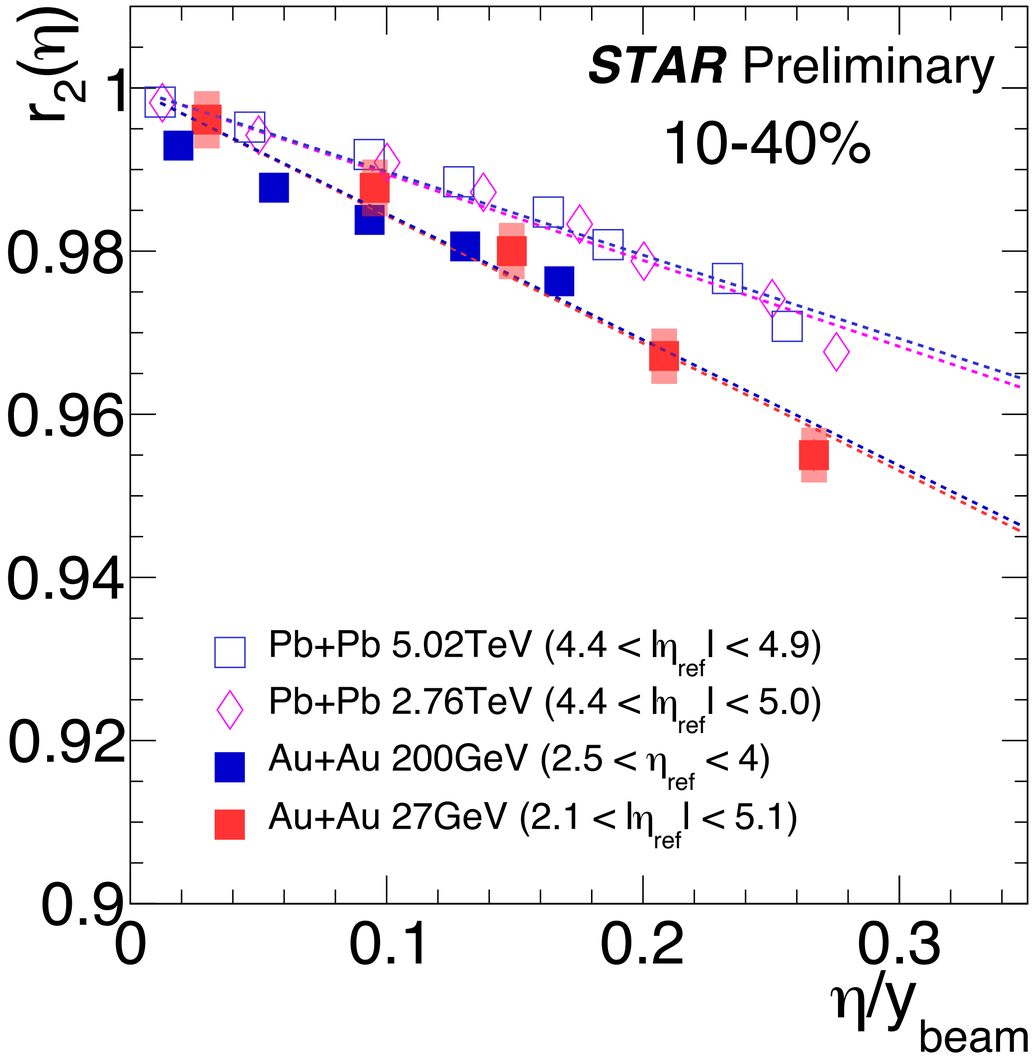


	Slope
Au+Au 27GeV	0.078 ± 0.002
Au+Au 200GeV	0.077 ± 0.001
Pb+Pb 2.76TeV	0.053 ± 0.001
Pb+Pb 5.02TeV	0.051 ± 0.001

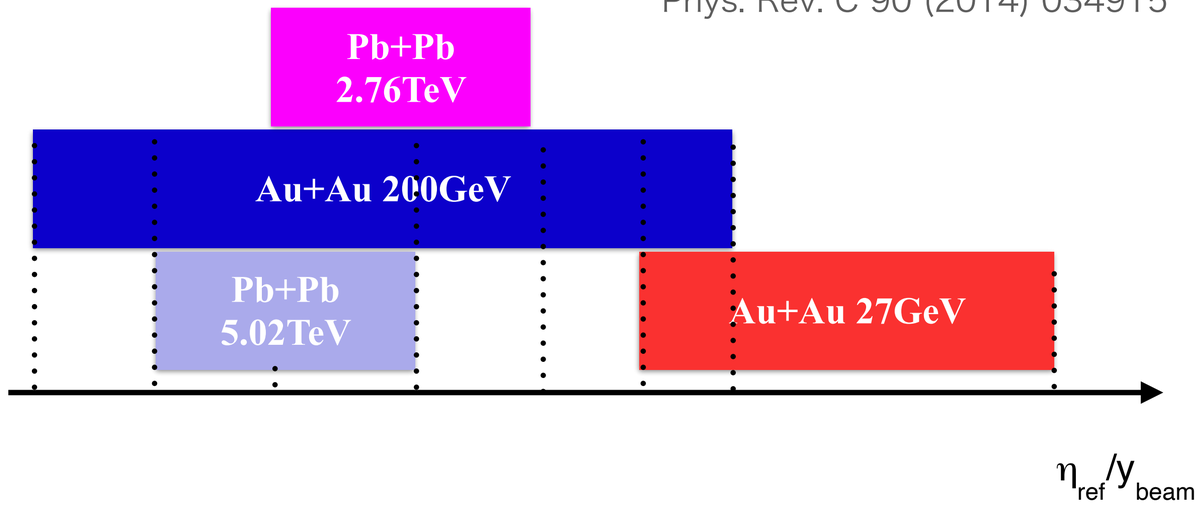
- No clear energy dependence for both RHIC or LHC energies.

r_2 comparison with LHC results

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



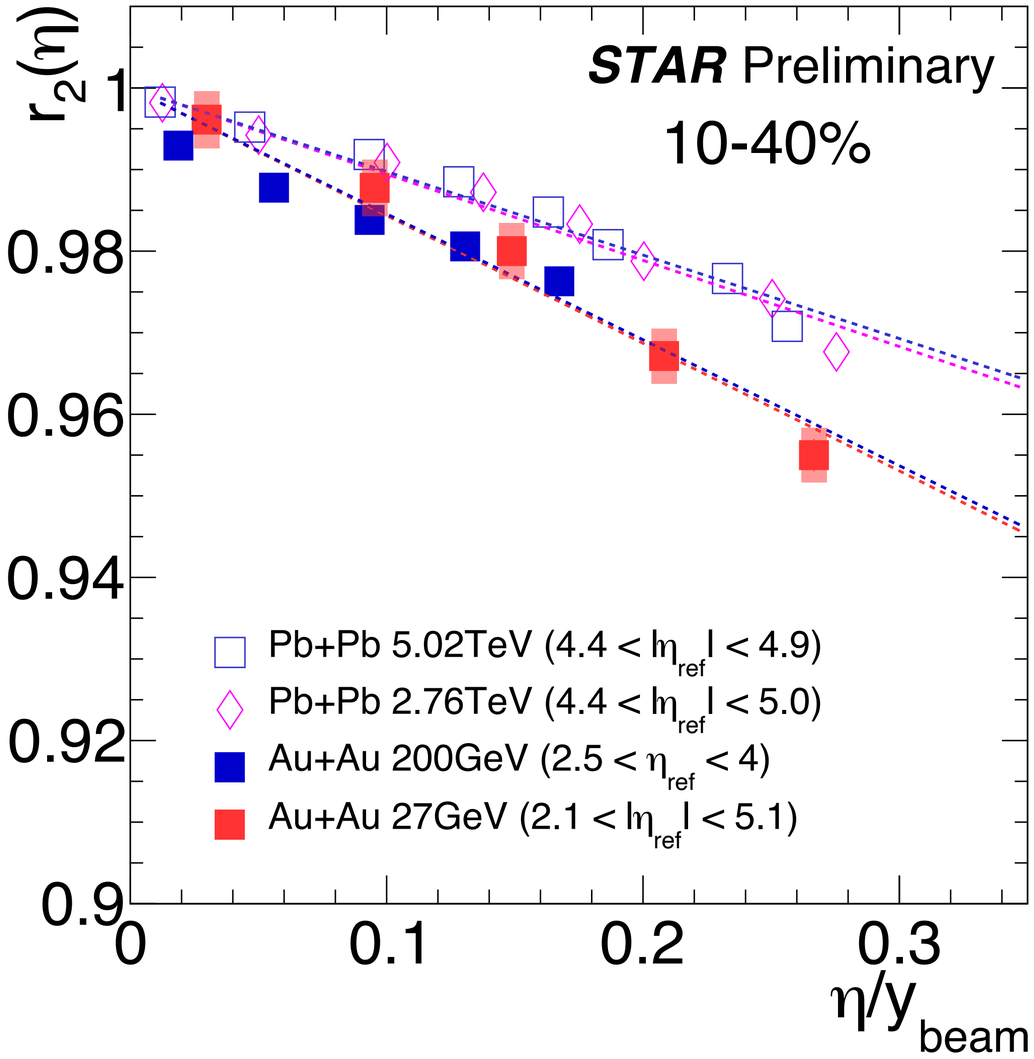
J. Jia, P. Huo,
Phys. Rev. C 90 (2014) 034915



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

r_2 comparison with LHC results

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



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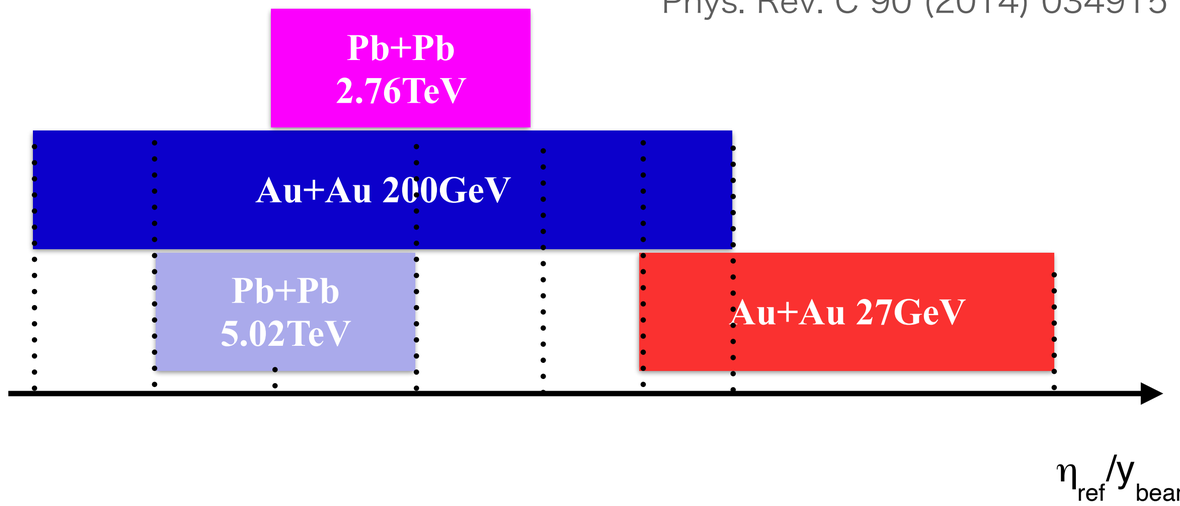
Phys. Rev. C 90 (2014) 034915



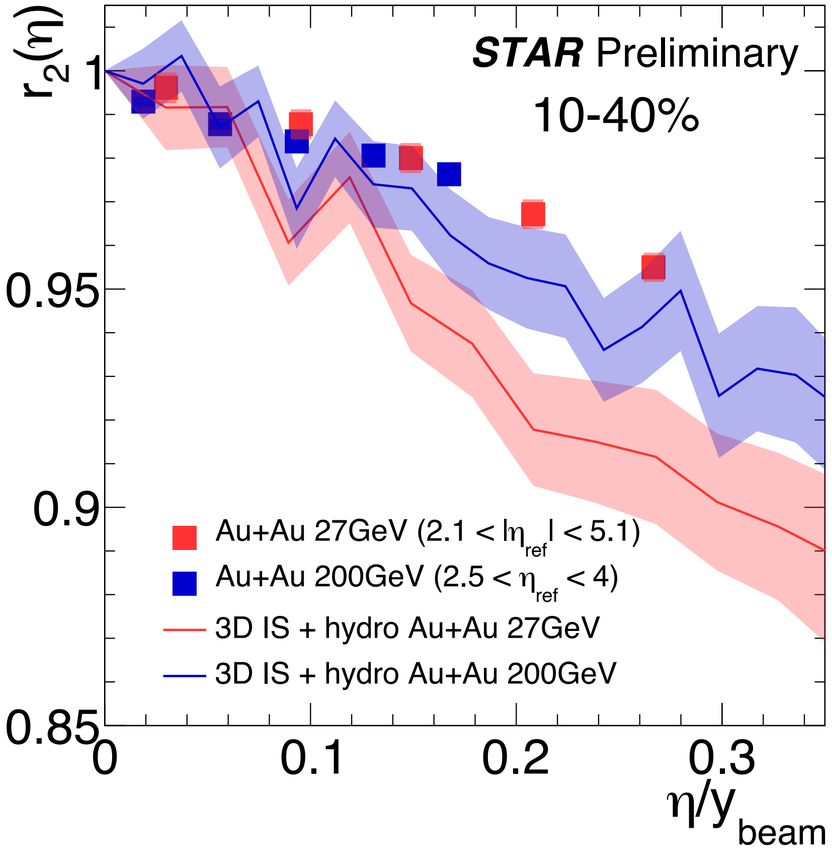
- No clear energy dependence for both RHIC or LHC energies.
- Potential non-linear behavior of decorrelation when reference is close to beam rapidity?
- Energy dependence can be further studied using BES-II data.

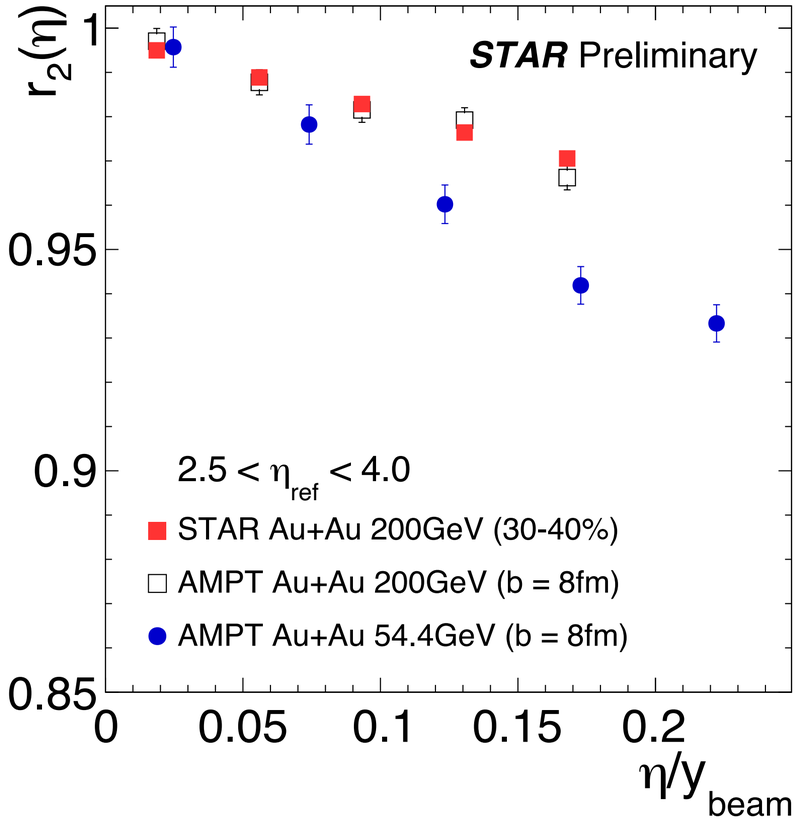
Zr+Zr/Ru+Ru vs Au+Au to further study system size dependence.

r_2 comparison with models study

- r_2 comparison with hydro and AMPT

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

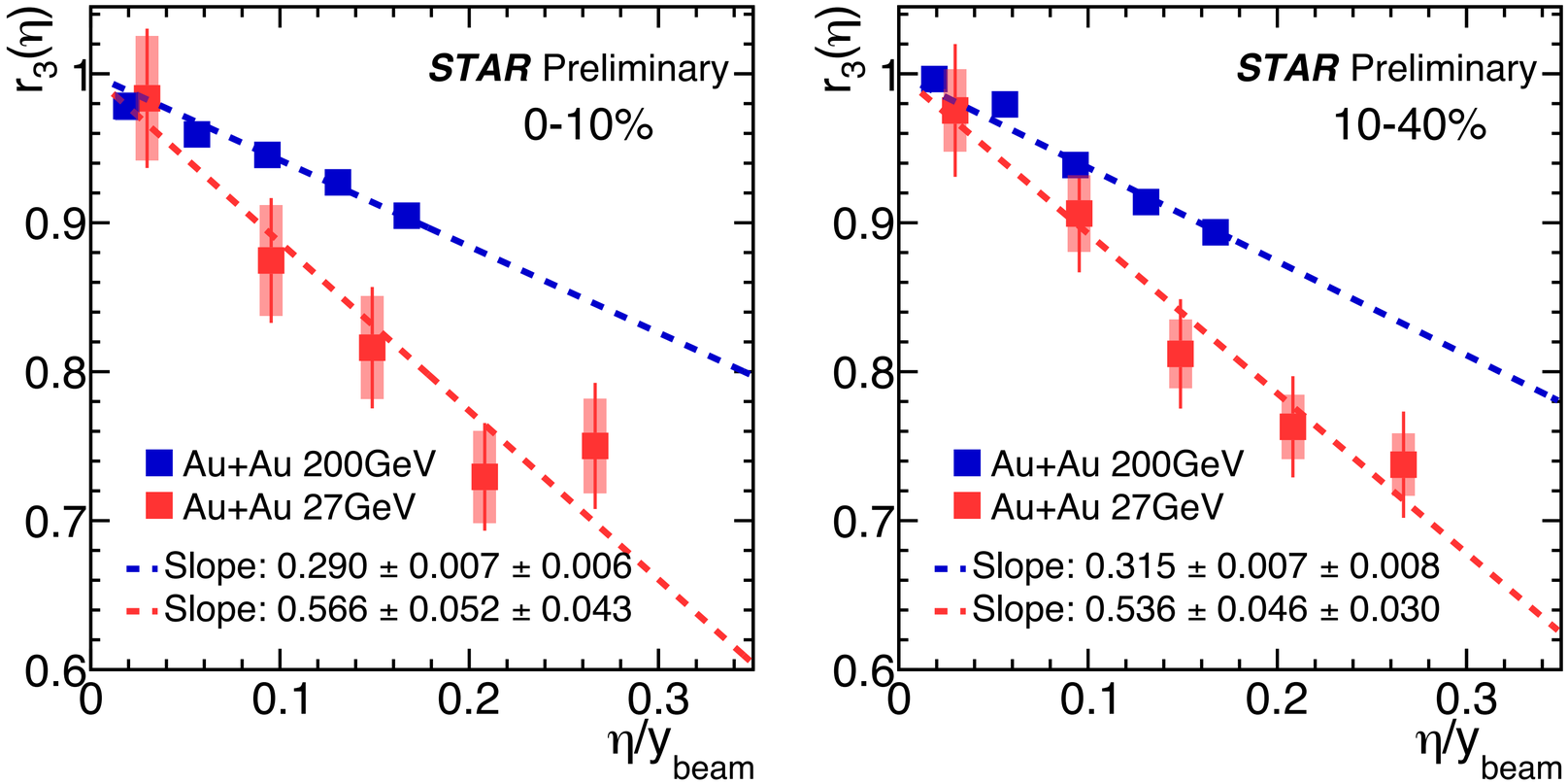




- Hydrodynamics and AMPT models predict stronger energy dependence than the data.

v_3 decorrelation scaled by beam rapidity

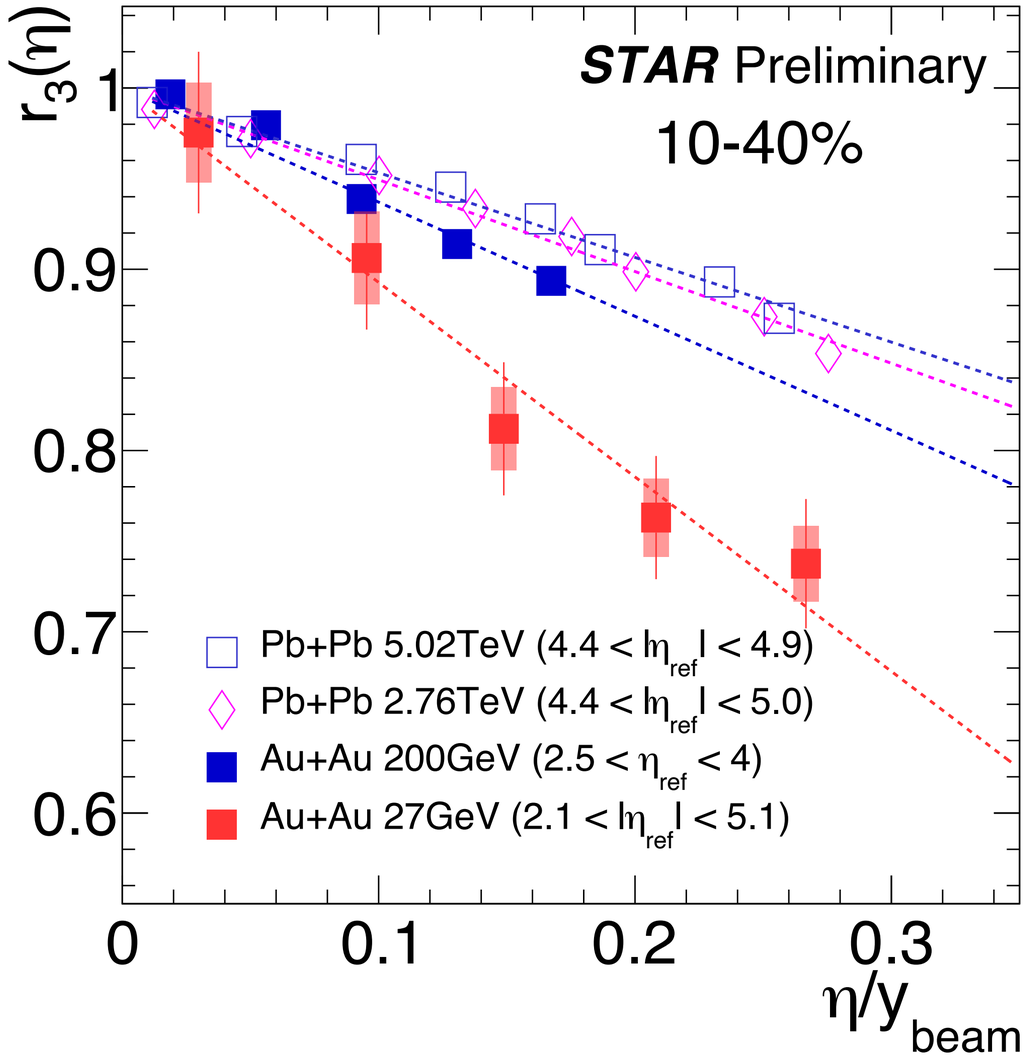
- r_3 comparison between 27GeV and 200GeV with rapidity normalization



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

r_3 comparison with LHC results

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

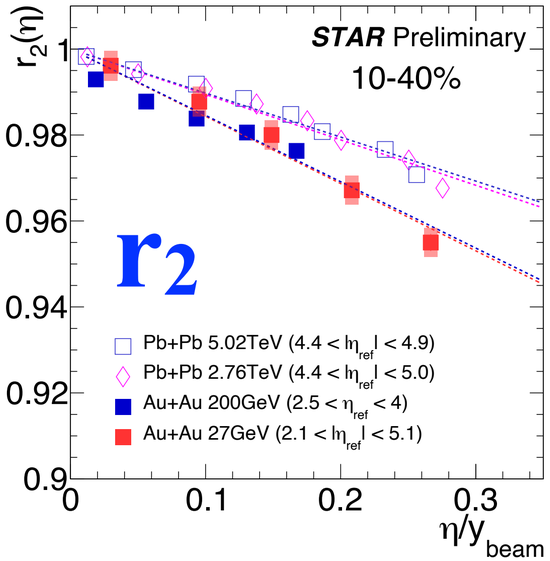


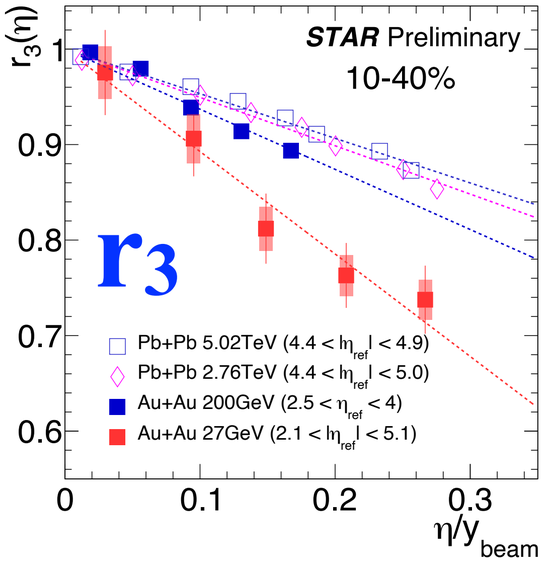
	Slope
Au+Au 27GeV	0.536 ± 0.046
Au+Au 200GeV	0.315 ± 0.007
Pb+Pb 2.76TeV	0.253 ± 0.002
Pb+Pb 5.02TeV	0.234 ± 0.001

- 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.



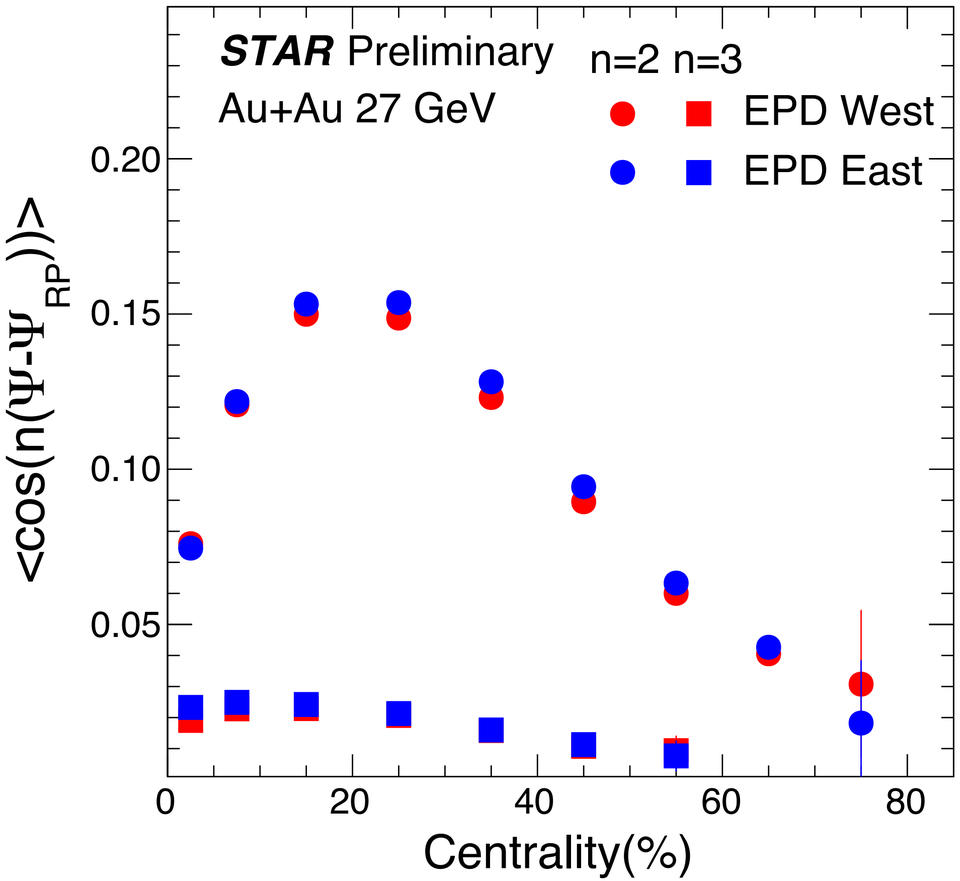


- Energy dependence can be further studied using STAR BES-II data.
- System size dependence: Zr+Zr/Ru+Ru vs Au+Au; small system scan (O+O vs Au+Au).

Backup

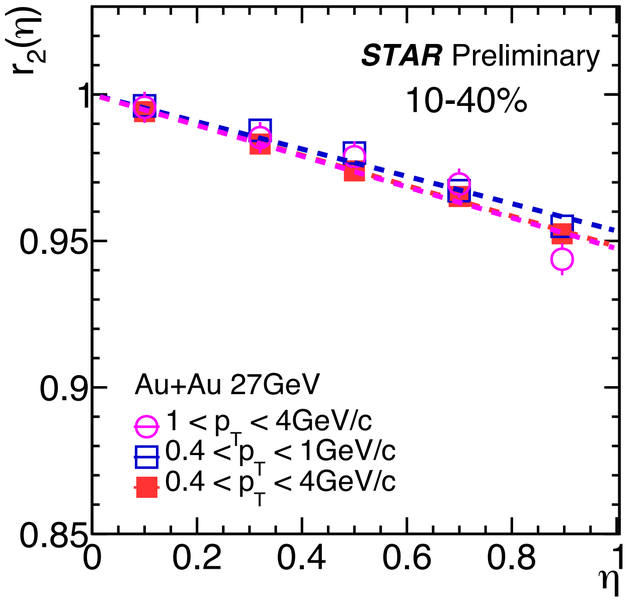
EPD as an event plane detector

✦ EPD event-plane resolution

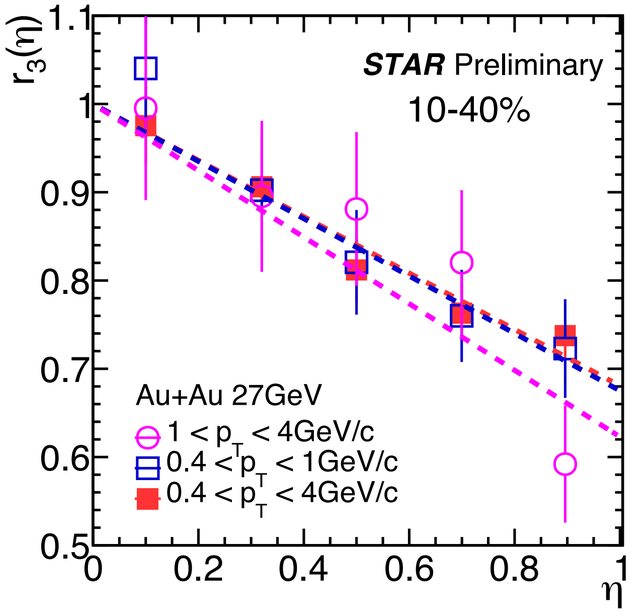


- EPD shows consistent results for 2nd- and 3rd-order event plane resolutions.

p_T dependence of r_n



r_2

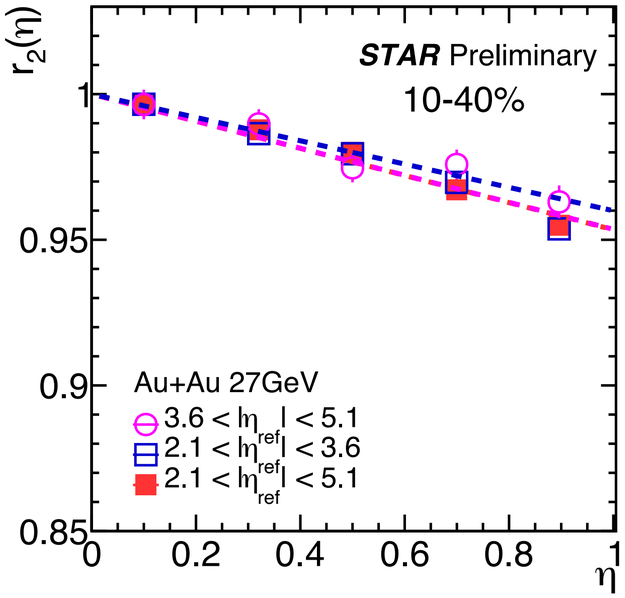


r_3

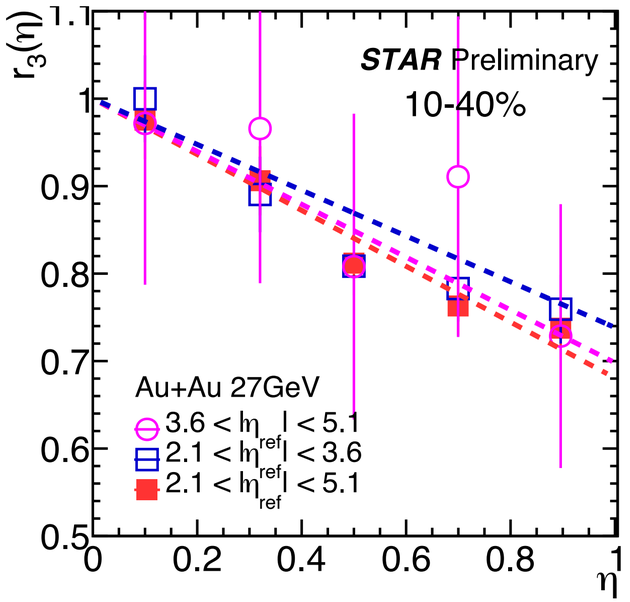
	r_2 slope	r_3 slope
0.4 < pT < 4GeV/c	0.026 ± 0.001	0.160 ± 0.014
0.4 < pT < 1GeV/c	0.023 ± 0.001	0.162 ± 0.022
1 < pT < 4GeV/c	0.026 ± 0.002	0.189 ± 0.029

- Both r_2 and r_3 are weak p_T dependent.

η_{ref} dependence of r_n



r_2



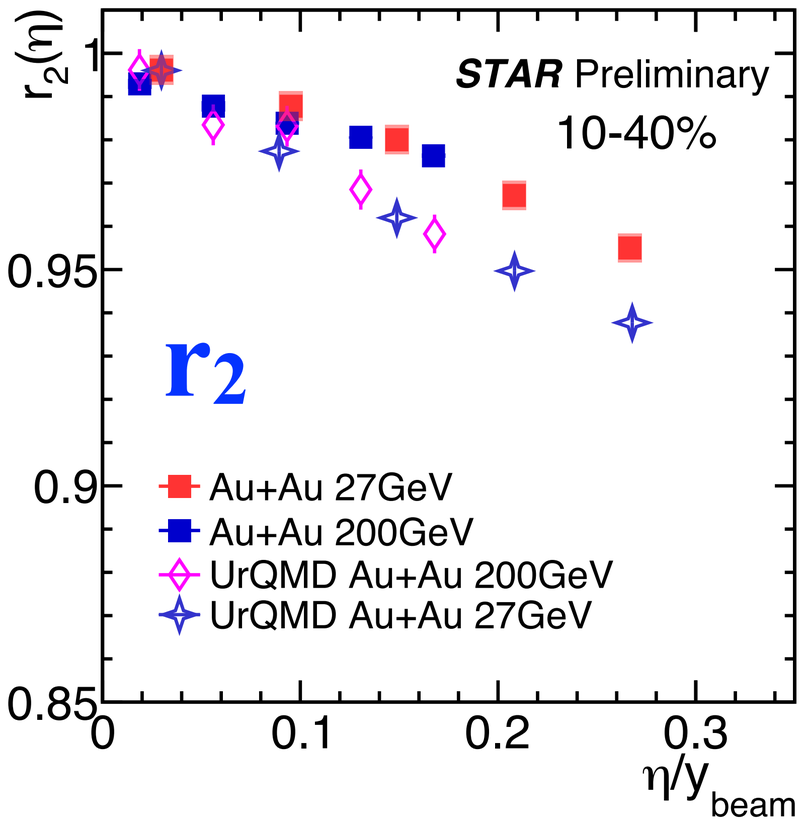
r_3

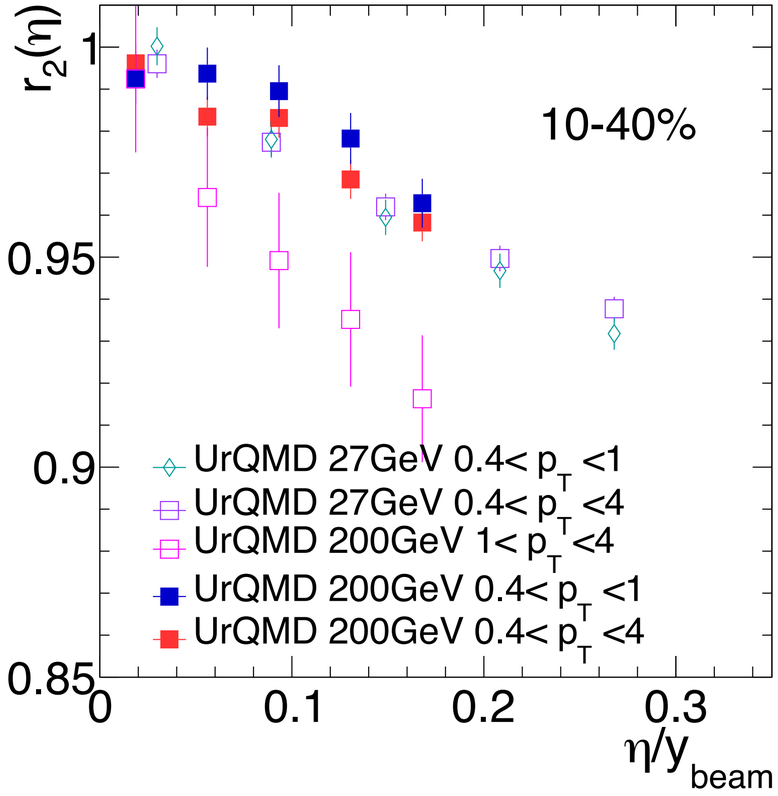
	r_2 slope	r_3 slope
$2.1 < \lvert\eta_{ref}\rvert < 3.6$	0.023 ± 0.001	0.131 ± 0.064
$3.6 < \lvert\eta_{ref}\rvert < 5.1$	0.026 ± 0.002	0.160 ± 0.014
$2.1 < \lvert\eta_{ref}\rvert < 5.1$	0.026 ± 0.001	0.160 ± 0.014

- 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.