Measurement of longitudinal decorrelation of anisotropic flow v_2 and v_3 in 200 GeV Au+Au collisions at STAR

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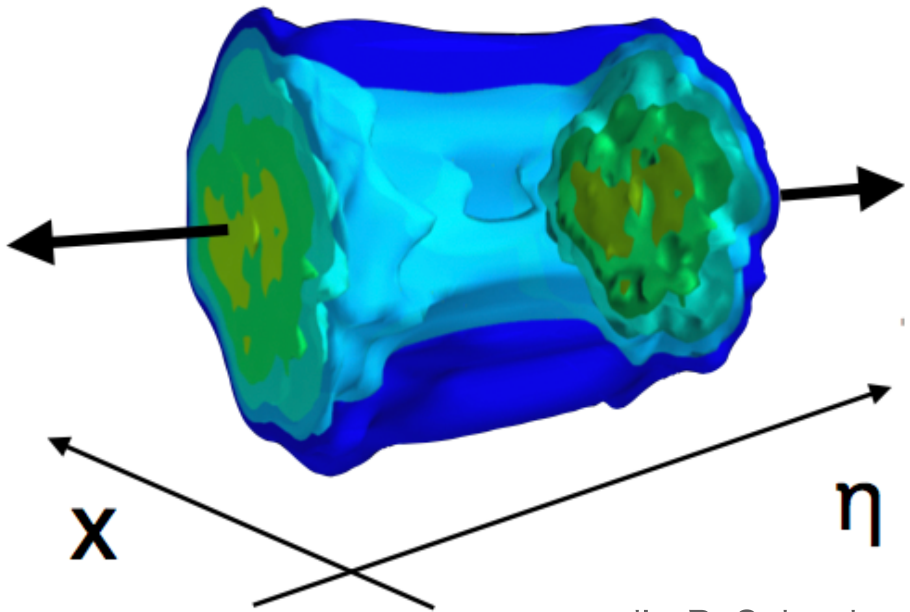
Longitudinal dynamics in heavy-ion collisions

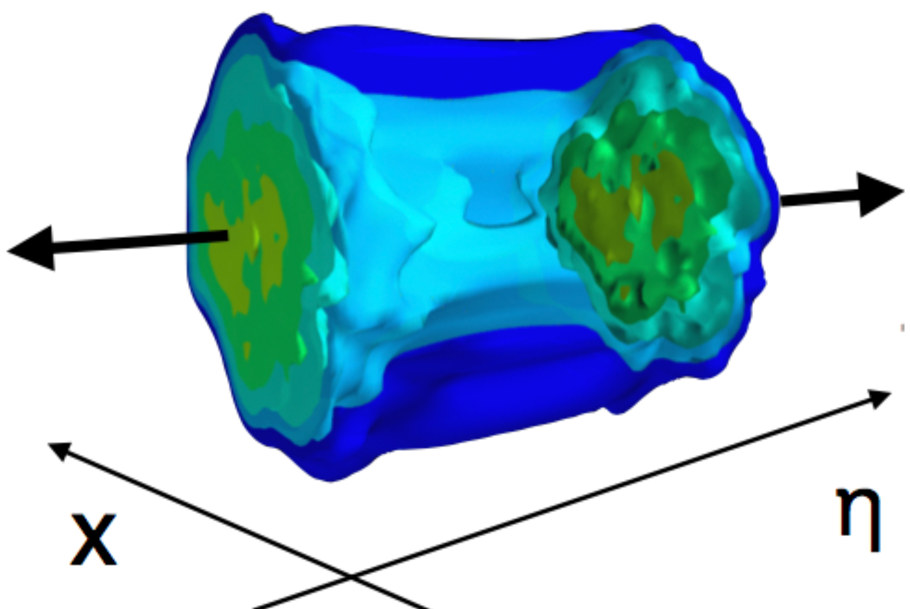
- Evolution of the QGP in (3+1)D



credit: B. Schenke

Longitudinal dynamics in heavy-ion collisions

- ✦ Evolution of the QGP in (3+1)D



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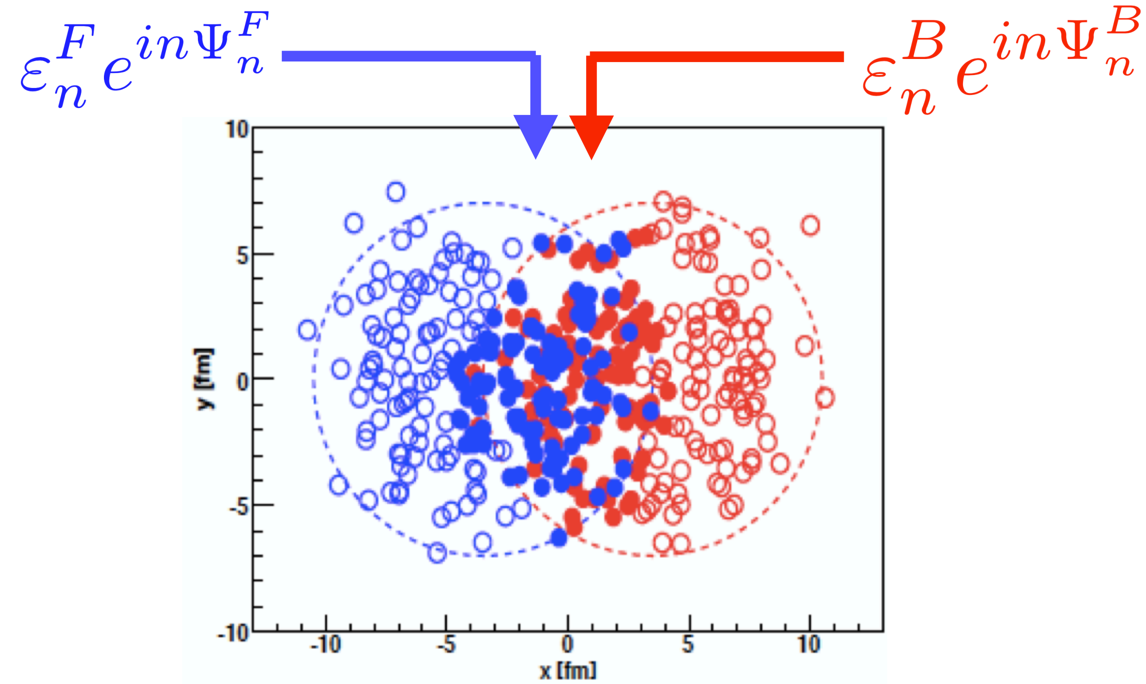
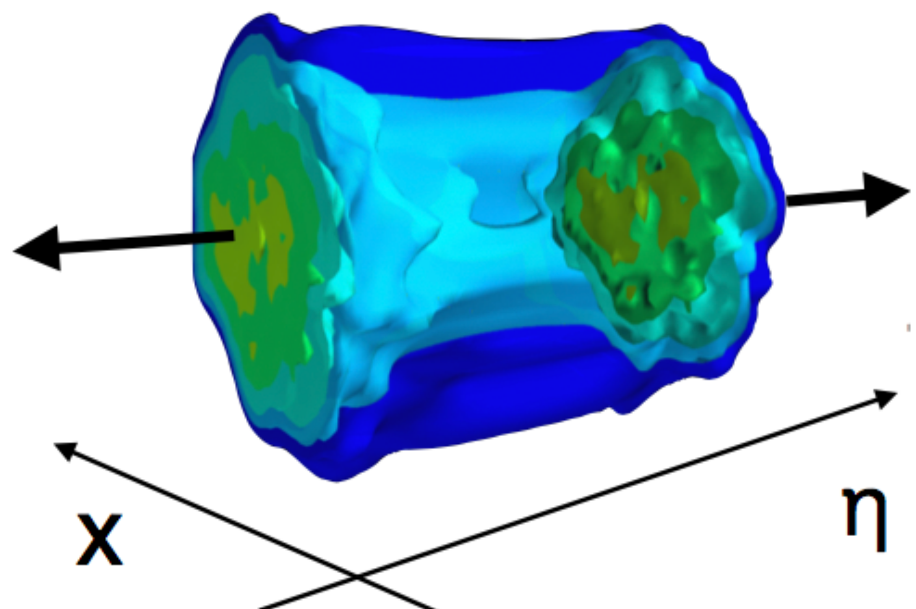
- ✦ Fluctuations in the overlapping region



Longitudinal dynamics in heavy-ion collisions

✦ Evolution of the QGP in (3+1)D



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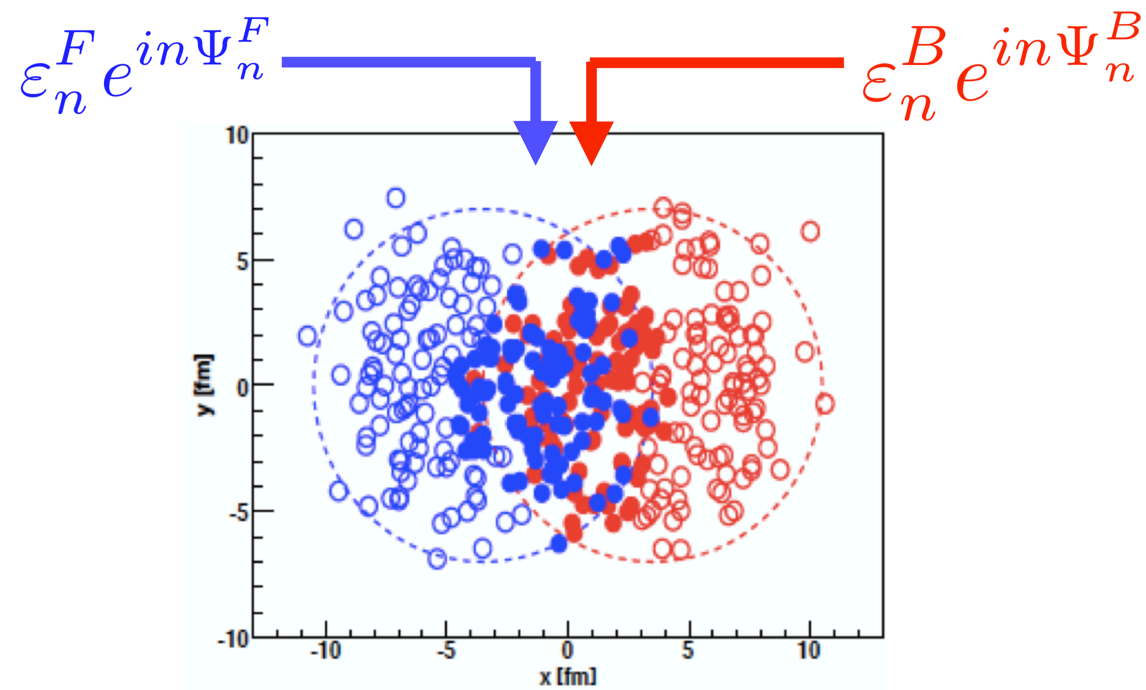
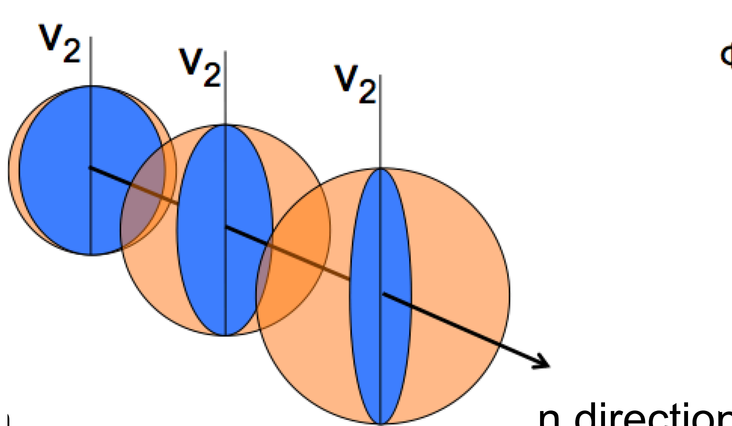
✦ Fluctuations in the overlapping region



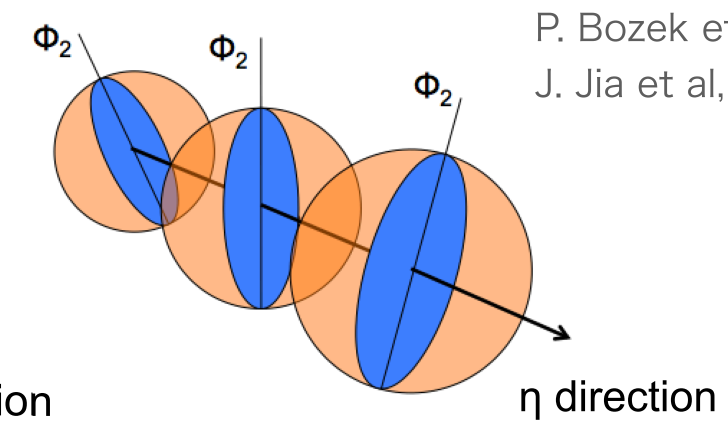
✦ Consequence: $V_n(\eta) = v_n(\eta) e^{in\Psi_n(\eta)}$

Asymmetry of a flow magnitude



$v_n(\eta_1) \neq v_n(\eta_2)$

Torque/twist of an event plane



$\Psi_n(\eta_1) \neq \Psi_n(\eta_2)$

P. Bozek et al, Phys.Rev. C 83 (2011) 034911

J. Jia et al, Phys. Rev. C 90 (2014) 034905

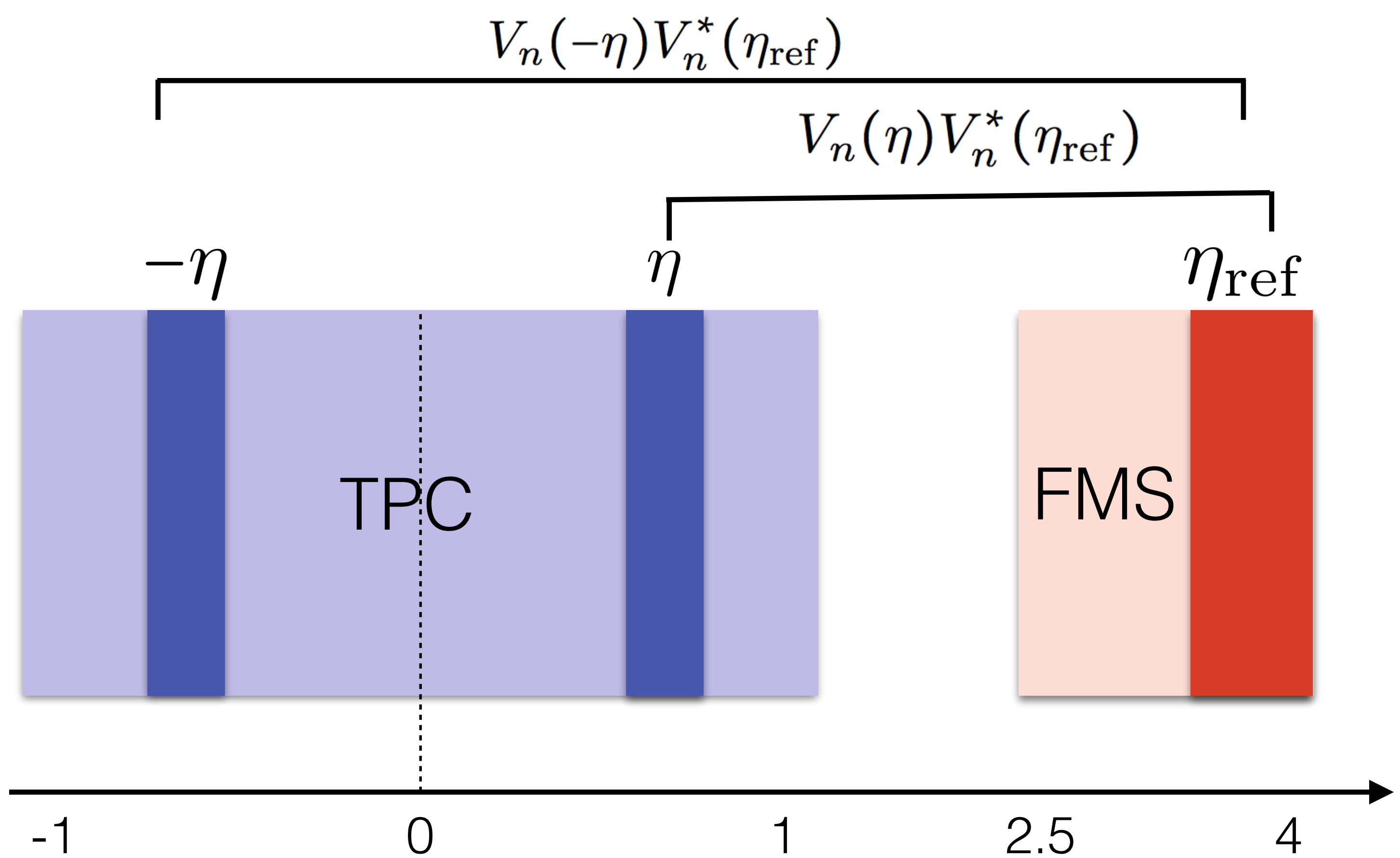
Flow decorrelation observables

✦ 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 $\mathbf{v}_n(-\eta)$ and $\mathbf{v}_n(\eta)$, and captures both the longitudinal flow asymmetry and the twist effect

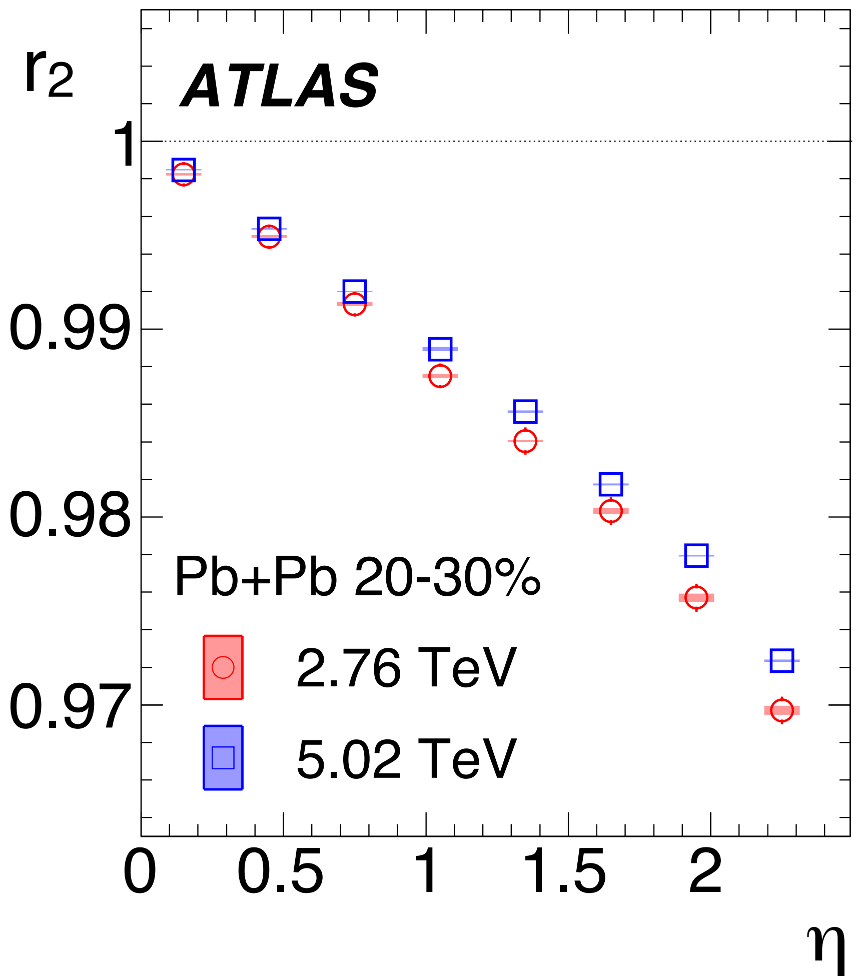


A large η gap is imposed to avoid short-range correlations.

Why are measurements at RHIC important?

- Energy dependence of r_2 at two LHC energies

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



- From 5.02 TeV to 2.76 TeV, slightly stronger decorrelation is observed.

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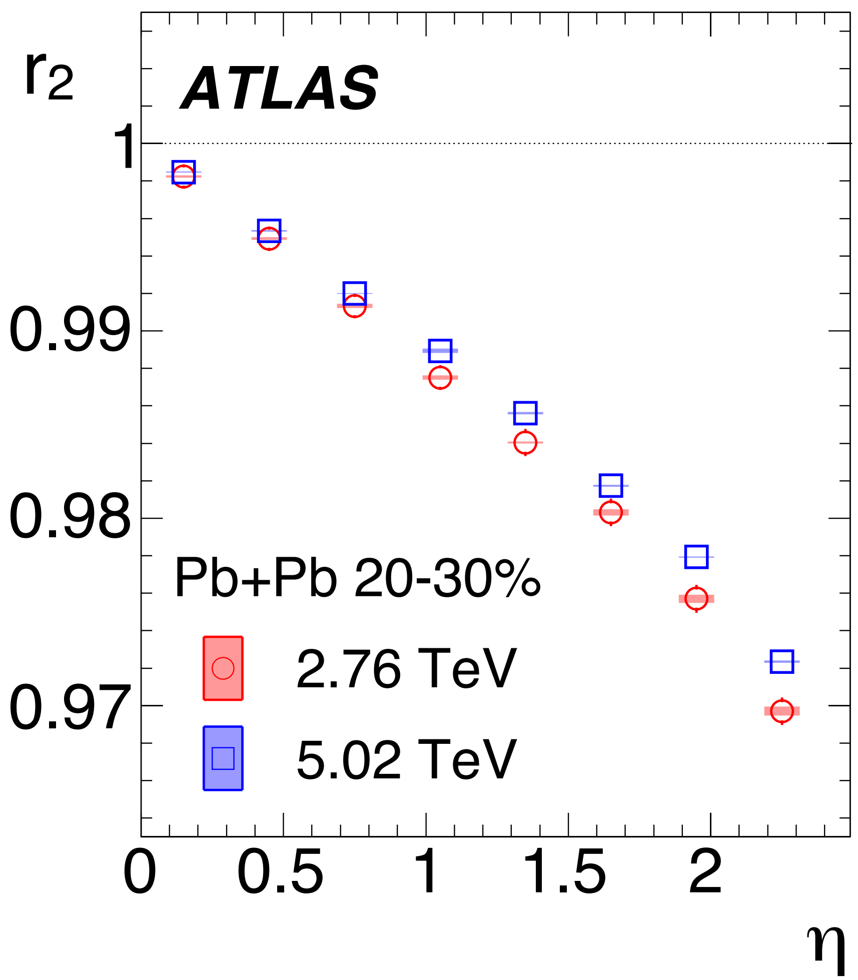
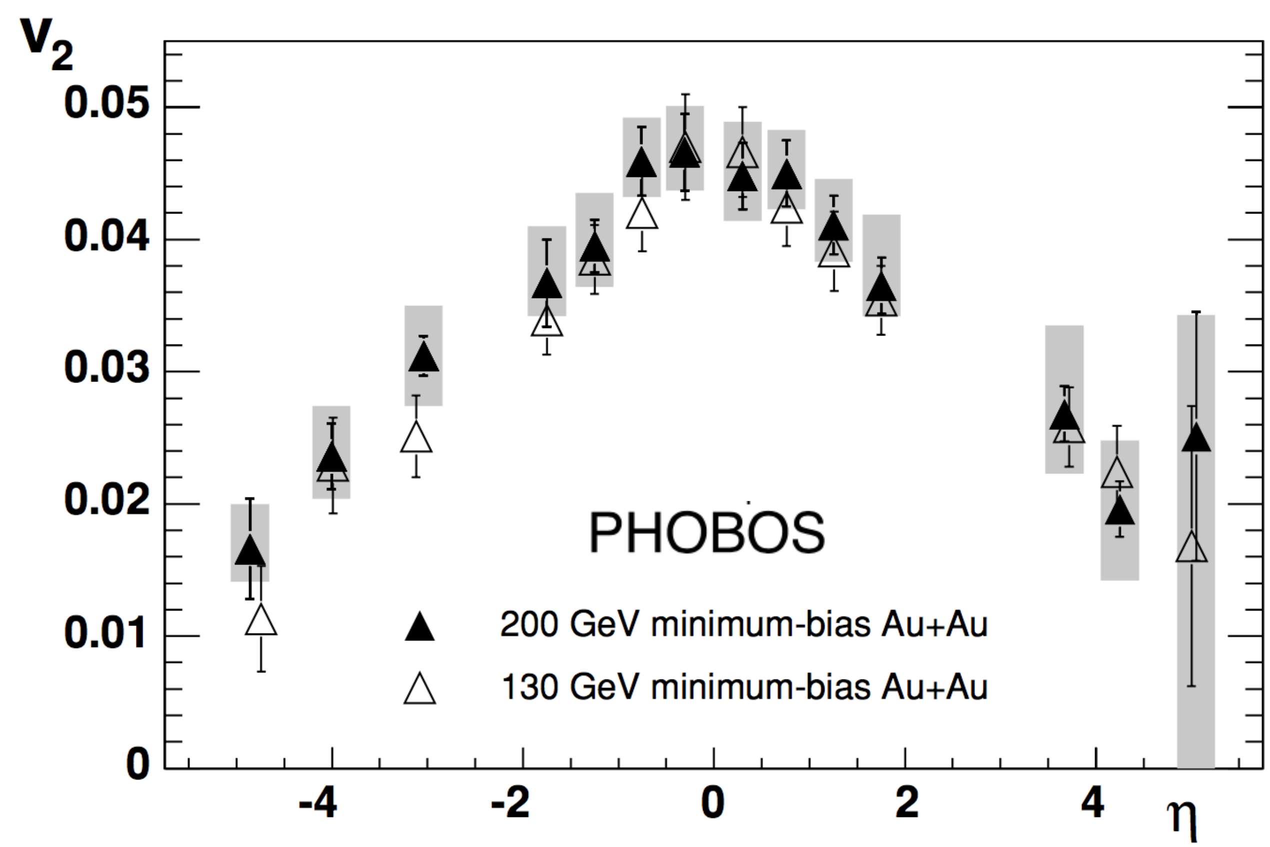
✦ Energy dependence of r_2 at two LHC energies

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



✦ Rapidity-dependent $v_2(\eta)$ at RHIC energies

PHOBOS Collaboration, Phys. Rev. C 72, 051901(R) (2005)

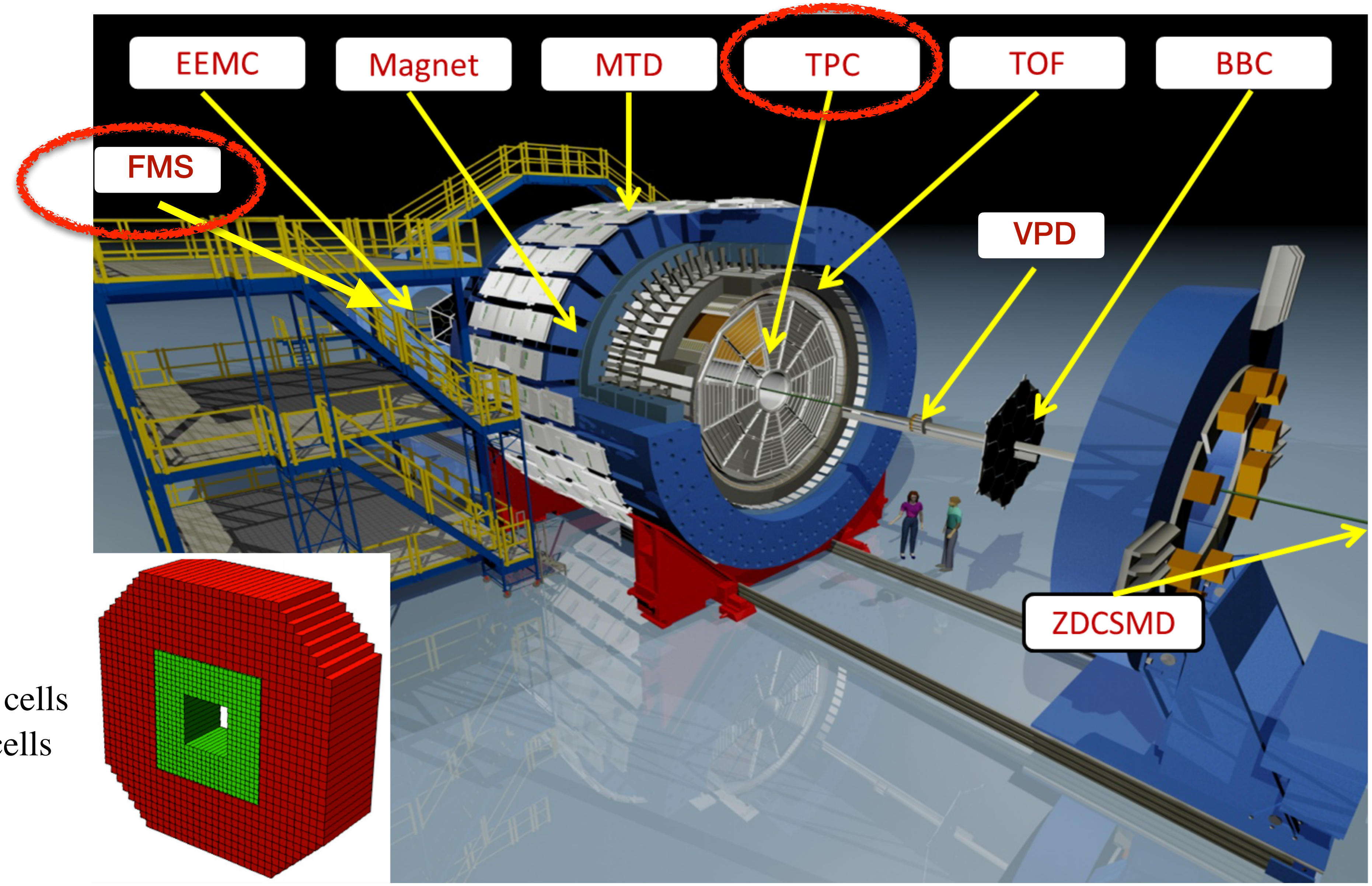


- From 5.02 TeV to 2.76 TeV, slightly stronger decorrelation is observed.
- Dramatic decrease of v_2 with rapidity at RHIC energies ⟷ strong longitudinal dynamics.

Expect an even stronger decorrelation at RHIC energies.

The STAR detectors

✦ A schematic diagram of the STAR detectors

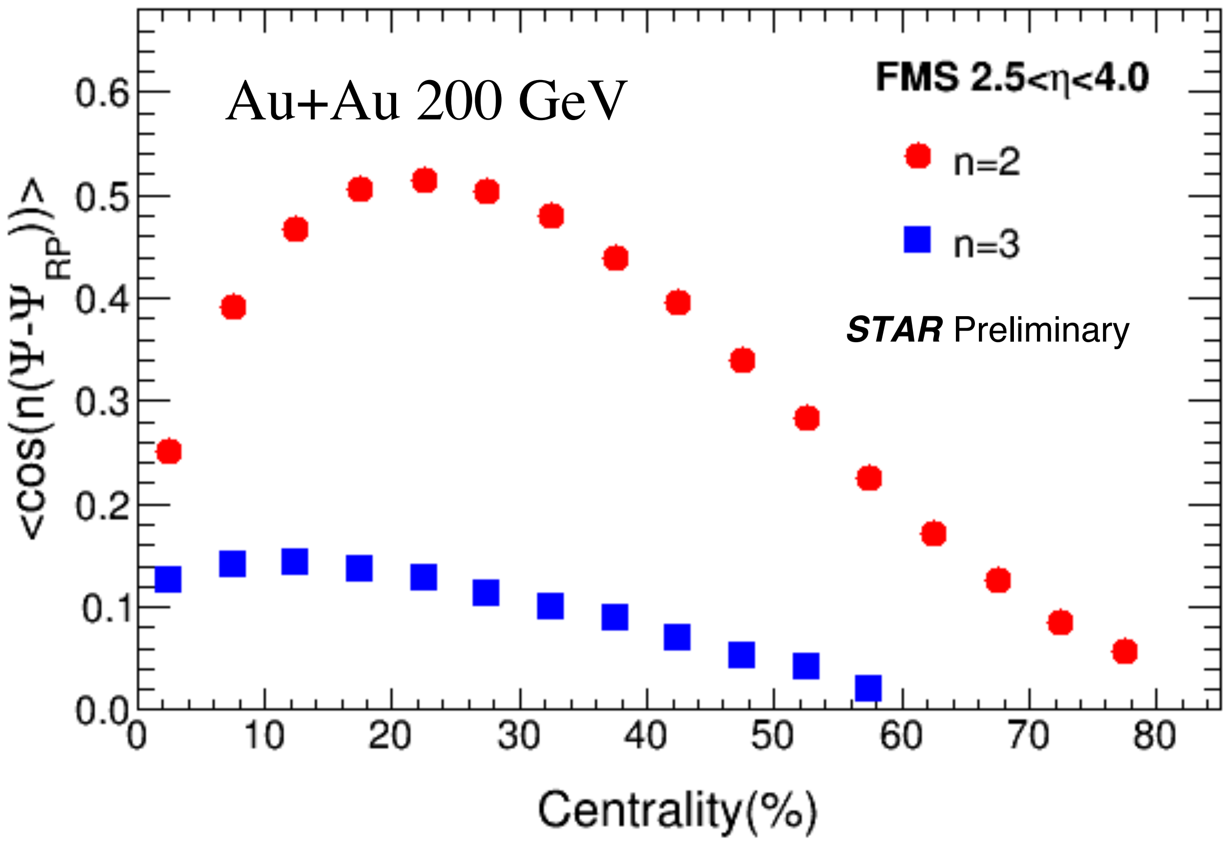


Inner: 476 smaller cells
Outer: 788 larger cells

- Forward Meson Spectrometer is an electromagnetic calorimeter.
- TPC acceptance : -1< η <1; FMS acceptance : 2.5< η_{ref} <4.
- TPC and FMS are used for this analysis, 2016 Au+Au data is used.

FMS as an event plane detector

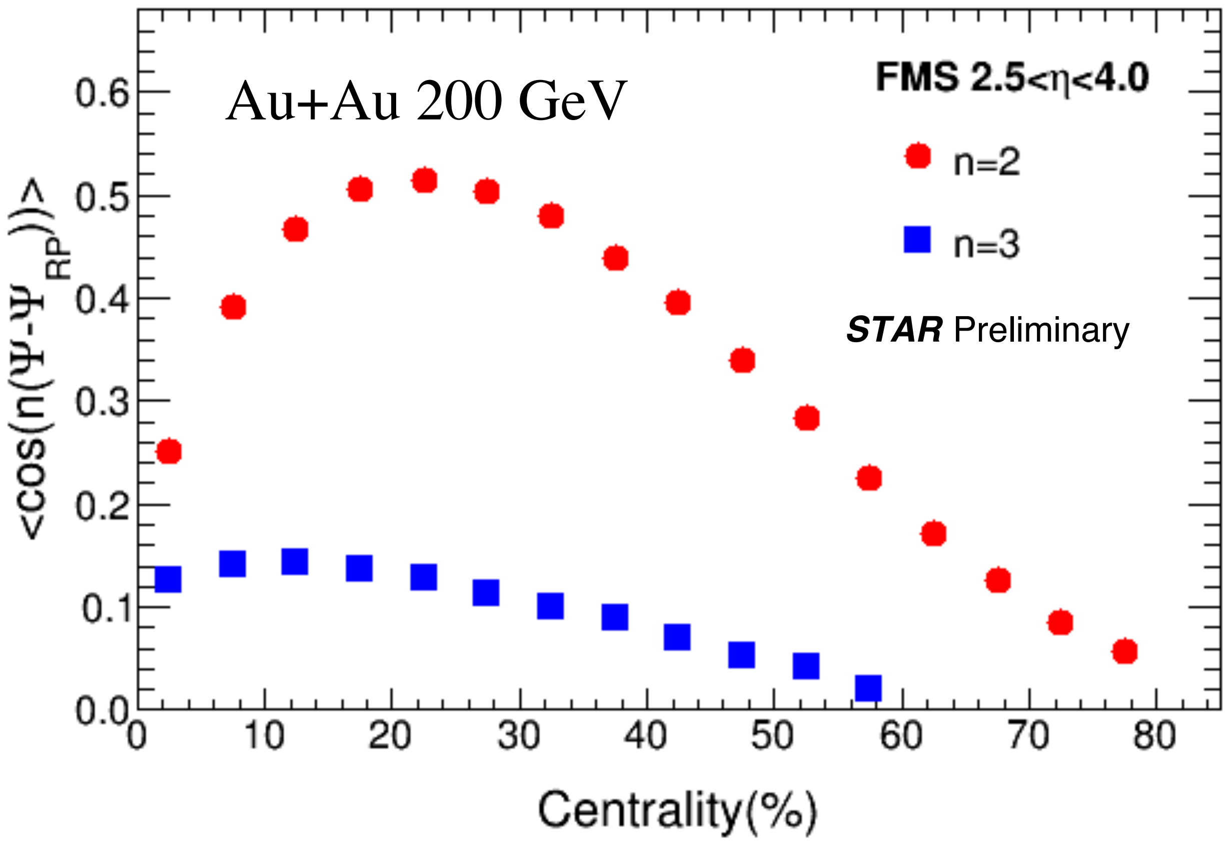
✦ FMS event-plane resolution



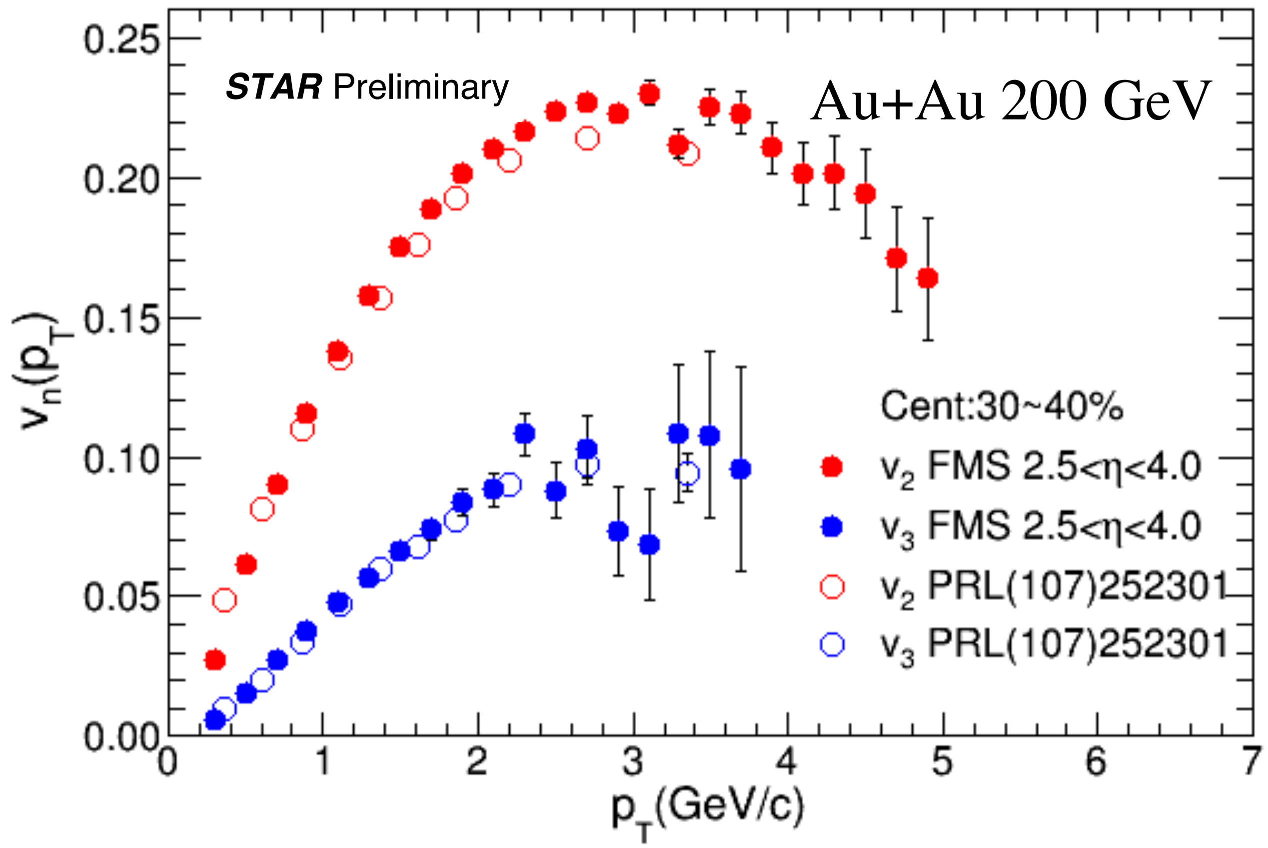
- FMS shows good 2nd- and 3rd-order event plane resolutions.

FMS as an event plane detector

✦ FMS event-plane resolution



✦ Comparison with the published results

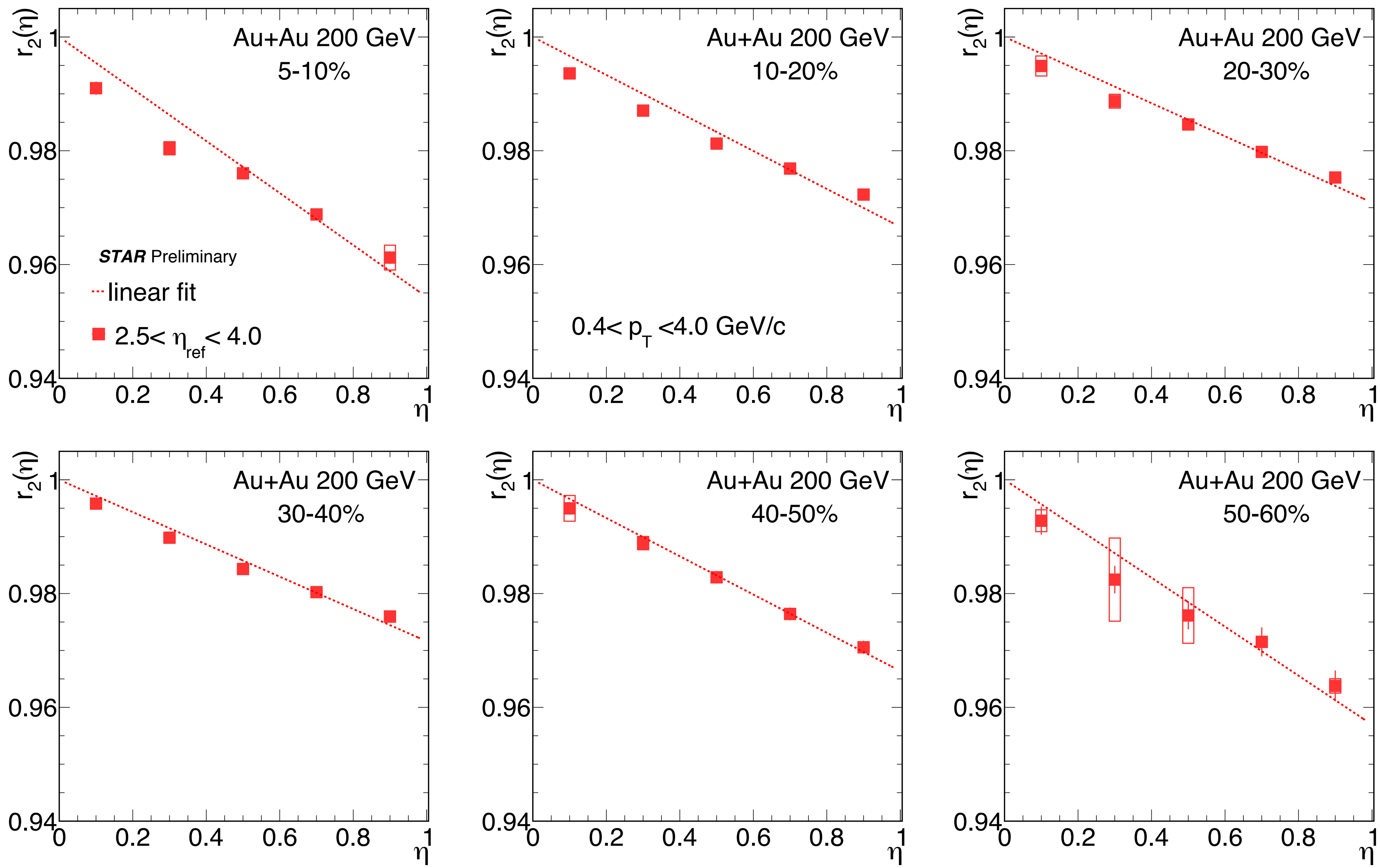


- FMS shows good 2nd- and 3rd-order event plane resolutions.
- Both v_2 and v_3 are consistent with the published results from 200 GeV Au+Au collisions.

v_2 decorrelation for different centralities

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

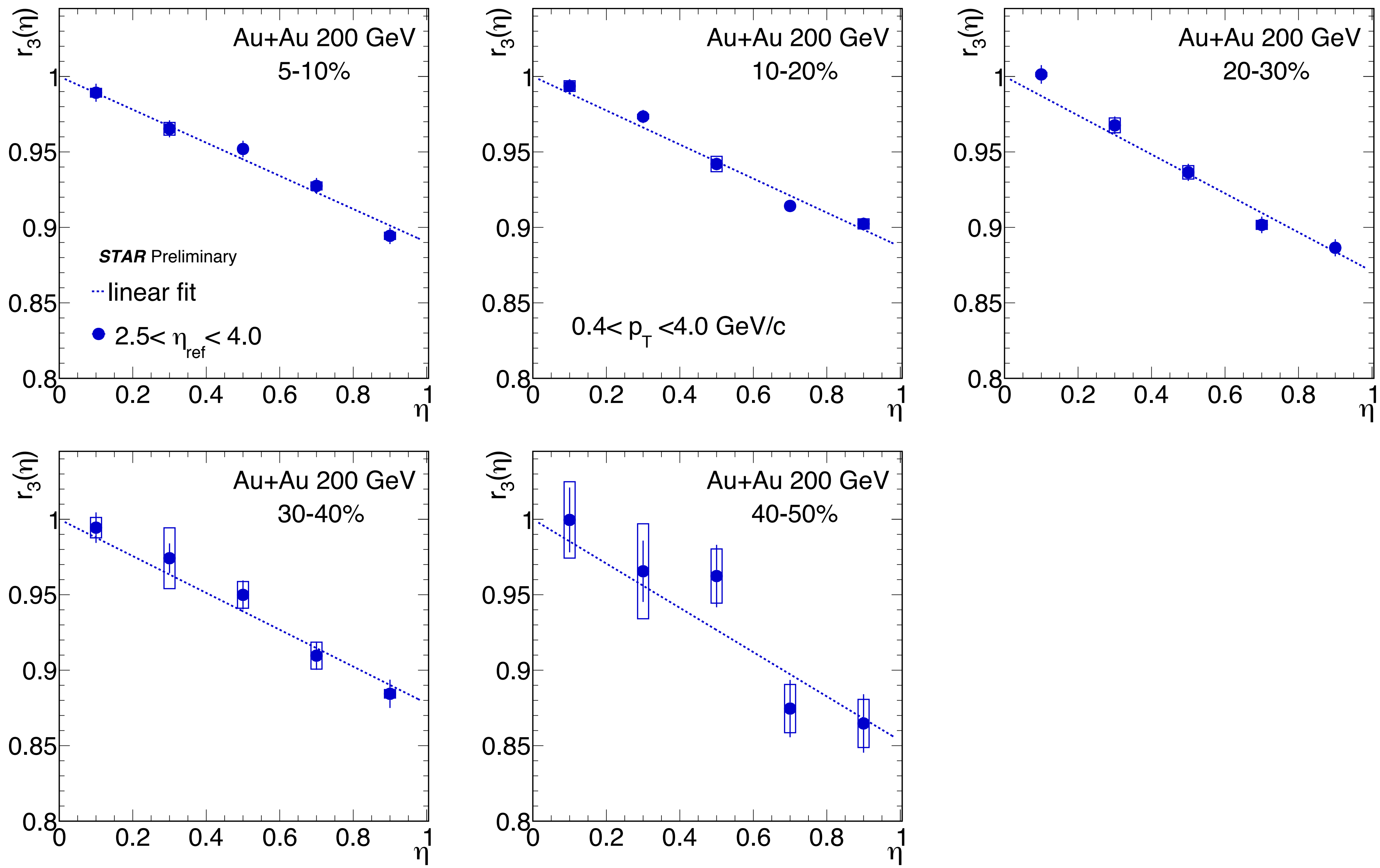
$$r_2 = 1 - 2F_2\eta$$



- $r_2(\eta)$ decreases linearly for the shown centralities.

v_3 decorrelation for different centralities

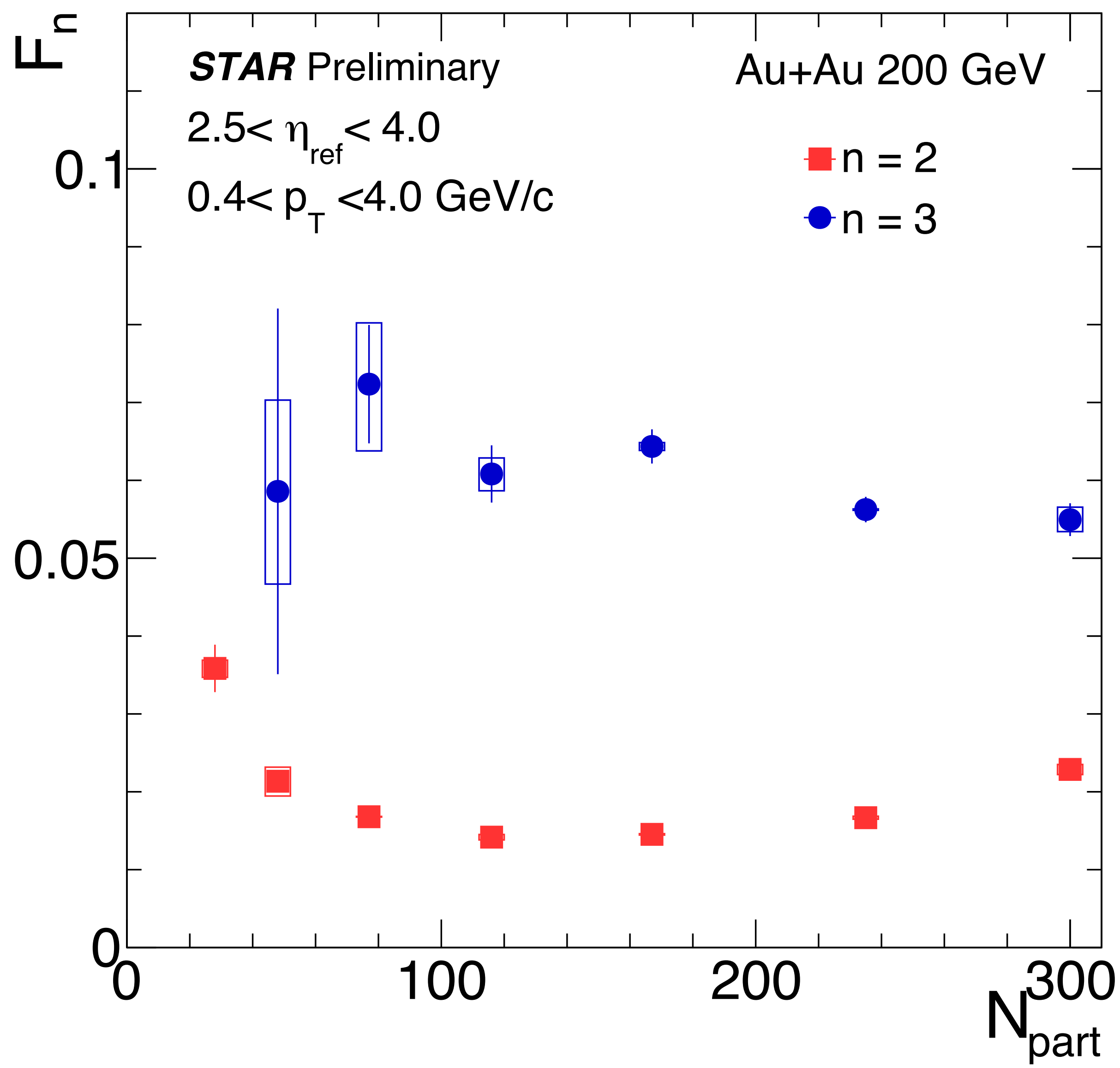
$$r_3(\eta) = \frac{\langle V_3(-\eta)V_3^*(\eta_{\rm ref})\rangle}{\langle V_3(\eta)V_3^*(\eta_{\rm ref})\rangle} \qquad r_3 = 1 - 2F_3\eta$$



- $r_3(\eta)$ decreases linearly for the shown centralities.

Centrality dependence of linear slope

✦ r_n is parameterized with a linear function $$r_n = 1 - 2F_n\eta$$



- For r_2: decorrelation is weakest in mid-central collisions.
- For r_3: weak centrality dependence.

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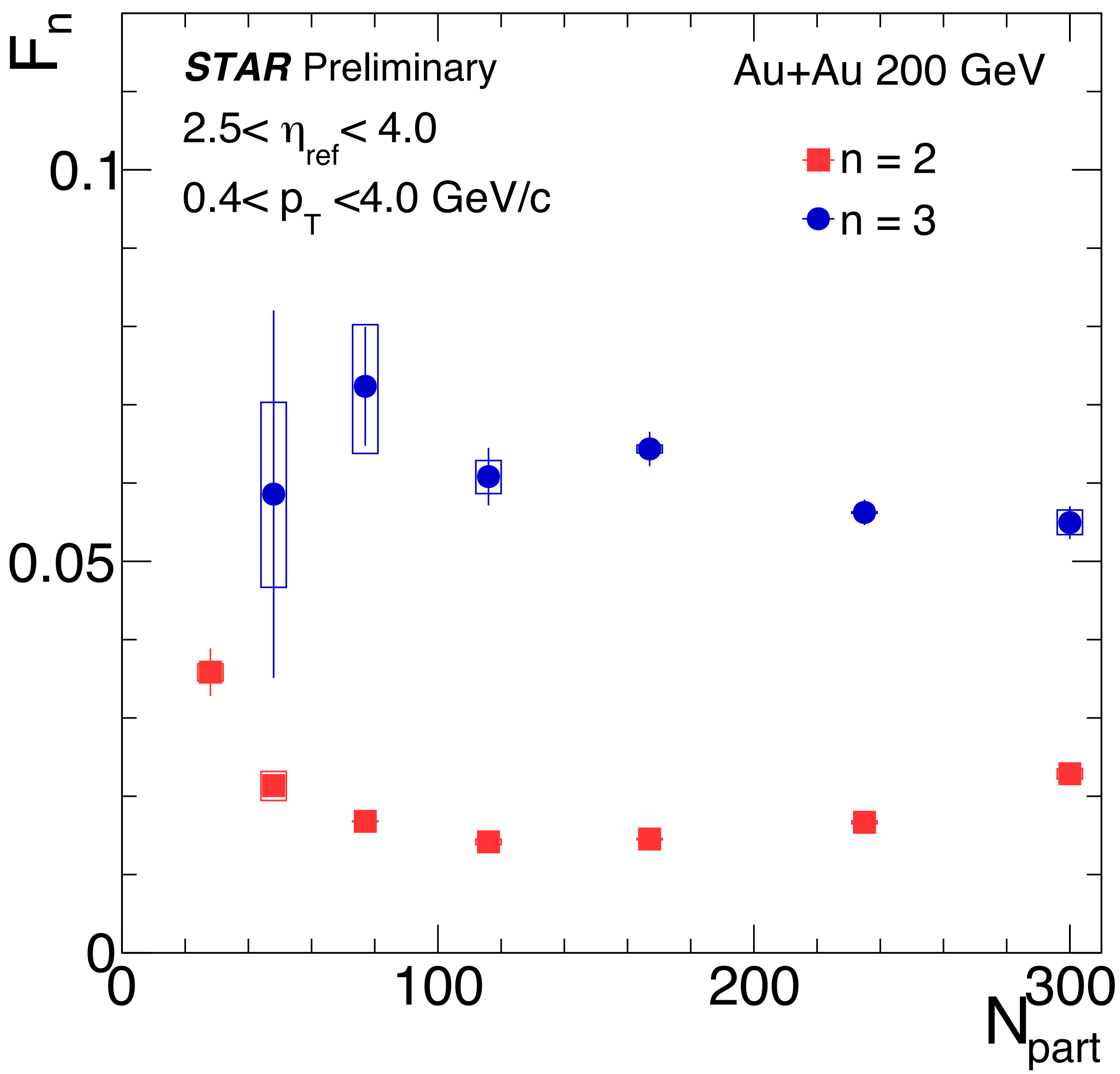
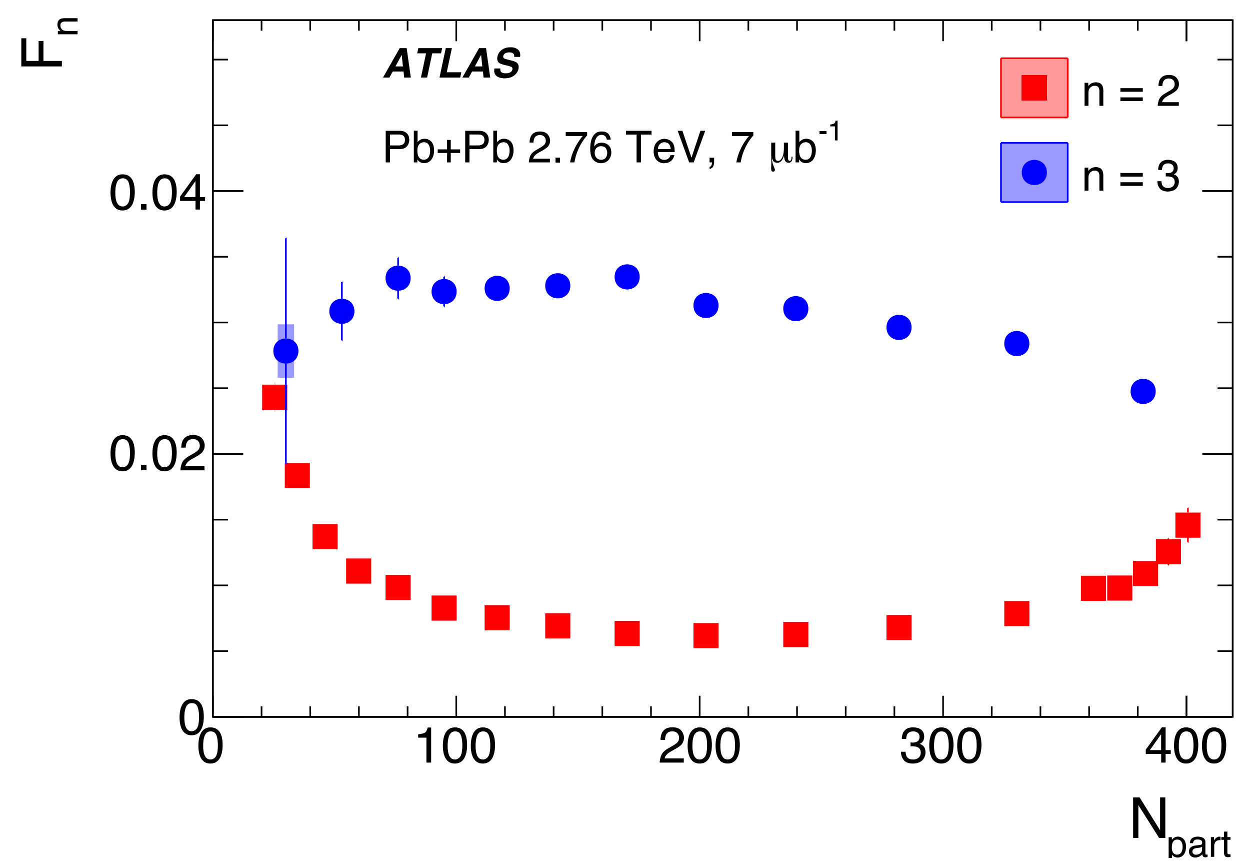


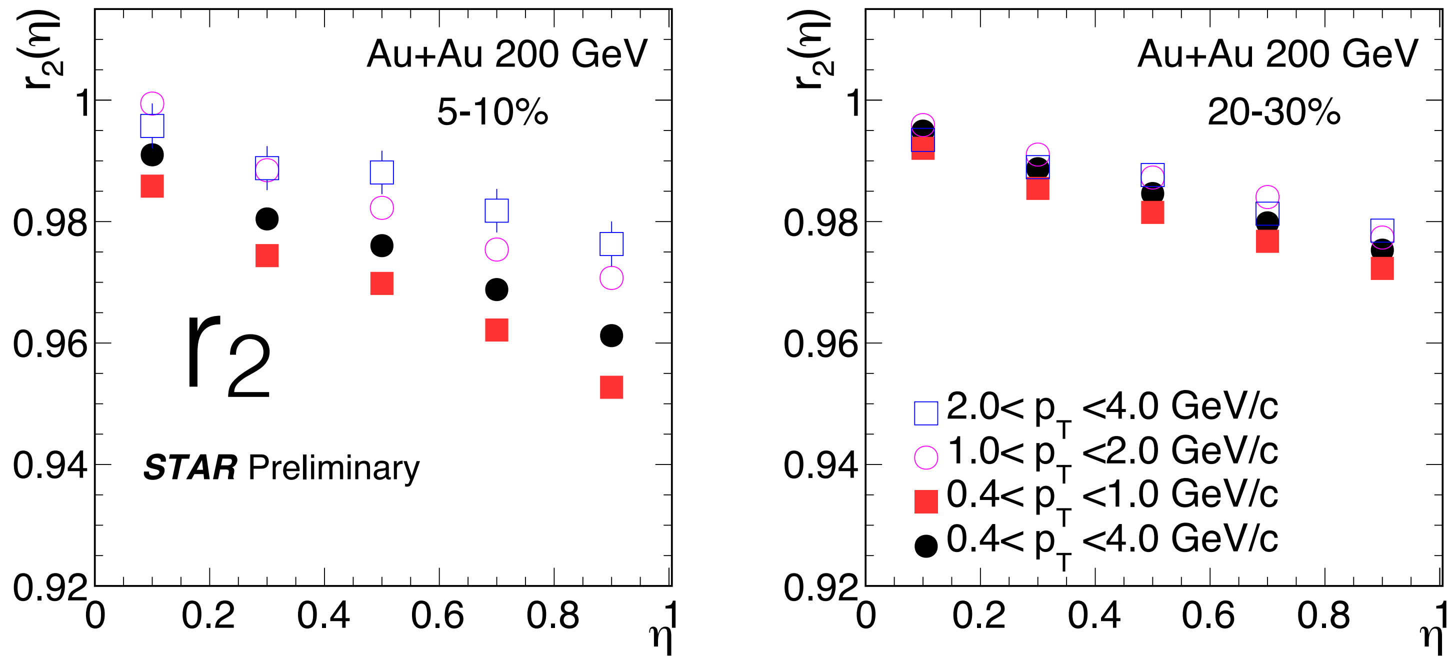
ATLAS Collaboration, Eur. Phys. J. C (2018) 78:142

ATLAS results



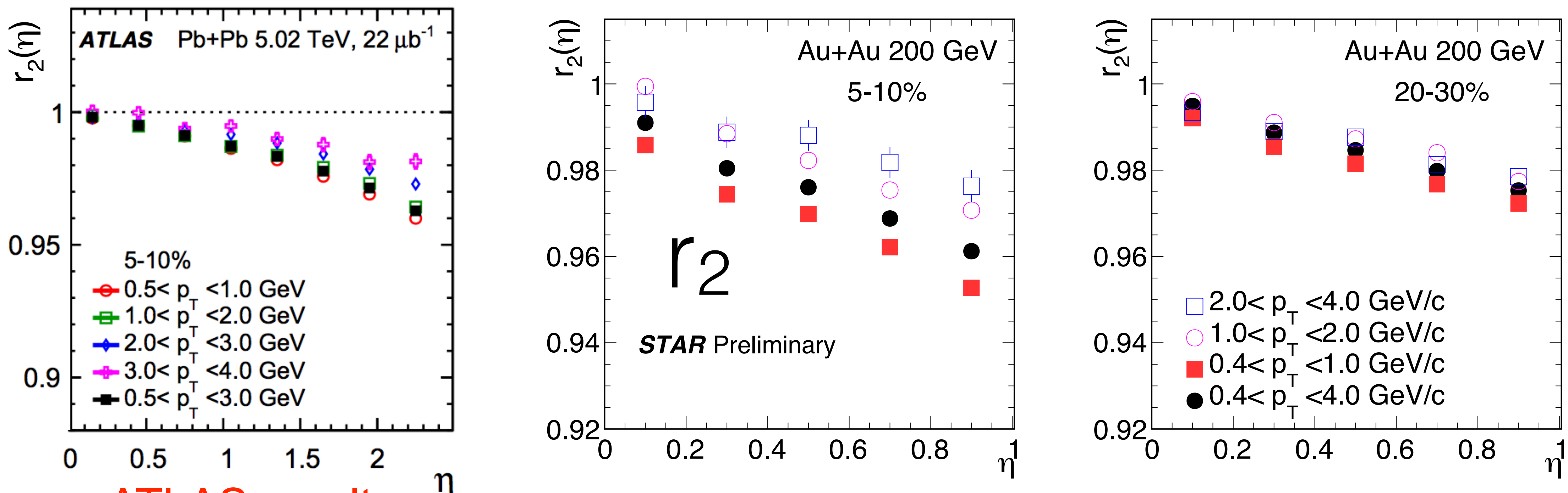
- For r_2: decorrelation is weakest in mid-central collisions.
- For r_3: weak centrality dependence.
- r_3 slope is factor of ~4 larger than r_2 slope, the trend is similar to LHC results.

p_T dependence of r_n



- For r_2: clear p_T dependence for central collisions.

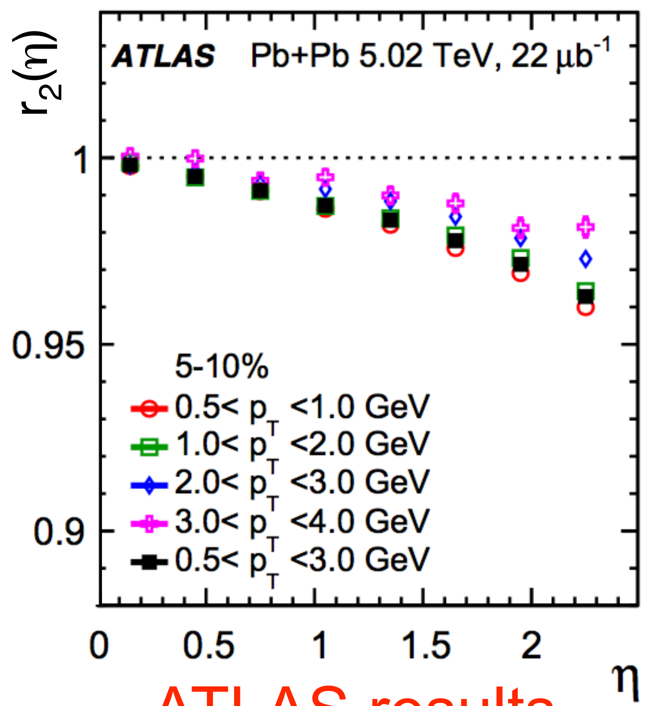
p_T dependence of r_n



ATLAS results

- For r_2: clear p_T dependence for central collisions.
- Similar p_T dependence in central collisions at LHC energy.

p_T dependence of r_n



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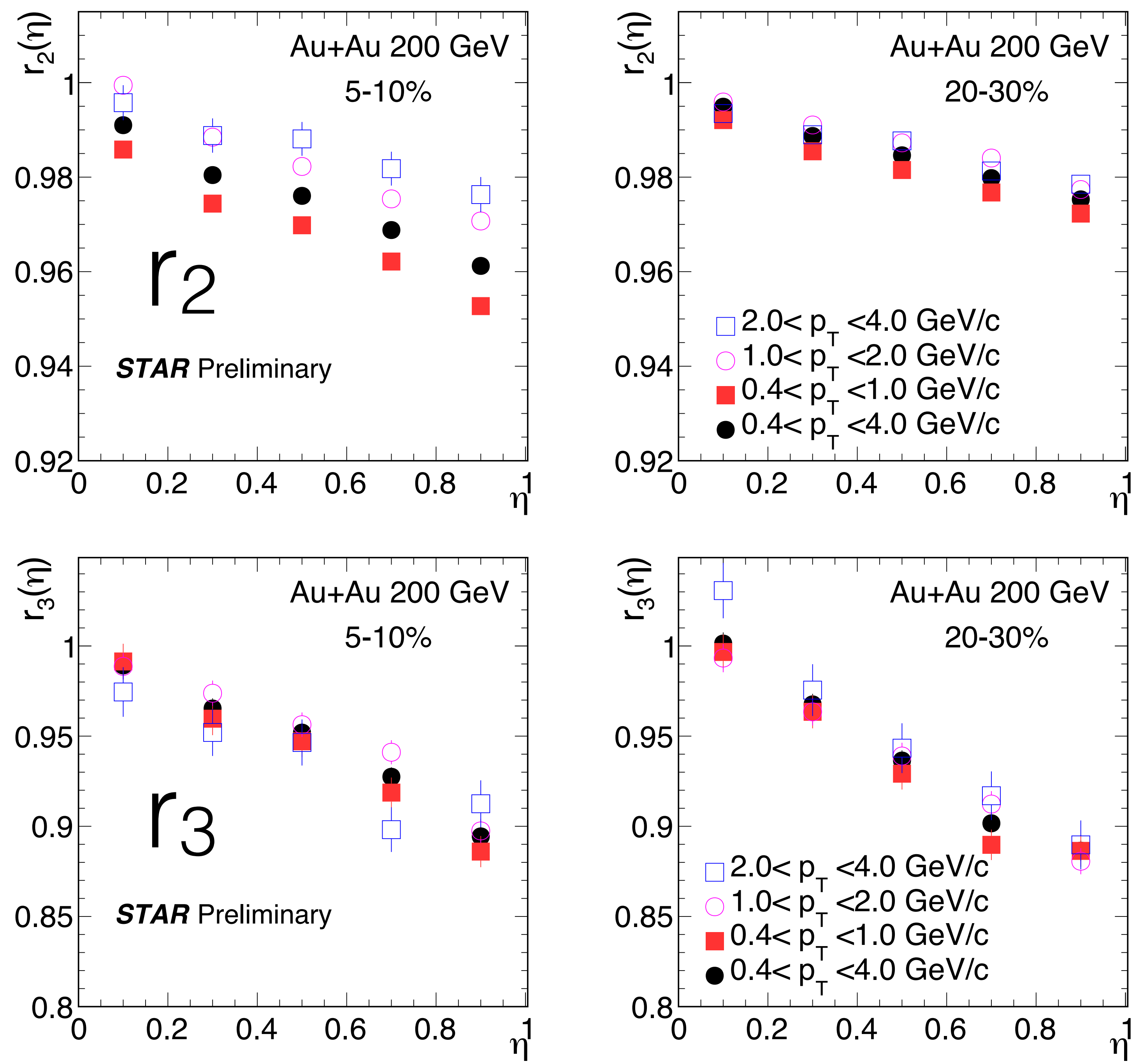
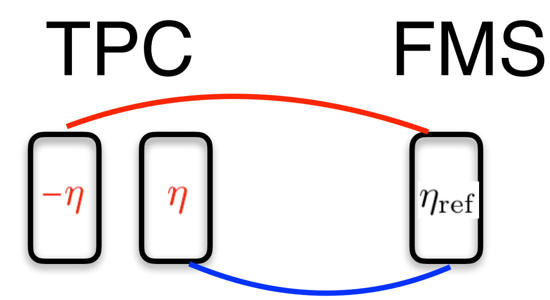
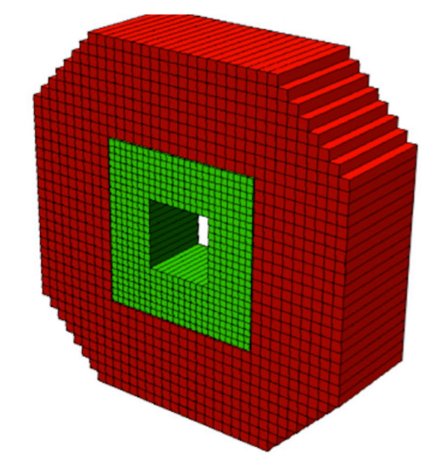


- For r_2: clear p_T dependence for central collisions.
- Similar p_T dependence in central collisions at LHC energy.
- For r_3: weak p_T dependence.

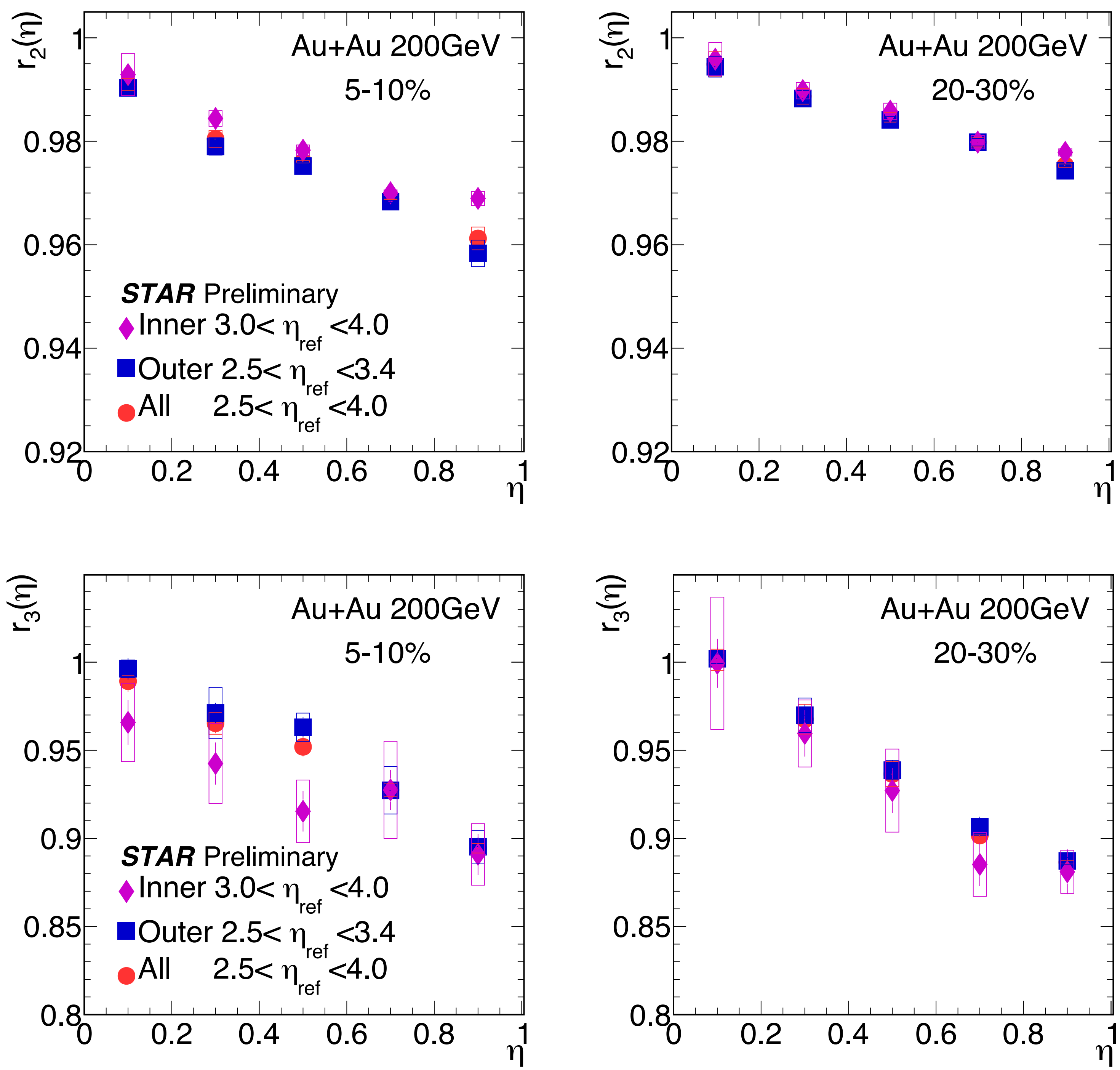
η_{ref} dependence of r_n





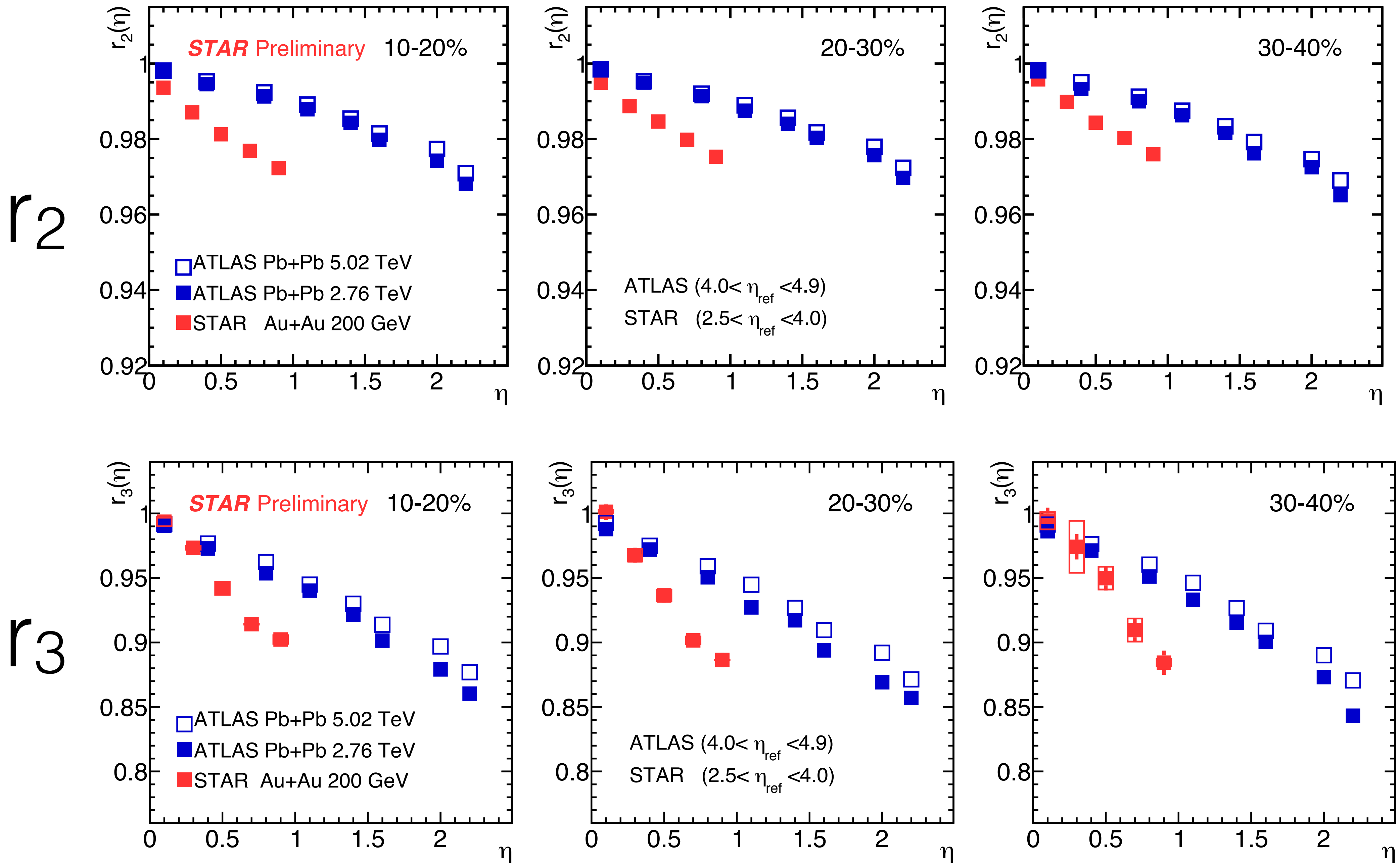
r_2

r_3



- Short-range correlations are significantly suppressed.
- For longitudinal correlations, both r_2 and r_3, show weak η_{ref} dependence.

Comparison to the LHC results

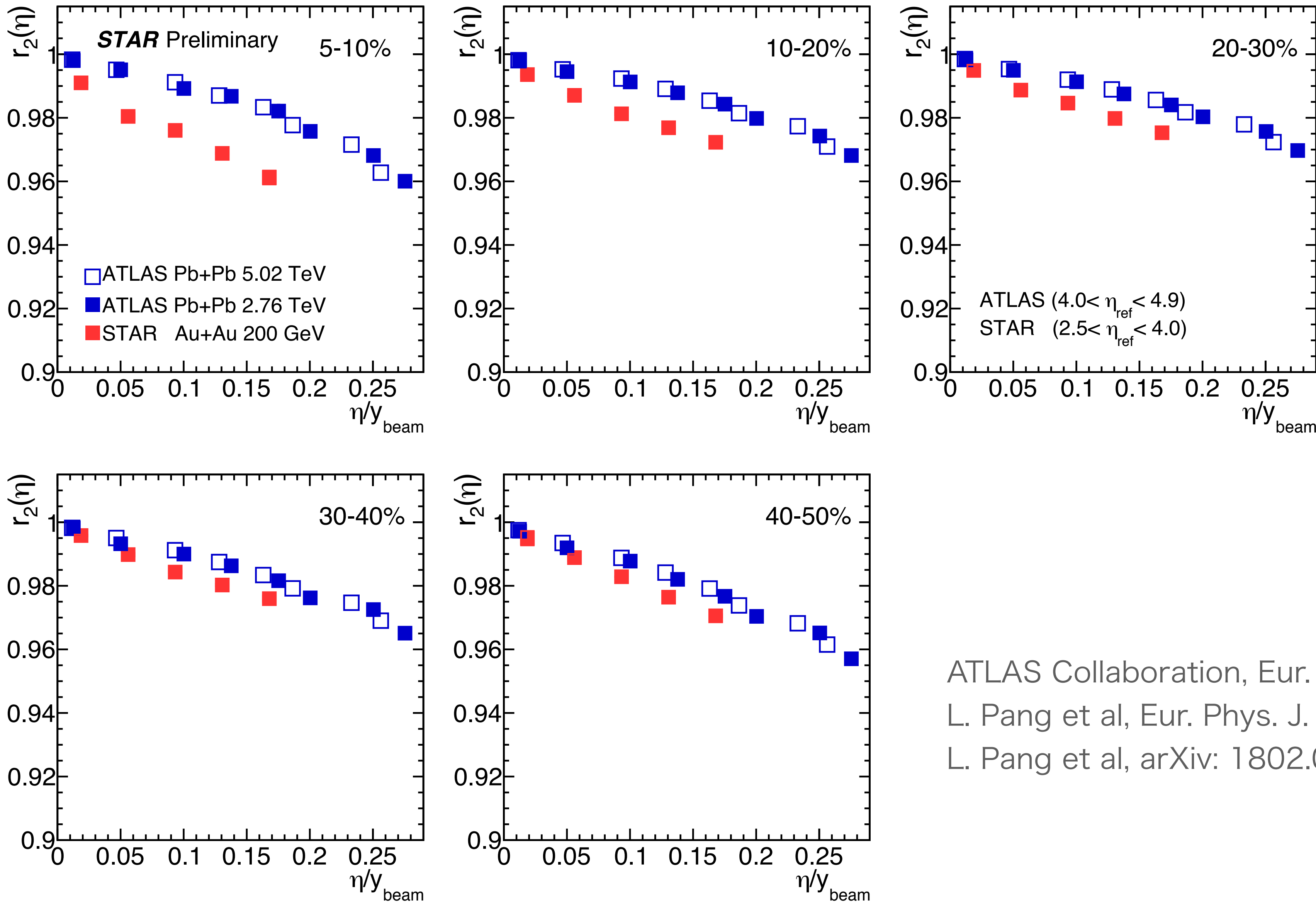


- Significant energy dependence is observed.
- ~2 times stronger decorrelation effect than at the LHC energy 2.76 TeV.

Comparison to the LHC and model calculations

✦ r_2 as a function of scaled rapidity: η/y_{beam}

r_2



$\sqrt{s_{NN}}$	y_{beam}
200GeV	5.36
2.76TeV	7.99
5.02TeV	8.59

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

- Energy dependence remains after y_{beam} normalization, and changes with centrality.

Non-trivial dynamics cannot be explained by simple beam rapidity scaling.

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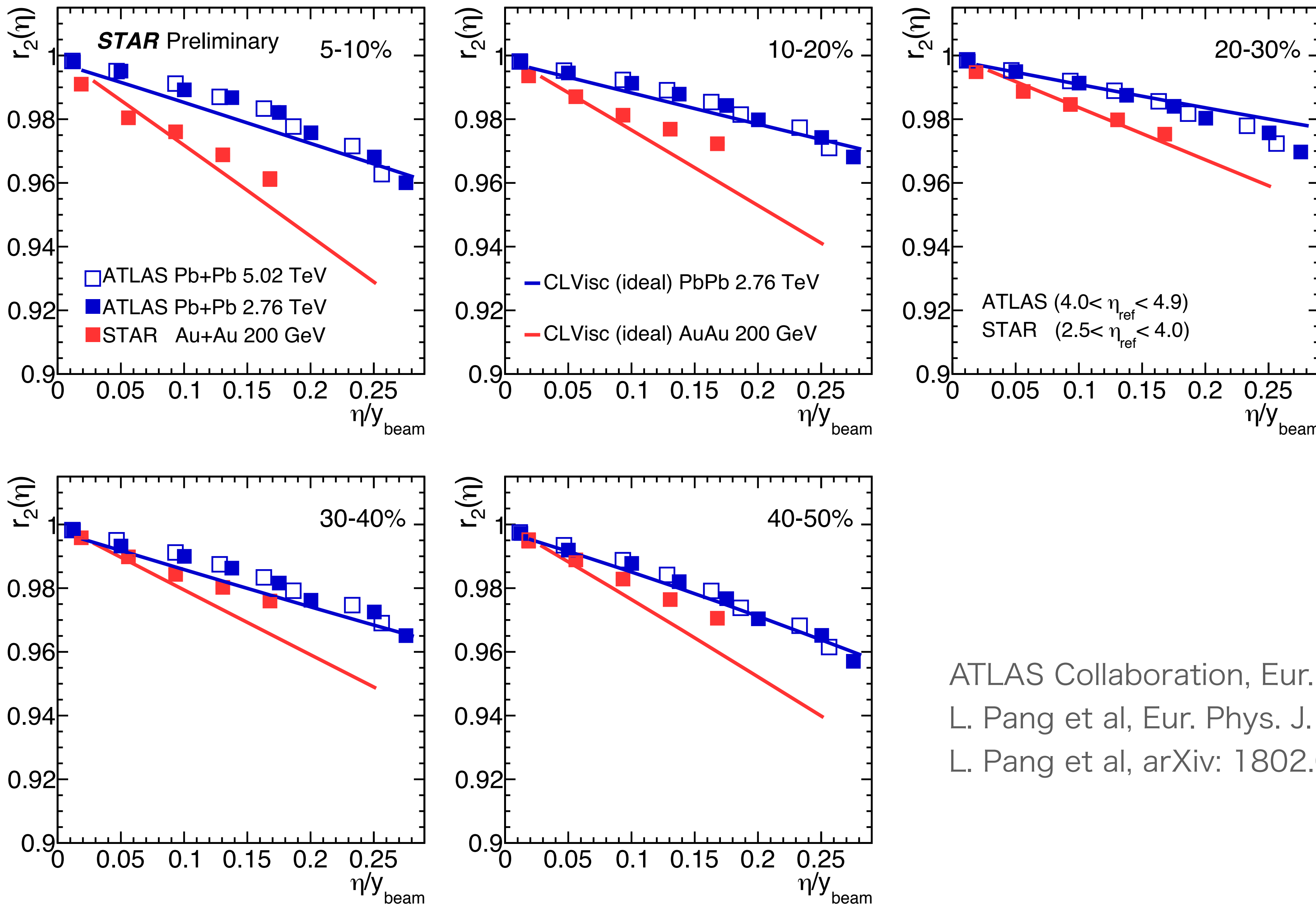

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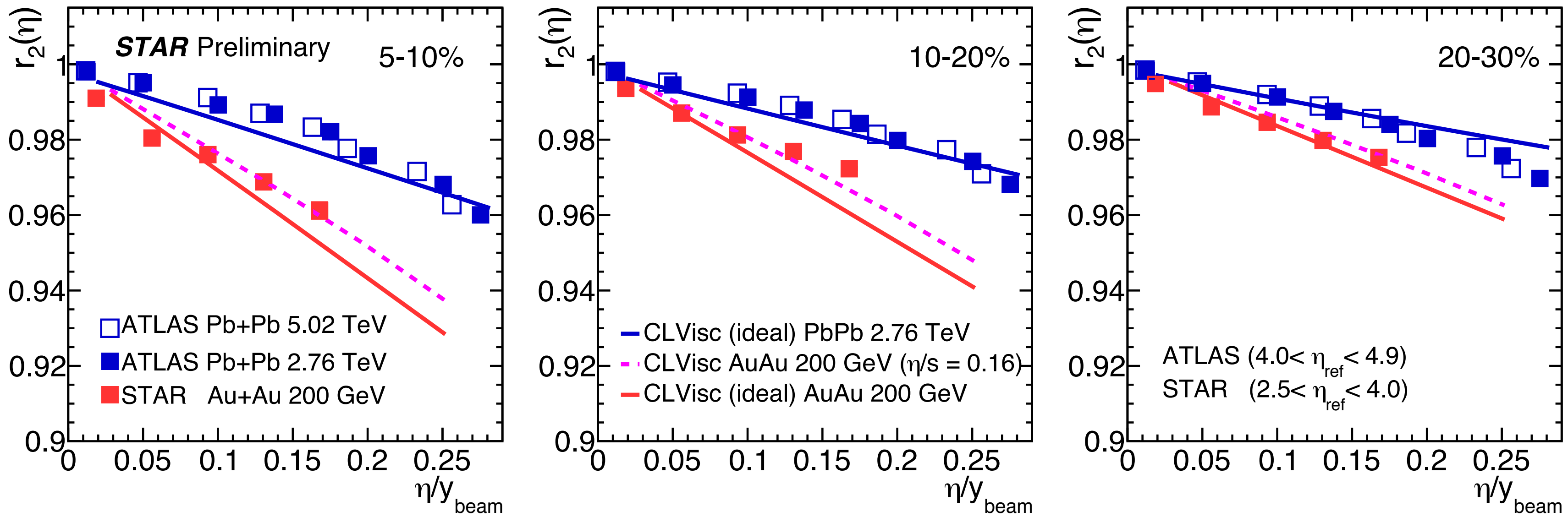

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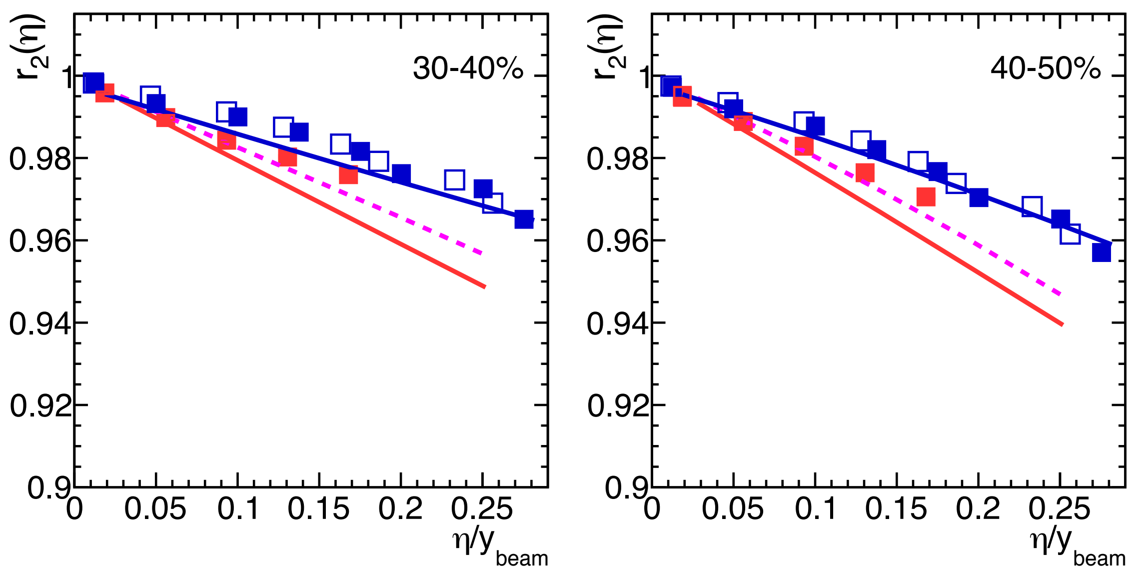

ATLAS Collaboration, Eur. Phys. J. C (2018) 78:142
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- Energy dependence remains after y_{beam} normalization, and changes with centrality.

  Non-trivial dynamics cannot be explained by simple beam rapidity scaling.

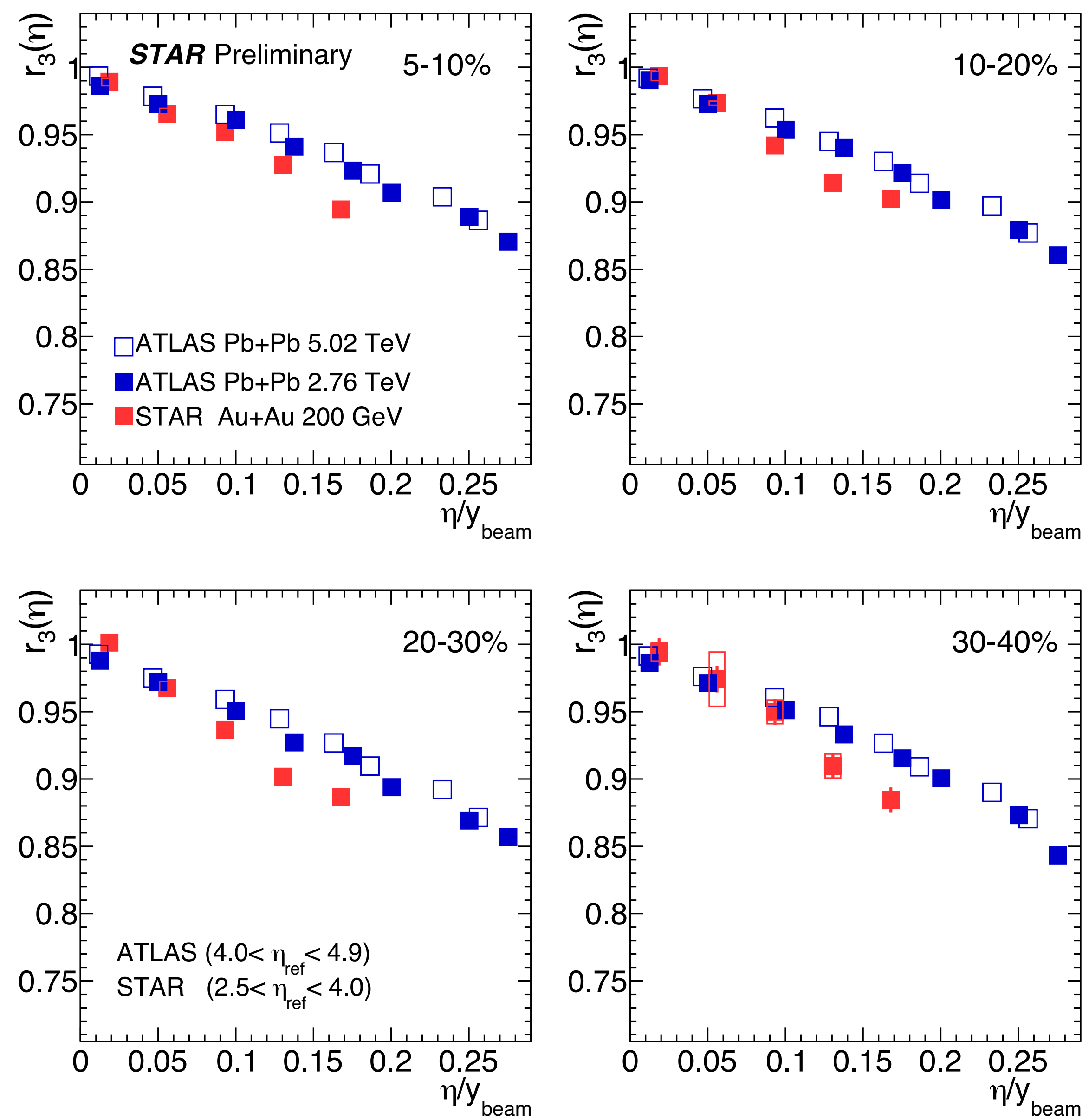
- Ideal hydro calculation can roughly describe the LHC data, but overestimates the decorrelation effect at RHIC.

- Including a viscosity correction can better describe the RHIC data.

Comparison to the LHC and model calculations

✦ r_3 as a function of scaled rapidity: η/y_{beam}

r_3

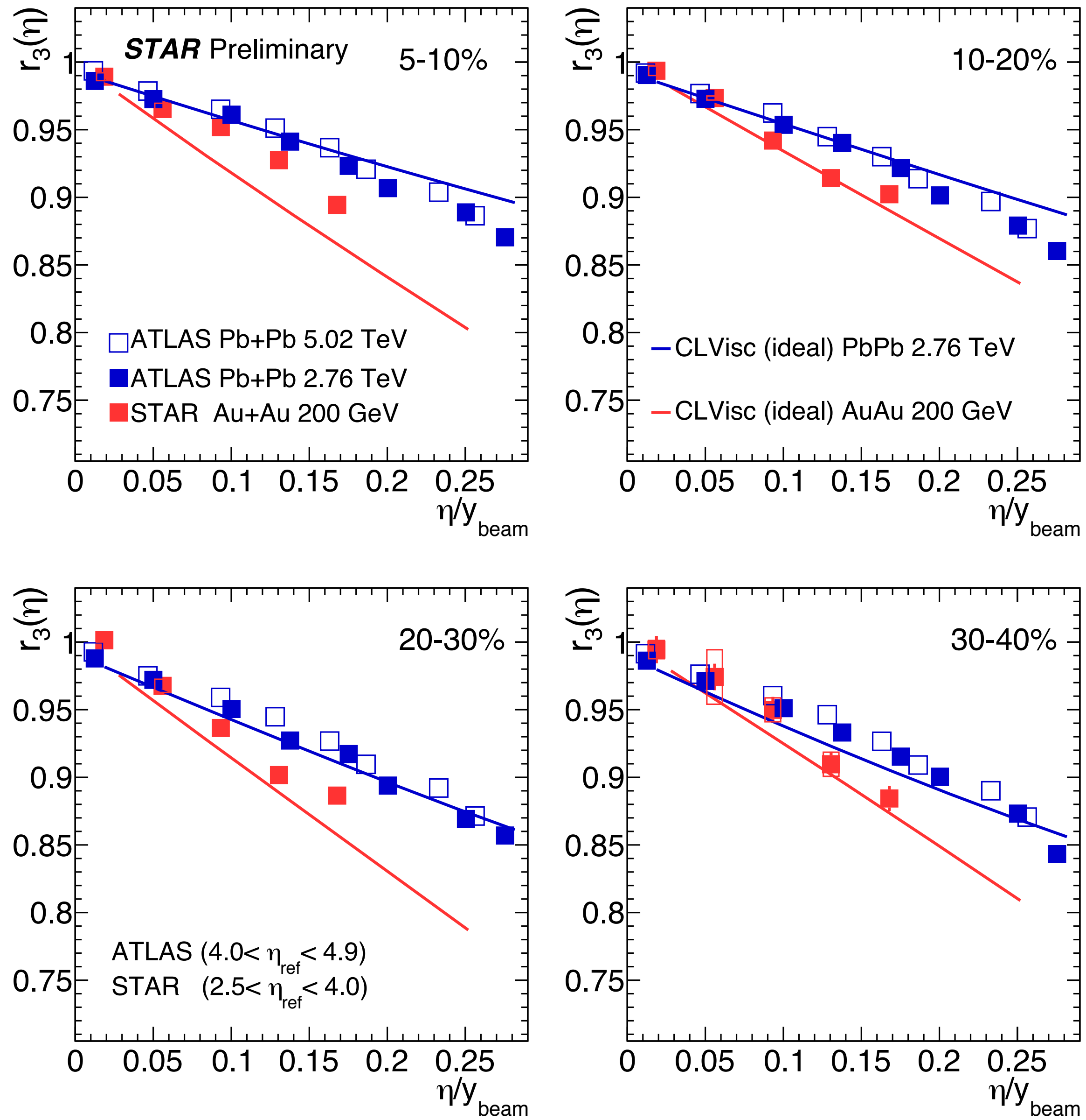


- Energy dependence remains after y_{beam} normalization, weak centrality changes.

Comparison to the LHC and model calculations

✦ r_3 as a function of scaled rapidity: η/y_{beam}

r_3



- Energy dependence remains after y_{beam} normalization, weak centrality changes.
- Ideal hydro still slightly overestimates the decorrelation effect at RHIC.

Comparison to the LHC and model calculations

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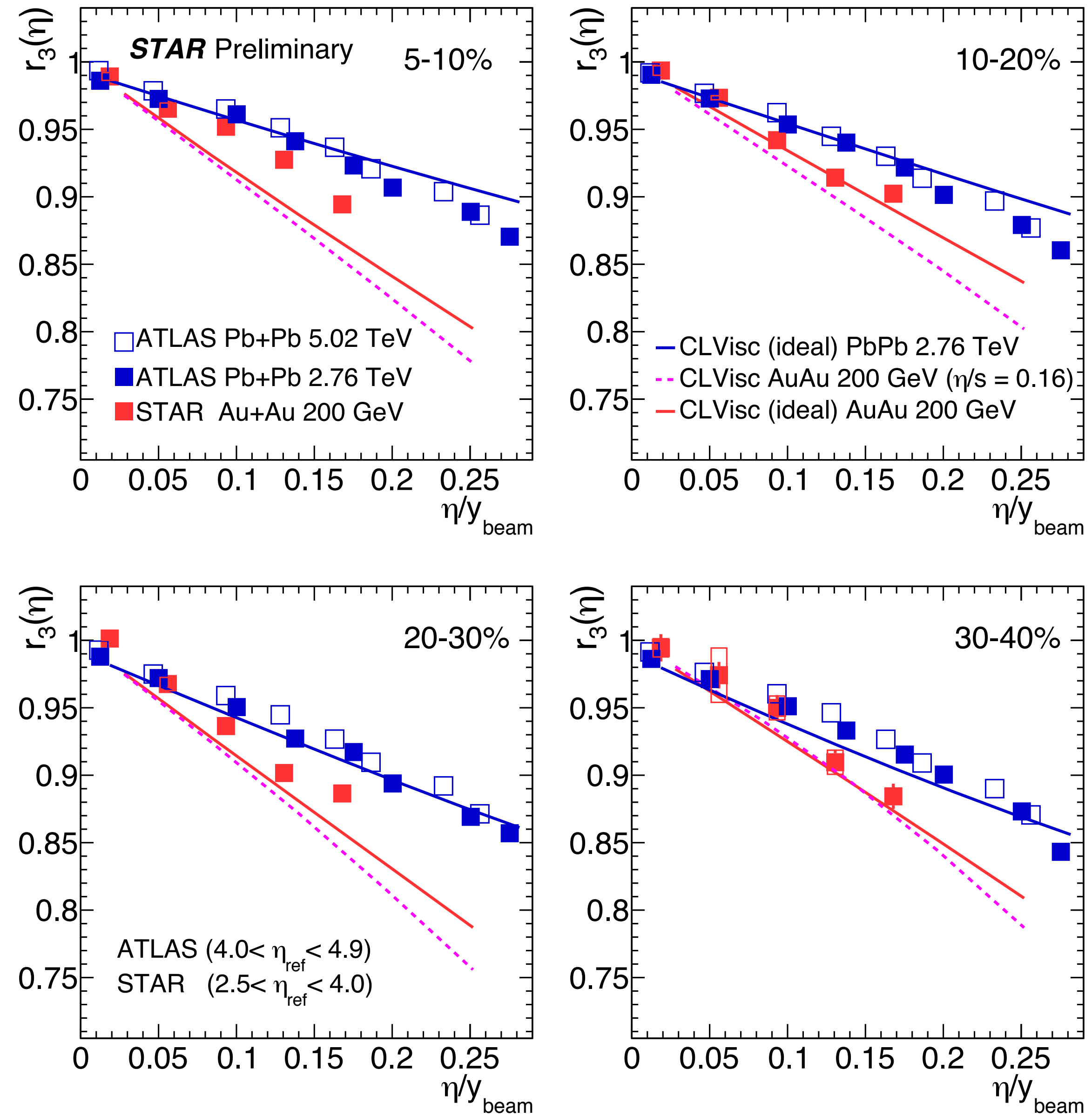
r_3

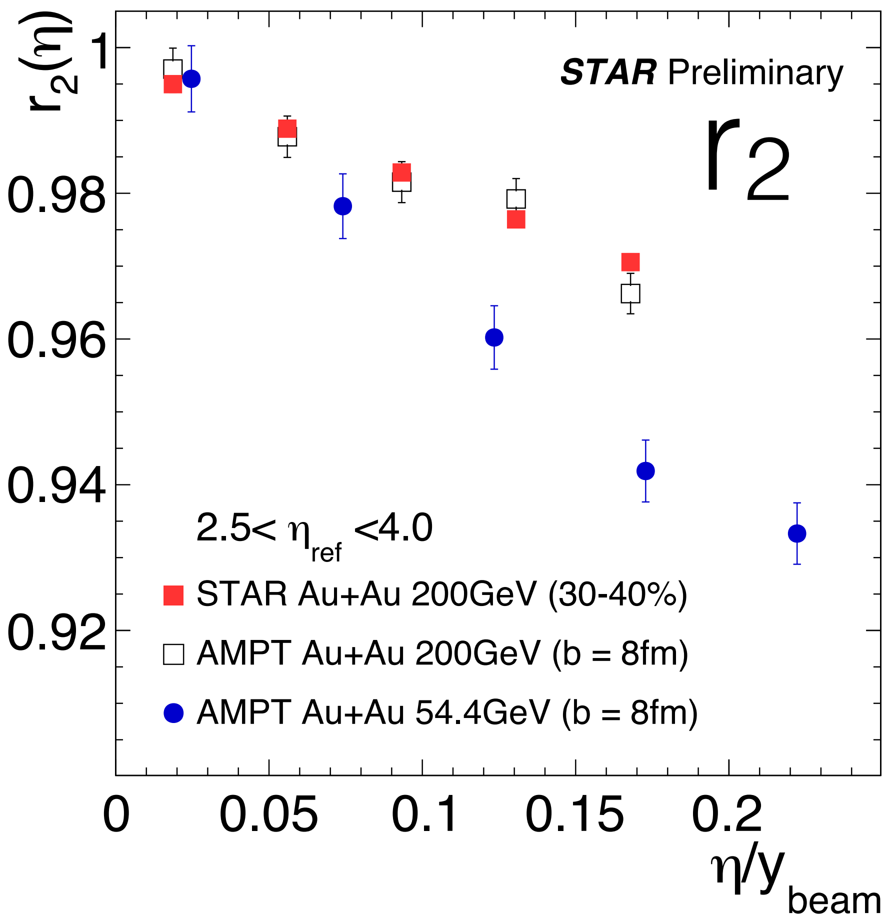


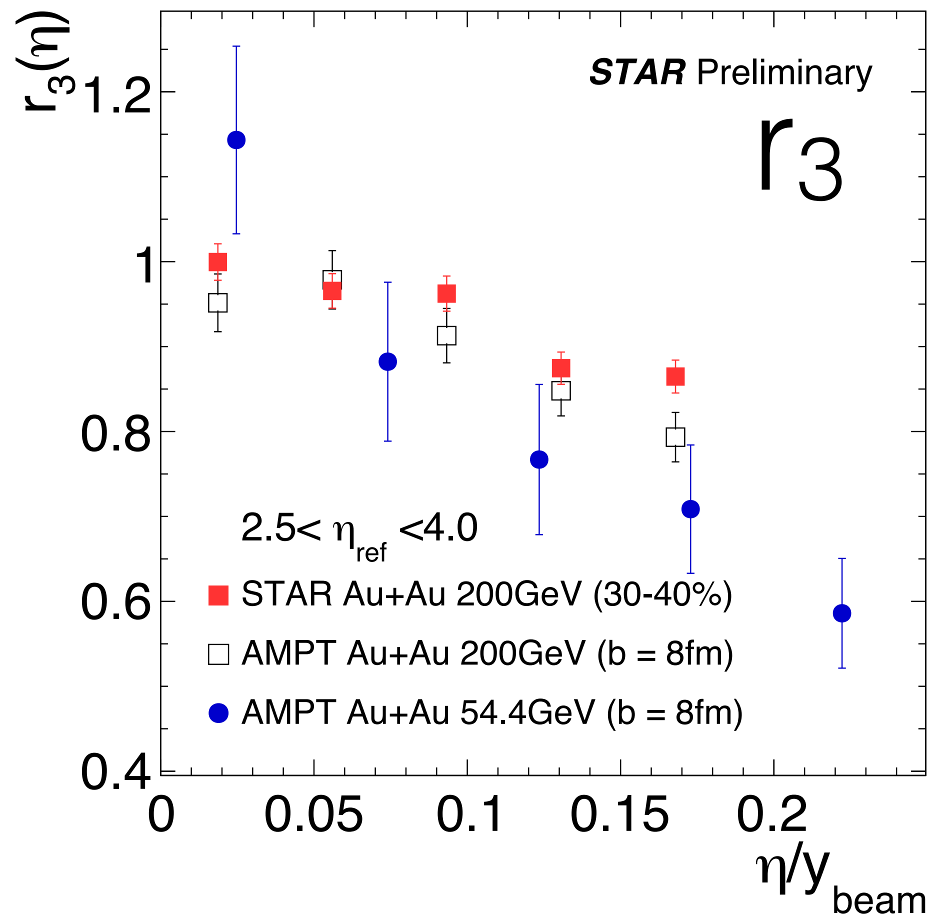
- Energy dependence remains after y_{beam} normalization, weak centrality changes.
- Ideal hydro still slightly overestimates the decorrelation effect at RHIC.
- Viscosity correction estimates an even stronger v_3 decorrelation.

What about decorrelation at even lower energy?

✦ Analysis of STAR data (2017 AuAu 54.4GeV data with ~800M min.bias events)

SM-AMPT parton-parton σ=3mb





- AMPT suggests even stronger decorrelation at lower energy.
- Future BES measurements will provide constraints on the initial and final conditions.

Summary

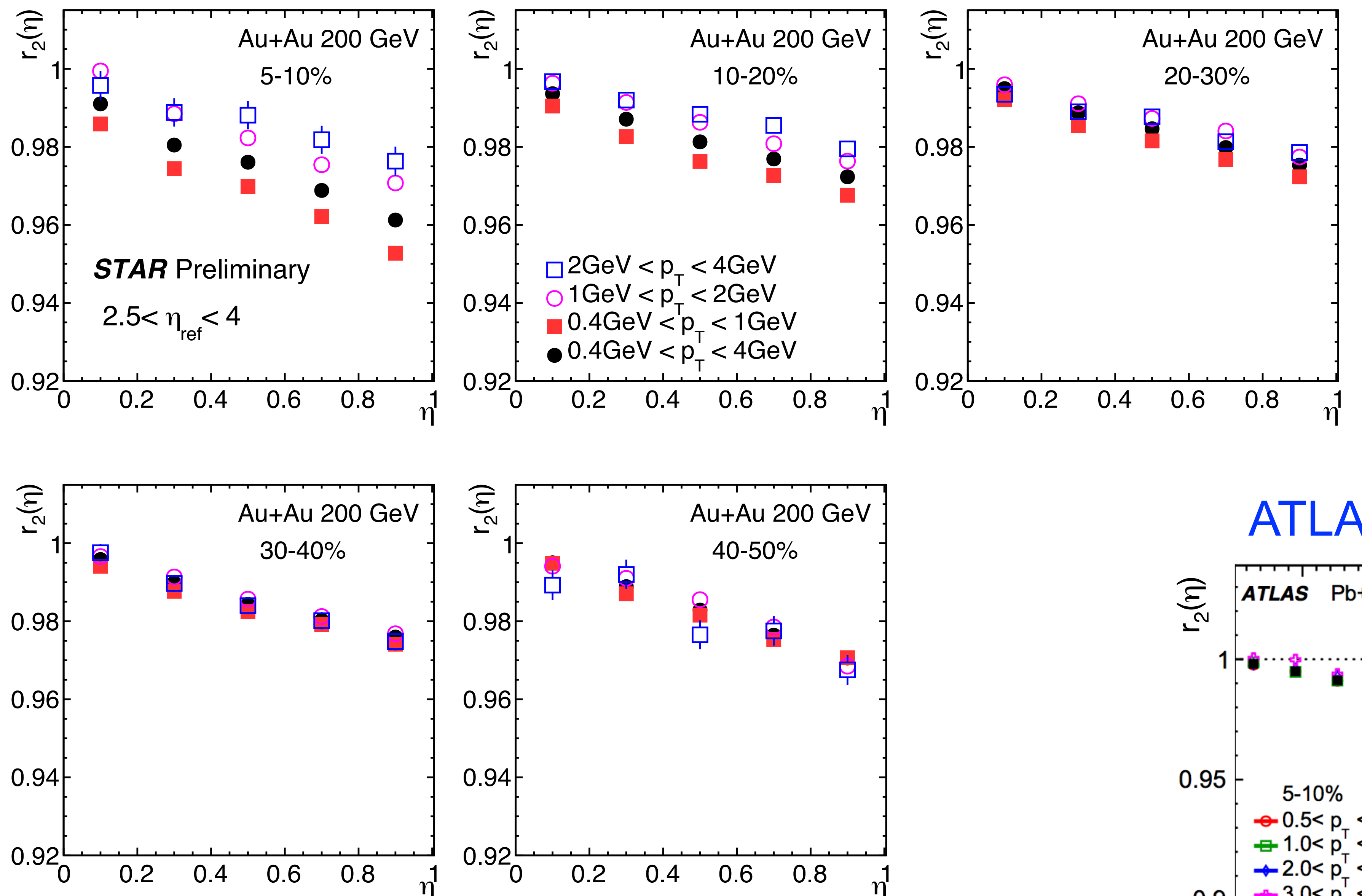
- First direct measurement of longitudinal flow decorrelation at RHIC.
  - r_2 shows non-monotonic centrality dependence; r_3 shows weak centrality dependence.
  - weak p_T dependence of v_n decorrelation suggests this is a global property of the events.
  - v_n decorrelation is η_{ref} independent.
- Decorrelation is ×2 stronger than at LHC energies, cannot be explained by simple beam rapidity scaling.
- Comparison with the (3+1)D hydro calculations:
  - Ideal hydro tuned to LHC data overestimates the decorrelation at RHIC.
  - The viscosity correction leads to a weaker decorrelation for v_2 and stronger decorrelation for v_3.
- The decorrelation measurements at even lower energies are necessary.
- The results provide new constraints on both the initial state geometry and final state dynamics of heavy-ion collisions.

Backup

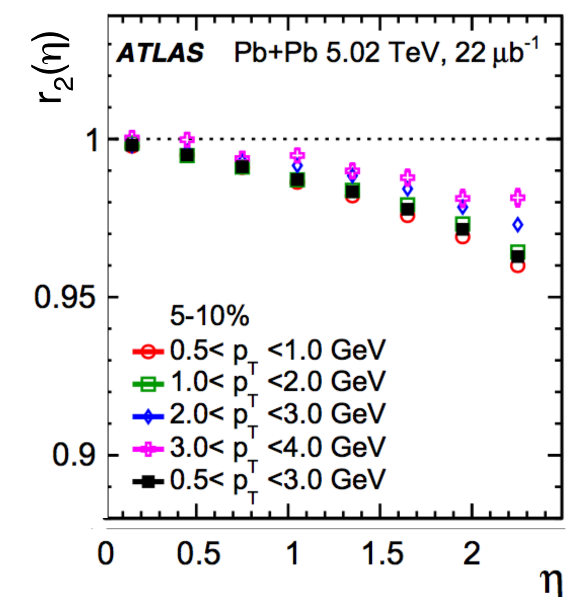
p_T dependence of r_2

✦ r_2 for different p_T ranges

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



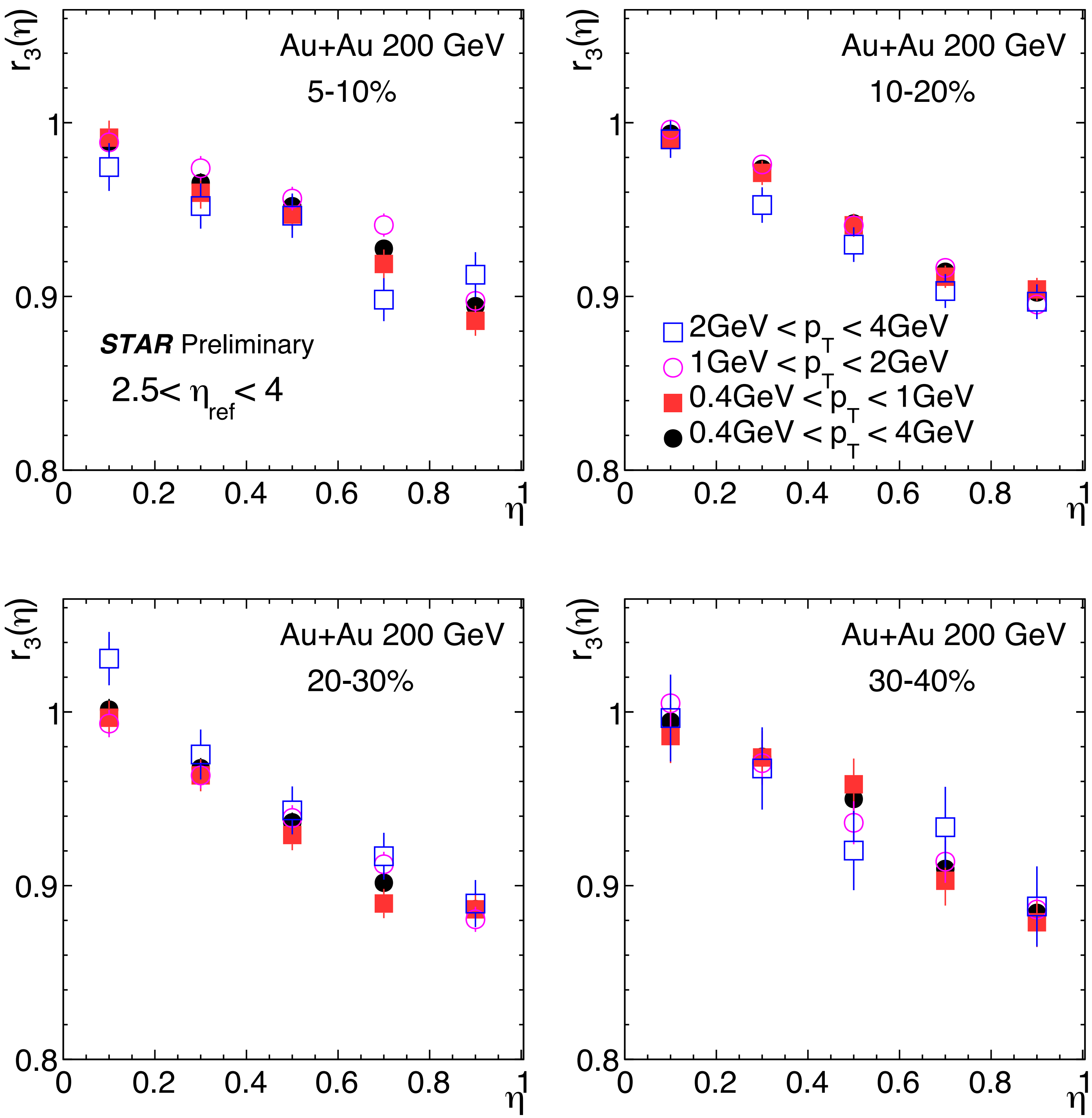
ATLAS results



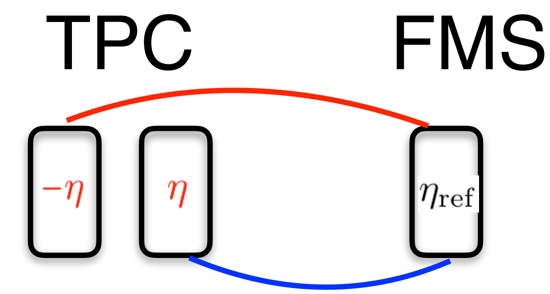
- A clear p_T dependence for central collisions.
- As centrality becomes more peripheral, r_2 becomes more p_T independent.
- Similar p_T dependence in central collisions is also observed at LHC energy.

p_T dependence of r_n

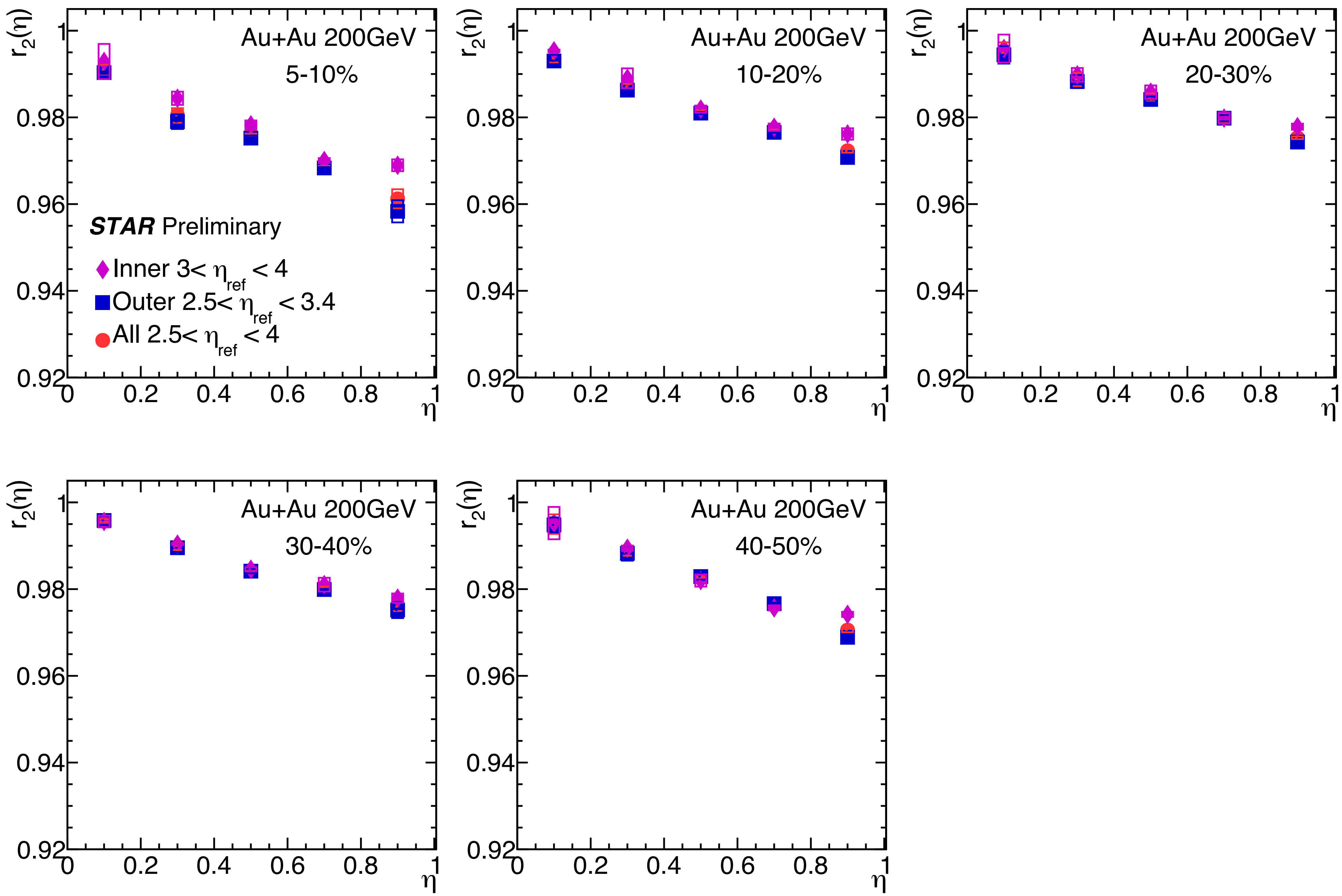
- r_3 for different p_T ranges



η_{ref} dependence of r_n



- ✦ r_2 for different η_{ref} ranges



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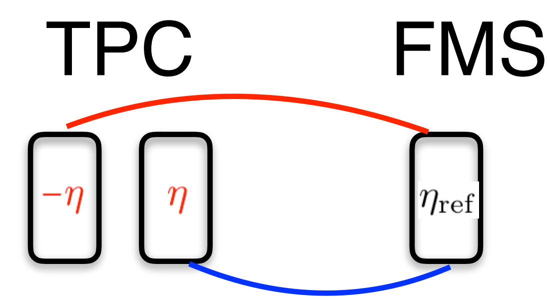
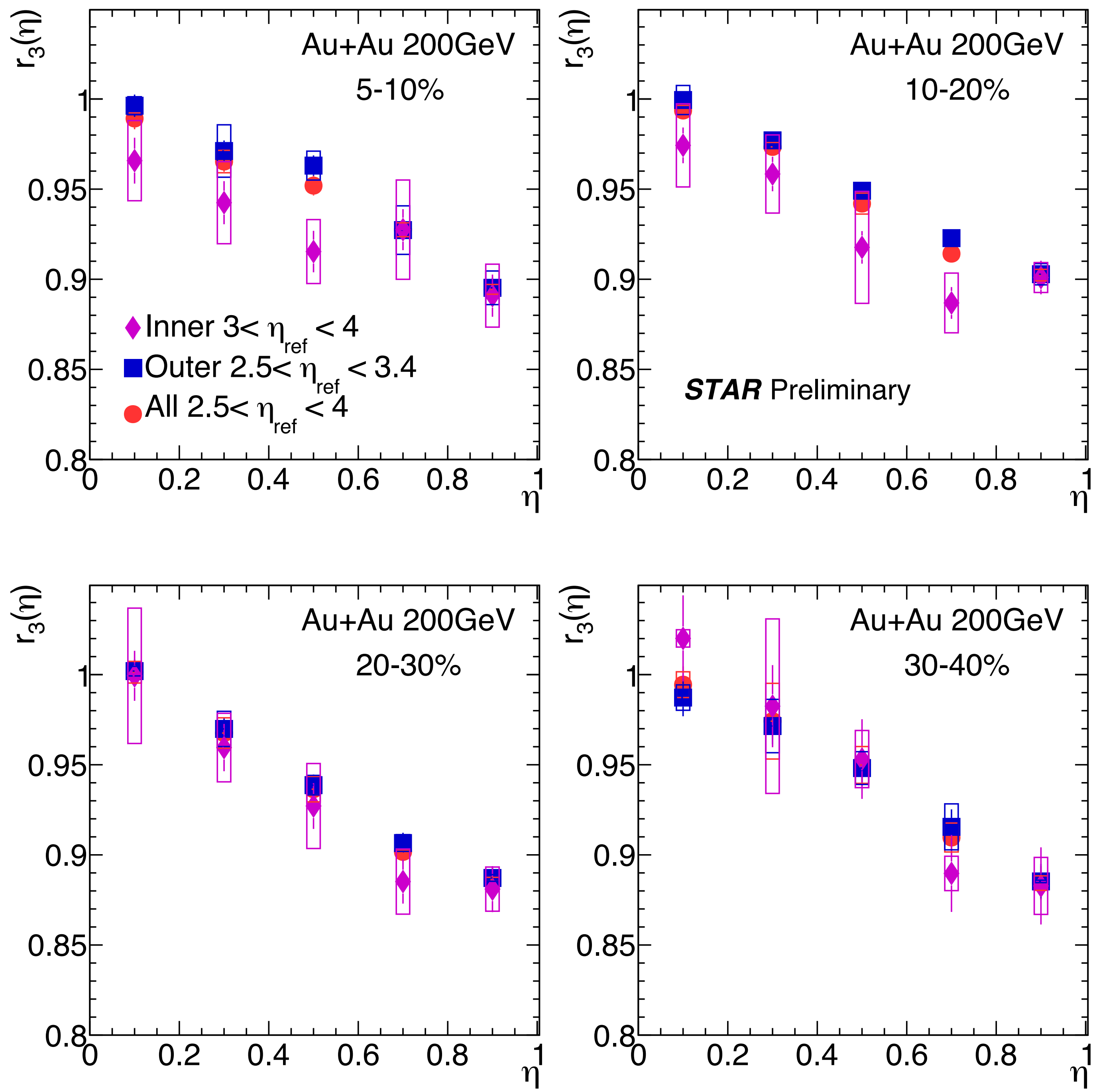


- r_3 for different η_{ref} ranges

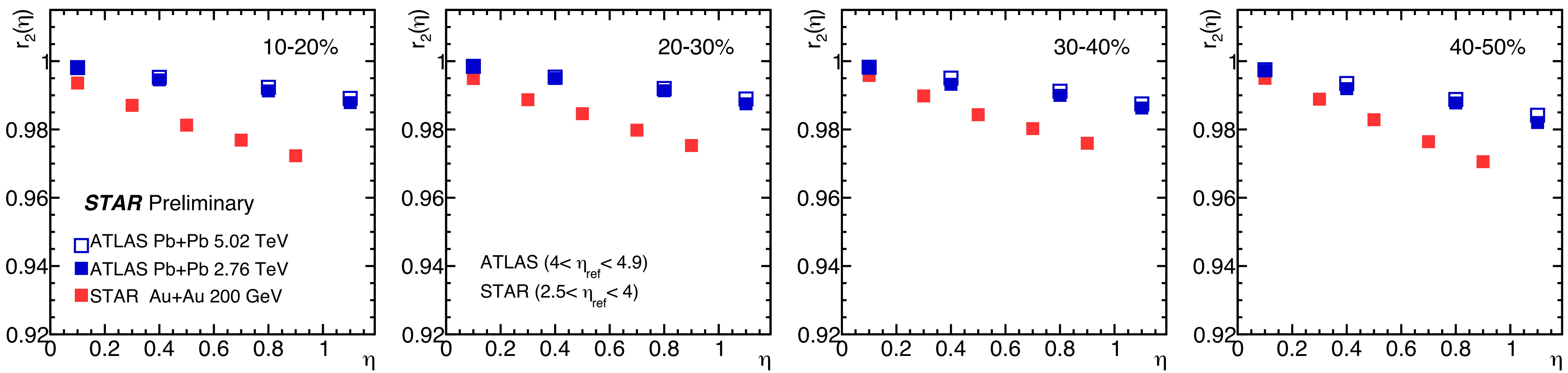


- For longitudinal correlations, r_3 shows weak η_{ref} dependence.

Comparison to the LHC results

✦ Decorrelation of $v_2(\eta)$

$$r_n = 1 - 2F_n\eta$$



	10-20%	20-30%	30-40%	40-50%
F_2(Au+Au 200 GeV)	0.017 ± 0.00022	0.014 ± 0.00021	0.014 ± 0.00027	0.017 ± 0.00045
F_2(Pb+Pb 2.76 TeV)	0.0065 ± 0.00010	0.0062 ± 0.00001	0.0072 ± 0.0001	0.0090 ± 0.00013
$\frac{F_2(Au+Au)}{F_2(Pb+Pb)}$	2.58 ± 0.021	2.33 ± 0.021	1.97 ± 0.024	1.86 ± 0.03

- Clearly energy dependence is observed.
- 5.02 TeV ⟶ 2.76 TeV ⟶ 200 GeV, decorrelation for v_2 gets stronger.
- ~2 times stronger decorrelation effect than at the LHC energy 2.76 TeV.