



Overview of STAR Light Ion Results

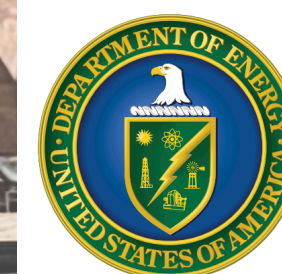
Sijie Zhang (张思婕) for the STAR Collaboration

Yale University

EMMI Workshop: Light-Ion Collisions 2026

Sep 21, 2026

Supported in part by



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Office of
Science

Independent Probes of Light Ion Collisions at STAR



1

→ Chunjian, Wed 11:30

Collectivity & Nuclear Structure

Anisotropic flow (v_2, v_3); $v_n - [p_T]$ correlations

2

→ Chunjian, Wed 11:30

Radial Flow & Mass Ordering

$v_0(p_T)$ fluctuations; mass-ordered across species

3

Medium Temperature

e^+e^- invariant-mass spectrum → extracted T

4

Strangeness Production

$\Lambda, \phi, \Xi, \Omega$ yields; Ω/ϕ as a coalescence probe

5

Jet Quenching

hadron-hadron and hadron-jet correlations

6

Quarkonium Suppression

J/ψ R_{AA} — hot vs. cold matter effects

Solenoidal Tracker at RHIC (STAR)

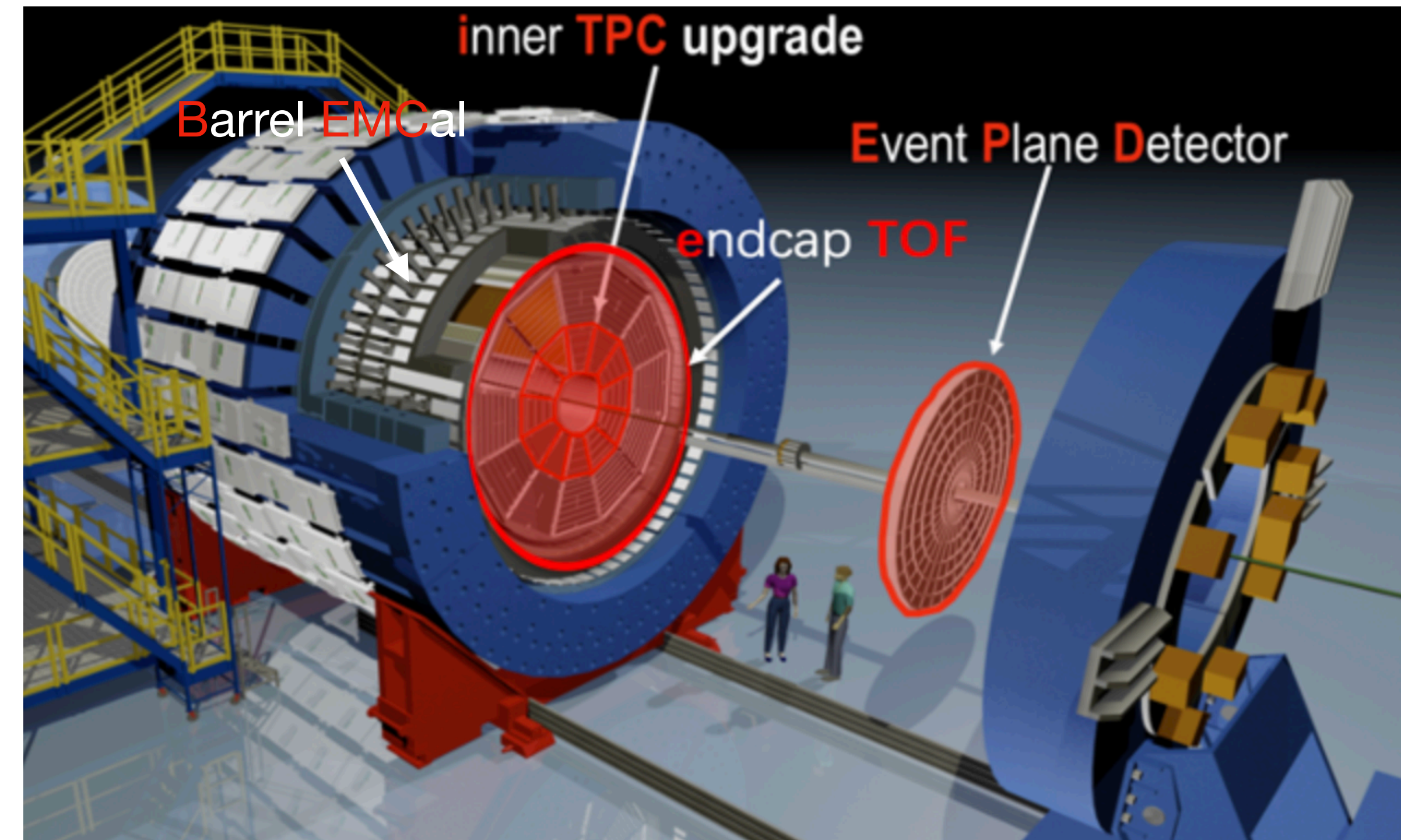


O+O $\sqrt{s_{NN}} = 200$ GeV

2021: ~ 500 M events

(2026: ~ 745 M events to be analyzed)

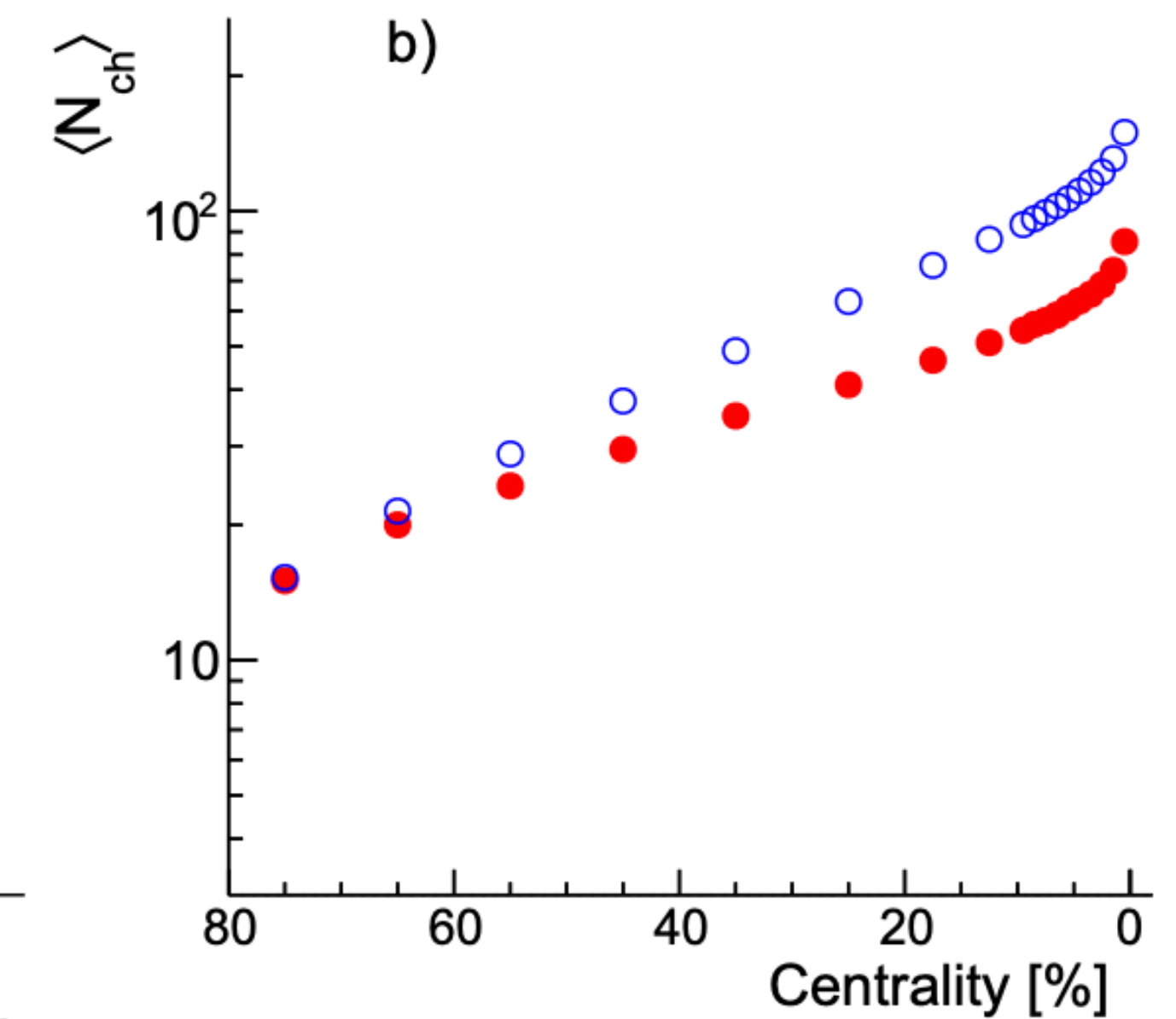
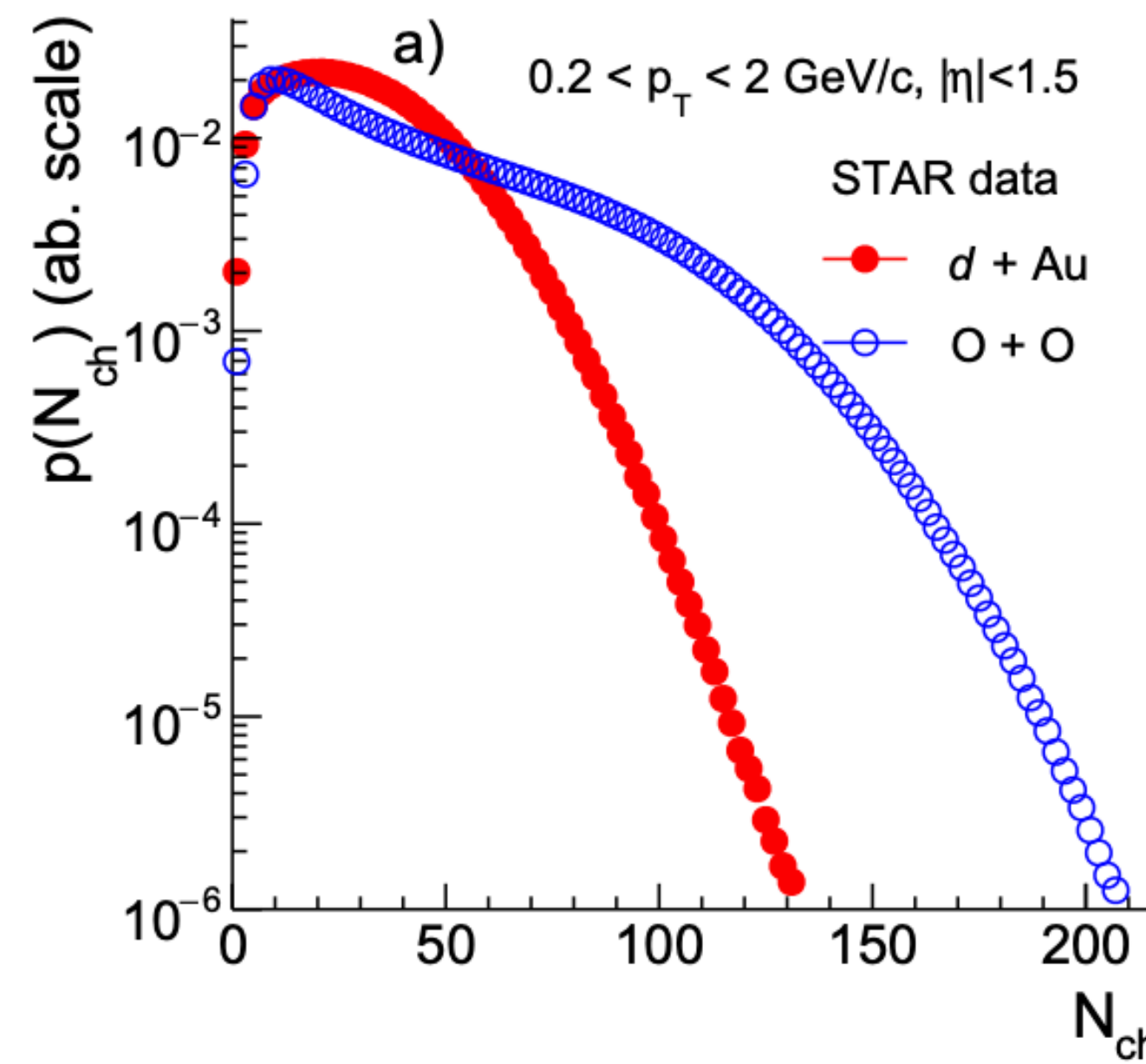
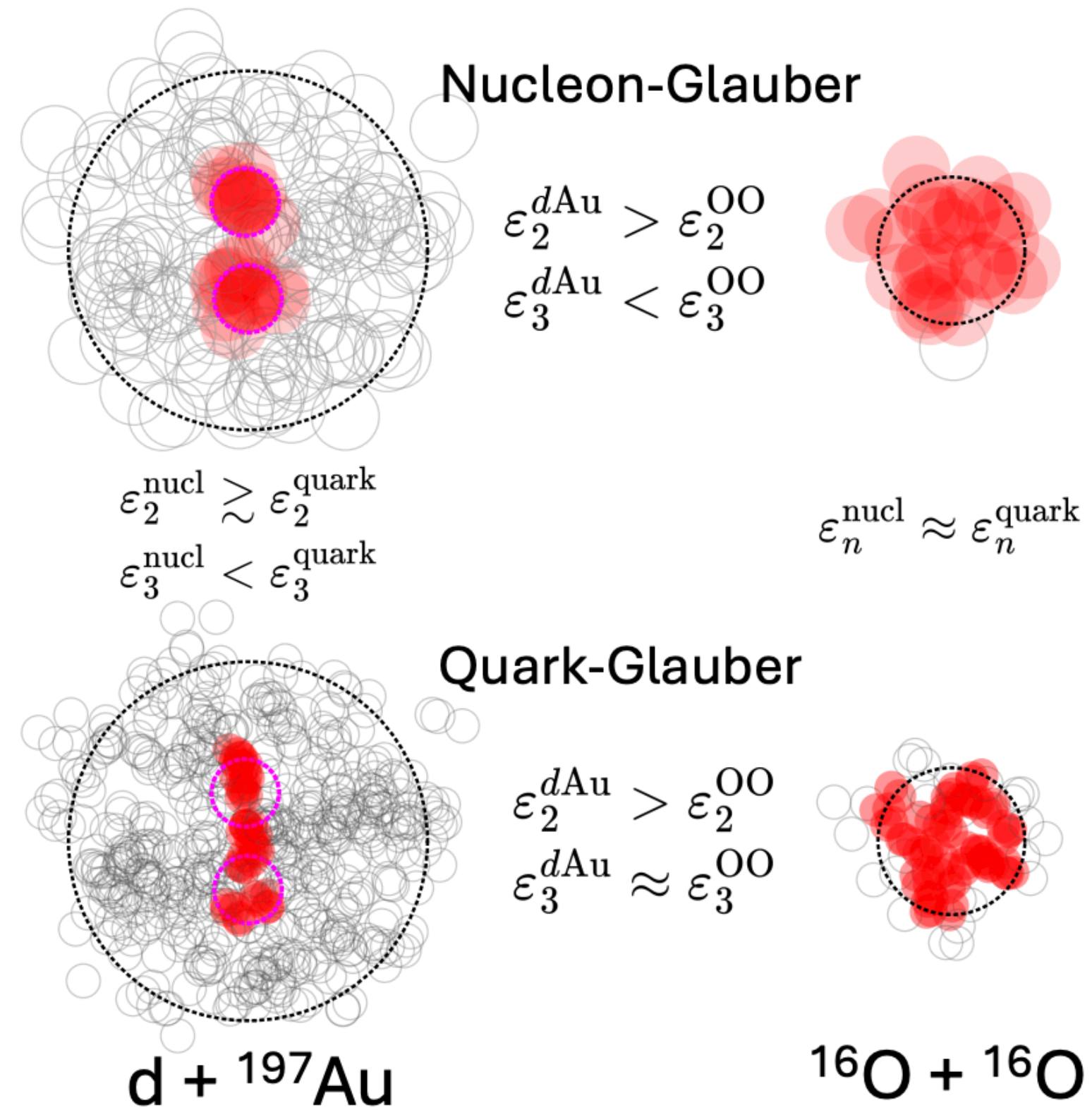
- **T**ime **P**rojection **C**hamber (iTTPC)
 $|\eta| < 1.5$
- **e**ndcap **T**ime **o**f **F**light (eTOF)
 $|\eta| < 1.0$
- **E**vent **P**lane **D**etector (EPD)
 $2.1 < |\eta| < 5.1$
- **B**arrel **E**lectromagnetic **C**alorimeter (BEMC)
 $|\eta| < 1.0$



Benefiting from the improved performance after the BES II upgrade

Flow: d+Au vs O+O

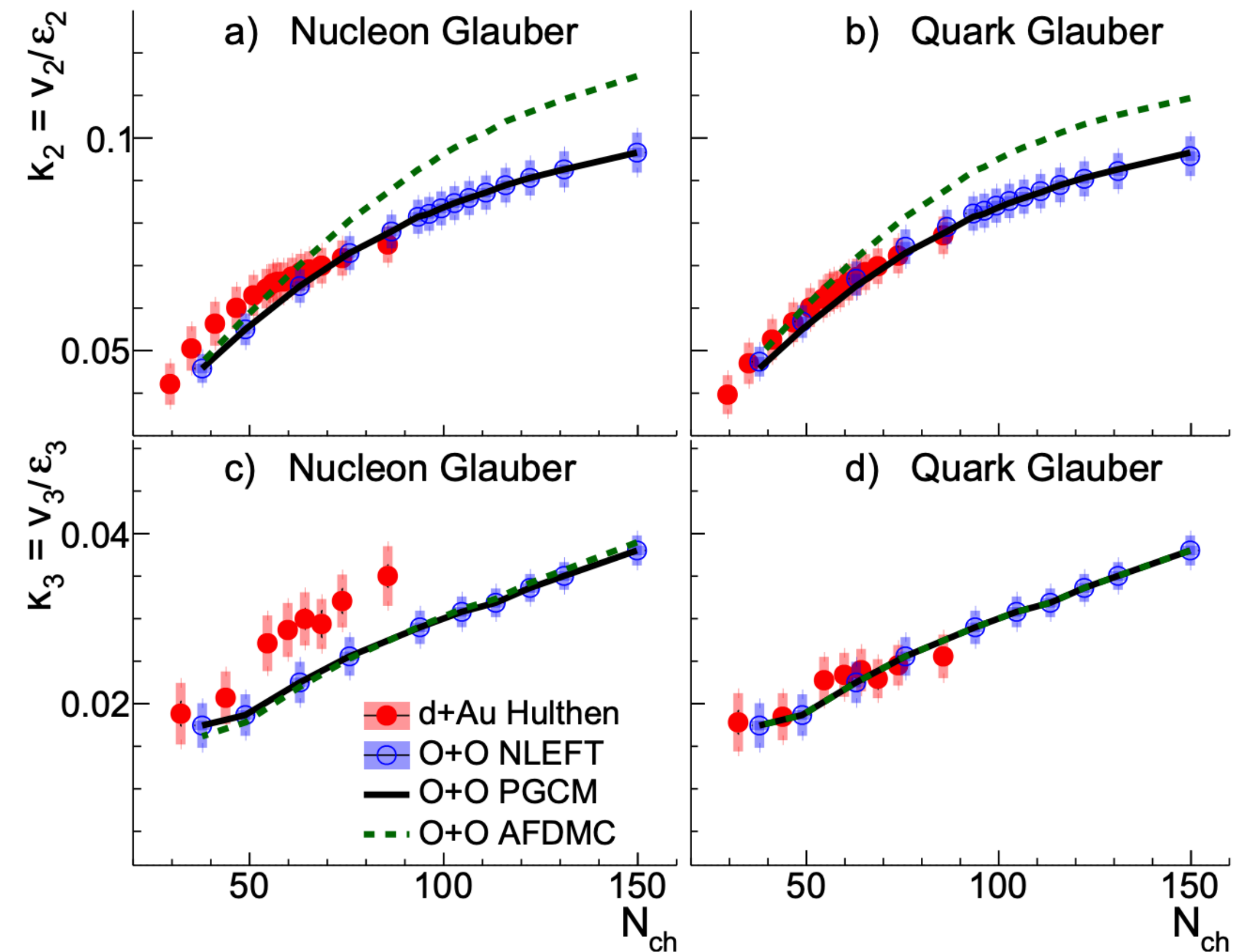
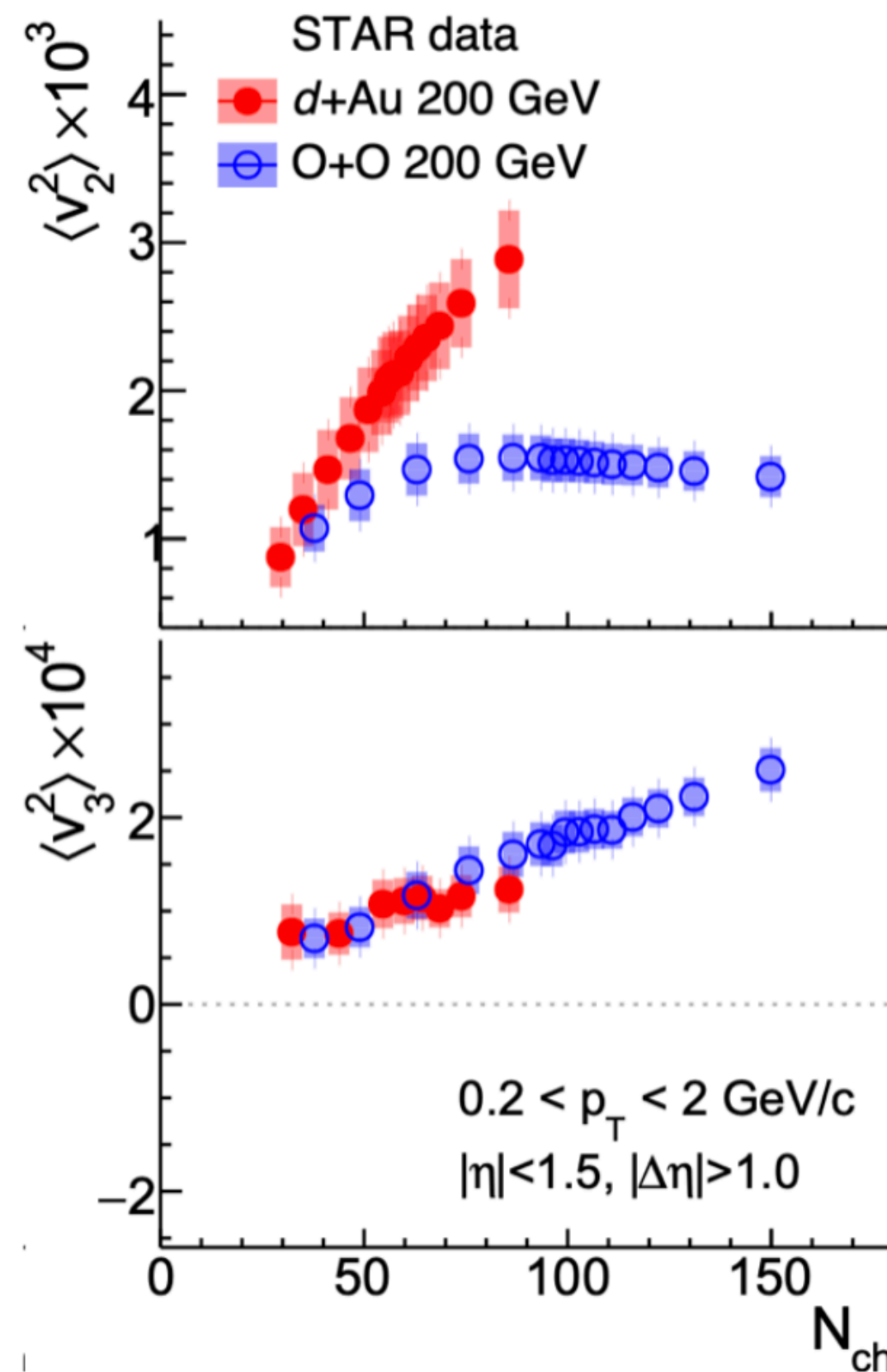
- Compare symmetric O+O with asymmetric d+Au at the same $\sqrt{s_{NN}} = 200$ GeV
- Comparable medium size, very different initial geometry



Flow: d+Au vs O+O

- v_2^2 : larger in d+Au → *elliptic shape*
- v_3^2 : Consistent between d+Au and O+O
→ *fluctuation-driven origin*

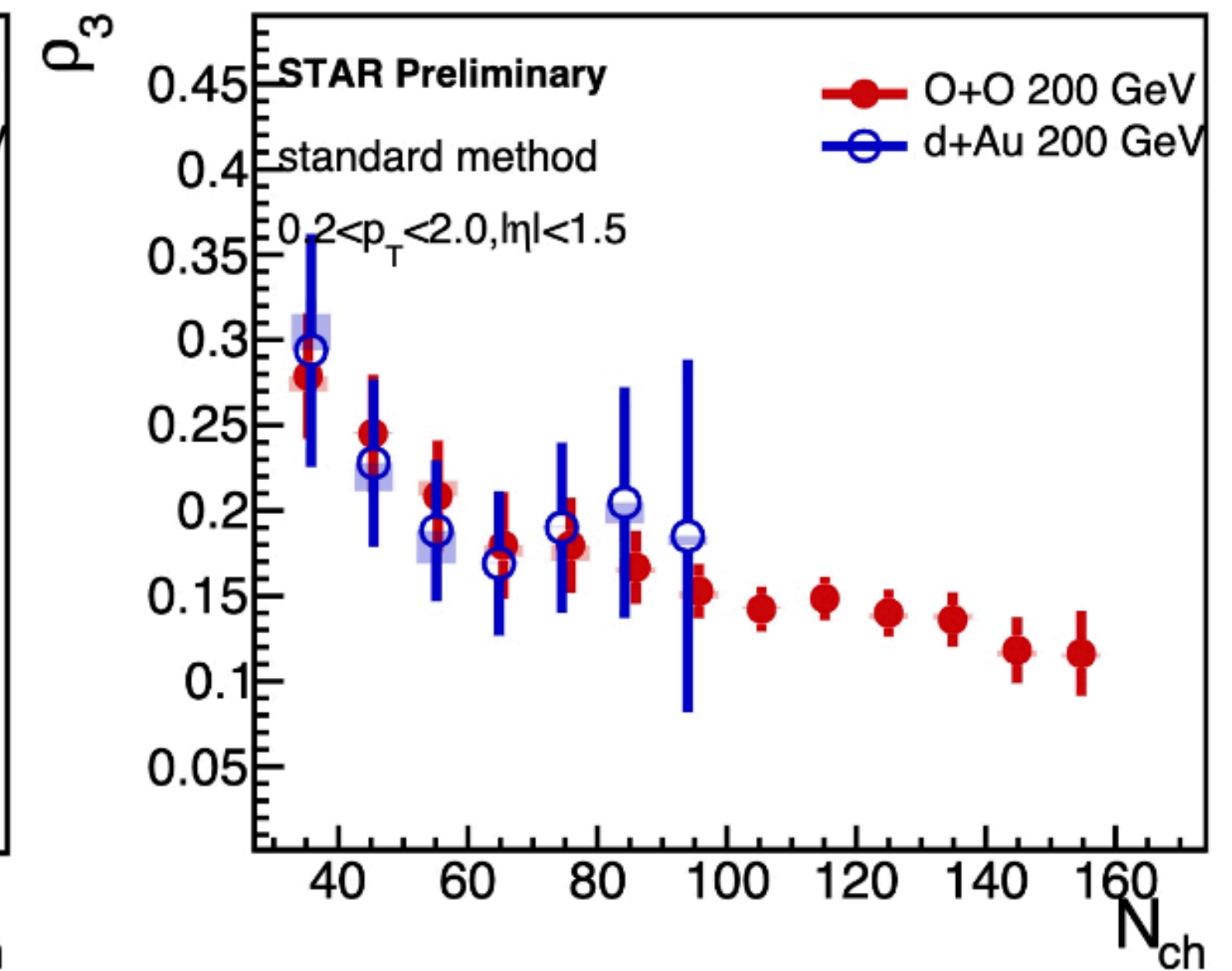
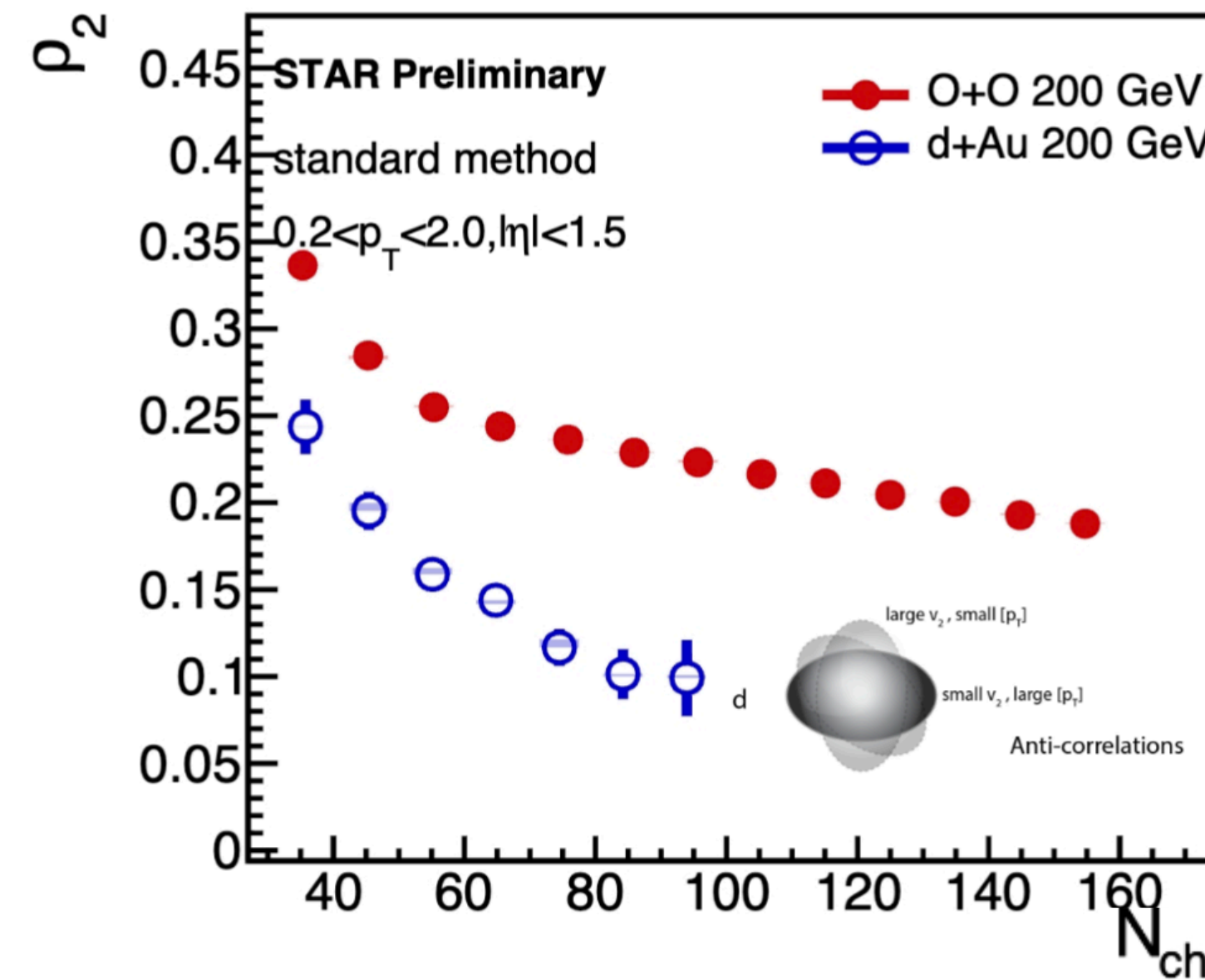
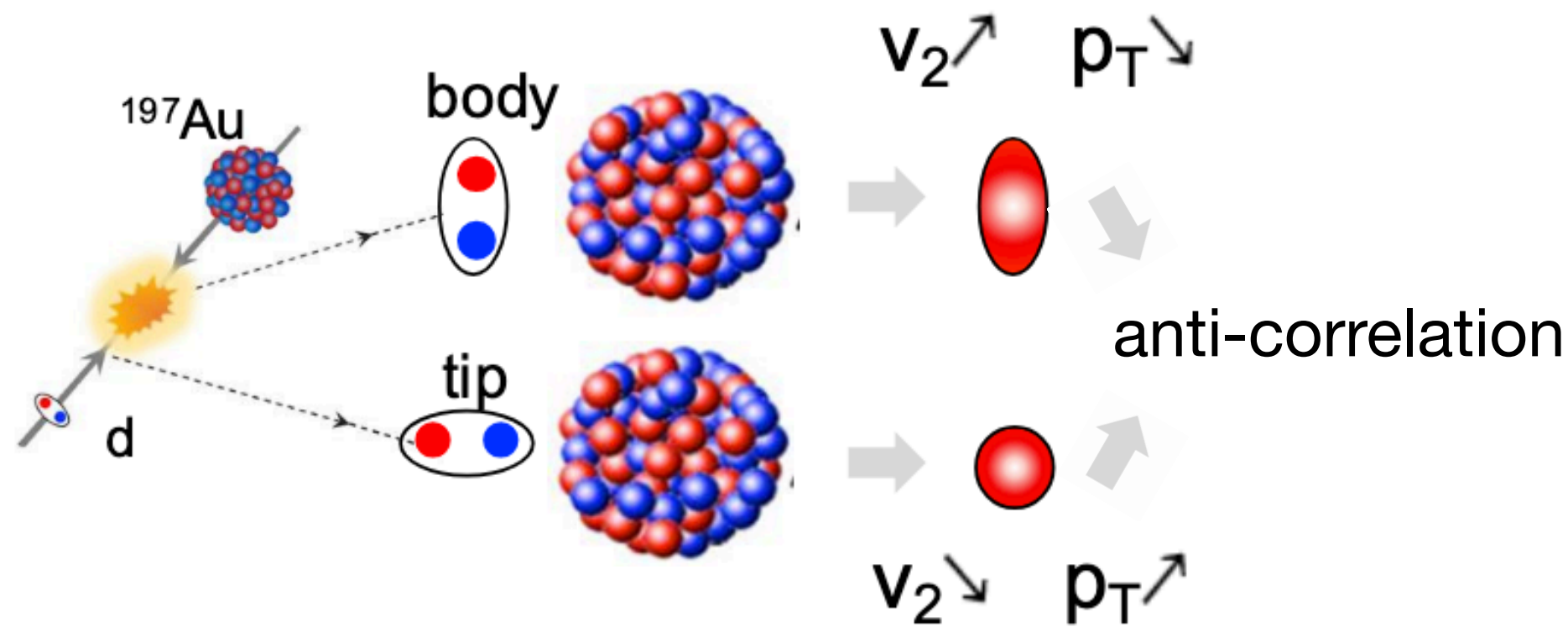
- Scale by eccentricity to disentangle nucleon and subnucleonic fluctuations
→ *subnucleonic fluctuations show better scaling*



Nuclear Structure

Probe nuclear structure through v_n - p_T correlations in d+Au and O+O collisions

$$\rho_n = \frac{\langle v_n^2 \delta[p_T] \rangle}{\langle v_n^2 \rangle \sigma[p_T]}$$



- v_2 - p_T : Significantly weaker correlations in d+Au than in O+O
- v_3 - p_T : Weaker system dependence → **consistent with fluctuation-driven triangular flow**
- Future model studies to explore nuclear structure effects in O+O collisions and their implications for collective flow and collision geometry



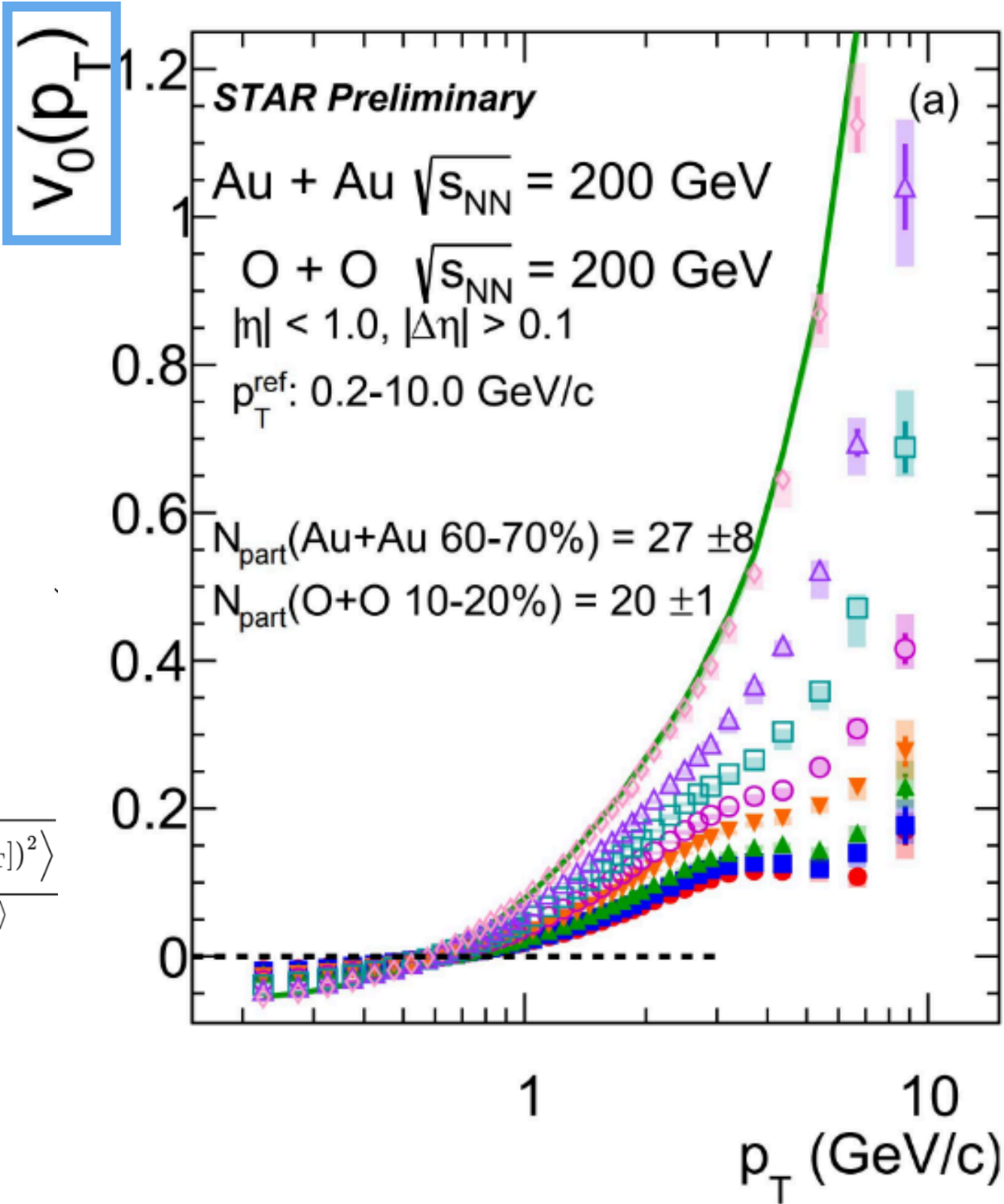
Radial Flow

New observable probes the p_T -differential radial flow fluctuation:

$$v_0(p_T) = \frac{\langle \delta n(p_T) \delta [p_T] \rangle}{\langle n(p_T) \rangle \langle [p_T] \rangle} \times \frac{1}{v_{0,int}}$$

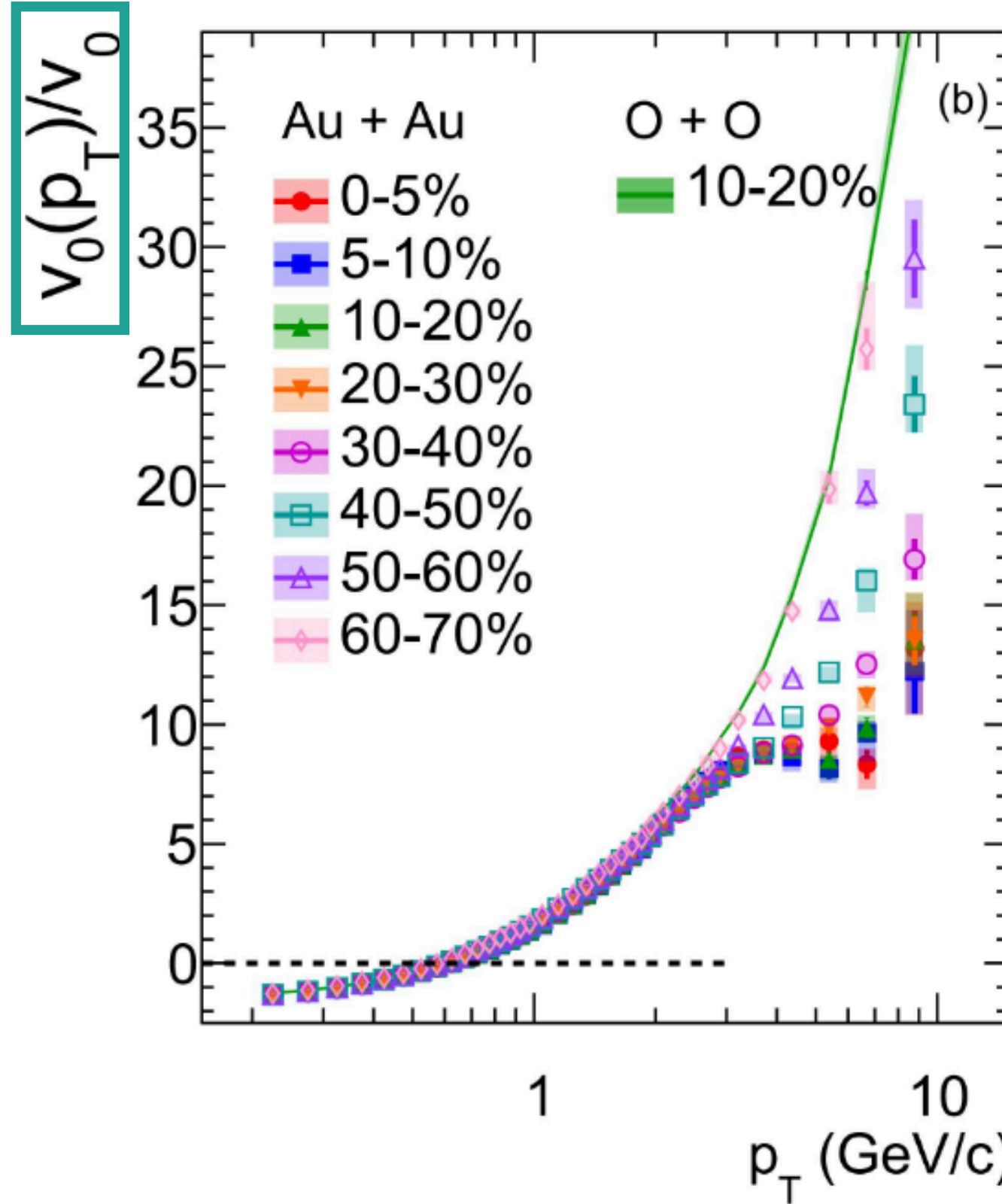
Normalized Covariance between local particle yield and mean p_T

$$v_{0,int} \equiv \frac{\sqrt{\langle (\delta [p_T])^2 \rangle}}{\langle [p_T] \rangle}$$



Strong centrality dependence

→ radial flow fluctuations driven by system-size



Collapses onto a coherent and universal curve

→ the hydrodynamic response $\frac{\kappa_0(p_T)}{\kappa_0}$ is independent of system-size

Hydrodynamic linear response assumption used to cancel the system-size dependence:

Hydrodynamic linear response:

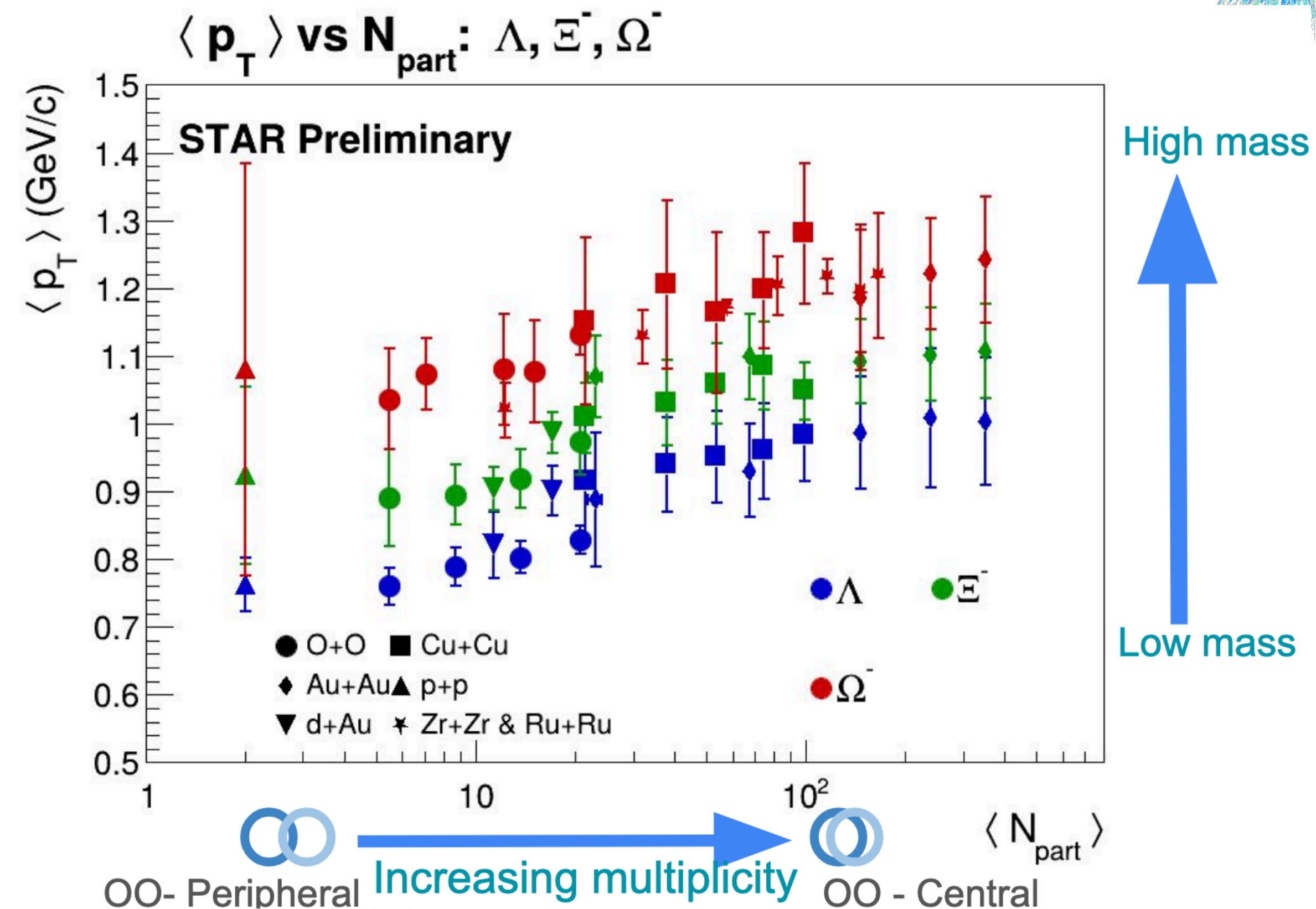
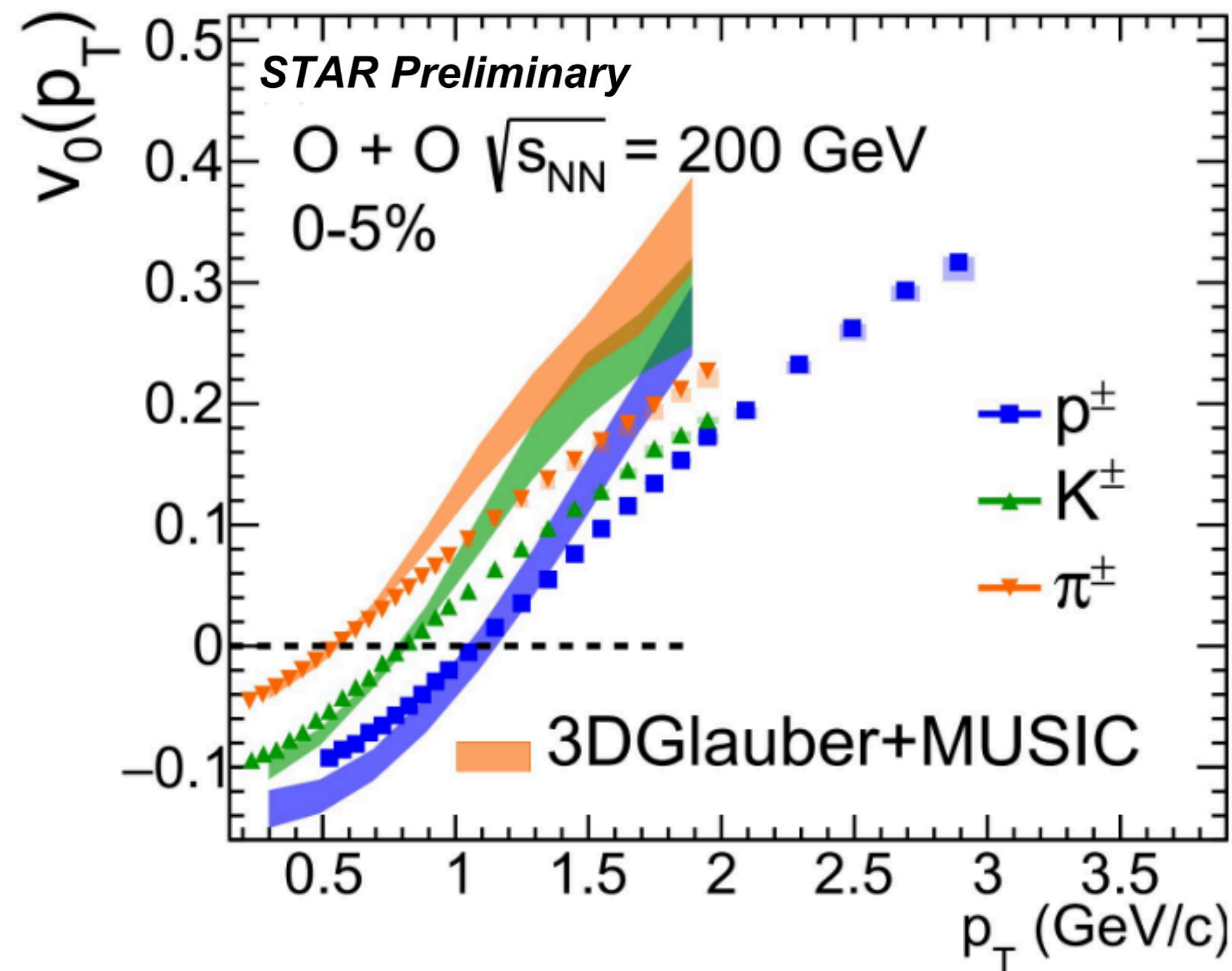
$$\frac{\delta [p_T]}{\langle [p_T] \rangle} = \kappa_0 \left(-\frac{\delta R}{R} \right)$$

Response coefficient (Size-independent)
Initial size (size-dependent)

$$v_0(p_T) = \kappa_0(p_T) \left(-\frac{\delta R}{R} \right)$$
$$v_0 = \kappa_0 \left(-\frac{\delta R}{R} \right)$$
$$\frac{v_0(p_T)}{v_0} = \frac{\kappa_0(p_T)}{\kappa_0}$$

Particle Mass Ordering

Model calculations taken from:
Syed Afrid Jahan, Hendrik Roch, Chun Shen,
Phys.Rev.C 113 (2026) 2, 024919



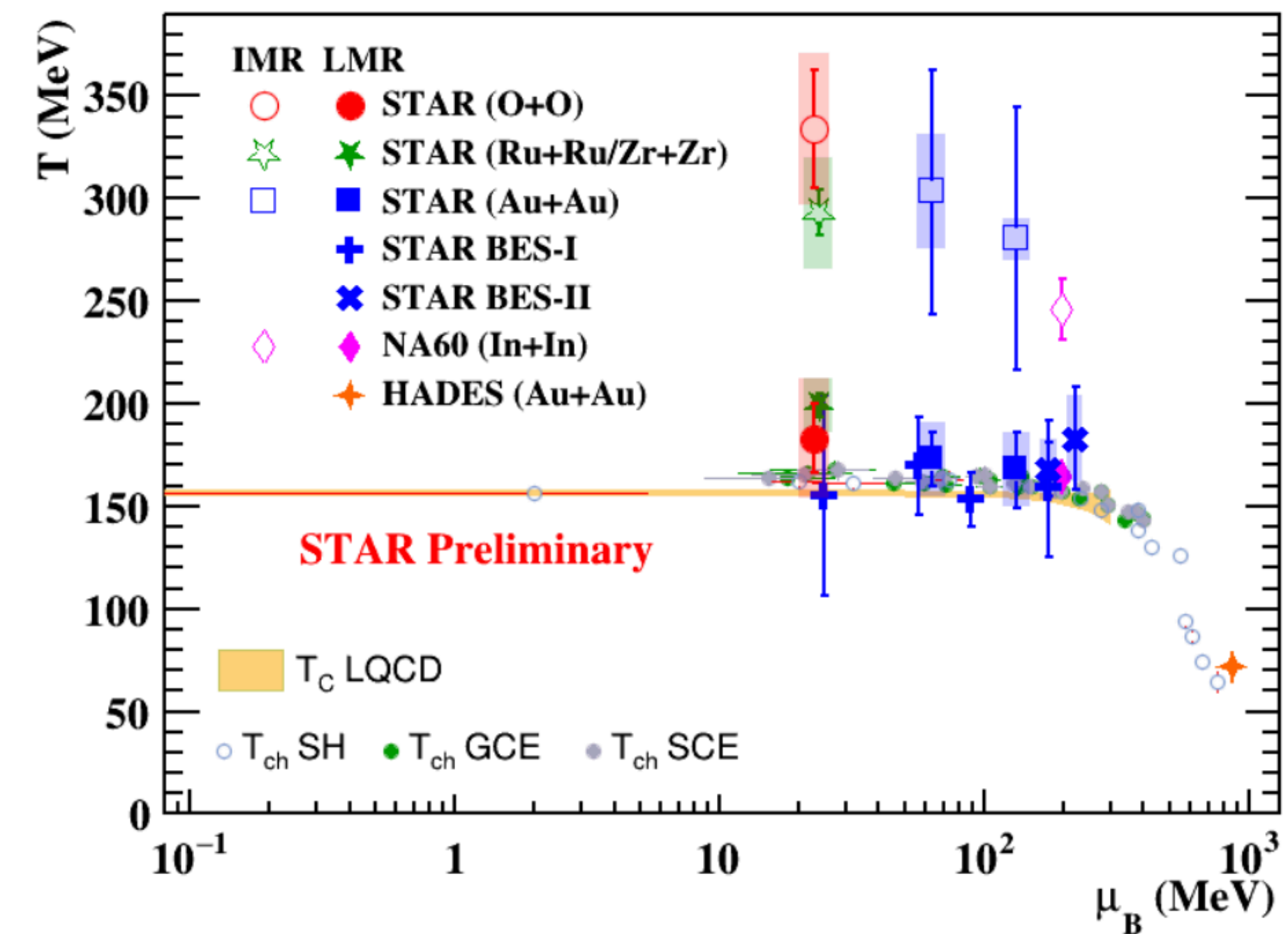
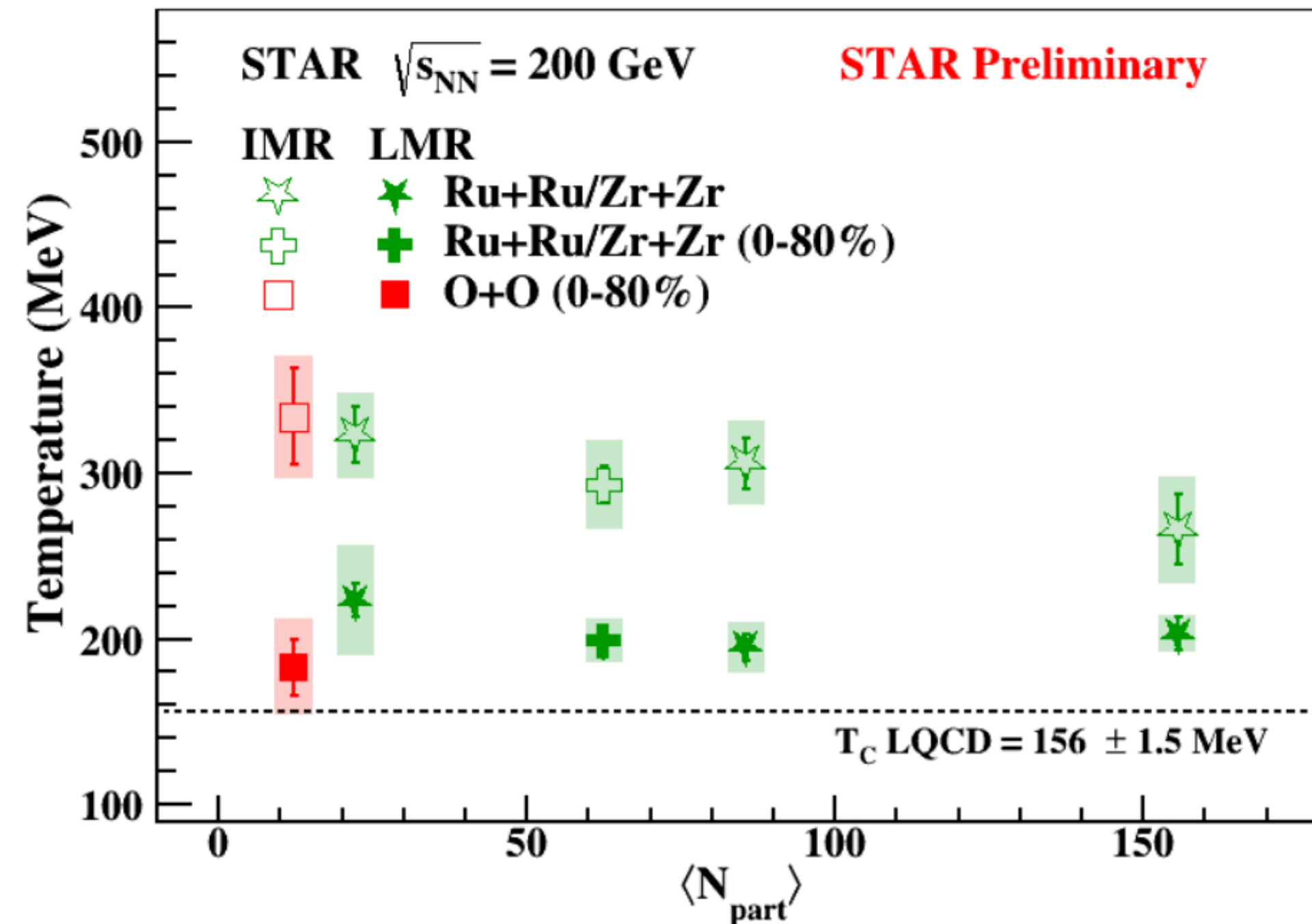
- Mass ordering → **consistent with collective radial flow picture**
- Hydrodynamic calculations describes the feature well
- $\langle p_T \rangle$ increases with $\langle N_{part} \rangle$ following a common trend, spanning small (p+p, O+O, d+Au) to large (Cu+Cu, isobar, Au+Au) collision systems

Thermal Dielectron Production



Electromagnetic probes: no strong interaction with the medium and sensitive to the QGP evolution

Temperature



- T_{LMR} (low-mass region): agree with the measurements in Ru+Ru/Zr+Zr and Au+Au collisions
- T_{IMR} (intermediate-mass region): higher than the pseudo critical temperature T_{PC} (156 MeV)
- $T_{IMR} > T_{LMR}$ for all systems and centralities

Suggests QGP formation in O+O collisions

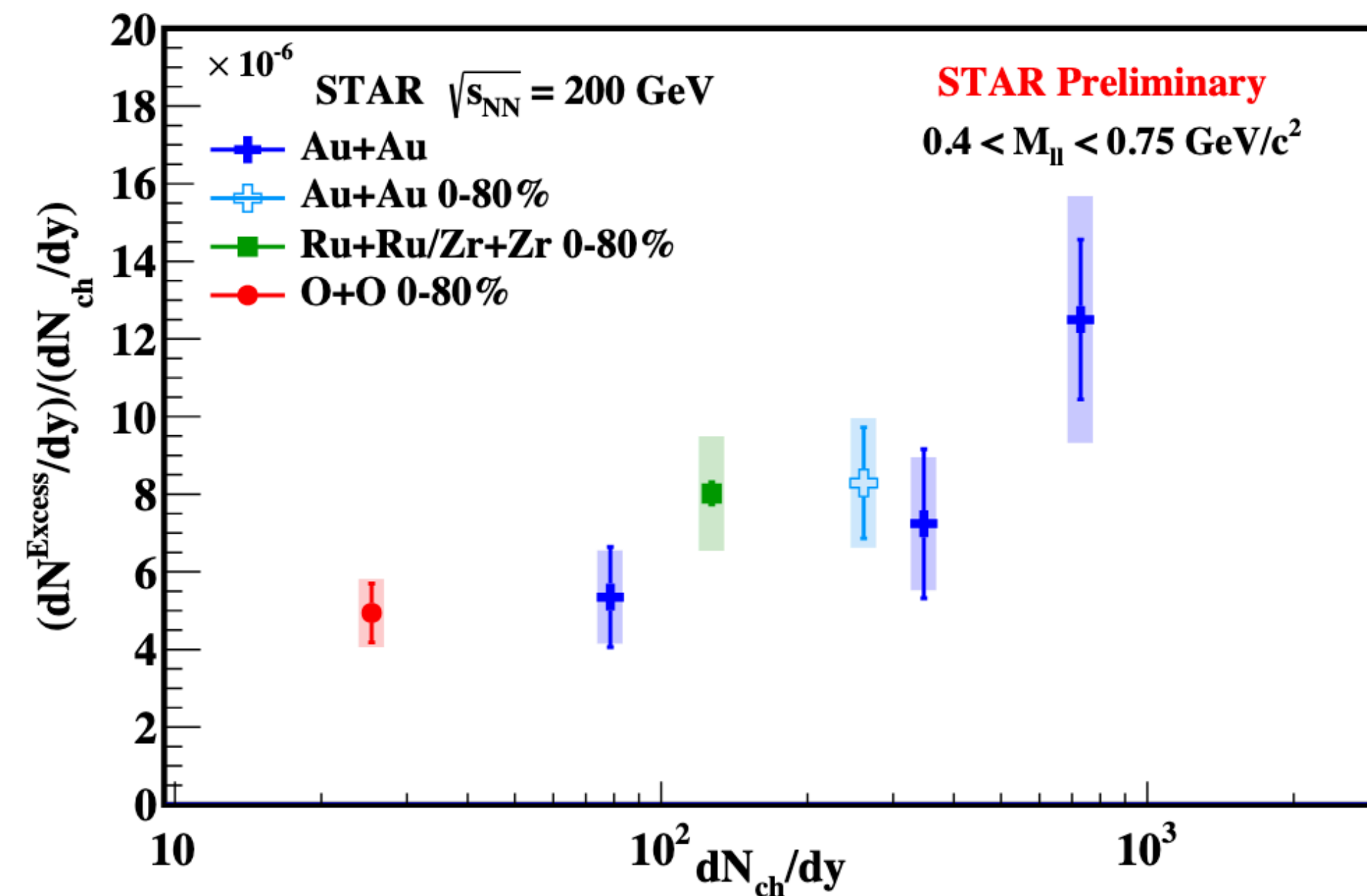
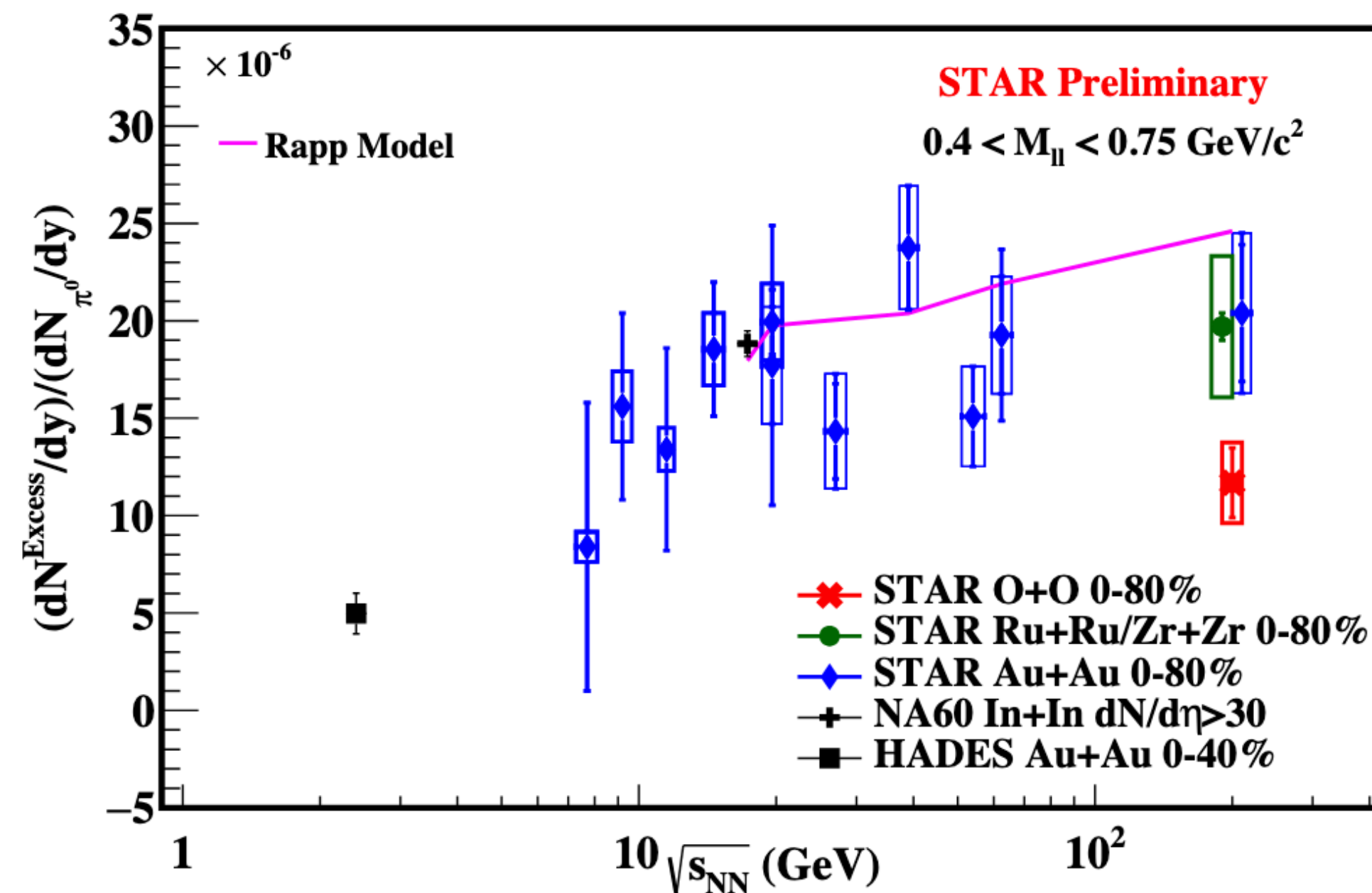
Thermal Dielectron Production



Electromagnetic probes: no strong interaction with the medium and sensitive to the QGP evolution

Integrated excess yield

excess = data – cocktail

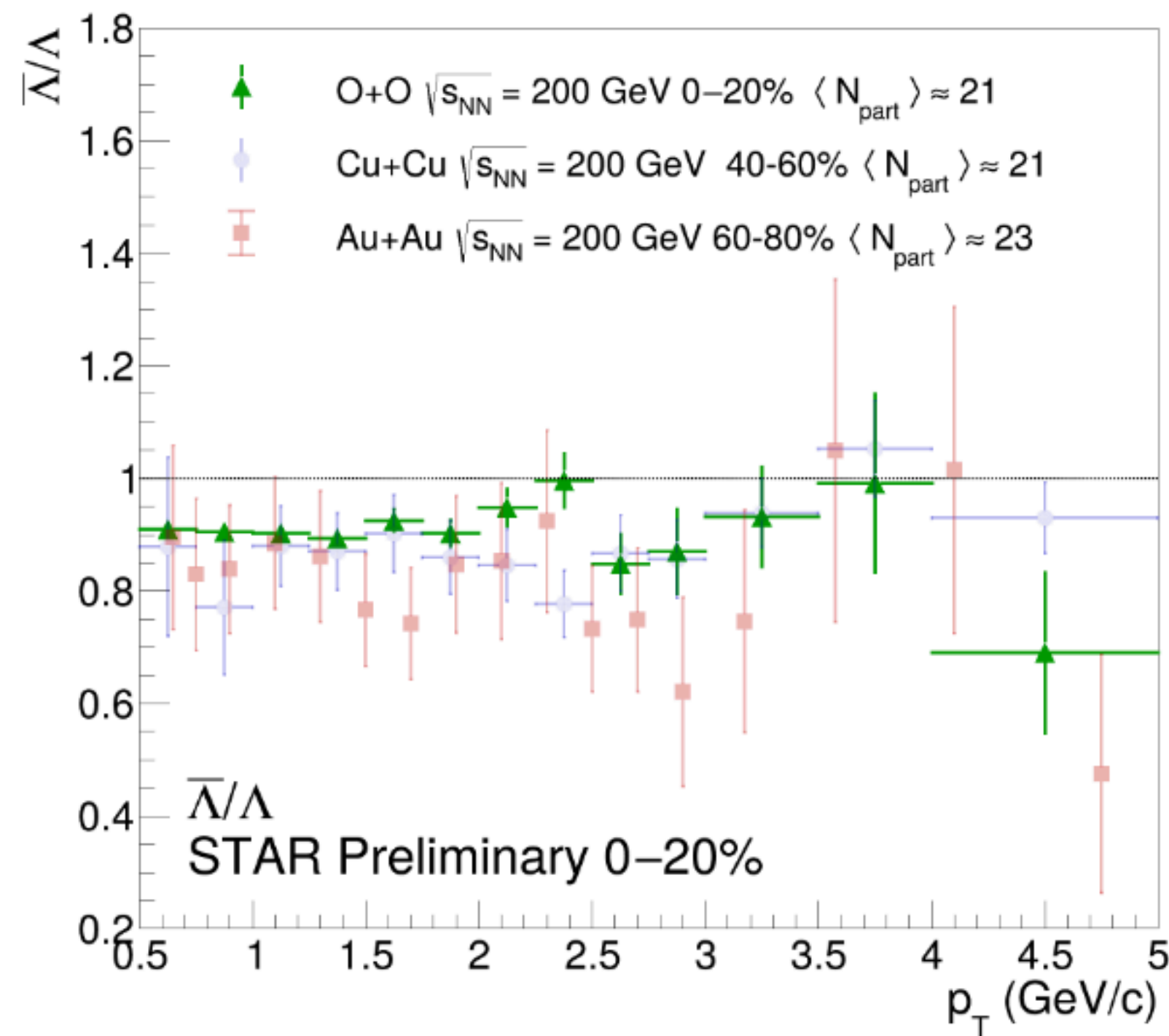


Smaller in O+O, consistent with the global trend across systems

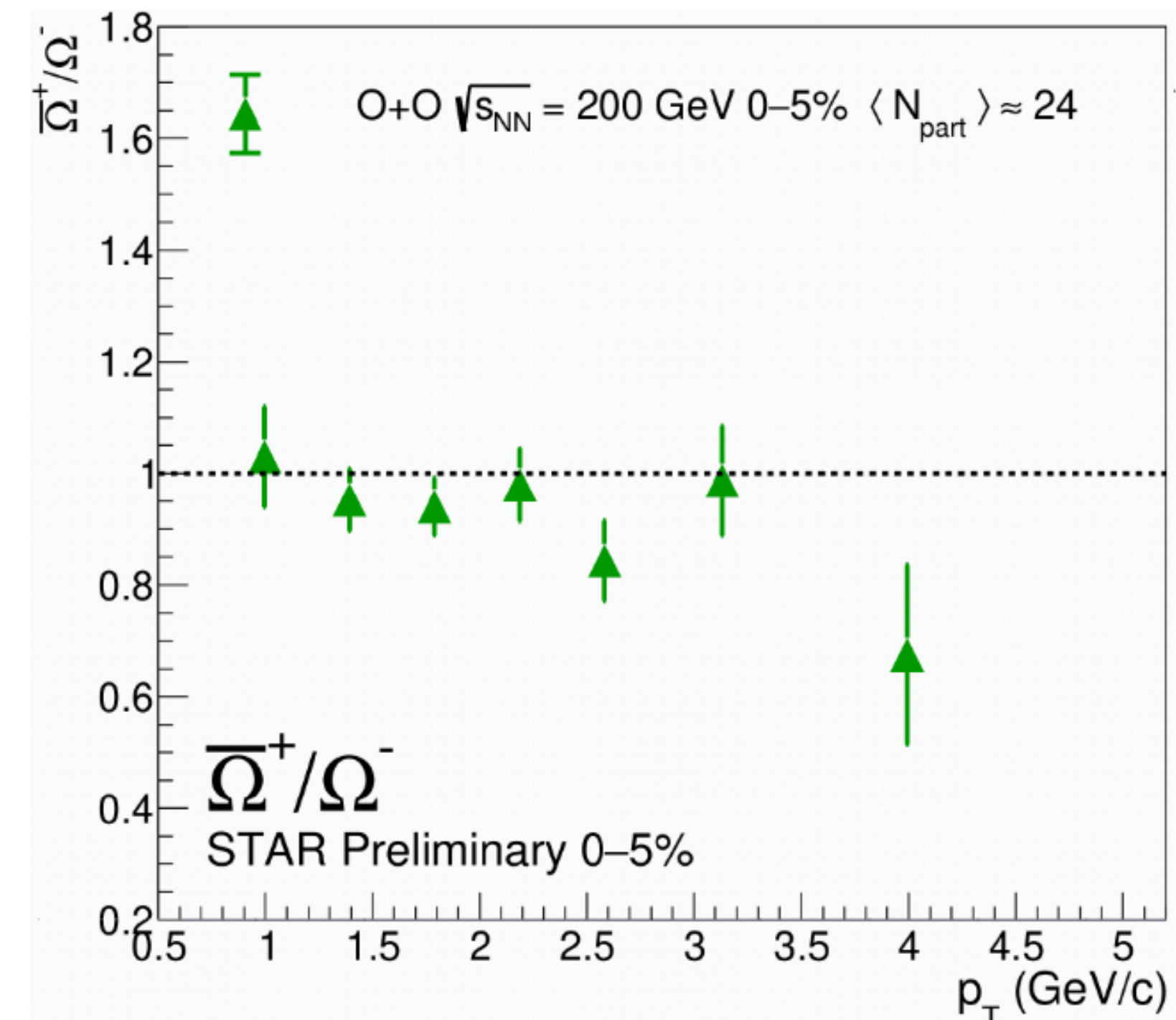
Suggest a shorter system lifetime in O+O compared to the larger systems within the model interpretation

Strange Antibaryon-to-baryon Ratios

- No significant p_T dependence is observed in the ratio
- The ratio is consistent across different system sizes within uncertainties
- $\bar{\Omega}/\Omega$ is closer to unity than $\bar{\Lambda}/\Lambda$ Consistent with Statistical Hadronization Models prediction:
 $\ln(\bar{B}/B) = -2\mu_B/T_{ch} + 2n_s\mu_S/T_{ch} (\mu_S \approx \mu_B/3)$, ratio $\rightarrow 1$ as n_s increases

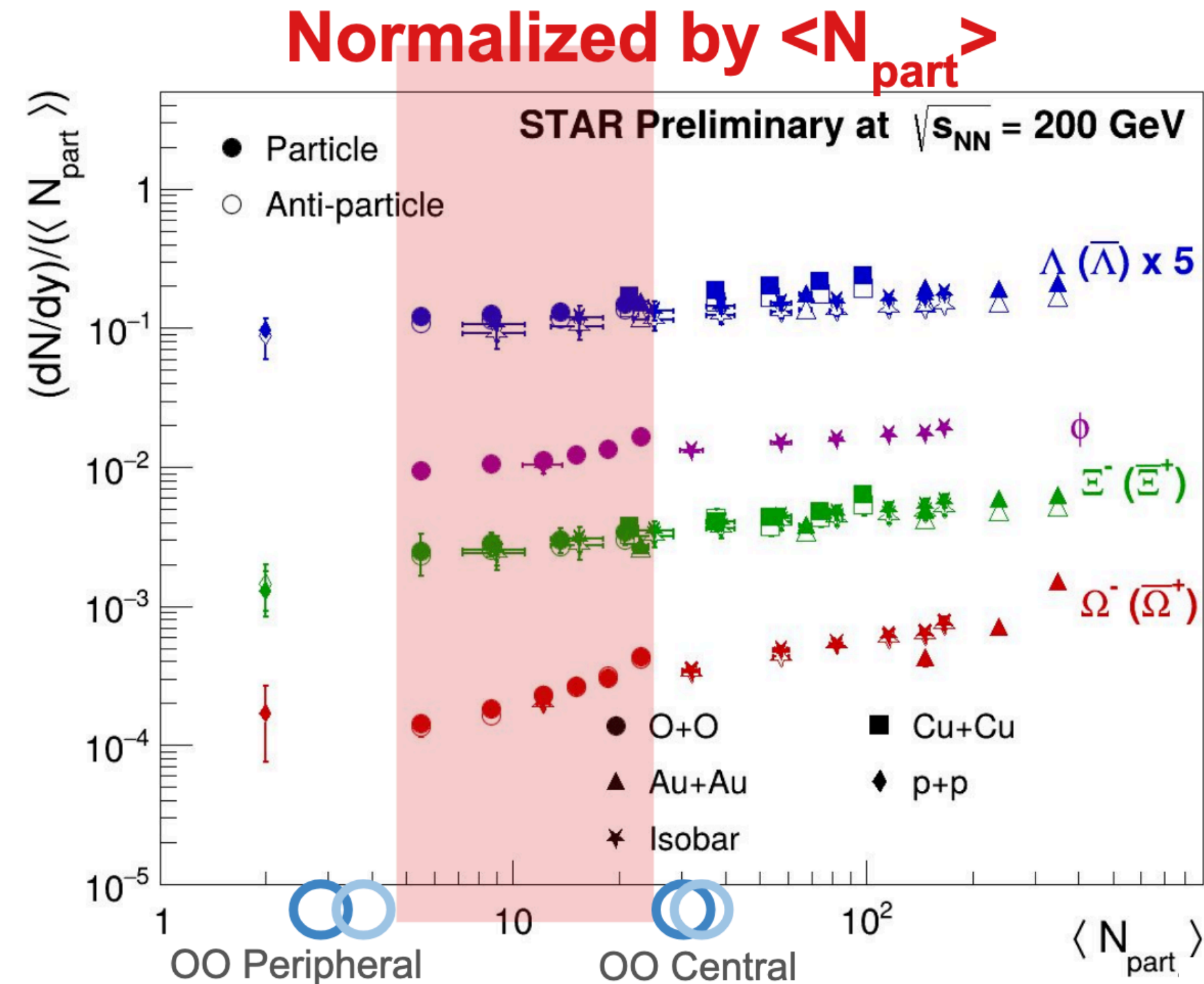
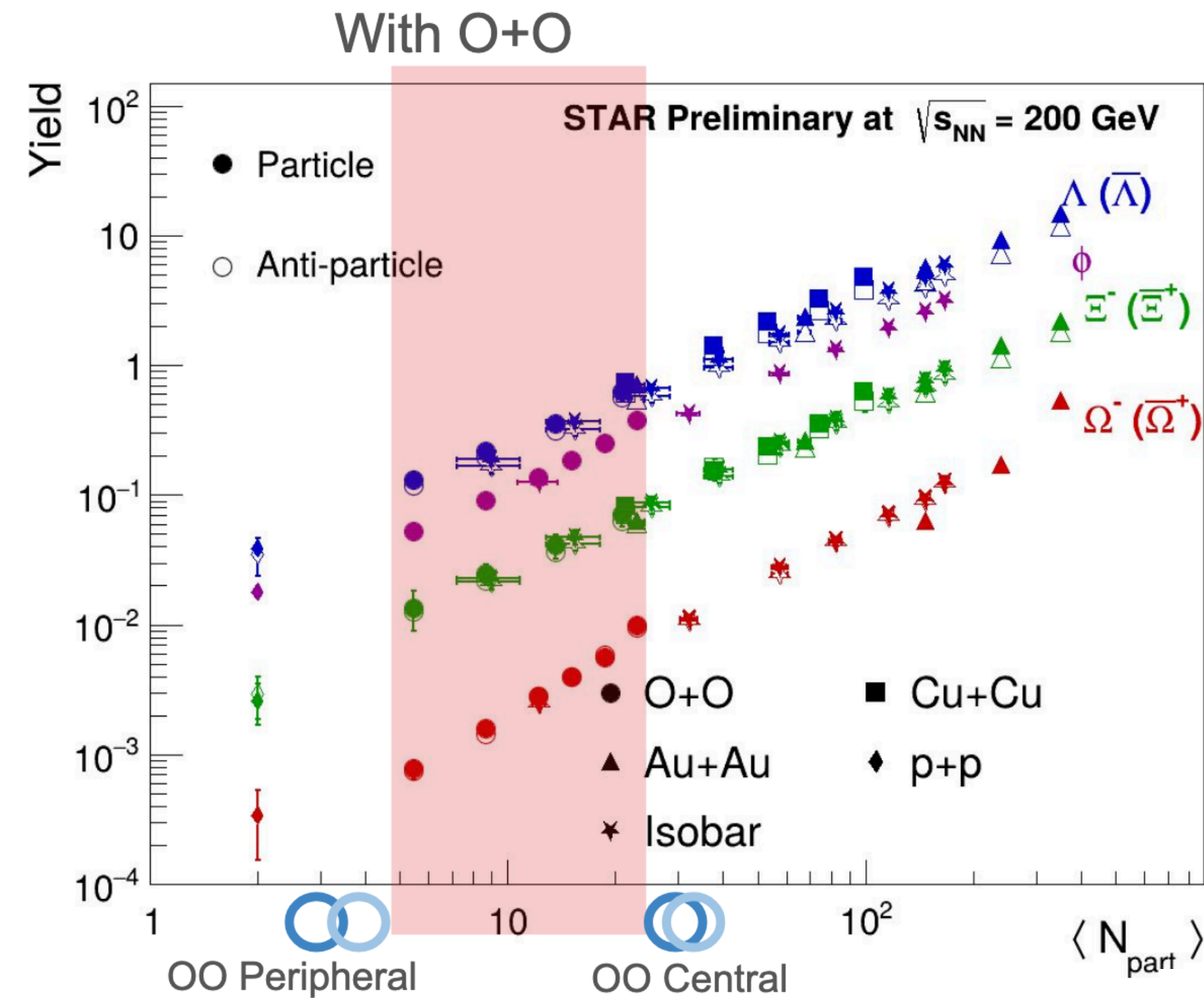


$\Lambda : n_s = 1$



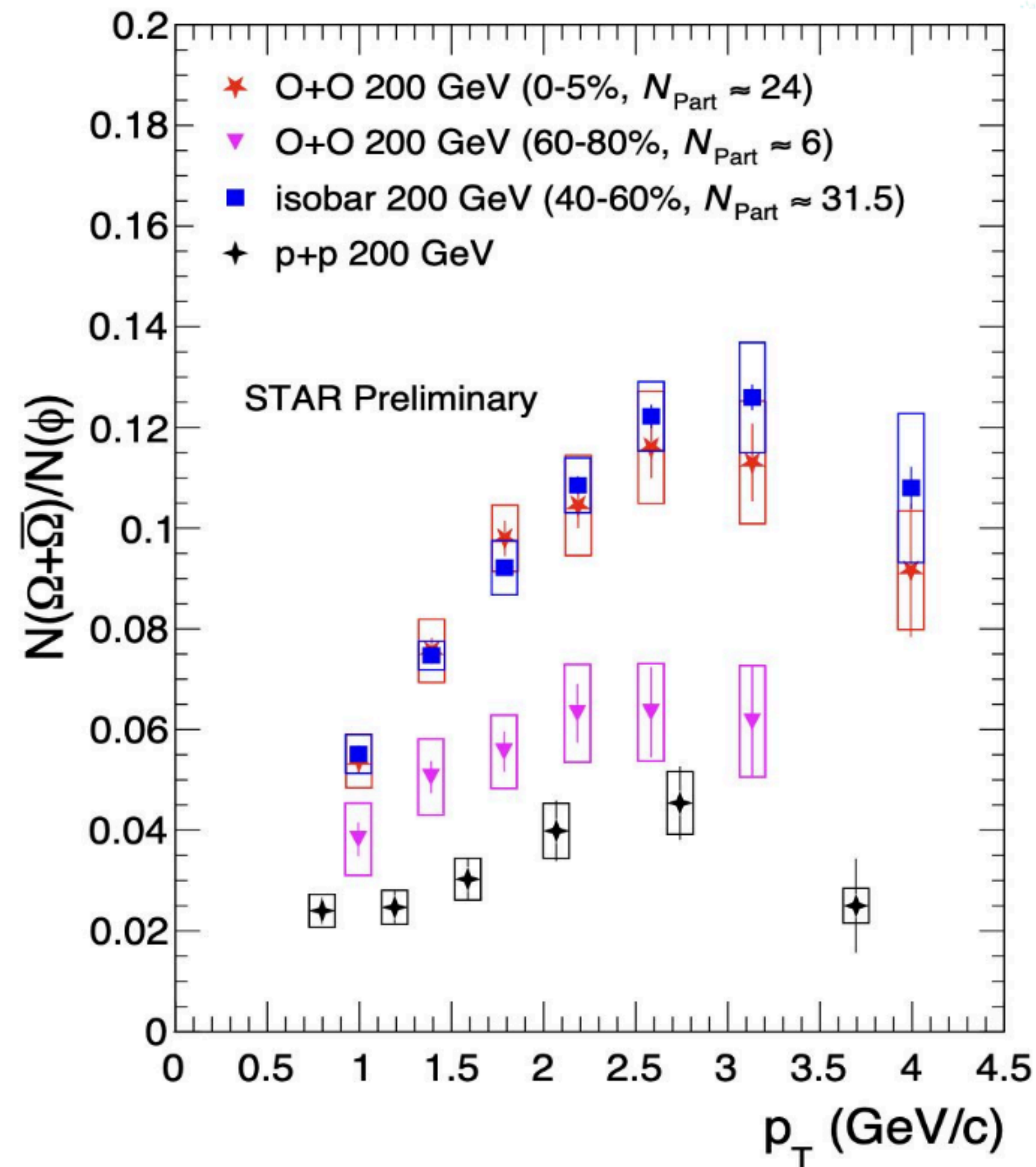
$\Omega : n_s = 3$

Strange Hadron Yields



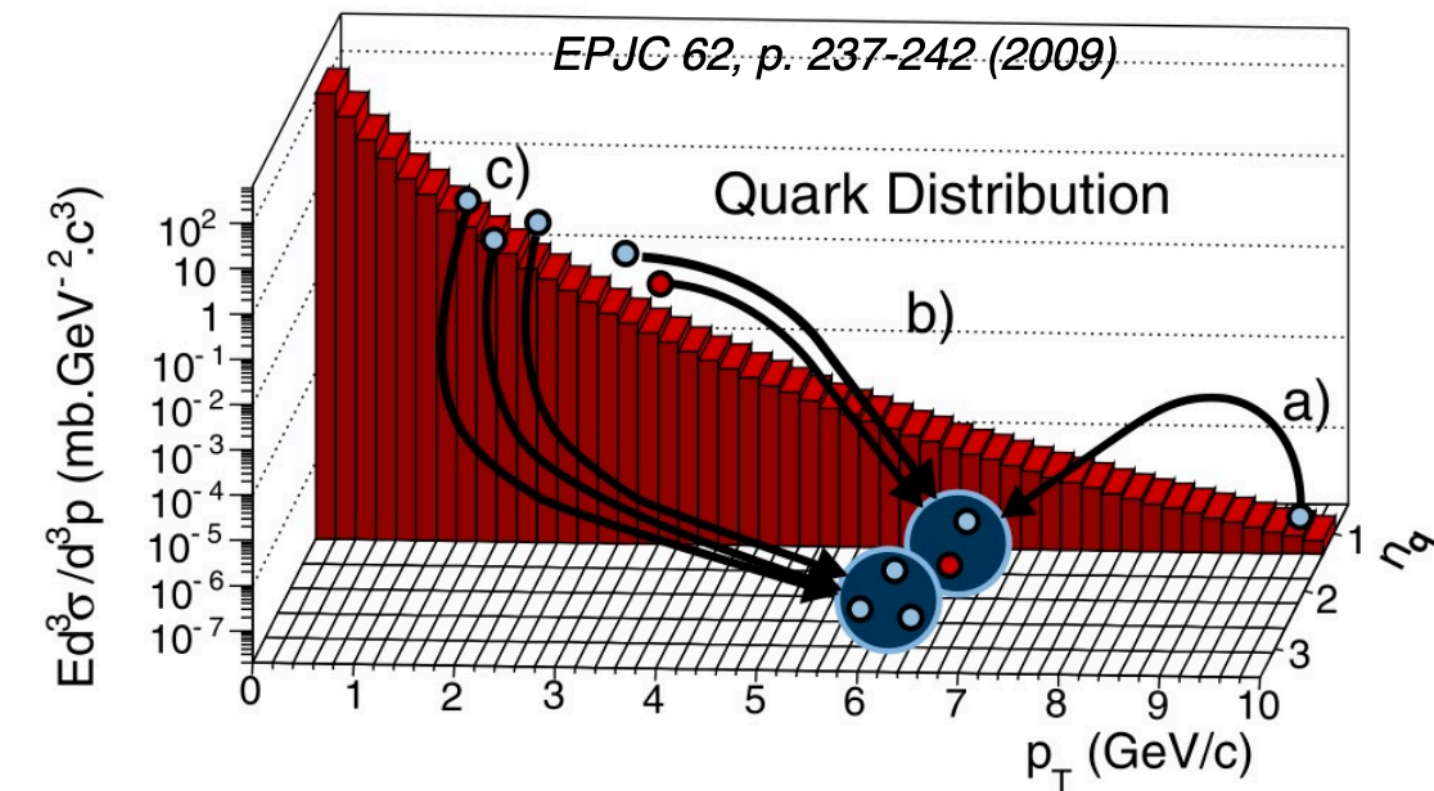
- O+O fills the gap at low $\langle N_{part} \rangle$ between p+p and A+A
- Smooth $\langle N_{part} \rangle$ scaling:
Normalized strange hadron yields (Λ , ϕ , Ξ , Ω) vary smoothly with $\langle N_{part} \rangle$ across all colliding systems

Ω/Φ Ratio



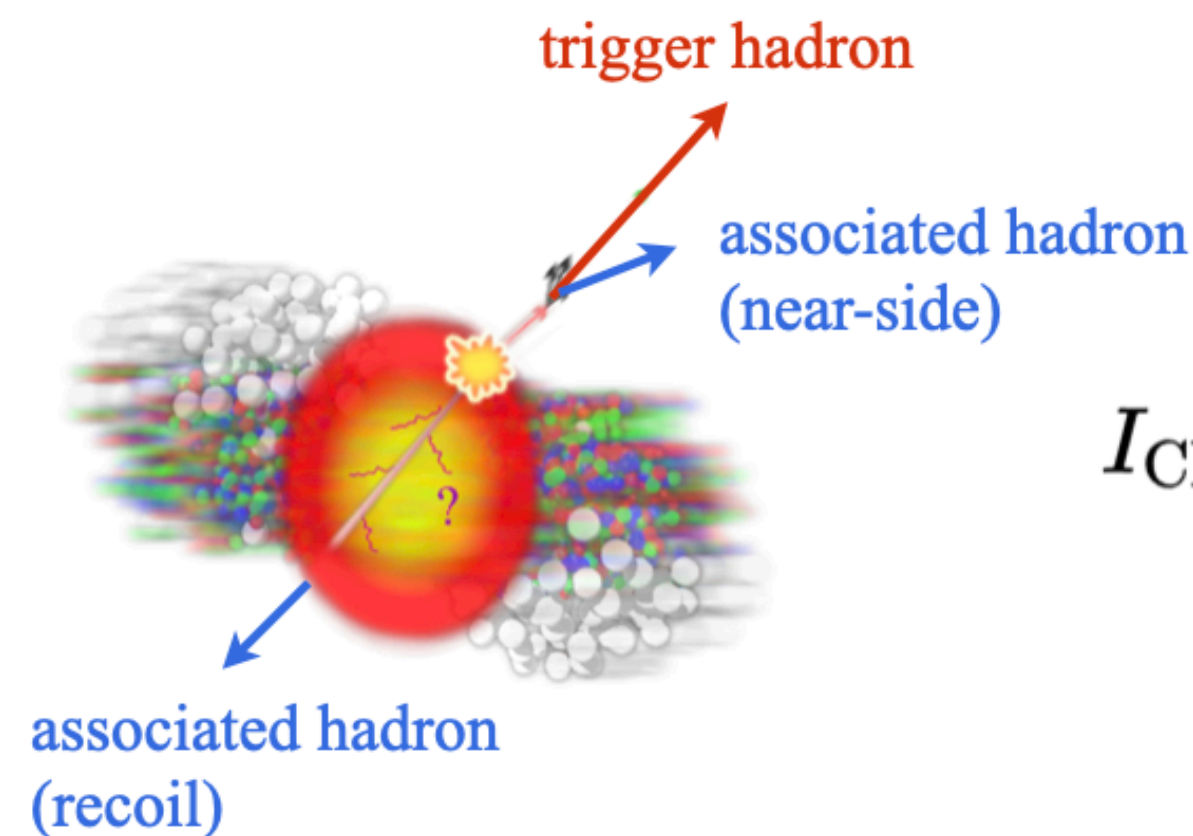
p+p 200 GeV: STAR, Phys. Rev. C 79(2009) 064903

Ω/ϕ ratio: sensitive probe of quark recombination/coalescence in hadronization



- Enhancement relative to p+p collisions, increases from 60-80% to 0-5% events
- With similar N_{part} , O+O 0-5% is consistent with isobar 40-60%

Evidence of Jet Quenching: Hadron-hadron Correlations

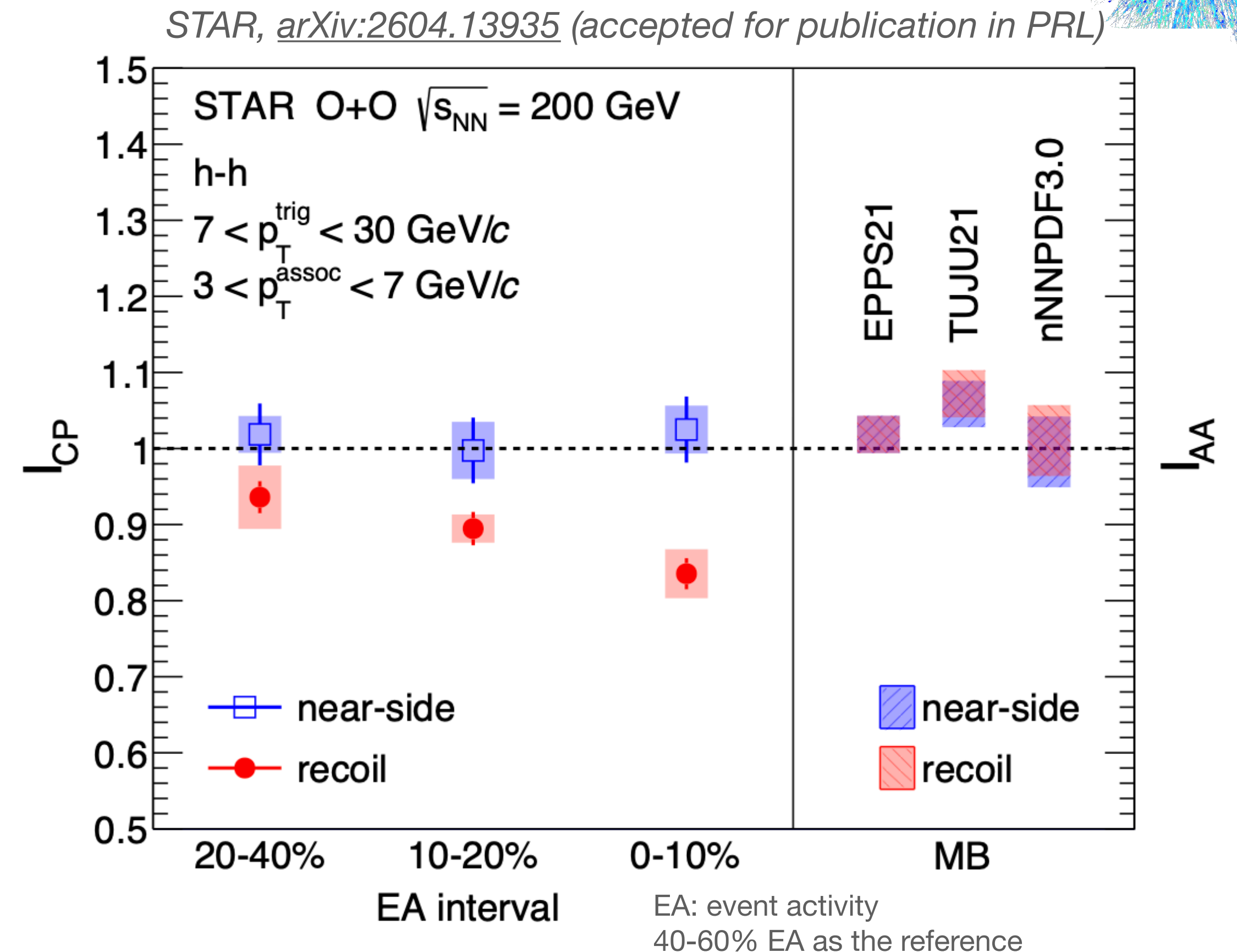


$$I_{CP} = \frac{\frac{1}{N_{trig}} \frac{dN_{assoc}}{d\Delta\phi} \Big|_{high-EA}}{\frac{1}{N_{trig}} \frac{dN_{assoc}}{d\Delta\phi} \Big|_{low-EA}}$$

Correlation observables:

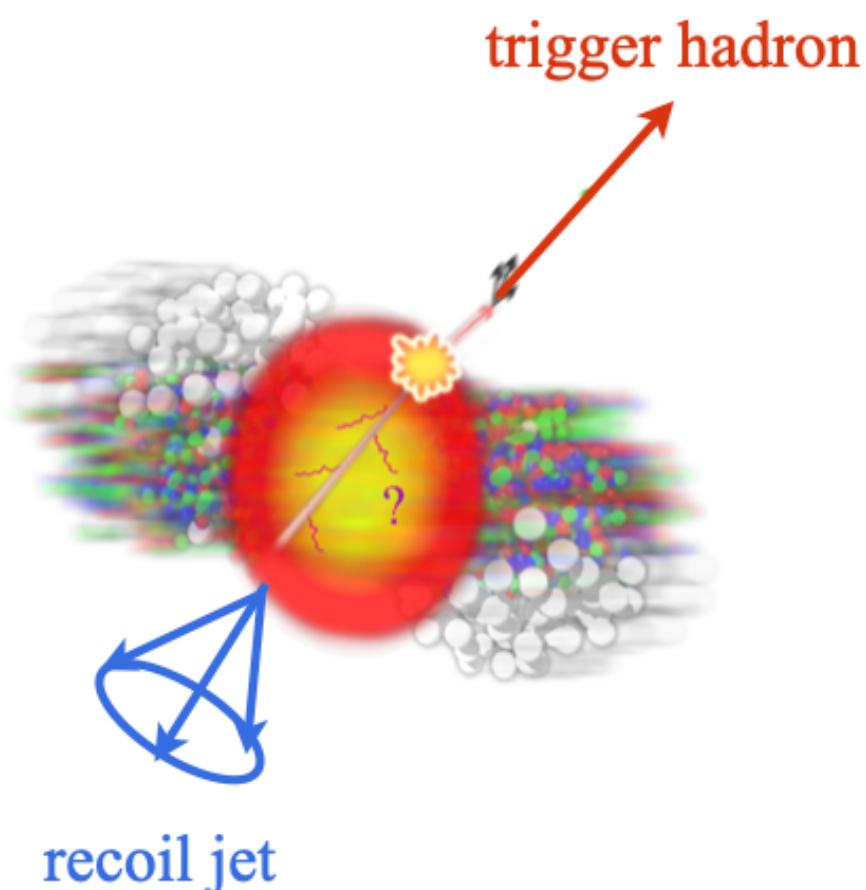
Surface bias

Avoid calculation of N_{coll} and selection bias



- nPDF predictions (w/o jet quenching): Similar I_{AA} on the near-side and recoil
- **Near side** $I_{CP} \approx 1$, while the **recoil** $I_{CP} < 1$
- Significance between 2.7σ and 5.2σ , depending on the choice of baseline

Evidence of Jet Quenching: Hadron-jet Correlations

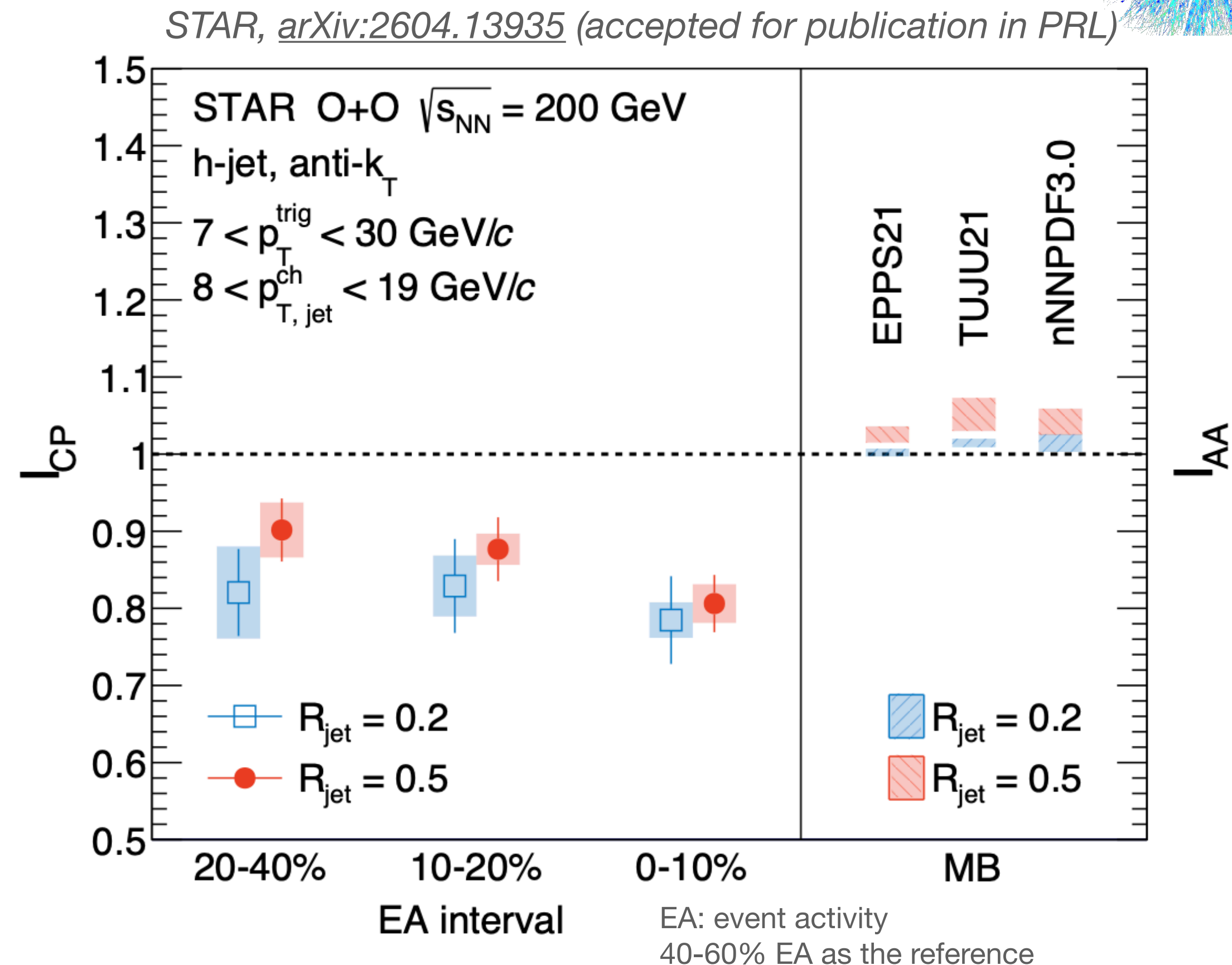


$$I_{CP} = \frac{\frac{1}{N_{trig}} \cdot \frac{d^2 N_{jet}}{dp_{T,jet}^{ch} d\eta_{jet}^{ch}} \Big|_{high-EA}}{\frac{1}{N_{trig}} \cdot \frac{d^2 N_{jet}}{dp_{T,jet}^{ch} d\eta_{jet}^{ch}} \Big|_{low-EA}}$$

Correlation observables:

Surface bias

Avoid calculation of N_{coll} and selection bias



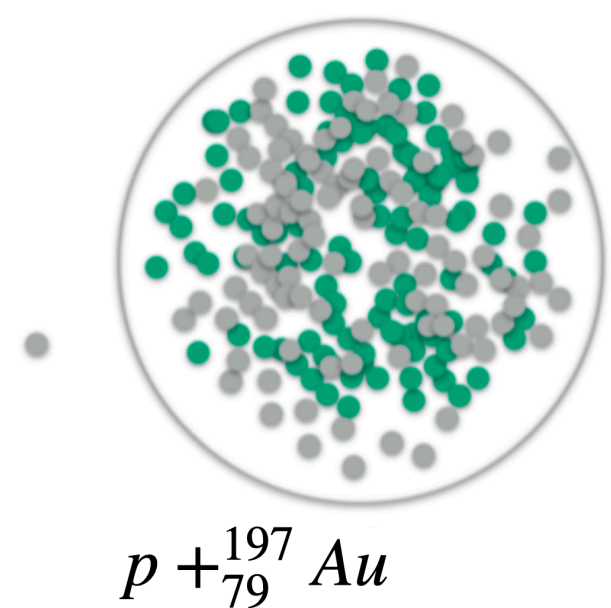
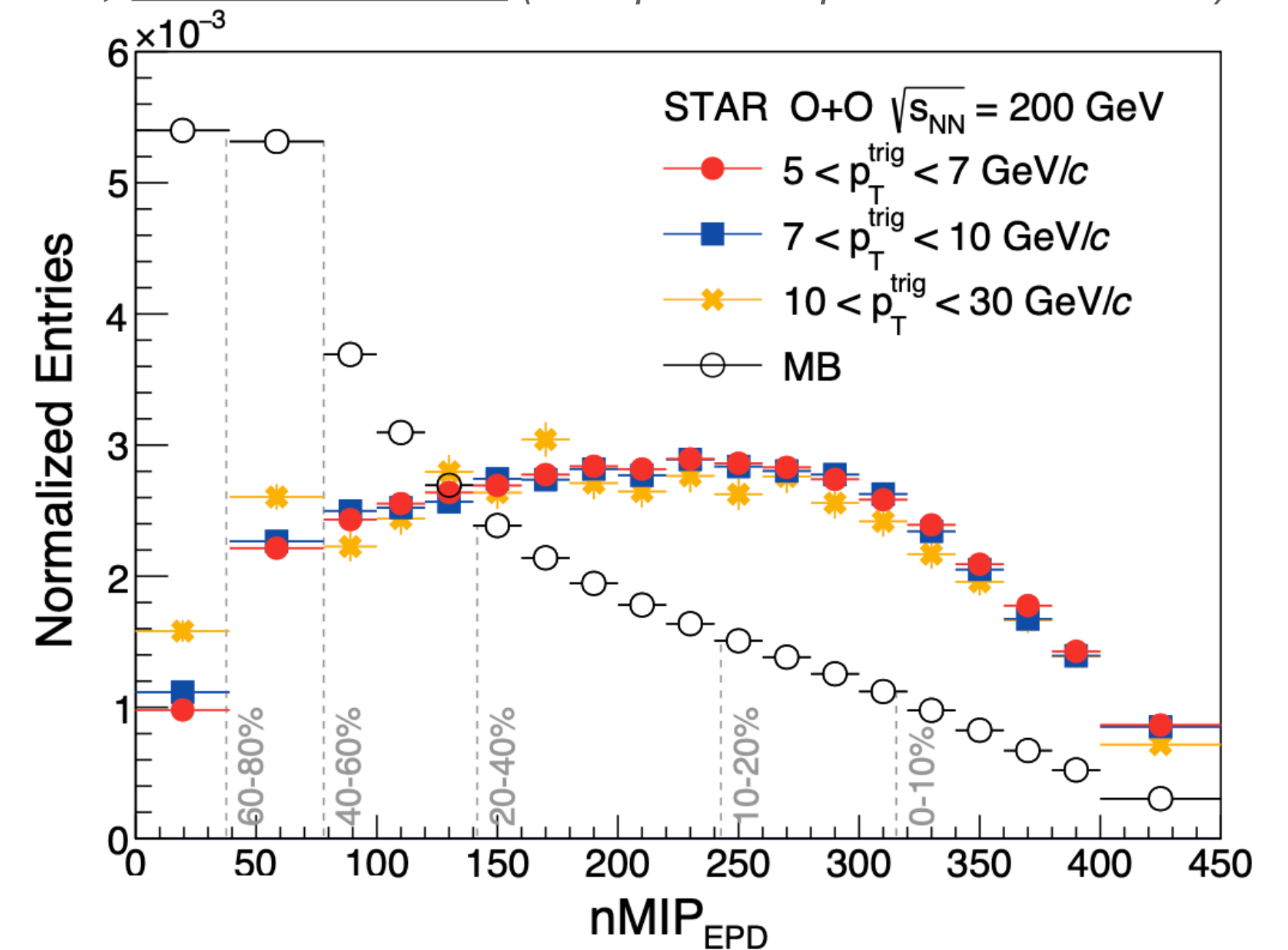
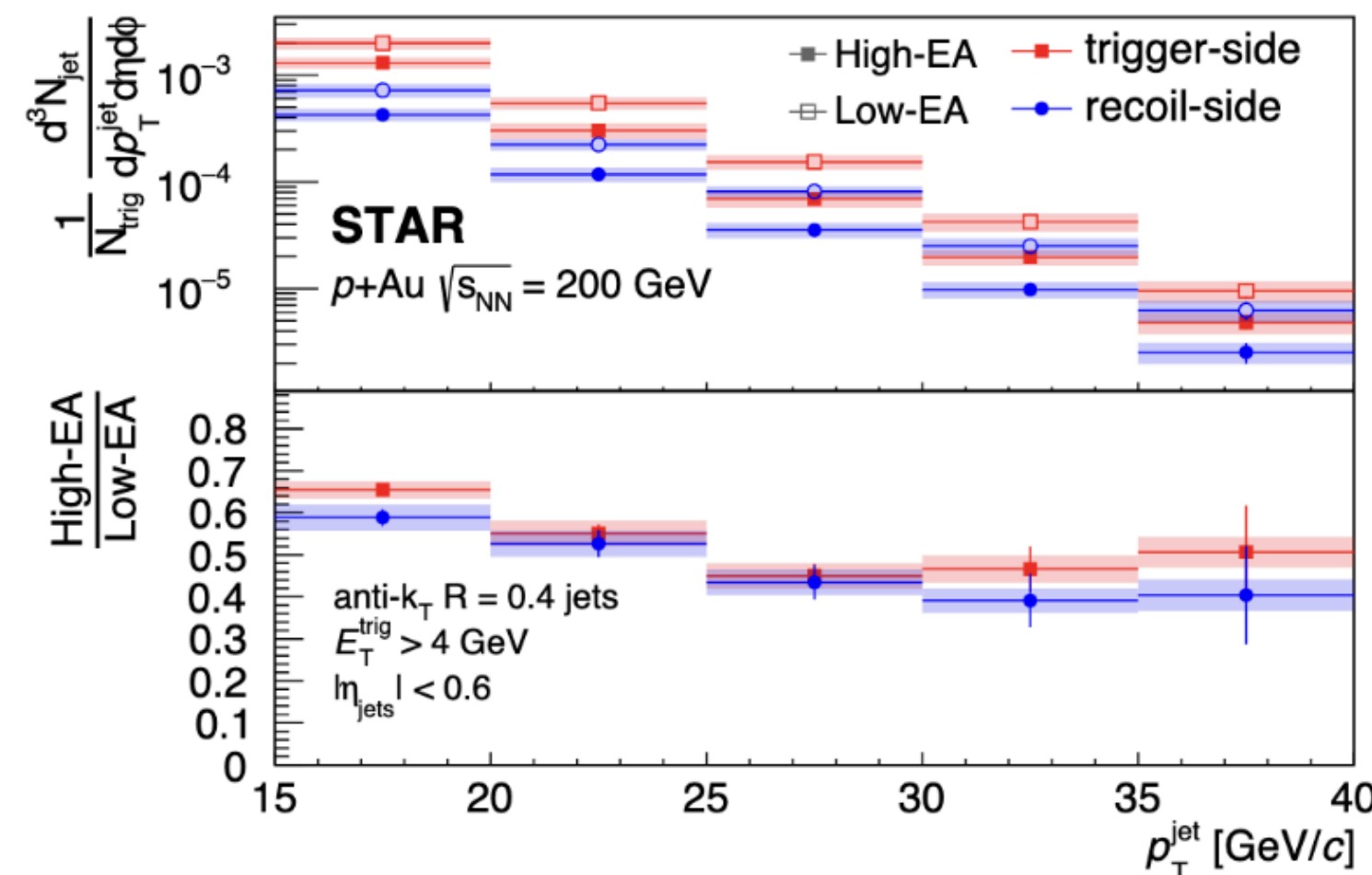
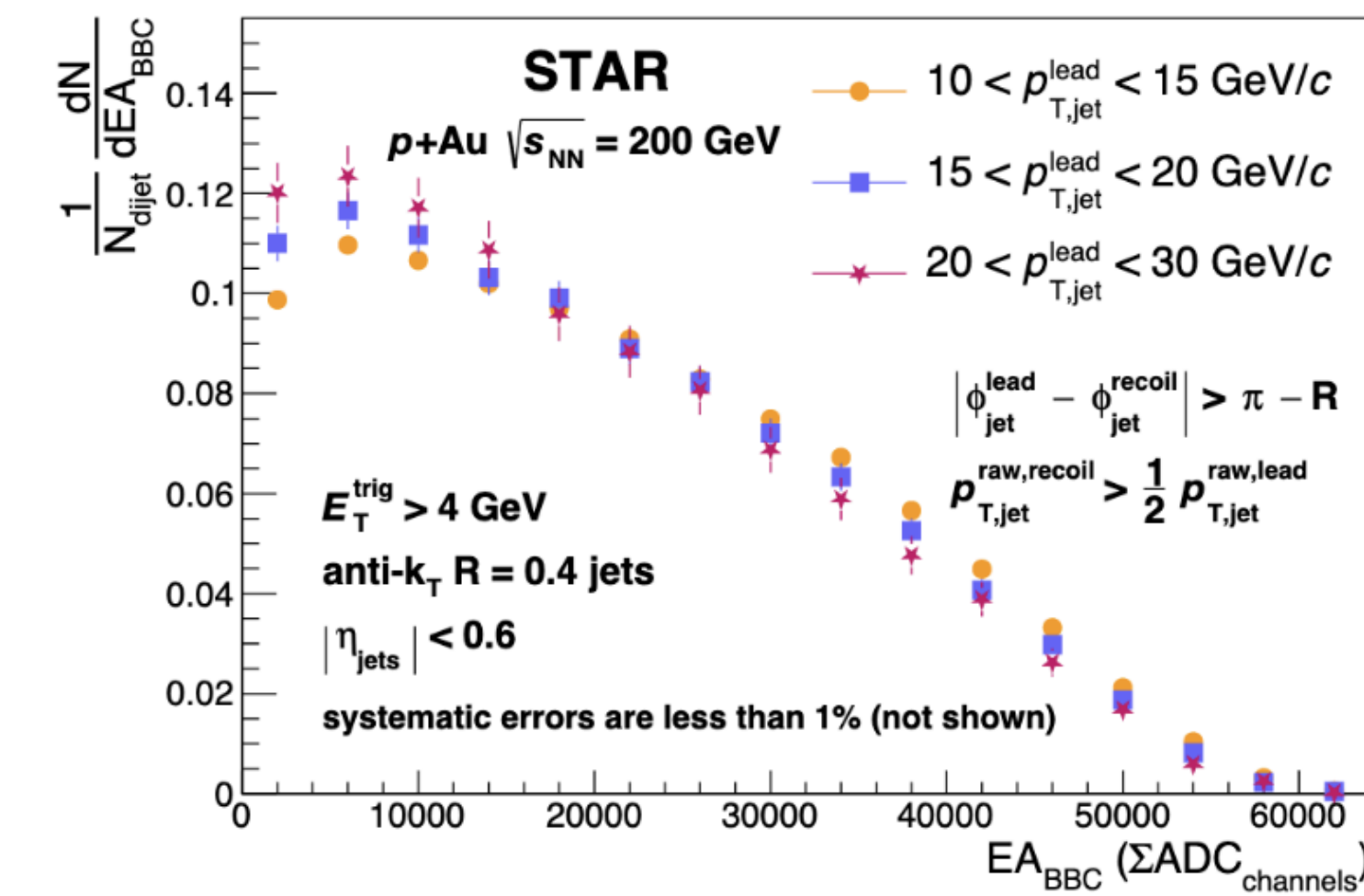
- $I_{CP} < 1$, similar suppression magnitude observed for $R = 0.5$ and $R = 0.2$
- nPDF predictions (w/o jet quenching) are insufficient to explain the suppression
- Significance between 3.5σ and 5.0σ , depending on the choice of baseline

Comparison with p+Au

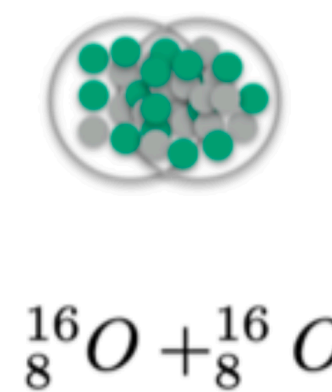


STAR, PRC 110, 044908 (2024)

STAR, arXiv:2604.13935 (accepted for publication in PRL)



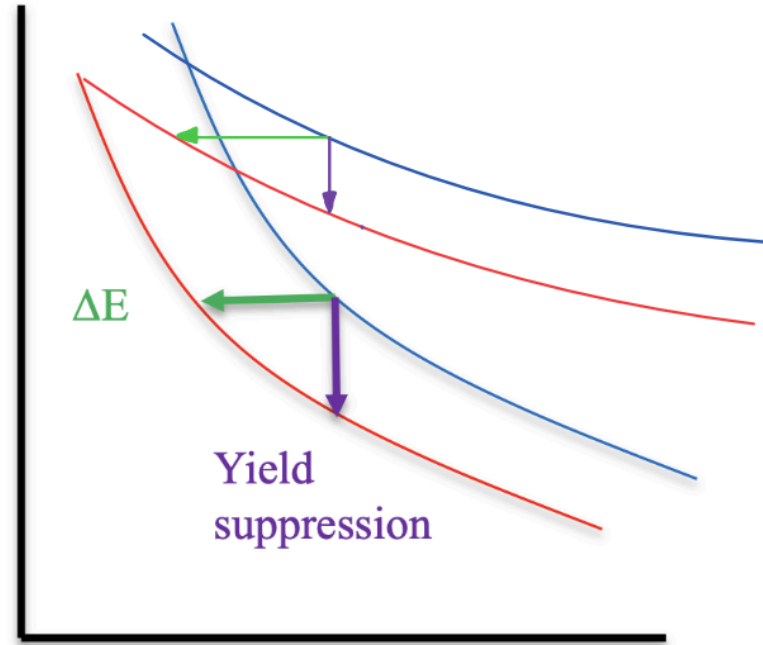
Anti-correlation between event activity and Q^2 is observed;
Yield suppression on both the near and recoil sides, can be explained by non-quenching effects



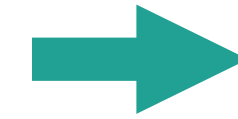
40–60% can serve as a reference range with no anti-correlation is observed

No jet quenching observed in p+A so far, but present in O+O!

System Size Dependence of Jet Quenching



To count for the shape of the recoil jet spectrum



Express suppression in terms of a spectrum shift

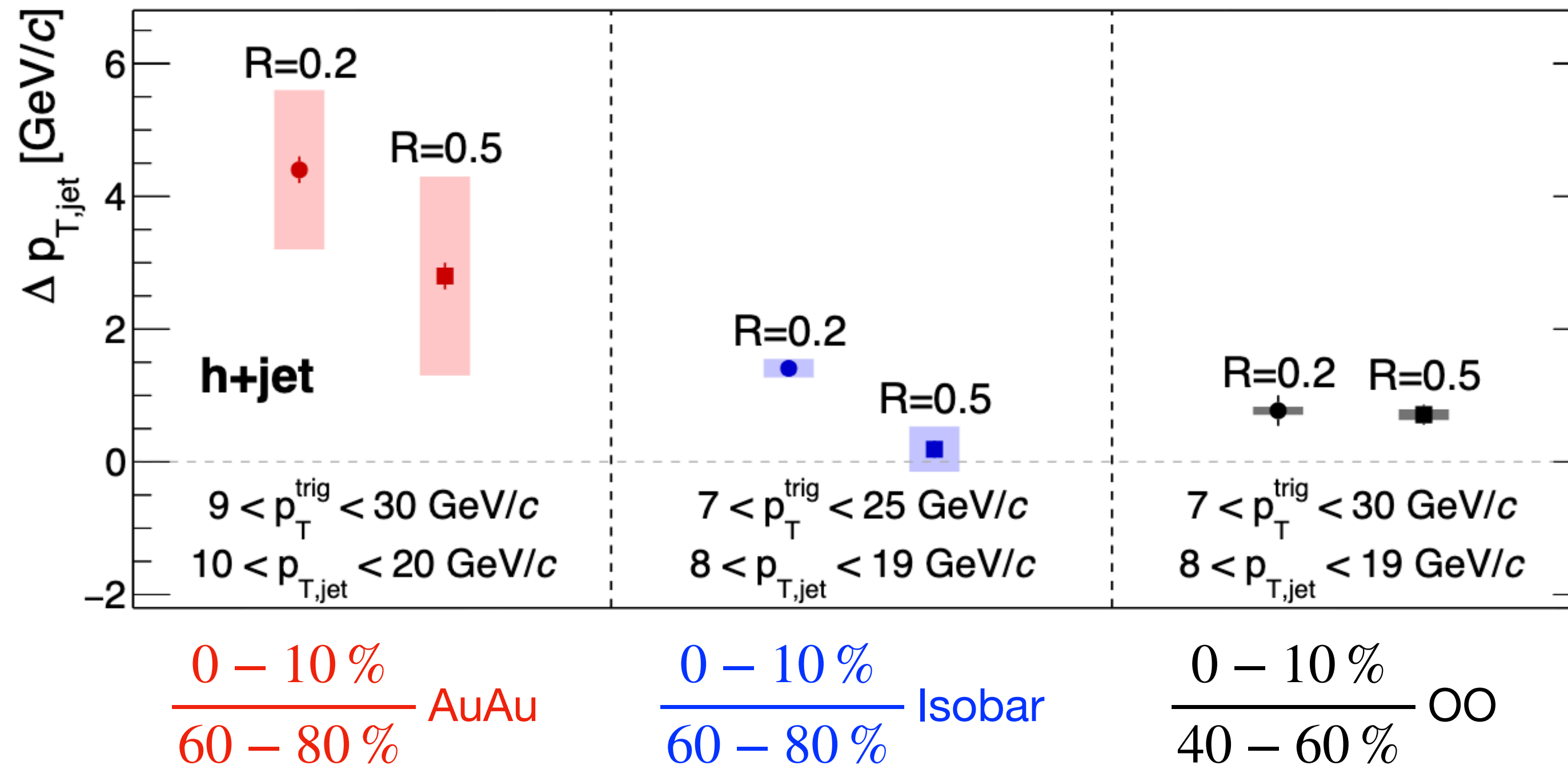
$$y = a \cdot \exp\left(-\frac{x}{b}\right)$$

$$\Delta p_{T,\text{jet}} = -b \ln(I_{\text{CP}})$$

STAR, Phys. Rev. C 96 (2017) 024905

STAR, arXiv:2606.00973

STAR, arXiv:2604.13935

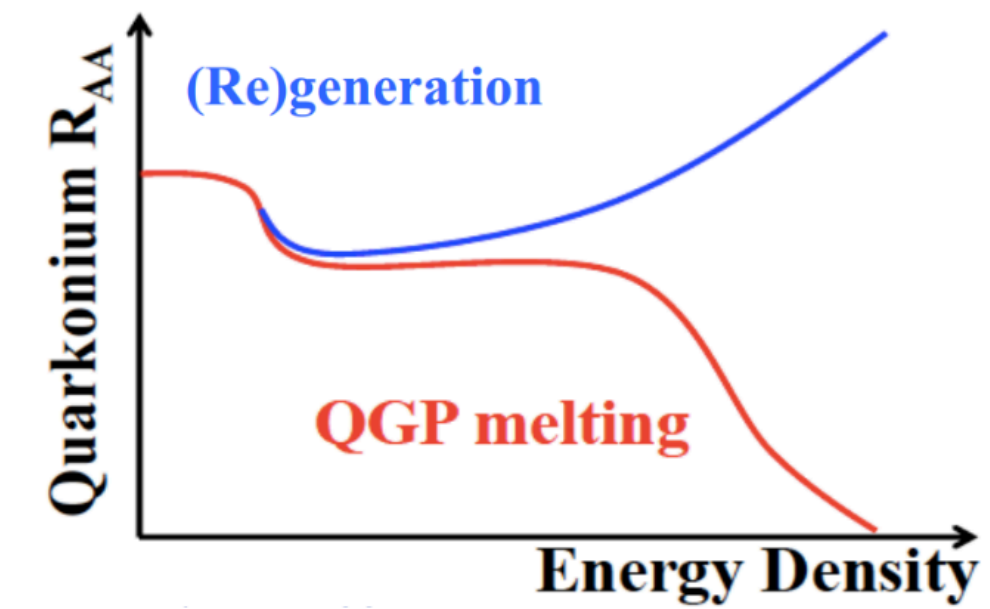


Direct comparison of out-of-cone energy loss across different systems
 (Caveat: peripheral references may not be equivalent for different systems)

$J/\psi R_{AA}$



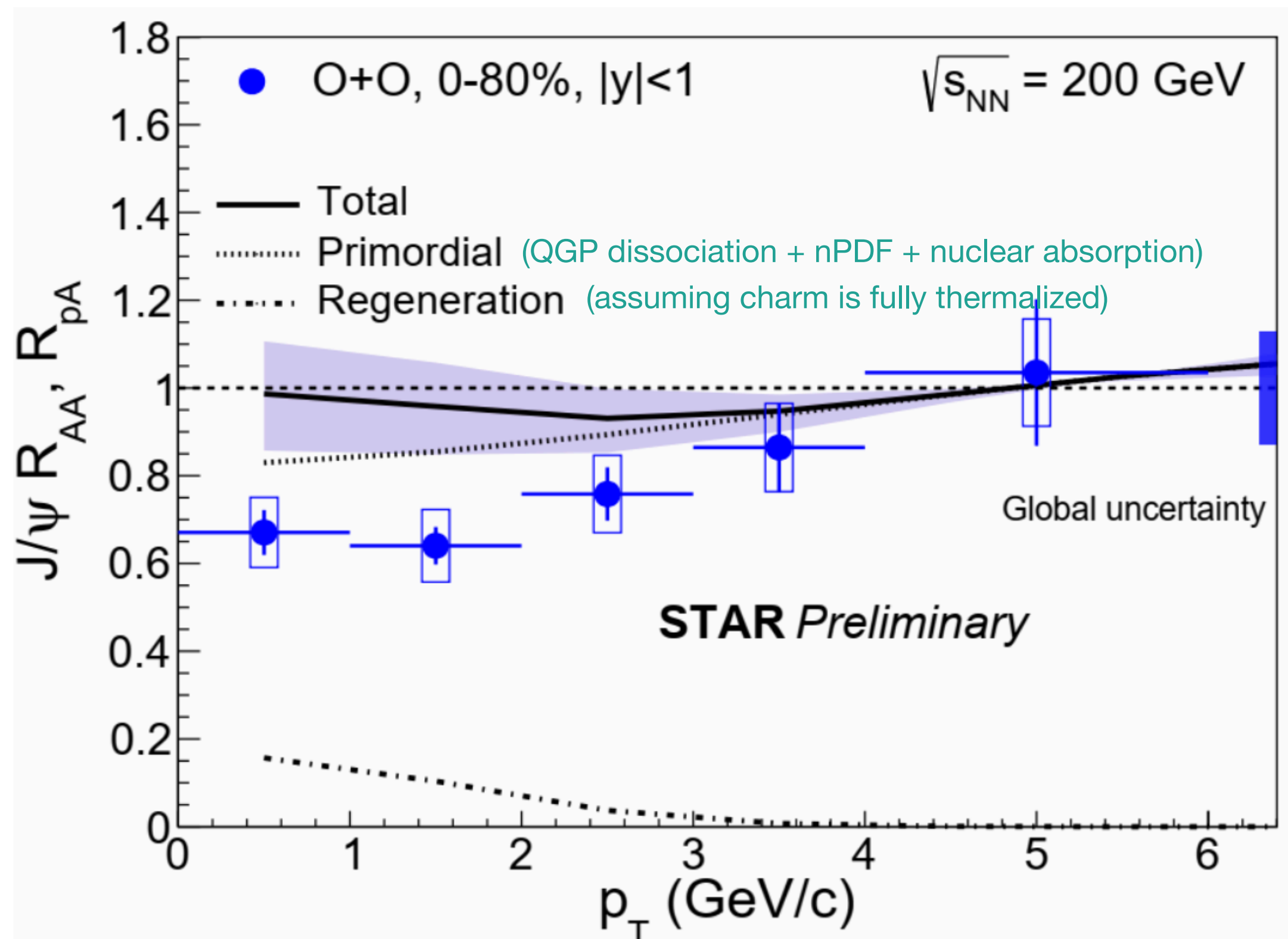
Color screening & dynamic dissociation suppress J/ψ ,
while regeneration from thermalized charm can enhance it



*Stronger suppression is observed at low p_T ,
with R_{AA} increasing toward higher p_T*

Model underpredicts low- p_T suppression,
while describing the data well at high p_T

TM Tsinghua: Jiaxing Zhao and Pengfei Zhuang, *Phys. Rev. C* 105, 064907 (2022)

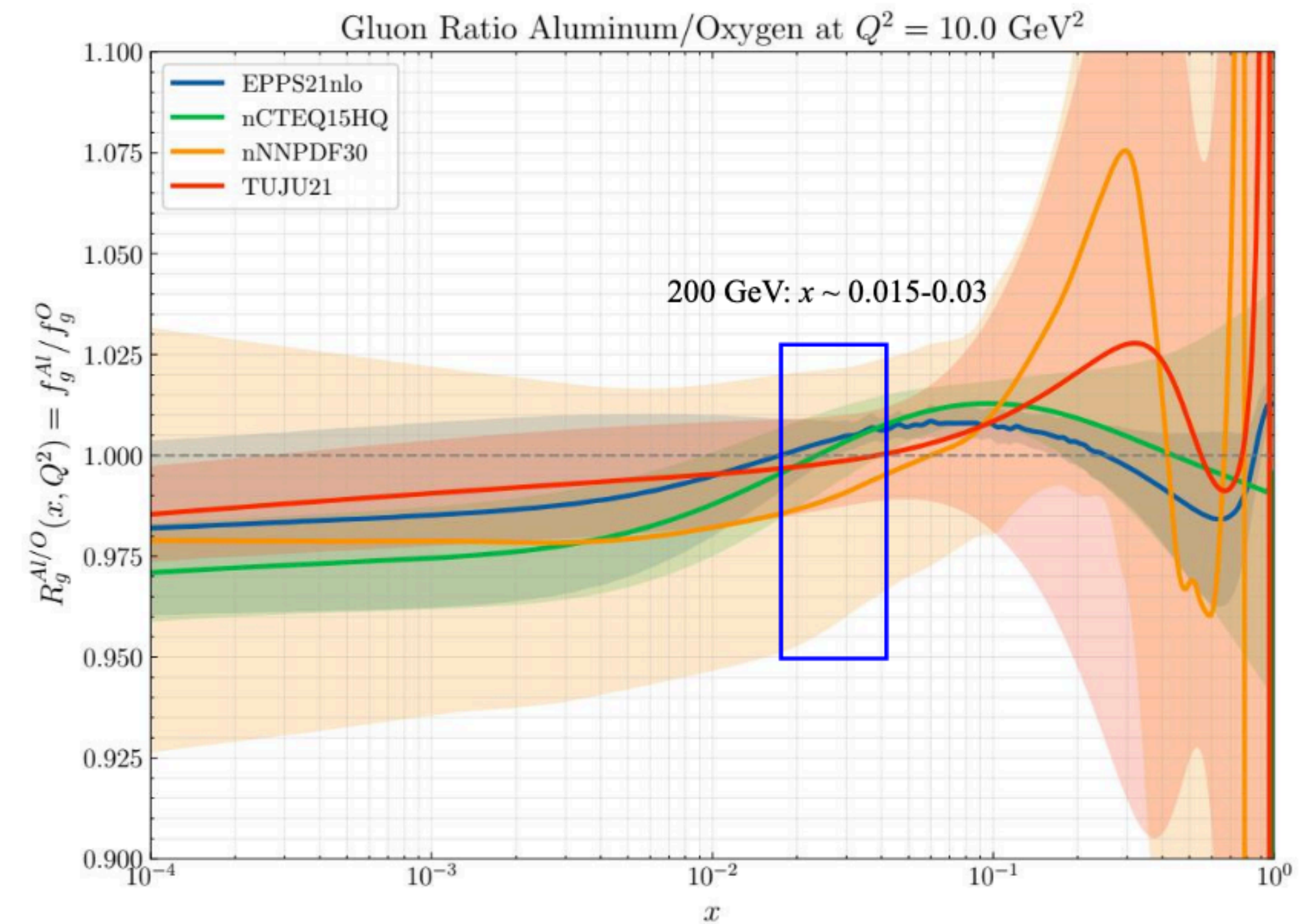
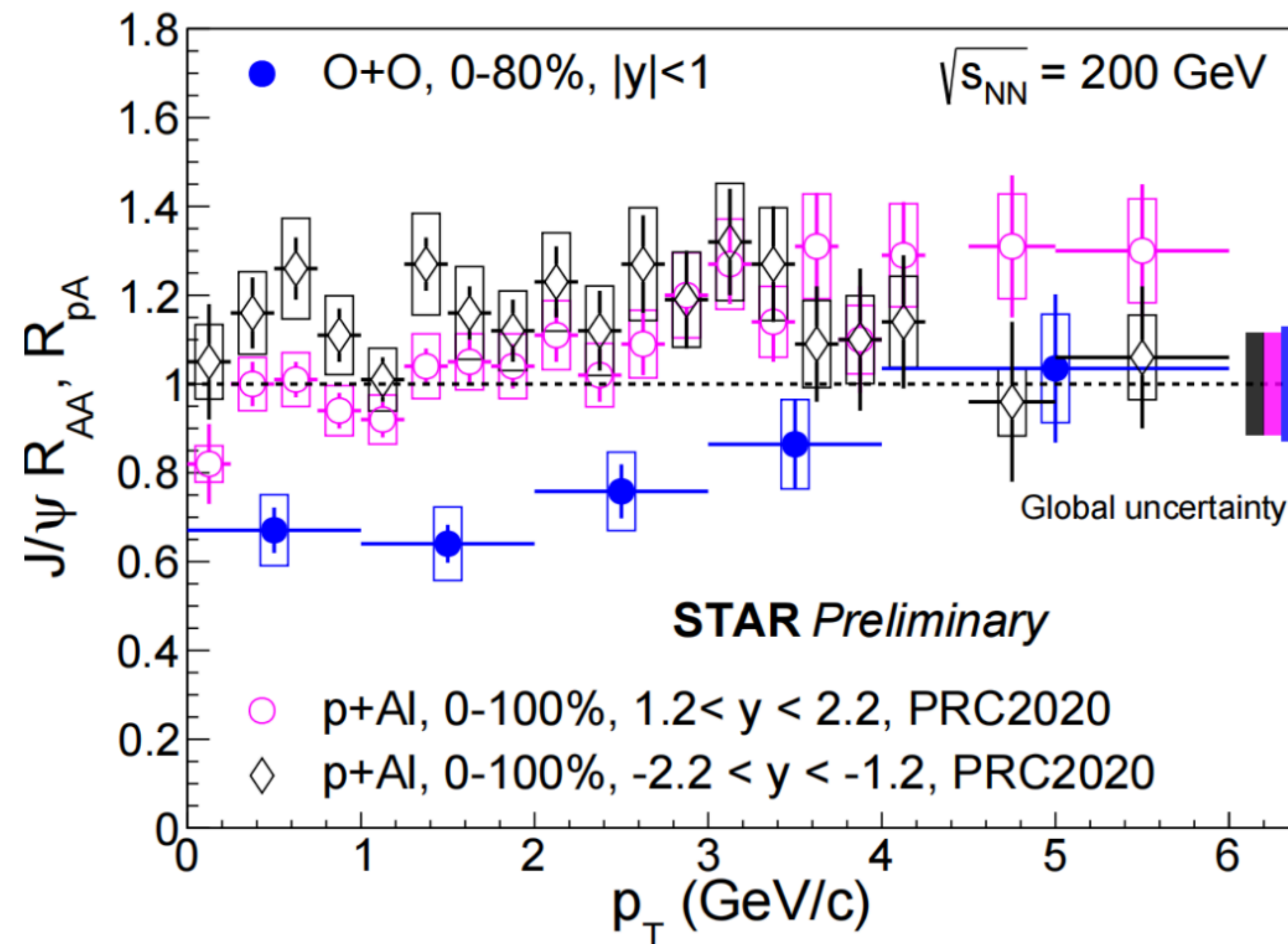


nPDF Effect on $J/\psi R_{AA}$

Cold Nuclear Matter effect?
p+Al R_{AA} is close to unity



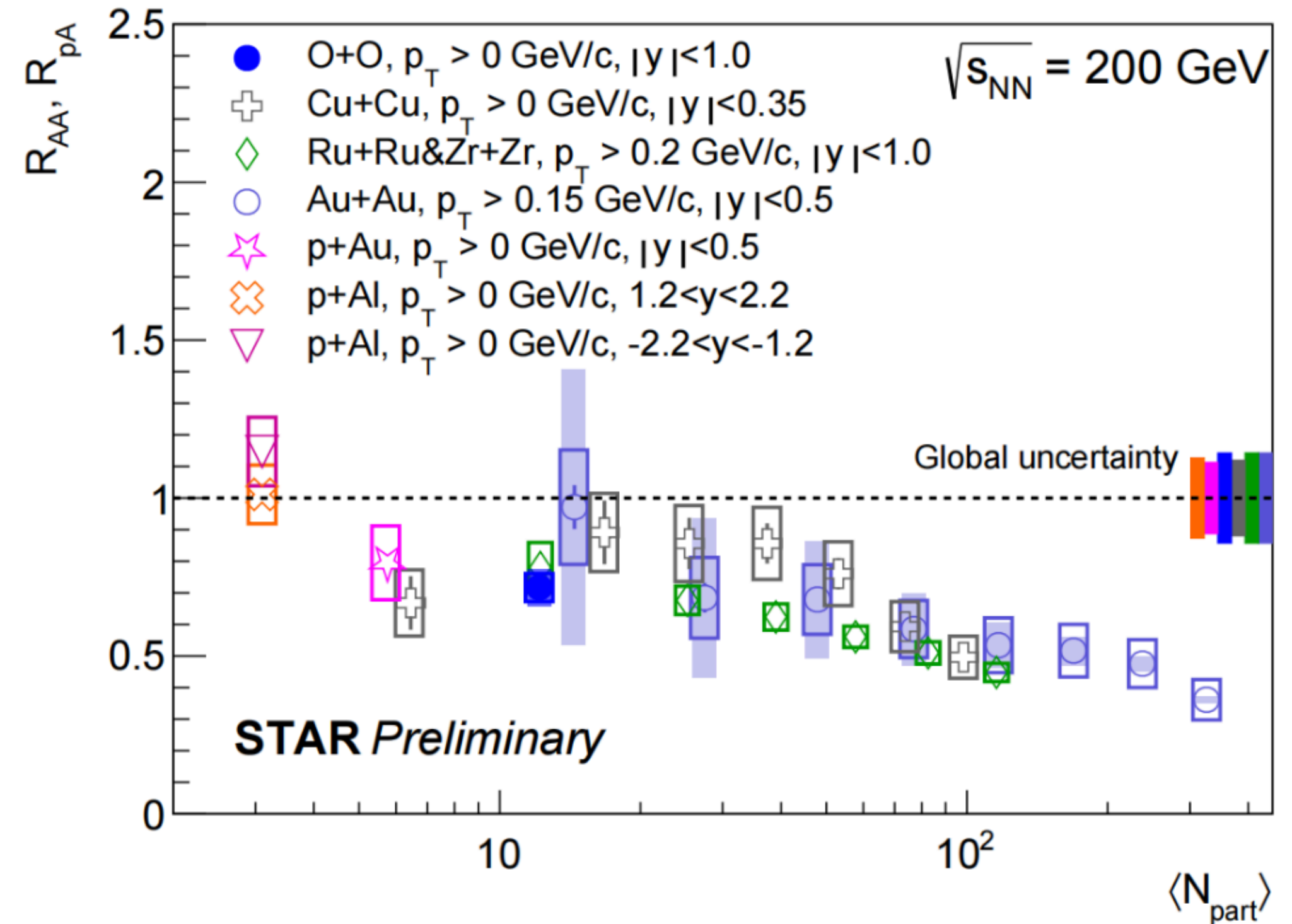
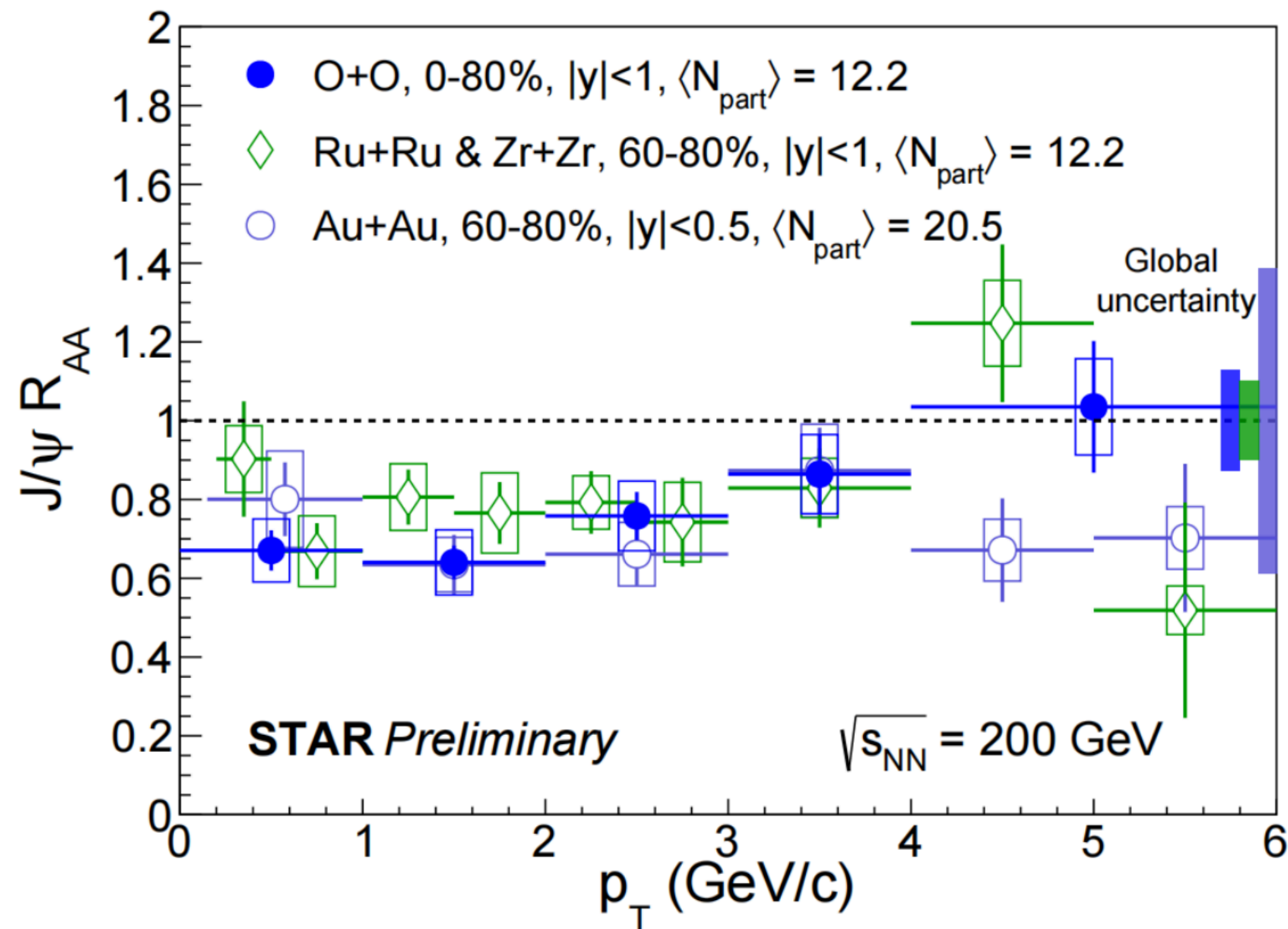
nPDF calculations suggest that p+O
and p+Al have comparable CNM effects



Additional suppression is observed in O+O relative to p+Al

Suggests the suppression is a QGP effect

System Size Dependence of J/ψ Suppression



- Across different collision systems, at similar $\langle N_{\text{part}} \rangle$, the R_{AA} suppression is similar

- $R_{AA}(R_{pA})$ decreases with increasing $\langle N_{\text{part}} \rangle$

No significant suppression is observed in p+A after accounting for CNM effects, while O+O shows additional suppression beyond CNM

Summary & Outlook



- Independent measurements consistently support the formation of QGP in O+O collisions at $\sqrt{s_{NN}} = 200$ GeV.
- What can we learn from the system size dependence?
 - Smooth trend across system size (collectivity, temperature, and strangeness production).
 - O+O breaks from p+A (jet quenching and J/ψ suppression).
- What else can we explore with the existing O+O data?
 - Run 2021: O+O $\sqrt{s_{NN}} = 200$ GeV, ~ 500 M events
 - Run 2026: O+O $\sqrt{s_{NN}} = 200$ GeV, ~ 745 M events, collected before RHIC completed operations (545M low-luminosity + 200M high-luminosity)
 - α -cluster, medium response, jet substructure...

Backup