

Search for the critical system size for jet quenching

聂茂武

2026年4月27日

STAR Collaboration, [arXiv:2604.13935](https://arxiv.org/abs/2604.13935)

2026

April 24-28

极端核物质前沿研讨会

Workshop on extreme nuclear matter frontiers

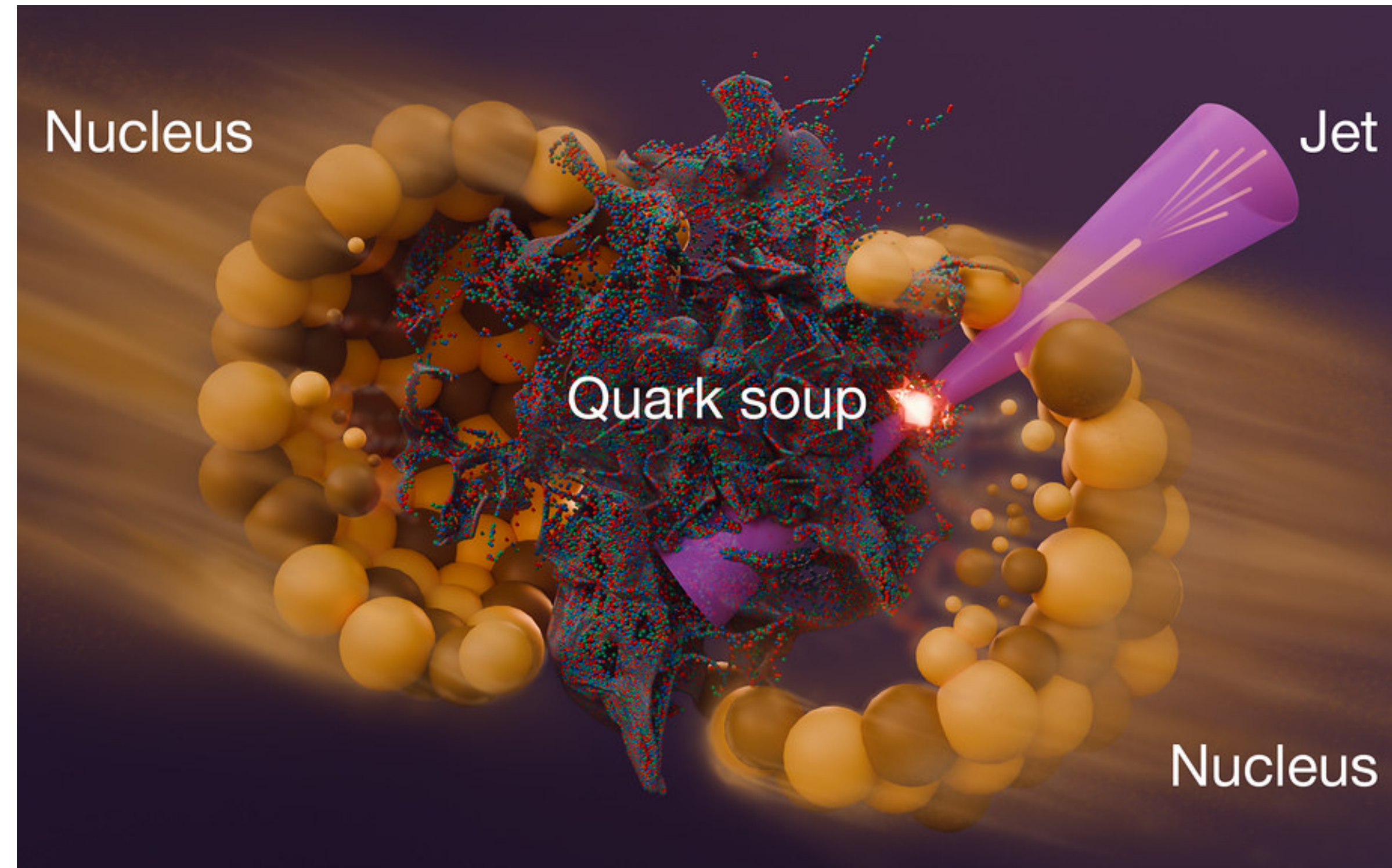
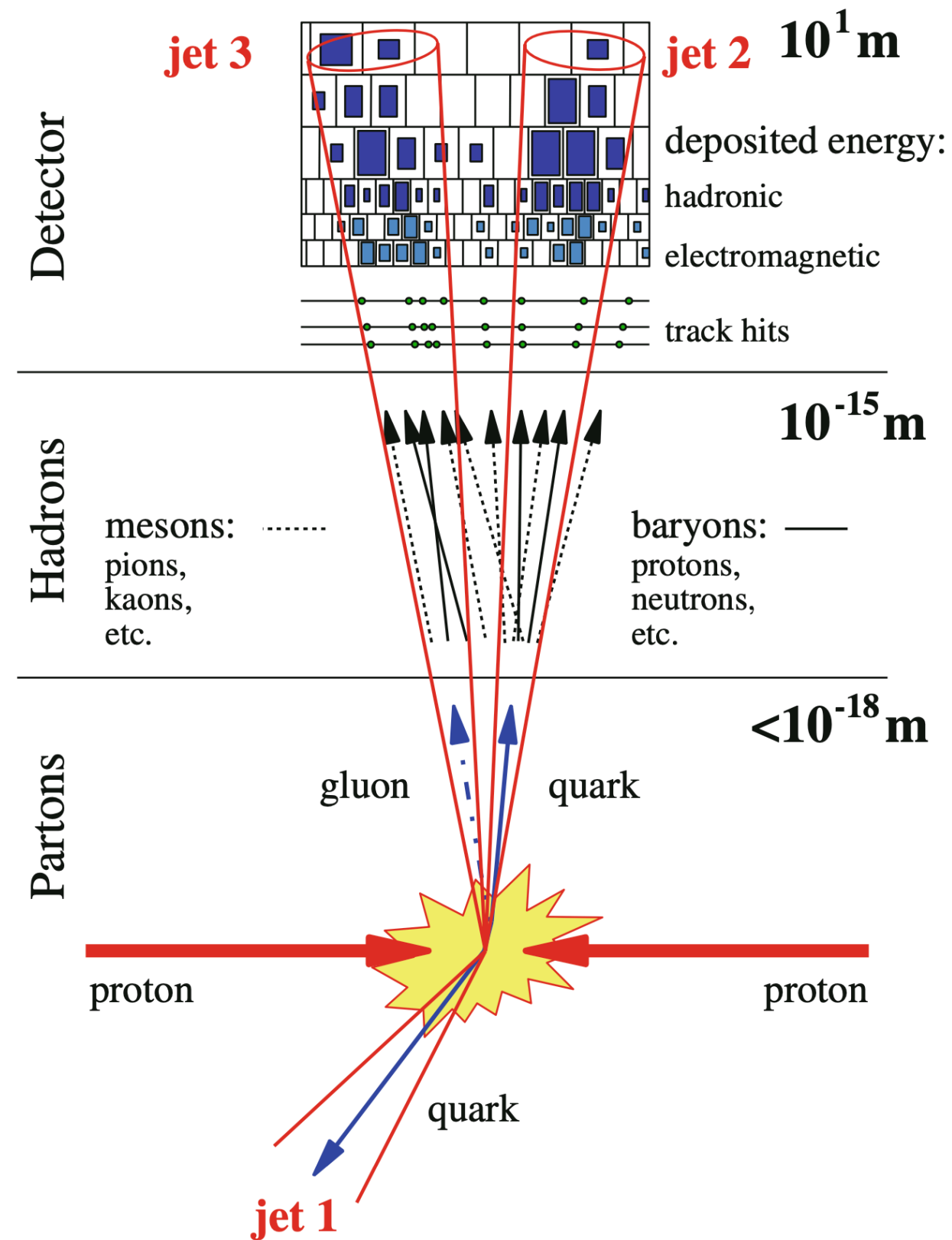


山东大学(青岛)

SHANDONG UNIVERSITY, QINGDAO

Jets in p+p and heavy-ion collisions

Jet: a collimated spray of particles originating from high p_T parton produced in initial hard scatterings.



- High energetic parton cannot be measured directly.
- Measure final state particles with jet reconstruction.

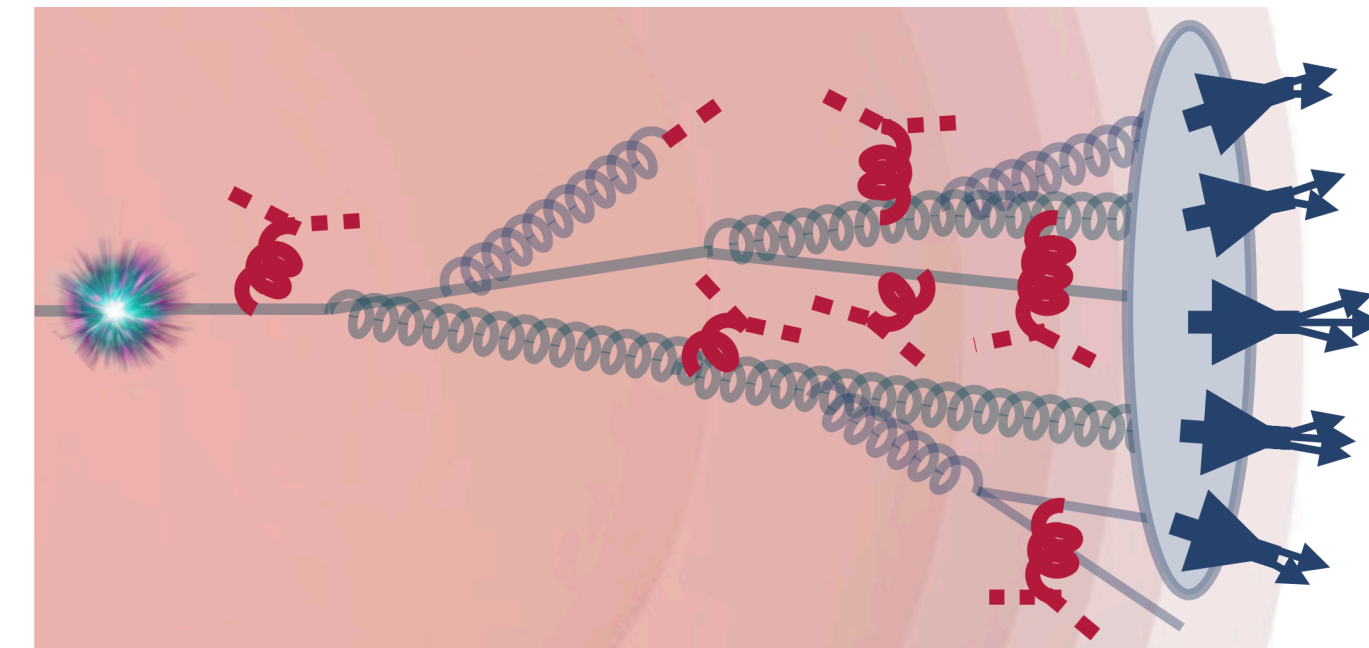
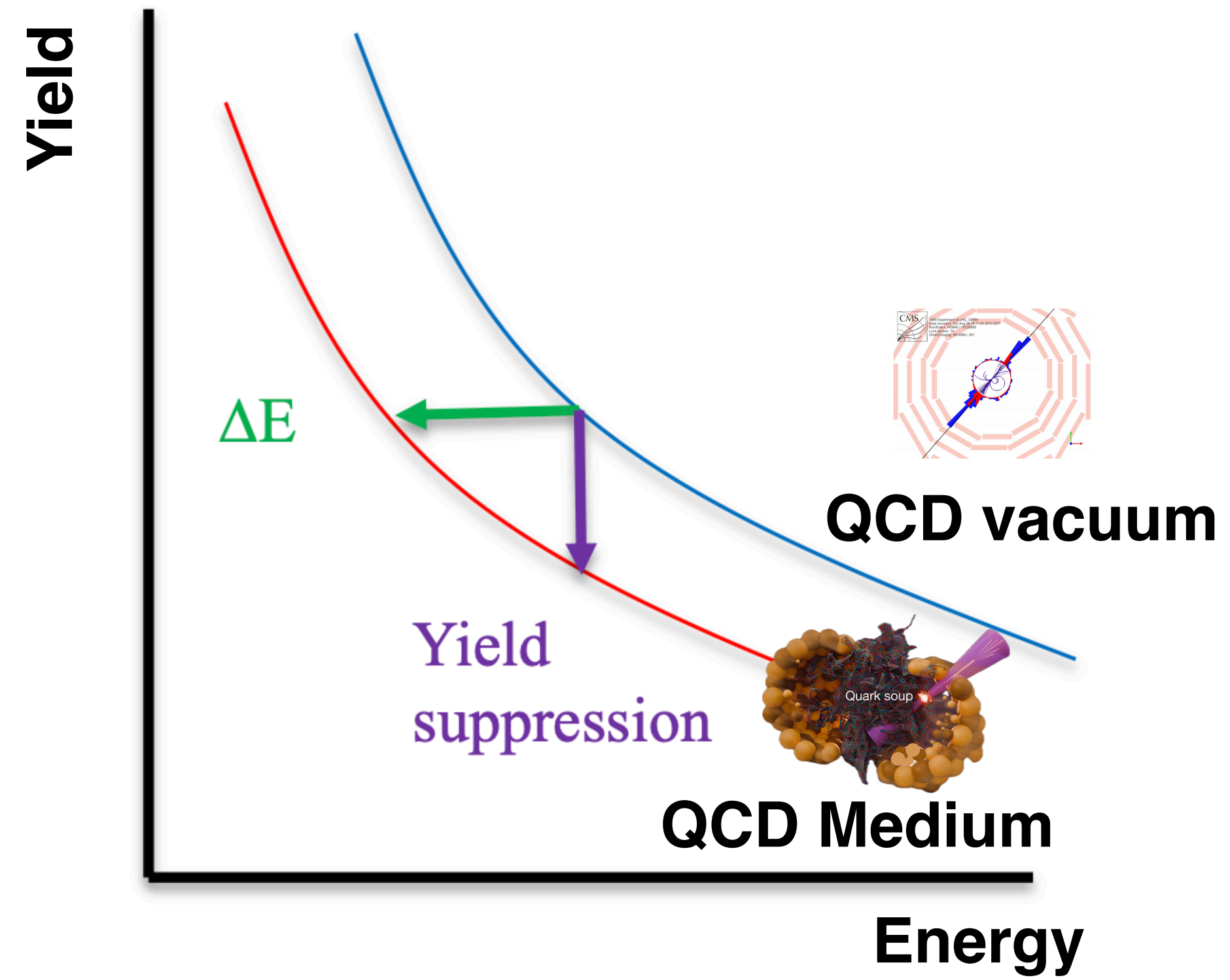
Key signature of QGP

Jet quenching: In medium parton energy loss

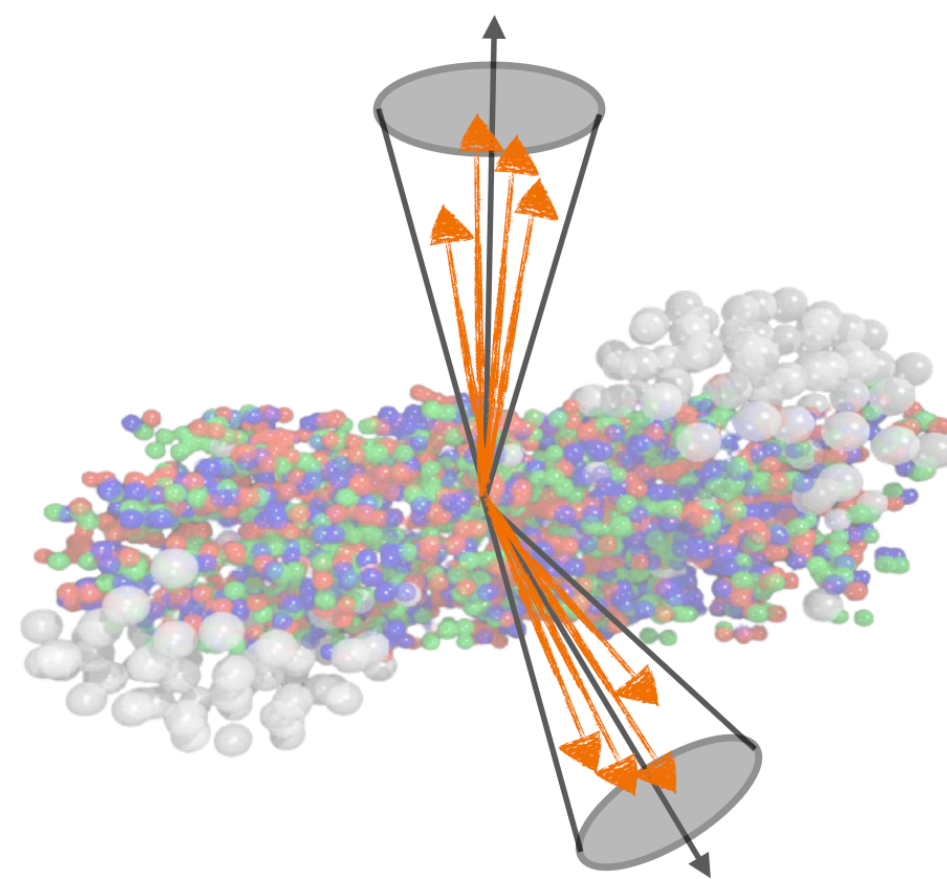
Jet quenching as a signature of QGP

Parton energy loss: leads to jet **yield suppression** in A+A collisions in comparison to p+p.

Medium response: medium-induced jet modification.



Modification of jet substructure



Deflection of the jet induced by multiple scatterings or single hard scatterings with QGP quasi-particles?

Where does the quenched energy go?

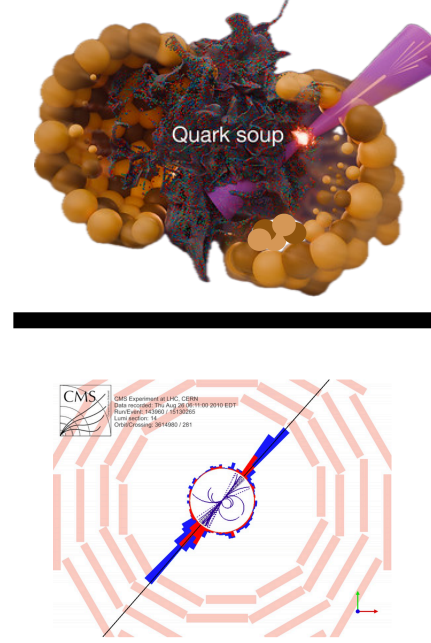
Jet quenching in A+A collisions

X. N. Wang and M. Gyulassy, Phys. Rev. Lett. 68 (1992) 1480-1483

X. N. Wang, Phys. Rev. C 58 (1998) 2321

Nuclear modification factor

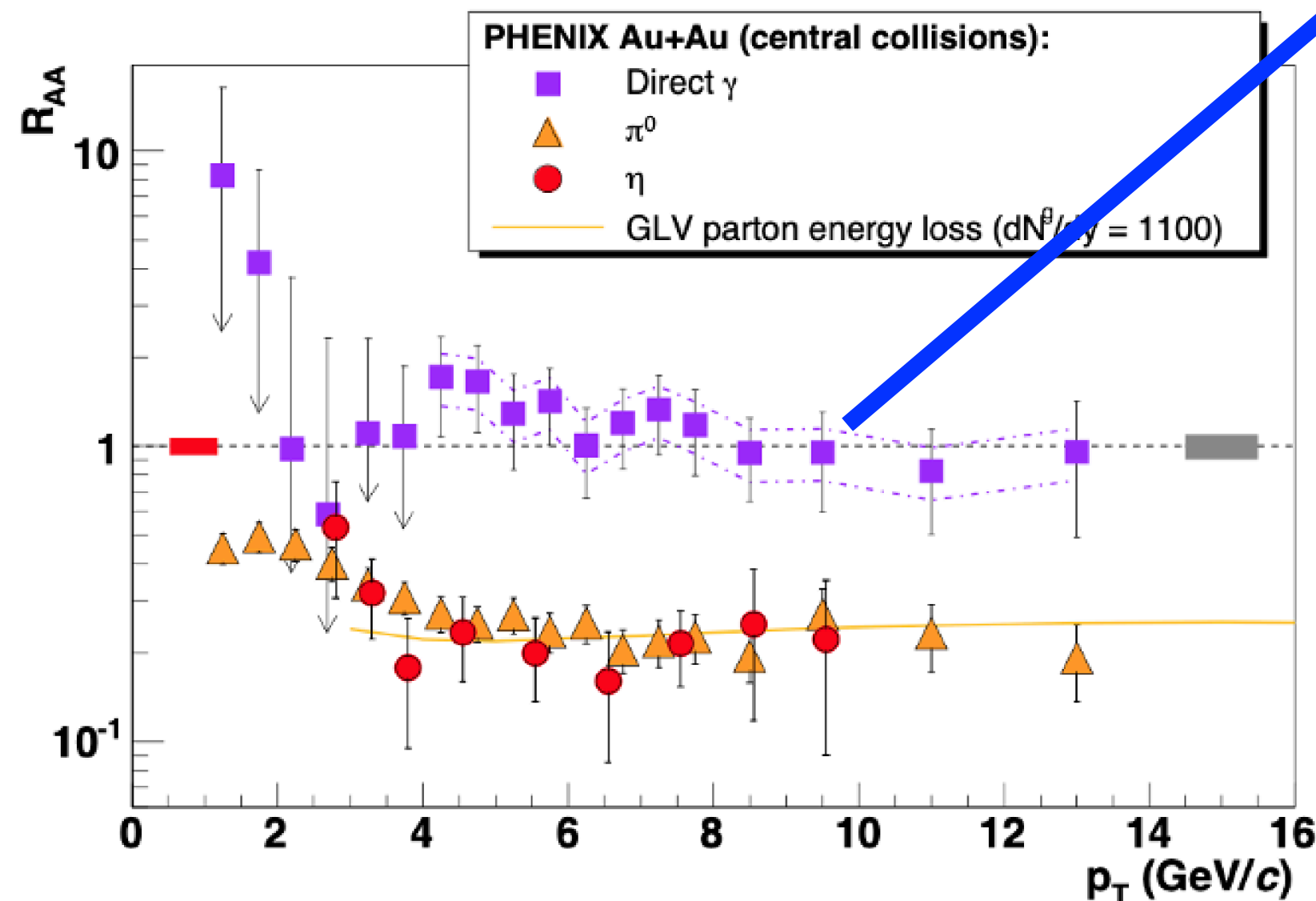
$$R_{AA} = \frac{\sigma_{pp}^{inel} d^2 N_{AA} / dp_T d\eta}{N_{coll} d^2 \sigma_{pp} / dp_T d\eta} \sim$$



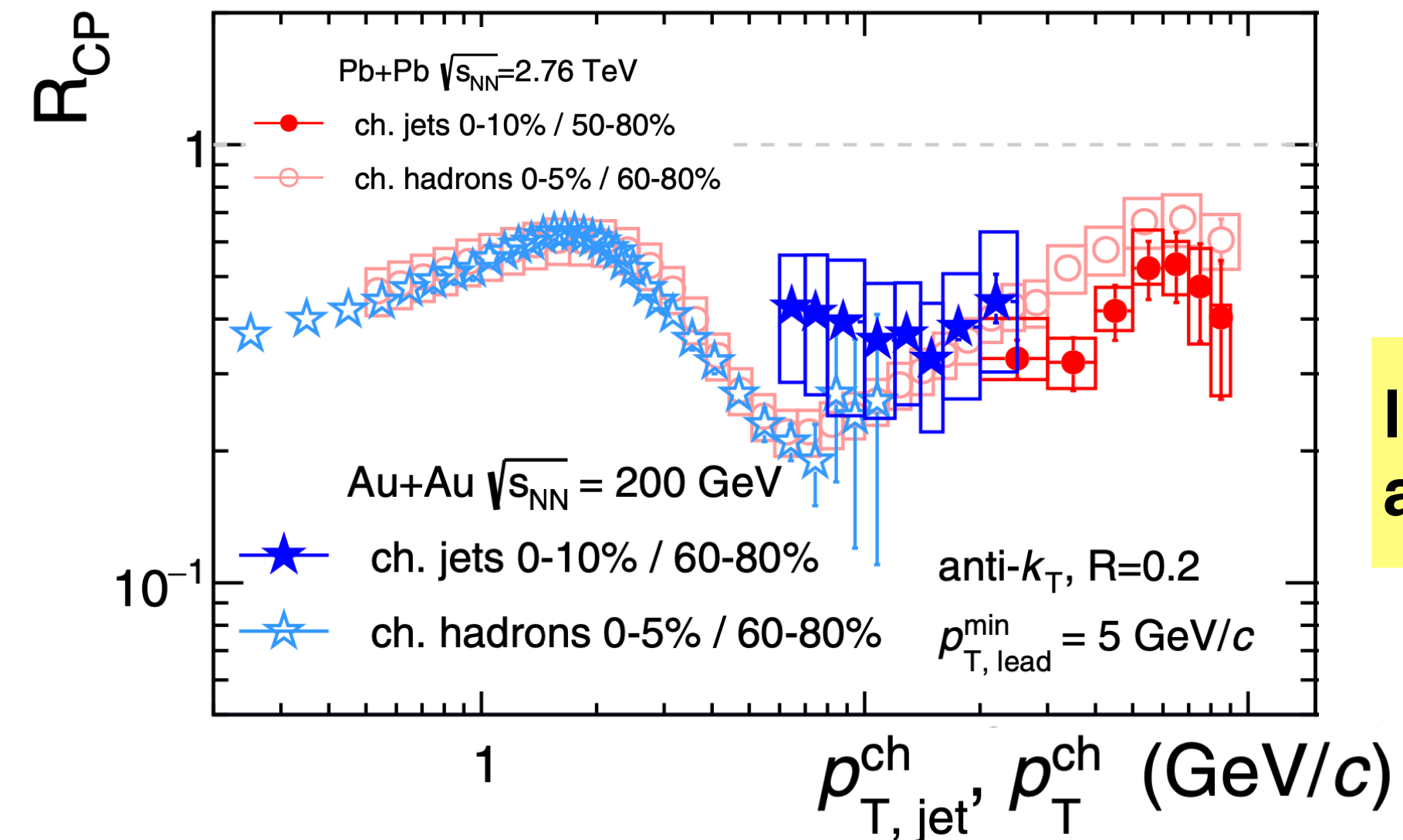
$R_{AA} > 1$ (enhancement)
 $R_{AA} = 1$ (no medium effect)
 $R_{AA} < 1$ (suppression)

Colorless probes validate the Ncoll scaling.

PHENIX, Phys. Rev. Lett. 109 (2012) 152302



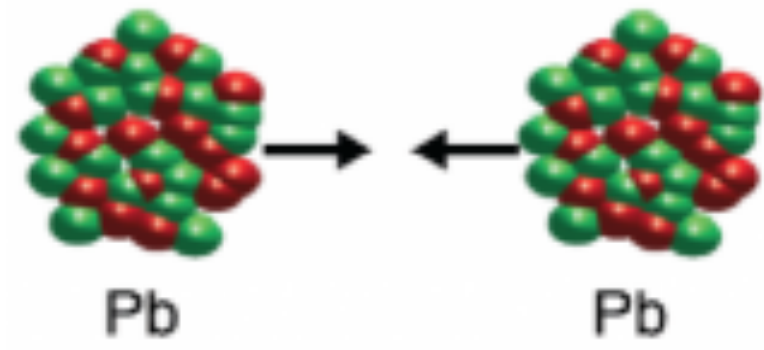
STAR Collaboration, Phys. Rev. C 102, 054913 (2020)



largely consistent across experiments

Jet quenching in A+A is seen clearly by inclusive suppression measurements.

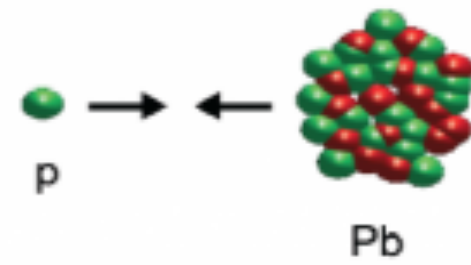
“Ridge” from large to small systems



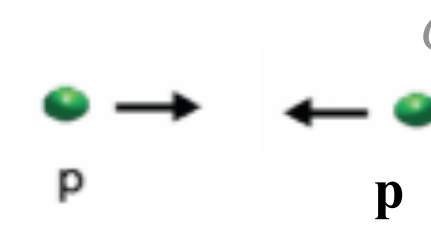
Pb Pb



CMS, PLB 718, 795 (2013)



CMS, PRL 116, 172302 (2016)

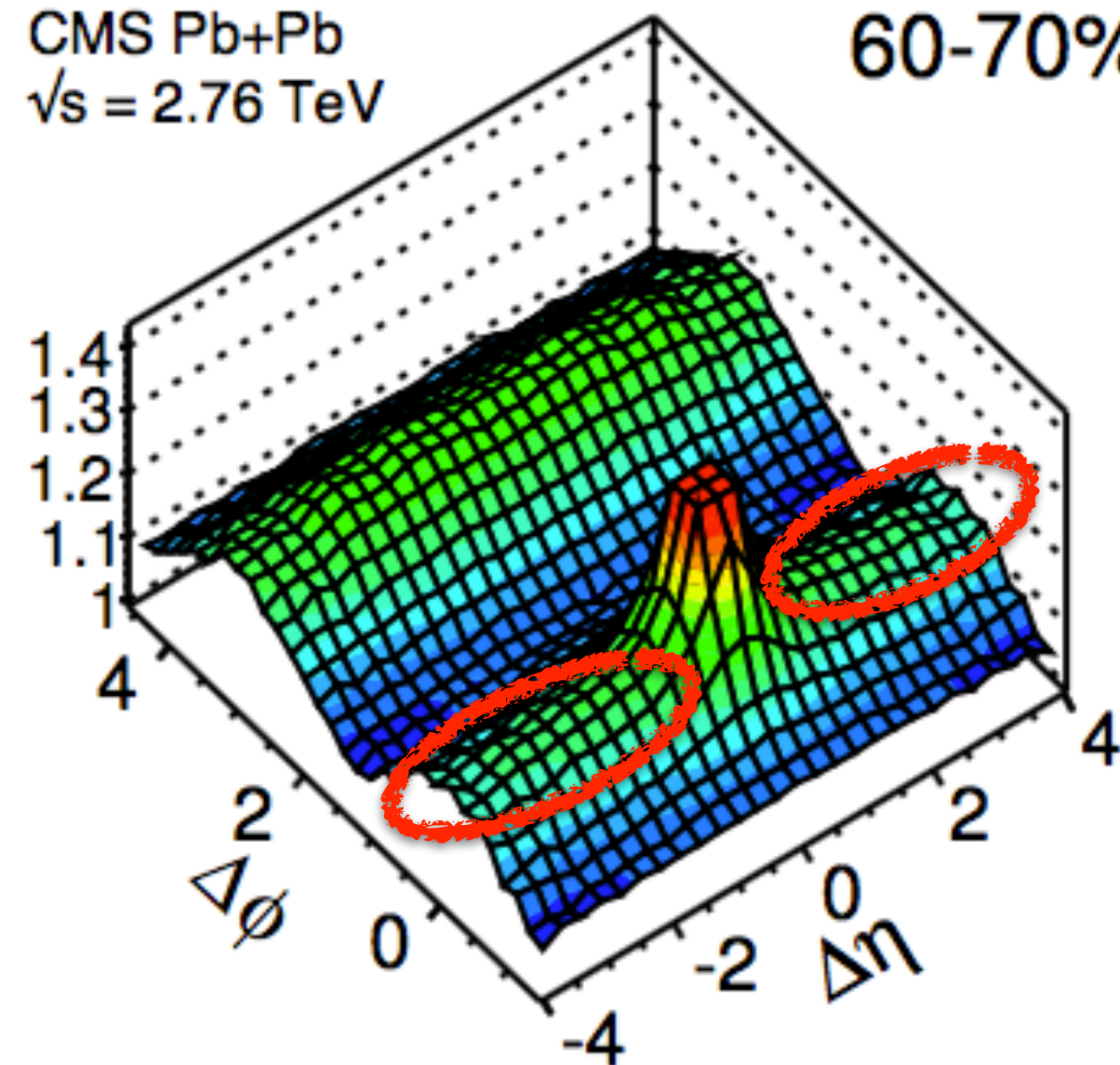


Credit: J. Schukraft, NBI 2017

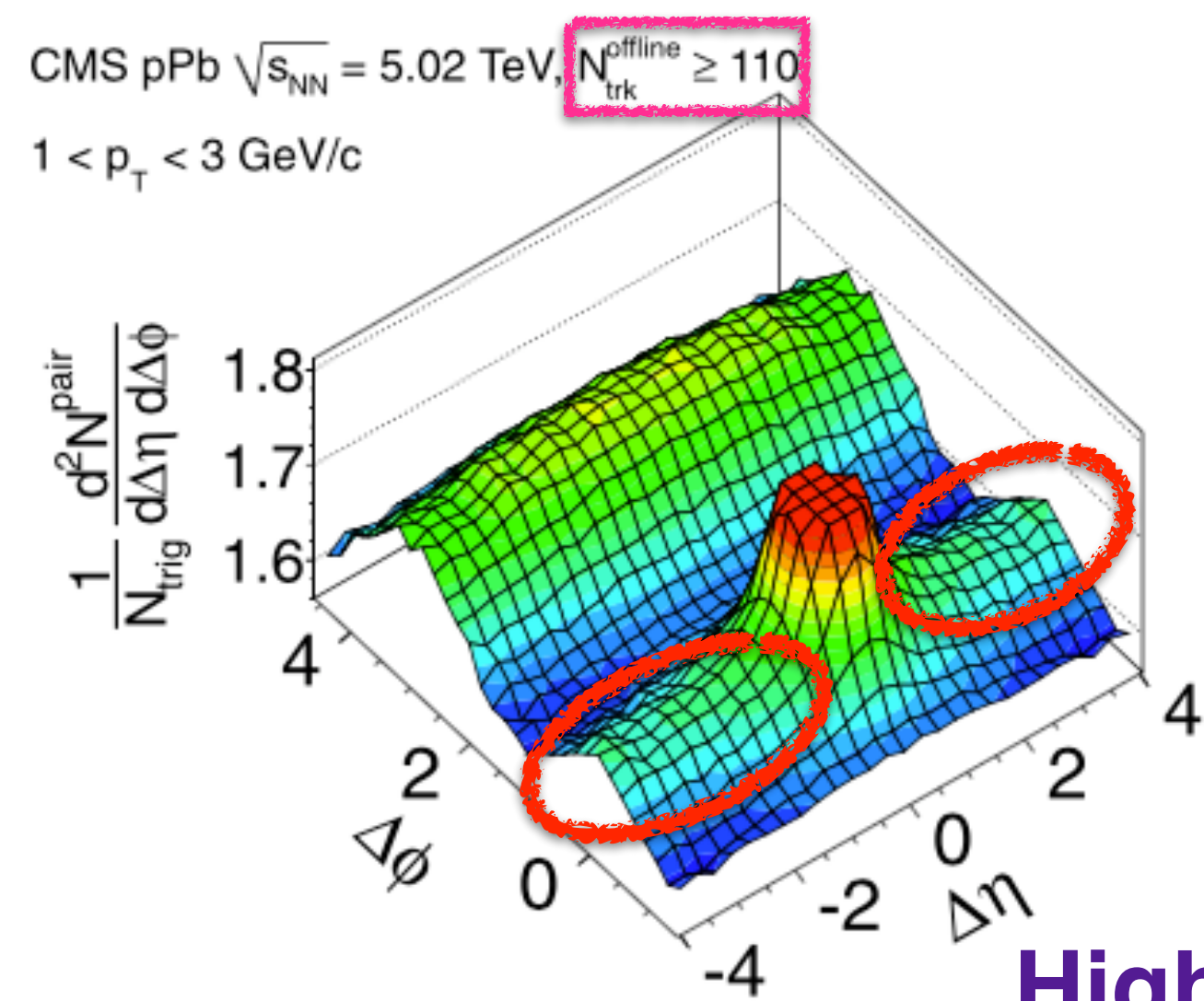


CMS, EPJC 72, 2012 (2012)

CMS Pb+Pb
 $\sqrt{s} = 2.76$ TeV
60-70%

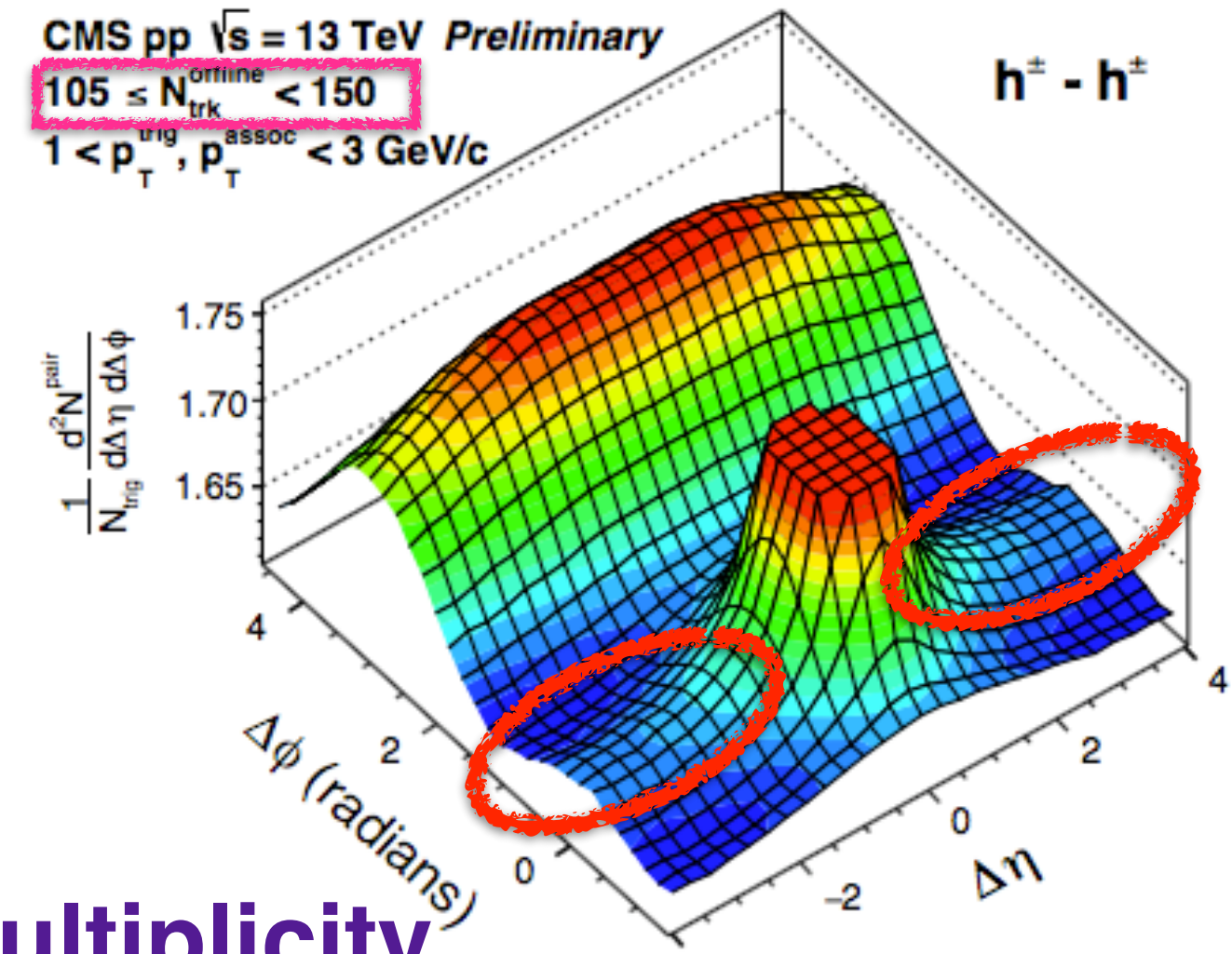


CMS pPb $\sqrt{s_{NN}} = 5.02$ TeV, $N_{trk}^{offline} \geq 110$
 $1 < p_T < 3$ GeV/c



High Multiplicity

CMS pp $\sqrt{s} = 13$ TeV Preliminary
 $105 \leq N_{trk}^{offline} < 150$
 $1 < p_T^{trig}, p_T^{assoc} < 3$ GeV/c

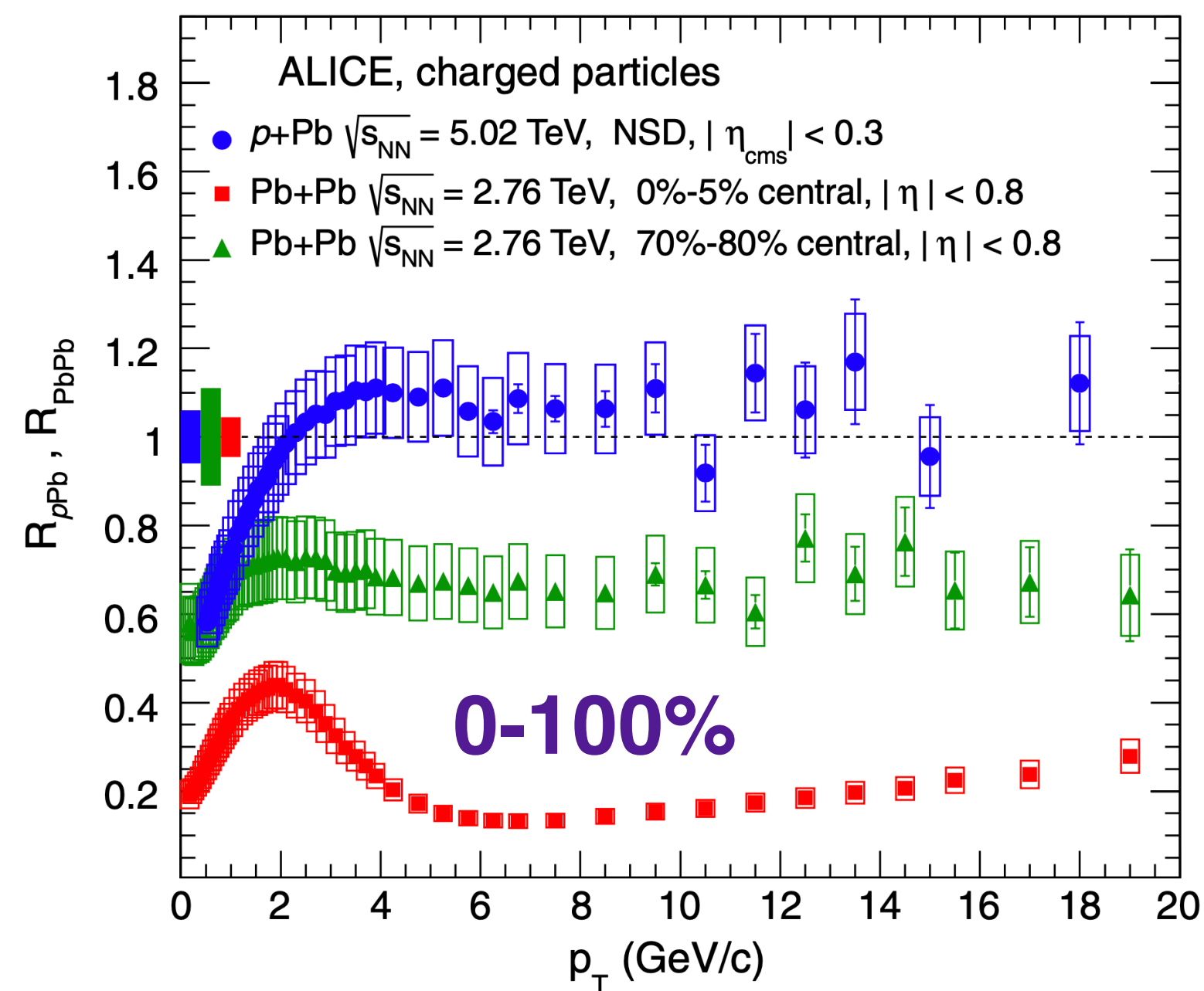


Do we also observe **jet quenching** in small systems?

Inclusive measurements in small systems

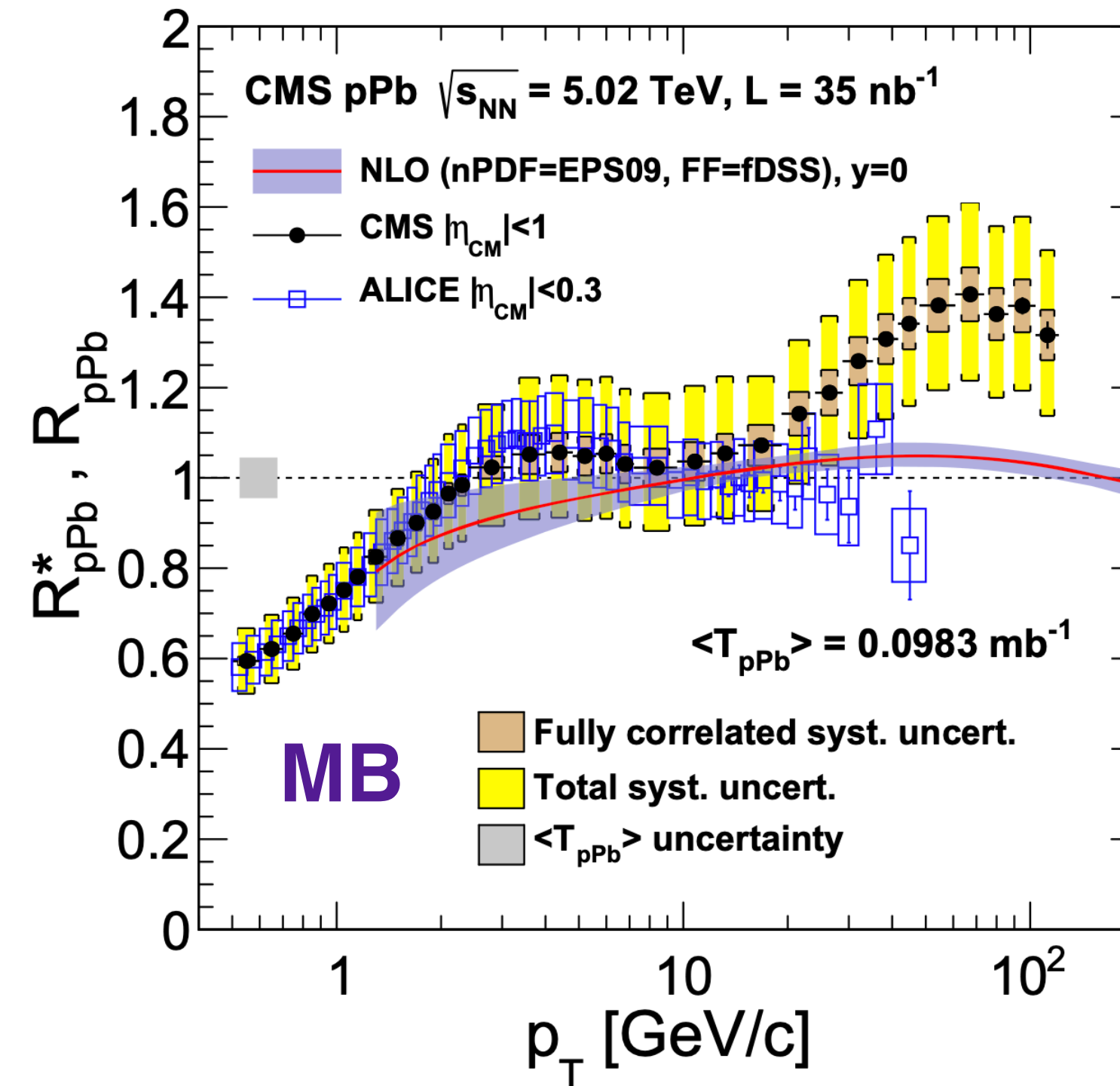
inclusive charged hadron

ALICE, Phys. Rev. Lett. 110, 082302 (2013)



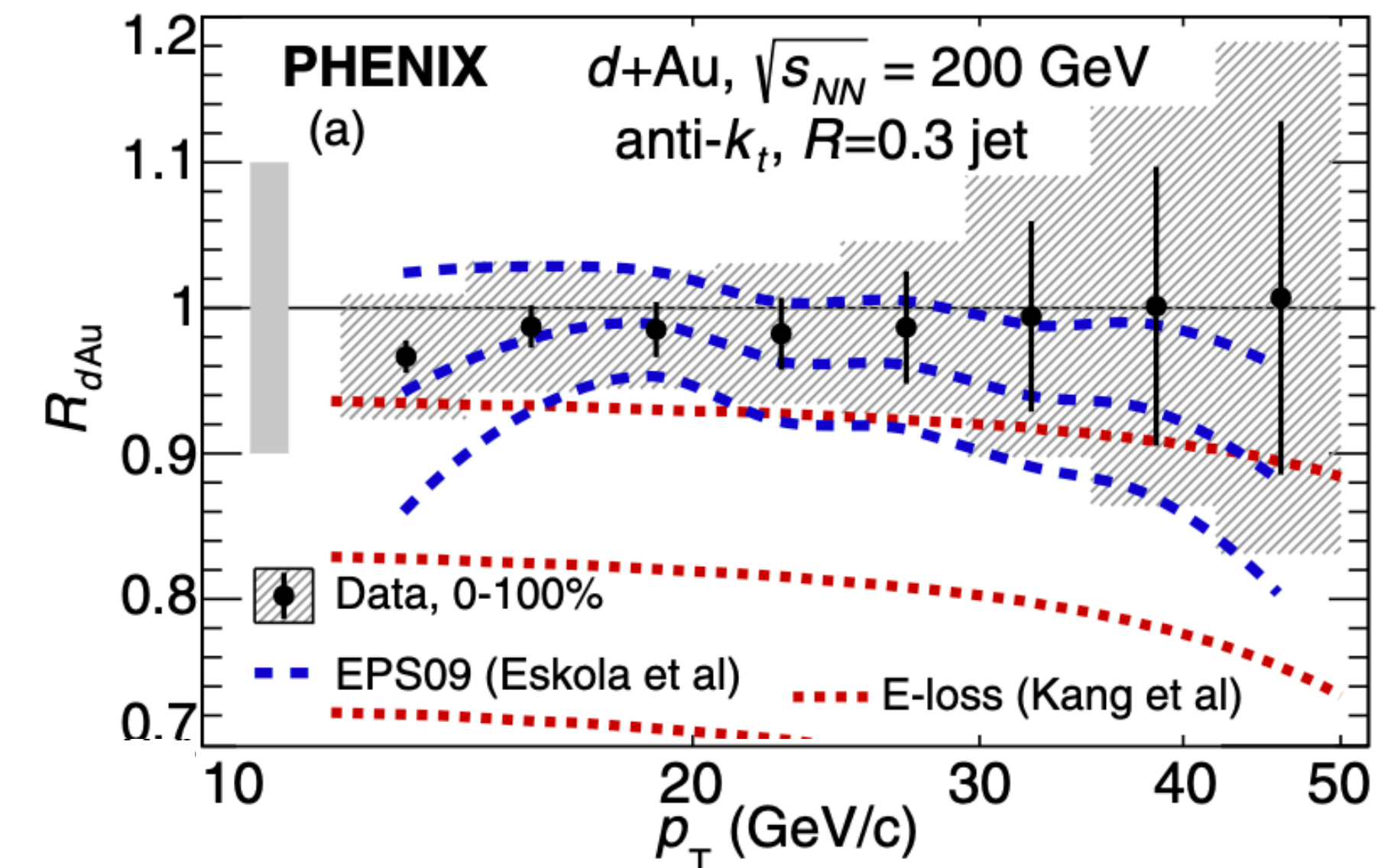
inclusive charged hadron

CMS, Eur. Phys. J. C (2015) 75:237



inclusive jet

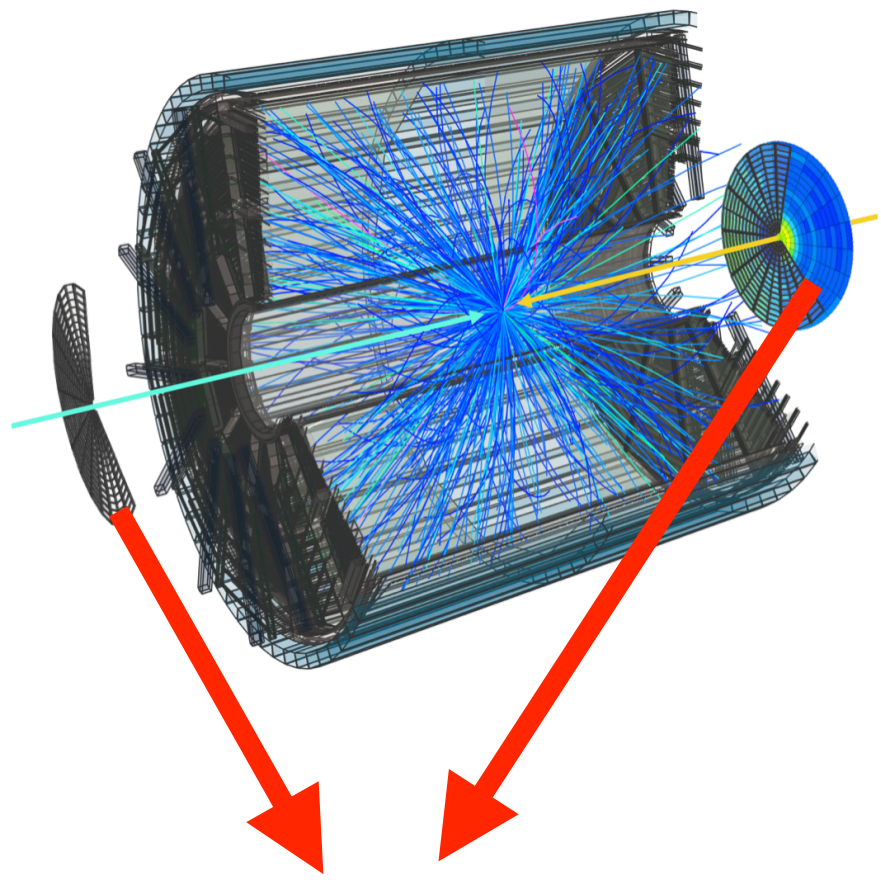
PHENIX, Phys. Rev. Lett. 116, 122301 (2016)



● $R_{pPb/dAu} \approx 1 \rightarrow$ No significant suppression in p/d+A collisions.

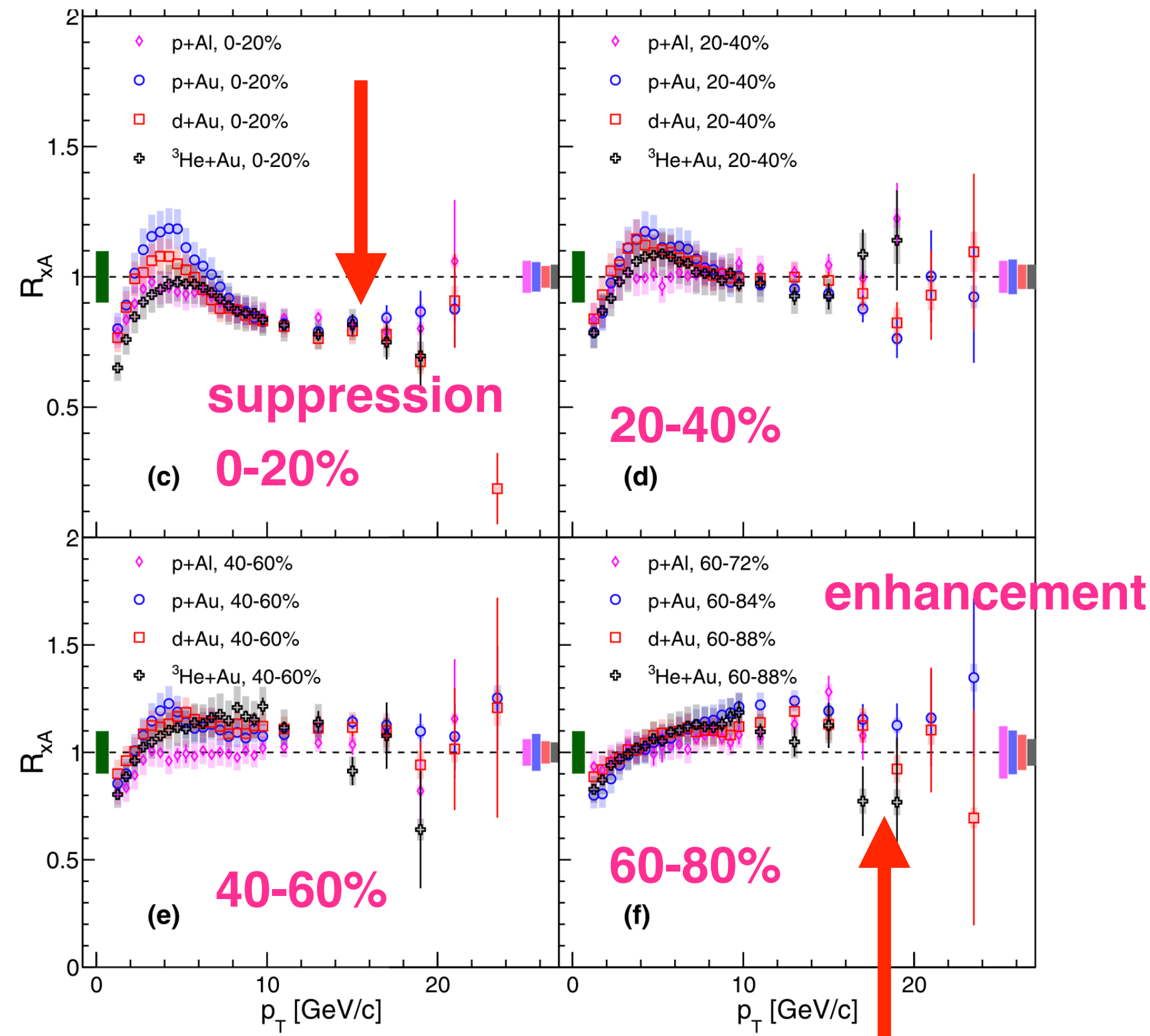
● \Rightarrow Investigate **high event activity** to enhance sensitivity to possible medium effects.

Inclusive measurements with EA selection

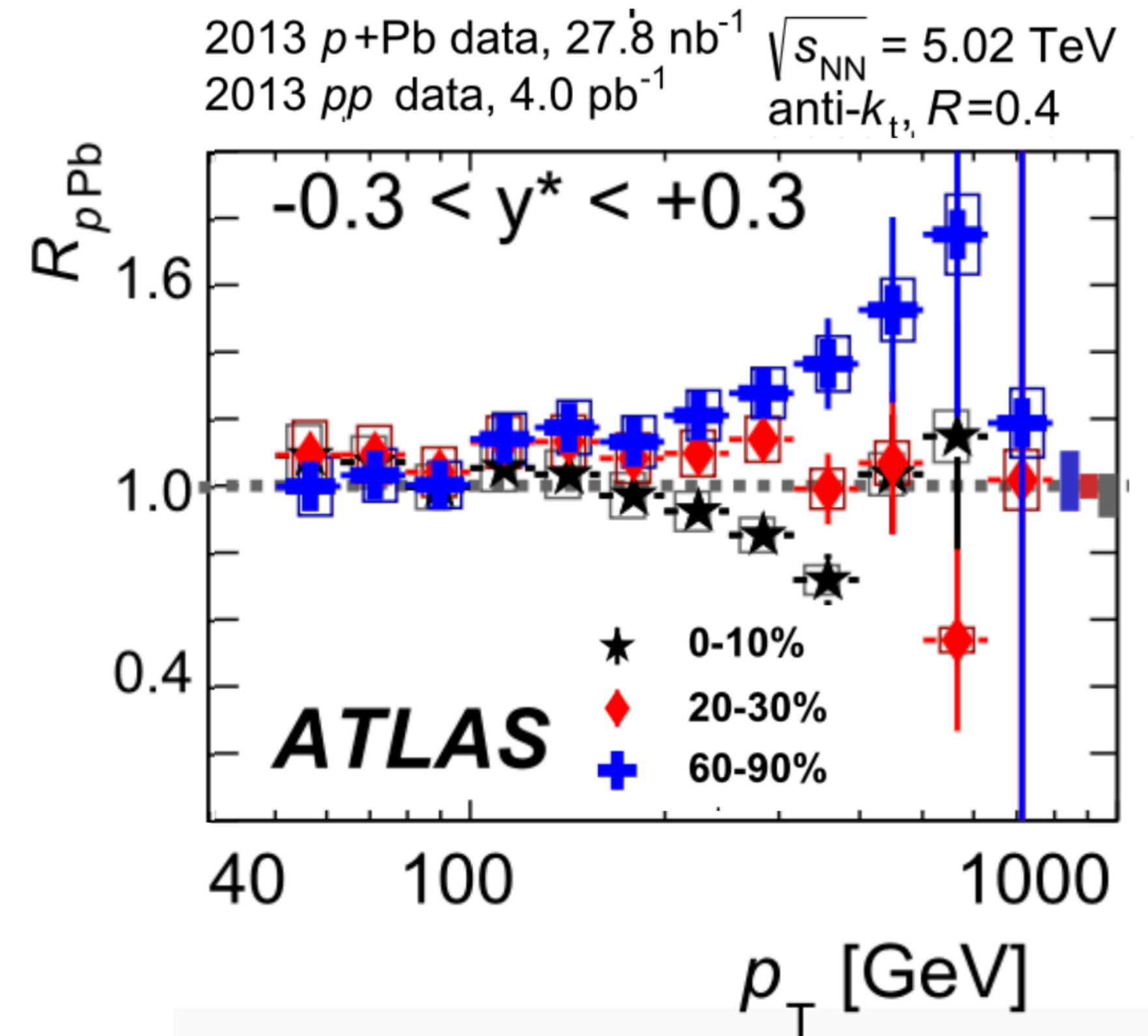


“Event activity” (EA) in small collisions using forward detector to avoid auto-correlation.

PHENIX, Phys. Rev. C 105, 064902 (2022)

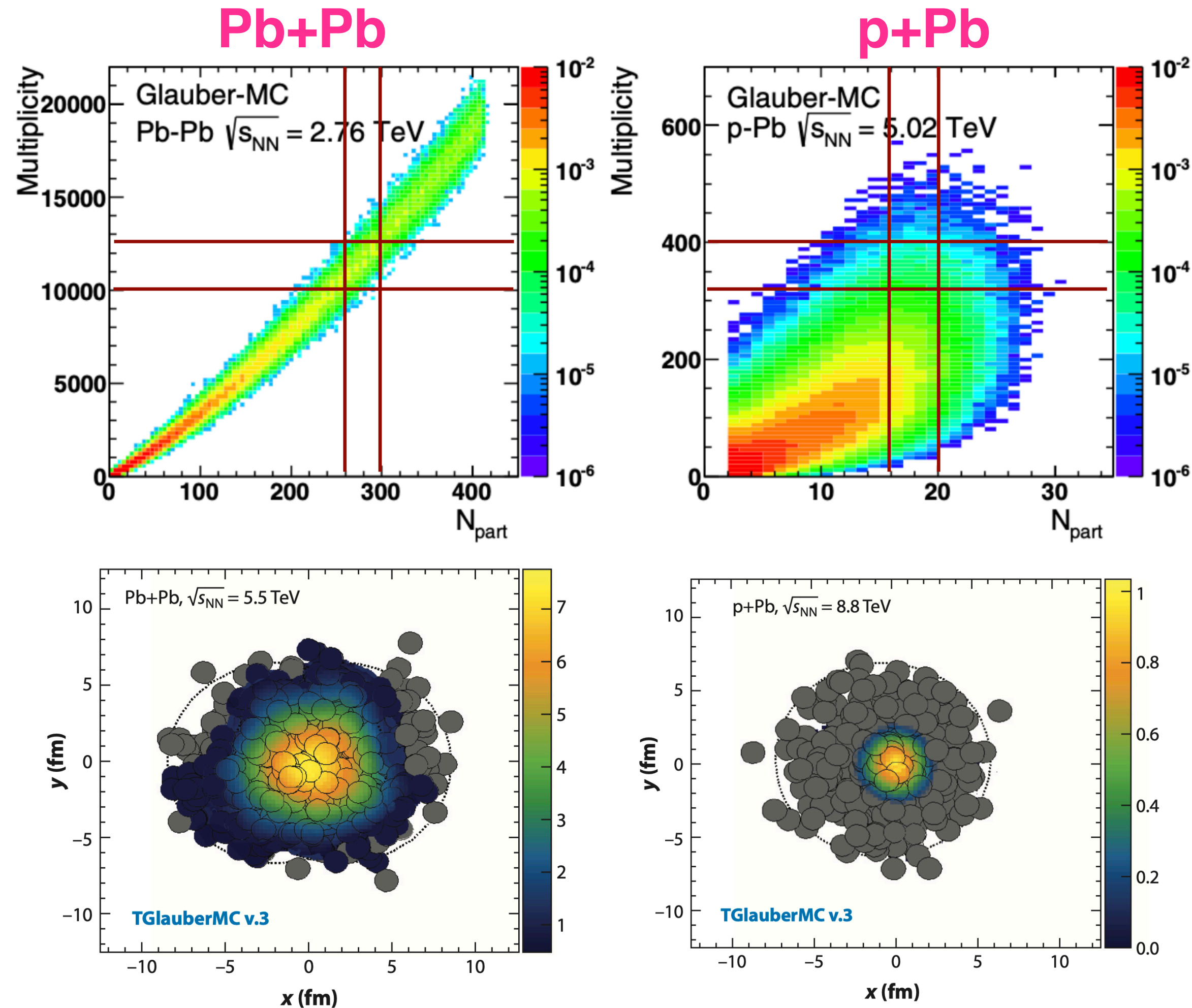


ATLAS, Physics Letters B748 (2015) 392–413



- Apparent suppression in high EA and enhancement in low EA — but the interpretation is not as straightforward as in A+A collisions.
- Medium-induced energy loss or EA selection bias?

Event selection in small system

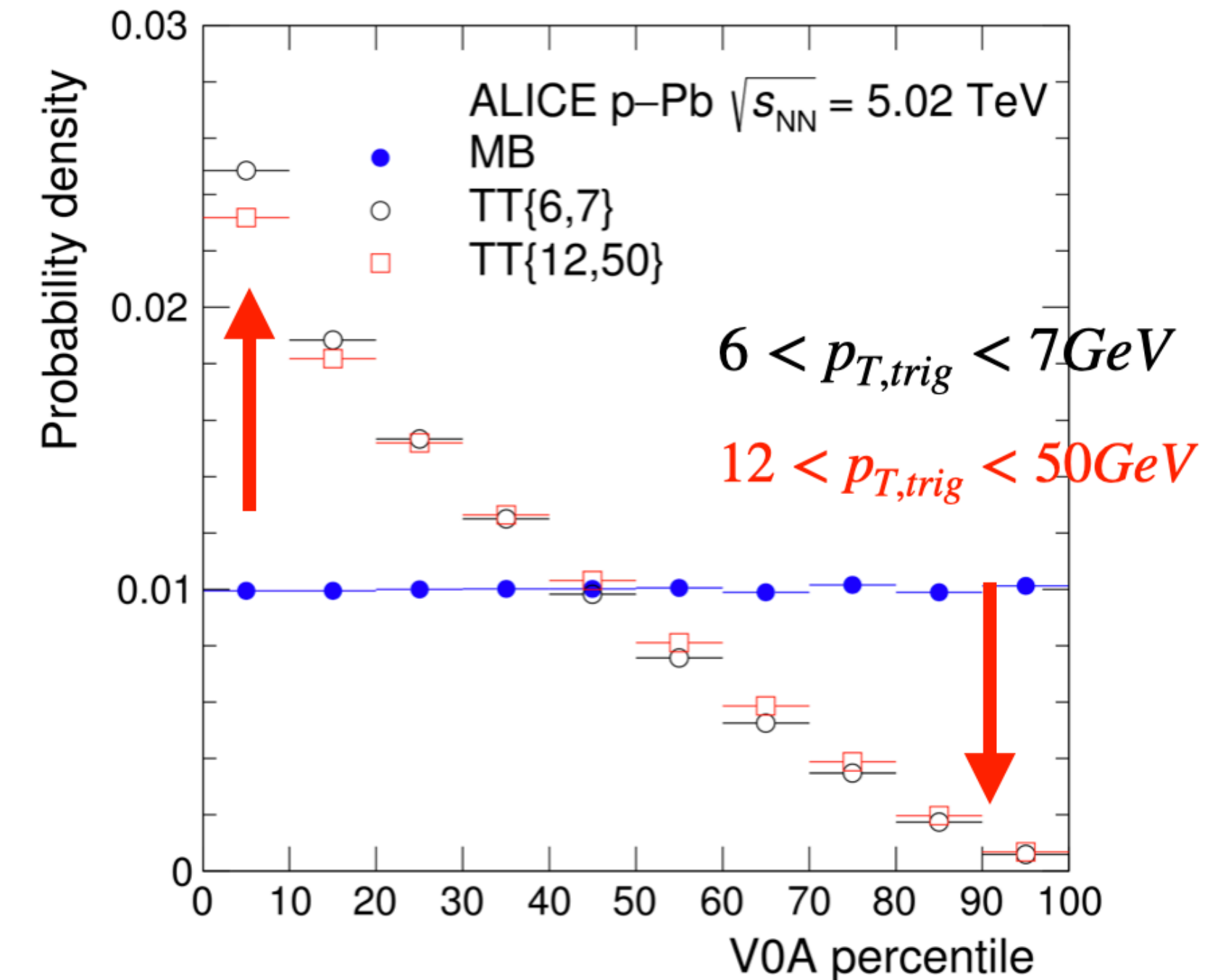


$$R_{AB} = \frac{1}{N_{coll}} \frac{Yield_{AB}}{Yield_{pp}}$$

$Yield_{AB}$ correctly reflect
“central” events?

N_{coll} scaling holds for small
systems?

EA and Q^2 correlation

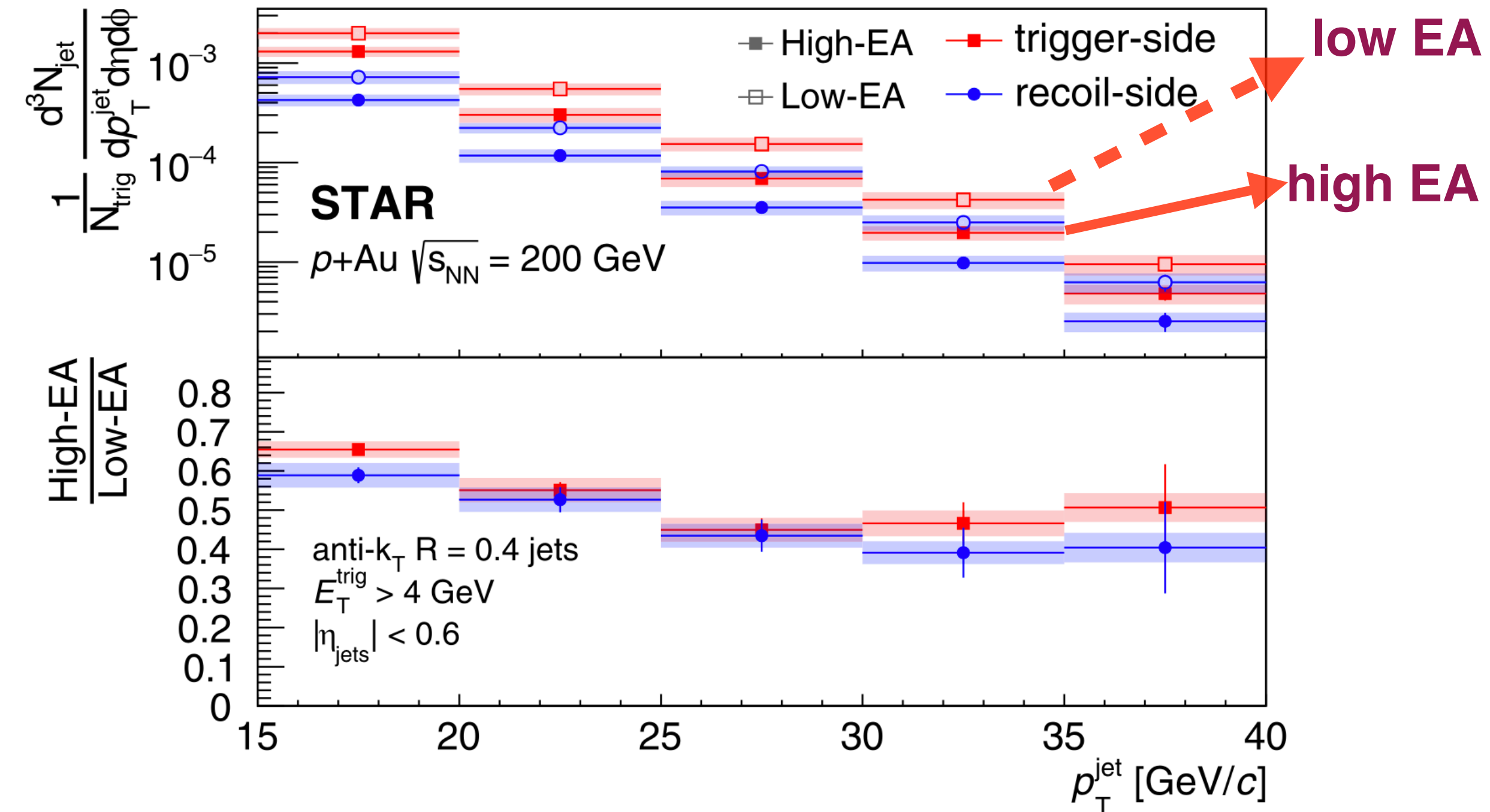
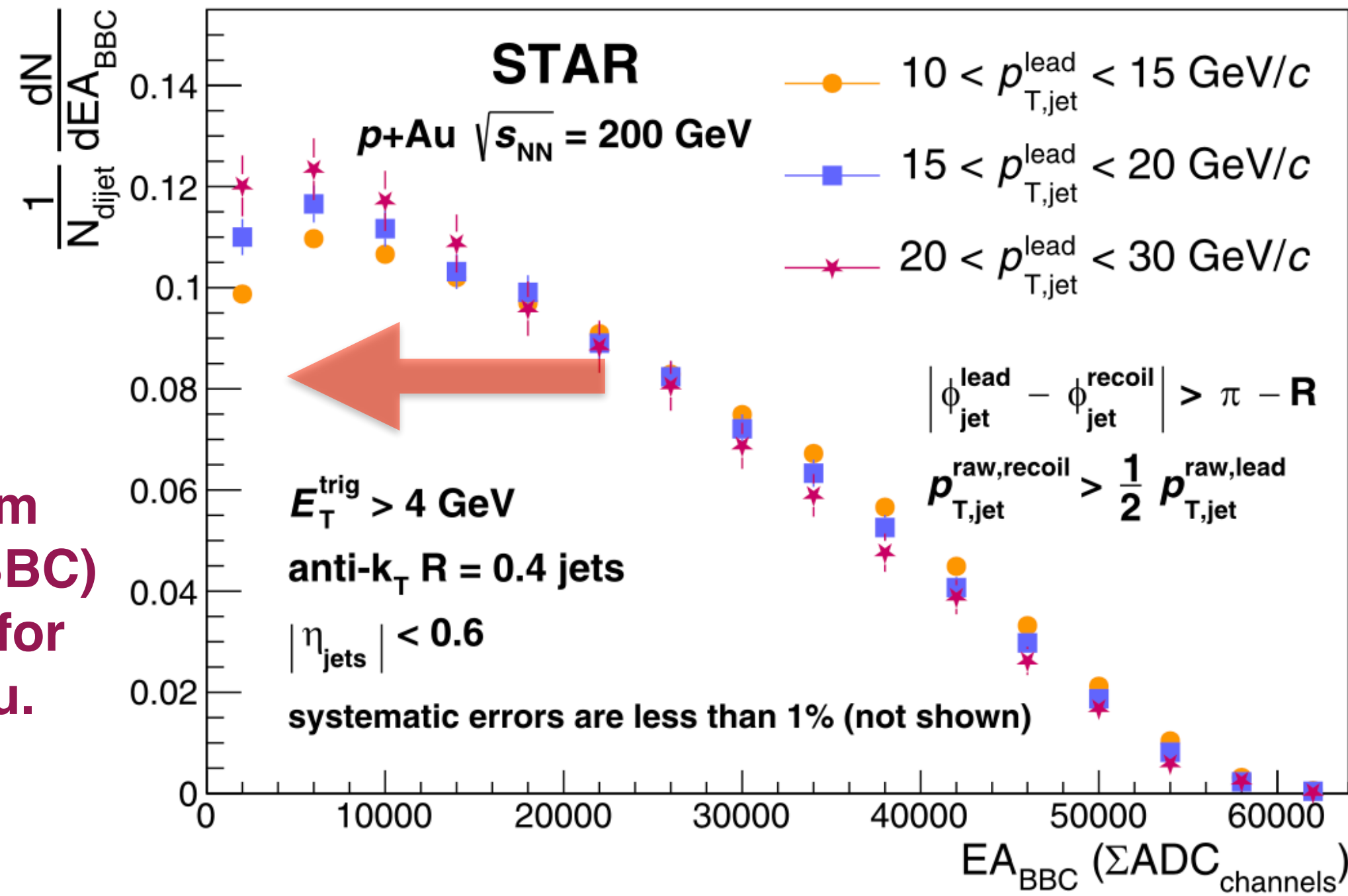


- EA reflects the collision geometry in Pb+Pb but not for p+Pb.
- Large fluctuation also biased N_{coll} .

- EA is largely biased with high p_T trigger.
- What else?

EA and Q^2 anti-correlation in p+Au

STAR, Phys. Rev. C 110, 044908 (2024)



Beam-beam counter (BBC) is utilized for EA in p+Au.

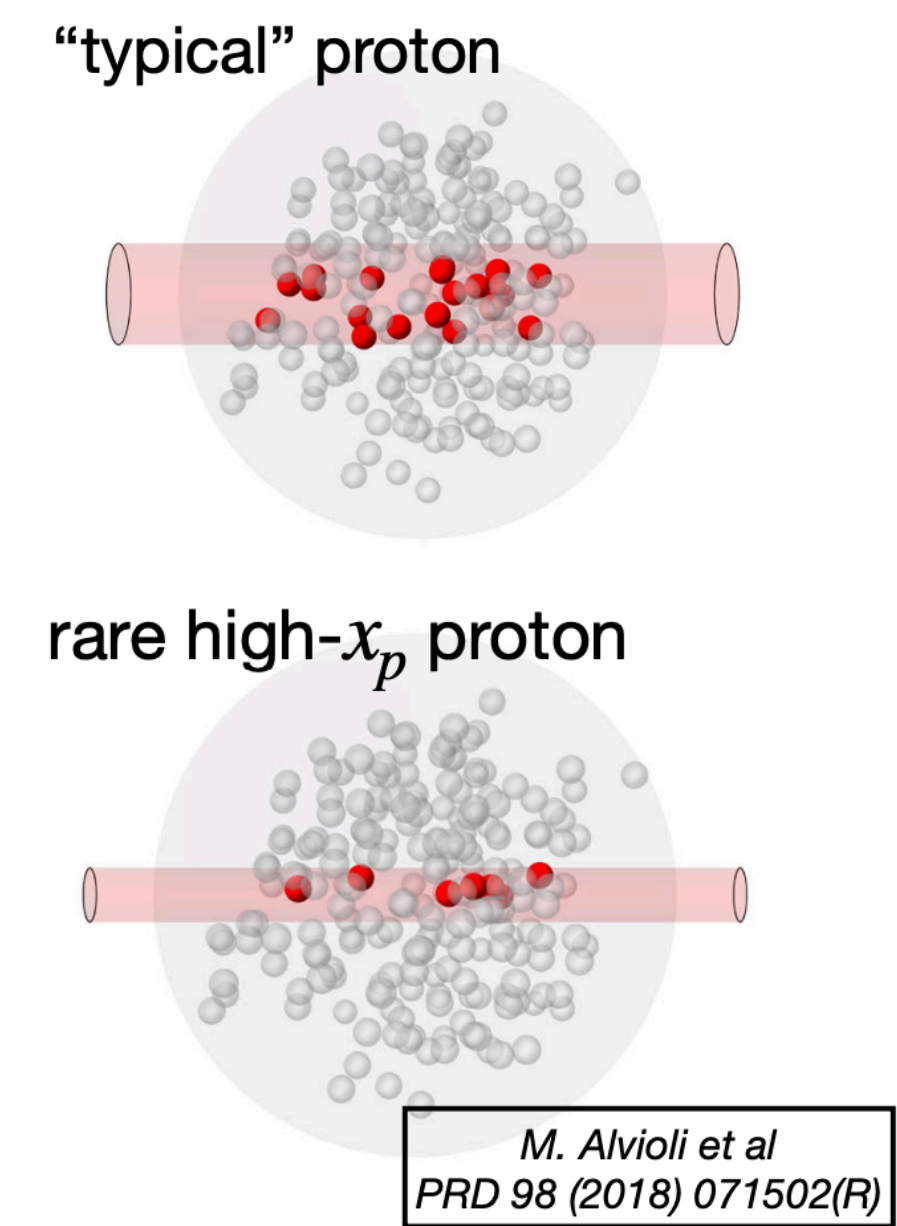
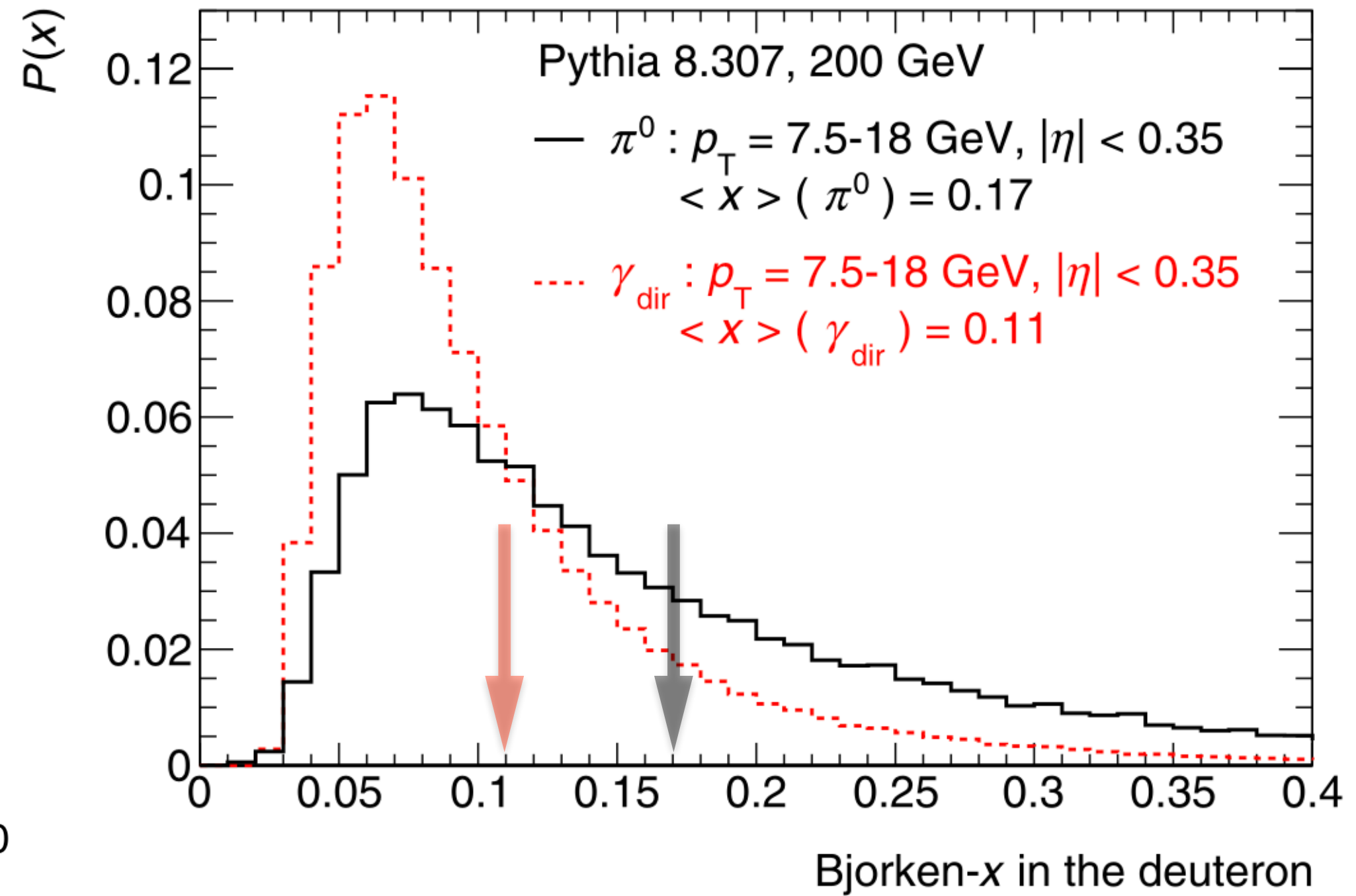
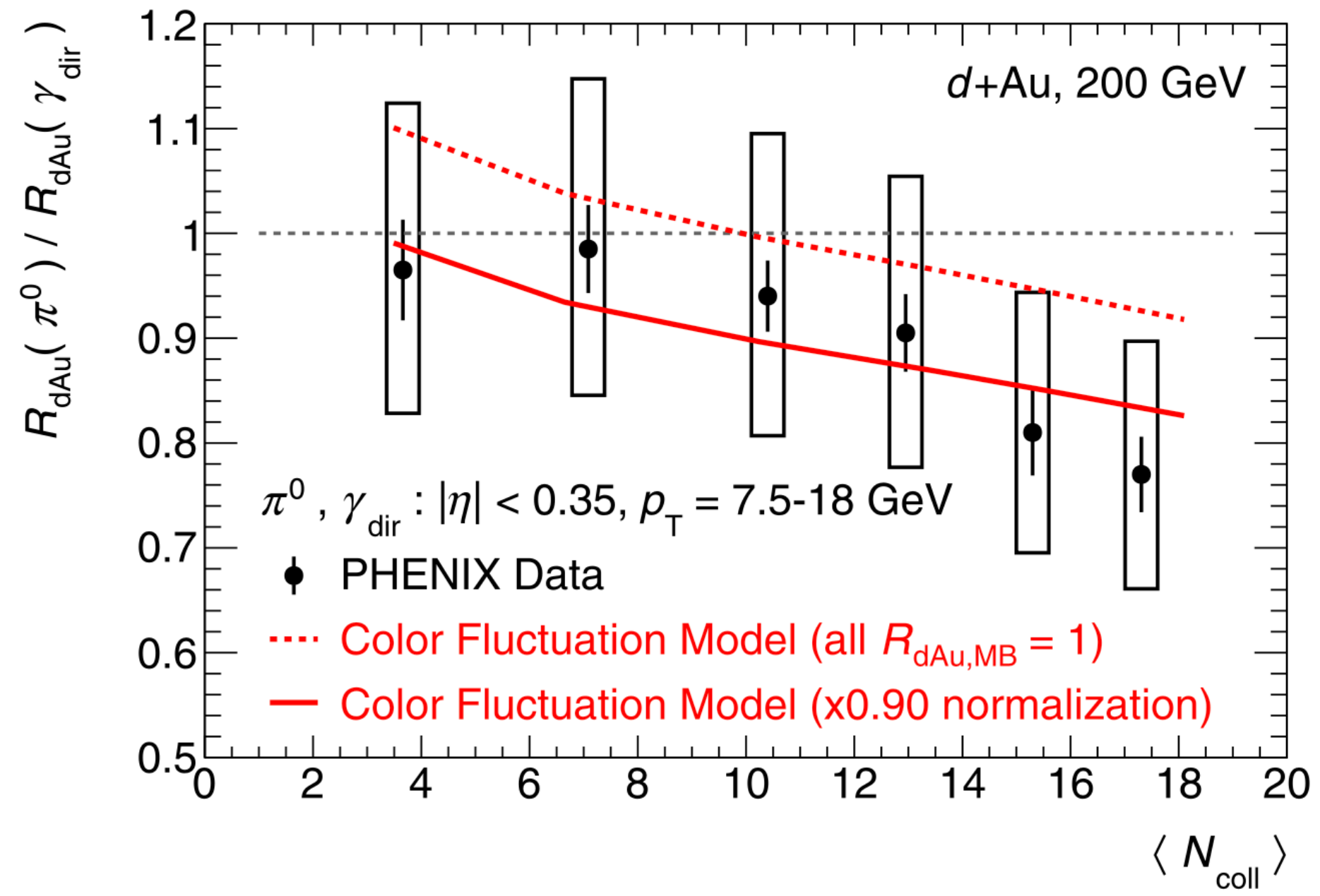
- Systematic shift of the multiplicity distribution toward lower EA with increasing high p_T trigger.
- EA and Q^2 **anti-correlation**: hard scattering yields are overestimated at high EA and underestimated at low EA.
- Similar suppression observed for both trigger and recoil side.**

Evidence of jet quenching in d+Au?

$$R_{dAu}(\pi^0)/R_{dAu}(\gamma_{dir}) = \frac{\frac{1}{N_{coll}} Y_{dAu}^{\pi^0} / Y_{pp}^{\pi^0}}{\frac{1}{N_{coll}} Y_{dAu}^{\gamma_{dir}} / Y_{pp}^{\gamma_{dir}}}$$

PHENIX, Phys. Rev. Lett. 134, 022302 (2025)
 D. Perepelitsa, Phys. Rev. C 110, L011901 (2024)

proton color fluctuation



- High Bjorken-x proton configurations “shrink”, weakening interactions and reducing hard scattering yields.
- Color fluctuation (initial state) vs. jet quenching (final state)?

Challenges of jet quenching measurement in small systems & why O+O?

Asymmetric system

EA and Q^2 correlation

EA and Q^2 anti-correlation

Ncoll scaling

...

Challenges of jet quenching measurement in small systems & why O+O?

Asymmetric system

Symmetric system?

EA and Q^2 correlation

EA selection: ZDC (uncorrelated with hard production) inclusive jet \rightarrow semi-inclusive jet

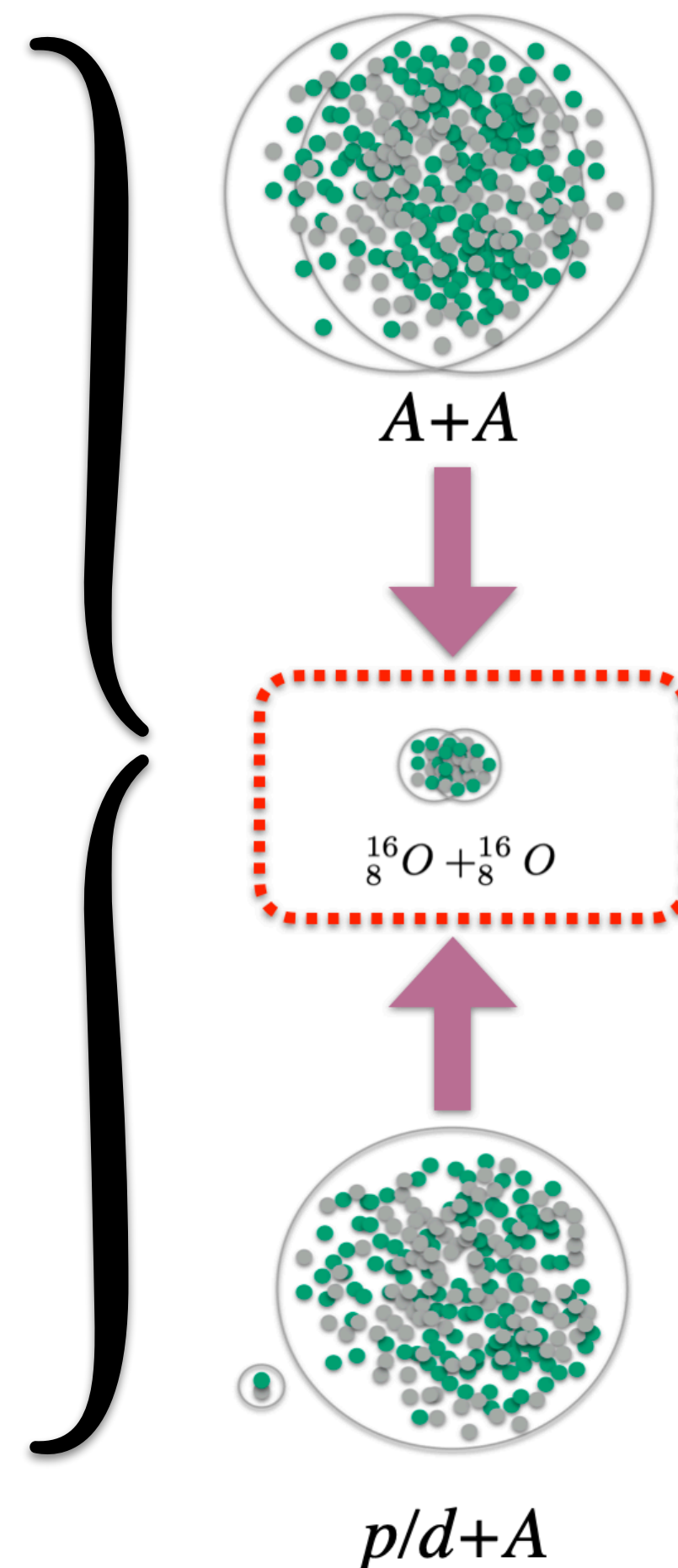
EA and Q^2 anti-correlation

Color fluctuation dilute as one increases the projectile size

Ncoll scaling

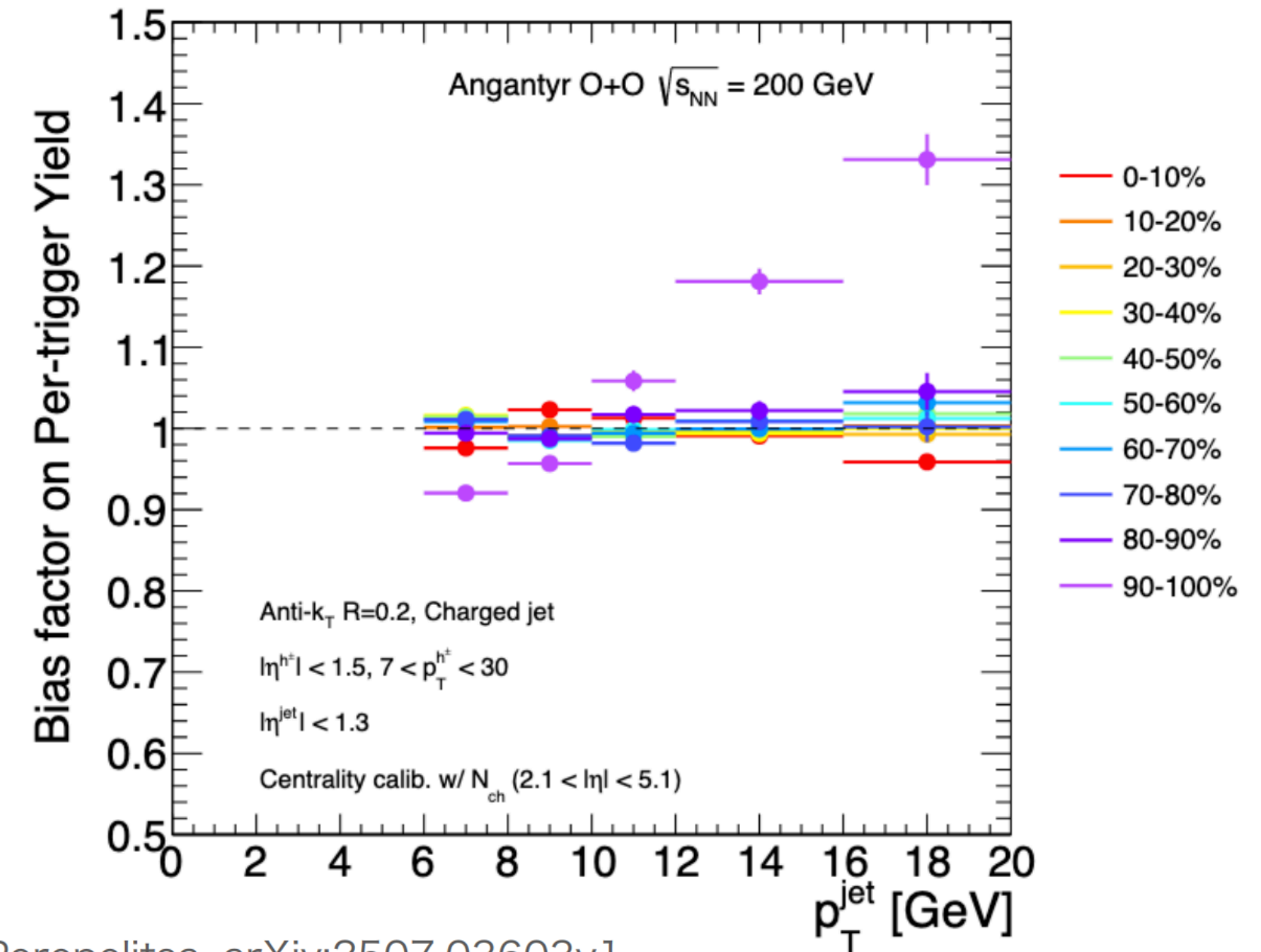
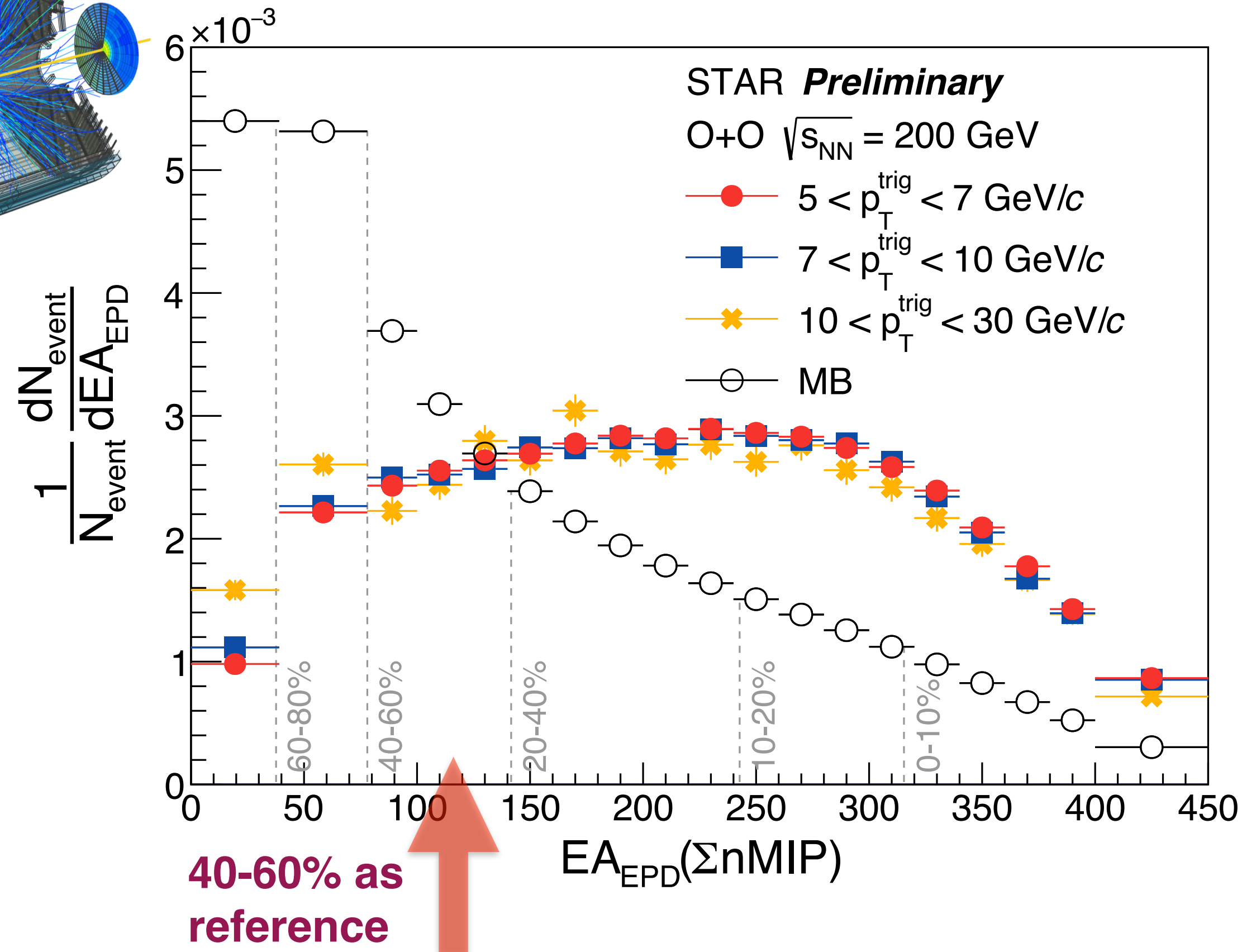
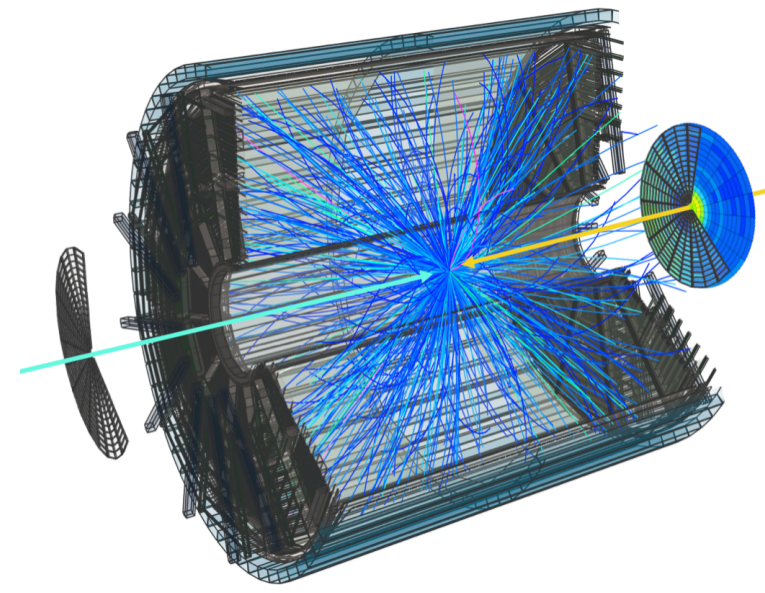
ratio of absolutely normalized hard cross sections

...



- Clear collision geometry
- Color fluctuation effects are expected to be negligible
- Sweet spot for jet quenching study

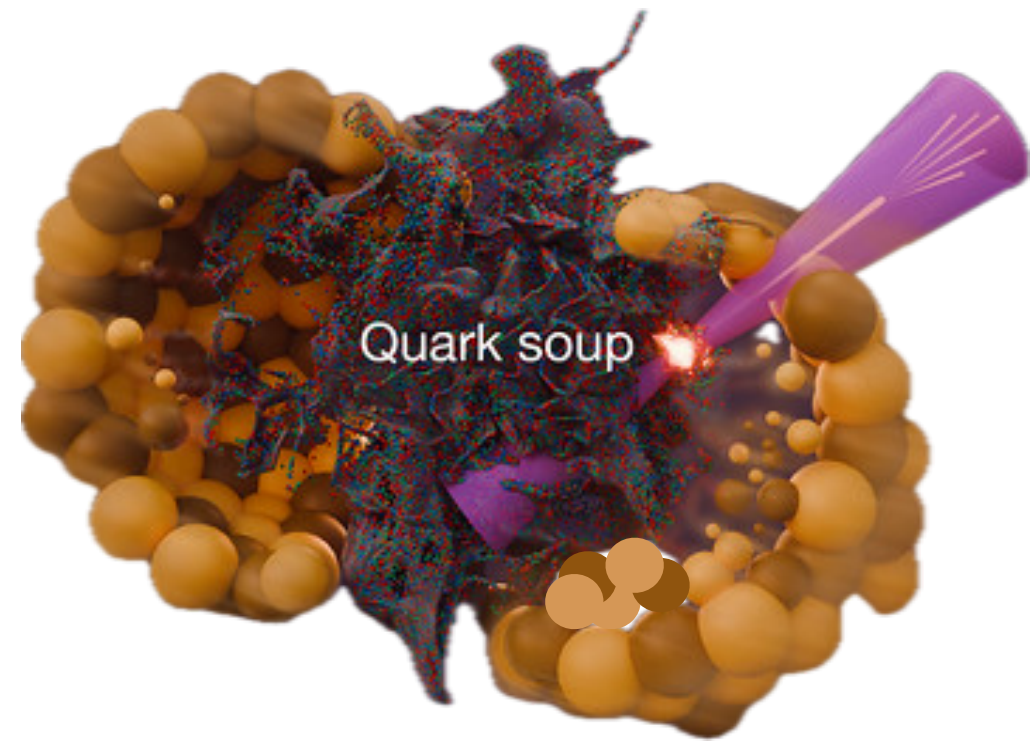
EA and Q^2 (anti-)correlation in O+O



D. Perepelitsa, arXiv:2507.03603v1

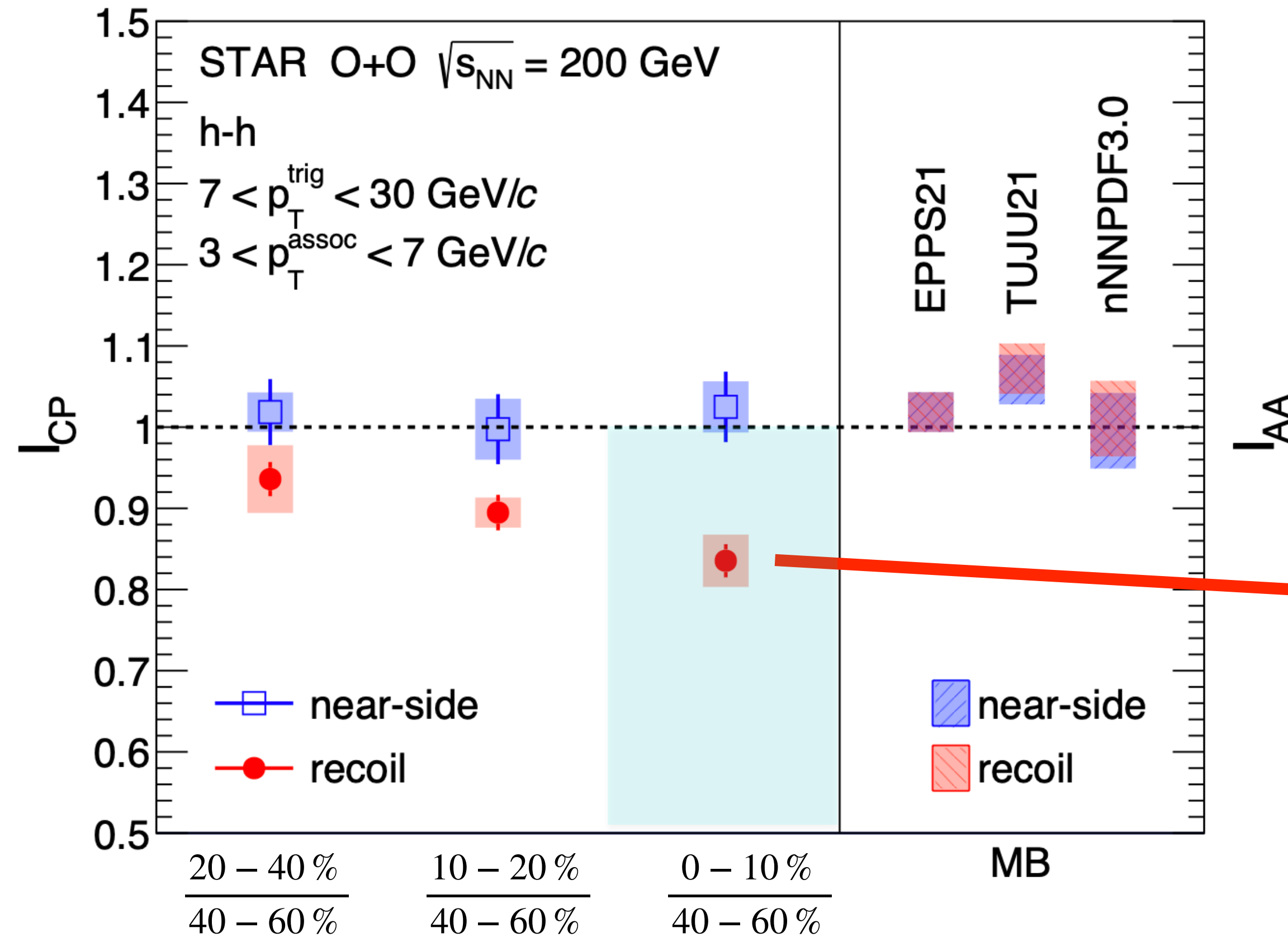
- Unlike p+Au, EA distributions in O+O are **independent** of the choice of trigger p_T .
- Theoretical calculation suggests a negligible centrality bias effect in O+O for per-trigger yield.
- A cleaner system for small system jet-quenching searches in O+O.

Dihadron correlation in O+O collisions



$$I_{CP} = \frac{Y_{central}}{Y_{peripheral}}$$

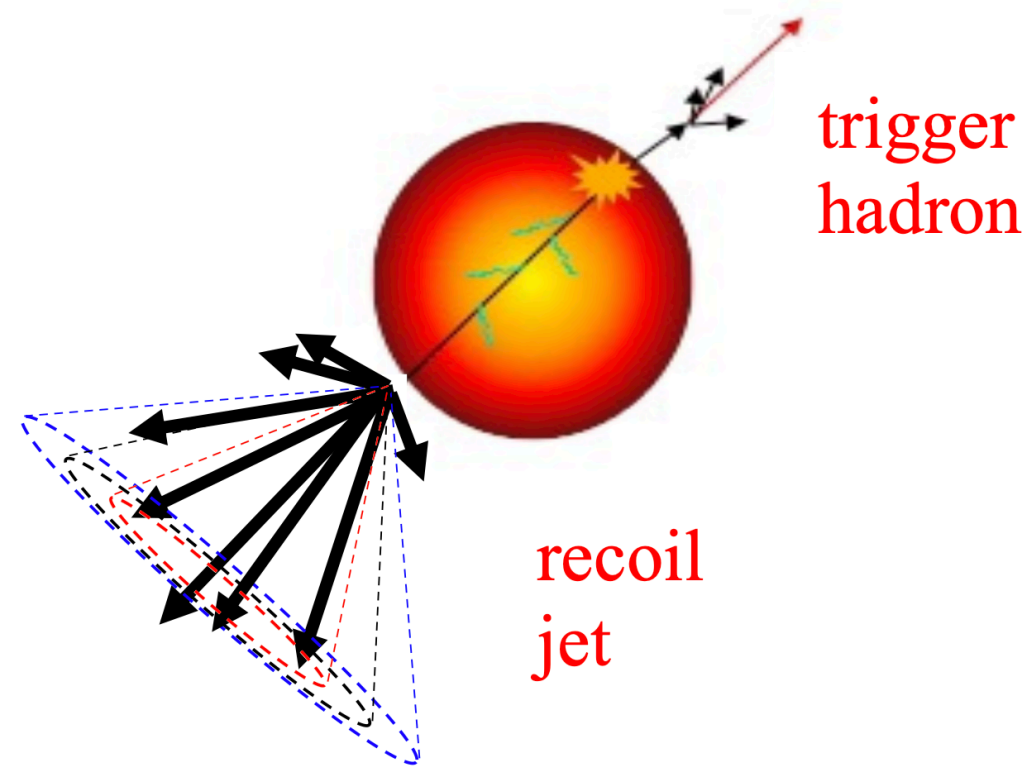
Ratio of recoil hadron yield to quantify jet quenching.



4.3 σ away from unity

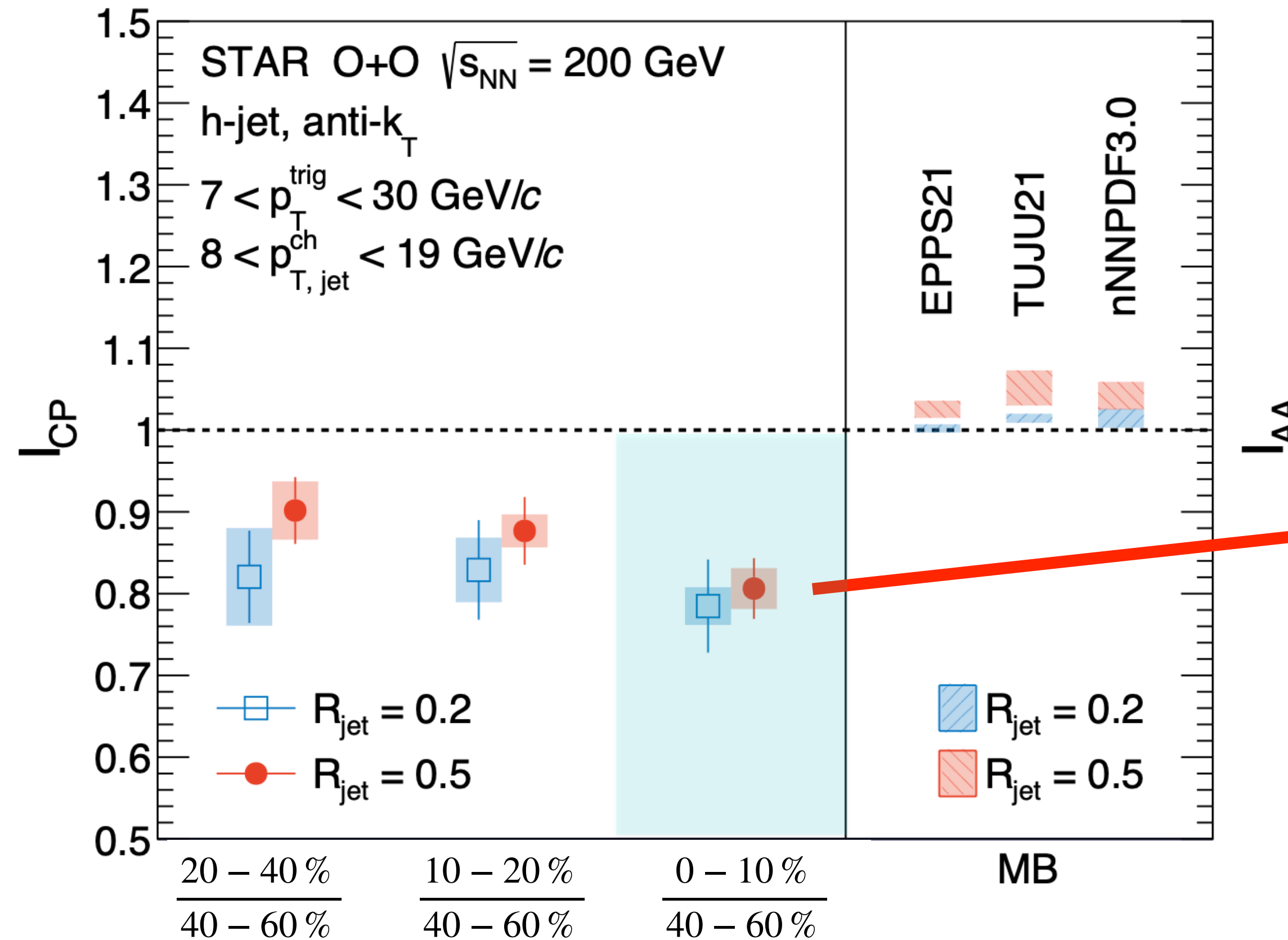
- Near-side I_{CP} is consistent with 1.
- Recoil: High-EA events show **significant suppression (4.3 σ)** compared to low-EA.
- Theoretical calculations (**without jet quenching**) reproduce the near-side only.

Semi-inclusive h-jet in O+O collisions



$$I_{CP} = \frac{\gamma_{central}}{\gamma_{peripheral}}$$

$\frac{d\sigma_{h+jet}}{\sigma_h}$ Ratio of absolutely normalized hard cross sections

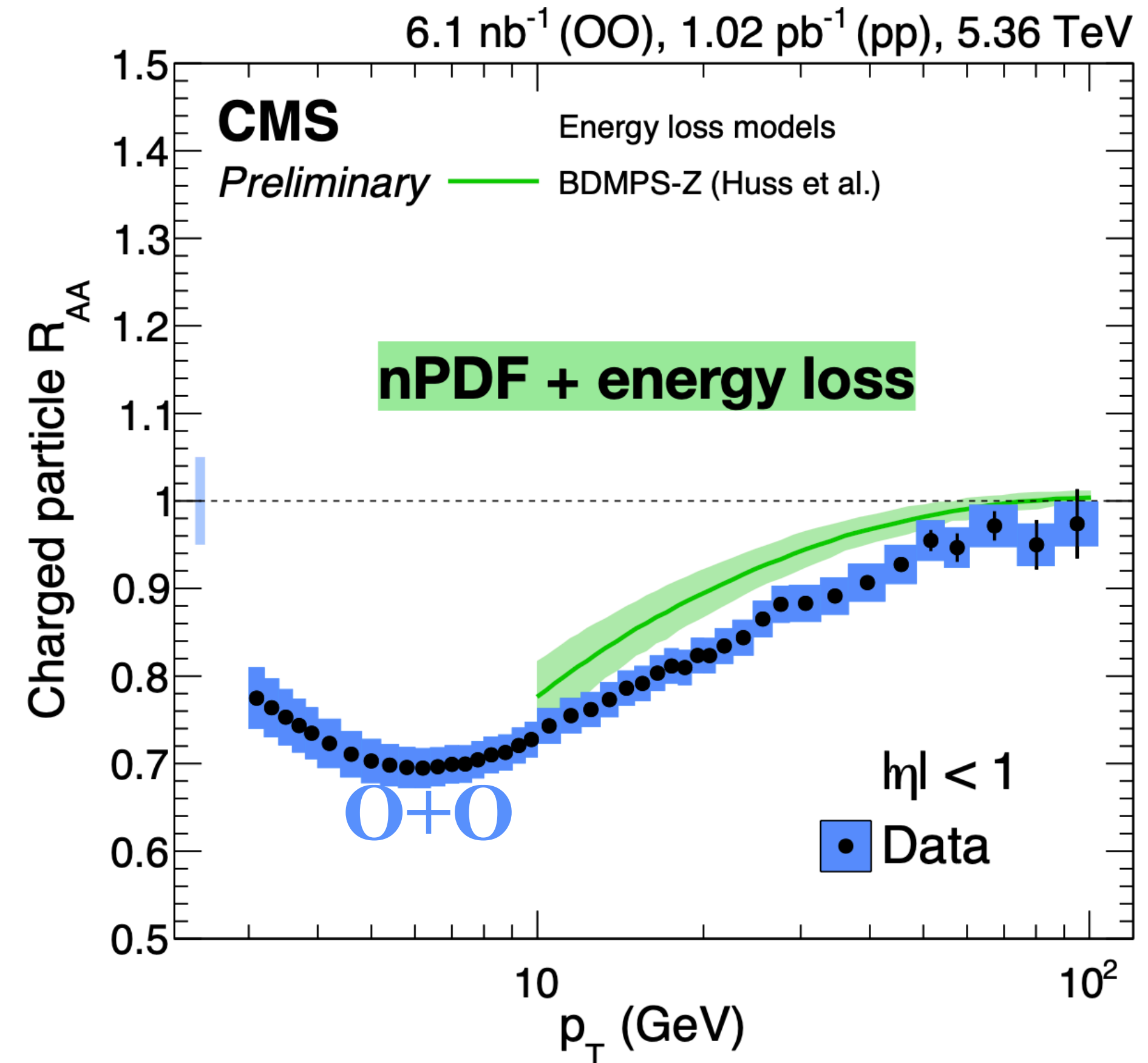
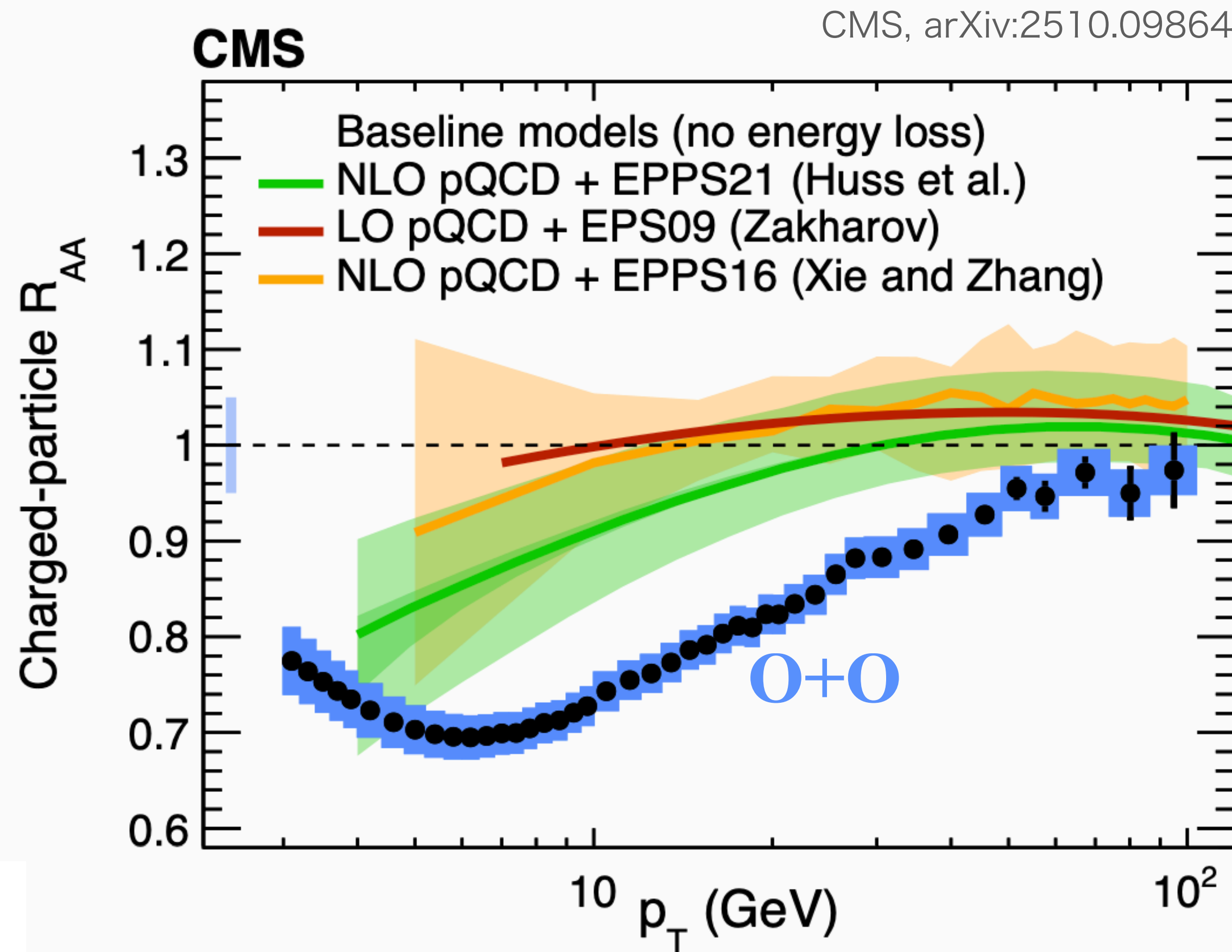


4.3 σ away from unity
Strong evidence of jet quenching!

- Recoil h-jet $I_{CP} < 1$ in high-EA O+O: suppression observed for both $R=0.2$ and $R=0.5$ (4.3 σ).
- Theoretical calculations (**without jet quenching**) fail to describe the experimental data.

Jet quenching in O+O at LHC

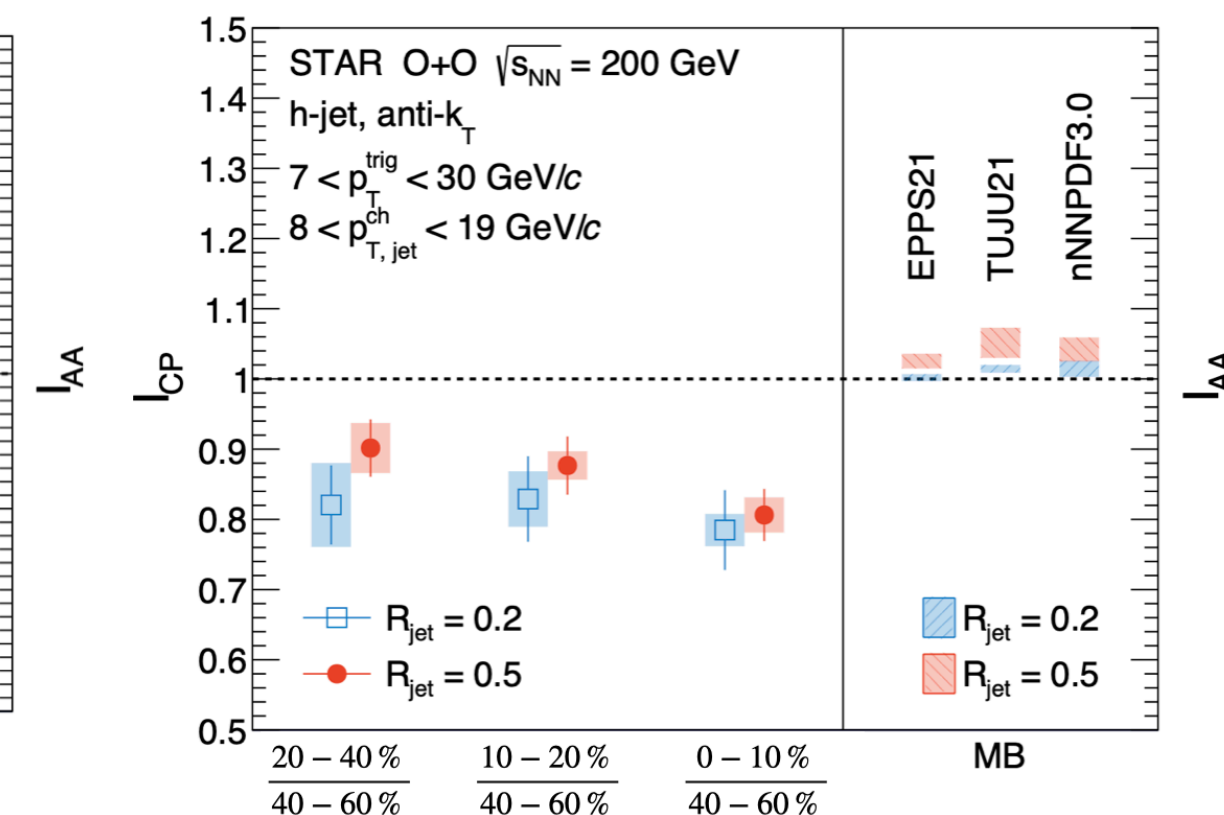
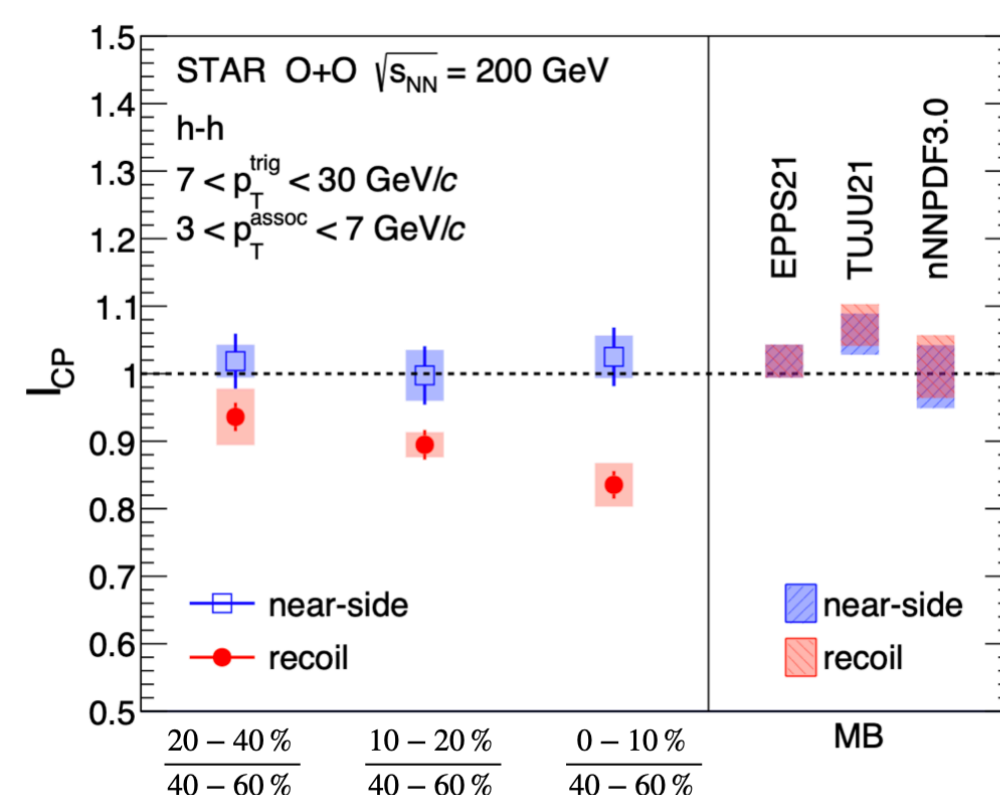
MB charge hadron



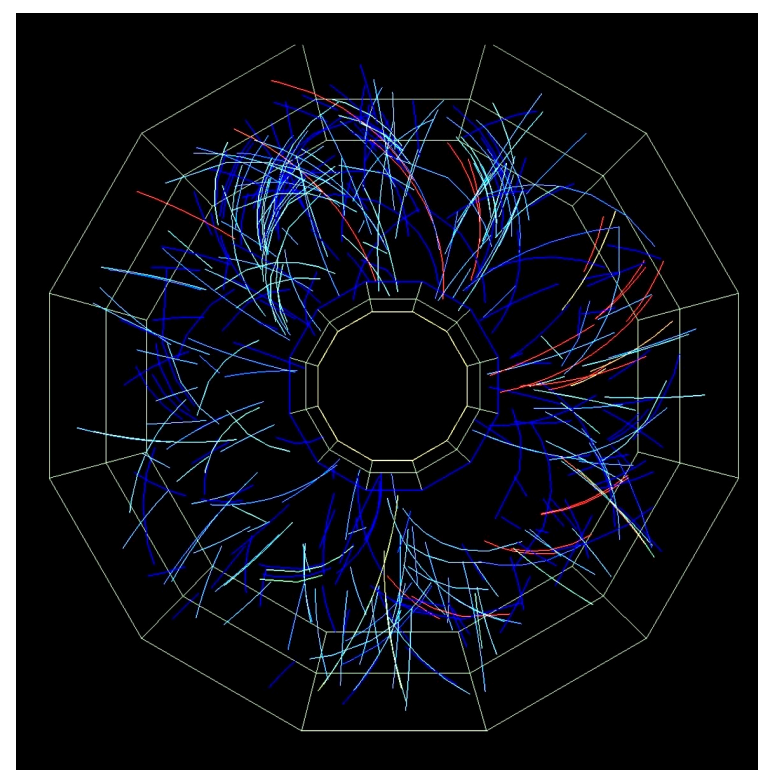
- Significant suppression in O+O, R_{AA} smaller than 1.
- Energy loss model predicts O+O data well.

Summary

- O+O collisions: **the smallest collision system** exhibiting evidence of jet quenching to date.



- Another ~ 745 M (545M low lumi. + 200M high lumi.) O+O@200GeV data was collected during the RHIC last run.



- Light-ion collisions \rightarrow Jet substructure and jet acoplanarity measurements.



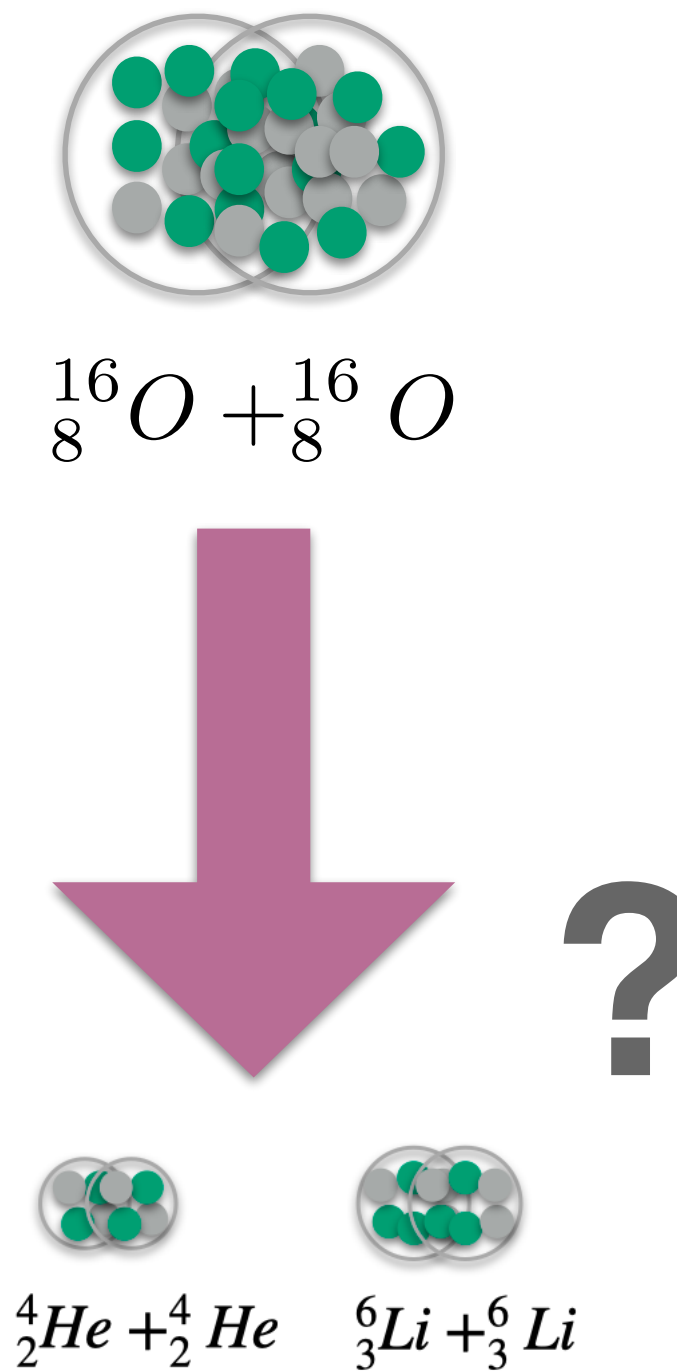
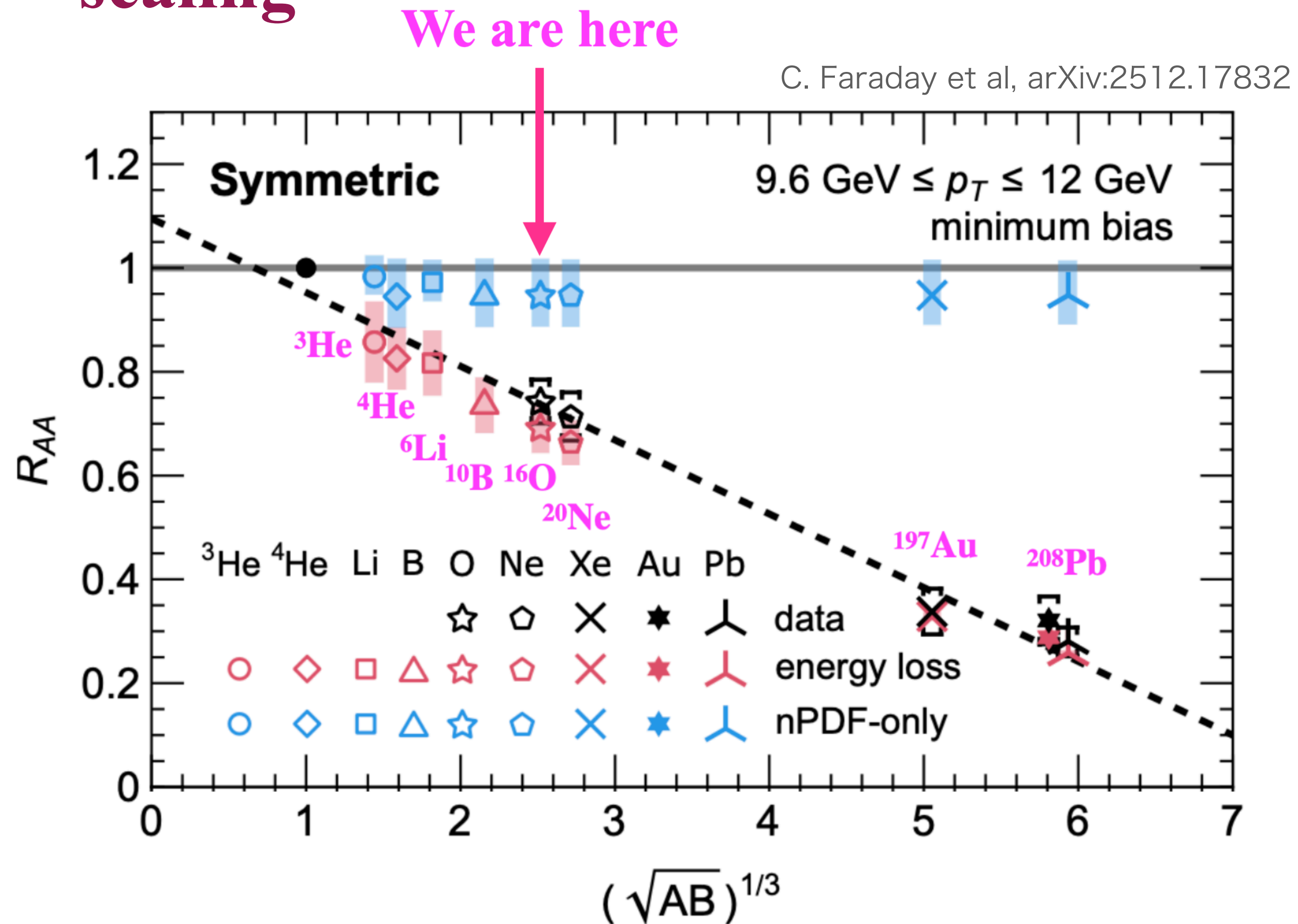
Contact information:

Maowu Nie: maowu.nie@sdu.edu.cn

Li Yi: li.yi@sdu.edu.cn

Outlook

R_{AA} vs. $A^{1/3}$ scaling

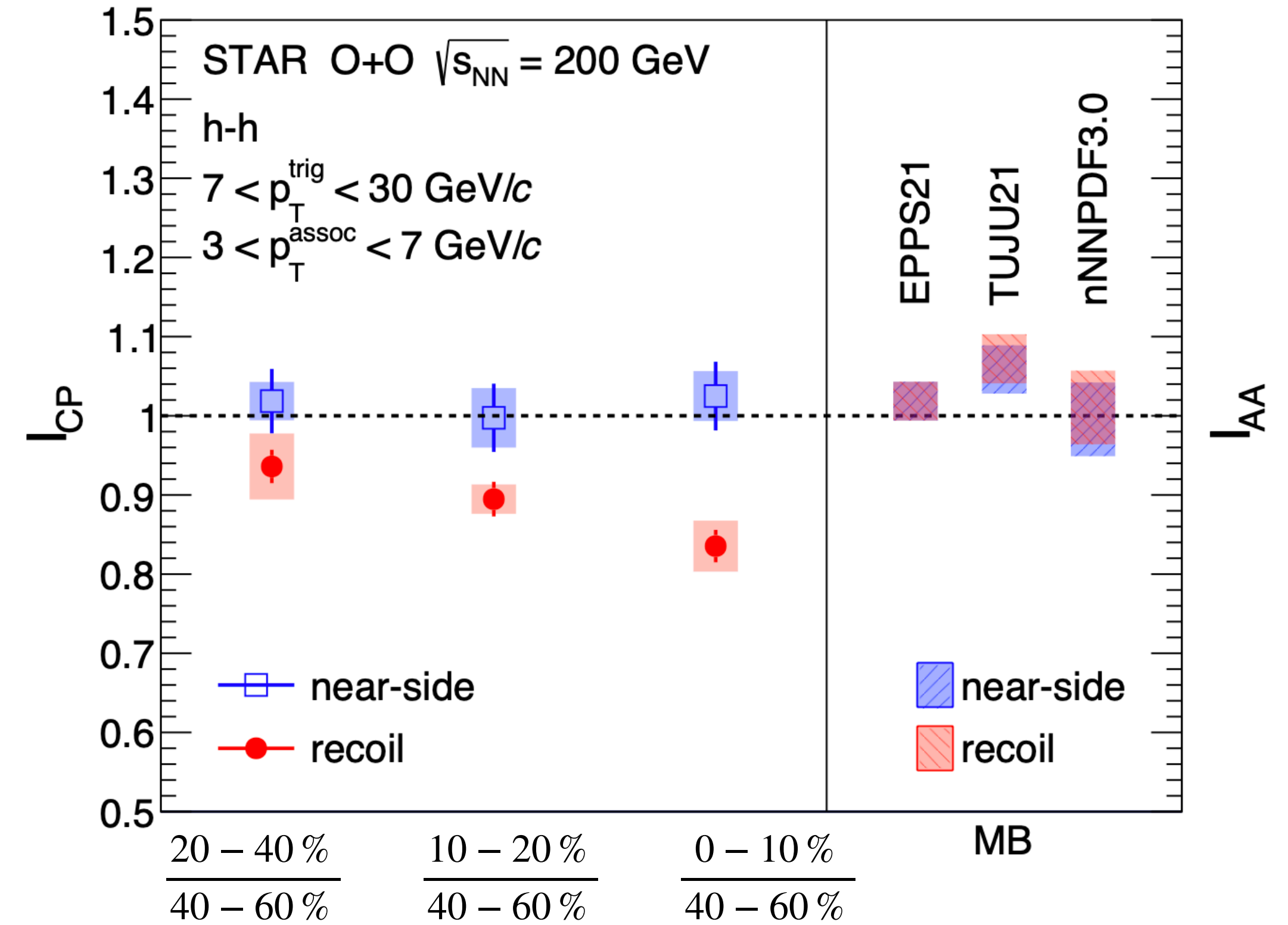
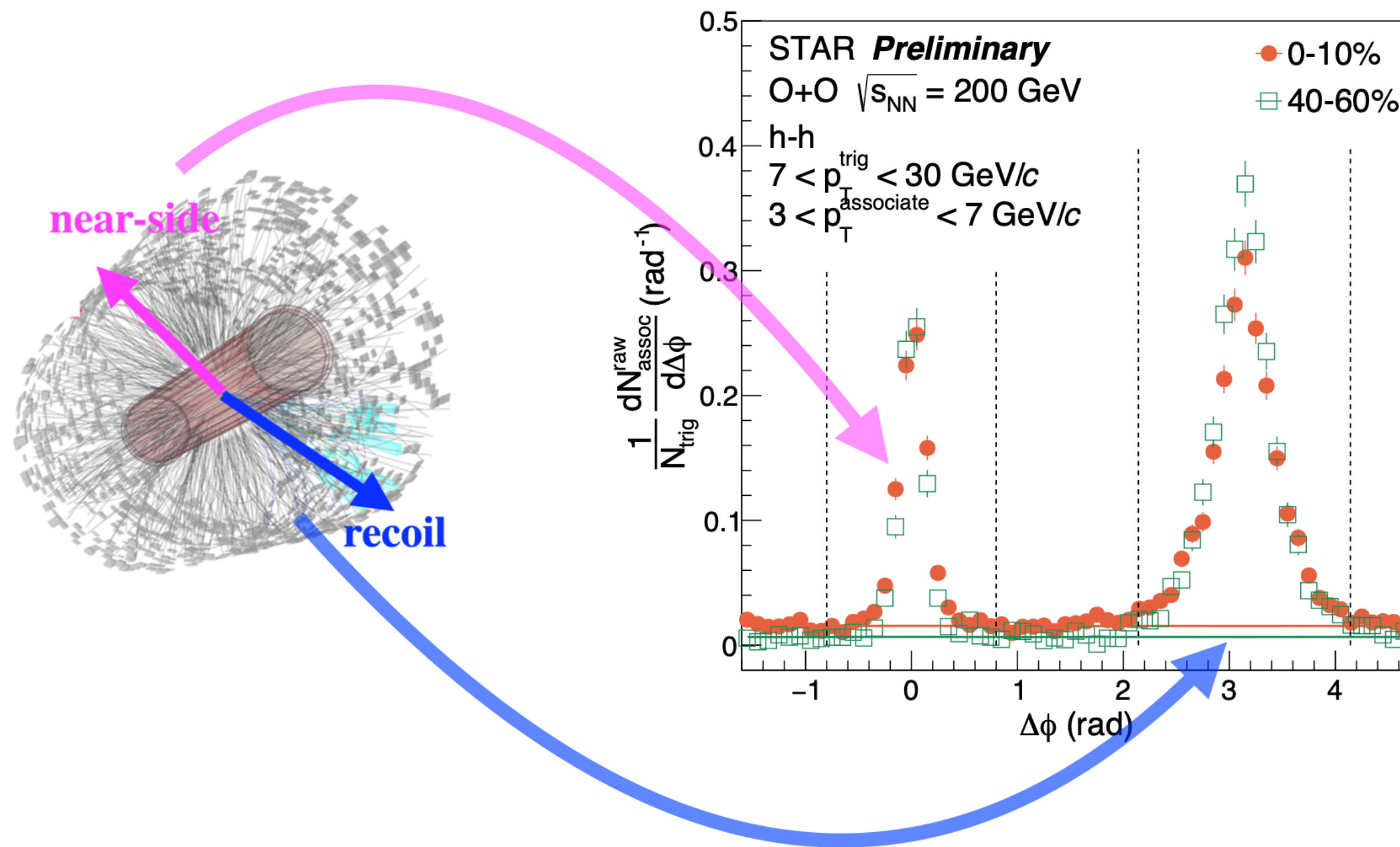
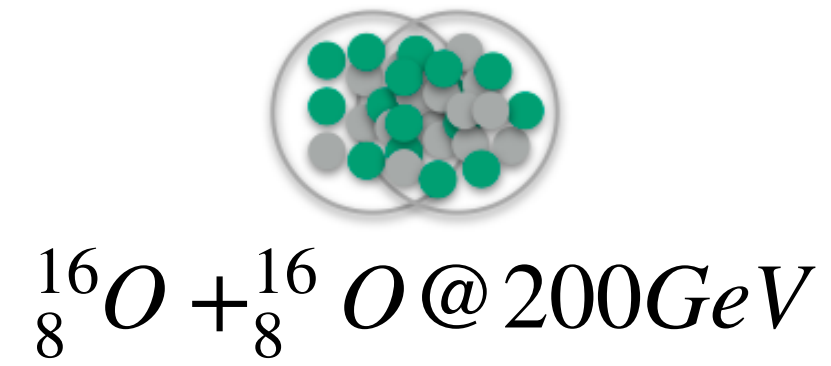


● What's the critical system size of jet quenching? ${}^4\text{He}+{}^4\text{He}$? ${}^6\text{Li}+{}^6\text{Li}$?



Backup

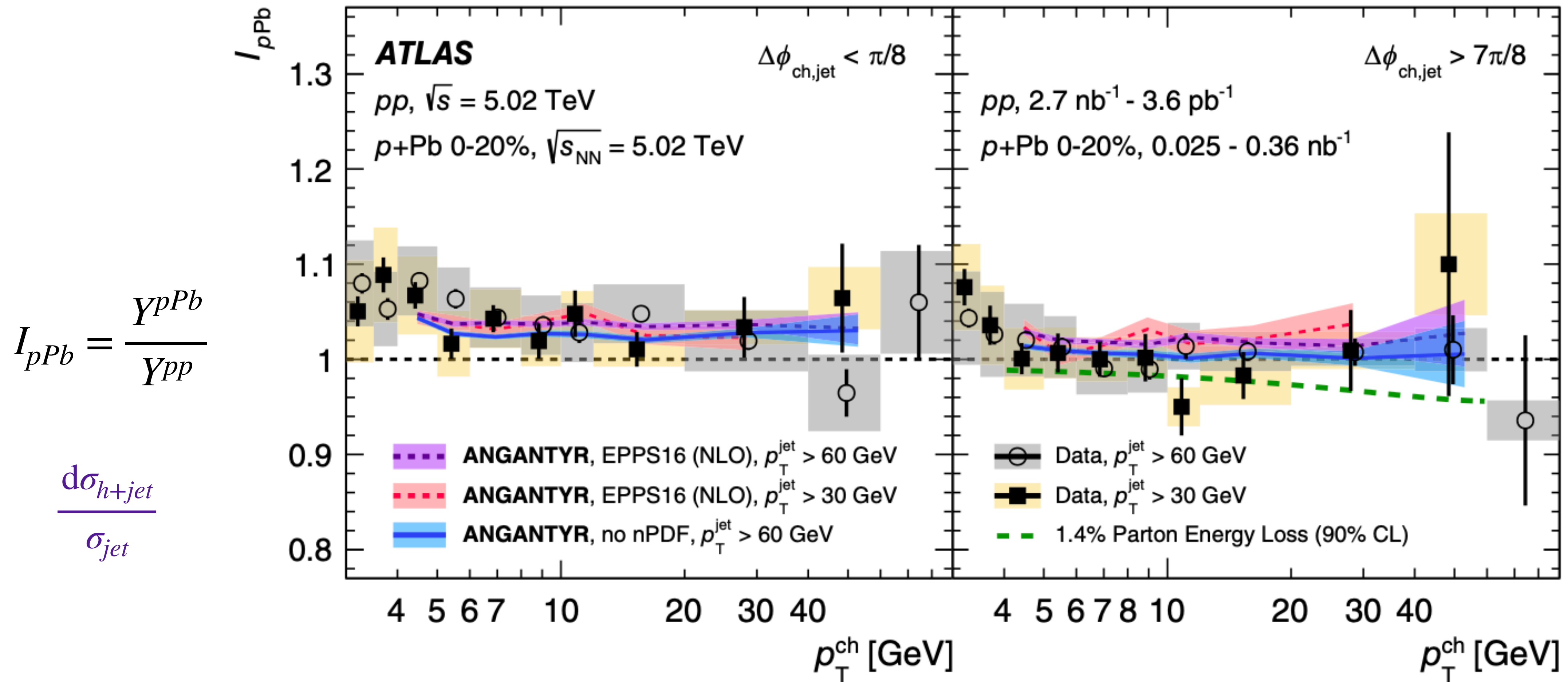
Dihadron correlation in O+O collisions



- Near-side consistent with 1.
- Recoil: High-EA events show **significant suppression** (4.3σ) compared to low-EA.
- Theoretical calculations (**without jet quenching**) match the near-side only.

Semi-inclusive measurements in small systems

ATLAS, Phys. Rev. Lett. 131, 072301 (2023)



● No evidence of modification of fragmentation in p+Pb.

EA and Q^2 anti-correlation in p+Au

