Studies of Jet Quenching in O+O Collisions at $\sqrt{s_{NN}}$ = 200 GeV by STAR

Sijie Zhang (张思婕) for the STAR Collaboration
Shandong University
Quark Matter 2025, Frankfurt, Germany

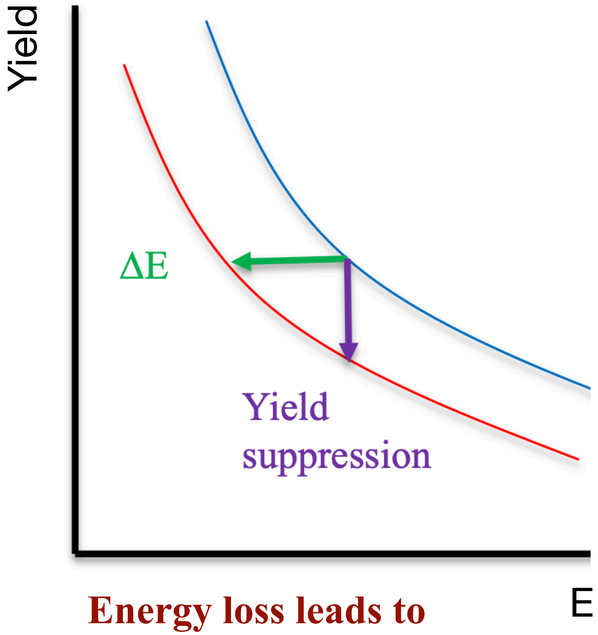
Supported in part by
U.S. DEPARTMENT OF ENERGY | Office of Science

STAR Collaboration

Jet Quenching in Large Systems

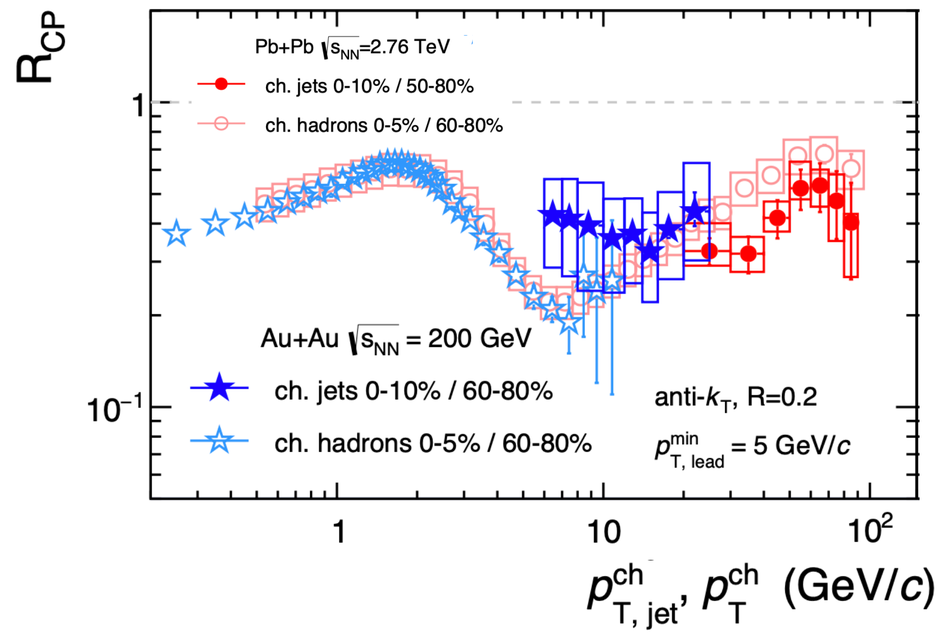
$^{197}_{79}Au + ^{197}_{79}Au$

Jet quenching: modifications to the energy and substructure of high-energy parton showers in QGP

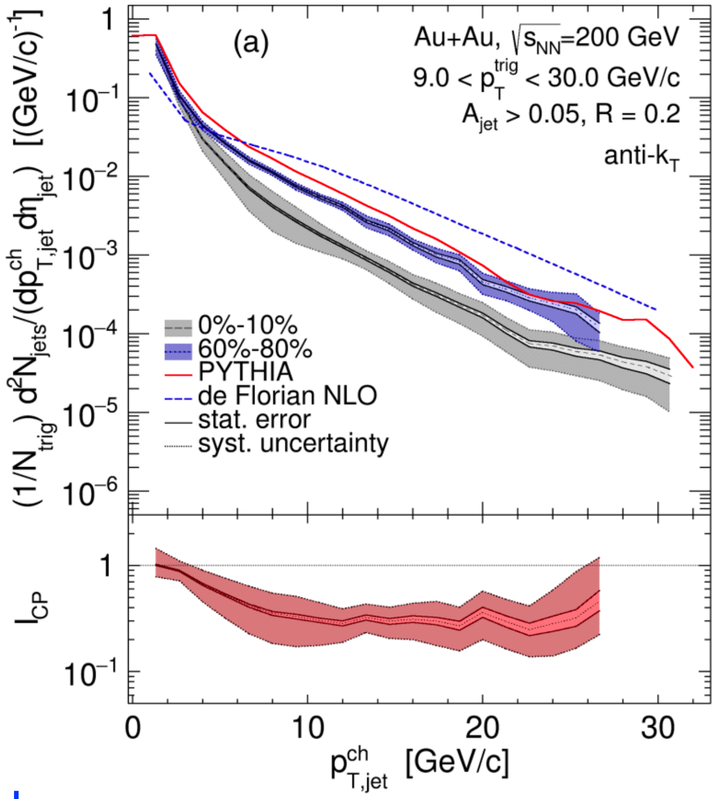


Energy loss leads to apparent yield suppression

STAR, PRC 102, 054913 (2020)



STAR, PRC 96, 024905 (2017)

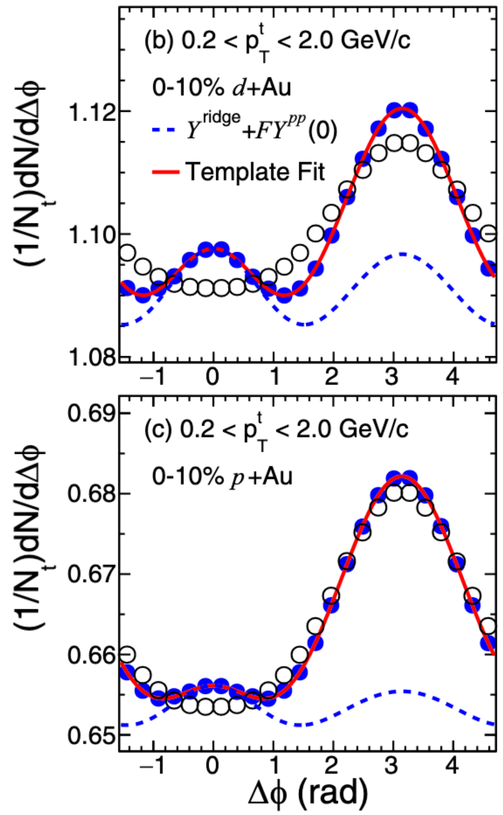


Jet quenching has been observed with single hadrons, inclusive and semi-inclusive jets in Au+Au collisions.

Small Systems(p/d+A): QGP or not QGP?

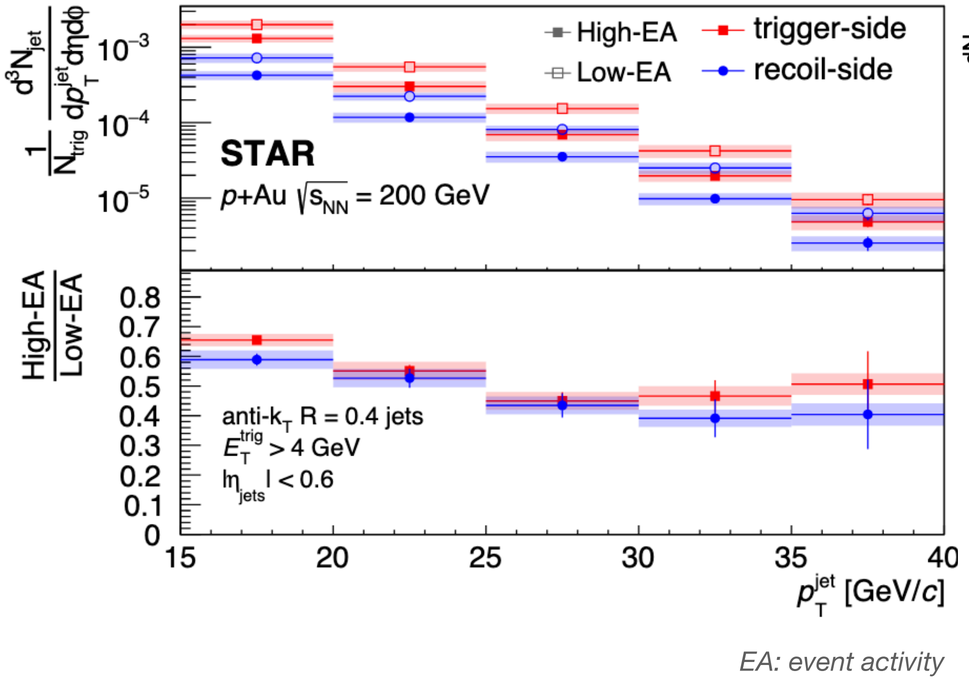
$p/d+^{197}_{79}Au$

STAR, PLB 747, 265 (2015)
STAR, PLB 743, 333 (2015)
STAR, PRC 110, 064902 (2024)

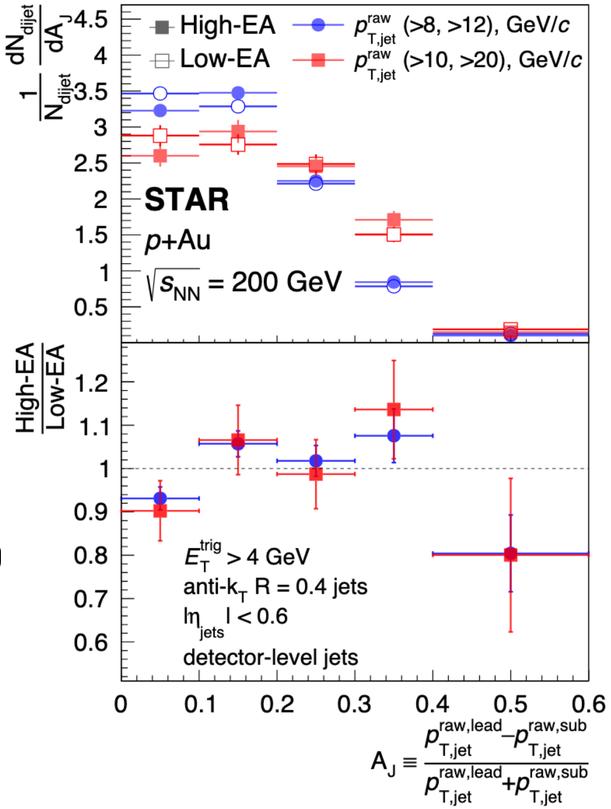


- Collectivity in p/d+Au

STAR, PRC 110, 044908 (2024)



EA: event activity



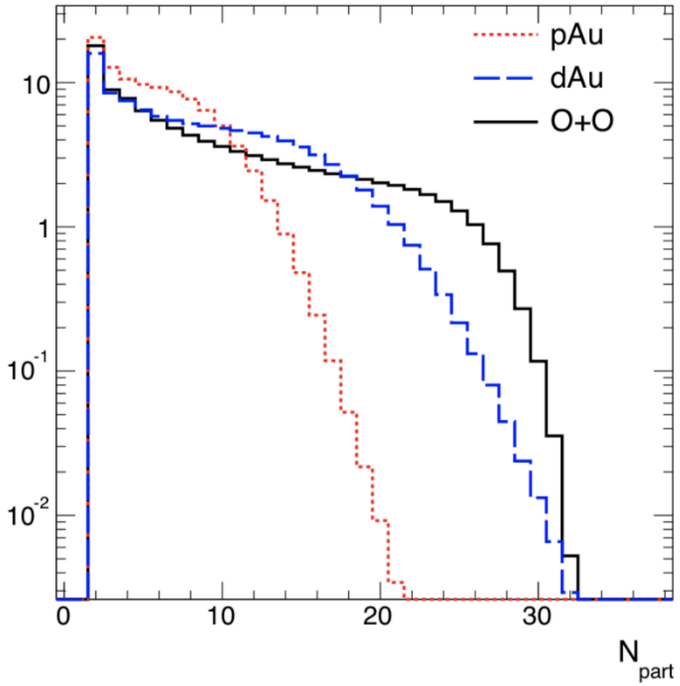
- Apparent h+jet suppression in high-EA events likely due to EA-Q^2 anti-correlation

Collectivity is observed but no clear jet quenching signal in small systems

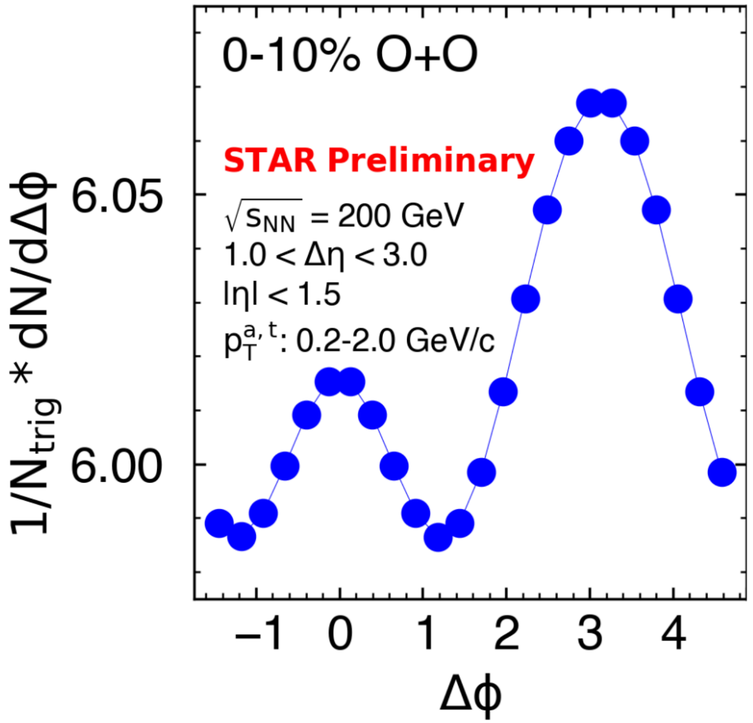
Opportunities with O+O Collisions

$^{16}_{8}O + ^{16}_{8}O$

STAR BUR 2020

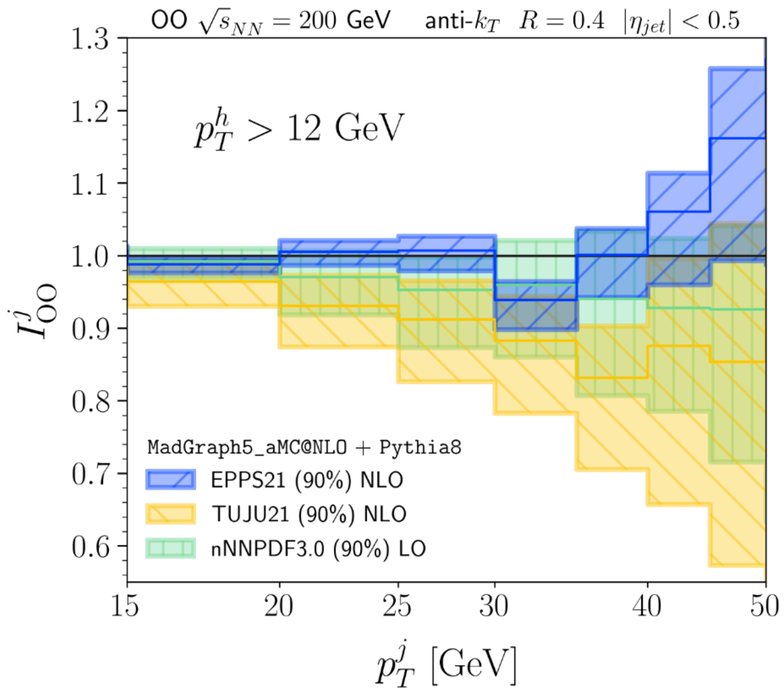


- Similar N_{part} coverage but less centrality fluctuation in O+O than p/d+Au



- Long-range ridge is observed in central O+O collisions

J. Gebhard et al., arXiv:2410.22405



- Theoretical: baseline with no quenching for MB I_{AA}

- Clear collective flow signal. How about jet quenching?
- An excellent opportunity to test jet quenching models!

Solenoidal Tracker at RHIC (STAR)

Data: 2021 O+O $\sqrt{s_{NN}}$ = 200 GeV

- **Time Projection Chamber (iTPC)**

  $|\eta| < 1.5$

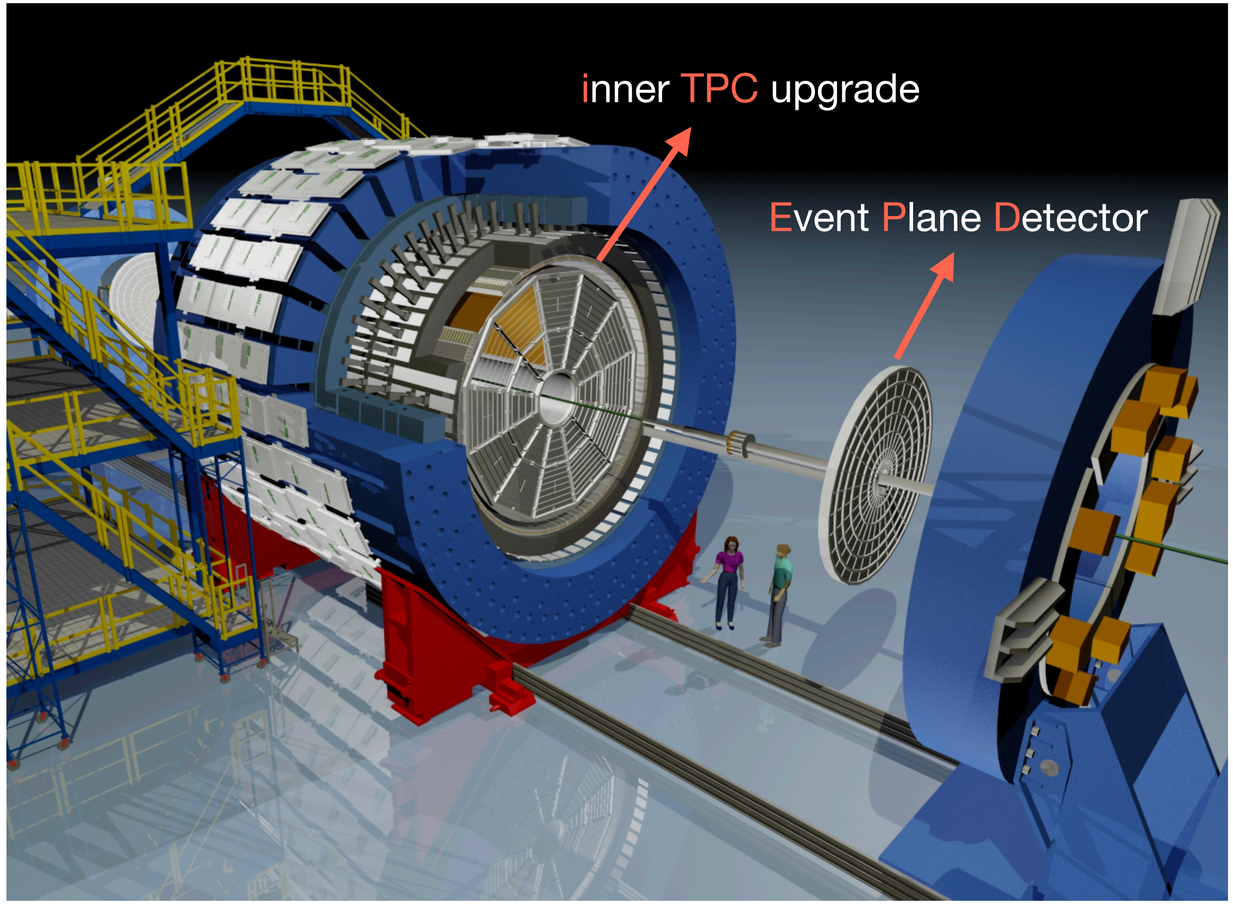
  Full azimuthal coverage

  Charged particles with $0.2 < p_T < 30$ GeV/c
  Charged jet reconstruction

- **Event Plane Detector (EPD)**

  $2.1 < |\eta| < 5.1$

  Centrality definition



Jet Quenching Observables

- **Inclusive charged hadrons**
  High p_T charged particles as proxies of parent partons

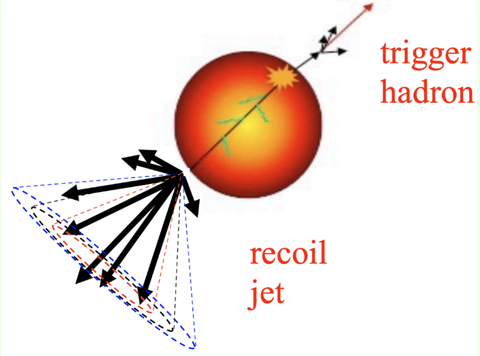
Y: yield

$$R_{AA} = \frac{Y_{AA}}{< N_{coll} > Y_{pp}} \qquad R_{cp} = \frac{< N_{coll} >^{peripheral} Y_{central}}{< N_{coll} >^{central} Y_{peripheral}}$$

- **Inclusive jets**
  Reconstructed jets better represent parent parton kinematics

N_{coll} from Glauber Model

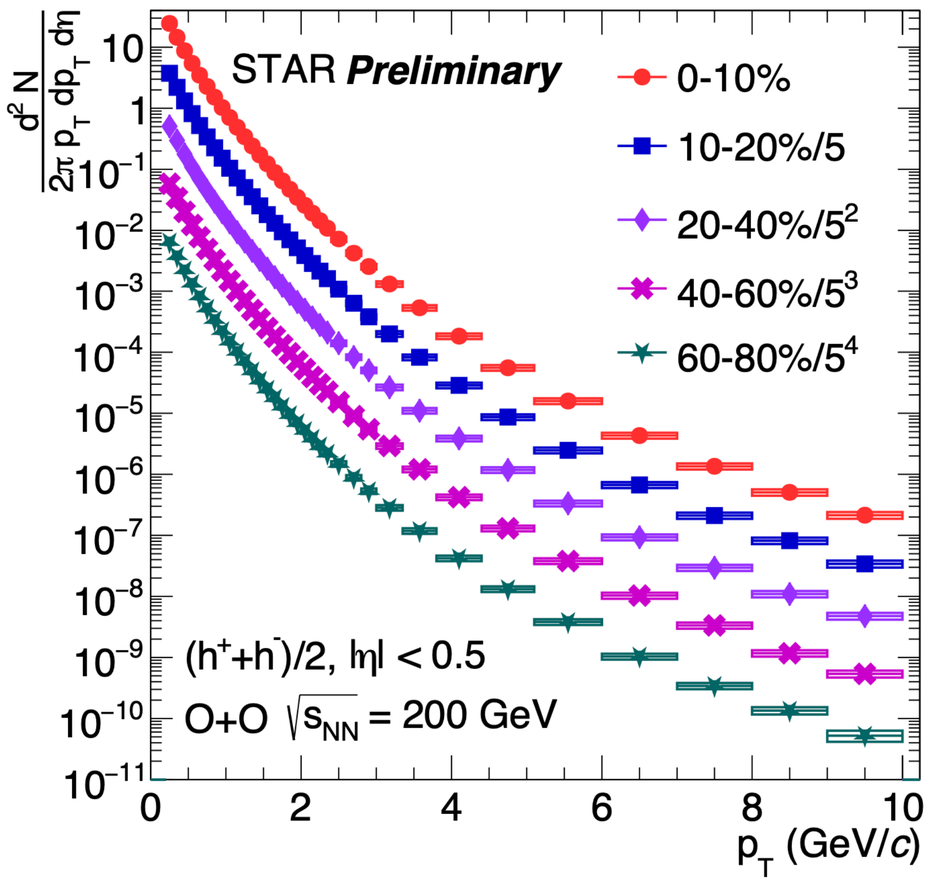
- **Semi-inclusive h+jet**
  High-p_T hadron triggered recoil jets

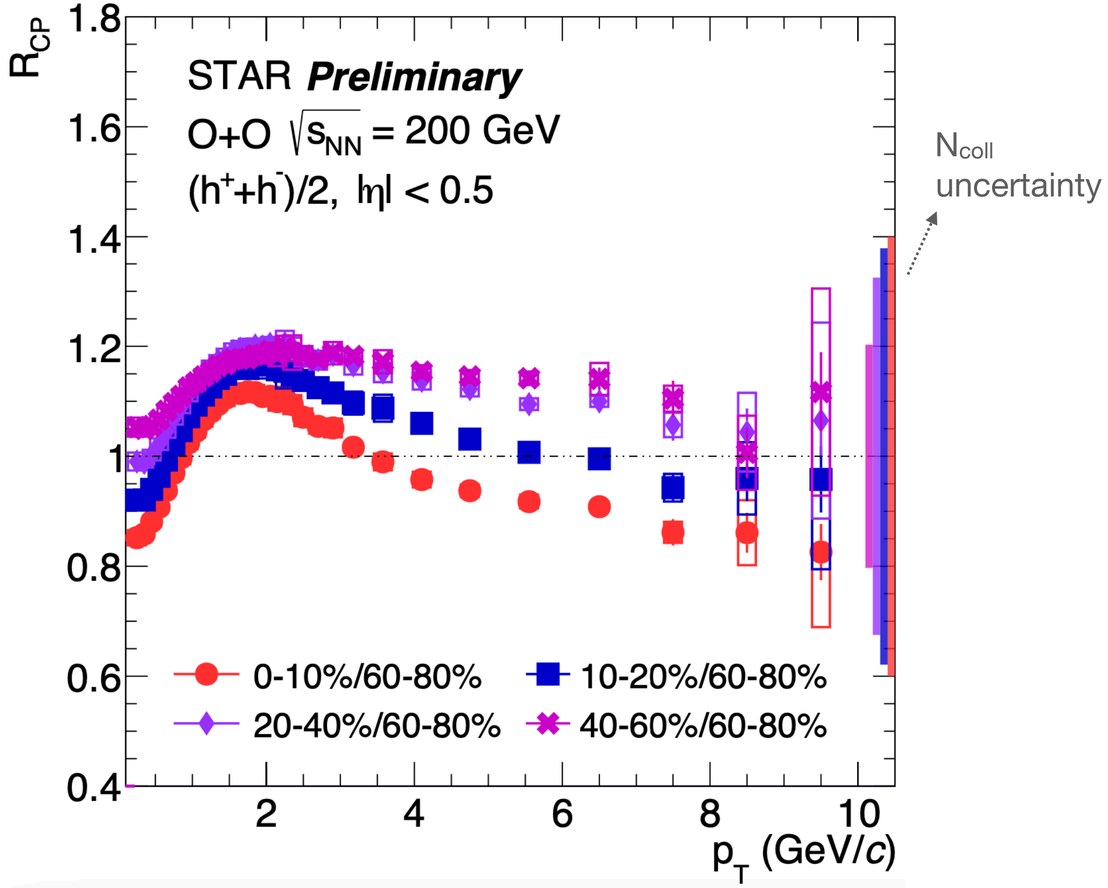


$$I_{AA} = \frac{Y_{AA}}{Y_{pp}} \qquad I_{cp} = \frac{Y_{central}}{Y_{peripheral}}$$

Normalized per trigger

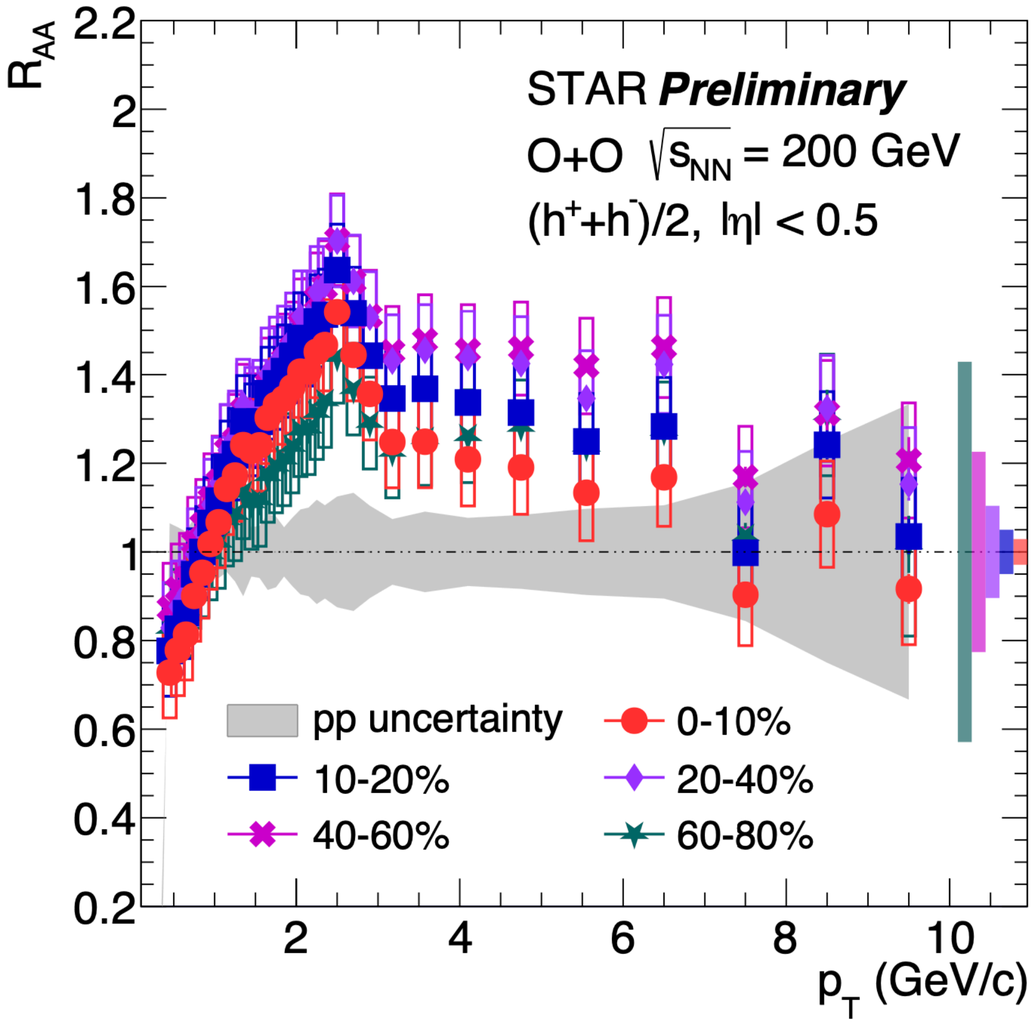
Inclusive Charged Hadron Yields and R_{cp}





- Fully corrected charged hadron yields at mid-rapidity ($|\eta| < 0.5$) in O+O collisions
- R_{cp} (0-10% / 60-80%) central value < 1 at high p_T, however large uncertainty from N_{coll}

Inclusive Charged Hadron R_{AA}



- $p_T < 2.5$ GeV/c: R_{AA} increases with p_T
- $p_T > 2.5$ GeV/c: R_{AA} decreases slightly
- $R_{AA} \sim 1$ for $p_T > 7$ GeV/c in 0-10% collisions
  - About 15% uncertainty

Jet Reconstruction and Background Removal

✓ **Jet reconstruction**:

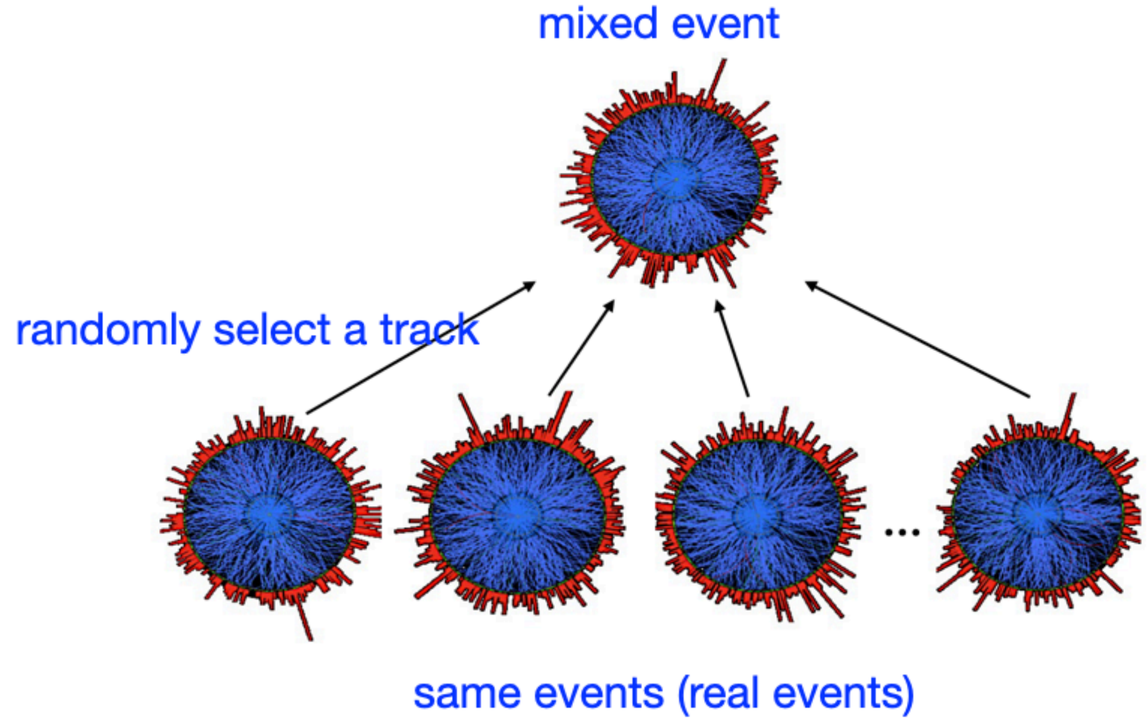
- $|\eta_{jet}| < 1.5 - R_{jet}$
- $|\phi_{\mathrm{trig}} - \phi_{\mathrm{jet}} - \pi| < \pi/4$ (h+jet)
- $p_{T,jet}^{reco,ch} = p_{T,jet}^{raw,ch} - \rho' A$
- Estimated background energy density:

$$\rho' = \underset{j \in \text{physical jets}}{\text{median}} \left\{ \frac{p_{\mathrm{T}j}}{A_j} \right\} \cdot \boxed{C}.$$

event occupancy C:
the area $\sum_j A_j$ covered by physical jets
divided by the total area A_{tot}

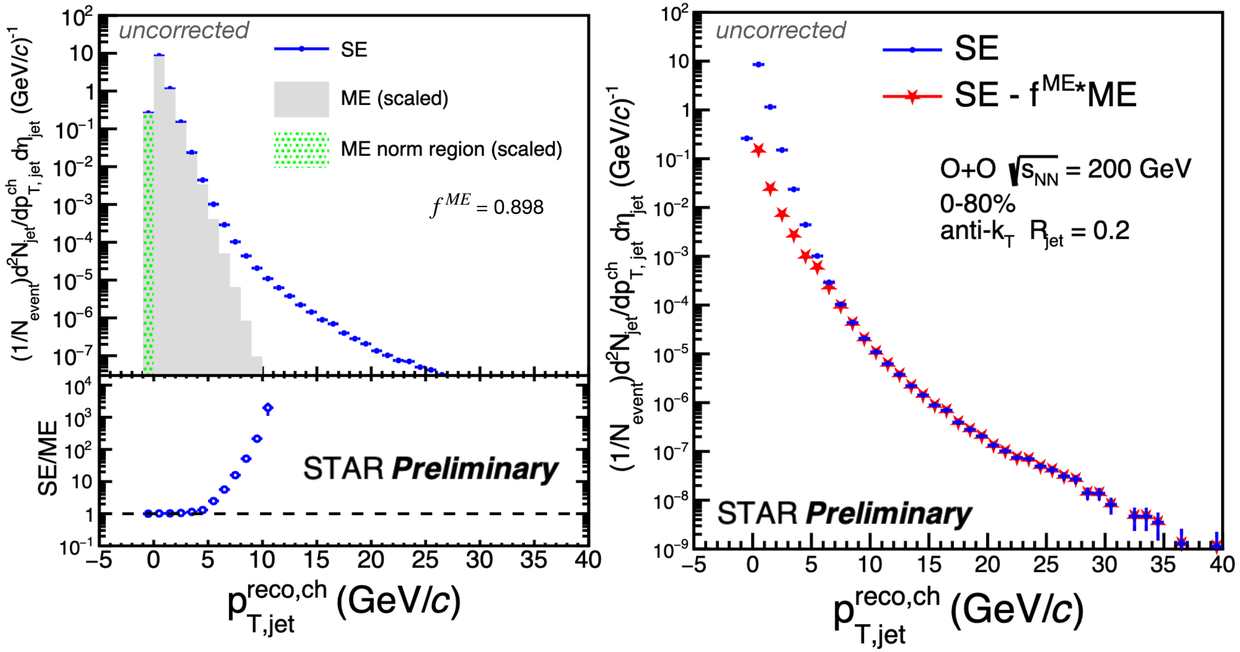
CMS, JHEP 08, 130 (2012)

✓ **Mixed event**:
construct combinatorial background

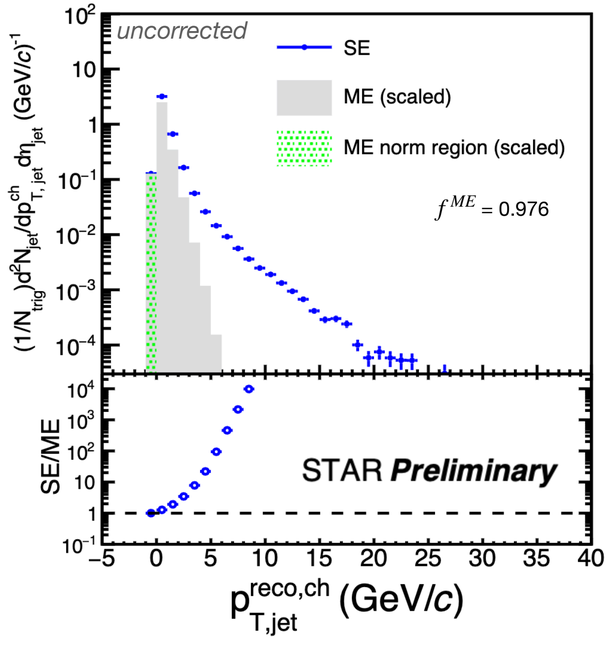


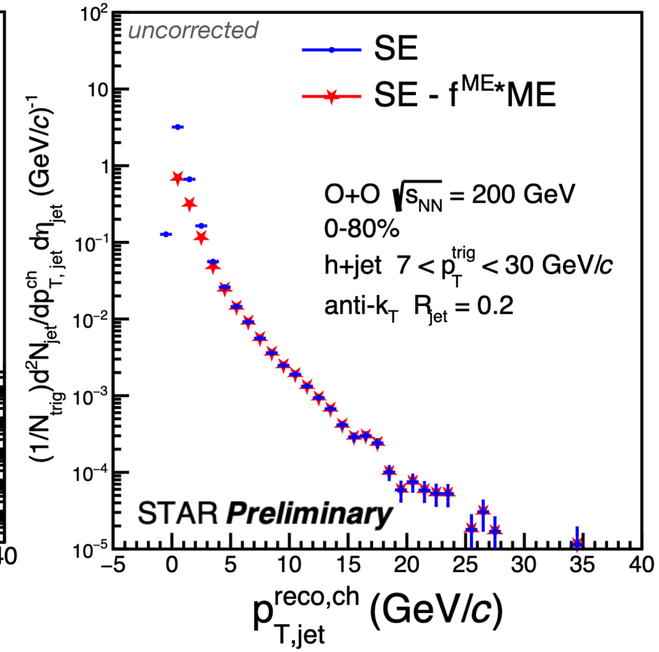
Raw Jet p_T Spectra

Inclusive jet



Semi-inclusive h+jet





f^{ME} : *normalization parameter*

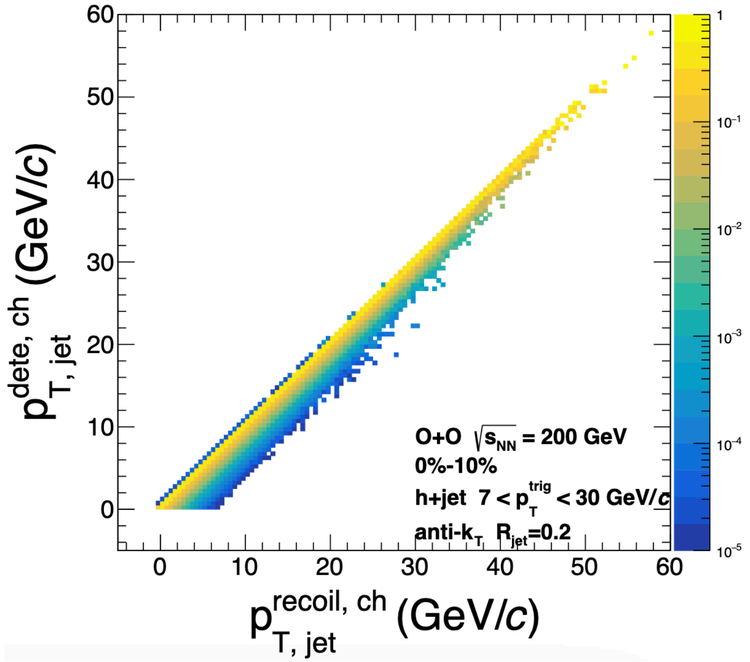
- Combinatorial jet distribution estimated by event mixing and subtracted from same event distribution

raw jet p_T spectra = Same Event - f^{ME} * Mixed Event

Unfolding

R_{bkg}

Background fluctuations

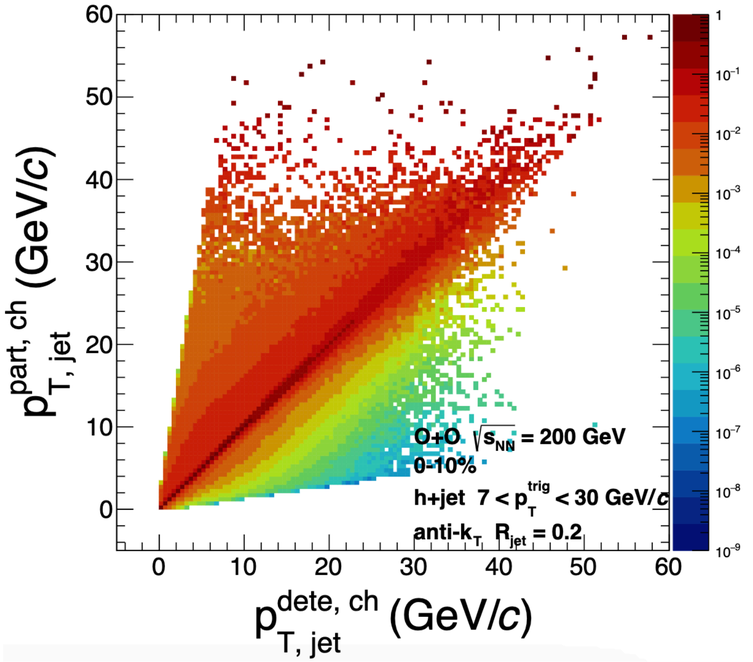


by embedding single hadrons to real O+O events

X

R_{det}

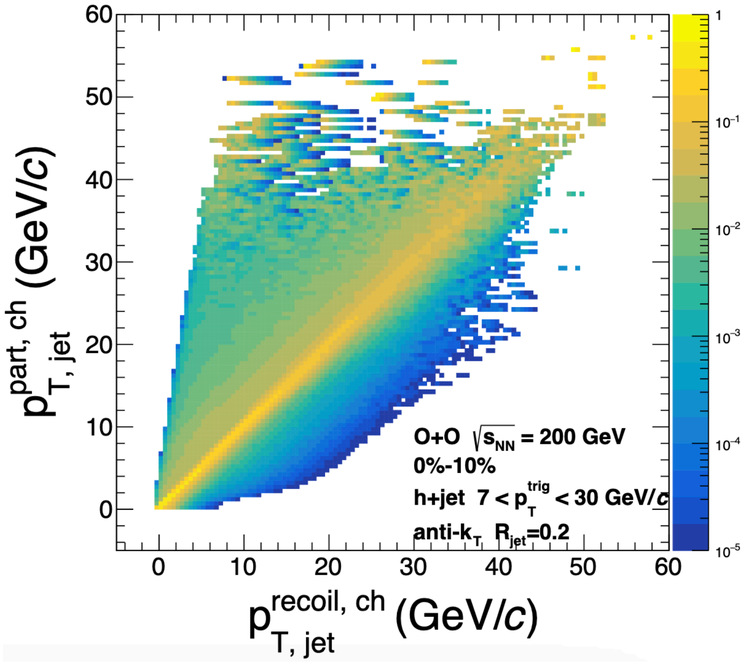
Detector response



by applying detector effects on PYTHIA8 events

=

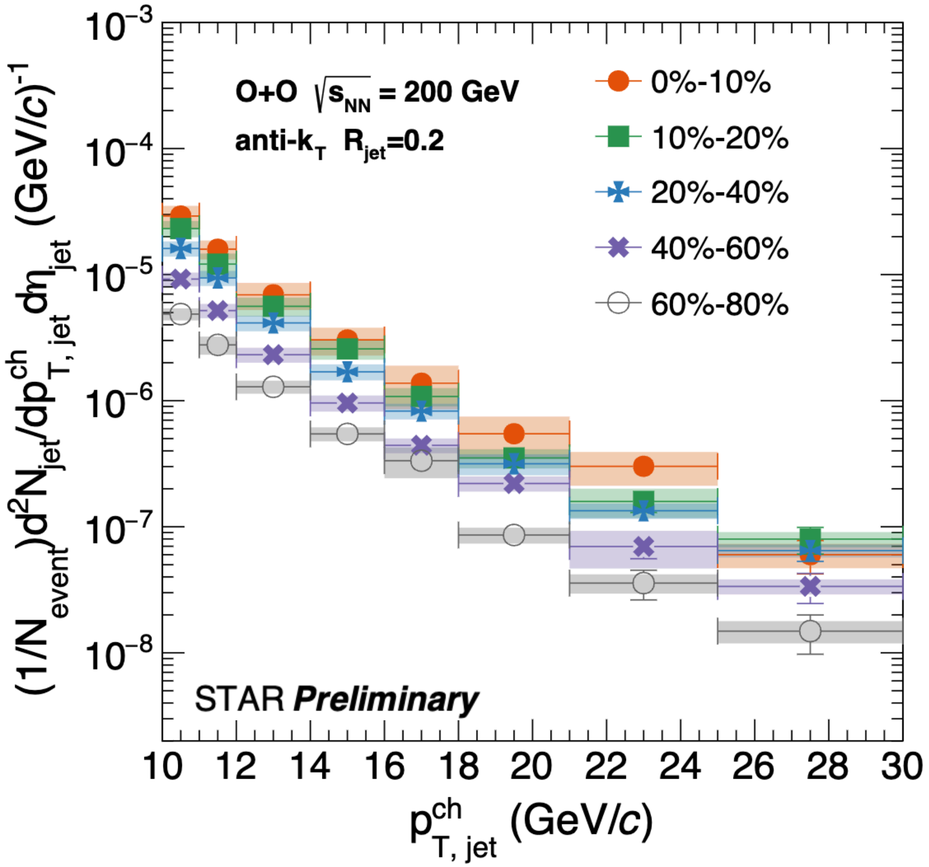
R_{full}

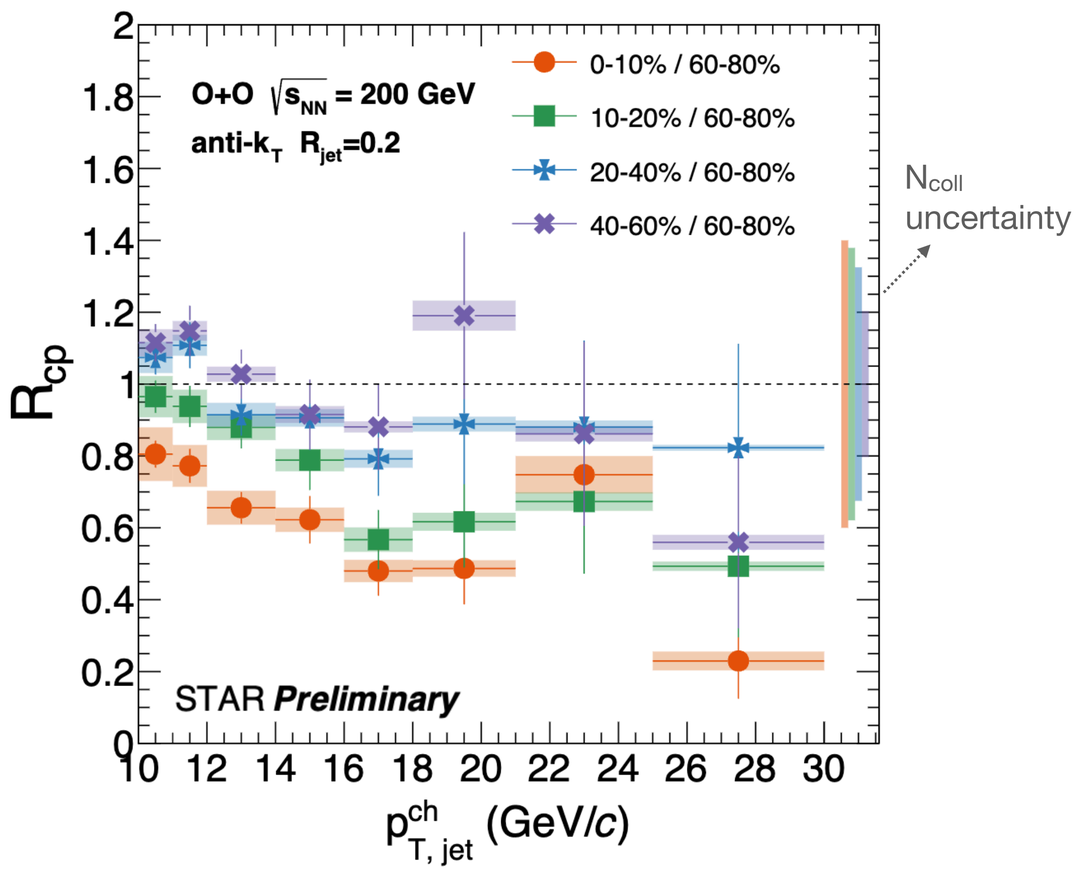


$$R_{\mathrm{full}}(p_{\mathrm{T,jet}}^{\mathrm{reco,ch}}, p_{\mathrm{T,jet}}^{\mathrm{part,ch}}) = R_{\mathrm{bkg}}(p_{\mathrm{T,jet}}^{\mathrm{reco,ch}}, p_{\mathrm{T,jet}}^{\mathrm{det,ch}}) \times R_{\mathrm{det}}(p_{\mathrm{T,jet}}^{\mathrm{det,ch}}, p_{\mathrm{T,jet}}^{\mathrm{part,ch}})$$

- Background fluctuations and detector effects are corrected by unfolding

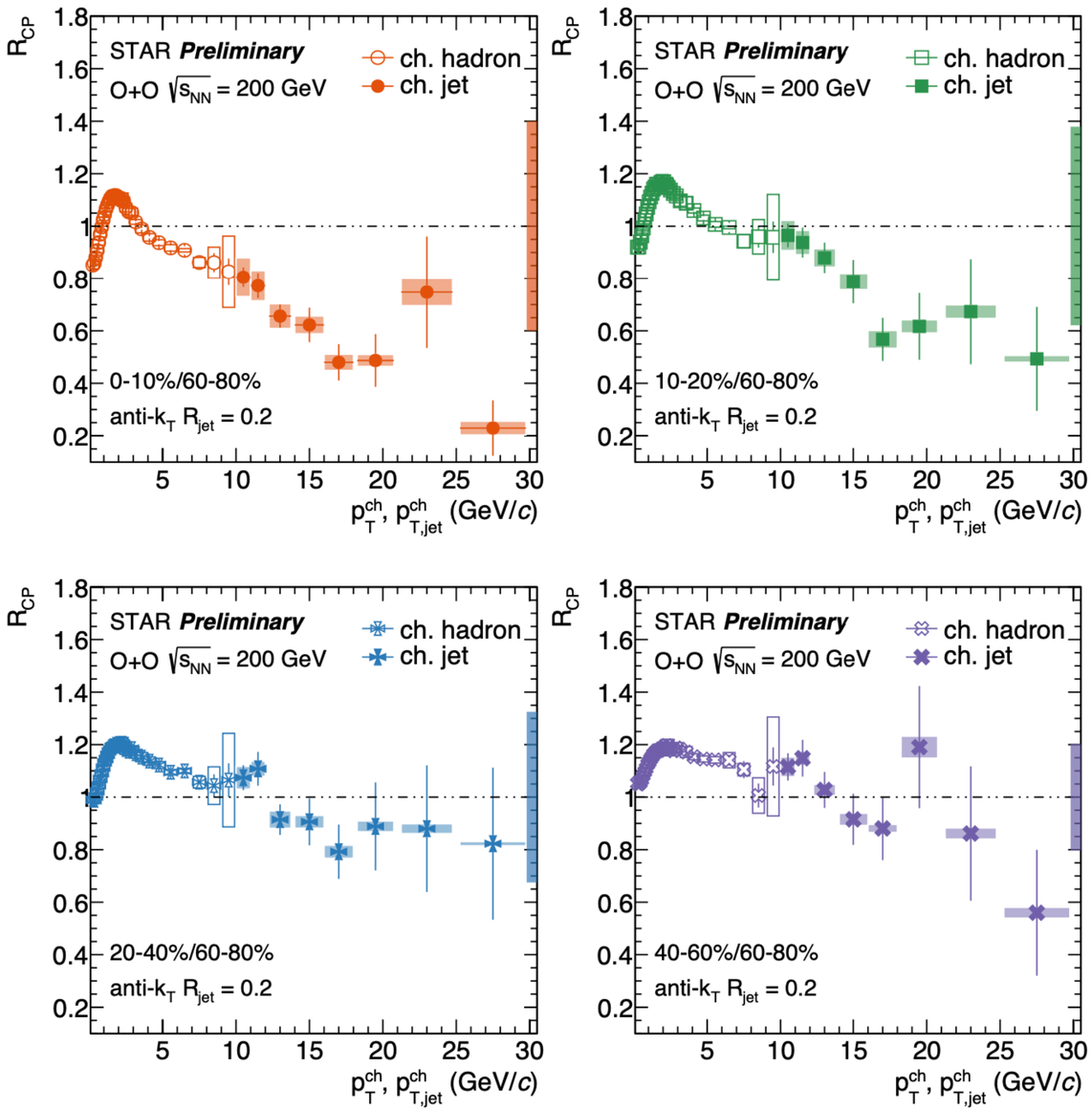
Inclusive Jet Yields and R_{cp}





- Jets extend measurement to high p_T region and provide better access to parton kinematics
- Inclusive jets also exhibit R_{cp} central value < 1, particularly for 0-10%/60-80%

R_{cp} of Inclusive Charged Hadron and Jet

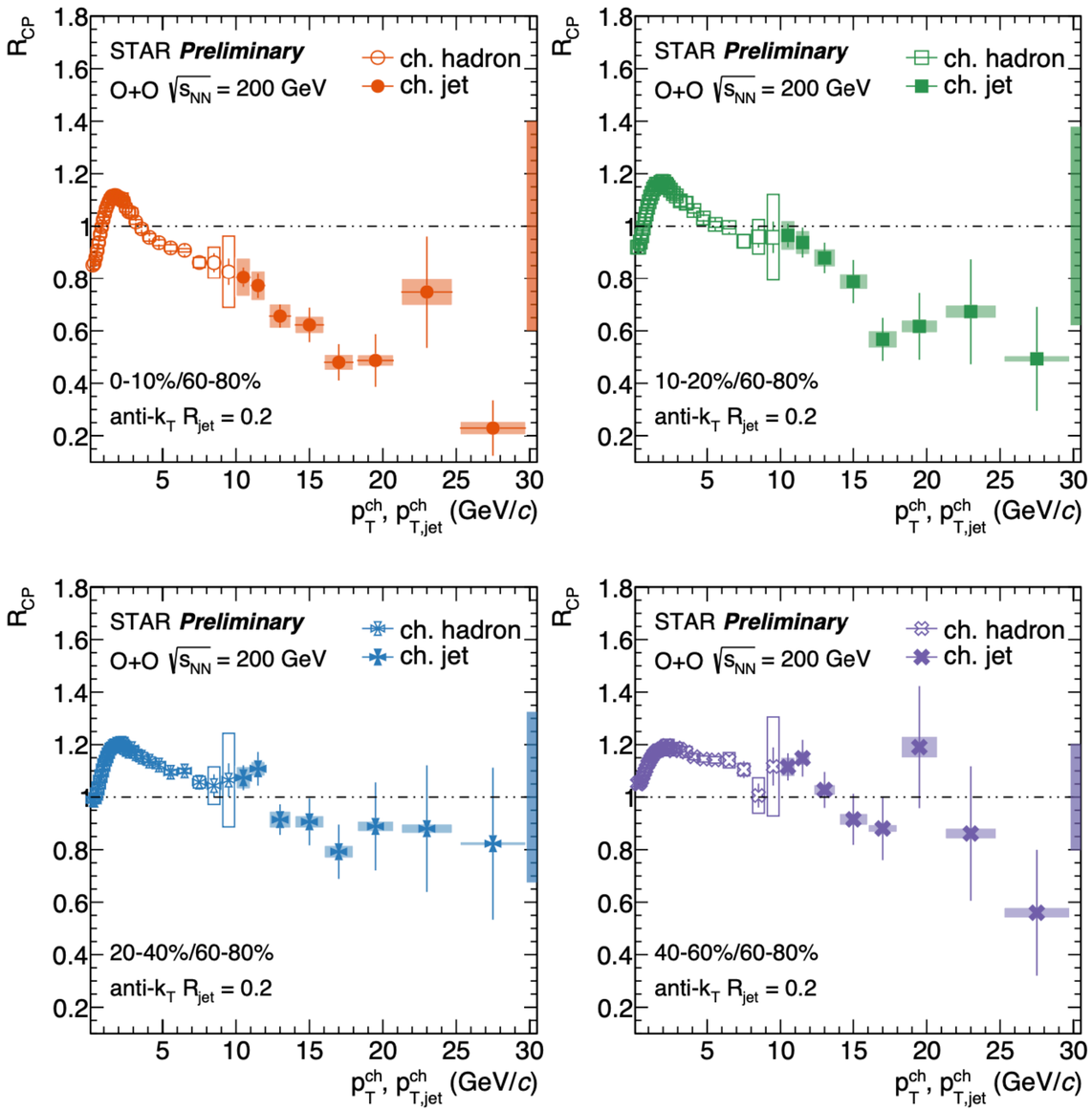


- Inclusive jet R_{cp} and hadron R_{cp} show consistent trends:

  R_{cp} decreases with increasing p_T and from peripheral to central collisions

- $R_{cp} < 1$ at high p_T for 0-10% centrality, but N_{coll} uncertainty is large.

R_{cp} of Inclusive Charged Hadron and Jet



- Inclusive jet R_{cp} and hadron R_{cp} show consistent trends:

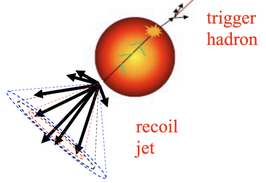
  R_{cp} decreases with increasing p_T and from peripheral to central collisions

- $R_{cp} < 1$ at high p_T for 0-10% centrality, but N_{coll} uncertainty is large.

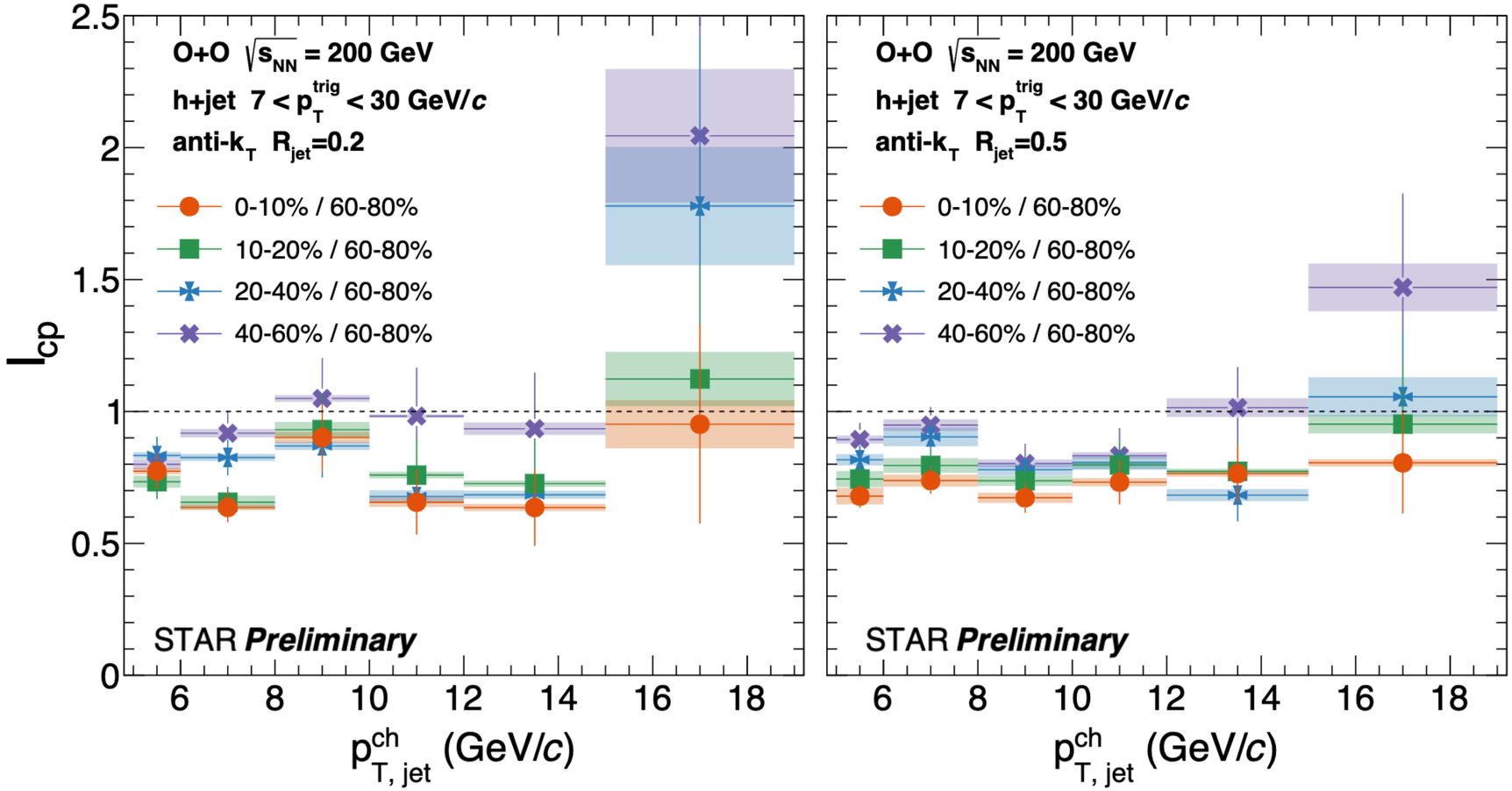
Both inclusive jet R_{cp} and hadron R_{cp} suffer from large N_{coll} uncertainty

⇩

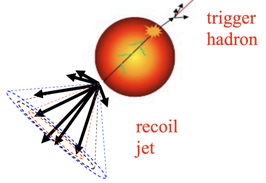
Semi-inclusive h+jet measurement



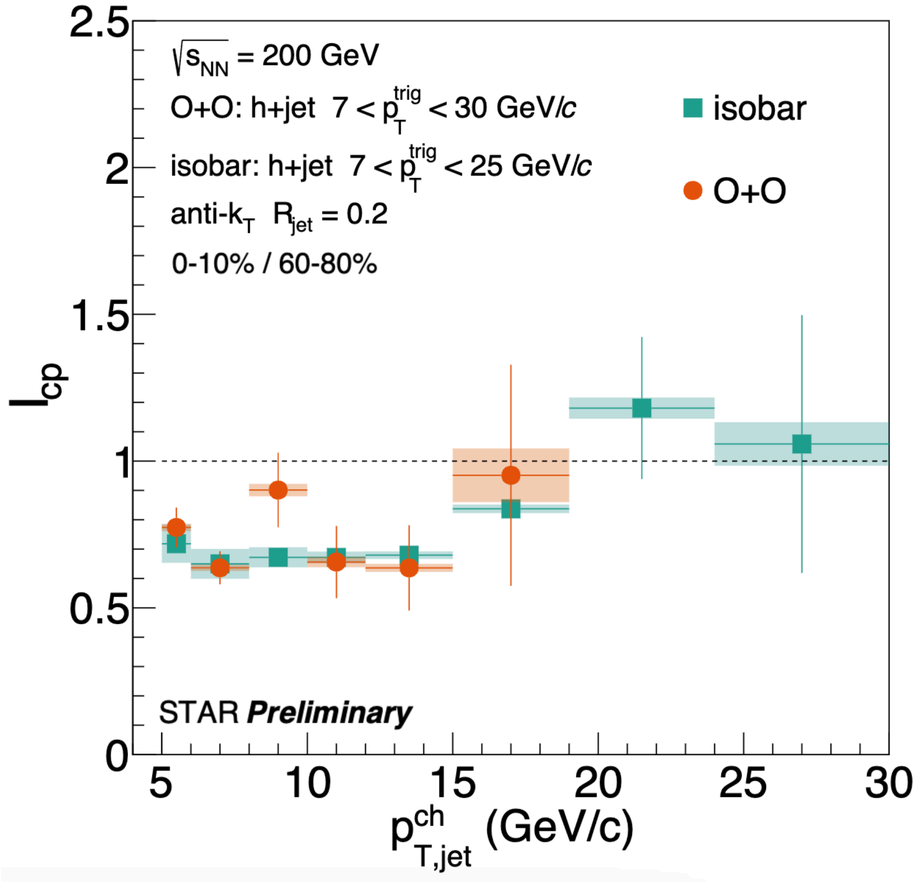
Semi-inclusive h+jet I_{cp}



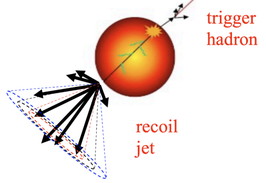
- No significant difference between R = 0.2 and 0.5
- $I_{cp} < 1$, suggest yield suppression



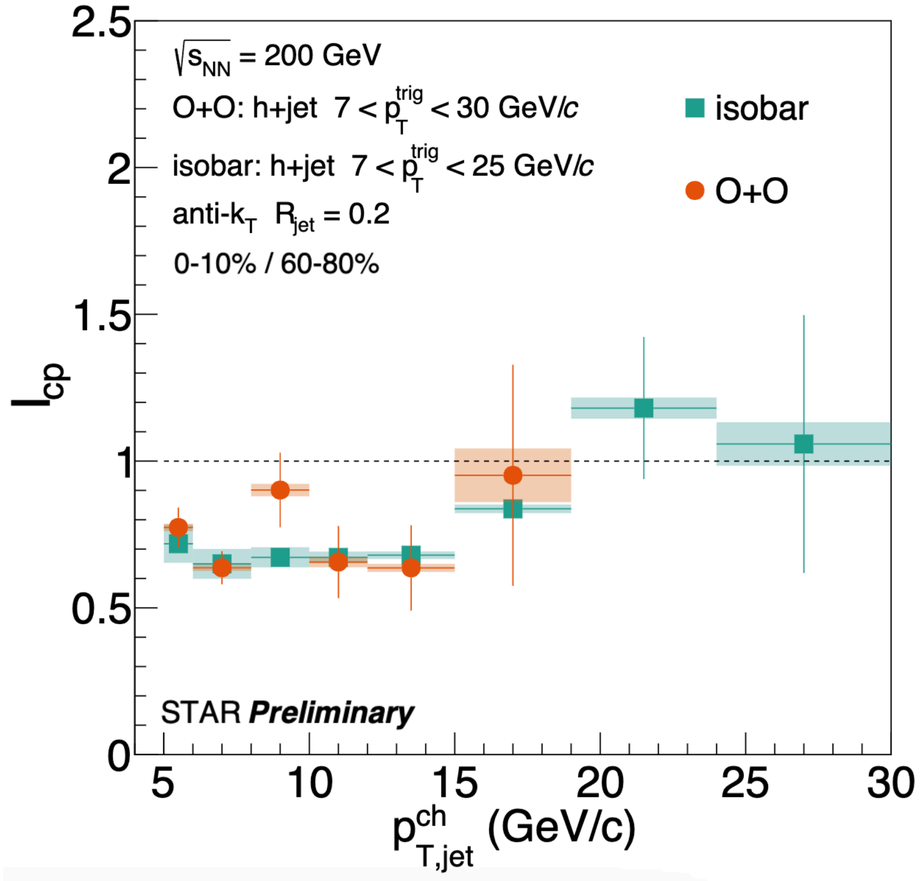
I_{cp}: O+O vs. Isobar



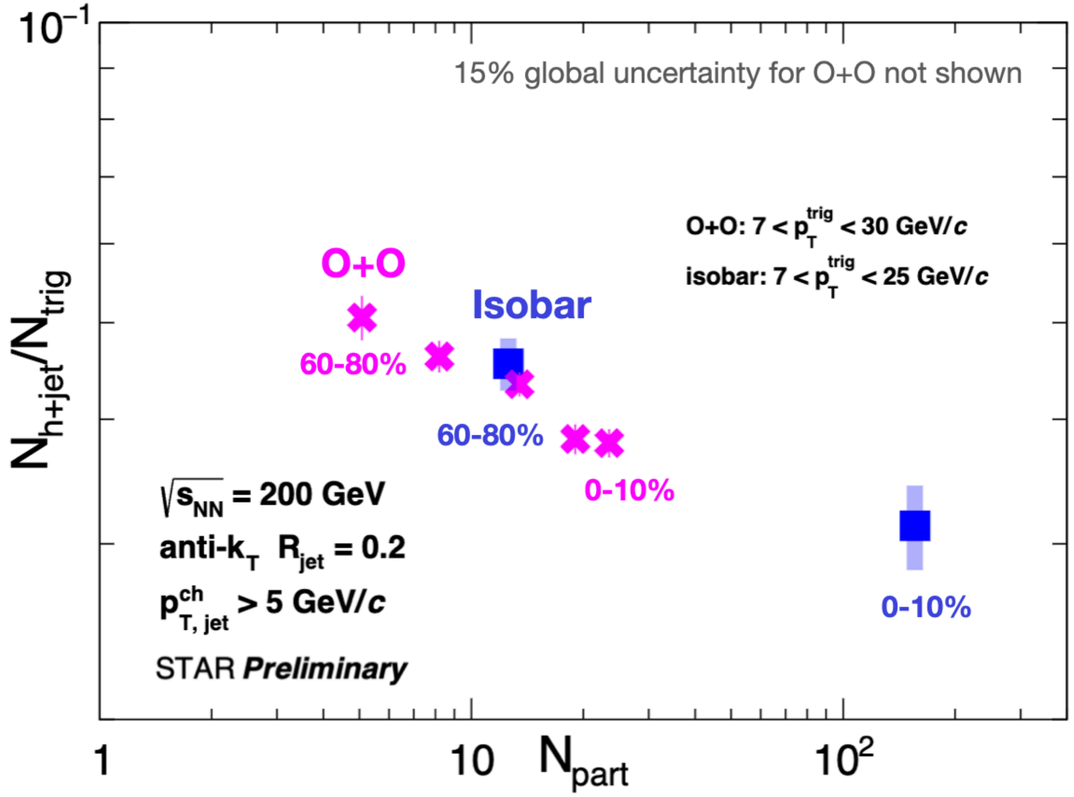
- Similar I_{cp} between O+O and Isobar



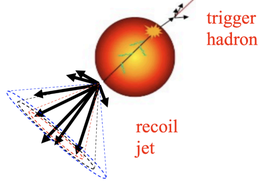
I_{cp}: O+O vs. Isobar



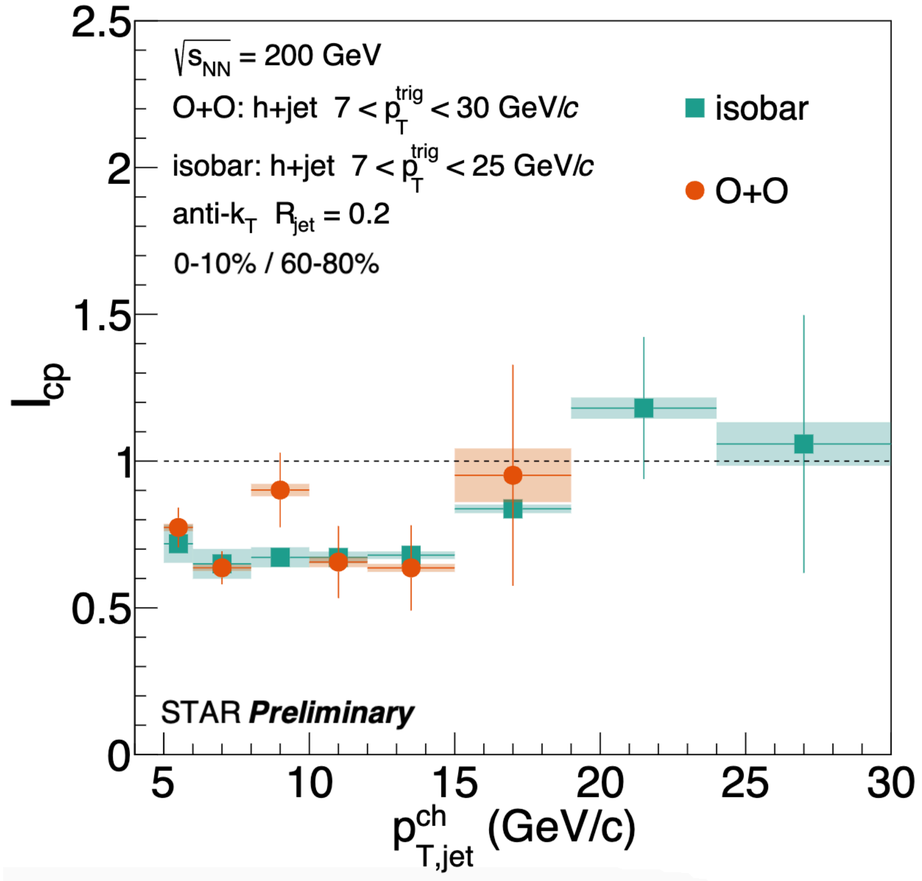
- Similar I_{cp} between O+O and Isobar

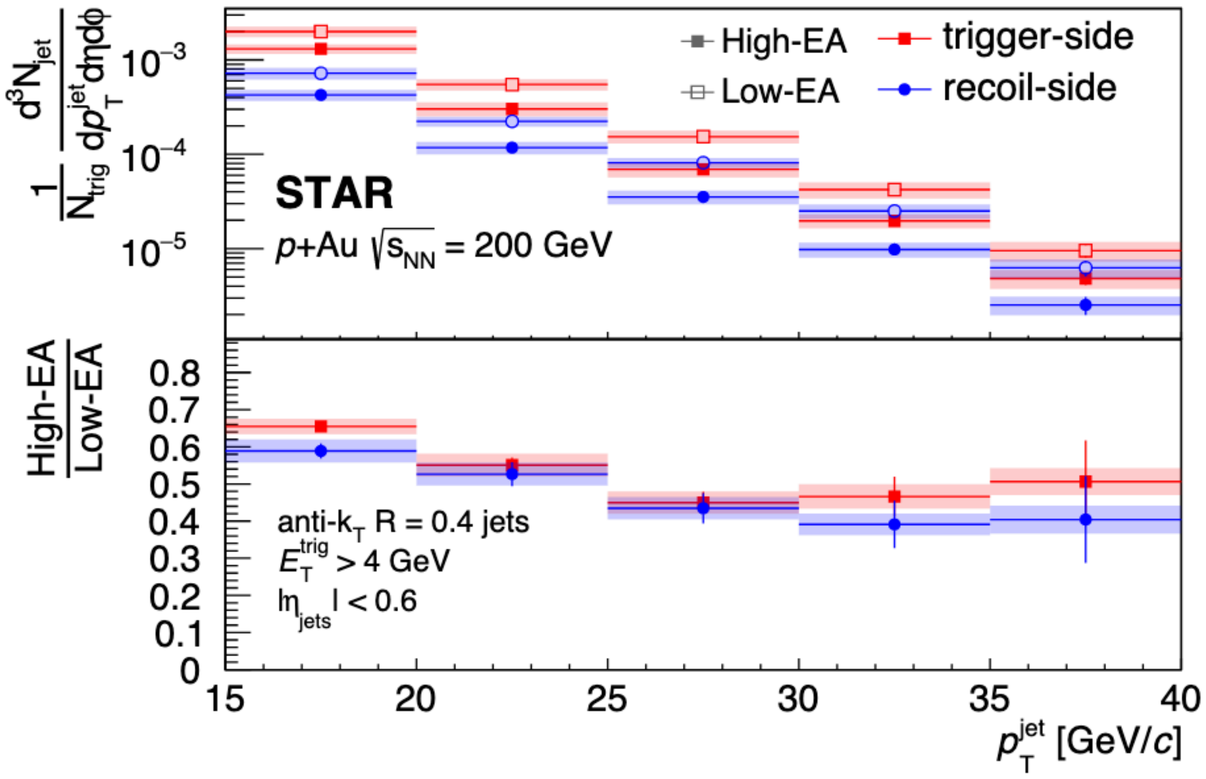


- Yield decreases with increasing N_{part}
- Similar I_{cp} indicates similar relative suppression



Interpretation of I_{cp} in O+O





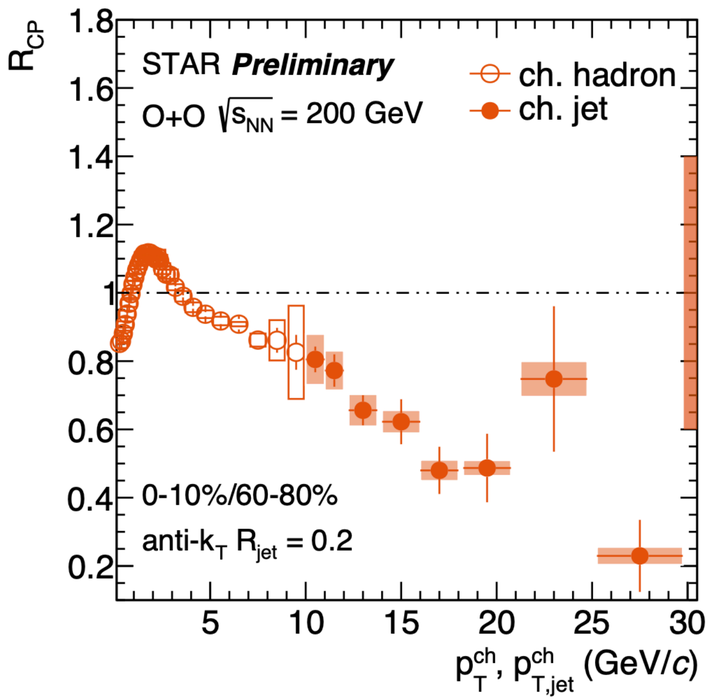
- **Isobar**: jet quenching **vs.** • **p+Au**: EA-Q^2 anti-correlation

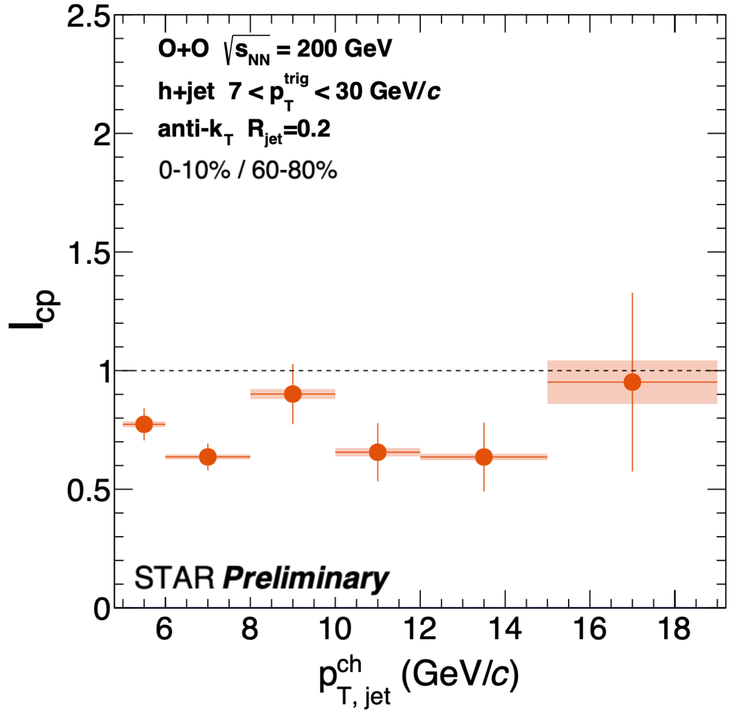
Further investigations are ongoing, theoretical inputs are welcome

Summary

✓ Hint of jet quenching in O+O collisions

- Charged hadron **R_{AA} ~ 1** (about 15% uncertainty)
- Charged hadron and jet **$R_{cp} < 1$** (large N_{coll} uncertainty)
- Semi-inclusive h+jet **$I_{cp} < 1$** (other effects?)

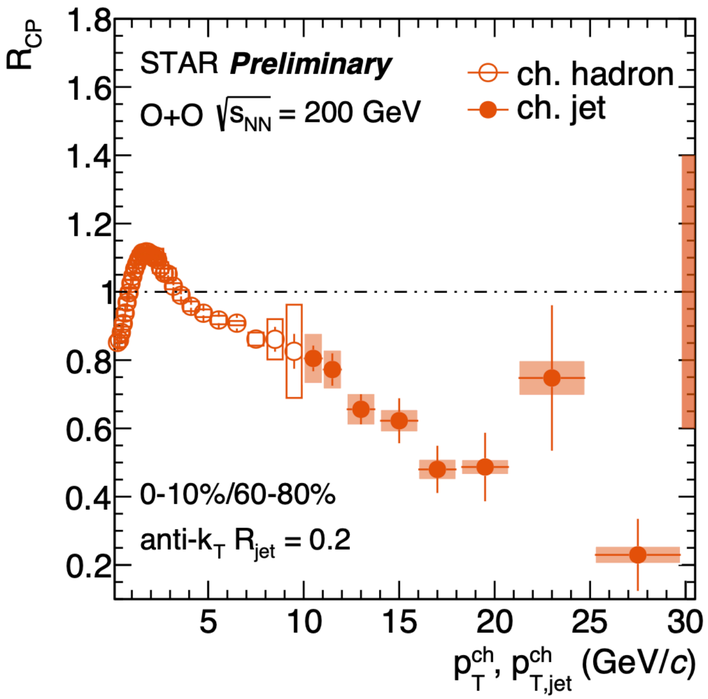


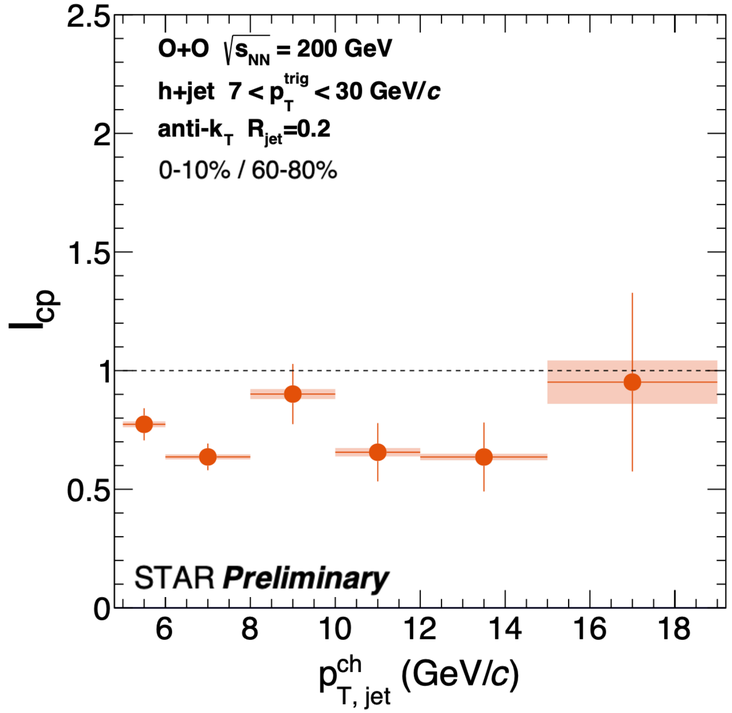


Summary

✓ Hint of jet quenching in O+O collisions

- Charged hadron **R_{AA} ~ 1** (about 15% uncertainty)
- Charged hadron and jet **$R_{cp} < 1$** (large N_{coll} uncertainty)
- Semi-inclusive h+jet **$I_{cp} < 1$** (other effects?)





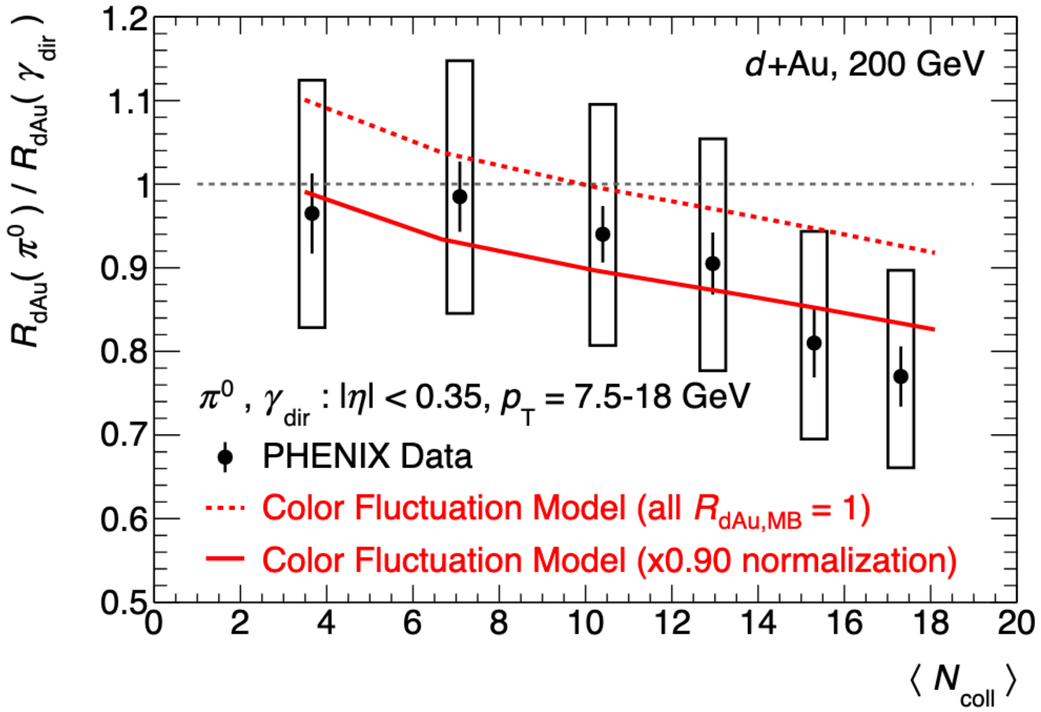
✓ **Outlook：**

- pp reference for jet R_{AA}
- h+jet: trigger-side jets to study EA-Q^2 anti-correlation
- Compare to model calculations
  - x_F dependent effect
  - Nuclear structure
- O+O collisions @ LHC

Backup

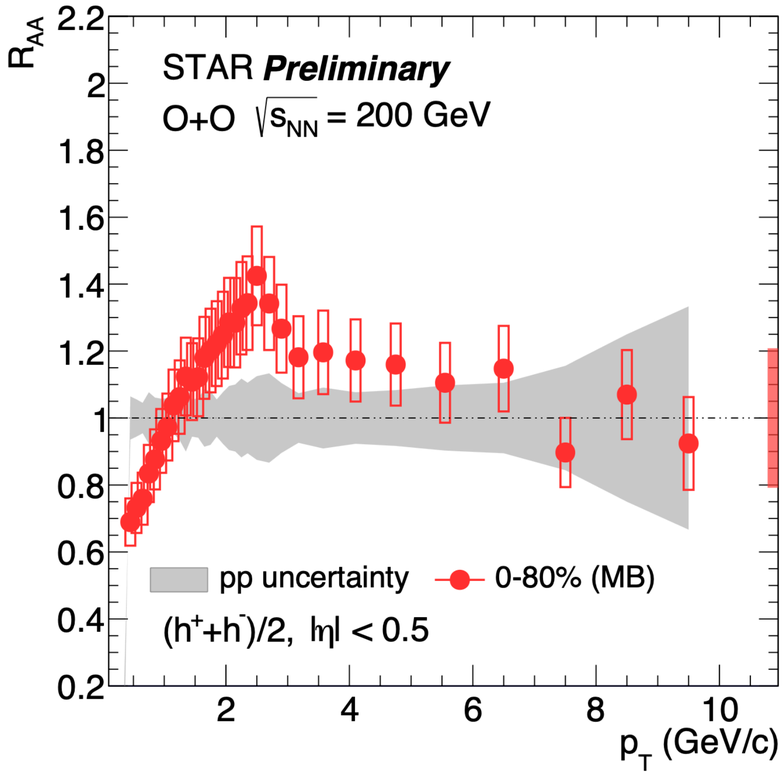
d+Au π^0 to γ_{dir} Suppression

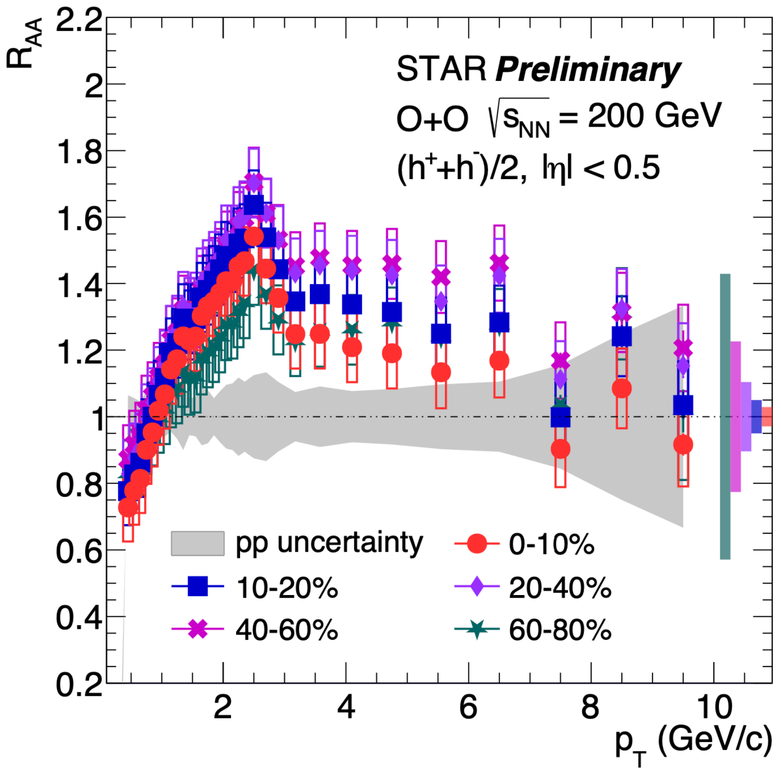
PHENIX, PRL 134, 022302 (2025)
D. Perepelitsa, PRC 110, L011901 (2024)

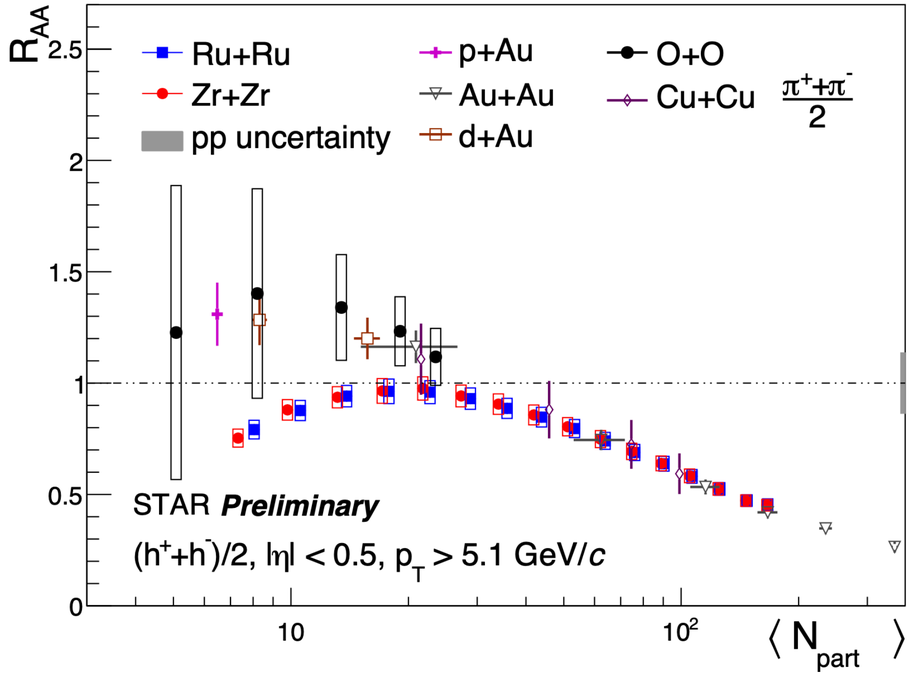


- Relative π^0 to γ_{dir} suppression can be reproduced by Color Fluctuation Model with absence of jet quenching

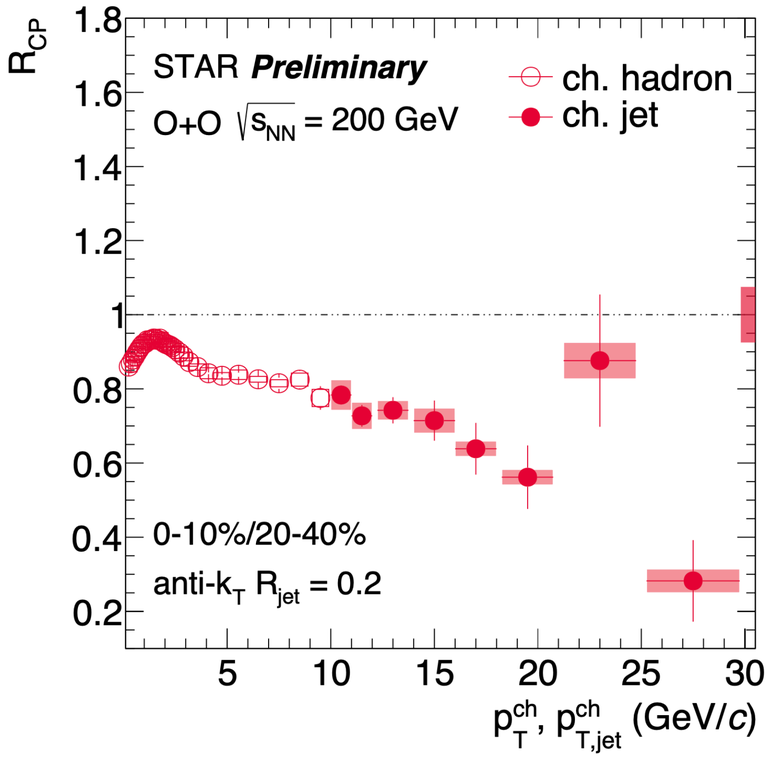
Inclusive Charged Hadron R_{AA}







R_{cp} of Inclusive Charged Hadron and Jet (0-10%/20-40%)



Cold nuclear matter effects also play a role:

- α-cluster vs. Woods-Saxon

D. Behera et al., PRC 109, 014902 (2024)

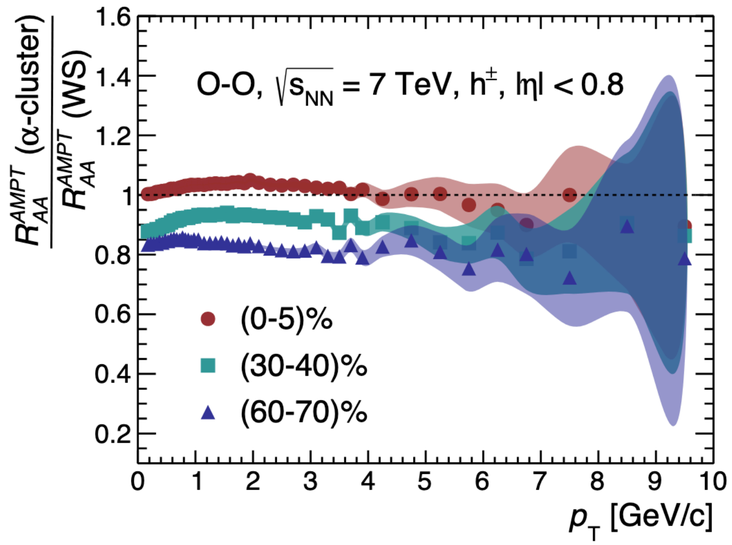
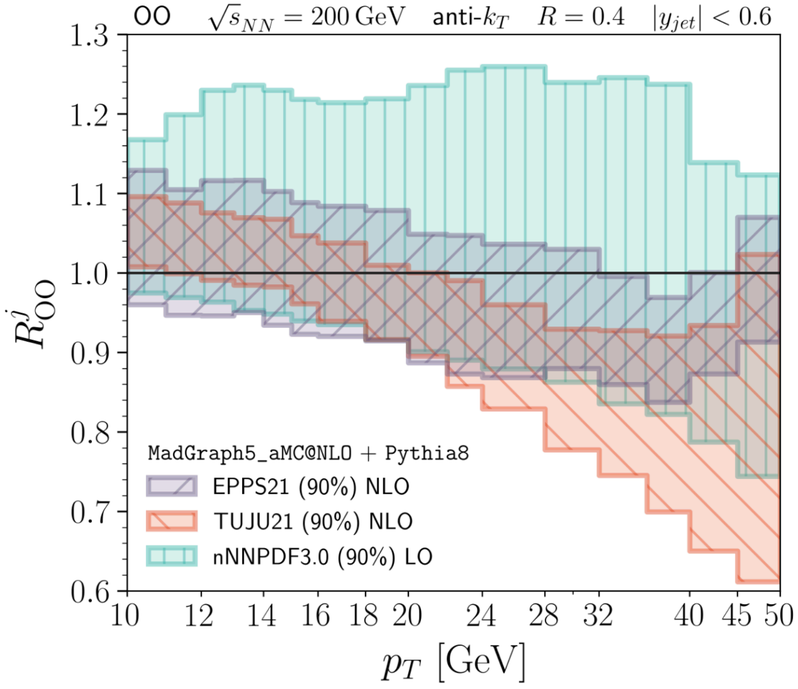


FIG. 12. (Color Online) Ratio between R_{AA} of $\alpha-$clustered to Woods-Saxon density potential of all charged hadrons ($h^{\pm}$) in O-O collisions at $\sqrt{s_{NN}} = 7$ TeV. The shaded region shows the statistical errors.

- nPDF

J. Gebhard et al., arXiv:2410.22405



Possible Effects

Inclusive hadron and jet:

- Jet quenching: RAA↓, Rcp↓
- nPDF effect: RAA↓ at high pT
- Cronin effect: RAA↑ at mid pT
- α-cluster structure effect: Ncoll↑, RAA↓, Rcp↓
- Color fluctuation effect: Rcp↓
- Fewer hard scatterings in peripheral events: RAA↓ at low Npart Tong Liu, QM22

Semi-inclusive h+jet:

- Jet quenching: IAA↓, Icp↓
- nPDF effect: IAA↓ at high pT
- EA-Q^2 anti-correlation: Icp↓