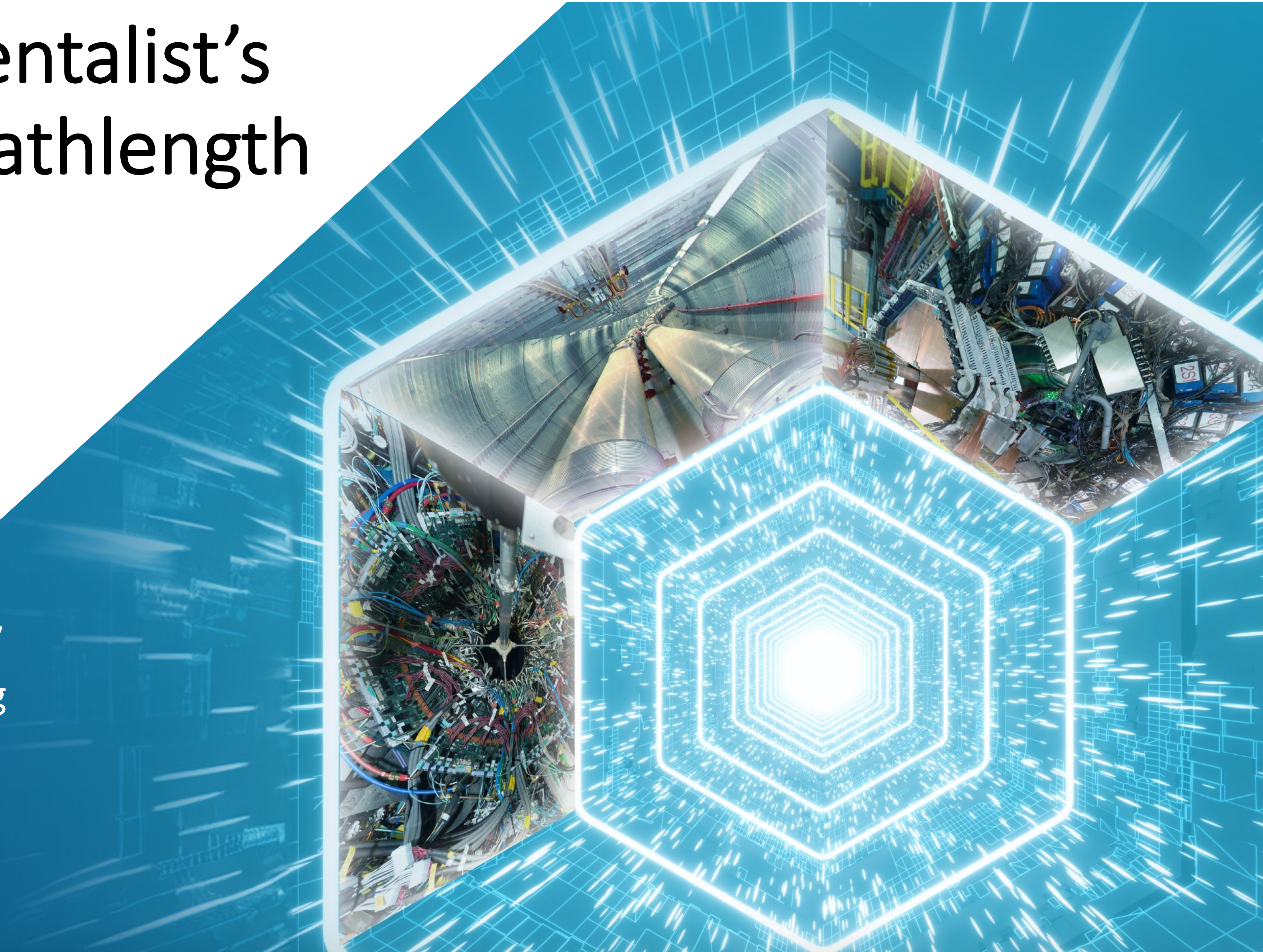
An Experimentalist's Search for Pathlength Dependent Energy Loss in the QGP



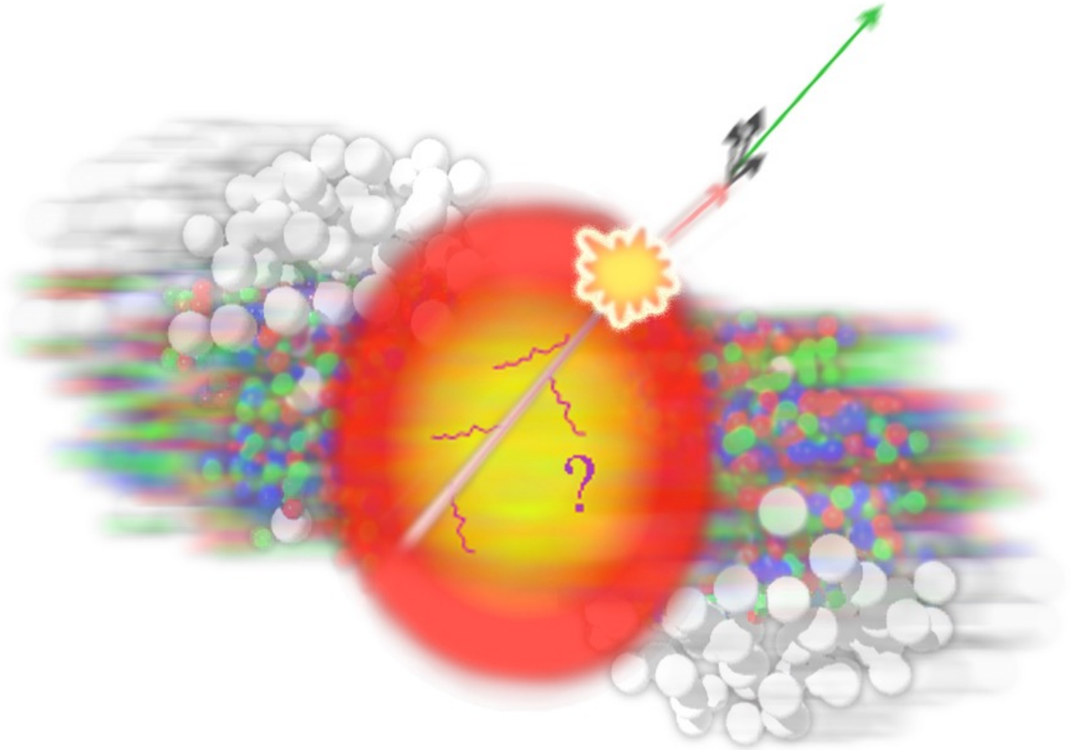
Megan Connors
Georgia State University
RHIC AGS Users Meeting
June 12, 2024

What is a Path Length Dependent energy loss

- Landau-Pomeranchuk-Migdal (LPM) effect
  - Due to interference of radiation with multiple scatterings in the QGP
  - Leads to an L^2 dependence
- Longer L results in greater energy loss
- Broadening also has L dependence

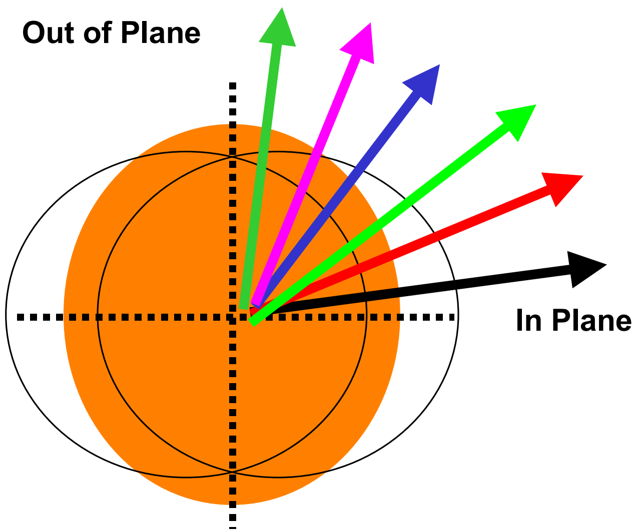
$$\langle k_\perp^2 \rangle \equiv \hat{q} L$$

- Experimentally we do not know L

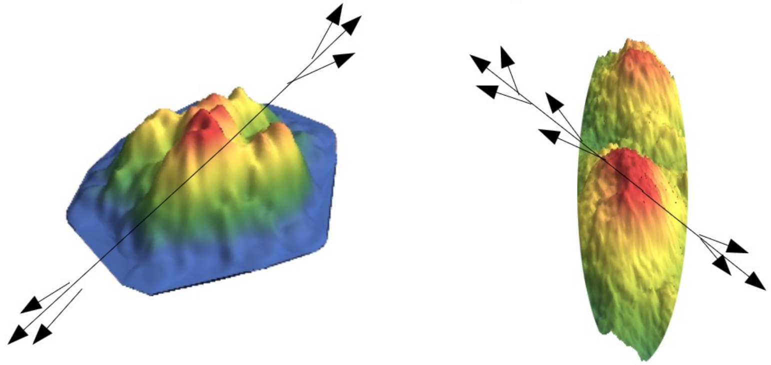


Experimentally measuring path length dependence

- In plane – less L – less E_{loss}
- Out-of-plane – more L – more E_{loss}
- How to vary path length?
  - System size
  - Angle with respect to reaction plane
  - Surface bias
- Challenges
  - Fluctuations
  - Surface bias
  - Energy density
  - Quark/gluon fractions
  - Flow



In the same centrality window



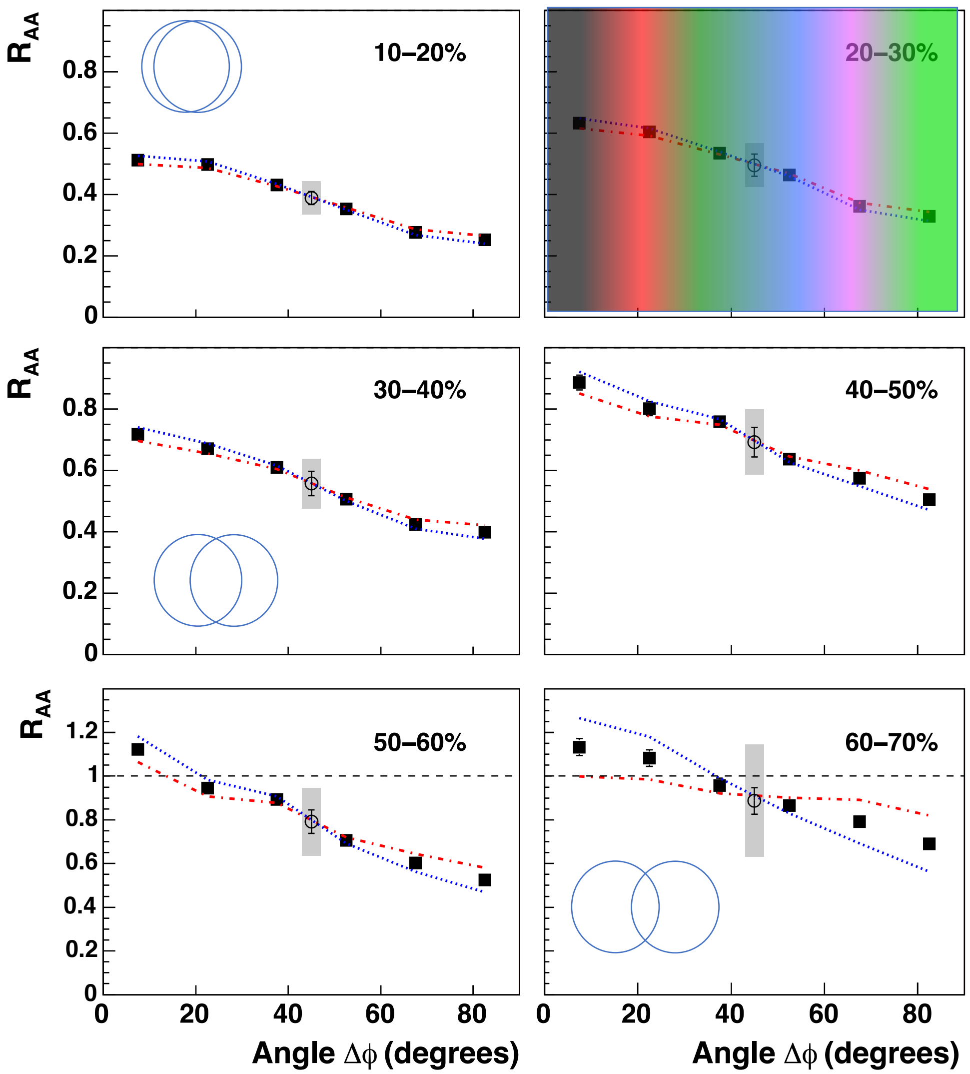
Round events=longer path length
↓ R_{AA}

Eccentric events=shorter path length
↑ R_{AA}

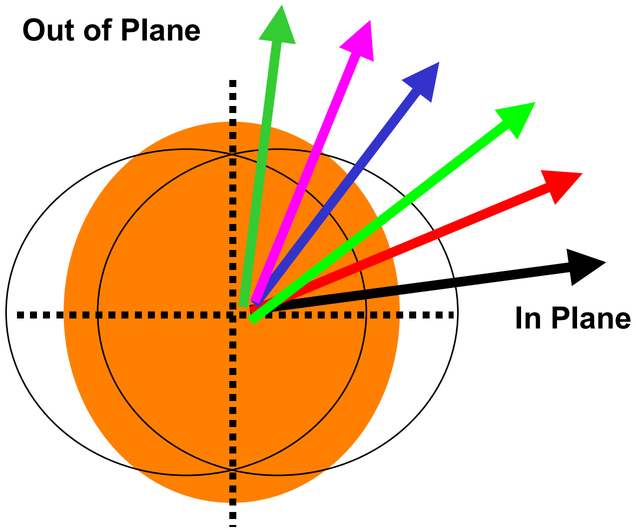
Noronha-Hostler 2016 J. Phys.: Conf. Ser. 736 012019

Early Pathlength Dependence at RHIC with hadrons

PHENIX [Phys. Rev. C 76, 034904 (2007)](#)



- Suppression of pions has pathlength dependence
- Toward out of plane:
  - Larger L→More E_{loss} →Lower R_{AA}

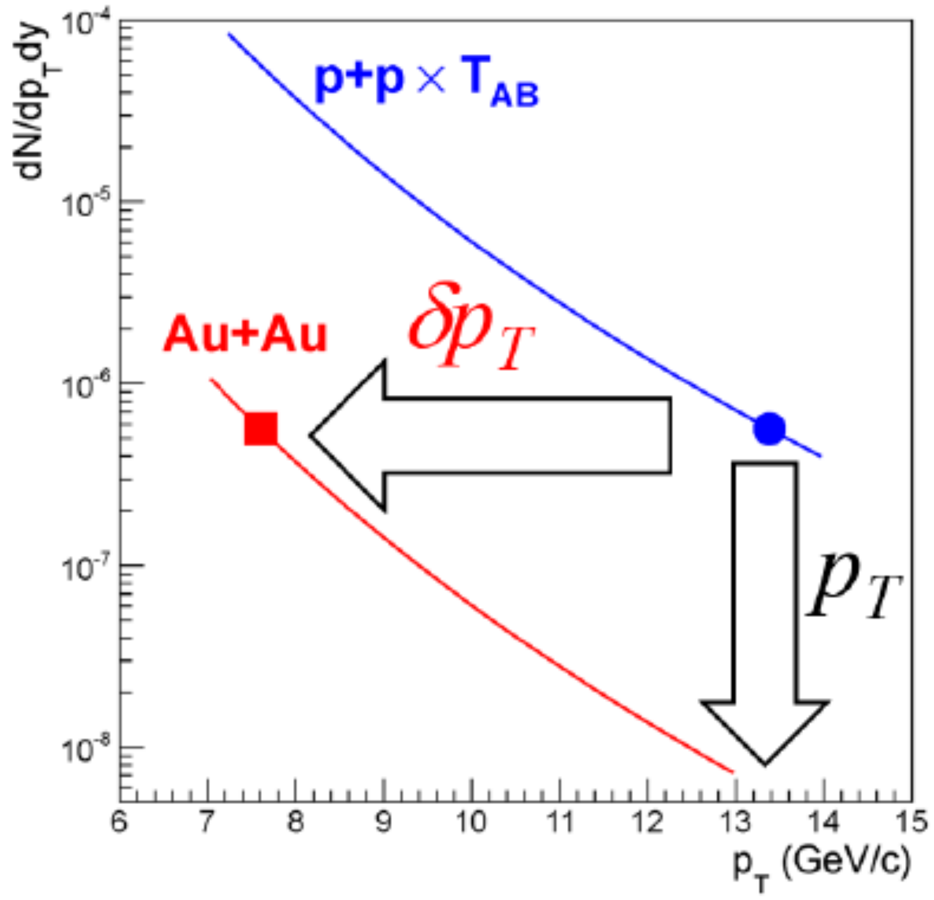


Relation between RAA(φ) and v_2:

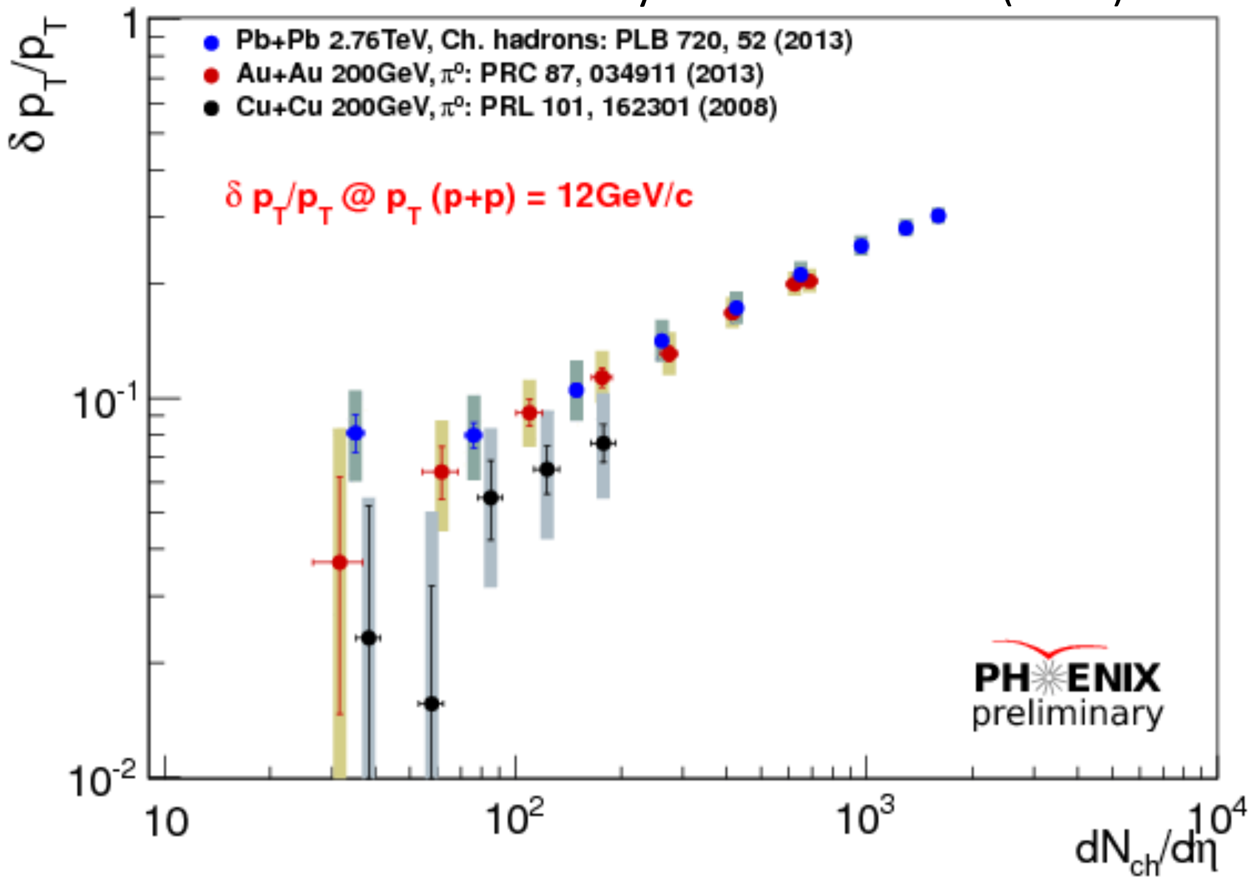
$$R_{AA}(\varphi) = R_{AA}\left(1 + 2v_2 \cos 2(\varphi - \psi)\right)$$

Early Fractional Momentum Loss Study

- Fractional momentum loss $S_{loss}=\delta p_T/p_T$
- Compare across systems and collision energy



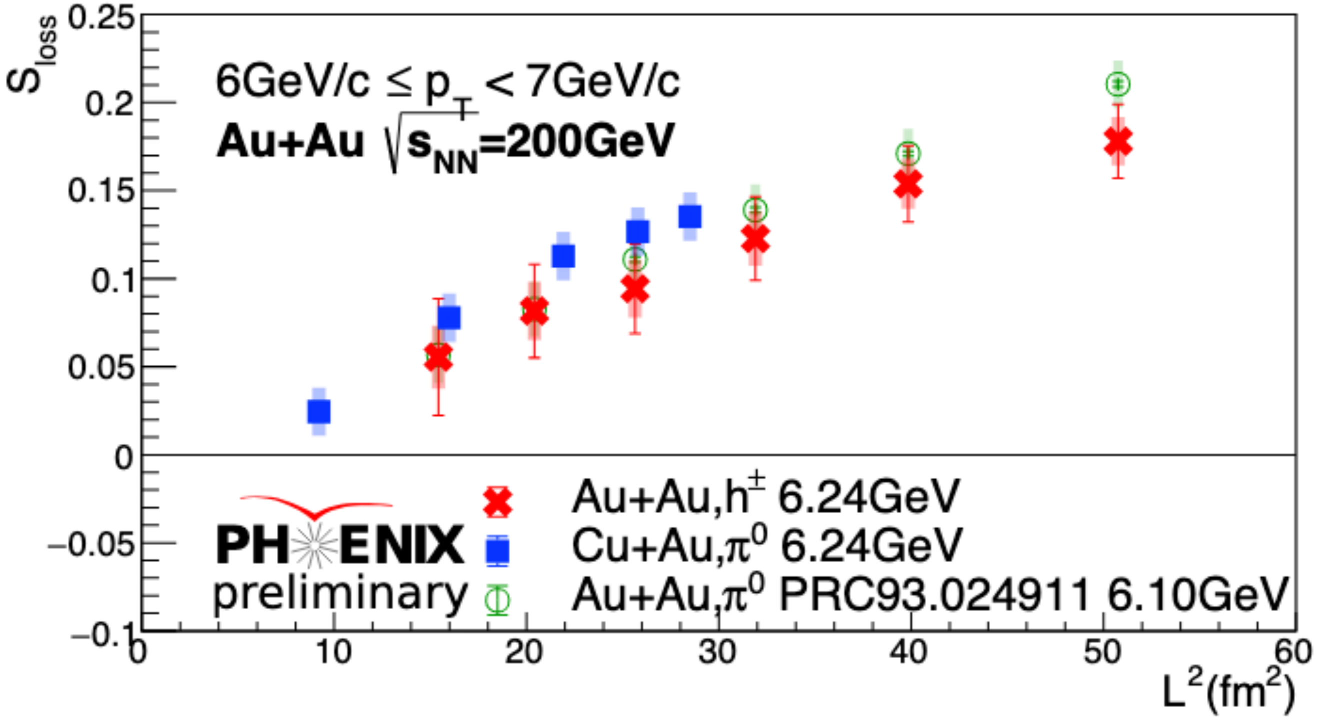
PhysRevC.93.024911 (2015)

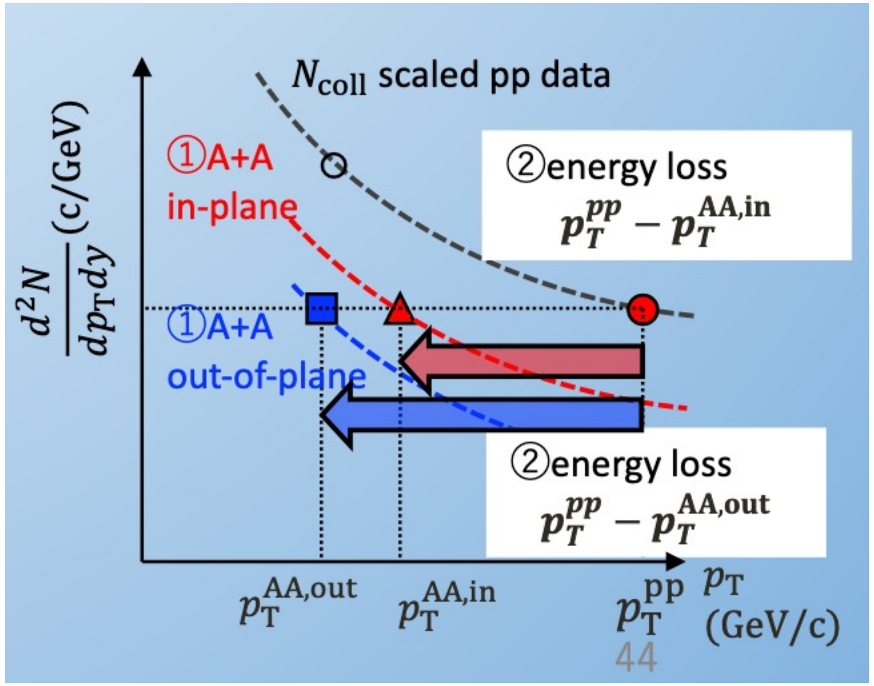


- S_{loss} scales with energy density

Pathlength Dependent Fractional Momentum Loss?

- L and N_{part} based on Glauber Model calculation
- Scales with L^2
- Next extend to in-plane vs out-of-plane:





in-plane $(\phi = 0°)$

$$\left.\frac{d^2N}{dp_T dy}\right|_{in} = \frac{d^2N}{dp_T dy} \times (1 + 2v_2)$$

out-of-plane $(\phi = 90°)$

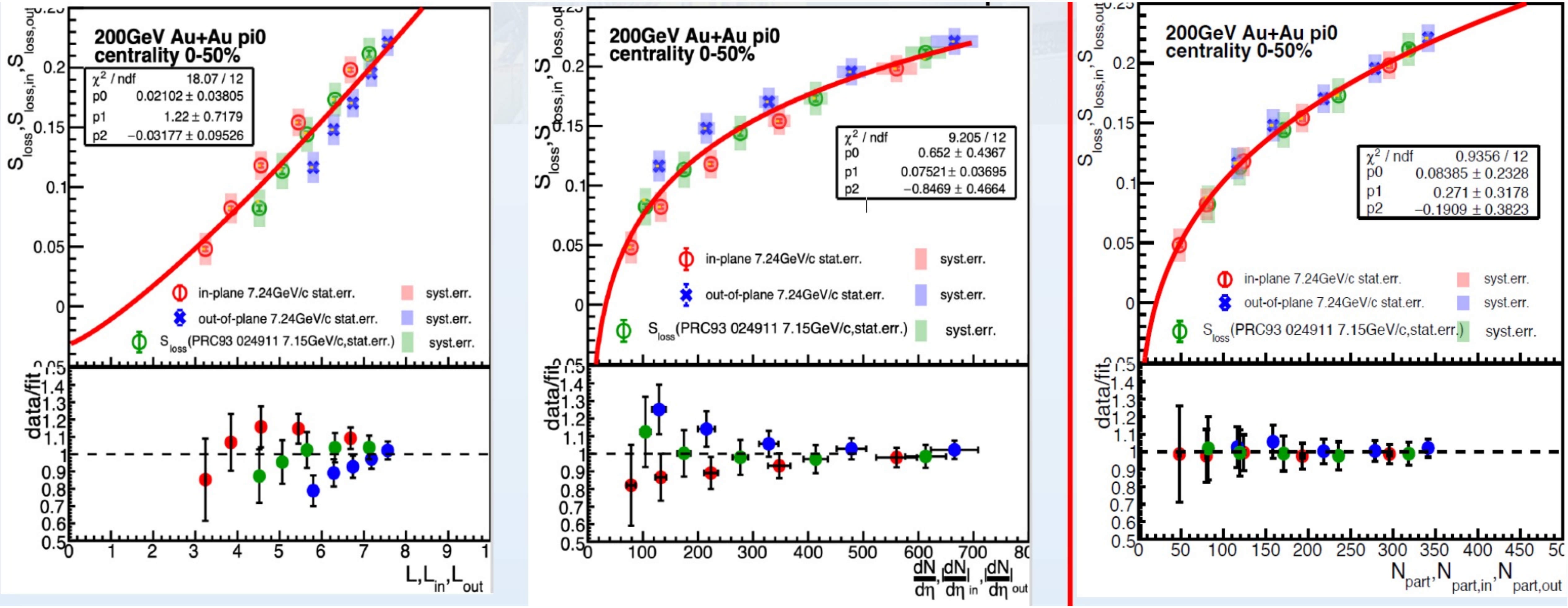
$$\left.\frac{d^2N}{dp_T dy}\right|_{out} = \frac{d^2N}{dp_T dy} \times (1 - 2v_2)$$

$$S_{loss}^{in} = \frac{p_T^{pp} - p_T^{AA,in}}{p_T^{pp}},$$

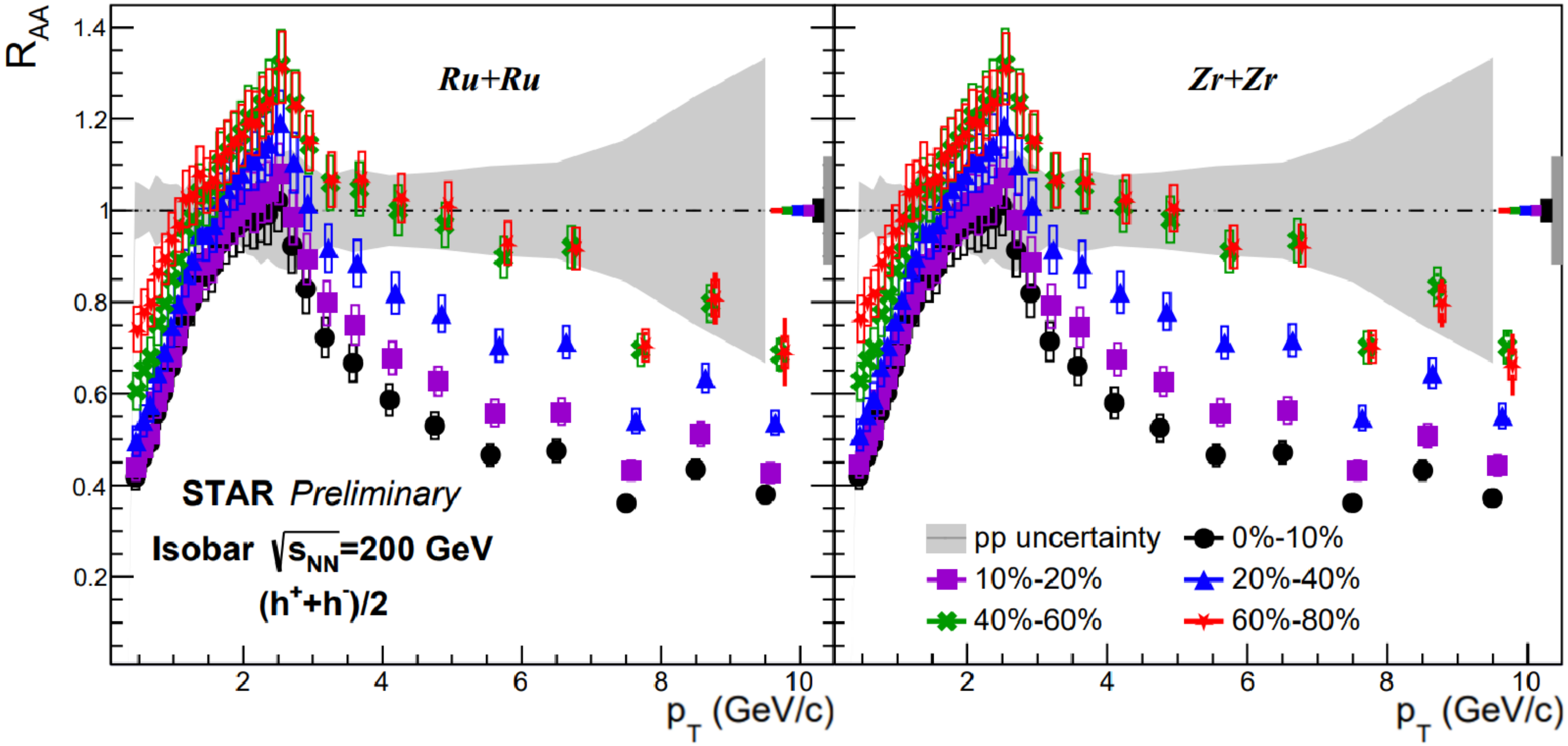
$$S_{loss}^{out} = \frac{p_T^{pp} - p_T^{AA,out}}{p_T^{pp}}$$

Scaling relationships for in vs out-of-plane

- Scales better with N_{part} than L or dN/dη



More systems at RHIC



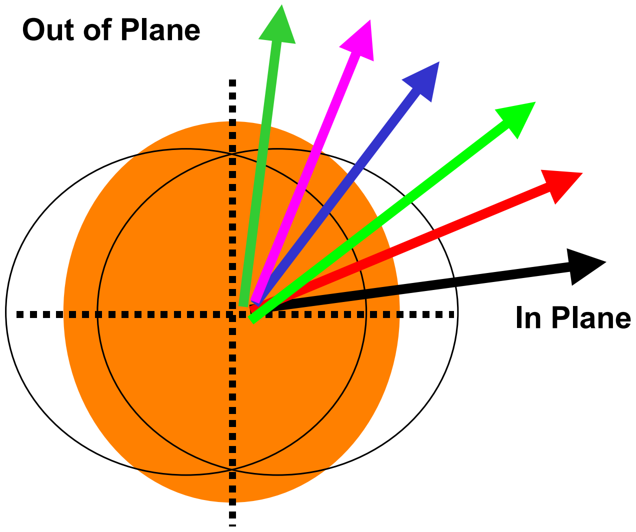
- Strong centrality dependence may indicate path-length dependent effects
- Need to disentangle from energy density

$$R_{AA} = \frac{1}{N_{ev}^{AA}} \frac{d^2N^{AA}/d\eta dp_T}{T_{AA} d^2\sigma^{NN}/d\eta dp_T}$$

$$T_{AA} = \langle N_{coll} \rangle / \sigma_{inel}^{NN}$$

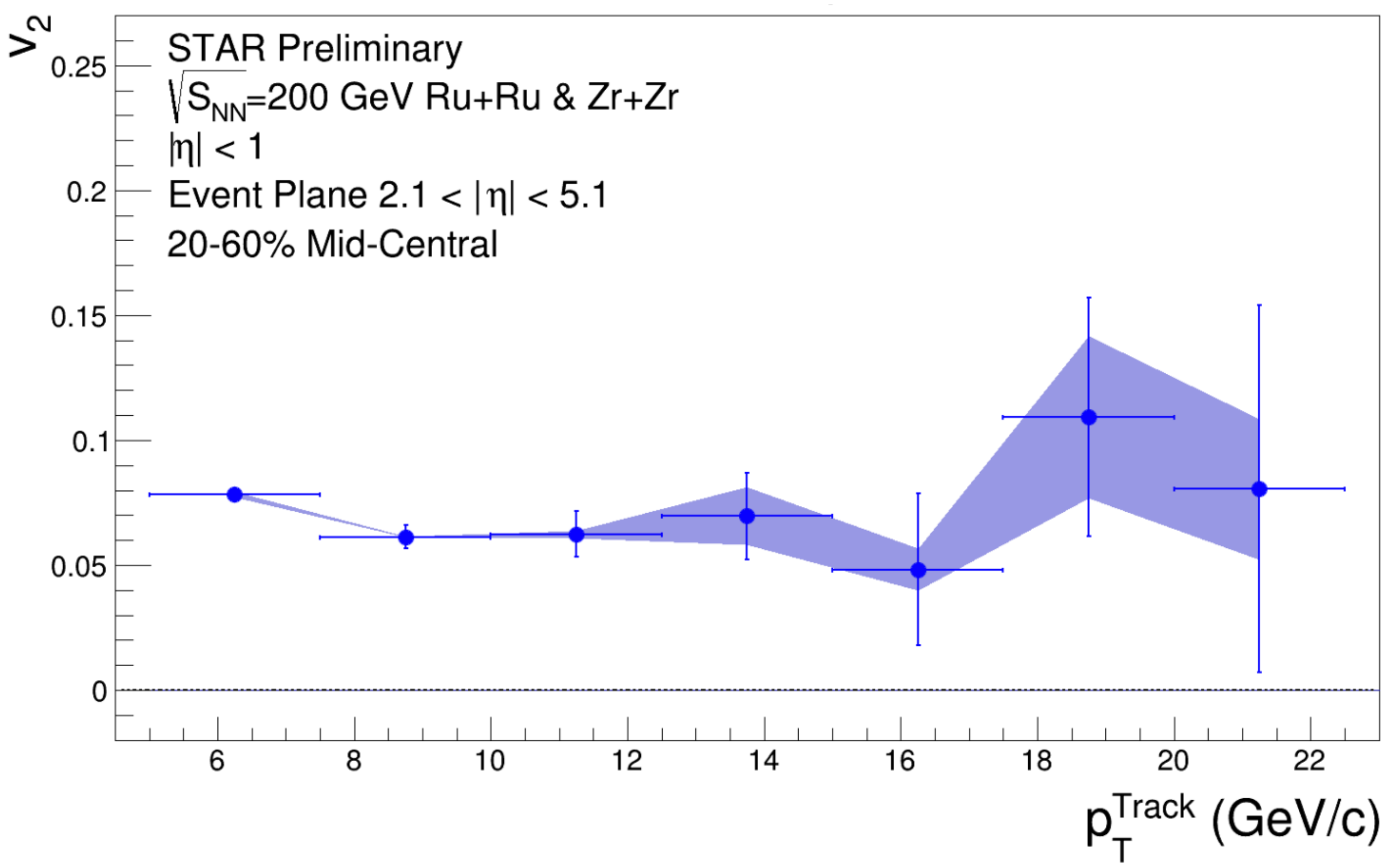
Using event plane angle

- High p_T track v_2 attributed to pathlength dependent energy loss



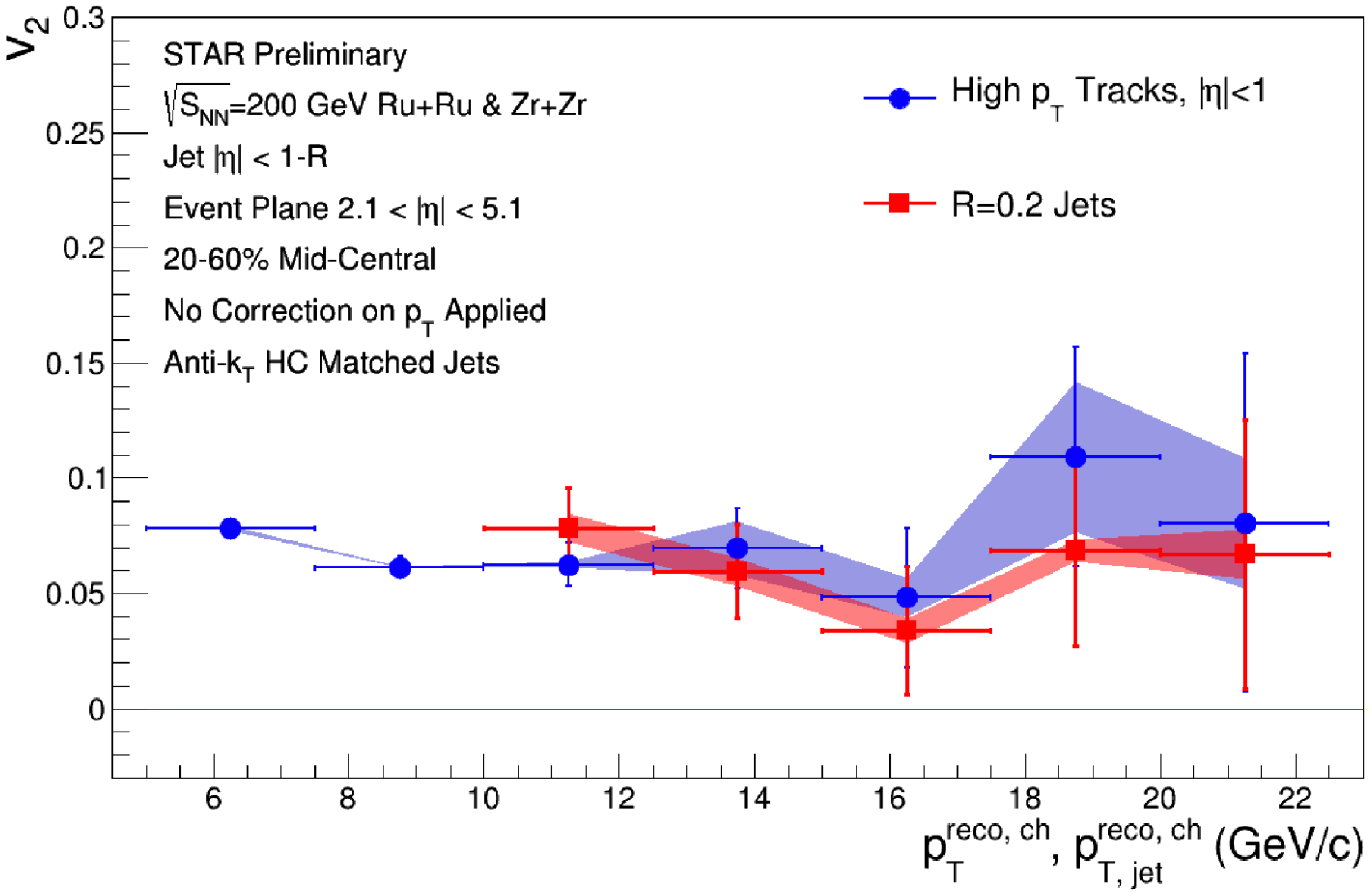
Relation between RAA(φ) and v_2:

$$R_{AA}(\varphi) = R_{AA}(1 + 2v_2 \cos 2(\varphi - \psi))$$



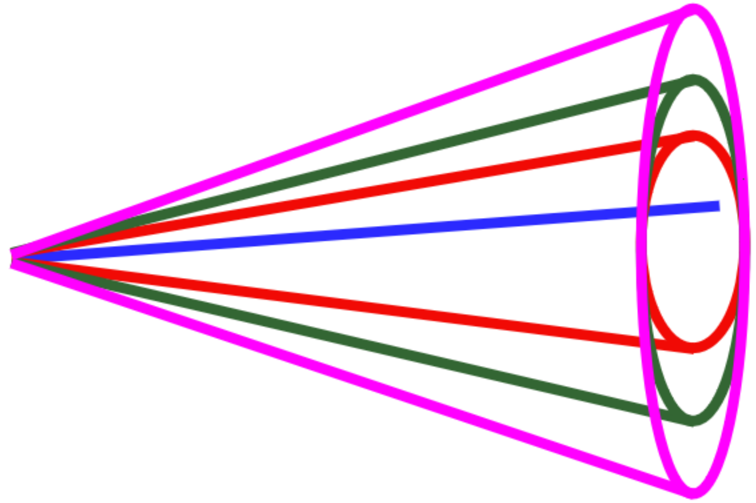
Reconstructed jet v_2

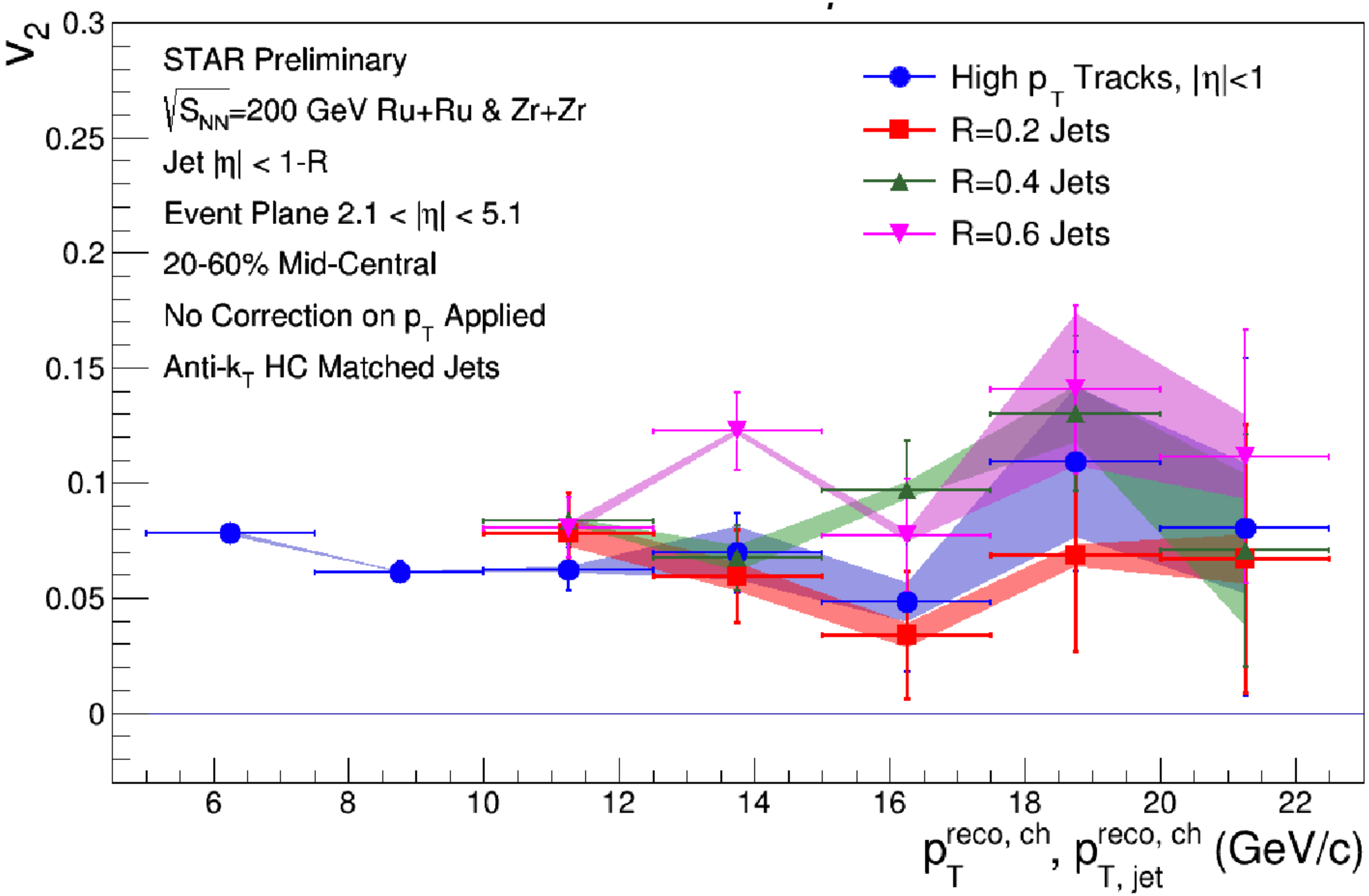
- v_2 for R=0.2 jets consistent with the track v_2
- v_2 appears flat vs p_T



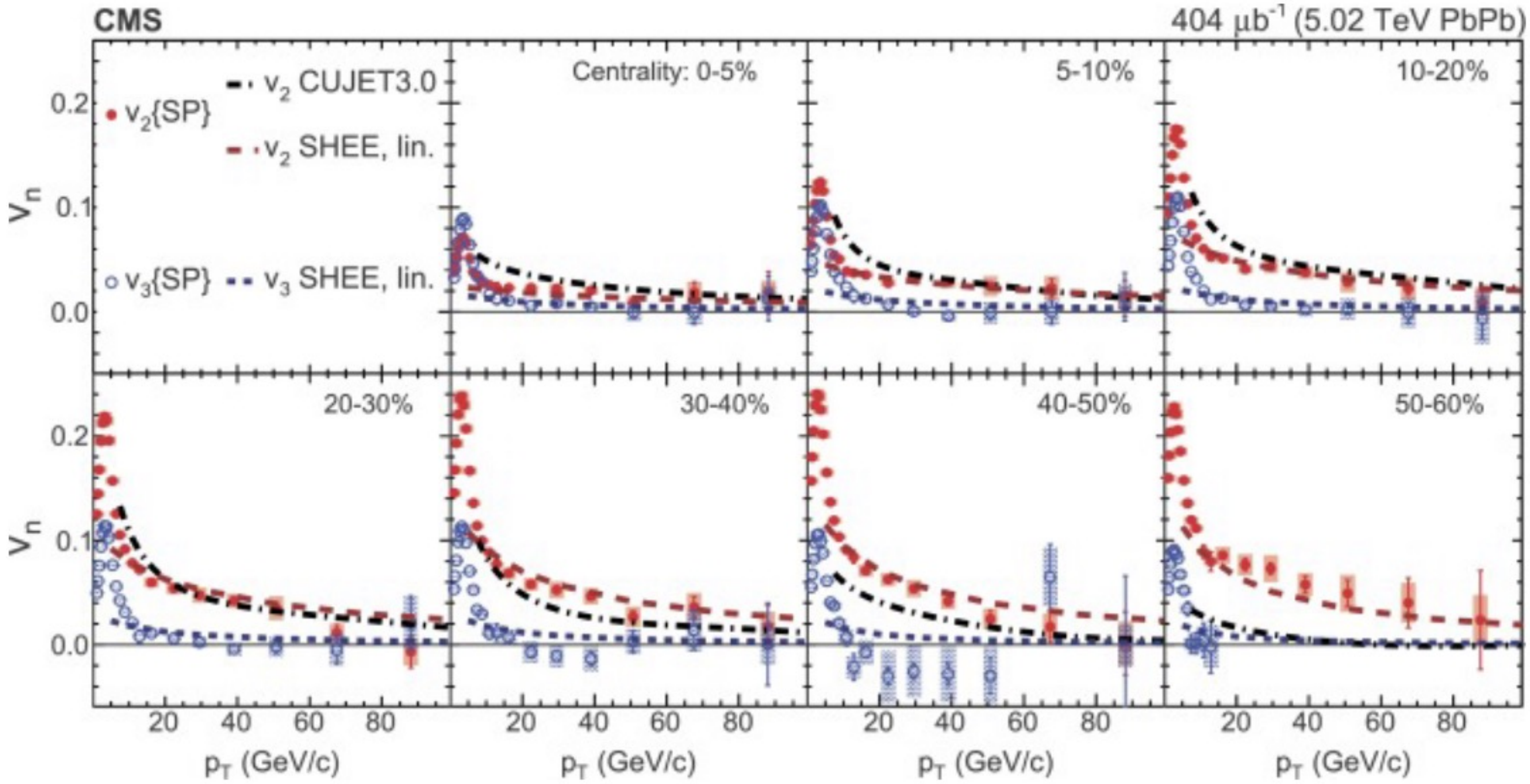
R dependence of reconstructed jet v_2

- Jet v2 measured for R=0.2, 0.4 and 0.6
- No clear R dependence





Pathlength Dependence at LHC with hadrons

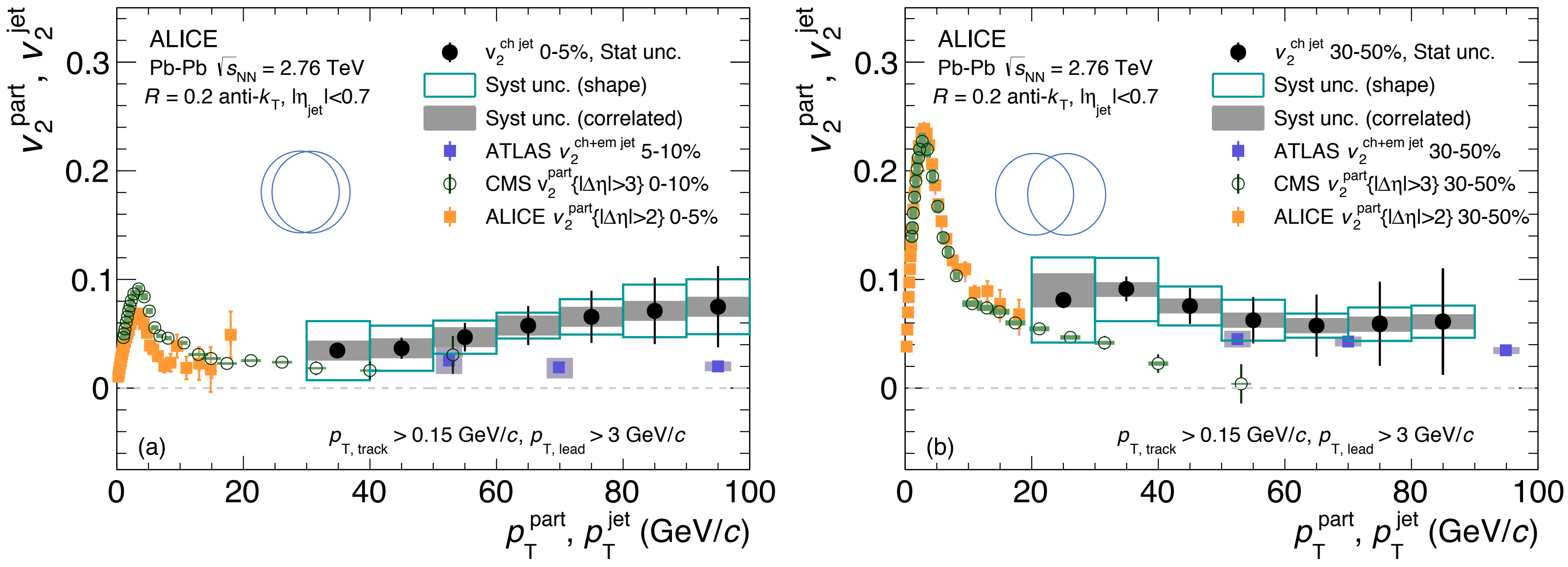


- v_2 persists to very high p_T
- v_3 goes to zero

Phys. Lett. B 776 (2018)

Pathlength Dependence at LHC with jets

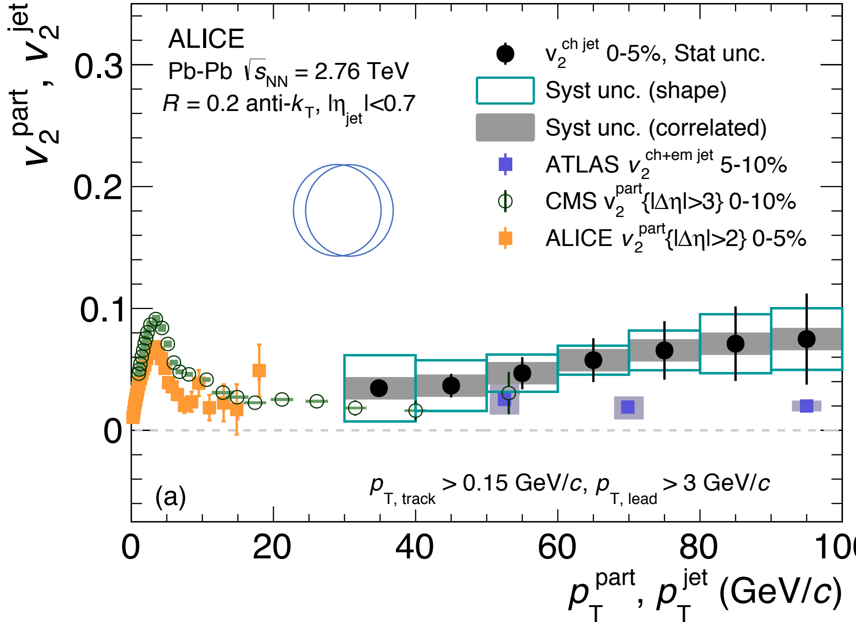
- Jet and track v2
- ~Agreement between LHC experiments

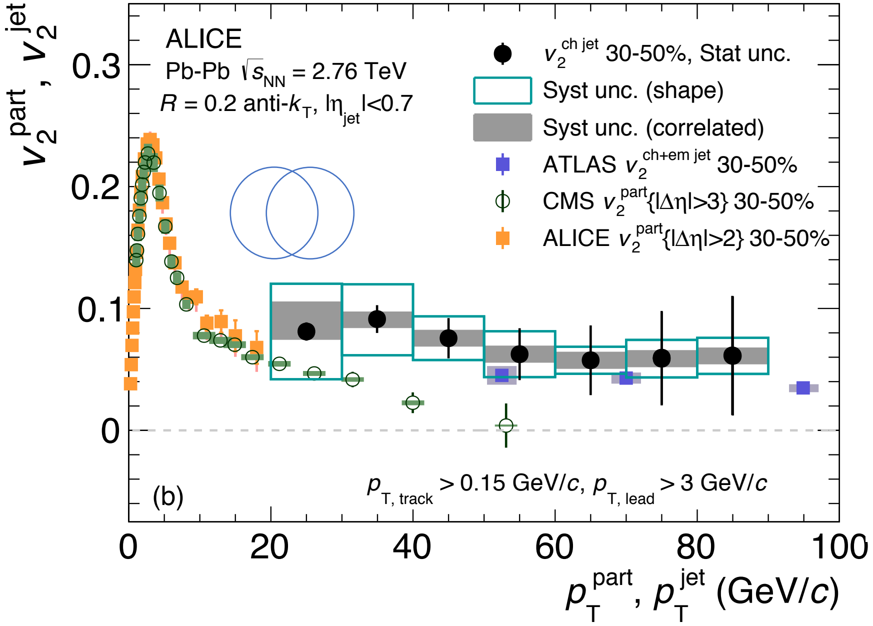


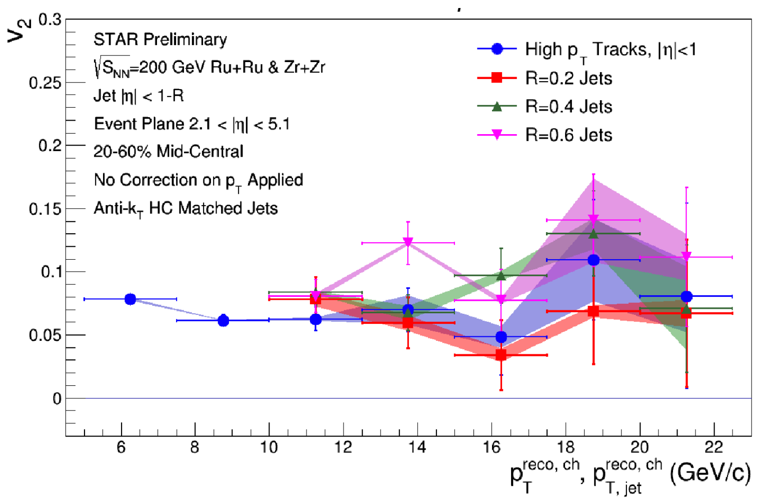
ALICE: PhysLetB.2015.12.047
ATLAS: PRL 111 152301 (2013)

Pathlength Dependence at LHC with jets

- Jet and track v2
- ~Agreement between LHC experiments
- Consistent with RHIC







ALICE: PhysLetB.2015.12.047
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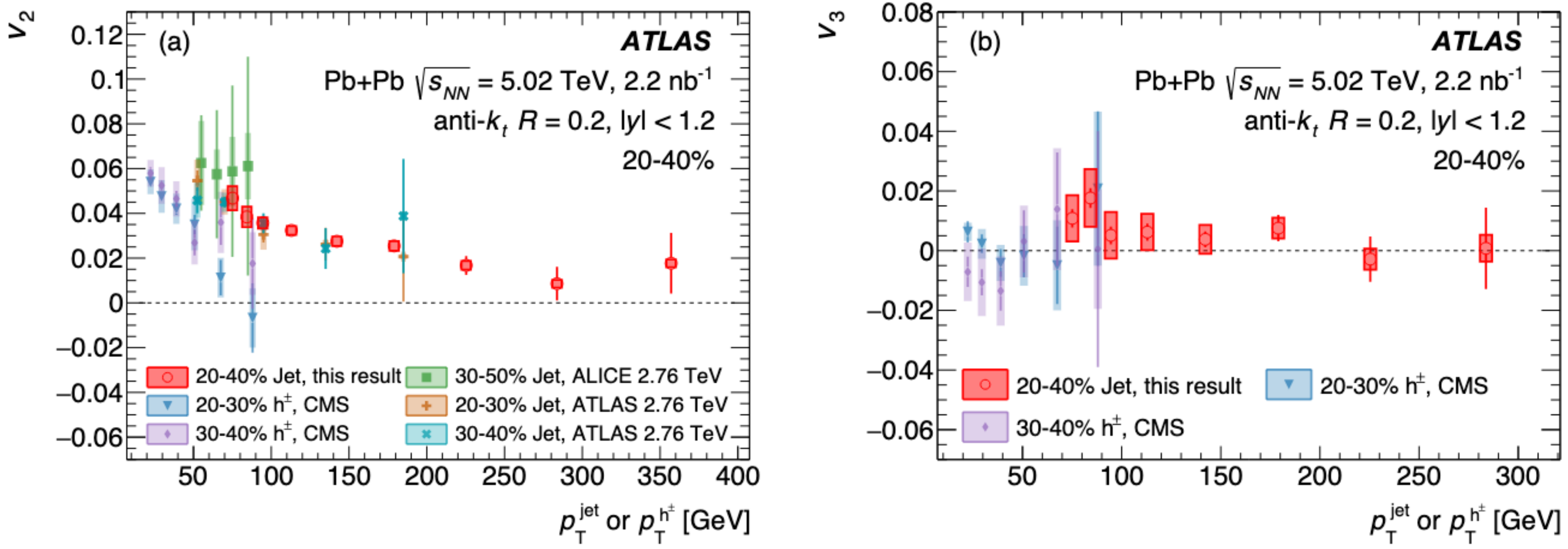
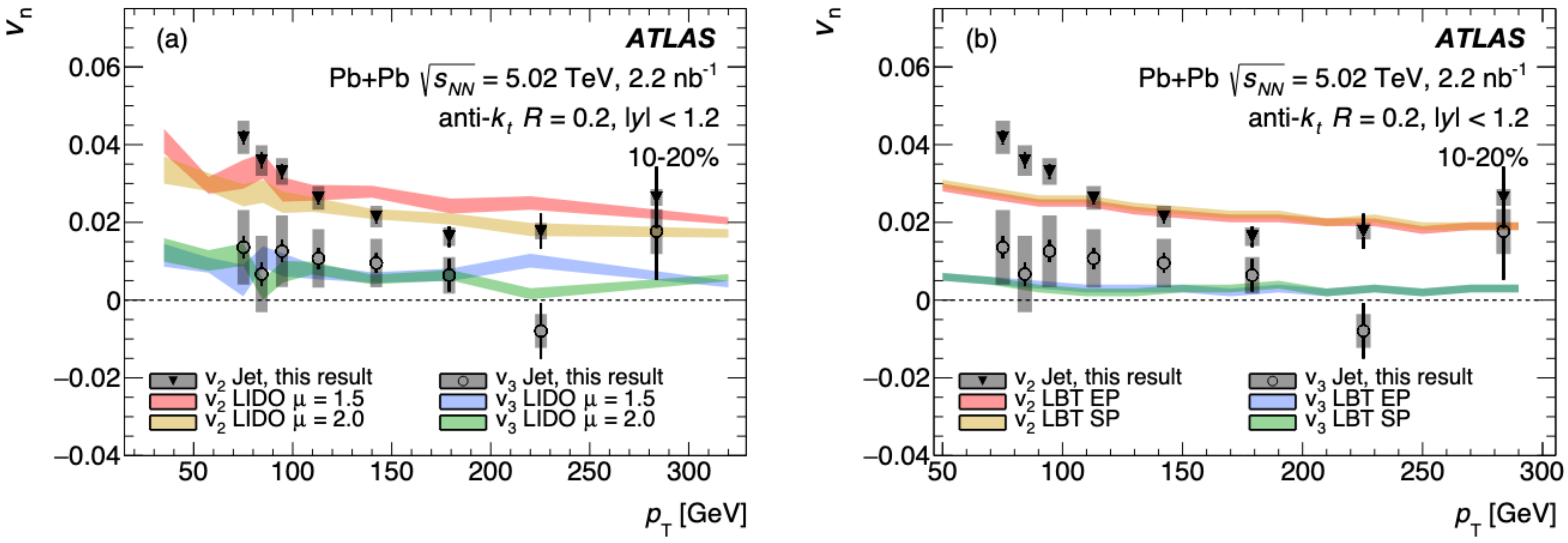
v_n with LHC jets

- 5.02 TeV extends to higher p_T
- Consistent with v_2 measured at 2.76 TeV
- Small jet v_3



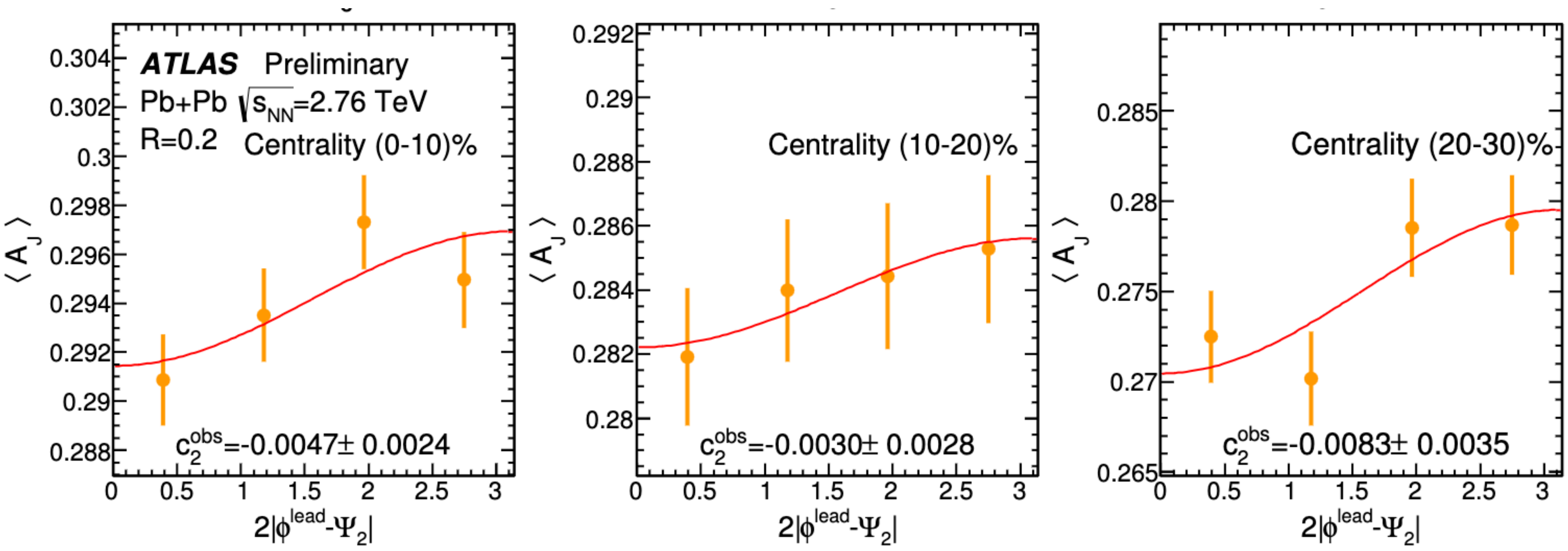
Jet v_n model comparison

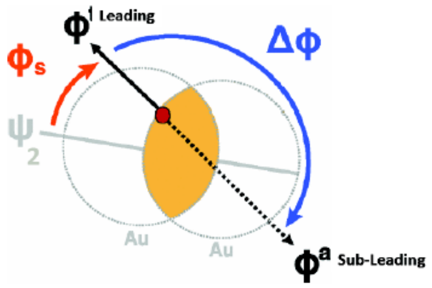
- Reasonable agreement with LBT and LIDO for v_2 and v_3 for jet p_T>100 GeV



Reaction Plane Dependence for Dijets

- Dijet asymmetry is higher for out-of-plane than for in-plane dijets



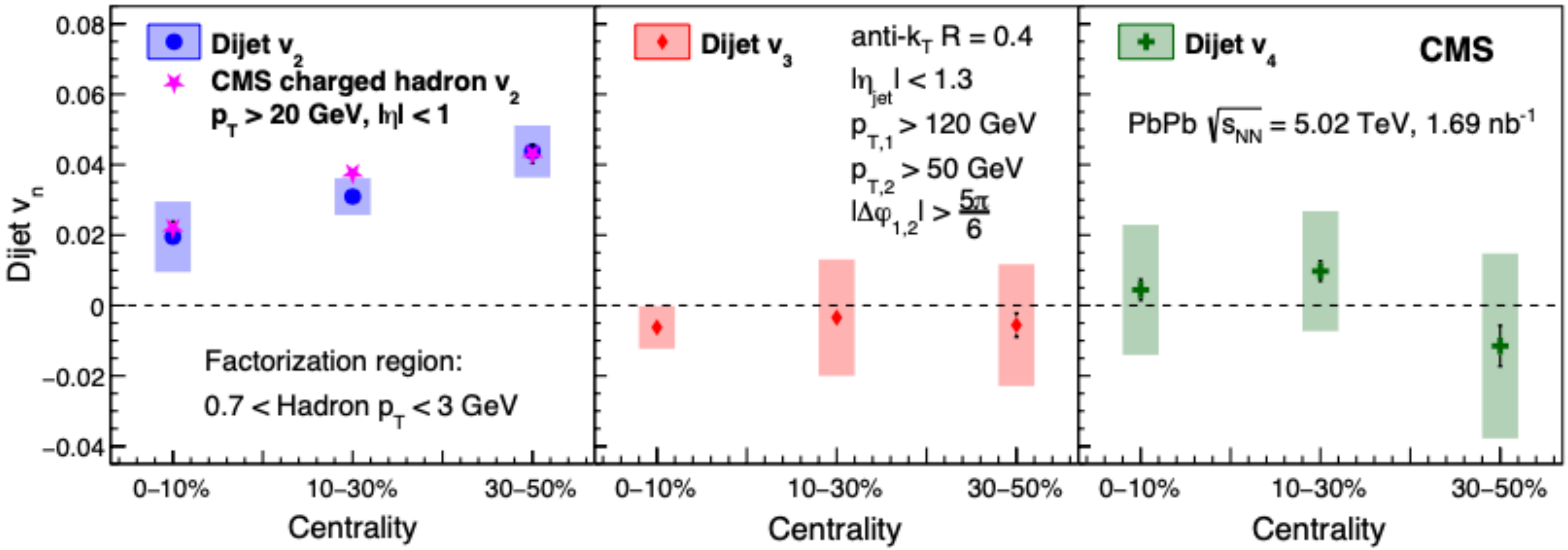


$$A_J = \frac{E_T^{lead} - E_T^{sublead}}{E_T^{lead} + E_T^{sublead}}$$

ATLAS-Conf-2015-021

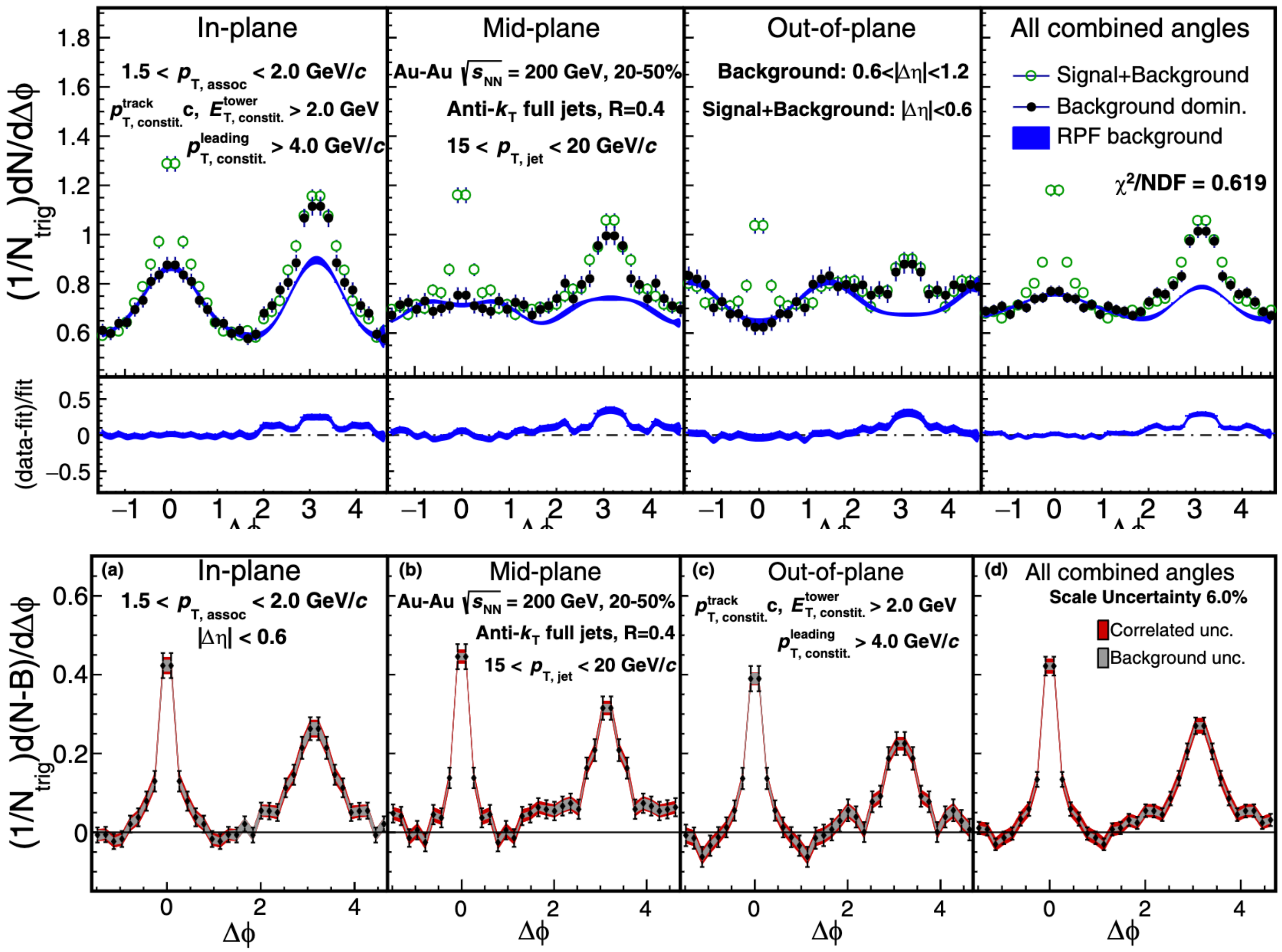
Dijets v_n

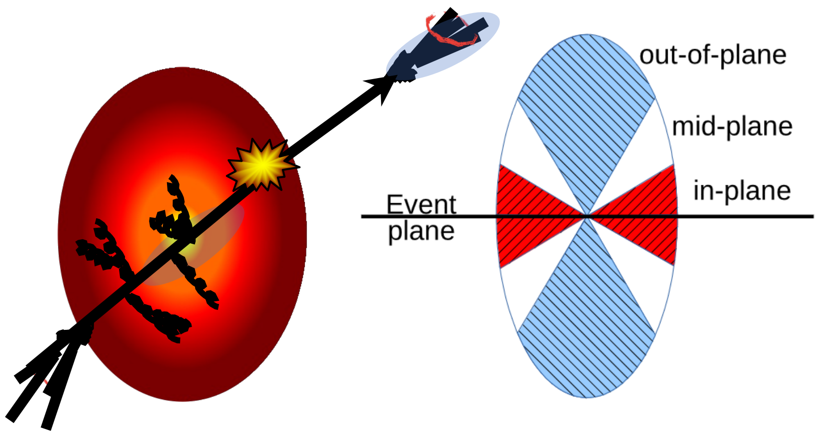
- Dijet v_2 consistent with hadron v_2
- Dijet v_3 and v_4 consistent with zero



JHEP07(2023)139

Jet-hadron correlations vs Reaction Plane



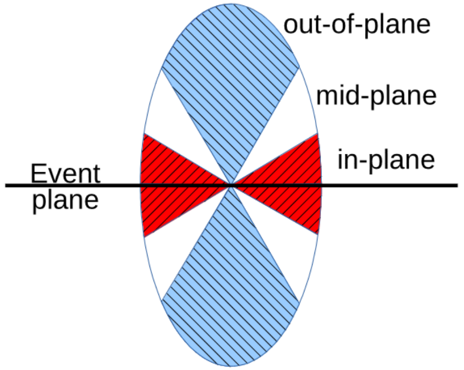


- Measure jet-h correlations for in, mid and out-of-plane jets
- Background subtraction to remove flow modulation

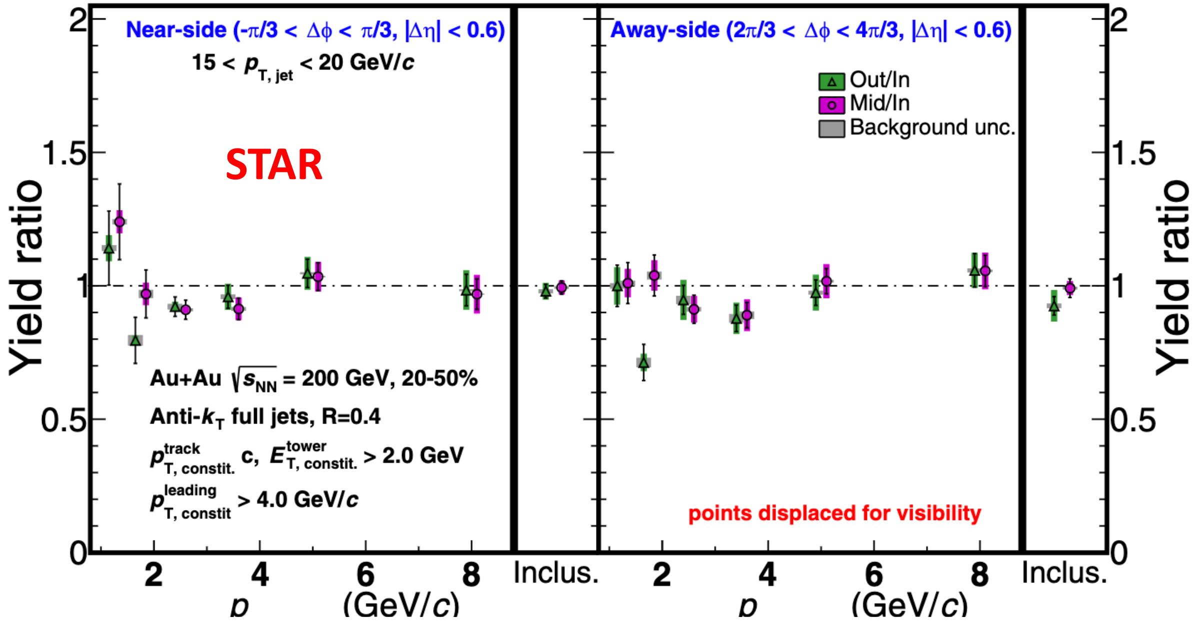
PhysRevC.109.044909 (2024)

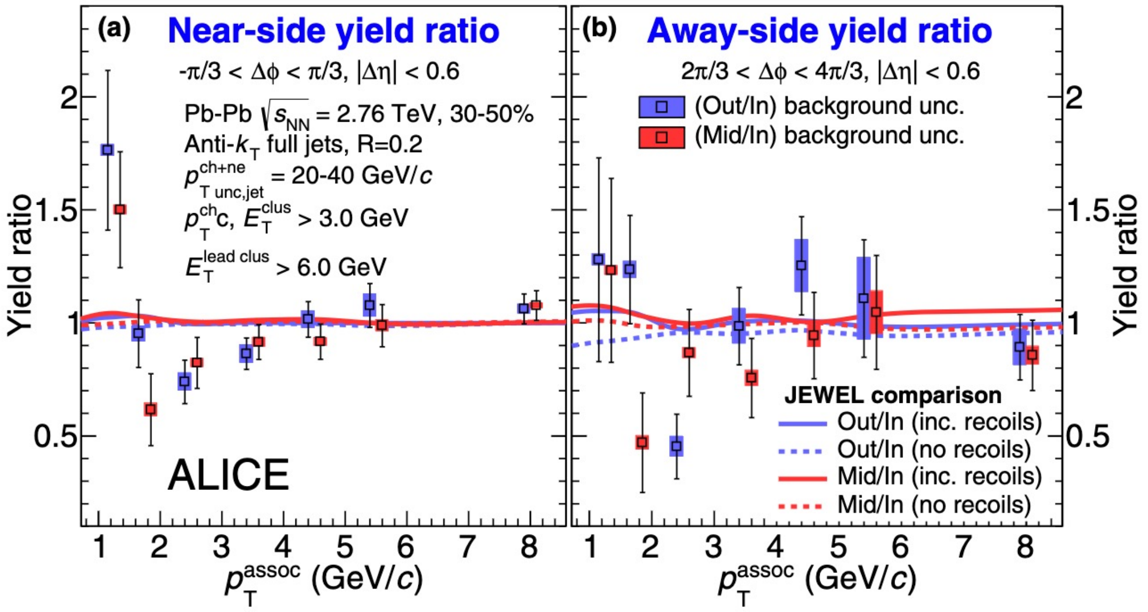
Jet-hadron correlations

- Compare integrated hadron yield out-of-plane/In-plane
- Ratio consistent with 1 implies no measured effect
- Same conclusion from RHIC and LHC
- Measurement is not sensitive to pathlength depedence
    - How does the leading particle affect surface bias
    - Can a bias be a tool?



PhysRevC.101.064901

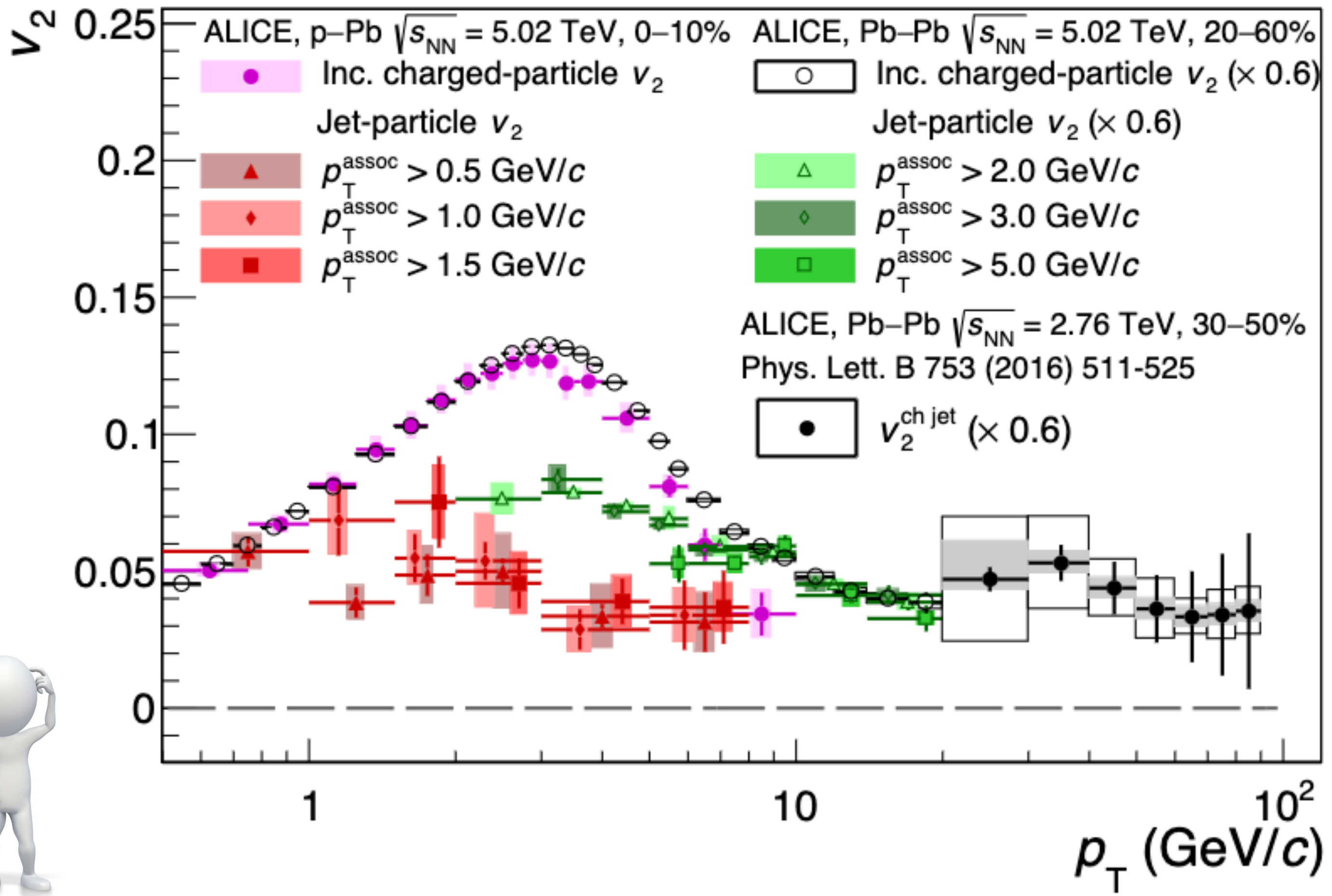




Small Systems

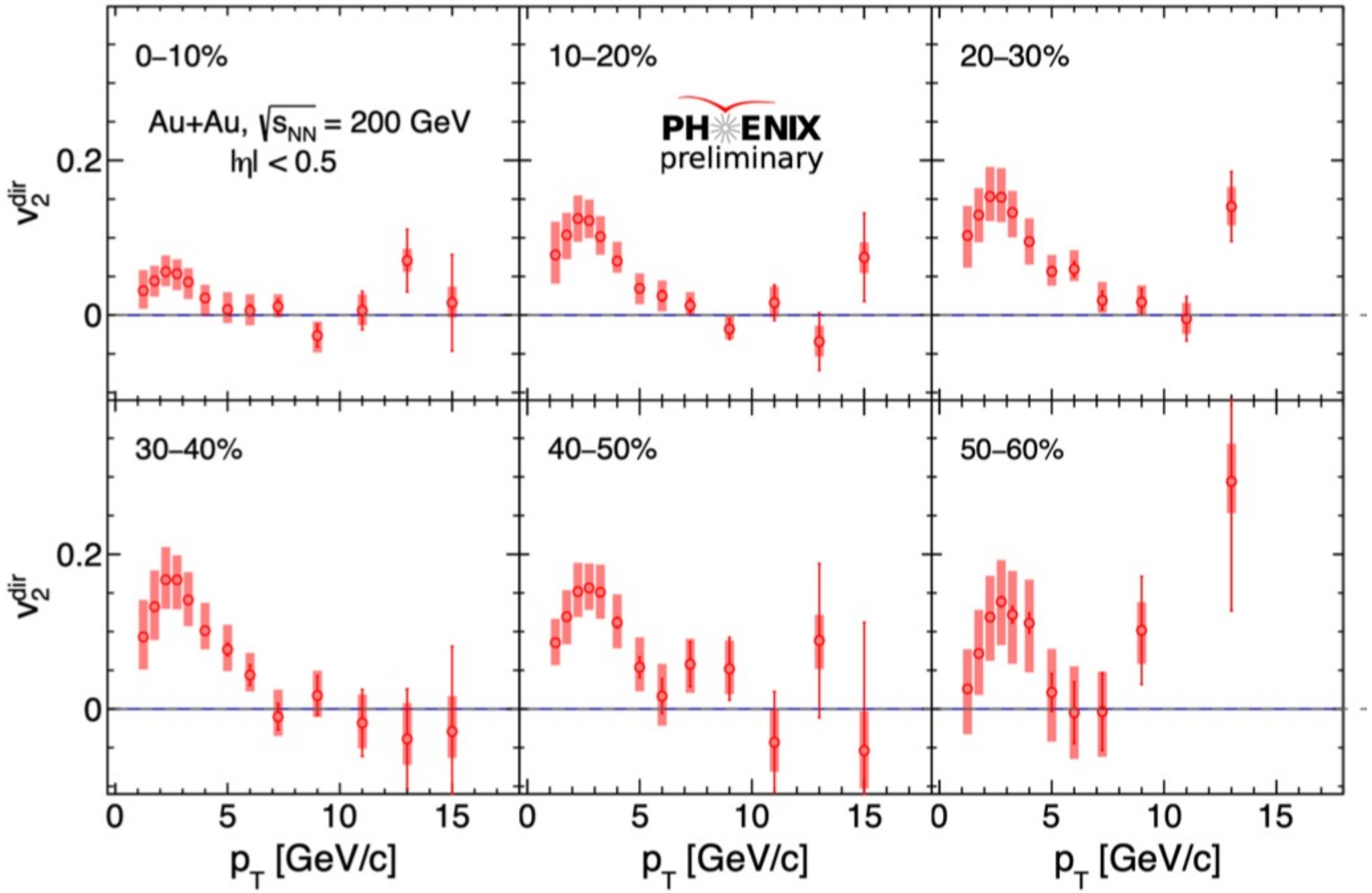
arXiv:2212.12609

- No clear energy loss observed in small system studies
- Yet non-zero jet v_2 and high p_T hadron v_2
- Small systems play in important role in understanding where these effects turn on
  - O+O at LHC
  - p+Au at RHIC?

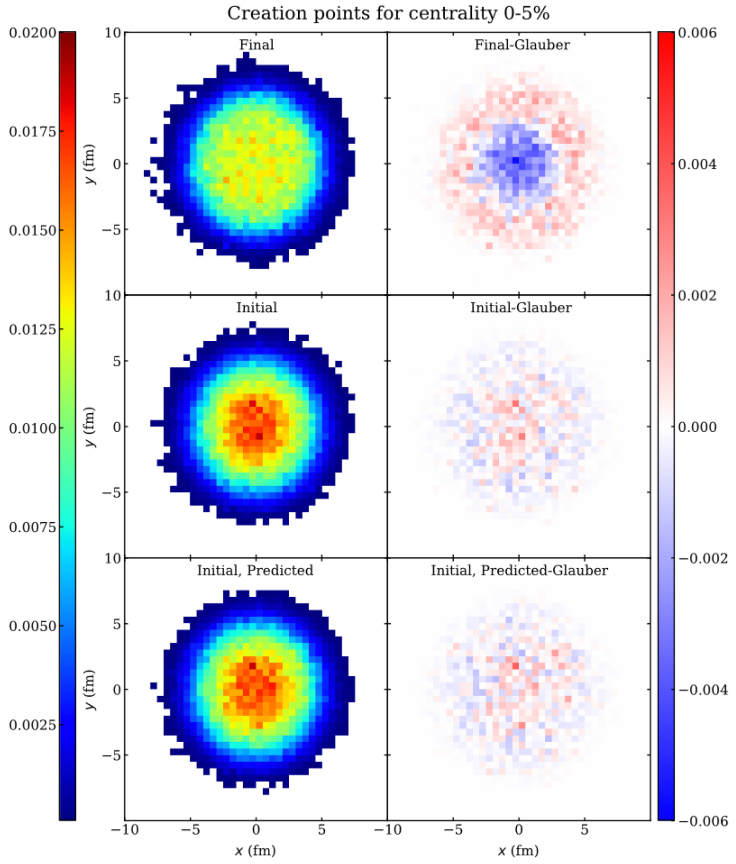


Can we turn off v_2?

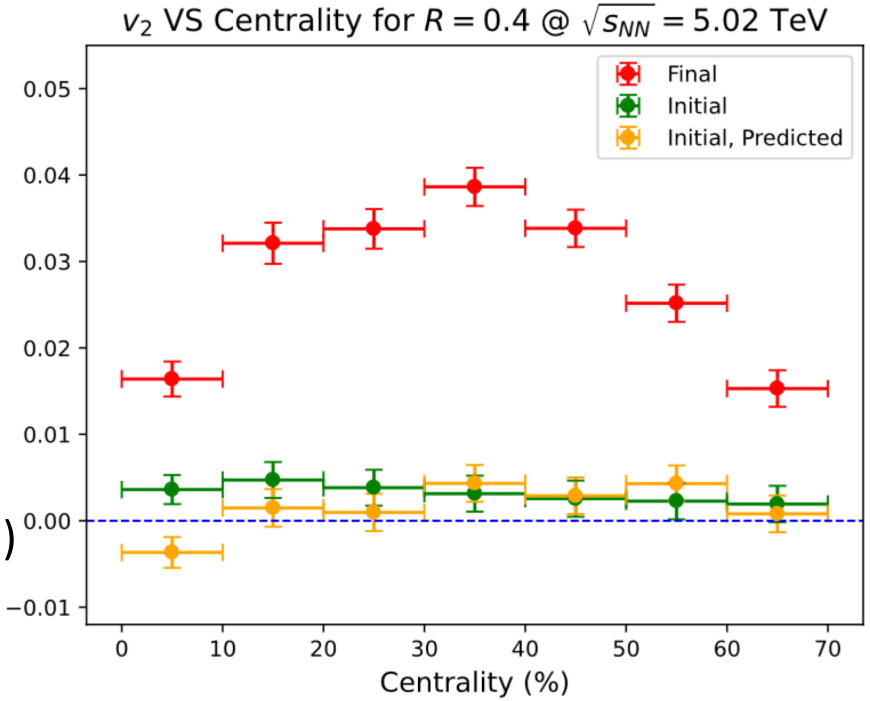
- Yes! High p_T direct photons
  - Expect no modification and see no v_2



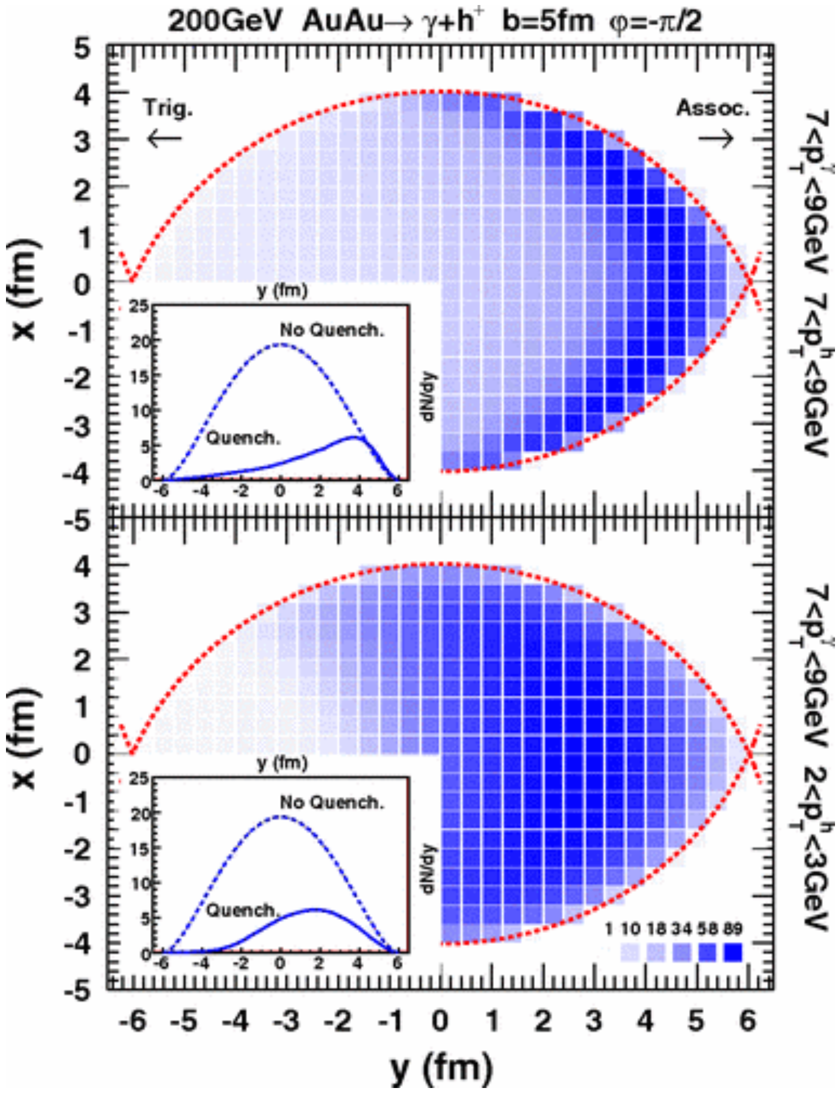
Controlling the origin of the jet



- Deep learning
- Neutral boson tagged jets
- Kinematic cuts

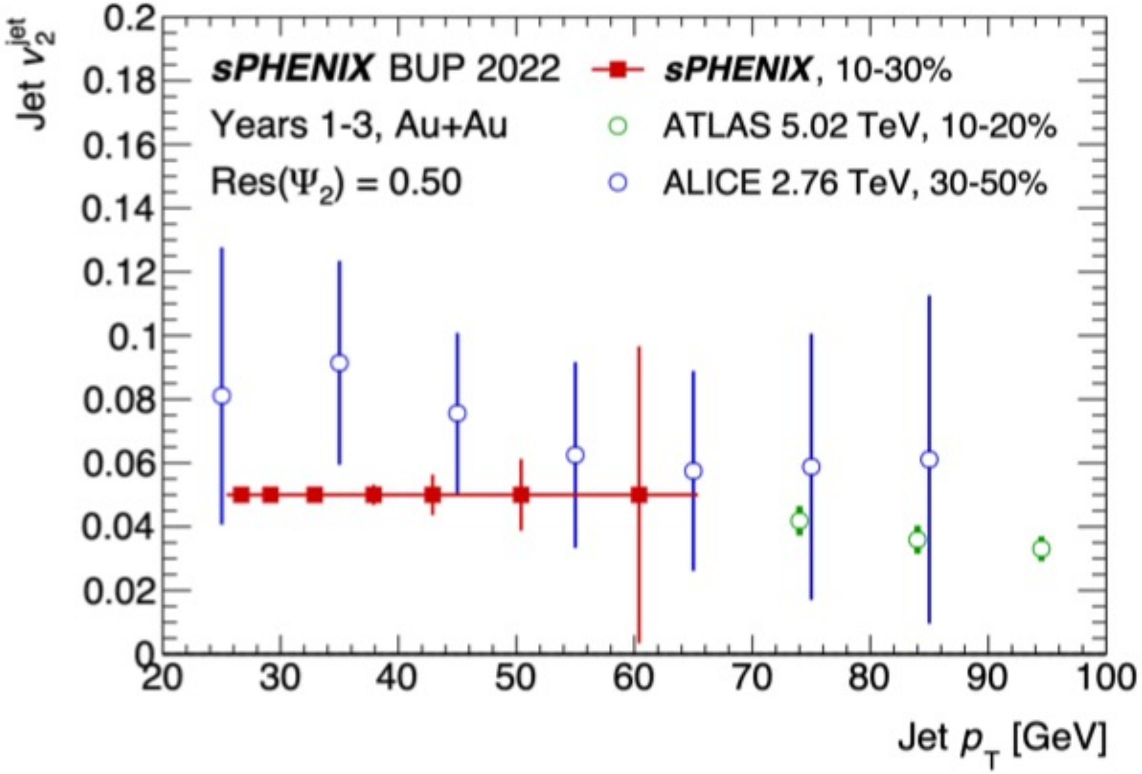


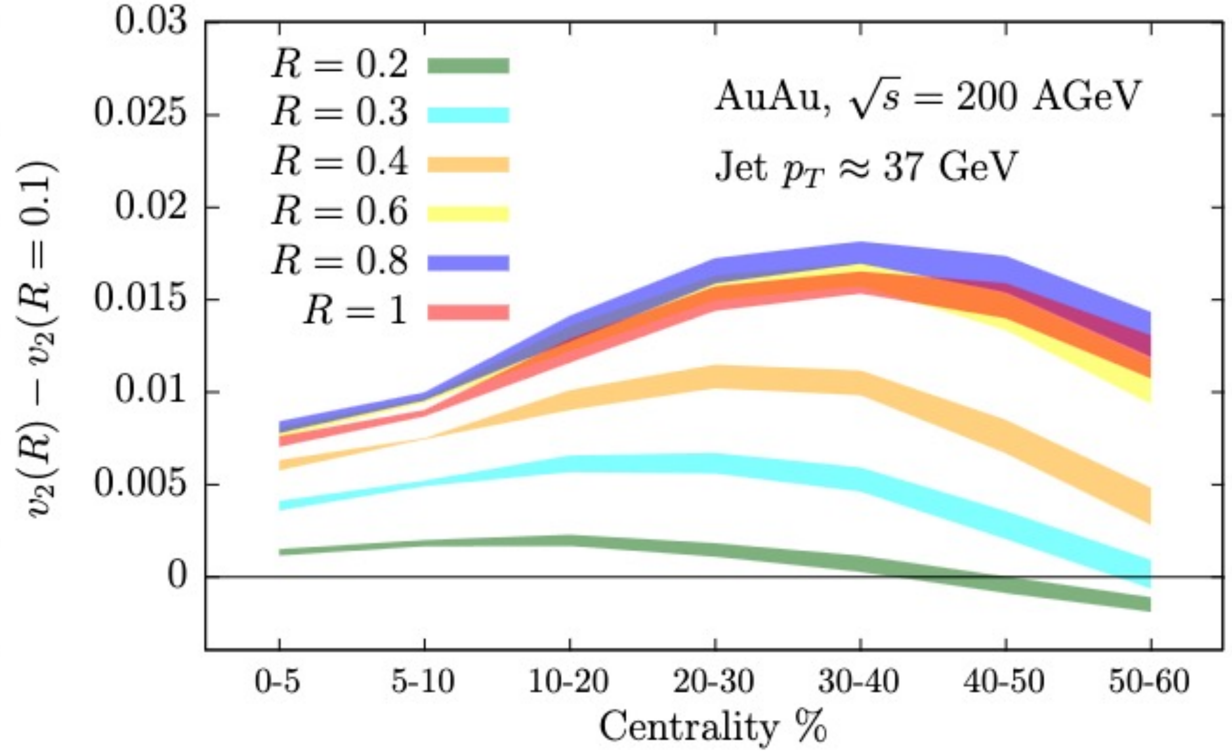
Du et al, PhysRevLett.128.012301 (2022)



ZOWW PhysRevLett.103.032302

How sPHENIX can weigh in





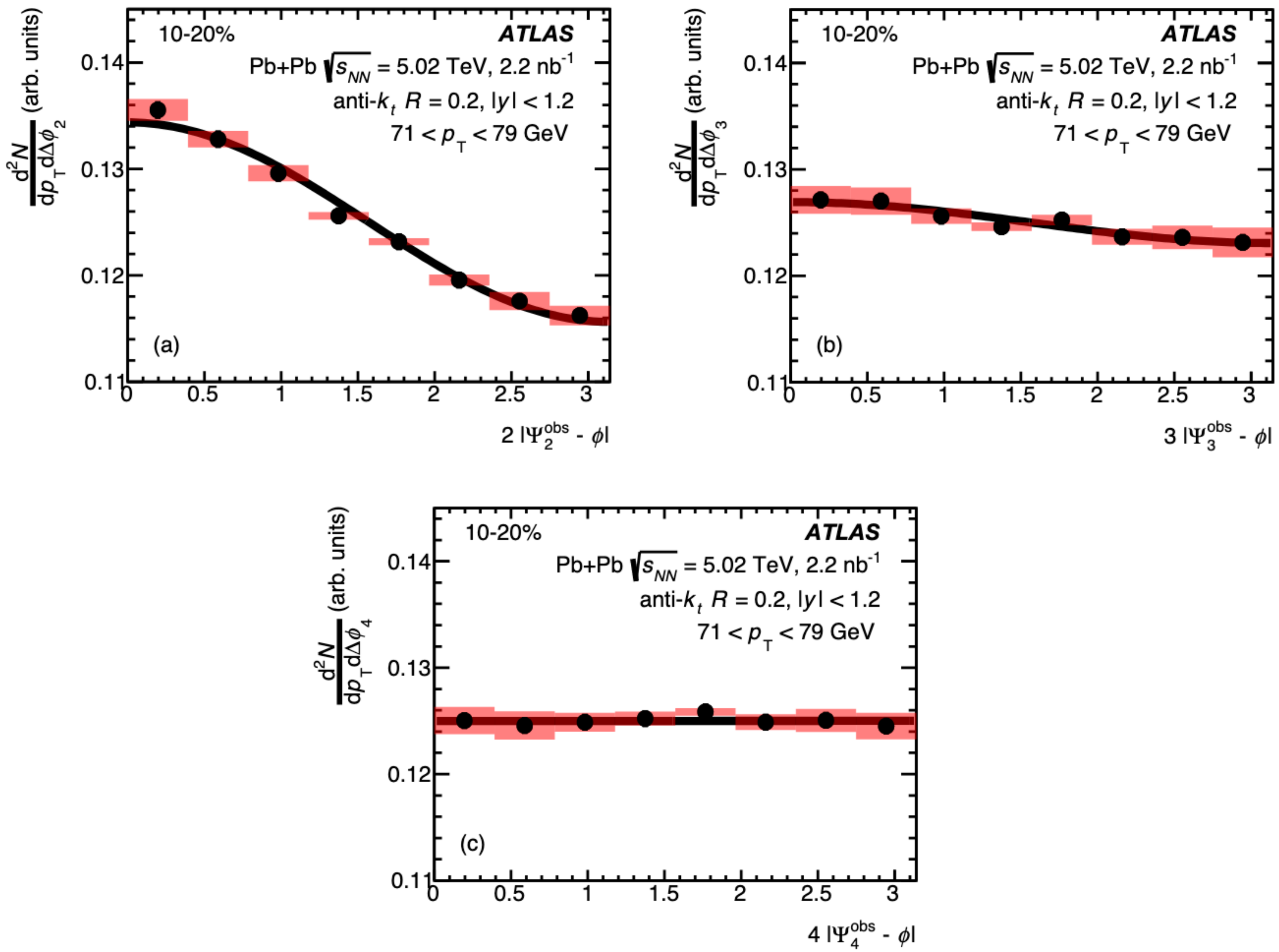
"Predictions for the sPHENIX physics program"
Nucl. Phys. A 1043, 122821 (2022).

- Jet v_n at low jet p_T overlapping with LHC results
- Predictions suggest R dependence
  - Not seen by STAR Isobar studies

Summary

- Pathlength dependent energy loss expected and observed
- But a more quantitative description is evolving
- Models should consider Jet R_{AA} and v_2 as well as dijet measurements to get a more complete picture of the QGP….jet tomography
- Experimentalists should utilize the various tools
- Small system measurements and implications need more investigation
- Looking forward to sPHENIX results from Run 2025

BACKUP



10-20%
ATLAS
Pb+Pb $\sqrt{s_{NN}}$ = 5.02 TeV, 2.2 nb^{-1}
anti-k_t R = 0.2, |y| < 1.2
71 < p_T < 79 GeV
$\frac{d^2N}{dp_T d\Delta\phi_2}$ (arb. units)
$2|\Psi_2^{obs} - \phi|$
(a)
$\frac{d^2N}{dp_T d\Delta\phi_3}$ (arb. units)
$3|\Psi_3^{obs} - \phi|$
(b)
$\frac{d^2N}{dp_T d\Delta\phi_4}$ (arb. units)
$4|\Psi_4^{obs} - \phi|$
(c)

Pathlength Dependent Fractional Momentum Loss?

- L and N_{part} based on Glauber Model calculation
- Can extend to in-plane vs out-of-plane

Yield(in-plane) : $\frac{d^2N}{dp_T dy} \times (1 + 2v_2)$

Yield in out-of-plane : $\frac{d^2N}{dp_T dy} \times (1 - 2v_2)$

$S_{loss}^{in} = \frac{p_T^{pp} - p_T^{AA,in}}{p_T^{pp}}, \quad S_{loss}^{out} = \frac{p_T^{pp} - p_T^{AA,out}}{p_T^{pp}}$