Jet studies with the ATLAS experiment

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2026.3.31

ATLAS detectors

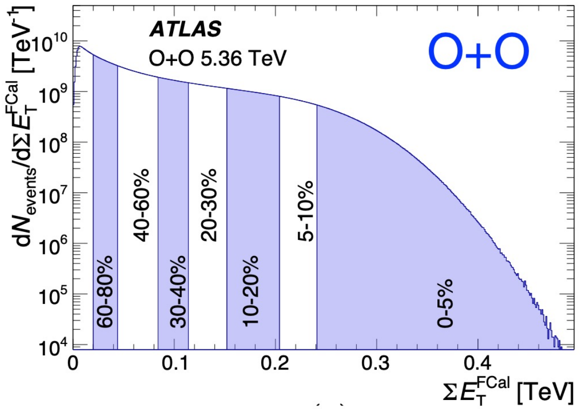
Inner-detector system

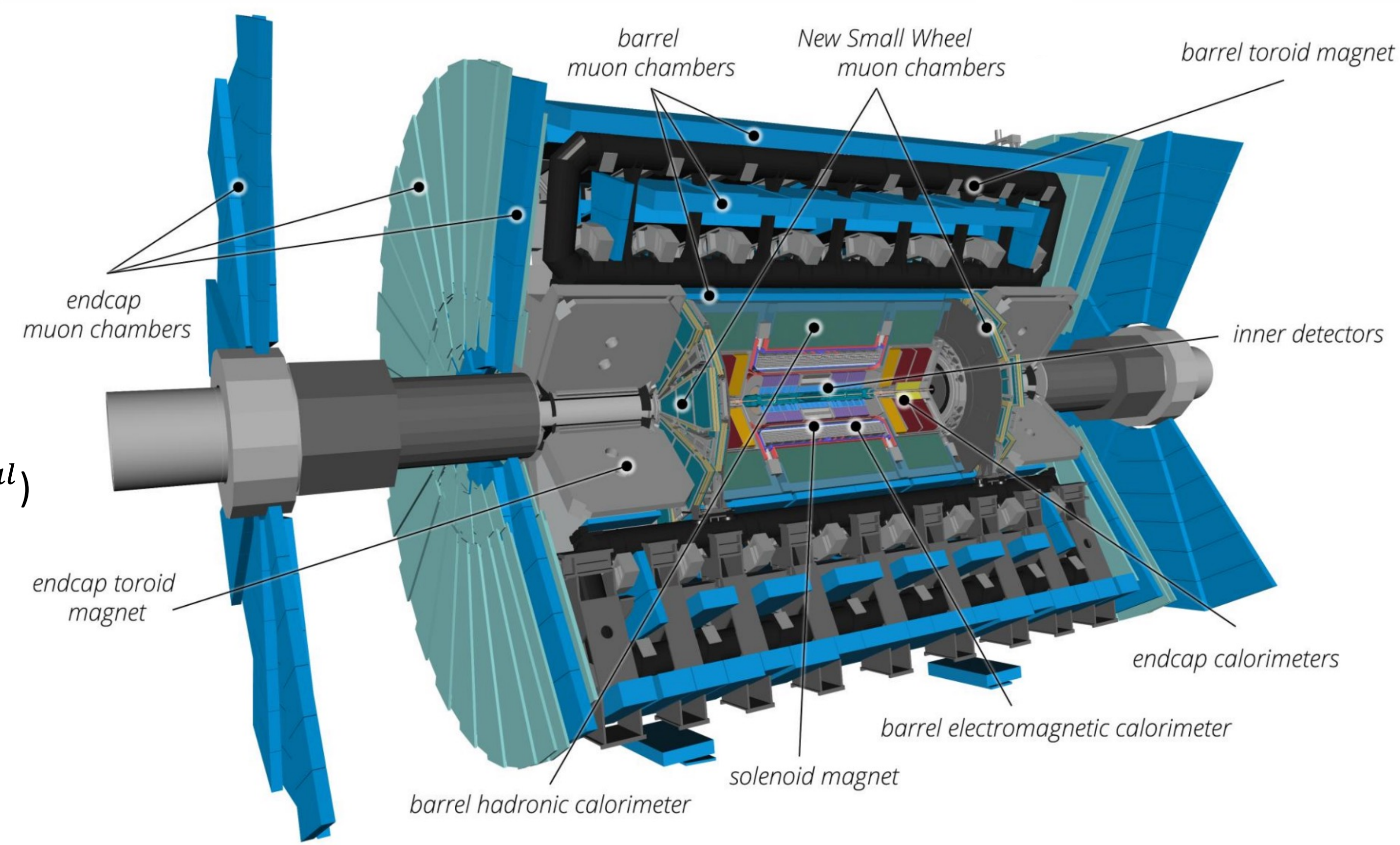
- charged particle tracking: $|\eta| < 2.5$

Calorimeter system

- energy measurement: $|\eta| < 4.9$
- Forward calorimeter (Fcal): $3.2 < |\eta| < 4.9$

centrality definition via total transverse energy ($\sum E_T^{Fcal}$)





Outline

Part 1. Recent progress from light ion collisions

Part 2. Probing jet-medium interactions

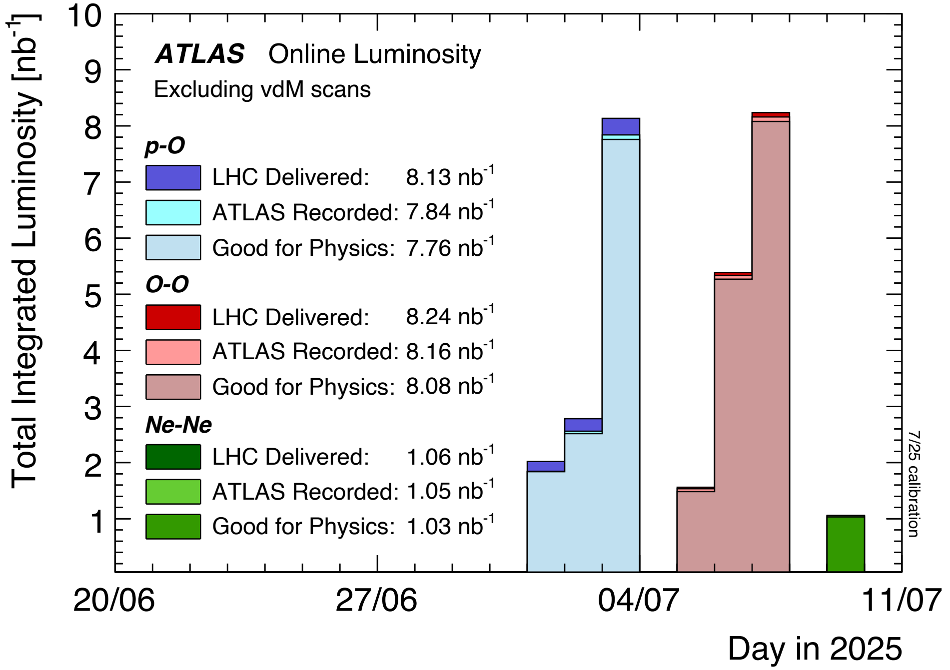
- Medium modification on jet showers
- Medium response to jet propagation

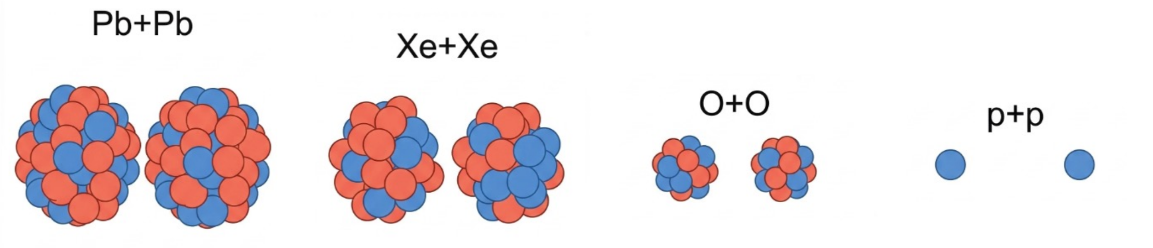
Part 3. Summary

Light ion runs at ATLAS

Successful data taking in July 2025

p+O 7.76 nb^{-1} O+O 8.08 nb^{-1} Ne+Ne 1.03 nb^{-1}





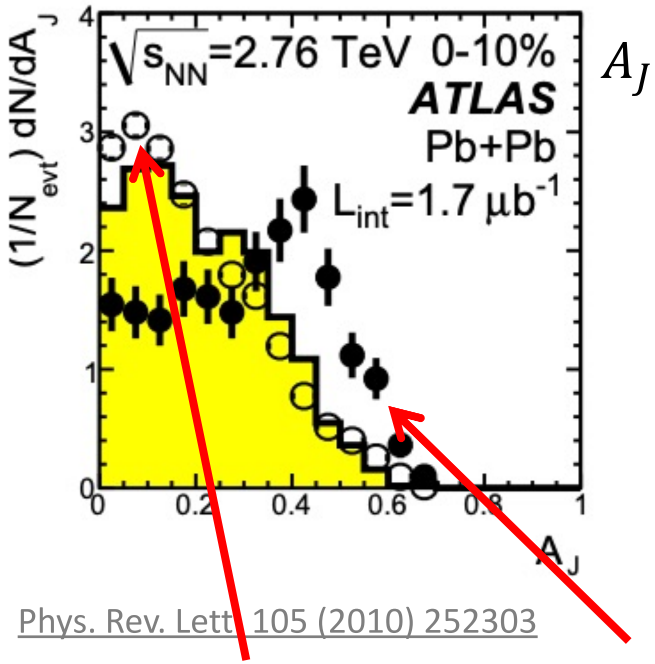
Enable system scan for jet quenching study

Toward understanding of minimal conditions for QGP

Outstanding DAQ efficiency!

Dijet asymmetry at ATLAS

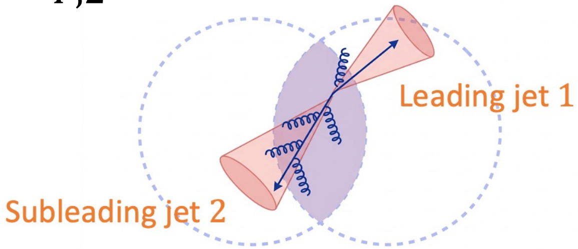
First one



Phys. Rev. Lett. 105 (2010) 252303

p+p **Pb+Pb**

$$A_J = \frac{E_{T,1} - E_{T,2}}{E_{T,1} + E_{T,2}}$$

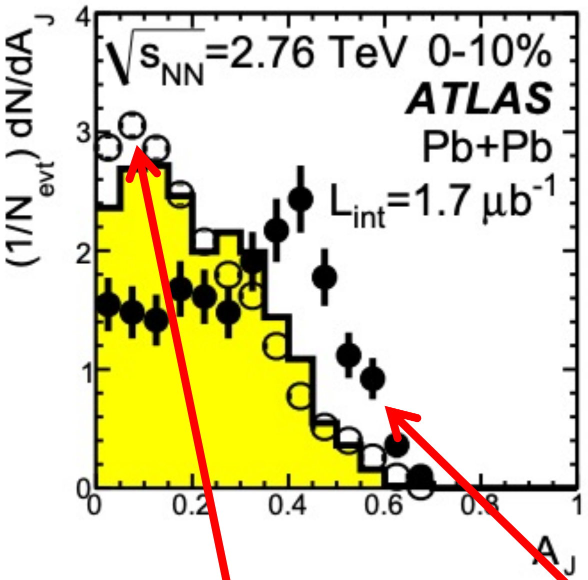


Larger dijet asymmetries in central Pb+Pb collisions

- strong jet energy loss in QGP

Dijet asymmetry at ATLAS

First one



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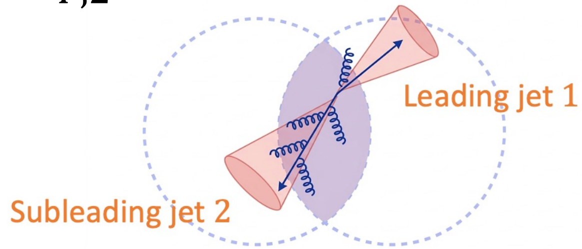
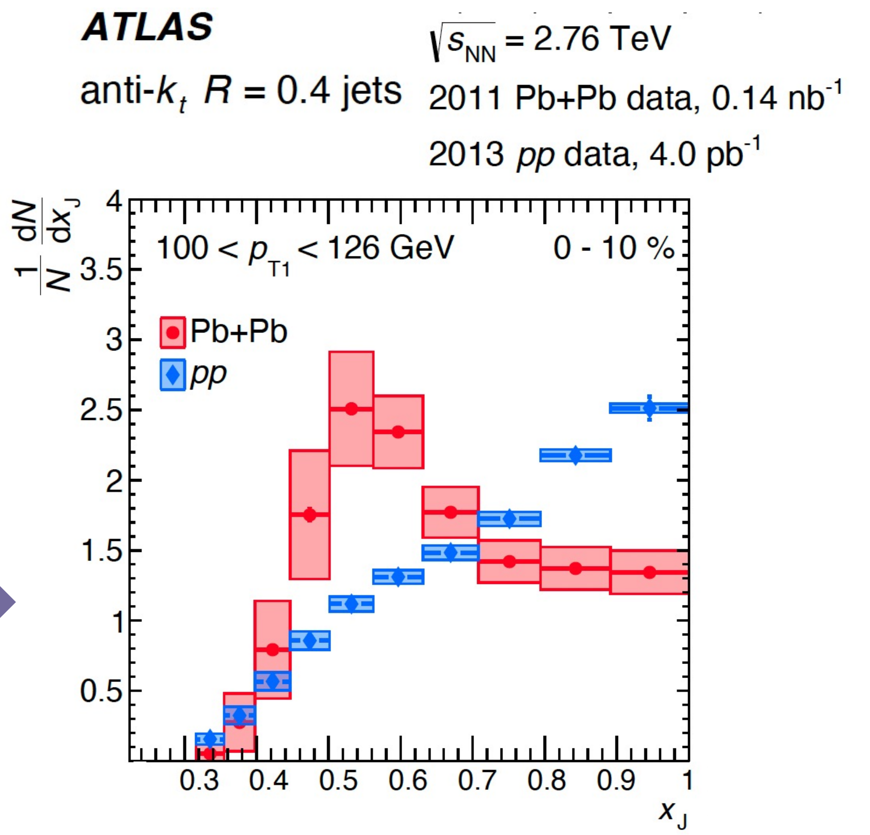


$$x_J = \frac{p_{T,2}}{p_{T,1}}$$

Refine the measurement



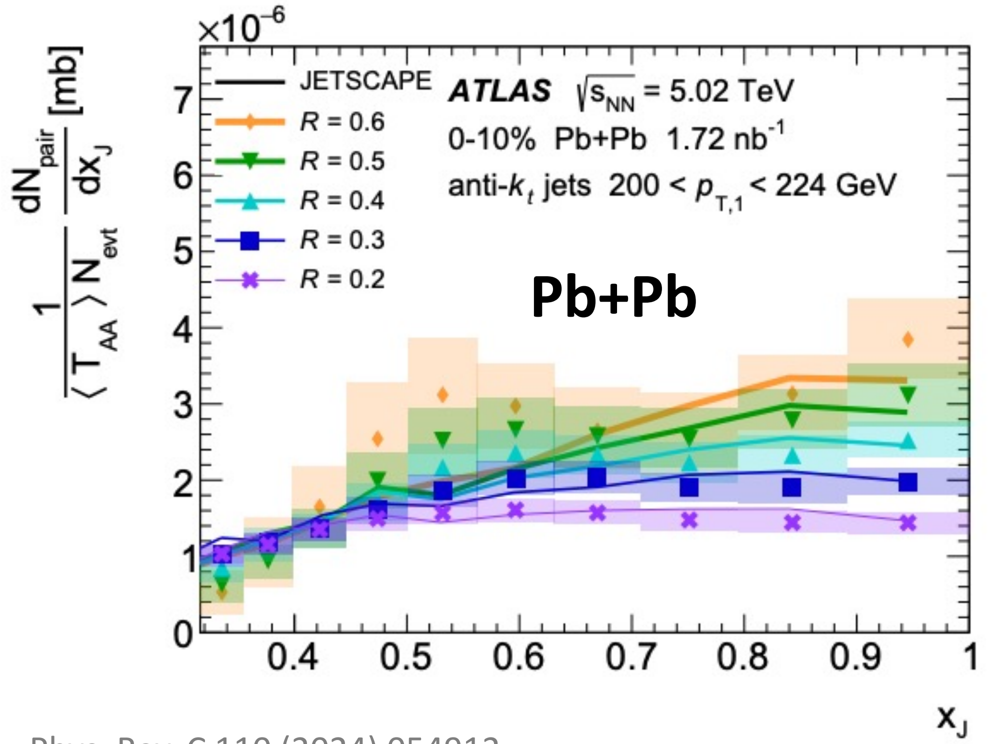
Phys. Lett. B 774 (2017) 379

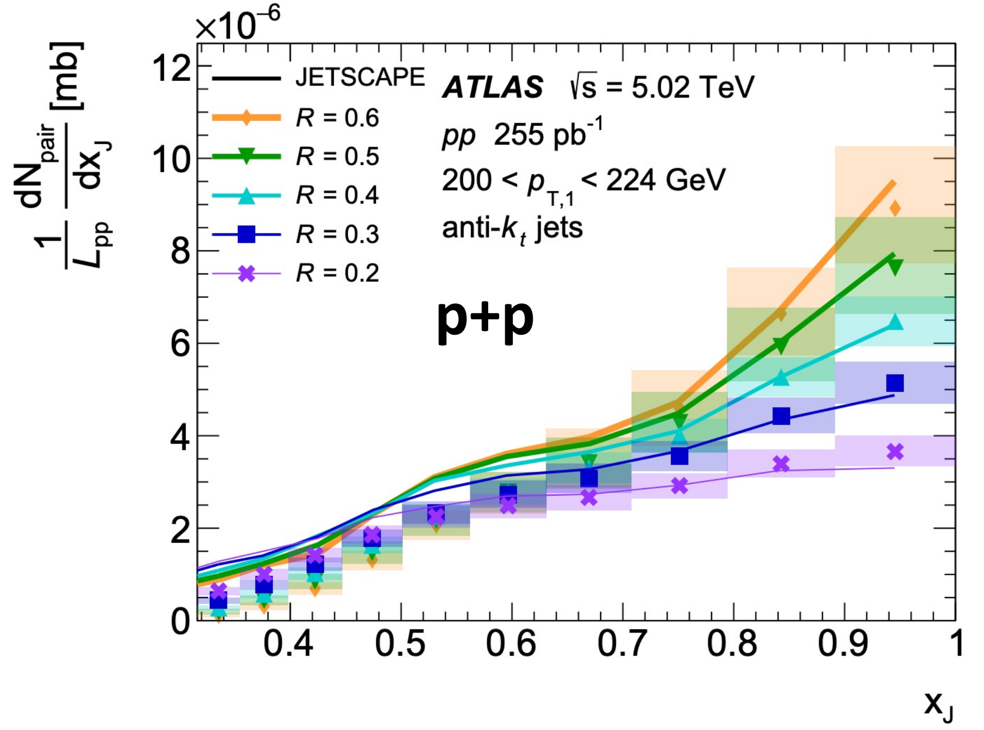
Larger dijet asymmetries in central Pb+Pb collisions
- strong jet energy loss in QGP

More complete and precise measurement

Dijet asymmetry at ATLAS

Latest published





$$x_J = \frac{p_{T,2}}{p_{T,1}}$$

~1 balanced
~0 unbalanced

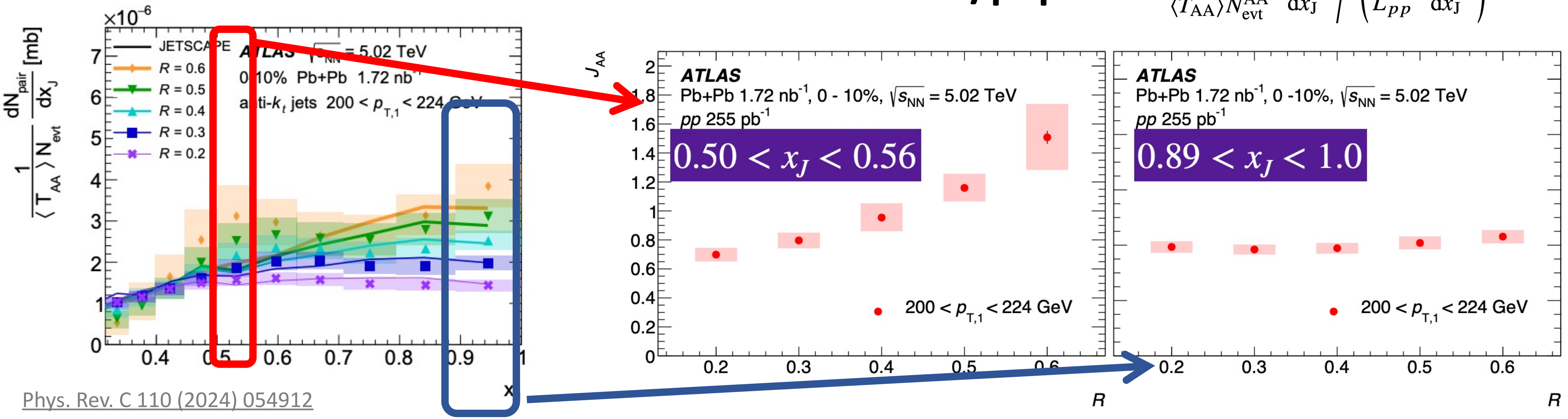
Phys. Rev. C 110 (2024) 054912

Larger radius jets give a sharper peak at $x_J \sim 1$

Dijet asymmetry at ATLAS

Pb+Pb/p+p

$$J_{AA} \equiv \frac{1}{\langle T_{AA}\rangle N_{evt}^{AA}} \frac{dN_{pair}^{AA}}{dx_J} \Bigg/ \left(\frac{1}{L_{pp}} \frac{dN_{pair}^{pp}}{dx_J}\right)$$

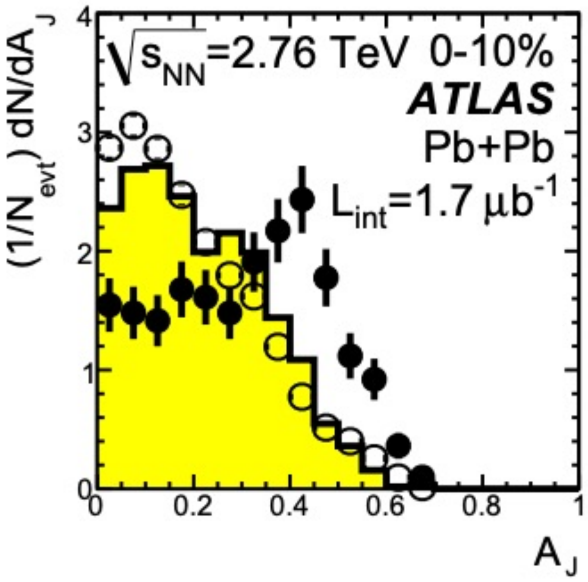


Phys. Rev. C 110 (2024) 054912

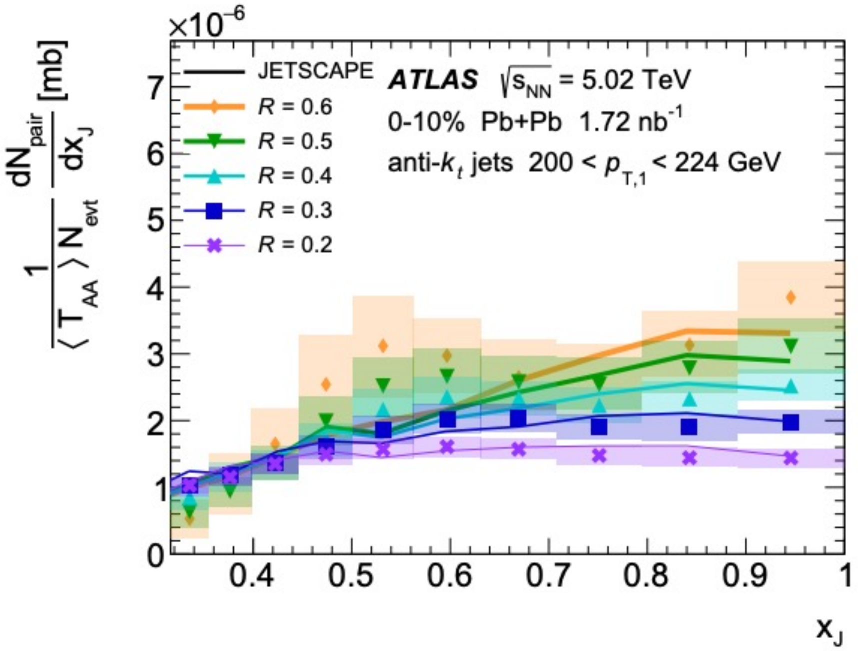
- More imbalanced dijets: jet suppression decreases with increasing jet radius
- More balanced dijets: much weaker dependence on jet radius

Dijet asymmetry at ATLAS

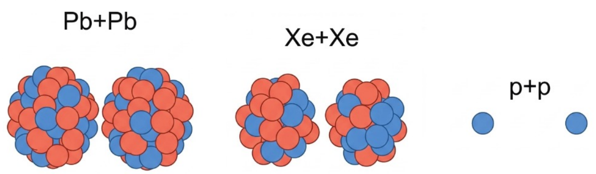
First one



Latest published



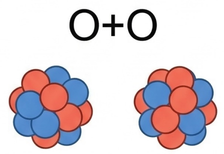
And so on …



Phys. Rev. Lett. 105 (2010) 252303
Phys. Rev. C 110 (2024) 054912

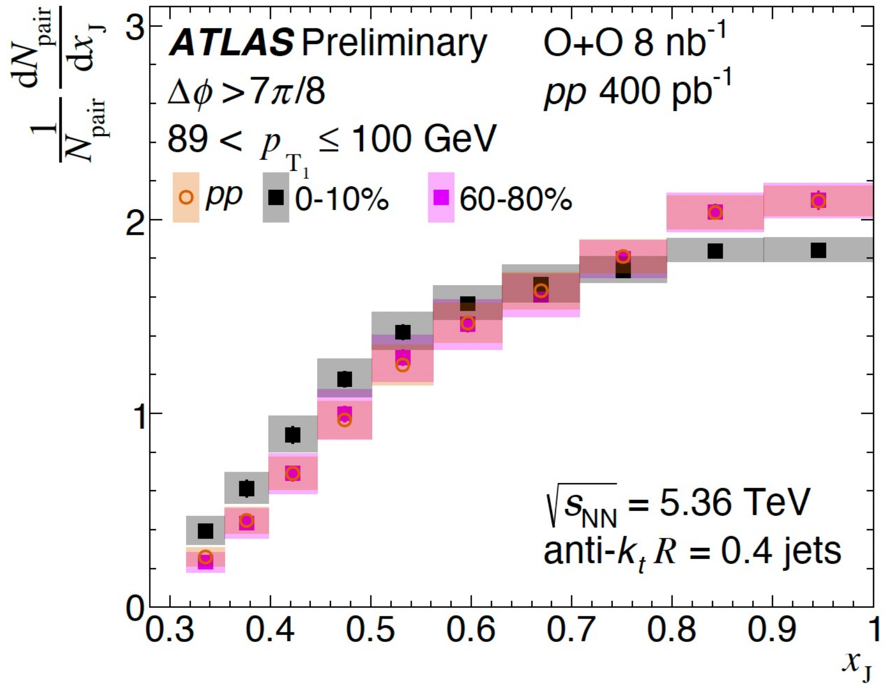
x_J measurements are well-established in ATLAS

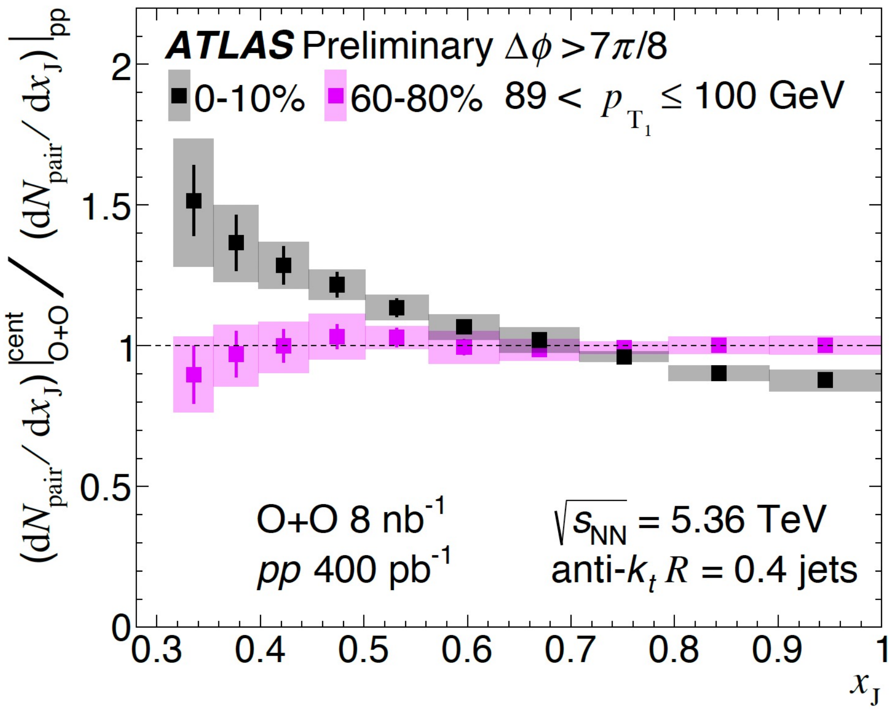
How about



Dijet asymmetry in O+O collisions

ATLAS-CONF-2025-010





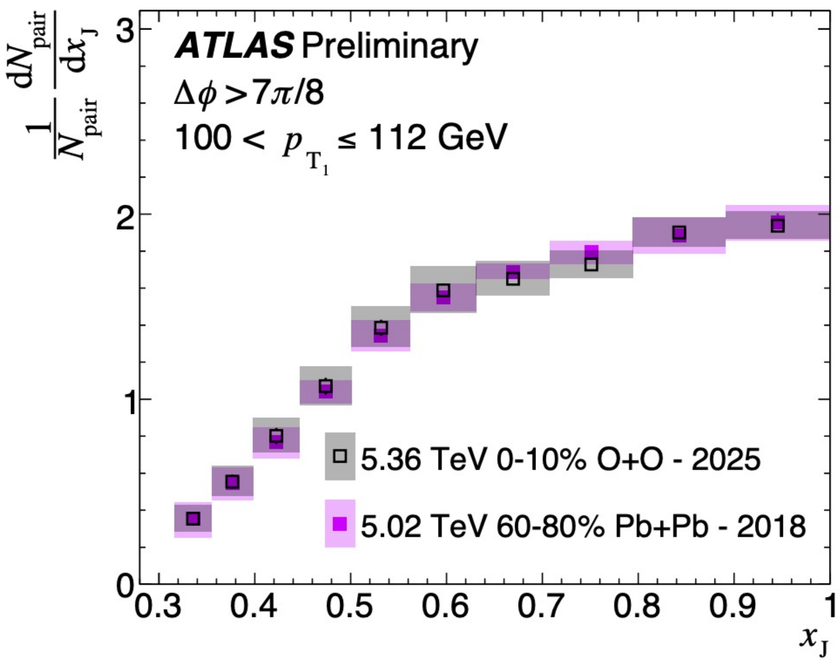
- Systematic uncertainties are further cancelled in the O+O/p+p ratio
- Modest but clear dijet imbalance in central O+O collisions

Dijet asymmetry in O+O collisions

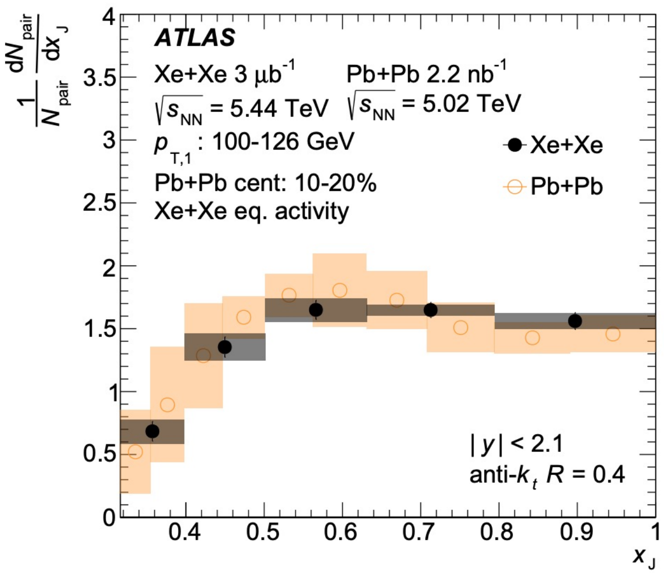
ATLAS-CONF-2025-010

Across systems

Match event activity (through $\sum E_T^{Fcal}$ bins)



Phys. Rev. C 108 (2023) 024906

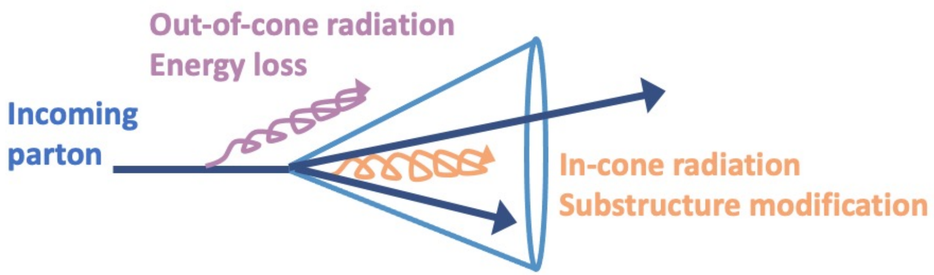


- Similar magnitude of modification observed in O+O and Pb+Pb at comparable event activity
- Similar consistency found in Xe+Xe and Pb+Pb collisions
- More jet studies in O+O collisions are on the way …

Jet-medium interactions

Medium modification of jet shower

Medium-induced in-cone and out-of-cone jet parton energy loss



Medium response

Energy deposition:

Mach-cone-like wake along jet direction

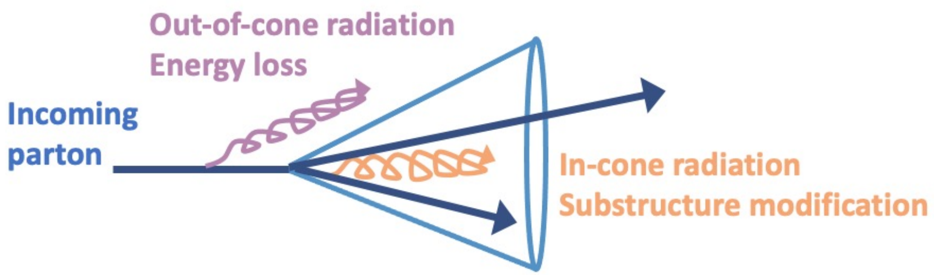
Energy depletion:

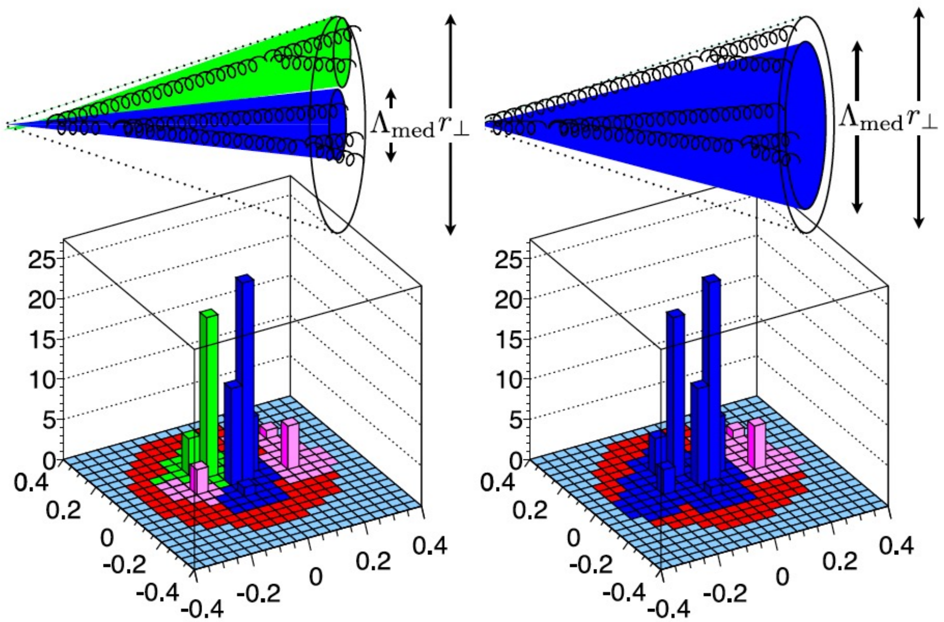
Diffusion wake in the opposite direction of jet

Jet quenching dictated by color coherence

Medium modification of jet shower

Medium-induced in-cone and out-of-cone jet parton energy loss





Λ_{med} -> medium resolution scale

Energy loss depends on the number of color emitters resolved by the medium

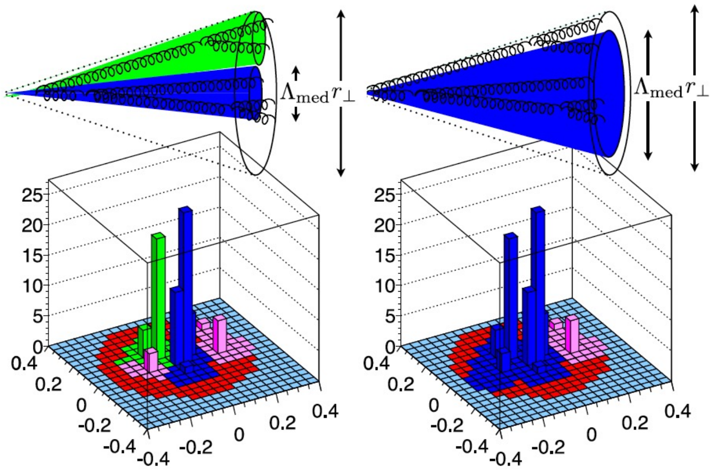
Physics Letters B 725 (2013) 357–360

Substructure dependence of jet quenching

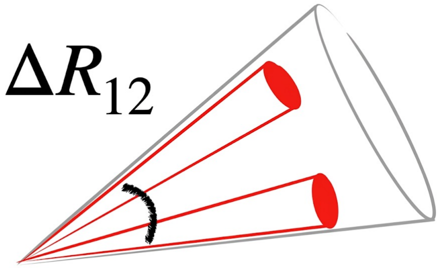
Medium modification of jet shower

Medium-induced in-cone and out-of-cone jet parton energy loss

Λ_{med} -> medium resolution scale



Physics Letters B 725 (2013) 357–360

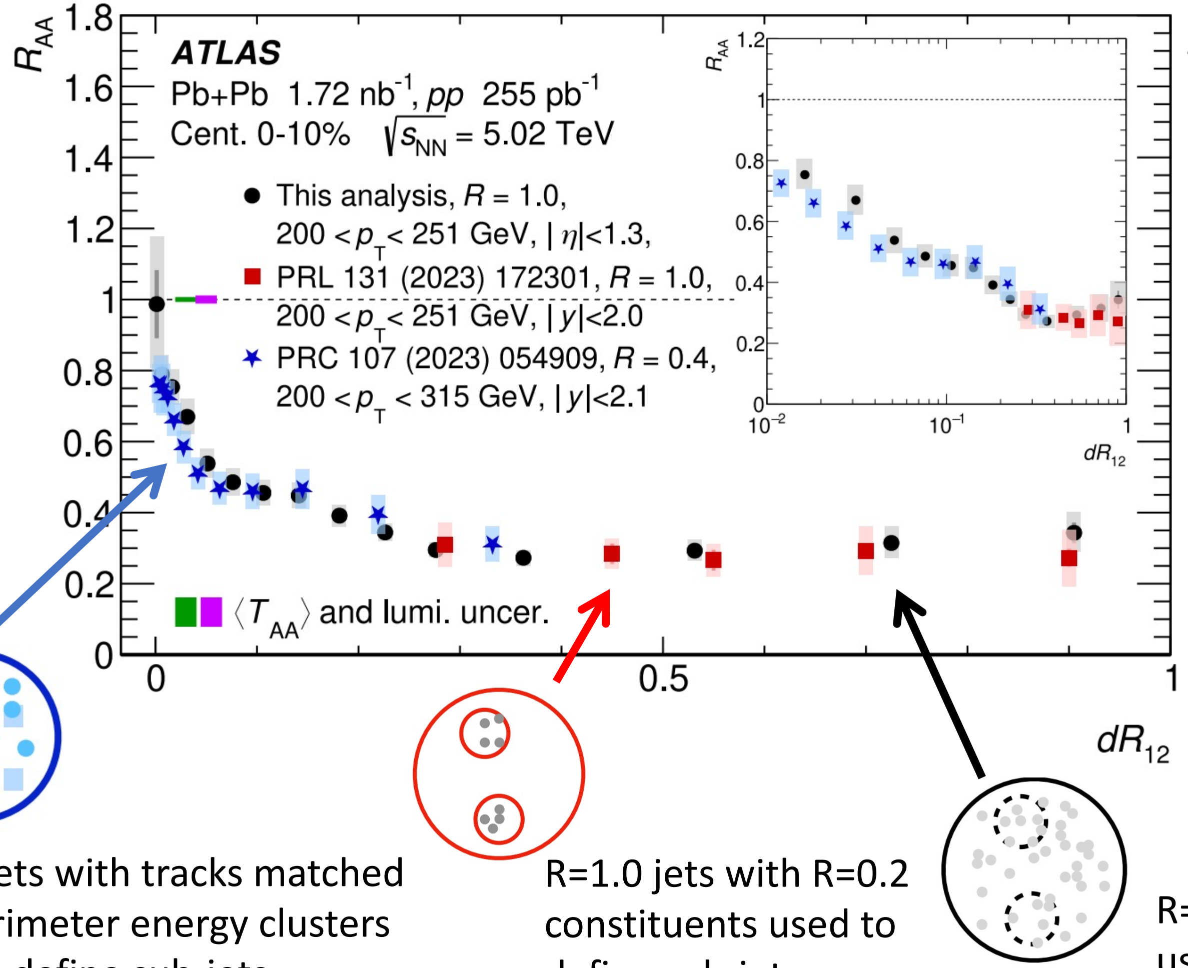


Angular separation of the hardest splitting

$$dR_{12} = \sqrt{(\Delta y_{12})^2 + (\Delta\varphi_{12})^2}$$

Does jet quenching depend on the jet substructure?

Substructure dependence of jet quenching



R=0.4 jets with tracks matched to calorimeter energy clusters used to define sub-jets

R=1.0 jets with R=0.2 constituents used to define sub-jets

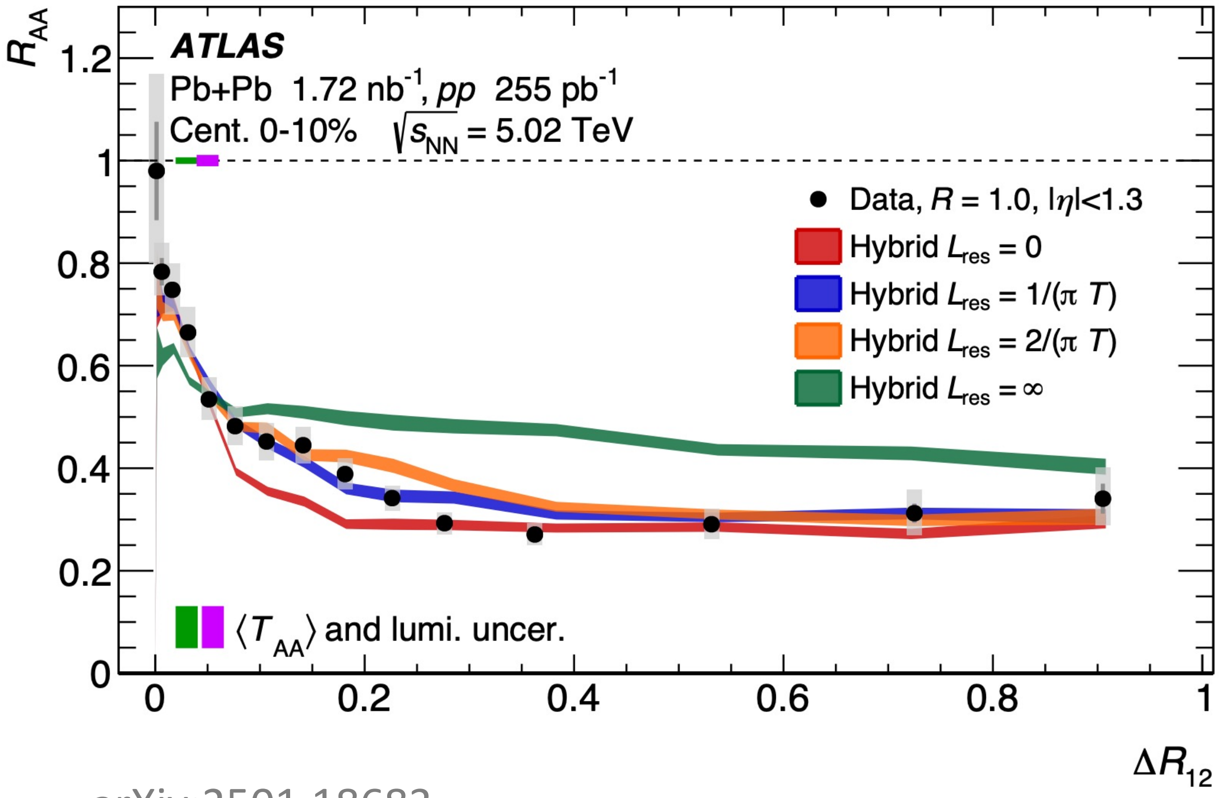
R=1.0 jets with tracks used to define sub-jets

Phys. Lett. B 871 (2025) 139929

Although the jet definition differs, the three measurements provide a consistent picture:

- $dR_{12} < 0.05$: R_{AA} decreases
- $0.05 < dR_{12} < 0.15$: plateau
- $0.15 < dR_{12} < 0.3$: R_{AA} decreases
- $dR_{12} > 0.3$: plateau

Substructure dependence of jet quenching



arXiv:2501.18683

Comparison of results from Hybrid model with different resolution scales

- favors a small nonzero QGP resolution length $L_{res} = 1/(\pi T)$

Jet-Induced Mach-cone-like wake in QGP

Medium response

Energy deposition:
Mach-cone-like wake along jet direction

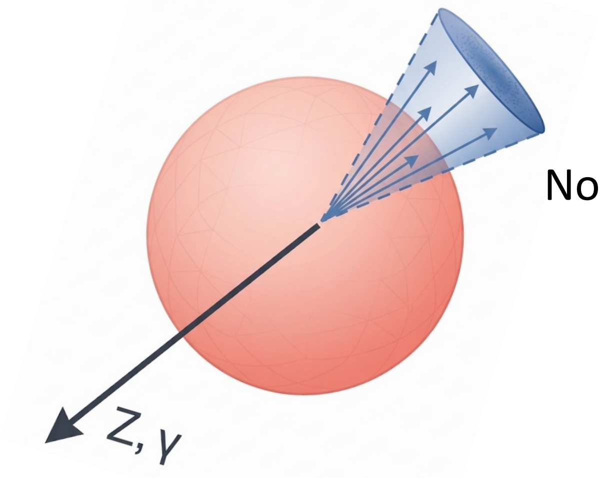
Per-Z yields of charged particles
(in recoil region: $\Delta\varphi_{ch,Z}>3\pi/4$)

$$Y(p_T) = \frac{1}{N_Z}\frac{d^2N_{ch}}{dp_T d\Delta\varphi}$$

Jet quenching observable

$$I_{AA}(p_T) = \frac{Y^{A+A}}{Y^{p+p}}$$

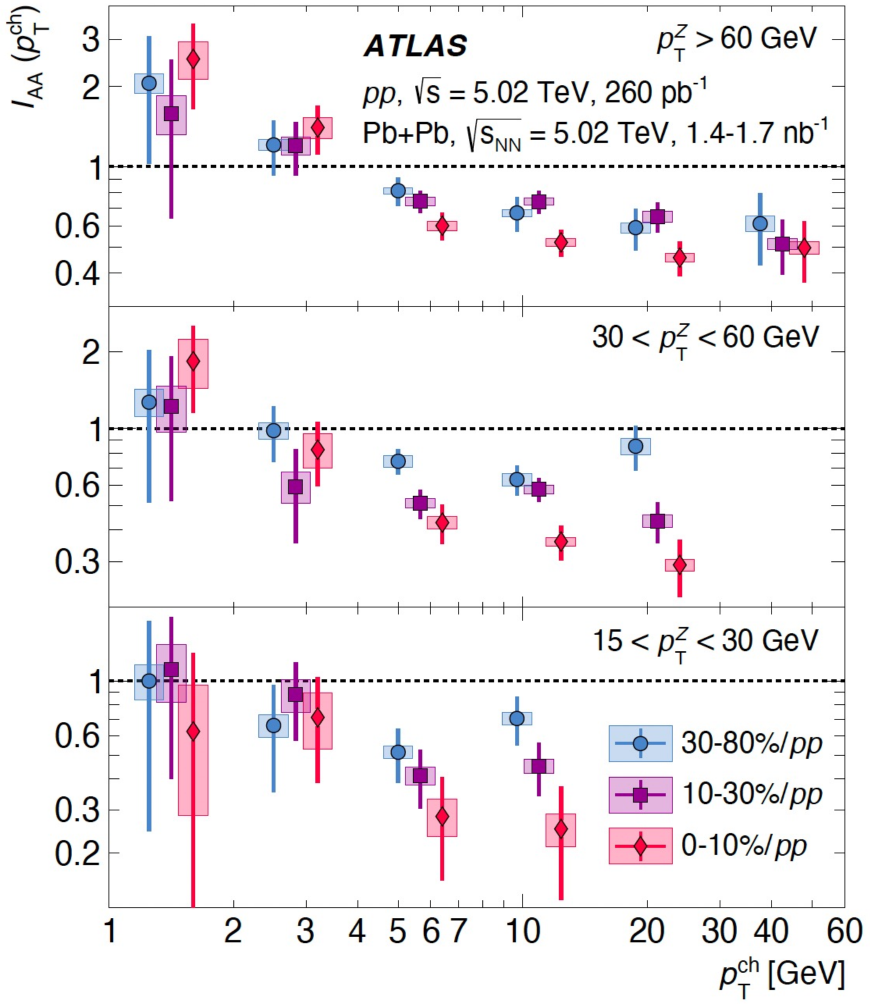
Enhance soft particle yield recoiling of Z boson

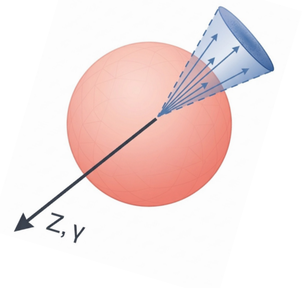


No back reaction from the electroweak boson

Modification of Z-tagged charged particle yields

Phys. Rev. Lett. 126, 072301



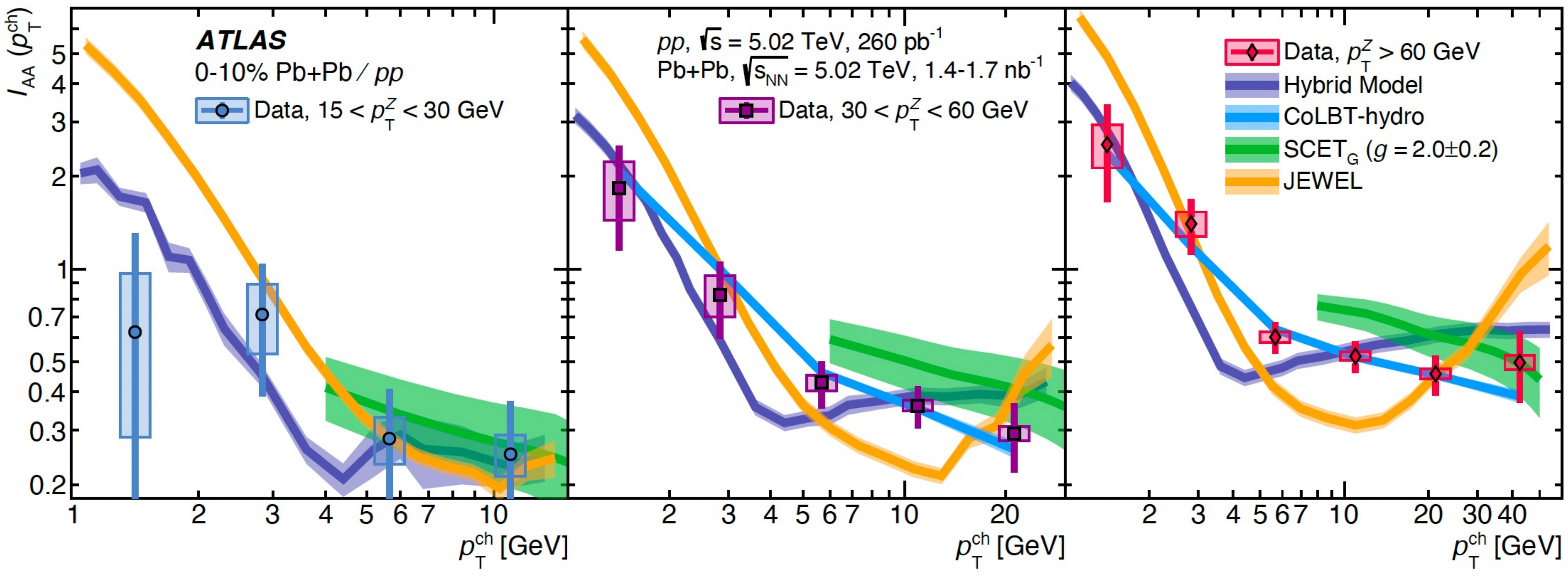


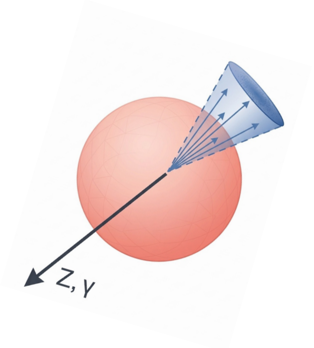
Recoil particle yield in Pb+Pb collisions:

- Suppressed at high p_T
  - -> medium induced jet energy loss
- Enhanced at low p_T
  - -> medium-induced soft gluon radiation
  - -> soft hadrons from Mach cone wake

Modification of Z-tagged charged particle yields

Phys. Rev. Lett. 126, 072301





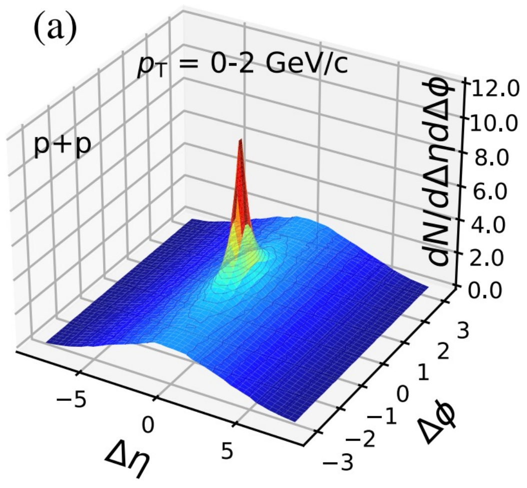
- The Hybrid model, JEWEL and CoLBT qualitatively capture the increase at low p_T
  - removing the medium response results in a significant underprediction

Jet-Induced diffusion wake in QGP

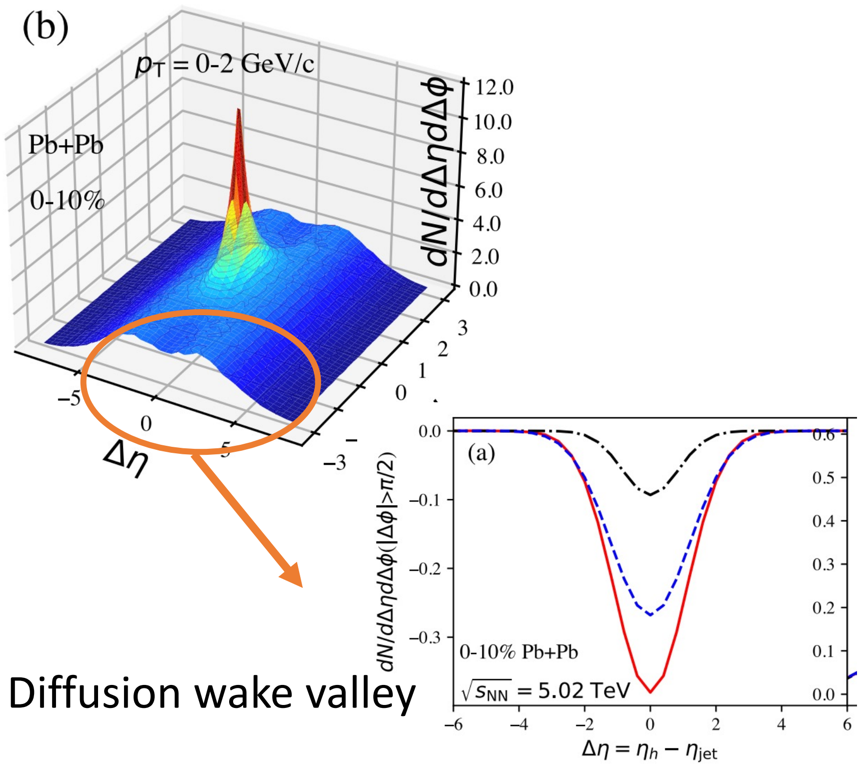
Medium response

Energy depletion:

Diffusion wake in the opposite direction of jet



Phys. Rev. Lett. 130, 052301



Diffusion wake valley

Diffusion wake manifests as a valley structure on top of a MPI ridge in rapidity and azimuthal angle

Jet-track correlations in photon tagged events

Medium response

Energy depletion:
Diffusion wake in the opposite direction of jet

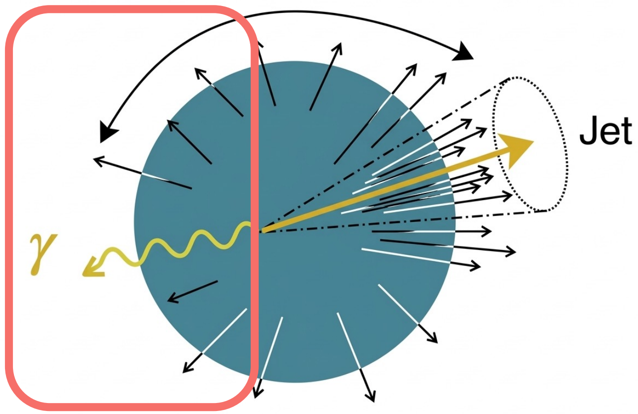
Suppress soft particle yield opposite to jet direction

$$\Delta\varphi_{ch,jet} > \frac{3\pi}{4}$$
$$0.5 < p_{T,ch} < 2 \text{ GeV/c}$$

Per-γ yields of charged particles

$$Y(\Delta\eta) = \frac{1}{N_\gamma}\frac{d^2N_{ch}}{d\Delta\eta d\Delta\varphi}$$

Photon does not interfere with the signal of the diffusion wake



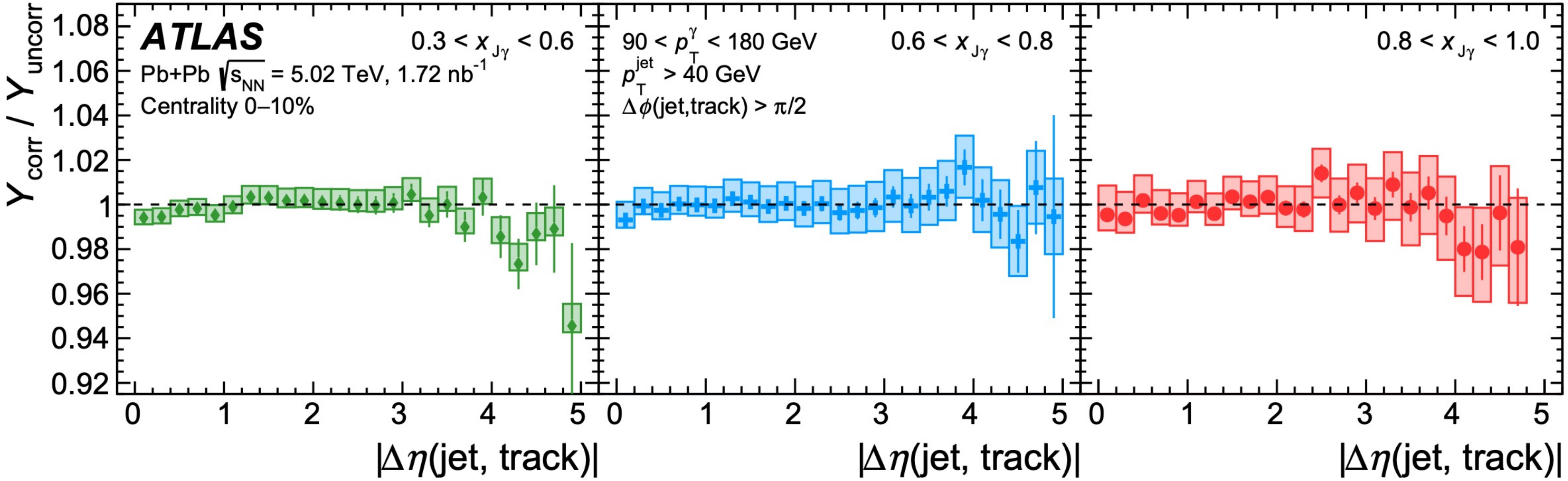
Y_{corr}: yield in signal event
- 90-180 GeV photon tagged events, with > 40 GeV leading jet in recoil region

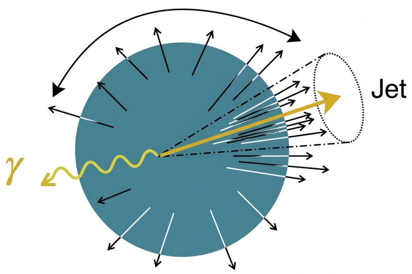
Y_{uncorr}: estimate of uncorrelated background
- Mix photon+jet pair with min-bias events

Signal of diffusion wake in QGP

Small $X_{J\gamma}$ → **Large $X_{J\gamma}$**

Highest jet energy deposition **Lowest jet energy deposition**





$\frac{\textit{Signal and background}}{\textit{background}}$

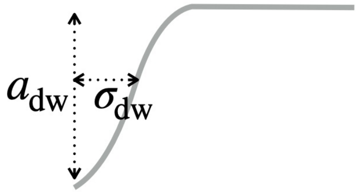
Phys. Rev. C 111 (2025) 044909

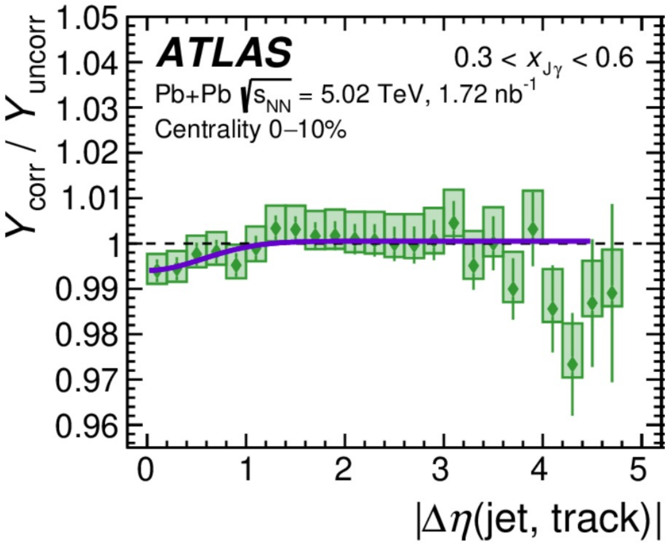
Small diffusion wake signal shown in the lowest $X_{J\gamma}$

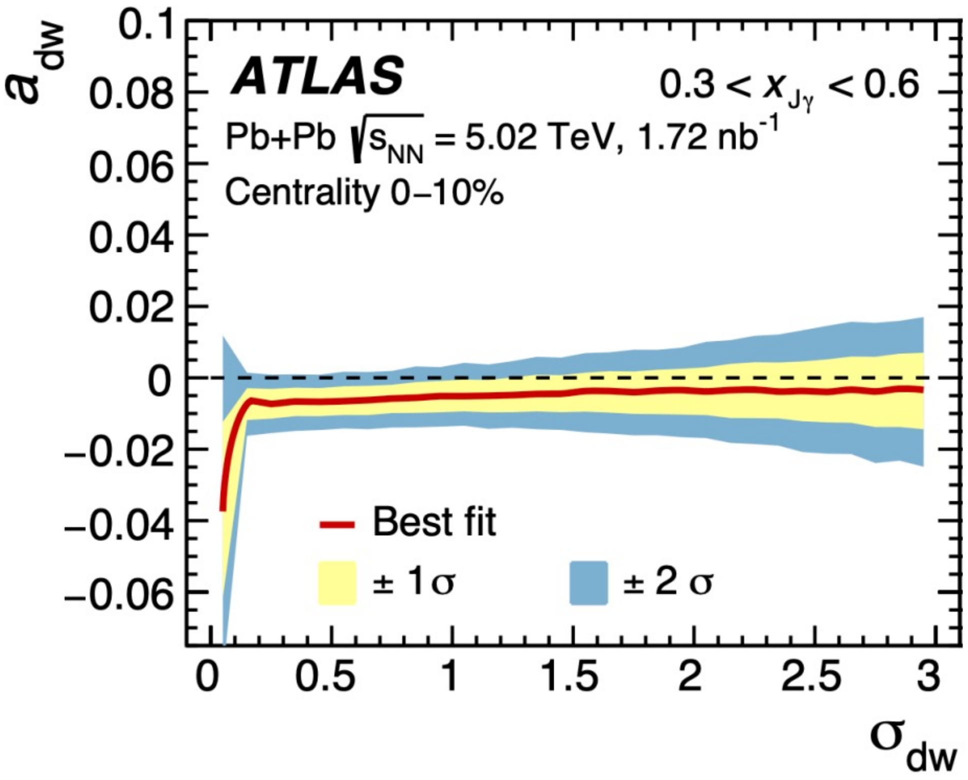
Quantifying strength of diffusion wake

Diffusion Wake Amplitude   Diffusion Wake Width

$$a_0 + a_{\mathrm{dw}} \cdot e^{-|\Delta\eta(\mathrm{jet,track})|^2/(2\sigma_{\mathrm{dw}}^2)}$$



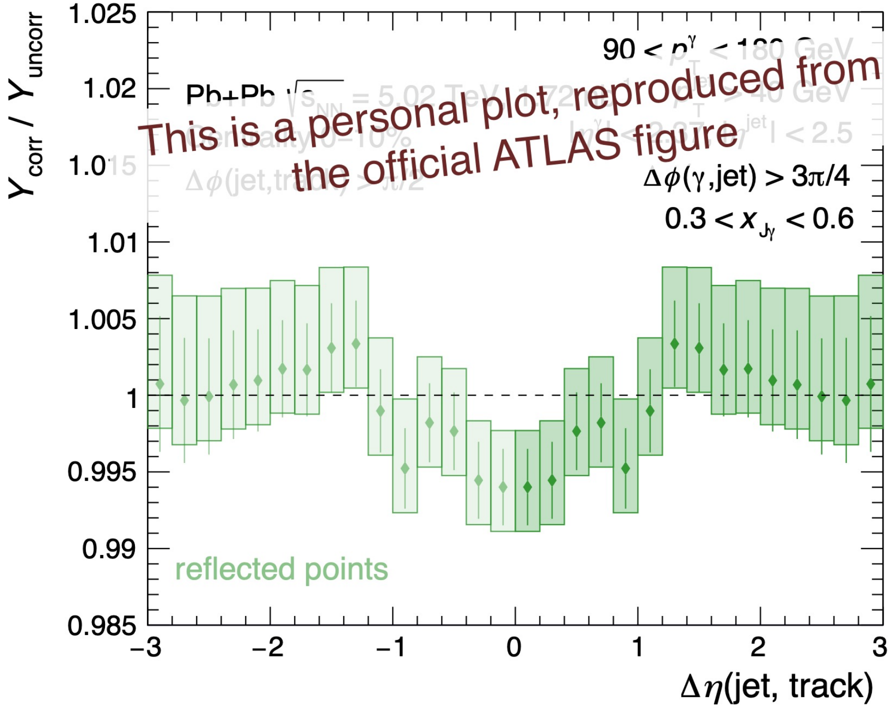




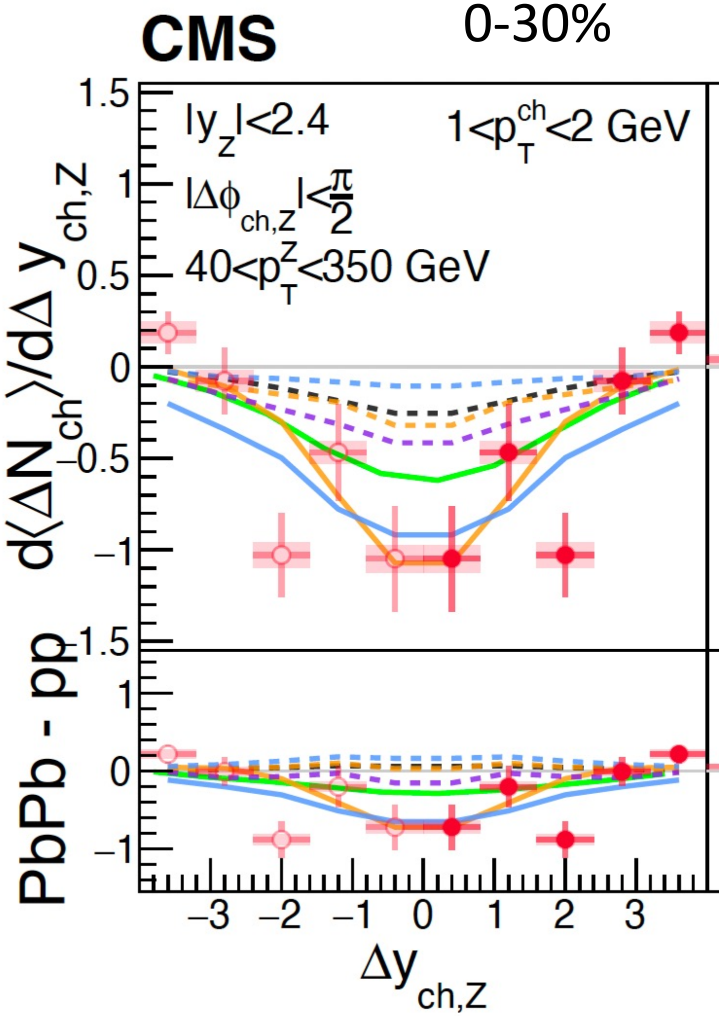
Phys. Rev. C 111 (2025) 044909

The best fit of the diffusion wake amplitude is about 0.5-0.8% for the diffusion wake width range of 0.5-1.0

Quantifying strength of diffusion wake



From Yeonju Go at SoftJet2024



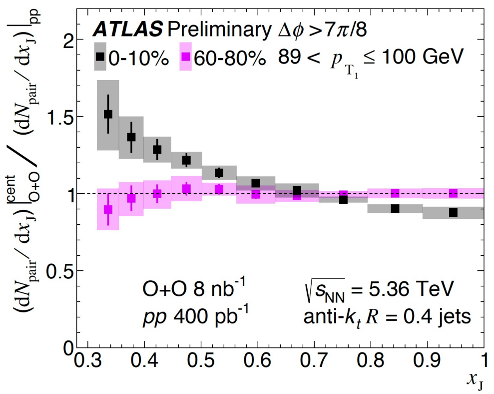
Phys. Lett. B 874 (2026) 140120

- $\frac{Y_{corr}}{Y_{uncorr}}$ is about 0.5%-0.8%

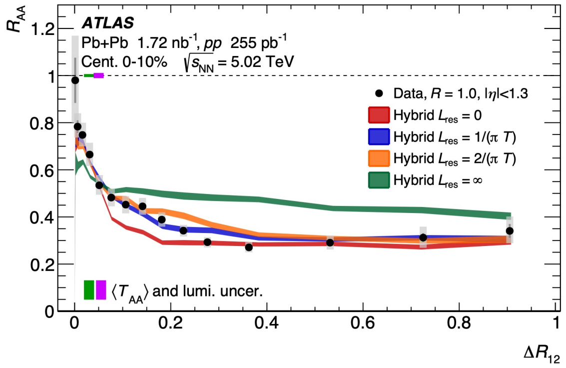
  -> 0.45-0.75 particles are reduced by diffusion wake
- Qualitatively consistent with CMS

Summary

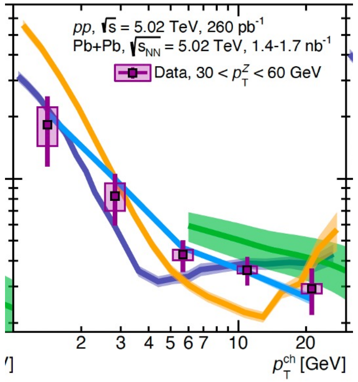
- Observe jet quenching in O+O collisions through enhanced dijet imbalance compared to p+p collisions

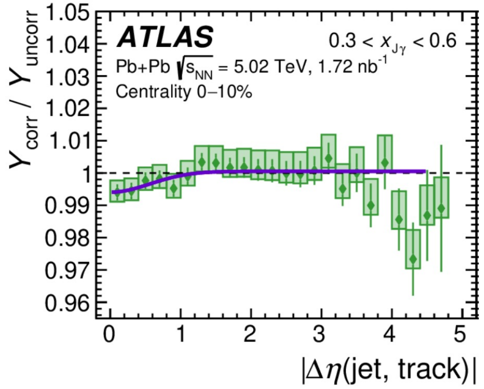


- Jet substructure measurements and theory descriptions favor a limited medium resolution scale



- Soft particle enhancement along the jet and depletion in the opposite direction support the medium response picture





Back up

Method comparison between ATLAS and CMS

ATLAS

Photon trigger:

- w background photon (decay from π^0...)

With jet reconstruction:

- can't access extremely quenched jets
- control jet energy loss by $X_{J\gamma}$

Charged hadron with $0.5 < p_T < 2$ GeV/c

Events mix with min-bias events for UE subtraction

Measure ratio

CMS

Z boson trigger: clean probe

Without jet reconstruction:

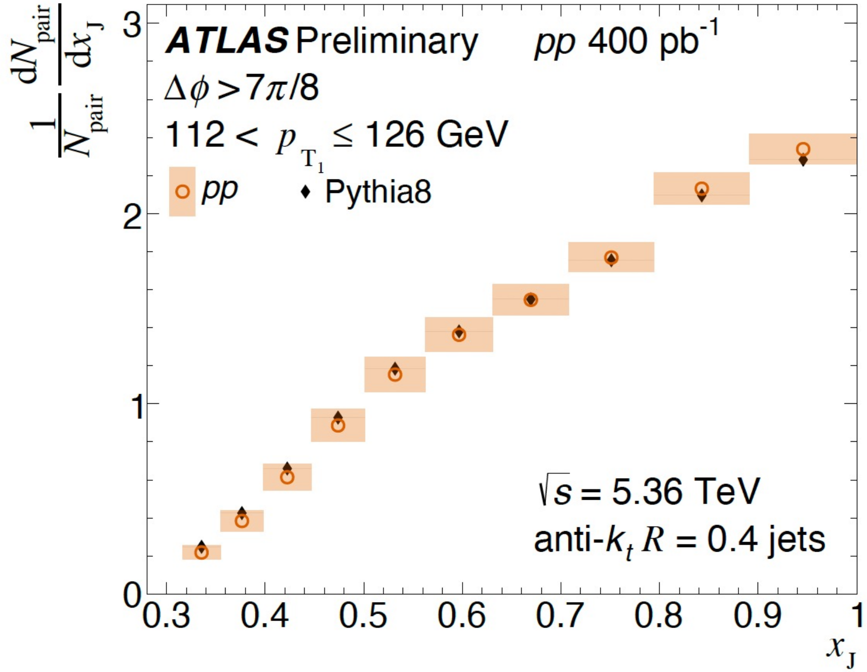
- reach highly quenched jets
- no control on jet energy loss and angular smear

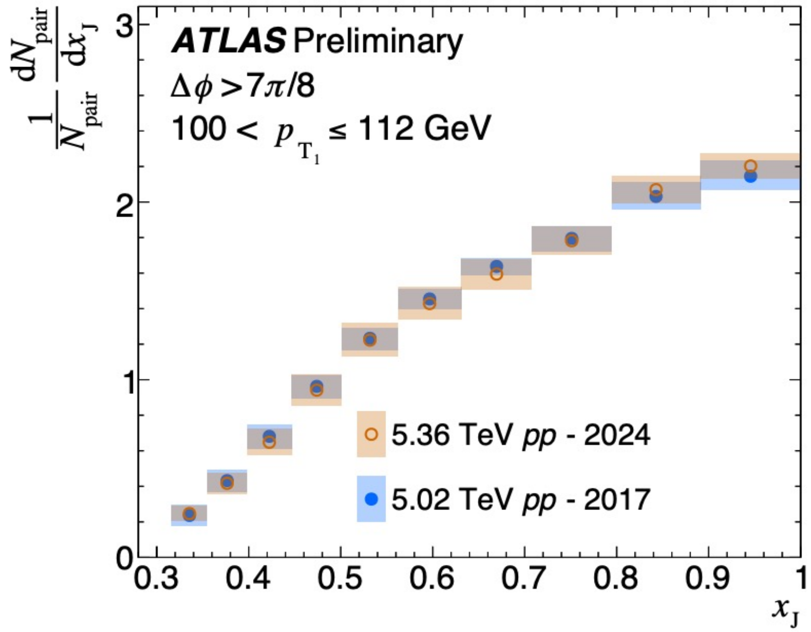
Charged hadron with $1 < p_T < 2$ GeV/c

Events mix with Z events for UE subtraction

Measure correlation function

Dijet asymmetry at different energy





- Well described by PYTHIA8
- Consistent within systematic uncertainties at the two collision energies

Dijet asymmetry in O+O collisions

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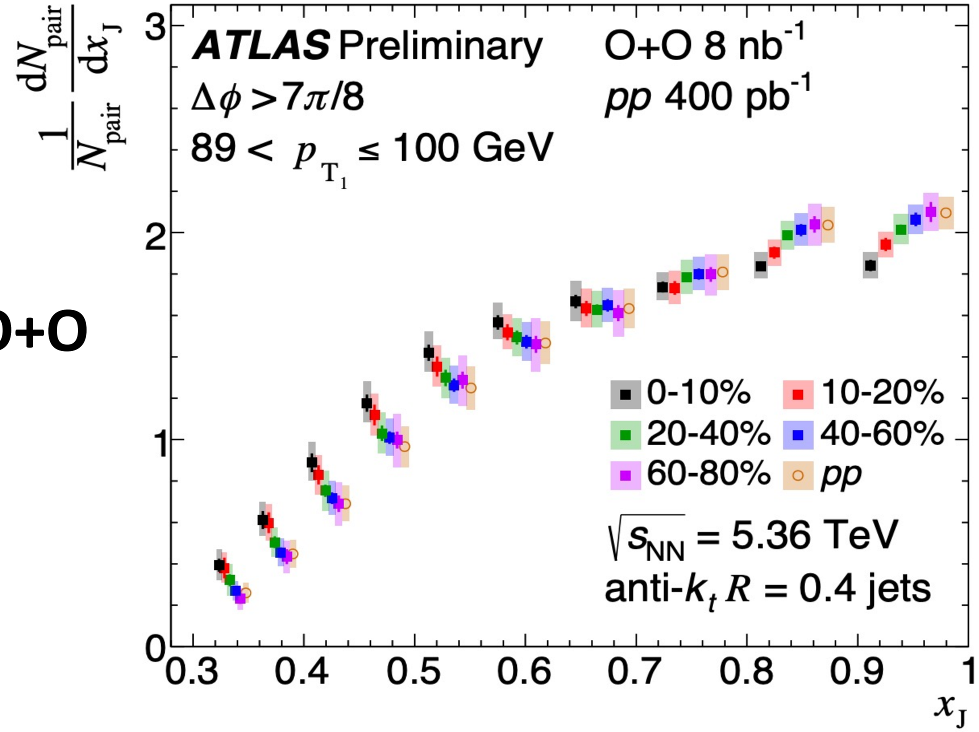
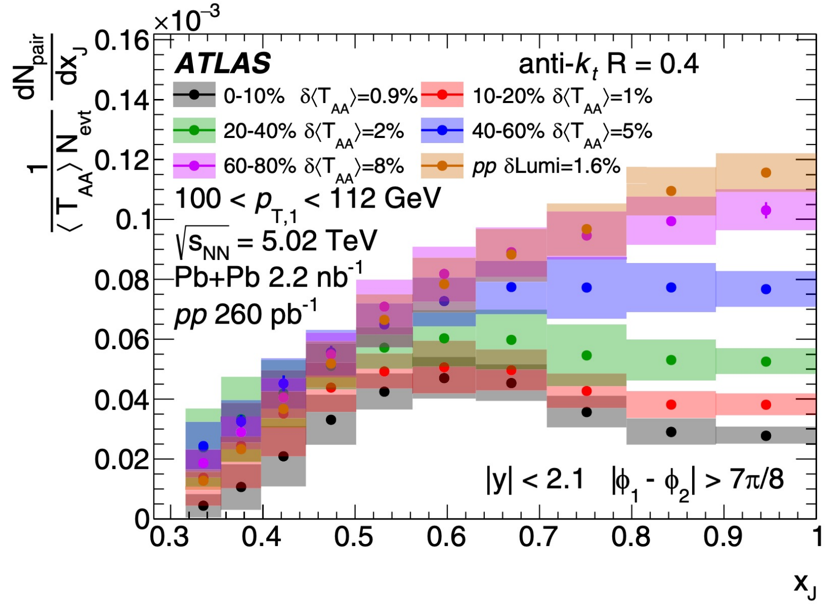
Across centrality

O+O



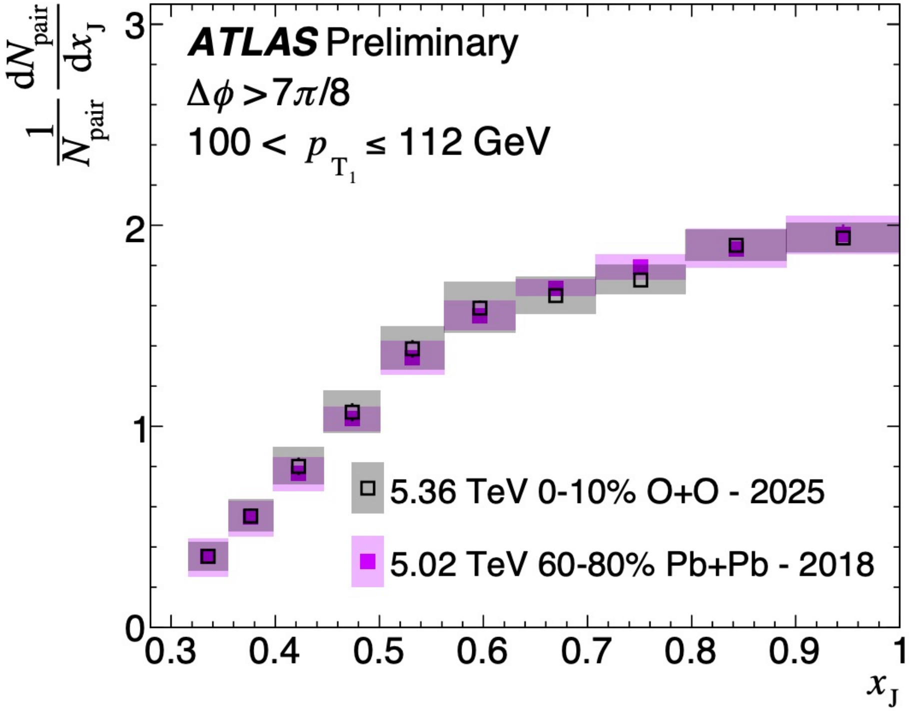
Phys. Rev. C 107 (2023) 054908

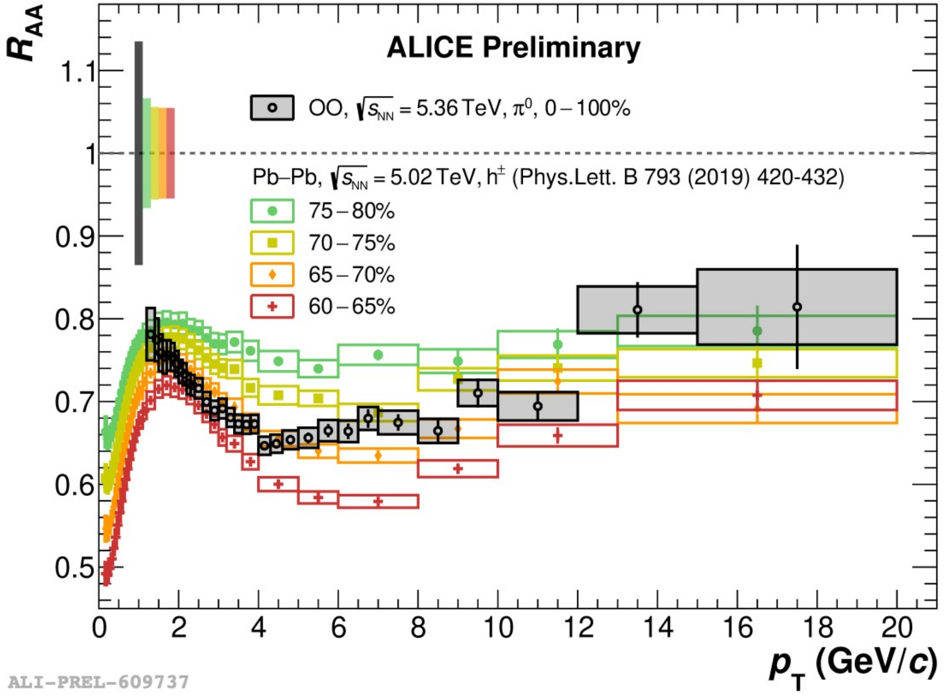


Pb+Pb

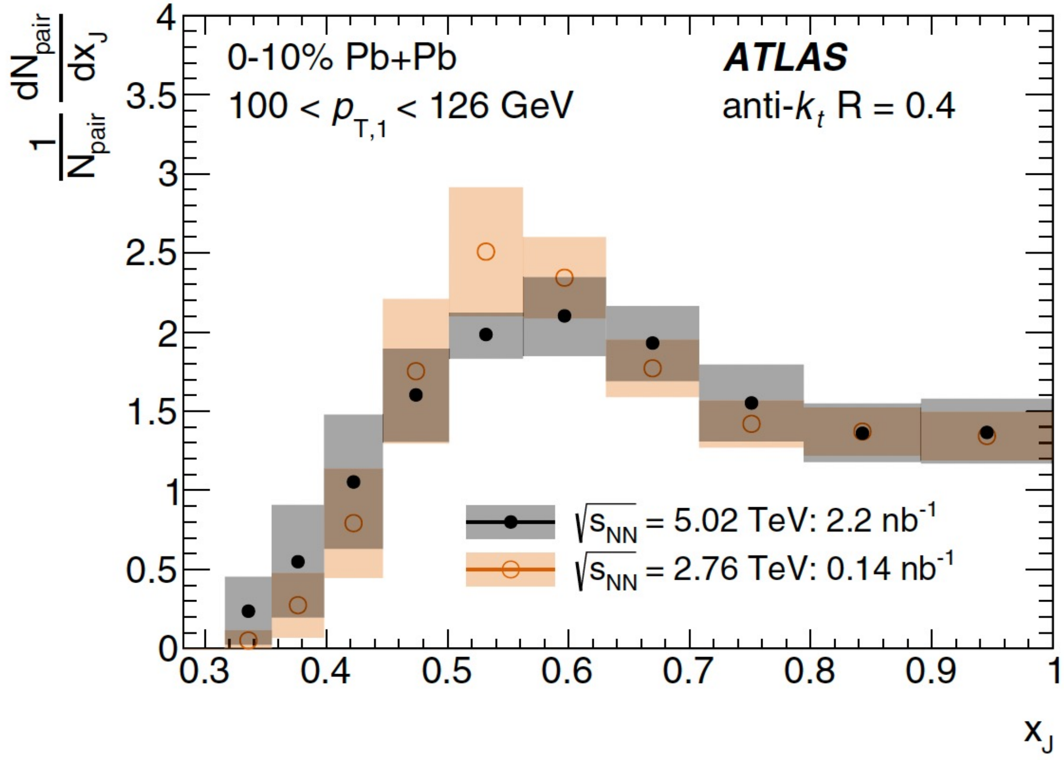
- A continuous evolution of the X_J distributions is observed from peripheral to central collisions
- Similar centrality dependence observed in Pb+Pb collisions

Comparison of O+O and peripheral Pb+Pb

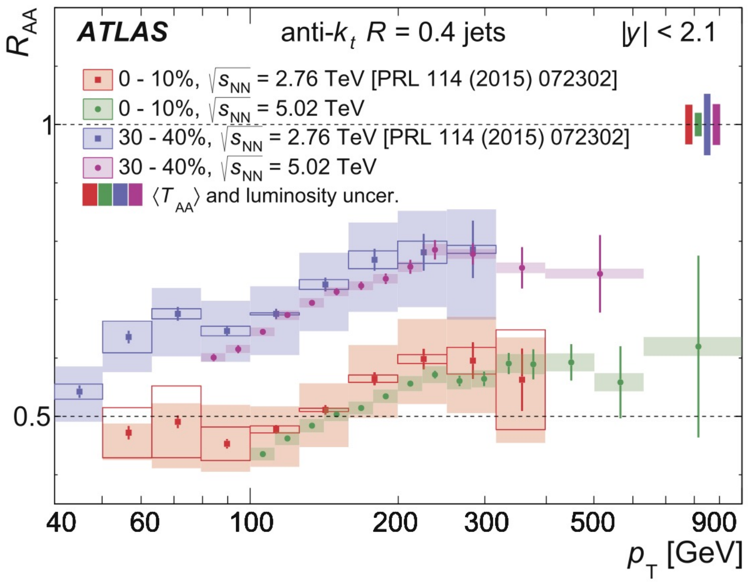




Dijet asymmetry at different energy



- Consistent within systematic uncertainties at the two collision energies
- As expected based on measurements of inclusive jets



Dijet asymmetry in O+O collisions

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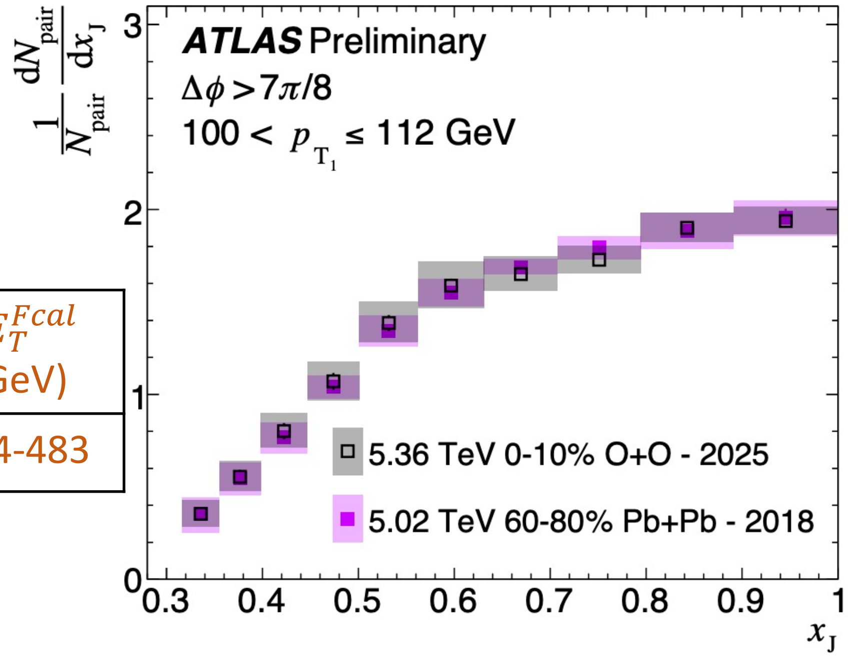
Across systems

Match event activity (through $\sum E_T^{Fcal}$ bins)

O+O	Pb+Pb	ΣE_T^{Fcal} (GeV)
0-10%	60-80%	204-483



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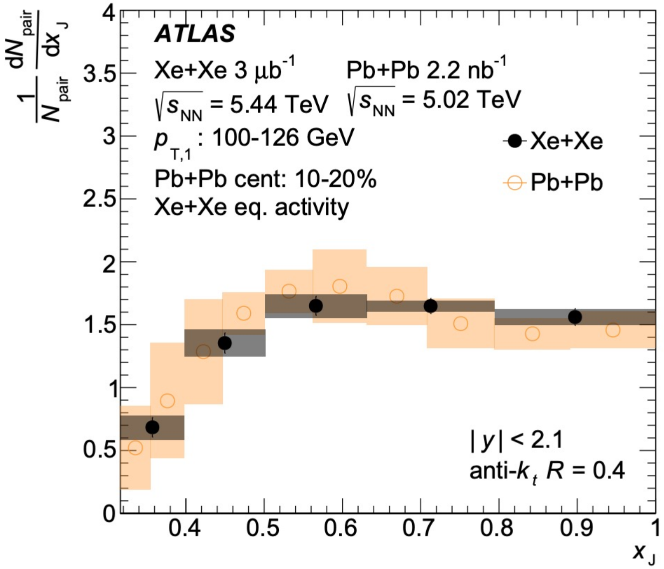
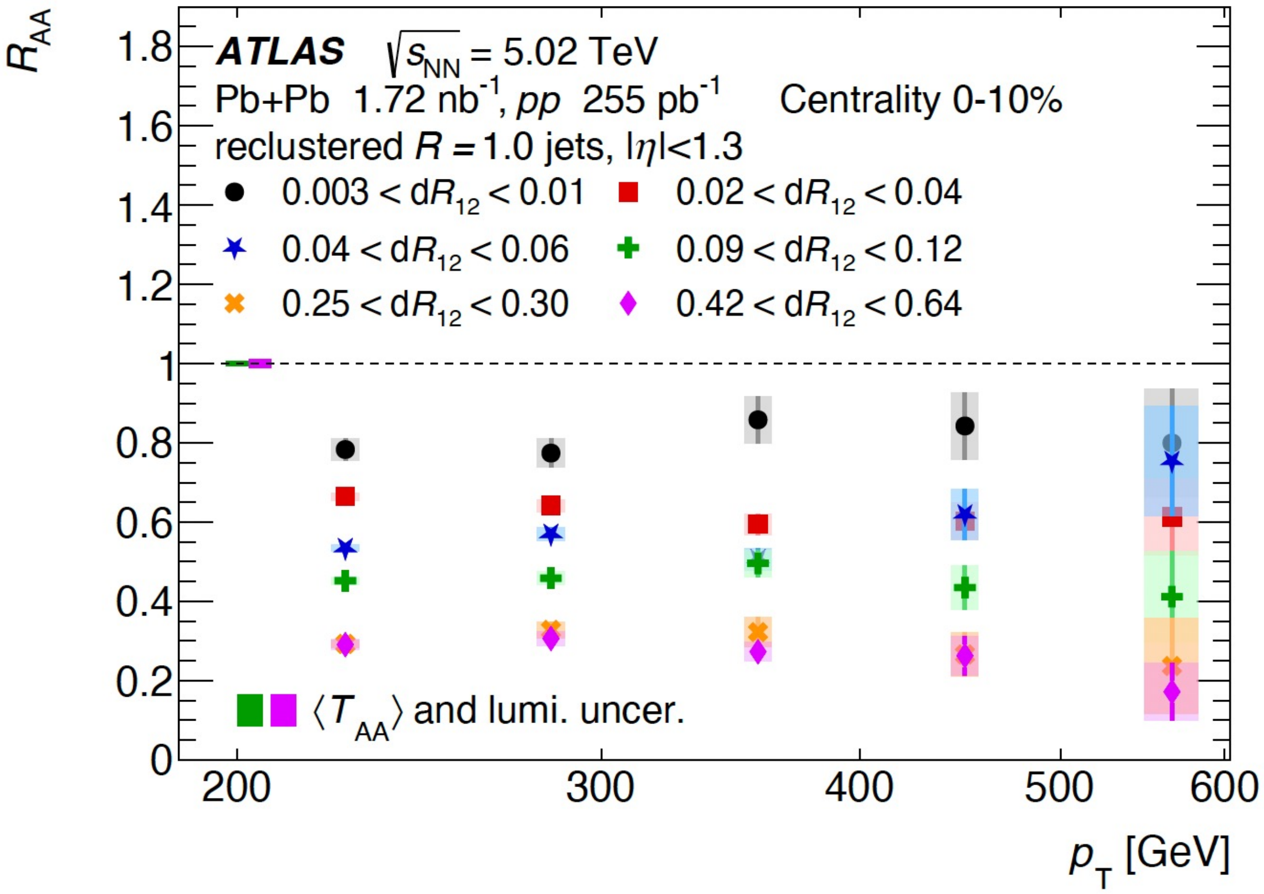


Xe+Xe	Pb+Pb	ΣE_T^{Fcal} (TeV)
0-7.7%	10-20%	2.06-3

- At comparable activity, the observed modification is of similar magnitude in O+O and Pb+Pb collisions
- Similar consistency found in Xe+Xe and Pb+Pb collisions
- More jet studies in O+O collisions are on the way …

R_{AA} as a function of p_T in dR intervals



Dependence on jet p_T is very mild or absent

ATLAS heavy ion data

System	Year	$\sqrt{s_{NN}}$ [TeV]	L_{int}
Pb+Pb	2010	2.76	7 μb^{-1}
Pb+Pb	2011	2.76	0.14 nb^{-1}
p+p	2013	2.76	4 pb^{-1}
p+Pb	2013	5.02	29 nb^{-1}
p+p	2015	5.02	28 pb^{-1}
Pb+Pb	2015	5.02	0.49 nb^{-1}
p+Pb	2016	5.02	0.5 nb^{-1}
p+Pb	2016	8.16	165 nb^{-1}
p+p	2017	5.02	270 pb^{-1}
Xe+Xe	2017	5.44	3 μb^{-1}
Pb+Pb	2018	5.02	1.76 nb^{-1}
Pb+Pb	2023	5.36	1.71 nb^{-1}
p+p	2024	5.36	465 pb^{-1}
Pb+Pb	2024	5.36	1.73 nb^{-1}