

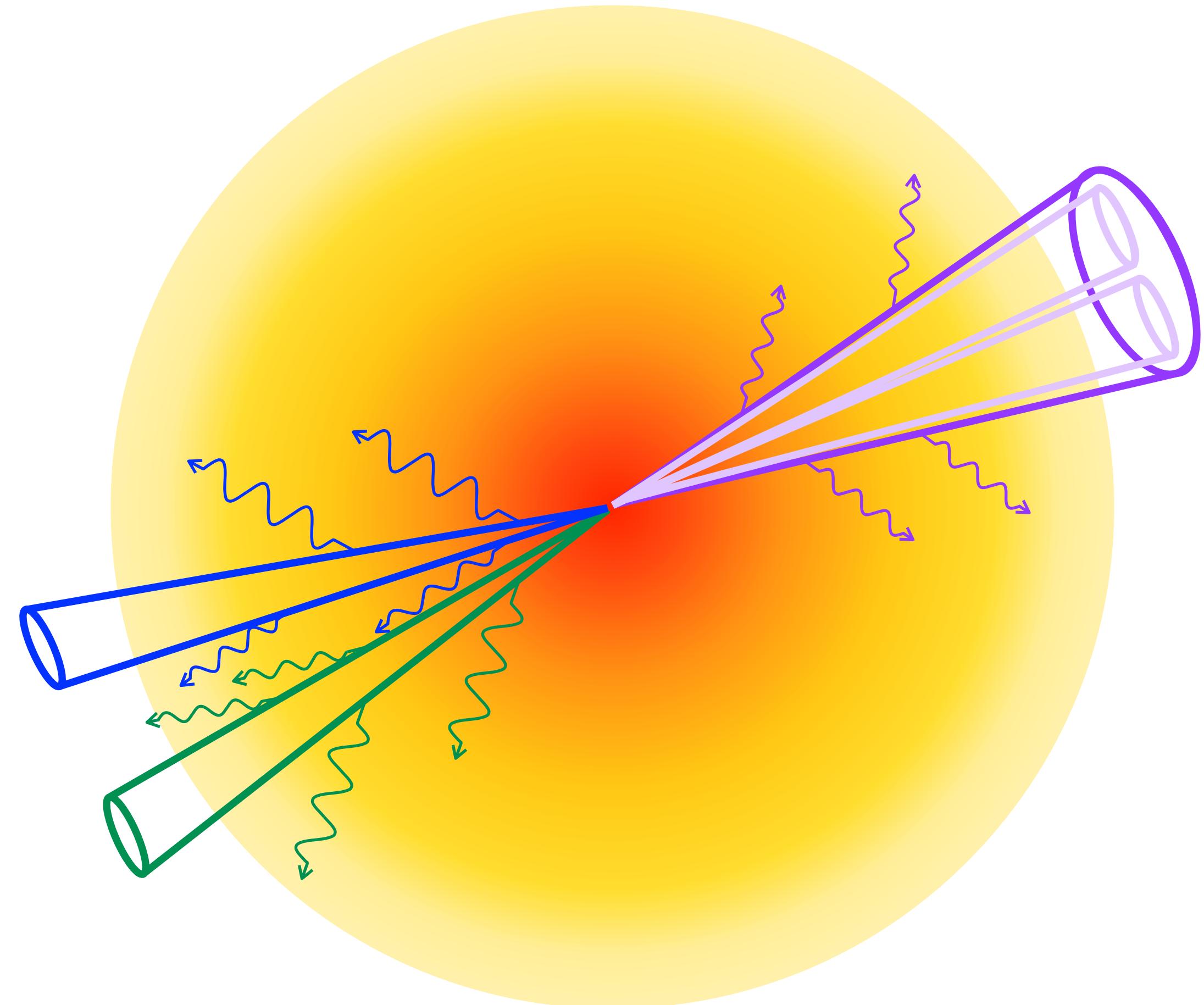
ATLAS Highlights

Aaron Angerami
on behalf of the ATLAS Collaboration

Quark Matter 2023
Houston, Texas, USA
September 3–9,
2023

The ATLAS Heavy Ion Physics Program

- ▶ Photon induced processes—UPCs
- ▶ Nuclear modification of parton densities
- ▶ Collective dynamics
 - Medium response
 - Role of fluctuating geometry
- ▶ Penetrating probes
 - Jet quenching
 - Heavy quarks



Best place to find new ATLAS results

<https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HeavyIonsPublicResults>

Photon-induced processes

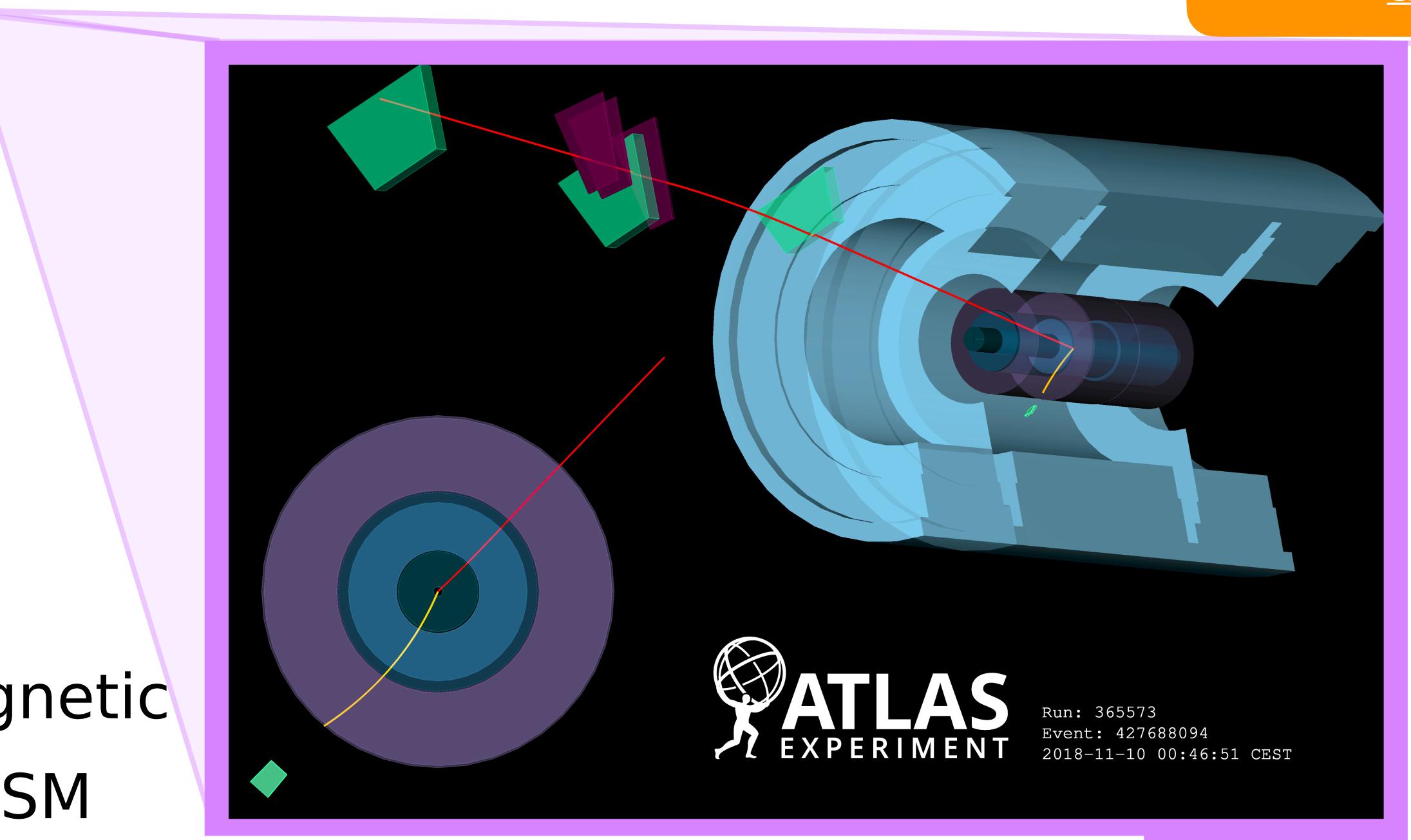
$\gamma\gamma \rightarrow \tau\tau$ and constraints on τ anomalous magnetic moment

See talk by P. Steinberg

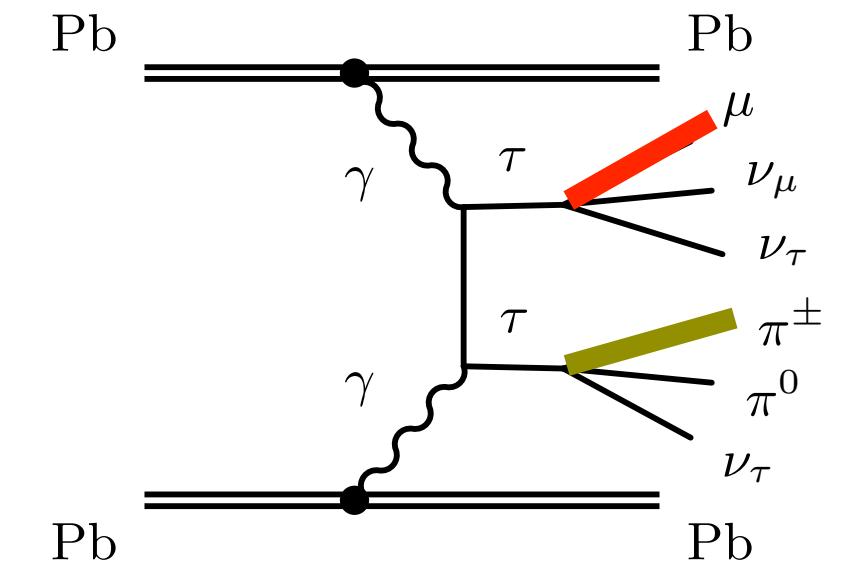
Tues. 4:50

ATLAS UPC results

Dileptons	$\gamma\gamma \rightarrow ee$	JHEP 06 (2023) 182
Exotica	$\gamma\gamma \rightarrow \mu\mu$	Phys. Rev. C 104 (2021) 024906
	$\gamma\gamma \rightarrow \tau\tau$	arXiv:2204.13478
Photo-production	$\gamma A \rightarrow jets$	Nature Phys. 13 (2017) 852 Phys. Rev. Lett. 123 (2019) 052001
	$\gamma A \rightarrow h+X$, 2PC	JHEP 03 (2021) 243
Photo-production	$\gamma A \rightarrow h+X$	ATLAS-CONF-2022-02 Phys. Rev. C. 104 (2021) 014903



Observation of $\gamma\gamma \rightarrow \tau\tau$
arXiv:2204.13478



- ▶ Observation of $\gamma\gamma \rightarrow \tau\tau$ process
 - Sensitive to anomalous magnetic moment $a_\tau = \frac{1}{2}(g_\tau - 2)$ and BSM physics
- ▶ Constrain $-0.057 < a_\tau < 0.024$ at 95% confidence level
 - Competitive with LEP2 limits

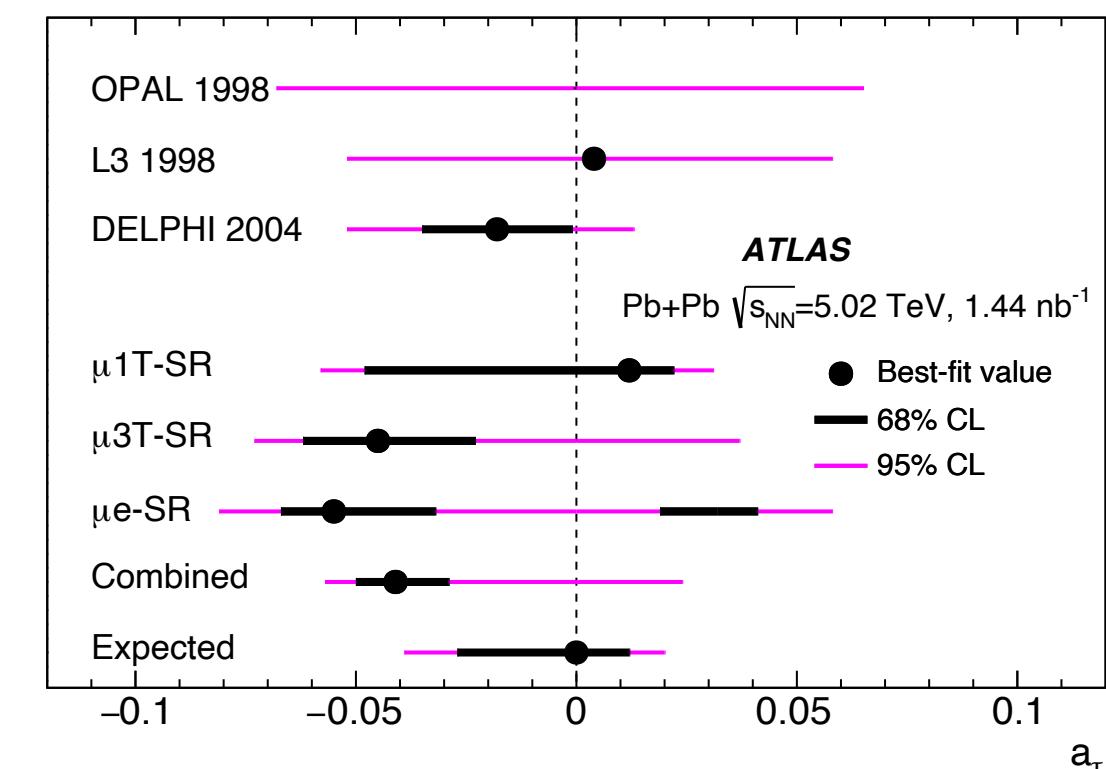


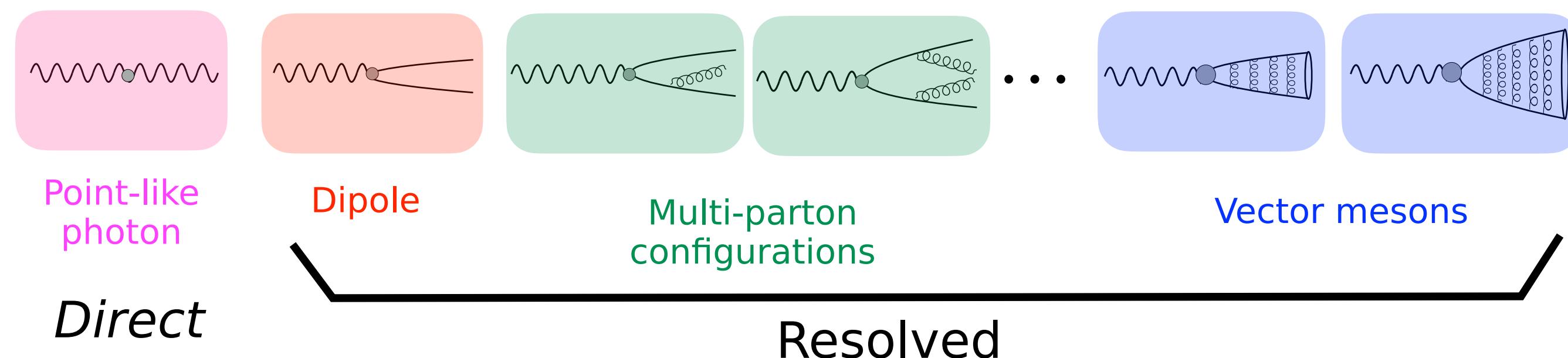
Photo-nuclear processes

Event characteristics

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	$\gamma A \rightarrow h+X$	

Accessible photon structure at high energy



- Flow-like correlations observed in $\gamma A \rightarrow X$
 - Dominated by *resolved* contributions
- How well do we understand these systems?
 - Aspects of geometry relevant for hydro calculations
- Natural to ask whether other signatures associated with QGP are observable

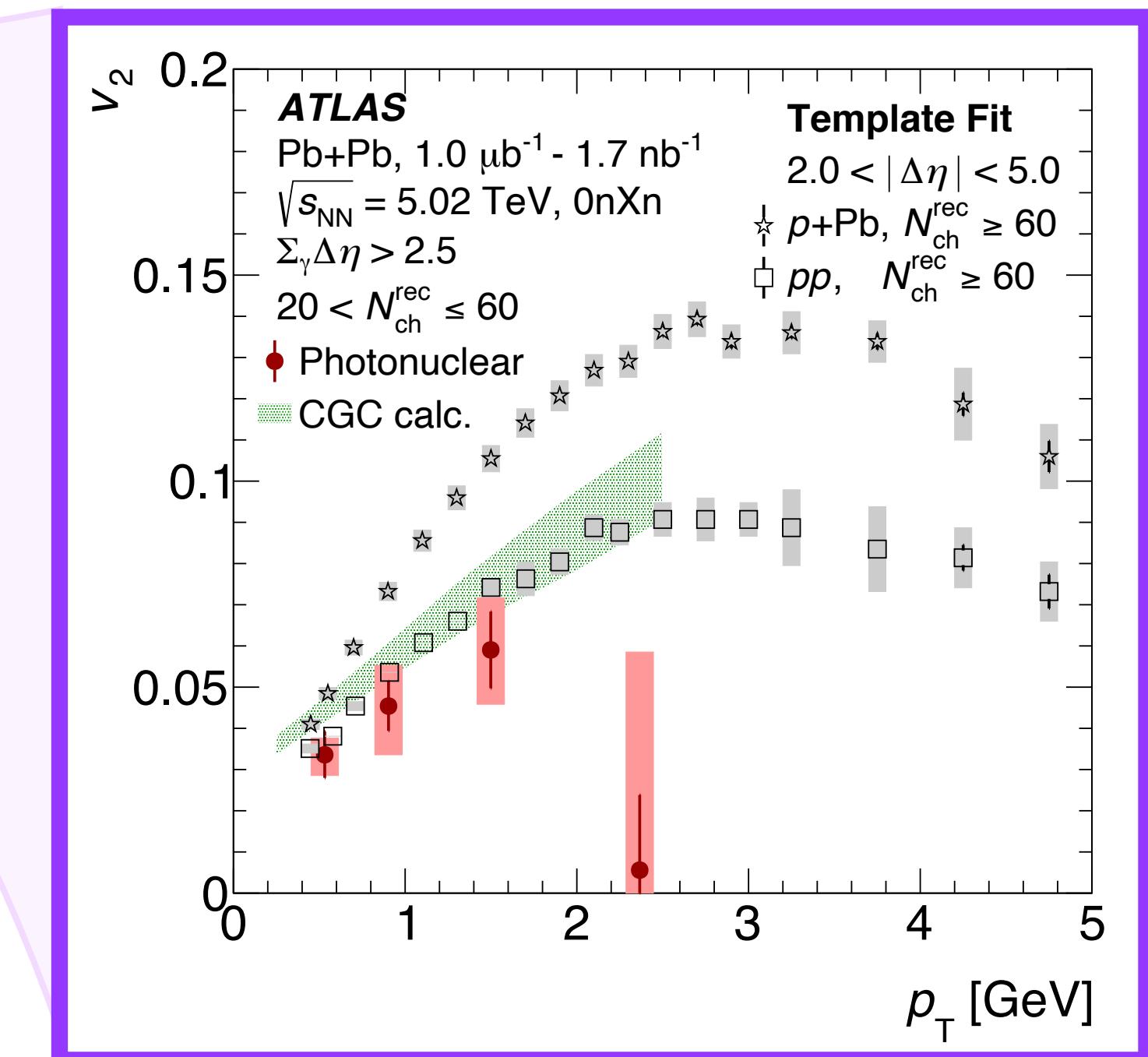


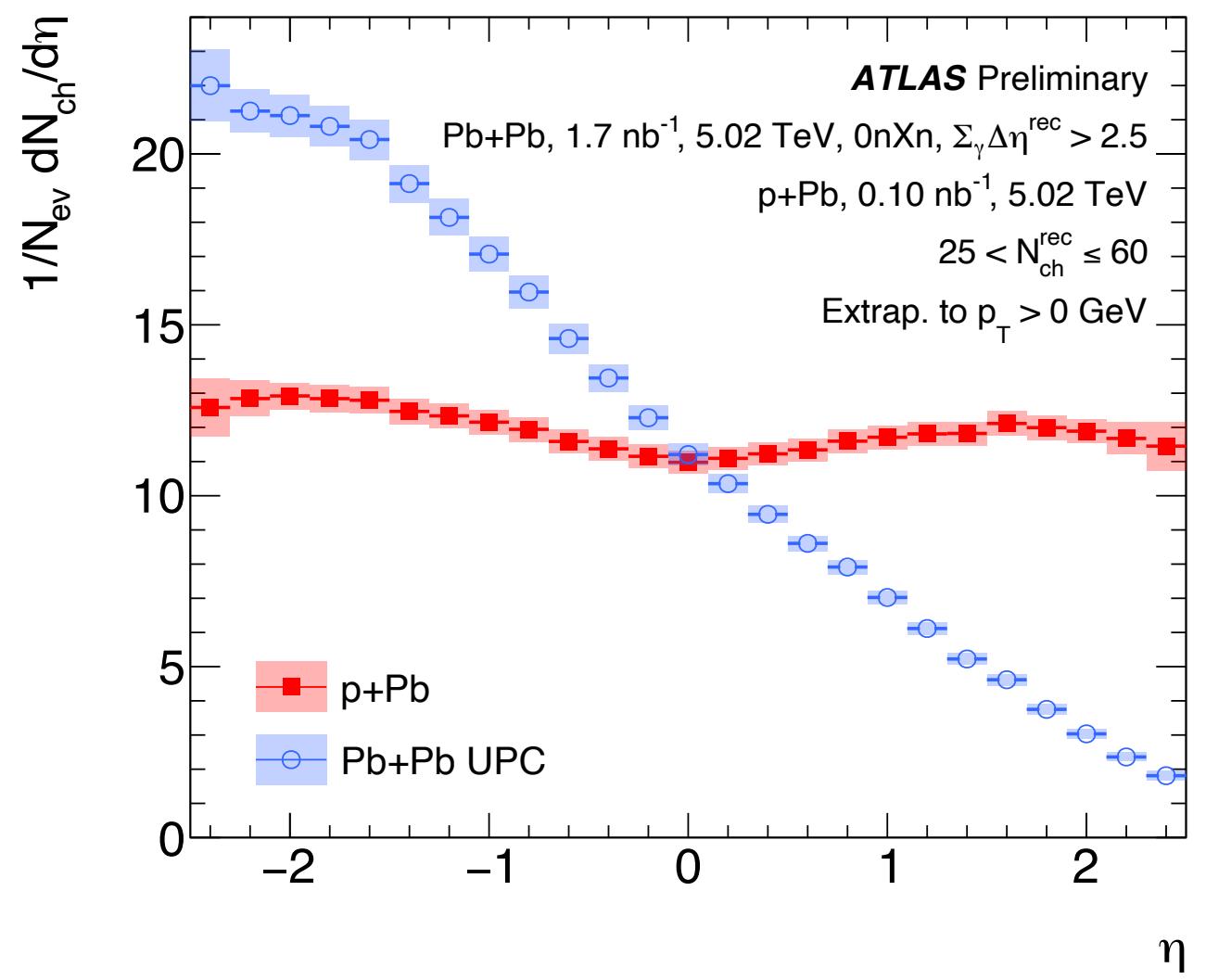
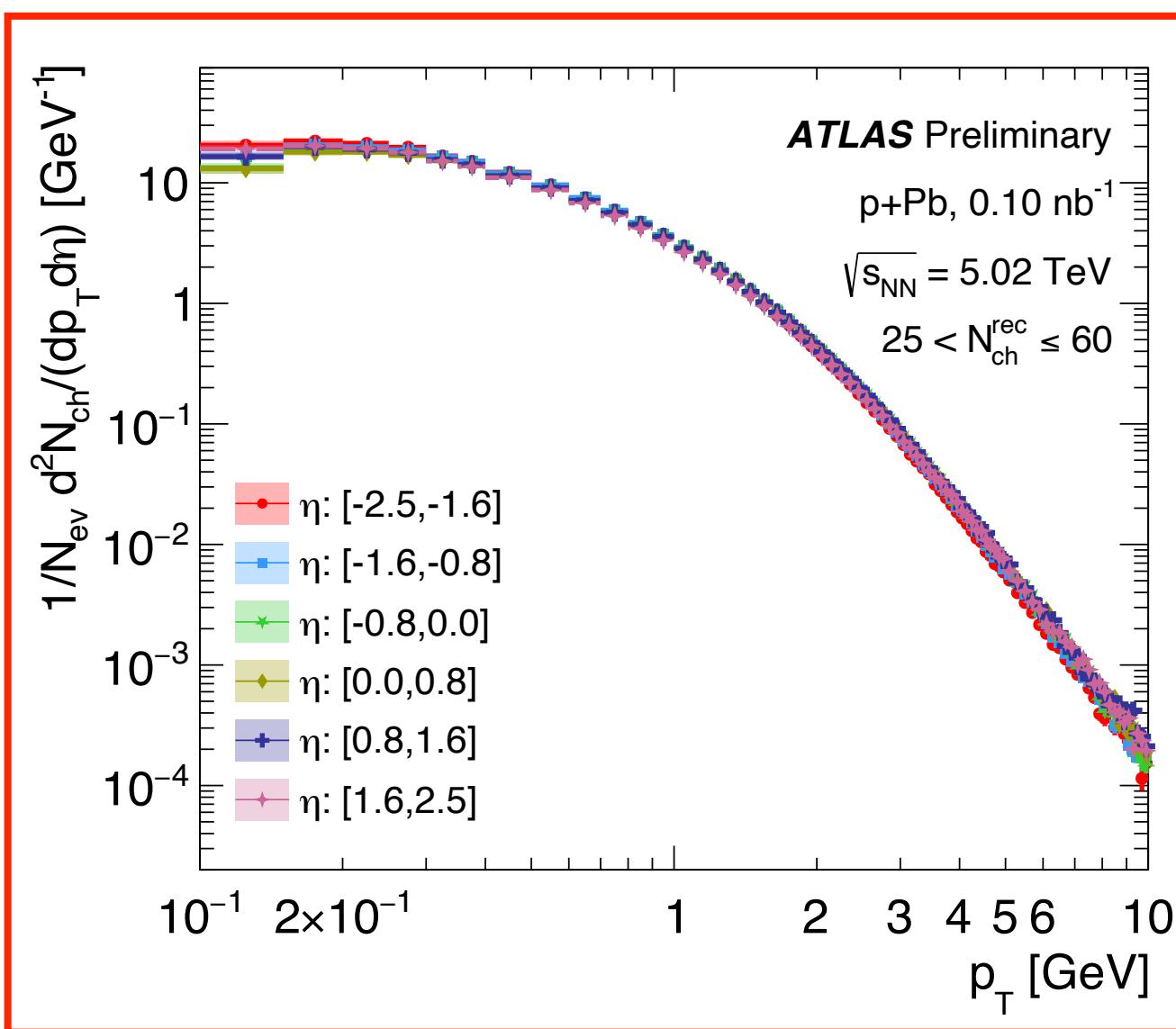
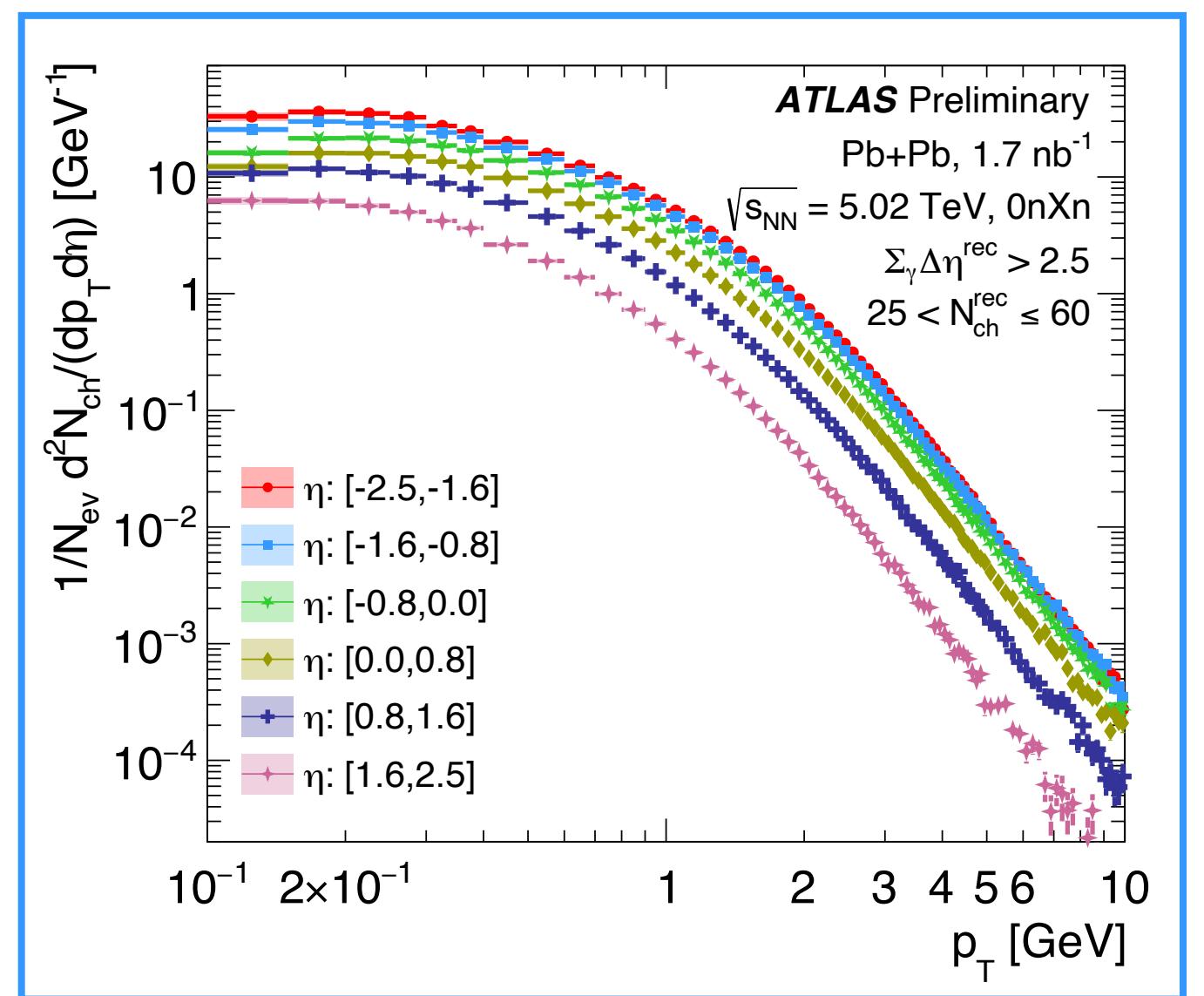
Photo-nuclear processes

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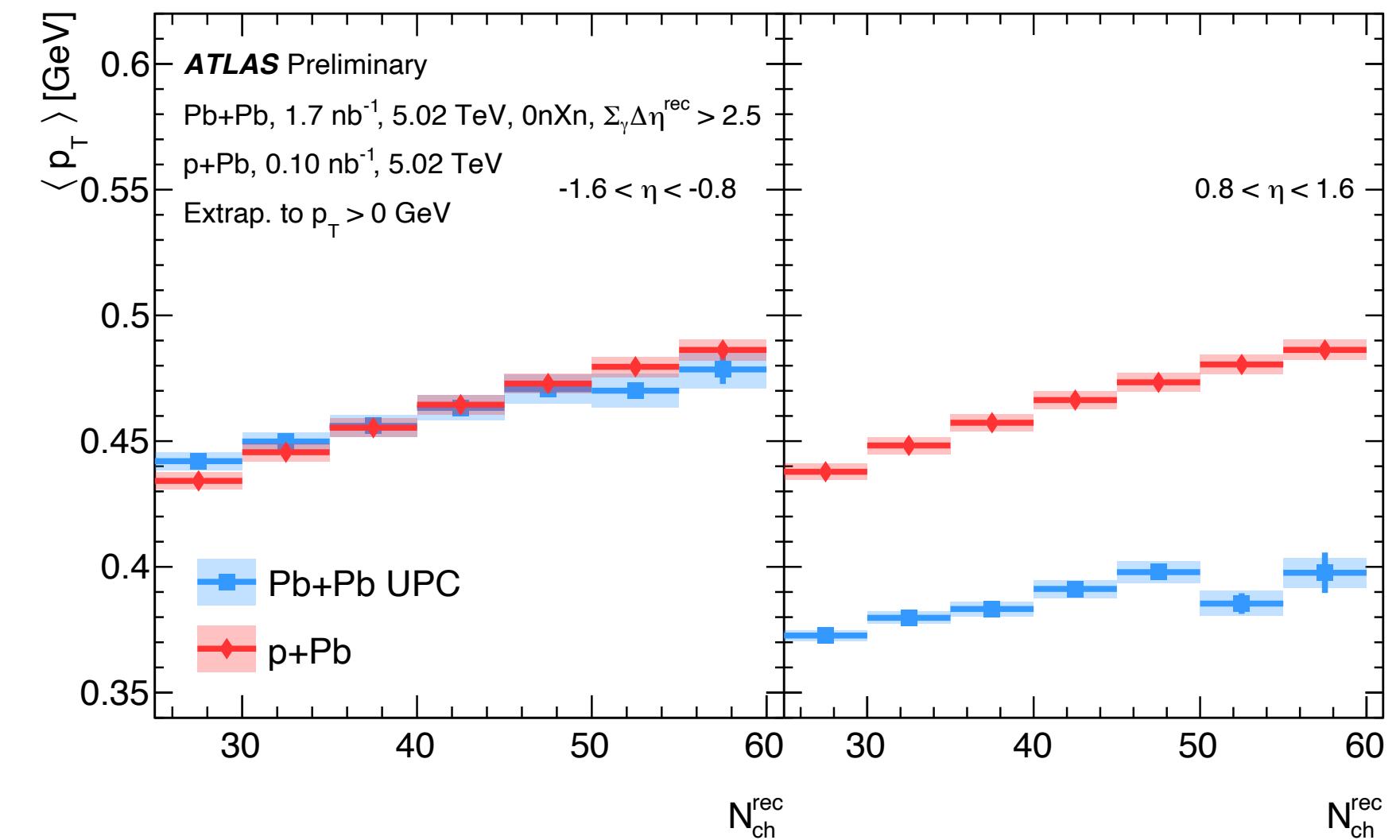
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$p + Pb$ compared with $\gamma + Pb$



Theory prediction at fixed multiplicity $\gamma + Pb$ and $p + Pb$ have same radial flow (PRL 129 (2022) 25, 252302) → compare $\langle p_T \rangle$

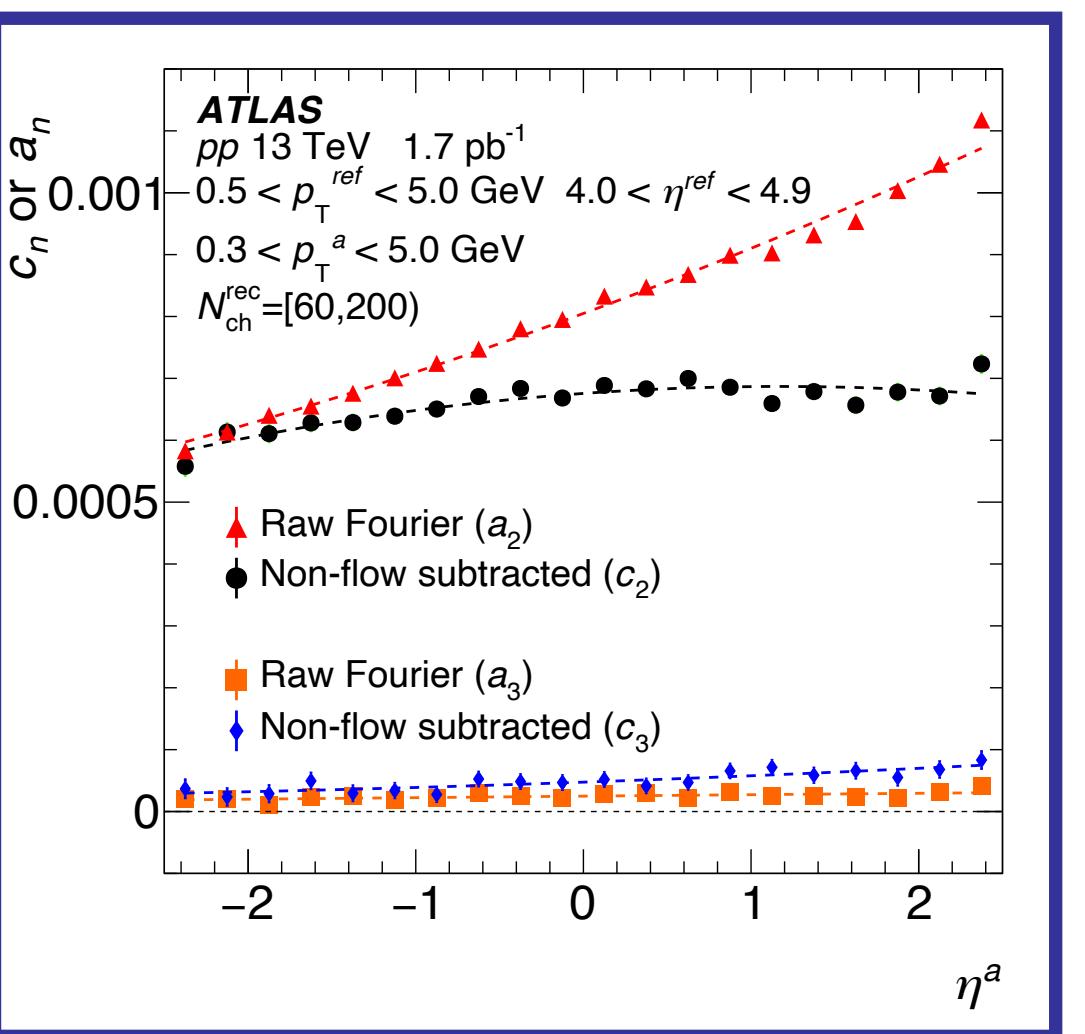


Longitudinal flow decorrelations

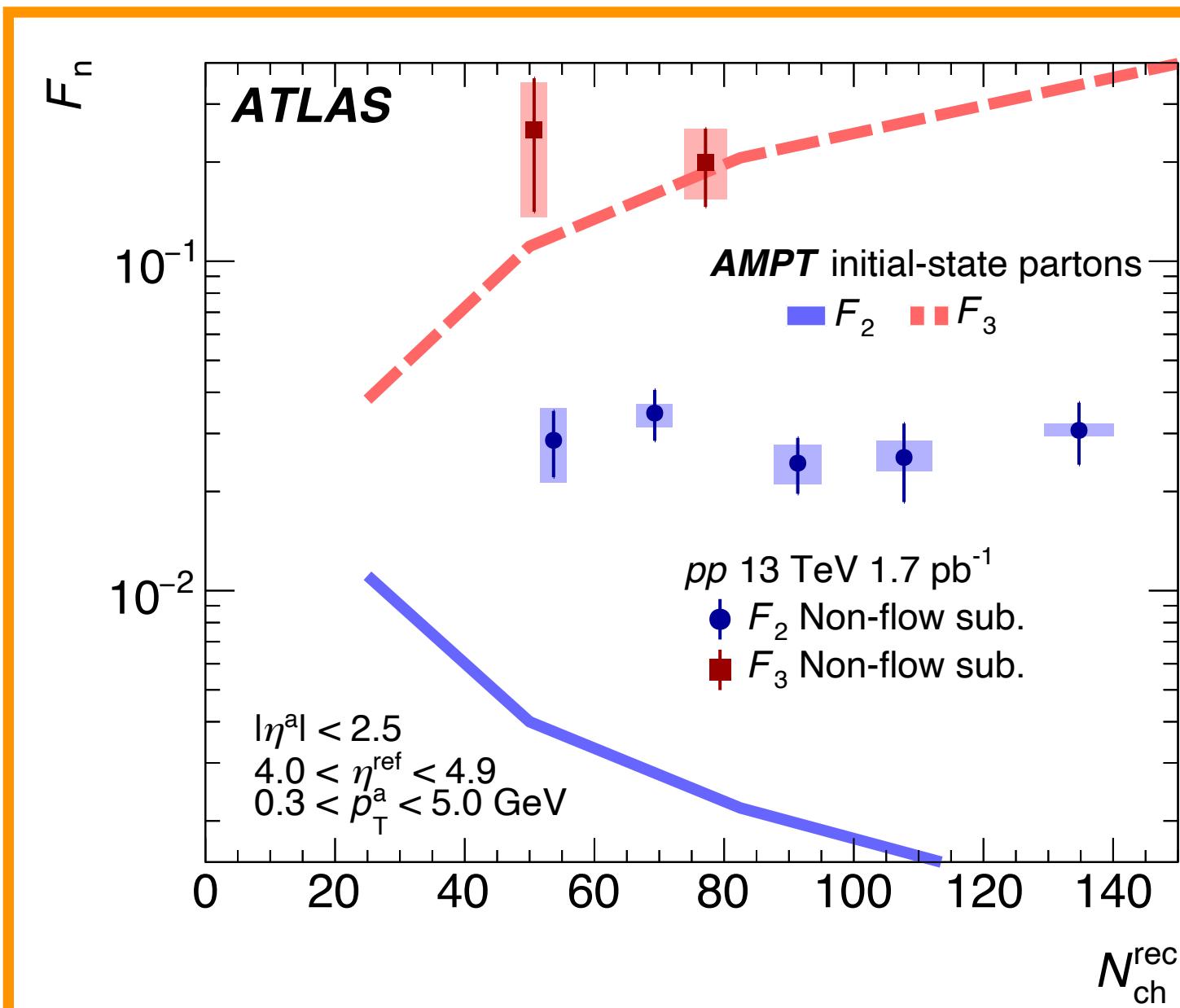
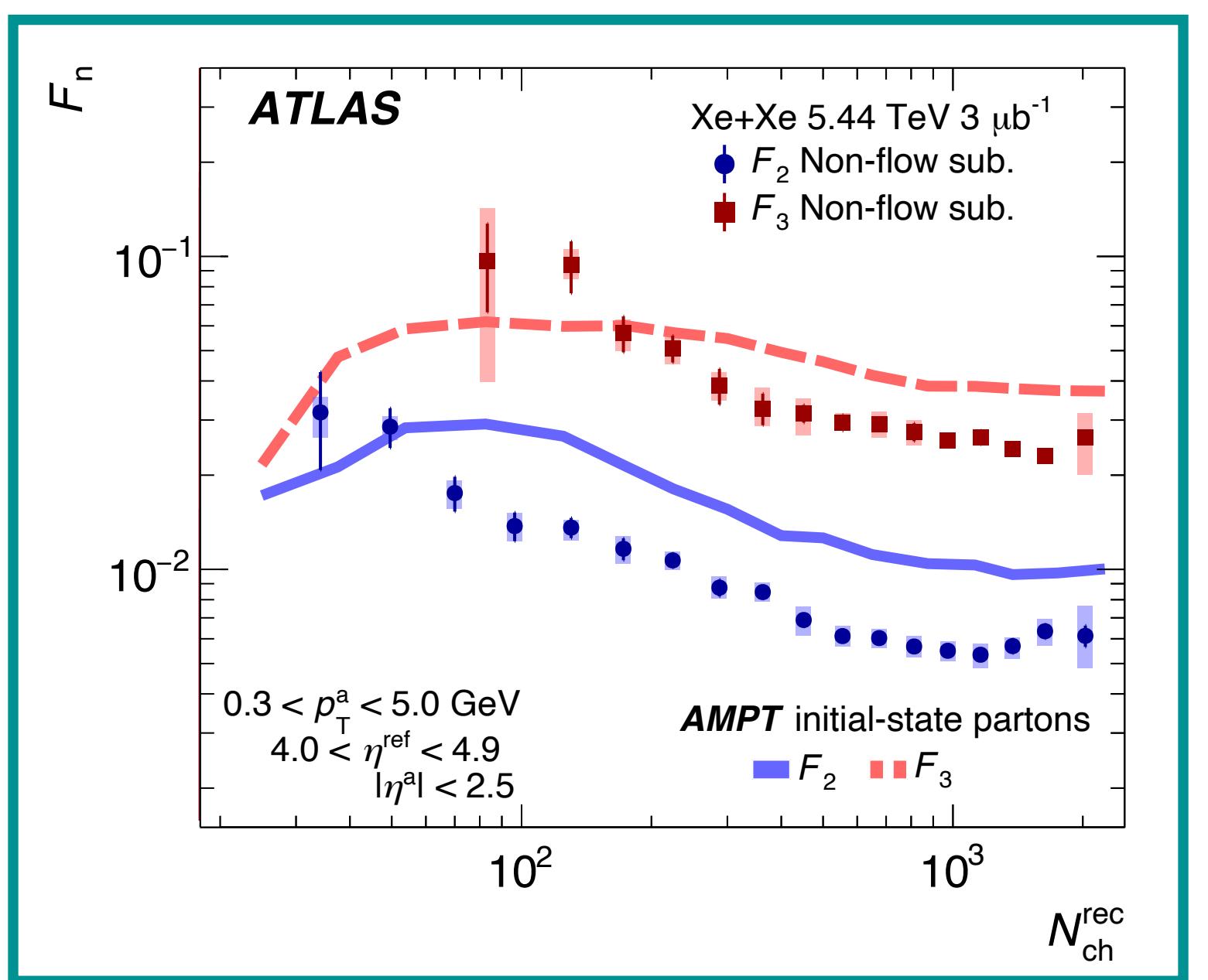
Constraints on geometry

See [talk](#) by B. Seidlitz
Tues. 12:40

- ▶ To improve the predictive power of hydro models we need accurate description of 3D geometry, especially important in small systems
- ▶ Constrain geometry in longitudinal direction using flow decorrelations
 - Measure 2PC between two regions in η and extract flow harmonics
 - Parameterize by $c_n = A (1 + F_n \eta + S_n \eta^2)$
- ▶ Compare with AMPT— per nucleon longitudinal strings, uniform in rapidity, serve as a simple model with *no geometric decorrelation*
- ▶ Works reasonably well in Xe+Xe
- ▶ Fails in pp
 - Evidence for longitudinal fluctuations in energy deposition possibly arising from sub-nucleonic structures



Longitudinal flow
decorrelation in pp & $Xe+Xe$
[HION-2022-17](#)



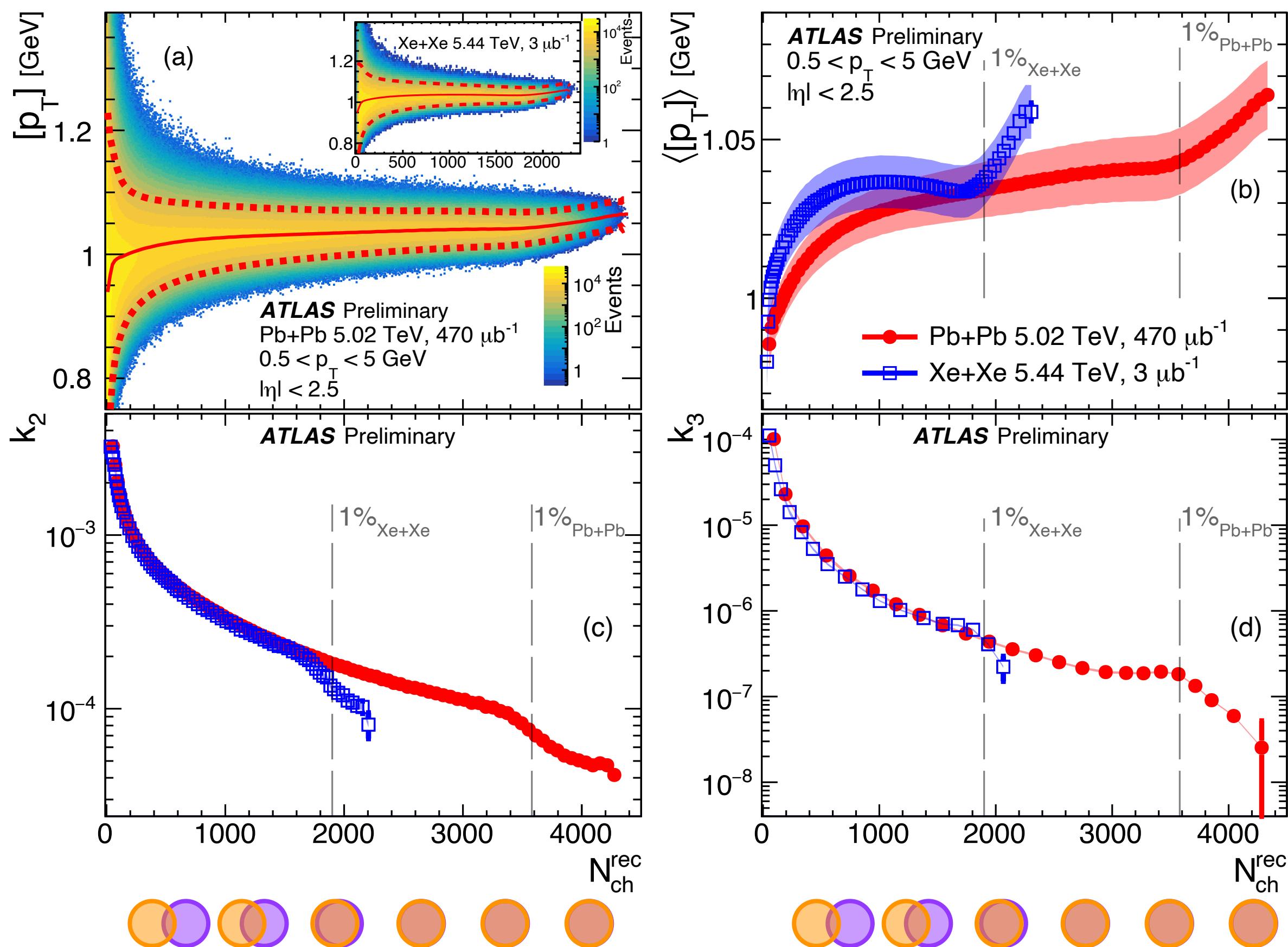
Ultra central collisions

Mean p_T fluctuations

See talk by T. Bold
Wed. 5:10

See poster by S. Bhatta

- Puzzle in ultra-central collisions (UCC)
 - $\nu_2 \sim \nu_3$ in data but $\nu_2 > \nu_3$ in hydro calculations
- Need to understand role of fluctuations in initial conditions
 - Geometric fluctuations vs
 - “Intrinsic” fluctuations
- Observe qualitative change in behavior in most central $\sim 1\%$ of collisions (“knee”)
 - Completely saturate overlap area and eliminate geometric fluctuations
 - Higher N_{ch} but fixed area more radial flow
 - Deviations from $1/N_{ch}$ and $1/N_{ch}^2$ scaling behavior in cumulants expected from independent source models



Hard-soft correlations

2PCs with jets in pp collisions

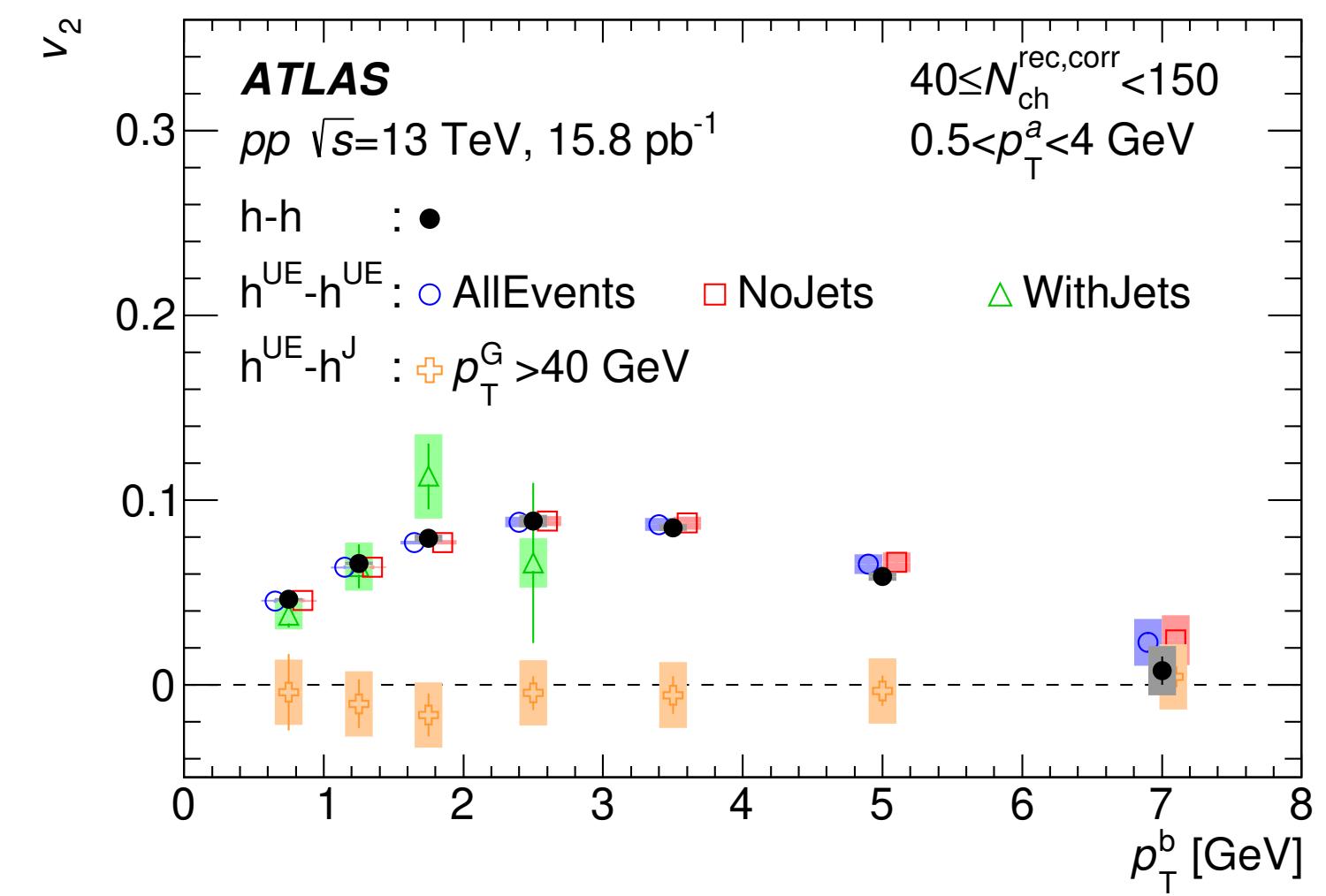
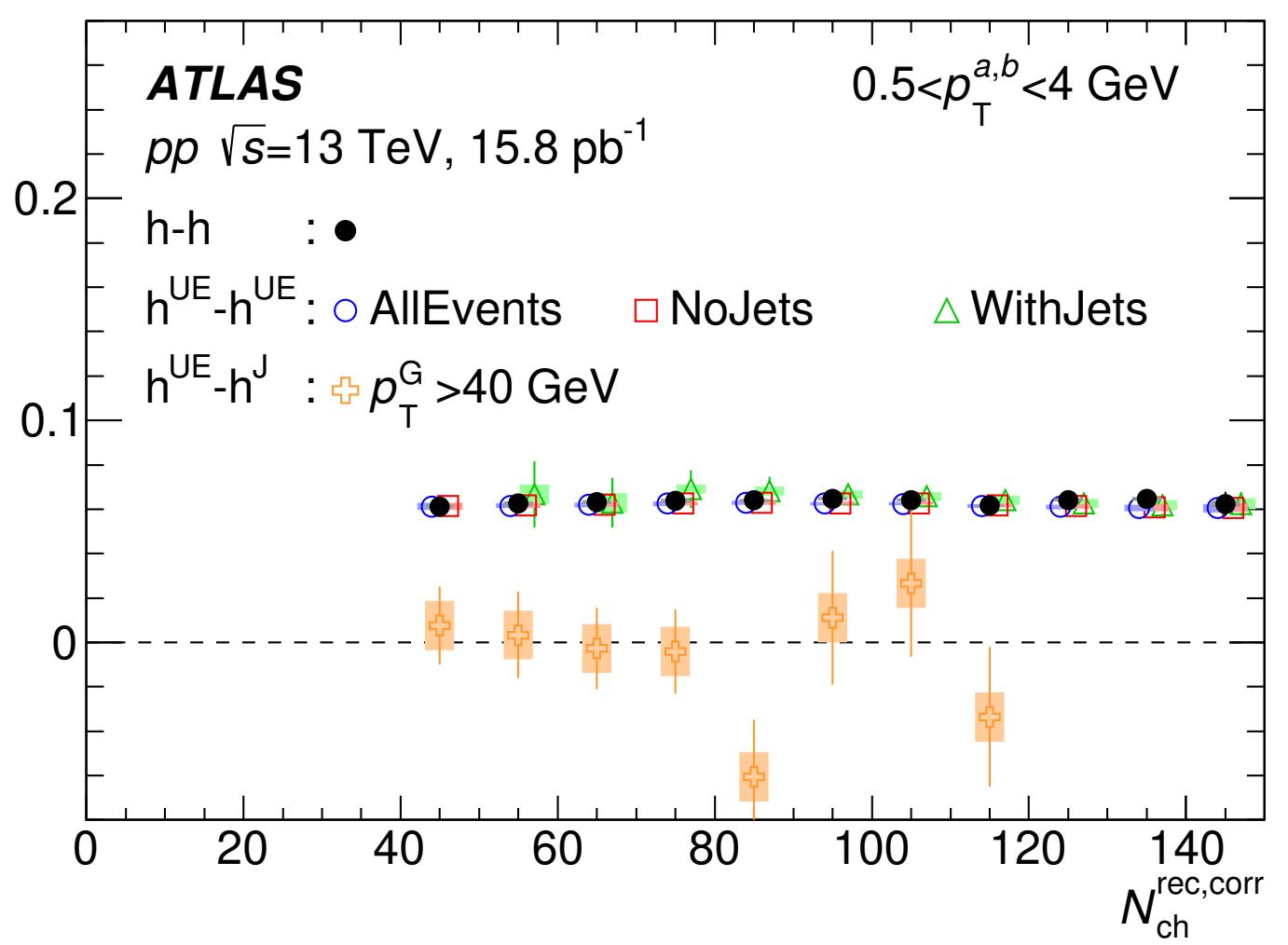
See talk by S. Mohapatra
Wed. 5:50

- ▶ Is the ridge associated with jet production?
- ▶ Define two-particle correlations among particles from different categories: UE or associated with jet
 - Careful to remove UE contribution to correlation within jet cone
- ▶ Also study different event selection related to jets

Events with jets have \sim the same $v_2^{a,b}$

v_2 doesn't depend on whether there are jets in the event

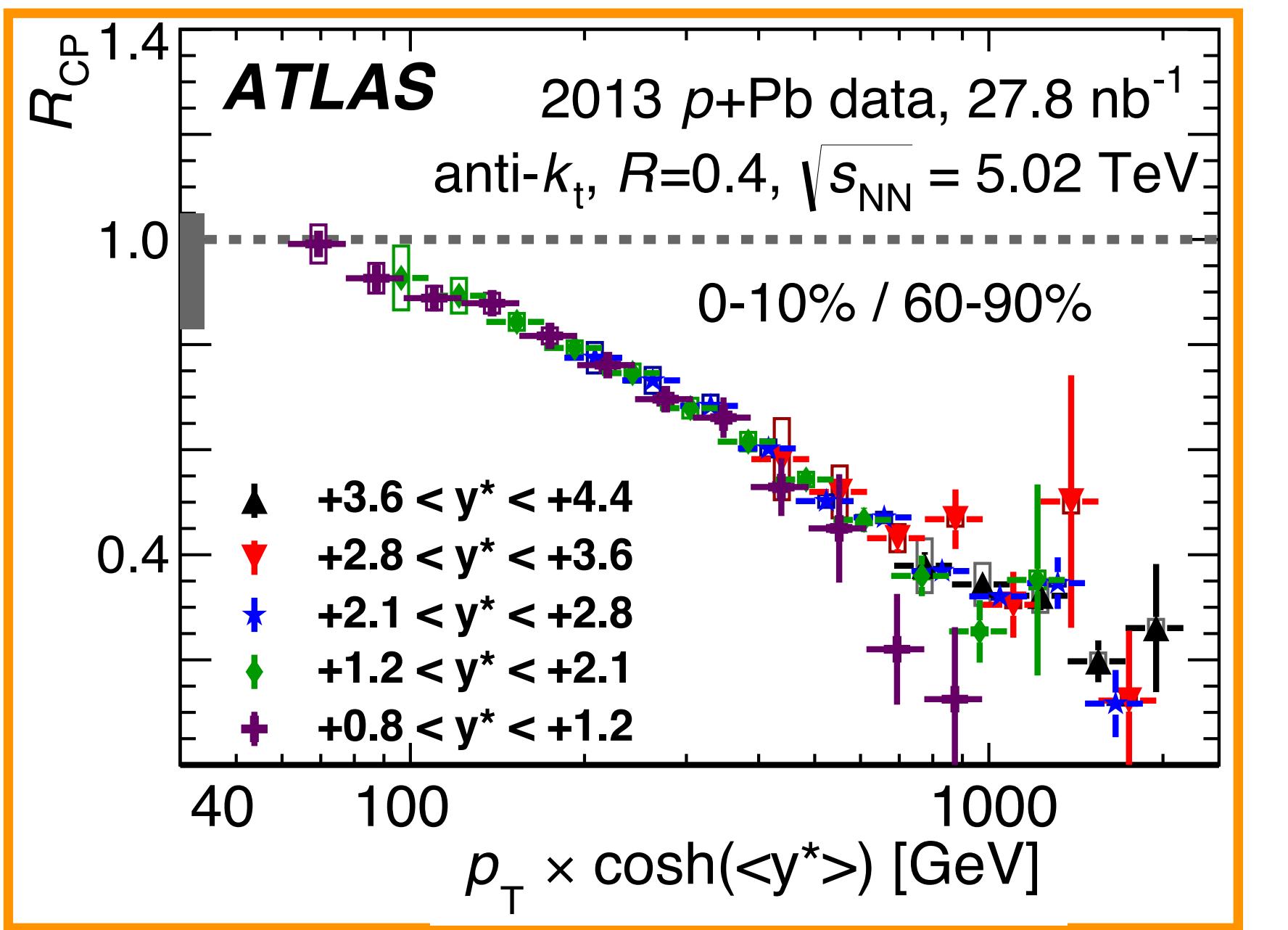
But correlations between jet particles and UE exhibit v_2 consistent with zero



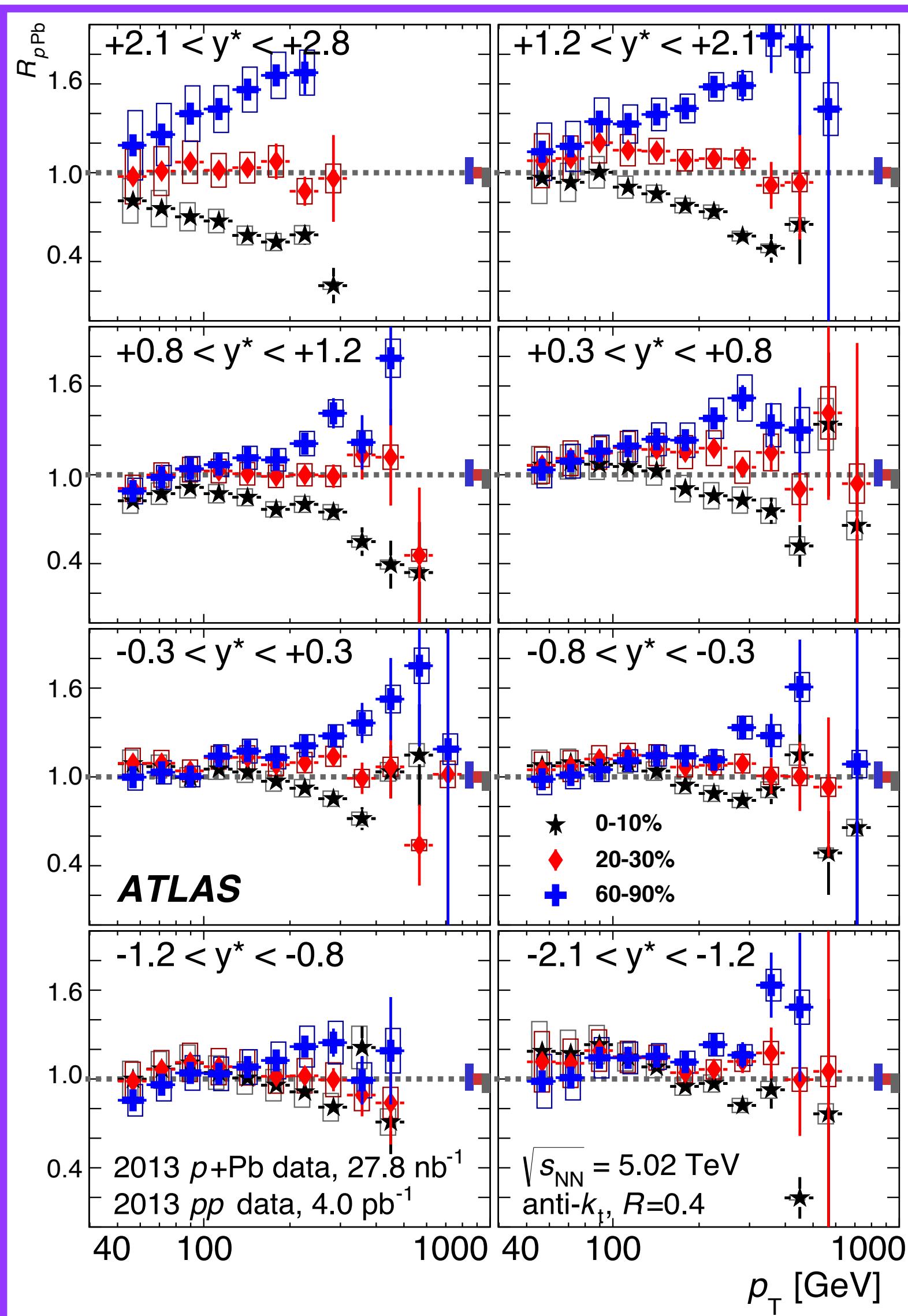
Geometry and hard-soft correlations

Updates from a curious scaling relation in $p + \text{Pb}$

- ▶ Recall some unresolved issues with jet production in $p + \text{Pb}$
- ▶ Centrality dependence of inclusive jet yields $R_{\text{pPb}} > 1$ for “peripheral” and < 1 for “central”
- ▶ Interesting kinematic dependence: increases with p_T with a slope that depends on rapidity (looks like $\cosh y$)
 - Depends solely on $E \sim p_T \cosh y$
- ▶ Correlated with x in the proton, when x_p is large



Possible explanation in terms of color fluctuations but need dijets to constrain parton kinematics

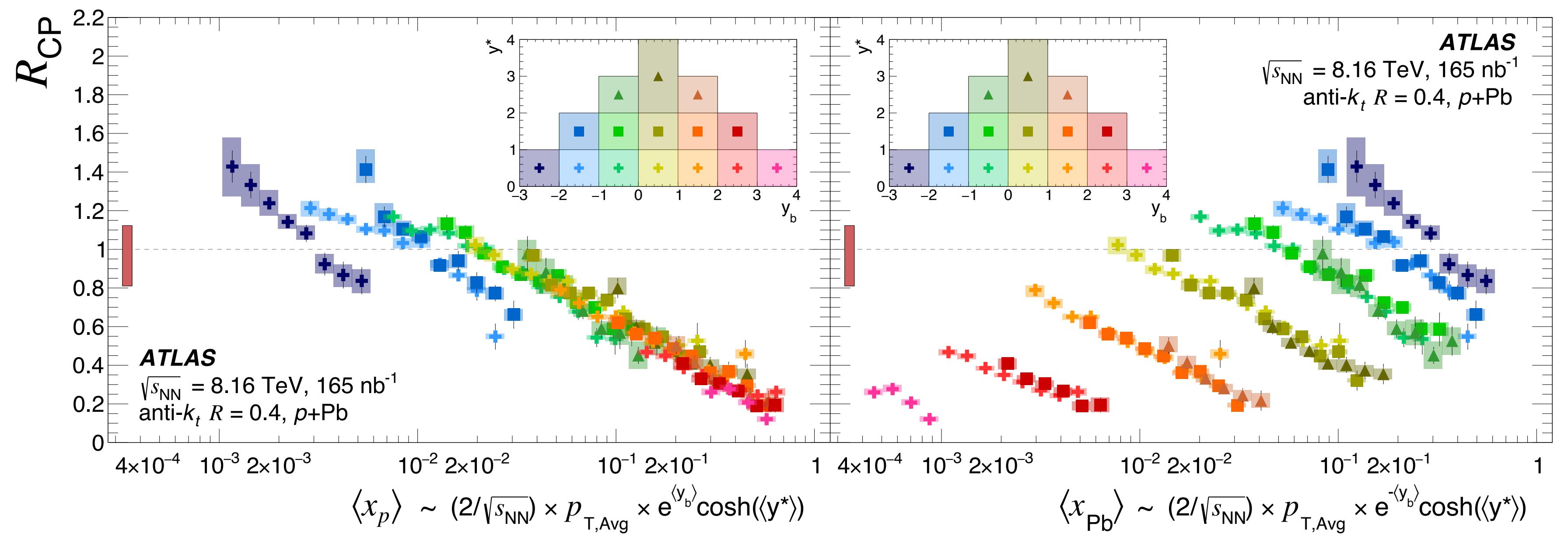
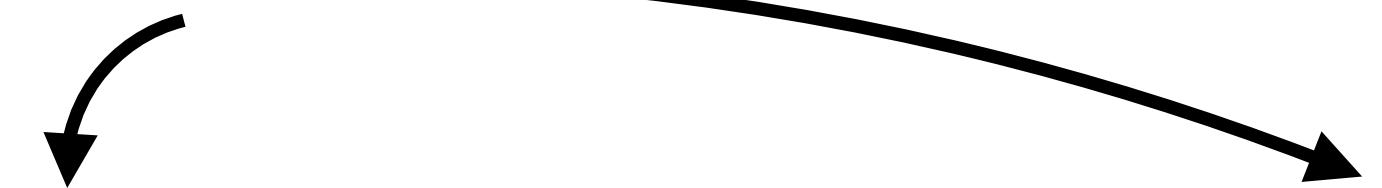


Geometry and hard-soft correlations

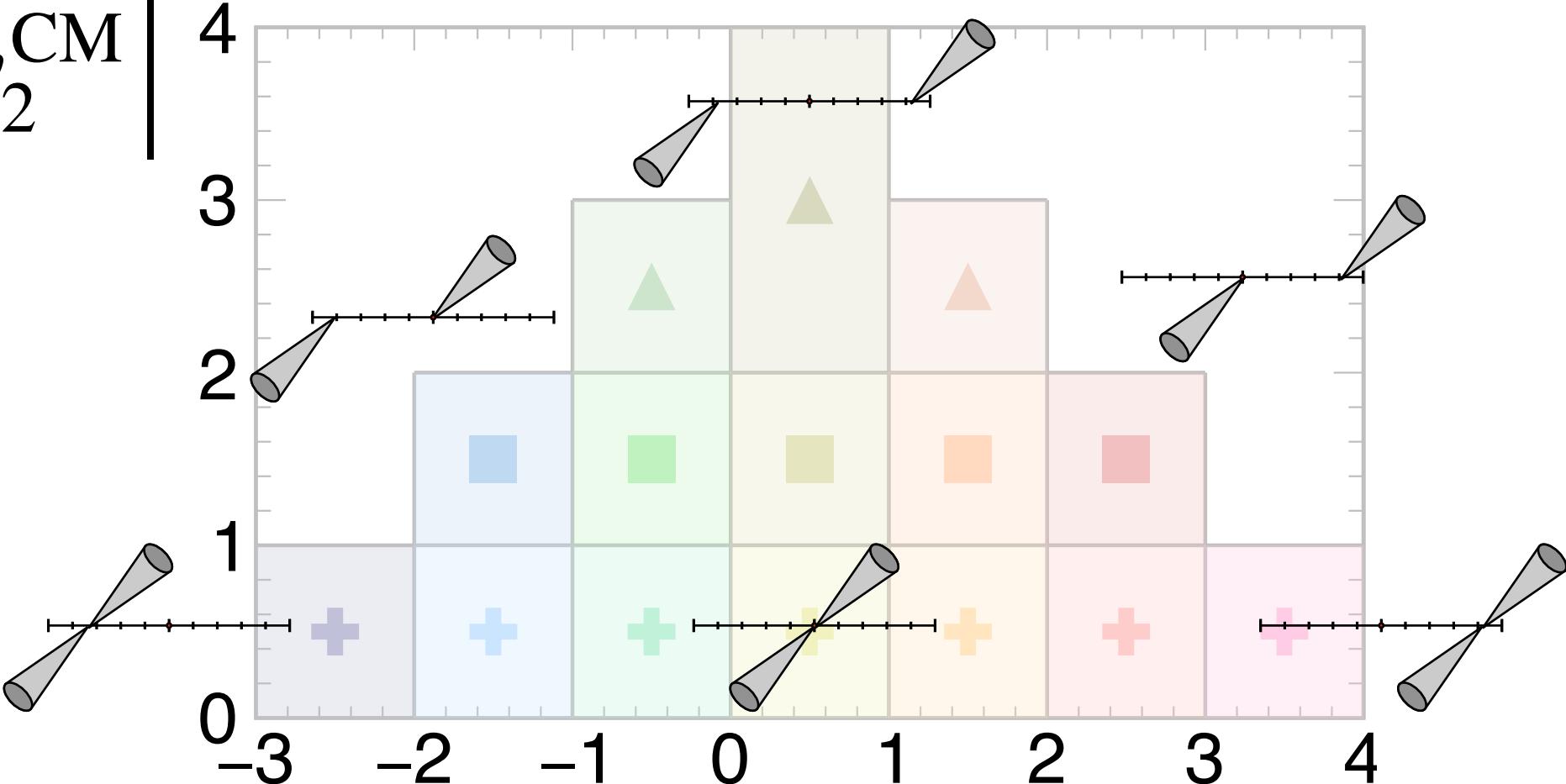
Updates from a curious scaling relation in $p + \text{Pb}$

Centrality dependence of
dijet yields in $p + \text{Pb}$
arXiv:2309.00033

- Measure using $p_{T,\text{avg}}, y_b, y^*$
- Can repeat previous mapping but separately for effective x_p, x_{Pb}



$$y^* \equiv \frac{1}{2} |y_1^{\text{CM}} - y_2^{\text{CM}}|$$

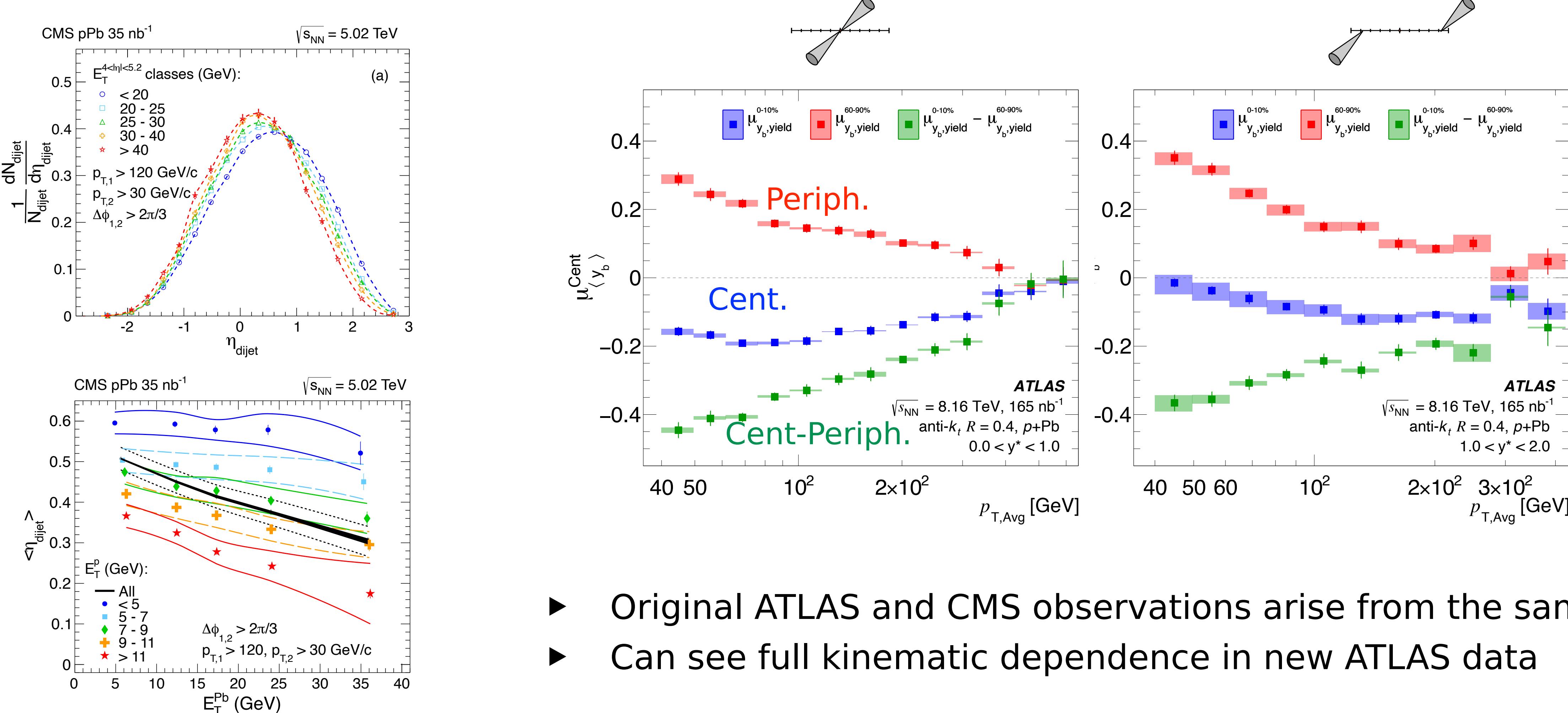


$$y_b \equiv \frac{1}{2} (y_1^{\text{CM}} + y_2^{\text{CM}})$$

See talks by
[B. Gilbert](#) Wed. 3:00
[P. Potepa](#) Wed. 5:50
 and poster by [R. Longo](#)

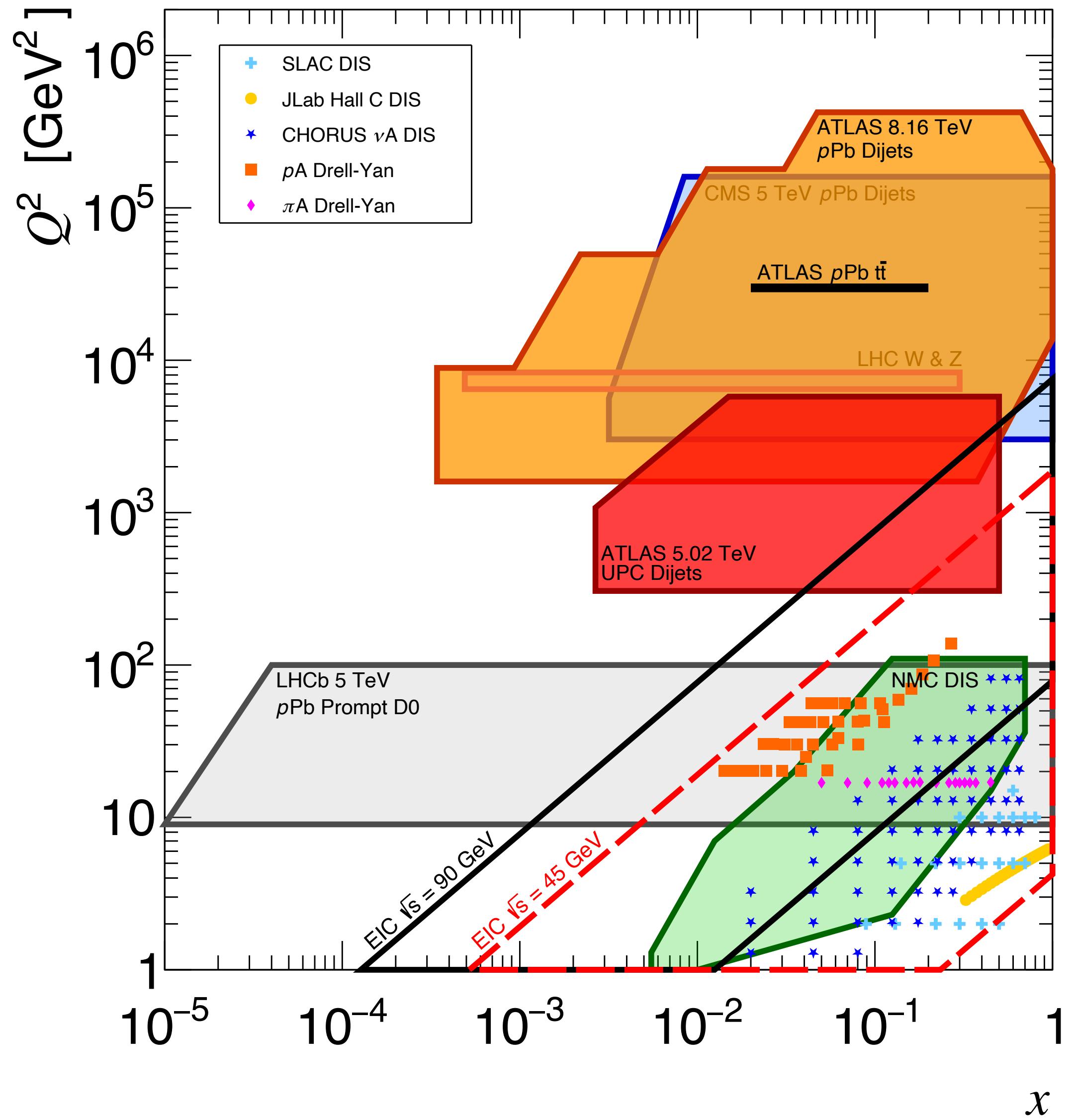
Geometry and hard-soft correlations

Comparison to CMS dijets



- Original ATLAS and CMS observations arise from the same feature
- Can see full kinematic dependence in new ATLAS data

Nuclear PDF constraints



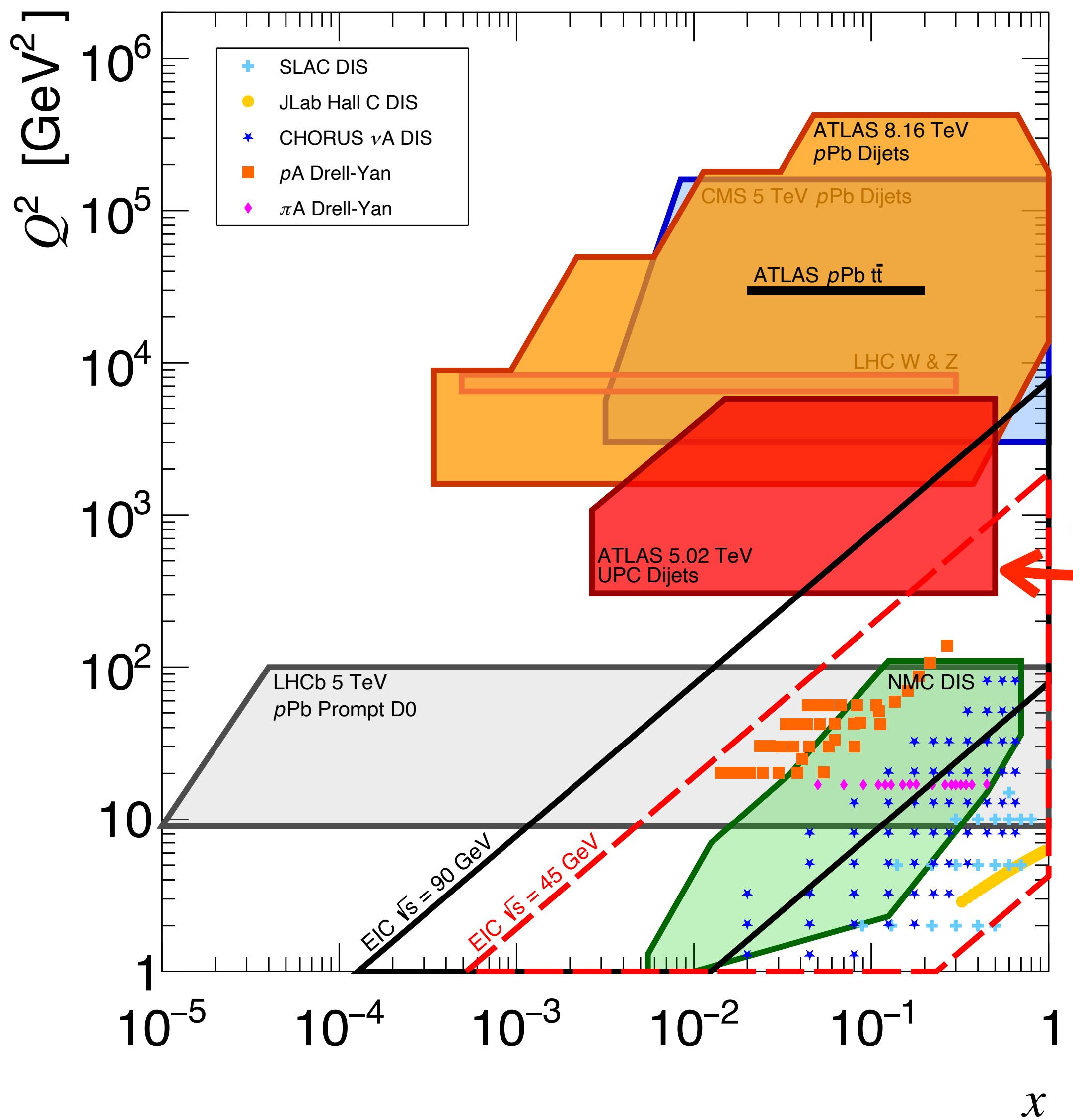
New $p + \text{Pb}$ dijet result →
precision measurement over
large phase space

UPC jets

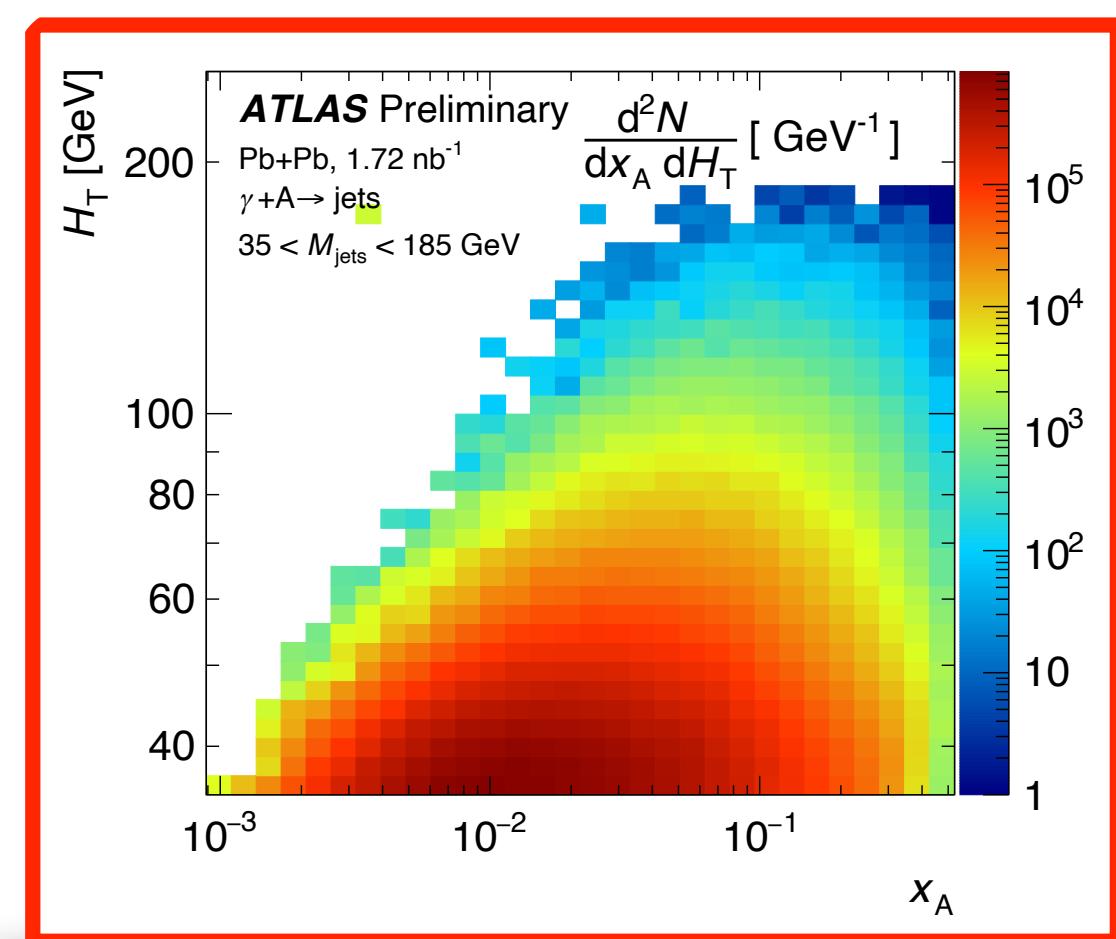
Unique $x - Q^2$ range connecting LHC to EIC

See talk by B. Gilbert

Wed. 3:00



Phase space coverage in 2018 Pb+Pb data



Preliminary measurement shown here, final precision measurement expected soon, stay tuned!

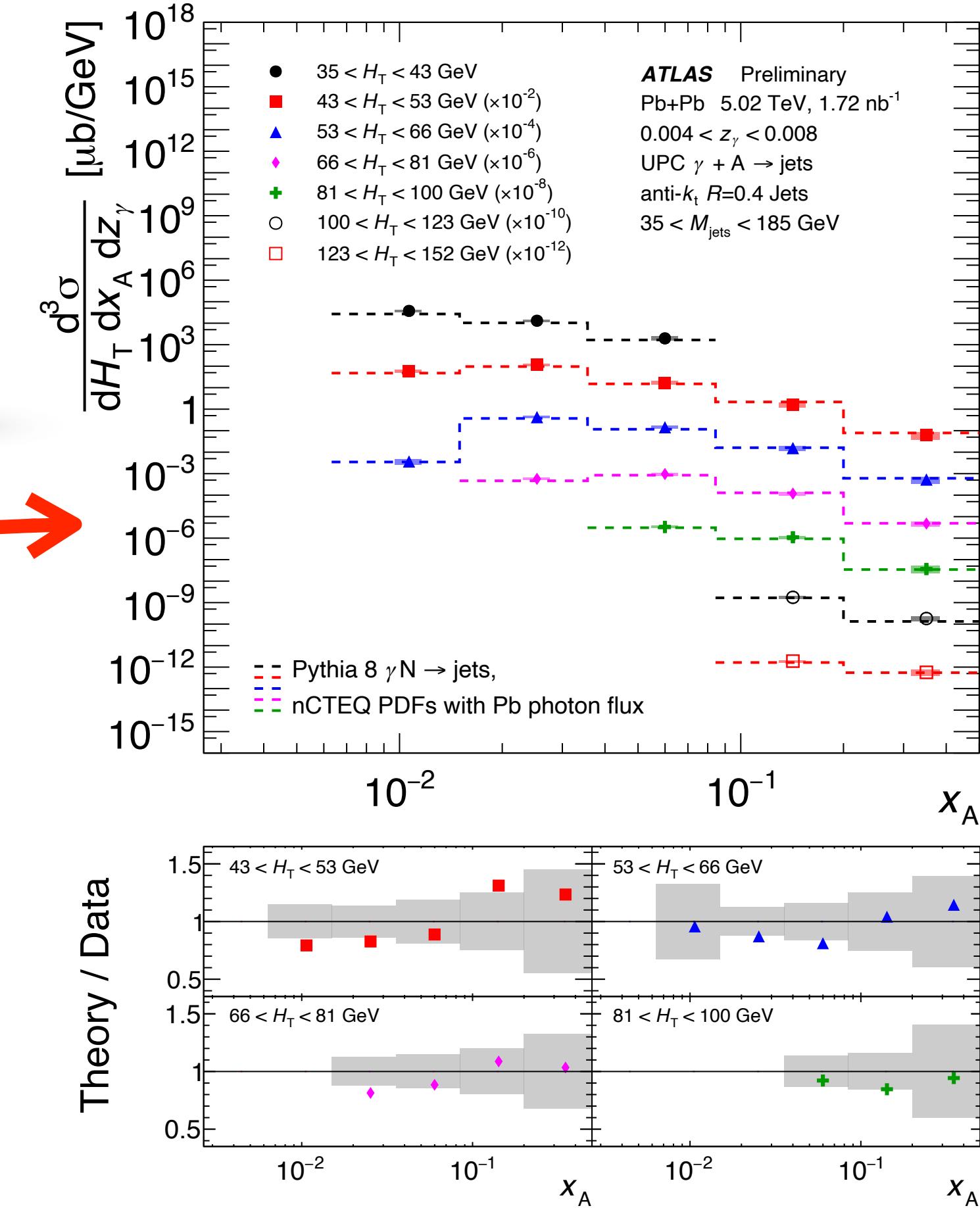
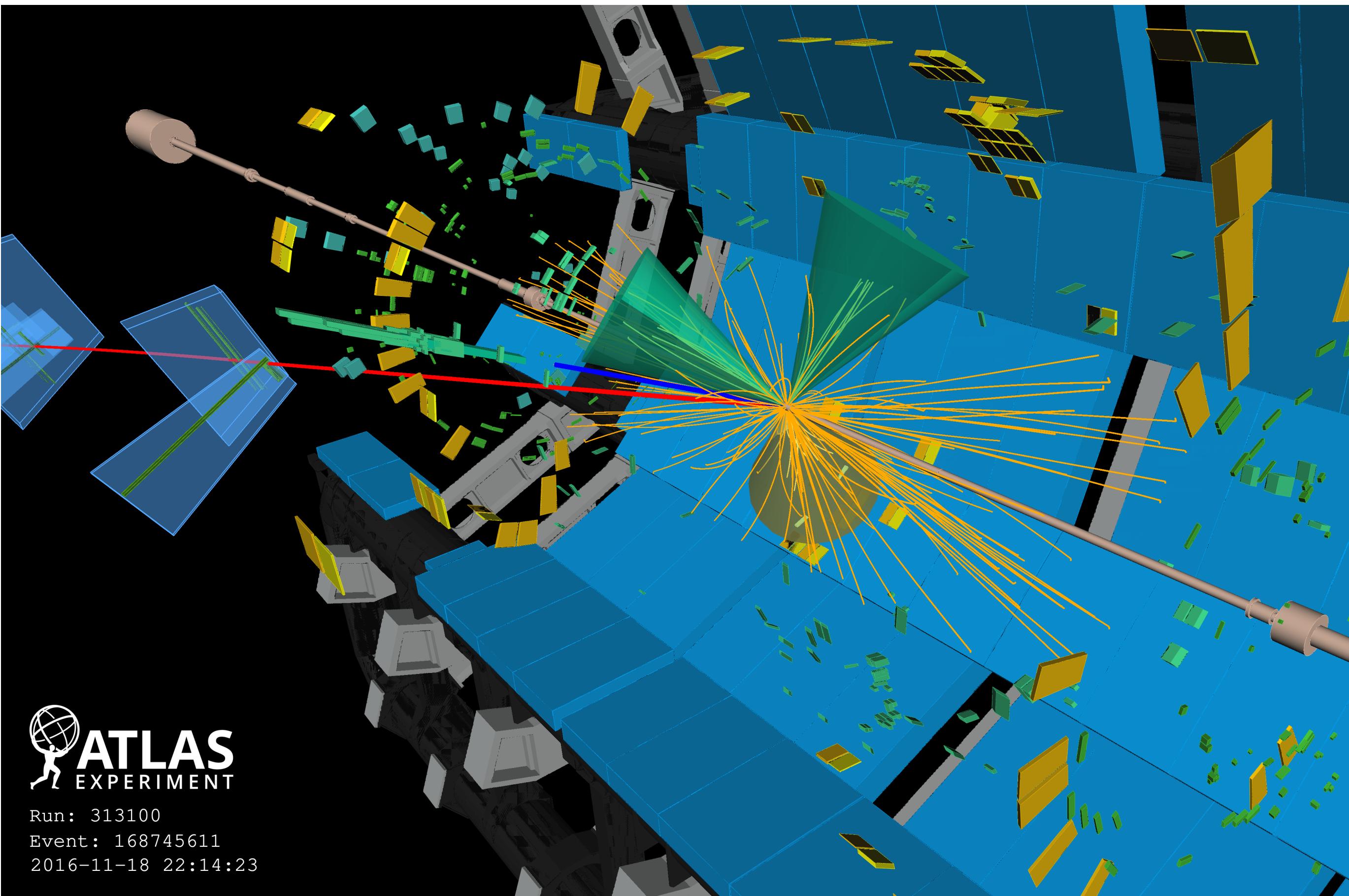


Photo-nuclear jets
[ATLAS-CONF-2022-02](#)

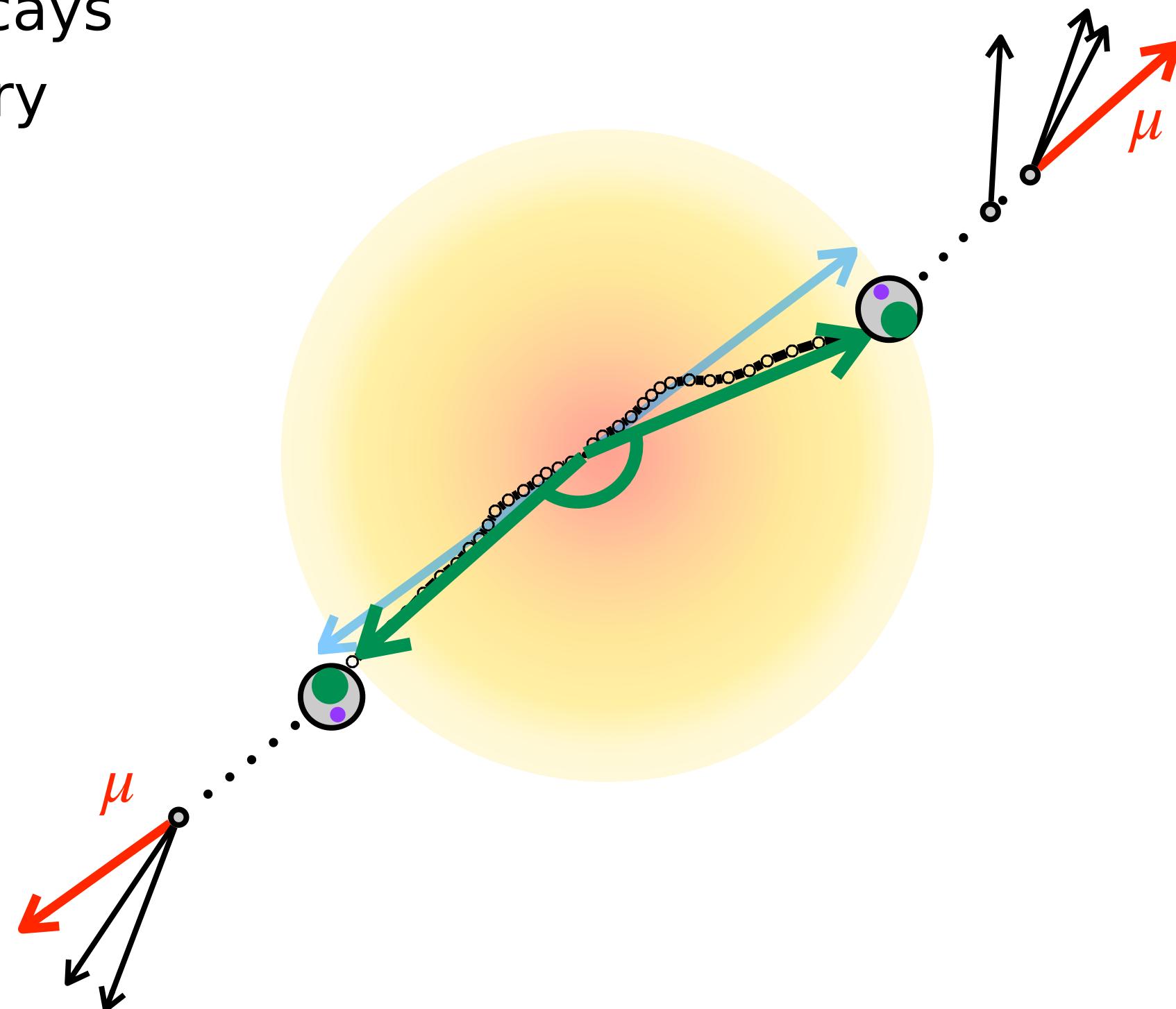
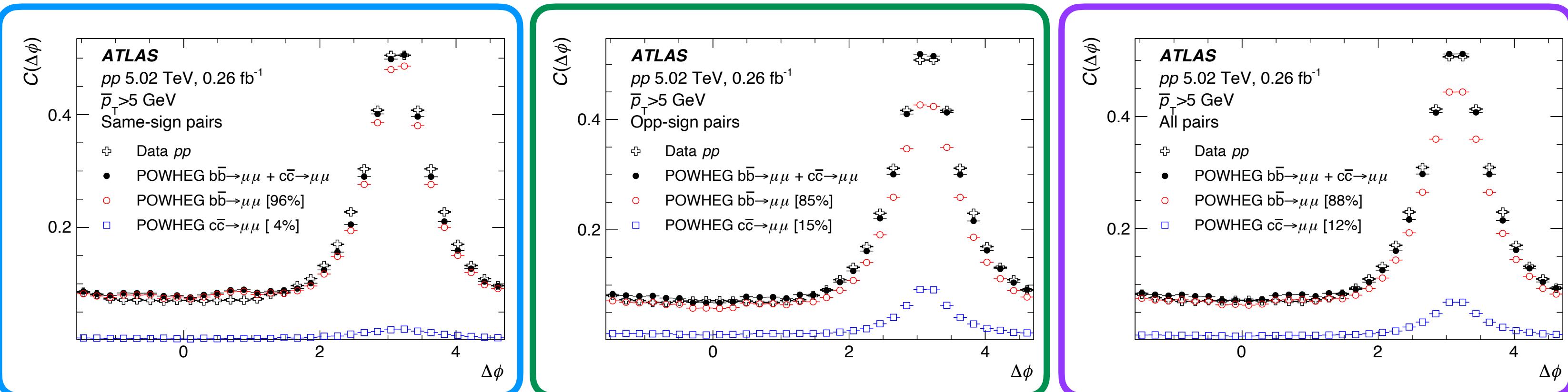
Top production in $p+\text{Pb}$

$$t\bar{t} \rightarrow e + \mu + 1 b\text{-jet} + 2 \text{ jets}$$


- ▶ Cross section extracted from fits to
$$H_{\text{T}}^{\ell j} = \sum_{\text{jets}} p_{\text{T}}^j + \sum_{\text{leptons}} p_{\text{T}}^{\ell}$$
in 6 signal regions in both single and dilepton channels
- ▶ Dileptons have poorer statistics but much better purity complements single leptons well
- ▶ Extends previous CMS measurement ([PRL 119, 242001 \(2017\)](#)), which used single lepton only
 - Uncertainty improved by $\sim 2x$

Dimuon angular correlations

- Heavy quark pairs are produced with an azimuthal correlation that may be distorted by scattering in the medium
 - Diffusion of heavy quarks and degree to which they thermalize
- Study angular (de)correlation between $\mu^\pm\mu^\pm$ pairs produced from c , b decays
 - **Same-sign, opposite-sign** and **combination** carry complementary information, different c/b composition
- Characterize away-side width and measure vs centrality



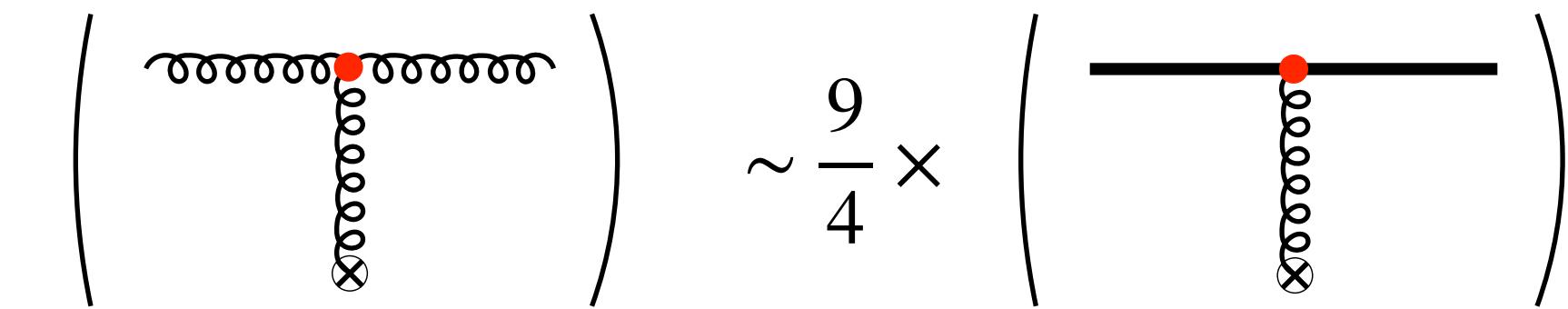
No significant broadening observed → new constraint on heavy quark diffusion

Jet suppression: photon-tagged jets

Flavor dependence of energy loss

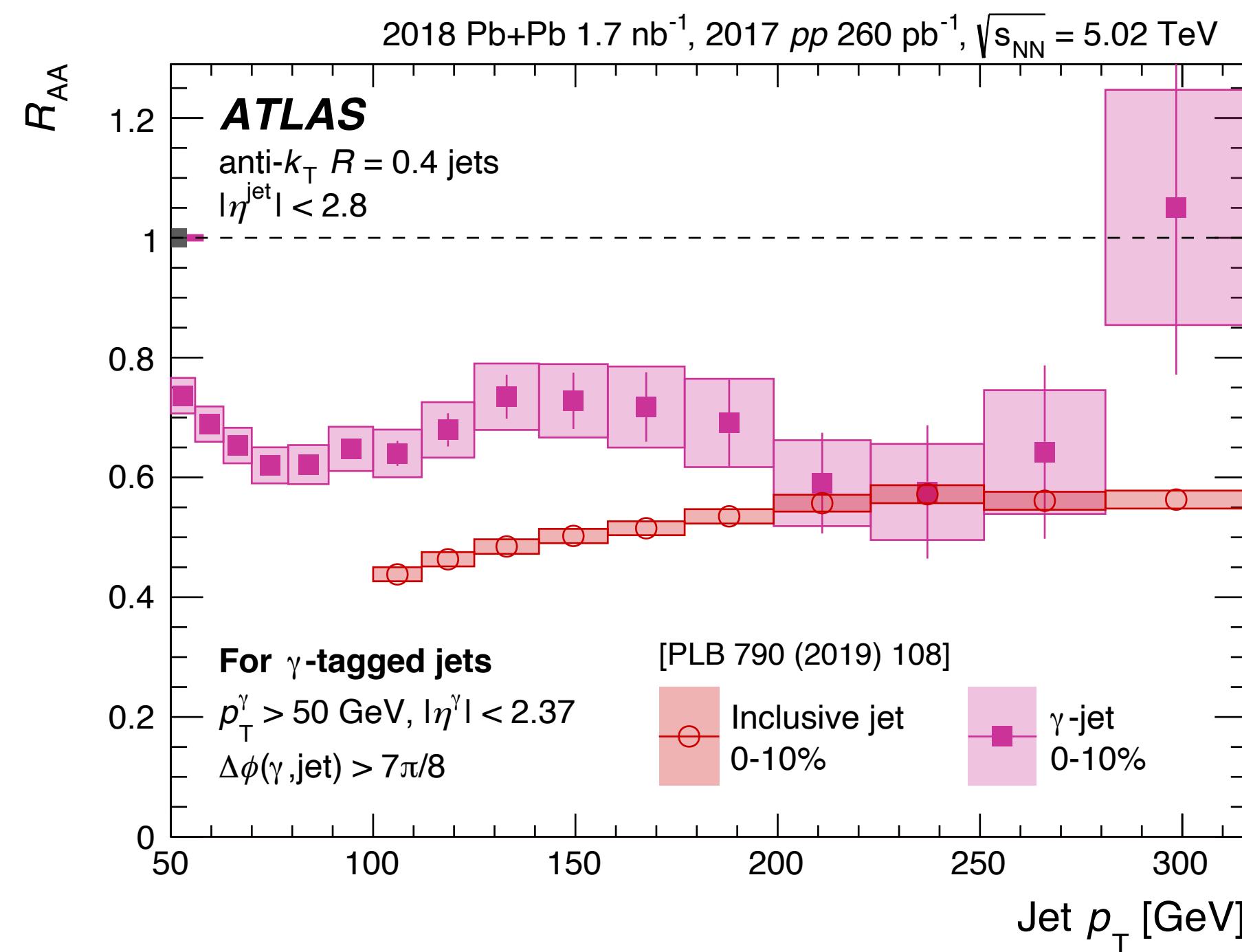
See talk by C. McGinn
Wed. 8:50

Expect gluon jets to lose more energy than quark jets, naively:



R_{AA} for γ -tagged jets
[arXiv:2303.10090](https://arxiv.org/abs/2303.10090)

Access this experimentally by measuring R_{AA} for γ -jet events: higher quark fraction



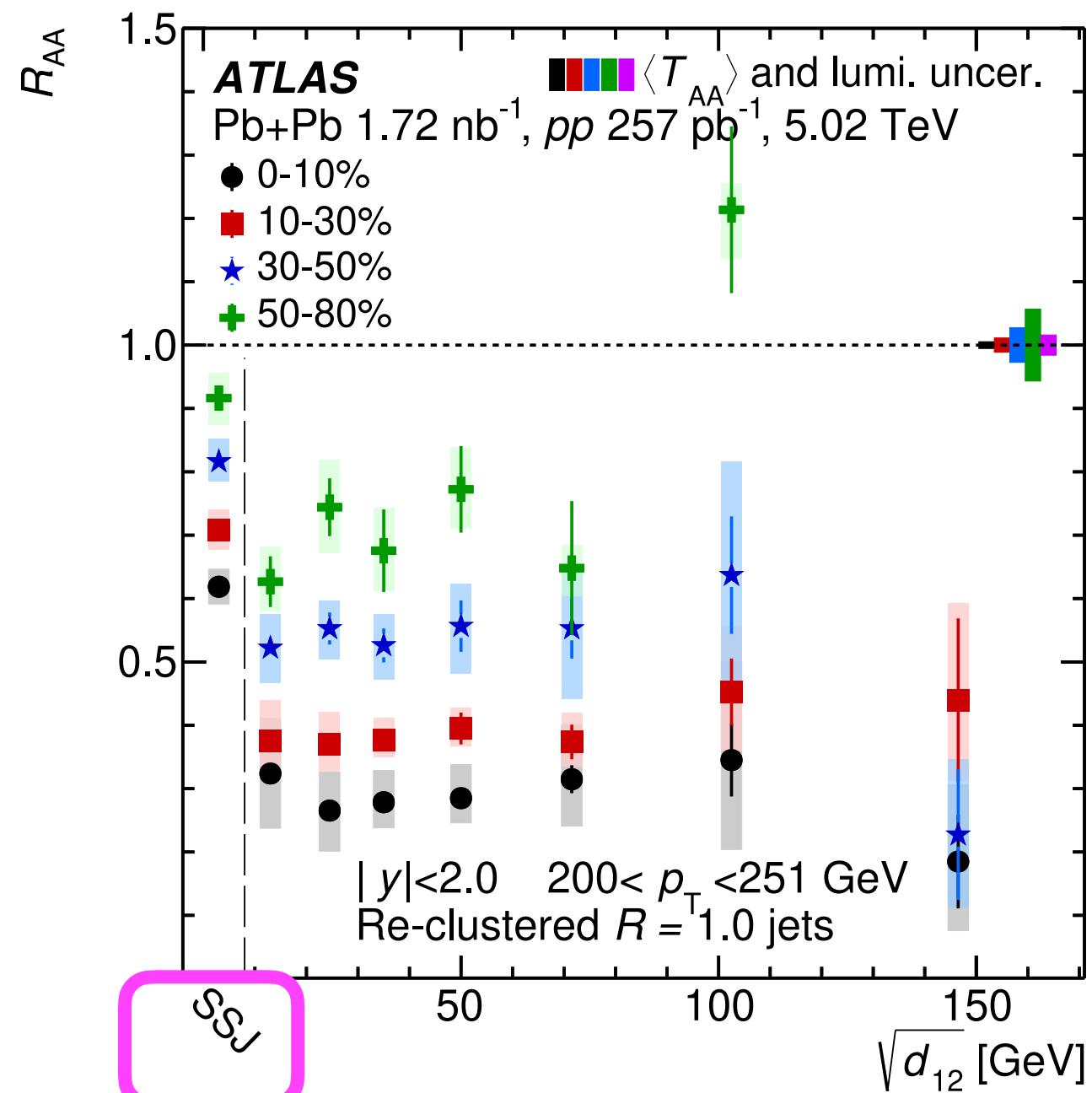
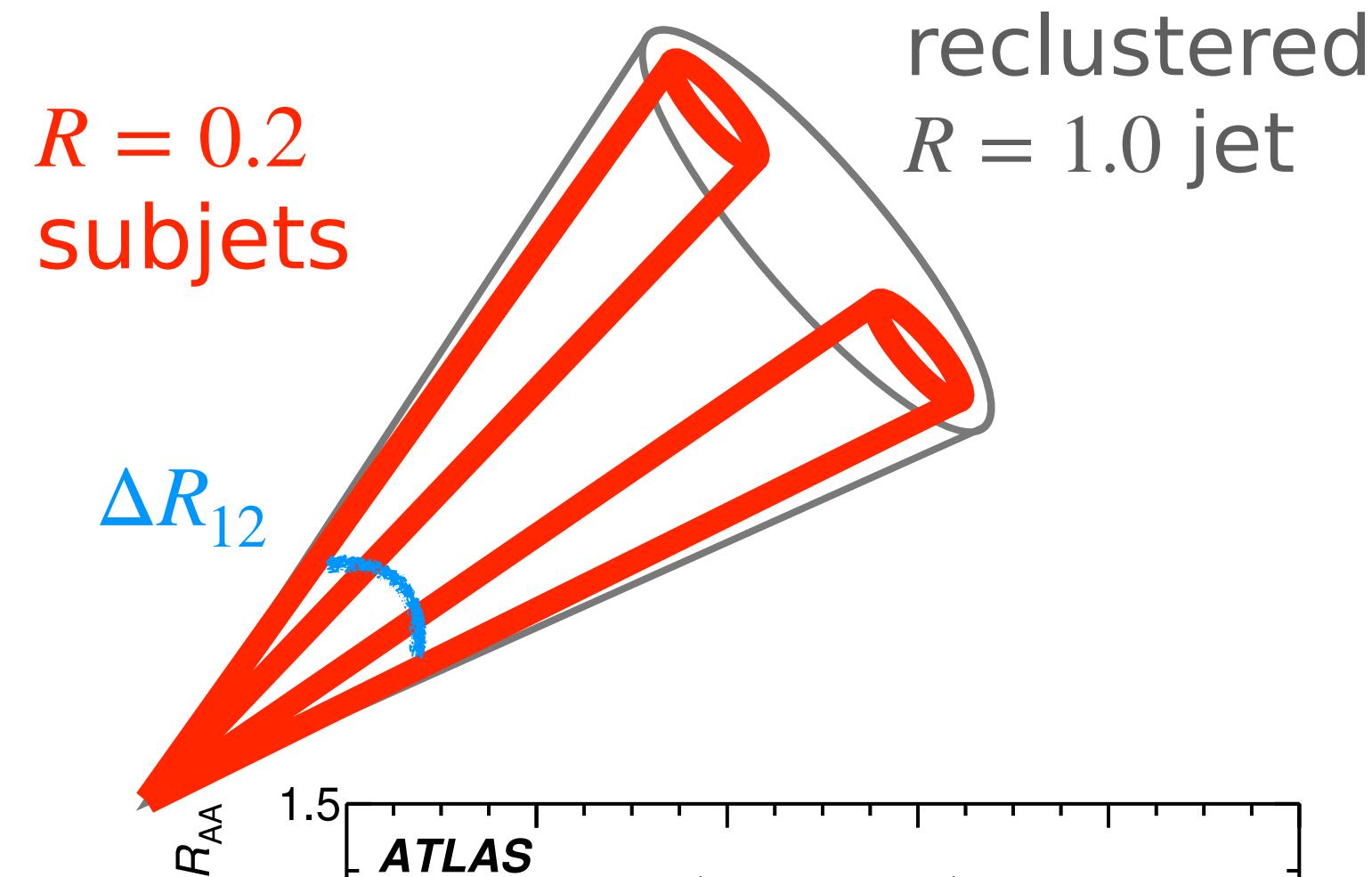
~ 80% quark jets

~ 40—50 % quark jets

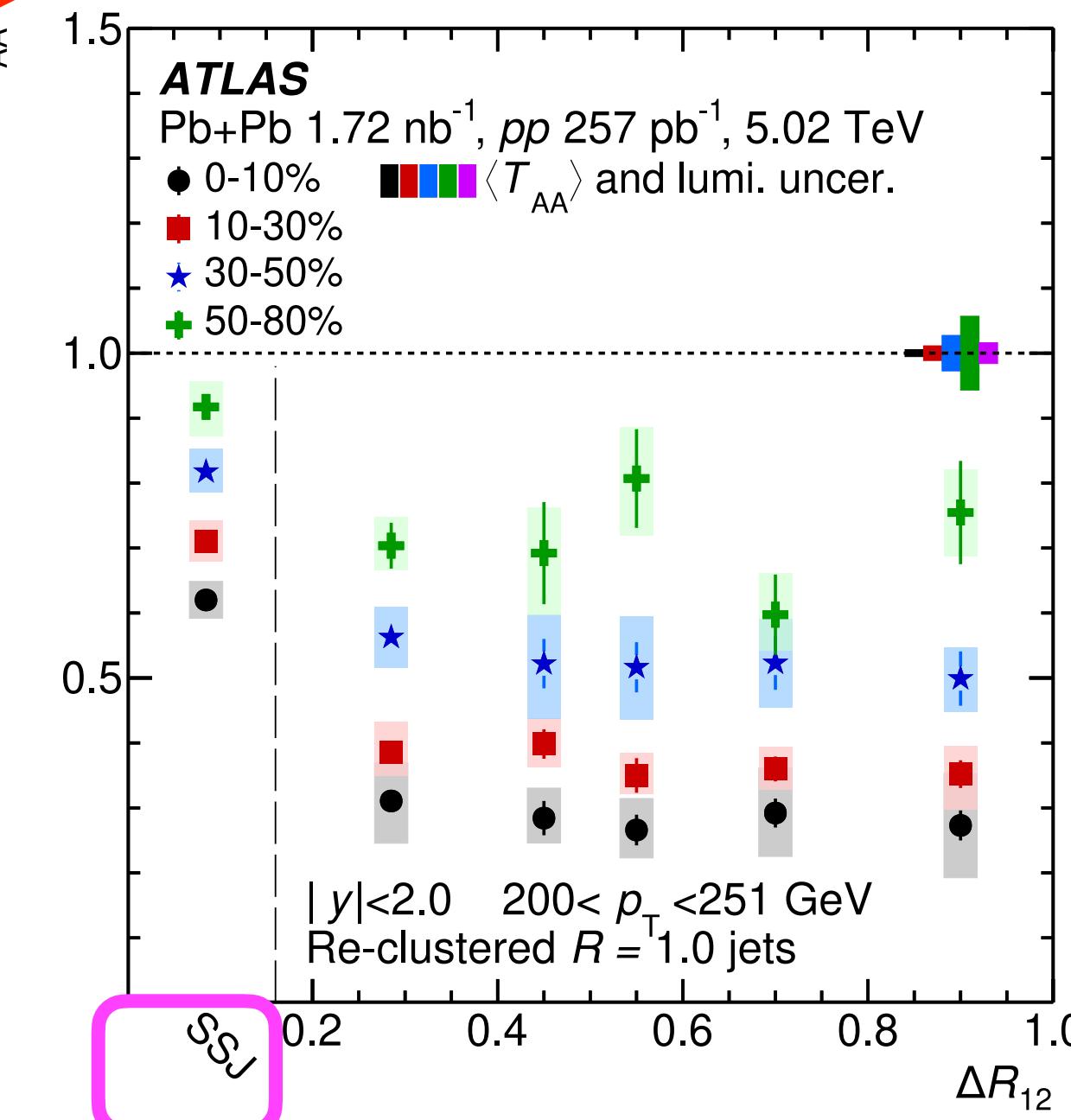
Jet suppression: substructure dependence

Large angles access jet's internal scales using reclustering

- ▶ Build large radius jets ($R = 1.0$) using small radius jets ($R = 0.2$) as constituents using k_t algorithm
- ▶ Decluster to find last splitting and define
 - Opening angle: $\Delta R_{12} \equiv \sqrt{\Delta y_{12}^2 + \Delta \phi_{12}^2}$
 - Splitting scale: $\sqrt{d_{12}} \equiv \min(p_{\text{T}1}, p_{\text{T}2}) \times \Delta R_{12}$



Single subjet (SSJ): single jet $R = 0.2$
Jets with multiple subjets are significantly more suppressed, but only weak dependence on $\sqrt{d_{12}}$ and ΔR_{12} beyond this.

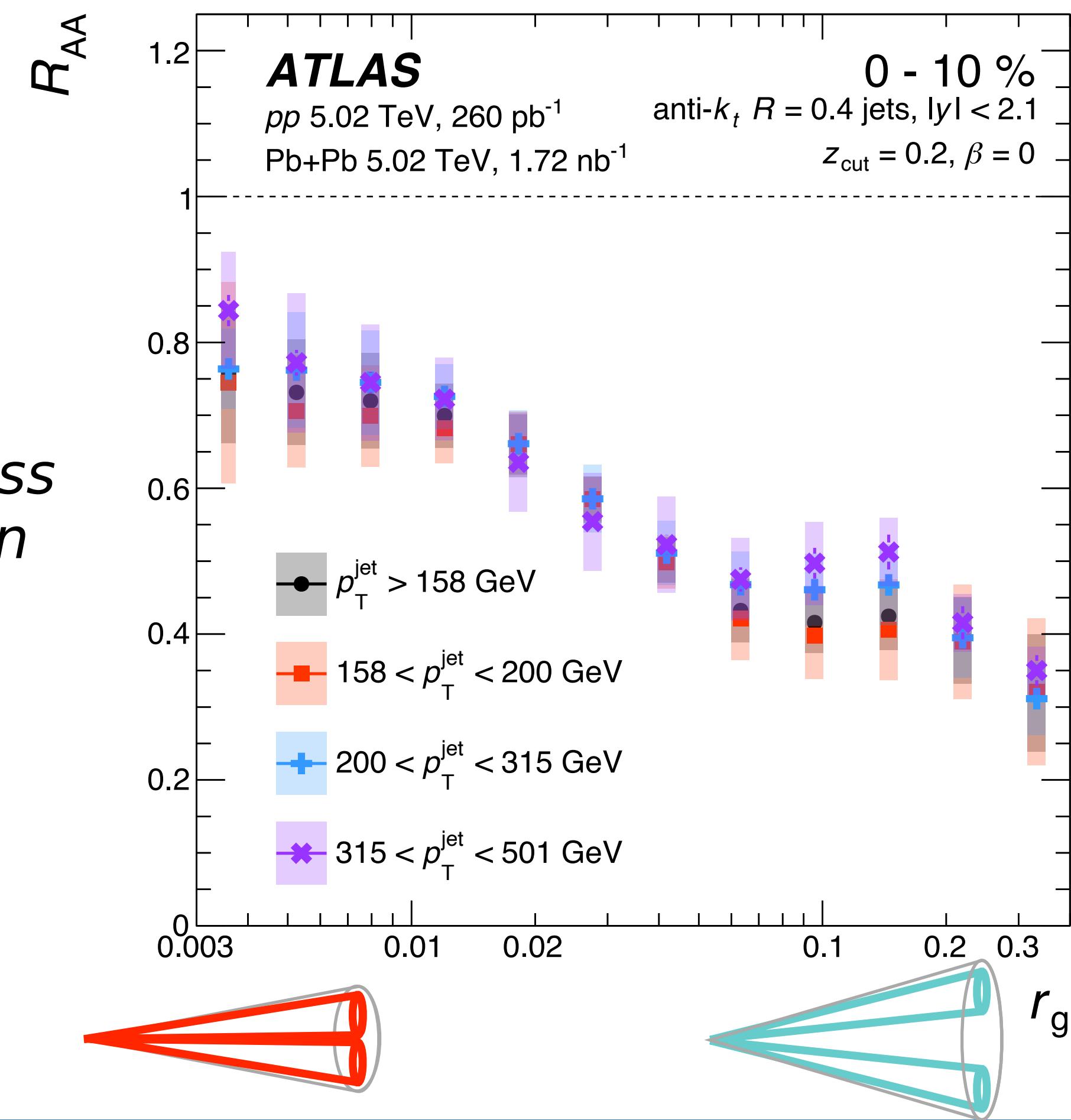
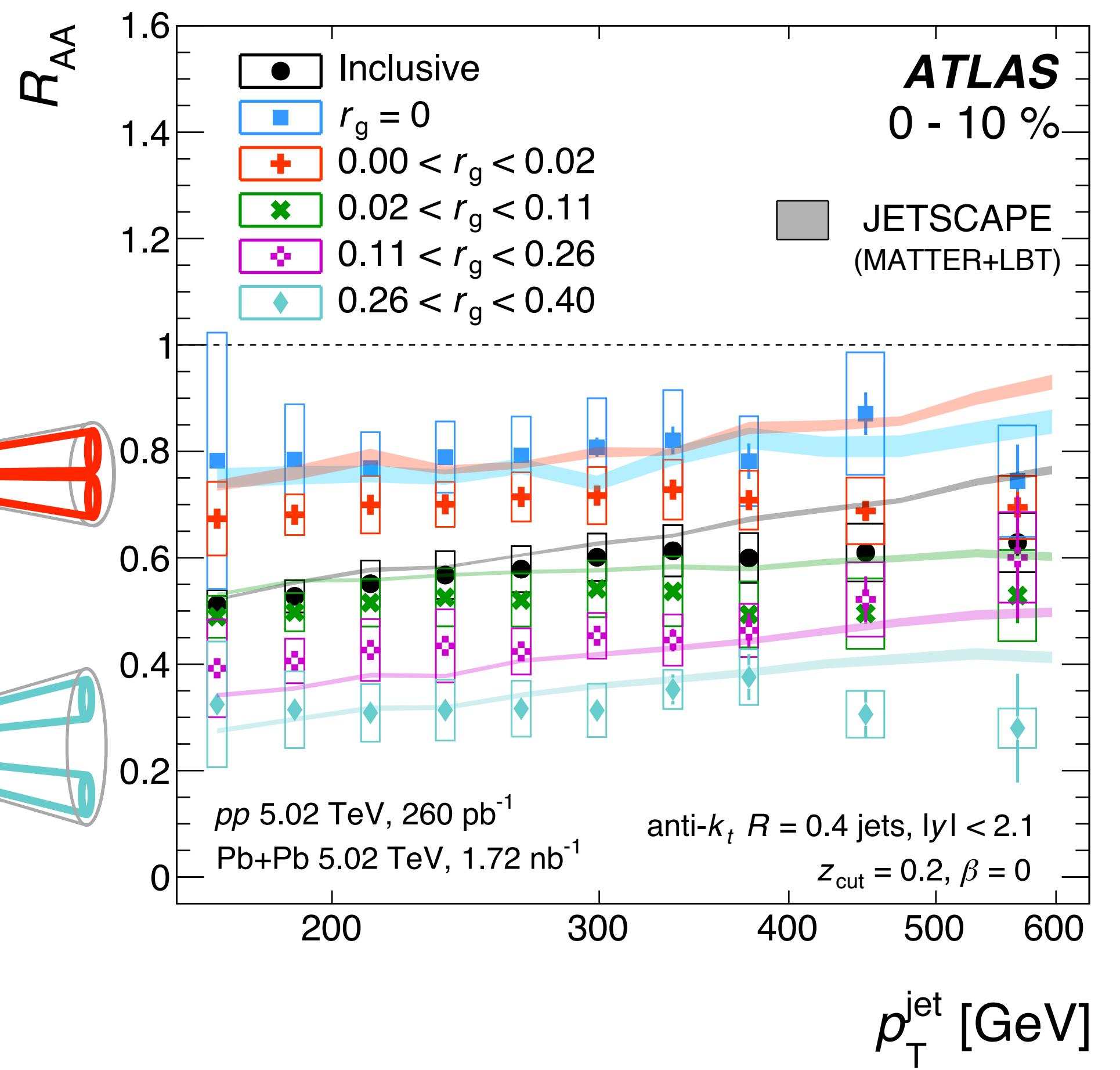


Jet suppression: substructure dependence

Access hard splittings at small angles using grooming

Apply SoftDrop ($z_{\text{cut}} = 0.2, \beta = 0$) to $R = 0.4$ jets
Identify “hardest” splitting to define r_g

Relative suppression exhibits little p_T dependence

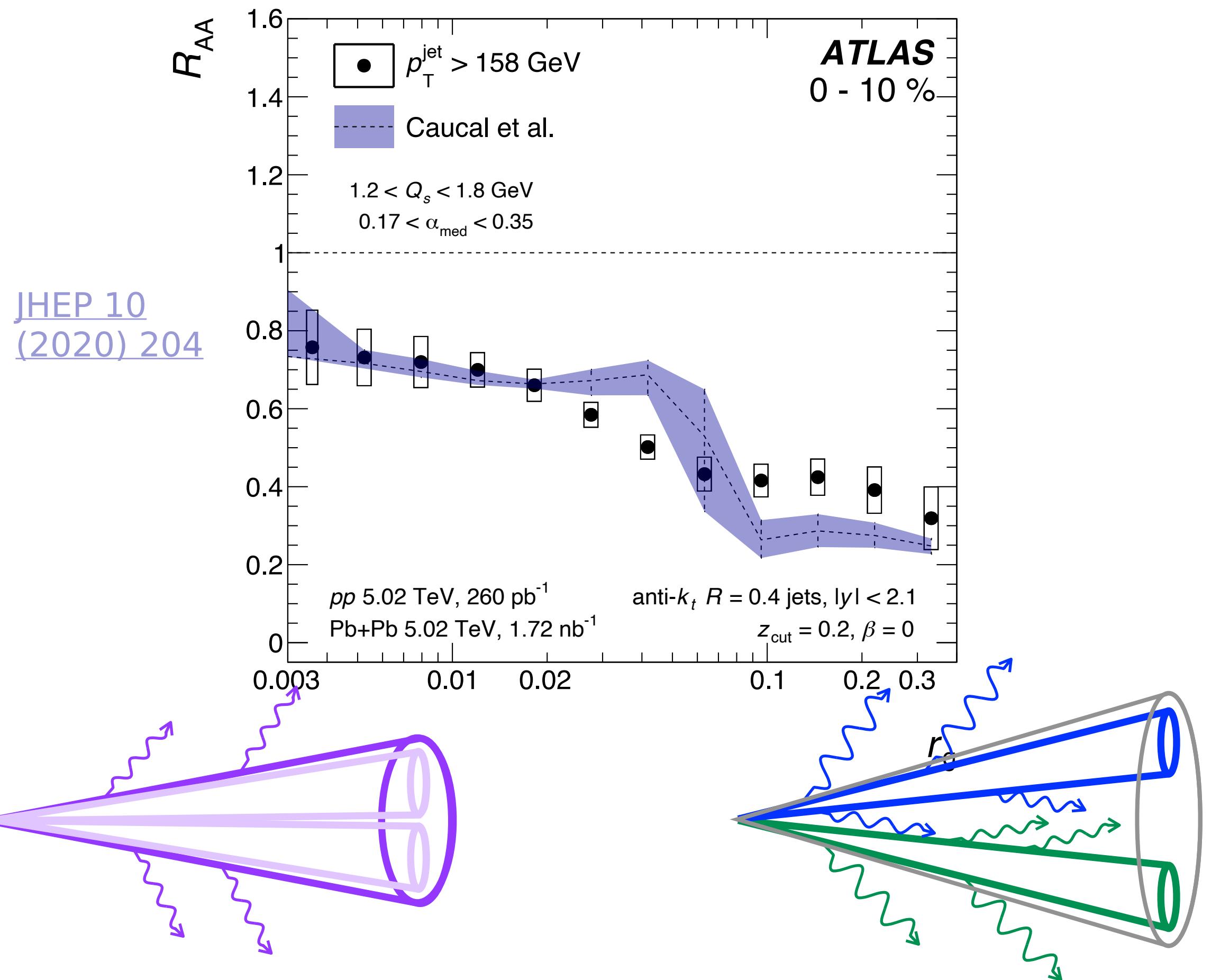


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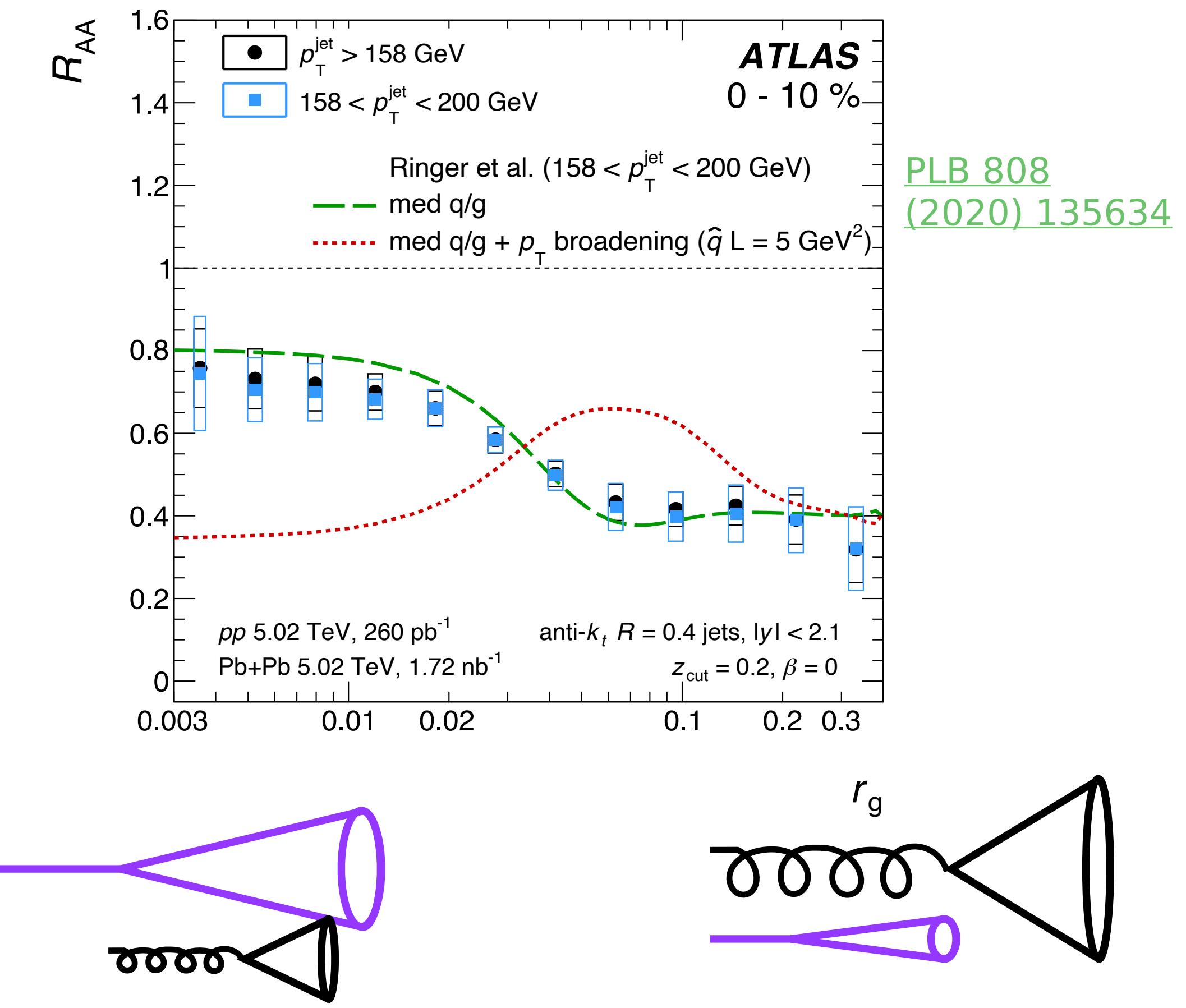
Model comparisons

See talk by D. Hangal
Wed. 8:30

r_g dependence of energy loss may arise due to loss of **coherence**



However, behavior also described by models implementing empirical **quark vs gluon energy loss**



Jet suppression: substructure dependence

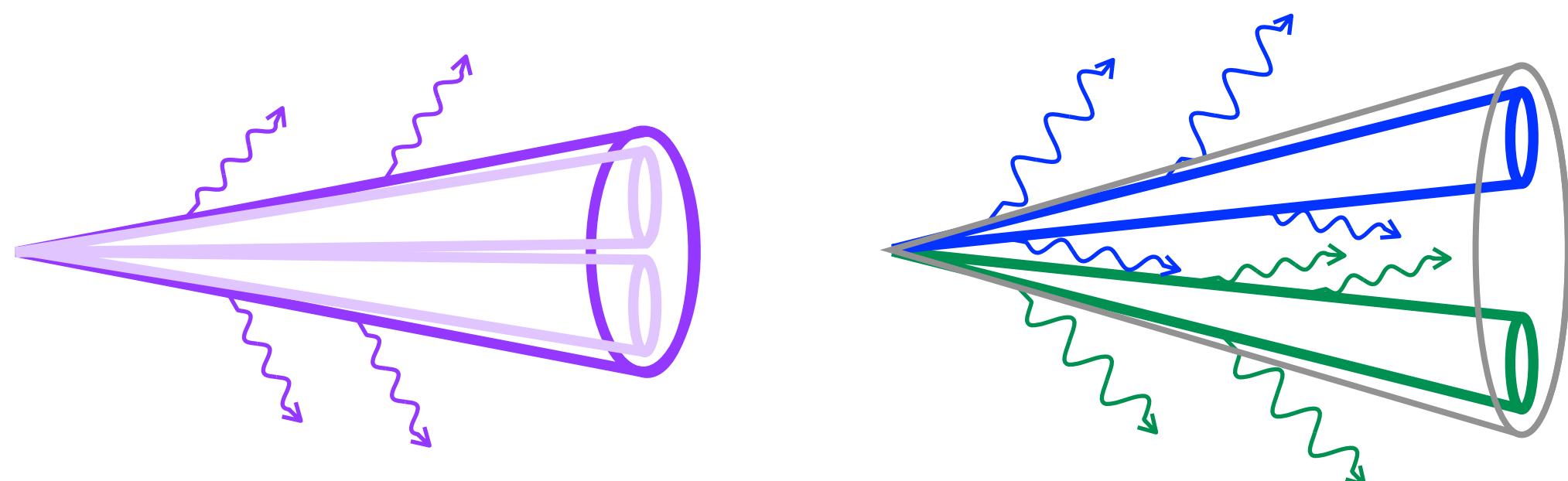
Interpretation

See talk by D. Hangal
Wed. 8:30

Does this observation arise from “trivial” flavor effects?

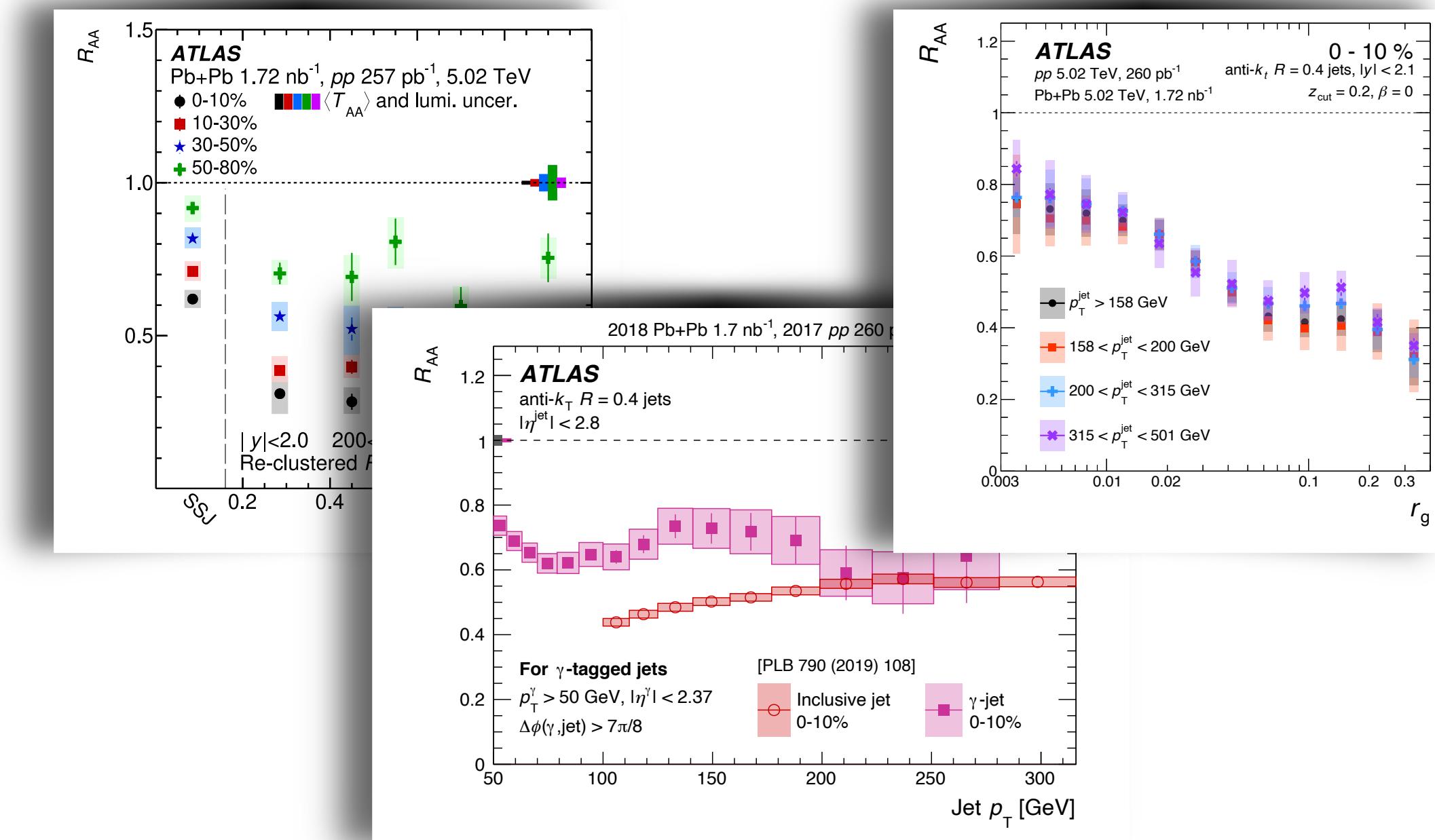
$$= \frac{9}{4} \times$$

vs from decoherence effects?



Or is it more subtle, gluon jets are **both**:

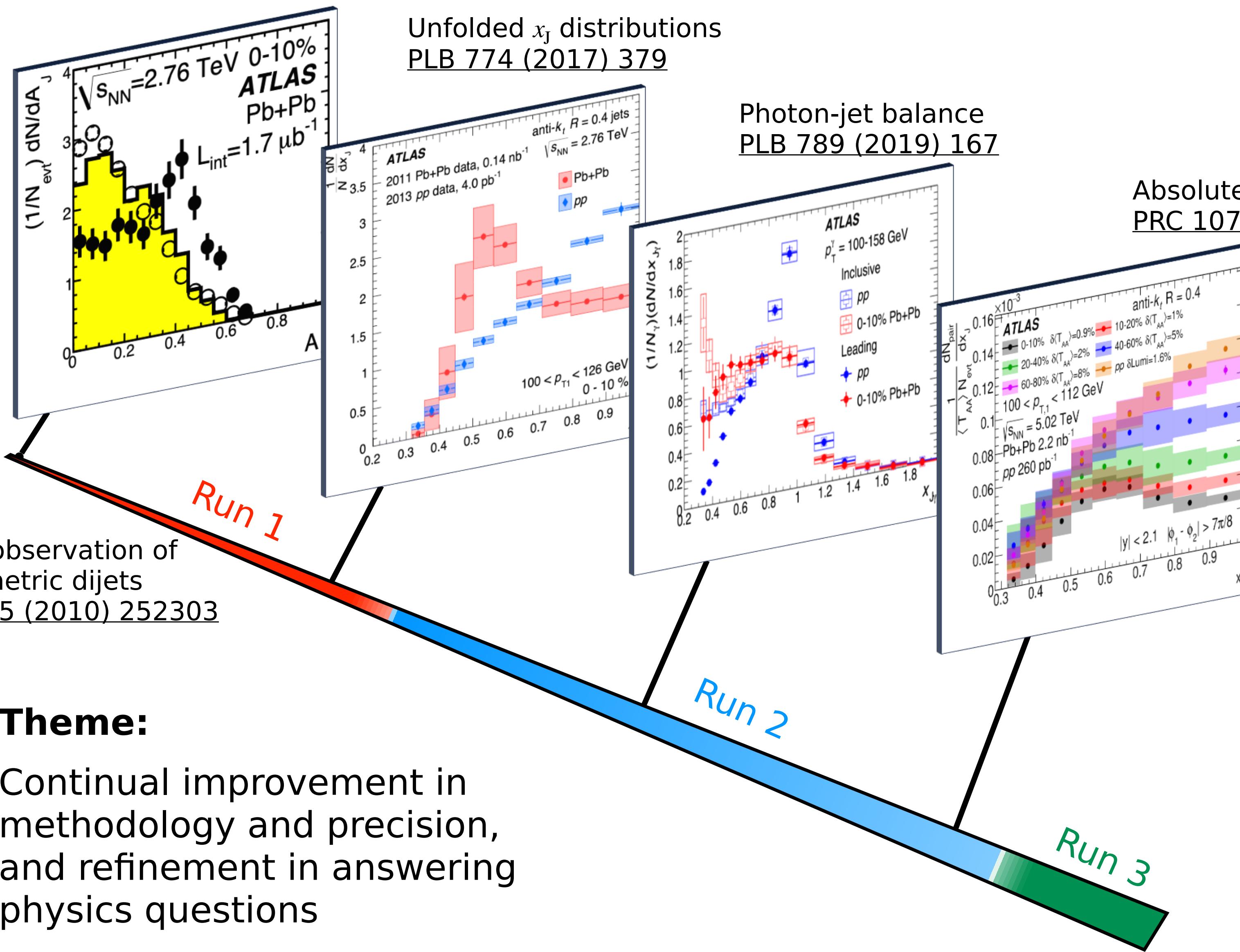
- Wider in general and also
- Expected to have a larger coupling to the medium



We have lots of new results sensitive to both aspects that we should be able to address these subtleties through detailed model comparisons

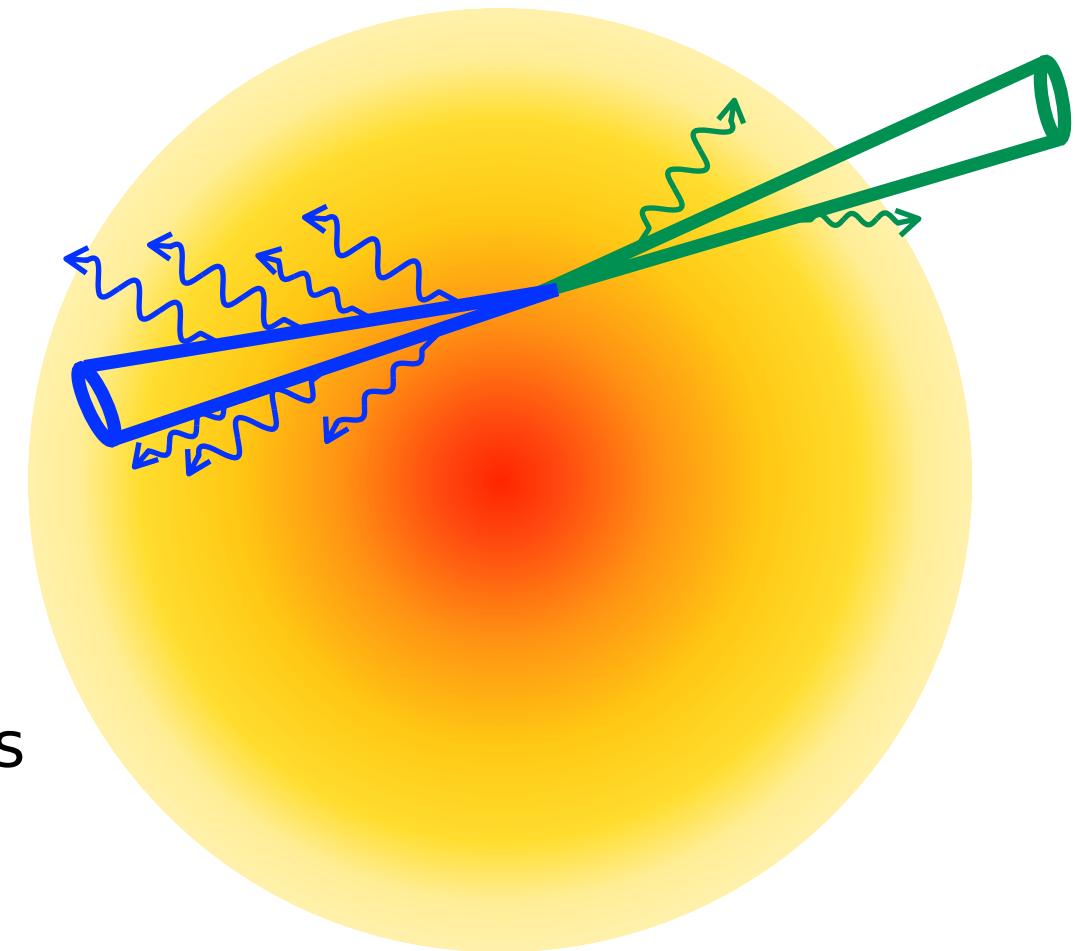
Dijet asymmetry

Historical perspective



Today:

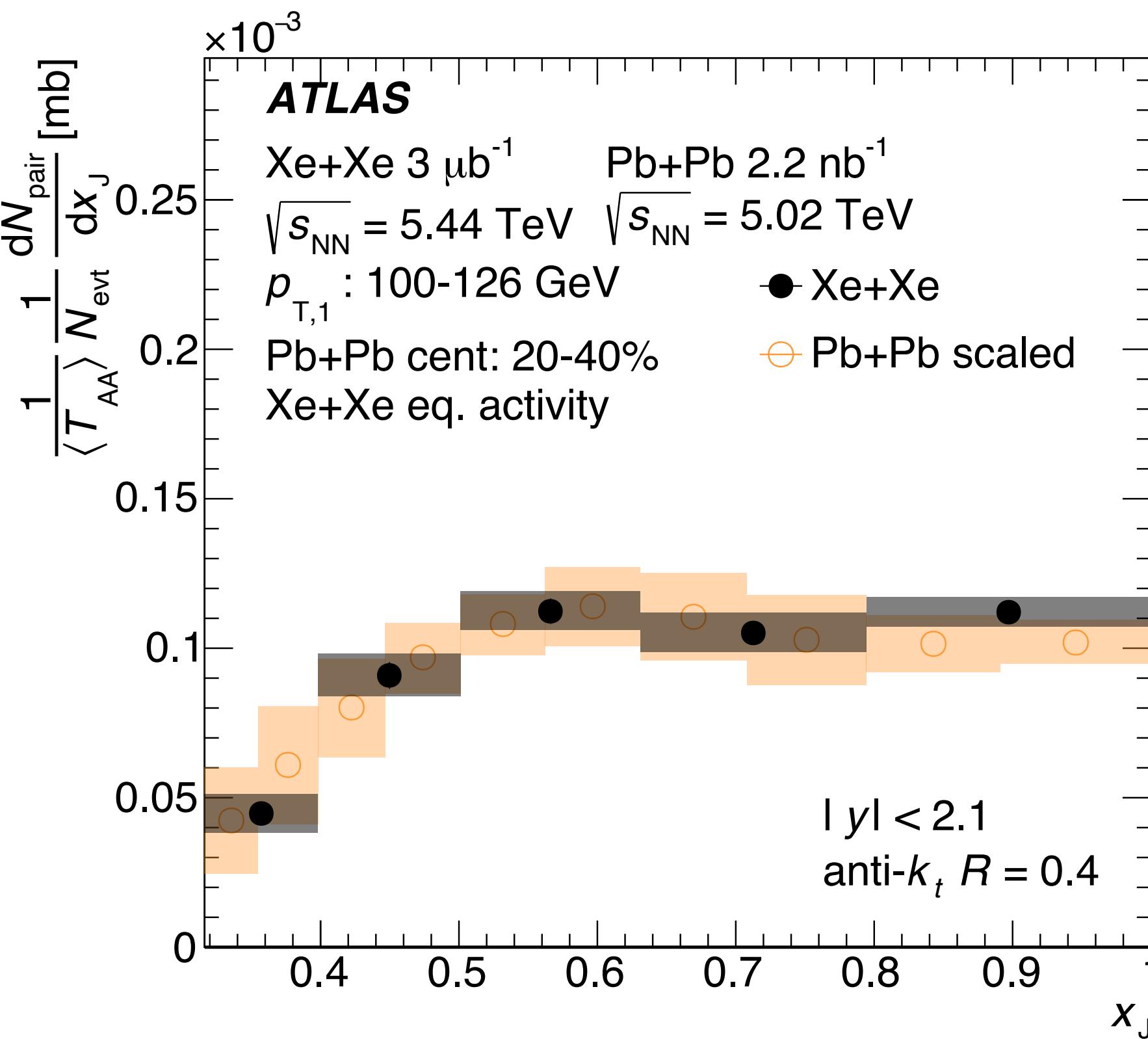
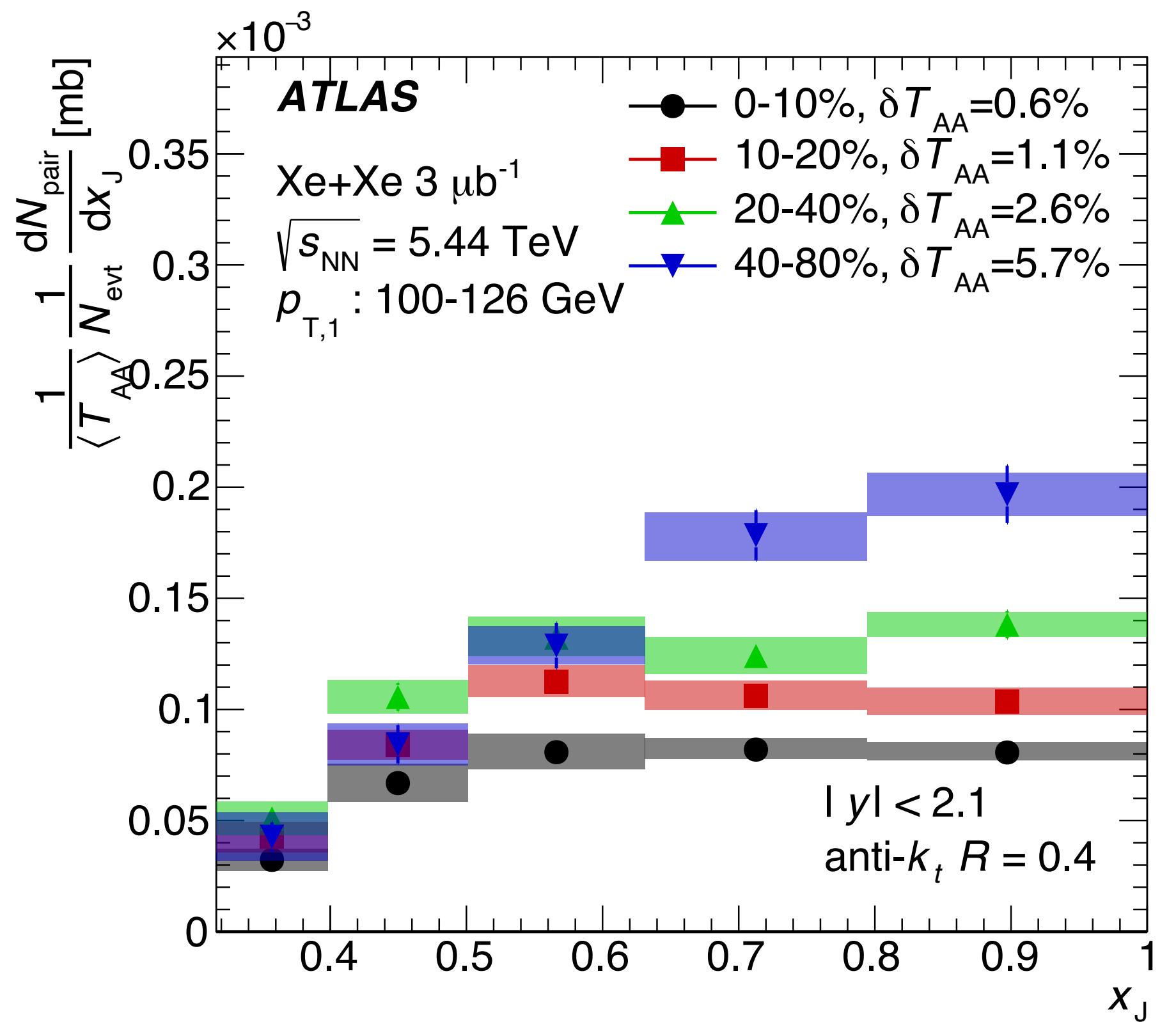
- Geometric dependence Xe+Xe vs Pb+Pb
- New/final results comparing Different R values



Dijet Asymmetry

Dependence on system size and shape

Xe+Xe data shows qualitatively same features as Pb+Pb both in terms of shape and suppression



Dijet asymmetry in Xe+Xe
[PRC 108 \(2023\) 024906](#)

In quantitative agreement when matching equivalent event activity levels and accounting for different CM energies

In sensitive to path length differences in Pb+Pb and Xe+Xe

Suggests fluctuations in energy loss itself dominating the behavior

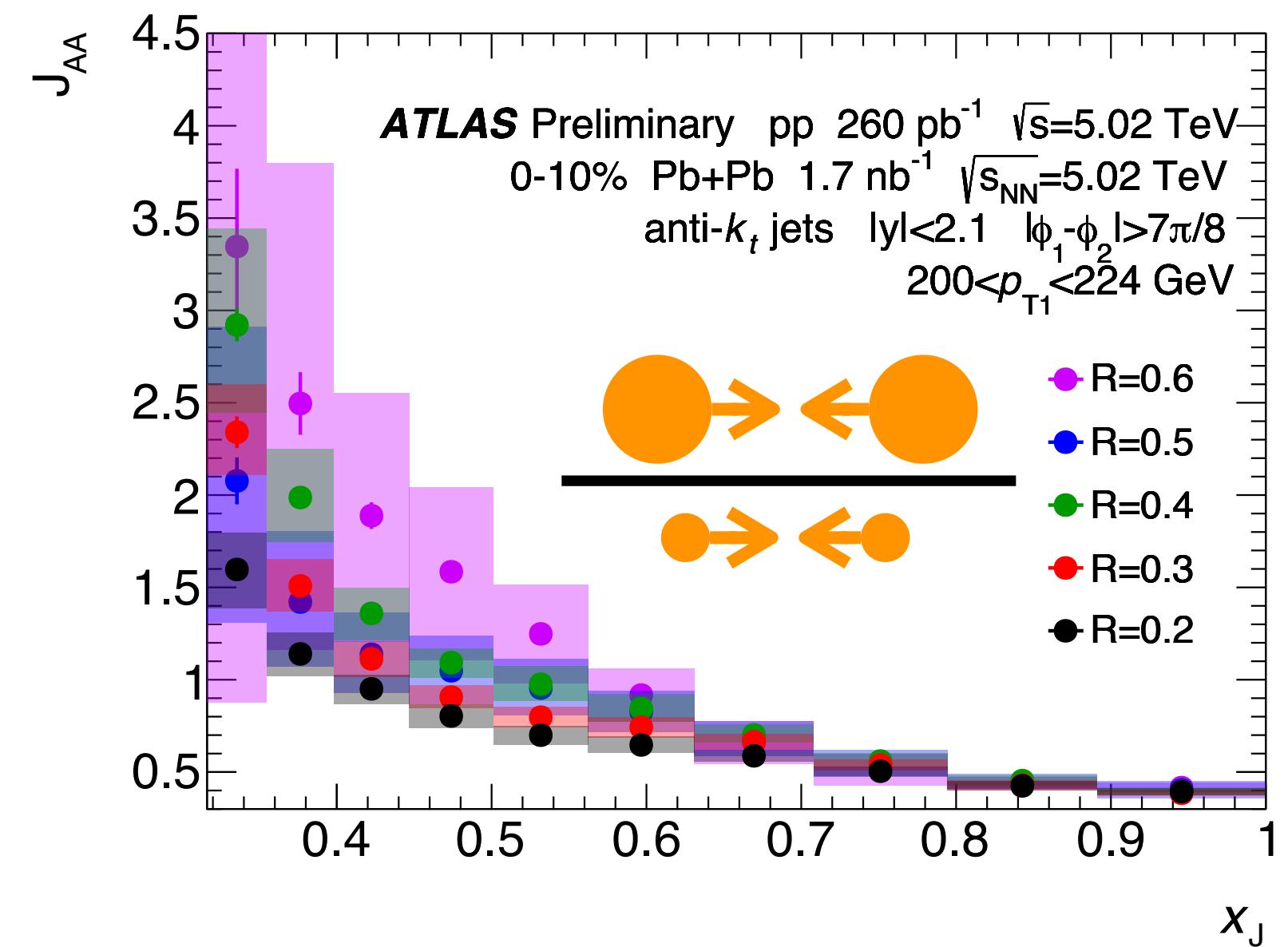
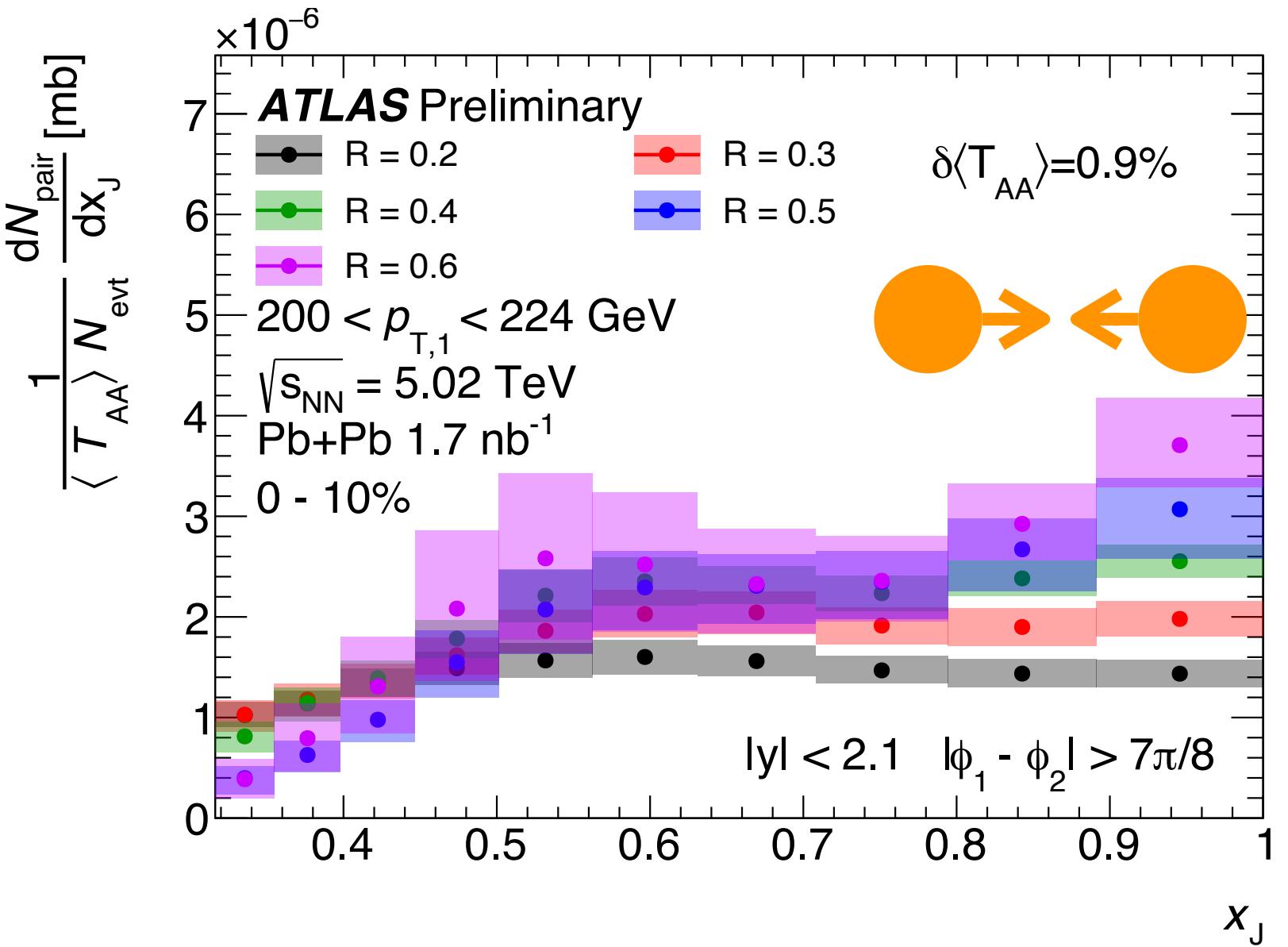
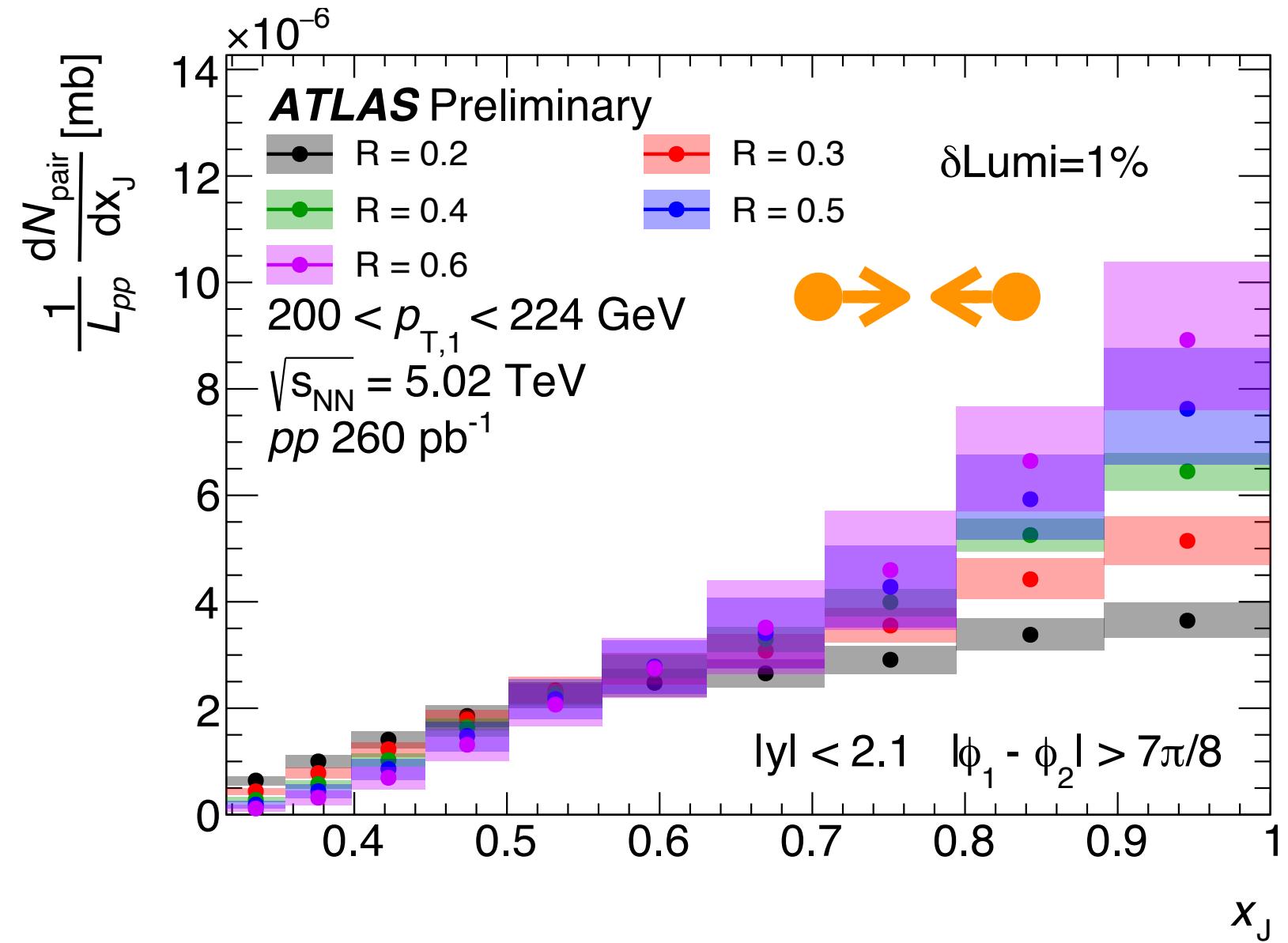
Dijet asymmetry

Dependence on jet radius

See talk by A. Sickles
Tues. 9:30

See poster by A. Romero

In pp , x_J becomes more narrow with large R



In ratio, modification is small at large x_J ,
For small x_J , $R = 0.6$ has much higher yield

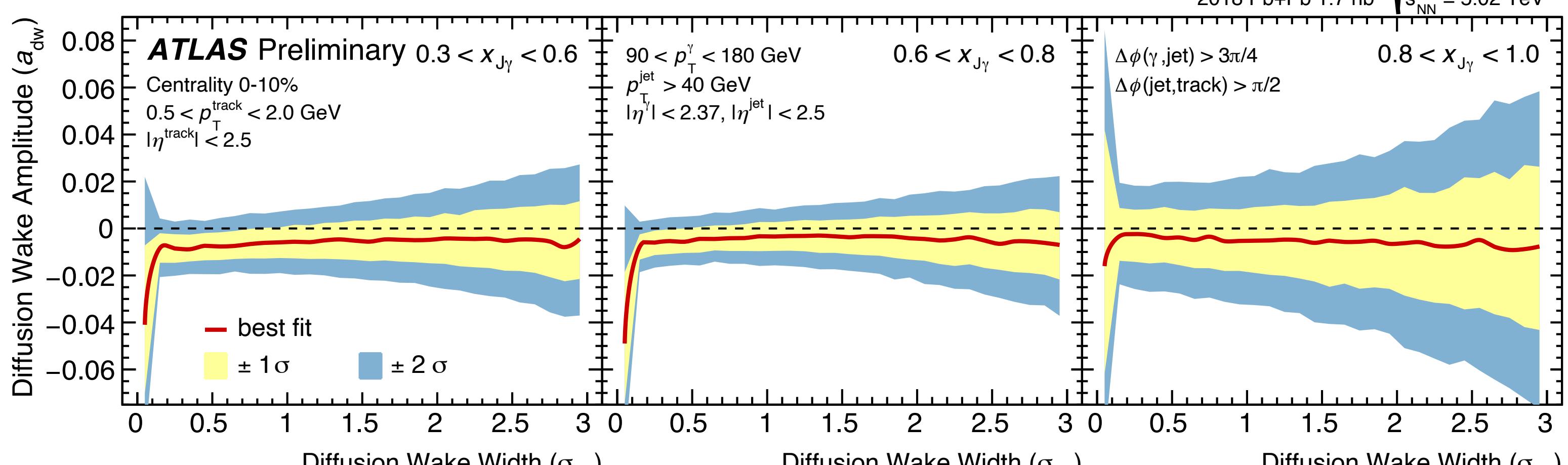
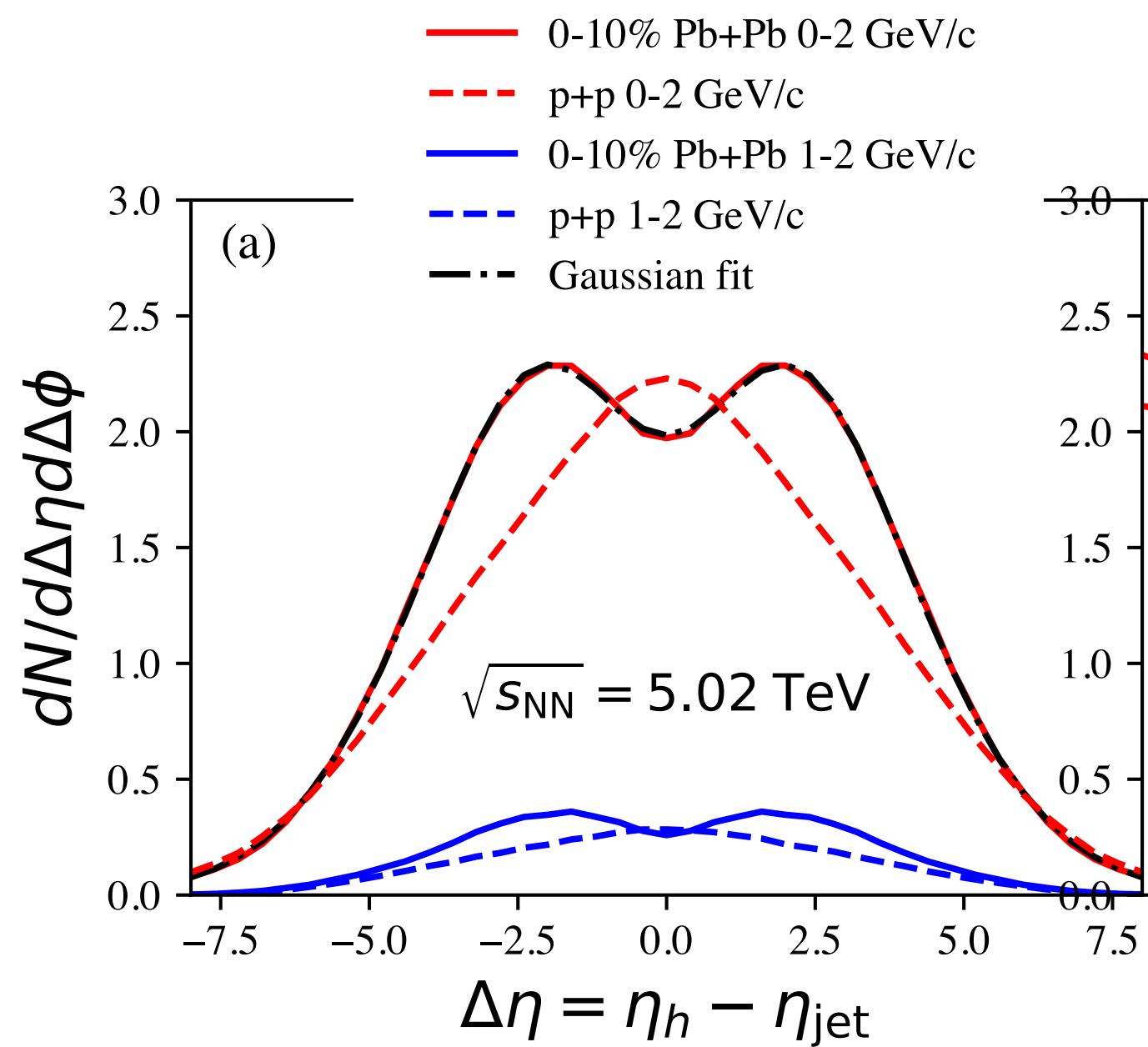
Medium response

Search for diffusion wake

See talk by C. McGinn
Wed. 8:50

- ▶ Lost energy serves as a source term in the hydrodynamic evolution → diffusion wake
- ▶ Follow proposal of (PRL 130 (2023) 5, 052301) look at photon-jet
- ▶ Signature depletion in particle production in photon-direction
 - Larger with more energy loss → study vs $x_{\gamma J}$
- ▶ Measure soft hadron yield dividing out uncorrelated background

Search for diffusion wake
[ATLAS-CONF-2023-054](#)



Theory prediction from [PRL 130 \(2023\) 5, 052301](#)

Summary

- ▶ ATLAS has a diverse and vibrant physics program
- ▶ Detailed studies of collision geometry
 - Flow decorrelations, fluctuations ultra-central collisions
- ▶ Hard-soft correlations
 - Jet contribution to ν_2 in small systems, color fluctuations in $p + \text{Pb}$ dijets
- ▶ Comprehensive program mapping out dependence of nuclear PDF modifications
 - $p + \text{Pb}$ dijets, UPC dijets, $t\bar{t}$ production in $p + \text{Pb}$
- ▶ Jet quenching
 - Pinning down the relationship between flavor and substructure and how they determine energy loss
 - Continuing program looking at dijets

ATLAS talks at posters at QM23

Anne Sickles
Tues. 9:30

Sruthy Das
Wed. 9:30

Blair Seidlitz
Tues. 12:40

Ben Gilbert
Wed. 3:00

Zvi Citron
Tues. 4:10

Tomasz Bold
Wed. 5:10

Peter Steinberg
Tues. 4:50

Patrycja Potepa
Wed. 5:50

Dhanush Hangal
Wed. 8:30

Soumya Mohapatra
Wed. 5:50

Chris McGinn
Wed. 8:50

Anabel Romero

Riccardo Longo

Xiaoning Wang

Somadutta Bhatta

Best place to find new ATLAS results
<https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HeavyIonsPublicResults>