Recent results from heavy ion collisions with ATLAS

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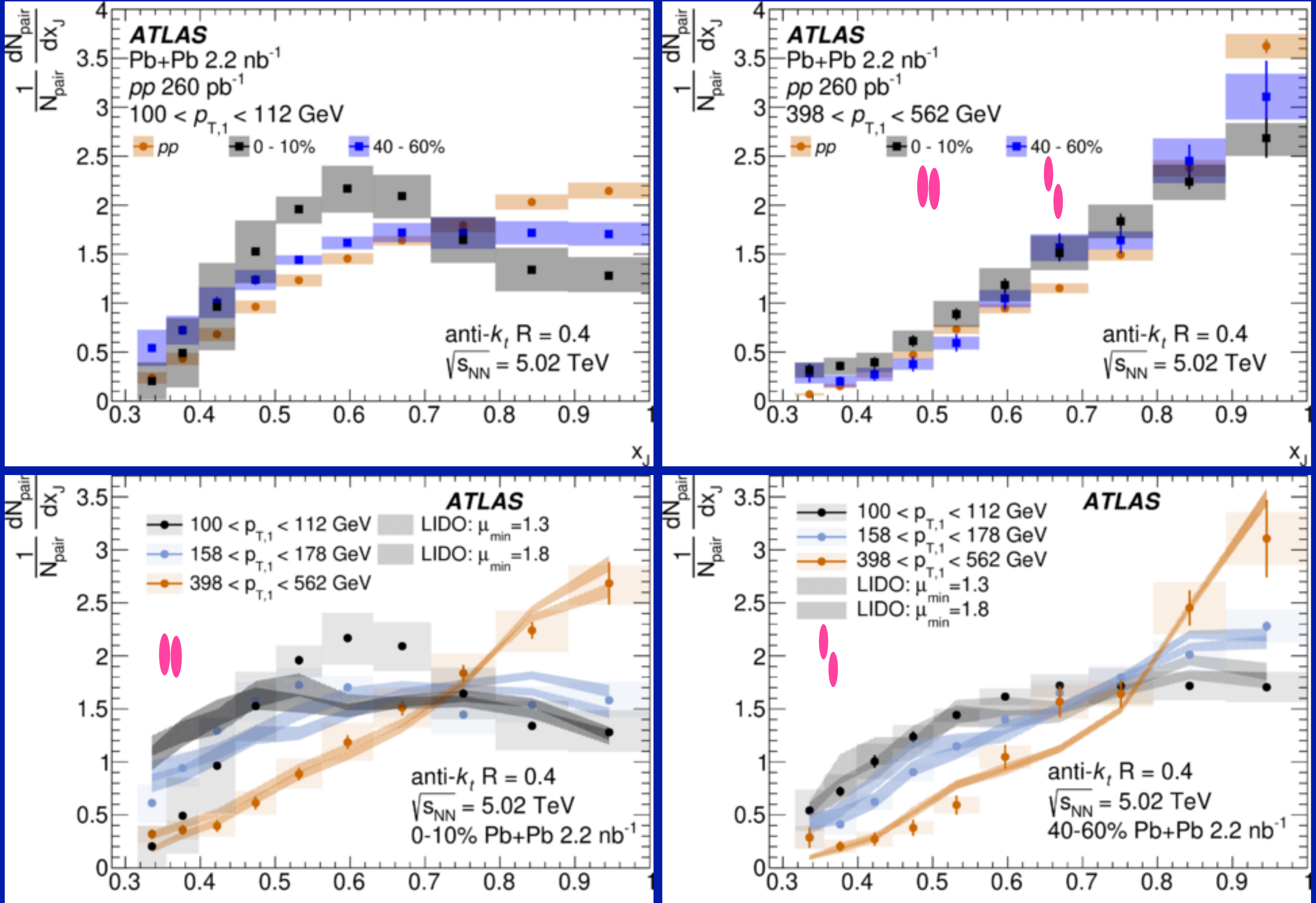
on behalf of the ATLAS Collaboration

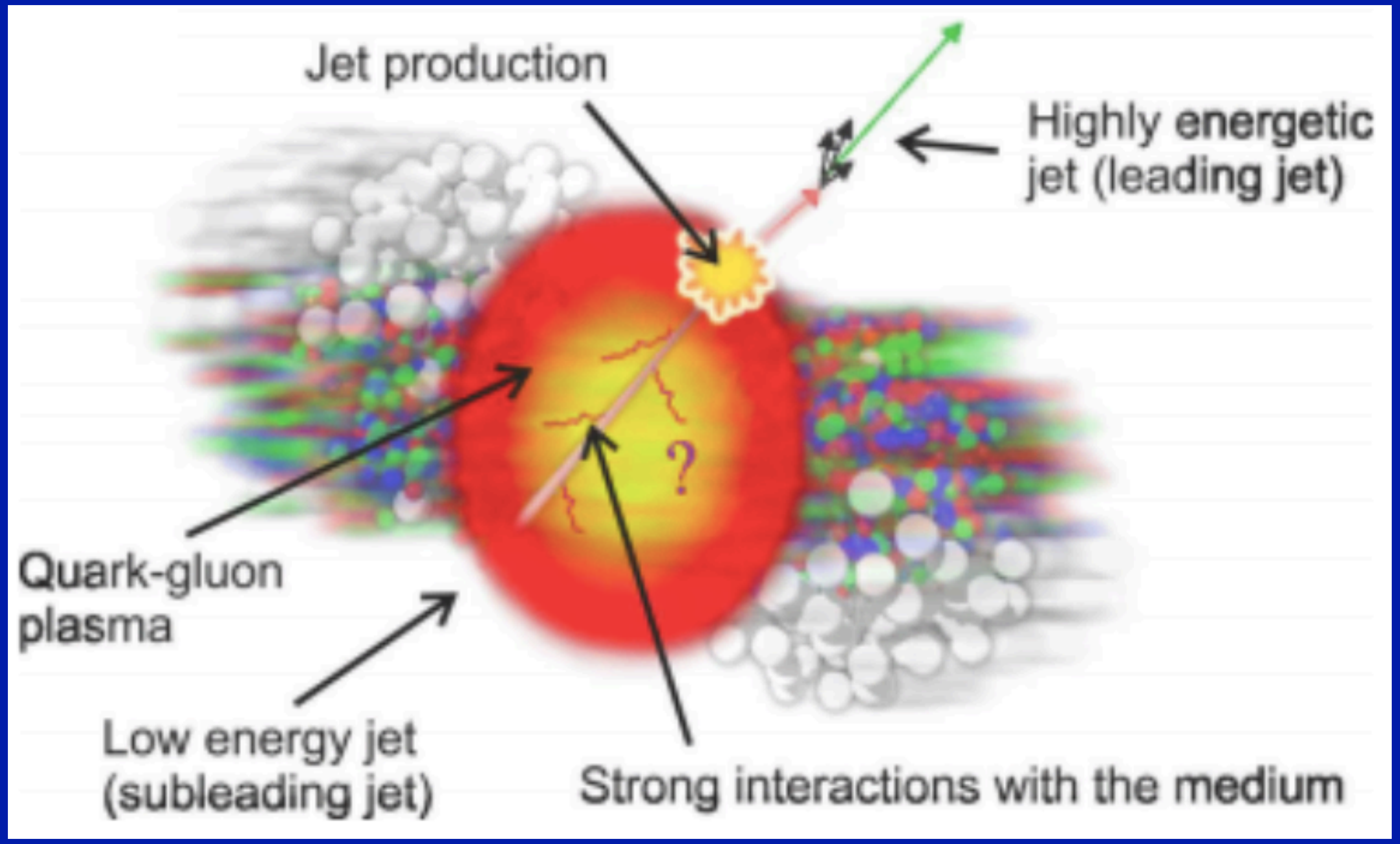
Discovery Physics at the LHC, 4-9 December, South Africa

Dijet asymmetry in PbPb and *pp* collisions

dijet distributions as a function of $x_J = p_{T2}/p_{T1}$



arXiv:2205.00682 [nucl-ex]



dijets get asymmetric in p_T with increasing collisions centrality

in central collisions (0-10%) the asymmetry gets weaker with increasing leading jet p_T

LIDO captures globally the x_J distributions

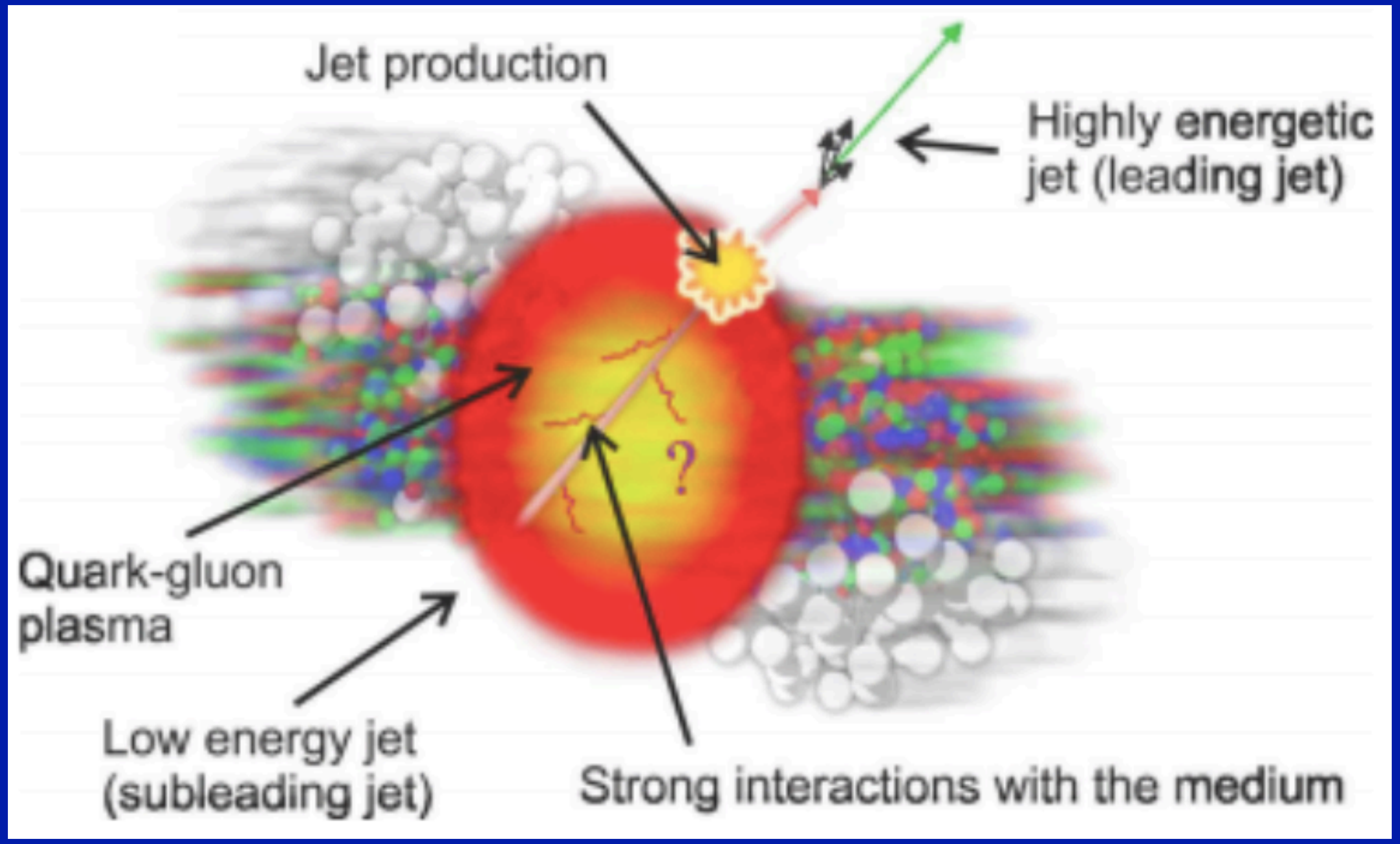
Nuclear Modification Factor - R_{AA}

$$R_{AA} = \frac{N_{AA}}{\langle T_{AA} \rangle \times \sigma_{pp}}$$

Yields in Pb+Pb collisions, (in medium)

Nuclear thickness function $<N_{coll}>/\sigma_{NN}$

Cross section in pp collisions (in vacuum)

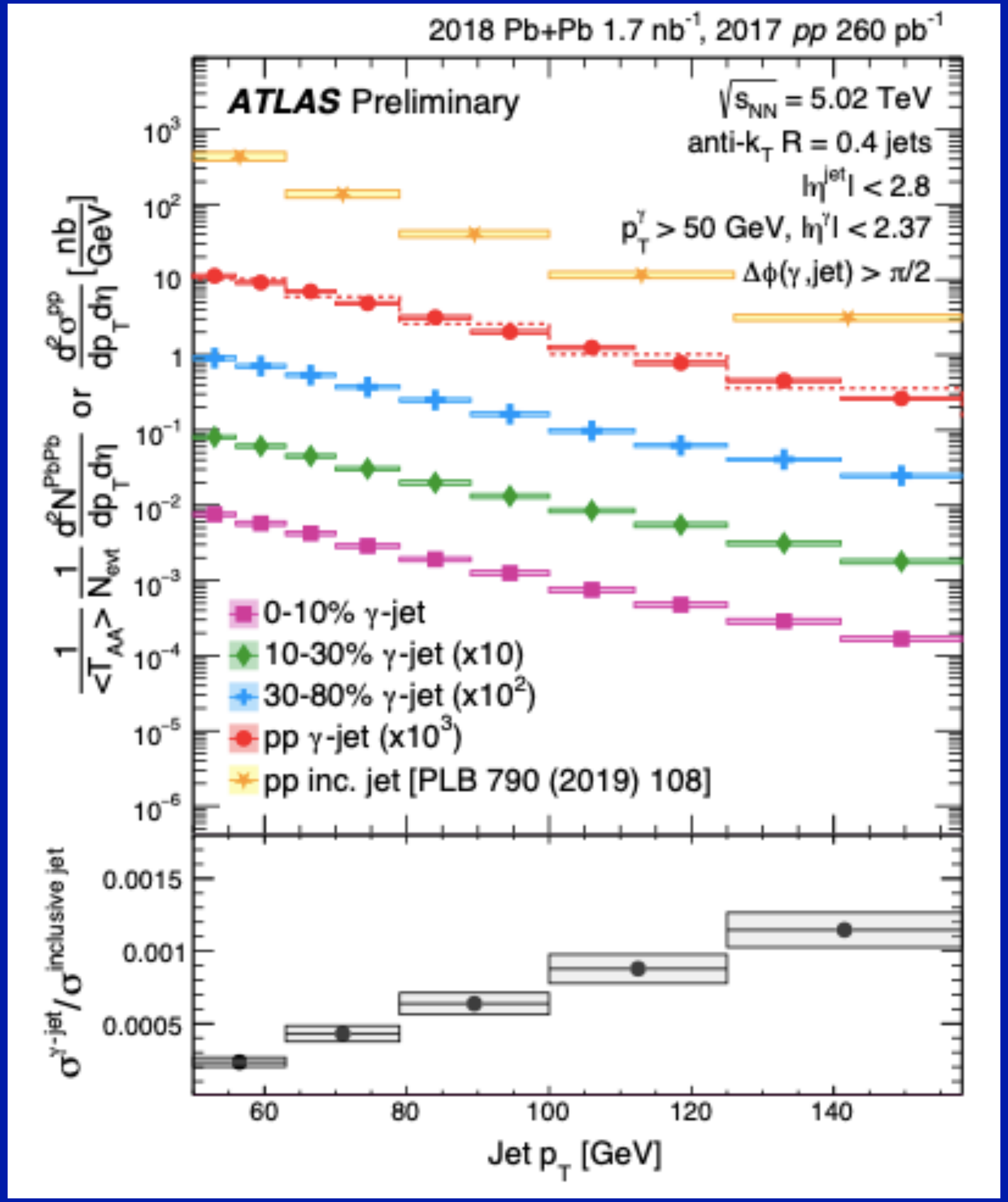


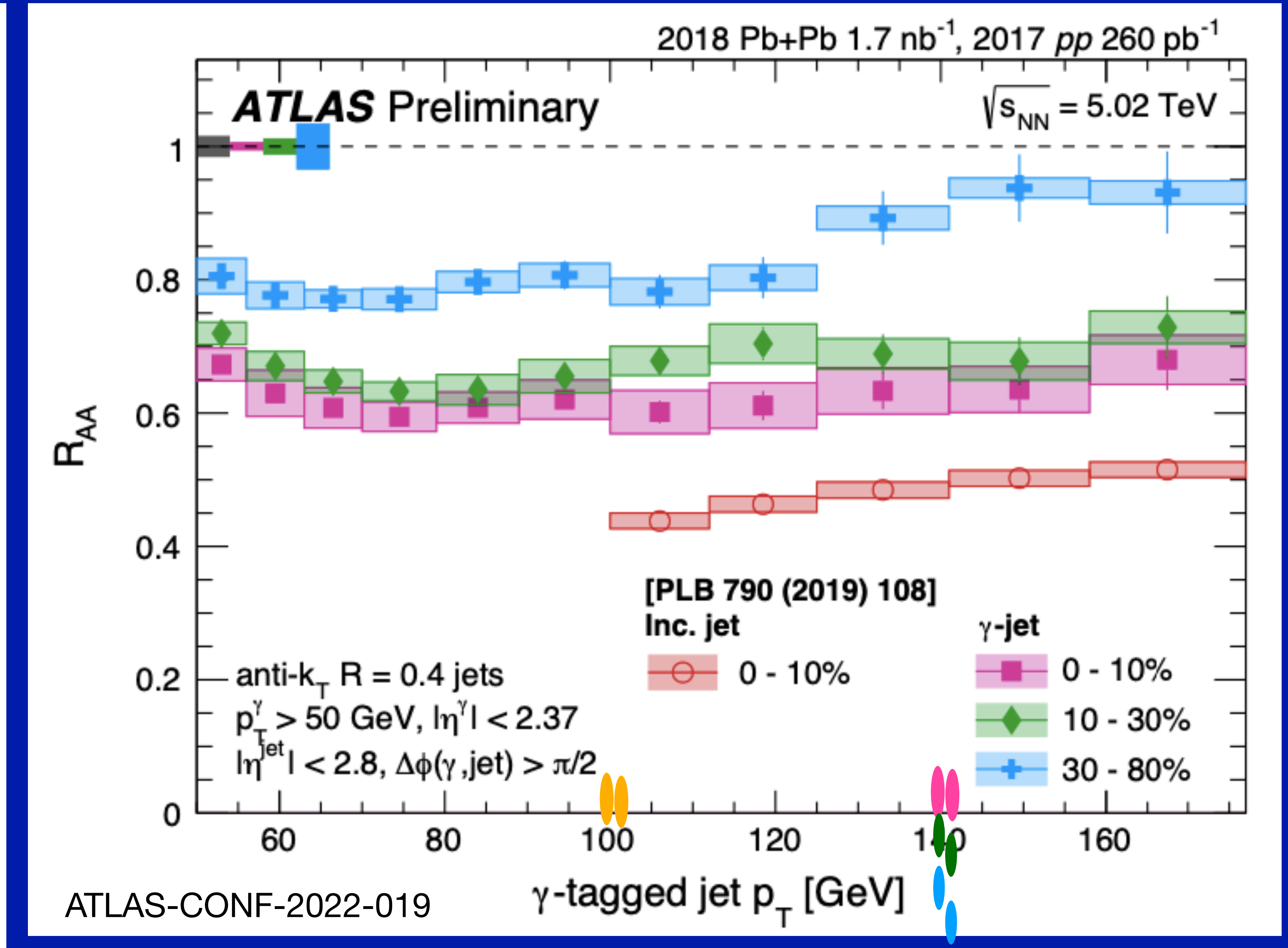
- nuclear thickness function , T_{AA}, accounts for the nuclear orverlap
- nuclear modification factor quantifies the change of yields, relatively to the production in vacuum

❋ any deviation from 1 points to suppression or enhancement of the Pb+Pb yields (jets, particles)

γ-tagged jets: probing the colour charge of the initiating parton

- in scenarios of radiative energy loss quarks and gluons are expected to lose their energy proportionally to their colour factor
- at LHC energies inclusive jet production is dominated by gluon-initiated jets, but jets recoiling against a photon are more likely to be quark-initiated





$$R_{AA} = \frac{N_{AA}}{\langle T_{AA} \rangle \times \sigma_{pp}}$$

quark-initiated jets are less suppressed than gluon-initiated jets

measure R_{AA} for photon-tagged jets and for inclusive jets and compare

γ-tagged jets: probing the colour charge of the initiating parton

- in scenarios of radiative energy loss quarks and gluons lose their energy proportionally to their colour factor
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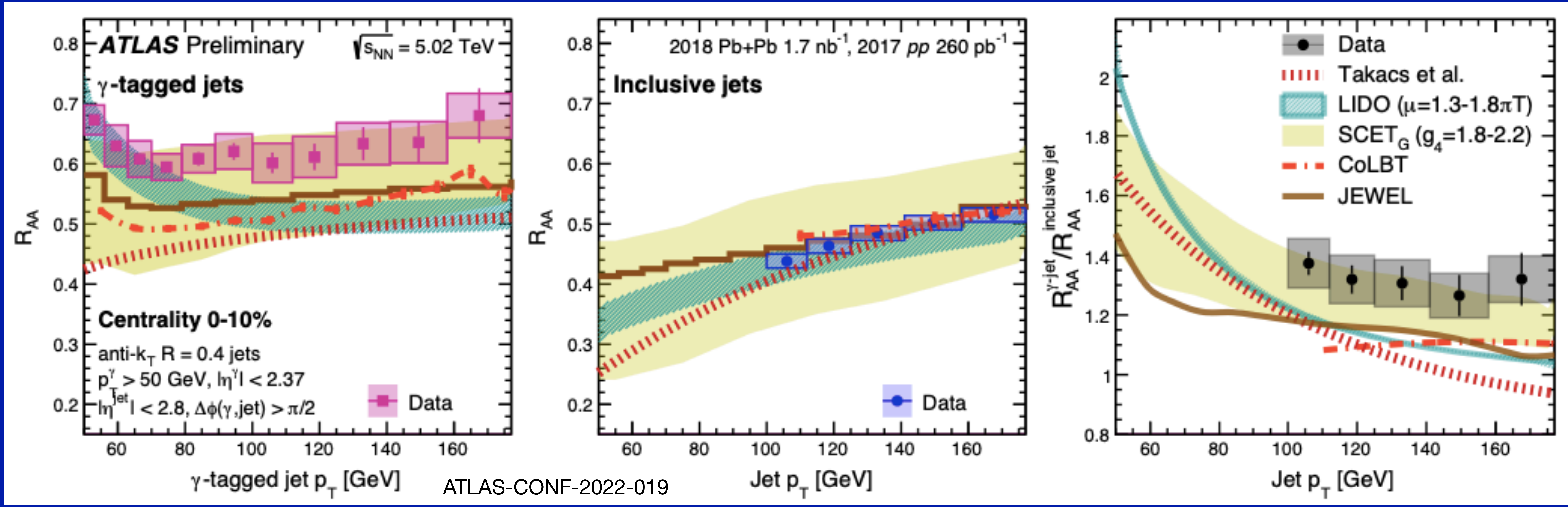
measure R_{AA} for photon-tagged jets and for inclusive jets and compare



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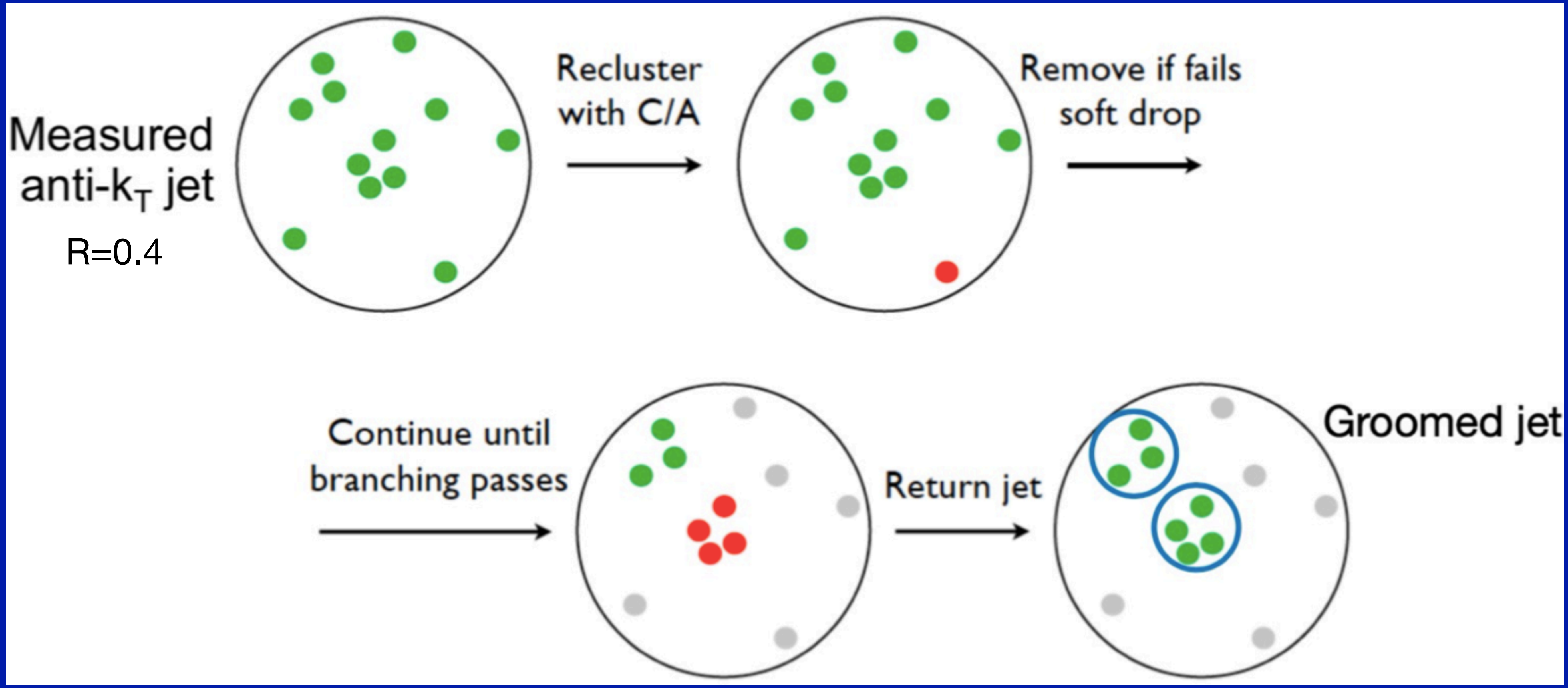
models overestimate the suppression of photon-tagged jets and reproduce the inclusive jet one

Jet substructure

- recent studies have shown an emergence of a critical angle between hard splittings, above which the jet loses energy incoherently

- it can tell us about the nature of the jet energy loss and so infer the properties of the quark gluon plasma



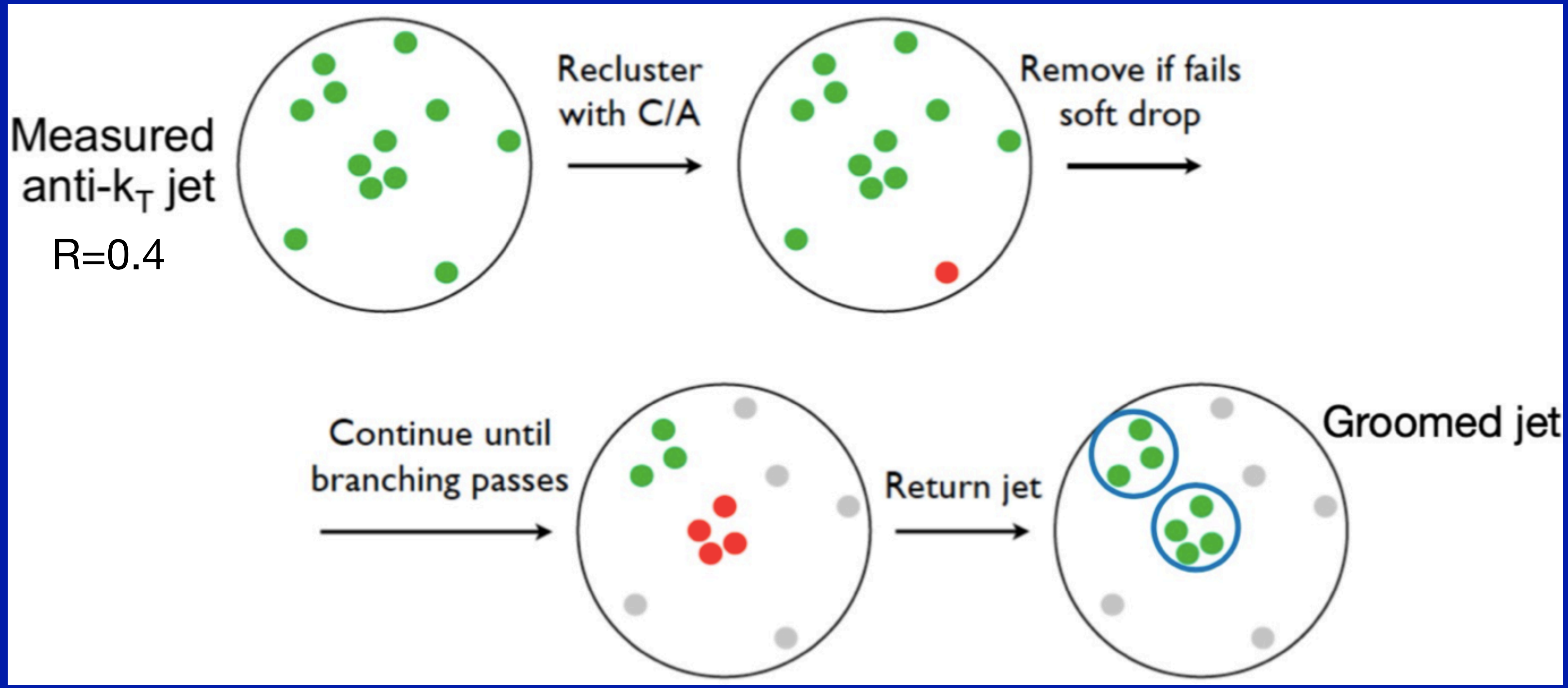
$$\frac{\min(p_T^{sj_1}, p_T^{sj_2})}{p_T^{sj_1} + p_T^{sj_2}} > z_{cut} \left(\frac{\Delta R_{12}}{R}\right)^{\beta}$$

$$\Delta R_{12} = \sqrt{\Delta\eta_{12}^2 + \Delta\phi_{12}^2}$$

z_{cut}=0.2, β=0

r_g = ΔR_{12} between sub-jets satisfying the soft drop condition

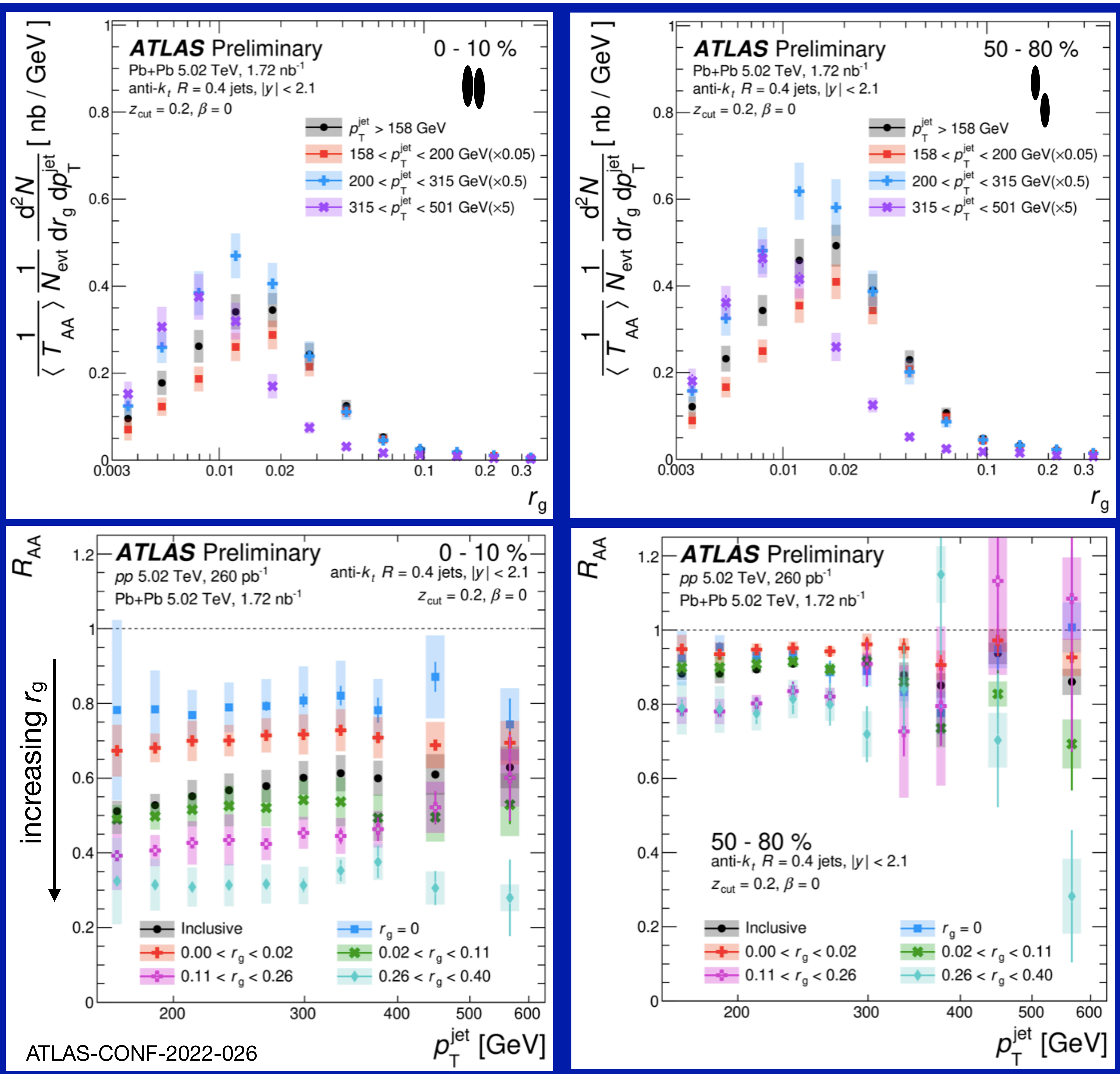
Jet substructure



$$\frac{\min(p_T^{sj_1}, p_T^{sj_2})}{p_T^{sj_1} + p_T^{sj_2}} > z_{cut} \left(\frac{\Delta R_{12}}{R}\right)^{\beta} \qquad \Delta R_{12} = \sqrt{\Delta\eta_{12}^2 + \Delta\phi_{12}^2}$$

z_{cut}=0.2, β=0

$r_g = \Delta R_{12}$ between subjets satisfying the soft drop condition



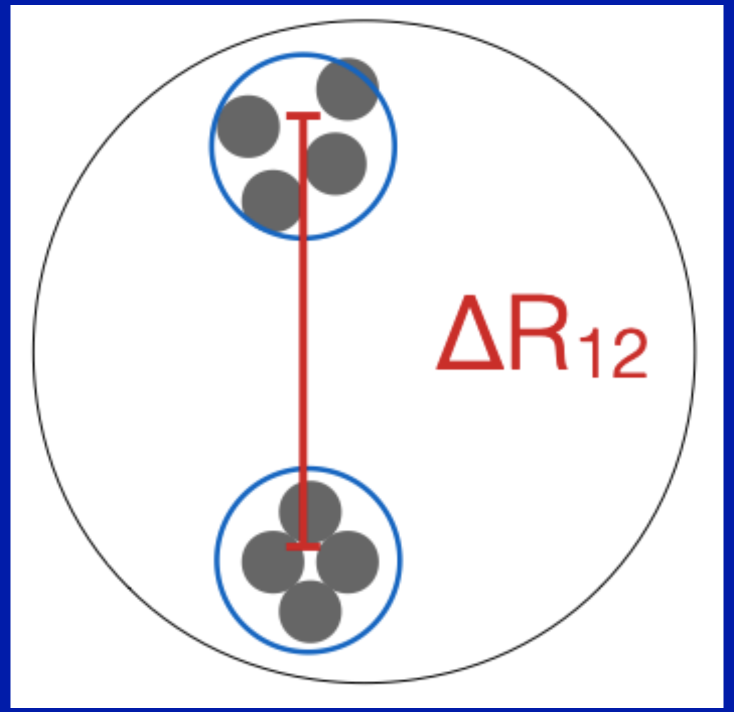
- jets get narrower with increasing p_T, independently on centrality
- jets with wider hard splittings are significantly more suppressed in central collisions
- result points to decoherent energy loss

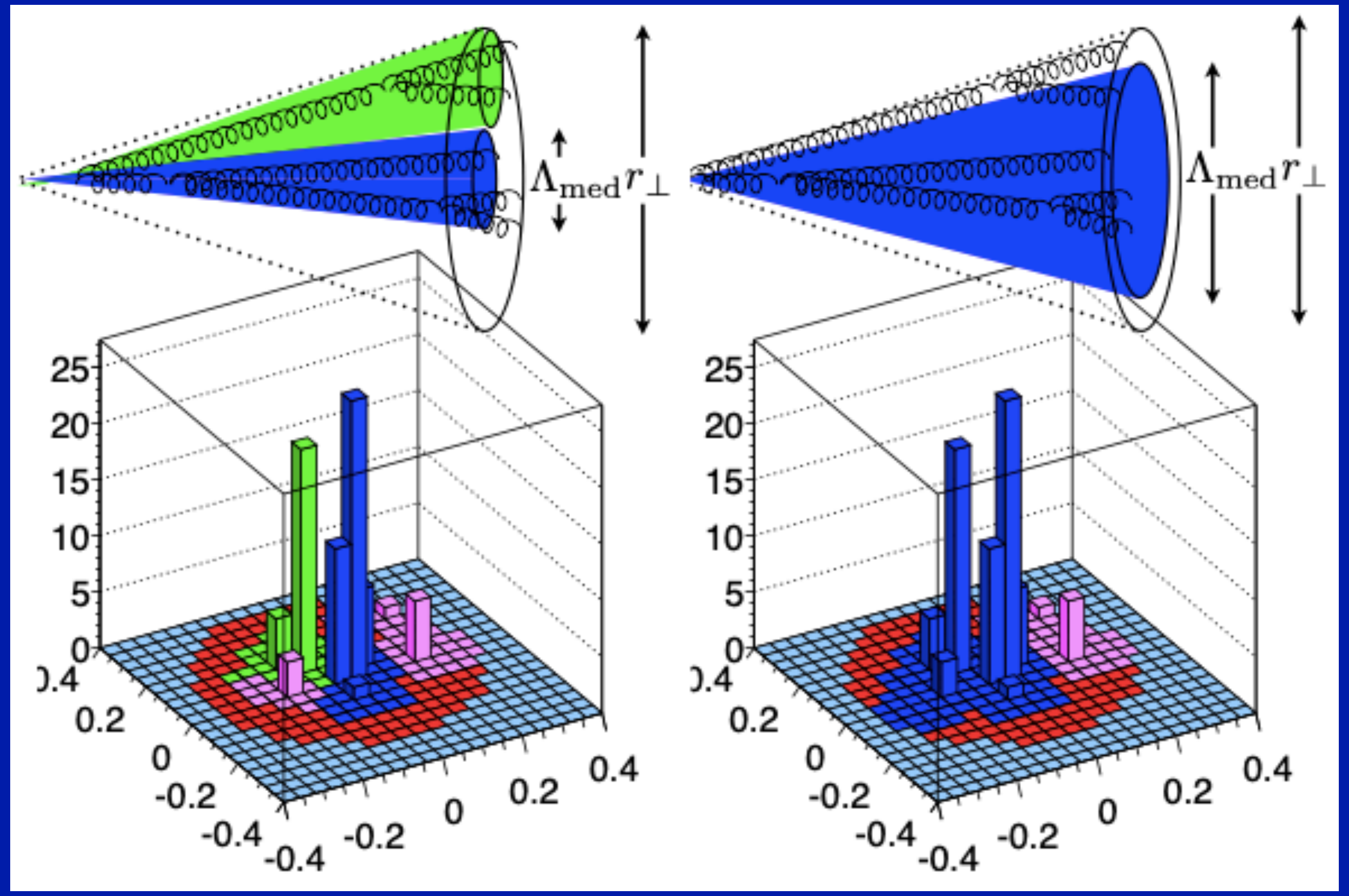
Reclustered large jets ($R = 1.0$)

R = 0.2 jets with p_T > 35 GeV reclustered into anti-k_t R =1.0

study of k_t splitting scale

$$\sqrt{d_{12}} = \min(p_{T,1}, p_{T,2}) \cdot \Delta R_{12}$$





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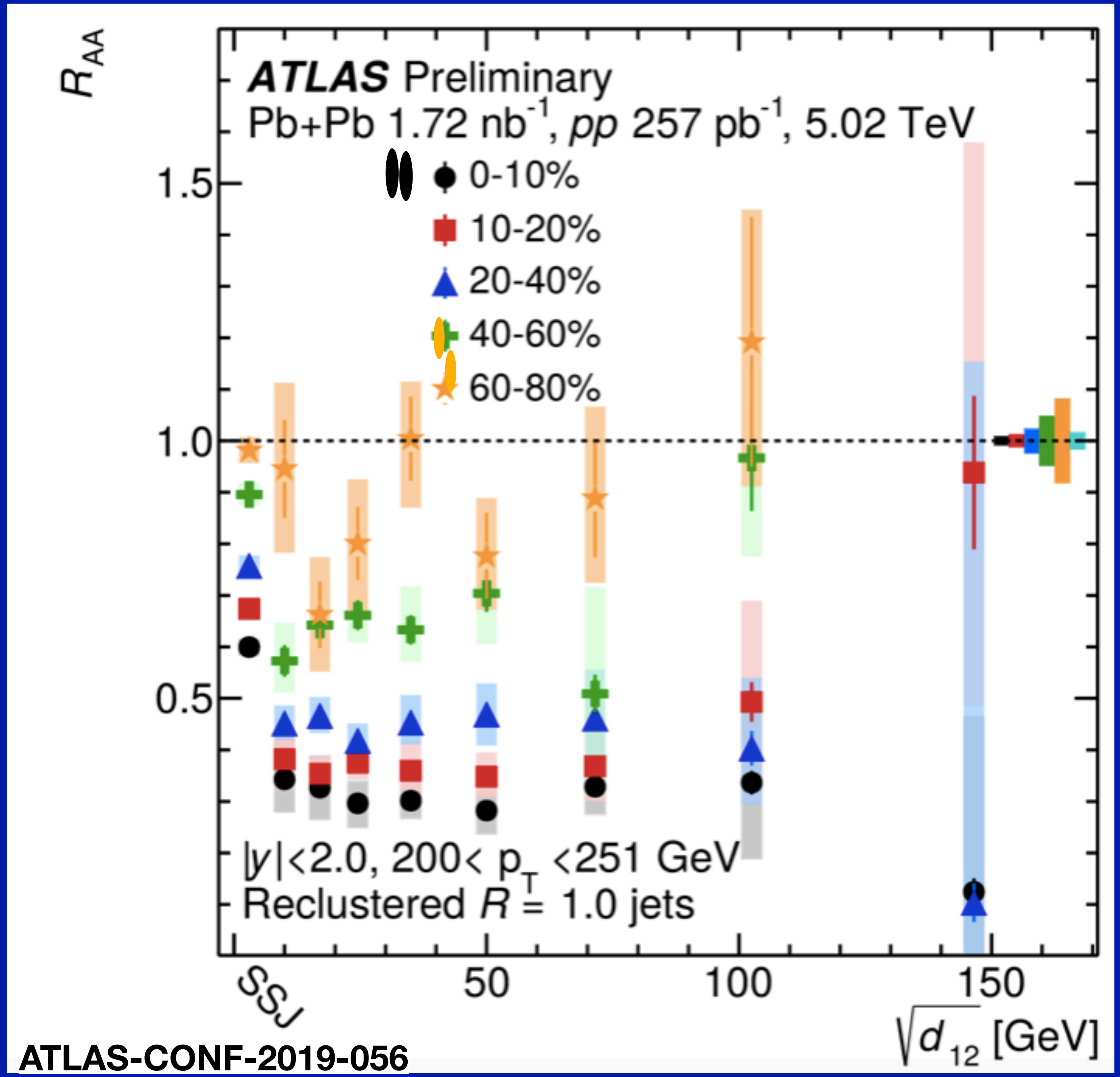
Recluster jets and remove soft contributions



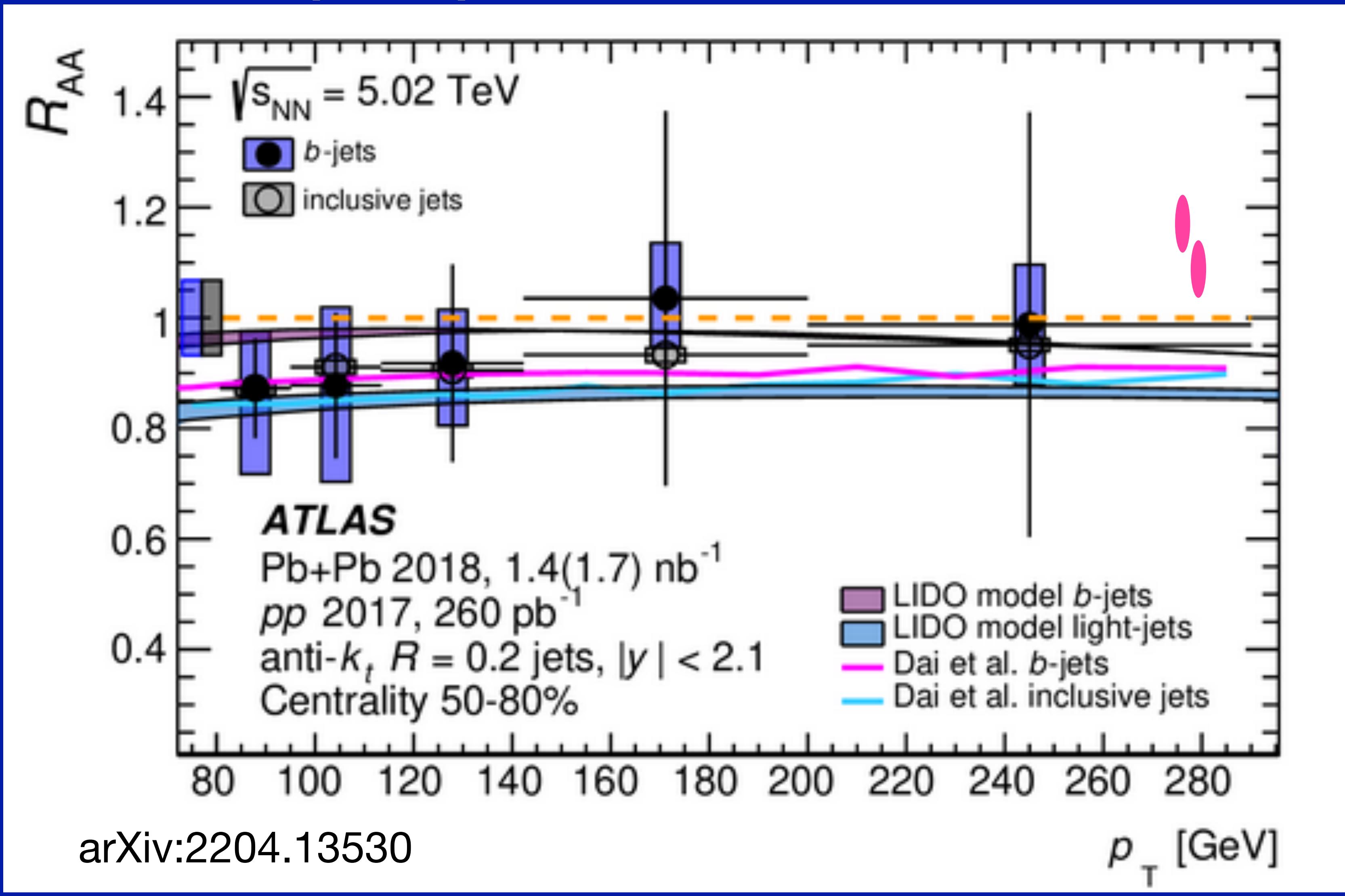
$$R_{AA} = \frac{N_{AA}}{\langle T_{AA} \rangle \times \sigma_{pp}}$$

The lowest $\sqrt{d_{12}}$ interval is populated with jets with single "isolated" sub-jet, SSJ ($\sqrt{d_{12}}$=0).

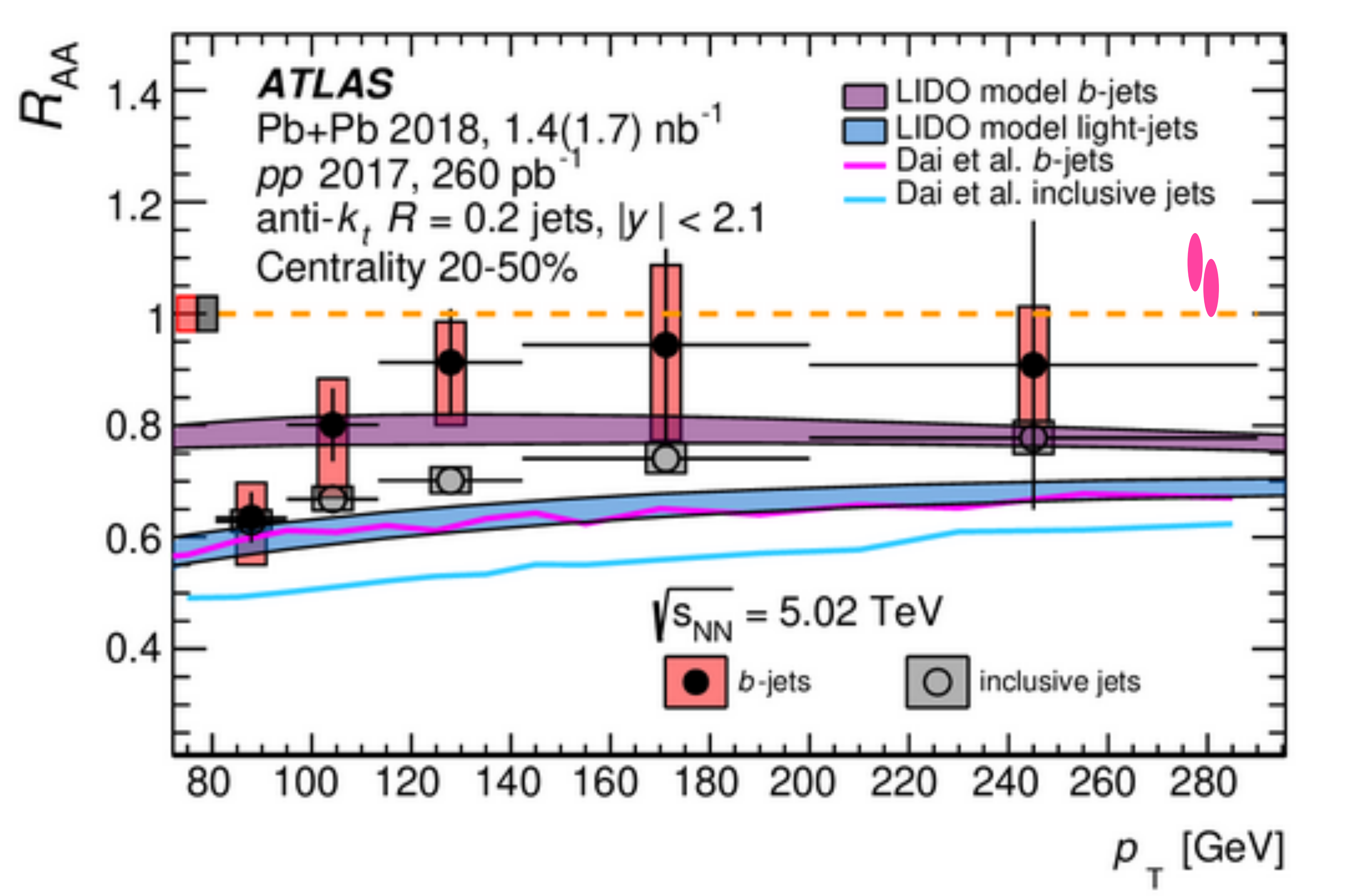
- significant change of the R_{AA} magnitude between jets with SSJ and those with more complex substructure
- then R_{AA} is not dependent on $\sqrt{d_{12}}$
- result points to decoherent energy loss

R_{AA} for *b*-jets and inclusive jets

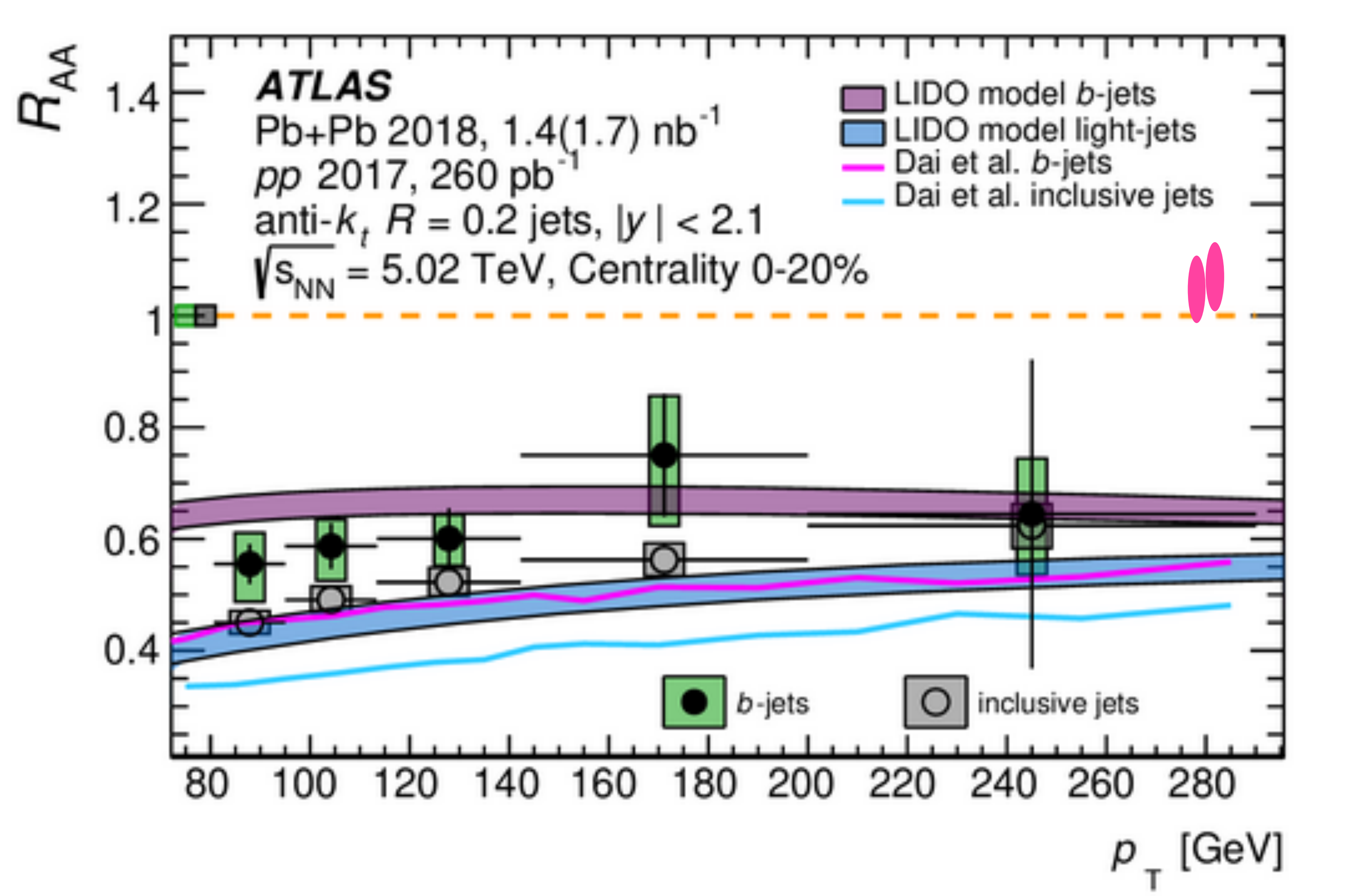
peripheral collisions



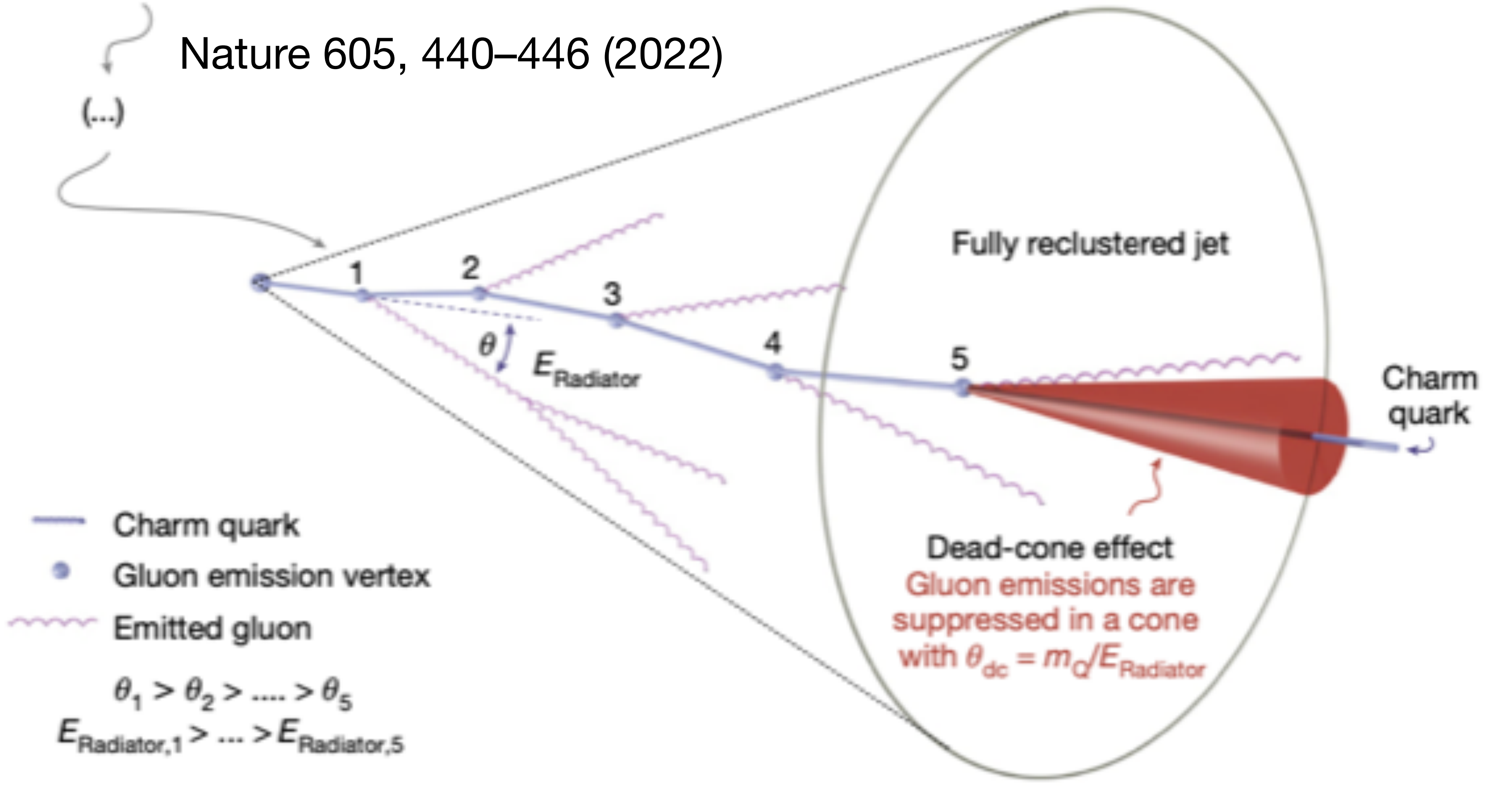
mid-central collisions



central collisions



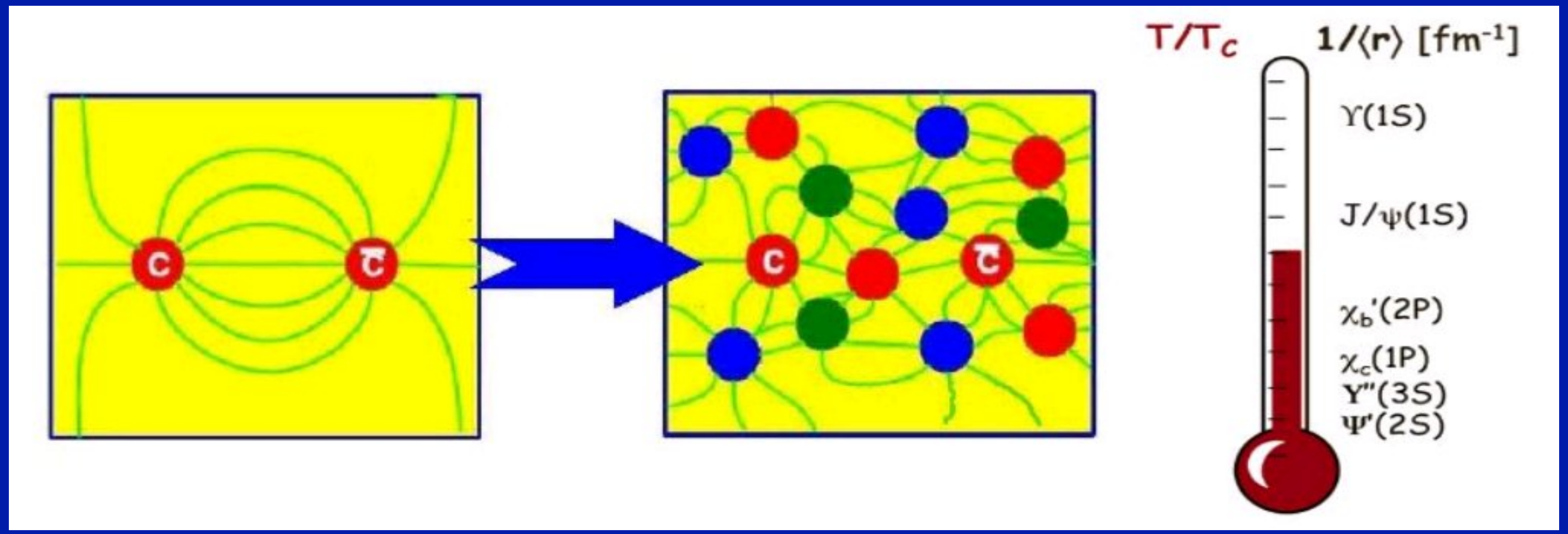
- *b*- and inclusive *R*=0.2 jets compatible in peripheral collisions
- *b*-jets less suppressed in central and mid-central
- R_{AA} slightly increases with p_T in the measured range
- LIDO describes relatively well the R_{AA}
- results support the dead cone effect



Upsilon suppression

J/psi anomalous suppression by Debye colour screening (Matsui and Satz, 1986)

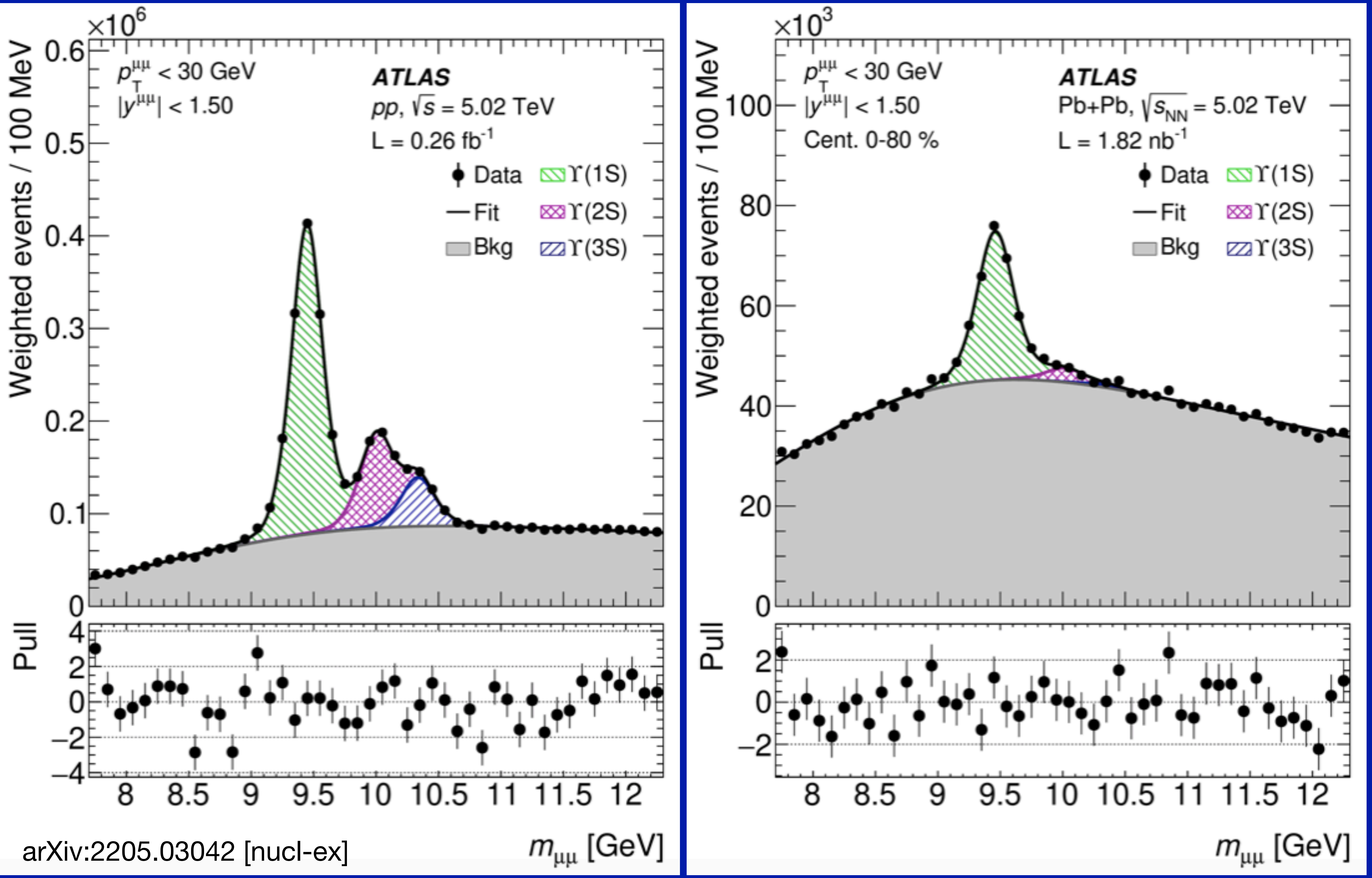
→ one of the most striking signatures of the QGP



further theoretical work predicted the weaker the bound state the sooner the suppression

→ explore this to probe the temperature of the QGP

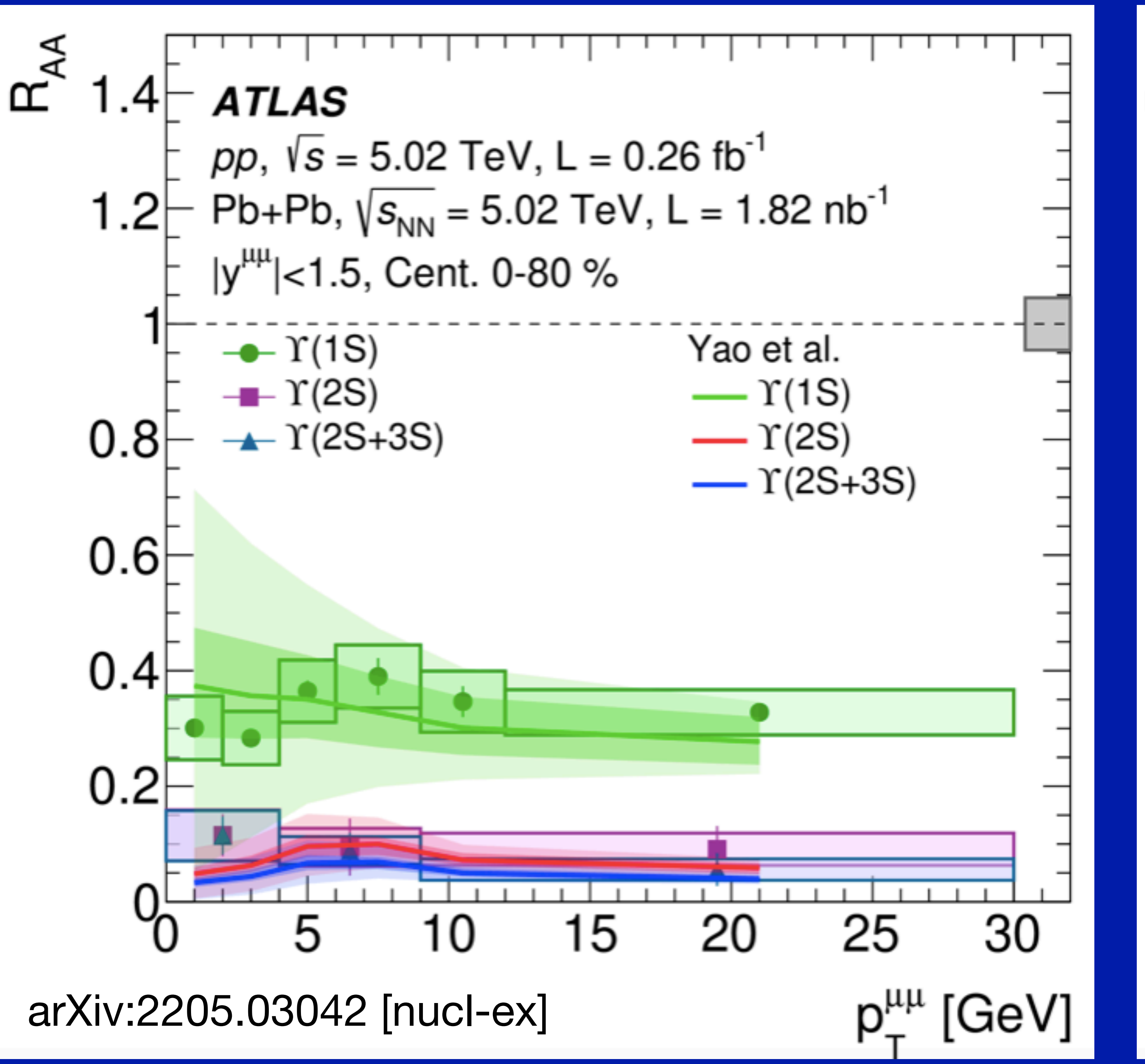
invariant dimuon mass spectra of Upsilon mesons



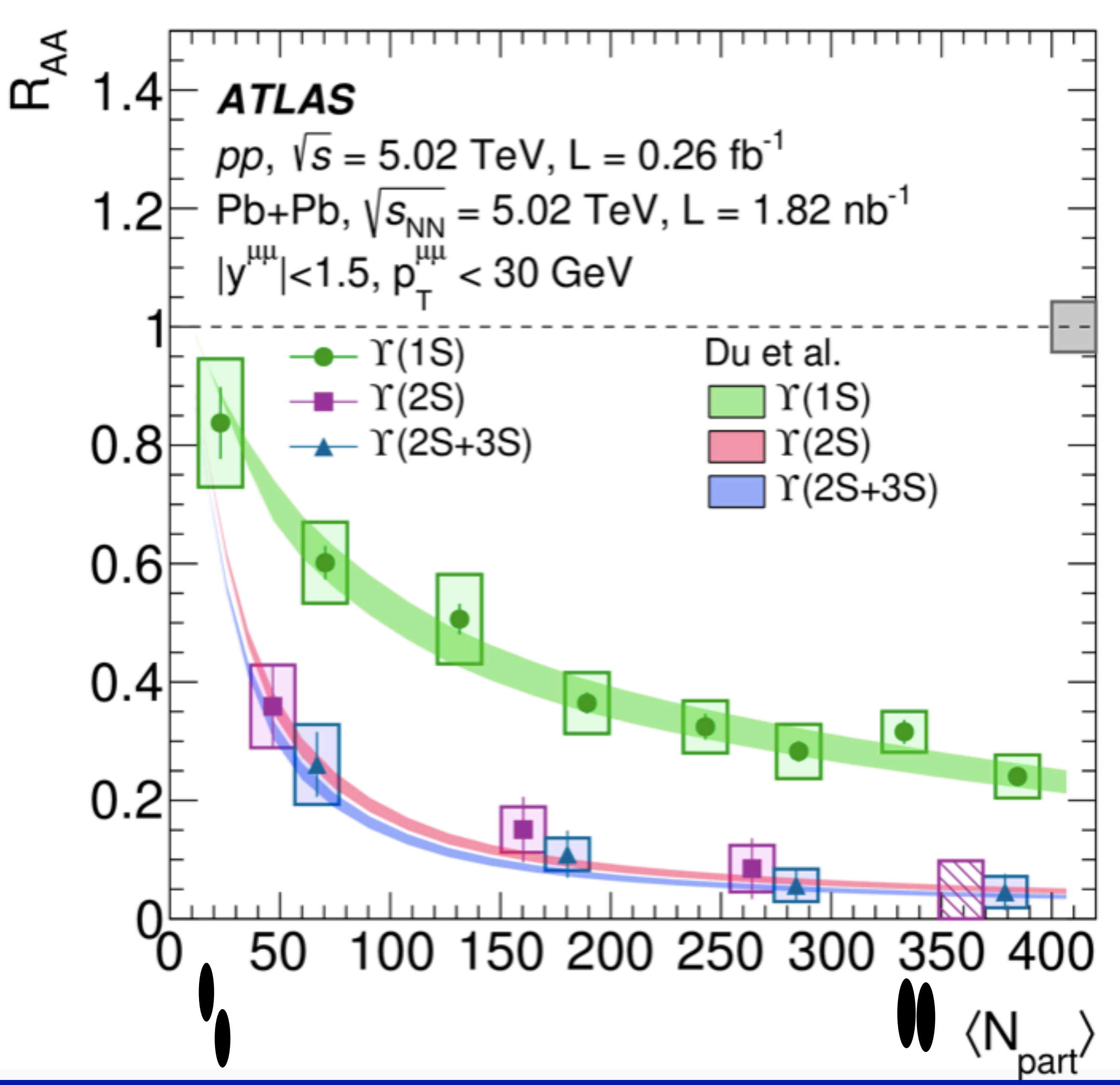
Upsilon R_{AA}

$$R_{AA} = \frac{N_{AA}}{\langle T_{AA} \rangle \times \sigma_{pp}}$$

R_{AA} as a function of dimuon p_T



R_{AA} as a function of N_{part}



excited ϒ states significantly more suppressed than the ground state

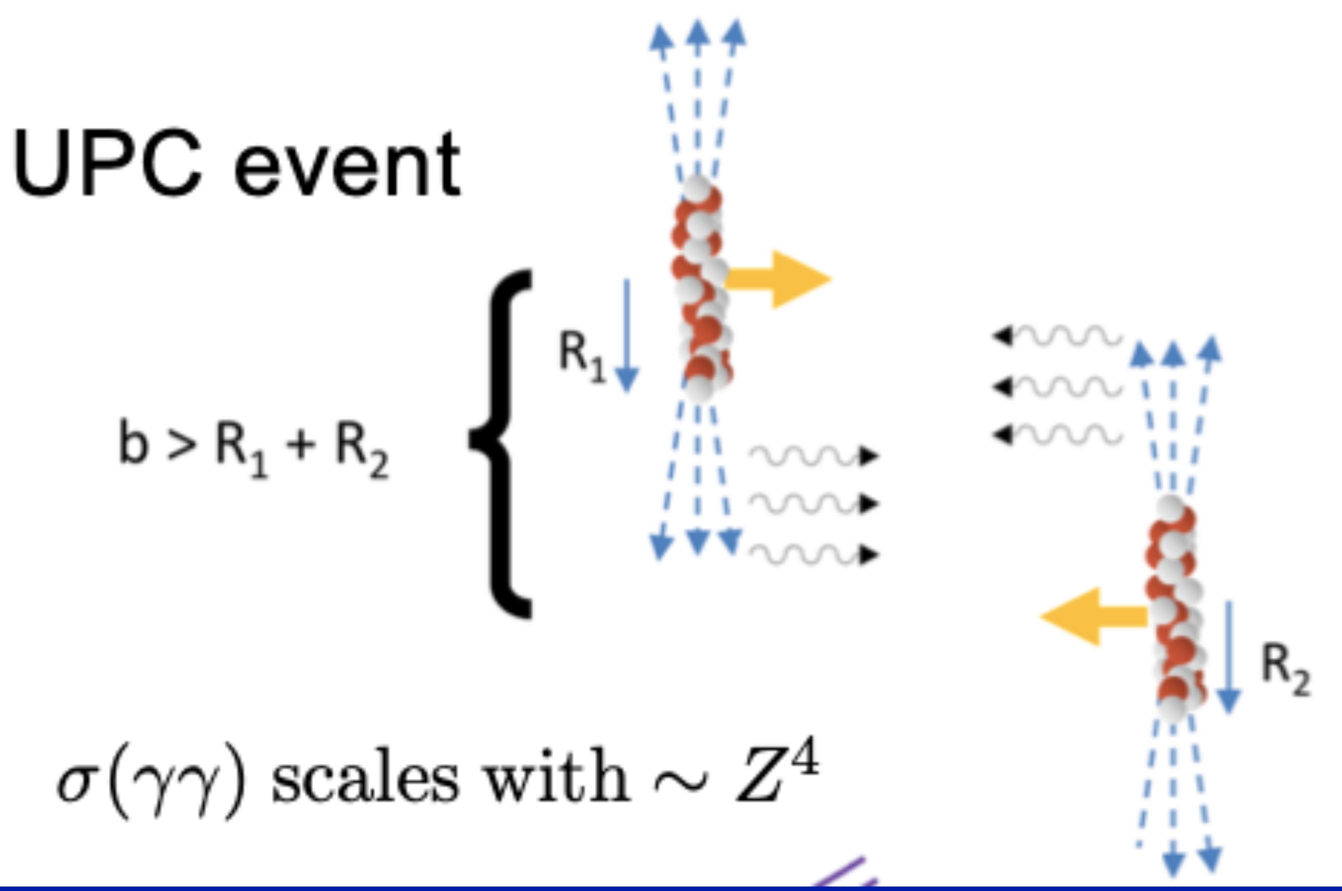
no dependence with dimuon p_T

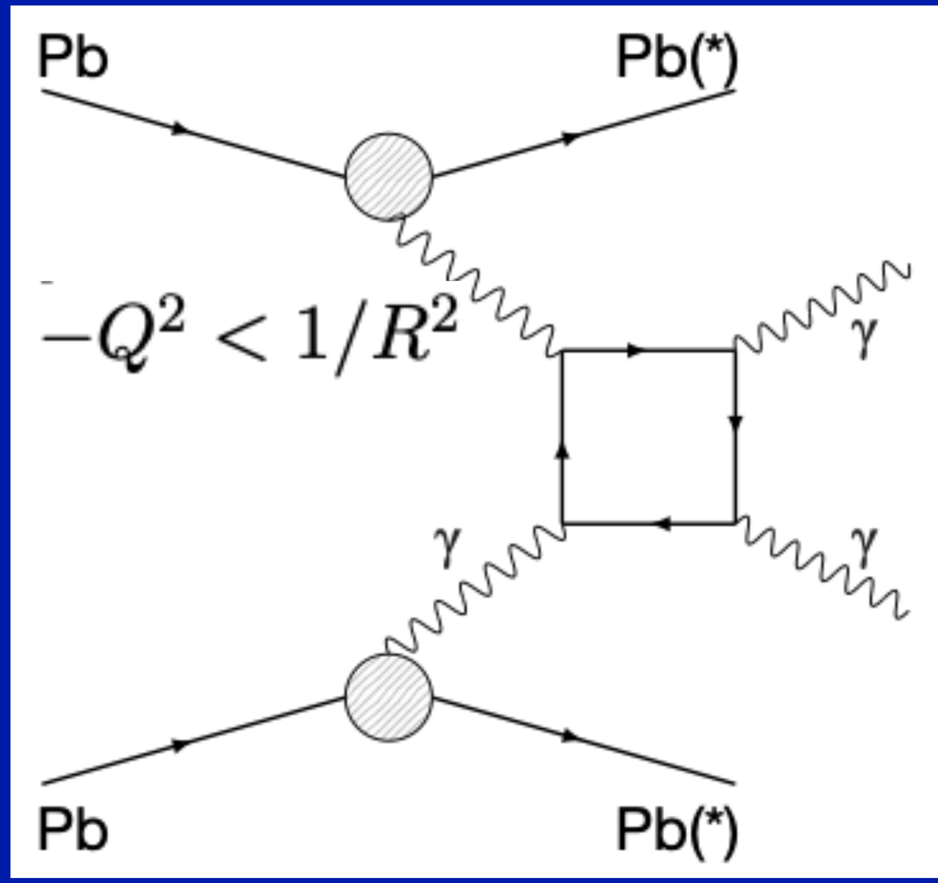
steady increase of suppression as a function of the number of the nucleon participants, N_{part}

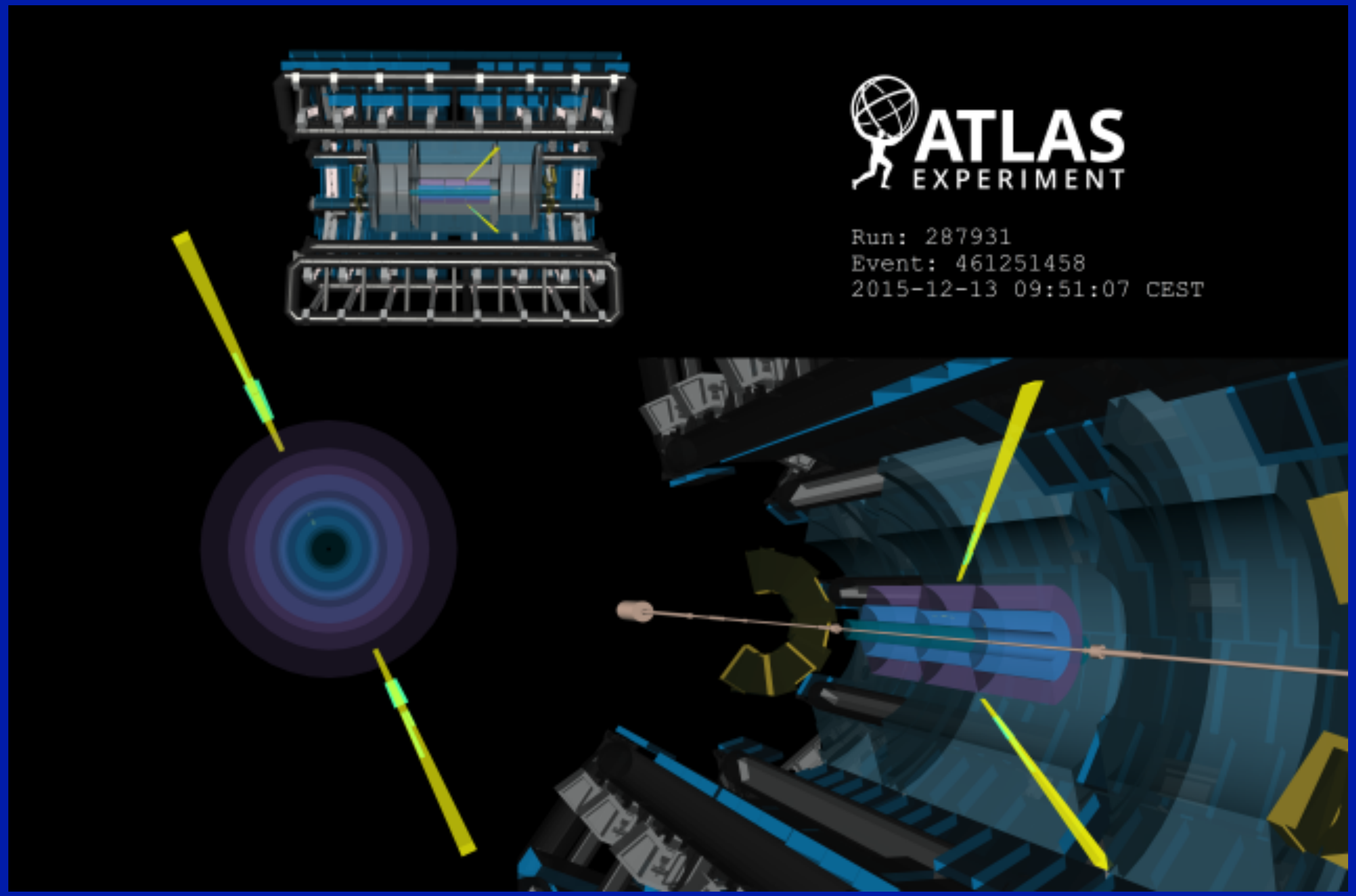
data well described by the models in the whole p_T range and centrality

An 80 years old prediction - Light by Light

Heisenberg, W., Euler, H. Folgerungen aus der Diracschen Theorie des Positrons. Z. Physik 98, 714–732 (1936). The fact that electromagnetic radiation can be transformed into matter and vice versa leads to modifications of the Maxwell's equations…



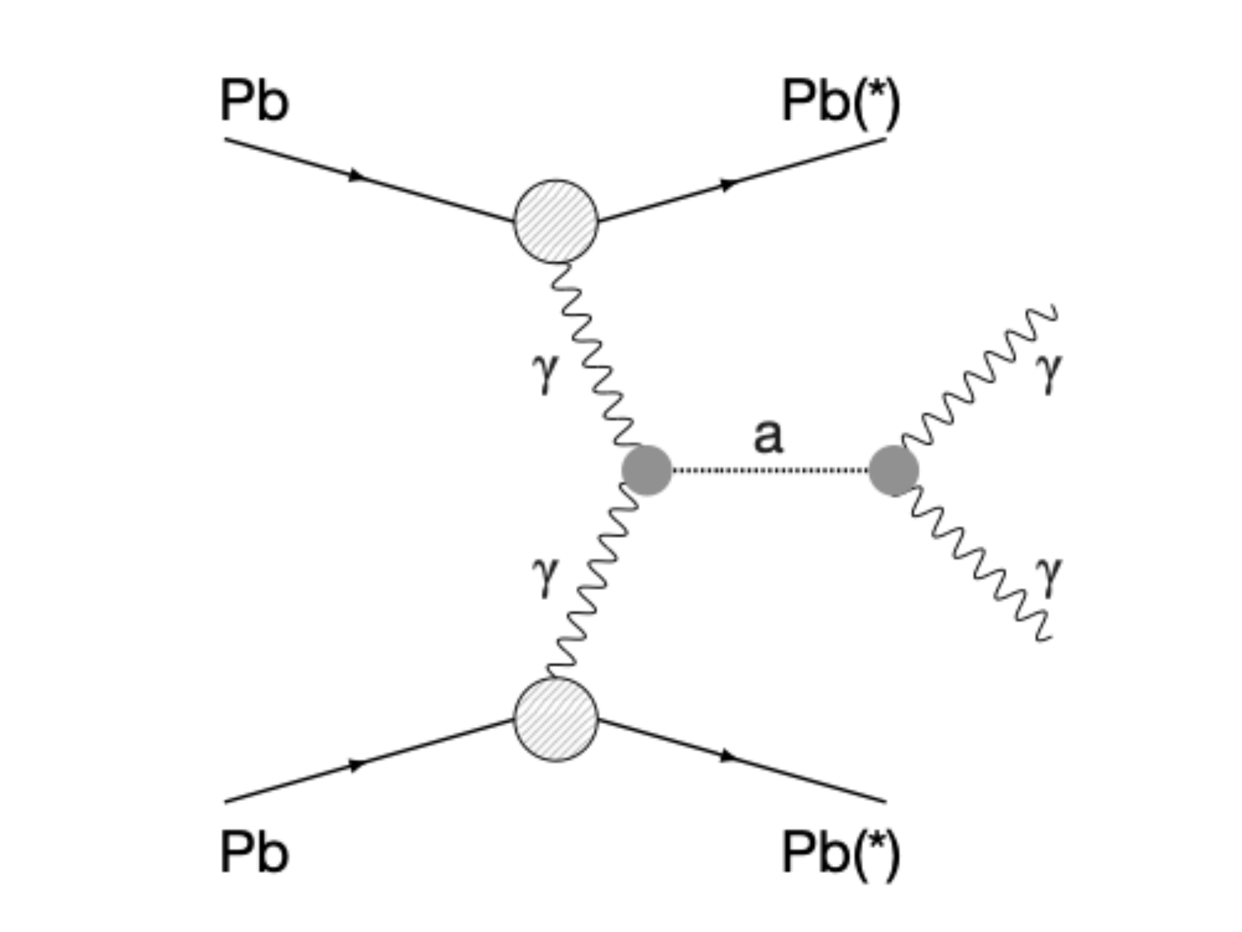




Evidence of LbyL scattering (Nature Physics 13, 852–858(2017)):

4.4 (3.8) σ

σ_{fid} = 70 ± 24 (stat) ± 17 (syst) nb, in agreement with SM predictions.

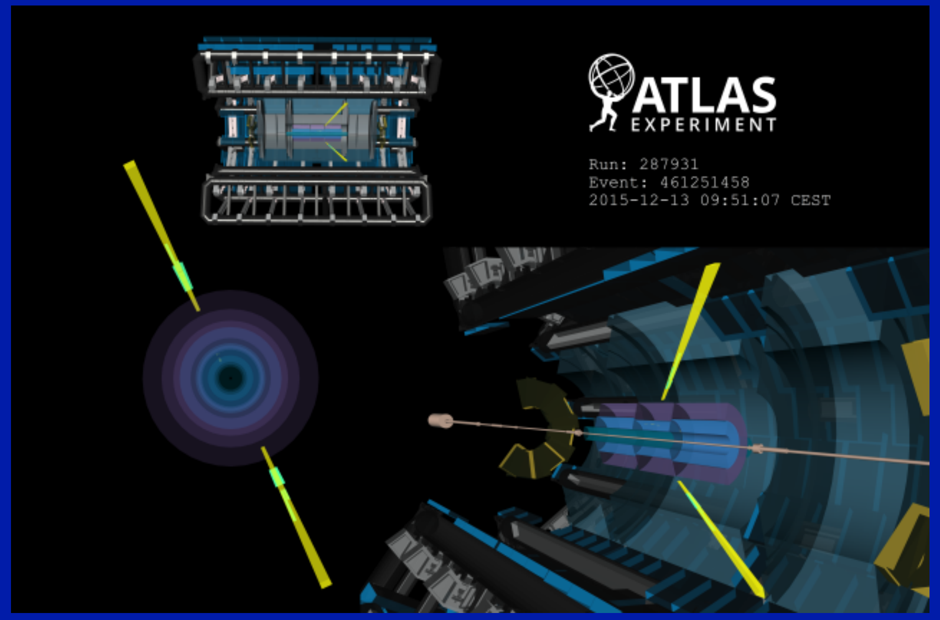


LbyL may be sensitive to BSM

- exotic charged particles
- extra dimensions
- axion-like particles - ALP

γγ→γγ in UPC

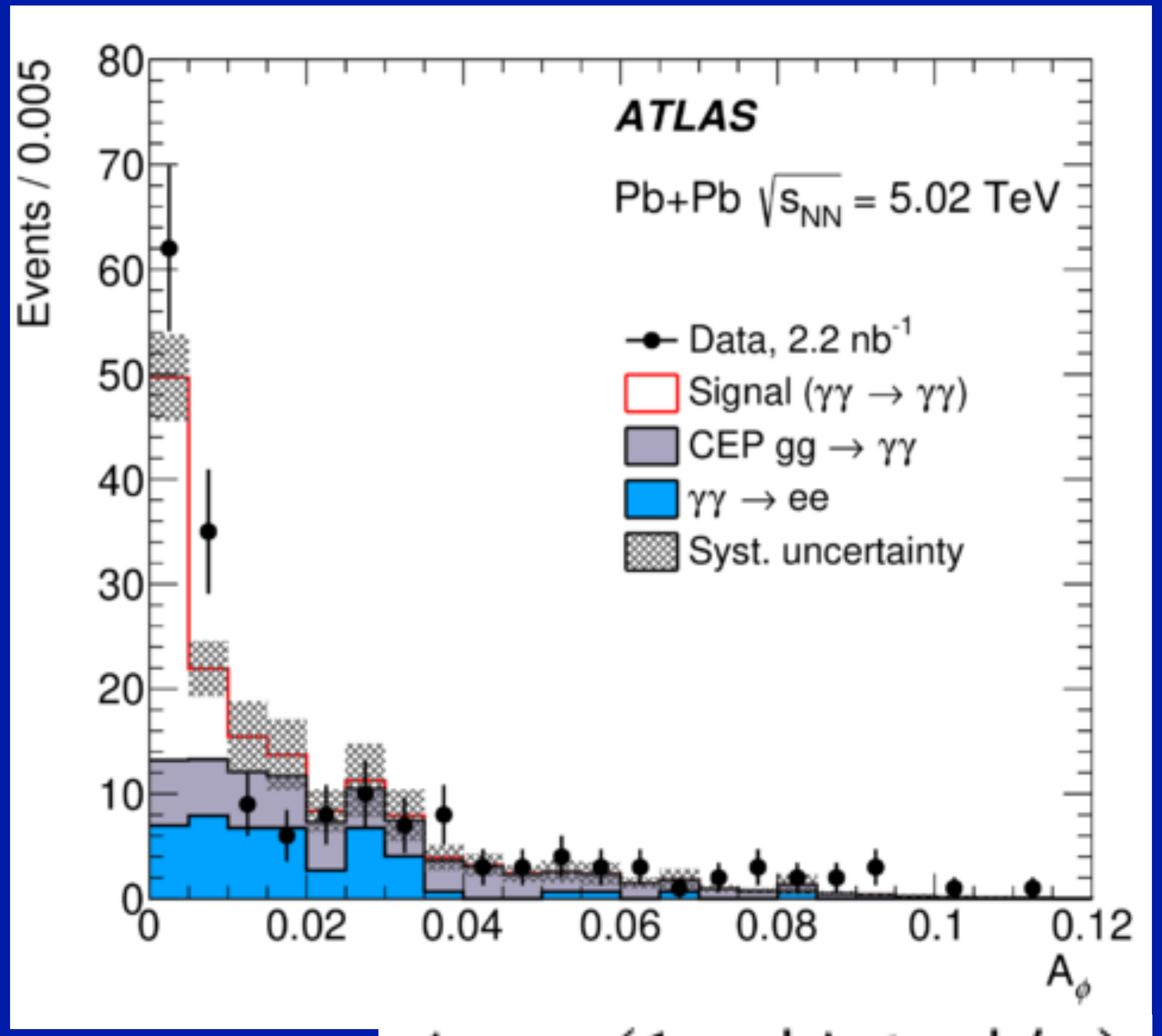
Most recent analysis (JHEP 03 (2021) 243)



$p_T^{\gamma} > 2.5$ GeV; $|\eta| < 2.4$;

$m_{\gamma\gamma} > 5$ GeV; $p_T^{\gamma\gamma} < 1$ GeV

acoplanarity, A_φ



$$A_\phi = (1 - |\Delta\phi_{\gamma\gamma}|/\pi)$$

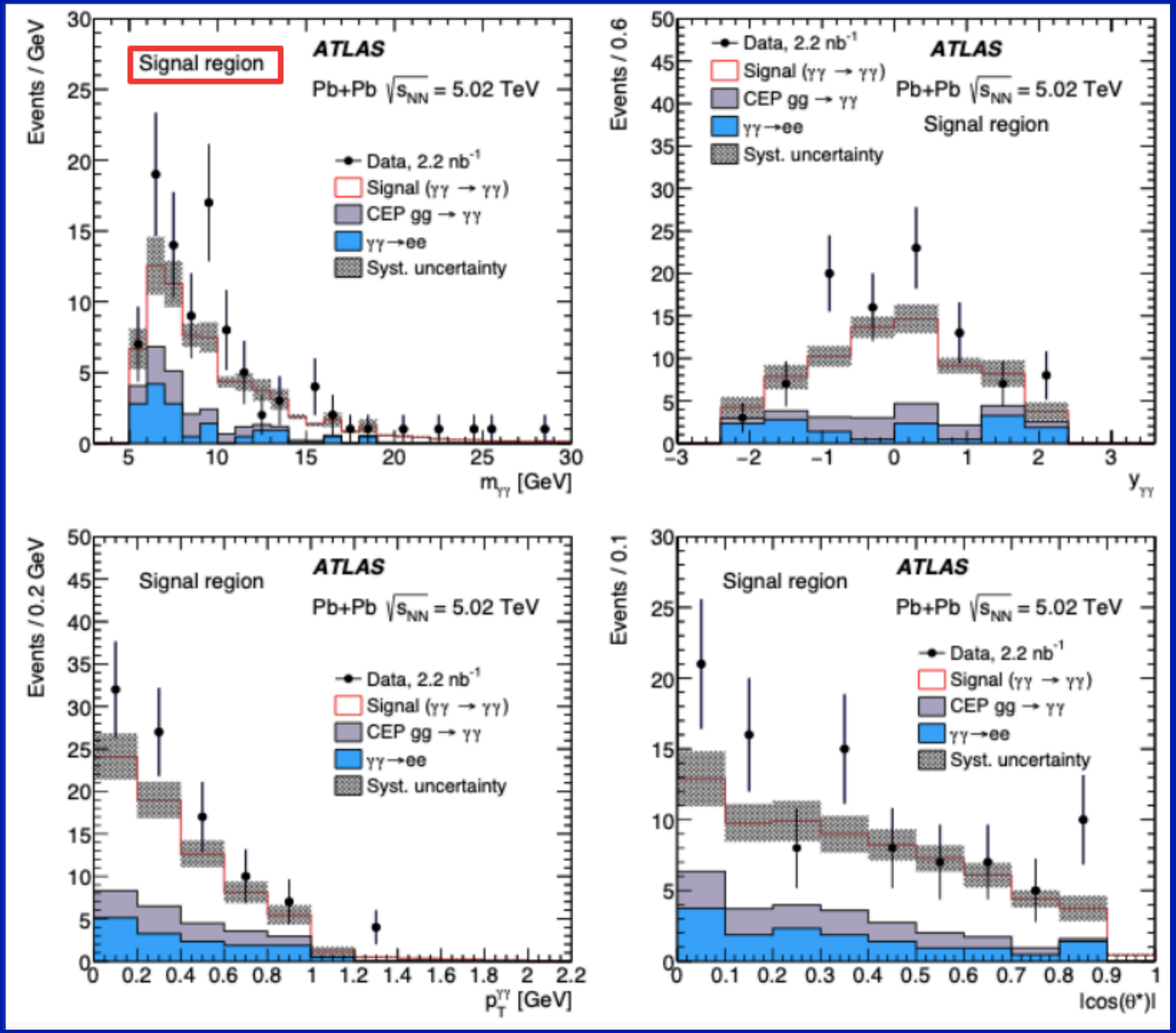
$A_\varphi < 0.01$ defined as the signal region

Xsection for γγ→γγ

$\sigma_{\text{fid}} = 120 \pm 17$ (stat)

± 13 (syst) ± 4 (lumi) nb

predicted: 80 ± 8 nb



kinematic distributions are consistent with SM

$\gamma\gamma \to \gamma\gamma$ in UPC - search for axion-like particles

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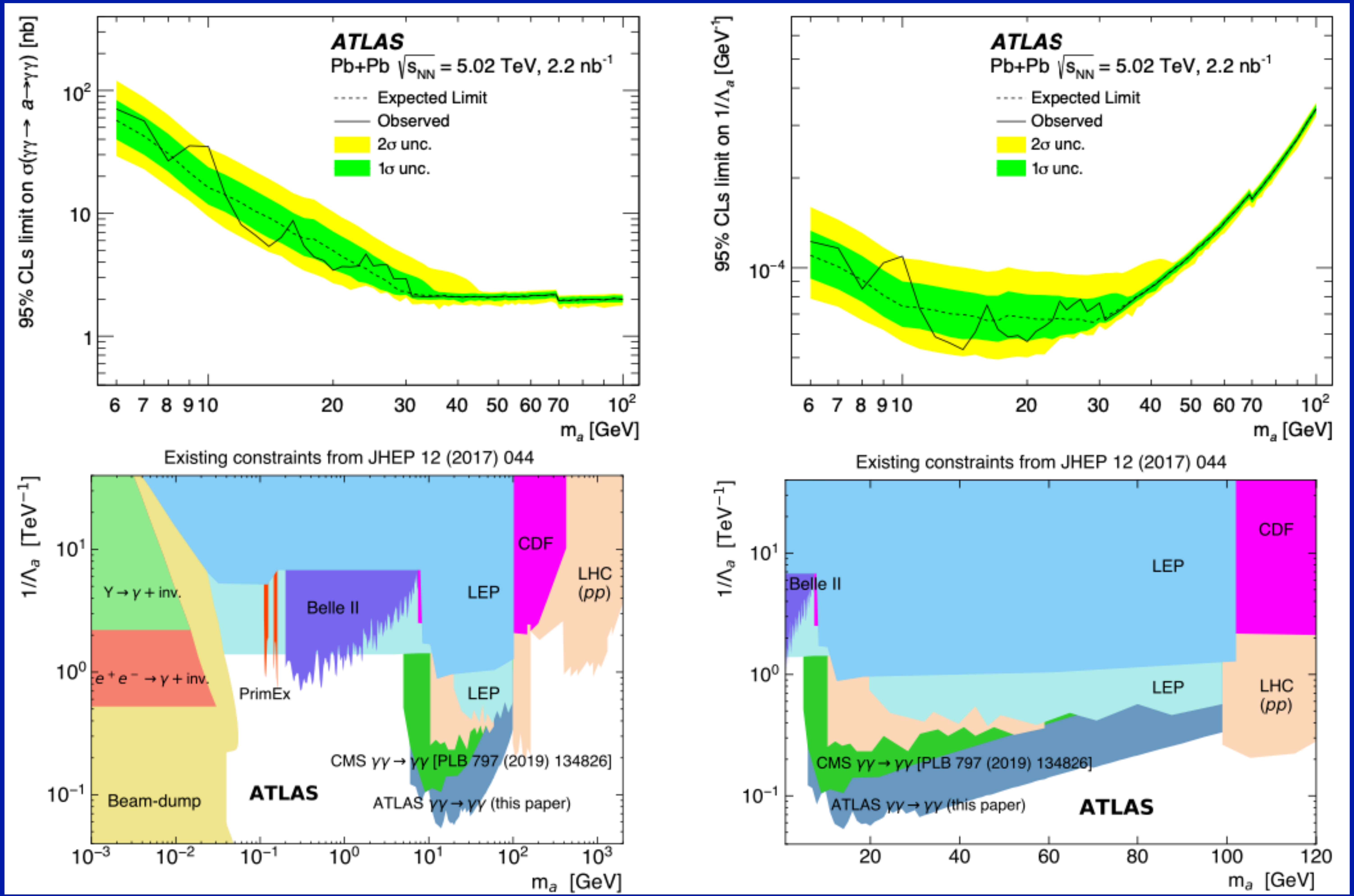
95% CL upper limit for $\gamma\gamma \to a \to \gamma\gamma$

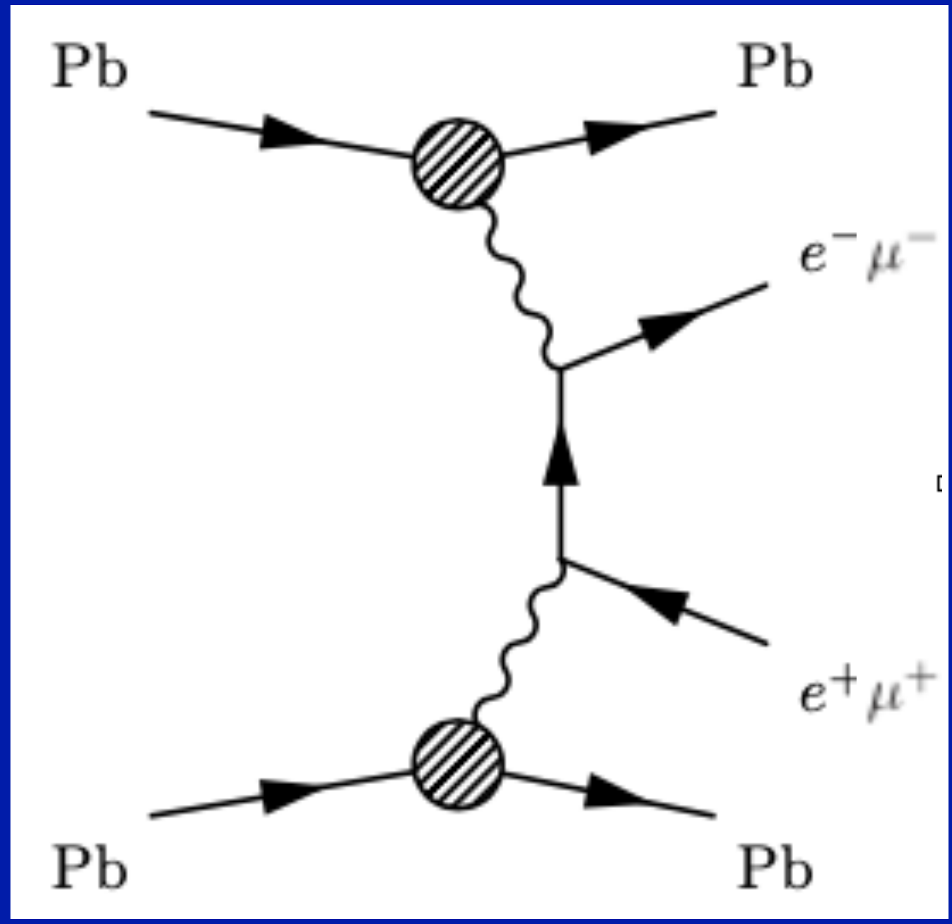
limits set on the cross section $\sigma_{\gamma\gamma \to a \to \gamma\gamma}$ for an axion with mass of 6 –100 GeV from 70 nb to 2 nb.



constraints on $1/\Lambda_a$ from 0.3 TeV^{-1} to 0.06 TeV^{-1}

important contribution of ATLAS to the exclusion limits for $6 < m_a < 100$ GeV

$\gamma\gamma\rightarrow ee$ in UPC

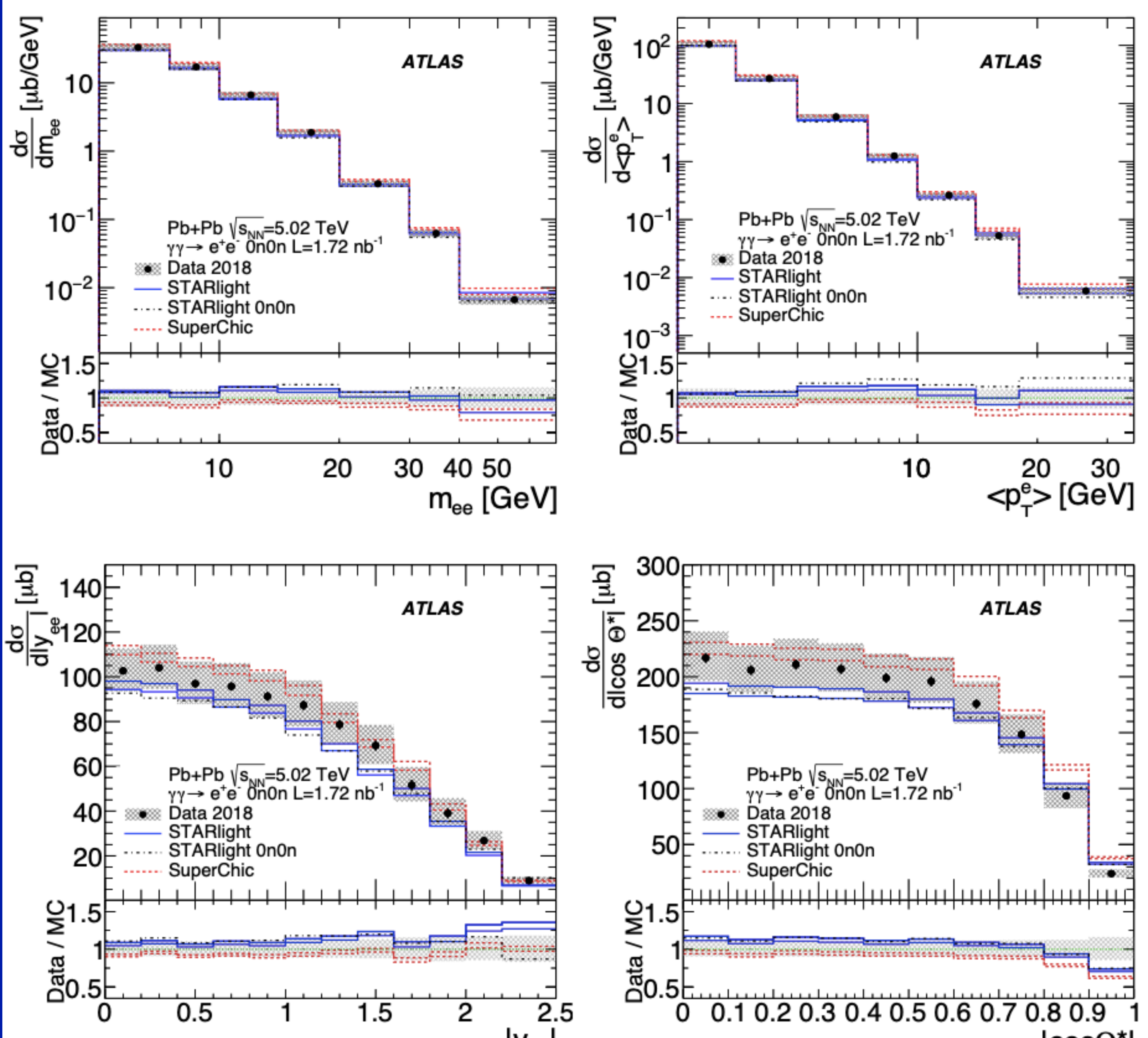


$p_T^e > 2.5$ GeV; $|\eta| < 2.5$;

$m_{ee} > 5$ GeV; $p_T^{ee} < 2$ GeV

backgrounds: dissociative e-pair production; Υ-meson; exclusive $\tau\tau$

Xsection as a function of m_{ee}, $<p_T^e>$, $|y_{ee}|$ and $|\cos\theta^*|$



arXiv:2207.12781 [nucl-ex]

Xsection for $\gamma\gamma\rightarrow ee$

$\sigma_{fid} = 215 \pm 1 \text{ (stat)} ^{+23}_{-20} \text{ (syst)} \pm 4 \text{ (lumi) } \mu b$

predicted: STARLIGHT 196.9 μb; SUPERCHIC 235.1 μb

differential Xsections well described by STARLIGHT and SUPERCHIC, with exception for high $|y_{ee}|$ and $|\cos\theta^*|$

Messages from Runs 1 & 2 data

✓ dijet p_T balance is recovered at large leading jet p_T

✓ jet suppression is sensitive to the Casimir colour factor of the initial parton

✓ reclustered R=1.0 jets with single sub-jet less quenched than those with complex substructure; jets with wider hard splittings are significantly more suppressed in central collisions suggesting decoherent energy loss

✓ *b*-jets less suppressed (20%) in central and mid-central collisions at the same reconstructed p_T as expected from the dead-cone effect

✓ increase of suppression of the Υ states with centrality. Excited states significantly more suppressed

✓ important contribution of ATLAS to axion exclusion limits for $6 < m_a < 100$ GeV

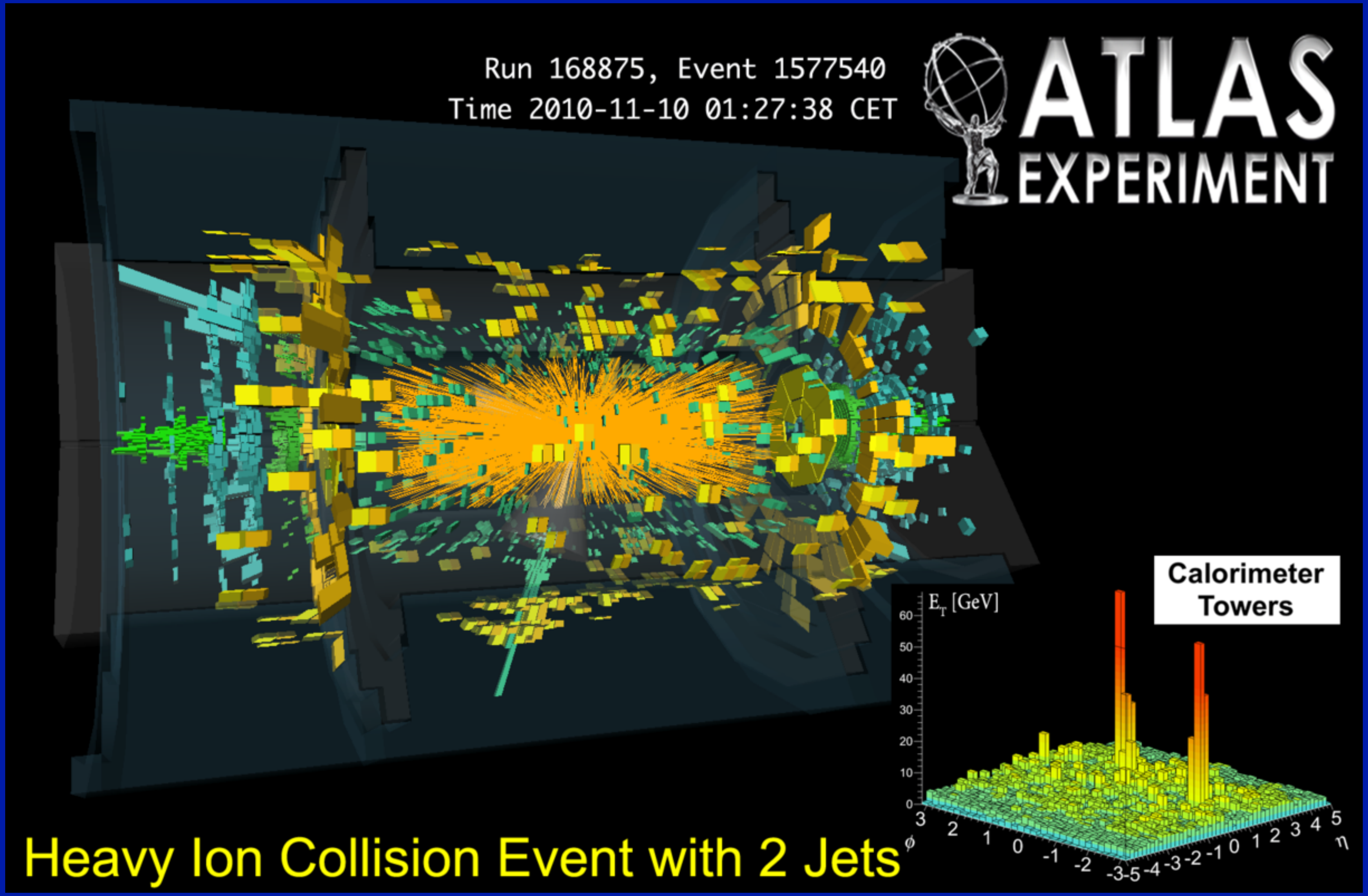
✓ $\gamma\gamma \rightarrow ee$ cross-sections confirm Standard Model predictions

Good progress in the interpretation of the data

Outlook

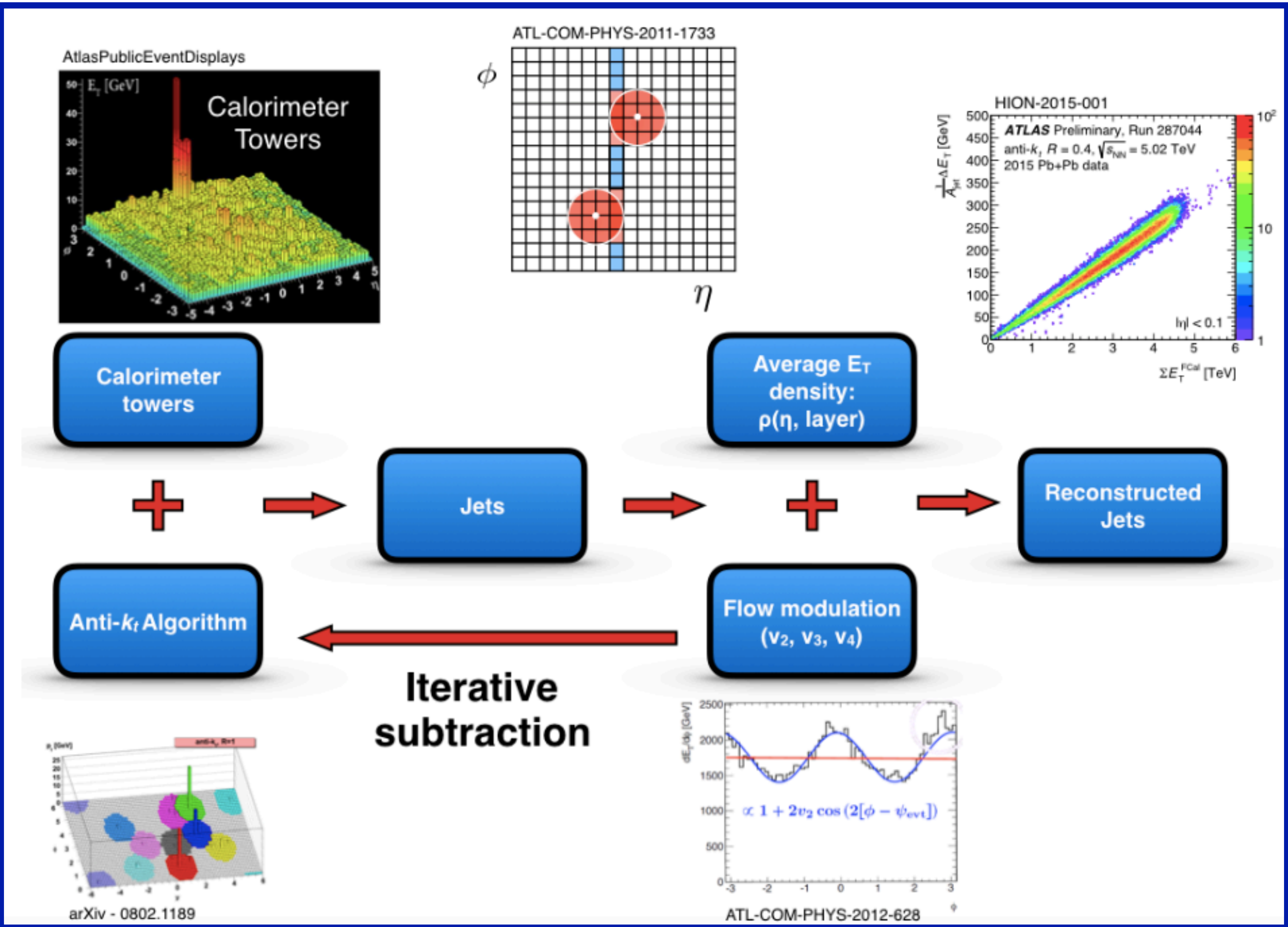
Stay tuned to Run 3 data (first run postponed to 2023)

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

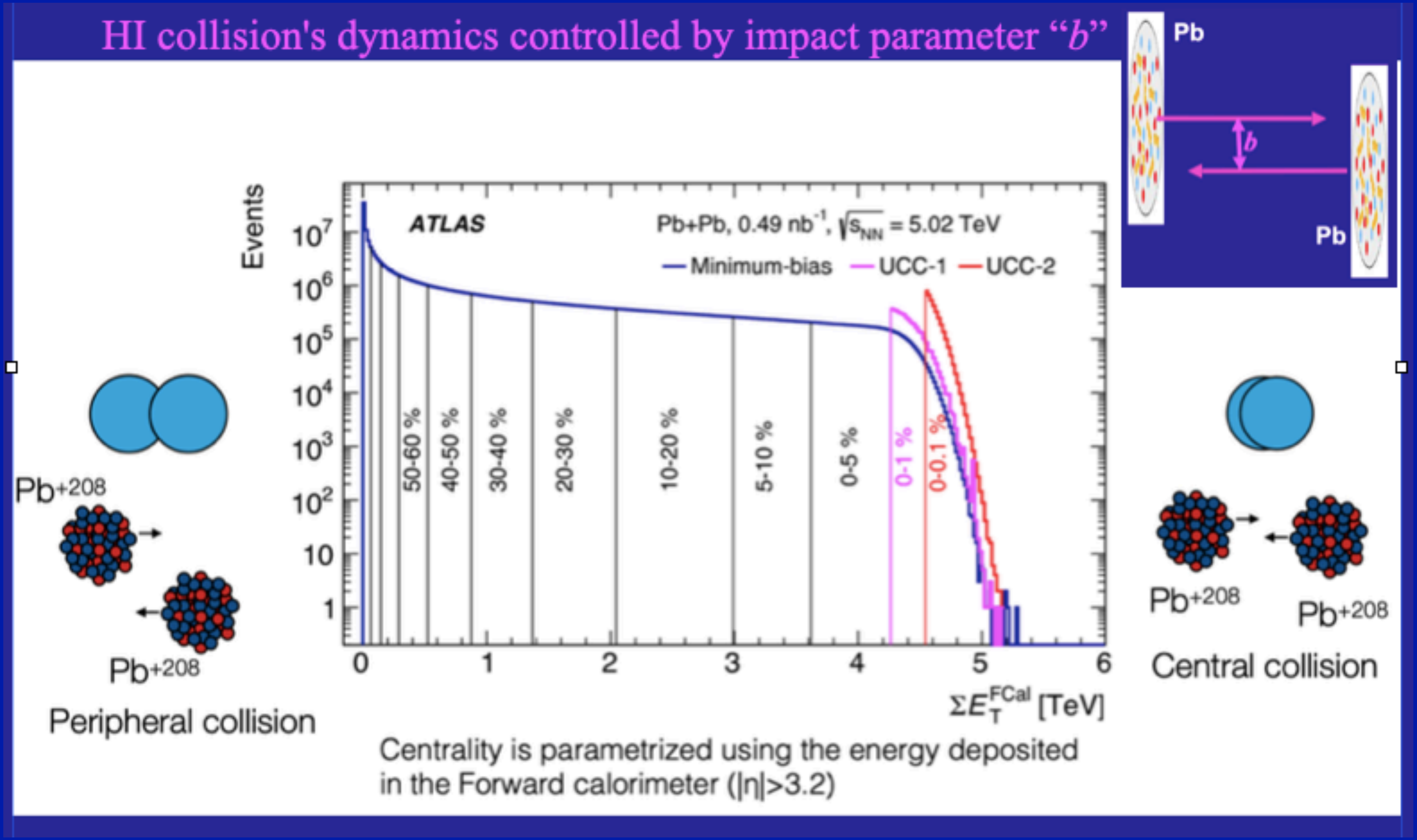


backup

Jet reconstruction in Pb+Pb collisions

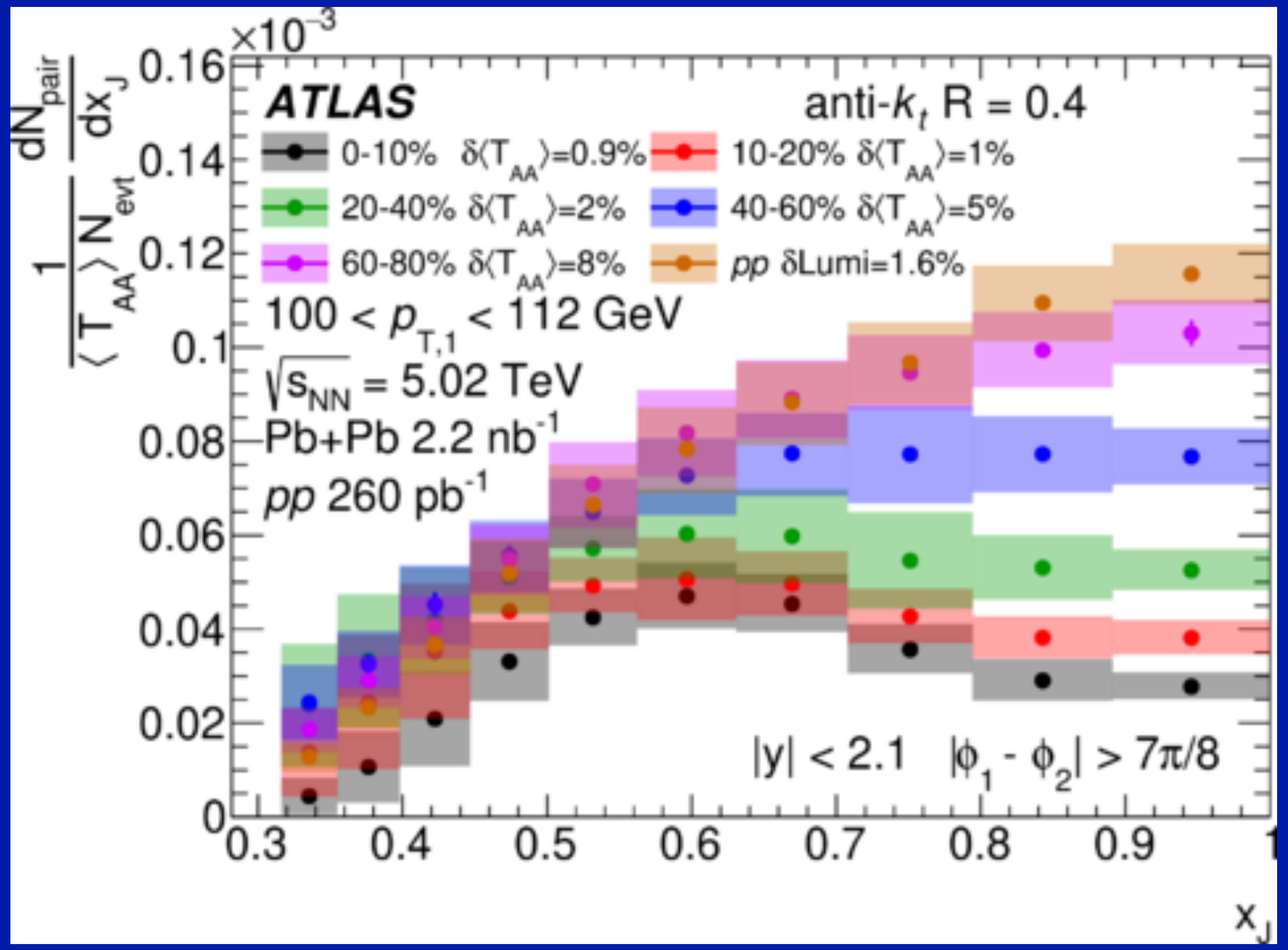


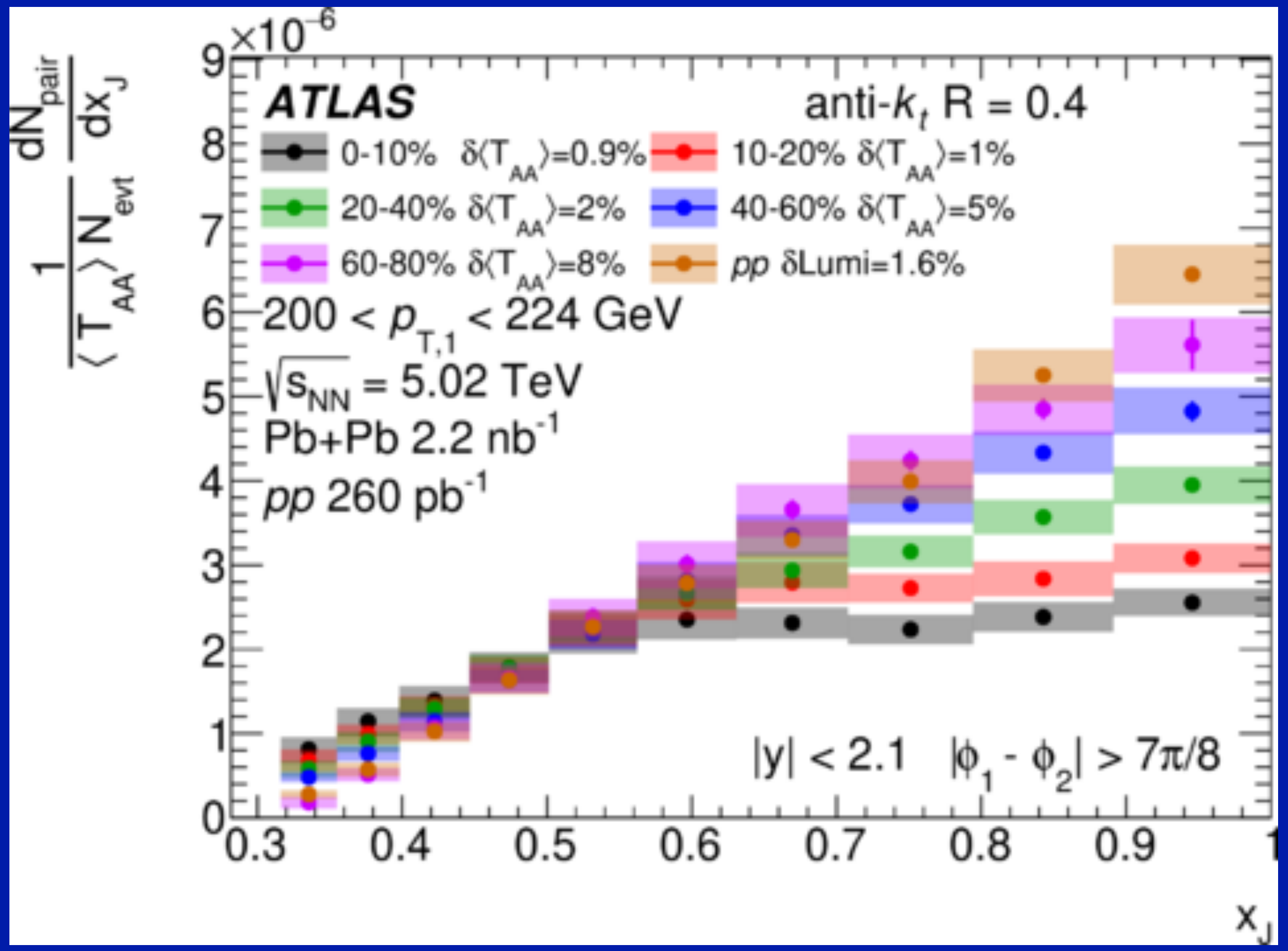
Collisions centrality

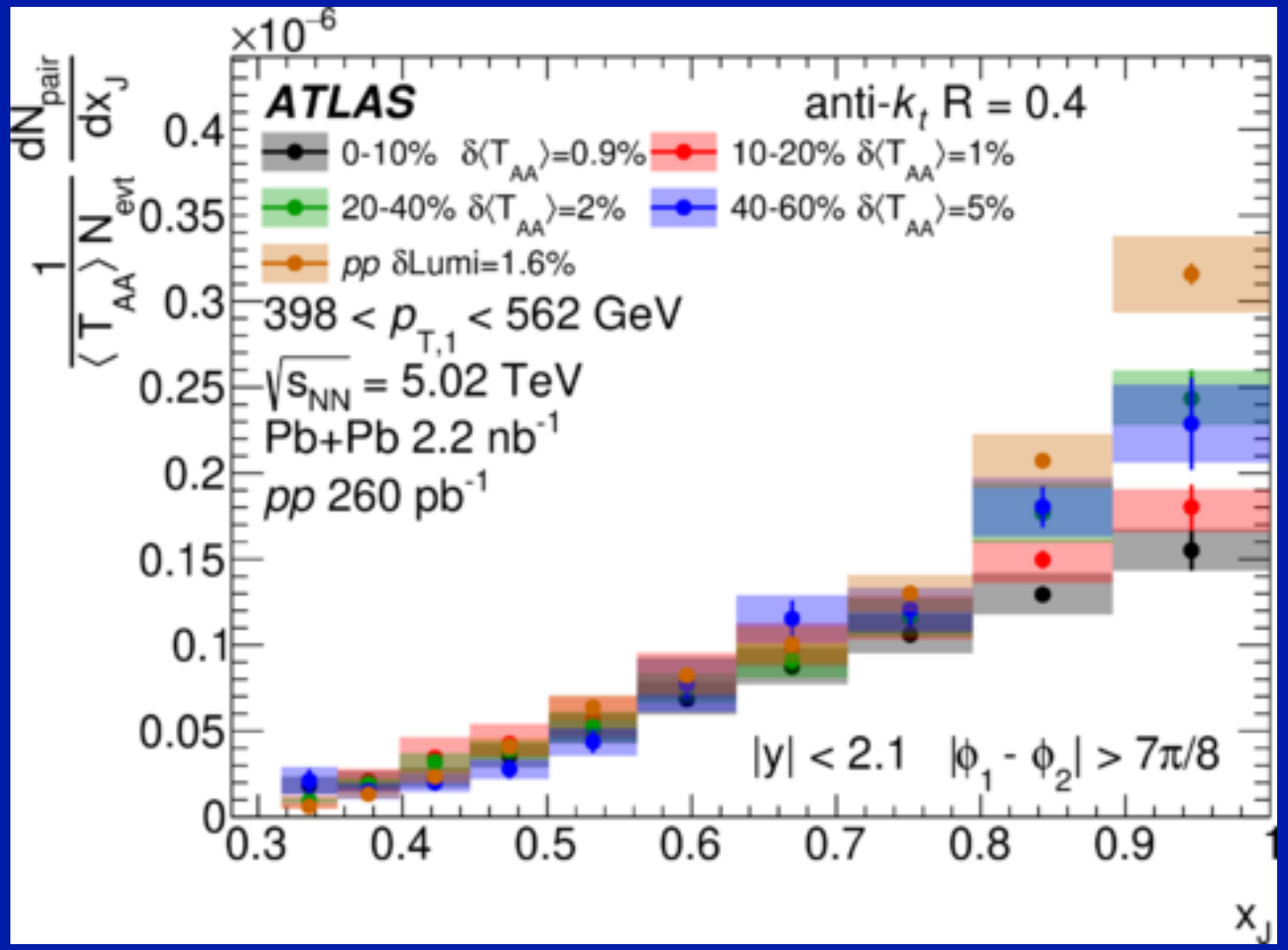


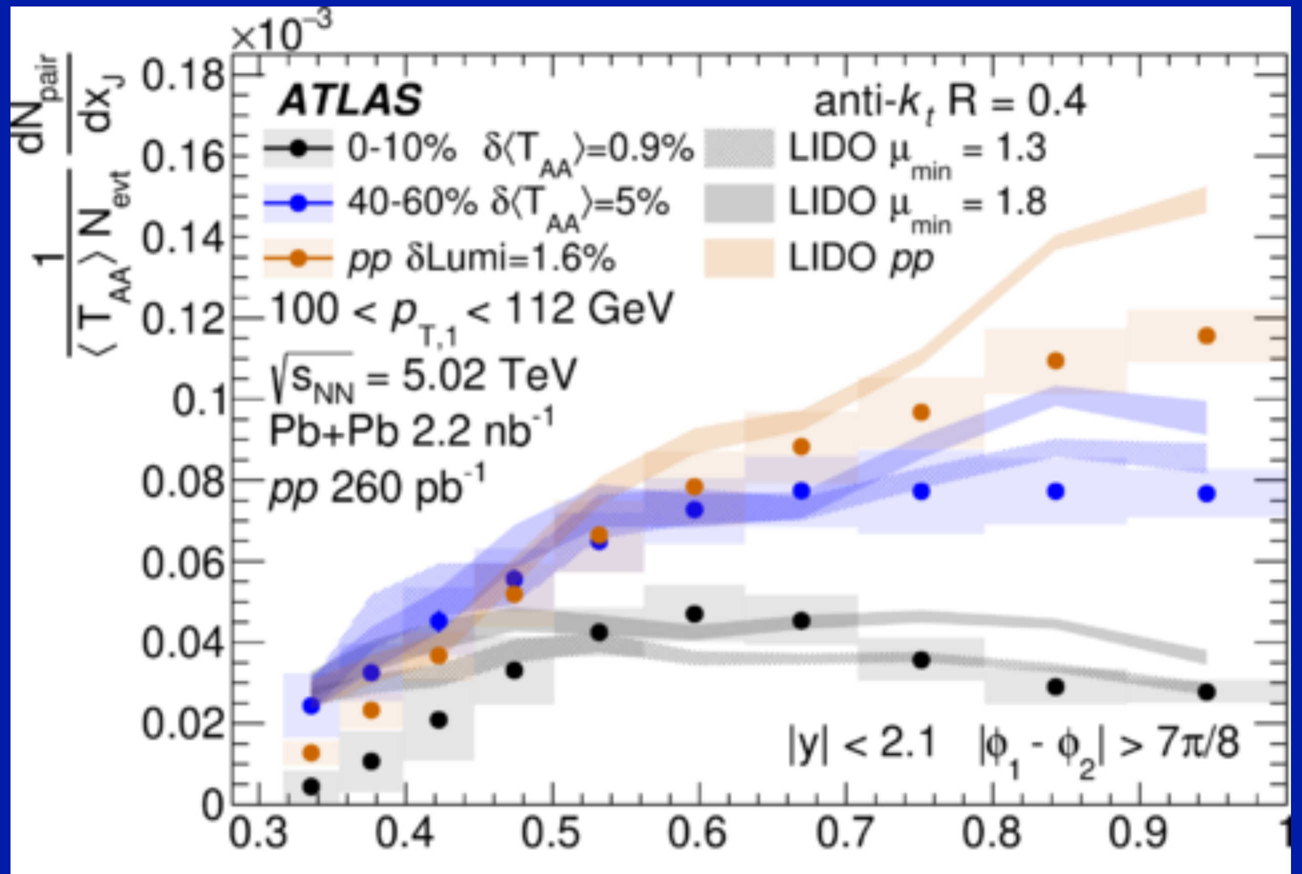
Dijet asymmetry in PbPb and *pp* collisions

dijet distributions as a function of $x_J = p_{T2}/p_{T1}$

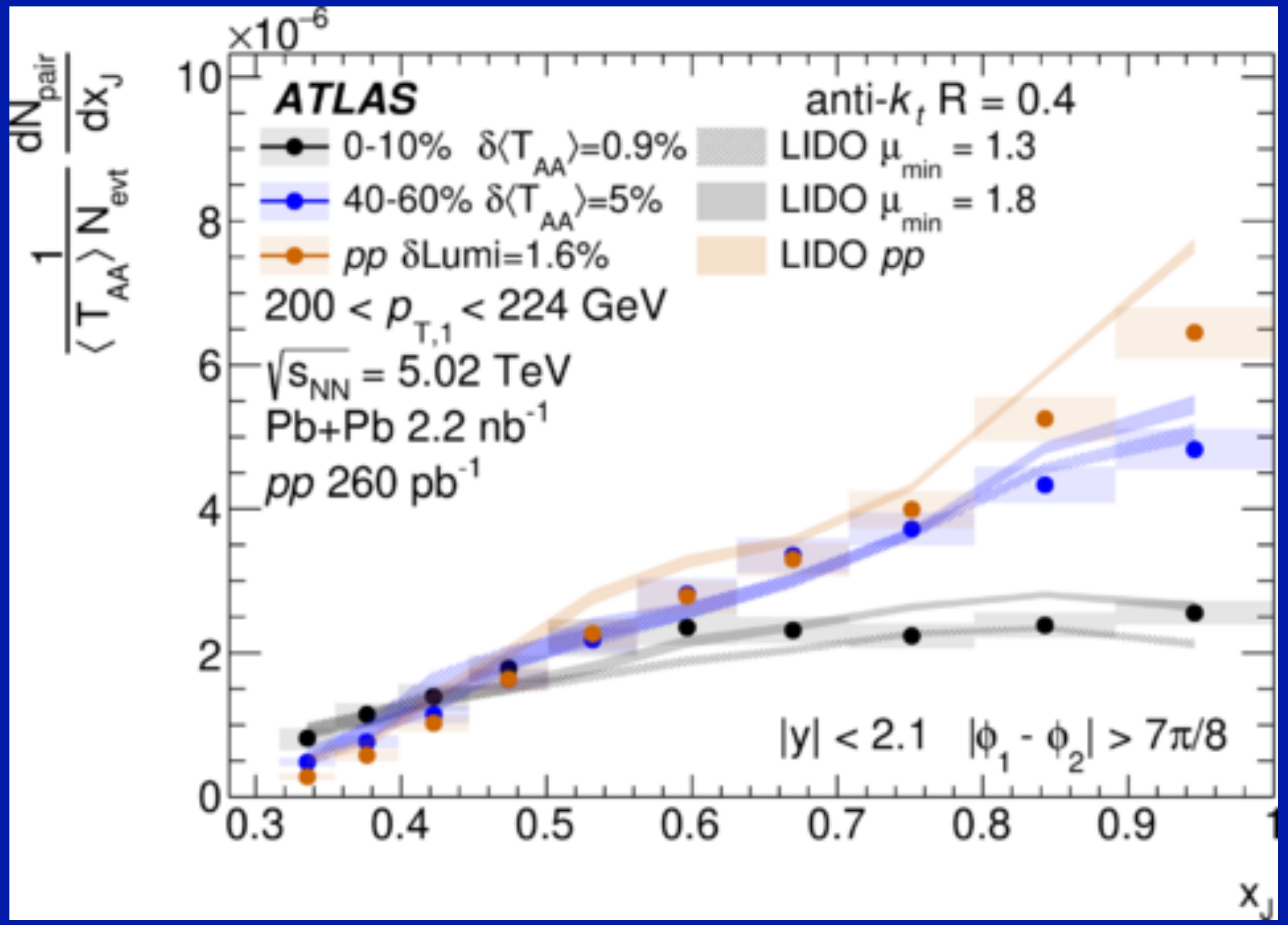








arXiv:2205.00682 [nucl-ex]



Quark jet fraction

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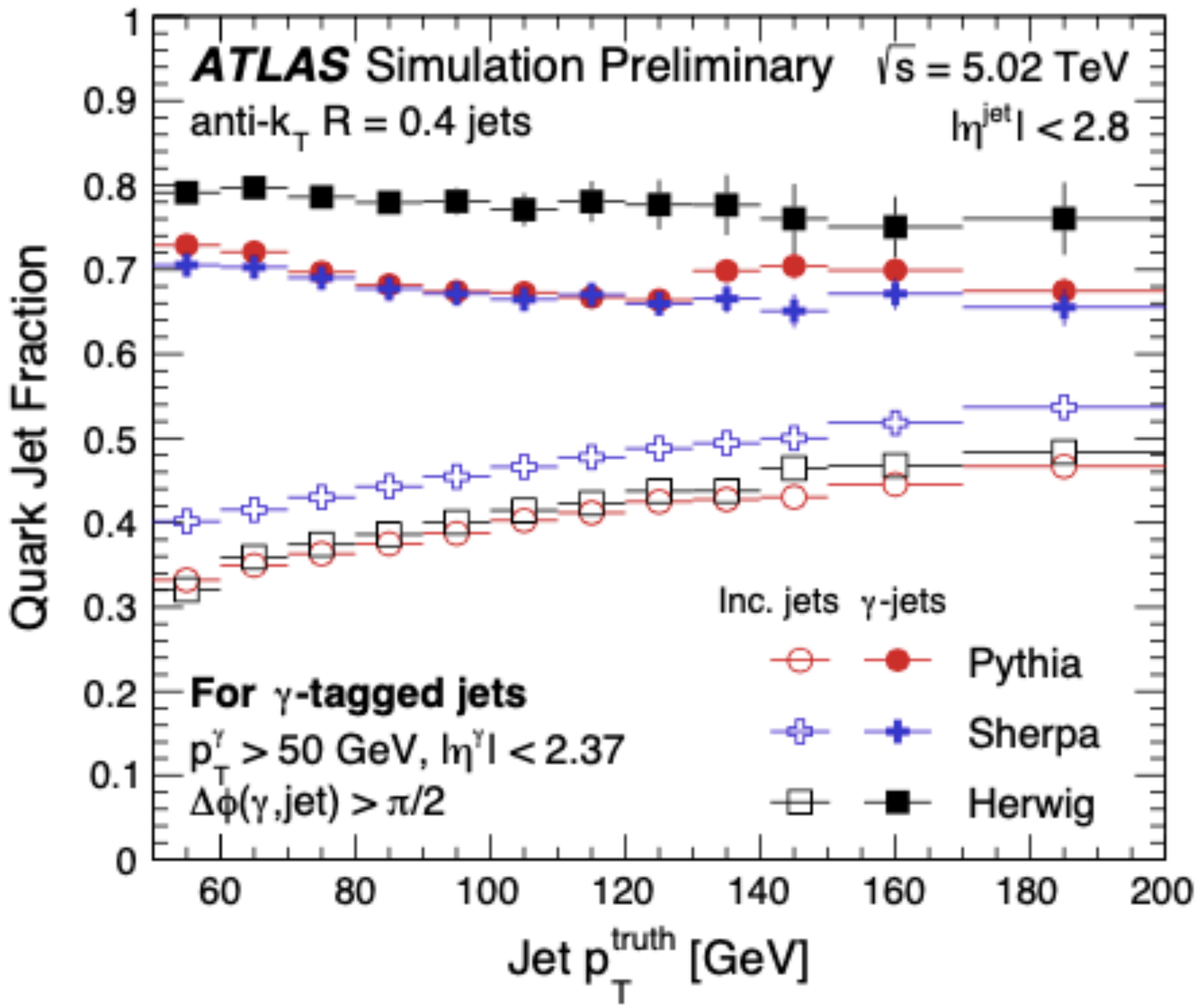
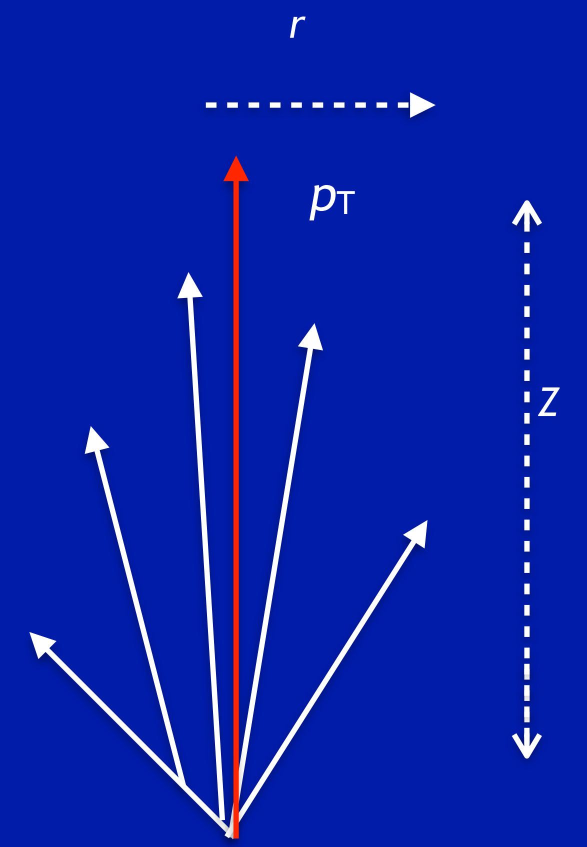


Figure 1: Fraction of photon-tagged jets (filled markers) and inclusive jets (open markers) initiated by a quark, as a function of p_T^{jet}, in the PYTHIA (red), HERWIG (black), and SHERPA (blue) event generators.

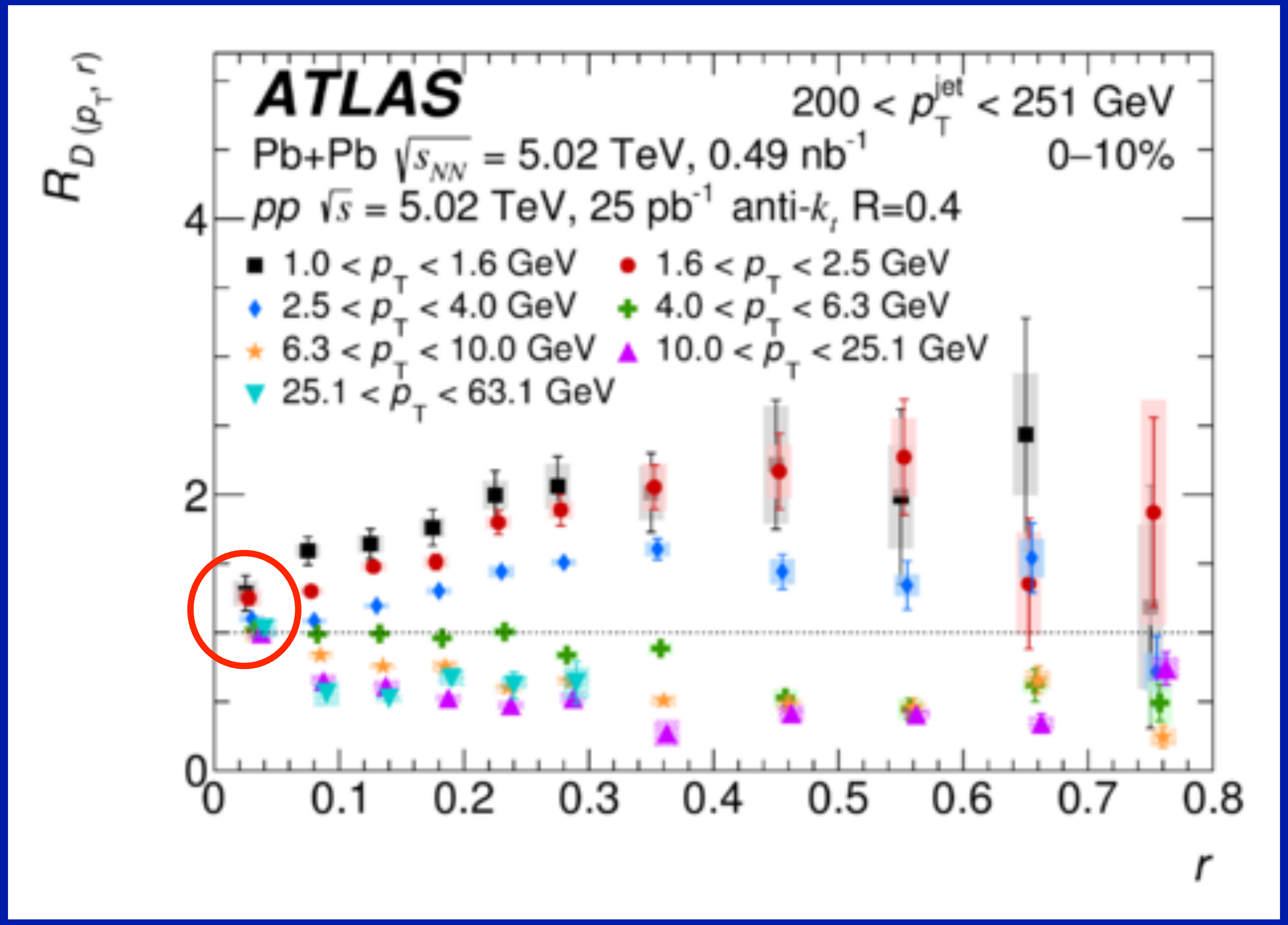
PRC 100 (2019) 064901

Study *FF* as a function of the angular distance between the charged particle and the jet axis.



$$D(p_{\mathrm{T}}, r) = \frac{1}{N_{\mathrm{jet}}} \frac{1}{2\pi r} \frac{\mathrm{d}^2 n_{\mathrm{ch}}(r)}{\mathrm{d}r\,\mathrm{d}p_{\mathrm{T}}}$$

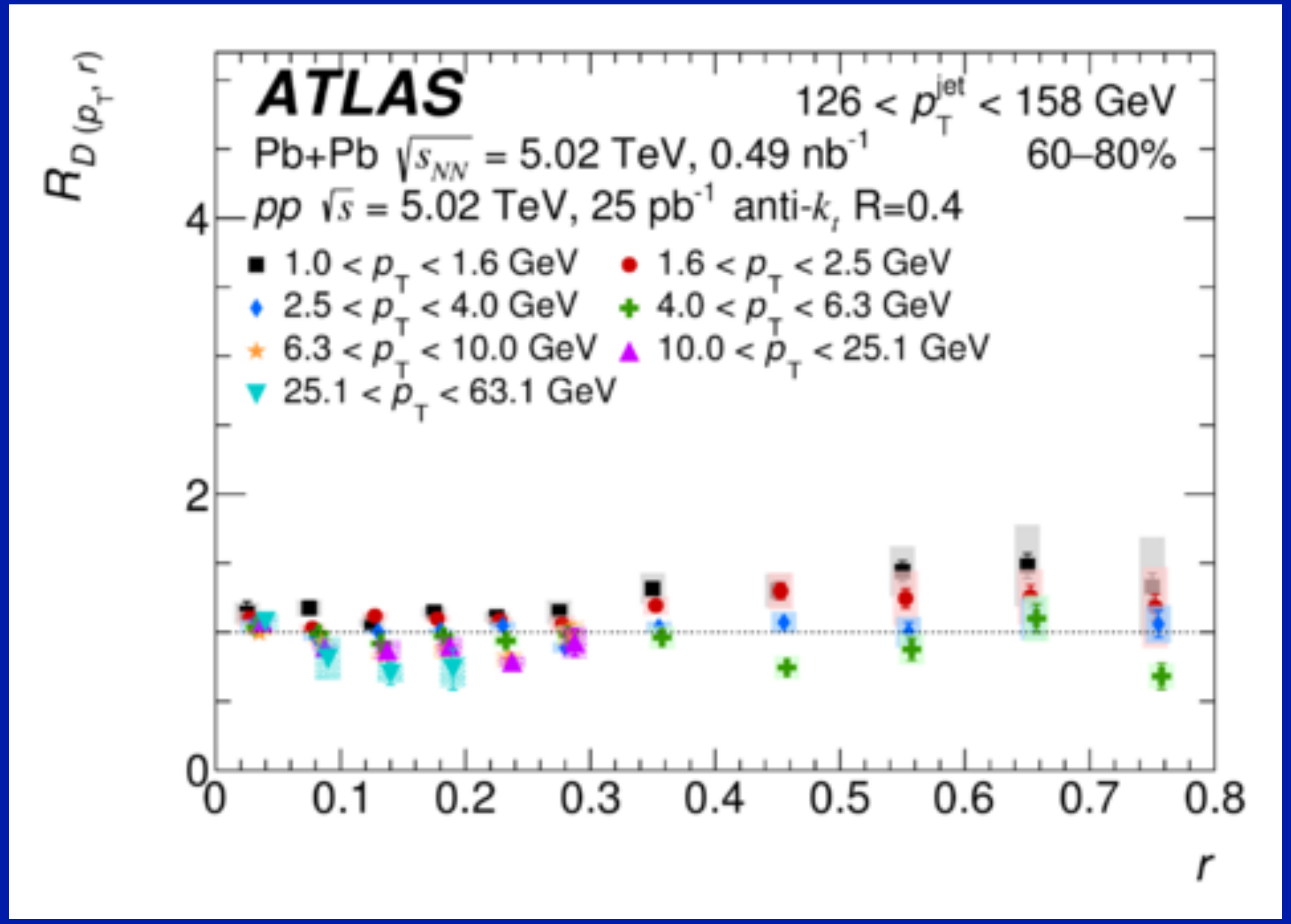
$$r = \sqrt{\Delta\eta^2 + \Delta\phi^2}$$



In central collisions $R_{D(p_{\mathrm{T}},r)}$ is above unity at all r for all $p_{\mathrm{T}} < 4$ GeV —> Energy lost by jets is being transferred to particles with $p_{\mathrm{T}} < 4$ GeV with larger radial distance.

Modification much lower in peripheral collisions.

Jet core remains unmodified.



Jet substructure uncertaitnties

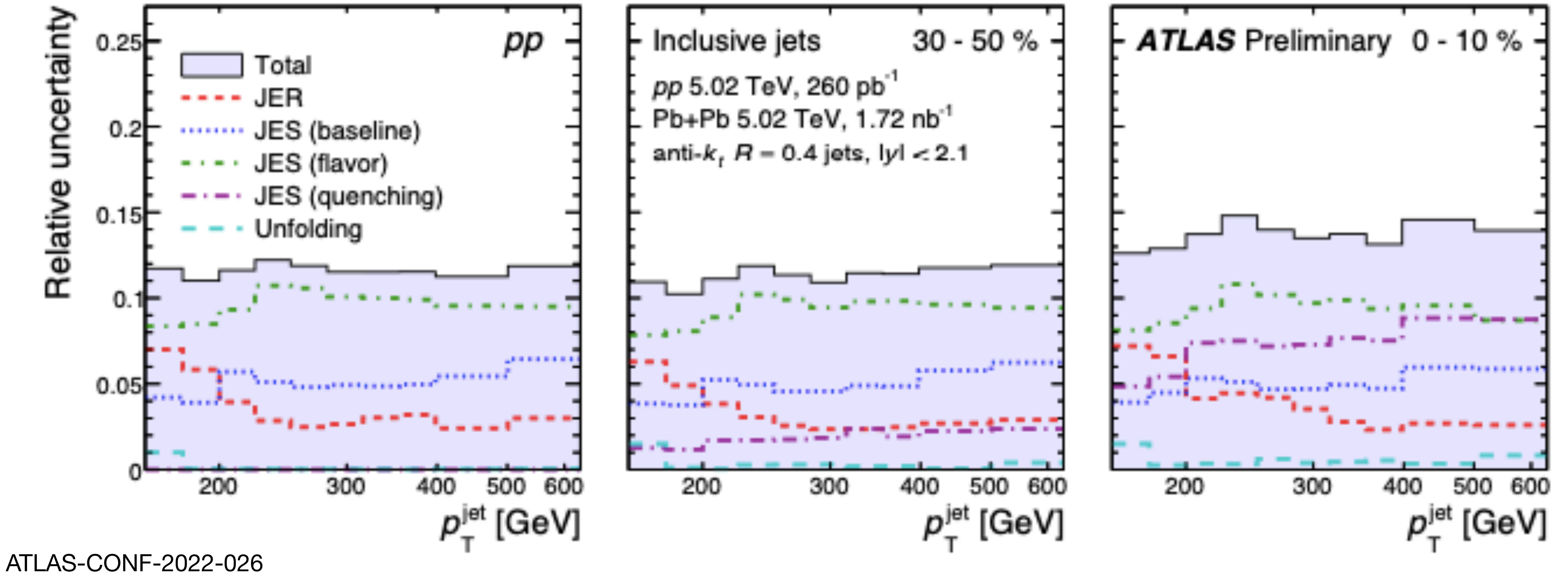


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Figure 2: The relative systematic uncertainties on inclusive p_T^{jet} cross-section and per-event jet yield measurements in pp collisions at $\sqrt{s}$ = 5.02 TeV (left) and for different event centralities in Pb+Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV (second and third panels). The legend applies to all the panels.

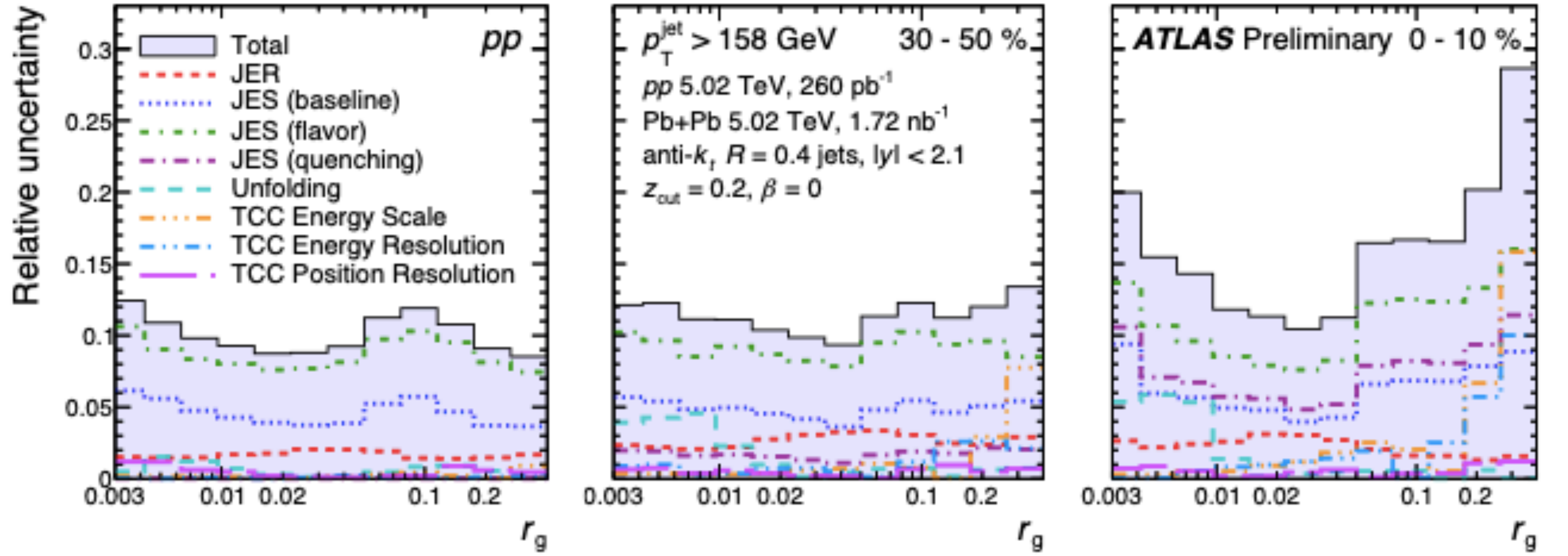


Figure 3: The relative systematic uncertainties on inclusive r_g cross-section and per-event jet yield measurements in pp collisions at $\sqrt{s}$ = 5.02 TeV (left) and for different event centralities in Pb+Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV (second and third panels) shown for soft-drop parameters z_{cut} = 0.2 and β = 0. The legend applies to all the panels.

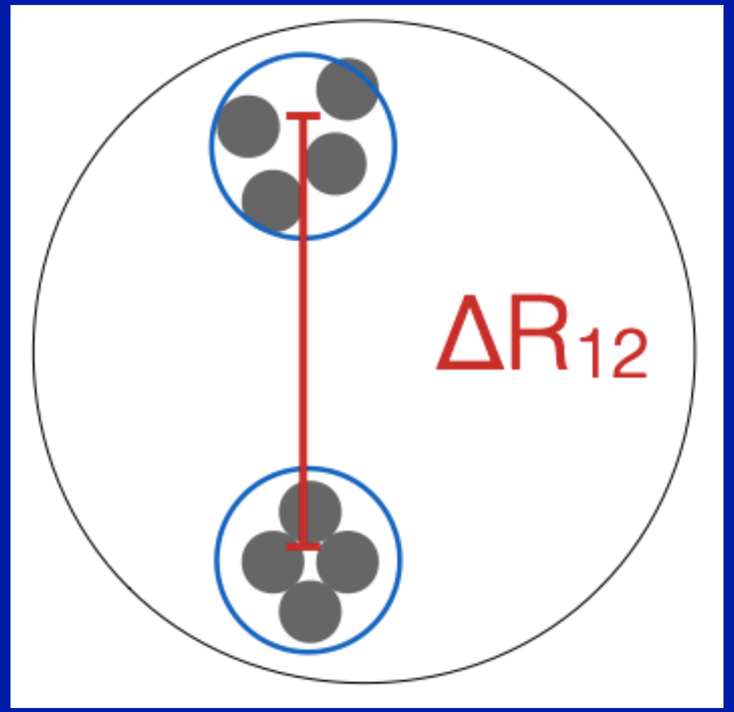
Reclustered large jets ($R = 1.0$)

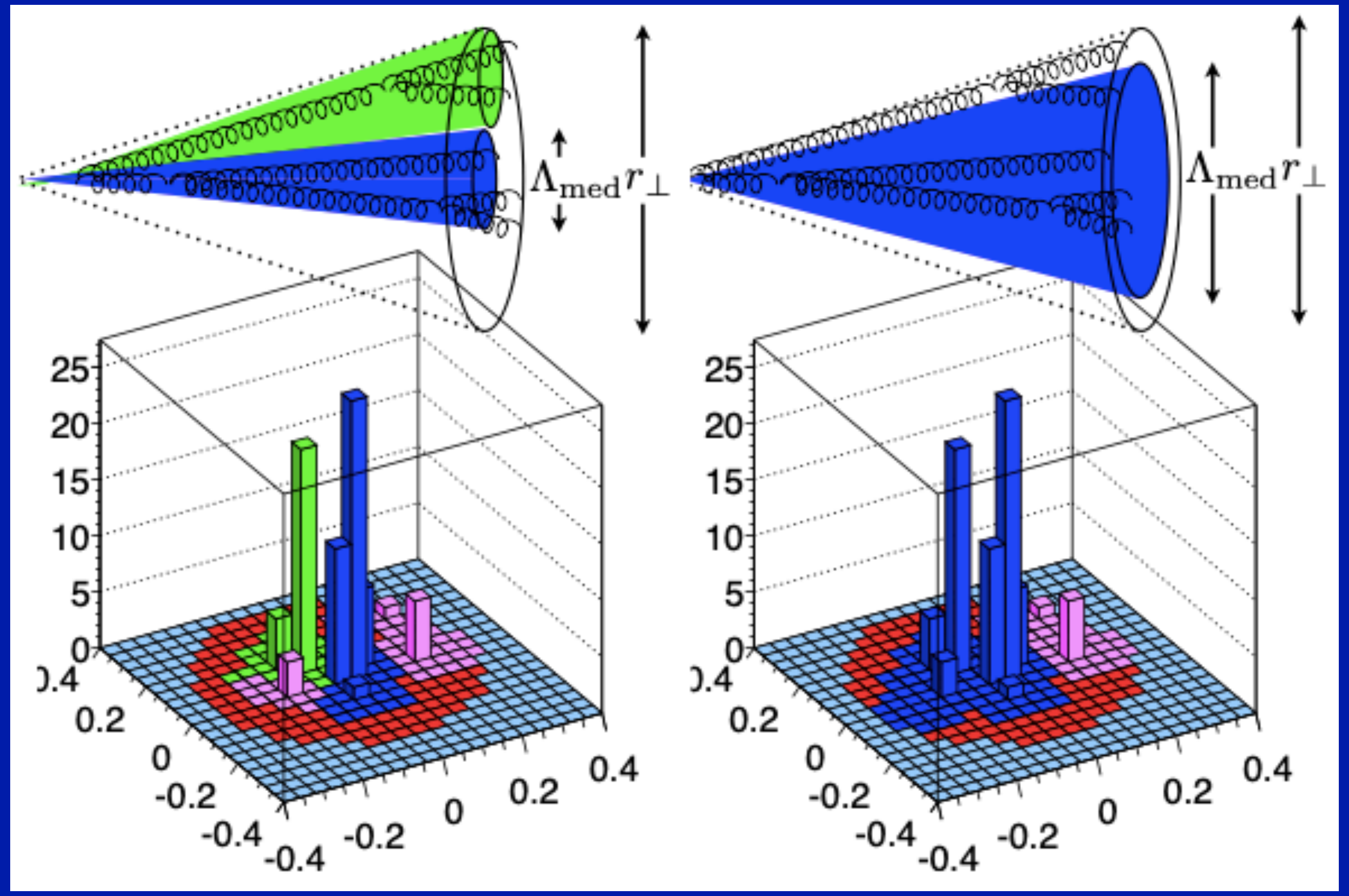
R = 0.2 jets with p_T > 35 GeV reclustered into anti-k_t R =1.0

$$R_{AA} = \frac{N_{AA}}{\langle T_{AA} \rangle \times \sigma_{pp}}$$

study of k_t splitting scale

$$\sqrt{d_{12}} = \min(p_{T,1}, p_{T,2}) \cdot \Delta R_{12}$$





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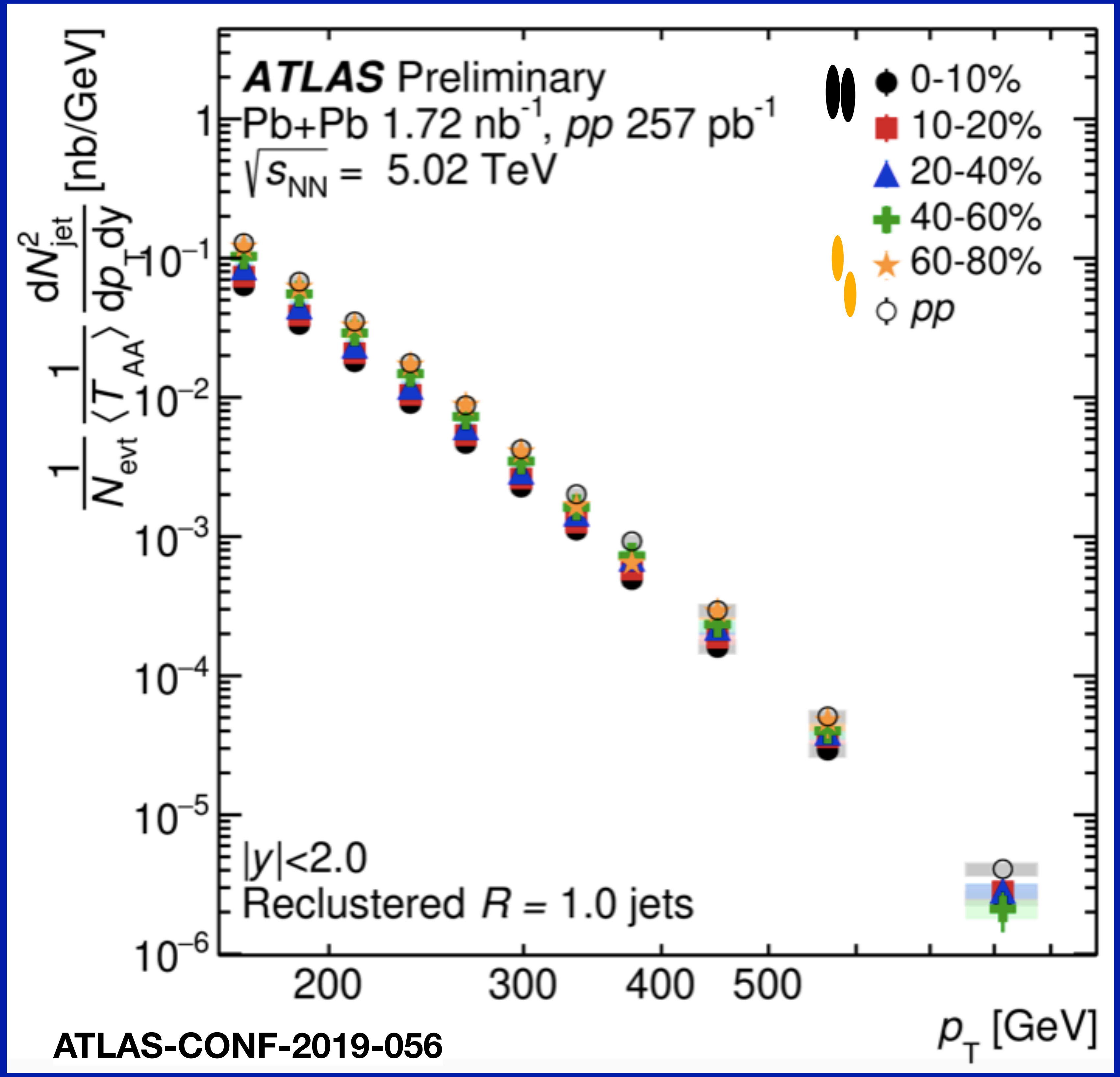
Recluster jets and remove soft contributions



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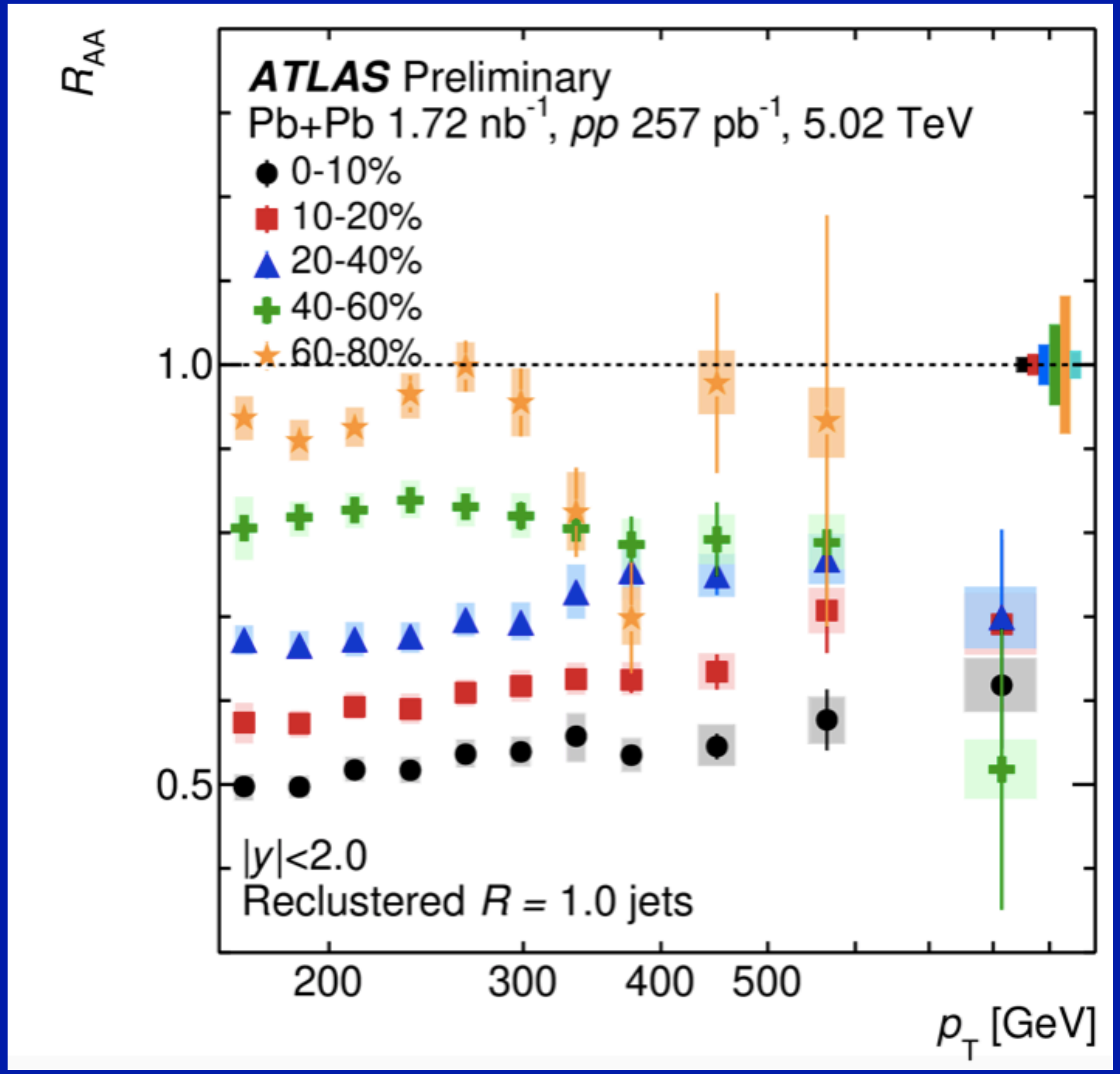
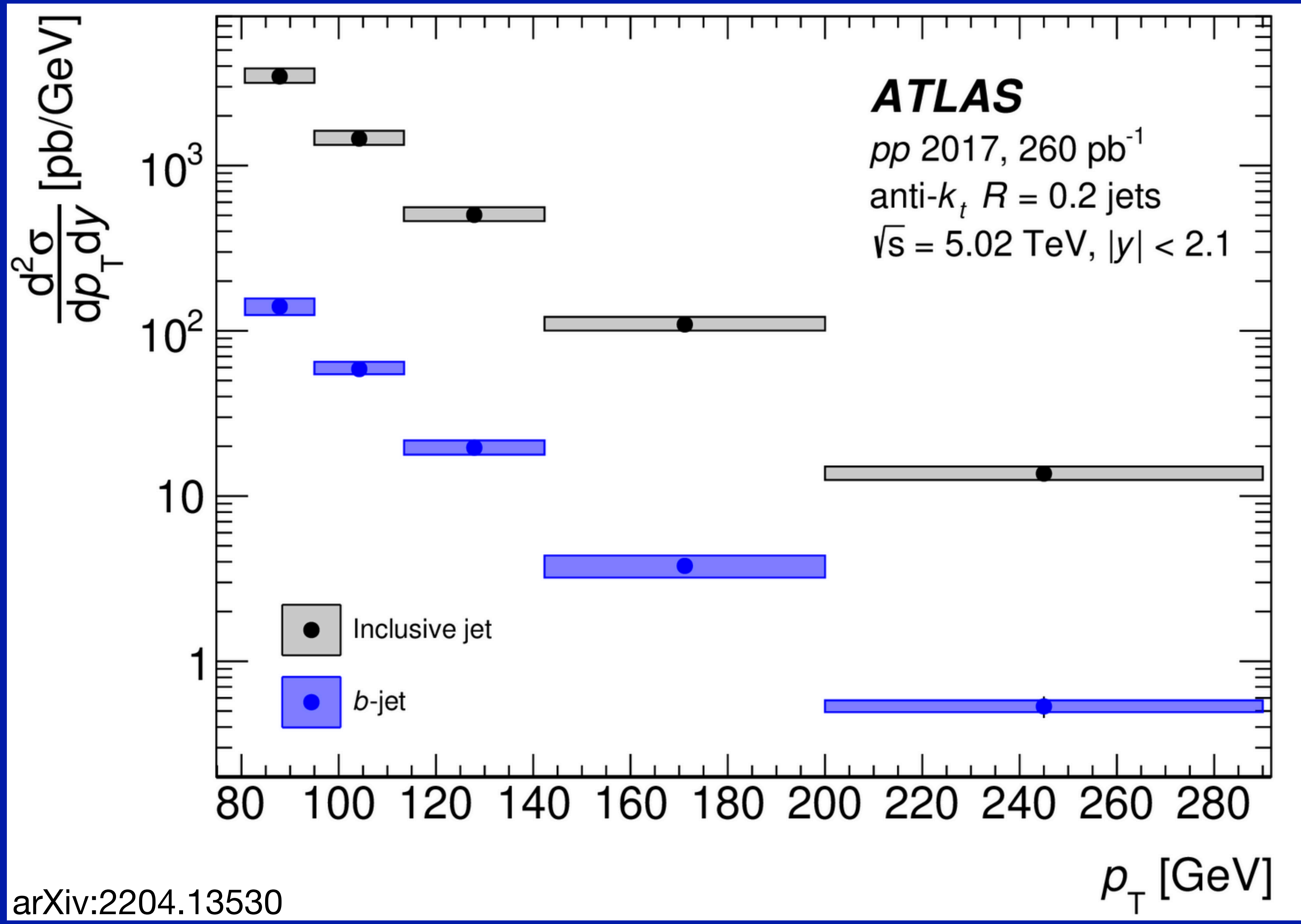


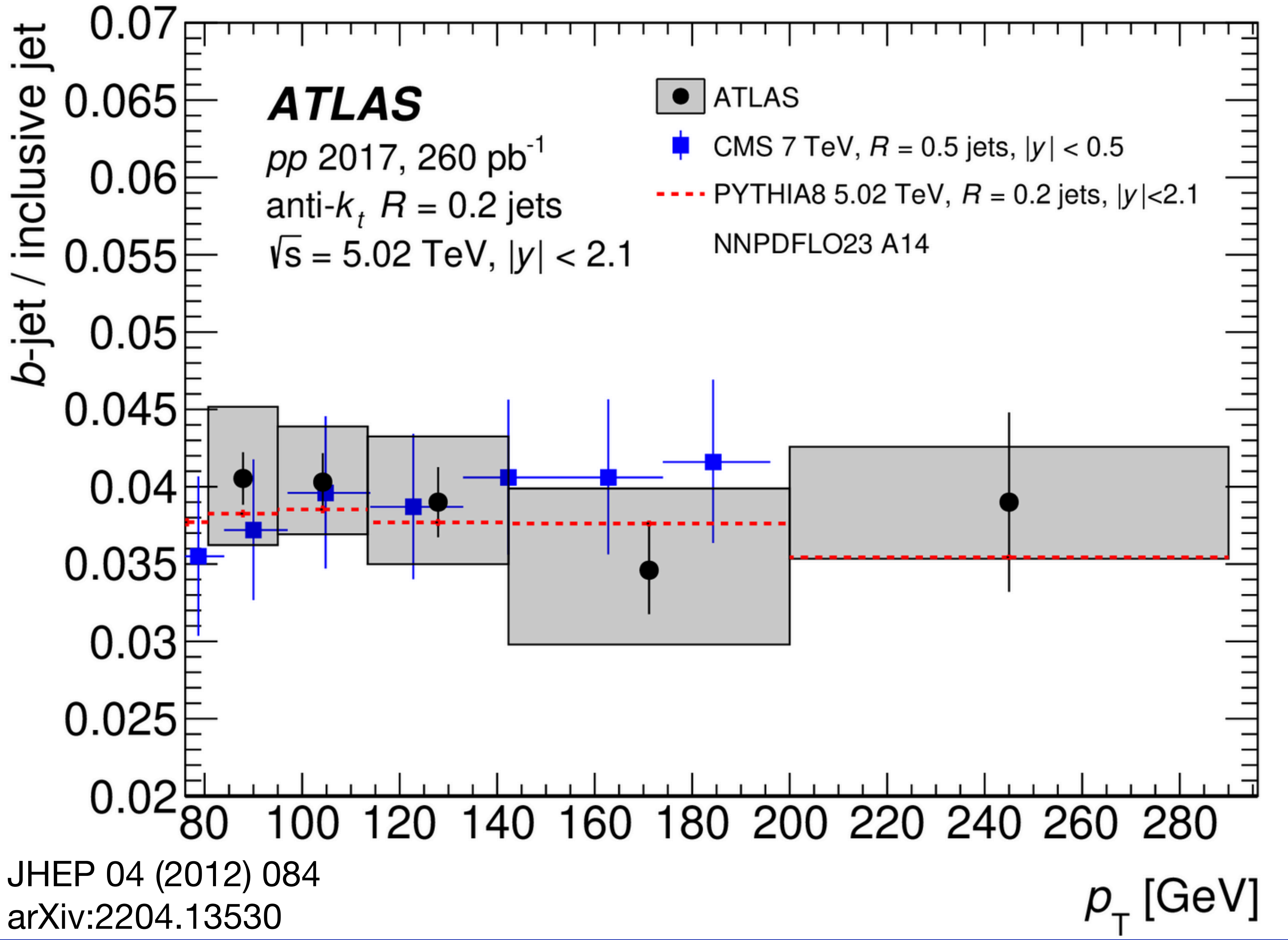
Large-R jets (reclustered with R = 0.2 jets and soft particles removed) are increasingly suppressed with centrality.

b-jets and inclusive jets cross section in *pp* collisions

Cross-section of R=0.2 *b*- and inclusive jets in *pp* collisions at 5.02 TeV



b-jet to inclusive jet cross-section ratio

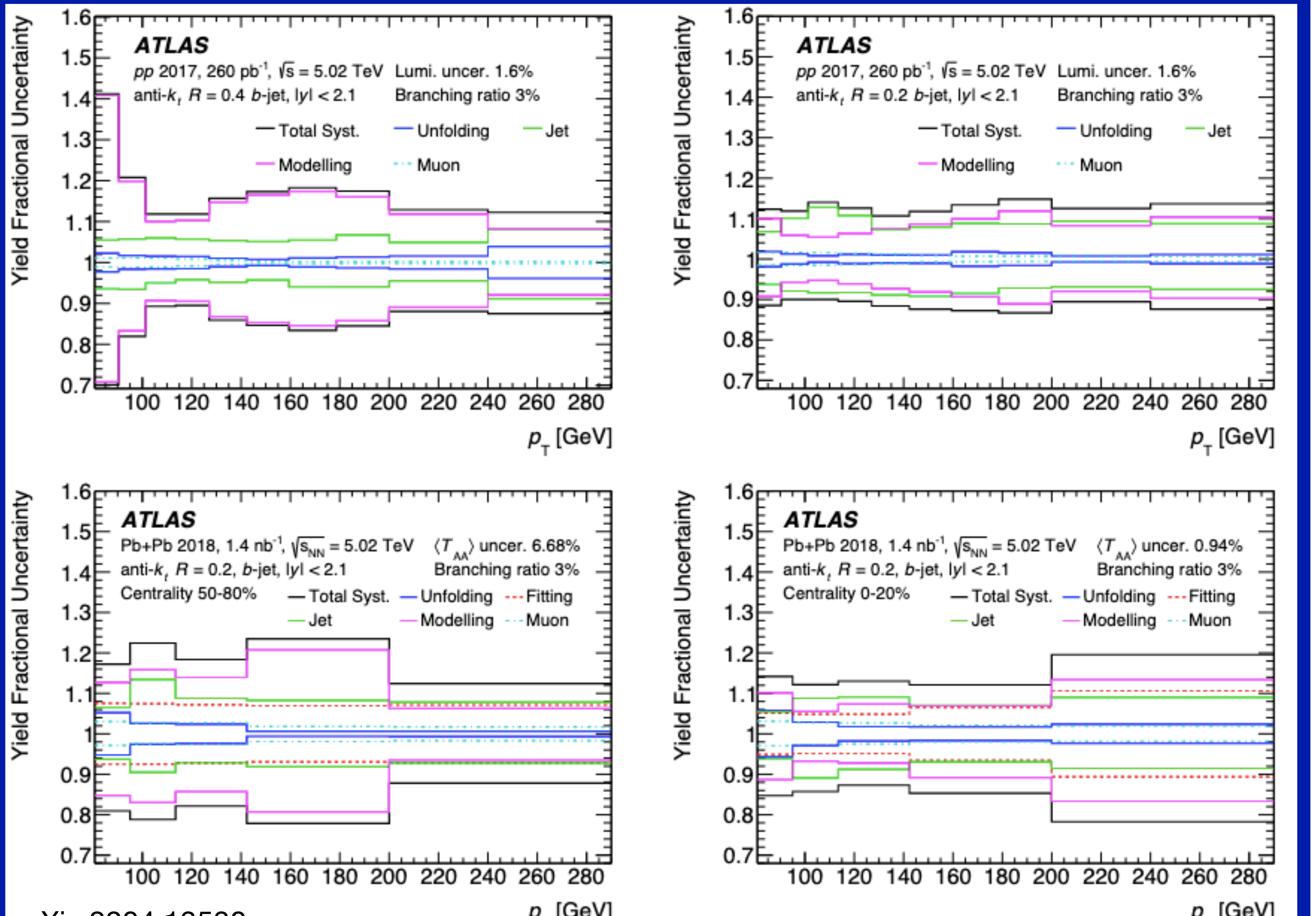


- Ratio of cross sections is flat in the measured range in *pp*
- ATLAS and CMS consistent
- Good agreement with Pythia8

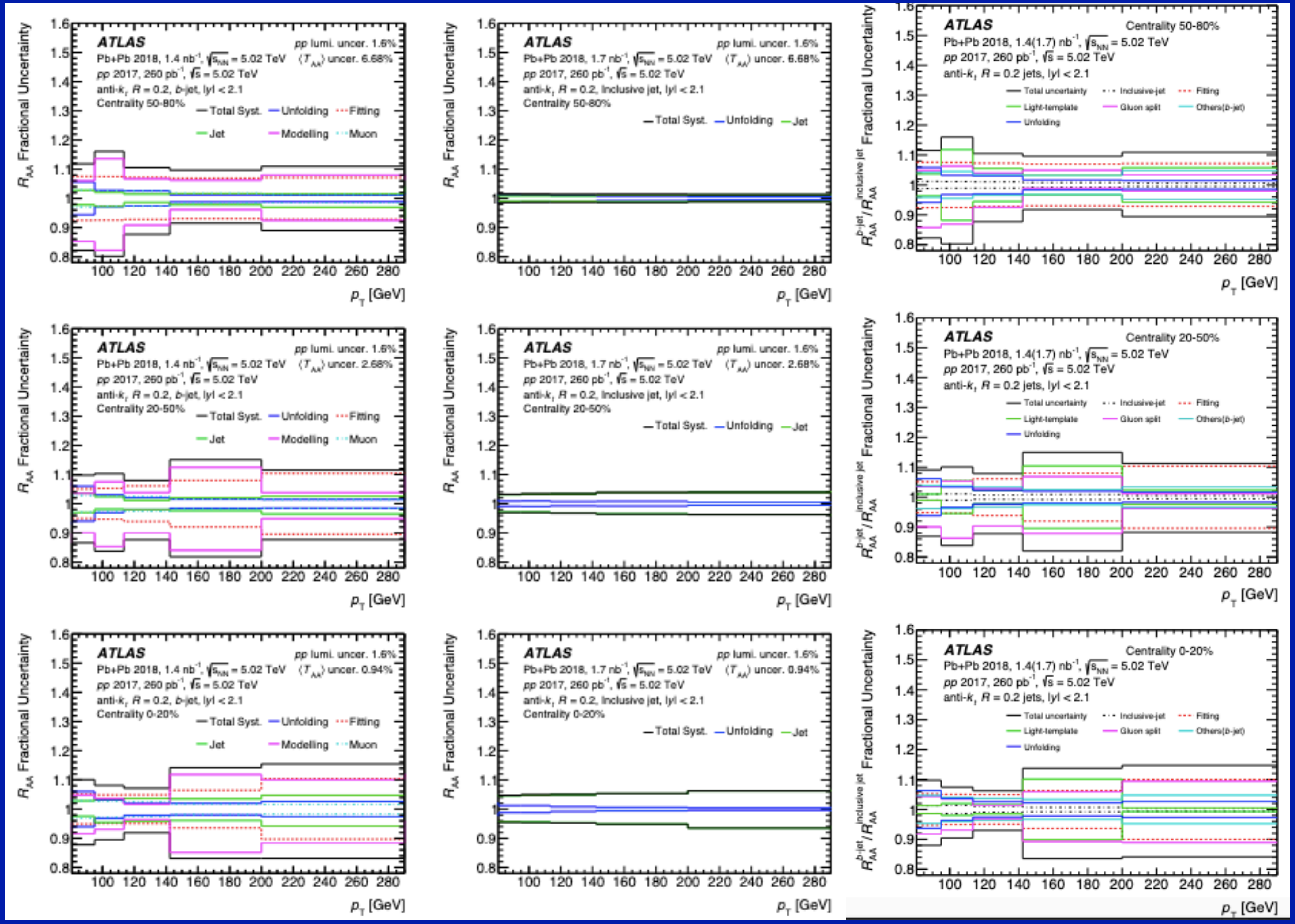
Ratio of R_{AA} between *b*-jets and inclusive jets

- At the same reconstructed p_T R_{AA} of *b*-jets is 20% higher
- Consistent in peripheral collisions
- Dai et al. captures the ratios of R_{AA}

Systematic uncertainties on *b*-jets R_{AA}



arXiv:2204.13530



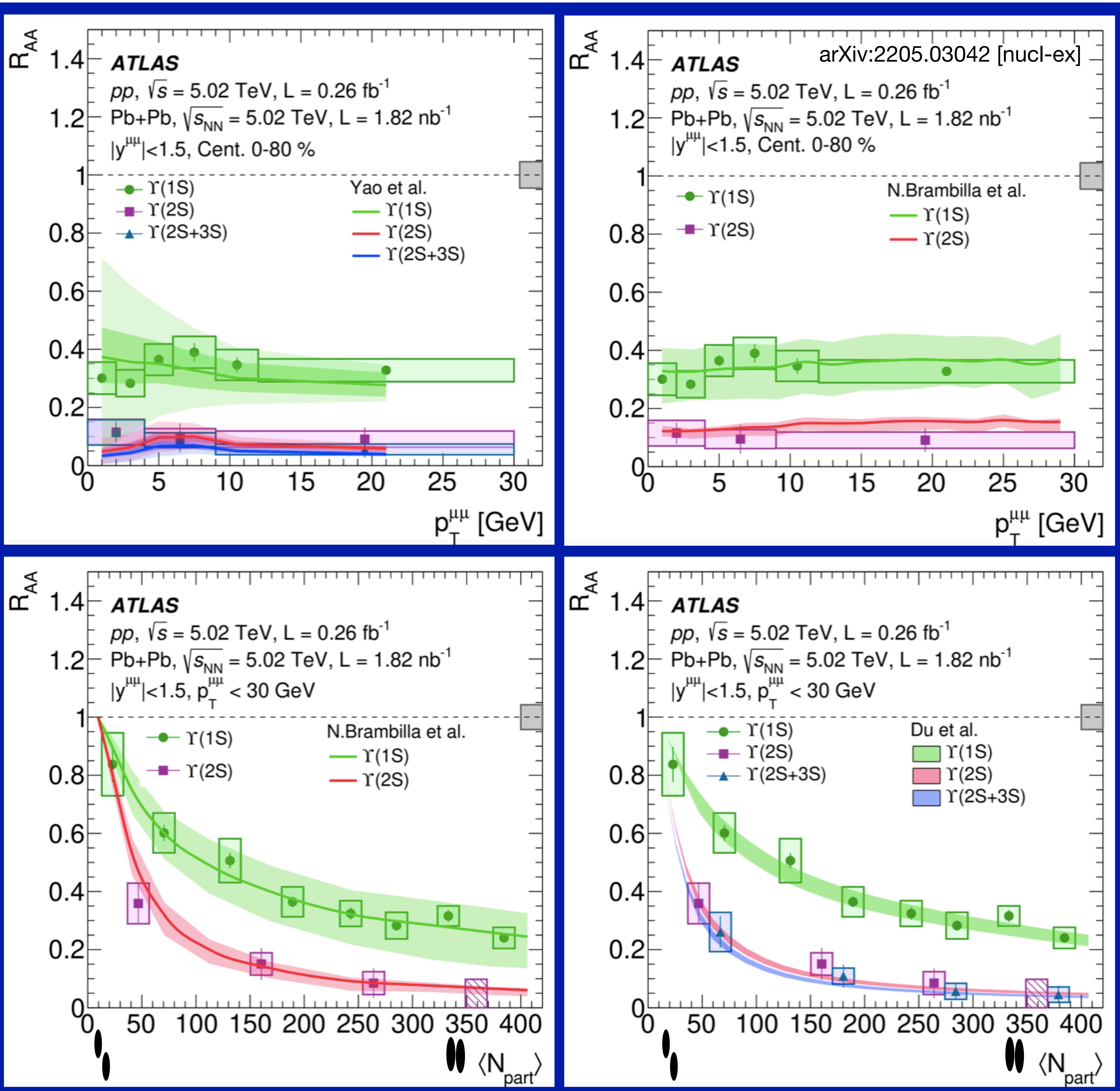
Upsilon analysis

arXiv:2205.03042 [nucl-ex]

Table 1: Summary of the sources of systematic uncertainty.

Collision type	Sources	$\Upsilon(1S)$ [%]	$\Upsilon(nS)$ [%]	$\Upsilon(nS)/\Upsilon(1S)$ [%]
pp collisions	Luminosity	1.6	1.6	-
	Acceptance	0.3–9.3	0.2–4.1	-
	Efficiency	2.7–7.0	2.8–4.0	3.0–7.1
	Signal extraction	3.1–10.2	4.3–11.9	4.5–12.2
	Bin migration	<1	<1	-
	Primary-vertex association	2.0	2.0	-
Pb+Pb collisions	$\langle T_{AA} \rangle$	0.8–8.2	0.8–8.2	-
	Acceptance	0.3–9.3	0.2–4.1	-
	Efficiency	4.0–15.0	3.9–25.3	4.4–28.8
	Signal extraction	3.8–16.3	14.6–28.7	16.6–31.5
	Bin migration	<2	<2	-
	Primary-vertex association	3.4	3.4	-

Upsilon R_{AA}



$$R_{AA} = \frac{N_{AA}}{\langle T_{AA}\rangle \times \sigma_{pp}}$$

- excited ϒ states significantly more suppressed than the ground state
- no dependence with dimuon p_T

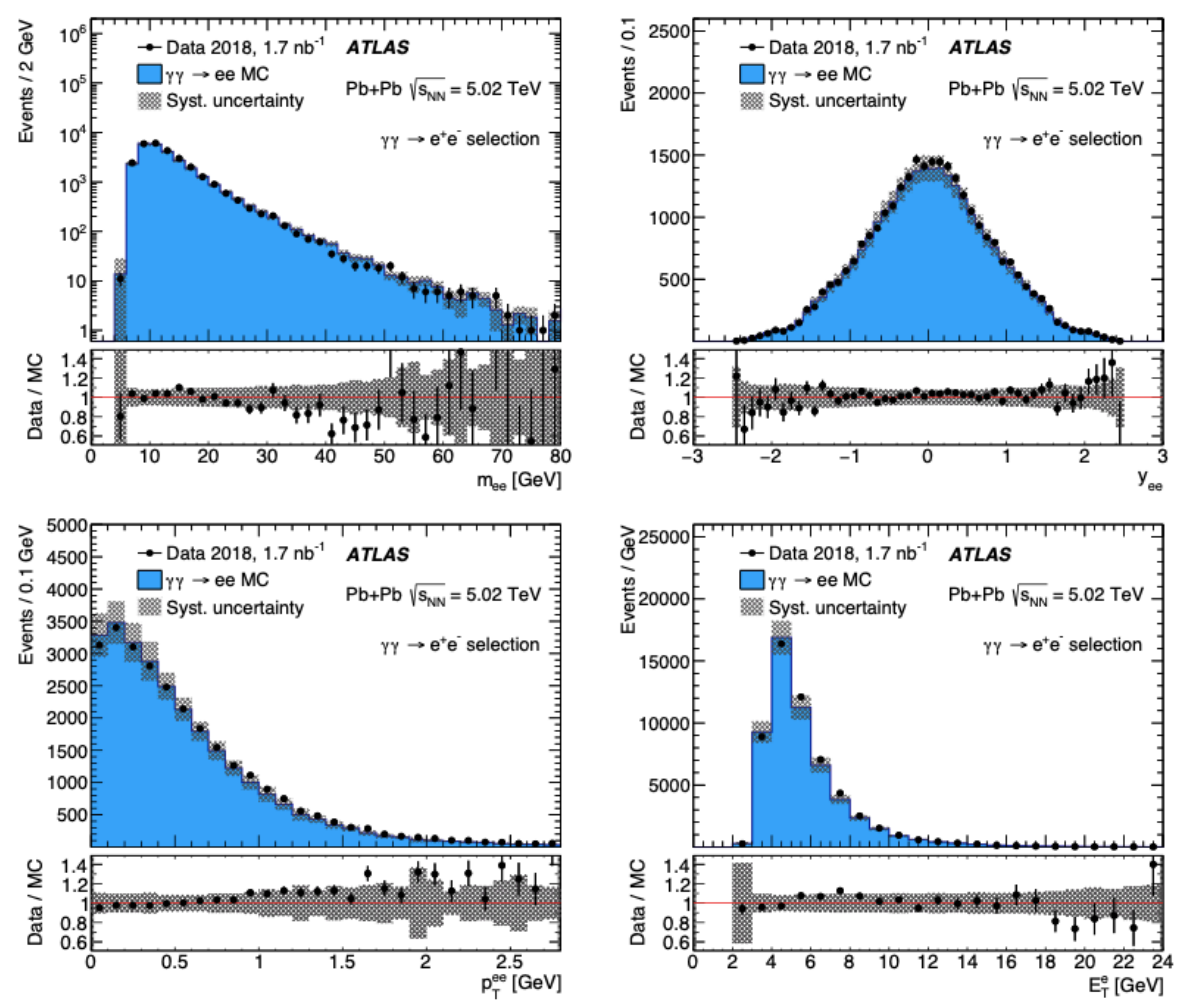
- steady increase of suppression as a function of the number of the nucleon participants, Npart.

- data well described by the models in the whole p_T range and centrality

γγ→γγ in Ultra Peripheral Collisions

Detector calibrated with $\gamma\gamma \to e^+e^-$

arXiv:2008.05355



STARlight MC describe kinematics well, in general

γγ→ee in UPC

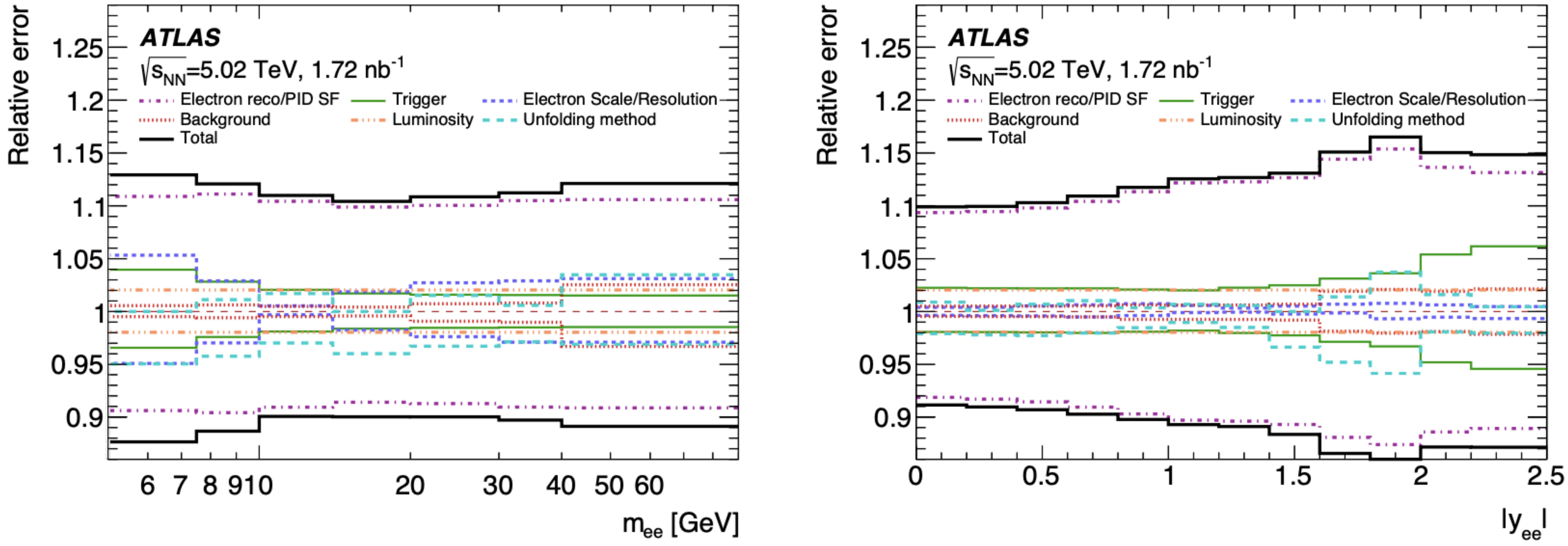
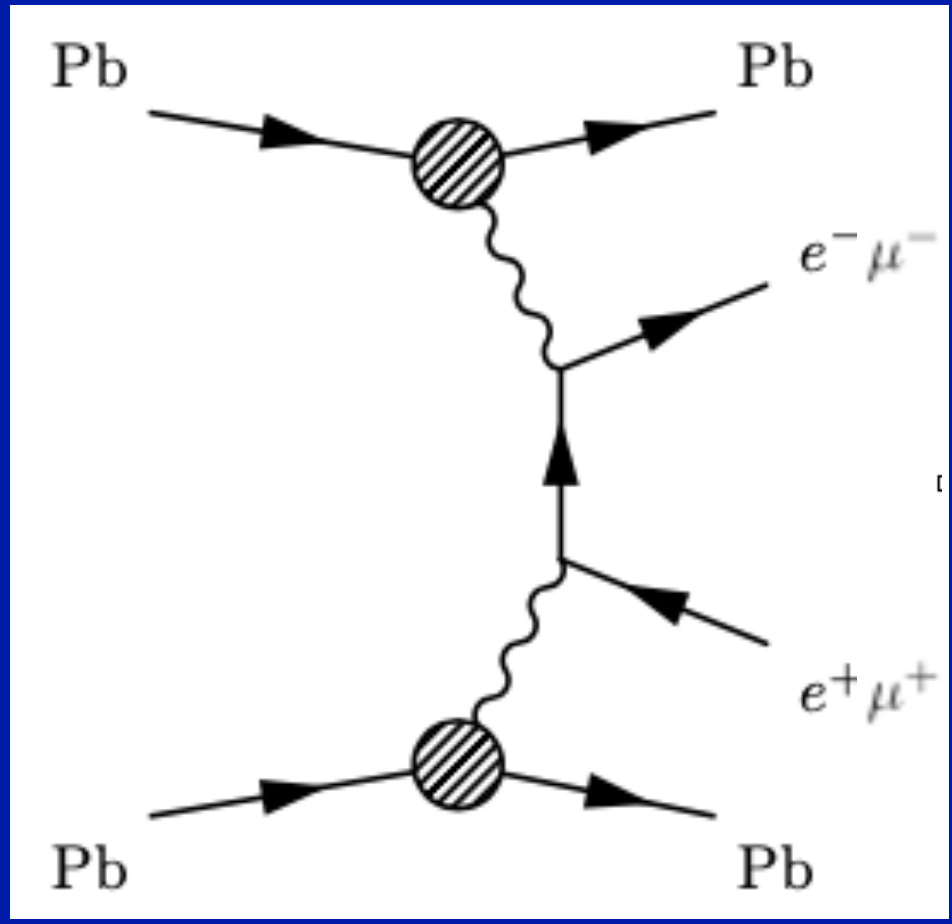


Figure 5: Breakdown of relative systematic uncertainties in the differential cross-section as a function of m_{ee} (left) and $|y_{ee}|$ (right).

arXiv:2207.12781 [nucl-ex]

$\gamma\gamma\rightarrow\mu\mu$ in UPC



$p_T^{\mu} > 4$ GeV; $|\eta| < 2.4$;
$m_{\mu\mu} > 10$ GeV; $p_T^{\mu\mu} < 2$ GeV

backgrounds: HF decays, DY, dissociative μ-pair production; Υ-meson; exclusive ττ

Xsection for $\gamma\gamma\rightarrow\mu\mu$

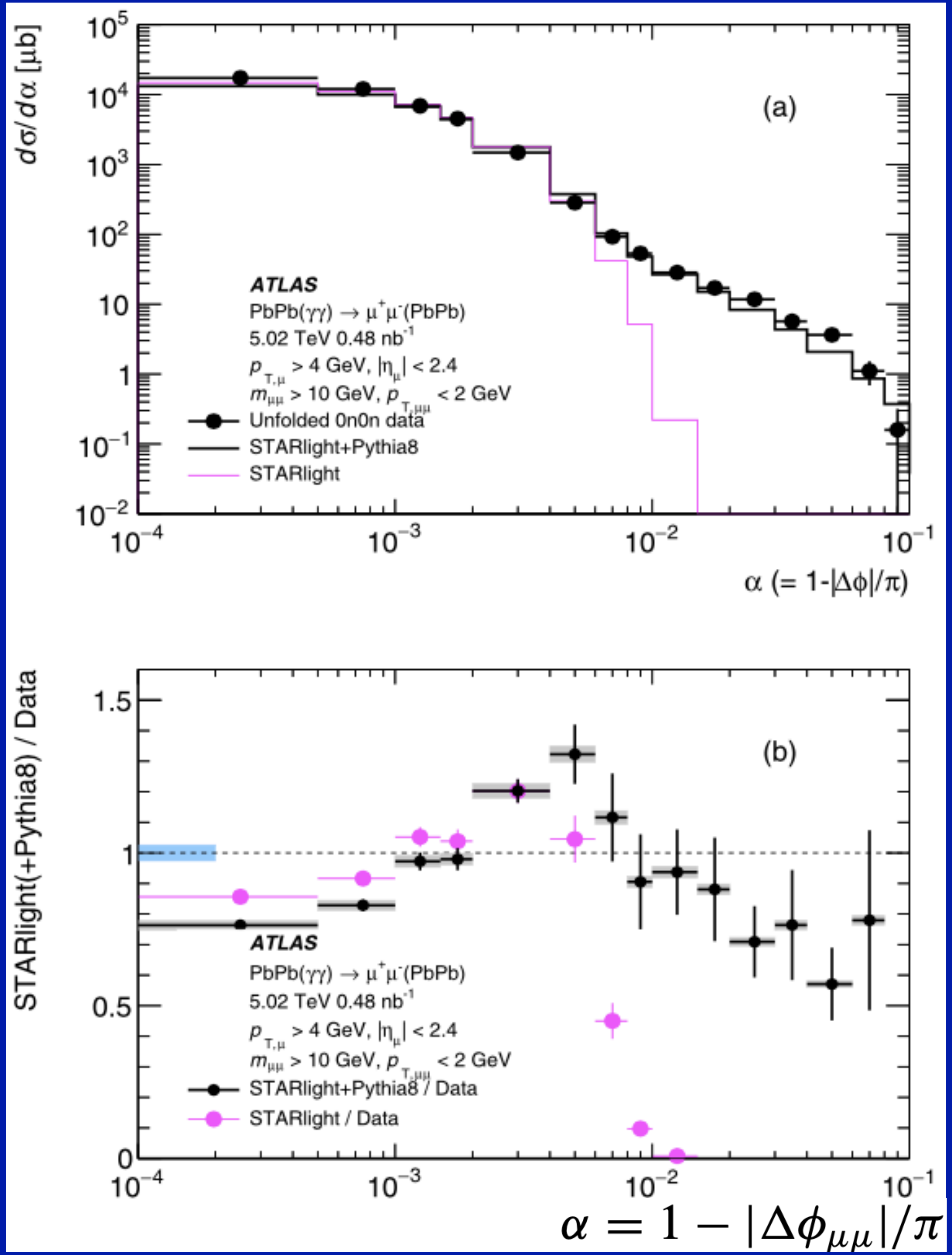
$\sigma_{fid} = 34.1 \pm 0.3$ (stat) ± 0.7 (syst) μb

predicted:

STARLIGHT 32.1 μb;

STARLIGHT+PYTHIA8 30.8 μb

Xsection as a function of the acoplanarity, α



differential Xsection fairly consistent with STARLIGHT+PYTHIA8