Centrality and rapidity dependence of inclusive jet production in $\sqrt{s_{NN}}$ = 5.02 TeV p+Pb collisions with the ATLAS detector

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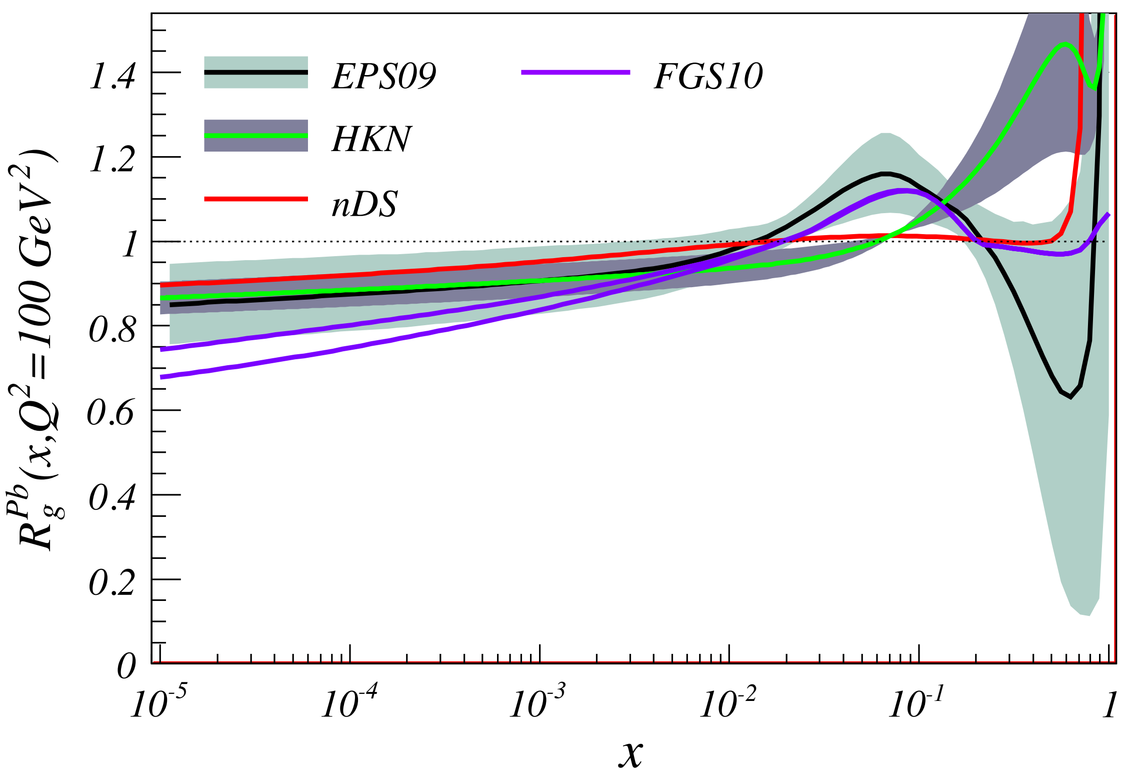
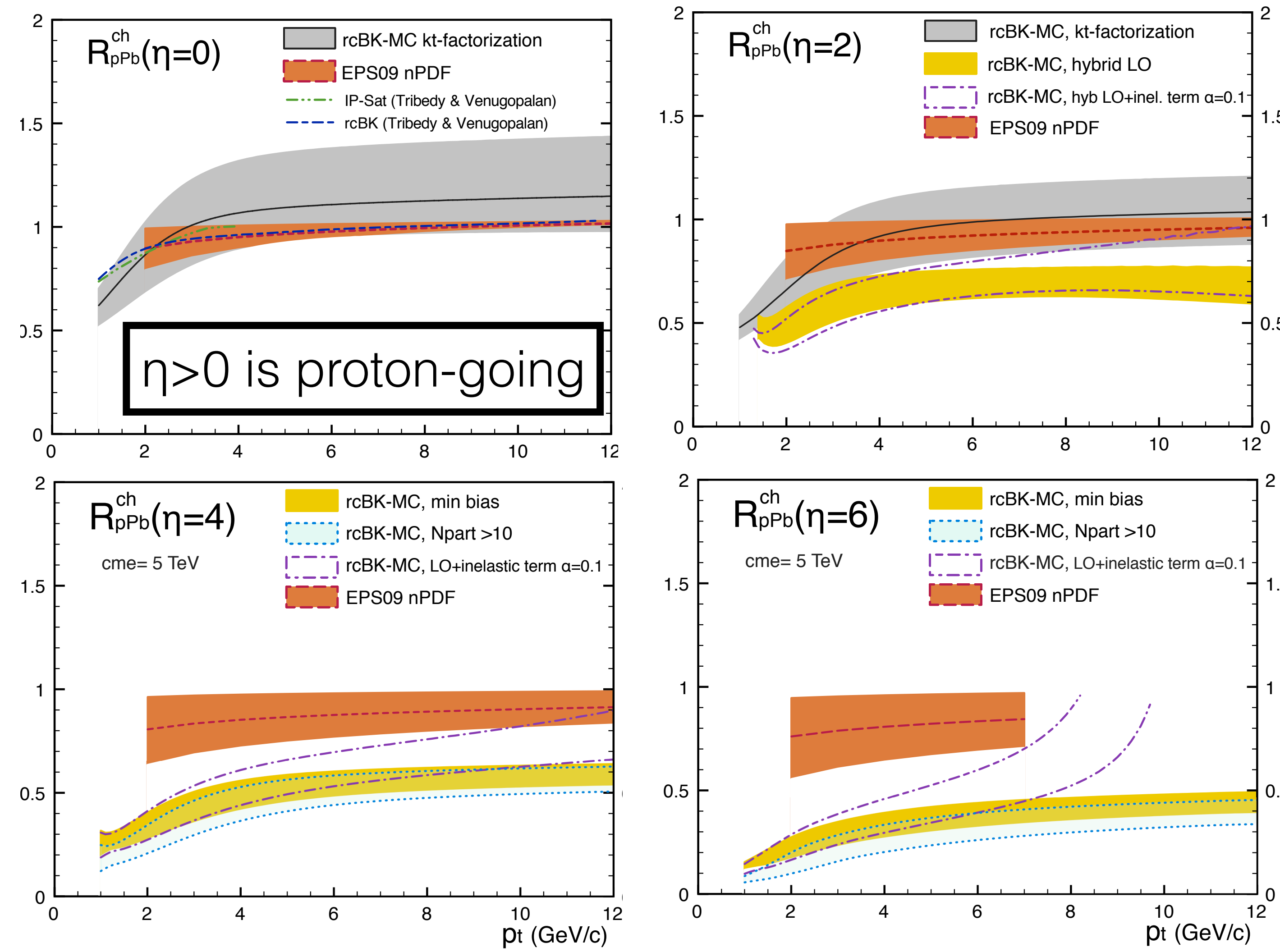
Hard probes of *p*(*d*)+A



Salgado et al., hep-ph/1105.3919
current best knowledge of nPDFs

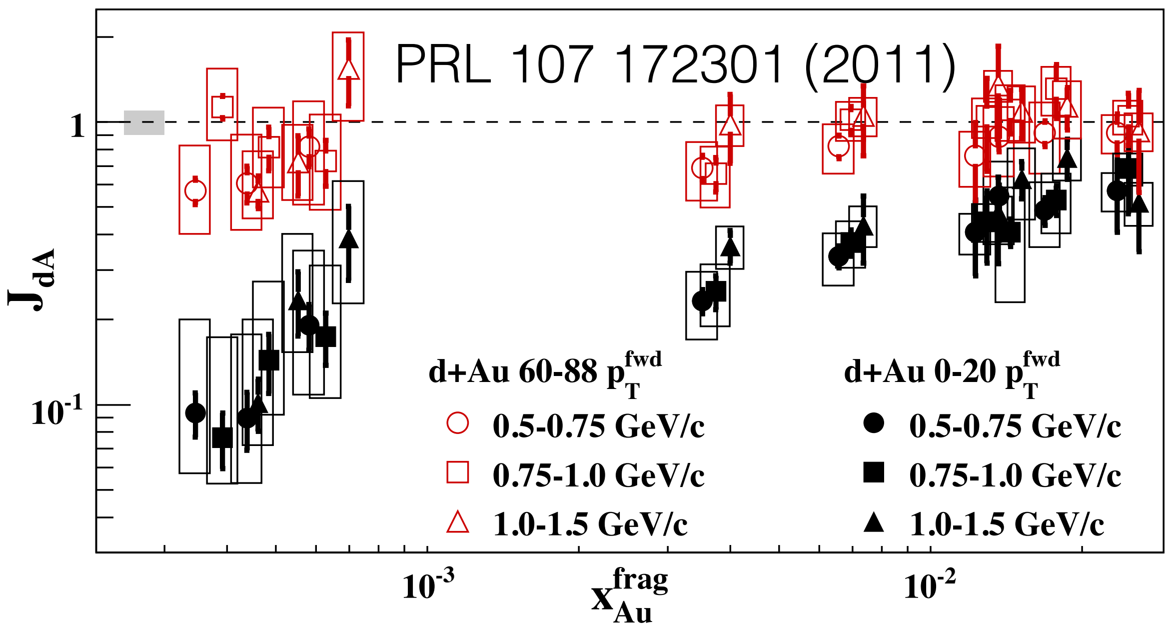


Albacete et al., hep-ph/1209.2001
η-dependence of CGC vs. nPDF predictions

- Hard probes access the partonic structure of the nucleus
    - Jets allow us to explore this over a large kinematic range
    - Can probe *b*-dependent nPDFs, initial state energy loss, saturation phenomena (at very low p_T, large y*), etc.

Hard probes of $p(d)$+A @ RHIC

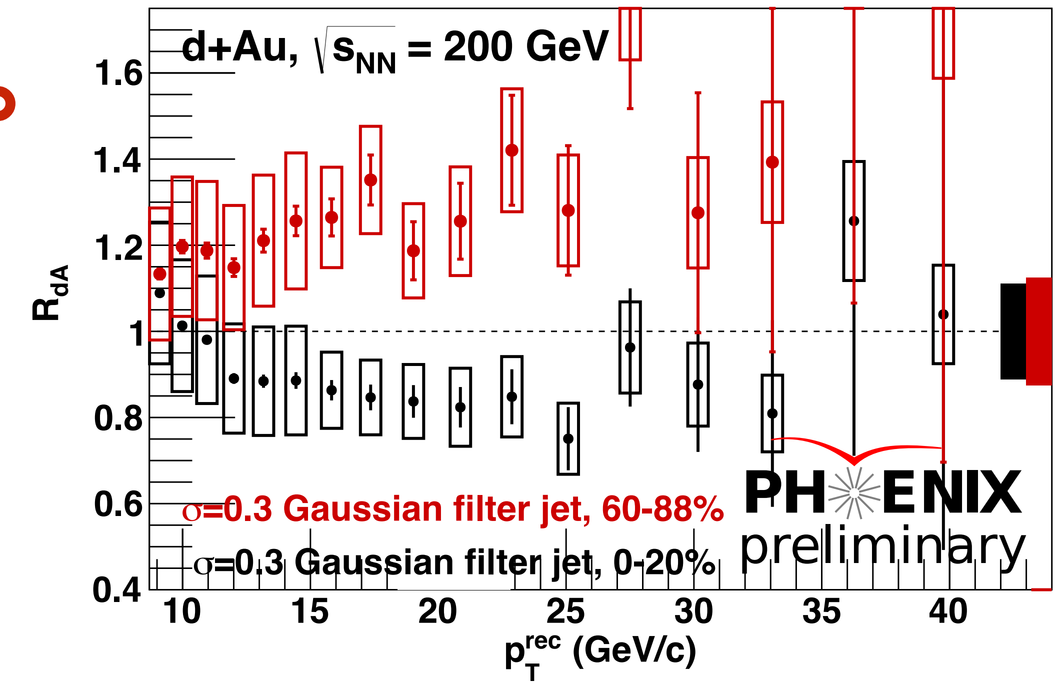
di-hadron J_{dA}



60-88%

0-20%

jet R_{dAu}

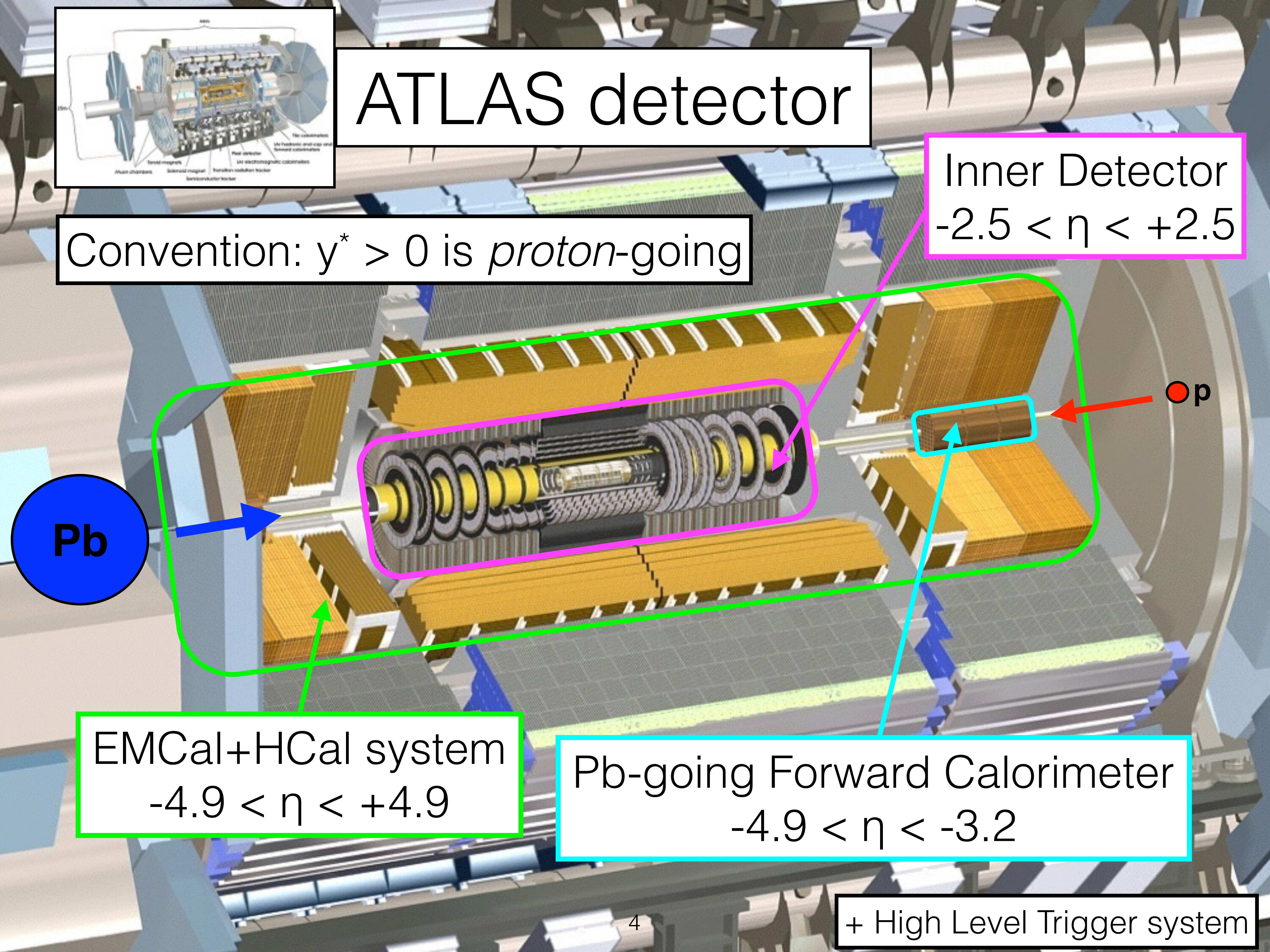


10.1016/j.nuclphysa.2013.02.184

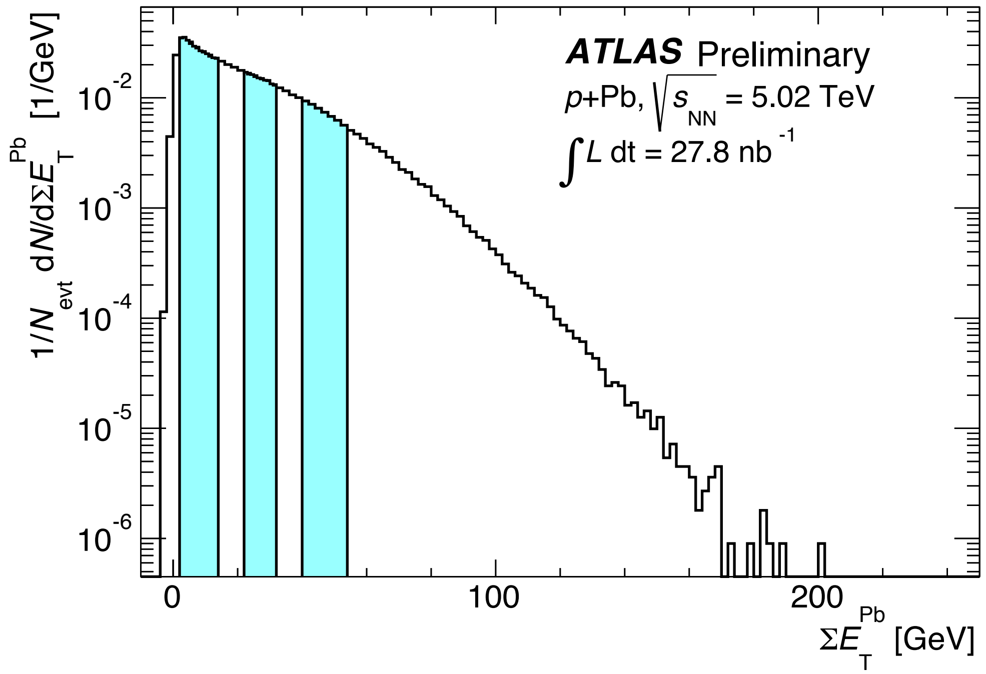
- At forward rapidity, large centrality dependent suppression
  - single- and di-hadrons
  - attributed to shadowing / saturation / CGC phenomena

- At mid-rapidity, anomalous centrality dependence
  - for high-p_T jets
  - **central** suppression
  - enhanced **peripheral** (!?)

- What happens in central & peripheral collisions in between?
  - ➡ ATLAS can explore the kinematic range in the middle


ATLAS detector
Convention: y^* > 0 is *proton*-going
Inner Detector
$-2.5 < \eta < +2.5$
p
Pb
EMCal+HCal system
$-4.9 < \eta < +4.9$
Pb-going Forward Calorimeter
$-4.9 < \eta < -3.2$
+ High Level Trigger system

p+Pb collisions & centrality



- 28 nb^{-1} of p+Pb/Pb+p data @ 5.02 TeV
- Centrality determined using ΣE_T in Pb-going FCal, $-4.9 < \eta < -3.2$, default Glauber
  - best sensitivity to collision geometry & allows measurements of very forward jets
- Reasonable behavior in **soft** & **hard** observables

R. Debbe, 10:30 Monday

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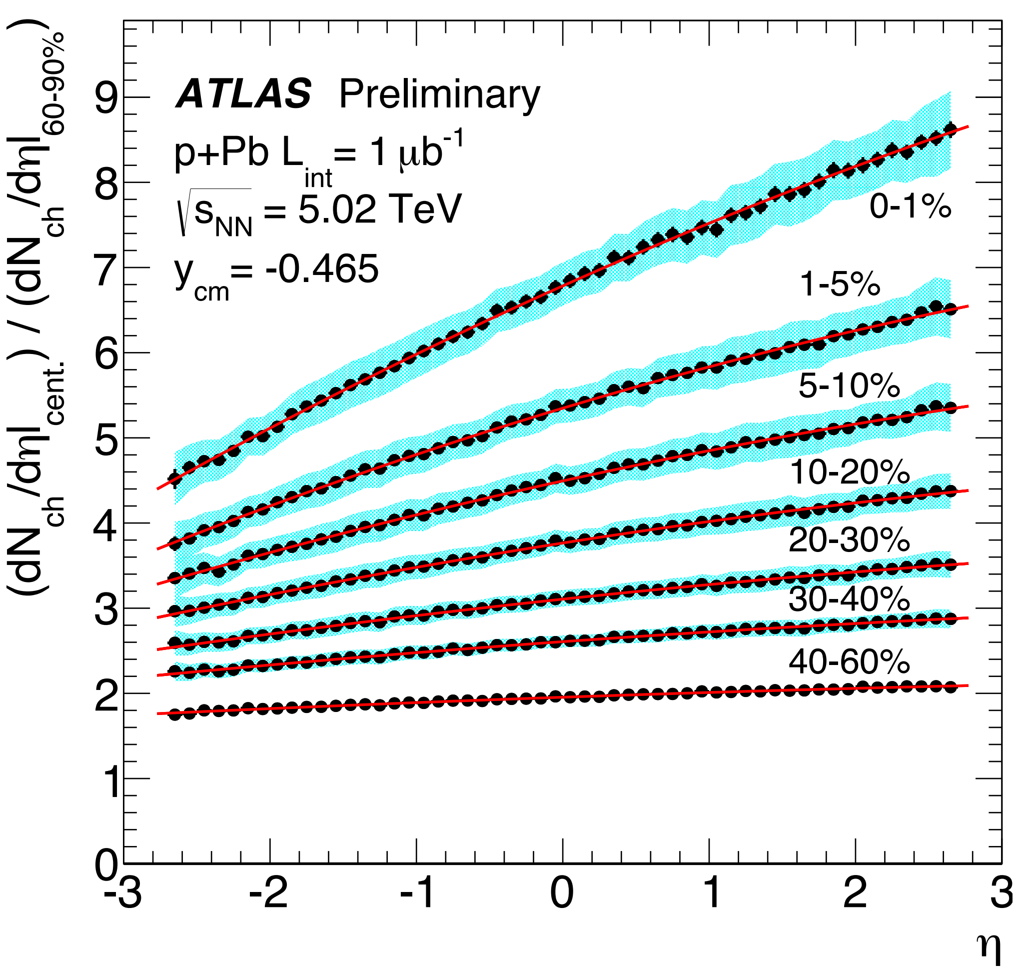
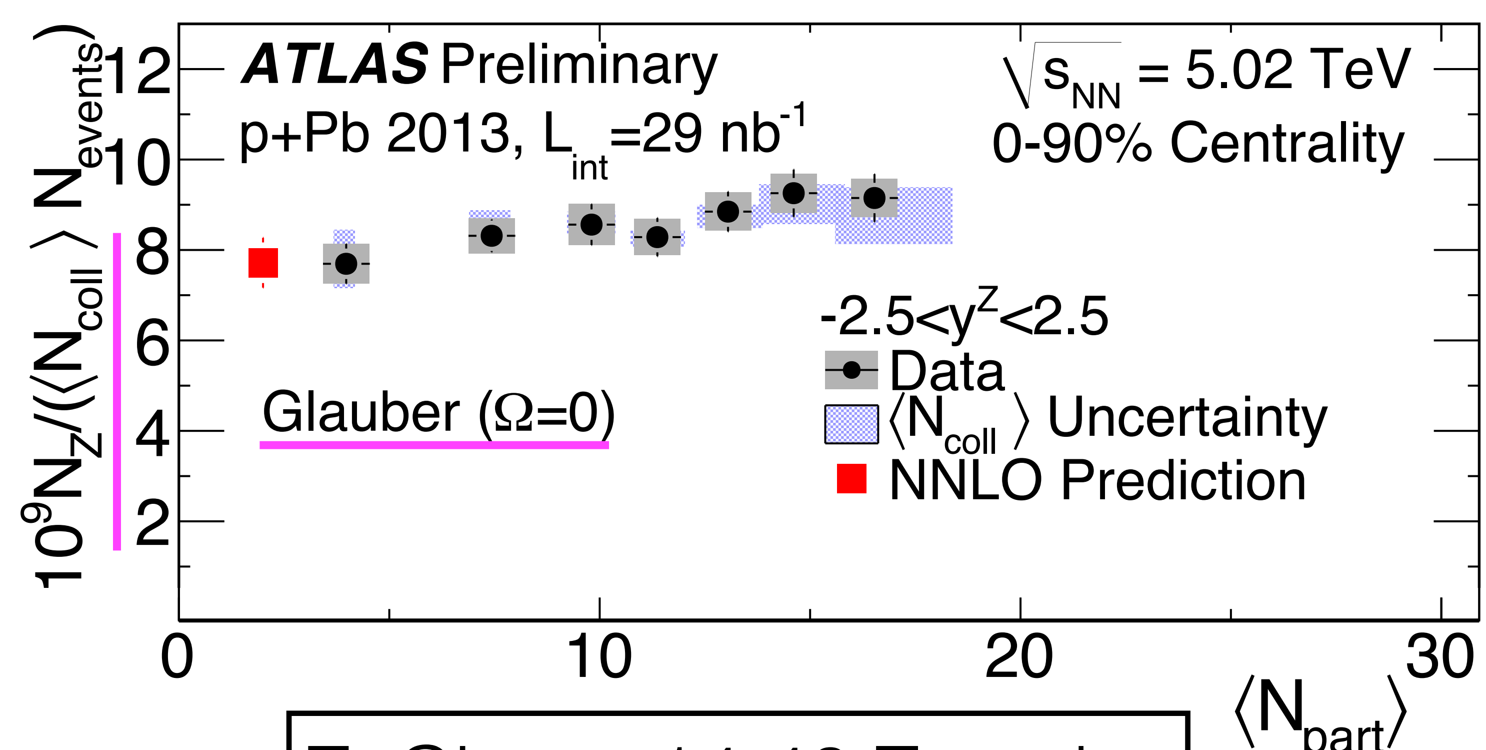


<u>N_{coll}-scaling of Z production in p+Pb</u>



Z. Citron, 14:40 Tuesday

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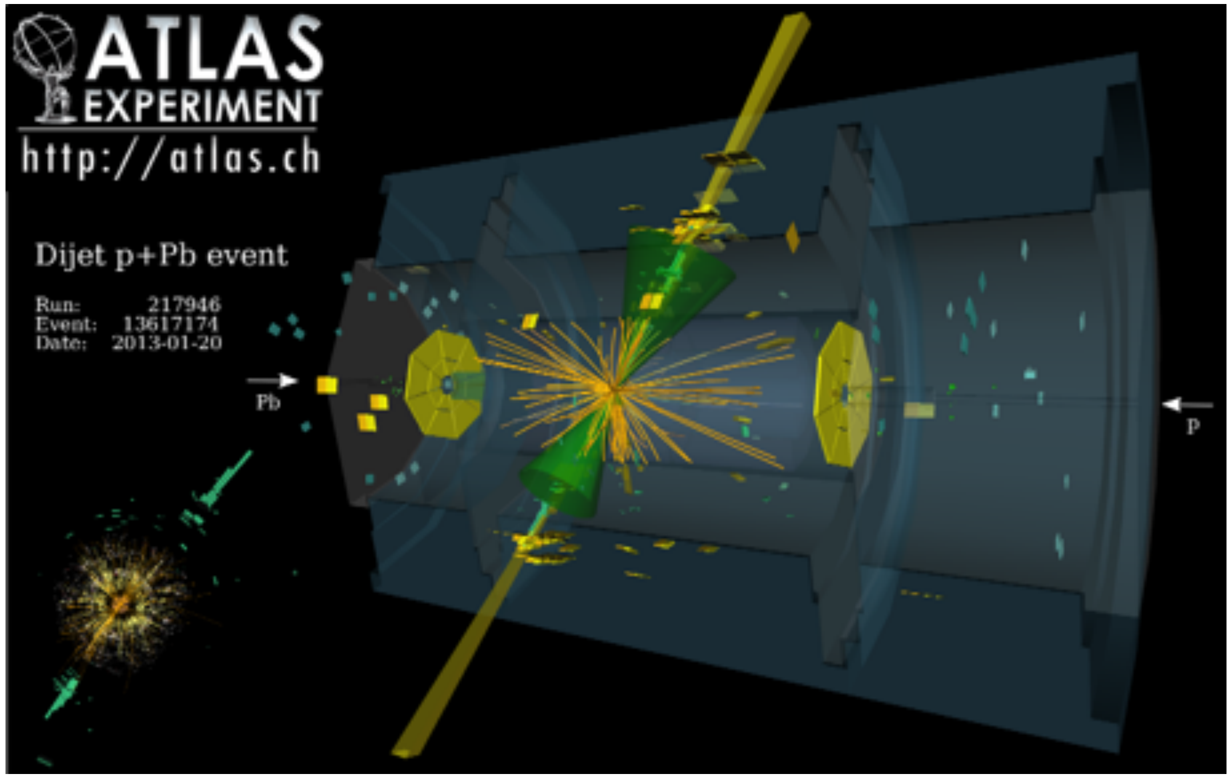
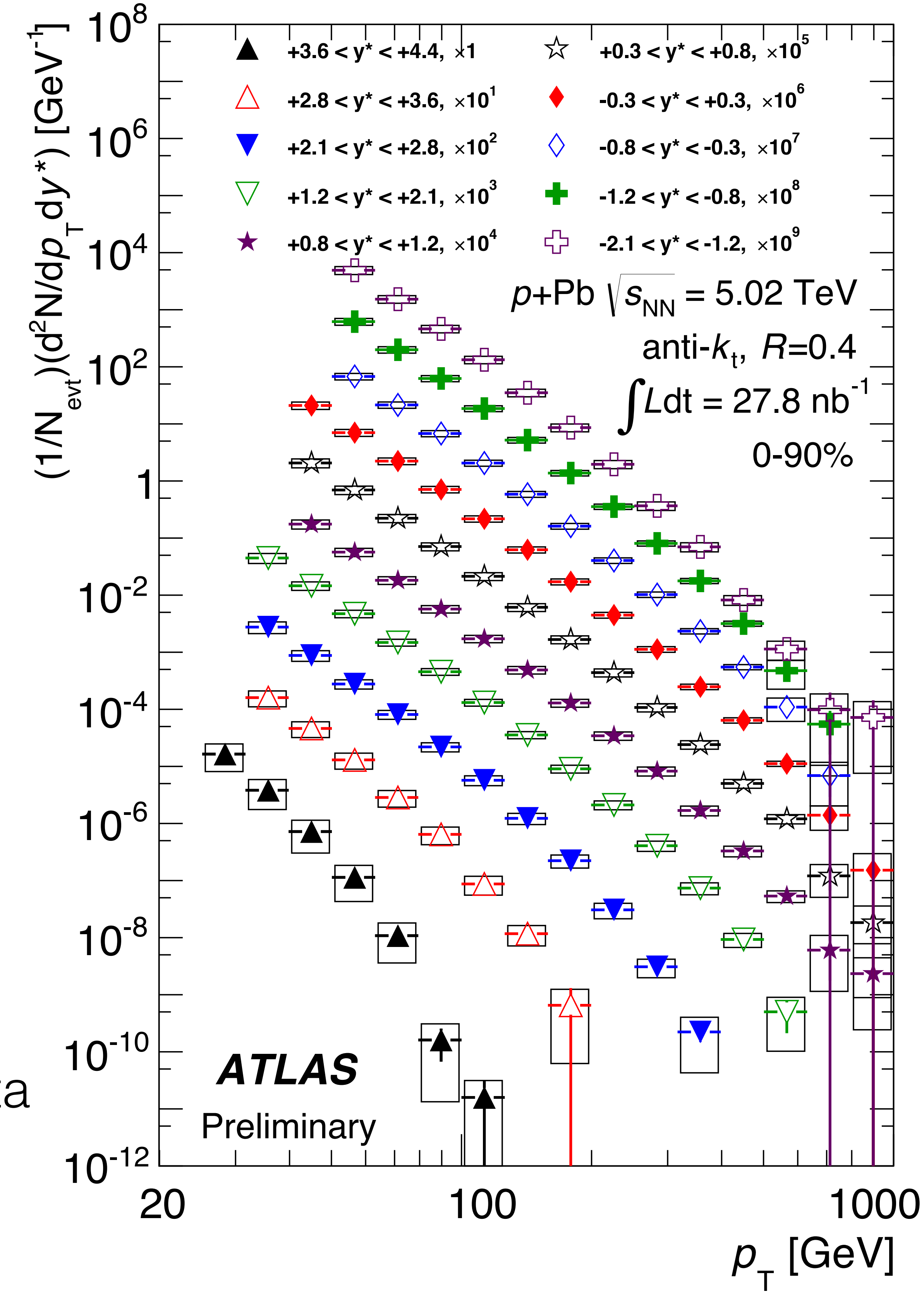
Jets in *p*+Pb



- anti-k_t, R=0.4 calorimeter jets
  - UE estimation & subtraction
  - designed for Pb+Pb, cross-checked in *pp*
- Selected by online high-level jet trigger
- 36m PYTHIA *pp* dijets overlaid onto *p*+Pb data
  - corrections are modest (10-30%)
  - and mostly cancel in the R_{CP} and R_{pPb}



0-90% yields

See poster E-15 by T. Kosek

Jet R_{pPb}

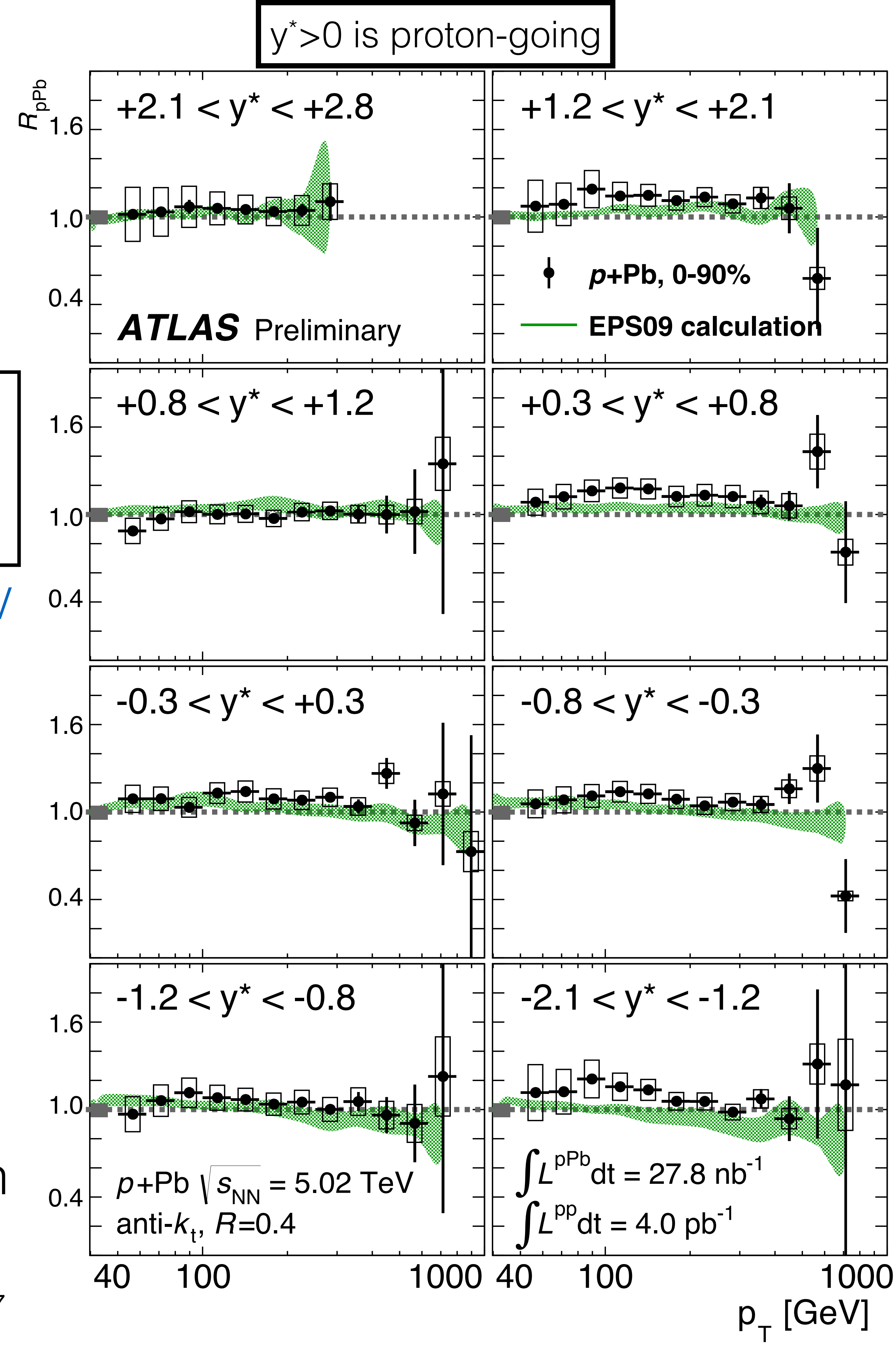
jet yield in p+Pb

$$R_{pPb} = \frac{(1/N_{evt})\, d^2N/dp_T dy^*}{\langle T_{pA} \rangle\, d^2\sigma/dp_T dy^*}$$

Pb nucleon flux seen by proton

2013 pp data @ 2.76 TeV (x_T-scaled to 5.02 TeV)

- R_{pPb} for 0-90% events
  - ≈5 units of rapidity, 50-1000 GeV
- 5-10% enhancement
  - weak p_T dependence?
  - consistent with **EPS09** prediction



y*>0 is proton-going

Jet R_{CP}

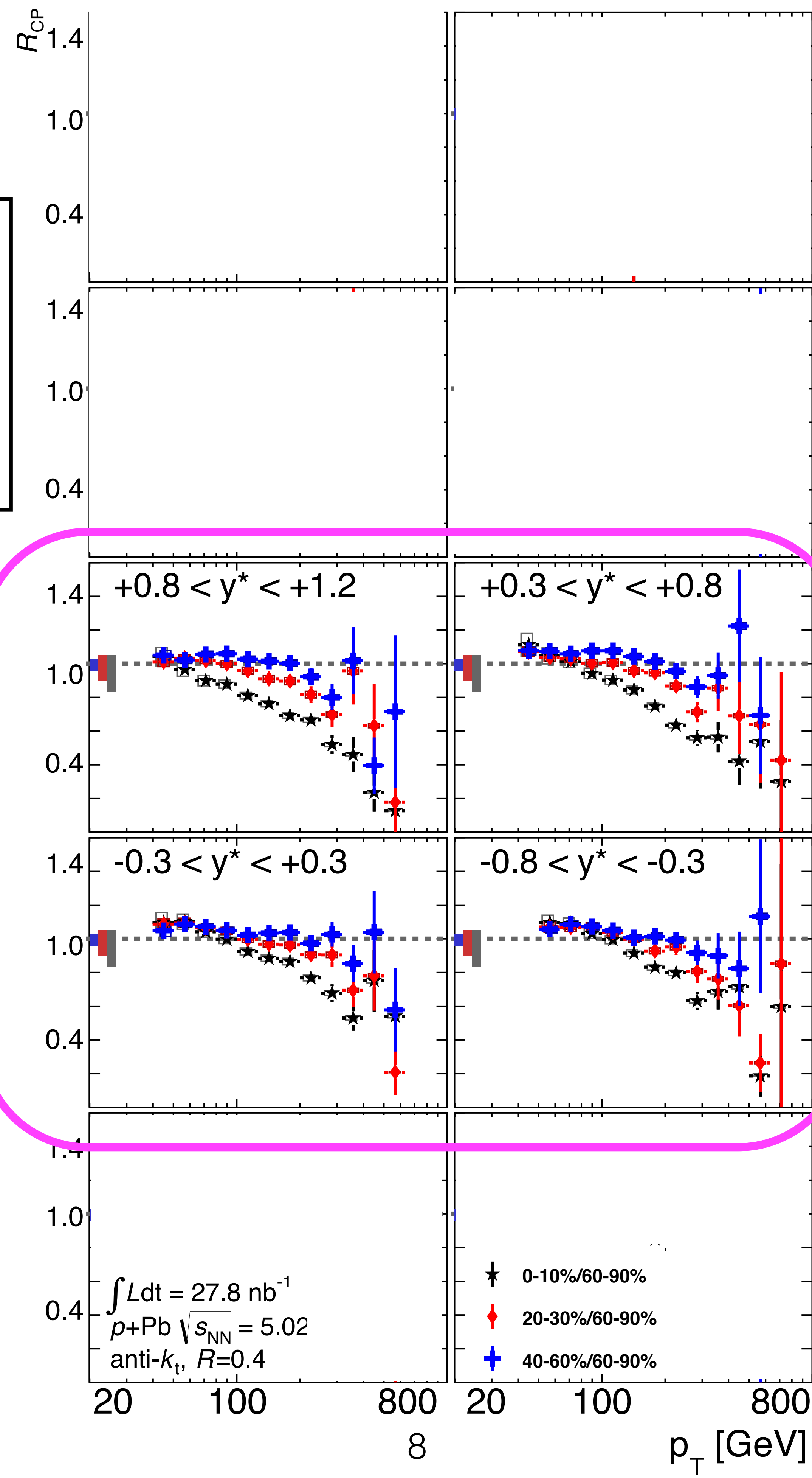
0-10%/60-90%
20-30%/60-90%
40-60%/60-90%

central yield

$$R_{CP} = R_{coll}\,\frac{(1/N_{evt})\,d^2N/dp_T dy^*}{(1/N_{evt})\,d^2N/dp_T dy^*}$$

N_{coll} ratio

peripheral yield



> 100 GeV jets suppressed at mid-rapidity!

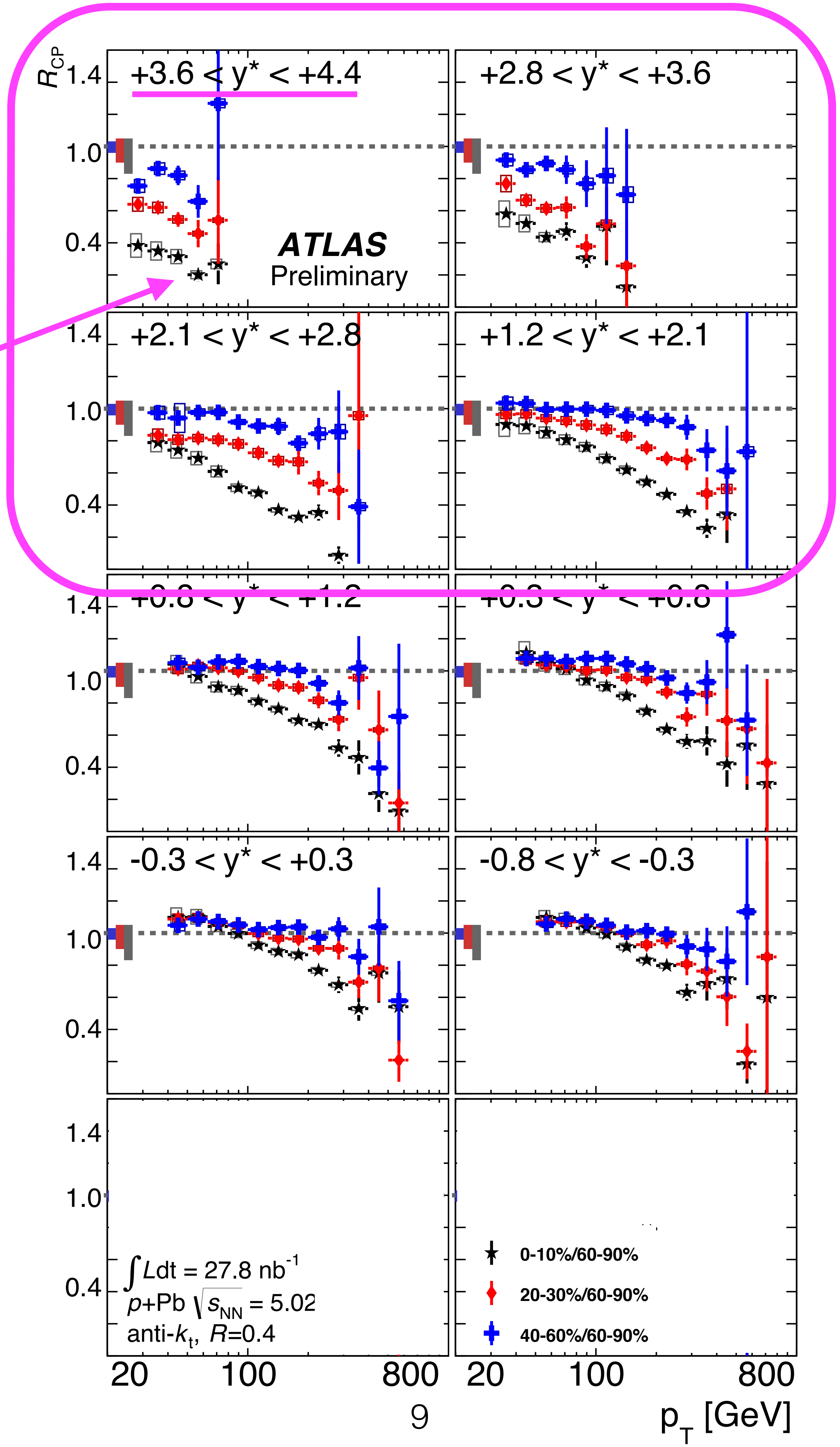
suppression pattern smooth with centrality

larger suppression at higher p_T

y*>0 is proton-going

Jet R_{CP}

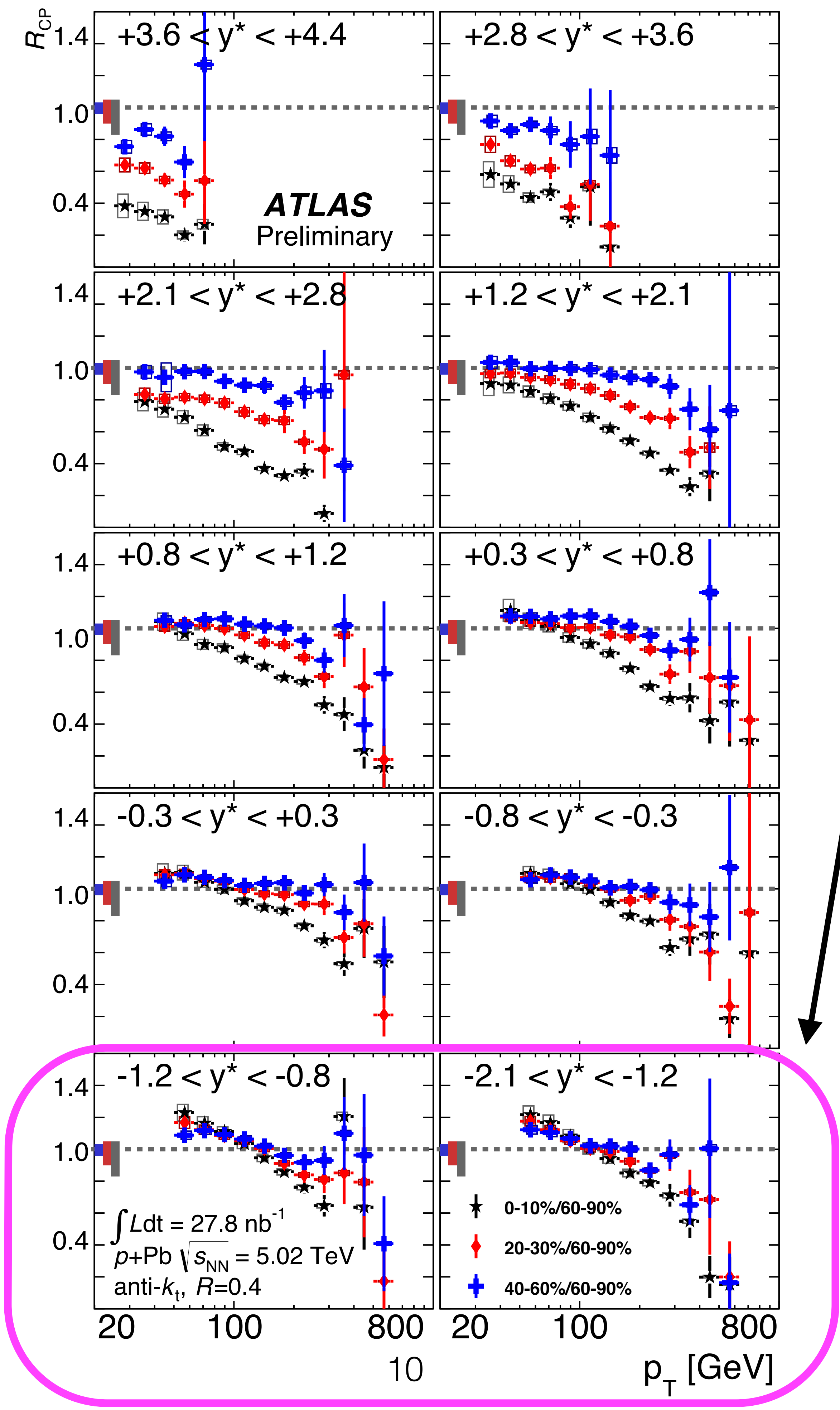
$R_{CP} \approx 0.2$ here!



increasing suppression at more forward rapidities

y*>0 is proton-going

Jet R_{CP}



suppression even at backward rapidities

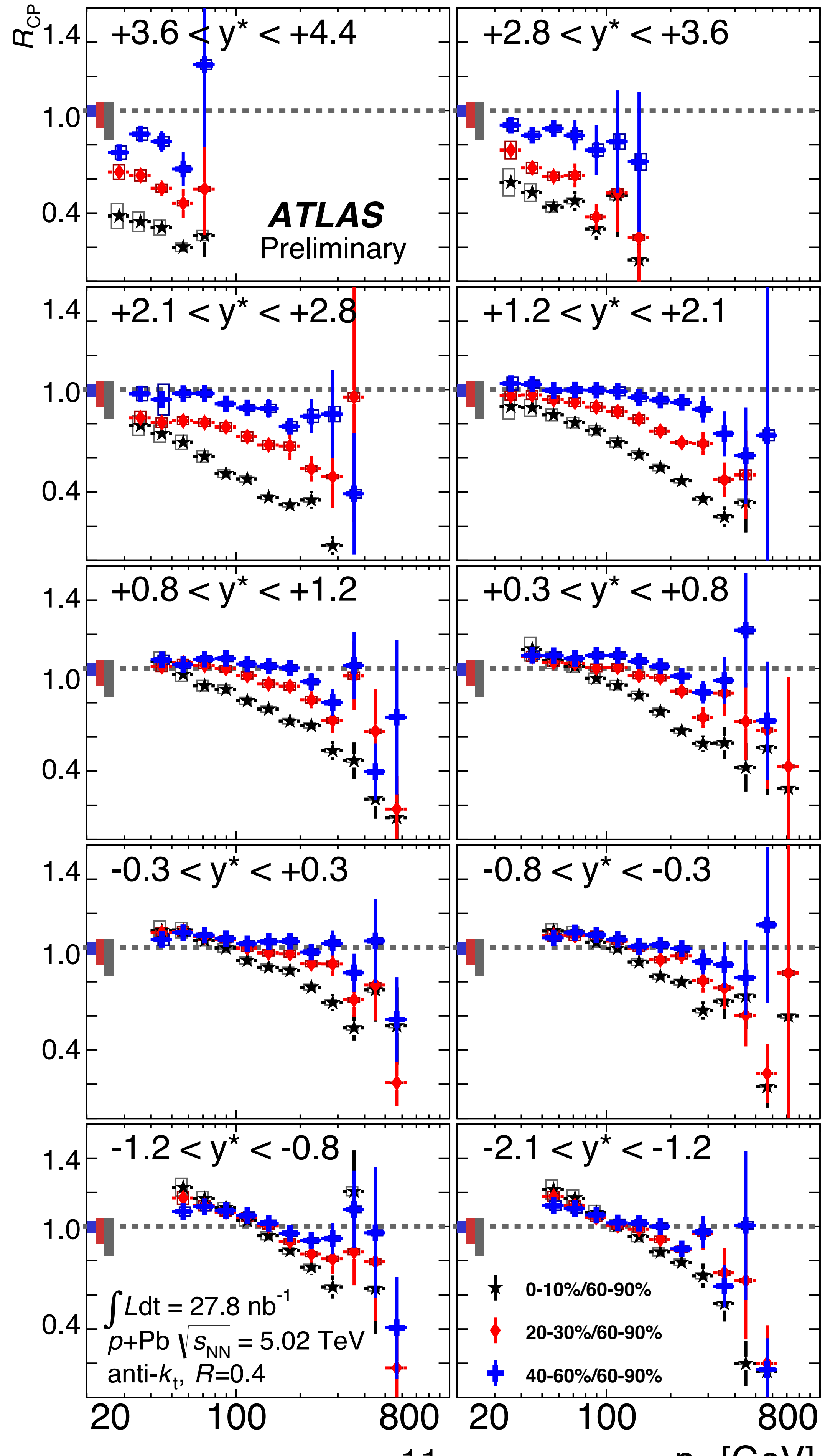
thus, the data is incompatible with a centrality-dependent y* "shift"

y*>0 is proton-going

Jet R_{CP}

Modification pattern over 6.5 units of rapidity, from 25-800 GeV!

<ins>How does this make sense with the R_{pPb}?</ins>

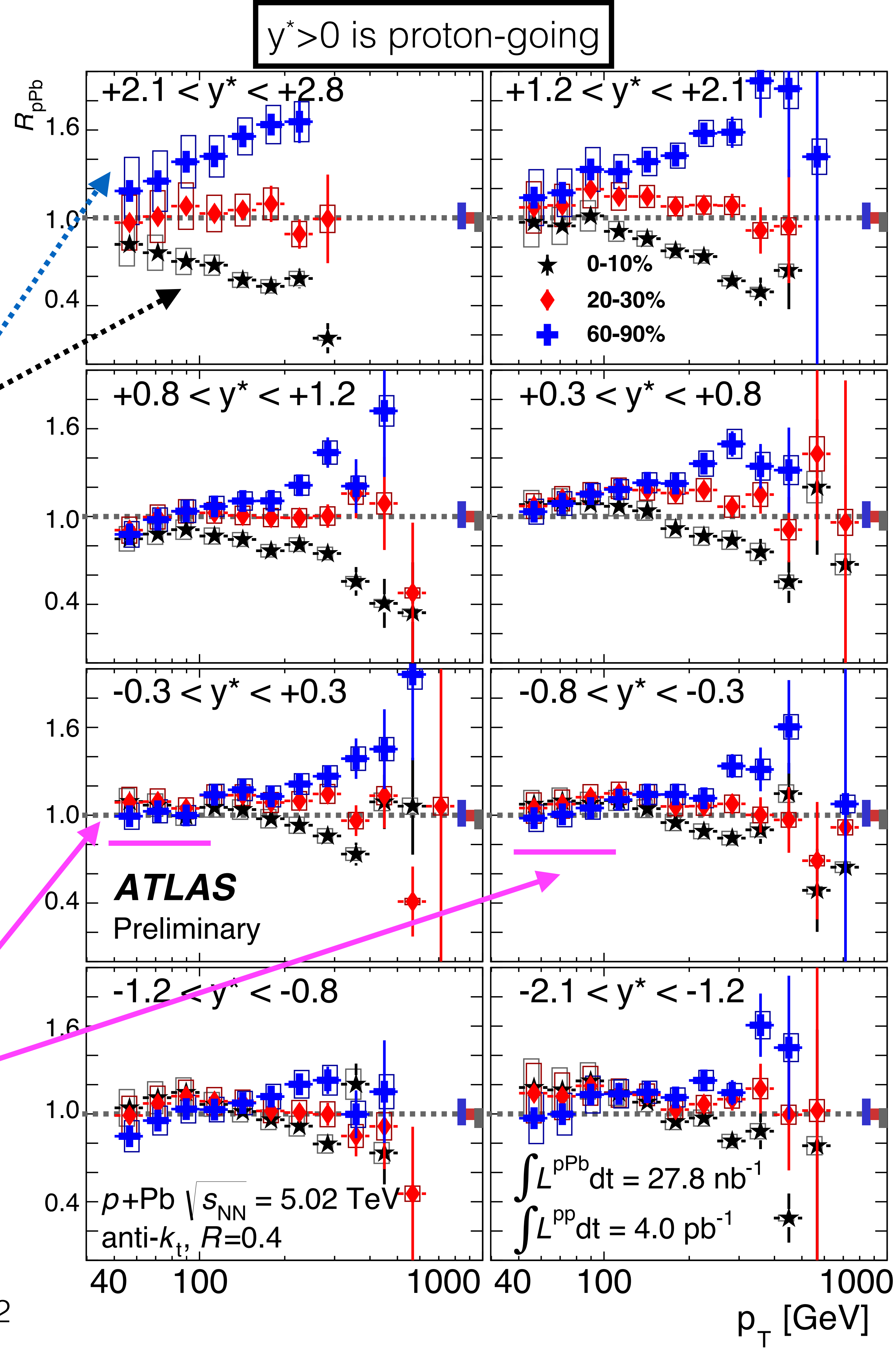


Jet R_{pPb}

➡ Centrality-selected R_{pPb} must split the difference

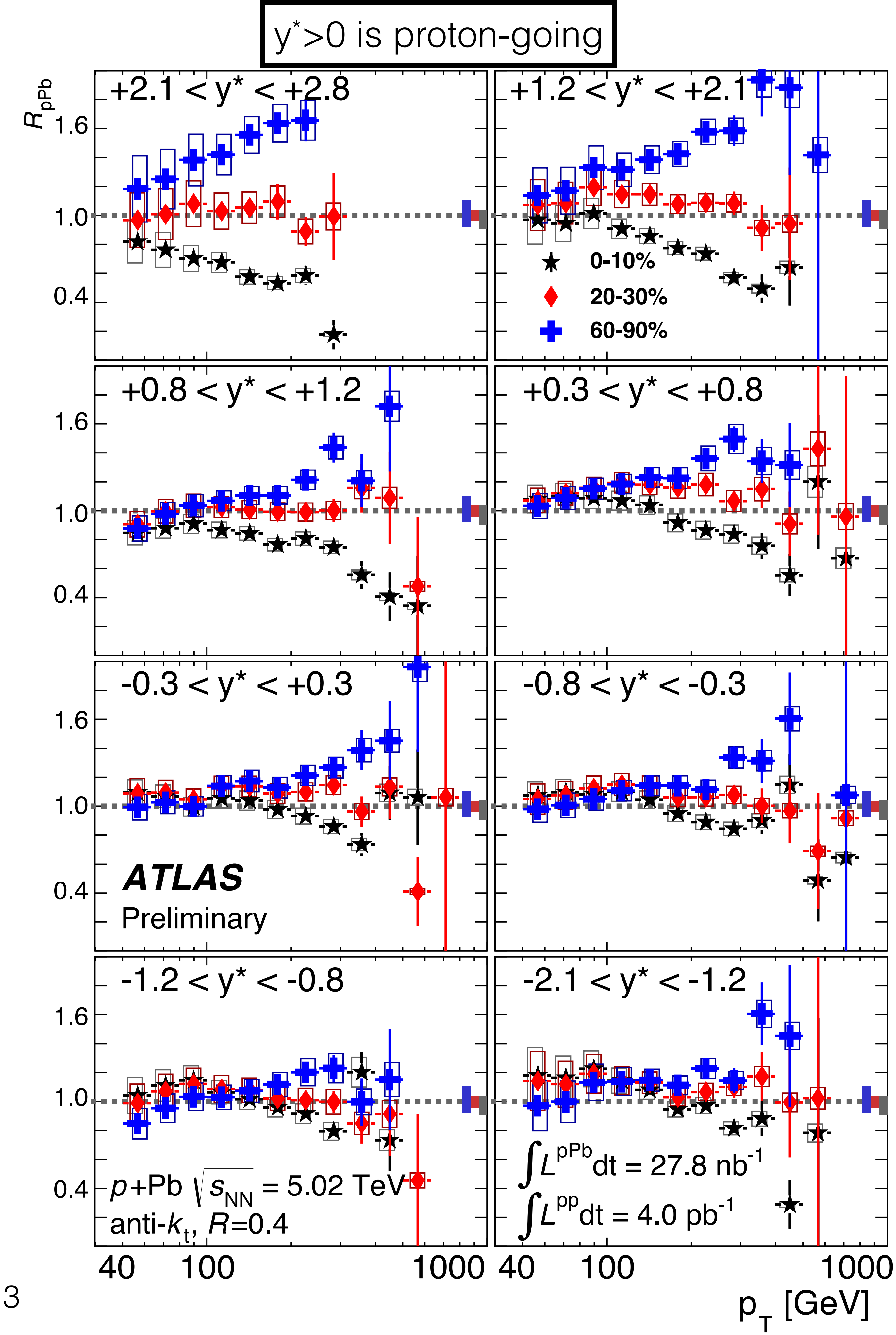
- **0-10%** R_{pPb} suppressed
- **60-90%** R_{pPb} enhanced(!)

- Larger modifications at high-p_T and forward rapidities
  ➡ Backwards & at low p_T, we recover **geometric scaling**



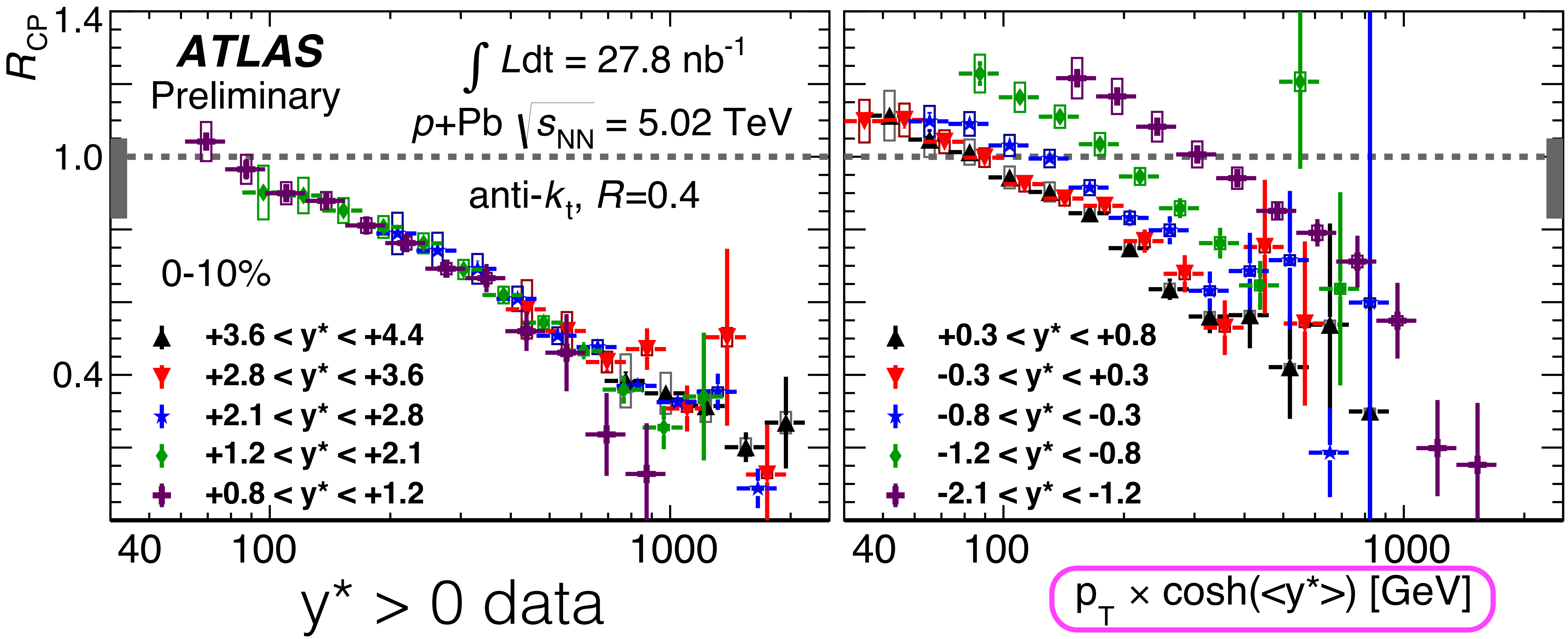
Jet R_{pPb}

<u>How can we understand the rapidity dependence?</u>



Scaling in the R_{CP} vs. p

- Replot the R_{CP} at all rapidities vs. $p = p_T \cosh(y^*)$
  - — e.g. **the total jet energy**

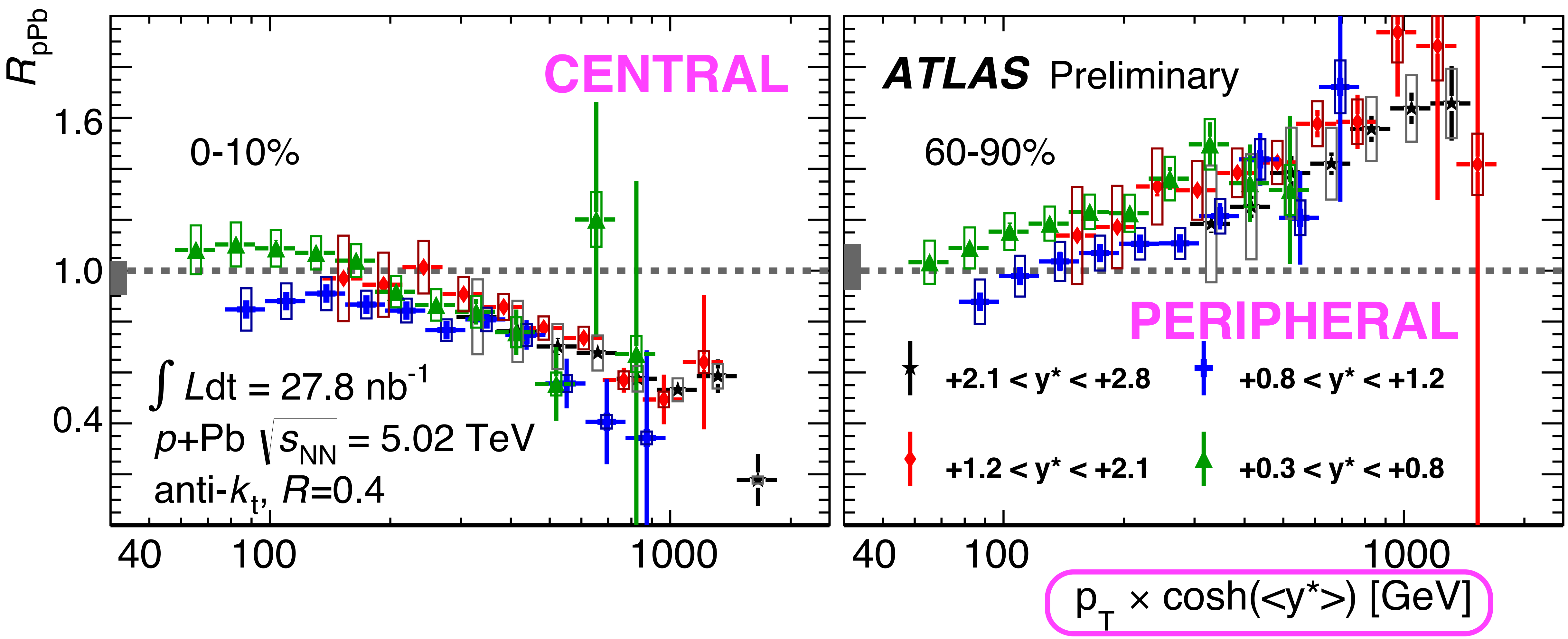


$y^* > 0$ data follow a single trend! $R_{CP}(p_T, y^*) = R_{CP}(p)$

$y^* < 0$ data do not…

What is this telling us about the suppression mechanism?

Scaling in the R_{pPb} vs. p



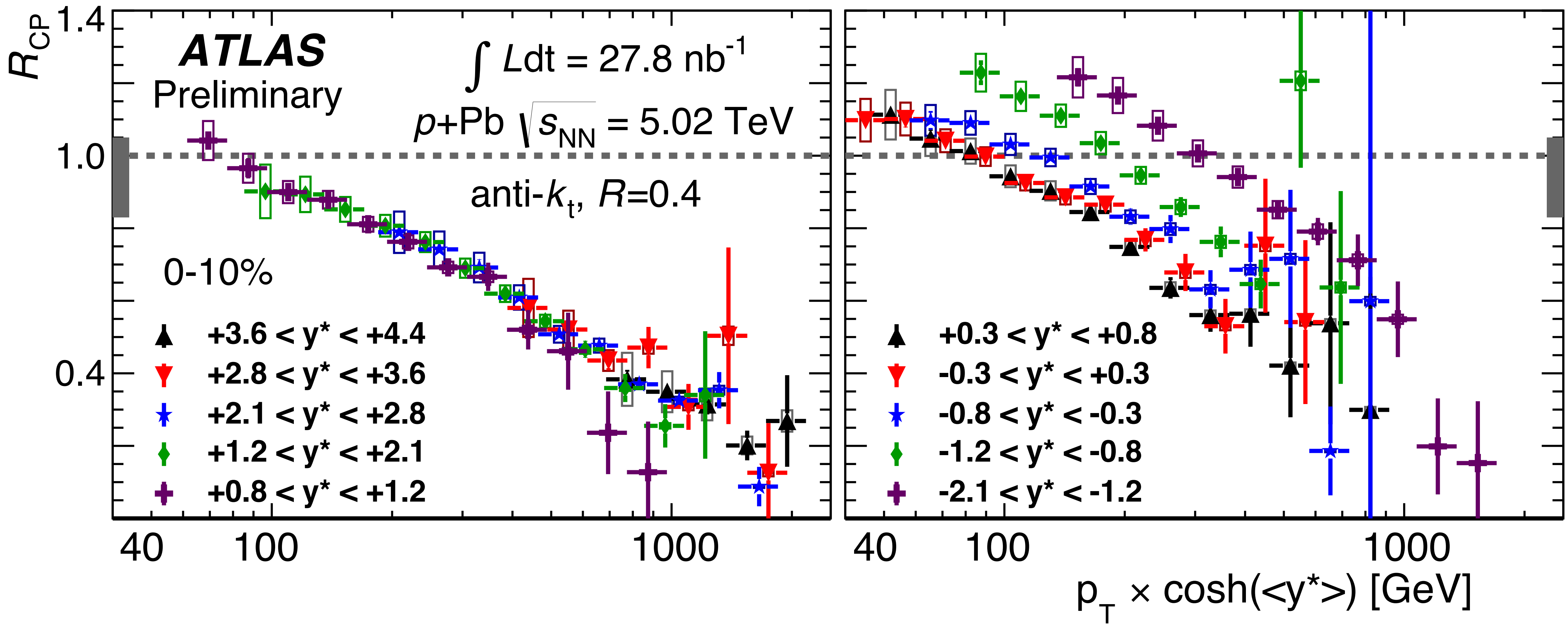
- At high p_T, central and peripheral R_{pPb} scale with p separately!
- Events with a forward jet with energy p typically have $x_p = p / (\sqrt{s}/2)$
    - <u>are we learning something about the *proton* wavefunction?</u>

Conclusion

- ATLAS has measured inclusive jets in *p*+Pb collisions
  - R_{pPb} for > 50 GeV, -2.1 < y* < +2.8
  - R_{CP} for > 30 GeV (at forward rapidities), -2.1 < y* < +4.4
- The jet rate in 0-90% *p*+Pb collisions is mildly enhanced
  - consistent with nPDF expectations
- Strong, centrality dependent effects in the R_{CP} & R_{pPb}
  - geometric scaling at low p_{T}
  - at high $p_{\mathrm{T},}$ suppression/enhancement in central/peripheral R_{pPb}
    - large changes in the number of partons available for hard scattering?
    - or strong correlation between scattering kinematics and soft interactions?
      - challenging for factorization pictures of hard processes in nuclei
- The modifications exhibit a c*ontinuous y* dependence* that can be described in terms of simple kinematics alone

Conclusion

- The modifications exhibit a *continuous y* dependence* that can be described in terms of simple kinematics alone

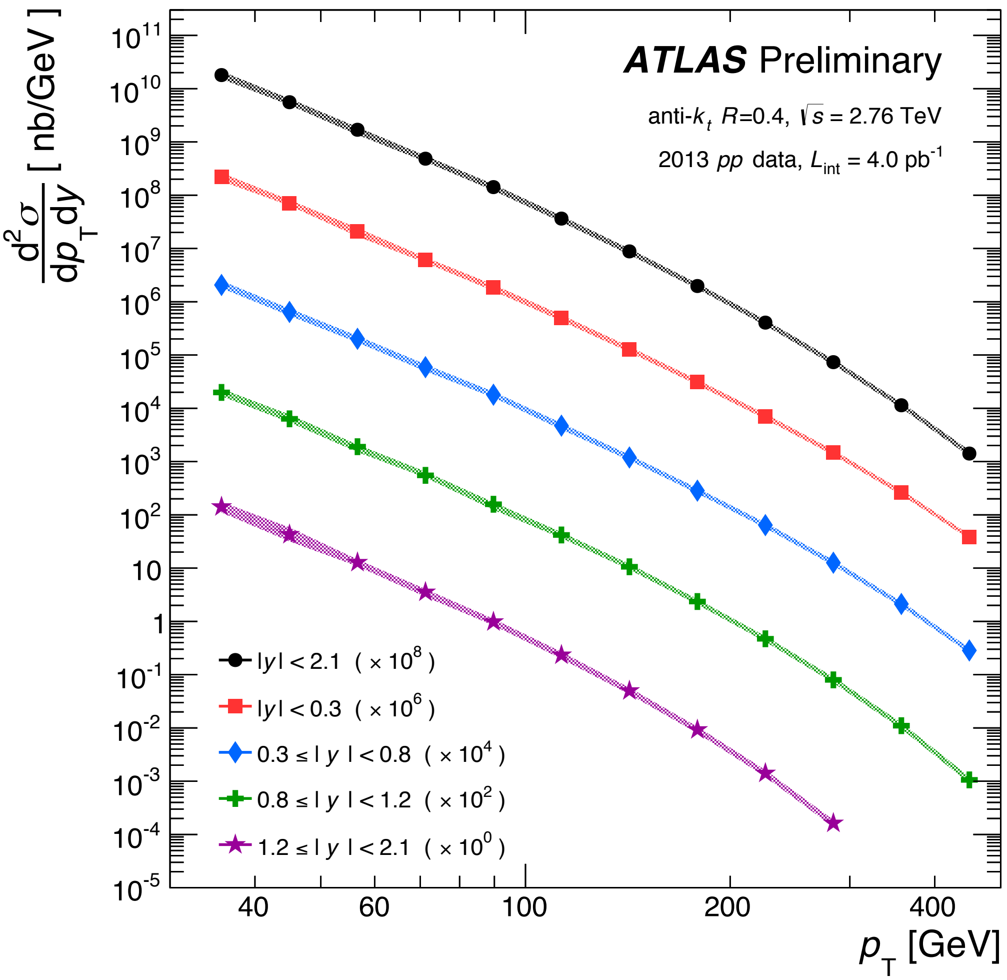


ATLAS-CONF-2014-033

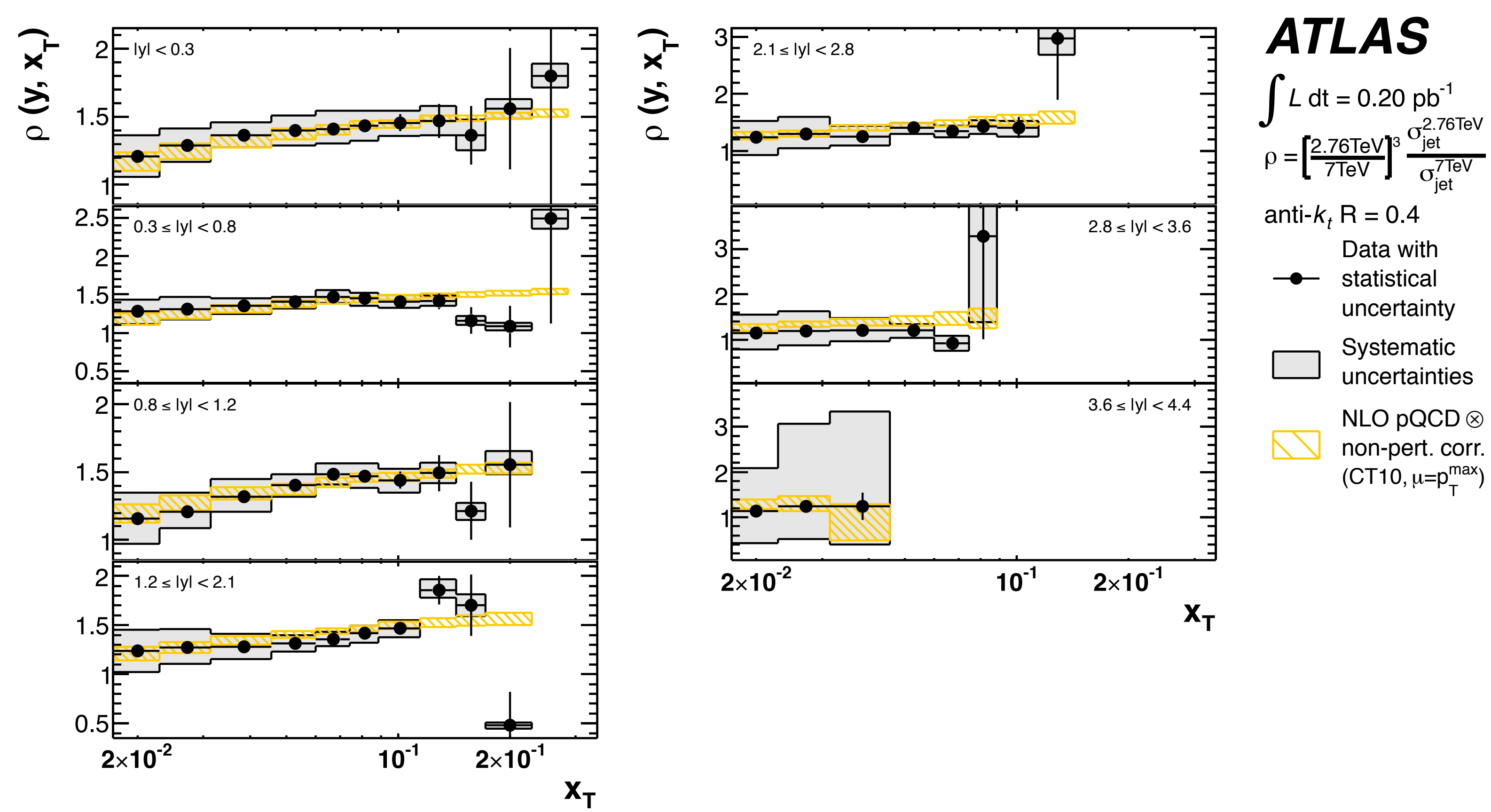
⇒ https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HeavyIonsPublicResults ⇐

Backup: *pp* reference

ATLAS-CONF-2014-025

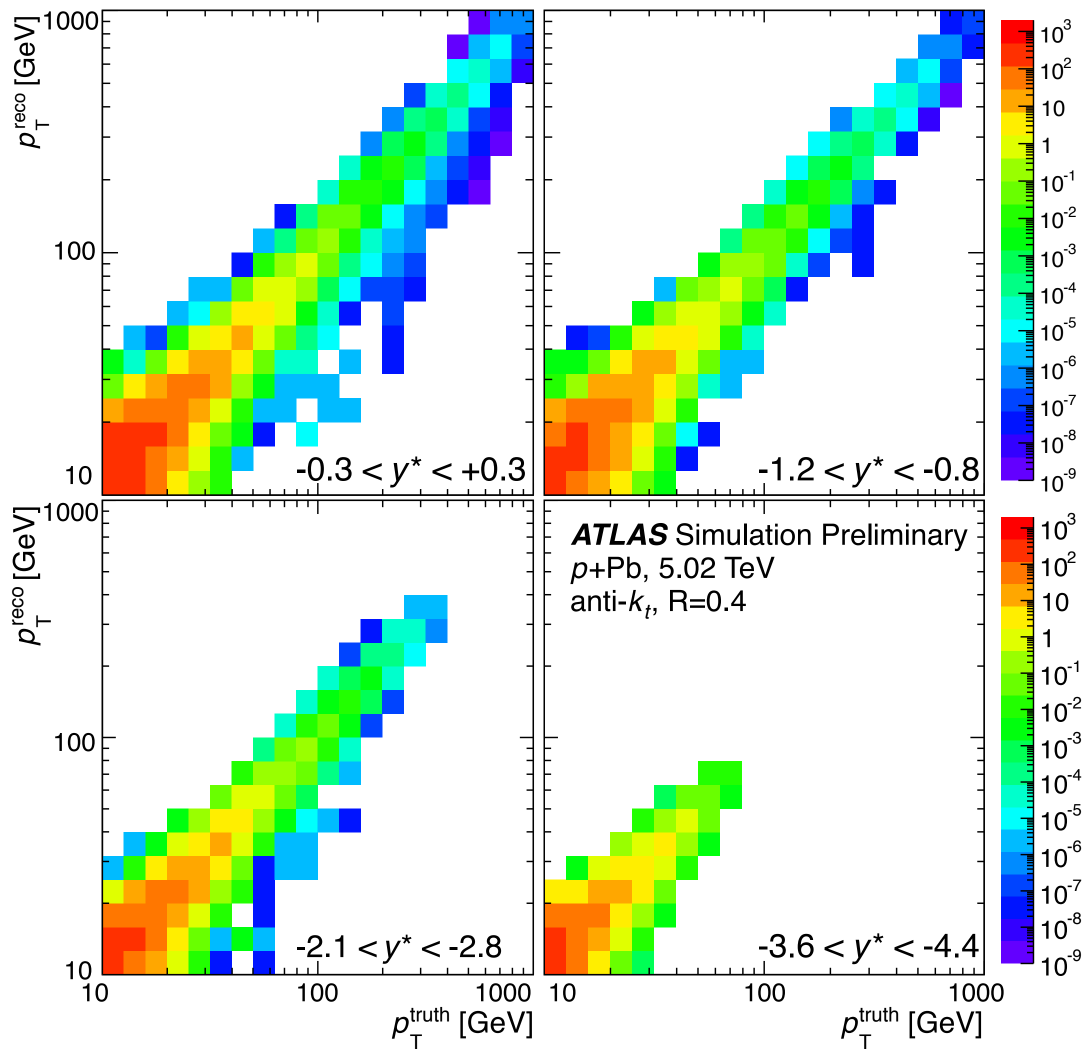


ATLAS, hep-ph/1304.4739



- *pp* jet cross-section, high-statistics February 2013 running
  - same reconstruction procedure & corrections as in *p*+Pb data
  - consistent with 2.76 TeV *pp* jet cross-section from 2011 running & NLO calculations
- ATLAS measurement of x_T scaling between 2.76 and 7 TeV
  - full treatment of correlations in systematic uncertainties
  - we interpolate to 5.02 TeV between two ATLAS data measurements

Backup: jet performance



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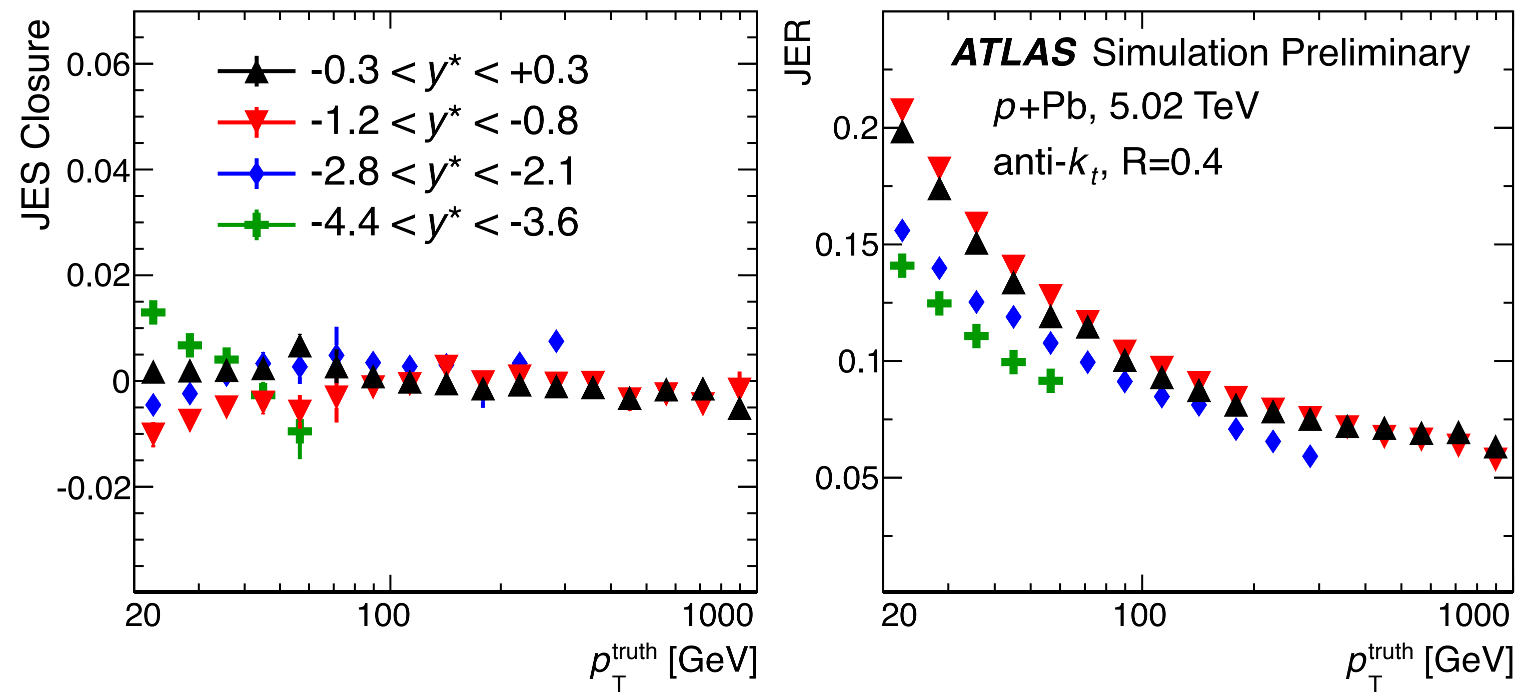
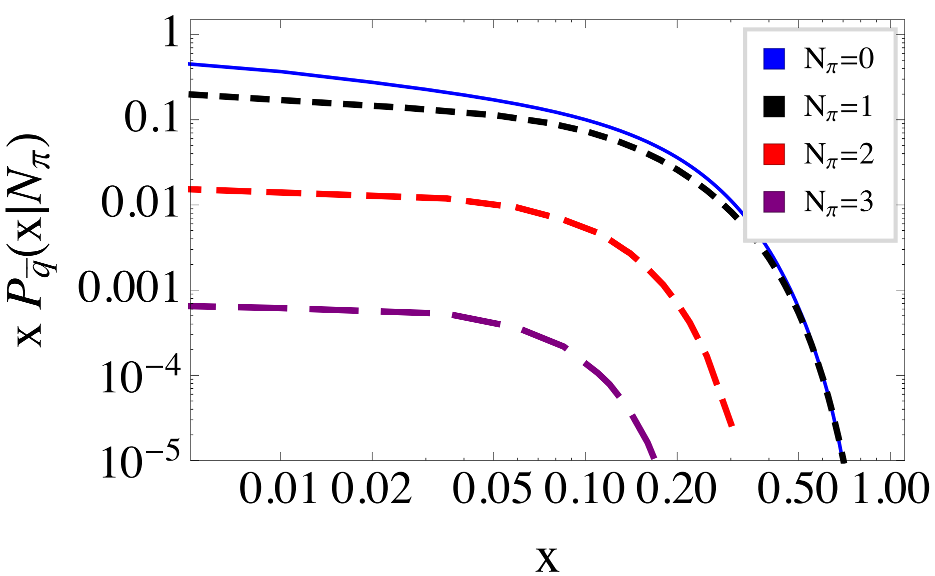


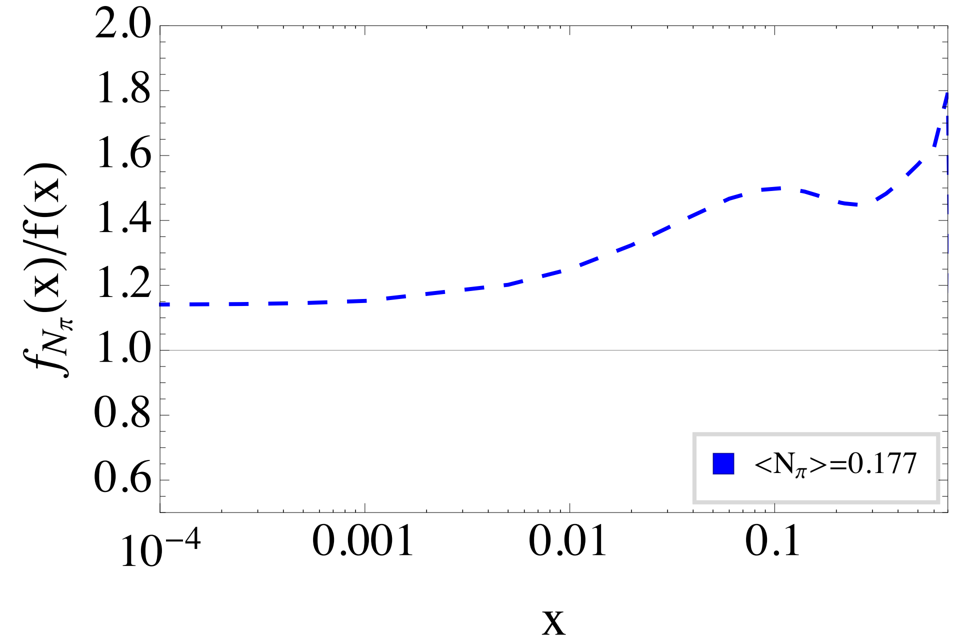
Also see poster E-15 by T. Kosek

- Jet Energy Scale Closure ($\langle p_T^{reco}/p_T^{truth} - 1\rangle$) always better than 2%
  - typically 1%, with small centrality-dependent differences at low p_T
- Jet Energy Resolution $\sigma(p_T^{reco}/p_T^{truth} - 1)$, 7-20%, p_T and y^* dependent
- Bin-by-bin correction factors typically 10-30%, but largely cancel in the R_{CP} and R_{pPb} ratios anyway

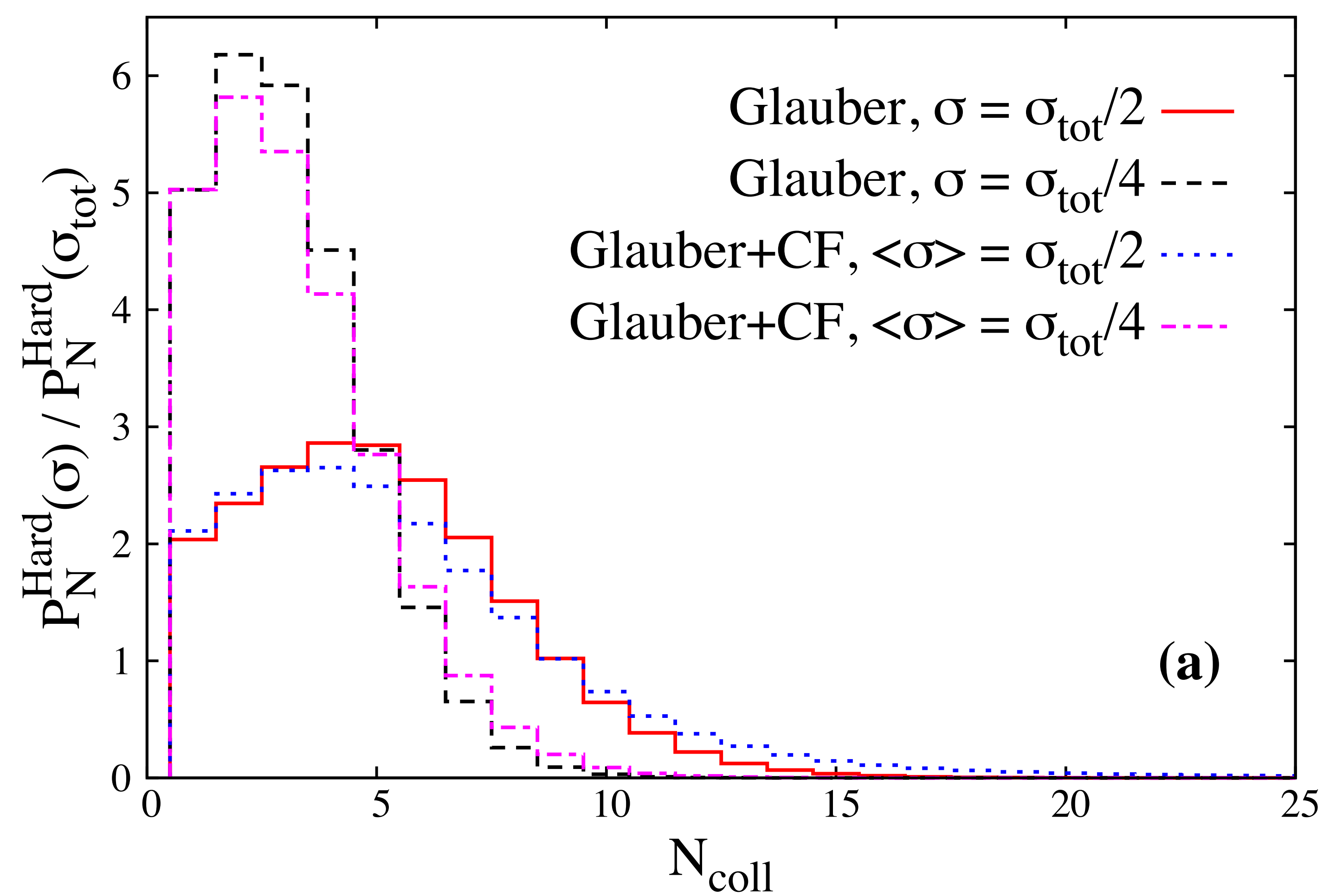
Backup: x_p dependence?

Idea: (anti-)correlation between proton wave function with large transverse extent and high *x*?



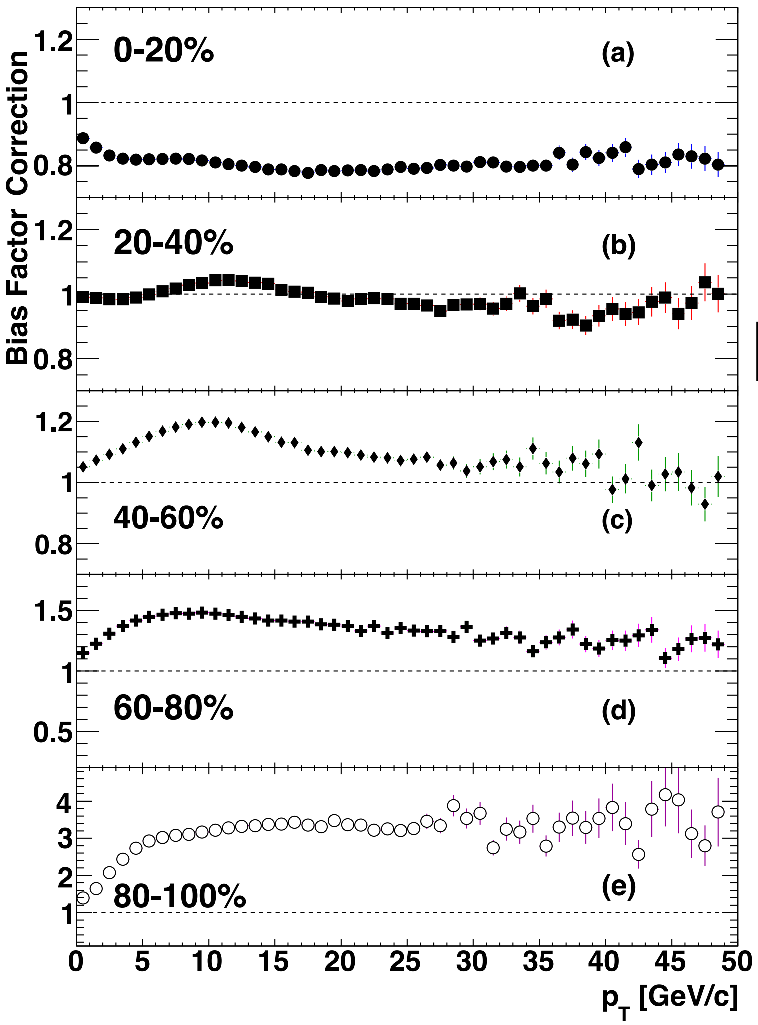


Coleman-Smith, Mueller
hep-ph/1307.5911



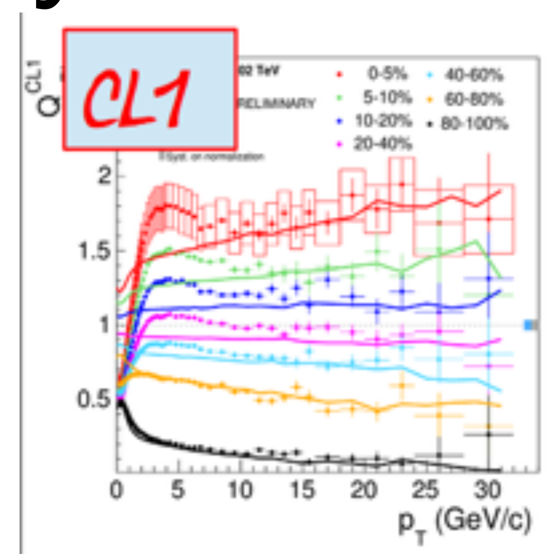
Alvioli, Frankfurt, Guzey, Strikman
hep-ph/1402.2868

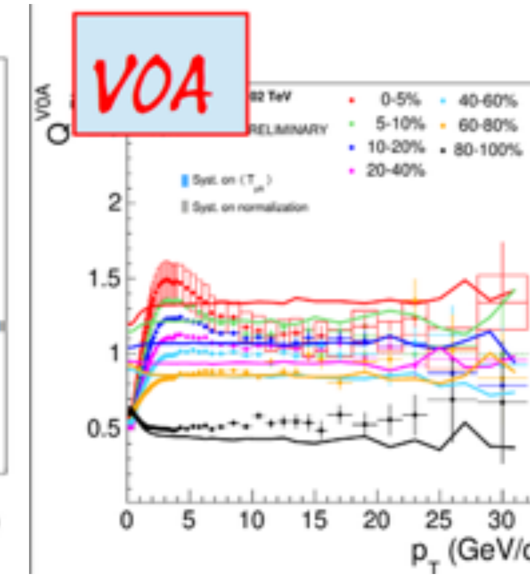
Backup: centrality "bias"?



PHENIX
bias correction factors
nucl-ex/1310.4793

S. Campbell,
12:20 Monday





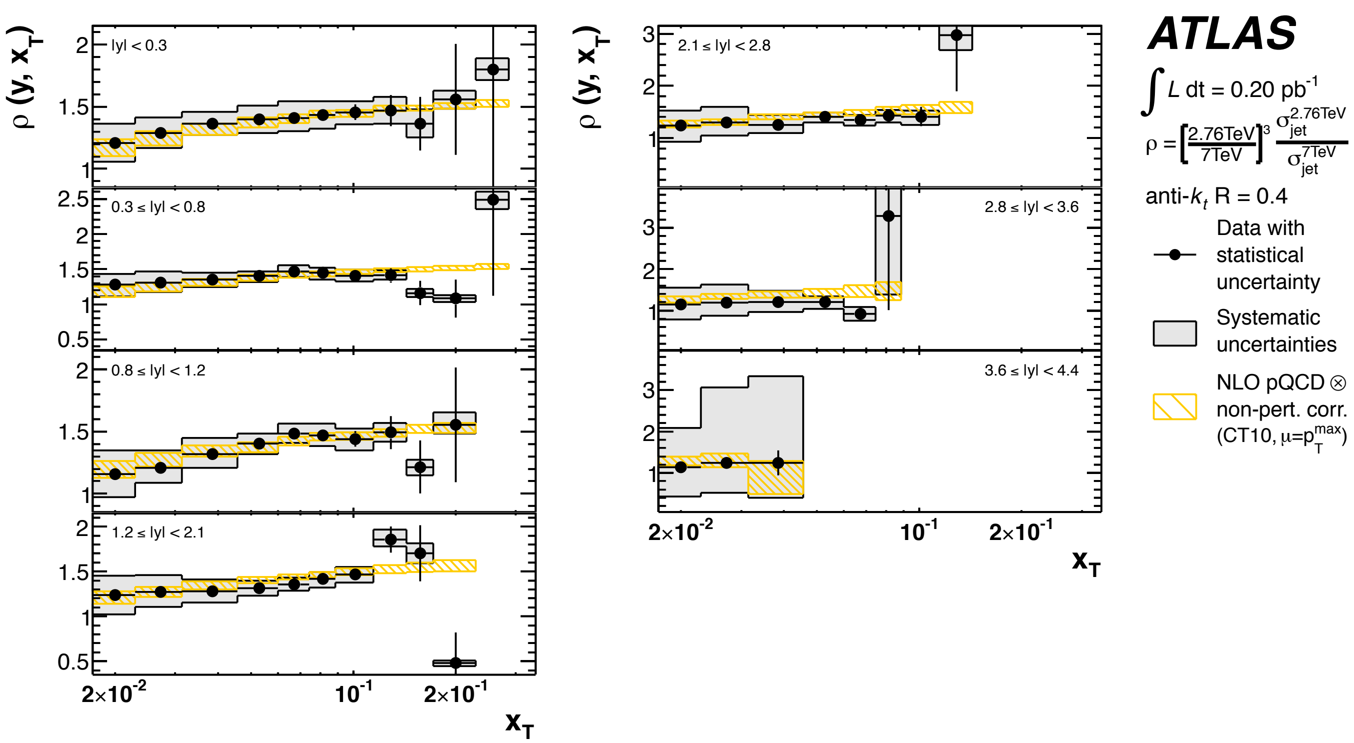
- Q_{pPb} spread between centrality
Reduces with increasing rapidity gap: CL1→V0M→V0A

A. Toia, 16:50 Monday

- Much discussion of a centrality "bias": event activity reflecting the presence of a hard process in additional to just the collision geometry
  1. All result in increases/decreases in central/peripheral events
  2. All show a weaker "bias" farther from the centrality-determining detector
     ➡ the ATLAS data show the opposite effects
- The ATLAS data show an entirely different phenomenon

Backup: dominant systematics

ATLAS, hep-ph/1304.4739



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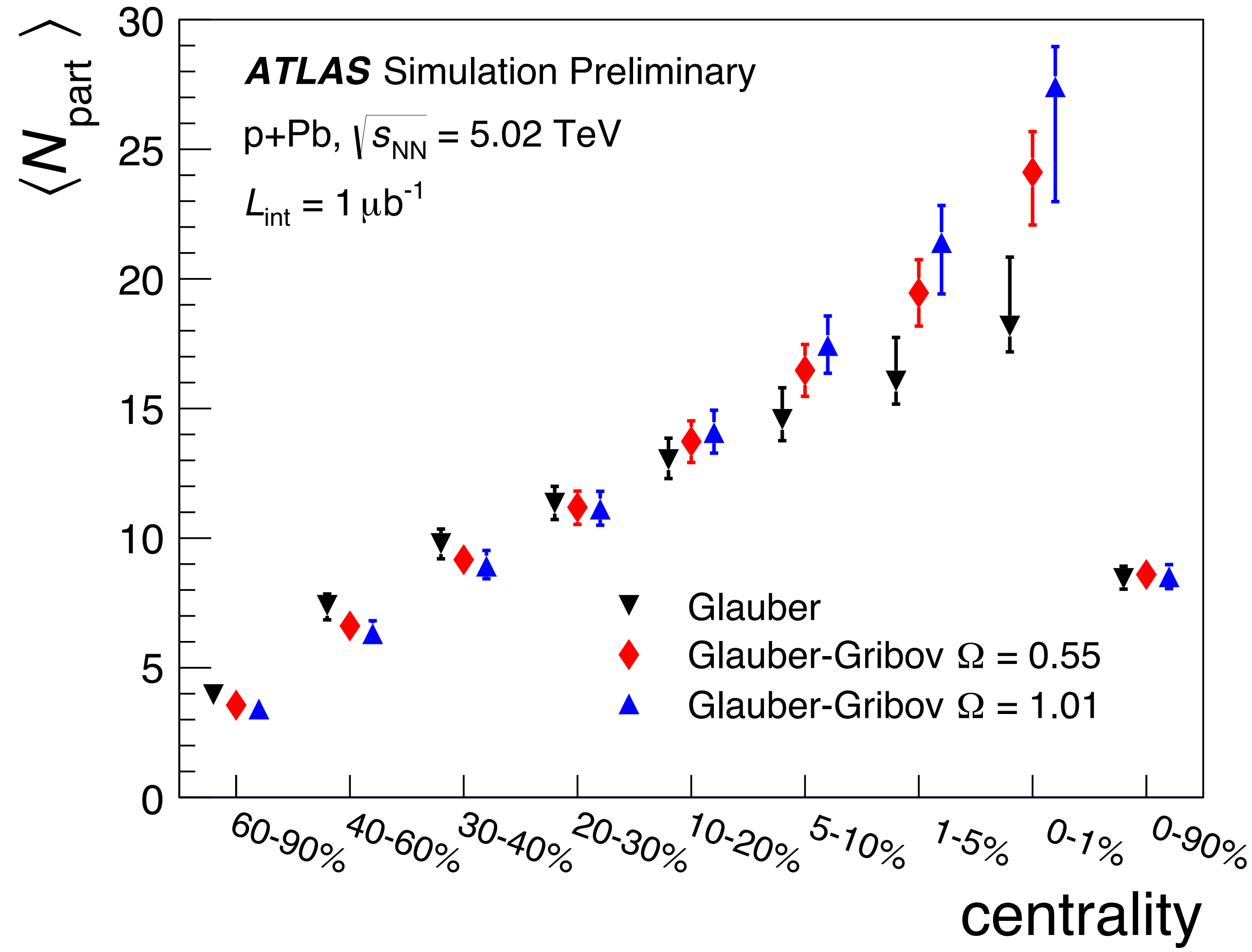
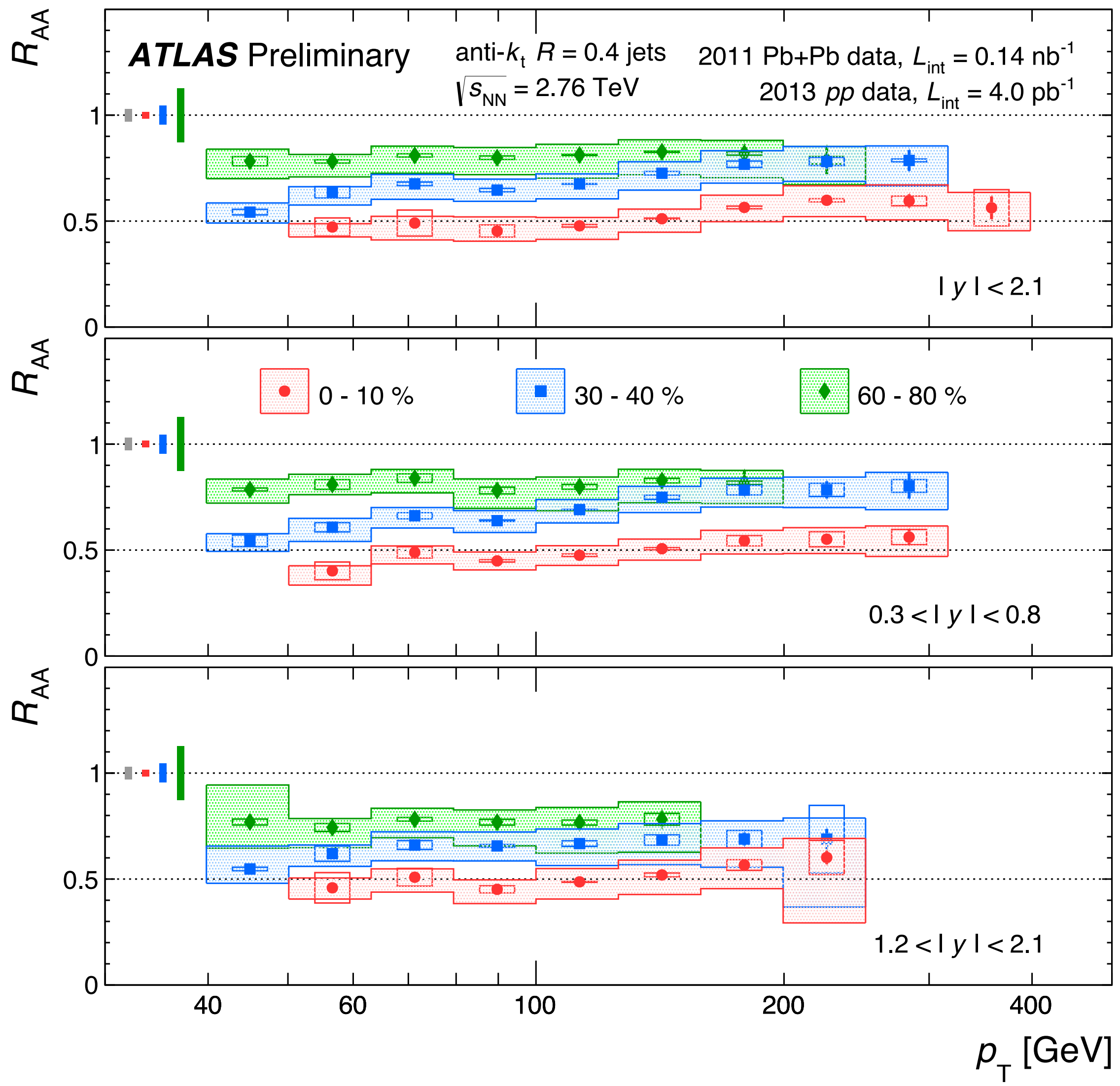
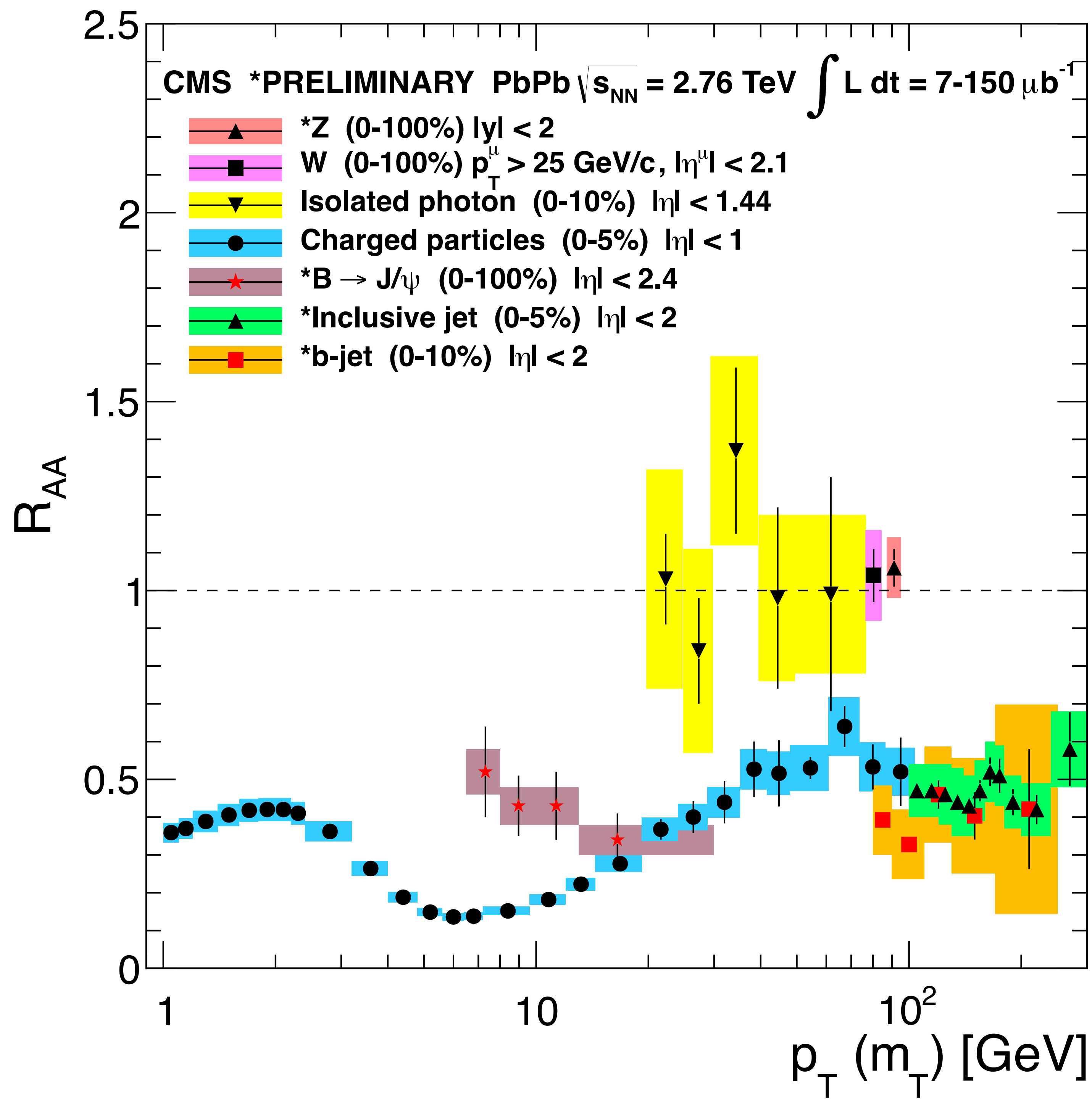


- Systematics on the ratios of p+Pb/pp spectra are small
  - same detector, same running period, same analysis procedure
- For R_{pPb}, dominant systematics are from the x_{T} interpolation (6-15%) and T_{pA}
- For R_{CP}, dominant systematics are actually from R_{coll}

Backup: implications for quenching in Pb+Pb?



ATLAS-CONF-2014-025
A. Angerami,
Tuesday 10:00



https://twiki.cern.ch/twiki/pub/CMSPublic/HIRaaCompilation