COLUMBIA UNIVERSITY
IN THE CITY OF NEW YORK

ATLAS EXPERIMENT

Measurements of jet suppression with ATLAS

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Jet suppression

ATLAS EXPERIMENT

If we assume:

- ⋆ **Standard collinear factorization of hard cross section**
- ⋆ **Parton density set by nucleon PDFs times density of nucleons in geometric overlap region**

Number of expected jets per event of a given centrality

$$= \langle T_{\mathrm{AA}} \rangle_{\mathrm{cent}} \times \frac{\mathrm{d}^2 \sigma_{\mathrm{jet}}^{pp}}{\mathrm{d}p_{\mathrm{T}} \mathrm{d}y}$$

$$R_{\mathrm{AA}} = \frac{\left. \frac{1}{N_{\mathrm{evt}}} \frac{\mathrm{d}^2 N_{\mathrm{jet}}}{\mathrm{d}p_{\mathrm{T}} \mathrm{d}y} \right|_{\mathrm{cent}}}{\langle T_{\mathrm{AA}} \rangle_{\mathrm{cent}} \times \frac{\mathrm{d}^2 \sigma_{\mathrm{jet}}^{pp}}{\mathrm{d}p_{\mathrm{T}} \mathrm{d}y}}$$

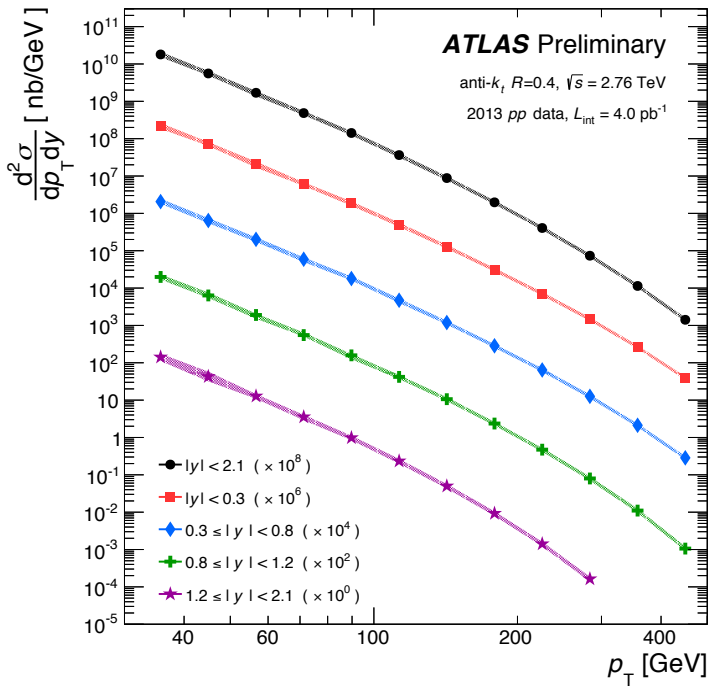
Is a test of ordinary QCD factorization in AA collisions

Tests magnitude of factorization breaking via final-state interactions: jet quenching

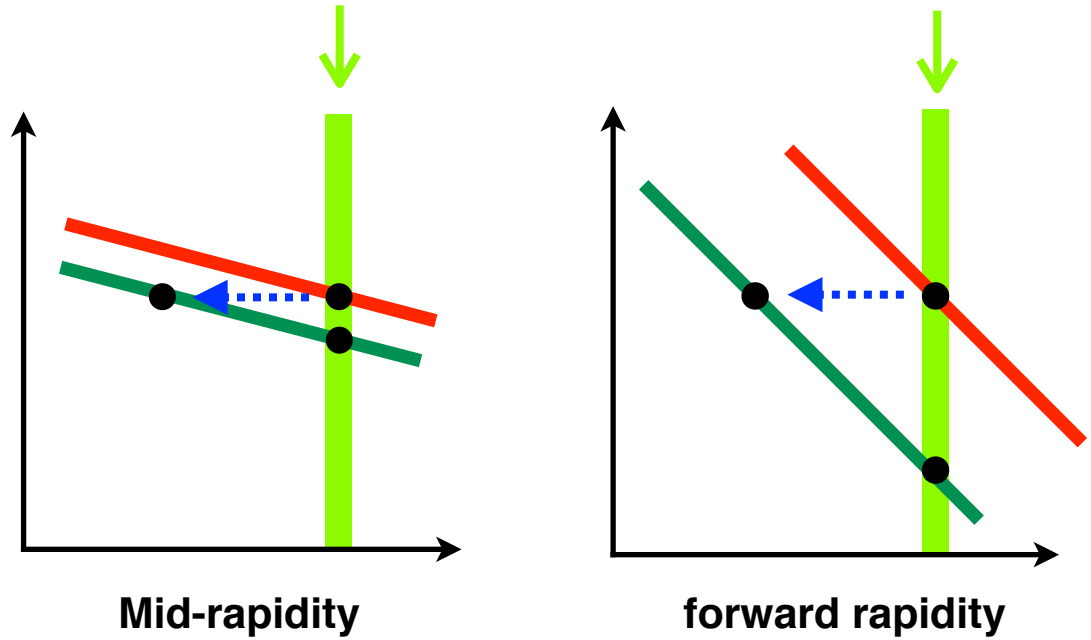
Single jet measurements

- Given new *p*+Pb measurements it is even more important we understand difference between peripheral and no nuclear effects
  - Updated measurements of color neutral probes
- Measure absolute magnitude of suppression with respect to unquenched reference, R_{AA}
- What do we know from existing measurements:
  - Jets are generally suppressed relative to peripheral by a factor of two
  - This suppression does not show a strong p_T dependence
  - Larger radius jets show less suppression
- Improve precision of measurement to identify trends
  - Improvements over previous R_{CP} measurement
  - Measure more differentially
    - Rapidity dependence, finer centrality bins

The effect of the production spectrum



R_{AA} ~ GREEN / RED at fixed p_T



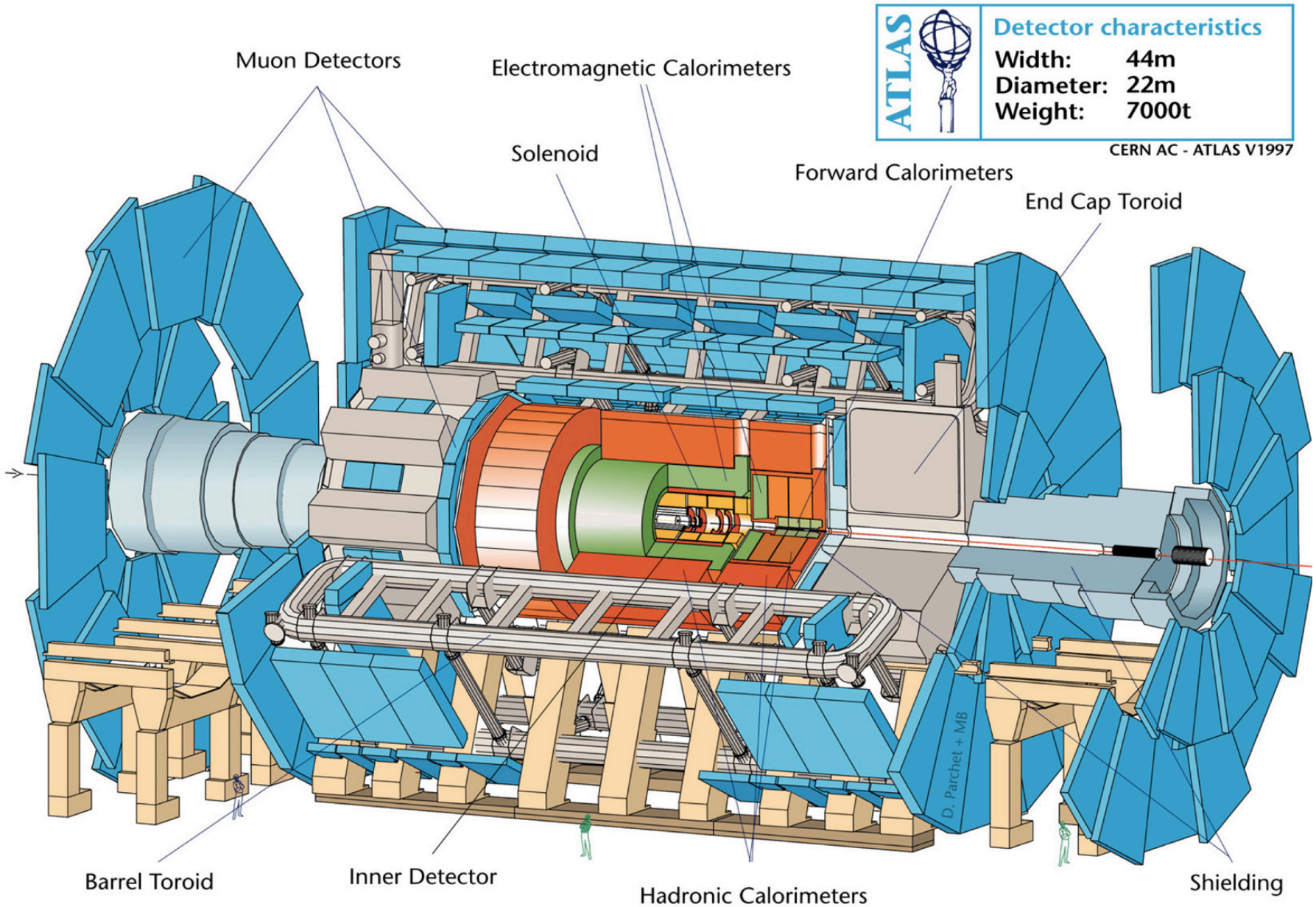
At more forward rapidity (lower points) the spectrum becomes steeper, e.g. at 100 GeV power law index drops from -5.8 to -6.6
At 200 GeV, -6.7 to 8 over the rapidity range measured here (0 — 2.1)

Same energy loss convolved with steeper spectrum results in lower R_{AA}

Also, at increasingly forward rapidities, jet production dominated by hard scattering with outgoing quarks which have a different parton shower, may lose less energy (naive color factor) yielding a higher R_{AA}

Which effect wins out? Answer likely depends on kinematic region…

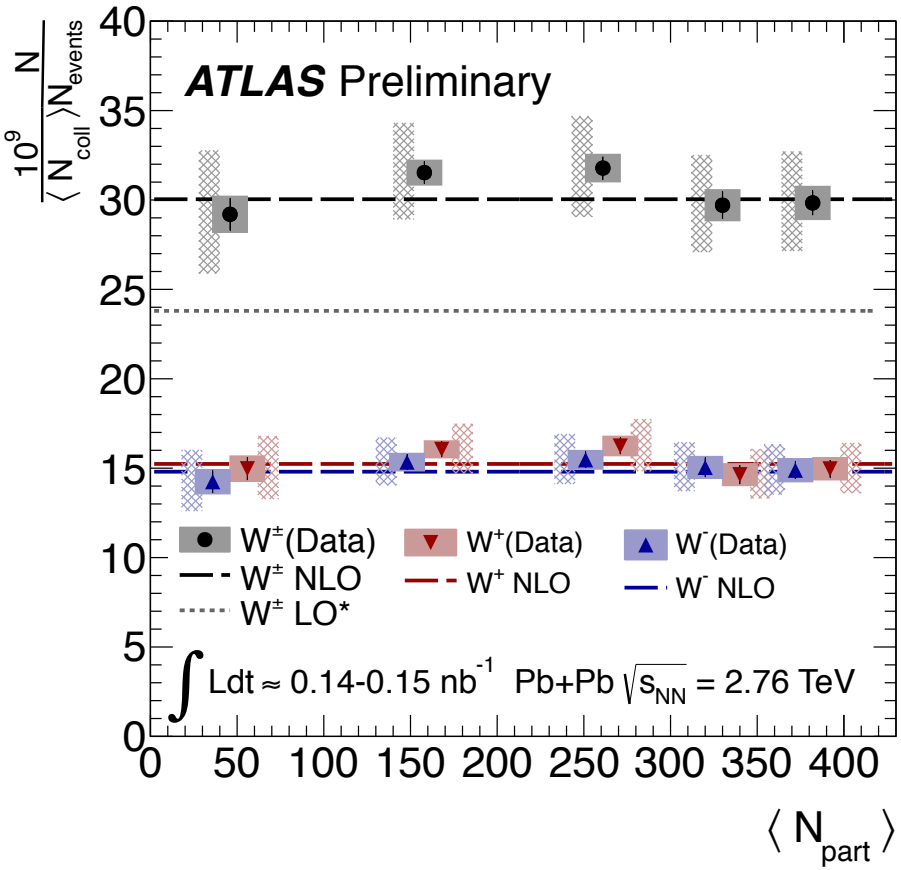
The ATLAS detector



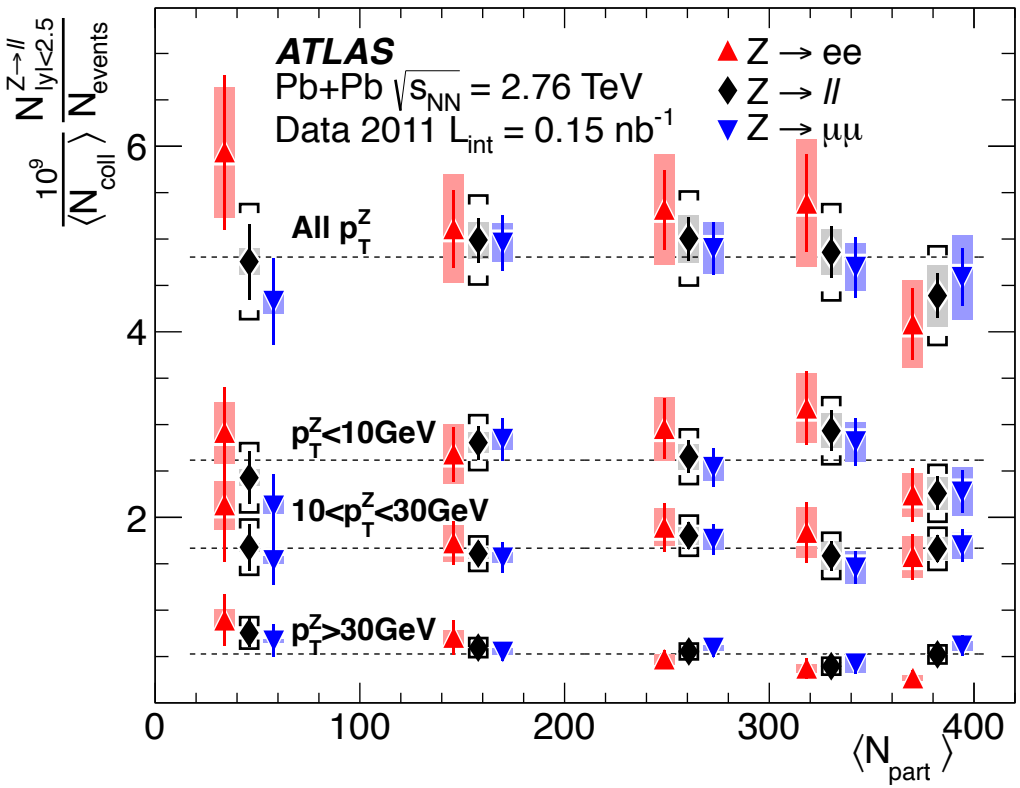
Geometry from electroweak probes: *W* and *Z*

in situ determination of T_{AA}

W

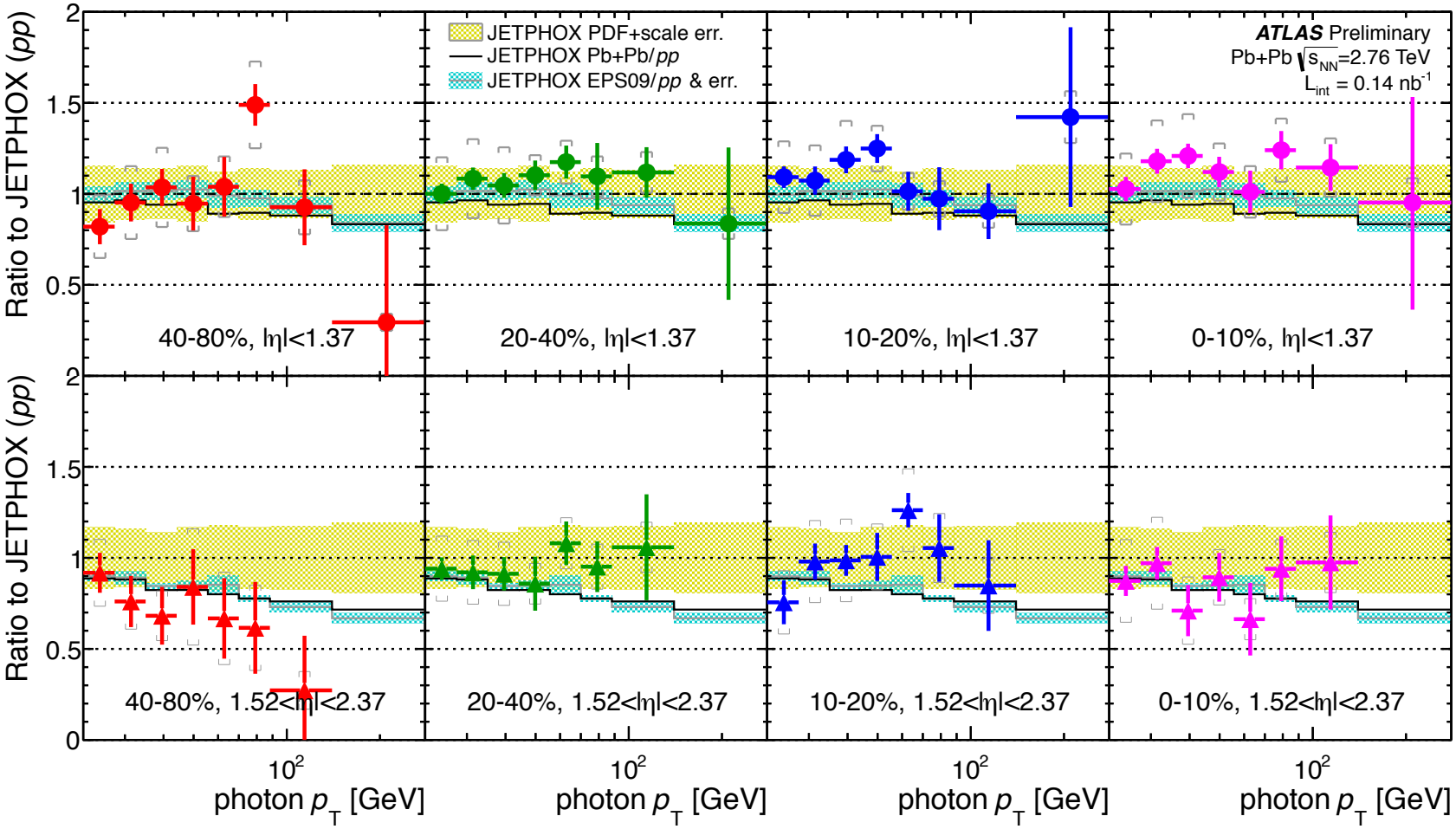


Z



Binary scaled Pb+Pb data compared to NLO

Geometry from electroweak probes: γ



| η | < 1.37

1.52 < | η | < 2.37

T_{AA} scaled Pb+Pb compared with cross sections from JETPHOX

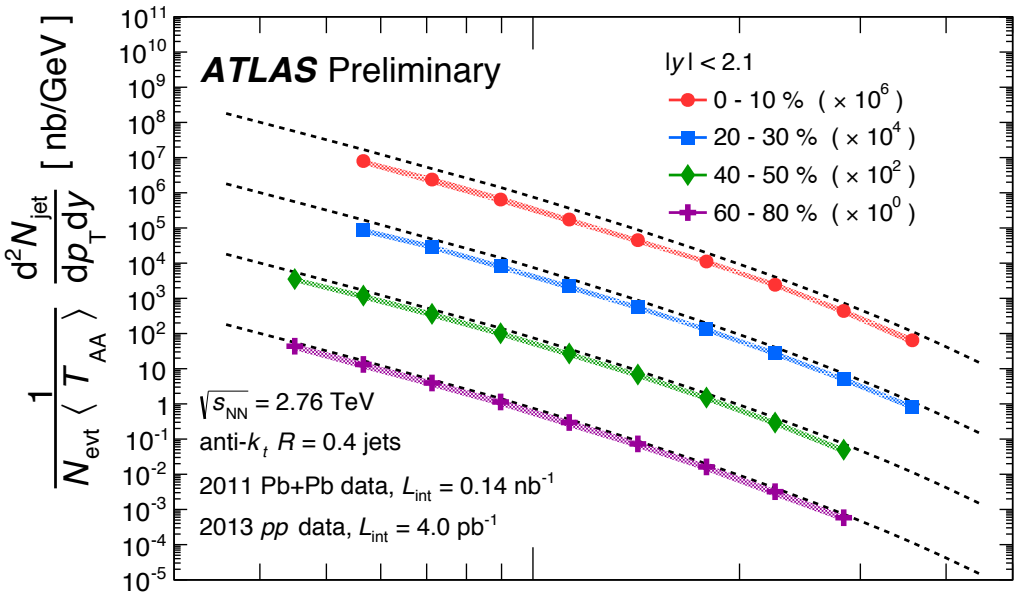
Control over geometry

- Have multiple checks in data that rates for hard processes scale with the expected geometric enhancement
- T_{AA} is controlled experimentally to ~ 10%
  - At the level of expected NPDF effects
- Significant departures of R_{AA} = 1 for jets (< 10%) cannot be explained without significant final state interactions

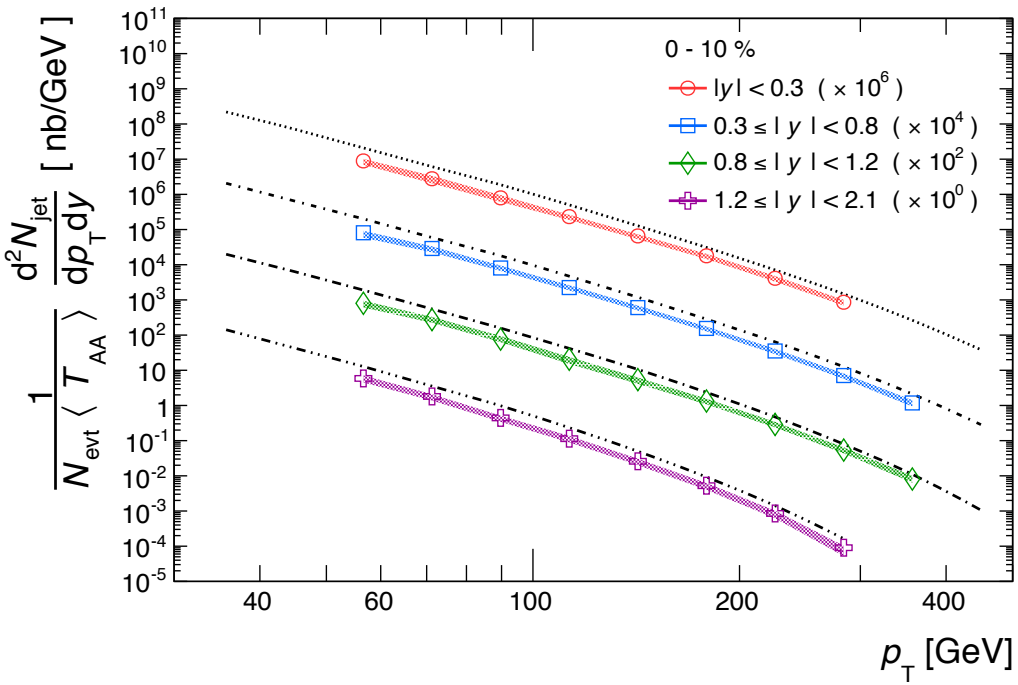
Improvements over R_{CP} measurement

- Now using 2011 Pb+Pb data and 2013 *pp* data
  - Factor of 20 improvement in statistics
- Using overlay procedure to evaluate response and perform unfolding
  - Previously had embedded PYTHIA jets into HIJING simulation
  - Now embedding into real Pb+Pb data
    - Sample contains UE contribution that is identical to data
    - Contains ALL UE fluctuations/correlations
- Improvements to background subtraction procedure
- Exhaustive studies of jet energy scale (JES)
  - Determine response and uncertainties using direct balance methods in γ/Z+jet events in high statistics 8 TeV *pp* data
  - Evaluated response to jets of different flavor and parton showers produced by different generators
  - Determined effects on JES when measuring jets modified due to quenching using measurements of fragmentation function

Jet production in Pb+Pb collisions



Centrality variation at fixed rapidity (| *y* | < 2.1)

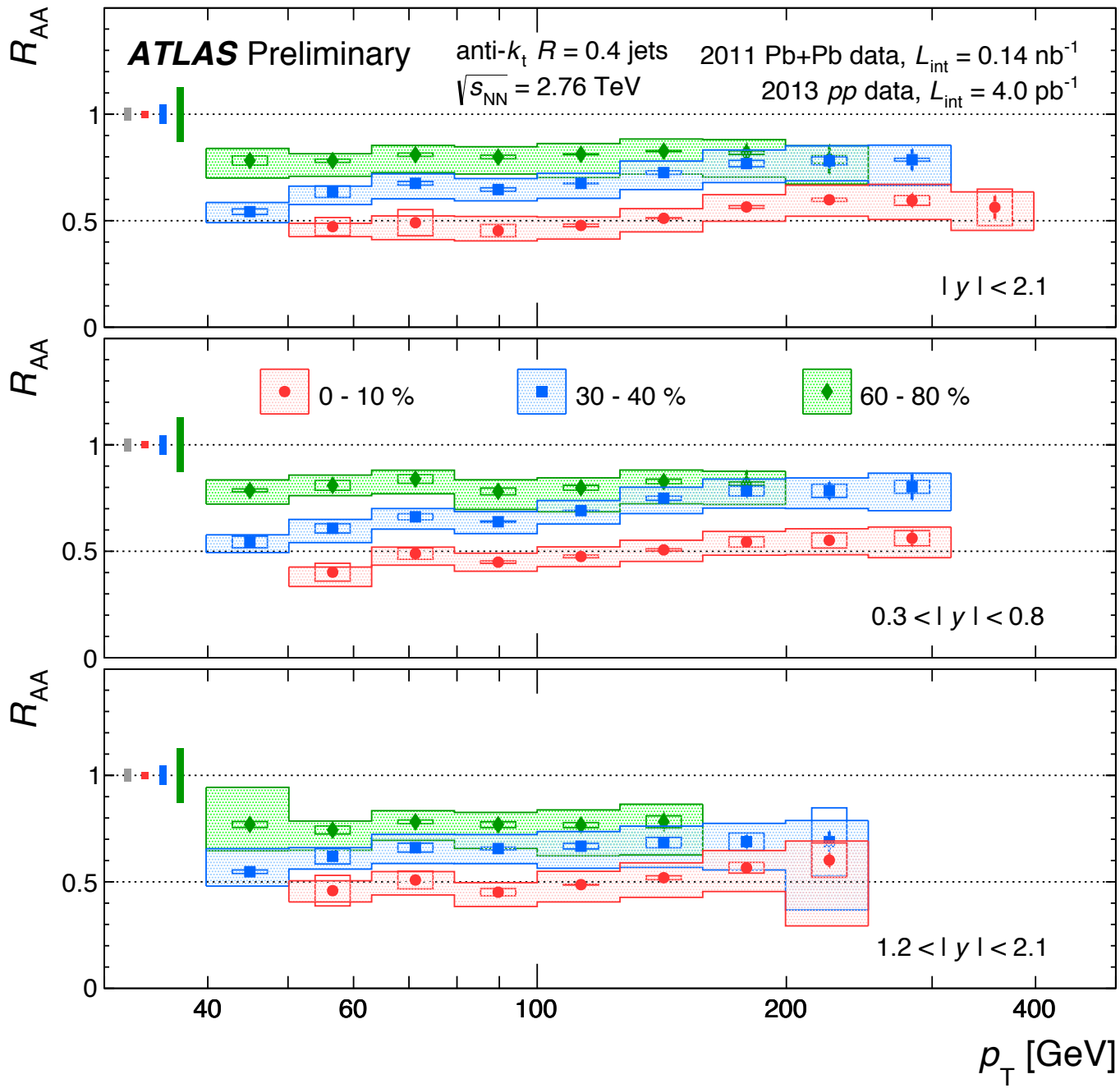


Rapidity variation at fixed centrality (0—10 %)

Dashed lines are *pp* reference

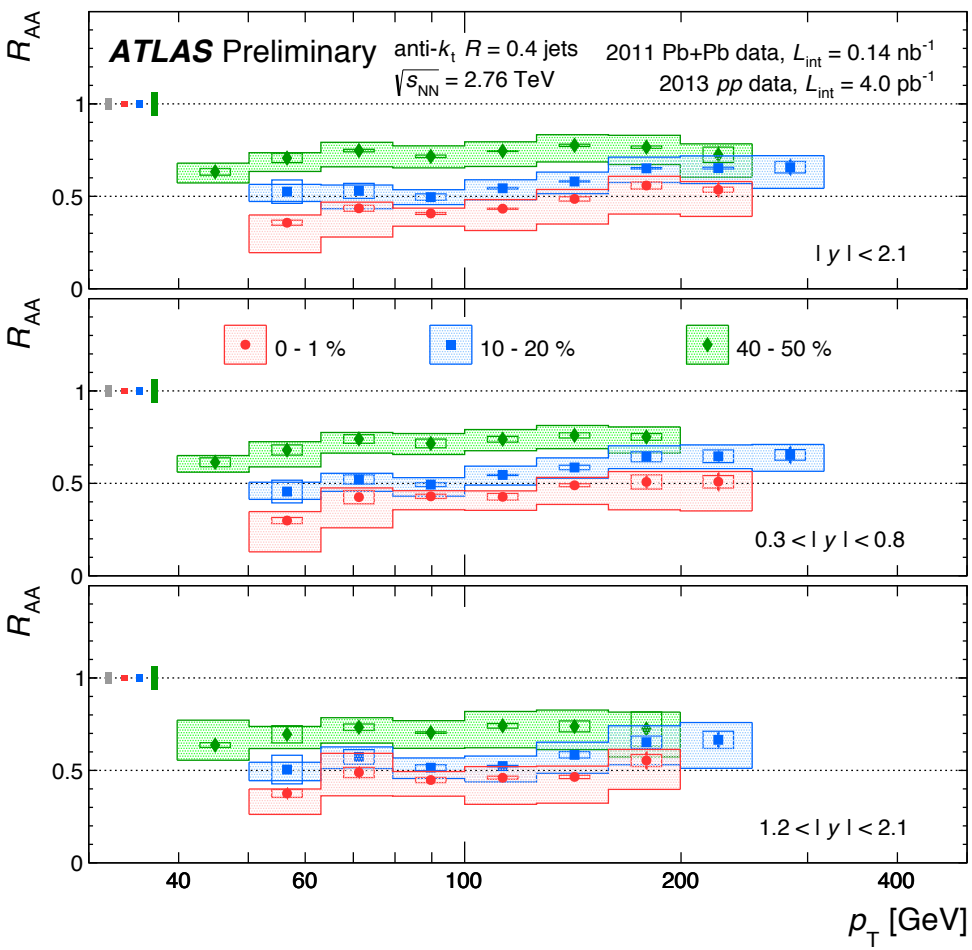
Suppression evident from fact that points fall below reference

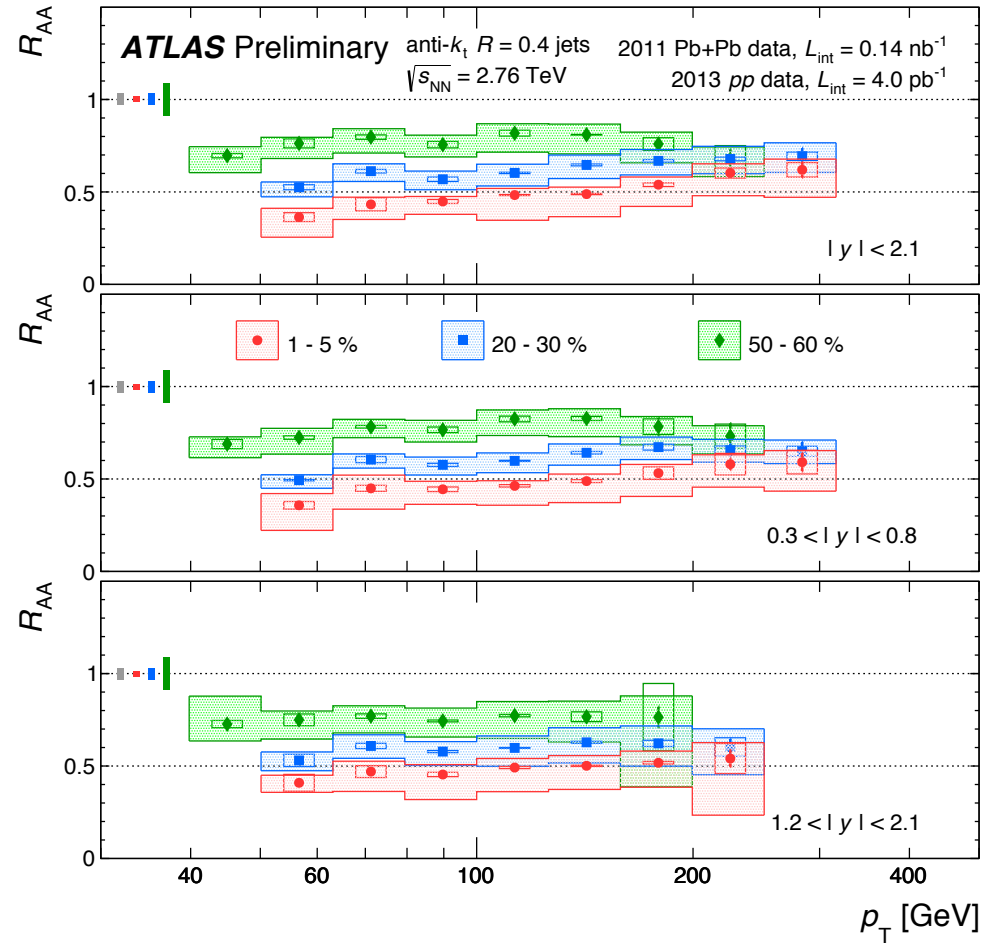
Jet suppression : R_{AA} vs p_T



Centrality variation at fixed rapidity ($|y| < 2.1$)

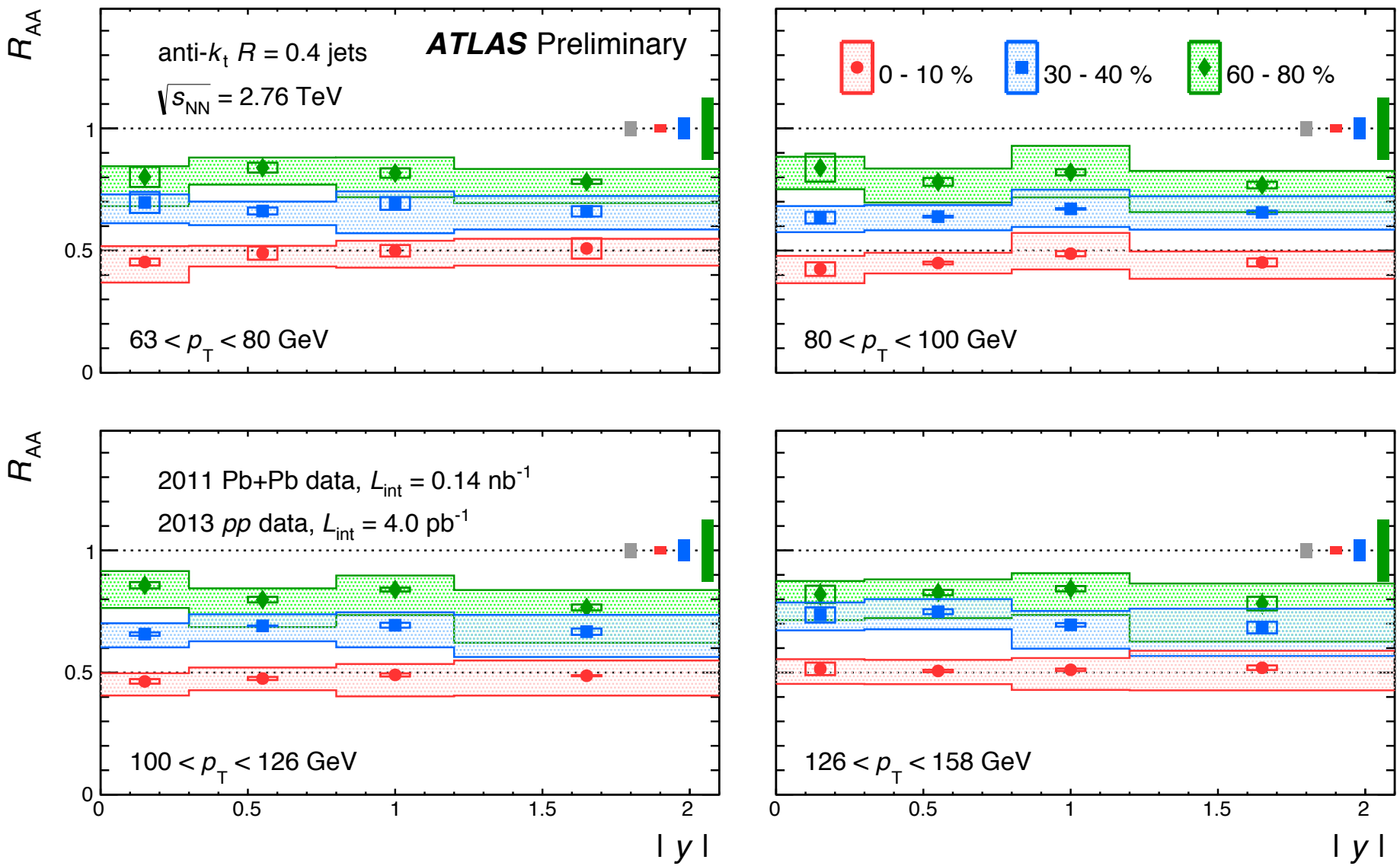
Jet suppression : R_{AA} vs p_T





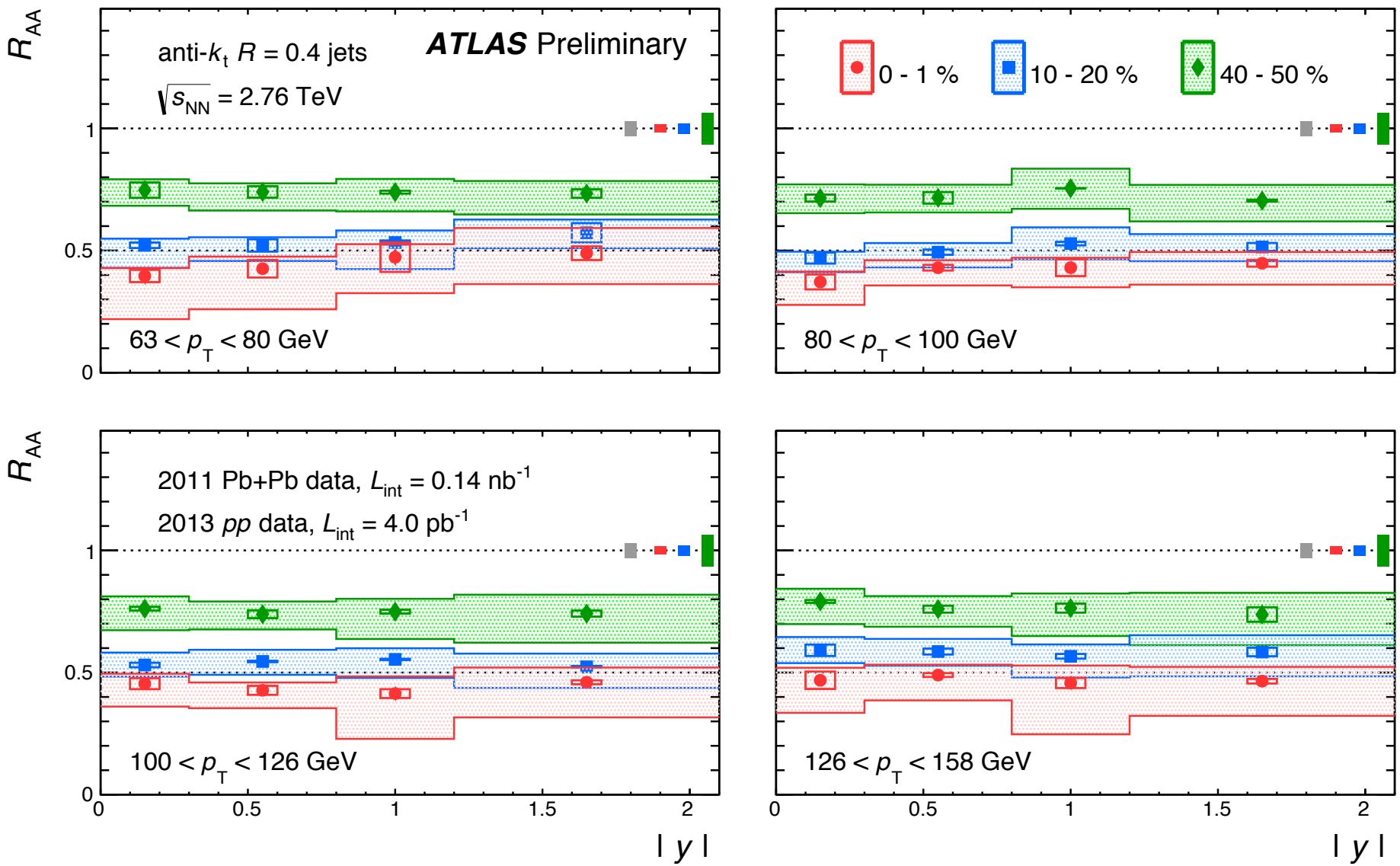
Now showing different centrality bins

Jet suppression : R_{AA} vs y



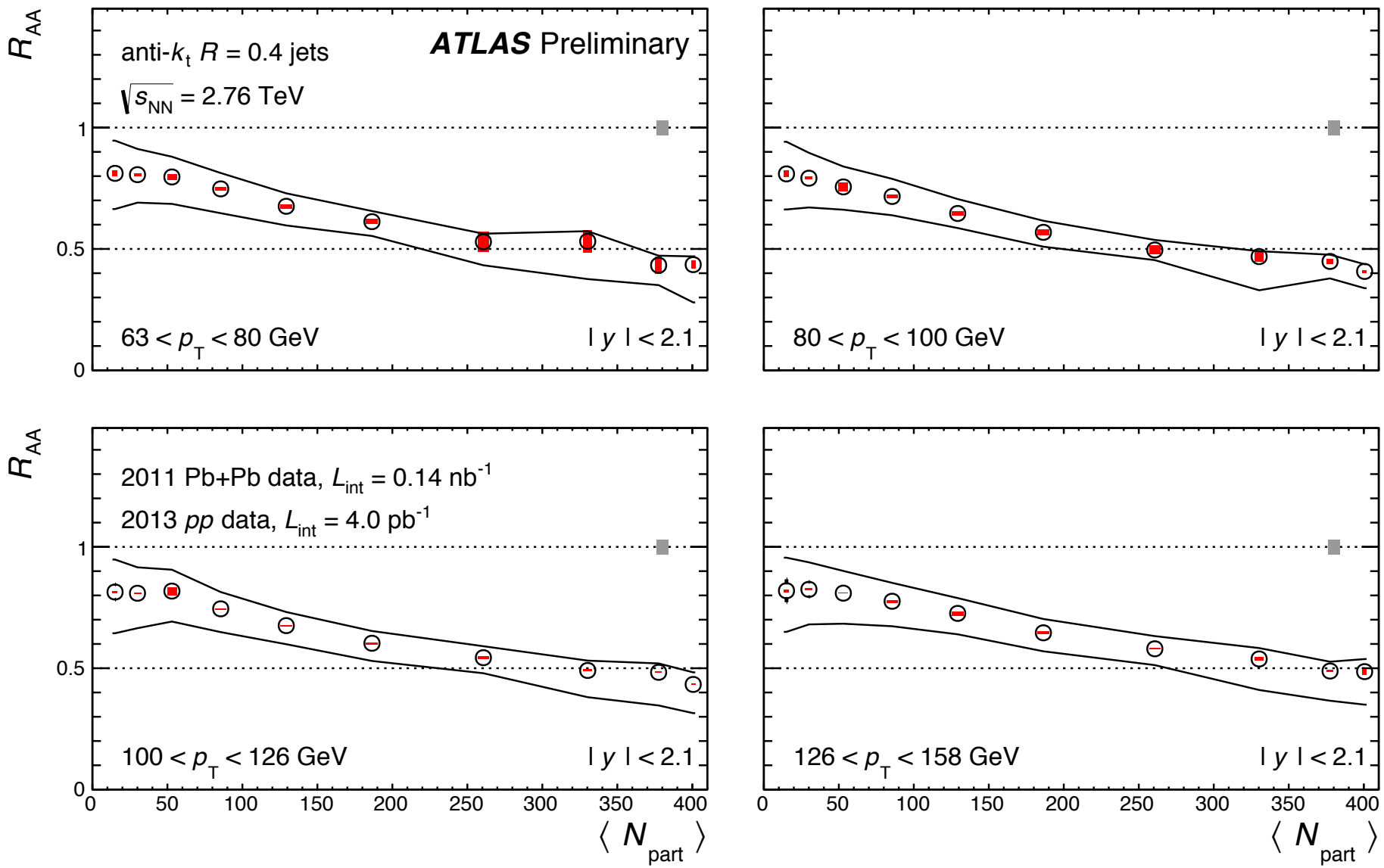
May see hints of some variation with | y | but nothing significant

Jet suppression : R_{AA} vs y



May see hints of some variation with | y | but nothing significant

Jet suppression : R_{AA} vs N_{part}



Smooth behavior with N_{part}, maximal suppression in 0—1% is 0.4

Conclusions

- ATLAS has measured the R_{AA} for jets over wide range of jet p_T, rapidity and collision centrality
- Jets are suppressed by more than a factor of two in central collisions with respect to *pp* collisions
- This suppression shows a weak dependence on p_T
  - For central collisions the R_{AA} changes from 0.47 to 0.56 from 50 to 350 GeV.
- Do not see a large rapidity dependence
  - Magnitudes of effects contributing to this need to be sorted out via comparisons to theoretical calculations accounting for both

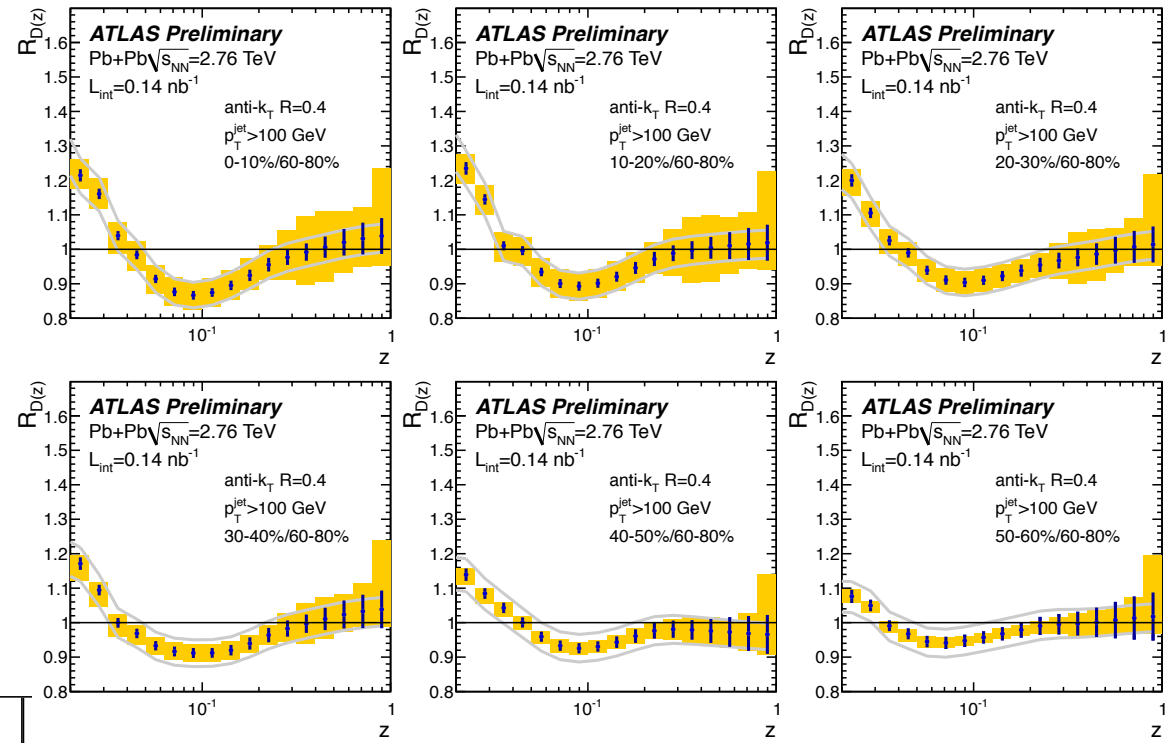
Extras

Measuring quenched jets

We know we have a centrality dependent modification to the fragmentation function

Have extensively studied how our ability to measure a jet's energy changes when it has a different fragmentation function

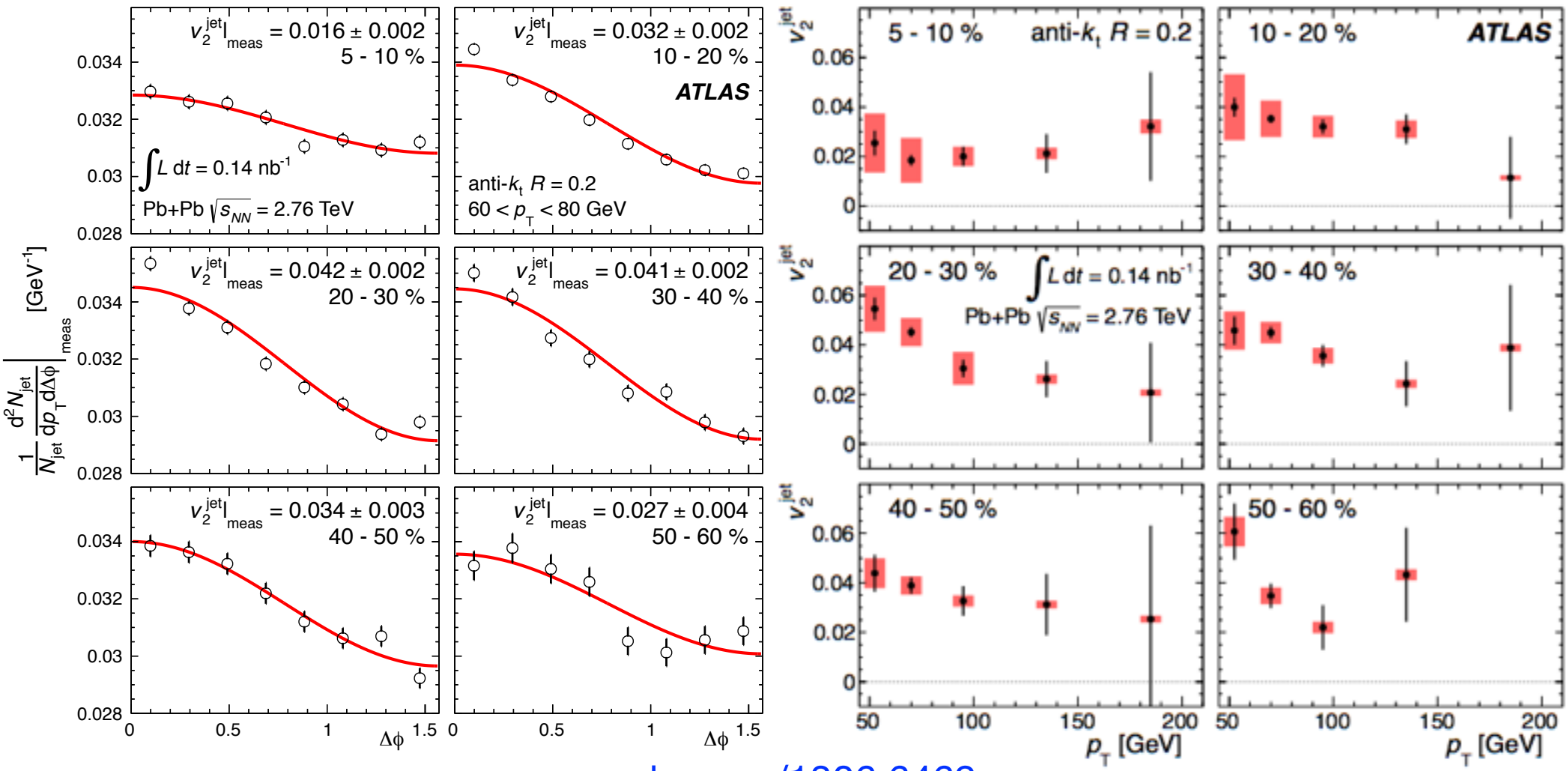
Most significant effects from from depletion of jet's energy at mid-z (0.4-0.2)



centrality	$z = 0.04 - 0.2$	
	$\int \Delta D(z)dz$	$\int z\Delta D(z)dz$
0-10%	$-1.7^{+0.6}_{-0.8}$	$-0.14^{+0.04}_{-0.06}$
10-20%	$-1.6^{+0.7}_{-0.8}$	$-0.12^{+0.05}_{-0.06}$
20-30%	$-1.3^{+0.6}_{-0.6}$	$-0.12^{+0.04}_{-0.04}$
30-40%	$-1.3^{+0.6}_{-0.7}$	$-0.10^{+0.04}_{-0.05}$
40-50%	$-0.6^{+0.6}_{-0.8}$	$-0.07^{+0.04}_{-0.06}$
50-60%	$-1.2^{+0.9}_{-0.7}$	$-0.08^{+0.06}_{-0.06}$

Pyquen can be configured to produce fragmentation functions that differ from those from Pythia in a way that is similar to the measured centrality-dependent variation

Jet suppression and collision geometry



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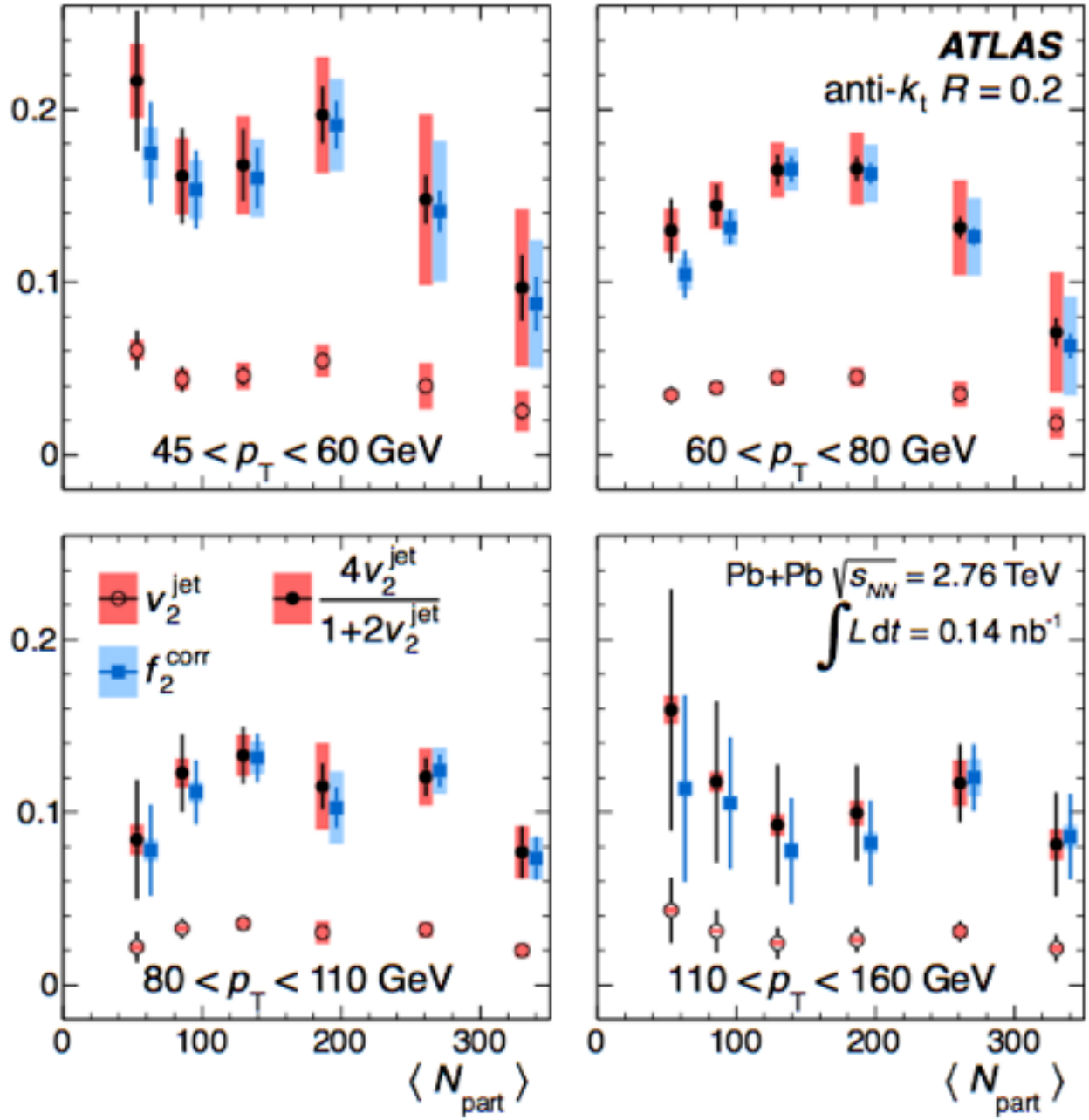
- **Jets in the direction of the event plane are less suppressed**
- **cos(2$\Delta\phi$) modulation of yield of 1-5%**

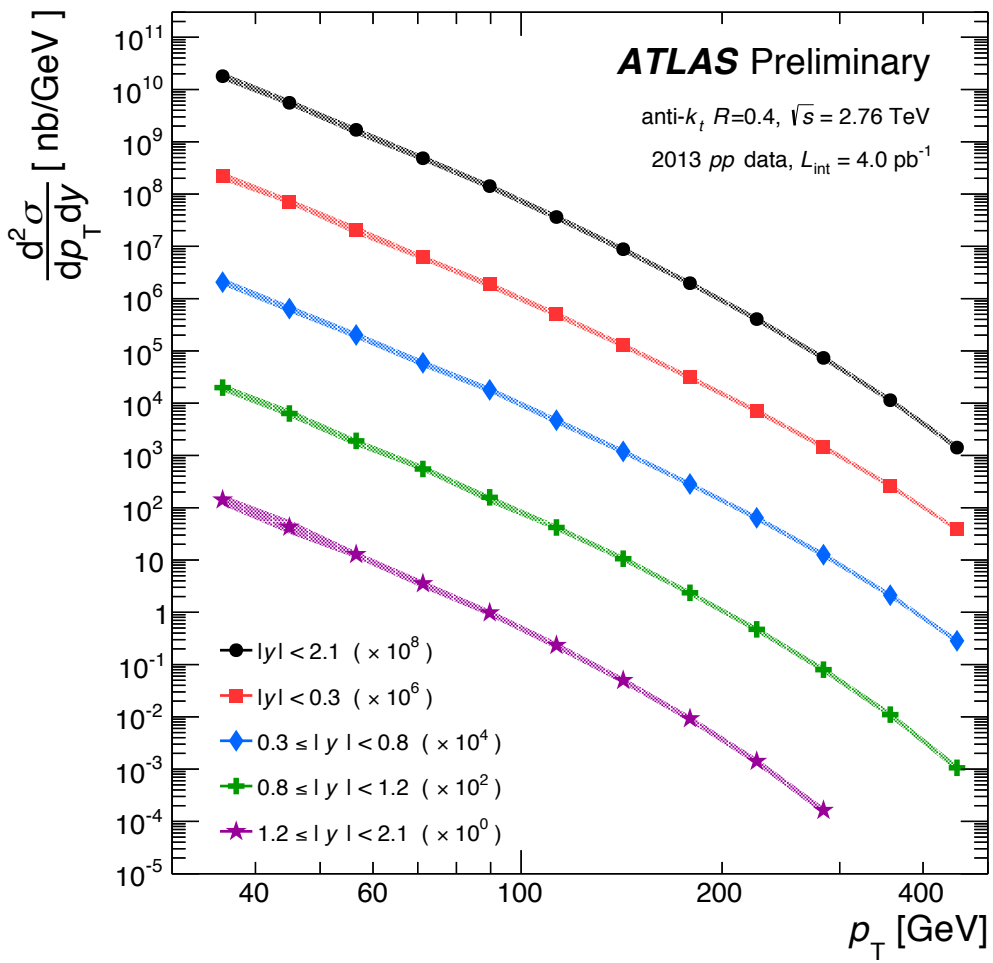
Jet suppression and collision geometry

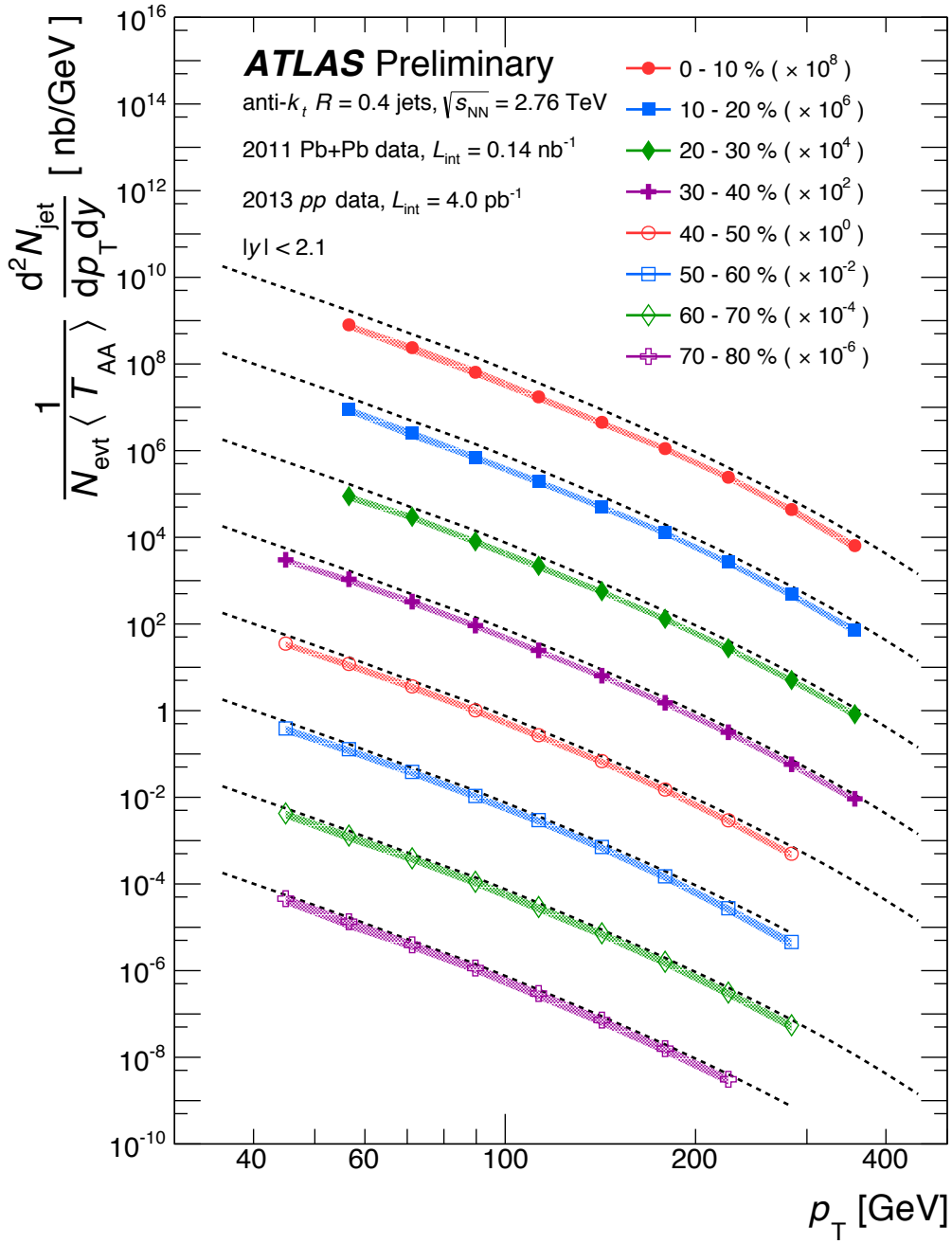
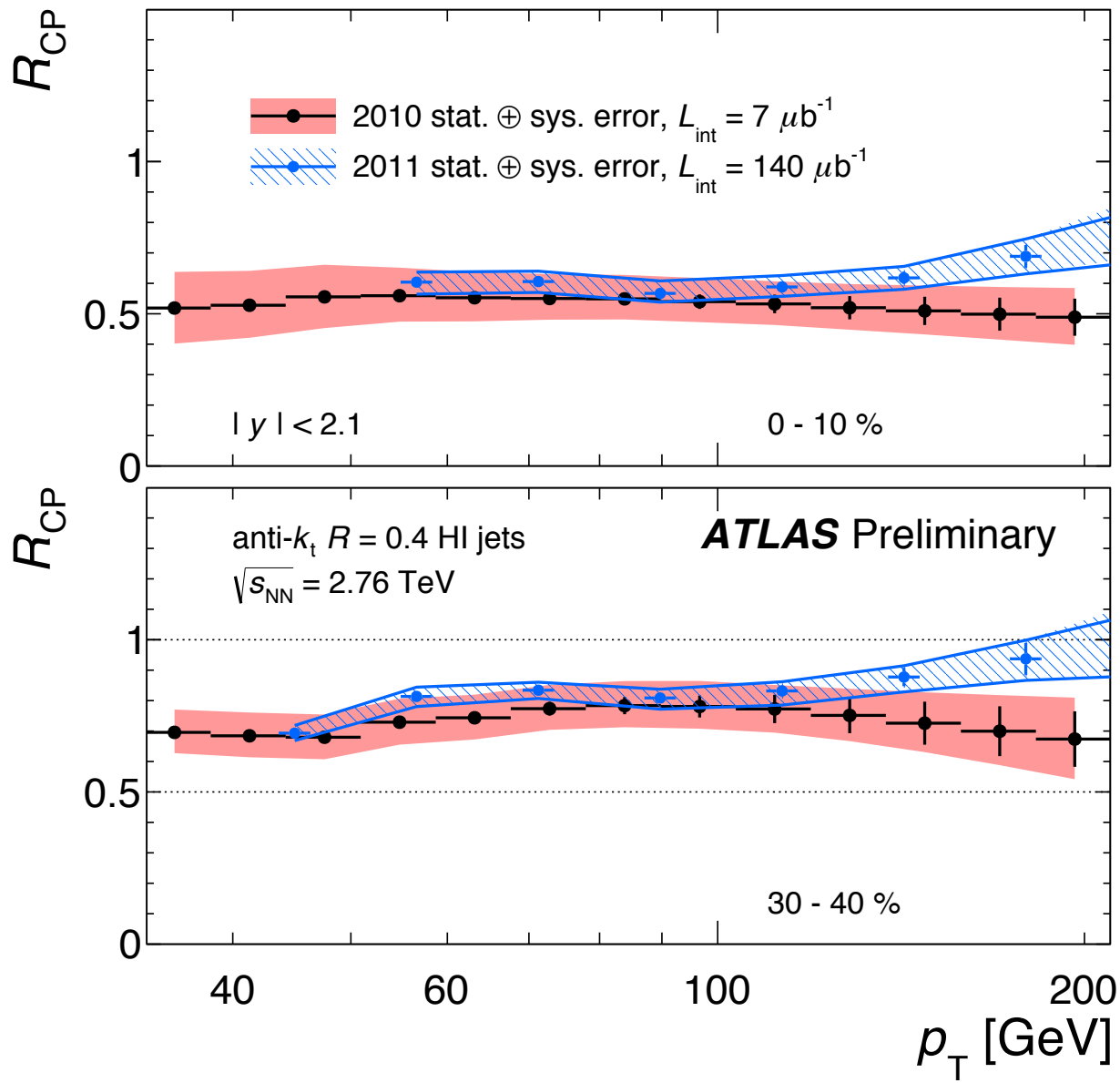


hep-ex/1306.6469

- Compare ratio of yields at Δϕ=0 and π/2 to expectation from pure second harmonic modulation
- Almost no room for different modulation modulation (e.g. $\cos^2 2\Delta\phi$) which may be expected from non-linear path length dependence
- Need calculation with full realistic geometry

Jet yields and cross sections





Comparison with published R_{CP}