Recent Heavy Ion Results with the ATLAS Detector at the LHC

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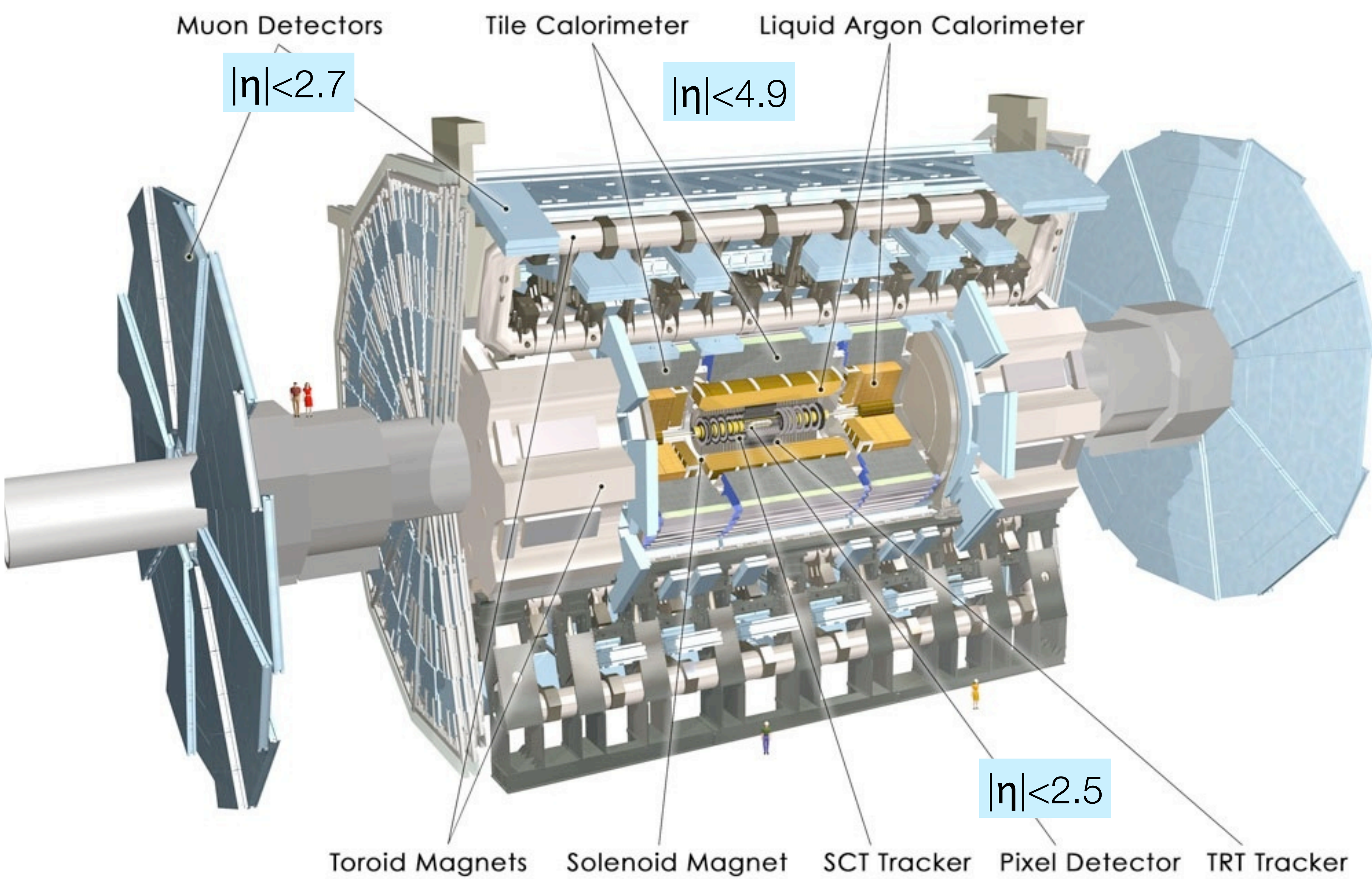
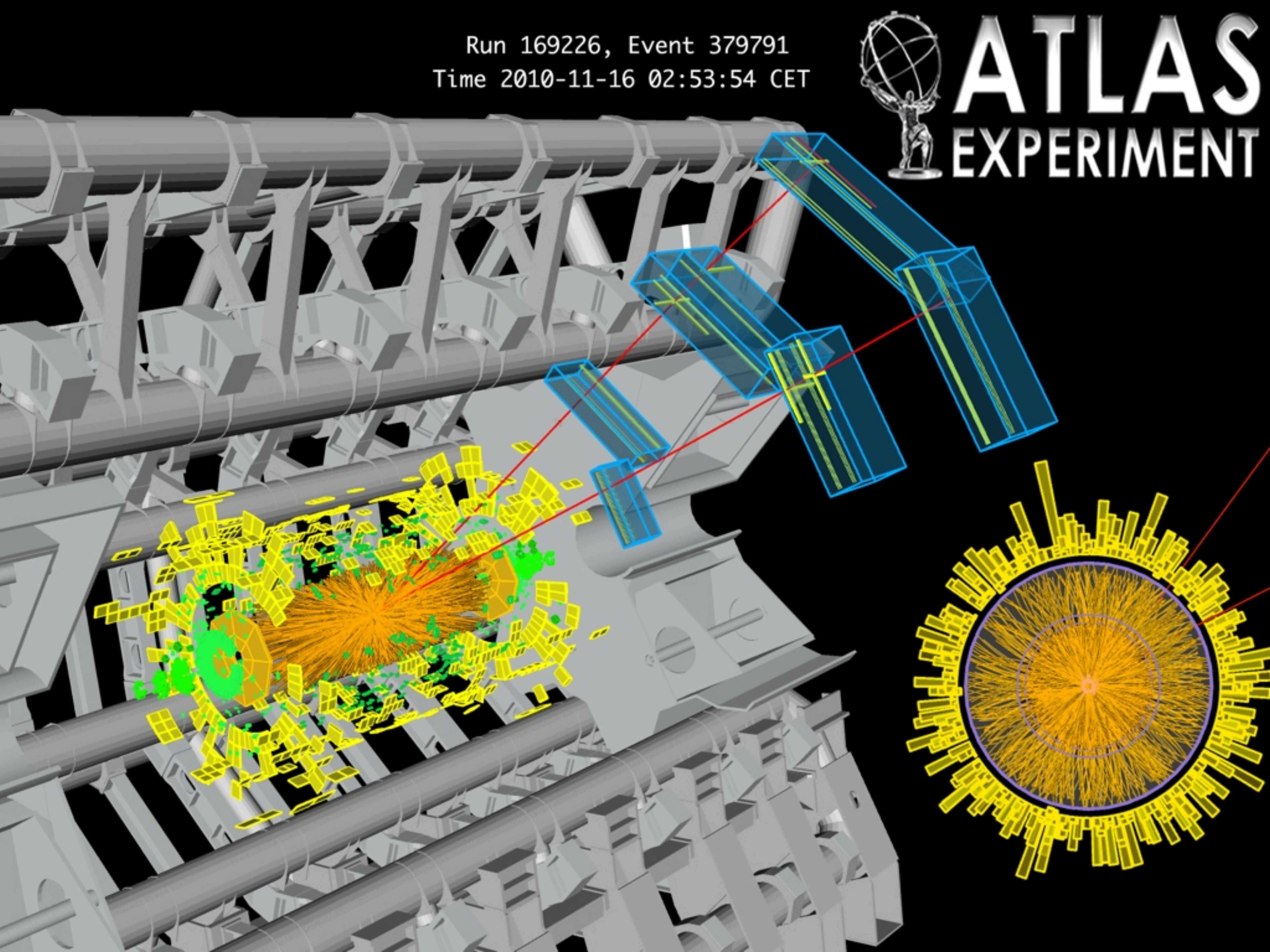
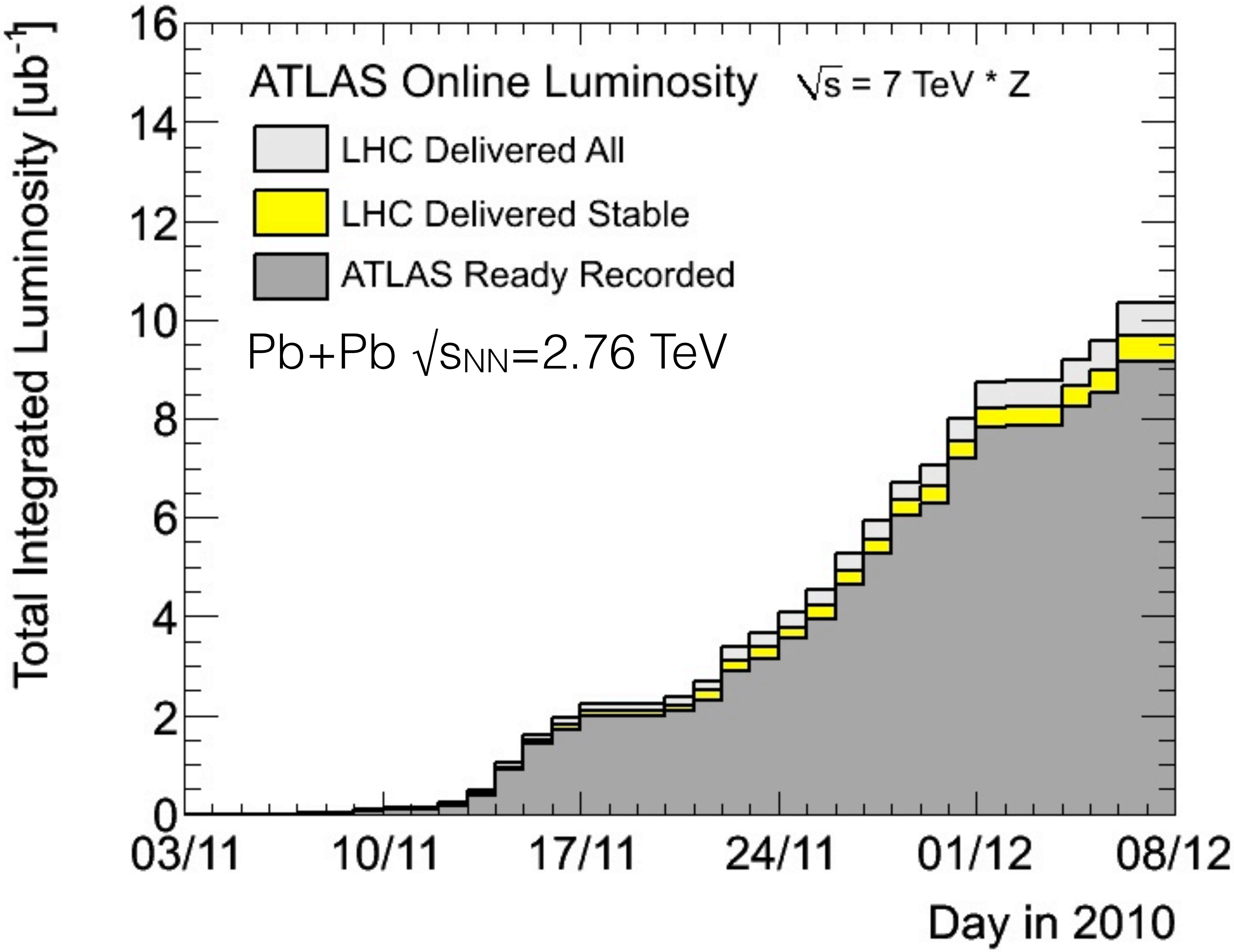
Brookhaven National Laboratory
May 23, 2011
Quark Matter 2011

The ATLAS Detector




Run 169226, Event 379791
Time 2010-11-16 02:53:54 CET
ATLAS
EXPERIMENT

Integrated luminosity for 2010 Pb+Pb run

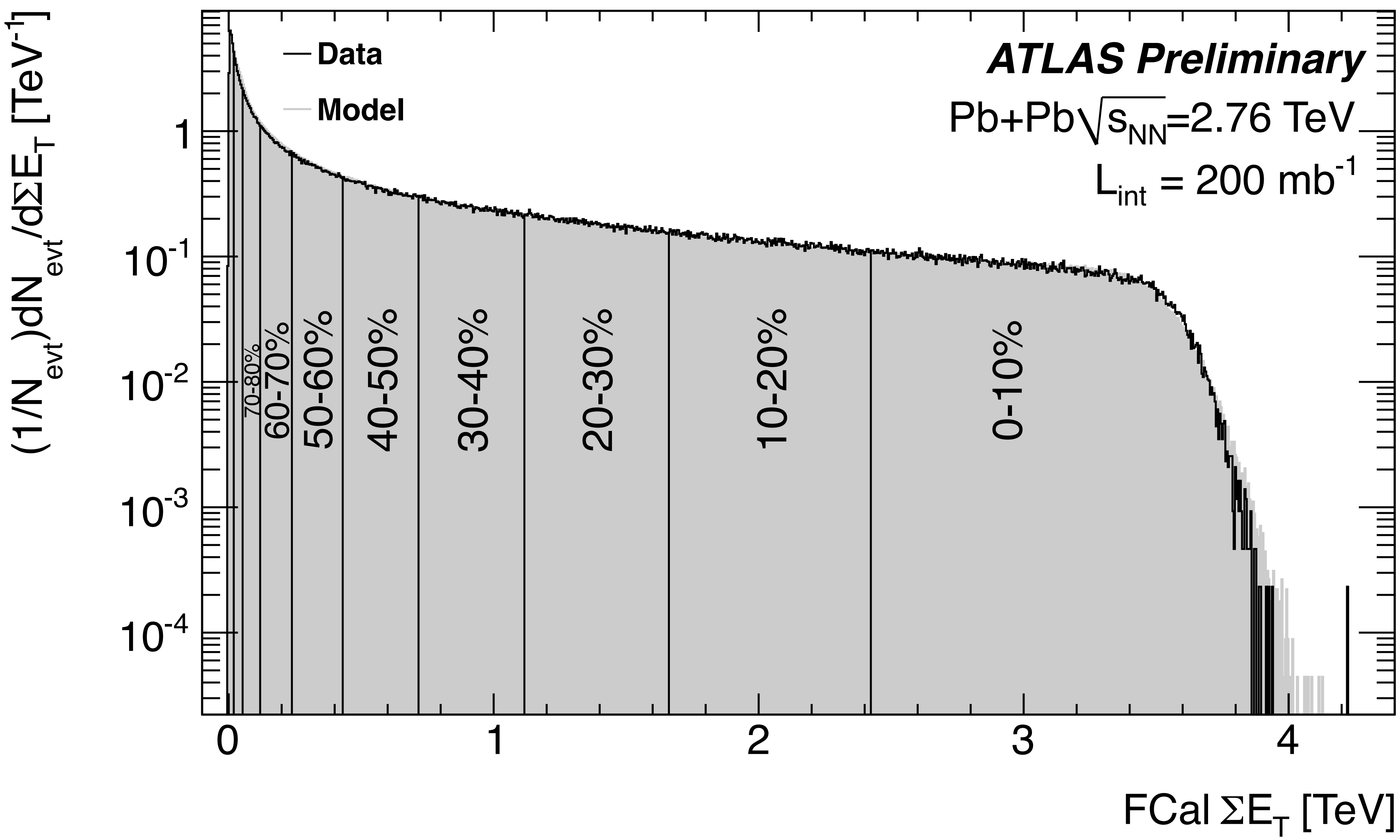


10 μb^{-1} delivered, 9 μb^{-1} recorded by ATLAS, ~8 μb^{-1} w/ solenoid

Survey of basic properties of heavy ions @ LHC

- **What changes from RHIC to the LHC?**
- **What changes from midrapidity to forward rapidity?**
- **How do various observables, soft and hard, vary with centrality?**
- **We have addressed this with a large sample of minimum bias events**
  - Triggered on combination of forward scintillators and zero degree calorimeters
  - No high p_T triggers (jets, muons, etc.) used to select events

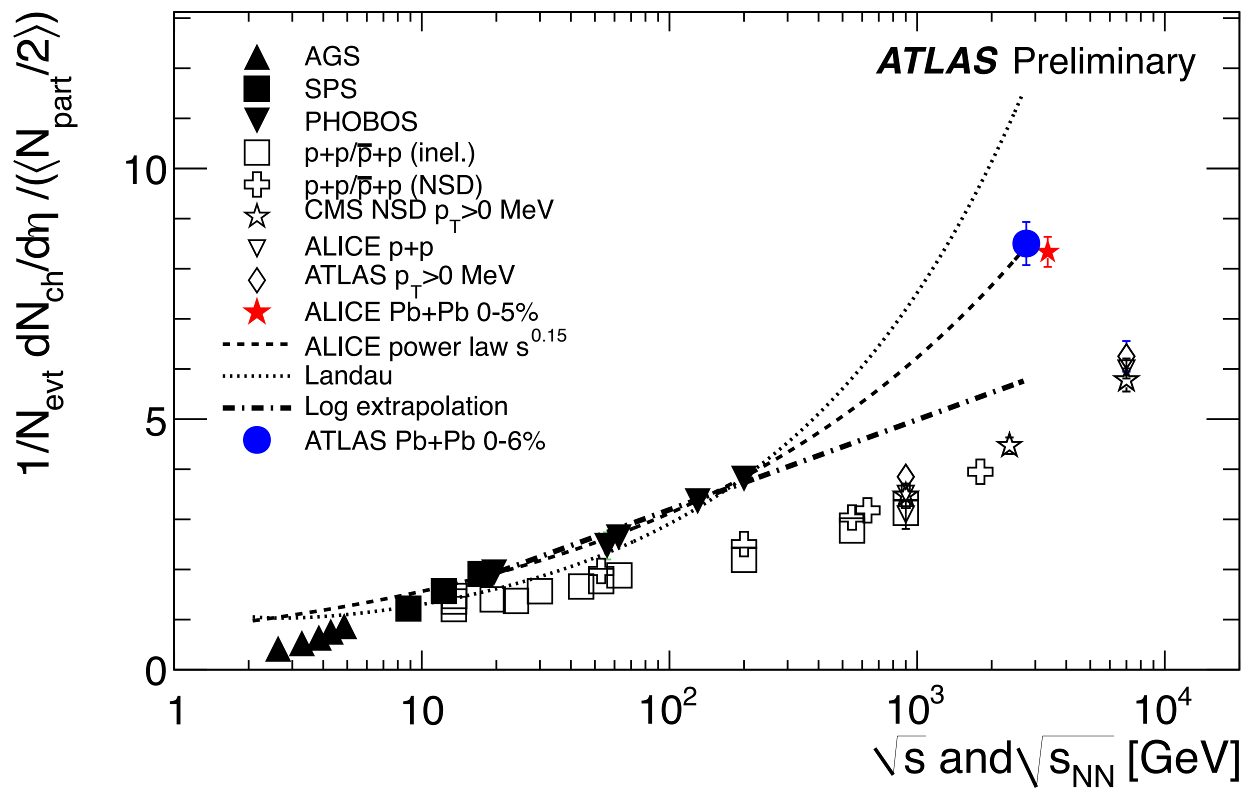
Centrality estimation



Energy sum in FCal (3.2<|**η**|<4.9) compared with Glauber MC ⊗ p+p data

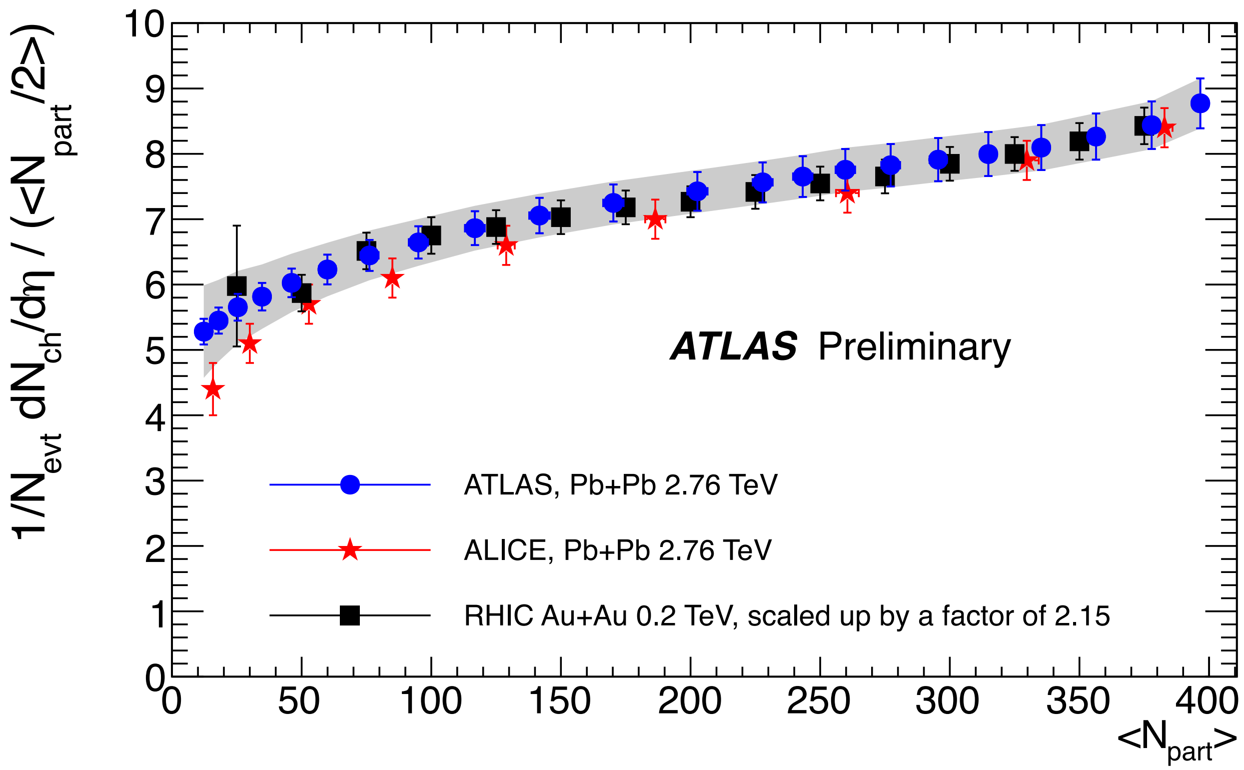
Integrals of normalized data & MC distributions agree to 2% above & below range of fiducial **Σ**E_T cut, consistent with sampling *f*=100±2% of inelastic total cross section. We calculate <N_{part}> and <N_{coll}> by binning in the simulated FCal variable.

Charged particle multiplicity



Pixel “tracklets” in solenoid-off data, to measure down to p_T>0

Yield per participant pair increases by factor of two relative to RHIC, in agreement with ALICE measurement



<u>Similar centrality dependence</u> to that found at RHIC (which itself was similar to top SPS energies):

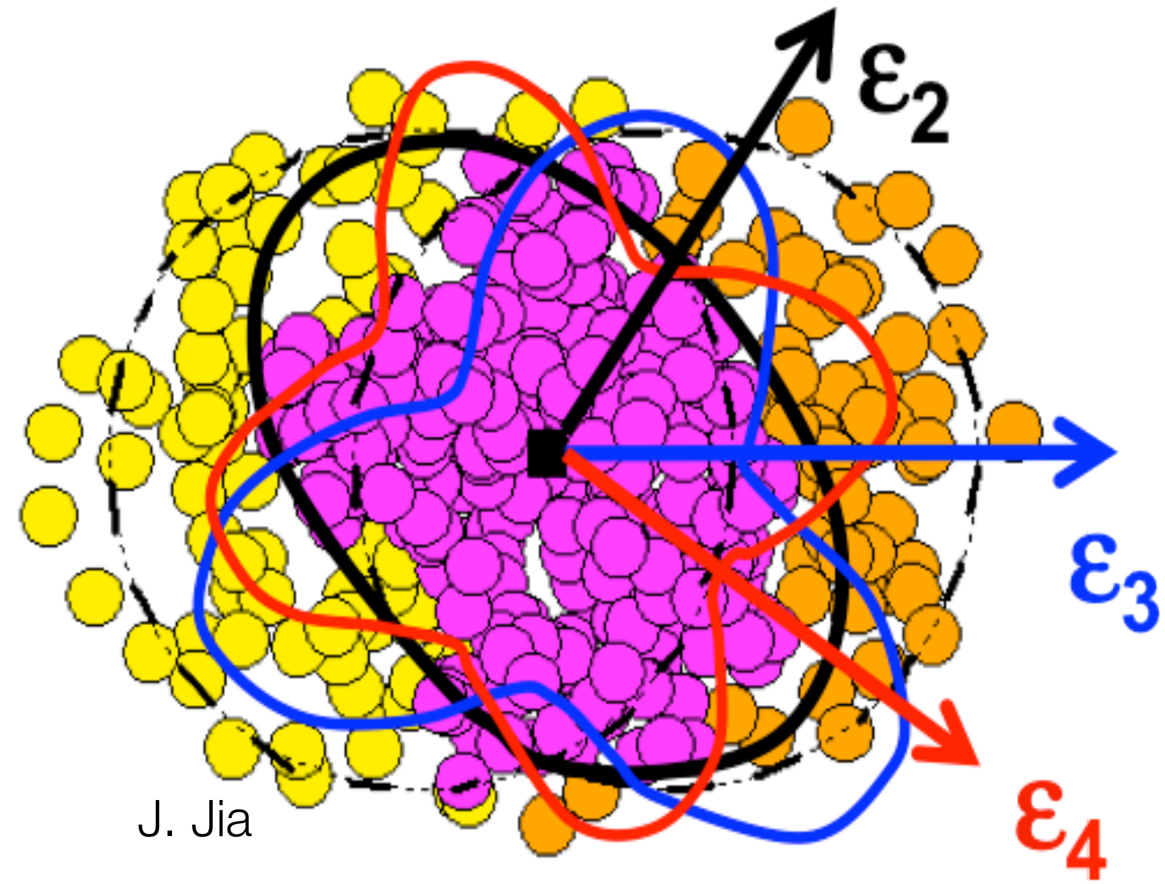
Confirmation of what appears to be a robust scaling feature in HI

for details, see talk by Yujiao Chen (4pm Mon.)

Flow measurements

Elliptic flow at RHIC showed that spatial deformations in the initial overlap region closely correlated with momentum anisotropies:

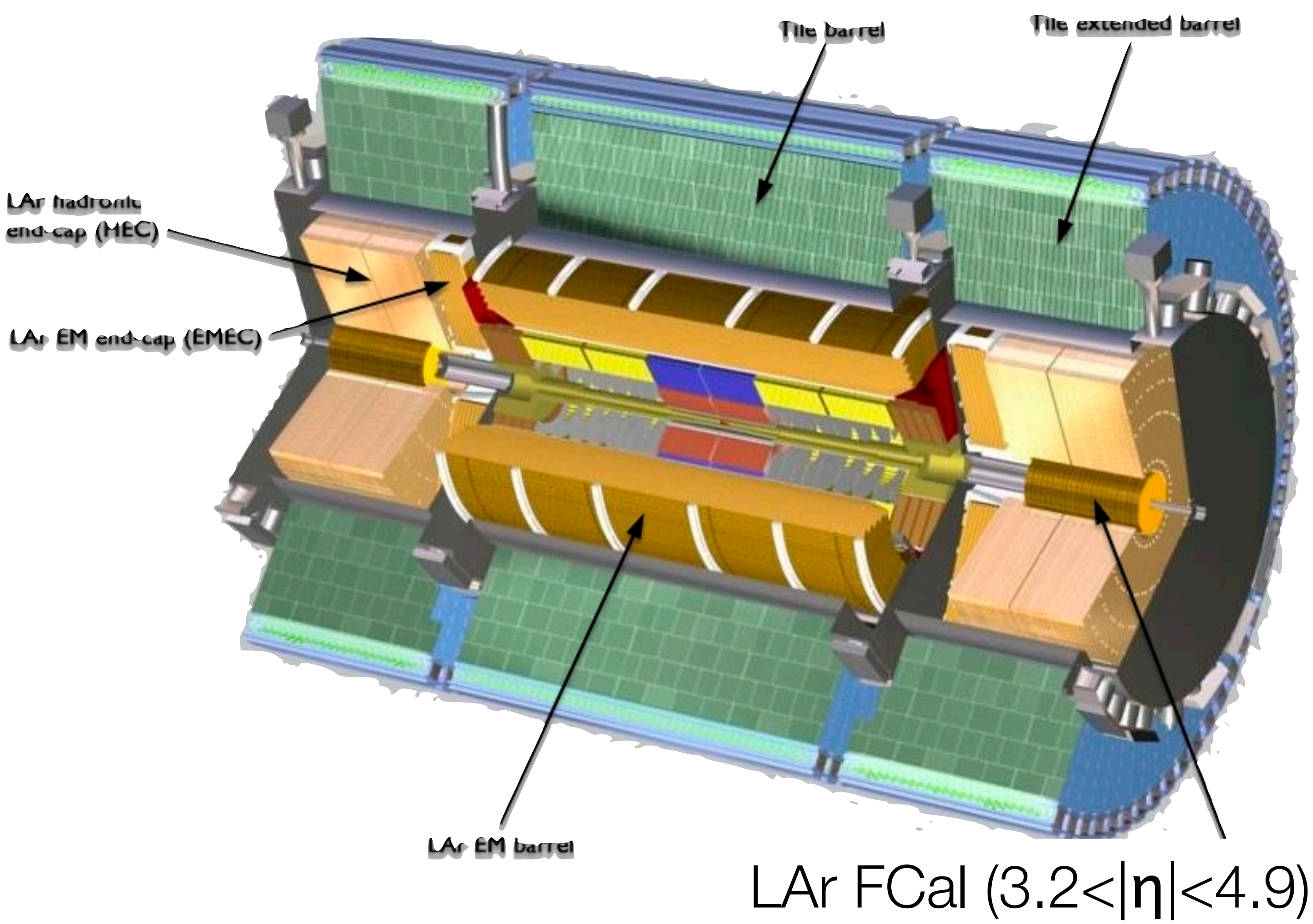
ATLAS has new measurements with increased η dependence, and at high p_T

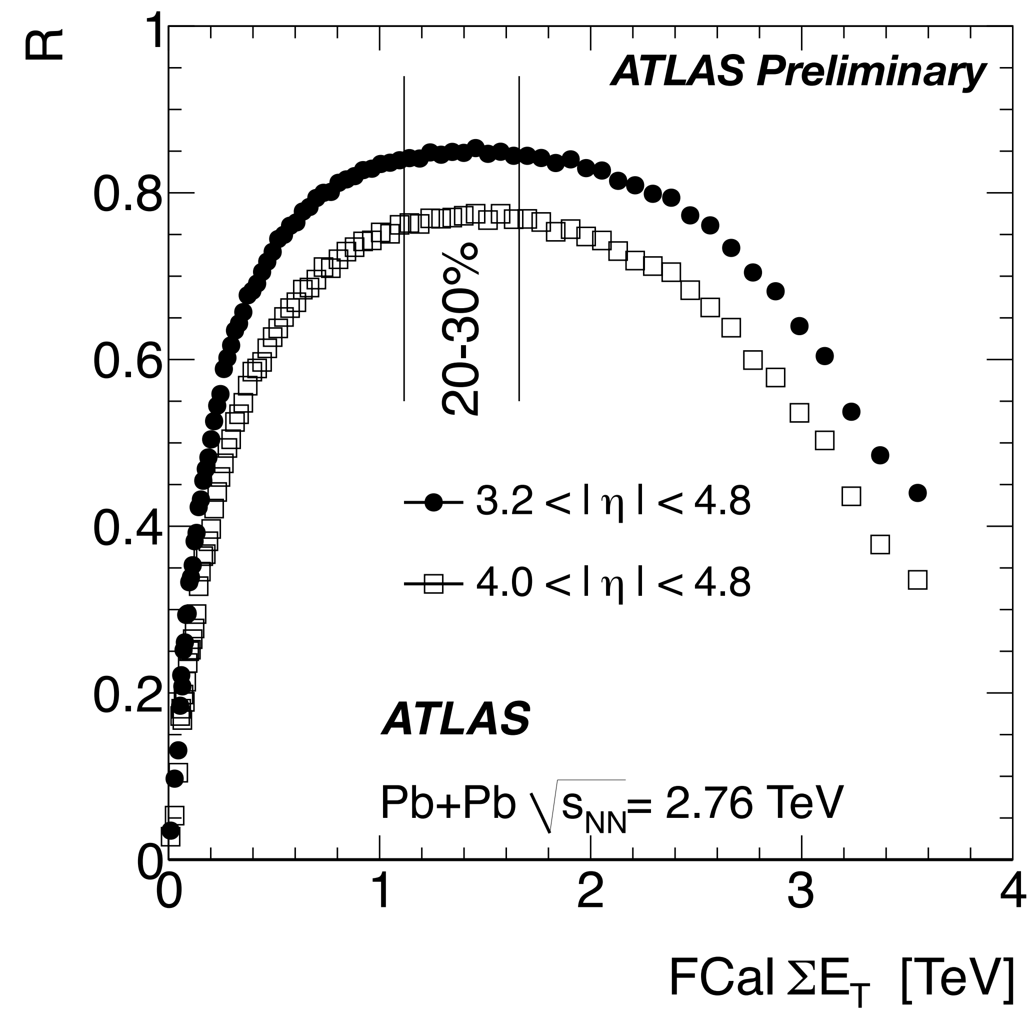


With the high multiplicities & large acceptance of ATLAS, we are also studying higher order components of the transverse flow

Do v_n directly reflect higher order deformations in initial state? Higher modes should be more sensitive to viscous effects

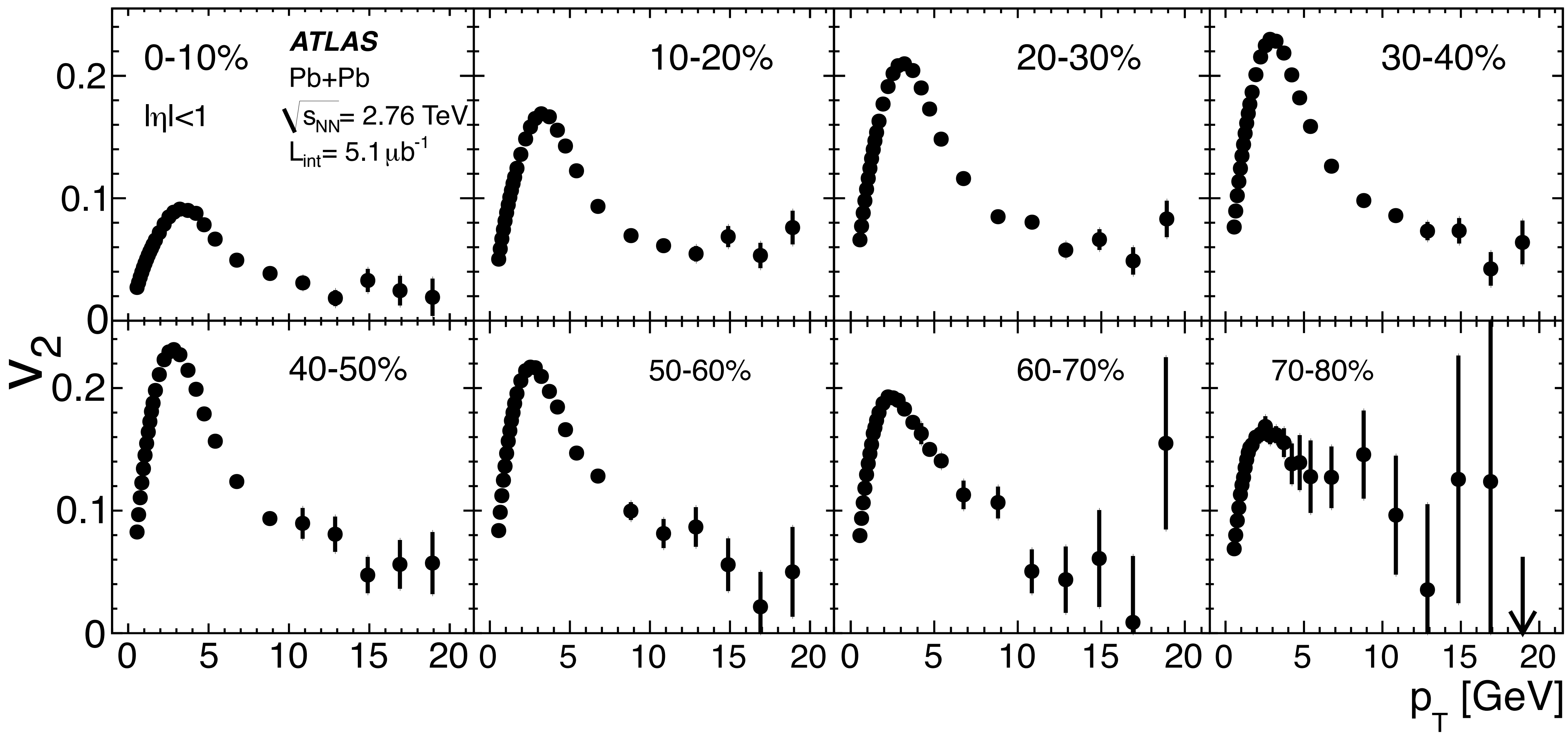
Elliptic flow measurements





ATLAS forward calorimeter used for event plane determination.
Resolution correction factor 75-85% in mid-central events.
Tested in subregions of calorimeter acceptance.

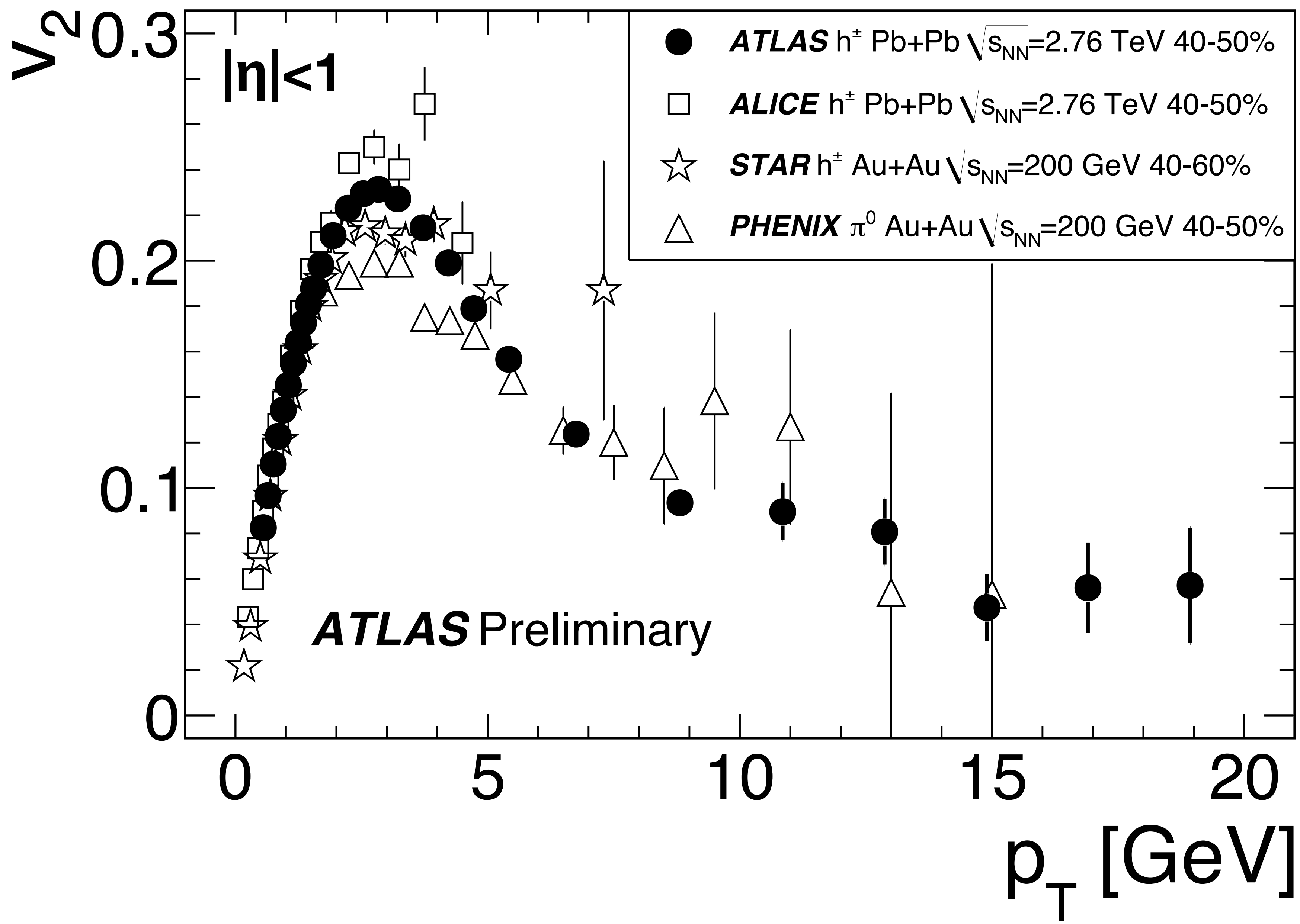
Transverse momentum dependence of v_2



Centrality and p_T dependence of v_2:
Rapid rise up to 3-4 GeV, less rapid decrease to 8-9 GeV, and then weak p_T dependence out to 20 GeV.

for details, see talk by Adam Trzupek (3pm Fri.)

Comparison to previous measurements

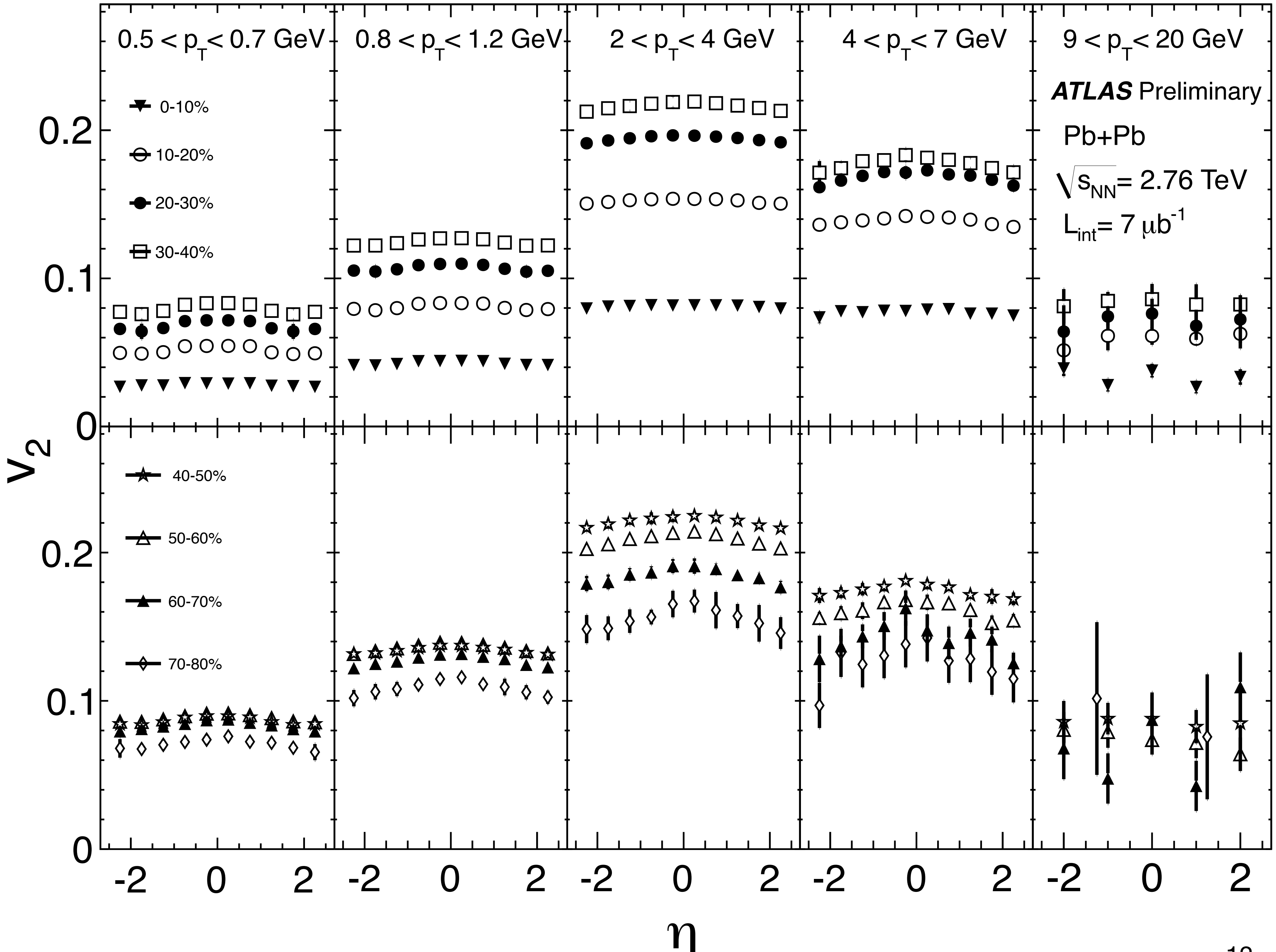


At fixed centrality, the p_T dependence seems to scale (within large errors for PHENIX at high p_T): differential parton energy loss?

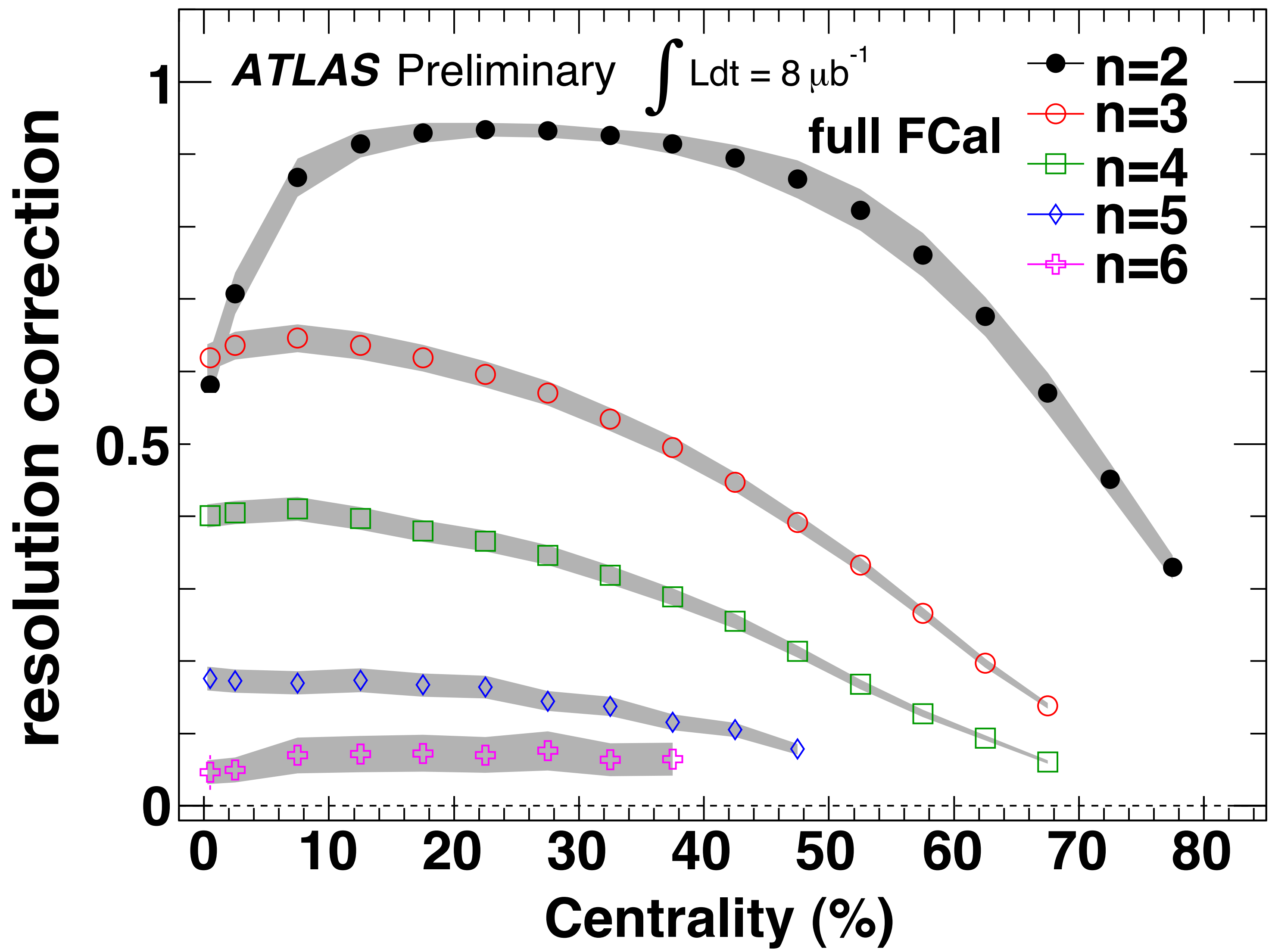
Pseudorapidity dependence

<u>Very weak</u>
η dependence
above 500 MeV

Measurements
out to |η|=2.5
show systematic,
but <u>small</u>
decrease of v_2



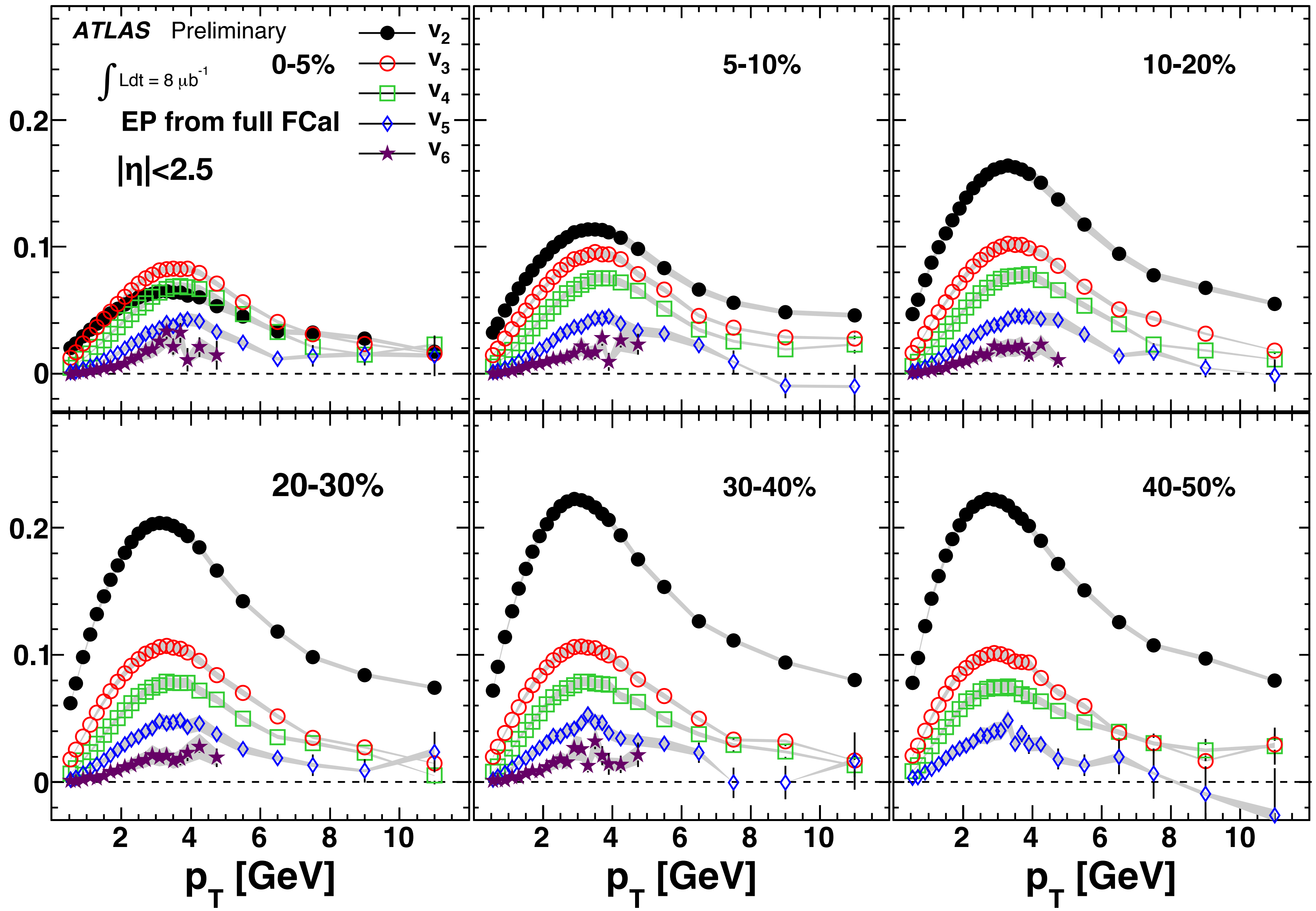
Higher order Fourier coefficients



In next iteration, have extended the event plane analysis to v_n, n=2-6.
Significant resolution for v_6 for the 40% most central events

for details, see talk by Jiangyong Jia (Tues. plenary) & Adam Trzupek

Higher order moments vs. p_T and centrality

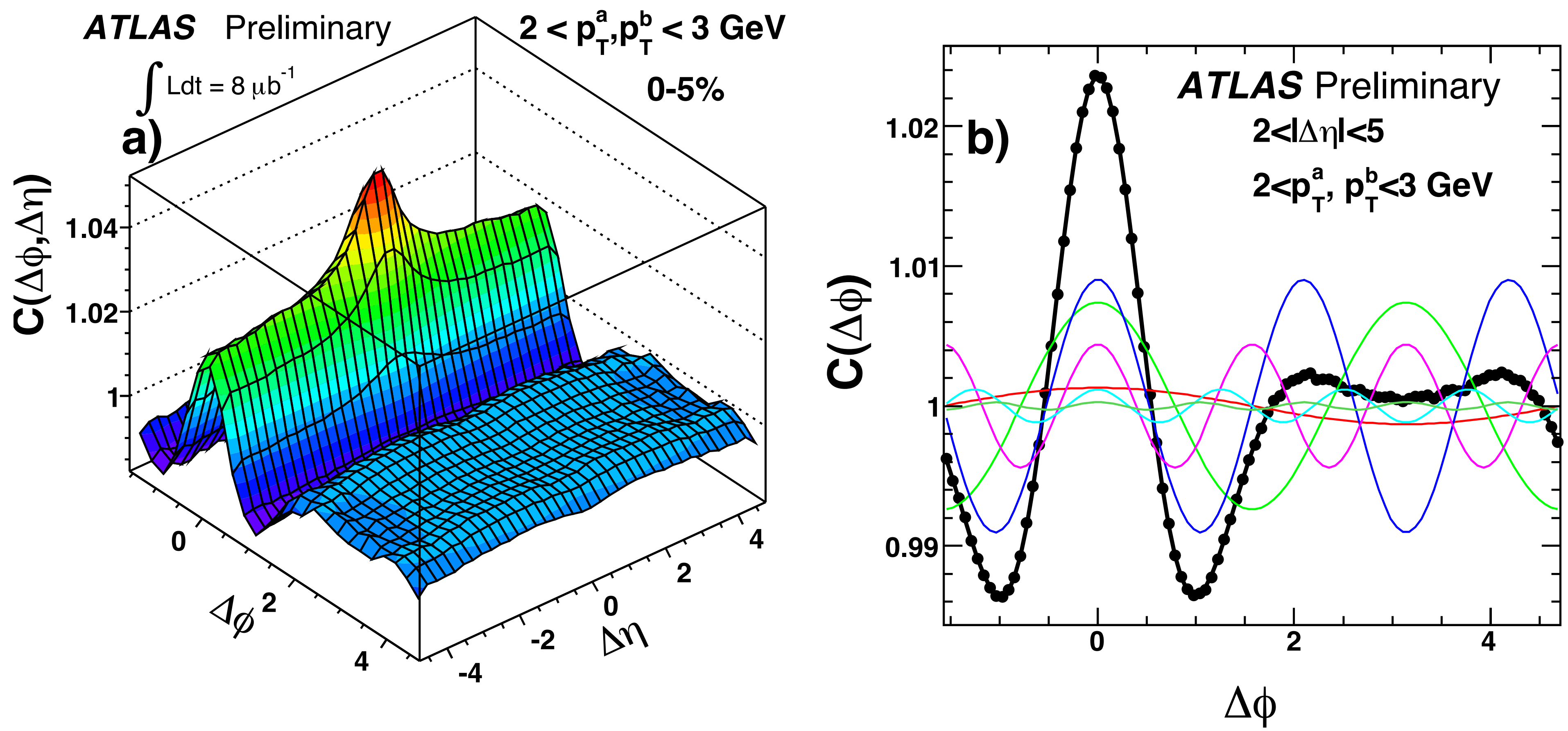


Similar p_T dependence for all flow coefficients.

Weak centrality dependence observed for v_3-v_6

For the 5% most central events $\mathbf{v_2 < v_3}$

Two particle correlations



Two-particle correlations studied using discrete Fourier transform (DFT): $v_{n,n} \sim v_n^2$

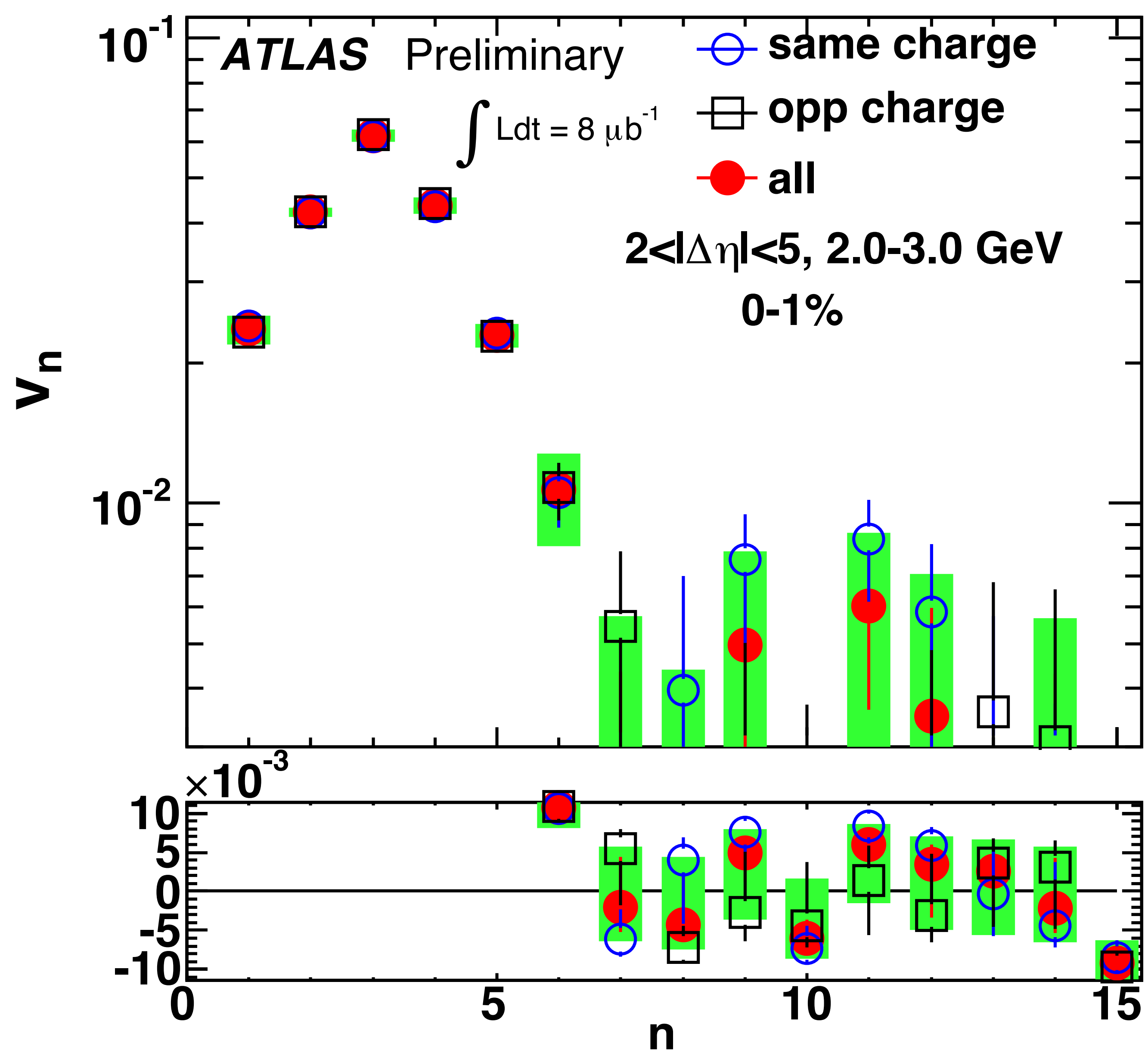
$$C(\Delta\phi) = \frac{\int N_{\rm s}(\Delta\phi, \Delta\eta) d\Delta\eta}{\int N_{\rm m}(\Delta\phi, \Delta\eta) d\Delta\eta} \qquad v_{n,n} = \langle \cos(n\Delta\phi) \rangle = \frac{\sum_{m=1}^{N} \cos(n\Delta\phi_m) C(\Delta\phi_m)}{\sum_{m=1}^{N} C(\Delta\phi_m)}$$

Complementary approach to event plane, to check consistency:
at long range, no more jet & resonance correlations (but non-trivial structure)

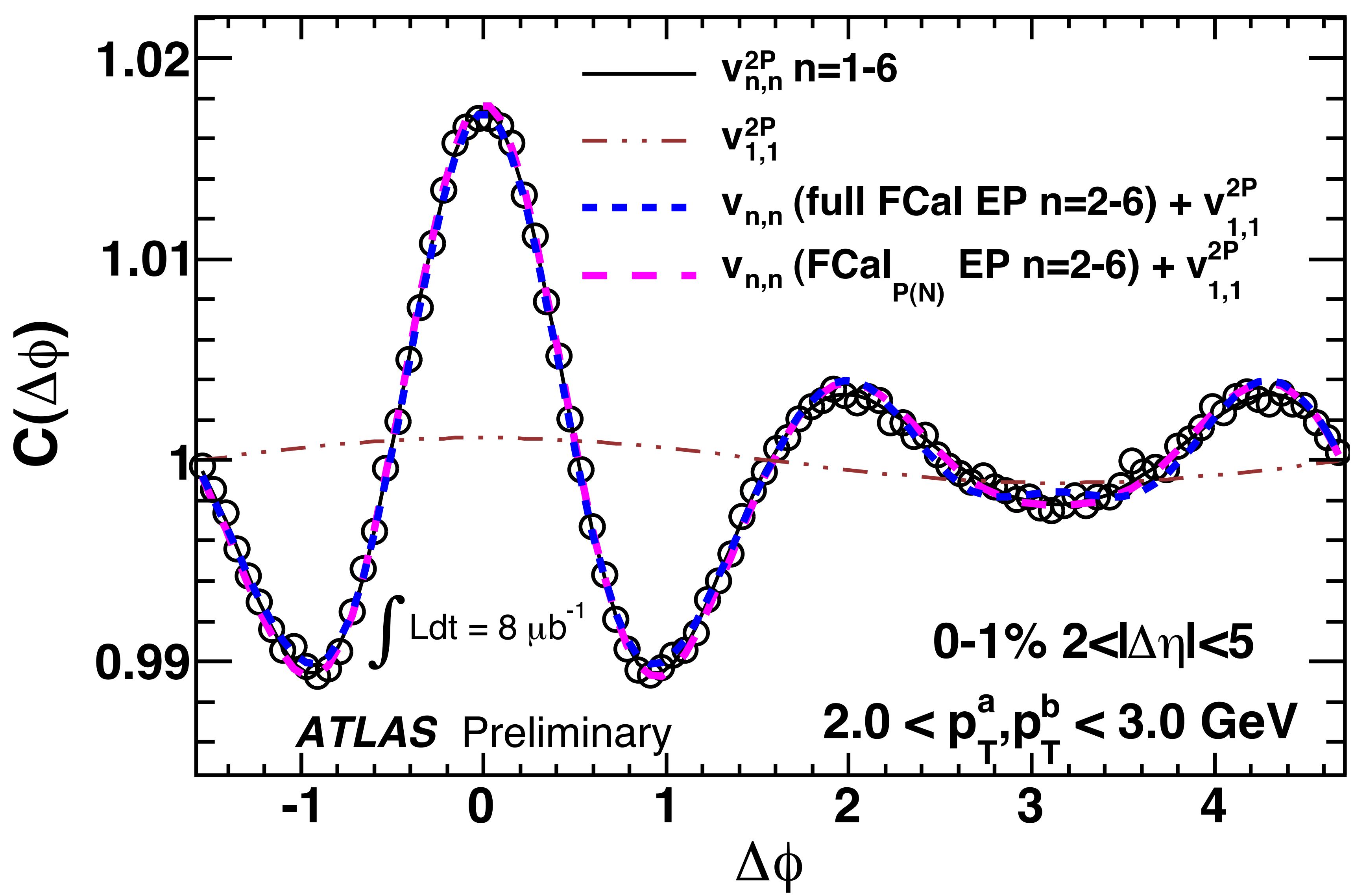
Higher order coefficients from DFT

In central events, extract significant non-zero coefficients out to v_6: in the 1% most-central events, v_3 is the largest for p_T=2-3 GeV

v_1 is extracted, but does not show “flow like” factorization: v_1 in 2PC does not factorize into $v_1(p_{T,a})v_1(p_{T,b})$, unlike other modes

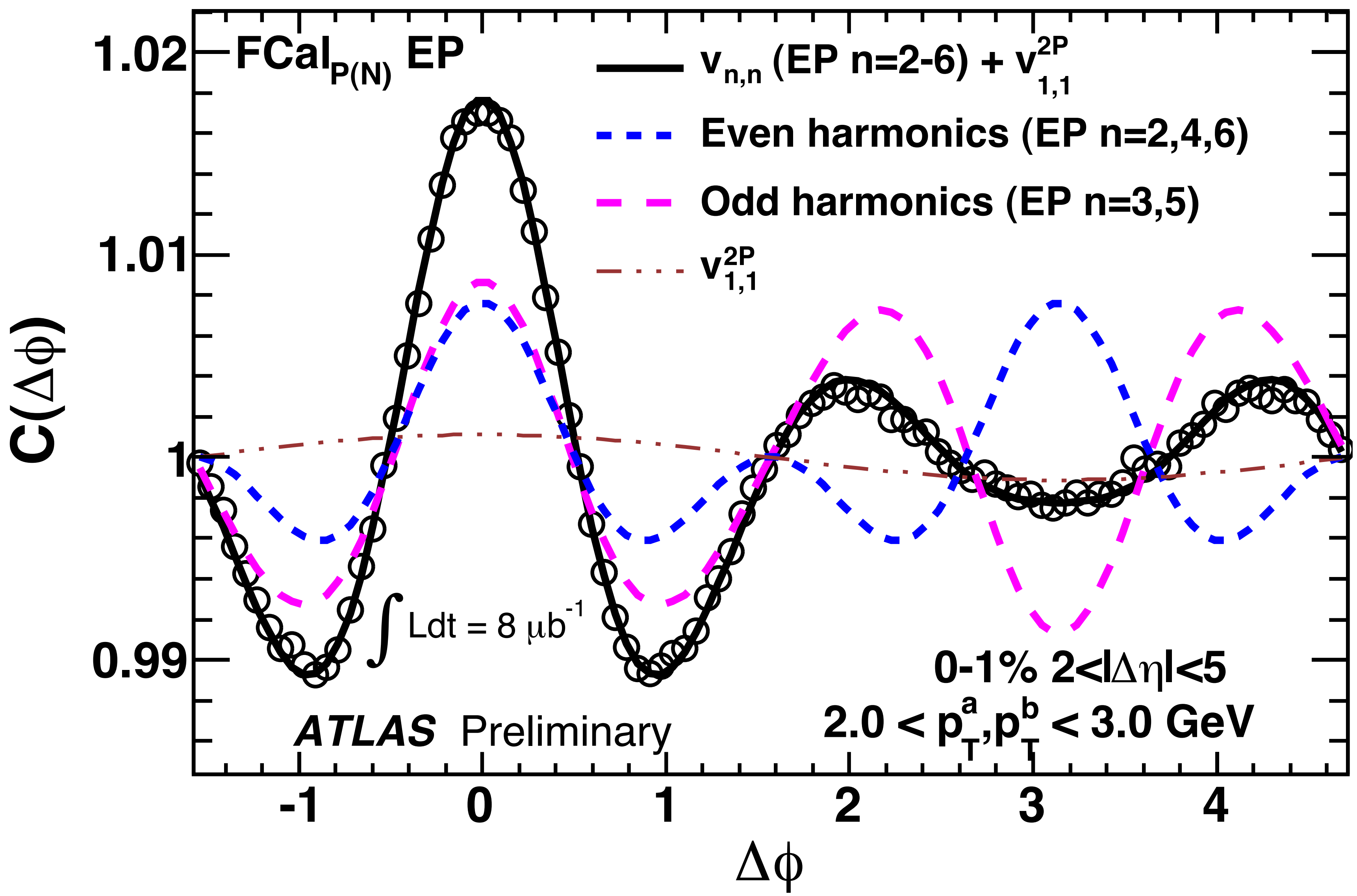


Reconstructing 2PC with event plane results



We find excellent agreement of DFT and EP results.
In fact, event plane measurements provide nearly-identical information as 2 particle correlations: provide "ridge" and "cone" at large Δη

Contributions from higher harmonics



Fourier decomposition shows interplay of even and odd contributions: "ridge" and "cone" appear as consequences of global event properties

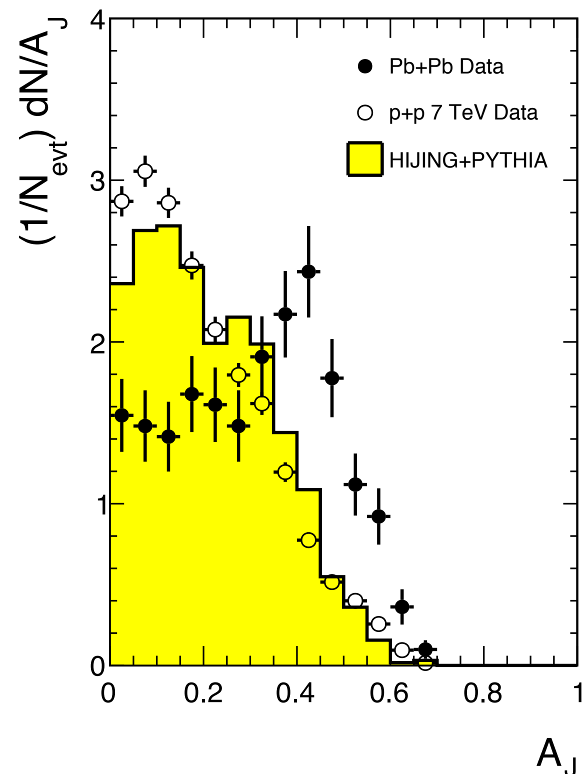
Hard probes of heavy ion collisions

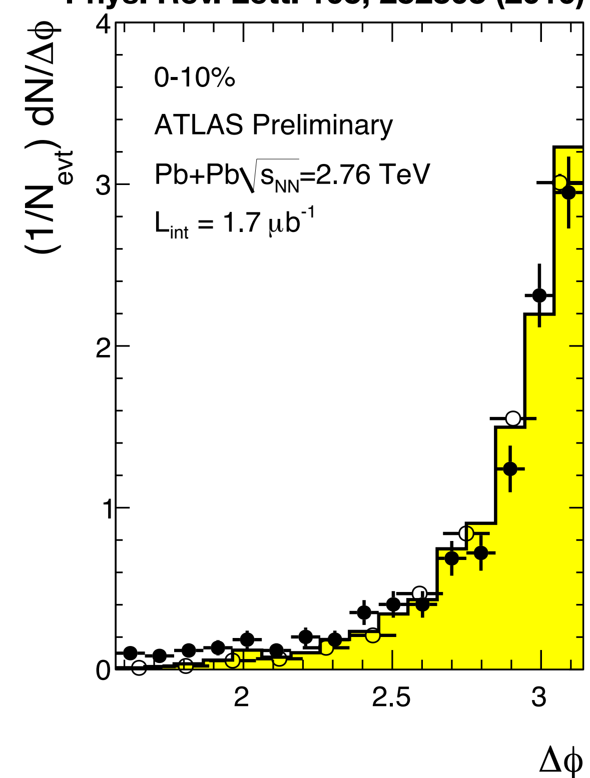
The LHC provides much higher rates of hard processes than provided previously: new opportunities for studying the microscopic properties of the medium

ATLAS published first observations of the centrality dependence of dijet asymmetries

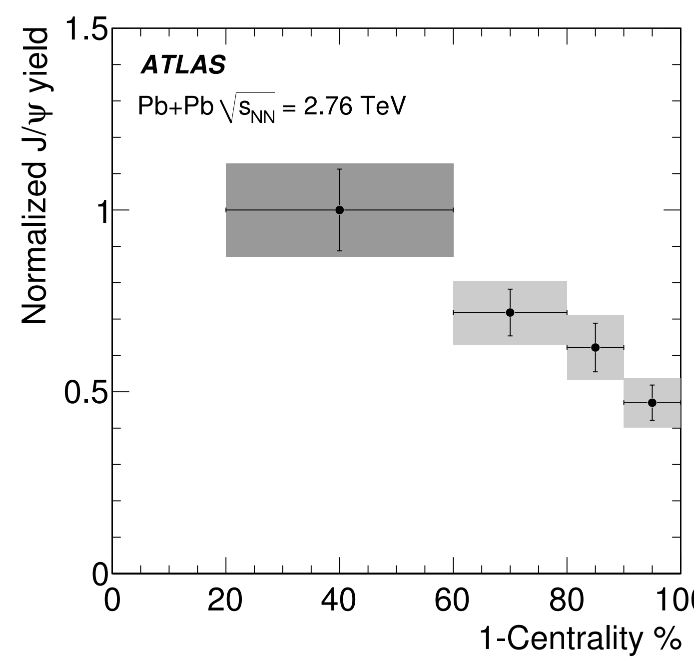
ATLAS also first measured suppression of J/ψ & observed production of Z bosons

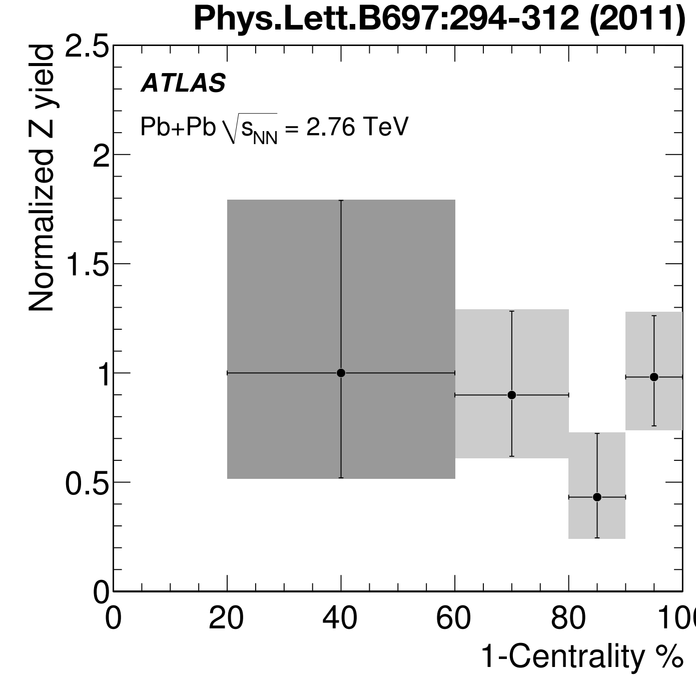
Phys. Rev. Lett. 105, 252303 (2010)



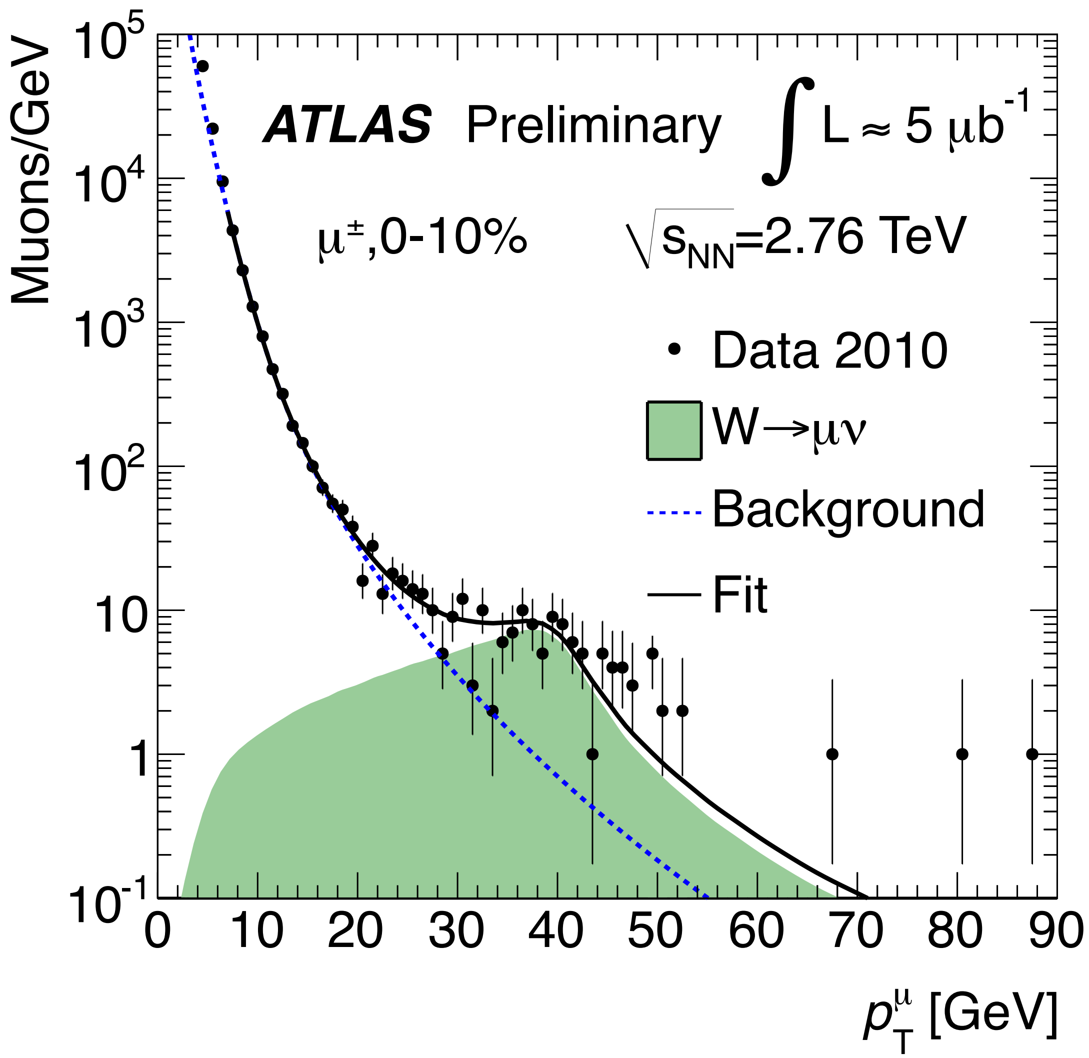


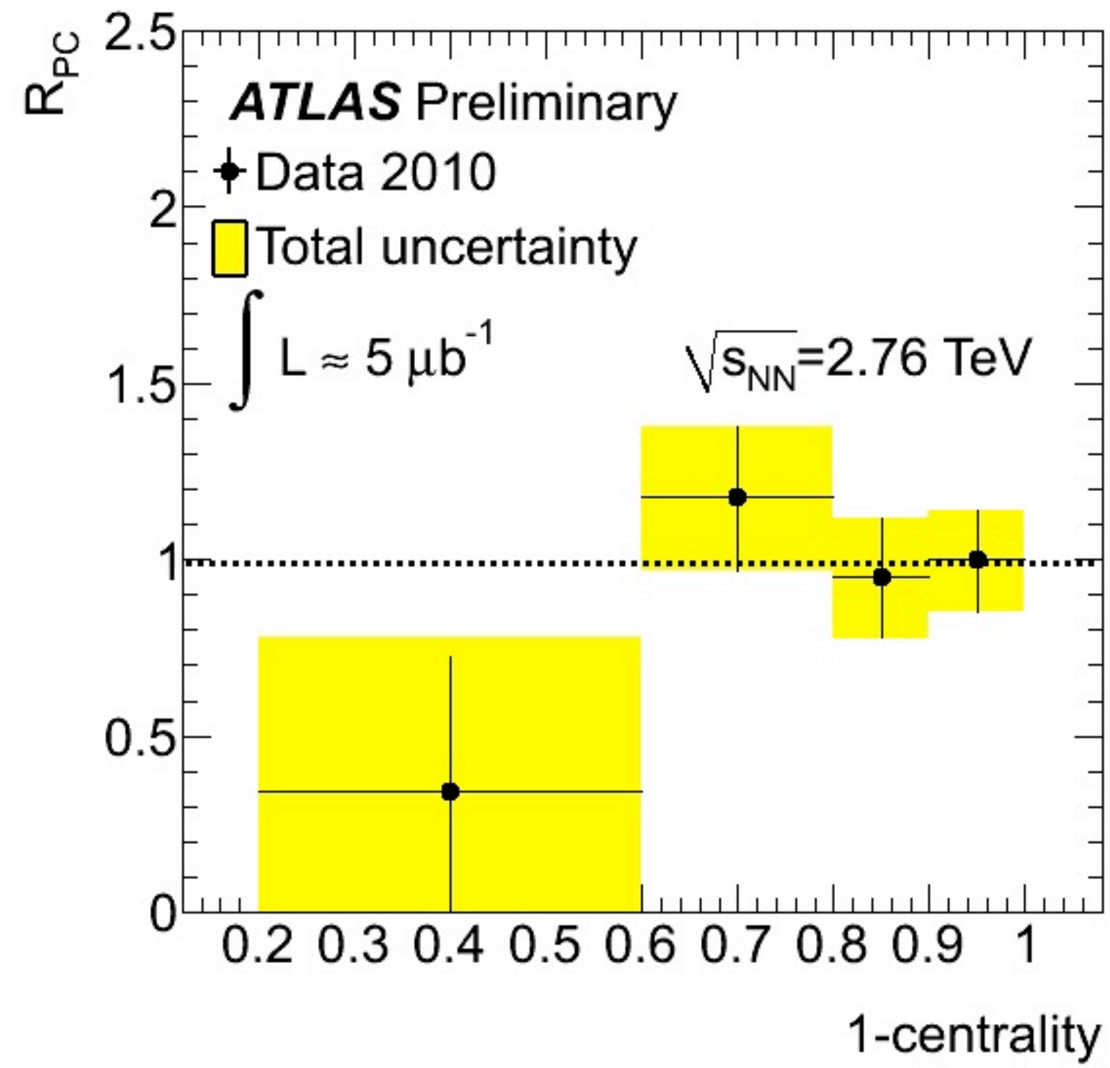
Phys.Lett.B697:294-312 (2011)





Hard probes: N_{coll} scaling from $W^{\pm}$ production





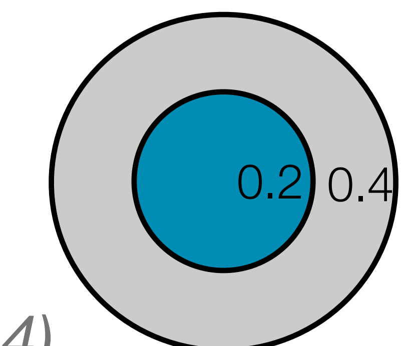
W yields extracted using an empirical fit to single muon spectra: heavy flavor (adapted from p+p) and simulated PYTHIA $W^{\pm}$ template

Pinned to most central events (R_{PC}), N_{coll} scaling observed.

for details, see talk by Rikard Sandström (3:20pm Thurs)

Jet yields in HI

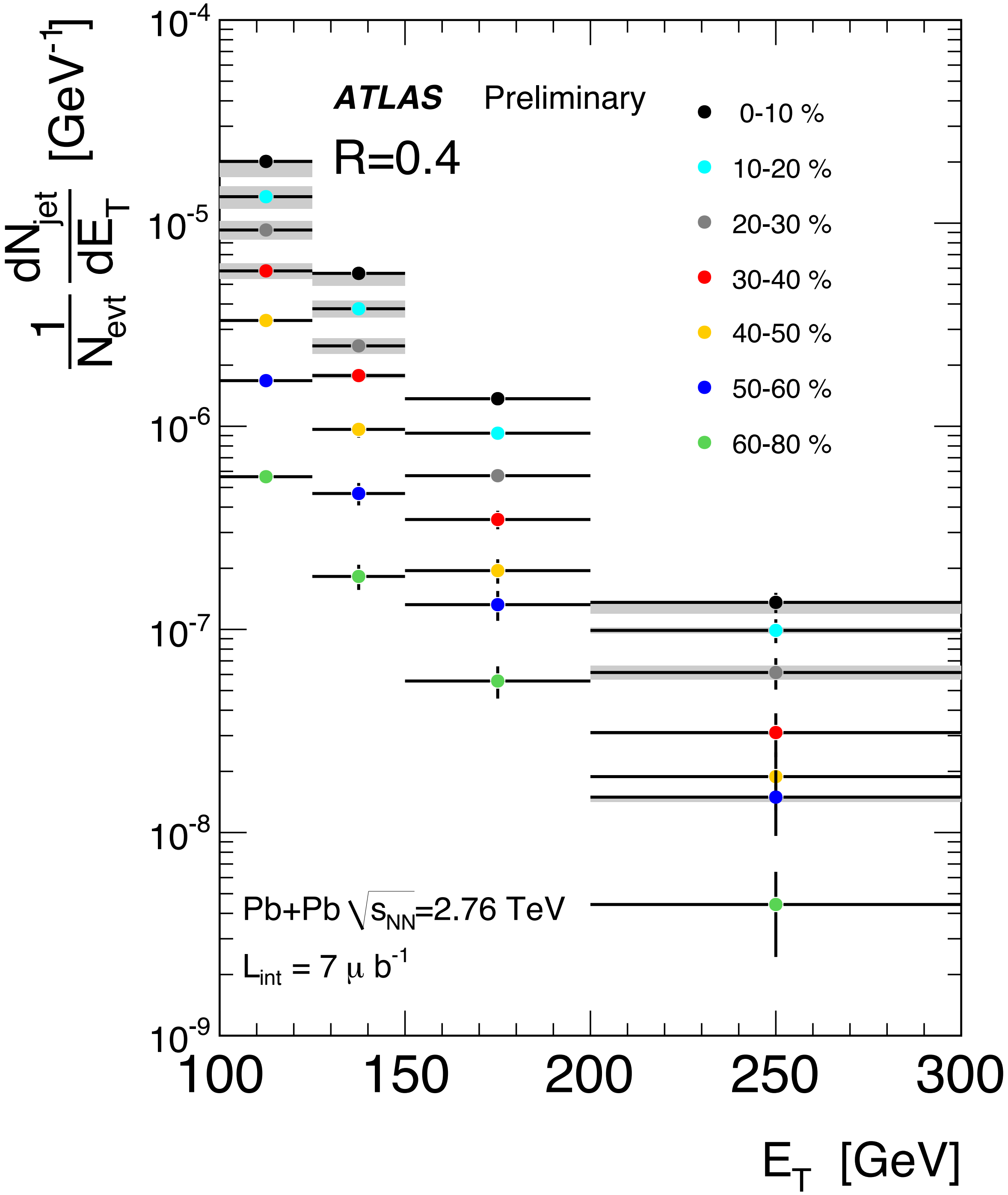
- **First ATLAS results were an observation of asymmetric dijets, with a relative rate that increased with collision centrality**
- **Recent work involves more detailed background subtraction**
  - Elliptic flow
  - Iterative method to remove bias of jet on background
  - Systematic comparison of jets of different sizes
    - *R=0.2 without flow correction used.* E_T *(R=0.2) ~ 0.7 x* E_T *(R=0.4)*

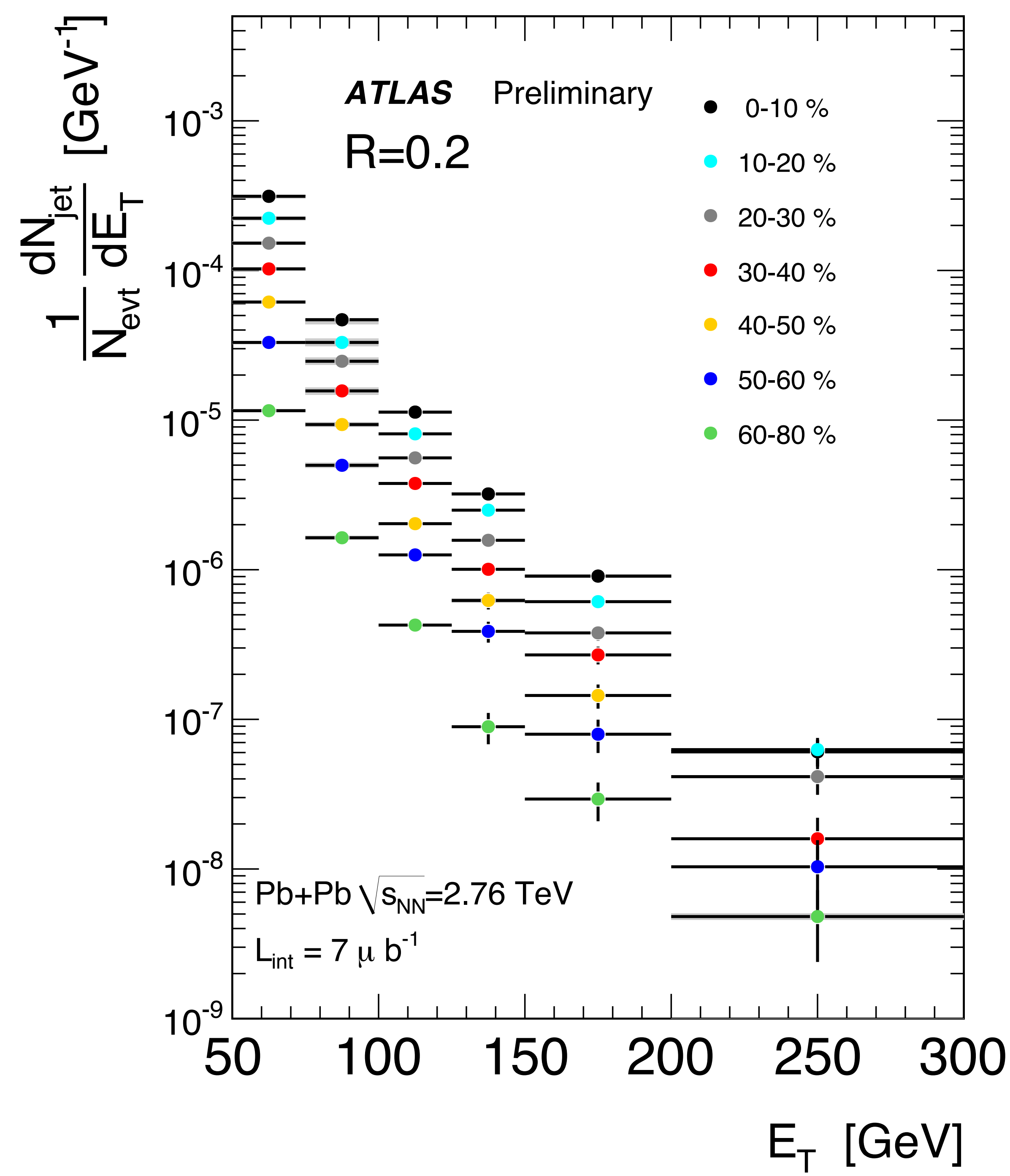


- **Extensive MC studies of jet performance**
  - jet energy scale (JES) and jet energy resolution (JER) based on PYTHIA dijets embedded into HIJING with a flow afterburner
- **Centrality-dependent spectral unfolding**

for details, see talks by Aaron Angerami (3:20pm Tues) & Brian Cole (12pm Weds)

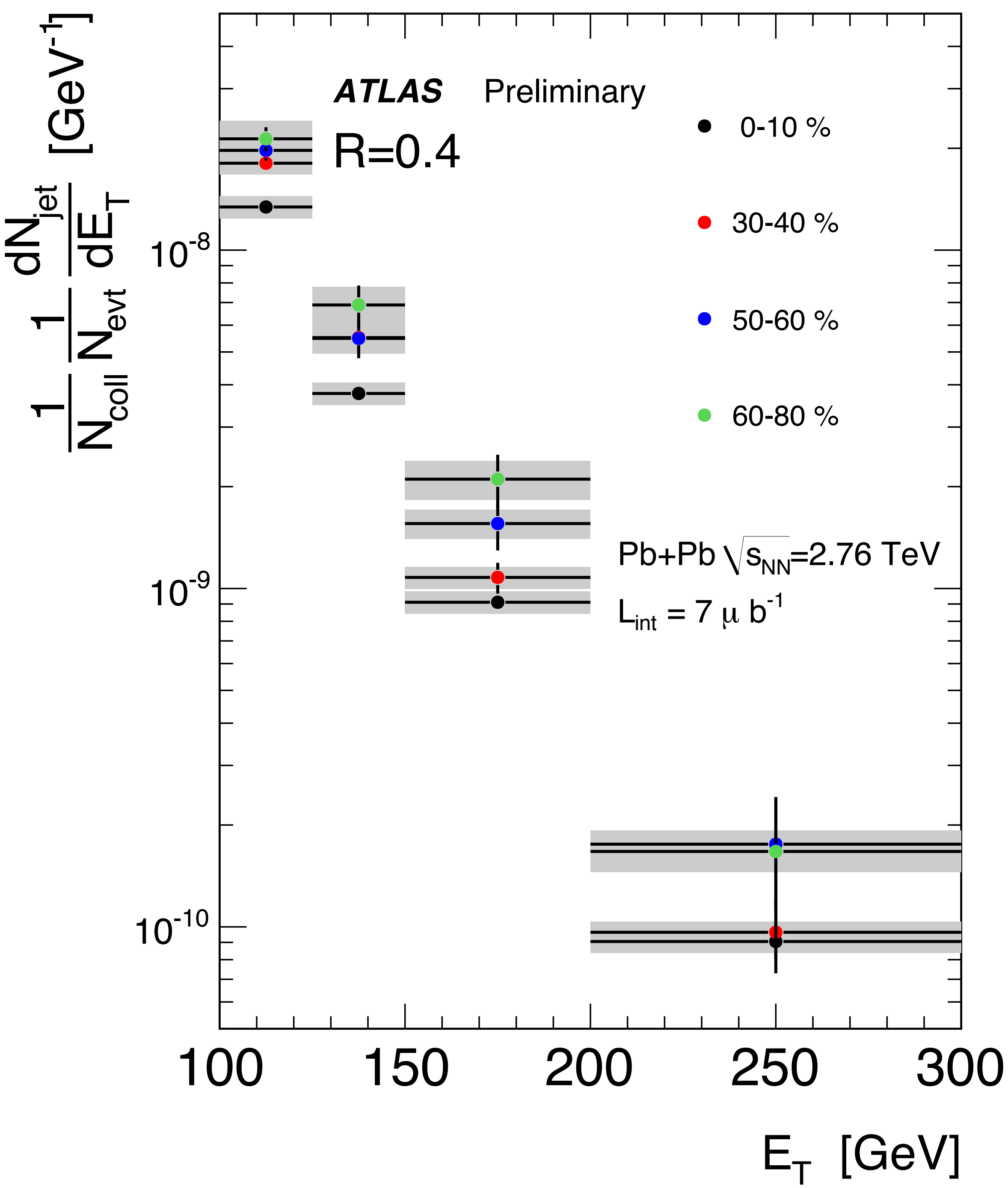
Jet Spectra R=0.4 & R=0.2



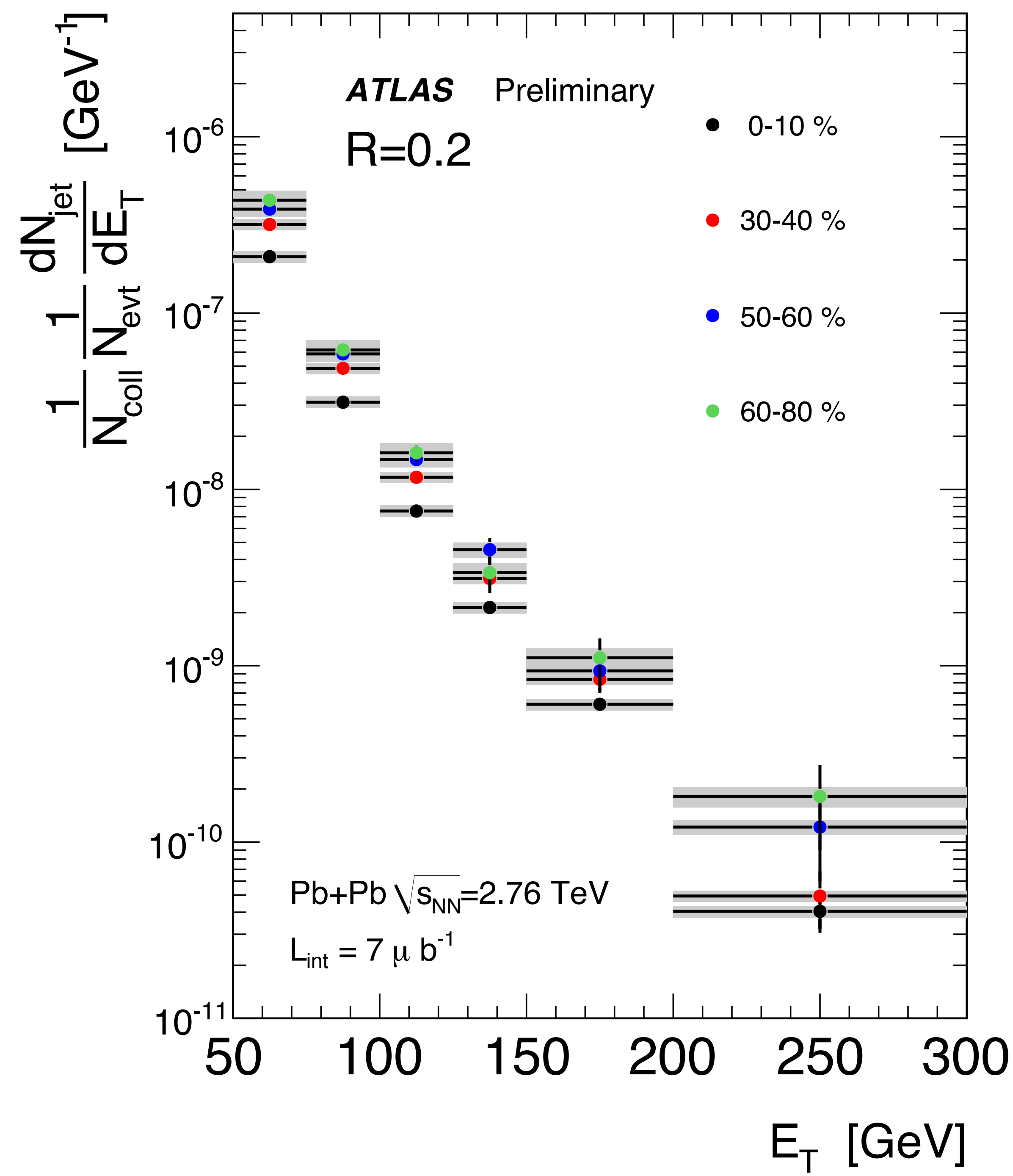


R=0.4 **R=0.2**

Scaled by N_{coll} (selected bins)

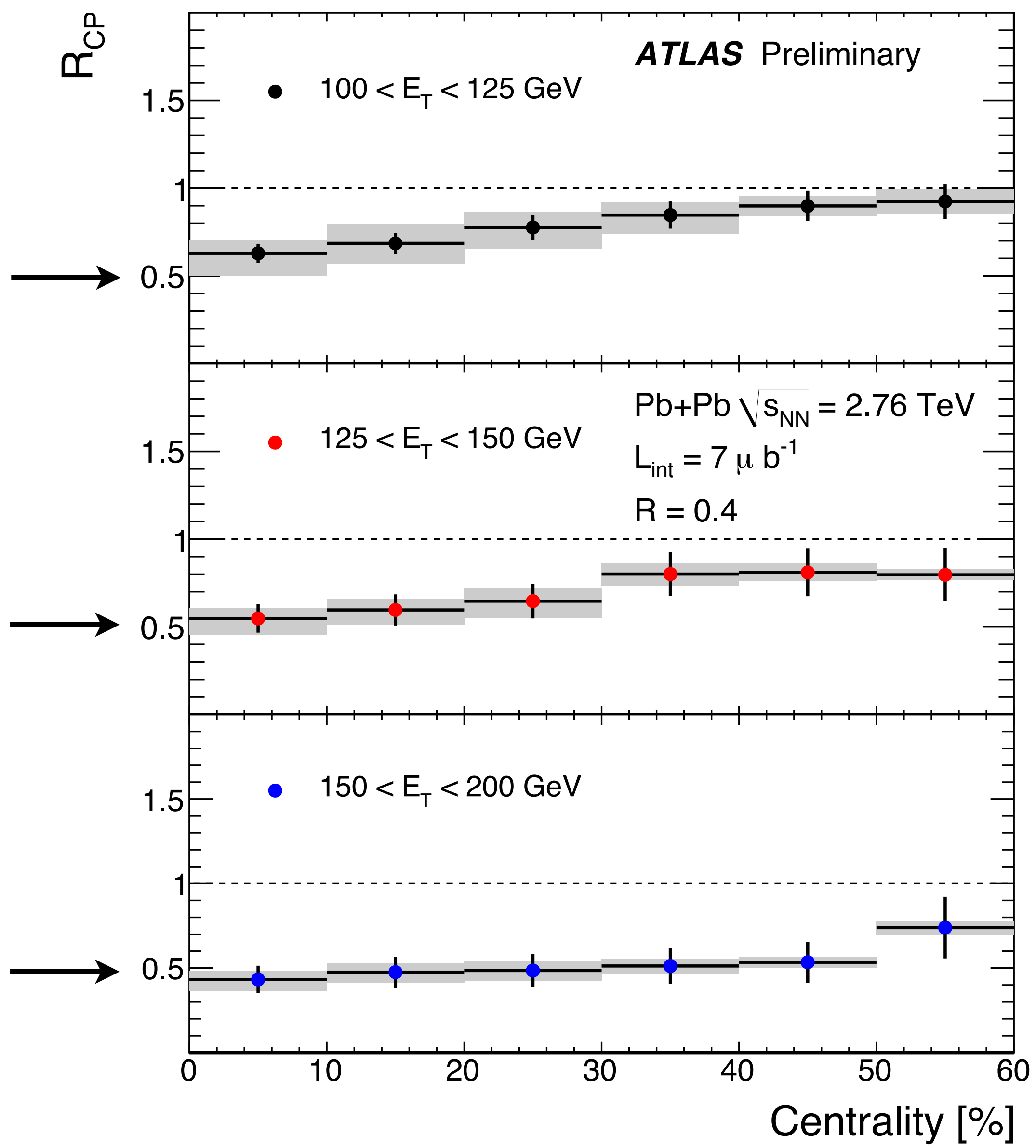


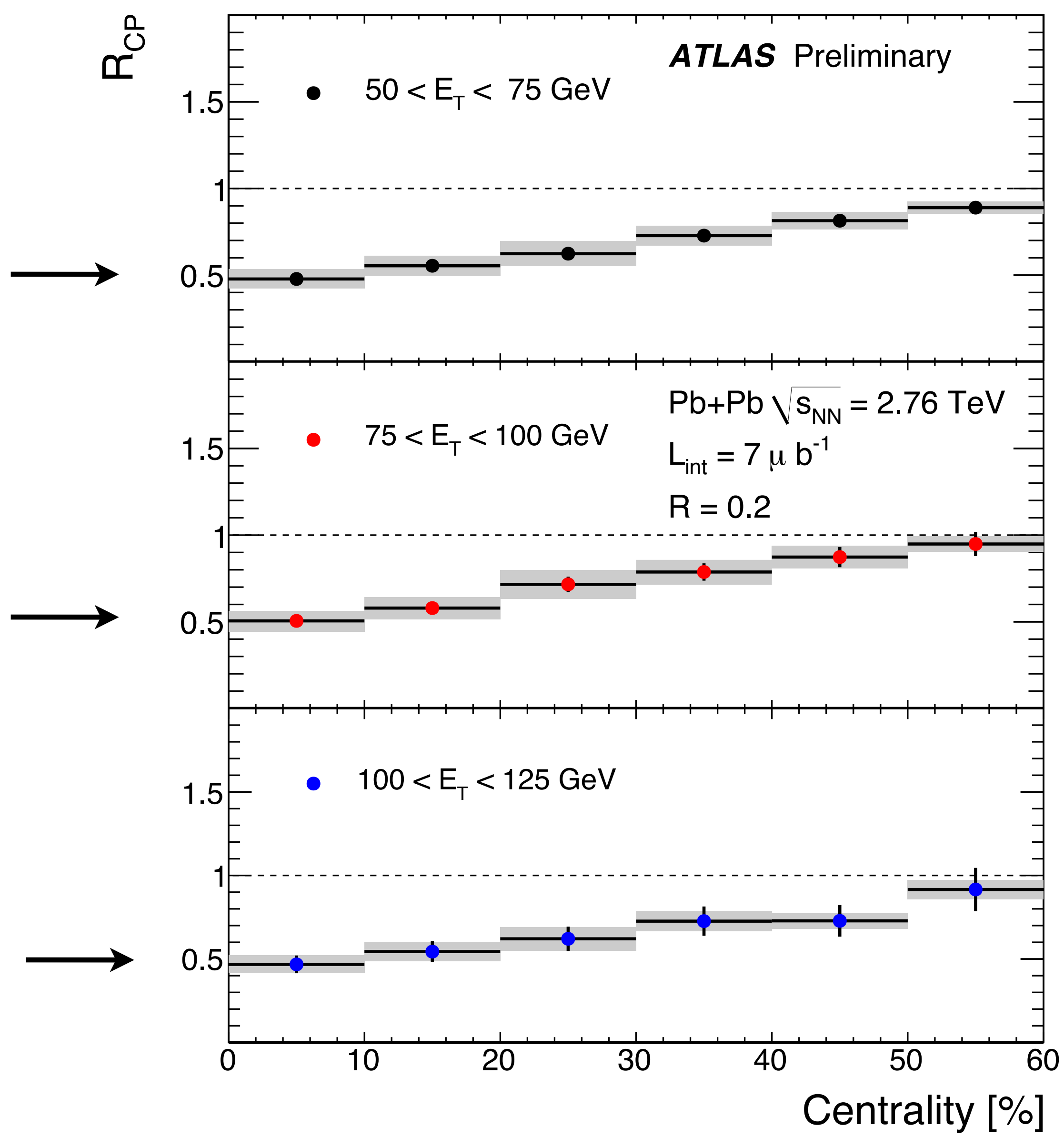
R=0.4



R=0.2

R_{CP} vs. centrality in E_T bins



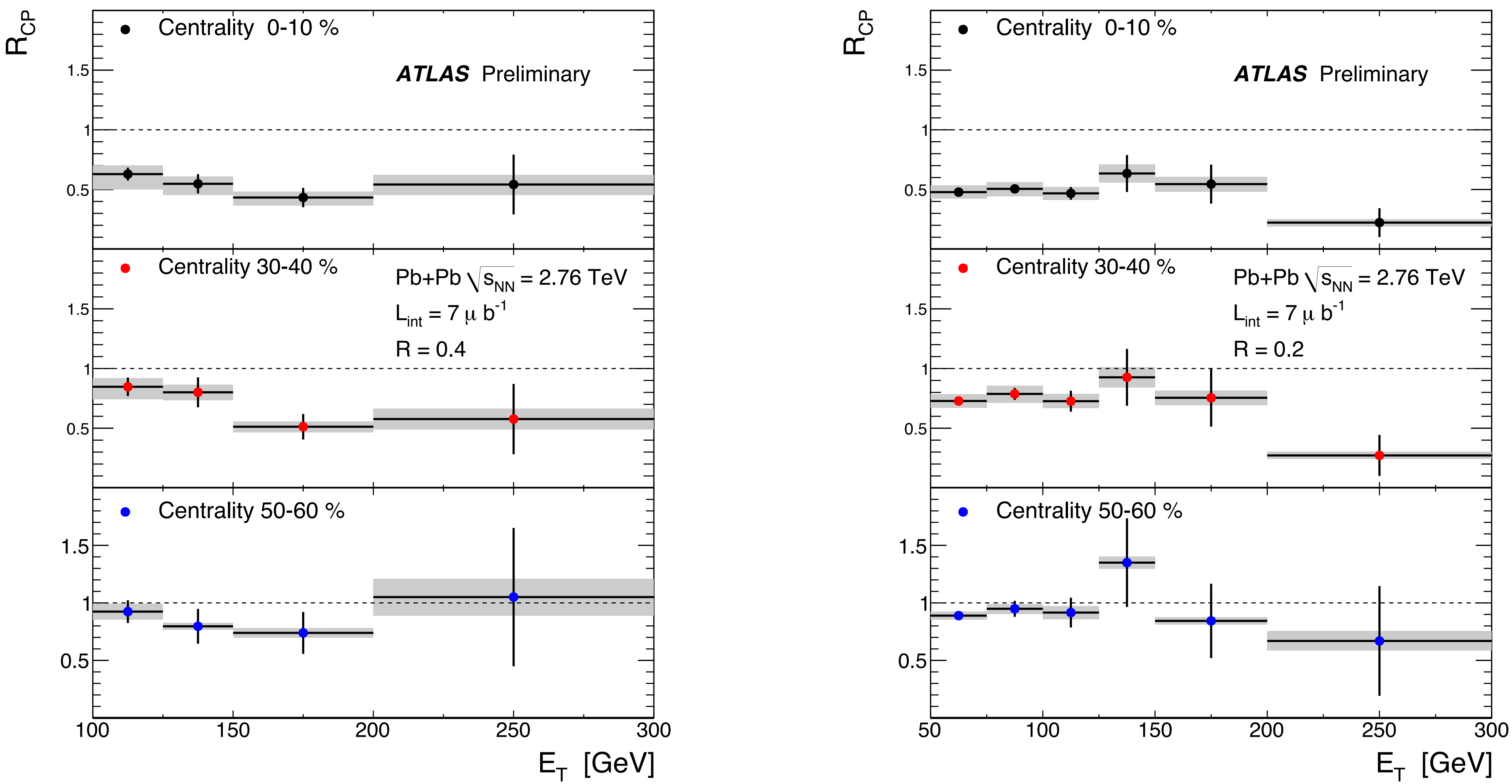


Suppression characterized by central/peripheral ratio (pinned on 60-80%)

$$R_{CP} = \frac{\frac{1}{N_{\rm coll}{}^{cent}}\, E\frac{{\rm d}^3N^{cent}}{{\rm d}p^3}}{\frac{1}{N_{\rm coll}{}^{periph}}\, E\frac{{\rm d}^3N^{periph}}{{\rm d}p^3}}.$$

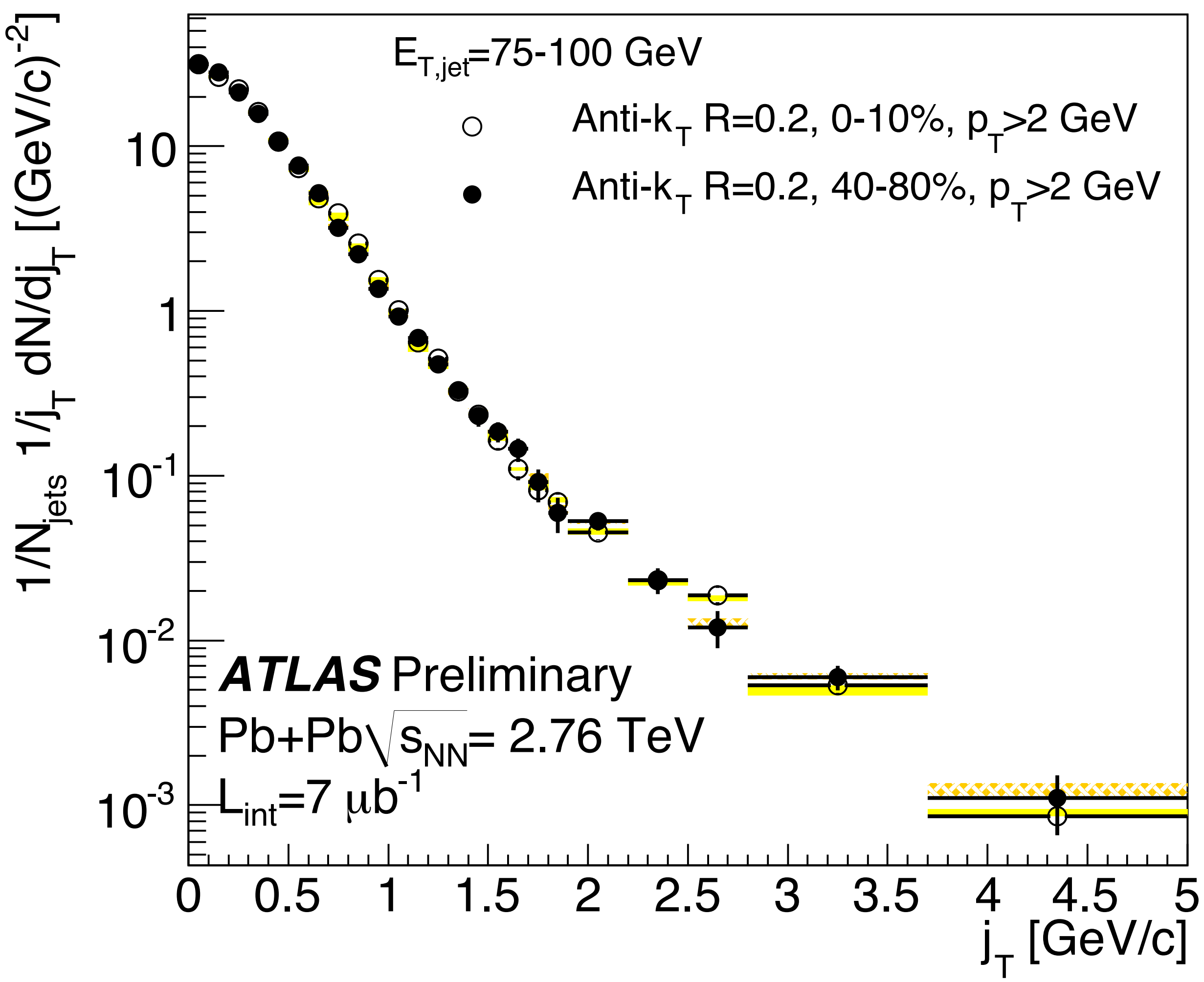
tends to ~0.5 in central bin

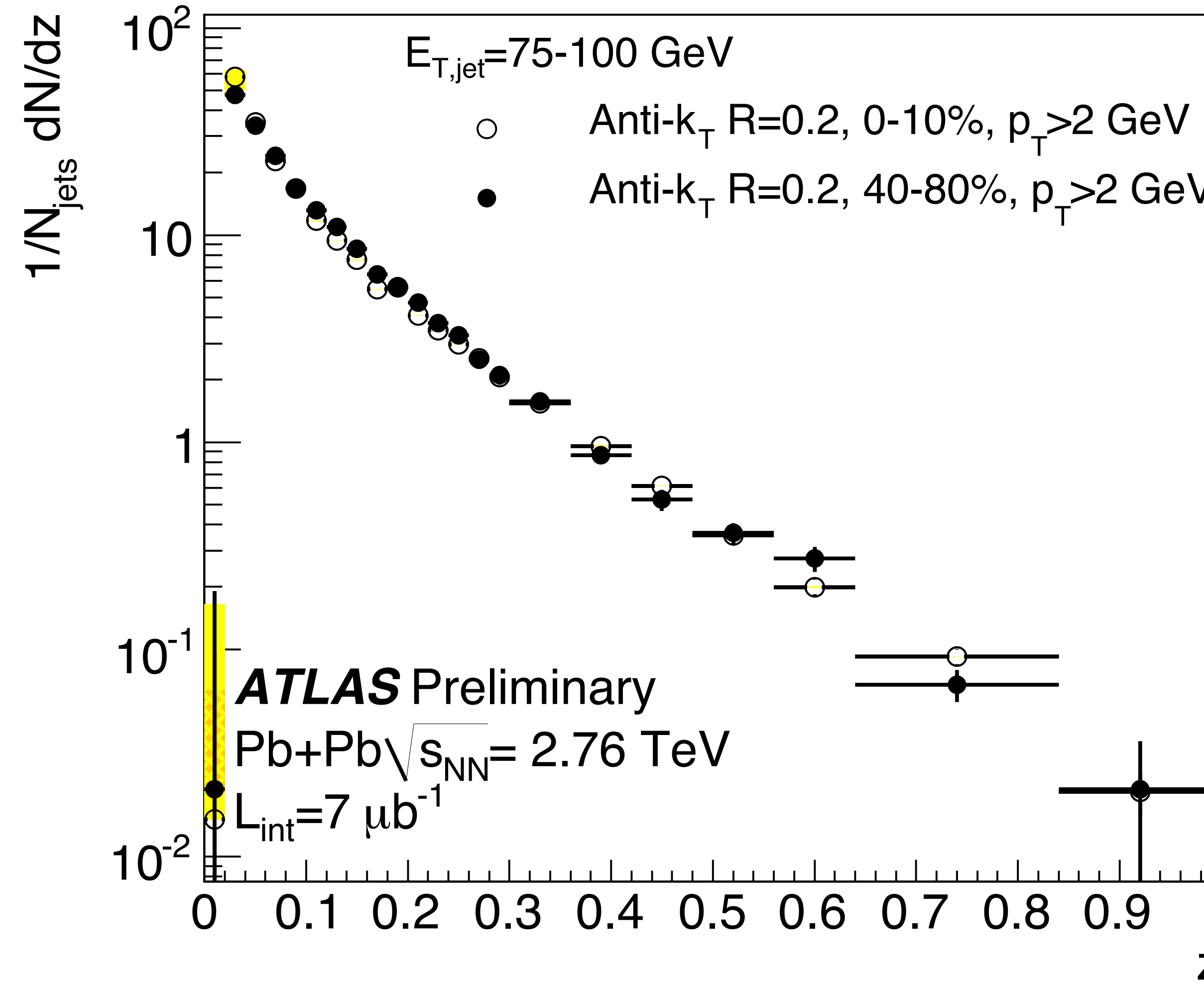
R_{CP} vs. E_T in centrality bins



No appreciable E_T dependence of R_{CP} for R=0.4 & 0.2

Fragmentation Functions



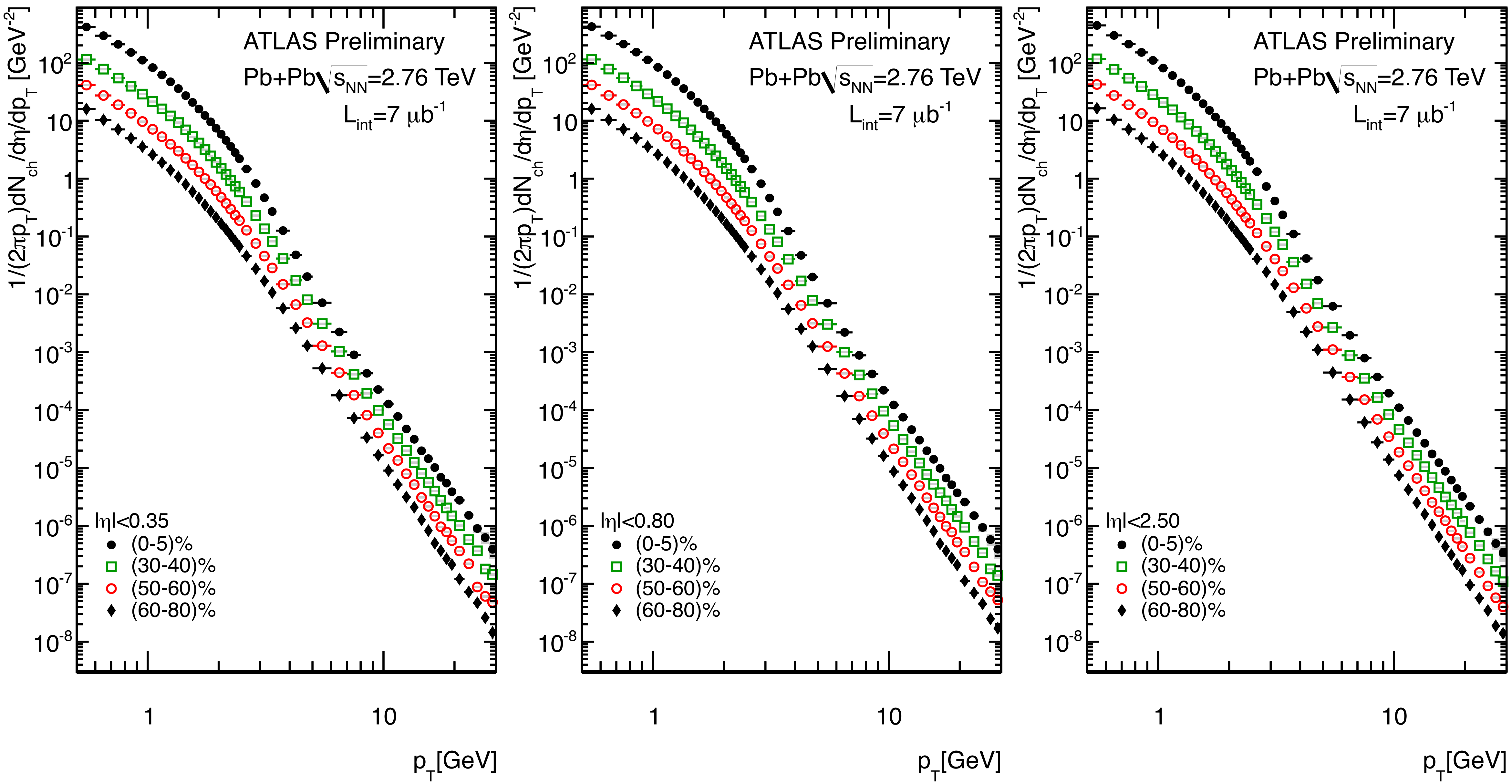


p_T cut to suppress underlying event, and background subtracted using region outside jet cone

Yellow bands represent uncertainties from background subtraction

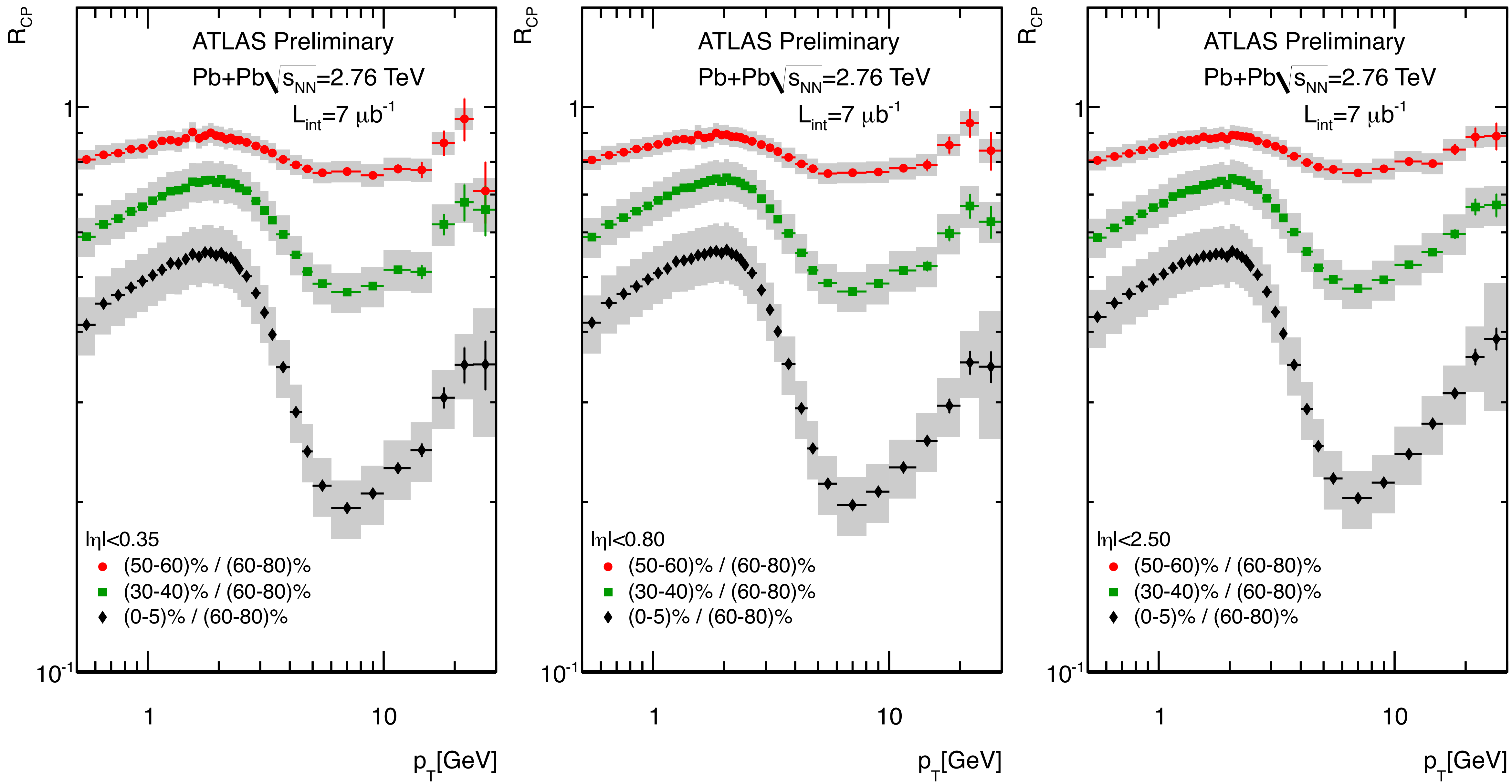
No strong modification of fragmentation functions between peripheral and central: surprising in a radiative energy loss scenario?

Charged particle spectra



Corrected for efficiency, secondaries, fakes, resolution.
Cutoff at 30 GeV due to small, systematic differences in track errors between data and MC (under investigation)

Charged particle R_{CP}

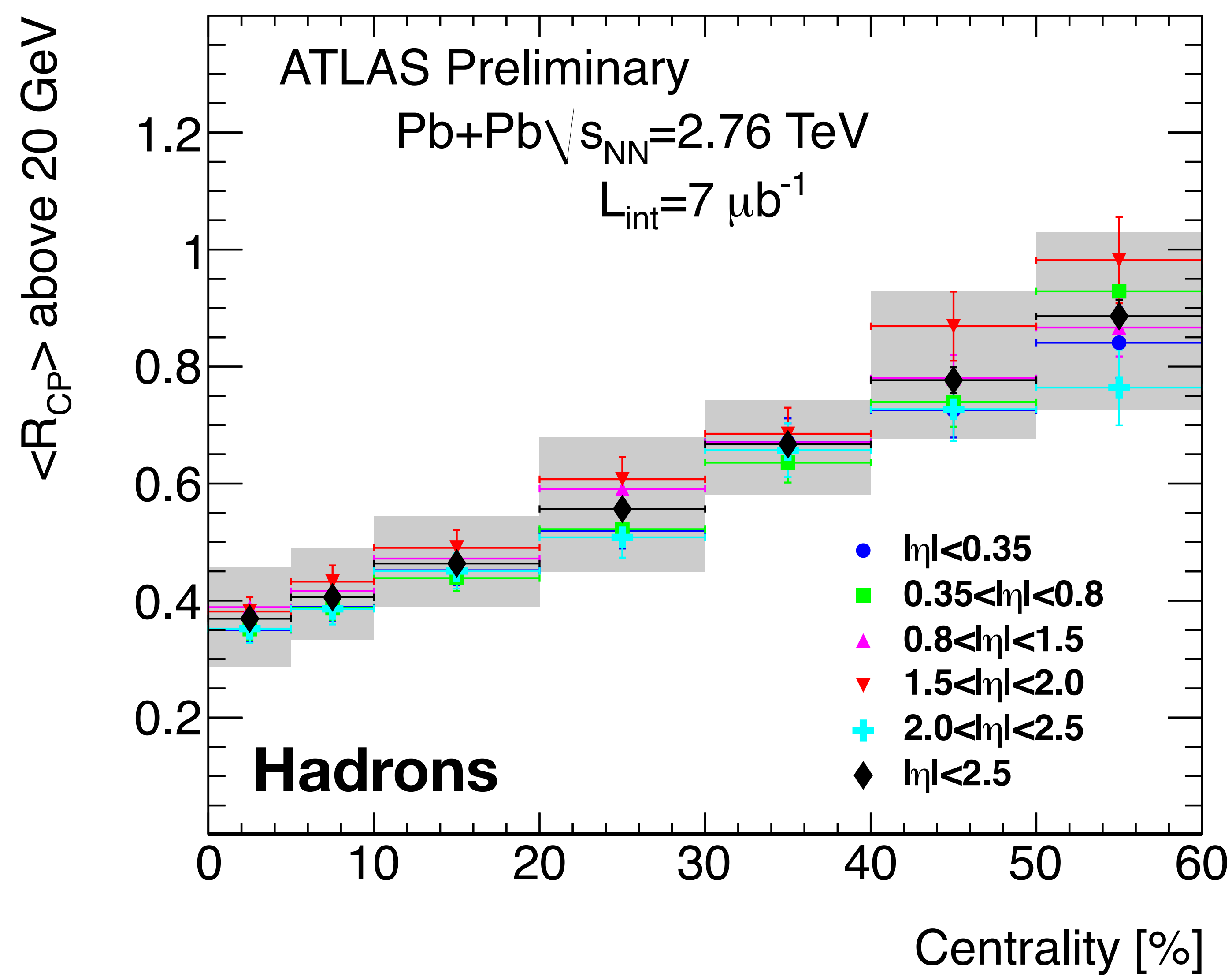


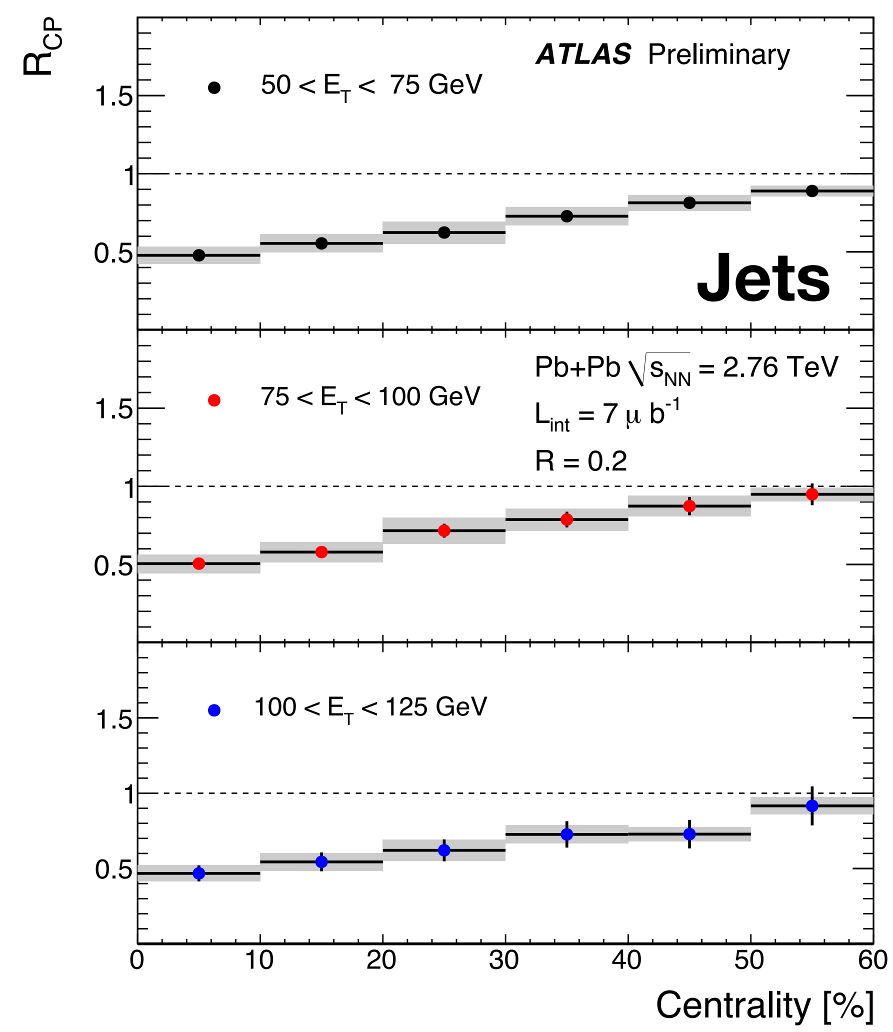
Strong suppression seen in more central events via charged R_{CP}

No η dependence observed

for details, see talk by Sasha Milov (3:20pm Thurs.)

Centrality dependence of charged hadron R_{CP}





R_{CP}(p_T>20 GeV) shows systematic suppression, <u>very similar to jets</u>

(but R_{CP} still rising with p_T at 30 GeV)

Pseudorapidity dependence dominated by statistics in 60-80%

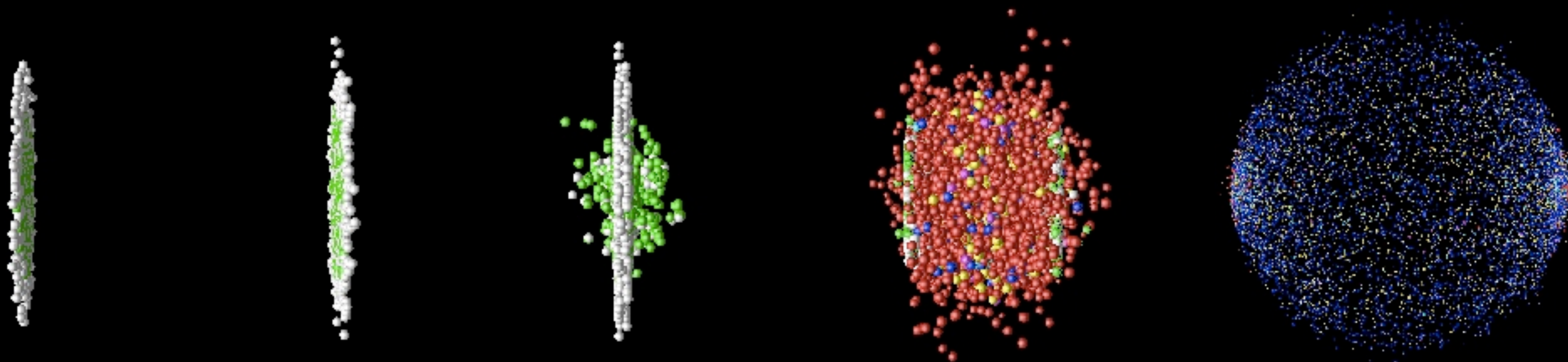
Conclusions

- **Global observables**
  - Centrality dependence of inclusive multiplicity scales with beam energy
  - Transverse momentum dependence of v_2 scales out to highest p_T (modulo large errors at RHIC)
  - η dependencies of flow and multiplicity very weak within $|\eta|<2.5$
  - Detailed study of higher order flow coefficients challenges ridge & cone interpretation. New information to help constrain viscous hydro models.
- **High p_T observables**
  - $W^{\pm}$ production consistent with simple scaling with N_{coll}
  - Jet production systematic suppressed by a factor of ~2 relative to peripheral collision.
  - Charged hadron R_{CP} measured out to 30 GeV: centrality dependence of suppression similar to jets

M11

Logo idea from D. Morrison

Heavy ion collisions: the first $3x10^{-23}$ seconds



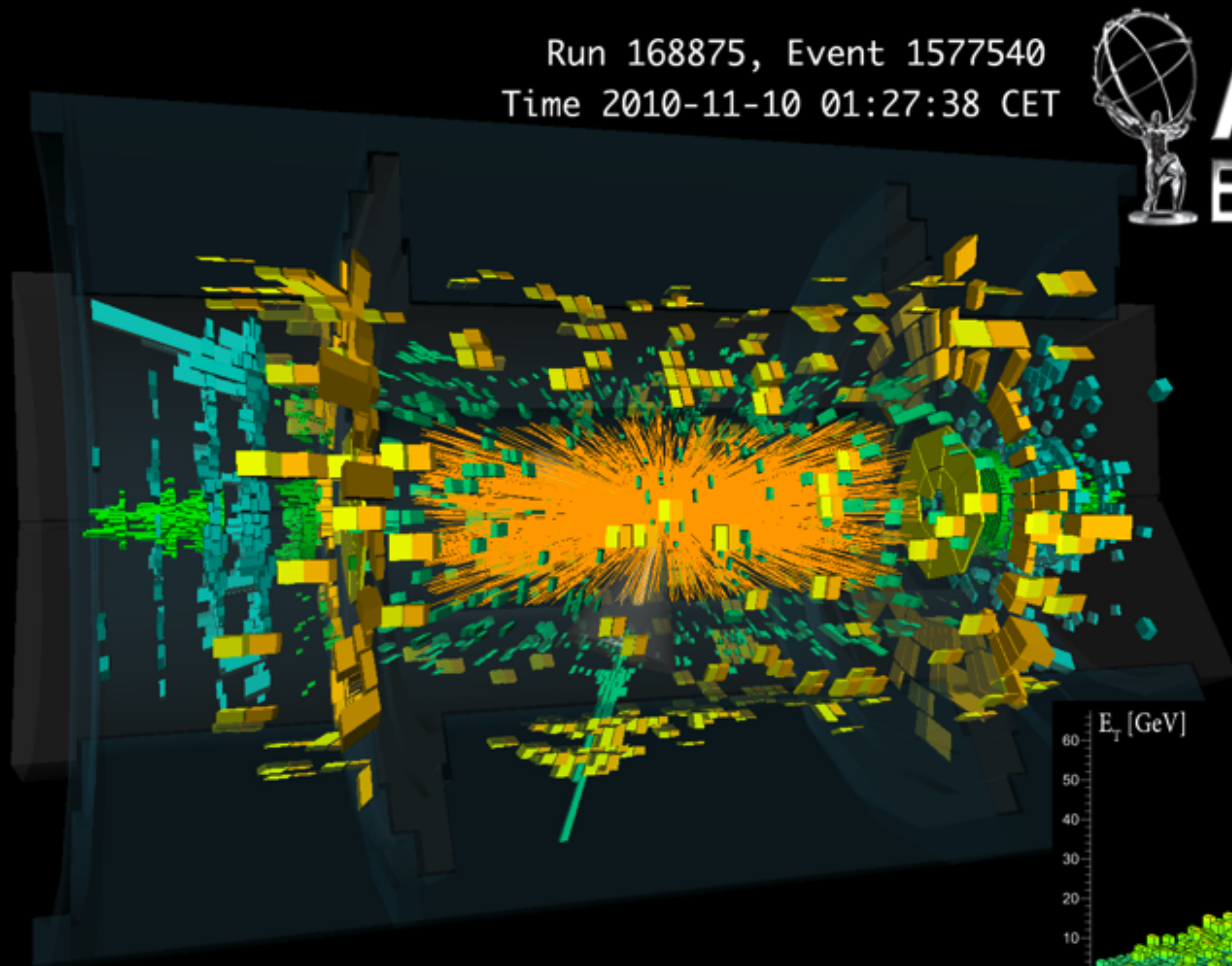
Initial
Nuclei

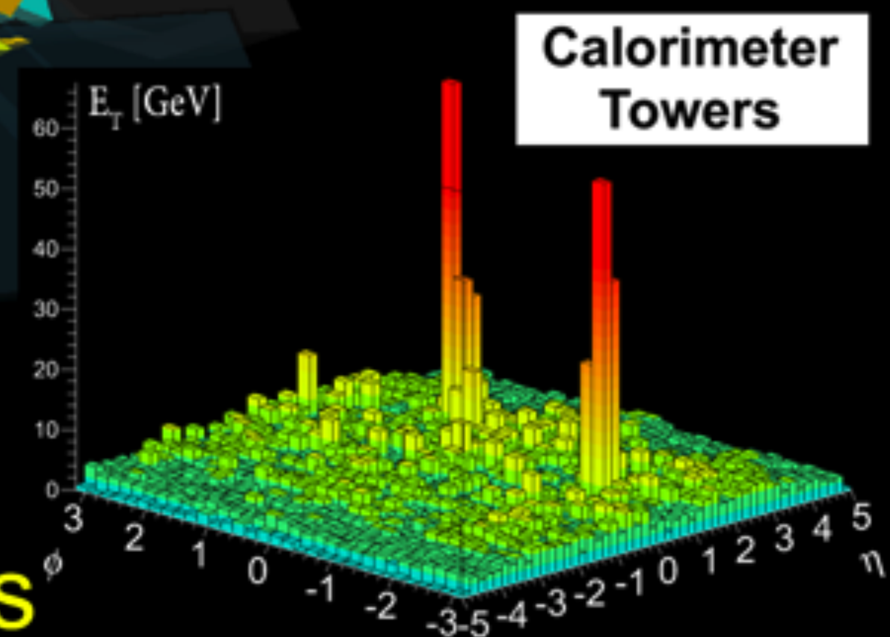
Energy Stopping &
Hard Collisions

Hydrodynamic
Evolution

Hadron
Freezeout

The goal of heavy ion physics is to “rewind the movie” to study the hot, dense medium formed in the early moments

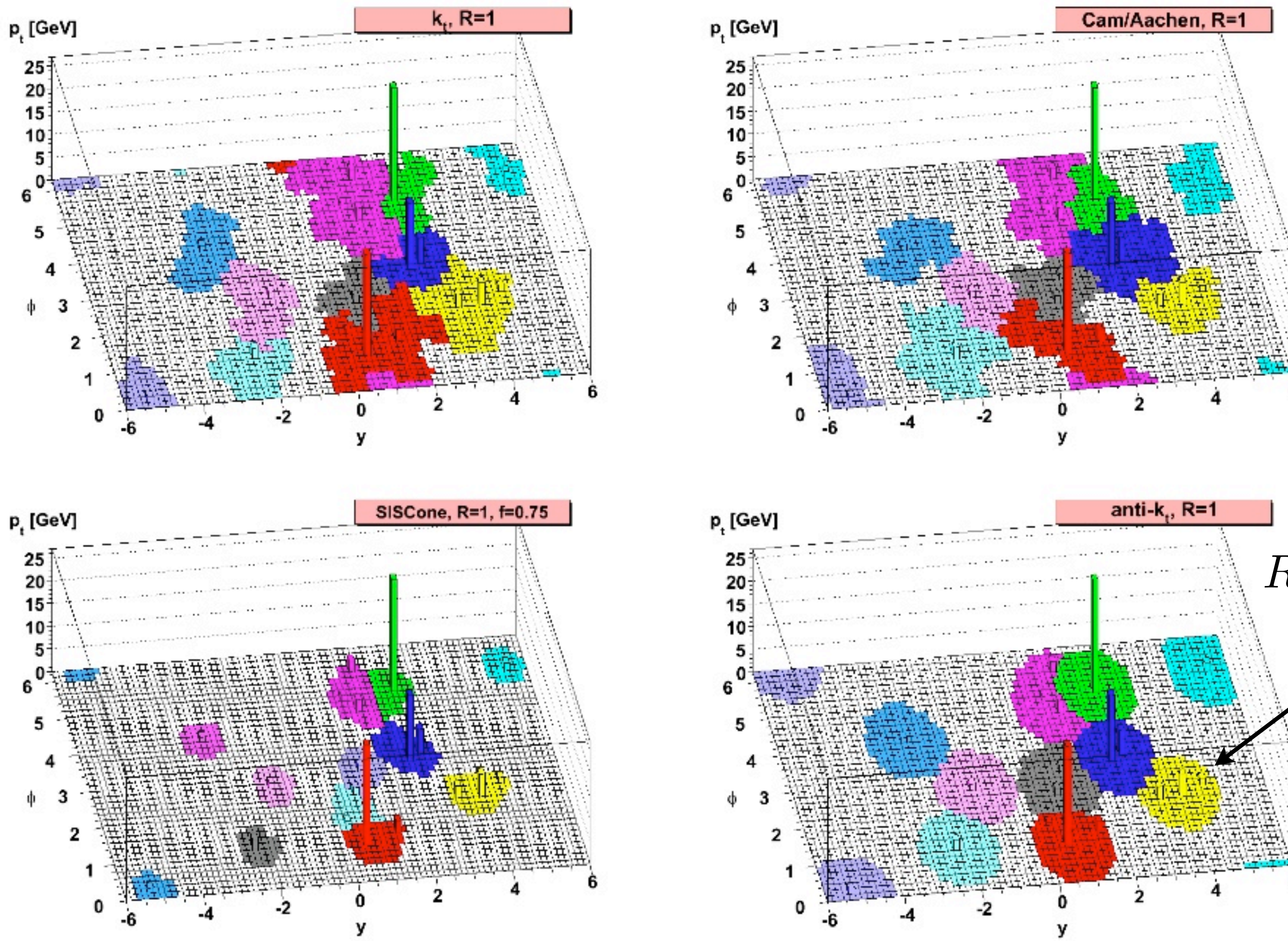




Heavy Ion Collision Event with 2 Jets

Jet reconstruction algorithms

Cacciari, Soyez, Salam (2008)



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

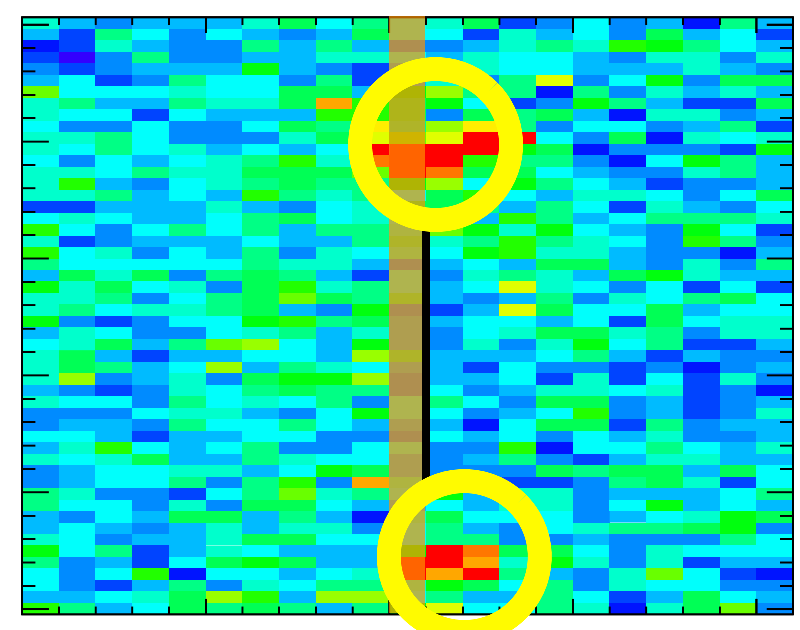
Out of large variety of algorithms, ATLAS uses "anti-k_t": consistent jet shape (e.g. R=0.4), widely used in HEP & HI

Subtracting the underlying background

- **ATLAS has excellent longitudinal segmentation**
  - Underlying event estimated and subtracted for each layer, and in 100 slices of $\Delta\eta=0.1$

$$E_{T\,sub}^{\;cell} = E_T^{cell} - \rho^{layer}(\eta) \times A^{cell}$$

  - ρ is estimated event by event, averaged over full azimuth



- **Remove jets from the averaging**
  - We use the anti-k_t algorithm to remove jets which have a large “core” region

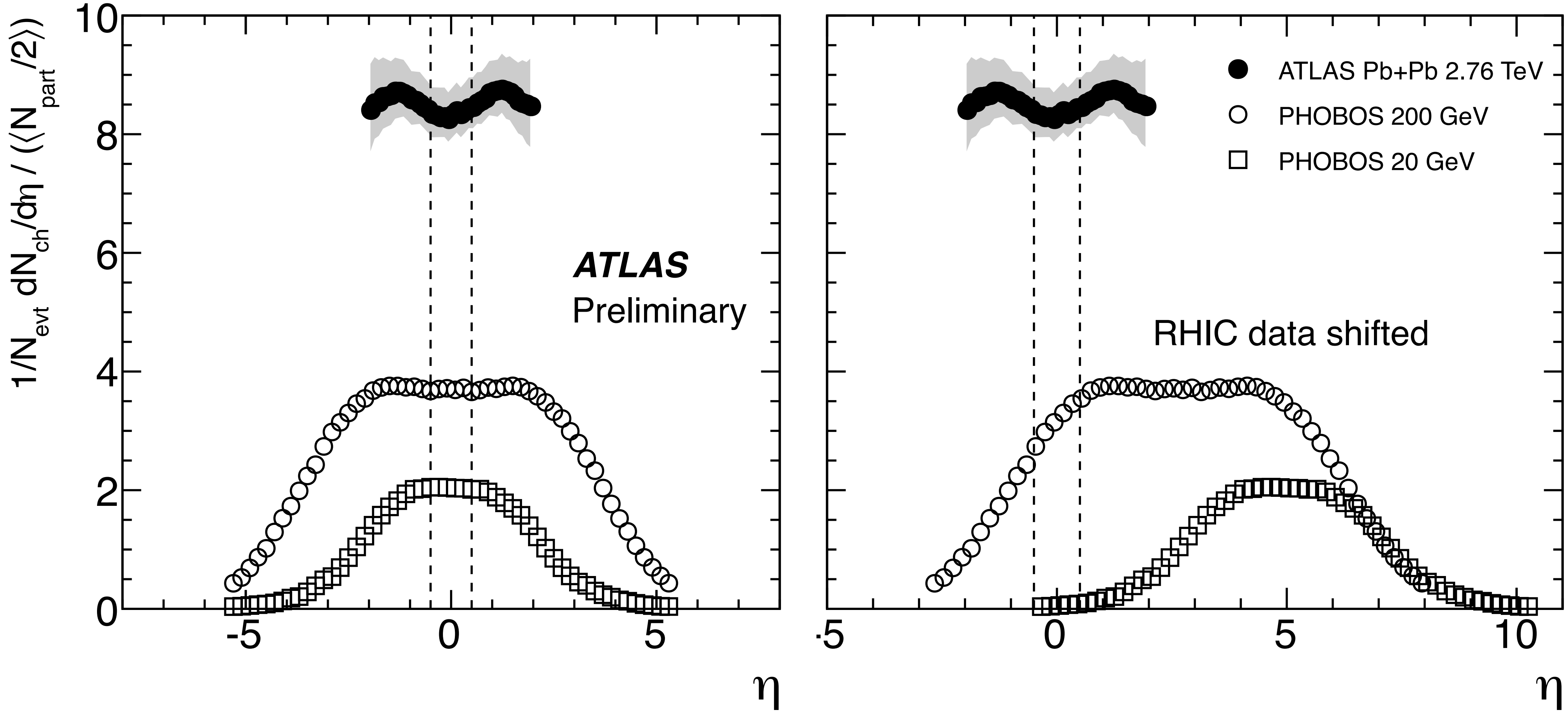
$$D = E_{T\,max}^{\;tower} / \langle E_T^{tower} \rangle > 5$$

  - Cross checked with a standard “sliding window” algorithm
- **NB: No jets are removed - but only real jets will have a large energy above the background level!**

Minimum bias triggering

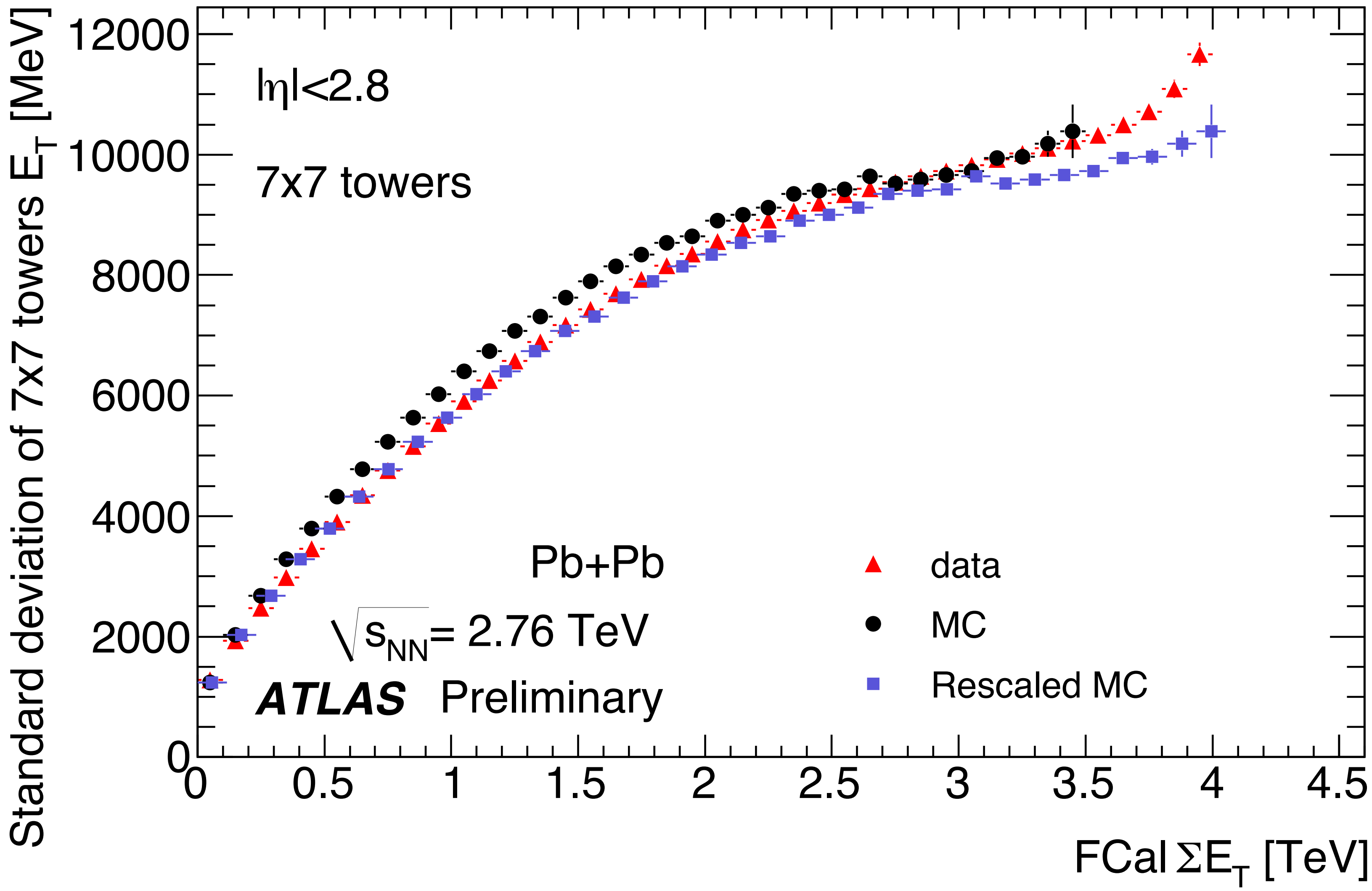
- **The 2010 data set was taken with a minimum bias trigger configuration**
  - Coincidence of minimum bias trigger scintillators ($2.1<|\eta|<3.9$)
  - Coincidence of neutrons in Zero Degree Calorimeters
- **Offline requirements of**
  - MBTS time difference $|\Delta t|<3$ ns
  - Coincidence in ZDC
  - Reconstructed vertex in Inner Detector
- **Efficient rejection of**
  - Beam-gas events
  - Inelastic photonuclear events
- **No physics triggers (e.g. jets, muons) used in event selection**

Pseudorapidity density



ATLAS **η** reach extends well beyond midrapidity
but not high enough yet to address limiting fragmentation at LHC:
still does the physics change away from |**η**|~0?

Underlying event fluctuations



Detailed look at variable-size square patches in data and MC. After 15% adjustment of FCal ΣE_T scale, good agreement over nearly full centrality range

Higher order moments vs. p_T and centrality

At all moderate p_T values (only 2-3 GeV shown here) weak centrality dependence for v_3-v_6

v_2 is <u>not</u> the largest component for central events.