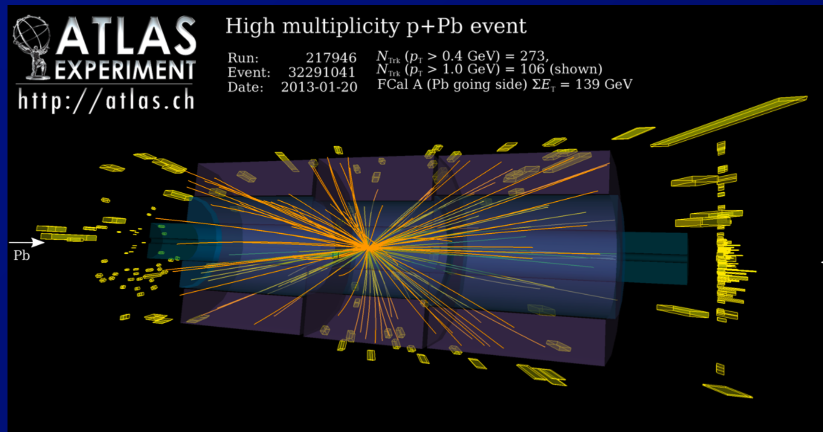
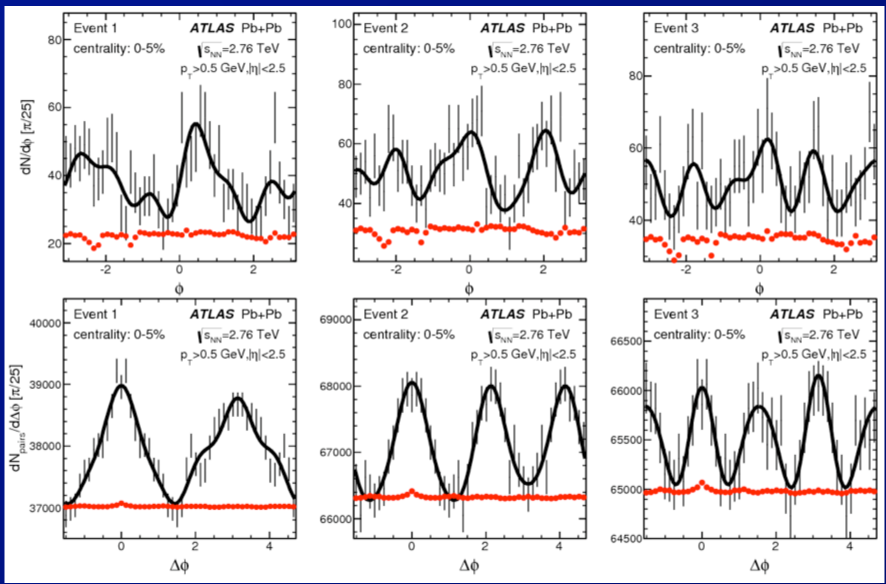
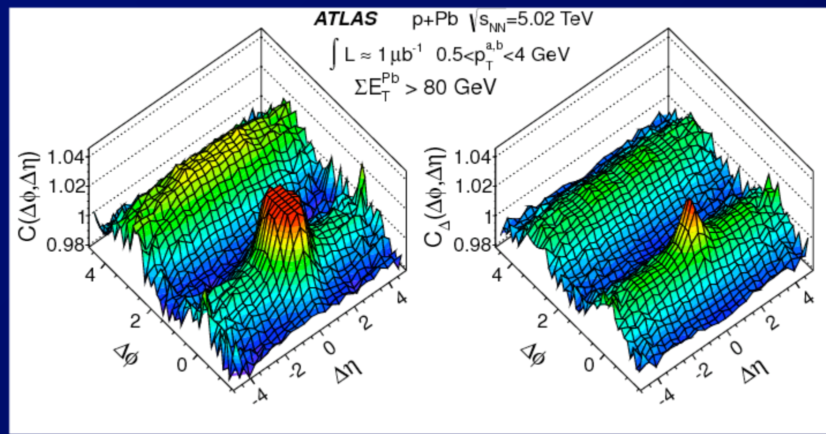
ATLAS measurements of event-by-event flow in Pb+Pb collisions and collective flow(?) in p+Pb collisions

Brian. A Cole
June 16, 2013





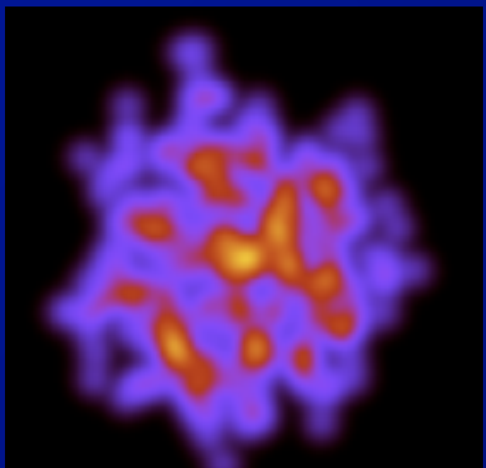


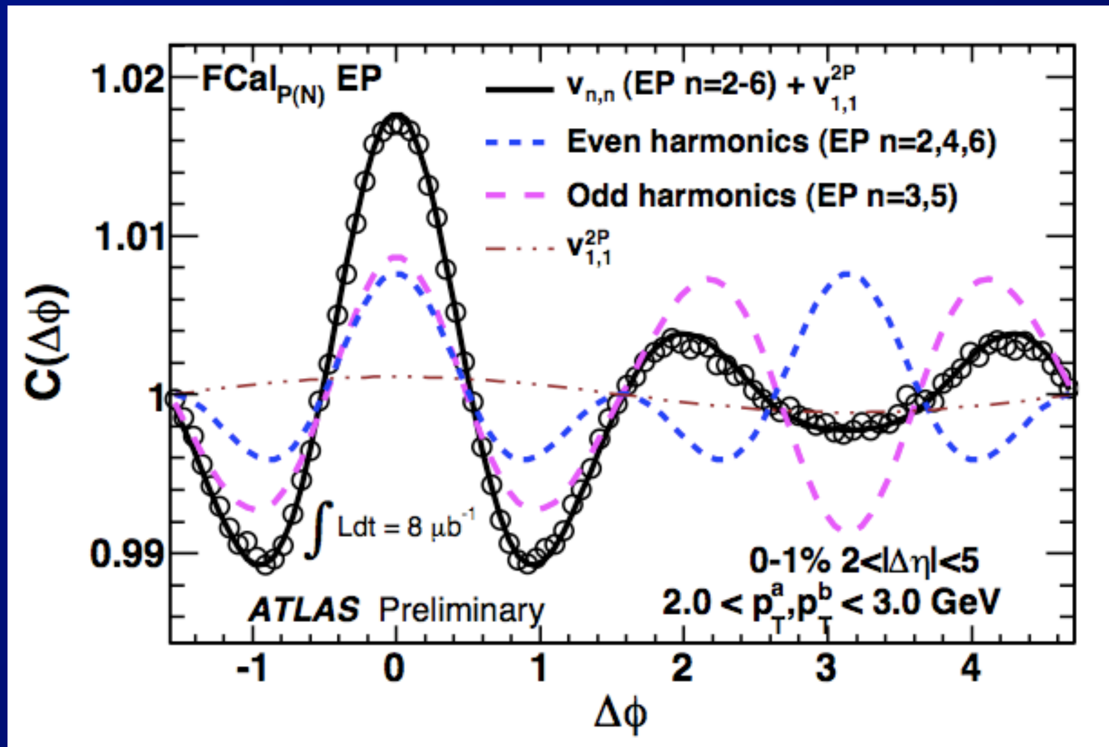
Higher Flow Harmonics

- Major paradigm shift in the field in last 3 years
  - Higher flow harmonics arising from initial-state fluctuations in transverse positions of participants

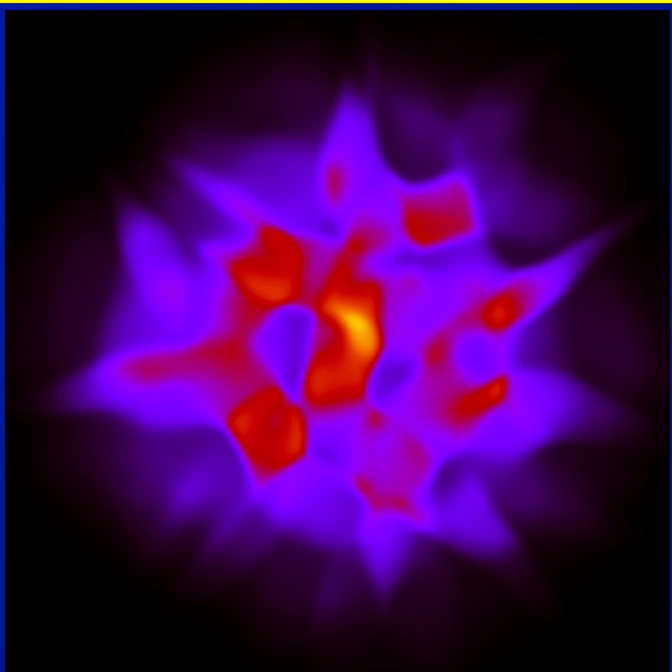
$$\frac{dN}{d\phi dp_T d\eta} = \frac{dN}{2\pi dp_T d\eta}\left(1 + \sum_n 2v_n \cos\left[n(\phi - \psi_n)\right]\right)$$

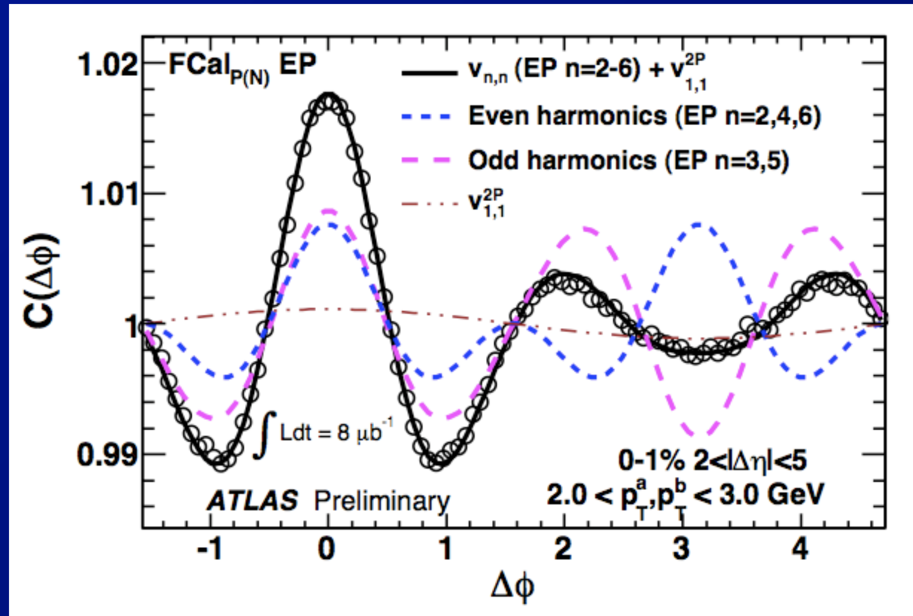
- Frequently measured using pairs of particles



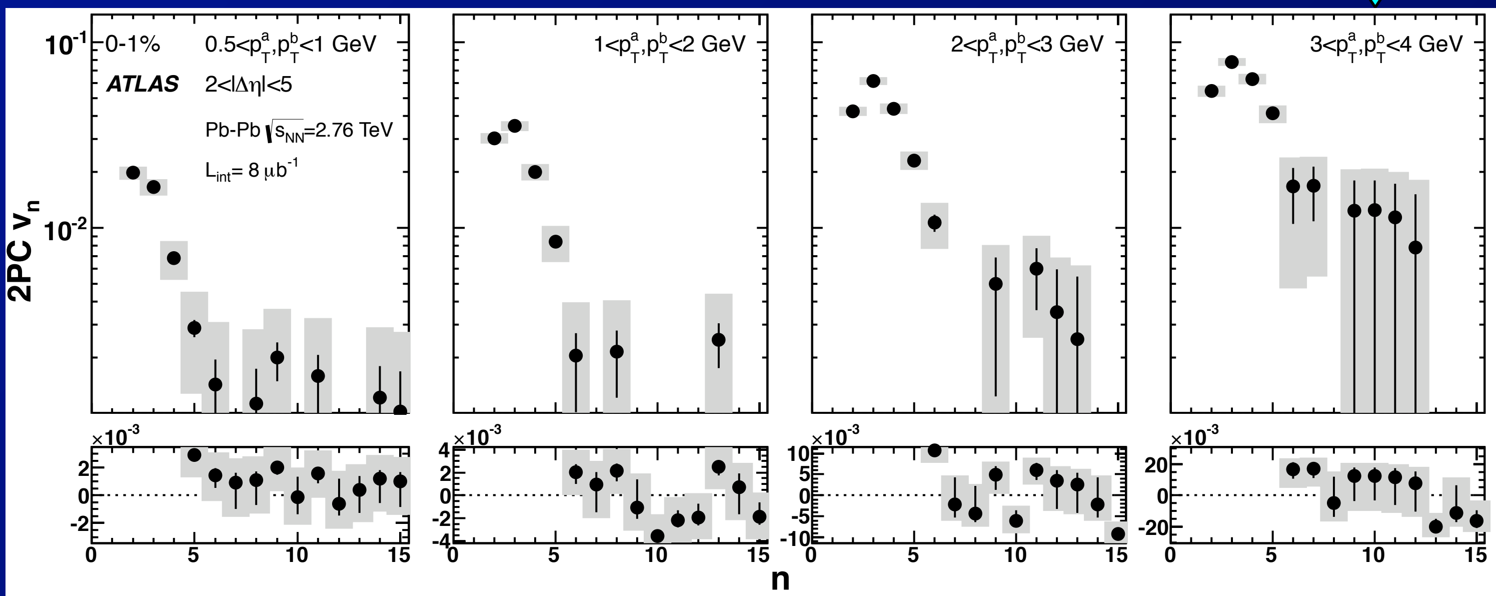


Fluctuations, Fourier amplitudes

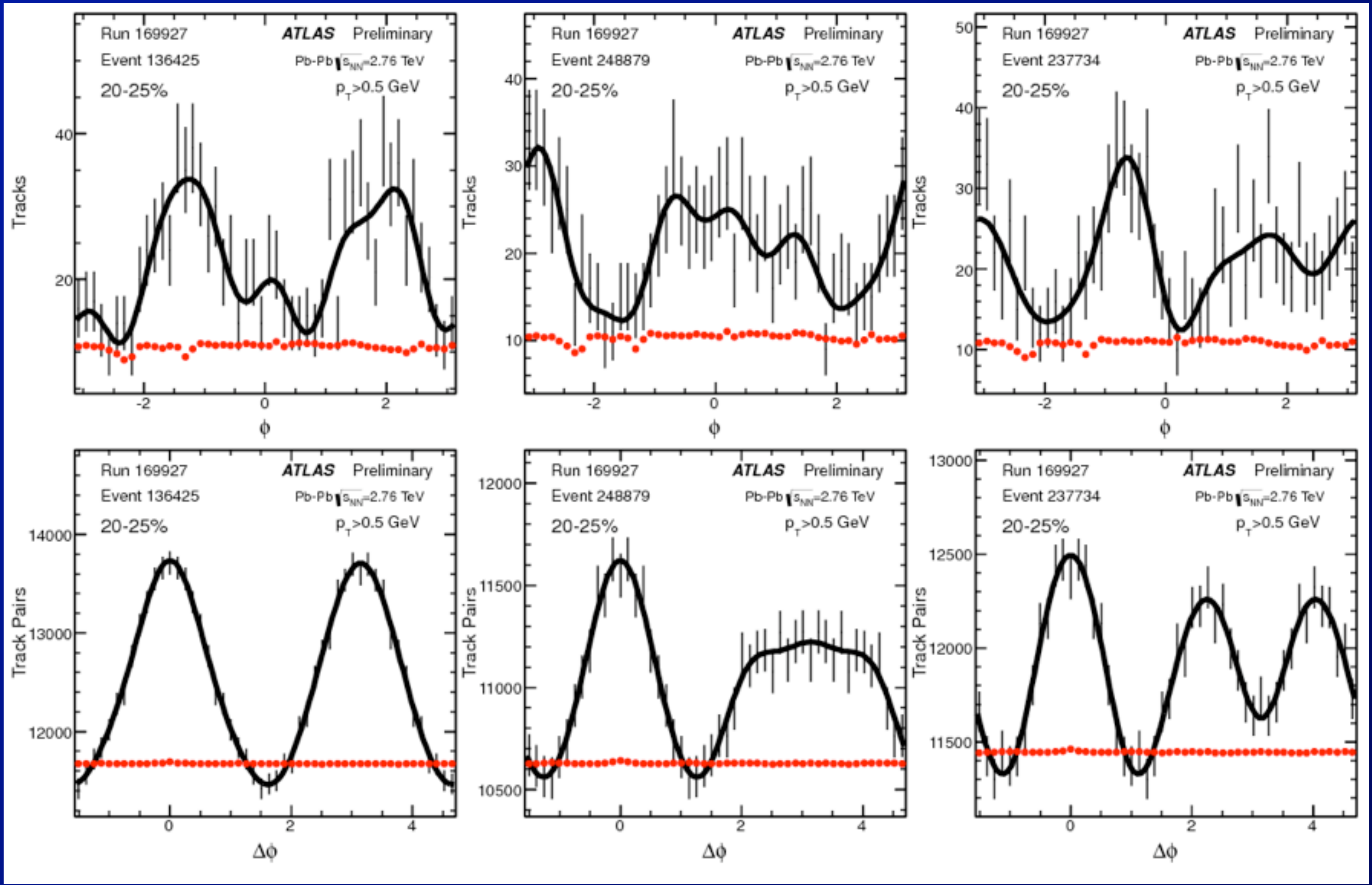




Increasing momenta →



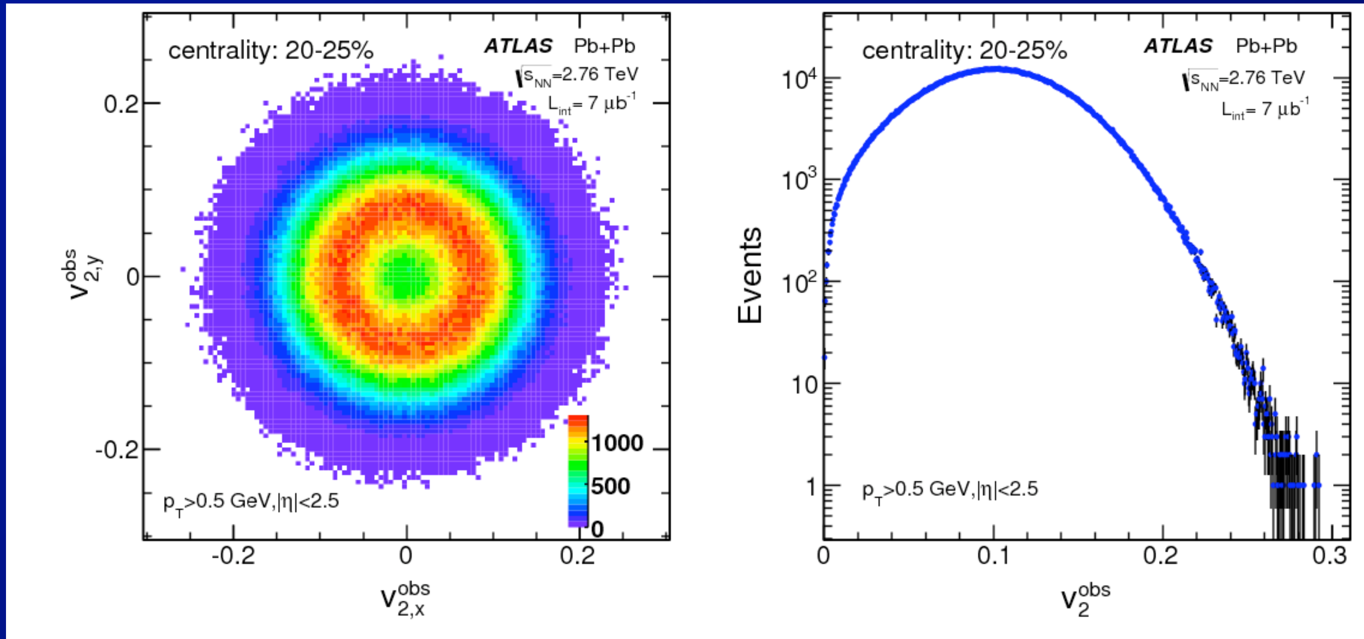
Event-by-event v_n



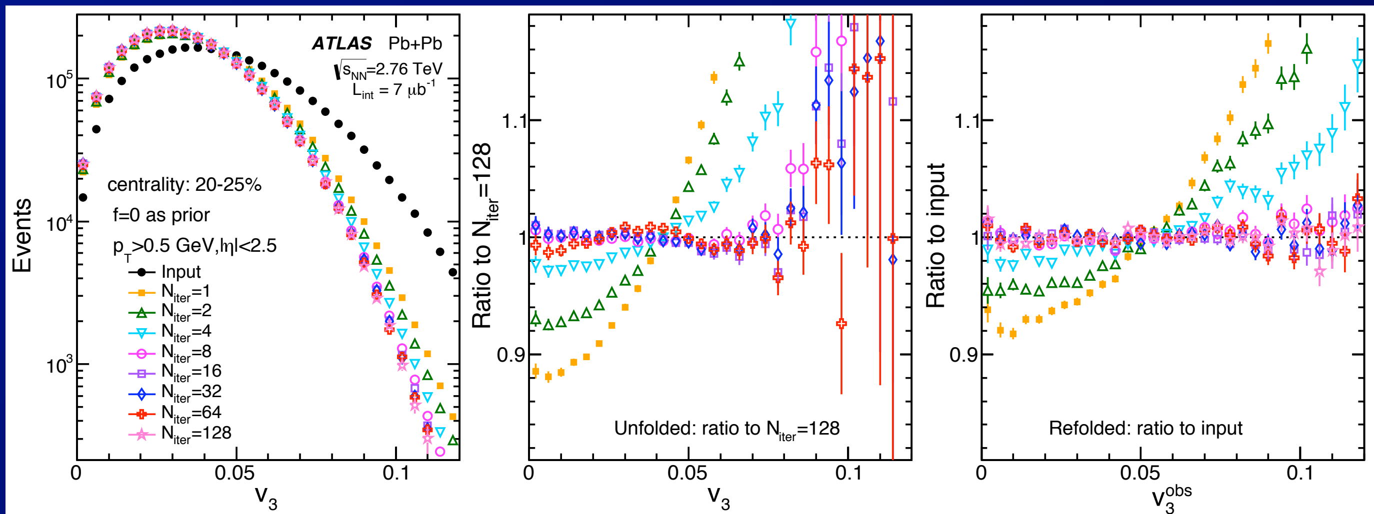
- **Experimental breakthrough by ATLAS**
  - ⇒ **event-by-event v_n measurement**

Event-by-event flow measurement

Measured distribution of event-by-event v_2 flow vector and v_2 dist.



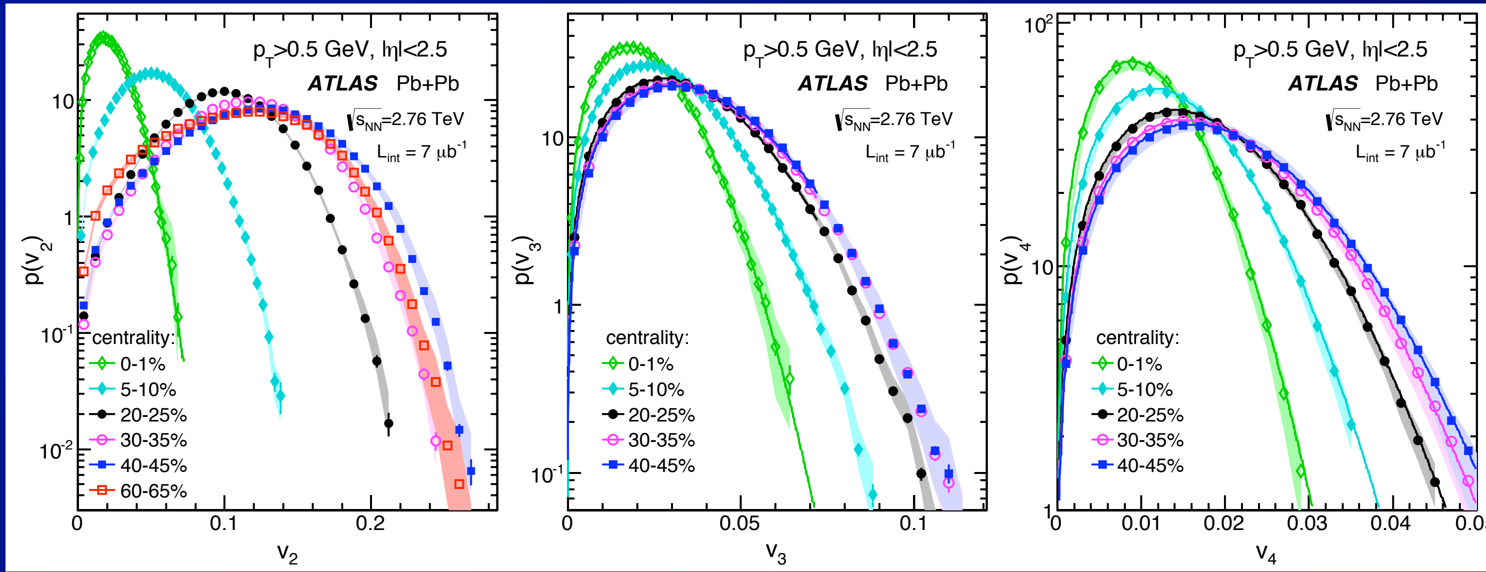
Unfolding of the measured event-by-event v_3 dist.



Event-by-event flow: results

v_2 v_3 v_4

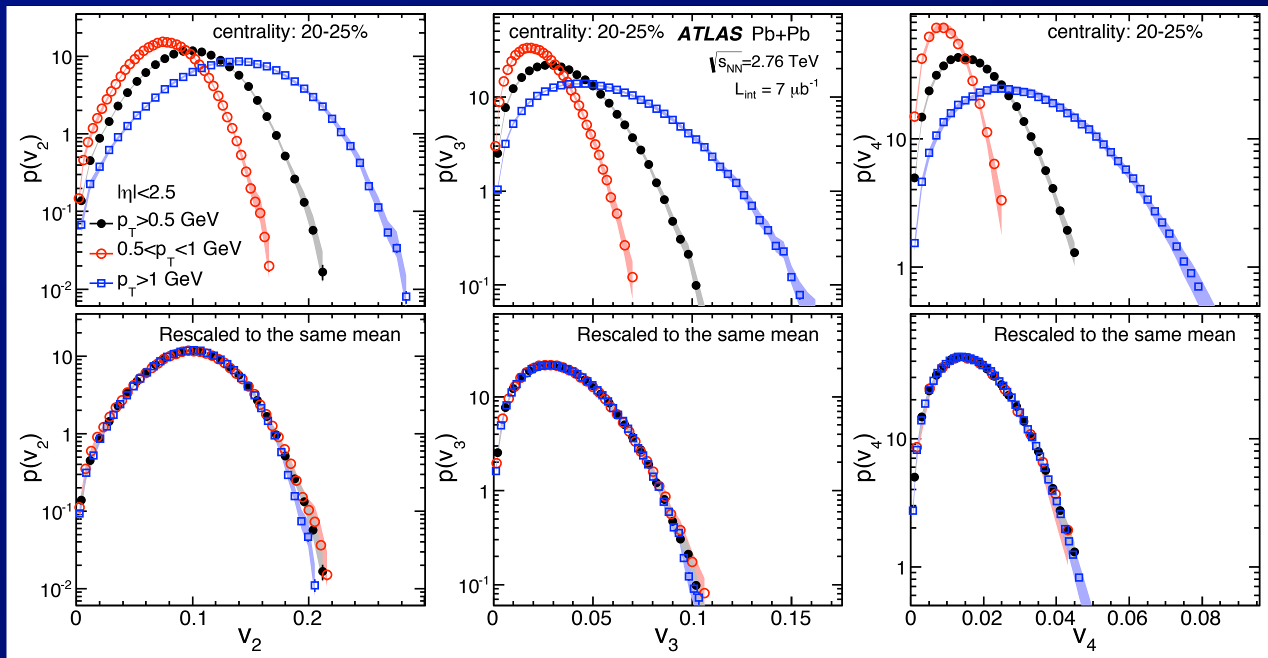
$p_T > 0.5$ GeV



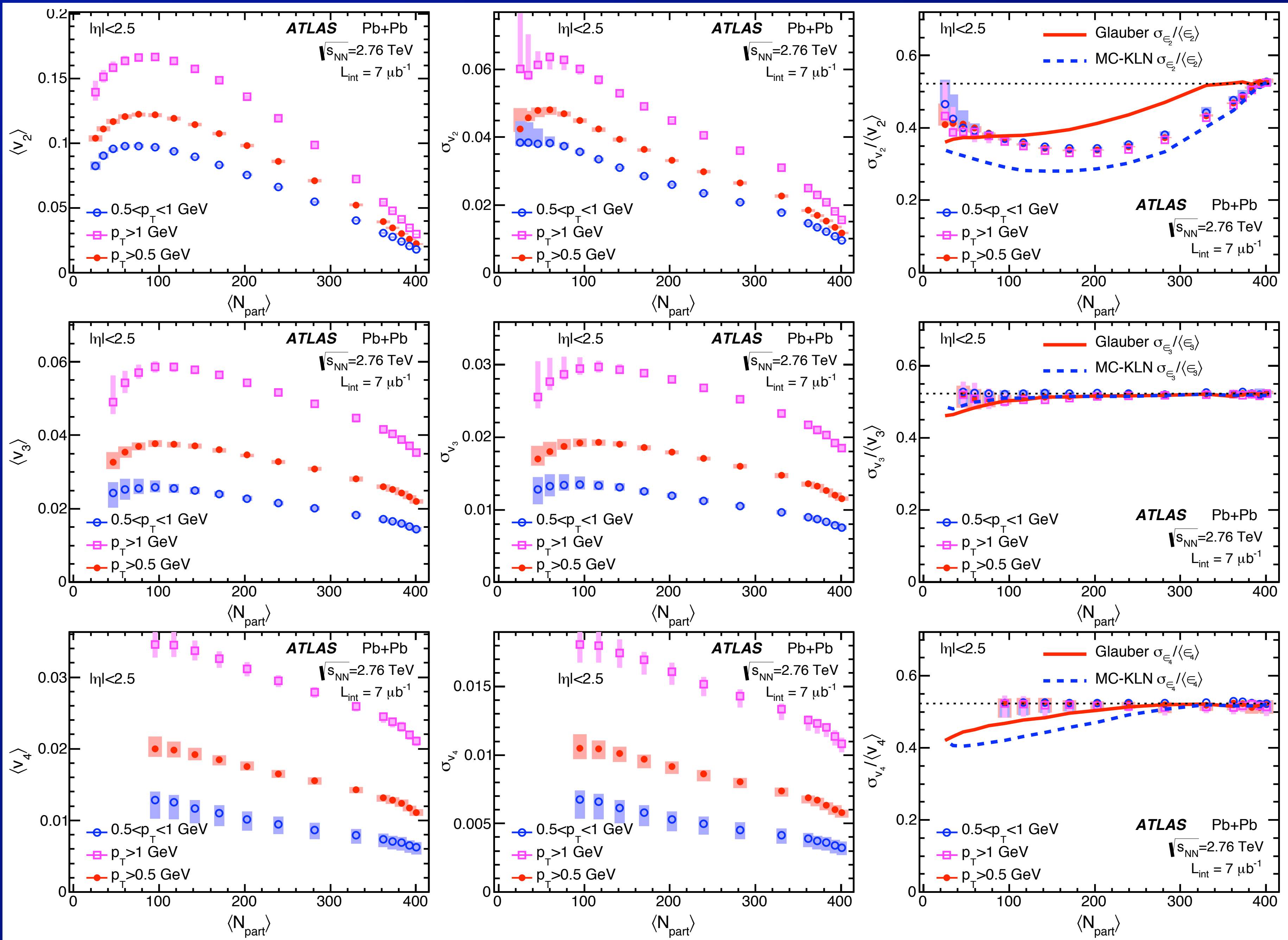
v_2 v_3 v_4

$p_T > 0.5$ GeV,
$0.5 < pT < 1$ GeV,
$p_T > 1$ GeV

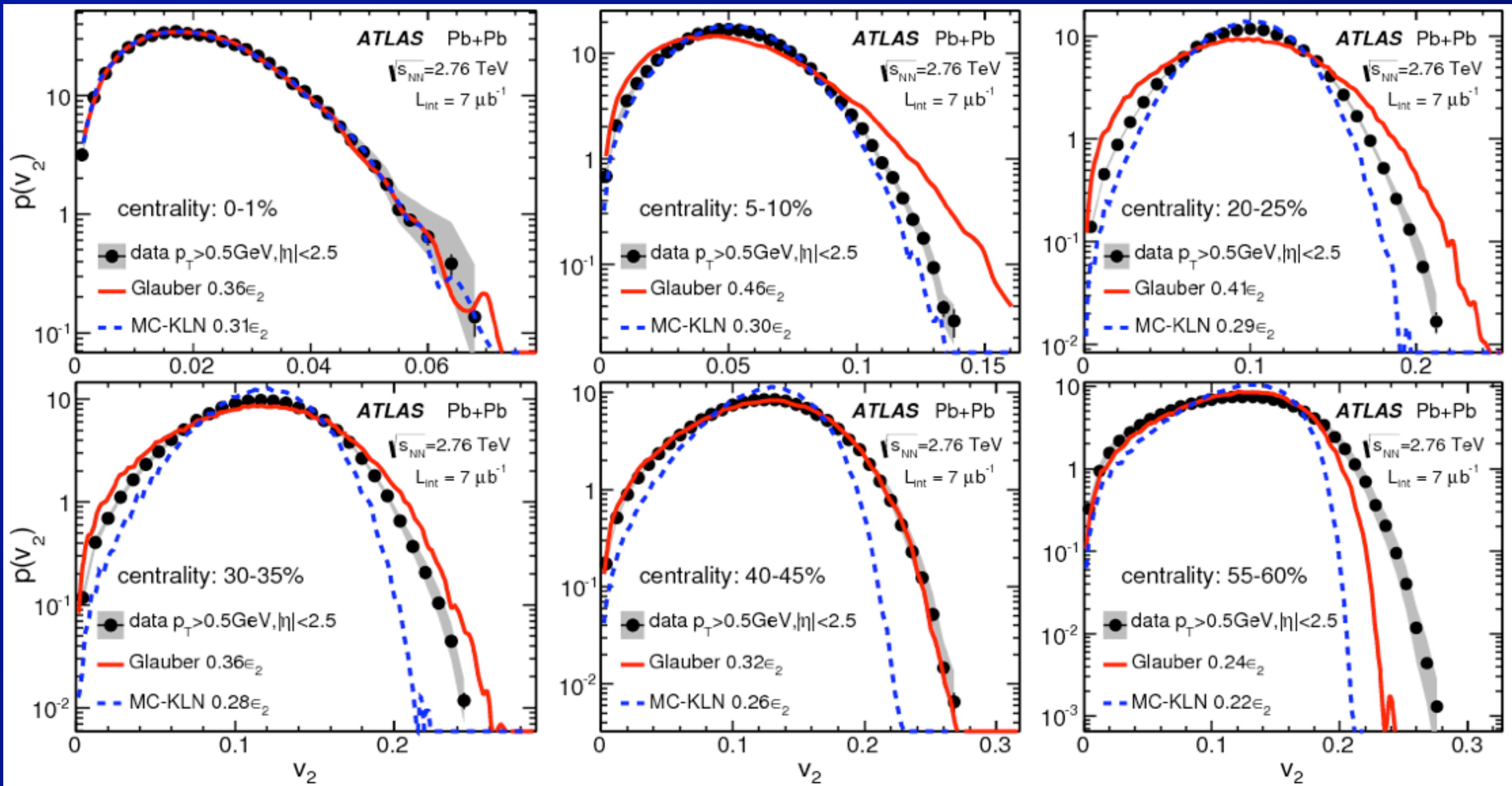
3 p_T ranges re-scale by mean



Event-by-event: moments



Event-by-event: model comparisons



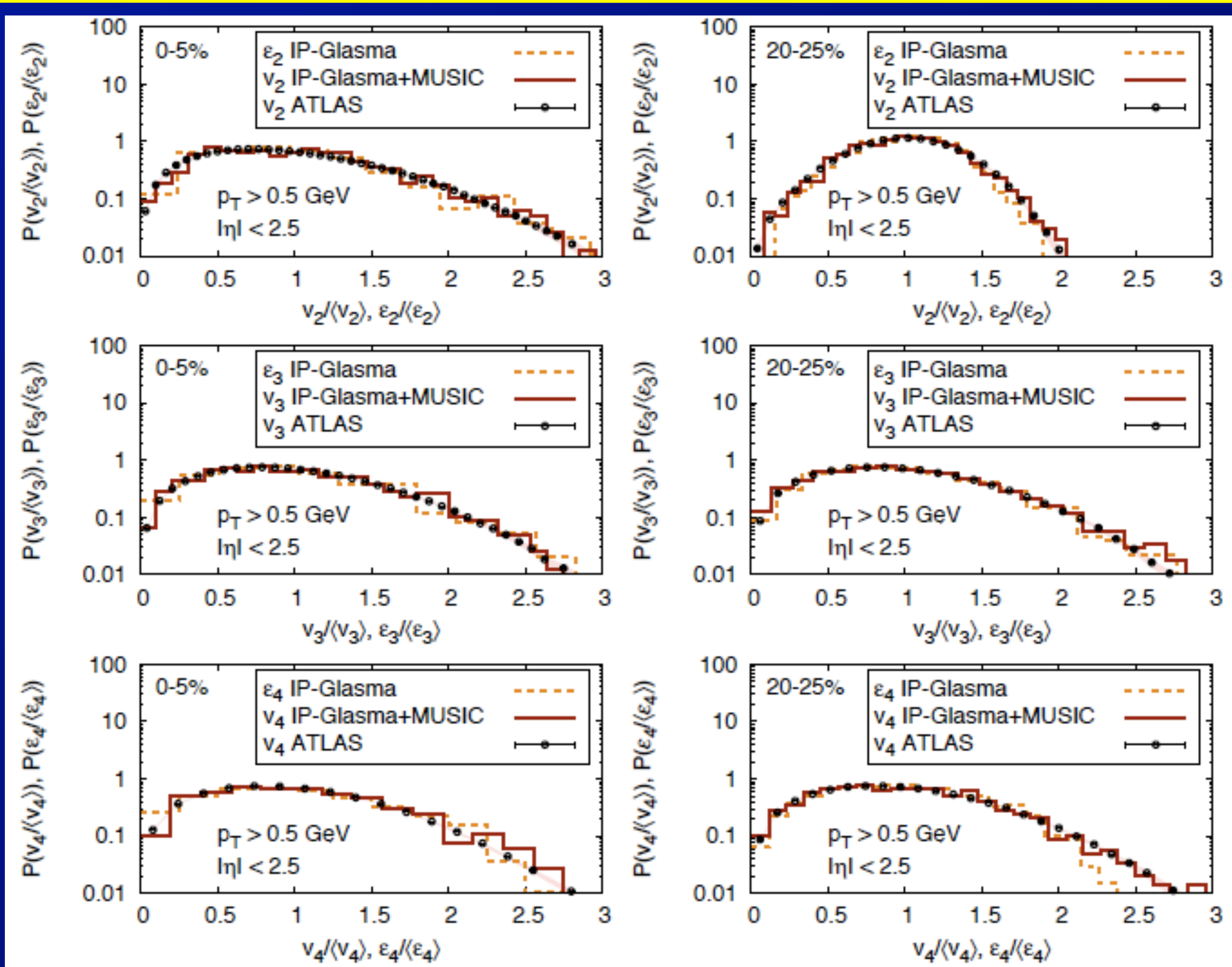
- For more central collisions (5-10%), data better described by MC-KLN (need better)
  - in more peripheral collisions, data better described by Glauber.

Event-by-event: hydro comparisons

MUSIC: Gale et al, arXiv: 1210.5144

Saturated initial conditions + viscous hydrodynamics

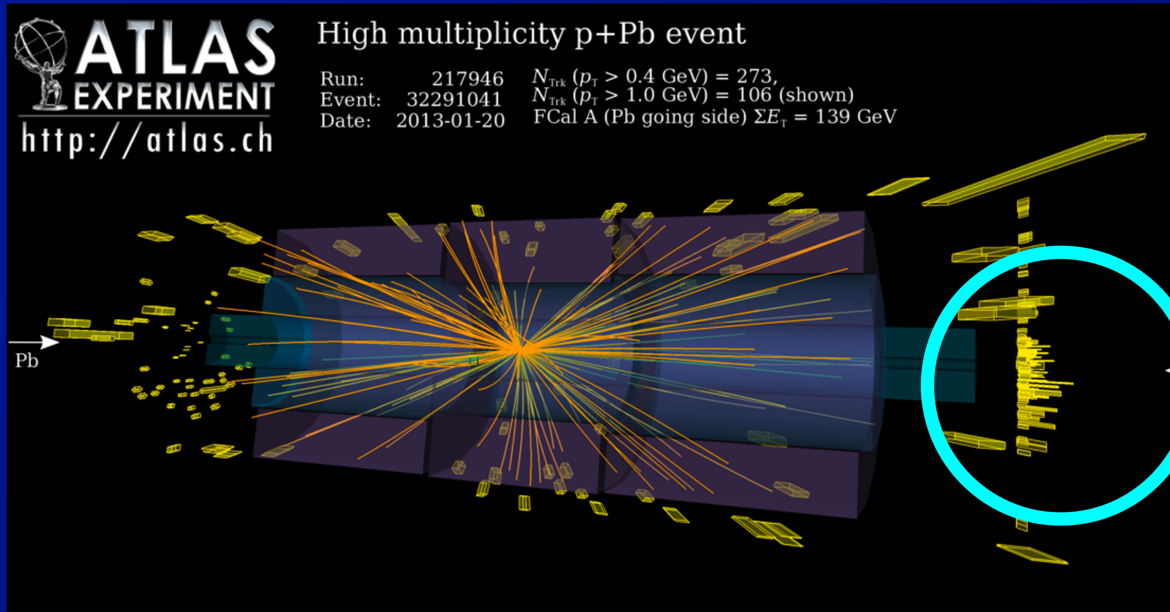
lattice + hadron gas equation of state



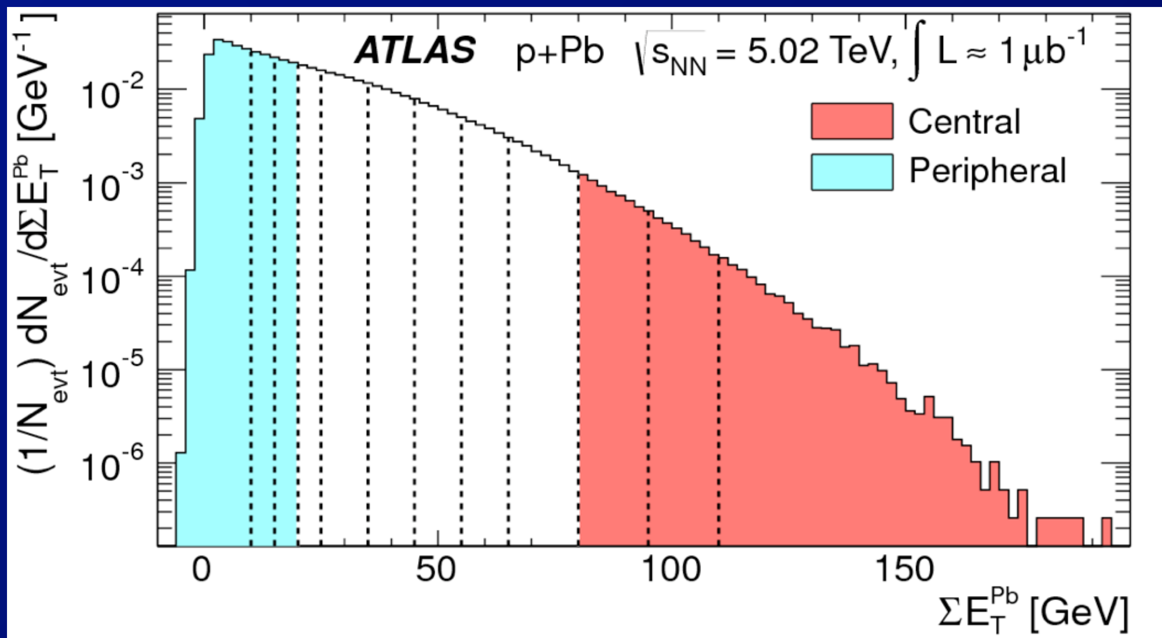
- (Implausibly?) good agreement with data

  $\Rightarrow$ Event-by-event v_n probing both initial state and hydrodynamic evolution (here $\eta/s = 0.2 \approx 2.5/4\pi$)

ATLAS p+Pb collisions

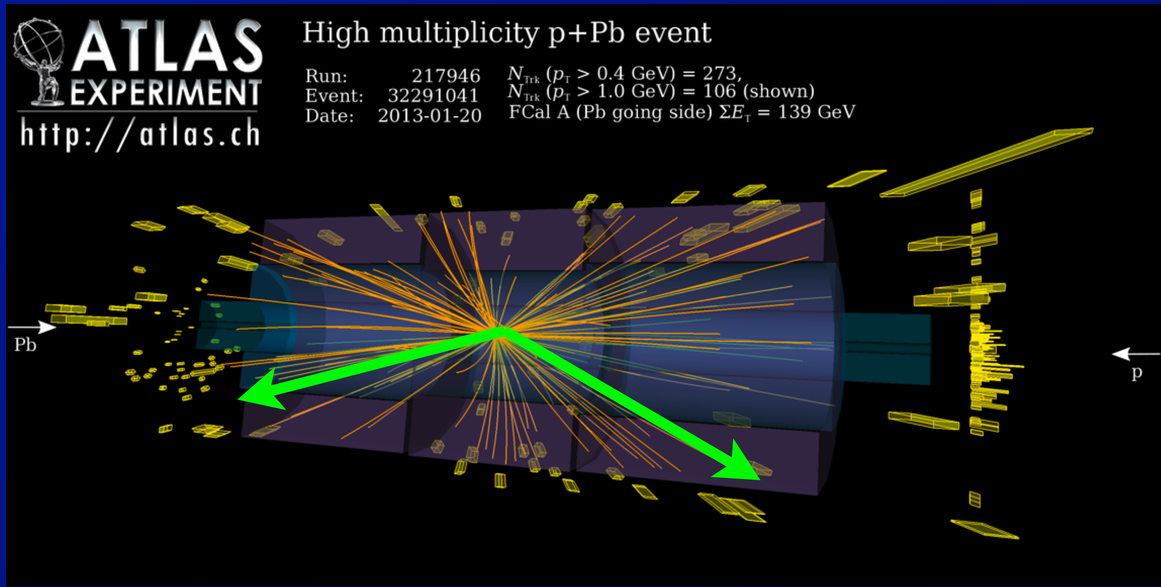


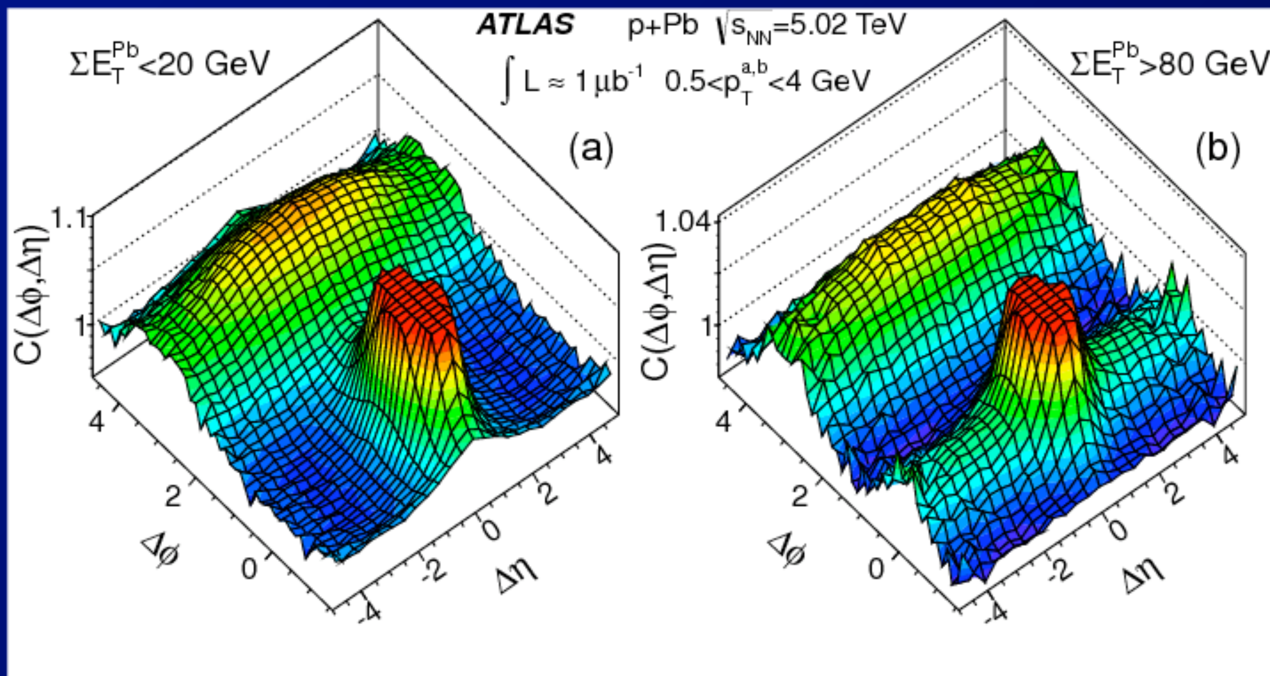
Characterize "multiplicity" or event activity using forward calorimeter on Pb-going side



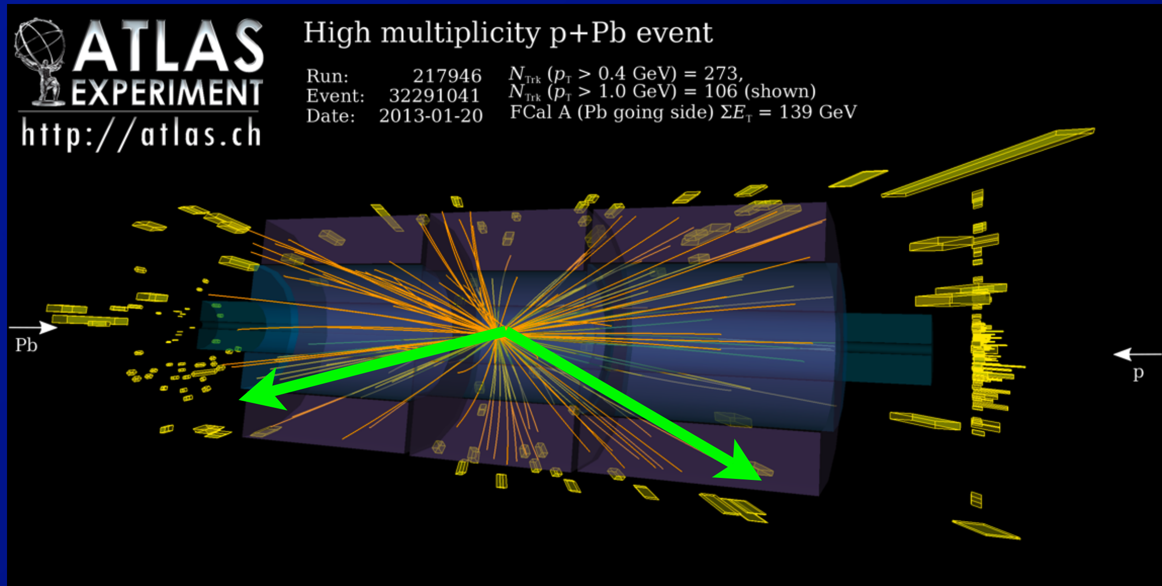
ATLAS p+Pb collisions

charged particles,
|η| < 2.5
0.5 < pT < 4 GeV





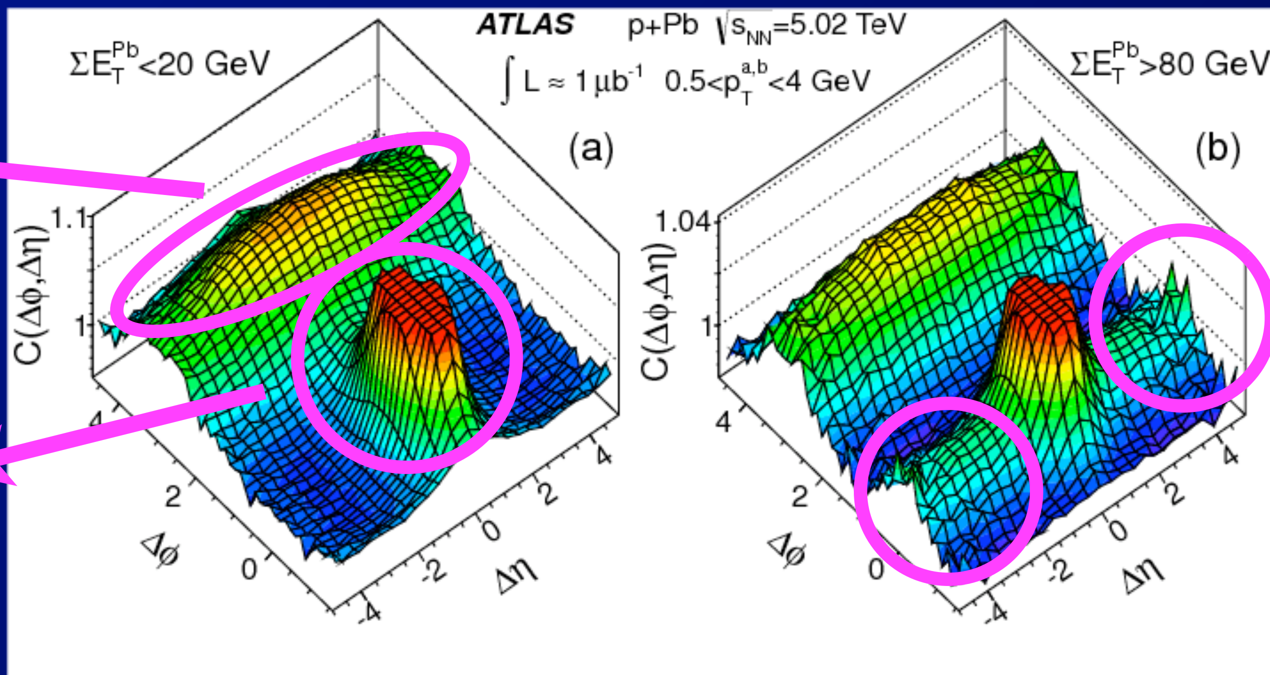
ATLAS p+Pb collisions



charged particles,
|η| < 2.5
0.5 < pT < 4 GeV

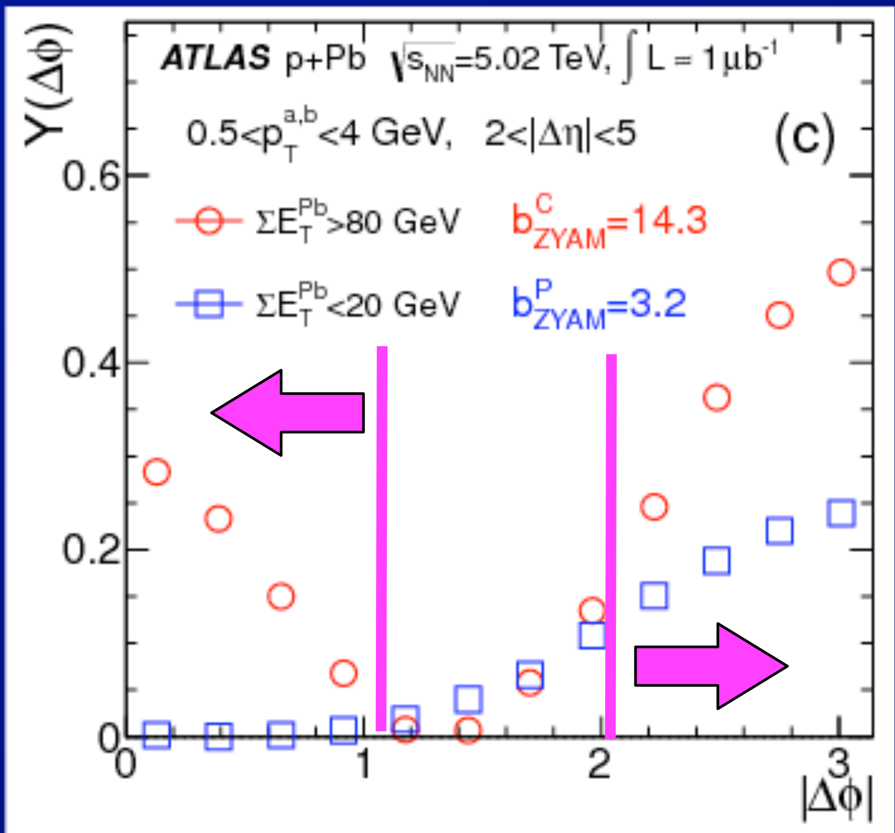
dijets, momentum conservation

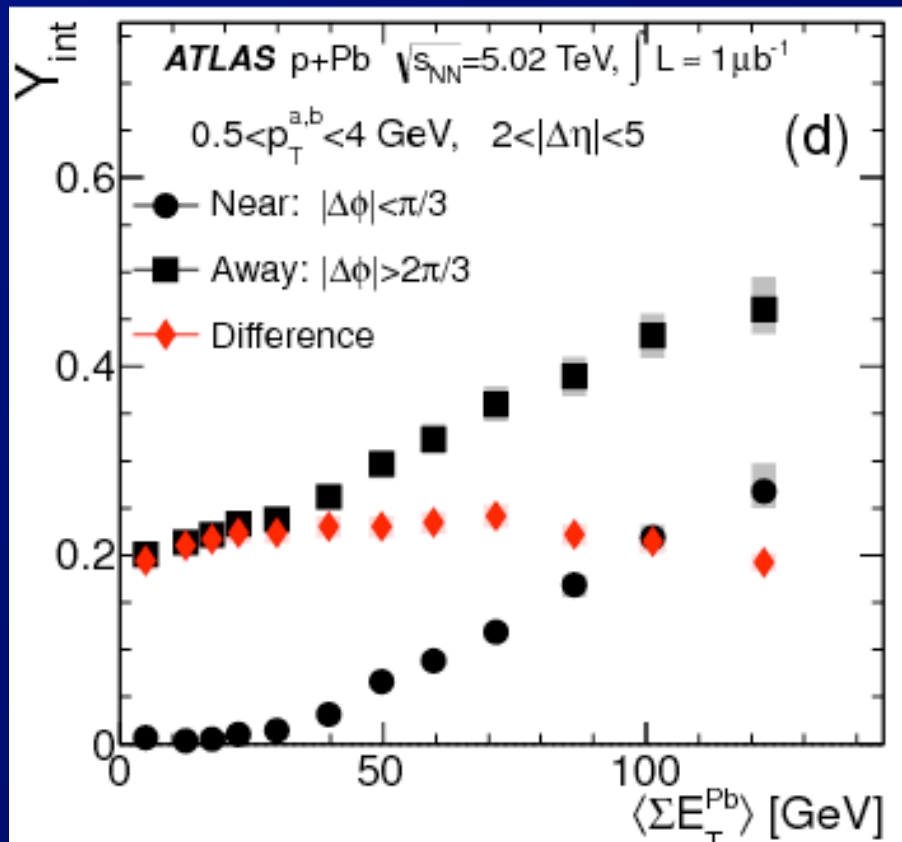
Jets/resonances



ATLAS 2-particle correlations (3)

- Per trigger yields Y(Δφ) integrated over η
  - peripheral and central
    - ⇒"Ridge" clearly present in central
    - ⇒Similar increase in the away side yield between peripheral, and central collisions

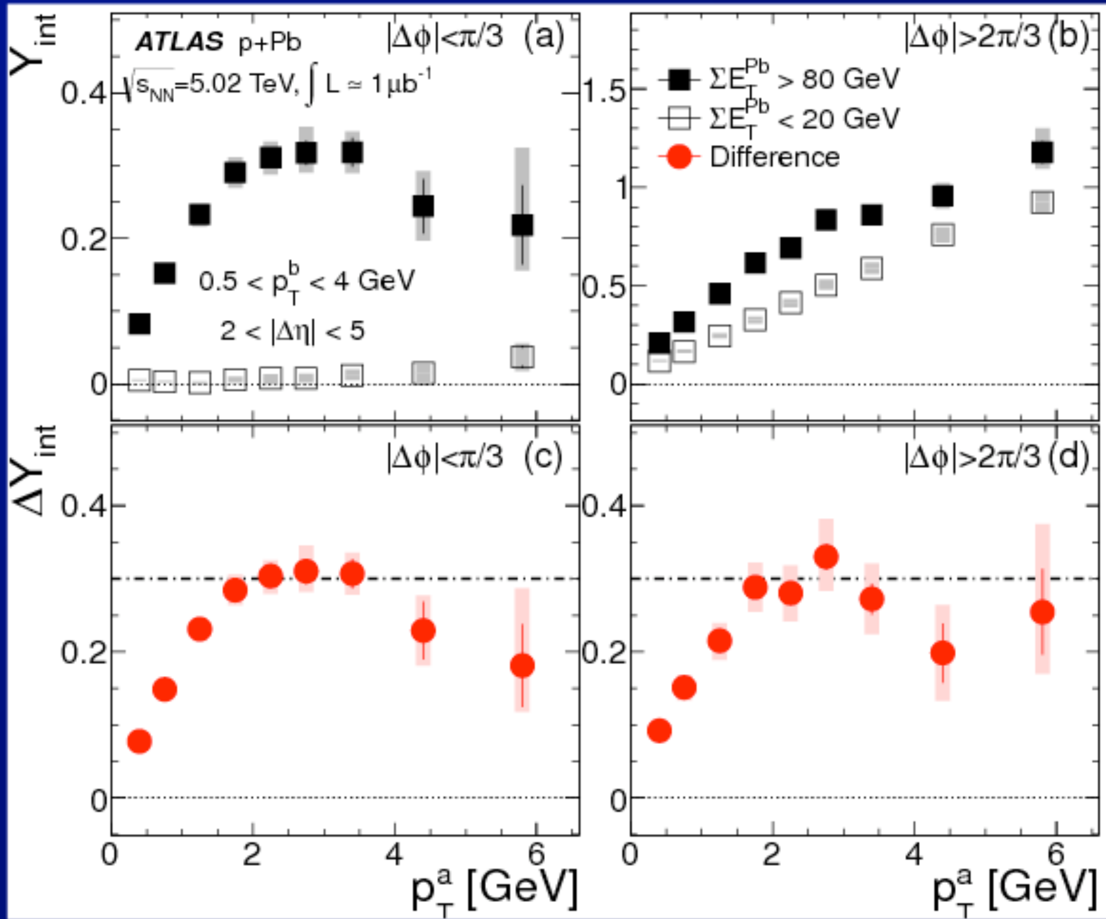




ATLAS 2-particle correlations (5)

- Study variation of integrated per-trigger yields with trigger p_T
  - For associated $0.5 < p_T < 4$ GeV
- Evaluate difference between peripheral and central
  - difference ≈ same on near and away sides, and similar p_T dependence

near away

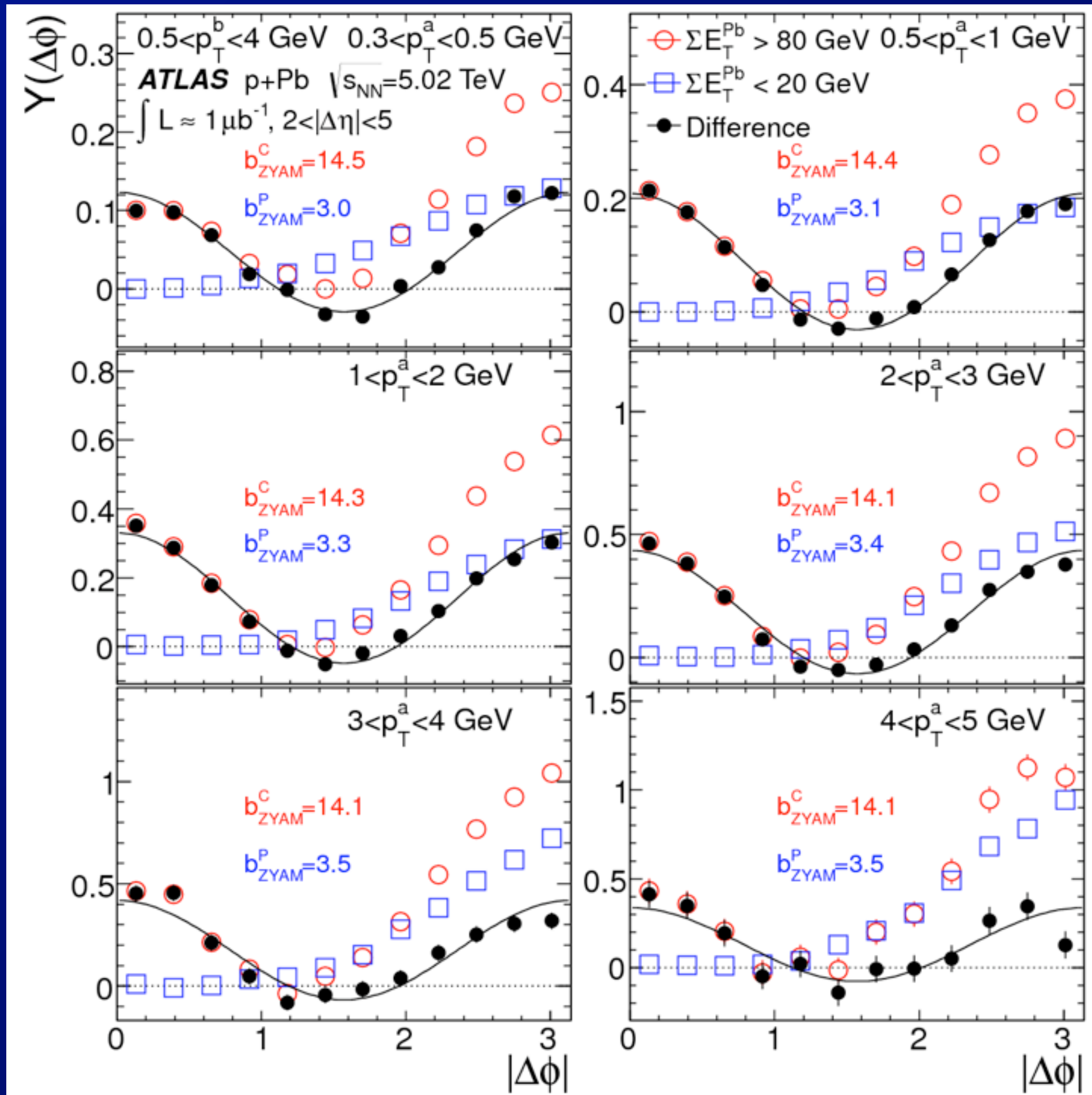


Beware different vertical scales on top panels

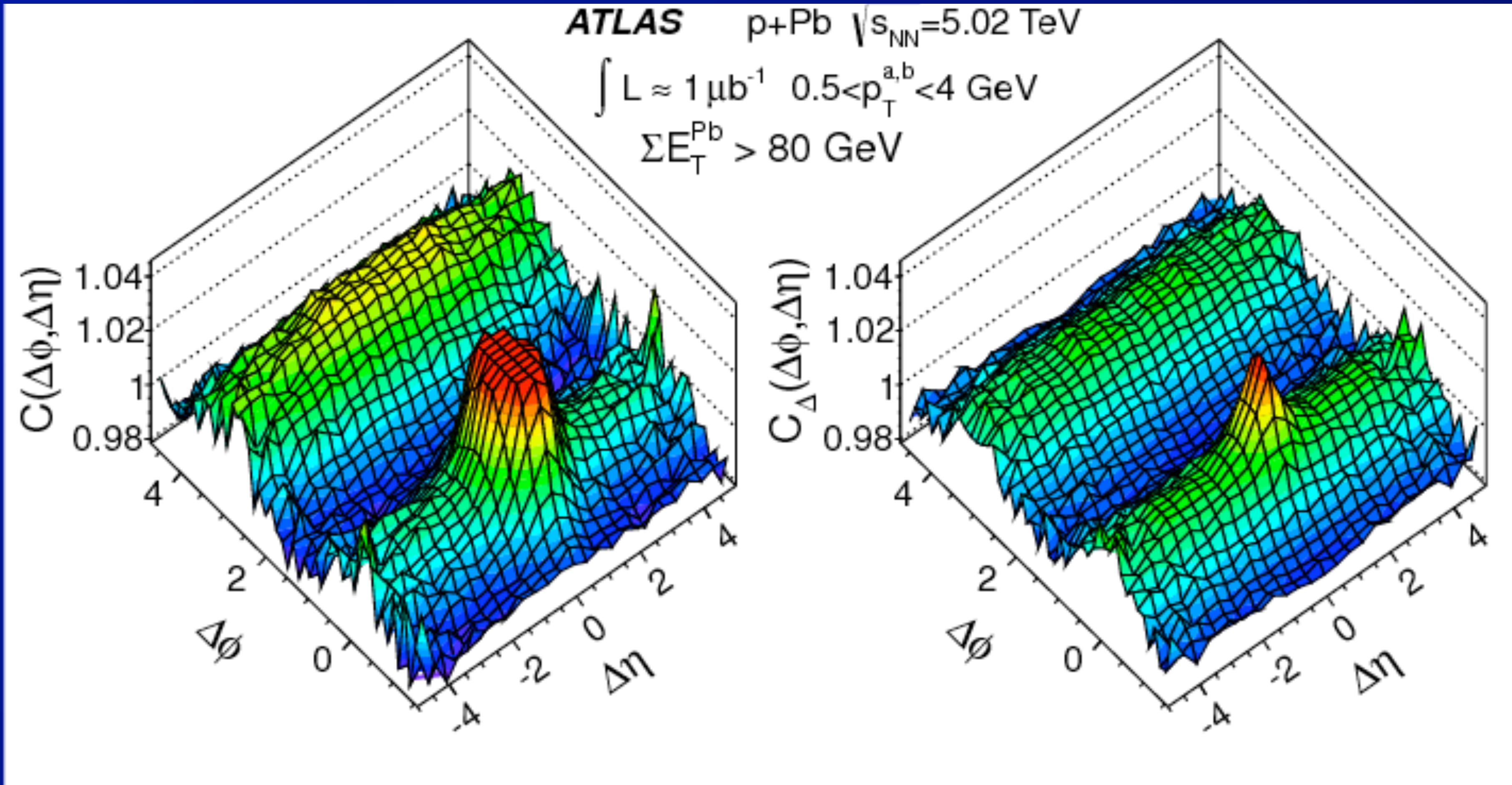
ATLAS 2-particle correlations (6)

- Motivated by above observations subtract peripheral Y(Δφ) from central Y(Δφ)
  - With associated $0.5 < p_T < 4$ GeV
  - In different trigger p_T bins

    ⇒ Observe an approximately symmetric modulation in all bins

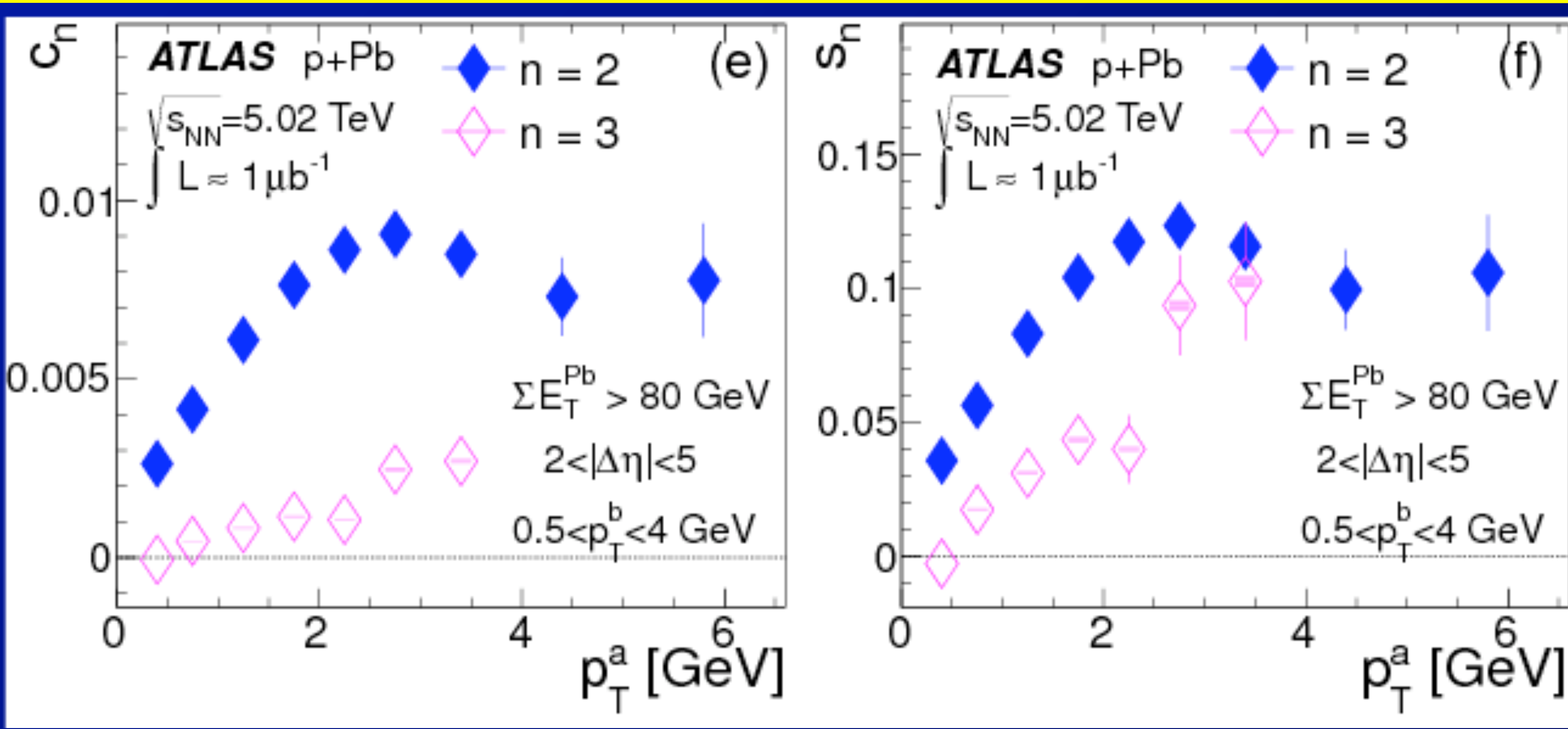


ATLAS 2-particle correlations (7)



- Central correlation function before and after subtraction of peripheral per-trigger yields, and converting back to C(Δφ,Δη)
  - ⇒Long-range modulation

Fourier decomposition

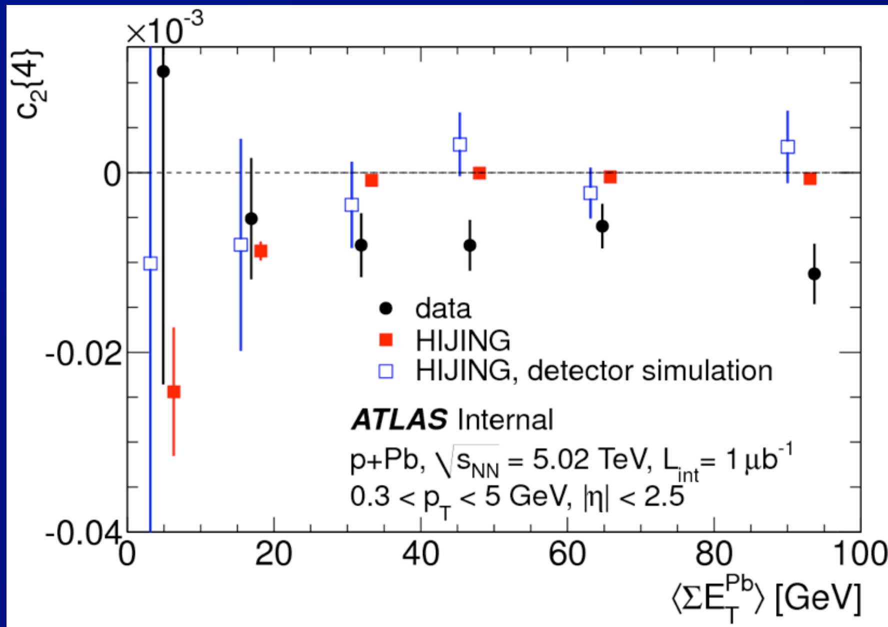


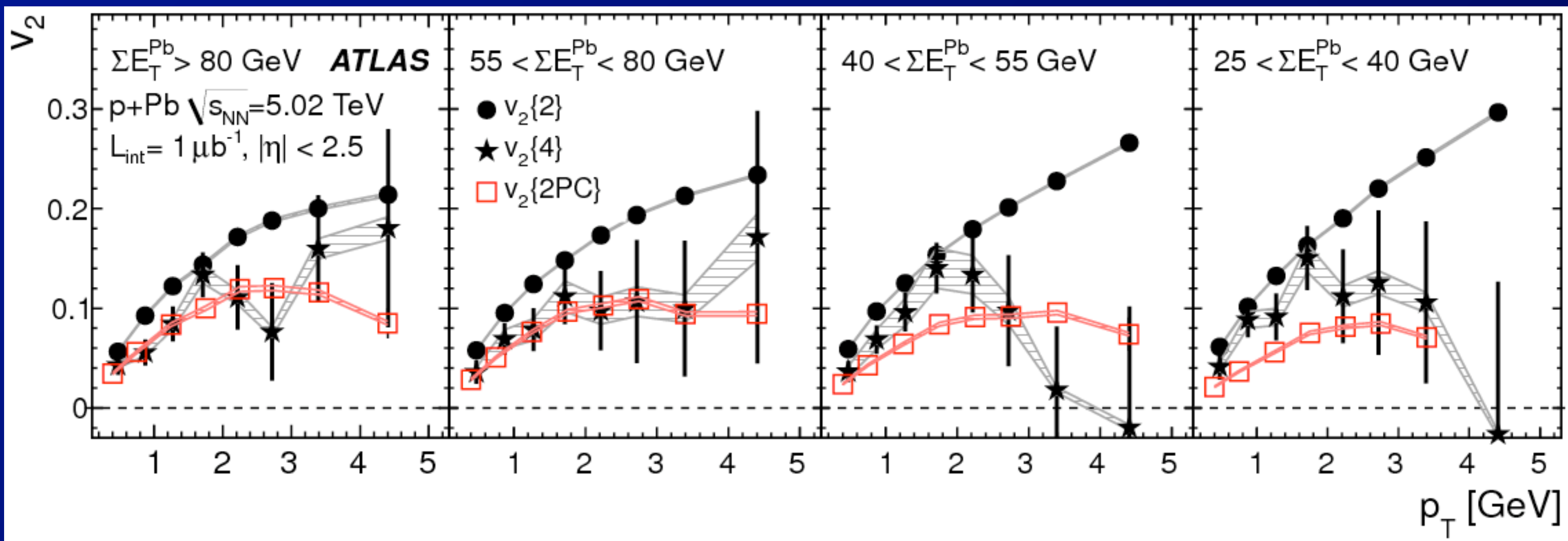
- **Extract Fourier coefficients for the pair distributions (c_2, c_3)**
  - analog of 2-particle $v_{2,2}$, $v_{3,3}$
- **Assume factorization** $c_2(p_T^a, p_T^b) = s_2(p_T^a)\, s_2(p_T^b)$
  - checked

  ⇒To obtain s_2, s_3 → if flow, v_2, v_3

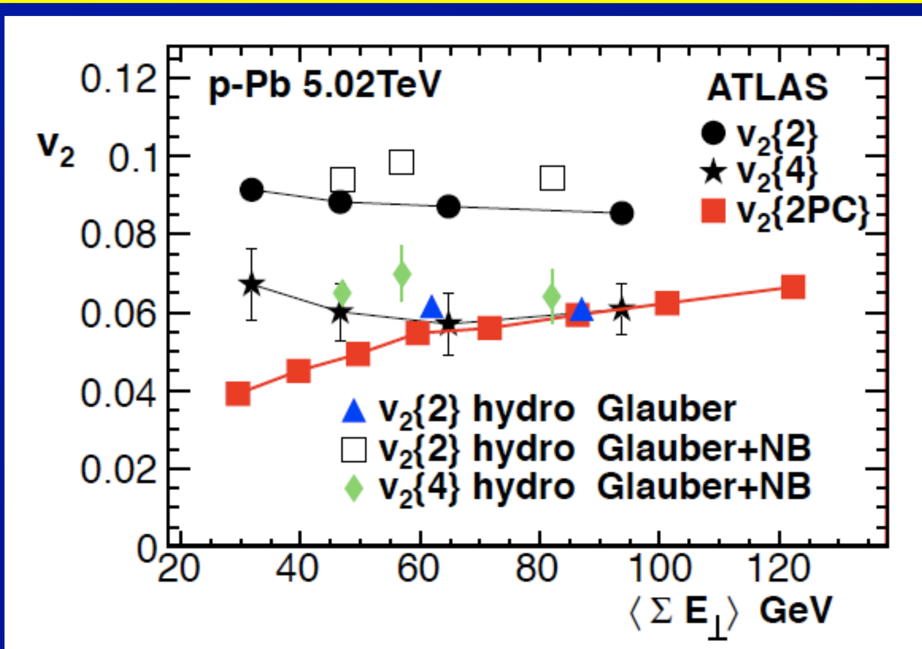
p+Pb 4-particle cumulants

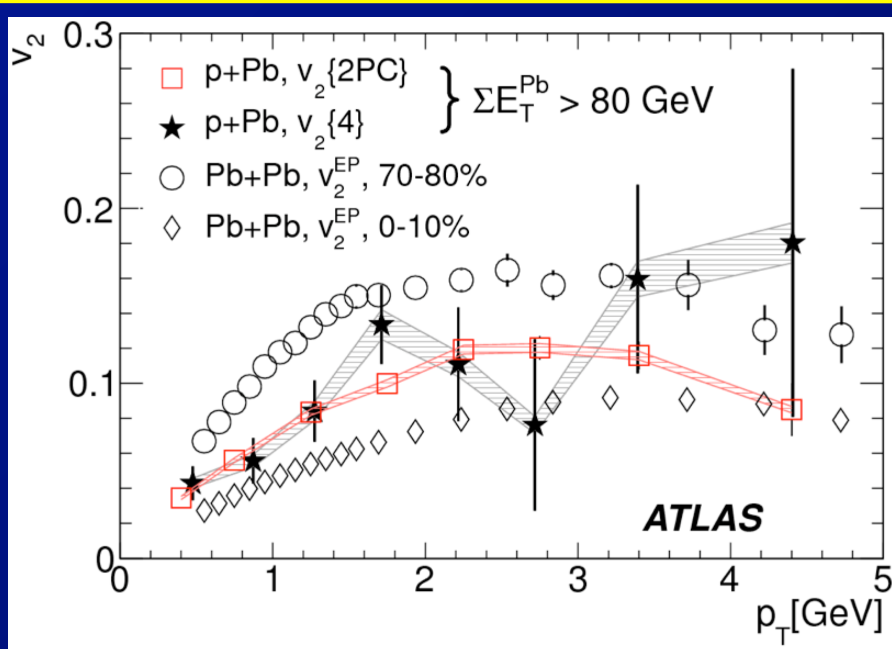
- pilot run 4-particle cumulant analysis
  - Negative $c_2\{4\}$ indicates "global" correlation
    ⇒flow
  - Similar v_2 values for 4-particle cumulants, 2-particle correlations





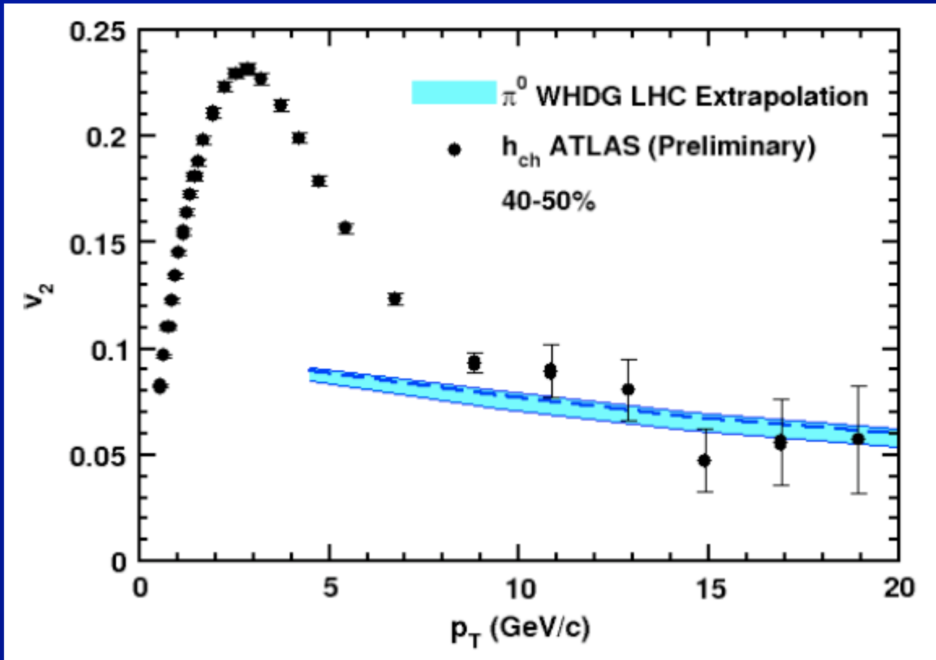
4-particle v_2, comparison to Pb+Pb

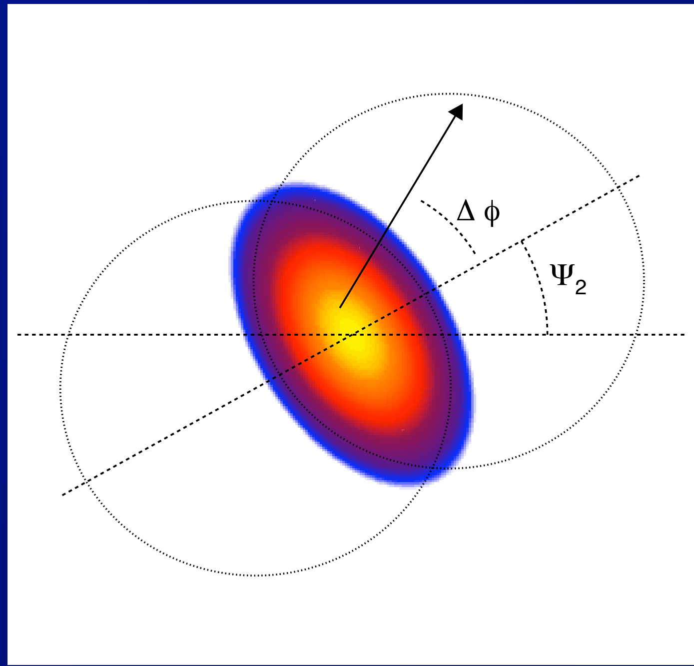




- v_2 varies only slowly with p+Pb multiplicity/event activity/centrality
  - ⇒ridges are larger in central p+Pb due to the larger multiplicity of the events
- p_T dependence of v_2 similar to that observed in Pb+Pb collisions
- Hydrodynamics (unrealistic?) can reproduce data
  - ⇒But understanding the initial state is crucial

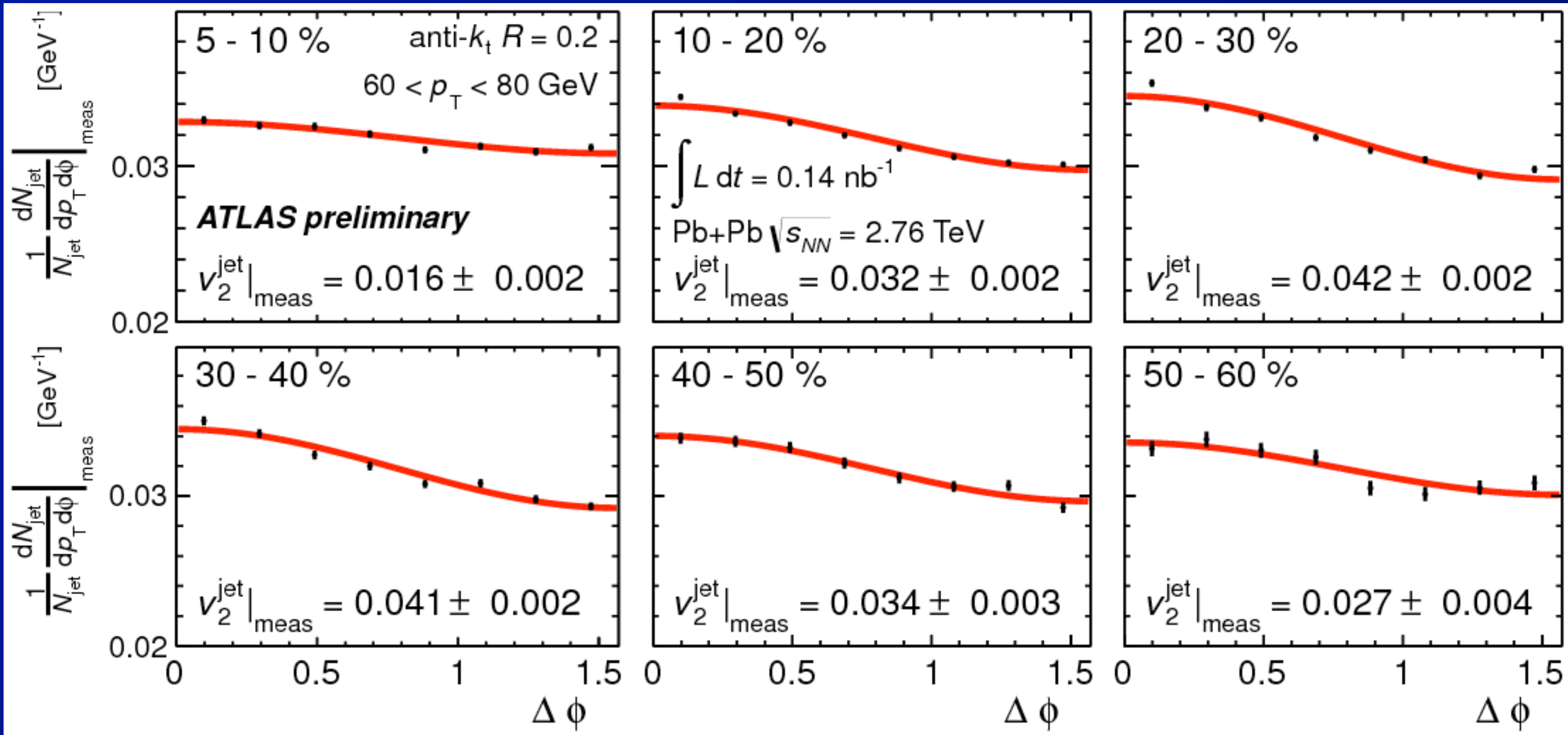
ATLAS: Charged particle $v_2(p_T)$



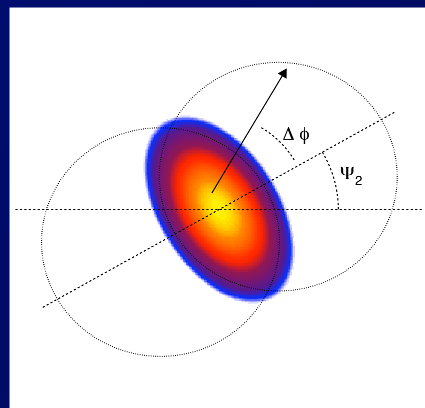


- Evolution from flow at low p_T to differential jet quenching at higher p_T
  - WHDG energy loss describes $v_2(p_T)$ for p_T > 10
  - Flow/other dominates for p_T <~ 8 GeV?

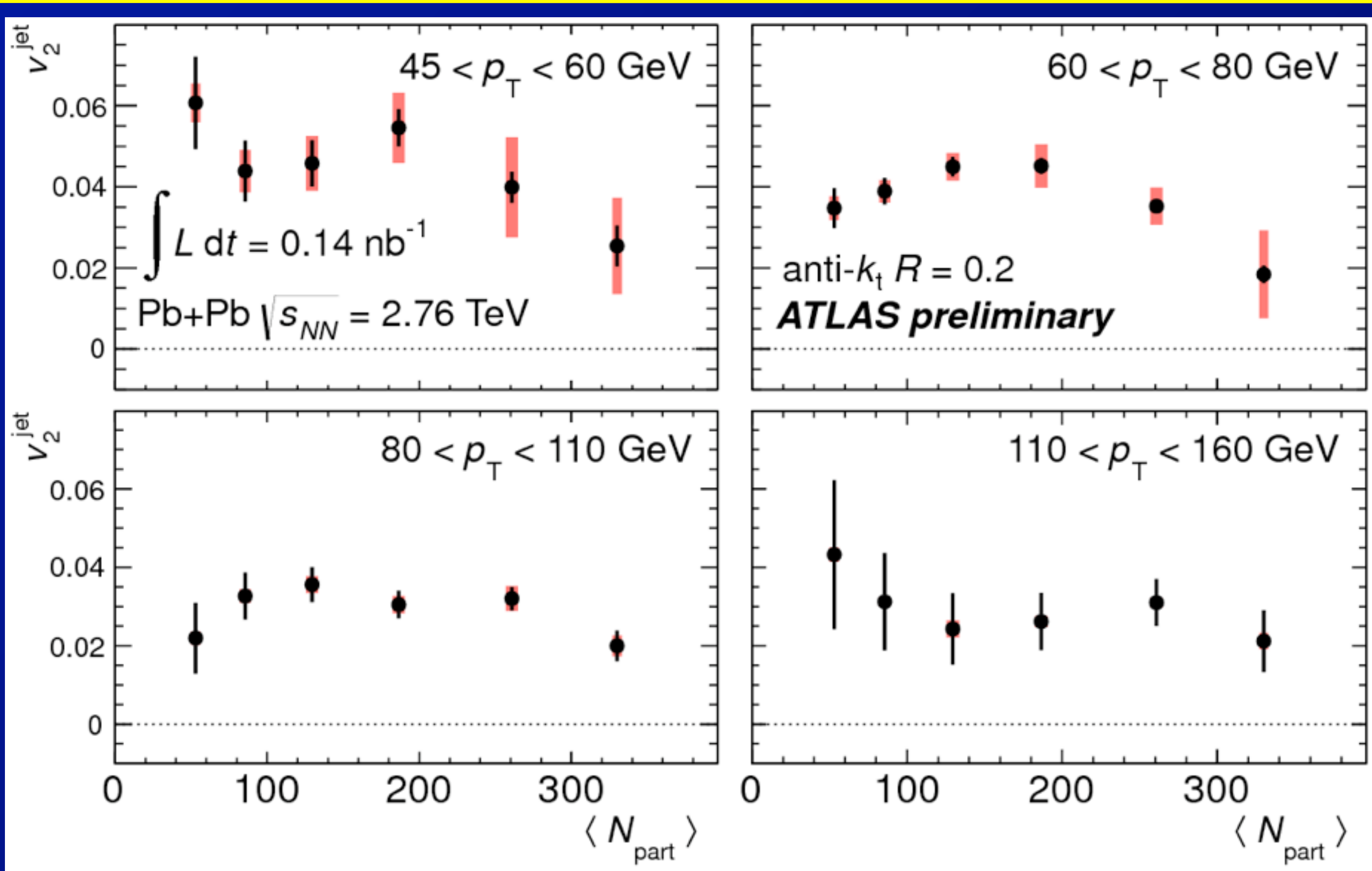
Differential jet suppression



- **Measure jet yields in 8 bins of Δϕ with respect to the elliptic event plane**
  - Here for R = 0.2 jets, 60 < p_T < 80 GeV
    - ⇒UE subtraction corrected for elliptic flow modulation in calorimeter

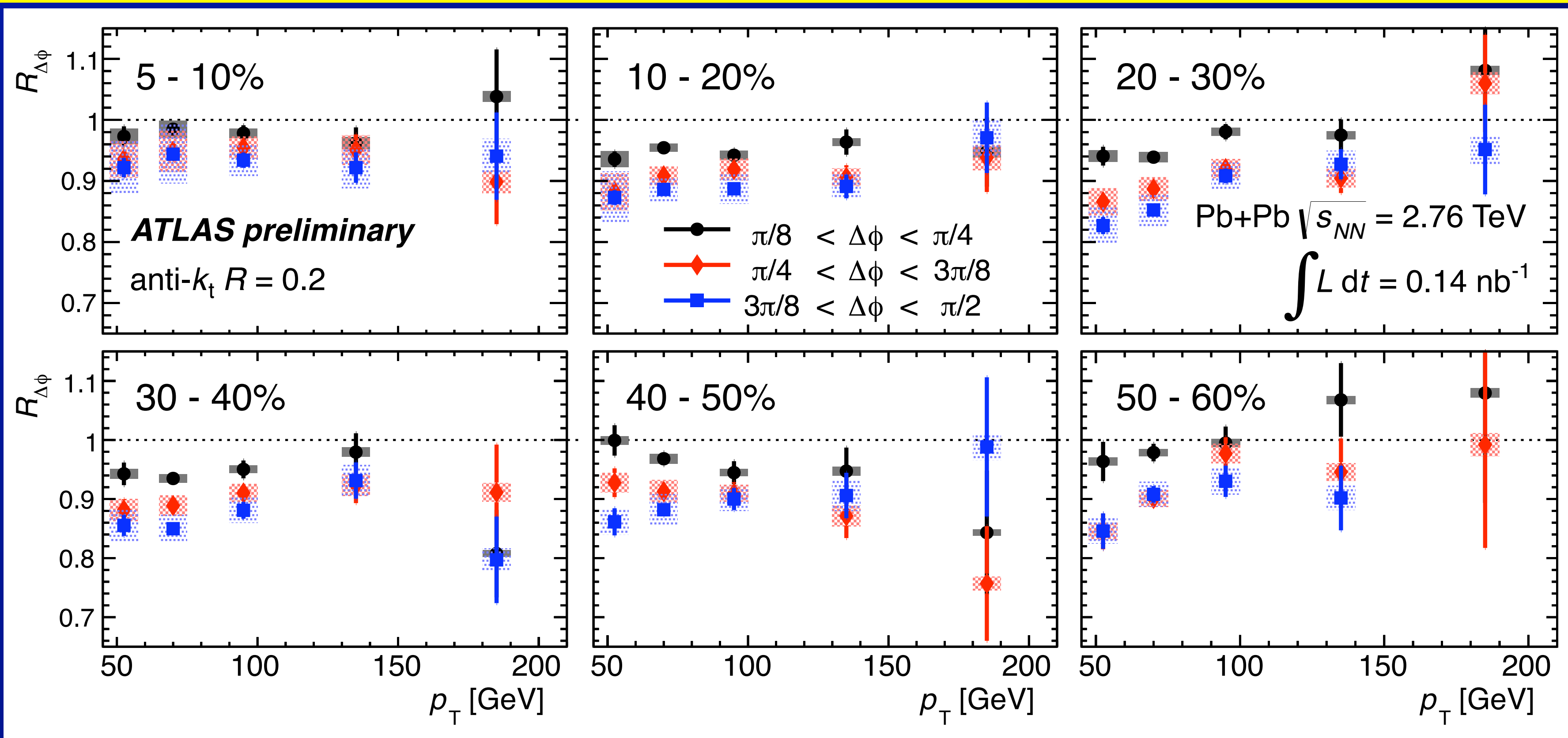


Differential jet suppression



- Observe non-zero jet v_2 for (R = 0.2) p_T values > 100 GeV
  - ⇒jet quenching clearly sensitive to initial geometry out to very high p_T

Differential jet suppression



- Evaluate ratio of jet yields in different Δφ bins to the yield in 0 < Δφ < π/8.
  - $R_{AA}(\Delta\phi)/R_{AA}(0\text{-}\pi/8)$

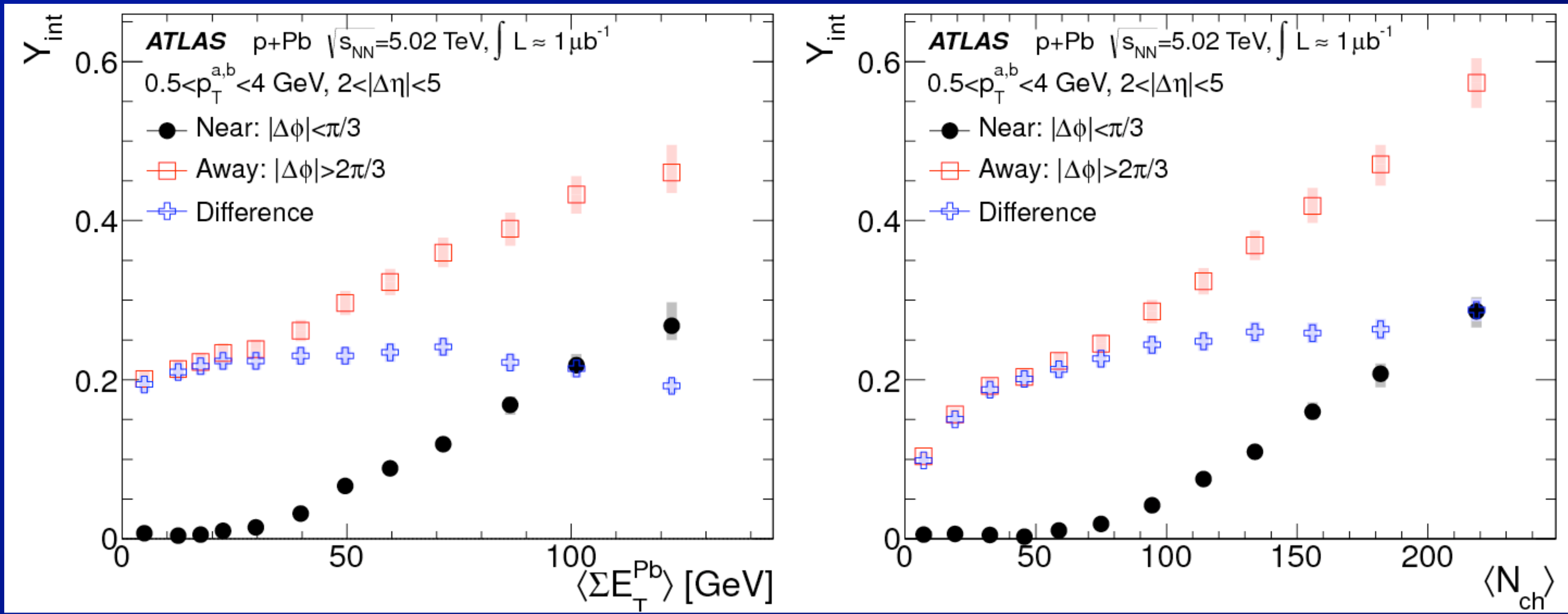
    ⇒ ~15% change in single jet suppression between in-plane, out-of-plane @ high p_T

Putting it all together

- In Pb+Pb collisions, initial state fluctuations survive and are imprinted on particle $dN/d\phi$
  - Sensitive to physics of initial particle production, thermalization(?), hydrodynamic expansion.
- In p+Pb collisions, data suggest behavior consistent with that observed in Pb+Pb
  - final-state collectivity
    - ⇒as preposterous as that seems
  - Any collectivity in p+Pb highly sensitive to initial particle production, thermalization, ….
- In Pb+Pb collisions, we can probe gross features of initial geometry with jets
  - what is the impact of initial state energy density fluctuations on jet quenching in Pb+Pb (p+Pb?)

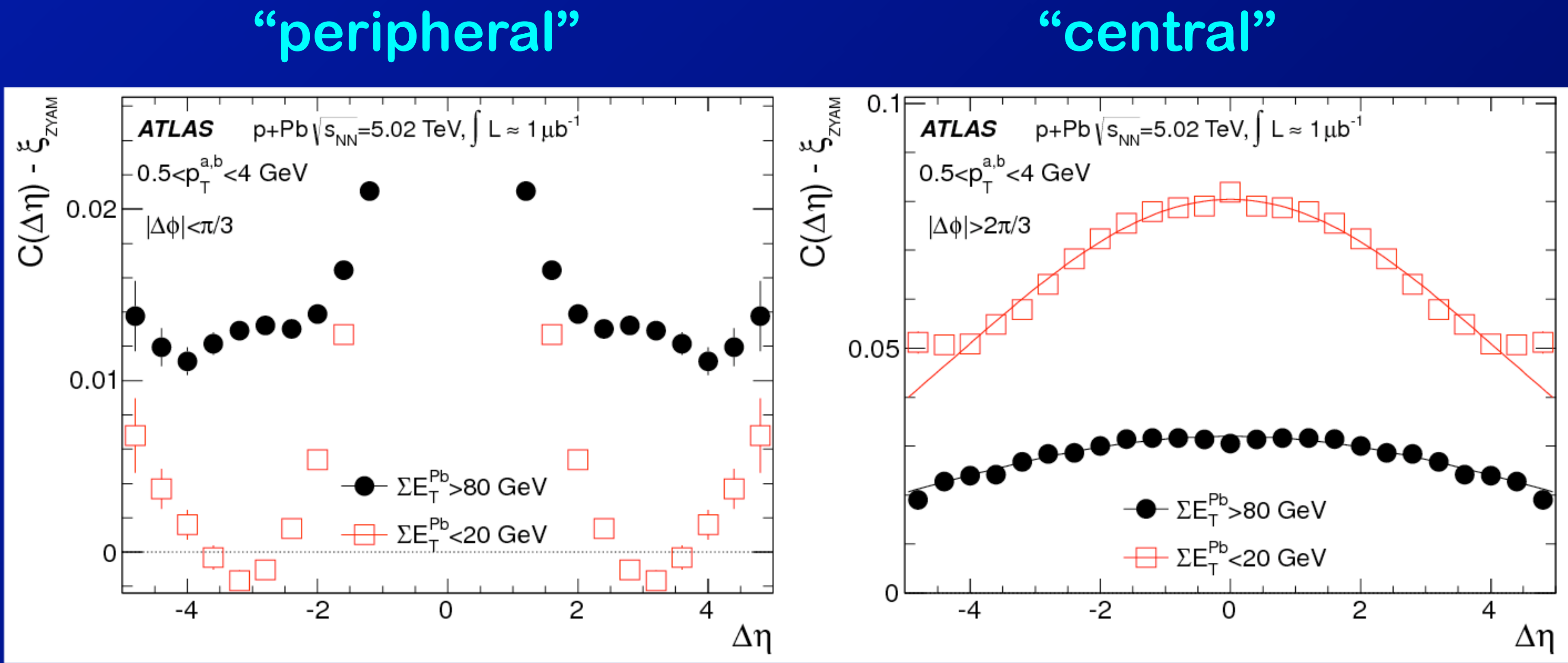
backup

Why E_T not N_{ch} for "centrality" ?



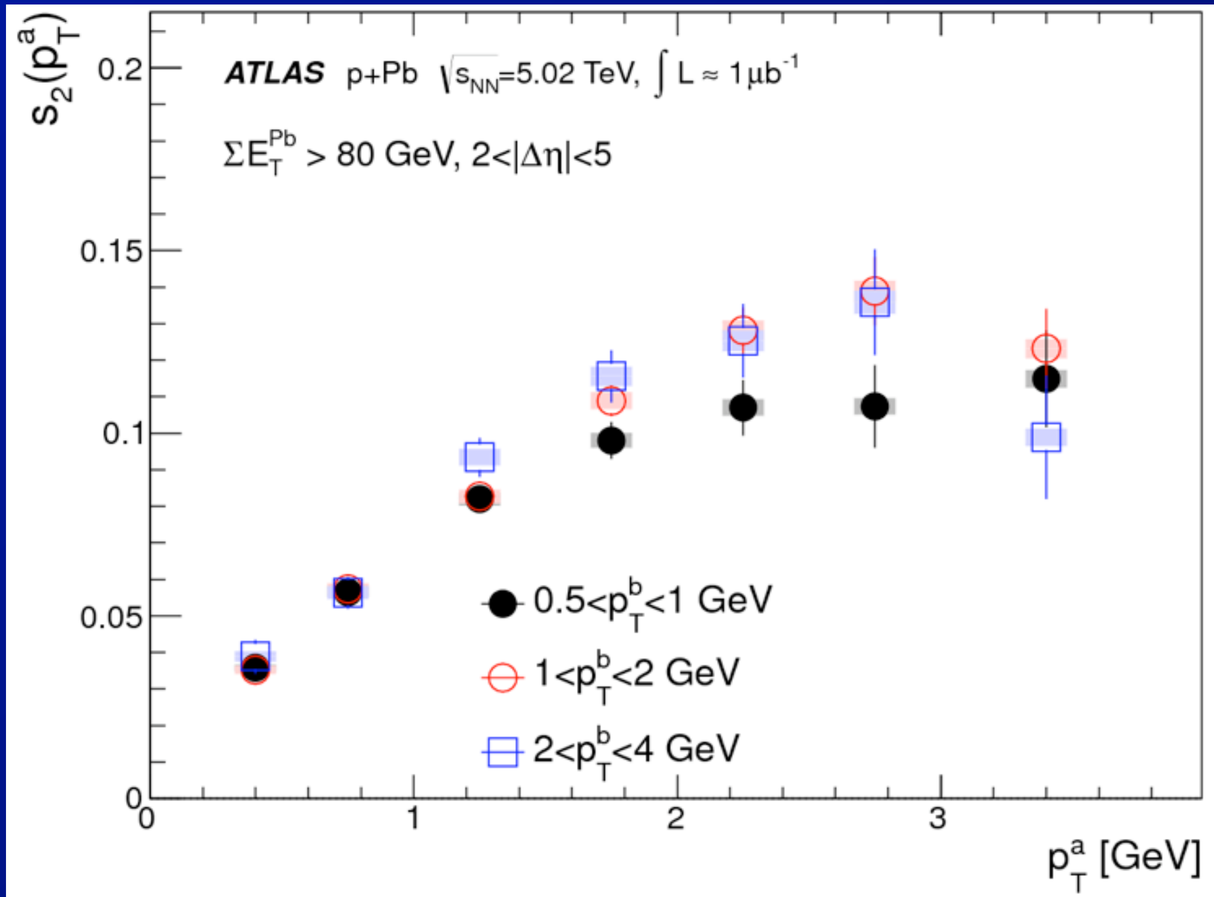
- There is an auto-correlation between N_{ch} and the number of particles & pairs
  - ⇒Distorts the per-trigger yields from the "recoil" contribution at low N_{ch}
  - ⇒Why the different behavior of away-near difference at large N_{ch} / ΣE_T?

ATLAS 2-particle correlations (2)



- To better see Δη dependence, project ZYAM-subtracted correlation function.
  - For near (Δφ<π/3) and away (Δφ>2π/3) sides.
    - ⇒In central collisions see ridge and broadening of away-side component relative to peripheral collisions.

Test factorization



- If factorization holds, should obtain same s2 values for different associated p_T
  - ⇒true for $p_T < 1$ GeV
  - ⇒start to see deviations at higher p_T

ATLAS 2-particle correlations (7)

- Subtracted correlation functions for 2 other centrality bins.