Recent results on flow and correlations from the ATLAS experiment

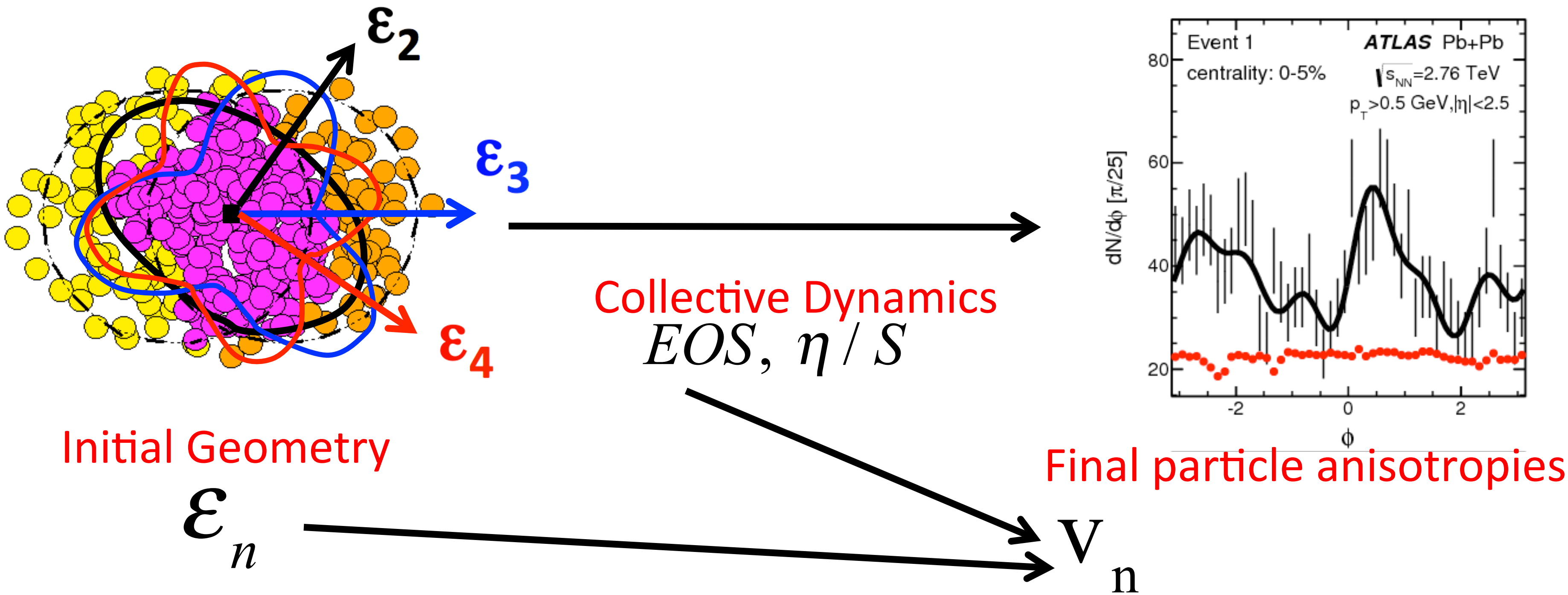
Soumya Mohapatra
Columbia University

- ATLAS Event-by-Event v_n paper: JHEP11(2013)183
- ATLAS Event-Plane correlation paper: Phys. Rev. C 90, 024905 (2014)
- ATLAS flow correlation ConfNote: ATLAS-CONF-2014-022

The 2nd International Conference on the Initial Stages in High-Energy Nuclear Collisions
3-7 December 2014

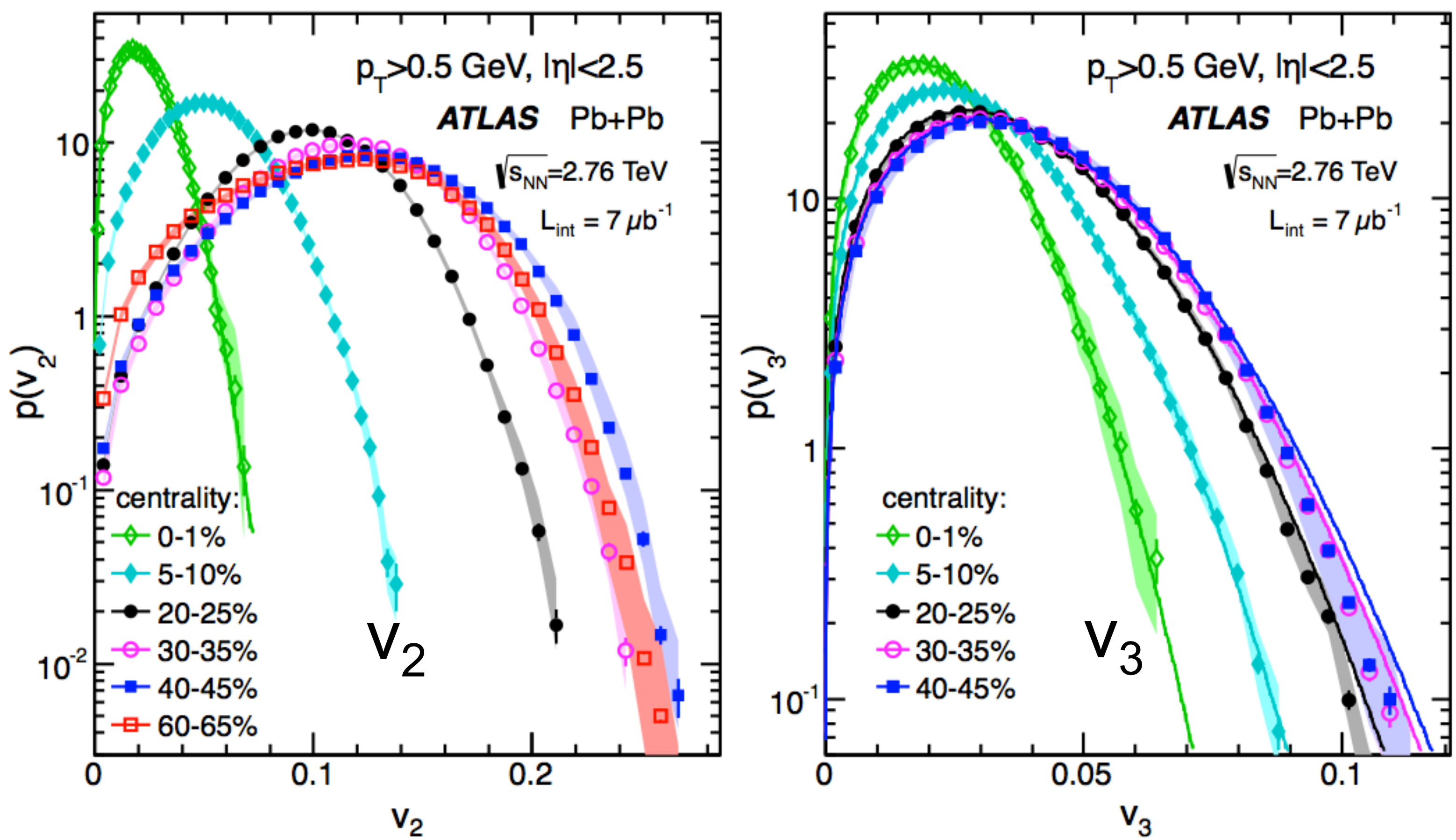
Introduction

- Initial spatial fluctuations of nucleons lead to higher moments of deformations in the fireball, each with its own orientation.
- The spatial anisotropy is transferred to momentum space by collective flow.



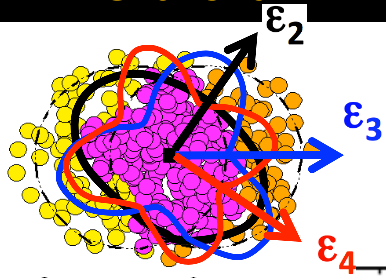
- The harmonics v_n carry information about the medium: initial geometry, η/s.
- Measuring harmonics = Understanding initial geometry & medium properties

v_2-v_3 probability distributions



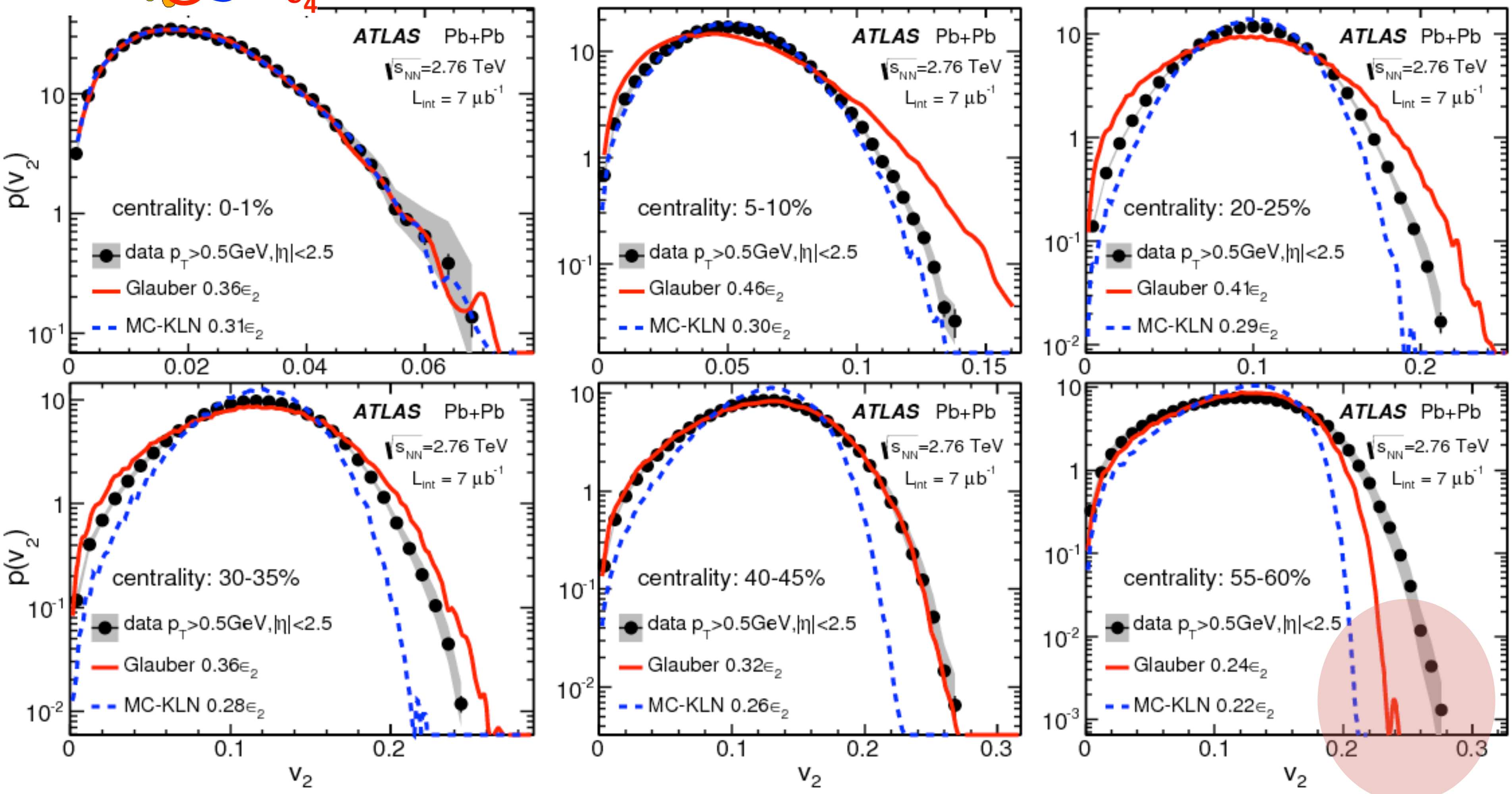
Event-by-Event Probability distributions

Measuring the hydrodynamic response: v_2



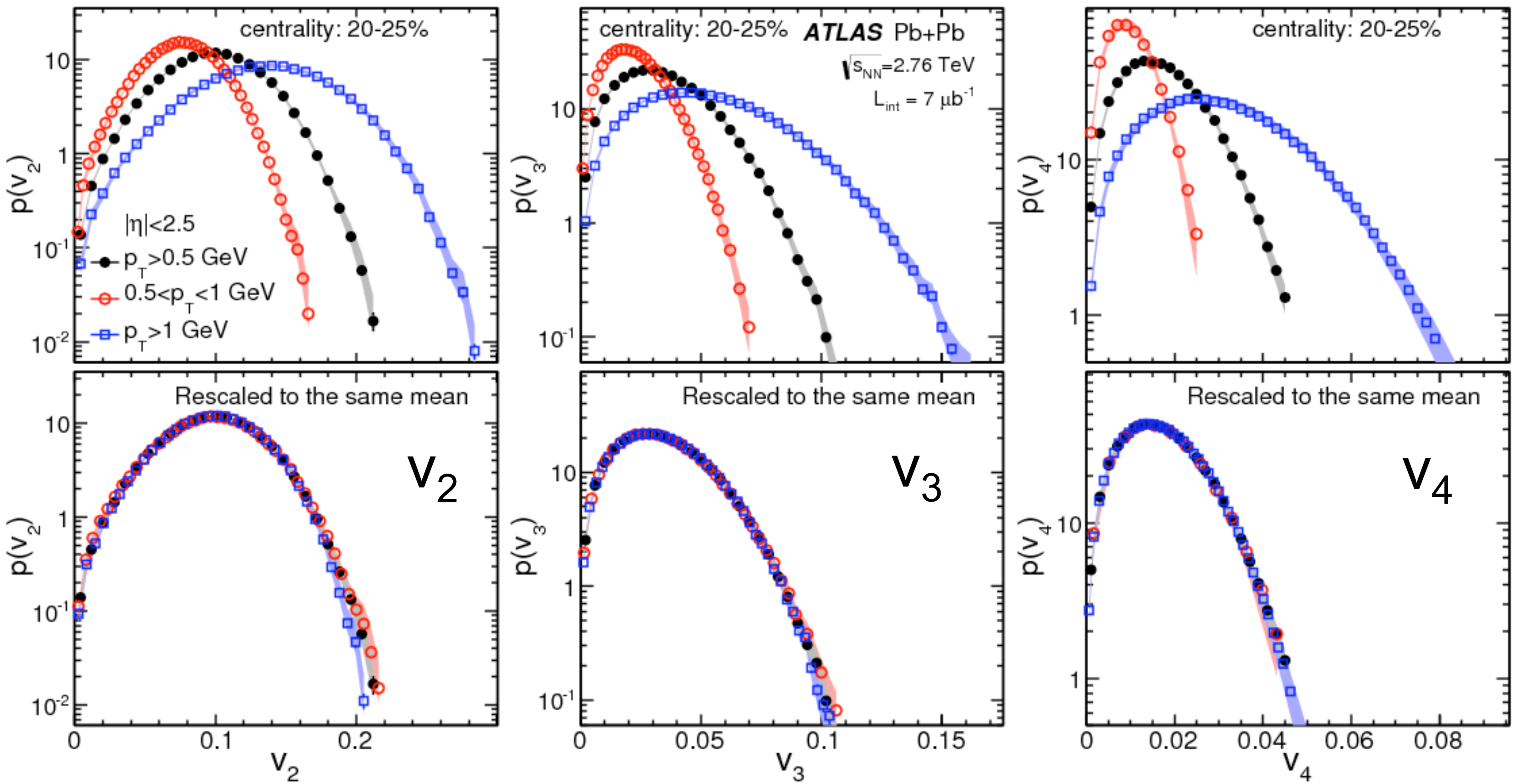
$$v_n \propto \epsilon_n = \frac{\sqrt{\langle r^n \cos n\phi\rangle^2 + \langle r^n \sin n\phi\rangle^2}}{\langle r^n\rangle}$$

For Glauber and CGC mckln



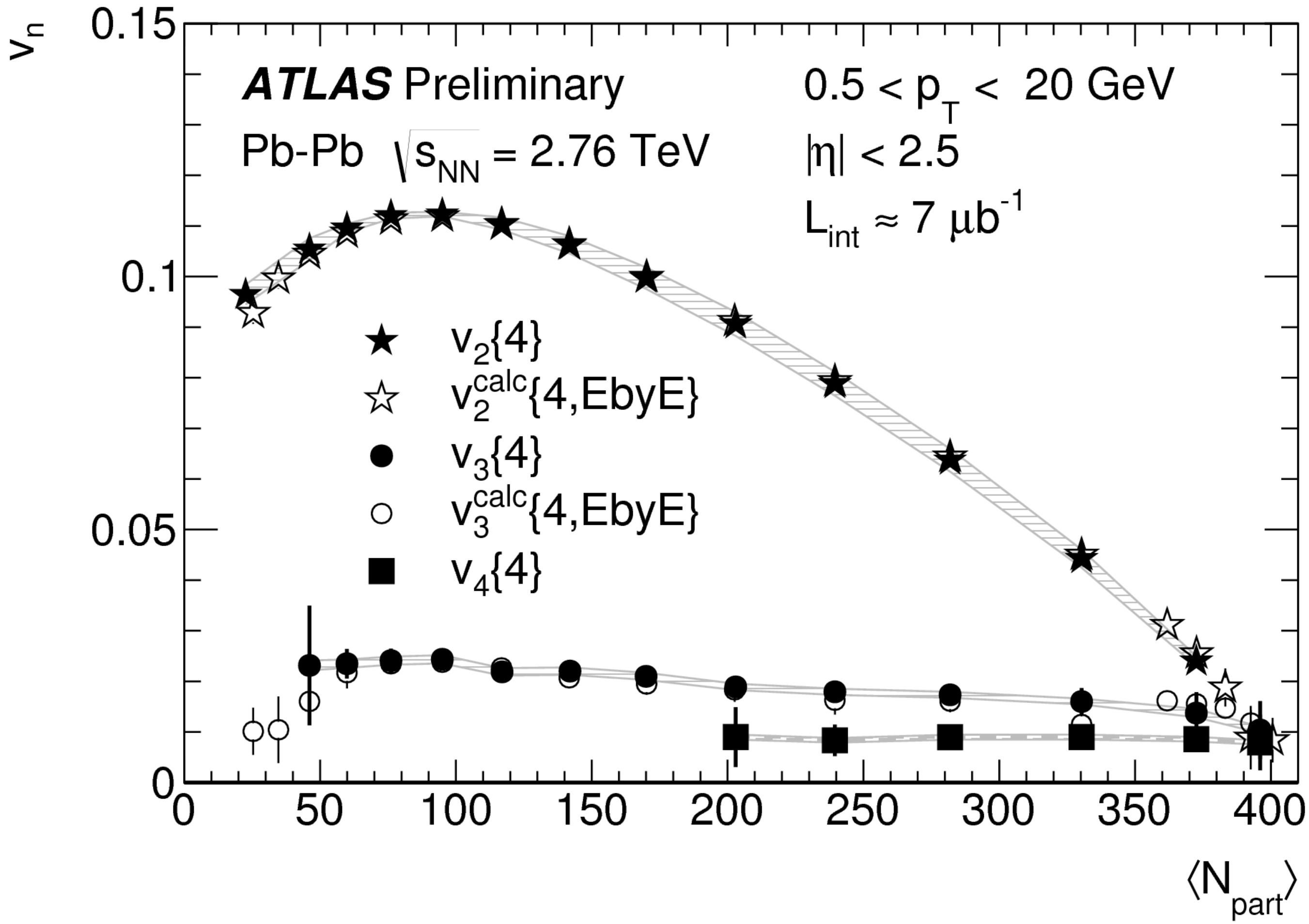
Both models fail describing $p(v_2)$ across the full centrality range

Unfolding in different p_T ranges: 20-25%



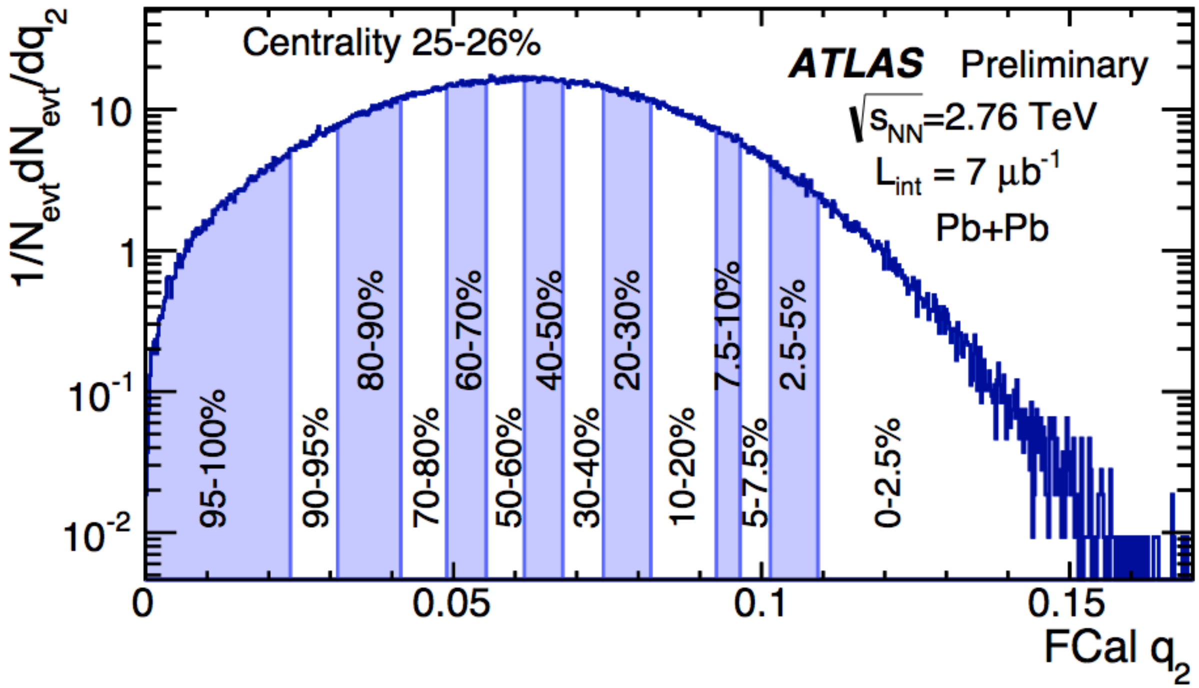
Distributions for higher p_T bin is broader, but they all have ~same reduced shape. Hydrodynamic response factorizes into a p_T dependent and geometry dependent part.

Cumulant measurements



Can directly calculate cumulants from EbyE v_n measurements and compare

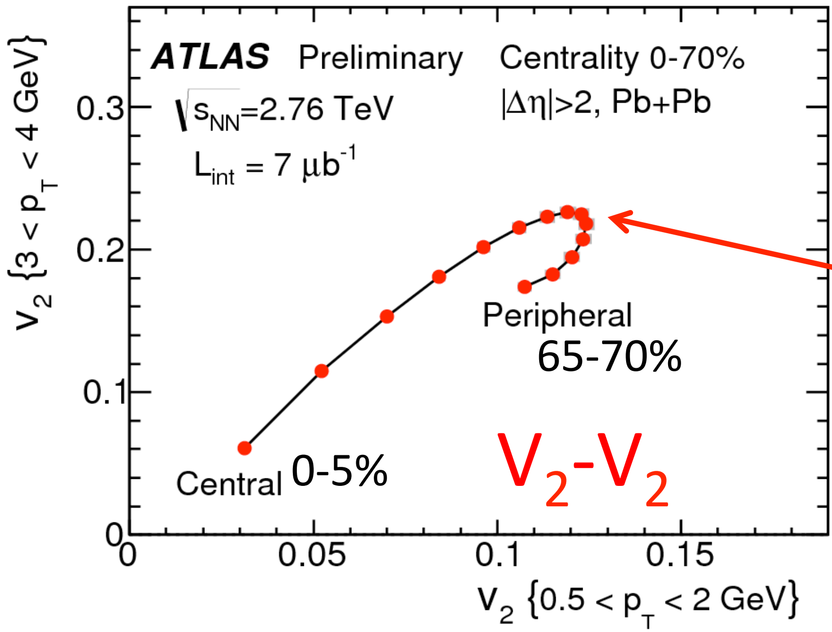
Event-shape selection

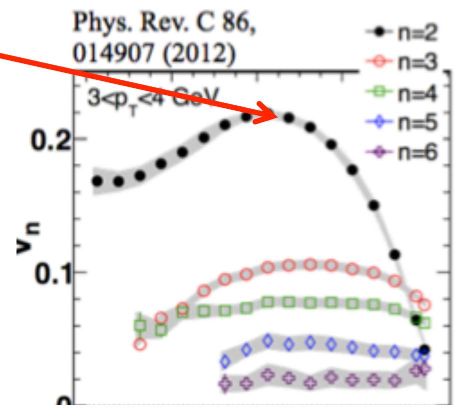


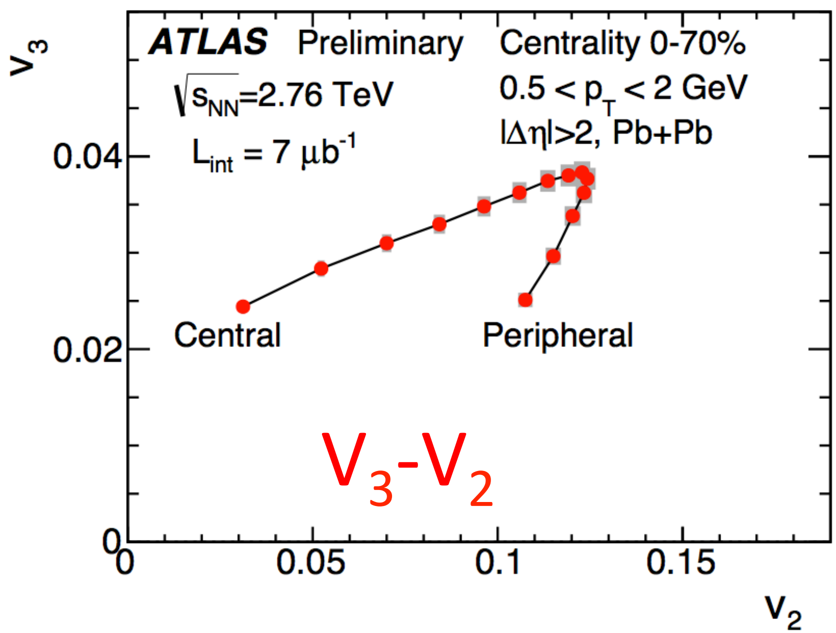
- Traditionally centrality is used as proxy for geometry
- Entangles "event-shape" effects with "event-size" effects
- Can now select events within same centrality that have different geometries.
- Such "shape selected" measurements reveal insights into correlations in the initial geometry and hydro response
- Study correlations between harmonics

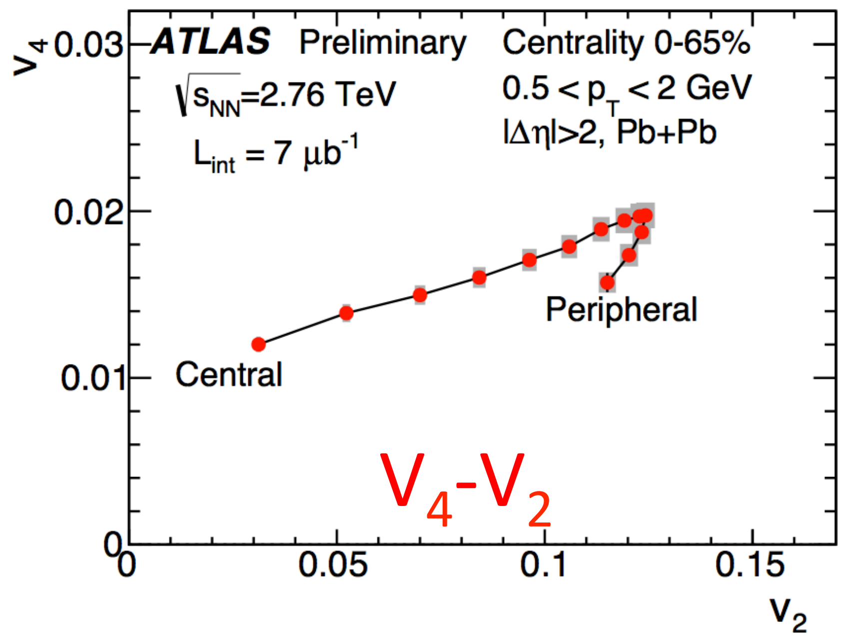
v_m-v_2 correlations : inclusive

- v_2-v_2 correlation at different p_T
- v_m-v_2 correlation in the same p_T range
  - Reflects different centrality dependence of v_n

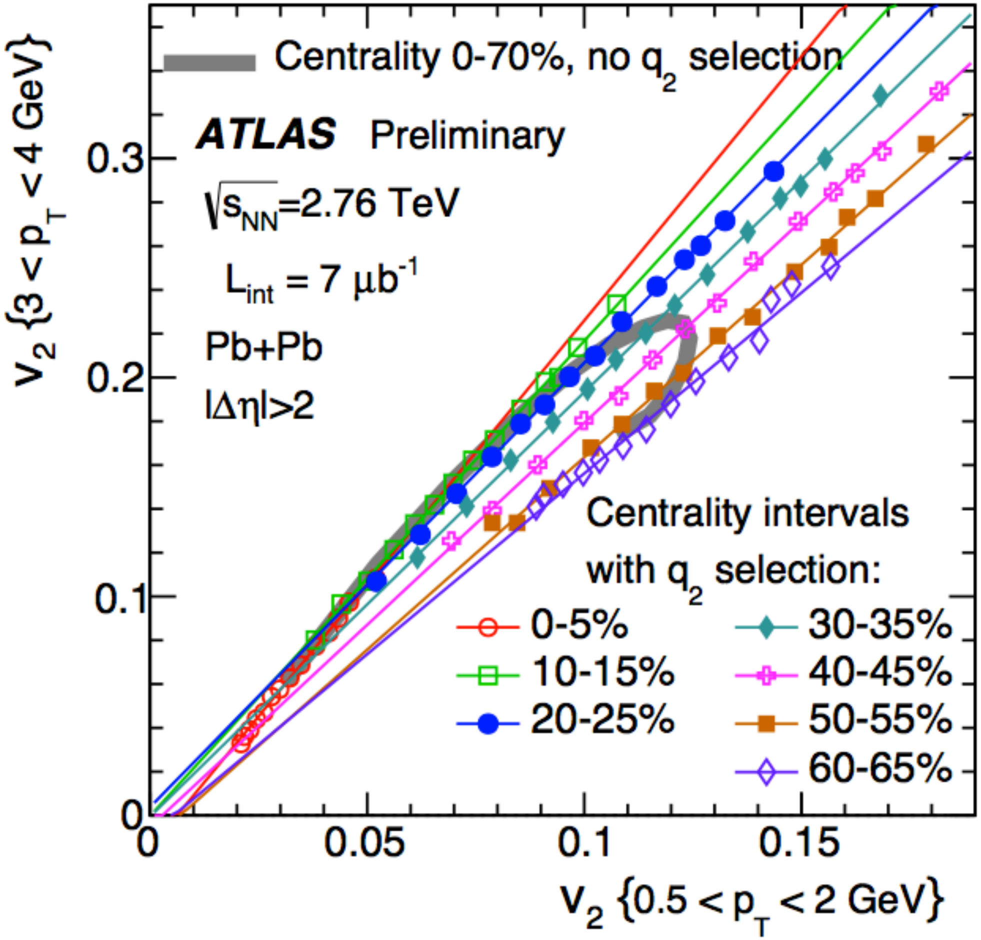






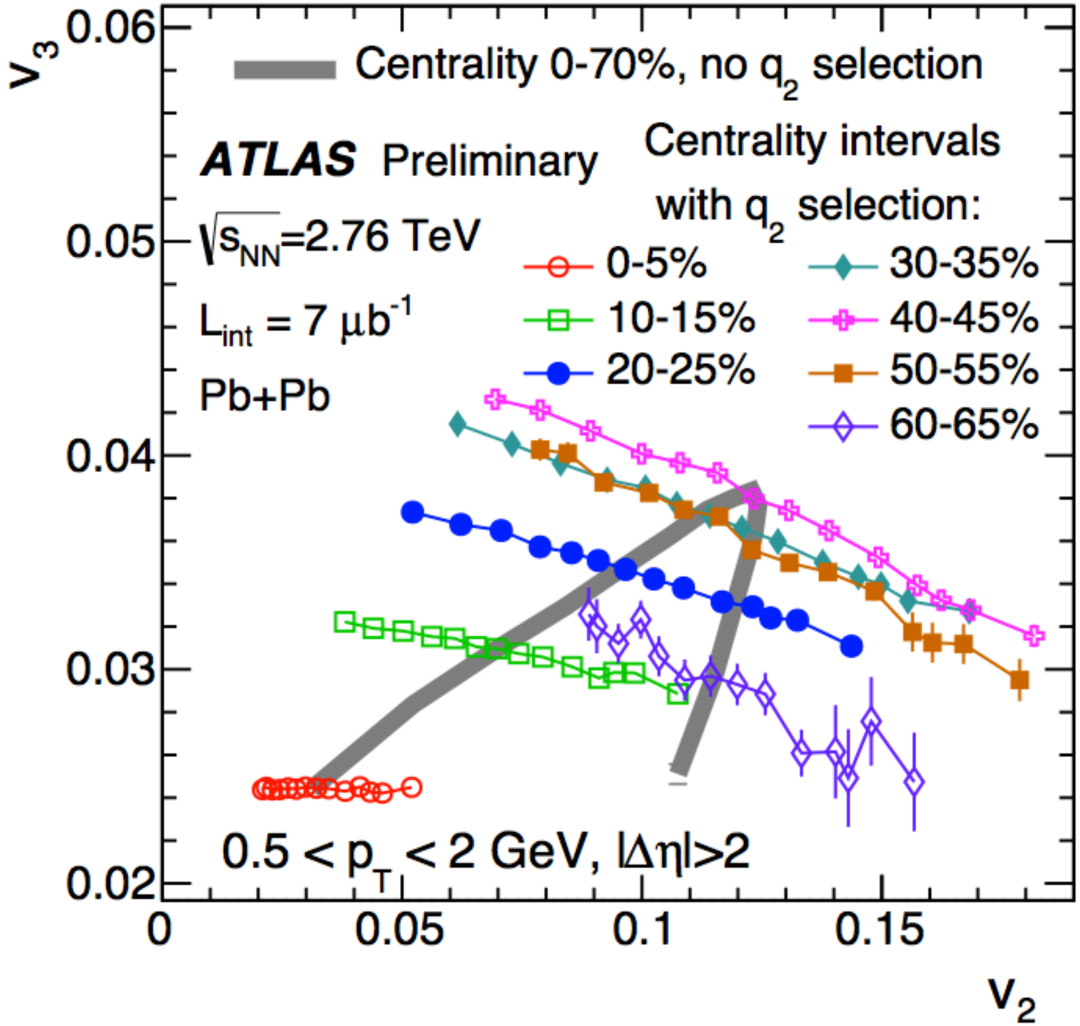


v_2-v_2 correlations : q-bins



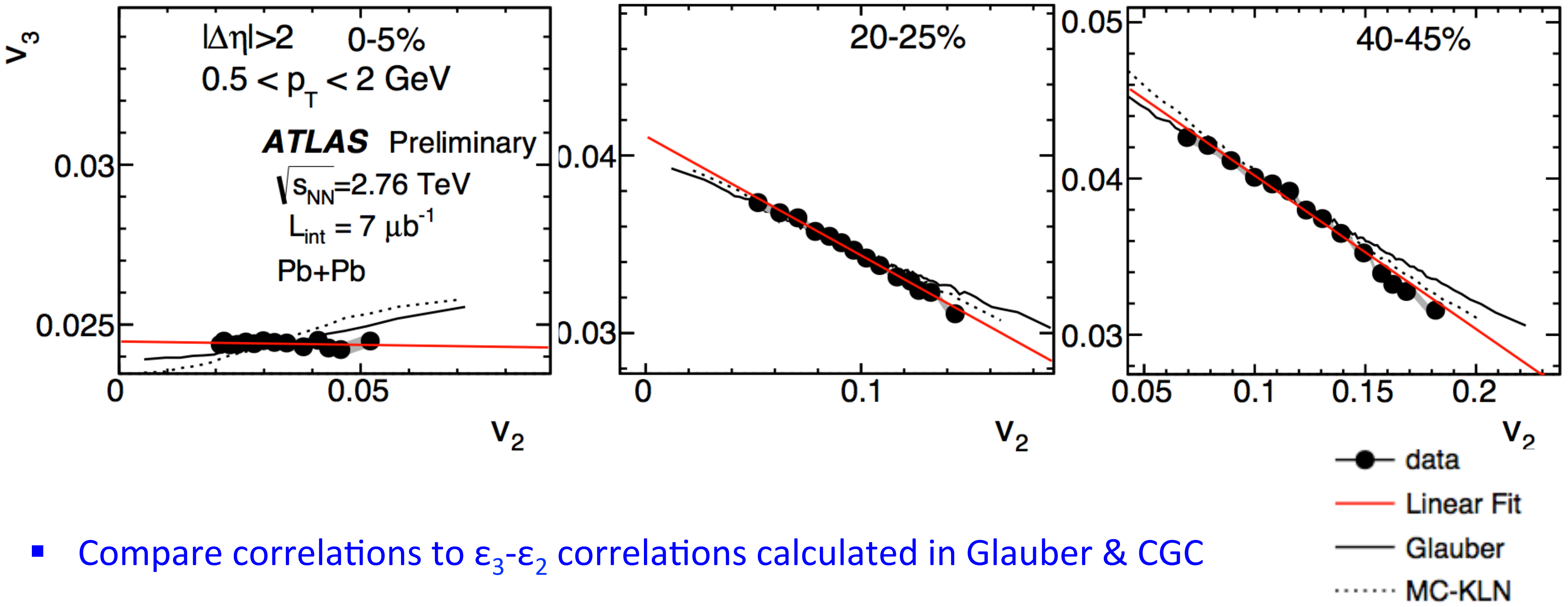
- Saw non-trivial dependence with centrality (boomerang),
  - but within one centrality dependence is linear!
- Indicates that viscous correction mostly controlled by system size, not shape!

v_3-v_2 correlations : q-bins



- See anti-correlation between v_2 and v_3 at fixed centrality!
- Initial geometry effect?

v_3-v_2 correlations : Glauber & CGC comparison



- Compare correlations to ε_3-ε_2 correlations calculated in Glauber & CGC models

$$(\varepsilon_3 - \varepsilon_2) \text{ correlation} \propto (v_3 - v_2) \text{ correlation}$$

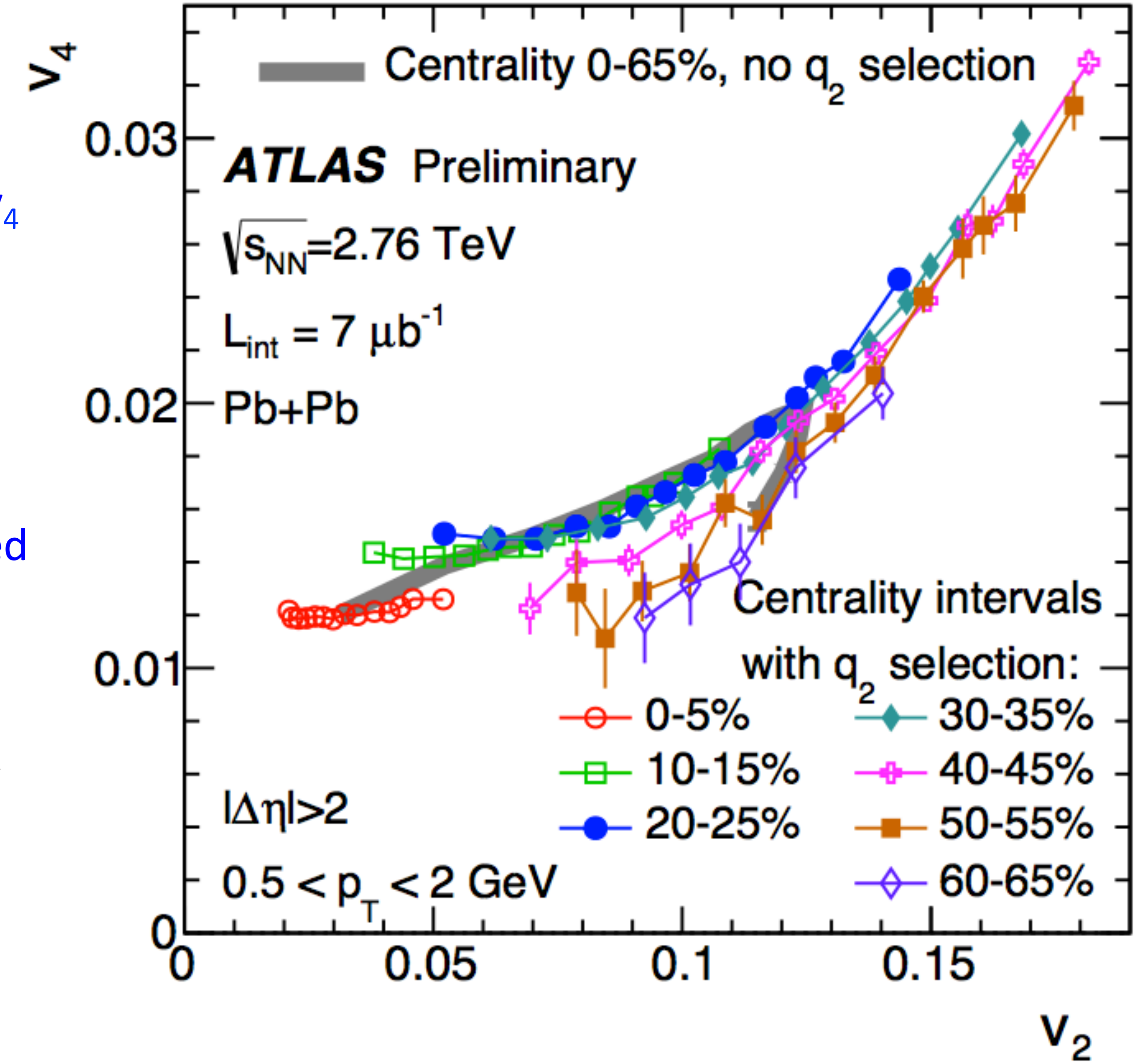
- See good agreement in most centralities but some deviation in (0-5)% central events
- Measurements can constrain initial geometry models
- Lines are linear fits $v_3 = kv_2 + v_3^0$

v_4-v_2 correlations : q-bins

- Clear non-linear correlations seen in v_4-v_2 case: upward bending of v_4 at large v_2.

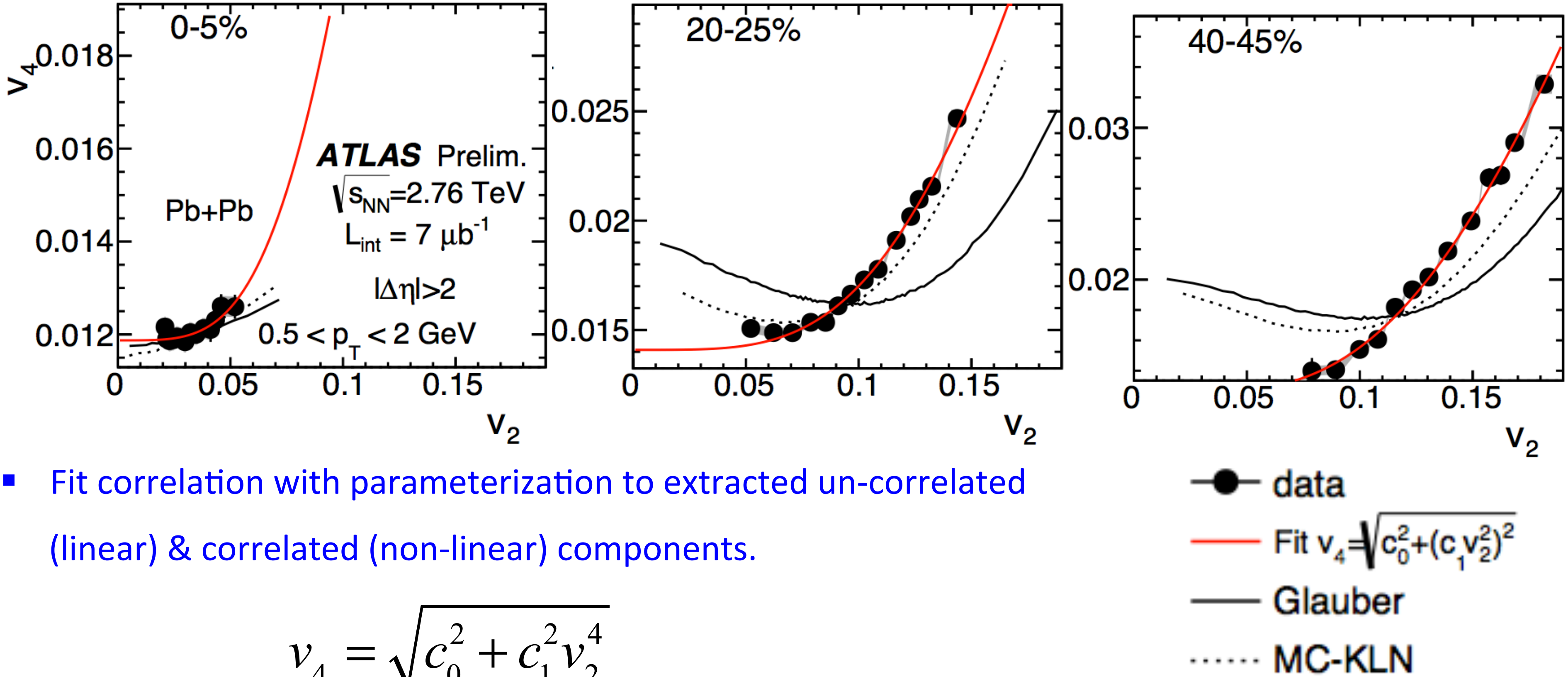
- Can parameterize v_4 into two components, one that is correlated to v_2 and one that is independent

$$v_4 e^{i4\Phi_4} = c_0 e^{i\Phi_4^*} + c_1 \left(v_2 e^{i2\Phi_2} \right)^2$$
$$\Rightarrow v_4 = \sqrt{c_0^2 + c_1^2 v_2^4}$$



- The c_0 component is driven by ε_4 while the c_1 component is driven by ε_2.

v_4-v_2 correlations : linear & non-linear components

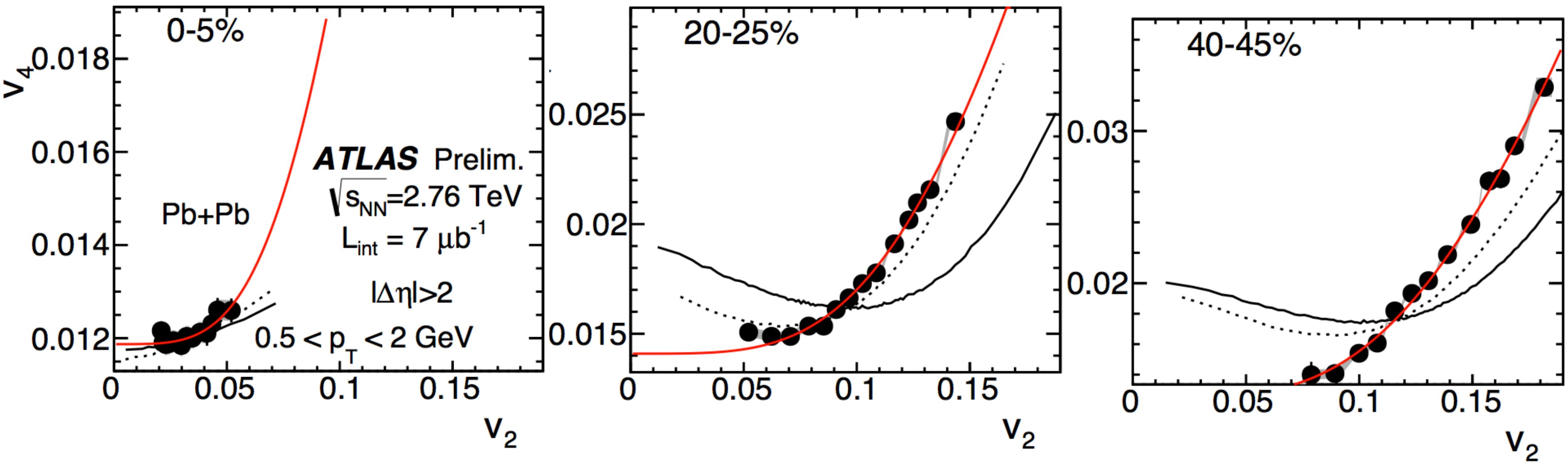


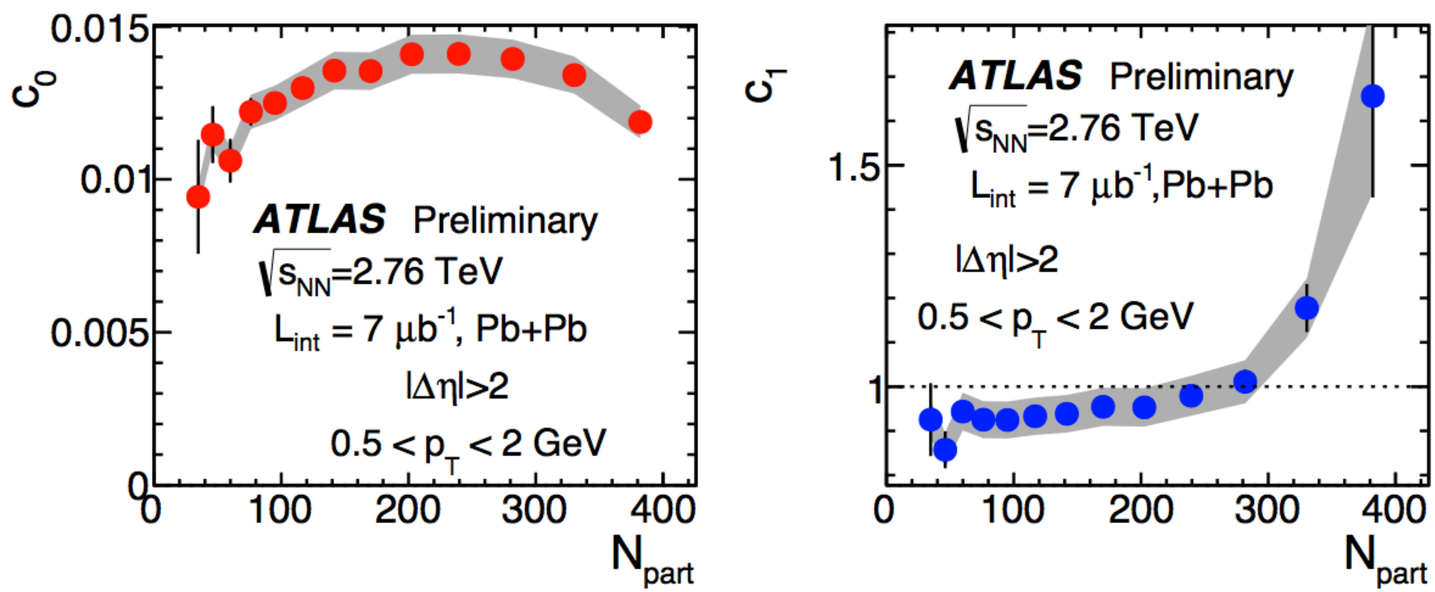
- Fit correlation with parameterization to extracted un-correlated (linear) & correlated (non-linear) components.

$$v_4 = \sqrt{c_0^2 + c_1^2 v_2^4}$$

- Also compare correlations to (rescaled) ε_4-ε_2 correlations calculated in Glauber & CGC models
  - Fits work quite well, but initial geometry models do not
  - Indicate that non-linear dynamical mixing produces these correlations

v_4-v_2 correlations : linear & non-linear components

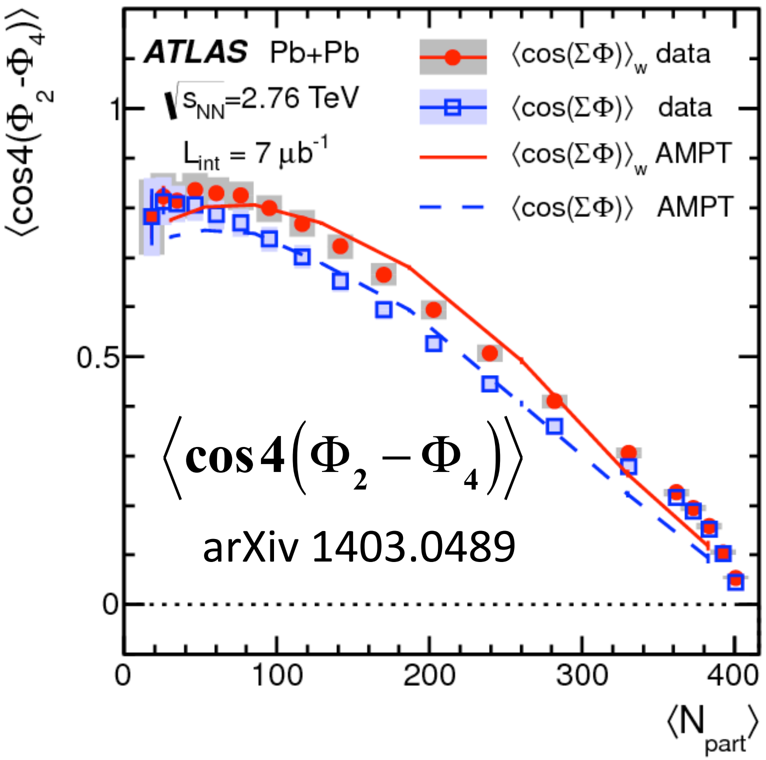




$$v_4 = \sqrt{c_0^2 + c_1^2 v_2^4}$$

Each N_{part} point corresponds to 5% centrality bin

v_4-v_2 correlations : comparison to EP correlations



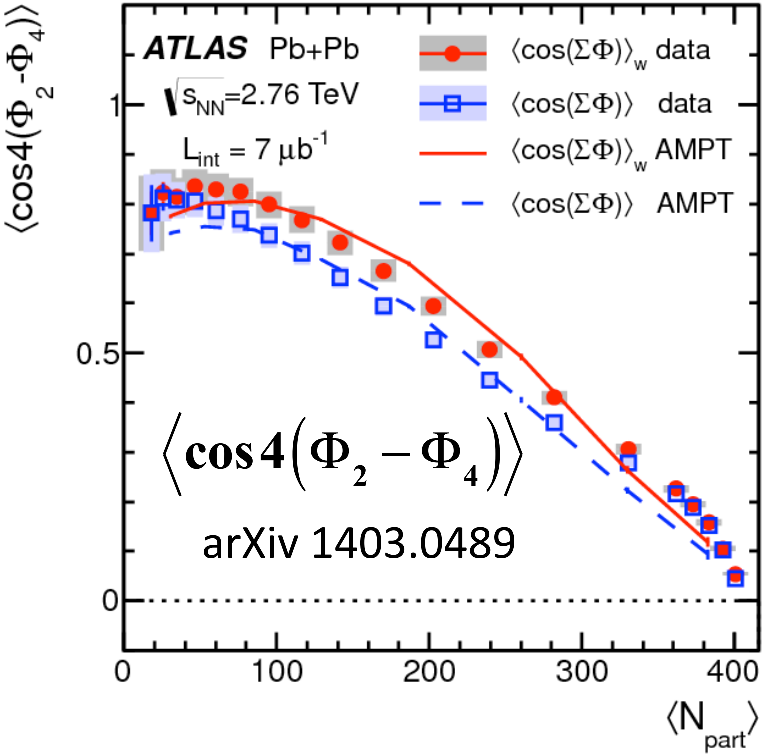
$\left\langle \cos 4\left(\Phi_2 - \Phi_4\right)\right\rangle$

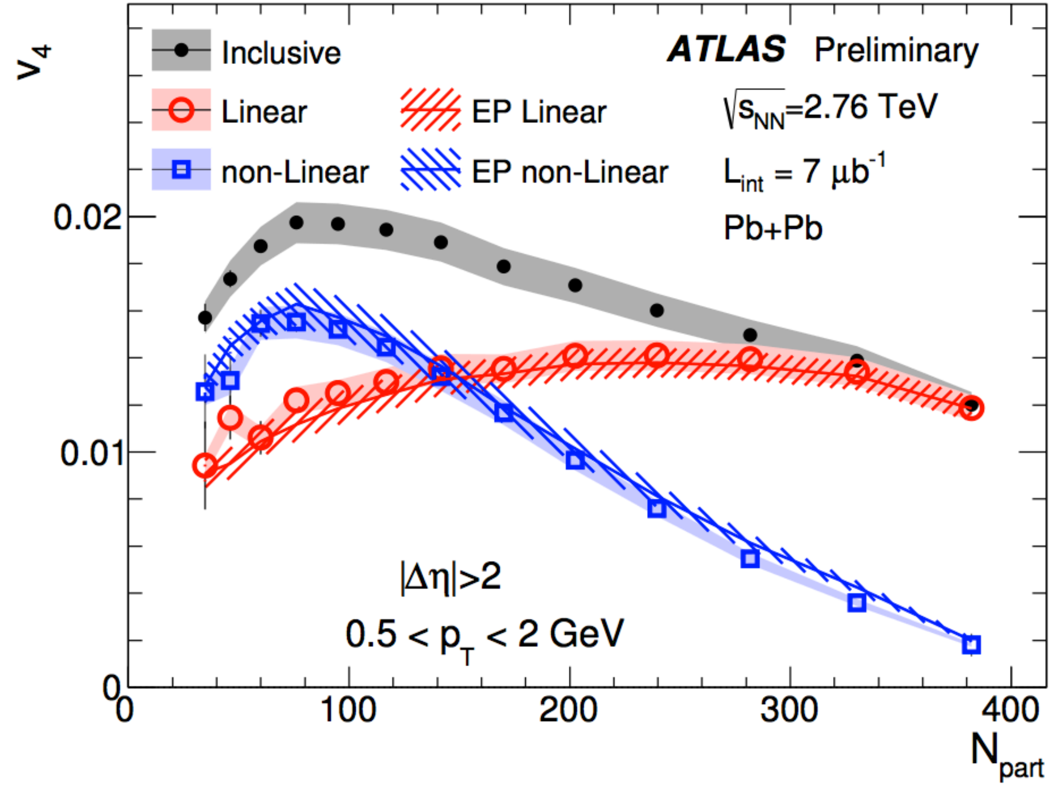
arXiv 1403.0489

- The non-linear & linear components from EP correlations are obtained as:

$$v_4^{\mathrm{NL}} = v_4 \left\langle \cos 4(\Phi_2 - \Phi_4)\right\rangle, \quad v_4^{\mathrm{L}} = \sqrt{v_4^2 - (v_4^{\mathrm{NL}})^2}$$

v_4-v_2 correlations : comparison to EP correlations



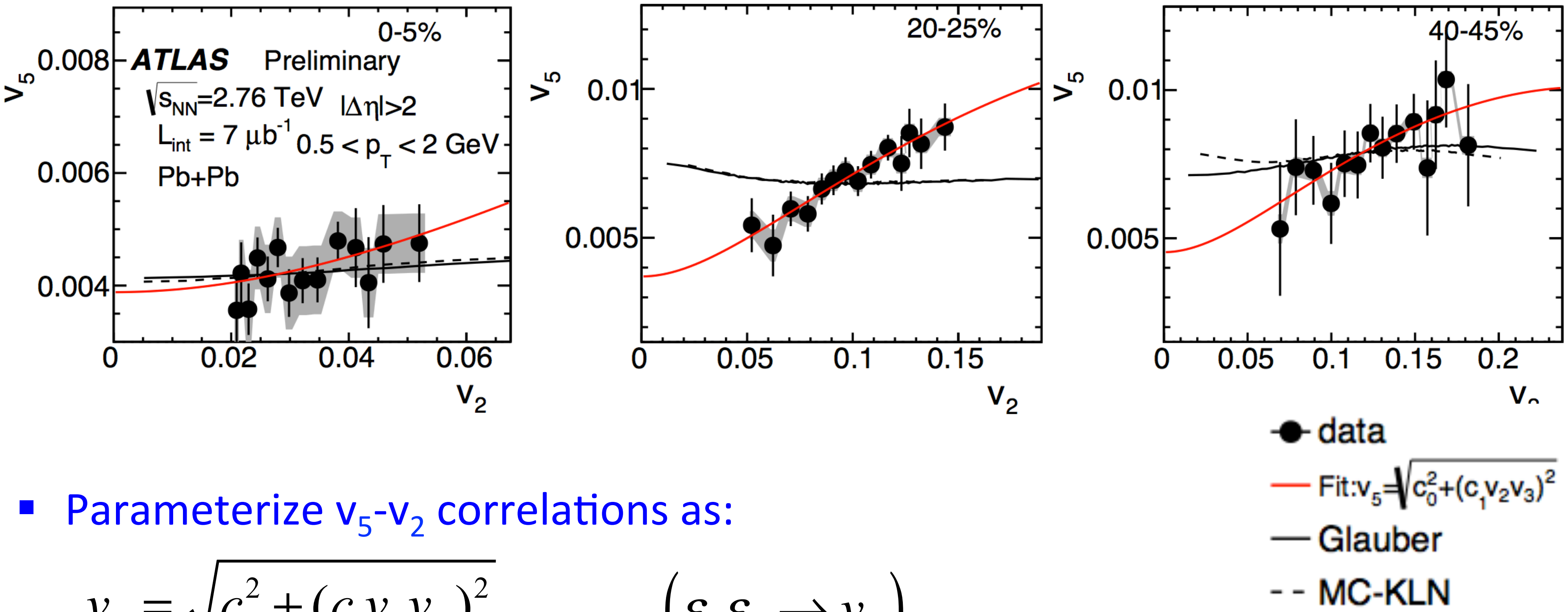


- The non-linear & linear components from EP correlations are obtained as:

$$v_4^{\mathrm{NL}} = v_4 \langle \cos 4(\Phi_2 - \Phi_4) \rangle, \quad v_4^{\mathrm{L}} = \sqrt{v_4^2 - (v_4^{\mathrm{NL}})^2}$$

- The results from the two procedures compare quite well
- In most central cases almost all v_4 is uncorrelated with v_2
- Correlated component gradually increases and overtakes linear component as N_{part}~120

v_5-v_2 correlations : q-bins

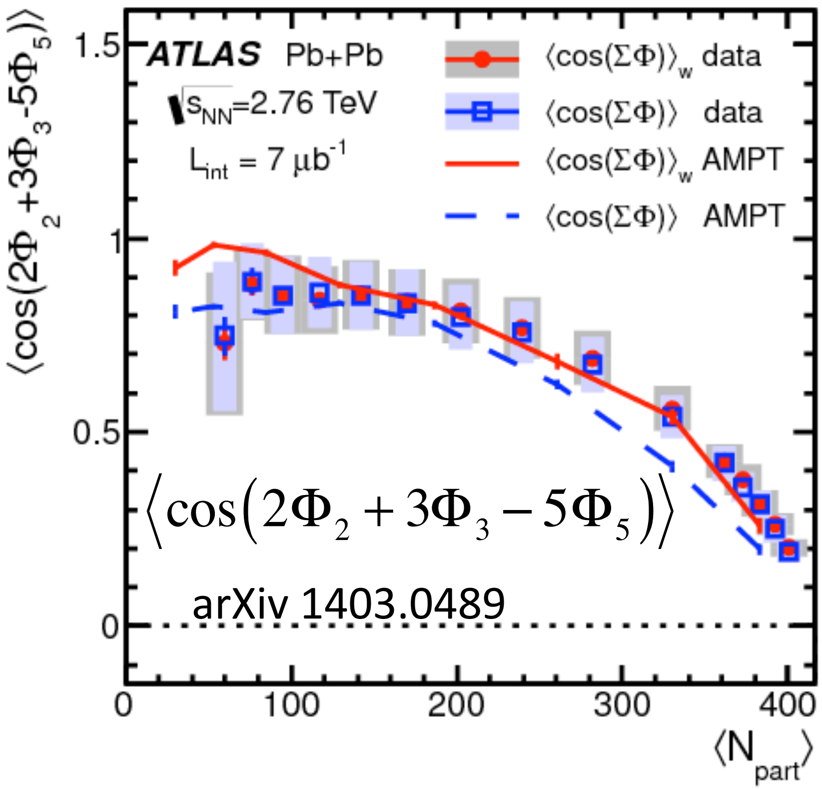


- Parameterize v_5-v_2 correlations as:

$$v_5 = \sqrt{c_0^2 + (c_1 v_2 v_3)^2} \qquad \left(\varepsilon_2 \varepsilon_3 \rightarrow v_5\right)$$

- Fit v_5-v_2 correlation with above functional form to extract linear & non-linear components
- Comparison to Glauber & CGC models also shown, don't do a good job in describing data

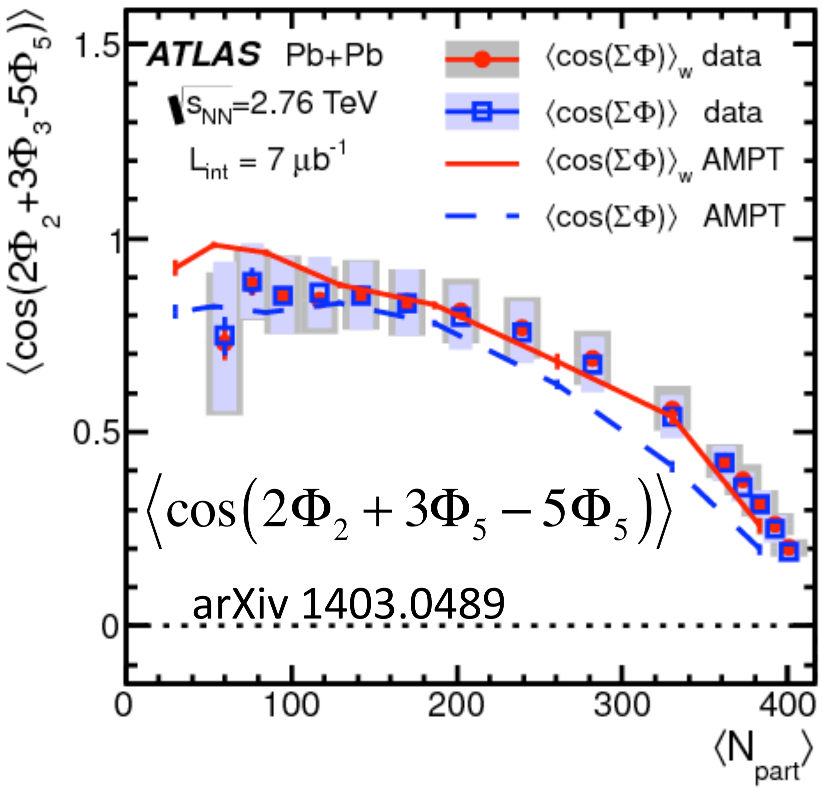
v_5-v_2 correlations : comparison to EP correlations

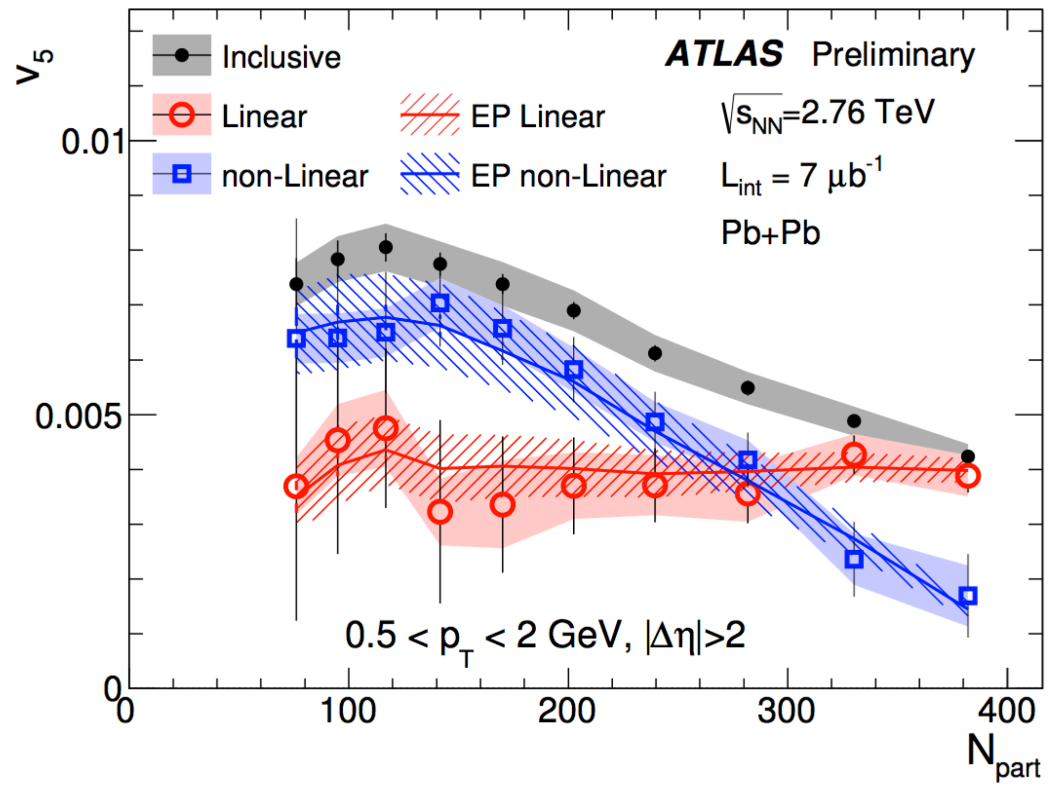


- Compare linear & non-linear components from this analysis to EP correlation results
- The non-linear & linear components from EP correlations are obtained as:

$$v_5^{NL} = v_5 \langle \cos(2\Phi_2 + 3\Phi_3 - 5\Phi_5) \rangle, \quad v_5^{L} = \sqrt{v_5^2 - (v_5^{NL})^2}$$

v_5-v_2 correlations : comparison to EP correlations

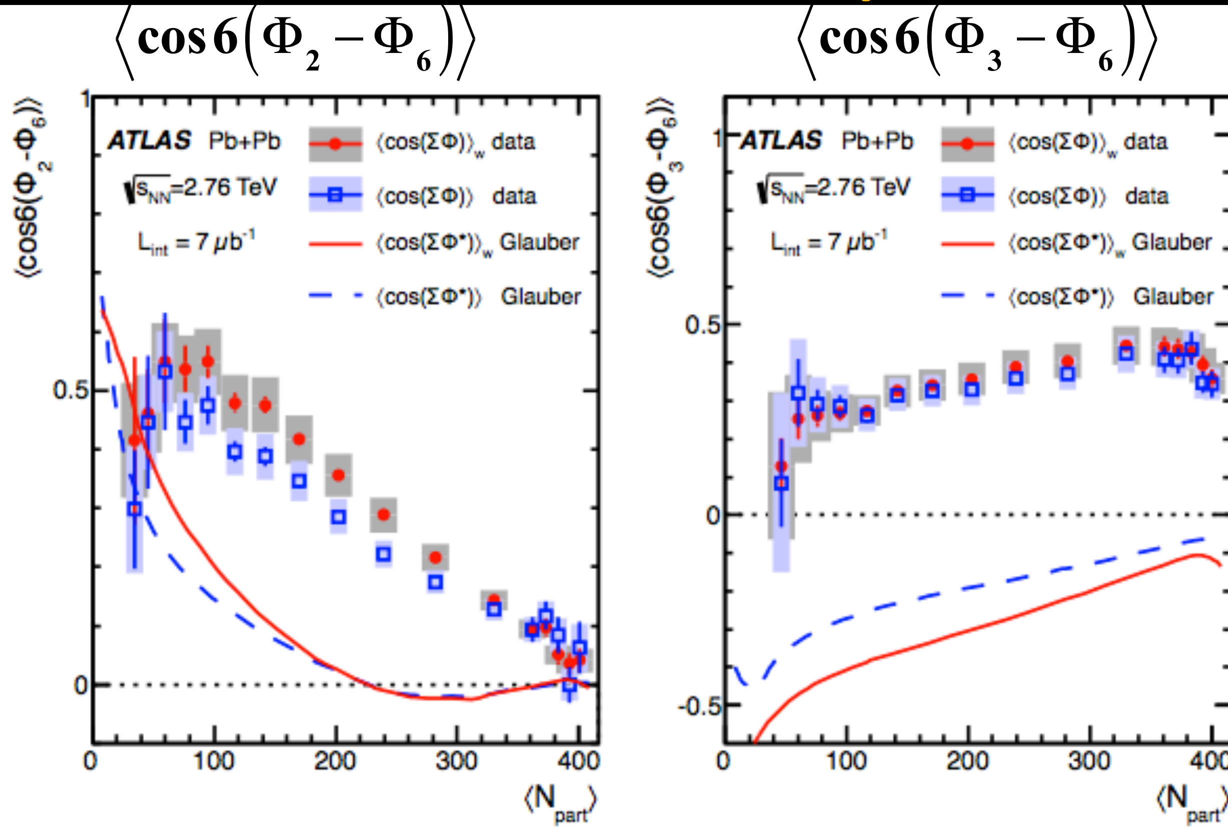




- Compare linear & non-linear components from this analysis to EP correlation results
- The non-linear & linear components from EP correlations are obtained as:

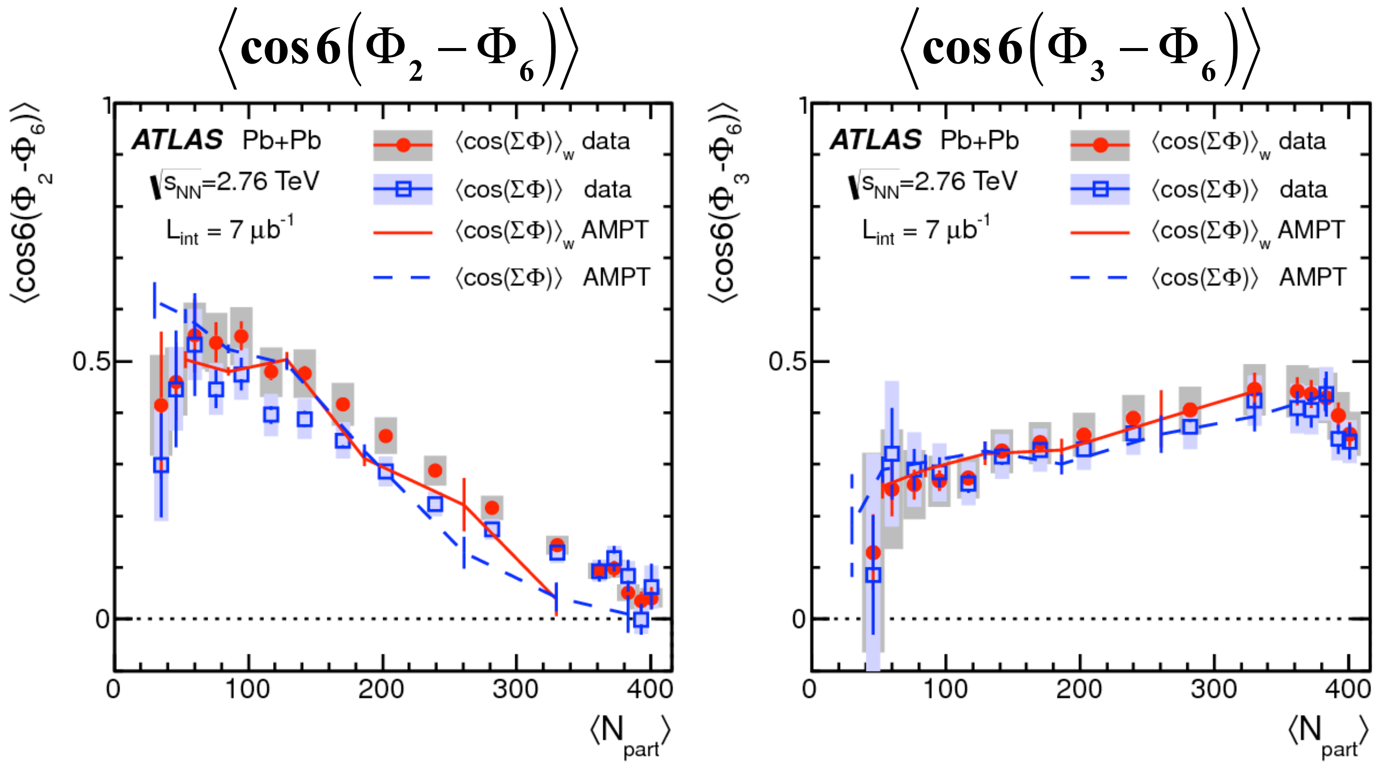
$$v_5^{NL} = v_5 \langle\cos(2\Phi_2 + 3\Phi_3 - 5\Phi_5)\rangle , \quad v_5^{L} = \sqrt{v_5^2 - (v_5^{NL})^2}$$

Non-linear response for v_6



- Φ_2 and Φ_3 weakly correlated, but both strongly correlated with Φ_6.
- They show opposite centrality dependence
  - v_6 dominated by non-linear contribution: v_2^3, v_3^2 ?

Non-linear response for v_6

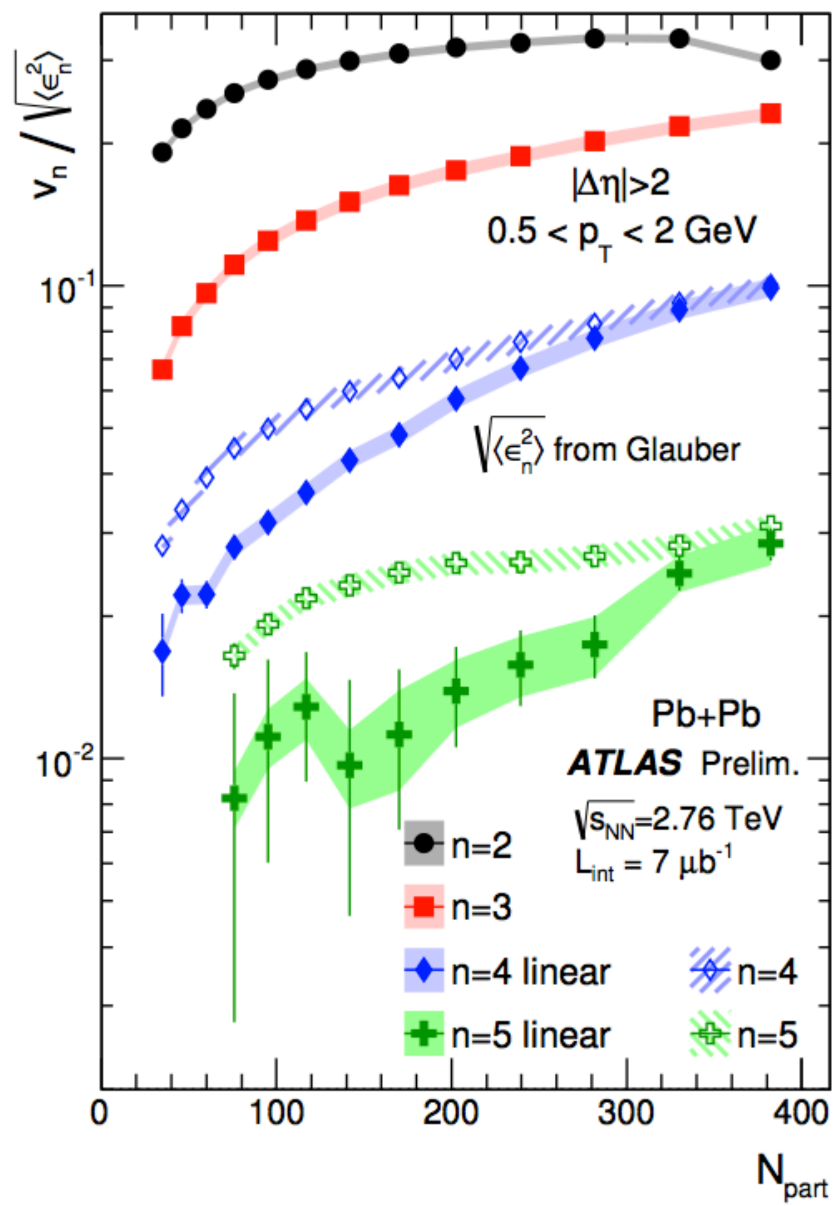


- Final state interactions reproduce the correlations

R. S. Bhalerao, J.-Y. Ollitrault, and S. Pal, Phys. Rev.C 88, 024909 (2013)

ε_n scaling of linear components

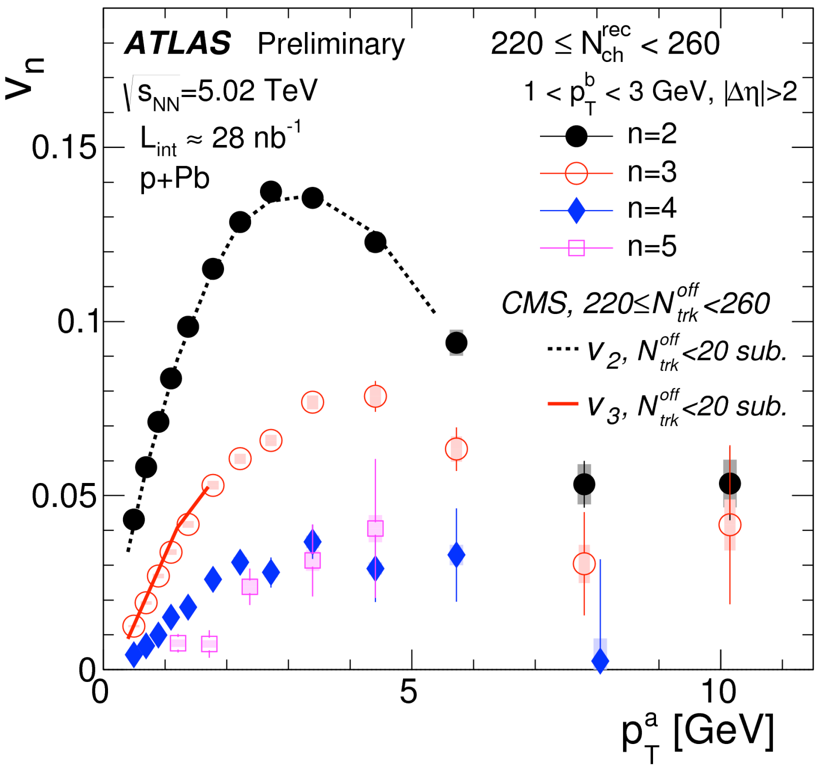
- The v_n/rms-ε_n ratios are shown as a function of centrality
- For v_4 & v_5, the ratio is shown for the linear component as well as the total v_n.
- The linear component show greater variation
- indicates larger viscous dampening for higher harmonics, with decreasing centrality.

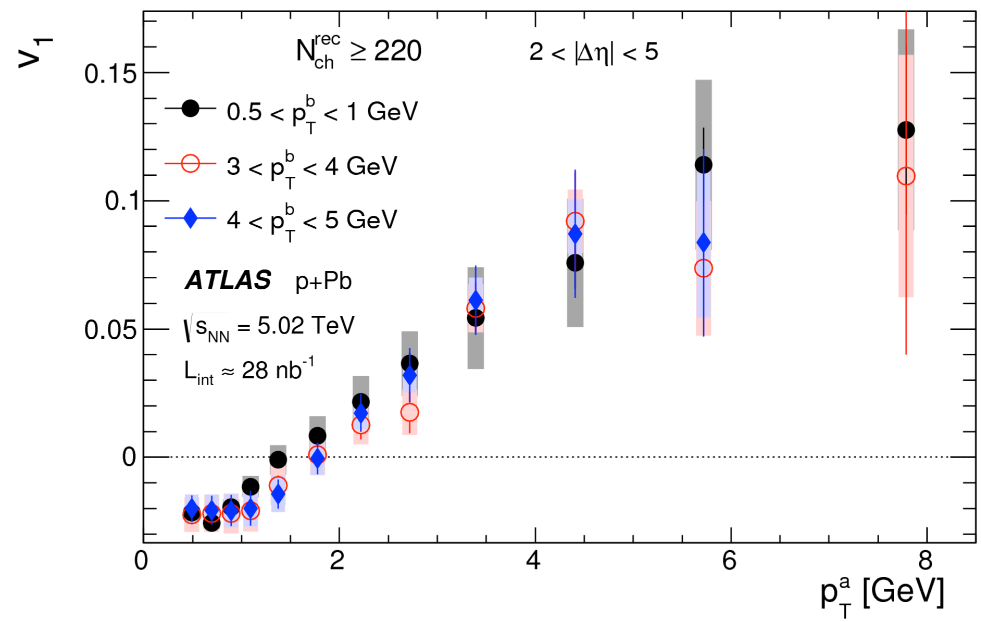


Summary

- Measurements:
  - EbE Probablity distributions
  - Event-plane correlations
  - Correlations between v_2 and v_m, m=2-5.
- $v_2(p_T^a)$-$v_2(p_T^b)$ correlations indicate viscous effects controlled by system size
  - Not system shape!!!
- See small anti-correlation between magnitudes of v_2 & v_3
  - Initial geometry effect, reasonably weak described by CGC & Glauber models
- See strong correlation between v_4-v_2 and v_5-v_2.
  - Indicate non-linear response to initial geometry (not described by initial geometry models)
  - Extracted linear & non-linear contributions by two component fits
  - Correlated with v_2 incase of v_4-v_2 correlation
  - Correlated with both v_3 and v_2 incase of v_5-v_2 correlation
- Results show good agreement with independent EP correlation results
- Dependence of the linear components on the rms-ε_n were also studied
  - Stronger damping seen for higher order harmonics as expected from hydrodynamics
- v_n-v_m and EP correlations are new flow observables
  - Have much potential in improving our understanding of HI collisions.

Prospects for p+Pb



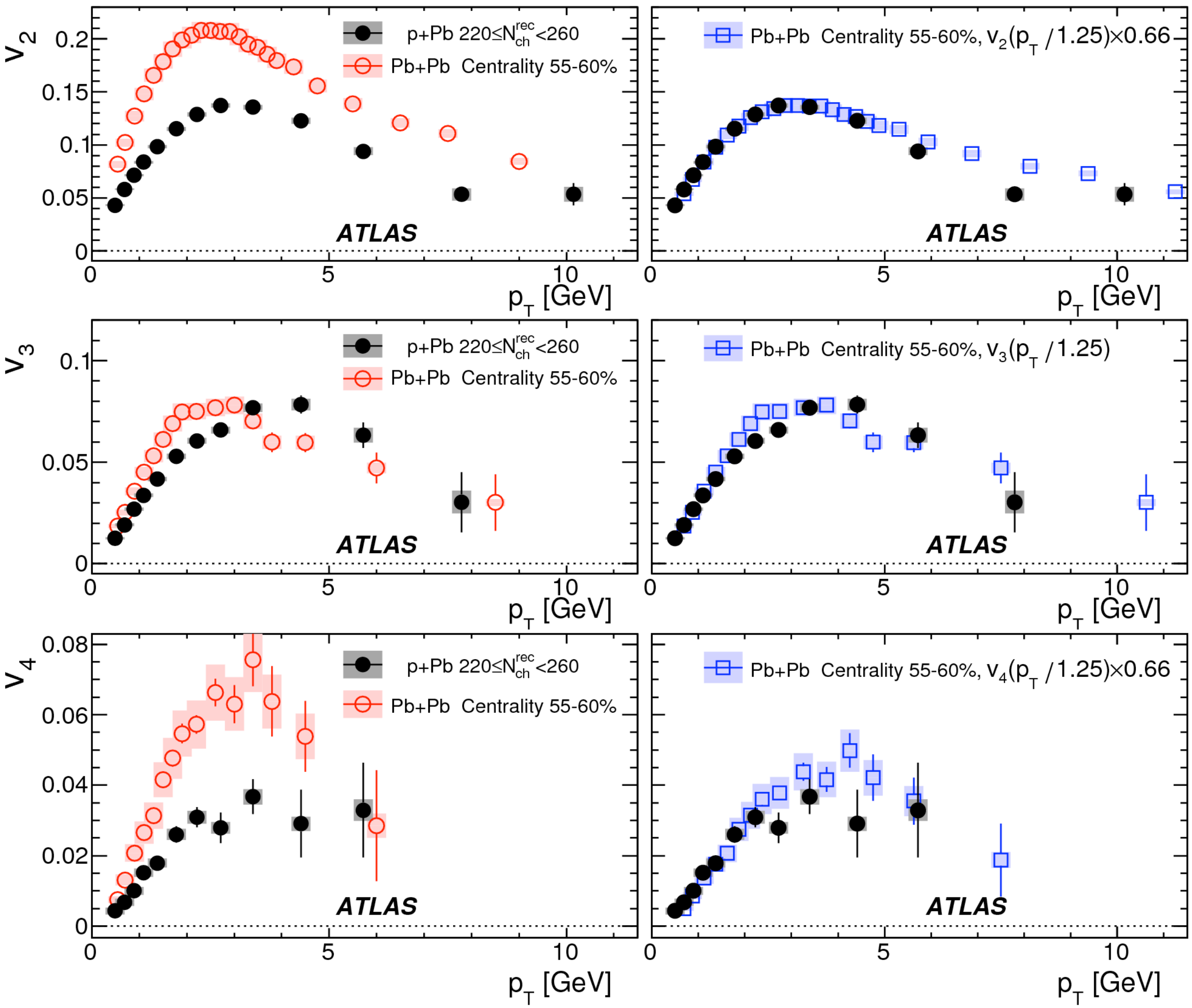


Phys. Rev. C 90.044906 (2014)

Measured harmonics v_1-v_5 in p+Pb collisions using recoil subtraction

Recoil subtraction critical for determining v1

Prospects for p+Pb v_n



Phys. Rev. C 90.044906 (2014)

Right panels adjust p+Pb p_T scale by 4/5 to account for difference in <p_T> (Teaney et al arXiv:1312.6770)

Pb+Pb v_2 and v_4 multiplied by 0.66 to match p+Pb

Good agreement between p+Pb and Pb+Pb when including p_T and v_2, v_4 rescaling