Measurements of v_n at high-p_T and correlation between v_n and mean-p_T in p+Pb collisions with the ATLAS detector

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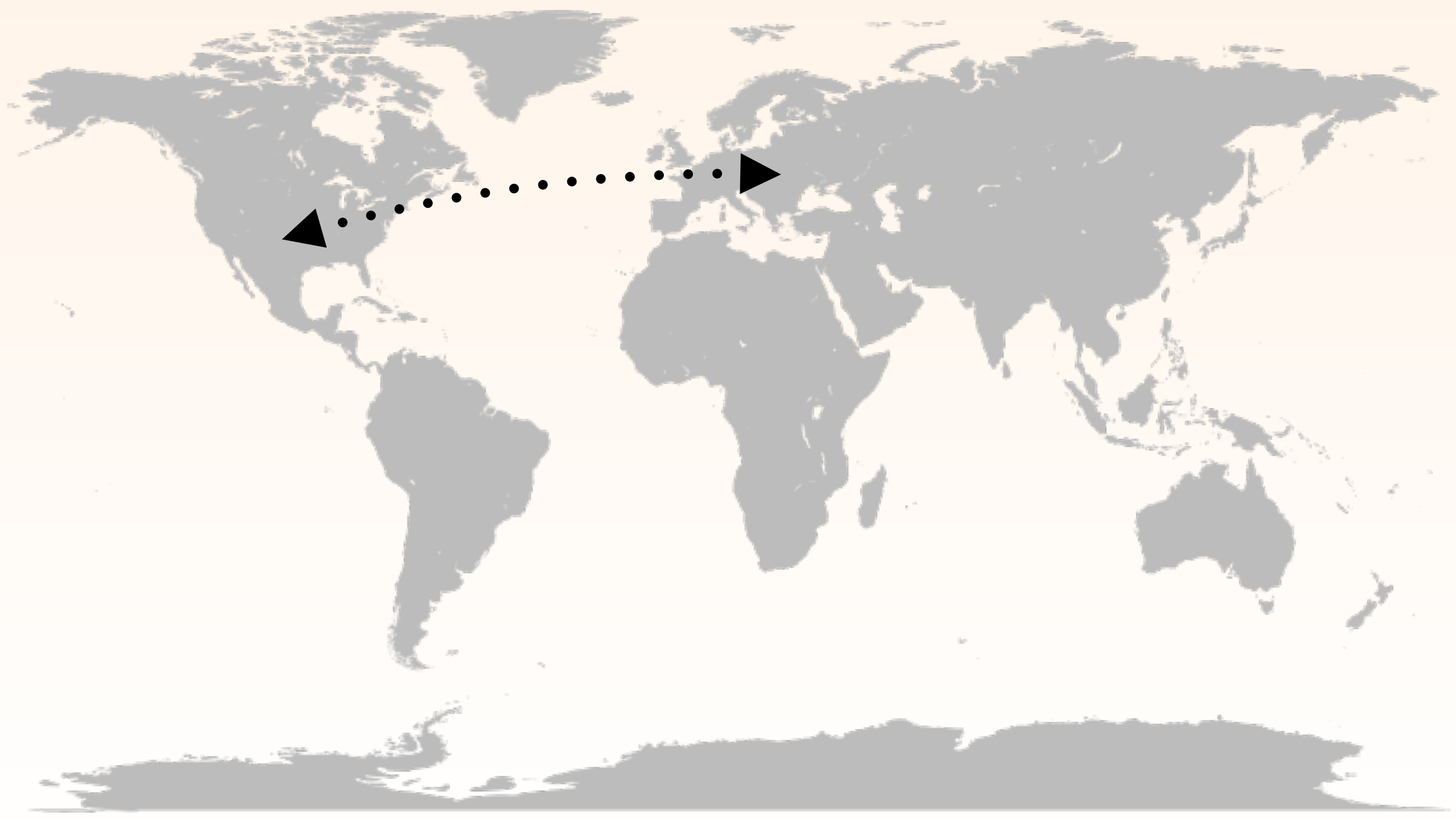
on behalf of the ATLAS Collaboration

Hard Probes 2020



v_n and mean p_T correlation

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The idea

- Relate initial state quantity (event mean-$[p_T]$) with evolution towards the final state (flow harmonics)
- Known that the correlation exists (ALICE Phys. Rev. C93, 034916)
- Pearson correlation coefficient R distorted by the limited event multiplicity
- A modified correlator ρ proposed (P. Bozek, Phys. Rev. C93 044908)
  - Replaces variances by dynamic counterparts $\mathrm{Var}_{\mathrm{dyn}}$, c_k
  - Reproduces true R even with limited event multiplicity → detector independent measurement

$$R = \frac{\mathrm{cov}(v_n\{2\}^2, [p_T])}{\sqrt{\mathrm{Var}(v_n\{2\}^2)}\sqrt{\mathrm{Var}([p_T])}},$$

$$\rho = \frac{\mathrm{cov}(v_n\{2\}^2, [p_T])}{\sqrt{\mathrm{Var}(v_n\{2\}^2)_{\mathrm{dyn}}}\sqrt{c_k}}.$$

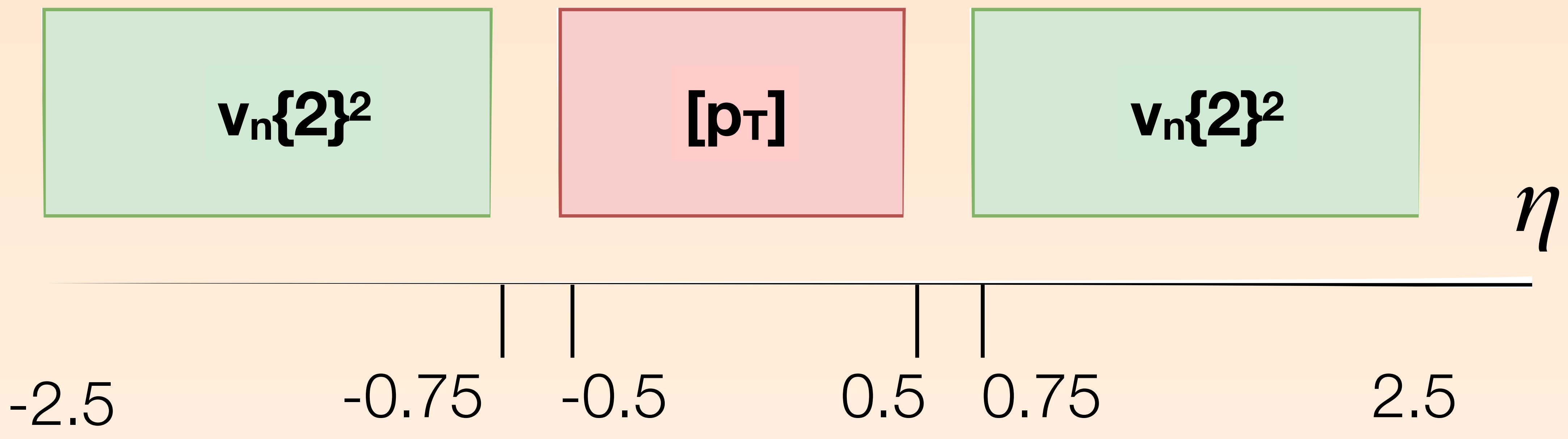
- **Is the correlation present & positive or negative? Is it strong? Is it the same for all harmonics? Is it the same in Pb+Pb an p+Pb?**

$$\mathrm{Var}(v_n\{2\}^2)_{\mathrm{dyn}} = \langle corr\{4\}\rangle - \langle corr\{2\}\rangle^2$$

$$c_k = \left\langle \frac{1}{N_{\mathrm{pair}}} \sum_i \sum_{j \neq i} (p_{T,i} - \langle [p_T]\rangle)(p_{T,j} - \langle [p_T]\rangle) \right\rangle$$

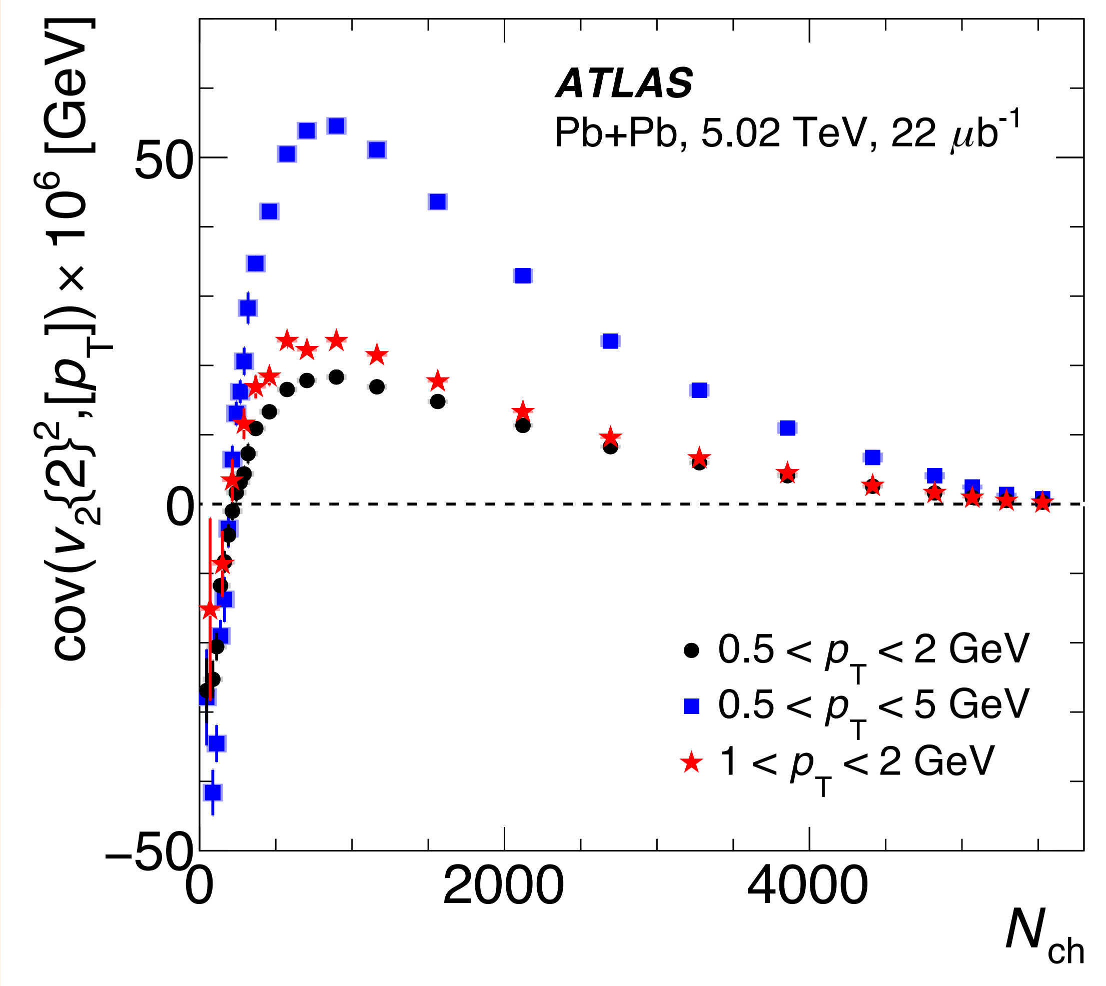
Details

$$\rho = \frac{\mathrm{cov}(v_n\{2\}^2, [p_\mathrm{T}])}{\sqrt{\mathrm{Var}(v_n\{2\}^2)_\mathrm{dyn}}\sqrt{c_k}}.$$



- Dataset: $\sqrt{s_{NN}} = 5.02\ TeV$,
  2015 *Pb+Pb* 22$\mu\mathbf{b}^{-1}$, 2013 *p+Pb* 28$\mathbf{nb}^{-1}$
- Distinct sets of particles for $[p_\mathrm{T}]$ and $v_n\{2\}^2$
- Rapidity gaps to suppress non-flow
- Analysis in narrow bins of multiplicity in forward regions
  - Mapped to $N_\mathrm{ch}(p_T < 0.5\ GeV, |\eta| < 2.5)$ and N_part
- Flow harmonics: v_2, v_3, v_4
- Several p_T intervals: hydrodynamics region, energy loss region & region to test sensitivity to multiplicity change

Ingredients of the ρ for v_2 in *Pb+Pb*



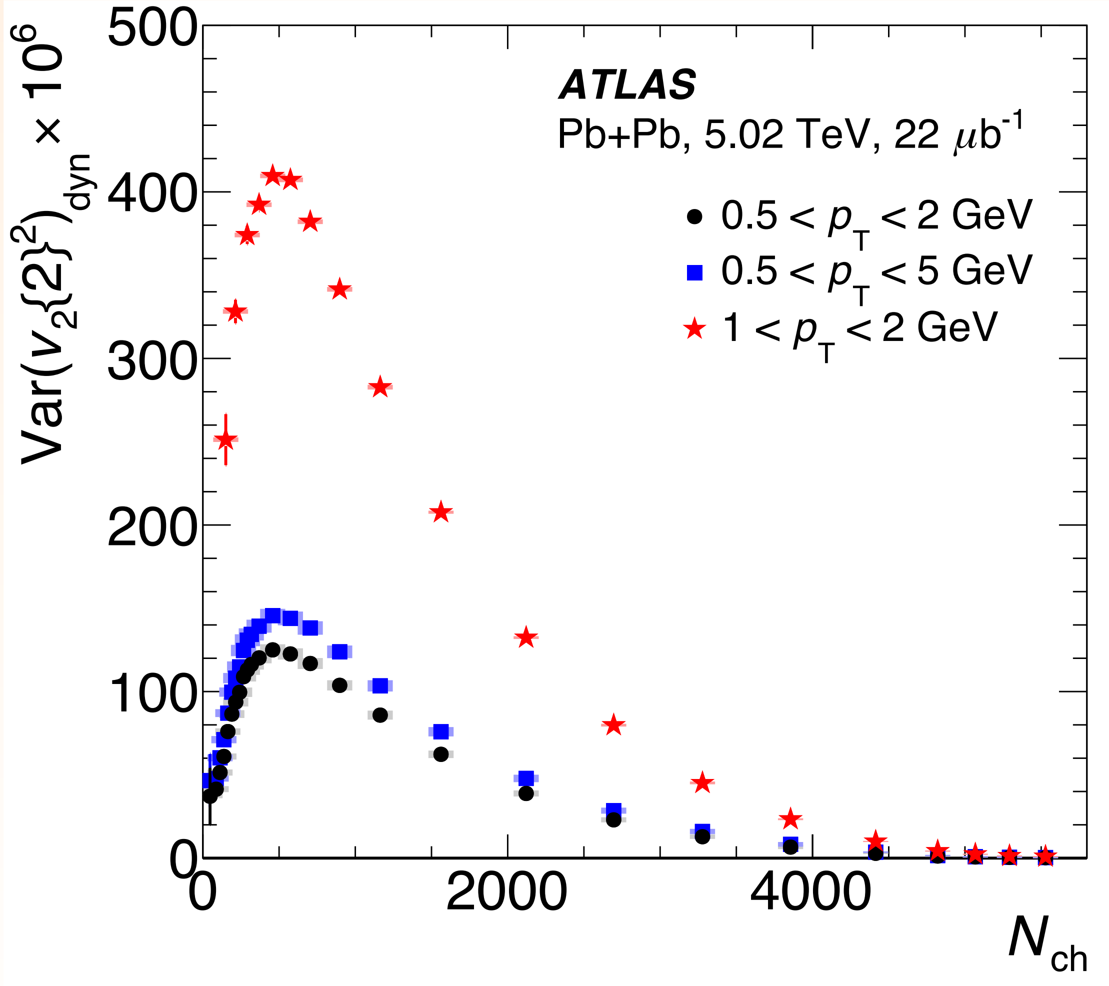
Significant variation with centrality

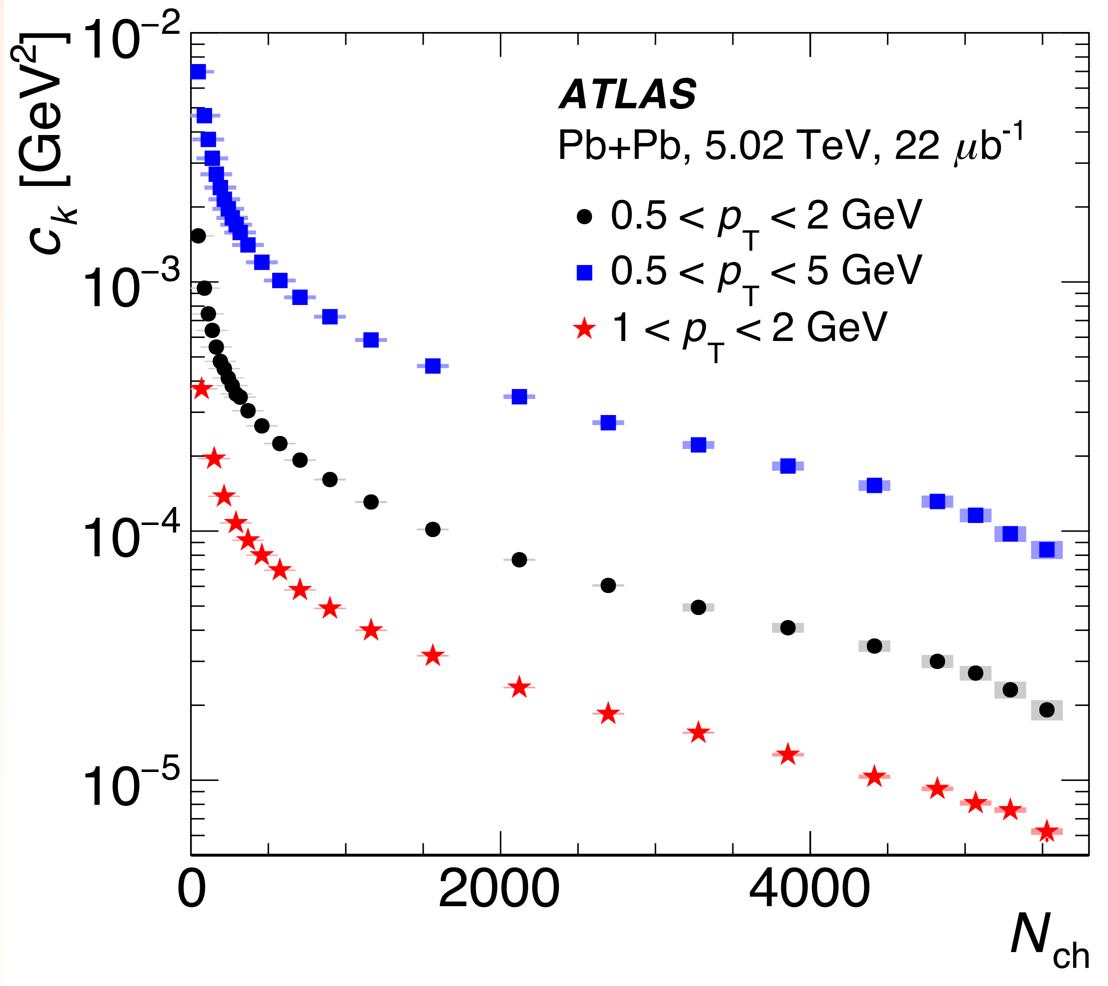
Trend follows the v_2 magnitude

Negative in peripheral events!

⟶ $0.5 < p_T < 5$ GeV, $|\eta| < 2.5$

$\rho =$





Magnitude of v_2 fluctuations

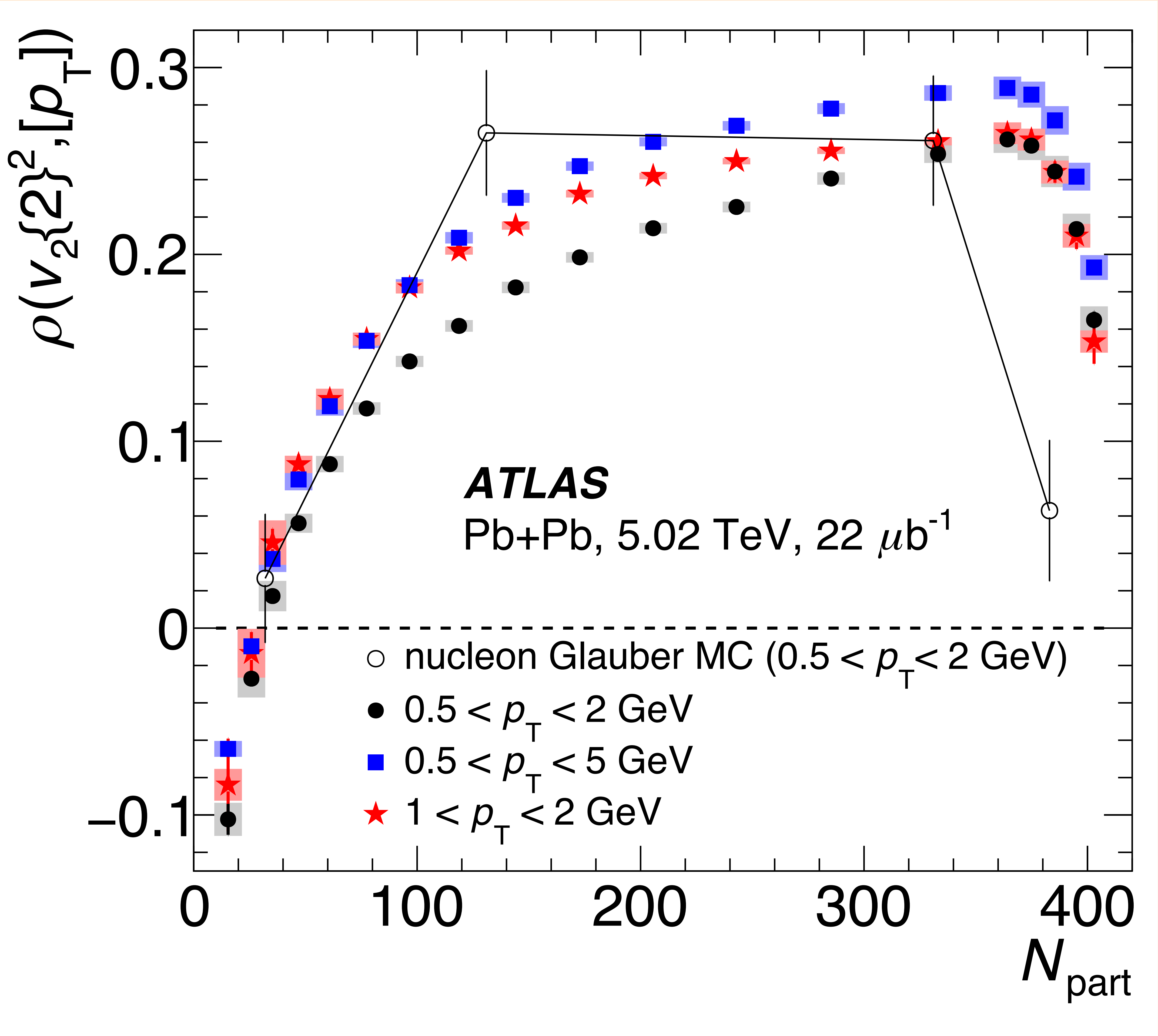
Similar trend to v_2

Different p_T ordering as compared to cov

c_k quantifies magnitude of $[p_T]$ fluctuations

Nontrivial p_T interval ordering, different than for cov and Var_{dyn}

Correlation coefficient ρ for v_2



Negative correlation for v_2 in peripheral collisions
→ related to ecc. ~ 1/r

Gentle rise in mid central
→ stronger hydrodynamic response to initial eccentricities - interplay between radial and elliptic flow

Fall in most central events

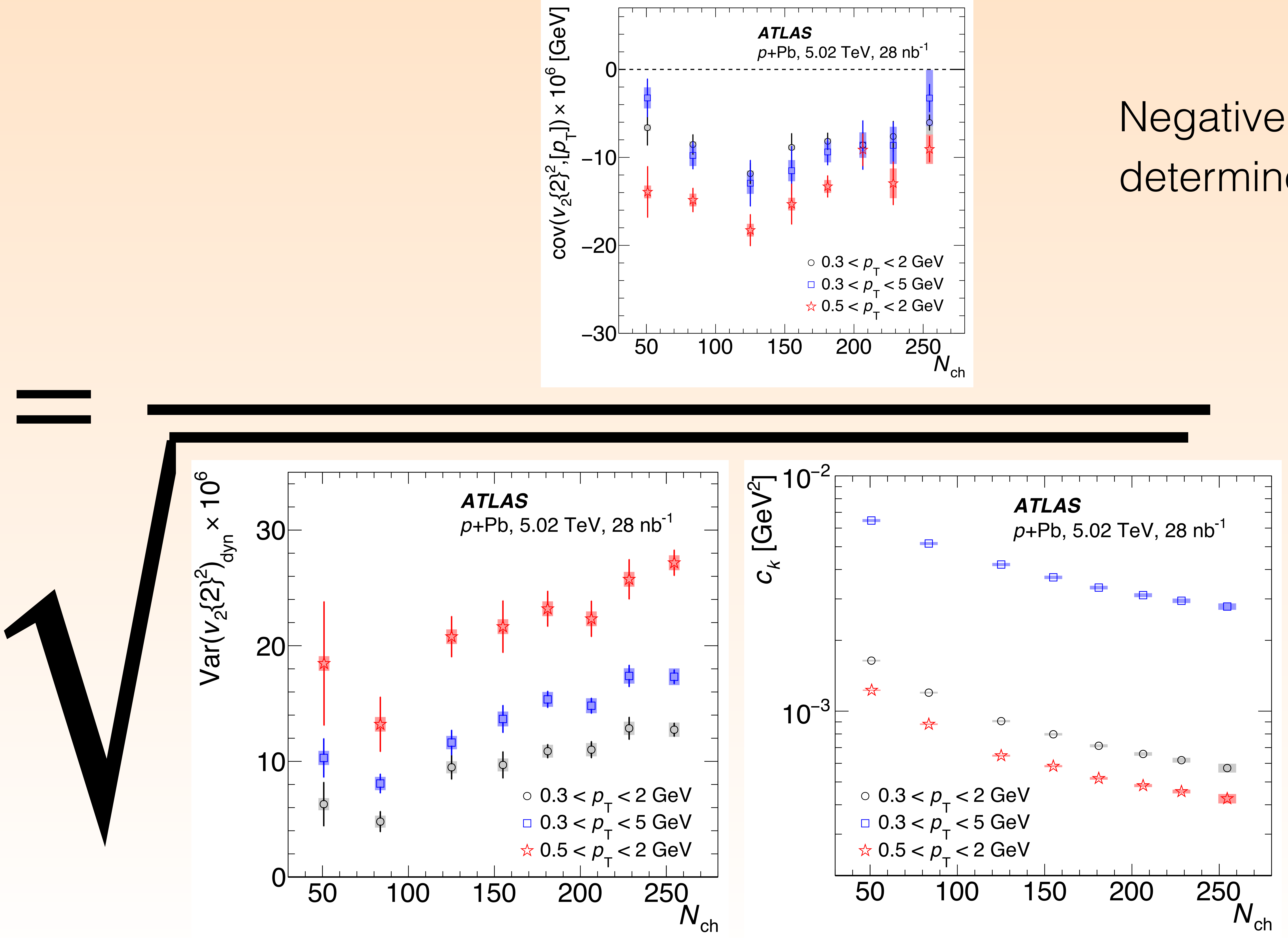
Hydrodynamics 1+3D (Phys. Rev. C93 044908), reproduces the behaviour qualitatively

Also see comparison with IP-Glasma+hydro models: arxiv: 2004.00690

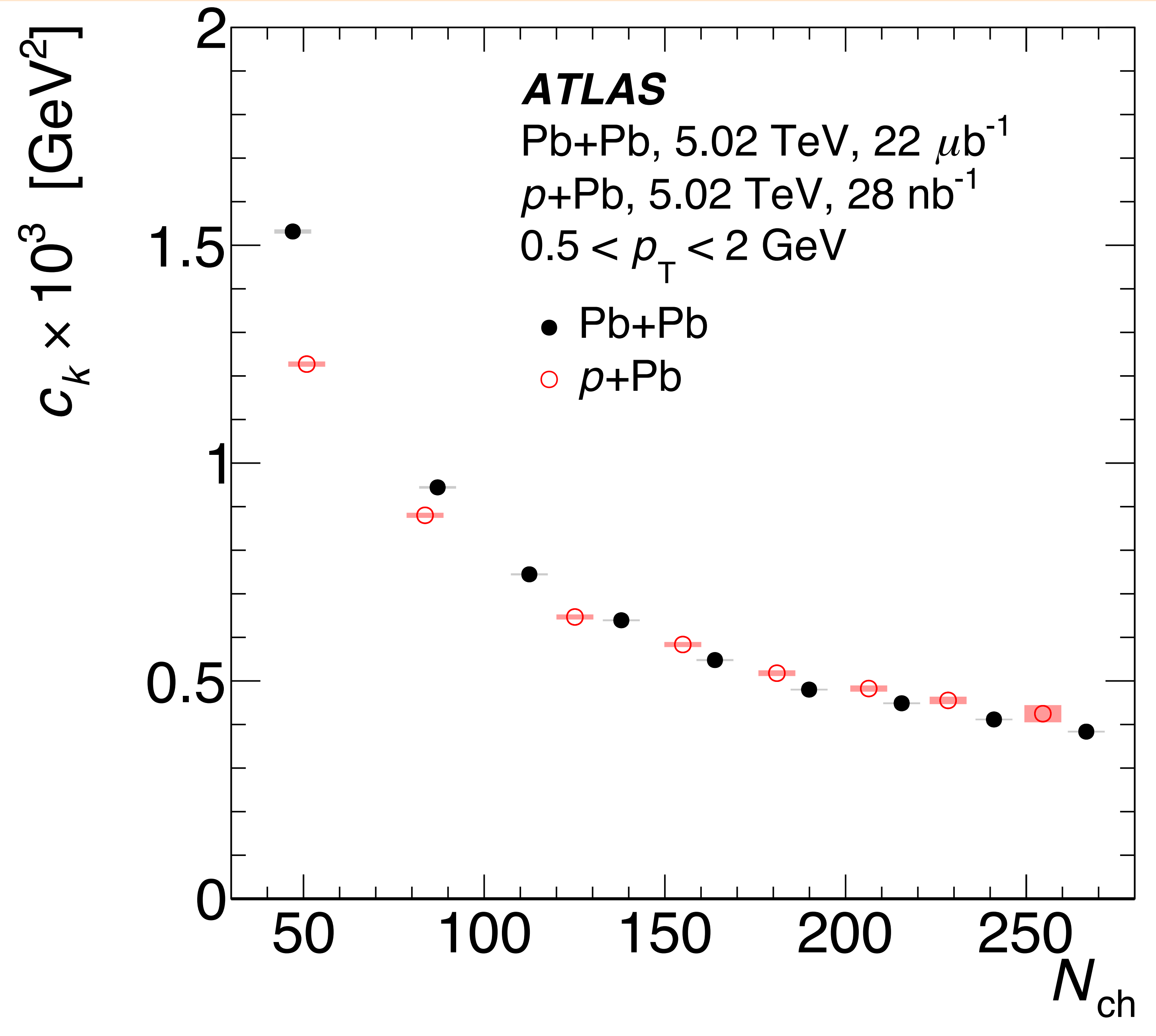
Ingredients of ρ for v_2 in p+Pb

Negative covariance, will determine sign of ρ

$\rho =$



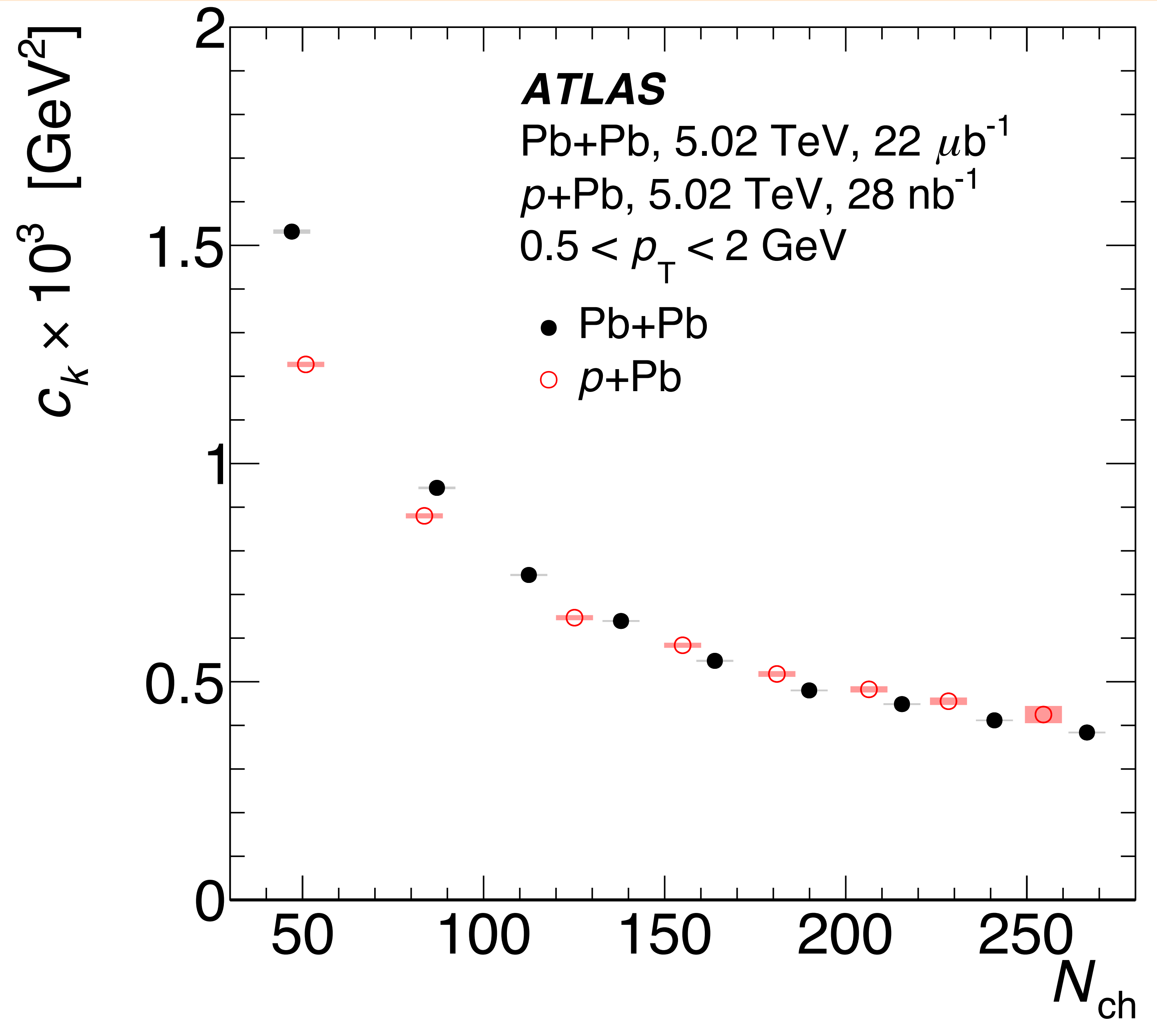
The ρ for v_2 in *p+Pb* vs *Pb+Pb*

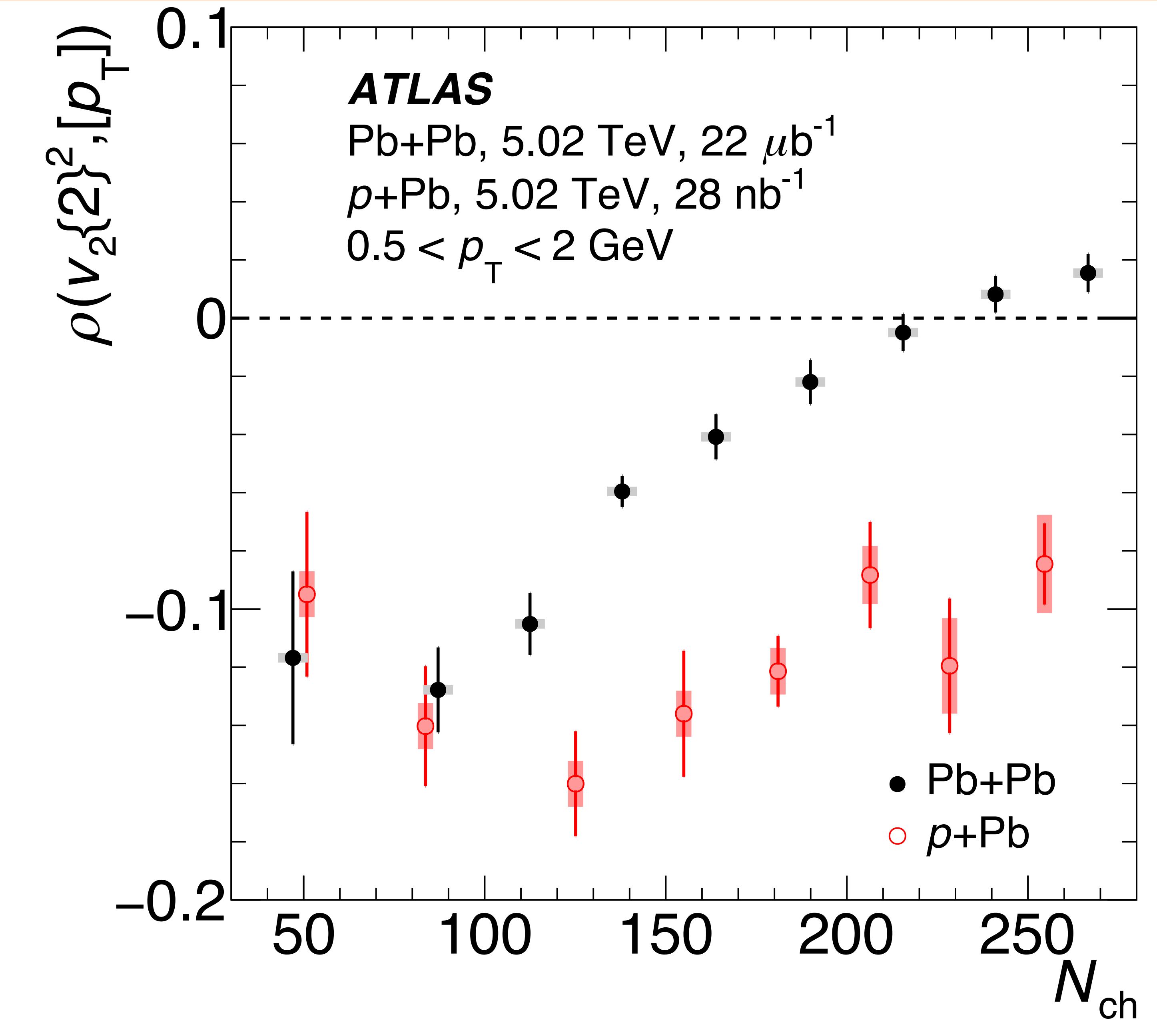


The $[p_{\mathrm{T}}]$ fluctuations are of similar magnitude in *p+Pb* and peripheral *Pb+Pb* when matched N_{ch}

The difference in the ρ values driven by the flow

The ρ for v_2 in *p+Pb* vs *Pb+Pb*





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The difference in the ρ values driven by the flow

The ρ for v_2 is negative in high multiplicity *p+Pb* collisions, for $N_{ch} < 100$, compatible with *Pb+Pb*

No geometry driven trend observed in *p+Pb* compared to a clear effect in *Pb+Pb*

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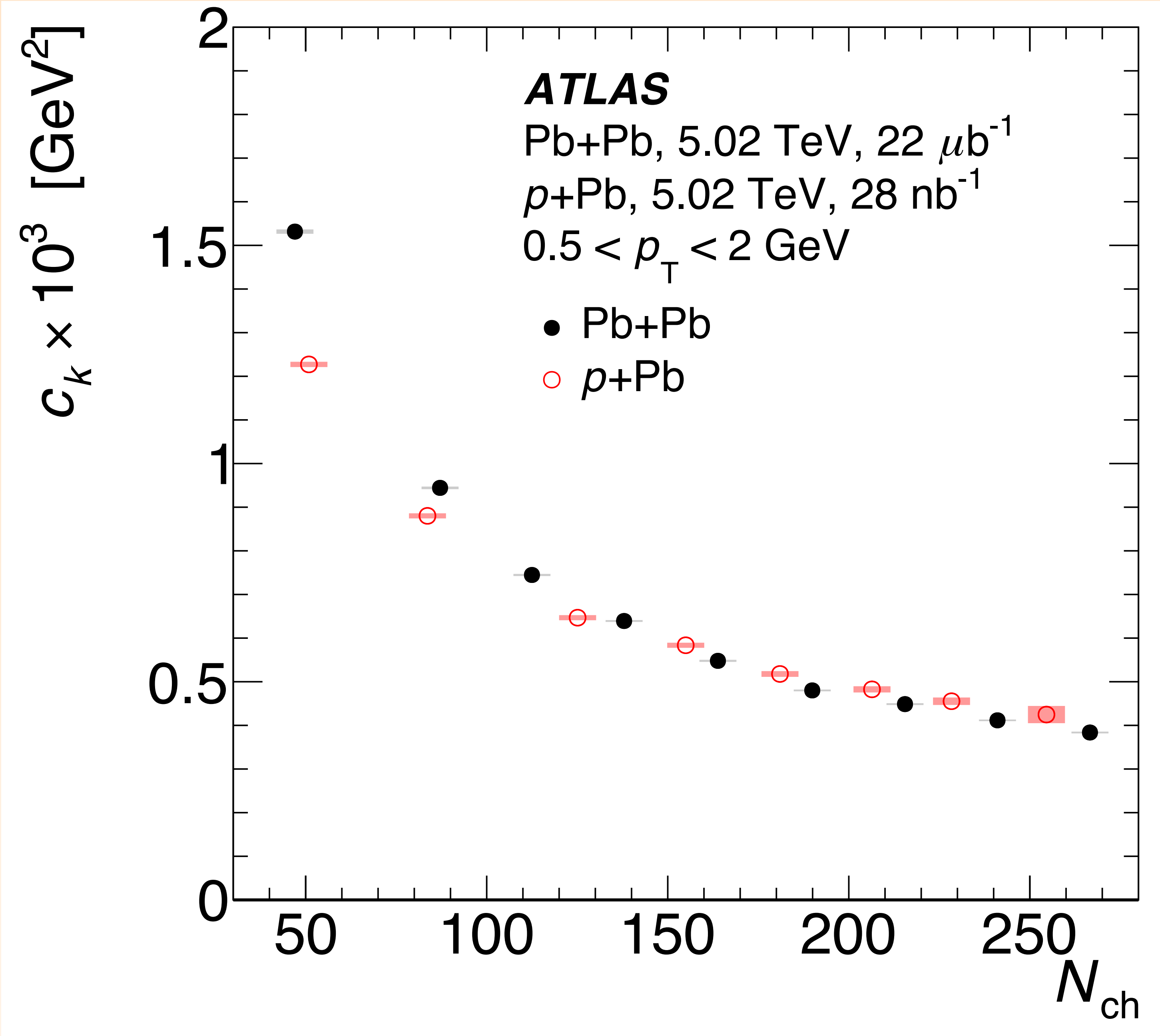

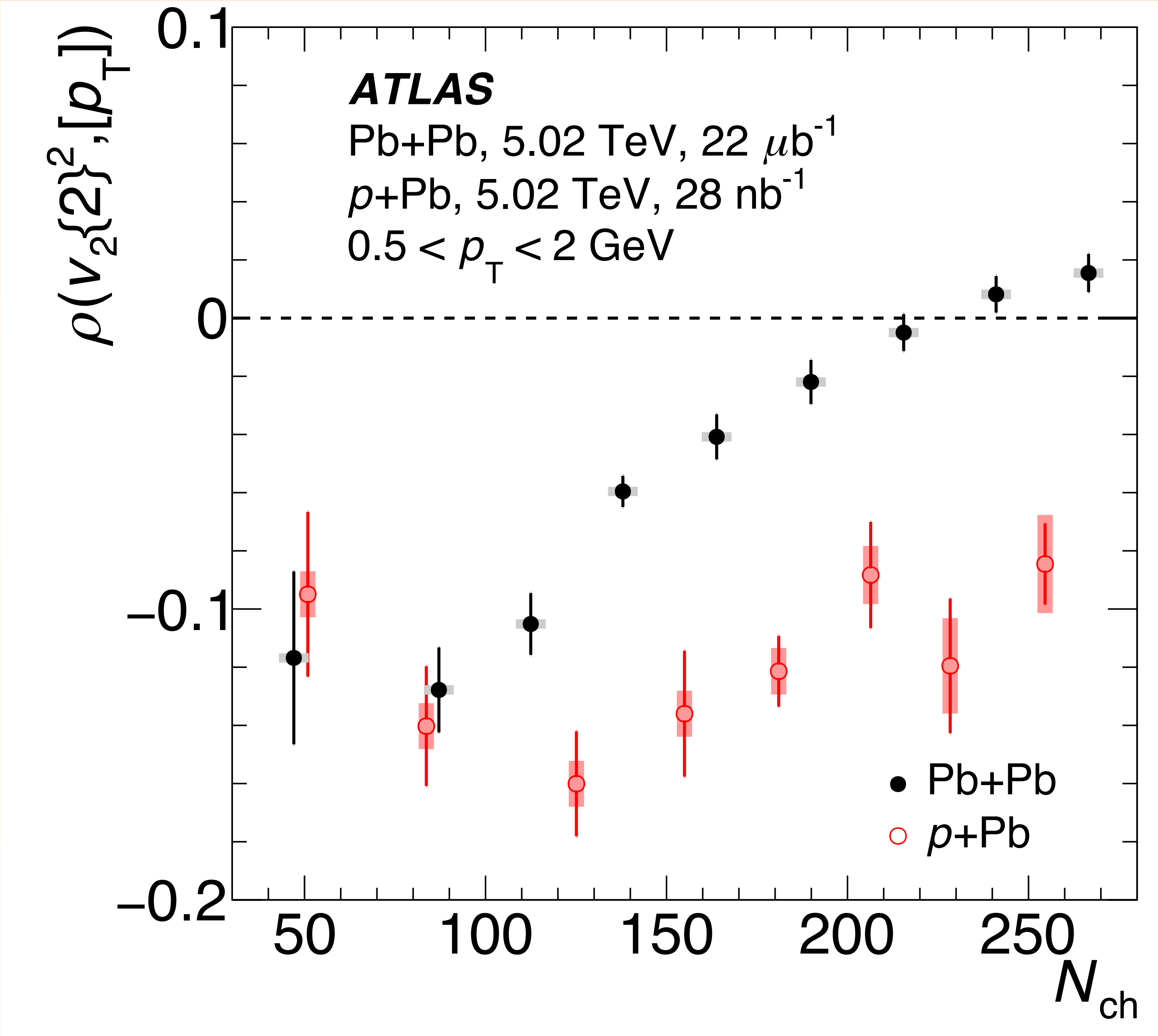

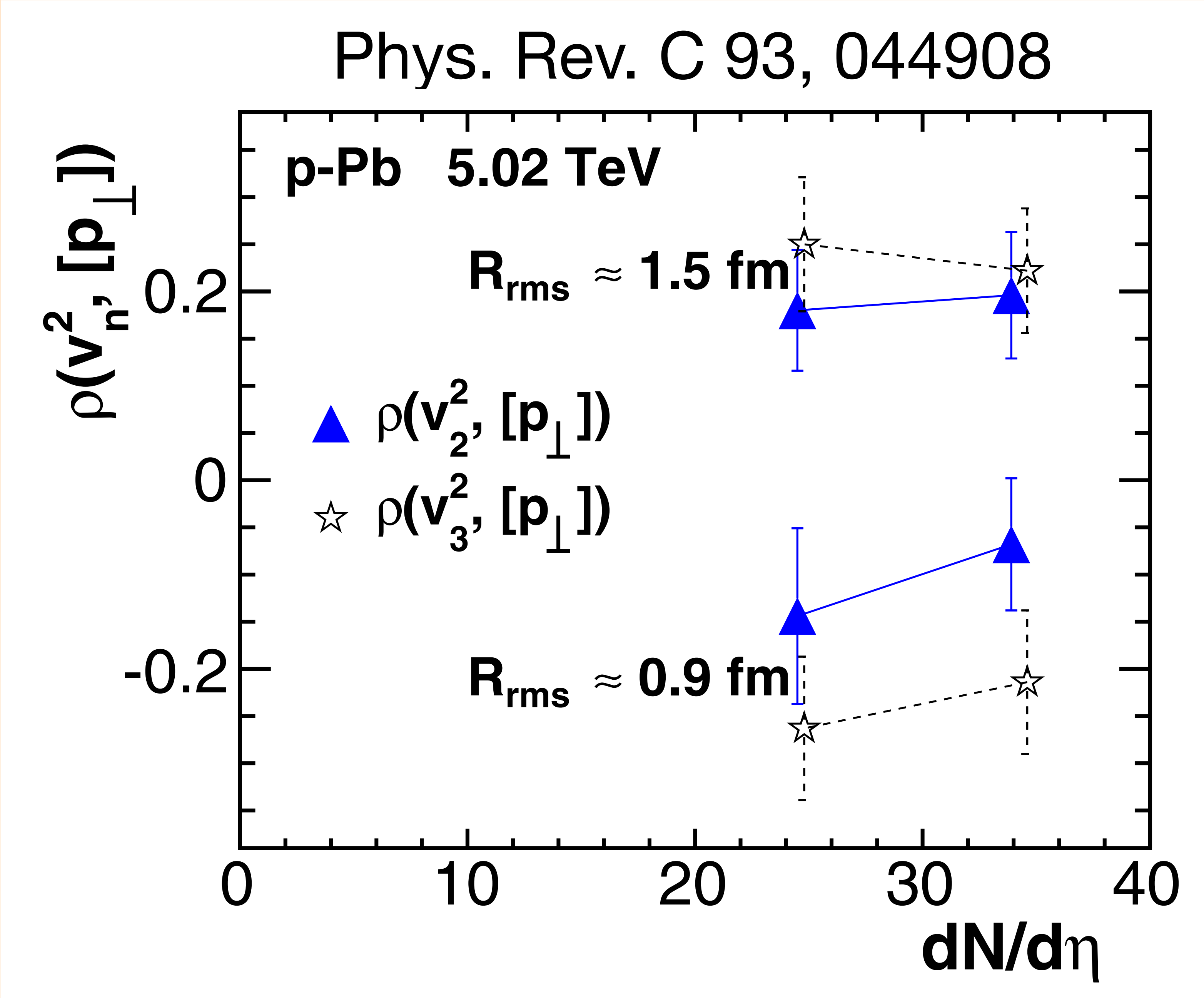

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The difference in the ρ values driven by the flow

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No geometry driven trend observed in *p+Pb* compared to a clear effect in *Pb+Pb*

Favours small dimensions of the initial state —> higher pressure ($[p_T]$), low eccentricity (v_2)

High p_T v_n in p+Pb

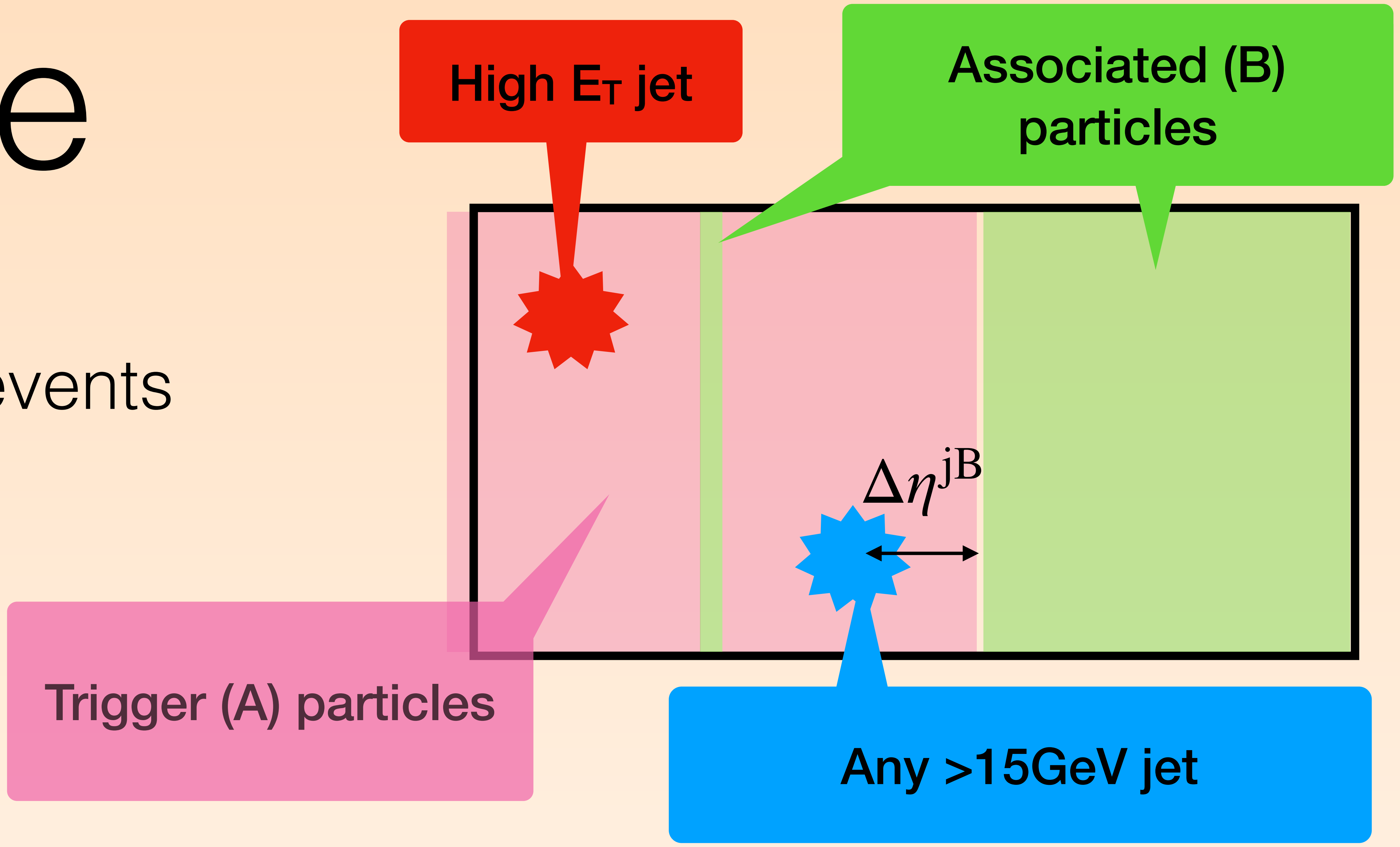
Eur. Phys. J. C 80 (2020) 73

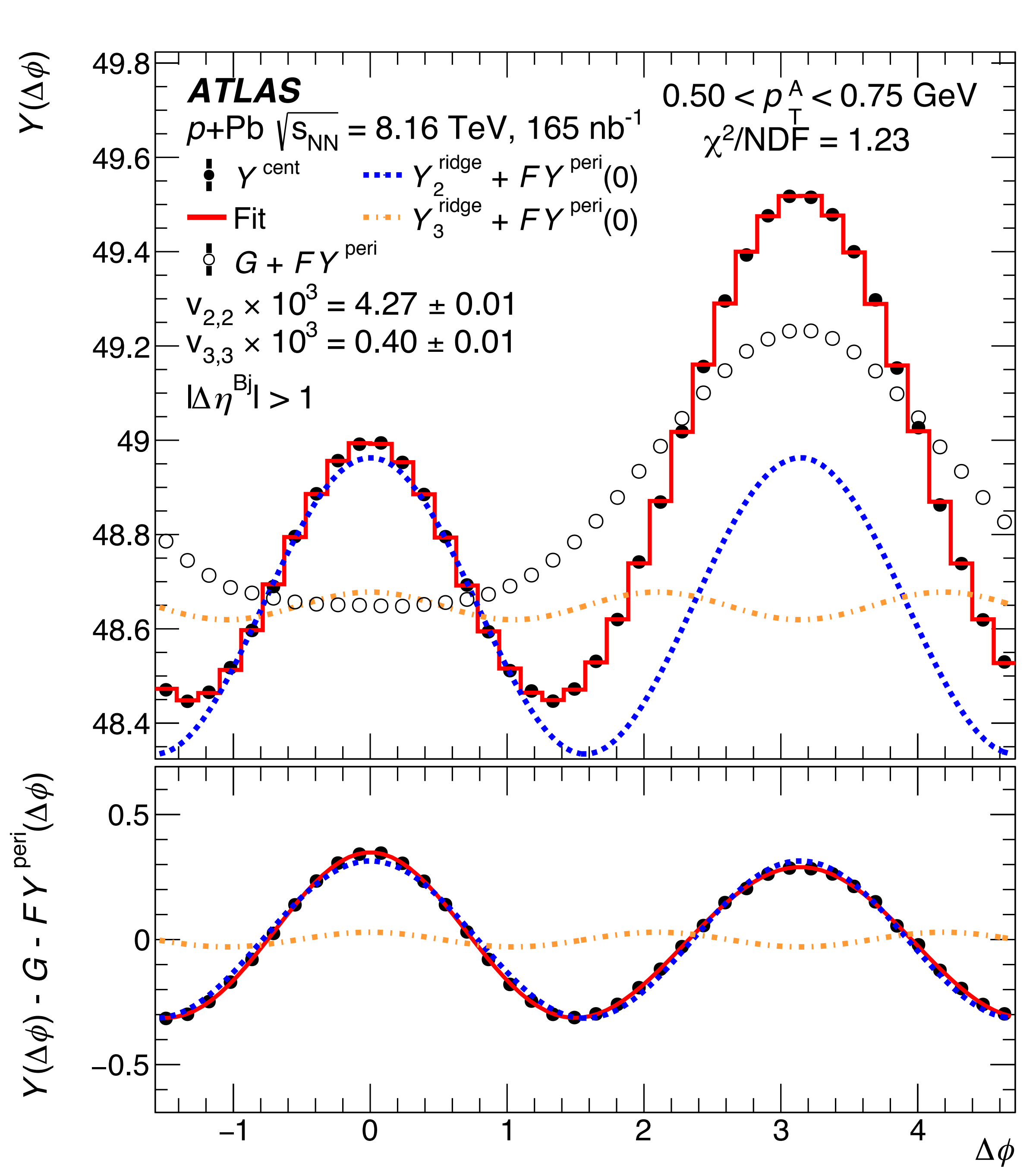
The idea

- Low p_T behaviour of the flow signal in p+Pb collisions confirmed to be produced by hydrodynamical evolution of QGP, what about high p_T?
  - The mechanism is different - jet energy loss sensitive to an average path in QGP medium
  - Yet jet-quenching not observed in p+Pb collisions!
  - And no spectra modification at high-p_T!

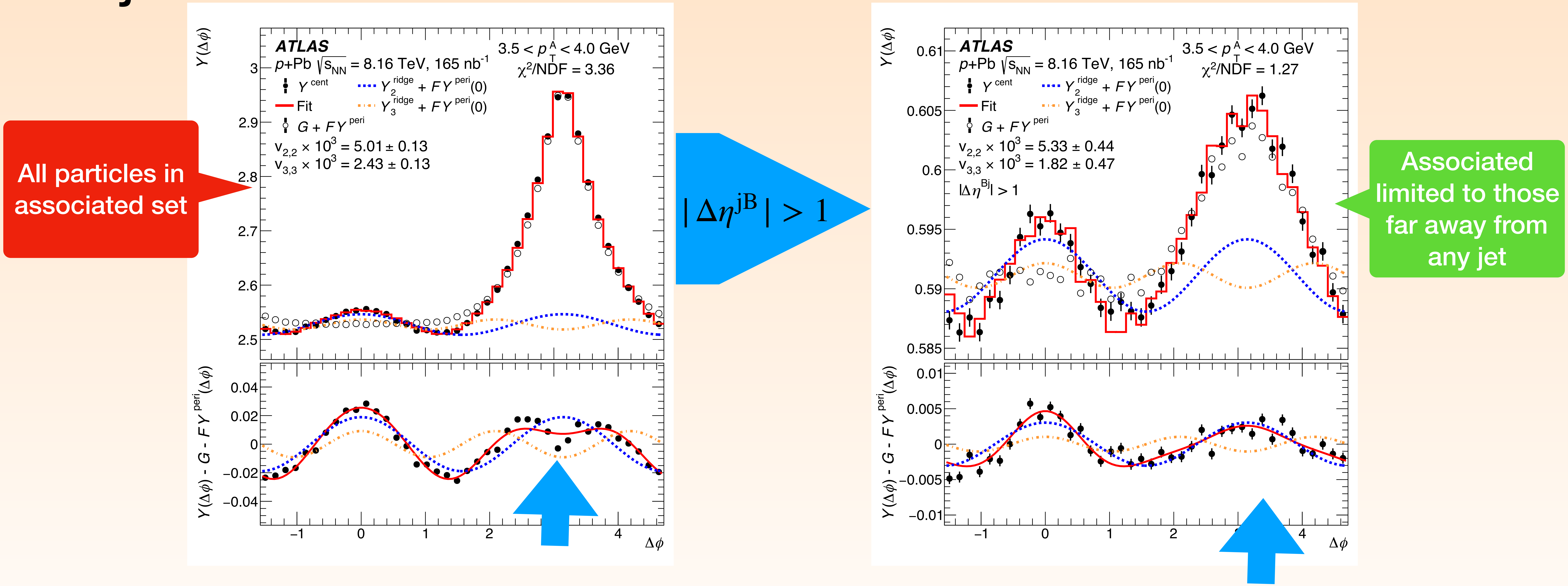
Analysis procedure

- Inclusive & jet ($E_T > 75$ and $100\ GeV$) triggered events
- Construct 2PC using ID tracks ($p_T > 0.4\ GeV$):
  - Trigger (A) particles: inclusive or in jets
  - Associated (B) particles:
    $|\Delta\eta^{AB}| > 2$ - inclusive analysis
    away from any $15\ GeV$ jet $|\Delta\eta^{jB}| > 1$ - jet triggered sample
- ATLAS peripheral templates fit to extract genuine flow signal $v_{n,n}$ and assuming factorisation v_n is obtained





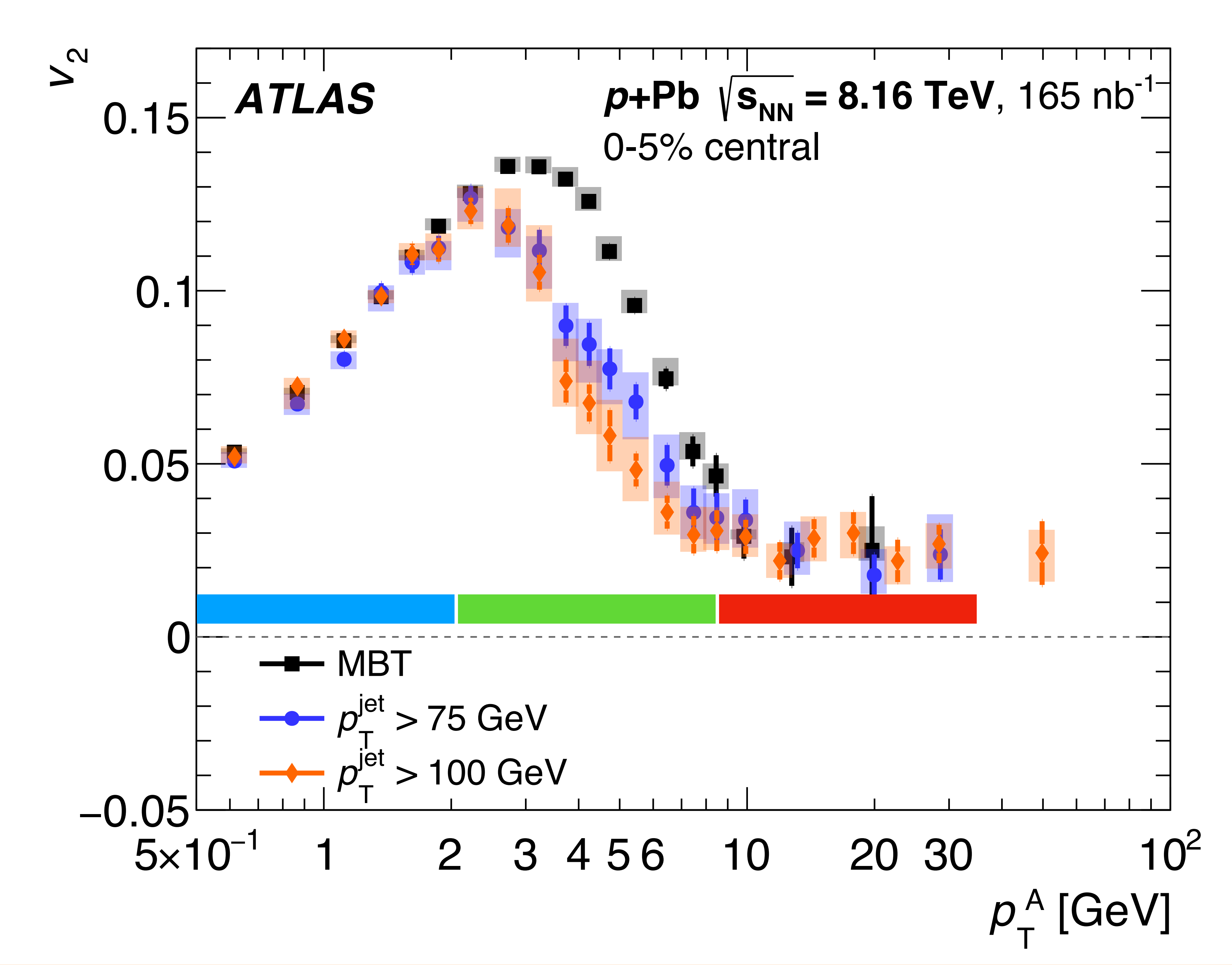
Restriction of associated particles in jet events

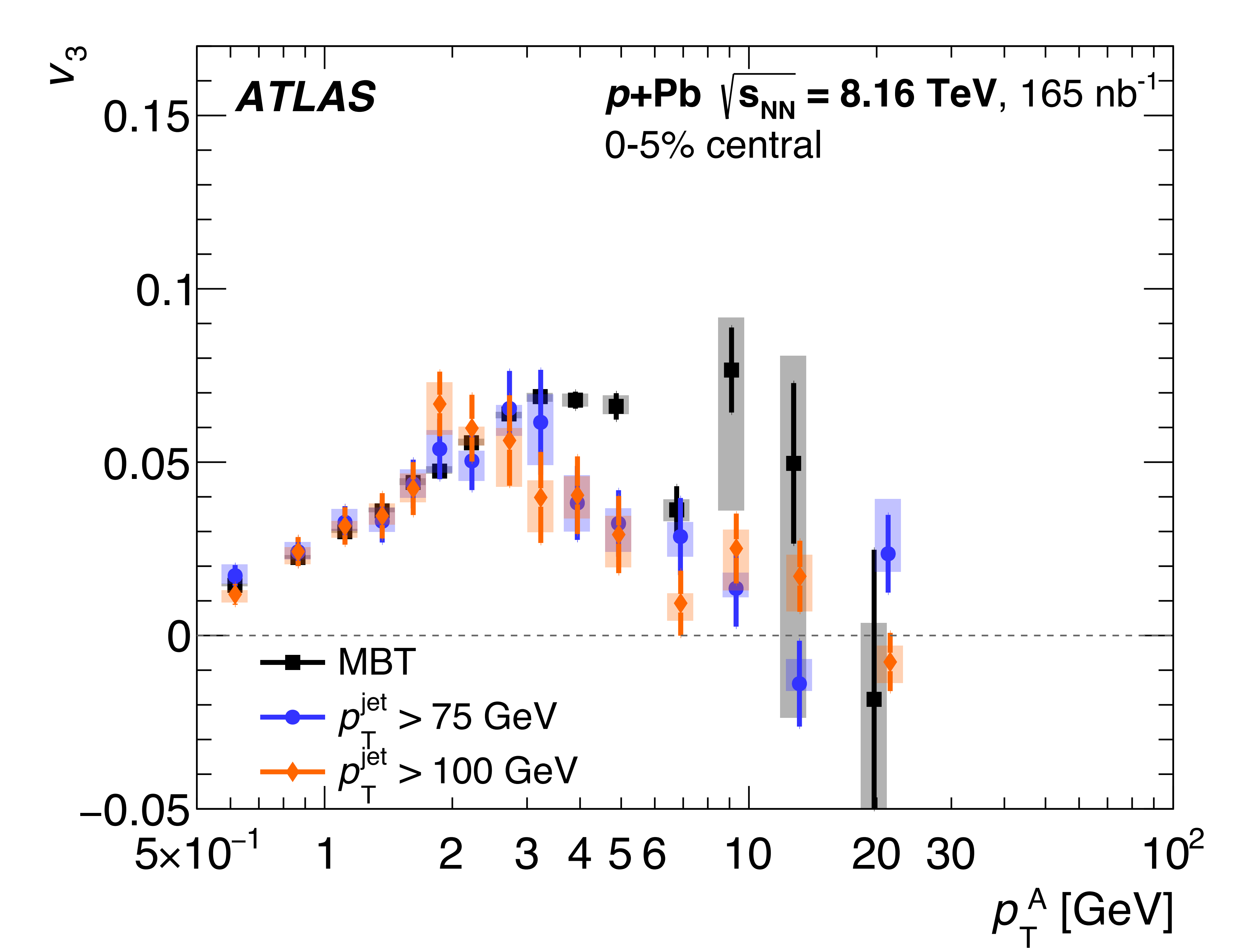


- Reduced statistics but improved fit quality: better S/B ratio

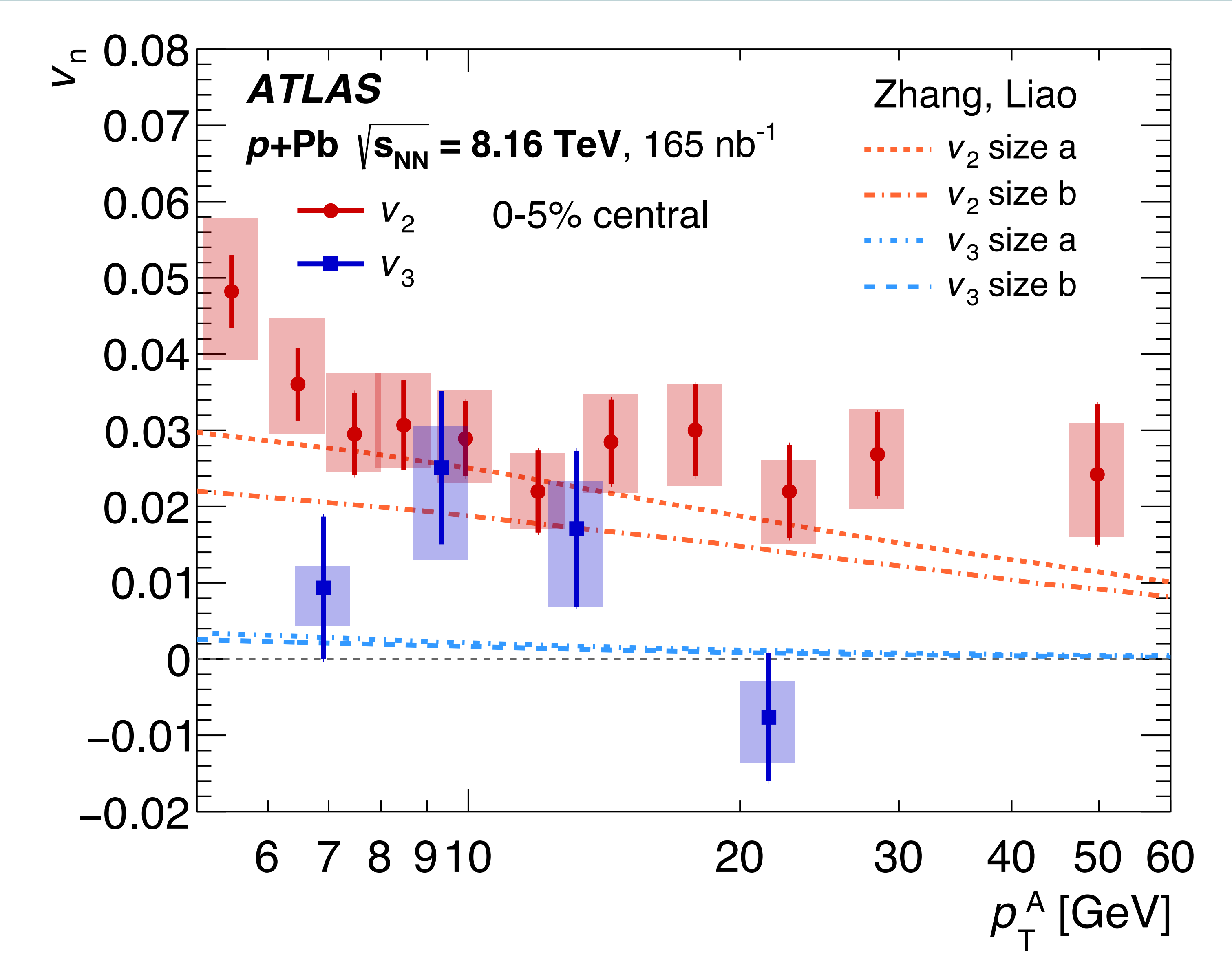
$v_n(p_T)$

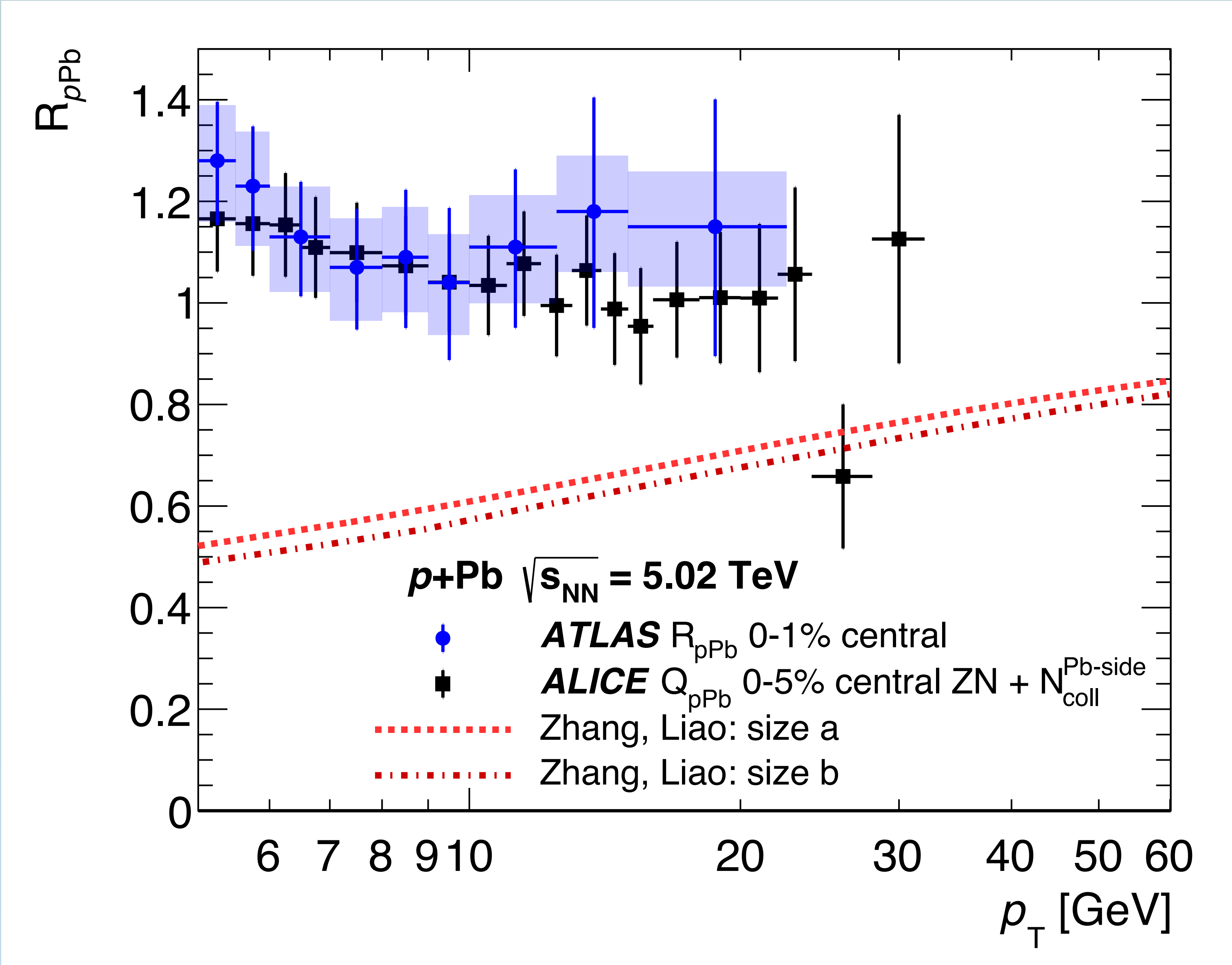
- v_2
  - Both classes of events agree at low $p_T < 2.5\ GeV$ - hydrodynamics
  - Also agree at high $p_T > 10\ GeV$
  - $v_2 \simeq 2.5\ \%$ at high pT
  - Transition region: sensitive to the mixture of “bulk” and “jet” particles
- v_3
  - Similar behaviour as for v_2 - lack of statistics precludes firms statement about high p_T

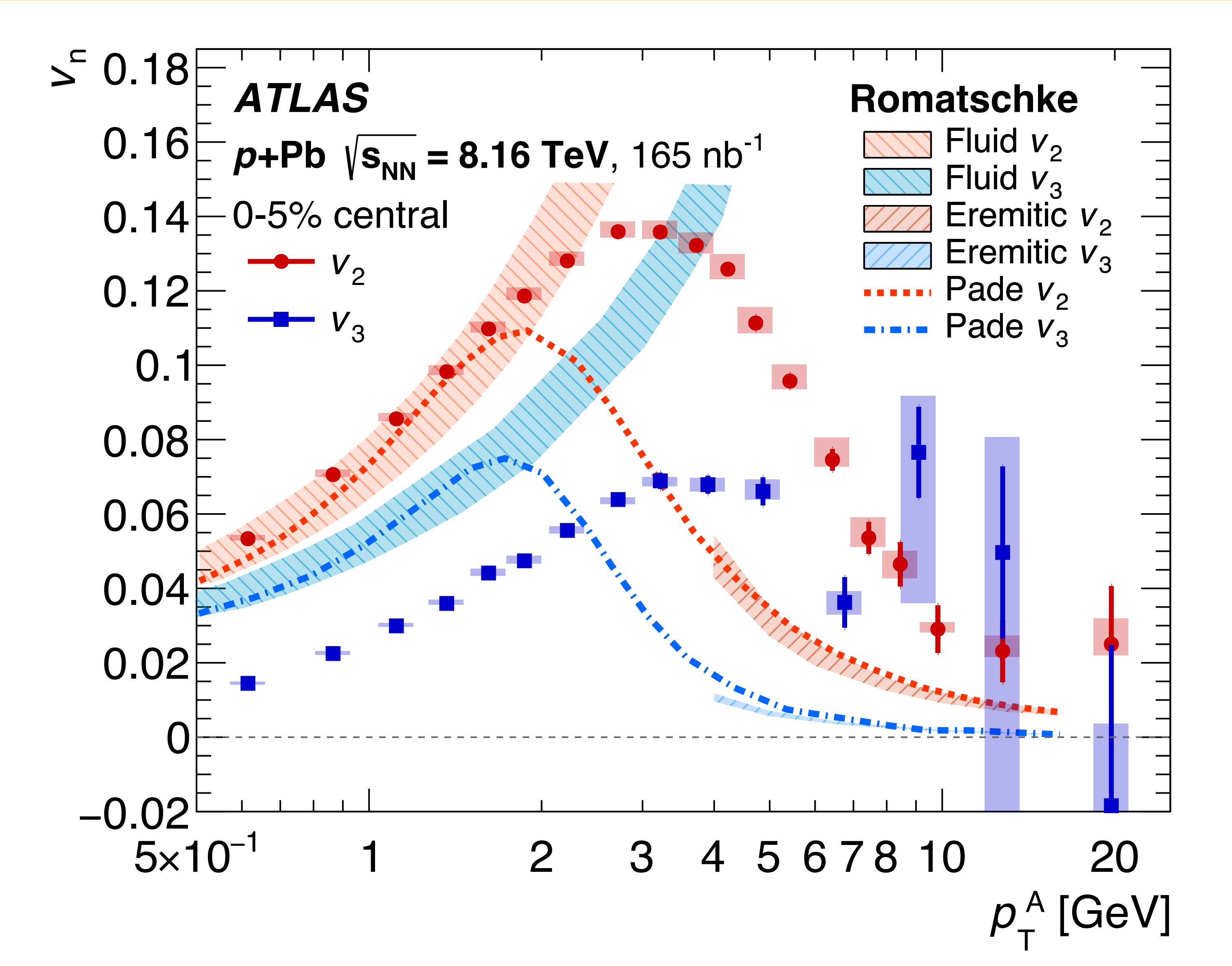




Comparison to models







Jet-quenching calculations (X. Zhang and J. Liao arXiv: 1311.5463)

→ predict flow signal at high p_T yet,

→ however, also predict strong suppression of high p_T hadrons,

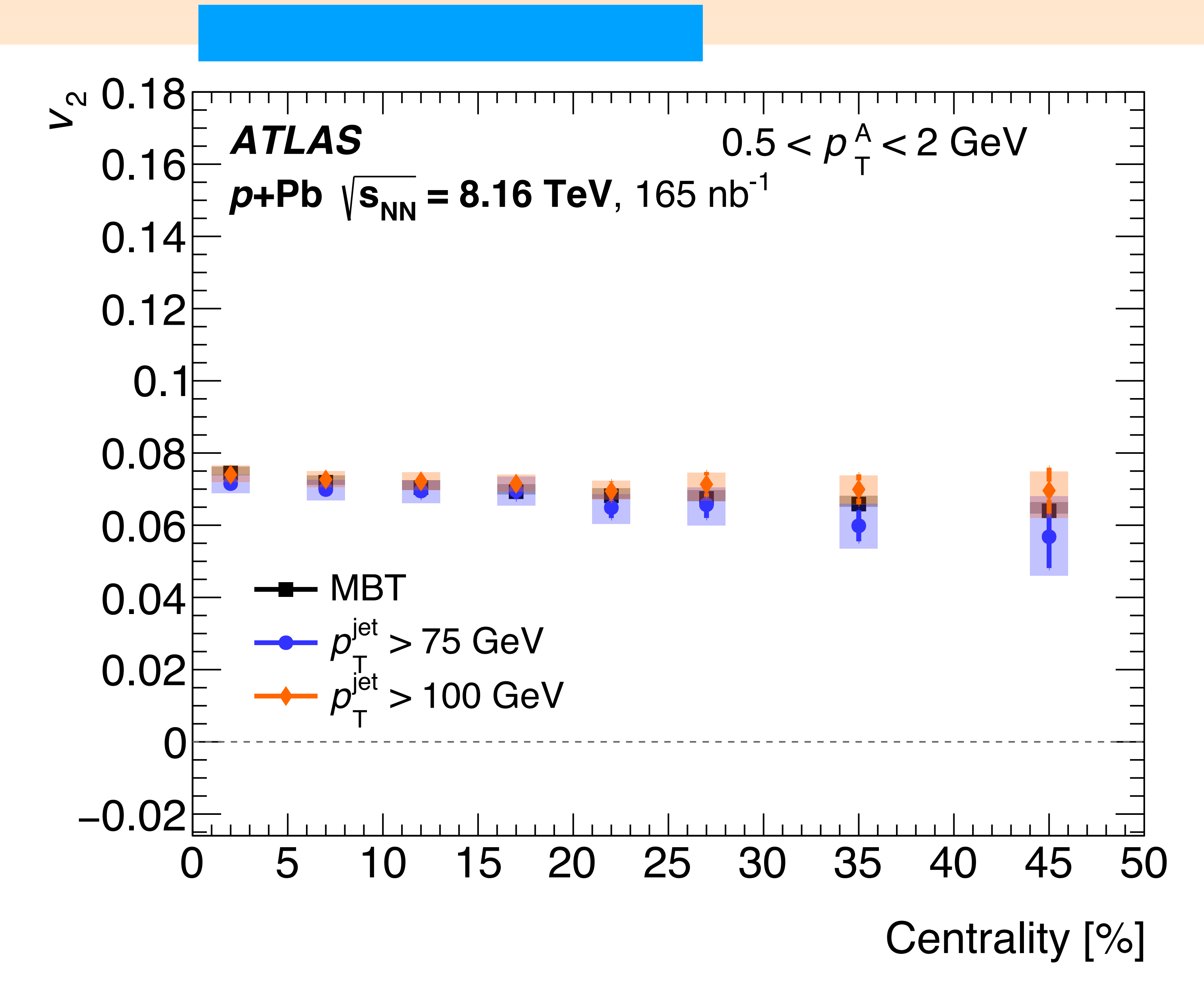
A two component model (Romatschke arXiv: 1712.05815)

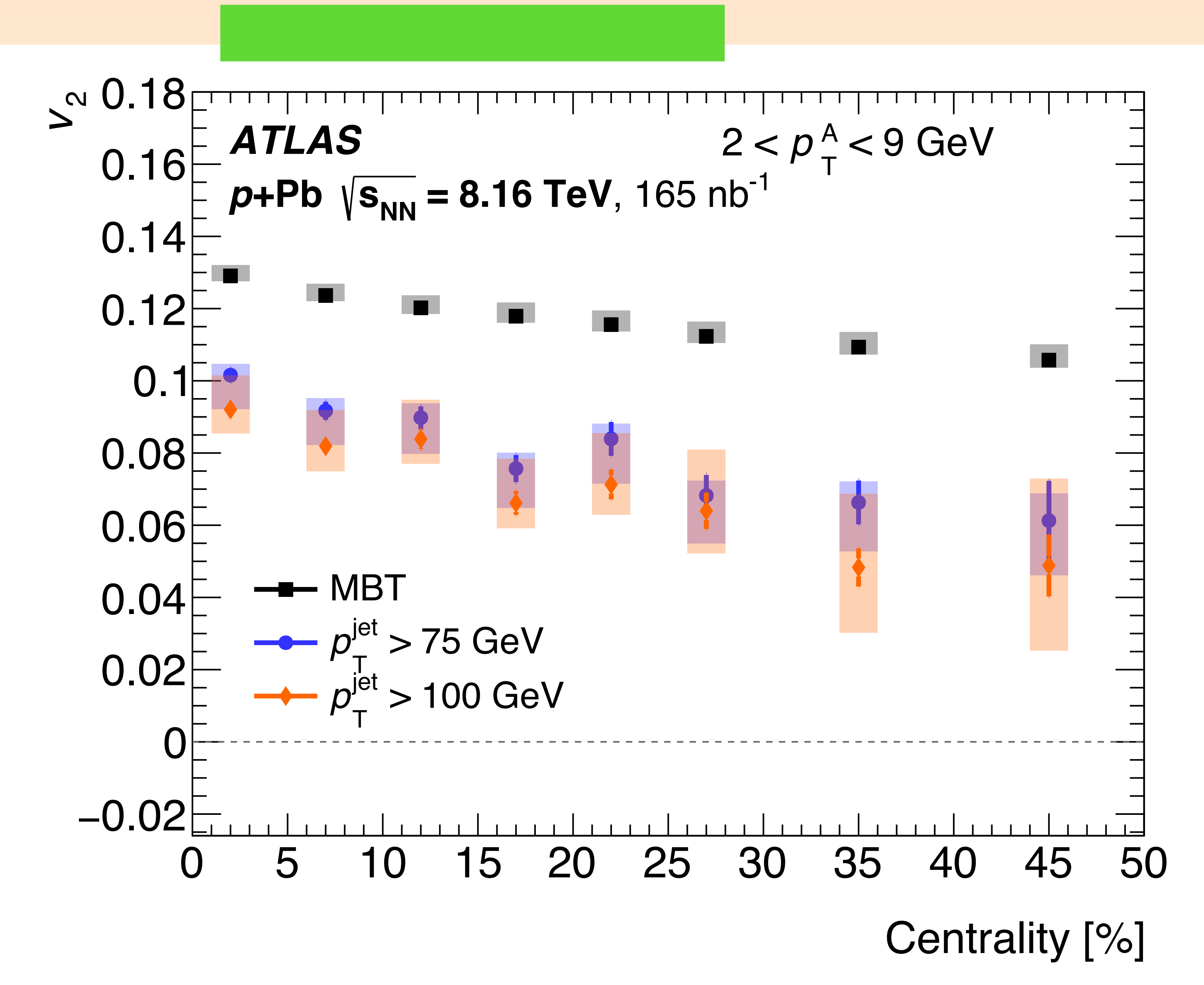
→ quantitatively describe v_2 at low p_T

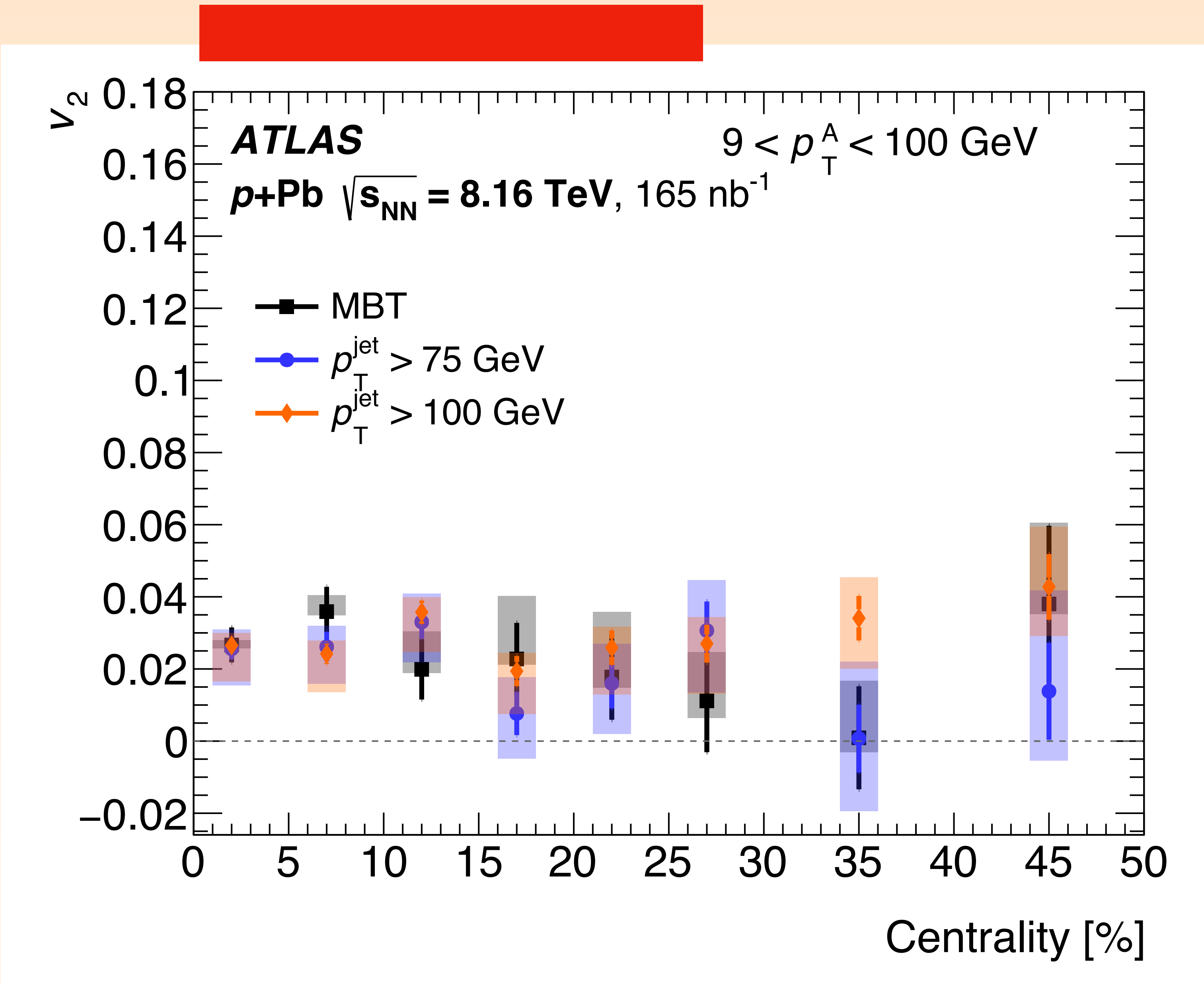
→ hint features at high p_T

→ yet well below observed values.

Centrality dependence







- Measured v_2 independent of centrality at low & high p_T
- Transition region depends on mixture of bulk- and jet-particles

Conclusions

- ATLAS measured correlations of v_n with event mean-p_{T} in *Pb+Pb* and *p+Pb*
  - Significant values for all harmonics in central *Pb+Pb*
  - For peripheral *Pb+Pb* collisions and *p+Pb* the ρ for v_2 correlation is negative and $\sim$ compatible
  - Hydrodynamical simulations predicted such behaviour, useful insight into **initial conditions** in *p+Pb*
- ATLAS measured flow coefficients at high p_T in *p+Pb*
  - Found significant values for v_2, same in inclusive and jet enhanced sample
  - Theoretical models can describe this particular behaviour - yet not a complete picture