Flow harmonics and mean p_T correlations in 5.02 TeV Pb+Pb and p+Pb collisions with the ATLAS detector

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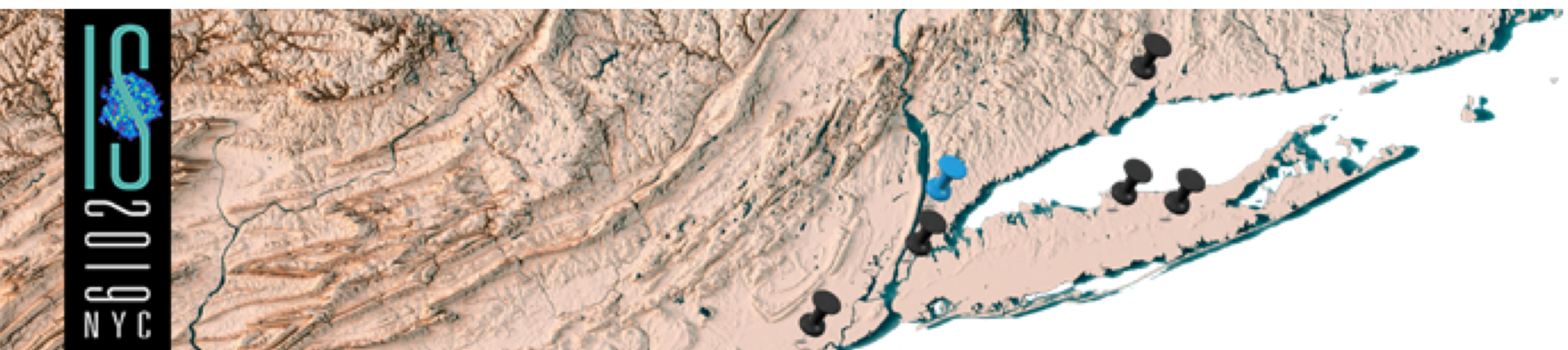
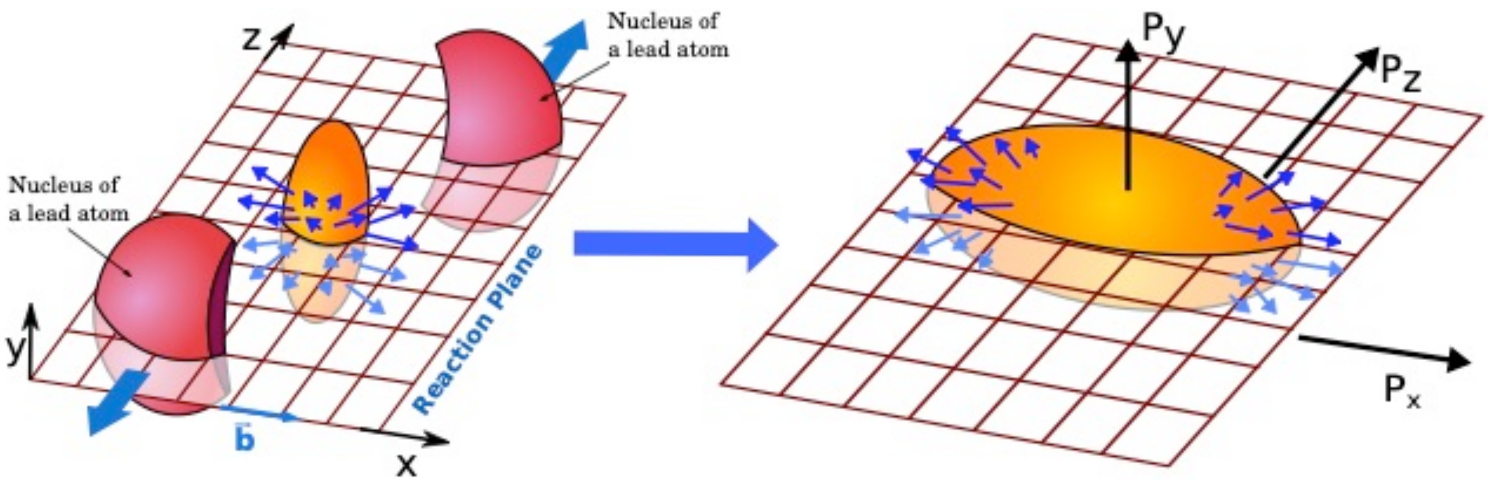


Flow harmonics and mean p_T correlations

Pressure gradients in QGP lead to azimuthal anisotropy

Pressure gradients in QGP lead to variation in the $[p_T]$



As a consequence, its expected that, event-by-event azimuthal flow harmonics should be correlated with the mean p_T, $[p_T]$, of the event.

ALICE measured that the spectra of charged particles become harder when the azimuthal asymmetry in an event increases

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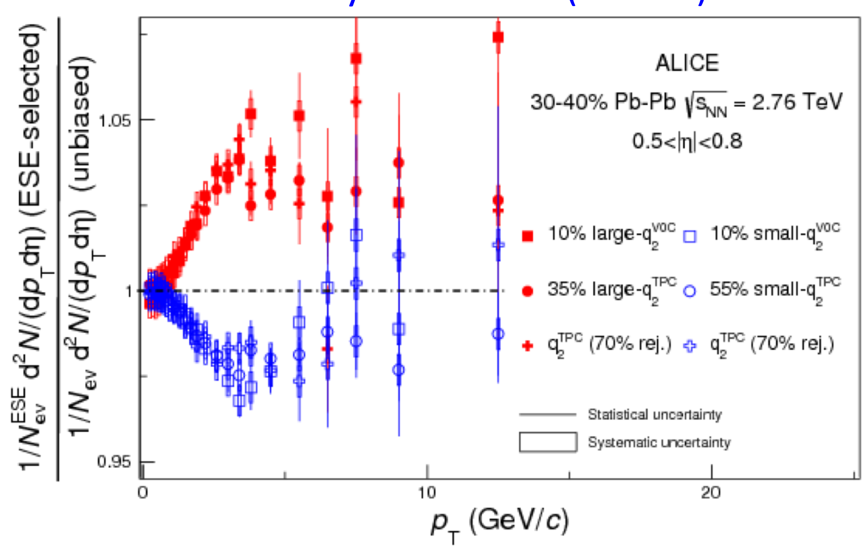


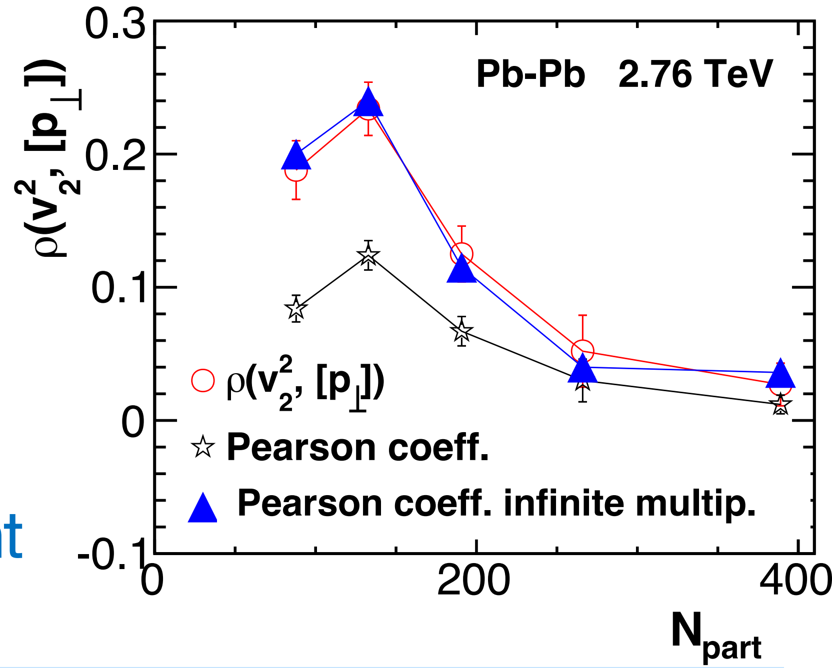
Measurement of flow harmonics and mean p_T correlations

The new method to measure the relationship is proposed:

→ study the $p_T - v_n$ correlations via a modified Pearson correlation coefficient (P. Bozek, PRC 93 (2016) 044908)

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

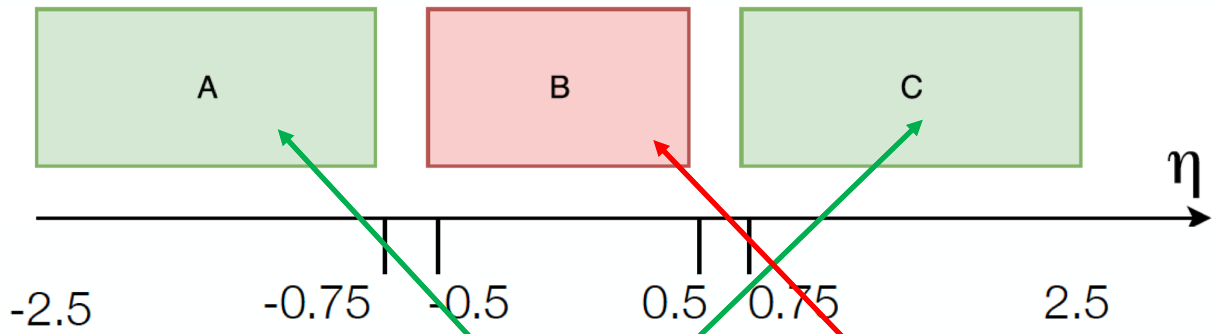
- Variances of $[p_T]$ and $v_n\{2\}^2$ contain additional terms due to limited multiplicities
  → replaced by better "dynamical" estimators



→ detector independent measurement

Measurement details

Define three sub-events:



$$\mathrm{cov}(v_n\{2\}^2, [p_\mathrm{T}]) = \left\langle \langle cos\left(n\left[\phi_a - \phi_c\right]\right)\rangle \left([p_\mathrm{T}] - \langle [p_\mathrm{T}]\rangle\right) \right\rangle$$

- v_n^2 measurement in sub-events A and C: $v_n^2 = \langle cos\left(n\left[\phi_a - \phi_c\right]\right)\rangle$
- Mean event p_T measured in sub-event B: $[p_\mathrm{T}] = \frac{1}{N_b}\sum_b p_{\mathrm{T},b}$
- Multiplicity used to estimate „event activity" classes
- Rapidity gaps used to suppress non-flow

Scope of the analysis

- Measurement of correlation of $[p_T]$ with v_2, v_3 and v_4 in 5.02 TeV Pb+Pb (22μb^{-1}) as a functions of N_{ch} and N_{part}
- Correlation of $[p_T]$ with v_2 in 5.02 TeV p+Pb (28nb^{-1}) as a function of N_{ch} **New at this conference!**
  - For each of above the covariances and dynamical v_n variances and c_k are also obtained
- Measurements performed for complementary p_T intervals for each system:

	p+Pb	Pb+Pb
„hydrodynamical" region (main result):	0.3 - 2 GeV	0.5 - 2 GeV
including higher p_T for energy loss sector:	0.3 - 5 GeV	0.5 - 5 GeV
low p_T and low multiplicity:	0.5 - 2 GeV	1 - 2/5 GeV

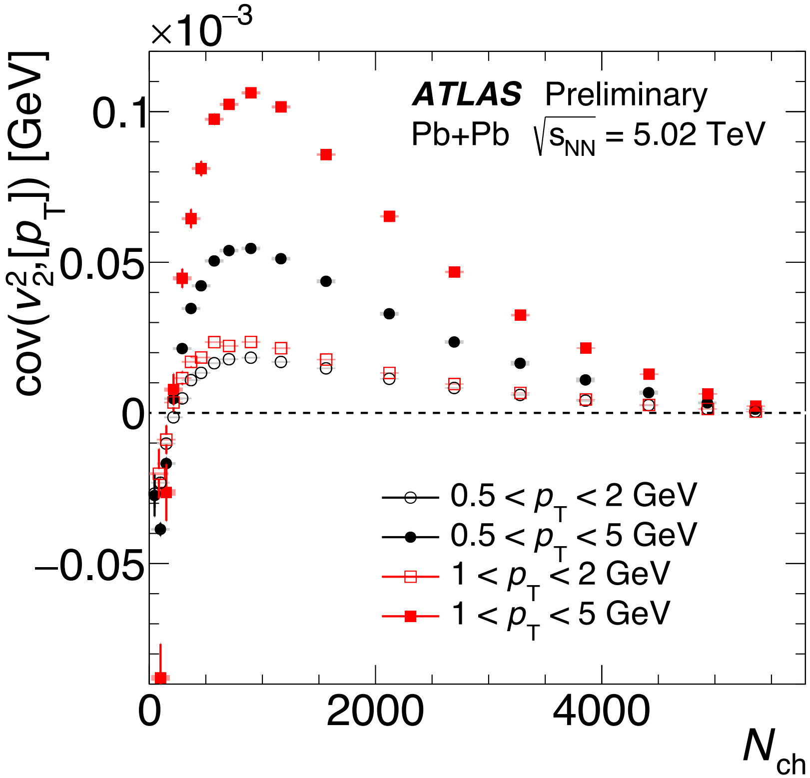
- Final results are presented as a function of charged particle multiplicity, N_{ch}, of p_T = 0.5-5GeV and $|\eta|<2.5$, with detector effects unfolded

“Ingredients” of $\rho(v_2,[p_T])$: covariance

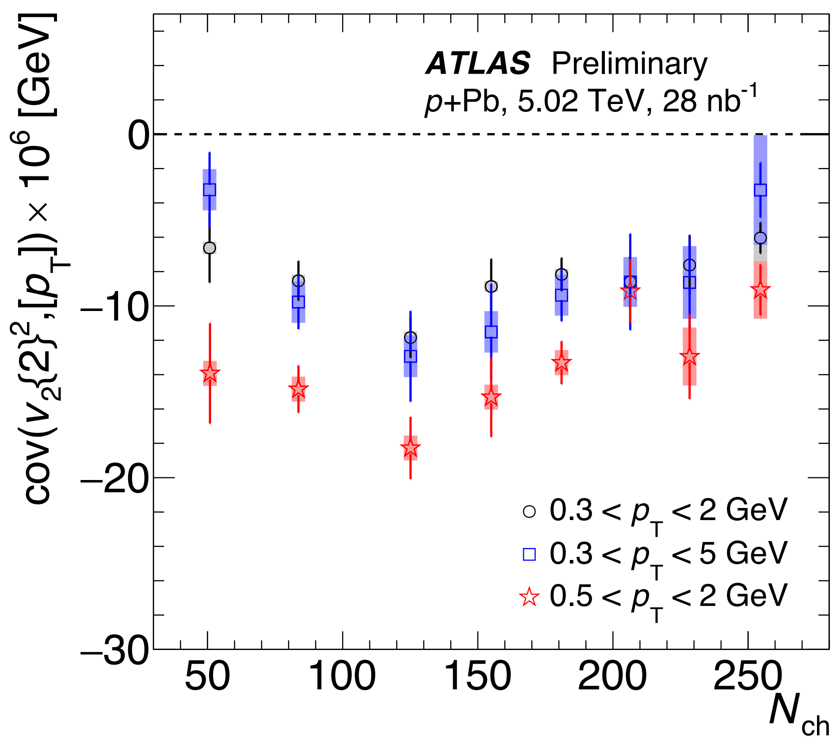
ATLAS-CONF-2018-008

$$\mathrm{cov}(v_n\{2\}^2,[p_\mathrm{T}]) = \left\langle \langle cos\,(n\,[\phi_a - \phi_c])\rangle \; ([p_\mathrm{T}] - \langle [p_\mathrm{T}]\rangle) \right\rangle$$

PbPb



pPb



- ✧ Pb+Pb: cov(v_2) rapidly changes from negative to positive values in peripheral events, after reaching maximum decreases
- ✧ p+Pb: covariance is negative, no apparent dependence on N_{ch} is observed

Dynamical "ingredients" of $\rho(v_2, [p_T])$: c_k, Var_{dyn}

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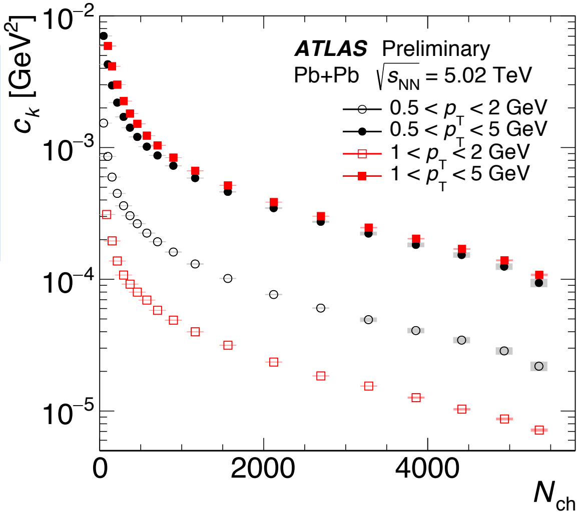
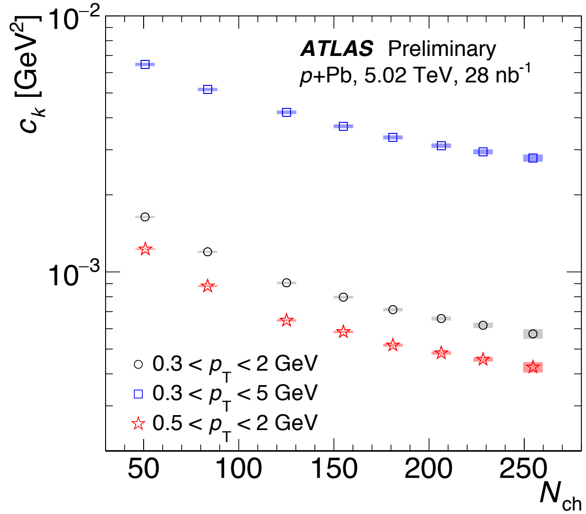
$$c_k = \langle \frac{1}{N_{pair}} \sum_i \sum_{j \neq i} (p_{\mathrm{T},i} - \langle [p_{\mathrm{T}}] \rangle)(p_{\mathrm{T},j} - \langle [p_{\mathrm{T}}] \rangle) \rangle$$

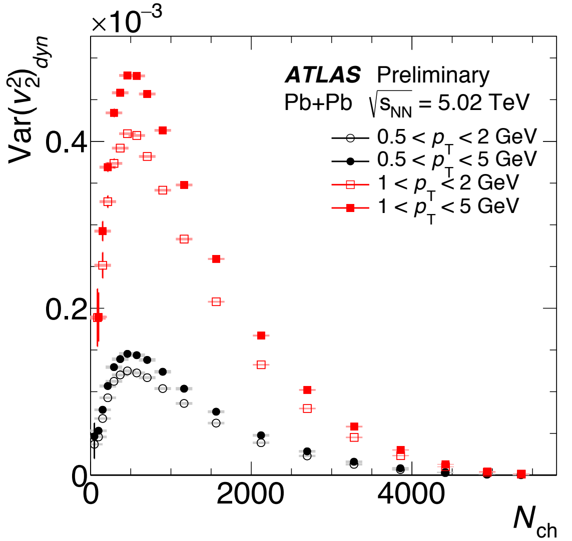
PbPb **pPb**

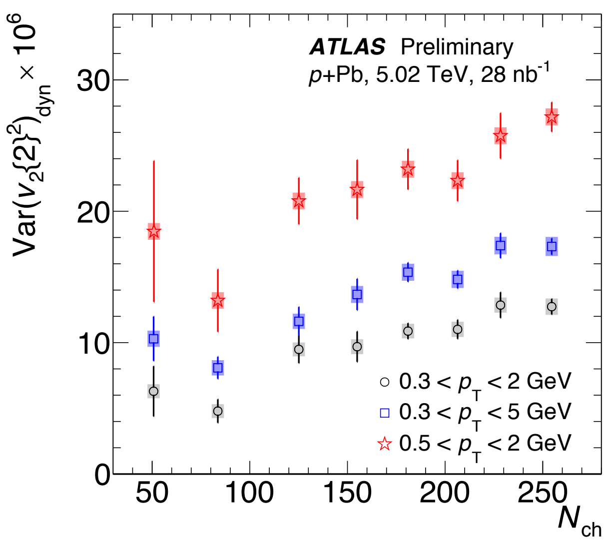
c_k





Var_{dyn}





- c_k decreases with increasing N_{ch} and significantly depends on p_T interval
- $Var(v_n)_{dyn}(N_{ch})$ dependence is similar to $v_n(N_{ch})$ in Pb+Pb
- A weak increase of $Var(v_n)_{dyn}(N_{ch})$ with N_{ch} is observed in p+Pb

$$Var(v_n\{2\}^2)_{dyn} = v_n\{2\}^4 - v_n\{4\}^4$$

$v_n - p_T$ correlations: $\rho(v_2, [p_T])$:

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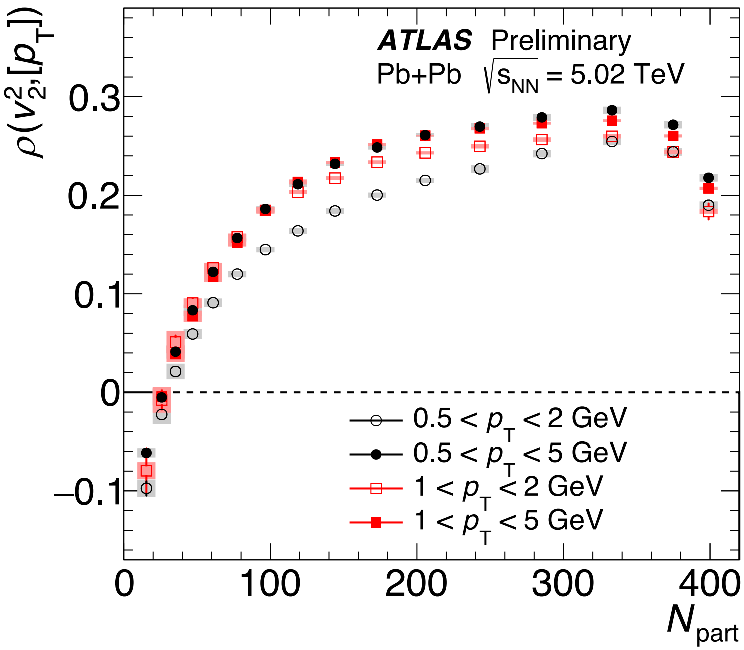
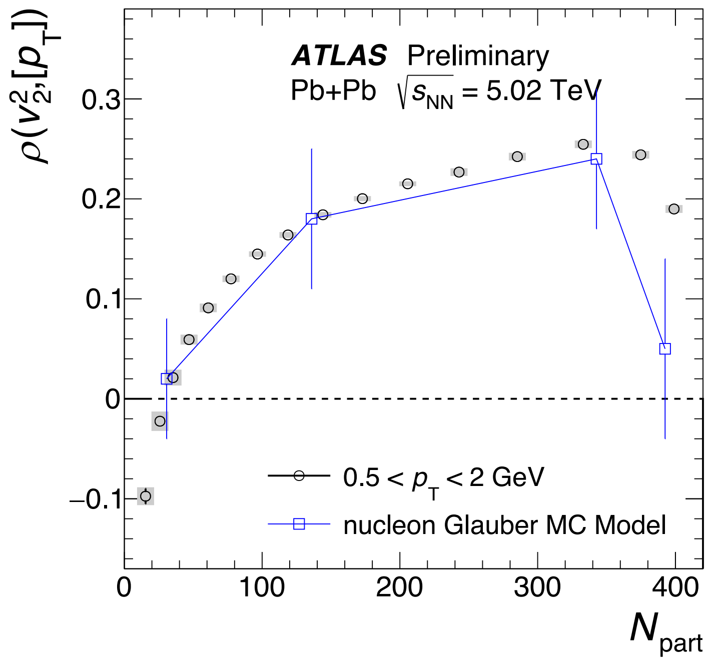
PbPb



PR C93 (2016) 044908



- Positive ρ for all v_n in mid-central & central events
- ρ increases with collision centrality starting from negative values at $N_{part} < 40$
- In the most central collisions ρ decreases with N_{part}
- Reasonable agreement with the theory prediction

$v_n - p_T$ correlations: $\rho(v_3, [p_T])$ & $\rho(v_4, [p_T])$

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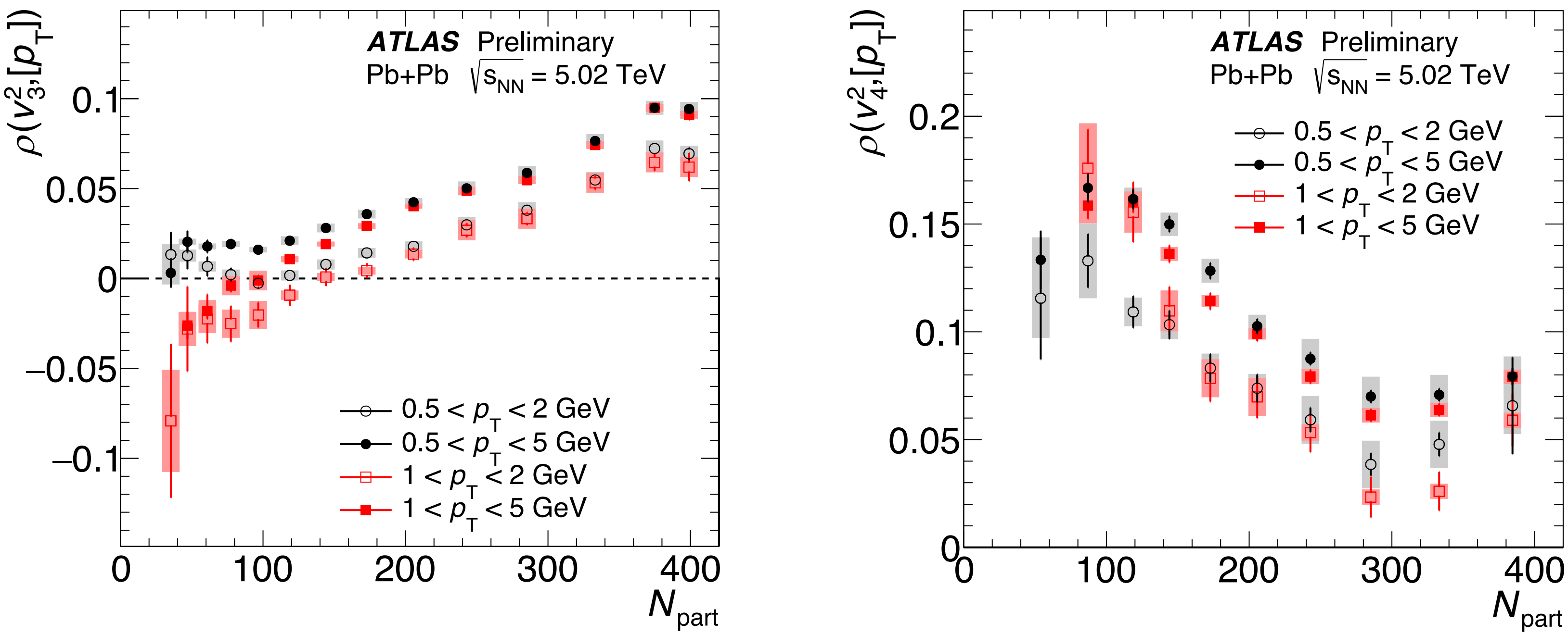
PbPb

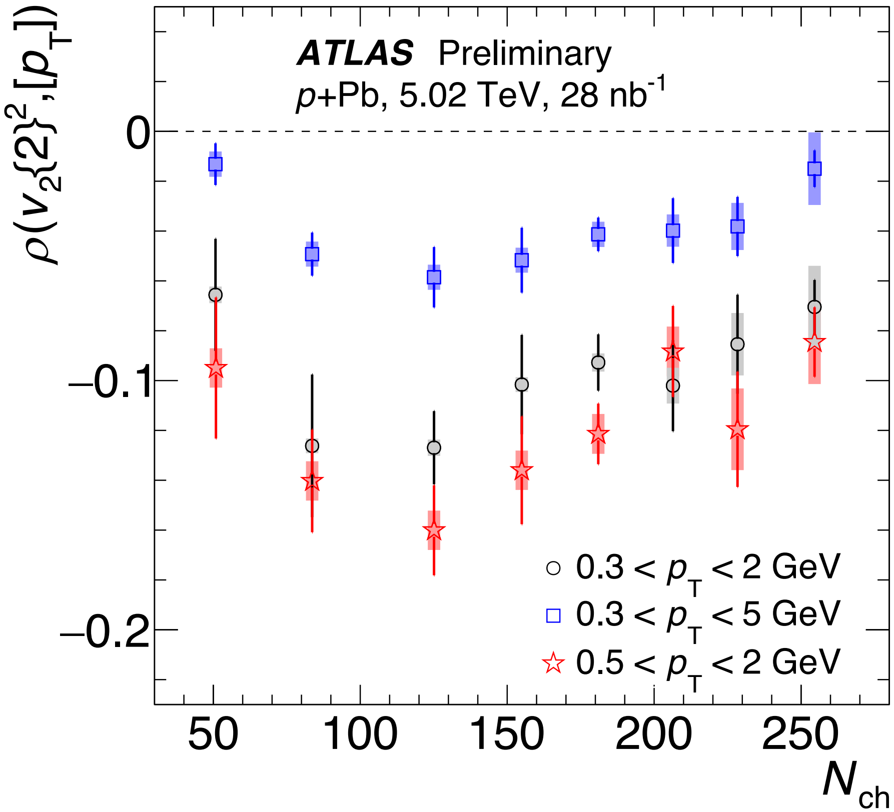


- Positive ρ for all v_n in mid-central & central events
- A weaker N_{part} dependence for v_3 as compared to v_2
- Non-monotonic dependence for v_4
- For higher order v_n the ρ correlation is lower than for v_2

$v_n - p_T$ correlations: $\rho(v_2, [p_T])$ in p+Pb collsions

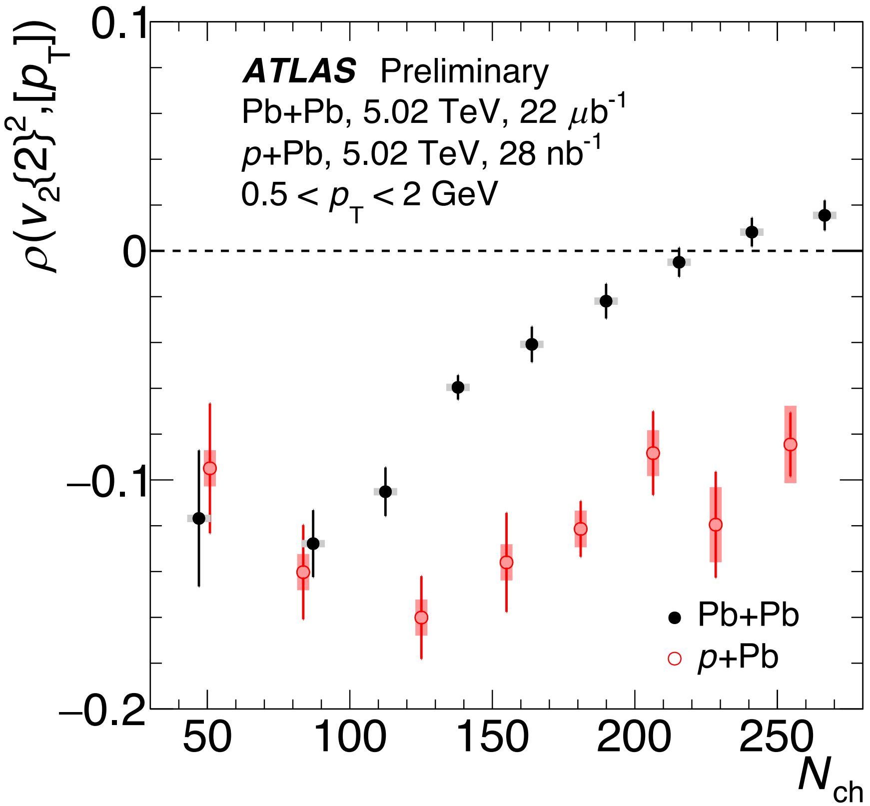
pPb

New at this conference!



- p+Pb: negative values of ρ
- No apparent dependence on N_{ch} → constant within uncertainties
- Similar ρ for 0.3-2/0.5-2 GeV
- ρ magnitude for larger max p_T is smaller

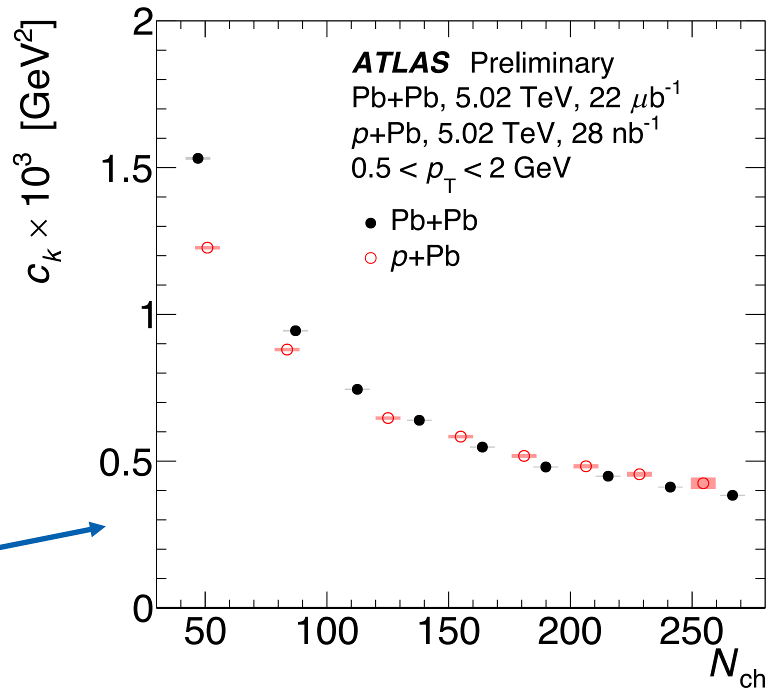
$v_n - p_T$ correlations: $\rho(v_2, [p_T])$ in p+Pb collsions



New at this conference!

p+Pb and Pb+Pb comparison:

- ✧ Correlation in peripheral Pb+Pb and p+Pb events is negative → insight into the small system initial stage
- ✧ The N_{ch} dependence of ρ is different for two collision systems



- ✧ c_k comparable in Pb+Pb and p+Pb for the same p_T interval and N_{ch}

Summary

- ATLAS obtained quantitiative estimate of correlation strenght between v_n and $[p_T]$ in 5.02 TeV Pb+Pb and p+Pb collisions using the modified Pearsons coefficient ρ

  - Found significant values of ρ for harmonics v_2, v_3 and v_4 in Pb+Pb and for v_2 in p+Pb collisions
  - For p+Pb and peripheral Pb+Pb collisions the ρ for v_2 is negative
  - In other centralities the Pb+Pb ρ for v_2 is dominant
  - The correlation for Pb+Pb v_3 is much weaker than for v_2, a weak N_{part} dependence of the ρ for v_3 is observed
  - The ρ for v_4 shows non-monotonic behaviour with N_{part}

- The hydrodynamic model can qualitatively predict that behaviour

- The ρ results provide a quantitative and experimentaly unbiased measure of a connection between anisotropic and radial flows

Thank you for your attention!

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Measurement details

- Variances of $[p_T]$ and $v_n\{2\}^2$ contain additional terms due to limited multiplicities
  - They can be replaced by better "dynamical" estimators

$$R = \frac{cov(v_n\{2\}^2, [p_T])}{\sqrt{var(v_n\{2\}^2)}\sqrt{var([p_T])}} \longrightarrow \rho = \frac{cov(v_n\{2\}^2, [p_T])}{\sqrt{var(v_n\{2\}^2)_{dyn}}\sqrt{c_k}}$$

$var(v_n\{2\}^2)$

EPJ. C74 (2014) 3157

$$var(v_n^2)_{dyn} = v_n\{2\}^4 - v_n\{4\}^4$$
$$= \langle corr_n\{4\}\rangle - \langle corr_n\{2\}\rangle^2$$

$$\langle corr_n\{4\}\rangle = \left\langle \frac{(Q_{n,a}^2 - Q_{2n,a})(Q_{n,c}^2 - Q_{2n,c})^*}{S_a S_c} \right\rangle$$

$$Q_{n,a} = \sum_a w_a e^{in\phi_a} \quad S_a = \left(\sum_a w_a\right)^2 - \sum_a w_a^2$$

$$\langle corr_n\{2\}\rangle = \langle q_{n,a} q_{n,c}^* \rangle$$

$$q_{n,a} = \frac{1}{\sum_a w_a} \sum_a w_a e^{in\phi_a}$$

$var([p_T])$

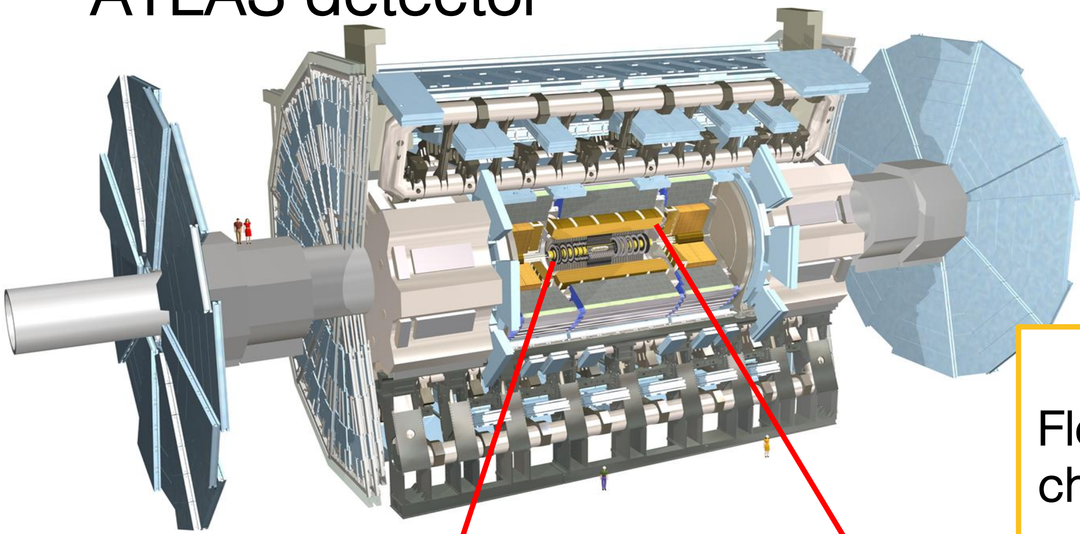
PRC 72 (2005) 044902

$$c_k = \left\langle \frac{1}{(\sum_b w_b)^2 - \sum_b w_b^2} \sum_b \sum_{b' \neq b} \right.$$
$$\left. w_b(p_{T,b} - \langle [p_T] \rangle) w_{b'}(p_{T,b'} - \langle [p_T] \rangle) \right\rangle$$

As in symmetric-cumulants

ATLAS detector ⟶ v_n measurement

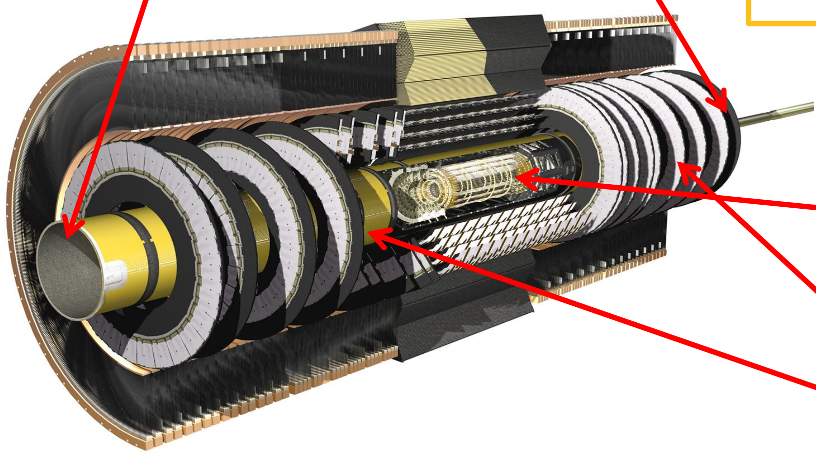
ATLAS detector



Inner Detector (Pixel+SCT)

Flow measurements is based on charged tracks reconstructed in ID

- $|\eta| < 2.5$
- 2π ϕ acceptance
- $p_T > 0.5$ GeV



Pixel detector

SCT detector