Recent flow and correlation measurements in large and small collision systems with ATLAS

Alexander Kevin Gilbert, on behalf of ATLAS Collaboration.

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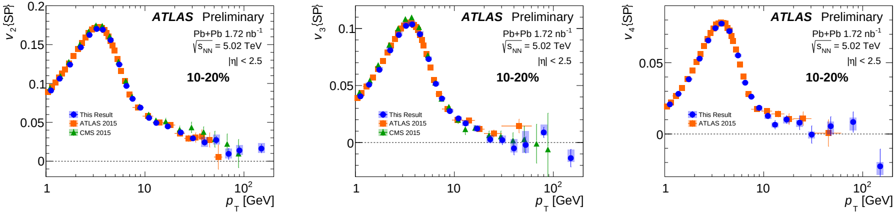
Azimuthal anisotropies of charged particles with high transverse momentum in Pb+Pb collisions at 5.02 TeV

ATLAS-CONF-2023-007

v_n as a function of p_T

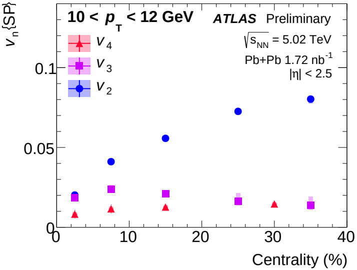
- The measurements of v_n at high-p_T provides an information to constrain the path-length dependence of jet quenching in Pb+Pb collisions.
- The v_n here are measured from real part of the event-averaged scalar products of the flow vectors.
- v_n keeps increasing up to 3 GeV, then decrease.

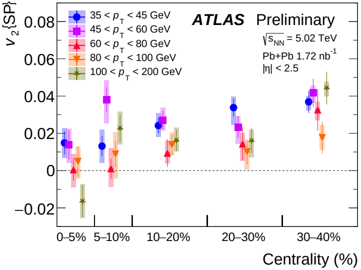


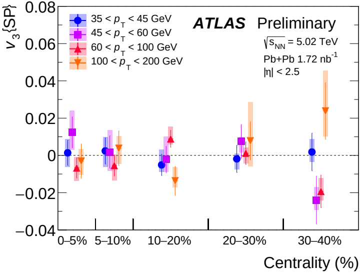
- Better resolution at high p_T thanks to increased luminosity.

v_n as a function of centrality

- v_2 increases with centrality.
- Weak centrality dependence on higher harmonics.







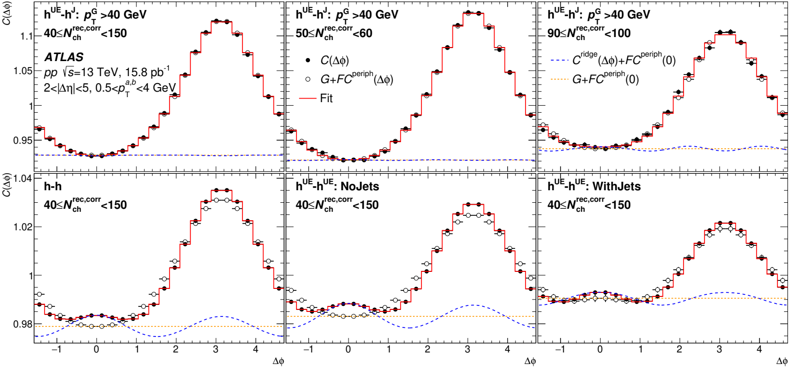
Measurement of the Sensitivity of Two-Particle Correlations in *pp* Collisions to the Presence of Hard Scatterings.

Phys. Rev. Lett. 131, 162301

Introduction

- Are jets or their soft fragments are correlated with particles in the underlying event?
- To address this question, v_2 from two-particle correlations are measured in pp collisions at $\sqrt{s} = 13$ TeV using data with an integrated luminosity of 15.8 pb^{-1}, in two different configurations:
  1. Charged particles associated with jets are excluded from the correlation analysis.
  2. Correlations are measured between particles within jets and charged particles from the underlying event.

Template fitting

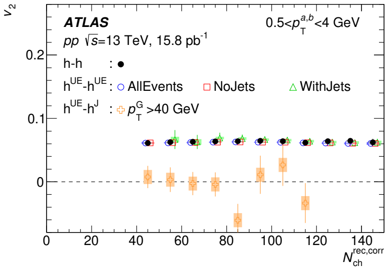


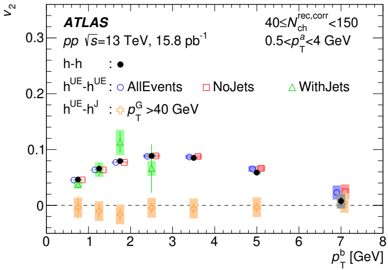
- To eliminate dijet contribution, correlation $C^{\text{perip}}(\Delta\phi)$ from $10 < N_{\text{ch}} < 30$ serves as low multiplicity (peripheral) reference.

$$C(\Delta\phi) = FC^{\text{periph}}(\Delta\phi) + G\left(1 + 2\sum_{n=2} v_{n,n}\cos(n\Delta\phi)\right)$$

$$\equiv FC^{\text{periph}}(\Delta\phi) + C^{\text{ridge}}(\Delta\phi)$$

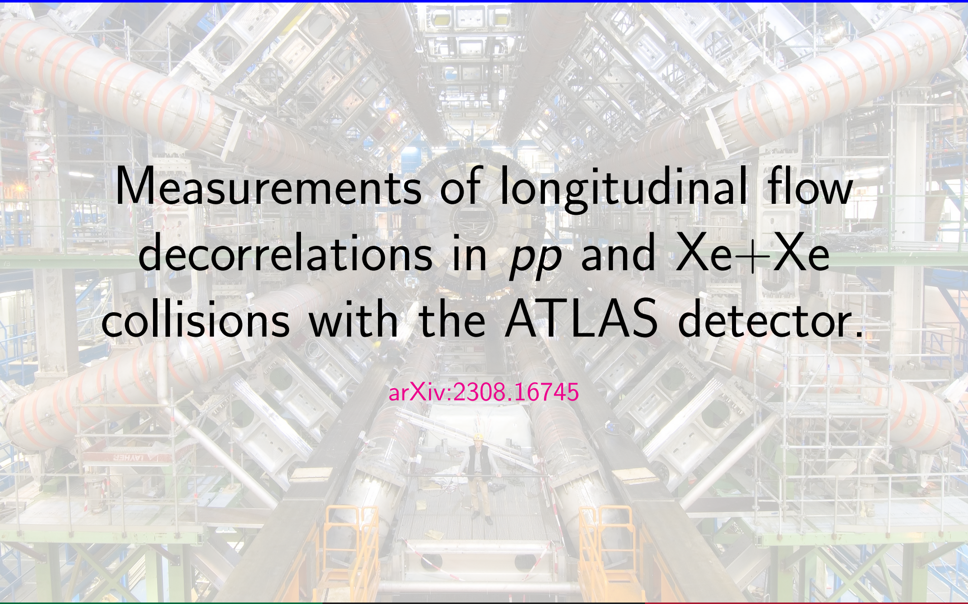
v_2 as a function of event multiplicity and transverse momentum.





- Excluding particles associated with jets > 15 GeV (h^{UE}-h^{UE} No Jets) does not affect the measured correlations.
- Particles associated with jets > 40 GeV do not exhibit any significant azimuthal correlations with the underlying event, ruling out hard processes contributing to the ridge.

Part 3:



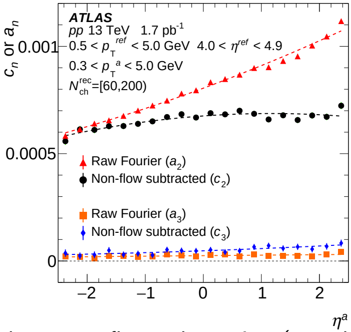
Measurements of longitudinal flow decorrelations in *pp* and Xe+Xe collisions with the ATLAS detector.

arXiv:2308.16745

Introduction

- The symmetric collision systems are expected to have same v_n in backward and forward η.
- The measured quantity is the longitudinal decorrelation parameters F_n obtained from fitting c_n and a_n with function:

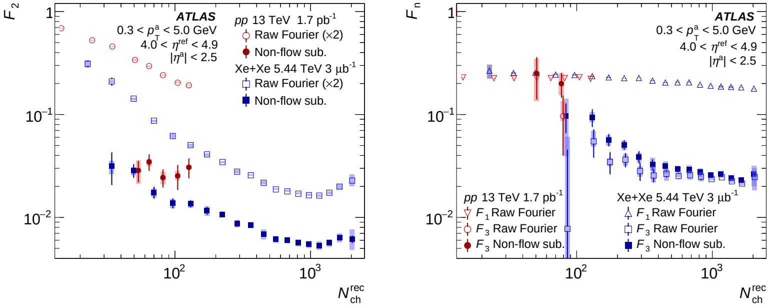
$$v_{n,n}(\eta^a) = A(1 + F_n \times (\eta^a) + S_n \times (\eta^a)^2)$$

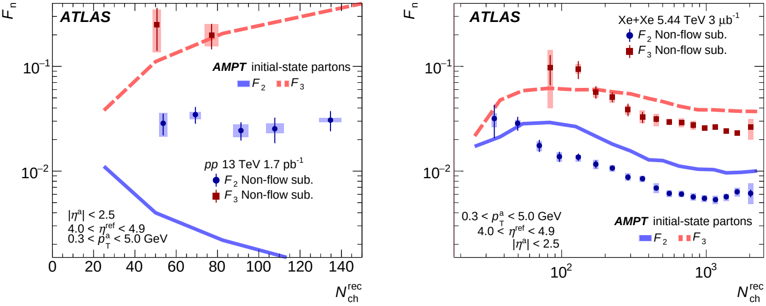


- a_n: v_n extracted without non-flow subtraction (template fitting).
- c_n: v_n extracted after non-flow subtraction.

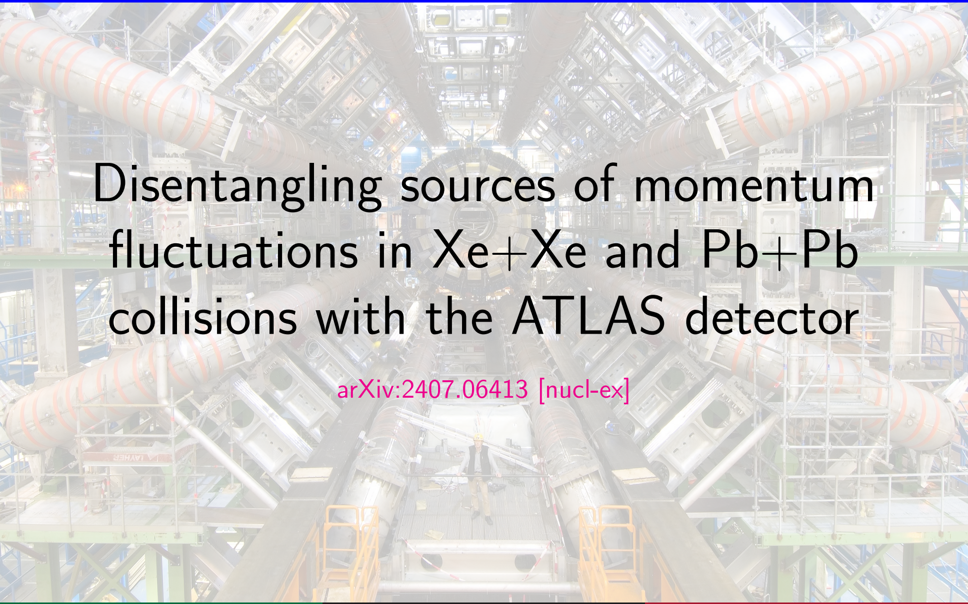
Longitudinal decorrelation parameters F_n

- F_n before and after NFS.
- Non-zero F_n values show that there is decorrelation over η.





- The AMPT reproduces v_n from spatial eccentricity vectors (arXiv:1511.04131 [nucl-th]), avoiding non-flow effects from 2-PC.
- Qualitative agreement for Xe+Xe but predicts higher values than observed, while in p+p, it is inconsistent with data.



Disentangling sources of momentum fluctuations in Xe+Xe and Pb+Pb collisions with the ATLAS detector

arXiv:2407.06413 [nucl-ex]

Introduction

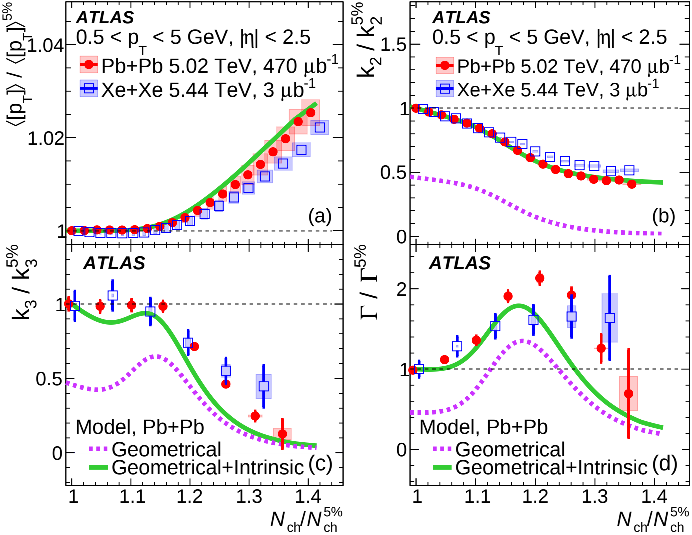
- The mean p_T in single event $[p_T]$ averaged over an ensemble of events $\langle[p_T]\rangle$ and variance of n particle correlation c_n:

$$[p_{\mathrm{T}}] = \frac{\sum_{i_1} w_{i_1} p_{\mathrm{T},i_1}}{\sum_{i_1} w_{i_1}}\,, \quad c_n = \frac{\sum_{i_1 \neq \ldots . \neq i_n} w_{i_1}..w_{i_n} (p_{\mathrm{T},i_1} - \langle[p_{\mathrm{T}}]\rangle)\ldots(p_{\mathrm{T},i_n} - \langle[p_{\mathrm{T}}]\rangle)}{\sum_{i_1 \neq \ldots . \neq i_n} w_{i_1}\ldots w_{i_n}}.$$

- It can measure the temperature and speed of sound c_s in QGP, recently done by CMS (arXiv:2401.06896 [nucl-ex]).
- Skewness

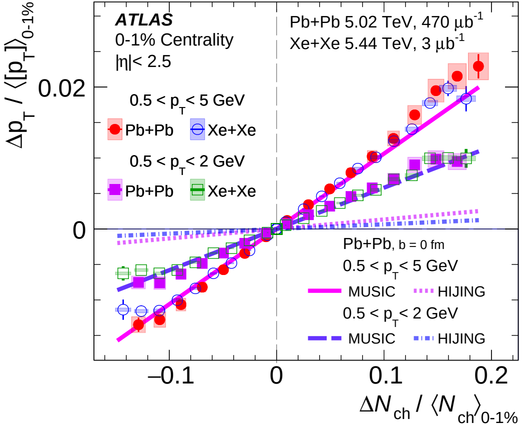
$$k_2 = \frac{\langle c_2\rangle}{\langle[p_{\mathrm{T}}]\rangle^2}, \quad k_3 = \frac{\langle c_3\rangle}{\langle[p_{\mathrm{T}}]\rangle^3}, \quad \gamma = \frac{\langle c_3\rangle}{\langle c_2\rangle^{3/2}}, \quad \Gamma = \frac{\langle c_3\rangle\langle[p_{\mathrm{T}}]\rangle}{\langle c_2\rangle^2}$$

- Source of $\langle[p_T]\rangle$ fluctuation:
  1. Geometrical: impact parameter fluctuations.
  2. Intrinsic: other sources of fluctuations at fixed impact parameter.



- The 2D Gaussian model (arXiv:2306.09294 [nucl-th]) describes reasonably the increase of $\langle [p_T] \rangle$ and the decrease of k_2.
- The larger k_3 and Γ values in the data require the model to include additional sources of skewness.

$$\Delta p_T = \langle [p_T] \rangle - \langle [p_T] \rangle_{0\text{-}1\%} \;\; \& \;\; \Delta N_{ch} = N_{ch} - \langle N_{ch} \rangle_{0\text{-}1\%}$$



- The positive slope is the c_s^2:

$$c_s^2 = \frac{dP}{d\varepsilon} = \frac{s dT}{T ds} = \frac{d\langle p_T \rangle / \langle p_T \rangle}{dN_{ch} / N_{ch}}$$

- MUSIC produce a slope similar to data while HIJING slope is smaller due to the lack of final state interactions or thermalization mechanisms.

Summary

- The increased luminosity enables additional precision of v_n measurement at high p_T which is dominantly come from the fragmentation of jets in Pb-Pb collisions.
- In *pp* and Xe-Xe:
  1. No significant change if charged particles associated with jets are excluded from the correlation analysis.
  2. No correlations between jets with $p_T > 40$ GeV and charged particles from the underlying event.
  3. Large longitudinal decorrelations are observed
- The study of $[p_T]$ fluctuations in Pb-Pb and Xe-Xe provides a way to measure c_n^2 at effective temperature T_{eff} of QGP. The study obtains $c_n^2 \approx 0.23$ at $T_{\text{eff}} \approx 222$ MeV from the agreement between the slopes in Pb-Pb data and MUSIC.

Thank you.

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BACKUP

Scalar product v_n

- The flow vector of the objects of interest, $q_{n,j} = \exp^{in\phi_j}$.
- The flow vector of the reference sub-event, $Q_n = \frac{\Sigma_j \omega_j q_{n,j}}{\Sigma_j \omega_j}$ weighted by E_{T} measured in the FCal towers ω_j.
- Utilizing sub-event Q_n reference: Negative (N) for $\eta < 0$, Positive for $\eta > 0$.
- The v_n are obtained by real part of the event-averaged scalar products of the $q_{n,j}$ and Q_n.

$$v_n\{\mathrm{SP}\} \equiv Re \frac{\left\langle q_{n,j} Q_n^{N|P^*} \right\rangle}{\sqrt{\left\langle Q_n^N Q_n^{P^*} \right\rangle}} = \frac{\left\langle |q_{n,j}||Q_n^{N|P}| \cos\left[n\left(\phi_j - \Psi_n^{N|P}\right)\right]\right\rangle}{\sqrt{\left\langle |Q_n^N||Q_n^P| \cos\left[n\left(\Psi_n^N - \Psi_n^P\right)\right]\right\rangle}}$$

Two-particle correlation (2-PC) function

- 2D correlation function:

$$Y(\Delta\phi, \Delta\eta) = \frac{1}{N_a}\frac{d^2 N_{\mathrm{pair}}}{d\Delta\phi d\Delta\eta} \tag{1}$$

- N_a is the total yield of particles with selection for particle a.
- 2D correlation function corrected for acceptance effects:

$$C(\Delta\phi, \Delta\eta) = Y(\Delta\phi, \Delta\eta) : \left(\frac{1}{N_{\mathrm{pair}}^{\mathrm{mixed}}}\frac{d^2 N_{\mathrm{mixed}}}{d\Delta\phi d\Delta\eta}\right) \tag{2}$$

Nonflow subtraction template fitting

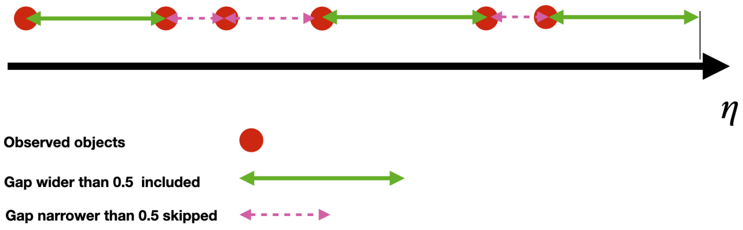
- 1D correlation function (projection to $\Delta\phi$):

$$Y(\Delta\phi) = \int_{|\Delta\eta|=2}^{|\Delta\eta|=5} Y(\Delta\phi, \Delta|\eta|) d\Delta|\eta| \quad (3)$$

- The shape of the nonflow contribution is assumed to be the same in the LM (low-multiplicity) and HM (high) samples.
- Nonflow subtraction:

$$\begin{aligned} Y^{HM}(\Delta\phi) &= FY^{LM}(\Delta\phi) + G\left\{1 + 2\Sigma_{n=2}^{4} v_{n,n}\cos(n\Delta\phi)\right\} \\ &= FY^{LM}(\Delta\phi) + Y^{\mathrm{ridge}}(\Delta\phi) \\ \therefore Y^{\mathrm{ridge}}(\Delta\phi) &= Y^{HM}(\Delta\phi) - FY^{LM}(\Delta\phi) \quad (4) \end{aligned}$$

Sum of gap $\Sigma_\gamma \eta$



- $|\Delta\eta| > 0.5$ is chosen to eliminate contribution from jets.

$v_{n,n}$ factorization test

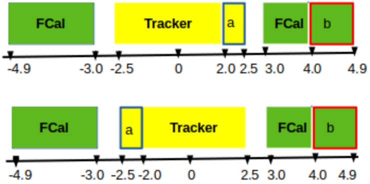
- In hydrodynamic picture, $v_{n,n}$ can be factorized for individual particle $v_{n,n} = v_{n,n}(p_T^a, p_T^b) = v_n(p_T^a)v_n(p_T^b)$.
- $v_n(p_T^a) = v_{n,n}(p_T^a, p_T^b)/v_n(p_T^b) = v_{n,n}(p_T^a, p_T^b)/\sqrt{v_{n,n}(p_T^b, p_T^b)}$
- $-v_{n,n}$ value violates the expected factorization.

Longitudinal decorrelation

- The ratio:

$$r_n(\eta^a, \eta^b) = \frac{v_{n,n}(-\eta^a, \eta^b)}{v_{n,n}(\eta^a, \eta^b)} = \frac{v_n(-\eta^a)v_n(\eta^b)}{v_n(\eta^a)v_n(\eta^b)} \qquad (5)$$

- $|\eta^a| < 2.5$ and η^b from FCal clusters $4.0 < |\eta^b| < 4.9$.



- Since *pp* is symmetric, we expect $v_n(-\eta^a) = v_n(\eta^a)$ and $r_n = 1$. However, if there is a longitudinal decorrelation, which is expected to be larger for larger η-gap, $r_n < 1$.
- r_n can be expanded:

$$r_n = \frac{1 - F_n|\eta^a|}{1 + F_n|\eta^a|} = 1 - 2F_n|\eta^a| + 2F_n^2|\eta^a|^2 - 2F_n^3|\eta^a|^3 \ldots$$