New Results Related to QGP in Small Systems with ATLAS

Adam Trzupek on behalf of the ATLAS experiment
Institute of Nuclear Physics PAS
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Ridge in Pb+Pb

Strongly interacting QGP

Pressure gradients lead to azimuthal anisotropy

\[ v_n = \langle \cos(n(\phi - \Phi_{RP})) \rangle \]

Single-particle \( v_n \) was measured

Ridge in p+Pb and pp Collisions

**p+Pb ridge**

\[ \text{ATLAS } p+Pb \ \sqrt{s_{NN}} = 5.02 \text{ TeV}, \ L_{\text{int}} = 28 \text{ nb}^{-1} \]

\[ 1 < p_T^{a,b} < 3 \text{ GeV} \quad N_{ch}^{\text{rel}} \geq 220 \]

**pp ridge**

\[ \text{ATLAS } \quad pp \ \sqrt{s} = 13\text{ TeV} \]

\[ 0.5 < p_T^{a,b} < 5.0 \text{ GeV} \quad N_{\text{ch}}^{\text{rec}} \geq 120 \]

\[ C(\Delta n, \Delta \eta) \]

**v_n** was measured

ATLAS PRL 116, 172301 (2016)
ATLAS-CONF-2016-026 - **v_n** in 2.76, 5.02 and 13 TeV pp were measured

Strongly interacting QGP in small systems?
Three main subsystems:

- **Inner Detector (ID)** – tracking $|\eta|<2.5$
- **Calorimetry** – $|\eta|<4.9$
  - FCal $3.1<|\eta|<4.9$
- **Muon Spectrometer** - $|\eta|<2.7$

Fast trigger systems:

- **Level 1 (L1)**
- **High Level Trigger (HLT)**
In addition to minimum bias triggers, High Multiplicity Triggers (HMT) are used:

- **p+Pb collisions**
  - six HMT triggers
- **pp collisions**
  - \( N_{\text{ch}}^{\text{rec}} > 60, > 90 \)

**Event activity:**
- For **p+Pb collisions**, both \( E_T^{\text{Pb}} \) in the FCal on Pb-going side and the number of charged particles with \( p_T > 0.4 \) GeV in ID, \( N_{\text{ch}}^{\text{rec}} \) are used.
- For **pp collisions**, only \( N_{\text{ch}}^{\text{rec}} \) is used.

\( N_{\text{ch}}^{\text{rec}} \) - number of tracks at primary vertex

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![Graphs showing distribution of \( N_{\text{ch}}^{\text{rec}} \) for different collisions](image)
Two-particle Correlations in 13 TeV pp

ATLAS, PRL 116, 172301 (2016)
To quantify the strength of the ridge, the “per-trigger-particle yield” is defined as:

\[ Y(\Delta \phi) \equiv C(\Delta \phi) \times \left( \frac{\int B(\Delta \phi) d\Delta \phi}{N^a \int d\Delta \phi} \right) \]
Two-particle Correlations in 13 TeV pp

With increasing \( N_{\text{ch}}^{\text{rec}} \), the minimum at \( \Delta \phi = 0 \) fills in, and the “ridge” peak appears and increases.
Two-particle Correlations in 13 TeV pp

Template fit function:

\[ Y(\Delta \phi)_{\text{high-mult}} \equiv F \cdot Y(\Delta \phi)_{\text{low-mult}} + G \left( 1 + 2 \sum_{n,n} v_{n,n} \cos(n \Delta \phi) \right) \]

\[ N_{\text{ch}}^\text{rec} < 20 \]

azimuthal modulation

\[ \Delta \phi \]

Graphs showing the fit function with conditions for high- and low-multiplicity events.
Template-fitting method

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Fit function successfully describes $Y$ distributions in all $N_{\text{ch}}^{\text{rec}}$ intervals

If $v_{n,n} \cos(n\Delta \phi)$ modulation arises from modulation of the single-particle $\phi$ distributions, then $v_{n,n}$ should factorize:

$$V_{n,n} = V_n V_n$$

The factorization was cross-checked in different $p_T$-ranges
First measurements with the new template fitting method showed that $v_2$ very weakly depends on energy and multiplicity in pp collisions.
- $v_n^{pp}$ very weakly depends on energy and multiplicity
- $v_n^{pp}$ and $v_n^{p+Pb}$ are similar at low multiplicity, but $v_n^{p+Pb}$ increases with $N_{\text{ch}}^{\text{rec}}$
- $v_2 >> v_3 >> v_4$ for all systems
$v_2(p_T^a) = v_{2,2}(p_T^a, p_T^b) / \sqrt{v_{2,2}(p_T^b, p_T^b)}$

- $v_2(p_T)$ shows a rise & fall, trend characteristic for collective flow observed in PbPb
- $v_2(p_T)$ in 5.02 and 13 TeV pp collisions agree

- $v_{3,4}(p_T)$ in p+Pb collisions are similar to $v_{3,4}(p_T)$ in 13 TeV pp collisions but a faster increase is observed for p+Pb system
The ratio is constant for both systems but is higher in pp than in p+Pb collisions

- stronger non-linear coupling in pp
Summary

- Using a template fit method ATLAS has observed elliptic, triangular and quadrangular harmonics in 5.02 and 13 TeV pp collisions
  - $v_n^{pp}$ are almost constant with multiplicity and energy
  - $v_n^{pp}$ and $v_n^{p+Pb}$ are similar at low multiplicity, but $v_n^{p+Pb}$ increase with multiplicity
    - $v_2^{pp}$ and $v_2^{p+Pb}$ have similar $p_T$ dependence
  - $v_4/v_2^2$ ratios in pp and pPb collisions are constant with multiplicity
    - Larger ratio for pp is observed due to larger non-linear contribution to $v_4$