PROCEEDINGS OF SCIENCE

Measurements of long-range correlations in γA and *pp* collisions with ATLAS

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Measurements of long-range correlations in small systems have resulted in the observation of very similar signatures as in large systems. The correlations in large systems are known to arise from the hydrodynamic flow of the quark-gluon plasma (QGP). In small systems like pp collisions, the interpretations of these collective signatures are much more diverse, ranging from a small droplet of QGP to initial-state correlations. To test the origin and sensitivity of these correlations to semi-hard processes, this proceeding presents the results of a two-particle correlation analysis that explicitly rejects particles from low-p_{T} jets. The sensitivity of the correlations to the presence of Z-boson production in the event is also tested in pp collisions. To further understand the origin of collective behavior of small systems, it is essential to study a diverse set of systems. This proceeding presents the observation of long-range correlations in photo-nuclear collisions. This behavior is possibly the result of the hadronic nature of the photon wave function. The process studied here is a subset of those available at the future Electron Ion Collider.

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1. Z-tagged two-particle correlations in pp collisions

Measurements of long-range correlations in small systems [1] have led to the observation of many collective signatures similar to those that are present in large collision systems [2]. One striking distinction is the lack of multiplicity dependence of v_2 in pp collisions. In large systems the charged-particle multiplicity is correlated with the initial-state geometry and thus the dependence follows. One possible explanation for the discrepancy is that the charged-particle multiplicity in pp collisions is not correlated with the impact parameter. However, as proposed in [3], a high-Q^2 interaction is. To study this, an analysis of the long-range correlation coefficient v_2 was performed in pp collisions that produce a Z-boson [4].

The datasets used in this analysis were from the 2012 8 TeV and 2015-2016 13 TeV pp collision data-taking periods at high luminosity and were recorded with the ATLAS detector [5]. In all cases a large portion of the data was collected with single high-p_{T} muon triggers. All muons in this analysis were required to have a $p_{\mathrm{T}} > 20$ GeV and the invariant mass of the dimuon system was required to be between 80 and 100 GeV. This constitutes a Z-boson tagged event in which a two-particle correlation analysis using the other charged-particle tracks was performed. An innovative pileup correlation subtraction procedure was implemented due to the high-pileup environment. After the correlations were corrected for acceptance and pileup effects, the template fitting procedure was used to extract correlation coefficients [1]. The extracted v_2 as a function of charged-particle p_{T} is shown in Figure 1. Also shown is v_2 for an inclusive set of pp events (no required Z-boson). No significant difference is present between the Z-tagged and inclusive event selections, which can be most clearly seen in the right panel of Figure 1, a ratio to the inclusive selection.

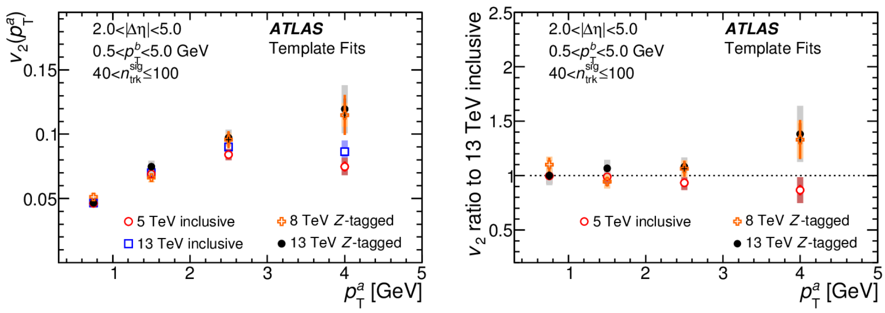

Figure 1: Left: Elliptic flow moments as a function of charged-particle p_{T}, $v_2(p_{\mathrm{T}})$, measured with a two-particle correlation analysis and the template fitting method at collision energies of 8 and 13 TeV. These measurements utilized pp events either tagged by a Z-boson candidate or an inclusive (minimum bias) set of events. Right: common ratio to inclusive 13 TeV data [4].

2. Sensitivity of two-particle correlations to the presence of jets in pp collisions

Although in the above section no correlation between the strength of the ridge and the presence of a $Q^2 \gtrapprox (80\mathrm{GeV})^2$ process was observed, it is natural to investigate the role of semi-hard processes at lower scales. This is also motivated by other explanations of the long-range correlations in pp events [6]. This motivates a ridge analysis that is sensitive to semi-hard processes [7].

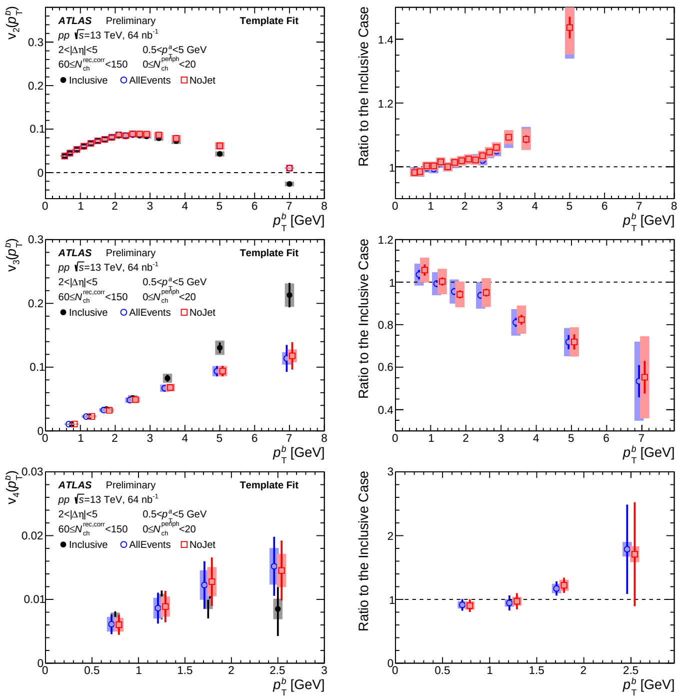

Figure 2: Measured v_n coefficients in high multiplicity 13 TeV pp events with various event selections: minimum bias or inclusive events (black), inclusive events with charged particles near jets not entering the correlation (red), and events without jets (red squares) [7].

The data utilized in this analysis were taken during two running periods in 2015 at $\sqrt{s}$ = 13 TeV at low and intermediate luminosities. Several triggers, with various lower bounds on charged-particle track multiplicity, were utilized, among which the trigger with a threshold of 90 charged-particle tracks sampled the full 64 nb^{-1}. Charged particles were reconstructed from tracks with $p_T > 0.5$ GeV and $|\eta| < 2.5$, and were used to reconstruct jets with $p_T > 10$ GeV. Each jet p_T was corrected by subtracting the contribution of underlying event tracks given the position of the jet and the total event multiplicity. Finally, $N_{ch}^{rec,corr}$ was defined by taking the total number of charged particles in the event and subtracting the estimated number of particles associated with jets.

To test the sensitivity of two-particle correlations to the presence of semi-hard processes, charged particles were used, removing particles from the correlation that were within $\Delta\eta = \pm 1$ of any jet with p_T greater than 10 GeV. Correlations with different $N_{ch}^{rec,corr}$ selections were used in conjunction with the template fitting method to measure v_n coefficients for various sets of events [1]. This process leads to three distinct measurements.

- *Inclusive* : Analysis with no rejection of charged-particle tracks based on the presence of jets applied.
- *AllEvents* : Analysis where charged particles near jets are rejected, as described above.
- *NoJet* : Analysis performed using events with no jets of $p_T > 10$ GeV.

Figure 2 presents the result of the correlation analysis for the three analysis selections itemized above. At low p_T, the different flow coefficients (different rows) are consistent between the different analysis selections. This would indicate that the long-range correlations in pp collisions are not impacted by the presence of semi-hard processes and the observed correlation arises from the underlying event, which is present in all three event and charge-particle samples.

3. Azimuthal anisotropy in photo-nuclear collisions

In relativistic heavy-ion collisions, large static electric fields are present around the ions and are boosted to high energies [8]. These boosted fields are equivalent to a flux of photons that can reach energies of tens of GeV. At these energies and virtualities the photon wave function is dominated by vector meson states. These conditions give rise to boosted, seemingly hadronic-like, collisions – somewhat resembling other small systems studied for the purpose of understanding the origin of long-range correlations. Thus a two-particle correlation analysis in the photo-nuclear system can probe many aspects of small system physics [9].

Data for this analysis were taken in 2018 during the 5.02 TeV Pb+Pb running period where a specific set of photo-nuclear triggers were used, sampling up to the maximum luminosity of 1.73 nb^{-1}. Photo-nuclear events are selected, mainly from a background of peripheral Pb+Pb collisions, via the presence of a rapidity gap and single-sided nuclear breakup. This selection is loosely imposed at the trigger level and also in the offline analysis with gap quantities that are more robust against noise and fake signals. These gap quantities utilize calorimeter clusters ($|\eta| < 4.9$ and $p_T > 0.2$ GeV) and charged-particle tracks ($|\eta| < 2.5$ and $p_T > 0.4$ GeV). The events passing the gap selection are used in a two-particle correlation analysis based on charged-particle tracks. The template fitting method is used to extract the flow-like correlation coefficients as a function of charged-particle multiplicity and charged-particle p_T as shown in Figure 3. The left panel displays v_2 as a function of the number of reconstructed charged particle (with $|\eta| < 2.5$ and $p_T > 0.4$ GeV). The photo-nuclear event selection (in red) shows a significant long-range correlation but is lower than that in pp events. The right panel shows that the $v_2(p_T)$ trend in γA events is similar to other

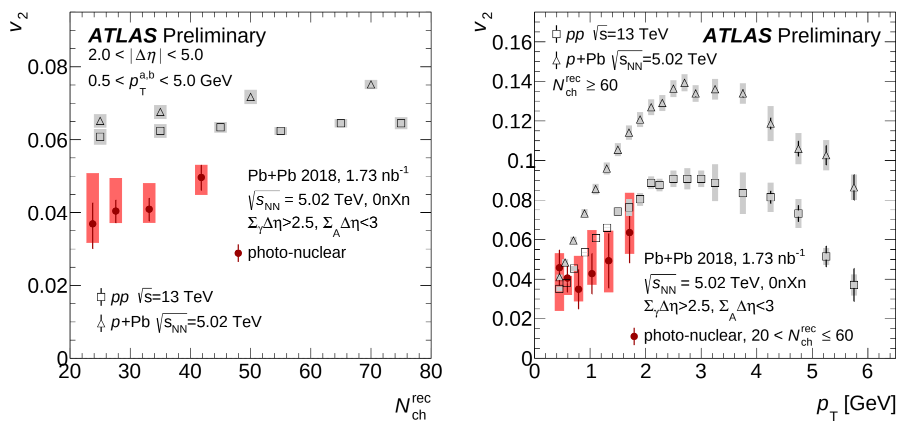

Figure 3: Measured v_2 as a function of the number of reconstructed charged particle (left) and as a function of charged-particle p_T (right). These correlation coefficients were measured in a set of events passing a photo-nuclear event selection. The v_2 was measured by a two-particle correlation and the application of a template fitting procedure [9].

hadronic systems but is also systematically lower. These results could naturally be explained by the vector meson part of the photon wave function, giving rise to similar collision conditions as pp or p+Pb. However, many differences arise from the collision energy and center-of-mass rapidity acceptance, which presents a challenge to understand quantitatively.

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