Two-particle correlations in p-Pb collisions at the LHC with ALICE

Leonardo Milano, on behalf of the ALICE Collaboration

CERN - Organisation européenne pour la recherche nucléaire

E-mail: Leonardo.Milano@cern.ch

Abstract. The double ridge structure previously observed in Pb-Pb collisions has also been recently observed in high-multiplicity p-Pb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV. These systems show a long-range structure (large separation in $\Delta\eta$) at the near- ($\Delta\varphi \simeq 0$) and away-side ($\Delta\varphi \simeq \pi$) of the trigger particle. In order to understand the nature of this effect the two-particle correlation analysis has been extended to identified particles. Particles are identified up to transverse momentum $p_{\rm T}$ values of 4 GeV/c using the energy loss signal in the Time Projection Chamber detector, complemented with the information from the Time of Flight detector. This measurement casts a new light on the potential collective (i.e. hydrodynamic) behaviour of particle production in p-Pb collisions.

1. Introduction

The study of particle correlations is a powerful tool to probe the mechanism of particle production in collisions of hadrons and nuclei at high beam energy. This is achieved by measuring the distributions of relative angles $\Delta\varphi$ and $\Delta\eta$, where $\Delta\varphi$ and $\Delta\eta$ are the differences in azimuthal angle φ and pseudorapidity η between two particles. In small systems, such as minimum-bias proton–proton (pp) collisions, the correlation at ($\Delta\varphi \approx 0$, $\Delta\eta \approx 0$) is dominated by the "near-side" jet peak, and at $\Delta\varphi \approx \pi$ by the recoil or "away-side" structure due to particles originating from jet fragmentation [1]. Additional ridge-like structures, which persist over a long range in $\Delta\eta$, emerge in nucleus–nucleus (A–A) collisions in addition to the jet-related correlations [2–4]. A similar long-range ($2 < |\Delta\eta| < 4$) near-side ($\Delta\varphi \approx 0$) structure has been observed in pp collisions at a centre-of-mass energy $\sqrt{s} = 7$ TeV in events with significantly higher-than-average particle multiplicity [5] and in high-multiplicity proton–lead (p–Pb) collisions at a nucleon–nucleon centre-of-mass energy $\sqrt{s_{\rm NN}} = 5.02$ TeV [6]. Recent measurements in p–Pb collisions employed a procedure for removing the jet contribution by subtracting the correlations extracted from low-multiplicity events, revealing essentially the same long-range structures on the away side in high-multiplicity events [7–9]. These ridge structures have been attributed to mechanisms that involve initial-state effects, such as gluon saturation [10] and colour connections forming along the longitudinal direction [11], and final-state effects, such as parton-induced interactions [12], and collective effects developing in a high-density system possibly formed in these collisions [13]. To further characterize this effect in p–Pb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV, these ridge structures are studied via a Fourier decomposition [14] and the v_2 of pions, kaons and protons[1] has been measured.

[1] Pions, kaons and protons, as well as the symbols π, K and p, refer to the sum of particles and antiparticles.

2. Analysis

A detailed description of the ALICE detector and the event and track selection can be found in Ref. 7, 15. Events are classified in four classes defined as fractions of the analyzed event sample, based on the charge deposition in the VZERO-A detector, and denoted "0–20%", "20–40%", "40–60%", "60–100%" from the highest to the lowest multiplicity. Particle identification is based on the difference (expressed in units of the resolution σ - N_σ) between the measured and the expected signal for π, K, or p in the Time Projection Chamber (TPC) and the Time Of Flight detector (TOF) detectors. The $N_{\sigma,\mathrm{TPC}}$ versus $N_{\sigma,\mathrm{TOF}}$ correlation is reported in Fig. 1 for tracks with momentum (p) $1.5 < p < 1.6\,\mathrm{GeV}/c$, when the kaon mass is assumed. For a given species, particles are selected with a circular cut defined as

$$\sqrt{N^2_{\sigma,\mathrm{TPC}} + N^2_{\sigma,\mathrm{TOF}}} < 3.$$

In the region where the areas of two species overlap, the identity corresponding to the smaller distance is assigned. Contamination from misidentified particles is significant only for K above 1.5 GeV/c and is less than 15%.

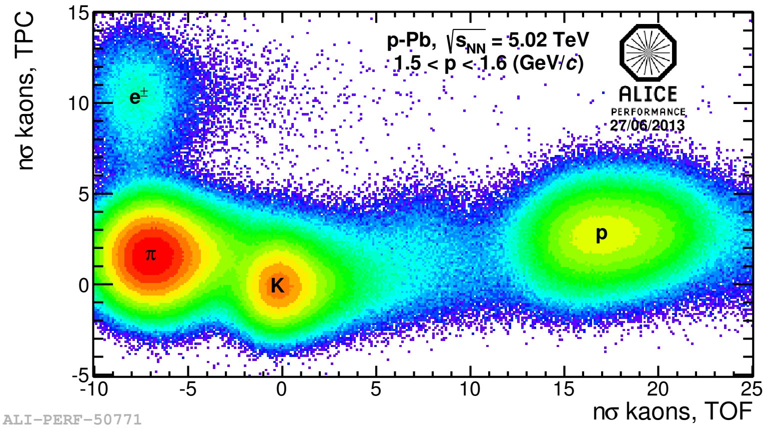

Figure 1. $N_{\sigma,\mathrm{TPC}}$ versus $N_{\sigma,\mathrm{TOF}}$ for tracks with $1.5 < p < 1.6\,\mathrm{GeV}/c$ in the kaon mass hypothesis.

This analysis uses unidentified charged tracks as trigger particles and combines them with either unidentified charged hadrons or with π, K and p as associated particles (denoted $h-h$, $h-\pi$, $h-$K and $h-$p, respectively). The correlation is expressed in terms of the associated yield per trigger particle where both particles are from the same transverse momentum p_T interval in a fiducial region of $|\eta| < 0.8$:

$$\frac{1}{N_\mathrm{trig}}\frac{\mathrm{d}^2N_\mathrm{assoc}}{\mathrm{d}\Delta\eta\mathrm{d}\Delta\varphi} = \frac{S(\Delta\eta,\Delta\varphi)}{B(\Delta\eta,\Delta\varphi)} \tag{1}$$

where N_trig is the total number of trigger particles in the event class and p_T interval. The signal distribution $S(\Delta\eta,\Delta\varphi) = 1/N_\mathrm{trig}\ \mathrm{d}^2N_\mathrm{same}/\mathrm{d}\Delta\eta\mathrm{d}\Delta\varphi$ is the associated yield per trigger particle for particle pairs from the same event. The background distribution $B(\Delta\eta,\Delta\varphi) = \alpha\ \mathrm{d}^2N_\mathrm{mixed}/\mathrm{d}\Delta\eta\mathrm{d}\Delta\varphi$ is constructed by correlating the trigger particles in one event with the associated particles from other events of the same event class and within the same 2 cm-wide z_vtx interval and corrects for pair acceptance and pair efficiency.

3. Results

The per-trigger yield of the 60–100% event class is subtracted from that in the 0–20% event class in order to reduce the jet contribution as in Ref. 7. In the left panel of Fig. 2 the resulting $h-$p correlation for $1.5 < p_\mathrm{T} < 2\,\mathrm{GeV}/c$ is shown. Fourier coefficients can be extracted from the $\Delta\varphi$ projection of the per-trigger yield by a fit with:

$$\frac{1}{N_\mathrm{trig}}\frac{\mathrm{d}N_\mathrm{assoc}}{\mathrm{d}\Delta\varphi} = a_0 + 2\,a_1\cos\Delta\varphi + 2\,a_2\cos 2\Delta\varphi + 2\,a_3\cos 3\Delta\varphi. \tag{2}$$

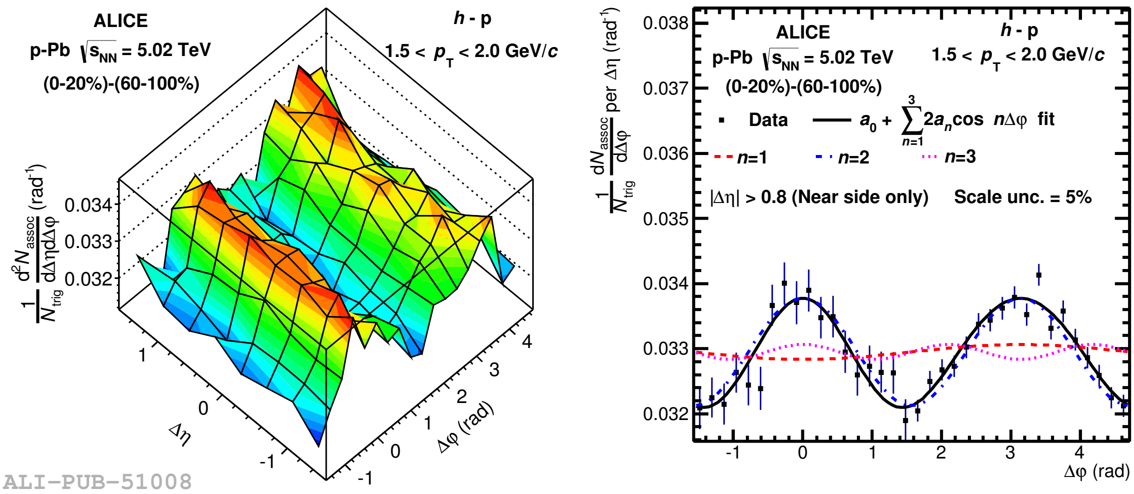

Figure 2. Left panel: associated yield per trigger particle as a function of $\Delta\varphi$ and $\Delta\eta$ for $h-\mathrm{p}$ correlations for $1.5 < p_{\mathrm{T}} < 2\,\mathrm{GeV}/c$ for the 0–20% event class where the corresponding correlation from the 60–100% event class has been subtracted. Right panel: projection of the left panel to $\Delta\varphi$ averaged over $0.8 < |\Delta\eta| < 1.6$ on the near side and $|\Delta\eta| < 1.6$ on the away side. The figure contains only statistical uncertainty. Systematic uncertainties are mostly correlated and are less than 5%.

The projection is averaged over $0.8 < |\Delta\eta| < 1.6$ on the near side and $|\Delta\eta| < 1.6$ on the away side. From the relative modulations $V_{n\Delta}^{h-i}\{2\mathrm{PC,sub}\} = a_n^{h-i}/(a_0^{h-i} + b)$, where a_n^{h-i} is the a_n extracted from $h-i$ correlations and b is the combinatorial baseline of the lower-multiplicity class which has been subtracted (b is determined on the near side within $1.2 < |\Delta\eta| < 1.6$), the $v_n\{2\mathrm{PC,sub}\}$ coefficient of order n for a particle species i (out of h, π, K, p) are then defined as:

$$v_n\{2\mathrm{PC,sub}\} = \sqrt{V_{n\Delta}^{h-h}} \qquad\qquad v_n\{2\mathrm{PC,sub}\} = V_{n\Delta}^{h-i}/\sqrt{V_{n\Delta}^{h-h}}. \tag{3}$$

Figure 3 shows the extracted $v_2\{2\mathrm{PC,sub}\}$ coefficients for h, π, K and p as a function of p_{T}. The coefficient v_2^{p} is significantly lower than v_2^{π} for $0.5 < p_{\mathrm{T}} < 1.5\,\mathrm{GeV}/c$, and larger than v_2^{π} for $p_{\mathrm{T}} > 2.5\,\mathrm{GeV}/c$. The crossing occurs at $p_{\mathrm{T}} \approx 2\,\mathrm{GeV}/c$. The coefficient v_2^{K} is consistent with v_2^{π} above $1\,\mathrm{GeV}/c$; below $1\,\mathrm{GeV}/c$ there is a hint that v_2^{K} is lower than v_2^{π}. The mass ordering and crossing is qualitatively similar to observations in nucleus–nucleus collisions [16].

4. Summary

The Fourier coefficient v_2 of the double-ridge structure in p–Pb collisions, obtained using a procedure for removing the jet contribution, exhibits a dependence on p_{T} that is reminiscent of the one observed in collectivity-dominated Pb–Pb collisions at the LHC. These observations and their qualitative similarity to measurements in A–A collisions [16] are rather intriguing. Furthermore, a mass ordering at low transverse momenta [17] can be described by hydrodynamic model calculations [18, 19]. Their theoretical interpretation is promising to give further insight into the unexpected phenomena observed in p–Pb collisions at the LHC.

References

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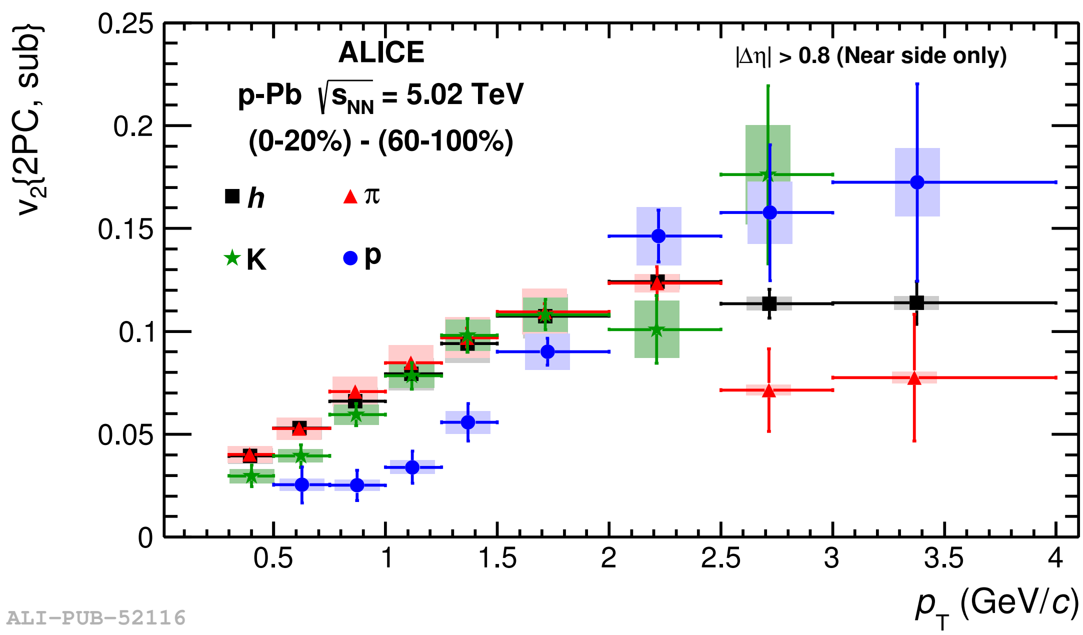

Figure 3. The Fourier coefficient $v_2\{2\text{PC}, \text{sub}\}$ for hadrons (black squares), pions (red triangles), kaons (green stars) and protons (blue circles) as a function of p_T from the correlation in the 0–20% multiplicity class after subtraction of the correlation from the 60–100% multiplicity class. The data are plotted at the average-p_T for each considered p_T interval and particle species under study. Error bars show statistical uncertainties while shaded areas denote systematic uncertainties.

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