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 $\sqrt{s_{\text{NN}}} = 5.02$ TeV. These systems show a long-range structure (large separation in $\Delta \eta$) at the near- ($\Delta \varphi \approx 0$) and away-side ($\Delta \varphi \approx \pi$) 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 $p_T$ 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 $\varphi$ and pseudorapidity $\eta$ 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–nucleus centre-of-mass energy $\sqrt{s_{\text{NN}}} = 5.02$ 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 $\sqrt{s_{\text{NN}}} = 5.02$ TeV, these ridge structures are studied via a Fourier decomposition [14] and the $v_2$ of pions, kaons and protons has been measured.

1 Pions, kaons and protons, as well as the symbols $\pi$, 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 $\sigma$) between the measured and the expected signal for $\pi$, K, or p in the Time Projection Chamber (TPC) and the Time Of Flight detector (TOF) detectors. The $N_{\sigma,TPC}$ versus $N_{\sigma,TOF}$ correlation is reported in Fig. 1 for tracks with momentum ($p$) $1.5 < p < 1.6$ GeV/c, when the kaon mass is assumed. For a given species, particles are selected with a circular cut defined as

$$\sqrt{N_{\sigma,TPC}^2 + N_{\sigma,TOF}^2} < 3.$$  

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%.

This analysis uses unidentified charged tracks as trigger particles and combines them with either unidentified charged hadrons or with $\pi$, 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 $|\eta| < 0.8$:

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

where $N_{\text{trig}}$ is the total number of trigger particles in the event class and $p_T$ interval. The signal distribution $S(\Delta\eta, \Delta\varphi) = 1/N_{\text{trig}} d^2N_{\text{same}}/d\Delta\eta d\Delta\varphi$ is the associated yield per trigger particle for particle pairs from the same event. The background distribution $B(\Delta\eta, \Delta\varphi) = \alpha d^2N_{\text{mixed}}/d\Delta\eta d\Delta\varphi$ 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 $1.5 < p_T < 2$ GeV/c is shown. Fourier coefficients can be extracted from the $\Delta\varphi$ projection of the per-trigger yield by a fit with:

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

Figure 1. $N_{\sigma,TPC}$ versus $N_{\sigma,TOF}$ for tracks with $1.5 < p < 1.6$ GeV/c in the kaon mass hypothesis.
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 $V_{n\Delta}^{h-i} \{2PC, sub\} = a_{n}^{h-i}/(a_{0}^{h-i} + b)$, 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 $v_{n} \{2PC, sub\}$ coefficient of order $n$ for a particle species $i$ (out of $h$, $\pi$, $K$, $p$) are then defined as:

$$v_{n} \{2PC, sub\} = \sqrt{V_{n\Delta}^{h-h}} \quad v_{n} \{2PC, sub\} = V_{n\Delta}^{h-i}/\sqrt{V_{n\Delta}^{h-h}}. \quad (3)$$

Figure 3 shows the extracted $v_{2} \{2PC, sub\}$ coefficients for $h$, $\pi$, $K$ and $p$ as a function of $p_{T}$. The coefficient $v_{2}^{h}$ is significantly lower than $v_{2}^{\pi}$ for $0.5 < p_{T} < 1.5$ GeV/$c$, and larger than $v_{2}^{\pi}$ for $p_{T} > 2.5$ GeV/$c$. The crossing occurs at $p_{T} \approx 2$ GeV/$c$. The coefficient $v_{2}^{K}$ is consistent with $v_{2}^{\pi}$ above 1 GeV/$c$; below 1 GeV/$c$ there is a hint that $v_{2}^{K}$ is lower than $v_{2}^{\pi}$. 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**

[1] Wang X N 1993 *Phys.Rev.* **D47** 2754–2760 (Preprint hep-ph/9306215)

[2] Aamodt K *et al.* (ALICE) 2012 *Phys.Lett.* **B708** 249–264 (Preprint 1109.2501)
Figure 3. The Fourier coefficient $v_2\{2PC,\text{sub}\}$ 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.