Study of h-h and \( V^0 \)-h angular correlations in Pb–Pb collisions at \( \sqrt{s_{NN}} = 2.76 \) TeV

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Abstract. Two-particle angular correlations provide a powerful tool to study jets and their modification in ultra-relativistic heavy-ion collisions. The study of the particle species dependence of correlation structures as a function of transverse momentum provides additional information on particle production mechanisms. In this contribution we present studies of a near-side jet-like correlation peak in h-h correlations in Pb–Pb collisions at \( \sqrt{s_{NN}} = 2.76 \) TeV. We observe significant broadening of the jet-like peak that increases with decreasing \( p_{\text{trans}} \) and \( p_{\text{assoc}} \) and with increasing centrality and additional broadening of the jet-like peak in \( \Delta \eta \) with respect to broadening in \( \Delta \phi \) in most central collisions.

The prospects of expanding these studies to include strange particles (\( \Lambda \), \( \bar{\Lambda} \) and \( K^0_S \)) is explored.

1. Introduction
In Pb–Pb collisions at LHC the jet shapes and fragmentation functions show modifications at low \( p_T \) (large jet cone radii) in comparison to pp collisions but the high \( p_T \) core is unchanged [1]. It was also predicted for heavy-ion collisions that the jet shape can be deformed by a longitudinally flowing medium [2] and therefore we might observe jets with asymmetrical cones in central heavy-ion collisions. Jets highly modified by such mechanisms might be difficult to reconstruct by jet-finding algorithms. In addition, full jet reconstruction in central heavy-ion collisions is restricted to the jet high \( p_T \) core due to fluctuations in the bulk. Since two-particle correlations are less sensitive to these effects, they provide a complementary approach to full jet reconstruction.

Quark and gluon jets can be distinguished (on a statistical basis) due to differences in their multiplicity and width [3] and also baryon and meson content [4]. Baryon production in gluon jets is enhanced with respect to quark jets. Studying \( K^0_S \)-h and \( \Lambda \)-h (\( \bar{\Lambda} \)-h), denoted \( V^0 \)-h (i.e. \( V^0 \)-hadron), correlations could provide samples enhanced in gluon or quark jets. An advantage of \( V^0 \)-h correlations is that it is possible to get a clean sample even at high \( p_T \) (~20 GeV/c) via reconstruction of the daughter tracks (\( K^0_S \to \pi^+\pi^- \), \( \Lambda \to p\pi^- \) and \( \bar{\Lambda} \to p\pi^+ \)).

2. Analysis
The ALICE experiment is designed to study hot and dense nuclear matter created in heavy-ion collisions [5]. In the h-h analysis, \( 15 \times 10^6 \) Pb–Pb collisions taken in 2010, at \( \sqrt{s_{NN}} = 2.76 \) TeV and \( 55 \times 10^6 \) pp collisions at \( \sqrt{s} = 2.76 \) TeV taken in 2011 were investigated. The centrality of the Pb–Pb collision was estimated using the VZERO detector and tracking was performed using information from the TPC (Time Projection Chamber). In the correlation
technique we select a high \( p_T \) (trigger) particle in a specific \( p_T^{\text{trig}} \) interval and associated particles with \( p_T^{\text{assoc}} < p_T^{\text{trig}} \). Calculating angular differences \( \Delta \phi = \phi^{\text{assoc}} - \phi^{\text{trig}} \) and \( \Delta \eta = \eta^{\text{assoc}} - \eta^{\text{trig}} \) and plotting these two variables as 2D histogram (same-event pairs), we obtain a jet-like peak sitting on a triangular shaped background. The triangular shape can be reproduced by mixed pairs, where the trigger and the associated particles come from different events. The acceptance corrected distribution can be estimated as:

\[
\frac{d^2N^{\text{raw}}}{d\Delta \phi d\Delta \eta}(\Delta \phi, \Delta \eta) = \frac{N^{\text{same}}(\Delta \phi, \Delta \eta)}{N^{\text{mixed}}(\Delta \phi, \Delta \eta)} \beta
\]

The normalization factor \( \beta \) was chosen in such a way that the \( N^{\text{mixed}}(\Delta \phi, \Delta \eta) \) is 1 at \( \Delta \phi = \Delta \eta = 0 \). There were also additional corrections applied for the single track efficiency and contamination correction (from secondary particles) and also for track merging/splitting.

The corrected angular correlations can be quantified by the per-trigger associated particle yield:

\[
\frac{d^2N}{d\Delta \phi d\Delta \eta}(\Delta \phi, \Delta \eta) = \frac{1}{N^{\text{trig}}} \frac{d^2N^{\text{assoc}}}{d\Delta \phi d\Delta \eta}
\]

for \( p_T^{\text{trig}} \) and \( p_T^{\text{assoc}} \) intervals. We can usually see the near-side peak located at (0,0) and the away-side peak (recoiling jet) located at \( \Delta \phi \approx \pi \) and spread out in \( \Delta \eta \). Both peaks sit (in Pb–Pb) on a flow-modulated background (more pronounced for low \( p_T^{\text{trig}} \) and \( p_T^{\text{assoc}} \) intervals). To estimate this background we assume that the flow is independent of \( \Delta \eta \) within (-1.8,1.8) and the jet does not contribute to \( |\Delta \eta| > 1.0 \). The signal is then extracted by subtracting the scaled side bands \( 1 < |\Delta \eta| < 1.6 \) (\( \eta \)-gap method).

3. Results for jet shape analysis in h-h correlations

The near-side peak in h-h correlations was fitted with a sum of two 2D Gaussians centred at \( \Delta \phi = \Delta \eta = 0 \). The fit parameters were used to calculate \( \sigma \) in \( \Delta \phi \) and in \( \Delta \eta \). The results for five \( p_T^{\text{trig}} \) and \( p_T^{\text{assoc}} \) intervals in pp collisions and in Pb–Pb collisions with five centrality bins are shown in fig. 1 and 2. As can be seen in fig. 1, the \( \sigma_{\Delta \phi} \) is, within our uncertainties, independent of centrality, and decreases with increasing \( p_T^{\text{assoc}} \) and \( p_T^{\text{trig}} \). The \( \sigma_{\Delta \eta} \) (fig. 2) increases as collisions become more central, but decreases as \( p_T^{\text{assoc}} \) and \( p_T^{\text{trig}} \) increase.

Another way of studying the jet-like peak is the kurtosis (K

\[
K_{\Delta \phi} = \frac{\mu_4}{\mu_2^2} - 3
\]

(note: \( \mu_n \) - \( n \)th moment about the mean): which is a measure of the peakedness of the distribution (Laplace: K=3, Gaussian: 0, semicircle: -1, uniform: -1.2). Both kurtoses (fig. 3 and 4) decrease going to lower \( p_T \) (the peaks are less sharp) and decrease in more central events. Interestingly, for the lowest \( p_T \) interval in \( \Delta \eta \) the peak is almost flat at the top.

4. Outlook for studying \( V^0 \)-h correlations

In \( V^0 \)-h analysis we have used \( 30 \times 10^6 \) Pb–Pb collisions at \( \sqrt{s_{NN}} = 2.76 \) TeV, triggered on centrality, taken in 2011. \( V^0 \) candidates were selected using track topological cuts and \( |y| < 0.75 \). Invariant mass distributions for most central events (0-10\%) are shown in the fig. 5 and 6. \( V^0 \) candidates in the shaded area were used for the correlation analysis. For the \( p_T^{\text{trig}} \) interval we selected \( V^0 \) candidates with \( 6 < p_T^{\text{trig}} < 15 \) GeV/c and for associated charged unidentified particles we chose \( 3 \) GeV/c < \( p_T^{\text{assoc}} < p_T^{\text{trig}} \). Fig. 7 and 8 present the acceptance corrected correlations for \( K_{S}^{0} \)-h and \( \Lambda \)-h, respectively. The plots are not efficiency corrected. Very clear jet-like peaks can be seen well above background, indicating that the analysis is feasible.
Properties of the jet-like peaks in di-hadron correlations were investigated. We observe a significant broadening at lower $p_T$ intervals of trigger and associated particles and in more central Pb–Pb collisions. Jet-like peak widths in $\Delta \phi$ show no centrality dependence while the widths in $\Delta \eta$ increase in central Pb-Pb collisions. This might be an indication of interaction of jets with longitudinal flow. In the kurtosis study we see the peak narrowing at high trigger and associated $p_T$ and widening in central Pb-Pb collisions. $V^{0}$-h studies can be used for tagging quark and gluon jets on a statistical basis and therefore could be an interesting alternative for measuring colour charge dependent energy loss. Clear jet-like peaks in $V^{0}$-h correlations show the feasibility of these measurements in central Pb-Pb collisions.

5. Summary

Figure 5. Invariant mass distribution for $\pi^+\pi^-$ pairs

Figure 6. Invariant mass distribution for $p\pi$ pairs

Figure 7. Acceptance-corrected $K^0_S-h$

Figure 8. Acceptance-corrected $(\Lambda+\bar{\Lambda})-h$

References

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