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# TWO- AND THREE-PARTICLE AZIMUTHAL CORRELATIONS AT SPS ENERGY*

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We report on azimuthal correlations of high-$p_{\rm t}$ charged particles in Pb–Au collisions at 158 $A$GeV, recorded with the CERES spectrometer at the CERN-SPS. We observe a significant dependence of the extracted associated yield on the charges of the particles. The correlation functions exhibit a very broad away-side structure in central collisions. The results of a three-particle correlation analysis are consistent with cone-like emission of jet-correlated hadrons.

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## 1. Introduction

Charged hadrons with high transverse momentum were shown to be suppressed in $A$–$A$ collisions relative to $p$–$p$ at RHIC energy [1, 2]. This was interpreted as a consequence of partons interacting with the colored medium [3] in a deconfined phase. Similar observations were made at SPS studying the nuclear modification factor [4] and comparing it to model calculations including initial state effects. The interactions of partons with the medium will significantly change the shape of jets emerging from hard parton–parton collisions. The shape is analysed by measuring azimuthal angular correlations between a high-$p_{\rm t}$ trigger particle and associated particles at lower $p_{\rm t}$. Early RHIC data demonstrated a complete disappearance of the away-side jet signal in central Au–Au collisions [5]. At SPS energy the CERES collaboration reported significant broadening of the away-side peak in Pb–Au [6]. Extending the analysis to lower $p_t$, broadening has also

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been observed at RHIC [7]. Moreover, the away-side exhibited a double-humped structure which was connected to interactions of the partons with the medium, such as Mach cone shock waves [8], induced gluon radiation [9] or Cherenkov-like radiation [10]. Analysing the correlations among two associated particles with respect to the trigger particle may help to disentangle the different proposed scenarios. We present an analysis of two- and three-particle correlations at high $p_{\mathrm{t}}$ in central Pb–Au collisions at 158 $A$GeV. The analysis is based on 30 million Pb–Au events recorded with the CERES-Time Projection Chamber, covering full azimuth and $2.1 < \eta < 2.7$.

## 2. Data analysis

The two-particle correlation function $C_2(\Delta\phi) = \frac{\int B(\Delta\phi)}{\int S(\Delta\phi)} \frac{S(\Delta\phi)}{B(\Delta\phi)}$ is constructed as the normalised ratio of a signal- $S(\Delta\phi)$ and mixed event $B(\Delta\phi)$ distribution of the difference in the azimuthal angle $\Delta\phi$ of a trigger particle with $2.5 < p_t < 4.0$ GeV$/c$ and associated particles with $1.0 < p_t < 2.5$ GeV$/c$. Acceptance effects are taken into account in the mixed event distribution where the trigger and associated particles are taken from different events. In a two-source approach the CF is decomposed in jet-like correlations $C_{2,\mathrm{jet}}$, and the correlations due to the elliptic flow: $C_2(\Delta\phi) = C_{2,\mathrm{jet}}(\Delta\phi) + b\,(1 + 2 < v_2^{\mathrm{T}} v_2^{\mathrm{A}} > \cos(2\Delta\phi))$. The $p_{\mathrm{t}}$-dependent elliptic flow coefficients for the trigger ($v_2^{\mathrm{T}}$) and associated ($v_2^{\mathrm{A}}$) range of positive and negative hadrons have been measured by a reaction plane analysis method [6, 11]. Assuming Zero Yield At Minimum (ZYAM) [7], the elliptic flow contribution is adjusted to a fit to the CF and subtracted. After normalisation we obtain the conditional yield as the number of jet-associated particles per trigger $N^{\mathrm{T}}$: $\hat{J}_2(\Delta\phi) = \frac{1}{N_{\mathrm{T}}} \frac{dN^{\mathrm{TA}}}{d\Delta\phi} = \frac{C_{2,\mathrm{jet}}(\Delta\phi)}{\int (C_2(\Delta\phi') d(\Delta\phi'))} \frac{N^{\mathrm{TA}}}{N^{\mathrm{T}}}$. Fig. 1 shows the CF as well as the extracted yield for different charge combinations of trigger and associated charge. As reported earlier [12] a strong broadening for all charge combinations is observed on the away-side, indicating significant medium modifications in central Pb–Au collisions at SPS. The relative magnitude of the near- and away-side depend on the trigger and associated particle charges. For a given trigger charge, the associated yield on the near-side is larger for unlike-sign combinations as compared to like-sign. This is qualitatively explained by local charge conservation in the fragmentation process. The trend is different on the away-side: For both trigger charges, the yield is significantly larger for positive associated particles compared to negative associated. This observation is in qualitative agreement with the conjecture that partonic energy was transferred to the medium, which bears significant positive netcharge at SPS. However, also initial state effects may lead to a charge asymmetry on the away-side and need detailed investigation.

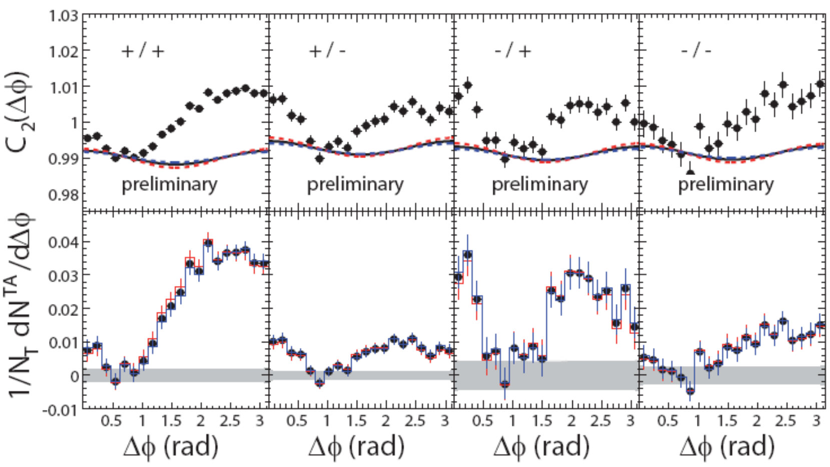


Fig. 1. Two-particle CF (top) and conditional yield (bottom) for different charge combinations (trigger/associated) in central collisions (0–5%). The flow contribution is indicated by the black lines in the upper row. In the lower panel, the errors show the systematic uncertainties from the flow contributions to both trigger and associated distributions. The shaded band shows the systematic uncertainty in the flow adjustment with the ZYAM method, (color online).

For the three-particle correlations two associated particles are combined with the trigger to obtain the two dimensional signal distribution $J_3(\Delta\phi_1, \Delta\phi_2)$. The CF $C_3(\Delta\phi_1, \Delta\phi_2)$ (Fig. 2(a)) is obtained by dividing the signal by a mixed event distribution where all three particles are taken from different events. The signal distribution is composed of the genuine three-particle jet yield $\hat{J}_3(\Delta\phi_1, \Delta\phi_2)$ and several other components which are subtracted from the signal as described in detail in [13]: $\hat{J}_3(\Delta\phi_1, \Delta\phi_2) = J_3(\Delta\phi_1, \Delta\phi_2) - a\, \hat{J}_2 \otimes B_2 - ba^2(B_3^{\text{mb}} + B_3^{\text{mb,flow}})$. The hard-soft component $\hat{J}_2 \otimes B_2$ corresponds to the case when only one associated particle is jet-like correlated to the trigger. It is constructed by folding the two-particle conditional yield $\hat{J}_2$ with the flow-modulated background. The third term is denoted as soft-soft background and corresponds to the case when the trigger is a non-jet particle. $B_3^{\text{mb}}$ is constructed by mixing two associated particles from one event with a trigger particle from another event to account for all correlations among the associated particles which are not correlated to the trigger. The term $B_3^{\text{mb,flow}}$ accounts for all three particles being flow-like correlated. The mixing is based on events without trigger condition labeled 'mb' (minimum bias). The parameter $a$ accounts for the different multiplicities in triggered and non-triggered events. Subtracting the hard-soft background, one is left with the correlations where all particles are background particles or jet-like correlated. Deploying the ZYAM method for the genuine jet-like correlations the soft–soft background is adjusted with the parameter $b$ and subtracted to obtain the jet-correlated yield of the associated particles (Fig. 2(b)). Clear off-diagonal components are observed, consistent with cone-like emission of the associated particles in high-$p_{\rm t}$ triggered events.

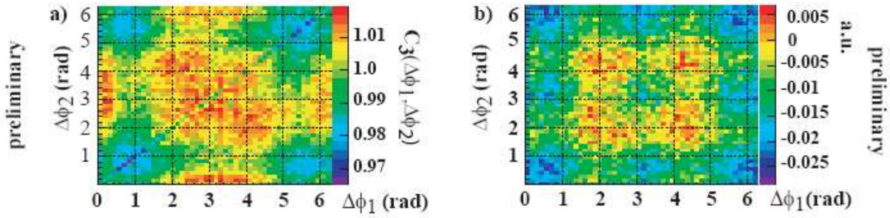


Fig. 2. Three-particle CF (a) and jet-like three-particle yield after background subtraction (b) for all charge combinations in central Pb–Au collisions at 158 $A$GeV$/c$.

In summary, two- and three-particle correlations for high-$p_{\rm t}$ charged hadrons at 158 $A$GeV$/c$ were presented, supplementing the earlier observations of medium effects on high-$p_{\rm t}$ particles at SPS energy [6] in two directions: Shape and magnitude of the jet yields depend on the charge of the trigger and associated particles. In addition, three-particle correlations indicate that the shape on the away-side of the two-particle distribution may be related to cone-like emission.

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