Two- and three-particle azimuthal correlations of high-p_t charged hadrons in Pb-Au collisions at 158A GeV/c

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Abstract. Azimuthal correlations of hadrons with high transverse momenta serve as a measure to study the energy loss and the fragmentation pattern of jets emerging from hard parton-parton interactions in heavy ion collisions. Preliminary results from the CERES experiment on two- and three-particle correlations in central Pb-Au collisions are presented. A strongly non-Gaussian shape on the away-side of the two-particle correlation function is observed, indicating significant interactions of the emerging partons with the medium. Mechanisms like deflection of the initial partons or the evolution of a mach cone in the medium can lead to similar modifications of the jet structure on the away-side. An analysis based on three-particle correlations is presented which helps to shed light on the origin of the observed away-side pattern.

1. Introduction

The suppression of high-p_t charged hadrons in A-A relative to p-p collisions observed at RHIC [1, 2] was assumed to arise from the interaction of partons emerging from hard collisions within a dense colored medium [3]. In such a picture hard collisions close to the surface of the reaction zone could lead to a jet fragmenting into the vacuum while the second jet would have to traverse the medium suffering energy loss and hence redistributing part of its energy to the medium. Measuring azimuthal angular correlations between a high-p_t trigger particle and associated particles revealed differences in the shape of the correlation function close to the trigger particle (near-side) and around $\Delta\phi = \pi$ (away-side). Depending on the momentum of the associated and trigger particles a strong suppression of the yield on the away-side of the correlation function was observed [4, 5, 6, 7] as compared to p-p data. In addition, the away-side exhibited a double peak structure which was proposed to arise from Mach cone shock waves [8], induced gluon radiation [9] or Cherenkov-like radiation in the medium [10]. Those scenarios can not be distinguished from an event-by-event deflection of the jets in the medium based on two-particle correlations only. Three-particle correlation measurements, i.e. measurements of correlations among two associated particles in an event with respect to a trigger particle can help to disentagle the different proposed scenarios. The two-particle analysis follows previous measurements of non-triggered azimuthal correlations performed by the CERES collaboration [5] which already indicated modifications on the away-side of the di-jet correlation function in Pb-Au collisions at SPS energy. The present analysis is based on 30 million Pb-Au events at 158A GeV/c recorded with the upgraded CERES spectrometer including a Time Projection Chamber covering the full range in azimuthal angle, and $2.1 < \eta < 2.7$.

2. Two-particle correlations

The (jet-) associated particles are investigated by measuring the distribution $S(\Delta\phi)$ of the difference in the azimuthal angle $\Delta\phi$ of a trigger particle with $2.5 < p_t < 4.0$ GeV/c and all associated particles with $1.0 < p_t < 2.5$ GeV/c from the same event. To account for acceptance effects, the signal distribution is divided by a background distribution $B(\Delta\phi)$ where trigger and associated particles are taken from different events. The correlation function $C_2(\Delta\phi) = \frac{n_{backgr}}{n_{sig}} \cdot \frac{S(\Delta\phi)}{B(\Delta\phi)}$, normalized to the ratio of background to signal pairs (n_{backgr}/n_{sig}), is assumed to be composed of two components: The jet-like correlations, and the correlations due to the elliptic flow. In this two-source approach the measured correlation function can be written in the form:

$$C_2(\Delta\phi) = C_{2,jet}(\Delta\phi) + b \cdot (1 + 2 < v_2^T v_2^A > \cos(2\Delta\phi)).$$

The elliptic flow coefficients for the trigger (v_2^T) and associated (v_2^A) range are determined by a reaction plane analysis method [5, 11]. Assuming Zero Yield At Minimum (ZYAM) [7] for the jet-like correlation, $C_{2,jet}$, the elliptic flow contribution is determined and subtracted from the correlation function. After normalisation we obtain the conditional yield as the number of jet-associated particles per trigger N^T: $\hat{J}_2(\Delta\phi) = \frac{1}{N_T}\frac{dN^{TA}}{d\Delta\phi} = \frac{C_{2,jet}(\Delta\phi)}{\int (C_2(\Delta\phi')d(\Delta\phi'))}\frac{N^{TA}}{N^T}$. The upper row of Figure 1 shows the correlation functions $C_2(\Delta\phi)$ and the estimated flow contributions for different charge combinations of trigger and associated particles. The lower row shows the extracted conditional yield corrected for efficiency which was estimated to be 85% for momenta above 1 GeV/c. As reported earlier [5, 12] a non-Gaussian shape is observed on the away-side, indicating significant medium modifications in central Pb-Au collisions at SPS energy. The observed shape and relative magnitude of 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 associates. PYTHIA [13] calculations at $\sqrt{s_{\rm NN}} = 17.3$ GeV indicate isospin-dependent effects when comparing positive and negative associated yields in pp, pn and nn collisions. This situation arises due to the dominant contribution of large-x (valence quark) scattering to the di-jet yield around mid-rapidity at SPS energy. However, a full account of the observed charge asymmetry could not be achieved based on PYTHIA calculations. It should be noted that PYTHIA shows little or no charge asymmetries at RHIC and LHC due to the increasing

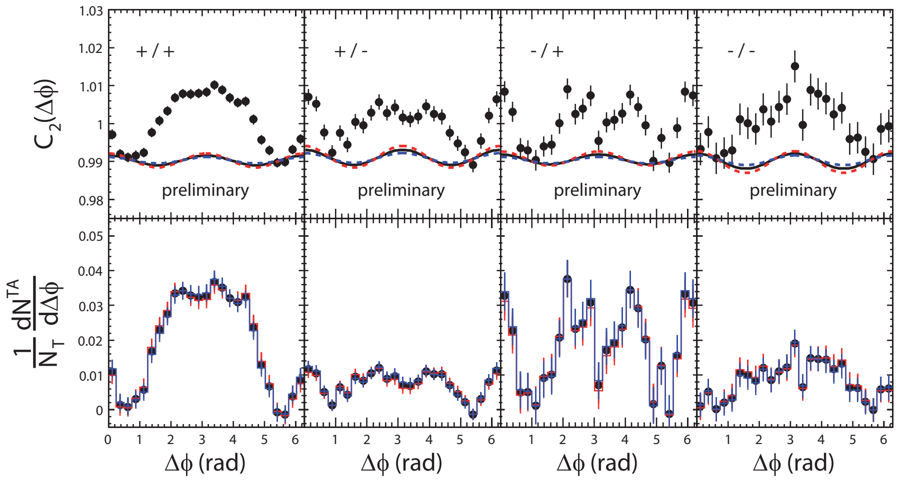

Figure 1: Two-particle correlation function (upper row) and conditional yield (lower row) for different carge combinations (trigger charge/associated charge) in the centrality range σ/σ_{geom}= (0-5)%. The flow contribution is indicated by the black lines in the upper row. The dashed and dotted curves show the systematic uncertainties in the flow contribution ($\sigma_{<v_2^A>} \approx 15\%$, $\sigma_{<v_2^T>} \approx 25\%$) . The effect of the flow uncertainty on the conditional yield is shown by the blue and red line (lower row) (color online).

contribution from gluons. For all charge combinations, a significant broadening of the away-side peak compared to the expectation in pp is observed, perhaps even indicating the occurance of a slight dip at $\Delta\phi = \pi$ in the case of unlike-sign combinations.

3. Three-particle correlations

To analyze the shape on the away-side the differences in the azimuthal angle for two associated particles with respect to a trigger particle $(\Delta\phi_1, \Delta\phi_2)$ are acquired to obtain the three-particle signal distribution $J_3(\Delta\phi_1, \Delta\phi_2)$. The same p_t-intervals for trigger and associated particles are used as for the two-particle analysis. Dividing the signal by a normalized background distribution where all three particles are taken from different events the three particle correlation function $C_3(\Delta\phi_1, \Delta\phi_2)$ is obtained as depicted in Figure 2(a). The signal distribution is composed of the genuine three particle jet yield $\hat{J}_3(\Delta\phi_1, \Delta\phi_2)$ and several background components which are subtracted from the signal as described in detail in [14]: $\hat{J}_3(\Delta\phi_1, \Delta\phi_2) = J_3(\Delta\phi_1, \Delta\phi_2) - a \cdot \hat{J}_2 \otimes B_2 - ba^2(B_3^{mb} + B_3^{mb,flow})$. The hard-soft component $\hat{J}_2 \otimes B_2$ corresponds to the case when one associated particle is jet-like correlated to the trigger while the second one is from the background. It is constructed by folding the 2-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^{mb} is constructed by mixing two associate 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 $B_3^{mb,flow}$ accounts for all three particles being flow-like correlated. The mixing is based on events without trigger condition labled mb (minimum bias). The paramter 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

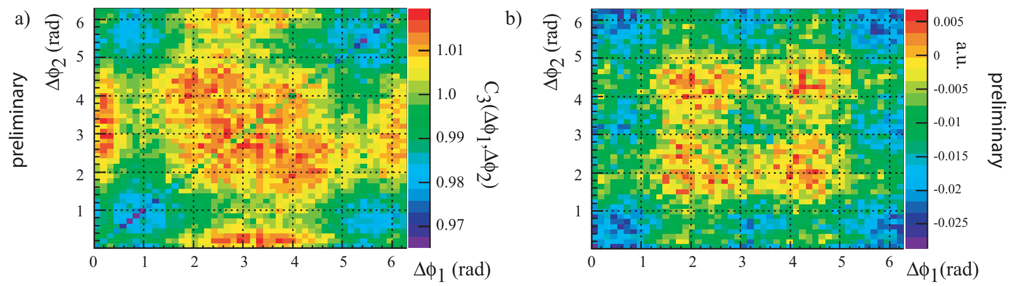

Figure 2: Three-particle correlation function a) and jet-like three-particle yield after background subtraction b) for all charge combinations in central Pb-Au collisions at 158A GeV/c.

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 (Figure 2(b)). Clear off-diagonal components are observed indicating a cone-like emission of the associated particles in high-p_t triggered events.

4. Conclusion and Outlook

We presented two- and three-particle correlations for high-p_t charged hadrons at 158A GeV/c indicating that already at SPS energy medium effects on high-p_t particles are observed. The magnitude and shape of the two-particle jet yield depends on the charge combination of trigger and associated particles. In addition, a non-Gaussian shape on the away-side is observed which is reflected in off-diagonal structures in the three-article jet yield. Further investigations are needed to substantiate these findings.

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