Modification of jet-like correlations in Pb-Au at the SPS

Harald Appelshäuser[a] and Stefan Kniege[a] for the CERES Collaboration

[a] *Institut für Kernphysik, Johann Wolfgang Goethe-Universität Frankfurt, 60438 Frankfurt am Main, Germany*

Abstract

A high statistics study of high-p_t two-particle azimuthal correlations in Pb-Au at $\sqrt{s_{\rm NN}} = 17.2$ GeV, performed by the CERES experiment at the CERN-SPS, is presented. A broad away-side correlation with significant dip at $\Delta\phi \approx \pi$ is observed. The shape and magnitude of the correlation is similar to measurements at RHIC. In comparison to PYTHIA calculations, we observe a significant excess of soft particles at the away-side. A study of charge correlations between trigger and associated particles disfavors vacuum fragmentation of the away-side jet and suggests significant energy transfer of the hard-scattered parton to the medium.

The modification of jet properties in heavy-ion collisions at RHIC has been interpreted by a strong final state interaction of hard-scattered partons with the surrounding matter. In particular, it has been argued that the strong suppression of particles at high transverse momentum p_t is consistent with energy loss of a parton in a QGP. Such modifications show a distinct dependence on the p_t range under study. At moderate p_t, the away-side jet correlation exhibits significant broadening and possibly a two-peak structure which may be a manifestation of the dissipated parton energy in the medium. The so-called *medium response* is of particular interest because it may reflect properties of the medium created in heavy-ion collisions, such as the velocity of sound. In this context it is of utmost importance to understand the collision energy dependence of such modifications as they should be sensitive to qualitative changes of the medium properties, such as the creation of a QGP [1].

At the SPS, pioneering studies on jet modifications in Pb-Au collisions have been reported by CERES, albeit with considerable statistical uncertainties [2]. In this presentation, we report on results of a recent analysis of a high statistics Pb-Au data sample at 158A GeV/c [3, 4], recorded with the CERES Time Projection Chamber [5].

We study jet-like correlations by measuring, for a trigger particle and all associated particles in an event, the distribution $S(\Delta\phi)$ where $\Delta\phi = \phi_1 - \phi_2$ is the difference in the azimuthal angle between trigger and associated particle. Within a given event, the trigger is the particle of highest p_t within a defined trigger p_t range. Non-uniformities in the detector acceptance are accounted for by division by a mixed-event distribution $B(\Delta\phi)$, where trigger and associate particle are taken from different events. The normalized correlation function

$$C_2 = \frac{\int B(\Delta\phi' d(\Delta\phi')}{\int S(\Delta\phi' d(\Delta\phi')} \cdot \frac{S(\Delta\phi)}{B(\Delta\phi)} \tag{1}$$

contains correlations due to jets and elliptic flow:

$$C_2(\Delta\phi) = J(\Delta\phi) + b \cdot (1 + 2\langle v_2^T \rangle \langle v_2^A \rangle \cos(2\Delta\phi)), \tag{2}$$

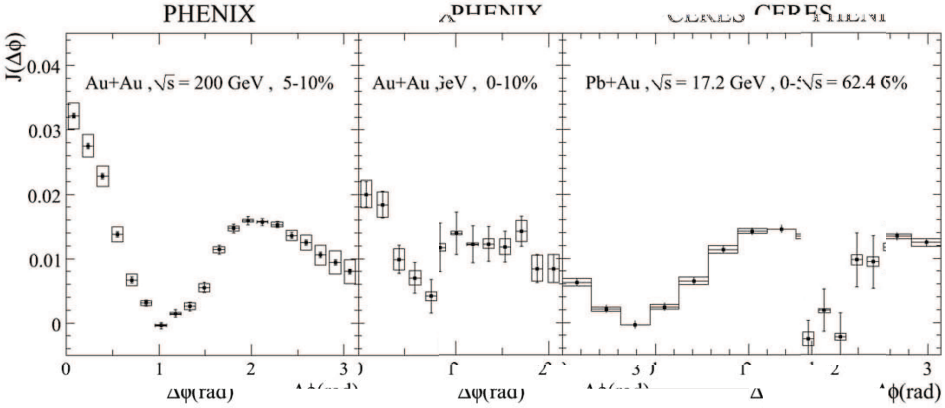

Figure 1: $J(\Delta\phi)$ in central events at different collision energies [3, 8]. The trigger and associate p_t ranges are $2.5 < p_t(T) < 4.0$ GeV/c and $1.0 < p_t(A) < 2.5$ GeV/c, respectively.

where $\langle v_2^T \rangle$ and $\langle v_2^A \rangle$ are the average elliptic flow coefficients determined in the trigger and associate p_t range, respectively. Assuming that the jet yield vanishes at its minimum (the ZYAM conjecture [6, 7]), the elliptic flow contribution is adjusted by variation of b. We obtain the conditional yield $\hat{J}_2(\Delta\phi)$ as the number of jet-associated particles per trigger:

$$\hat{J}_2(\Delta\phi) \equiv \frac{1}{N_T}\frac{dN_{TA}}{d\Delta\phi} = \frac{1}{\epsilon}\frac{J(\Delta\phi)}{\int C_2(\Delta\phi')d(\Delta\phi')}\frac{N_A}{N_T}, \tag{3}$$

where N_T and N_A are the total numbers of triggers and associates, N_{TA} is the number of jet-associated particles with the trigger after subtraction of the flow-modulated background, and ϵ the single track efficiency. See [3, 4] for more details on the analysis.

In Fig. 1 the correlation function after subtraction of the flow contribution, i.e. the jet-like part $J(\Delta\phi)$, in central Pb-Au collisions is compared to results from Au-Au at RHIC [8]. At the near-side, the correlation is gradually decreasing as the c.m.s. energy is lowered. This can be explained in terms of a steeper jet spectrum at the SPS, leading to less associated particles for a given trigger p_t. At the away-side, there is little variation of the correlation strength with $\sqrt{s_{\rm NN}}$. At all energies a broad correlation of similar magnitide with significant dip around $\Delta\phi \approx \pi$ is observed, which is in contrast to observations in pp. The occurence of a seemingly universal response of the medium to a trigger particle of given p_t in central nucleus-nucleus collisions suggests that the properties of the medium created at different collision energies exhibit surprising similarities in terms of opaqueness to energetic partons.

In Fig. 2 the jet-associated yield in different ranges of the trigger and associated p_t is shown. Associated particles at $|\Delta\phi| < 1$ have been assigned to the near-side, and $1 < |\Delta\phi| < 2\pi - 1$ to the away-side. We observe that the spectrum at the near-side is significantly softer than at the away-side. This is a consequence of the trigger requirement of an energetic leading particle at the near-side, leaving less energy for the associated particles. The away-side is not biased by the trigger condition, hence leading to a harder spectrum of the associated particles. The effect of the trigger bias is also observed in PYTHIA simulations, shown as the ratio of yields away/near in Fig. 2 (right panel). This qualitative agreement corroborates the fragmentation picture. In the data, however, we observe a significant excess of soft particles with $p_t < 2$ GeV/c compared to the

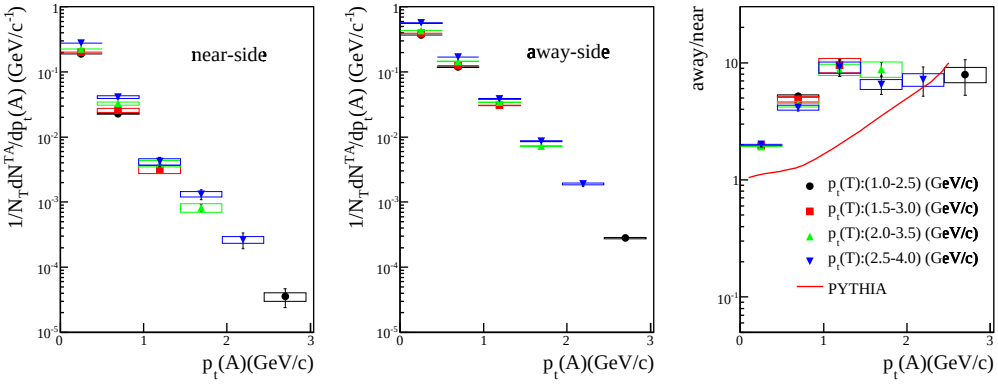

Figure 2: Jet-associated yield as function of associated p_t at the near-side (left) and away-side (middle). The ratio away/side compared to PYTHIA is shown in the right panel (from [3]).

PYTHIA calculation, indicating significant medium modification of the fragmentation spectrum at the away-side. We have verified that the shape of the away-side spectrum is undistinguishable from the inclusive p_t distribution.

In the following, electric charge correlations between the trigger and associated particles are investigated. At the near-side, local charge conservation in the fragmentation process implies an enhanced probability to detect an associated particle with charge opposite to the trigger particle. This behaviour has been observed at higher collision energy [9], in accordance with simulations by PYTHIA [4].

At the away-side, no charge correlations between trigger particle and associated particle have been observed at RHIC [9], again in agreement with PYTHIA calculations [4]. We emphasize that this situation is different at SPS energies, which provides a unique tool to investigate the modification of jet properties in A-A via the study of charge correlations, as outlined in the following.

At large $x_t = 2 \cdot p_t / \sqrt{s_{\rm NN}}$ particle production is dominated by valence quark scattering. This implies that net charge conservation becomes relevant in this kinematic range, leading to correlations among the particles associated to a jet or di-jet. Moreover, the large x_t domain at SPS ($\sqrt{s_{\rm NN}} = 17.2$ GeV) is reached at rather moderate p_t, like those investigated in this study, i.e. $p_t \approx 3-4$ GeV/c. At such p_t, the total number of hadrons produced in the final state of a $2 \rightarrow 2$ parton scattering is rather small, leading to correlation effects due to *global* charge conservation in the di-jet system. A study of simulated "Pb-Au events" at $\sqrt{s_{\rm NN}} = 17.2$ GeV generated with PYTHIA by proper superposition of pp, np and nn collisions confirms that, at SPS energy, charge correlations extend to the away-side. This leads to enhanced correlations of unlike-sign combinations of trigger and associated particles due to global charge conservation. Moreover, there is a dominance of positive particles as a consequence of the positive net charge of the valence quarks. These correlation patterns, characteristic for parton-parton scattering in elementary collisions at SPS energy, can be used as a reference for studies in Pb-Au, where modifications or a disappearance of charge correlations at the away-side may indicate a large degree of dissipation of the parton energy to the surrounding medium.

In Fig. 3 (left panel) the conditional yield for different trigger/associated particle charge com-

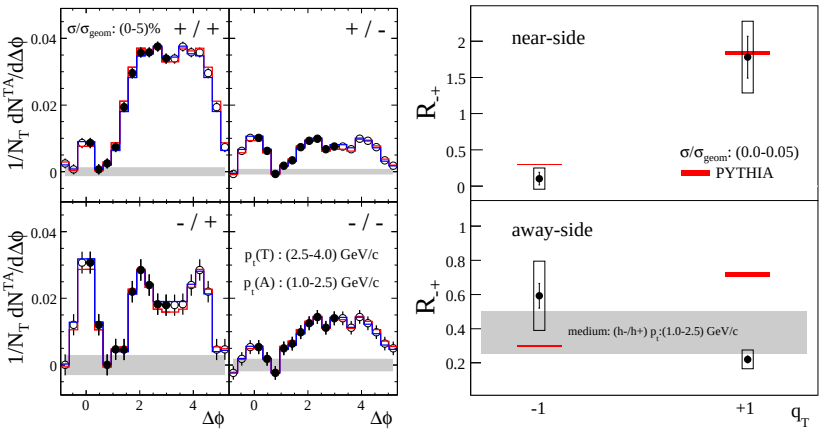

Figure 3: Left panel: Jet-associated yield in Pb-Au for different trigger/associate charge combinations. Right panel: The ratio R_{-+} in comparison to PYTHIA calculations. The inclusive ration h^-/h^+ is indicated by the grey band (from [3]).

binations is shown. At the near-side and for a given trigger charge, we observe a larger yield for the unlike-sign charge combinations, consistent with the expectation for jet fragmentation.

In the following we study, for a given trigger charge, the ratio R_{-+} of the jet-associated yields of negative over positive associated particles [3]. The integration limits in $\Delta\phi$ are as stated above. We observe very good agreement of R_{-+} at the near-side with predictions from PYTHIA, see Fig. 3 (right panel), corroborating that jet fragmentation is the origin of the observed correlations. In contrast, the data deviate significantly from the PYTHIA reference at the away-side, in particular for positive trigger particles. The data are, however, in good agreement with the inclusive ratio of negative to positive particles in this p_t range, indicated by the grey band. This suggests that the correlation pattern expected from jet fragmentation in elementary collisions is modified as a consequence of significant energy transfer from the parton to the medium.

In summary, the observed charge correlation patterns at the near-side give strong evidence that the origin of high-p_t correlations are jets. At the away-side, shape and magnitude of the correlation is similar to measurements at RHIC. In comparison to PYTHIA calculations, we observe at the away-side an excess of soft particles and a strong modification of the charge correlations. Both spectrum and charge composition of the near-side are consistent with the bulk medium. These observations are suggestive of significant final state interactions of hard-scattered partons with the hot and dense medium formed in heavy-ion collisions at SPS.

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