Two-particle Azimuthal Correlations of High-$p_T$ Charged Hadrons at the CERN SPS

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Two-particle azimuthal correlations of high-$p_T$ hadrons can serve as a probe of interactions of partons with the dense medium produced in high-energy heavy-ion collisions. First NA49 results on such correlations are presented for central and mid-central Pb+Pb collisions at 158A GeV beam energy, for different centrality bins and charge combinations of trigger and associate particles. These results feature a flattened away-side peak in the most central collisions, which is consistent with expectations of the medium-interaction scenario. A comparison with CERES Pb+Au results at the same energy, as well as with PHENIX Au+Au results at the top RHIC energy, is provided.

I. INTRODUCTION

It is believed that one of the signatures of a hot, dense medium expected to appear in most central high-energy collisions of heavy ions, will be modification of properties of jets — highly collimated streams of particles, originating from hard scattering of partons and therefore produced early in a collision — as a result of their interaction with that medium [1]. Unfortunately, direct reconstruction of jets in the presence of a large background typical of such events is an extremely challenging task. One possible answer to this problem is studying two-particle azimuthal correlations, which allow one to extract the jet signal from the soft background by taking advantage of the fact jet particles are strongly correlated in azimuth. In recent years RHIC experiments have made this approach highly successful by not only observing the expected signatures, but also providing, through further investigations, evidence which has led to a major change of expectations regarding properties of the hot medium (the “perfect liquid” description; see e.g. [2, 3]). However, until recently ([4]) no analyses of this sort were performed in the energy range of the CERN SPS.

II. EXPERIMENTAL SETUP

The NA49 detector is a large-acceptance spectrometer dedicated to the study of hadron production in fixed-target nucleon-nucleon, nucleon-nucleus and nucleus-nucleus collisions at a wide range of energies offered by the CERN SPS [5]. During its eight years of running it was used to register Pb+Pb collisions at 20A, 30A, 40A, 80A and 158A GeV, C+C and Si+Si collisions at 40A and 158A GeV, along with p+p and p+Pb interactions at 158A GeV.

The main components of the detector are four time projection chambers, used for tracking as well as particle identification by dE/dx. Two of the chambers, the so-called Vertex TPCs, are located inside two superconducting magnets (with field intensity of 1.5 and 1.1 T, respectively) positioned along the beam axis right downstream of the target, with the other two (“Main TPCs”) placed further downstream on both sides of the beam line. Two Time of Flight walls located beyond the MTPCs complement particle identification in the intersection region of Bethe-Bloch dE/dx bands. Centrality selection in nucleus-nucleus collisions is based on the projectile spectator energy deposited in the Veto Calorimeter, located at the downstream end of the experiment.
The present analysis is based on 3 million central Pb+Pb collisions at 158\textit{A} GeV recorded by NA49 in the year 2000.

### III. DATA ANALYSIS

The two-particle correlation function is calculated independently in four event-centrality bins: 0-5 \%, 5-10 \%, 10-15 \%, and 15-20 \%. The transverse momentum bins are 2.5 GeV/c \(\leq p_{t\text{rg}} \leq 4.0\) GeV/c for trigger particles and 1.0 GeV/c \(\leq p_{t\text{rg}} \leq 2.5\) GeV/c for associates.

Following the prescription of the PHENIX Collaboration \[6\] we define the correlation function as a ratio of two normalised distributions of \(\Delta\phi = \phi_{\text{asc}} - \phi_{\text{trg}}\), where \(\phi\) is the azimuthal angle: \(N_{\text{corr}}(\Delta\phi)\), in which both particles come from the same event, and \(N_{\text{mix}}(\Delta\phi)\), in which the trigger and the associate originate from different events. Division by the mixed-event spectrum accounts for non-uniform detector acceptance.

\[
C_{2}(\Delta\phi) = \frac{N_{\text{corr}}(\Delta\phi) \int N_{\text{mix}}(\Delta\phi')d(\Delta\phi')}{N_{\text{mix}}(\Delta\phi) \int N_{\text{corr}}(\Delta\phi')d(\Delta\phi')} \tag{1}
\]

In this analysis the mixing is accomplished with a sliding window of up to 50 most recent events in each centrality bin. The resulting correlation functions are shown in the top row of Fig. 1. Although the correlation function as defined in Eq. 1 is free of acceptance effects, it still includes all physical correlations: conservation laws, resonance decays, flow, quantum statistics, parton fragmentation \textit{etc}. The two-source model \[7\], a widely-used description of azimuthal correlations in nucleus-nucleus collisions, postulates that the function \(C_{2}\) can be decomposed into only hard-scattering and flow contributions:

\[
C_{2}(\Delta\phi) = C_{2}^{\text{jet}}(\Delta\phi) + a \left[ 1 + 2 \langle v_{T}^{2} \rangle \langle v_{A}^{2} \rangle \cos(2\Delta\phi) \right] \tag{2}
\]

The two flow terms \(v_{T}^{2}\) and \(v_{A}^{2}\) have been obtained from an independent reaction-plane analysis \[8\], see Table I for the values. Finally, we obtain the factor \(a\) by employing the Zero Yield At Minimum (ZYAM) assumption \[7\]. The flow contribution to the correlation function is illustrated in the top row of Fig. 1 by the solid line, with the dashed lines indicating modulation due to statistical uncertainties of \(\langle v_{T}^{2} \rangle\) and \(\langle v_{A}^{2} \rangle\).

| Centrality | \(v_{T}^{2}\)     | \(v_{A}^{2}\)     |
|------------|-----------------|-----------------|
| 0-5 \%     | 0.022 \(\pm\) 0.003 | 0.01395 \(\pm\) 0.00027 |
| 5-10 \%    | 0.073 \(\pm\) 0.003 | 0.04079 \(\pm\) 0.00029 |
| 10-20 \%   | 0.117 \(\pm\) 0.003 | 0.06570 \(\pm\) 0.00026 |

\textbf{TABLE I: Flow coefficients used in the analysis. Only statistical errors are listed.}

Having subtracted the flow one can use the hard-scattering component of the correlation function to calculate per-trigger conditional yield of associate particles:

\[
\hat{J}(\Delta\phi) = \frac{1}{N_{T}} \frac{dN^{TA}}{d\Delta\phi} = \frac{C_{2}^{\text{jet}}(\Delta\phi)}{\int C_{2}(\Delta\phi')d(\Delta\phi')} \frac{N^{TA}}{N_{T}}, \tag{2}
\]

where \(N_{T}\) is the number of trigger particles, and \(N^{TA}\) — the number of same-event trigger-associate pairs. Yields obtained this way are shown in the bottom row of Fig. 1.

Next, Fig. 2 shows correlation functions obtained by imposing additional constraints on the electric charge of trigger and associate particles. Like- and unlike-sign pairs have been considered separately and compared to the correlation functions without charge selection, for centrality bins 0-5 \% and 10-20 \%.

Finally, Fig. 3 compares the conditional yield of NA49 with that from Pb+Au collisions at 158\textit{A} GeV as observed by the CERES experiment at the SPS \[9\] and that from Au+Au collisions.
FIG. 1: Top: Two-particle azimuthal correlation functions of charged hadrons in Pb+Pb collisions at 158.4 GeV, for centrality bins 0-5 % (left), 5-10 % (middle) and 10-20 % (right). The solid lines illustrate ZYAM-normalised flow contribution to the function, with the dashed ones indicating modulation due to statistical uncertainties on flow coefficients. Bottom: per-trigger conditional yield of associate particles obtained by normalising the flow-subtracted correlation function, again in three centrality bins. All errors are statistical only.

FIG. 2: Two-particle azimuthal correlation functions for different combinations of electric charge of trigger and associate particles: like-sign pairs (open squares), unlike-sign pairs (open triangles) and no constraints (full circles).

at \( \sqrt{s_{NN}} = 200 \) GeV as observed by the PHENIX experiment at the RHIC [6]. In order to facilitate comparison of the shape of the functions, PHENIX results have been scaled down by the factor 0.4 to match the amplitude of SPS yields near the minimum. All three yields have been obtained for the same centrality bin as well as trigger and associate particle \( p_T \) ranges.
FIG. 3: Per-trigger conditional yield for most central ($\sigma/\sigma_{geom} = 0 - 5\%$) nucleus-nucleus collisions. Full circles: Pb+Pb at 158\,A\,GeV (NA49 preliminary). Open squares: Pb+Au at 158\,A\,GeV (CERES preliminary). Open triangles: Au+Au at $\sqrt{s_{NN}} = 200$ GeV (PHENIX), scaled down to match SPS results around the minimum.

IV. RESULTS AND SUMMARY

NA49 has measured two-particle azimuthal correlation functions in central and mid-central Pb+Pb collisions at 158\,A\,GeV. The away side of the correlation function in the most central collisions shows plateau-like structure, visible even before subtraction of flow and significantly different from the away-side shape in more peripheral bins. Such behaviour is consistent with qualitative expectations for a hot, dense medium in the most central high-energy nucleus-nucleus interactions. Moreover, NA49 results agree with those from the CERES experiment at the SPS and are in qualitative agreement with RHIC results. Finally, the observed difference in amplitude of the near-side peak of the correlation function of like- and unlike-sign pairs, is consistent with local charge conservation which could be associated with fragmentation of partons.

References

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