Investigating Sources of Angular Correlations at High $p_T$
in Nucleon–Nucleon and Nucleus–Nucleus Collisions
at the CERN SPS

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Abstract

Angular 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 but other effects may also be
important at SPS energies. To study the various contributions, NA49 has performed an energy
and system-size scan of two-particle azimuthal correlations in $Pb+Pb$, $Si+Si$ and $p+p$ collisions
at $\sqrt{s_{NN}} = 17.3$ GeV, as well as central $Pb+Pb$ collisions at 6.3, 7.6, 8.8 and 12.3 GeV. These
results were compared to UrQMD simulations.

NA49 results show a flattened away side of $C_2(\Delta\phi)$ in central $Pb+Pb$ ($Au+Au$) collisions
which depends weakly on collision energy even for low SPS energies. This is at odds with
the standard scenario of parton energy loss. On the other hand, the near-side peak amplitude
drops visibly with decreasing collision energy, turning into a depletion below $\sqrt{s_{NN}} = 8.8$ GeV.
UrQMD describes the correlation functions on the away side but disagrees on the near side.

1. Introduction

In early 2008 the NA49 Collaboration presented its first results on two-particle azimuthal
correlations of non-identified charged hadrons, concluding that the flattening of the away side of
the correlation function in most central $Pb+Pb$ collisions at $\sqrt{s_{NN}} = 17.3$ GeV, as well as the
observed dependence of the near-side amplitude on the charge of trigger and associate particle,
was consistent with qualitative expectations of QGP presence in central high-energy heavy-ion
interactions [1].

Subsequently, we studied the behaviour of the two-particle azimuthal correlation function in
central collisions on other observables: system size and collision energy. With deconfinement in
heavy-ion collisions believed to set in at low SPS energies [2], observation of evolution of the
correlation function may shed light on the mechanism responsible for the away-side flattening.
For central collisions subtraction of flow is not necessary, an advantage in view of the criticism
of the commonly employed subtraction techniques [3, 4].

The present analysis is based on the following data sets of NA49: central $Pb+Pb$ collisions,
$\sigma/\sigma_{geom} = 0–5 \%$, at $\sqrt{s_{NN}} = 17.3$, 12.3, 8.8, 7.6 and 6.3 GeV; central $Si+Si$ collisions, $\sigma/\sigma_{geom}
= 0–5 \%$, at $\sqrt{s_{NN}} = 17.3$ GeV; $p+p$ collisions ($\approx 90 \%$ inelastic) at $\sqrt{s_{NN}} = 17.3$ GeV.

We have compared the experimental correlation functions to results from simulated events
using the string-hadronic model UrQMD 2.3 [5, 6], which allows optional incorporation of jet
production from PYTHIA [7].
The Method

The method of calculating two-particle azimuthal correlation functions was described in detail in our previous report [1]. Acceptance-corrected correlation functions $C_2(\Delta \phi)$ were obtained in the $\Delta \phi$ range of $[0, \pi]$. The transverse momentum selections remain unchanged: $2.5 \text{ GeV}/c \leq p_T^{trg} \leq 4.0 \text{ GeV}/c$ for trigger particles and $1.0 \text{ GeV}/c \leq p_T^{asc} \leq 2.5 \text{ GeV}/c$ for associates.

Additionally, two new techniques have been introduced. The “central Pb+Pb at $\sqrt{s_{NN}} = 17.3 \text{ GeV}”$ correlation function used as reference for other functions in the scan was parametrised with a two-part polynomial fit (third-order on the near side, linear on the away side). This has greatly improved the ease of comparisons. Secondly, each correlation function from the energy scan has been fitted with two linear functions (one for the near side, one for the away side), substituting the comparison of peak values by comparing the slopes of lines fitted to $C_2(\Delta \phi)$.

For all correlation functions statistical errors are plotted as bars, with systematic uncertainties illustrated using gray boxes. In case of values extracted from fits, their error bars combine statistical and systematic uncertainties.

2. Results

2.1. System-size Scan

Figure 1 shows two-particle azimuthal correlation functions from $p+p$ and central Si+Si collisions at $\sqrt{s_{NN}} = 17.3 \text{ GeV}$, compared to a parametrisation of Pb+Pb results [1]. Overall strength of the correlation becomes significantly larger as the system size decreases. Moreover, no flattening of the away-side peak, as present in central heavy-ion events, is visible in Si+Si and $p+p$ collisions — indeed, the peak becomes narrower with decreasing system size.

![Figure 1](image1.png)

Figure 1: Two-particle correlation functions from $p+p$ (left) and central Si+Si (right) events at $\sqrt{s_{NN}} = 17.3 \text{ GeV}$, compared to a parametrisation of central-Pb+Pb results at the same energy (curves).

2.2. Energy Scan

In Figure 2 the correlation function from central Pb+Pb collisions at $\sqrt{s_{NN}} = 17.3 \text{ GeV}$ is compared to results from the same system at 12.3, 8.8, 7.6 and 6.3 GeV; for illustration we also included a function obtained by PHENIX at the RHIC ($Au+Au$ collisions at $\sqrt{s_{NN}} = 200 \text{ GeV}$), for the same centrality and $p_T$ ranges [8]. Dashed lines depict linear fits of the near and away
sides of $C_2(\Delta \phi)$. The resulting slope parameters are plotted in Figure 4. The near-side peak appears to turn into depletion with decreasing energy, whereas shape and amplitude of the away-side enhancement remains mostly unchanged throughout the scan. Should the flattening of the latter be considered a quark-gluon plasma signature, these results are at odds with present-day expectations that the QGP is produced only at higher energies.

Figure 2: Two-particle correlation functions from central $\text{Pb}+\text{Pb}$ ($\text{Au}+\text{Au}$) events at $\sqrt{s_{NN}} = 200, 12.3, 8.8, 7.6$ and 6.3 GeV compared to results from central $\text{Pb}+\text{Pb}$ collisions at 17.3 GeV. Dashed lines illustrate linear fits used to extract slope parameters, plotted in Figure 4.

2.3. Comparison with UrQMD

A comparison of real-data azimuthal correlation functions from central-$\text{Pb}+\text{Pb}$ and $p+p$ collisions at $\sqrt{s_{NN}} = 17.3$ GeV with results obtained from UrQMD simulations can be found in Figure 3. For both systems good agreement can be observed between the data and the simulations, especially on the away side. Moreover, strong similarity of correlation functions with and without jet contribution imply this particular correlation source not to play a major role in the SPS energy range.

Correlation functions for lower-energy UrQMD data sets were also produced but are not shown due to limited space. Slopes of linear fits to both UrQMD simulations and real data are shown in Figure 4. It can clearly be seen here that the weak dependence of away-side slope on energy in real data is also present in UrQMD simulations. However, data and simulations follow different trends on the near side.

3. Summary

A system-size and energy scan of two-particle correlation functions at high $p_T$ was performed by NA49. A flattening of the function’s away side was observed in central heavy-ion collisions even at low SPS energies, raising doubts about the standard parton energy loss interpretation. Interestingly, UrQMD predictions agree well with the away-side experimental results.

On the other hand, clear energy dependence of the correlation function was observed on the near side. As the energy decreases an enhancement changes into a depletion in the region close
Figure 3: Comparison of experimental and simulated correlation functions for central Pb+Pb (left) and p+p (right) collisions at $\sqrt{s_{NN}} = 17.3$ GeV. Points: experimental data, solid lines: UrQMD with PYTHIA, dashed lines: UrQMD without PYTHIA. Systematic errors have been omitted for clarity.

Figure 4: Dependence of slope values extracted from real-data (full points) and UrQMD (open points) correlation functions as a function of collision energy. Left: away side, right: near side.

to the probable onset of deconfinement. Further studies are required to find out whether the coincidence of these two features is related or accidental.

References

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