Dissipation and fragmentation of low-$Q^2$ scattered partons in Au-Au collisions at RHIC

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Abstract. Two-particle correlations and event-wise fluctuations in transverse momentum $p_t$ are reported for Au-Au collisions at $\sqrt{s_{NN}} = 62$ and 200 GeV on pseudorapidity $\eta$ and azimuth $\phi$. Distributions of all pairs of particles (no leading trigger particle) reveal jet-like correlations, or peaks at pair-wise opening angles of order 1 radian or less. The width of this same-side correlation peak increases dramatically on pseudorapidity and decreases on azimuth for increasing collision centrality. Evolution of the same-side peak with centrality suggests dissipation of low-$Q^2$ partons via strong coupling to an expanding bulk medium. $p_t$ correlations, which provide access to temperature and/or velocity distributions in the colliding system, are also presented.

Keywords: correlations, fluctuations, Au-Au collisions, minijets

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1. Introduction

Theoretical descriptions of relativistic heavy-ion collisions predict abundant low-$Q^2$ gluon production in the early stages of the collision with rapid parton thermalization driving the formation of a colored medium [1, 2, 3]. Remnants of these semi-hard processes may survive to the final, decoupling stage owing to the finite size and lifetime of the collision volume. If so, there should be contributions to nonstatistical event-wise fluctuations of mean-$p_t$ $\langle p_t \rangle$ and two-particle correlations. Large nonstatistical $\langle p_t \rangle$ fluctuations have been reported for Au-Au collisions at 130 GeV [4] and 200 GeV [5] which are much larger than was observed at the SPS [6, 7]. Study of the related two-particle correlations facilitates interpretation of event-wise fluctuations in terms of underlying dynamics. In this paper we report preliminary two-particle correlations for Au-Au collisions at 62 GeV on $(\eta, \phi)$ and $\langle p_t \rangle$ fluctua-
tions and \( p_t \) correlations for Au-Au at 200 GeV [8] from the STAR Collaboration. Low-\( Q^2 \) partons are emphasized in order to probe nonperturbative QCD medium effects. These data complement the two-particle correlations for Au-Au collisions at 130 GeV reported in [8, 9].

Data for the present analysis were obtained with the STAR detector [11] where charged particles were accepted in \(|\eta| \leq 1, \ 2\pi\) azimuth, and \( p_t \geq 0.15 \) GeV/c. Corrections were made for two-track inefficiencies and charge-sign dependent cuts were applied to minimize quantum and Coulomb correlation contributions. These cuts do not significantly affect the correlation structures shown here. Cuts based on \( dE/dx \) in the STAR Time Projection Chamber tracking detector were applied to reduce photon conversion \( e^{\pm} \) contamination. See Ref. [10] for discussion of the various cuts.

2. Autocorrelations

In conventional jet analysis event-wise concentrations of transverse momentum or energy localized on angle variables \((\eta, \phi)\) are identified. In heavy ion collisions, where such identification is impractical, jet studies are based on a high-\( p_t \) ‘leading particle’ which may estimate a parton momentum direction and some fraction of its magnitude. However, for low-\( Q^2 \) partons identification of a ‘leading particle’ is not possible. Furthermore the number of correlated hadrons from each low-\( Q^2 \) parton is expected to be relatively small while the number of such partons per event is large (of order tens). Observation of these relatively soft correlated hadrons is accessed via autocorrelations which are well-known in signal processing disciplines to enable weak but repetitive signals, which cannot be detected individually, to be accurately measured in aggregate. An autocorrelation is a projection by averaging from subspace \((x_1, x_2)\) onto difference variable \( x_{\Delta} \equiv x_1 - x_2 \). The autocorrelations reported in [9,10] and here do not require a leading- or trigger-particle, but instead use all particle pairs within the acceptance.

The two-particle correlation density per final state particle is defined by

\[
\Delta \rho / \sqrt{\rho_{mix}} = [\rho_{sib}(\vec{p}_1, \vec{p}_2) - \rho_{mix}(\vec{p}_1, \vec{p}_2)] / \sqrt{\rho_{mix}},
\]

where \( \rho_{sib}(\vec{p}_1, \vec{p}_2) \) is the object distribution comprised of particle pairs from single events (sibling pairs) and the reference distribution, \( \rho_{mix}(\vec{p}_1, \vec{p}_2) \), consists of pairs formed by sampling each particle of the pair from two different but similar events (mixed-event pairs). Studies of measured two-particle correlation projections onto subspaces \((p_{t1} \text{ vs } p_{t2}), (\eta_1 \text{ vs } \eta_2)\) and \((\phi_1 \text{ vs } \phi_2)\) indicate that the principle dependences for Au-Au collision data are on \((p_{t1} + p_{t2}), (p_{t1} - p_{t2})\), and the differences \( \eta_{\Delta} \equiv \eta_1 - \eta_2 \) and \( \phi_{\Delta} \equiv \phi_1 - \phi_2 \). For the latter two the correlation distributions are simultaneously projected onto difference variables \( \phi_{\Delta} \) and \( \eta_{\Delta} \); the projection is then referred to as a joint autocorrelation.
3. Charge-Independent Joint Autocorrelations on \((\eta_\Delta, \phi_\Delta)\)

Plotted in Fig. 1 are perspective views of preliminary charge-independent joint autocorrelations \(\Delta \rho/\sqrt{\rho_{\text{mix}}}\) on difference variables \((\eta_\Delta, \phi_\Delta)\) for three centrality bins (approximately 80-90\%, 50-60\% and 10-20\%) for Au-Au collisions at 62\,GeV. The distributions are dominated by 1) a \(\cos(2\phi_\Delta)\) component attributed to elliptic flow; 2) a \(\cos(\phi_\Delta)\) component associated with transverse momentum conservation, and 3) a 2D same-side \(|\phi_\Delta| < \pi/2\) peak, which is the principal object of interest here, and assumed to be associated with low-\(Q^2\) scattered parton fragmentation. In addition, for the most-peripheral data, a \(\phi_\Delta\) independent gaussian distribution on \(\eta_\Delta\) is observed similar to that seen in correlation studies of p-p collision data \([12]\) and assumed to be due to charge-ordering associated with longitudinal string fragmentation. This feature vanishes quickly with centrality. The same-side peak in Fig. 1 varies strongly with centrality, transitioning from nearly symmetric on \((\eta_\Delta, \phi_\Delta)\) for peripheral collisions to dramatically broadened along \(\eta_\Delta\) and narrowed on \(\phi_\Delta\) for the more central collisions. Resonance (e.g. \(\rho^0, \omega\)) decays contribute about 3\% of the peaks at \((0,0)\) \([10]\). Electron conversion pairs which remain after the \(dE/dx\) cuts add to the bin at \((0,0)\) producing the narrow spike there.

Mean-\(p_t\) fluctuation measure \(\Delta \sigma^2_{p_t:n}(\delta \eta, \delta \phi)\) \([4]\) obtained for particles within a two-dimensional bin of size \((\delta \eta, \delta \phi)\), is equivalent to an integral of \(p_t\) autocorrelation \(\Delta \rho(p_t : n; \eta_\Delta, \phi_\Delta)/\sqrt{\rho_{\text{mix}}}\) over difference variables from \((0,0)\) to \((\delta \eta, \delta \phi)\) \([8]\). Inversion of this integral equation yields \(p_t\) autocorrelations. The latter provide access to temperature and/or velocity distributions in the colliding system independent of that afforded by number of pair correlations \([8]\). Fig. 2 shows \(\Delta \sigma^2_{p_t:n}(\delta \eta, \delta \phi)\) (left panel), the resulting \(p_t\) autocorrelation (middle panel), and \(p_t\) autocorrelation with \(\cos(2\phi_\Delta)\) and \(\cos(\phi_\Delta)\) subtracted \([8]\) (right panel). The same-side peak structure broadens dramatically with centrality (not shown) on \(\eta_\Delta\) as in Fig. 1 but remains narrower than the corresponding number of pair correlations.
4. Conclusions

In STAR we are studying how the same-side autocorrelation structures evolve with centrality in Au-Au collisions at $\sqrt{s_{NN}} = 62, 130$ and 200 GeV. Same-side charge-average pair number and $p_t$ autocorrelations strongly elongate on $\eta$ and narrow on $\phi$. The STAR experiment results reported here and elsewhere \cite{8, 9, 10} are consistent with a picture in which (1) semi-hard parton scattering transfers momentum ($p_t$) to the bulk medium, inducing temperature/velocity fluctuations in the soft $p_t$ range whose correlation amplitudes scale with the number of binary collisions per participant, and (2) particles correlated with semi-hard scattered partons in the early stages of the collision interact with the longitudinally expanding medium resulting in larger average $|\eta_\Delta|$. The reduced width on $\phi$ is not understood.

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