Abstract.

We present a systematic study of two-particle angular correlations in p+p, Cu+Cu and Au+Au collisions over a broad range of pseudorapidity and azimuthal angle. The PHOBOS detector has a uniquely large angular coverage for inclusive charged particles, which allows for the study of correlations on both long- and short-range scales. A complex two-dimensional correlation structure emerges which is interpreted in the context of a cluster model. The cluster size and its decay width are extracted from the two-particle pseudorapidity correlation function. The cluster size found in semi-central Cu+Cu and Au+Au collisions is comparable to that found in p+p but a non-trivial increase of cluster size with decreasing centrality is observed. Moreover, the comparison between Cu+Cu and Au+Au systems shows an interesting scaling of the cluster size with the measured fraction of total cross section (which is related to b=2R), suggesting a geometric origin. These results should provide insight into the hadronization stage of the hot and dense medium created in heavy ion collisions.

Multiparticle correlation analyses have proven to be a powerful tool in exploring the underlying mechanism of particle production in high energy hadronic collisions. Both short-
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and long-range correlations have been discovered in the past decades [1, 2, 3] suggesting that particles tend to be produced in a correlated fashion [4, 5]. In this scenario, hadronization proceeds via "clusters", high mass states which decay isotropically in their center of mass frame to final-state hadrons. Two-particle angular correlations can provide detailed information about the cluster properties, e.g. their multiplicity ("size") and extent in phase space ("width"). In heavy ion collisions at RHIC, the expected formation of a Quark Gluon Plasma (QGP) could lead to a modification of the clusters relative to p+p collisions [6]. A comprehensive analysis of cluster properties in p+p and A+A collisions should provide essential information for understanding the hadronization stage in A+A collisions.

Covering pseudorapidity range $(-5 < \eta < 5)$ over almost full azimuthal angle, the PHOBOS Octagon detector [7] is ideally suited for studying the angular correlations of the particles emitted from clusters. The detailed analysis procedure has been described in Ref. [3]. The inclusive two-particle correlation function in $(\Delta \phi; \Delta \eta)$ space is defined as follows:

$$ R(\Delta \phi; \Delta \eta) = \frac{1}{n} \frac{F_n(\Delta \phi; \Delta \eta)}{B_n(\Delta \phi; \Delta \eta)} $$

where $F_n(\Delta \phi; \Delta \eta)$ is the foreground distribution obtained by taking two-particle pairs from the same event and $B_n(\Delta \phi; \Delta \eta)$ is the background distribution constructed by randomly selecting two particles from two different events with similar vertex position and centrality. The event multiplicity, $n$, is introduced to compensate for the trivial dilution effects from uncorrelated particles. $R(\Delta \phi; \Delta \eta)$ is defined in such a way that if a heavy ion collision is simply a superposition of individual p+p collisions, the same correlation function should be observed.

Fig. 1 shows the two-particle inclusive correlation function in p+p collisions at $p_{T} = 200$ GeV as a function of $\Delta \phi$ and $\Delta \eta$. A set of correction procedures has been applied, based on MC simulations, to extract the correlations between primary particles. The complex correlation structure suggests that the short range correlation is approximately Gaussian in and persists over the full range, becoming broader toward higher $p_T$. If clusters are the precursors to the measured hadrons, a high $p_T$ cluster would contribute to a narrow
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Figure 4: $K_e$ as a function of fractional cross section measured by PHOBOS (solid symbols) and from the AMPT model (open symbols) in Cu+Cu (squares) and Au+Au (circles) collisions at $P_{NN} = 200$ GeV.

Figure 5: Near-side (squares) and away-side (triangles) $K_e$ as a function of fractional cross section measured by PHOBOS in Cu+Cu (open symbols) and Au+Au (solid symbols) collisions at $P_{NN} = 200$ GeV.

peak at the near-side (near 0°) region of the correlation function in Fig.1, while a lower $p_T$ cluster will contribute to the broader away-side.

To study one aspect of the correlation function quantitatively, the two-dimensional (2D) correlation function is projected into a one-dimensional (1D) correlation function $R(\Delta\phi)$ shown in Fig.2. It is to a functional form defined in Ref. [5] in an independent cluster emission model:

$$R(\Delta\phi) = \frac{(\Delta\phi)}{B(\Delta\phi)} 1 \tag{2}$$

where $B(\Delta\phi)$ is the background distribution obtained by event-mixing. The parameter $\frac{h_K(\Delta\phi)}{h_K}$ contains the information about the cluster size $K$ and $(\Delta\phi)$ is a Gaussian function $\exp(-\frac{(\Delta\phi)^2}{2})$ characterizing the correlation of particles produced by a single cluster, where $\Delta\phi$ corresponds to the decay width of the clusters in space. The effective cluster multiplicity, or "size" defined to be $K_e = \frac{h_K(\Delta\phi)}{h_K} + 1 = h_K i + \frac{2}{h_K K}$. Of course, without any knowledge of the distribution of $K$, it is impossible to directly measure the average cluster size $h_K$. However, by a $\Delta\phi$ of Eq.2 to the measured two-particle correlation function, an example of which is shown in Fig.2, the effective cluster size $K_e$ can be estimated, as well as the cluster decay width $\Delta\phi$. $K_e$ of about 2.5 indicates that on average every charged particle is produced in association with another 1.5 particles, if it is assumed that $\Delta\phi = 0$.

In heavy ion collisions, not only the cluster-like structure but also a $\cos(2\phi)$ elliptic $\omega$ component is observed in the 2D correlation function as shown in Fig.3 for the most central 10% of the Au+Au collisions at $P_{NN} = 200$ GeV. As for p+p, we average over in order to study only the cluster properties in pseudorapidity space. In this procedure, the $\omega$ signal averages to zero. As described above, the two-particle pseudorapidity correlation function in A+A is by Eq.2 in a similar way to p+p. The resulting effective cluster size as a function of fractional cross section (collision centrality) is shown in Fig.4 for Cu+Cu and Au+Au collisions at $P_{NN} = 200$ GeV. The dashed line indicates the value found in $P_{NN} = 200$ GeV.
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p+p collisions, which suggests that the cluster properties are similar in p+p and A+A systems. This implies that the phenomenological properties of hadronization appear to be similar in p+p and A+A systems. However, it is also observed that the cluster size systemically decreases with increasing collision centrality in both Cu+Cu and Au+Au collisions. Furthermore, by comparing the two systems at the same fraction of the inelastic cross section (which is related to b=2R) it appears that the cluster size scales with collision geometry of the system, e.g., the shape of the overlap region. This feature is unexpected since the information of clusters is extracted from pseudorapidity space and not directly connected to the transverse geometry of the system. In comparing the data with dynamical models, AMPT gives the same qualitative trend as the data. Note that the values of $K_{\perp}$ are extracted in a limited acceptance of $j_{\perp} < 3$, and therefore are slightly smaller than for a full acceptance measurement. Detailed studies are underway in order to quantify this acceptance effect. The decrease in cluster size with centrality in AMPT is related to the hadronic rescattering stage. Turning on hadronic processes leads to a larger cluster size in both Au+Au and Cu+Cu that is approximately invariant for all centralities.

Further detailed studies on cluster properties have also been performed. Instead of averaging over the whole region, the near- and away-side cluster size can be extracted in a limited range of $(0,\beta_{0})$ and $(90,\beta_{80})$ respectively. In this restricted averaging, the $\cos(2\phi)$ elliptic component again averages to zero. The results are shown in Fig. 5 as a function of fractional cross section for Cu+Cu and Au+Au collisions at $p_{\text{lab}}^{\text{CM}} = 200$ GeV. For the more central collisions, the away-side cluster size decreases by about 30-40%, whereas the near-side cluster size decreases more slowly. Such a behavior could be understood in a scenario if the medium is extremely dense and only clusters produced close to the surface can survive. Then, for away-side clusters, it is more likely that part of its decay particles travel into the medium and get absorbed, resulting in the loss of away-side correlations. As for the observed collision geometry scaling of the cluster size, it might be related to the surface to volume ratio of the system. More detailed modeling is still being investigated to understand these phenomena.

In conclusion, the two-particle correlation function for inclusive charged particles has been extensively studied over a broad range in and in p+p, Cu+Cu and Au+Au collisions. In particular, it has already been shown that the observed short-range correlations in pseudorapidity have a natural interpretation in terms of clusters. In this approach, multiple particles are understood to be emitted close together in phase space, with a typical cluster size of 2-3 in p+p collisions. In the new A+A data, clusters have a similar size but show a non-trivial decrease in size with increasing centrality and a geometry scaling feature between Cu+Cu and Au+Au reactions. Analysis of near- and away-side clusters provides additional information on the details of the cluster properties. Future work will focus on model studies in order to understand the observed phenomena in heavy ion collisions.

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