PROCEEDINGS OF SCIENCE

Two-particle angular correlations in p+p and Cu+Cu collisions at PHOBOS

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We present results on two-particle angular correlations in p+p and Cu+Cu collisions over a broad range of (η,ϕ). The PHOBOS detector has a uniquely large angular coverage for inclusive charged particles. This allows for the study of correlations on both long and short range pseudorapidity 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. Relative to p+p collisions, Cu+Cu reactions show a non-trivial decrease of cluster size with increasing centrality. These results may provide insight into the hadronization stage of the hot and dense medium created in heavy ion collisions.

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1. Introduction

Multiparticle correlation analyses have proven to be a powerful tool in exploring the underlying mechanism of particle productions in high energy hadronic collisions. Both short- and long-range correlations have been discovered in the past decades [1, 2] which have been given a simple interpretation via the concept of clustering [3, 4]. In a cluster model, clusters of hadrons are formed first and emitted independently according to some basic scheme. They then decay isotropically in their center of mass frame into the observed hadrons. Two-particle angular correlations 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 [5]. This study should provide a useful baseline measurement for understanding hadronization stage in A+A collisions.

2. Analysis method

Covering pseudorapidity range ($\eta = -\ln(\tan(\theta/2))$) $-3 < \eta < 3$ over almost full azimuthal angle, the PHOBOS Octagon detector [6] is ideally suited for direct study of the angular correlations of the particles emitted from clusters. Following a similar approach as in Ref. [2], the inclusive two-particle correlation function in $(\Delta\eta, \Delta\phi)$ space is defined as follows:

$$R(\Delta\eta,\Delta\phi) = \left\langle (n-1)\left(\frac{F_n(\Delta\eta,\Delta\phi)}{B_n(\Delta\eta,\Delta\phi)} - 1\right)\right\rangle \tag{2.1}$$

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

3. Two-particle correlations in p+p collisions

Fig. 1 shows the two-particle inclusive correlation function in p+p collisions at $\sqrt{s}$ = 200 GeV as a function of $\Delta\eta$ and $\Delta\phi$. To achieve the correlations between primary particles, a set of correction procedures has been applied, based on MC simulations. The complex correlation structure suggests that the short range correlation is approximately Gaussian in $\Delta\eta$ and persists over the full $\Delta\phi$ range, becoming broader toward higher $\Delta\phi$. If clusters are the precursors to the final measured hadrons, a high p_T cluster would contribute to a narrow peak at the near-side ($\Delta\phi$ near 0^o) region of the correlation function in Fig. 1, while a lower p_T cluster will contribute to the broader away-side.

To study these features quantitatively, the two-dimensional (2D) correlation function is projected into a one-dimensional (1D) correlation function $R(\Delta\eta)$ shown in Fig. 3.1. It takes a form derived in Ref. [4] in an independent cluster emission model:

$$R(\Delta\eta) = \alpha\left[\frac{\Gamma(\Delta\eta)}{B(\Delta\eta)} - 1\right] \tag{3.1}$$

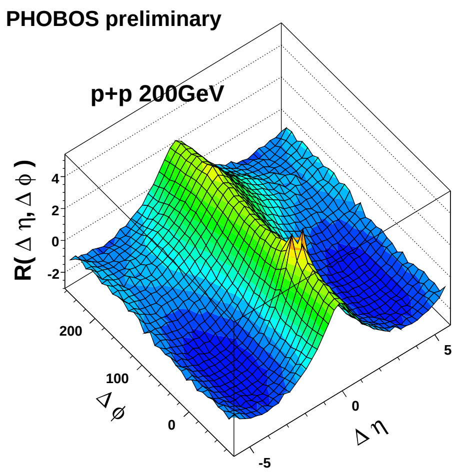

Figure 1: Final fully corrected two-particle correlation function in $(\Delta\eta, \Delta\phi)$ for p+p collisions at $\sqrt{s}$ = 200 GeV. A small region near ($\Delta\eta$, $\Delta\phi$) of (0,0) has been removed due to its large experimental uncertainty arising from the secondary effects.

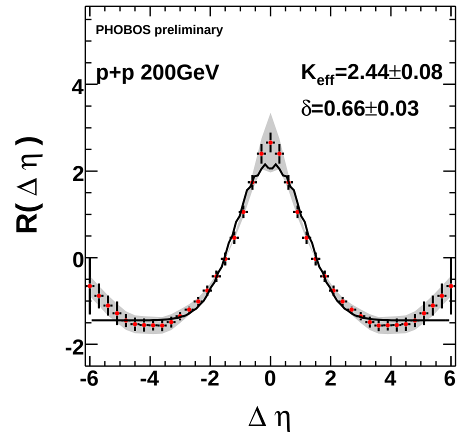

Figure 2: 1D two-particle rapidity correlation function in $(\Delta\eta)$ for p+p collisions at $\sqrt{s}$ = 200 GeV together with a fit from a cluster model. The fit parameters are: $K_{\rm eff}$=2.44±0.08 and δ=0.66±0.03 with 90% C.L. errors

where $B(\Delta\eta)$ is the background distribution obtained by event-mixing. Here the multiplicity dependence of $B(\Delta\eta)$ is not considered since the multiplicity distribution in p+p collisions is relatively narrow with $\sigma(n)/<n>$ of around 0.25. The parameter $\alpha = \frac{<K(K-1)>}{<K>}$ contains the information about the cluster size K and $\Gamma(\Delta\eta)$ is a Gaussian function $\propto exp(-(\Delta\eta)^2/(4\delta^2))$ characterizing the correlation of particles produced by a single cluster, where $\sqrt{2}\delta$ corresponds to the decay width of the clusters. The effective cluster multiplicity, or "size" is defined to be $K_{\rm eff} = \frac{<K(K-1)>}{<K>} + 1 = <K> + \frac{\sigma_K^2}{<K>}$. Of course, without any knowledge of the distribution of K, it is impossible to directly measure the average cluster size $<K>$. However, by a χ^2 fit of Eq. 3.1 to the measured two-particle correlation function, an example of which shown in Fig. 2, the effective cluster size $K_{\rm eff}$ can be estimated, as well as the cluster decay width $\sqrt{2}\delta$. A $K_{\rm eff}$ of about 2.5 indicates that on average every charged particle is strongly correlated with another 1.5 particles, if it is assumed that σ_K^2=0.

Fig. 3 shows the collision energy dependence of $K_{\rm eff}$ and δ. PHOBOS data at $\sqrt{s}$ = 200 GeV and 410 GeV are consistent with the previous UA5 measurements [1] and show a significant increase of the cluster size with energy. The cluster decay width is essentially constant with collision energy. The observed cluster size exceeds the expectation from resonance decay (about 1.7) [1] even at very low collision energy [2, 7], suggesting additional sources of short-range correlations are required to account for the experimental results.

4. Two-particle correlations in Cu+Cu collisions

In Cu+Cu collisions, a $\cos(2\Delta\phi)$ dependence is observed, and attributed to collective flow. However, in this work, the $\Delta\phi$ dependence is integrated out in order to just study the cluster properties in pseudorapidity. As was explained above, the two-particle pseudorapidity correlation function in Cu+Cu is fit by Eq. 3.1. The resulting effective cluster size as a function of participating nucle-

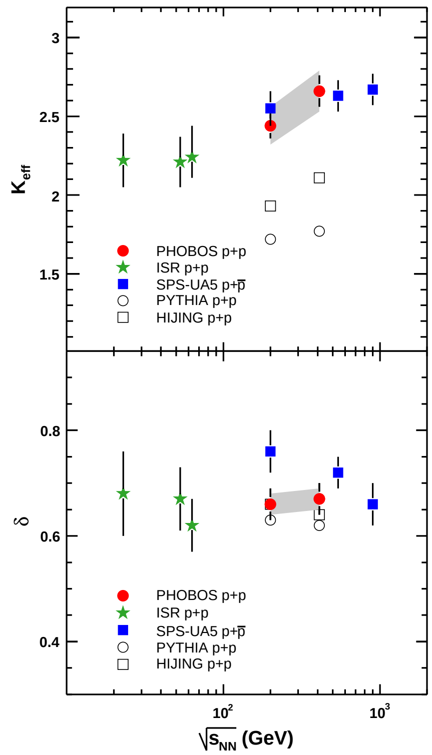

Figure 3: K_{eff} (top) and δ (bottom) as a function of $\sqrt{s}$ measured by PHOBOS (solid circle), UA5 [1] (solid square) and ISR [2, 7] (solid star) experiments in p+p and p+$\overline{\mathrm{p}}$ collisions.

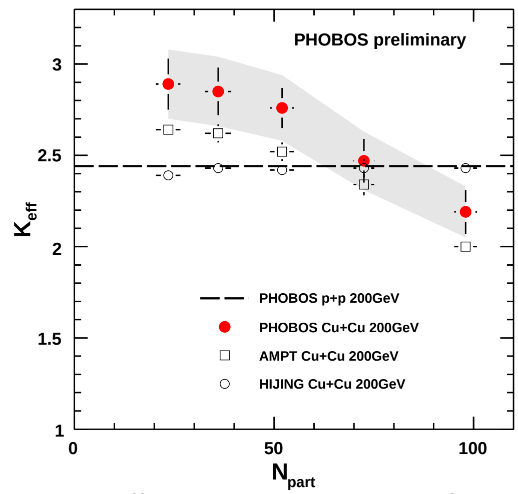

Figure 4: Effective cluster size K_{eff} as a function of N_{part} in Cu+Cu collisions at $\sqrt{s_{NN}}$ = 200 GeV (solid circle).The dashed line shows the corresponding value in p+p collisions measured by PHOBOS.

ons (N_{part}) is shown in Fig. 4 for Cu+Cu collisions at $\sqrt{s_{NN}}$ = 200 GeV. The dashed line indicates the value found in $\sqrt{s}$ = 200 GeV p+p collisions, and suggests that the cluster properties are similar in the two systems. This seems reasonable if clusters are produced in the late stages of the collision evolution and mainly reflect the hadronization process. However, it is observed that the cluster size decreases with increasing collision centrality. In comparing the data with dynamical models, it is found that AMPT gives the same qualitative trend as the data, but is systematically lower in magnitude. By contrast, HIJING remains constant with increasing centrality. Further comparison of Cu+Cu and Au+Au data with p+p should provide more information on the dynamical origins of the centrality dependence seen in the Cu+Cu data.

5. Conclusion

In conclusion, the two-particle correlation function for inclusive charged particles has been studied over broad range in η and ϕ. In particular, it is 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 Cu+Cu, clusters have a similar size but show a non-trivial decrease in size with increasing centrality. Future work will extend this study by providing a comprehensive study of two-particle correlations in p+p, d+Au, Cu+Cu and Au+Au reactions.

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