Forward-Backward Multiplicity Correlations in $\sqrt{s_{NN}} = 200$ GeV Au+Au Collisions

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Forward-backward correlations of charged-particle multiplicities in symmetric bins in pseudorapidity are studied in order to gain insight into the underlying correlation structure of particle production in Au+Au collisions. The PHOBOS detector is used to measure integrated multiplicities in bins defined within $|\eta| < 3$, centered at η and covering an interval $\Delta\eta$. The variance σ_C^2 of a suitably defined forward-backward asymmetry variable is calculated as a function of η, $\Delta\eta$, and centrality. It is found to be sensitive to short range correlations, and the concept of "clustering" is used to interpret comparisons to phenomenological models.

1. Introduction

It is often presumed that particle correlations are only "short-range" in rapidity. Short range correlations have been observed at all energies [1], in two-particle correlation measurements. However, they have never been shown to be the only source of correlation in multiparticle production. Indeed, single-particle distributions of inclusive charged particles produced in heavy ion collisions reveal a distinct "trapezoidal" structure stretching across the full rapidity range available in these reactions. More importantly, there is no evidence of an extended boost invariance, which would imply independent emission from different rapidity regions. Rather, two non-trivial effects are visible in the centrality dependence of particle production, which are apparently long-range in rapidity. Integrating over the full phase space reveals that particle production is linear with the number of participants [2]. This occurs despite a significant change in the shape of the pseudorapidity dependence as a function of centrality, which happens to be collision-energy independent in the forward region [3]. All of this suggests that charged-particle production at mid-rapidity is highly correlated with particle production in the forward region, which naturally begs the question of the underlying structure of the single-particle distributions. In these proceedings, we discuss how to take first steps in this direction via the study of forward-backward multiplicity correlations.

*For the full PHOBOS collaboration author list and acknowledgements, see the appendix 'Collaborations' appendix of this volume.

2. Forward-Backward Correlations from Fluctuations

In this work, particle correlations are studied by the event-by-event comparison of the integrated multiplicity in a bin defined in the forward ($\eta > 0$) region, called N_F, centered at η with width $\Delta\eta$, with the multiplicity measured in an identical bin defined in the backward hemisphere (called "N_B"). With these definitions, one can construct the event-wise observable $C = (N_F - N_B)/\sqrt{N_F + N_B}$, and measure its variance σ_C^2 for a set of events with nominally similar characteristics (e.g. centrality). If particle sources tend to emit into the forward *or* backward region, such that the partitioning is binomial, this leads to $\sigma_C^2 = 1$, since $\sigma^2(N_F - N_B) = N_F + N_B$. Short-range correlations arise if the objects emitted into either hemisphere tend to break into k particles, each of which stay close in rapidity (e.g. due to isotropic emission). If each cluster decays into exactly k particles, then $C \rightarrow \sqrt{k}C$, so $\sigma_C^2 \rightarrow k\sigma_C^2$. Such intrinsic short-range correlations have in fact been measured in $\overline{p}+p$ and $p+p$ experiments by direct construction of the 2-particle correlation function in η [1,4]. By varying $\Delta\eta$ and measuring the ratio $4\sigma_F^2/\langle N_F\rangle$ as a function of N_F+N_B, they found an "effective" cluster multiplicity ($k_{eff} = \langle k\rangle + \sigma_k^2/\langle k\rangle$) of approximately 2 charged particles, which exceeds the value of 1.5 estimated for a resonance gas [5].

3. Experimental Setup and Analysis Method

The data analyzed here were taken with the PHOBOS detector [6] during Runs 2 and 4, in 2001 and 2004, respectively. The pseudorapidity acceptance was restricted to that of the "Octagon" detector, which is a tube of silicon sensors covering $|\eta| < 3$ and full azimuth except for a region near midrapidity. To simplify the analysis for different values of η and $\Delta\eta$, only the regions of the detector with complete rapidity coverage were kept, restricting the total azimuthal acceptance to $\Delta\phi = \pi$, in four 45-degree wedges [7]. The multiplicity in each bin is estimated event-by-event by summing up the angle-corrected deposited energy of all hits and then dividing by the average energy per particle [8]. Beyond the usual lower threshold to define a hit in the silicon, an η-dependent upper bound of the deposited energy per hit is applied to reduce the effect of slow secondaries on the fluctuations. The average $\langle C\rangle$, calculated as a function of η, centrality, and event vertex, is subtracted event-by-event to correct for gaps in the Octagon (a process which, according to simulations, leaves the fluctuations unaffected).

To provide information that can be directly applied to models, a procedure was developed to estimate and remove the detector effects from the raw measured value of σ_C^2 ($\sigma_{C,raw}^2$) by using Monte Carlo (MC) simulations of the PHOBOS apparatus. The basic idea is to assume that $\sigma_{C,raw}^2 = \sigma_C^2 + \sigma_{det}^2$, where σ_{det}^2 is the contribution from detector effects, and use the MC to subtract it on average, leaving behind only the physical correlations. However, it is found that there are several sources which contribute differently as a function of η and combine in quadrature to a nearly-constant value over the pseudorapidity range covered by the Octagon [8]. These are corrected on average by calculating σ_C^2 using a modified HIJING simulation with all intrinsic correlations destroyed, which allows a direct estimation of σ_{det}^2. There remains a subdominant correlation of σ_{det}^2 with σ_C^2 which is also removed. Finally, we correct for using only half-azimuth acceptance by $\sigma_C^2 \rightarrow 2(\sigma_C^2 - 1) + 1$, a formula obtained using MC simulations, assuming that the limited acceptance only affects the clustering properties of particle production.

Systematic uncertainties were calculated by varying several assumptions about the estimation of σ_C^2 and found to be around $\Delta\sigma_C^2 \sim 0.1$. The bin-to-bin variation of the systematic error calculation was averaged over η to reduce fluctuations in the error determination procedure.

4. Results

After correcting for detector effects, the results on σ_C^2 can be directly compared with model calculations based on charged primary particles. We have focused mainly on HIJING [9] and AMPT [10], which have been used to describe various features of heavy ion collisions at RHIC energies.

The first set of results concern the η dependence, for forward and backward bins that are $\Delta\eta = 0.5$ units wide, as shown in Fig. 1. In this case, HIJING and AMPT already show some interesting differences. For peripheral (40-60%) events, both models have a similar magnitude and a monotonically-rising η dependence. Central events show a substantial difference extending over most of the rapidity range, with AMPT showing a systematically smaller value of σ_C^2. This may be due to initially produced clusters being destroyed by the hadronic rescattering stage. Also, it is observed that both data and MC show $\sigma_C^2 \sim 1$ at $\eta = 0$. Although this is suggestive of the effect predicted by Jeon et al [11], it can also be explained if clusters produced at $\eta = 0$ emit particles into *both* the N_F and N_B side, inducing an "intrinsic" long-range correlation that decreases σ_C^2.

The next set of results is the $\Delta\eta$ dependence of σ_C^2, with a fixed $\eta = 2.0$, as shown in Fig. 1. One sees that for both peripheral and central data, σ_C^2 rises monotonically with increasing pseudorapidity interval. This can be explained in the context of cluster emission: by increasing $\Delta\eta$, one increases the probability of observing more than one particle emitted from a single cluster in either N_F or N_B. Clearly, the rate of change with $\Delta\eta$ should reflect the full cluster distribution (both $\langle k \rangle$ and σ_k), but these studies have not yet been done. It is striking that the peripheral data has already reached $\sigma_C^2 \sim 3$ for the largest $\Delta\eta$ in peripheral events, while this number is closer to 2 for central data. Finally, it is interesting that neither HIJING nor AMPT can explain both the centrality and $\Delta\eta$ dependence simultaneously, as HIJING reproduces the central data but has no centrality dependence, while AMPT is lower than the central data, but also sees a decrease in the overall magnitude moving from peripheral to central events.

5. Conclusions

In conclusion, measurements of forward-backward fluctuations provide insight into the structure of long and short range correlations in pseudorapidity space. The new PHOBOS data for 200 GeV Au+Au collisions are now fully corrected for detector and background effects, so direct comparisons can be made to phenomenological models. We see significant short-range correlations at all centralities and pseudorapidities, instead of just at mid-rapidity. There is a non-trivial centrality and rapidity dependence of these correlations, in both η and $\Delta\eta$. Finally, neither HIJING nor AMPT reproduces even the qualitative features, but the way in which they fail to do so may well provide information on the underlying physics. In particular, more theoretical attention should be paid to

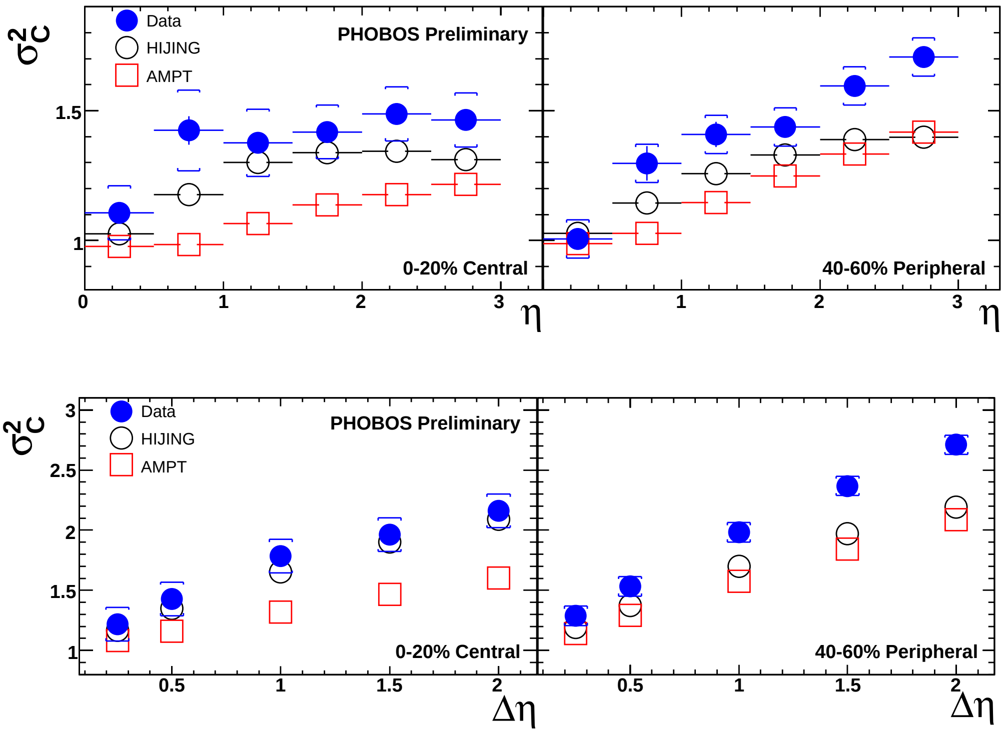

Figure 1. (upper) σ_C^2 for a fixed $\Delta\eta = 0.5$ as a function of η. (lower) σ_C^2 as a function of $\Delta\eta$ for a fixed bin center at $\eta = 2.0$.

the properties of "clusters" required to explain our data. Jeon et al have proposed, in Ref. [11], that the formation of a QGP near mid-rapidity should destroy any sort of cluster structure seen in p+p, and thus lead to a reduction in σ_C^2, beyond the detector-related effects discussed here. The data shown here should provide means to study such effects, or set upper limits on their occurrence.

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