Effect of Rescattering on Forward-Backward Correlations

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Abstract. We use the Ultra-relativistic Quantum Molecular Dynamic model (UrQMD v2.2) to study forward-backward fluctuations and compare our results with the data published by the PHOBOS experiment. The extracted effective cluster multiplicities show a clear centrality dependence within the present hadron-string transport approach. This behavior is not reproduced with models not taking into account final state rescattering.

INTRODUCTION

One of the main goal of the relativistic heavy ion program is to understand the nature of hadron production mechanisms (e.g. parton coalescence, string fragmentation or cluster decay). Numerous data suggest the formation of a quark gluon plasma (QGP) during the collision of two heavy nuclei at ultra-relativistic energies. Using correlations and fluctuations to probe the nature and properties of the highly heated, high density matter created in the course of these collisions has been proposed by many authors, see for example [1, 2, 3, 5, 6, 4, 7, 8, 9, 10]. In particular, one can get insight about cluster decay with the help of such fluctuation studies.

The UA5 experiment performed a study of cluster size in $p + \bar{p}$ collisions by analyzing forward-backward charged particle multiplicity fluctuations [11]. They found a cluster multiplicity around two, in line with the expected result in case clusters correspond to decaying resonances (e.g. $\pi^0 \rightarrow \pi^+ + \pi^-$. A similar analysis was recently performed by the PHOBOS experiment for $Au + Au$ reactions at $\sqrt{s_{NN}} = 200$ GeV [12].

In Refs. [2, 3], a simple model was introduced to extract the effective cluster multiplicity $K_{eff}$ from the PHOBOS data. Within this approach, $K_{eff}$ is found to be 2.7 for mid-peripheral events and $K_{eff} \sim 2.2$ for central events. The value of $K_{eff}$ in central collisions is close to the $p + \bar{p}$ value reported by UA5 [11]. Note that all measured cluster multiplicities $K_{eff}$ are larger than the one computed for a hadron resonance gas ($K_{HG} = 1.5$) [13], indicating that the measured charge correlations can not be described by simple statistical models based on hadronic degrees of freedom. The STAR collaboration has measured the long range correlations and it was shown that also within a string fusions approach, the data for central $A + A$ reactions can not be reproduced [14].

In this study we calculate a baseline estimate for forward-backward fluctuations based on the microscopic hadronic transport model UrQMD. For a complete review
of the model see [15]. The centrality, rapidity $\eta$ and rapidity window $\Delta \eta$ dependence of the dynamical fluctuations are studied and interpreted in term of effective cluster multiplicities. For this analysis, $5 \times 10^5 \, pp$ and minimum bias Au+Au events at $\sqrt{s_{NN}} = 200$ GeV were used.

**FORWARD-BACKWARD FLUCTUATIONS**

In this section, we introduce the variable $C$ that measures the asymmetry between the forward and backward charges. We define two symmetric rapidity regions at $\pm \eta$ with equal width $\Delta \eta$. The number of charged particles in the forward rapidity interval $\eta \pm \Delta \eta/2$ is $N_F$ while the corresponding number in the backward hemisphere $-\eta \pm \Delta \eta/2$ is given by $N_B$. We define the asymmetry variable $C = (N_F - N_B)/\sqrt{N_F + N_B}$, in each event. The variance of the charged particle multiplicity in the forward hemisphere is given by $D_{FF} = \langle N_F^2 \rangle - \langle N_F \rangle^2$ and similarly for the backward hemisphere $D_{BB} = \langle N_B^2 \rangle - \langle N_B \rangle^2$. We also introduce the covariance of charged particles in both hemispheres by $D_{FB} = \langle N_F N_B \rangle - \langle N_F \rangle \langle N_B \rangle$, where $\langle \ldots \rangle$ stands for the average over all events. The PHOBOS measure of the dynamical fluctuations $\sigma_C^2$ can be written as

$$\sigma_C^2 = \langle C^2 \rangle - \langle C \rangle^2 \approx \frac{D_{FF} + D_{BB} - 2D_{FB}}{\langle N_F + N_B \rangle}. \quad (1)$$

Recently, STAR [14] reported preliminary results of the so called correlation strength parameter $b = D_{FB}/D_{FF}$. The effective cluster multiplicity $K_{\text{eff}}$ is proportional to $\sigma_C^2$, such that if $b=0$, then the covariance $D_{FB}$ vanishes. In this case we have $\sigma_C^2 = K_{\text{eff}}$. We emphasize that $K_{\text{eff}}$ should be understood as a product of the true cluster multiplicity times a leakage factor $\xi$ that takes into account the limited observation window $\Delta \eta$ [2, 3]. The event by event fluctuations of the asymmetry parameter (variance) $\sigma_C^2$ in the absence of any correlations among the produced particles will be $\sigma_C^2 = 1$. If there is only long range correlation, then $0 < \sigma_C^2 < 1$.

**COMPARISON TO DATA**

We compare the UrQMD model calculations with the existing experimental data reported by PHOBOS for $Au+Au$ collisions at $\sqrt{s_{NN}} = 200$ GeV in Figs. 1, 2. Also shown here are the HIJING result as reported by PHOBOS [12]. Fig. 1 depicts $\sigma_C^2$ as a function of the pseudo-rapidity $\eta$ while the window is fixed at $\Delta \eta = 0.5$. In Fig. 2 we show $\sigma_C^2$ as a function of $\Delta \eta$ while $\eta$ is fixed at $\eta = 2$. Central data correspond to the 0$\%$–20$\%$ most central events while peripheral data correspond to 40$\%$–60$\%$ events as determined from the number of charged particles at mid-rapidity. We find that the present transport approach is able to reproduce mid-peripheral PHOBOS data roughly for both pseudo-rapidity $\eta$ and window $\Delta \eta$ dependence (Fig. 1 right and Fig. 2 right). As a function of the pseudo-rapidity window $\Delta \eta$, UrQMD can mimic the mid-peripheral experimental data, however, it fails to reproduce the central one.
As a function of $\eta$ (Fig. 1), $\sigma_C^2$ increases from $\sigma_C^2 \approx 1$ to $\sigma_C^2 \approx 1.75$ for mid-peripheral events. For central events, it increases from $\sigma_C^2 \approx 1$ to $\sigma_C^2 \approx 1.6$. The value $\sigma_C^2 \approx 1$ when $\eta = 0.25$ can be explained by the competition between long range and short range correlations which almost cancel out when the forward and backward acceptances are very close. The negative long range component then decreases with $\eta$ and let $\sigma_C^2$ increase.

Fig. 2 depicts the dependence of $\sigma_C^2$ on the size of the rapidity window $\Delta \eta$. The experimental value of $\sigma_C^2$ increases up to 2.8 for mid-peripheral events and reaches $\sigma_C^2 = 2.2$ for central events. UrQMD result overshoots PHOBOS data for central events. In Ref. [2, 3], we argued that by increasing the observation window $\Delta \eta$ one can see the whole cluster structure. The only process able to destroy the cluster structure in UrQMD is hadronic rescattering. The failure to reproduce central data can thus be seen as an indication for a lack of rescattering in UrQMD.

HIJING does not yield any centrality dependence and does not correctly reproduces the data for peripheral events, however, surprisingly reproduces the central data.

**CENTRALITY DEPENDENCE**

In this section, we study the centrality dependence of the forward-backward fluctuations calculated from UrQMD for a set of $Au + Au$ and $p + p$ events at the highest RHIC energy available. $\sigma_C^2$ as a function of $\eta$ is shown in Fig. 3(left) for different centralities. We observe a clear increase of $\sigma_C^2$ from $p + p$ ($\sigma_C^2 = 1.1$ at $\eta = 2.75$) up to the 20–40% $Au + Au$ most central events ($\sigma_C^2 = 1.8$ at $\eta = 2.75$). With even higher centrality, the behavior then changes and $\sigma_C^2$ gets now smaller ($\sigma_C^2 = 1.6$ at $\eta = 2.75$ for the 0–20% most central events). The same trend is observed as a function of the pseudo-rapidity window $\Delta \eta$ shown in Fig. 3(right). $\sigma_C^2$ increases from $p + p$ ($\sigma_C^2 = 1.25$ at $\Delta \eta = 2$) to the 20–40% $Au + Au$ most central events ($\sigma_C^2 = 2.75$ at $\Delta \eta = 2$). In [2, 3] we predicted that
FIGURE 2. Dynamic fluctuations as a function of pseudo rapidity window $\Delta \eta$ at $\sqrt{s_{NN}} = 200$ GeV, with $\eta = 2$ (Left) 0% – 20% central Au+Au, (right) 40%-60% peripheral Au+Au collisions. Full circles are PHOBOS data [12], open squares HIJING and open circles are UrQMD results.

FIGURE 3. UrQMD results of dynamic fluctuations as a function of pseudo rapidity $\eta$ (left, $\Delta \eta = 2$) and the observation window $\Delta \eta$ (right, $\eta = 2$).

for PHOBOS data, $\sigma_C^2$ may be reduce to 1.9 with tighter centrality cuts. This reduction in $\sigma_C^2 \sim K_{eff}$ may be regarded as an indication for cluster melting at RHIC.

A summary of the centrality dependence is presented in Fig. 4 where $\sigma_C^2$ is shown for fixed $\eta = 2$ and $\Delta \eta = 2$. With this acceptance window, $\sigma_C^2$ increases from $\sigma_C^2 = 2.1$ for peripheral events up to $\sigma_C^2 = 3$ for the 20 – 30% most central events. Followed by a decrease down to $\sigma_C^2 = 2.7$ for the 0 – 10% most central events. From Fig. 2 we see that a model without final state rescattering like HIJING seem not to be able to mimic the decreasing cluster size with the most central events.
SUMMARY AND CONCLUSION

In this paper we computed forward-backward fluctuations and compared UrQMD calculations results to the available experimental data measured by the PHOBOS collaboration. The study of proton-proton collisions indicated that the long range correlation persists over a wide rapidity gap between the two rapidity hemispheres. The variance of the asymmetry parameter $C$ was found to increase with increasing $\Delta \eta$ such that $\sigma^2_C$ changes from $\sigma^2_C(\eta = 2, \Delta \eta = 0.25) \approx 1$ to $\sigma^2_C(\eta = 2, \Delta \eta = 3) \approx 1.6$, this can be due the saturation of the leakage factor $\xi \to 1$.

For Au+Au collisions, we found that for both centrality bins $0\% - 20\%$ and $40\% - 60\%$, $\sigma^2_C \approx 1$ for small $\eta$. This can be seen as a cancellation between short and long range correlations. By increasing $\eta$ we observed that $\sigma^2_C$ also increases and approaches 1.6 and 1.8 for $0\% - 20\%$ and $40\% - 60\%$, respectively. This increase can be attributed to the decrease in the long range correlations. This will be true if the particle production mechanism does not change with $\eta$. To see the whole cluster structure, we fixed the center of the observation window at 2 and allowed $\Delta \eta$ to increase. We found that UrQMD can reproduce the peripheral data while it overestimates the experimental results for central collisions. This might indicate an additional cluster melting process not accounted for in the present hadron-string model.

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