Entropies in nucleus-nucleus collisions at AGS and SPS energies

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Introduction

Net entropy, which is believed to be roughly conserved between initial thermalization and freeze-out[1,2] is regarded as a useful quantity in probing the state of matter in early stages of relativistic AA collisions. After freeze-out, when particles freely stream, entropy remains essentially unchanged. It has been suggested[2] that event coincidence probability method of measuring entropy, proposed by Ma[2-4], is well suited for analysing local properties of multiparticle systems produced in hadronic and heavy-ion collisions at high energies. Moreover, entropy may serve as an additional tool for studying event-by-event (ebe) fluctuations and particle correlations. An attempt, therefore, is made to investigate entropy production in AA collisions by analysing the experimental data on ^{16}O-AgBr collisions at 14.5, 60 and 200A GeV/c and ^{32}S-AgBr collisions at 200A GeV/c. All the relevant details about the data may be found in our earlier publications[2-3]. In order to compare the findings of the present work with the predictions of Monte Carlo model, AMPT, event samples matching the real data are simulated using the code ampt-v-1.2.21 and these events are also analysed.

Formalism

Shannon and R enyi entropies in particle production may be estimated from their probability distributions using the following relations, $S = -\sum_n P_n l_n P_n$ and $H_k = \sum_n (P_n)^k$. Where, P_n is the probability of production of n relativistic charged particles in an interaction. Since entropy is invariant under an arbitrary change of multiplicity scale, one may choose sub-sample of particles, e.g. relativistic charged particles in limited pseudorapidity (η) windows. It has been observed that Shannon entropy in hadron-hadron collisions in the centre of mass energy range, from 22 GeV to 7 TeV, increases with beam energy, whereas the entropy normalized to maximum rapidity becomes almost energy independent[2, 3, 5]. Similar observations have been made in the case of AA collisions too[2,3]. The study of entropy dependence on the charged particle multiplicity in a limited η-window is, therefore expected to provide useful information on multiparticle production.

Results and Discussion

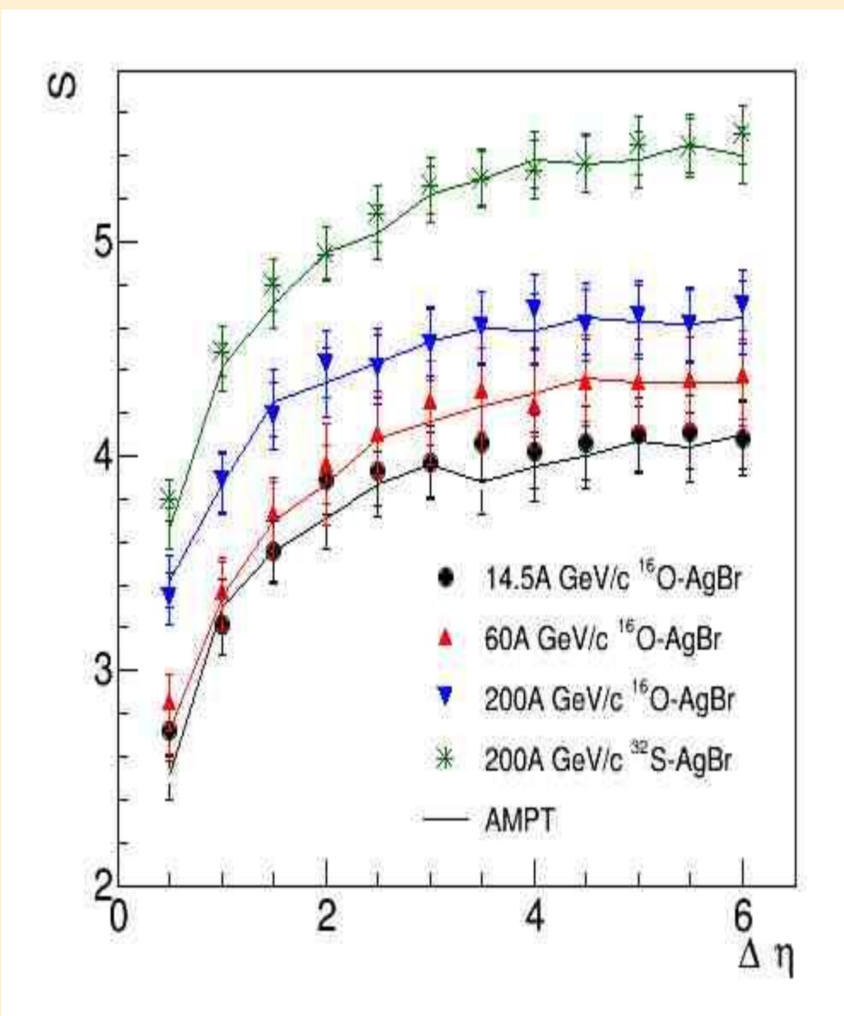

FIG.1: Variation of S With Δη for the real and AMPT event .

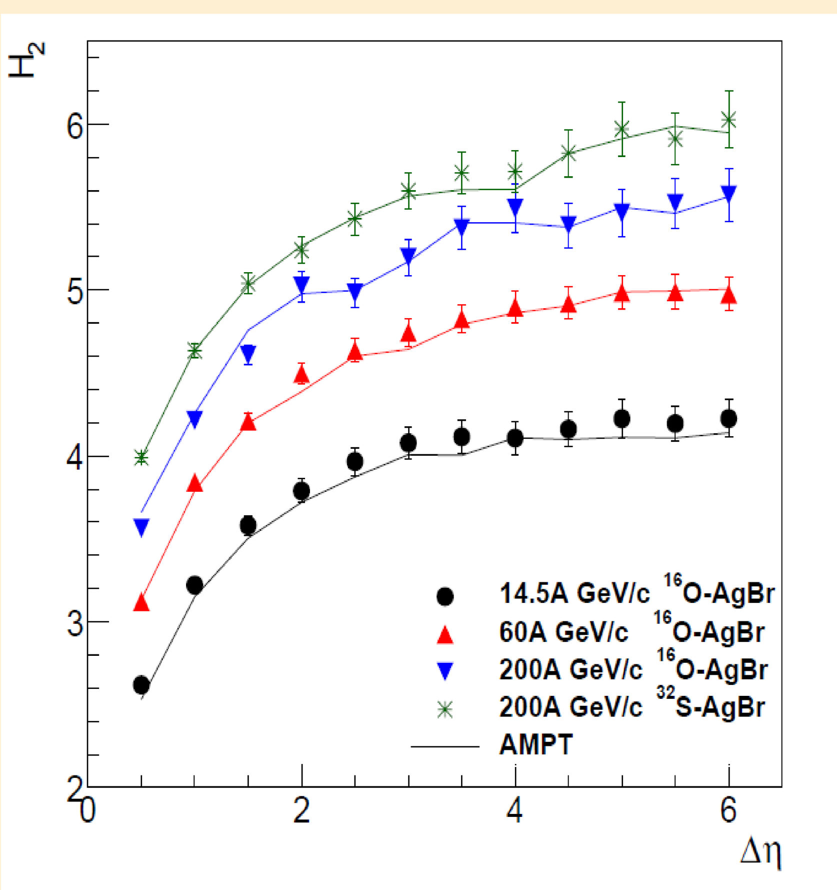

FIG.2: Dependence of H_2 on Δη for the real and AMPT event samples.

Probability P_n (Δn), of producing n relativistic charged particles in a η window of fixed width is calculated by choosing a window of width Δη = 0.5. This window is selected in such a way that its mid position coincides with the centre of symmetry of η distribution, η_c. Thus, all the charged particles with η lying in the range $\eta_c - \Delta\eta/2 \le \eta < \eta_c + \Delta\eta/2$ are counted to estimate P_n. The window width is then increased in a step of 0.5 until the region $\eta_c \pm 3.0$ is covered. Variations of Shannon entropy, S and R´enyi entropy of 2nd order, H_2 with Δη for the real and AMPT events are plotted in Figs.1 and 2. It is observed that both S and H_2 first increase with increasing Δη up to Δη ~2.5 and thereafter acquire nearly constant values. Furthermore, for a given Δη, S and H_2 values are found to be larger for higher beam energy or projectile mass. It may also be noted from these figures that the trends of variations of S and H_2 with Δη are nicely reproduced by AMPT Model. Variations of Shannon entropy normalized to the maximum rapidity, S/Y_m with Δη also normalized to maximum rapidity for the various data sets are displayed in Fig.3. It is noted from the figure that the value of S/Y_m first increases up to $\Delta\eta/Y_m \sim 0.5$ and thereafter tend to acquire almost a constant value. Variations of R´enyi entropy, H_2 with mean charged particle multiplicity in limited η bins, < η > are shown in Fig.4. It is interesting to note from Fig.3 and 4 that the data points for various energies/beam sizes overlap on a single curve.

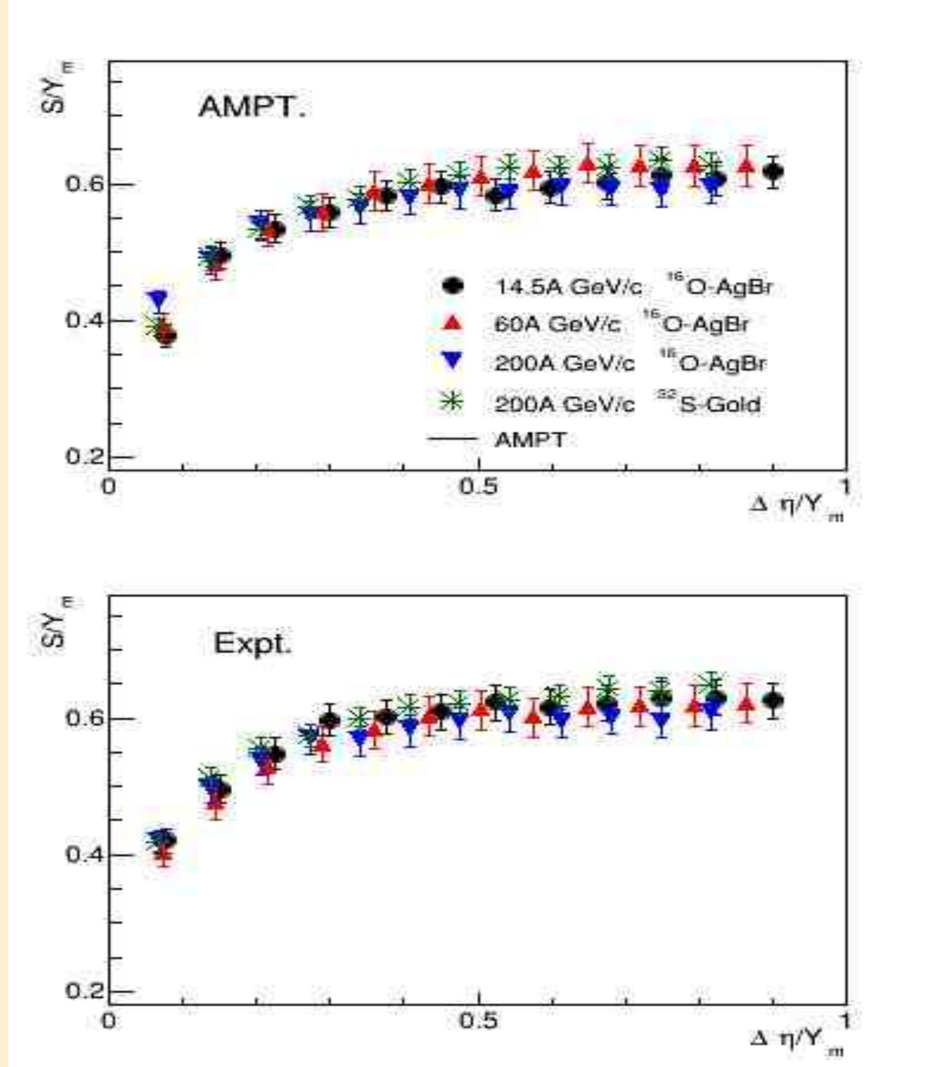

FIG.3: Dependence of S/y $_m$ on Δη/y_m for the real and AMPT samples.

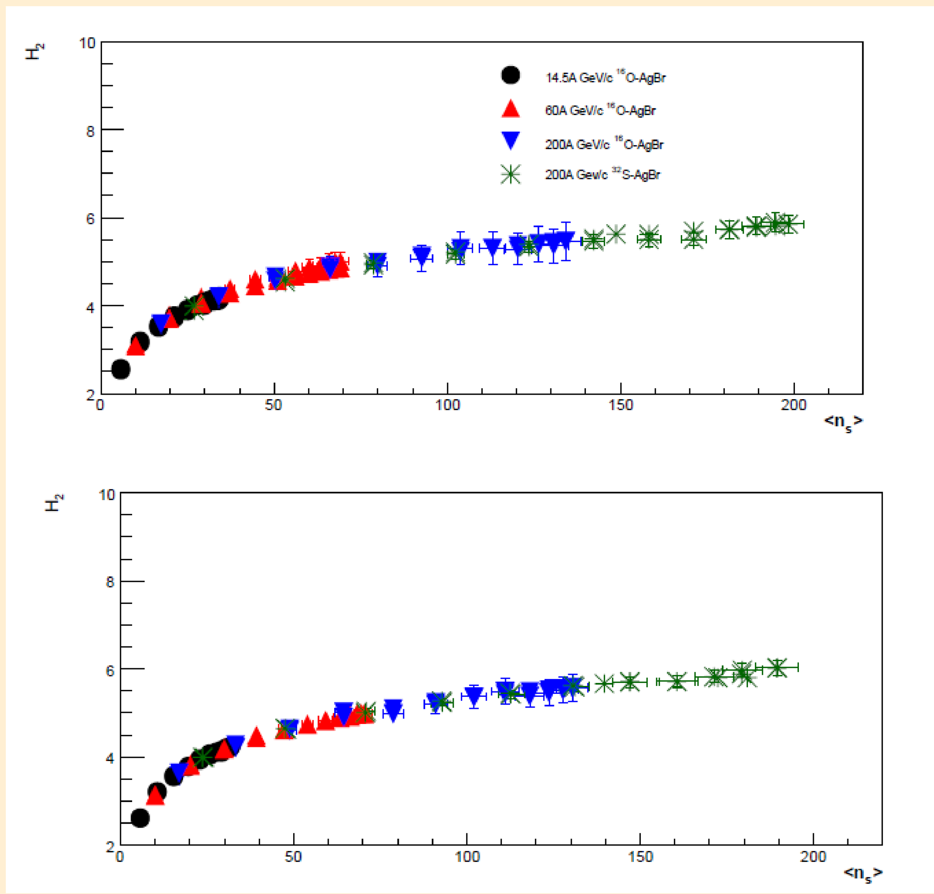

FIG.4: Dependence of H_2 on <n_s> for the real and AMPT samples.

In order to test whether the entropy difference in the two regions is a distinct feature of the data or arises simply due to the fluctuations in the event multiplicities, correlation-free Monte Carlo events matching the real data, are generated in the frame work of IEH (Independent Emission Hypothesis) Model [2,3]. Results of the analysis of these events are presented in the bottom panel of Fig.5. It is observed that for the correlation-free events, value of S in both F and B regions are nearly the same. Thus, the entropy difference in F and B regions observed for the real and AMPT data might be due to strong correlations existing between the particles emitted to the adjacent F and B regions. These correlations may be of short-range arising due to the decay of clusters or resonances produced in the central pseudorapidity regions.

Furthermore, the trends of variations of S/Y_m with $\Delta\eta/Y_m$ and H_2 with < n_s > are very well supported by the AMPT Model. These observations, thus, indicate towards entropy scaling at AGS and SPS energies. The observed ebe F-B multiplicity asymmetry in the earlier investigations[2,3] indicates that the entropies in the two regions should be different. In order to confirm this trend, variation of Shannon entropy, S, with Δη in the F and B regions are plotted in Fig.5. It is observed from the figure that entropy in the F region is higher than those in an identical η window for the corresponding B region. Such a difference in S values in F and B regions might be due to strong F-B correlations around the mid rapidity.

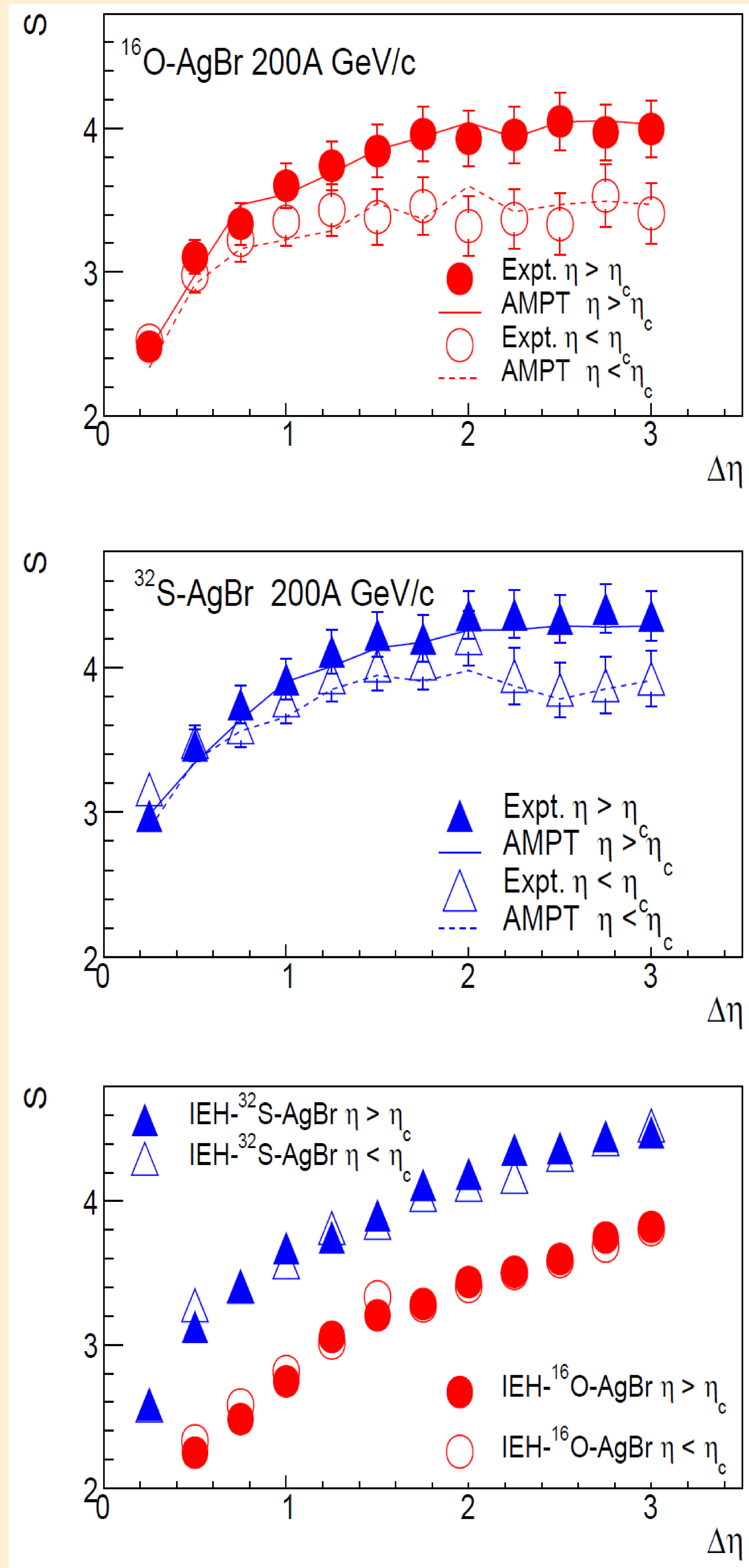

FIG.5: Variations of S on Δη in F and B for real , AMPT and IEH samples.

Conclusions

On the basis of the findings of the present work, the following conclusions may be drawn :

- Values of R enyi and Shannon entropies, for a given η-window are found to be higher for higher beam energy and projectile mass.
- Variations of S/y_m with $\Delta\eta/y_m$ and H_2 with < n_s > indicate the presence of entropy scaling in AA collisions at AGS and SPS energies.
- Comparison of entropy values in forward and backward η-region indicates the presence of strong short-range correlations around the mid rapidity.

References

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