On Entropy in Multiparticle Production and Multiplicity Scaling

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After the availability of the experimental data from Large Hadron Collider (LHC), events with very high multiplicities and several other new features have attracted a great deal of attention of high energy physicists. The study of multiplicity distributions, multiparticle correlations, statistical moments and scaling laws may lead to draw some new conclusions[1]. Dependence of multiplicity of produced particles on the incident beam energy was nicely explained by KNO scaling[2] from ∼ few GeV up to ISR energies. However, KNO scaling violations were observed when the energy increased to SPS range[3] and it was pointed out that the scaling of multiplicity distributions observed so far is approximate and accidental. To explain the shape of multiplicity distributions at SPS and also at lower energies, a new empirical regularity, in place of KNO scaling, was proposed[3]. Entropy estimation using the event coincidence probability method is regarded as another important method to study the multiplicity distributions and their scaling in high energy hadronic in nuclear collisions[1, 4]. It has been observed[5, 6] that in high energy heavy-ion collisions at AGS and SPS energies, entropy values estimated in limited pseudorapidity windows($\Delta\eta$) and normalized to maximum rapidity when plotted against $\Delta\eta$ (also normalized to maximum rapidity) exhibit a kind of scaling. Results based on hadron-hadron collision data from ISR upto LHC energies[1, 4] also indicate the presence of such kind of entropy scaling. An attempt, therefore, is made to examine the entropy scaling predicted by various Monte Carlo Models at LHC energies and compare the findings with those exhibited by the real data, reported by other workers[1]. Monte Carlo events are simulated using the code HIJING-1.35 and AMPT-v1.21-v2.21.

Entropy of the produced particles may be estimated[5, 6] from their multiplicity distribution, using the relation $S = -\sum P_n ln P_n$, where P$_n$ is the probability of production of n relativistic charged particles in an event. The invariance of entropy under an arbitrary change of multiplicity scale allows one to choose a subsample of particles, like charged particles. Probability of production of n relativistic charged particles in an η window of fixed width is calculated by choosing a window of width $\Delta\eta$=0.5. This window is so chosen that its mid position coincides with the centre of symmetry of η distribution, η_c. Probability P$_n$ for the charged particles falling in this window is calculated to estimate the entropy value. The window width is then increased in steps of 0.5 until a region η_c± 3.0 is covered. Variations of entropy, S with $\Delta\eta$ for the HIJING and AMPT simulated samples (each with 10^5events) at 0.9, 2.76, 7.0 and 13.0 TeV are plotted in Fig.1. It may be observed from the figure that with increasing $\Delta\eta$, entropy increases first rapidly, then slows down and finally saturates beyond $\Delta\eta \sim 4.0$. Such a trend is expected because of the fact that with widening of η-windows, particle multiplicity will increase first rapidly and then slowly resulting in the increase of entropy in a similar fashion. However, for $\Delta\eta \geq$4.0 multiplicity increases nominally yielding essentially a constant value of entropy. It may also be noted from the figure that for a given η-window entropy increases with increasing beam energy. It is also evidently clear from the figure that at a given energy and $\Delta\eta$, AMPT predicts somewhat larger multiplicity, and hence higher entropy as compared to those predicted by HIJING.

In order to find the evidence of entropy scaling with these data sets, entropy values normalized to maximum rapidity S/Y$_m$ are plotted against $\xi = (\Delta\eta/Y_m)$ in Fig.2; $Y_m = (l_n\sqrt{s}/m_\pi)$ being the maximum rapidity. The values of S/Y_m are increased by 0.2 units to have a better visibility. It is interesting to notice in the figure that the values of various energy data overlap and fall on a single curve indicating the presence of entropy scaling. HIJING and AMPT models, thus support the kind of entropy scaling in hadronic and heavy-ion collisions as observed with the real data[1, 4–6]. To check whether the observed entropy scaling is a distinct feature of the data and (or) HIJING and AMPT models, or arises solely due to fluctuations in the event multiplicities, correlation free Monte Carlo events corresponding to various event samples (HIJING /AMPT) are generated and analyzed.

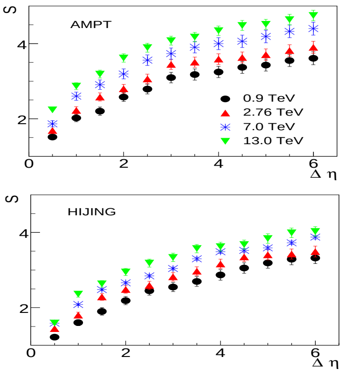

FIG. 1: Variations of S with $\Delta\eta$ for the HIJING and AMPT events.

These events are simulated in the framework of independent emission hypothesis (IEH) model by adopting the criteria, as discussed in ref.5. S/Y_m vs ξ plots for these data sets are presented in Fig.3. It is evidentally clear from the figure that IEH data do not exhibit the kind of entropy scaling as is predicted by the HIJING and AMPT. Thus, it may be remarked that the entropy scaling observed earlier with real data on pp and AA collisions is nicely supported by these models and hence these models (HIJING and AMPT) seem to be quite suitable to predict the multiplicity distributions in full and limited phase space in hadronic and ion-ion collisions at energies ranging from AGS and SPS to LHC.

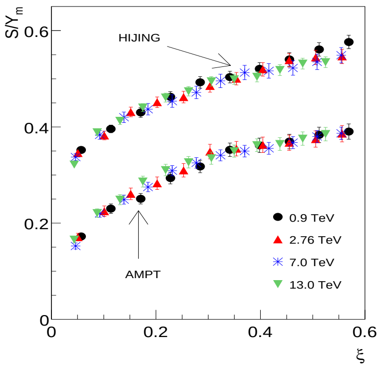

FIG. 2: Dependence of S/Y_m on ξ for the HIJING and AMPT event samples.

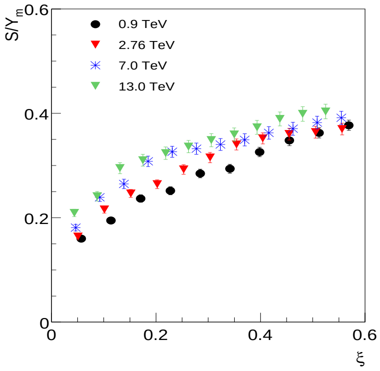

FIG. 3: S/Y_m vs ξ plots for the IEH event samples.

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