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Pseudorapidity and Pseudorapidity-Gap Distributions of Shower Particles Produced in Pb-Pb Collisions at CERN SPS

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Abstract:- An attempt has been made to study the multiplicity, pseudorapidity and pseudorapidity-gap distributions of relativistic charged particles produced in ^{208}Pb-^{208}Pb collisions at 158A GeV/c. A few remarks on the said characteristics of multiparticle production in relativistic nucleus-nucleus collisions has been made. The two-, three-, four- and five-particle correlations have been studied. The rapidity-gap distributions reveal the evidence of short-range correlation which hints towards the well-established fact that the secondary particles are produced via the process of clustering. The contribution of long-range correlation is negligible while as the short-range correlations seems to play a significant role.

Keywords:- *Pseudorapidity; Rapidity-Gap; Multiplicity; Correlation; Clustering.*

I. INTRODUCTION

One of the main goals for studying the characteristics of multiparticle production in relativistic heavy-ion collisions is to understand the underlying dynamics involved in phase-transition of produced nuclear matter into final state hadrons and to recreate the conditions that existed just after the Big Bang. A further impetus to these studies has emerged after the promising chance of quark-gluon plasma (QGP) formation at RHIC and LHC. Under the conditions of extreme density and temperature; the heavy nuclei collisions at high enough energy serve as a unique tool to study the strongly interacting matter. The fluctuations in hadron multiplicity produced in heavy-ion collisions may provide some clues for the occurrence of phase-transition [1-5].

At high energies; nucleons of the colliding nuclei deposit a huge amount of energy in a very small region of space resulting in the very high energy density (of the order GeV/fm^3) for a very short duration of time [6-8]. The final state particles produced from the space-time evolution of such collisions carry important information about the mechanism of particle production. To analyze these type of collision processes, the investigation of charged secondary particles plays a significant role.

The study of various aspects such as distributions of global observables (multiplicity of produced particles, their pseudorapidity distributions, transverse momentum distribution etc.), fluctuations and correlations related to particle production in these collisions play an important role. These are also helpful in understanding the matter produced after a few microseconds after the Big Bang, the QGP. The QGP is a de-confined state consisting up of quarks and their binding particles i.e., gluons. The theory of strong interactions, i.e., Quantum Chromodynamics (QCD), predicts the existence of QGP under extreme conditions of temperature and baryonic density.

In the experiments where nuclear emulsion is used, a special preference is given to singly charged particles having velocity more than 70 percent of the light velocity. The shower particles are such singly charged particles with the relative speed, $\beta \geq 0.7$. These particles are mostly the relativistic charged pions with a few kaons and protons. The ionization on the tracks of these particles is $g < 1.4g_o$; where g_o is the minimum ionization on the tracks of singly charged particles. It has been found more suitable to study the properties of only shower particles than an admixture of all the charged particles; because such an admixture also contains fragments from both the nuclei having totally different mass, energy and centrality dependence.

II. BRIEF DATA DETAILS

We have only considered the shower particles for our analysis. We have carried out an analysis of 58 events produced in ^{208}Pb-^{208}Pb collisions at 158A GeV/c retrieved from some of the irradiated Pb-chambers at CERN Super Proton Synchrotron (SPS). The collisions were recorded with initial momentum of 158A GeV/c ^{208}Pb beam accelerated towards the 250 µm thick stationery lead foil. The other details of the data can be found from the EMUO1 collaboration [9-12]. Due to its 4π solid angle coverage, the conventional emulsion technique has an advantage over other detectors. The full phase space acceptance in emulsions results in bias-free data while as the acceptance cone of other detectors is limited.

To carry out a comparative analysis, the simulated data is also considered. The 2000 events of Pb-Pb collision at 158A GeV/c have been simulated using event generator HIJING [13].

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III. MULTIPLICITY AND PSEUDORAPIDITY DISTRIBUTIONS

The rapidity variable (y) is of specific interest and is defined as y= 1/2 ln(E+P_l)/(E-P_l) where P_l and E respectively denote the longitudinal momentum and total energy of a particle. In the nuclear emulsion experiments, it is not possible to directly measure the rapidity variable and hence pseudorapidity is preferred.

The pseudorapidity distribution can be obtained directly in the relativistic heavy-ion interactions. Thus it provides a viable method to study the process and mechanism of particle production. The emission angle (θ) for shower particles can be measured precisely, and it is usually presented in the terms of pseudorapidity variable $\eta = -\ln\tan(\theta/2)$. Pseudorapidity variable is considered as one of the vital kinematical variables and its distribution is very helpful in yielding the information related to the multiparticle production mechanism.

Furthermore, the multiplicity of shower particles (N_S) is shown directly to be a parameter of the number of nucleons involved. One of the most common global observable to study the characteristics of the nucleus-nucleus collisions is particle multiplicity; and it provides significant information about the underlying dynamics of the mechanism of particle production. It is an important parameter to know about centrality of the collision and how the energy available at initial stage is distributed for the production of final state particles.

For a very large number of heavy-ion collisions, it becomes necessary to study the mean value of multiplicity both experimentally and theoretically. The mean value of multiplicities in relativistic charged particles produced in Pb-Pb collisions for both experimental and simulated data is presented in Table 1.

The multiplicity (N_S) distribution of both the experimental and simulated data has been presented in Figure 1.

The pseudorapidity distribution variation for shower particles per unit rapidity $P(N,\eta) = (1/N_{ev})(dn/d\eta)$ is shown in Figure 2; where N_{ev} represents the total number of events considered and dn represents the particle number in the pseudorapidity bin.

Data	Number of events(N_{ev})	Mean multiplicity<N_S>
Experimental	58	1120.55
HIJING	2000	668.85

Table 1: Mean multiplicities of relativistic charged particles.

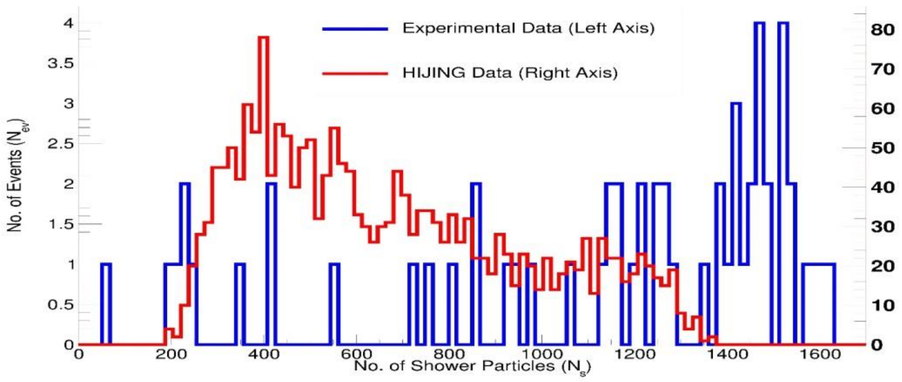

Fig 1:- Multiplicity Distribution of Shower Particles for both Experimental and HIJING Data.

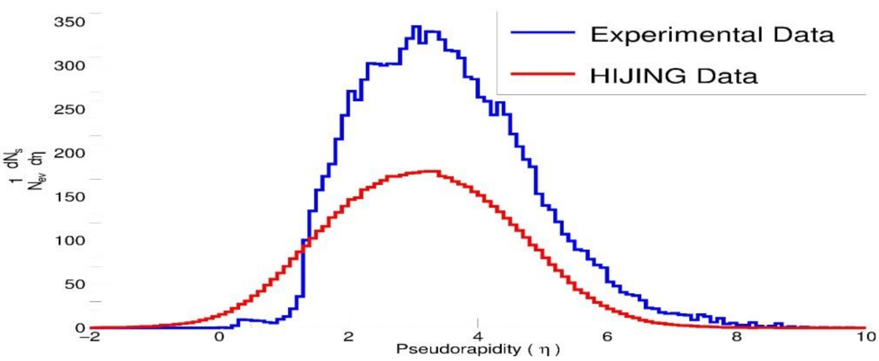

Fig 2:- Pseudorapidity Distribution of Shower Particles for both Experimental and HIJING Data.

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IV. RAPIDITY-GAP DISTRIBUTION

The mechanism of multiparticle production in heavy-ion collisions can be studied by observing the correlation behavior among the relativistic charged particles. This can be achieved by observing the correlations for different rapidity intervals. The secondary particles produced in high-energy hadronic interactions emerge through the decay of clusters is revealed by the phenomena of clustering among the relativistic charged particles. The higher peak at small rapidity gaps reveal the existence of clustering while as the randomly occurring particles in rapidity would result in an exponential distribution.

The pseudorapidity (η) of final-state particles is arranged in descending (or ascending) order such that $\eta_1 \geq \eta_2 \geq \eta_3 .... \geq \eta_N$. For each event; the pseudorapidity of particles at extremes is not considered; to exclude the contribution of diffraction dissociation, as these are considered as leading and target particles. The two-particle rapidity-gap is defined as the difference of pseudorapidity of two adjacent particles i.e., $r(2) = \Delta\eta_2 = \eta_i - \eta_{i+1}$. This difference is known as two-particle correlation where i = 1,2,3…N-1. The three-particle rapidity-gap; also known as three-particle correlation; can be defined as $r(3) = \Delta\eta_3 = \eta_i - \eta_{i+2}$ where i = 1,2,3…N-2. Similarly, four- and five-particle rapidity-gaps can be defined. In general, n-particle rapidity-gap can be written as $r(n) = \eta_i - \eta_{i+n-1}$ where i = 1,2,3…N-n+1; where N is the total number of relativistic charged particles produced in an event.

The Figure 3 (a-b), (c-d), (e-f) and (g-h) respectively show the two-, three-, four- and five-particle rapidity-gap distributions of relativistic singly charged particles for both experimental and simulated data of Pb-Pb collisions at 158A GeV/c. The higher peak of distribution at lower values of r(n) indicate the strong short-range correlations; giving an evidence that cluster formation leads to the production of secondary particles .

The rapidity-gap i.e., r(n) has been calculated for n = 2,3,4,5. The r(n) distributions have sharp peaks at lower values of rapidity-gap giving an evidence for lower order correlation. Similar results have been reported in nucleus-nucleus, hadron-nucleus and nucleus-nucleus collisions at different energies [14,15]. It is apparent from the figure that a single exponential function cannot describe the distribution. The two-channel generalization of Chew Pignotti model [16] can be used to describe the rapidity-gap distribution as follows:

$$dn/dr = A \exp(-Br) + C \exp(-Dr)$$

Where dn/dr represents the cluster density and B represents the correlation strength.

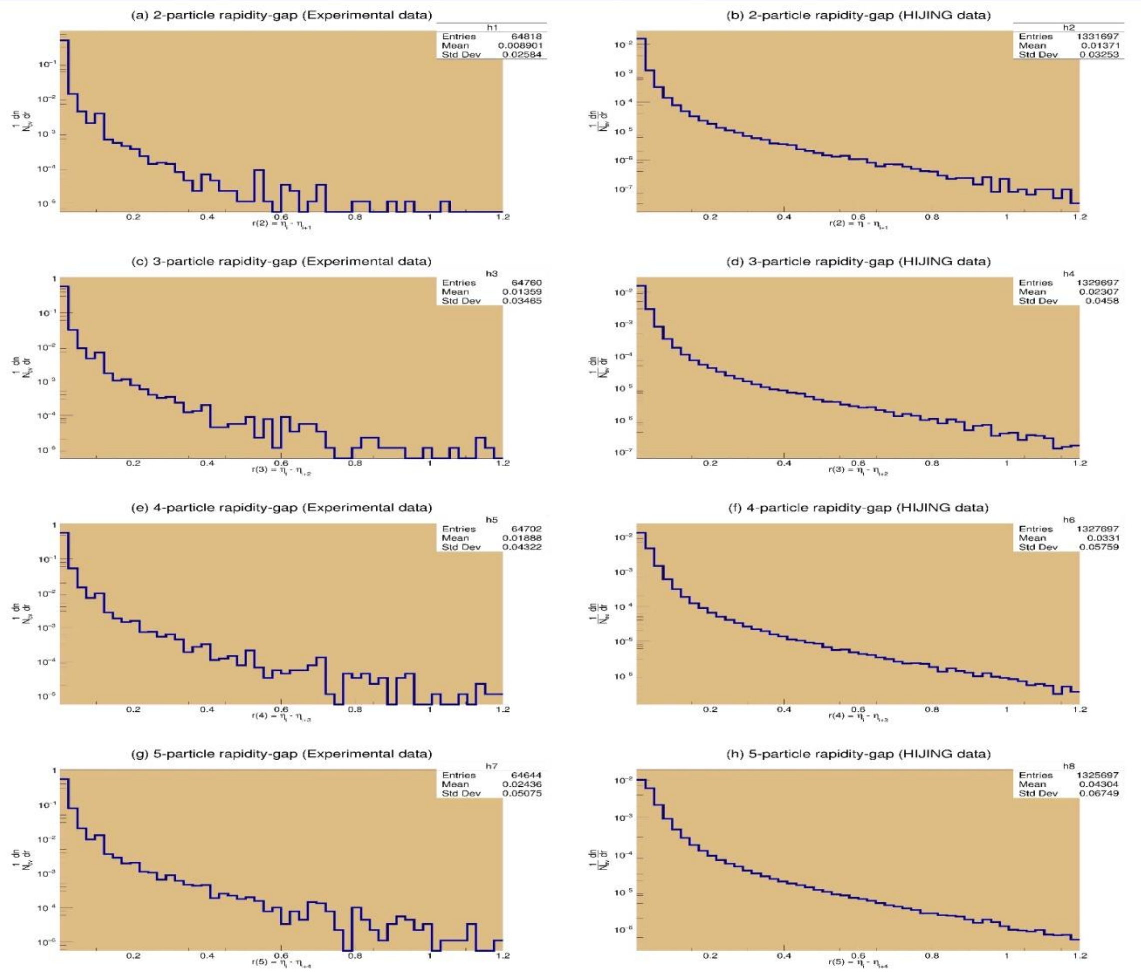

Fig 3:- Rapidity-gap Distributions for Experimental and HIJING Data.

V. CONCLUSION

The multiplicity, pseudorapidity and rapidity-gap distributions have been studied for the experimental and simulated data. It is observed from the distributions that the presence of high multiplicity events is proportionally more in experimental data as compared to the simulated data which results in lower value of <N_S> in the HIJING data. It may be due to the lesser statistics of considered experimental data.

The value of $(1/N_{ev})(dn/d\eta)$ in η-distribution is lower for HIJING data (where N=2000) as compared to the experimental data (where N=58); again owing to the lower statistics available. However, the peak is around η=3.0 for both the experimental and simulated data. The shape of the η-distribution is similar to the distribution as reported by EMU01 collaboration [17].

The peak of rapidity-gap distribution at lower values of r(n) i.e, more particles having smaller rapidity-gap results from the fact that more particles are closely spaced in rapidity space. The existence of short-range correlation implies that the secondary particles are produced via the process of clustering. The contribution of long-range correlation is negligible while as the short-range correlarion plays a significant role. The Chew-Pignotti model can be used to represent the correlation in rapidity-gap distributions.

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