A STUDY OF GENERAL CHARACTERISTICS OF Si-EMULSION COLLISIONS AT 14.6 AGeV

ABSTRACT
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Relativistic nucleus-nucleus collisions provide an opportunity to probe the high energy density region in the laboratory. It is expected that at extreme energy densities, there will be a phase transition of ordinary nuclear matter to a new state of matter – the quark-gluon plasma (Q.G.P.). The experimental challenge is to confirm Q.G.P. formation and study the properties of the new state of matter. The study of relativistic nuclear collisions will also provide the knowledge of the equation state of nuclear matter at densities relevant to the interior of neutron stars and for our understanding of the creation of the universe. But the relativistic nucleus-nucleus collision is a very complex process and in order to know and detect the signatures of Q.G.P. formation one must have a thorough understanding of the mechanism of the multiparticle production and fragmentation processes. Thus it is important to study different aspects of nucleus-nucleus collisions at relativistic energies. The availability of heavy ions with relativistic energies at CERN, Dubna and BNL made it possible to study nucleus-nucleus collisions in a systematic manner.

After giving a brief introduction to the subject in chapter I, the experimental technique has been described in chapter II. An emulsion stack exposed horizontally to 14.6A GeV silicon beam from Alternating Gradient Synchrotron at Brookhaven National Laboratory has been used for the present work. Nuclear emulsion having the highest special resolution among all particle detectors is an ideal detector. The dimensions of emulsion pellicles are 16.0×10.0×0.06 cm<sup>3</sup>. The sensitivity of emulsion is about 24 grains per 100 μm for singly charged particles with minimum ionizations.

Primary collisions are picked up by along the track scanning. Each primary track is followed until it collided or left the pellicle. Collisions lying within 3mm of the leading edge are not recorded. Each emulsion stack is doubly scanned along the tracks, fast in the forward directions and slowly in the backward one. 1107 collisions of 28Si are picked up by following 12258.8 cm of primary beams, leading to the collision mean free path of 28Si in emulsion λ = 11.07±0.48 cm. Scanning is carried out with almost 100% efficiency. Collisions that are within 20 μm from the top or bottom surface of the emulsion stack and caused by primaries making an angle greater than 2° with the mean beam direction are not recorded. In this way 784 inelastic collisions (events) of 14.6A GeV silicon ions in nuclear emulsion are recorded.

In each event polar and azimuthal angles of all secondary particles are measured under high magnification. The accuracy in the measurement of polar angle is 1 mrad and
in the measurement of azimuthal angle it is about 5°. Depending on ionization, all secondary tracks emitted from the collision vertices are classified as shower, grey, black particles and projectile fragments using the commonly accepted emulsion terminology described in chapter II.

Events are classified into different target groups using the following standard emulsion criteria:

- **AgBr events:** (i) \( N_h \geq 8 \) or (ii) \( N_h < 8 \) and at least one track with \( R \leq 10 \mu m \) and no track with \( 10 < R \leq 50 \mu m \)

- **CNO events:** \( 2 \leq N_h < 8 \) and no track with \( R < 10 \mu m \)

- **H events:** (i) \( N_h = 0 \) or (ii) \( N_h = 1 \) but falling in none of the above categories.

In this way out of 784 inelastic collisions in Emulsion, we have separated 360 collisions with AgBr target group, 287 collisions with CNO target group and 137 collisions with H target.

In chapter III we have studied the general characteristics of these collisions. The dependence of the percentage of collisions with nuclei of different target groups in emulsion on the mass of the projectile is studied. The mean multiplicities of all the secondary charged particles are calculated and are observed to depend on the mass of the target nucleus whereas the average multiplicity of shower particles depends on the energy of the projectile also. These dependences are well described by the relation \( <N_\gamma> = a_i <\Lambda_T>^b_i \).

The pseudorapidity distributions of shower particles produced in \(^{28}\text{Si}-\text{Emulsion}\) collisions at 4.5A GeV and 14.6A GeV are plotted. It is observed that with increase in the energy of the projectiles, the peak of the pseudorapidity distribution shifts towards the higher value of \( \eta \), which corresponds to small angle of emission. The pseudorapidity distributions of shower particles are fitted well with Gaussian distribution for \(^{28}\text{Si}-\text{AgBr}\), \(^{28}\text{Si}-\text{CNO}\) and \(^{28}\text{Si}-\text{H}\) collisions. It is observed that the distributions are almost the same at higher values of pseudorapidity and the centroids of the distribution grow and shift towards smaller values of pseudorapidity as the target mass increases from H to AgBr group.

Further, pseudorapidity distributions of shower particles are used to describe the target fragmentation region, the central region and the projectile fragmentation region.
The target fragmentation region corresponds to the lower $\eta$ values, that is, larger values of emission angle, which is characterized by the target nuclei. The projectile fragmentation region is assumed to be populated by fragments of projectile nucleus corresponding to larger values of $\eta$, that is, small angles of emission. The central region is believed to be enriched by the particles produced in collisions of the participants of colliding nuclei and is independent of either of the fragmentation regions.

The charged particle multiplicity correlations in $^{28}\text{Si-Emulsion}$ collisions at 14.6$A$ $GeV$ are studied. It is found that these correlations have a linear dependence with positive slope. The strongest correlation is observed between $<N_s>$ and $N_g$ with a slope $2.67 \pm 0.13$ for $^{28}\text{Si-Emulsion}$ collisions at 14.6$A$ $GeV$. The angular distributions of relativistic charged particles are independent of target mass and prominent peaks are observed at smaller angles. However, the angular distributions of grey and black particles (target fragments) show no significant peaks.

The study of multiplicity moments shows that the values of the ratio $<N_s>/D$ for various projectiles are almost the same that indicates a similar mechanism of shower particle production. The values of dispersion increase linearly with increase in the mean multiplicity of shower particles and the values of multiplicity moments $C_q$ increase with increasing value of $q$. The same trend is followed by the data on different projectiles as well. The shape of the multiplicity distribution of shower particles strongly depends on target mass. The multiplicity distributions of grey and black particles show that the distributions for $^{28}\text{Si-AgBr}$ collisions are broader than those for $^{28}\text{Si-CNO}$. The tail of the multiplicity distribution of shower particles extends to much higher values of $N_s$ with the increase in projectile energy. This is due to the production of more relativistic charged particles with increasing energy.

The negative binomial distribution is found to describe well the shower particle multiplicity distributions for $^{28}\text{Si-Emulsion}$, $^{28}\text{Si-AgBr}$ and $^{28}\text{Si-CNO}$ collisions for windows of different sizes in both the pseudorapidity ($\eta$) and azimuthal angle ($\phi$) phase spaces. In both the phase spaces, increasing values of clan size $\bar{N}_c$ are observed corresponding to each window size for $^{28}\text{Si-CNO}$, $^{28}\text{Si-Emulsion}$ and $^{28}\text{Si-AgBr}$ collisions. This is an evidence of the increase in the size of clusters with increase in the target mass.

From the results obtained from the analysis of the charged particles in the forward and backward hemispheres, it is clear that the backward particle production may be a consequence of the isotropic decay of a highly excited target nucleus in its rest frame.
after the forward particle production. The average multiplicities of shower and grey particles in both the hemispheres increase with increasing target size. These dependences on the target size are well parameterized by the power law form \( \langle N_s^k \rangle = \beta_s^k \langle A_T \rangle^{\alpha_s^k} \). A mild dependence of the forward backward ratio on the size of the projectile is observed for target fragments, whereas in the case of relativistic charged particles, a strong dependence is observed. The results obtained from the analysis of multiplicity distributions of the shower and grey particles emitted in the backward hemisphere confirm the limiting fragmentation hypothesis. Further, the results of the forward-backward multiplicity correlations show that the dependences of \( \langle N_s^F(N_s^B) \rangle \) on \( N_s^B \) and \( \langle N_s^B(N_s^F) \rangle \) on \( N_s^F \) are linear. The average number of shower and grey particles in the forward hemisphere depend strongly on the total number of shower and grey particles emitted in the backward hemisphere, whereas the average number of grey and shower particles in the backward hemisphere depends weakly on the total number of shower and grey particles emitted in the backward hemisphere. This shows that pions and protons emitted in the backward hemisphere are somewhat different from those emitted in the forward hemisphere.

In chapter IV, the modified moments \( G_q \) and the scaled factorial moments \( F_q \) are used to study of multifractality in \( ^{28}\text{Si}-\text{AgBr} \) collisions at 14.6\( A \) GeV in both the \( \eta \) and \( \varphi \) spaces. The connection between the \( G_q \) moments and the scaled factorial moments \( F_q \) has also been investigated. Presence of dynamical fluctuations and multifractality in our data in both the \( \eta \) and \( \varphi \) spaces are observed. Further, experimental results are compared with the string hadronic \( UrQMD \) model. It is observed that \( UrQMD \) model fails to explain the observed dynamical fluctuations and multifractality in our data in both the \( \eta \) and \( \varphi \) spaces. It also fails to explain the observed power law growth of the scaled factorial moment with decreasing bin size in both the spaces.

We have also used Takagi method to study multifractality in our data and observed that the results for the random and \( UrQMD \) events are about the same as those obtained for the experimental events in both the spaces. Thus no meaningful conclusion regarding multifractality in the data could be drawn from the analysis done using the Takagi method. We therefore suggest that only \( F_q \)-moment or \( G_q \)-moment method should be used for the study of multifractality in multiparticle production as the multiplicity moments calculated using the Takagi method are dominated by statistical fluctuations.
The generalized dimension $D_q$ are determined from $G_q$-moment and $F_q$-moment analyses for experimental and UrQMD events in both the spaces. $D_q$ values for our experimental events are found to decrease with increasing $q$. This shows the presence of multifractality in our data. However, for UrQMD events, $D_q$ values for different $q$ values are equal within the errors. Thus, the model again fails to explain the observed dynamical fluctuations and multifractality in our data. Therefore, we conclude that the string hadronic UrQMD model could not explain the experimental results on the generalized dimensions. The multifractal specific heat $\Delta c$ is also determined from $G_q$-moment and $F_q$-moment analyses. Differences in the values of $D_q$ and $\Delta c$ from the two methods are mainly due to the difference in the definitions of $G_q$-moments and $F_q$-moments.

In chapter V, we have studied the scaled factorial cumulant moments for shower particles produced in $^{28}$Si-$^{197}$AgBr collisions at 14.6$A$ GeV. We observed that both the second and third order scaled factorial cumulant moments $K_2$ and $K_3$ have non-zero values that is an evidence of the presence of dynamical two particle and three particle correlations. To compare our results with the string hadronic model UrQMD, we have simulated 1400 UrQMD events. The scaled factorial cumulant moments $K_2$ and $K_3$ for UrQMD events are also studied. It is observed that the values of $K_3$ for UrQMD events for different $M$ are almost zero, indicating the absence of three particle correlations in these events. However, $K_2$ values for different $M$ deviate significantly from zero, indicating that significant two particle correlations are present in UrQMD events. Further, to extract more information from the scaled factorial cumulant moment analysis we have investigated the slopes of $K_q$ versus $\ln M$ plots (cumulant indices). The cumulant indices for experimental events are $\rho_2 = 0.018 \pm 0.004$, $\rho_3 = 0.012 \pm 0.003$, whereas for UrQMD events they are $\rho_2 = 0.002 \pm 0.001$, $\rho_3 = -0.000 \pm 0.000$. The cumulant indices for UrQMD events are consistent with being zero. However, not only two particle correlations but also significant three particle correlations are present in our data. Moreover, the values of cumulant indices for our data are also not zero. Thus the model UrQMD fails to explain the observed correlations in our data.

We have observed that the cumulant indices show an inverse dependence upon the pseudorapidity density. This indicates that all types of interactions involve similar physics in terms of the types of particle sources created. We have calculated the number of independent sources for $^{28}$Si-$^{197}$AgBr collisions at 14.6$A$ GeV. The value of the average number of independent sources ($\bar{N}$) obtained using independent source model deviates
significantly the value obtained using the negative binomial distribution. One of the reasons for different values of $\bar{N}$ obtained from two methods could be the assumption used in arriving at $\bar{N} = \frac{3a(\rho)}{b}$ that is used to find $\bar{N}$. It has been assumed that the second order scaled factorial cumulant of the number of sources is zero. This assumption is not valid because the multiplicity distribution is not Poissonian as $K_2 \neq 0$. The other assumption that three particle correlations are negligible compared to two particle correlations is also not valid as significant three particle correlations are present in our data.

Additional information about the dynamics of multiparticle production can be obtained by investigating bin-bin correlations through the study of factorial correlators. The correlators measure not only the non-statistical local density fluctuations but also give important information about the correlations between the local density fluctuations in different regions of phase space. We have studied factorial correlators for $^{28}$Si-AgBr collisions at 14.6 A GeV and for UrQMD events in the full range of correlation length ($D$) and observed power law behaviour in the region $D < 0.5$. The slopes ($\phi_j$) obtained for UrQMD events are very nearly equal to zero. In the experimental events we observed that the slopes ($\phi_j$) increase with increase in the order of correlations but for UrQMD events for $\delta \chi = 0.125$ and 0.036, we observed no such pattern. Thus UrQMD model fails to explain our experimental results on factorial correlators also. Further, we have observed results in favour of $\delta \chi$ independence of $C_{ij}$ for small values of $D$, but the scaling seems to fail at large values of $D$ ($D > 0.5$). The results obtained for our data are in agreement with the $\alpha$-model, which predicts that the factorial correlators have a power law increase with decreasing distance between intervals and have no dependence on the size of the intervals ($\delta \chi$). But this does not guarantee the success of $\alpha$-model, as other models with short-range order have similar predictions.

Further, the scaled factorial moments $F_q$ are studied for $^{28}$Si-AgBr collisions at 14.6 A GeV. These moments follow the generalized power law $<F_q(M)> \propto [g(M)]^{\mu}$. The values of $\phi_j/\phi_2$ obtained from the linear fits of $\ln<F_q>$ versus $\ln<F_2>$ graphs are found to obey the Brax-Peschanski formula for intermittency indices with Levy index $\mu = 1.635 \pm 0.012$ for $\eta$ space and $\mu = 1.801 \pm 0.003$ for $\phi$ space. These values lie within the Levy stable region $0 < \mu < 2$. The generalized dimensions $D_q$ decreases with increasing $q$, which
indicates that the multiparticle production in $^{28}\text{Si-AgBr}$ collisions at 14.6A GeV is a self-similar cascade process. The multifractal spectra $f(a_q)$ in $\eta$ and $\varphi$ spaces are obtained. $f(a_q)$ spectra are smooth and concave downward, indicating the presence of dynamical fluctuations in our data.

We have collected very useful information about the dynamics of multiparticle production in nucleus-nucleus collisions at relativistic energy. Significant dynamical fluctuations have been observed in our data. It is believed that the fluctuations could be due to the formation of quark-gluon plasma (Q.G.P.) in these collisions. But evidence of dynamical fluctuations has also been obtained in low energy nucleus-nucleus collisions where the formation of Q.G.P. is not expected. Even in target fragmentation process, where the Q.G.P. phase transition is most unlikely, evidence of dynamical fluctuations has been reported by some investigators. So Q.G.P. phase transition cannot be the only reason for the fluctuations observed in our data. It may be possible that the observed fluctuations may have a more conventional explanation. The presence of random cascade mechanism or short-range correlations or some collective phenomena may be responsible for the observed dynamical correlations in relativistic nucleus-nucleus collisions.