Proton emission in asymmetric nuclear interactions at 14.5 AGeV: Evidence of strong dynamical fluctuation

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An analysis of data of medium energy protons emitted in $^{28}$Si-Br interactions at 14.5 AGeV reveals the existence of strong emission asymmetry in the azimuthal plane which is found to depend on the target excitation. A comparison with the data of $^{20}$S-AgBr (at 200 AGeV) and $^{16}$O-AgBr (at 60 AGeV) interactions indicates that emission asymmetry depends on the projectile mass and energy.

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1 Introduction

Search for non-statistical fluctuations in the pionization process has developed a spur of interest in the last few years and various methods\(^1\) have been applied for the identification of such fluctuations. Fluctuation studies have gained so much momentum because large local fluctuations have been conjectured to be a possible signal of quark gluon plasma (QGP) phase transition. One of the signatures of QGP formation is larger non-statistical fluctuations among produced pions. Recently a large number of studies have been reported, where fluctuations have been studied for the pions in pseudo rapidity space. Generally the emphasis is on the relativistic produced particles (mostly pions) in theories as well as in experiments to disclose the fundamental dynamics of the relativistic interactions. But studies on medium energy (30-400 MeV) knocked out target protons which manifest themselves as grey tracks in nuclear emulsion, can also provide important information for understanding the physical process involved. In this paper the dynamical fluctuations have been studied in the spatial distribution of the medium energy protons emitted as a result of $^{28}$Si-AgBr interactions at 14.5 AGeV.

The nuclear fragmentation data are very conveniently provided by nuclear emulsion experiments. Due to its high spatial resolution, nuclear emulsion is capable of registering all the charged particles (even of very short life) in a 4$\pi$ geometry. During a relativistic heavy ion collision, the projectile as well as the target undergo fragmentation. The target on fragmentation, produces highly ionizing particles responsible for heavy tracks in the nuclear emulsion. Conveniently the heavy tracks are sub-divided into two groups: (i) black tracks and (ii) grey ones. The black particles are the slow target evaporated particles, whereas the grey tracks are due to fast knocked out protons.

According to the evaporation model\(^2\), these particles are the low energy part of the internucleon cascade and they leave the nucleus during or shortly after the passage of the incident projectile nucleus. Since they are produced immediately after the collisions, they are believed to carry relevant information about the dynamics of the multi-particle production process. The characteristics about the dynamics of medium energy knocked out protons are not revealed as yet in detail. So the study of these particles is essential. The existence of non-statistical fluctuations in the azimuthal angle distribution of the medium-energy protons has been studied.

The non-statistical fluctuations in the azimuthal angle distribution of target protons produced by $^{28}$Si-AgBr interaction at 14.5 AGeV have been investigated. The data set used in the present analysis
were obtained by irradiating Ilford-G5 emulsion stacks by an $^9$Si beam with incident energy 14.5 GeV/nucleon.

2 Experimental Details

The emulsion plates have been scanned to identify the events with the help of a Leitz-Metallplan microscope, using a 10 x objective in conjunction with a 25 x ocular lens. The final measurements are done using an oil immersion 100 x objective. The microscope is provided with a semi-automatic scanning stage. The measuring system fitted with it has 1μm resolution along X- and Y-axis and 0.5 μm along the Z-axis. Here the events have been selected which satisfy the following criteria:

1. The beam-track should not be at an angle greater than 3° to the mean beam direction of the pellicle, because if it exceeds more than 3°, it may not be a projectile;
2. The interaction should not be within 20 μm from the top or bottom surface of the pellicle. This is done to reduce the loss of tracks as well as to reduce the error in angle measurement;
3. All the primary beam tracks are followed back to ensure that the events chosen do not include interaction from the secondary tracks of other interaction and it is a projectile beam starting from the beginning of the pellicle.

According to the emulsion terminology all the charged secondaries from an event of an interactions, are identified as follows:

(i) The heavily ionizing particles with ionization $> 10 I_p$, where $I_p$ is the minimum ionization of a singly charged particle having their traces as 'black' tracks less than 3 mm in the emulsion; (ii) The tracks formed with the particles of medium ionisation ($1.4 I_p < I < 6 I_p$) and having ranges greater than 3 mm are identified as 'grey' tracks in the emulsion; (iii) shower tracks (the relativistic particles) with ionization $I < 1.4 I_p$.

3 Calculation

The events containing heavy tracks $N_h (= N_s + N_l)$ more than eight are considered to be associated with heavy target (AgBr) in nuclear emulsion. Here the authors calculate the azimuthal angle ($\phi$) for each grey track around the beam axis by taking the coordinates of the interaction centre, one point on the incident beam track and one on the respective secondary track. To calculate the azimuthal angle using the coordinate geometry, the coordinate normal to the emulsion plate (i.e. along the Z-axis) is corrected for the shrinkage of emulsion during processing. Finally 350 events of $^9$Si-AgBr interactions at 14.5 AGeV energy, are analyzed.

The whole azimuthal plane, having 2π angular range is divided into two equal angular intervals and the difference in the number of particles emitted in the two intervals for each of the events are found out. The process is repeated by shifting the line of division over the azimuthal plane by $10^\circ$ and by taking the difference in the number of grey particles in the two halves, each time. This process is carried out till the position of the line of division is repeated. The maximum difference obtained for each event is taken as $\Delta n_i$, where $i$, indicates the event number. The probability of azimuthal asymmetry for the $i$-th event is defined as

$$W_i = \Delta n_i / n_i$$

where $n_i$ is the total number of grey tracks in the $i$-th event of the group of events in a particular $N_g$ interval. For a group of $m$ events in an $N_g$ interval, the probability of azimuthal asymmetry is given as:

$$\overline{W} = \sum W_i / m$$

To calculate the asymmetry parameter ($\overline{W}$) the data sample is divided into groups such that all the events in a particular group have almost equal number of grey tracks. Then the authors calculate $\overline{W}$ for different $N_g$ intervals. For any particular $N_g$ interval the weighted average of $N_g$ is given by:

$$\overline{N_g} = \sum P_{N_g} N_g$$

where $P_{N_g}$ represents the probability of getting an event with $N_g$ number of grey tracks.

4 Results and Discussion

To study the variation of the azimuthal asymmetry with the number of grey tracks, the calculated values of the probability $\overline{W}$ of azimuthal asymmetry and their corresponding weighted averages $\overline{N_g}$ for the data are presented in Table 1. The variation of $\overline{W}$ against $\overline{N_g}$ for the experimental data set is shown in Fig.1. From Fig.1 it is revealed that $\overline{W}$ decreases with the increase of $\overline{N_g}$ indicating that asymmetry decreases with the increase in the number of grey tracks.

To understand whether the characteristics revealed above is a reflection of mere statistics, the original data set has been randomly shuffled. The same procedure has been followed in determining the probability of azimuthal asymmetry with the randomized data set. Probability $\overline{W}$ calculated from the randomized data set of 28 $\overline{N_g}$ has also been plotted against $\overline{N_g}$ on Fig. 1 for the experimental data set. The results for the randomized data set show that the probability of
azimuthal asymmetry for most of the points differ appreciably from that of the experimental values (considering the error bars).

To have a comparative view the authors have plotted the probability $\bar{W}$ against $N_g$ for the $^{28}$Si-AgBr interactions at 14.5 AGeV along with the combined experimental points from $^{16}$O-AgBr interactions at 60 AGeV and $^{32}$S-AgBr interactions at 200 AGeV in Fig. 2.

Both the current data and the combined data of $^{16}$O-AgBr and $^{32}$S-AgBr interactions follow a power law of the form:

$$\bar{W} = p \cdot N_g^{-q}$$  \hspace{1cm} (4)

The dependence of $\bar{W}$ against $N_g$ in $^{32}$Si-AgBr interactions is different from that in case of combined

<table>
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<th>Interactions</th>
<th>$N_g$</th>
<th>$N_g$</th>
<th>Experimental value</th>
<th>Randomized value</th>
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</thead>
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<tr>
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<tr>
<td></td>
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Fig. 1—Plot of the probability $\bar{W}$ of azimuthal asymmetry against $N_g$ for both the experimental and simulated data of $^{28}$Si-AgBr interaction at 14.5 AGeV.

Fig. 2—Plot of the probability $\bar{W}$ of azimuthal asymmetry against $N_g$ for the experimental data sets of $^{16}$O-AgBr interactions at 60 AGeV, $^{32}$S-AgBr interactions at 200 AGeV and $^{28}$Si-AgBr interactions at 14.5 AGeV along with the power law best fit curves.
Table 2—Values of $p$ and $q$ per degrees of freedom for $^{16}$O-AgBr interactions at 60 AGeV, $^{32}$S-AgBr interactions at 200 AGeV and $^{28}$Si-AgBr interactions at 14.5 AGeV.

<table>
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<tr>
<th>Interactions</th>
<th>$p$</th>
<th>$q$</th>
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<tbody>
<tr>
<td>$^{16}$O - AgBr at 60 AGeV</td>
<td>1.3</td>
<td>-0.35</td>
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<tr>
<td>&amp; $^{32}$S - AgBr at 200 AGeV</td>
<td></td>
<td></td>
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<tr>
<td>$^{28}$Si - AgBr at 14.5 AGeV</td>
<td>1.4</td>
<td>-0.48</td>
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</tbody>
</table>

$^{16}$O-AgBr and $^{32}$S-AgBr interactions. The values of $p$ and $q$ obtained from the best fit (Fig. 2) for $^{28}$Si-AgBr data are given in Table 2. The corresponding values for the combined data set of $^{16}$O-AgBr and $^{32}$S-AgBr interactions are also included in Table 2.

5 Conclusion

From the above analysis it can be concluded that the target protons are emitted asymmetrically in azimuthal space and the degree of asymmetry decreases with increase of proton multiplicity. It is interesting to note that the asymmetry value for any multiplicity is less than that at ultra high energy interactions ($^{16}$O-AgBr at 60 AGeV and $^{32}$S-AgBr at 200 AGeV). The comparison with the simulated data confirms that the observed behaviour is only due to the dynamics of the emission process. Similar results have also been observed in case of pion production and for emission of heavy target fragments in relativistic nuclear collisions.

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References