International Journal of Scientific Engineering and Research (IJSER)
ISSN (Online): 2347-3878 (UGC Approved, Sr. No. 48096)
Index Copernicus Value (2015): 62.86 | Impact Factor (2015): 3.791

Signal of Dynamical Long-Range Rapidity Correlation among Pions in Ultra-Relativistic Nuclear Interactions

Md. Abdul Kayum Jafry[1], Dipak Ghosh[2]

[1]Shibpur Dinobundhoo Institution (College), 412/1 G.T.Road (South), Howrah711102, India

[2]Nuclear and Particle Physics Research Centre, Department of Physics, Jadavpur University, Kolkata-700032, India

Abstract: ***This paper reports an investigation on the two-particle long - range rapidity correlation among the pions produced in ^{16}O–AgBr interactions at 60 AGeV and ^{32}S–AgBr interactions at 200 AGeV. The experimental results have been compared with those of Monte Carlo simulated events to extract dynamical correlation. The data show two-particle long-range correlation among the pions in rapidity space at both the energies.***

Keywords: Heavy ion interactions, produced particles, two-particle rapidity correlation

PACS: 25.70 Pq, 25.75-q

1. Introduction

Nuclear matter under extremes of energy and density has been extensively studied with the use of relativistic heavy ion collisions. The insight into the extreme matter with experimentally controlled initial energies serve as an examination of existing models and theories. The models and approaches that are used to describe the processes occurring in the reaction region are examined by comparing theoretical predictions with experimental data on single, two-and many-particle momentum spectra, which contain information of the source in the early stage. The study of correlation among the produced particles provides significant features of the nuclear interactions and is a potential source of information. Two-particle correlations give information about the space time structure and dynamics of the emitting source [1–3]. Several studies using well-known two-and three-particle correlation functions have been reported in different types of interactions at various energies [4–15].

In most of the previous investigations short-range correlation of pions has been studied. It is also important as well as interesting to study long-range correlation among pions. But study in this respect is practically nil. For this reason, we are trying to investigate long-range correlation of pions in pseudorapidity space.

This work presents new data on two-particle long-range correlations among pions in ^{16}O–AgBr interactions at 60 AGeV and ^{32}S–AgBr interactions at 200 AGeV.

2. Experimental Method

The data sets used in this present analysis were obtained from Illford G5 emulsion tracks exposed to ^{32}S beam of energy 200 AGeV and ^{16}O beam of energy 60 AGeV were obtained from CERN SPS. A Leitz Metaloplan microscope with a 10x objective and 10x ocular lens provided with a semi-automatic scanning stage was used to scan the plates. Each plate was scanned by two independent observers to increase the scanning efficiency. The final measurements were done using an oil-immersion 100x objective. The measuring system fitted with it has 1 µm resolution along the x and y axes and 0.5 µm resolutions along the z axis.

Our detector can resolve particles differing by 0.1 unit in pseudorapidity scale and about 5^0 in azimuthal angle space. It is worthwhile to mention that the emulsion technique possesses a very high spatial resolution which makes it a very effective detector for studying correlation phenomena.

After scanning, the events were chosen according to the following criteria:

1) The incident beam track should not exceed 3^0 from the main beam direction in the pellicle. It is done to ensure that we have taken the real projectile beam.
2) Events showing interactions within 20 µm from the top or bottom surface of the pellicle were rejected. It is done to reduce the loss of tracks as well as to reduce the error in angle measurement.
3) The selection of the primary interactions is made by following the incident beam track in the backward direction until it reaches the leading edge.

According to the emulsion terminology [16] the particles emitted after interactions are classified as:

a) *Black particles*: Black particles consist of both single and multiple charged fragments. They are target fragments of various elements like carbon, lithium, beryllium etc with ionization greater or equal to 10 I_0, I_0 being the minimum ionization of a singly charged particle. Ranges of them are less than 3 mm and the velocity less than 0.3 c and the energy less than 30 MeV, where c is the velocity of light in vacuum.

b) *Grey particles*: They are mainly fast target recoil protons with energy up to 400 MeV. They have ionization 1.4

$I_0 \le I \le 10 I_0$. Their ranges are greater than 3 mm and having velocities (v), 0.7 c $\ge$ v $\ge$ 0.3 c.

c) *Shower particles*: The relativistic shower tracks with ionization I less than or equal to 1.4 I_0 are mainly produced by pions and are not generally confined within the emulsion pellicle. These shower particles have energy in GeV range.

d) The projectile fragments are a different class of tracks with constant ionization, long range and small emission angle. To ensure that the targets in the emulsion are silver or bromine nuclei, we have chosen only the events with at least eight heavy ionizing tracks of black and grey particles. For our present analysis, we have taken into consideration shower tracks (which are mostly pions) for rapidity correlation.

According to the above selection procedure, we have chosen 250 events of ^{16}O–AgBr interactions at 60 AGeV and 140 events of ^{32}S–AgBr interactions at 200 AGeV . The shower tracks are identified from each event and their emission angles (θ) with respect to beam direction were measured for each track by taking the coordinates of the interaction point (X_0, Y_0, Z_0), coordinates (X_1, Y_1, Z_1) at the end of the linear portion of each secondary track and the coordinates (X_i ,Y_i ,Z_i) of a point on the incident beam. After measuring the emission angles (θ) of the shower tracks, we can obtain the pseudorapidity variable (η) using the relation $\eta = -\ln \tan(\theta/2)$.

For our present analysis we have used the variable η .

3. Method of Analysis

3.1 Two-particle correlation

For the phase space variable z, the two-particle normalized correlation function is defined [14] as

$$R(z_1, z_2) = \frac{\rho_2(z_1, z_2) - \rho_1(z_1)\rho_1(z_2)}{\rho_1(z_1)\rho_1(z_2)}$$

$$= \frac{\rho_2(z_1, z_2)}{\rho_1(z_1)\rho_1(z_2)} - 1$$

where the quantities

$$\rho_1(z) = \frac{1}{\sigma}\frac{d\sigma}{dz}; \rho_2(z_1, z_2) = \frac{1}{\sigma}\frac{d^2\sigma}{dz_1 dz_2}$$

represent one and two particle densities respectively.

In terms of number of particles, R can be represented as

$$R(z_1, z_2) = N_T \frac{N_2(z_1, z_2)}{N_1(z_1)N_1(z_2)} - 1$$

where N_T is the total number of inelastic events, $N_1(z_1)$ is the number of pions at the phase space interval z_1 to z_1+dz_1 and $N_1(z_2)$ is the number of pions at the phase space interval z_2 to z_2+dz_2. $N_2(z_1, z_2)$ is the number of pairs of particles having one particle between the interval z_1 to z_1+dz_1 other particle between z_2 to z_2+dz_2 in an event .

For the purpose of study of rapidity correlation among pions, η is chosen as phase space variable. In terms of η ,

$$R(\eta_1, \eta_2) = N_T \frac{N_2(\eta_1, \eta_2)}{N_1(\eta_1)N_1(\eta_2)} - 1 \quad \text{.........(1)}$$

The idea of using the correlation function of the above form comes from the work of Kirkwood [17] in statistical physics. R = 0 implies the absence of correlation, i.e. the case of completely independent particle emission.

3.2. Monte Carlo Simulation

Correlation between the particles produced in high energy heavy ion collisions can be studied by observing pseudo rapidity correlation (η) among them. Apart from the presence of any true dynamics, correlation may arise due to the following reasons:

a) The broad multiplicity distribution of produced particles.
b) The dependence of single particle spectrum $\frac{1}{\sigma}\frac{d\sigma}{dz}$ on the multiplicity.
c) Trivial statistical fluctuations.

We have compared the experimental data with the data obtained by Monte Carlo Simulation assuming independent emission model (IEM), to search for the non-trivial dynamical correlation among the produced particles in ^{16}O–AgBr interactions at 60 AGeV and ^{32}S–AgBr interactions at 200 AGeV. The simulation is made using the following assumptions:

a) The produced particles (pions) are emitted independently.
b) The multiplicity distribution of the Monte Carlo events is the same as the empirical multiplicity spectrum of the real ensemble.

c) The single particle spectrum $\frac{1}{\sigma}\frac{d\sigma}{dz}$ of the simulated events reproduces the empirical multiplicity distribution $\frac{1}{\sigma}\frac{d\sigma}{dz}$ of the real ensemble.

It may be concluded that if one finds any excess in experimental values over the Monte Carlo simulated values, then there may be some kinematical reason within the reaction process which may leads towards long range dynamical correlation among produced particles. We will denote the experimental normalized correlation function by R and that of the Monte Carlo calculated events by R_M. The difference between experimental and Monte Carlo values can be interpreted as the dynamical surplus which arises due to some dynamics in the reaction process. The dynamical surplus can be written as

$$R_D = R - R_M \quad \text{...........(2)}$$

4. Results and Discussion

The normalized two-particle correlation function R is calculated for different values of pseudorapidity (η) for both the data sets with the help of Eqn. (1) . We have calculated the correlation function R for the off-diagonal elements of the correlation matrix $(\eta_1 \neq \eta_2)$ which characterizes the magnitude of the long-range correlation at different phase space intervals. We have also calculated the correlation function R_M for the simulated events for the same values of phase space intervals.

We have calculated the dynamical surplus values R_D from Eqn. (2). It is observed that long-range dynamical correlations are very prominent in some pseudo rapidity regions. The details of which are shown in Table I.

Table 1: The types of interactions with their specified energies, raipidity η_1 , η_2 , the differences between η_1 and η_2 and few maximum values of the dynamical surplus R_D for each interactions.

Interactions	η_1	η_2	$\eta_1 \sim \eta_2$	R_D
$^{16}O - AgBr$ (60 AGeV)	0 5	7 -1	7 6	40.13 15.60
$^{32}S - AgBr$ (200 AGeV)	-1 8	7 0	8 8	56.44 55.28

The table shows indication of significant dynamical long range rapidity correlation both in ^{16}O–AgBr interactions at 60 AGeV and ^{32}S–AgBr interactions at 200 AGeV.

The data are new and important for better understanding of the dynamics of pionisation process at high and ultra high energies.

5. Acknowledgement

The authors are grateful to Prof. P. L. Jain, Buffalo State University, USA for providing us with the exposed and developed emulsion plates used for this analysis. Md. Abdul Kayum Jafry would like to acknowledge the financial help sanctioned by the University Grant Commission (Govt. of India) under his Minor Research Project.

References

[1] M. Gyulassy, S.K. Kauffmann and L.W. Wilson Phys. Rev. C 20 (1979) 2267
[2] D.H. Boal, C.K. Gelbke and B.K. Jennings, Rev. Mod. Phys. 62 (1990) 553
[3] U. Heinz, B.V. Jacak, Ann. Rev. Nucl. Part. Sci. 49 (1999) 529
[4] J. Plutta et al., Eur. Phys. J. A9 (2000) 63
[5] A.B. Larionov, Eur. Phys. J. A7 (2000) 507
[6] D.V. Anchishkin, Eur. Phys. J. A7 (2000) 229
[7] A. El Naghy et al., Nuovo Cimento A110 (1997) 125
[8] A. Breakstone et al., Mod. Phys. Lett. A6 (1991) 2785; F.W. Bopp, Riv. Nuovo. Cim. 1 (1978) 1
[9] D. Ghosh et al., Phys. Rev. D 26 (1982) 2983
[10] D. Ghosh et al., Acta Phys. Slov. 47 (1997) 425; Z. Phys. A 327(1987)233; Indian J. Phys. A76(2002)277
[11] I. Derado et al., Z. Phys. C56 (1992) 553
[12] P.L. Jain and G.Singh, Nucl. Phys. A596(1996)700, J. Phys.G 23(1997)1655
[13] E. M. Levin et al: Z. Phys. C5(1980)285
[14] W. Bell et al: Z. Phys. C22(1984)109
[15] E.L. Berger, Nucl. Phys. B85 (1975) 61; A.M. Chao and C. Quigg, Phys. Rev. D 9(1974) 2016; C. Quigg, P. Pirilla and G.H. Thomas, Phys. Rev. Lett. 34 (1975) 2091
[16] C.F. Powell, P.H. Fowler and D.H. Perkins, The Study of Elementary Particles by Photographic Methods, Pergamon, Oxford, pp. 450–464 and references therein
[17] I. Kirkwood, J. Chem. Phys. 7 (1935) 919