Chinese Journal of Physics 000 (2016) 1–10

Contents lists available at ScienceDirect

Chinese Journal of Physics

journal homepage: www.elsevier.com/locate/cjph

Two and three particle correlations in target fragmentation at relativistic nucleus–nucleus collisions

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ARTICLE INFO

Article history:
Received 21 February 2016
Revised 1 June 2016
Accepted 3 July 2016
Available online xxx

PACS:
25.75.-q
25.70.Mn
25.70.Pq
29.40.Rg

Keywords:
Relativistic heavy ions collision
target fragmentation
correlation
nuclear emulsion

ABSTRACT

Two and three particle short-range correlations among the target evaporated fragments as well as the target recoil protons produced in 12 A GeV ^{4}He-, 3.7 A GeV ^{16}O-, 60 A GeV ^{16}O-, 1.7 A GeV ^{84}Kr- and 10.7 A GeV ^{197}Au-AgBr interactions are investigated in emission angle space and azimuthal angle space, respectively. The experimental data exhibit two and three particle correlations among the target fragments in emission angle space, which indicate the occurrence of so-called side splash phenomena and disfavor the evaporation model. In azimuthal angle space the data exhibit strong two particle correlations for both the target evaporated fragments and target recoil protons, and three particle correlations only for target recoil protons.

1. Introduction

In high energy nucleus–nucleus collisions, investigation of correlation effect in terms of two and three particle correlation function is one of the most popular trends because the study of correlation can encapsulate rich information about the space time structure and the dynamics of the emitting source in the late stage of the collision where the nuclear matter is highly excited and diffused [1–3]. The correlation which prevails at the early stage of interaction cannot be expected to survive in the final stage due to the rigors of the initial violent dense stage. The effect of two and three produced particle short range correlations has been investigated in different type of interactions [4–17]. It was observed that in all types of nuclear interactions stated above [4–17], the produced particles shown a tendency to be emitted in a correlated fashion. The reason behind this may be the formation of exotic nuclear matter, hot multi-nuclear fire ball or formation of heavier intermediate states, clusterization or the so called side splash phenomenon [18–23] *etc*. So up to now it is still an open question whether the particle production processes are basically weakly correlated phenomena or whether strong correlations are present. The matter is further complicated by the fact that conservation laws impose certain kinematical correlation which can not always be separated from correlations of a more dynamical nature. It has been shown by Gulamov et al. [24] from a comparison of correlation functions calculated in the random stars generated according to the cylindrical phase space model and the independent emission model, that the conservation laws lead to the increase of long-range correlations and to the decrease

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http://dx.doi.org/10.1016/j.cjph.2016.07.001

of short-range correlations, especially in the beam fragmentation region. Therefore, a detailed correlation study is essential to search for the exact reason of correlated emission of particles speculated by different theorists.

It should be mentioned that during the previous investigations, emphasis has been given on pions because the pions are most frequently produced particles in relativistic hadron–hadron, hadron–nucleus and nucleus–nucleus collisions and the knowledge of pion production mechanism is essential for understanding the main features of high energy multi-particle production. On the contrary, very little attention was paid on the target fragments. The target fragments include target recoil protons and target evaporated fragments. The target recoil protons are formed due to fast target protons of energy ranging up to 400 MeV, and they are supposed to carry relevant information about the hadronization mechanism because the time scale of emission of these particles is of the same order as that of the produced particles. The target evaporated particles are of low-energy (<30 MeV) singly or multiply charged fragments, and they are emitted at the late stage of nuclear reactions and are expected to remember the parts of the history of interactions. So the study of target evaporated fragments and target recoil protons is of great importance and a potential source of information.

In emulsion terminology [25], the target recoil particles are referred to as "grey track particles" and the target evaporated particles are referred to as "black track particles". According to the cascade evaporation model [26], the shower particle and the grey track particle are emitted from the nucleus very soon after the instant of impact, leaving the hot residual nucleus in a highly excited state. Indeed, the excitation energy may sometimes be comparable with the total binding energy of the nucleus. Emission of black track particles from this state, however, now takes place relatively slowly. In order to escape from the residual nucleus, a particle must await a favorable statistical fluctuation arising out of random collisions among the nucleons. Emission occurs if, due to a fluctuation, the particle is both close to the nuclear boundary, traveling in an outward direction, and if its kinetic energy is greater than its binding energy. After the evaporation of this particle, a further relatively long period on a nuclear time scale, say 10^{-17} s, will commonly elapse before a second particle is also placed in conditions favorable for escape, and so on. The process continues until the excitation energy of the residual nucleus is so small that transition to the ground state is likely to be effected by the emission of gamma rays. In the rest system of the target nucleus, the emission of evaporated particles is assumed to be isotropic over the whole phase space. The evaporation model is based on the assumption that statistical equilibrium has been established in the decaying system and the lifetime is much longer than the time taken to distribute the energy among nucleons within the nucleus. In our recent studies [27,28], it has been shown that the angular distribution of black track particles from relativistic nucleus–nucleus interactions are not isotropic, and the averaged multiplicities in the forward hemisphere (emission angle $\theta \leq 90°$) are greater than in the backward hemisphere. These results could not be explained satisfactorily by the evaporation model.

The non-isotropic emission means that the target evaporated fragments are not emitted independently. One of the methods to measure these dependent emission is the study of two and three particle correlation. According to our investigation, two and three particle correlations of target fragments were studied by two groups [29–35] in emission angle space and azimuthal space. A strong two and three particle correlation among the target evaporated fragments as well as the target recoil protons was observed in these studies.

In this paper, two and three particle correlations of target evaporated fragments as well as target recoil protons emitted from 12 A GeV ^{4}He-AgBr, 3.7 A GeV ^{16}O-AgBr, 60 A GeV ^{16}O-AgBr, 1.7 A GeV ^{84}Kr-AgBr and 10.7 A GeV ^{197}Au-AgBr interactions are investigated in emission angle space and azimuthal angle space respectively.

2. Experimental details

Five nuclear emulsion stacks, provided by the EMU01 Collaboration, were used in the present investigation. The stacks were exposed horizontally to 12 A GeV ^{4}He, 3.7 A GeV ^{16}O, 60 A GeV ^{16}O, 1.7 A GeV ^{84}Kr and 10.7 A GeV ^{197}Au. BA2000 and XSJ-2 microscopes with a 100 × oil immersion objective and 10 × ocular lenses were used to scan the plates. The tracks were picked up at a distance of 5 mm from the edge of the plates and they were carefully followed until they either interacted with emulsion nuclei or escaped from the plates. Interactions within 30 μm of the top or bottom surface of the emulsion plates were not considered for final analysis. In each interaction all of the secondaries were recorded, including shower particles, target recoil protons, target evaporated fragments and projectile fragments.

According to the emulsion terminology [25] the particles emitted after interaction are classified as:

(a) Shower track particles correspond to the produced single-charged relativistic particles having velocity $\beta \geq 0.7$. Most of these particles belong to pions contaminated with small proportions of fast protons and K mesons. Ionization power of shower particles is less and equal to $1.4I_0$, where I_0 being the minimum ionization of a singly charged relativistic particle, which is about 30–32grains/100 μm for 12 A GeV ^{4}He, 3.7 A GeV ^{16}O, 60 A GeV ^{16}O and 10.7 A GeV ^{197}Au-emulsion interactions, and about 12grains/100 μm for 1.7 A GeV ^{84}Kr-emulsion interactions because the emulsion is not enough developed.

(b) Grey track particles, with a range in emulsion $L > 3$ mm and velocity $0.3 < \beta < 0.7$, are mostly recoil protons in the kinetic energy range $26 \leq E_k \leq 375$ MeV and a few kaons of kinetic energies $20 \leq E_k \leq 198$ MeV and pions with kinetic energies $12 \leq E_k \leq 56$ MeV. Ionization power of grey particles lies between $1.4I_0$ to $9I_0$.

(c) Black track particles, with a range in emulsion $L \leq 3$ mm and velocity $\beta < 0.3$, correspond to protons with kinetic energies $E_k \leq 26$ MeV and other target fragments of various elements like carbon, lithium, beryllium and helium *etc*. Ionization power of black particles is greater or equal to $9I_0$.