

# Projectile Helium Fragmentation in $^{28}\text{Si}$ Collisions with Different Nuclear Emulsion Target Nuclei at 14.6 A Gev

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**Abstract:** In present article, an investigation of fragmentation process of the  $^{28}\text{Si}$ -emulsion interactions at 14.6 A GeV has been carried out. The emission of multiply charged projectile fragments (mainly projectile helium fragments with charge  $z = 2$ ) in a narrow forward cone is analysed. Transverse momentum distribution of Helium fragments with different target groups (H, CNO and AgBr) are presented and discussed. In each case, the transverse momentum distribution of projectile helium fragments ( $z = 2$ ) with different emulsion target groups are found to be well described by Gaussian behaviour.

**Keywords:** Nucleus–nucleus interactions, emulsion targets, helium fragments, projectile fragments, inelastic interactions.

## 1. Introduction

Nucleus-nucleus collision experiments at relativistic energies aims to study the properties of QCD matter and other phenomenon happening during the collision process<sup>1</sup>. Experiments performed at SPS and AGS energies confirmed that the two colliding nuclei are not transparent to each other but undergo a violent reaction in central most collision events. In the

early phase of the reaction the participating nucleons deposits a large fraction of their kinetic energy in the central region and give rise to other degrees of freedom. The amount of the initial energy carried by colliding nuclei is distributed over the new degrees of freedom depending on the strength of stopping achieved in the nuclear reaction. If sufficiently high temperature and energy density is achieved through nuclear collisions, the nucleons of the colliding nuclei lose their identity and form a deconfined state of quarks and gluons. The amount of transverse energy measured at mid-rapidity region provides us a good estimation of the nuclear stopping achieved in the collision process. Studies such as multiplicities of secondary particles, charges hadron spectra, the net proton rapidity densities, transverse momentum spectra, transverse energy, etc. gives more detailed informations. Nuclear collision process undergoes various sub-stages and finally gives rise to the production charged particles which are measured at detectors. During the first stage of the collision process, the participating nucleons from the two colliding nuclei interact via a strong force and deposit some fraction of the available energy and the rest part is transferred to the spectator parts of colliding nuclei, leaving those residual part in an excited state. On a longer time scale, the de-excitation of the nuclear remnants takes place. This process is generally known as nuclear fragmentation. This picture of nuclear collision process can be well understood in the view of participant-spectator model<sup>2</sup>. In the nuclear collision experiments performed at AGS and SPS energies, the spectator part of the projectile as well as the spectator part of the target can be distinguished easily based on different selection criteria. Projectile fragments (PF<sub>s</sub>) have momentum per nucleon almost equal to that of the incident nucleus therefore are usually emitted inside a narrow forward-angular cone along the direction of the incident projectile nuclei and keep on moving with relativistic speed. Thus, the target fragments and the fragments of the projectile nucleus are well separable from all other particles emitted out of the collision zone.

In this article, a special emphasis is given to the investigation of the fragmentation process of the relativistic projectile nucleus in the nucleus-nucleus collisions at 14.6 A GeV. The fragmentation of projectile nuclei leads to the emission of fragments with a broad mass spectrum ranging from the lightest fragments, i.e., nucleons, to the fragments as comparable to the mass of the disintegrating projectile nucleus. This broad mass range is correlated with the large range of fragment multiplicities and gives ample information much needed to understand the fragmentation mechanism. Various theoretical models has been developed to describe the diversity of

fragmentation modes via different break-up mechanisms involved in the fragmentation process<sup>3-7</sup>.

We present the results on the fragmentation of the  $^{28}\text{Si}$  projectile nuclei after an interaction with Nuclear emulsion targets at 14.6 A GeV. The scope of this article is to study the characteristics of minimum-bias inelastic events having one or multiple projectile fragments produced in  $^{28}\text{Si}$  nuclear interactions with nuclear emulsion at 14.6 A GeV. The article is organized as follows: In Section 2 the experimental details and measurements are given. Section 3 includes results and discussion of the collision events occurring at AGS energies on qualitative basis. In this section, the results based on the characteristics of the fragmentation of the  $^{28}\text{Si}$  projectile nuclei in the terms of transverse momentum distribution of projectile helium fragments for different emulsion target groups (H, CNO and AgBr) are presented and discussed. In Section 4, the summary of the results obtained and conclusion drawn are discussed.

## 2. Experimental Details

The present data used in this work was collected using a stack of Fuji emulsion pellicles exposed horizontally with a  $^{28}\text{Si}$  beam at 14.6 A GeV at BNL AGS, New York. An along-the track scanning technique was used to locate the minimum bias  $^{28}\text{Si}$ - Emulsion interaction events. An OLYMPUS BH2 microscope was used for the scanning procedure using a  $100\times$  oil immersion objective with a total magnification of 2250. In nuclear emulsion pellicles, the primary beam tracks were carefully followed up to a distance of 4 cm from the entrance edge of the emulsion plate. Interactions caused very close to top or bottom surface of the nuclear emulsion ( $\sim$ up to 20  $\mu\text{m}$ ) were excluded. For the present analysis work, total 855 inelastic events were taken into account. Charged secondary particles emitted in each collision events were categorized depending on their ionization, range in nuclear emulsion plate and velocity. Based on the criteria, these were categorized as black (b), grey (g), shower (s) and projectile fragments (PFs) with charges  $z \geq 2$ . Slow moving particles with  $\beta < 0.3$  were called as black particles. These have a range less than 3 mm in nuclear emulsion and having ionization  $g > 6 \text{ g}_{\text{min}}$ , where  $\text{g}_{\text{min}}$  is the grain density of singly charged particle having velocity nearly equal to the velocity of the initial projectile nuclei. These are low energy multiply charged fragments and are evaporated particles from the target nuclei embedded in the nuclear emulsion. Whereas grey particles are those having range greater than 3 mm and having ionization  $1.4 \text{ g}_{\text{min}} < g \leq 6 \text{ g}_{\text{min}}$ . These particles are contributed by knocked

out protons from the target nucleus in the collision process. Black and Grey both the particles originates from the target nucleus. Shower particles are fast moving particles having ionization  $g$  not greater than 1.4 gmin and move with a velocity  $\beta$  greater than 0.7. Shower particles are generally relativistic pions, small fraction of K-mesons and fast protons. Projectile fragments (PFs) with charge  $z \geq 2$  and are characterized by their grain density  $g \geq 4$  g min. These are emitted in a narrow forward cone of  $5^\circ$  along the direction of projectile nuclei. The number of black, grey, shower and projectile fragments are known as multiplicity and are denoted by  $n_b$ ,  $n_g$ ,  $n_s$  and  $n_F$  respectively. Black and grey particles collectively are called heavily (h) ionizing particles such that  $n_h = n_b + n_g$ . Black, grey and shower particles collectively are called the total charged (ch) particles such that  $n_{ch} = n_b + n_g + n_s$ . Projectile fragments (PFs) with charge  $z=2$  are called Projectile Helium fragments and their multiplicity is denoted by  $n_\alpha$ .

Nuclear emulsion is composed of different targets H, C, N, O, Ag, Br, and I nuclei. A clear identification of these different targets in nuclear emulsion is not easily possible. Their identification in nuclear emulsion is carried out on the basis of the multiplicity of heavy particles (nh) emitted in collision events. On the basis of mean multilpicities of heavily ionizing particle(h), It is categorized in different target groups (H, CNO and AgBr target groups) <sup>8,9</sup>.

### 3. Results

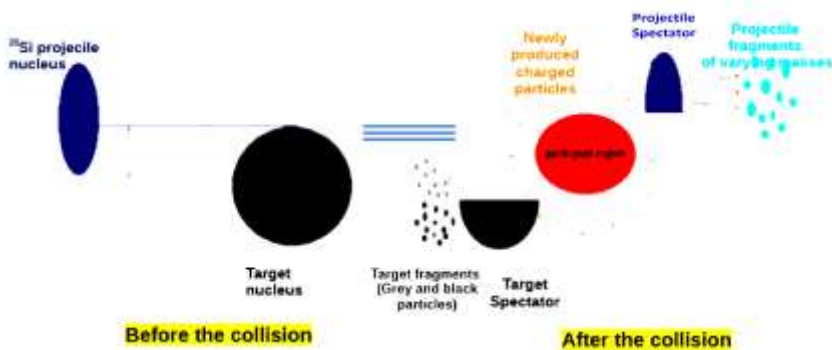


**Figure 1.** Pictorial representation of nucleus-nucleus interaction in the view of the participant-spectator model

High energy nuclear collisions<sup>1</sup> can be well described by considering the straight line motion of the projectile which defines a simple picture of the collision geometry. The assumption of clean cut geometry states that all the nucleons of the projectile and target nuclei are separated into participant part and spectator part. The straight line motion defines the impact parameter  $b$ . The impact parameter make a clear separation of the nucleons into (1) participants i.e., the participating nucleons in nucleon-nucleon collisions and (2) spectators which proceed along the original direction of projectile nuclei with slight perturbation. Thus a geometrical picture arises having (1) Participants, (2) Projectile spectators and (3) Target spectators. Spectators keep moving along the straight trajectory as of the projectile nuclei before the collision<sup>2</sup> as depicted in Figure 1.

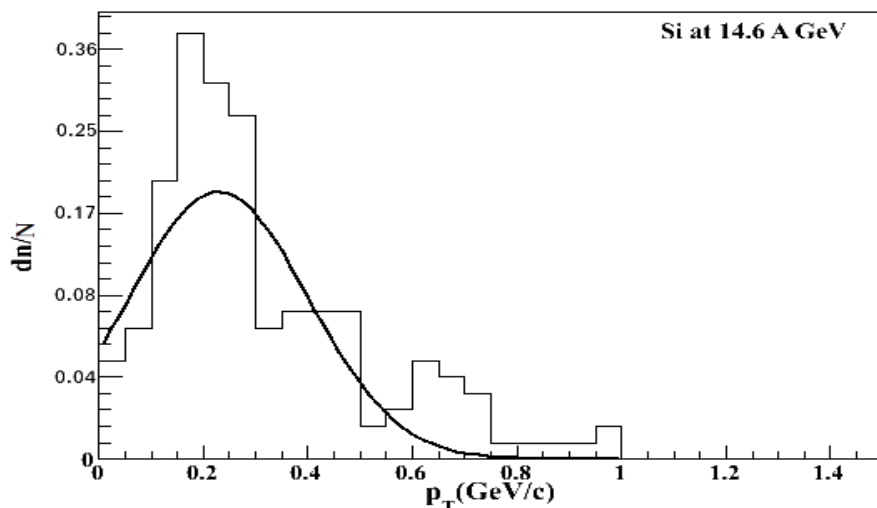


**Figure 2.** Transverse momentum distribution of Projectile Helium fragments ( $z = 2$ ) in H-events.

The transverse momentum of projectile helium fragments is measured indirectly from their initial beam momentum per nucleon and the space angle<sup>9</sup>.

In Figure 2, Transverse momentum distribution of projectile helium fragments (with charge  $z = 2$ ) in H-events is displayed. It is well described by a Gaussian function. It shows a peak around  $p_t \sim 0.2$  GeV/c and the distribution extends upto  $p_t = 1$  GeV/c.

In Figure 3, Transverse momentum distribution of projectile helium fragments (with charge  $z = 2$ ) in CNO-events is displayed. It is well described by a Gaussian function. It is well described by a Gaussian function. It shows a peak around  $p_t \sim 0.2$  GeV/c and the distribution extends upto  $p_t = 1.5$  GeV/c.

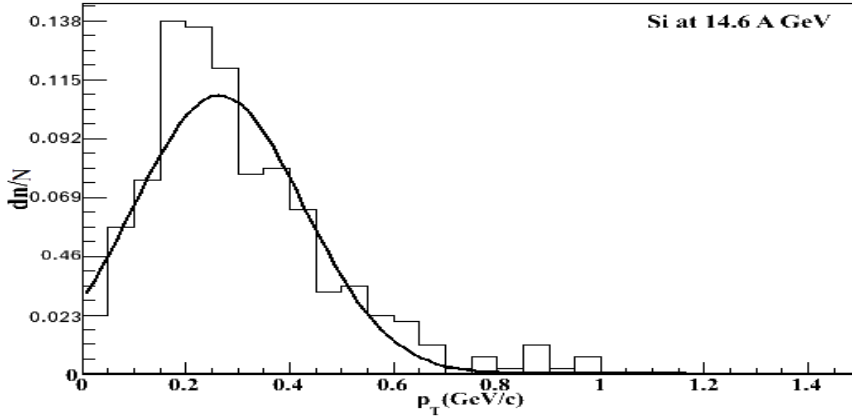


**Figure 3.** Transverse momentum distribution of Projectile Helium fragments ( $z = 2$ ) in CNO-events.

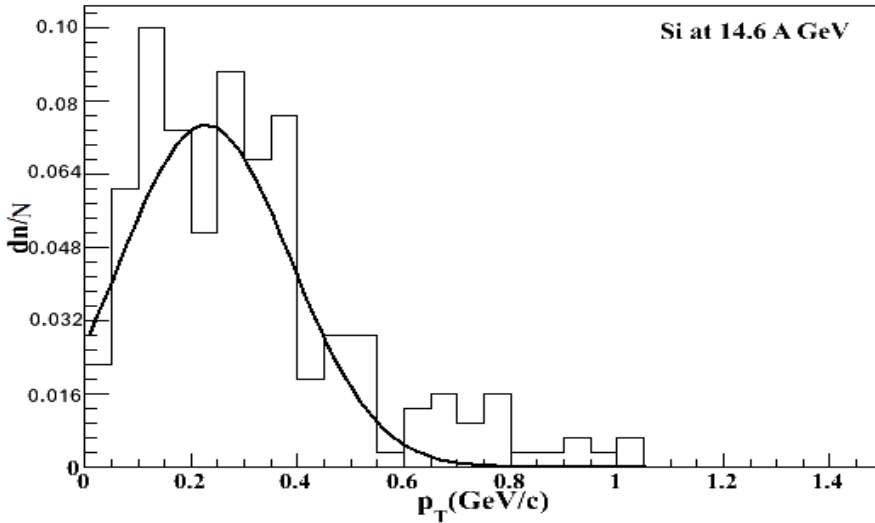


**Figure 4.** Transverse momentum distribution of Projectile Helium fragments ( $z = 2$ ) in AgBr-events.

Similarly, Figure 4 depicts the transverse momentum distribution of projectile helium fragments (with charge  $z = 2$ ) in AgBr-events. It is well described by a Gaussian function. In Figure 3, Transverse momentum distribution of projectile helium fragments (with charge  $z = 2$ ) in CNO-events is displayed. It is well described by a Gaussian function. It shows a peak around  $p_T \sim 0.1$  GeV/c and the distribution extends upto  $p_T = 1.05$  GeV/c.

#### 4. Discussion

The transverse momentum distribution of secondary particles is one of the most essential measurements in the nuclear collision experiments. It can be assumed according to the participant-spectator concept and the fireball model that the emission of the projectile fragments follow a Maxwell-Boltzmann distribution in projectile rest frame with a certain temperature  $T$ . Using their prescription, the temperature of the source responsible for projectile helium emission can be evaluated. The transverse momentum distributions of projectile helium fragments ( $z = 2$ ) are found to be well described by Gaussian behaviour for each case of the interaction with individual emulsion target groups i.e., H-events, CNO-events and AgBr-events. Therefore we may conclude that the excitation of the projectile nuclei is directly correlated with the emission of projectile helium fragments ( $z = 2$ ). The temperature of emission sources responsible for the production of projectile helium fragments ( $z = 2$ ) can be evaluated from the  $p_t$  distribution.

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