Study of Projectile Fragments Charge Distribution at Relativistic Energy

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Introduction

Nuclear emulsion detector (NED) is one of the oldest detector technologies and has been in use from the birth of the experimental nuclear and astroparticle physics. Fortunately, it is a unique and simple detector till today, due to very high position resolution of the order of $< 1\mu$m along with several unique features. Nuclear emulsion detector has 4π detection capability with grain density of 300 to 500 grains per mm, compactness of the size and large range of ionization sensitivity depends upon the nature and need of the experiment. The high resolution allows easy detection of short-lived particles like the lepton or charmed mesons [1]. When charged particle passes through the detector medium, it transfer partial or/and total energy to the atoms or molecules of the surrounding medium due to interactions or scattering. If the transferred energy is large enough to make the outer most orbital electron free and make the medium ionized. The rate of ionization depends on the square of the charge and inverse of the square of the velocity of the ionizing particle. Ionization measurements are a great help in the estimation of the charge of the projectile fragments (PFs) [1]. When the ionization is low, the certainty in such estimation is large but as the grain density increases and the adjacent grain becomes unresolved even under a high magnification microscope that increases the uncertainty in the estimation. In case of higher charge tracks, the grains get clogged to each other to form blobs and it is not possible to count the individual grains. Since, one method of charge estimation will not be suitable and valid for the wider range of charge PFs therefore, different methods for a quantitative measurement of the rate of energy loss have been devised [1] and are described as a) Grain Density b) Blob and Grain Density or Gap Length Coefficient c) Mean Gap Length d) Delta Rays e) Relative Track Width and f) Residual Range Method.

We have selected 500 MB events of ^{84}Kr +Em interactions of kinetic energy around 1 GeV per nucleon for this analysis. As we know, single method cannot be applied to estimate the charges over the entire range (1-36 charge units), as every method has its own limitations. Therefore, we have adopted the grain density method for estimation of charge of PFs having $Z \leq 4$. The gap length coefficient method is among the most accurate methods for determining the charge from 5 to 9 and from 10 to 19 is estimated by the delta (δ) rays density measurement. In this experiment, δ-ray defines as a recoil electron with kinetic energy more than 5 keV and acquires δ-shape with inclination opposite to the beam direction. The fragments having charge $19 \leq Z \leq 30$ could be estimated by the relative track width measurements and residual range method is applicable for the fragments having charge above 30, up to the beam charge (36). Various experiments of heavy-ion interaction has been used these methods [2-5]. Due to space limitation, only δ–ray density method is explained here.

In a sensitive nuclear emulsion detector, a particle moving at relativistic velocity shows a narrow, dense central core around the trajectory of the primary particle and a number of δ-rays which becomes more and numerous as the value of the charge of a primary increases. The tracks of which have virtually no gaps, consistent in measuring the number and/or track lengths of δ-rays produced by a charged particle as it ionizes the substance along its track. This method is based on the fact that the energy and range distributions of δ-electrons are dependent on ionizing particle charge (Z). The number of δ-rays exceeding a particular minimum energy W_{min} will becomes N_δ which is defined in Ref. [1].

If δ-ray density of the charged particle is known then with the help of calibration Fig.1 fragment charge can be estimated with good accuracy. In this study, we explored the nature of distribution of PFs at relativistic energy. The cross checks of charge estimated with other methods reveals that the obtained charge spectrum has reached accuracy better than ± 1 charge unit. Error bar as shown in figures 2 and 3 are the statistical errors.

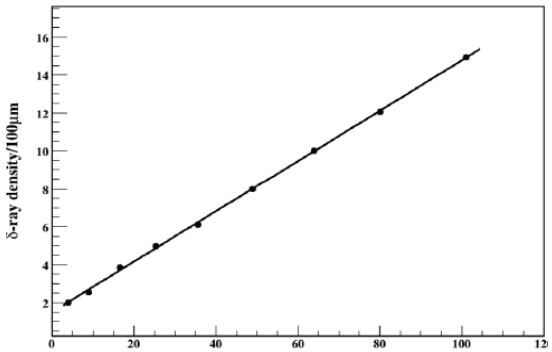

Fig. 1: Calibration curve for the charge estimation in terms of delta-ray density as a function of (Z^2).

Results and Discussion

We have adopted methods for charge estimation of PFs as described in Ref. [1], up to the 10 charge units and after that we clubbed all other heavier fragments and called it as more than 10 charge units. ^{84}Kr PFs spectrum was compared with other heavier and lighter projectiles fragments charge spectrum having similar beam energy as shown in Fig. 2 and in Fig. 3 charge spectrum of similar projectile having variable beam energy was compared.

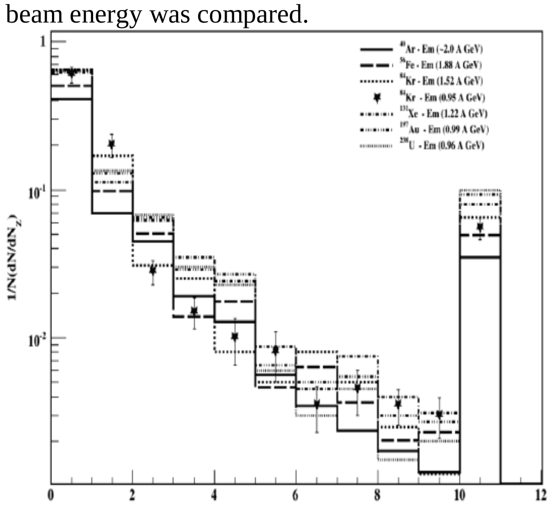

Fig. 2: Normalized estimated charge spectrum of different projectile at similar energy. ^{84}Kr at 0.95 is compared with the results of ^{40}Ar at 2 [2], ^{56}Fe at 1.88 [2], ^{84}Kr at 1.52 [3], ^{131}Xe at 1.22 [3], ^{197}Au at 0.99 [4], ^{238}U at 0.96 A GeV [4].

The data points are from the present analysis results and histograms are the results from other experiments. It is evident from Fig. 2 that the production of single, double and more than 10 charge unit PFs have dependence on projectile mass number. Whereas other charged PFs production shows mixed nature. The minimum and maximum production ranges of PFs for the projectile mass number ranging in between 40 to 238 are 40-65%(Z=1); 7-18%(2); 3-7%(3); 1-4%(4); 0.8-3%(5); 0.4-0.9%(6); 0.3-0.9%(7); 0.2-0.8%(8); 0.1-0.5%(9); 0.1-0.3%(10) and 4-10.5% (≥11). Due to large statistical error and very narrow energy range, it is hard to conclude any dependence of PFs production on energy of projectile from figure 3.

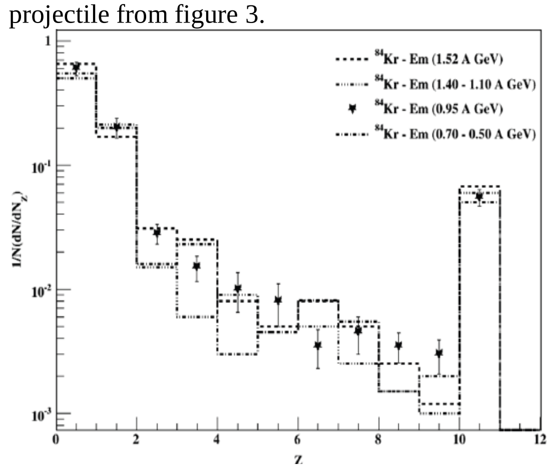

Fig. 3: Normalized estimated charge spectrum of same projectile with different energy. Data from ^{84}Kr at 1.52 [3], ^{84}Kr at 1.4-1.1 [5], ^{84}Kr at 0.7-0.5 A GeV [5].

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