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Fragmentation of gold nuclei at 4 GeV/nucleon on light targets

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Abstract. New data on fragmentation of 4 GeV/nucleon gold nuclei after collision with hydrogen and C/N/O targets are presented. Multiplicities and charge spectra of the fragments are shown and compared with analogous data on gold fragmentation at 10.6 GeV/nucleon.

1 Introduction

Heavy ion interactions on fixed targets provide an opportunity to study particle production in conjunction with the fragmentation processes of the colliding nuclei. Availability of relativistic beams of heavy ions makes this studies much easier than before. Nuclear emulsion has been widely used as particle detector to study nuclear interactions due to its superb spatial resolution and 4π acceptance. The emulsion is, however, a composite target consisting basically of three groups of nuclei: hydrogen, light (C/N/O) and heavy (Ag/Br). For heavy nuclei interactions, e.g. gold nuclei on emulsion, it is possible to divide a minimum bias sample of interactions into subsamples of interactions with these three groups of targets. Thus, study of particle production in conjunction with fragmentation processes of both colliding nuclei as a function of target mass is possible. For cosmic ray studies, interactions with light components of emulsion are of particular interest. In this paper, we show preliminary results on gold nuclei fragmentation on H and C/N/O targets at beam kinetic energy 4 GeV/nucleon.

2 Experiment

Stacks of BR-2 emulsion pellicles were exposed to 4 GeV/nucleon gold beam at the AGS accelerator at Brookhaven National Laboratory. The stacks were oriented so that the beam was parallel to the pellicles. Interactions were found by microscope scanning along the primary tracks in order to obtain a sample with minimum detection bias. In each event analyzed, multiplicities and emission angles of all produced particles and fragments of the colliding nuclei were measured. In addition, charges of projectile nucleus fragments were determined. Singly-charged fragments (released protons) were distinguished unambiguously from heavier fragments. However, a distinction in emulsion between proton fragments of the projectile and produced pions is very difficult. Charges of heavier fragments ($Z \geq 2$) were measured using a photometric method with a CCD camera.

The method of charge determination in emulsion was developed (Kudzia et al., 1999) using images of tracks in emulsion, obtained with a CCD camera. The photometric profiles of tracks, acquired from a number of fields of view under a microscope need to be averaged in order to minimize the fluctuations. The shape of a track profile depends on illumination of the field of view and depth of the track in emulsion. These dependences were parameterized and necessary corrections were applied. After these corrections, both profile height and width can be used as a measure of the particle charge over the full charge range up to $Z = 79$. The regions of best sensitivity of charge measurements based on height and on width of the profile are complementary to each other. The profile height is better for measuring small charges, while the measurements based on profile width are more accurate for large charges. The combined accuracy of charge measurements is better than 7% for charges up to $Z \approx 20$ and between 2 and 2.7 charge units for larger charges (between 30 and 79). Using this photometric method, the charges can be measured quicker and more reliably than by the traditional delta-ray counting method, especially when only a short track is available for measurements.

The inclusive sample of 488 Au-Em interactions was divided into subsamples of interactions on different targets using a procedure developed for 10.6 GeV/n Au-Em interactions, which was published in (Cherry et al., 1998). This procedure, slightly modified, was used for our 4 GeV/n interactions. First, all events were divided into two groups of interactions on H/C/N/O and Ag/Br targets using a clear sep-

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Table 1. Average multiplicities of gold projectile fragments at 4 GeV and 10.6 GeV per nucleon: heavy ($Z > 2$) fragments, N_f; alpha particles, N_α; and released protons, N_{prot}. Also, charge of heaviest fragment, Z_{max}, and average over all $Z > 2$ fragments, Z_f, are shown.

4 Gev/nucleon		
target	H	CNO
No. of events	94	191
$< N_f >$	1.82 ± 0.11	2.51 ± 0.18
$< N_\alpha >$	3.13 ± 0.25	4.33 ± 0.21
$< N_{prot} >$	9.73 ± 0.92	25.20 ± 1.30
$< Z_{max} >$	55.76 ± 1.82	36.92 ± 1.89
$< Z_f >$	34.64 ± 2.08	17.97 ± 1.04
10.6 Gev/nucleon		
target	H	CNO
No. of events	373	348
$< N_f >$	1.90 ± 0.06	2.07 ± 0.07
$< N_\alpha >$	3.56 ± 0.14	4.42 ± 0.18
$< N_{prot} >$	10.71 ± 0.49	23.43 ± 1.07
$< Z_{max} >$	53.98 ± 1.02	39.81 ± 1.50
$< Z_f >$	32.18 ± 1.04	22.50 ± 0.96

aration on the ($N_\pi - N_b$) scatter plot, where N_π is the multiplicity of produced charged pions and N_b is a multiplicity of slow fragments of the target nucleus. Next, the H/C/N/O group was further divided into interactions on H and those on C/N/O targets: the interactions with $N_b = 0$ and no more than one target recoil proton ($N_g \leq 1$) and $N_\pi \leq 10$ were classified as interactions on hydrogen target. The remaining events were labeled as interactions on the C/N/O target. Out of a total of 488 Au-Em interactions, 94 are the interactions on hydrogen, 191 on C/N/O and 203 on Ag/Br targets.

3 Fragmentation of gold projectile

The average values of multiplicities of alpha-, proton- and heavy fragments of the projectile are shown in Table 1. For comparison, analogous data for 10.6 GeV are also given.[1] The multiplicity of released protons, N_p, is determined as $N_p = Z_{Au} - (\sum Z_f + 2N_\alpha)$, where Z_f is the charge of a heavy fragment of the projectile. The 10.6 GeV data were published earlier (Cherry et al., 1995, 1998). In order to compare the data at 4 GeV and 10.6 GeV, in a subset of the 10.6 GeV events, charges of heavy projectile fragments were remeasured by the new CCD method (shown in Table 1).

As can be seen, the average fragment multiplicities and charges are very similar in interactions at these two energies.

[1] In the 10.6 GeV/n data, the sample of interactions on hydrogen was enriched in a special scanning in order to get similar event numbers on H and C/N/O targets.

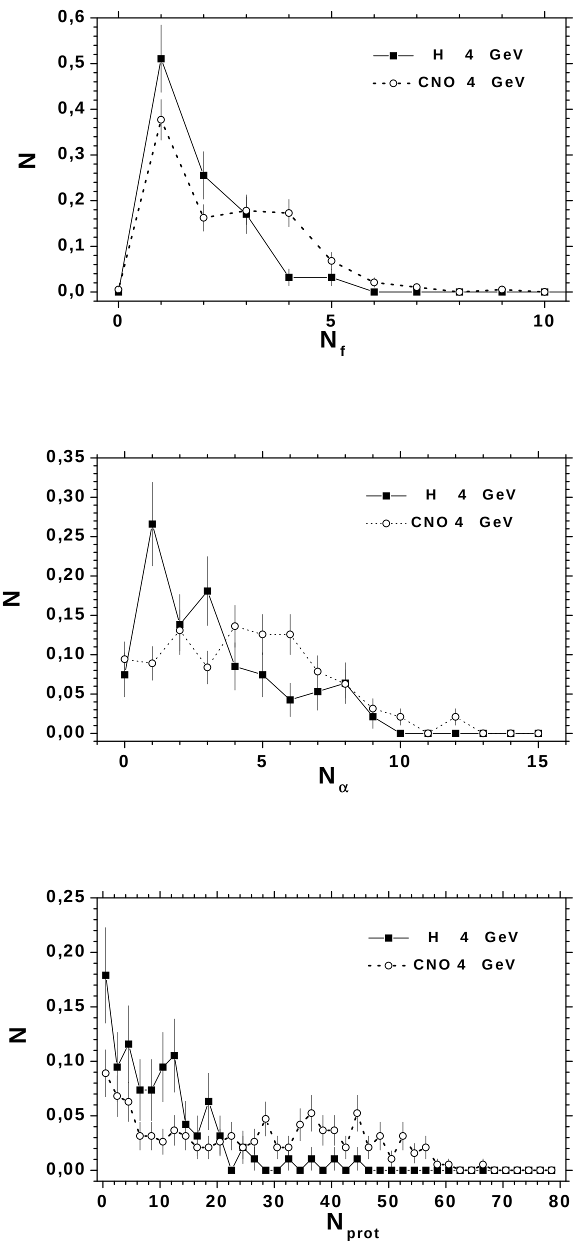

Fig. 1. Multiplicity distributions of gold projectile fragments in interactions on H and C/N/O targets at 4 GeV/nucleon: heavy ($Z_f > 2$), N_f; alpha fragments, N_α; and released protons, N_{prot}.

The distributions of N_f, N_α, N_{prot} are shown in Figure 1. The multiplicities of all kinds of fragments are considerably larger on C/N/O target than in interactions on H target. In projectile collisions with a heavier target, there are more nucleons participating in the collision, so that a larger breakup of the colliding nuclei is to be expected. In consequence, the average charge of the fragments must decrease, and this effect is observed in Table 1.

The charge distribution of heavy fragments of the projectile is shown in Figure 2. A rather large dip is present in

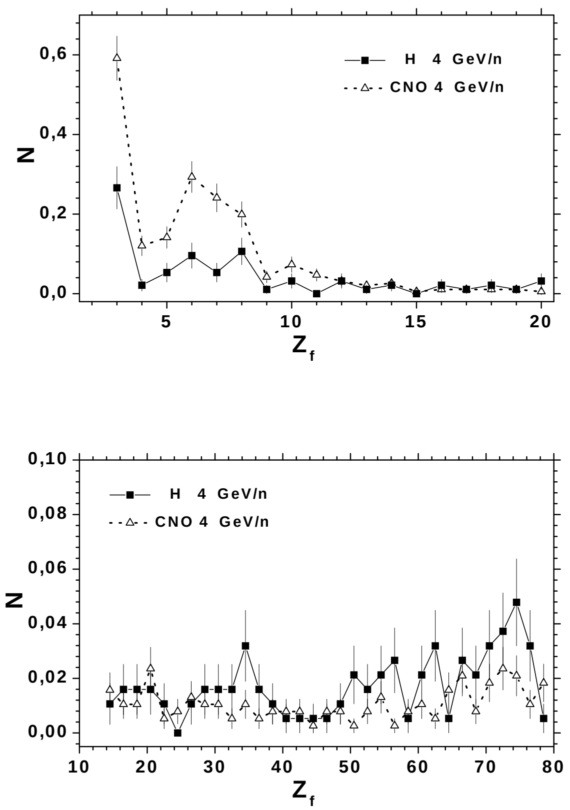

Fig. 2. Charge distribution of heavy fragments of the Au projectile in collisions with H and CNO targets at 4 GeV/n shown in the ranges of smaller and larger fragment charges.

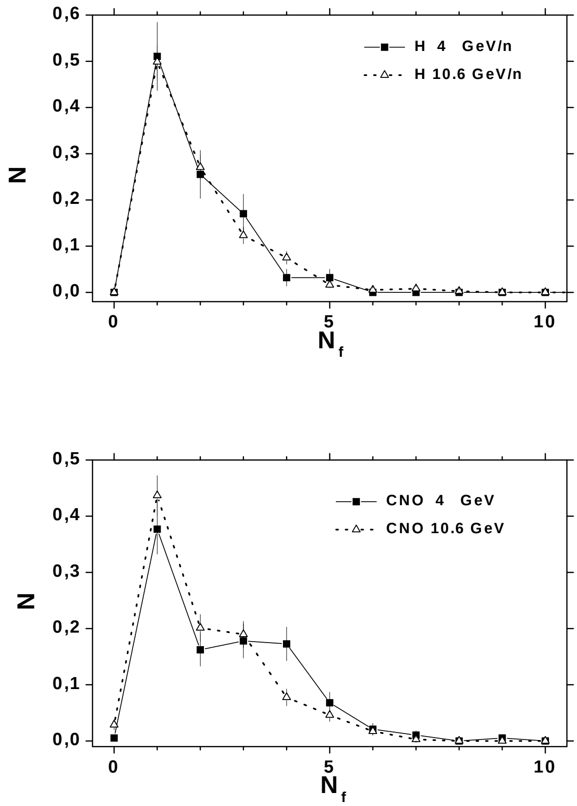

Fig. 3. Comparison of heavy fragment multiplicity distributions in collisions of Au on H and C/N/O targets at energies 4 GeV/nucleon and 10.6 GeV/nucleon.

the distribution at $Z = 4 - 5$ for both targets H and C/N/O. The charge determination accuracy for these charges is better than 0.5 charge unit, so that this depletion is unlikely to be an experimental artifact. We note also that this charge distribution of Au fragments resembles the cosmic ray abundance curve. It may be interesting to observe a similar elemental abundance curve among fragments of a nucleus as heavy as gold ($Z = 79$).

Among the heavy fragments of the Au projectile, small charge fragments ($Z < 10$) are more numerous in interactions on C/N/O, while very heavy fragments ($Z > 50$) are more frequent on hydrogen target. This is well understood on the basis of general properties of nucleus-nucleus collisions: in Au interactions on hydrogen target, the breakup of the projectile nucleus is smaller than on heavier targets, so that very heavy fragments are found more often.

A comparison of Au fragmentation at energies 4 and 10.6 GeV/nucleon shows that not only average multiplicities N_f, N_α, N_{prot} presented in Table 1 are very similar at both energies. Also, the whole distributions of these multiplicities coincide. The largest difference, if any, is observed in N_f distribution on C/N/O target, but this is insignificant within the available statistics. These N_f distributions are shown in Figure 3.

Similarly, distributions of charges of the heavy fragments of the projectile at both energies and on both targets are very similar as shown in Figure 4. In all charge distributions, the depletion at charges 4 and 5 is significant.

The data presented suggest that fragmentation of the projectile nucleus does not depend on energy between 4 and 10.6 GeV/nucleon, thus the limiting fragmentation is reached already below 4 GeV/nucleon.

4 Summary

New data are presented on fragmentation of gold nuclei after collisions with emulsion nuclei at kinetic energy 4 GeV/nucleon. The charge distribution of fragments of the projectile shows a clear minimum at fragment charges 4 and 5. Basic characteristics of the fragmentation process derived from the data leads to a conclusion that there is practically no difference in fragmentation process between energies 4 and 10.6 GeV/nucleon.

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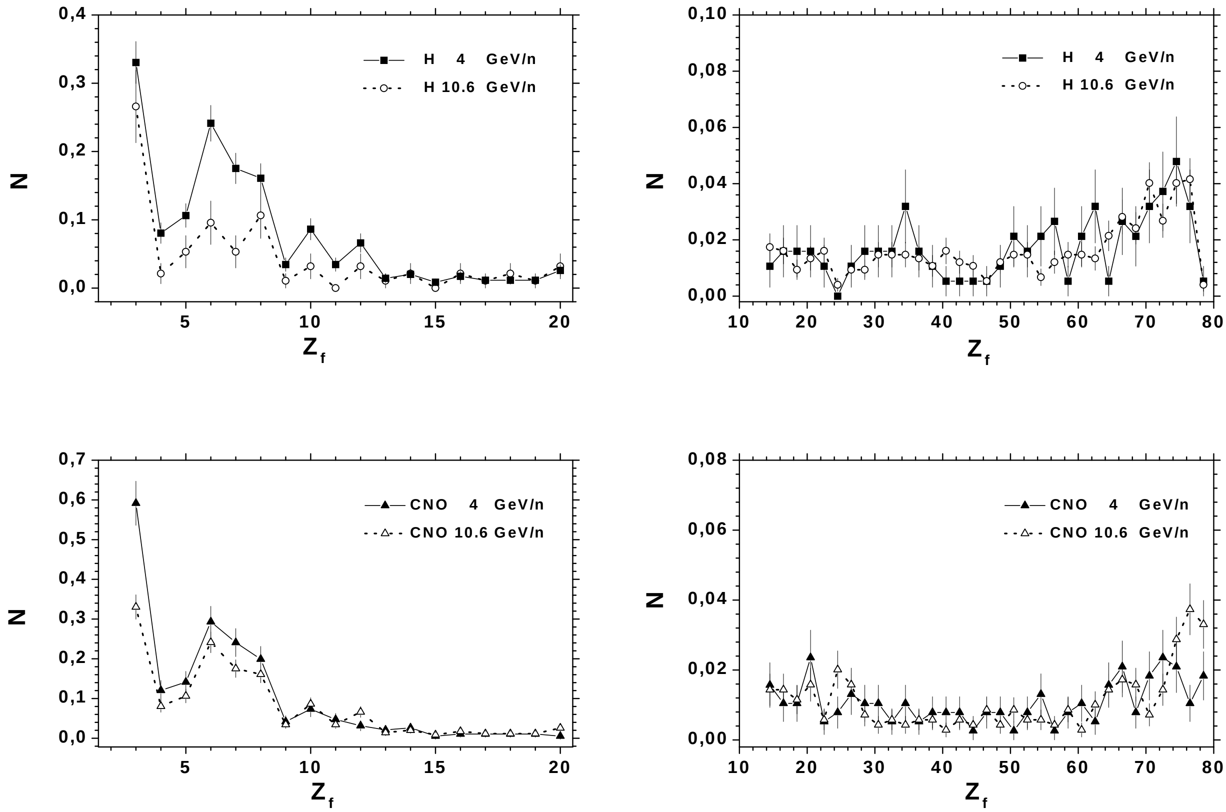

Fig. 4. Comparison of fragment charge distributions on H and C/N/O targets at energies 4 and 10.6 GeV/nucleon.

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