Study of Projectile Fragmentation for Fe and Si Nuclei in Collisions with H, C, Al, Cu, Ag and Pb

F. Flesch[1], **W. Heinrich**[1], **H. Röcher**[1], **T. Streibel**[1] **and H. Yasuda**[2]
[1]*Department of Physics, University of Siegen, 57068 Siegen, Germany*
[2]*National Institute of Radiological Sciences (NIRS), Chiba-shi, Inage-ku, Anagawa 4-9-1, Chiba 263, Japan*

Abstract

We have used stacks containing CR-39 track detectors and targets C, CH_2, Al, Cu, Ag and Pb to measure elemental fragmentation cross sections of fragments with charges $Z \geq 6$. Cross sections of iron projectiles at 700 A MeV, for different targets, have been presented at the last cosmic ray conference. For the fragments produced in these interactions we have measured the transverse momenta. Furthermore, simultaneously emitted light fragments produced in multifragmentation of iron projectiles were studied.

Recently a set of stacks has been exposed to a Si beam with 490 A MeV at the HIMAC (Chiba, Japan). In this paper we present first results for fragmentation cross sections of Si projectiles in collisions with carbon target nuclei. These results are compared to our earlier data measured at higher beam energy and to the results of Webber, Kish & Schrier.

1 Experimental technique:

Stacks of thin layers (600 μm) of CR-39 plastic nuclear track detectors were used to determine the trajectories and charges of projectile ions and of their fragments. In our experimental set ups 4 detector foils are mounted upstream and 9 to 12 detector foils downstream a target. Total charge changing and elemental fragmentation cross sections can be determined from the charge distributions measured on both sides of the target. The detection threshold of the CR-39 restricts the result to fragments with charge number $Z \geq 6$. For details describing the experimental technique see Flesch et al. (1997). The target dependence of fragmentation cross section for iron projectiles has been discussed in Flesch et al. (1998).

2 Transverse momentum distributions:

The trajectories of the particles traversing the stack can be reconstructed by tracing the positions of the etch cones over individual detector foil sides. Thus the deflection angle between the incoming projectiles and the outgoing projectile fragments can be determined. However, velocity and mass of the outgoing fragments can not be measured. It has been shown that for a beam energy of 1 GeV/nucleon (Greiner et al., 1975) and for 213 MeV/nucleon (Viyogi, 1979) projectile fragments have velocities which are on the average only slightly reduced in comparison to that one of the projectile nuclei. Based on this we assume that in our experiments the fragment velocities are identical to those of the projectiles. Mean fragment masses can be calculated from the fragment charge number using a relation by Sümmerer et al. (1990). These assumptions allow to calculate the transverse momenta $\vec{P}_F$ of fragments from the deflection angles by:

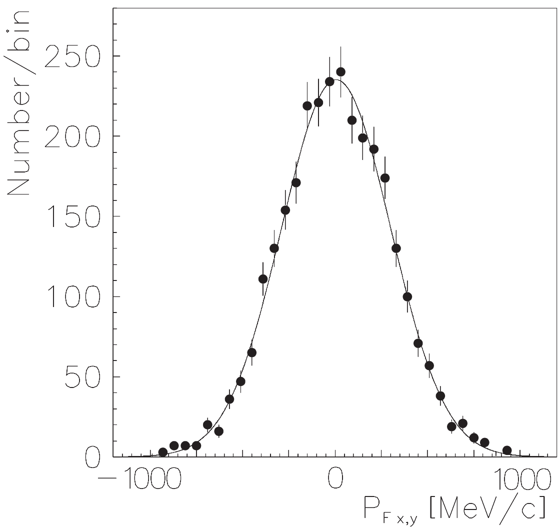

Figure 1: Transverse momentum component distribution

$$\vec{P}_F = A_F \cdot \sqrt{(2 \cdot m_n + E_p) \cdot E_p} \cdot \tan\Theta \cdot \binom{\cos\Phi}{\sin\Phi}$$

where E_p is the kinetic energy of the projectile in MeV/nucleon, $m_n = 931.5 MeV$ is the mass of a bound nucleon, A_F is the calculated mass number of the produced fragment and Θ and Φ are the polar angles.

For C and O projectiles (Greiner et al., 1975) and for Ar projectiles (Viyogi et al., 1979) it has been shown that the distribution of the transverse momentum components of produced fragments are Gaussian. This observation is confirmed by our data for Fe projectiles. Fig. 1 shows as an example the measured transverse momentum component distribution of fragments with charge number $Z_F = 24$ produced from iron nuclei in collisions with CH_2 target nuclei. The curve is a Gaussian which has been fitted to the data. By this fit we determine the standard deviation σ of the transverse momentum component distribution for the fragments. It has to be considered, that the transverse momenta, which are derived from the deflection angles, are affected by multiscattering of the particles inside the target material. The measured variance for the transverse momentum component distribution have been corrected for this systematic bias by subtracting the variance σ_{ms}^2 of the contribution caused by multiscattering. This quantity can be determined for the beam particles and scaled with Z^2/A^2 to describe the influence of multiscattering for fragments.

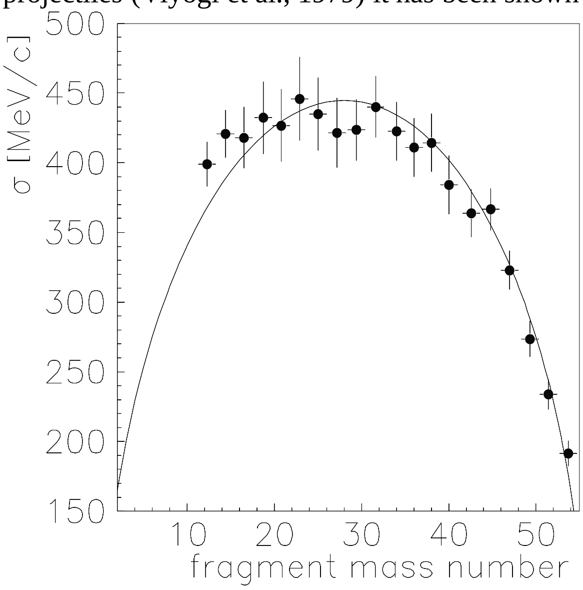

Figure 2: Measured standard deviation of the transverse momentum component distribution for an Al target

In Fig. 2 measured standard deviations σ which have been corrected for multiscattering are shown as a function of the mean fragment mass number for all fragments observed in the experiment with the Al target. A similar set of data was determined for all other targets. The statistical model described by Goldhaber et al. (1974) predicts that the σ dependence of these Gaussian distributions on the fragment mass number A_F, is given by:

$$\sigma = \sigma_0 \cdot \sqrt{\frac{A_F \cdot (A_P - A_F)}{A_P - 1}}$$

where A_P is the mass number of projectile and $\sigma_0 = P_{Fermi}/\sqrt{5}$ with the Fermi momentum P_{Fermi} of the projectile nucleons. The curve shown in Fig. 2 was determined as a fit to the data points based on the relation given above with σ_0 as a free parameter. We have determined σ_0 separately for all targets. These values are summarized in Table 1. Using a value of P_{Fermi}=256 MeV for the iron nucleus (Moniz et al., 1971) the predicted value of σ_0 results as 114 MeV. This value is in general agreement with those given in Table 1. However, the measured values of σ_0 show a systematic increase with the charge of the target nucleus. This can be attributed to an additional Coulomb deflection of the incoming projectile and the outgoing fragment from the target nucleus and the fireball, which is formed in the collision. The data given in Table 1 have not been corrected for this effect.

Target	CH_2	C	Al	Cu	Ag	Pb
$\sigma_0[MeV/c]$	109.1 ± 2.5	112.7 ± 3.1	117.8 ± 5.8	117.6 ± 6.1	125.3 ± 7.3	135.0 ± 8.2

Table 1: Fitted values for the parameter σ_0 for the different targets

3 Multifragmentation:

Several fragments may be simultaneously emitted from the same projectile nucleus with transverse momenta that are small in comparison to the initial longitudinal momentum of the projectile. In the CR-39 we can measure the individual fragments (with $Z \geq 6$) produced in these multifragmentation interactions. Altogether 115 and 34 interactions in which two fragments with $Z \geq 6$ had been produced, were found among

8266 and 7587 interactions in the targets Al and Cu, respectively. Based on these numbers we determined the probabilities to produce fragment pairs of different combination which are given in Fig. 3. Multifragmentation can be observed, when a large prefragment is formed in a peripheral collision with an excitation energy sufficiently large to cause successive breakup into several larger parts. These interactions can be observed for 700 A MeV iron projectiles in collisions with the Al target nuclei. If the excitation energy is enlarged like in collisions with the Cu target nuclei the prefragment more likely disintegrates into many smaller pieces.

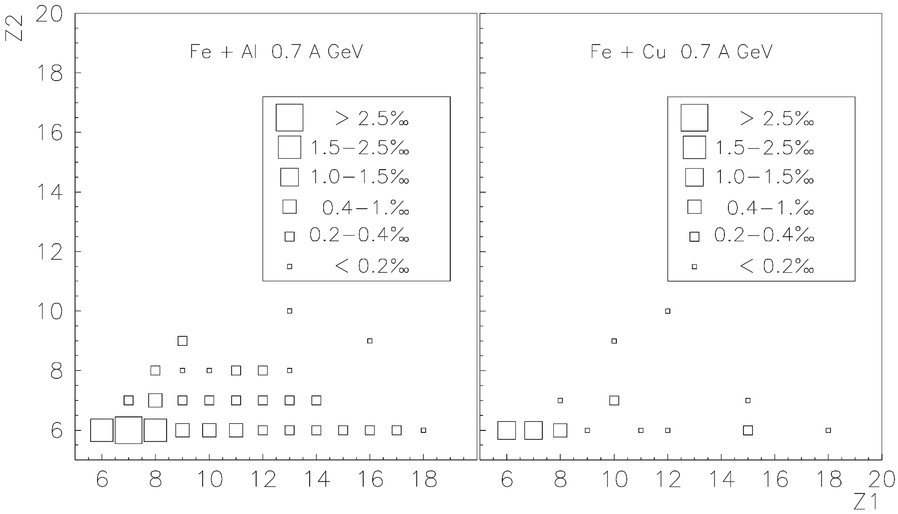

Figure 3: Probability for interactions in which two fragments with $Z \geq 6$ are produced

4 Fragmentation of Si projectiles:

In February 1999 we have exposed a set of 8 stacks with targets C, CH_2, Al, Cu, Ag and Pb to a 490 A MeV beam at the HIMAC in Chiba, Japan. Until now we have analyzed the fragmentation of Si projectiles in collision with carbon target nuclei. We have determined total charge changing cross sections and elemental fragmentation cross sections. These results are presented in Fig. 4 and 5. Additionally to these new data results from our earlier experiments at 1 and 2 A GeV (Hirzebruch, 1993) and 14.5 A GeV (Brechtmann, Heinrich & Benton, 1988) are shown. Furthermore we compare our results with the measurements of Webber, Kish & Schrier (1990).

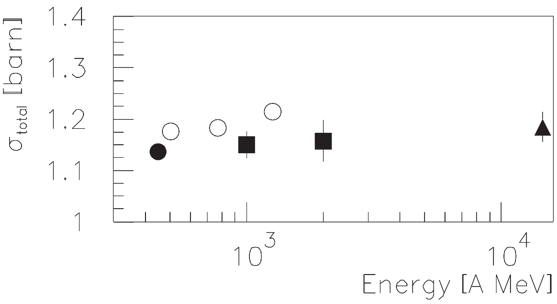

Figure 4: Comparison of our total charge changing cross sections (filled circles) measured for C target to data from Brechtmann (1988) (filled triangles), from Hirzebruch (1993) (filled squares) and to data from Webber, Kish & Schrier (1990) (open circles)

From our data shown in Fig. 5 the general behavior can be seen, that for small values of charge changes $\Delta Z = Z_B - Z_F \leq 4$ the cross sections increase with decreasing energy, whereas this behavior can not be observed for charge changes $5 \leq \Delta Z \leq 8$. Similar systematics like we have observed for the carbon target are well established for collisions with hydrogen target.

The cross sections which have been measured by Webber, Kish & Schrier (1990) at different energies show a general disagreement with our results, which is for almost half of the data points larger than three standard deviations. It must be emphasized, that the deviations show some systematics. For fragments with large charge numbers Webbers cross sections at all energies tend to exceed our results, whereas for lower charge numbers the behavior is vice versa. We have seen the same systematic deviations before for cross sections of S projectiles (Brechtmann et al., 1988, Webber et al., 1990) and of iron projectiles (Flesch et al., 1997).

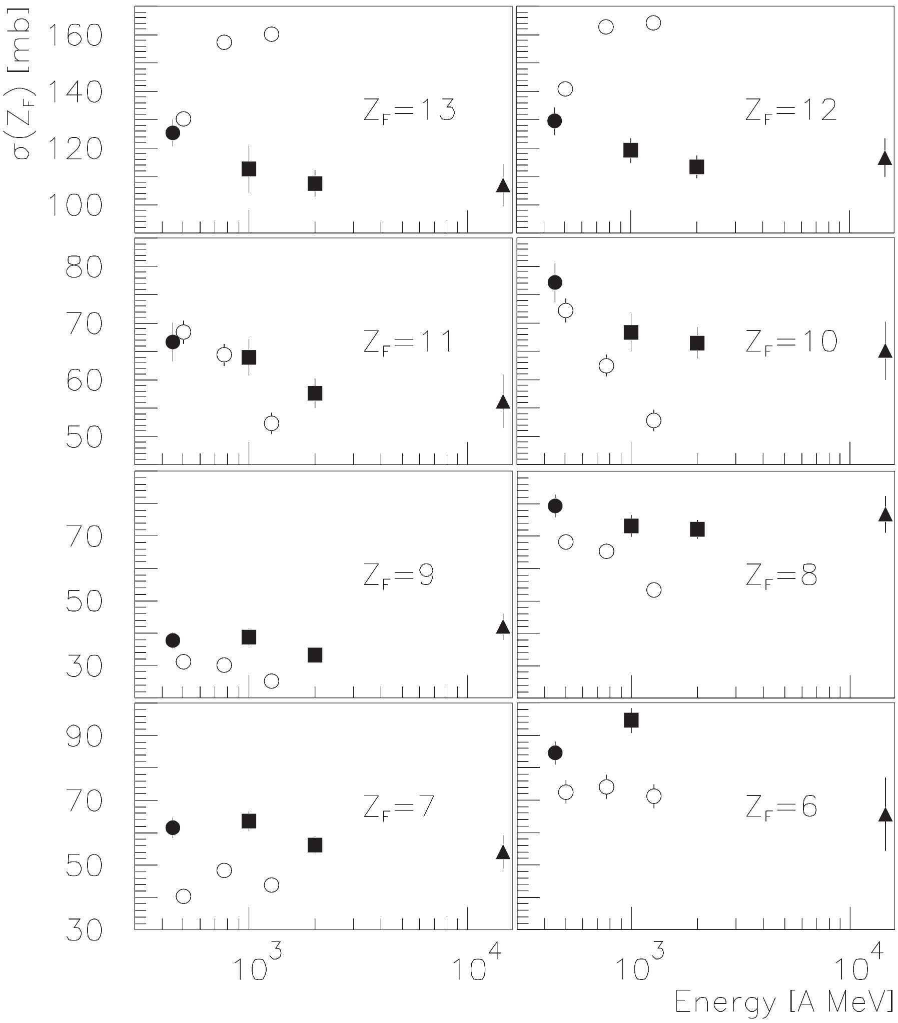

Figure 5: Comparison of cross sections measured in this experiment (filled circles) for C target to data of Brechtmann (1988) (filled triangles), of Hirzebruch (1993) (filled squares) and to data of Webber, Kish & Schrier (1990) (open circles)

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