Fragmentation of 158 A GeV Pb ions on various targets

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Abstract

Some experimental results of total and partial fragmentation charge-changing cross sections of 158 A GeV Pb ions on various targets, measured using the CR39 nuclear track detector, are presented.

1 Introduction and Experimental Procedure

Six stacks of CR39[1] nuclear track detectors with different targets were exposed in November 1996, to a lead beam (charge $Z = 82e$) of 158 A GeV at the CERN-SPS, with a normal incidence, in order to study the fragmentation properties of ultra-relativistic lead nuclei. The typical number of events in a stack was about 5.8×10^4. The presented analysis refers to a sample of ~ 12000 incident ions. Total charge-changing cross sections, partial fragmentation cross sections for $-7e \leq \Delta Z \leq -1e$ and $\Delta Z = +1e$ pick-up cross sections were measured. The detectors used were foils of CR39 manufactured by the Intercast Europe Co. of Parma (Italy).

Target	A_T	Z_T	ρ_T (g/cm^3)	t_T (cm)	$t_{CR39(b)}$ (cm)	$t_{CR39(a)}$ (cm)	σ_{tot} (mb)
H	1	1					1944 ± 275
CH_2	4.67	2.67	0.952 ± 0.002	1.02 ± 0.01	0.73 ± 0.01	1.35 ± 0.01	2266 ± 156
CH_2+CR39	6.42	3.5	1.19 ± 0.01	3.09 ± 0.01			2515 ± 81
CR39	7.41	3.95	1.310 ± 0.003	3.07 ± 0.01			2642 ± 81
C+CR39	8.67	4.54	1.44 ± 0.01	3.18 ± 0.01			2726 ± 84
Al+CR39	11.49	5.99	1.75 ± 0.01	3.26 ± 0.01			2882 ± 66
C	12	6	1.733 ± 0.004	1.01 ± 0.01	0.69 ± 0.01	1.48 ± 0.01	2910 ± 210
Cu+CR39	22.03	11.25	3.65 ± 0.01	3.22 ± 0.01			3282 ± 93
Al	27	13	2.692 ± 0.002	1.04 ± 0.01	0.72 ± 0.02	1.50 ± 0.01	3804 ± 164
Pb+CR39	30.99	15.86	4.34 ± 0.01	3.23 ± 0.01			3842 ± 116
Cu	63.5	29	8.901 ± 0.002	0.99 ± 0.01	0.72 ± 0.01	1.51 ± 0.01	5089 ± 274
Pb	207	82	11.331 ± 0.003	0.98 ± 0.01	0.72 ± 0.01	1.53 ± 0.01	12847 ± 638

Table 1: Atomic mass (A_T), atomic number (Z_T), density (ρ_T), thickness of the target (t_T), of the CR39 before and after the target ($t_{CR39(b)}$ and $t_{CR39(a)}$), when is the case, and total cross sections (σ_{tot}) for each target. The quoted uncertainties are statistical only.

When an ion crosses a nuclear track detector foil, it produces damages at the level of molecular bonds, forming the so called "latent track". During a suitable chemical etching of the detector, when the etching velocity along the latent track, v_T, is larger than the velocity in the bulk material, v_B, etch-pit cones are formed on both sides of the foil. The base area and the height of the cones are functions of the Restricted Energy Loss (REL) of the incident ion and therefore of the charge Z of the nucleus, [(Fleischer, R., Price, P.B. & Walker, R.M. (1975) and Giacomelli et al. (1998)].

[1]CR39, $(C_{12}H_{18}O_7)_n$, is a Registered Trade Mark of PPG Industries Inc.

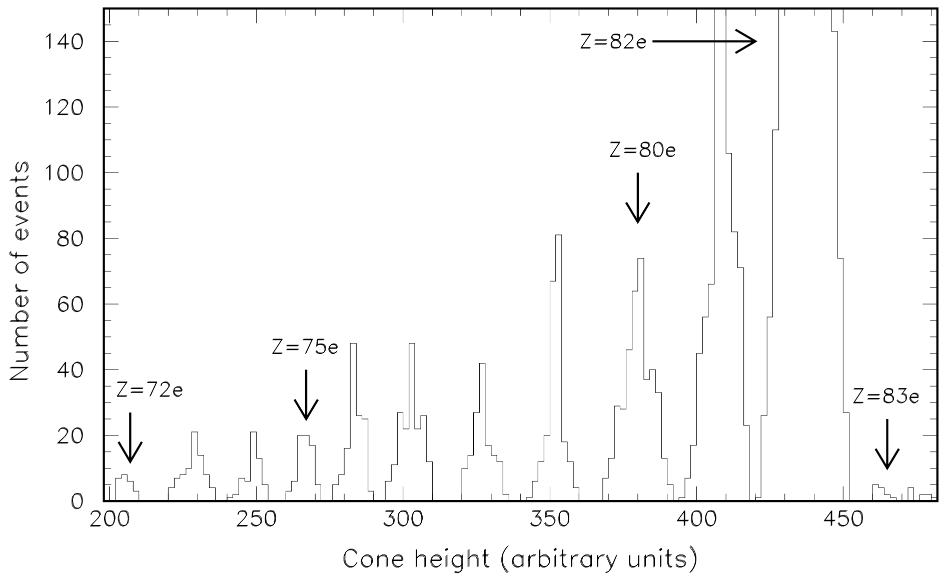


Figure 1: Distribution of etched cone heights for the "B" CR39 sheet located after the lead target.

Each stack had the following composition: (i) a 1.4 mm thick CR39 foil (which we refer to in the following as plate "A"); (ii) ~ 5.6 mm of CR39; (iii) a target, typically 10 mm thick (the targets consisted of Pb, Cu, Al, C, CH_2 and CR39 sheets); (iv) about 15 mm of CR39; (v) a 1.4 mm CR39 plate labelled "B". In the presented analysis the CR39 plates "A" and "B" were used as detectors (4 measured faces).

In Table 1 the target densities and thicknesses are reported. Each stack was first used as if it had target with A_T, Z_T and ρ_T equal to the corresponding mean values. Using data from the CR39 stack, it was then possible to obtain results on pure targets.

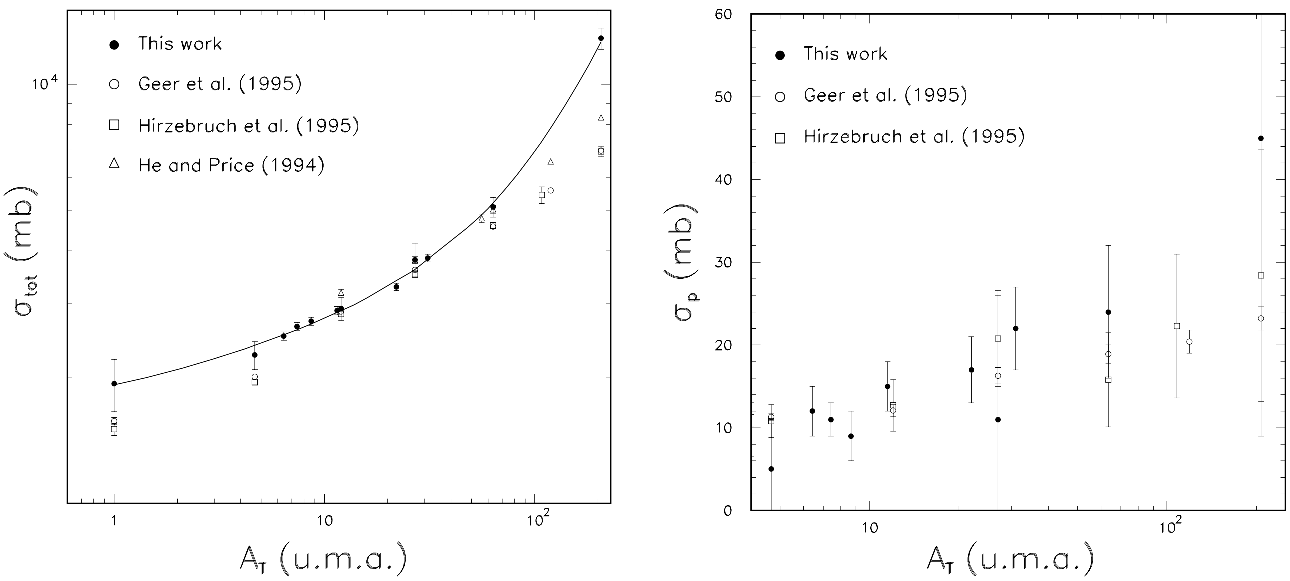
In this experiment, after exposure, the CR39 detectors were etched for 268 h in a 6N NaOH water solution at a temperature of 45 °C. As reported in Giacomelli et al. (1998), with these etching conditions the cone base diameter of a track produced by an ion with charge $Z \geq 75e$ is around 75 μm, while the smallest track corresponding to $Z = 7e$ has a diameter of ~ 7 μm. The base area of each cone and the absolute $x,\ y$ coordinates of its center were measured on both sides of the "A" and "B" plates with an automatic image analyzer. To reconstruct the path of the ions, we used a tracking procedure requiring the existence of the signal on at least three out of four faces and then we performed an average on the base area values. For relativistic ions, this procedure has an acceptable charge resolution up to $Z \sim 75e$; from $Z \geq 75e$ the fragment tracks and the lead tracks cannot be distinguished.

At high Z the height of the etched cone is more sensitive to Z than its base area [Giacomelli et al. (1998)]; to find out the percentage of survived lead ions and fragments with charge $Z \geq 75e$, we performed manual cone height measurements on a single face before and after the targets with a suitable microscope. The charge resolution obtained from this measurement technique is about $0.2e$. Fig. 1 shows an example of a cone height distribution. The percentages of non-lead tracks with diameter ≥ 75 μm in the sample defined by the tracking procedure are about 1% before and $18\% \div 35\%$ after the different targets.

2 Total charge-changing cross sections

Using the survival fraction of lead ions for each stack, it was possible to determine the total charge-changing cross sections quoted in Table 1, where the errors are statistical only. The estimated systematic uncertainties, due mainly to the merging of two different experimental procedures and to the uncertainties on densities and thicknesses of the materials, are less than 5%.

The contribution to the cross sections due to fragmentation in ions with $Z < 7e$ (threshold of the CR39



(a) (b)

Figure 2: Measured total fragmentation charge-changing cross sections (a) and pick-up cross sections (b) for 158 A GeV Pb projectiles in various targets (black points); the solid line in (a) represents the fit of our data to formula (1). The data from He and Price (1994), Geer et al. (1995) and Hirzebruch et al. (1995) are shown for comparison.

detector) has been extimated as 10% of that of fragments with $7e \leq Z \leq 75e$. The experimental values are inclusive of nuclear and electromagnetic effects. The cross section on Hydrogen target has been determined using the measured cross sections in CH_2 and C.

Following suggestion from He and Price (1994), Geer et al. (1995) and Hirzebruch et al. (1995), we fitted our data with the equation:

$$\sigma_{tot} = a(A_P^{1/3} + A_T^{1/3} - b)^2 + \alpha Z_T^{\delta} \quad (1)$$

where A_P and A_T are the atomic masses of projectile and target, Z_T is the atomic number of the target. With: (i) $a = 54$ mb and $\delta = 1.88$ we obtain $b = (0.96 \pm 0.03)$ and $\alpha = (1.57 \pm 0.17)$ mb with $\chi^2/D.o.F. = 0.7$, (ii) $b = 0.96$ and $\alpha = 1.57$ mb, we obtain $a = (54.0 \pm 0.5)$ mb and $\delta = (1.88 \pm 0.03)$ with $\chi^2/D.o.F. = 0.7$. The results are shown in Fig. 2a, where data from He and Price (1994), Geer et al. (1995) and Hirzebruch et al. (1995), referring to a 10 A GeV Au beam on various targets, are also reported. In the central A_T region there is an agreement; for $A_T = 207$ u.m.a., our cross section is greater, probably due to the increasing of electromagnetic contribution. The different value for $A_T = 1$ may be connected with some sistematic effect. Our data are in agreement with Giacomelli et al. (1997) referring to a similar exposure.

3 Partial fragmentation cross sections

The partial fragmentation cross sections were calculated for each stack using the propagation formula as in Brechtmann and Heinrich (1988), which takes into account successive fragmentation inside a thick target. The target, in this case, has $A_T,\ Z_T$ and ρ_T equal to the corresponding mean values in the stack. For the computation we need the total charge-changing cross sections σ_i $(i = 75 \div 81)$ and the partial charge-changing cross sections $\sigma_{j,i}$ $(j > i,\ 75 < j \leq 82)$. The total charge-changing cross section for lead nuclei (σ_{tot}) was experimentally measured. For the fragments, the σ_i were evaluated with the help of formula (1). The partial fragmentation cross sections for lead ions $\sigma_{82,i}$ were directly measured. The other partial fragmentation cross sections σ_{ji} $(75 \leq j < 82,\ i < j)$ were computed using a constant fragmentation probability for the same ΔZ.

A_T	σ_{-1}	σ_{-2}	σ_{-3}	σ_{-4}	σ_{-5}	σ_{-6}	σ_{-7}
6.42	297 ± 27	107 ± 10	100 ± 10	67 ± 7	63 ± 7	26 ± 3	21 ± 3
7.41	232 ± 23	126 ± 12	93 ± 9	52 ± 6	50 ± 6	36 ± 5	18 ± 3
8.67	201 ± 19	103 ± 11	98 ± 10	77 ± 8	58 ± 7	32 ± 4	16 ± 3
11.49	258 ± 27	168 ± 16	117 ± 12	68 ± 8	29 ± 4	29 ± 4	38 ± 5
22.03	314 ± 31	161 ± 16	78 ± 9	97 ± 10	76 ± 9	30 ± 4	24 ± 4
30.99	671 ± 60	289 ± 23	139 ± 12	80 ± 8	123 ± 12	80 ± 8	31 ± 3

Table 2: The measured partial break-up charge-changing cross sections for lead ions of 158 A GeV for each stack. All values are in mb; quoted uncertainties are statistical only.

The measured partial charge-changing cross sections for "mean" targets are given in Table 2, where the quoted uncertainties are statistical only.

The pick-up cross sections for all the targets were determined using the simple equation

$$\sigma_p = \frac{1}{x}\frac{N_p}{N_{82}} \tag{2}$$

where N_p is the number of nuclei with $Z = 83e$ produced inside the target, N_{82} is the number of unfragmented beam nuclei and $x = \rho_T t_T N_A / A_T$ ($N_A =$ Avogadro's number). The pick-up cross sections for lead ions were directly measured for the "mean" stacks and, after removal of interactions in CR39, even for pure targets. The results are shown in Fig. 2b. Comparison of our data with Geer et al. (1995) and Hirzebruch et al. (1995) indicates a general agreement inside errors.

4 Conclusions

Using stacks of CR39 nuclear track detectors, we measured the total, partial break-up and pick-up charge-changing cross sections for lead nuclei of 158 A GeV in different targets. The comparison with similar data obtained with 10 A Gev Au beam indicates a similar A_T dependence of the cross sections with the exception of Pb-Pb interactions which are considerably higher.

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