CALIBRATION OF THE INTERCAST CR39

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ABSTRACT

We present new calibration results of the CR39 nuclear track detector made in collaboration with the Intercast Europe Co. of Parma, Italy. Upper limit on the production of nuclei with fractional charge has also been established. Results are also presented on the determination of the total and partial charge changing fragmentation cross sections of $^{28}$Si$^{14+}$ ions of 14.5 GeV/nucleon and of $^{32}$Si$^{16+}$ ions of 200 GeV/nucleon in Copper targets.

KEYWORDS

CR39; calibration; charge resolution; fractional charge; charge changing fragmentation cross section.

INTRODUCTION

The main purpose of this work was the calibration of the CR39 polymer of so-called type L6, made in collaboration with the Intercast Europe Co. of Parma, Italy and used as track etch detector in the MACRO experiment at Gran Sasso. The MACRO track etch detector is of more than 1000 m$^2$, and the final size will be about 1300 m$^2$, with 3 layers of CR39 and 3 layers of Lexan polycarbonate (MACRO Coll. 1991). The chemical composition, the curing cycle and a former calibration curve of the CR39 of type L6 are reported in the previous reference. We present here new calibration results obtained using relativistic silicon, sulphur and gold ion beams. Calibrations of the CR39 with low velocity ions are in progress.

Stacks of 13 x 7 cm$^2$ foils of CR39 of different batch production, were exposed to 14.5 GeV/nucleon $^{28}$Si$^{14+}$ ions at the AGS accelerator (BNL, June 1990), to 200 GeV/nucleon $^{32}$S$^{16+}$ ions at the SPS (CERN, July 1990) and to 11.3 GeV/nucleon $^{197}$Au$^{79+}$ ions at the AGS (BNL, May 1992). The relativistic ion density was about 1500 ions/cm$^2$. Each stack contained from 6 up to 12 foils of CR39 upstream and downstream of 14 mm thick Copper target; the CR39 foils were each 1.4 mm thick. We may thus identify the incoming and outgoing particle projectiles and fragment particles.

CALIBRATIONS

After exposures the CR39 foils were etched in 6.0 N NaOH water solution at (70.0±0.1)$^\circ$C (for 45h the stacks exposed to Si and S beams and 27h the stacks exposed to Au beam). The surface areas of the etch pits were measured with a fully automated Tiber image analyzer system (Noll et al., 1988). The calibrations are based on the measurements of the mean track areas produced by the ion beam particles and by the fragment particles. Figure 1 shows a distribution of the track areas of sulphur ions and their fragments using a single surface measurement after background reduction obtained with a cut on the track central brightness value and eccentricity.

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From the measurements of the track areas and of the bulk etching rate \( v_B \), the reduced etch rate \( p = v_B / v_B \) was calculated using the usual formulae (Fleischer et al., 1976). The values of \( p \) obtained for each detected ion from silicon, sulphur and gold ion exposures are plotted in Fig. 2 versus the Restricted Energy Loss (REL) that was calculated using the expression given by the Particle Data Group. The new measurements with gold ions do not indicate any change either in sensitivity or threshold compared to two year old measurements with silicon and sulphur ions.

![Graph](image)

**Fig. 1:** Track surface area distribution of 200 GeV/nucleon \( S^{16+} \) nuclei and their fragments measured on a single surface of a CR39 foil located downstream of the copper target.

![Graph](image)

**Fig. 2:** Experimental calibration data points of the reduced etch rate \( p \) versus REL from \( Si^{14+} \), \( S^{16+} \) and \( Au^{79+} \) exposures. The line is the best fit to the experimental data.

**CHARGE RESOLUTION AND SEARCH FOR FRACTIONALLY CHARGED NUCLEI**

It has been suggested (De Rujula et al., 1978) that fragments with fractional charge might be formed in high energy nucleus-nucleus collisions. Upper limits on the production probability of fragments with
fractional charge in the collisions of 14.5 GeV/nucleon Si nuclei in copper and in CR39 were estimated. For this purpose the trajectory of each single fragment nucleus was reconstructed by tracking the etch cones successively from surface to surface throughout six foils of CR39 after the copper target. Charge changing nuclear fragmentations are detected as a change in the area of the etch pits. We introduced a correction on a small variation of the area from one surface to the other. For each track a mean area was calculated as the average of 7 to 12 individual measurements. After calibration we obtained the charge distribution shown in Fig. 3. The standard deviation is $\sigma_Z=0.05e$ for $Z=7$ and $\sigma_Z=0.07e$ for $Z=13$. The slight worsening of the charge resolution with increasing $Z$ is due to the non linear increase of the etch-pit areas with increasing charge.

In Fig. 3 there is no indication of nuclei with fractional charge produced in the copper target. We measured 9200 fragment tracks with charge $7 \leq Z \leq 13$. From the number of detected fragments we determined the upper limit for the production in Cu of projectile fragments with charges 20/3 up to 40/3 (integer $\pm 1/3e$), using the relation:

$$F = \frac{K(N_C)}{(\epsilon N_F)}$$

(1)

where $N_C$ is the number of fragments with charge differing by more than 0.22e from an integer charge in the above intervals, $N_F$ is the number of measured ordinary fragments in the same charge intervals, $\epsilon$ is the product of detection and selection efficiencies of fractionally charged nuclei relative to ordinary nuclei and is estimated to be 98% ; $K = 2.3$ when $N_C = 0$ for 90% C.L.

There are no candidate events which differ by more than 0.22e from integer charge. The upper limit on the production of fragments in Cu with fractional charge at 90% confidence level is $F \leq 2.6 \times 10^{-4}$. This limit is valid for projectile fragments penetrating at least 7 mm of CR39 and 14 mm of Cu.

Fig. 3: Charge distribution of 14.5 GeV/nucleon Si$^{14+}$ ions and their fragments based on ten surface area measurements for each detected particle. The points in the horizontal axis show the expected positions of the fractional charges. There is no indication of nuclei with fractional charge.

**CHARGE CHANGING FRAGMENTATION CROSS SECTIONS OF $^{28}$Si$^{14+}$ AND $^{32}$Si$^{16+}$ IN Cu TARGET**

To determine the total and partial charge changing fragmentation cross sections in Cu of 14.5 GeV/nucleon silicon nuclei and of 200 GeV/nucleon sulphur nuclei, we reconstructed the trajectories of the beam and fragment nuclei through four foil surfaces upstream and downstream of the target. We corrected our measurements for the fragmentation in the CR39 foils. A propagation formula (Brechmann et al., 1988a) for the relation between the distributions of the incoming and outgoing particles on the target surfaces was used. A correction was made for the electromagnetic dissociation effect (Brechmann et al., 1988b). For the total charge changing fragmentation cross sections we obtained:
\[ \sigma = (2446 \pm 36) \text{ mb for } {}^{28}\text{Si} \]
\[ \sigma = (3147 \pm 40) \text{ mb for } {}^{32}\text{S} \]

The partial cross sections in copper for silicon and sulphur ions are plotted in Fig. 4 versus \( \Delta Z \), which is the charge difference between the beam ions and the fragments; errors are only statistical. Our results, within errors, are in good agreement with those reported by others (Brechtmann et al., 1988a, b, Price et al., 1988).

![Graph showing cross section vs. \( \Delta Z \)](image)

**Fig. 4**: Partial fragmentation cross sections in Cu for silicon ions of 14.5 GeV/nucleon and sulphur ions of 200 GeV/nucleon into various nuclear fragments for \( \Delta Z \) ranging from 1 to 9.

**CONCLUSIONS**

We have performed a new calibration of the INTERCAST CR39 of type L6; there is no indication of aging in the reduced etch rate \( \rho \) for two year old CR39. We have placed an upper limit at 90% confidence level for the production of nuclei with fractional charge at the level of less than \( 2.6 \times 10^{-4} \) of the analysed fragments. We have measured the total and partial charge changing fragmentation cross sections of silicon and sulphur in Cu targets.

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**REFERENCES**


