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Determination of the detection threshold for Polyethylene Terephthalate (PET) Nuclear Track Detector (NTD)

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ABSTRACT

In this work we investigated the detection threshold of the polymer material Polyethylene Terephthalate (PET) intended to be used as Nuclear Track Detector (NTD) in the search for rare events (e.g. strangelets) in cosmic rays. 11 MeV ^{12}C and 2 MeV proton beams from the accelerator at the Institute of Physics (IOP), Bhubaneswar were utilized for this study. The results show that the PET detector has a much higher detection threshold ($Z/\beta \sim 140$) compared to many other commercially available and widely used detector materials like CR-39 ($Z/\beta \sim 6$–20) or Makrofol ($Z/\beta \sim 57$). This makes PET a particularly suitable detector material for testing certain phenomenological models which predict the presence of strangelets as low energy, heavily ionizing particles in cosmic radiation at high mountain altitudes.

1. Introduction

Search for exotic events like strangelets (which are hypothetical particles with anomalous *Z/A* ratios) in cosmic rays is an active field of research [1–3]. Several studies point to a measurable strangelet flux in our part of the galaxy [4–6]. AMS-02, a particle detector currently installed on the International Space Station, has, as one of its science goals, the search for strangelets in primary cosmic rays [7]. Phenomenological models as well as observations have also offered some tantalizing hints about the possible presence of strangelets in cosmic rays at high mountain altitudes, albeit with a very low flux [8,9]. So any experiment looking for strangelets at mountain altitudes will require a very large area array. Nuclear Track Detectors (NTDs), which have been used in charged particle detection for many years [10,11] constitute an ideal choice of detector material for such an experiment. NTDs are rugged, relatively inexpensive, easy to handle and have intrinsic thresholds of detection. This last point is particularly important in rare event search as the choice of a material with high detection threshold provides a natural and easy way to suppress the large low-Z background (protons, neutron recoil tracks, radon alphas, etc.) expected in such an experiment.

We plan to use a commercially available polymer, identified as Polyethylene Terephthalate (PET) [12], as a NTD in the search for strangelets in cosmic rays, through the deployment of large area arrays at high mountain altitudes. Systematic studies were previously carried out on PET to determine its ideal etching condition and also to determine its charge response to various ions using accelerators as well as natural radioactive sources. A calibration curve for PET (dE/dx vs.V_T/V_B, where dE/dx is the specific energy loss, V_T and V_B are the track etch rate and the bulk etch rate respectively while their ratio V_T/V_B is the reduced etch rate or charge response) utilizing ^{16}O, ^{32}S, ^{56}Fe, ^{238}U ions was obtained [13]. It was then updated [14] with additional data points corresponding to ^{129}Xe, ^{78}Kr and ^{49}Ti ions obtained from the REX-ISOLDE facility at CERN. In addition, studies were carried out on PET which show that it has good energy and charge resolution [15].

The charge response or reduced etch rate (V_T/V_B) of NTDs depend on the specific energy loss (dE/dx) of the incident charged particle and hence is related to Z/β by the Bethe equation [16], where Z is the atomic number of the incident particle and $\beta = v/c$, gives a measure of its velocity. This Z/β ratio for an incident particle has to be above a certain value for it to be detected in a particular material used as NTD and that particular value of Z/β is regarded as the detection threshold for that NTD. The question of detection threshold becomes important and choice of a material with very high detection threshold assumes particular significance, if the strangelets, as described in certain propagation models of strangelets in earth's atmosphere [8], have low energies (few MeV/n) at mountain altitudes and hence may not be able to penetrate multiple detector films in the detector stack.

The commercially available NTDs like CR-39, Makrofol, etc. which are in widespread use today have Z/β detection thresholds

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lying in the range 6–60 [17–19]. Since earlier studies [13] indicated that PET could have a detection threshold of around 120, we carried out further investigations focused on the issue of detection threshold where the PET detector films were exposed to 11 MeV ^{12}C and 2 MeV proton beams from a particle accelerator. We found that for the optical system we are using, PET has a practical detection threshold $Z/\beta \sim 140$ making it particularly suitable as a detector for low energy rare event search. We present the results of those studies in this paper.

2. Experiment

The experiment was performed at the Ion Beam Laboratory, Institute of Physics, Bhubaneswar. PET (Desmat, India) as well as standard CR-39 (Intercast, Italy) detectors used as control were exposed to carbon and proton beams of different energies inside a target chamber. The energies and the charge states of the beams used are given in Table I. Energy values of the ion beams were so chosen that they remain above the Bragg Peak energies for the respective ions (80 keV for proton, 5 MeV for carbon) on PET, because for energies lower than that, the Bethe equation starts to break down due to charge neutralization. PET and CR-39 films of thickness 100 μm and 700 μm respectively, were cut into pieces (8.5 cm × 1.5 cm) and mounted on the different faces of a target ladder (an octagonal block) as shown in Fig. 1. One of the eight faces of the target ladder was covered by a tape which glows when the beam impinges on it. This was done to enable beam monitoring during the setup process. Fig. 2 shows the target ladder as seen through the observation window of the target chamber. Once the setup was done, beam was let into the evacuated (2.8×10^{-5} mbar) target chamber. Initially beam current was set at ~ 500 nA to enable beam monitoring and necessary adjustments. Then the beam current was reduced to a very low value ~0.5 nA to prevent detector burnout. During every run the target ladder was given one full rotation within 10 s to irradiate all the detector films attached to the different faces. After exposing the detectors, the standard etching procedures for PET as well as CR-39 were followed. The irradiated PET samples were etched in 6.25 N NaOH solution at 55.0 ± 0.5 °C which was found [13] to be the ideal etching condition for the PET detectors. The CR-39 detectors, on the other hand, were etched in 6.25 N NaOH solution at 70.0 ± 0.5 °C. The resulting track parameters were then measured under ×100 dry objective of a Leica DM 4000 optical microscope which was interfaced with a computer preloaded with image analysis software.

3. Results and discussions

3.1. Results using proton beam

Tracks due to protons could be seen on CR-39 films exposed to proton beams of energy 2 MeV. Fig. 3 shows some such tracks due to 2 MeV proton beams after 4 h etching. But no particle tracks could be detected on PET detector films irradiated by proton beams (For 2 MeV protons, $Z/\beta \sim 15$) even after they have been etched for 9 h as shown in Fig. 4. This shows that PET has a much higher detection threshold compared to CR-39.

Table I
Beams used for this experiment.

Ion	Energy (MeV)	Beam current (nA)	Charge state
Proton	2	0.5	1
Carbon	11	0.5	4

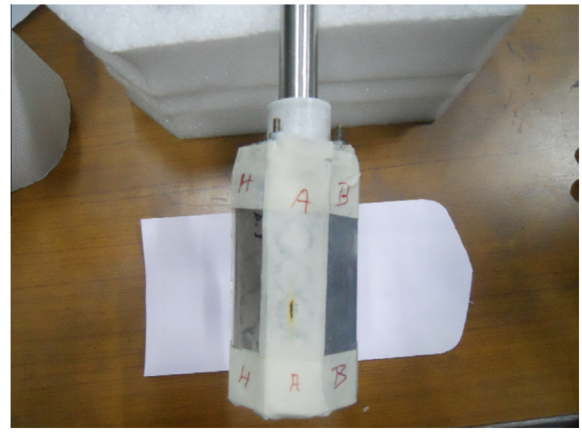

Fig. 1. Detector films mounted on the target ladder. One of the faces was covered with a glowing tape for beam monitoring. Burnt portion of the tape is due to long time exposure to incident carbon beam.

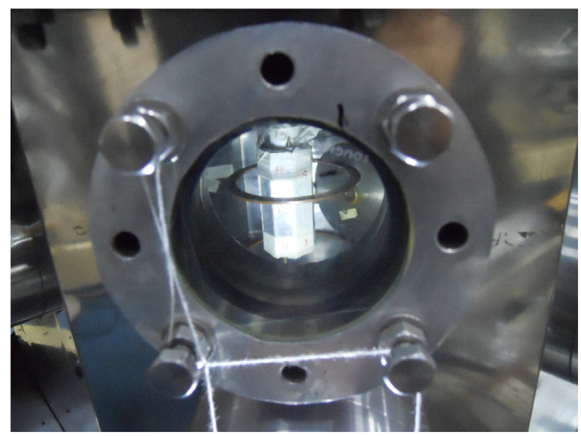

Fig. 2. Detectors mounted on the target ladder as seen through the window of the target chamber.

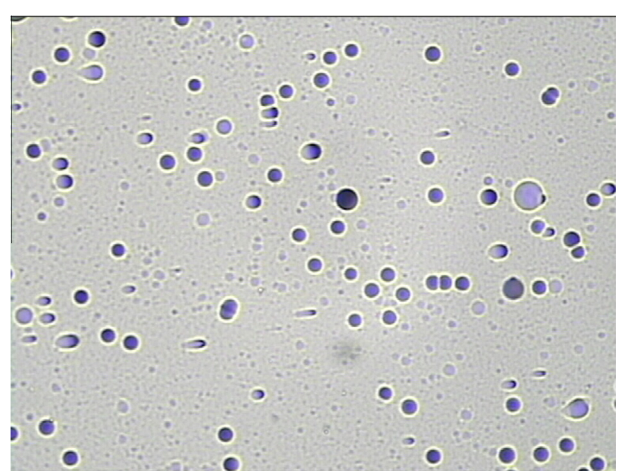

Fig. 3. Tracks on CR-39 due to 2 MeV protons could be seen after etching for 4 h with the microscope focussed on the surface of the detector film. The size of the image frame is 117 μm × 87 μm.

3.2. Results using carbon beam

PET detectors exposed to ^{12}C beam of energy 11 MeV were etched in successive stages of 1 h duration to determine the point