The STARTRACK experiment: first measurements
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INTRODUCTION

STARTRACK experiment (acronym of STructure of hAdRonic TRACK) aims to measure ionisation cluster distributions in nanometric sites placed at different distances from an accelerated charged particle track. STARTRACK uses a 20 nm wall-less detector [1], already used for studying the nanometric track structure of a ²⁴⁴Cm alpha particle [2], and then it will use a new detector designed for measuring ionisation clusters in 10 nm sites. The experiment is mounted at the beam line of the Tandem-Alpi accelerator facility of Legnaro Laboratories, which supplies ion beams from hydrogen to gold in the energy range of 7-28 MeV/amu.

Track nanodosimetry aims to measure ionisation clusters along and aside the ion track down to occurrence probability of 10⁻⁵. To reach such an aim at least 10⁶ events have to be collected and the cluster pile-up probability reduced to less than 10⁻⁶. By using a beam profile detector, which is sensible to very weak currents, and an event rejector counter, such an aim is feasible.

This paper is concerned with the preliminary measurements achieved with the new apparatus.

BEAM PROFILE DETECTOR

The STARTRACK acquisition system can handle some hundreds Hertz of input data. When the ion track crosses the detector sensitive volume, the particle fluence rate has to be lowered to the maximum data acquisition rate. When the ion track is several tens of nanometres far from the sensitive volume, the particle fluence rate can be increased up to 10 kHz or more. Before opening the shutter, which allows the beam to cross the measuring chamber, the beam profile has to be measured in order to optimize the beam optics and reduce the beam intensity down to the wished value. For such an aim a beam profile detector is used in vacuum. The vacuum chamber is separated from the measuring chamber by a 1.5 µm aluminated Mylar window. The detector is made of two micro-channel plates (MCP Hamamatsu Type: F1551) and a 2D matrix of anode-pads printed on a circuit board. The micro-channel-plate microscopic tubes have a diameter of 12 µm and a pitch of 15 µm and are bent of 8° with respect to the axis of the plate. Therefore, almost all particles hit a micro-channel wall. Any initial electron impinging on the MCP is multiplied by a factor of about 10⁴. In order to obtain a gain of about 10⁸, two MCP have been coupled. Behind the MCPs, the anode matrix consists of 9x9 pixels of 1 mm² each. Each pad is connected to an operational amplifier AD542. The readout of the amplifiers is performed by 5 analogue multiplexers. The charge collected by every pixel is integrated by about 1 ms and transformed in voltage by 1 GΩm resistor. The 81 voltage signals are processed online by a PC-resident software, which gives a coloured imagine of the beam cross section intensity.

The detector characteristics have been studied by using 1µCi ²⁴⁴Cm alpha source placed in the front of MCP at 1.5 cm of distance. In figure 1 the pulse height of one pixel has been plotted against the chamber pressure. The figure shows that the detector efficiency has a maximum at 1.5 10⁻⁵ mbar of pressure. More details are published in reference 3.

FIG.1: Average signal height of 1 pixel against the pressure in the measurement chamber.

PILE-UP EVENT REJECTION

After having reduced the beam intensity to the wished value by defocusing the original ion beam, we have a very large and divergent ion beam. A system of collimators defines a narrow beam, which allows determining with precision the distance d of the ion track from the nanodosimetric sensitive volume SV. Figure 2 shows the layout with the 5 collimators. After the last collimator before the nanodosimetric counter, we have four populations of ions:

(i) the primary beam I, which triggers the cluster acquisition,
(ii) the primary beam II, which does not trigger the cluster acquisition since it has too large divergence (bigger than 3 mrad) to enter into the last collimator 5, but small enough to enter into collimator 4 (less than 6 mrad),

The nanodosimetric counter is a thin-wall detector made of a thin aluminium plate in which 81 pixels have been engraved.

FIG.2: Layout of the collimators.
(iii) the secondary beam III, which emerges at medium angles from the fourth collimator after having been scattered by its border,
(iv) the secondary beam IV, which is scattered at very large angle.

In order to count one by one the electrons belonging to the ionisation cluster generated inside the $SV$ at the passage of an ion, the nanodosimeter spends about 10 µs of time. Therefore, at 1 kHz of ion fluence rate the probability that the measured ionisation cluster is due to more than one ion is rather high: $10^{-2}$. The trigger is a silicon detector, which is quite fast. It is able to detect a second ion, belonging to the population I, arriving few tens of nanosecond after the triggering ion and, in such a case, to trigger the rejection procedure. Ions belonging to populations II and III are detected with a large area counter (rejector), which triggers the rejection procedure if an electron cluster is in course of acquisition. Ions belonging to population IV are not detected neither by the rejector.

We have used a 20 MeV proton beam to test both the beam profile detector and the trigger-rejector system and hence to assess the pile-up total probability. First we have lowered the proton fluence rate to get 0.8 kHz of trigger counting. The ratio rejector/trigger counts was measured to be $2.23 \pm 0.02$. This ratio, in combination with the assumption of an uniform beam and of rejector counts due to ions of population I and II, allows us to calculate the mean beam divergence. Being the irradiation geometry known (see figure 2), the beam divergence is calculated to be 1.5 mrad. The size of populations III and IV have been calculated by modelling the beam interaction with the collimator border and using the Monte Carlo code SRIM [4]. The probability that an ion belongs to such populations is the product of the probability of entering in the border of the collimator 4 (as a result of the beam divergence) and the probability that an emerging proton reaches the rejector plane at distance $R$ from the beam centre (see fig. 2). The scattering probability, for 1 mm diameter Nb collimator, is plotted in figure 3 against the radial distance from the beam centre. The probability that an emerging proton reaches the rejector plane at distance $R$ from the beam centre (see fig. 2). The probability that a piled-up event is not rejected is the product of the probability that an ion is scattered outside the rejector by the probability that such an ion crosses the measuring chamber within 10 µs from the last triggered ion. This probability reaches the relatively high value of $4.6 \times 10^{-4}$ for 0.8 kHz. However, it is enough to reduce the collimator 3 diameter to 0.9 mm, to avoid primary protons hit the border of the fourth collimator. In such a way, the probability that a piled-up event is not rejected becomes less than $10^{-7}$.

![FIG. 2: Layout of the irradiation geometry. 1,2,3,4,5, are collimators. SV is the nanodosimeter sensitive volume.](image)

![FIG. 3: Scattering probability of a 20 MeV proton passing throughout collimator 4 against the radial distance at the rejector plane. The two vertical dashed lines define the rejector border. See text.](image)

ACKNOWLEDGEMENTS

This work is supported by the 5th scientific commission of the Istituto Nazionale di Fisica Nucleare of Italy. We thank Luciano Costa of LNL user service and Gastone Donà of LNL mechanical workshop for the important help they have given in installing STARTRACK on the beam line.

This work has been partially supported by the EU contract 506665-I3-EURONS-FP6-2002 INFRASTRUCTURES-1.