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## Microdosimetry at the 62 MeV Proton Beam of CATANA: preliminary comparison of three detectors

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**Abstract.** A microdosimetric characterization of the 62 MeV proton beam line of CATANA has been performed all along the Spread Out Bragg Peak with three different detectors. Two silicon detectors and a Tissue Equivalent Proportional Counter measured at approximately the same depths of the SOBP. The TEPC is a new miniaturized gas counter developed at the Legnaro National Laboratories of INFN, modified to work without gas flow. The first silicon detector has been developed at the Politecnico of Milano and it is a monolithic telescope composed by a matrix of 2  $\mu\text{m}$  thick cylindrical diodes with a diameter 9  $\mu\text{m}$ . that compose the  $\Delta E$  layer. The  $E$  and  $\Delta E$  layers are fabricated on a single substrate of silicon. The third detector is the MicroPlus probe developed at the CMRP - University of Wollongong, it is an array of 3D sensitive volumes each with dimension 30x30  $\mu\text{m}$  and 10  $\mu\text{m}$  thick fabricated on SOI. Measurements performed with the three detectors are presented and discussed.

### 1. Introduction

Proton therapy is a widespread tumour treatment technique, which takes advantage of being more spatially selective and more biological efficient in killing cancer cells as compared to conventional radiotherapy. This enhanced efficiency is taken into account by weighting the physical dose with the Relative Biological Effectiveness (RBE). In proton therapy a RBE of 1.1 is mostly used, as recommended in the ICRU Report 78 [1], despite biological evidence of higher RBE values, in particular in the distal edge [2]. The radiation effectiveness depends on spatial density of energy deposition, generally described by the Linear Energy Transfer ( $LET$ ), higher energy density corresponding to more severe effects [3]. Microdosimetry offers a detailed study of the stochastics of energy deposition in micrometric-sized volumes [4]. The frequency and dose-weighted distributions of the lineal energy ( $y$ ), the stochastic equivalent of the  $LET$ , can be used to assess the biological



effectiveness of mixed and unknown radiation fields, for instance applying the Microdosimetric Kinetic Model [5].

Tissue Equivalent Proportional Counters are the reference detectors in experimental microdosimetry but silicon detectors are also spreading worldwide because of their easier employment [6]. The main aim of this paper is to study the characterization of the Spread Out Bragg Peak of the 62 MeV proton beam of CATANA at the Southern National Laboratories of the Italian National Institute of Nuclear Physics (LNS – INFN) using three different detectors: a miniaturized TEPC and two different silicon microdosimeters. The results of the characterization in terms of shape of the spectra will be presented and discussed in this paper.

## 2. Detectors and data analysis

Measurements were performed at the 62 MeV Spread Out Bragg Peak of CATANA, which is a passive half-modulate SOBPs of 1.1 cm used to treat ocular melanomas [7].

The three detectors were all centred at the beam isocentre, and the same stack of PMMA layers was interposed between the collimator and the detectors. The different depths were obtained sequentially adding thin PMMA layers and taking into account the different water equivalent thicknesses of the detectors. Data analysis has been performed in the standard way used in microdosimetry [8], and specifically for each detector the analysis can be found in references [9] for the mini-TEPC, [10] for the silicon telescope and [11] for the MicroPlus probe. All the frequency spectra  $f(y)$  have been linearly extrapolated down to 0.01 keV/ $\mu\text{m}$ , the lineal energy calibration was performed for water.

### 2.1 The mini-TEPC

The gas detector is a miniaturized TEPC of 0.9 mm of diameter, developed at the Legnaro National Laboratories of INFN to work without gas flow [9]. The new design is based on that of the mini-TEPC described in [12], the geometry and the materials employed are the same but the gas ducts have been widened in order to better optimize the use of this new detector without gas flow. The operative conditions of pressure and high voltage used are the same described in [9]. The detector is connected to an in-house low noise and fast preamplifier to better fit the detector specifications. The lower detection threshold was around 0.4 keV/ $\mu\text{m}$ .

### 2.2 The silicon telescope

The silicon telescope is composed by a  $\Delta E$  stage made of a matrix of 2  $\mu\text{m}$  thick cylindrical diodes surrounded by a guard-ring used to confine the lateral charge. The  $E$  stage is 500  $\mu\text{m}$  thick, both stages are fabricated from a single silicon substrate separated by a deeply implanted p+ cathode [11]. Each cylindrical diode works as a single microdosimeter while the  $E$  stage records the initial energy of the incident protons when their residual range is smaller than the telescope thickness. The  $E$  stage allows to perform an event-by-event correction of signals from the  $\Delta E$  multiplying the energy deposited in silicon by the ratio of the stopping powers in water and silicon when the energy of the incident protons is lower than 8 MeV, i.e. in the distal edge. The detection threshold was around 8 keV/ $\mu\text{m}$ .

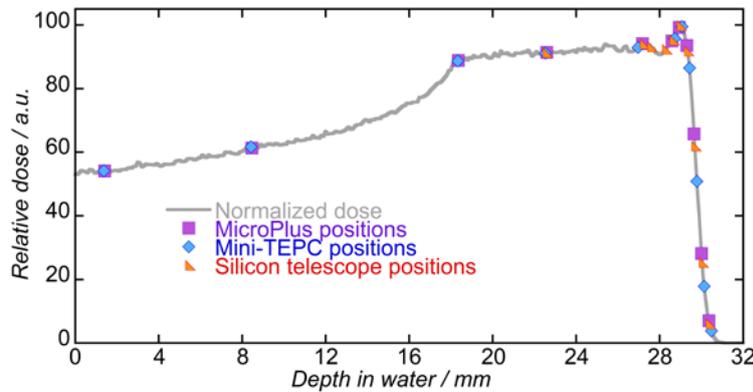
### 2.3 The MicroPlus probe

The MicroPlus probe detector is an array of 3D sensitive volumes (diodes) of dimension 30  $\mu\text{m}$  x 30  $\mu\text{m}$  and 10  $\mu\text{m}$  thick fabricated using silicon-on-insulator (SOI) wafers with thickness of an active layer of 10  $\mu\text{m}$ . Each silicon diode is connected in parallel through aluminium tracks [11]. The lower detection threshold is around 0.5 keV/ $\mu\text{m}$ .

## 3. Results

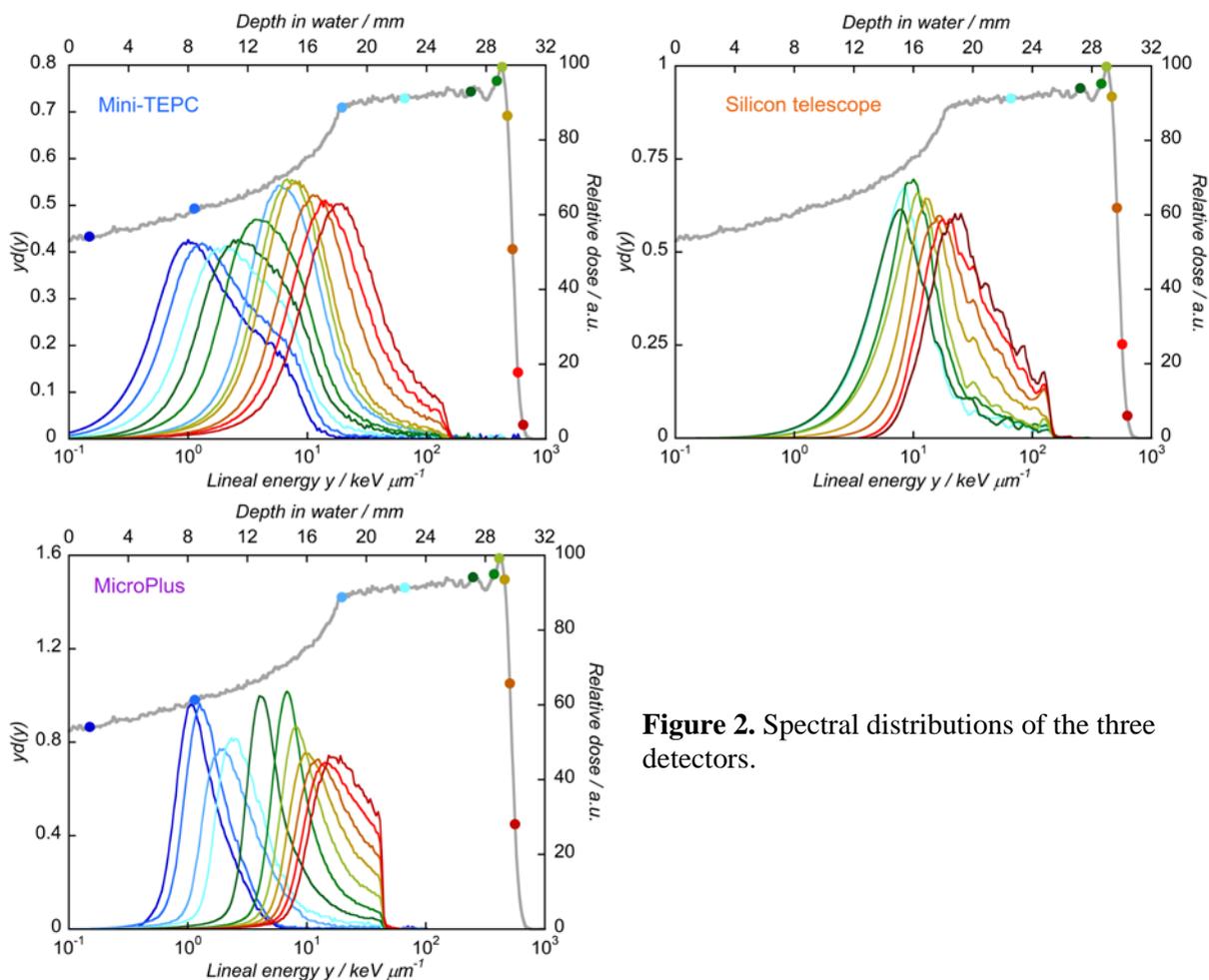
In this paper, 11 points measured with the mini-TEPC and the MicroPlus probe and 8 points of measurement for the silicon telescope are analysed and compared in shape. In figure 1 an overview of

measurement positions for the three detectors are marked with symbols along the dose profile measured with the Markus chamber and used as reference dosimetry.



**Figure 1.** Measurement positions of the three detectors.

In figure 2 the spectral distributions obtained from the measurements of the three detectors are also shown together with the dose profile.



**Figure 2.** Spectral distributions of the three detectors.

From the top-left panel of figure 2 it is possible to observe that the mini-TEPC has a larger spectral distribution that covers about 4 orders of magnitude. The microdosimetric characterization at  $1 \mu\text{m}$  shows the proton edge at  $160 \text{ keV}/\mu\text{m}$ , corresponding to the maximum stopping power of protons in

water. Moreover, pulses of high  $y$  values are also observed in the proximal region, likely due to fragments produced in nuclear reactions of fast protons with the target molecules.

The spectral distribution of the silicon telescope, top-right of figure 2, lacks of spectra in the entrance region because of the high threshold, this prevents from measuring in the proximal region of the SOBP where the imparted energy from fast proton is lower than the 8 keV/ $\mu\text{m}$  threshold. The spectra of the silicon telescope are similar to those of the mini-TEPC where the comparison is possible, with the proton-edge at about 160 keV/ $\mu\text{m}$ , also corresponding to the maximum stopping power of protons in water, thanks to the event-by-event correction.

Finally, from the plot on the bottom of figure 2 it is possible to observe that the MicroPlus probe can measure in the entrance part of the SOBP because of its larger thickness, 10  $\mu\text{m}$  in silicon, that results in a larger energy deposit by fast protons with range larger than 10  $\mu\text{m}$ . At the end of the SOBP protons of low energy, in particular those with maximum stopping power, stop inside the sensitive volume because they have range shorter than 10  $\mu\text{m}$  in silicon. The proton edge, in this case, is due to the exact stoppers, that means protons with a range exactly equal to the detector thickness. For 10  $\mu\text{m}$  of silicon these are protons at about 750 keV [13]. Taking into account that the water equivalent thickness is 17.24  $\mu\text{m}$ , the lineal energy at the proton edge results to be about 43 keV/ $\mu\text{m}$ . Rare contributions at larger  $y$  values are likely due to fragmentation of the target molecules.

#### 4. Conclusions

In conclusion, both the mini-TEPC and the MicroPlus probe can measure all along the SOBP and in the proximal edge while the silicon telescope measures only in the distal part of the SOBP and in the fall-off region. As far as the spectral distribution is concerned, the mini-TEPC shows a broad spectrum of  $y$  events, the size of which starts from 0.1 keV/ $\mu\text{m}$  and shows also events up to 500 keV/ $\mu\text{m}$  in the proximal edge.

The silicon telescope shows spectral distributions of similar shape, but has a large lineal energy threshold that prevents measurements in the proximal region. As a result of its larger thickness (10  $\mu\text{m}$  of silicon equivalent to 17.24  $\mu\text{m}$  of water), the MicroPlus can measure all across the SOBP, and the spectral distributions span on about 2 orders of magnitude.

#### 5. Acknowledgments

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