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Extended calibration range for prompt photon emission in ion beam irradiation

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ABSTRACT

Monitoring the dose delivered during proton and carbon ion therapy is still a matter of research. Among the possible solutions, several exploit the measurement of the single photon emission from nuclear decays induced by the irradiation. To fully characterize such emission the detectors need development, since the energy spectrum spans the range above the MeV that is not traditionally used in medical applications. On the other hand, a deeper understanding of the reactions involving gamma production is needed in order to improve the physic models of Monte Carlo codes, relevant for an accurate prediction of the prompt-gamma energy spectrum. This paper describes a calibration technique tailored for the range of energy of interest and reanalyzes the data of the interaction of a 80 MeV/u fully stripped carbon ion beam with a Poly-methyl methacrylate target. By adopting the FLUKA simulation with the appropriate calibration and resolution a significant improvement in the agreement between data and simulation is reported.

1. Introduction

In the last decade, the use of proton and carbon beams has become more and more widespread as an effective therapy for the treatment of solid cancer (hadrontherapy). Due to their very favorable profile of the released dose in tissue, the hadron beams can be very effective in destroying the tumor and sparing the adjacent healthy tissue in comparison to the standard X-ray based treatment [1]. On the other hand, the space selectivity of the hadrontherapy asks for a new approach to the delivered dose monitoring. Indeed, a precise monitoring of the dose is essential for a good quality control of the treatment. Furthermore, the dose monitoring would be particularly useful if provided during the treatment (in-beam monitoring) in order to provide a fast quality check of a treatment.

Several methods have been developed to determine the Bragg Peak position online by exploiting the secondary particle production induced by the hadron beam [2–9]. In this paper we concentrate on the "prompt-photon" method [10–13]: since the irradiation of tissues with hadron beams produces photons within fractions of nanoseconds (prompt photons) by nuclear disexcitations, their rate and production can be related to the released dose profile.

A key element in such studies is the measurement of the energy spectrum of the prompt photons. Ref. [13] presents such a measurement performed by irradiating a Poly-methyl methacrylate (PMMA) target with 80 MeV/u fully stripped carbon ions at the Laboratori Nazionali del Sud (LNS) of the Istituto Nazionale di Fisica Nucleare (INFN) in Catania [13]. For the prompt γs it uses a detector composed of four $1.5 \times 1.5 \times 12\,\mathrm{cm}^3$ crystals of

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cerium-doped lutetium-yttrium ortho-silicate (LYSO) coupled to an EMI 9814B PMT, read by a 12-bit QDC (CAEN 792N). Such detector was calibrated with the standard ^{22}Na and ^{60}Co sources, emitting 511 keV and 1.17 plus 1.33 MeV photons respectively.

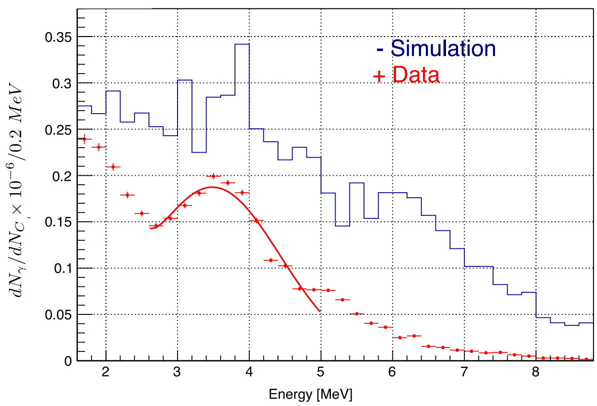

Fig. 1. Energy spectrum of the prompt photons produced by irradiating a PMMA target with 80 MeV/u fully stripped carbon ions as measured in Ref. [13]. The simulation was performed with the GEANT program [14]. The details of the detector response are in Ref. [13].

The measured energy spectrum, including the detector effects discussed in the following, shows that the photons of interest are in the 2–10 MeV range (Fig. 1), and that therefore the calibration was extrapolated to energies higher than those that the sources could provide. Non-linearities in the light yield or in the PMT or in the readout chain could therefore spoil the measurement.

Furthermore, Fig. 1 shows that the Monte Carlo (MC) program used (GEANT [14]) does not properly reproduce the main features of the data. Finally, the only visible structure around 4.4 MeV, due to disexcitation lines of ^{12}C*, ^{11}C*, and ^{11}B* and the corresponding escape lines, is offset in energy with respect to the expected position.

To address these issues left open by the original paper [13], this paper shows an alternative calibration method based on the detection of monochromatic photons of energies up to 9 MeV and the comparison between the measured spectra and rates with an alternative simulation based on the FLUKA program [15].

2. The extended-range calibration

In order to extend the calibration above 1 MeV an indirect production mechanism needs to be implemented since the isotopes

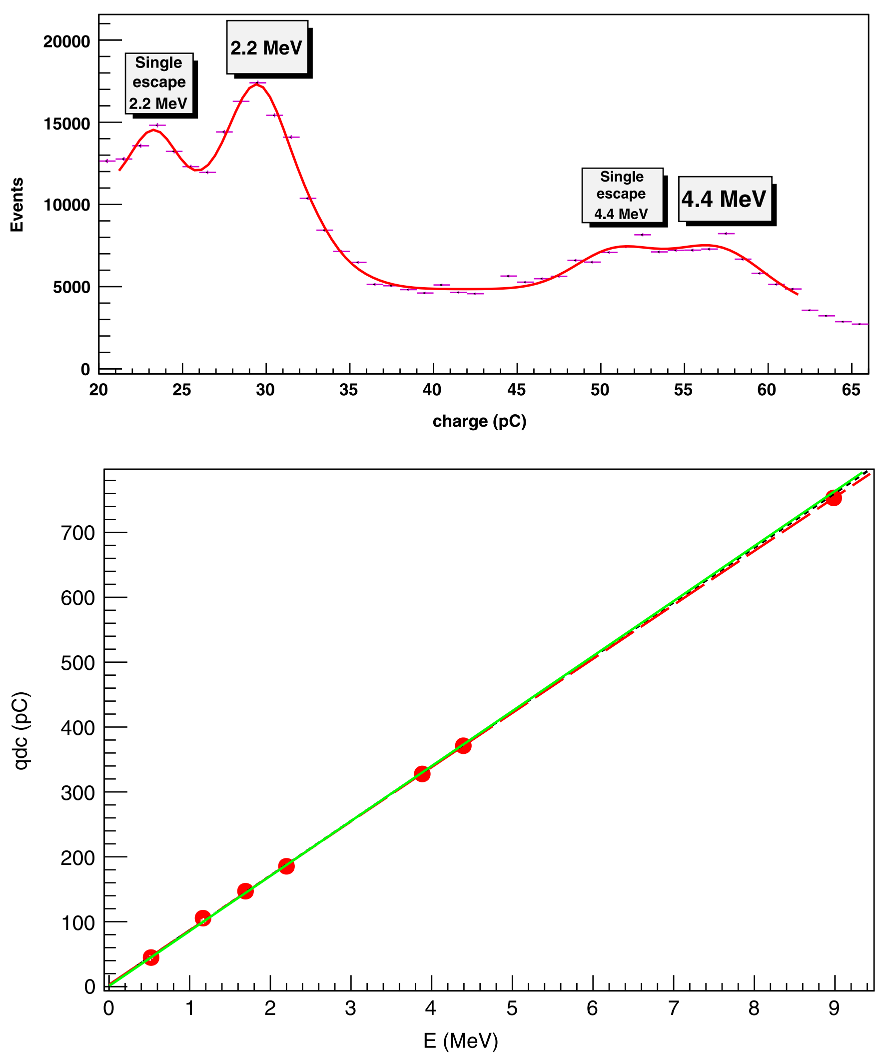

Fig. 2. Top: Example of energy spectrum as obtained with an AmBe source moderated with paraffin with the detector used in Ref. [13]. Bottom: The new calibration curve assuming a linear behavior (dashed red line) compared with the one published in Ref. [13] (full green line). (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this article.)