GAMMA EMISSION IN HADRON THERAPY — EXPERIMENTAL APPROACH*

A. Wrońska[a], P. Bednarczyk[b], D. Böckenhoff[c], A. Bubak[d]
S. Feyen[c], A. Konefał[d], K. Laihem[c], A. Magiera[a], A. Stahl[c]
M. Zięblński[b]

[a]Institute of Physics, Jagiellonian University, Kraków, Poland
[b]The H. Niewodniczański Institute of Nuclear Physics PAN, Kraków, Poland
[c]RWTH Aachen University, Aachen, Germany
[d]Department of Nuclear Physics and its Applications, Institute of Physics
University of Silesia, Katowice, Poland

(Received March 23, 2015)

Experiment Gamma-CCB at the Cyclotron Centre Bronowice focuses on investigation of gamma emission in experimental modelling of hadron therapy, searching for manifestation of the Bragg peak in gamma spectra. Experimental program comprises a series of measurements for different energies of the beam accelerated in the cyclotron Proteus C-235, as well as for several phantom materials. The paper reports on the results of the first measurements performed at 70 MeV proton beam energy and for two target materials: graphite and polymethyl methacrylate PMMA. Two different experimental techniques were tested, resulting in differential gamma spectra or spectra integrated over whole proton penetration path in a phantom. Strong correlation of the intensity of the carbon and oxygen excitation lines with the Bragg peak position has been observed in both types of measurements, confirming potential of the method in the future application in hadron therapy.

DOI:10.5506/APhysPolB.46.753
PACS numbers: 87.53.Xd

1. Introduction

Proton and carbon ion therapy has become a well recognised clinical technique for cancer treatment (for review, see [1–4]). Although well established in clinical practice, hadron therapy still needs detailed studies in some aspects. One of the urgent issues, indicated by the 2014 NuPECC report Nuclear Physics for Medicine [5], is a precise on-line determination of the

* Presented at the Zakopane Conference on Nuclear Physics "Extremes of the Nuclear Landscape", Zakopane, Poland, August 31–September 7, 2014.

ion range in the patient tissue. Currently reached uncertainty of that range reaches $4.6\% + 1.2$ mm [6], thus new tools for quality assurance are sought after. They would enable to fully benefit from the very well defined ion depth dose profile. Here, Ref. [5] lists prompt gamma (PG) imaging among most promising options.

Although commonly used simulation engines describe reasonably well the observed differential distributions of neutrons and charged particles, large discrepancies were found for the data for γ production in carbon-ion therapy [7]. This calls for an extension of the scarce experimental data base. The first experiments demonstrating the correlation between prompt γ intensity and the proton range in material were performed only recently [8, 9]. Those studies were extended to carbon ion therapy [10]. These results allow to expect that PG emission may be used for in-beam single photon emission tomography. The project, currently conducted at the Cyclotron Centre Bronowice, aims to measure with high precision the correlation between the depth of penetration of the beam in phantoms and the spectral and angular distribution of the emitted γ radiation. Such data will be of great importance for construction of a new type of a detection system for monitoring of the delivered dose distribution during radiotherapy.

2. Experimental setup

So far, the group performed two pilot measurements to investigate experimental conditions at the new Cyclotron Centre Bronowice, which is a part of IFJ PAN in Cracow [11]. The measurements were conducted using the 70 MeV proton beam delivered by the Proteus C-235 cyclotron. The Beam Current Monitor (BCM) in form of a pair of telescopes made of plastic scintillators was used. The telescopes, located about 3 m from the Ti exit window of the beam pipe registered protons scattered on that window, thus enabling relative beam intensity monitoring independently on the target thickness. The proton beam impinged onto one of the two phantoms (graphite or polymethyl methacrylate PMMA), simulating realistic conditions reached during patient treatment. The two materials were used for comparison, since also various human tissues differ significantly in their elemental composition. Two versions of target setup were tested, one of them enabling an integrated gamma emission study, the other a differential measurement (in Fig. 1 exploited simultaneously by the two detectors). The target thickness was modified remotely from the control room, which allowed to optimise the measurement time and ensured stability of experimental conditions over the whole measurement series (a measurement series means here a set of γ spectra collected for a chosen phantom material at one angle, with target thickness varying from well below to a few millimetres more than the expected proton range in the material). The γ rays were detected

using two detection modules, each consisting of a HPGe detector and an anti-Compton veto made of scintillators. The detectors were mounted on movable platforms, allowing measurements at different angles.

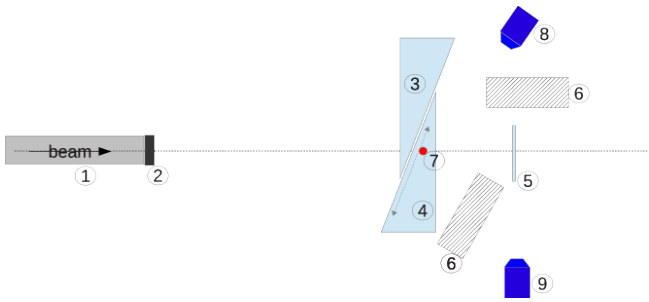

Fig. 1. Detection setup enabling simultaneous measurements of gamma spectra. 1 — beam pipe, 2 — Ti exit window, 3 and 4 — wedges forming the thick target setup, 5 — thin target, 6 — lead shielding, 7 — expected Bragg peak position, 8 and 9 — HPGe detectors. Detector 8 registers gamma spectrum integrated over the whole beam penetration path in the thick target, while detector 9 registers a differential spectrum.

3. Preliminary results

The very first analysis of the data collected so far focused on the signals of the transition in carbon $^{12}\mathrm{C}_{4.44\to\mathrm{g.s.}}$ and in oxygen $^{16}\mathrm{O}_{6.13\to\mathrm{g.s.}}$, as those elements are present in the human tissue. Examples of preliminary results obtained for $\theta_{\mathrm{LAB}} = 90°$ for the PMMA phantom are presented in Fig. 2.

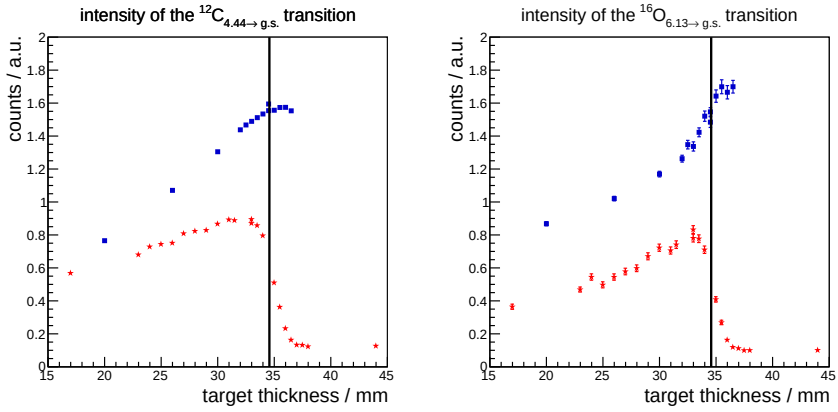

Fig. 2. Left: intensity of the $^{12}\mathrm{C}_{4.44\to\mathrm{g.s.}}$ *versus* phantom thickness. Two graphs represent two measurement series: with the thick target setup (squares/blue) and thin slice target setup (stars/red). Right: analogous data for the $^{16}\mathrm{O}_{6.13\to\mathrm{g.s.}}$ transition. (Preliminary results.)

In the left pad, intensity of the $^{12}C_{4.44\to g.s.}$ is presented as a function of target thickness. Squares (blue) represent the integrated measurement series, while stars (red) depict differential results obtained with the thin slice target setup. The spectra have been normalised using the BCM count. In the right pad, the same information is plotted for the $^{16}O_{6.13\to g.s.}$ transition. Error bars represent statistical uncertainties. Strong correlation with the Bragg peak position (depicted with the black line) is clearly visible as a build-up of a plateau in the thick target setup data or a steep fall-off for the differential data. Moreover, the feature is present for both investigated phantom materials. This correlation proves that the proposed method has large potential. In the further course of analysis, the continuum part of the gamma spectrum will be analysed and parametrised as well.

4. Outlook

It is planned to continue the experimental program with systematic measurements for different γ emission angles as well as other target materials (*e.g.* polyoxymethylene POM) and higher beam energies. This will allow to optimise working conditions for new single photon tomographs, which will be designed and built in the future.

The project *Investigation of gamma emission in experimental modelling of hadron therapy* is carried out within the POMOST programme of the Foundation for Polish Science, co-financed from the European Union under the European Regional Development Fund.

REFERENCES

[1] W.P. Levin *et al.*, *Br. J. Cancer* **93**, 849 (2005).
[2] G. Kraft, *Prog. Part. Nucl. Phys.* **45**, S473 (2000).
[3] T. Terasawa *et al.*, *Ann. Intern. Med.* **151**, 556 (2009).
[4] U. Amaldi, G. Kraft, *Rep. Prog. Phys.* **68**, 1861 (2005).
[5] `http://www.nupecc.org/pub/npmed2014.pdf`
[6] H. Paganetti, *Phys. Med. Biol.* **57**, R99 (2012).
[7] F. Le Foulher *et al.*, *IEEE Trans. Nucl. Sci.* **57**, 2768 (2010).
[8] C.H. Min *et al.*, *Appl. Phys. Lett.* **89**, 183517 (2006).
[9] J.C. Polf *et al.*, *Phys. Med. Biol.* **54**, N519 (2009).
[10] E. Testa *et al.*, *Appl. Phys. Lett.* **93**, 093506 (2008).
[11] `http://www.ifj.edu.pl/`; `http://www.ifj.edu.pl/ccb/`
[12] N. Kanematsu *et al.*, *Med. Phys.* **40**, 041724 (2013).