Proton beam range monitoring in proton radiotherapy with J-PET system

Wiktor Mryka[1,2], Paweł Moskal[1,2] and Ewa Stępień[1,2]
on behalf of the J-PET Collaboration

1. Faculty of Physics, Astronomy, and Applied Computer Science, Jagiellonian University, Łojasiewicza 11, 30-348 Kraków, Poland
2. Center for Theranostics, Jagiellonian University, Poland

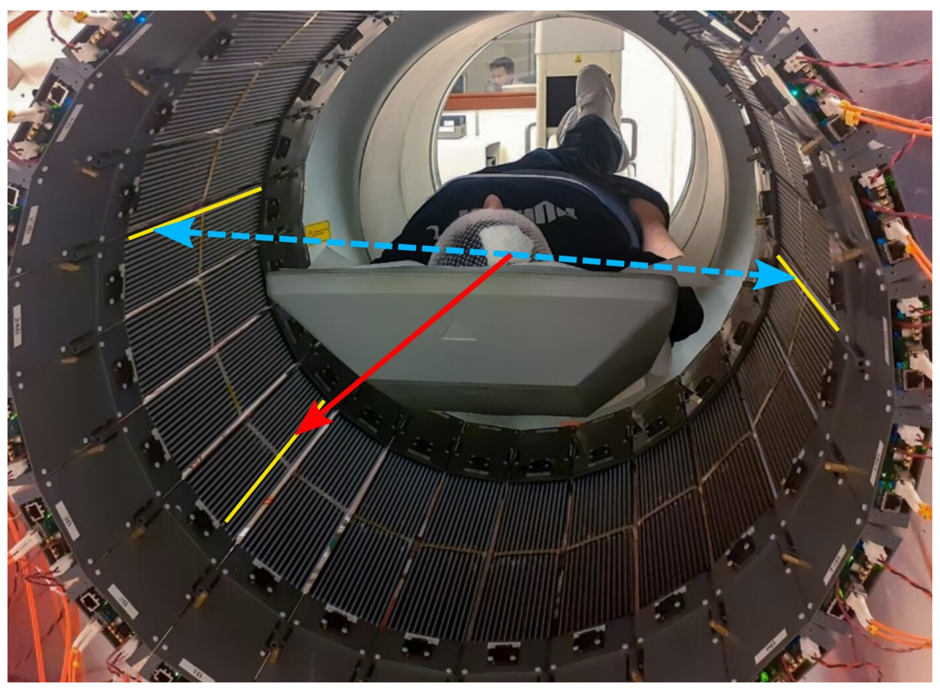
Abstract

J-PET is the PET system based on plastic scintillators. Here we demonstrate that J-PET may be used for proton range beam monitoring and present indications that it can be used for positronium imaging during proton therapy. Proton therapy is a quickly developing type of radiotherapy. Using its advantages - especially finite range of protons and maximum energy deposition at the end of the path (Bragg peak), one can obtain more uniform dose distribution and better coverage of a tumor volume than in popular radiotherapy techniques. To exploit those advantages, one needs to precisely know the position of a Bragg peak in the tissue. Thus, the beam monitoring system is needed. This role could be filled with PET scanner [1]. Additional advantage of this approach would be also enabling positronium lifetime measurements [2].

Experimental setup

Experiment took place in the Cyclotron Center Bronowice (CCB) in Kraków. During the experiment several PMMA and water phantoms were irradiated with proton beams – both therapeutic and pencil beam. In this study we focus on the irradiation of the cuboid PMMA phantom, of the dimensions 5x5x20 cm^3, with a proton pencil beam.

Modular J-PET:
- Modular design
- 24 modules
- 13 scintillator strips per module
- 4 SiPM per scintillator side
- 2 constant thresholds per SiPM
- 50 cm FOV
- Digital data at the module output
- 76.2 cm in diameter
- Light design – weight about 60 kg



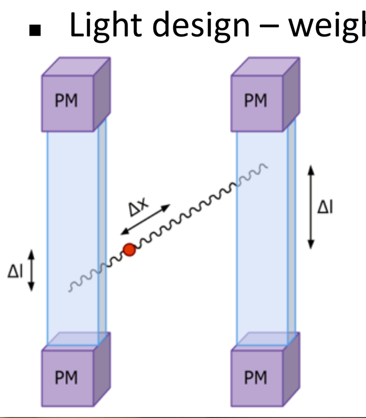


Fig. 1.: Schematic view of two plastic strips (right), PET measurement with a patient in the hospital using J-PET detector [2].

Detection system:
- Two-head system
- Each head consist of three layers of modules
- Each layer consist of four modules – 52 scintillator strips
- Heads placed 30 cm apart
- Each head is 39.6 cm high and 50 cm long (FOV)

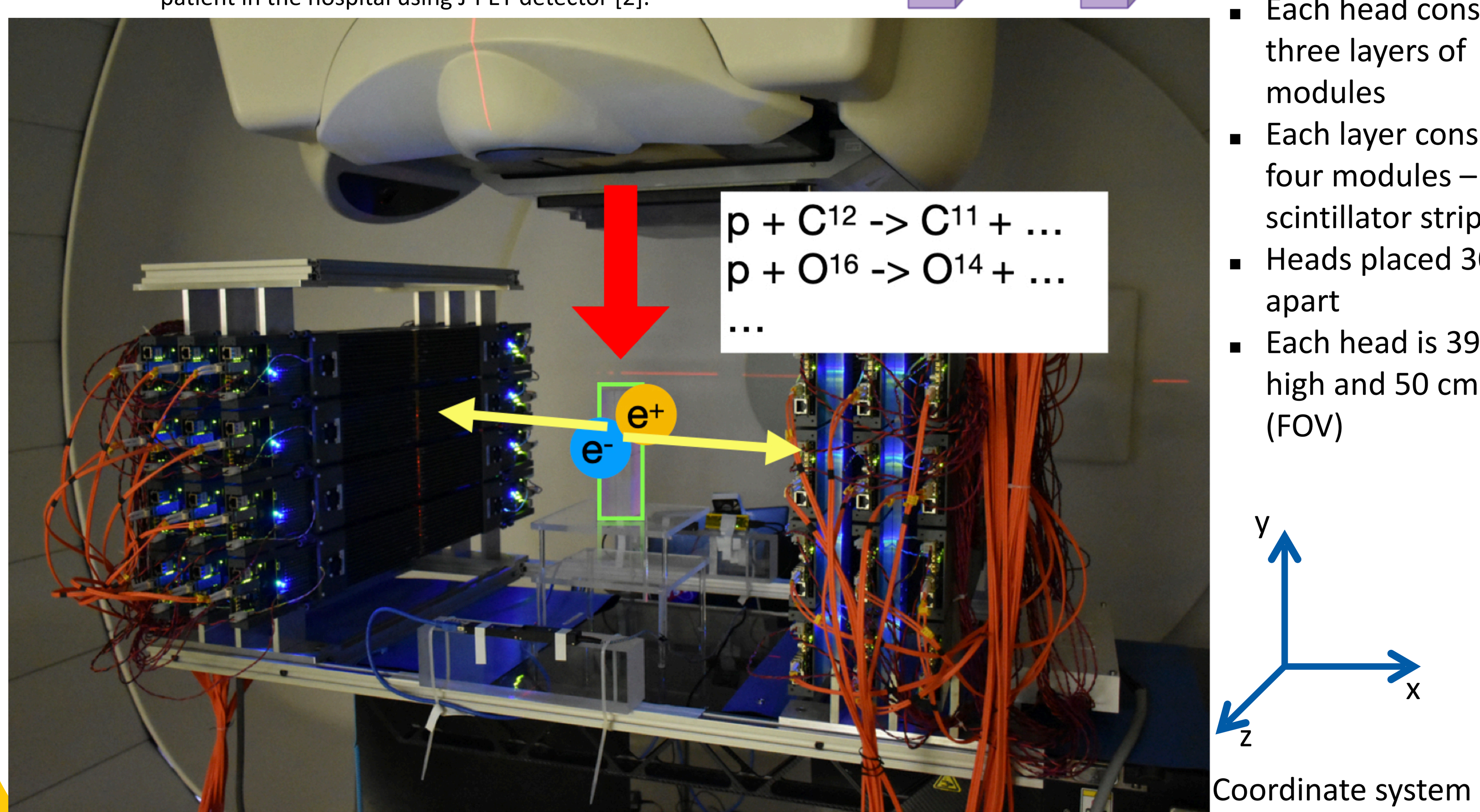


Fig. 2.: Experimental setup used during the experiment in CCB.

Beam profiles

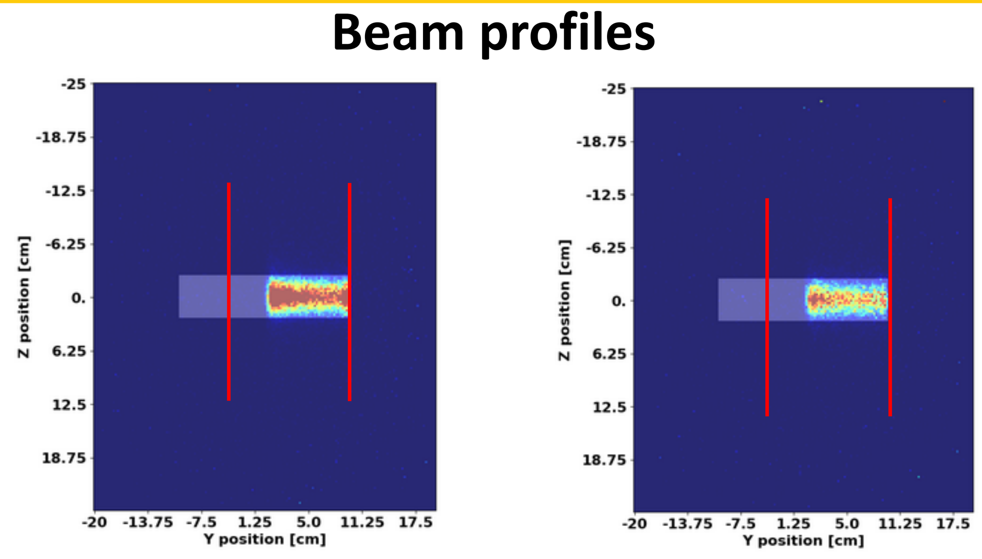


Fig. 3.: Figure showing the region of interest to obtain a beam profile. Off-beam image is on the left and In-beam image is on the right.

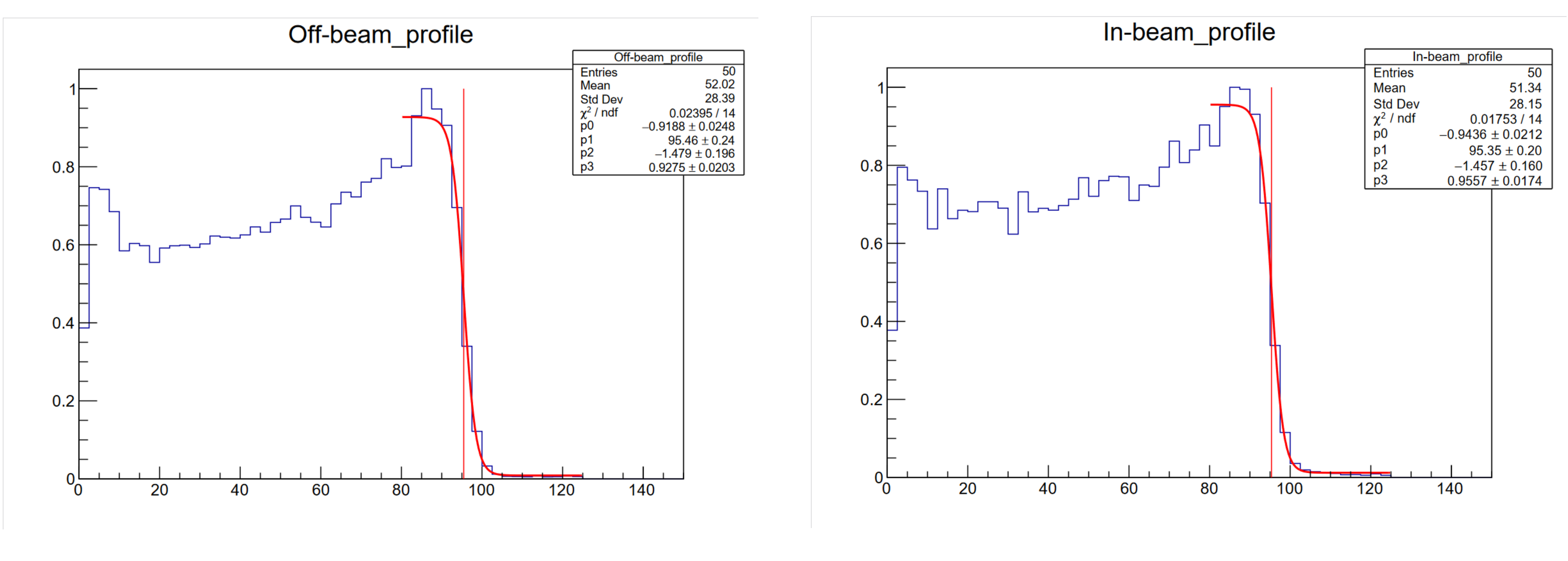


Fig. 4.: Beam profiles for off-beam image (left) and in-beam image (right). The red curve is a fitted sigmoid function to estimate the range of the beam. The vertical , red line marks the obtained range.

Acknowledgements

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Analysis

1 Data:

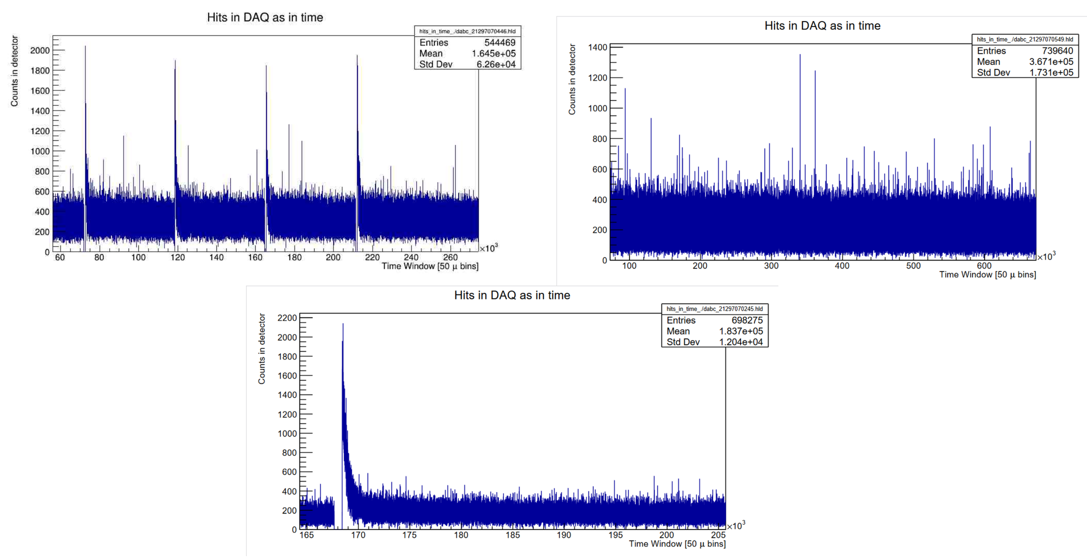

Fig. 5.: Figures show the counts in the detector as a function of time. The up-left figure shows the hits in DAQ system during the irradiation of the Phantom - the high peaks mark the injection of the pencil beam in the phantom, the up-right figure shows the hits in DAQ system after the irradiation – there are no high peaks. The bottom figure shows the close-up so we can see one injection of the pencil beam.

2 Selection criteria:

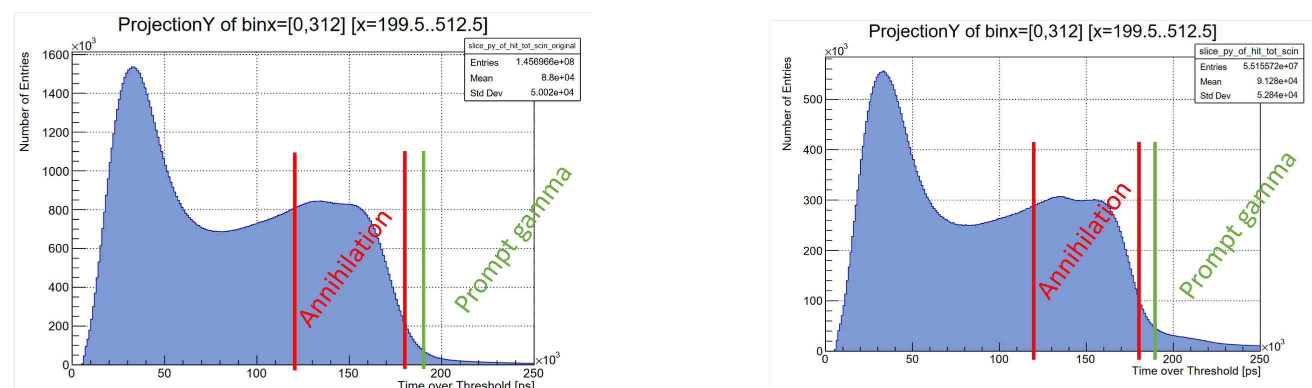

Fig. 6.: TOT – time over threshold - plots for off-beam (left) and in-beam (right) data sets. The region between red, vertical lines is the TOT we identify as a signal from annihilation gammas.

3 Off-beam proton beam 2 gamma image:

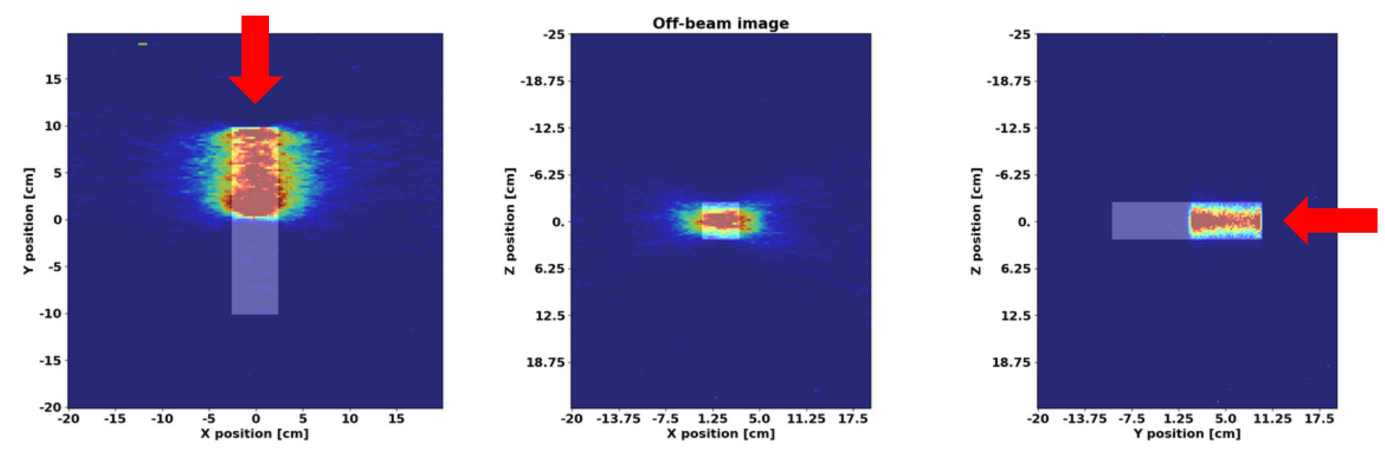

Fig. 7.: Results of the image reconstruction of the off-beam data, gathered by J-PET. The red arrows show the beam direction.

4 In-beam proton beam 2 gamma image:

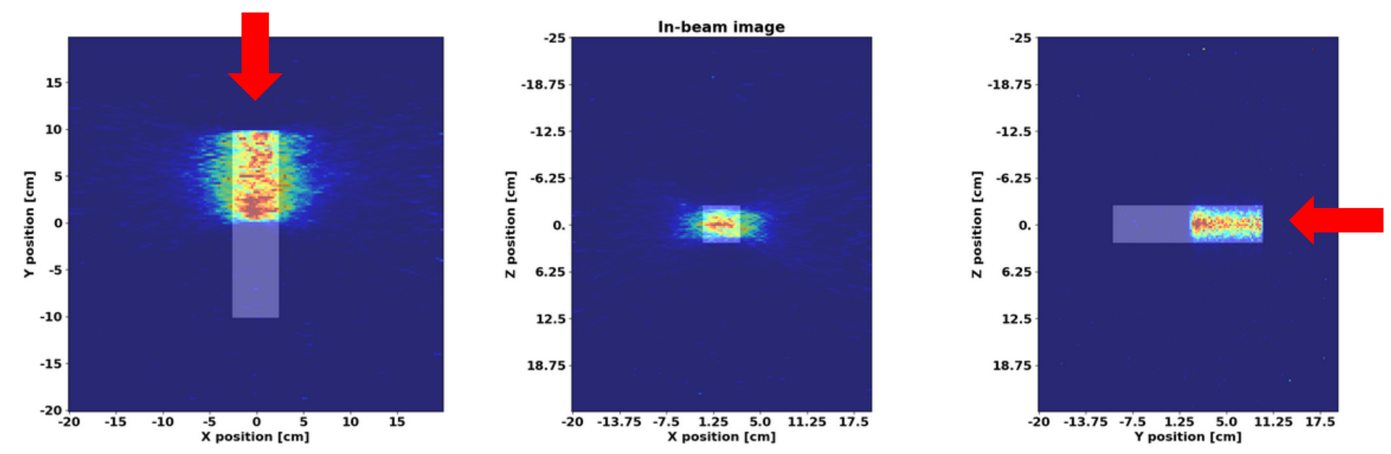

Fig. 8.: Results of the image reconstruction of the in-beam data, gathered by J-PET. The red arrows show the beam direction.

5 First indications – the search for positronium:

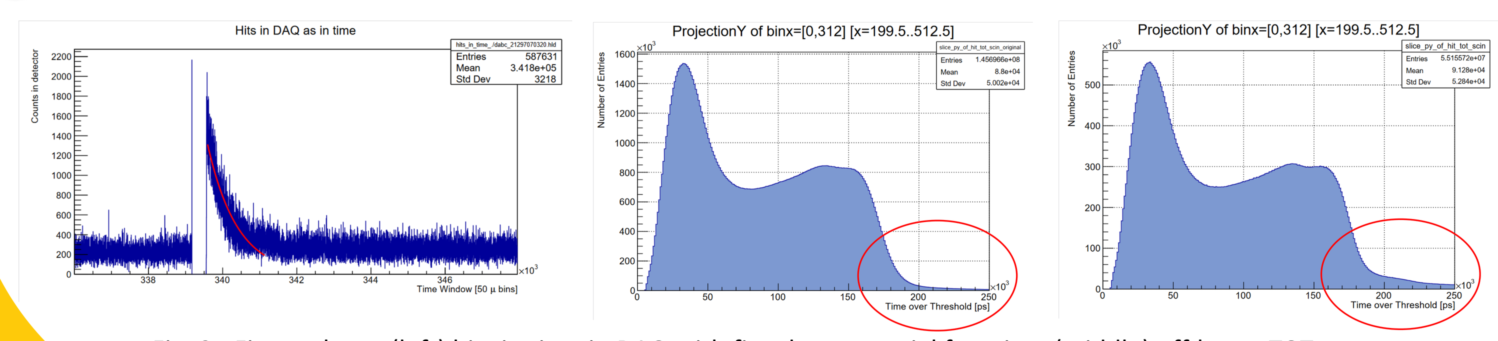

Fig. 9.: Figure shows (left) hits in time in DAQ with fitted exponential function, (middle) off-beam TOT spectrum, (right) in-beam TOT spectrum. TOT spectra show the region of interest were the prompt gammas should appear.

Summary

In this research we prove that the J-PET system is suitable for the proton beam range monitoring purposes. It useful in off-beam mode as well as in the in beam mode. This allows to monitor the proton beam during the irradiation and verify the range after the irradiation proces. Beam profiles show the same shape and the range obtained by fitting sigmoid function is in the agreement within the error: off-beam range = 95.46 ±0.24 mm and in-beam range = 95.35 ±0.20 mm.
However the range of the beam was set to be 100 mm, this means that there is a need to apply corrections. Proton, at the end of its path, does not have enough energy to induce nuclear reactions [2,3,4,5]. Fig. 9. shows the potential for positronium imaging. This is only first step of the long analysis, however it shows that it is a worthwhile work to be done. Positronium imaging could enable additional possibilities in proton beam therapy treatment [6,7].

References

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