# Towards the positronium studies in proton beam therapy with the J-PET system

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**on behalf of the J-PET Collaboration**

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## 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 in addition it can be used for positronium imaging during proton therapy. Proton therapy is a quickly developing type of radiotherapy. To exploit the advantages of using this type of therapy, one needs to precisely know the position of a Bragg peak in the tissue. The role of the monitoring modality could be taken over by the J-PET system [1]. Additional advantage of this approach would be also enabling positronium lifetime measurements. This detector is prepared to register signal in wide energy range – thus it is posible to detect prompt gammas emitted after the $\beta^+$ decay. Measurement of the time difference between prompt gamma emission and annihilation gammas emission could provide the inforamtion about positronium lifetime in the material.

## 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 terapeutic and pencil beam. In this study we focus on the irradiation of the cuboid PMMA phantom, of the dimensions 5x5x20 cm³, with a pencil beam.

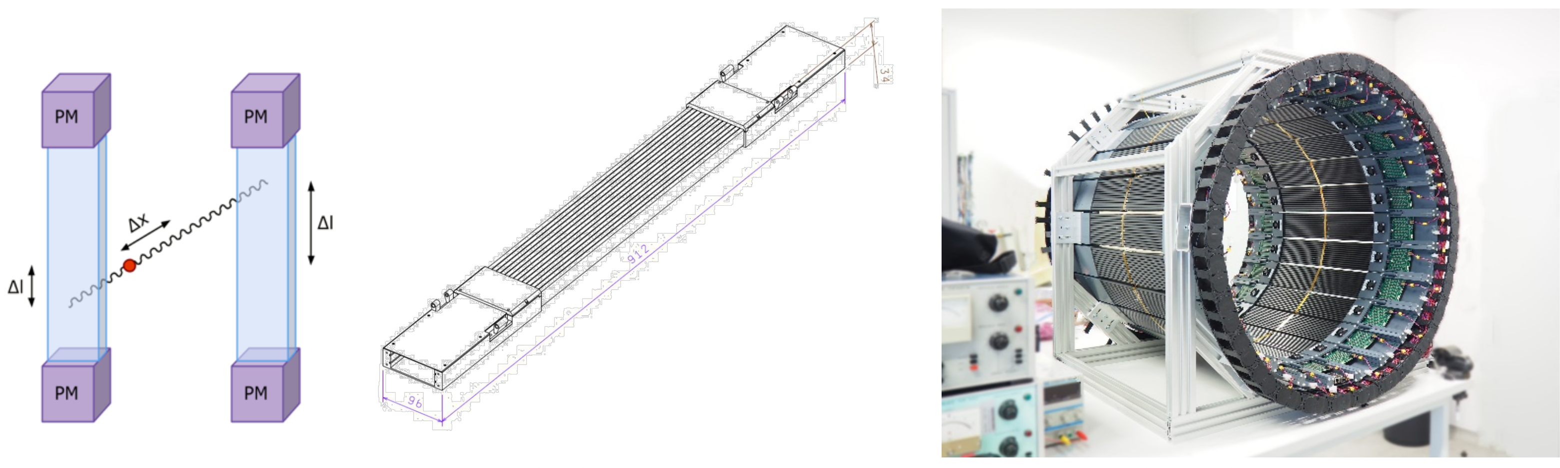
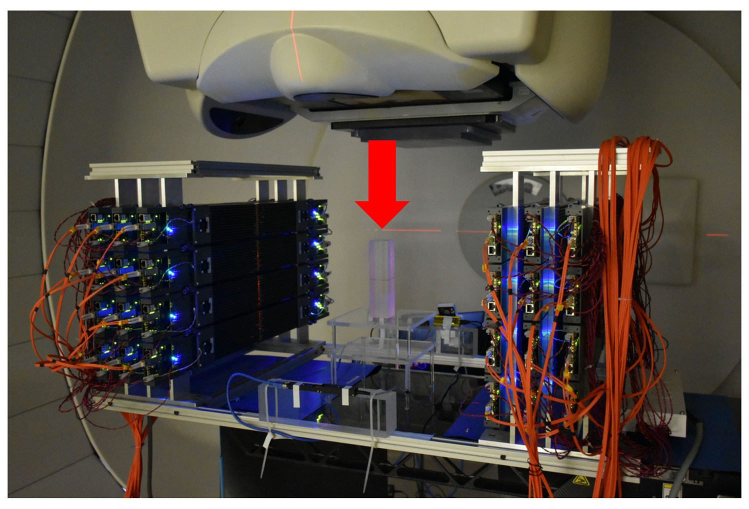
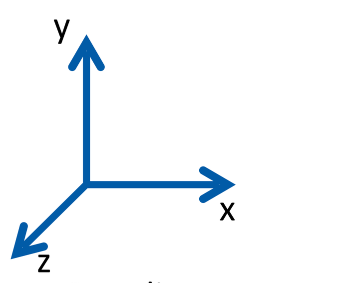



Fig. 1.: Schematic view of two plastic strips (left), schematic view of one module of the detector (middle) and modular J-PET system in its cylindrical form (right).

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

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






Coordinate system

Fig. 2.: Experimental setup used during the experiment in CCB. The red arrow marks the direction of the beam.

## Beam-range monitoring

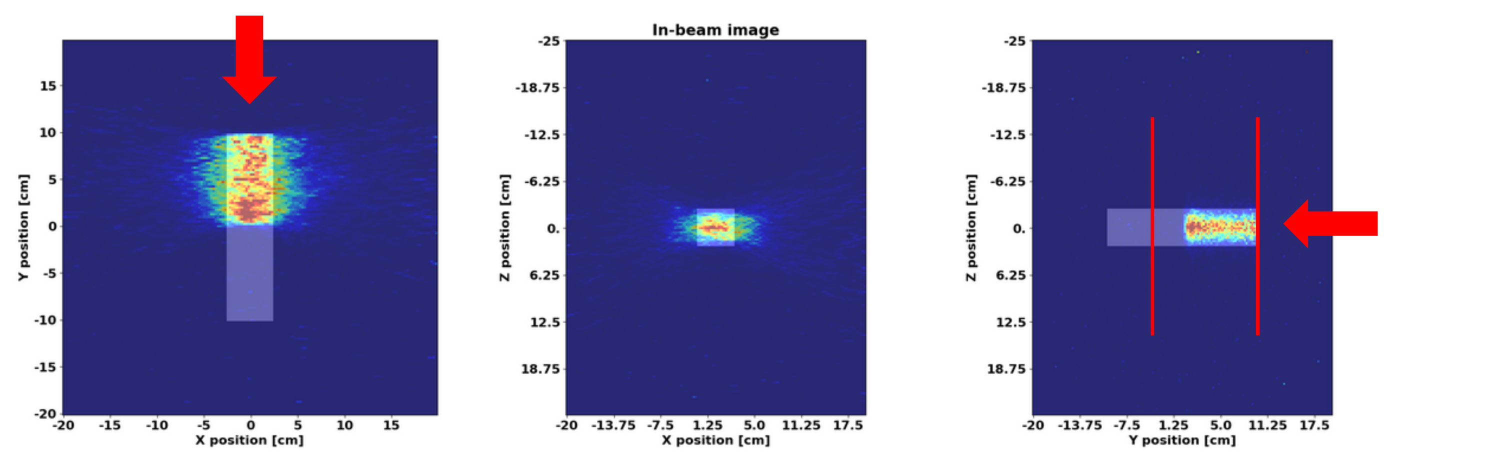



Fig. 3.: Results from CASToR software of the image reconstruction of the in-beam data, gathered by J-PET. The red arrows show the beam direction.

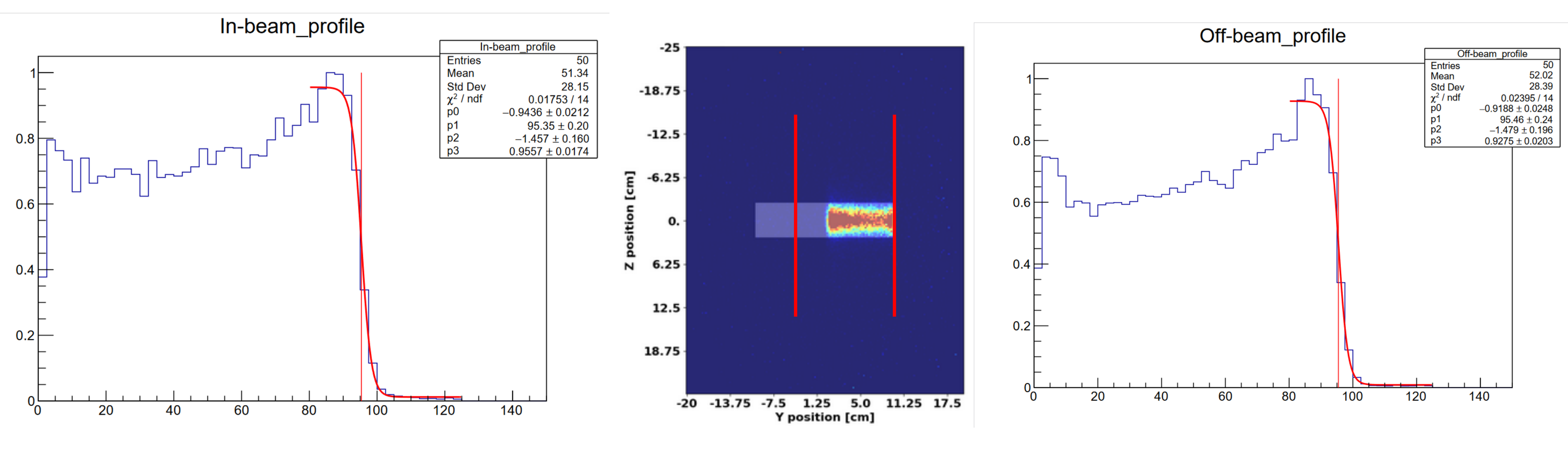



Fig. 4.: Beam profile for in-beam image (right). The red curve is a fitted sigmoid function to naively estimate the range of the beam. The vertical , red line marks the obtained range. In the middle we show the result for the off-beam monitoring and on the left we present the beam profile for off beam reconstruction.

## Acknowledgements

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## In search for positronium

**1** Data:

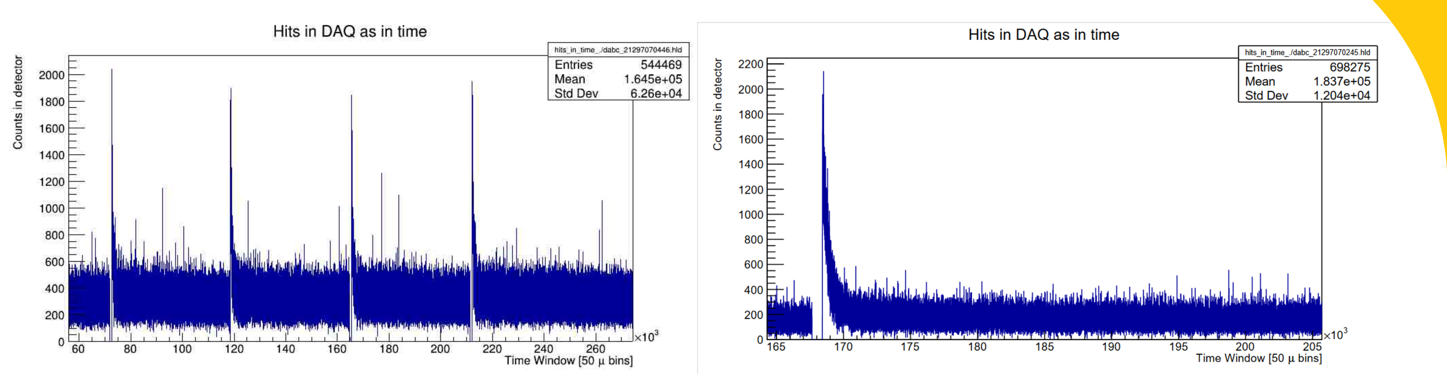


Fig. 5.: Figures show the counts in the detector in the function of time. The left figure shows the hits in DAQ system during the irradiation of the Phantom - the high peaks mark the injection of the pencil beam in the phantom. The right figure shows the close-up so we can see one injection of the pencil beam.

**2** Selection criteria:

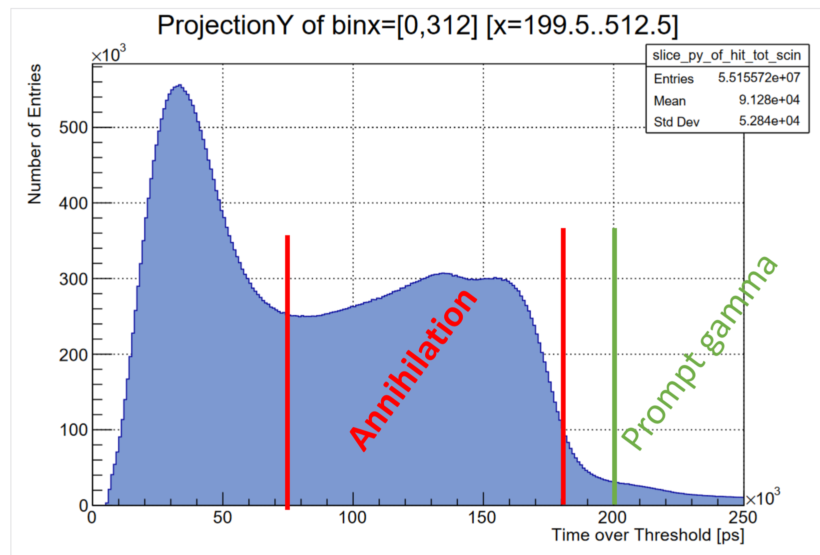


Fig. 6.: TOT – time over threshold - plots for in-beam data set. The region between red, vertical lines is the TOT we indentify as a signal from annihilation gammas. Green line marks the region that we consider to be signal from prompt gammas.

**3** Verification of 2 annihilation gamma identification:

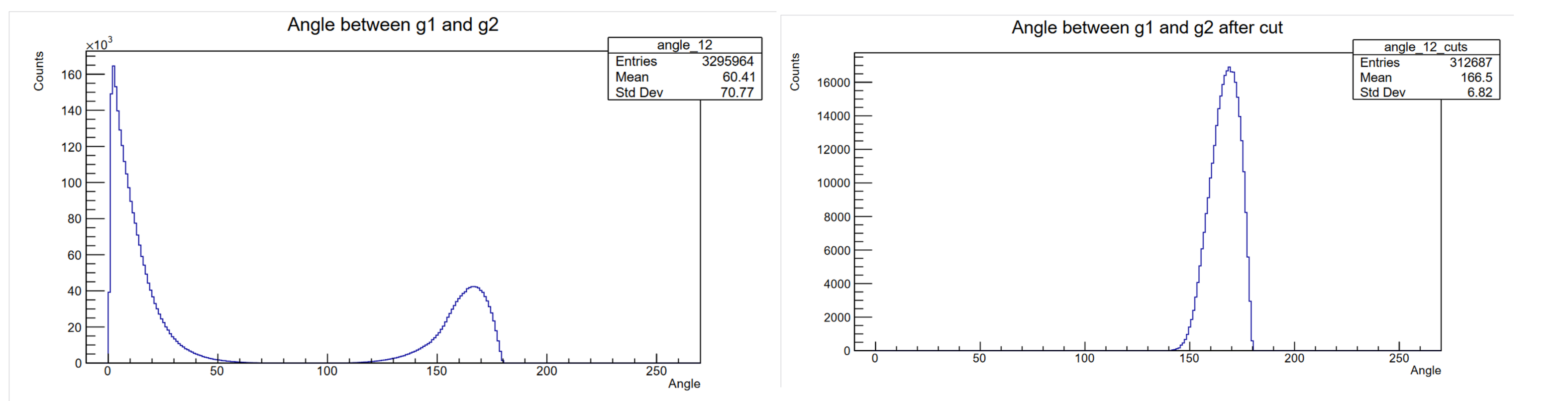


Fig. 7.: Figures show the measured angles between two suspected annihilation photons. Left one shows the raw analysis and the right shows the angle between annihilation gammas after the cuts.

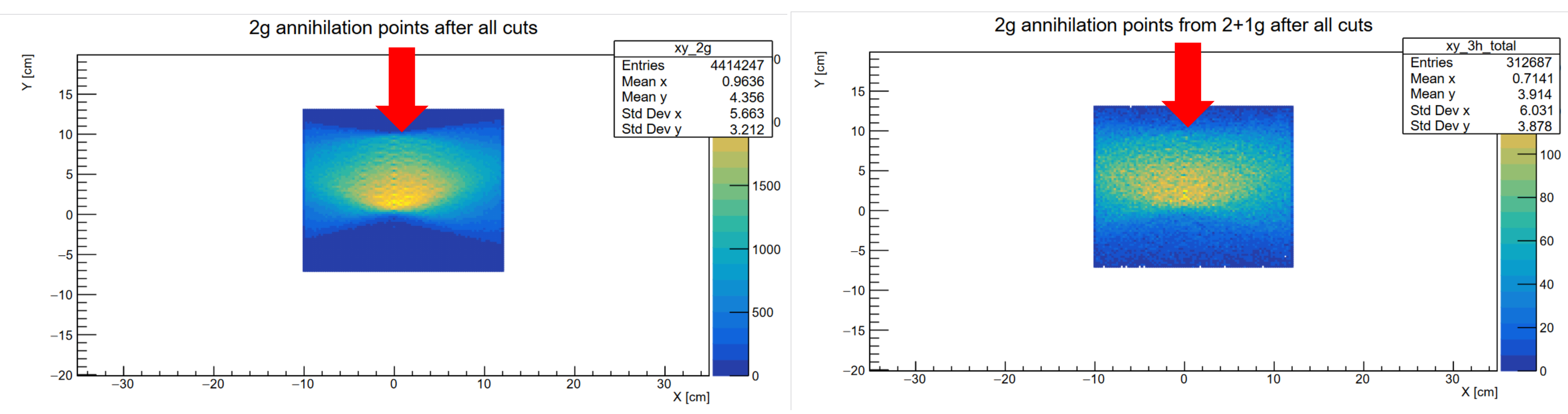


Fig. 8.: Figures show the reconstructed annihilation points from the 2 hit events (left) and the 3 hit (2+1 – annihilations and prompt) events (right).

**4** First suspected lifetime spectra for positronium lifetime measurements:

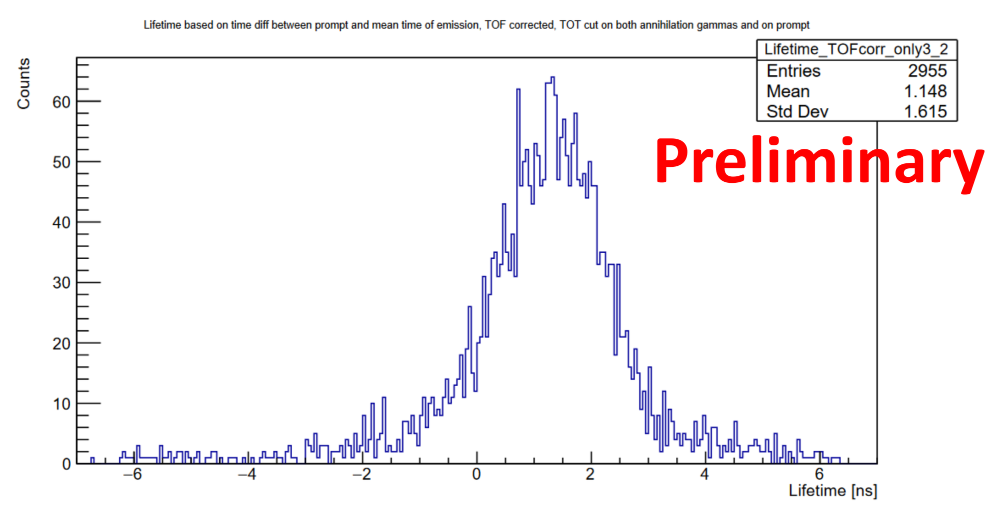


Fig. 9.: Figure shows a spectrum of time difference between prompt and annihilation gammas obtained for the PMMA phantom.

## Summary

In this reasearch we prove that the J-PET system is suitable for the proton beam range monitoring purposes. This allows to monitor the proton beam during the irradiation proces. Beam profile shows the range obtained by (naively) fitting sigmoid function is 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 – main one being positron range correction and then proton energy correction. Proton, at the end of its path, does not have enough energy to induce nuclear reactions [2,3,4,5].
Fig. 7. and 8. present the applied criteria to properly identify the annihilation gammas. In search of positronium the identification of hits is crutial to measure time differences correctly.
Fig. 9. shows the histogram conjectured to be the lifetime spectrum with the potential for positronium imaging. Positronium imaging could enable additional posibilities in proton beam therapy treatment. Crucially it could be helpful with determining hypoxia levels in the tissues and the tumors' malignancy levels [6,7]. That informations can provide better treatment planning.

## References

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