

Developing positron range correction for beam range monitoring with J-PET system in proton beam therapy

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Abstract

Proton beam therapy is a quickly emerging modality of radiation treatment. Its advantages over the conventional methods - finite range, maximal energy deposition at the end of the range and low energy deposition elsewhere - provide more conformal dose distribution over the tumor volume, save surrounding tissues and make the therapy more comfortable for the patient. However, to make an efficient use of those advantages one needs to develop a beam range monitoring system. One of the possible solutions is utilizing the PET system for monitoring purposes [1,2,3,4]. The J-PET system was already tested in the irradiation conditions in the proton therapy facility and proved to be able to conduct beam range monitoring during and after the irradiation. Although, the data gathered by a PET detector provide only information about annihilation points and can serve to reconstruct the activity image, the range of the proton beam and the activity range are correlated. In this work we present an estimation of positron range influence to the range read-out. It is one of the crucial factor that needs to be correctly applied in the process.

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 cm³, with a proton pencil beam.

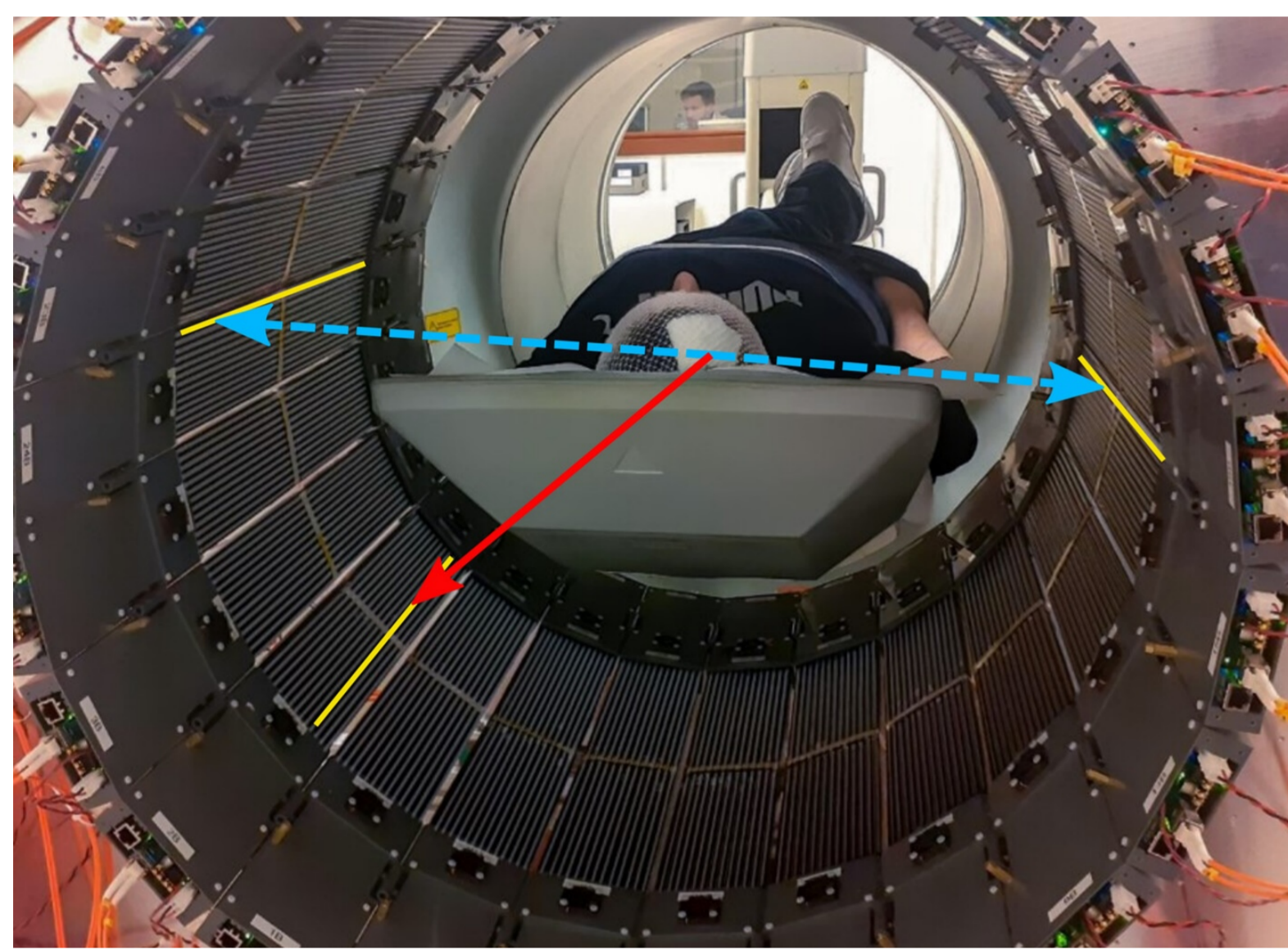
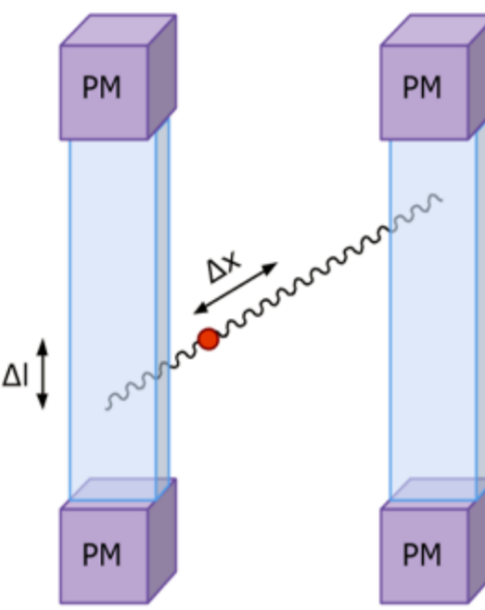


Fig. 1.: Schematic view of two plastic strips (right), PET measurement with a patient in the hospital using J-PET detector.

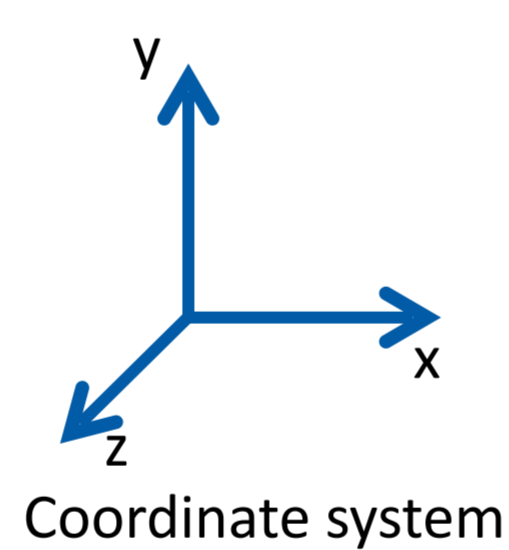
Modular J-PET:

- 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



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)



Coordinate system

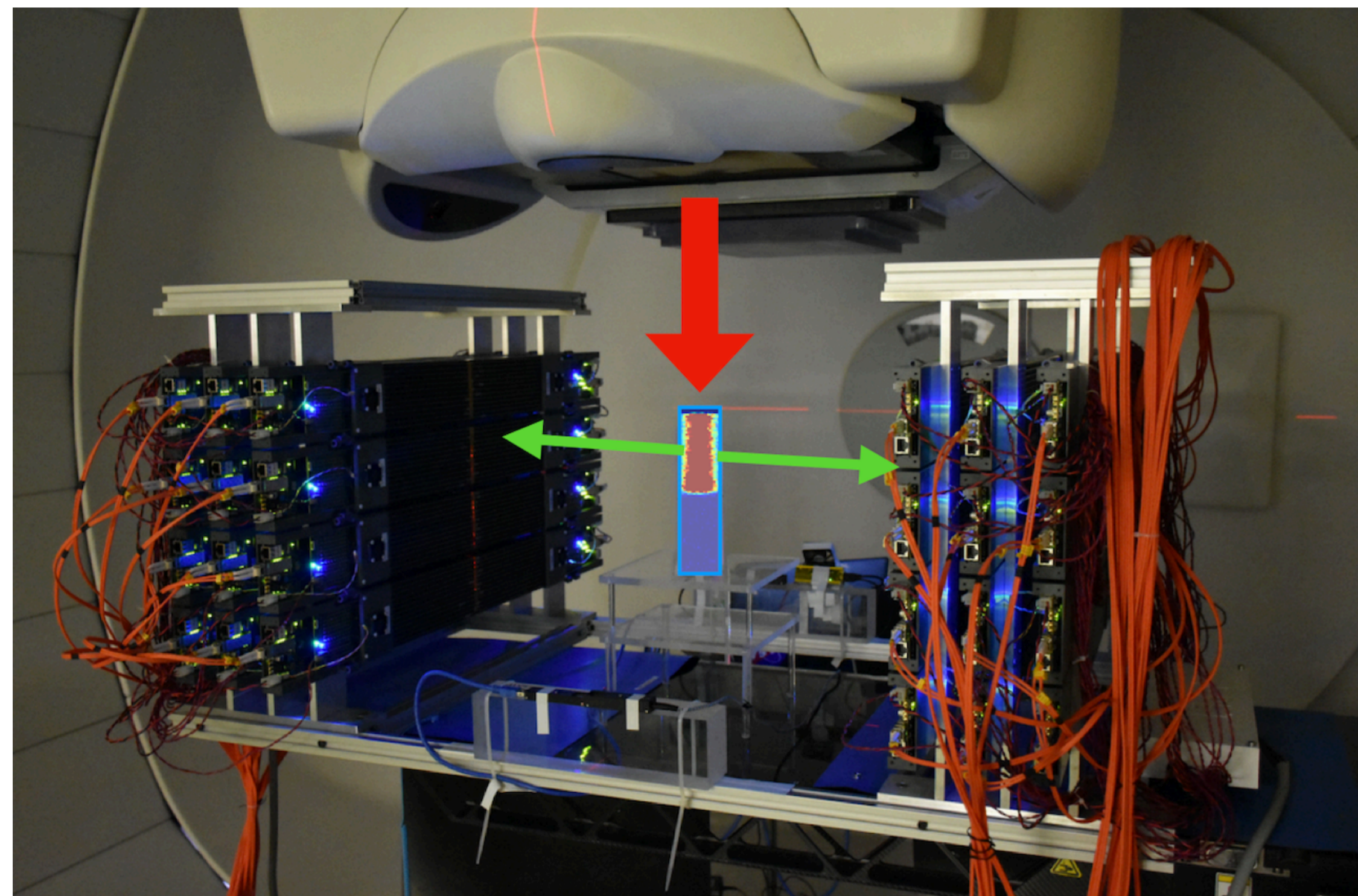


Fig.2.: Experimental setup with a 2D image reconstructed with CASToR software of the proton beam in the PMMA phantom.

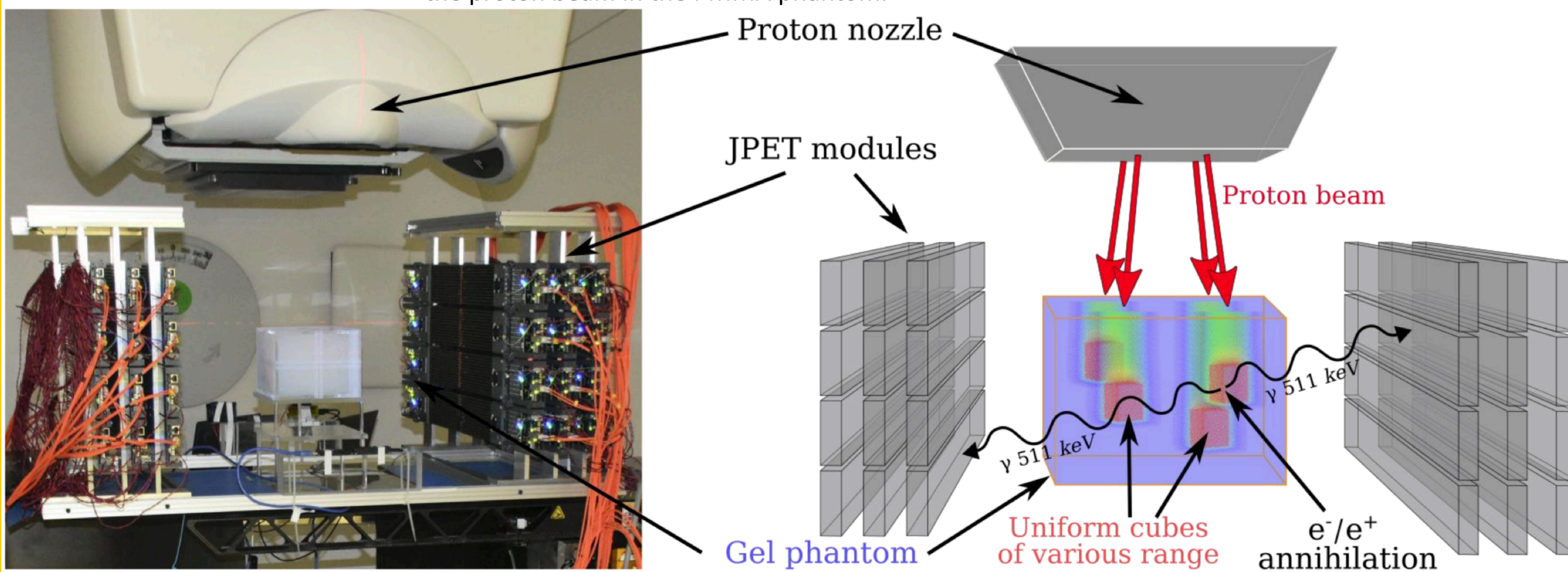


Fig.3.: Experimental setup for range measurements in water.

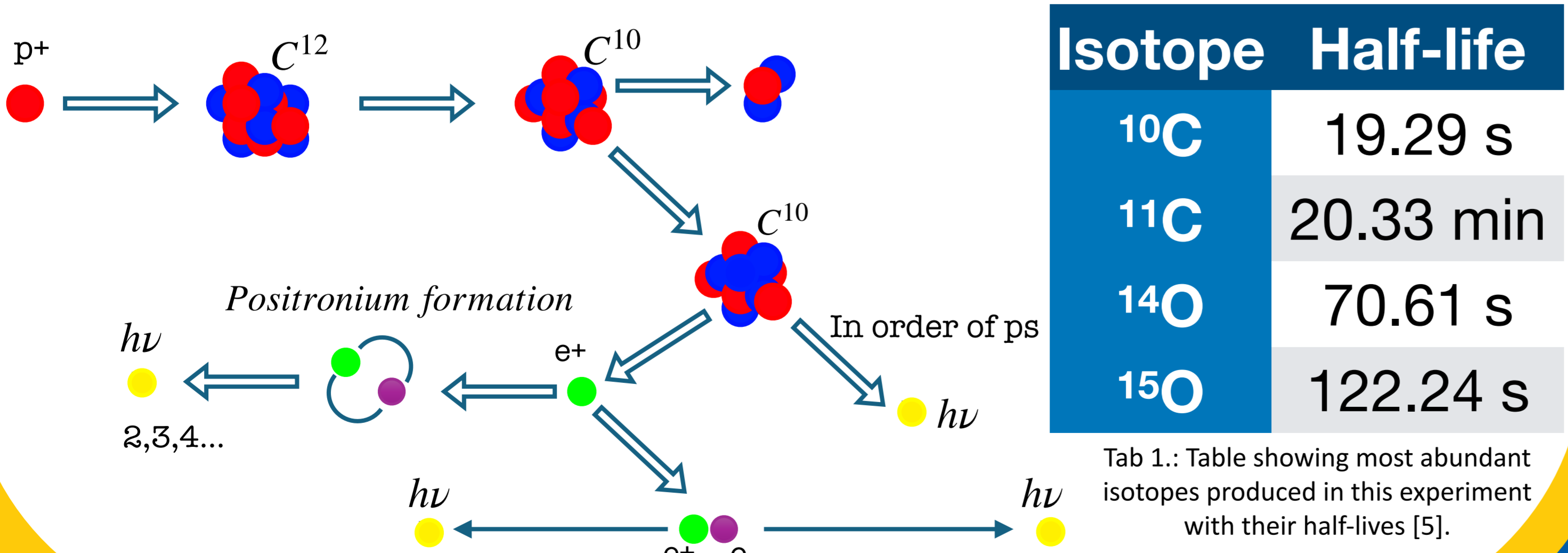


Fig.4.: Schematic view of the proton induced nuclear reaction and what follows.

Acknowledgements

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Beam-range monitoring with PMMA phantoms

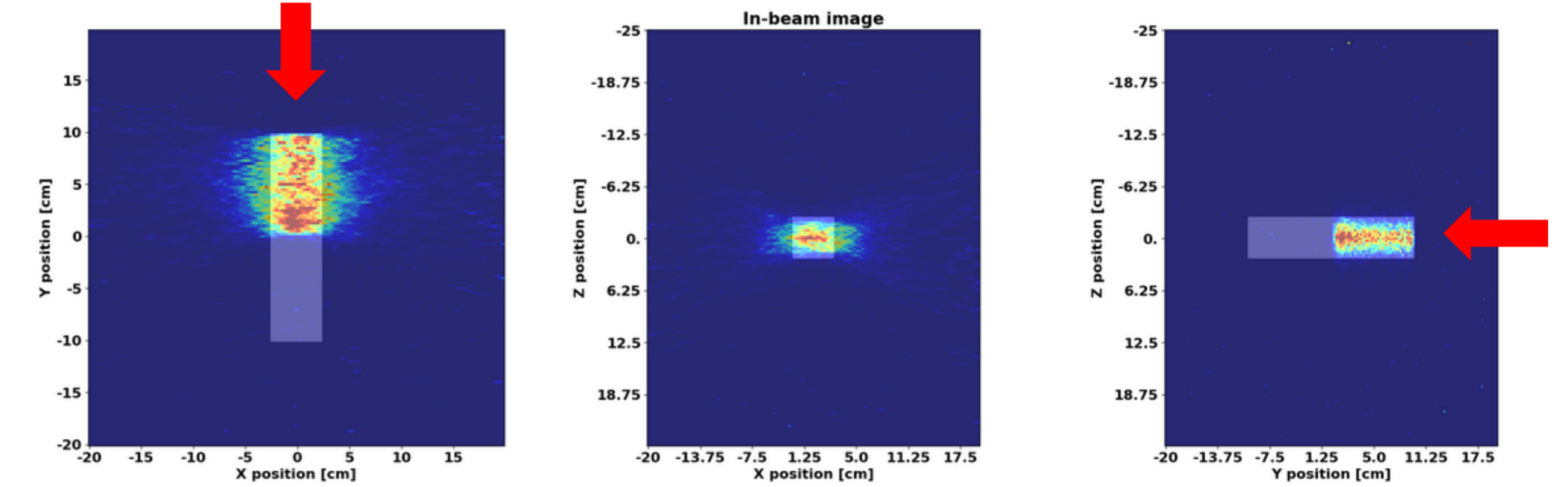


Fig. 5.: Results from CASTOR software of the image reconstruction of the in-beam data, gathered by J-PET. The red arrows show the beam direction.

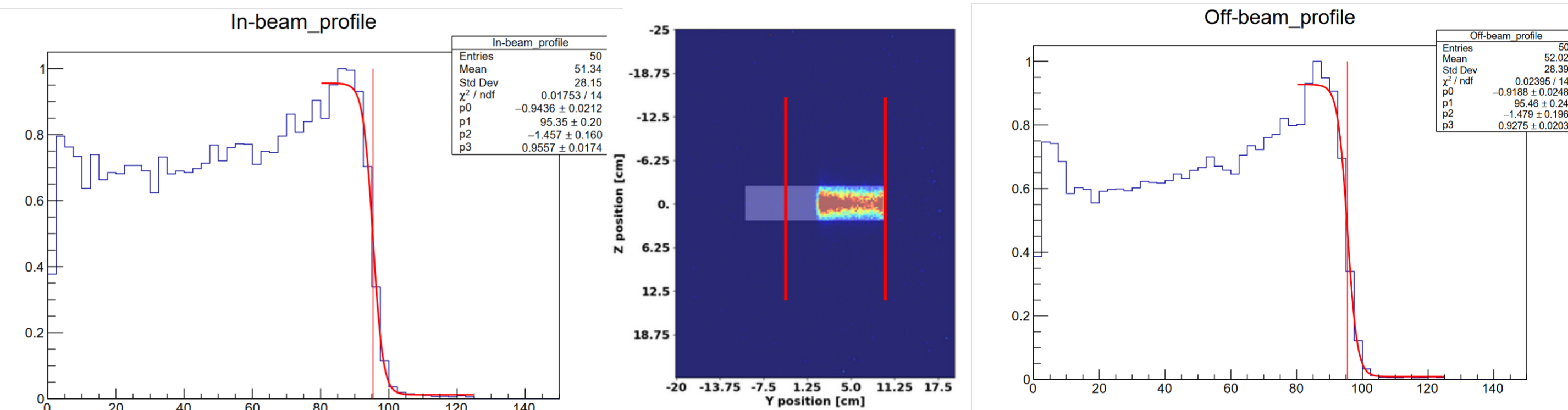


Fig. 6.: Beam profile for in-beam image (right). The red curve is a fitted sigmoid function to estimate the range of the beam. The vertical red line marks the obtained range. In the middle we show the result for the off-beam monitoring and on the left we present the beam profile for off beam reconstruction.

Results

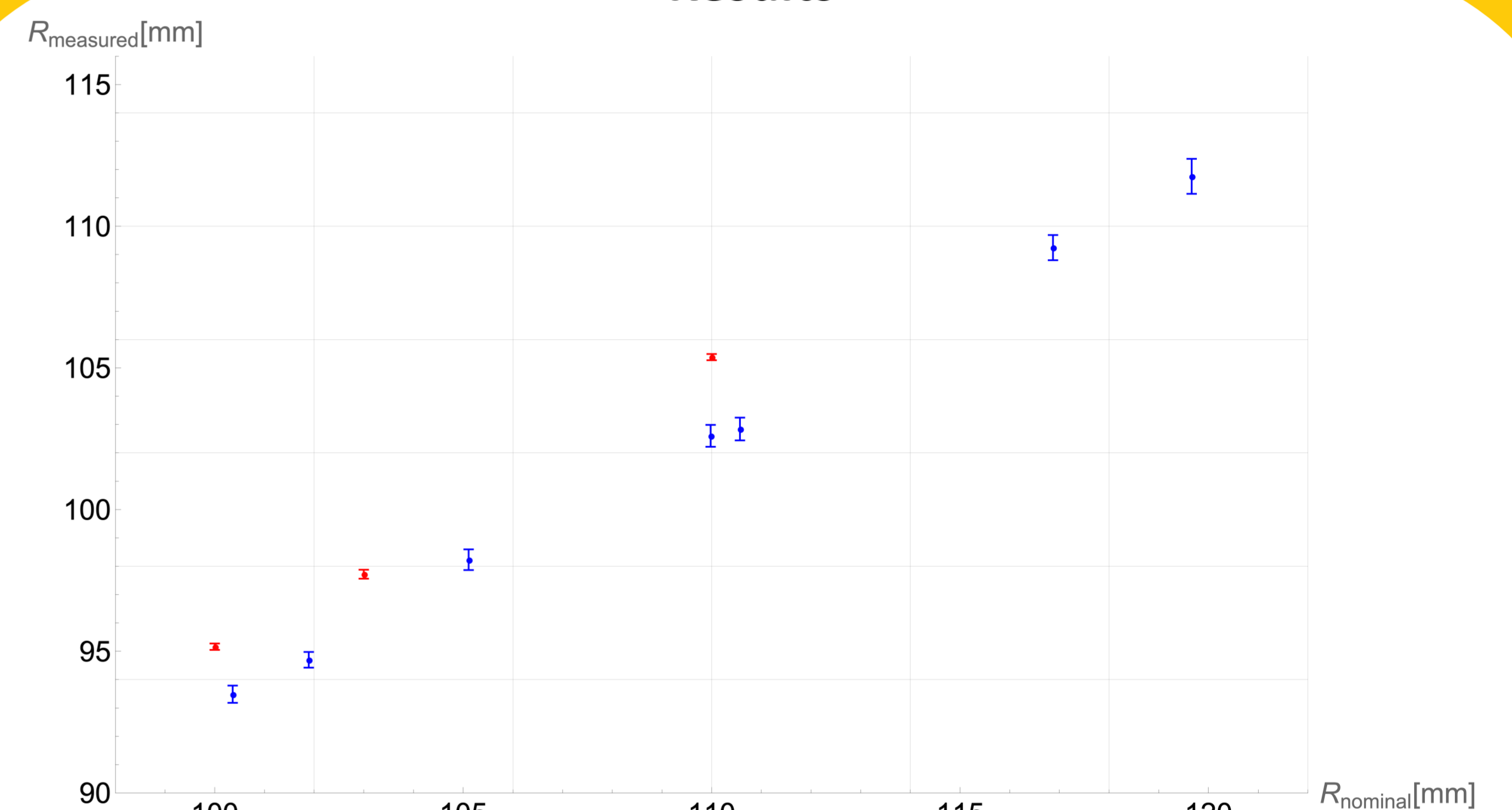
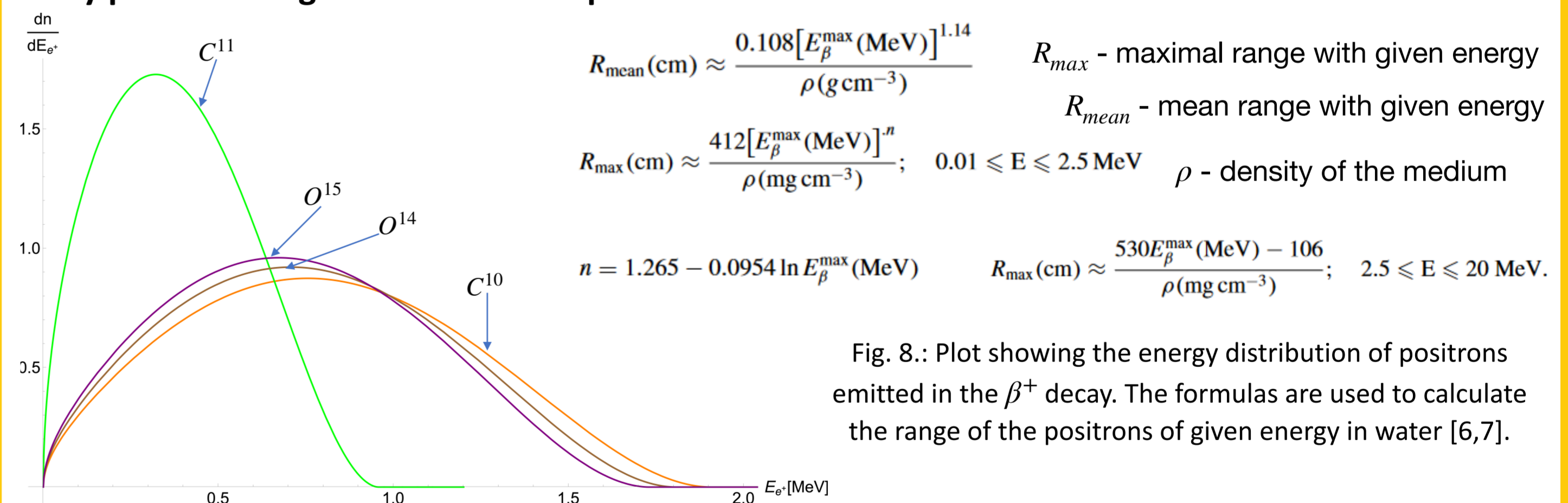


Fig. 7.: Plot presents the relation between the measured activity range ($R_{measured}$) and the nominal range obtained from the treatment planning system ($R_{nominal}$), red dots are results from measurements with PMMA phantom and blue - gel phantom.

Why positron range correction is required?



Isotope	E_{mean} [keV]	R_{mean} [mm]	R_{max} [mm]	E_{max} [keV]	R_{mean} [mm]	R_{max} [mm]
¹⁰ C	814	0.9	3.2	1908	2.3	9.0
¹¹ C	386	0.4	1.1	960	1.0	3.9
¹⁴ O	771	0.8	3.0	1808	2.1	8.5
¹⁵ O	735	0.8	2.8	1732	2.0	8.0

Tab.2.: Table presents the mean and maximal energy of positron emitted in the β^+ decay of the isotopes produced during irradiation. For those energies the table contains calculated mean and maximal range of the positrons.

Summary

In this work we attempt to experimentally verify the possibility of beam range monitoring in the proton beam therapy using J-PET detector. J-PET system proves to be a useful solution in beam monitoring process. However, we are able to measure only the activity range that has to be translated into actual beam range. We found that there is a correlation between measured range and beam range calculated by treatment planning system. One of the crucial factor in the calculation of proton beam range seems to be positron range. Positrons can travel even few millimeters in water, giving the substantial input into the activity distribution image.

References

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