The Henryk Niewodniczański
Institute of Nuclear Physics
Polish Academy of Sciences

Intra-treatment PET imaging in Proton Therapy with the J-PET System: System Overview and First Experimental Results

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M. Pawlik-Niedźwiecka[1,2], Sz. Pawlik-Niedźwiecki[2], P. Moskal[2]

On behalf of the J-PET collaboration

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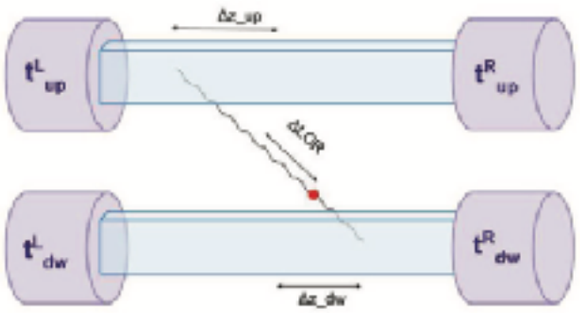
The National Centre for Research and Development
LIDER
European Funds Smart Growth
Republic of Poland
FNP Foundation for Polish Science
European Union
European Regional Development Fund

Jagiellonian-PET (J-PET)

Cost effective method for the Total-body PET

Principle



CRT = 0.266 ns.

$$t_{hit}=(t^L+t^R)/2$$
$$\Delta LOR=(t_{hit}^{up}-t_{hit}^{dw})c/2$$

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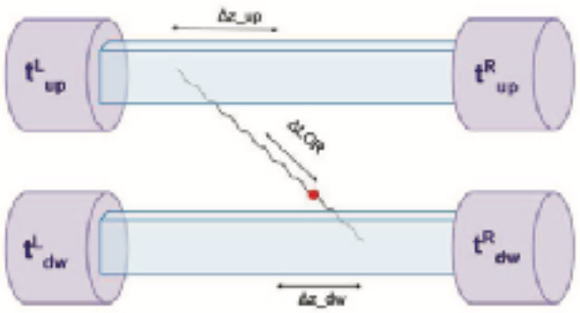

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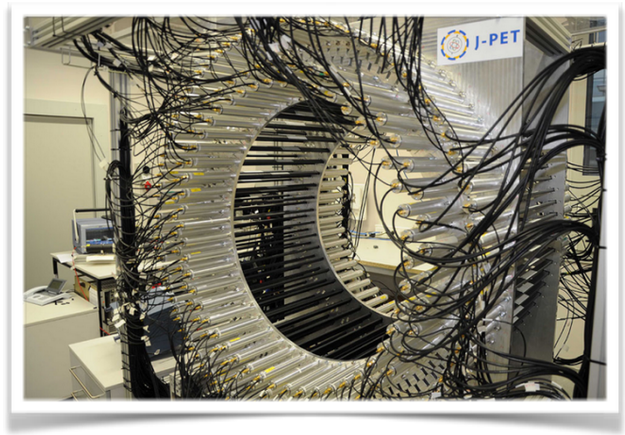

- Three cylindrical layers of EJ-230 plastic scintillator strips (7×19×500mm3)
- Vacuum tube photomultipliers

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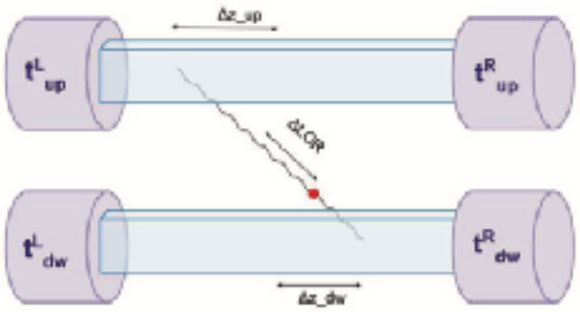

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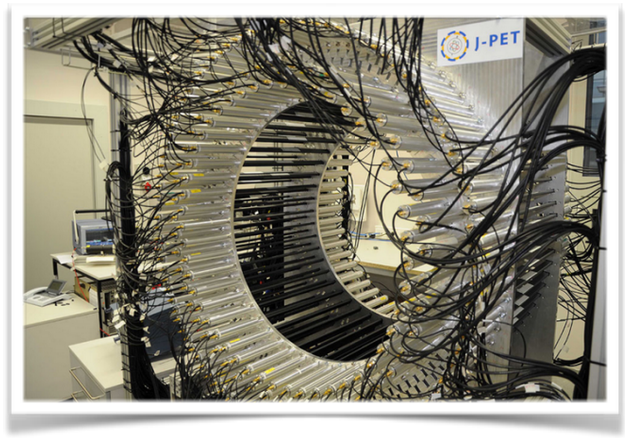

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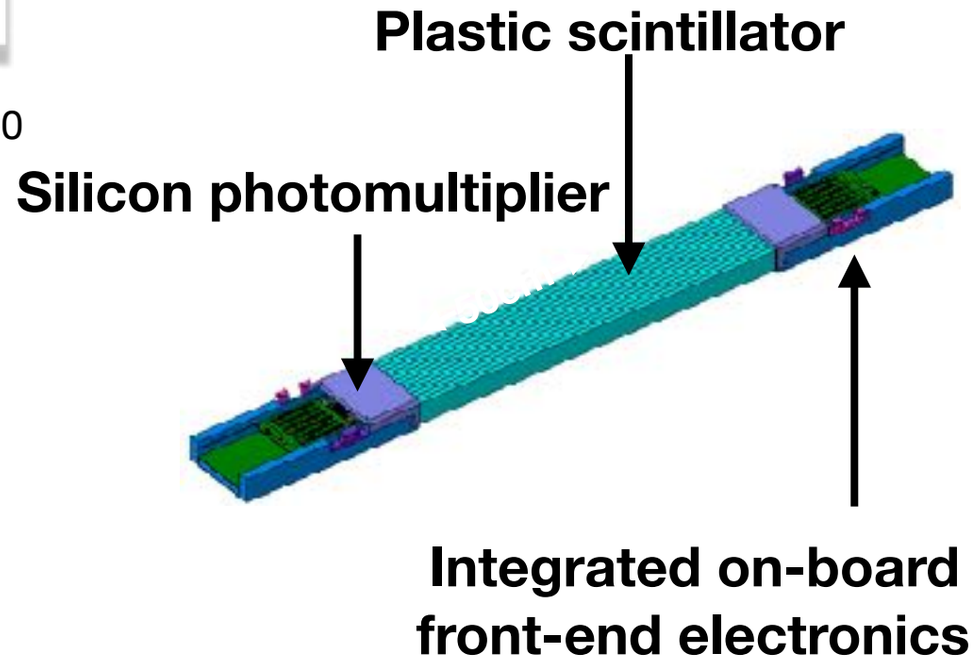
Modular Prototype

light weight, portable, reconfigurable



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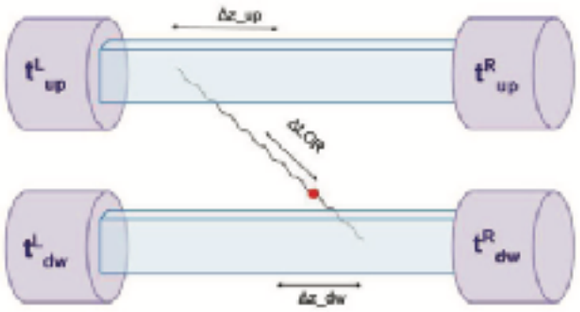

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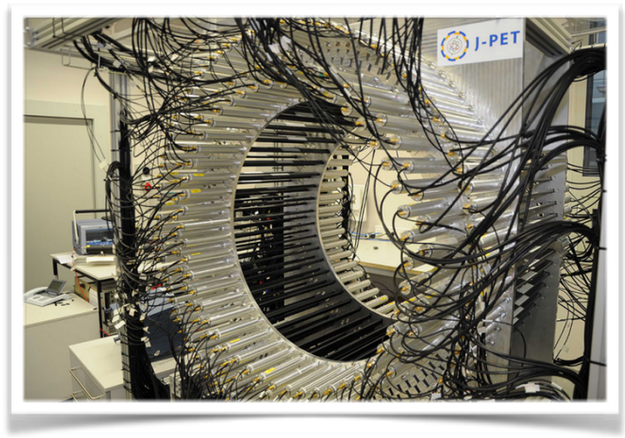

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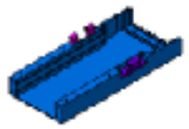

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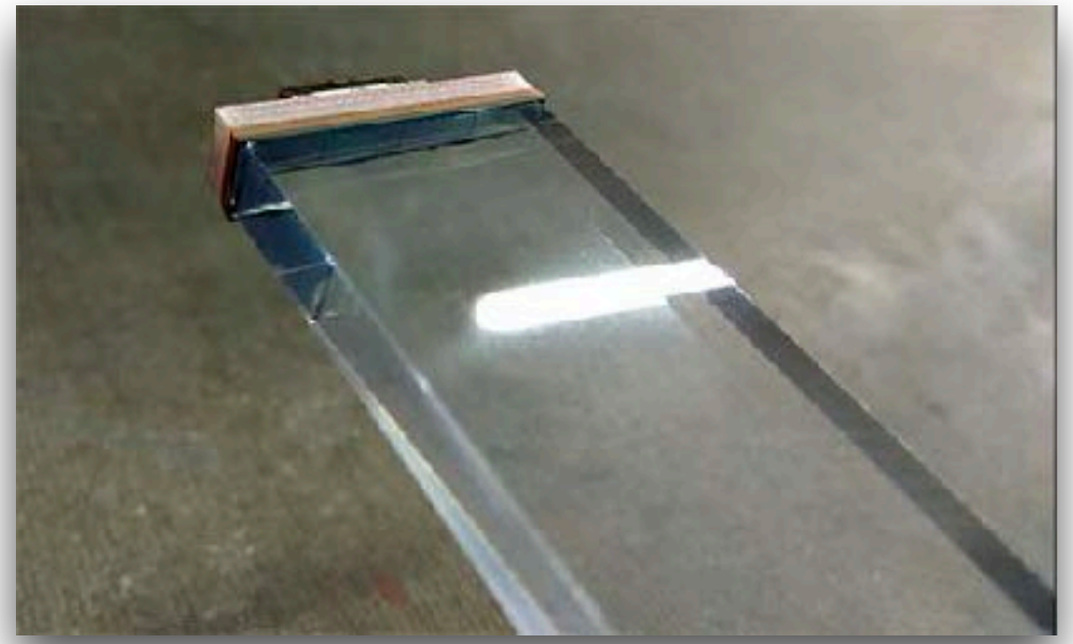

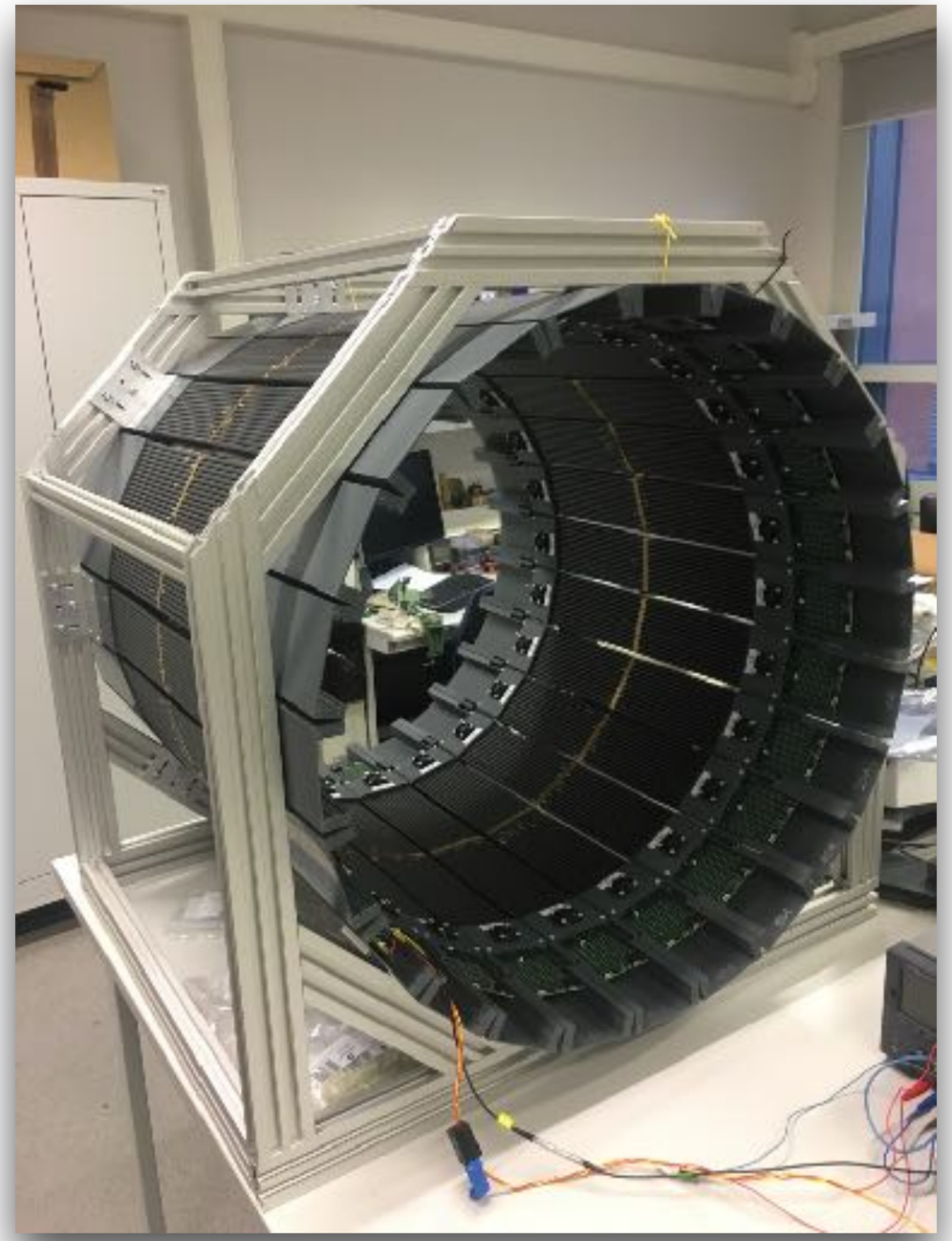

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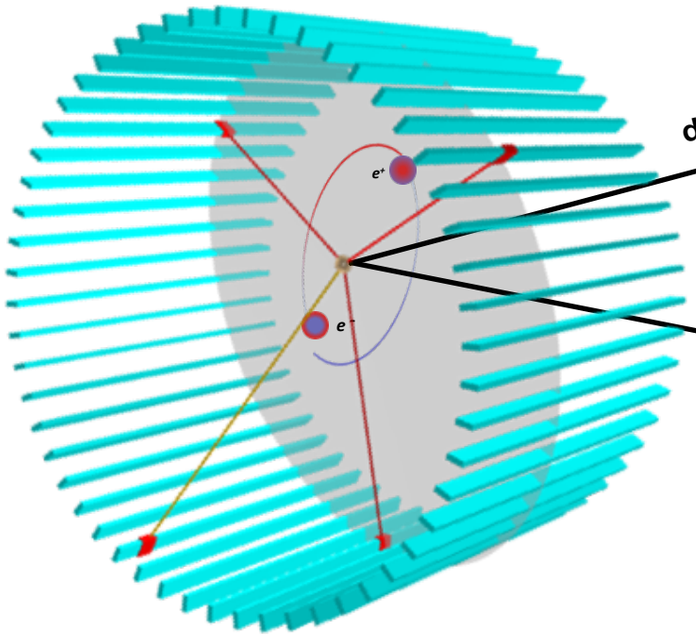
Research with J-PET

Positronium imaging:

In PET, in 30-40% cases e+e- annihilations proceed via production of positronium atom

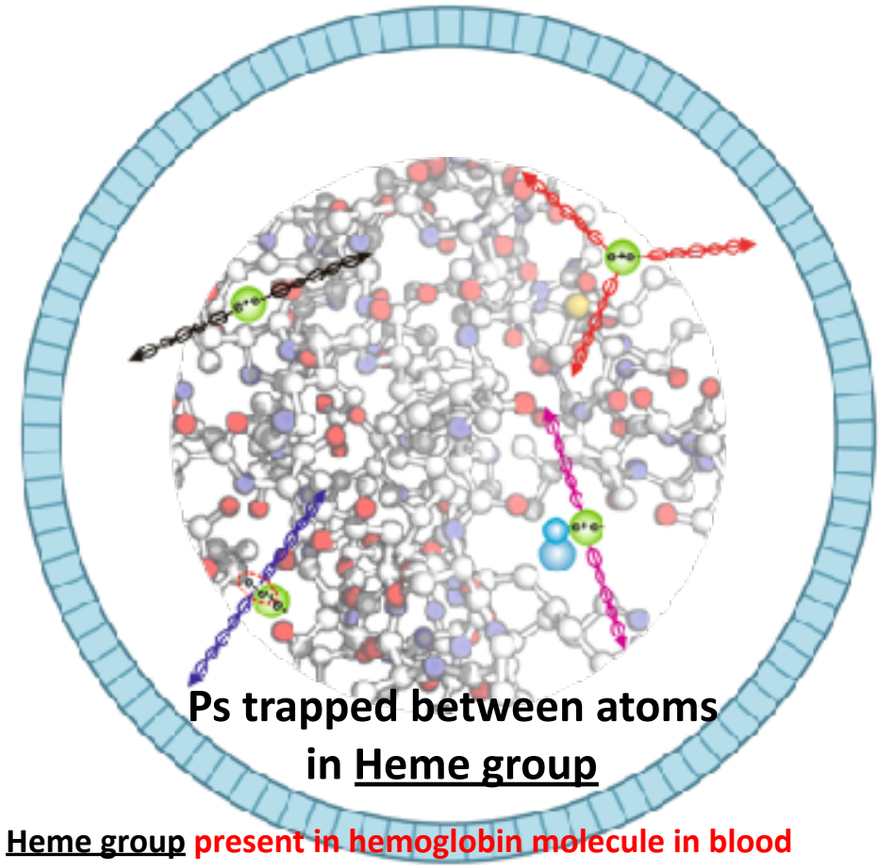


decays to 2γ → **Para-positronium (p-Ps)**
τ = 125ps, $^1S_0$

or

decays to 3γ → **Ortho-positronium (o-Ps)**
τ = 142ns, $^3S_1$

- J-PET for imaging of positronium properties inside human body
- Searching for the differences in properties of positronium atoms in healthy and cancerous tissues …and imaging of these properties in-vivo.



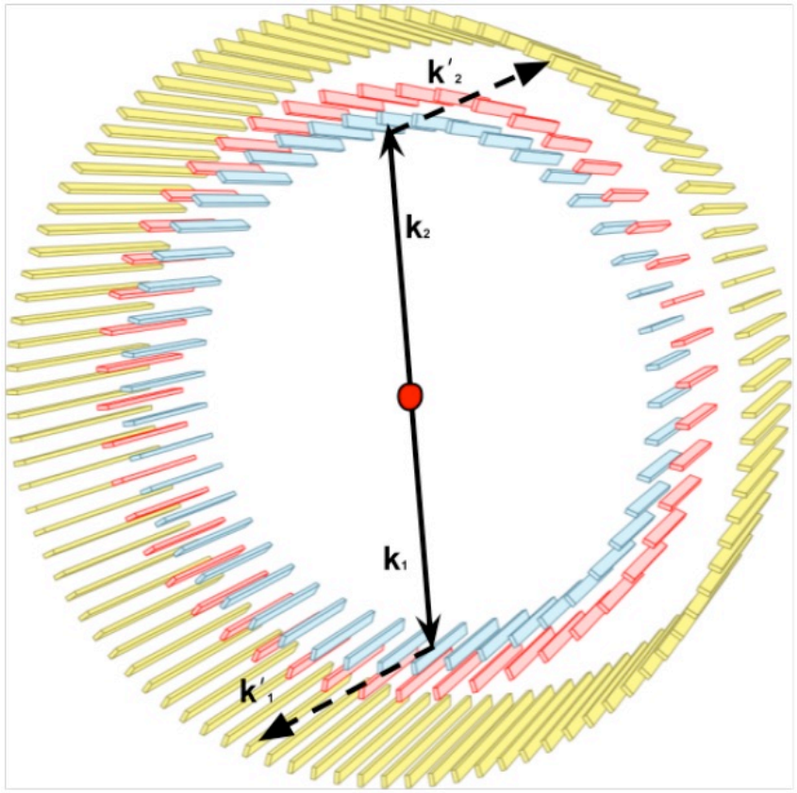
Ps trapped between atoms in Heme group

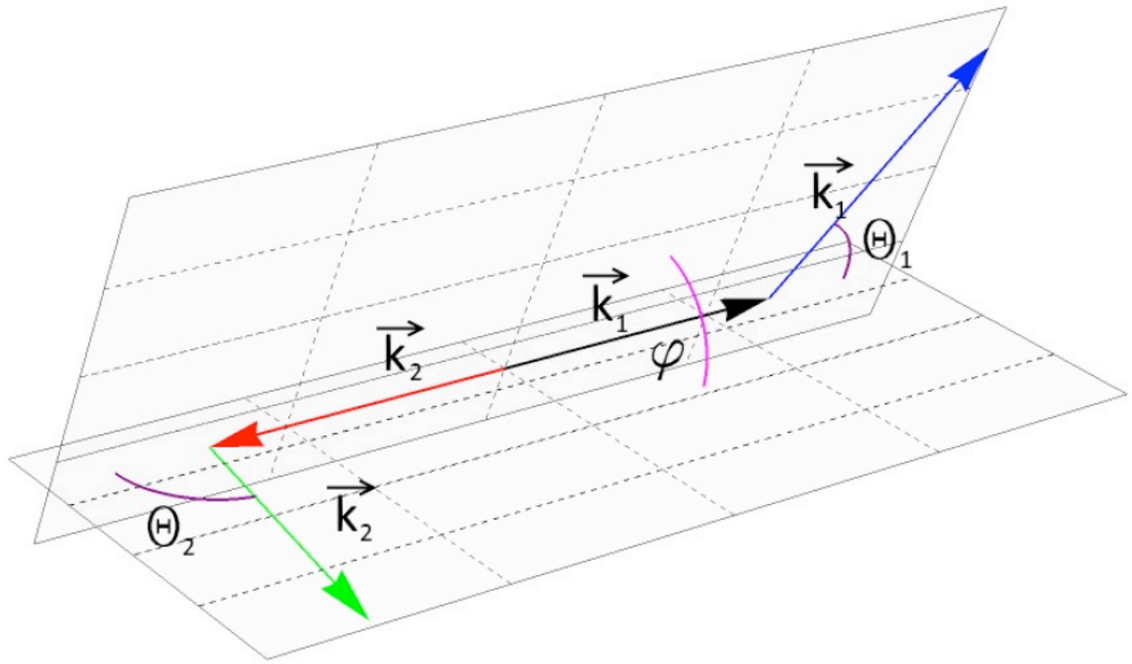
Heme group present in hemoglobin molecule in blood

[1] J-PET: Moskal P et al., arXiv:1805.11696, submitted to Phys. Med. Biol. (2018).
[2] J-PET: Moskal P et al., Patent No: US 9851456 (2017); PL 227658 (2013); PCT/EP2014/068374.
[3] Hiesmayr B and Moskal P, arXiv:1807.04934, submitted to Scientific Reports (2018).
[5] J-PET: Moskal P et al., (2015) Nucl. Instr. Meth. A775, 54.
[6] J-PET: A. Gajos et al. (2016) Nucl. Instr. Meth. A819, 54.
[7] J-PET: Moskal P et al., (2016) Phys. Med. Biol. 61, 2025.
[8] J-PET: Moskal P et al., (2016) Acta Phys. Polon. B47, 509.
[9] J-PET: D. Kamińska et al., (2016) Eur. Phys. J. C76 (2016) 455.

Research with J-PET

Quantum entanglement imaging:





- Determination of the linear polarisation direction of photon at the moment of its interaction with the detector and the quantum entanglement properties of photons.
- Correlation between the degree (type) of quantum entanglement and tissue properties.

[1] J-PET: Moskal P et al., arXiv:1805.11696, submitted to Phys. Med. Biol. (2018).
[2] J-PET: Moskal P et al., Patent No: US 9851456 (2017); PL 227658 (2013); PCT/EP2014/068374.
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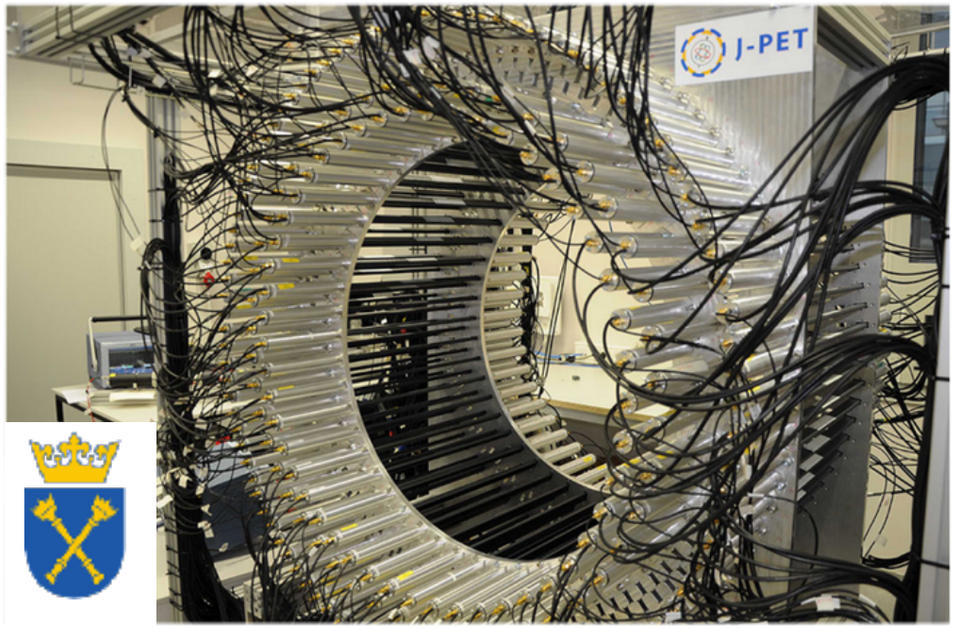
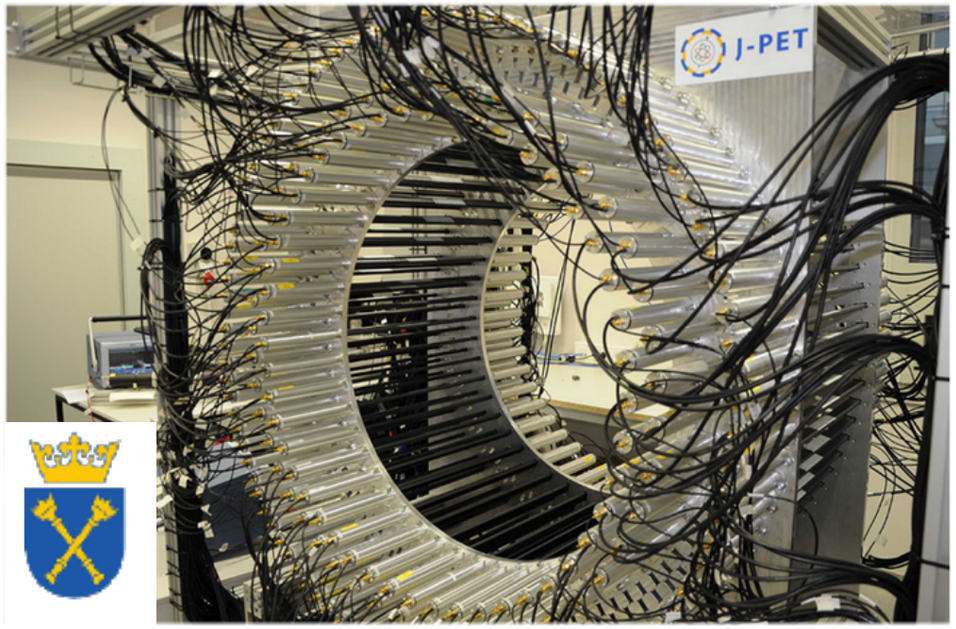
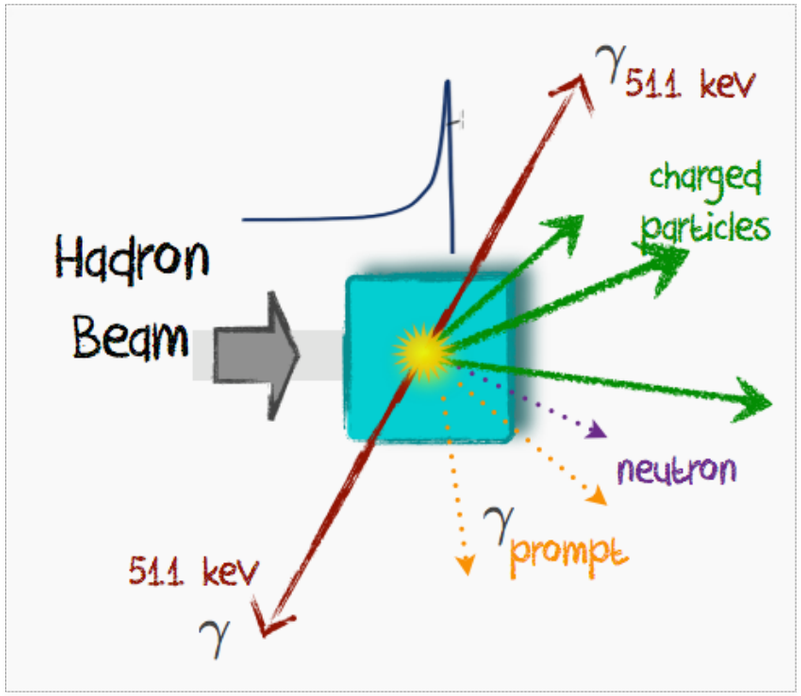
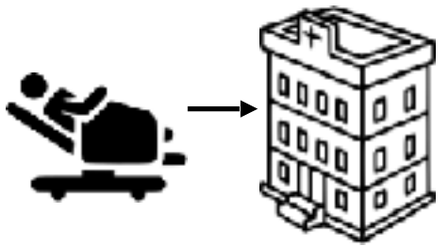


Research with J-PET





Proton therapy treatment



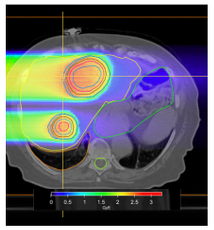
Clinical diagnosis

Computed tomography

CT calibration (HU → RPSP)

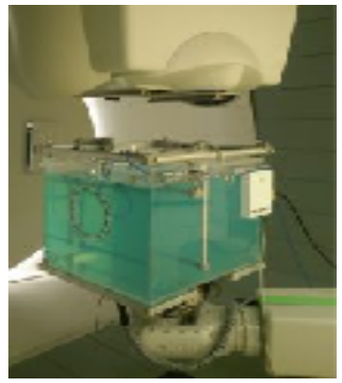
Treatment planning

Beam model (commissioning)



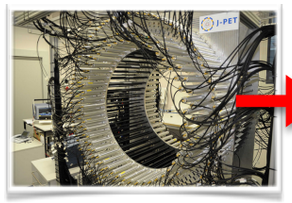
Dose measurements

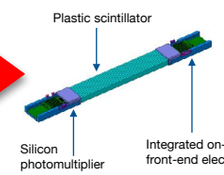
Time consuming process



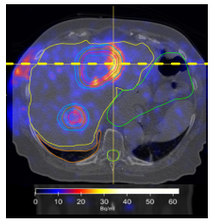
Treatment plan verification

β+ activity measurements



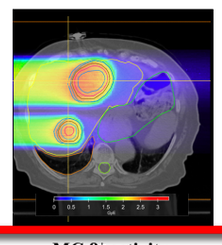


Measured β+ activity

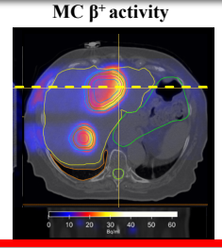


Treatment 20-35 fraction

Independent MC dose computation



MC based PET activity prediction



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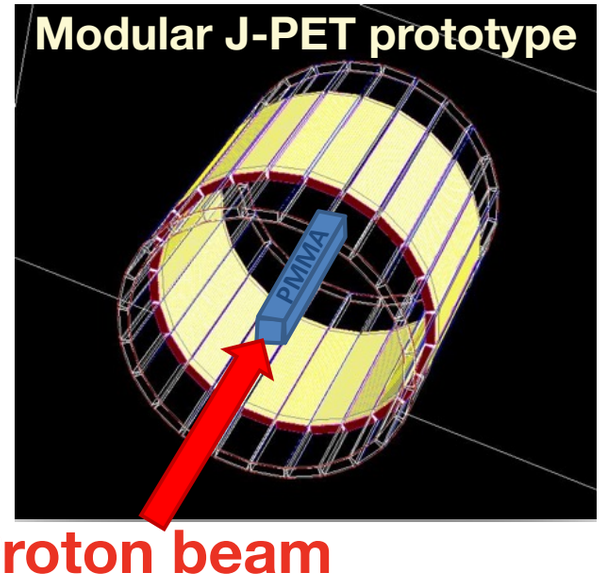
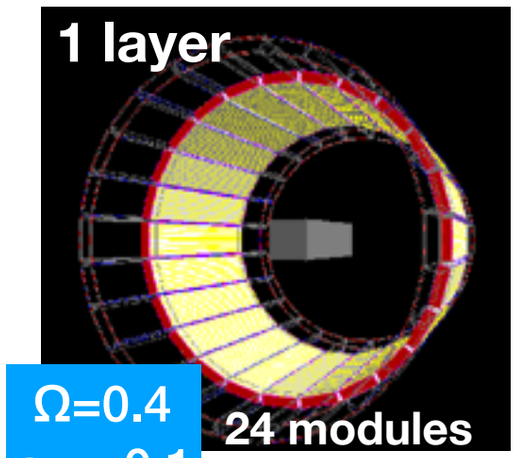
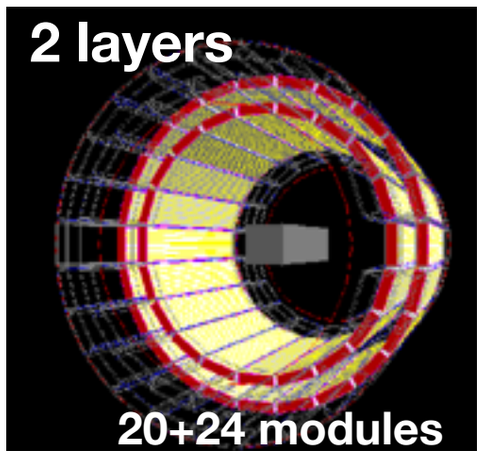
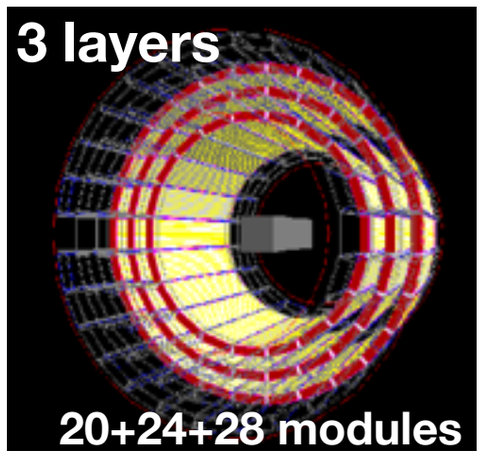
Design by Monte Carlo simulations



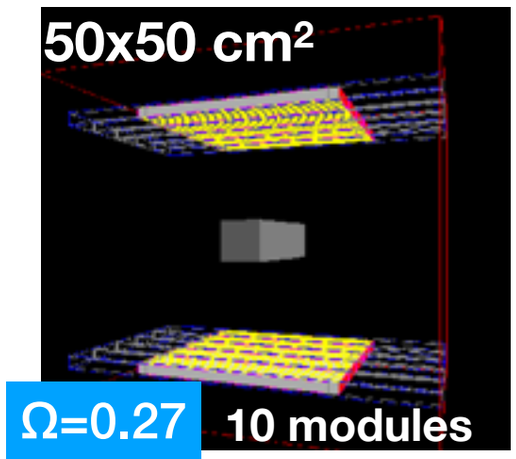
- The modular J-PET gives large freedom of choice of geometrical arrangement
- The number of layers should improve the efficiency
- Barrel could be integrated away from the gantry using e.g. rail-system
- Dual head can be integrated in the treatment position (studied in GSI and CNAO)

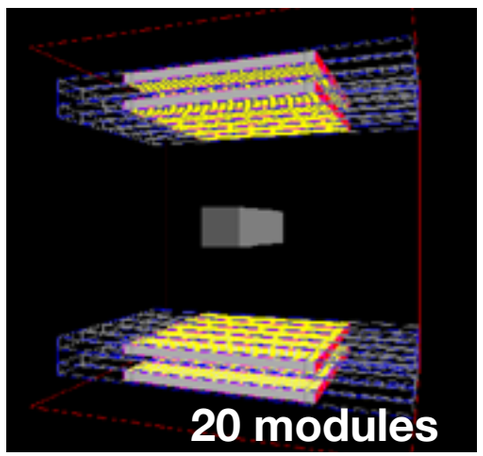


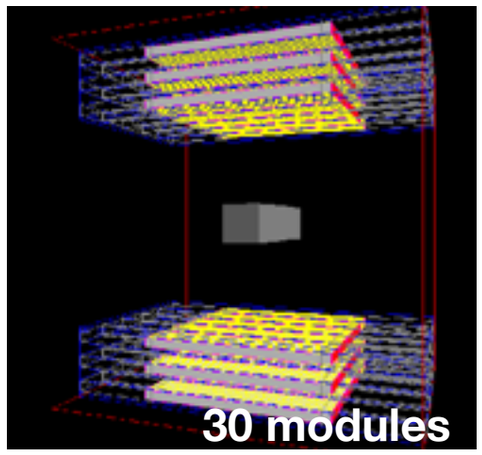




Ω=0.4
ε_{det}=0.1





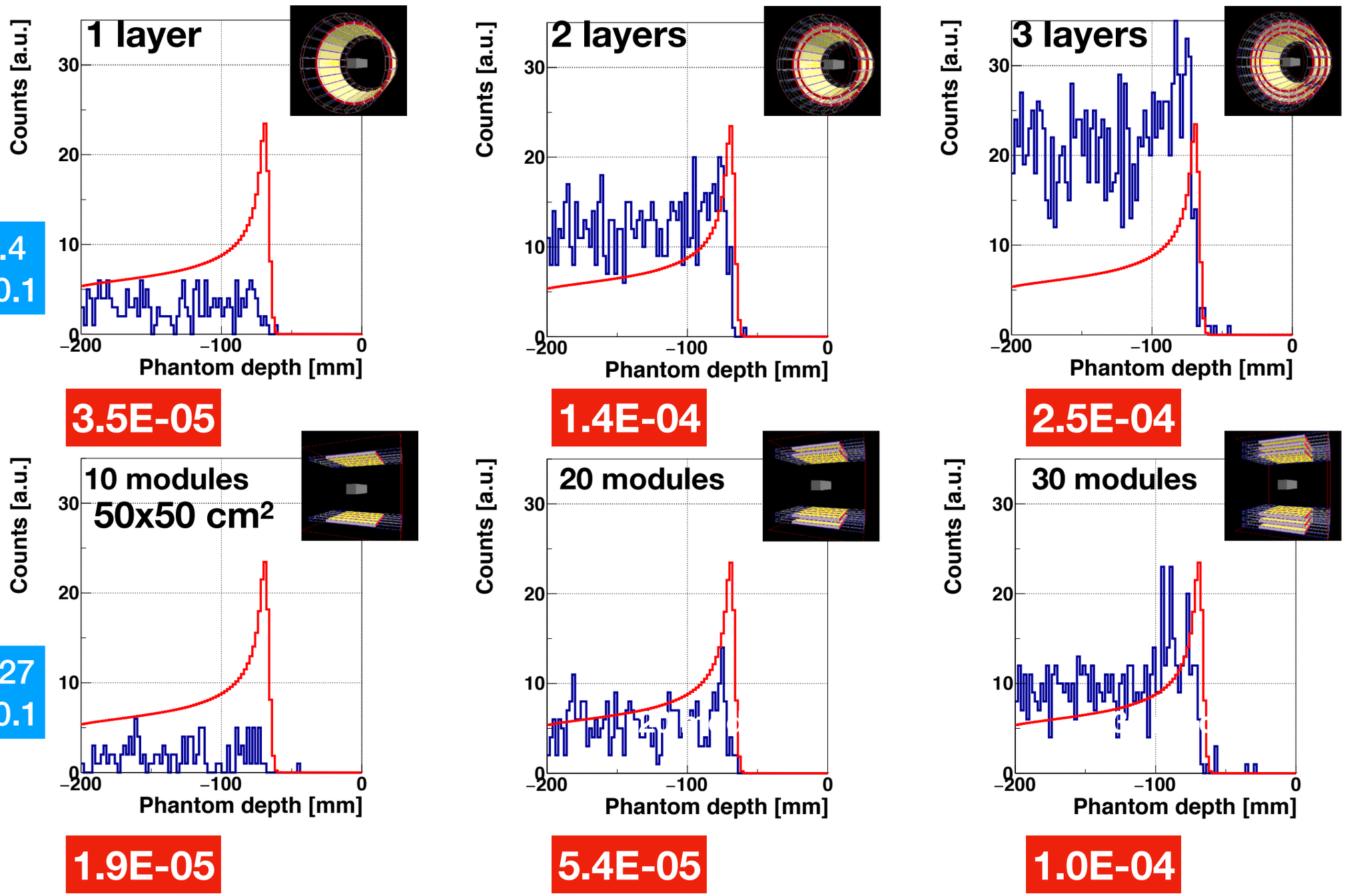


Ω=0.27
ε_{det}=0.1

Signal

coincidences per primary:

	24 modules	20+24 modules	20+24+28 modules
Ω=0.4, ε_{det}=0.1	1 layer	2 layers	3 layers
	3.5E-05	1.4E-04	2.5E-04
Ω=0.27, ε_{det}=0.1	10 modules 50x50 cm²	20 modules	30 modules
	1.9E-05	5.4E-05	1.0E-04



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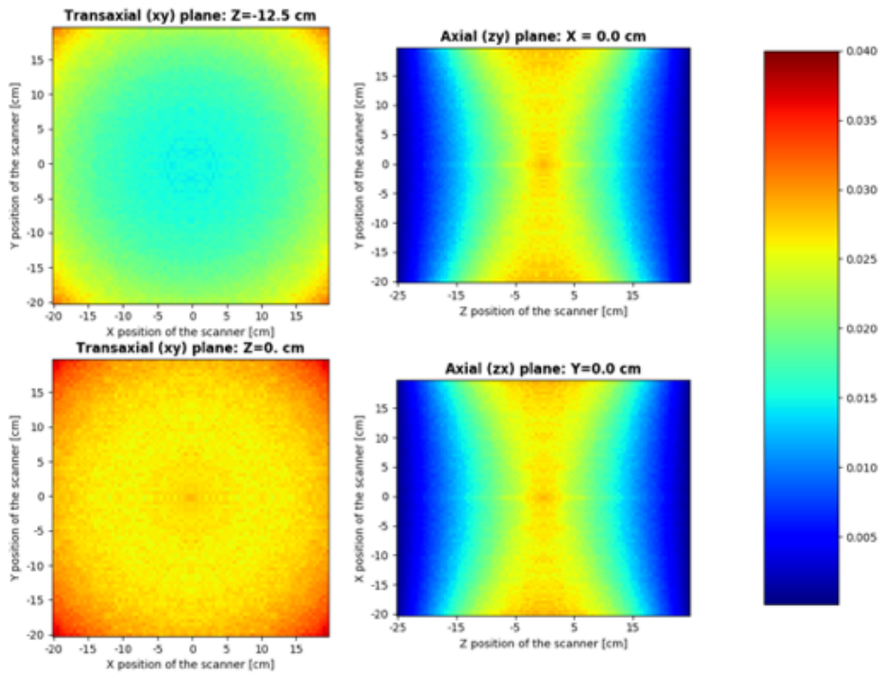
CASTOR for the J-PET image reconstruction

- **Reconstruction software requirements for the J-PET**

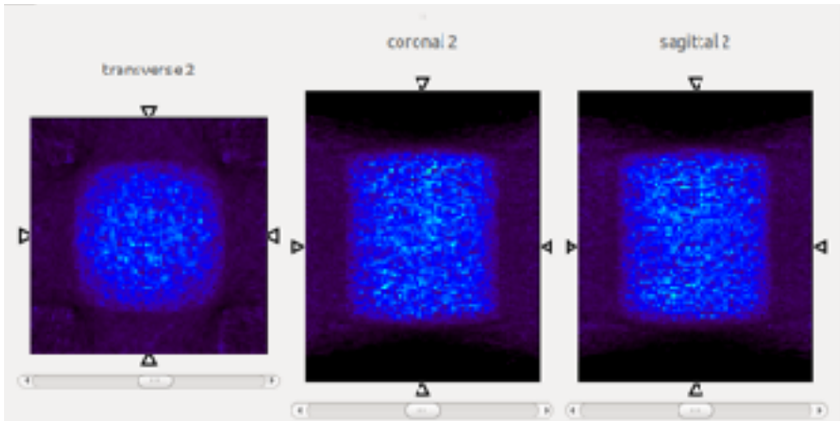
- long axial FOV (2m)
- multi-layer, non-cylindrical geometry
- inclusion of TOF
- continuous position determination along the axial direction

CASTOR for the J-PET image reconstruction

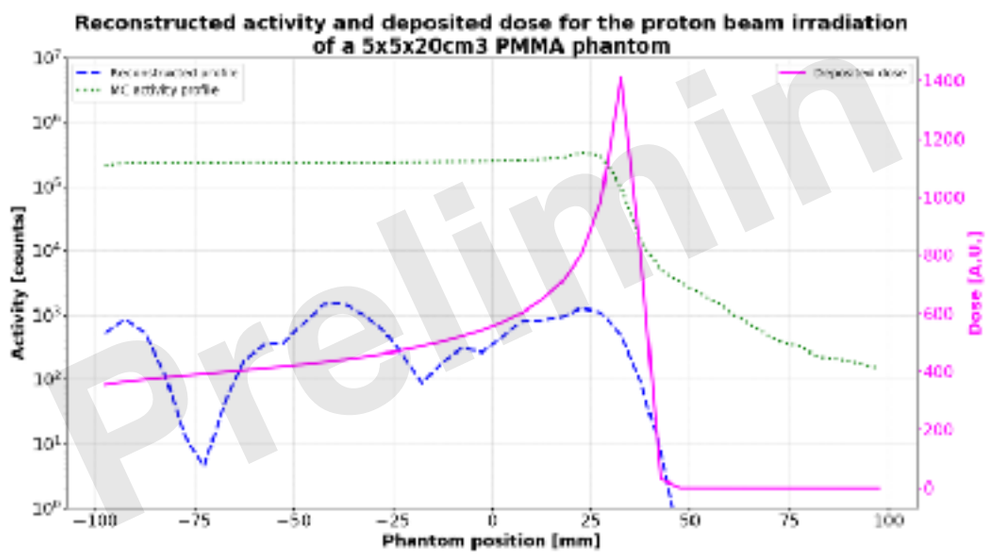
Simulations of system matrix



First reconstruction of cylindrical water phantom

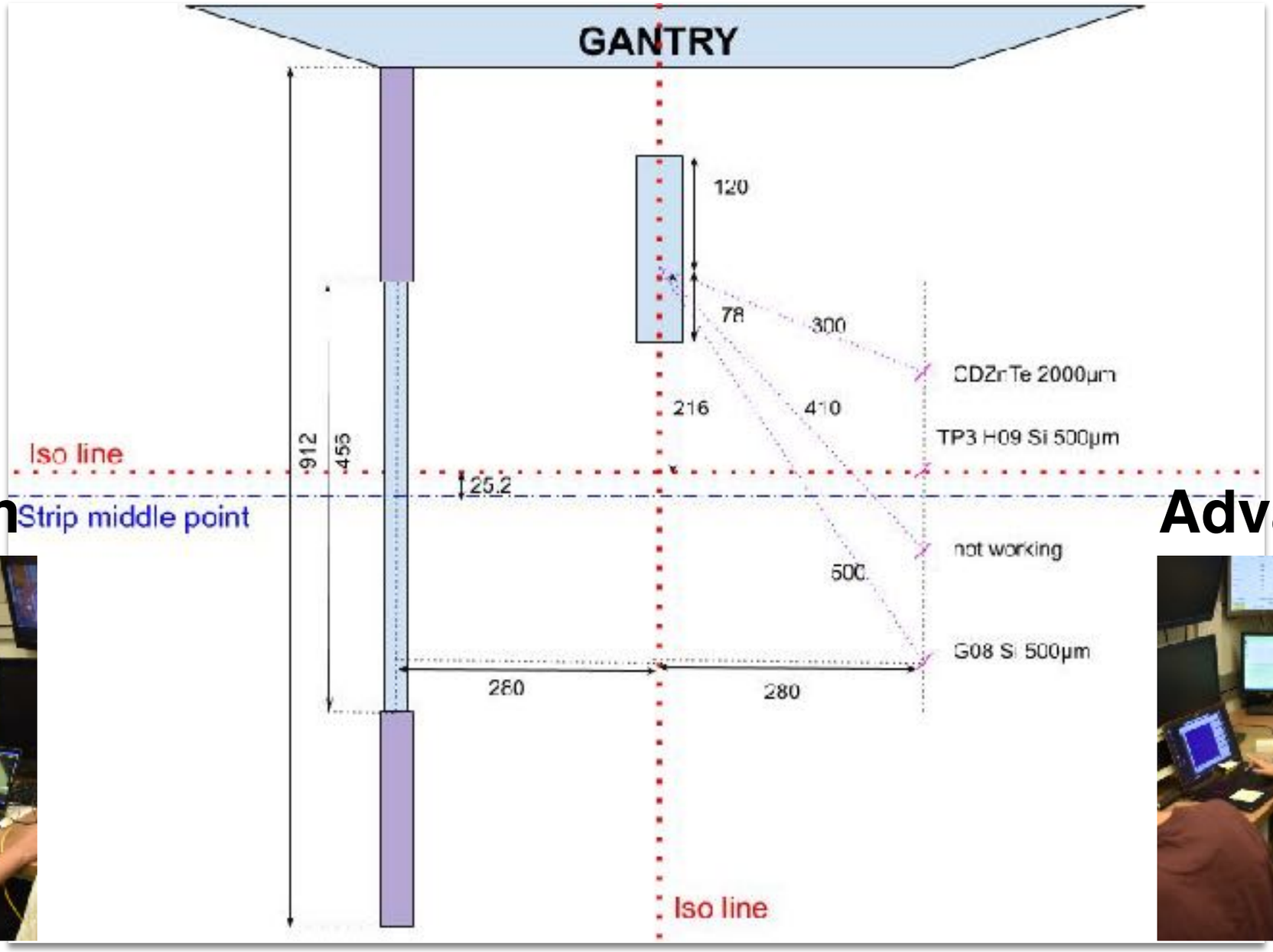


Corrections: sensitivity, attenuation, scatter, random



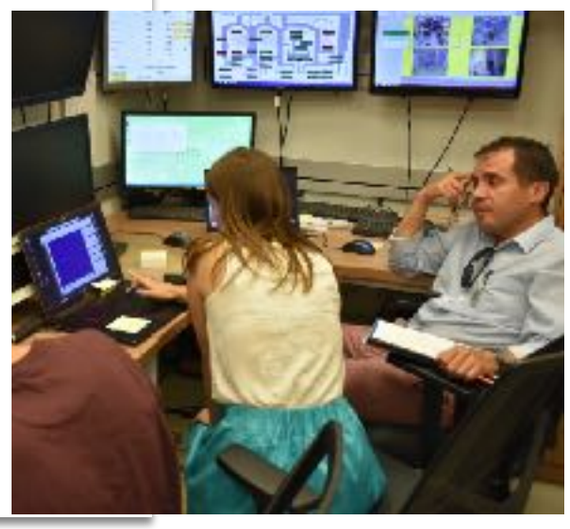
First Experiment

Aim: Characterize secondary radiation counting rate in J-PET detector during the proton therapy irradiation.



J-PET team

Advacam team



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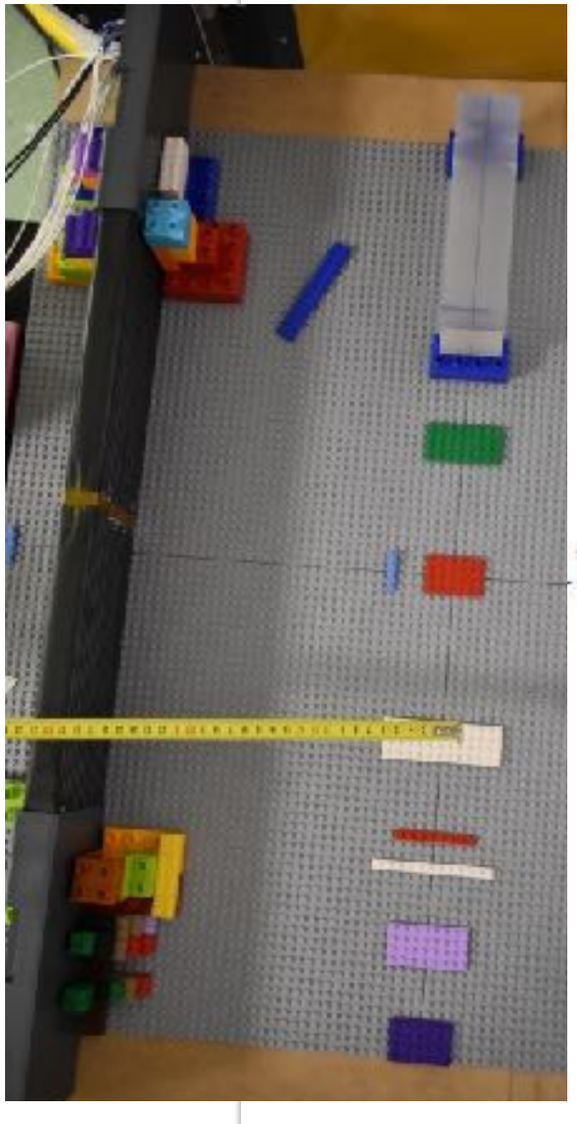
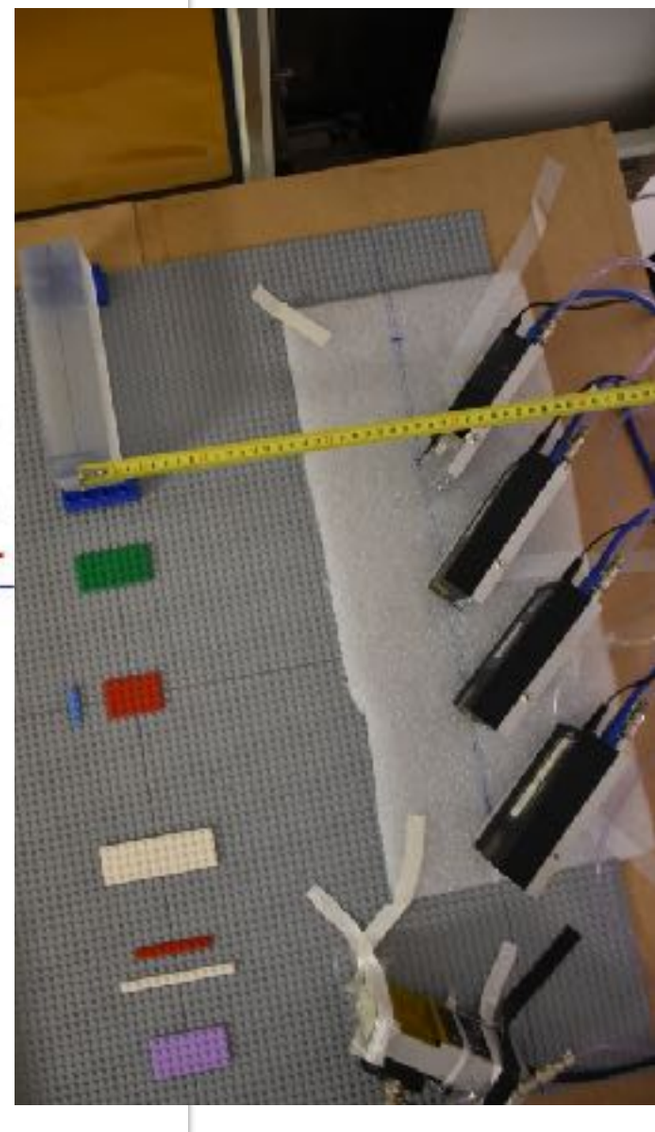
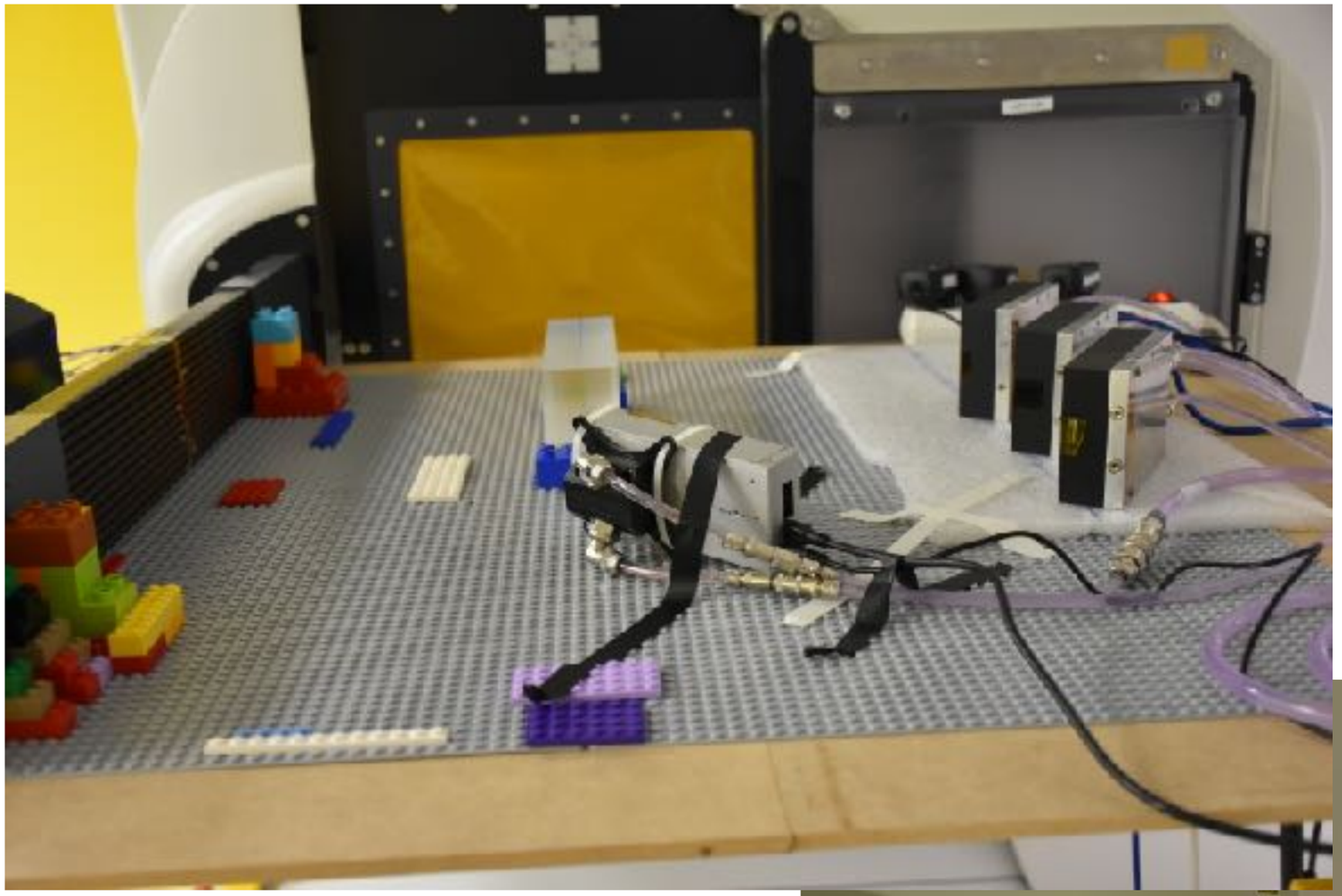







iba

J-PET settings

SCINT	13	12	11	10	9	8	7	6	5	4	3	2	1	SIDE B
PMT	4	4	4	4	4	4	4	4	4	4	4	4	4	
	3	3	3	3	3	3	3	3	3	3	3	3	3	
	2	2	2	2	2	2	2	2	2	2	2	2	2	
	1	1	1	1	1	1	1	1	1	1	1	1	1	

Scope readout

Readout at both sides

Digitizer readout

Digitizer and scope measurements are had to be started separately.

Slide from Szymon and Greg

Secondary radiation signal in J-PET

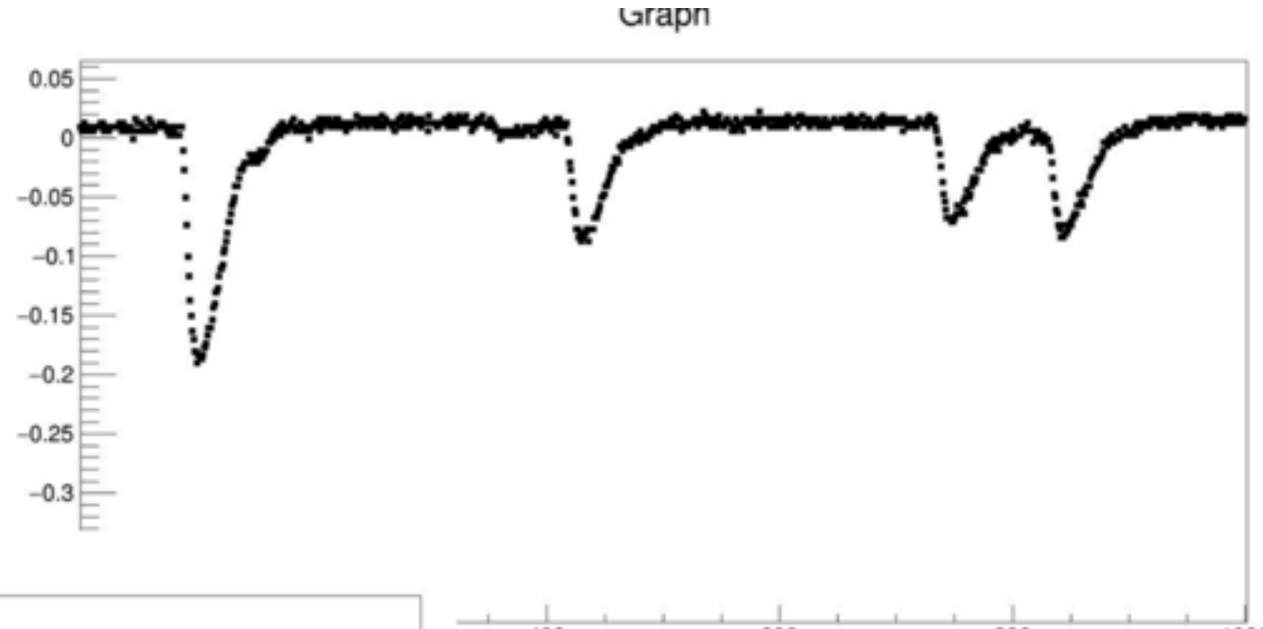
55V @ SiPM power supply

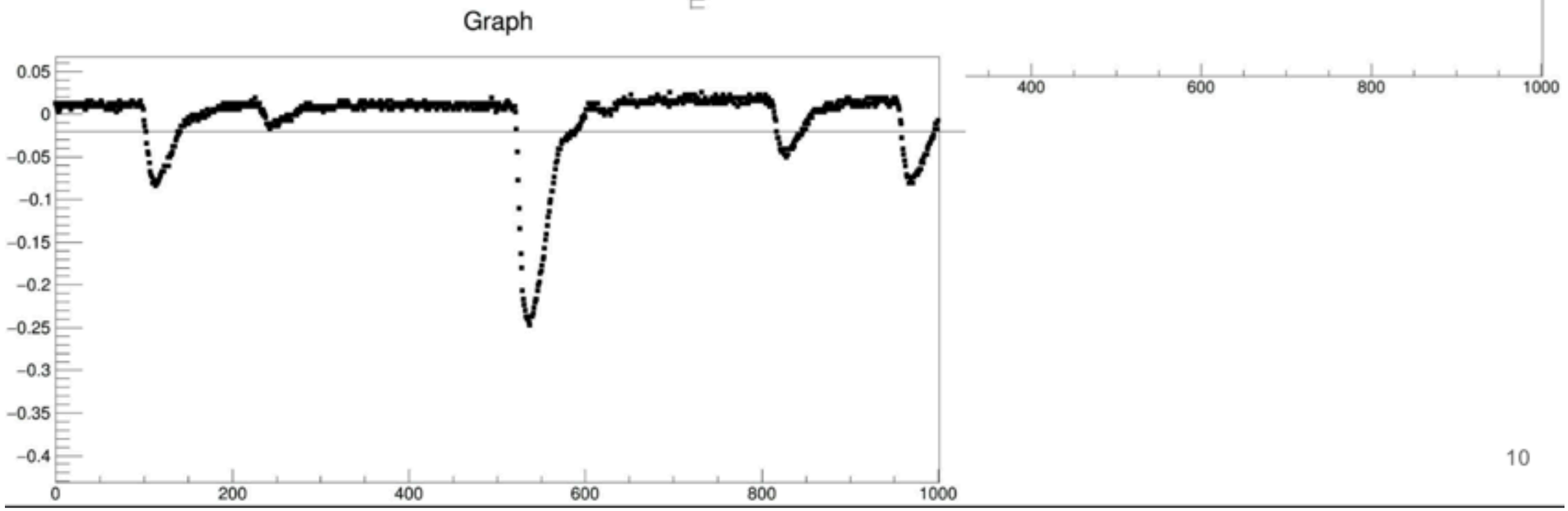
~181 nA protons with 150 MeV

therapeutic beam for ~1.5 m

signals sampled with scope

1 us time window





Slide from Szymon and Greg

Summary

- J-PET is a plastic scintillator based PET detector developed at Jagiellonian University

- New applications include:
  - positronium imaging
  - quantum entanglement imaging
  - proton therapy applications
  - ...

Thank you :)

Thank you

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