

Range monitoring in proton therapy using the J-PET scanner

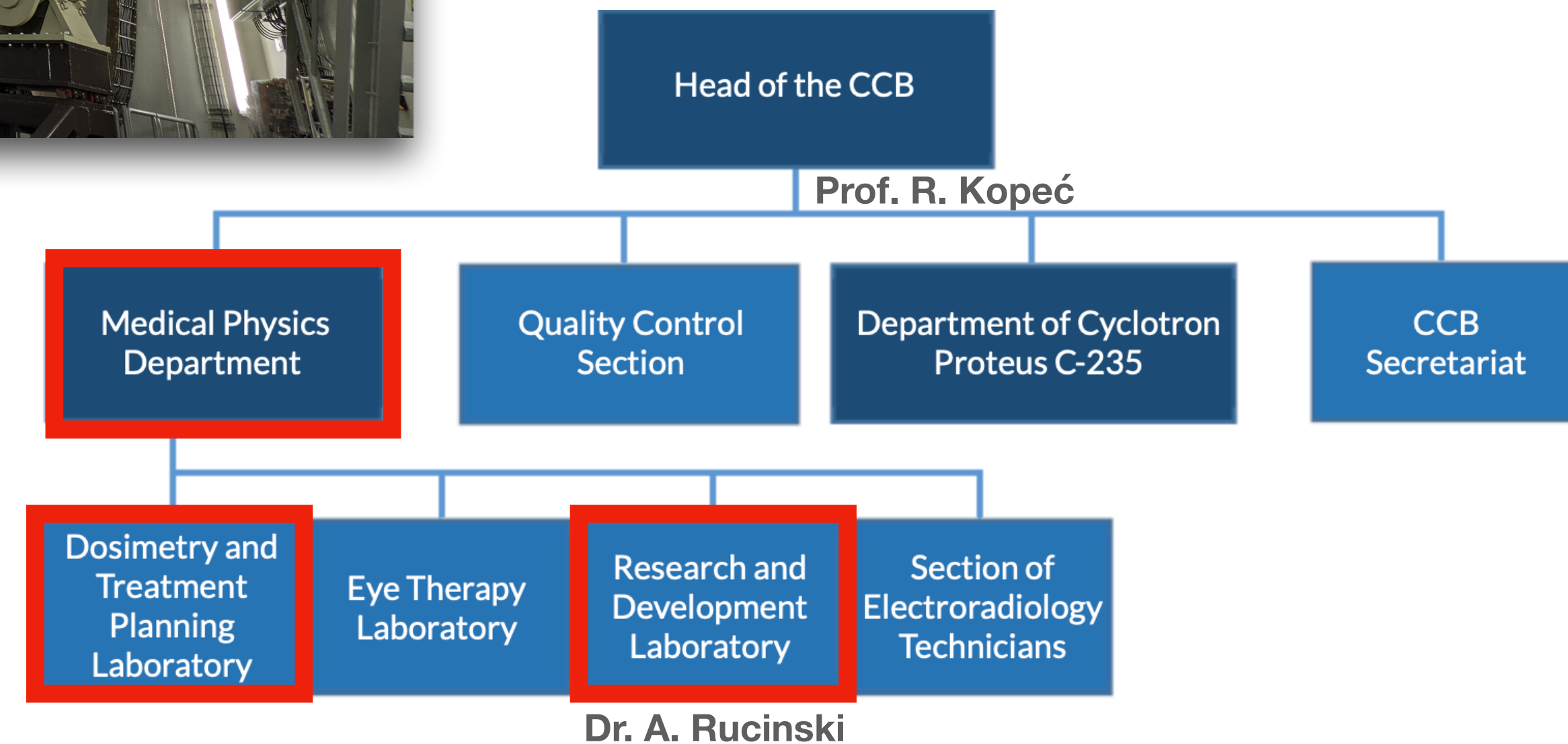
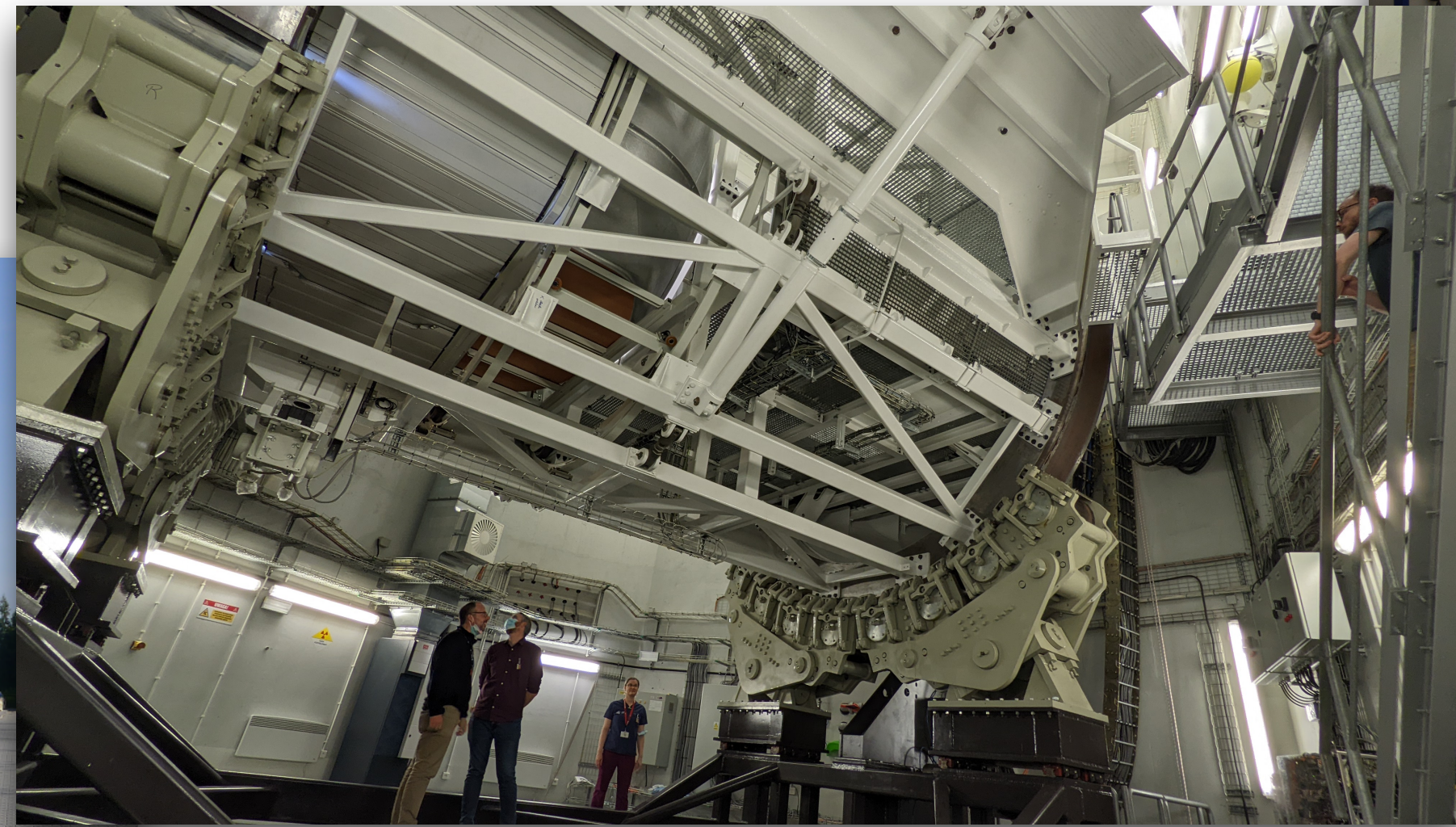
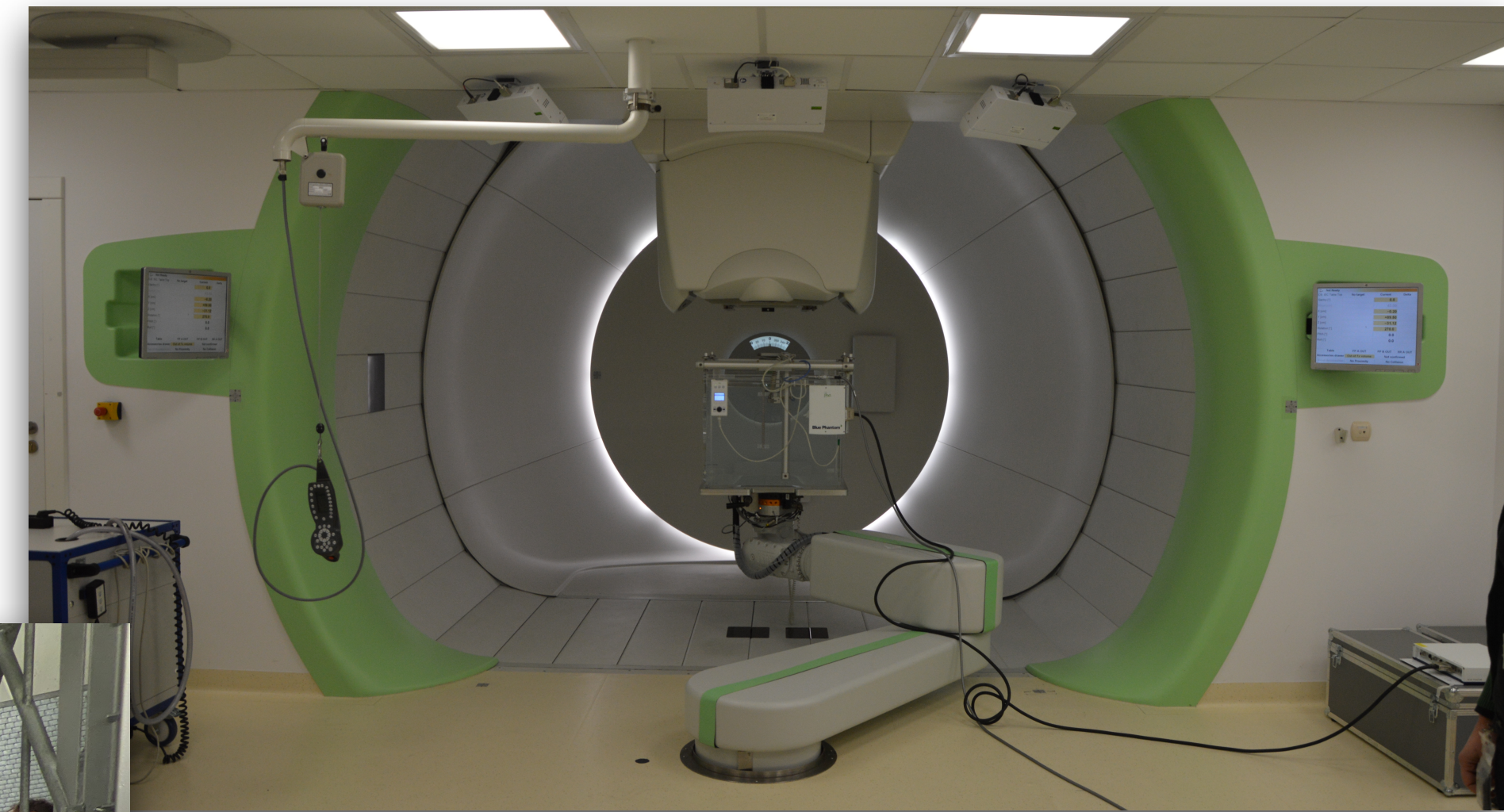
A. Ruciński, S. Niedźwiecki, P. Moskal for the J-PET collaboration.

Outline

- CCB IFJ PAN Krakow proton therapy center
- ProTheRaMon platform for PET range monitoring simulations
- Sensitivity simulations
- Simulations of patient treatments
- First experiment
- Literature

CCB Kraków proton center

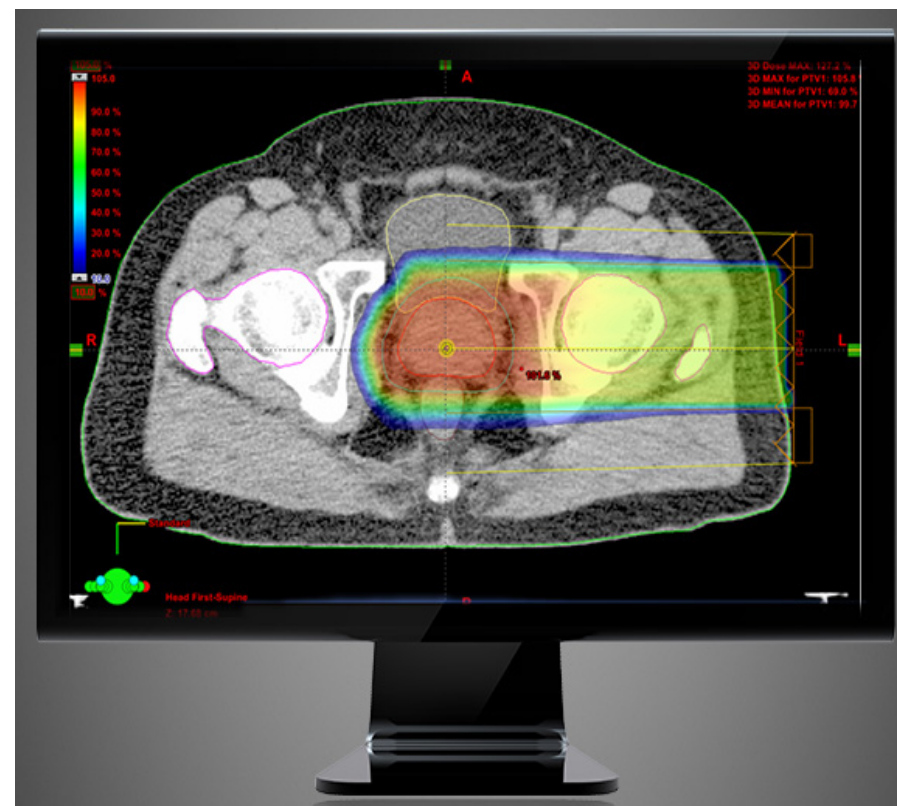
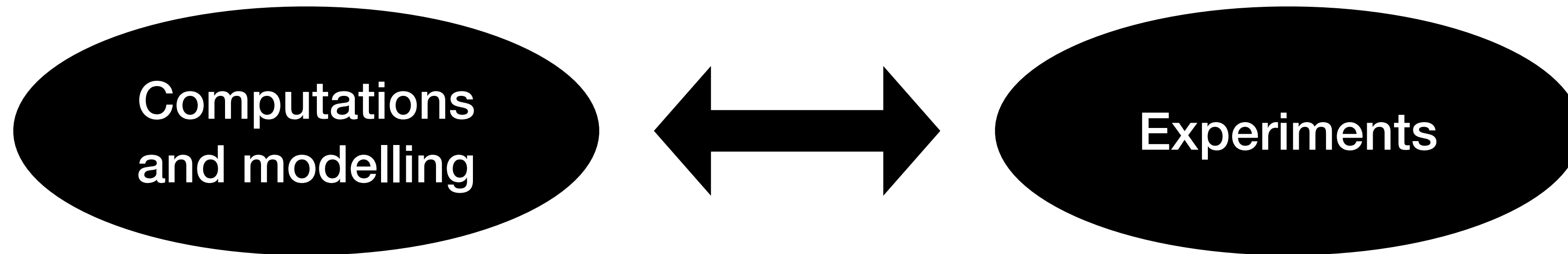
Structure and relevant data/equipment



- IBA proton therapy facility equipped with 2 gantry rooms with scanning beam, horizontal line for eye treatment, and research room, isochronous cyclotron, proton energy up to 230 MeV
- ~1500 patients treated from 2017
- Brain, Head and neck, CNS, recently moving targets (Hodkin lymphomas), pediatric patients
- Research and commercial physics experiments

Translational research at CCB proton center

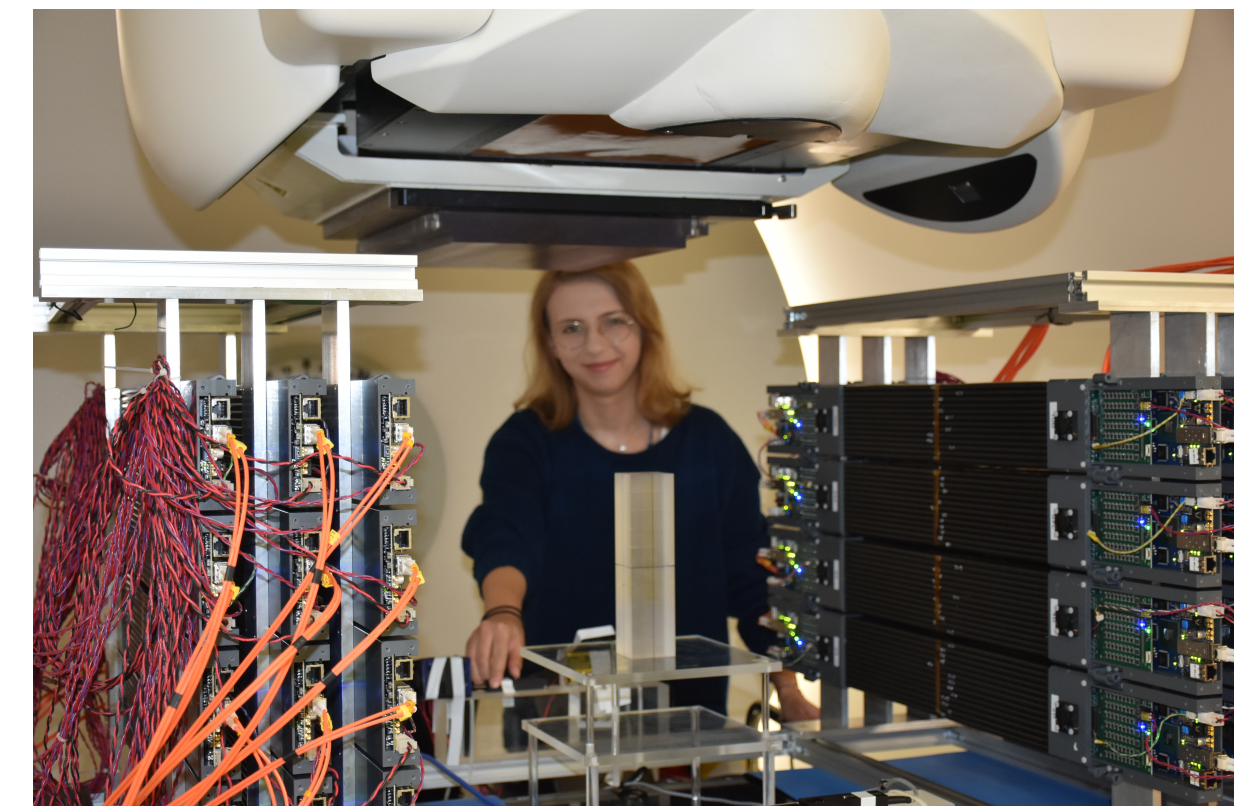
Physics, radiation biology, and oncology to improve clinical protocols



Biologically and LET weighted treatment planning



Quality assurance

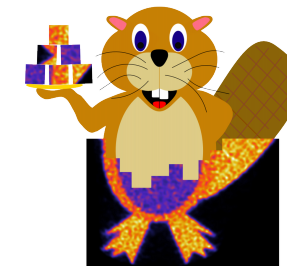
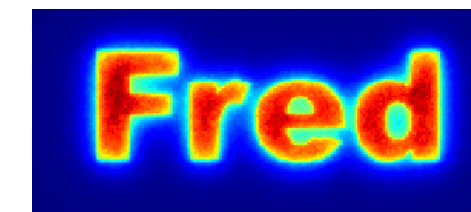


Detectors for range monitoring for therapy adaptation

ProTheRaMon framework

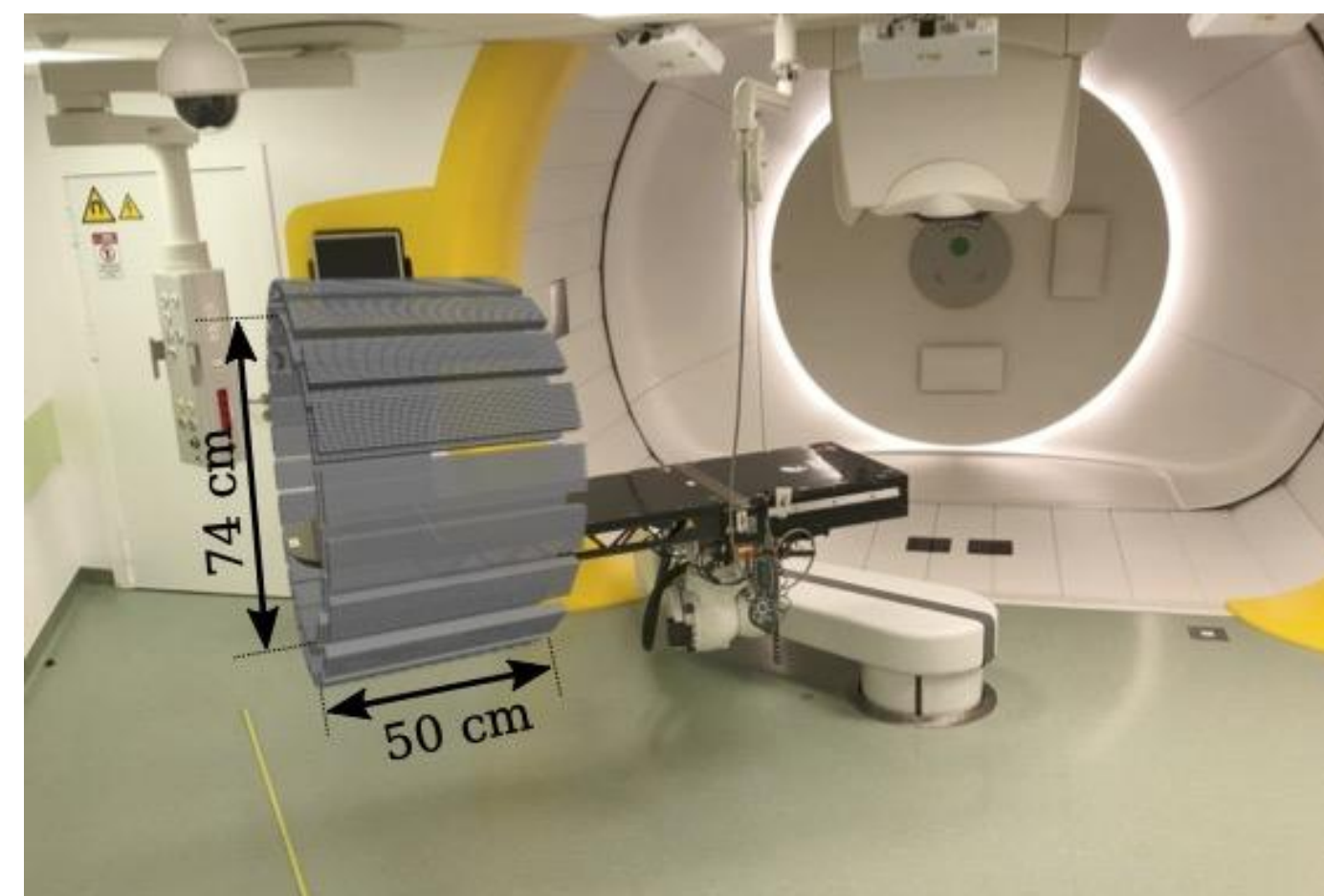
PET activity production and reconstruction simulations

- Stage 1: Data pre-processing,
- Stage 2: GATE Monte Carlo simulation of β^+ emitting isotope production,
- Stage 3: Activity map modeling,
- Stage 4: GATE Monte Carlo simulation of β^+ emission and PET acquisition,
- Stage 5: CASTOR image reconstruction.

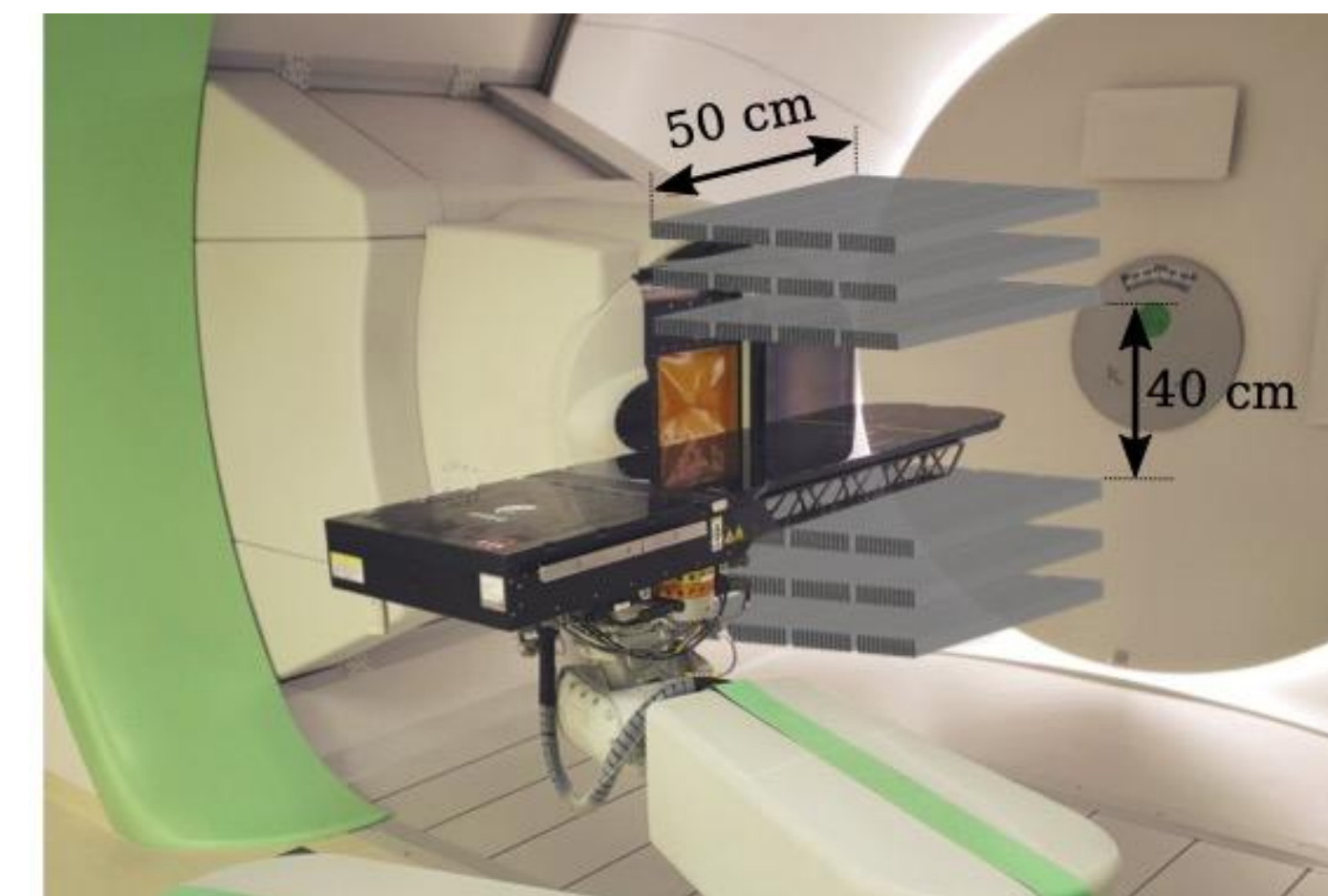


STAGE 1	STAGE 2	STAGE 3	STAGE 4	STAGE 5
IN-HOUSE (Python / Bash)	GATE	IN-HOUSE (Python / Bash)	GATE	CASToR
GATE coordinate system	GATE coordinate system	Activity coordinate system	PET scanner coordinate system	GATE coordinate system
CT			CT	
Treatment Plan			Treatment Plan	
Beam model				
CT callibration			CT callibration	
		Production maps	Activity maps	Coincidences list
			PET scanner geometry	

In-room PET imaging protocol



In-beam PET imaging protocol



K. McNamara et al. PMB 2022 <https://doi.org/10.1088/1361-6560/aca515>

D. Borys et al. PMB 2022 <https://doi.org/10.1088/1361-6560/ac944c>

β^+ production with proton beams

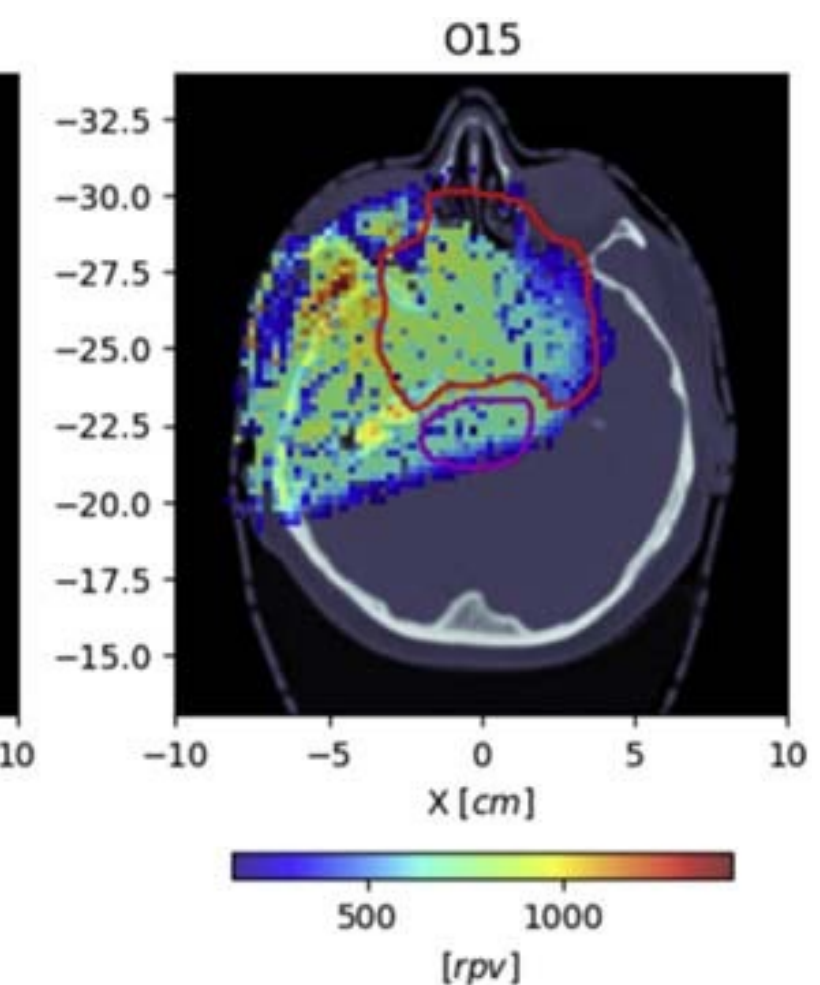
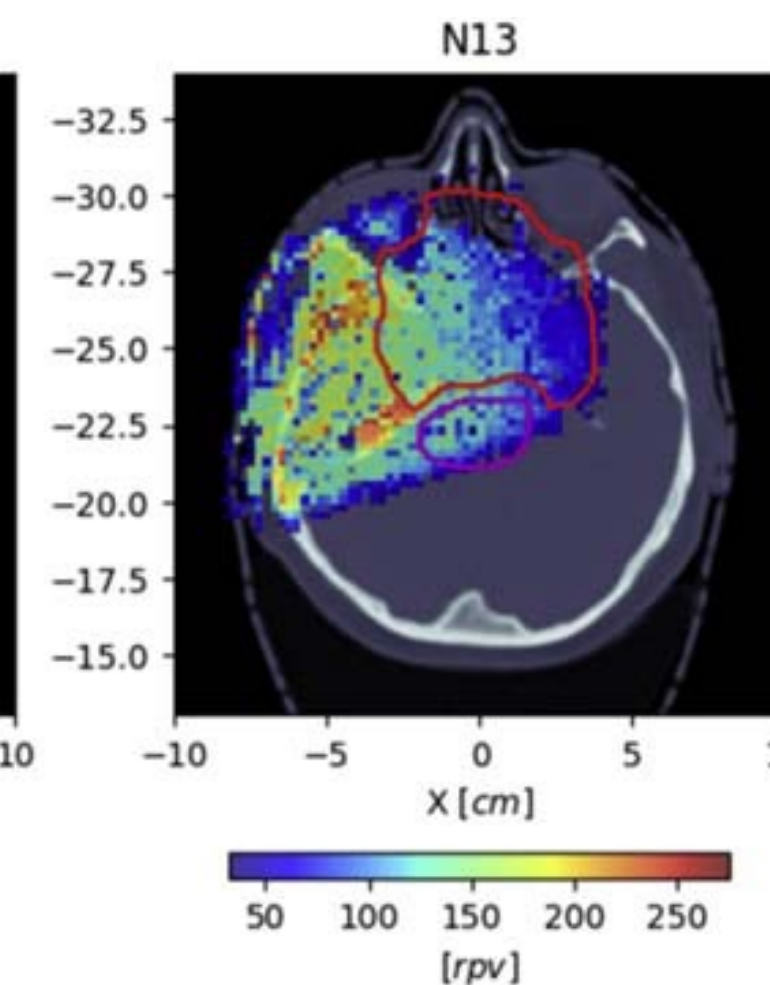
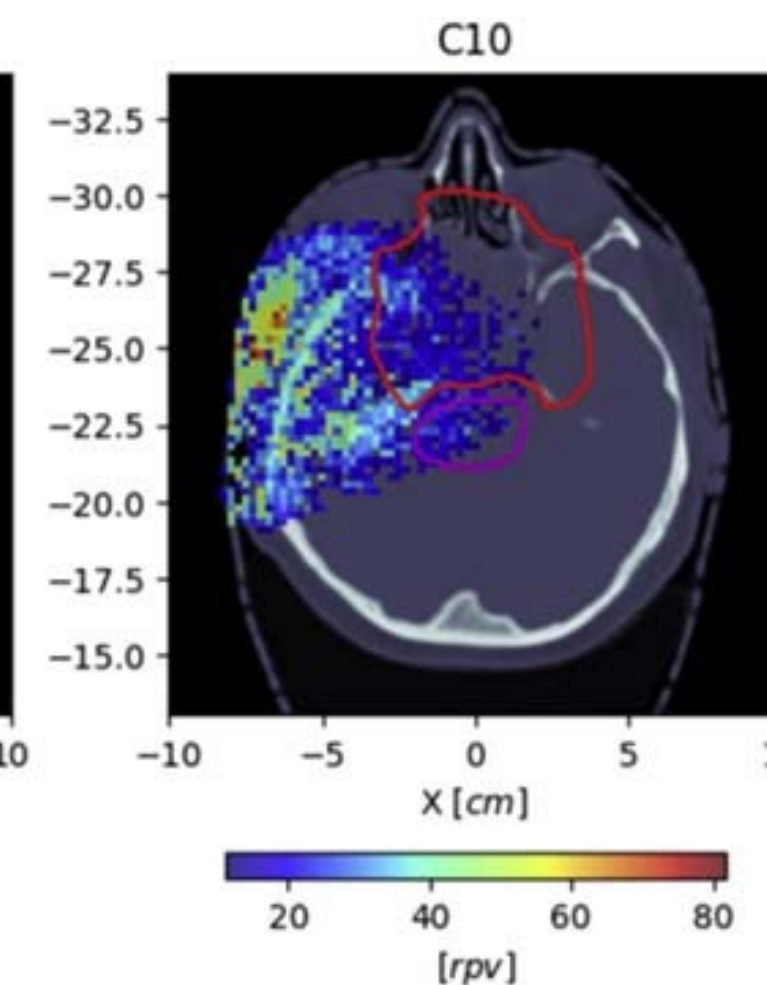
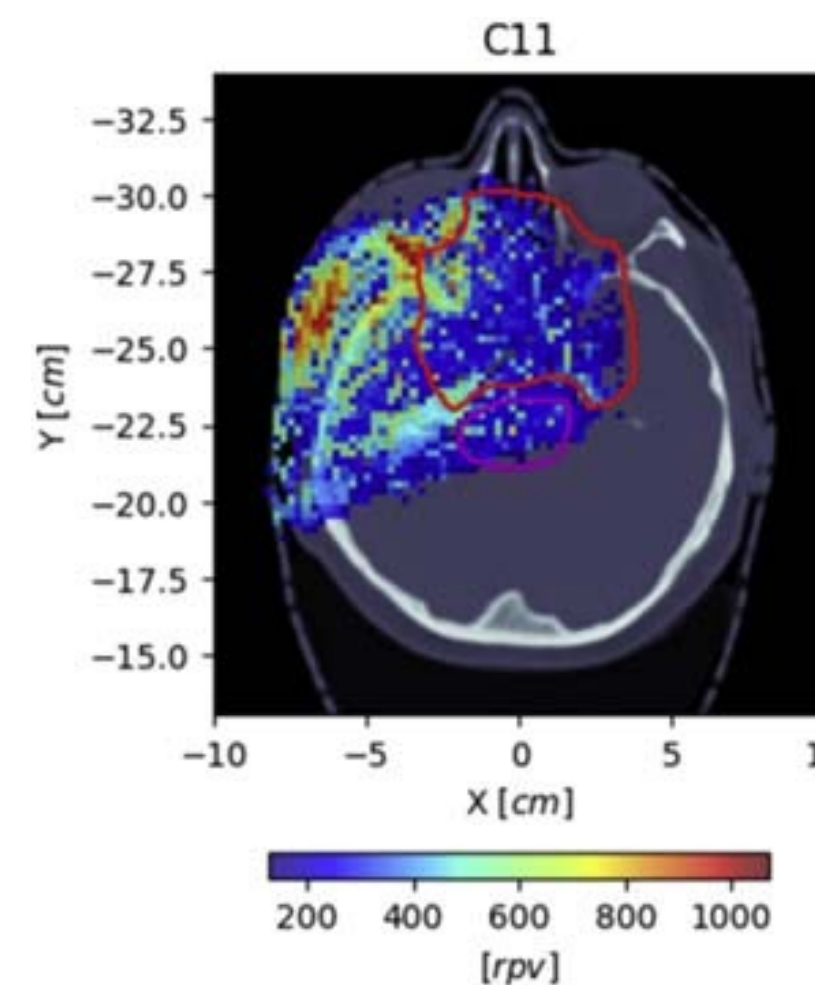
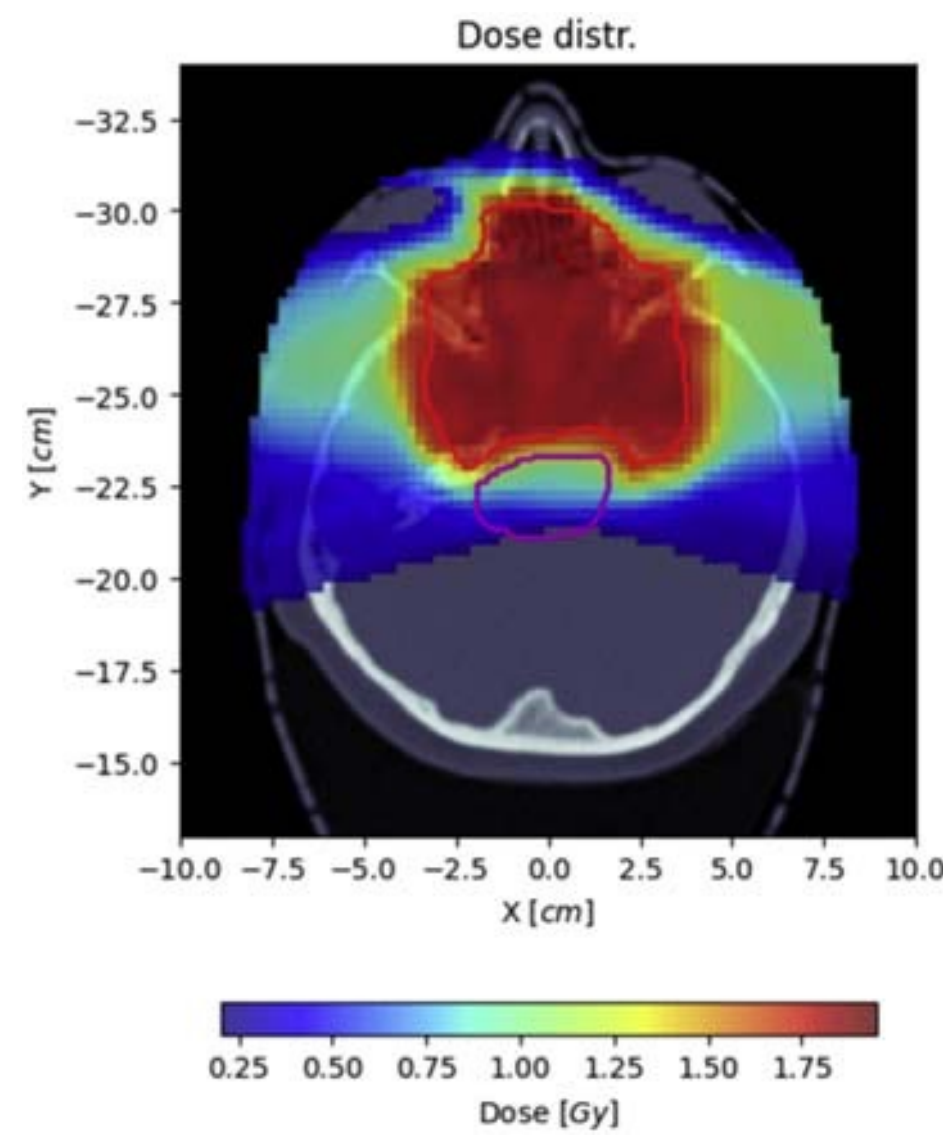
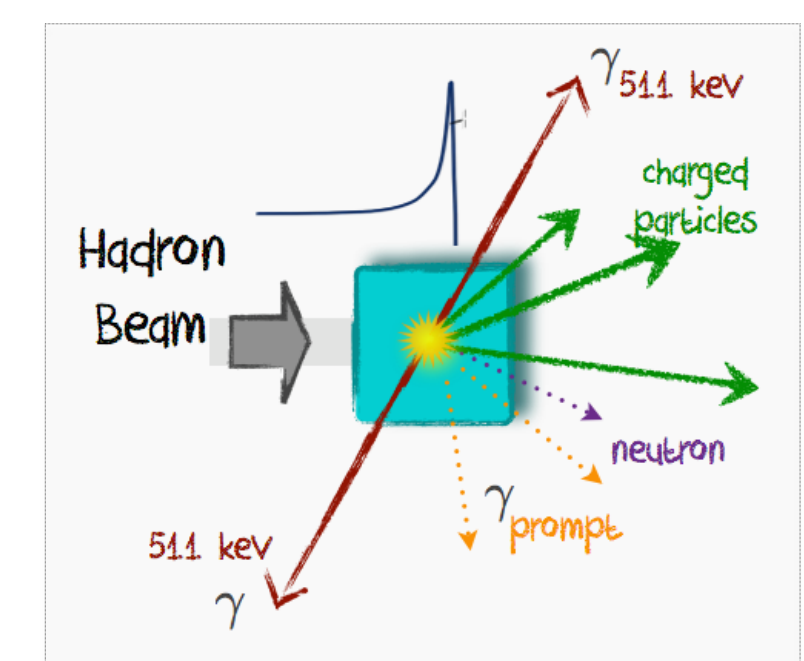
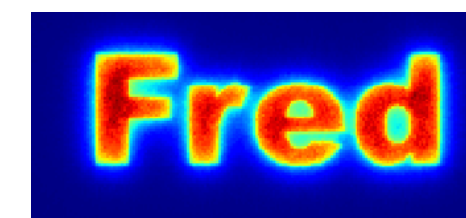
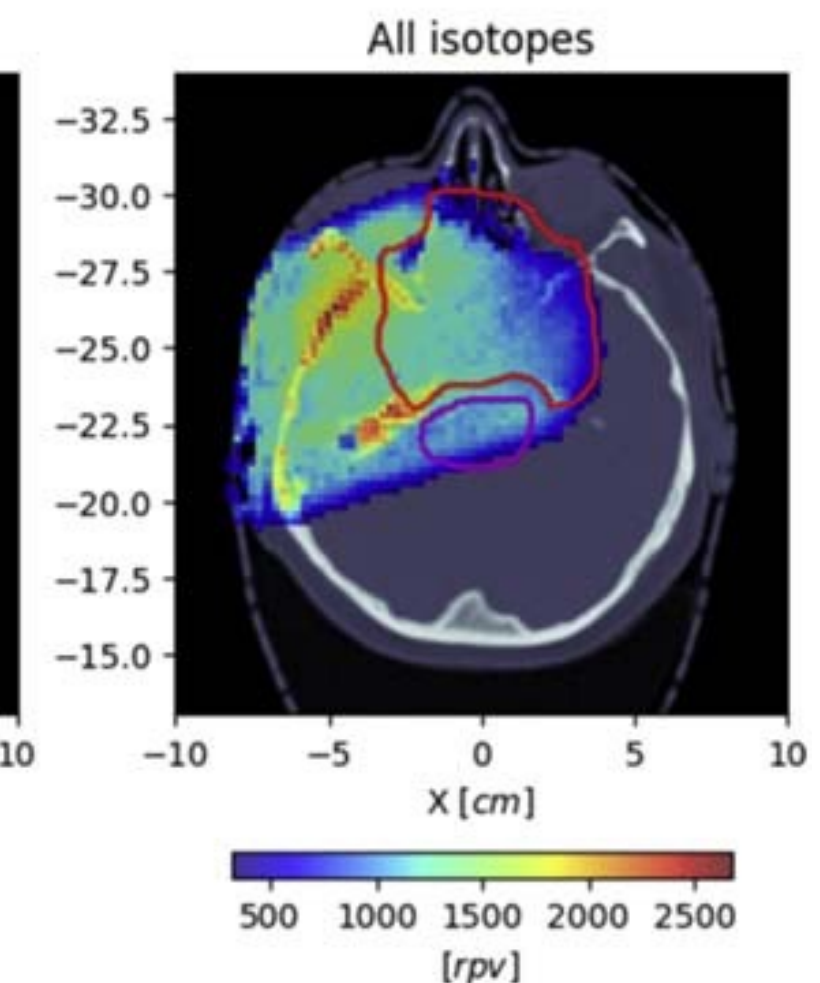
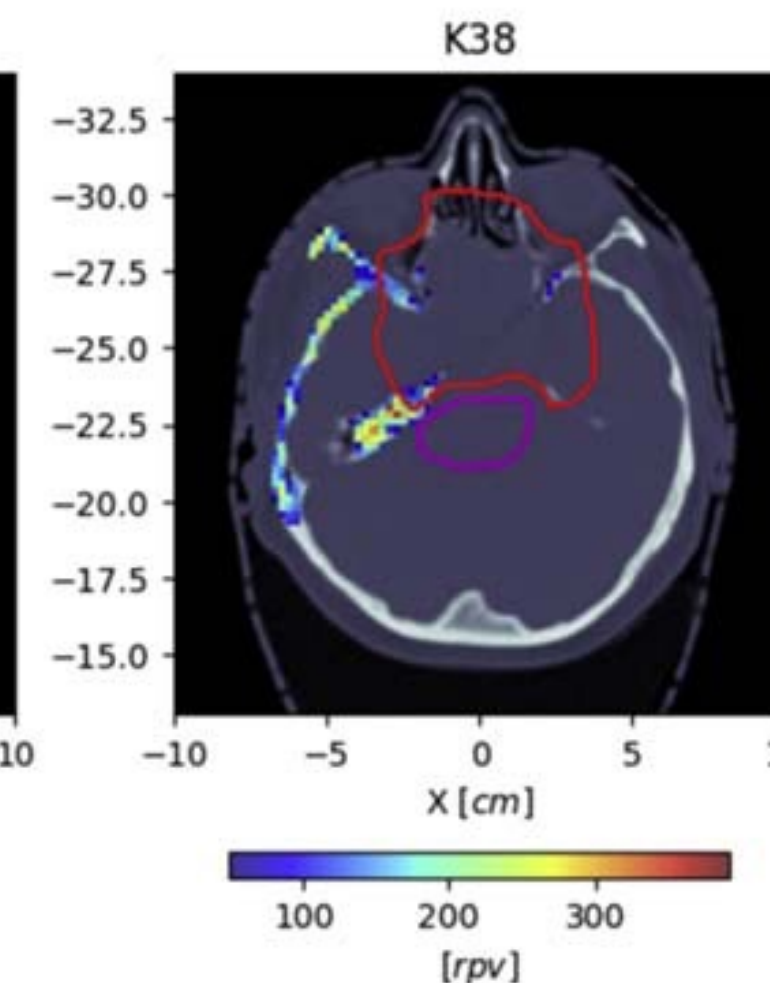
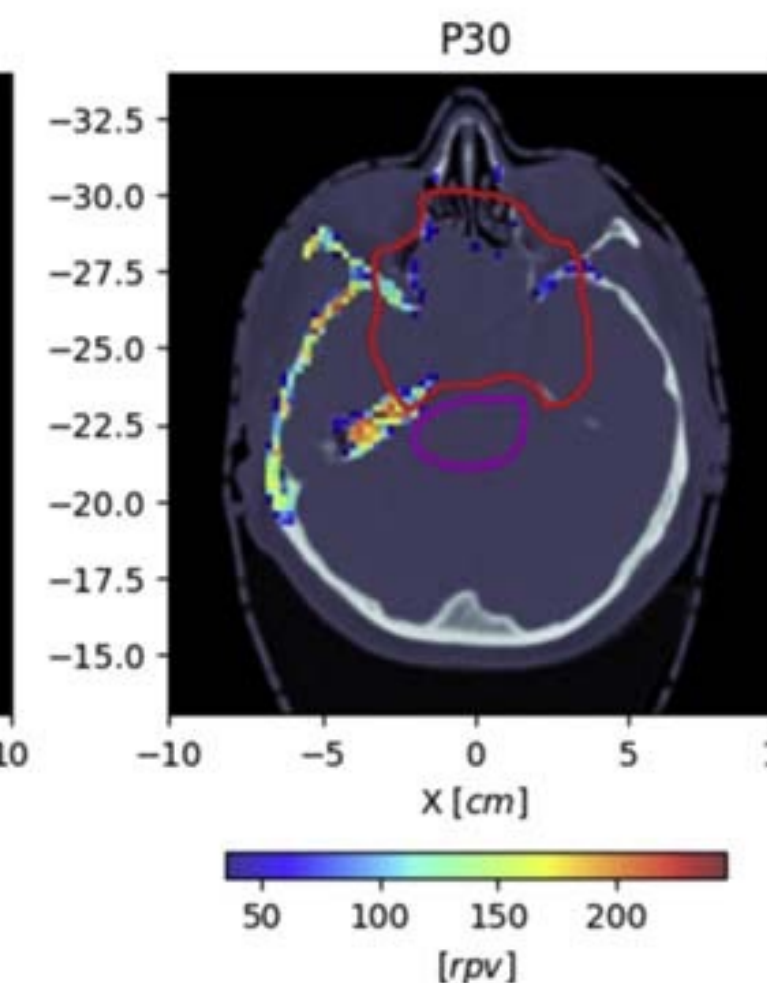
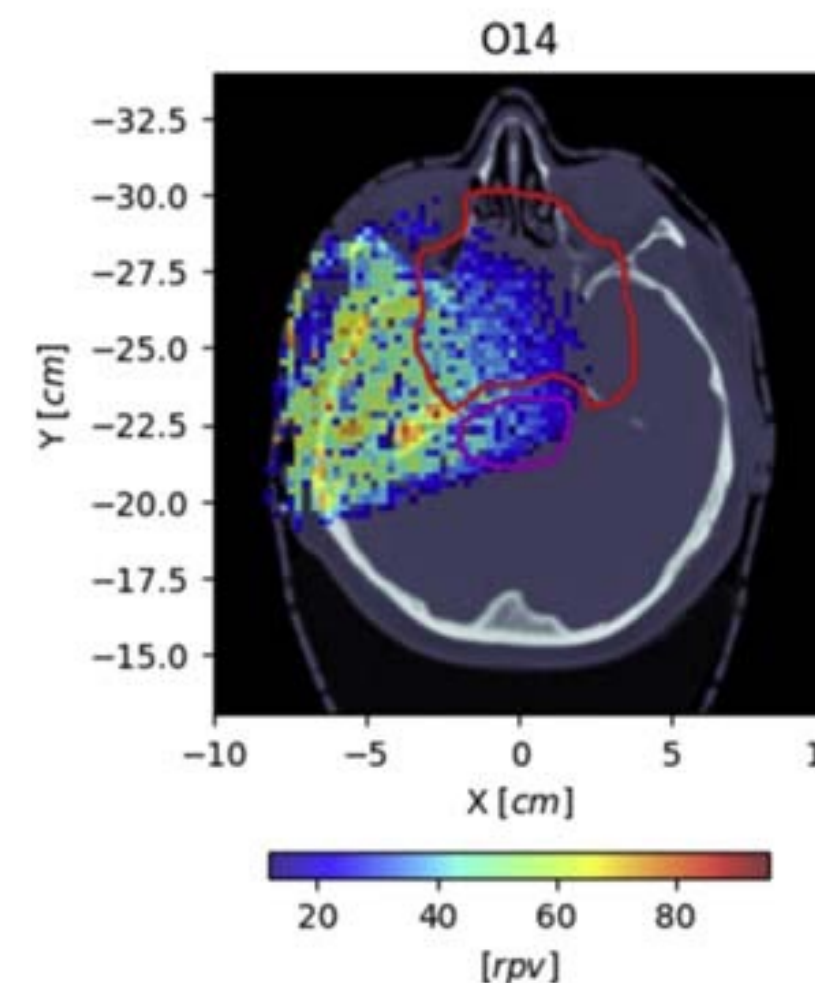


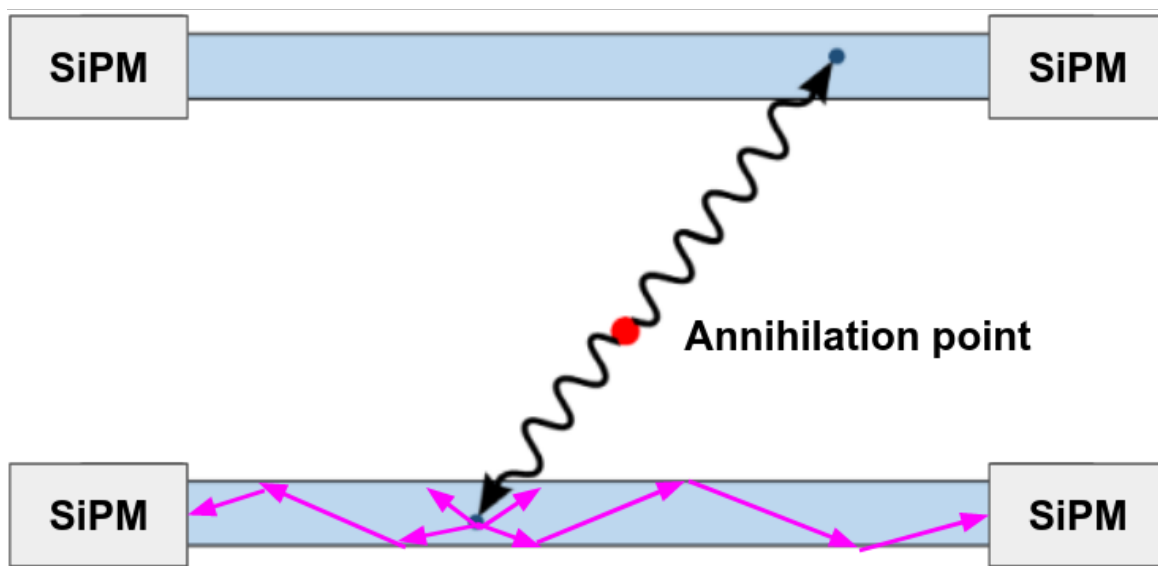
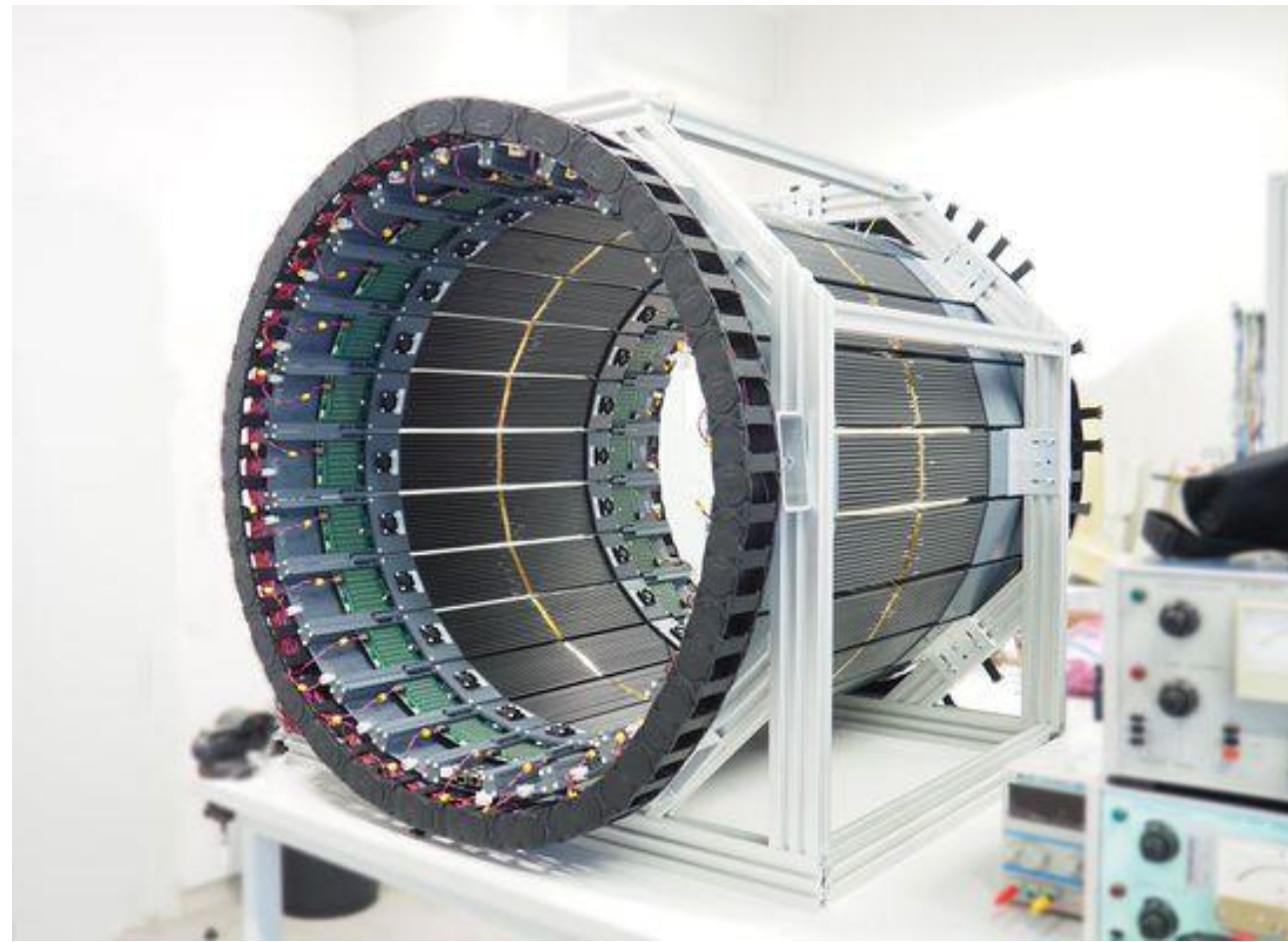
Table 1. Isotopes scored in the form of production maps.

isotope	half-time [s]
^{15}O	122.2
^{14}O	70.6
^{13}N	597.9
^{11}C	1223.4
^{10}C	19.2
^{30}P	149.9
^{38}K	458.2

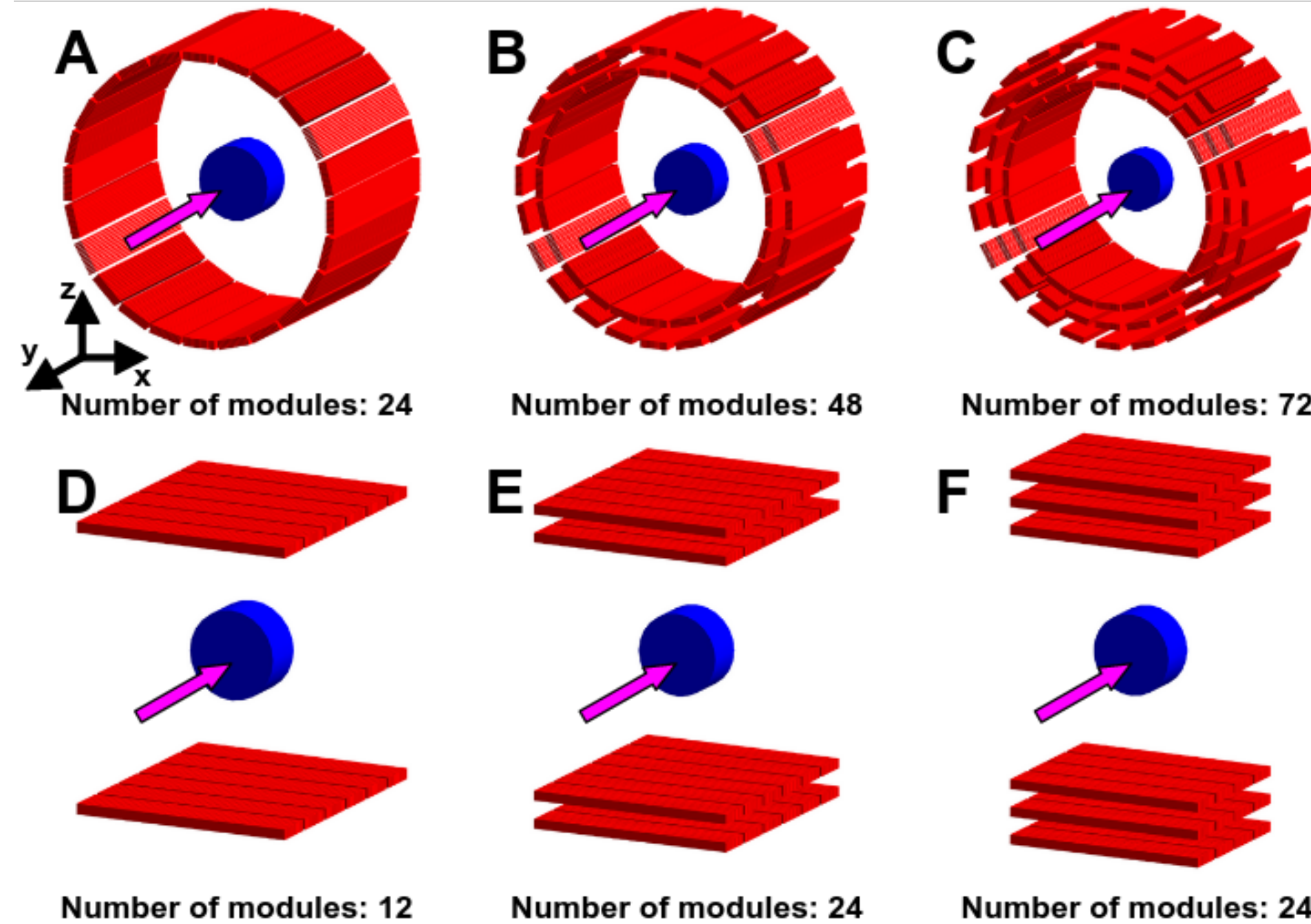


J-PET for range monitoring in PT

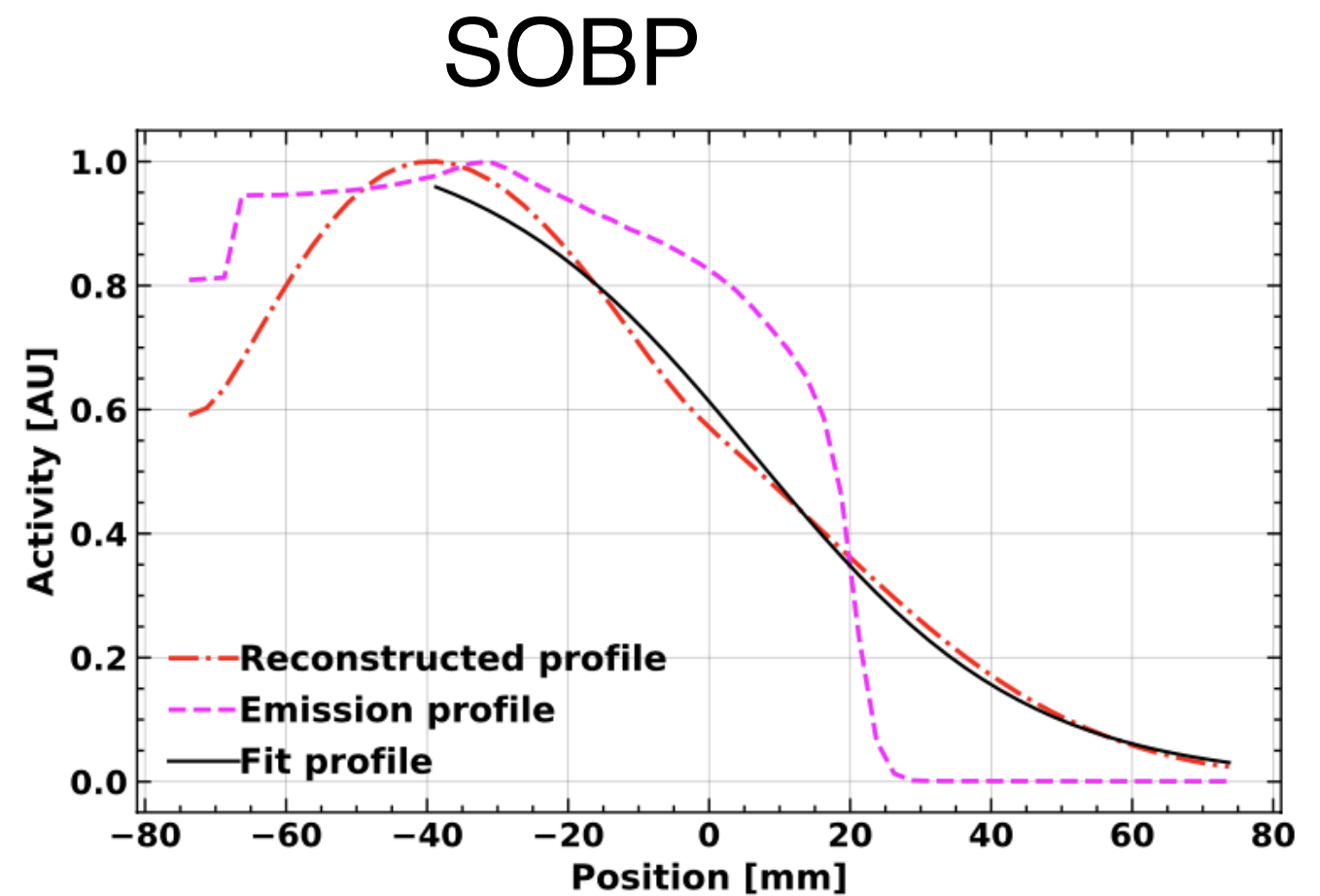
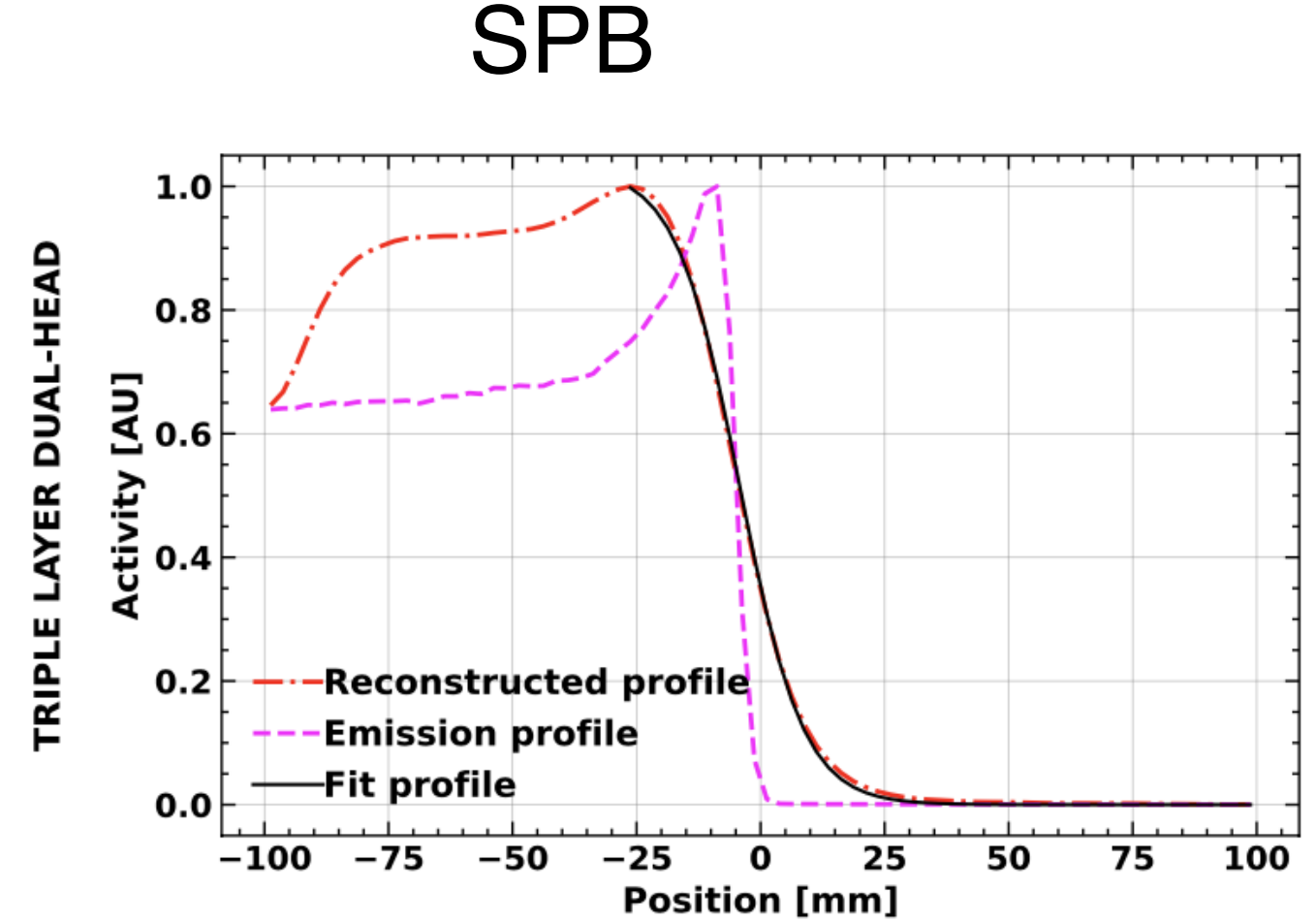
J-PET operation principle



Sensitivity



Range estimation



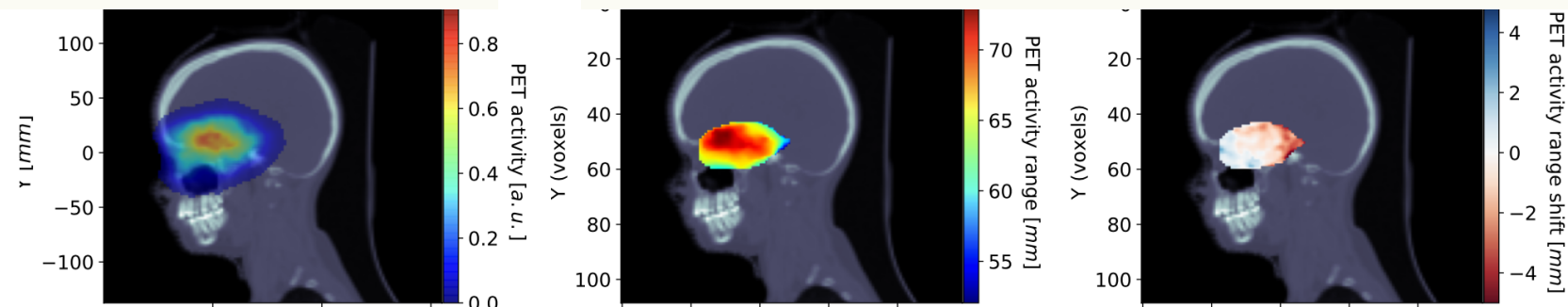
Setup	SPB			SOBP		
	$\eta[10^{-6}]$	$\sigma(\eta)[10^{-6}]$	\bar{H}	$\eta[10^{-6}]$	$\sigma(\eta)[10^{-6}]$	\bar{H}
Single layer cylindrical	9.45	0.29	1.0	3.64	0.22	1.0
Double layer cylindrical	27.41	0.80	2.9	10.76	0.65	2.9
Triple layer cylindrical	45.72	1.26	4.8	18.00	1.11	5.0
Single layer dual-head	3.79	0.13	0.4	2.45	0.19	0.7
Double layer dual-head	10.55	0.35	1.1	7.21	0.56	2.0
Triple layer dual-head	10.22	0.26	1.1	8.92	0.78	2.4

Range shift detection in patients

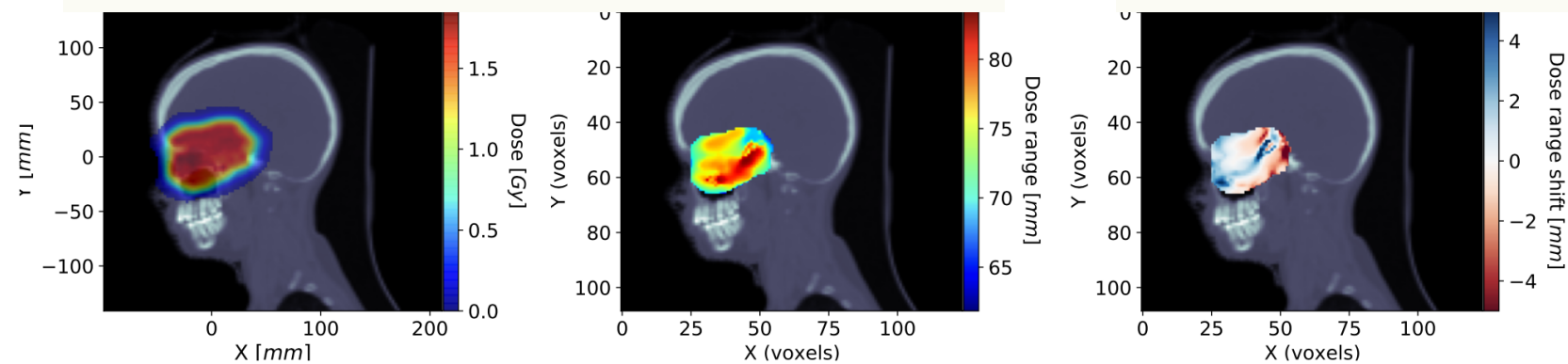
Patient simulation studies with J-PET

94 patients x 27 scenarios
(24 shifts + 2 CT cal. + reference)

Activity BEV → Range → Range diff.



Dose BEV → Range → Range diff.

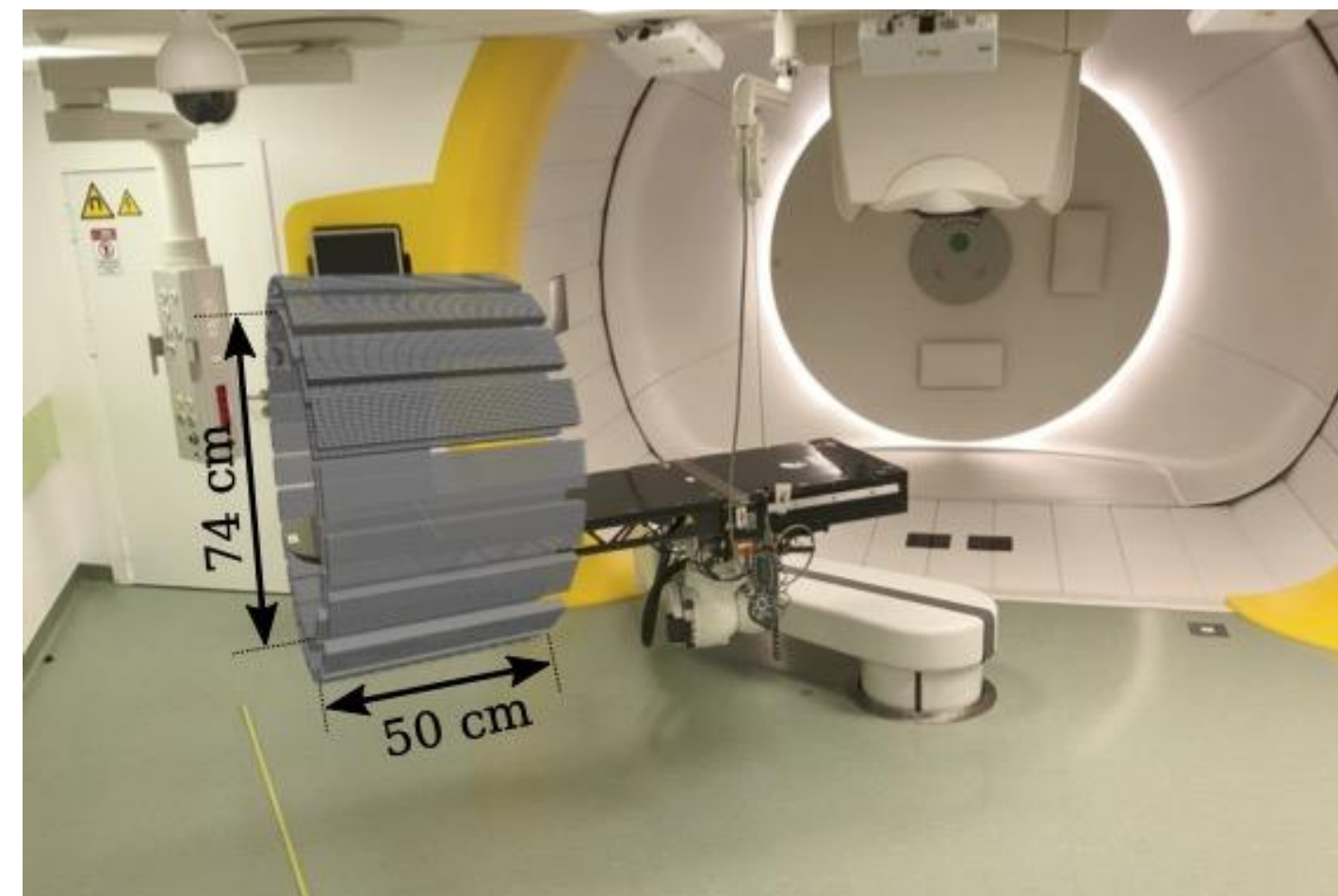


(d)

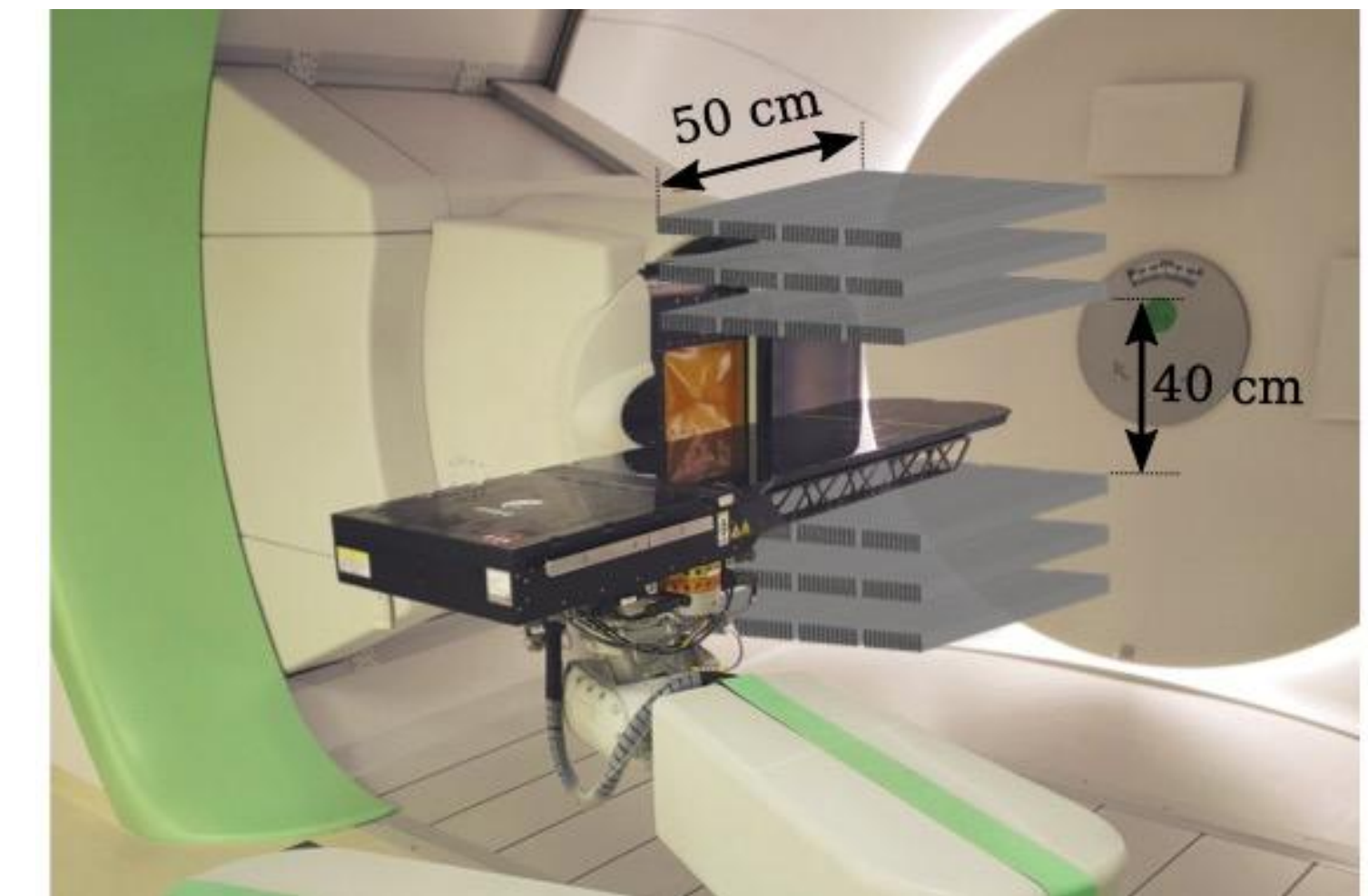
(e)

(f)

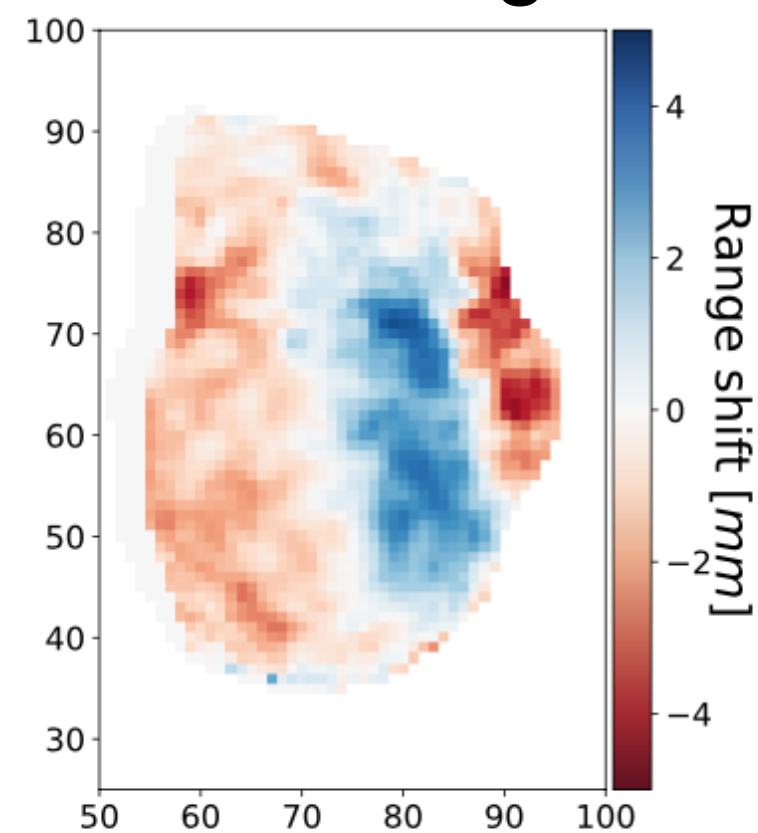
In-room PET imaging protocol



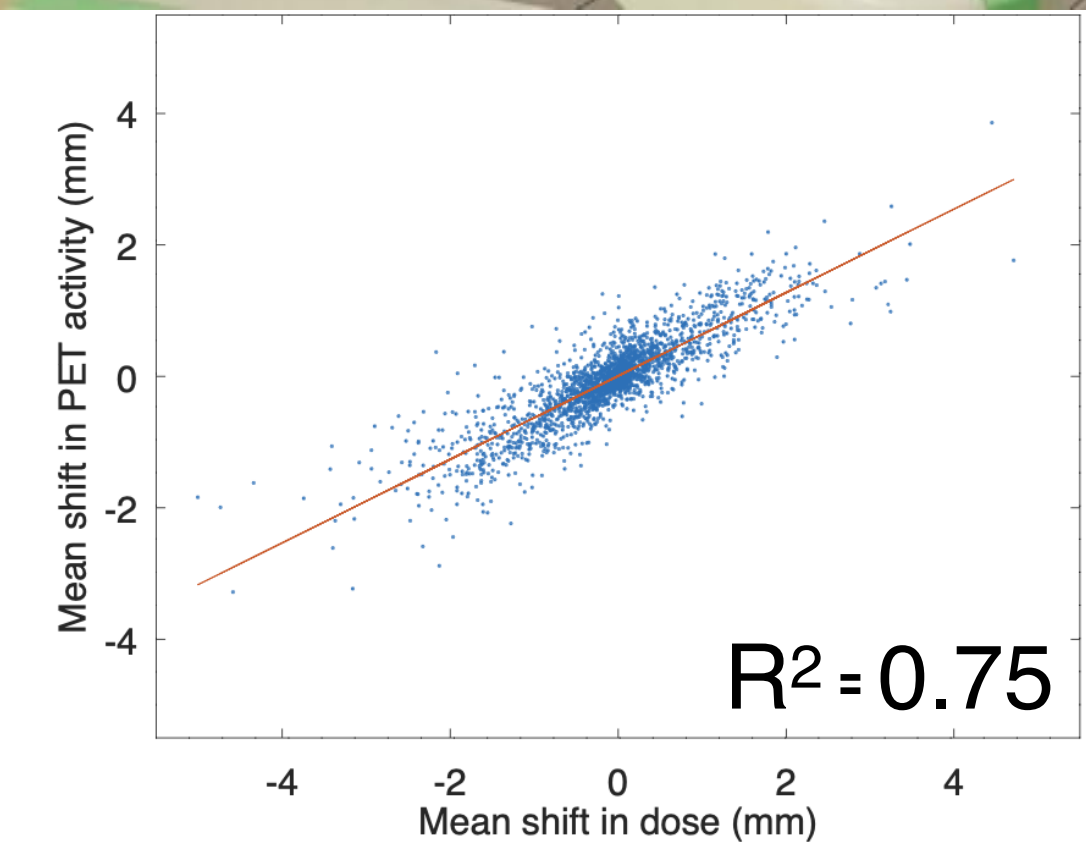
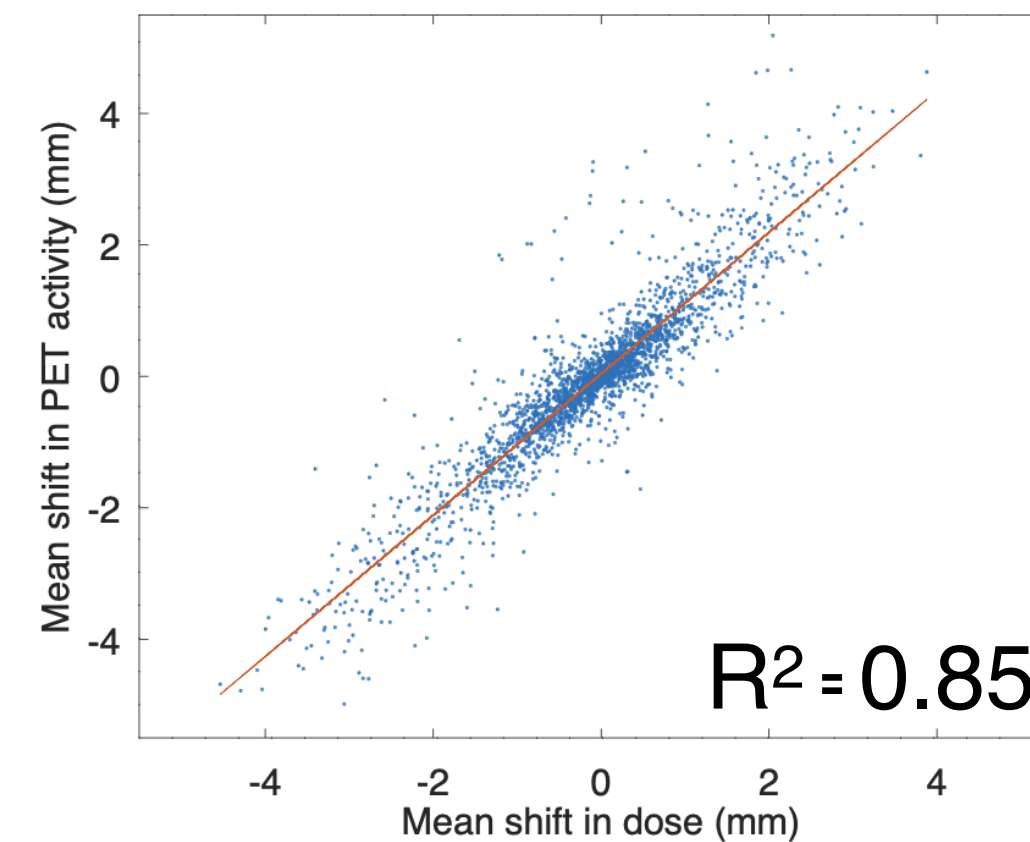
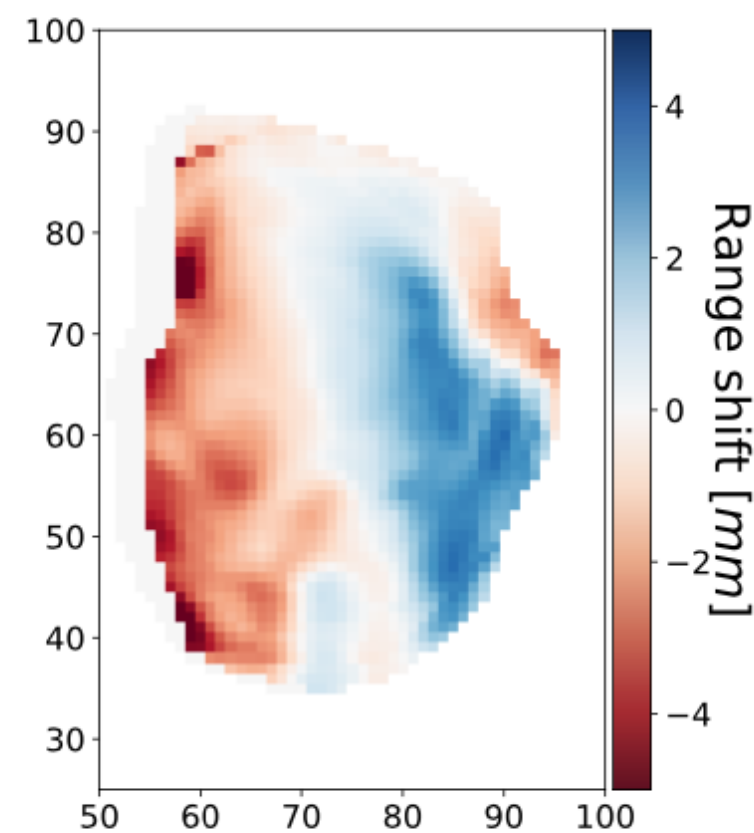
In-beam PET imaging protocol



PET image

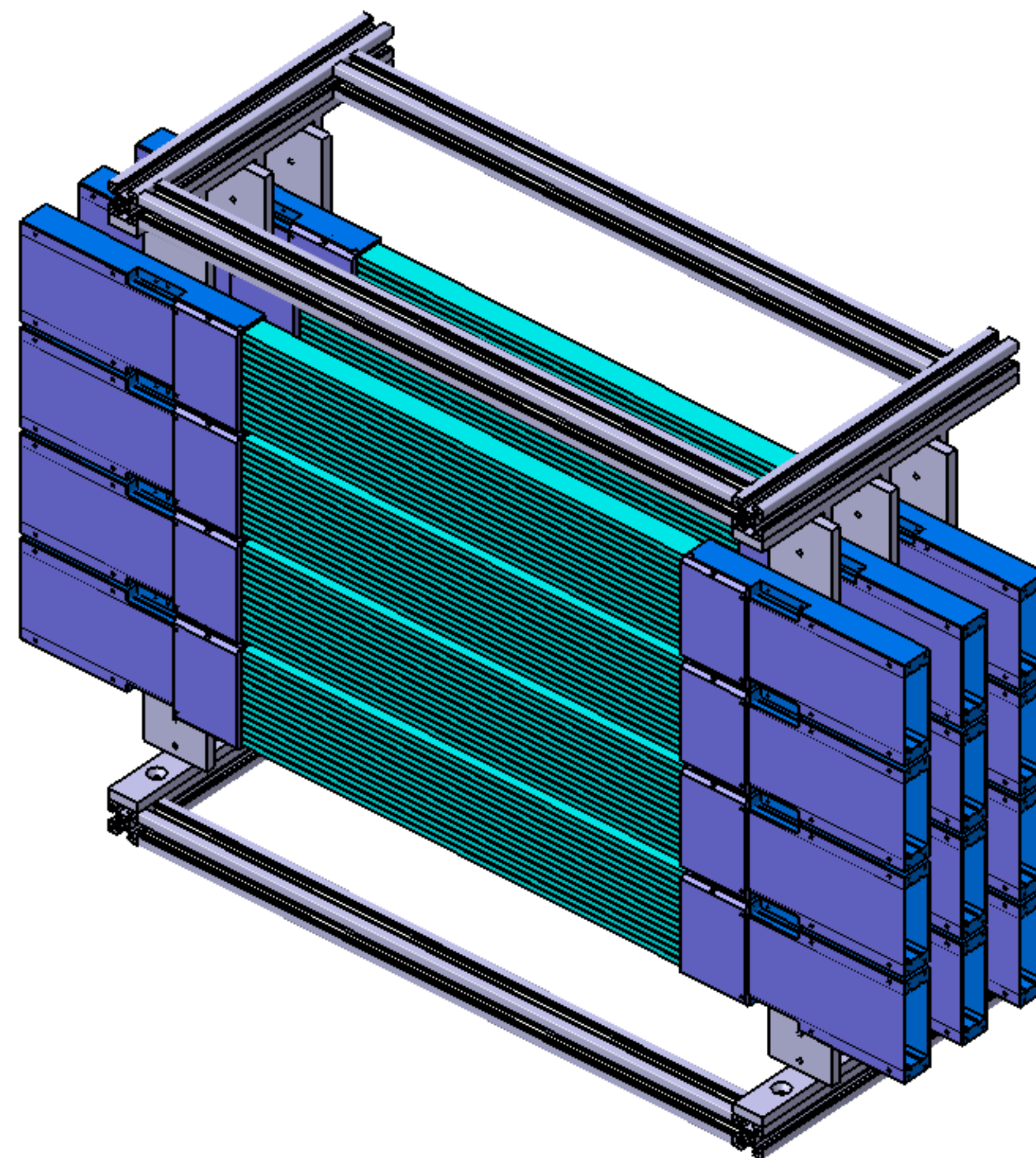
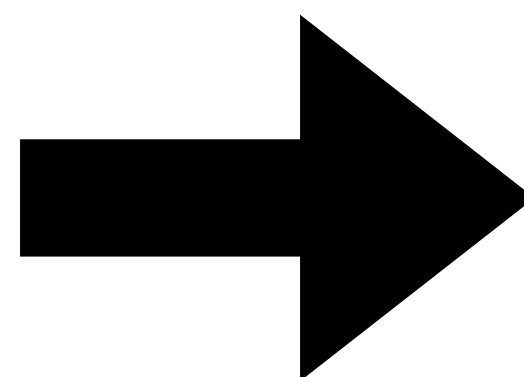
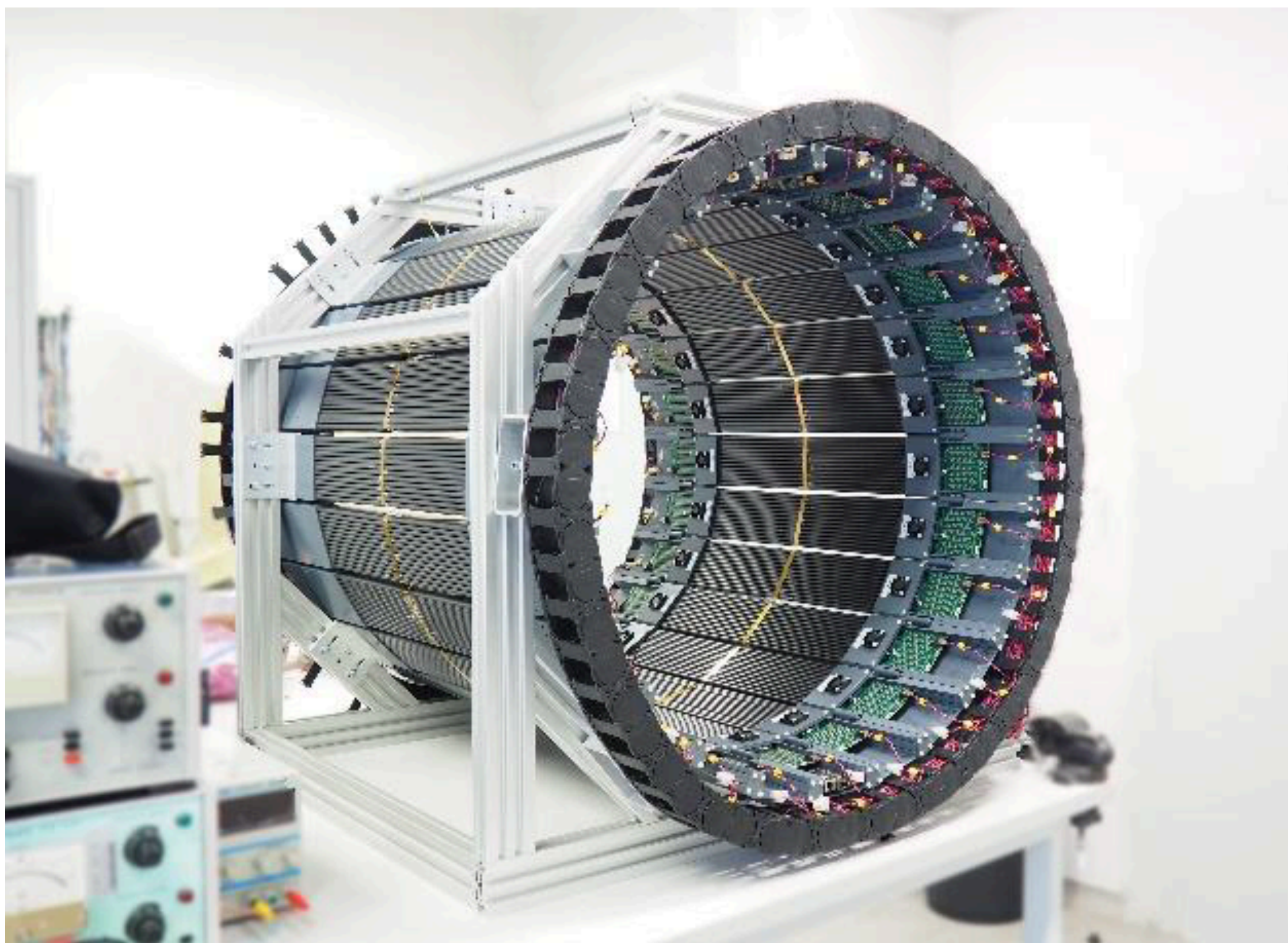


Dose image

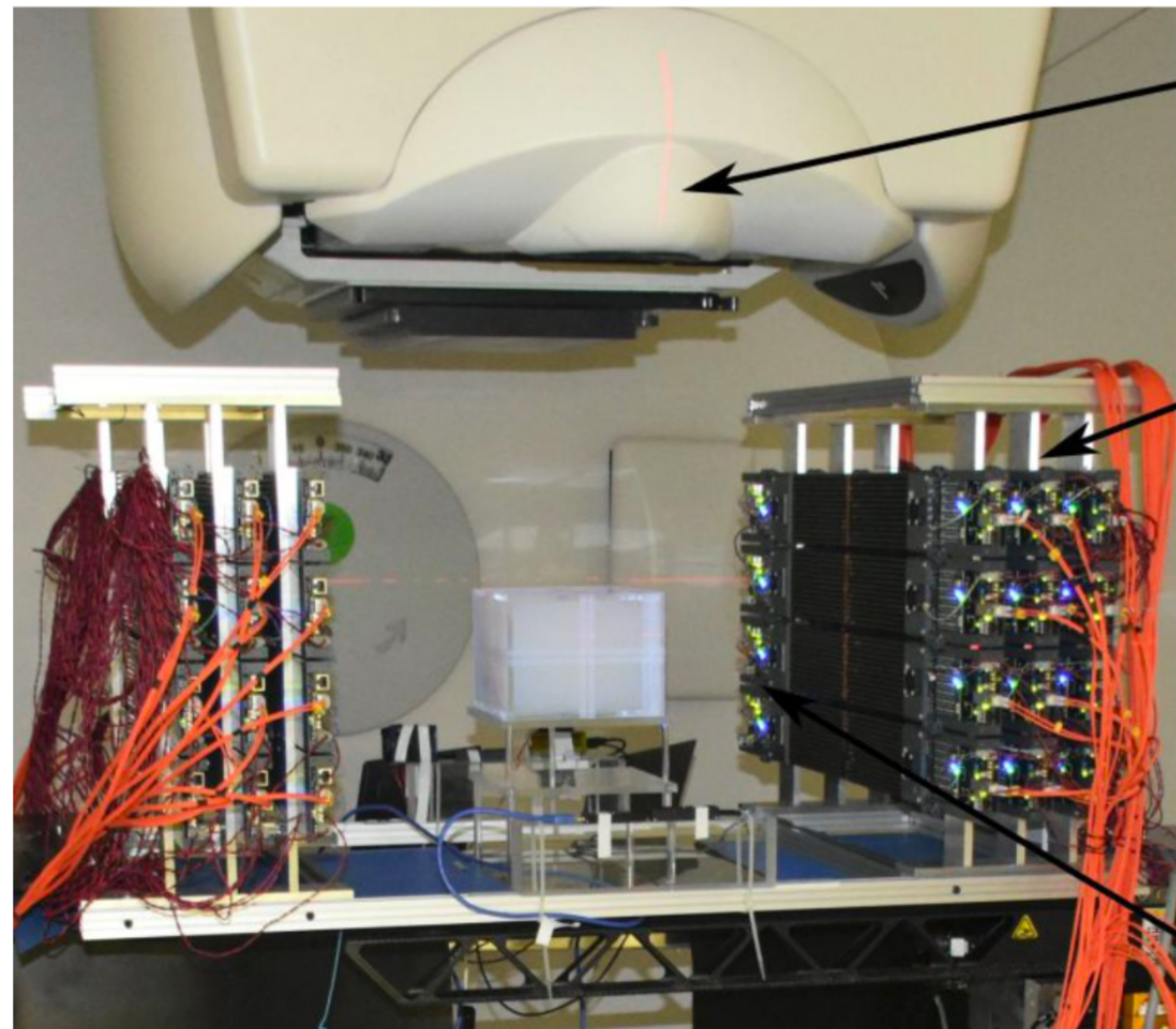
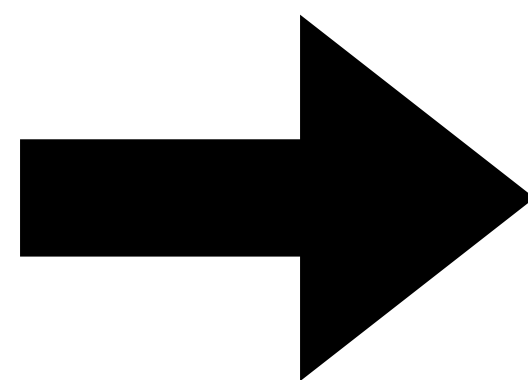
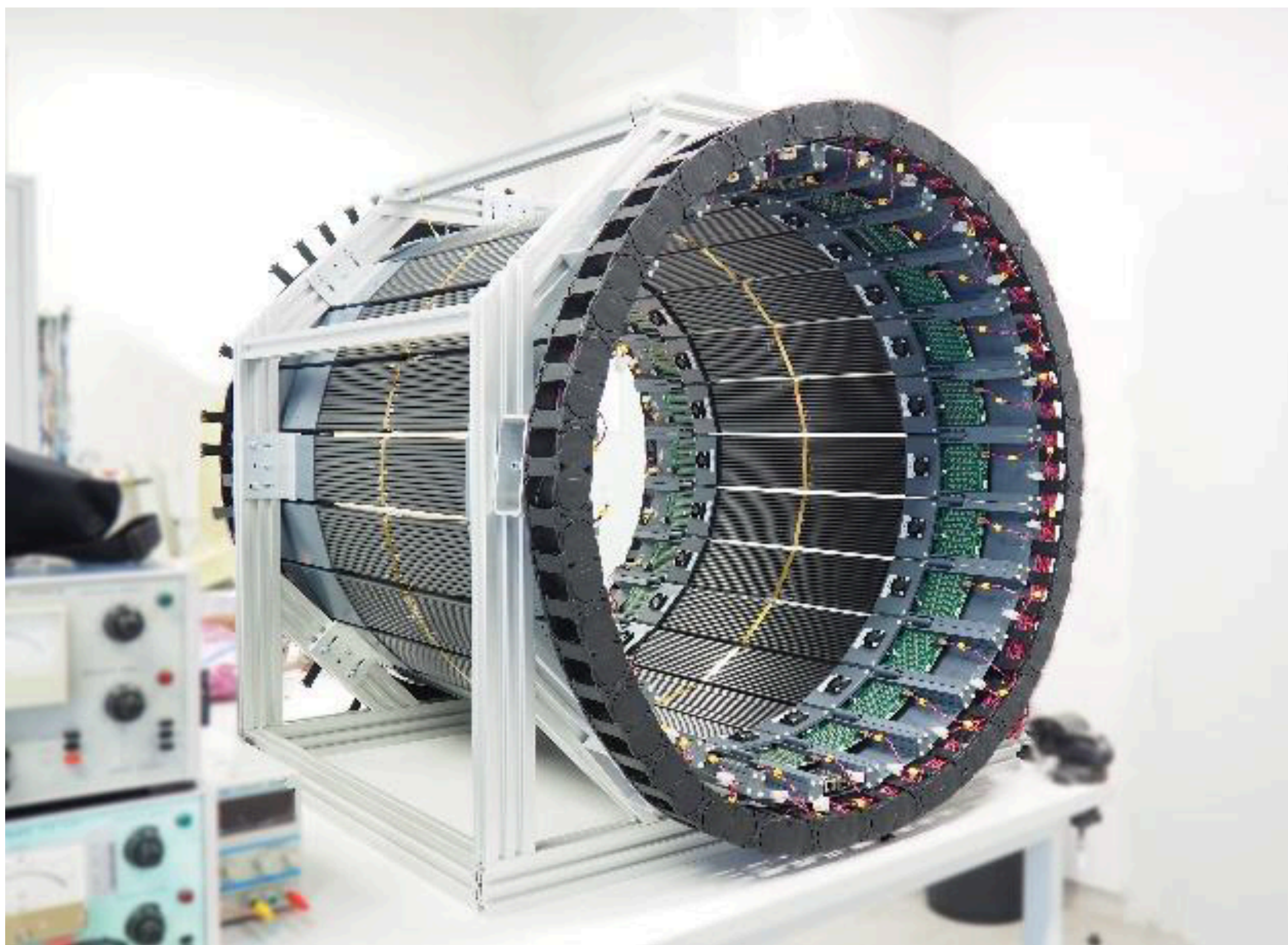


K. Brzezinski, et al., PMB (2023) <https://doi.org/10.1088/1361-6560/acdd4c>

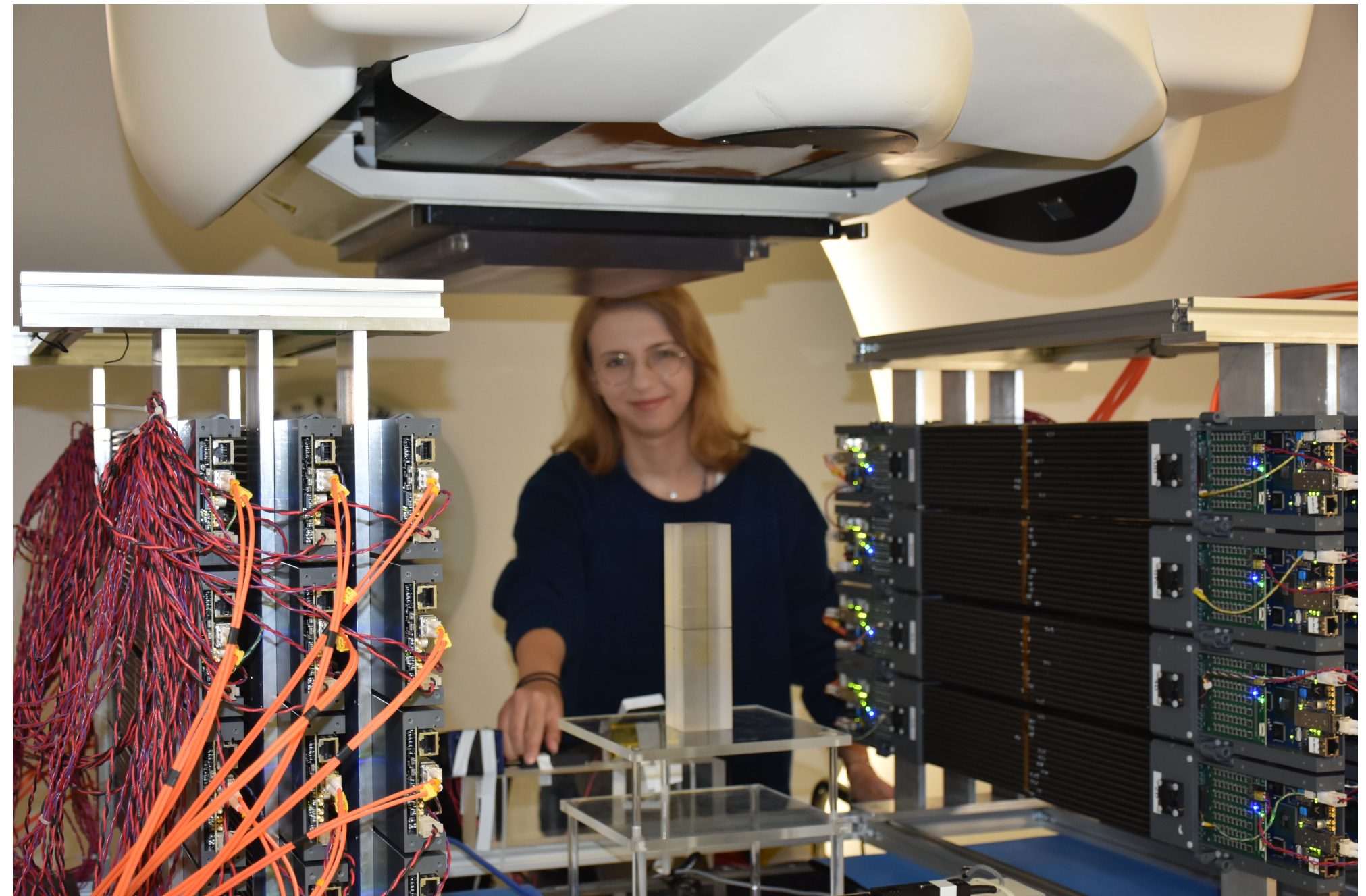
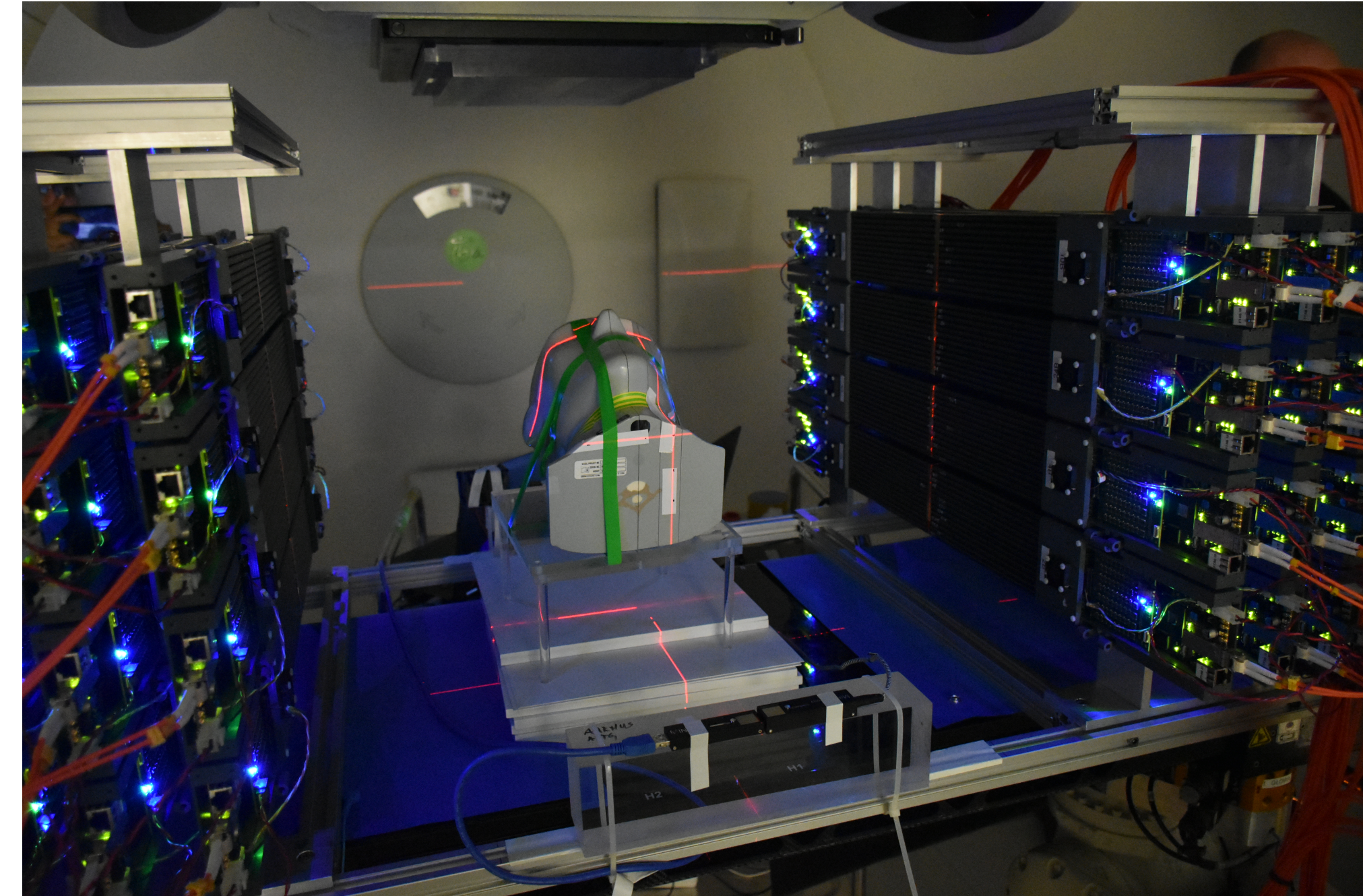
From the J-PET ring to the J-PET head



From the J-PET ring to the J-PET head

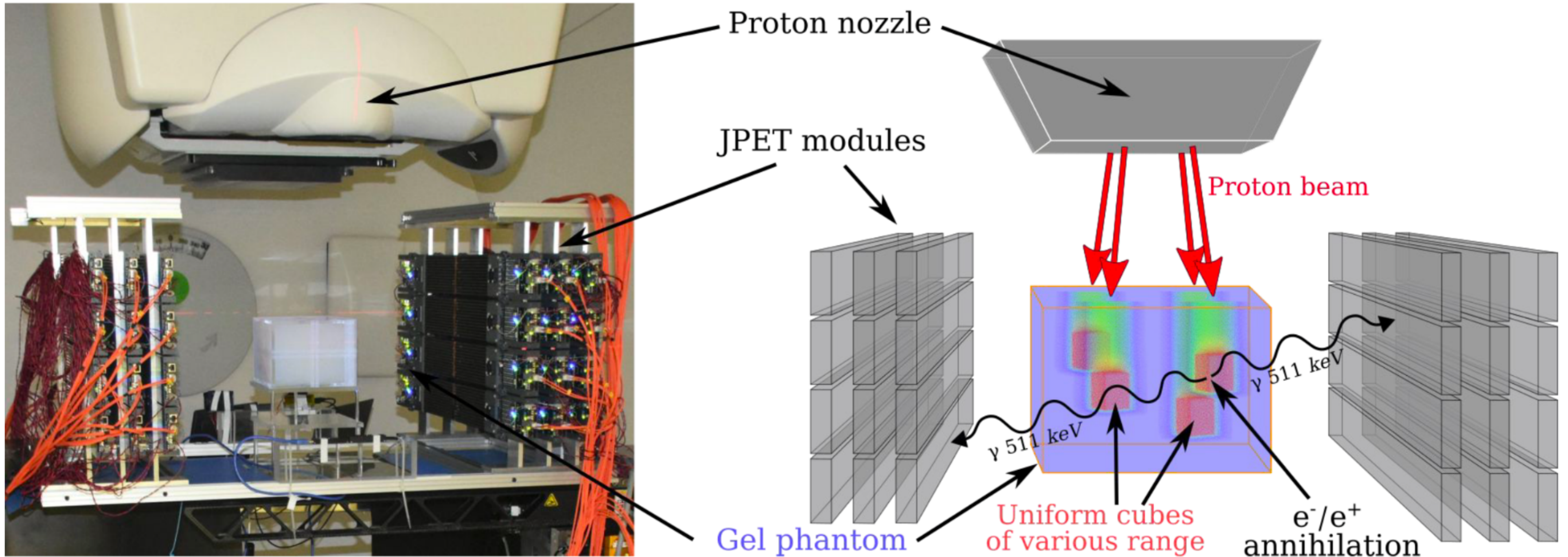


J-PET & proton beams 2021

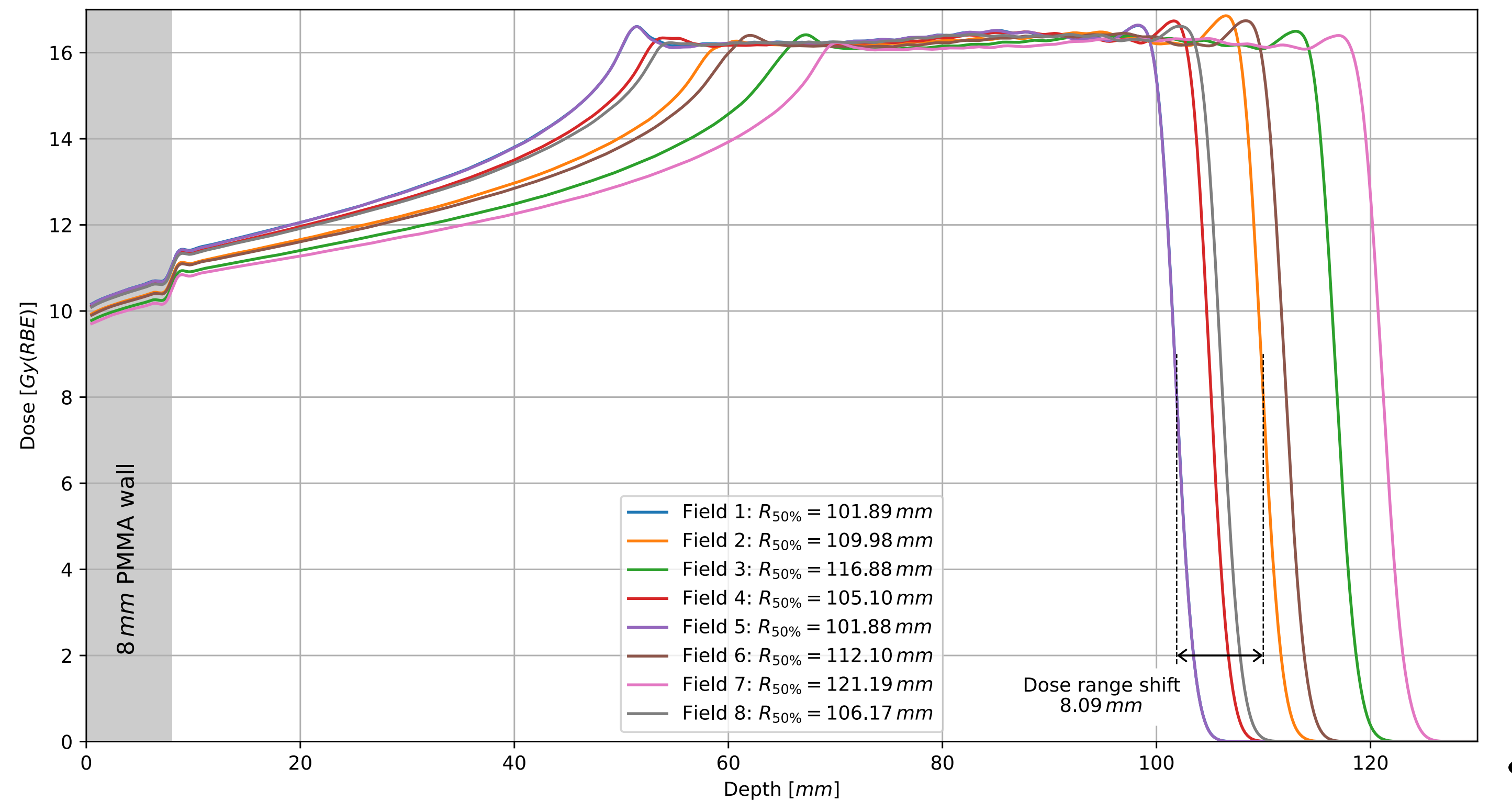
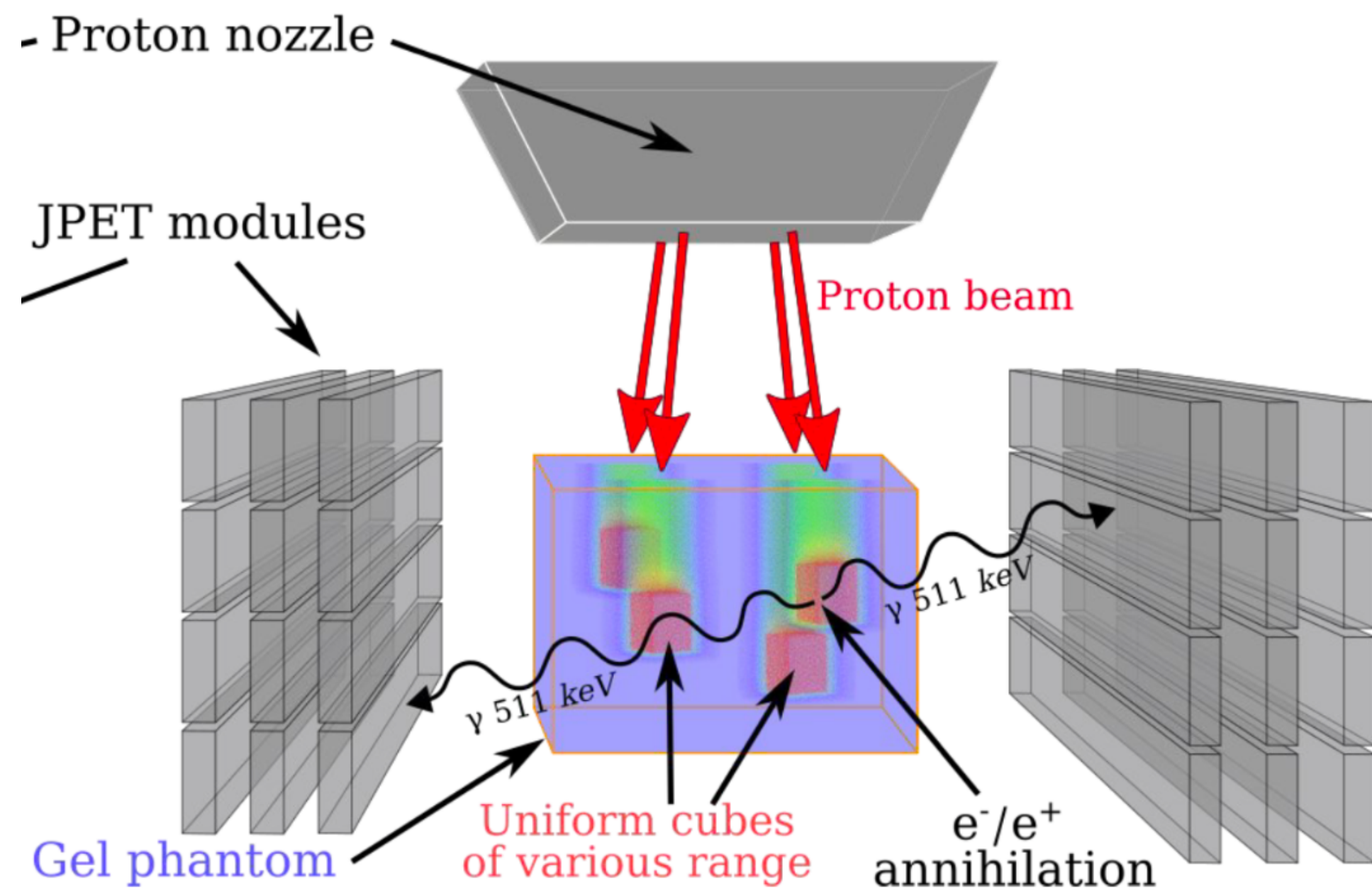
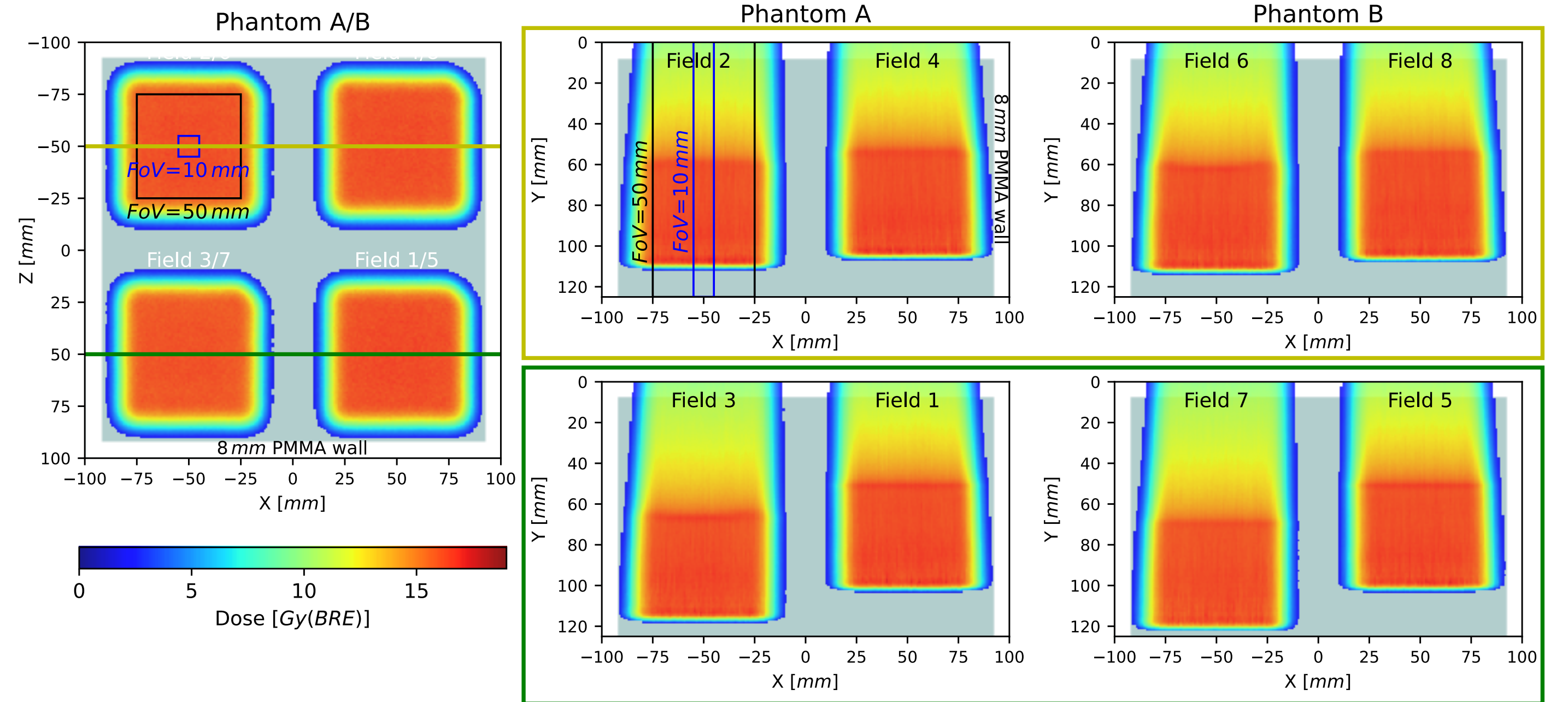


J-PET for range monitoring in PT

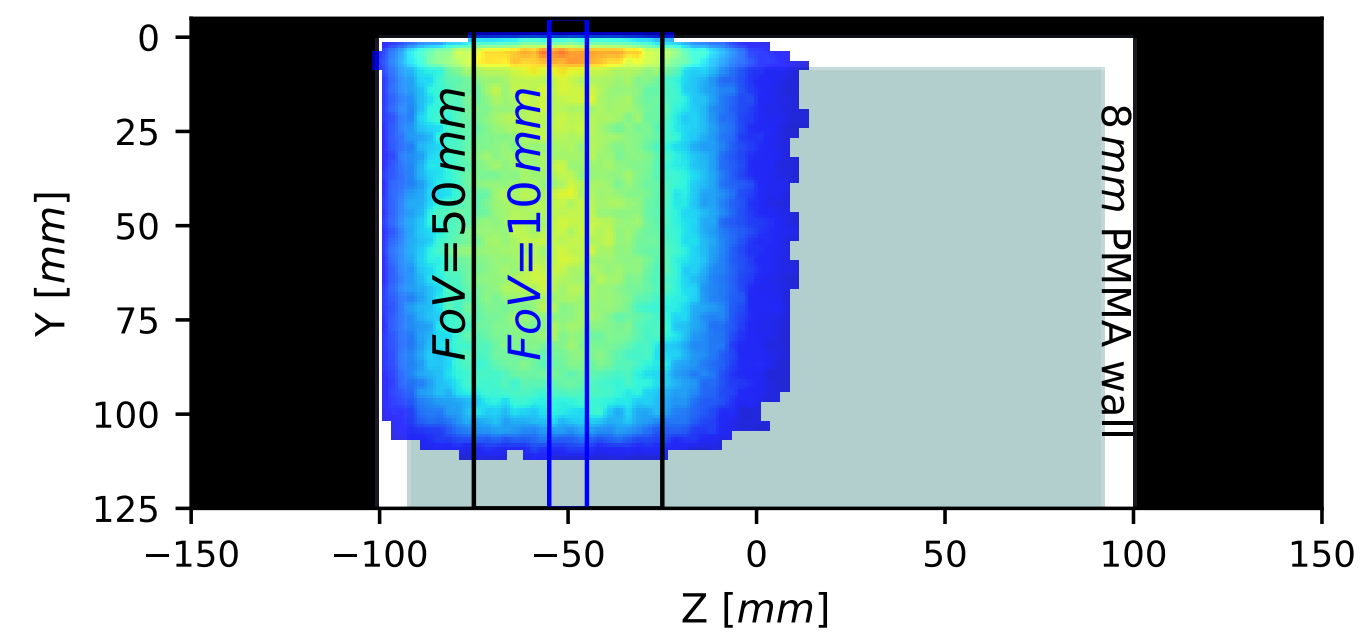
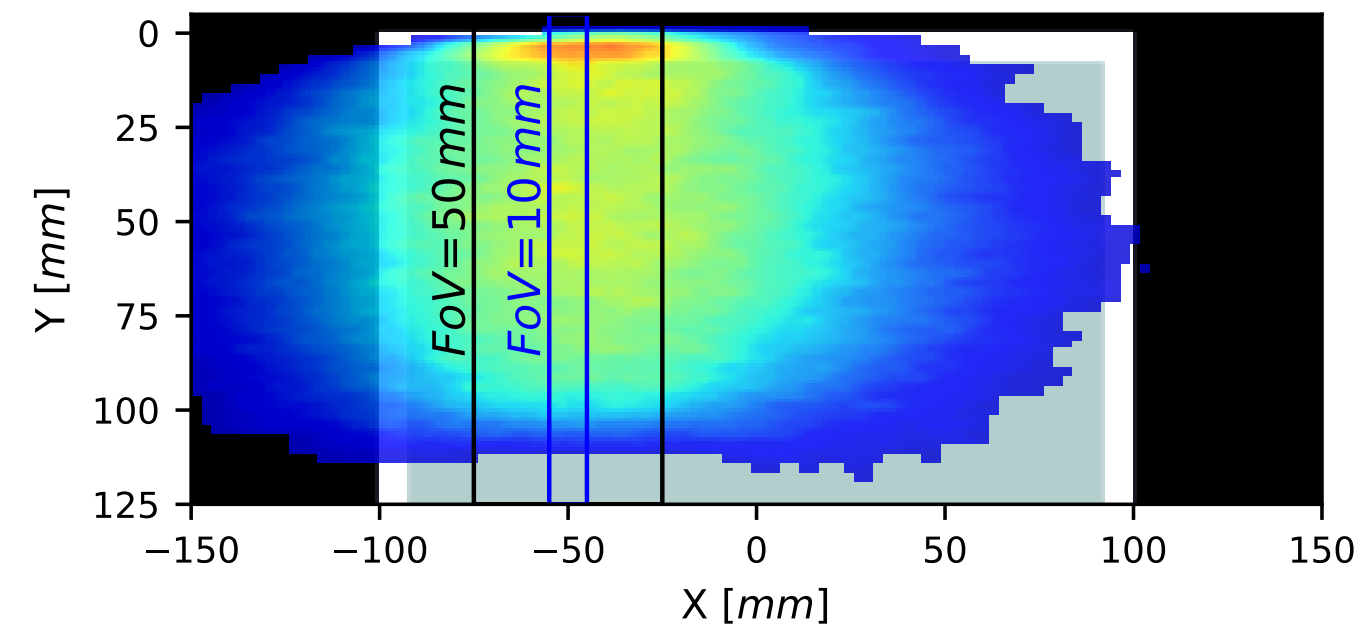
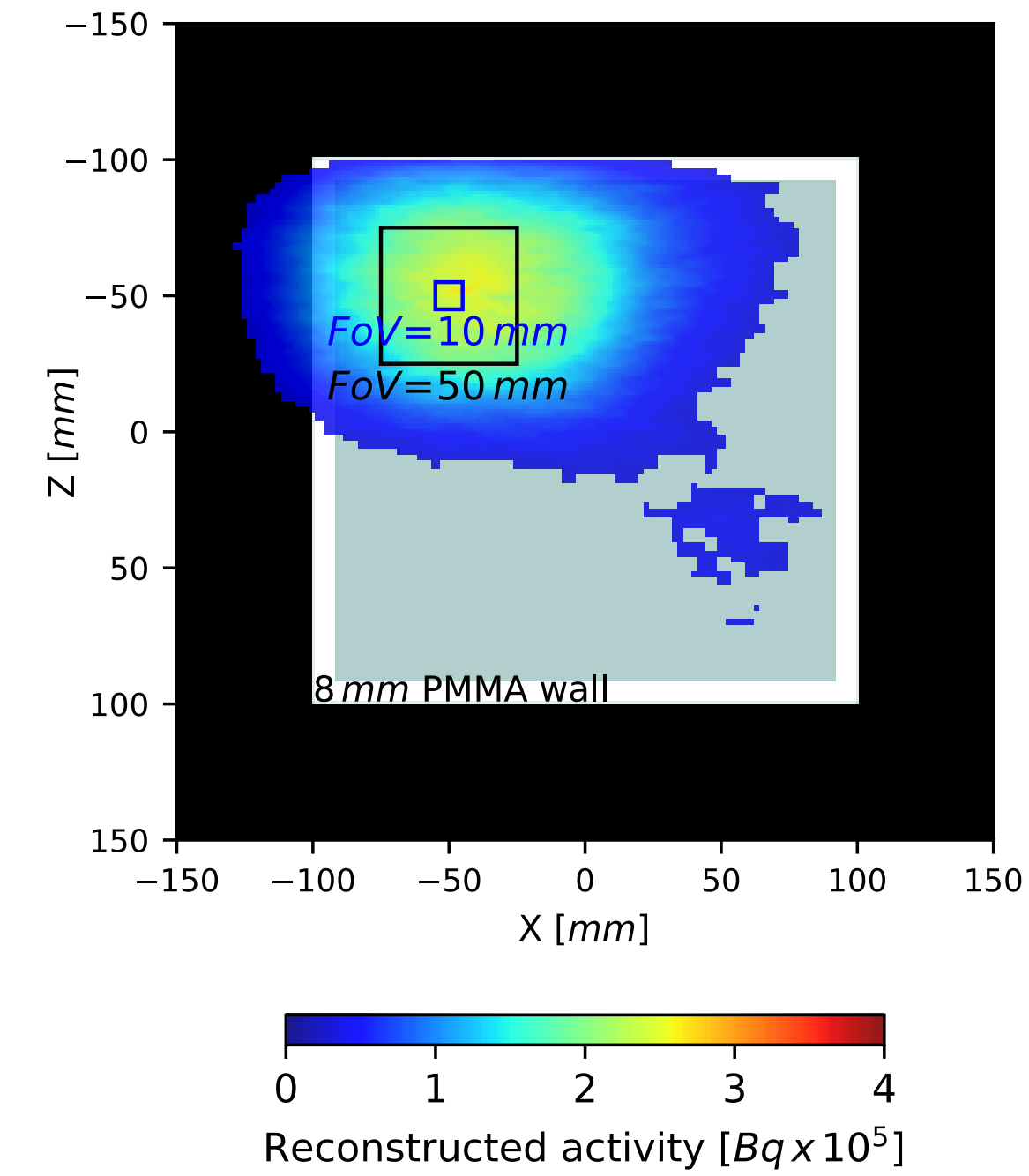
Experimental validation with proton beams at CCB



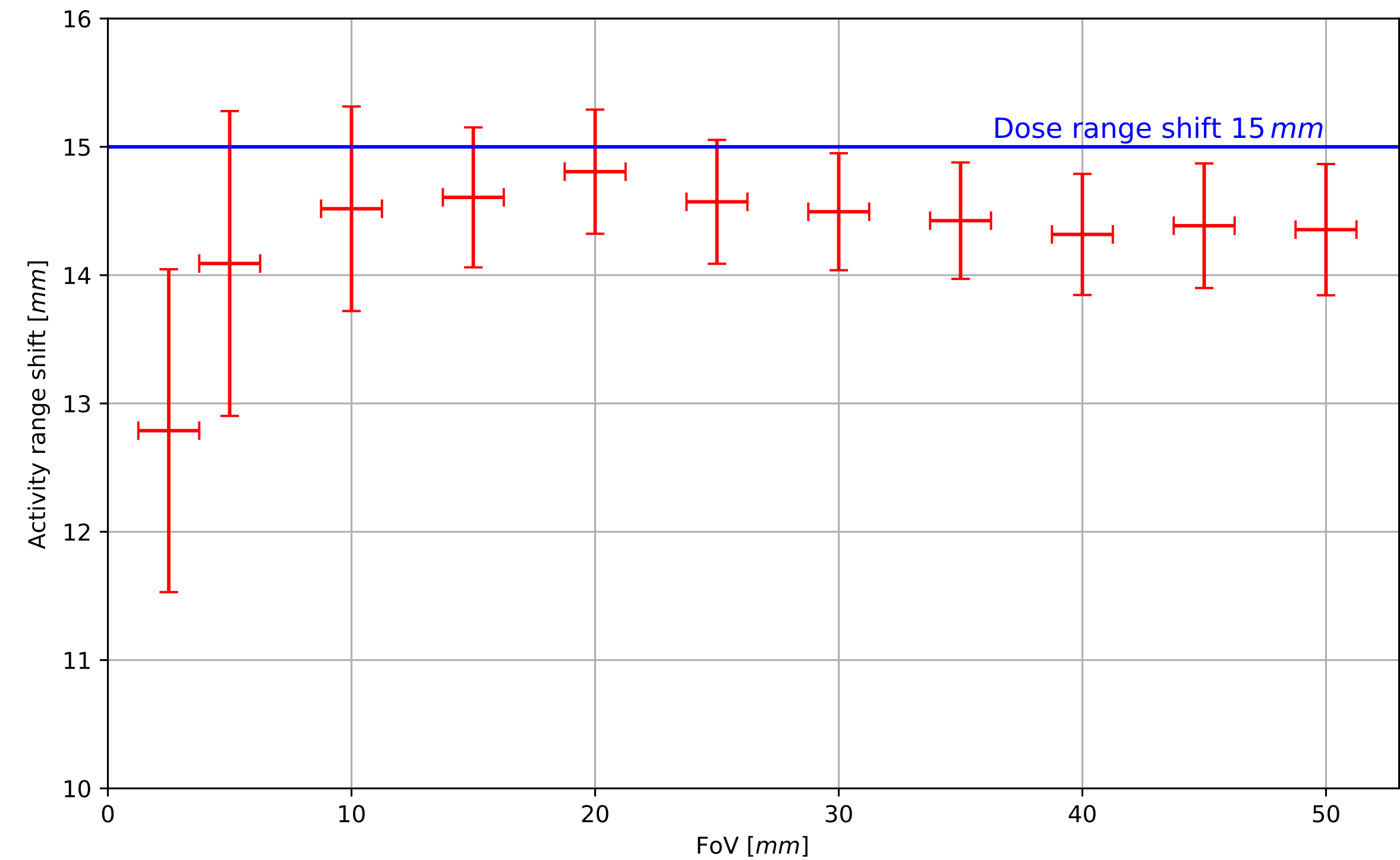
SOBP setup



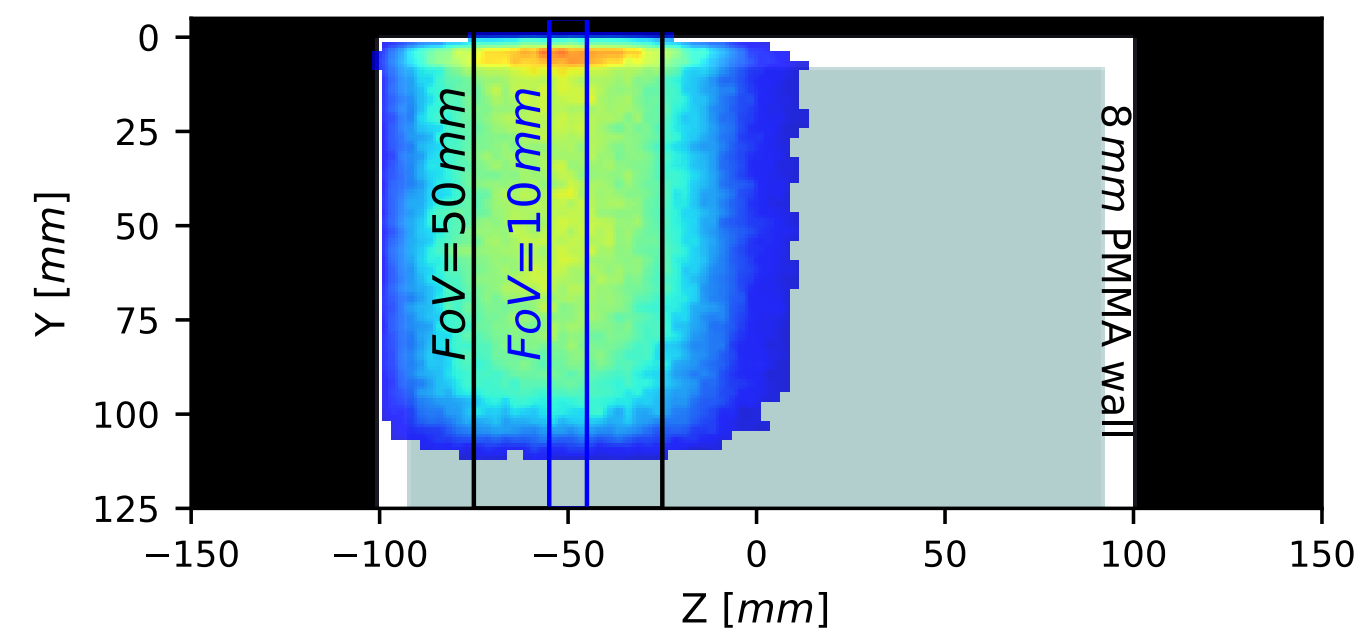
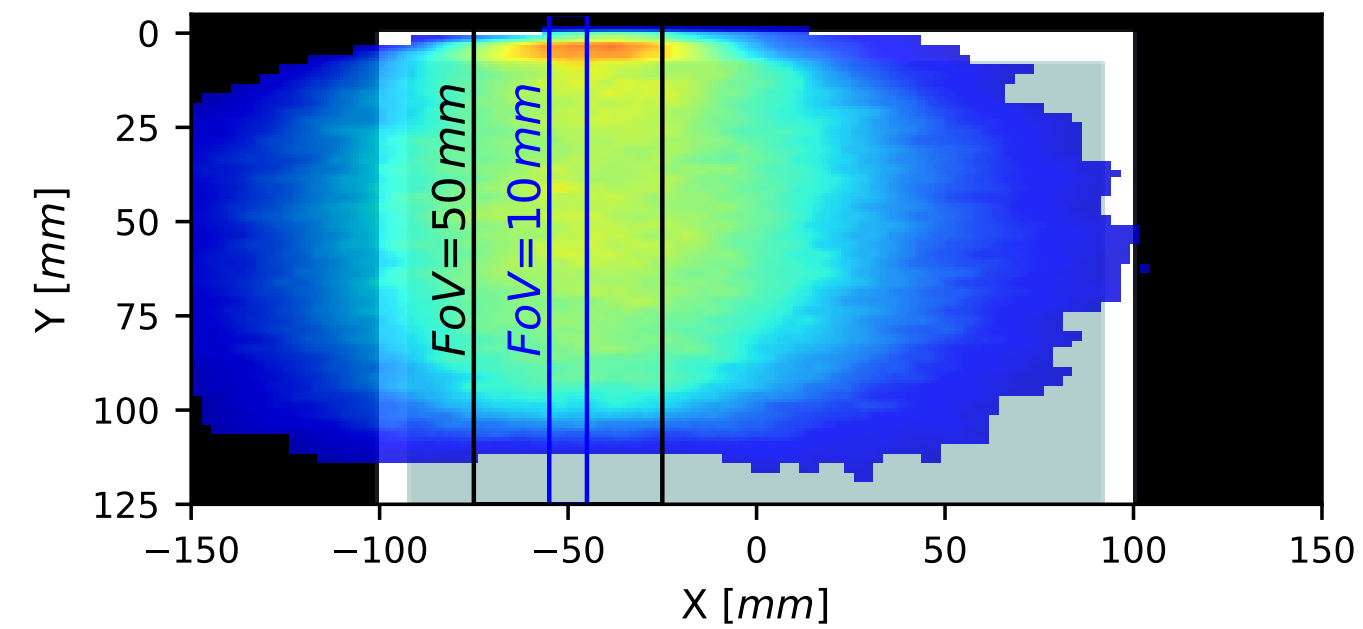
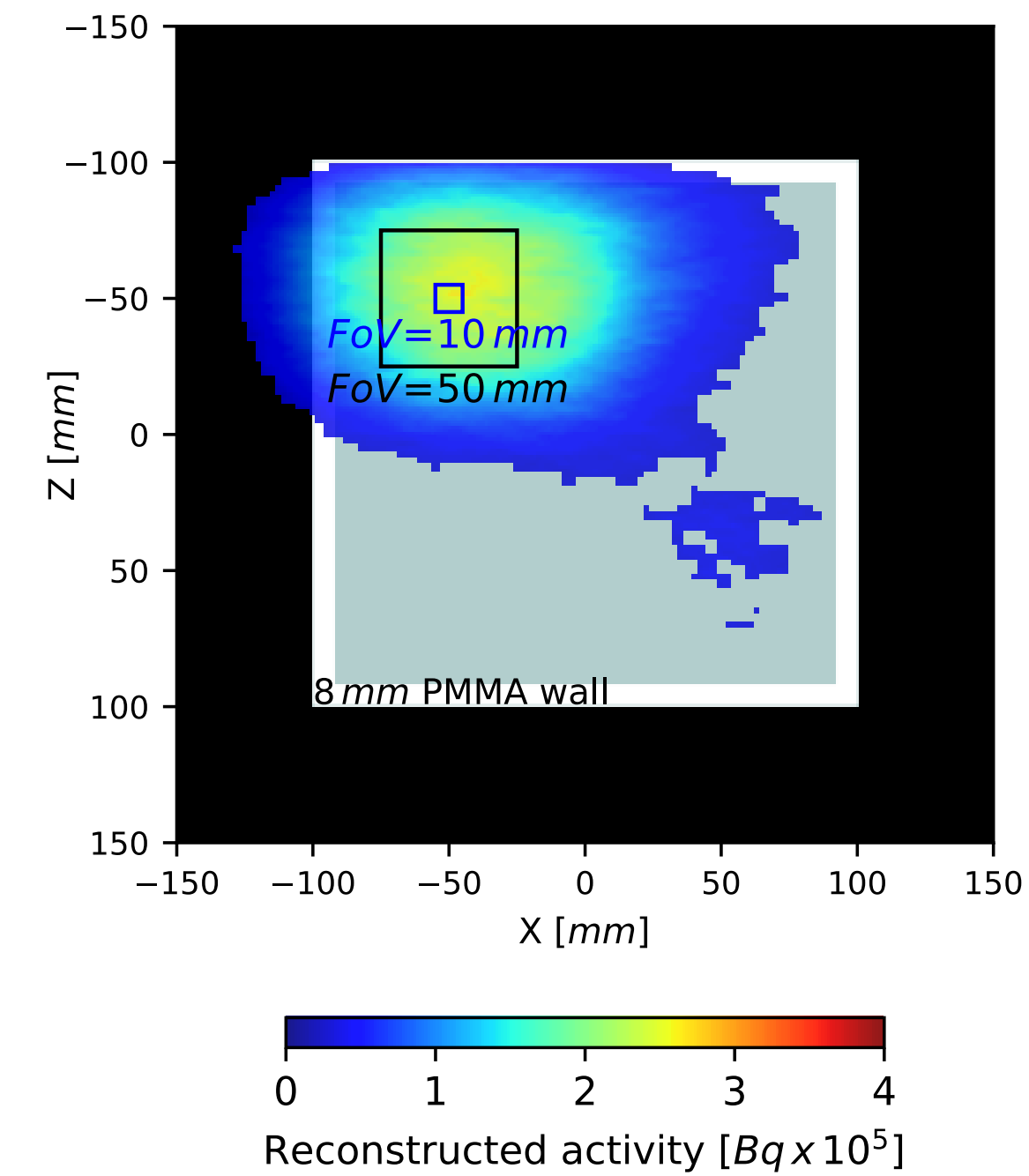
The first J-PET image acquired with protons



FOV dependence

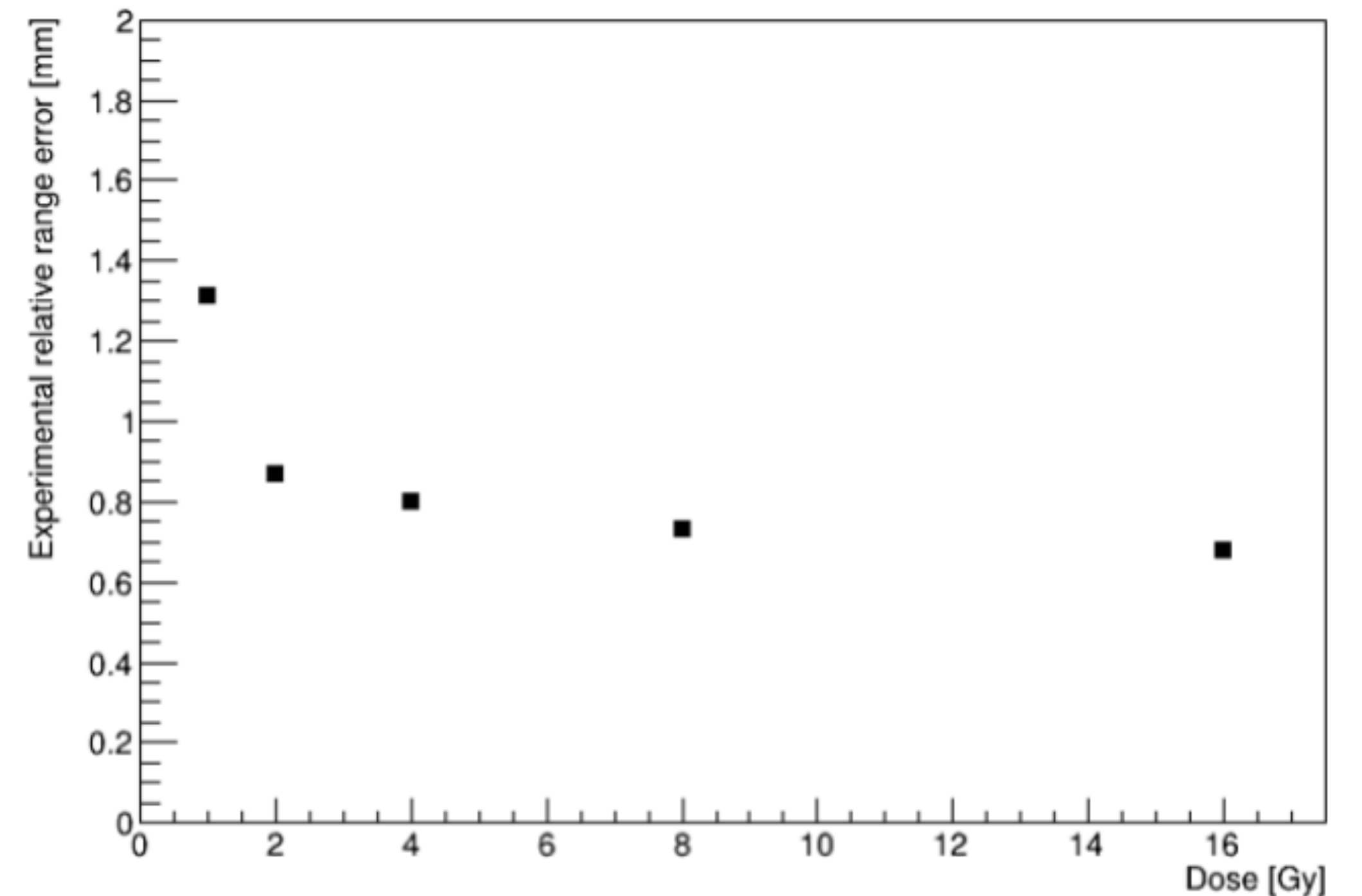


The first J-PET image acquired with protons

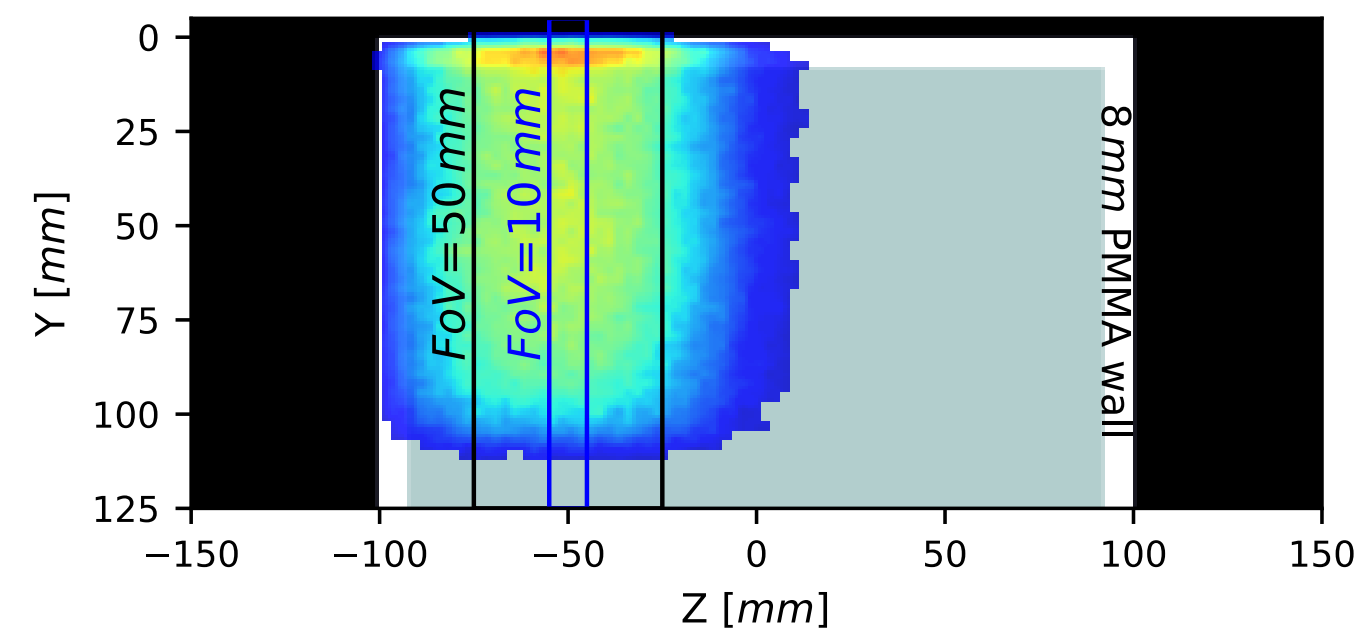
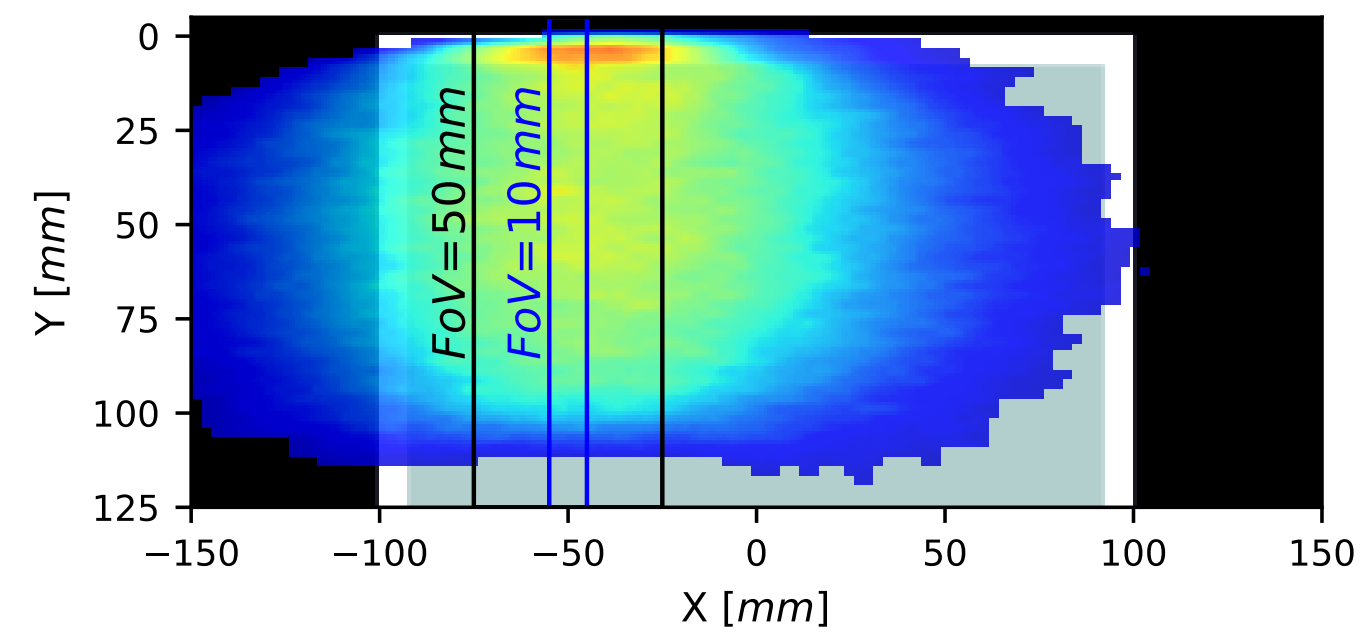
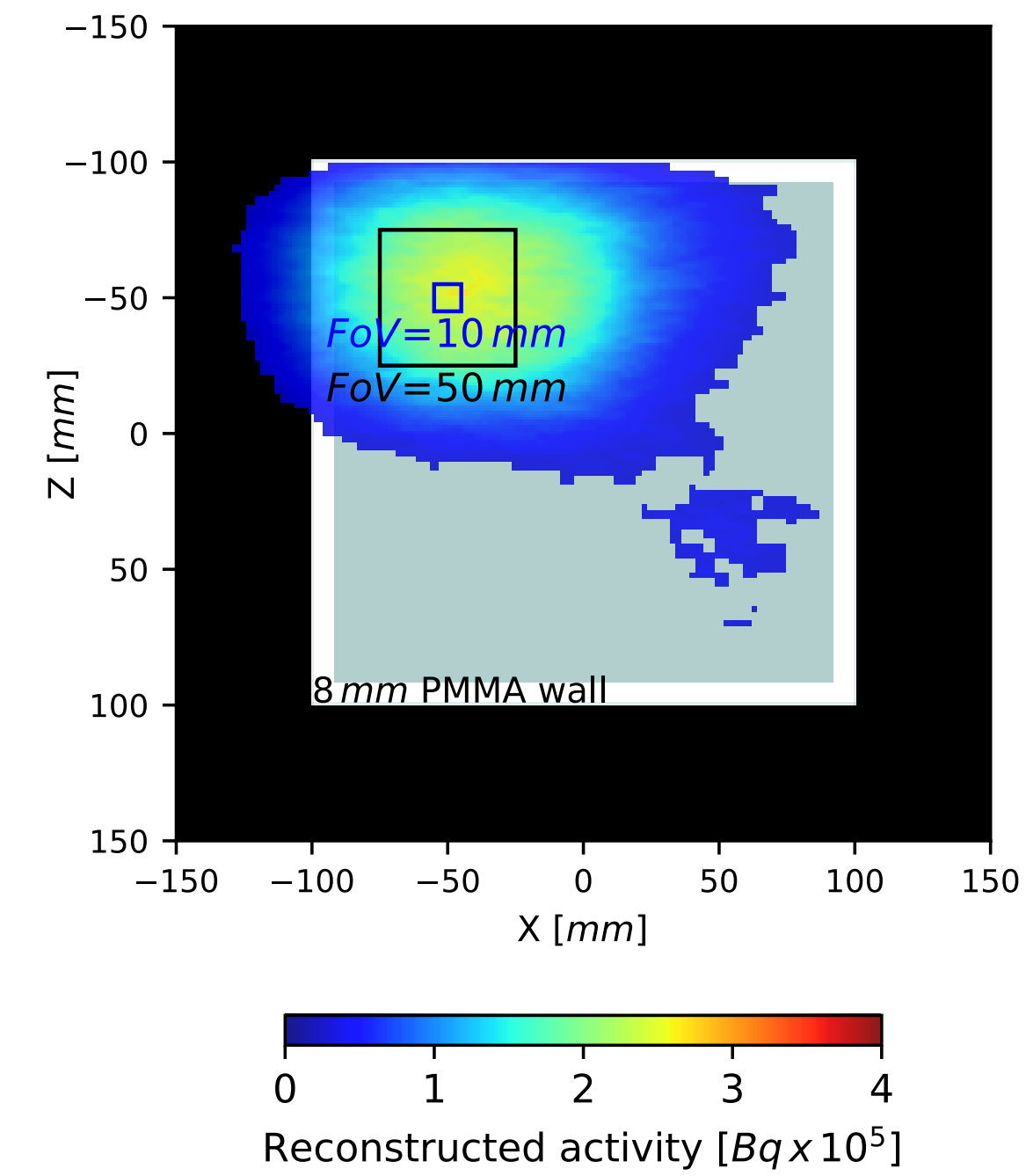


Dose dependence

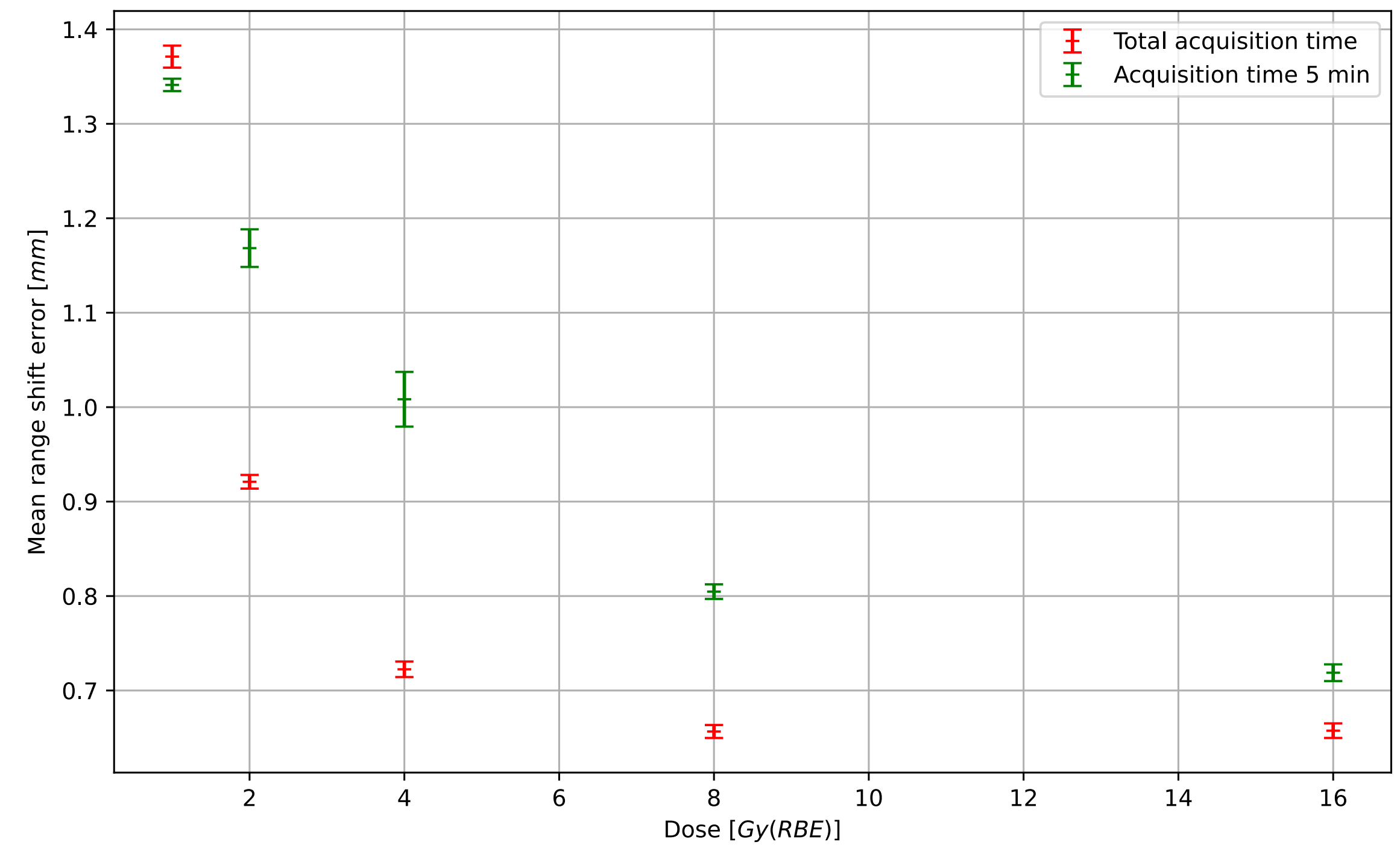
Measured range error vs dose for range -15



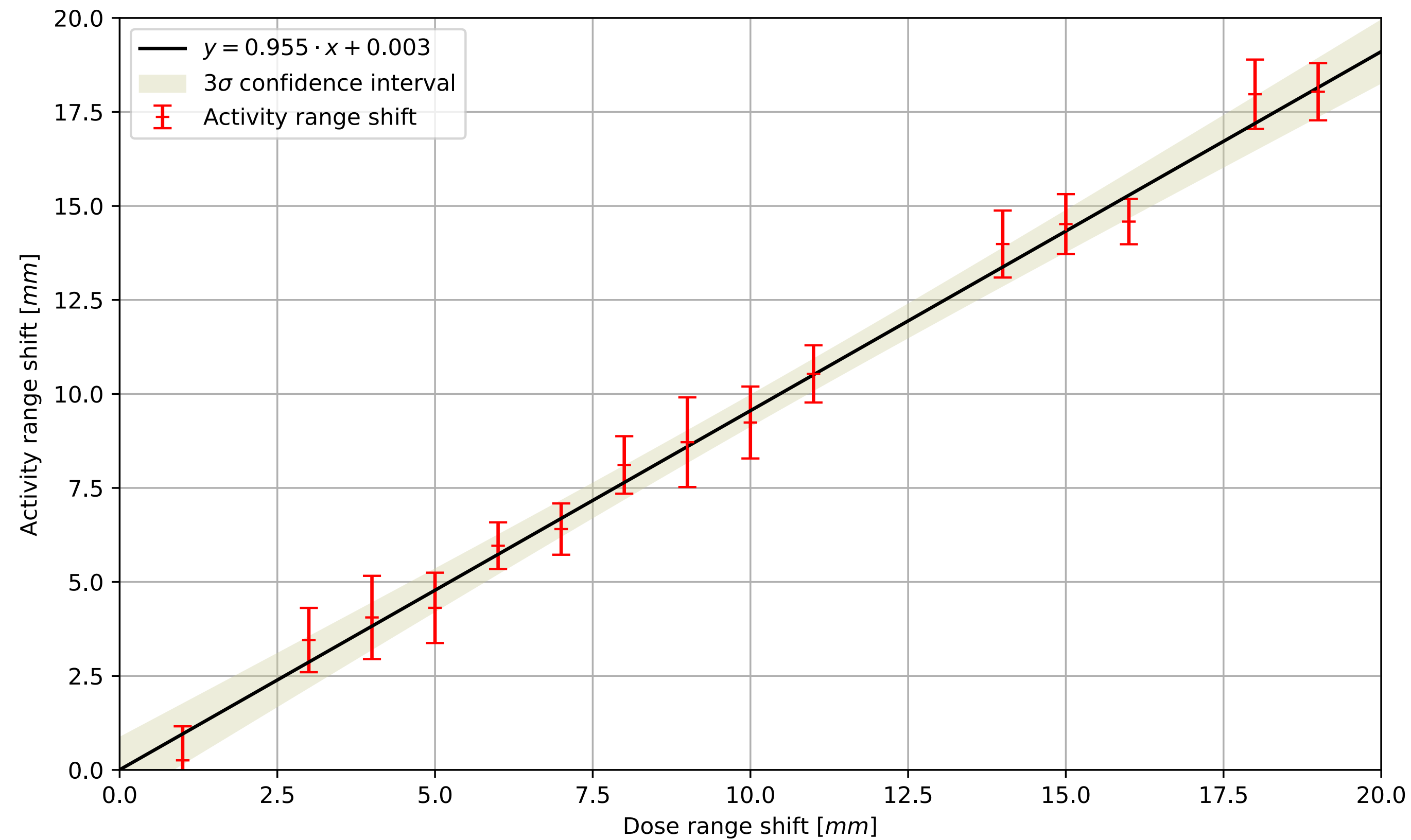
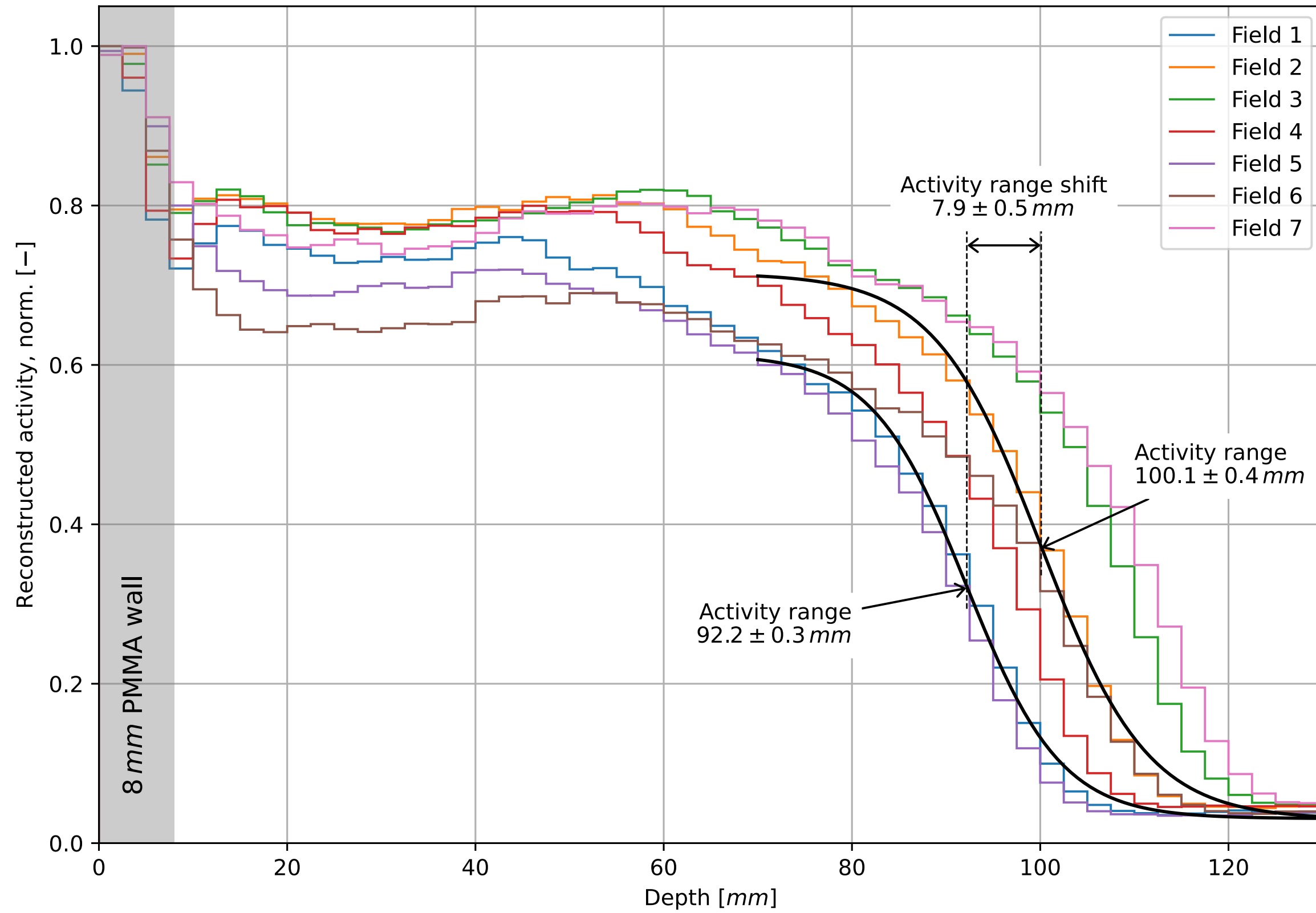
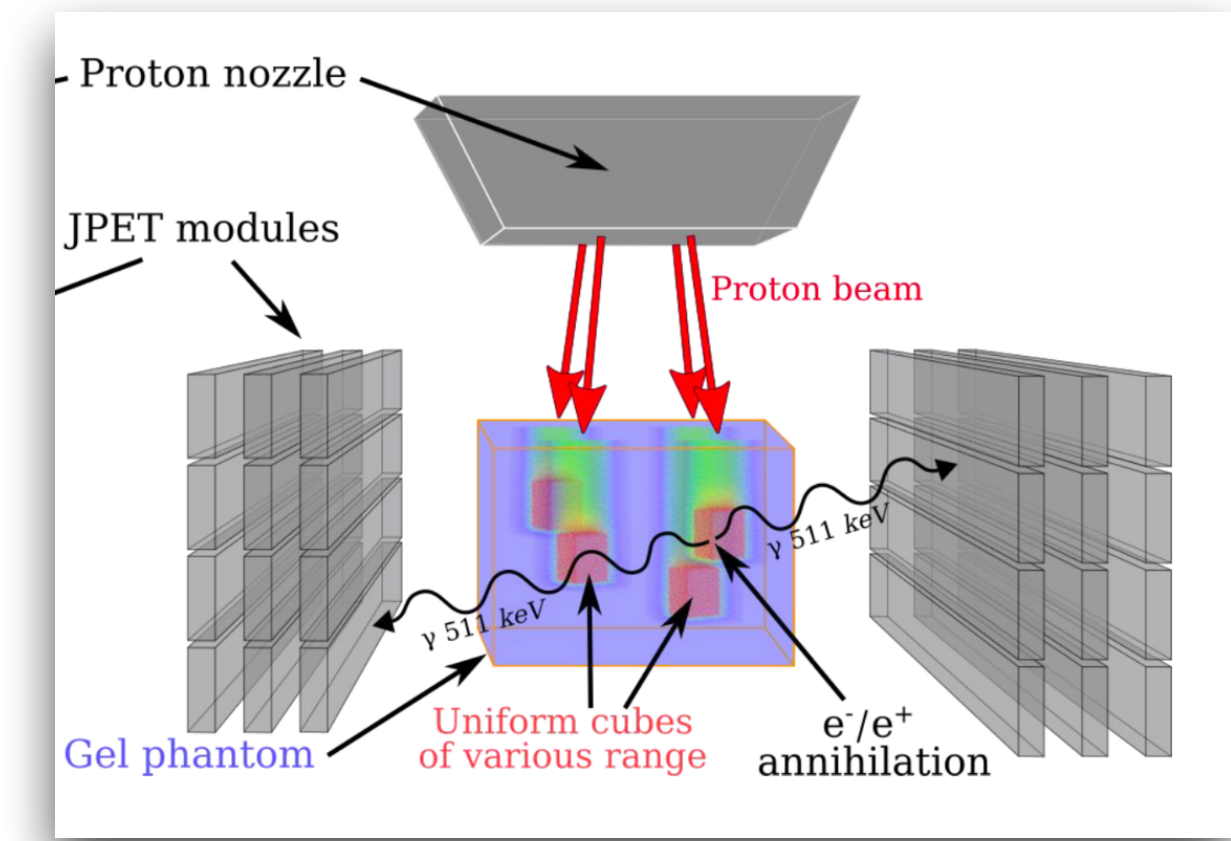
The first J-PET image acquired with protons



Acquisition time dependence



Activity vs. dose range



Summary

- ProTheRaMon: The simulation framework based on FRED, GATE, and CASTOR for predicting PET activity production and emission for any PET system
- Patient simulation studies show relationship between activity and dose range for ~100 patients
- From the J-PET ring to the J-PET heads
- First experimental results demonstrate feasibility of the J-PET to acquire PET signal in the off-line mode and monitor range of proton SOBP fields
- Simulations and experiments with J-PET suggest feasibility of the clinical application
- Next steps: On-line acquisition of the PET signal and clinical translation.

Literature

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- A. Rucinski et al. Experimental validation of J-PET applicability for proton therapy range monitoring (in prepreparation).

Thank you

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R. Kopeć, M. Kozani, D. Krzempek, K. Krzempek, G. Mierzwińska, J. Miszczyk,
N. Mojżeszek, M. Rydygier, P. Stasica, A. Zając-Grabiec



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