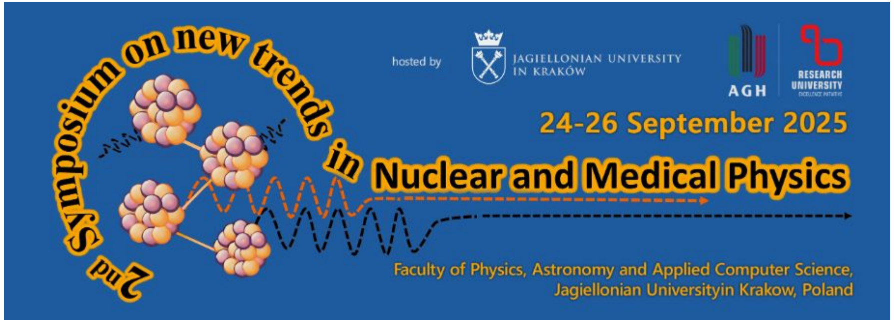
JAGIELLONIAN UNIVERSITY
IN KRAKÓW

J-PET

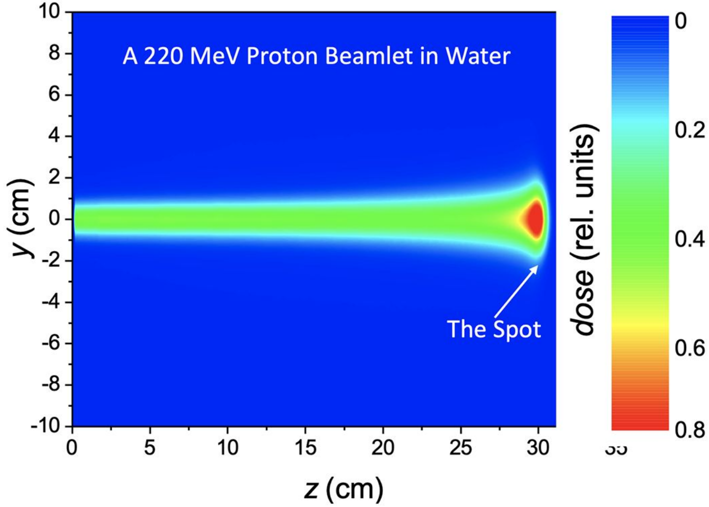
Range Monitoring in Proton Therapy Using the J-PET Scanner: First Experimental Insights

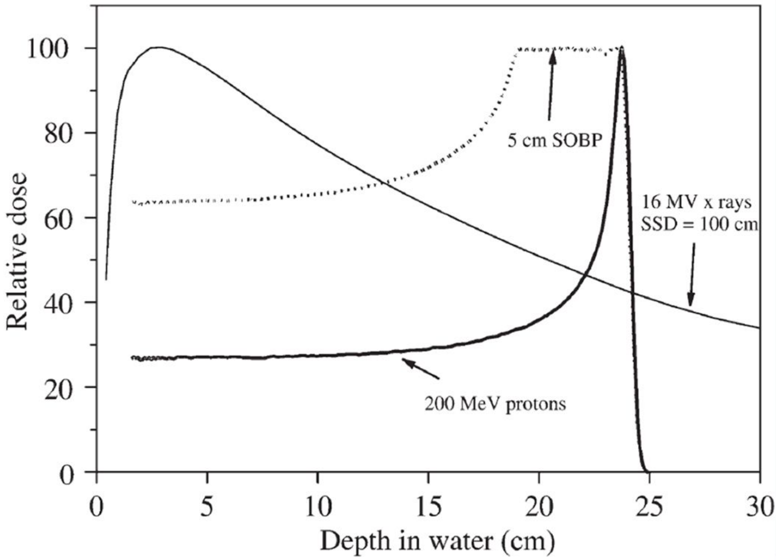
Szymon Niedźwiecki
on behalf of the J-PET collaboration



Proton therapy

- Protons deposit most energy at the Bragg peak leading to a sharp distal dose fall-off.
- Enables high tumor dose with reduced integral dose to adjacent normal tissues.
- Dosimetric advantage forms the rationale for proton therapy.





Mohan R. A Review of Proton Therapy - Current Status and Future Directions. Precis Radiat Oncol. 2022 Jun;6(2):164-176. doi: 10.1002/pro6.1149. Epub 2022 Apr 27. PMID: 36160180; PMCID: PMC9499036.

Proton range determination

Main sources of uncertainty:

- morphological changes,
- anatomical deformation due to motion
- HU to RSP conversion error

J-PET

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1. Dual-energy CT (DECT) / photon-counting CT (PCCT)

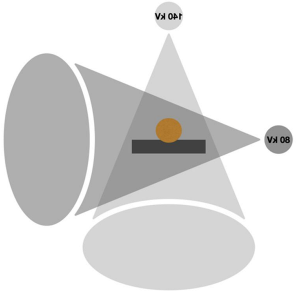
Charles Ekene Chika, World J Radiol. 2025 Jun 28;17(6):105728. doi: 10.4329/wjr.v17.i6.105728

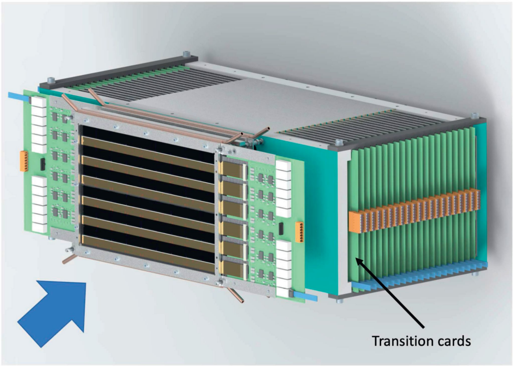
2. Proton CT (pCT) / proton radiography (pRad)

Alme J, et al.(2020) A High-Granularity Digital Tracking Calorimeter Optimized for Proton CT. Front. Phys. 8:568243. doi: 10.3389/fphy.2020.568243

3. Machine learning & Monte-Carlo aid

Wildman VL, et al.. Recent advances in applying machine learning to proton radiotherapy. Biomed Phys Eng Express. 2025 Jul 23;11(4):042005. doi: 10.1088/2057-1976/adeb90. PMID: 40609552; PMCID: PMC12284894.





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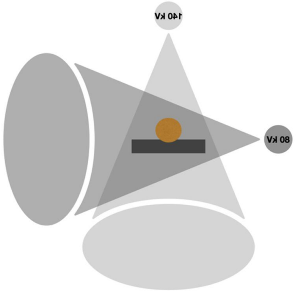
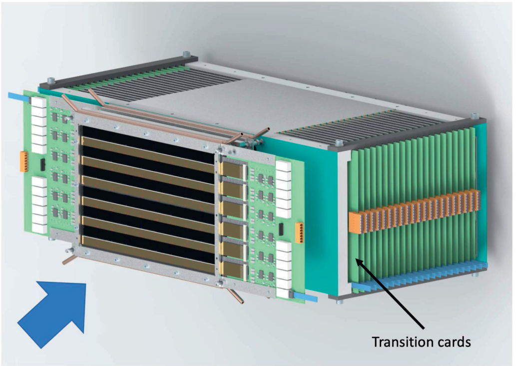




1. Prompt Gamma Imaging (PGI) / Prompt Gamma Spectroscopy (PGS) / Prompt Gamma Timing (PGT)

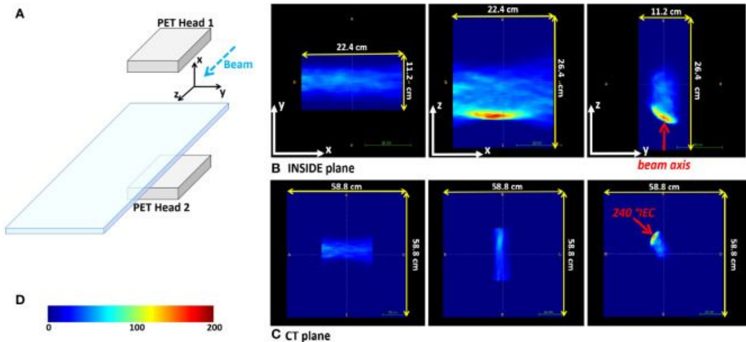
Everaere P, et al. Prompt gamma energy integration: a new method for online-range verification in proton therapy with pulsed-beams. Front. Phys. 12:1371015. doi: 10.3389/fphy.2024.1371015

2. Ionoacoustic / protoacoustic imaging

Alme J, et Wang S, et al. Real-time tracking of the Bragg peak during proton therapy via 3D protoacoustic Imaging in a clinical scenario. Npj Imaging. 2024;2(1):34. doi: 10.1038/s44303-024-00039-x. Epub 2024 Sep 17. PMID: 40078731; PMCID: PMC11893450.

3. In-beam PET and delayed gamma imaging

Moglioni M, et al. In-vivo range verification analysis with in-beam PET data for patients treated with proton therapy at CNAO. Front Oncol. 2022 Sep 26;12:929949. doi: 10.3389/fonc.2022.929949. PMID: 36226070; PMCID: PMC9549776.



J-PET

Phys. Med. Biol. 68 (2023) 145016 https://doi.org/10.1088/1361-6560/acdd4c

Physics in Medicine & Biology

IPEM Institute of Physics and Engineering in Medicine

PAPER

Detection of range shifts in proton beam therapy using the J-PET scanner: a patient simulation study

Karol Brzeziński[1,2,*], Jakub Baran[3,4,5], Damian Borys[6,7], Jan Gajewski[1], Neha Chug[3,4,5], Aurelien Coussat[3,4,5], Eryk Czerwiński[3,4,5], Meysam Dadgar[3,4,5], Kamil Dulski[3,4,5], Kavya V Eliyan[3,4,5], Aleksander Gajos[3,4,5], Krzysztof Kacprzak[3,4,5], Łukasz Kapłon[3,4,5], Konrad Klimaszewski[8], Paweł Konieczka[8], Renata Kopeć[1], Grzegorz Korcyl[3,4,5], Tomasz Kozik[3,4,5], Wojciech Krzemień[9], Deepak Kumar[3,4,5], Antony J Lomax[10,11], Keegan McNamara[10,11], Szymon Niedźwiecki[3,4,5], Paweł Olko[1], Dominik Panek[3,4,5], Szymon Parzych[3,4,5], Elena Perez del Rio[3,4,5], Lech Raczyński[8], Sushil Sharma[3,4,5], Shivani[3,4,5], Roman Y Shopa[8], Tomasz Skóra[12], Magdalena Skurzok[3,4,5], Paulina Stasica[1], Ewa Ł Stępień[3,4,5], Keyvan Tayefi[3,4,5], Faranak Tayefi[3,4,5], Damien C Weber[10,13,14], Carla Winterhalter[10,11], Wojciech Wiślicki[8], Paweł Moskal[3,4,5] and Antoni Rucinski[1]

Physica Medica 118 (2024) 103301

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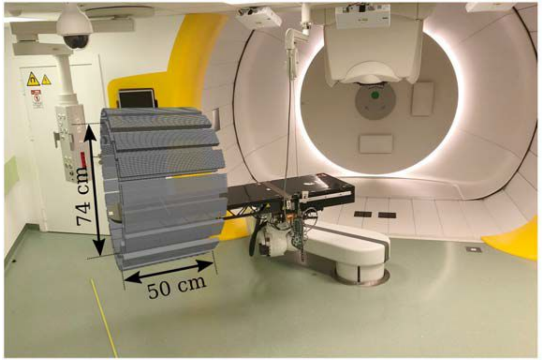
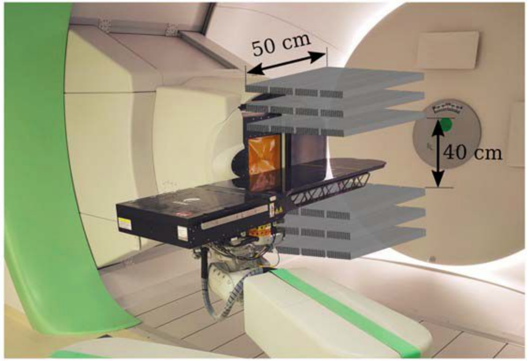


(a)



(b)

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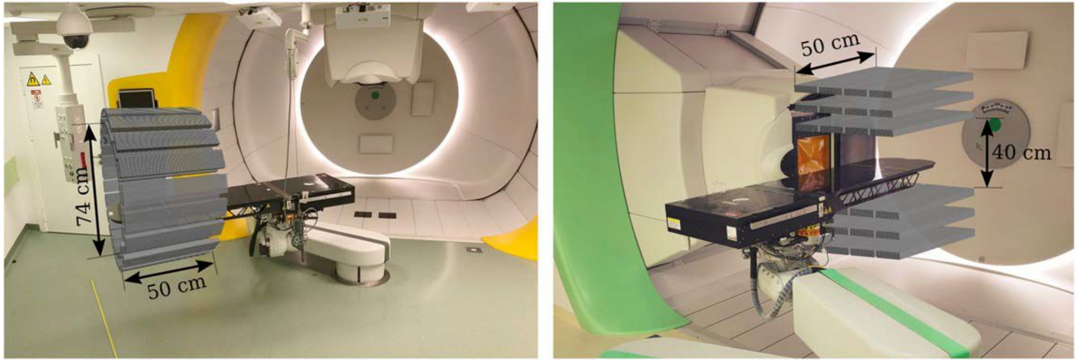
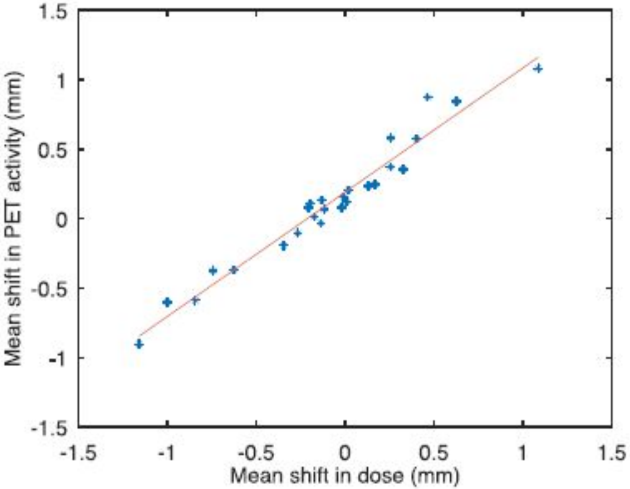
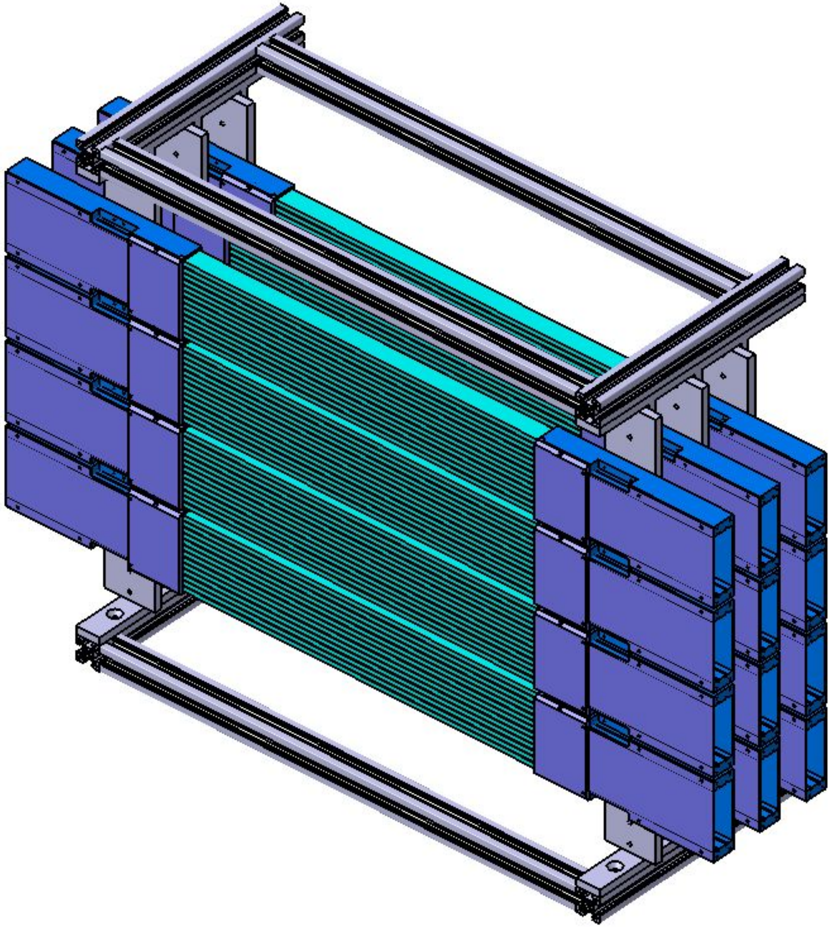


(a) (b)

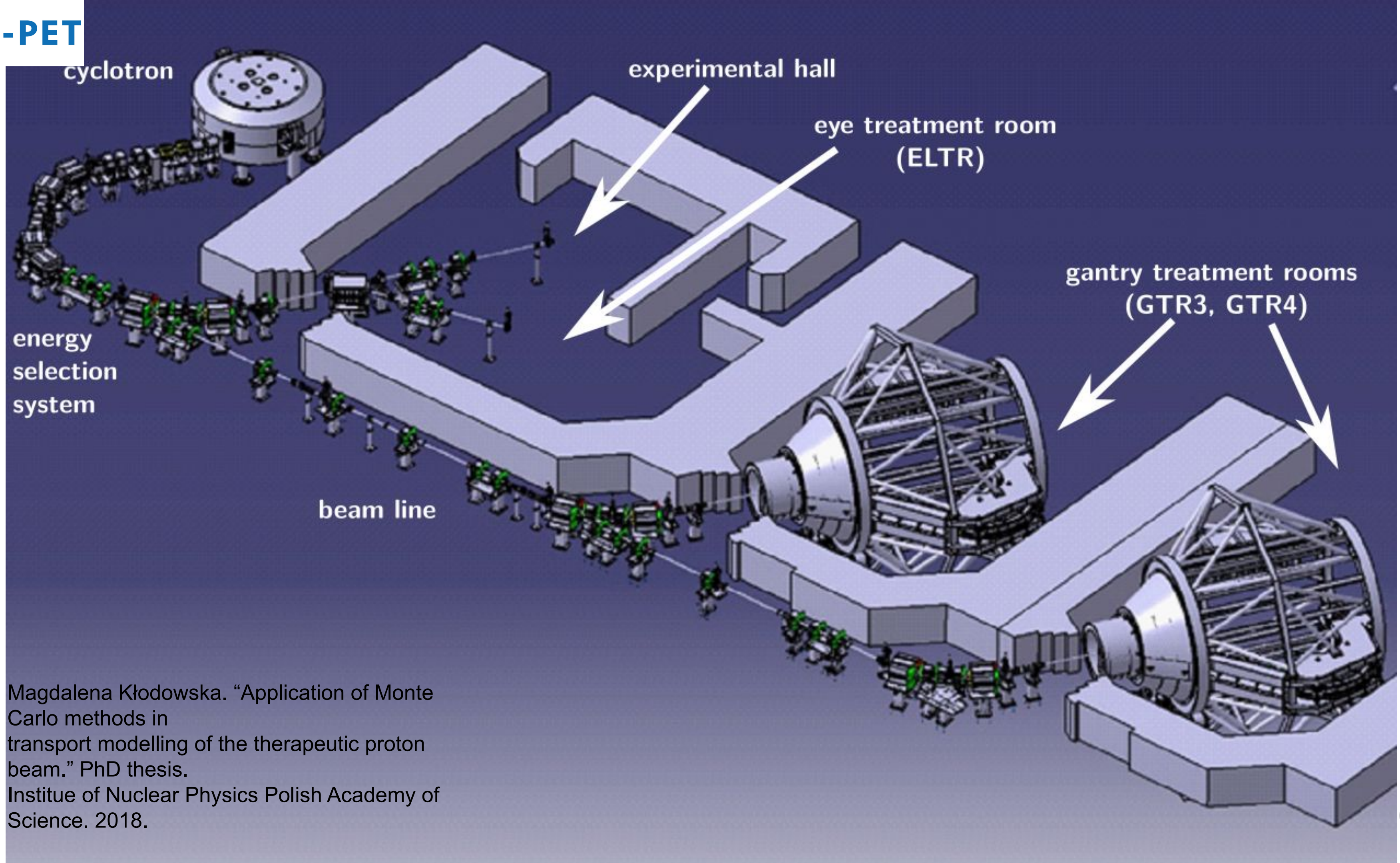


J-PET modular configuration

J-PET

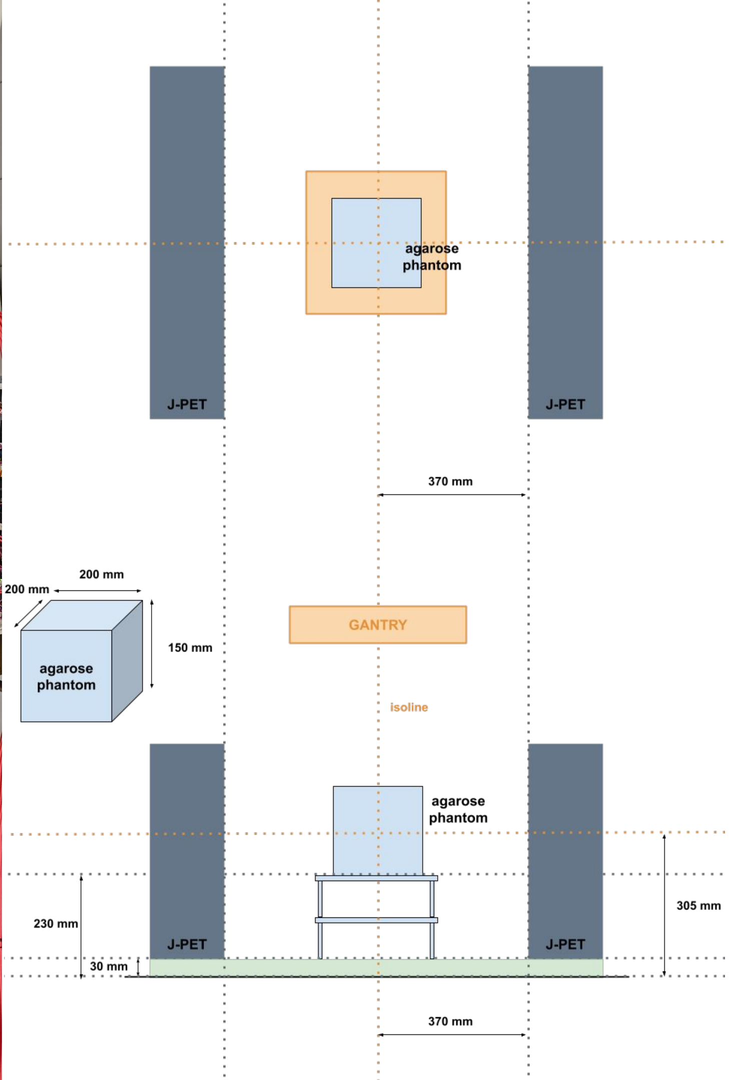


J-PET

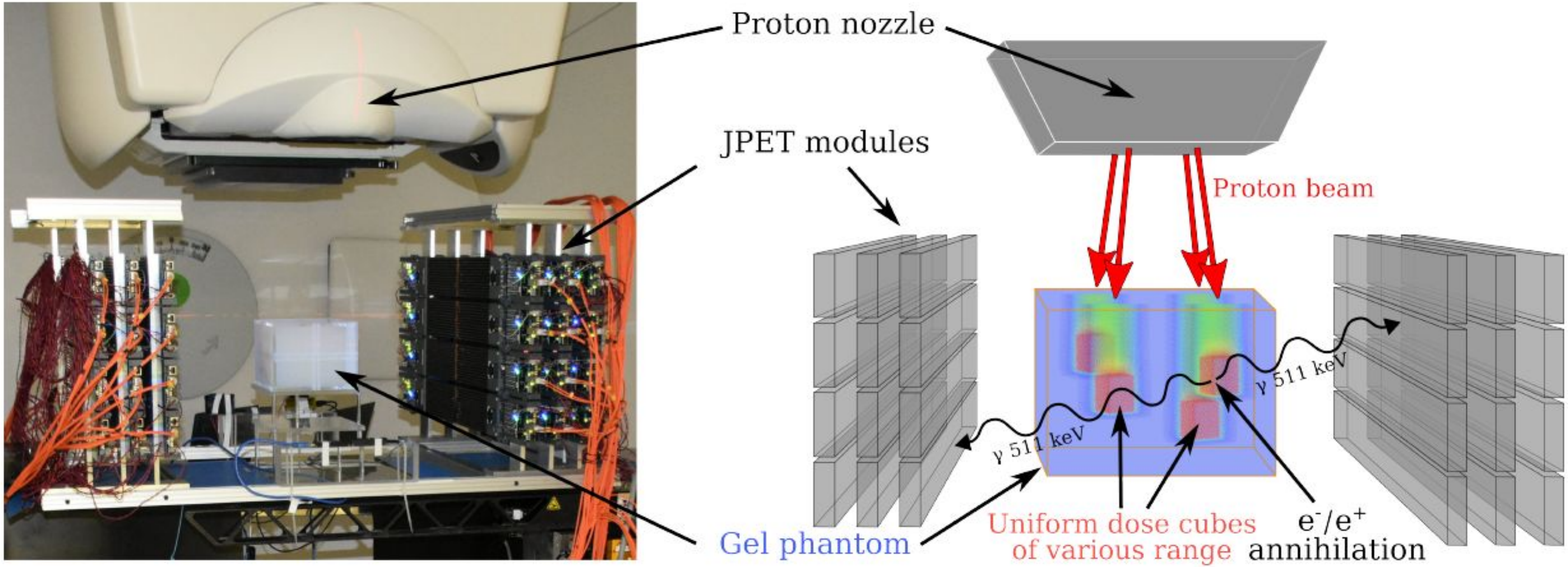


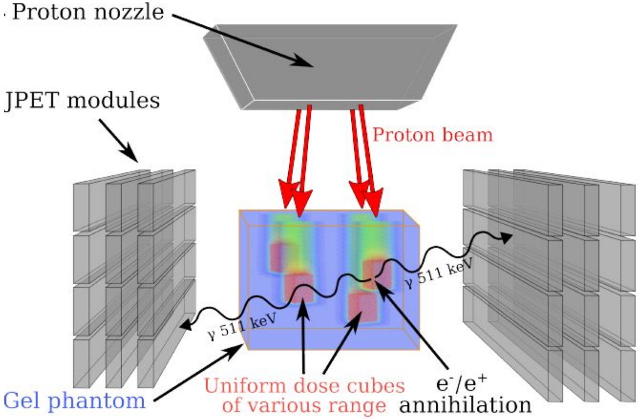
Magdalena Kłodowska. “Application of Monte Carlo methods in transport modelling of the therapeutic proton beam.” PhD thesis. Institue of Nuclear Physics Polish Academy of Science. 2018.

J-PET



agarose phantom
J-PET
J-PET
370 mm
200 mm
200 mm
150 mm
agarose phantom
GANTRY
isoline
agarose phantom
J-PET
J-PET
230 mm
30 mm
305 mm
370 mm


Proton nozzle
JPET modules
Proton beam
γ 511 keV
γ 511 keV
Gel phantom
Uniform dose cubes
of various range
e-/e+
annihilation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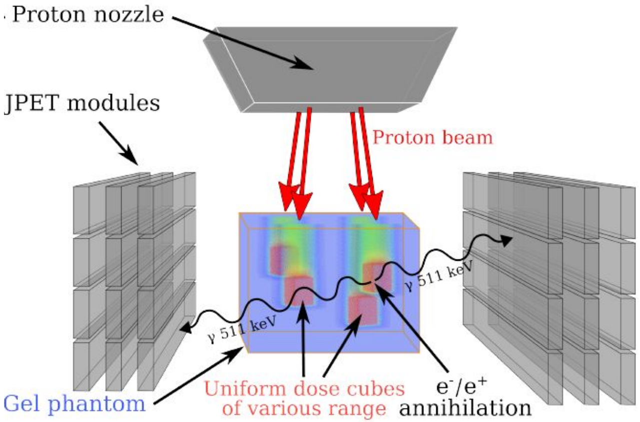

Proton nozzle
JPET modules
Proton beam
γ 511 keV
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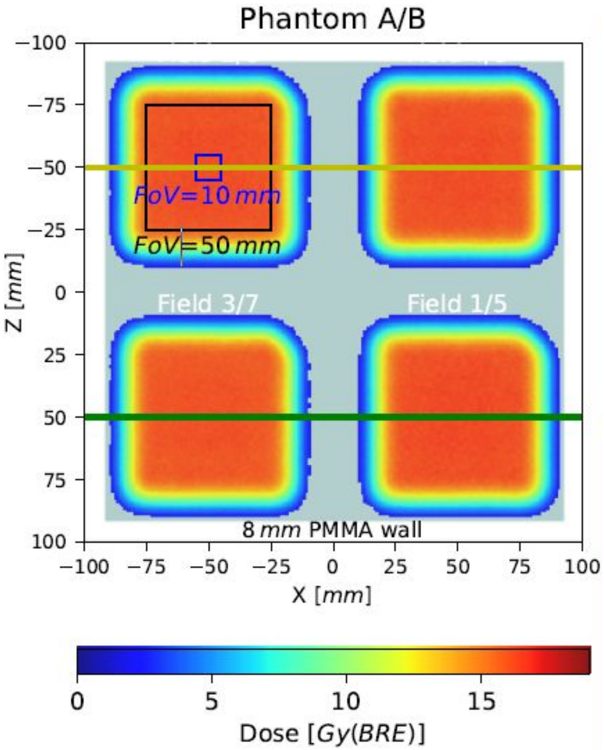
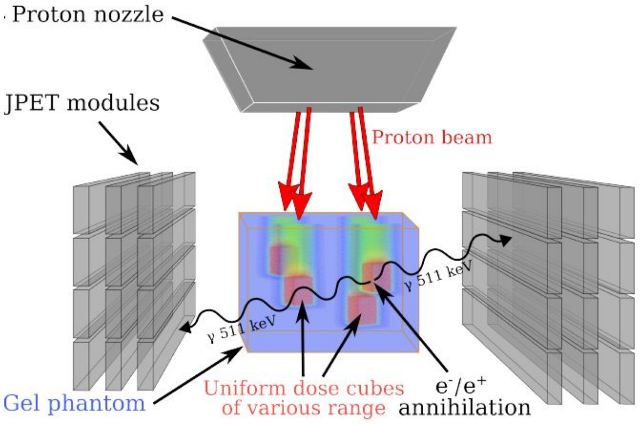
Gel phantom
Uniform dose cubes
of various range
e⁻/e⁺
annihilation



Phantom A/B
FoV=10 mm
FoV=50 mm
Field 3/7
Field 1/5
8 mm PMMA wall
Z [mm]
X [mm]
Dose [Gy(BRE)]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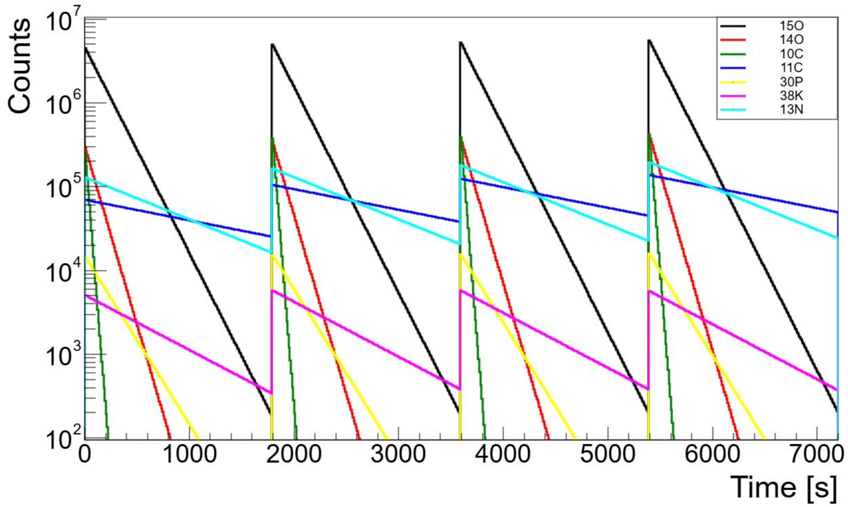
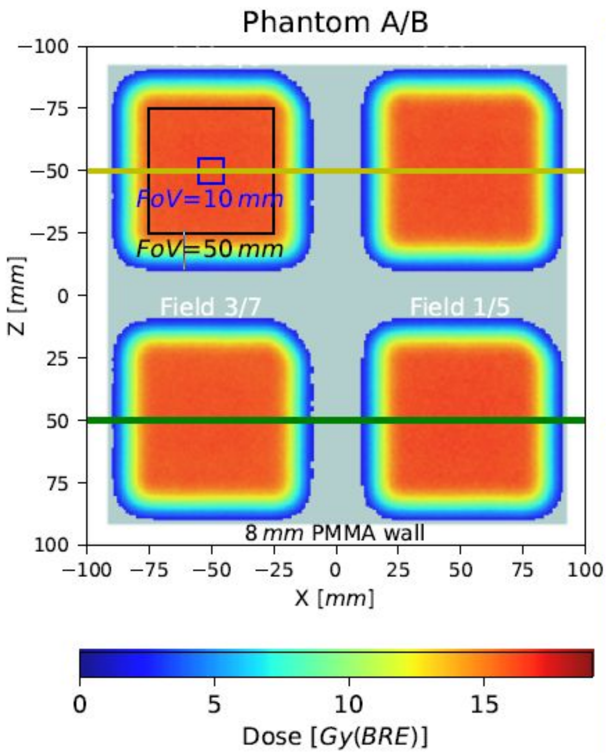

Counts
Time [s]
15O
14O
10C
11C
30P
38K
13N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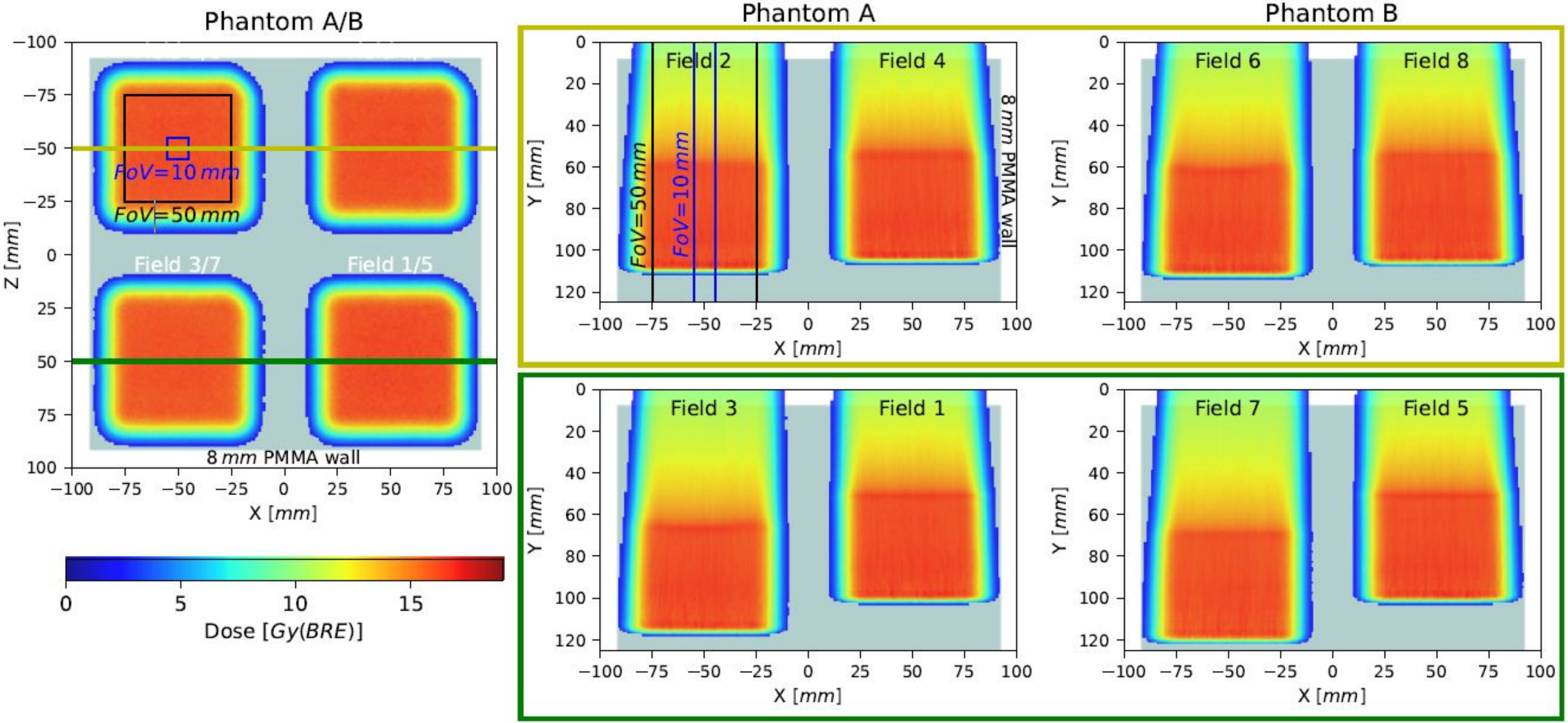
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FoV=10 mm
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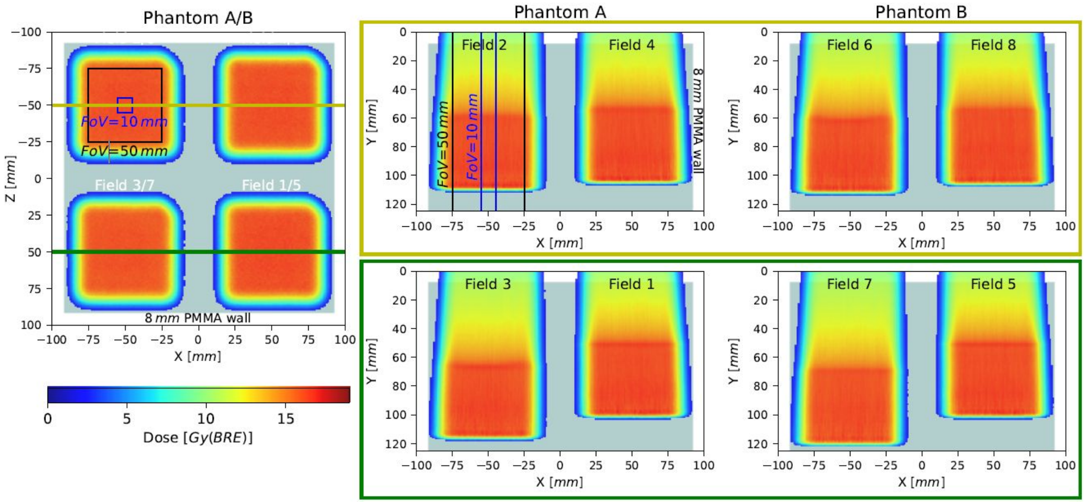
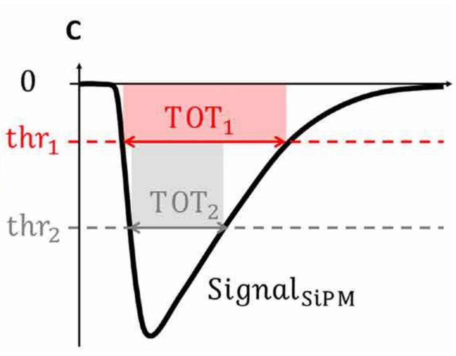
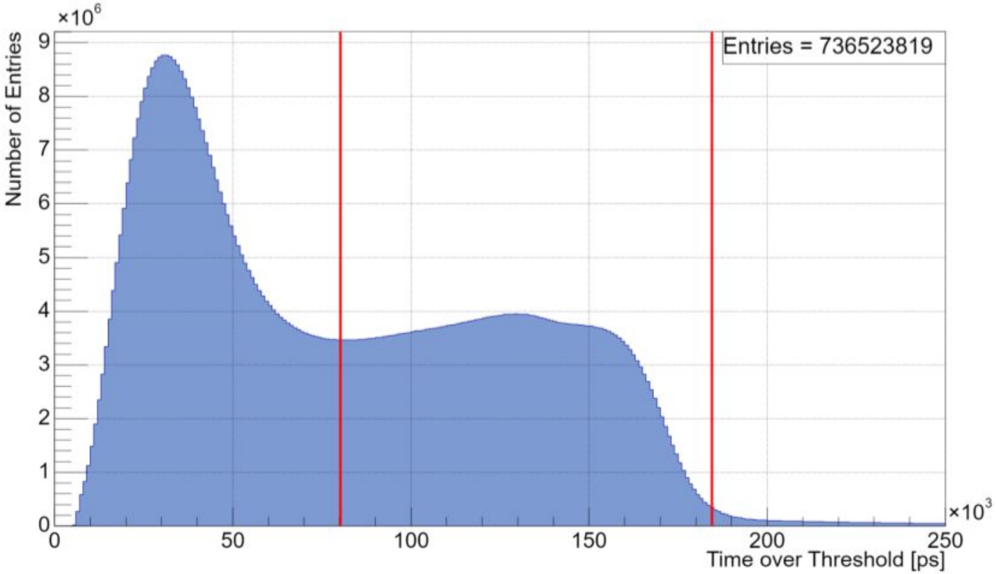
Field 3/7
Field 1/5
8 mm PMMA wall
Z [mm]
X [mm]
Dose [Gy(BRE)]
Phantom A
Phantom B
Field 2
Field 4
Field 6
Field 8
Field 3
Field 1
Field 7
Field 5
FoV=50 mm
FoV=10 mm
8 mm PMMA wall
Y [mm]
X [mm]

Phantom	Field	Nominal Range [mm]	Range at 50% [mm]	Acquisition time [min]
A	1	100	101.89	30
	2	108	109.98	31
	3	115	116.88	29
	4	103	105.10	30
B	5	100	101.88	33
	6	110	112.10	32
	7	119	121.19	32
	8	104	106.17	35



Data selection

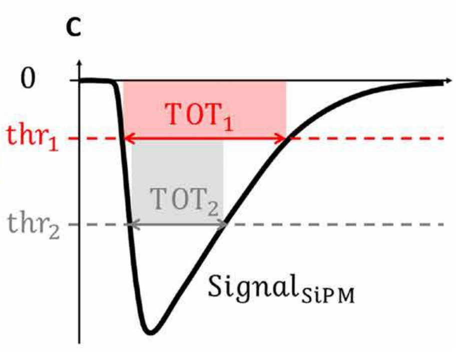


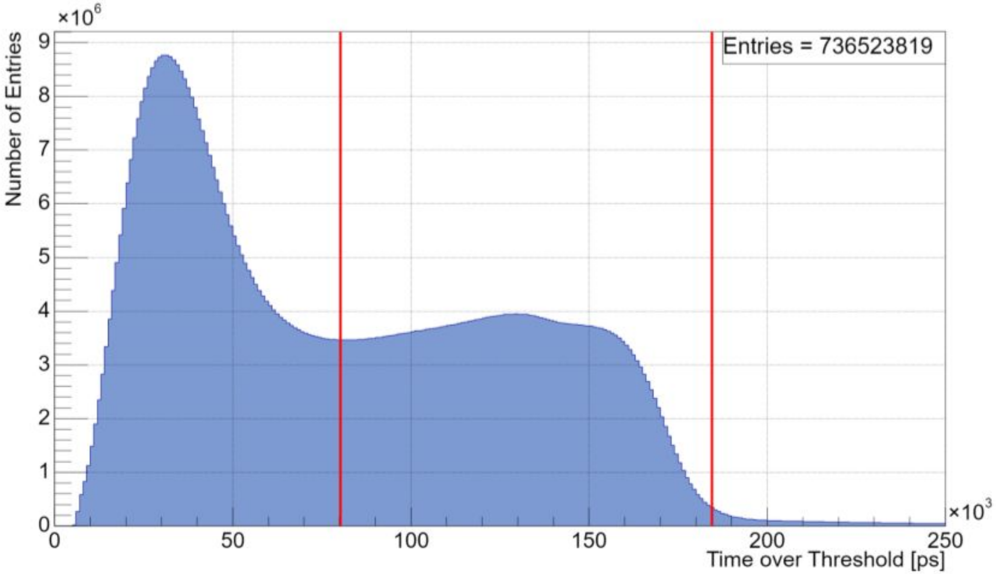


Data selection:

- **unscattered annihilation gamma quanta**
- only two interactions each within different head
- annihilation point within system FOV
- scatter test > 40 cm

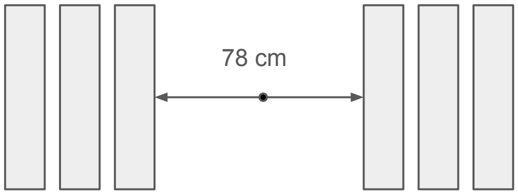
J-PET





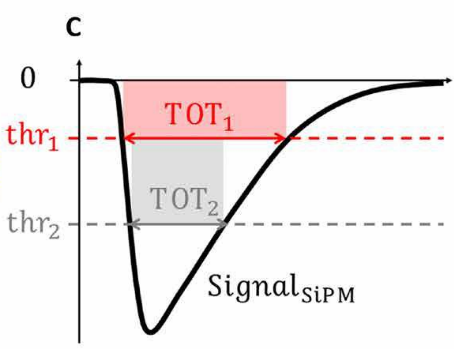
Data selection:

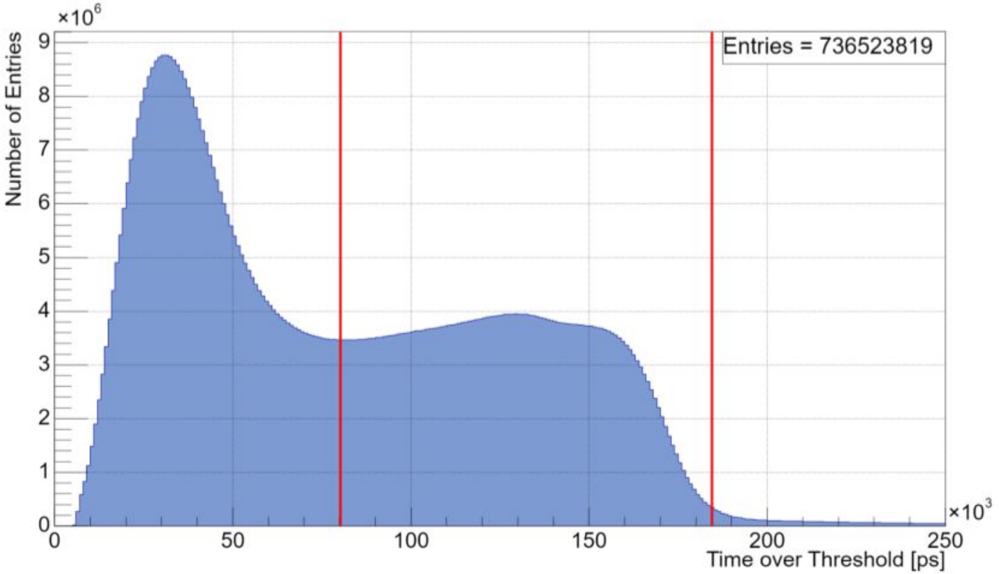
- unscattered annihilation gamma quanta
- **only two interactions each within different head**
- **annihilation point within system FOV**
- scatter test > 40 cm



left head

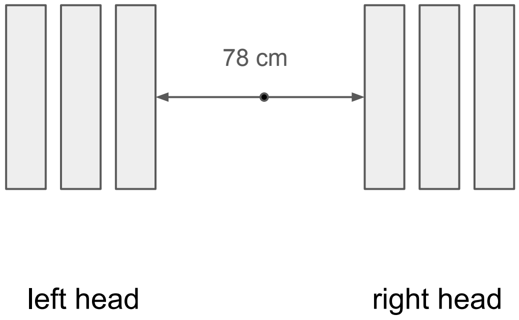
right head

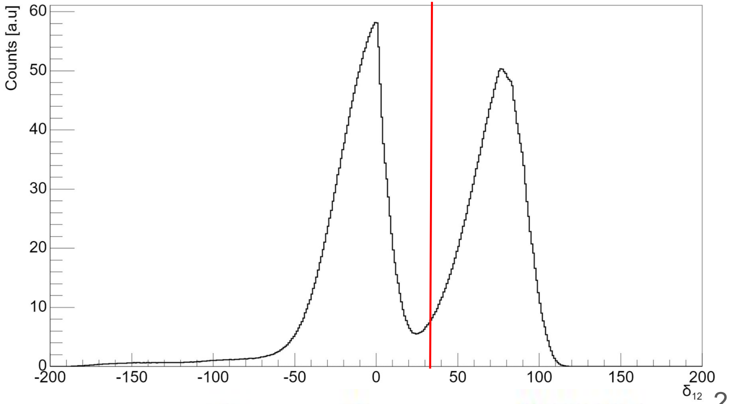




Data selection:

- unscattered annihilation gamma quanta
- only two interactions each within different head
- annihilation point within system FOV
- **scatter test > 40 cm**



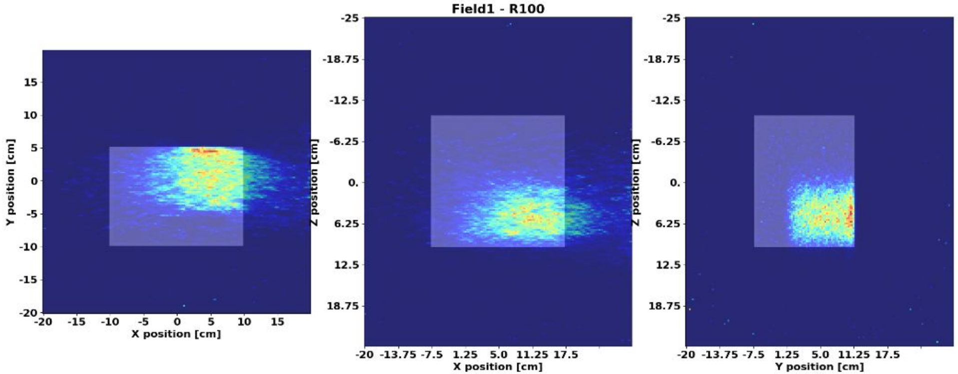


$$\delta_{12} = d_{12} - c * |TOF|$$

Reconstruction

For the J-PET data reconstruction, the CASToR software has been used with following settings:

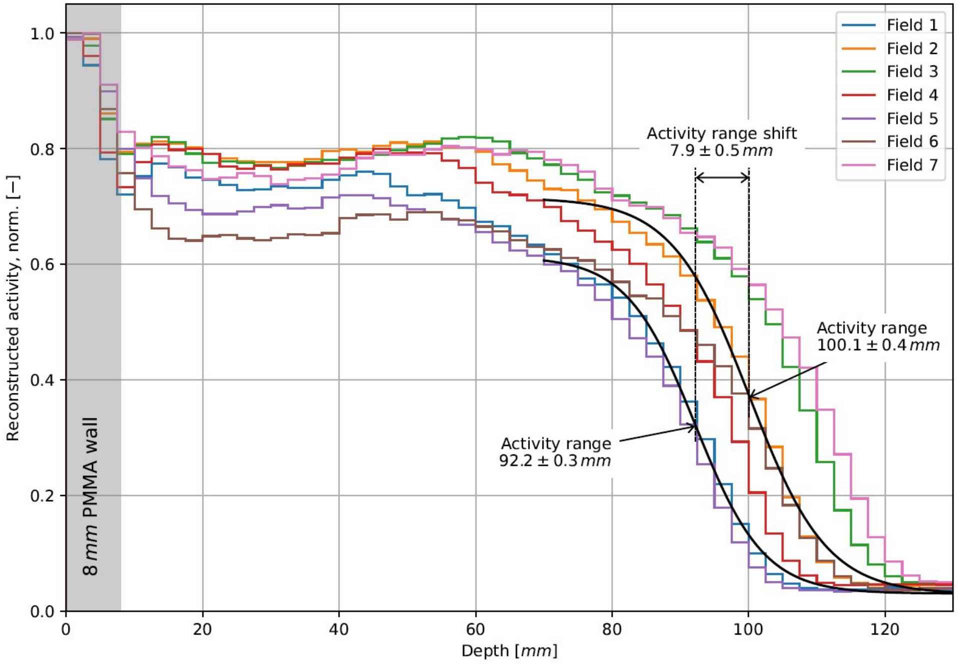
- TOF LM-MLEM (5 iterations) with TOF=600 ps
- Ray-tracing Siddon projector (10 rays)
- Attenuation and sensitivity corrections incorporated
- All (true, scatter, random) coincidences taken into account
- No additional PSF modeling added



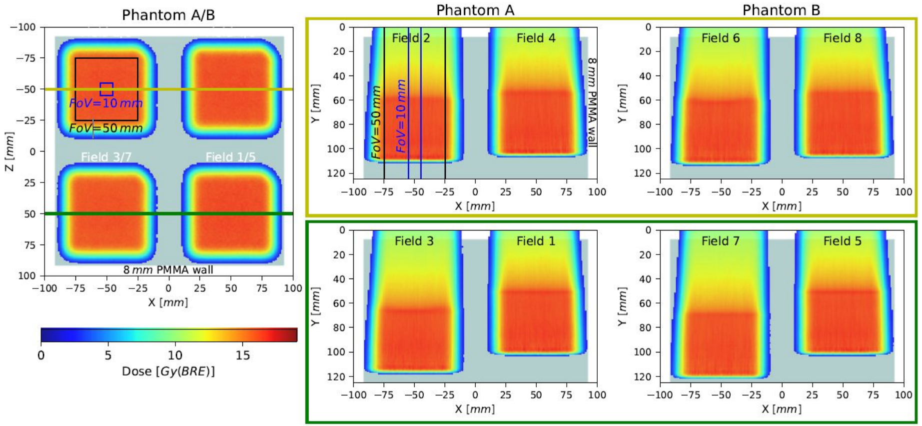
Front view from side B

View from the top

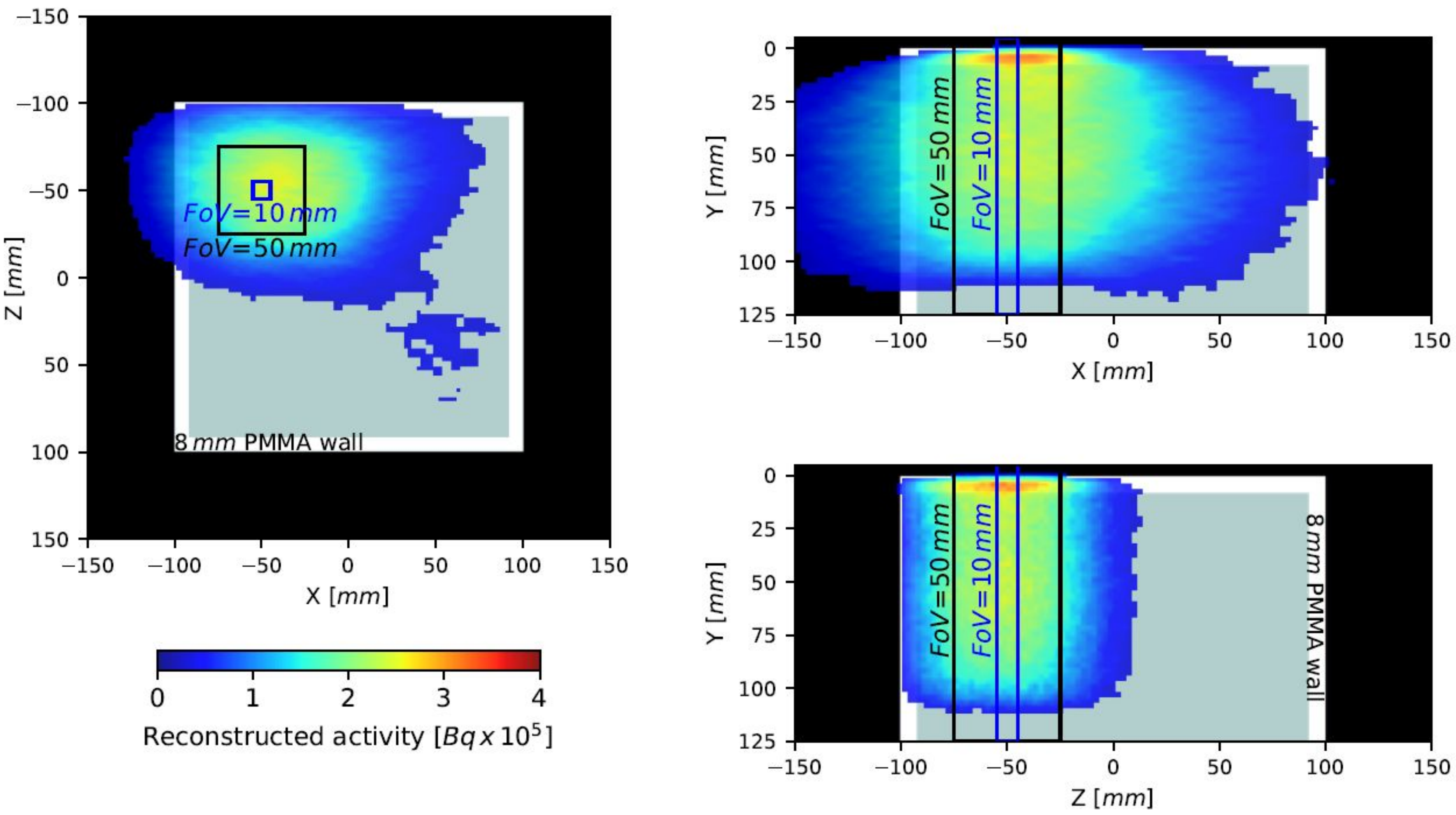
Determination of activity shifts



Activity range shift
7.9 ± 0.5 mm
Activity range
100.1 ± 0.4 mm
Activity range
92.2 ± 0.3 mm
8 mm PMMA wall
Field 1
Field 2
Field 3
Field 4
Field 5
Field 6
Field 7
Reconstructed activity, norm. [−]
Depth [mm]



Phantom A/B
FoV=10 mm
FoV=50 mm
Field 3/7
Field 1/5
8 mm PMMA wall
Z [mm]
X [mm]
Dose [Gy(BRE)]
Phantom A
Field 2
Field 4
Field 3
Field 1
FoV=50 mm
FoV=10 mm
8 mm PMMA wall
Phantom B
Field 6
Field 8
Field 7
Field 5
Y [mm]
X [mm]



FoV=10 mm
FoV=50 mm
8 mm PMMA wall
Z [mm]
X [mm]
Y [mm]
Reconstructed activity [Bq x 10^5]
0
1
2
3
4

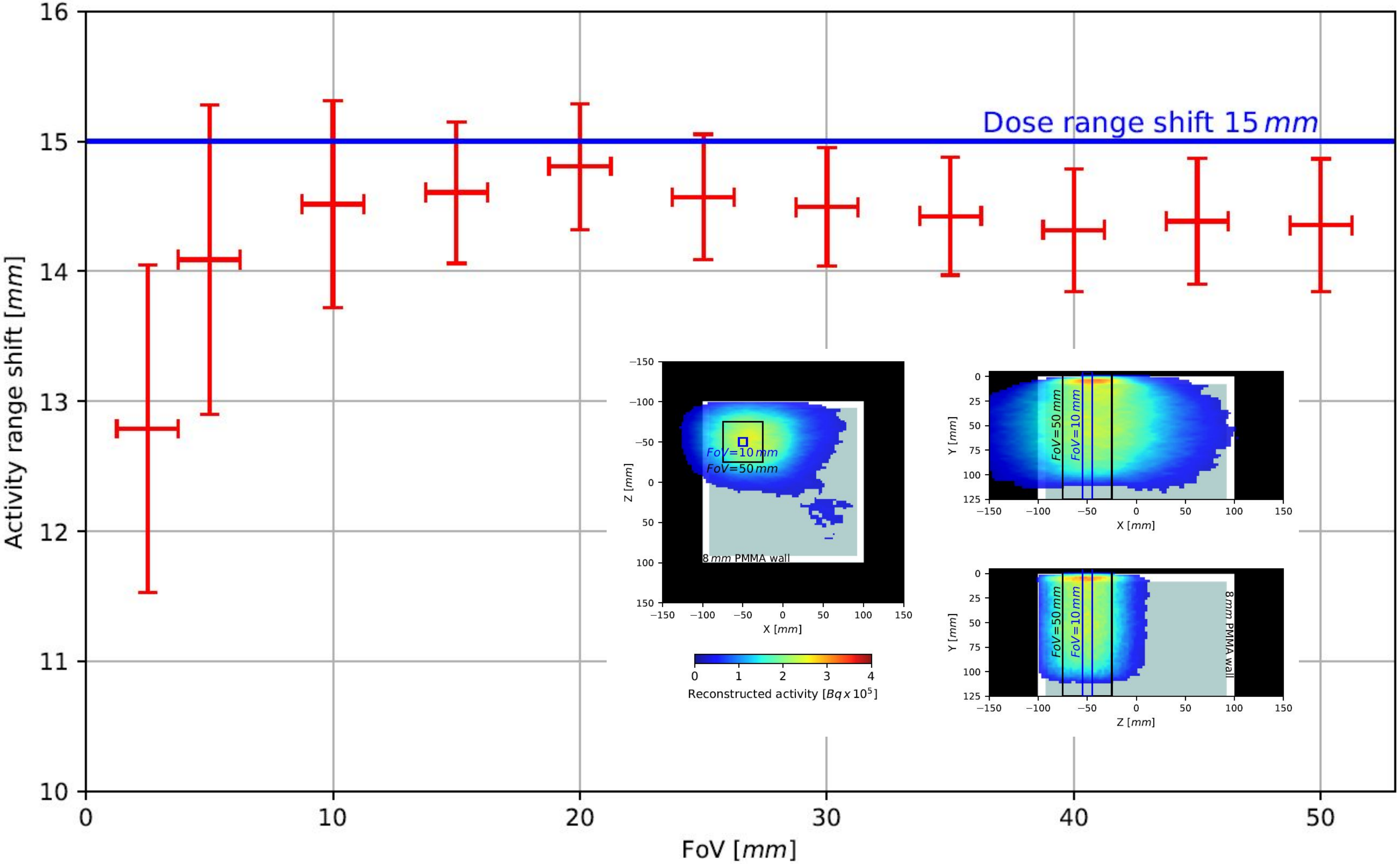
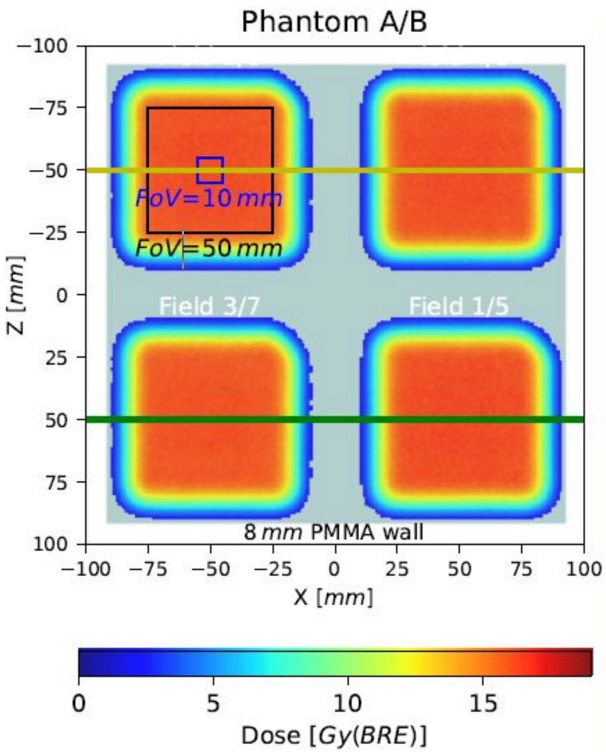

Dose range shift 15 mm
Activity range shift [mm]
FoV [mm]
FoV=10 mm
FoV=50 mm
8 mm PMMA wall
Z [mm]
X [mm]
Y [mm]
Reconstructed activity [Bq x 10^5]

Illustration of all possible combinations:

Phantom	Field	Nominal Range $[mm]$	Range at 50% $[mm]$	Acquisition time $[min]$
A	1	100	101.89	30
	2	108	109.98	31
	3	115	116.88	29
	4	103	105.10	30
B	5	100	101.88	33
	6	110	112.10	32
	7	119	121.19	32
	8	104	106.17	35



Phantom A

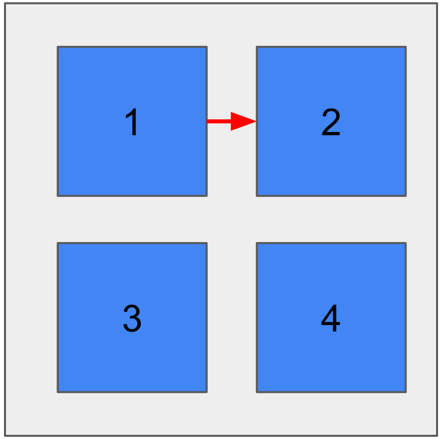


Illustration of all possible combinations:

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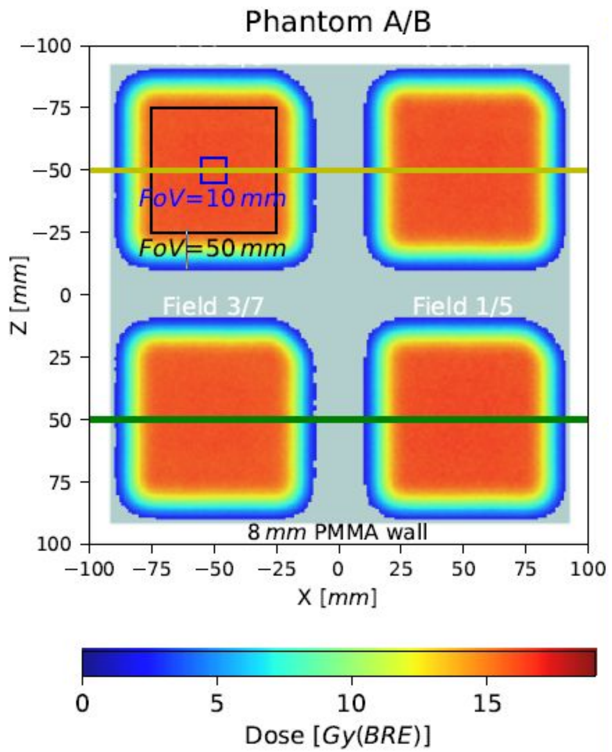

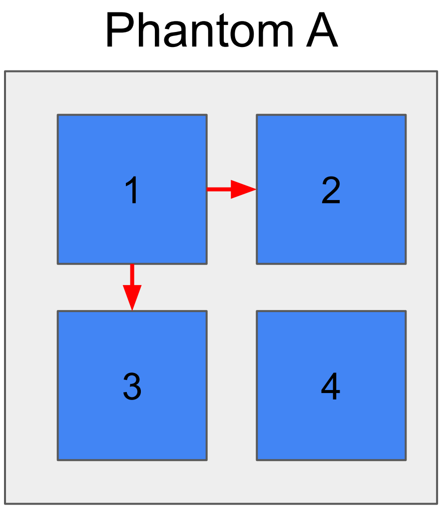

J-PET

Illustration of all possible combinations:

Phantom	Field	Nominal Range [mm]	Range at 50% [mm]	Acquisition time [min]
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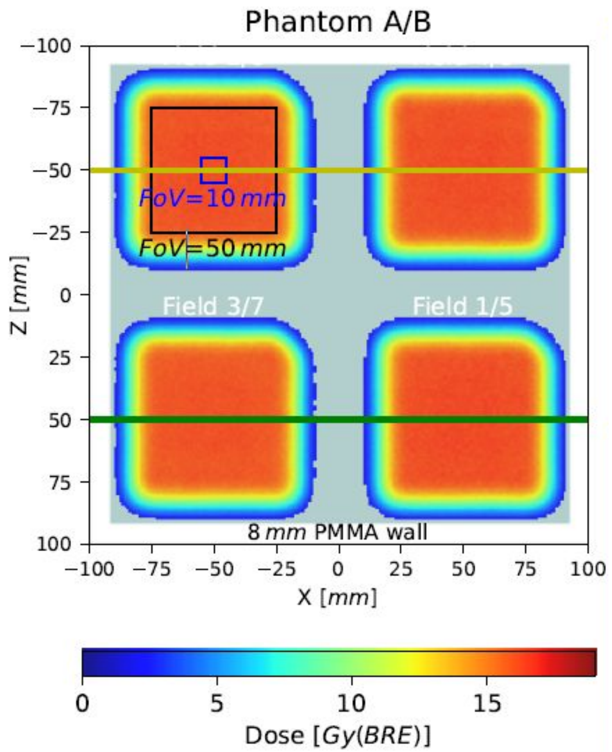

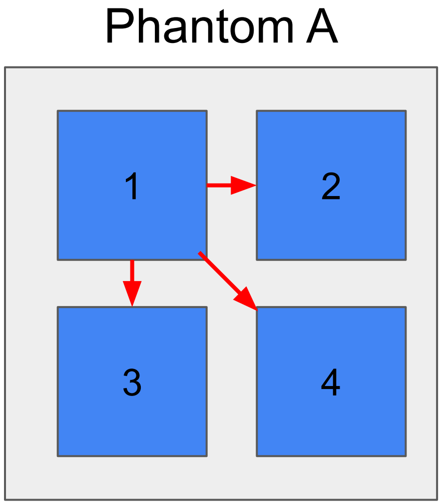

J-PET

Illustration of all possible combinations:

Phantom	Field	Nominal Range $[mm]$	Range at 50% $[mm]$	Acquisition time $[min]$
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	7	119	121.19	32
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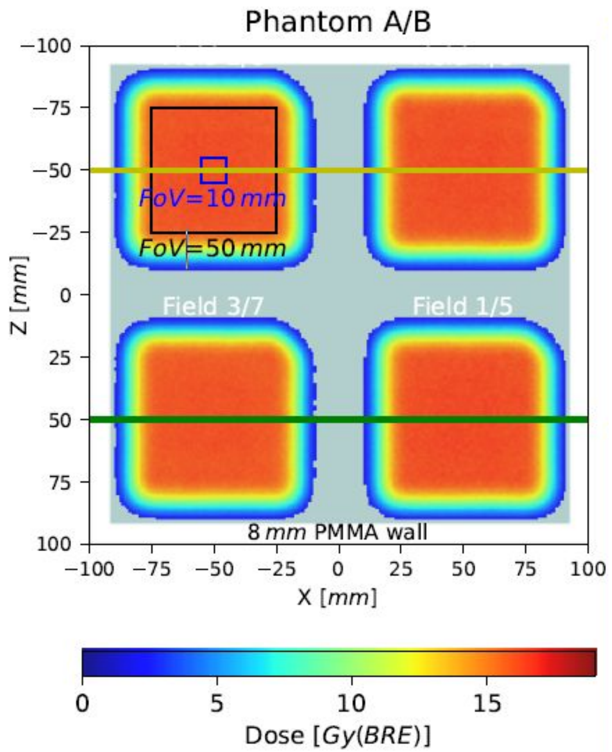

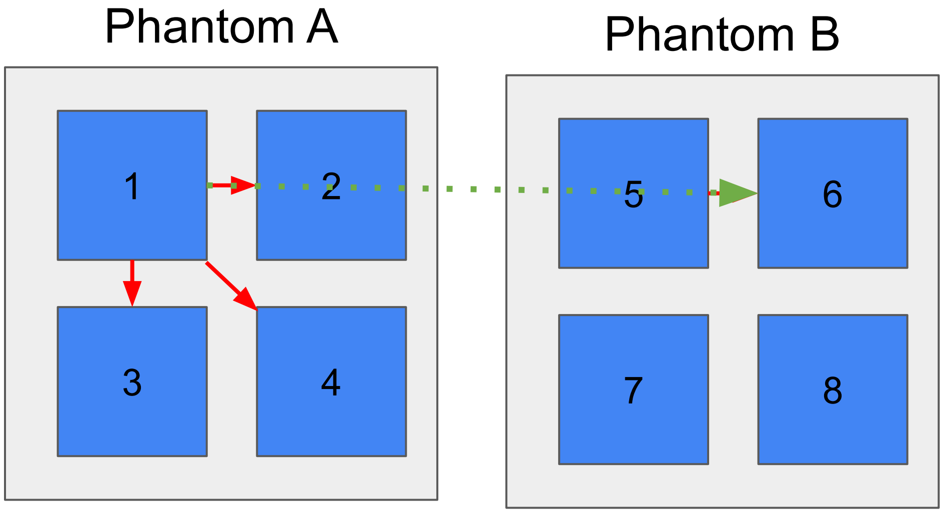

Illustration of all possible combinations:

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	6	110	112.10	32
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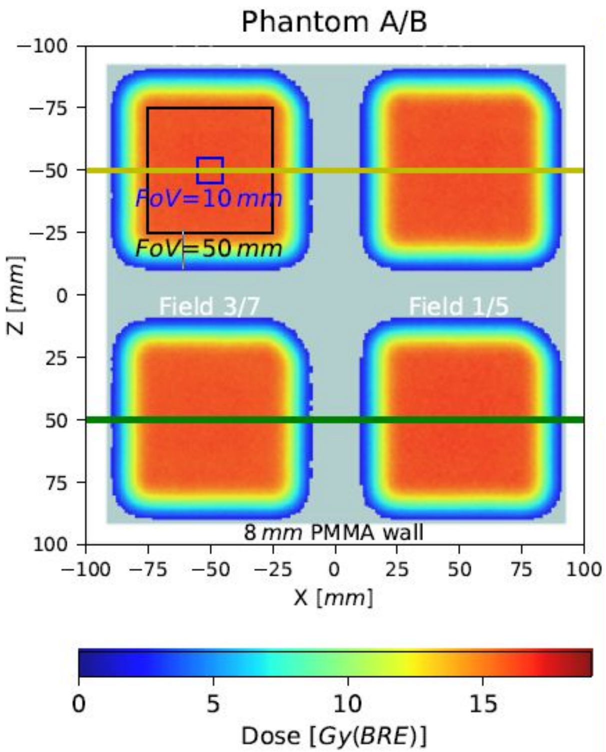
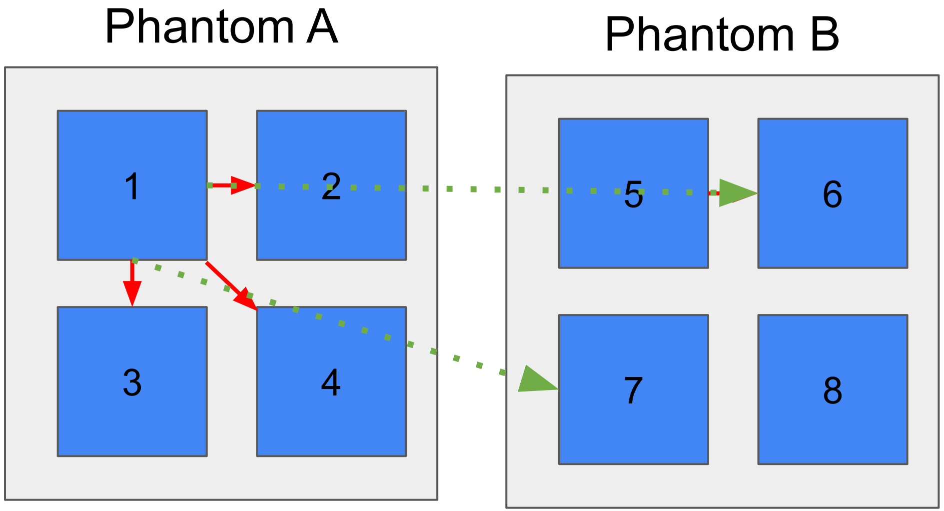
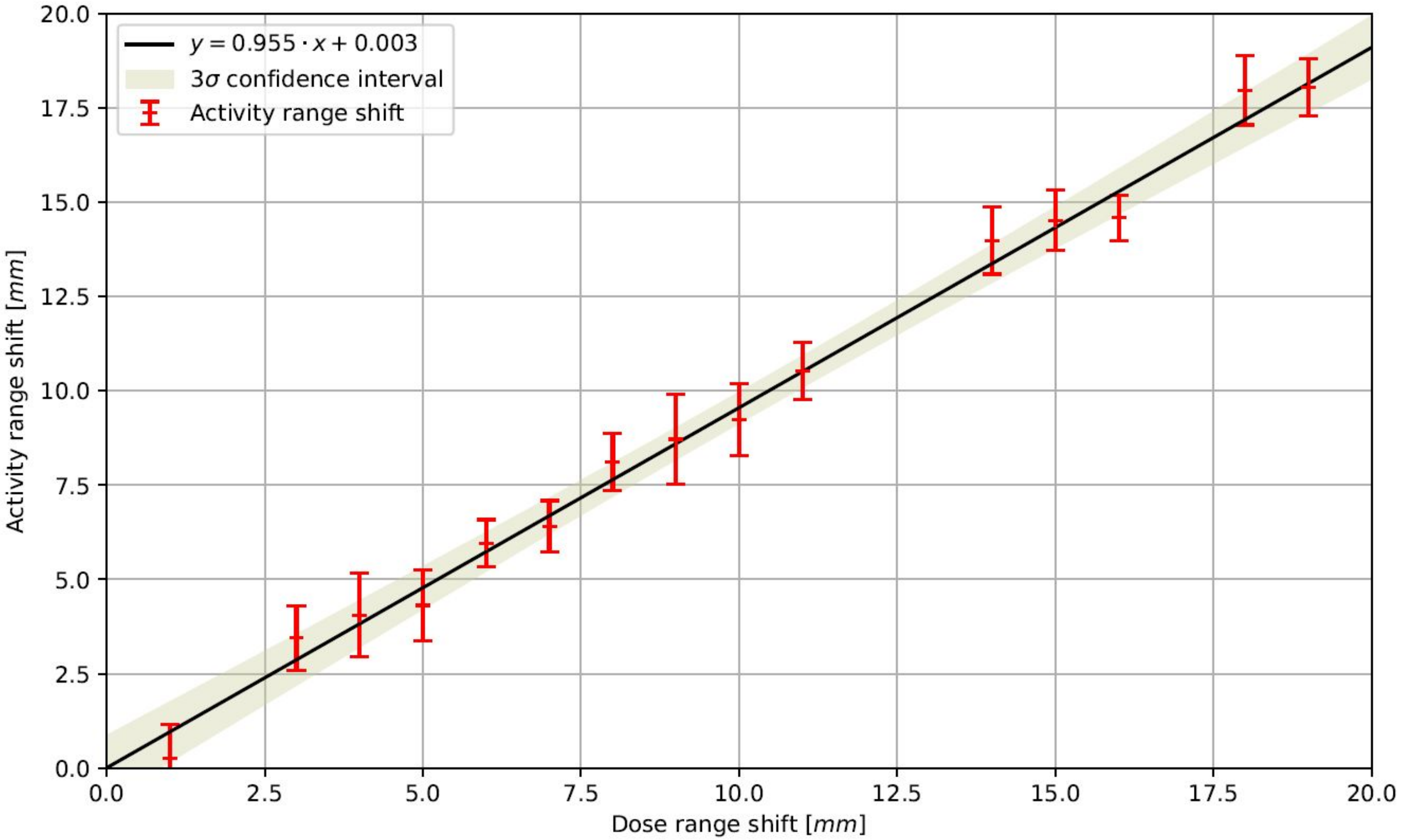
	8	104	106.17	35

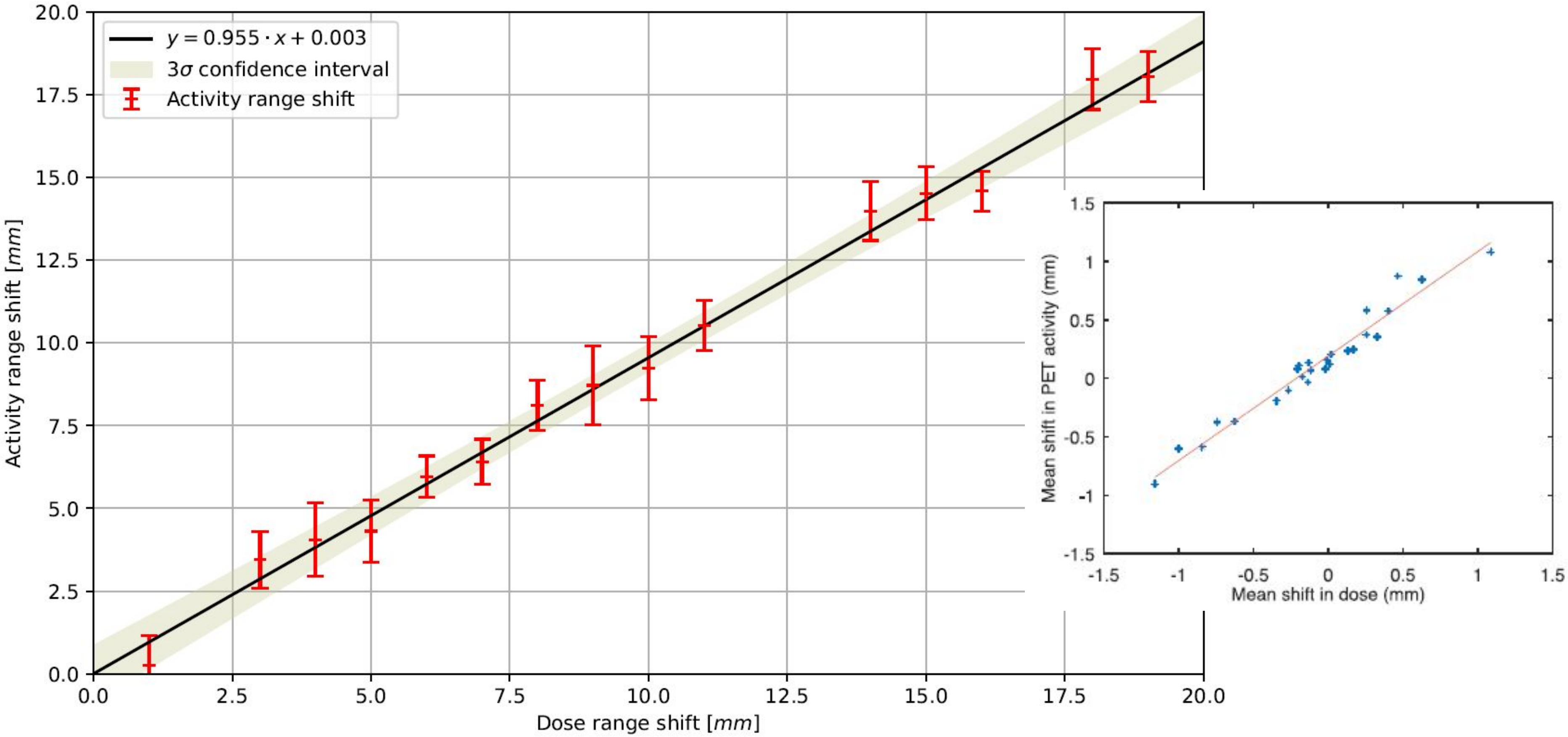




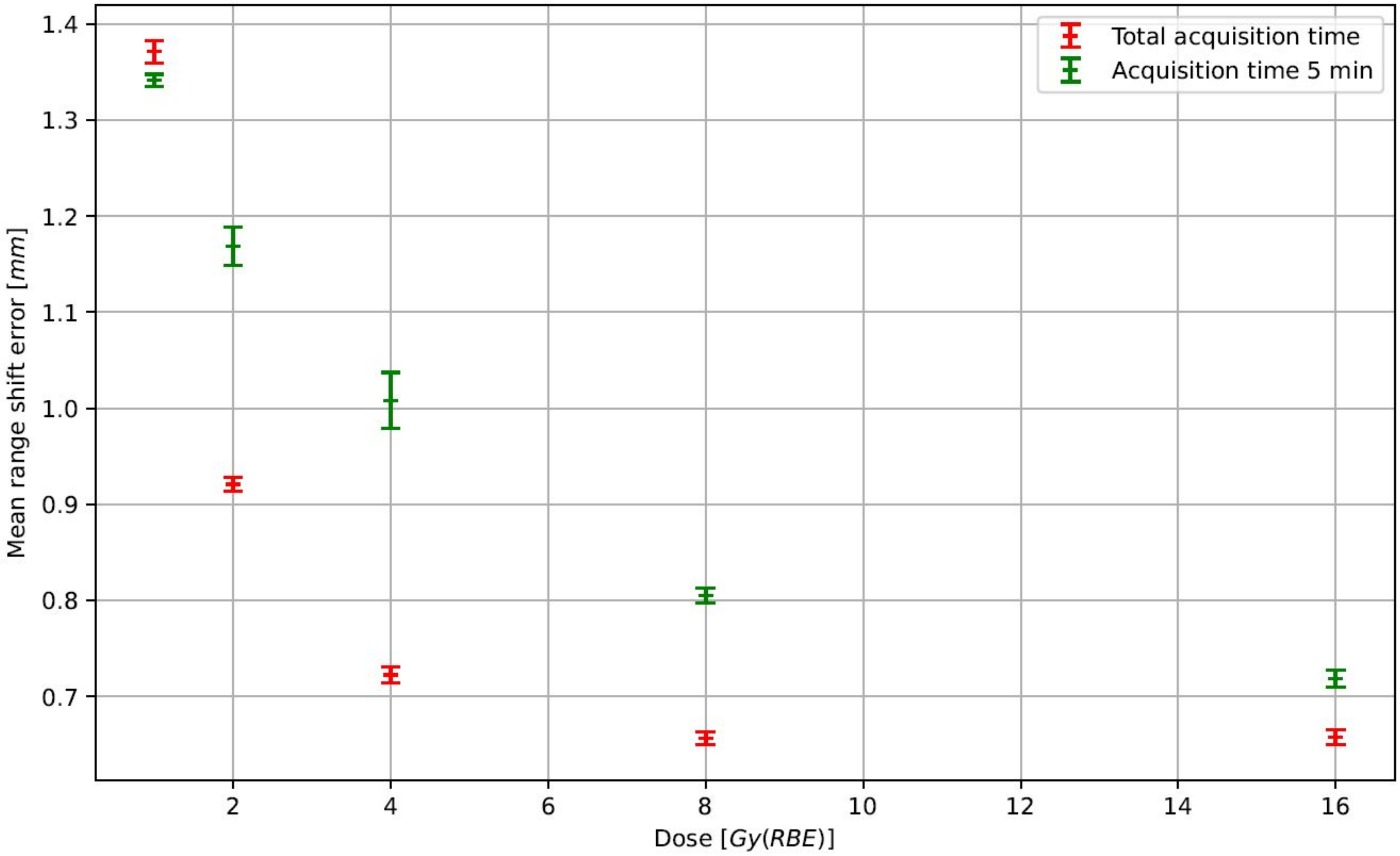
Results



$y = 0.955 \cdot x + 0.003$
3σ confidence interval
Activity range shift
Activity range shift [mm]
Dose range shift [mm]
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0

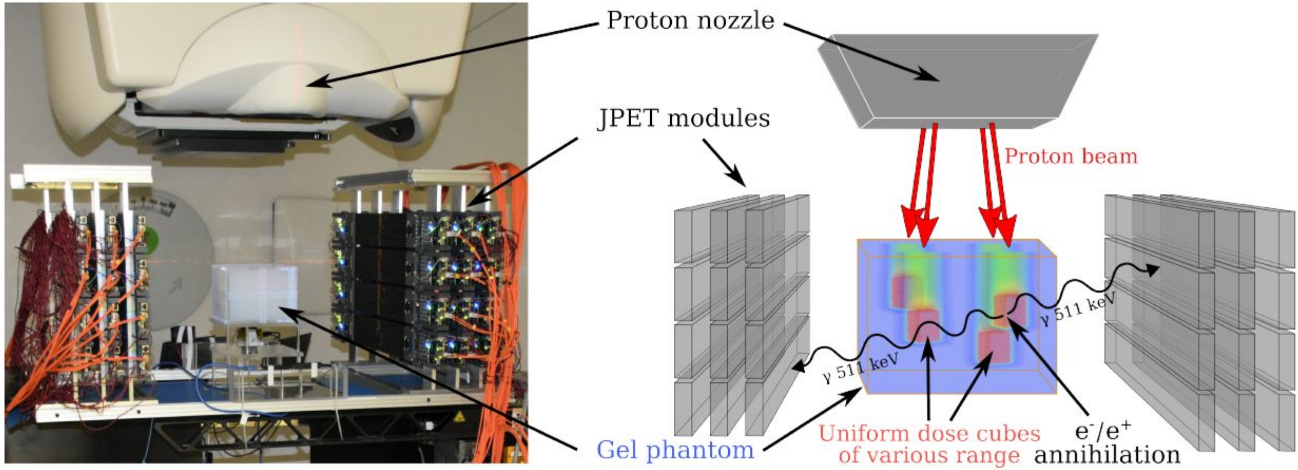


$y = 0.955 \cdot x + 0.003$
3σ confidence interval
Activity range shift
Activity range shift [mm]
Dose range shift [mm]
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
Mean shift in PET activity (mm)
Mean shift in dose (mm)
-1.5
-1
-0.5
0
0.5
1
1.5

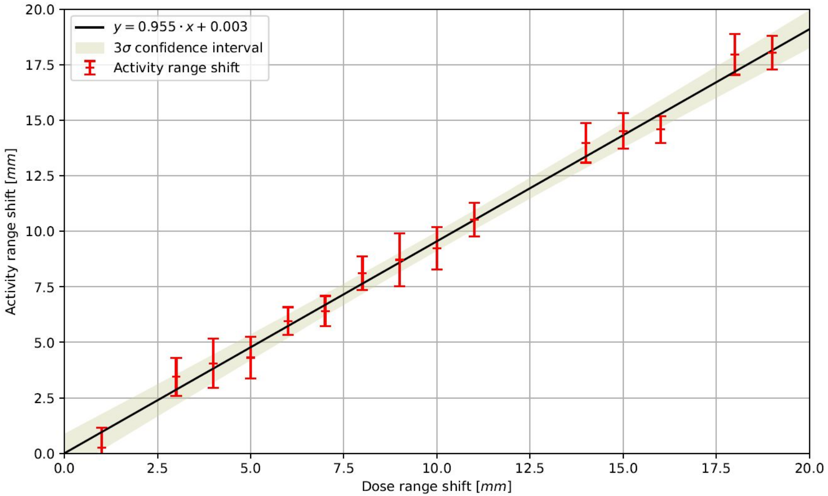


Total acquisition time
Acquisition time 5 min
Mean range shift error [mm]
Dose [Gy(RBE)]
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
2
4
6
8
10
12
14
16

Summary



- we have successfully determined proton range shifts in agarous phantoms with modular J-PET
- a linear dependence between dose and activity shifts was observed
- after system upgrade an on-beam measurements will be possible



Thank you for your attention

Paweł Moskal, Grzegorz Korcyl, Maciej Bakalarek, Damian Borys, Antoni Ruciński, Jan Gajewski, Karol Brzeziński, Jakub Baran, Paulina Stasica et al.

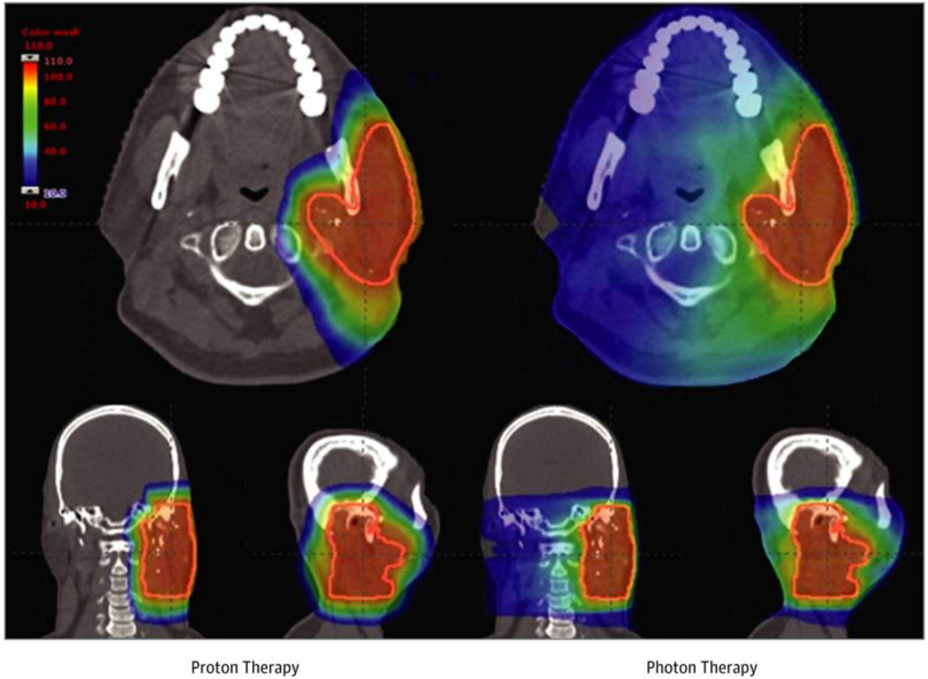
Backup

Proton therapy

- Pediatric tumors: reduced late toxicity and secondary malignancy risk.
- Head & neck, skull-base tumors: improved sparing of salivary glands/brainstem.
- Ocular and selected CNS tumors: excellent local control.
- Some studies show comparable tumor control to photons.

Chen Z, et al. Proton versus photon radiation therapy: A clinical review. Front Oncol. 2023 Mar 29;13:1133909. doi: 10.3389/fonc.2023.1133909

Efstathiou, J.A. et al., Prostate Advanced Radiation Technologies Investigating Quality of Life (PARTIQoL): Phase III Randomized Clinical Trial of Proton Therapy vs. IMRT for Localized Prostate Cancer
International Journal of Radiation Oncology, Biology, Physics, Volume 120, Issue 2, S1 October 01, 2024.



Baumann BC, Mitra N, Harton JG, et al. Comparative Effectiveness of Proton vs Photon Therapy as Part of Concurrent Chemoradiotherapy for Locally Advanced Cancer. JAMA Oncol. 2020;6(2):237–246. doi:10.1001/jamaoncol.2019.4889

Proton range determination

Main sources of uncertainty:

- morphological changes,
- anatomical deformation due to motion
- HU to RSP conversion error

1. Dual-energy CT (DECT) / photon-counting CT (PCCT)

Charles Ekene Chika, World J Radiol. 2025 Jun 28;17(6):105728. doi: 10.4329/wjr.v17.i6.105728

2. Proton CT (pCT) / proton radiography (pRad)

Alme J, et al.(2020) A High-Granularity Digital Tracking Calorimeter Optimized for Proton CT. Front. Phys. 8:568243. doi: 10.3389/fphy.2020.568243

3. Machine learning & Monte-Carlo aid

Wildman VL, et al.. Recent advances in applying machine learning to proton radiotherapy. Biomed Phys Eng Express. 2025 Jul 23;11(4):042005. doi: 10.1088/2057-1976/adeb90. PMID: 40609552; PMCID: PMC12284894.

1. Prompt Gamma Imaging (PGI) / Prompt Gamma Spectroscopy (PGS) / Prompt Gamma Timing (PGT)

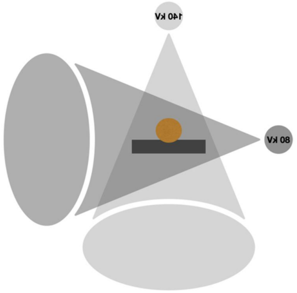
Everaere P, et al. Prompt gamma energy integration: a new method for online-range verification in proton therapy with pulsed-beams. Front. Phys. 12:1371015. doi: 10.3389/fphy.2024.1371015

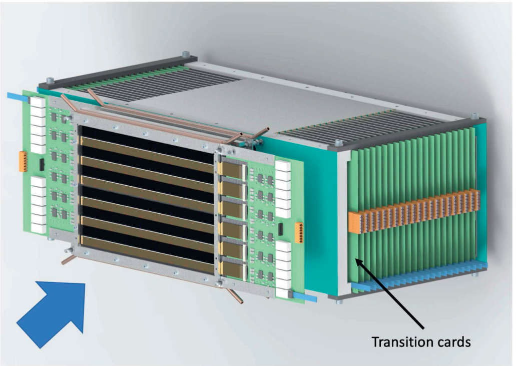
2. Ionoacoustic / protoacoustic imaging

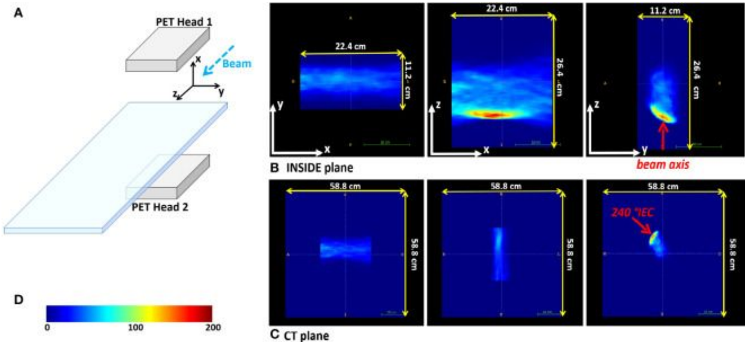
Alme J, et Wang S, et al. Real-time tracking of the Bragg peak during proton therapy via 3D protoacoustic Imaging in a clinical scenario. Npj Imaging. 2024;2(1):34. doi: 10.1038/s44303-024-00039-x. Epub 2024 Sep 17. PMID: 40078731; PMCID: PMC11893450.

3. In-beam PET and delayed gamma imaging

Moglioni M, et al. In-vivo range verification analysis with in-beam PET data for patients treated with proton therapy at CNAO. Front Oncol. 2022 Sep 26;12:929949. doi: 10.3389/fonc.2022.929949. PMID: 36226070; PMCID: PMC9549776.







J-PET

Phys. Med. Biol. 68 (2023) 145016 https://doi.org/10.1088/1361-6560/acdd4c

Physics in Medicine & Biology

IPEM Institute of Physics and Engineering in Medicine

PAPER

Detection of range shifts in proton beam therapy using the J-PET scanner: a patient simulation study

Karol Brzeziński[1,2,*], Jakub Baran[3,4,5], Damian Borys[6,7], Jan Gajewski[1], Neha Chug[3,4,5], Aurelien Coussat[3,4,5], Eryk Czerwiński[3,4,5], Meysam Dadgar[3,4,5], Kamil Dulski[3,4,5], Kavya V Eliyan[3,4,5], Aleksander Gajos[3,4,5], Krzysztof Kacprzak[3,4,5], Łukasz Kapłon[3,4,5], Konrad Klimaszewski[8], Paweł Konieczka[8], Renata Kopeć[1], Grzegorz Korcyl[3,4,5], Tomasz Kozik[3,4,5], Wojciech Krzemień[9], Deepak Kumar[3,4,5], Antony J Lomax[10,11], Keegan McNamara[10,11], Szymon Niedźwiecki[3,4,5], Paweł Olko[1], Dominik Panek[3,4,5], Szymon Parzych[3,4,5], Elena Perez del Rio[3,4,5], Lech Raczyński[8], Sushil Sharma[3,4,5], Shivani[3,4,5], Roman Y Shopa[8], Tomasz Skóra[12], Magdalena Skurzok[3,4,5], Paulina Stasica[1], Ewa Ł Stępień[3,4,5], Keyvan Tayefi[3,4,5], Faranak Tayefi[3,4,5], Damien C Weber[10,13,14], Carla Winterhalter[10,11], Wojciech Wiślicki[8], Paweł Moskal[3,4,5] and Antoni Rucinski

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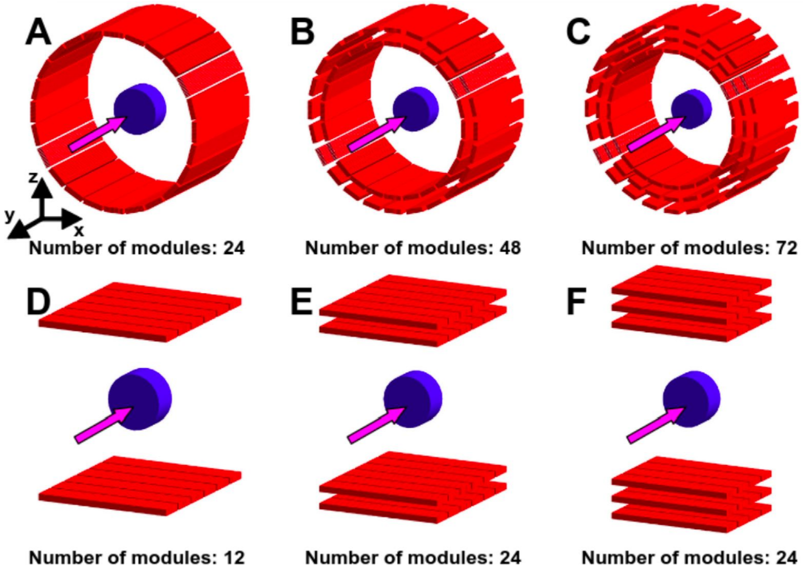
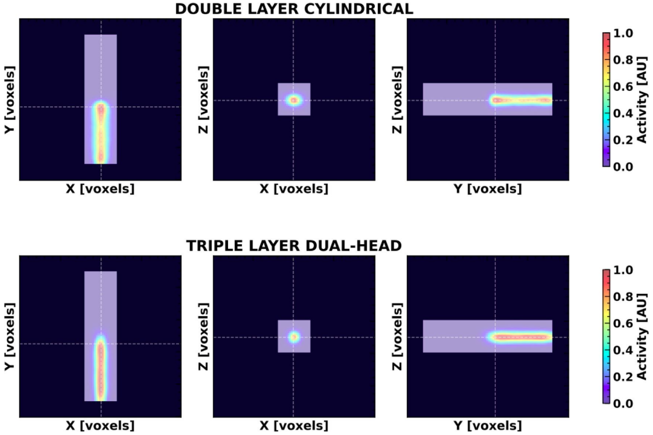
ELSEVIER

Technical note

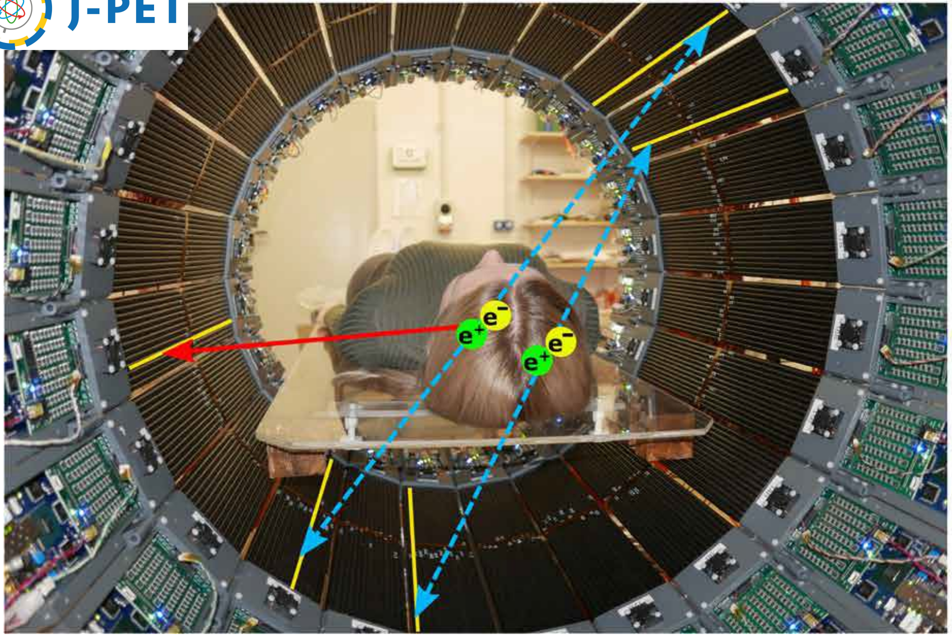
Feasibility of the J-PET to monitor the range of therapeutic proton beams

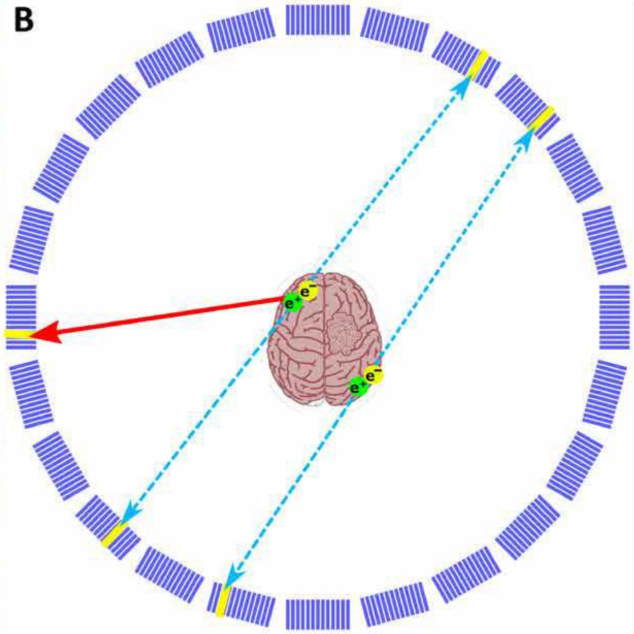
Jakub Baran[a,b,c,*], Damian Borys[d,e,f], Karol Brzeziński[f,g], Jan Gajewski[f], Michał Silarski[a,b,c], Neha Chug[a,b,c], Aurélien Coussat[a,b,c], Eryk Czerwiński[a,b,c], Meysam Dadgar[a,b,c], Kamil Dulski[a,b,c], Kavya V. Eliyan[a,b,c], Aleksander Gajos[a,b,c], Krzysztof Kacprzak[a,b,c], Łukasz Kapłon[a,b,c], Konrad Klimaszewski[h], Paweł Konieczka[h], Renata Kopeć[f], Grzegorz Korcyl[a,b,c], Tomasz Kozik[a,b,c], Wojciech Krzemień[i], Deepak Kumar[a,b,c], Antony J. Lomax[l,m], Keegan McNamara[l,m], Szymon Niedźwiecki[a,b,c], Paweł Olko[f], Dominik Panek[a,b,c], Szymon Parzych[a,b,c], Elena Perez del Rio[a,b,c], Lech Raczyński[h], Moyo Simbarashe[a,b,c], Sushil Sharma[a,b,c], Shivani[a,b,c], Roman Y. Shopa[h], Tomasz Skóra[n], Magdalena Skurzok[a,b,c], Paulina Stasica[f], Ewa Ł. Stępień[a,b,c], Keyvan Tayefi[a,b,c], Faranak Tayefi[a,b,c], Damien C. Weber[j,k,l], Carla Winterhalter[l,m], Wojciech Wiślicki[h], Paweł Moskal[a,b,c], Antoni Ruciński[f]

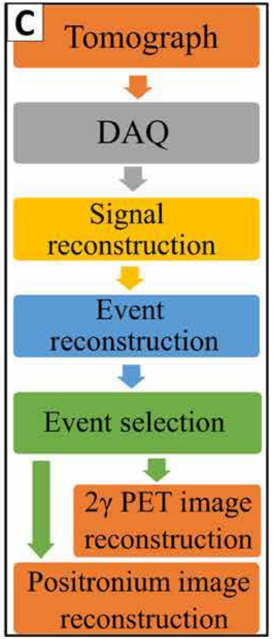




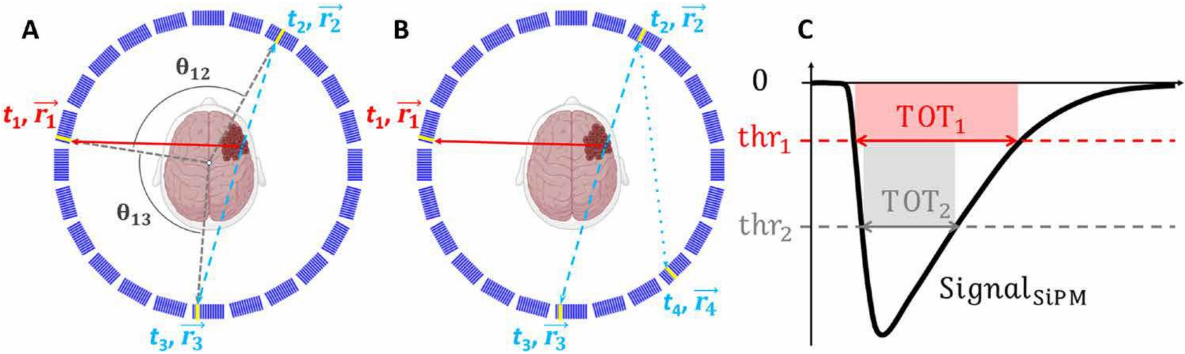
J-PET modular - general

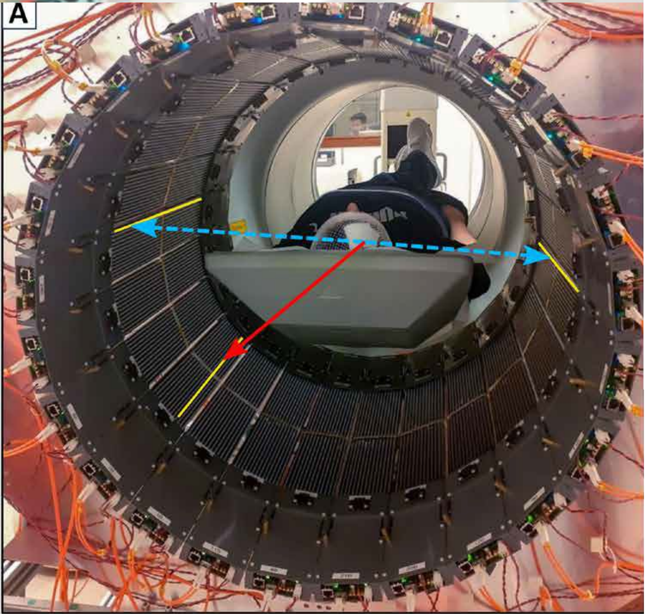






- **modular design**
- 24 modules
- 13 scintillators per module
- 4 SiPM per scintillator side
- 2 constant threshold per SiPM
- 50 cm FOV
- digital data at the module output
- 74 cm diameter
- very light ~60 kg





	Modular J-PET	Total Body uExplorer	PENPET Explorer	Biograph Vision Quadra
Company/facility	Jagellonan University, J-PET group	UC Davis and United Imaging Healthcare	UPenn, KAGE Medical and Philips	Siemens Healthineers, Turku PET
Scintillator type	BC-404	LSO (18.1 mm)	LYSO (19mm)	LSO (20 mm)
Light sensor	MPPC-1X4CH-ARRAY S13361-6674	SensL J-series	Philips Digital Photon Counting	MRD 85
Type of light sensor	Analog	Analog	Digital	Analog
Scintillator cross section (mm^2)	24 $\times$ 6	2.76 $\times$ 2.76	3.86 $\times$ 3.86	3.2 $\times$ 3.2
Axial length (cm)	50	194	64	106
Diameter (cm)	73.9	74	76.4	82
No. of modules	24	-	18	38
No. rings	1	-	3	32
Time window (ns)	4	4.5-6.9	4	4.7
Energy window (keV)	$>$ 200	430–645	440-600	435 - 585
Sensititvity in center (cps/kBq)	2.1	174	54	82.6
Sensitivity in 10 cm offset from center(cps/kBq)	1.8	177	57	84.1
Scatter fraction (%)	41.68 $\pm$ 0.19	36.3	32	37
Radial FWHM (mm)	4.9 $\pm$ 0.2	3.0	3.9 $\pm$ 0.4	3.19
Tangential FWHm (mm)	7.3 $\pm$ 0.1	3.0	3.9 $\pm$ 0.4	3.58
Axial FWHM (mm)	30.10 $\pm$ 0.01	2.8	4.1 $\pm$ 0.2	3.78

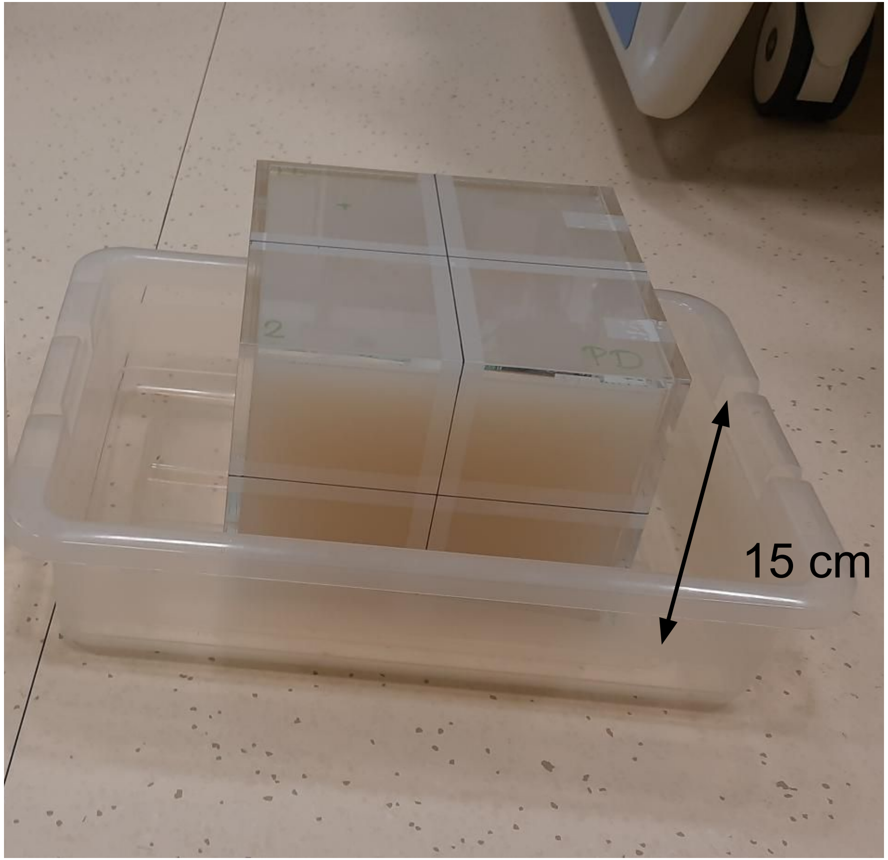
CCB and phantoms

J-PET

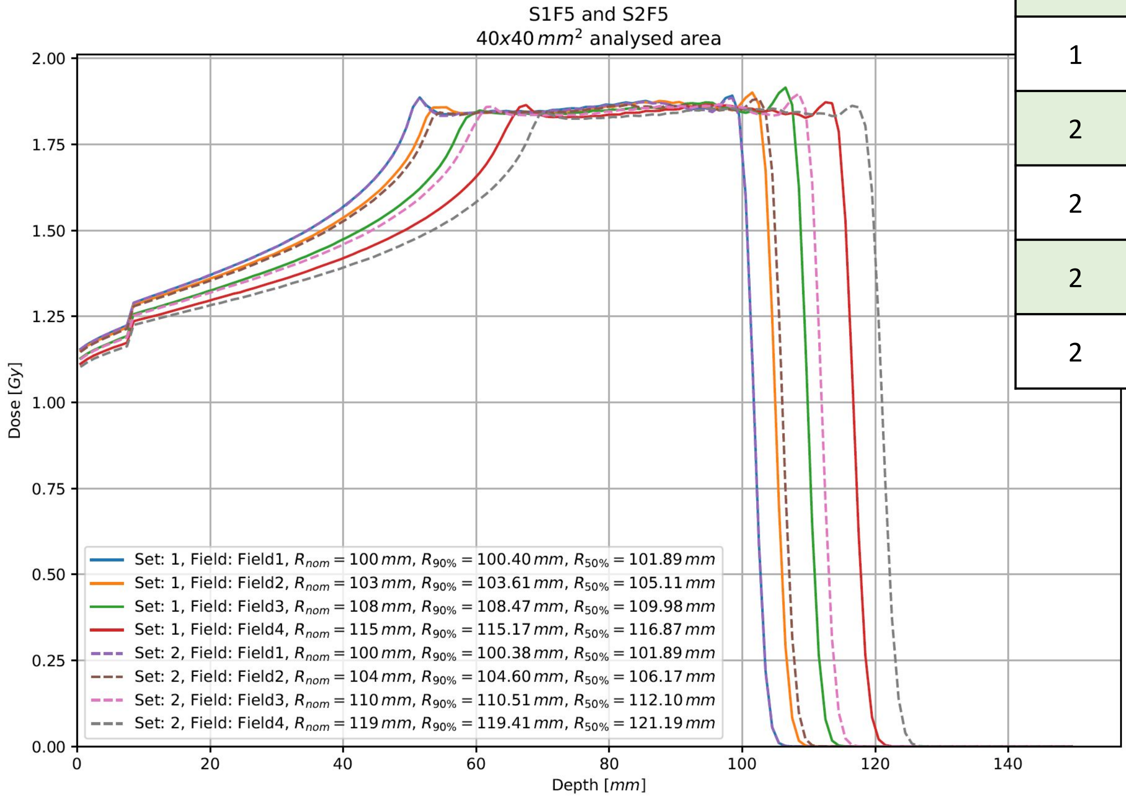
- The Cyclotron Centre Bronowice (CCB) produces and accelerates protons to therapeutic energies from 70 to 230 MeV using the isochronous cyclotron C-230 (IBA, Belgium).
- In Poland, proton therapy is used clinically for radiation therapy at Cyclotron Centre Bronowice (CCB), Krakow Proton Beam Therapy Center of the Institute of Nuclear Physics PAS (IFJ PAS) to treat patients from Krakow and neighboring oncology hospitals, where over 1500 patients have been treated so far.

Agarose gel phantom:

- $20 \times 20 \times 15\ cm^3$
- 6 mm PMMA walls
- filled with agar + water

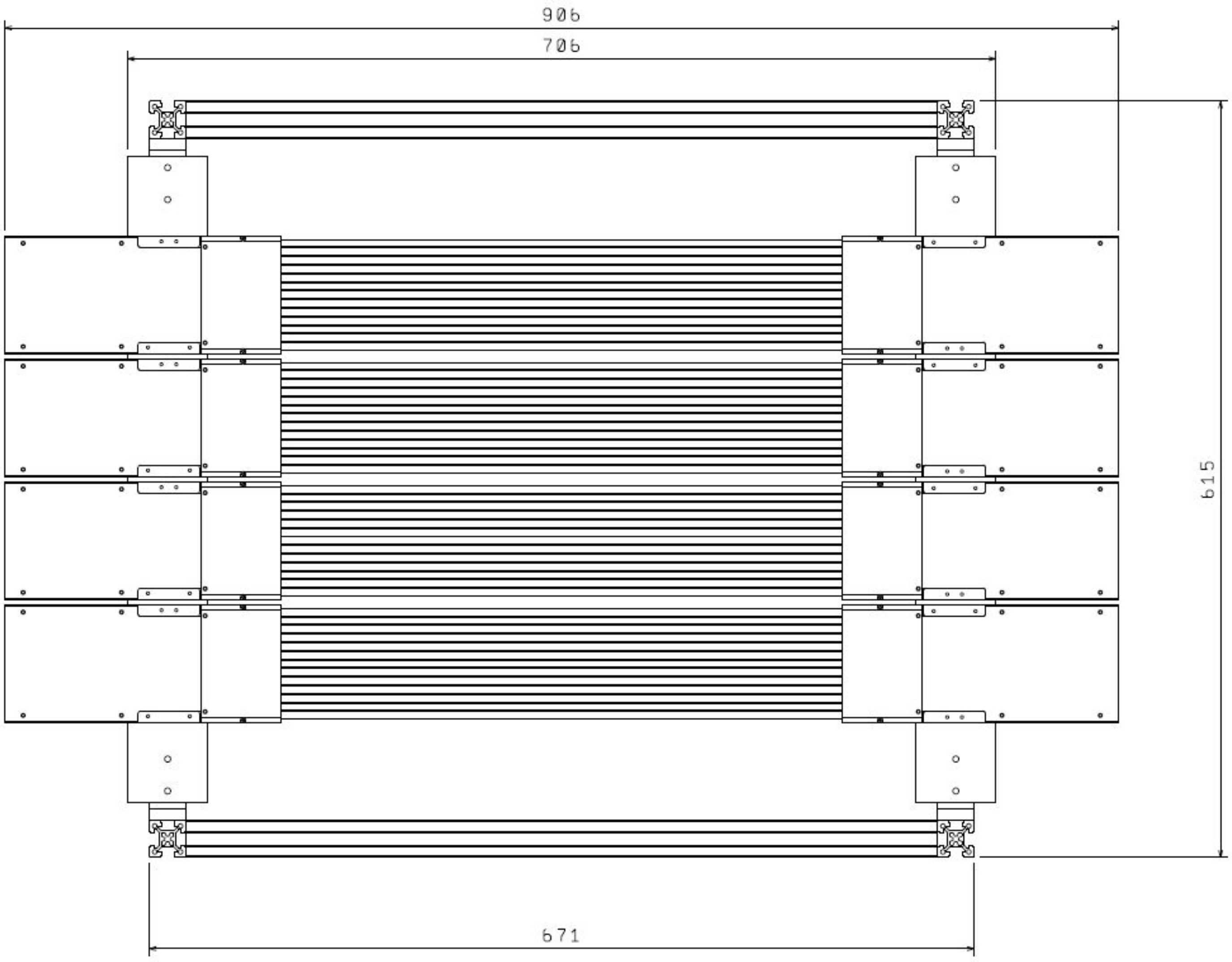


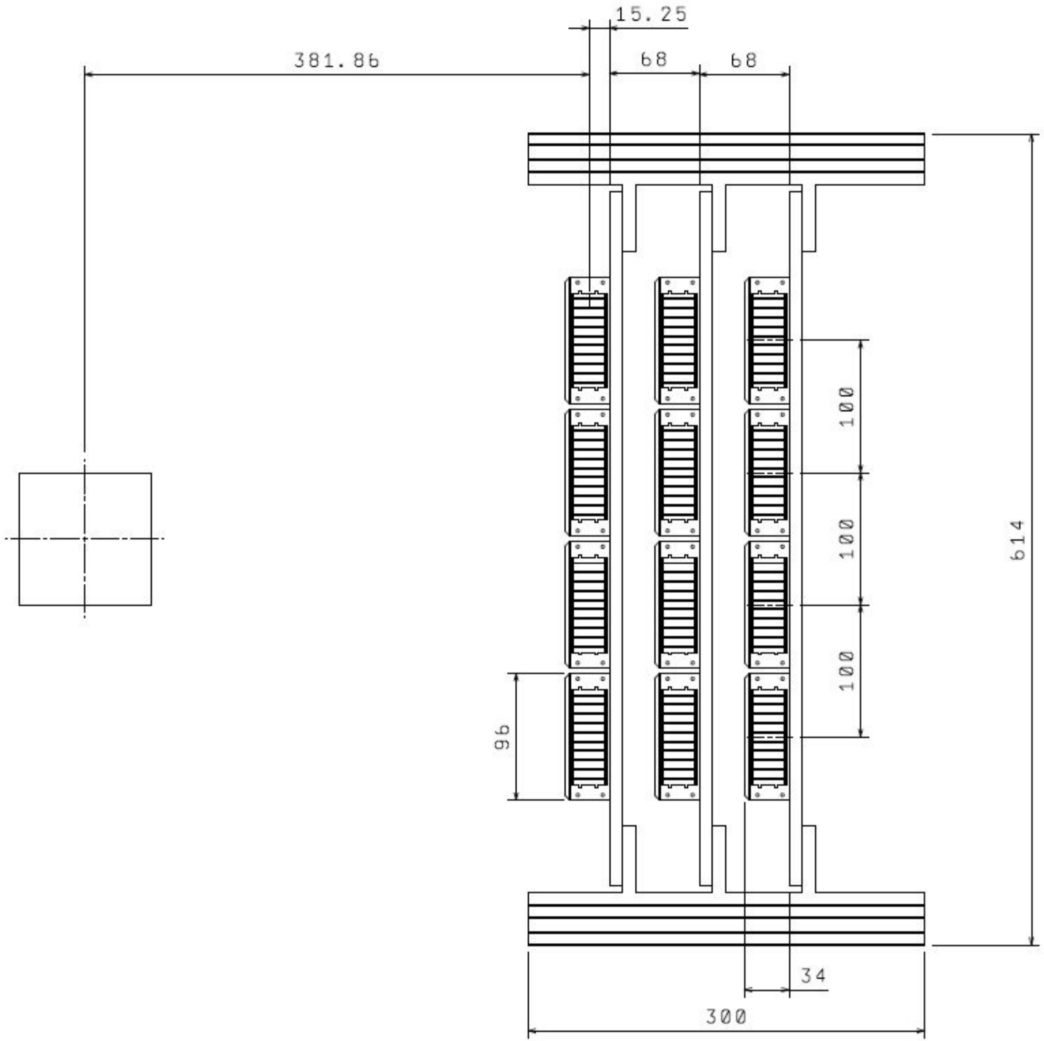
J-PET

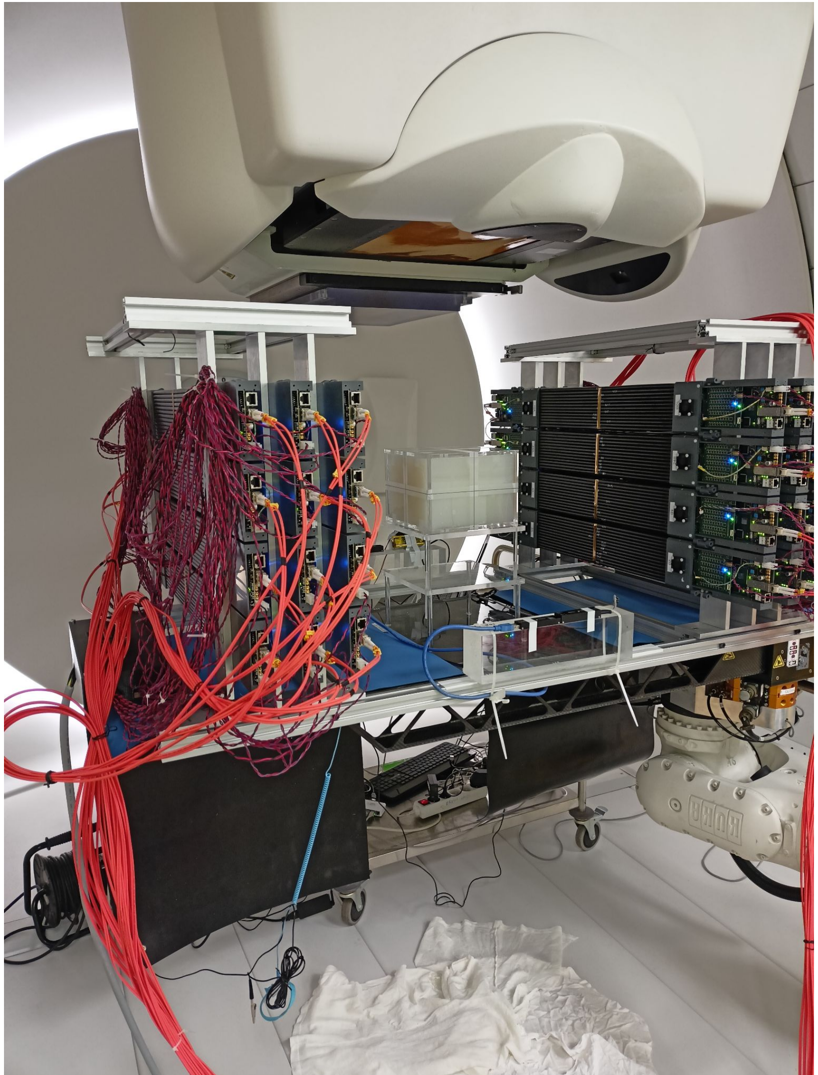


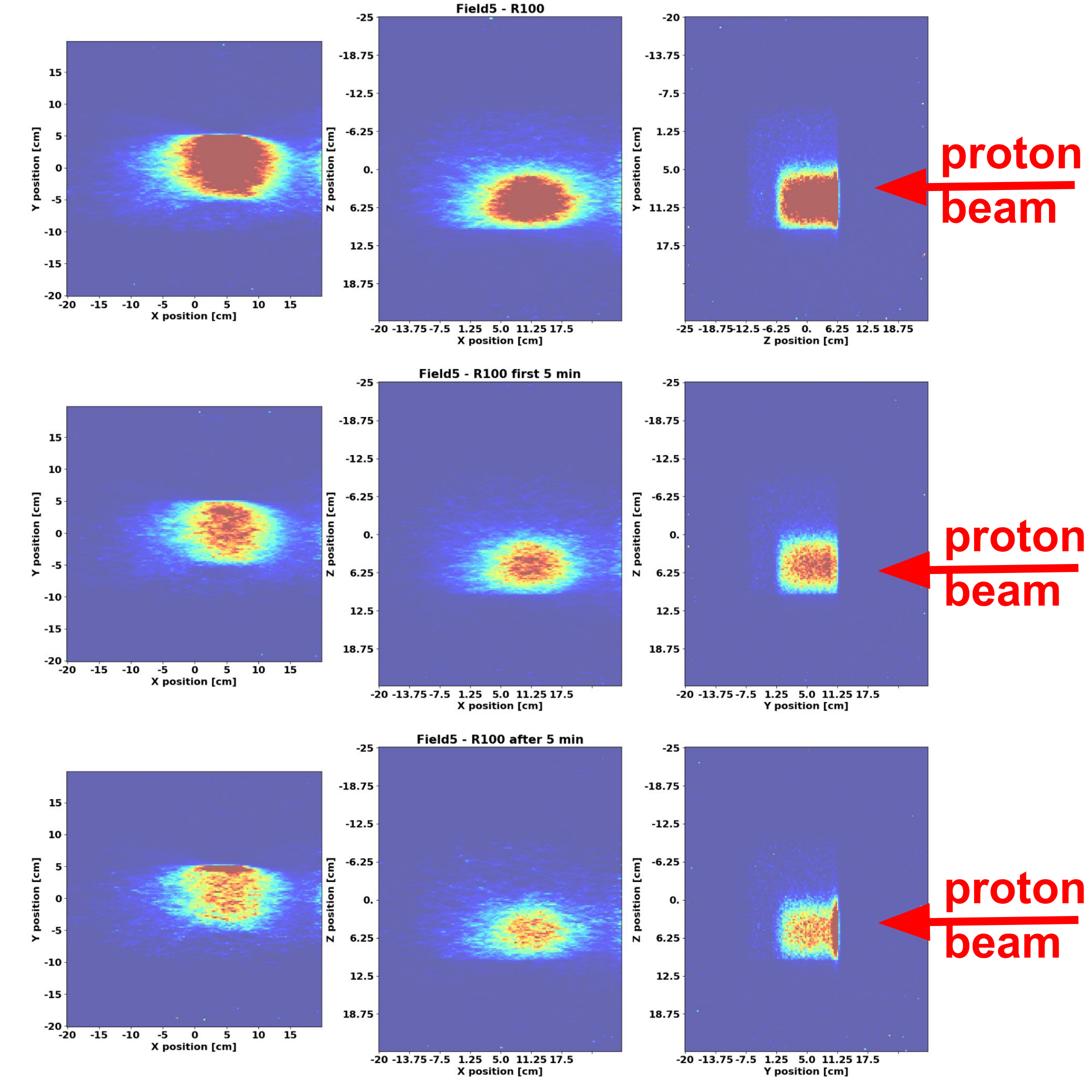
setNo	fieldName	fieldNo	nomRange	range90	range50
1	Field1	1	100	100.40	101.89
1	Field2	2	103	103.61	105.11
1	Field3	3	108	108.47	109.98
1	Field4	4	115	115.17	116.87
2	Field1	1	100	100.38	101.89
2	Field2	2	104	104.60	106.17
2	Field3	3	110	110.51	112.10
2	Field4	4	119	119.41	121.19

J-PET

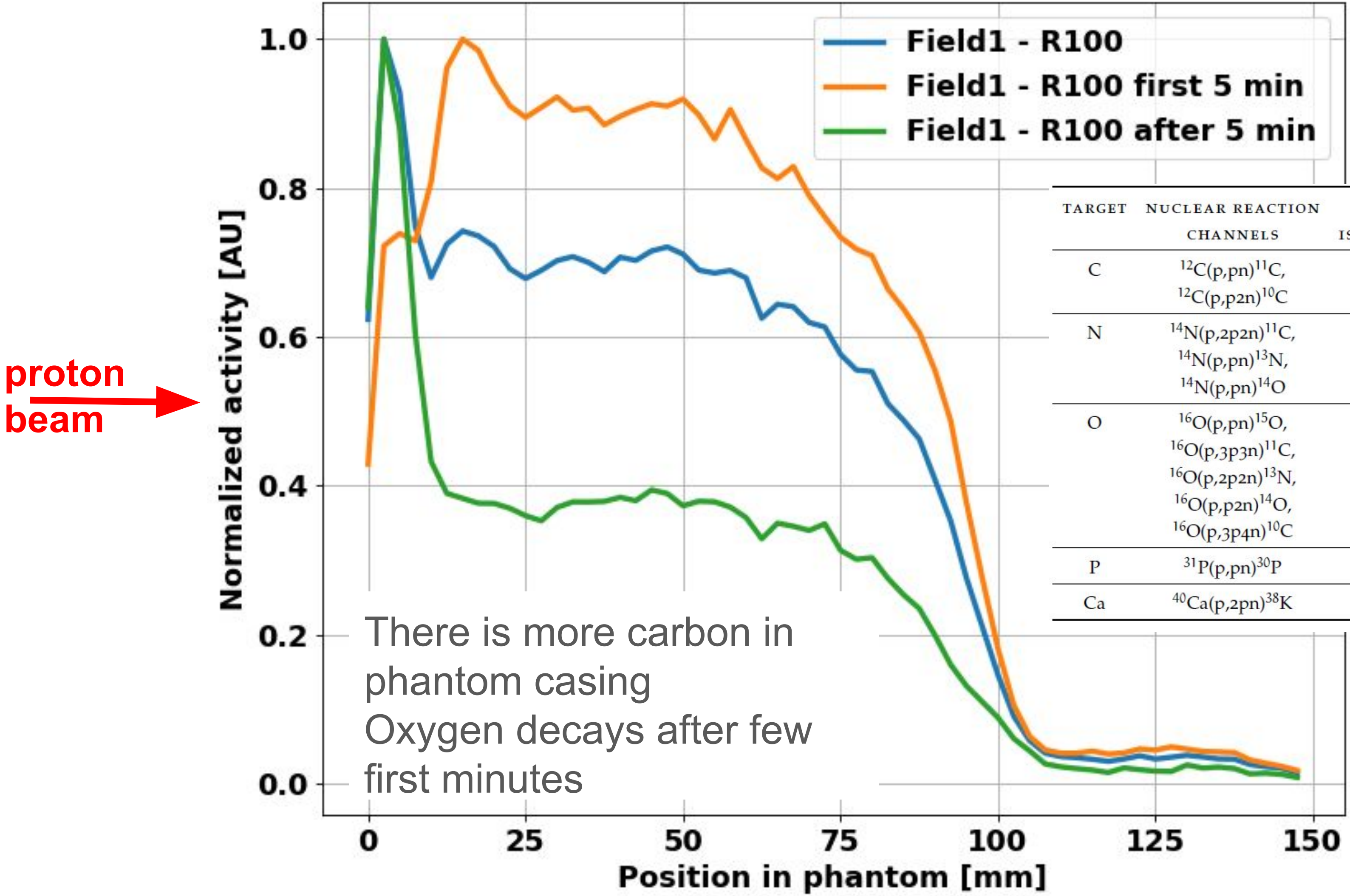



15.25
381.86
68
68
100
100
100
614
96
34
300





TARGET	NUCLEAR REACTION CHANNELS	β^+ ISOTOPES	HALF-LIFE
C	$^{12}C(p,pn)^{11}C$, $^{12}C(p,p2n)^{10}C$	^{10}C, ^{11}C	19.29 s, 20.33 min
N	$^{14}N(p,2p2n)^{11}C$, $^{14}N(p,pn)^{13}N$, $^{14}N(p,pn)^{14}O$	^{13}N	9.96 min
O	$^{16}O(p,pn)^{15}O$, $^{16}O(p,3p3n)^{11}C$, $^{16}O(p,2p2n)^{13}N$, $^{16}O(p,p2n)^{14}O$, $^{16}O(p,3p4n)^{10}C$	^{14}O, ^{15}O	70.61 s, 122.24 s
P	$^{31}P(p,pn)^{30}P$	^{30}P	2.50 min
Ca	$^{40}Ca(p,2pn)^{38}K$	^{38}K	7.64 min

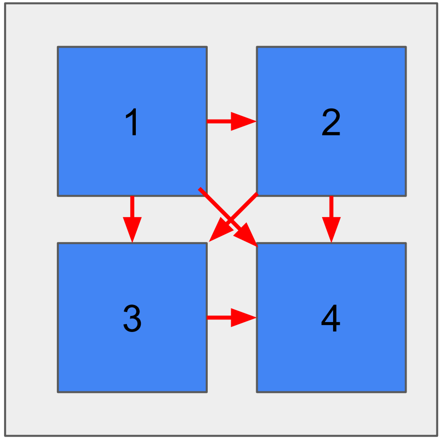


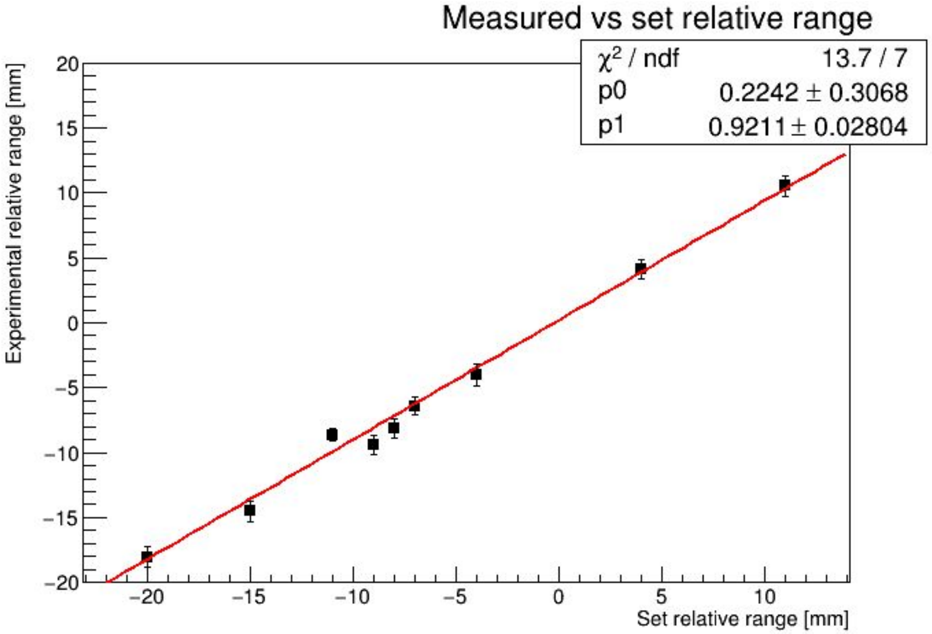
TARGET	NUCLEAR REACTION CHANNELS	β^+ ISOTOPES	HALF-LIFE
C	$^{12}C(p,pn)^{11}C$, $^{12}C(p,p2n)^{10}C$	^{10}C, ^{11}C	19.29 s, 20.33 min
N	$^{14}N(p,2p2n)^{11}C$, $^{14}N(p,pn)^{13}N$, $^{14}N(p,pn)^{14}O$	^{13}N	9.96 min
O	$^{16}O(p,pn)^{15}O$, $^{16}O(p,3p3n)^{11}C$, $^{16}O(p,2p2n)^{13}N$, $^{16}O(p,p2n)^{14}O$, $^{16}O(p,3p4n)^{10}C$	^{14}O, ^{15}O	70.61 s, 122.24 s
P	$^{31}P(p,pn)^{30}P$	^{30}P	2.50 min
Ca	$^{40}Ca(p,2pn)^{38}K$	^{38}K	7.64 min

There is more carbon in phantom casing
Oxygen decays after few first minutes

Remark 2 - make combinations between different fields

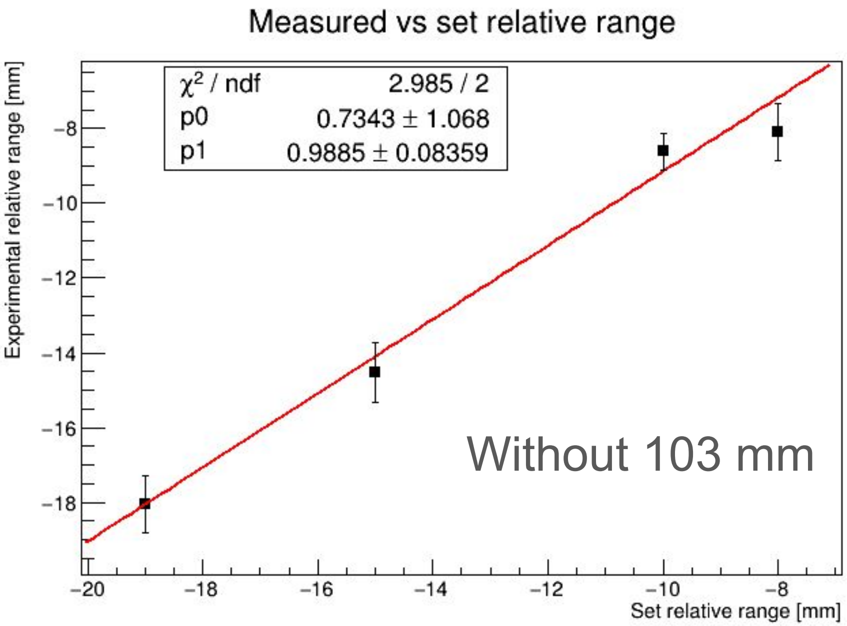
New set of combinations:
1-2; 1-3; 1-4; 2-3; 2-4; 3-4;



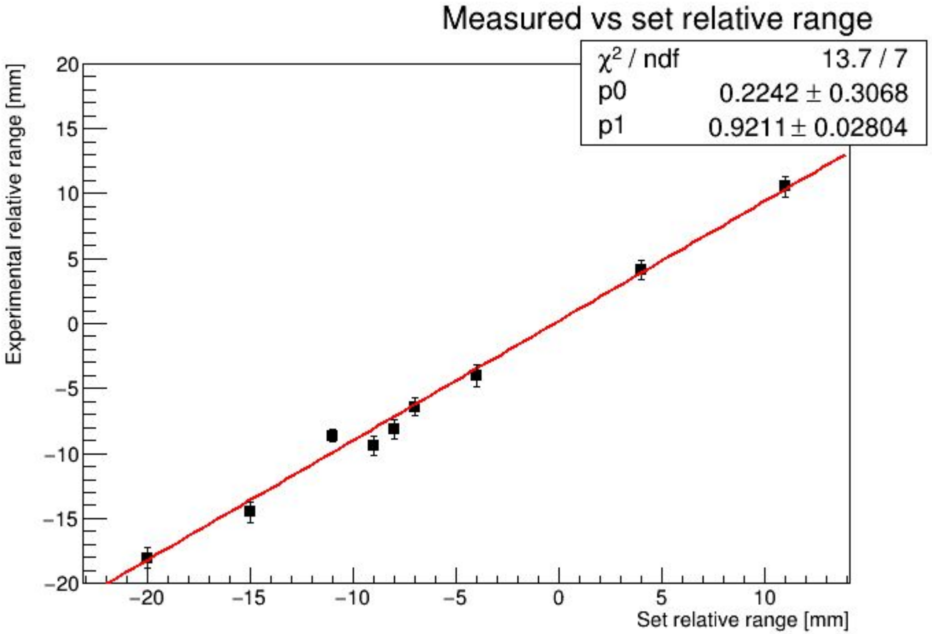


Remark 2 - make combinations between different fields

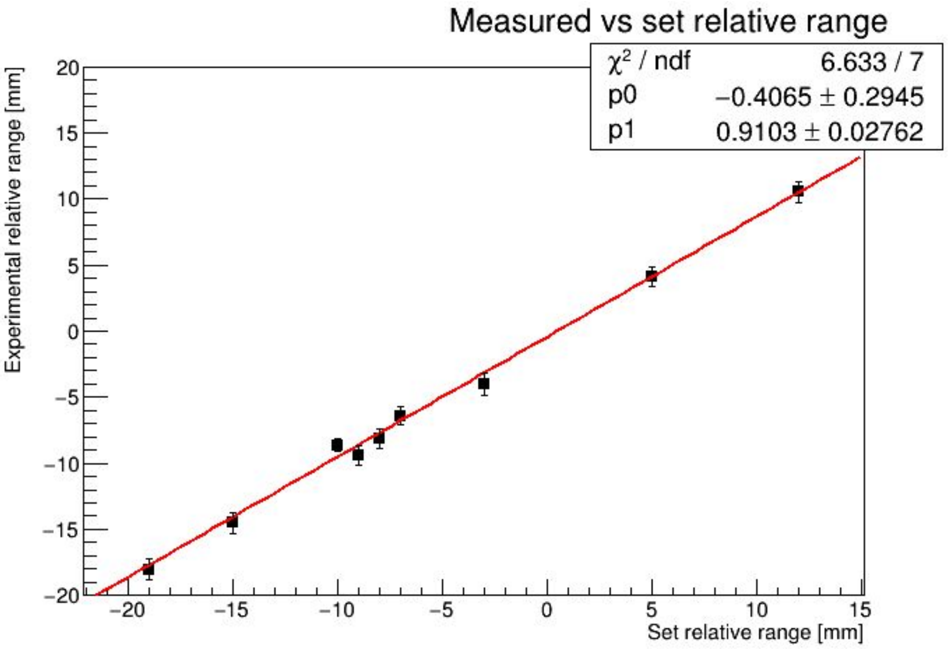
4 Gy data



Without 103 mm



Remark 2 - make combinations between different fields ranges from JG



Phantom	Field	Nominal Range $[mm]$	Range at 50% $[mm]$	Acquisition time $[min]$
A	1	100	101.89	30
	2	108	109.98	31
	3	115	116.88	29
	4	103	105.10	30
B	5	100	101.88	33
	6	110	112.10	32
	7	119	121.19	32
	8	104	106.17	35

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J-PET experiment at CCB - offline data

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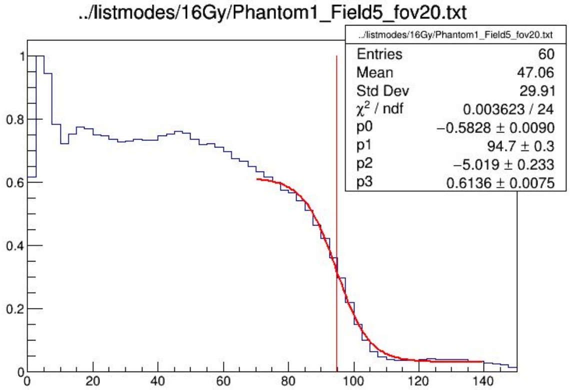
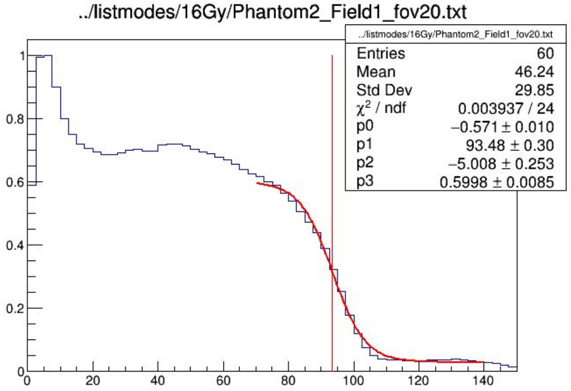
Difference between 100 mm range in two phantoms





16 Gy data!