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INSTITUTE OF NUCLEAR PHYSICS
POLISH ACADEMY OF SCIENCES

J-PET

The National Centre
for Research and Development

LIDER

InterDokMed

CASToR for image reconstruction with J-PET: diagnostic and proton therapy applications

CASToR User's Meeting IEEE NSS/MIC 2019

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On behalf of the J-PET collaboration

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Manchester, 30 X 2019

PRESENTATION PLAN

1. J-PET technology

2. Proton range monitoring

3. CASToR for the J-PET based proton range monitoring

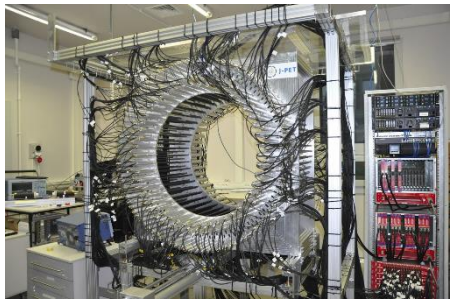
    - GATE Monte Carlo simulations
    - Sensitivity and attenuation correction
    - Homogenous phantom reconstructions
    - Proton beam range monitoring

4. Conclusions

J-PET TECHNOLOGY

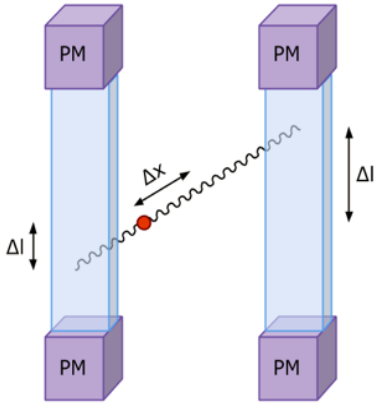
- **Cost-effective, plastic based technology**
- **Towards total-body PET imaging**

J-PET tomograph prototype (2016)



3-layer scanner consists of 192 EJ-230 plastic scintillators (7x19x500mm^3)

J-PET tomograph principle

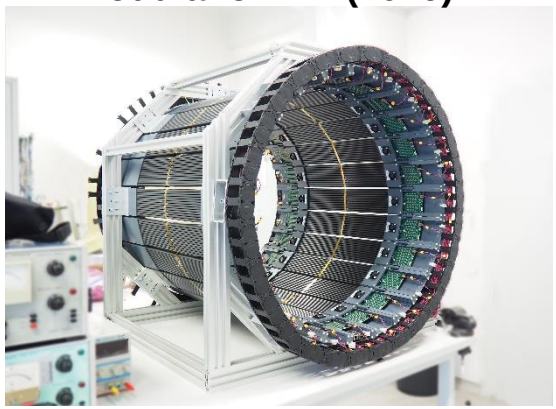


- **Compton scattering instead of fotoelectric absorbtion**
- **Two TOFs: in plastic and at the LOR level**
- **CRT = 400 ps**

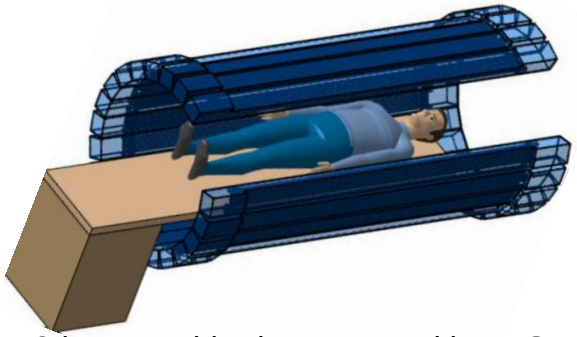
Photos by courtesy of Sz. Niedźwiecki and J-PET team

Modular J-PET (2019)

2nd generation, light, portable and easy reconfigurable JPET tomograph consists of 24 modules (13 single 5x24x500mm^3 plastic strips in each module).

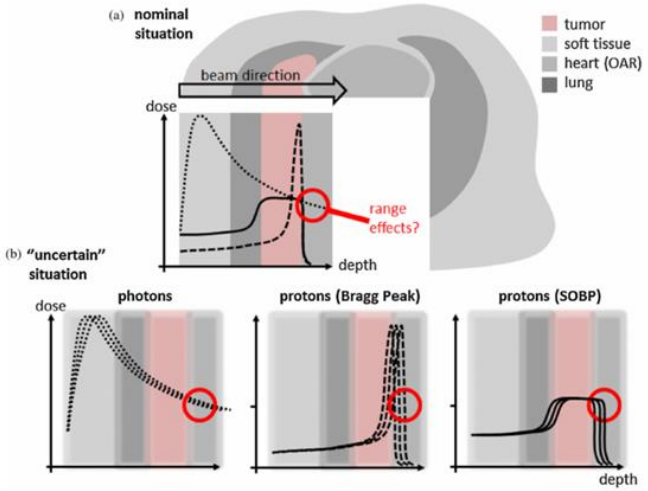


Total-body J-PET (202X)

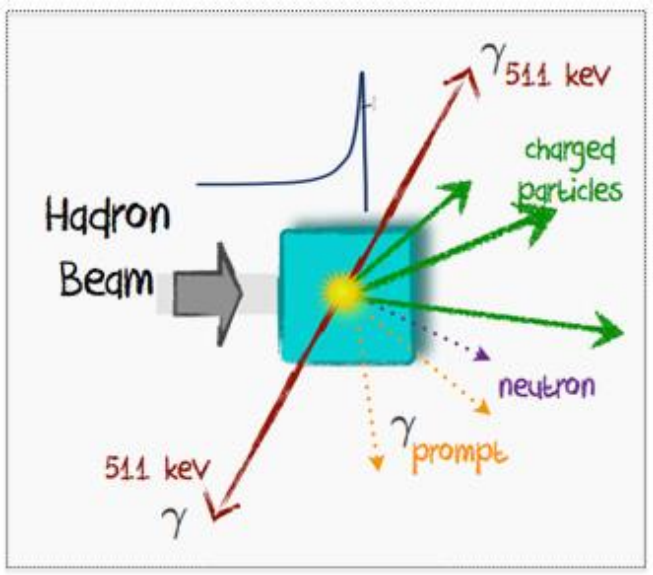


2-layer total-body scanner with WLS and 2 m long axial FOV

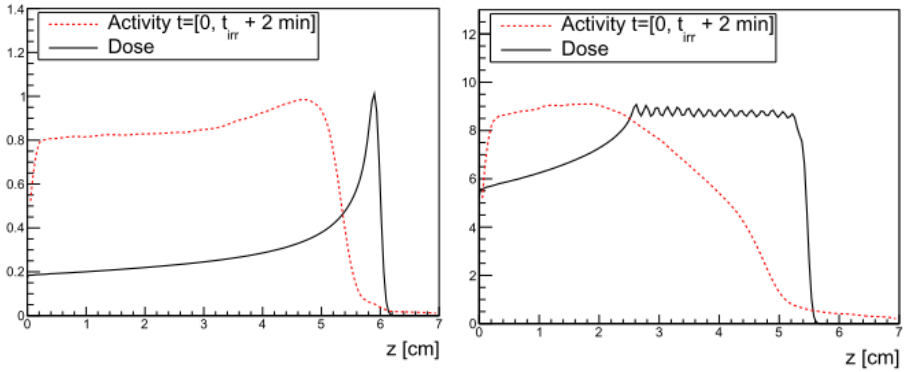
PROTON RANGE MONITORING



Dose distribution profiles for conventional photon radiotherapy vs proton radiotherapy (Knopf and Lomax, PMB 2013)



Secondary radiation produced during the protons interactions with matter (courtesy of Antoni Ruciński)



Dose and β^+ profiles from Monte Carlo simulations for 95 MeV protons (left) and 2Gy irradiation plan (Krann AC. et al. JINST 2010)

GATE MONTE CARLO SIMULATIONS

Simulated setups are as follows:

A. **single layer barrel – 24 modules**

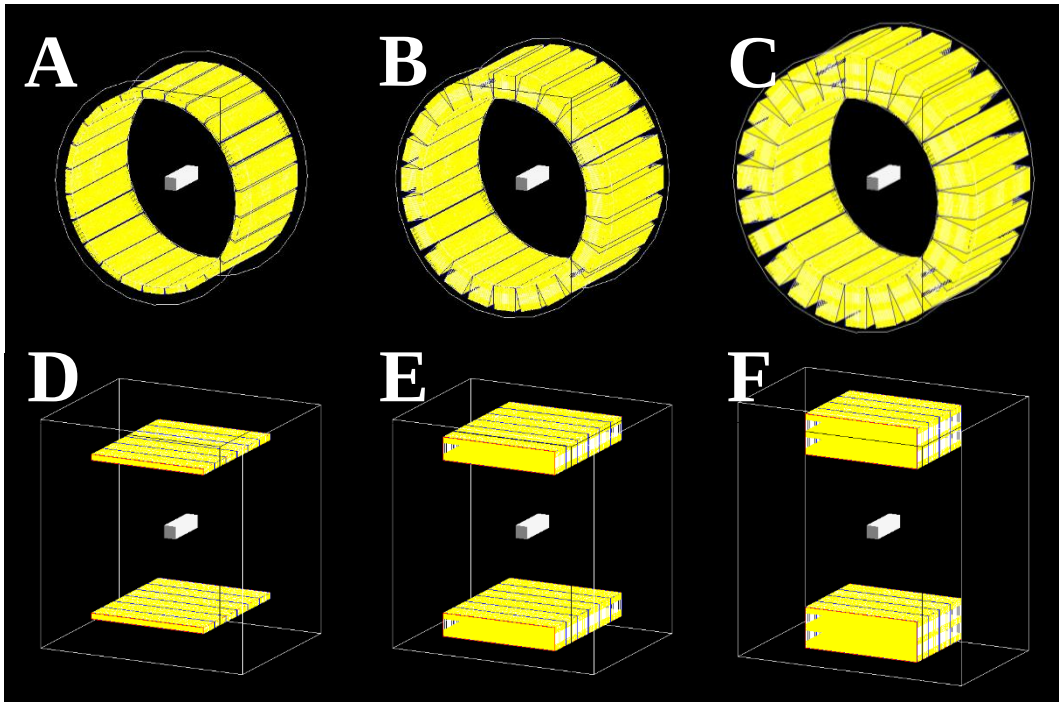
B. **double layer barrel – 48 modules**

C. **triple layer barrel – 72 modules**

D. **single layer dual-head – 12 modules**

E. **double layer dual-head – 24 modules**

F. **triple layer dual-head – 24 modules**



Simulated J-PET configurations: single layer barrel (A), double layer barrel (B), triple layer barrel (C), single layer dual-head (D), double layer dual-head (E), triple layer dual-head (F)

GATE MONTE CARLO SIMULATIONS

PHANTOM

J-PET detector

PROTON BEAM

J-PET detector

- Uniformly distributed 10^9 back-to-back 511 keV gammas within water phantom
- Water phantom 25x25x30 cm^3
- emlivermore physics list

- $2 \cdot 10^9$(single layer barrel) and 10^8 primary protons with the therapeutic beam model of the CCB (150 MeV)
- PMMA phantom 5x5x20 cm3
- QGSP_BIC_HP_EMY physics list

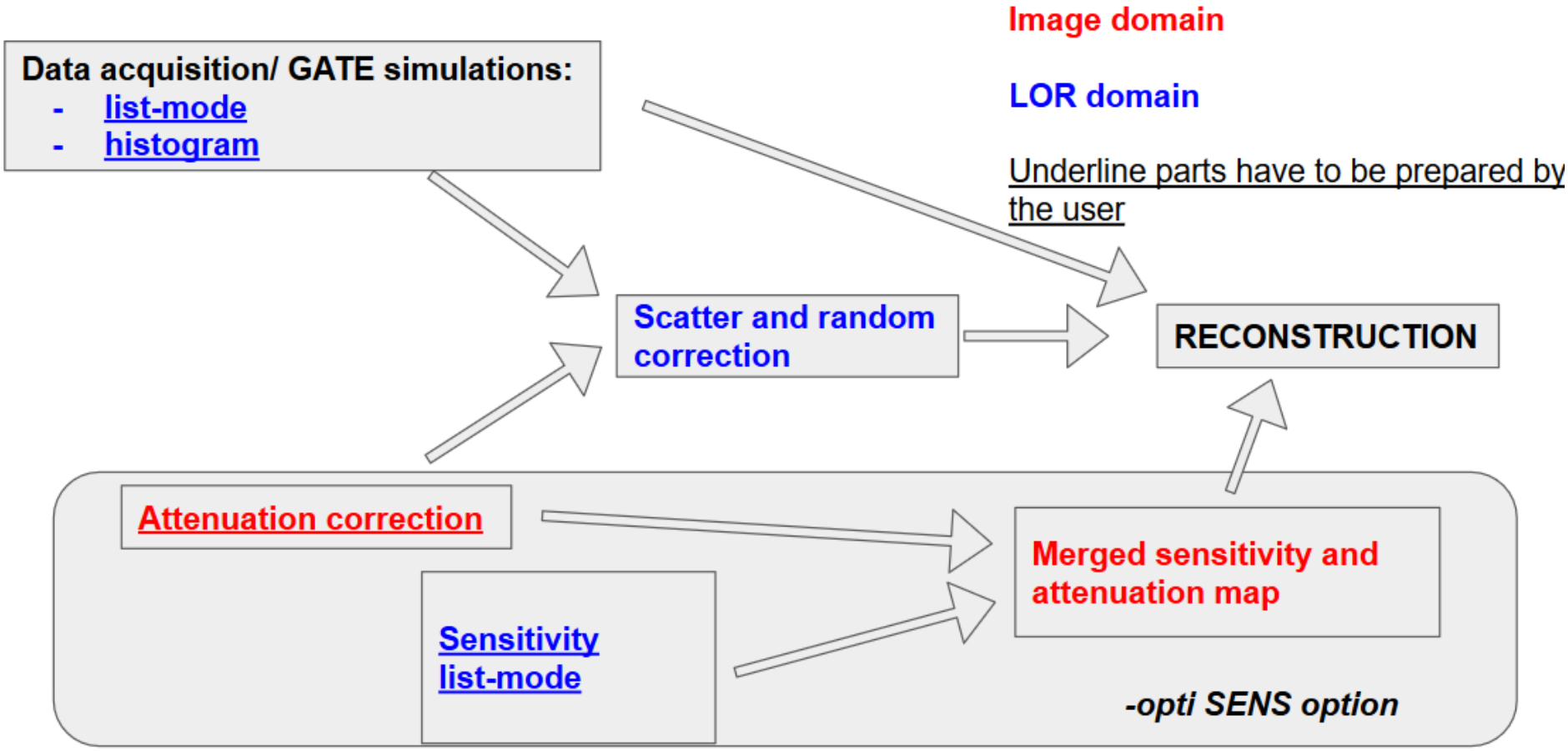
- PET reconstruction grid: 2.5 mm^3 isotropic
- TOF resolution: 500 ps

Time window: 3 ns, energy window: 200 keV

- Applied corrections: sensitivity, scatter, random, attenuation, post-smoothing

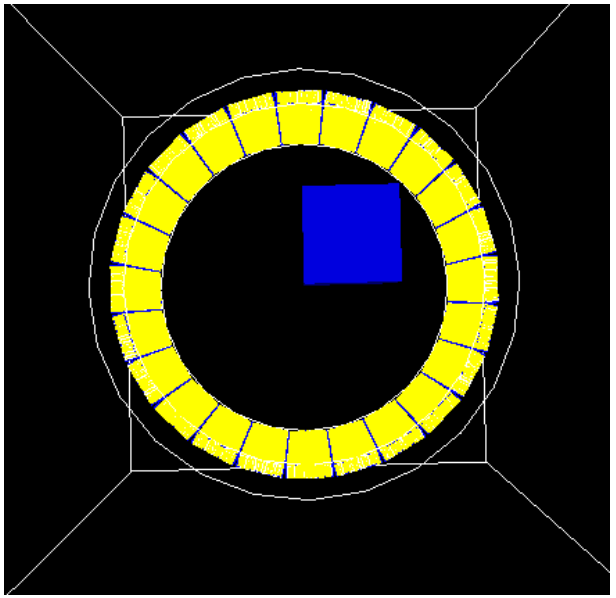
SENSITIVITY AND ATTENUATION CORRECTION

(Very) Basic CASTOR ver. 2.0.3 reconstruction workflow

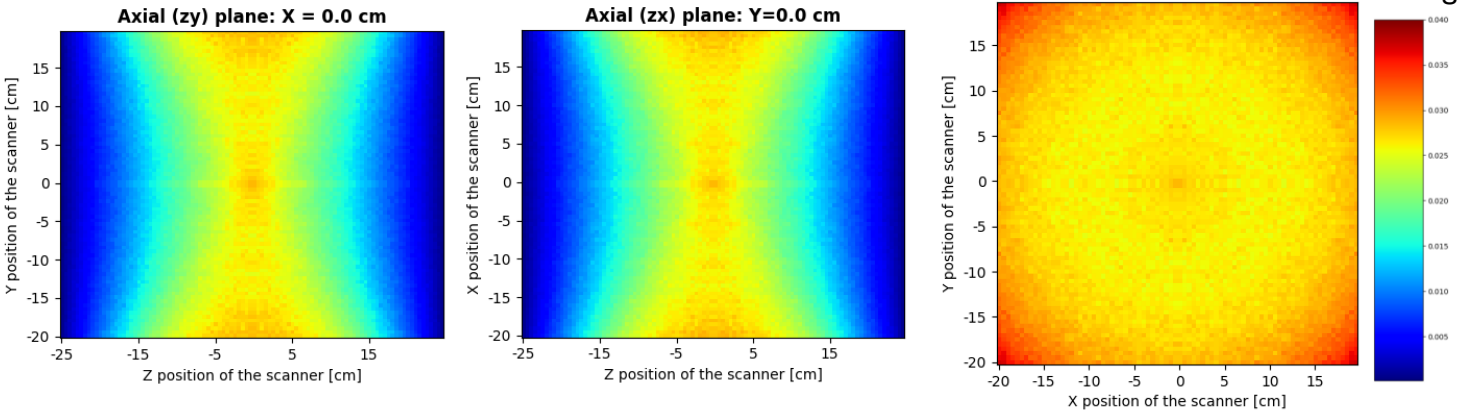


SENSITIVITY MAP

- **Uniformly distributed 10^{11} back-to-back 511 keV gammas within air phantom**
- **Air filled phantom 20x20x25 cm^3 (1/8 FOV)**
- **emlivermore physics list**
- **8 PET symmetries were used to obtain list-mode covered full FOV**
- **High statistics is needed due to low plastics' efficiency**

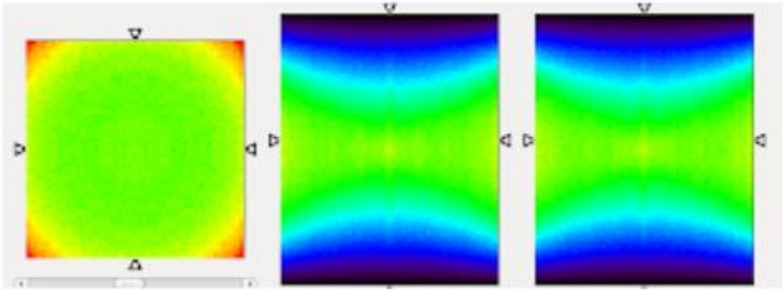


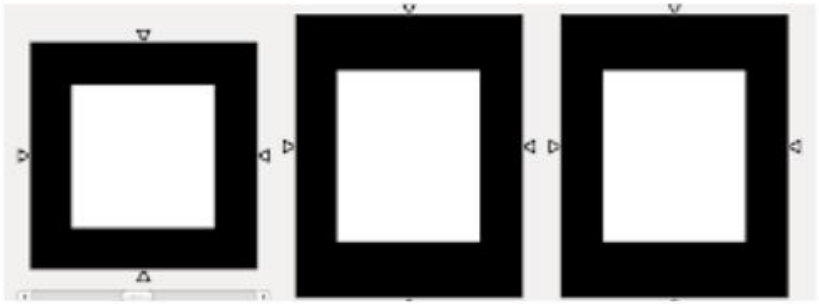
Example sensitivity map simulation setup for the single layer barrel configuration



Example sensitivity map for the single layer barrel configuration for the saggital (left), coronal (center) and axial (right) view.

MERGED SENSITIVITY AND ATTENUATION MAP





Sensitivity list-mode

Attenuation map

!!! TIME CONSUMING !!!

Merged sensitivity and attenuation map

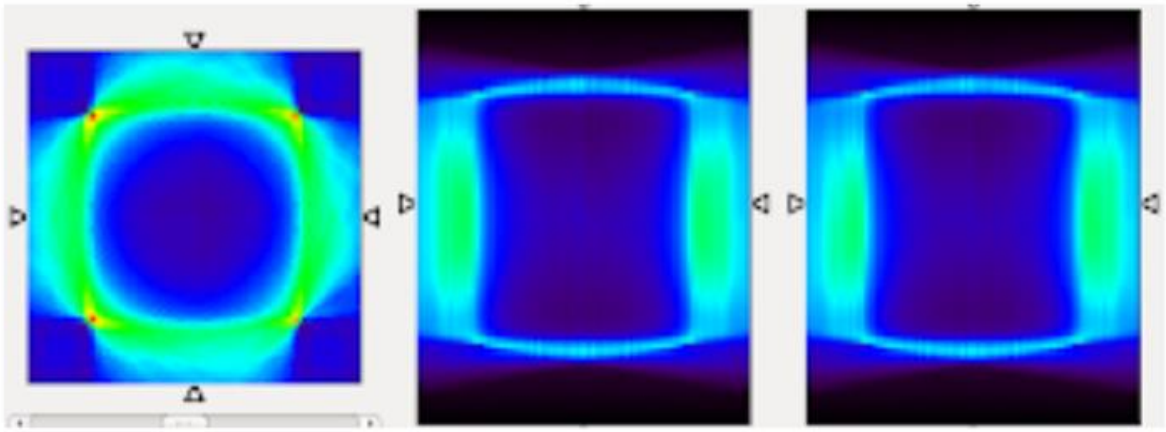


Image domain

LOR domain

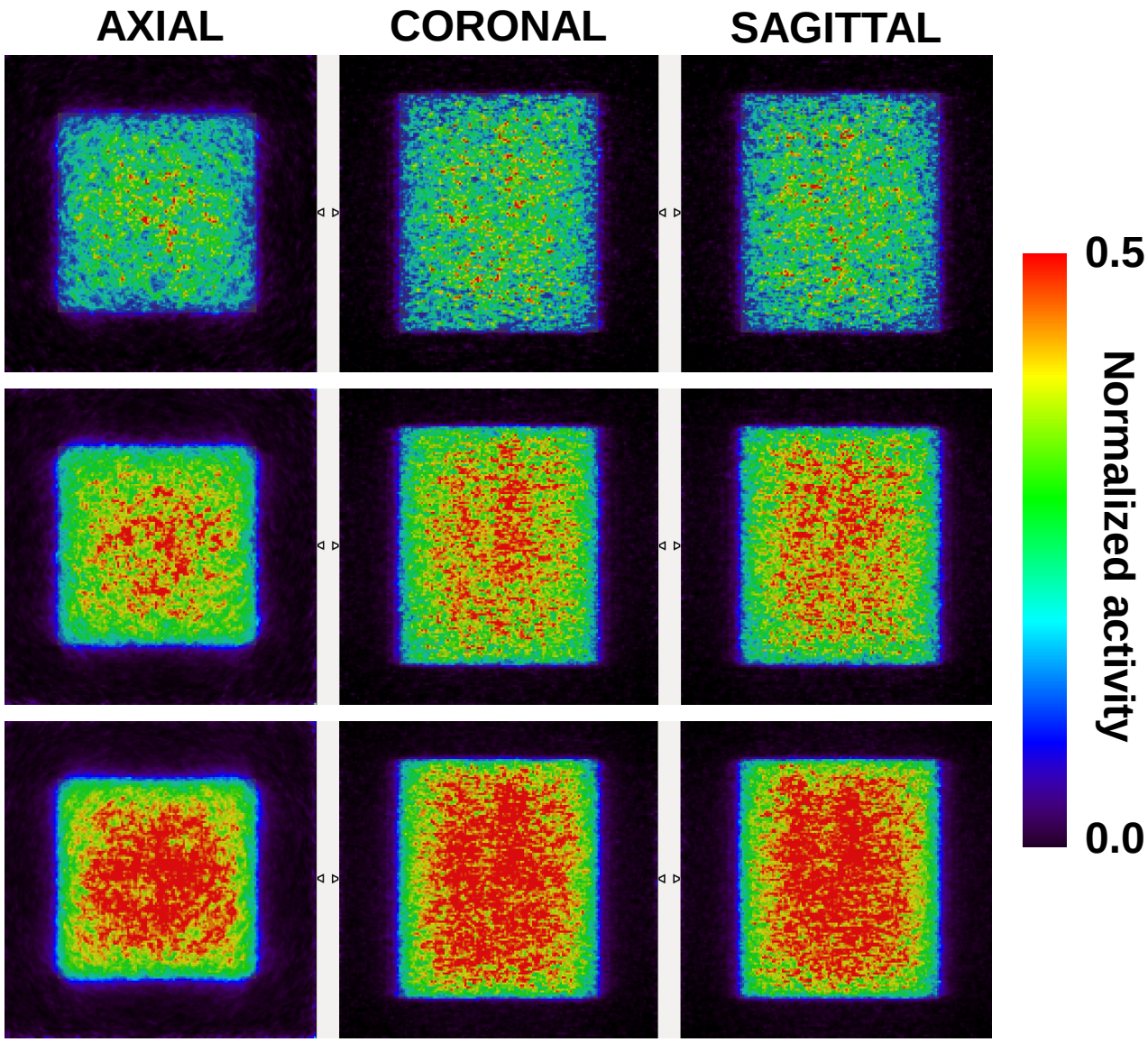
Underline parts have to be prepared by user

PHANTOM RECONSTRUCTION

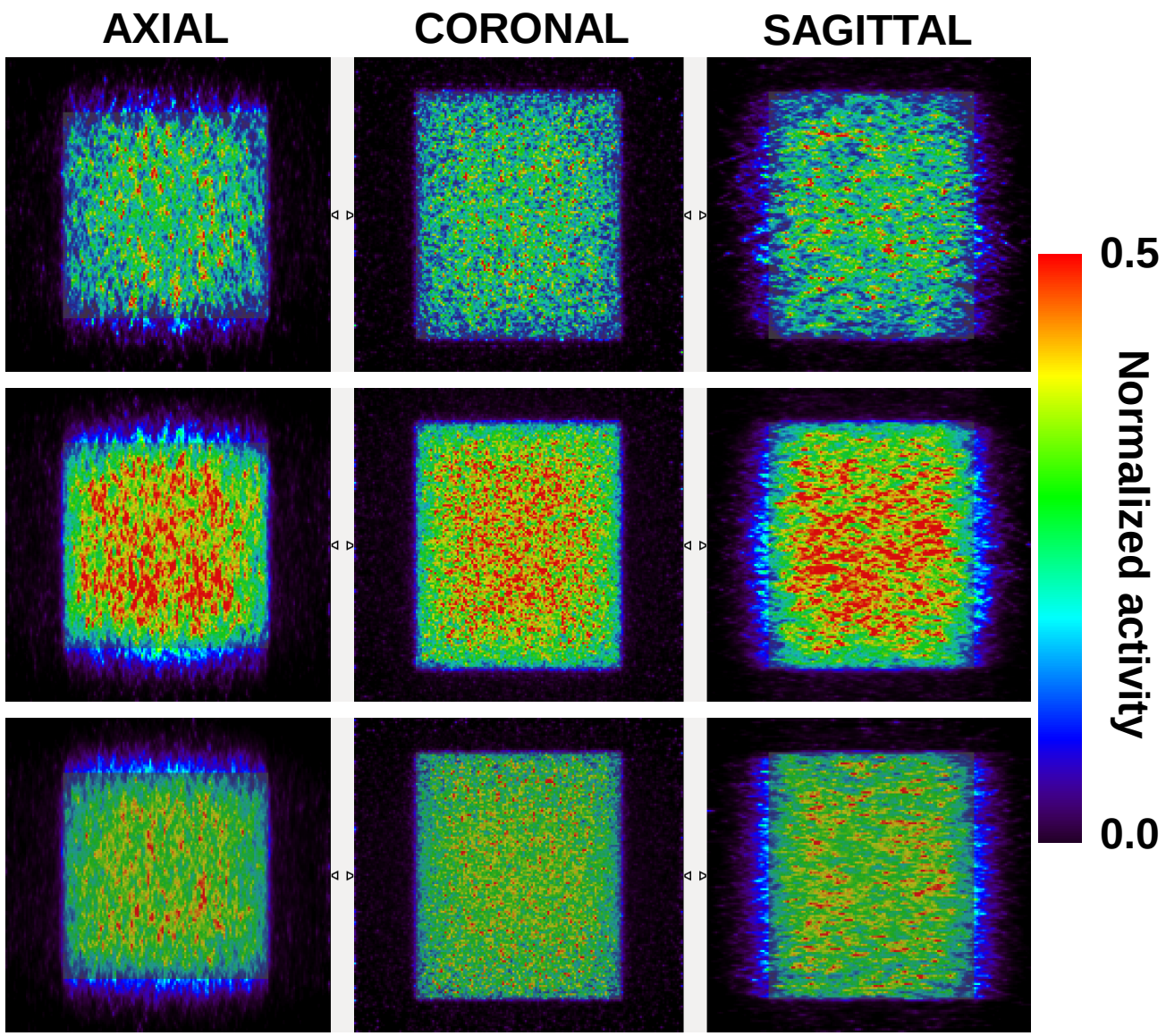
- Uniformly distributed 10^9 back-to-back 511 keV gammas within water phantom
- Water phantom 25x25x30 cm^3

SETUP	REGISTERED COINCIDENCES		
	ALL [×E05]	TRUE [%]	SCATTERED [%]
Single layer barrel	6.6	48.5	51.5
Double layer barrel	19.2	49.0	51.0
Triple layer barrel	32.2	50.0	50.0
Single layer dual-head	2.6	53.8	46.2
Double layer dual-head	7.7	51.9	48.1
Triple layer dual-head	7.2	51.4	48.6

PHANTOM RECONSTRUCTION

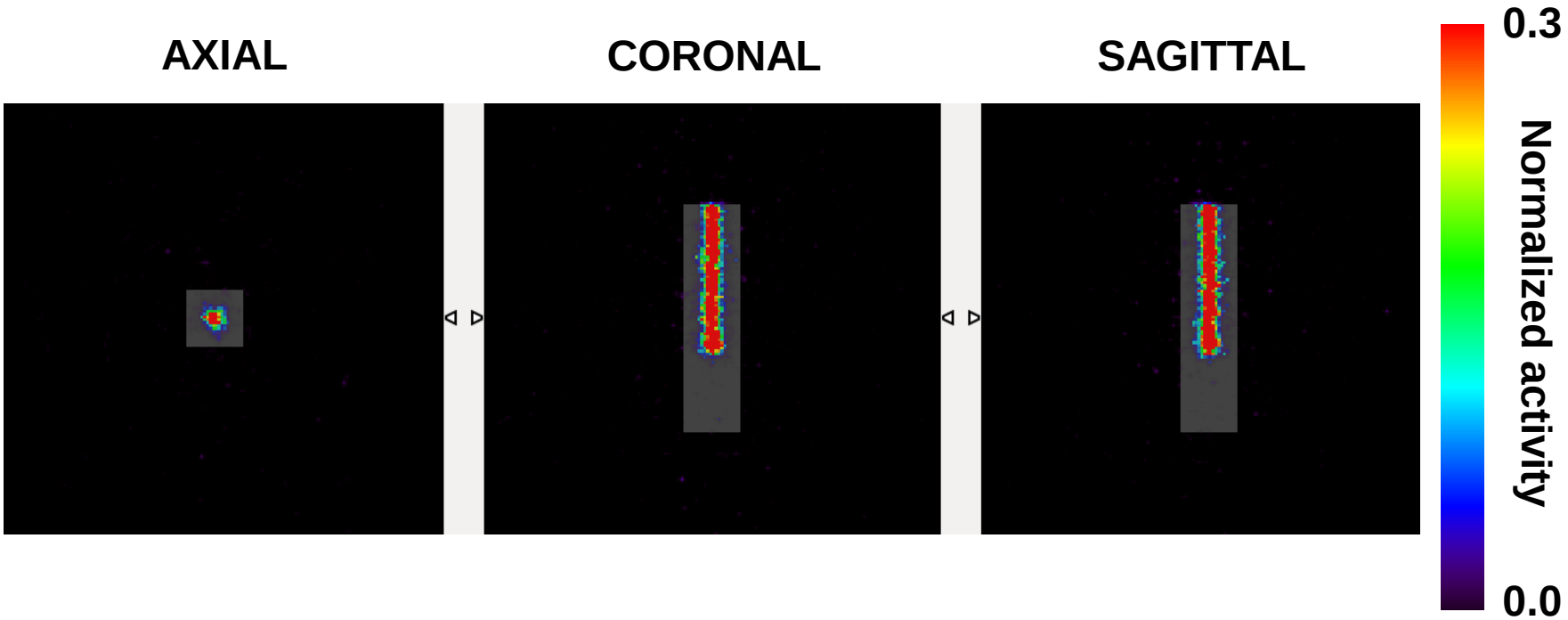


PHANTOM RECONSTRUCTION



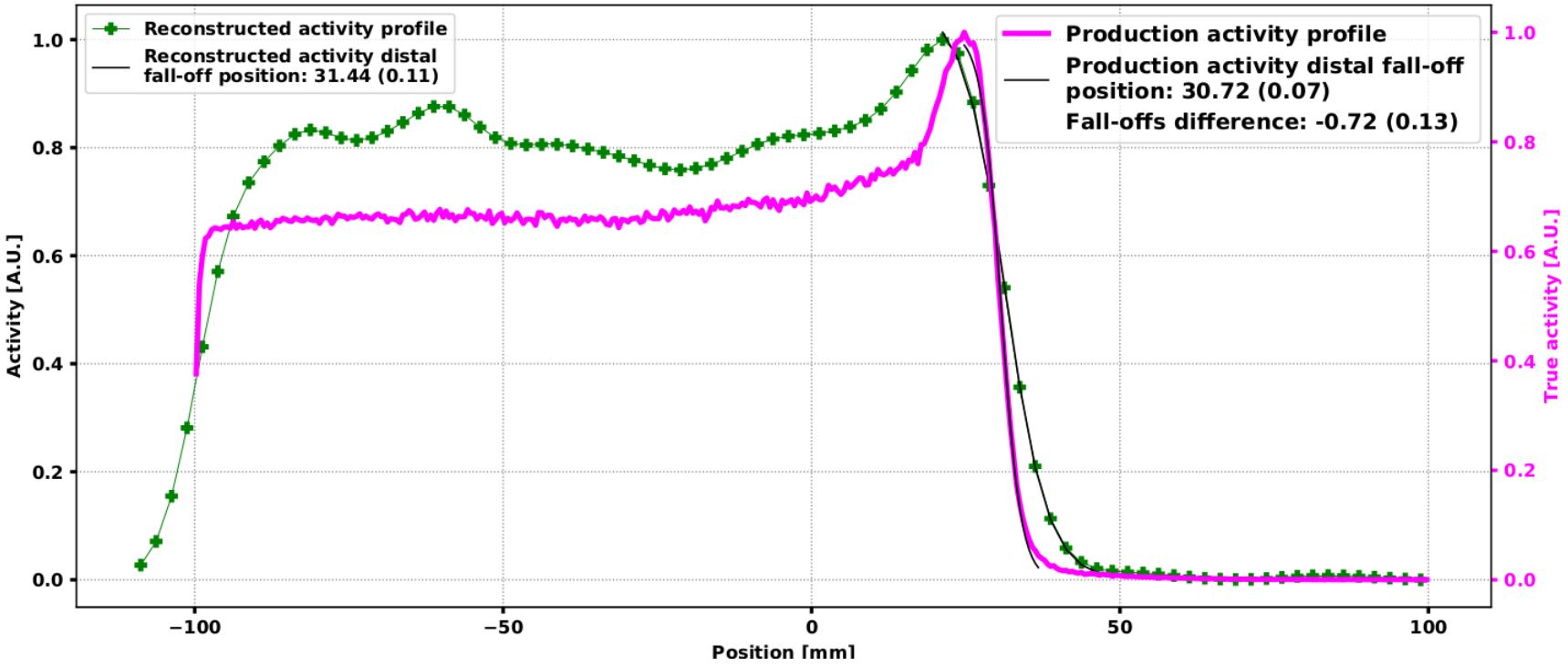
PROTON BEAM RANGE MONITORING

- **$2 \cdot 10^9$ primary protons with the therapeutic beam model of the CCB (150 MeV)**
- **PMMA phantom 5x5x20 cm3**
- **Number of registered coincidences: ~12k (75% true, 18% scattered, 7% randoms)**



PROTON BEAM RANGE MONITORING

SINGLE LAYER BARREL

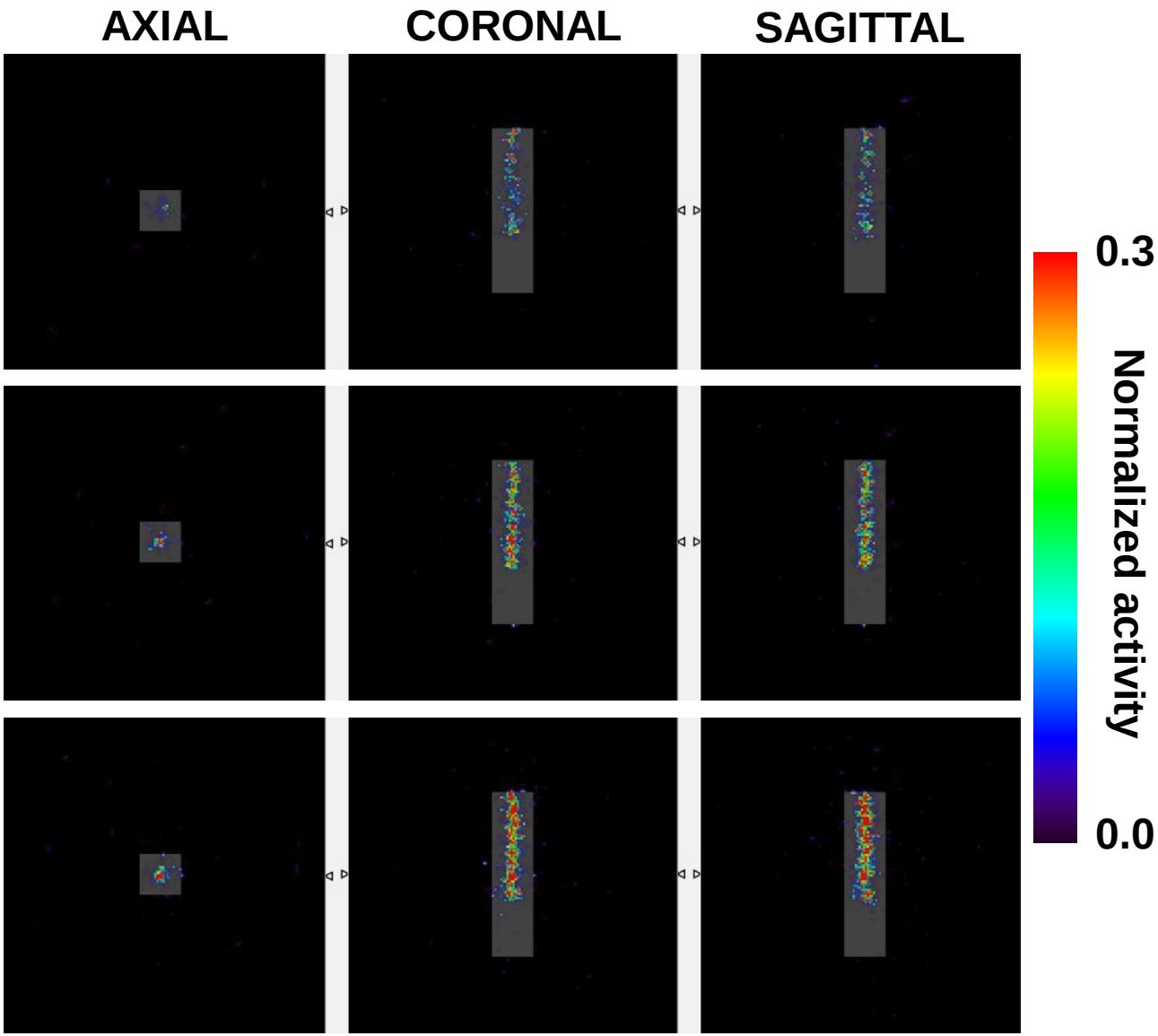


PROTON BEAM RANGE MONITORING

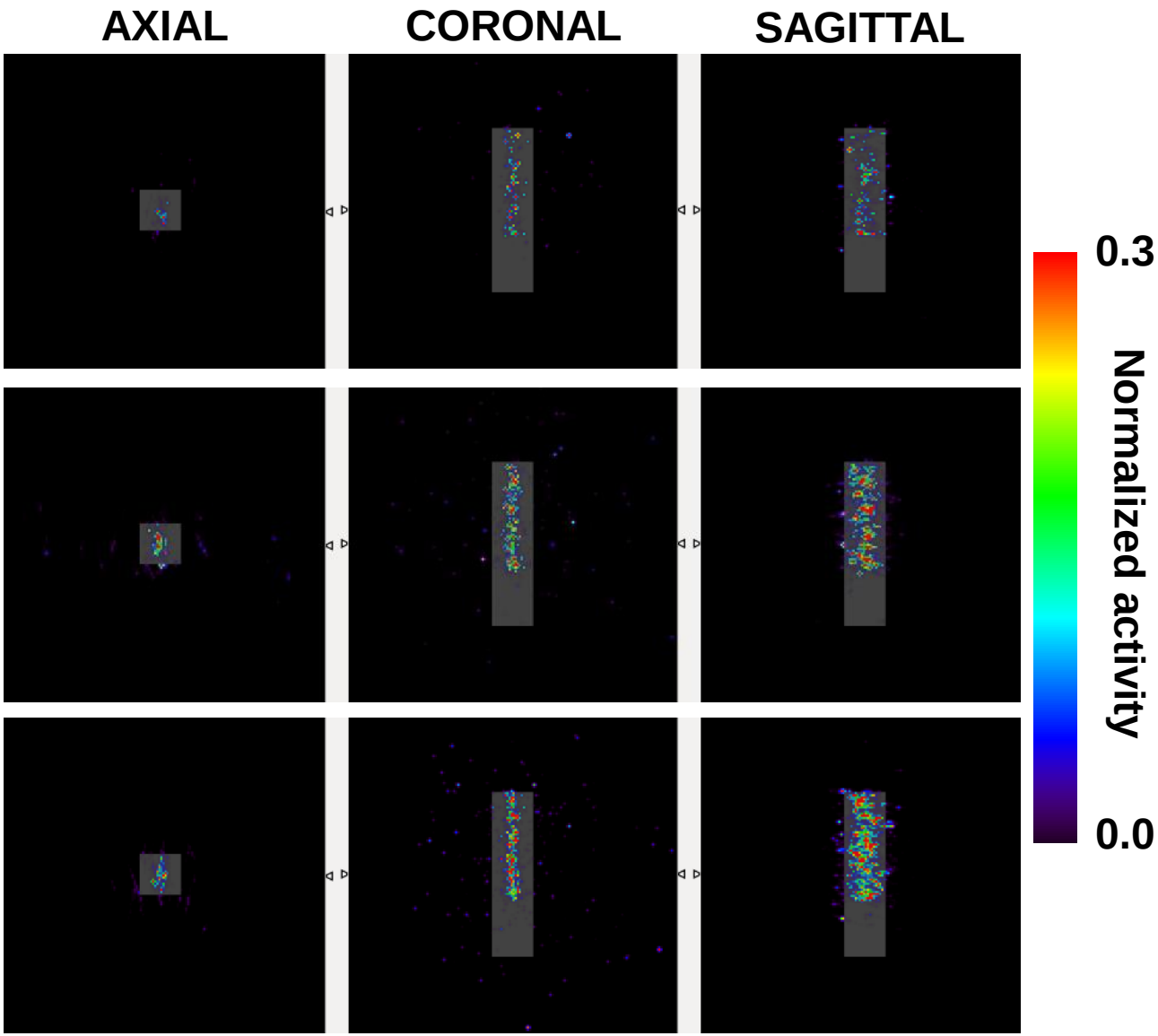
- **10^8 primary protons with the therapeutic beam model of the CCB (150 MeV)**
- **PMMA phantom 5x5x20 cm3**

SETUP	REGISTERED COINCIDENCES			
	ALL	TRUE [%]	SCATTERED [%]	RANDOM [%]
Single layer barrel	590	77.1	15.9	7.0
Double layer barrel	1202	78.5	18.1	3.4
Triple layer barrel	1657	79.5	17.2	3.3
Single layer dual-head	280	82.5	14.6	2.9
Double layer dual-head	948	80.6	17.0	2.4
Triple layer dual-head	1043	83.5	14.6	1.9

PROTON BEAM RANGE MONITORING

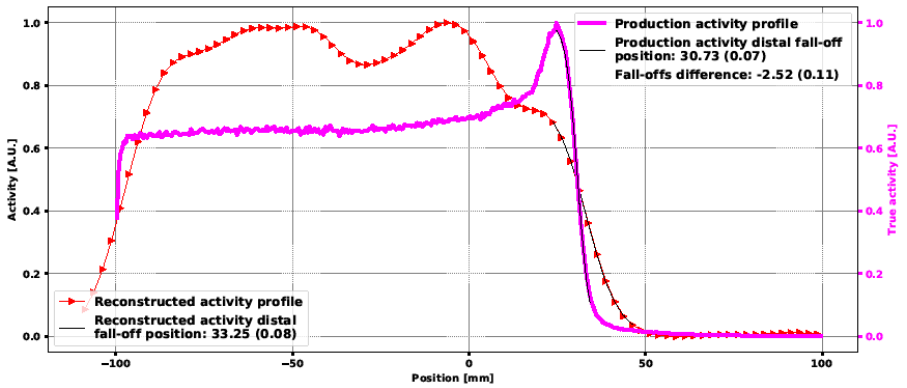


PROTON BEAM RANGE MONITORING

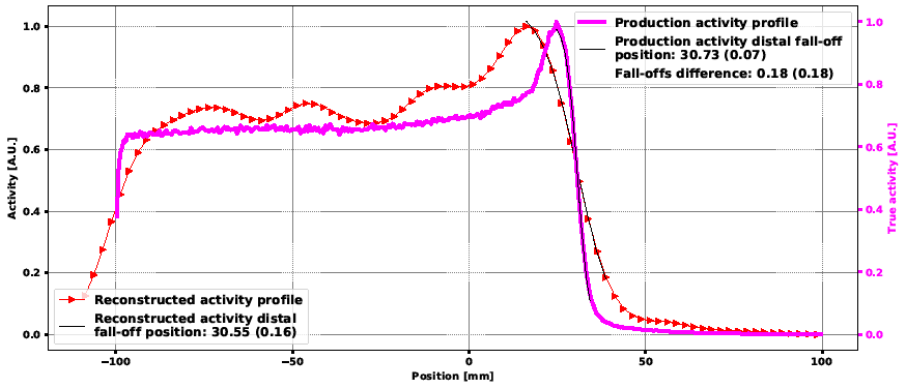


PROTON BEAM RANGE MONITORING

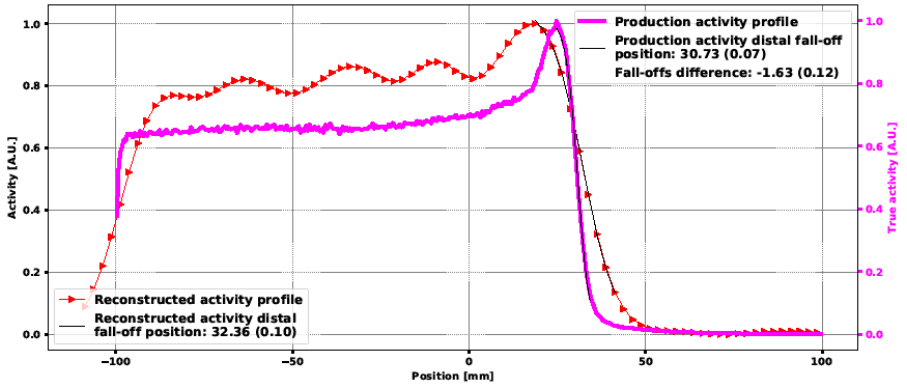
SINGLE LAYER BARREL



DOUBLE LAYER BARREL

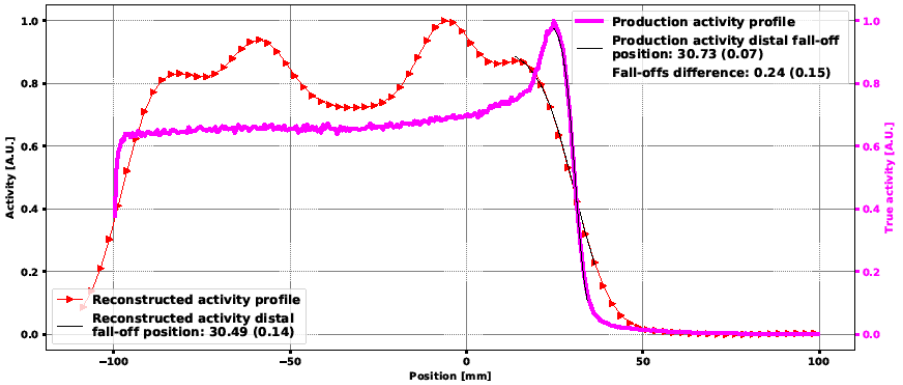


TRIPLE LAYER BARREL

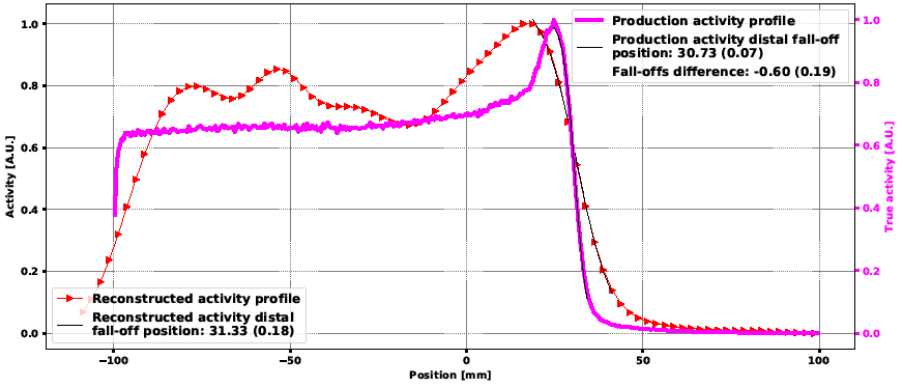


PROTON BEAM RANGE MONITORING

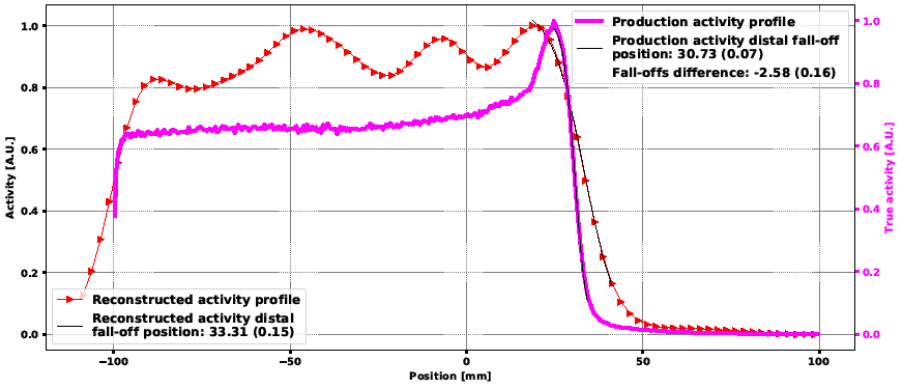
SINGLE LAYER DUAL-HEAD



DOUBLE LAYER DUAL-HEAD



TRIPLE LAYER DUAL-HEAD



CONCLUSIONS

1. J-PET detector is feasible to acquire the β^+ activity produced during proton therapy treatment and the offline 3D reconstruction of PET activity images is possible using CASToR toolkit.

2. Full patient irradiation simulation is currently under investigation. **(GATE Workshop || TOMORROW || Exchange 2&3 || 12:15)**

3. Experimental validation of the single beam irradiation results is planned.

4. Further development is needed to fully exploit the whole body J-PET technology:

   - TOF-based continuous signal modeling along the strip.
   - Attenuation and sensitivity corrections in the image domain to speed up the reconstruction preparation.
   - Reconstruction of β^+ decays to 3γ (i.e. Na-22).
   - Total-body reconstruction.
   - Various TOF resolution for specific layers pair, between which the coincidence was registered.

A BIT OF ADVERTISEMENT…

POSTER ID: 376 !!!

TODAY !!!

A BIT OF ADVERTISEMENT…

POSTER ID: 376 !!!
TODAY !!!

GATE Workshop
TOMORROW
Exchange 2&3 || 12:15

ACKNOWLEDGMENTS

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Leszek Grzanka, PhD

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BACKUP SLIDE

SENSITIVITY MAP

- Uniformly distributed 10^{11} back-to-back 511 keV gammas within air phantom
- Air filled phantom 20x20x25 cm^3 (1/8 FOV)

SETUP	REGISTERED COINCIDENCES [$\cdot 10^9$]
Single layer barrel	1.9
Double layer barrel	4.9
Triple layer barrel	8.1
Single layer dual-head	1.4
Double layer dual-head	3.4
Triple layer dual-head	4.0