



Studies of attenuation effects in two- and three-photon positronium decays in phantom models

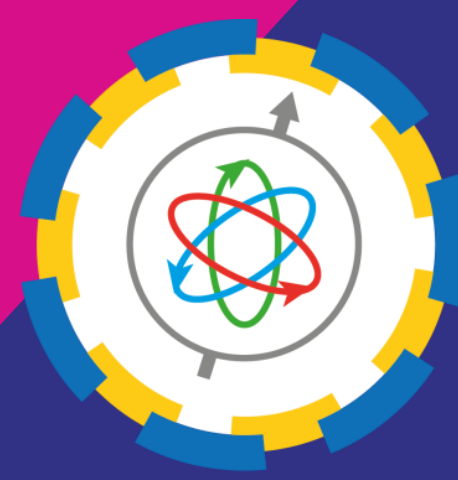
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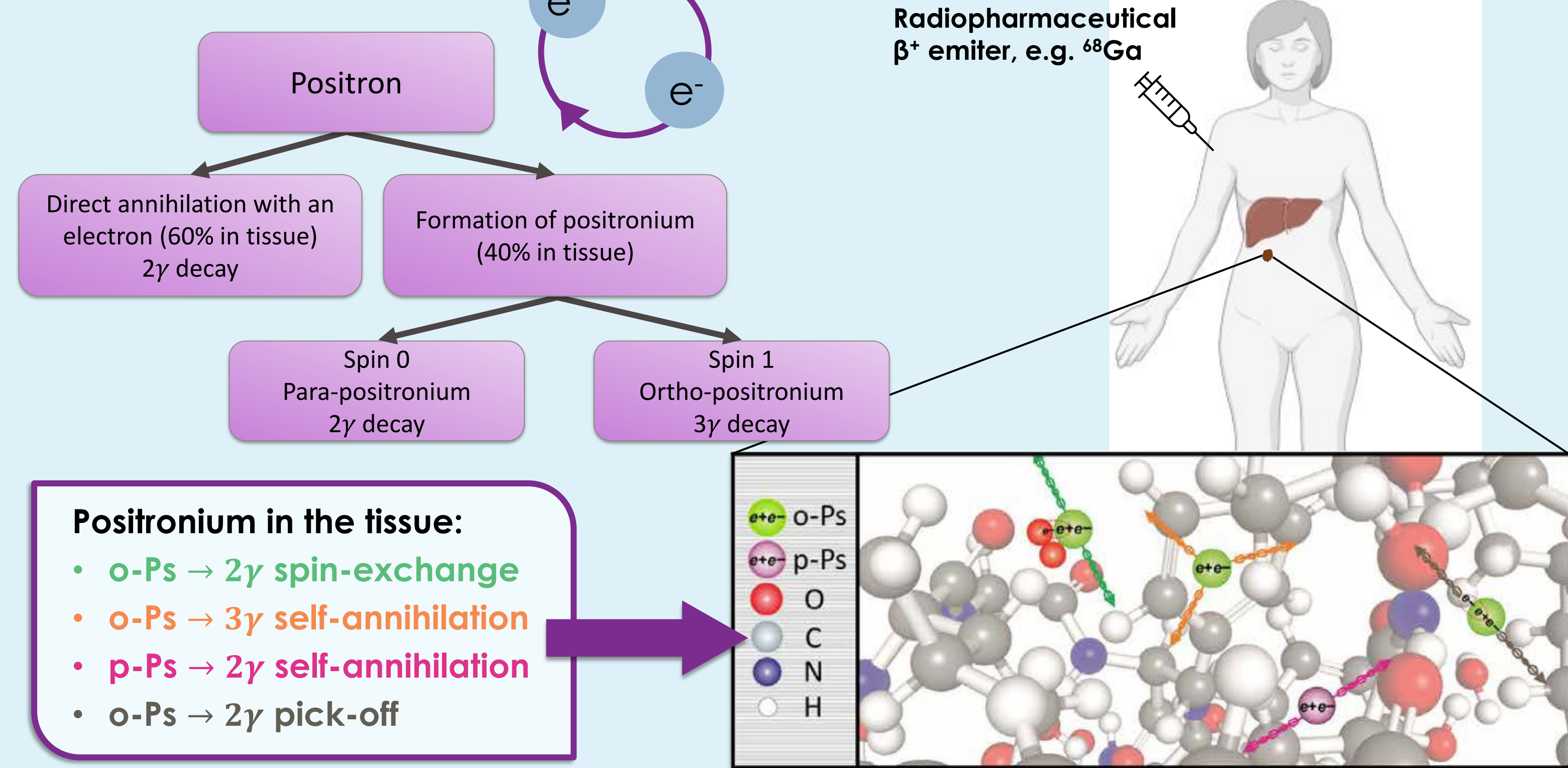


J-PET

Introduction

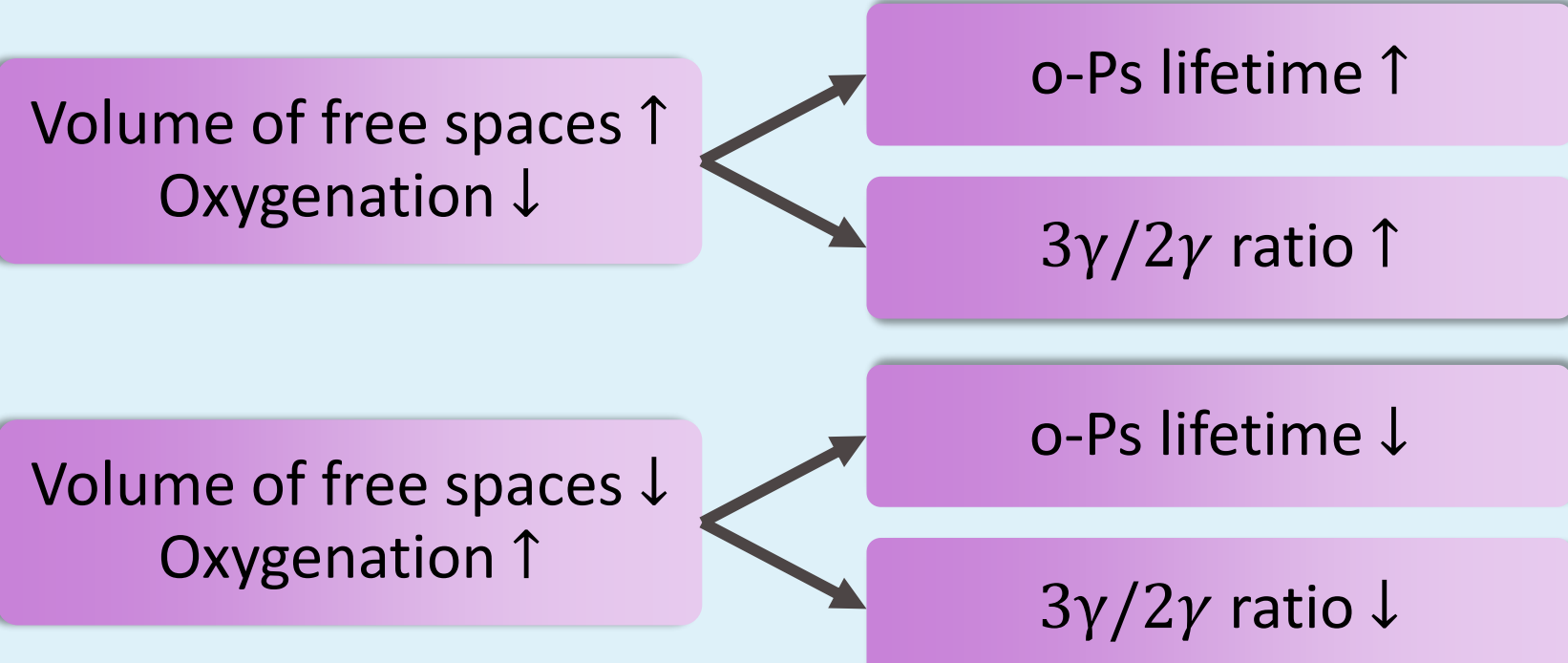
Up to 40% of positron annihilations in PET occur via positronium formation. Positronium properties, including its lifetime and the $3\gamma/2\gamma$ annihilation ratio, are sensitive to the tissue's submolecular structure. This enables positronium imaging, a novel PET technique that provides complementary information on tissue microstructure beyond conventional PET [1,2].

Positronium imaging



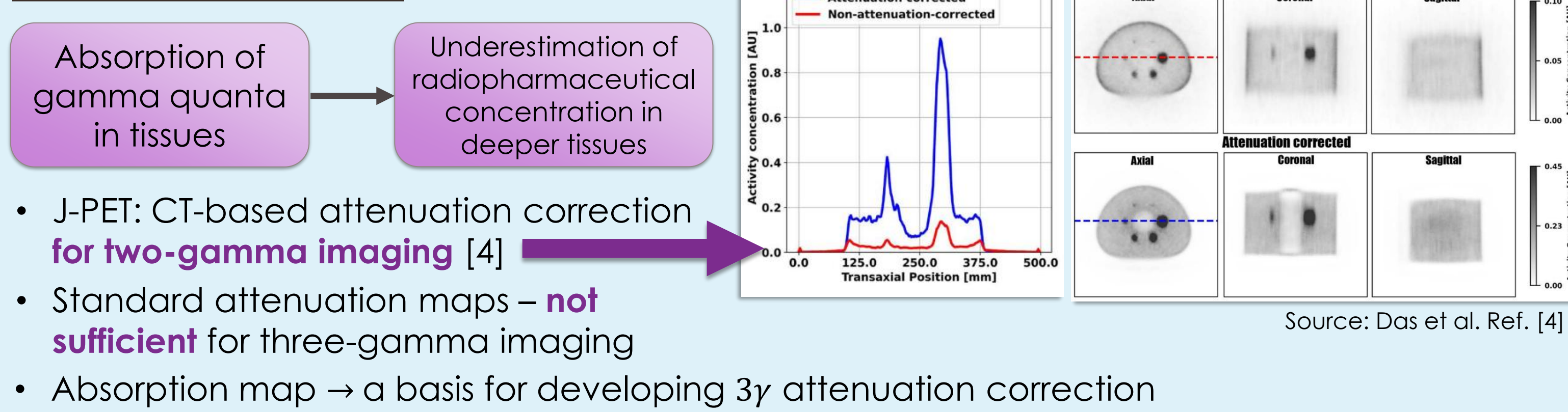
J-PET collaboration:

- Positronium Lifetime Imaging demonstrated in [1, 2]
- Complementary $3\gamma/2\gamma$ annihilation ratio imaging under development → need corrections for physical processes (e.g. **attenuation**)



Positronium properties → **promising biomarkers** of tissue pathology and oxygenation [1-3].

Attenuation correction



Monte Carlo Simulation [5]

Para-positronium $p\text{-Ps}$ $\vec{p}_1, \vec{p}_2$

Isotropic decay into 2 back-to-back photons with energies of 511 keV

Decay simulation:

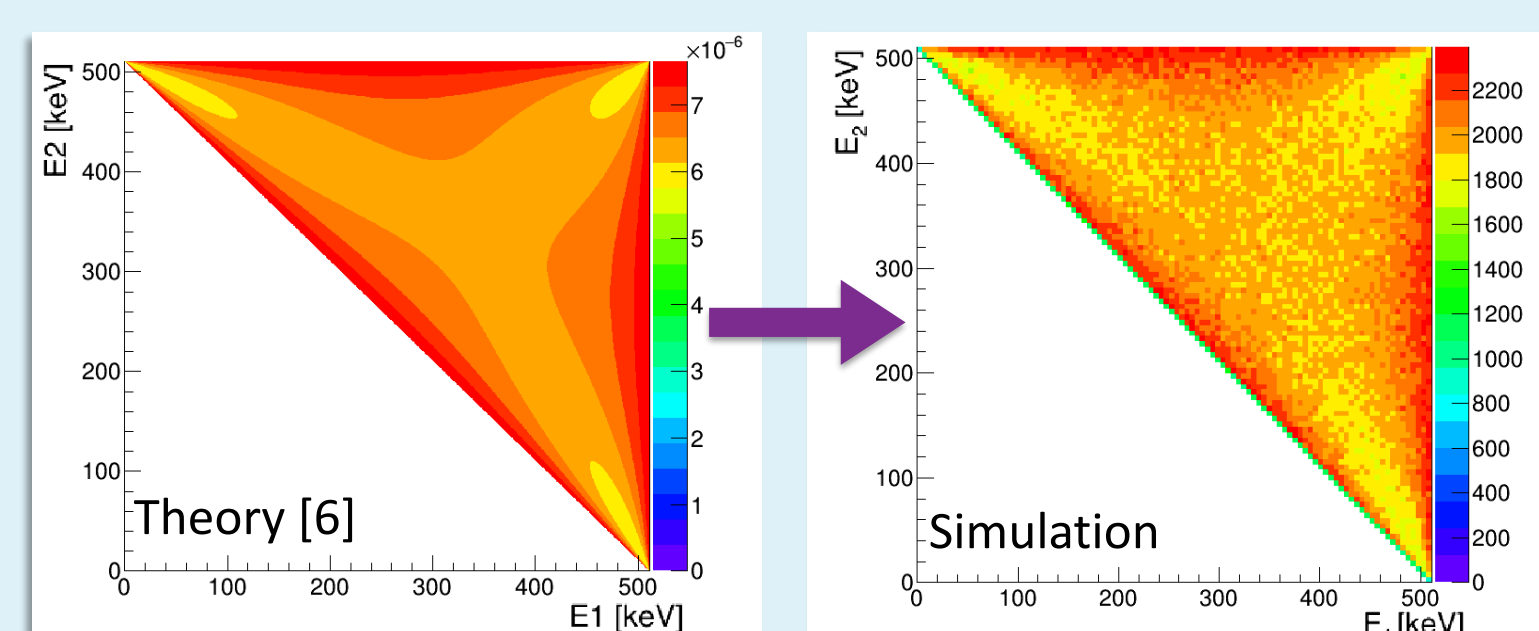
- Randomize the direction of $\vec{p}_1$
- Assigning the energy of 511 keV
- Determining the momentum $\vec{p}_2 = -\vec{p}_1$

Ortho-positronium

Described with the matrix element $M_{oPs \rightarrow 3\gamma}$:

$$M_{oPs \rightarrow 3\gamma} = \left(\frac{m_e - E_1}{E_2 E_3} \right)^2 + \left(\frac{m_e - E_2}{E_1 E_3} \right)^2 + \left(\frac{m_e - E_3}{E_1 E_2} \right)^2,$$

where m_e - electron mass, E_1, E_2, E_3 - gamma quanta energies



Photons interact with matter primarily through:

- Photoelectric effect
- Compton scattering
- Pair production (for $E_\gamma > 2m_e$)

Probability that a photon with energy E_i **escapes** the material:

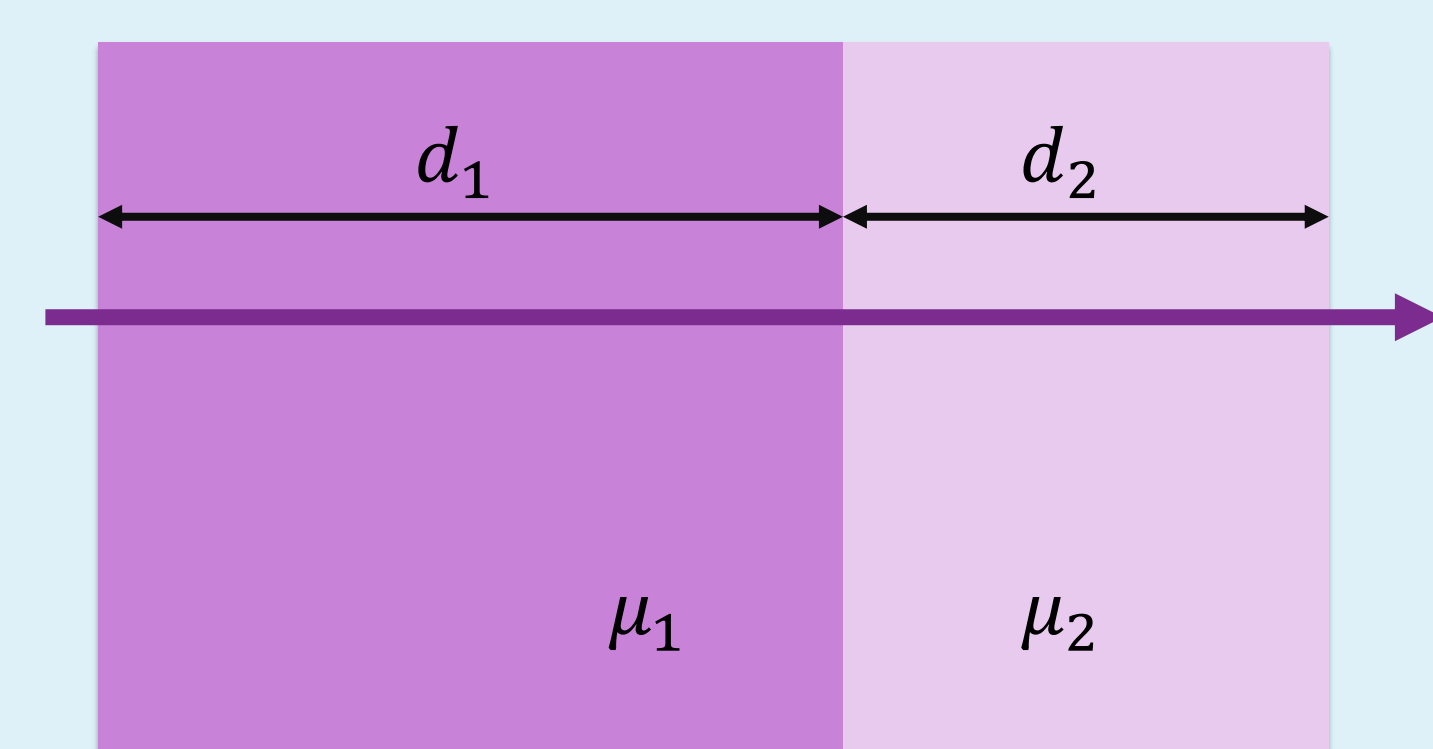
$$P_i = \prod_m e^{-\mu_m(E_i)d_m}$$

distance

linear attenuation coefficient

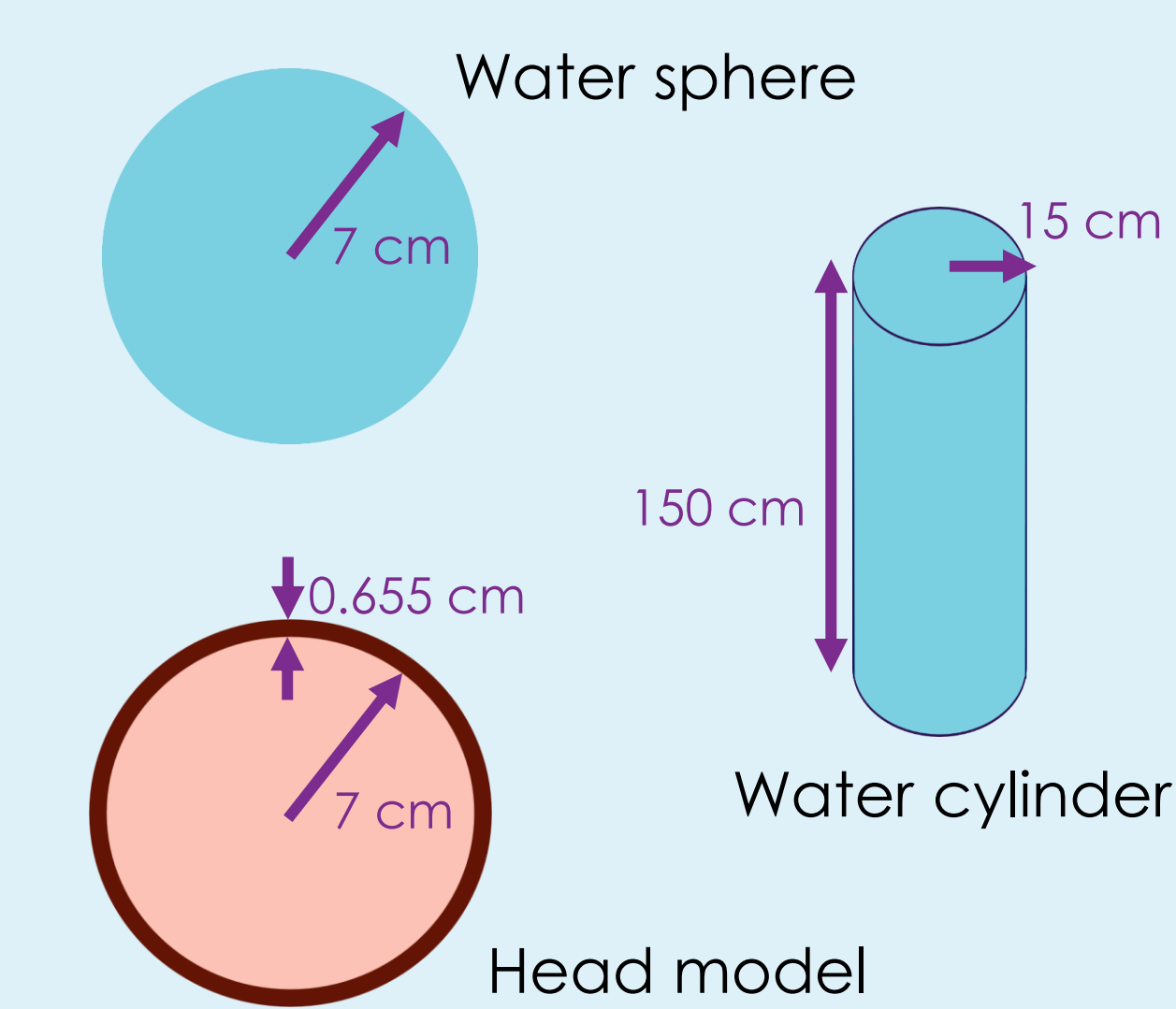
Total probability that **all** of the photons escape:

$$P_{tot} = \prod_i P_i$$



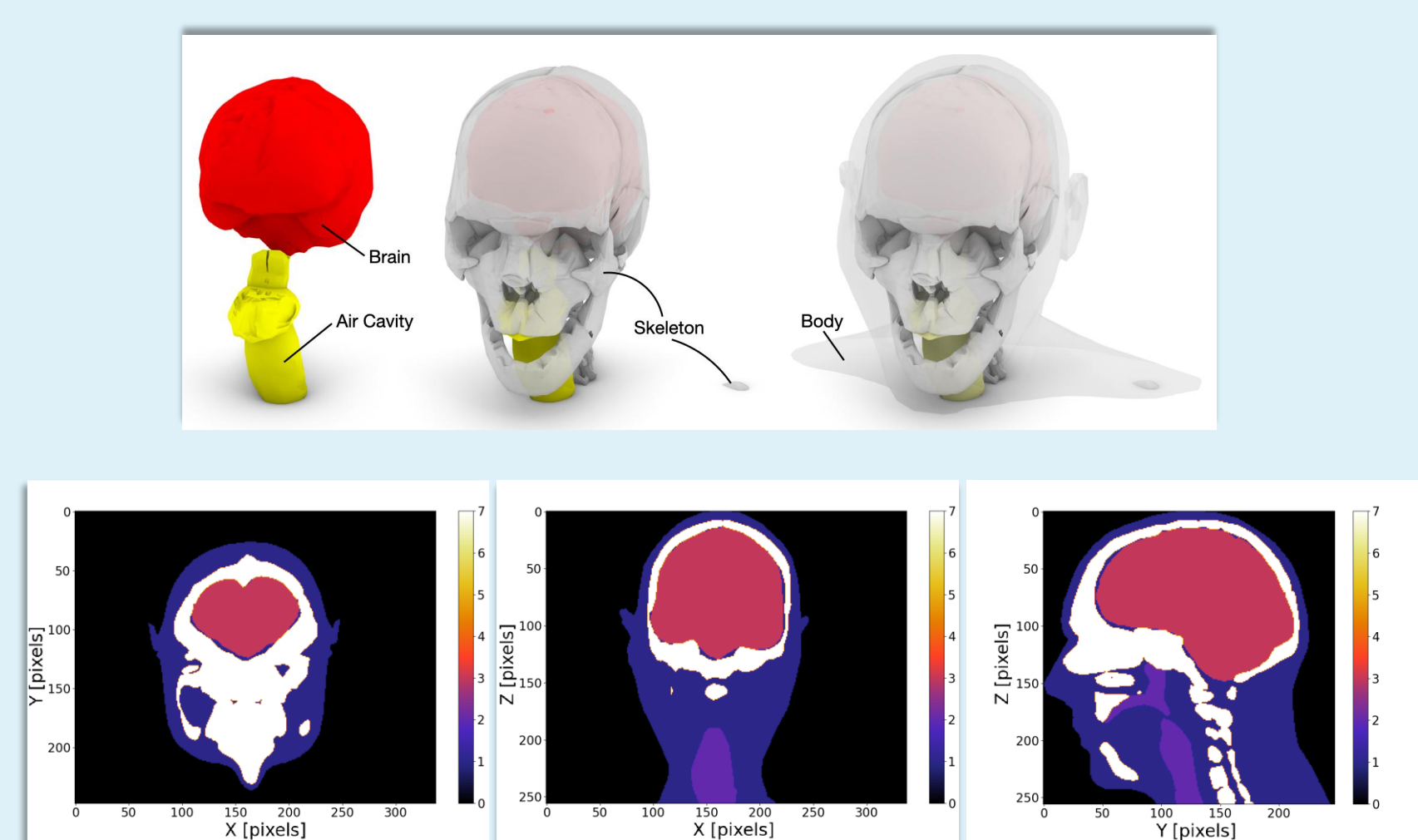
Phantom models – simplified models [5]

Simplified models were implemented in a toy Monte Carlo simulation and validated against equivalent simulations performed with the **GATE** toolkit [7].



Phantom models – human body phantom

- Mesh-based **XCAT** phantom (mesh50_XCAT) [8, 9]
- Highly detailed male anatomy
- Source – voxelized version of the phantom
- Head Only model (computational limitations)
- Simulations performed using the **GATE** toolkit [7]

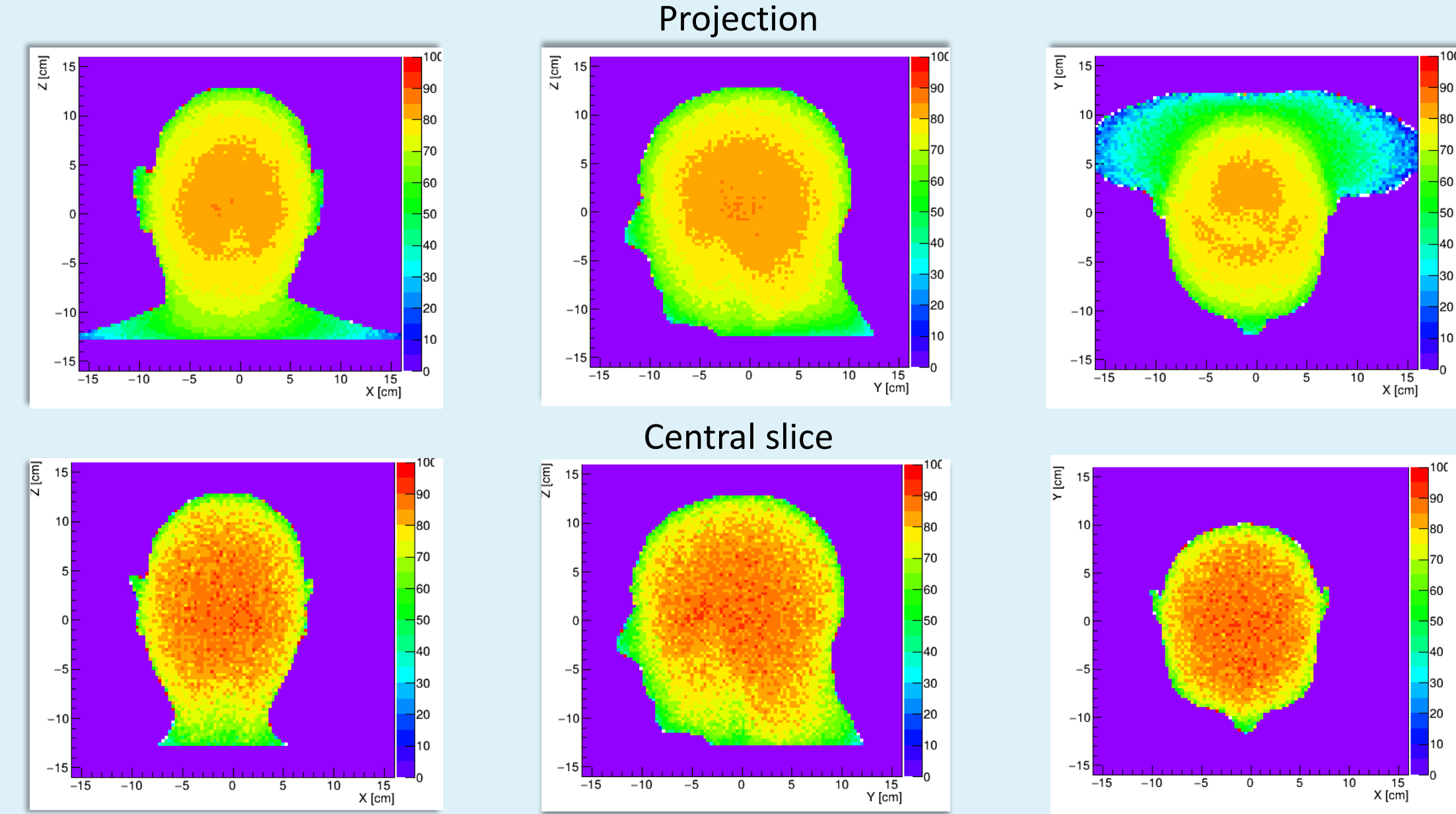


Absorption maps [5]

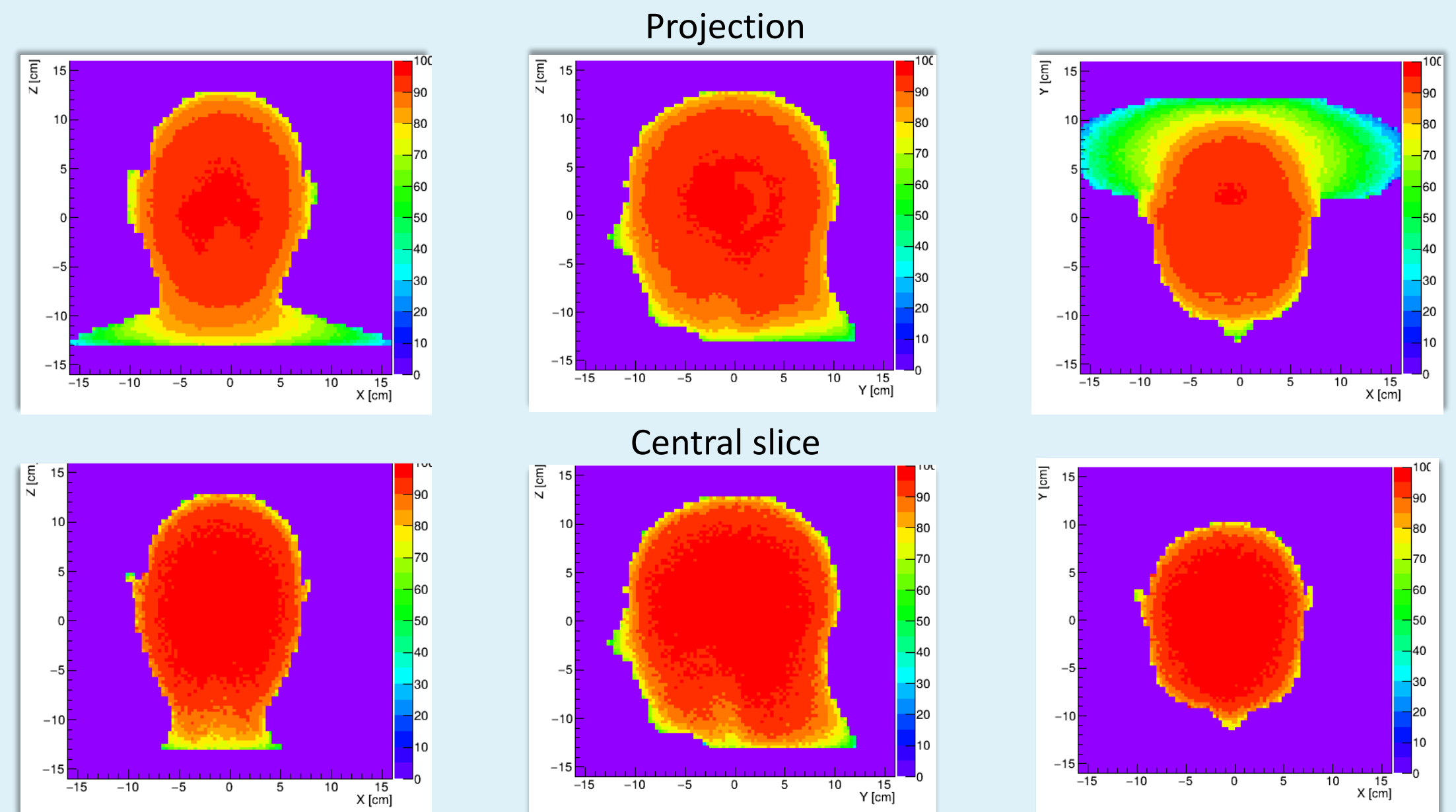
Percentage of gamma quanta pairs or triplets, from which **at least one** of the photons **interacted** with the model specific to the annihilation point.

Human body model

p-Ps → 2γ , 10^7 events, 25% pairs not absorbed



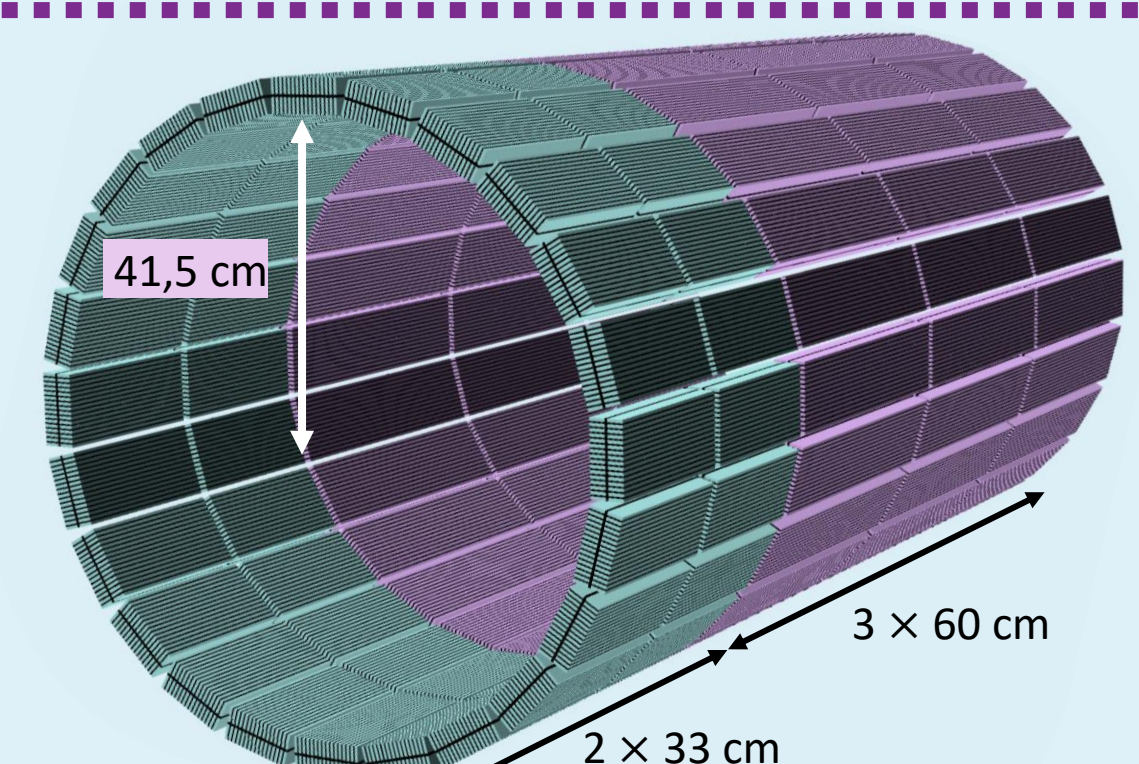
o-Ps → 3γ , $4.4 \cdot 10^7$ events, 10% triplets not absorbed



Simulations conducted using CYFRONET AGH computing cluster

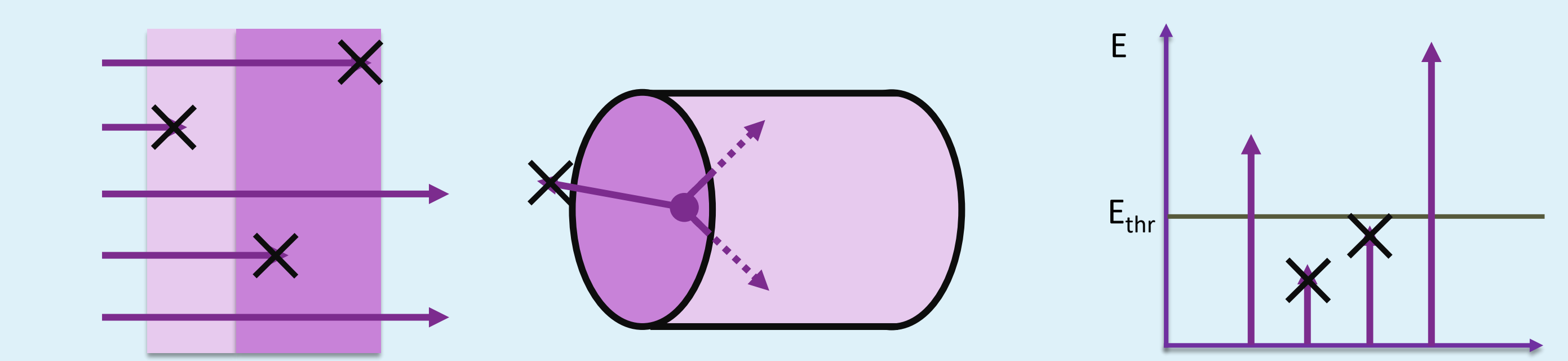
Total-Body J-PET

- Plastic scintillator strips with dimensions 30 × 6 mm and 330 or 600 mm length
- 5 rings with 24 modules:
 - 2 rings with 330 mm strips
 - 3 rings with 600 mm strips
- 2 layers
- 16 scintillator strips per layer
- Total AFOV 254 cm [10]

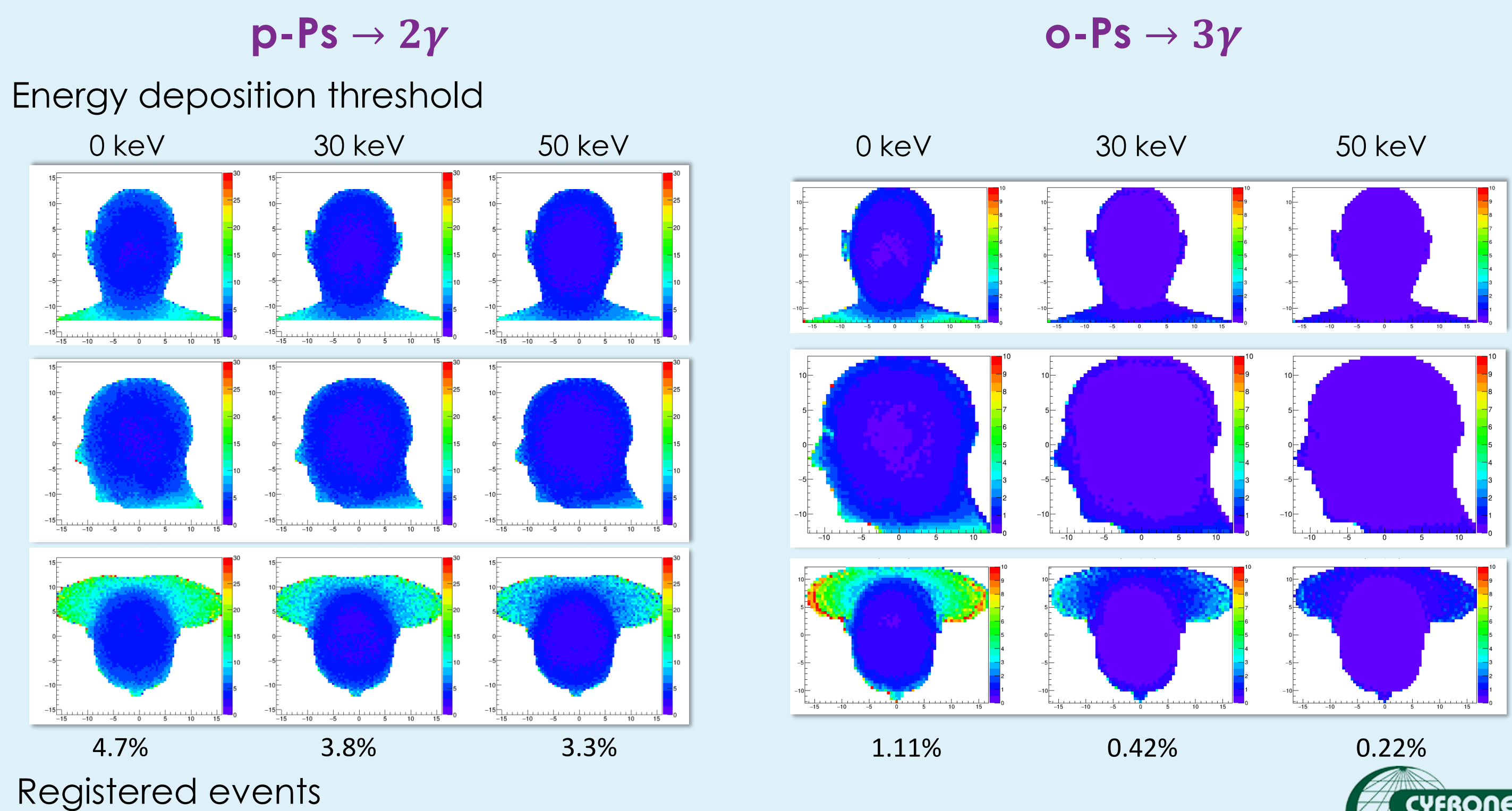


Detection in Total-Body J-PET

absorption + geometrical acceptance + detection energy thresholds



Percentage of gamma quanta pairs or triplets for which **no** photon was **attenuated** in the phantom, **all** photons **reached the detector**, and **each** deposited **energy above the detection threshold**.



Simulations conducted using CYFRONET AGH computing cluster

Perspectives

Simulations using whole-body XCAT human phantom

Simulation using a phantom created based on the patient's CT scan

Acknowledgements

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References

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