UNIVERSITÄT ZU LÜBECK
INSTITUT FÜR MEDIZINTECHNIK

GATE Activities @IMT/UzL

Hong Phuc Vo[1], Jorge Roser[1], Christian Pommranz[2], Jona Kasprzak[1]

[1] *Nuclear Imaging Group - Prof. Dr. Magdalena Rafecas*
Institute of Medical Engineering, Universiät zu Lübeck
[2] *Institut für Astronomie und Astrophysik Tübingen,* University of Tübingen

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MERMAID: Small aquatic animal PET

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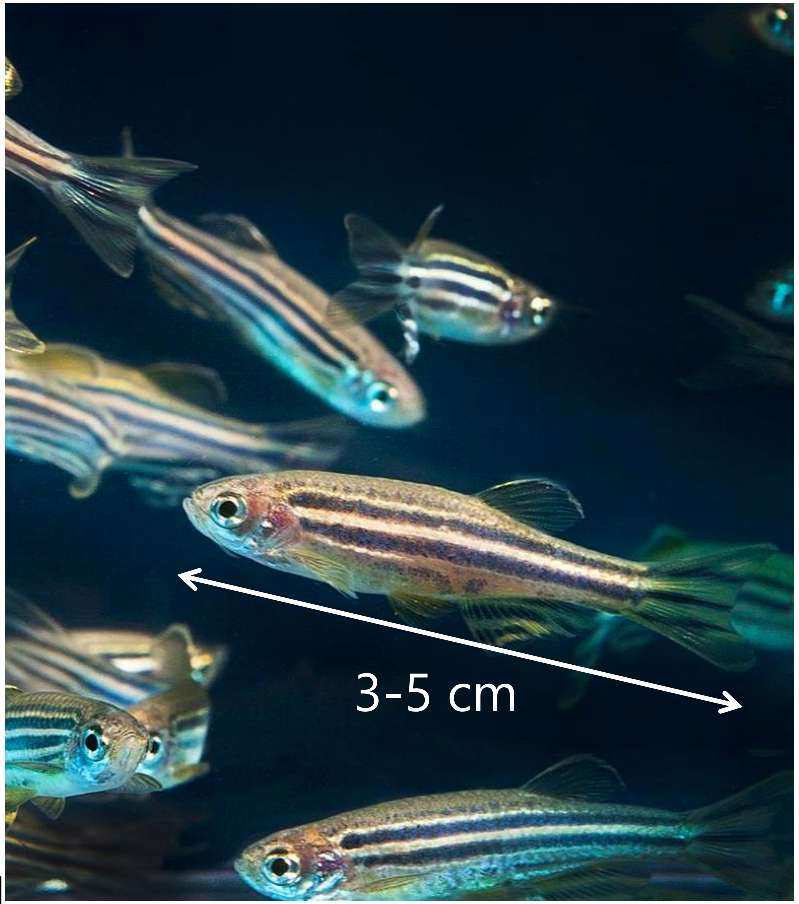
Motivation: Why zebrafish imaging?



[1]

1. **High genetic similarity to mammals**
   Genetically modifiable

2. **Small size, easy to keep, high reproduction rate**
   → inexpensive compared to mice and rats

3. **Transparent embryos**
   → valuable model organisms for biomedical research

4. **Increasing interest in positron emission tomography (PET) imaging of adult zebrafish (non-transparent)**

→ **MERMAID Project**
(Multi-Emission Radioisotopes-Marine Animal Imaging Device)

[1] https://blog.addgene.org/zebrafish-genetics-developmental-biology, Accessed: 30.10.23

MERMAID: Small aquatic animal PET

Current prototype

MERMAID-v1:

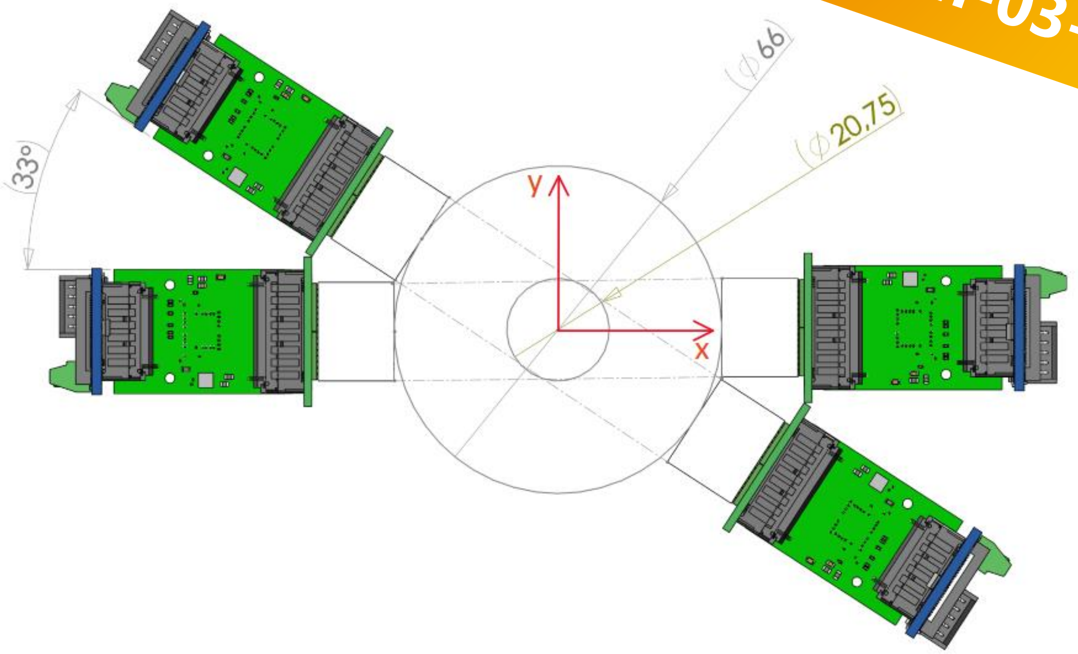
- **4 existing modules:**
- **16x8 LYSO crystal matrix**
- **Crystal size: 1.12 x 1.12 x 15 mm3**
- **One-to-one readout**

Limitation:

- **Long crystal and small scanner radius**
- **Lack of depth-of-interaction (DOI)**

→ parallax error

More recent result @Poster M-03-106

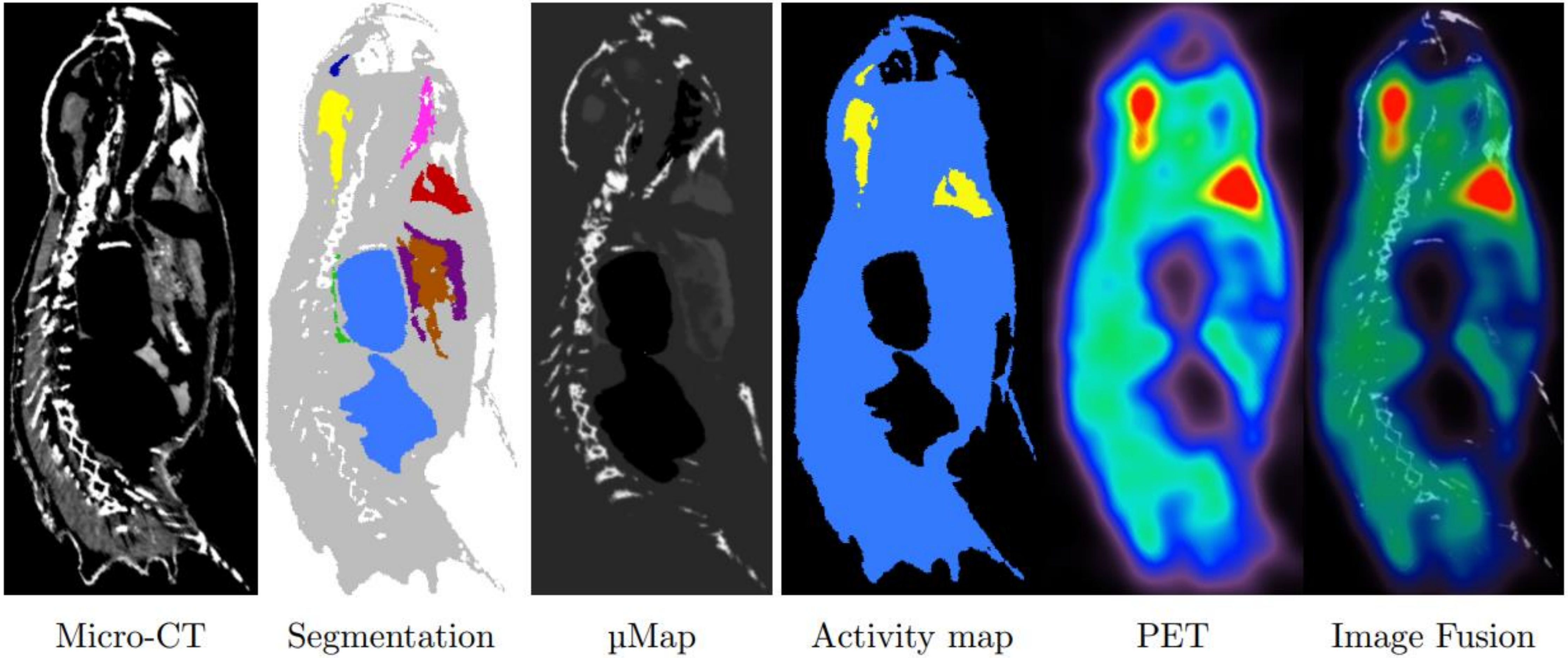


Long term goal

implement a step-by-step system upgrade towards a cost-effective solution

Digital zebrafish phantom

Pipeline



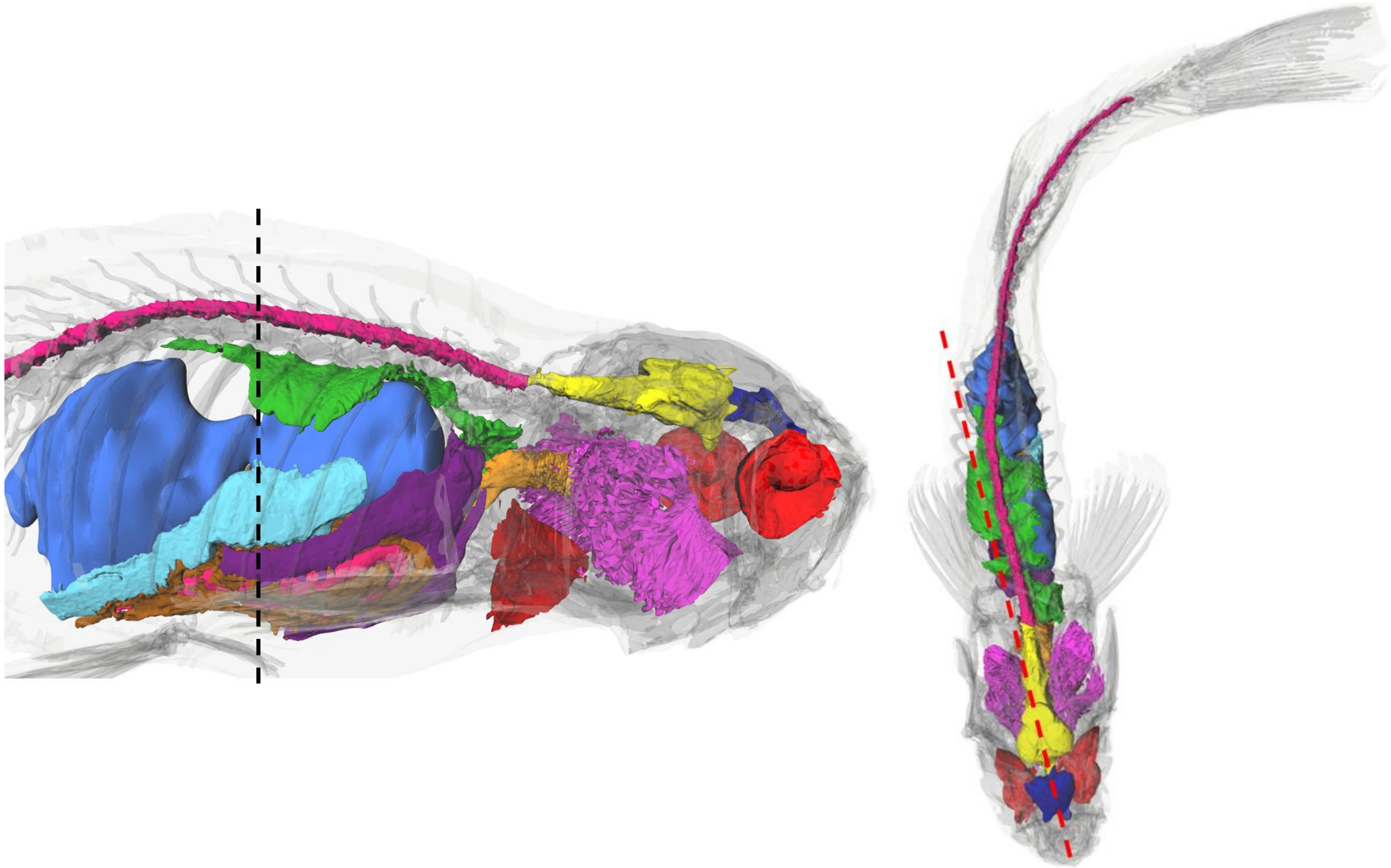
M Zvolský et al 2022 Phys. Med. Biol. 67 175005

Digital zebrafish phantom

Detailed mapping for each organ using voxelized phantom

STL Volumes of:

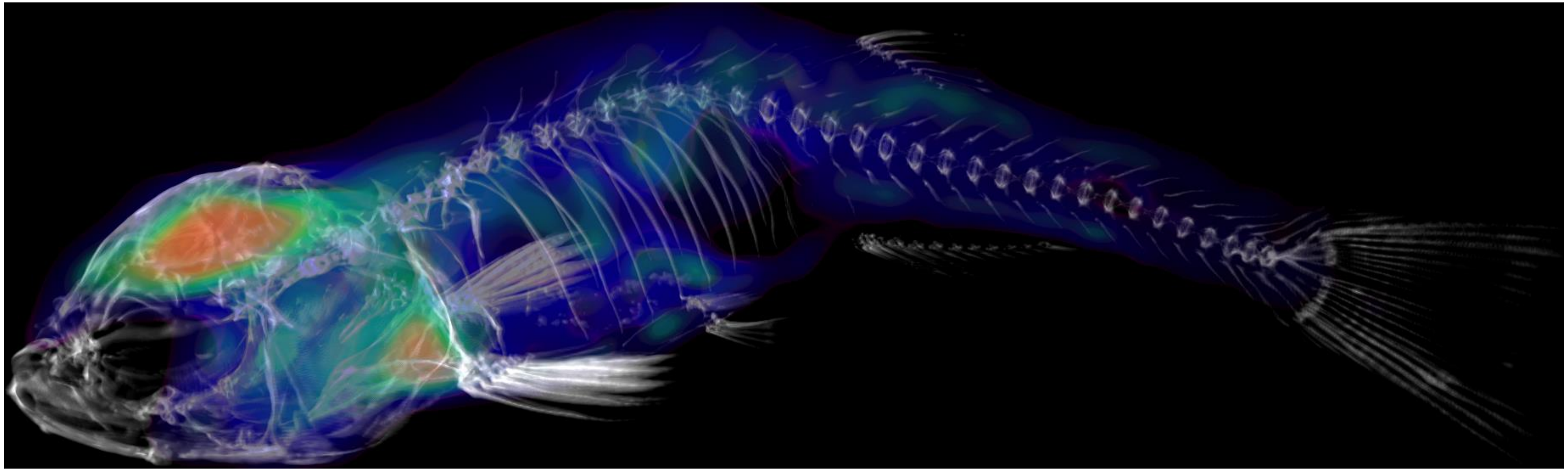
1. **Skin & bones (transparent gray)**
2. **Intestinal contents & spinal cord (pink)**
3. **Swim bladders (blue)**
4. **Intestine (ochre)**
5. **Gonads (light blue)**
6. **Kidney (green)**
7. **Liver (dark purple)**
8. **Pharynx (orange)**
9. **Heart (dark red)**
10. **Gills (magenta)**
11. **Mid- and hindbrain (yellow)**
12. **Forebrain (dark blue)**
13. **Eyes(red)**



M Zvolský et al 2022 Phys. Med. Biol. 67 175005

Digital zebrafish phantom

Activities distribution using



Currently using *confine* option.

Future plan: develop a script to generate and modify each organ independently as voxelized phantom

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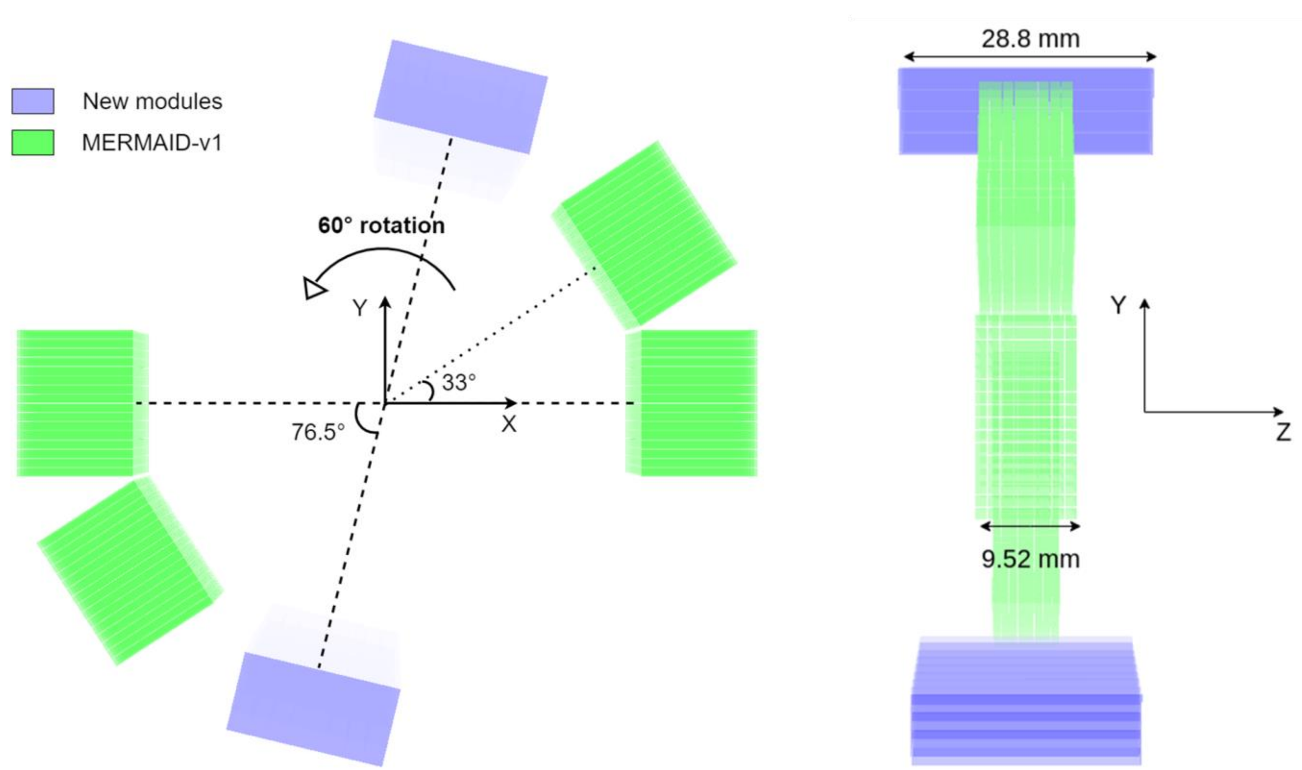
MERMAID: Small aquatic animal PET

Why the need of upgrade?

MERMAID-v2 (next upgrade):

- **Adding two new modules:**
- **4 layers of 8 axially-oriented LYSO crystals (2.4 x 2.4 x 28.8 mm3)**
- **Dual readout on both side to provide continuous information with σ_{axial} = 3.5 mm and σ_{radial} = 1.2 mm**
- **Layer number provides DOI**



MERMAID-v2 configuration. Left: transaxial view; Right: axial view

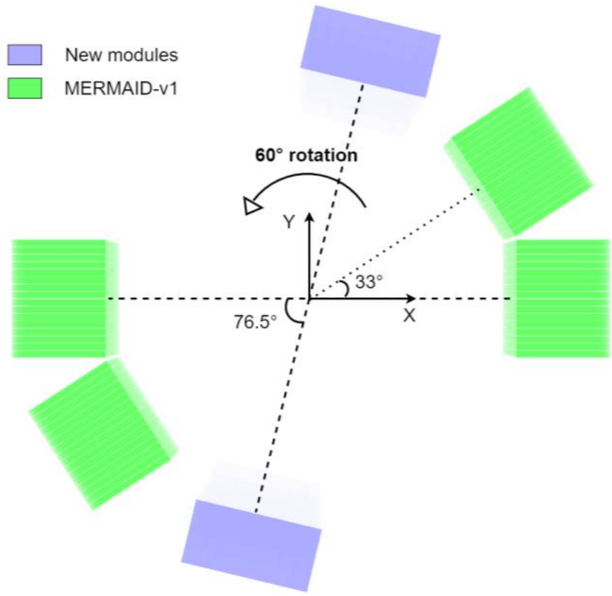
Goal of this work

Study of image performance through simulations and adapted reconstruction to assess potential benefits of new modules

MERMAID: Small aquatic animal PET

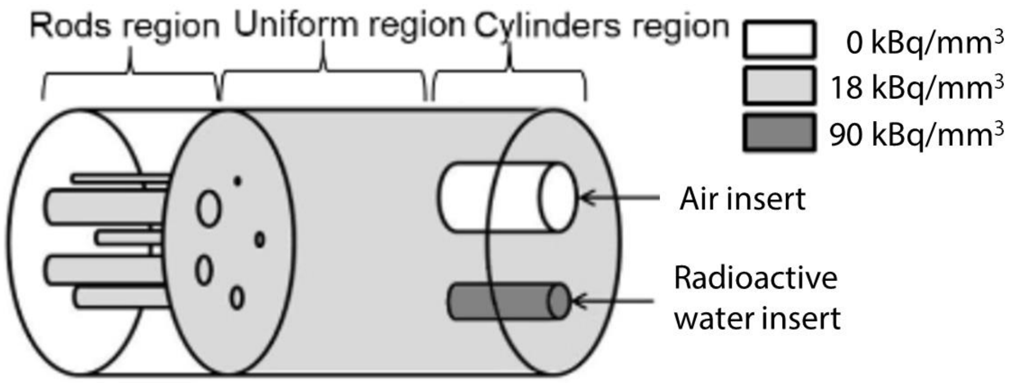
Monte-Carlo Simulation

- **Both systems are simulated using GATE[1], v9.1**
- **Acquisition time: 20 minutes, including 3-step rotation for both scanners.**



Modified version of NEMA NU4 IQ phantom[2]

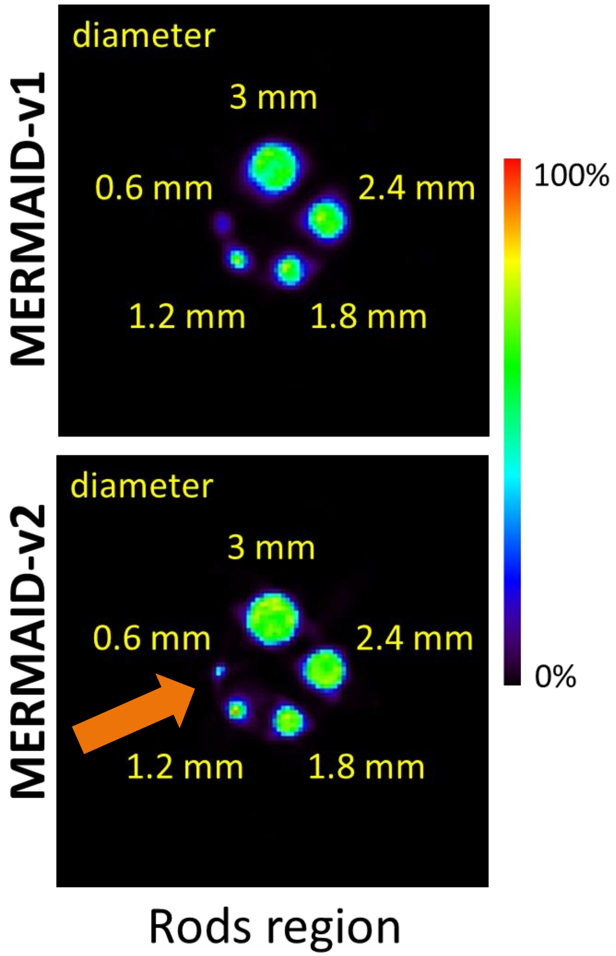
- **Downscaled by factor of 0.6**
  → size of zebrafish
- **Modified cylinder region**
  → emulate active lesion with background (5:1 activity concentration)
- **Water-filled, back-to-back photons**



[1] D. Sarrut et al., "Advanced Monte-Carlo simulations of emission tomography imaging systems with GATE," Phys Med Biol, 66, 881, 2021.
[2] NEMA standard publication NU4-2008: performance measurements of small animal positron emission tomographs. National Electrical Manufacturers Association, Rosslyn, VA, 2001.

MERMAID: Small aquatic animal PET

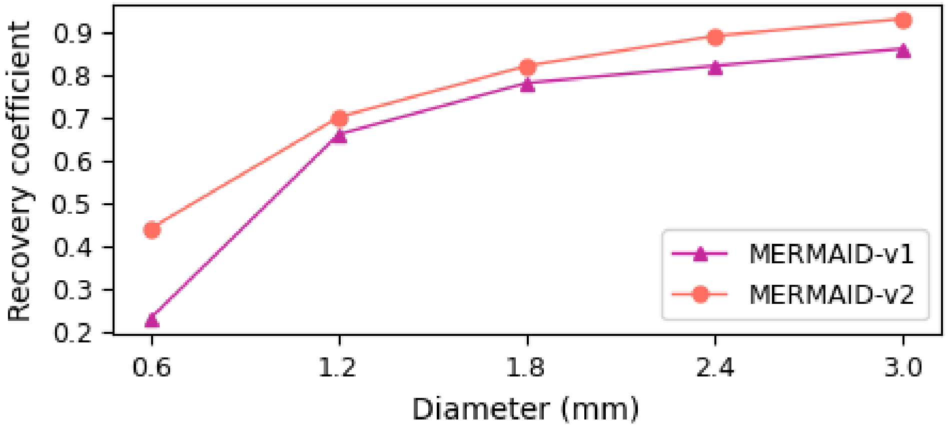
Recovery coefficient



- **Both system able to reconstruct 4 out of 5 rods**
- **0.6-mm rod is only visible in MERMAID-v2**
- **With no DOI in MERMAID-v1, rods' size are smaller than their true size**

  → solved by MERMAID-v2

- **Recovery coefficient (RC) shows that MERMAID-v2 outperforms MERMAID-v1 across all radii**



Vo, H., Seeger, S., Werner, J. and Rafecas, M.: Towards Full-body Small Aquatic Animal PET: a Simulation Study of MERMAID-v2, 1–1, 2023, DOI: 10.1109/NSSMICRTSD49126.2023.10338525

Breast insert prototype for whole-body PET/MRI scanner

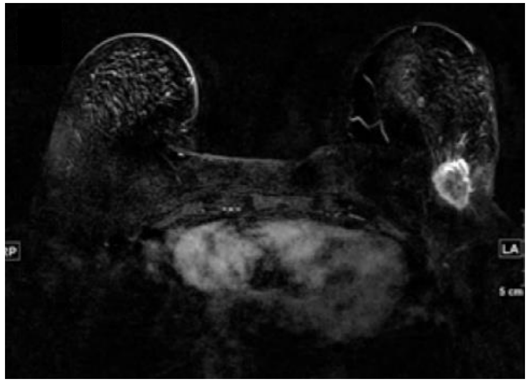
Breast insert for commercial PET/MRI scanner

Motivation

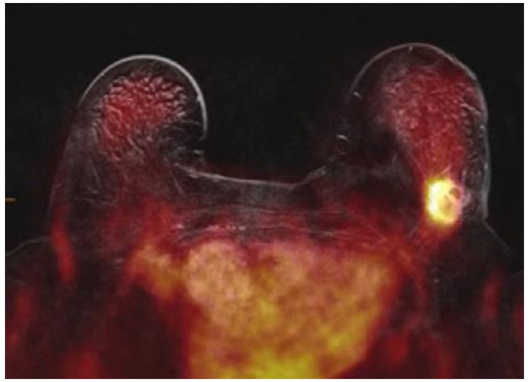
- **Breast cancer leading cause of cancer mortality for women**
- **Limitation of the image quality impede accurate identification of small structures (intratumoral, lesions)**

⟶ Motivation: Improvement of Accuracy for Breast Imaging

PET



MRT



PET/MR

3T PET/MRT Scanner Biograph mMR

Breast insert for commercial PET/MRI scanner

Motivation

Goal: Improvement of PET breast imaging ⟶ Integration of breast insert in breast coil and Biograph mMR

Coincidences:

I. Total-body PET Scanner

Consistent resolution (Total-body)

II. Breast Insert

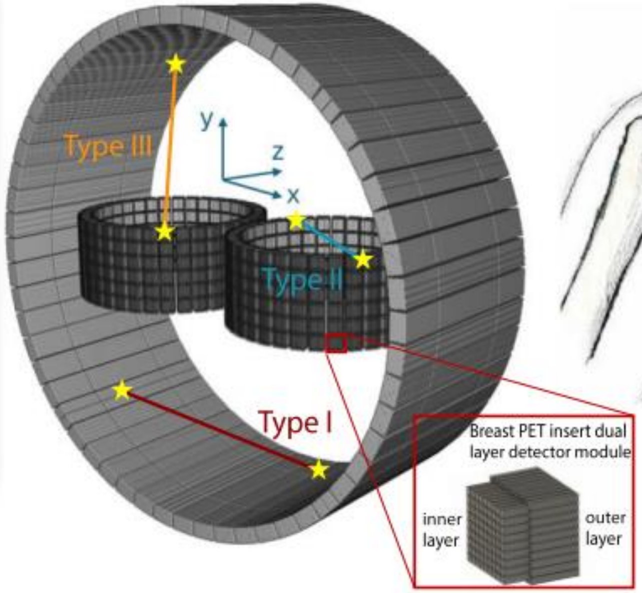
Higher resolution (Breast)
Potential for higher performance

III. Mixed coincidences

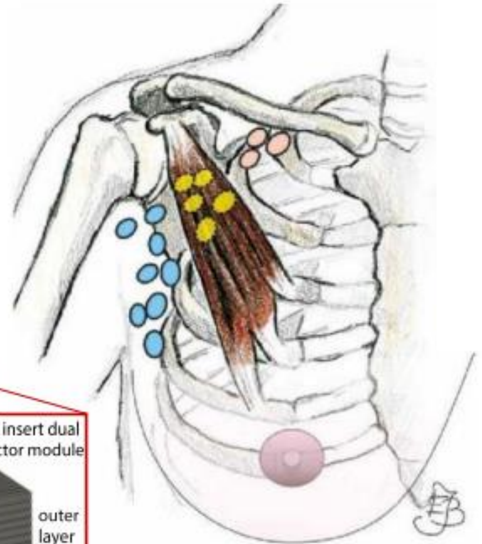
Increase resolution + Thorax

Siemens Biograph mMR as our model for whole-body PET (WB-PET) scanner with the breast coil"

https://www.siemens-healthineers.com/fr/magnetic-resonance-imaging/mr-pet-scanner/biograph-mmr



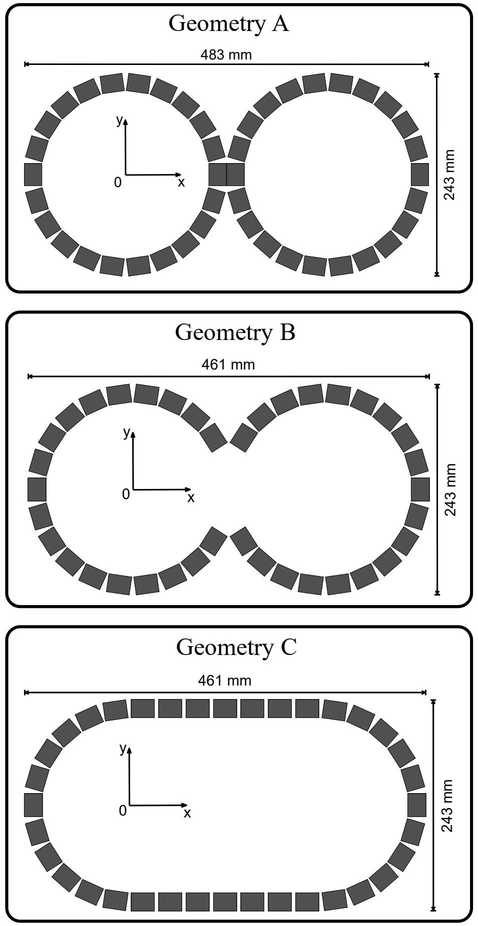
Proposed PET insert inside Biograph mMR based on previous study [5] with zoomed dual layer detector module



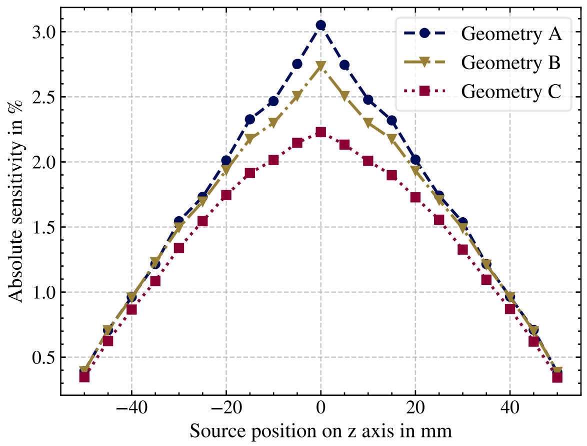
Level I (blue), II (yellow), and III (pink) axillary lymph nodes of the lymphatic drainage of the breast (by Nieciecki [6] is licensed under CC BY-NC-ND 3.0)

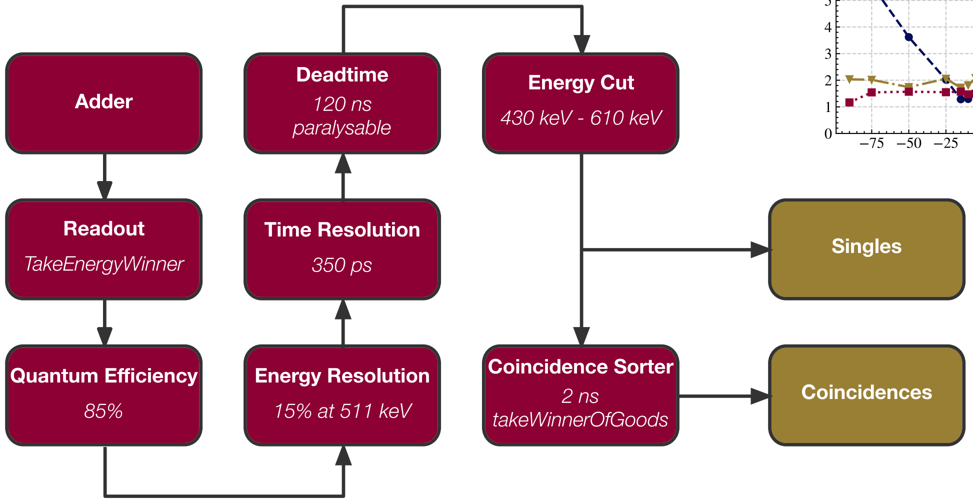
Breast insert for commercial PET/MRI scanner

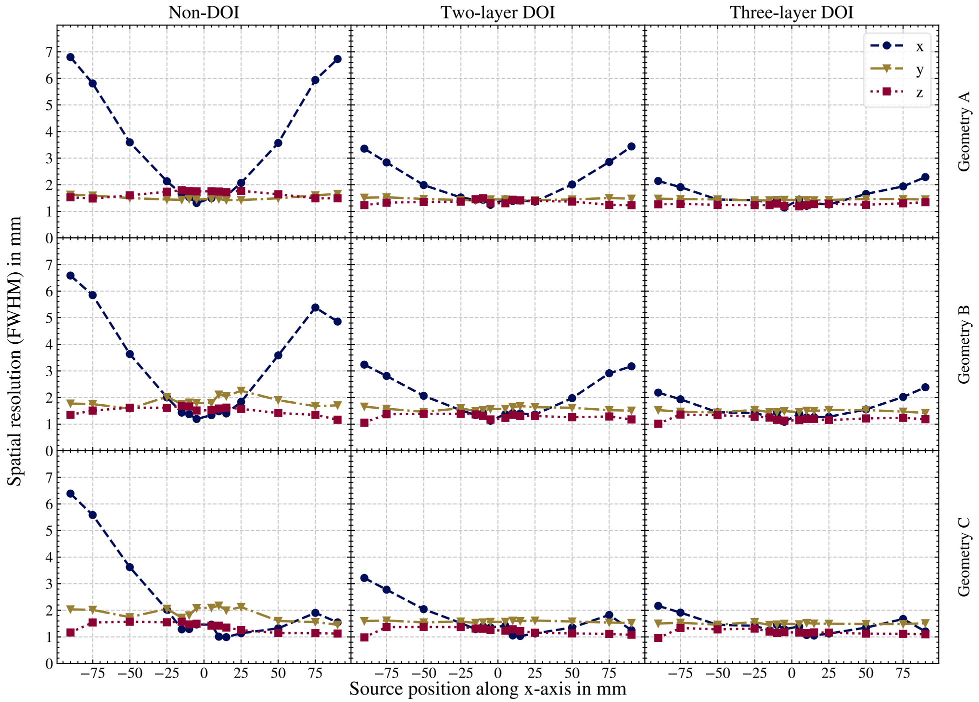
Motivation

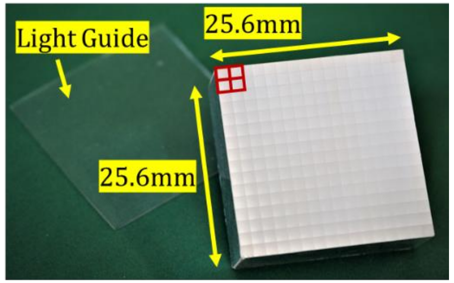


(b)





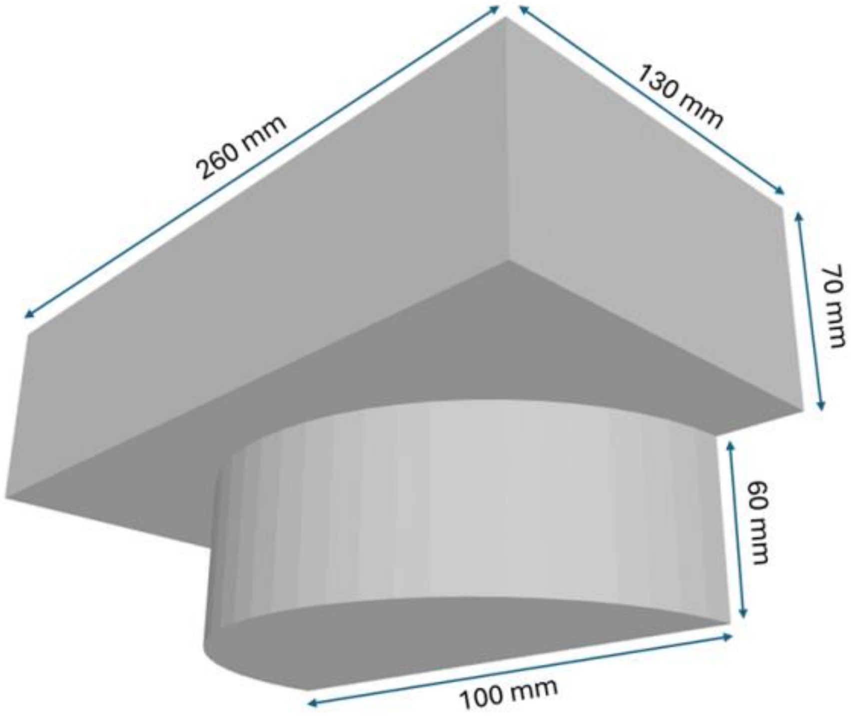




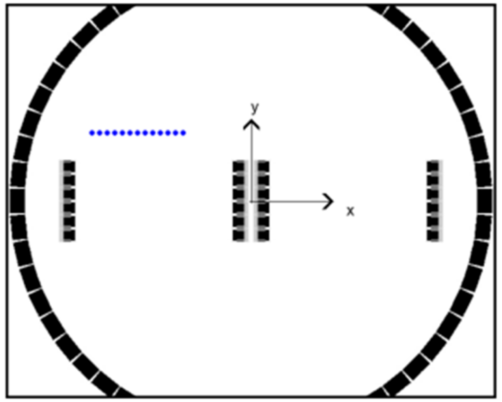
Pommranz et al, „Design and performance simulation studies of a breast PET insert integrable into a clinical whole-boy PET/MRI scanner, PMB, 2023

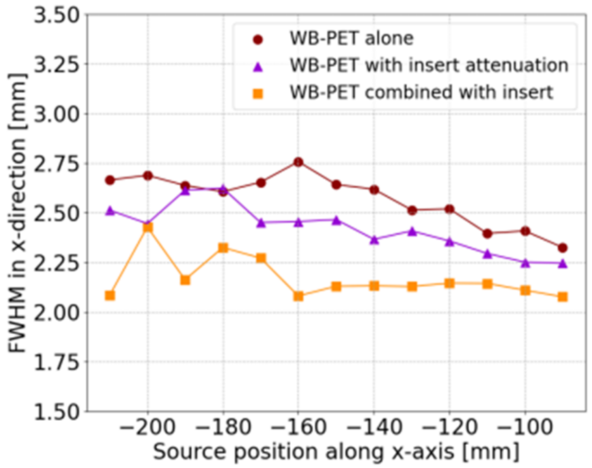
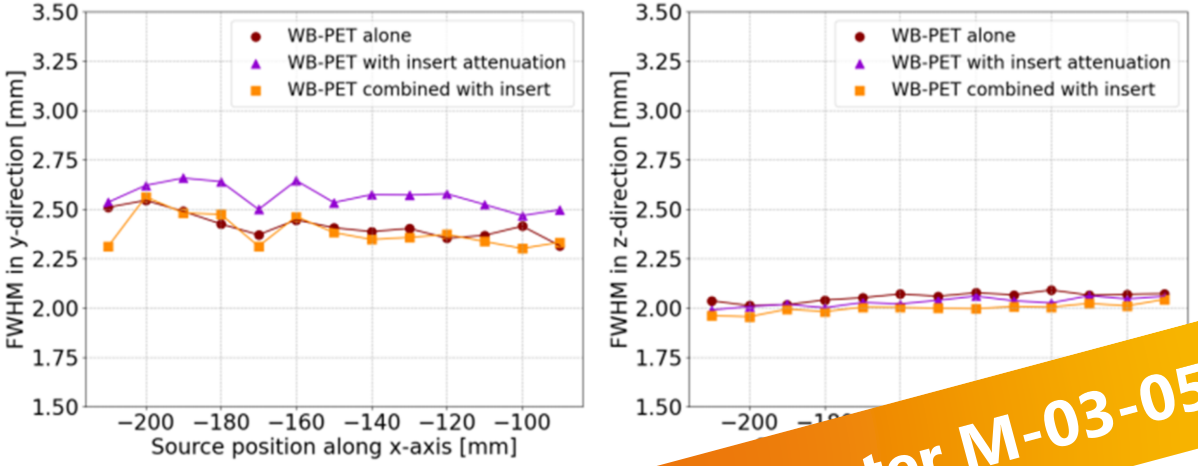
Study of improving axillary lymp nodes resolution

Towards enhancing axillary lymp nodes



Point sources (blue) placements outside of insert FOV (transaxial view)



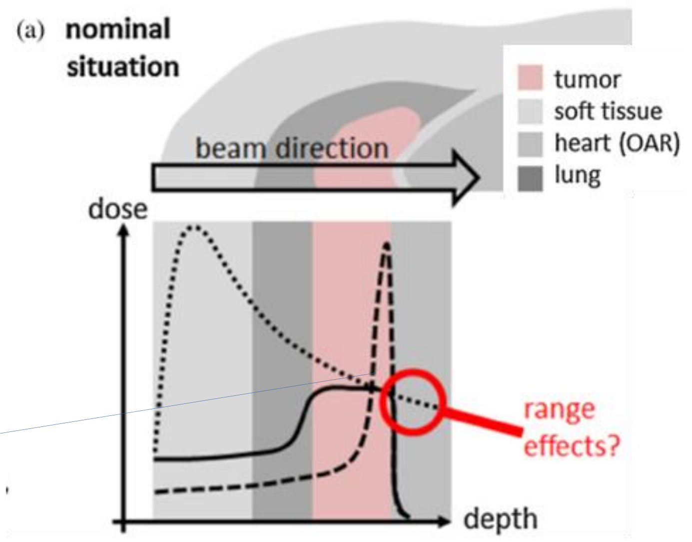
Poster M-03-058

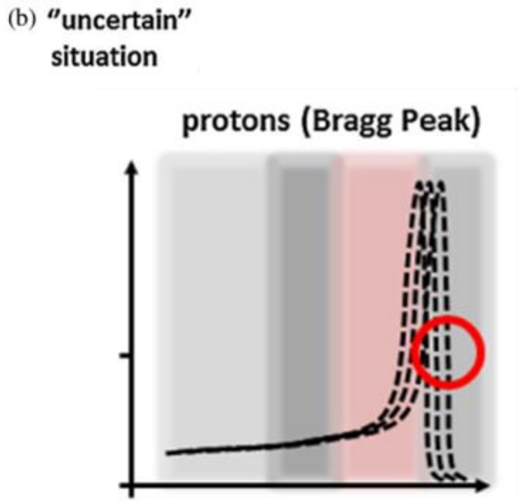
Imaging with Compton cameras for range verification in proton therapy

Imaging with Compton cameras

Proton therapy

- **Particle therapy: cancer treatment technique using proton or heavier ion beams**
  - **Distinct depth-dose deposition pattern (Bragg peak)**
  - **Potential higher distribution conformity & reduced healthy tissue-to-tumor dose ratio**
  - **Disadvantage: high sensitivity to range deviations (caused e.g. by changes in the anatomy of the patients)**
  - **Need for an online range verification method**



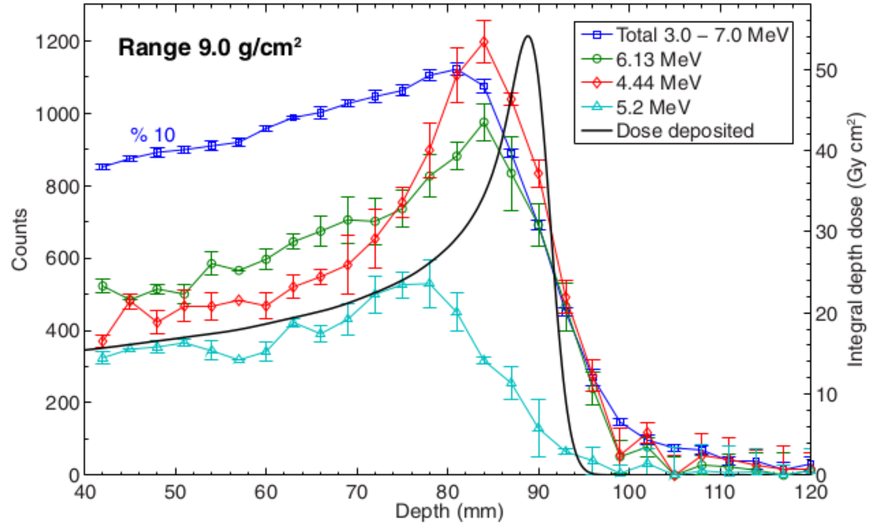


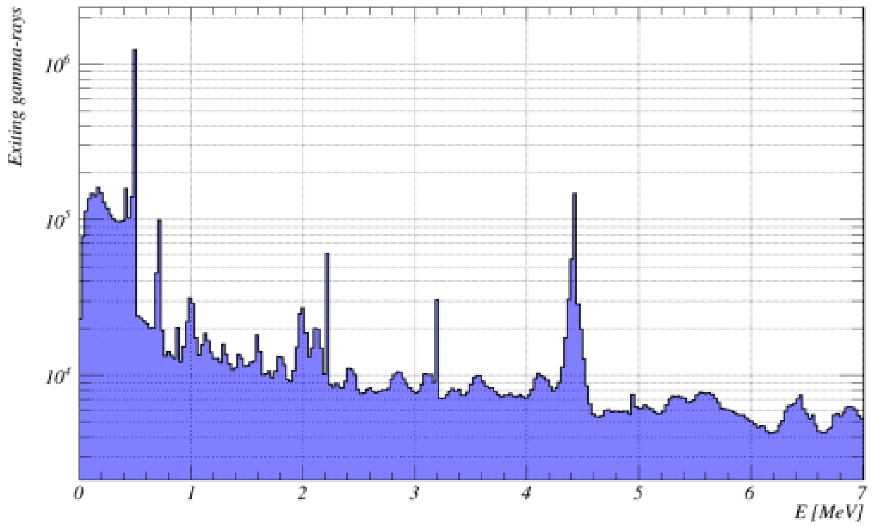
Adapted from [1]

[1]A. Knopf and A. Lomax, „In vivo proton range verification: a review" Phys. Med. Biol. 58 R131, 2013

Imaging with Compton cameras
Range verification

- **Candidate for online range verification method: Prompt Gamma (PG) imaging**
  - **Gamma-rays generated as a consequence of the nuclear inelastic interactions of the beam particles inside the patient**
  - **Nearly-instantaneous emission (no biological washout degradation)**
  - **PG spatial emission distribution is correlated to the depth-dose distribution.**
  - **Polychromatic spectrum**





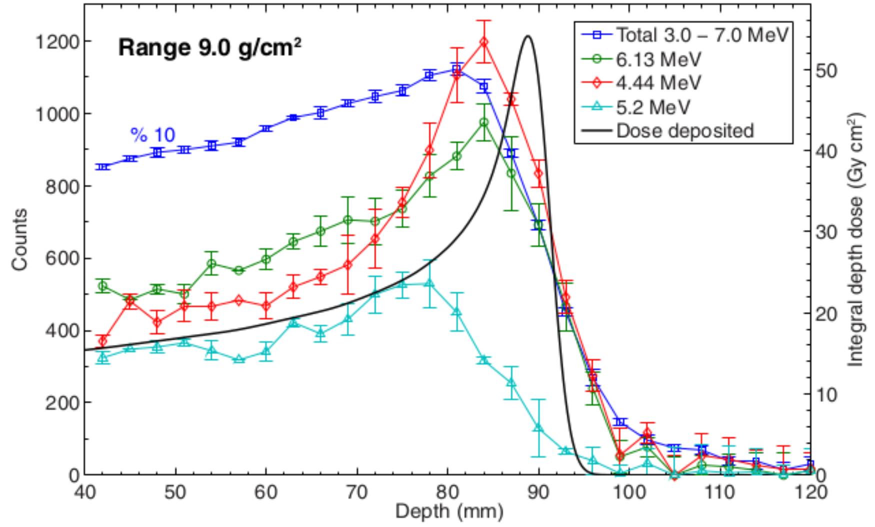
PG spectrum obtained with a GATE Phase Space actor after proton irradiation on a RW3 phantom

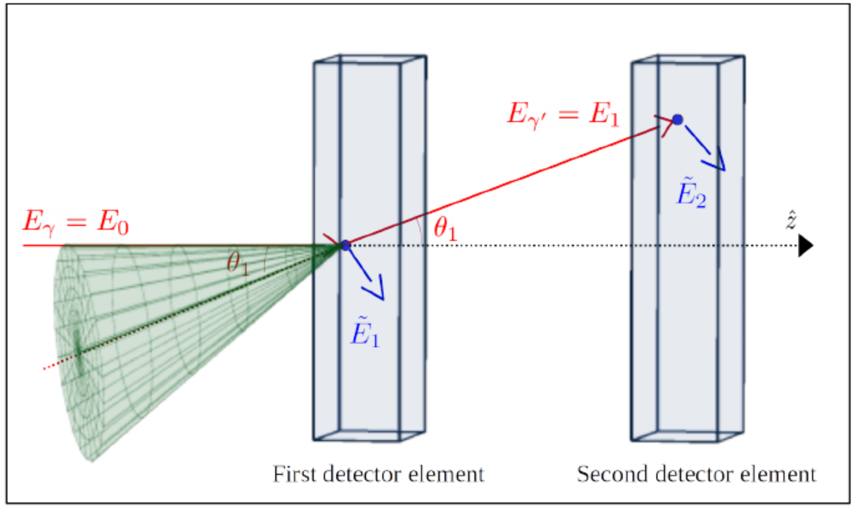
[1]JM Verburg et al. „Energy- and time-resolved detection of prompt gamma-rays for proton range verification“ Phys. Med. Biol. 58 L37, 2013

Imaging with Compton cameras

Range verification

- **Candidate for online range verification method: Prompt Gamma (PG) imaging**
  - **Gamma-rays generated as a consequence of the nuclear inelastic interactions of the beam particles inside the patient**
  - **Nearly-instantaneous emission (no biological washout degradation)**
  - **PG spatial emission distribution is correlated to the depth-dose distribution.**
  - **Polychromatic spectrum, anisotropic emission (implemented?)**
  - **Detetection candidate: Compton cameras**





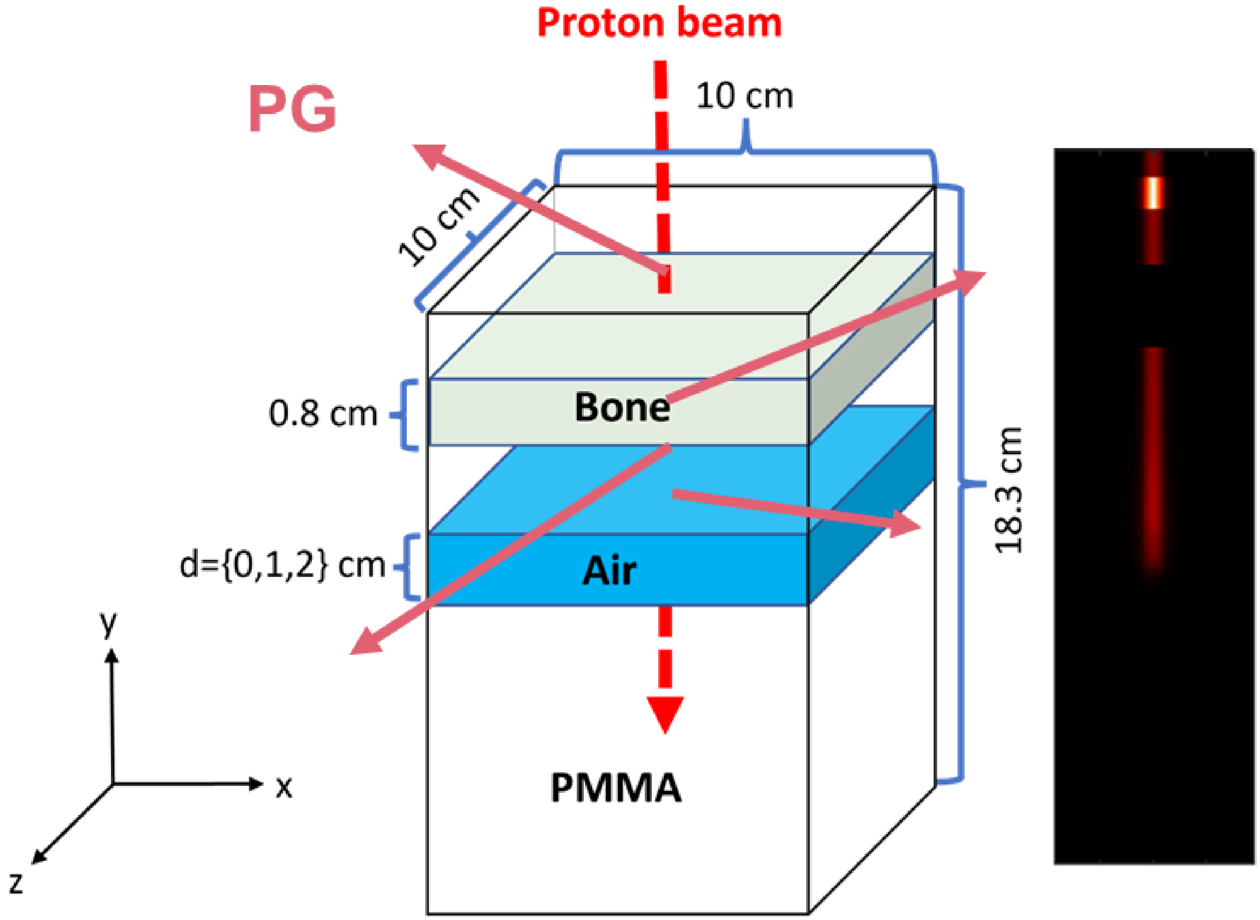
More on this @Poster M-08-347

[1]JM Verburg et al. „Energy- and time-resolved detection of prompt gamma-rays for proton range verification" Phys. Med. Biol. 58 L37, 2013

Imaging with Compton cameras

GATE simulations @ IMT/UzL

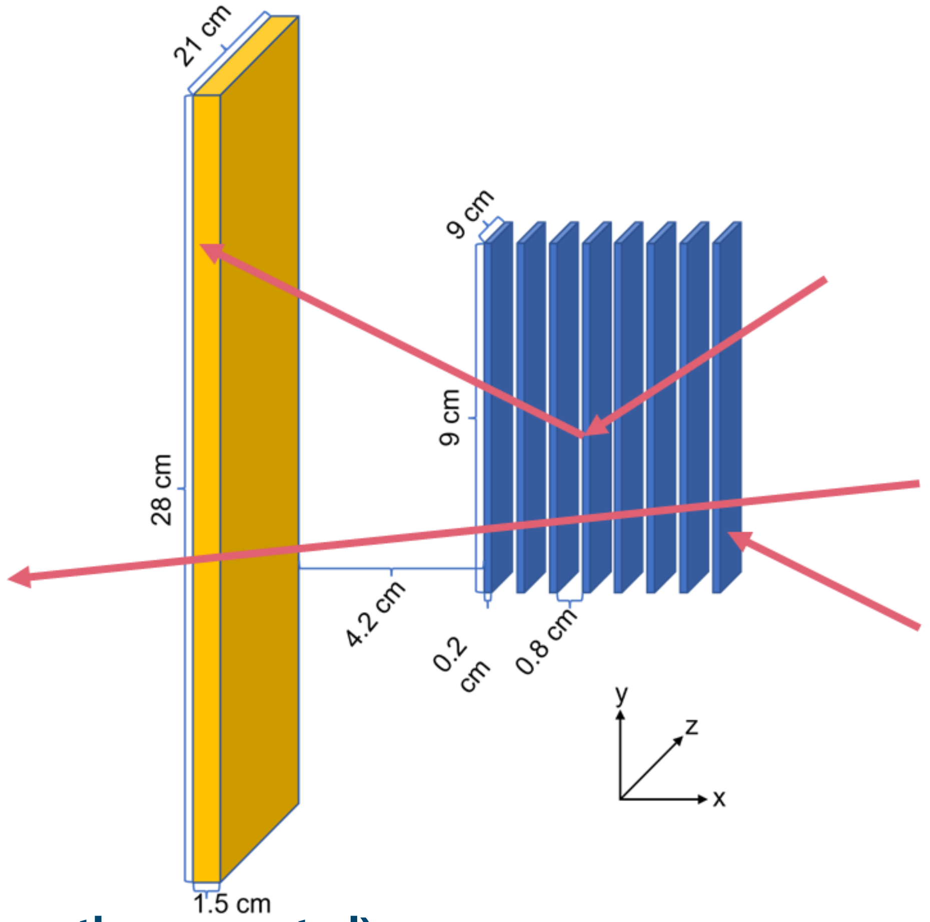
- **Simulation in two steps**
  - **First step: GATE simulation of proton beam on heterogeneous phantom**
  - **Hadronic physics list**
  - **Prompt-gammas stored using Phase Space actor**



Imaging with Compton cameras

GATE simulations @ IMT/UzL

- **Simulation in two steps**
  - **Second step: PGs stored in Phase Space actor used as a source to irradiate Compton camera**
  - **Electromagnetic physics list**
  - **Prompt-gammas stored using Phase Space actor**
  - **Compton camera module actor**
    … but only <u>storing the Singles</u>
    - **GATE coincidence sorter not working for us (much less coincidences than expected)**
    - **Related to the fact that same eventID hits have potentially very different times**
    - **Potentially affecting other applications (e.g. in-beam PET)?**
    - **Potentially solved in GATE 9.4?**



[1]J Kasprzak et al. „Regularized Origin Ensemble with a beam prior] {Regularized Origin Ensemble with a beam prior for range verification in particle therapy with Compton-camera data" Submitted to Phys. Med. Biol., 2024

Thank you
for your attention!