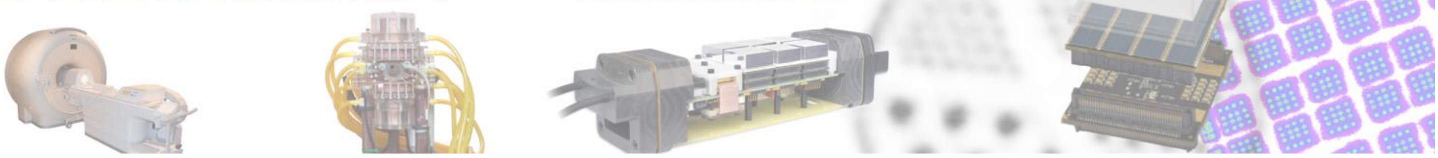
PMI PHYSICS OF MOLECULAR IMAGING SYSTEMS | RWTH AACHEN UNIVERSITY | Hyperion Hybrid Imaging Systems



Research focus of the department of “Physics of Molecular Imaging Systems” (**PMI**) of the University RWTH Aachen is on exploring the physical limits of current and future molecular imaging technologies. These areas range from simulations of new detector concepts, hardware prototypes, high-speed data processing, image reconstruction algorithms and applications using our research imaging prototypes. Our group consists of students and researchers from different disciplines: physics, engineering, computer science and medicine. PMI is part of a large institute with international network with a close link to industry and RWTH spin-offs.

Compton Scatter Correction for PET Image Reconstruction

In Positron Emission Tomography (PET), a non-invasive imaging technique, radiopharmaceutical tracers are utilized to visualize metabolic processes within a patient's body. PET imaging relies on the detection of gamma photons resulting from positron-electron annihilation events within the body. This annihilation event defines a Line of Response (LOR), a theoretical line connecting the decay origin in the patient's body to the detection points on the scanner ring. The precision of PET scans is affected by Compton scattering, a process where photons interact with electrons, resulting in energy loss and deviation of their path. This process leads to Lines of Response (LORs) that do not accurately align with the tracer locations. Traditional approaches to mitigate noise from Compton scattering in PET scans involve techniques such as energy windowing, which only considers events retaining their full energy. However, this strategy results in a decreased overall system sensitivity. We offer multiple thesis topics on scatter correction methods.

1. **Analytical Scatter Correction with Compton Kinematics**: Develop algorithms that trace photons back to their approximate scatter positions, using the principles of Compton scattering kinematics, probability theory and leveraging available CT imaging data.

2. **Deep Learning for Fast Scatter Simulation**: Utilize generative deep learning models to rapidly create approximate scatter distributions which can be leveraged during iterative image reconstruction, e.g. model the random walk photons undergo utilizing models such as Markov Chains, Convolutional Neural Networks or Denoising Diffusion Probabilistic Models.

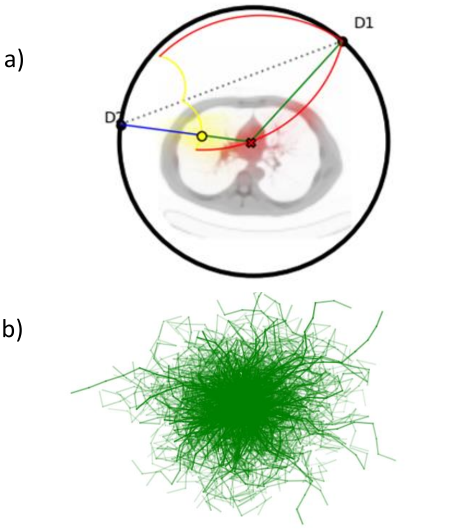


***Fig**: a) 2D scatter position modelling from listmode data; b) scattered photon paths in 2D*

We utilize OpenGATE [1], a particle-physics simulation framework developed at CERN to perform simulations a well as STIR [2], a software for tomographic image reconstruction, to translate measurements into images. We are looking for highly motivated and creative people with a strong background in physics, mathematics, electrical engineering, computer science or related fields. We offer an interdisciplinary working environment where you can gather hands-on experience to the field of PET imaging and image reconstruction.

[1] http://opengatecollaboration.org/ [2] https://stir.sourceforge.net/

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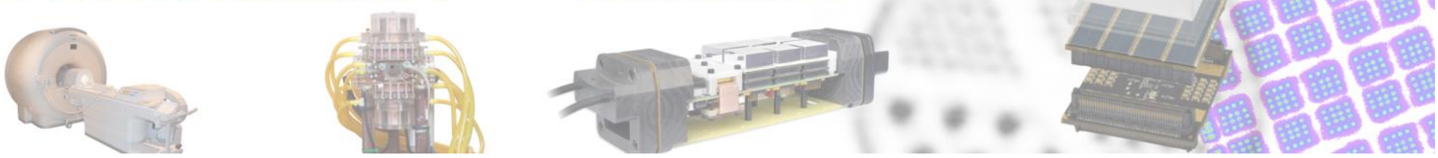

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Various Topics in PET Image Reconstruction for the HD-MetaPET project

HD META PET

Positron Emission Tomography (PET) is a vital tool in functional imaging yet requires complementary anatomical context from other imaging modalities. Traditionally, PET/CT systems have been the standard, however the combination of PET and Magnetic Resonance (MR) imaging has gained increasing interest due to the higher soft-tissue contrast of MR compared to CT.

The HD-MetaPET project is at the forefront of this innovation, focusing on the development of a clinical-scale PET/MR system. A key advancement of this project is the incorporation of an additional local detector, positioned on the patient. This approach aims to significantly enhance local image resolution, thereby elevating the capabilities of PET/MR imaging in clinical settings. We offer various thesis topics with respect to PET image reconstruction on this project.

- **Image Reconstruction Using Local Detector Data:**
  Develop new methods to reconstruct images using coincidence data from outer PET ring as well as a single or multiple local detectors.
- **Attenuation Correction Techniques from MR-Imaging:**
  Develop methods for PET attenuation correction, leveraging the MR imaging data.
- **Scatter Correction for Local Detectors:**
  Address challenges of Compton scatter inside local detectors to enhance image contrast. Utilize Compton kinematics as well as machine learning to design novel scatter correction algorithms.

a)

b)

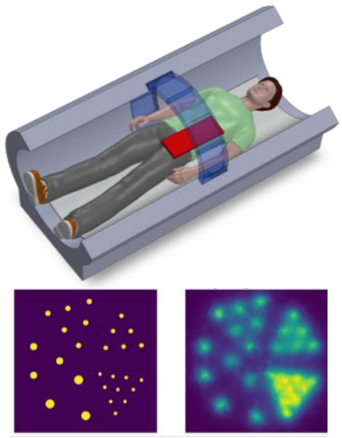

***Fig**: a) HD-MetaPET scanner setup;*
b) phantom ground truth and reconstruction

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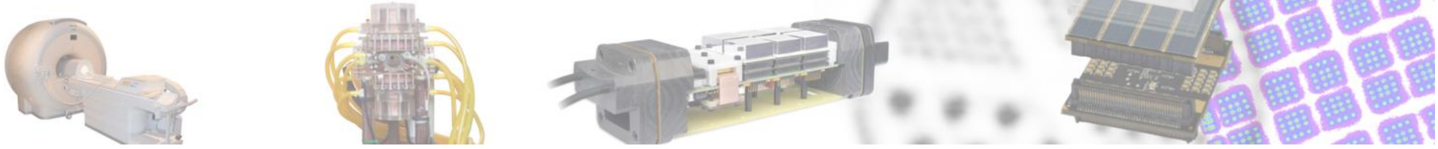

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Development of an Advanced PET Simulation and Image Reconstruction Pipeline: Integrating OpenGate and STIR

OpenGate [1], developed at CERN, is a powerful particle-physics simulation framework. We utilize Gate for simulating PET scanners, followed by the application of STIR [2], a specialized software for tomographic image reconstruction, to convert raw measurements into reconstructed images. Currently, an automated pipeline for image reconstruction from generic Gate PET geometries is not available. This project's goal is to create an effective pipeline to facilitate this process. This will include:

1. **GATE Macro parsing**: It is necessary to parse GATE's macro files which define scanner geometries. This process involves extracting the volume hierarchy, essential for determining individual crystal positions.
2. **List-mode data generation**: The goal is to convert recorded data into a list-mode format compatible with STIR. Although the SAFIR format supports generic crystal positions, the introduction of continuous crystals will require the **development of a new list-mode format**.
3. **STIR scanner parametrization**: Scanners must be parametrized in a format compatible with STIR to facilitate effective image reconstructions.

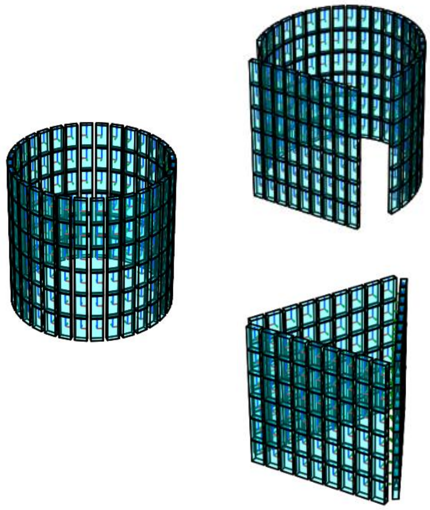

Fig: *Different possible scanner geometries*

We are currently developing our own python codebase for this, which will serve as a starting point for your project. STIR is open-source and the development of a custom list-mode format will be done in C++. Currently all reconstructions are performed using the OSEM algorithm.

We are looking for highly motivated and creative people with a strong background in physics, mathematics, electrical engineering, computer science or related fields. We offer an interdisciplinary working environment where you can gather hands-on experience to the field of PET imaging and image reconstruction.

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