# PSMR2024 10th Conference on PET, SPECT, and MR Multimodal Technologies, Total Body and Fast Timing in Medical Imaging

Sunday, 19 May 2024 - Thursday, 23 May 2024

La Biodola, Isola d'Elba

# Book of Abstracts

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# AI enhanced PET detectors

**Assing** is an Italian company founded in 1971 with ambitious ideas: to develop responsible innovation and internationalization. Our goal has always been to produce technological innovation by collaborating with the most important researchers from both the public and private sectors.

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The company relies on a stable staff of over 120 employees spread across three Italian locations and various foreign offices.

In addition to the research and development area, which ensures the acquisition and renewal of technical skills, the company operates along three main directions, and three distinct but integrated business units.

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*Clean Rooms*

For over 30 years, Assing has been designing, building, and managing controlled contamination environments, clean rooms, cell factories.

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## Refining Position Estimates of PET Detector Blocks with Stochastic Gradient Descent

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Mechanical misalignments of PET detectors, resulting from manufacturing imprecisions, significantly compromise image quality. Precise position estimation becomes crucial amidst the complexities of evolving whole-body imaging systems and the introduction of new scanner technologies. Traditional methods utilize single point source measurements. We propose an alignment strategy that works for arbitrary tracer distributions. Our method optimizes transaxial alignment parameters to match a differentiable approximation of the sinogram with the analytical solution for tracer line integral distributions, given by the Radon transformation. We utilize the Adam optimizer and use an adaptive normalization strategy and convex hull regularization to counteract effects of missing data due to gaps between detector elements. Our study utilized GATE simulations of a small animal PET scanner with intentionally introduced detector misalignments. We assessed our method's efficacy by comparing found detector configurations against the ground truth. Results indicate the method's potential in estimating detector alignment with $\sim 300\mu m$ precision, albeit with limitations towards y-axis rotations due to their minimal impact on the sinogram. In conclusion, our approach presents a viable solution for PET detector alignment, offering a foundation for future enhancements, including z-axis alignment and additional corrections for effects like attenuation, scatter or randoms.

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## On-Chip Analog Neural Networks for In-Sensor Image Reconstruction Towards PET Scanners with Large Fields of View

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We present a novel detector concept for emission tomography imaging based on monolithic scintillators in which the reconstruction of the scintillation coordinates is performed in real time by an artificial neural network (ANN) implemented on a silicon chip in charge domain. Each neuron sums the input values weighted by means of banks of selectable capacitors. We designed and fabricated a first proof-of-concept ASIC prototype in CMOS 0.35um process, compatible with other analog ASICs for SiPM readout, whose preliminary characterization is here reported. It implements an artificial neural network with 64 inputs (corresponding to the signals of an 8 by 8 arrays of SiPM), 2 hidden layers with 20 neurons each and 2 output neuron estimating the X and Y coordinates of the scintillation position. Quantization-aware training of the ANN was based on a simulated dataset and weights are stored in RAM cells. In simulations, the performance of the ASIC-embedded estimation is close to the computer-based one for both simulated and experimental data, with a spatial resolution below 2mm with standard PET detectors. Here we report the preliminary experimental results of the ASIC with an area and a power efficiency of 93.5 GOP/s/W. A development roadmap to improve the computational efficiency (adopting more scaled technologies and different topologies for

the programmable network of neurons) of the chip and for its integration with a detector module will be presented at the conference.

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## Characterisation of an AI-enhanced TOF-PET detector module with monolithic BGO crystals

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We present an autonomous, monolithic scintillator-based PET detector that incorporates our newly developed artificial intelligence algorithm for real-time, on-board event characterization. This new design achieves state-of-the-art performance metrics including spatial resolution, depth-of-interaction (DOI), coincidence time resolution (CTR), and maximum event rate capabilities while maintaining scalability, low costs and the ability to process all data internally.
We present two detector designs equipped with 16- and 20-mm-thick monolithic BGO crystals coupled to a 8 x 8 SiPM matrix with a 6 mm pitch. Each SiPM is individually read by an HRFlexToT ASIC with 16 channels apiece, for a total of 4 ASICs. The detector incorporates an internal artificial intelligence algorithm that effectively consolidates the digital outputs from each sensor into 3D position, time of interaction, and amount of energy deposited.
Both variants achieved spatial resolutions below 2 mm FWHM and timing resolutions below 450 ps. The data acquisition architecture is able to sustain an event rate of up to 1.1 Mcps over a 50 mm x 50 mm active area. Notably, the design confines the entire detector volume within the 50 mm x 50 mm footprint of the crystal, enabling a completely tileable architecture with no loss of space on the two planar sides.

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## Improving Timing Resolution of BGO with and without Deep Learning

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The renewed interest on BGO scintillators for TOF-PET is driven by the improved Cherenkov photon detection with new blue-sensitive SiPMs. However, its slower scintillation light causes time walk,

degrading coincidence time resolution (CTR) measured with leading edge discrimination (LED). To address this, a time walk correction (TWC) can be done by using the rise time measured with a second threshold. Deep learning, particularly convolutional neural networks (CNNs), can also enhance CTR by training with digitized waveforms. It remains to be explored how timing estimation methods, utilizing one, two, or multiple waveform data points, compare in the quest for superior CTR. In this work, we compare classical timing estimation methods (LED, TWC) with a CNN-based method using BGO crystals read out by NUV-HD-MT SiPMs and high-frequency electronics. For 2x2x3 $mm^3$ crystals, employing TWC results in a CTR FWHM of 129 ± 2 ps, while the CNN yields 115 ± 2 ps, marking an improvement of 18% and 26% compared to LED, respectively. For 2x2x20 $mm^3$ crystals, both methods yield similar CTR (around 240 ps FWHM), offering a ~15% gain over LED. The CNN, however, exhibits better tail suppression in the coincidence time distribution. The higher complexity of waveform digitization needed for CNNs could potentially be mitigated by adopting a simpler two-threshold approach, which appears to capture most of the essential information for improving CTR in longer BGO crystals.

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## 3D In-System Calibration of PET Detectors

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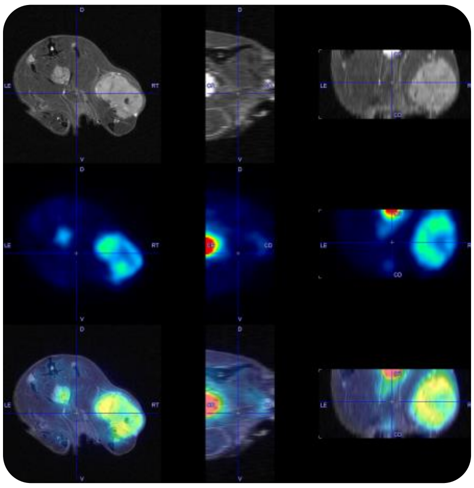
In PET science, numerous high-performance detector designs are being investigated that are slowed in their system integration, e.g., due to a complex positioning calibration, including depth-of-interaction (DOI), required for several light-sharing designs. This process usually happens in benchtop setups, but a prerequisite for system integration is the fast acquisition of the training data for machine-learning applications and a practicable re-calibration and quality control.
We propose a new 3D in-system calibration with data acquisition inside the scanner by software-collimating a radioactive point source combined with angular detector irradiation for DOI. Experiments were conducted with a point source mounted to a 3-axis motor and placed inside a scanner dummy (120 mm diameter). The source was moved in front of a slab detector ((24 × 10 × 1) $mm^3$ slabs). By selecting orthogonally incident gamma rays, a planar calibration was conducted using Gradient Tree Boosting. Then, the DOI was calibrated by selecting oblique angles and calculating the DOI label from the geometric ray path and the planar position estimate.
For planar positioning, the results were within 1% of state-of-the-art calibration at 0.8 mm MAE and 1.19 mm FWHM. For DOI, 1.13 mm MAE and 2.47 mm FWHM were achieved. The method's applicability to different scanner geometries was analytically calculated and investigated.
The proposed in-system calibration method is suitable for 3D-calibrating assembled PET systems.

# AI enhanced PET imaging

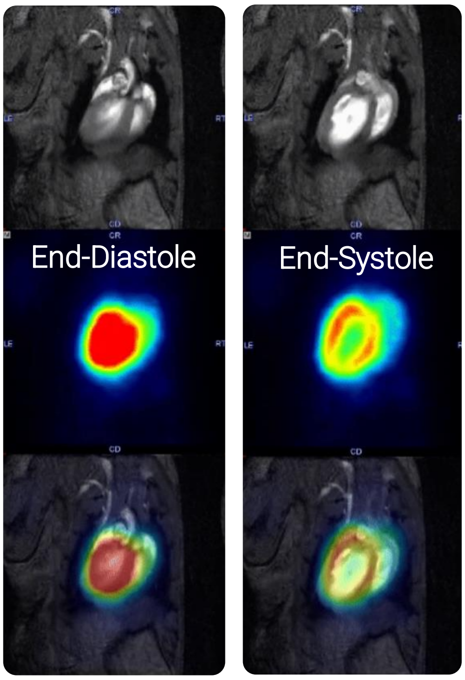
# Simultaneous or Sequential PET/MRI at 9.4 Tesla, 7 Tesla & 3 Tesla

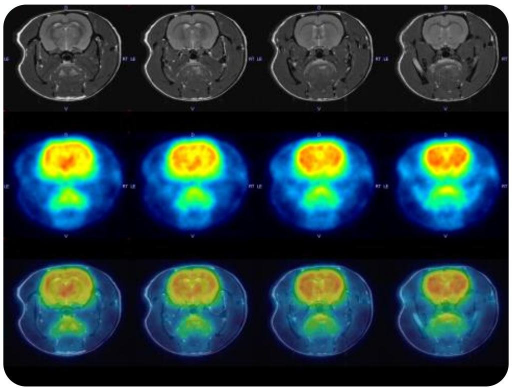
- ✓ Designed for BioSpec Maxwell MRI
- ✓ Ready-to-use PET/MR protocols
- ✓ PET/MRI optimized animal cradles
- ✓ PET/MRI optimized RF coils
- ✓ Comprehensive Attenuation Correction for fully quantitated PET


**Oncology**
[18F] FDG PET/MRI and MR 7T reveals details of heterogenous tumor micro-environment in mice



**Cardiac Imaging**
[18F] FDG PET/MR 9.4T IntraGate in mice. PET gated reconstruction guided by MR



**Neuroimaging**
[18F] FDG PET/MRI 9.4T in a healthy rat reveals brain cortex within minutes

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## Metabolite-Corrected Plasma Input Function Estimation in Dynamic PET Imaging Using Physically Informed Deep Neural Networks

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The full quantification of dynamic Positron Emission Tomography (PET) data requires the measurement of the arterial input function(AIF),i.e. the concentration of the free tracer in the plasma over time. This invasive measure heavily constrains the more extensive adoption of dynamic PET imaging for clinical research studies and diagnostic workups. Current alternatives include image-derived or population-averaged input functions, which still face many challenges and requires correction for rediometabolites in plasma. We introduce a novel approach for the evaluation of the metabolite corrected plasma input function and validate it on dynamic [11C]PBR28 PET data. Our method employs 3D depthwise separable convolutional layers to analyze dynamic PET images together with a physically informed deep neural network, which incorporates a priori knowledge about the functional form and shape of the AIF, for the prediction of the whole blood and metabolite-corrected plasma curves. We found an average cross-validated Pearson correlation between measured and predicted whole blood and parent plasma curves of 0.86 and 0.89, respectively demonstrating the model's effectiveness in retrieving information related to the tracer metabolism in blood from brain images only.Furthermore, the volumes of distribution obtained by fitting tissue time activity curves of several key regions of interest while using true and predicted AIFs with a two-tissue compartmental model showed no statistical differences.

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## Dopaminergic PET to SPECT Domain Adaptation: A Cycle GAN translation approach

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Dopamine transporter imaging is routinely used in the diagnosis of Parkinson's disease (PD), although unreliable in distinguishing PD from atypical parkinsonian syndromes (APS). While [11C] CFT PET is common in East Asia, with a substantial APS database to support AI advancements, Europe primarily relies on [123I] FP-CIT SPECT, with limited APS data. Cross-modality translation is appealing to facilitate multicenter/long-term studies. We aim to develop a deep learning(DL)-based cross-modality synthesis between CFT PET and FP-CIT SPECT.
Methods: A 3D CycleGAN was trained with CFT PET and FP-CIT SPECT images from PD and non-parkinsonian (NC) subjects and used to generate synthetic SPECT from the real PET test set. Quantitative and qualitative evaluations were performed.
Results: The Fréchet Inception Distance between synthetic and real SPECT was lower than between synthetic SPECT and real PET. The striatal specific binding ratios values of synthetic SPECT were not significantly different from those of real SPECT. The DL model for NC vs PD classification achieved an AUC of 0.992. Visual grading analysis showed no significant differences between real and synthetic SPECT.
Conclusion: The CycleGAN generated visually indistinguishable synthetic SPECT images, preserving disease-specific classification information. This can improve reproducibility of quantitative measures and AI classification accuracy, aiding in the diagnosis of PD and APS.

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## Deep Learning Image Denoising for a cost-effective WT-PET design with sparse detector coverage

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This work presents a method for denoising images of a sparse detector design of the Walk-Through PET (WT-PET). This is a cost-effective long axial field-of-view (AFOV) PET scanner with patients being scanned while standing between two vertical flat panels of monolithic detectors. This configuration of the WT-PET promises to achieve higher patient throughput and lower system cost than other cylindrical long AFOV PET scanners, given the reduction in detector volume/surface. To further reduce the WT-PET system cost, axial gaps are introduced uniformly along the AFOV with a

70% detector coverage (sparse WT-PET). To address the higher image noise coming from the design' s sparsity and reduced scan time (less than 1 minute), we implement a deep learning (DL) solution for image denoising. The fully populated system (full WT-PET) is simulated in GATE, and images of XCAT anthropomorphic phantoms were reconstructed with MLEM in full WT-PET and 70% sparse WT-PET modes. To train the 2D neural network, input-target pair used 20s sparse WT-PET and 40s full WT-PET reconstructed images, respectively. The DL model was tested on two XCAT and the NEMA IQ phantoms. Contrast recovery coefficient, contrast-to-noise ratio and background variability were calculated for quantification. The results suggest that when combined with DL-based denoising, the sparse WT-PET design based on 70% detector coverage with scans of less than 30s gives good images where noise is reduced, and image quality preserved.

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# PETAL-3D: Progressive Elimination of Noise Towards Accurate Ultra Low-Dose PET Images Using 3D U-Net

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Positron Emission Tomography (PET) is a functional imaging technique used in nuclear medicine to investigate metabolic and physiological activities. The dose delivered to the patient can be reduced by decreasing the injected activity of the radiotracer. However, this reduction would lead to increased noise levels in the reconstructed image. Several techniques, including image filters and Artificial Intelligence (AI) algorithms, can be employed to reduce the noise in the post-reconstructed images, thereby enhancing the quality of low-dose PET scans. In this work, we proposed a Progressive Elimination of Noise Towards Accurate Ultra Low-Dose PET Images Using 3D U-Net (PETAL-3D) for recovering images of dose reduction factor of 100. PETAL-3D operates by passing the low-dose PET image (the input) through multiple 3D U-Net networks. This helps eliminate the noise gradually from the image. PETAL-3D was trained on data obtained from both Siemens Biograph Vision Quadra PET/CT scanner and a United Imaging uEXPLORER PET/CT scanner. Scans from thirty subjects were utilized to assess the performance of PETAL-3D and draw a comparison with a 4 mm Gaussian filter. The results showcased strong performance in recovering the image quality compared to the Gaussian filter using global and local metrics without the introduction of artefacts within the image.

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# Sinogram Denoising Using Transformer-based Learned Sinusoidal Patterns

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Low-Dose Positron Emission Tomography (LDPET) technique, designed to minimize radiation burden to patients, is increasingly garnering attention in the PET imaging field. Given the degradation of image quality associated with reduced radiation levels, LDPET imaging requires specialized reconstruction methods or denoising algorithms to enhance image quality and diagnostic accuracy. Most of the recent effective denoising methods utilize CNN. Yet, these architectures often fall short in capturing long-range non-local interactions, potentially resulting in inaccuracies when representing global structures. Considering the benefits of transformer architectures compared to CNNs, our study presents a novel sinogram denoising algorithm customized to improve the quality of PET sinograms. Furthermore, we introduce a sinogram transformer module designed to learn sinusoidal patterns rather than projections from different view angles or radial positions, thereby enhancing sinogram feature extraction. By leveraging a transformer architecture with a self-attention mechanism, this module effectively preserves sinogram inner-structure, leading to superior performance in sinogram denoising and preventing noise from propagating into the image domain. Evaluations conducted on a clinical dataset reveal that our transformer module, which learns sinusoidal patterns, outperforms other methods that learn projections from various view angles or radial positions both qualitatively and quantitatively.

# Fast timing sensors and electronics

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## Time of flight: the last frontier in PET

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PET, through recent advancements comes close to the absolute limits of its potential. Spatial resolution matches the positron range; TB PET offers as good as complete coverage of the subject; machine learning-driven algorithms make the most out of each coincidence. ToF, in contrast, remains away from its own limit. Clinical state of the art is down to 178 ps with Siemens Biograph Vision X, while laboratory development struggles to overcome 100 ps, combined with sufficient sensitivity. ToF offers a whole new dimension for PET. Effective sensitivity improvement, higher data rates, high-order data corrections, small lesion detection, faster convergence and more robust data. This comes on top of the potential for reduced radiation dose, faster examination and better geographic coverage. For the set target of 10 ps, the whole detector chain is being revisited: scintillator (metascintillators, Cherenkov imaging); photodetection (ultra-fast single photon avalanche diodes, micro-channel plates, metal in trenches silicon photomultipliers); data acquisition systems (ASICs, FPGAs); signal processing and reconstruction (multi-kernel, event-by-event characterization, timewalks). Difficult though the task, high is the reward: Reconstructionlessness, minimizing computational resources; ToF-based scatter rejection, further augmenting sensitivity; new radioisotopes, allowing new and multiple examinations in the same time. Combined with other PET advances, ToF can herald a new era in medicine.

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## NUV-sensitive Deep-junction (NUV-DJ) SiPMs, a new technology optimized for fast timing applications

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In recent years, Fondazione Bruno Kessler (FBK) in Trento, Italy, has been actively involved in the development of several Silicon Photomultiplier (SiPM) technologies, particularly for applications such as time of flight-positron emission tomography (TOF-PET) where a fast timing is crucial. This work presents FBK's latest development, the Near-Ultraviolet Deep-junction (NUV-DJ) SiPM technology, which has an improvement in photo detection efficiency (PDE) and single photon time resolution (SPTR) with respect to the state-of-the-art SiPMs. The NUV-DJ microcell has 40 µm pitch and features a unique design with the high-electric field region placed deeper in the device enabling an enhancement of the avalanche triggering probability even with longer wavelength photons.
The PDE showed outstanding values of 70% (including a nominal fill factor of the microcell of 80.8%), at 420 nm of wavelength and 9 V of excess bias. For a 4x4 $mm^2$ SiPM using a high-frequency readout, it was measured a SPTR of 60 ps FWHM at 20 V of excess bias, and a CTR of less than 100 ps FWHM with 2.76x2.76x18 $mm^3$ LYSO:Ce crystal at 10 V of excess bias. The measured CTR using standard readout electronics showed excellent values of about 115 ps FWHM at overvoltage larger than 10 V. These findings represent cutting-edge advances in timing and PDE and are very promising for TOF-PET applications employing LYSO, LSO, BGO, and LaBr3 crystals or in scenarios where a high PDE in the NUV range is imperative.

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# The new PETsys TOFPET3 ASIC

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A new PETsys ASIC in the TOFPET series, named TOFPET3, has been developed aiming at high performance PET applications. The new chip has a 64-channel analog front-end with baseline stabilization, pulse tail cancelation, dark noise rejection and gain configuration. In each channel, three 10-bit digitization of pulses above a configurable threshold are performed (2 TDC, 1 QDC). The maximum event rate per channel is 500 kHz, and the output bandwidth is 3.8 Gb/s matching the input rate. The new timing and energy circuits have outstanding performance: 1) the TOFPET3 contribution to CTR is 24 ps FWHM, implying that a CTR=80(120) ps due to crystal and SiPM, increases to 83(123) ps with TOFPET3; 2) the contribution to 511 keV photopeak resolution is 1.1% and the deviation to linearity is ±1% in the range 3000 p.e for SiPM gain 3.5x106 . Charge integration of single photons is possible with S/N=12. The chip includes four additional channels with sums of 16, 32 or 64 cannels (configurable) suitable for light sharing applications, as well as advanced triggering features allowing the selective readout of a group of channels triggered by the energy of one channel. The power consumption is 8 mW per channel. We present simulation results of the chip performance.

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# Second Generation Readout Electronics Design for a PET Detector That Achieves ~100 ps CTR and <2 mm DOI Resolution

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This study introduces second-generation front-end electronics design for side-readout detectors, with the ultimate goal of realizing near 100 ps CTR Time-of-Flight 3D Position Sensitive (TOF-3DPS) detectors. Leveraging a previously proposed timing signal multiplexing scheme based on RF amplifiers and summing circuits, this design utilizes complex programmable logic devices (CPLDs) and discrete components to facilitate high-precision measurements of energy and Depth of Interaction (DOI). Experimental results on a single 3×3×10 $mm^3$ LYSO:Ce crystal demonstrated an 11.66% energy resolution, a 1.44±0.44 mm FWHM DOI resolution, and a ~112 ps FWHM DOI-calibrated CTR. Further tests on a detector unit comprising a 4×2 array of 3×3×10 $mm^3$ LYSO:Ce crystals, side-coupled with a 4×6 array of 3.16×3.16 $mm^2$ SiPMs, yielded a 12.29±1.16% energy resolution and a DOI-calibrated CTR of 120.56±5.38 ps FWHM. The front-end circuit, designed to read out two detector units, occupies a compact footprint of only 27 mm × 95 mm, enabling easy integration and stacking of multiple units to form a complete TOF-3DPS detector module.

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# Fast Detectors Viewed from a Different Angle: Scintillators and SiPMs for Photon-Counting CT

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**Corresponding Author:** d.r.schaart@tudelft.nl

Photon-counting computed tomography (PCCT) is a rapidly emerging medical imaging technology. Several PCCT scanners were recently developed based on finely pixelated room-temperature semiconductor detectors. Although scintillation detectors were traditionally considered too slow to handle the X-ray fluence rates > 108 photons s-1 mm-2 encountered in PCCT, the fast signals provided by modern scintillators and silicon photomultipliers (SiPMs) allow us to rethink this paradigm. SiPM-based scintillation detectors are commonly used in time-of-flight PET systems and have enabled the integration of PET and SPECT with MRI. Recent research indicates that SiPMs combined with ultrafast scintillators can also provide a robust, scalable, and affordable X-ray photon-counting technology. This offers new perspectives for the development of cost-effective X-ray photon-counting imaging equipment for different applications, including multimodal imaging and image-guided interventions. This presentation offers an overview of recent theoretical and experimental work, demonstrating the potential of SiPM-based scintillation detectors as an alternative for direct-conversion detectors. It will be shown how the choice of scintillator and other factors affect detector performance parameters such as count-rate capability and spectroscopic performance. Moreover, research opportunities in the areas of scintillator development, SiPM design, and X-ray photon counting medical imaging devices will be outlined.

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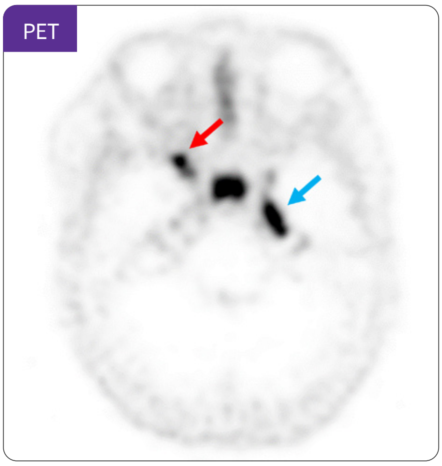


Axial $^{68}$Ga-DOTATATE PET


Post-contrast 3D axial T1-BRAVO


Fused PET/MRI

Images are courtesy of Dr. Ali Pirasteh, University of Wisconsin-Madison

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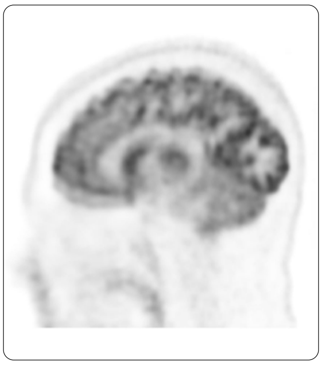

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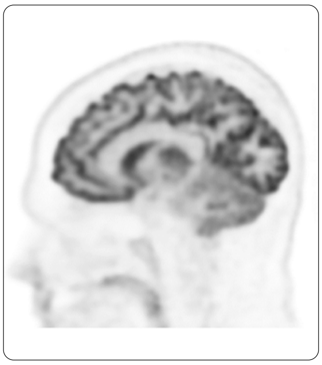

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†Results may vary.
‡Volunteer testing, compared to conventional coil technology. Deller et al, Radiology 2021; 298:166–172.



GE HealthCare

**High-performance preclinical and organ-specific systems / 2**

## ISOLPHARM project: Development of two preclinical imaging devices for Ag-111 β and γ radiation

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Interesting radionuclides for nuclear medicine applications are usually produced in cyclotrons or in nuclear research reactors. These production methods are typically associated with highly enriched target costs and with contaminated products. In this context, the ISOLPHARM project, the medical application of ISOL SPES facility, aims to produce radionuclides of medical interest with high purity. The ISOLPHARM project is backed by a wide and interdisciplinary collaboration of several University departments and Institutes. During the last six years, three INFN-CSN5 experiments and a PRIN project ,ISOLPHARM_CORE, demonstrated the feasibility of this production method for carrier-free β-emitting radionuclides. This technology will overcome the limits of the current radiopharmaceutical production methods: the low specific activity and the high costs of the enriched material.
Ag-111 is a radionuclide that can be produced by the ISOLPHARM method with high purity and high production rate with respect to the standard neutron irradiation of enriched Pd-110 targets in nuclear reactors. Ag-111 is a β- (average energy 360 keV) and γ emitter (342 keV and 245 keV) with a half-life of 7.45 days. It has the potential to be a theranostic radionuclide thanks to its gamma emission that can be used to perform diagnosis with Single Photon Emission Computed Tomography (SPECT).
The ISOLPHARM project is currently promoting a three-year INFN-CSN5 experiment called ADMIRAL, the aim is to investigate the therapeutic and diagnostic potential of Ag-111. Regarding preclinical diagnosis, two complementary devices are under development: a detector sensitive to the β emission of the radionuclide and a γ camera sensitive to the gamma emission. A commercial multimodal imaging system will be used as a reference system for both devices. In fact, it can perform scintigraphy and Cerenkov Luminescence Imaging (CLI) using the β and γ radiation respectively. The γ-camera optimized for the Ag-111 radiation energy is the first step toward a clinical SPECT that could be used for imaging of Ag-111-based radiopharmaceuticals.
In this contribution, preliminary data regarding the β detector and the γ camera under development are presented. These data are integrated with the Geant4 simulation toolkit that is designed to track the passage of particles through matter

**High-performance preclinical and organ-specific systems / 36**

## Characterize the Effective Half Life for Instant Single Time Point Dosimetry using Machine Learning

**Authors:** Carlos Vinícius Gomes Ferreira[1]; Song Xue[None]; Andrei Gafita[None]; Jiaxi Hu[None]; Robert Seifert[None]; Lorenzo Mercolli[None]; Julia Brosch-Lenz[None]; Jimin hong[None]; Marc Ryhiner[None]; Sibylle Ziegler[None]; Wolfgang Weber[None]; Ali Afshar-Oromieh[None]; Axel Rominger[None]; Matthias Eiber[None]; Thiago Viana Miranda Lima[None]; Kuangyu Shi[2]

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Single time point (STP) dosimetry offers a more convenient approach for clinical practice in radiopharmaceutical therapy (RPT) compared to conventional multiple time point (MTP). Despite numerous advancements, STP methods are limited and challenging by the need for strict and late timing in data acquisition. This study introduces a new concept of instant STP (iSTP), which is achieved by predicting the effective half-life (Teff) using machine learning (ML) based on pre-therapy data.

Methods: Data from 23 patients who underwent pre-therapy [68Ga]Ga-PSMA PET imaging and subsequently [177Lu]Lu-PSMA I&T RPT was analysed. A ML model was developed for Teff predictions for the kidneys (left and right), liver, and spleen. Estimated iSTP values were compared against to MTP method and from Hänscheid values.
Results: The ML-model achieved predicted Teff with mean errors below 9% for the kidney left and right, liver, and spleen. Comparing the predicted Teff with the MTP method, the differences were below 14% for all organs. The iSTP achieved differences less than 26.0 ± 21.0% for both kidneys, 63.7 ± 103.6% for liver, and spleen of 84.2 ± 209.4%. With notable lower differences at 2 h time point.
Conclusion: Given the intrinsic characteristic of effective half-life, our preliminary results prove the concept in prediction and achieving STP shortly and flexibly after RPT. This method could potentially expedite the application of dosimetry in broader contexts, such as outpatient treatment.

**High-performance preclinical and organ-specific systems / 15**

# SAFIR-II: Design and performance of a high-rate preclinical PET-MR System

**Author:** Jan Debus[1]

**Co-authors:** Afroditi Eleftheriou [2]; Agnieszka Zagozdzinska-Bochenek [3]; Bruno Weber [2]; Charalampos Tsoumpas [4]; Christian Ritzer [5]; Günther Dissertori [3]; Jan Sörensen [3]; Lubomir Djambazov [3]; Matthias Wyss [2]; Michael Ritzert [6]; Pascal Bebie ; Peter Fischer [6]; Robert Becker [3]; Ulf Röser [3]; Volker Commichau ; Werner Lustermann [3]

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The SAFIR collaboration has developed a high-performance PET insert compatible with a Bruker BioSpec 70/30 MRI scanner. This system, named SAFIR-II, was designed to acquire data at activities of up to 500 MBq, enabling truly simultaneous preclinical PET-MR imaging for mice and rats using image acquisition times of up to 5 s.
We present an overview of the system's design, as well as several performance evaluations done using low and high activity measurements. SAFIR-II features an axial FOV of 145 mm covered by 11'520 LYSO crystals ($2.0\times2.0\times13$ mm$^3$), which are coupled one-to-one to Hamamatsu SiPM arrays. PETA8 ASICs developed at the University of Heidelberg are used to digitize the SiPM's analog signals, and read out using Xilinx Kintex7 FPGAs and 10 GBit SFP+ optical Ethernet links. All data analysis is handled offline using custom coincidence sorting software, and reconstructed using STIR. Custom MR-compatible DC-DC converters and LDO voltage regulators are used to condition the system's internal voltages. SAFIR-II exhibits a coincidence timing resolution of 217 ps FWHM and a coincidence energy resolution of 11.8 %, with a peak sensitivity of 2.23 % observed following the NEMA-NU4 standard. It is capable of resolving 1.8 mm hot rods within a Derenzo phantom filled with up to 500 MBq $^{18}$F. We furthermore present an evaluation of the system's image quality determined using a NEMA IQ-phantom, and an evaluation of its MRI-compatibility.

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# Reaching new horizons in pre-clinical imaging: trimodal PET-FUS-MR technology

**Authors:** Andrea Gonzalez-Montoro[1]; Marta Freire[1]; Fernando López[1]; Adolfo González-Tamarit[1]; Santiago Jiménez-Serrano[1]; Koldo Vidal[1]; Antonio Gonzalez[1]

**Co-authors:** Carlos de Alfonso [1]; Irene Torres [2]; Diana Andrés [1]; Juan J. R. García [1]; Jose L. Alonso [1]; Alicia Carrión [1]; Teresa Guallart-Naval [1]; José M. Algarín [1]; Rubén Bosch [1]; Eduardo Pallás [1]; Stuart S. Berr [3]; Mark B. Williams [3]; María J. Rodriguez-Álvarez [1]; Francisco Camarena [1]; Joseba Alonso [1]; José María Benlloch Baviera [1]

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Combining PET with other imaging techniques such as MR or US devices has gained interest to, for example, provide anatomical information or to improve drug administration, respectively.
Recently, special interest has arisen in the use of Focal US (FUS) to open the Brain Blood Barrier (BBB) to allow drugs pass through the brain. However, since the FUS lacks of visual information it is difficult to ensure that the US are being delivered accurately and, therefore, its combination with imaging techniques such as PET or MR would represent a great advance.
To improve this area of medical imaging, we have designed and validated a pre-clinical PET device that can be used as a part of a trimodal system that combines PET-MR-FUS.
We report in this contribution the preliminary performance evaluation of the PET system as well as its compatibility to simultaneously work with our home-made low-field MR and FUS devices.
In particular, we show the preliminary NEMA results obtained with our custom PET insert, as well as the first reconstructed images (PET and MR) acquired with the trimodal system. For the trimodal study we designed a phantom that contains a layer of melting gelatin and a mixture of Cooper Sulfate and 18F. PET and MR data were simultaneously acquired while the phantom was being heated-up using FUS. The reconstructed images showed the mixing process of the elements inside the phantom when the gelatin was melting which is comparable to the process of opening the BBB.

**High-performance preclinical and organ-specific systems / 59**

## The HYPMED Breast PET/MRI Insert: MRI Compatibility and Comparison to Whole Body PET/MRI

**Author:** Bjoern Weissler[1]

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Commercially available PET/MRI scanners have been designed as whole-body systems. In these, PET spatial resolution and sensitivity are limited. Dedicated PET inserts can potentially overcome these limitations. The EU H2020 project HYPMED developed a local PET insert for a clinical 1.5 T MRI for breast cancer research.
The HYPMED insert combines a local MRI receive coil and two PET rings that allow simultaneous imaging of the female breast in prone position in a 1.5 T MRI. The PET system is based on the Hyperion III PET detector platform. Each PET ring has a FOV of approximately 10 cm and a diameter of 20 cm. The detector stacks consist of three-layer LYSO crystal arrays with a pitch of 1.3 mm.
MRI compatibility studies were conducted: The homogeneity of the static magnetic field of the MRI is not significantly deteriorated by the insert and the excitation field B1 is within 84 % and 119 % in the breast area. Clinical routine MRI sequences were tested, and the SNR is comparable to reference scans from a commercial breast coil.
A Jaszczak-like phantom was scanned, both with the breast insert and with a commercial whole-body scanner (Siemens Biograph mMR). Whereas only the 3-mm rods can be seen on the whole-body PET scanner, the HYPMED insert allows to separate the 1.5-mm rods, which clearly demonstrates the advantage in spatial resolution of the dedicated device over the generalized whole-body approach.

**High-performance preclinical and organ-specific systems / 75**

# PET Imaging of the Human Brain at 2 μL Resolution with a Next-Generation Ultra-High-Resolution (UHR) Scanner

**Author:** Roger Lecomte[1]

**Co-authors:** Vincent Doyon [1]; Étienne Auger [2]; Christian Thibaudeau [2]; Jean-François Beaudoin [3]; Jean-Daniel Leroux [4]; Maxime Toussaint [1]; Maxime Gaudreault [1]; Francis Loignon-Houle [5]; Otman Sarrhini [3]; Étienne Croteau [3]; Éric Lavallée [3]; Stephan Blinder [6]; Jean-Paul Soucy [6]; Udunna Anazodo [7]

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PET is an ideal imaging modality for studying human brain biochemistry *in vivo*, but its potential is limited by its poor spatial resolution, which is currently well below the theoretical limit. The brain-dedicated UHR scanner is designed to achieve 2 μL volumetric resolution for accurate characterization of brain regions previously indistinguishable without MRI. Unlike most PET systems, the UHR relies on fully pixelated detectors with 1:1:1 coupling of the scintillation crystal, photodetector, and electronic readout to avoid degradation caused by light/charge sharing schemes. UHR physical performance was characterized using NEMA NU4-2008/NU2-2018 standards, while imaging performance was evaluated using phantoms and pilot studies in patients undergoing medically prescribed 18F-FDG scans. Point source OSEM reconstruction yields resolution better than 2 μL (<1.25 mm quasi-isotropic) up to ~3.5 cm from FOV center and remains below 2 mm radially up to ~7 cm. This is confirmed in images of hot spot phantoms in which 1.2 (1.6) mm hot spots can be resolved up to 5 (10) cm from center. Sensitivity, count rates and contrast recovery were also measured. In patients, small deep brain regions are visually delineated, particularly in the thalamus and brainstem, while hypermetabolic areas are visible along the cortical surface and regions of the subcortical anatomy rarely seen as separate entities, such as subthalamic and brainstem nuclei, which can now be better quantified in UHR images.

# MR methods

# Convergent transcriptomic and neuroimaging signature of Autism Spectrum Disorder

E. Ferrari[1], A. Retico[2,1], D. Bacciu[3,1] and A. Cellerino[4,1]

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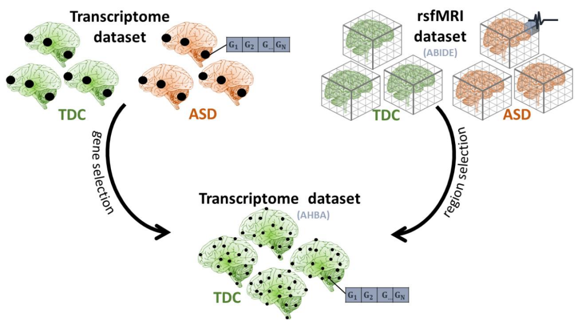
[2] Istituto Nazionale di Fisica Nucleare, Pisa, Italy.
[3] University of Pisa, Pisa, Italy.
[4] Scuola Normale Superiore, Pisa, Italy.

QUANTABRAIN

## IMAGING TRANSCRIPTOMICS STUDY

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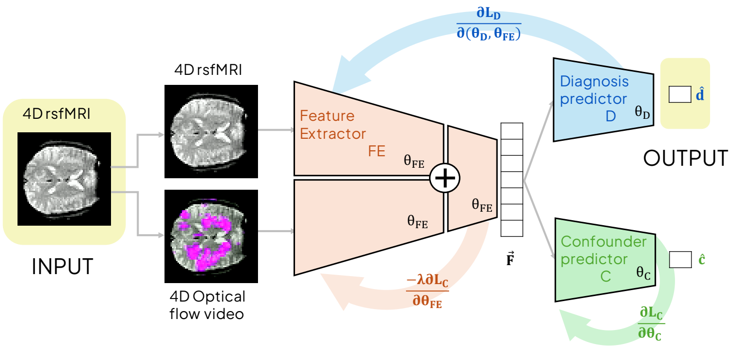


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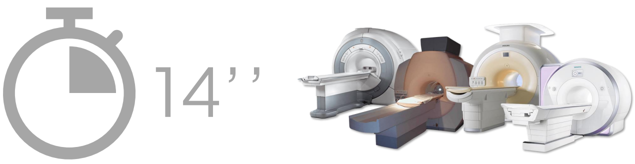


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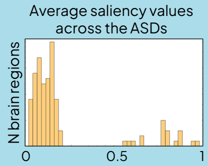
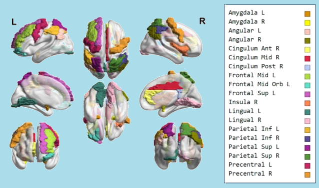
| Dataset | Data | Age | Acc. | Sens. | Spec. | AUC |
|---|---|---|---|---|---|---|
| Training | 1281 | 4-64 | 0.88 | 0.89 | 0.87 | 0.95 |
| Validation | 142 | 4-64 | 0.89 | 0.88 | 0.88 | 0.92 |
| Test | 684 | 4-64 | 0.88 | 0.89 | 0.88 | 0.95 |
| Hold-out | 54 | 4-64 | 0.91 | 0.89 | 0.93 | 0.95 |

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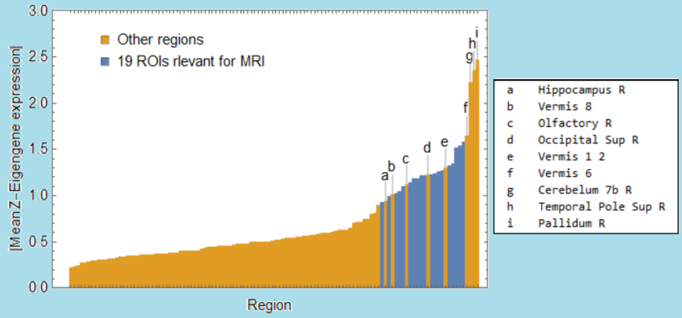


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**MR methods / 108**

## The promise of a new generation of affordable hybrid technologies exploiting low-field MRI

**Corresponding Author:** joseba.alonso@i3m.upv.es

Multimodal technologies combining different physical principles have enhanced medical imaging, diagnostic, treatment and monitoring tasks [1]. In hybrid devices, MRI systems are often integrated for their excellent soft-tissue contrast and multidimensional structural and morphological information. Unfortunately, they require cryogenic refrigeration, they are bulky, heavy, environmentally unfriendly, expensive to build, site, operate and maintain, and they ultimately constitute a formidable barrier to the accessibility and democratization of medical devices.

At present, there is a new wave of low-cost and portable MRI devices based on low-field (LF) magnets [2]. The rather undemanding hardware and infrastructural requirements associated to LF-MRI make it an ideal platform to expand the accessibility and applications of MRI beyond the restrictive environment of radiology departments in large clinical centers [3,4]. Moreover, low fields greatly facilitate integration with e.g. PET and US modules, making LF-MRI an auspicious new starting point for hybrid medical devices.

In this talk, I will provide an overview of the state of the art of LF-MRI, and share a vision of a prospective new generation of affordable hybrid technologies.

[1] L. Martí-Bonmatí et al., Con. Med. & Mol. Im., 5.4 (2010): 180-189.
[2] J.P. Marques et al., JMRI, 49 (2019), 1528–42
[3] T. Guallart-Naval et al., Sci. Reps., 12 (2022), 1–11
[4] J.M. Algarín et al., Portable MRI Journal Vol. 1 Issue 1, (2024)

**MR methods / 54**

## Estimation of T2* values in hyperpolarized 13C MRI of healthy and ischemic kidneys in a porcine model.

**Author:** Malene Aastrup[1]

**Co-authors:** Liu Xiaoxi [2]; Emmeli Lykkegaard [1]; Nikolaj Bøgh [1]; Uffe Kjaergaard [1]; Mohsen Redda [1]; Lotte Bonde Bertelsen [1]; Peder Larson [2]; Esben Hansen [1]; Jeremy Gordon [2]; Christoffer Laustsen [1]

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**Background:** Performing hyperpolarized-<sup>13</sup>C MRI, knowledge of T2*values plays an important role for the sake of correct quantification of the metabolites (pyruvate, lactate, and bicarbonate) to increase the SNR and optimize image interpretation.Aim(s):To estimate T2* values of pyruvate and lactate in both healthy and ischemic porcine kidneys at different concentrations (250mM, 150mM, and 80mM). To elucidate variation of T2*values under these circumstances.Method:An animal study including 4 female Danish domestic pigs subjected to unilateral ischemic reperfusion injury.Results:Linear regression showed positive correlation between increasing means of pyruvate and lactate T2* values in healthy kidneys and increasing concentrations of pyruvate-infusion.
**Discussion:** This preliminary study suggests a method determining T2*-mapping in hyperpolarized-<sup>13</sup>13C MRI quantifying T2*-values of pyruvate and lactate, which can be used to optimize SNR and image-interpretation. Further studies should explore other organs to determine organ-specific T2*-values and possible variations.

**MR methods / 79**

## Elucidating the effect of respiratory motion on in vivo 31P magnetic resonance spectroscopic imaging in the human liver at 7 Tesla

**Authors:** Woutjan Branderhorst[1]; Mark Gosselink[2]; Ahyan Gursan[None]; Dennis Klomp[1]; Jeanine Prompers[3]

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**Introduction:** Respiratory motion affects the reconstructed spectra in magnetic resonance spectroscopic imaging (MRSI), as it changes the location of the nuclei and the B0 field they experience during the signal acquisition. B0 changes lead to a frequency shift of the acquired signal. This study aimed to determine the maximum frequency shift due to respiratory motion in a typical 31P liver MRSI scan at 7 Tesla.
**Method:** We instructed a human volunteer to control his breathing, guided by an audio signal, during the acquisition of a 3D 31P MRSI liver scan. The breathing pattern contained two breath holds, one after maximal inhalation and another after full exhalation. The obtained spectra were compared with a prospectively gated scan.
**Results:** In addition to increased peak line widths compared to the gated scan, we found that several spectra exhibited a splitting of the signals into two separate peaks, with frequency shifts between the peaks of up to 0.57 ppm depending on the location in the liver.
**Conclusion:** Respiratory motion induces significant frequency shifts of the signal obtained in liver 31P MRSI, leading to both an increase in line width and a frequency shift of the peaks. This may result in overlapping or masking of peaks, which hampers the quantification of metabolite concentrations. The application and further development of prospective gating and other motion correction methods is highly recommended.

**MR methods / 48**

## Musculoskeletal MR Fingerprinting at 7T using spectral-spatial RF pulses

**Author:** Matteo Cencini[1]

**Co-authors:** Rolf F. Schulte [2]; Carolin M. Pirkl [2]; Paolo Cecchi [3]; Marta Lancione [4]; Bianca Buchignani [4]; Giacomo Aringhieri [3]; Roberta Battini [5]; Laura Biagi [4]; Michela Tosetti [4]

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[3] *IMAGO7 Foundation*

[4] *IRCCS Stella Maris*

[5] *Università di Pisa*

Quantitative relaxometry and fat fraction mapping at ultrahigh field are important areas of research, hindered by the significant challenges imposed by the high field inhomogeneities. Here, we used a modified MR Fingerprinting scheme based on a spectral-spatial excitation to obtain robust water T1/T2 quantification and fat fraction mapping of the lower extremities of a healthy volunteer within a relatively short acquisition time. Using the proposed approach, we successfully obtained water-fat M0, water-only T1/T2 and fat fraction maps of MSK tissues. In future work, we will use advanced iterative or deep-learning based reconstruction techniques to accelerate the acquisition and compensate for the increase in scan time due to the dual pulse scheme while maintaining a reasonable imaging quality and spatial resolution, together with parallel transmission techniques to further increase image homogeneity.

# PET technologies

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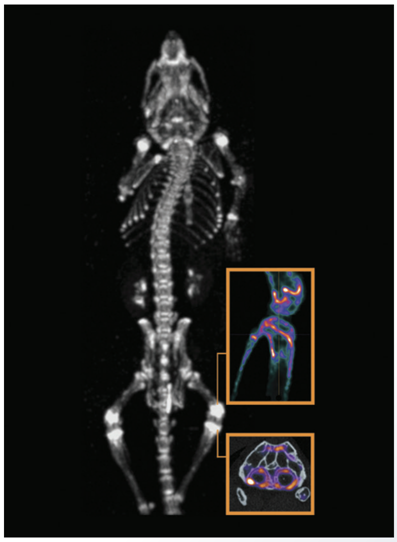

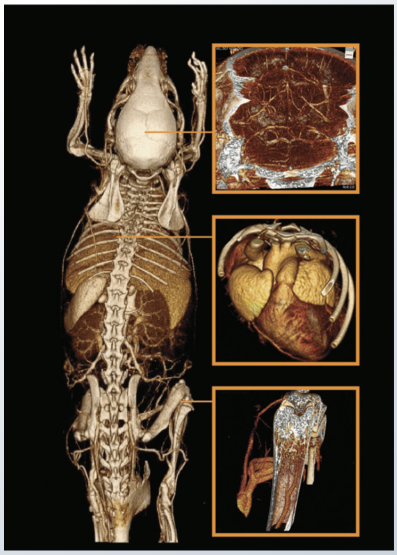

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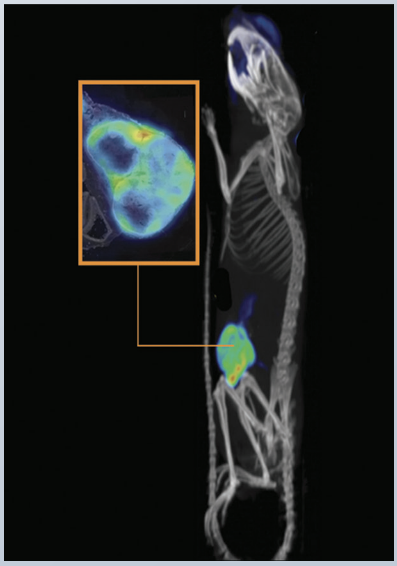

**PET technologies / 44**

## Investigation on Timing Performance of Cherenkov TOF PET Detector with Bismuth Germanate Scintillators and Segmented SiPMs

**Authors:** Minseok Yi[None]; Daehee Lee[None]; Alberto Giacomo Gola[None]; Stefano Merzi[None]; Michele Penna[None]; Jae Sung Lee[None]; Simon Cherry[None]

**Co-author:** Sun Il Kwon

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This study investigates the potential of utilizing a BGO crystal coupled with a segmented SiPM detector. Recent findings suggested the viability of BGO as a cost-effective option for TOF-PET detectors when employed as a hybrid scintillator/Cherenkov radiator. The OctaSiPM, featuring a pixel active area of ~2.5 × 1.4 mm², was employed in a 2 × 4 array configuration with a 3 × 3 × 15 mm3 BGO crystal. The study emphasizes the advantages of segmentation and explores the utilization of multiple timestamps from a gamma-ray event. Coincidence measurements with back-to-back 511 keV gamma rays demonstrated improved timing resolution with an adaptive timestamp pickoff method. Systematic analysis of trigger time differences and initially detected photon count offer insights into event classification and holds promise for Cherenkov TOF PET imaging with BGO crystals, emphasizing the potential for future optimization using OctaSiPMs.

**PET technologies / 81**

## Cryogenic CsI as a potential PET material

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This study explores the possibility of employing pure cesium iodide (CsI) crystals for a total-body positron emission tomography (TB-PET) device.
When operated at cryogenic temperatures, these crystals exhibit an excellent light yield, up to 110 photons/keV, which is approximately four times larger than LYSO. Although CsI has a slightly lower stopping power and a slower decay time compared with BGO and LYSO, its significantly lower price (3 to 5 times cheaper than its counterparts) could enable the realization of accessible TB-PET devices. The performances in terms of energy and time resolution of a pair of cryogenic CsI crystals have been measured in a dedicated setup and a small-animal PET is currently being assembled.
In this project we also investigate the feasibility of using larger, monolithic crystals read out by an array of solid-state photosensors. This approach significantly simplifies the device's design and assembly, further reducing costs. While monolithic crystals typically face challenges in reconstructing the interaction point of the gamma radiation, recent advancements in machine learning algorithms for image processing could potentially enable the realization of a monolithic PET with performances analogous or better than a pixelated one.

**PET technologies / 64**

## How to improve timing performance in TOF-PET with segmented SiPMs coupled to BGO and LYSO

**Author:** Katrin Herweg[1]

**Co-authors:** Stefan Gundacker [1]; Vanessa Nadig [1]; Volkmar Schulz [1]

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Fast timing in ToF-PET improves signal-to-noise ratio for better patient comfort through either a lower dose or a shorter measurement time. Currently, lutetium-based crystals in clinical PET scanners achieve a coincidence time resolution (CTR) of around 200 ps, which is limited by the scintillation process. Therefore, BGO with its Cherenkov radiation is being investigated as an alternative. However, it cannot reach its full potential due to a too low bandwidth of the electronics and time resolution of the photosensors. Segmenting the photosensor into an array of µSiPMs, which can be read out individually, allows to better utilize the prompt time information of the Cherenkov photons through an effectively higher bandwidth and thus is a promising approach to improve timing. In this work, we simulated the optical photon production with Geant4 and applied a signal model with a leading-edge threshold to determine timestamps and calculate the CTR from the first timestamp. Two detectors using either 3 mm long BGO or LYSO crystals, were investigated with varying segmentations of the photosensor. Segmenting the photosensor resulted in a 2.6-fold improvement of the CTR for BGO, reducing it to 39 +/- 20 ps. Segmentation is beneficial to BGO with its higher Cherenkov-to-scintillation ratio, while LYSO does not show an improvement due to its lower Cherenkov yield, which is additionally spoiled by its higher scintillation photon yield.

**PET technologies** / **26**

## Wedge-Based Side Readout for Minimizing Uncertainty in the Optical Path of Cherenkov Photons

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**Corresponding Author:** minseok0408@snu.ac.kr

This study aims to improve the radiator structure of a system that achieved a 30 ps CTR to approach a 10 ps CTR. The 30 ps CTR was achieved using a 3 mm lead-glass, which introduces a timing uncertainty of 18.2 ps depending on the interaction depth. To improve upon this, a wedge-based side readout is proposed. This structure uses a wedge-shaped light guide to correct for the time difference depending on the interaction depth. To validate this structure, simulations were conducted on four different detector structures: a 3 mm thick flat back readout, a 1 mm thick flat back readout, a 3 mm thick wedge-based side readout, and a 1 mm thick wedge-based side readout. The flat back readout showed a linear increase in timing uncertainty with thickness, while the wedge-based side readout showed negligible difference in timing uncertainty even as the radiator thickness increased from 1 mm to 3 mm. Although the wedge-based side readout has the disadvantage of degraded sensitivity, it can improve sensitivity by cascading multiple detectors.

**PET technologies** / **100**

## Low-Dose Total-Body Time-of-Flight PET Using High-Resolution Gamma Ray Multiplier Tubes (HGMTs)

**Author:** Cameron Poe[1]

**Co-authors:** Kepler Domurat-Sousa [1]; Bernhard Adams [2]; Camden Ertley [3]; Henry Frisch [1]; Ian Goldberg [1]; Peter Scheidt [1]; Neal Sullivan [4]

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**Corresponding Author:** cameronpoe@uchicago.edu

The high-resolution gamma ray multiplier tube (HGMT$^{TM}$) is a large-area gamma ray detector with high space and time resolution with applications in low-dose total-body time-of-flight positron emission tomography (TOF-PET). HGMTs are composed of a vacuum container containing laminar microchannel plates (LMCPs$^{TM}$) optimized for surface direct conversion (SDC) of a gamma ray into an electron cascade and LMCPs optimized for cascade amplification. SDC produces electrons from the gamma ray interacting in the LMCP substrate via Compton scattering or the photoelectric effect, bypassing the need for an intermediate step of converting the gamma ray into optical photons. HGMTs together with picosecond-precision electronics and strip-line pickup boards provide high-resolution time and space measurements of gamma ray interactions.

We will present simulation results of HGMTs for TOF-PET and summarize current progress towards building an HGMT. TOPAS and Geant4 simulations of HGMT-based whole-body PET scanners indicate possible dose reductions by a factor of 100. Line-of-response (LOR) reconstruction methods may differ for HGMTs built from low-atomic number (Z) and high-Z substrates in order to optimize accurate reconstruction to include time-ordering of Compton scatters. We are exploring manufacturing techniques and vendors as well as creating test stands.

**PET technologies** / **56**

## Amorphous Silicon Microchannel Plates: A new photon detector with 10 ps timing and 15 µm spatial resolution

**Authors:** Luca Antognini[1]; Georgios Konstantinou[1]; Samira Frey[1]

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In this work, we present the principle, development, functionality, and characterization of a new type of photon detector. The technology of amorphous silicon Micro-channel plates (AMCPs) uses a versatile approach to stack hydrogenated amorphous silicon in thicknesses up to 100 um, using plasma-enhanced chemical vapor deposition and etch microchannels of diameter 2 um, every 4.5 um, on a hexagonal pattern, by deep reactive ion etching. Five generations of these devices have led to significant improvements in specifications. The versatile fabrication process allows etching of funnel-shaped channels, leading to an active area close to 100%. Measurements have shown excellent timing resolution ($\sigma$ < 10 ps FWHM) for low incoming fluxes, along with a maximum single-channel gain around 1500, in reverse voltage of 500 V. The flexibility of the fabrication processes allows to grow the detector directly on top of a CMOS cascade of low-noise amplifiers with a spatial resolution of 15x15 um2, offering 400000 channels on chip.

# PET/MR applications

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**PET/MR applications / 107**

## Clinical PET/MR of the brain: visions from the past and for the future

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Hybrid PET/MRI systems have been available 2011 with diseases of the brain being identified as the most obvious application in routine clinical use. It was envisioned that the combination of advanced MRI methods, such as classical and hyperpolarized spectroscopy, contrast and non-contrast based perfusion, tractography and diffusion imaging combined with PET molecular imaging would be groundbreaking. From the perspective of nuclear medicine a number of technical MRI challenges became apparent including measurement robustness and the lack of a adequate attenuation correction solutions. The primary patient groups investigated are those with a need for both modalities and a PET tracer solution, primarily dementia ([18F]FDG, amyloid tracers), brain tumors (amino acid tracers, [68Ga]-DOTATOC), epilepsy ([18F]FDG), and Parkinsons disease ([18F]FE-PE2I, [18F]FDOPA). The added value of advanced MRI methods to diagnostic accuracy have only been limited owing to the high diagnostic accuracy of the PET tracers leading to an overall simplification with short PET/MRI scan of 20 min and only standard MRI sequences. Looking forward the next generation PET/MRI scanner will provide better image quality, faster scans and novel MRI sequences. This will increase patient through-put and convenience, that will be useful in monitoring the effects of new treatment directed at dementia and glioma. New patient groups (eg. MS), however, would require PET tracer development. Furthermore, the image simultaneity positions the method in novel generative AI approach build on both imaging modalities.

**PET/MR applications / 102**

## Integrated PET/MR Scanner as Reference Imaging Tool in the Study of Dementia: Results from the PM-D project

**Author:** Marco Aiello[1]

**Co-authors:** Carlo Cavaliere [1]; Vincenzo Alfano [1]; Angelica Di Cecca [2]; Elena Salvatore [3]; Pasquale Gissoni [1]; Emanuele Nicolai [1]; Sabina Pappatà [1]; Marco Salvatore [1]

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The challenge of screening and follow-up of subjects at risk of dementia is becoming of crucial importance for the sustainability of the national healthcare system. Although imaging biomarkers play an essential role in supporting the diagnosis and prognosis of dementia, several MR markers are still being evaluated in terms of technical and clinical suitability. In this context, hybrid PET/MR imaging offers a unique opportunity for a comprehensive collection of imaging biomarkers within the same diagnostic session. In this work, we present the preliminary results of the PM-D project, funded by the Italian Ministry of Health. To evaluate the impact of PET/MR imaging in terms of diagnostic accuracy and patient benefits/compliance, data from a cohort of 130 dementia subjects, scheduled to perform MR and PET imaging, was acquired and processed. Different processing pipelines were implemented to emulate PET/MR as well as standalone PET/CT and MR data availability, also using accelerated MR sequences. The assessment of both diagnostic accuracy and the mutual relationship among imaging variables suggests the clinical suitability of an effective PET/MR imaging protocol that maximizes the trade-off between diagnostic accuracy and patient compliance.

**PET/MR applications / 87**

# Validation of MotionFree Brain algorithm in an 11C-Methionine PET/MRI study of pediatric patients with brain tumors

**Authors:** Ilaria Neri[1]; Matthew Spangler-Bickell[2]; Federico Fallanca[1]; Maurizio Barbera[1]; Giovanna Gattuso[3]; Samuele Ghezzo[1]; Carolina Bezzi[1]; Annarita Savi[1]; Paolo Verdelio[3]; Sara Pizzamiglio[3]; Maura Massimino[3]; Andrea Falini[1]; Filippo Spreafico[3]; Maria Picchio[1]; Arturo Chiti[1]; Cristina Baldoli[1]; Paola Vittoria Scifo[1]

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In this study, we tested a data-driven head motion correction method on 11C-methionine brain PET images of a cohort of paediatric patients and we investigated its impact qualitatively and quantitatively. Twenty-seven paediatric patients with treated high grade glioma underwent 11C-methionine PET/MRI exam using a fully hybrid PET/MR scanner. During PET scan, MRAC and ZTE sequences were acquired to generate attenuation correction maps. Additional diagnostic MR sequences were acquired, before, simultaneously and after PET acquisition. For each patient, PET images were reconstructed offline with and without the data-driven head motion correction algorithm (PETddMoCo and PETnoMoCo, respectively). PET images were qualitatively and quantitatively evaluated. An expert nuclear medicine physician segmented brain lesions. SUVmax, SUVmean, SUVpeak, and MTV were extracted using a fixed threshold of 42%. Their absolute mean percentage differences between PETddMoCo and PETnoMoCo are calculated and compared. Eight-teen patients had a "low"degree of motion, 5 patients "medium"and 4 patients "high". Twelve/27 patients had positive uptake. Qualitatively, no difference was shown in negative patients, while in positive ones two lesions were better defined. The mean percentage differences with the standard deviation for SUVmax, SUVmean, SUVpeak and MTV are: 2.66±1.91%, 1.65±1.71%, 2.77±2.11%, 13.32±9.79% respectively. The difference in SUVmean before and after motion correction was significant.

# PET/MR reconstruction

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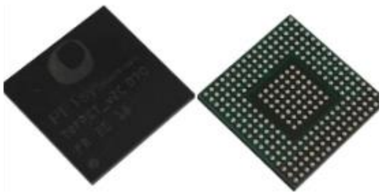

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- complete readout solutions, including electronics, firmware and software, scalable up to hundred thousands electronics channels

**PET/MR reconstruction / 8**

## Multi-Spatial Resolution MRI Guided PET Image Reconstruction with Adaptive Prior Strength

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**Corresponding Author:** jorge.cabello@siemens-healthineers.com

MRI-guided PET reconstruction has shown to reduce noise, and increase spatial resolution and quantification accuracy in PET imaging. However, its application has mainly been limited to brain imaging due to the availability of high resolution isotropic 3D MRI sequences, which are rarely used in whole-body MRI. The present works employs multi-parametric PET-MRI reconstruction to combine more than one MRI sequence with different spatial resolutions in different directions applied to non-brain MRI-guided PET reconstruction, in order to achieve high 3D PET spatial resolution. Results show that using MRI-guided PET reconstruction overall improves image quality in terms of noise and spatial resolution compared to OSEM, but the use of MRI sequences with anisotropic spatial resolution may cause the loss of detail. The combination of multiple sequences with different anisotropic voxel sizes in the PET reconstruction, prevents any loss of information while obtaining improved image quality compared to OSEM.

**PET/MR reconstruction / 80**

## Anatomically Guided PET Reconstruction using MR Information for Low Dose Imaging

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**Co-authors:** Jack McCarty [1]; Daniel Litwiller [1]; Elizabeth Mormino [2]; M. Mehdi Khalighi [3]

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Regularized PET reconstruction using anatomical priors has the potential to improve the resolution of the images while suppressing noise and Gibbs artifacts. An algorithm is investigated which calculates a similarity metric between an initial PET reconstruction and multiple MR contrasts, and penalizes the reconstruction in combination with a standard BSREM regularizer. The effect of the anatomically guided reconstruction is analyzed in the context of low dose imaging and found to produce images of a similar quality to the full dose images.

**PET/MR reconstruction / 92**

## Hybrid Reconstruction of PET data for Spinal Cord Imaging in PET/MRI.

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Spinal cord PET is challenging in PET/MR due to the absence of vertebral bone in attenuation correction and the impact of partial volume effects. The aim of this study is to investigate whether a hybrid image reconstruction method can improve quantification accuracy in the spinal cord and PET image quality in PET/MR. Simulated PET data created with the XCAT phantom to represent physiological [$^{18}$F]FDG uptake is reconstructed using the Hybrid Kernelised Expectation Maximisation (HKEM) algorithm, implemented in SIRF, with a simulated T2-weighted MR image as an anatomical prior. This is compared to Ordered Subset Expectation Maximisation (OSEM) for measured uptake, contrast to noise ratio (CNR) and coefficient of variation (CoV). Measured uptake in the spinal cord is increased in HKEM images at vertebral positions C4 - T4 compared to OSEM when both algorithms use an attenuation map without bone features ($P$=0.002). Overall, HKEM increases measured uptake in the spinal cord compared to OSEM ($P$=0.016) but was not significant for OSEM with a post-reconstruction filter ($P$=0.19). HKEM leads to higher image quality (CNR 0.9, CoV 18%) than OSEM without bone attenuation correction (CNR 0.3, CoV 46%, $P$=0.003) and is comparable to OSEM with a post-reconstruction filter (CNR 0.7, CoV 5%, $P$=0.36). We conclude that HKEM used with T2-weighted anatomical MR could be beneficial in PET/MRI for improving both the accuracy of measured spinal cord uptake and PET image quality.

**PET/MR reconstruction / 96**

## Structurally Guided PET Image Reconstruction for Improved Localisation of Pituitary Adenomas

**Author:** Pawel Markiewicz[1]

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Abstract—Pituitary adenomas, occurring in approximately 1 in 1100 individuals, can lead to a spectrum of symptoms by disrupting normal pituitary gland function, thereby significantly impacting quality of life. Positron emission tomography (PET) using [$^{11}$C]-methionine offers additional information in surgical planning, crucial for precise localisation of metabolically active pituitary adenomas, especially in smaller tumours where magnetic resonance imaging (MRI) alone may fail detecting such tumours. In this work we evaluate 3D variational regularisation using directional total variation (dTV) with different MRI-based structural information incorporated in PET reconstruction. The integration of structural details in PET reconstruction enhances image resolution, however, careful selection of anatomical information is essential to prevent structurally imposed PET distributions which are functionally improbable.

**PET/MR reconstruction / 3**

## Improving Small Renal Mass Delineation and Quantification in PET by Contrast-Enhanced MR-Guided Reconstruction: A Pilot Study Using Hybrid PET/MR Data

**Author:** Jaewon Yang[1]

**Co-authors:** Kyungsang Kim [2]; Junyu Guo [1]; Hongli Fan [3]; Nghi Nguyen [1]; Clive Musonza [1]; Ivan Pedrosa [1]

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**Purpose:** 18F-FDG PET/MR offers a unique opportunity to probe the biology of small renal masses (SRMs; cT1a ≤4cm). To address the low spatial resolution of PET (4-5 mm), our aim is to improve the delineation and quantification of SRMs in PET through contrast-enhanced MR-guided reconstruction.

**Method:** A FDG PET/MR examination was performed in an mMR for a patient with a known SRM. Furosemide (20 mg) was injected to suppress background uptake in the kidney. As the SRM did not show activity above the renal parenchyma, a PET-avid SRM with the same size and location of the known SRM was inserted into PET images, realistically and efficiently simulating a lesion with low uptake (signal-to-background ratio of 2). High resolution PET images were reconstructed through the One-Step Late Bowsher (OSL-Bow) algorithm with a high-resolution MR prior and compared with post-smoothed conventional reconstruction.

**Result:** In terms of visually comparing the synthetic SRM, our OSL-Bow implementation is superior to the post-smoothed reconstruction. Higher regularization enhances the edges of the SRM, reduces bias, but leads to increase variance compared to lower regularization.

**Discussion and Conclusion:** We have demonstrated the feasibility of MR-guided image reconstruction to improve the delineation and quantification of SRMs. For further investigation, we will assess our implementation with clinical data, including PET-avid SRMs.

# Scintillators for fast timing

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**Scintillators for fast timing / 22**

## Harnessing the Purcell Effect for Faster Metascintillators

**Authors:** Avner Shultzman[None]; Ido Kaminer[1]; Georgios Konstantinou[2]; Paul Lecoq[3]

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**Corresponding Author:** paul.lecoq@cern.ch

This study proposes a second-generation metascintillator to improve the coincidence time resolution of scintillators, critical for enhancing signal-to-noise ratio in time-of-flight positron emission tomography (TOF-PET). Leveraging nanophotonic features, particularly the Purcell effect, we enhance scintillation properties. Our findings show a 1.6-fold improvement in coincidence time resolution, a significant advancement for TOF-PET applications.

**Scintillators for fast timing / 83**

## Comparative Experimental and Simulation DOI Analysis on Semi-Monolithic Metascintillators

**Author:** Riccardo Latella[1]

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[1] *Universidad Politécnica de Valencia*

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[4] *EPFL*

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This study compares the depth of interaction (DOI) performance of semi-monolithic metascintillators (SMMS) of dimensions 25.4x25.4x24 mm³ and standard semi-monolithic scintillators (SMON) of dimensions 25.4x25.4x20 mm³. The SMMS comprises LYSO:Ce interleaved with EJ232 organic scintillators, while the SMON contains eight slabs of LYSO:Ce.
The experimental findings demonstrated comparable behaviors regarding centroid positions and Full Width at Half Maximum (FWHM) of the DOI distributions. Indeed, using the logarithmic behavior of the centroid positions and the FWHM values, the average DOI resolution computed revealed values of 2.73 ± 0.51 mm for SMMS and 2.47 ± 0.45 mm for SMON. Additionally, simulation results indicate a close correlation with experimental results, especially in the logarithmic behavior of the DOI distribution centroid positions, while showing a discrepancy in the FWHM. From the timing perspective, simulation results show significant improvement in timing through DOI-time walk correction starting from a raw 136 ps up to 98 ps, thus staging a 28% CTR improvement. These outcomes validate the practical applicability of SMMS in PET imaging, showcasing comparable performance to traditional semi-monolithic structures, thereby reinforcing the potential of SMMS in advancing PET technology.

**Scintillators for fast timing / 30**

## TlCl:Be,I: a high sensitivity scintillation and Cherenkov emitter for TOF-PET

**Author:** Nicolaus Kratochwil[1]

**Co-authors:** Jared Schott [2]; Edgar van Loef [2]; Lakshmi Soundara Pandian [2]; Emilie Roncali [3]; Jaroslaw Glodo [2]; Gerard Arino-Estrada [1]

[1] *UC Davis, Department of Biomedical Engineering*

[2] *RMD*

[3] *UC Davis, Department of Biomedical Engineering and Department of Radiology*

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The material requirements for gamma-ray detectors for medical imaging applications are multi-fold and sensitivity is often overlooked when aiming for the best timing performance. High effective atomic number ($Z_{eff}$) Cherenkov radiators have raised the attention in the community due to their potential for harvesting prompt photons. A material with one of the highest ($Z_{eff}$) and thus short gamma-ray attenuation length is thallium chloride (TlCl, $Z_{eff}$ = 76).

By doping TlCl with beryllium (Be) or iodine (I), scintillation photons are produced upon gamma-ray interaction on top of the prompt Cherenkov luminescence. The scintillation response of TlCl:Be,I is investigated in terms of intensity, energy resolution, kinetics, and timing capability with and without energy discrimination.
The scintillation light yield of 0.9 ph/keV is sufficient to discriminate events with low energy deposition in the crystal which is used to improve the measured coincidence time resolution from 360 ps (580 ps) FWHM without energy selection down to 235 ps (402 ps) FWHM after energy discrimination and time walk correction for 2.8 mm (15.2 mm) thick TlCl:Be,I crystals.

Already with the first generation of doped TlCl encouraging timing capability close to other materials with lower effective atomic number has been achieved. Improvements in the crystal surface finishing and doping optimization to increase the energy resolution will broaden possible applications.

**Scintillators for fast timing / 55**

## High loading nanocomposites of cesium lead halide nanocrystals for fast timing

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Cesium lead halide nanocrystals are widely studied in many fields for their excellent luminescent properties. Recently, their potential for fast timing applications in radiation detection has been demonstrated. To ensure material stability, these nanocrystals are often embedded into a polymer matrix, forming nanocomposite scintillators. However, most research on nanocomposites focuses on

low loadings (around 1 w%)—insufficient for detecting high-energy X-rays or $\gamma$-rays, with only a few studies exploring materials with higher loading but with limited success in terms of transparency of the final material. In our work, we present nanocomposites of cesium lead halide nanocrystals with loading up to 40 w%. We employ copolymerizable ligands to enhance nanocrystal dispersion within the matrix, thereby improving the final material transparency. We characterise the radioluminescent properties of nanocomposites of cesium lead bromide and cesium lead bromochloride nanocrystals with varying chloride content and asses their timing capabilities under X-rays. Our findings reveal a significant improvement in time resolution under X-rays compared to previously published values for cesium lead bromide polymer nanocomposites. When combined with increased stopping power of high nanocrystal content, this advancement holds great promise for practical applications in TOF-PET, TOF-CT or high energy physics.

**Scintillators for fast timing / 82**

## Comparative Analysis of Novel Time-Walk Correction Methods for Metascintillators

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Development of novel scintillator materials and effective Time-Walk Correction (TWC) methods aim to improve coincidence time resolutions (CTRs) in Time-of-Flight Positron Emission Tomography (ToF-PET) systems. This study introduces an innovative approach using metascintillators coupled with advanced photodetector technologies to address the limitations of time-walk effects on CTR. We evaluated Linear (L-), Differential (D-), and Hyperbolic (H-) TWC strategies, focusing on their impact on enhancing CTR in ToF-PET applications. The H-TWC method aims to mitigate long-tailed coincidence time distributions, thus leading to a more standardized Gaussian distribution and improving the CTR.

Our experimental setup employed 3×3 mm² NUV-HD-MT photodetectors from Fondazione Bruno Kessler (FBK) coupled with 3×3×5 mm³ LYSO:Ce,Ca reference crystals and novel 3×3×15 mm³ BGO-EJ232 metascintillator heterostructures. Results indicate that while all the TWC methods do not improve the CTR values on the reference crystals measurements, the H-TWC demonstrates improvements from 50 ps up to 60 ps when metascintillator pixels are used. Our findings indicate that while L-TWC and D-TWC methods demonstrate similar improvements, the hyperbolic approach significantly enhances CTR values by effectively neutralizing heavy-tailed distributions.

# Special Track on Image reconstruction

**Special Track on Image reconstruction / 11**

## Fast and memory-efficient reconstruction of sparse Poisson data in listmode with non-smooth priors with application to time-of-flight PET

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TOF sinograms of TOF PET scanners have a large memory footprint. Currently, they contain ~4e9 data bins which amount to ~17GB in single precision. Using iterative algorithms to reconstruct such enormous TOF sinograms becomes challenging due to the memory requirements and the time needed to evaluate the forward model. This is especially true for more advanced optimization algorithms such as the SPDHG algorithm which allows for the use of non-smooth priors using subsets with guaranteed convergence. SPDHG requires the storage of additional sinograms in memory, which severely limits its application to data sets from TOF PET systems.
Motivated by the sparse nature of the TOF sinograms, we propose a new listmode (LM) extension of the SPDHG algorithm for reconstruction of sparse data following a Poisson distribution. LM-SPDHG is evaluated in 2D and 3D simulations and a real dataset acquired on a TOF PET/CT system. The performance of the proposed LM SPDHG algorithm is compared against the conventional sinogram SPDHG and listmode EM-TV.
We show that the speed of convergence of LM-SPDHG is equivalent to the original SPDHG. However, we find that for a TOF PET system with 400ps TOF resolution, LM-SPDHG reduces the required memory from ~56GB to 0.7GB for a short dynamic frame and to 12.4GB for a long static frame.
In contrast to SPDHG, the reduced memory requirements of LM-SPDHG enable a pure GPU implementation on state-of-the-art GPUs which drastically accelerates reconstruction times.

**Special Track on Image reconstruction / 84**

## Stochastic Optimisation Framework using the Core Imaging Library and Synergistic Image Reconstruction Framework for PET Reconstruction

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This study introduces a flexible, plug-and-play style stochastic optimization framework into the Core Imaging Library (CIL), facilitating the development and evaluation of diverse stochastic algorithms for image reconstruction tasks.

By plugging stochastic gradient estimators into base algorithms (including gradient descent and ISTA), we can produce a range of stochastic algorithms, including stochastic gradient descent (SGD), stochastic average gradient (SAG), and stochastic variance reduced gradient (SVRG), among other techniques.

We demonstrate the stochastic framework on positron emission tomography (PET) reconstruction, thanks to the combined use of the Synergistic Image Reconstruction Framework (SIRF).

We assess the performance of the algorithms with respect to the number of 'data passes,' i.e., how many times the algorithm has processed all the data in expectation. Results demonstrate that the stochastic algorithms achieve the optimal solution in fewer data passes than their deterministic counterparts. The plug-and-play nature of the software also allows for an easy comparison between different stochastic methods.

Future research endeavours will concentrate on expanding and testing the framework on other imaging modalities and data, and expanding the portfolio of implemented algorithms. We also aim to integrate further step-size rules and preconditioning options for further performance enhancement.

**Special Track on Image reconstruction / 90**

## Comparison of Synergistic and Single Modality Anatomically-Informed Structural Priors for Yttrium-90 PET and SPECT Reconstruction

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This research presents a synergistic method for the combined reconstruction of PET/CT and SPECT/CT data, aimed at improving image quality for Selective Internal Radiotherapy (SIRT) in treating unresectable liver tumours using Yttrium-90 ($^{90}Y$) microspheres. Given the challenges posed by sparse positron emissions in PET and the wide energy spectrum and electron range of bremsstrahlung X-rays in SPECT, our method takes advantage of information shared between modalities during the reconstruction process. We used a smoothed directional total nuclear variation (dTNV) prior using anatomical information from a CT and reconstructed images using the block-sequential regularised expectation maximisation (BSREM) algorithm. Data used in this research involved a ($^{90}Y$)-filled NEMA phantom scanned by Mediso's AnyScan Triple Modality scanner. This technique was benchmarked against reconstructions using the channel-specific directional total variation prior, again using CT for anatomical information. Synergy yielded enhancements in image quality for both modalities, especially for SPECT reconstructions.

**Special Track on Image reconstruction / 69**

# Primal-Dual Hybrid Gradient Algorithm for emission tomography: A Comparative Study of Convergence under Poisson Likelihood with ML-EM

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The Primal-Dual Hybrid Gradient Algorithm (PDHG) holds relevance in image reconstruction due to its ability to implement non-smooth penalties. This algorithm also serves as the base for the "learned primal dual"method, which enables an AI-based, physics-inspired reconstruction. A unique challenge in emission tomography is that the optimization metric is the Poisson-likelihood, which often implies slower convergence. In this study, we compare the convergence properties of the preconditioned PDHG with the commonly used Maximum Likelihood Expectation Maximization (ML-EM) method in Positron Emission Tomography (PET). We provide theoretical considerations and simulations performed on an idealized 2D setup. Our findings indicate that the convergence speed of PDHG is independent of signal contrast, unlike ML-EM. When implementing a diagonal preconditioner, we achieved a performance comparable to ML-EM. However, we discovered that rescaling data in the PDHG algorithm significantly impacts the rate of convergence. This optimal value is found when the average image values are of the order of 1. This issue appears to be due to the different values of the Hessian of the primal and the dual problem. However, it can be addressed by appropriate scaling before the reconstruction

# Specialized fast detectors

**Specialized fast detectors / 20**

## Fast Timing Detectors for Prompt Gamma Time Imaging

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We are developing a Prompt Gamma (PG) detector (TIARA, for Tof Imaging ARrAy) dedicated to the real-time monitoring of Particle Therapy treatments through the exclusive measurement of particle Time-Of-Flight. The current prototype consists of 8 gamma detection modules placed downstream the patient and read in time coincidence with a beam hodoscope placed upstream: the time elapsed between an ion trigger in the hodoscope and a gamma trigger depends on the PG vertex position and provides an indirect measurement of the ion range in the patient. The gamma modules developed are based on pure Cherenkov radiators (PbF2) readout by SiPMs and therefore provide excellent time resolution and virtually perfect neutron rejection for SNR optimisation. The beam monitor is based on a fast plastic scintillator readout by SiPMs and provides sub-millimetric information on the beam position by charge sharing with only four electronic channels. We will show that the fast response of both detectors is crucial to improve the system accuracy on the ion range. The compactness of the system is conceived to cover the patient in 4⊠ while allowing beam irradiations from different sides.
We will present the design and characterization of the gamma and proton detectors developed, as well as the tests performed on phantoms with the full prototype at clinical accelerators.

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## Demonstration of LGADs and Cherenkov gamma detectors for prompt gamma timing range verification of proton therapy

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The great potential for precision dose delivery with proton therapy remains to be fully exploited, largely due to uncertainties in range that require conservative treatment margins. Analysis of time distributions from prompt gamma-ray emissions offers a means to precisely verify the range in real time and shrink treatment margins, thus increasing effectiveness and reducing toxicity.

We demonstrate a prototype prompt gamma timing system to detect proton range shifts, based on Low Gain Avalanche Detectors, used to time incoming protons, and Cherenkov detectors, to time the outgoing prompt gammas.Using this system, we are able to detect range shifts induced in a PMMA phantom with about 1 mm precision consistently with several LGAD pixels and 3 different Cherenkov detectors. These detector concepts deliver promising performance and are suitable for scaling to intense particle rates and backgrounds in realistic clinical environment.

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## First Radionuclide Imaging Tests with MACACOIII+ Compton camera

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The intial tests carried out with MACACO III Compton camera for radiotherapeutical therapy (RPT) assessment developed by the IRIS group of IFIC-Valencia yielded encouraging results. Derenzo-like phantoms filled with 18F-FDG and 131I-NaI allowed visualization of 3 mm and 4 mm diameter rods, while in the first tests with patients treated with 131I-NaI it was possible to correlate the lesions observed with the Compton camera with those of a gamma camera.
The system performance has been improved in MACACO III+ by enlarging the second detector layer for enhanced sensitivity and imaging capabilities.
Tests have been carried out addressing the difficulties in visualizing alpha-emitting radionuclides by gamma cameras. Imaging tests with Ac-225 have been carried in collaboration with the Léon Bérard hospital in Lyon. The three 6 mm diameter rods of the phantoms were filled with Ac-255 and successfully visualized. Additional tests with I-131 have been carried out in collaboration with La Fe hospital in Valencia, employing a home-made thyroid-shaped phantom. The phantom was imaged both with uniform activity and also including hot spots of different sizes in a 10:1 activity ratio. Preliminary images reproduce the phantom shape and clearly distinguish between the two situations. In addition, simulation studies with GATE support the experimental activities and allow us to estimate the potential performance with the system.

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## Time-of-Flight Requirements to Mitigate Blurring Induced by Annihilation Photon Acollinearity

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One of the limiting factors of spatial resolution in positron emission tomography (PET) imaging is the acollinearity of the annihilation photons (APA). For a whole-body PET scanner, APA induces a blurring of about 2 mm FWHM. We have previously shown that perfect TOF resolution can reduce the blurring induced by APA, i.e., overcome the conventional theoretical limit of spatial resolution. However, the requirements to achieve an observable gain in this regard have yet to be explored. We propose a preliminary study of these requirements for whole-body and total-body scanners, in terms of TOF resolution and coincidence event statistics. Using a fictive 81-cm diameter scanner with 2-mm wide detectors, we show that ultrahigh TOF resolution—13 ps FWHM—enables an observable gain in spatial resolution for a range of coincidence event statistics. In addition, we show that lower TOF resolutions (i.e., 26 or 65 ps) can be sufficient to mitigate APA for the oblique tubes of response

of large 3D systems subjected to larger APA blurring. This last observation is of particular interest since it suggests that the non-stationary nature of spatial resolution in PET imaging can be further mitigated with high and ultrahigh TOF precision.

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## Dual-panel geometry for PET-guided therapy to be enabled by super-fast detector: simulation study

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TOF information is essential to the improvement of image quality in PET reconstruction. However, the fastest TOF resolution currently available commercially, at around 200 ps, is not good enough to realize reconstruction-free imaging, and therefore, PET systems still require a ring geometry to satisfy the completeness condition in image reconstruction. On the other hand, a 30 ps TOF resolution has been achieved with Cherenkov-radiator-integrated microchannel-plate photomultiplier tubes (CRI-MCP-PMTs). In other words, a conventional ring geometry will not be necessary in future PET systems, and any other geometry like a dual-panel open geometry, which may enable PET imaging during cancer therapy, will be possible. Therefore, the aim of this work was to investigate the feasibility of a novel panel PET system with CRI-MCP-PMTs. A 5.75 mm-pitch position-sensitive CRI-MCP-PMT with a BGO window (5.0 mm thick) was simulated by GEANT4, as a future possible extension from the current devices that use a lead-glass Cherenkov radiator. A panel PET (142 mm x 142 mm, 300 mm panel separation) was modeled. A rod phantom was simulated, and the ML-EM reconstruction was applied. As a figure of merit, the peak-to-valley (P2V) ratio was measured for 4 mm diameter rods. The P2V ratio of the 30-ps panel PET was 15.9, which was higher than the 14.7 ratio of the 210-ps ring PET. The simulation results supported the feasibility of the proposed dual-panel geometry.

# Technologies for total body PET imaging

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## Clinical Potential of Total-body PET

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## IMAS: a total body PET with TOF and DOI capabilities

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Total-Body PET (TB-PET) technology has become very popular in recent years. These systems are very attractive because of their high sensitivity, achieved through their extended axial field of view and, potentially, Time of Flight capabilities, allowing for the simultaneous study of the kinetics of multiple organs. Most of TB-PET designs are based on LYSO crystal pixels without DOI. In this work we present a TB-PET system based on semi-monolithic crystals and, therefore, simultaneously enabling TOF and depth of interaction capabilities. Our design, named IMAS, makes furthermore use of a reduction of signals without compromising performance. We first carried out exhaustive simulation studies of the system geometry, based on 5 rings of 10 cm in the axial direction each, and gaps of about 5 cm, with a total axial length of 71.4 cm. These studies confirm the good performance of the system in terms of spatial resolution, sensitivity and other relevant parameters. The system has been constructed and installed (June 2023) at the largest hospital in our region named La Fe. Very preliminary experimental tests, already predict an almost homogeneous spatial resolution below 4 mm in the whole FOV (as far as at 30 cm off-radial), outperforming any other scanner with a long axial FOV. The system sensitivity is 7.6% with a source at the Center of Field of View. The detectors reached a TOF of about 350 ps. We aim to report a full characterization of the scanner during the workshop.

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## Development of Total Body J-PET from plastic scintillators

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Total body PET has started to be used in clinics, however, for its wide applications in hospitals there is a need to decrease the costs of its construction [1], [2]. We are developing cost-effective total body PET based on plastic scintillators [2], [3]. This study discusses the preparation status based on new simulation results and the test of single detectors with the SiPMs. The simulation part has been carried out using the GATE software to investigate sensitivity, scatter fraction, and spatial resolutions of the total body J-PET. In the experimental phase, we tested the single detector units employing SiPMs connected to the plastic scintillator strips at the axial ends. Using a collimated beam of 511 keV photons from the Na-22 isotope we characterized the detector performance for different lengths of the scintillator. Total body J-PET (TB-J-PET) will be built using the newest generation of J-PET technology that will be presented and discussed. The first generation was built from 192 plastic strips with 50 cm lengths read out by PMT [4], and the second one is a 50 cm long, modular, and portable PET built from 312 plastic strips [5]. In this presentation, we report on the 243 cm long system, which is being constructed based on funds provided by the Polish Ministry of Education and Science. The TB-J-PET will enable standard PET imaging, positronium imaging [6], multi-photon imaging [7], and also application in imaging of photon's polarisation [8].

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## Investigating the Influence of TOF and DOI on Spatial Resolution in Flat-Panel and Cylindrical Total-Body PET

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Background: As a cost-efficient alternative to cylindrical total-body PET systems, our group is developing a dual panel system based on monolithic BGO detectors with intrinsic DOI-decoding capabilities (2 mm FWHM) and good TOF resolution (327 ps).
Objective: Comparing the spatial resolution of a monolithic dual panel system and a pixelated cylindrical system throughout the full FOV, with an emphasis on the impact of varying TOF and DOI resolutions.
Methods: Point sources in a 2 cm radius warm background were simulated in GATE every centimeter along the main axes of both scanners, and images were reconstructed iteratively using MLEM. Slices and line profiles were plotted and analyzed visually.
Results: No clear differences were observed between reconstructions without TOF and those with a very high TOF resolution. In both systems, not measuring DOI information resulted in blurring of the point sources and mispositioning of the peaks. The WT-PET outperformed the Quadra-like device, even when it would be able to measure DOI information.
Conclusion: Increasing the TOF resolution may improve overall image quality but has no effect on the spatial resolution. DOI measurements are indispensable to achieve high and homogeneous spatial resolution over the full FOV, as parallax effects deteriorate the spatial resolution when the DOI is unknown. The WT-PET offers better spatial resolution than the cylindrical device thanks to the high intrinsic resolution of its monolithic detectors.

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## Utility of total-body PET in monitoring carbon ion therapy: Demonstration in rat

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Positron emission tomography (PET) has been studied for range verification in particle therapy, in which positron emitters are produced through nuclear fragmentation reactions in body. Due to the physical and biological washout decay, PET imaging during irradiation and/or immediately after irradiation have been thought to be necessary. On the other hand, the new technology of total-body PET may enable PET imaging in a separate room thanks to its high sensitivity. Therefore, we demonstrated the utility of total-body PET in monitoring carbon ion therapy by conducting a small animal irradiation study using our original total-body small-animal PET that can cover the whole body of a rat. The tumor of a rat was irradiated by a 12C ion beam, and PET scan was performed for 30 min starting ~2 min after the irradiation. Magnetic resonance angiography was also performed to determine the tumor vascular conditions. The PET data were divided into ~30 s duration time frames, and image quality was investigated by changing the time frames to a sum. PET images of the late phase were almost the same as those of the whole phase. Also, a heterogeneous distribution in the tumor was observed in the PET image even with the late phase; the high activity intensity region corresponded to the hypoxic region that was observed in MRA images. In conclusion, the utility of total-body PET in monitoring carbon ion therapy was demonstrated in rats not only for range verification but also for tumor diagnosis.

# Total body PET imaging

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## Different Deep Learning Training Strategies for Attenuation and Scatter Correction in PET

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Attenuation correction (AC) and scatter correction (SC) are essential in PET for accurate tracer quantification. Current AC methods use CT scans to derive AC factors but CT-based AC introduces extra radiation and can lead to artefacts due to spatial mismatch between PET and CT. Single scatter simulation is widely used for SC but is sensitive to errors in the attenuation map and relies on iterative reconstruction of emission images. Deep learning (DL) shows promise to improve the accuracy and efficiency of PET AC and SC. Yet, it is challenging to develop a DL solution that works for long axial field-of-view (LAFOV) images and is also tracer-independent. We study different DL frameworks for AC and SC, starting from a non-corrected (NC) PET image as input. Two training strategies are proposed to fine-tune such neural networks for LAFOV PET and multiple tracer studies: (1) A two-stage neural network is trained separately for the tasks of AC and SC, under the premise that AC is multiplicative and object-dependent, while SC is subtractive and distribution-dependent. (2) A co-learning strategy uses NC PET and radiographic projection (scout) images in a multi-branch neural network to extract complementary, modality-specific features. The rationale is to leverage the scout scans for anatomical information to constrain network training. Qualitative and quantitative evaluations showed that both approaches removed artefacts seen with CT-based AC and reduced liver and lung SUVmean bias.

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## Multi-Organ Segmentation on CT-free Total-Body Dynamic PET Scans

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The evolution of high-resolution total-body (TB) PET/CT has expanded dynamic PET applications, yet the temporal resolution gap between PET and CT presents challenges for quantitative accuracy. Organ segmentation from CT exacerbates errors in kinetic modeling. This study aims to utilize enhanced anatomical details from TB PET for attenuation (AC) and scatter correction (SC), incorporating frame-by-frame multi-organ segmentation to address temporal resolution disparities and improve quantitative precision in dynamic PET imaging. Deep learning algorithms were developed using static TB PET images from 430 patients scanned with the United Imaging uExplorer system. A 3D UNet was trained for multi-organ segmentation, using non-corrected PET images and CT-derived ground-truth segmentation maps. A dedicated decomposition-based network was trained for AC and SC. In dynamic data application, organ segmentations were predicted for each frame, followed by AC and SC. Comparative analysis involved Dice coefficients for concordance against manually refined CT-based segmentation labels. The trained model achieved an average Dice coefficient of 0.96 across eight organs and dynamic frames, outperforming the CT-based approach with an average Dice coefficient of 0.77. The developed deep learning method shows promise for CT-free

multi-organ segmentation, AC, and SC in dynamic TB PET scans. Its potential to enhance accuracy and efficiency in dynamic PET imaging could broaden its application scope.

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## Recovery coefficient corrected image derived input function from a long axial field of view PET/CT-scanner

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Long axial field of view (LAFOV) PET scanners enables measurements in the aorta or similar arteries with high time resolution which can used for definition of input functions to obtain the blood concentration as a function of time directly from reconstructed images.
Here we present the application of a novel model-based recovery coefficient (RC) for partial volume correction to obtain quantitative and robust input functions down to single-slice levels. The methodology was tested across a range of different tracers including [64Cu]Cu-DOTATATE, [18F]FDG and [15O]H2O.
An image derived input function (IDIF) was obtained from a central long axial part of the descending aorta assumed to be partial volume free. From this volume a RC was estimated which was used to correct a volume covering the cross-sectional area of the aorta with an axial coverage corresponding to a total volume of 0.2 ml.
The method proved robust and improved the IDIF increasing the signal to noise ratio (SNR) and generally providing physiologically more plausible input functions. The RC correction regained absolute quantification of the IDIF which can be affected due to partial volume effects (PVEs).
This approach of IDIF determination minimizes intra-volume dispersion and delay differences creating input functions of high quality across multiple tracers. Additionally, as a future perspective, this type of approach can be extended enabling IDIF extraction from other arteries in the body.

**Total body PET imaging / 42**

## Motion analysis of Subjects standing in walk-through total body PET using infrared based localization

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The introduction of the Dual Flat Panel Walk-Through Total Body PET (WT-TB-PET) scan system has revolutionized imaging procedures, albeit presenting challenges stemming from patient motion while standing upright. Understanding motion patterns is pivotal for optimizing image quality and diagnostic accuracy. This study aims to analyse subject motion within the designed mock-up for the WT-TB-PET scanner, evaluating head and respiratory motion during normal breathing and breath-hold conditions. 18 volunteers participated, undergoing evaluation within the WT-TB-PET scanner with infrared markers placed on key anatomical points. 3D coordinates were captured over time for each marker using a depth camera, followed by image processing techniques. The results revealed

distinct motion patterns across markers. Head marker exhibited minimal motion, with average deviations of 0.85 mm during normal breathing and 0.94 mm during breath-hold conditions. Conversely, the abdomen displayed the greatest range, with average deviations measuring 2.68 mm during normal breathing and 2.32 mm during breath-hold. Notably, during breath-hold, all markers exhibited reduced motion compared to normal breathing, except for the head marker. In conclusion, our findings elucidate dynamic motion patterns in WT-TB-PET imaging and underscore the necessity of motion correction strategies. Despite observed motion, integrating WT-TB-PET systems into clinical practice remains feasible under normal breathing conditions.

**Total body PET imaging / 97**

## Estimation of the sensitivity for quantum entanglement imaging with total-body J-PET

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In positron emission tomography, the density distribution of electron-positron annihilations in the patient's body is reconstructed based on the measurement of the time and position of the annihilation photon's interactions in the detection system. In this study, we demonstrate that J-PET scanner based on plastic scintillators enables the effective application of polarization of annihilation photons as an additional parameter having the potential to improve the specificity of PET diagnosis. The polarization of annihilation photons can be determined by measuring the primary and Compton scattered photons. In the J-PET scanner, annihilation photons scatter only via the Compton effect, making J-PET especially suited for measuring their polarization. Using a 192-strip prototype scanner, we have performed measurements of the distribution of the relative angle between the polarizations of annihilation photons, demonstrating that the J-PET tomograph enables the application of photon polarisation for diagnosis. Moreover, using the GATE software we have estimated the sensitivity profile for imaging the relative angle between annihilation photons' polarisation with the total-body J-PET scanner, which is under construction at the Jagiellonian University. In this presentation, the experimental results achieved with the J-PET prototype and the results of simulations for the total-body J-PET will be presented and discussed.

# Poster Session

**Poster Session** / **35**

## Performance Evaluation of a Fast Tomographic Reconstruction Software for PET

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This study presents a performance assessment of the Fast Tomographic Reconstruction (FTR) software for SAFIR PET insert with a non-cylindrical geometry. For this purpose, an image quality phantom and a Derenzo phantom were measured in the SAFIR-I and SAFIR-II scanners. The PET data were reconstructed by FTR and the well-known Software for Tomographic Image Reconstruction (STIR) and then evaluated based on NEMA NU4-2008 standards. According to the results, FTR produced high-quality images, preserving the finest details, while reducing the reconstruction time by factors of 0.22 (SAFIR-I) and 2.74 (SAFIR-II) compared to STIR. The evaluation of uniformity, recovery coefficients (RCs), and spill-over ratios (SORs) suggested comparable results with improved values in most cases for FTR relative to STIR at all iterations up to 10. NEMA characteristics didn't vary significantly after 6 iterations for both software. The results demonstrate the high performance of FTR in reconstructing SAFIR's images in terms of image quality and reconstruction time. In conclusion, FTR can accelerate the accurate image reconstruction for SAFIR scanners, particularly for SAFIR-II.

**Poster Session** / **29**

## Positron-Range Correction for an On-Chip PET Scanner using Deep Learning

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Background: Organs-on-Chips (OOCs) are a novel technology that aim to
mimic the functions and physiology of human organs in a laboratory setting. Positron Emission Tomography (PET) is a widely-used imaging modality that enables non-invasive monitoring of biological processes in vivo. However, the spatial resolution of current small-scale PET systems is not sufficient for OOC imaging. One of the main factors limiting the spatial resolution of a PET scanner is the positron range, which is the distance that a positron travels before it collides with an electron. In this study, we present a novel Deep Learning (DL)-based approach for correcting the positron-range effect in our previously introduced
On-Chip PET scanner.

Results: We created a dataset of pairs of non-corrected and corrected images using a Monte-Carlo simulation of a realistic OOC phantom and a fully three-dimensional Maximum-Likelihood Expectation-Maximization (MLEM) iterative reconstruction algorithm. Our results demonstrate the effectiveness of the DL-based positron-range correction algorithm in improving the overall quality of the reconstructed images.

**Poster Session / 21**

## 18F-SMBT-1: First Study Shows Pharmacokinetics and Metabolism in Healthy Human Subjects.

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Purpose:
Monoamine oxidase-B (MAO-B) is one of the promising targets for the imaging of astrogliosis in the human brain. 18F-SMBT-1 was developed to image astrocytes in various neurological diseases (NDs). Nevertheless, 18F-SMBT-1 real time pharmacokinetics and metabolism in human subjects has not been studied yet.
Objective:
This study aimed to present the technical approaches for setting up 18F-SMBT-1 PET scans and procedures for pharmacokinetics and metabolism in health human subjects.
Study participants were injected with 5-10 mCi of 18F-SMBT-1 and scan time consisted of a 90-min/ 30-min break/ subsequent 60-min scan. The 90-min scan consists of 28 frames, 60-min scan consists of 12 frames. Arterial blood was collected during the PET scan. Each set of samples obtained will be separated into two tubes, one for whole blood sampling and the other will be centrifuged to separate the plasma from the red blood cells. The plasma and the whole blood will be taken to the gamma counter and HPLC was performed for plasma sample alone to be analyzed for radioligand compounds.
Results:
Blood and plasma data demonstrate that 18F-SMBT-1 showed excellent pharmacokinetics profile such as rapid washout from the plasma and blood samples. Also, 18F-SMBT-1 was completely metabolized in humans without leaving harmful radiolabeled metabolite remnants.
Conclusion:
Based on the results from blood and plasma samples, 18F-SMBT-1 could be suitable for MAO-B imaging in the human brain.

**Poster Session / 24**

## Profiles of Short Chain Fatty Acid Metabolism as Genetic Biomarkers for Primary Brain Gliomas

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Genetic factors play a crucial role in diagnosis and treatment of glioblastoma multiforme (GBM). The key biomarker, isocitrate dehydrogenase (IDH), is associated with better survival rates in its mutated forms than in wild-type. GBM diagnosis is complex due to tumor heterogeneity and risks in sampling, and this highlights the need for non-invasive diagnostic methods. We examined the impact of glioma-specific short chain fatty acid (SCFA) transcellular flux mechanisms for energy production on genotypes and patient survival. We analyzed the genetic profiles of 10 GBM patients (5 mutants and 5 wild-types) using dynamic 18F-fluoropivalate (FPIA) PET scans focusing on 25,202(±14,337) time activity curves(TACs). We identified four distinct metabolic SCFA oxidation profiles within the lesion through time-series k-means clustering and then used deep learning to associate them with GBM genotypes. Our model accurately differentiated mutant and wild-type GBMs with a 96.75%(±3.24) accuracy, when used features extracted from the combination of the first 2 clusters'TACs only. However, its effectiveness significantly decreased when ignoring SCFA metabolism heterogeneity (i.e. the clustered metabolic profiles), as shown by the lower accuracy rates obtained using the full range of FPIA TACs(70.42%±16.25). Of note, the TACs belonging to the cluster with the lowest FPIA SUV, showed the worst performance (23.67%(±16.83)acc) confirming SCFA metabolism to be a potential biomarker of GBM genotype.

**Poster Session / 65**

## Performance analysis of in-beam PET range verification system for carbon ion beams

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The SIG (Superconducting Ion Gantry) project focuses on enhancing online monitoring performances of in-beam PET during ion treatments, developing new image reconstruction algorithms and analyses that consider fast-decaying isotope signals. In this study we presented the performance evaluation of an in-beam PET system for carbon ion irradiations. The Range Verification System prototype under investigation is based on state-of-the-art PET modules featuring segmented Luthetium Fine Silicate crystals coupled to Silicon Photomultiplier matrices. It was tested on carbon ion beams at two energies (144 MeV/u and 213 MeV/u) at the CNAO facility. The beams were impinging on homogeneous PMMA phantoms and data were acquired during the irradiation. The performance analysis was designed to evaluate the stability of range difference estimation considering several consecutive subsets of coincidence events with different event amounts. The range difference values were calculated between the two irradiated energies for each pair of images of the two energies from the subset lists. Our result indicates that the performance of the PET system appears to be minimally affected by the statistics included in the PET images and the average experimental range difference is compatible with the expected value. The obtained results are valuable for the ongoing design and implementation of a customized image reconstruction method focused on highlighting fast isotopes.

**Poster Session / 39**

## Preliminary results of metabolic MRI technology and PET in patient with liver metastases

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Introduction: Metabolic MRI can reveal simultaneous detection of multiple metabolites involved in cell proliferation and energy metabolism without the need for radio-isotopes, however, this is so far not available throughout the human body.
Methods: We designed a metabolic body MRI system using a double-tuned RF bore transmitter for uniform excitation of 2H and 31P spins, an 8-channel 1H dipole transceiver, and 8 dual-tuned receiver loops for 2H and 31P at 7T. After careful assessment of the system and safety performance, a patient with liver metastases was enrolled to investigate altered metabolism compared to healthy controls and compared to FDG-PET/CT. The patient drank a deuterium-labeled glucose solution (20 grams of deuterated glucose in 100ml water) 40 min prior to the 1H-2H-31P MRI exam of 60 minutes.
Results: We were able to see full metabolic maps throughout the liver (and a large part of the body) for both 2H as well as 31P MR signals. While almost no deuterated lactate was observed in the healthy part of the liver, we see clear evidence of deuterated lactate signals in the metastases that match the elevated SUV area of the PET. Compared to a healthy liver, a substantial elevation of phosphomonoesters (PME) was observed in the metastases.
Conclusion: The first in man study of 2H and 31P metabolic MRI from a patient was shown. While only from one patient, PME and deuterated lactate levels were clearly elevated in the metastases compared to a healthy liver.

**Poster Session / 57**

## Hardware acceleration for fast MRF map reconstruction: FPGA porting of a deep learning algorithm

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Magnetic Resonance Fingerprinting (MRF) is an MR imaging technique that allows for the reconstruction of brain parameters within the same acquisition session. Despite its strengths, MRF implies a large amount of data to be processed and a complex analytical function that is not well defined.

Recently, a neural network (NN) has been proposed to reconstruct brain quantitative maps starting from the MRF signal. While the NN offers rapid parameter estimation once trained, its training demands substantial computational resources and time. To address this challenge, hardware accelerators like Field-Programmable Gate Arrays (FPGAs) are increasingly replacing traditional software-based tools, significantly enhancing processing speed and reducing power consumption in MR image analysis. By redesigning the original NN onto an FPGA, the project aims to dramatically reduce reconstruction time for both simulated and real clinical MR parameter maps. The NN needs to be quantized to meet the available hardware resources of an FPGA without affecting the accuracy of the model. This multidisciplinary approach has the potential to outperform traditional software in speed and energy efficiency, paving the way for real-time brain analysis, even on mobile devices. This could revolutionize clinical decision-making and telemedicine by enabling faster, more efficient, and potentially more accessible brain imaging.

**Poster Session / 76**

## Cardiac protocol including anatomic proton MRI at 3T and 31P metabolic imaging at 7T

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**Introduction**

Phosphorus (31P) MRSI monitors cardiac energetics in vivo. Previous studies have shown that the PCr/ATP ratio predicts mortality, however widespread use has been hampered by low sensitivity and spatial resolution.
We set out to solve these limitations by applying our dipole array coil for 31P MRSI at 7T. We aim to correlate the 7T 31P metabolic and cardiac energetics information with 3T volume and ejection fraction analysis on the same patients. We show here the performance of such an array and the set up of a 3T protocol, ahead of a future study in heart failure patients.

**Methods**

The full study protocol consisting of 7T 31P-MRSI and a 3T scan is detailed in Figure 1.
For this study, we have been using our novel transmit/receive dipole array. A total of 8 volunteers consented to an in vivo 7T MRI scan and 5 to a 3T MRI. Experimental B1+ maps were acquired on a phantom. A 50mL tube was also placed in the center of this shaft to enable for a single point B1+ value at heart depth.

**Results**
The B1+ maps show good uniformity around the position of the heart. Spectra from the dipole array coil are of excellent quality.
The corrected PCr/γATP ratio is consistent and lies in the expected range. 3T data analysis shows that the LVEF of the healthy volunteers are within the normal range.

**Conclusion**
Dipole array coils present a promising new approach for human cardiac 31P-MRSI at 7T and may increase the power of clinical trials measuring energetics.

**Poster Session / 89**

## Glioma Segmentation in PET/MRI studies: a preliminary comparative study between Swin Transformer and state-off-the-art CNN

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In the quantitative analyses of PET/MRI studies of Glioma patients, one of the crucial steps of the pipeline is represented by the fast, correct and, possibly, automatic segmentation of the tumors on multiple contrast MR images and PET. As a first preliminary study, we aim to compare the performance of the Swin Transformer and the current reference-standard nnUNET models in glioma segmentations on the MR images. We sought to determine how well these models can accurately delineate various glioma compartments, especially in high-grade cases. Swin UNETR and nnU-NET were trained on different datasets and evaluated on a retrospective glioma dataset. The assessment metrics included Dice coefficients and interclass correlation coefficients. High agreement between models, especially in high-grade gliomas, was observed in terms of DSC and ICC. In conclusion, we emphasize the ability of Swin Transformer to segment a necrotic-core compartment and its potential in glioma diagnosis and treatment. A further step will be to extend Swin UNETR and nnU-NET models extension to the segmentation of PET images. This study lies the groundings to investigate the concordance and variability among various segmentation software tools and clinicians with the aim of establishing a reference-standard for application to PET/MRI studies.

**Poster Session / 47**

## Validation of CT-free Template-Based Attenuation Correction in Brain PET Imaging

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This study aims to validate a template-based attenuation correction (AC) method for clinical brain PET systems without CT, previously proposed for the new NeuroLF brain-PET. Method: The validation process involved simulating a diverse (patients/tracers) set of clinical images. This is done by transforming 142 reference PET/MR and 8 PET/CT brain images to NeuroLF image space, converting them to sinograms, then uncorrecting the sinograms for attenuation and scatter using original patient-derived attenuation maps. These uncorrected sinograms serve as a surrogate for real clinical raw data. From this, images were then re-reconstructed with both patient-specific reference and tracer-specific template attenuation maps and compared using a range of similarity metrics. Results: The stability of the template-based AC method across a diverse set of tracers for brain PET

imaging could be shown. The used metrics identified cases where the MR-to-CT conversion was inadequate, but were less capable of detecting failures intentionally induced in the template map co-registration. Tracer-specific templates showed better performance than a universal (i.e. [18F]-FDG derived) template. Conclusion: The validation confirms the adequacy of the template-based AC method for clinical routine brain-PET imaging, with a recommendation for visual inspection to detect co-registration failures. We aim to further validate the template-based attenuation maps in a blinded clinical evaluation.

**Poster Session / 45**

# Actual trajectory measurement for multi-echo GRE at 7T using a field camera system

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Ultrahigh Field (UHF) MRI can provide images with unprecedented spatial resolution and SNR. Together with the increased sensitivity towards longitudinal relaxation time and magnetic susceptibility effects, this allows for a better tissue characterization (i.e., QSM, T1/T2 relaxometry). Efficient quantification of such parameters requires k-space sampling strategies which fully exploit the capability of the gradient system (e.g., Non-Cartesian, EPI). However, these are more sensitive to the effects of the eddy current fields induced by the waveforms themselves, leading to deviations from theoretical k-space trajectories and subsequent image distortions. To fully take advantage of the benefits offered from UHF, it is necessary to correct these artifacts by measuring the actual sampling pattern. Here, we used a field-camera (Skope Magnetic Resonance Technologies) to measure the actual gradient waveforms employed during the acquisition and reconstruct artifact-free quantitative T2* maps of the brain of an healthy volunteer at 7 T. In future works, we will apply the corrections to more efficient but more error-prone acquisition strategies such as non-Cartesian and EPI-based Magnetic Resonance Fingerprinting, QSM, fMRI and Diffusion.

**Poster Session / 86**

# Estimating skeletal muscle metabolism from 31P MRSI at 7 Tesla using a dual-tuned volume coil preliminary in-vivo results

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Phosphorus Magnetic Resonance Spectroscopy (31P MRS) is a non-invasive imaging technique that estimates concentrations of high-energy phosphates, offering insights into cell metabolism and neuromuscular disorders. Its clinical adoption is hindered by the need for specialized coils, but using a

volume coil dual-tuned to 1H and 31P for 3D Magnetic Resonance Spectroscopy Imaging (3D-MRSI) can overcome this difficulty. Our approach allows for fast acquisition with improved spectral resolution at Ultra-High Field (7T). This approach can potentially enhance 31P metabolic imaging in clinical settings.

**Poster Session / 93**

## Rigid Motion Detection for Abrupt Motion in FDG Brain PET Imaging

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In this study, we employed a dedicated brain positron emission tomography (PET) scanner to simulate controlled motion through the use of a voxelised phantom. The resulting output was converted to listmode and subsequently transformed into pseudo-displacement time series via a moving mean technique. To locate time points of motion, we applied a statistical approach known as bottom-up segmentation, a form of change point detection. This facilitated the identification and separation of frames into motion-free segments. Bottom-Up Segmentation consistently detected spatial resolutions as fine as 2mm and identified motions of 3mm within intervals, up to, 6 seconds consistently.

**Poster Session / 37**

## Panel Detectors in PET Imaging: Leveraging TOF-DOI for High-Quality Performance

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This work explores the potential of panel detectors in developing flexible, modular PET scanners that can be tailored to specific patient needs and imaging objectives. It aims to demonstrate that even a simple 2-panel configuration can produce image quality suitable for practical applications, while using significantly less detector material compared to conventional PET scanners. The flat panel detector design enables us to position detectors very close to the patient, with the intent to enhance both sensitivity and spatial resolution. This design approach leverages improved geometric coverage and reduced noncollinearity blurring, while the parallax error can be mitigated through the utilization of DOI information. A Monte Carlo study using GATE software and large HPC clusters evaluates the performance of these detectors, featuring TOF resolution down to 70~ps and DOI

resolution down to 1.25~mm. Comparisons with various phantoms and the Siemens Biograph Vison PET/CT scanner validate the approach. Findings reveal that a relatively small 2-panel PET scanner can fulfill the roles of conventional scanners and produce distortion free images of the same quality. Additionally, its mobility and flexibility open doors to novel applications, including bedside imaging and ICU diagnostics. Moreover, the modularity of panel detectors creates an opportunity to construct a long axial FOV scanner while conserving the same amount of detector material as employed in current clinical scanners.

**Poster Session / 19**

## Synergistic Effects of Intrinsic Defects and Material Composition on the Scintillation Properties of Bismuth-Based Scintillators

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We conduct a comprehensive analysis of the structural, electronic, and optical properties of bismuth-based scintillators, with a particular focus on the role of intrinsic defects and material composition. We employ density functional theory (DFT) calculations with the PBE0 hybrid functional, we delve into the nuances of defect processes in Bi4Ge3Si3O12 (BGO) scintillators and explore the influence of varying Ge/Si ratios in Bi4Ge3xSi3(1-x)O12 (BGSO) crystals. Our investigation reveals that intrinsic defects, particularly antisite types, significantly influence the scintillation performance by introducing ingap states and affecting charge trapping mechanisms.

**Poster Session / 34**

## Determination of lutetium density in LYSO crystals: methodology and PET detector applications

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Lutetium yttrium oxyorthosilicate (LYSO) scintillation crystals are favored in positron emission tomography (PET) imaging for their high gamma-ray attenuation, satisfactory energy resolution, and rapid scintillation decay rates. The natural 176Lu isotope, with a half-life of 37.9 billion years, contributes a steady background radiation (BG) profile influenced by the crystals' geometry and composition. This study introduces a method for determining the composition of LYSO crystals when the precise Lutetium content is unknown. By exploiting the relationship between BG spectrum intensity and intrinsic radioactivity, we can accurately estimate the Lutetium concentration within LYSO crystal samples. Initially tested on a well-documented LYSO sample, our method closely matched the sample's known composition. This estimation technique was applied to various unidentified LYSO samples, including both individual crystals and arrays, finding remarkable consistency in Lutetium content across samples of the same material, with discrepancies under 1%. Additionally, the background spectrum for LYSO-based arrays representing a PET detector is generated by simulations using the Geant4 library. Our approach, combined with simulation, effectively predicts the background radiation spectra for different LYSO detector designs. This research has provided implications for

enhancing the predictive capabilities and autonomous adjustment of system settings in LYSO-based PET detectors.

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## Optimizing the Performance of a Total-Body PET scanner based on a new crystal design: A Monte Carlo Study

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PET is a vital molecular imaging modality using positron-emitting radionuclides to assess organ metabolism. Cherry et al. introduced an extended AFOV scanner in 2006 to overcome W-B PET limitations, yet designing an efficient crystal for T-B PET remains challenging. This study aims to optimize T-B PET with a new crystal design combining pixelated and monolithic advantages. Our simulated T-B PET scanner has 16 heads (32×105 cm), forming a 41 cm diameter cylindrical scanner, each with 1×1×2 cm crystals. Using GATE, we evaluated sensitivity, spatial resolution, and scatter fraction based on NEMA NU-2 2018. Common scintillator crystals (BGO, LYSO, LaBr3(Ce)) were simulated, and analytical sensitivity was compared with simulation. Analytical vs. simulated sensitivity showed ~8% error. GATE results showed BGO with lower scatter fraction than LYSO and LaBr3(Ce) (5% and 7%, respectively) and higher sensitivity (27% and 41% more than LYSO and LaBr3(Ce)), due to its density and stopping power. LYSO had superior spatial resolution from high stopping power and light yield, while LaBr3(Ce) had lower resolution despite high light yield. Conversely, BGO had degraded spatial resolution due to low light yield. Compared to walk-through PET, our design had slightly weaker spatial resolution but higher sensitivity across all crystals. The designed T-B PET scanner shows promising sensitivity and spatial resolution, outperforming conventional PET scanners.
keywords:PET, total Body- NEMA

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## Performance characteristics of multi-mouse imaging on monolithic large flat panel PET

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This study introduces a novel small animal PET scanner aimed at overcoming limitations in preclinical imaging, specifically addressing the constraint of scanning a limited number of samples daily. The proposed scanner, featuring two flat panels with 16 BGO monolithic detectors each, demonstrates excellent spatial resolution (0.94 - 1.12 mm) with a 2mm depth of interaction (DOI) and high sensitivity (~38%). Capable of simultaneously imaging 12-60 mice, the scanner maintains spatial resolution across the entire imaging volume, making it a promising tool for high-population preclinical studies. The presented pre-clinical PET scanner significantly expedites small animal-based studies, offering researchers enhanced flexibility to include larger sample populations. With excellent system performance and the ability for multi-sample imaging, this advancement not only improves experimental efficiency but also broadens the potential insights derived from pre-clinical investigations.

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## Comparison of automatic segmentation methods for total body PET/CT imaging

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Segmenting regions of interest from total body Positron Emission Tomography/Computed Tomography (PET/CT) images is time-consuming and susceptible to variability between different operators. Automatic segmenting tools have been developed to address these challenges. In this study, we assessed the performance of two deep learning-based methods, MIWBAS and TotalSegmentator, in segmenting tissues and organs in 30 total-body CT images obtained from the Biograph Vision Quadra total body PET/CT system. The Jaccard index was used to measure the overlap between the segmentation results. The findings indicate a high degree of resemblance between MIWBAS and TotalSegmentator in segmenting the brain, lungs, and liver (Jaccard index ≥ 0.9). MIWBAS failed to segment the brain region in 6 out of the 30 images for unclear reason. Notable differences were observed in the heart region by these two methods, with a mean Jaccard index of 0.566. A systematic difference in the aorta was observed. Next, we plan to expand our analysis by including one more method (MOOSE), and perform a comparison to the manual segmentation approach for more comprehensive assessment.

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## Quality control of plastic scintillators for the total-body J-PET scanner

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Total-body Jagiellonian positron emission tomography (TB-J-PET) is based on long plastic scintillators [1] which decrease cost of the scanner [2]. TB PET scanners enable positronium imaging [3], measurements of polarization of photons [4] and beam therapy monitoring [5]. Development of TB-J-PET requires application of transparent plastic scintillators with low light attenuation [6] to build modules with SiPMs attached at both ends of the scintillators. For modular TB-J-PET construction we choose BC-408, one of the most transparent plastic scintillator from our previous measurements [7]. Purpose of this research is to verify quality of received scintillators. Transmittance at the wavelength of maximum emission through 6 mm thick scintillator and technical attenuation length along 330 mm long scintillator were measured on linear CCD array spectrometer for random selected scintillators from each delivered batch. Additionally, scintillators optical homogeneity was measured on light transfer setup consisting of exciting LED and photodiode matrix.

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**Poster Session / 43**

## Energy based scatter correction for the Walk-Through PET system

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We implement and evaluate an energy-based scatter correction method for the Walk-Through PET (WT-PET) system. The WT-PET is a new, long axial field-of-view (AFOV) PET currently under development, based on a vertical, dual flat panel design using monolithic detector technology. In the energy-based scatter correction framework, scatter fractions are estimated from the dual energy distributions of scattered and unscattered photons in coincidence events. An estimate of the attenuation map is not required, enabling CT-less scatter correction for dose reduction purposes on the system. The algorithm is implemented within a custom, iterative listmode image reconstruction framework. Performance is evaluated using GATE Monte Carlo simulations of the NEMA IQ phantom. We find that the influence of scatter is properly corrected for, resulting in a uniform background for the phantom, with only a small loss in contrast recovery compared to a reconstruction using true coincidences only.

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## Development and Evaluation of a Portable MVT-based All-Digital Helmet PET Scanner

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We report a novel portable All-Digital Helmet PET system with a hemispherical detector arrangement, based on the Multi Voltage Threshold technology. It allows to scan subjects in a standing, sitting, and lying position, facilitate emergency and interventional image-guided surgery. The scanner exhibits a noise equivalent count rate peak of (151 ± 2) kcps at the activity of 40.65 kBq/mL, a sensitivity of (55.24 ± 0.05) cps/kBq, and a spatial resolution at the center of the Field Of View of approximately 2 mm. Time-dynamic human brain imaging shows the distinctive traits of tracer uptake within 30 s time frames. The usability of the device in the diagnostics of Alzheimer's Disease by imaging human subjects has been tested.

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## Timing performance of FBK SiPM NUV-HD-MT technology

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The improvement of the timing performance is one of the main focus for several fields from big physics experiments to biomedical applications such as Time of Flight Positron Emission Tomography (ToF-PET). In this study we will present Single Photon Time Resolution (SPTR) and Coincidence Time Resolution (CTR) results of the recently introduced FBK NUV-HD Metal in Trench (MT) SiPM technology. Thanks to the addition of the optically insulating material inside the trenches, FBK NUV-HD-MT devices show an extremely low CrossTalk (CT). Moreover, the Photon Detection Efficiency (PDE) reaches the $\simeq 65\%$ at $420nm$.
By using a femto-second laser with a wavelength of $390nm$, we have measured the SPTR for SPADs with different microcell sizes and different versions with a metal mask outside the active area (capacitive coupling). Moreover, a $1mm \times 1mm$ and a $3mm \times 3mm$ SiPM with $40\mu m$ cell size and M0 masking version have been tested. The CTR has been measured using a $4mm \times 4mm$ SiPM to match the $3mm \times 3mm \times 5mm$ LYSO:Ce:Ca crystal. By using a high frequency readout electronics, we achieved a CTR of about $\simeq 80ps$ FWHM and an outstanding SPTR of about $\simeq 19ps$ and $\simeq 30ps$ FWHM for the SPAD and $1mm \times 1mm$ SiPM with $40\mu m$ M0 masking respectively.
This work opens the door to further investigations in order to study the role of the metal masking in the timing performance and to discuss about limitations and further improvements.

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## Advancements in DOI-capable TOF-PET modules based on High-Frequency Readout

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High-frequency (HF) front-end electronics offer a solution for exploiting fast light production in crystals and enhancing the performance of TOF-PET applications. Demonstrating improved time resolution by lowering the leading-edge detection threshold, they enable the use of the fastest photons, such as Cherenkov emission, and facilitate event discrimination in heterostructures.
Heterostructured scintillators consist of stacks of alternating layers of two materials with complementary properties: high stopping power (BGO) and ultrafast timing (plastic). However, layering poses a challenge to the best achievable time resolution due to worsened light transport. This issue can be mitigated by retrieving depth-of-interaction (DOI) information and using it to correct for the induced bias, through a double-sided readout method or a light-sharing mechanism in single-side readout using a matrix of scintillators coupled to an array of SiPMs. Readout integration in a multi-channel scheme is required for the light-sharing method to work.

We present the achievement of 174 $\pm$ 6 ps coincidence timing resolution (CTR) and 6.40 $\pm$ 0.04 mm DOI resolution in single-pixel heterostructures of 3x3x20 $mm^3$ using double-sided HF readout. Additionally, the integration of a multi-channel HF readout board to a matrix of 4x4 LYSO 3.1x3.1x15

mm$^3$ allows for a CTR lower than 130 ps. Finally, we outline the steps toward the implementation of this readout to a heterostructured scintillator matrix.

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## A Deep Learning Approach for Semantic, Multi-Organ Segmentation of PET Images

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Within the last decade, algorithms built on convolution neural networks have become the de facto methods for semantic segmentation of imaging data and currently yield state-of-the-art results. Early efforts focused on natural images, but applications related to segmentation of 2D and 3D medical images soon followed. Currently however, most of the published literature in the segmentation space is dominated by research related to high-resolution, anatomical imaging modalities like CT or MRI. There is a much smaller amount of work involving PET or SPECT emission images, largely due to the limitations pertaining to image noise and relatively poor spatial resolution of these functional modalities. This work investigates a deep learning approach for total-body anatomical segmentation, directly on PET image volumes. A single network, once trained, was found to be capable of performing high quality segmentations simultaneously for a large number of organs on emission images acquired from a variety of radiotracers. The segmentations derived from the PET images in a small number of test subjects were visually assessed and compared to those generated from the corresponding CTs within the same subjects.

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## The reSPECT project for a flexible and fast total body nuclear imaging diagnoses with high-Z organic scintillators

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In this contribution we present a new total body SPECT gamma detector concept that relies on a tungsten metal frame, that serves both as a collimator and as a container for the scintillator segments, organized in a grid geometry with holes of few millimeter (diameter). The active material is organic scintillators enriched with high-Z elements allowing to profit of the extremely fast scintillation process and a reduction in costs. The enriched scintillator produced for this reSPECT project have been loaded with Bismuth in concentration from 2 up to 10%. The results are promising in terms of light output and photon-interaction probability via photoelectric effect. A readout system that can properly integrate the short signals and handle high event rates is needed; we therefore considered a custom design tuned for fast scintillation events with an independent channel for each scintillator segment allowing for possible applications of SPECT in advanced theragnostic. Multiple FPGA-based modules will combine the readout channels and pre-process the data in real-time.
Images from patients of Policlinico Umberto I Hospital have been exploited as starting point for a Montecarlo based reconstruction study with the aim of optimizing the detector geometry and of evaluate the achievable performances. In this contribution, the expected performances of a total body system will be presented together with the results obtained with the first prototypes.

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## Fast-Timing Detector through Redshifted Cherenkov Radiation

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This study explores advancements in Time-of-Flight PET (TOF-PET) technology, specifically focusing on Redshifted Cherenkov Radiators (RCR) to enhance time resolution in radiation detectors. TOF-PET utilizes radiotracers labeled with positron-emitting radionuclides to track biological targets, aiding in diagnosis, treatment planning, and therapeutic monitoring. Recent hardware, radiotracer, and image analysis advancements have expanded TOF-PET's clinical applications. This study concentrates on the development of RCRs to further improve TOF-PET capabilities. Evaluation of solvents—ODE, CHCl3, DMSO—reveals ODE's superior UV transparency. The addition of POPOP dopant in ODE significantly enhances the detection of Cherenkov photons, demonstrating the potential of RCR. Time-correlated single photon counting (TCSPC) analysis indicates that RCR detectors offer competitive time responses compared to pure Cherenkov detectors. Coincidence measurements with LYSO detectors demonstrate favorable Coincidence Time Resolutions (CTR) for RCR detectors. These findings offer insights into the optimization of RCRs, suggesting their role in advancing TOF-PET imaging for enhanced diagnostic accuracy and therapeutic monitoring.

**Poster Session / 6**

## Compositional engineering of timing properties in Ce-doped multicomponent garnet-type scintillators

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Scintillators substantially faster than LYSO:Ce are currently in demand for medical imaging, particularly, for TOF-PETs. Ce-doped multicomponent garnets are prospective candidates due to the freedom for engineering of their scintillation properties by varying their composition without detrimental deterioration of the crystal structure and by appropriate codoping. We report on a study of the capability to substantially improve the timing properties of Ce-doped multicomponent garnets by engineering of gallium and gadolinium content in their lattice. Cathodoluminescence and photoluminescence spectroscopies with temporal resolution in picosecond domain were exploited, and the interpretations were supported by the simulations of excitation transfer. Lu0.75Gd2.25Ga2.5Al2.5O12:Ce codoped with Mg and Y3(Al1-xGax)5O12:Ce with different Al and Ga contents were studied. Our measurements and simulations show that the excitation transfer to the activator ion Ce3+ is delayed for tens or a few hundreds of nanoseconds due to the transfer of a part of the excitation through the Gd-sublattice. However, the delayed excitation transfer can be blocked by aliovalent codoping, in particular, by Mg. The PL intensity dependence on temperature fitted well with the Arrhenius formula, however, the extracted activation energies changed irregularly with Ga content. The experimental results were interpreted by the influence of a new channel for nonradiative recombination as the Ga content increases.