PetVision Newsletter; 2nd edition

December 2024

Welcome!

Enter the world of the PetVision Newsletter for a glimpse into an innovative project reshaping cancer diagnostic in the EU. Explore insights into the performance evaluation of panel detectors in PET imaging. Follow the current research results of PetVision project that were recently presented at the 2024 IEEE Nuclear Science Symposium, USA. Join us in tracking PetVision's progress and expect exciting updates on achievements and simulations in upcoming Newsletter editions.

About the project

Over 2.7 million people in the EU were diagnosed with cancer in 2020, while 1.3 million people lost their lives to it. Cancer cases are predicted to increase by 24% by 2035, making it the leading cause of death in the EU. The current leading imaging diagnostic technique sensitive to cancer is Positron Emission Tomography (PET). Due to the high implementation cost of PET, this highly sensitive diagnostics is only available in less than 0,5 % of the medical centers in the world. One of the main components of the overall cost is the cost of PET scanners.

The main objective of PetVision EIC Pathfinder project is to develop a flexible, modular PET scanner, based on planar detector panels with exquisite time-of-flight (TOF) resolution and sensitivity. It will enable affordable, fast and precise dynamic scanning, and hence improve access to early cancer detection and therapy follow-up, paving the way for personalized medicine.

Have a look at the PetVision video presentation and visit our website and LinkedIn.

Panel Detectors in PET Imaging: performance evaluation through Monte Carlo simulations

Traditional PET scanners with a full-ring design have proven invaluable in clinical diagnosis and research; however, they are not without limitations. Besides its high cost, the ring geometry, with its relatively large radius, may not always be optimal for detector placement across all applications. In the PetVision project, we aim to enhance the flexibility of PET systems and tailor their design to accommodate both patient-specific needs and the specific objectives of a PET scan.

A flat-panel detector design allows for positioning the detectors very close to the patient, enhancing both sensitivity and spatial resolution. Our exploration begins with a 2-panel PET system (Figure 1A). We aim to demonstrate that, with adequate technical characteristics, even a simple 2-panel configuration can produce image quality suitable for clinical applications despite providing only limited angular coverage.

PET scanners with limited angular coverage typically produce distorted 3D images with artifacts. However, in time-of-flight (TOF) PET, a high-precision measurement of the difference in the arrival times of the two annihilation photons helps to “precisely” (21 mm) localize the emission point along the line of response (LOR). This additional information reduces the angular sampling requirement needed to obtain distortion-free and artifact-free PET images as well as reduces the level of noise (Figure 1A).

To meet the described aim, in the PetVision project we are developing extremely fast PET detectors with a target coincidence time resolution of around 70 ps. Compact 30 x 30 cm2 panels using 3x3x10 mm3 L(Y)SO crystals are evaluated through detailed Monte Carlo simulations on high-performance computing clusters. The results highlight the benefit of excellent time-of-flight information in enhancing image quality as well as in terms of spatial resolution and noise (Figure 1B). Simulations of larger panels, 120 x 60 cm2, consisting of a 4 x 2 configuration of smaller panels, show that the design is scalable and can be used for total-body (extended field of view) imaging (Figure 1C).

The panel detector design’s notable advantage lies in its flexibility and modularity, allowing the assembly of cost-effective long axial field-of-view (LAFOV) scanners by combining multiple panels. This flexibility, combined with mobility, will open new application avenues, such as imaging in sitting or standing positions, providing higher comfort during scans, and improving accessibility for patients with mobility issues. Additionally, its open geometry will offer access to the patient, which is particularly useful for procedures like biopsies or particle therapy, as well as imaging in Intensive Care Units (ICUs). Moreover, the open design will allow for novel combinations with other imaging modalities, such as MRI, paving the way for integrated and comprehensive diagnostic approaches.

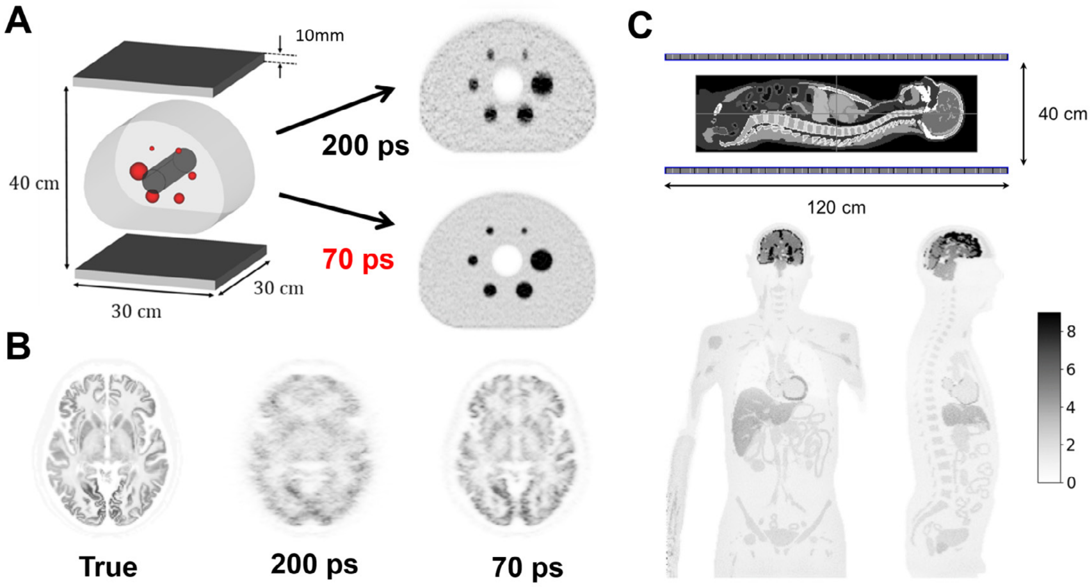

Figure 1: *(A) Schematic illustration of the flat-panel PET scanner design. The panel design allows for a flexible distance between panels, and sensitivity can be greatly improved by reducing this distance. Excellent coincidence timing resolution enables imaging with such an open geometry without distortions or artifacts. (B) Impact of time-of-flight (TOF) information on the reconstructed images of a Monte Carlo simulated brain scan. (C) Panels are modular, allowing for the construction of long axial field-of-view scanners. The image shows the reconstructed result of a simulated 4-minute FDG scan, where the panels have a 70 ps coincidence time resolution.*

PetVision participated at the 2024 IEEE Nuclear Science Symposium

Partners of the PetVision consortium participated at the 2024 IEEE Nuclear Science Symposium, Medical Imaging Conference, and Room-Temperature Semiconductor Detectors Symposium that was held in Tampa, Florida from 26. October to 2. November 2024. In this scope, also we presented some of our main recent research.
David Gascon from University of Barcelona summarized current developments in the PetVision project. In scope of the project, we aim to develop a simple pilot demonstrator - a modular panel PET device with a coincidence timing resolution of about 80 ps FWHM, close to the intrinsic timing limit of currently available PET scintillators. This resolution is several times better than the current gold standard of 214 ps FWHM achieved with the current clinical state-of-the-art device. With such excellent timing, the panel detectors can cover only a limited solid angle to reach the same sensitivity or improve the sensitivity in the case of a total-body imager. To realize the device, a package of breakthrough innovations in the detector design, photo-sensor, and front-end electronics are planned:

- We plan to Integrate the SiPM photo sensor with the readout ASIC by using medium-density interconnection and Flip Chip packaging techniques (2.5D integration).
- We are developing the next generation of fast and efficient SiPM photosensor to increase the detection efficiency of the scintillation light by maximizing the sensitive area of the latest FBK HD-NUV SiPMs by using Through Silicon Vias (TSV).
- Based on the FastIC family, we are developing a new front end ASIC optimized for vertical integration and consisting of the analog front-end, discriminator and integrated digitization that will enable both timing and energy measurements with a jitter floor of 10 ps or better.

The breakthrough technological advances in Time-of-Flight PET detection can translate to a revolutionary, fully modular, cost-accessible, flexible family of devices for applications from the standard PET center to the surgery, epilepsy clinics, intensive care units and even emergency rooms and in mobile units installed in vans.

Alberto Gola from Fondazione Bruno Kessler (FBK) presented their development of NUV-sensitive Deep-junction (NUV-DJ) SiPMs, a new technology optimized for fast timing applications. In recent years, FBK has developed several Silicon Photomultiplier (SiPM) technologies, particularly for applications such as time of flight-positron emission tomography (ToF-PET) where fast timing is crucial. A recent development is the Near-Ultraviolet, Deep-junction (NUV-DJ) SiPM technology that provides improved photon detection efficiency (PDE) and single photon time resolution (SPTR) with respect to the state-of-the-art SiPMs. The NUV-DJ microcell has a 40 µm pitch and features a modified design with the high-electric field region placed deeper inside the epitaxial layer, enabling an increased avalanche triggering probability even with longer-wavelength photons. The photon detection efficiency showed outstanding values of 70% at 420 nm, and single photon time resolution of 36 ps FWHM and 65 ps FWHM were measured using a high-frequency readout on 1x1 mm² and 4x4 mm² SiPMs, respectively. Coincidence time resolution of less than 100 ps FWHM in the readout of 2.76x2.76x18 mm³ LYSO:Ce crystals was achieved with a high frequency readout (115 ps FWHM with standard readout electronics). These findings represent cutting-edge advances in timing and photon detection efficiency performance and are very promising for TOF-PET and high-energy physics applications employing LYSO, LSO, BGO, and LaBr3 crystals, in scenarios where a high photon detection efficiency in the near-ultraviolet range combined with excellent timing is needed.

Michele Penna from Fondazione Bruno Kessler (FBK) discussed the limits of the time resolution and avalanche build-up analysis of FBK NUV-HD-MT SiPMs. Silicon Photomultipliers (SiPMs) timing performance, in particular the coincidence time resolution (CTR), is of paramount importance in applications like Time-of-Flight Positron Emission Tomography (ToF-PET). In turns, the coincidence time resolution strongly depends on the single photon time resolution (SPTR) defined as the time jitter when a single photon is detected by the SiPM. The FBK performed a characterization of the recently introduced FBK Near Ultra- Violet-High Density with Metal-filled Trenches (NUV-HD-MT) technology in terms of its timing performance by measuring the single photon time resolution of single Single Photon Avalanche Diodes (SPADs) with different cell sizes. The single SPADs show an excellent single photon time resolution of 17.6 ps, 22.5 ps and 24.4 ps FWHM for the 30µm, 40µm and 50µm microcell respectively. To investigate the effect of a peculiar metal-layer layout, involving the metal masking of the border regions of the SPAD, we compared SPADs with 40µm cell size and two different masking versions having 0 µm and 3 µm overlap with the nominal active area, showing that the SPTR is strongly improved by the metal masking in the microcell layout due to the better capacitive coupling. Additional single photon time resolution measurements performed on SiPMs with different active areas show that the masking is more effective on larger sensors. Thus, additional studies are ongoing to further investigate this effect and to deeply study the avalanche build-up jitter in different injection positions inside the microcell and of the SiPM.

Matic Orehar from University of Ljubljana presented results of a simulation study of the flat panel detectors for positron emission tomography. Flat panel detectors provide a cost accessible, compact, flexible and modular alternative to standard cylindrical scanners. The modular nature means that a scanner could be assembled by combining the detectors in any number of ways, such as using two or four panels to achieve different angular coverages or placing panels consecutively to achieve total body coverage. This new geometry also comes with significant challenges in image reconstruction. Sufficient coincidence timing resolution is required to avoid artifacts in reconstructed images due to limited angular coverage and to compensate for the reduced sensitivity. The flat panel scanners were simulated using GATE software and images were reconstructed using CASToR. Over a million core hours were utilised to obtain these results, making heavy use of high-performance computing. Various phantoms and metrics were used to compare the performance of the flat panel scanners to a reference scanner based on the current state-of-the-art clinical scanner, Siemens Biograph Vision. The results demonstrate that with improved timing resolution, flat panel scanners can achieve image quality comparable to the reference scanner while using less than a third of the scintillator material or achieve long axial coverage (1.2 m) while using the same amount of material and achieving homogeneous contrast across the axial length of the scanner.

Thibault Marin from Yale presented simulation results for a PET system under development, with ultra-high TOF resolution and depth-of-interaction (DOI). The proposed system is arranged for long axial field-of-view scanning using flat detector panels. The performance of the system for varying TOF and DOI resolutions while incorporating geometric corrections during reconstruction was evaluated. Results demonstrate the promising performance of a 2-panel, 70 ps TOF resolution system with 2.5 mm DOI resolution, as evidenced by traditional and task-based image quality metrics.

The listed presentations show that PetVision consortium is making considerable progress in developing the technologies required to build the pilot demonstrator of a modular panel PET device with very high timing resolution and thus towards meeting the goals of the project.

You can meet us here:

- Society of nuclear Medicine and Molecular imaging (SNMMI) 2025 (New Orleans, USA, June 2025)
- IEEE Medical Imaging Conference 2025 (Yokohama, Japan, November 2025)

What to expect in the next Newsletter?

Early results of the assessment of photosensors and front-end chips (FASTIC+).

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101099896. You have received this email because you have subscribed to our newsletter. If you wish to unsubscribe, please send a feedback e-mail.

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