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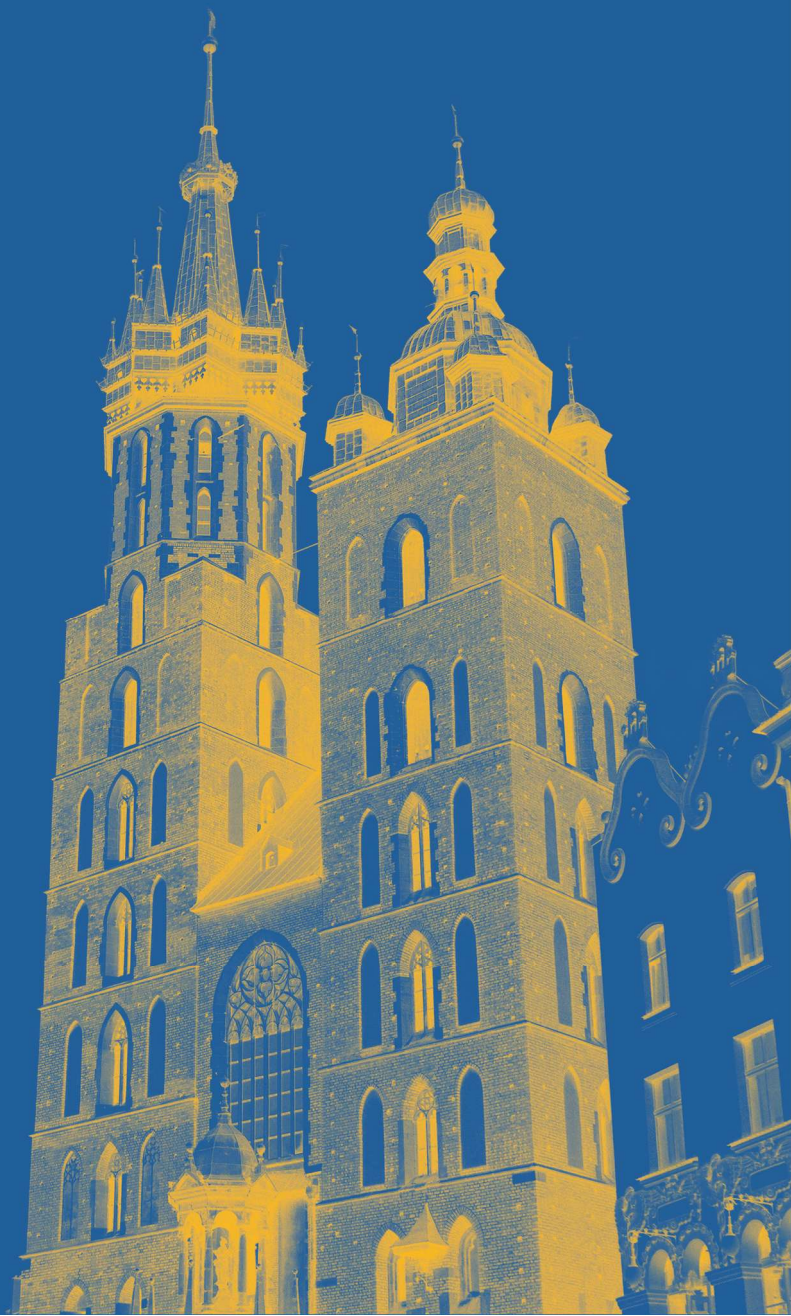
Faculty of Physics, Astronomy and Applied Computer Science,
Jagiellonian Universityin Krakow, Poland

BOOK OF ABSTRACTS



Abstract list

1. The 103Pd and 109Pd Bisphosphonate Complexes for Auger Electron Therapy of Bone Metastatic Tumor Cells

Geeva Prasanth Annamalaisamy[1], Monika Lyczko[1], Aleksander Bilewicz[1]

Institute of Nuclear Chemistry and Technology, Warsaw, Poland

Palladium radioisotopes ^{103}Pd and ^{109}Pd emit Auger electrons, which are known for their high linear energy transfer (LET) and ability to induce lethal damage in malignant cells at the subcellular level. These properties make them promising candidates for targeted radiotherapeutic applications.

For application of these radionuclides in bone cancer therapy, we synthesized ^{103}Pd and ^{109}Pd complexes containing one alendronate molecule and two bipyridyl ligands. The resulting compounds exhibited high stability and strong binding affinity toward hydroxyapatite, the primary inorganic component of bone tissue.

In comparative cytotoxicity assays, these radioactive complexes demonstrated higher cytotoxic effects against human prostate cancer cells (DU 145) and HER2-positive ovarian cancer cells (SKOV-3) than both ^{125}I-labeled trastuzumab (an established Auger emitter conjugate) and cisplatin.

The biological evaluation revealed that ^{103}Pd (Auger emitter) and ^{109}Pd (dual beta and Auger emitter) display pronounced cytotoxicity. It was also observed that, following the decay of ^{109}Pd, the decay product ^{109m}Ag dissociates from the complex. In contrast, the decay product of ^{103}Pd, ^{103m}Rh, remains bound within the complex. This retention is likely due to the stabilizing influence of the delocalized electron system in the aromatic bipyridyl ligands, which hinders the release of ^{103m}Rh.

These findings support the feasibility of employing the ^{109}Pd/^{109m}Ag and ^{103}Pd/^{103m}Rh pairs as in situ generators for radiotherapeutic applications and justify further investigation of this strategy in preclinical models.

This project was funded by the National Science Center Poland, grant no. 2022/45/B/ST4/00825.

The radionuclide ^{103}Pd was produced as part of the European Medical Isotope Program: PRISMAP.

2. Constraining CP Violation in Ortho-Positronium Decays at 7 Tesla with NeuroSphere PET Modules

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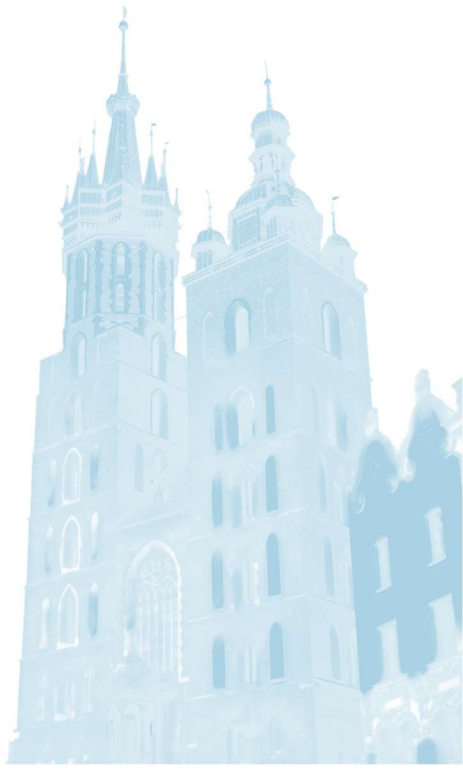
The decay properties of ortho-positronium (o-Ps), a bound state of a positron and an electron that can form prior to annihilation, serve as a probe of material properties (e.g., differentiating porosity or tissue pathology) and fundamental physics (e.g., testing quantum electrodynamic theory or constraining fundamental symmetry violation). In this work, we demonstrate the capability of the NeuroSphere MR-compatible PET modules to measure the o-Ps à 3g decay lifetime and kinematics under an applied 7-T magnetic field. A target comprised a Na-22 positron source was placed between two slabs of polyvinyltoluene (PVT), which serve both as the formation region for o-Ps and positron emission time trigger. The target was positioned at the center of a ring of 20 NeuroSphere PET detectors (pixelated LSO arrays coupled to silicon photomultipliers), and the system was mounted on a motorized turntable at isocenter of the 7-T MRI base field for data acquisition. The long-lived component of the o-Ps decay lifetime in PVT was measured to be 31.2 ns. The measured asymmetry in o-Ps decays under the effective reversal of the magnetic field direction, as a function of the angle between the most energetic decay photon and o-Ps spin polarization axis, was measured to be 0.0102 +/- 0.0100, consistent with zero asymmetry (no CP violation).



3. SiPM Performance Characterization for Total-Body J-PET: Hamamatsu vs. Onsemi

Keyvan Tayefi Ardebili[1,2], Szymon Niedźwiecki[1,2], Pawel Moskal[1,2]

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Total-body Positron Emission Tomography (PET) has begun to see clinical use; however, widespread adoption in hospitals requires a significant reduction in construction costs [1]. We are developing a cost-effective total-body J-PET system based on plastic scintillator strips coupled with Silicon Photomultipliers (SiPMs) at their axial ends [2]. A critical aspect of optimizing this involves the comparison of different SiPM types.
SiPMs, representing the latest generation of photomultipliers, offer significant advantages over traditional Photomultiplier Tubes (PMTs) [3], including low operating voltage and insensitivity to magnetic fields, making them ideal for various applications, including nuclear medicine. This study focuses on characterizing and comparing the performance of different SiPM types from leading manufacturers, Hamamatsu and Onsemi, to identify the optimal SiPM for the total-body J-PET system. In the experimental phase, individual detector units comprising plastic scintillator strips (6 × 6 × 25 mm3) coupled with Hamamatsu (S14160-6050HS) and Onsemi (MICROFJ-60035-TSV) SiPMs of identical active surface area were thoroughly characterized. A collimated beam of 511 keV photons from a Na-22 isotope source was employed to evaluate key detector performance parameters, including signal amplitude, rise time, fall time, charge, and Time of Flight (TOF) resolution [4]. Following this thorough characterization and comparative analysis, the optimal SiPM was identified for integration into the total-body J-PET system, contributing to its cost-effective and high-performance design.

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4. Cryo-TEM and Python-Driven 3D Reconstruction of breast cancer-derived extracellular vesicles for radiopharmaceutical characterization

Kriti Awasthi[1,2] , Narendra Rathod[3], Magdalena Kostkiewicz[4] and Ewa Stepien[1,2]

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Extracellular vesicles are upcoming versatile nano-carriers for the use in diagnosis and therapeutic delivery in the oncological studies. In triple negative breast cancer (TNBC), EVs secreted by MDA-MB-231 cells are specifically designated to use for radiopharmaceutical applications due to their intrinsic tumour tropism and biocompatibility. However, their functional usage in nuclear medicine needs to be discovered and unrevealed, which requires a deeper understanding of their nanoscale morphology and its surface architecture, which impacts the radionuclide labelling, stability and targeting efficiency. In this research, we employed cryo-TEM images combined with a custom Python-based computational pipeline to perform 3D tomographic reconstructions of MDA-MB-231 derived EVs. The EVs were isolated via differential ultracentrifugation and used for high-resolution cryo-TEM imaging. The tilt series arrangements were processed using IMOD and 3D reconstruction, segmentation and rendering were processed using python tools which includes NumPy, scikit-learn image and pyTom. These reconstructions reveal diverse morphologies ranging from single membrane and multivesicular forms to membrane protrusions and internal cargo compartments features critical for understanding vesicle behaviour in vivo. The characterisation of potential radiolabelling sites and evaluated surface geometry relevant for conjugating PET/SPECT tracers was also studied. This consolidative approach provides a structural foundation for optimizing EV-based radiopharmaceutical workflow. By using open source python tools for tomographic analysis, this workflow allows reproducible and high resolution EV characterisation which is important for advancing precision imaging and targeted radiotherapy in the field of oncology.

Acknowledgements :
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research infrastructure of the National Synchrotron Radiation Centre SOLARIS" under contract nr 1/SOL/2021/2. We acknowledge the SOLARIS Centre for access to the cryogenic electron microscope, where the measurements were performed.

5. Fluorescence-Guided Analysis of EV Behavior in 3D Breast Cancer Spheroids: Toward PET-Compatible Theranostics

Kriti Awasthi[1,2] , Magdalena Kostkiewicz[3], Maciej Słotwiński[1,2] and Ewa Stepien[1,2]

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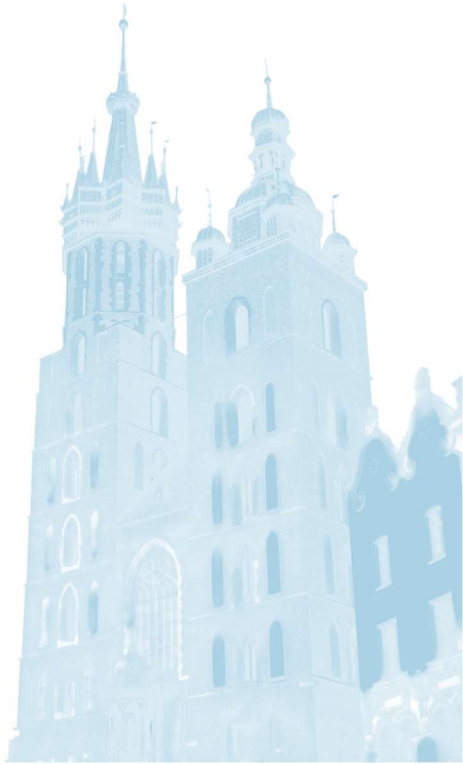
To study the characteristics of in-vivo tumours with respect to its cellular heterogeneity and their spatial architecture, the most impactful approach will be three-dimensional (3D) tumor modeling of spheroids, which is a powerful alternative to existing traditional 2D monolayer models. With respect to triple-negative breast cancer (TNBC), as per the disease's aggressiveness and limited treatment options these models are valued. In this research, we utilised GFP-expressing MDA-MB-231 cells to generate reproducible 3D spheroids for investigating naturally secreted extracellular vesicles (EVs). EVs are versatile and play an important role in intercellular communication and recently highlighted both as biomarkers and potential carriers in precision oncology. Our model allows real time fluorescence based imaging of EV uptake and distribution within spheroid layers, eliminating the need for artificial dye labelling and preserving EVs integrity. The major highlight of this project is the comparative profiling of EVs derived from 2D versus 3D cultures, with focusing on identifying the dimensionality which can influence EV production and surface markers. Importantly, this model also provides a platform for the future integration of radiopharmaceuticals , specifically for PET based tracking and theranostic applications. By enhancing imaging workflows with physiological relevance to the microenvironment, this study paves the way for EV based radiotracer development in oncology. Our results depict the utility of 3D spheroid systems in EV research and carve their translational potential for future radiopharmaceutical imaging and delivery schemes in cancer biology.

Acknowledgements :
The research was financed by the Polish agency National Science Center as part of the OPUS project for E.S. (2022/45/B/NZ7/01430)

The research was financially supported by the Research Support Module 1 in the Strategic Programme Excellence Initiative at Jagiellonian University, 2025. ID: RSM/109/AK



6. Radiation Damage Monitoring in the Upgraded VELO Detector at LHCb

Saliha Bashir, Tomasz Szumlak, Agnieszka Oblakowska-Mucha

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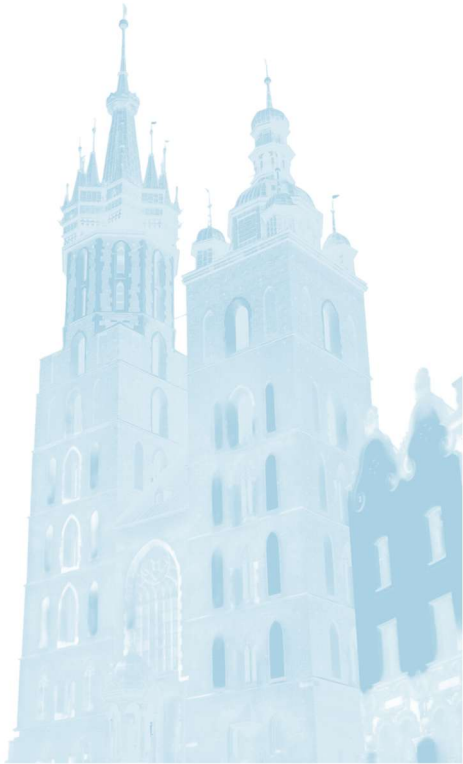
The upgraded VELO (VErtex LOcator) is a lightweight hybrid pixel silicon vertex detector that surrounds the interaction region of the LHCb experiment. It plays a critical role in the precise reconstruction of both primary and secondary vertices. Silicon-based semiconductor detectors are well-suited for this purpose, offering high spatial resolution, fast response times, and the ability to handle high interaction rates.

However, the intense radiation environment of the Large Hadron Collider (LHC) poses a significant challenge to the longevity of silicon sensors. Radiation-induced damage—including increased leakage current, charge trapping, and shifts in depletion voltage—progressively degrades detector performance. Accurate understanding and quantification of this damage are essential for optimizing current detector performance and guiding the design of future upgrades.

This work focuses on radiation damage monitoring in the upgraded VELO detector. A data-driven study of particle fluence is presented to characterize the radiation environment during LHC operation. By correlating fluence estimates with observed changes in detector behaviour, this study aims to refine predictive models of radiation damage and contribute to the development of robust long-term operational strategies for silicon vertex detectors.



7. Modern Data Correction Approaches in Positron Emission Tomography

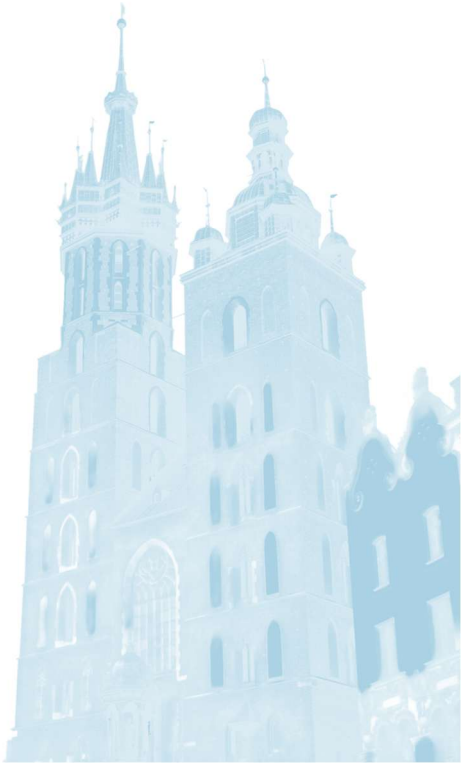
Reimund Bayerlein

University of California Davis, USA

Positron Emission Tomography (PET) is a powerful molecular imaging modality widely used in oncology, neurology, and cardiology. However, the accuracy and diagnostic value of PET images depend heavily on the application of robust data correction techniques. In hybrid PET/CT and PET/MR systems, attenuation correction (AC), scatter correction (SC), and motion correction (MC) are essential to mitigate various physical effects that compromise image quality and quantitative accuracy.

Attenuation correction addresses the reduction of photon intensity due to tissue absorption, a critical factor for accurate tracer quantification. Scatter correction compensates for Comptonscattered photons that otherwise introduce image blurring and quantitative bias. Motion correction targets patient motion – caused by respiration, cardiac activity, voluntary movement, or physiological processes – aiming to restore lesion sharpness and improve quantification across the extended duration of PET acquisitions.

The presentation will highlight recent advances in each correction category, driven by innovations in instrumentation, detector materials, scanner geometries, and clinical demands. We will cover both classical analytical methods and emerging deep learning-based approaches, emphasizing their theoretical foundations, practical implementations, and comparative effectiveness in modern PET workflows.



8. Developing efficiency maps for double isotope studies with J-PET

E. Y. Beyene[1, 2], P. Moskal[1, 2], E. Stepien[1, 2] for the J-PET Collaboration

[1]*Faculty of Physics, Astronomy and Applied Computer Science, Jagiellonian University, Cracow, Poland*.
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The study is aimed at developing efficiency maps for both two-photons (2γ) as well as two-photons and prompt gamma (2γ + γ_P) detection modes for the simultaneous double isotope studies using the modular prototype Jagiellonian Positron Emission Tomography (J-PET) scanner [1, 2]. Simulations were performed using Gate 9.4 modeling back-to-back 511 keV annihilation photons and 1275 keV prompt gammas from ^{22}Na source.

A uniform cylinder volume source (radius = 18.475 cm) was simulated for the 2γ and 2γ + γ_P cases. For representing a continuous ^{22}Na source, events were registered in the 3D grid of 2.5 mm × 2.5 mm × 2.5 mm voxel width. The candidates of 2γ and 2γ + γ_P events were selected based on the energy loss, time and positions of interactions [1, 3]. The Efficiency maps were plotted using Cartesian coordinates and also transformed into polar coordinates aligned with the cylindrical geometry of the scanner. Additionally, absolute efficiency line profiles were evaluated for both prompt and 511 keV using the single photon emission model, with comparisons made to experimental measurements.

The acquired profiles and maps reveal performance differences between the two types of events and efficiencies, providing insight into how image reconstruction, analysis, and separation can be improved in modular J-PET systems for double isotope studies using pure $\beta^+$and $\beta^+ + \gamma_P$ emitting isotopes [1].

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[3] P. Moskal et al., Sci. Adv., vol. 10, p. eadp2840, 2024.

9. Treatment and online PET imaging of a mouse tumor with radioactive ion beams

Daria Boscolo[1], Giulio Lovatti [2], Olga Sokol[1], Tamara Vitachio[1], Martina Moglioni[1], Francesco Evangelista[2], Emma Haettner[1], Walter Tinganelli[1], Christian Graeff[1], Uli Weber[1], Christoph Schuy[1],Munetaka Nitta[2], Daria Kostyleva[1], Sivaji Purushothaman[1], Peter Thirolf[2], Jonathan Bortfeldt[2], Katia Parodi[2], Marco Durante[1], Christoph Scheidnberger[1]

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While charged particle therapy is potentially the most effective radiotherapy technique available, it is highly susceptible to range uncertainties. Radioactive ion beams (RIBs) have long been proposed for therapy applications, offering the potential for image-guided treatment through positron emission tomography (PET). In this contribution, we will present the results of the first preclinical study using 11C ion beams combined with real-time PET imaging. The study investigated whether RIB could provide precise tumor control while minimizing toxicity to organs-at-risk (OAR) [1].
In particular, 11C-ion beams were produced via in-flight separation, characterized, and precisely modulated to treat synergetic tumors implanted in the mouse neck area. The tumors were close to the spinal cord, increasing the risk of radiation-induced myelopathy. Mice were treated with a single dose application of 5 Gy or 20 Gy, and all the irradiations were imaged in real-time using a custom-built PET scanner. Tumor growth, spinal cord toxicity, and PET-based activity were evaluated. Complete tumor control was obtained with the highest dose. Low-grade neurological side effects were correlated to the positron activity measured in the spine. Additionally, a dose depenent biological washout of the PET signal was observed, indicating a potential component of vascular damage at high doses. This experiment marks the first instance of tumor treatment using RIB and paves the way for future clinical applications.

[1] D. Boscolo et al., First image-guided treatment of a mouse tumor with radioactive ion beams, submitted. [Online]. Available: https://doi.org/10.48550/arXiv.2409.14898

10. In vivo radiation sensing using phase-change ultrasound contrast agents

Bram Carlier[1], Edmond Sterpin[1], Uwe Himmelreich[1]

[1]*KU Leuven, Belgium*

Radiotherapy is one of the most effective cancer treatment strategies, able to benefit up to 50% of the cancer patients [1]. In the majority of treatments, external photon beam radiotherapy is used. Yet, photons feature unfavourable depth-dose characteristics resulting in undesired exposure of healthy tissue. Therefore, proton therapy has emerged as a promising alternative. Owing to the Bragg peak, the proton dose can be accumulated precisely in the tumour, with minimal damage to healthy tissue. Nevertheless, the sharp dose gradients associated with proton treatments, make them sensitive to uncertainties, e.g. induced by the conversion of CT HU to proton stopping powers, patient setup errors, patient motion or anatomical changes throughout the treatment [2]. While they are accounted for during treatment planning, e.g. by using margins around the tumour, the resulting (often overly conservative) treatment plans again increase exposure risks to healthy tissue and less efficient irradiation of the tumour, obscuring the true benefits of proton therapy.

Therefore, uncertainties are ideally reduced by using *in vivo* dosimetry or range verification technologies. Nevertheless, despite decades of research giving rise to technologies like PETbased range verification, prompt gamma imaging and ionoacoustics, none of the proposed approaches have entered standard clinical practice due to various limitations including poor resolution, indirect relationship to the proton range, complex detector development or weak signals [2–4].

To overcome these limitations, we proposed an alternative method for *in vivo* radiation sensing based on radiation-sensitive phase-change ultrasound contrast agents. In particular, we developed superheated nanodroplets, which can be converted into echogenic microbubbles upon proton irradiation [5–7]. The radiation deposition is subsequently derived from the resulting ultrasound contrast. In a first phase, we demonstrated the submillimetre range retrieval performance of the proposed technology in nanodroplet-containing gel phantoms [5–7]. Afterwards, we confirmed the biocompatibility of the used contrast agents *in vitro*, and confirmed the dose and energy dependent radiation response *in vivo*, in the liver of healthy rats [8]. Finally, we are also developing computational prediction models able to convert the original treatment plan into a predicted vaporization map. This way a clinician simply needs to compare the observed and predicted response to determine whether the treatment was indeed delivered as intended.

Together these results form a convincing foundation to promote clinical translation and pave the way for alternative applications, like radiation-induced drug delivery employing these radiation-sensitive contrast agents as theranostic drug delivery vehicles.

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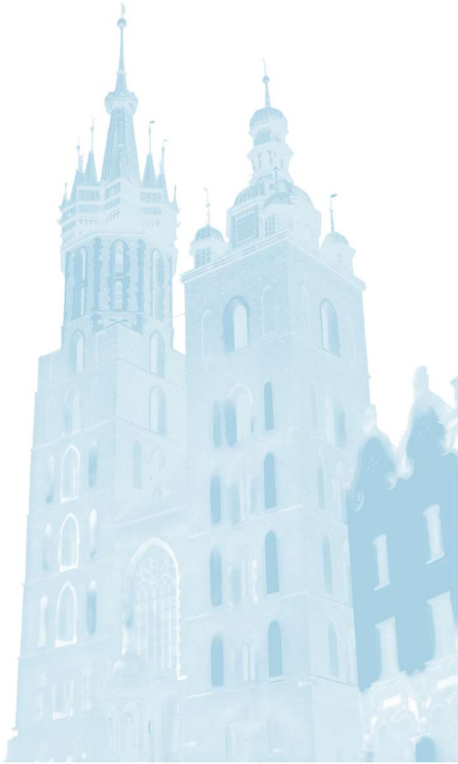
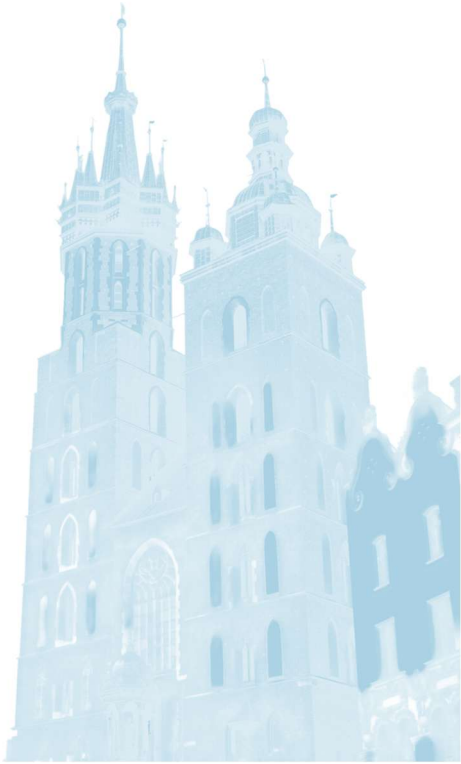


11. 30th anniversary of the Heavy Ion Laboratory of the University of Warsaw and its contribution to the production of medical radioisotopes

Jarosław Choiński

Heavy Ion Laboratory, University of Warsaw, Poland

In 2024, the Heavy Ion Laboratory of the University of Warsaw (HIL) celebrated its 30th anniversary. When designing the Laboratory building, one of the boxes was designated for an installation dedicated to the production of radioisotopes using U-200P heavy ion cyclotron beams. The presentation will provide a brief history of the HIL construction. The team's involvement in the production of radioisotopes obtained in heavy ion nuclear reactions will be emphasized. The history of HIL's expansion to include the Radiopharmaceutical Production and Research Center (RPRC) will also be discussed. The center houses the PETtrace cyclotron, which allows for the acceleration of protons or deuterons. In the course of implementing two research projects: "Alternative Methods for the 99mTc Production" Agreement No PBS1/A9/2/2012 funded by the National Centre for Research and Development and "The development of methods for production of new radiopharmaceuticals based on Sc radionuclides used in positron tomography (PET)" [PET-SKAND] agreement no PBS3/A9/28/2015 awarded to a consortium, and financed by the National Centre for Research and Development, an external stand for irradiation of solid targets in metallic or powder form was built at the RPRC. Having such an experimental setup in Poland allowed HIL to enter a joint program implemented by the Jagiellonian University, the Institute of Nuclear Chemistry and Technology and HIL called Development of three-photon emitting radiotracers for positronium imaging, agreement no UMO-2021/43/B/ST2/02150, financed by the National Science Centre.



12. New precision limits on CPT symmetry test in positronium with J-PET

Neha Chug[1,2] and Paweł Moskal[1,2]

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[2]*Center for Theranostics, Jagiellonian University, Cracow, Poland*.

We present new results from a test of CPT symmetry in ortho-positronium (o-Ps) decays with the Jagiellonian Positron Emission Tomograph (J-PET) detector. The test investigates a CPT-odd angular correlation involving the o-Ps spin and the normal to its decay plane. J-PET is a novel technology employed to detect the multi photons from positronium annihilation [1,2]. Its high geometrical acceptance and high angular resolution of annihilation photons enable the detection of various kinematic configurations, allowing for high-precision measurements of angular correlations in o-Ps decays [3,4]. We will discuss the future perspective of increasing the sensitivity of such tests with a new J-PET prototype.

Research supported by NCN projects 2019/35/B/ST2/03562, 2021/42/A/ST2/00423 and 2022/45/N/ST2/04084.

[1] P. Moskal et al., Sci. Adv., vol. 7, p. eabh4394, 2021.
[2] P. Moskal et al., Sci. Adv., vol. 10, p. eadp2840, 2024.
[3] P. Moskal et al., Nat. Commun., vol. 12, p. 5658, 2021.
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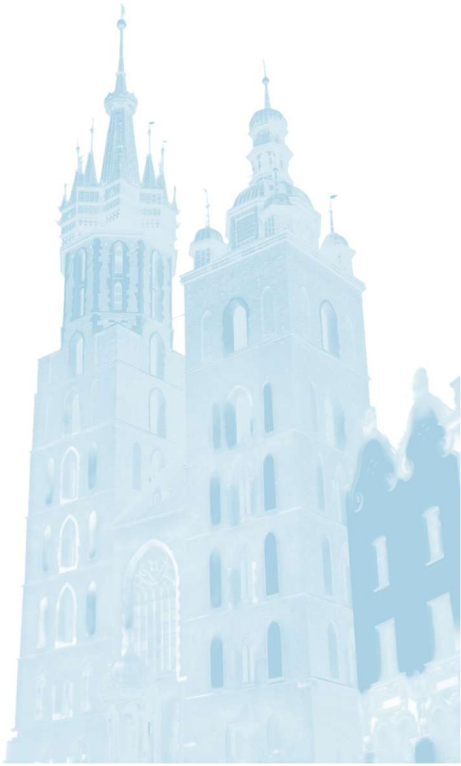

13. Graph-based event reconstruction for segmented detectors: SiFi-CM case study

Philippe Clement[1,2], Aleksandra Wrońska[1], Alexander Fenger[2], Ronja Hetzel[2,3], Achim Stahl[2], Dominik Szubartowski[1], Monika Kercz[1], Katarzyna Rusiecka[1]

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[2]RWTH Aachen, Germany
[3]GSI Darmstadt, Germany

The contribution presents a newly developed approach based on Graph Neural Networks (GNN) for event reconstruction in the 1D coded-mask gamma camera for prompt-gamma imaging in proton therapy, developed within the SiFi-CC collaboration. The aim is to determine the position and energy deposit of individual gamma interactions in the detector to enable online beam range monitoring. Its sensitive part consists of scintillating LYSO fibers, read out from both sides via silicon photomultipliers (SiPMs).

The input to the GNN is formed by raw experimental data: clustered SiPM responses within 15-ns time windows. The GNN processes this cluster data – consisting of the position, timestamp, and photon count of each SiPM – as an undirected graph.

The GNN approach enables robust reconstruction of hit positions and energy even in the presence of faulty or non-functional channels, helping to bridge acceptance gaps. The goal is to improve spatial and energy resolution compared to classical methods. The model has already been integrated into the existing data processing pipeline of the research group and thus supports the evaluation of future experiments.

This contribution highlights the potential of graph-based learning methods to address detector-specific challenges in medical imaging and lays the foundation for learning-based event processing in future PGI systems.

14. Cd(Zn)Te in Medical Imaging: Academic Innovation and Market Transformation

Tuba Conka

Fraunhofer IIS, Germany

Cadmium Telluride (CdTe) and Cadmium Zinc Telluride (CdZnTe, commonly referred to as CZT) are II-VI compound semiconductors that have emerged as pivotal materials in medical imaging due to their exceptional ability to detect X-rays and gamma rays with high efficiency and energy resolution. Their high atomic numbers (Cd: 48, Te: 52, Zn: 30) and densities (~5.8–5.85 g/cm^3) enable superior absorption compared to traditional silicon or germanium detectors, while their wide bandgaps (CdTe: 1.44 eV, CdZnTe: 1.44–2.2 eV) allow room-temperature operation, eliminating the need for cryogenic cooling. These properties make CdTe and CdZnTe ideal for advanced imaging modalities, including Single-Photon Emission Computed Tomography (SPECT), Photon-Counting Computed Tomography, and emerging applications in Positron Emission Tomography (PET). This abstract synthesizes recent academic research and market developments, to elucidate the transformative potential of CdTe and CdZnTe in medical imaging, emphasizing their material differences, current applications, and future prospects

15. Preclinical Ac-225 Imaging for Targeted Alpha Therapy: Accelerating Cancer Therapeutics

Biswajit Das[1,2], Jingjie Yu[1], David Goodman[3], Michael Streicher[3], Qihui Lyu[1], Youngho Seo[1], Javier Caravaca[1,2]

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Radiopharmaceuticals based on Actinium-225 for targeted alpha therapy (TAT) have shown encouraging results in both preclinical studies and clinical trials [1], expecting them as a promising approach for future cancer treatments [2]. In vivo imaging of small animals plays a vital role in understanding the biokinetics of 225Ac-labeled compounds and in accelerating the development and evaluation of new radiopharmaceuticals [3]. Precise imaging across a wide photon energy spectrum is essential in nuclear medicine not only for accurate diagnosis and dosimetry but also for effective monitoring of therapeutic outcomes. Although Single Photon Emission Computed Tomography (SPECT) has been the dominant technique for imaging of single gamma-emitting radionuclides over recent decades, its limited sensitivity and narrow energy range make it inadequate for imaging of therapeutic isotopes like 225Ac with broad and complex emission profiles. There remains a pressing clinical need for a high-sensitivity imaging system capable of detecting both low- and high-energy gamma rays. To address this, we propose the development of a high-sensitivity Compton imaging system and a collimated Compton camera featuring a 3D-positioning gamma-ray tracking detector [4,5]. This system is designed to enable efficient imaging of 225Ac and its decay products. At the conference, the imaging results of 225Ac daughters using these advanced imaging modalities, along with a discussion on future directions for in vivo imaging of 225Ac in small-animal models will be presented.

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16. First experimental demonstration of positronium lifetime imaging with the novel radionuclide 52Mn using J-PET scanner

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Positronium lifetime imaging (PLI) [1,2], an extension of PET, provides insight into the sub molecular properties of tissues by imaging the lifetime of the positronium atom [3]. Currently, the method is undergoing rapid development in terms of image reconstruction [4,5] and detection systems [6,7]. The first studies with the J-PET scanner using 68Ga have demonstrated the feasibility of this technique in human subjects [6]. However, 68Ga isotope has limitation mainly due to its low yield of de-excitation photons necessary for positronium lifetime estimation. In this context, 52Mn emerges as a promising candidate for PLI [8], offering a half-life of 5.59 days and a cascade of three high-energy prompt photons (1434 keV, 936 keV, and 744 keV) in almost 100% cases following the positron emission, thereby increasing the sensitivity for PLI. In this work, we report the results of the successful demonstration of PLI with 52Mn using the Modular J-PET tomograph, featuring triggerless data acquisition that enables simultaneous multiphoton detection [9]. 52Mn was produced at the Hevesy Laboratory in Department of Health Technology at Technical University of Denmark via 52Cr(p,n)52Mn nuclear reaction and transported to Jagiellonian University in Krak´ow. A NEMA IQ phantom with six spheres was used for this study. The spheres were filled with 52Mn, diluted in water to achieve required activity concentration. Event selection was based on the simultaneous detection of two 511 keV photons and one de-excitation photon, enabling reconstruction of images of the mean positronium lifetime [3,6]. The measured mean o-Ps lifetime shows good agreement with previously reported values in water [10]. This study presents the first-ever demonstration of PLI with 52Mn, marking a significant advancement and opening new possibilities for the development of PLI for clinical applications.

Acknowledgments
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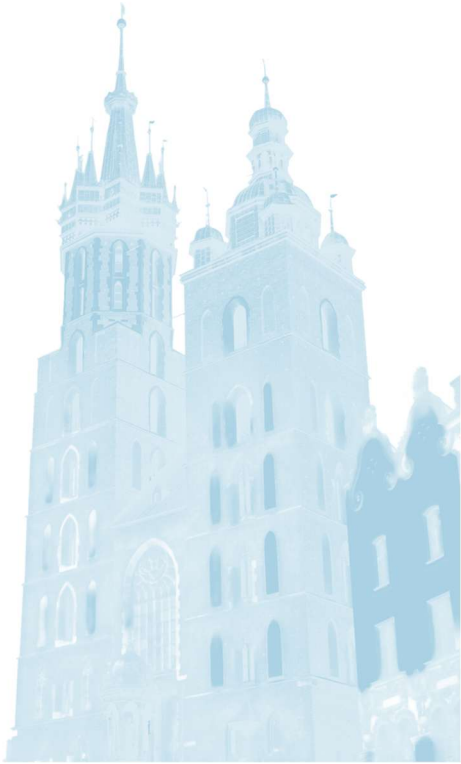

17. Application of Positron Annihilation Lifetime Spectroscopy in Polymer Composites

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In biomedical applications, polymer composites are used in tissue engineering, drug delivery systems, and implant design. Generally, the wide range of performance requirements induces active, continuous development of various polymer matrix composites—including thermoplastics, thermosets, and elastomers reinforced with micro- and nano-scale fillers. The markedly different properties of these fillers compared to the polymer matrix, their tailored architectures, and their adhesion strength to the matrix contribute to the desired performance characteristics of the resulting composites. While the properties of the matrix and filler materials can usually be determined with relative ease, assessing interfacial adhesion characteristics experimentally remains a significant challenge. Positron annihilation lifetime spectroscopy (PALS) has been proposed and explored in the literature. That is because PALS is highly sensitive to nanoscale voids or free volumes between polymer chains, which strongly influence various functional properties such as electrical and thermal conductivity, mechanical performance, and gas permeability. This sensitivity makes PALS a valuable tool for characterizing polymer structures.
It has also been successfully applied to characterize polymer-based composites, e.g, [1]. Beyond measuring the size and fraction of free volume, PALS also enables the evaluation of interfacial interaction strength between composite fillers and the polymer matrix. This is done using the interfacial interaction parameter, introduced by Liu and Jean [2] for polymer blends. The parameter is conceptually analogous to the dimensionless Flory–Huggins interaction parameter, , which describes enthalpic contributions to mixing polymers and solvents in non-ideal solutions [3]. The use of this parameter will be reviewed. Attention was also paid to studies on the influence of filler particle size and dispersion on annihilation characteristics [4,5], and changes of the free volume structure accompanying crack initiation and propagation in tensile tests in fiber reinforced polymers [6,7].

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18. Time-Based Separation of Scattering and Capture Processes in NAA Based on Monte Carlo Simulations in Geant4 toolkit

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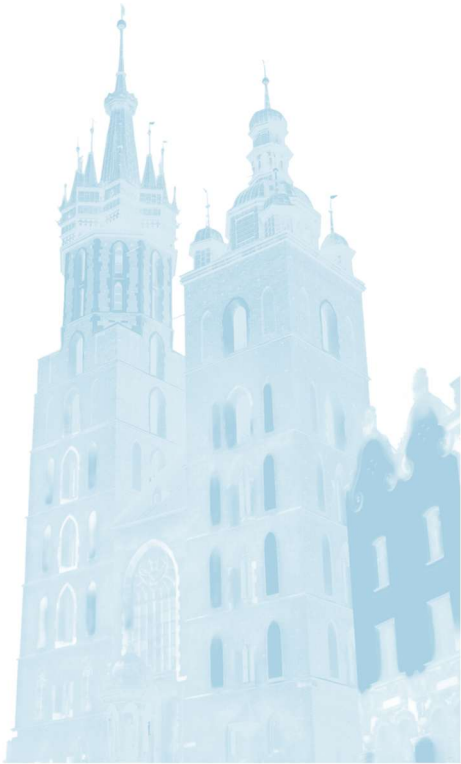
Neutron activation analysis (NAA) is a widely used method for the identification and quantification of elements, based primarily on two processes: neutron scattering and neutron capture. Each element is characterized by a unique spectrum; however, the analysis becomes challenging when spectral peaks overlap. Such a case is hydrogen and sulfur 2.23 MeV line superposition which is significant for the identification of illicit substances in aqueous environments.

We present an approach that separates spectrum originating from different processes using their temporal characteristics. Using Monte Carlo simulations, we will demonstrate how, by taking advantage of the time difference between neutron generation and the detection of a photon from neutron-matter interactions, we can successfully distinguish signals from neutron capture and inelastic neutron scattering. In addition to correctly quantifying the signals from individual atoms, this will also help reduce background from peak ambiguity, such as that for the 2.23 MeV peak mentioned above.



19. Developing analysis criteria for studies of CP symmetry with photons from o-Ps decay and Compton scattering with the Modular J-PET Detector

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Charge conjugation (C) and parity (P) transformation, both discrete symmetries, are coupled to generate Charge-Parity (CP) symmetry [1-8]. Charge conjugation (C) exchanges particles with their antiparticles, whereas parity (P) reflection reverses spatial coordinates [1-8]. Positronium is a suitable leptonic bound system to test CP discrete symmetry involving the correlations of photons momenta originating from ortho-Positronium (o-Ps) annihilation [1-8]. This work aims on developing new analysis criteria towards improving the sensitivity level for CP discrete symmetry studies in o-Ps decay. After the analysis selection chain, expectation value of CP odd operator ($\varepsilon_i \cdot k_j$) will be calculated for each event, with three hits from o-Ps → 3γ decay and a fourth hit assigned as scattering to one of the annihilation photons. The goal is to achieve substantial (factor of 2 or more) improvement compared to previously published expectation value result of 0.0005±0.0007 for the operator ($\varepsilon_i \cdot k_j$) [7]. These studies will be carried out using the modular J-PET tomograph that has 20 times higher sensitivity for o-Ps registration [7, 9]. The modular J-PET tomograph is a newly developed, flexible, and portable variant of the J-PET detection system [9].

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20. Miniature Scintillating Detectors and SiPMs: a brief Summary and a few Applications

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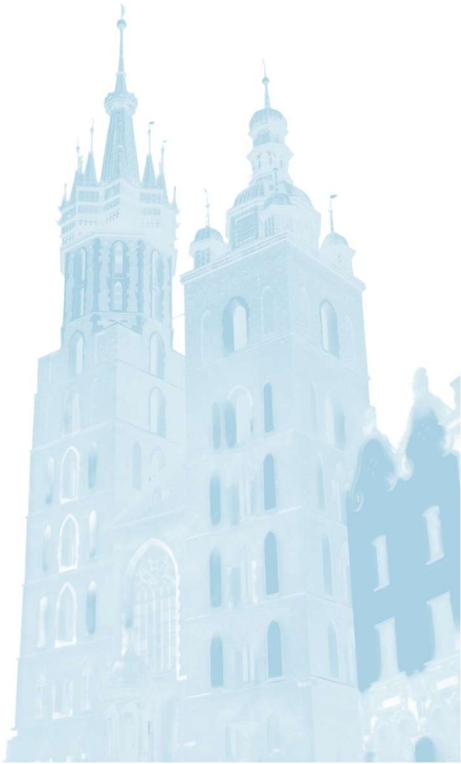
During the last decades the development of silicon photo multipliers (SiPM) has reached a high degree of maturity. A wide variety of devices from several manufacturers is available nowadays on the market, both as single sensors and as arrays. Due to the low cost of the single sensor, along with its relevant performance and the limited requirement for supporting electronics, the development of high performance miniature radiation detectors has become possible and convenient. In this contribution the main characteristics of the SiPM will be described, and the implications of its coupling with miniature scintillators will be discussed highlighting benefits and drawbacks. Afew application examples in different fields will be presented and current results will be shown, also with interesting perspectives in terms of Internet Of Things (IOT).



21. Direct imaging of the three-photon annihilation process beyond PET

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This research presents a novel imaging approach designed to visualize the three-photon annihilation of ortho-positronium (o-Ps), with the goal of obtaining diagnostic insights beyond conventional positron emission tomography (PET). Ortho-positronium, a metastable bound state of an electron and a positron, decays into three gamma photons, whose characteristics are influenced by environmental factors like oxygen concentration and molecular void size. To leverage this sensitivity, we introduce a direct imaging method that determines the location of each three-photon event based on energy and momentum conservation, without requiring traditional tomographic reconstruction or time-of-flight information.

A quadratic equation derived from the energy and momentum conservation of the detected photons forms the basis of a straightforward analytical model for estimating decay positions. The imaging system employs HR-GAGG scintillator arrays coupled with silicon-based multipixel photon counters (MPPCs) arranged in a PET-like ring configuration. Experimental validation was performed using 18F-FDG sources placed in 3D-printed phantoms with varying geometries. Three-photon images were generated and compared with simulation results to evaluate spatial resolution.

Furthermore, both porous and non-porous materials were imaged simultaneously to assess differences in the 3/2 annihilation ratio, which may serve as an indicator of tissue structure or hypoxic conditions. The system achieved spatial resolutions of approximately 2 mm axially and 8–11 mm transversely. The observed variation in decay ratios between materials agrees well with predictions and previous findings from positron annihilation lifetime spectroscopy (PALS).

These results confirm the feasibility of direct three-photon imaging using standard PET isotopes like 18F, and highlight its potential of providing complementary information on tissue hypoxia, morphology, and density.

22. Decay Law of Selected Fluorescent Substances

Francesco Giacosa[1], Milena Piotrowska[1], Krzysztof Kyziol[1], Arthur Vereijken[1], Anna Kołbus[1], Karol Szary[1], Magdalena Płódowska[1]

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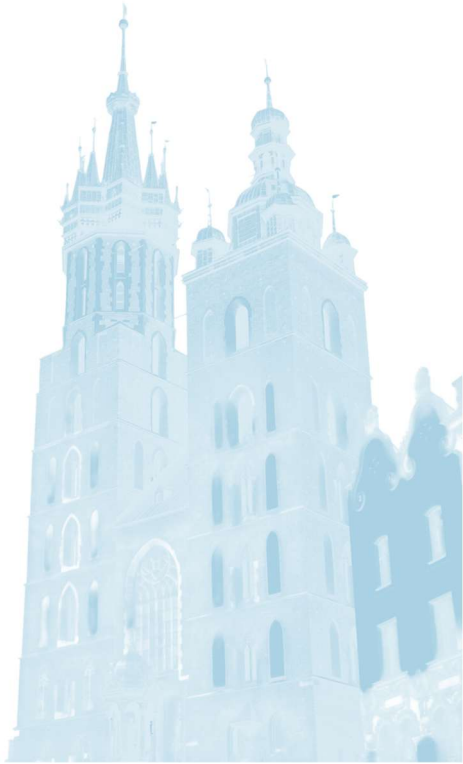
We present results from measurements of selected chemical compounds that decay via fluorescence photon emission. We examine to what extent the measured decay rates can be described by single- or double-exponential functions. We also investigate the emergence of non-exponential decay law that includes a power-law tail at long times.



23. Characterization of new SiC detectors for further experiments with exotic nuclei at barrier energies

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In recent years, silicon carbide detectors (SiC) have become an alternative to conventional silicon detectors due to their similarity to diamonds but a lower cost [1]. Their radiation resistance and wide bandgap make SiC's semiconductor detectors with great possibilities like high intensity beam particle detection [2] or dosimetry for hadron therapy and FLASH radiotherapy [3]. The 4-H SiC prototypes developed at IMB-CNM [4-5] are being characterized in IEM-CSIC to study their viability to be part of the ISRS spectrometer [6], on its focal plane detection array and its beam profile monitors. This work is focused on the study of the energetic (about 40 keV of FWHM measured) and temporal resolution (lower than 200 ps reported [7]) of the devices, as well as the possibility of developing a SiC matrix system that allows spatial resolution in ion separation.

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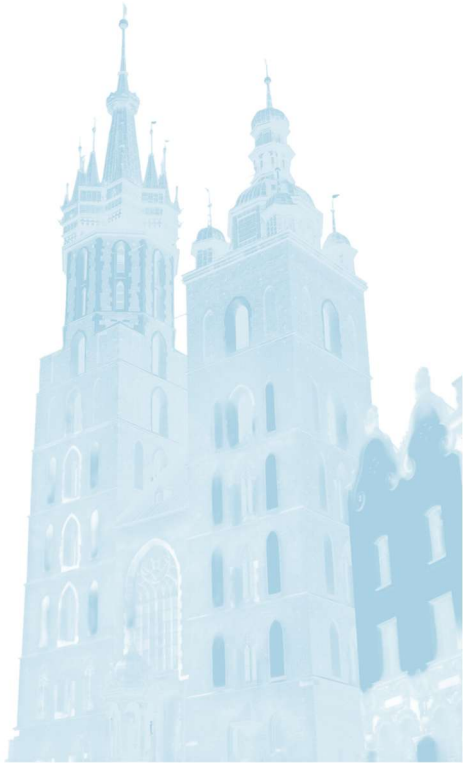

24. Perspectives on Preclinical Molecular Imaging Research at the Radiopharmacy Centre, Medical University of Bialystok

Anna Gromotowicz-Poplawska[1,2], Izabela Suwda Kalita[1], Magdalena Bruzgo-Grzybko[2], Adam Olichwier[1]

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The Radiopharmacy Centre at the Medical University of Bialystok, inaugurated in January 2024, is a newly established scientific unit designed to support the development and evaluation of novel radiopharmaceuticals through advanced preclinical research. Equipped with state-of-the-art infrastructure, the Centre houses fully operational laboratories for the synthesis, quality control, and preclinical assessment of radiopharmaceuticals, including facilities for in vitro and in vivo molecular imaging. The unit operates under national authorizations for radioactive isotope handling, genetic engineering (GMO/GMM), and experimental procedures involving laboratory animals (mice and rats), and is prepared for GMP-compliant manufacturing.

Key imaging capabilities include high-resolution PET/MR (3T) and SPECT/CT hybrid systems dedicated to small animal studies. These modalities enable detailed anatomical and functional imaging to support biodistribution studies, tumor visualization, pharmacokinetic modeling, and evaluation of new diagnostic markers. Current in vitro research focuses on identifying specific PET radiotracers targeting pancreatic and prostate cancer, using cell lines and radiometric techniques to assess receptor expression and ligand binding. The Centre is equipped with advanced devices including radiodetectors, flow cytometry, ELISA readers, and confocal microscopy systems.

The Centre integrates radiopharmacy expertise with advanced imaging and molecular biology tools, creating a unique platform for translational research in nuclear medicine – from bench to bedside. Its multidisciplinary team, comprehensive technical facilities and compliance with regulatory standards position it as a strategic national and international partner for academic and industrial collaborations in the development and validation of innovative diagnostic and therapeutic radiopharmaceuticals.

25. Impact of the Midkine expression on the uptake of [^{18}F]FDG and [^{18}F]FET in chicken chorioallantoic membrane glioblastoma models

Daniel Gündel [1], Katarína Benčurová [2,3], Silvester Bartsch [4], Joachim Friske [4], Maximilian Scheer [5], Sandra Leisz [5], Leonie Roß [5], Thomas H. Helbich [4], Markus Mitterhauser [2,3], Marcus Hacker [2], Klaus Kopka [1,6], Andreas Maurer [1,7], Cécile Philippe [2,3], Theresa Balber [2,3]

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The utilization of fertilized chicken eggs, in which vascularized solid tumors can be grown on the chorioallantoic membrane (CAM), has recently garnered interest for the investigation of radiotracers [1, 2, 3]. In this study, we investigated the glucose and amino acid utilisation of chicken CAM glioblastoma (GBM) models and the influence of a human Midkine (hMDK) overexpression, a heparin-binding growth factor acting as a mediator for the acquisition of critical hallmarks of cancer, including cell growth, survival, metastasis, migration, and angiogenesis [4].

Eight different GBM cell lines were investigated regarding the MDK protein expression and secretion kinetics by Westernblot analysis. The human GBM cell lines U87 wildtype (U87(WT)), U87 overexpressing the human Midkine protein (U87(hMDK)), and the endogenic high midkine-expressing T98G were implanted on the CAM on embryo development day (EDD) 9 in a Matrigel® matrix. The injection of [^{18}F]FDG or [^{18}F]FET was performed between EDD15 to EDD18 followed by a simultaneous PET/MRI acquisition with a dedicated PET insert and an 86 mm PET-compatible coil (Bruker Biospin, Ettlingen, Germany) ($n \geq 4$). For the semi-quantitative analysis of the radiotracer uptake with PMOD (v.4.205), a time frame of 30 to 40 min p.i. was reconstructed with a 3D MLEM algorithm.

The MDK expression and secretion kinetics are independent and vary between investigated cell lines. The uptake of [^{18}F]FDG was comparable between U87(WT) and

U87(hMDK) tumors with 10.9 ± 2.9 and 9.4 ± 2.4 %ID/cm^3 (p-value = 0.3232), respectively, whereas the uptake into MDK-expressing T98G tumors with 2.9 ± 0.8 %ID/cm^3 was significantly lower (p-value < 0.001). In contrast to T98G, the tumor-to-blood and tumor-to-brain ratios indicated a high glucose utilisation of both U87 subclones. The [^{18}F]FET uptake was also comparable between U87(WT) and U87(hMDK), with 4.7 ± 1.3 and 5.3 ± 1.1 %ID/cm^3 (p-value = 0.4513), respectively, and again with 3.0 ± 1.1 %ID/cm^3 significantly lower in T98G (p-values < 0.0300). Interestingly, a 3.8-fold higher [^{18}F]FDG uptake compared to [^{18}F]FET uptake in both U87 subclones (p-value = 0.0003) was determined, whereas the uptake of both radiotracers was comparable in T98G (p-value = 0.8846). The lower amino acid utilisation was reflected by the tumor-to-blood ratio of [^{18}F]FET < 1 and the low brain uptake of [^{18}F]FETfavored a better tumor-to-brain ratio compared to [^{18}F]]FDG for all three tumor models.

The glucose and amino acid utilisation are independent of the *h*MDK overexpression, however, significant differences between glioma cell lines U87 and T98G could be demonstrated. The here investigated chicken CAM brain tumor models will be further used in the next steps for the development and evaluation of a novel class of hMDK-targeting radiotracers, which can provide further insights into the molecular development of brain tumors by means of non-invasive molecular imaging beyond glucose utilisation and amino acid uptake characteristics.

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26. Automated Simulation Workflow for 3D-Printed Scintillator Phantoms in Radiotherapy Planning

Jakub Hajduga[1], Bartłomiej Rachwał[1], Tomasz Szumlak[1], Tomasz Fiutowski[1], Kamila Kalecińska[1], Damian Kabat[2], Stefan Koperny[1], Maciej Kopeć[1], Dagmara Kulig[1], Bartłomiej Lach[1], Piotr Wiacek[1], Jakub Moroń[1], Bartosz Mindur[1]

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Reconfigurable detector for the measurement of spatial radiation dose distribution for applications in the preparation of individual patient treatment plans was a research and development project aimed at improving radiation dose distribution measurement techniques for therapeutic applications. The core objective was to modernize current methodologies employed in individualized radiotherapy treatment planning by enabling precise, spatially-resolved, real-time dose measurements.

To this end, a prototype of a fully three-dimensional phantom composed of modular, 3Dprinted plastic scintillators was designed and constructed. This detector system allows for dose mapping at high spatial granularity. Complementing the hardware, a full simulation and data processing ecosystem was developed, with Monte Carlo simulations playing a central role in the calibration, optimization, and validation of the system. These simulations were implemented within a custom simulation platform named **G4RT**, built on top of the Geant4 toolkit. The simulation environment was tailored to the geometry and materials of the prototype phantom, including realistic representations of clinical treatment setups, such as beam-table interactions and attenuation profiles in tissue-equivalent media.

From a software architecture perspective, the project proposed a modular and reconfigurable approach to Geant4 simulation design. Unlike many existing systems constrained to standard geometries, the G4RT platform enables dynamic construction of complex, patient-specific detector arrangements. The geometry definitions, material databases, and simulation parameters are all externally configurable, allowing rapid iteration and scenario modeling. Integration with logging (LogSvc), configuration (TOML), and versioning mechanisms was a crucial part of maintaining transparency and reproducibility.

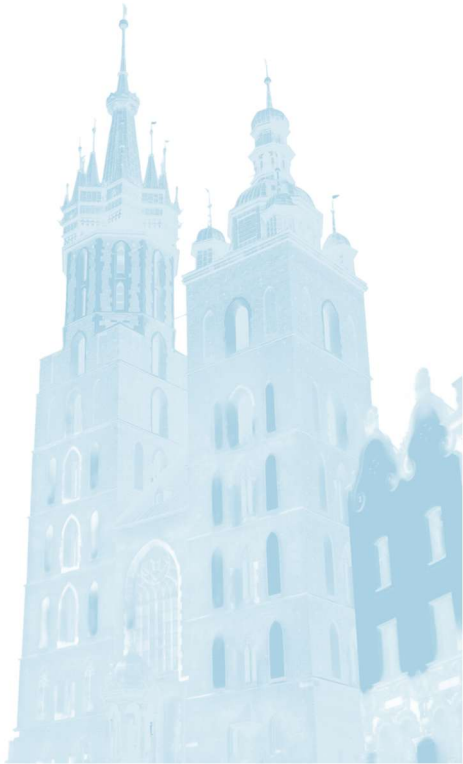
Another key development was the implementation of an automated geometry construction system designed to interface with CAD modeling software. Initially introduced during the **IMPRESS-U NAVA** project, this system enabled seamless integration of geometries created in **FreeCAD**. The approach relied on a structured, database-driven pipeline in which geometry metadata, positioning, and material assignments were extracted and processed from exported CAD data. This modular pipeline supported the automated construction of Geant4-compatible geometries

directly from CAD designs, minimizing manual intervention and ensuring reproducibility.

The framework was later extended and refined in the **Dose3D-Future** project to support models exported from **Autodesk Fusion 360**. The current implementation uses a **3MFbased CSV database** format as the intermediate representation. This format combines the geometric structure exported from Fusion (via the 3MF format) with associated metadata—such as volume names, material assignments, and hierarchical relationships—stored in structured CSV files. Material properties are automatically assigned using predefined mapping tables or explicit annotations, and spatial transformations are reconstructed from relative positioning information.

This automation drastically accelerates the preparation of patient-specific or experimentspecific simulations and ensures consistency between the physical phantom design and its digital counterpart. By embedding the geometry builder into the larger G4RT simulation ecosystem, the project established a scalable and reconfigurable architecture where CAD-driven geometry definitions are tightly coupled with physical modeling, logging, and configuration workflows.

An important component of the project also involved adaptation of the G4IAEAphspReader to enable efficient simulation of particle phase-space (phsp) files. The reader was extended to allow dynamic filtering, precise scoring, and threading optimizations. This enabled realistic modeling of test beam conditions using experimentally obtained phsp data and enhanced the performance of simulations involving large datasets.



27. Study of Total-Body J-PET sensitivity as a function of the Ring Number

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Positron Emission Tomography (PET) is a key molecular imaging technique in nuclear medicine, enabling the detection of physiological changes in lesions prior to morphological alterations through the use of radiotracers. The Total-Body PET scanner, due to its extended detection area, offers significantly higher sensitivity, which is a key factor in overall tomographic performance [1]. The J-PET collaboration is currently developing a novel Total-Body PET prototype with an Axial Field Of View (AFOV) exceeding 250 cm, enabling low-dose imaging, reduced scan times, and dynamic imaging capabilities. A distinguishing feature of this design is the use of cost-effective plastic scintillators, which have the potential to make large-FOV PET scanners more widely accessible [1, 2]. One of the key performance metrics in PET is sensitivity, defined as the rate of true coincidence events detected per second per unit source strength [2, 3]. This study employs GATE simulations [4] to evaluate and compare the sensitivity of the Total Body J-PET and plastic-based brain PET scanner. Additionally, it investigates the combined sensitivity of brain PET integrated with the Total-Body J-PET system. The results of this study will be presented at the conference.

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28. First Laboratory Tests of the SABAT Project Sensor with a D-T Neutron Generator

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Neutron Activation Analysis (NAA) is a non-destructive method enabling the determination of the elemental composition of substances and materials. This capability makes it suitable for identifying the contents of barrels sunk in the Baltic Sea that may contain hazardous substances. For this purpose, portable detectors of minimal size and without the need for cooling are required. In this study, a $LaBr_3$:Ce:Sr scintillation detector with dimensions 3 × 3 inch was characterized, with optimal operating conditions and internal absorption determined. The obtained results were compared with earlier studies of a detector made of the same material with dimensions 2 × 2 inch. Furthermore, NAA was performed with a D-T neutron source (IGN-14) at IFJ PAN, using boric acid, seabed samples contaminated with fuel oil, and melamine as a nitrogen carrier. The measurements confirmed the feasibility and effectiveness of applying this detector in such analyses.

29. Plan-Guided Super-Resolution of Dose Distribution

Kamila Kalecińska[1], Bartosz Mindur[1]; Bartłomiej Rachwa[1], Bartłomiej Lach[1], Dagmara Kulig[1], Damian Kabat[2], Jakub Hajduga[1], Jakub Moroń[1], Maciej Kopeć[1], Piotr Wiacek[1], Stefan Koperny[1], Tomasz Fiutowski[1], Tomasz Szumlak[1]

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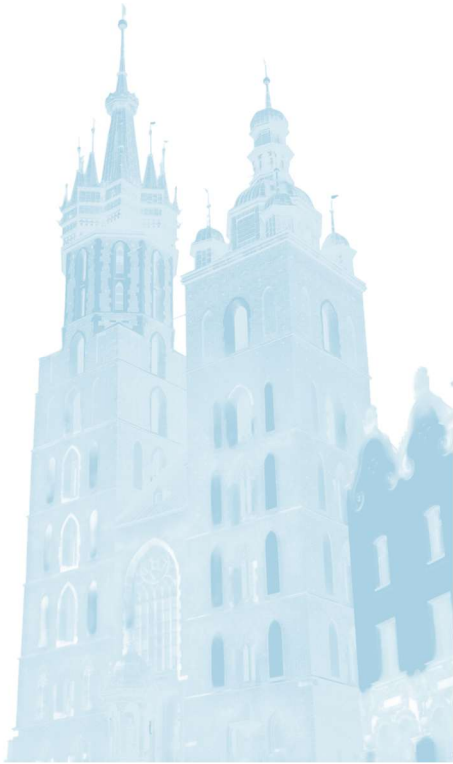
This study centers on the design and evaluation of a Plan-Guided Super-Resolution framework, which seeks to enhance the fidelity and granularity of radiotherapeutic dose distribution measurements. These measurements are obtained from the Dose-3D-F detector, which is currently being developed as part of the project *"A reconfigurable detector for measuring the spatial distribution of radiation dose for applications in the preparation of individual patient treatment plans"* (https://dose3d.fis.agh.edu.pl/). The native resolution of the measurement is determined by the shape and size of a single detector cell (10 mm^3). By employing 3D convolutional neural networks, it is possible to increase this resolution to 1 mm^3, ultimately contributing to improved accuracy in treatment planning. Comprehensive series of Monte Carlo simulations are conducted to produce training datasets as well as to validate the entire approach.



30. Design and construction of Cross-Staged Gantry System of Total-Body J-PET/CT Scanner for Motion Artifact Free anatomic and metabolic imaging

T. Kaplanoglu[1,2], P.Moskal[1,2] on the behalf of the J-PET Collaboration

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Total-body scanning rapidly acquires comprehensive, wide-volume metabolic data along with anatomical images using a lower radiopharmaceutical dosage [1,2], compared to conventional whole-body examinations performed through partial imaging steps. The Jagiellonian total-body PET/CT scanner [3,4] features a unique operational geometry that enables the examination of patients up to 2.5 meters in length without the need for discrete imaging approximations. To minimize artifacts caused by involuntary patient movement, both the patient and the examination table remain stationary during the scan, while the PET and CT gantries sequentially move around the patient from different axes. Due to the weight of the scanners and the precision required for the scanning processes, a custom-built mechanical motion system was developed. A custom motion system [5] was designed and constructed to move the total-body J-PET and CT devices along imaging X and Y axes within the examination room at the Center of Theranostics. The system consists of discrete rails and custom machine elements that allow the total-body J-PET and CT scanners to operate on the same platform. The designed system has been installed at the Theranostics Center in Kraków and will be used to integrate a commercial CT scanner with the total-body J-PET scanner, which was developed for research in both physics [6,7] and medicine [8,9] applications.

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31. Optical properties and time-of-flight resolution of plastic scintillators for the total-body J-PET scanner

Łukasz Kapłon[1,2], on behalf of the J-PET Collaboration

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Total-body Jagiellonian positron emission tomography (TB-J-PET) is based on long plastic scintillator strips [1]. The application of plastic scintillators as gamma detection material can decrease cost of the scanner [2] and increase its field-of-view. The J-PET scanner is capable of positronium imaging [3], measurements of entanglement of photons from positron-electron annihilation [4] and beam therapy monitoring [5]. The construction of long modules of the TB-J-PET requires use of plastic scintillators with high transparency to the emitted light [6] and with fast timing resolution. The two best manufacturers producing plastic scintillators with the highest transparency for the emitted light were selected for further research [7].

The aim of the research is to select the best plastic scintillator to be used in the construction of the TB-J-PET tomograph. The optical properties and timing resolution of six types of plastic scintillators manufactured by Eljen Technology, with dimensions of 6 mm × 30 mm × 500 mm, were measured. The emission spectra, transmittance at the wavelength of maximum emission through 6 mm thick scintillator, and technical attenuation length along 500 mm long scintillator, were measured on a linear CCD array spectrometer. The timing resolution was measured at three points along the scintillator using a setup consisting of silicon photomultipliers, oscilloscope, black box and collimated Na-22 source. The EJ-200 plastic scintillator has the best timing and optical properties for the TB-J-PET modules assembly.

We acknowledge support from the National Science Centre of Poland through grant No. 2023/07/X/ST11/01694.

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32. Can decay gammas from radioactive ion beams enhance prompt gamma imaging?

Monika Kercz[1], Gabriel Ostrzolek[1], Daria Boscolo[2], Marco Durante[2], Ronja Hetzel[2], Rafał Lalik[1], Katarzyna Rusiecka[1], Aleksandra Wrońska[1]

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In recent decades, ion beam radiotherapy has gained popularity, i.e. both the number of patients treated annually and the number of clinical facilities in operation have increased. One of the key objectives to increase the precision of proton therapy is the development of a technique for online beam range verification. As the proton beam deposits its energy in the tissue, it can excite atomic nuclei, which then emit almost immediate (prompt) characteristic gamma radiation upon returning to the ground state. Additionally, if radioactive ions are used, they not only initiate nuclear excitations, but also decay, emitting additional gammas. These radiation channels carry information about the deposited dose distribution.

The SiFi-CC project aims to register such radiation to reconstruct the distribution of promptgamma vertices in real time, providing insight into the beam range. The detector is made of LYSO scintillating crystals and was developed specifically for prompt-gamma radiation detection. However, in the most recent experiment, we registered prompt and decay gammas from a phantom irradiated with a radioactive ^{11}C beam, using a coded mask setup.

Carbon ions offer greater precision in energy deposition compared to protons, which results in higher dose conformity, as well as better biological effectiveness. Using radioactive ions, the local dose in the tumour region where those ions stop, is enhanced due to their decay radiation. Moreover, such beams provide not only prompt gammas, but also annihilation gammas stemming from β^+ decay of ^{11}C, increasing the total gamma yield available for imaging. A series of measurements with a ^{11}C radioactive ion beam (RIB) was performed at GSI/FAIR, within the BARB (Biomedical Applications of Radioactive ion Beams) project.

The poster will present the results of the SiFi-CC subproject, including both simulations and preliminary experimental results.

33. Simulated Signal Database for Improved Resolution in Position Sensitive Planar Germanium Detector

Priyanka Khandelwal[1], S. Mandal[1], R. Palit [2], J. Gerl[3], A. Sharma[4]

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[2]Department of Nulcear and Atomic Physics, Tata Institute of Fundamental Research, Mumbai, India
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[4]Universite Paris-Saclay, CNRS/IN2P3, IJCLab, Orsay, France

The progress in gamma-ray spectroscopy has been greatly influenced by the introduction of highly segmented germanium detectors. Their integration with advanced methods like pulse shape analysis (PSA) and gamma-ray tracking (GRT) has opened up new possibilities for high-resolution gamma-ray imaging. However, the accuracy of pulse shape analysis is fundamentally limited by the availability and quality of realistic signal database, which are often difficult to generate experimentally with sufficient resolution and coverage.

To address this, we have developed a detailed simulation to construct a comprehensive signal database for a double-sided, planar segmented HPGe detector with 10 orthogonal strips along both X and Y directions. The whole simulation framework has been developed with the help of two simulation tools. Gamma-ray interactions were simulated using the Geant4 toolkit, while charge transport modeling was carried out using the open-source Julia package SolidStateDetectors.jl [1]. Detector specific electric field and potential distributions were calculated on an adaptive grid, incorporating full geometry and biasing conditions provided by the manufacturer. Charge carrier dynamics including drift and diffusion were simulated using mobility parameters from the AGATA Detector Library (ADL) [2]. The resulting signals induced at AC and DC electrodes were convoluted with a preamplifier response for including electronics effects [3]. The relationship between pulse shapes has been analyzed in more detail by examining the variation in rise-time between signals induced on opposing detector surfaces, as a function of depth, for different strips. This generated database enables dense spatial sampling of interaction points and provide waveforms necessary for PSA. Validation is currently underway through comparison with scanning data from the planar segmented PSPGe detector at GSI, Germany [4]. By bridging the gap between simulation and experiment, our work provides a solution to support gamma-ray reconstruction in future tracking arrays. Full simulation and comparison results will be discussed in detail during the conference.

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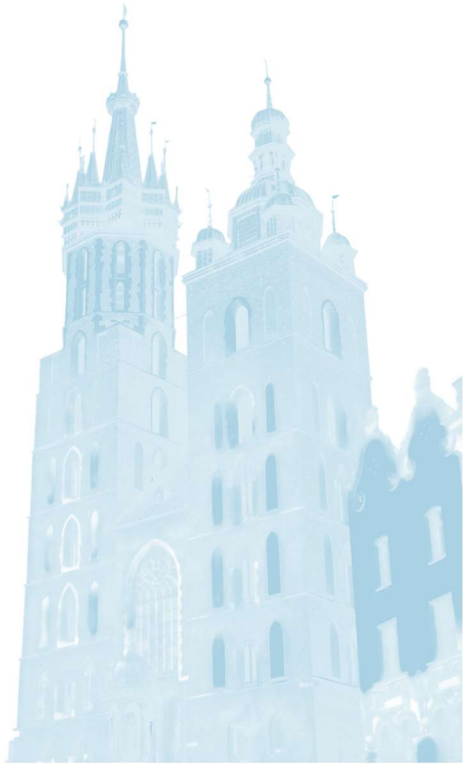
34. Titanium-Scandium Radionuclide Generator: A New Approach for Sustainable Isotope Production

Aleksander Khreptak[1,2], Paweł Moskal, Ewa Stępień[1,2]

[1]Faculty of Physics, Astronomy and Applied Computer Science, Jagiellonian University, Cracow, Poland
[2]Center for Theranostics, Jagiellonian University, Cracow, Poland

Advancing positronium imaging requires a reliable supply of suitable radionuclides and efficient radiolabeling strategies. The poster will present the concept of a titanium-scandium radionuclide generator as a practical and sustainable solution for producing scandium-44, a radionuclide offering a unique prompt gamma emission for triple-photon detection. This generator system could provide a steady, on-demand source of high-purity ^{44}Sc for the synthesis of novel positronium imaging agents. This approach has the potential to simplify logistics, reduce production costs, and support the wider adoption of positronium imaging in both preclinical and clinical settings.



35. MERMAID – prototype PET scanner for small aquatic animals

Magdalena Kolodziej, Steven Seeger, Hong Phuc Vo, Rebecca Kantorek, Jorge Roser, Christian Schmidt, Magdalena Rafecas

Universität zu Lübeck, Germany

MERMAID (Multi-Emission Radioisotopes - Marine Animal Imaging Device) is the first PET scanner prototype dedicated to small aquatic animals. Particularly, MERMAID aims to support biomedical research using zebrafish as a model of human diseases, as well as marine biology research and sustainable aquaculture.
Even though there are small-animal PET scanners commercially available, they are optimised for rodents, so their spatial resolution might be insufficient for small fish. Other requirements related to imaging aquatic animals further restrict their use. Therefore, there is a need for a dedicated system. The current prototype, with four crystal modules composed of LYSO crystals and SiPMs, has proved its capability of imaging sub-mm structures; PET scans of radioactive phantoms and zebrafish have been successfully conducted. The current field-of-view is being extended with new crystal modules, currently in the assembly process.
In the talk, I will present the MERMAID system, including characterization and status of the latest development and show reconstructed images of fish-like phantoms and zebrafish.

36. Silicon as beam-activated tumour tracer for online proton therapy monitoring – experimental study

Magdalena Kolodziej[1,2], Aleksandra Wrońska[2]

[1]*Universität zu Lübeck, Germany*
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In this study, the feasibility of utilizing silicon as a new kind of tumour tracer in proton therapy was experimentally investigated. Our approach can potentially become a method of online monitoring in proton therapy, allowing for more efficient healthy tissue sparing and thus for better and safer treatment. So far, there is no method of online proton beam monitoring applied routinely in clinics. This results in a necessity to apply safety margins, increasing the risk of long-term side effects. The underlying principle of the tracer method is that certain elements emit prompt gamma (PG) quanta of characteristic energy when irradiated with a proton beam. It is also necessary that the cross section for PG emission peaks for low energies, then the PG vertex distribution will follow the dose distribution with good approximation. Previous research indicated silicon as the optimal element for this purpose. Optimal tracer concentrations were also determined. If the tracer is selectively delivered to the tumour volume, one expects to see the silicon peak in the PG energy spectrum only when the Bragg peak reaches the tumour volume, thus providing feedback for the clinician in real time. An experiment in clinical conditions was conducted to quantify this effect (predicted by simulations): a PMMA phantom with a silicon-doped insert was irradiated with beams of different energies (with the Bragg peak either inside or outside the insert volume) and a high purity germanium detector was placed to the side of the phantom to register the PG spectrum. Additional measurements were done with an extra PMMA plate in front of the phantom, to induce a beam range shift. In my talk, I will present preliminary results from this experiment and discuss the feasibility of the method for use in proton therapy monitoring.

37. Fragmentation measurements for particle therapy with the FOOT experiment

Aafke Kraan

INFN - Sezione di Pisa, Italy

Fragmentation measurements FOOT (FragmentatiOn Of Target) is an innovative experiment in applied nuclear physics, dedicated to the understanding of nuclear fragmentation processes. The understanding of such processes is relevant in oncological treatments with hadron beams and in the field of radiation protection in space. The FOOT physics program foresees a set of measurements conducted in both direct and inverse kinematics, employing particle beams and targets similar to the composition of human tissues from one side and spacecraft shielding materials on the other.
The main goal of the experiment is to measure double differential cross-sections as a function of scattering angle and fragment energy within the 100-800 MeV/u range, achieving a precision level exceeding 5%. At present, the FOOT Collaboration has developed two experimental set-ups: one based on nuclear emulsions devoted to charges $Z \lt 4$ and another based on electronic detectors for fragments with $Z \ge 2$. In this presentation we will give an overview of the status of the experiment, present some preliminary and recent results, and give details on the upcoming experimental campaigns.

38. Usage of DL-based portal dose images for treatment error detection with transit dosimetry in radiotherapy

Aafke Kraan

INFN - Sezione di Pisa, Italy

Electronic portal imaging devices (EPIDs) can be employed for performing transit in-vivo dosimetry. However, a significant drawback of conventional amorphous silicon EPID detectors in this context is their non-linear response to water-equivalent dose. This necessitates complex calibration and correction processes, reducing their feasibility for routine clinical implementation. In this study, we propose a deep learning (DL) approach designed to reconstruct water-equivalent dose from transit EPID images, using both image data and dose simulations from a treatment planning system (TPS). The model was trained on a comprehensive dataset comprising more than 200 EPID acquisitions and corresponding portal dose outputs generated by the Monaco TPS, encompassing various phantom types and irradiation field configurations. A 2D U-Net architecture was developed to convert EPID transit images into water-equivalent portal dose maps. The model's performance was assessed using mean absolute error (MAE) and 2D gamma index analysis, applying 3mm/3% and 5mm/5% evaluation criteria. The average MAE across all test samples was 3.9×10^{-3} cGy. Gamma index passing rates averaged 94.5 ± 2.0% and 99.6 ± 0.3% for the 3mm/3% and 5mm/5% thresholds, respectively. Median gamma pass rates were 98.2% and 100% for the two criteria, underscoring the model's high accuracy in dose reconstruction from EPID images. Furthermore, the model generates portal dose predictions in less than one second, indicating its potential for real-time clinical application. Overall, our DL framework provides a fast and reliable method for estimating water-equivalent dose from EPID images, presenting a viable path toward more accurate and efficient in-vivo dosimetry.

39. Normalisation Strategies in ToF-SIMS Analysis of Liver Tissue - Critical Impact on Comparative Molecular Profiling in a Diabetic Rat Model

Michalina Kaźmierczak[1], Magdalena E. Skalska[1,2], Marcela Capcarova[4], Anna Kalafova[4], Peter Massanyi[4], Klaudia Jaszcza[5], Dorota Wojtysiak[3]

[1]Faculty of Physics, Astronomy and Applied Computer Science, Jagiellonian University, Cracow, Poland;
[2]Centre for Theranostics, Jagiellonian University, Cracow, Poland;
[3]Department of Genetics, Animal Breeding and Ethology, University of Agriculture in Cracow, Cracow, Poland
[4]Institute of Applied Biology, Faculty of Biotechnology and Food Sciences, Slovak University of Agriculture in Nitra, Nitra, Slovak Republic
[5]Department of Animal Physiology and Endocrinology, University of Agriculture in Cracow, Cracow, Poland

Time-of-flight secondary ion mass spectrometry (ToF-SIMS) enables high-resolution molecular imaging of biological tissues, providing unique insights into chemical composition at the microscale. In this technique, the method of data normalisation plays a pivotal role in the reliability of biological comparisons, particularly in complex tissue analyses. In this study, we evaluated the influence of different normalisation approaches on the interpretation of ToF-SIMS results obtained from liver samples of diabetic rats treated with metformin or flaxseed mucilage.

Liver sections were analysed in both ion modes (positive, negative) using ToF-SIMS 5, and ROIs (150 × 150 μm^2) were extracted from larger scanned areas to avoid topographic and edge artefacts. Several normalisation strategies were applied: total ion count (TIC), ion dose normalisation, and relative scaling to control groups. The impact of each method was assessed through quantitative comparison of ion group abundances (amino acids, lipids, metal ions, carbon-containing ions) and group separation capacity.

Our results indicate that TIC normalisation improves comparability across samples by reducing instrumental and matrix effects but may obscure biologically relevant changes. Normalisation to control group levels highlighted treatment-induced differences more clearly, particularly the elevated metal ion signals in metformin-treated livers and preserved amino acid profiles in flaxseed groups. Normalisation to ion dose provided consistent results in spatial analyses but was less sensitive in group discrimination.

This study underscores the critical importance of normalisation selection in ToF-SIMS-based tissue profiling. The appropriate strategy choice can enhance the biological relevance and reproducibility of findings, especially in comparative pharmacological studies involving subtle metabolic changes.

40. Ex-Vivo Positronium Lifetime Imaging with 44Sc Using J-PET Scanner

Karol Kubat[1,2], Manish Das[1,2], Sushil Sharma[1,2], Ewa Ł. Stępień[1,2] and Pawel Moskal[1,2] On behalf of the J-PET Collaboration

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Positronium Lifetime Imaging (PLI), an advanced extension of Positronium Emission Tomography (PET), is an emerging diagnostic modality [1,2,3]. It has potential to probe nano-scale environmental properties such as hypoxia, tumour microenvironment pathology by mapping the spatial distribution of Ps lifetime in biological tissues [4, 5, 6].

Despite the common consensus on its advantages and ongoing progress in adaptation of reconstruction algorithms and detector technology, PLI faces slow translation in clinical applications mainly due to two reasons: (1) measurement of nano-second positronium lifetimes requires fast gamma-ray detectors, and (2) new radioisotopes that provide both medically suitable half-life and high positron yield accompanying a prompt gamma signal for Ps lifetime estimation. The first in-vivo results on PLI of human brain was reported by J-PET collaboration using ^{68}Ga radioisotope [7]. However, the low prompt gamma yield of ^{68}Ga, only a ~1.34% prompt-γ branching ratio, poses challenges for accurate lifetime estimation due to limited statistics [8].

To address this, 44Sc has emerged as a highly promising isotope for PLI [9], boasting an optimal decay profile: a clinically suitable half-life of 4.04 hours, an ultrashort deexcitation delay of 2.61 ps, and a 100% decay probability producing a single, high-energy (1157 keV) prompt gamma following positron emission [8].

In this work, we report the successful application of PLI using ^{44}Sc, performed with the state-of-the-art Modular J-PET tomograph, featuring triggerless data acquisition enabling simultaneous multiphoton detection [7]. For this study ^{44}Sc was produced at the Heavy Ion Laboratory in Warsaw and transported to Jagiellonian University in Kraków. Four phantoms containing cardiac myxoma tissue, blood thrombi, adipose tissue, and Fused Silica were used, where the Fused Silica serving as the certified material with a known o-Ps lifetime for quality control. Event selection was based on the simultaneous detection of two 511 keV photons and one de-excitation photon, enabling the reconstruction of positronium lifetime images. The reconstructed annihilation positions, obtained using the two 511 keV photons along with the positron lifetime, was used to identify regions of interest (ROIs) in image samples. Whereas the o-Ps lifetime was estimated utilizing the registration time of an additional prompt gamma as the o-Ps formation time. The obtained o-Ps lifetime shows good agreement with previously reported values for biological tissues [3, 10].

In this presentation, we will show the first-ever demonstration of ex-vivo PLI with ^{44}Sc,

marking a significant advancement and opening new possibilities for developing PLI for clinical applications.

This work was supported by the National Science Centre of Poland (Grants: 2021/42/A/ST2/00423, 2021/43/B/ST2/02150, 2022/47/I/NZ7/03112), SciMat and qLife under the Excellence Initiative at Jagiellonian University, and PLGrid (ACK Cyfronet AGH, PLG/2024/017688).

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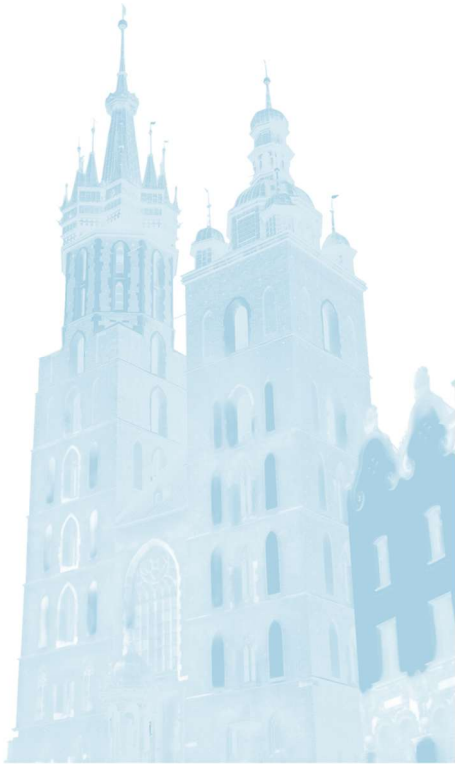

41. Measuring the degree of entanglement in matter using a plastic-scintillator based PET scanner

D. Kumar[1,2], S. Sharma[1,2] and P. Moskal[1,2], on behalf of the J-PET collaboration

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Understanding quantum entanglement of photons produced in positron–electron annihilation offers exciting prospects for both fundamental physics and quantum-enhanced medical imaging [1,2]. According to quantum electrodynamics, annihilation photons from the singlet state of positronium decay exhibit entangled polarization [3]. This entangled nature can be accessed by measuring the correlation between their polarization states. However, the high energy of these photons (511 keV) makes it impossible to use traditional polarizers. We address this issue by utilizing Compton scattering as a polarization analyser, exploiting the strong dependence of the scattered photon direction on the polarization of incident photon [4].

In this study, a plastic-scintillator-based PET scanner (J-PET) is used, which is particularly well-suited for this research, as photons predominantly register via Compton scattering, enabling the measurement of entanglement properties of 511 keV photons [5,6]. The recent results demonstrated the non-maximal entanglement between photons, when positrons annihilate in a porous polymer medium, with the observed degree of correlation sensitive to the annihilation environment [7]. These findings pave the way for further investigations into how entanglement varies across different physical and chemical surroundings. This is crucial because the degree of quantum correlation is expected to change with different annihilation modes within the material, potentially introducing new contrast mechanisms for quantuminformed imaging [7,8].

This presentation will highlight the advanced features of the J-PET detector and new findings on the polarization correlation of annihilation photons in medium and future goals [2,6,7].

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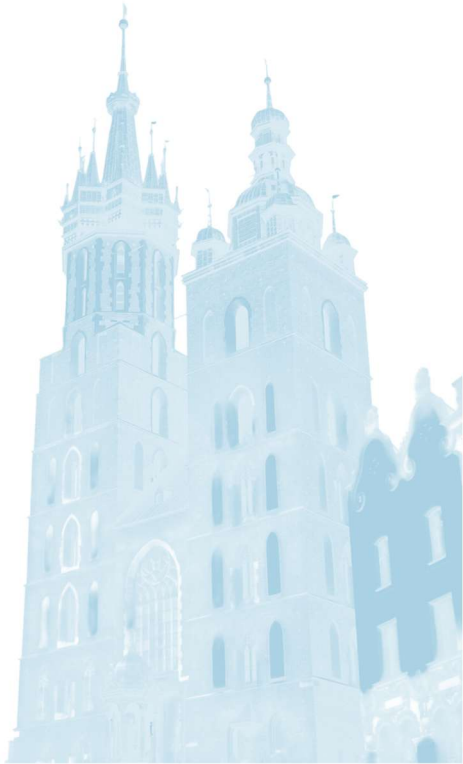

42. Nanobrachytherapy of Triple-Negative Breast Cancer and Glioblastoma Multiforme Using Auger Emitters

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Cancers that do not exhibit overexpression of specific receptors are a significant challenge for the development of novel radiopharmaceuticals. Metastatic triple-negative breast cancer (TNBC) is associated with a 12% survival rate [1], while glioblastoma multiforme (GBM) has a mortality rate of 93% [2].
Nanobrachytherapy enables the intratumoral administration of radiopharmaceuticals without the necessity of targeting specific receptors. Mercury radionuclides $^{197/197m}$Hg demonstrate remarkable efficacy, generating 42.6 Auger electron emissions per decay. By leveraging Auger electron-emitting radionuclides with their high linear energy transfer (LET) that causes DNA double-strand breaks, we can improve nanobrachytherapy by combining ¡sup¿197/197m¡/sup¿Hg with gold nanoparticles (AuNPs).

The Au($^{197/197m}$Hg)NPs-PEG radioconjugate was synthesized and subsequently evaluated in vitro for its therapeutic potential on MDA-MB-231 and T98G cancer cell lines. Cell cultures underwent internalization, subcellular fractionation, MTS assay, and spheroid studies. Additionally, flow cytometry analysis was used to evaluate the apoptosis and cell cycle of treated cells. Furthermore, the -H2AX phosphorylation technique was employed to measure the number of DNA double-strand breaks caused by the radioconjugate, revealing a significant level of DNA DSBs. Ex vivo biodistribution and therapeutic efficacy studies were conducted on mice bearing 4T1 tumors at the Radiochemical Studies Laboratory, INRASTES, NCSR Democritos in Athens, Greece.

Au($^{197/197m}$Hg)NPs-PEG showed significant internalization in both cell lines. In MDA-MB-231, 87.51 ± 0.16% internalization occurred after 24 hours, with 26.6 ± 0.48% localized in the cell nucleus. It caused a highly effective DNA double-strand break, which was 63 times higher than that of the control group after 24 hours. In the biodistribution study on mice, we established that most Au(^{197}/^{197m}Hg)NPs-PEG remained in the tumor two hours post-injection. The radioconjugate with a dose of 10 MBq indicated a 31.61 ± 6.83% reduction in tumor growth index (TGI) after 18 days of treatment.

We conjugated efficient Auger-electron emitting radionuclides $^{197/197m}$Hg —onto gold nanoparticles (AuNPs) for the nanobrachytherapy of TNBC and GBM. The in vitro and in vivo potential of Au($^{197/197m}$Hg)NPs-PEG has shown significant promise. A therapeutic efficacy ex vivo study on mice using smaller doses of this radioconjugate is scheduled to be conducted.

Acknowledgments
This research was financed by the PRELUDIUM 20 grant 2021/41/N/ST5/00322 from the National Centre of Science, Poland.

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43. High Precision X-ray Spectroscopy: from Kaonic Atoms to Societal Applications

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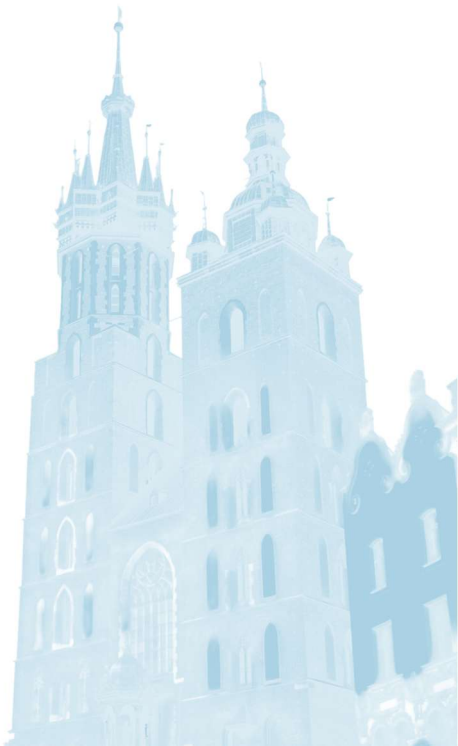
Understanding the strong interaction at low energies remains one of the fundamental challenges in nuclear and particle physics. Experimental studies of low-energy kaon-nucleon and kaonnucleus interactions provide critical insights for advancing Quantum Chromodynamics (QCD), with far-reaching implications from the structure of nuclei to the physics of neutron stars. At the DANE collider in Frascati (Italy), the SIDDHARTA and SIDDHARTA-2 collaborations have leveraged state-of-the-art X-ray detection technologies, such as Silicon Drift Detectors, to achieve unprecedented precision in the spectroscopy of exotic atoms, most notably kaonic hydrogen, deuterium and neon. These efforts are enabling the world's first measurements of kaonic deuterium, a milestone for the field. In this contribution, I will present the physics motivation for studying kaonic atoms, describe the experimental setup and detector developments, and discuss recent results on kaonic neon and future directions. In addition, I will report on the development of a novel setup for high-resolution X-ray spectroscopy based on a mosaic crystal, designed to push the limits of energy resolution in exotic atom experiments. This integrated approach, combining innovative detection systems and advanced spectroscopic methods, opens new avenues for precision measurements in understanding the role of strangeness in the universe, with, in the same time, numerous possible societal applications.



44. Preliminary tests of positronium gathering in microcavities connected to nanochannels

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Nanochanneled silicon samples produced via electrochemical etching have proven to efficiently convert positron to positronium in both reflection (positronium emitted from the same side of positron implantation [1-3]) and transmission geometry (positronium emitted from the opposite side of positron implantation [4]). In the last decade, these positron/positronium converters have been successfully employed for the production and emission into the vacuum of positronium for experiments of positronium laser excitation [5-8], antihydrogen production [9], and positronium laser cooling [10]. Further experiments of positronium inertial sensing [11] and entanglement of the 3 gammas generated by positronium self-annihilation [12] based on the use of such samples are planned.

Here, we investigate the potential of combining electrochemical etching and ultrafast laser direct writing [13] to fabricate silicon samples containing a network of nanochannels connected to buried microcavities. The aim is to gather positronium in these microcavities for future studies on positronium spectroscopy within the microcavities [14] and positronium-positronium interaction [15] with the new bunched positron beam at the Antimatter Laboratory of Trento [16, 17]. The structure of the produced samples was explored via Transmission Electron Microscopy and Scanning Electron Microscopy. Positronium formation and gathering in the microcavities were investigated via Positron Annihilation Spectroscopy. Samples, where over 20% of implanted positrons form positronium self-annihilating via 3 gammas inside microcavities, were obtained.

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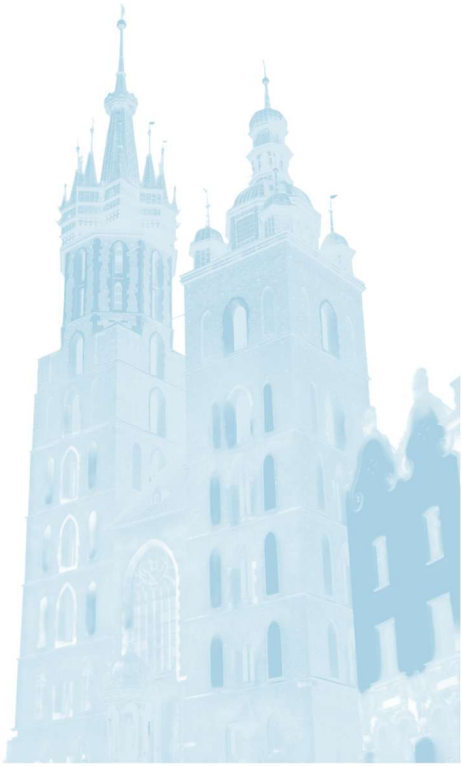

45. Development of a high-quality, energy-tunable positronium beam via photodetachment of positronium negative ions

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When an electron binds to its antimatter counterpart, the positron, they form a hydrogen-like bound state known as positronium (Ps). Although Ps decays into gamma-rays via annihilation within a short lifetime, it behaves as an electrically neutral particle until annihilation. Ps atoms are formed in the final stages of radiation-induced processes involving positron injection into matter, making them an important subject of study in positron-related radiation science. Ps has been increasingly utilized as a probe in applied research, such as the evaluation of pore structures in polymers and porous materials [1]. In recent years, its potential use in acquiring biological information in positron emission tomography (PET) has also attracted growing interest [2,3]. To advance such applications, it is essential to accumulate fundamental data on interactions between Ps and atoms/molecules. An energy-tunable Ps beam is a powerful tool for studying these interactions over a wide range of collision energies. However, due to its short annihilation lifetime and neutral charge, the generation of Ps beams has posed significant technical challenges.

To overcome this challenge, we have demonstrated a method for producing Ps beams using positronium negative ions, which are bound states consisting of a Ps atom and an additional electron. Owing to their negative charge, Ps negative ions can be accelerated to a desired energy using an electric field. By subsequently removing the extra electron via laser photodetachment [4], we successfully generated a monoenergetic, energy-tunable Ps beam [5]. Furthermore, by enhancing the system performance through the implementation of a trap-based positron beam, we developed a high-quality, energy-tunable positronium beam suitable for applied research [6,7]. The resulting beam is expected to contribute not only to fundamental science but also to the development of novel analytical techniques for material characterization

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46. In-beam PET monitoring during radioactive ion beams irradiation for real-time dose discrepacies and anatomical change detection

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In-beam Positron Emission Tomography (IB-PET) enables real-time monitoring of charged particle therapy by detecting 511 keV annihilation photons resulting from decays of radioisotopes produced during nuclear interactions of the primary beam with patient tissue. However, in proton and stable ^{12}C-ion beams treatment, IB-PET is limited by low count rates, biological washout, and broad activity distributions. Radioactive ion beams (RIBs), such as ^{11}C, while not yet used in clinical treatments, would yield an improved signal and a closer match with the dose fall-off, enabling a more precise in vivo beam range monitoring and tumor control. This study investigates whether RIBs can enable quasi-instantaneous detection of dose deviations and anatomical changes during treatment and compares the results with that of protons and ^{12}C beams.

We used the FLUKA Monte Carlo simulation tool to model isotope production and decays (referred here as the IB-PET signal) for 8 head-and-neck tumor treatments using proton, ^{12}C, and ^{11}C-ion beams. Simulations accounted for realistic clinical conditions, including anatomical changes and PET biological washout, and the PET signal was collected during irradiation (approx. 2 minutes). A dedicated computational framework was developed to compare voxel-wise PET activity distributions in the absence anf in the presence of anatomical changes. This framework produced 3D discrepancy maps and enabled quantitative analysis of range shifts and morphological variations.

At 30 seconds post-irradiation, the IB-PET images from ^{11}C beams showed significantly stronger signal intensity, lower noise, and more accurately reflected dose-related range variations compared to protons or stable C-ions. The discrepancy maps derived from ^{11}C PET data accurately localized regions affected by anatomical changes, which were less clearly identified using ^{12}C or proton data.

Radioactive ion beams combined with IB-PET imaging offer substantial improvements over conventional beams by enabling real-time, high-resolution detection of anatomical and doserelated changes during irradiation. The enhanced signal quality eliminates the need for long acquisition times and could reduce the need for control CT scans.

47. Quantification of Nanoscale Free Volumes in Human Plasma Clots Using Positron Annihilation Lifetime Spectroscopy

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Positron annihilation lifetime spectroscopy (PALS), interpreted via the Tao–Eldrup model, provides a sensitive and quantitative method for probing nanoscopic free volumes in biological systems [1]–[4]. This study investigates free volume characteristics in human plasma blood clots under variable thermal and preparation conditions. Using ortho-positronium (o-Ps) lifetime (τ_3) and intensity (I_3), we calculated the free volume radius (R), mean free volume size (V_f), and fractional free volume (f_v) across a range of clot states.

First, we evaluated fresh plasma clots at 22°C, 37°C, and 40°C. A temperature increase from 22°C to 37°C led to a rise in τ_3 from 1.87 to 1.94 ns and in R from 0.275 to 0.282 nm, with a corresponding increase in V_f from 0.087 to 0.094 nm^3 and in f_v from 0.00172 to 0.00186. These modest but consistent increases reflect enhanced molecular mobility and free volume expansion at physiological temperatures [5], [6].

At 37°C, we further compared clots in four physical states: fresh, fixed, desiccator-dried, and critical point dried. Fixed clots exhibited the highest free volume parameters (τ_3 = 2.03 ns, R = 0.290 nm, V_f = 0.103 nm3 , f_v = 0.00986), suggesting fibrin network loosening due to chemical stabilization [7]. Desiccator-dried clots showed the largest voids (R = 0.301 nm, V_f = 0.114 nm3), but with low I_3 (6%), leading to a lower effective f_v (0.00124). In contrast, critically dried clots maintained a balance between structural preservation and porosity (R = 0.283 nm, f_v = 0.00683).

These results highlight the combined impact of temperature and sample preparation methods on the nanoscale architecture of blood clots. Our findings demonstrate that positron annihilation lifetime spectroscopy (PALS) is a sensitive and reliable technique for quantifying clot porosity, with potential applications in thrombus characterization, biomaterial development, and diagnostic stratification in clinical practice [8]–[11].

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48. Towards feasibility study of Positronium yield in proton beam therapy.

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Proton beam therapy is a quickly emerging modality of radiation treatment. Its advantages over the conventional methods - finite range, maximal energy deposition at the end of the range and low energy deposition elsewhere - provide more conformal dose distribution over the tumor, save surrounding tissues and make the therapy more comfortable for the patient. However, to make an efficient use of those advantages one needs to develop a beam range monitoring system. Since the possible solution is utilizing the PET system for monitoring purposes, another curious possibility emerges [1,2,3]. A PET system (the J-PET system in particular) enables positronium life-time measurements in PET imaging for diagnostics [4,5,6]. The same information about positronium life-time can be obtained also during proton beam therapy. However, this information is more difficult to acquire due to the high background coming from prompt gamma radiation, various isotopes that emit positrons and other particles and the medium that affects the life-time. Developing the methods for enabling positronium studies in proton beam therapy is crucial for determination of hypoxia level in the tissues, especially in the tumor region. Hypoxic tissues are more resistant to radiation therapy than normoxic tissues. Hence, determining the oxygenation level tumor and surrounding tissues would enhance the effectiveness of the therapy [7,8]. In this work we study the feasibility to utilize the J-PET system to conduct positronium studies in proton beam therapy. Estimation of the $\beta+$ - emitting isotope production rate during irradiation will be presented together with positronium yield and efficiency of the positronium signal registration with the J-PET system in dual-head configuration.

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49. Mirror matter : towards precise measurement of orthopositronium lifetime

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Positronium (Ps) is an exotic atom composed of an electron and its antiparticle, the positron, bound together in a short-lived quantum system. This bound state serves as a unique system for probing fundamental physics, as its properties are precisely predicted by Quantum Electrodynamics (QED) within the Standard Model (SM). Furthermore, its decay processes, which are effectively modeled using Monte Carlo simulations, provide valuable information on various domains of particle physics.

At the Jagiellonian University, the J-PET detector (Jagiellonian Positron Emission Tomograph), a novel tomography system based on plastic scintillator detectors, has been developed [1]. This setup offers high angular and timing resolutions [2-4], enabling multidisciplinary studies of positronium decays. Therefore, it is possible to measure the lifetime of positronium with high precision with J-PET.

In this work, we report on ongoing searches for Dark Matter signatures in ortho-positronium
(o-Ps) decays using the J-PET detector. The primary objective is to explore the existence of Mirror Matter, a hypothetical form of matter proposed to restore parity symmetry and considered a plausible candidate for the Dark Matter component of the Universe. Our study aims to refine current experimental limits by achieving high-precision measurements of the o-Ps lifetime in its three-photon decay channel, comparing these results with QED predictions to search for potential deviations that could be interpreted as a signal of the presence of Dark Matter [5].

We acknowledge support from the National Science Centre of Poland through Grants No. 2019/35/B/ST2/03562, 2020/38/E/ST2/00112 and the SciMat and qLife Priority Research Area budget under the auspices of the program Excellence Initiative-Research University at Jagiellonian University.

50. Enhancement of Biological PET Imaging via Quantum Entanglement using GAGG-SiPM pixel ring detectors

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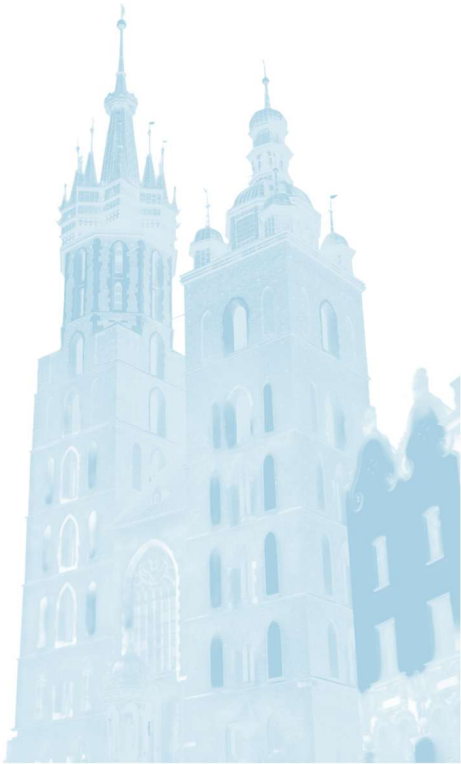
Exploiting the quantum entanglement of the annihilation -pair and deliberately inducing a second Compton interaction in each detector could furnish additional observables that enable more effective separation of true coincidences, thereby improving the signal-to-background ratio. A small-animal prototype PET / quantum-entangled PET system has been developed with three rings, each comprising eight 8 × 8 GAGG–SiPM pixel detectors whose pixel pitch is 3.2 mm. Pixel-level energy is derived from pulse-width measurements calibrated with standard sources such as Am-241 and Ba-133, and all energy-and-timing information is recorded in list mode to extract both photo-absorption and Compton events. The image quality of a phantom obtained with standard PET (utilizing two photo-absorption events) and with quantum-entangled PET (utilizing two Compton events) is evaluated visually and quantitatively by standard metrics including contrast-to-noise ratio, recovery coefficient, and spatial resolution. These results will be compared with Geant4-based simulation outputs to assess any discrepancies, and the first trial outcome of in-vivo small-animal imaging will also be presented.



51. Range Monitoring in Proton Therapy Using the J-PET Scanner: First Experimental Insights

Szymon Niedźwiecki[1,2], Antoni Rucinski[3], Jan Gajewski[3], Jakub Baran[1,2], Grzegorz Korcyl[1,2], Damian Borys[4], Karol Brzeziński[3], Paulina Stasica[3], Pawel Moskal[1,2]

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A method for experimental determination of the proton beam range in a water-equivalent phantom using the modular J-PET detector is presented. A series of 4×4×4 cm^3 dose volumes were irradiated with proton beams delivering uniform doses at varying penetration depths with 16 Gy dose. Data acquisition was performed using a dual-head configuration of the J-PET prototype, with each head consisting of three layers of four detection modules. The system operated in a triggerless acquisition mode during and after irradiation. For image reconstruction, only data collected in the post-irradiation period were utilized, employing the CASToR framework.

The reconstructed PET images represented spatial distributions of emitters produced by nuclear interactions of protons within the phantom. Activity profiles were extracted and fitted with a sigmoidal function to determine the range of activity distributions for each irradiated field. A linear correlation was observed between the simulated dose ranges and those derived from PET data. Lower doses were investigated by randomly rejecting part of the data sample. For 4 Gy dose, the mean range shift error was approximately 1 mm for a 5-minute acquisition window and decreased to below 1 mm when 30 minutes of post-irradiation data were used. These results indicate the feasibility of precise proton range verification using the J-PET system.

52. Targeted radioligand therapy

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Targeted radioligand therapy (RLT) involves the administration of a radiopharmaceutical—an agent composed of an α or β- emitting radionuclide bound to a molecule that selectively targets specific receptors on tumor cells. RLT is already considered the gold standard for the treatment of neuroendocrine tumors (NETs) and prostate cancer. However, an increasing number of early clinical trials are demonstrating its potential benefits in the treatment of other selected cancers.

In the case of NETs, RLT improves progression-free survival and helps control hormone secretion in functioning tumors, while generally causing relatively mild toxicity. The current standard of care involves administering fixed doses of radiopharmaceuticals over four treatment cycles. However, growing evidence suggests that treatment outcomes—in terms of both efficacy and toxicity—are closely related to the actual radiation dose delivered.

The fixed administered activity can result in a wide range of absorbed doses in tumors and healthy tissues, due to patient-specific metabolic differences and tumor heterogeneity. Therefore, the absorbed dose, rather than the administered activity, plays a critical role in determining treatment response. As a result, a one-size-fits-all approach—whether using a fixed or weight-adjusted dose—can easily lead to under-treatment or over-treatment, the latter increasing the risk of toxicity.

Dosimetry offers a way to optimize the efficacy of RLT and tailor treatment to individual patients. Unfortunately, performing full dosimetry requires at least four post-treatment imaging sessions along with extensive data processing, making it time-consuming and resource-intensive for medical staff.
We will discuss the available evidence to assess how dosimetry influences the treatment process and whether its effectiveness justifies the additional time and effort required.

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53. Probing nuclear structure using lifetime measurements

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Level lifetime measurements are crucial in nuclear structure studies to identify isomers and probe the different excitation phenomena in nuclei. The Digital INGA setup at TIFR [1] has been upgraded [2,3] with an array of LaBr¡sub¿3¡/sub¿(Ce) scintillator detectors in addition to the Compton-suppressed HPGe Clover detectors. Experiments have been conducted to probe the evolution of octupole collectivity in La and Zr isotopes [4,5] and the structure of a doubly odd ¡sup¿138¡/sup¿La isotope. The lifetime measurements in ¡sup¿88¡/sup¿Sr confirms the existence of an attractive shears between two particle blades for the first time in any nuclei [6]. Some of the results from these experiments, covering diverse aspects of nuclear structure near N=50 and 82 neutron shell gap will be presented.

54. Towards the development of an iterative algorithm for positronium lifetime imaging using 44Sc with the modular J-PET

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Positronium Lifetime Imaging (PLI) represents an emerging imaging modality which enhances PET capabilities through its ability to map the spatial distribution of mean lifetimes of positronium atoms (Ps) [1,2,3]. The high sensitivity of Ps lifetime, particularly of the ortho-Ps (a triplet state of Ps), to nano-scale environments makes PLI a promising tool for studying tissue microstructure and pathological behavior at scale non accessible by standard PET [4,5]. We aim to develop a PLI method using the 44Sc radioisotope, which has a clinically favorable profile featuring a suitable half-life (4.04 h) [6], a high branching ratio of positron emission (˜ 94.3%), and the emission of a 1157 keV prompt gamma photon [7,8]. PLI is based on the registration of three coincident photon events, where the annihilation position is reconstructed using the two 511 keV annihilation photons, while the prompt gamma provides the start signal for the formation of ortho-Ps [1,3].

In this work, we report the results from a recent study using the NEMA IQ phantom with the Modular J-PET. Out of the six spheres of the phantom, the three largest spheres were filled with 44Sc, and the remaining three with 18F, diluted with water such that the activity concentration ratio at the beginning of the experiment was 1:3 [8]. The analysis algorithm was developed primarily to reconstruct the PLI for the spheres filled with 44Sc [9].

The data were analyzed using the J-PET data analysis framework. We studied only those events in which two annihilation photons (511 keV) are in coincidence with the prompt gamma (1157 keV). For each event, the hit positions of both annihilation photons were used to define the Line of Response (LOR), which was processed using Siddon's ray-tracing algorithm to determine the voxel-wise intersections [10]. The Maximum Likelihood Expectation Maximization (MLEM) algorithm [11] is used to reconstruct the activity concentration image iteratively. The difference between the average registration time of the annihilation photons and the prompt gamma was used to compute the lifetime, which was then sorted voxel-wise to construct the lifetime histogram. The mean Ps lifetimes were then extracted from the histograms for lifetime imaging.

As a next step, we aim to integrate lifetime estimation directly into the iterative process [8], enabling simultaneous reconstruction of activity and lifetime images within a unified MLEM framework.

In this presentation, we will show the results obtained using Siddon's ray-tracing and MLEM reconstruction, and briefly discuss the plans to incorporate lifetime information to obtain positronium lifetime images.

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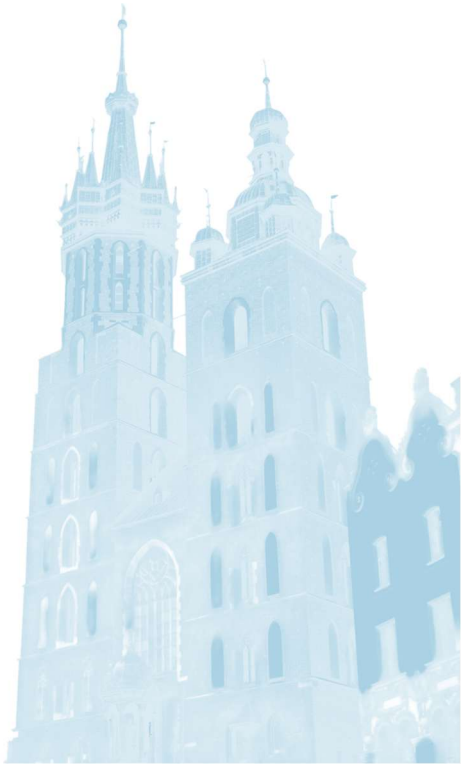

55. Feasibility study of Antihydrogen vertex imaging using the modular J-PET

Piyush Pandey[1,2], Sushil Sharma[1,2], Pawel Moskal[1,2], Anoop Kunimmal Venadan[1,2], Grzegorz Korcyl[1,2], Krzysztof Kacprzak[1,2]

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The Antihydrogen Experiment: gravity,Interferometry, Spectroscopy (AEgIS) at CERN aimsto measure thegravitational acceleration ofantihydrogen atoms totest the Weak Equivalence Principlefor antimatter systems [1,2]. The antihydrogen beamis produced through a chargeexchange reaction between Rydberg-excited positroniumand antiprotons, which subsequently passesthrough a moir´e deflectometer equipped with two precisely spacedgratings [3,4,5]. An accurate beam profile monitoring is essential to quantify the spatial characterization of antihydrogen beam for the precision of gravitational measurements [6]. The beam profile can be assessed by tracking the high energetic pions produced during the interaction of antihydrogen atoms with grating materials as they traverse through the deflectometer. To achieve this, J-PET collaboration is developing state-of-art detection modules [7,8,9]. In the planned experiment, two pairs of J-PET detection modules will be used to spans the full axial length of moir´e setup [10], complementing the existing detection systems [6,11]. The generated pions, beingminimum ionizing particles(MIPs), are expectedto travel in approximately straight trajectorieswhile depositing characteristicenergy in thescintillators. Their paths can be tracked through consecutive registrationsin any twodetectors ofeach J-PET module pair. The hit positions in these modules enable the reconstruction of individual pion trajectories, which are then back-projected to estimate the spatial coordinates of the annihilation vertex.

A customized Geant4 simulation application was developed to model the realistic generation of charged pions, originating from antihydrogen annihilations, as well as their propagation to J-PET modules for detection. An analysis algorithm was also developed based on the back-projection technique to image the annihilation vertices.

In this presentation, results from the feasibility studies will be presented and discussed.

Acknowledgments: We acknowledge the support from the National Science Centre of Poland through Grants No. 2019/35/B/ST2/03562, 2021/42/A/ST2/00423, 2021/43/B/ST2/02150, 2023/50/E/ST2/00574 and the SciMat and qLife Priority Research Area budget under the program Excellence Initiative—Research University at Jagiellonian University.

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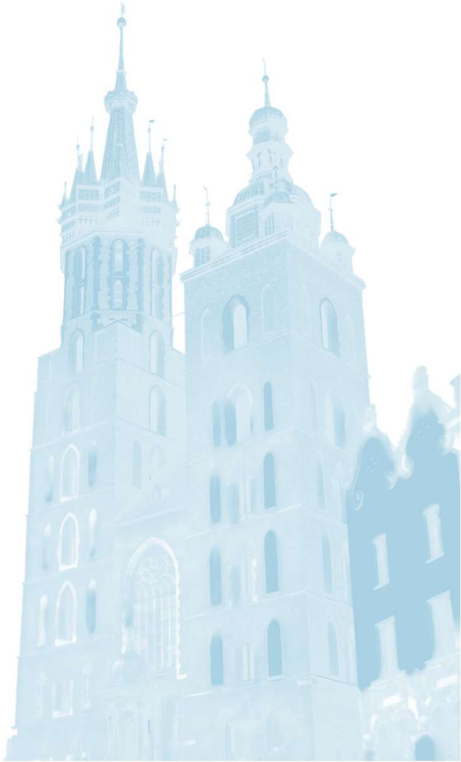
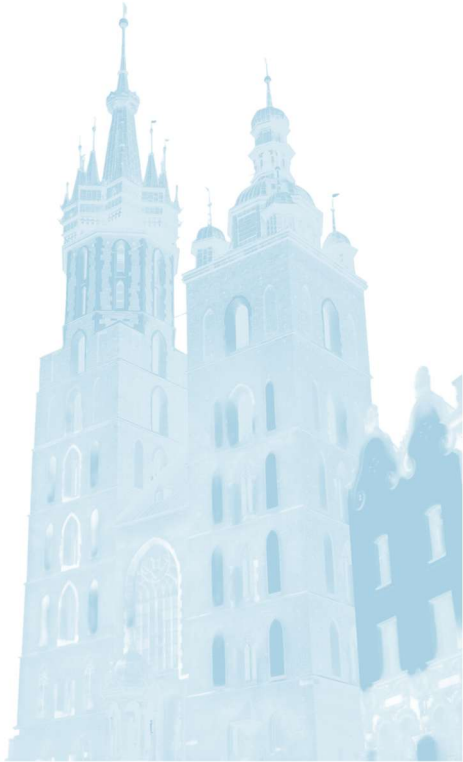


56. Development of Advanced PET Technology for Scientific and Clinical Applications

Qiyu Peng

ShenZhen Bay Laboratory, Shenzhen, China

Positron Emission Tomography (PET) is playing an increasingly critical role in biomedical research and clinical diagnostics, particularly in the fields of oncology, neurology, and cardiology. In this talk, I will introduce the recent progress from the Advanced Molecular Imaging Laboratory (AMIL) at Shenzhen Bay Laboratory, including innovations in high-resolution small-animal PET systems, brain-dedicated and cardiac-dedicated PET systems, wearable brain PET for both preclinical and human use, and the development of a 2-meter total-body TOF-DOI PET/CT system. I will also highlight strategies for translating these technologies into clinical applications to address unmet needs in precision medicine and global health. In this context, international joint effort is not only beneficial but essential, and it is the only viable path toward achieving truly affordable molecular imaging solutions for global health.

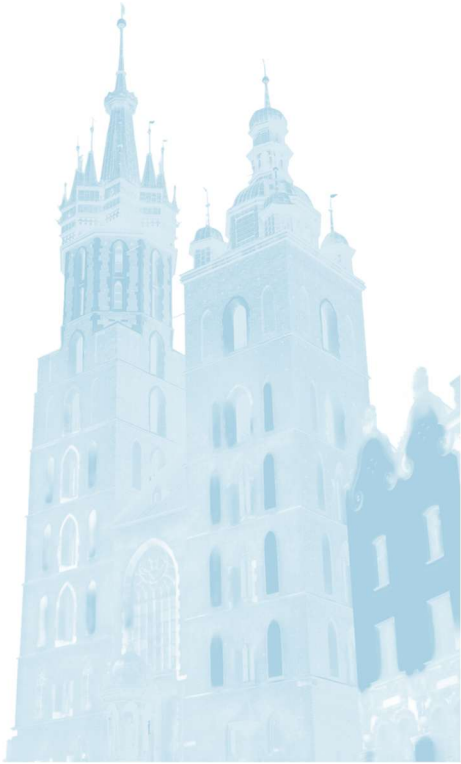


57. Para-positronium and beyond: probing two-photon annihilation in bound states

Milena Piotrowska, Francesco Giacosa

Jan Kochanowski University, Kielce, Poland

We investigate two-photon annihilation processes in neutral pseudoscalar bound states, focusing on para-positronium, the charmonium state c(1S) and the bottomonium state b(1S) , within a QFT framework that implements the Weinberg's compositeness condition. . By evaluating triangle loop diagrams with constituent fermions ((anti)electrons in positronium and (anti)quarks in c(1S) and b(1S)), we compare QED and QCD bound states. As additional applications, we evaluate the weak decay constants for both QED and QCD bound states, as well as rare positronium processes: the decay into one photon and two neutrinos and the possible mixing with the 'putative' axial-vector X(17) particle.



58. Extracellular vesicle flow cytometry: what's possible and what's next

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Extracellular vesicles (EVs) are increasingly recognized as mediators of intercellular communication and hold promise as disease biomarkers and therapeutic agents. Among available techniques, flow-based methods currently remain the only approach capable of quantifying EV concentrations - i.e. the absolute number of submicrometer, immunostained particles per milliliter of fluid - in a reproducible, standardized and practical manner. Nevertheless, detecting EVs with flow cytometry presents unique challenges.

In this talk, I will provide an overview of the capabilities and limitations of EV flow cytometry, based on our work at the Amsterdam Vesicle Center (vesiclecenter.com). Key topics will include: (1) detection sensitivity, addressing the challenges in distinguishing EVs from background noise, (2) standardization and calibration, discussing the importance of signal calibration to ensure reproducible experiments, (3) the dilution paradox, addressing assay design considerations for measurements on EVs in blood plasma, and (4) advancements in instrumentation, highlighting recent technological developments that enhance single-EV detection.

By examining these areas, I aim to delineate what is currently achievable with EV flow cytometry and identify avenues for future research and technological innovation.

59. µPPET, a J-PET application for cosmic rays investigation

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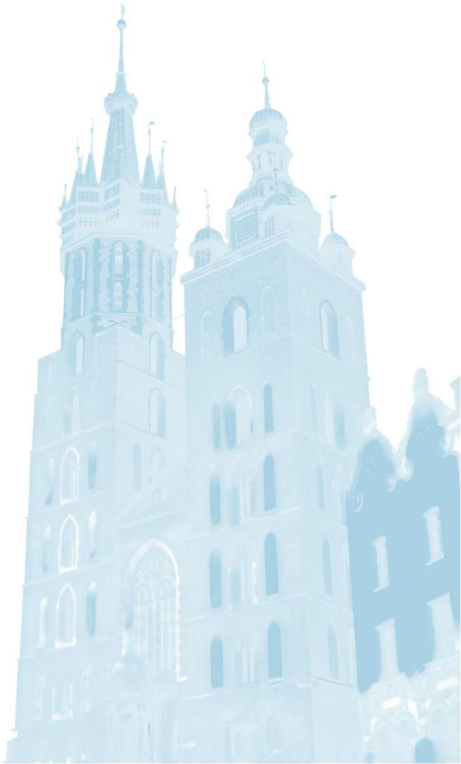
The J-PET machines at Jagiellonian University are advanced scintillator systems capable of precisely detecting particle positions. While designed to be a tomographer, they can also detect cosmic rays, especially muons. In fact, these particles are often considered background noise. However, reversing this perspective, J-PET can be used to study particles originating from air showers induced by cosmic rays. Notably, J-PET enables the study of air shower muons, which are crucial for identifying the atomic mass of primary cosmic rays.

Nevertheless, the current challenge lies in the hadronic interaction models correctly linking muon density at ground level to the mass of cosmic rays—the longstanding 15-year Muon Puzzle, for which the models predict far fewer muons compared to reality.

In this talk, we will show how J-PETs can investigate the Muon Puzzle, particularly by testing a new hypothesis aimed at solving it.



60. Cold Neutron Interferometry for Fundamental Physics Experiments

Luca Povolo, Philipp Heil, Gjon Markaj, Jakob Micko, Marc Persoz, Ciro Pistillo, Florian M. Piegsa

Laboratory for High-Energy Physics and Albert Einstein Center for Fundamental Physics, University of Bern, Switzerland

In the Fundamental Neutron and Precision Physics Group at the University of Bern, we are using cold and ultracold neutrons for fundamental physics research. In particular, we are interested in the neutron electric charge. Currently, the best measurement of the charge is (-0.4±1.1)×10-21e, where e is the elementary electric charge [1].
With the goal of improving this result, the group developed a novel high-visibility Talbot-Lau interferometer for cold neutron beams using absorption gratings with microscopic dimensions [2-3]. The apparatus consists of three gratings. The neutrons pass through the first two gratings and create an interference pattern at the position of the last. This pattern contains information of a potential force acting on the beam perpendicular to the interferometer path. By applying a strong electric field between the gratings, the possible electric force acting on the neutrons is measured by comparing the pattern formed for opposite electric field directions [3].
Detailed measurements with a prototype version of the apparatus have been performed successfully at the Institute Laue-Langevin (Grenoble, France) [3]. Presently, we are working on improvements for the construction of a final apparatus that would let us reach or even surpass the previous best limit on the neutron electric charge. To conduct systematic investigations, we built an approximately 1-meter-long scaled-down version of the interferometer. In this talk, we will present the status of the experiment, describe the operation and show first results obtained with the scaled-down Talbot-Lau interferometer.

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61. Development of high-Z organic scintillators for modern SPECT imaging and theranostic dosimetry

Flaminia Quattrini[1], Mattia Bonuso[2], Alberto Burattini[3], Marina Carruezzo[4], Maria Silvia De Feo[5], Angelica De Gregorio[6], Giuseppe De Vincentis[7], Gaia Franciosini[3], Viviana Frantellizzi[7], Marco Garbini[2], Leonardo Gasparini[8], Nils Krah, Marco Magi[3], Enrico Manuzzato[8], Michela Marafini[2], Leonardo Mattiello[3], Roberto Passerone[10], Vincenzo Patera[3], Daniele Rocco[3], Alessio Sarti[3], Angelo Schiavi[3], Marco Toppi[3], Samane Vahidi[10], Arianna Vannucci[2], Giacomo Traini[6]

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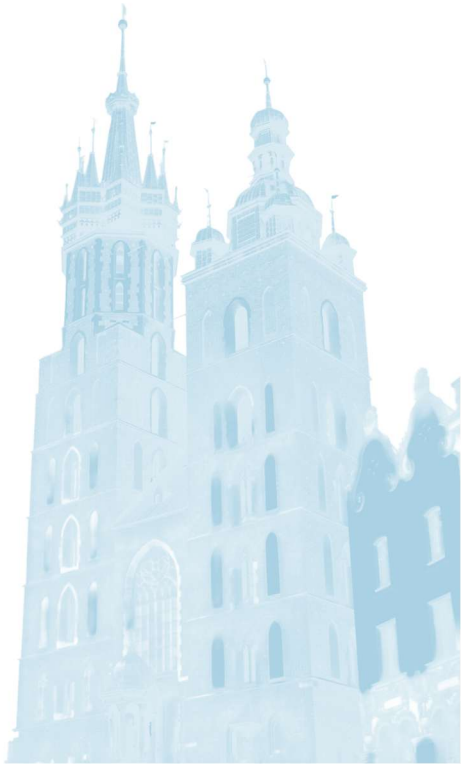

In the fight against cancer, improving the detectors performance is crucial to enhance diagnostic accuracy and optimize therapies. Current clinical SPECT systems predominantly rely on NaI(Tl) crystals, which, despite their advantages, suffer from limited count-rate due to long scintillation decay times. Our goal is to address this limitation by developing an innovative class of plastic scintillators doped with high-Z elements. These materials combine the fast timing characteristics of organic scintillators with improved gamma-ray detection efficiency via enhanced photoelectric interaction probability.

Our research focused on synthesizing novel organic fluorophores to fabricate plastic scintillators doped with various high-Z elements—including Bismuth, Cerium, Lead and Erbium—with concentrations up to 10%. The resulting prototypes show promising characteristics in terms of optical transparency, dopant homogeneity, light yield and timing performance, reaching levels comparable with commercial standards. Moreover, we explored different fabrication techniques, including polymerization inside molds of different materials (PE, PTFE, metal) and the use of 3D-printed resin as a scintillator substrate.

These novel detectors are at the core of two parallel projects. The first one involves the development of a next-generation SPECT detector, in which the doped scintillators are polymerized directly into the holes of a 3D-printed tungsten matrix that also serves as a collimator, with signal readout performed by tiled CMOS sensors to ensure optimal temporal resolution and system modularity. Additionally, FPGA matrices will be mounted on the back of the detector to perform data pre-processing. The second project aims at designing a compact portable dosimeter tailored for metastatic castration-resistant prostate cancer (mCRPC) patients undergoing Lu-177-PSMA-617 radio-metabolic therapy. The device is designed to retrieve the radiopharmaceutical washout curve without requiring multiple SPECT scans, which is crucial for patients experiencing pain or mobility limitations. The goal is the determination of the patient-specific radiometabolic parameters to customize the prescription, thus optimizing the effectiveness of the therapy.

62. High-Resolution Intravital Imaging: Novel On-Chip PET and iQID Camera for Personalized Radiopharmaceutical Therapy and Microdosimetry

Narendra Radhod

University of Bern, Switzerland

Advances in microdosimetry and personal radiopharmaceutical therapy necessitate imaging devices able to capture functional and molecular processes at cellular and sub-organ length scales with high spatial resolution and sensitivity. This article presents a two-platform approach to high-resolution intravital imaging using two new devices: an On-Chip Positron Emission Tomography (PET) scanner and an enhanced ionising radiation Quantum Imaging Detector (iQID) camera.

On-Chip PET is developed specifically for Organ-On-Chip (OOC) imaging, with monolithic LYSO crystals and multi-surface silicon photomultiplier (SiPM) readouts. A CNN trained on Monte Carlo simulation data enabled accurate gamma-ray interaction point determination. Initial experiment results yielded a spatial resolution of approximately 0.55 mm, validated by imaging of a fluorine-18 (18F) point-source grid. These results validate the system's capability for integration of functional molecular imaging into microphysiological platforms. First experimental results with real data will be presented for both point-like sources, demonstrating the system's capability in realistic imaging scenarios.

In addition, the high-resolution iQID camera system with a 2048 × 2448 pixel array was evaluated using ^{177}Lu-labelled and ^{18}F-labelled phantom / biological material. Systematic optimization of acquisition parameters and advanced Python-based analysis supplemented with machine learning enabled precise event localisation, radiotracer imaging, and real-time particle discrimination (alpha, beta and gamma). The iQID system was demonstrated to operate robustly for quantitative digital autoradiography with sub-millimeter accuracy.

Together, these tools constitute a strong preclinical radiopharmaceutical testing arsenal enabling high-resolution visualization of radiotracer distribution and radiation interaction. Combined, their potential offers new avenues for personalized therapy planning, drug discovery, and cell-level dosimetry in nuclear medicine

63. Optimizing the event selection of the total-body J-PET scanner with a brain PET insert: a simulation study

M. Rädler[1,2] and P. Moskal[1,2] for the J-PET collaboration

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The J-PET collaboration (Jagiellonian positron emission tomography) is working towards the realization of a large field-of-view (FOV) total body J-PET (TB-J-PET) scanner enabling, among others, low dose imaging, short scan times, and dynamic imaging. The key distinctive feature, i.e., the utilization of cost-effective plastic scintillators, could facilitate a wider adoption of large FOV scanners. Simultaneously, dedicated brain PET imaging has shown various exciting applications, hence we are currently studying the combination of the TB-J-PET with a brain PET insert via Monte Carlo simulations. In previous works, we investigated the performance characteristics of different geometries, such as a frontal detector versus a cylindrical insert or different plastic scintillator dimensions. In addition to sensitivity, spatial resolution was investigated via MLEM reconstructions of the Derenzo phantom.

In this work, we focus on the impact of more realistic event selection, taking into account temporal and spatial resolution limits. For this purpose we employ the software package GATE v9.4.1, enabling multi-detector geometries (including in-house corrections of the Compton interactions). Generally, PET imaging with plastic scintillators suffers from a significant background of scattered events among the detectors. In order to identify and suppress them, a scatter test is usually performed, excluding coincidences that are light-like. However, brain PET detectors are placed much closer to the patients (to decrease uncertainties from non-collinearity of the annihilation photons), so that under finite time resolution, one cannot distinguish scattered from real events. Secondly, previous simulation studies have relied on a lower energy deposition cut of 200 keV for both events in a coincidence. However, we show that this choice is sub-optimal leading to a higher percentage of incorrectly identified coincidences. After sorting the events into multiplicity groups, we propose an alternative time-based event selection, taking advantage of the excellent time resolution of plastic scintillators. We provide an in-depth quality analysis together with a comparison to an energy-based event selection.

64. Characterization of optical photon transport in Long Plastic Scintillators

Sushil Sharma[1,2], Neha Gupta[3], Sumit Kundu[1,2], Anoop Kunimmal Venadan[1,2], Lukasz Kaplon[1,2], Pawel Moskal[1,2]

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Plastic scintillators have long been used in nuclear and particle physics experiments as costeffective detectors [1]. The longer attenuation length for light transmission makes them ideal for applications requiring a larger field-of-view (FOV) [2]. The Jagiellonian PET (J-PET) collaboration has pioneered their use to build the first plastic scintillator-based PET scanner, which is composed of 50 cm long plastic scintillators[3,4]. With the successful demonstration of modules constructed based on J-PET technology in both medical [5,6] and fundamental physics[7,8,9,10], the collaboration now aims to construct standalone detection modules using even longer scintillators. Since light propagation in long plastic scintillators depends strongly on the interaction position and direction, it is required to perform a thorough study on scintillator light yield, light attenuation during the transport along the strip, variation in the time of detected photons, and how uniformly the light is collected [11]. Furthermore, the influence of surface reflectivity also plays a crucial role in shaping the detector response [12]. All these characteristic properties of the scintillator directly impact both the timing and spatial resolution [13], which are key parameters to optimize the overall performance, particularly when signals are read out only from the ends of the scintillator.

We have developed a Monte Carlo-based simulation package in Geant4 to characterize optical photon transport in plastic scintillators of various sizes [14]. The simulated results will be validated against experimental data to ensure reliability and accuracy. In this presentation, we will discuss the structure of the developed package and present the results obtained from the simulations.

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65. Direct three gamma positronium imaging and cascade gamma chemical imaging

Kenji Shimazoe

The University of Tokyo, Japan

Nuclear medical imaging devices, PET and SPECT, are powerful and highly sensitive to the accumulation of molecules with a small amount of radio-nuclides. Extracting physicochemical micro-environmental information in addition to accumulation could contribute to more accurate diagnosis and therapy in radio-theranosics. A novel direct imaging technique of three gamma decays from ortho-positronium together with two gamma decays for quantifying the 3g/2g ratio indicating oxygen concentration and void size in PET device, as well as the cascade gamma-ray sensing of pH with In-111 nuclides in SPECT device will be discussed in the presentation.

66. Scientific Computing: Remote Access, CNN Segmentation, and SARS-CoV-2 Dynamics

Udai Singh

Deutsches Elektronen-Synchrotron (DESY), Germany

This work presents an integrated application of scientific computing spanning cloud-based experimental control, biomedical image segmentation, and mathematical modeling of viral infection.

We begin with the deployment of a remote access infrastructure at DESY Photon Science that enables secure, scalable, and distributed beamline experiment control. This platform integrates Kubernetes clusters, Nomad, and Consul for orchestration and dynamic service discovery, with Traefik providing secure HTTP routing. The architecture ensures high availability, flexibility, and streamlined access for remote scientific workflows.

In biomedical imaging, we address the segmentation of knee osteoarthritis (OA) in MRI scans. We compare convolutional neural networks (CNNs) with Gaussian mixture modeling (GMM) as segmentation techniques. Masks are generated using the napari framework with preprocessing steps including thresholding, Gaussian blur, and image registration with ANTs. This approach enhances anatomical localization and supports robust segmentation of degenerated cartilage regions.

Lastly, we introduce a stochastic model of early SARS-CoV-2 infection, focused on the regulation of viral transcription. The model uses experimental data from early infection time points and captures the dynamics of transcription-translation conflict, particularly in discontinuous transcription events. This computational framework serves as a tool for identifying potential therapeutic targets in the early stages of viral replication. Ongoing work includes implementing 5' leader transcription, parameter optimization, and longer simulation times to improve predictive accuracy.

Together, these contributions showcase the power of integrated infrastructure and computation in enabling research across virology, medical imaging, and experimental physics.

67. Lipid Remodelling in Extracellular Vesicles from -Cells under Hyperglycemic Stress - Multimodal Mass Spectrometry Approach

Magdalena Skalska[1,2] Martyna Durak-Kozica[1,2], Weronika Hewelt-Belka[3]; Michal Mlynarczyk[3], Ewa Stepien[1,2]

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Extracellular vesicles (EVs) carry lipid cargo that reflects the metabolic state of their parent cells. We examined the lipid composition of EVs released by pancreatic -cells under normoand hyperglycaemic conditions. To gain both structural and spatial information, we combined two mass spectrometry methods: high-resolution reversed-phase liquid chromatography with quadrupole time-of-flight mass spectrometry (RP-LC-Q-TOF-MS) and time-of-flight secondary ion mass spectrometry (ToF-SIMS). The study explores how glucose-induced stress modulates the EV lipidome.

Pancreatic -cells were maintained in normoglycemic, medium containing 11 mM (control) and 35 mM (hyperglycaemic) glucose. EVs were isolated using filtration dialysis and ultracentrifugation. Lipids were analysed with RP-LC-Q-TOF-MS following organic extraction, and in semi-native form using label-free Tof-SIMS. The latter enabled spatial imaging of lipid fragments at submicron resolution. Differences in lipid profiles were assessed across conditions and EV subtypes using multivariate analysis. Due to variations in particle numbers, we compared the relative amounts of lipid species within specific lipid classes during the RP-LC-Q-TOF-MS analysis. We focused on lysophosphatidylcholines, phosphatidylcholines, and alkylphosphatidylcholines. Statistically significant differences were observed between groups cultured under varying glucose conditions, particularly between normal glucose levels and an 11 mM glucose concentration in the ectosome group. Additionally, we noted several differences in the content of individual lipids within these classes. These findings were compared with data from ToF-SIMS analysis, which showed significant differences in peak intensities for specific lipids across different populations of EVs and under varying conditions.

The combination of MS/MS and ToF-SIMS provides a powerful approach to lipidomics, especially in analyzing EVs. This integrates precise lipid quantification with spatial imaging, offering valuable insights into lipidomes. It is particularly useful for studying EVs, which carry lipid cargo reflecting their cellular origin and function. By examining both lipid composition and localization researchers gain a deeper understanding of EV biology.

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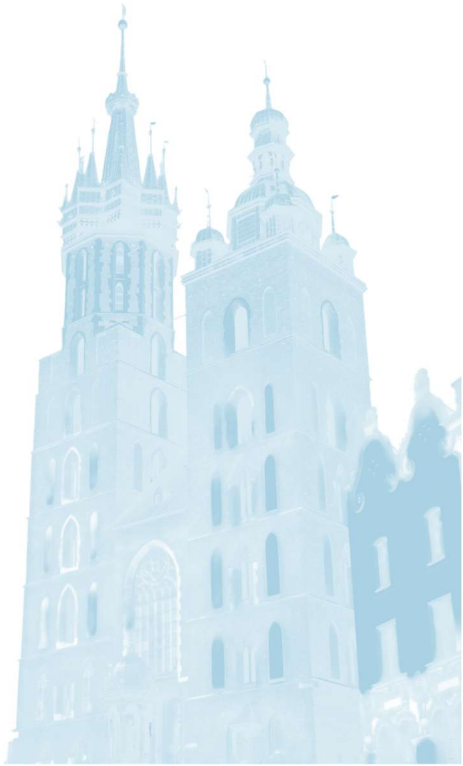

68. Studies of the absorption parameter 3/2 in positronium decays

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During Positron Emission Tomography (PET), as much as 40% of annihilations happen through the formation of positronium inside the patient's body. Its properties, such as the fraction of positronium annihilations into three photons (3/2), are highly influenced by the tissue's submolecular architecture. This has led to the development of a novel PET imaging techniques - positronium imaging - which provide additional insights into the imaged tissue. Conventional PET devices record only two annihilation photons and cannot assess the properties of positronium. However, the Jagiellonian PET (J-PET) scanner, capable of multiphoton detection, enables three-gamma imaging necessary for determining 3/2 ratio. The aim of this work is to study the absorption of gamma quanta in simplified models approximating the human body, as well as in the XCAT human phantom. For this purpose, toy Monte Carlo (MC) simulations of positronium decays into 2 and 3 and photon absorption in the models were performed and compared with the results obtained with GATE MC simulation tool. Based on the simulations, the dependence of absorption probability of photons in the phantoms on the location of the decay point is determined. As a result of this research, we present absorption maps of para- and ortho-positronium decays, required for data correction.

69. Proton-induced nuclear reactions in the hadrontherapy energy range

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Proton-induced reactions on tissue not only reduce the beam flux, but also generate radioactivity along the beam trajectory, influencing the effects of proton therapy. Therefore, precise knowledge of cross sections of proton-induced reactions on nuclei the tissue is composed of (oxygen, carbon and nitrogen) is needed for energies below 250 MeV. The production of + decaying isotopes 11C, 13N and 15O was studied during the past 50 years, but several discrepancies exist even in recent experiments. Furthermore, only few measurements were performed at higher proton energies.

We performed systematic measurements of cross sections using proton beams available at the Institute of Nuclear Physics (Kraków). The experimental set-up, made of 3 pairs of LaBr3:Ce detectors, was developed at the University of Warsaw. It enables the study of + decays from up to 16 simultaneously irradiated targets. Elementary targets (C, BN, SiO2) and animal tissue samples (liver, heart, bone) were irradiated at AIC-144 cyclotron with protons of energy below 58 MeV [1-6]. The obtained cross sections on C, N and O, are in general agreement with previous measurements, except the 11C production on 16O target [7]. The activity of soft tissues (liver, heart) are dominated by the 15O decay (T1/2=2 min) from (p,d) reaction on abundant oxygen nuclei. The production of 13N (T1/2=10m) is increased significantly at low proton energies, what might be related to the peak of the excitation function of 16O(p,alfa)13N reaction around 15 MeV.

The future experimental activities concern (i) completion of measurements on nitrogen at E¡58 MeV, (ii) verification of 16O(p,alfa d)11C reaction at E¡58 MeV, and (iii) measurements at higher proton energies available at CCB.

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70. Extracellular Vesicles and How to Find Them

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Extracellular vesicles (EVs) are a vital part of extracellular communication and transport systems in one's body. They carry various cellular components, such as proteins, mRNAs, miRNAs, DNA, and lipids. Because of their native function in the body, there is a major potential for them to be used in anticancer therapies. However, before that, the most important thing is to get to know them and their behavior as well as possible. For this, various methods could be employed. In this research, an emphasis was put onto quantitative and preliminary qualitative analysis of extracellular vesicles. Two parallel cell cultures with 4 biological repetitions each, were performed. Different glucose concentrations to check how hyperglycemic conditions influence extracellular composition and their production were used. Methods such as ATR-IR, NTA, ToF-SIMS and Cryo TEM were employed and evaluated for vesicle research. Following parameters were measured using ATR-IR and analysed: SFA/UFA ratio, lipid to protein ratio, acyl chain length. Parameters mentioned above, showed no significant difference between both cell culture conditions. For size distribution a comparison of NTA and Cryo TEM was performed. Cells in normoglycemic conditions produced about 100x more EVs and in such conditions exosomes possessed around twice as much cholesterol.

71. Theoretical untangling of photon entanglement detection in positronium annihilation processes

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When para-positronium annihilation occurs, two photons with exactly the same energy and mutually perpendicular, quantum-mechanically entangled polarizations are emitted in opposite directions. However, experimental confirmation of this effect is not straightforward, because direct detection of the polarization for high-energy gamma photons is not technologically possible. The recent beautiful experiment [1] investigating the angular correlations of Comptonscattered photons originating from annihilation has actually brought us much closer to experimental confirmation that the emitted photons are most probably entangled. During the lecture, however, I will show that it is still possible that the detected angular correlations come from classical correlations. Based on the methods of quantum metrology, I will also propose a direction in which the experiment should be modified to confirm the quantum entanglement of such photons.

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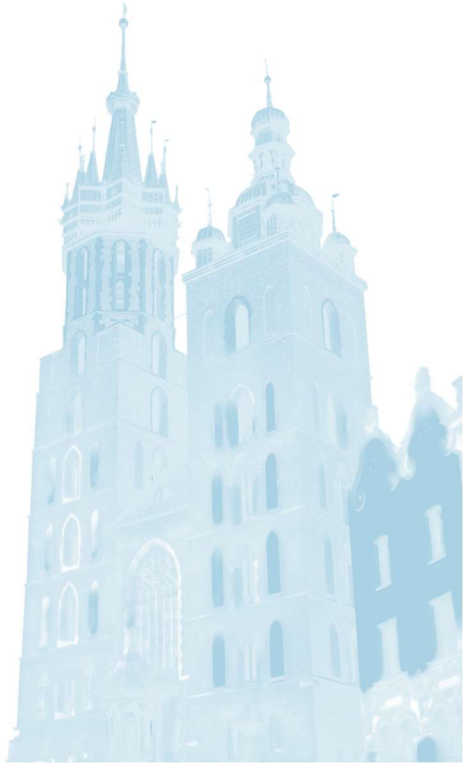

72. EVs as a non-invasive approach to diagnose and monitor metabolic diseases

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The molecular composition of EVs is very complex, with lipid and protein components dominating [1-3]. Although it is known that they are composed of the same macromolecules as the cells from which they originate, we have observed differences between the proportion of macromolecules in different subpopulations of EVs and cells [4]. The proportions and share of individual protein and lipid metabolites also change depending on the metabolic state of the cells from which the individual EV fractions originate [1,5]. One of the main factors influencing their molecular composition is hyperglycemia, which we have observed in an in vitro model of pancreatic beta cells and in clinical studies in patients with diabetes [5-8]. The presentation will show the results of metabolomic studies of small and large EVs isolated from patients with type 1 and 2 diabetes and from in vitro cultures of beta-pancreatic cells in conditions of mild and high hyperglycemia.

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73. A Geant 4 simulation of the positronium target cloud in the GBAR experiment

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The Gravitational Behaviour of Antihydrogen at Rest (GBAR) experiment at CERN aims to explore a fundamental property of neutral antihydrogen, the gravitational interaction. The Antiproton Decelerator and ELENA ring complex at CERN produces a beam of 100 keV antiprotons. An antiproton from this beam is merged with positronium cloud [1,2] to form a cold, positively charged antihydrogen ion, suitable for free-fall measurements. Antihydrogen ions are created via two successive reactions involving a dense positronium (Ps) cloud:

$p + Ps \rightarrow H + e$ followed by $H + Ps \rightarrow H^+ + e$

The Ps cloud is generated by reacting positrons with a nanoporous SiO converter. The cloud density plays a key role in the efficient H and H^- production.

A dedicated Monte Carlo simulation has been developed in Geant4 specifically for the GBAR experiment, including details of the generation and propagation of the positronium cloud inside the reaction cavity. An antiproton beam has been included, enabling in-simulation production of antihydrogen atoms directly within the reaction chamber through Ps–p interactions.

Data taken in 2024 should allow determination of the cross section for antihydrogen production in the first reaction at 4 and 6 keV antiproton beam energy. The results should provide a test of theoretical models that predict different values for this cross section.[3]

The poster presents the current status of the simulation, including updated geometry, Ps–H processes, and shows how the simulation of the H formation in the Ps cloud helps in the interpretation of the experimental data.

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74. Search for eta'-mesic nuclei with (p,dp) reaction at GSI/FAIR

Yoshiki Tanaka

RIKEN, Japan

We performed missing-mass spectroscopy of the $^{12}C(p,d)$ reaction near the η'-meson emission threshold to search for η'-mesic nuclei—bound states of the η' meson and a nucleus—in order to study in-medium η'-meson properties, which are closely related to the axial U(1) anomaly and chiral symmetry breaking in QCD. The experiment was conducted using a recently developed setup that integrates the WASA central detector into the fragment separator FRS at GSI. The missing mass of the reaction was measured using the FRS operated as a high-resolution forward spectrometer. In addition, the large-acceptance WASA detector was used in coincidence to tag particles, particularly high-momentum protons, emitted from the decay of η'-mesic nuclei. This tagging suppressed background contributions in the (p,d) reaction and thus enhanced the experimental sensitivity to η'-mesic nucleus formation. In this talk, we will introduce the experiment and present preliminary results obtained from the data analysis.

75. Towards Charge conjugation symmetry test in Electromagnetic Interaction using J-PET

Pooja Tanty[1,2], Elena Perez del Rio[1,2], Pawel Moskal[1,2], and for the J-PET Collaboration

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Charge conjugation symmetry (C symmetry) still remains a fundamental symmetry in the realm of physics. It is well-known to be maximally violated in weak interactions. However, its validity is yet to be tested in Electromagnetic (EM) and Strong interactions. With the aim to test this symmetry in EM interactions, the forbidden decay channel of the triplet Positronium state – the ortho-Positronium (oPs) shall be explored. The C symmetry forbids this state from decay into anything other than an odd number of photons; henceforth a search for four-photon decay extends the feasibility of testing the C symmetry in EM interaction using a J-PET detector. Furthermore, the bosonic nature of photons hints at a distinct configuration in the event of a C-symmetry violation. Known for its outstanding timing (~ 250 ps) and angular (~1°) resolutions,J-PET offers a viable and substantial platform to perform this symmetry test.
J-PET series of detectors has previously established its credibility in the tests of discrete symmetries, further supporting the feasibility of the aforementioned test. In this presentation, the motivation behind the study, the theoretical assumptions, and recent advancements in the test of C symmetry using J-PET shall be discussed.

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76. A Feasibility Study of Using Detector-Scattered Photons for Attenuation Map Generation in J-PET Scanner

Satyam Tiwari[1,2], Sushil Sharma[1,2] and Pawel Moskal[1,2] on behalf of the J-PET collaboration

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Quantitative accuracy in Positron Emission Tomography (PET) depends on reliable attenuation correction (AC) methods [1,2]. The clinical standard for AC in PET imaging remains computed tomography (CT). However, this approach increases patient radiation dose and imaging expenses. In recent years, several CT-less attenuation correction methodologies have been proposed to eliminate the need for CT scans [3,4,5]. In this work, we present a feasibility study for a CT-less AC approach that utilizes photons undergoing Compton scattering within the PET detector—data typically discarded in conventional analyses. This method is especially well-suited to the J-PET scanner [6], which is built from long plastic scintillators that inherently produce a significant number of detectable scattered photons [7,8].

We performed simulations using the GEANT4 Application for Tomographic Emission (GATE) [9] by modeling a modular J-PET scanner [10] with phantoms having varying attenuation profiles. We then analyzed the Lines of Response (LORs) formed between the first interaction at the detector and the subsequent detection of the scattered photon after it passes through the phantom and reaches the detector on the opposite side. An algorithm was developed to extract attenuation properties from these unique LORs, thereby generating coarse attenuation maps. Our initial findings show that these LORs contain spatial information about the phantom's attenuation distribution, enabling the distinction between soft tissue and bone-equivalent regions. These results demonstrate that detector-scattered photons can serve as an intrinsic data source for generating attenuation maps.

In this presentation, we will discuss the methodology and results of this feasibility study.

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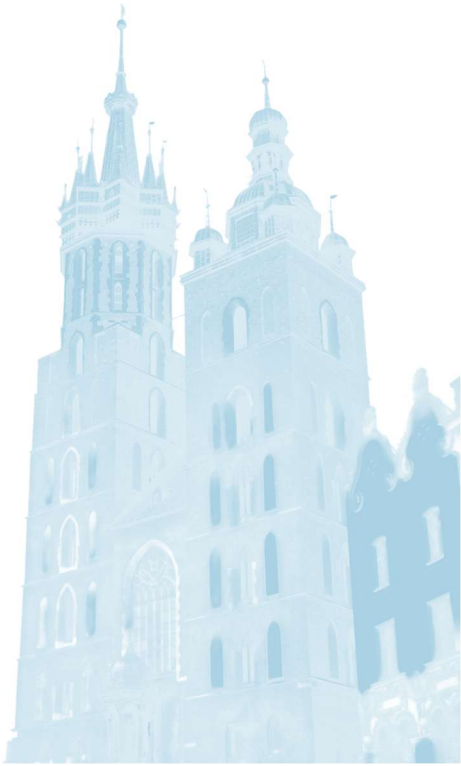

77. Development of a millifluidic platform for slow positron beam studies of biological samples

M. Vicini[1*], M. De Marchi[1], C. Martinelli[1], M. Laganà[2], P. Folegati[3], C. Giordano[1], M.T. Raimondi[1], C. Conci[1], R. Ferragut[3,4]

[1]Department of Chemistry, Materials and Chemical Engineering "G. Natta", Politecnico di Milano, Milan, Italy,
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Positron annihilation spectroscopy (PAS) gained increased attention in recent years for its ability to probe structural and chemical variations in cells and tissues. For instance, the technique successfully identified the presence of skin cancer or hypoxia in spheroids [1,2]. Because of this capability, added to the non-destructive nature of the method, PAS has the potential to improve the informative content of positron emission tomography (PET) acquisitions [3]. However, the quasi-totality of PAS studies is currently performed with a standard ^{22}Na drop-casted source and/or fixed tissues or cells. This means that it is still unknown how a particular cell type or tissue layer affects lifetime and energy spectra of positrons. Here, we present a system enabling the coupling of living biological matter to a variable energy positron beam, enabling precise control of implantation depth inside the sample.

The system prototypes consist of two 3D-printed parts: an upper one with a coverslip glass for optical access and a bottom one with a 2.5×2.5 mm square silicon nitride (Si_3N_4) window with a thickness of 200 nm. The window works as an interface between the high vacuum chamber of the positron beam and the biological sample at atmospheric pressure inside the culture chamber. In addition, a millifluidic circuit ensures the viability of cells throughout the acquisition. We performed preliminary PAS measurements on confluent monolayers of endothelial cells (H5V and bend.3), cultured directly inside the prototype, as a model of microcirculation capillaries.

In conclusion, we developed an innovative, compact, low-cost system for the measurements of complex biological systems with a variable energy positron beam. The prototypes resulted in being watertight and reliable when coupled to the vacuum chamber of the positron beam of our laboratory. The perfusion system provided optimal cell culture conditions for cell viability, as confirmed by epifluorescence and microscopy images acquired through the optical window. In addition, we tested the system using a high vacuum chamber and performed preliminary PAS measurements on cells. This technological advancement is a step forward in the understanding of the interaction of antimatter with biological systems at the nanoscale, important for the potential future application of the technique for diagnostic purposes.

Acknowledgments
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