Abstract ID : **14**

Low-Dose TOF-PET Based on Surface Electron Production in Dielectric Laminar MCPs

Content

We present simulations of whole-body low-dose time-of-flight positron emission tomo\-graphy (TOF-PET) based on laminar microchannel plates (LMCP^{TM}) packaged into High-Resolution Gamma Multiplier Tubes (HGMTs^{TM}) [1]. 511 keV gamma rays interact in the LMCP via the photoelectric and Compton effects to create an electron through surface direction conversion [2], eliminating the scintillator and photodetector sub-systems in PET scanners. The absence of a photocathode allows assembly of large arrays at atmospheric pressure and less stringent vacuum requirements. The laminae surfaces are micro-patterned to form channels, which can then be functionalized to support secondary electron emission in the manner of conventional MCPs.

We have simulated surface direct conversion using modifications to the TOPAS Ge\-ant4-based tool kit. A $20 \times 20 \times 2.54$ cm^3 LMCP composed of 150-micron thick lead-glass laminae is predicted to have a $\geq 30\%$ conversion efficiency to a primary electron that penetrates an interior wall of a pore. The subsequent secondary electron shower is largely confined to one pore and can provide high space and time resolutions.

TOPAS simulations of the Derenzo and XCAT-brain phantoms are presented with dose reductions of factors of 100 and 1000 from literature benchmarks. New applications of PET at orders of magnitude lower radiation dose include routine screening for early detection of pathologies and the use in previously unserved patient populations.

[1] K. Domurat-Sousa, C. Poe, H. J. Frisch, B. W. Adams, C. Ertley, N. Sullivan; *Low-Dose TOF-PET Based on Surface Electron Production in Dielectric Laminar MCPs*; To be published in Nucl. Instr. and Meth. A, arXiv:2307.02708.

[2] K. Domurat-Sousa, C. Poe, H. J. Frisch, B. W. Adams, C. Ertley, N. Sullivan; *Surface Direct Conversion of 511 keV Gamma Rays in Large-Area Laminated Multichannel-Plate Electron Multipliers*; Nucl. Instr. and Meth. A, v. 1055, Oct. 2023, 168538.

Early Career

No

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Presenter: POE, Cameron (Enrico Fermi Institute, University of Chicago)

Track Classification: RDC9: Calorimetry

Contribution Type: Oral

Submitted by **POE, Cameron** on **Thursday, 21 September 2023**

Abstract ID : **15**

Constructing Microchannel Plates from Thin Patterned Laminae

Content

We have proposed a method of construction and simulated the performance in TOPAS [1] of large-area microchannel plates (MCPs) assembled by stacking thin, patterned laminae on edge to form laminar microchannel plates (LMCPs^{TM}) [2]. The laminae are first patterned with channels of arbitrary shape and size so that when stacked, they form pores as in a traditional MCP. The laminae are typically coated with resistive and secondary-emitting materials to support electron multiplication in the pores, and since they are coated before stacking, methods other than atomic layer deposition (ALD), such as chemical vapor deposition (CVD), can be used. Functionalization of the pores is completed before stacking, introducing additional parameters for controlling the shower development, for example, non-uniform resistivity and customized voltage differences between strike surfaces along the pore. Unique slab geometries are also possible: The LMCP can be non-planar, allowing curved surfaces in both lateral dimensions. The laminar construction creates the possibility of incorporating structural elements in the LMCP for modular assembly in large-area arrays.

The LMCP construction allows for the use of substrates optimized for the direct conversion of various incoming particles to electrons in the bulk. For example, LMCPs built from thin laminae of high atomic number (high-Z) material, like lead glass, can be used in gamma ray detection via surface direct conversion. TOPAS simulations predict an efficiency for conversion of 511 keV gamma rays of $\geq$ 30% for a 2.54 cm-thick lead-glass LMCP. Large arrays of LMCPs would provide high resolution space and time measurements in searches for kaon and rare η decays and in shower-max detectors at the LHC and EIC. Since conversion happens in the bulk, a photocathode is not necessary, allowing assembly at atmospheric pressure and packages with reduced vacuum requirements.

[1] B. Faddegon, J. Ramos-Mendez, J. Schuemann, J. Shin, J. Perl, H. Paganetti, *The TOPAS tool for particle simulation, a Monte Carlo simulation tool for physics, biology and clinical research*, Eur. J. Med. Phys. 72 (2020) 114-121.

[2] K. Domurat-Sousa, C. Poe, H. J. Frisch, B. W. Adams, C. Ertley, N. Sullivan; *Surface Direct Conversion of 511 keV Gamma Rays in Large-Area Laminated Multichannel-Plate Electron Multipliers*; Nucl. Instr. and Meth. A, v. 1055, Oct. 2023, 168538.

Early Career

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Track Classification: RDC2: Photodetectors

Contribution Type: Oral

Submitted by **POE, Cameron** on **Thursday, 21 September 2023**

Abstract ID : **16**

A User-Friendly, Highly-Extendable Geant4 Wrapper for Process-Based Detector Development

Content

The development of new detector technologies requires high-accuracy simulations of the fundamental underlying processes with simple, transparent tools that newcomers can rapidly learn. TOPAS [1] fully satisfies these requirements as a well-documented, extendable wrapper for Geant4. We have used TOPAS to simulate and develop two photodetector designs: a whole-body time-of-flight positron emission tomography (TOF-PET) scanner using a low atomic number (low-Z) scintillator [2] and a laminar microchannel plate (LMCP^{TM}) utilizing surface direct conversion of a gamma ray to an electron, eliminating the scintillator and photodetector subsystems [3].

In TOPAS, a user can easily define basic detector geometries, generate particle sources with arbitrary energy spectra, render state-of-the-art phantoms, and modify the underlying software to track a particle's history in a medium, including position and 4-momentum. In simulating the low-Z scanner, we used the pre-built cylinder geometry components in TOPAS to model a Derenzo phantom. The whole-body XCAT phantom is easily simulated using a native TOPAS interface. We set tissue activities using volumetric sources with discrete energy spectra, thus accurately modeling the positron energy spectrum of fluorodeoxyglucose (FDG). TOPAS' default phasespace scorer can only record particle energy and position when a trajectory crosses a geometric boundary but does not natively record these data within a medium. However, TOPAS allows users to extend the underlying Geant4 code, which we exploit to record particle data throughout a volume to record Compton scatter locations.

While TOPAS was originally created as a tool for the medical community, we were able to use it to simulate the LMCP by extending the software to support arbitrary electric fields and by using the native phasespace scoring to generate secondary electrons in the LMCP pores. By modifying the existing code for non-uniform magnetic fields in Opera-3d format, we were able to render non-uniform electric fields generated by Ansys. To simulate secondary emission, we have TOPAS write particle data to a phasespace file, and then use a C program to read the file and generate secondary electrons as input for a next-iteration TOPAS run. This allows us to follow the first few generations of secondaries in the electron shower that largely determine the time jitter.

[1] B. Faddegon, J. Ramos-Mendez, J. Schuemann, J. Shin, J. Perl, H. Paganetti, *The TOPAS tool for particle simulation, a Monte Carlo simulation tool for physics, biology and clinical research*, Eur. J. Med. Phys. 72 (2020) 114-121.

[2] K. Domurat-Sousa, C. Poe; *Methods for simulating TOF-PET in TOPAS using a low-Z medium*; Nucl. Instr. and Meth. A, Sep. 2023, 168675.

[3] K. Domurat-Sousa, C. Poe, H. J. Frisch, B. W. Adams, C. Ertley, N. Sullivan; *Surface Direct Conversion of 511 keV Gamma Rays in Large-Area Laminated Multichannel-Plate Electron Multipliers*; Nucl. Instr. and Meth. A, v. 1055, Oct. 2023, 168538.

Early Career

No

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Track Classification: RDC2: Photodetectors

Contribution Type: Oral

Submitted by **POE, Cameron** on **Thursday, 21 September 2023**

Abstract ID : **18**

Design of a 40 GS/sec 10 mw/Channel Waveform Sampling ASIC in 65 nm CMOS

Content

The development of large-area MCP-based particle detectors with time resolutions of 5 ps or less [1] would allow substantive advances in particle identification at particle colliders such as the LHC and EIC, high precision mass reconstruction in searches for rare K and η decays, and a reduction by orders-of-magnitude of the radiation dose in positron-emission tomography [2, 3]. We describe a preliminary design for a 16-channel 40 GS/sec waveform sampling ASIC in the TSMC 65 nm process with the goal of achieving 1 ps resolution at 10 mW power per
channel. The buffer depth of each channel is 256 samples, corresponding to a recording window of 6.4 ns, long compared to a pulse from an MCP-based photomultiplier. In parallel for each channel, a 5 GS/sec 1024-deep sampling records a longer window of 204.8 ns for identifying pile-up and the temporal context for unusual signals. Recording of the data for each channel is triggered by a 10 ps resolution fast constant fraction discriminator [4] capable of multiple triggering during the window of the slow buffer. The sampling switches are implemented as 2.5V nMOSFETs controlled by 1.2V shift registers in order to achieve a large dynamic range, low leakage, and high bandwidth. Stored data is exported to be digitized by an external ADC at 10 bits or better. Specifications on operational parameters include a 4 GHz analog bandwidth and a deadtime of 20 microseconds, corresponding to a 50 kHz readout rate, determined by the choice of the external ADC. The current status will be presented.

[1] K. Inami, N. Kishimoto, Y. Enari, M. Nagamine, and T.
Ohshima; A 5-ps Tof-counter with an MCP-PMT; Nucl. Instr. Meth. A560, p.303, 2006

[2] P.~Lecoq, C.~Morel and J.~Prior, Case for setting up a 10ps challenge: A step toward reconstruction-less TOF-PET, Nuovo Cim. C (2020) no.1, 2 doi:10.1393/ncc/i2020-20002-y

[3] K. Domurat-Sousa, C. Poe, H. J. Frisch, B. W. Adams, C. Ertley, N. Sullivan; Low-Dose TOF-PET Based on Surface Electron Production in Dielectric Laminar MCPs; To be published in Nucl. Instr. and Meth. A, arXiv:2307.02708.

[4] Si Xie, Artur Apresyan, Ryan Heller, Christopher Madrid, Irene Dutta, Aram Hayrapetyan, Sergey Los, Cristián Peña, Tom Zimmerman,
Design and performance of the Fermilab Constant Fraction Discriminator ASIC, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 1056, 2023, 168655, ISSN 0168-9002

Early Career

Yes

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Track Classification: RDC4: Readout and ASICs; RDC11: Fast Timing

Contribution Type: Oral

Submitted by **PARK, Jinseo** on **Saturday, September 23, 2023**

Abstract ID : **74**

Underlying physics properties for identifying 511 keV gammas in high-Z crystal PET

Content

Due to the need to correctly determine the first interaction location of each of the two gamma rays to measure the line-of-response, Positron Emission Tomography (PET) scanner sensitivity changes rapidly with small changes in the efficiency at 511 keV. Current PET scanner designs use high atomic number (high-Z) scintillating crystals to detect photoelectric interactions in the detector. Due to photoelectric interactions having a lower cross-section than Compton scattering at 511 keV for high-Z materials, large losses in detector sensitivity occur. This loss in sensitivity can be countered by the inclusion of Compton scattering in the detection of the gamma rays.

Determination of the first scatter in a chain of Compton scatters requires precise measurement of the geometry of the scatter chain, requiring uncertainty in scattering locations to be substantially smaller than the distance between scatters. In typical high-Z detectors the crystal segmentation is on the same scale as the distance between scatters, making determination of the first scatter so difficult it is typically not done. TOPAS simulations show that sensitivity for lines-of-response can be increased by a factor of 3 with the inclusion of Compton scatters.

Early Career

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Presenter: DOMURAT-SOUSA, Kepler (Enrico Fermi Institute, University of Chicago)

Track Classification: RDC9: Calorimetry

Contribution Type: Oral

Submitted by **POE, Cameron** on **Friday, 29 September 2023**

Abstract ID : **76**

Minimum Requirements for a low-Z-medium detector for low-dose high-resolution TOF-PET

Content

Two major drawbacks to time-of-flight positron emission tomography (TOF-PET) are low spatial resolution and high radioactive dose to the patient, both of which result from limitations in detection technology rather than fundamental physics. To address these, a new type of TOF-PET detector employing low-atomic number (low-Z) scintillation media recording Compton scattering locations and energies in the detector has been proposed [1]. Here we present a preliminary comparison of the low-Z detector performance to conventional TOF-PET using high-Z scintillation crystals, and the minimum technical requirements for such a system. We have performed a simulation study using a customized TOPAS simulation [2] to evaluate the potential of a proposed low-Z detection medium, linear alkylbenzene (LAB) doped with a switchable molecular recorder. By quantifying contributions and tradeoffs for energy, spatial, and timing resolution of the low-Z detector, we show that a reasonable combination of detector specifications improves the TOF-PET sensitivity by more than 5x, with comparable or better spatial resolution and 40-50% enhanced contrast-to-noise as compared to state-of-the-art photoelectric based high-Z TOF-PET. These improvements enable imaging of a brain phantom simulated at less than 1% of a standard radiotracer dose. This would enable expanded access and new clinical applications for TOF-PET.

Early Career

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Track Classification: RDC9: Calorimetry

Contribution Type: Oral

Submitted by **DOMURAT-SOUSA, Kepler** on **Friday, 29 September 2023**

Abstract ID : **135**

An input buffer for PSEC5 –a waveform sampling ASIC –in 65nm CMOS Technology with a 5GHz analog bandwidth

Content

PSEC4 [1] has been utilized for waveform sampling in the PhD theses of E. Angelico[2] and E. Oberla[3] ,the Fermilab Test Beam, and the Accelerator Neutrino Neutron Interaction Experiment. PSEC5 aims to improve on its predecessor by raising the number of channels from 6 to 16, the sampling rate from 10 GSa/s to 40 GSa/s, and most importantly, achieving a timing resolution of 1 picosecond.

A buffer of high input and impedance and low output impedance is required to prevent any loading and disruption to the signal source, while driving the waveform to subsequent stages with minimal loss in signal quality.

We present an input buffer of said ASIC in the TSMC 65nm process, which provides an analog bandwidth of 5GHz, unitary gain, a significant DC offset to prevent a cutoff at 0V, and no AC phase difference using 2.5V nMOSFETs. The described input buffer is situated at the front end of the ASIC, feeding into three followers of a similar design. We will also discuss the larger scheme of the front end signal transmission.

We have simulated the buffer with a capacitive load of itself under a three times multiplier in order to account for the capacitance of the followers succeeding the input buffer using Cadence® Virtuoso® System Design Platform.

References

[1] Eric Oberla PSEC4 waveform sampler and Large-Area Picosecond PhotoDetectors readout electronics; Workshop on Picosecond Photon Sensors, Clermont-Ferrand

[2] Evan Angelico; Development of Large-area MCP-PMT Photo-Detectors for a precision time-of-flight system at the Fermilab Test Beam Facility; Doctoral Dissertation, Department of Physics, University of Chicago

1

[3] Eric Oberla; Charged Particle Tracking in an Optical Time Projection Chamber; Doctoral Dissertation, Department of Physics, University of Chicago

Early Career

Yes

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Presenter: YEUNG, Richmond (University of Chicago)

Track Classification: RDC4: Readout and ASICs

Contribution Type: Oral

Submitted by **YEUNG, Richmond** on **Sunday, October 1, 2023**

Abstract ID : **146**

Precision Timing Using Composite Microchannel Plates

Content

We propose a technique to use composite microchannel plate detectors to measure the arrival time of particles. The resistive and electron multiplying functions of a microchannel plate can be constructed by thin coatings on many insulating substrates. Suitable substrates could produce the initial electrons for multiplication in situ. Such composite microchannel plates produced without fiber drawing could function as both absorbing and amplifying elements in a detector system. We identify requirements in the detector to achieve 1 psec time resolution by this method.

Early Career

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Presenter: SPIEGLAN, Eric

Track Classification: RDC11: Fast Timing

Contribution Type: Oral

Submitted by **SPIEGLAN, Eric** on **Sunday, 1 October 2023**