Contribution ID: **16** | Type: **Poster**

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

Tuesday, 7 November 2023 19:40 (20 minutes)

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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Session Classification: Poster Session