Fast optical photon transport at GEANT4 with Dual-Readout Calorimeter at future e^+e^- colliders

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Dual-readout calorimeter (DRC) has been developed by DREAM and RD52 collaborators for last 20 years. It offers high-quality energy measurement for electromagnetic particles, hadrons and jets which is essential for the successful future lepton collider experiment [1]. CEPC (China) and FCC-ee (CERN) projects, the next e^+e^- colliders for Higgs factory and other electroweak processes, are under discussion by world-wide HEP community as a next generation experiment. The DRC has been proposed as a calorimeter of the IDEA detector concept published in Conceptual Design Reports of both future collider projects [2, 3]. The DRC would meet sufficient performance required by the CEPC and FCC-ee to achieve high precision measurements and indirect new physics searches.

The GEANT4 toolkit [4, 5, 6] has been the most widely used simulation software during the last decade in high energy physics (HEP). However, the detailed characteristics of optical fibers are occasionally over-simplified, especially when fibers themselves are not sensitive to high-energy particles but transmitting photons from sensitive material (*e.g.* scintillator) to readout systems. The impact of optical fibers on the detector response is limited compared to that of sensitive materials in the case, and therefore simplification is justified. However, in some detectors like the novel DRC where optical fibers act as sensitive materials, the impact of fiber characteristics on the detector response is crucial, hence detailed simulation on the interaction between optical fibers and high-energy particles is inevitable.

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Three types of optical fibers are most widely used in the HEP experiments, aside from plain data transmitting fibers: scintillation, wavelength shifting, and clear (often called Čerenkov) fibers. These optical processes are well-defined in the GEANT4 already. However, the tracking algorithm of the GEANT4 for optical photons manipulates energy and momentum of an individual photon in every reflection step, making it highly accurate but also unusually slow when it comes to high statistics as in scintillation fibers.

One of the efficient ways to handle the high statistics of the number of photons is to parameterize the characteristic response of optical fibers. Especially when the fiber is regular-shaped solid such as a tube or box, the final momentum of a photon can be calculated even without tracking every reflection within the fiber for the individual optical photon. It can significantly reduce the computing time while preserving accuracy since checking total internal reflection condition in every tracking iteration exaggerates the complexity of calculation then it requires.

Two approaches are going to be explored, reproducing the optical physics of standalone GEANT4, and expanding the simulation by parameterizing experimental data of optical fibers. While the former is straightforward and limited to speeding up GEANT4, the latter includes:

- Test several products of optical fibers, regarding the light yield and the spectrum of scintillation and wavelength shifting as a function of the fiber length, the spectrum of light attenuation, and the polarization.
- Parameterize fiber bending based on the bending loss data of optical fibers, to enhance the utility of the optical fiber simulation when using GEANT4 for more generic cases.

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