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Validation of upgrade of the Geant4 Simulation Toolkit to Model the Responses from TOP and ARICH Detectors

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Abstract

Belle II is the next generation B-Factory experiment at the world's highest luminosity accelerator the SuperKEKB collider, which is designed to collect 50 times more data than the previous generation experiments. A hallmark feature of B-Factory experiments is to use novel characteristics of Cherenkov detectors for identification of the flavor of charged particles passing through the detector. The TOP and the ARICH detectors can identify charged pions and kaons with high precision. The response to the passage of high energetic particles in the detector is modeled with the Geant4 simulation toolkit. Here we compare the performances of these two detectors of particle identification at the Belle II experiment following an upgrade of the list of physical processes simulated by the Geant4 toolkit. The new list is found to give consistent results when compared to the default list while improving the CPU requirement of the Geant4 toolkit by as much as 25%.

Introduction

The Belle II [1] experiment currently collecting data at the SuperKEKB collider is designed to search for new physics using the world's largest sample of the b-hadrons, c-hadrons, and the tau-leptons.[1]. The Time of propagation (TOP) [2] and Aerogel Ring Imaging Cherenkov (ARICH) [3] are sub-detectors used by Belle II to identify particles with high precision. Geant4 [4] is a toolkit for the simulation of the passage of particles through matter, which is why it's perfect for its use to simulate the response of the whole Belle II detector (Figure 1).

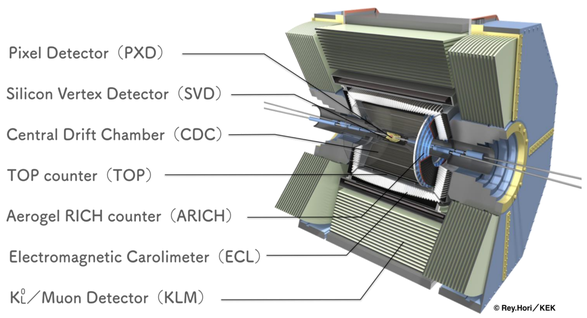

Figure 1: Belle II Detector

TOP and ARICH

The TOP detector is comprised of:

- A quartz radiator (2.7 m x 45 cm x 2 cm) with focusing mirror (6.5 m radius) and expansion block
  - The radiator is made up of 2 quartz bars, each 1.25m in length, which is glued to the focusing mirror.
- Microchannel plate photomultiplier tubes (MCP-PMT)
- A fast readout electronics (32 PMTs, 512 channels per module).

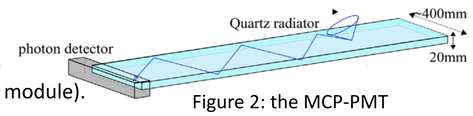

Figure 2: the MCP-PMT

The TOP detector (Figure 2) utilizes total internal reflection of Cherenkov photons produced in a quartz radiator and measures the position and precise arrival time of the propagated photons at the radiator ends. The effect of the mirror is to focus parallel rays of photons into a single pixel of a photo-sensor while the chromatically dispersed rays are detected by separate channels instead of a single channel[2].

The ARICH detector is comprised of:

- A double layer radiator of n_1=1.045 and n_2=1.55
  - 124 Aerogel tiles per layer
  - 248 total tiles
  - Each 2cm thick
- Hybrid Avalanche Photon Detector (HAPD) is comprised of
  - 420 HAPD Modules
  - Total of 60480 readout channels

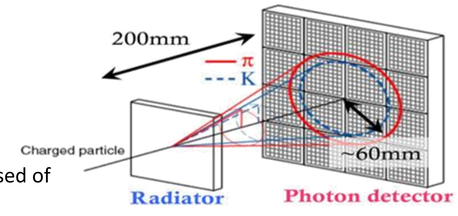

Figure 3: ARICH and HAPD

The ARICH detector (Figure 3) uses 2 layers of tiles of aerogel for the particle to transition through and a photon detector on the opposite side to measure the Cherenkov radiation. Each layer has a different level of refractive index[3].

GEANT4

Geant4 is a simulation toolkit for the passage of particles through matter. It is used in many different fields of science including the Belle II experiment. The Belle II software system is a framework named basf2, its simulation package is based on the Geant4. Originally the initialization of the Geant4 toolkit for the Belle II project was based on the FTFP_BERT (Fritiof model for high energies and Bertini-style cascade for low energy) Physics List, which was optimized for the LHC. The new Physics List is specifically tailored for the Belle II experiment. Information about momentum and vertex of each generated particle is sent to the Geant4 toolkit, which simulates the response of each detector element to each generated particle. Then Geant4 transports each primary particle inside the detector and creates their secondary particles. To simulate the propagation of particles in the detector, physics processes of the interactions between the particles and the detector materials are specified based on the Physics List and geometry of the entire detector including TOP and ARICH specification lists [4].

Kaon / Pion Likelihoods of TOP and ARICH

The likelihood is a statistical tool to tell us the relative probability of a particular outcome. The difference in likelihood is positive for pions and negative for kaons. The likelihood allows us to differentiate between these two kinds of charged particles. By studying Figures 4 and Figure 5, we observe the performance of Geant4 with the old and new Physics List is consistent.

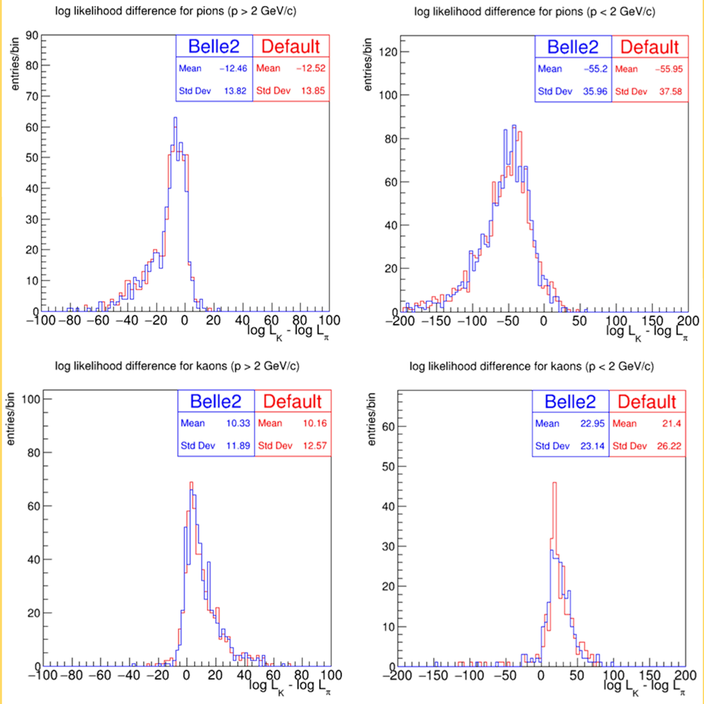

Figure 4: These are the log likelihood graphs; it show the difference between the likelihood of kaons and pions at momentum (p) greater than and less than 2GeV/c simulated in the TOP detector.

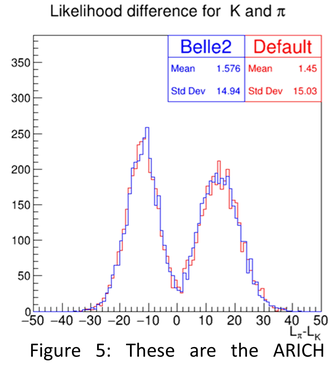

Figure 5: These are the ARICH simulations and they show its ability to identify between Kaon and Pions and their respective likelihoods.

Number of Photons

The number of photons detected in the simulation for both TOP (Figure 6) and ARICH (Figure 7) virtually mirrors one another, further supporting the consistency of the simulation after the upgraded Physics List.

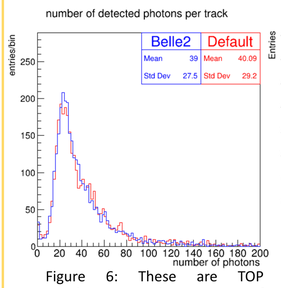

Figure 6: These are TOP simulations detection of Cherenkov photons that pass through the detector per track

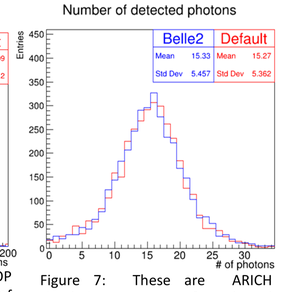

Figure 7: These are ARICH simulations rate of selected photons.

Summary and Acknowledgment

- By studying the pions and kaons from the TOP and ARICH detectors, we see a consistent spread in the standard deviations in the likelihood plots, validating the performance of the new Physics List.
- Using upgraded Physics List, we see consistent behavior in the simulation of the number of photons in the TOP and the ARICH detectors
- Replacing the previous default Physics List FTFP_BERT optimized for the LHC experiments, with a customized Physics List optimized for the Belle II experiment, we find consistent modeling of particle identification. While performance is similar, the CPU requirements of the Geant4 toolkit is reduced by 25% using the new Belle2 Physics List [5]
- This project could not have been completed without the extensive effort and guidance of Dr. Swagato Banerjee and Dr. David N. Brown. A special thanks go to Dustyn Hoffer, Stephen Temple, Nate Riche, and the rest of the UofL HEP group for their continued support.

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