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Abstract

Since the start of software development at the Belle II experiment operating at the KEK national laboratory in Tsukuba, Japan, the simulation tool kit Geant4 has undergone several updates. As a member in the ongoing collaboration, the University of Louisville's High Energy Physics (HEP) group is striving to validate newer versions of Geant4 to maximize improvements of physics performance. We have simulated the performance of a new physics list sub-module, the "Belle2 PhysicsList", with improved modeling of hadronic shower shape and standard electromagnetic processes. Using a reconstruction-based selection procedure on tau-pair events decaying into a final state consisting of electrons, photons, and pions, we have concluded that the Belle2 PhysicsList is consistent with the default present in Geant4 v10.1.2. Furthermore, using a sample of $b\bar{b}$ events, we find that the Belle2 PhysicsList decreases CPU requirements by up to 25%.

Introduction

The Belle II experiment [1] uses Geant4 toolkit v10.1.2 [2] to simulate its detector response. The default PhysicsList popularly used in Geant4 is called FTFP_BERT, where FTF refers to the Fritiof string model, P refers to the G4Precompound model used for nuclear de-excitation, and BERT refers to the Bertini-style Intra-nuclear Cascade hadronic models. However, FTFP_BERT was optimized for LHC experiments, not Belle II. The customized Belle2 PhysicsList contains optimization of primarily hadronic and electromagnetic process. Hence the best place to test these optimization is using a sample of tau-pair events containing electrons, pions and photons in the final state. We are using calorimeter shower-shape variables [3] to understand the modeling of these 3 kinds of particles in this study.

To properly validate the Belle2 PhysicsList, five primary results were checked: (1) shower shape, (2) electron/pion events, (3) visible energy, (4) effect of switching from electromagnetism (EM) standard options to option 1, and (5) effect of switching hadronic reconstruction from FTFP_BERT to a new model combination. By analyzing changes in the performance of the Monte Carlo simulation software using the newer Belle2 PhysicsList, we are able to justify an update to the software.

Particular variables of interest in these simulations include momentum (p) measurement in the central drift chamber [4], and the distributions of energy (E) over various regions of the electromagnetic calorimeter ($E1E9$, $E9E21$, $E9E25$) [3]. These parameters are used to identify specific particle events and properly group them so efficient results may be drawn from the collected data.

Methodology

We simulate 100,000 events of the type $e^- + e^+ \rightarrow \tau^- + \tau^+$ half of which decay as $\tau^- \rightarrow e^- + \bar{v_e} + v_\tau, \tau^+ \rightarrow \pi^+ + \pi^0 + \bar{v_\tau}$ and half of which decay as $\tau^- \rightarrow \pi^- + \pi^0 + v_\tau, \tau^+ \rightarrow e^+ + v_e + \bar{v_\tau}$ respectively. This provides us with a sample of electrons and pions, and through the prompt decay of π^0, photons, which are the prime targets of our study.
In our research, we employed a reconstruction-based selection process by using events with one parallel (or anti-parallel) track to the thrust axis with E/p > 0.8 for electron/positron particles, as well as one track parallel (or anti-parallel) to thrust axis with E/p < 0.8 for π particles associated with the presence of a π^0 particle decaying into a pair of for γ with invariant mass of the 2 γ system in the range 115-155 MeV/c^2

By running these simulations in Geant4 v10.1.2 with both the Belle2 and default PhysicsList, we were able to compare variables of importance to determine the extent to which the new PhysicsList agrees with the defaults.

Our primary research consisted of two stages: (1) comparing the physics performance of the default PhysicsList with the new Belle2 PhysicsList in Geant v10.1.2, and (2) comparing the simulation speed using the Belle2 PhysicsList against the default. The first stage involved the simulation of tau-pair events resulting in the production of electrons, photons, and pions, each with 9 respective histograms, while the second stage involved simulation of $b\bar{b}$ events. The end result is 27 histograms of variables of importance and two timing graphs, showing the improved speed of the new PhysicsList.

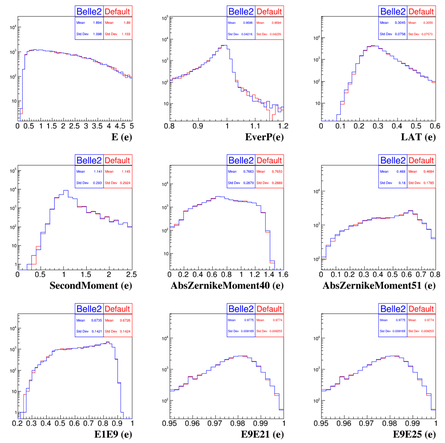

Fig. 1: Electron events comparing default and Belle2 PhysicsLists.

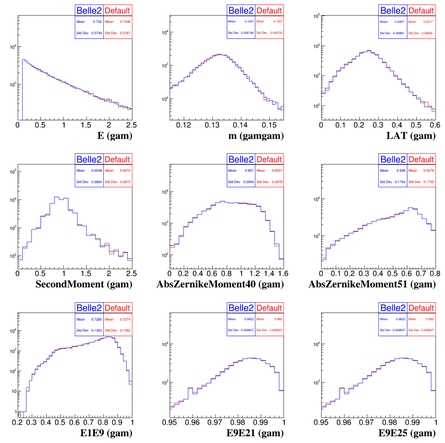

Fig. 2: Photon events comparing default and Belle2 PhysicsLists.

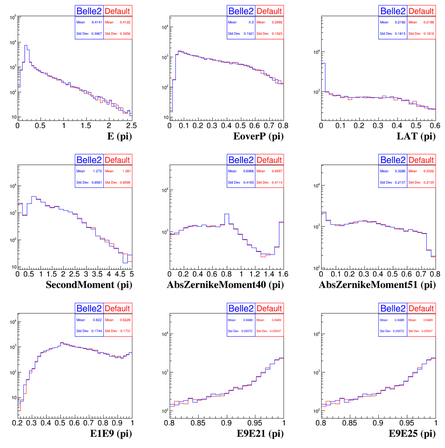

Fig. 3: Pion events comparing default and Belle2 PhysicsLists.

Results

In Fig. 1, the histograms for electron events, events were gathered by applying a firm cut to energy over momentum (E/p) values greater 0.8. The events that met this criteria were cross referenced with Monte Carlo particle identification (PID) schema to ensure their composition. Then, the collected distribution was organized into a histogram and overlaid with the distribution from a default simulation. Below Fig. 1 are the events for photons (Fig. 2), selected based on whether the invariant mass of the 2 γ system lies in the range 115-155 MeV/c^2, and pions (Fig. 3), cut based on E/p values of less than 0.8.
Our findings lead us to suggest the implementation of the Belle2 PhysicsList as an effective refinement of the present defaults in the Geant software. Using tau-pair decays into samples of electrons, photons and pions, we have successfully shown that the Belle2 PhysicsList is consistent with the present defaults.

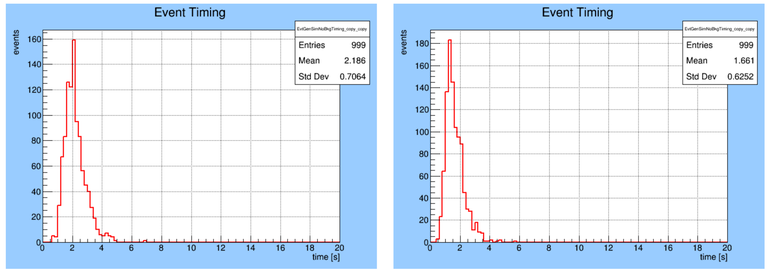

Fig. 4: A comparison of event simulation times for the defualt (left) and Belle2 (right) PhysicsLists.

Additionally, a timing simulation was ran in Geant v10.1.2 to determine if the updated Belle2 PhysicsList had improved simulation times for the software. As seen above (Fig. 4), the Belle2 PhysicsList reduced the CPU requirement by up to 25% in the simulation of 1,000 $b\bar{b}$ events.

Remarks

Our validation work is ongoing, yet these results are a positive development in the ongoing Belle II experiment. The Louisville High Energy Physics Group is committed to pursuing further research in the validation and implementation of refined simulation and reconstruction software for the experiment.

Acknowledgements

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