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Analysis of Neutral Long-Lived Kaons Reconstruction Efficiency via a Missing 4-Momentum Method at the Belle II Experiment

D. Kulakov[1], **S. Glazov**[2], **S. Raiz**[2], **E. Ganiev**[3]

[1] *Taras Shevchenko National University of Kyiv, Kyiv, Ukraine*
[2] *Deutsches Elektronen-Synchrotron (DESY), Hamburg, Germany*
[3] *Jozef Stefan Institute, Ljubljana, Slovenia*

In this report, we present a method for the reconstruction of neutral long-lived kaons (K_L^0) using Monte Carlo simulations of the Belle II detector at the SuperKEKB accelerator in Tsukuba, Japan. The detector's nearly 4π hermetic coverage, layered subdetector structure, and the precisely known initial kinematics of the e^- e^+ collisions provide a unique environment for the study of flavor physics via decays of B mesons, D mesons, and tau leptons.

Due to their long lifetime and primarily hadronic interactions, K_L^0 mesons are notoriously difficult to reconstruct. They often penetrate the inner tracking systems without leaving a trace and may only leave partial energy deposits in the Electromagnetic Calorimeter (ECL) or hits in the K_L^0 and Muon detector (KLM). While these subdetectors can capture a fraction of K_L^0 interactions, their overall reconstruction remains a significant challenge for many Belle II analyses.

The primary objective of this study is to estimate the K_L^0 reconstruction efficiency to ensure that Monte Carlo simulations accurately reproduce experimental data. While established methods exist for probing high-energy K_L^0 (E > 1.4 GeV), there is a critical need for a method targeting the low-energy regime (E < 1.4 GeV). Developing this capability is essential for "missing energy" analyses, such as the rare decay $B \rightarrow K \nu \bar{\nu}$, where an undetected K_L^0 could be incorrectly identified as a neutrino, leading to significant background contamination.

To address this, we identify inclusive, high-purity $e^- + e^+ \rightarrow K_L^0$ + *charged hadrons* events. We focus on five specific channels with high signal-to-background ratios: $K_L^0 5K\pi$, $K_L^0 3K\pi$, $K_L^0 3K3\pi$, $K_L^0 3K5\pi$, $K_L^0 2pK3\pi$. In this approach, we reconstruct only the charged particles (kaons, pions, and protons) and utilize the known e^- e^+ initial kinematics to predict the momentum and direction of the unreconstructed K_L^0 via a "missing 4-momentum" technique. Real K_L^0 mesons are identified as a distinct peak in the derived mass spectrum at 498 MeV/c^2. Finally, we calculate the efficiency by searching for associated energy clusters or hits in the ECL and KLM that correspond to these predicted K_L^0 candidates.