STUDY OF K_L^0 CLUSTER RECONSTRUCTION EFFICIENCY IN THE BELLE II CALORIMETERS USING THE RECOIL MOMENTUM TECHNIQUE

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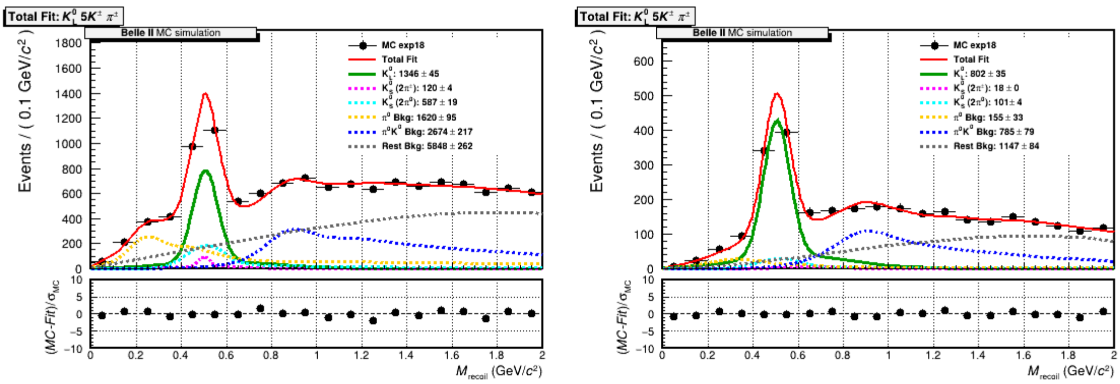
The search for rare B-meson decays offers a highly sensitive probe for Physics Beyond the Standard Model (BSM). In particular, decay modes with neutrinos in the final state, such as $B \to K^*\nu\bar{\nu}$, have attracted significant interest following the recently published $B^+ \to K^+\nu\bar{\nu}$ observation, which reveals a 2.7σ tension with respect to the Standard Model prediction in Ref. [1]. Investigating these rare processes is a primary objective of the Belle II experiment, a next-generation B-factory (It's international collaboration, over 1200 scientists across 28 countries). However, a major experimental challenge in these searches arises from background channels containing neutral particles, such as long-lived kaons ($\boldsymbol{K_L^0}$). These particles can escape detection or misidentify energy deposits, thereby mimicking the missing energy signature of the neutrinos.

This work presents a method for identifying $\boldsymbol{K_L^0}$ clusters in the Electromagnetic Calorimeter (ECL) and the $\boldsymbol{K_L^0}$ and Muon detector (KLM) using a technique primarily based on the detector's tracking system. The method reconstructs the recoil momentum to predict the $\boldsymbol{K_L^0}$ trajectory and subsequently searches for clusters within a 0.3-radian cone that pass basic selection criteria. This approach is particularly effective for events where the hadronic shower originates in the ECL and extends into the KLM. To further improve signal purity in the ECL, we utilize a cleaning method described in Ref. [2].

Our work utilizes the "recoil method". The $\boldsymbol{K_L^0}$ four-momentum is reconstructed as the missing momentum relative to the beam energy-momentum of collider after reconstructing all other charged particles in the $e^- + e^+ \to Charged\ hadrons\ + K_L^0$ process. Currently, this study is conducted exclusively using Monte Carlo (MC) simulation data. Within this simulation framework, we are able to decompose the reconstructed sample into a signal component and five distinct backgrounds, each corresponding to a specific particle type mimicking the neutral kaon signature.

Our results show that for events satisfying the cluster selection, the efficiency of the method reaches up to 95% depending on the decay channel. The recoil mass spectra demonstrate a significantly enhanced $\boldsymbol{K_L^0}$ peak after selection, confirming the method's effectiveness in background suppression for calculating efficiency and Data/Monte-Carlo correction of $\boldsymbol{K_L^0}$ reconstruction at the Belle II experiment.

The signal extraction and performance evaluation were performed using the RooFit framework in Ref. [3]. We employed an unbinned maximum likelihood fit to the recoil mass distribution to construct the probability density functions (PDFs). This approach allowed for a precise determination of the $\boldsymbol{K_L^0}$ yield and the evaluation of different backgrounds.



Recoil mass spectrum fits before cluster selection (left) and after the selection (right). Black points represent the MC sample, and the red line indicates the total fit. Colored components: signal K_L^0 (green), $K_S^0 \to \pi^+\pi^-$ (magenta), $K_S^0 \to \pi^0\pi^0$ (azure), π^0 background (yellow), $\pi^0 + K^0$ background (blue), and other backgrounds (grey).

1. I. Adachi et al. (Belle-II), Evidence for $B^+ \rightarrow K^+\nu\bar{\nu}$ decays, Phys. Rev. D 109, 112006 (2024), arXiv:2311.14647 [hep-ex], 2024.
2. S. Longo et al. CsI(Tl) pulse shape discrimination with the Belle II electromagnetic calorimeter as a novel method to improve particle identification at electron–positron colliders. Nucl. Instrum. Meth. A, 982:164562, 2020.
3. W. Verkerke and D. Kirkby, "The RooFit toolkit for data modeling", Statistical Problems in Particle Physics, Astrophysics and Cosmology, Oxford (2006), pp. 186-189.