Estimating K_L^0 identification efficiency of KLM detector in Belle II experiment using sPlot

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Abstract

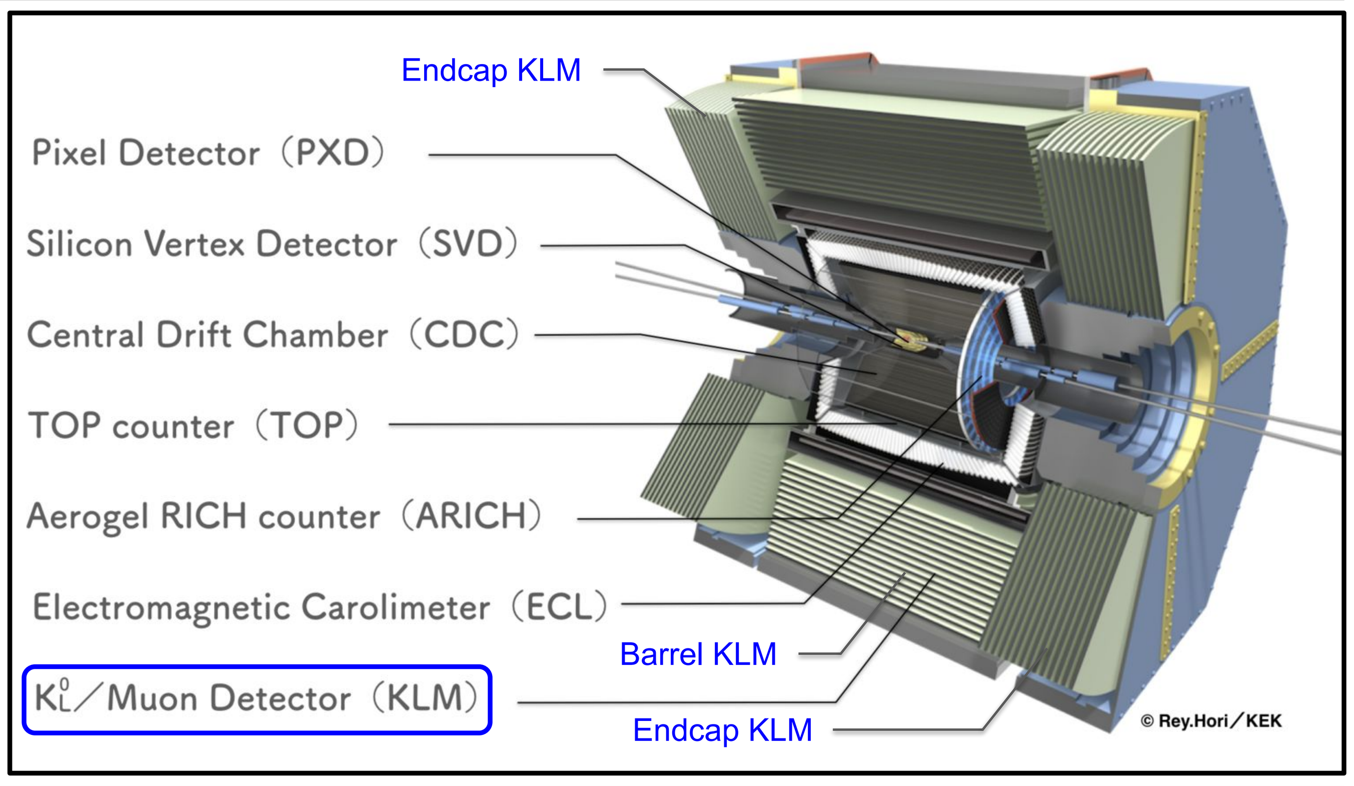
K_L^0 particles are identified by the energy deposits in the KLM, the outermost detector in the Belle II experiment. However, photons, neutrons and other neutral hadrons can also deposit some energy in the KLM detector. Here we present a statistical technique using sPlot, to distinguish between the patterns of energy deposits in KLM from K_L^0 vs other backgrounds. This technique allows one to make a robust determination of K_L^0 identification efficiency in the KLM detector.

Introduction

The KLM detector [1] is the outermost sub-detector in the Belle II experiment. The purpose of this detector is to detect K_L^0 mesons and measure the momentum of muons. It is made up of alternating sandwiches of 4.7 cm thick iron slabs and active detector elements located outside the superconducting solenoid. The iron plates serve as the flux-return for the solenoid.

The KLM detector has two parts [2,3] - Barrel KLM (BKLM) and Endcap KLM (EKLM). The BKLM is coaxial to the beam axis and has 15 active detector layers - 13 outermost layers made of resistive plate chambers and two innermost layers made of scintillators read out by photomultiplier tubes. The EKLM is located at the two ends of the Belle II detector, perpendicular to the beam axis.

Energy deposits in the KLM not associated with a track are K_L^0 candidates and those associated with a track are muon candidates. The magnitude of reconstructed K_L^0 momentum obtained from KLM detector is proportional to the size of KLM cluster, which provides a very rough estimate.



Control sample of $c\bar{c}$ events

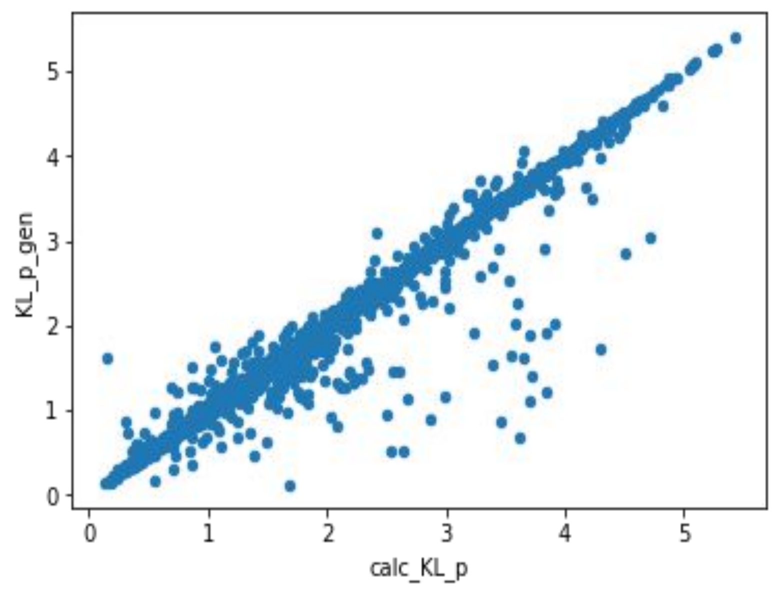
The signal and tag side decay channels chosen for this analysis are -

Signal: $D^{*-} \rightarrow [\bar{D}^0 \rightarrow K_L^0 \pi^+ \pi^-] \pi^-$

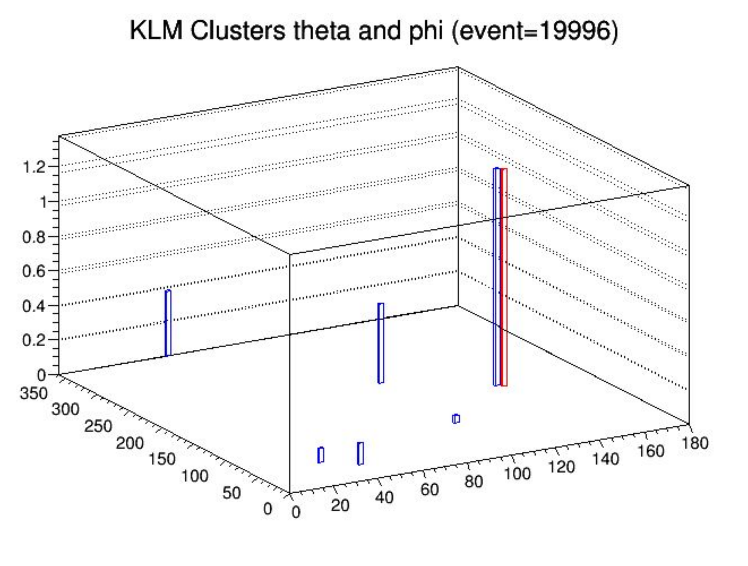
Tag: $D^{*+} \rightarrow [D^0 \rightarrow K^- \pi^+] \pi^+$

Such events contains only one K_L^0. Thus, we can effectively use conservation of momentum to calculate the momentum of the K_L^0, as shown in the adjacent figure. Then assuming the K_L^0 mass hypothesis, we reconstruct the 4-momenta of D^0 and D^{*+} and obtain the distribution of $\Delta m = (m_{D^{*-}} - m_{D0})$. The reconstructed K_L^0 candidate within a 10° cone in θ and ϕ within the calculated direction and momentum within 25% of the calculated momentum is marked as signal K_L^0 and the rest are marked as background K_L^0, as shown in red and blue respectively in adjacent figure.

$D^0 \rightarrow K^- \pi^+$ channel has branching fraction of 3.9%. In future we plan to add $D^0 \rightarrow K^- \pi^+ \pi^+ \pi^-$ and $D^0 \rightarrow K_s \pi^+ \pi^-$ channels with branching fractions 8.1% and 2.9% respectively for the tag side in order to improve statistics.



Correlation between the truth and calculated K_L^0 momentum



The reconstructed (in blue) and calculated (in red) K_L^0 momenta on θ - ϕ plane

Signal and Background PDFs for Δm distributions

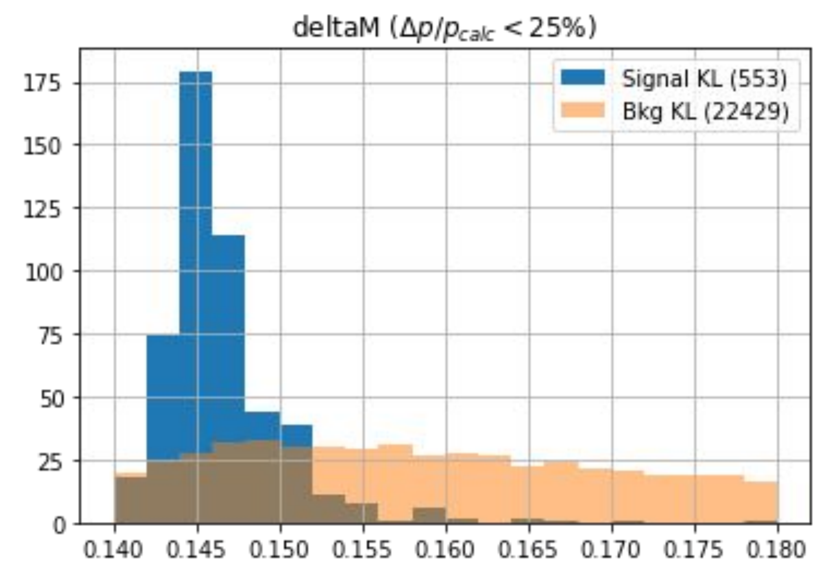
We obtain the signal and background probability density functions (PDF) for the discriminating variable by fitting Δm distributions obtained from signal and background samples separately as shown in the left plot below. Let's denote the fitted signal and background PDFs of Δm as $P_S(x)$ and $P_B(x)$ respectively. Then we perform a maximum likelihood fit to the whole set of reconstructed K_L^0 candidates as shown in the right plot below, to find the numbers of signal (n_S) and background candidates (n_B). This allows us to obtain the prior probabilities, $P(S) = n_S/(n_S+n_B)$ and $P(B) = n_B/(n_S+n_B)$.

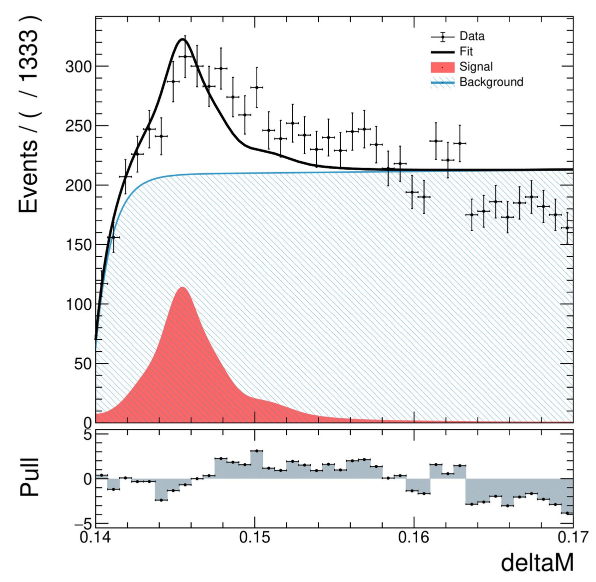
Then using Bayes' theorem, we obtain the probability for any candidate 'c' to be signal as -

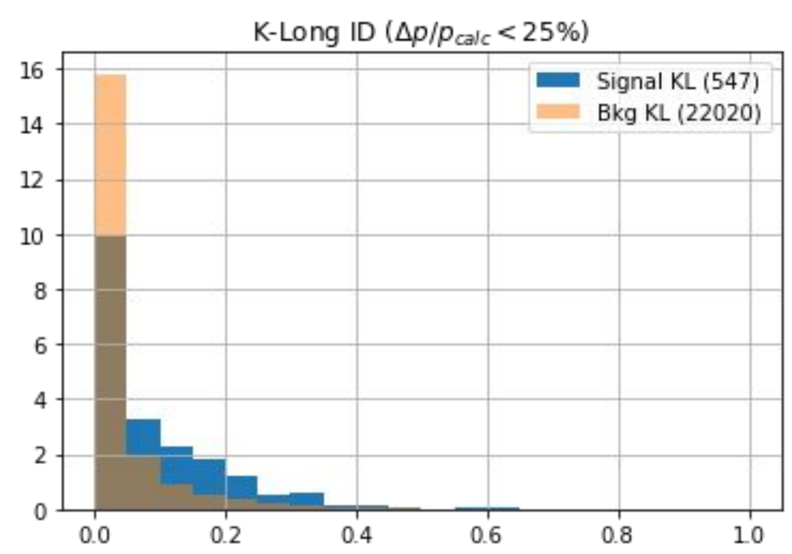
Prob(c ϵ Signal | c.Δm = x) = $P(S)P_S(x) / [P(S)P_S(x) + P(B)P_B(x)]$

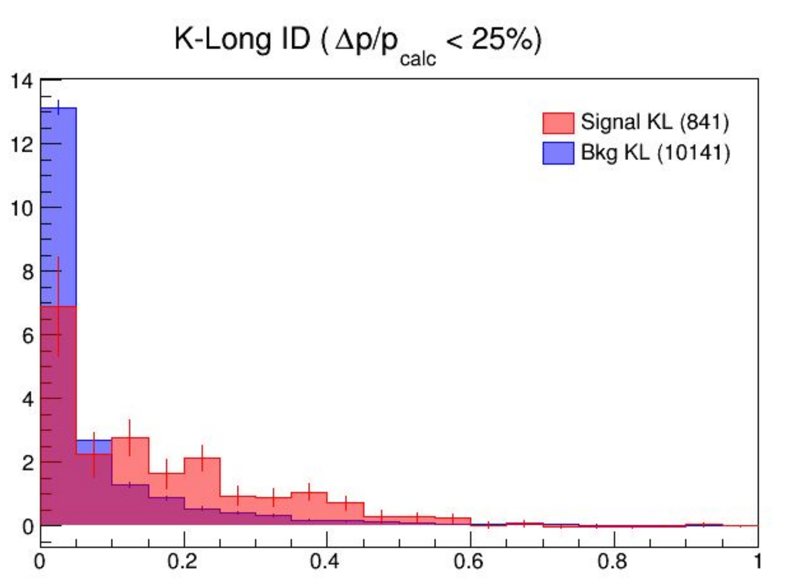
and the probability of being background as -

Prob(c ϵ Background | c.Δm = x) = $P(B)P_B(x) / [P(S)P_S(x) + P(B)P_B(x)]$







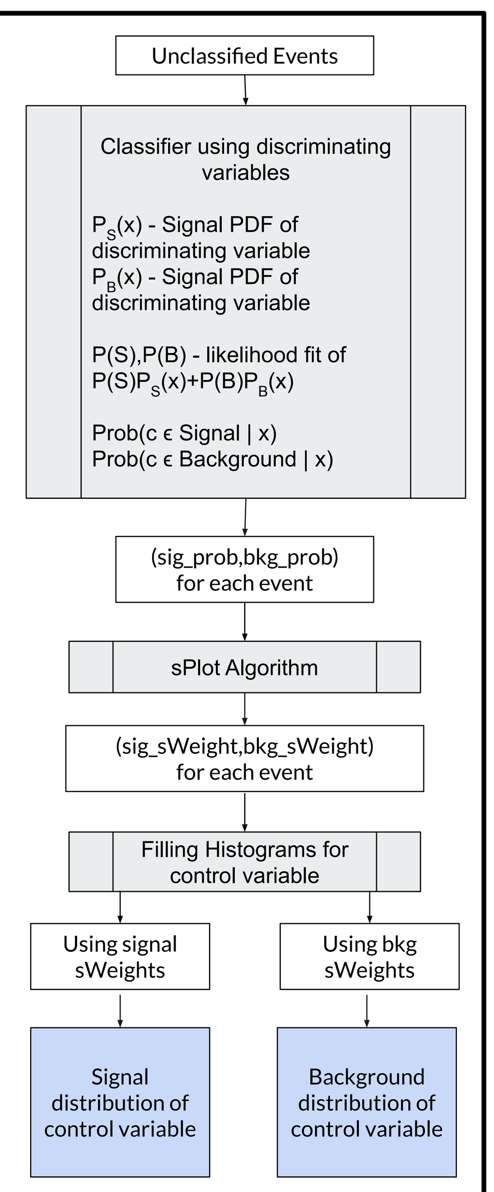


K_L^0 ID for signal and background using conventional vs sPlot technique

The signal and background probabilities for each reconstructed K_L^0 candidates is used to calculate signal and background sWeights for each candidate using sPlot technique [4]. Then we unfold the signal and background distributions of K_L^0 ID by filling two histograms with the set of all reconstructed candidates but weighted with signal and background sWeights respectively for each entry. The top plot shows the K_L^0 ID distribution for signal and background K_L^0 candidates, where the signal and background candidates were chosen based on the criteria described before. The bottom plot shows the same distributions obtained using sPlot technique [4]. By using this method, we get considerably higher statistics available to study K_L^0 reconstruction efficiency. The separation between signal and background candidates is observed to be much more prominent for the reconstructed candidates with K_L^0 ID greater than 0.2.

Summary and Outlook -

- This is a novel method of studying K_L^0 reconstruction efficiency in Belle II experiment using D^{*+}/D^{*-} decays, inspired by a similar analysis performed at the BaBar experiment [5].
- The present study is solely based on a signal MC sample but a data driven control sample will be used in future.
- The sPlot technique provides better statistical separation between real and fake reconstructed K_L^0 candidates.
- Current K_L^0 ID shows good performance above a value of 0.2 and the future plan is to understand the correct set of inputs to the K_L^0 ID algorithm.



References

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