Particle Identification in Belle II Silicon Vertex Detector

A. B. Kaliyar
(On behalf of the Belle II collaboration)

Tata Institute of Fundamental Research, Mumbai 400005
basithkaliyar@gmail.com

Abstract. We report a particle identification (PID) method developed for charged pions, kaons, and protons using specific ionization information in the silicon-strip vertex detector (SVD) of Belle II with $D^{*+} \to D^0[\to K^-\pi^+]\pi^+$ and $\Lambda \to p\pi^-$ decay samples. The study is based on e^+e^- collision data recorded at the $\Upsilon(4S)$ resonance by the Belle II detector. The introduction of additional information from the SVD is found to improve the overall PID performance in the low-momentum region.

Keywords: *dE/dx*, silicon, PID

1 Introduction

Identification of charged particles such as pions, kaons, and protons is important to the physics program of the Belle II experiment [1]. Belle II has an excellent particle identification (PID) system comprising three main subdetectors, the central drift chamber (CDC), time-of-propagation counter, and aerogel ring-imaging Cherenkov counter. Low-momentum charged particles having a transverse momentum $p_T < 65\,\mathrm{MeV}/c$ are unable to reach the CDC, owing to their highly curved trajectories. Our goal is to exploit specific ionization (dE/dx) [2] by these low-momentum particles in the silicon-strip vertex detector (SVD) to identify them. Even if the particles have a p_T greater than $65\,\mathrm{MeV}/c$ and are thus able to reach the CDC, the dE/dx values measured in the SVD can provide complementary information to that obtained from the main PID subdetectors [3].

The study is based on e^+e^- collision data recorded at the Υ (4S) resonance by the Belle II detector. We use relatively clean samples of $D^{*+} \to D^0(K^-\pi^+)\pi^+$ and $\Lambda \to p\pi$ decays to first obtain the SVD dE/dx calibration for pions, kaons, and protons. Later, we check the impact of dE/dx information on overall PID performance using the same decay channels. The charged tracks are identified based on a binary PID likelihood $\mathcal{L}(i/j) = \mathcal{L}_i/(\mathcal{L}_i+\mathcal{L}_j)$, where $\mathcal{L}_i$ and $\mathcal{L}_j$ are the individual likelihoods. To assess the impact of SVD dE/dx information on the overall PID performance, we study the identification efficiency and fake rate as a function of momentum. The efficiency ϵ_i is defined as the ratio of the number of charged particle tracks identified with PID requirement under the particle hypothesis i and the number of charged particle tracks identified kinematically under the hypothesis i. The fake rate ($f_{j\to i}$) is the ratio of the number of charged particle tracks identified with PID requirement under the hypothesis i and the number of charged particle tracks identified kinematically under the hypothesis j.

2 SVD *dE/dx* calibration

The $D^{*+} \to D^0(\to K^-\pi^+)\pi^+$ decay is used to calibrate the pion and kaon PIDs based on dE/dx information in SVD. We require the charged particle tracks to have a transverse (longitudinal) impact parameter less than 0.5 cm (2.0 cm). These tracks must have at least one SVD hit and a track-fit χ^2 probability value greater than 10^{-5}. To further purify the sample, we require the reconstructed D^0 mass to lie between 1.85 and 1.88 GeV/c^2, corresponding to a $\pm 3\sigma$ window around the nominal D^0 mass. The reconstructed D^* mass must be within 1.95 and 2.05 GeV/c^2. We apply a loose criterion on kaon and pion PID likelihoods, to remove low-momentum secondary pions and kaons produced due to hadronic interaction in the detector material. These loose PID criteria do not bias our dE/dx calibration since they are calculated without using SVD information.

The $\Lambda \to p\pi$ decay is used to calibrate the proton PID based on dE/dx information in SVD. We require the reconstructed $p\pi$ invariant mass of Λ candidates to be in the range $[1.10, 1.13]$ GeV/c^2, and they are further subjected to a vertex fit. To remove the random combination of two tracks, the distance between the interaction point and the vertex of the Λ candidates is required to be greater than 1.0 cm and the vertex-fit χ^2 probability must be greater than 10^{-3}. We also require at least one SVD hit for both daughter tracks. We suppress the contamination of charged pions coming from the K_S^0 decay by rejecting events that have the $M_{\pi^+\pi^-}$ value in the range $[488, 508]$ MeV/c^2, corresponding to a $\pm 3\sigma$ window around the nominal K_S^0 mass. Similarly, events with electrons from converted photons are suppressed by excluding $M_{e^+e^-} < 50$ MeV/c^2. We impose an additional requirement of at least one CDC hit and a loose criterion on the proton PID calculated without SVD information to remove low-momentum secondary pions produced due to hadronic interaction with the detector material.

We model the signal and background shape in the D^*–D^0 mass difference (Δm) by a sum of two Gaussian functions with a common mean and a threshold function, respectively. For $\Lambda \to p\pi$ decay, we model the signal shape in $M_{p\pi}$ with the sum of a Gaussian and two asymmetric Gaussian functions of a common mean and the background shape with a second-order Chebyshev polynomial. The fitted distributions of Δm from the D^* sample and $M_{p\pi}$ from the Λ sample are shown in Fig. 1. The ${}_s\mathcal{P}lot$ [4] technique is used to subtract the residual background contributions.

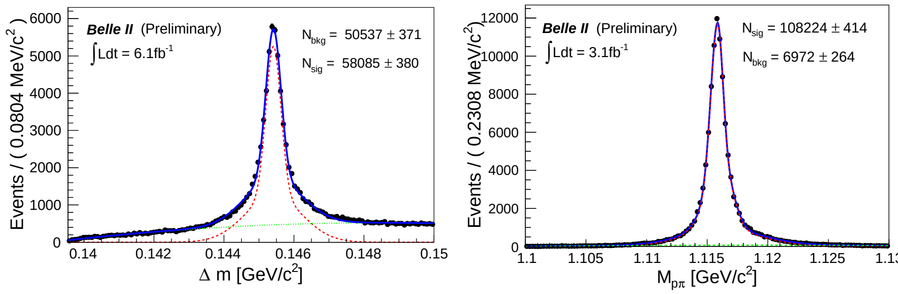

Fig. 1. Fitted distributions of Δm from the D^* sample (left) and of $M_{p\pi}$ from the Λ sample (right). The size of the dataset used for D^* calibration is larger to have enough low momentum kaon tracks.

As shown in Fig. 2, the two-dimensional distributions of dE/dx vs. momentum shows a clear separation between different particles in the low momentum region. These background subtracted two-dimensional histograms are used as probability density functions for various particle hypotheses and uploaded to the calibration database.

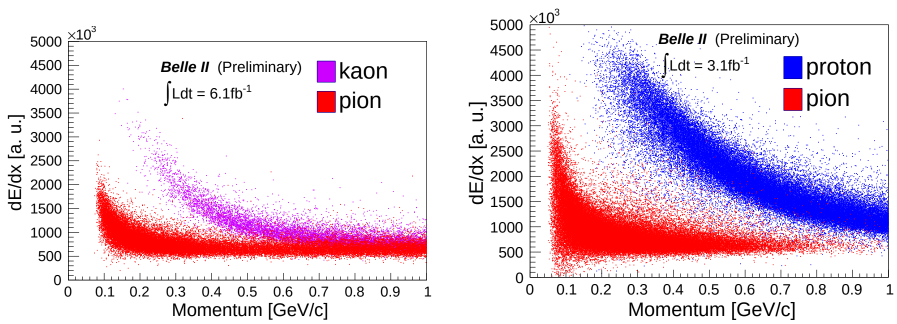

Fig. 2. Scatter plot of dE/dx values of pions and kaons as a function of their momentum for the D^* sample (left) and dE/dx values of protons and pions as a function of their momentum from the Λ sample (right).

3 PID performance

To assess the impact of the SVD dE/dx information to the overall PID, we use a separate set of data sample processed including the PID information from SVD. We study the efficiency and fake rate as a function of momentum by varying the PID likelihood $\mathcal{L}(i/j)$. The PID likelihood criterion is varied from 0 to 1 in order to produce these plots. The efficiency vs. fake rate distributions shown in Fig. 3 confirm the improvement in PID performance by adding the SVD dE/dx

information. The data-MC difference in performance arises due to imperfect simulation of the cluster energy distribution for which the work is underway. Nonetheless, our study confirms that for a given fake rate the addition of dE/dx information improves the efficiency in the low-momentum region.

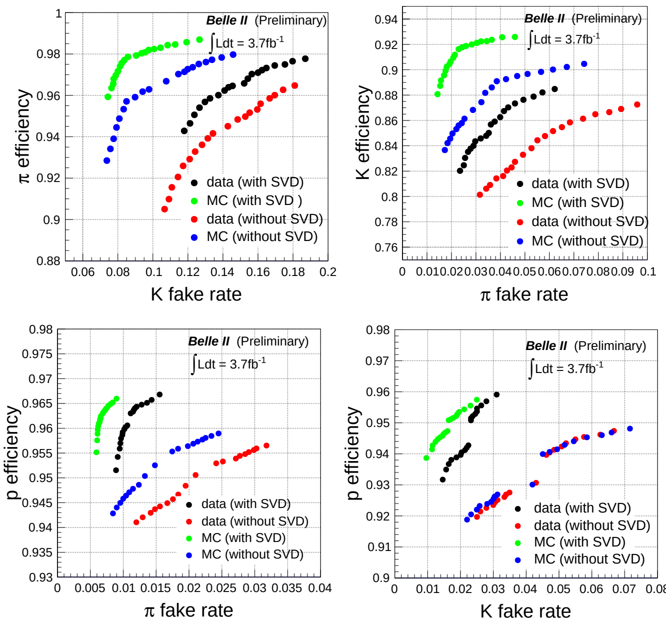

Fig. 3. Efficiency vs. fake rate distributions with and without SVD for $p < 1\,\mathrm{GeV}/c$.

4 Conclusion

We have developed a PID method for charged pions, kaons, and protons using energy loss information in Belle II SVD with $D^{*+} \to D^0(\to K^-\pi^+)\pi^+$ and $\Lambda \to p\pi^-$ decay samples. The study tells that adding the SVD information improves the overall PID performance in the low-momentum region.

References

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