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Low-momentum charged hadron identification using SVD

The Belle II Collaboration

Abstract

We report a particle identification (PID) framework developed using energy loss information in the silicon-strip vertex detector (SVD) of Belle II for charged pions, kaons and protons using $D^{*+} \to D^0[\to K\pi^+]\pi^+$ and $\Lambda \to p\pi^-$ decay samples. The study is based on $6.1\,\mathrm{fb}^{-1}$ data recorded at the $\Upsilon(4S)$ resonance by Belle II and the results are compared with that of a Monte Carlo sample. The introduction of additional information from the SVD is found to improve the overall PID performance in the low momentum region.

1. INTRODUCTION

Particle identification (PID) plays a central role in the physics program of Belle II. Low-momentum charged particles having a transverse momentum $p_{\mathrm{T}} \lesssim 65\,\mathrm{MeV}/c$ are unable to reach the central drift chamber (CDC), the main tracking system of the experiment, owing to their highly curved trajectories. Our goal is to exploit specific ionization (dE/dx) by these low-momentum particles in the silicon-strip vertex detector (SVD) towards identifying 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 detectors of Belle II: CDC, TOP, and ARICH.

We use 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 charged pions, kaons and protons. Later we check the impact of dE/dx information on overall PID performance using the same decay channels. We have also verified the dE/dx values to be independent of the mass of traversing particles depending only on their $\beta\gamma$ values. The study is based on e^+e^- collision data recorded at the $\Upsilon(4S)$ peak by Belle II and the results are compared with that of a Monte Carlo (MC) sample.

To assess the impact of SVD dE/dx information to the overall PID, we plot the identification efficiency and fake rate as a function of momentum applying a requirement on the PID likelihood $\mathcal{L}(i/j) > 0.5$. The efficiency is defined as:

$$\epsilon_i = \frac{\text{\# charged particle tracks identified kinematically as well as with PID requirement under the hypothesis } i}{\text{\# charged particle tracks identified kinematically under the hypothesis } i}$$

and the fake rate is given by:

$$f_{j\to i} = \frac{\text{\# charged particle tracks identified kinematically as well as with PID requirement under the hypothesis } i}{\text{\# charged particle tracks identified kinematically under the hypothesis } j}$$

2. RESULTS

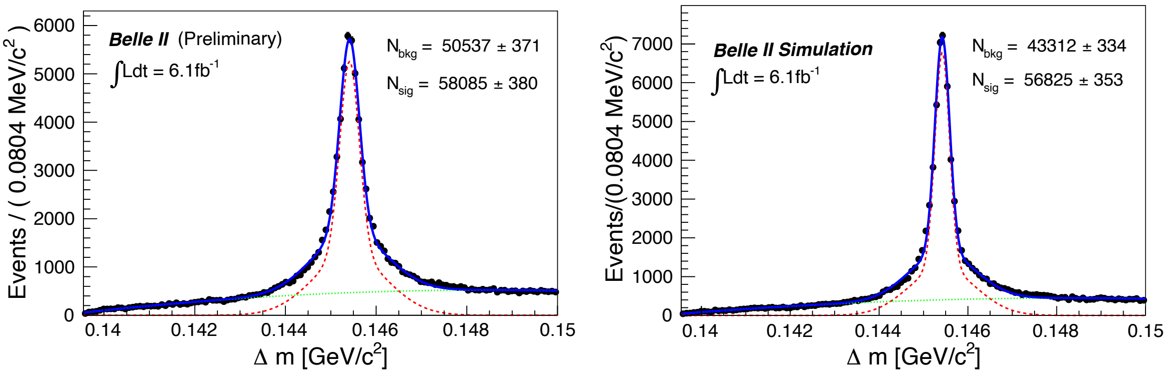

FIG. 1. Fitted distributions of D^{*}–D^{0} mass difference (Δm) from the D^{*} sample in data (left) and MC (right) events. We require the charged particle tracks to have a transverse (longitudinal) impact parameter less than 0.5 cm (2.0 cm). These tracks must have at least one SVD hit and a track-fit χ^2 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, calculated without SVD information, to remove low-momentum secondary pions and kaons produced due to hadronic interaction in the detector material. We model the signal and background Δm shape by a sum of two Gaussian functions with a common mean and a threshold function, respectively. The $_s\mathcal{P}lot$ [1] technique is used to subtract the residual background contributions.

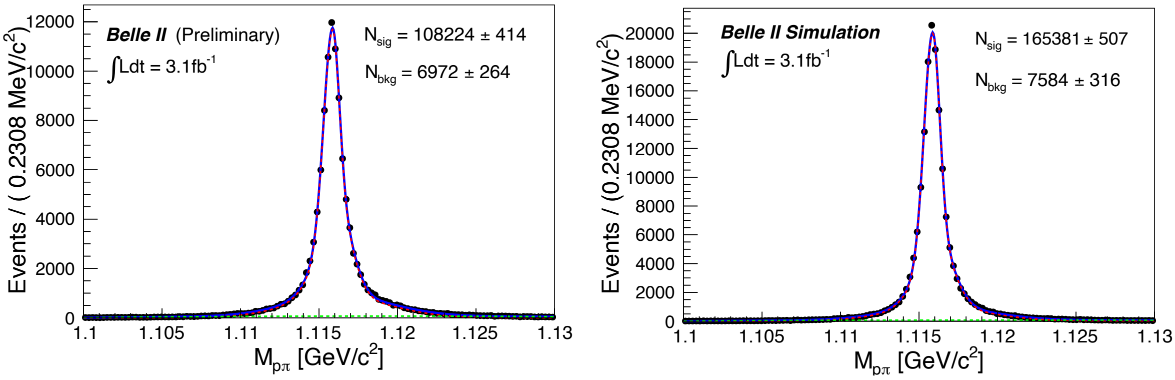

FIG. 2. Fitted $M_{p\pi}$ distributions from the Λ sample in data (left) and MC (right) events. We require the reconstructed $p\pi$ invariant mass of Λ candidates to be in the range $[1.10, 1.13]\,\mathrm{GeV}/c^2$, and they are further subjected to a vertex fit. The distance between the interaction point and the vertex of the Λ candidates is required to be greater than 1 cm and the vertex fit χ^2 must be greater than 10^{-3} to remove the random combination of two tracks. We also require at least one SVD hit for both daughter tracks of Λ candidates. 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 $[488, 508]\,\mathrm{MeV}/c^2$, 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 $M_{e^+e^-} < 50\,\mathrm{MeV}/c^2$, a veto decided by the figure-of-merit optimization. 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 shape 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 ${}_s\mathcal{P}lot$ [1] technique is used to subtract the residual background contributions.

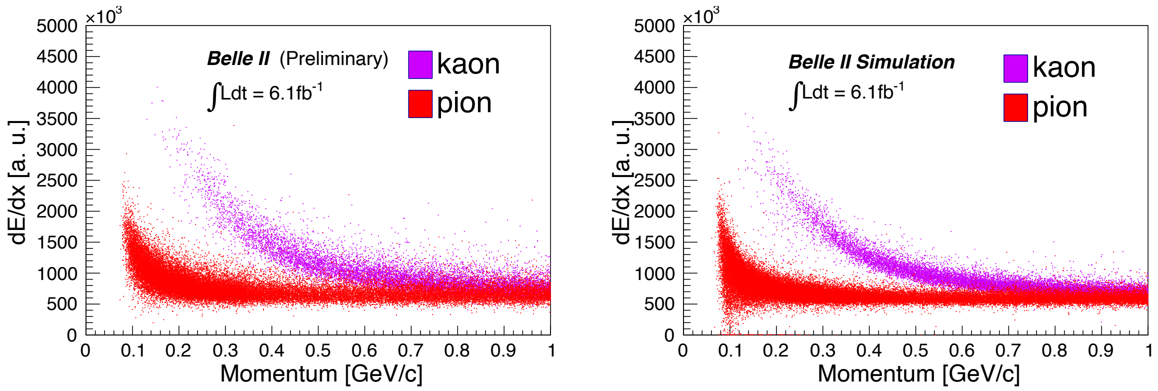

FIG. 3. Scatter plot of dE/dx values of charged pions and kaons as a function of their momentum for data (left) and MC (right) events from the D^* sample. The two-dimensional distributions of dE/dx vs. momentum show a clear separation between different particles in the low momentum region, and are uploaded to the calibration database.

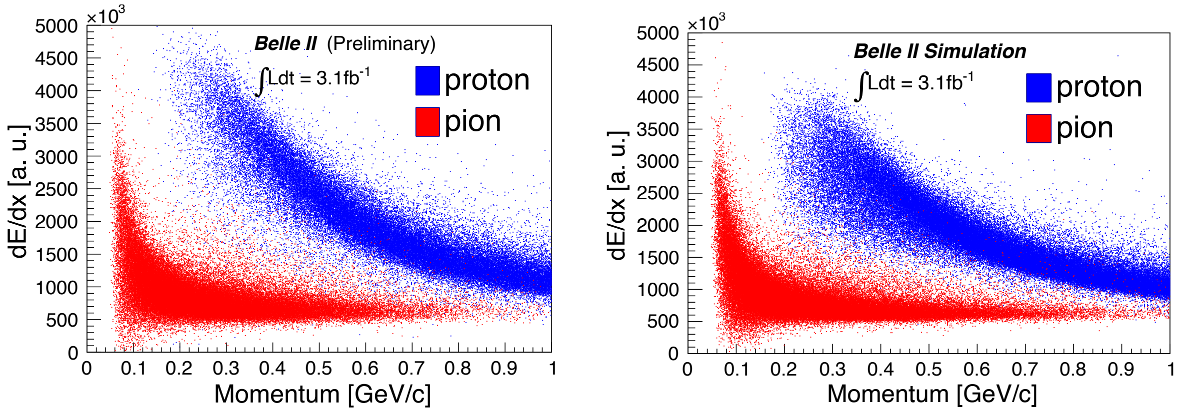

FIG. 4. Scatter plot of dE/dx of proton and pion as a function of their momentum in data (left) and MC (right) events from the Λ sample. The two-dimensional distributions of dE/dx vs. momentum show a clear separation between different particles in the low momentum region, and are uploaded to the calibration database.

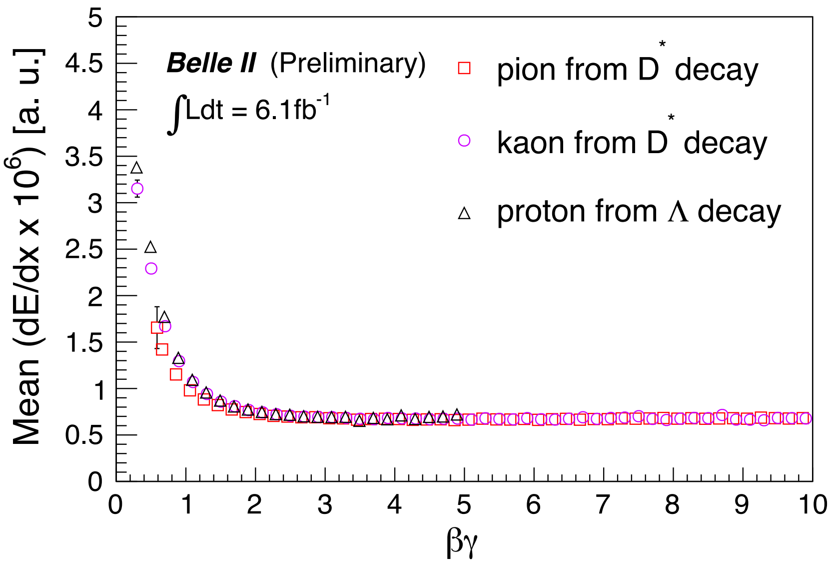

FIG. 5. The $\beta\gamma$ universality curve obtained in data with D^* and Λ samples. As the specific ionisation depends only on the velocity (β) of traversing particles, we check the $\beta\gamma$ universality of dE/dx values obtained from D^* and Λ samples. The minimum energy loss occurs at $\beta\gamma \approx 3$ regardless of the particle type. We get a flat curve beyond that threshold, as the relativistic rise of energy loss is suppressed by the density effect in silicon.

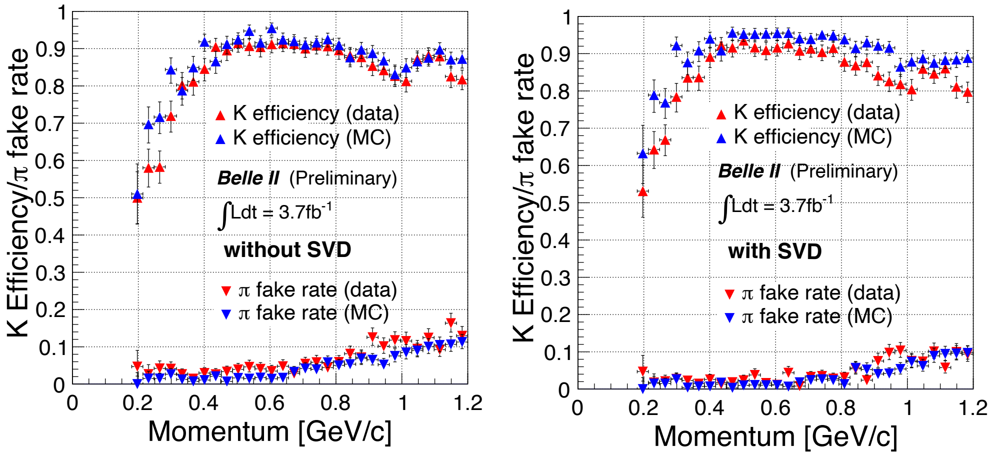

FIG. 6. K efficiency and π fake rate vs. momentum without (left) and with (right) SVD dE/dx information. To assess the impact of this information to the overall PID, we plot the efficiency and fake rate as a function of momentum applying a requirement on the PID likelihood $\mathcal{L}(K/\pi) > 0.5$. The study shows an improvement in kaon efficiency after adding SVD dE/dx information.

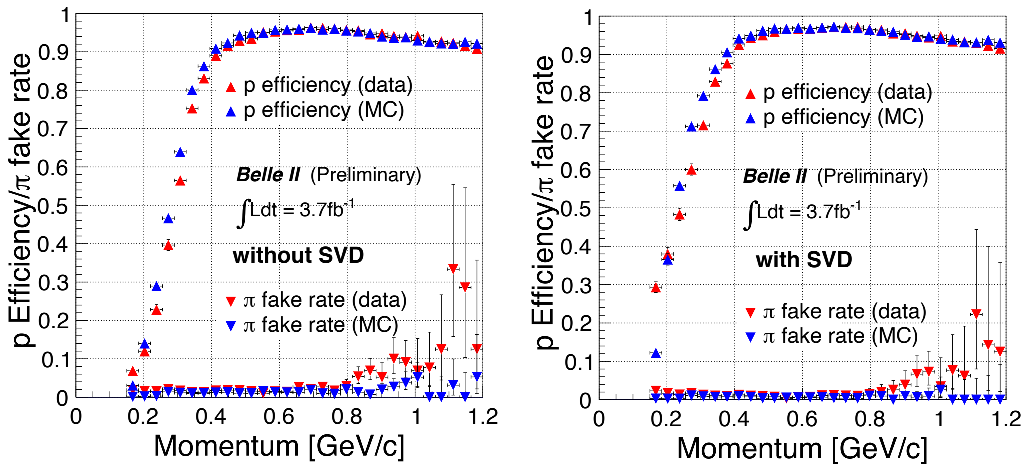

FIG. 7. p efficiency and π fake rate vs. momentum without (left) and with (right) SVD dE/dx information. To assess the impact of this information to the overall PID, we plot the efficiency and fake rate as a function of momentum applying a requirement on the PID likelihood $\mathcal{L}(p/\pi) > 0.6$. The study shows an improvement in proton efficiency after adding SVD dE/dx information.

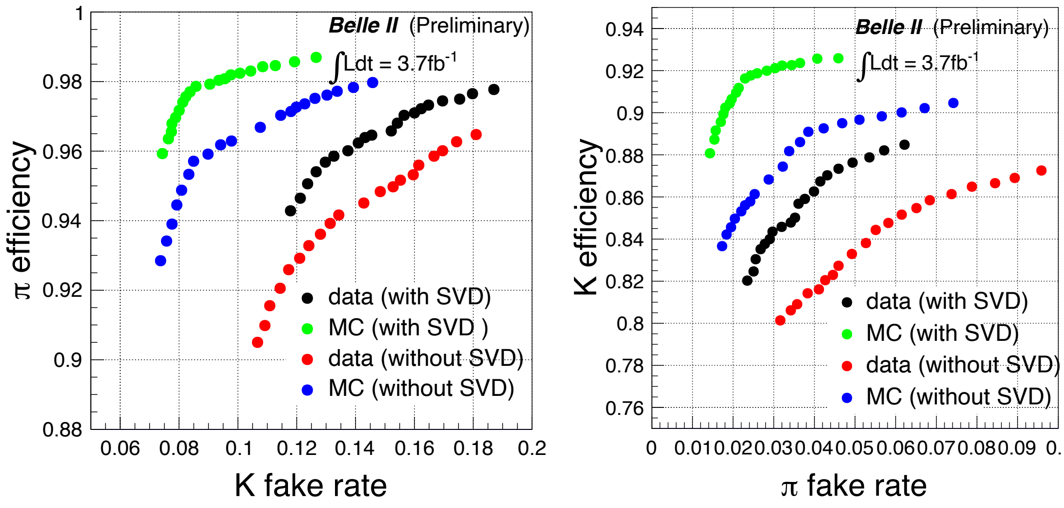

FIG. 8. π efficiency vs. K fake rate (left) and K efficiency vs. π fake rate (right) with and without SVD for $p < 1\,\mathrm{GeV}/c$. We plot the efficiency vs. fake rate to better appreciate the improvement in PID performance by adding the SVD dE/dx information. The PID likelihood criterion is varied from 0 to 1 in order to produce these plots. Our study confirms that addition of dE/dx information improves the pion (kaon) efficiency for a given kaon (pion) fake rate in the low momentum region.

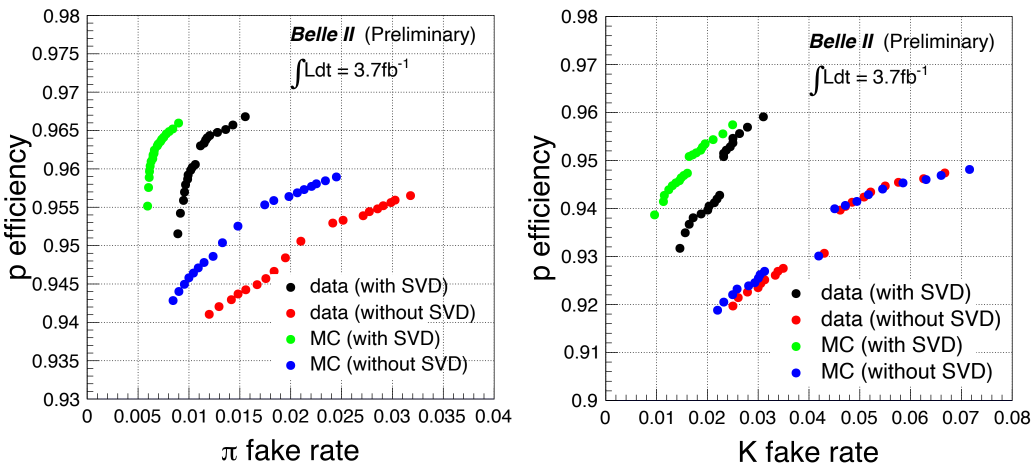

FIG. 9. p efficiency vs. π fake rate (left) and p efficiency vs. K fake rate (right) with and without SVD for $p < 1\,\mathrm{GeV}/c$. We plot the efficiency vs. fake rate to better appreciate the improvement in PID performance by adding the SVD dE/dx information. The PID likelihood criterion is varied from 0 to 1 in order to produce these plots. Our study confirms that addition of dE/dx information improves the proton efficiency for a given paon or kaon fake rate in the low momentum region.

[1] M. Pivk and F. R. Le Diberder, Nucl. Instrum. Meth. A555, 356 (2005).