Lepton Identification using the Belle II Silicon-strip Vertex Detector

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Abstract. We improve the identification performance of low-momentum leptons, especially electrons, using the specific ionisation information from the silicon-strip vertex detector (SVD) of the Belle II experiment.

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1 Introduction

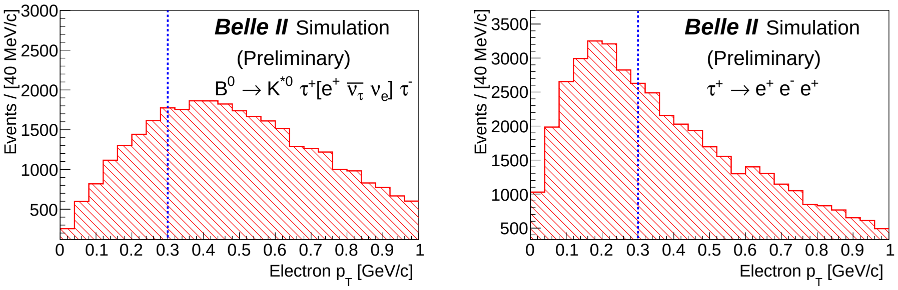
Particle identification (PID) serves a crucial role in any flavor physics experiment. At Belle II [1], we use information from various subdetectors to identify a track as a lepton [2]. The PID algorithm heavily relies on the information provided by the electromagnetic calorimeter (ECL) to identify electrons and the K_L^0 and muon detector (KLM) to identify muons. The performance deteriorates for low-momentum leptons that fail to reach the respective subdetectors and are instead reconstructed in the tracking system comprising the SVD and central drift chamber (CDC). We aim to improve the identification performance for such leptons using the specific ionisation information from the SVD and CDC; at very low momentum only the SVD counts.

Our study will aid physics studies involving low-momentum leptons such as semileptonic decays of B mesons: $B \to K^{(*)}\ell\ell$, $B \to K^{(*)}\tau\tau$, $B \to X_c\tau\nu$, and lepton-flavor-violating tau decays: $\tau \to e\ell\ell$ and $\tau \to \mu\ell\ell$, where ℓ is e or μ. Figure 1 shows generator-level distributions of the transverse momentum (p_{T}) for electrons from two such decays, where a good number of electrons are found to have a p_{T} below the threshold to reach the ECL.

2 Electron Identification using SVD

2.1 Event Selection

The study is performed using Monte Carlo (MC) simulated data for e^+e^- collisions recorded near the $\Upsilon(4\mathrm{S})$ resonance with the Belle II detector. We use electrons originating from photon conversions ($\gamma \to e^+e^-$) that occur within the material of the two inner tracking systems, including the SVD. Electrons are



(a) (b)

Fig. 1. Generator-level distributions of p_{T} for low-momentum electrons coming from (a) $B \to K^*$ and (b) $\to eee$ decays. The dashed vertical lines indicate the p_{T} threshold required to reach the ECL.

reconstructed as primary particles using track-level information from the detector. A converted photon candidate is reconstructed by combining two oppositely charged tracks. We apply various kinematic and vertex criteria to suppress background. We use the ${}_s\mathcal{P}$lot [3] technique to subtract the residual background. The ${}_s\mathcal{P}$lot extracted two-dimensional distribution of specific ionisation (dE/dx) vs. momentum is used as the SVD information to the total PID for electron tracks.

2.2 PID Performance

The total PID likelihood is constructed by combining the information from all subdetector components under different particle hypotheses. It can be written as:

$$\mathcal{L} = \prod_{\mathrm{det}} \mathcal{L}_{\mathrm{det}},$$

where the product is over the individual likelihoods of each subdetector. The SVD contribution to the total likelihood is obtained as in Ref. [4], with the likelihood for a particle mass hypothesis j defined as:

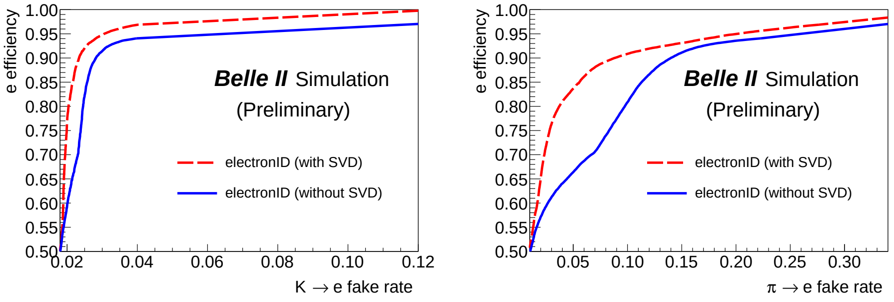
$$\mathcal{L}_j(dE/dx, p) = \prod_i \mathcal{P}_j[(dE/dx)_i, p],$$

where $j = e, \pi, K$ and i runs over all dE/dx values assigned to a track.

We compare the performance of the total PID evaluated with and without the SVD information. To calculate the electron identification efficiency, we use the $\gamma \to e^+e^-$ sample, while for calculating the rate of a pion (kaon) to be misidentified as an electron we use the $D^{*+} \to D^0[\to K^-\pi^+]\pi^+$ sample. The latter is also used for hadron identification studies [5]. The pion (kaon) to electron misidentification rate is also called the $\pi \to e$ ($K \to e$) fake rate. We define:

$$i \text{ efficiency} = \frac{\text{No. of tracks identified with PID under the hypothesis } i}{\text{No. of tracks kinematically identified under the hypothesis } i},$$

$$j \to i \text{ fake rate} = \frac{\text{No. of tracks identified with PID under the hypothesis } i}{\text{No. of tracks kinematically identified under the hypothesis } j}.$$



(a) (b)

Fig. 2. Electron efficiency vs. (a) *K* ! *e* and (b) ! *e* fake rate for different criteria on the total PID variable.

Figure 2 shows the improvement in electron ID performance [6] with the introduction of SVD information. For this study, we consider tracks within the detector fiducial region that have a momentum less than 1 GeV/c. We find the electron efficiency to increase from around 80% to 90% for a fixed 10% $\pi \to e$ fake rate in MC simulation. Similarly, for a fixed 4% $K \to e$ fake rate in MC simulation, the electron efficiency increases from around 94% to 97%.

3 Muon Identification using SVD

The performance of the SVD to separate dE/dx distributions of muons and pions is studied using simulated charged tracks. We generate 2×10^6 muon and pion tracks and let them pass through the detector simulation. Figure 3(a) shows the distribution of dE/dx vs. momentum for these tracks. We obtain the dE/dx distribution for muons and pions in momentum bins of 50 MeV/c. The distributions are fitted with a Gaussian function to obtain their mean (m) and width (w) values. We then look at the distribution of μ-π separation, defined as

$$\frac{|m_\mu - m_\pi|}{\sqrt{w_\mu^2 + w_\pi^2}},$$

vs. momentum as shown in Fig. 3(b). We observe that muon and pion tracks are not so well separated in the SVD owing to their small mass difference (around 30 MeV/c^2). There is a maximum separation of around 0.6 standard deviations between the two hypotheses. This means we can use the same dE/dx vs. momentum distribution as the SVD information to the total PID likelihood for both