Lepton Identification using the Belle II Silicon-strip Vertex Detector

R. Tiwary
(On behalf of the Belle II Collaboration)

Tata Institute of Fundamental Research, Mumbai 400 005
Email: rahul.tiwary@tifr.res.in

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.

Keywords: Belle II, SVD, PID, Lepton identification

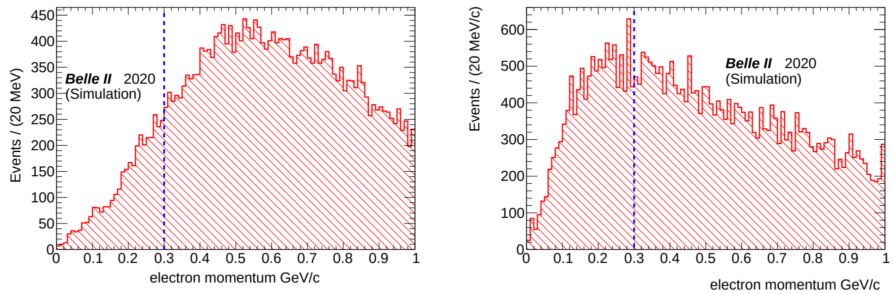
1 Introduction

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. We aim to improve the lepton identification performance for such tracks using the specific ionisation information from the SVD. Our study will aid the physics studies involving low-momentum leptons such as decays of B mesons to semileptonic final states: $B \to K^{(*)}\ell\ell$, $B \to K^{(*)}\tau\tau$ and lepton-flavor-violating decays of $\tau \to e\ell\ell$ and $\tau \to \mu\ell\ell$, where ℓ is e or μ. Figure 1 shows the momentum distribution of electrons from two such decays, where a good number of electron candidates are found to have a momentum 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 at the $\Upsilon(4S)$ peak with the Belle II detector. We use electrons coming from photon conversion ($\gamma \to e^+e^-$) that takes place within the material of the two inner tracking systems including SVD. Electrons are 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 requirements to suppress background



(a) (b)

Fig. 1. Momentum distributions of slow electrons coming from (a) $B \to K^{(*)}\tau\tau$ and (b) $\tau \to eee$ decays. The dashed vertical lines indicate the momentum threshold required to reach the ECL.

events. We use the ${}_s\mathcal{P}$lot [3] technique to subtract the residual background. The ${}_s\mathcal{P}$lot extracted two-dimensional distribution of energy loss (dE/dx) vs. momentum is used as the contribution of SVD to the total PID for electron tracks.

2.2 PID performance

The total PID is constructed by combining the information of different particle hypothesis obtained for each of the subdetector components. The total PID likelihood can be written as:

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

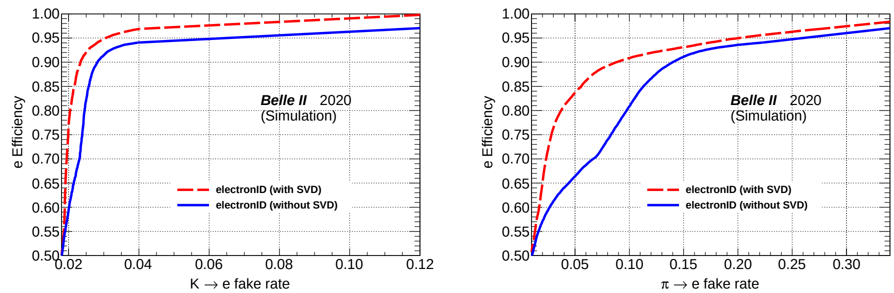
here the product is over the individual likelihoods of active subdetectors. The SVD contribution to the total likelihood is obtained as per the study [4], where the likelihood for a particle mass hypothesis m is defined as:

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

here $m = e, \pi, K$ 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 $\pi \to e$ and $K \to e$ fake rates we use the $D^{*+} \to D^0[\to K^-\pi^+]\pi^+$ sample. The latter is also used for hadron identification studies [5]. We define:

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

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



(a) (b)

Fig. 2. Efficiency vs fake rate plots for (a) $K \rightarrow e$ and (b) $pi \rightarrow e$ for different criteria on the total PID variable.

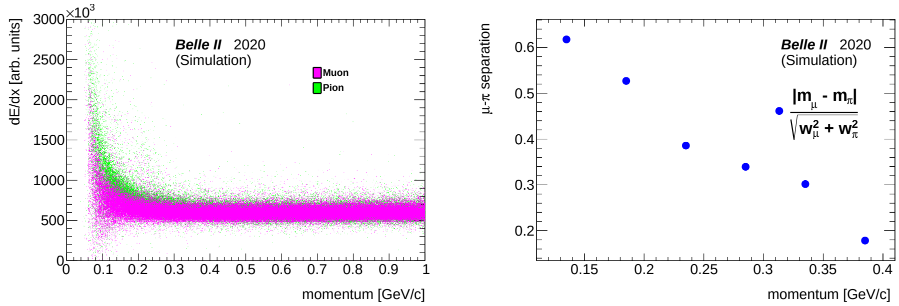
Figure 2 shows that the performance improves significantly with the introduction of SVD information in the PID. For a fixed 10% $\pi \rightarrow e$ fake rate in MC, the electron efficiency increases from around 80% to 90%. Similarly, for a fixed 4% $K \rightarrow e$ fake rate in MC, the electron efficiency 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 two million 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 vs. momentum as shown in Fig. 3(b). The μ–π separation is defined as

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

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 PID for both pions and muons. The SVD information to the PID for pions, the dE/dx vs. momentum distribution is obtained using slow pions coming from $D^{*+} \rightarrow D^0[\rightarrow K^-\pi^+]\pi^+$ channel, which is an experimentally clean sample with high statistics. Hence, we have decided to use the dE/dx vs.



(a) (b)

Fig. 3. dE/dx vs. momentum distributions for muons and pions (a), and the μ–π separation vs. momentum (b).

momentum distribution of pions as the common input of SVD to the total PID likelihood for muon and pion tracks.

4 Summary

We present a study to improve the performance of PID for leptons using information from the SVD of the Belle II experiment. Addition of SVD information to the total PID results in an excellent improvement of the electron identification performance. The study performed for simulated muon and pion tracks showed that low-momentum muons and pions can not be well separated with the SVD due to their small mass difference. We have decided to use the dE/dx vs. momentum distribution of pions as the common input from SVD to the total PID likelihood.

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