Particle Identification with the Belle II Calorimeter using Machine Learning

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Poster #700

Belle II at SuperKEKB

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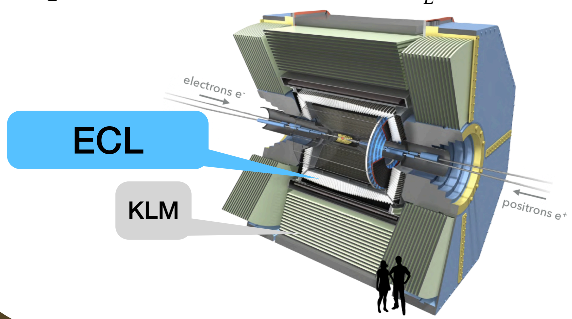
- Belle II is located at the asymmetric SuperKEKB e^+e^- collider in Tsukuba, Japan.
- It collects data mostly at $\Upsilon(4S)$ resonance.
- The Electromagnetic Calorimeter (ECL) in Belle II consists of 8736 CsI(Tl) crystals and it is immersed in a 1.5 T magnetic field. The dimension of each crystal is 5x5x30 cm which corresponds to 16.2 X_0.
- The ECL is critical for neutral particle reconstruction. It can also identify charged particles e.g. electrons, pions, and muons.
- The K_L and muon detector (KLM) is designed to identify K_L^0 and muons.



Convolutional Neural Network (CNN) for μ and π separation

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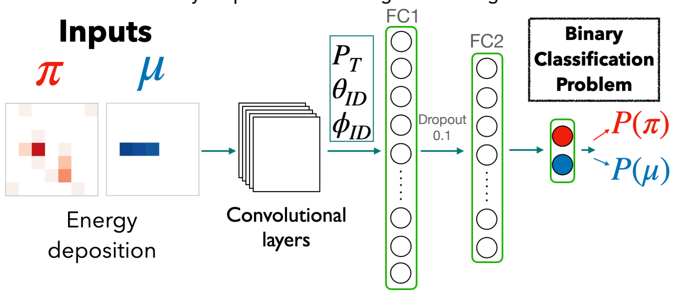
- The energy deposition patterns for pions are more dispersed than muons.
- CNNs are useful tools to find patterns in pixel images in the ECL.
- 10^6 single muon and pion candidates are generated with flat distribution of transverse momentum between 0.2 and 1.0 GeV/c. Each track is first reconstructed and then extrapolated into the ECL using the Belle II Analysis Software Framework [1].
- At the entry point of each track into the ECL, a window of 7x7 crystals with the measured deposited energy therein is selected as input for the CNN.
- For training the CNN, 10^6 7x7 pixel images are given as inputs. Later on, additional inputs e.g. transverse momentum and crystal positions are given to the feed-forward neural network. Crystal positions are also given as categorical variables.

CNN Parameters

- Kernel: (3, 3), Stride: (1, 1), Padding: (1, 1)
- Feature maps: 64
- # neurons in FC1: 3295
- # neurons in FC2: 128
- Dropout between FC1 and FC2: 0.1
- Optimizer: Adam
- Learning rate: 0.001
- Loss: CrossEntropy
- Batch size: 512



Energy threshold robustness

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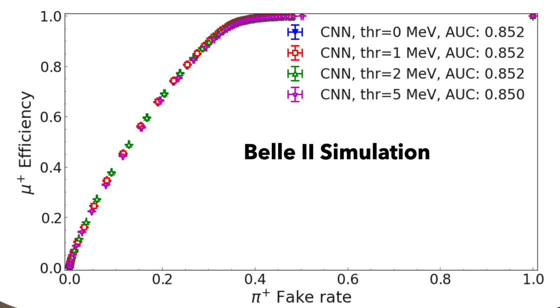
- There are different sources of beam backgrounds e.g. Touschek scattering. A higher minimal energy threshold for crystals may reduce the pile-up from beam backgrounds.
- In order to check the robustness of the CNN against different levels of beam background, different energy thresholds for crystals of 1, 2, 5 MeV are tested.



Low-momenta μ and π

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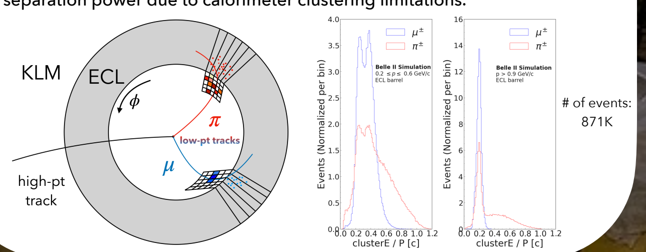
- The identification of low-momenta muons is beneficial for B physics with leptonic τ decays, since this can reduce fake muons at low momentum.
- Since low-momenta muons (p < 0.6 GeV/c) cannot reach the KLM, it is important to rely on the information in the ECL.
- Muons and pions both lose energy by ionization in the matter. Additionally pions undergo hadronic interactions.
- At low momenta, strong track bending across the ECL implies simple discriminating quantities used in the Belle II software such as E/p (i.e. ratio of reconstructed cluster energy over the momentum) lose separation power due to calorimeter clustering limitations.



CNN performance

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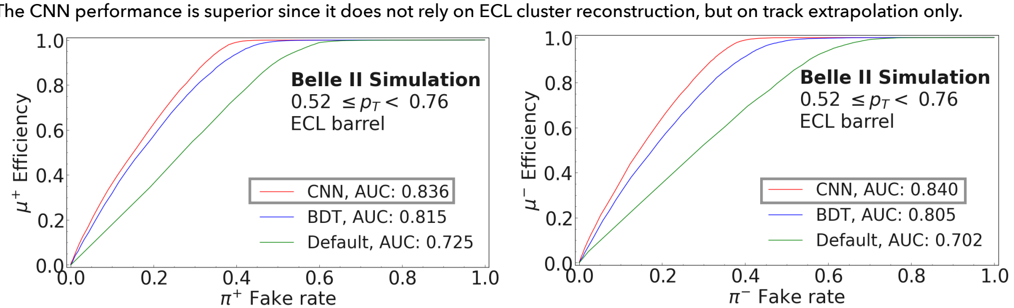
- Due to the geometry of the ECL i.e. the direction of crystals, two CNN models are trained for positive and negative charges separately.
- The best model is selected based on the minimum validation loss during training (one model for negative and the other for positive charges).
- Other methods currently investigated at Belle II are based on clustering information e.g. default (univariate likelihood) and alternative methods (BDT) [2]. Therefore, if no cluster is reconstructed, no particle identification can be attempted, which degrades selection efficiency.
- The CNN performance is superior since it does not rely on ECL cluster reconstruction, but on track extrapolation only.



Conclusion & Outlook

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- I have showed that using patterns of energy depositions in the ECL, particle identification can be improved for low-momenta muons and pions.
- The CNN model, trained with samples including beam backgrounds, is robust against different energy thresholds in crystals.
- This study can be extended using more low-level ECL crystal information e.g. pulse-shape discrimination which is useful to separate hadronic and electromagnetic interactions. [3]
- The CNN method is going to be integrated as part of the standard Belle II reconstruction software.
- In order to validate the CNN method on data, clean samples of muons and pions are selected using $ee \rightarrow \mu\mu\gamma$ and $D^* \rightarrow D^0[\rightarrow K\pi]\pi$, respectively. The study is still ongoing.

[1] Comput Softw Big Sci 3, 1 (2019), Kuhr, T., Pulvermacher, C., Ritter, M. et al.

[2] EPJ Web Conf.245(2020) 06023, M. Milesi, J. Tan, and P. Urquijo

[3] JINST 13 (2018) 03 P03018, S. Longo, J.M. Roney