Image Based Particle Identification at Low Momenta

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Belle II experiment

The **SuperKEKB accelerator**:

- asymmetric-energy e^+e^- collider

$$e^- \; 7\text{ GeV} \longrightarrow \Upsilon(4S) \longleftarrow e^+ \; 4\text{ GeV}, \quad \sqrt{s} \approx 10.58\text{ GeV}, \quad \Upsilon(4S) \to B\bar{B}$$

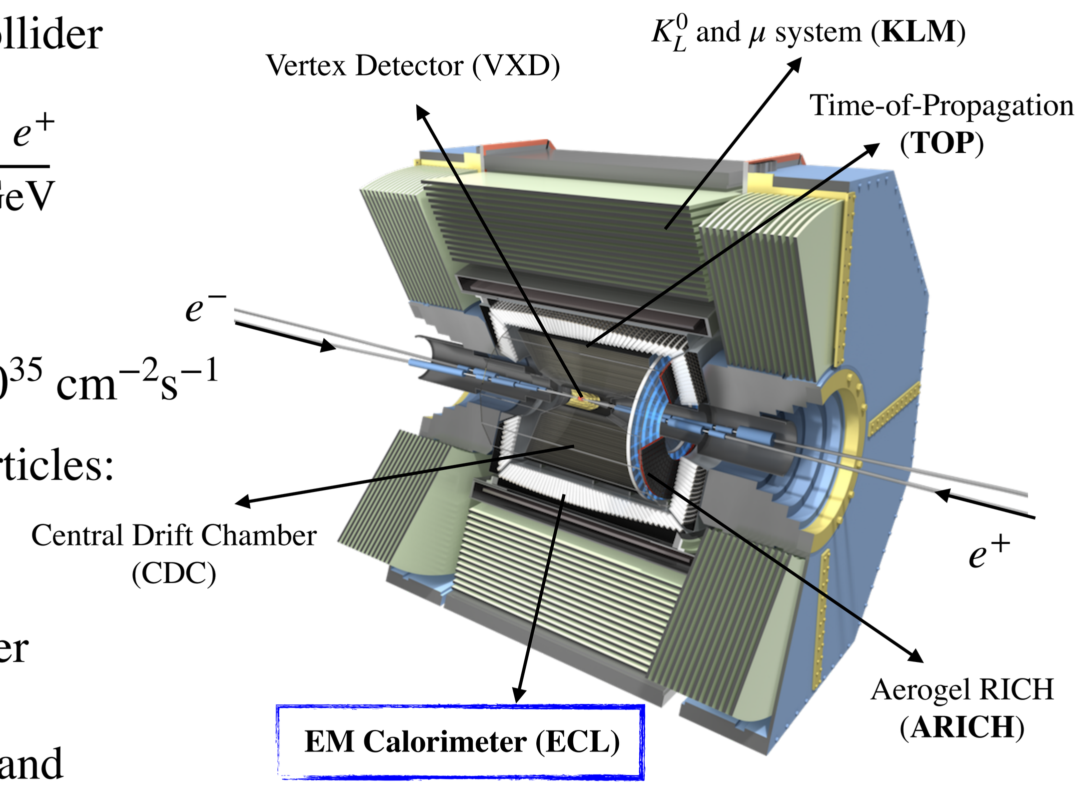
- designed luminosity: 8×10^{35} cm^{-2}s^{-1}

Final-state detectable charged particles:

e, μ, π, K, p, d

The **Belle II detector**:

- general purpose spectrometer
- 6 sub-detectors measure: tracks, momentum, energy and **identity of the particles** (TOP, ARICH, KLM)

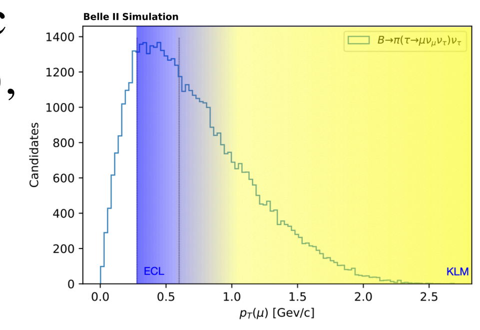


[1]

Particle Identification at Low Momenta

Interesting processes to search for New Physics are **semi-tauonic** decays of B meson. Charged decay products of τ lepton (e. g., **electrons** or **muons**) have **low momenta**.

- low identification efficiency for μ with $p_T < 0.6$ GeV/c (out the acceptance of the dedicated sub-detector KLM),
- low momentum e have increased energy losses from bremsstrahlung (reduced separation from hadrons)
- improve the separation of low momentum leptons from hadronic background (mainly pions) using the information from the ECL ($p_T > 0.28$ GeV/c)

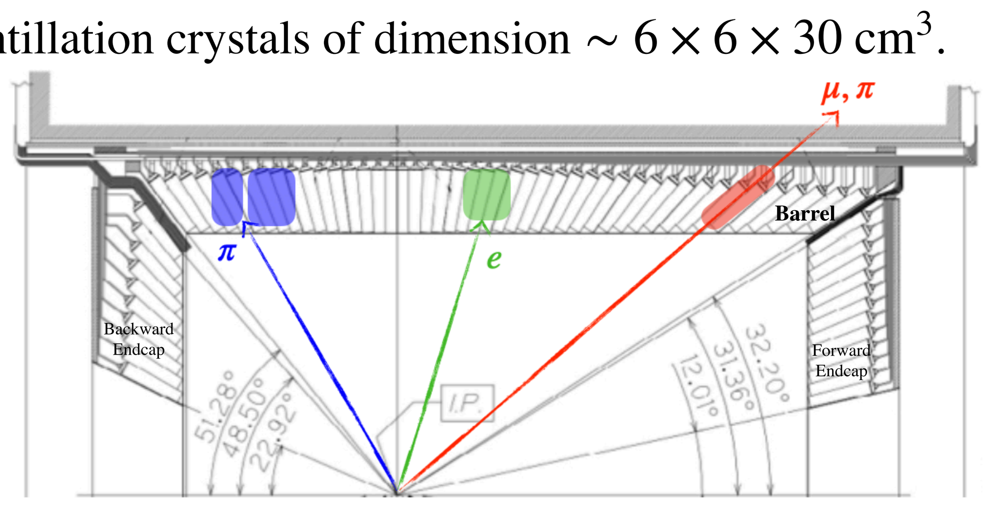


p_T distribution of μ from $B \to \pi\tau(\to \mu\nu_\mu\nu_\tau)\nu_\tau$.

Electromagnetic Calorimeter (ECL)

The ECL consists of 8736 CsI(Tl) scintillation crystals of dimension $\sim 6 \times 6 \times 30$ cm^3.

ECL	θcoverage	# of crystals
Barrel	32.2° - 128.7°	6624



Functions:

- event triggering,
- measure EM energy of γ and electrons,
- neutral particle reconstruction,
- **charged particle identification**:
  - log-likelihood difference $\Delta \mathrm{LL}^{\mathrm{ECL}} = \log \mathrm{L}^{\mathrm{ECL}}_{(\ell)} - \log \mathrm{L}^{\mathrm{ECL}}_{(\pi)}$ based on E/p (ratio between deposited energy - ECL and the reconstructed momentum - CDC).
  - Boosted Decision Trees using shower shape variables from the ECL as features (**BDT ECL**).

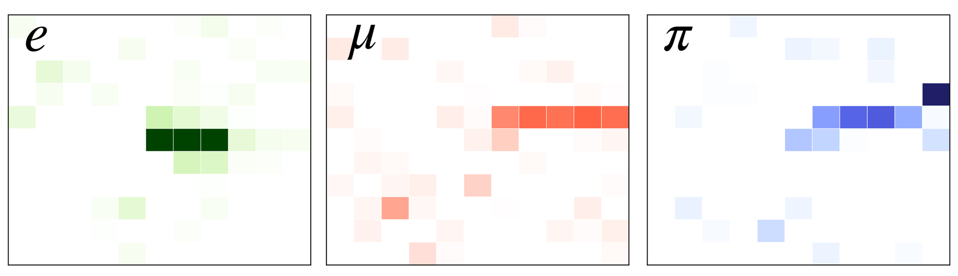
The dominant interaction in the ECL for μ and π in $p_T \in [0.28, 0.9]$ GeV/c is ionization. Additionally π can strongly interact with nuclei. Electrons generate EM showers depositing the majority of their energy in the ECL.

Are there some specific **patterns** in energy deposition?

[2], [3], [4], [5]

Convolutional Neural Network (CNN)

Use low-level information from the ECL in form of **images** and **CNN** as a classifier. Image production **does not** depend on **cluster reconstruction** or **track-cluster matching**.

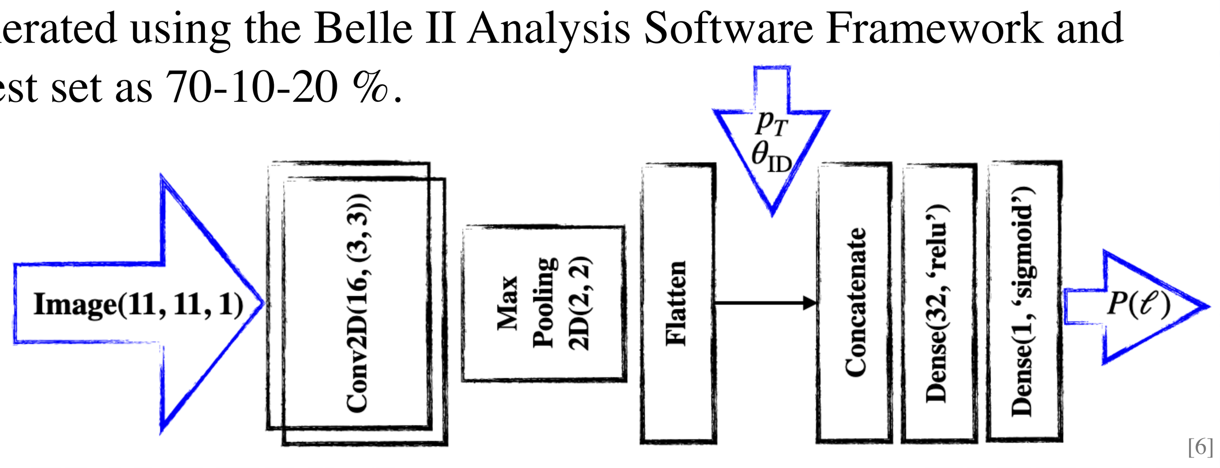


pixel intensity = **energy deposited in the ECL crystal**

Examples of images of energy depositions for electrons, muons and pions.

1.5×10^6 events were generated using the Belle II Analysis Software Framework and split on train- validation-test set as 70-10-20 %.

CNN architecture used for **binary classification** (e vs. π) and (μ vs. π).



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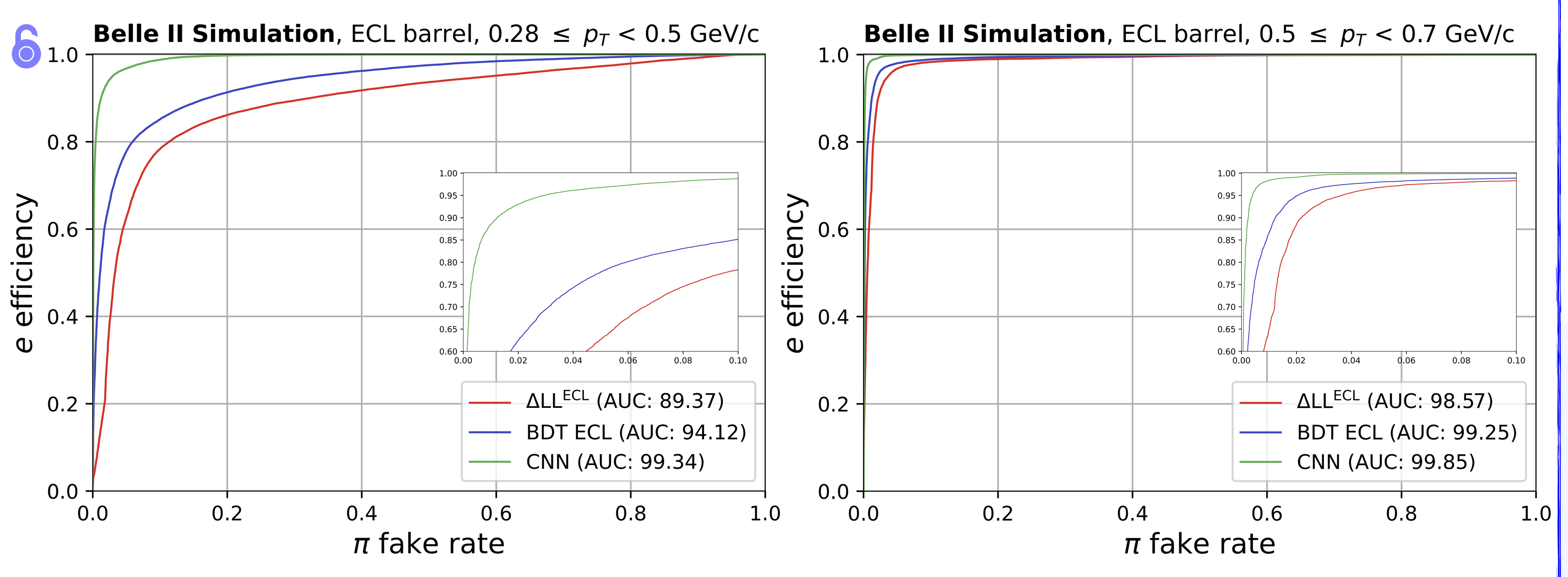
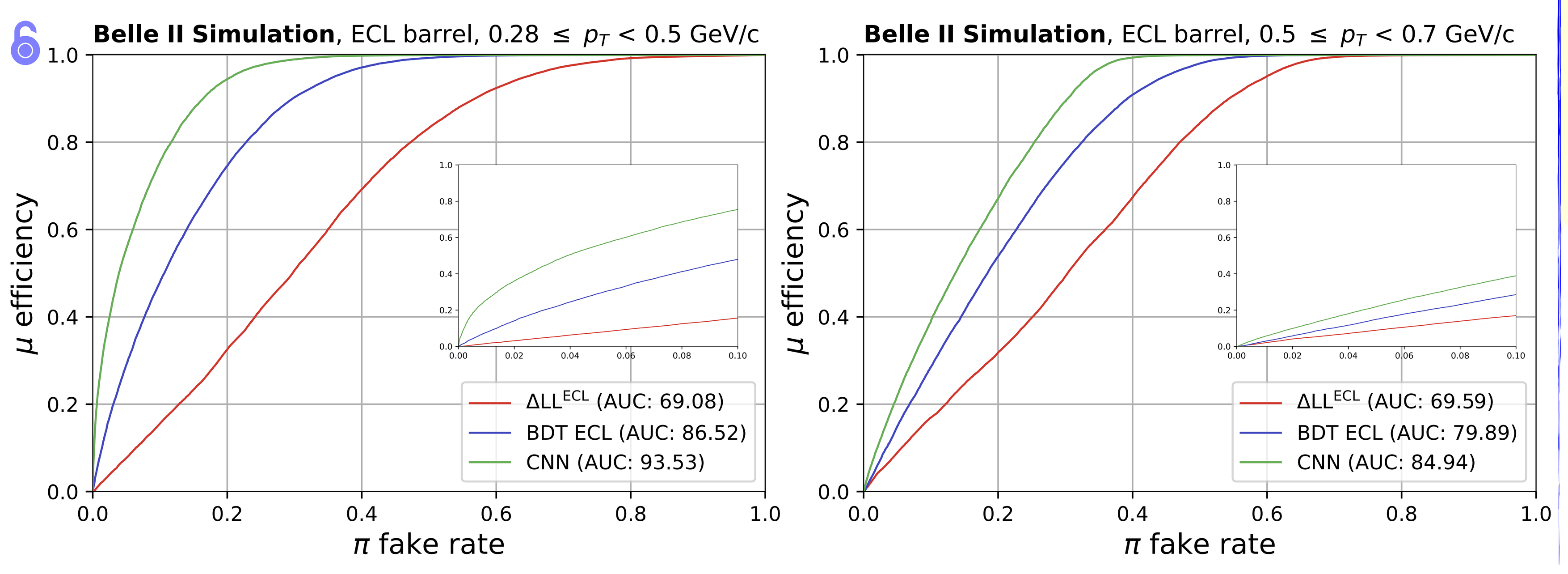
e vs. π classification

The performance of 3 different binary classifiers based on ECL information only: log-likelihood difference ($\Delta\mathrm{LL}^{\mathrm{ECL}}$), Boosted Decision Trees (BDT ECL), Convolutional Neural Network (CNN)

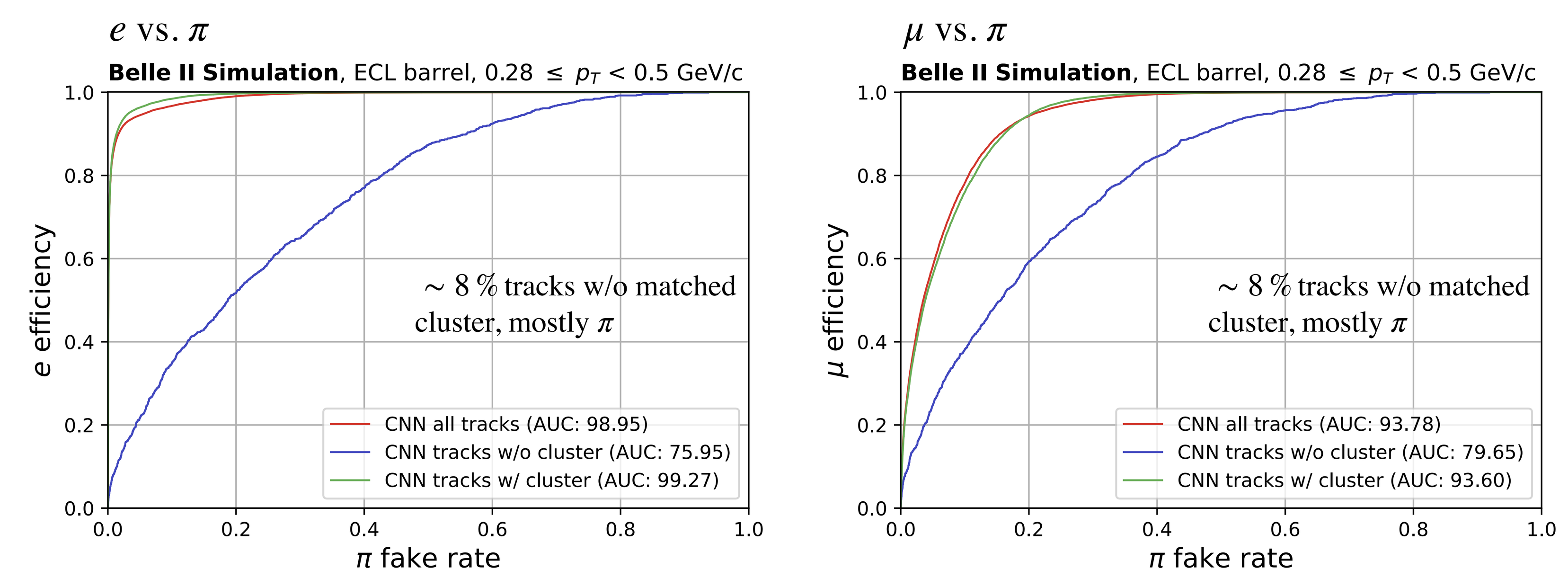


μ vs. π classification



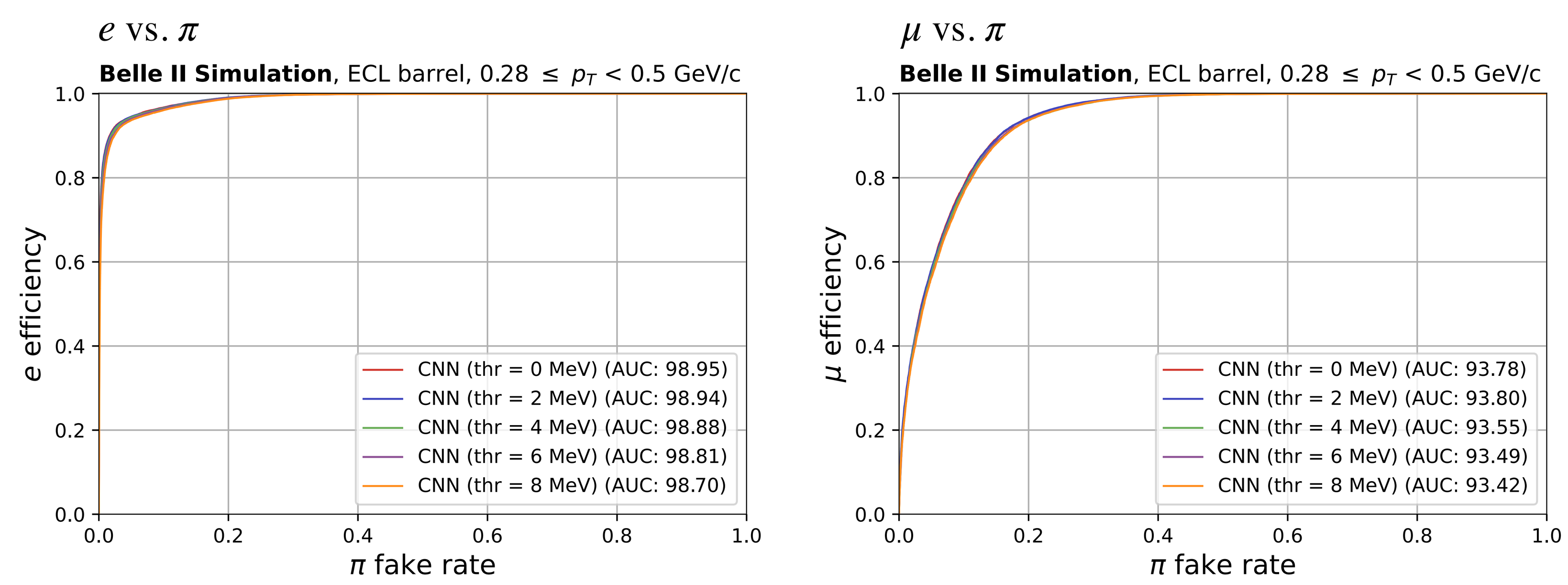
Clustering information

The existing classifiers based on ECL information rely on clustering information, while the CNN requires **only track extrapolation** but **no cluster reconstruction**.



Noise Reduction

The pixel's intensity is set to **0** if the pixel's intensity is **below the provided threshold**. The CNN is **not sensitive** to the choice of threshold.



Conclusion

Separation between low momenta **leptons** and **pions** can be **improved by using CNN** on **ECL-based images**. The improvement is most significant in low momentum regions (**$0.28 \le p_T < 0.7$ GeV/c**), where most of the charged τ decay products are found.

Additionally, the CNN can provide also the separation for **tracks without clustering** information and is **robust** against **applying different energy thresholds**, what could reduce the effect from the presence of beam background-related photons.

References

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[4] M. Milesi, J. Tan, P. Urquijo, *Lepton identification in Belle II using observables from the electromagnetic calorimeter and precision trackers*, EPJ Web of Conferences 245, 06023 (2020)
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[6] Kuhr, T., Pulvermacher, C., Ritter, M. *et al*, *The Belle II Core Software*, Comput Softw Big Sci **3**, 1 (2019)