Suppressing Beam Background and Fake Photons at Belle II using BDTs

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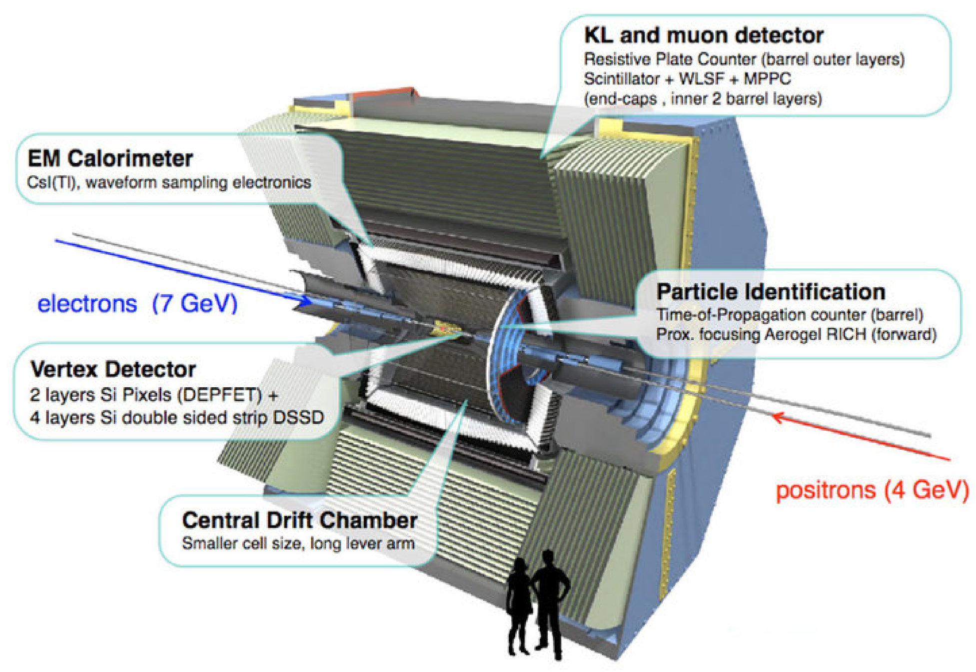
1. Introduction

The **residual energy** in the electromagnetic calorimeter (ECL), called E_{ECL}, is a key background-suppression tool for decays with missing energy (neutrinos). The power of E_{ECL} degrades when **beam background clusters** and **fake photons** are included in the residual energy calculation. To remove these photon contributions from E_{ECL}, and improve its signal-background separation, **two separate classifiers** have been built to identify beam background and fake photons. The framework used is `FastBDT` [1] - a stochastic gradient boosted decision tree (BDT). The two BDTs presented are useful for experiments using crystal calorimeters with near-4π coverage such as BES-III and KLOE.

The BDTs are used in the Belle II analyses of: $B \to D^*\ell\nu$, $B \to \pi\ell\nu$, $B \to K\nu\bar{\nu}$, $B \to \mu\nu$, $B \to \tau\ell$, $B \to \tau\tau$, $\Upsilon(4S) \to \eta h_b(1P)$ and inclusive $R(D)$

2. Belle II Detector

Belle II is located at the **SuperKEKB asymmetric e^+e^- collider** in Tsukuba, Japan. The collider operates at the CMS energy of $\sqrt{s} = 10.58$ GeV. This corresponds to the **$\Upsilon(4S)$ resonance**. The $\Upsilon(4S)$ meson decays almost exclusively to a **pair of B mesons** i.e. $e^+e^- \to \Upsilon(4S) \to B\overline{B}$. Since operation began in 2018, Belle II has recorded an integrated luminosity of $\int Ldt = 428$ fb^{-1}. Belle II has a **near-4π coverage** of the interaction point, so **full reconstruction** of the event can be achieved.



3. Background Photons

Beam background clusters originate from beam interactions like Touschek scattering, Bhabha scattering and beam-gas scattering. **Fake photons** are calorimeter energy deposits that are split into multiple clusters during the reconstruction process, for example due to hadronic split-offs. Photon samples for the BDT training were sourced from **Monte-Carlo simulated data**. True photons from the $\Upsilon(4S)$ decay are labelled **class 1** while beam background and fake photons are **class 0**.

4. BDT Features

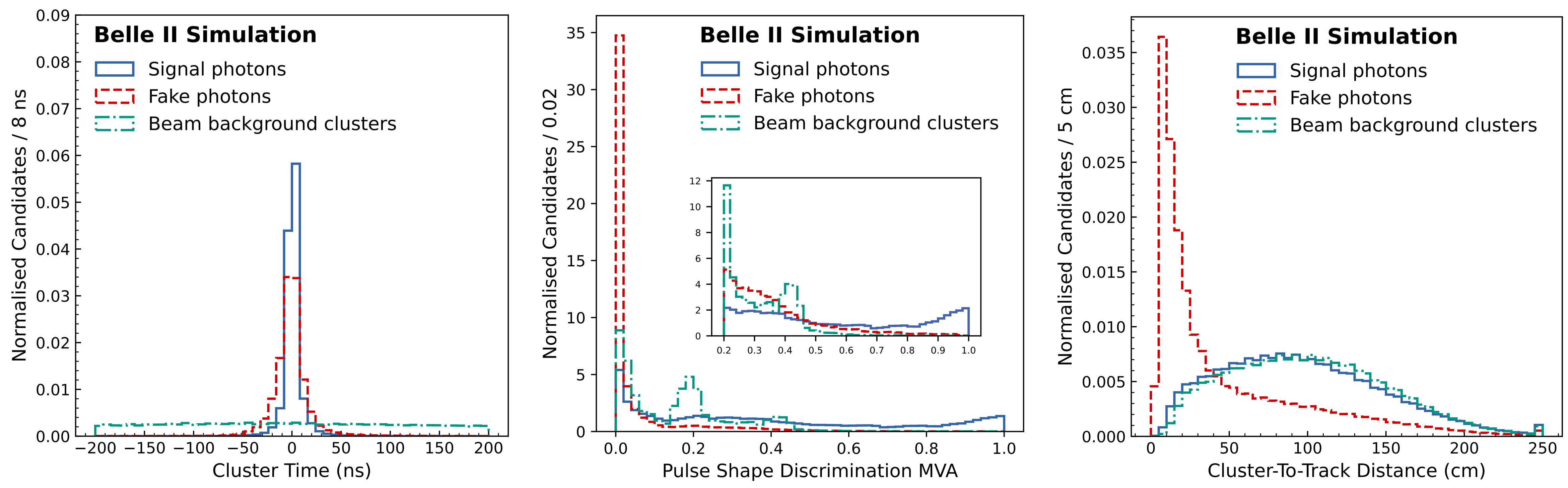
Important features were determined using the **total information gain** of each feature in BDT.

Beam Background BDT Features

- **Energy**, **timing** and **polar angle** of the cluster
- Output of a separate MVA that characterises **cluster shapes**
- Output of a separate MVA that uses **pulse-shape information** from activated ECL crystals, where class 0 = hadronic showers and class 1 = electromagnetic showers [2]

Fake Photon BDT Features - all the beam background BDT features plus

- Distance between the cluster and its **nearest track**

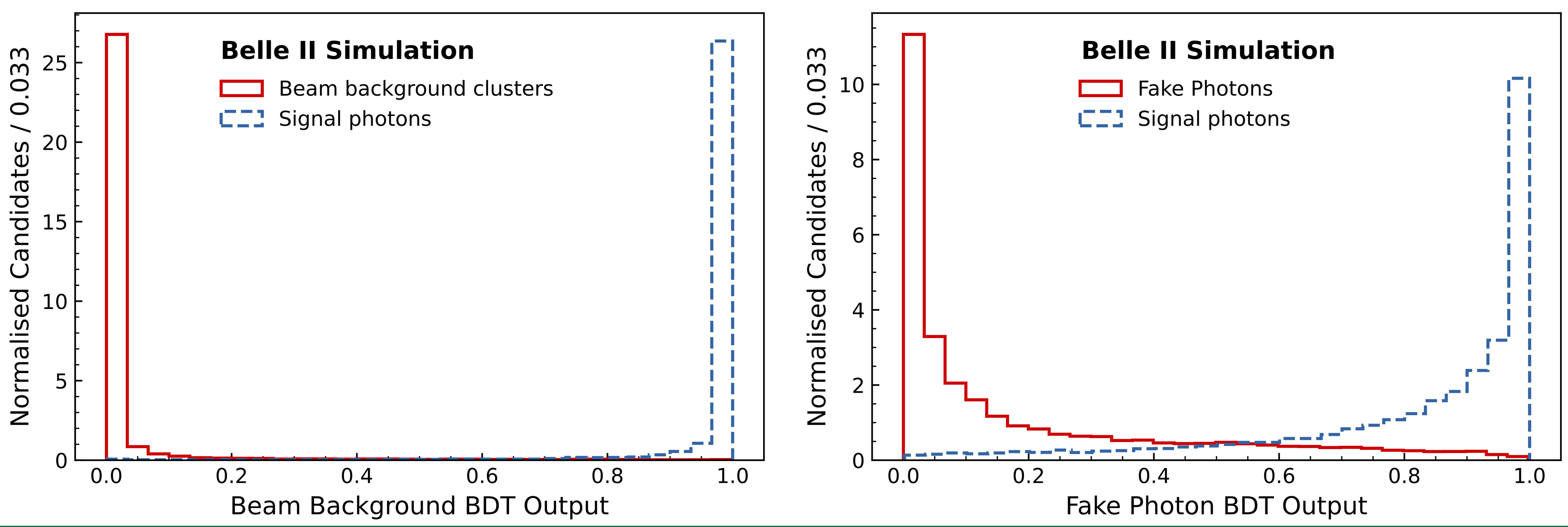


5. Classifier Performance

The optimal hyperparameters were chosen using **holdout** with results below:

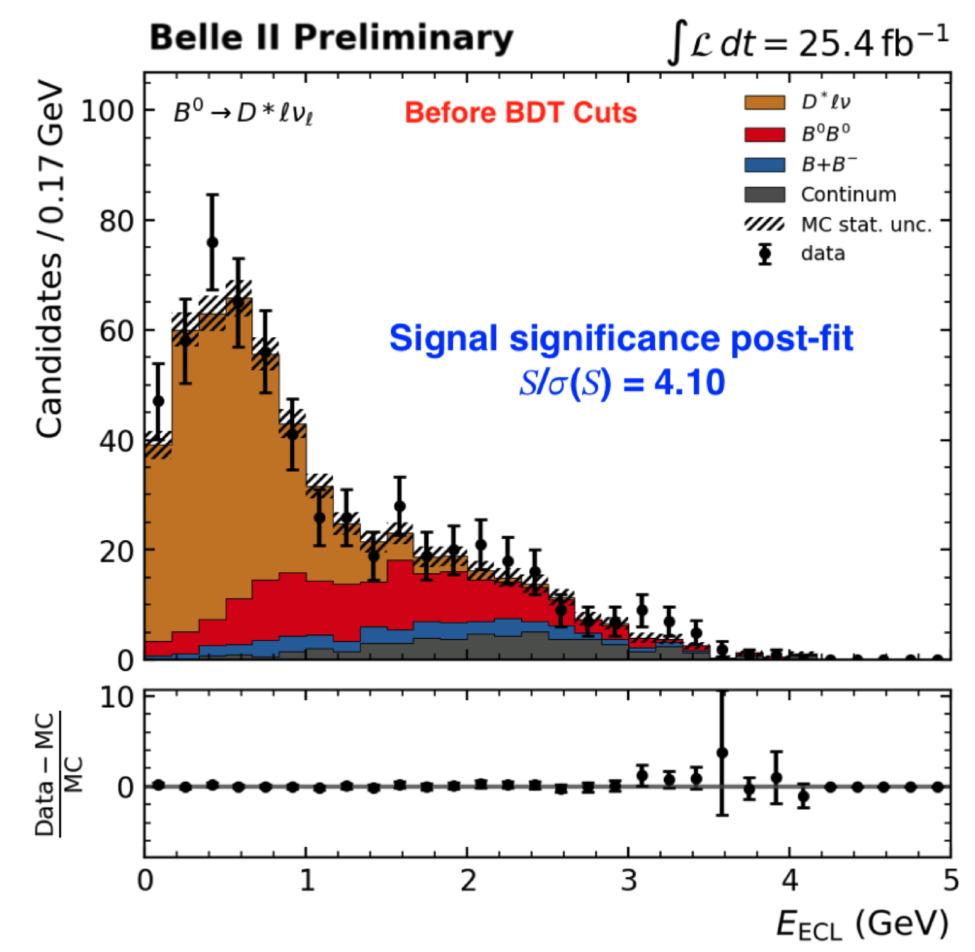
	# Trees	Max Depth	Shrinkage	Test AUC Score
Beam Background BDT	100	3	0.1	0.998
Fake Photon BDT	300	3	0.1	0.944

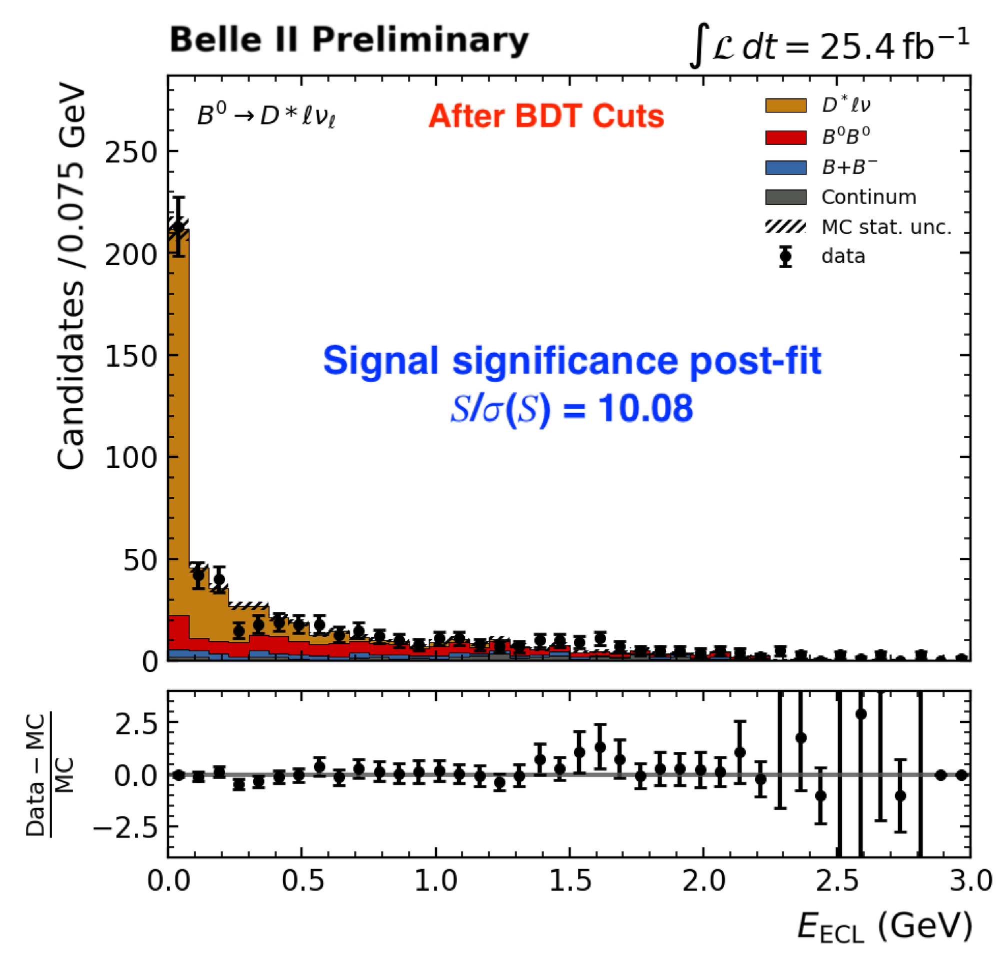
Output of beam background/fake photon BDT gives **probability of being class 1** (signal photon)



6. Testing On $B^0 \to D^*\ell\nu$

Cuts used on the BDT outputs: beam background BDT $>$ **0.6** and fake photon BDT $>$ **0.7**. A **two-template fit** (signal and combined background) to $E_{\text{ECL}} < 0.8$ GeV can be used to get the signal yield S, with fit uncertainty $\sigma(S)$.





7. References

[1] T. Keck. FastBDT: A speed-optimized and cache-friendly implementation of stochastic gradient-boosted decision trees for multivariate classification. 2016.

[2] S. Longo et al. CsI(Tl) pulse shape discrimination with the Belle II electromagnetic calorimeter as a novel method to improve particle identification at electron–positron colliders. *NIM A*, 982:164562, 2020.