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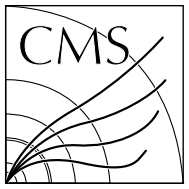
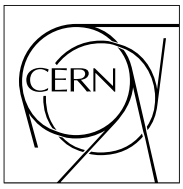
CMS DP -2023/089



The Compact Muon Solenoid Experiment

CMS Performance Note

Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland



14 November 2023 (v2, 16 November 2023)

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CMS Collaboration

Abstract

The ParticleNet b-tagging algorithm has been adapted for and integrated into the CMS High-Level Trigger (HLT) since the beginning of the Run-3 data-taking period, and used in a series of new triggers targeting HH→4b signal events. This note shows the measurement of the ParticleNet b-tag efficiency, in 2022 data and simulation as well as in 2023 data, as a function of the offline b-tag score. The data-to-simulation scale factors are consistent with unity, a crucial validation of the online b-tagger performance in data. During the 2023 data-taking period the online b-tagging threshold for the HH→4b trigger was loosened, further improving the efficiency.

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CMS Collaboration
cms-trigger-coordinator@cern.ch

Abstract

The ParticleNet b-tagging algorithm has been adapted for and integrated into the CMS High-Level Trigger (HLT) since the beginning of the Run-3 data-taking period, and used in a series of new triggers targeting HH→4b signal events. This note shows the measurement of the ParticleNet b-tag efficiency, in 2022 data and simulation as well as in 2023 data, as a function of the offline b-tag score. The data-to-simulation scale factors are consistent with unity, a crucial validation of the online b-tagger performance in data. During the 2023 data-taking period the online b-tagging threshold for the HH→4b trigger was loosened, further improving the efficiency.

Introduction

A graph neural network based jet flavour-tagging algorithm named ParticleNet has been deployed at the High Level Trigger (HLT) since the start of Run 3 data-taking in 2022 [1]. It has been observed that the use of this algorithm leads to increase the trigger efficiency significantly for the HH(4b), HH(2b2τ) and HHH(6b) processes [2] compared to the trigger used in Run 2.

In 2023, the threshold of the loosest unprescaled Level-1 (L1) trigger based on the scalar sum of the transverse momenta of jets in the event (H_T) was lowered from 360 GeV (as it was in 2018 and 2022) to 280 GeV.

To exploit this lower L1 threshold, a looser version of the "jets + b-tags" trigger used in 2022 was introduced at HLT in the Parking stream[†]. The working point of the ParticleNet b-tagger used in this Parking trigger was also loosened compared to the 2022 trigger, leading to increased efficiency within the rate constraints of the Parking stream. In addition, the ParticleNet online b-tagger was re-trained in 2023 based on the latest detector conditions, to further optimise its performance.

In this note, the performance of the ParticleNet based b-tag algorithm at the HLT has been measured in 2022 data and monte-carlo simulation, as well as in 2023 data.

[1] CMS DP 2023/021 [2] CMS DP 2023/050

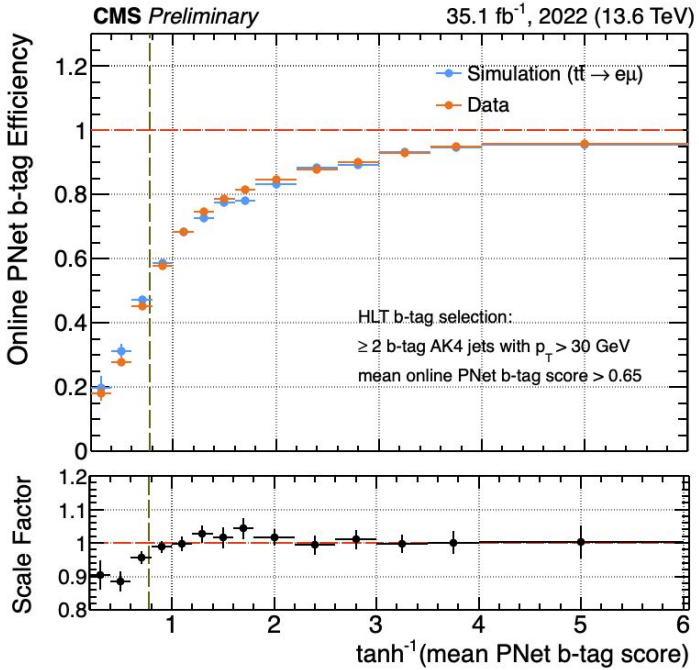
[†] Parking stream allows to store events with high L1 and HLT rates, gaining in acceptance but without immediate offline reconstruction.

Measurement of efficiency

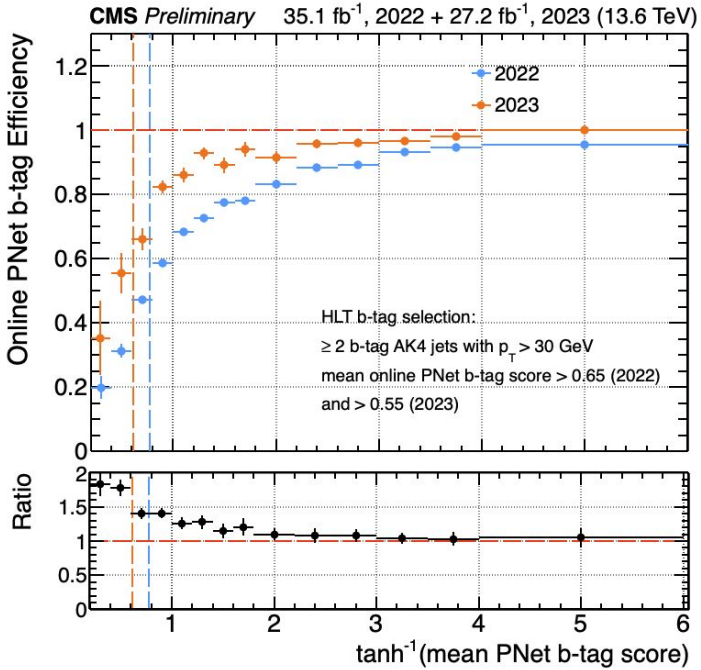
The ParticleNet HLT b-tag efficiency has been measured in a ttbar + jets(electron-muon) control region as a function of mean offline b-tag score of the two highest b-tagged jets with $p_T > 35$ GeV and inside $|\eta| < 2.5$. Events are selected with an e***μ*** + jet control HLT path, and at the offline level required to have an oppositely charged well isolated and identified electron-muon pair. The offline b jets must pass a ParticleNet b-tag threshold corresponding to a b-jet efficiency of about 84%, and a light quark and gluon jet misidentification rate of about 1%. A cross-cleaning has been applied for the two selected jets from the electron and muon candidate.

The definition of the measurement is as follows :

$$\text{Efficiency (mean offline b-tag score)} = \frac{\mathcal{N}_{\text{events}}(e\mu \text{ selection using control HLT} \otimes \text{two b-tag jet selection} \otimes \text{ParticleNet b-tag HLT})}{\mathcal{N}_{\text{events}}(e\mu \text{ selection using control HLT} \otimes \text{two b-tag jet selection})}$$



Online ParticleNet@HLT b-tag efficiency, as used in the High Level Trigger (HLT), as a function of the mean ParticleNet b-tag score of the two most b-tagged jets with p_T > 35 GeV. The efficiency is measured in a ttbar + jets (electron-muon) control region, and shown for 2022 data (orange) as well as simulated data events (blue) corresponding to the integrated luminosity ($\mathcal{L}$) of 35.1 fb^{-1}. The vertical dashed line shows the minimum threshold of the ParticleNet@HLT b-tag score applied at the HLT. The lower panel shows the associated data-to-simulation scale factors. The $\tanh^{-1}$ of the offline b-tag score is shown rather than the raw score to focus the efficiency measurement on the bulk of the distribution populated by real b jets. The emulated online b-tag efficiency in simulation models well the data, validating the online b-tagging trigger performance studies that have been performed on simulation.



Online ParticleNet@HLT b-tag efficiency, as used in the High Level Trigger (HLT), as a function of the mean ParticleNet b-tag score of the two most b-tagged jets with p_T > 35 GeV. The efficiency is measured in a ttbar+jets (electron-muon) control region, and shown for 2022 data (blue) and 2023 data (orange) corresponding to the integrated luminosity ($\mathcal{L}$) of 35.1 fb^{-1} and 27.2 fb^{-1} respectively. The vertical dashed lines show the minimum threshold of the ParticleNet@HLT b-tag score applied at the HLT. The lower panel shows the relative efficiency gain from the 2023 trigger. The more inclusive 2023 trigger has higher efficiency, particularly at lower b-tag scores near the online threshold value, because the 2023 data has been collected with a lower minimum threshold on the online b-tag score.