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Real-time flavor tagging selection in ATLAS

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Abstract

In high-energy physics experiments the online selection is crucial to reject the overwhelming uninteresting collisions. The ATLAS experiment includes b-jet selections in its trigger system, in order to select final states with significant heavy-flavor content. Dedicated selections are developed to timely identifing fully hadronic final states containing b-jets and maintaining affordable trigger rates. ATLAS successfully operated b-jet trigger selections during both 2011 and 2012 Large Hadron Collider data-taking campaigns. Work is on-going now to improve the performance of online tagging algorithms to be deployed in Run 2 in 2015. An overview of the Run 1 ATLAS b-jet trigger strategy along with future prospects is presented in this paper. Data-driven techniques to extract the online b-tagging performance, a key ingredient for all analyses relying on such triggers, are also discussed and preliminary results presented.

Keywords: Trigger, online b-tagging, HLT

1. Introduction

The ATLAS [1] experiment at LHC employs a sophisticated trigger system, capable of real-time track reconstruction to reject most of the events containing uninteresting background collisions while preserving as much as possible the interesting physics signal. Triggering on jets originating from the hadronization of b-quarks, *b-jets*, allows ATLAS to collect events characterized by heavy flavour jets in the final state and by the absence of high p_T leptons. By using this class of trigger, the large multi-jet background can be substantially reduced without the need of increasing the jet p_T thresholds to keep the rate to sustainable values. b-jet triggers are essential for physics analysis which have large jet multiplicity and b-quarks in the final state, such as : fully hadronic $t\bar{t}$, $t\bar{t}$ with hadronic tau in the final state [2]; VBF $H(H \to b\bar{b})$; fully hadronic $t\bar{t}H \to b\bar{b}$; supersymmetric $bH \to bb\bar{b}$.

2. The ATLAS trigger system

During Run 1 the ATLAS trigger system consisted of three different levels:

Level 1 (L1) : It is a hardware trigger implemented in custom-built electronics. It uses the calorimeters and muon spectrometer with coarse granularity to select Regions of Interest (RoI), which are analysed by the following subsequent levels.
Level 2 (L2) : It processes data from all sub-detectors at full granularity but only in limited detector RoIs seeded by L1. Access to ID allows track reconstruction.
Event Filter (EF) : Guided by L2 result it has the ability to access all sub-detectors data at full granularity.
Jets are reconstructed at L1, L2 and EF. Tracking information for b-tagging is available at L2 and EF.

The upgrade for Run 2 provides ATLAS with a robust configuration for higher luminosity running, enabling the experiment to take full advantage of the accelerator upgrades. The major updates will be:

- L1 Calorimeter Trigger, inclusion of new algorithms for event selection based on topological variables, i.e. depending on angular correlation between objects, like ΔR and invariant mass.
- Read Out System upgrade to sustain increased rate.
- L2, Event Builder and EF farms become a unique High Level Trigger (HLT) farm to match with net-

work evolution and have automatically balanced distribution of computing resources.

- Reduced latency since there is no need to pack and-transport informations of the accepted events from L2 to the EF.
- Addition of Fast TracKer ID hardware-based tracking finding after L1. It will be installed in late 2015 [3].

3. How b-tagging works

The identification of jets originating from the hadronization of b-quarks (b-tagging) is possible thanks to the peculiar properties of b-quark decays. The relatively long lifetime of B-hadrons − of the order of 1.5 ps − allows them to travel several millimetres before decaying. Jets originating from B-mesons decay will be prone to be originated from a Secondary Vertex (SV), separated from the primary vertex where the hard process occurred. For these reasons tracks within a b-jet tend to have larger impact parameter than the ones coming from the primary vertex. Combination of secondary vertex properties and tracks informations has been proved to be an excellent discriminator between jets coming from the hadronization of b-quarks and the ones coming from light quarks or gluons.

4. ATLAS online b-tagging algorithms at 8 TeV

A combination of two likelihood-based algorithms, exploiting the impact parameter significances (IP3D) and the secondary vertex properties (SV1) were used during the 2012 data taking campaign for online b-tagging.

4.1. IP3D

The IP3D tagging algorithm uses a likelihood ratio technique in which input variables are compared to pre-defined distributions for both the b- and light jet hypotheses, obtained from Monte Carlo simulation. The discriminating variable used is the 2D distribution of transverse and longitudinal impact parameter significance, $z_0/\sigma(z_0)$ and $d_0/\sigma(d_0)$ of tracks within jets [4]. Left plot in Fig. 1 shows the jet weight distribution for this tagger.

4.2. SV1

SV1 is a likelihood-based tagger exploiting secondary vertex properties: the invariant mass of all tracks associated to the vertex, the ratio of the sum of the energies of the tracks in the vertex to the sum of the energies of all tracks in the jet, and the number of tracks associated to the SV. It is different from the offline version that uses, instead of the latter variable, the number of two track vertices that can be formed with the tracks in the jet. In the figures shown the peaks at zero correspond to jets in which no secondary vertex could be

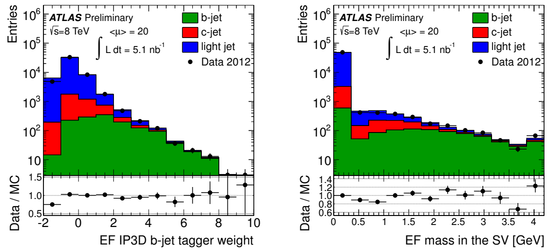

Figure 1: *Left*: Jet weight distribution for the likelihood-ratio tagger based on the longitudinal and transverse impact parameter significance IP3D [4]. *Right* Invariant mass at the EF jets' secondary vertex. In EF jets with $p_T > 55$ GeV and $|\eta| < 2.5$. Only statistical errors are shown [5].

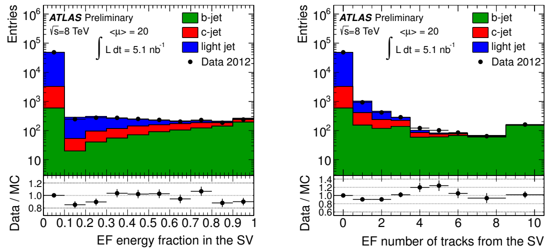

Figure 2: *Left*: Ratio of energy sum of quality tracks associated with the EF jets' secondary vertex and the energy sum of all quality tracks in the jet. *Right* Track multiplicity at the EF jets' secondary vertex. In EF jets with $p_T > 55$ GeV and $|\eta| < 2.5$. Only statistical errors are shown [5].

reconstructed. Right plot in Fig. 1 and plots in Fig. 2 show the jet weight distribution for this tagger.

Thanks to the likelihood ratio method used for IP3D and SV1, the algorithms can be easily combined, the result is a combined tagger. Plots in Fig. 3 show the jet weight distribution for this tagger.

5. Calibration of offline b-tagging algorithms

In order for online b-tagging to be used in physics analyses it is necessary to measure the difference in the performance between data and Monte Carlo simulation. Calibration adresses in particular: b-tagging efficiency, i.e., the efficiency with which a jet originating from a b-quark is tagged by a b-tagging algorithm; c-tagging efficiency and mistag rate, i.e., the probabilities of mistakenly b-tagging a jet originating from a c-quark or a light-flavour parton respectively. Calibration results are expressed in the form of p_T-binned scale factors to be applied to simulation to match the tagging rate observed in data.

b-tagging efficiency with the $p_T$rel method: This calibration technique exploits the different properties of muons embedded in b-jets and light-jets (muon-jets). The muon-jet sample offers advantage of being enriched in heavy flavour jets since ∼ 20% of B-mesons decay

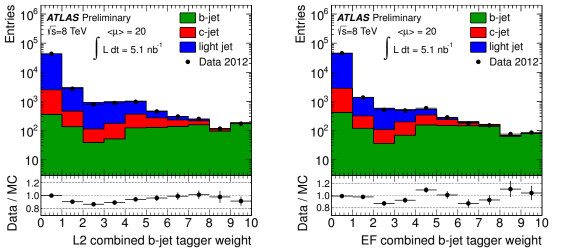

Figure 3: Jet weight distribution for the tagger based on the combination of the impact parameter significance and the secondary vertex likelihood-based taggers, calculated from L2 and EF track in, respectively, L2 jets with $p_T > 50$ GeV and $|\eta| < 2.5$ and EF jets with $p_T > 55$ GeV and $|\eta| < 2.5$. Only statistical errors are shown [5].

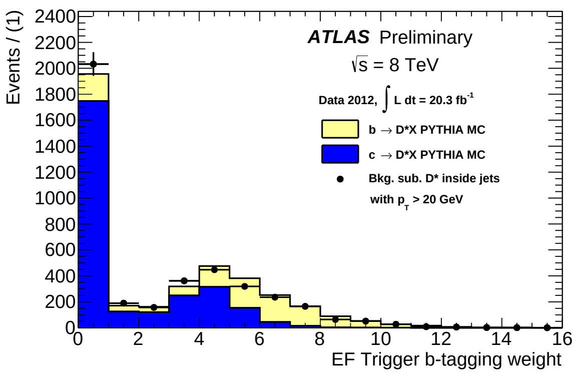

Figure 4: Comparison between the EF Trigger b-tagging weight distribution on a background-subtracted jets, containing D^{*+} mesons, data sample with the corresponding simulated PYTHIA sample. The statistical uncertainty of the simulation is below a few percent and not shown in this figure. The data sample is collected in 2012 using single jet triggers, and the transverse momentum of the selected jets is required to be above 20 GeV [5].

into muons [6].

c-tagging efficiency with the D^* method: The fractional abundance of jets can be measured from data reconstructing exclusive charm meson decays within a jet, such as $D^{*+} \rightarrow D^0(\rightarrow K\pi^+)\pi^+$ and charge conjugated. The beauty to charm jet fraction in the simulation is constrained to the value obtained by a pseudo-proper time fit on data for the D^0 mesons arising from the D^{*+} decays [7].

Mistag rate with the negative tag method : Light-flavour jets are mistakenly tagged as b-jets mainly because of the finite resolution of the ID and the presence of tracks stemming from displaced vertices from long-lived particles or material interactions. The negative tag rate is computed defining a negative version of the tagging algorithm which internally reverses the selections of the discriminant parameters [8].

6. Prospects for Run 2

The possibility of efficiently triggering on b-jets can be crucial for many analyses present in the ATLAS Run 2 physics program. ATLAS used ever-improving b-tagging algorithms at the trigger level in the data taking in 2011 and 2012 and calibrated these for data analysis. For the LHC Run 2 data, more advanced b-jet triggers will be used thanks to the merged HLT and the ability to use complex offline b-tagging algorithms directly to the HLT level. In Run 2 the Fast TracKer (FTK), an electronics system to reconstruct tracks for every event selected at L1, will also be incorporated inside the ATLAS trigger system. Part of FTK will be installed in late 2015, it will give full η coverage by the end of 2016. FTK tracks, freed from the CPU constraints of L2 tracking, will be an important tool box for the ATLAS HLT, allowing it to have improved event selection. This opens up the possibility of doing b-tagging on multi-jet triggers at a higher rate than currently possible and could potentially give the ATLAS trigger sensitivity to models with lower momentum b-quarks than were previously accessible.

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