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Real-time Flavour Tagging Selection in ATLAS

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In high-energy physics experiments, online selection is crucial to select interesting collisions from the large data volume. ATLAS b-jet triggers are designed to identify heavy-flavour content in real-time and provide the only option to efficiently record events with fully hadronic final states containing b-jets. In doing so, two different, but related, challenges are faced. The physics goal is to optimise as far as possible the rejection of light jets, while retaining a high efficiency on selecting b-jets and maintaining affordable trigger rates without raising jet energy thresholds. This maps into a challenging computing task, as tracks and their corresponding vertices must be reconstructed and analysed for each jet above the desired threshold, regardless of the increasingly harsh pile-up conditions.

We present an overview of the ATLAS strategy for online b-jet selection for the LHC Run 2, including the use of novel methods and sophisticated algorithms designed to face the above mentioned challenges. A first look at the performance in Run 2 data is shown and compared to the performance during Run 1.

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1. Introduction

The ATLAS experiment [1] is one of two general-purpose detectors at the LHC designed to explore a wide range of physics processes. The detector is designed to discern signal events from a large amount of background events through the use of a trigger system. The presence of a jet originating from a b-quark (b-jet) is a signature of a potential signal event in measurements or searches involving fully hadronic top-quark pairs ($t\bar{t}$), single top-quarks, Higgs bosons decaying to a b-quark pair (H$\rightarrow b\bar{b}$), fully hadronic $t\bar{t}$H, 2HDM[1] CP-odd Higgs bosons produced in association with a b-quark (bA$\rightarrow bb\bar{b}$), exotic signatures decaying to multi b-jet final states (e.g. graviton$\rightarrow$hh$\rightarrow b\bar{b}b\bar{b}$), and supersymmetric signatures such as third-generation squarks. Thus, identifying and tagging b-jets (flavor tagging) at the trigger level is a vital component in detector operations and many physics analyses.

The general aim of the b-jet trigger is to maximize the b-jet tagging efficiency while maxmizing the light- and c-jet rejection. The trigger decision must be made within the CPU-time and memory constraints. Run 1 saw extensive use of b-jet triggers from a variety of physics groups. Run 2 brings a number of different upgrades related to the b-jet trigger in both hardware and software, such as the Insertable B-Layer (IBL), L1 topological triggers (L1Topo), the Fast TracKer (FTK), Super-RoIs (Regions of Interest) and adoption of offline-based taggers.

2. b-Jet Topology

The ATLAS detector takes advantage of the distinct nature of a b-jet's decay topology. B mesons will practically always decay to strange or charm mesons and 10% of the time with a non-isolated lepton. The B^0 meson [2] has a proper lifetime of about 1.5 ps and mass of 5 GeV. This results in an average decay length of 5 cm when $\frac{p_x}{m_0 v_x} = 100$. This relatively long decay length creates a detectable secondary vertex (SV) in addition to the primary vertex (PV). The tranverse impact parameter (d_0) for hadrons containing b-quarks is biased toward positive values due to their long decay length[2]. It is these quantities that are useful in determining whether or not a jet originated from a b-quark.

3. Hardware Upgrades

The ATLAS trigger system decides which collision events are saved to disk for offline reconstruction and analysis. For Run 2 the ATLAS trigger consists of two levels: Level 1 (L1) is a hardware-based trigger made of custom electronics while the high-level trigger (HLT) is a software-based trigger that runs on commercial-grade computing farms. L1 uses a reduced portion of the detector (calorimeter and muon systems) to construct Regions of Interest (RoIs). These RoIs are used to make trigger decisions at L1 and are used in the HLT. The HLT has access to the entire detector readout including the inner detector for tracking and finer calorimeter granularity. During the long shutdown (LS1[3]) several new additions were made to the trigger hardware relevant for the

[1] 2HDM stands for two-Higgs doublet model

[2] The sign of d_0 is defined as whether the track passes in front of (+) or behind (-) the PV with respect to the jet axis. The jet axis points in the direction of the jet's 3-momentum.

[3] Period of LHC and detector upgrade from 2012 to 2015.

b-jet trigger: the IBL, L1Topo, and FTK.

The IBL and FTK bring improved track reconstruction that is vital for vertex finding. The IBL [3] is an additional, fourth pixel layer in the inner detector located 33 mm from the beam axis. It provides tracking robustness and precision in the face of the increased luminosity and center-of-mass energies of Run 2. The FTK [4] is specialized hardware that finds and reconstructs charged-particle tracks candidates using pattern matching on specially pre-processed data in an associative memory. It's planned to be first used in 2016. It will receive all data from the Semi-conductor Tracker components at each L1 accept signal at up to a 100 kHz rate. The track quality of the FTK can be further improved at the HLT by refitting pre-existing patterns. This is expected to have a significant impact on SV reconstruction. Additionally, it should allow the possibility of constructing track-based jets at the HLT level in order to probe lower p_T regions. The E_T distribution for offline b-tagged jets in simulated $t\bar{t}$ events, before and after matching with L1 calorimeter jets or track jets reconstructed using FTK is shown in Figure 1.

L1Topo is currently being commissioned and brings the ability to topologically associate L1 trigger objects with one another. It is a new hardware component that performs realtime event selection based on the geometric and kinematic relationships between trigger objects. Thus, an L1 decision can be made based on angular separation, invariant masses, and total transverse momentum. For the b-jet trigger this means that a muon can be associated to a jet within a ΔR cone at L1. This muon-in-jet trigger can then be used by the b-jet trigger to select semi-leptonic b-decays.

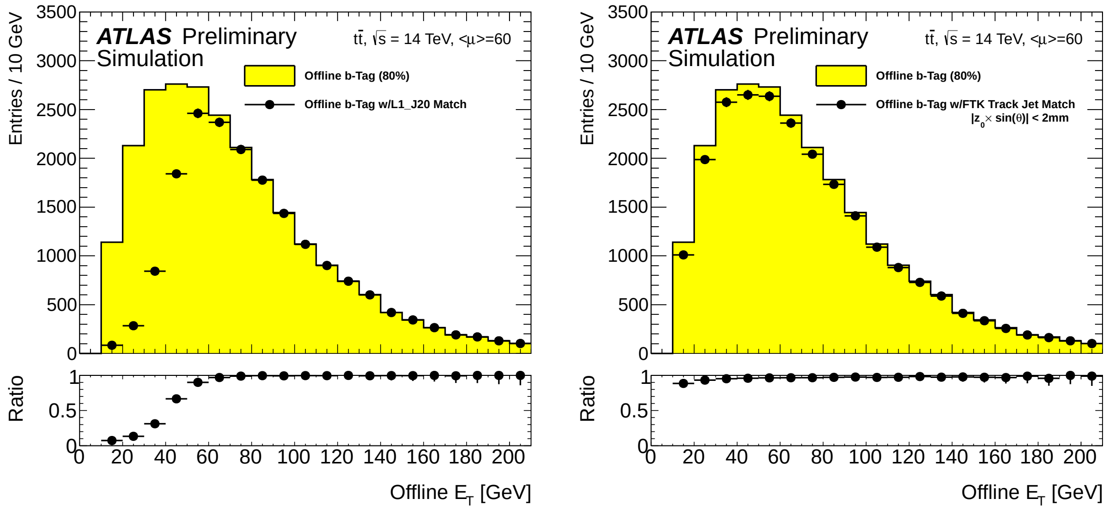

Figure 1: E_T distribution for offline b-tagged jets in simulated $t\bar{t}$ events. All jets, shown in yellow, are reconstructed using the anti-k_t ($R = 0.4$) algorithm and are required to have $|\eta| < 2.5$. The black points show the sub-set of offline jets matching a 20 GeV L1 jet (left) or an FTK track-jet (right) [4].

4. Software Upgrades

A new approach to processing RoIs and reconstructing tracks and the PV is to merge the individual RoIs into a single RoI into what is known as a Super-RoI. The procedure is as follows: merge the L1 RoIs at the HLT level into a single Super-RoI, perform fast tracking and find a PV for the Super-RoI, then perform precision tracking on the individual RoIs, but constrain their tracks by the PV found in the previous step. In high-pileup[4] scenarios this will reduce the number of redundant track calculations and track duplication.

Another improvement in software comes from the adoption of b-tagging algorithms used in offline reconstruction. These algorithms are more robust and their use in the trigger allows for better correlations between the online and offline working points. The primary algorithm used for b-tagging is a Boosted-Decision-Tree-based discriminant called MV2c20. MV2c20 refers to the second generation of multivariate discriminate (MV2 versus MV1 from Run 1) with 20% c-jet contamination to obtain better c-jet rejection while retaining excellent light-jet rejection. It uses the IP2D, IP3D, SV1, and JetFitter algorithms as input [5]. IP2D and IP3D are likelihood ratio techniques that uses the longitudinal (IP3D) and transverse (IP2D and IP3D) impact parameter significances of charged-particle tracks within the jet cone to discriminate b- and light-jets. SV1 is a likelihood ratio technique used to find an secondary vertex. Finally, JetFitter is a likelihood technique that exploits the topology of weak decays of b- and c-quark-based hadrons. The improvements in rejection power achieved by adopting the offline algorithms are shown in Figure 2.

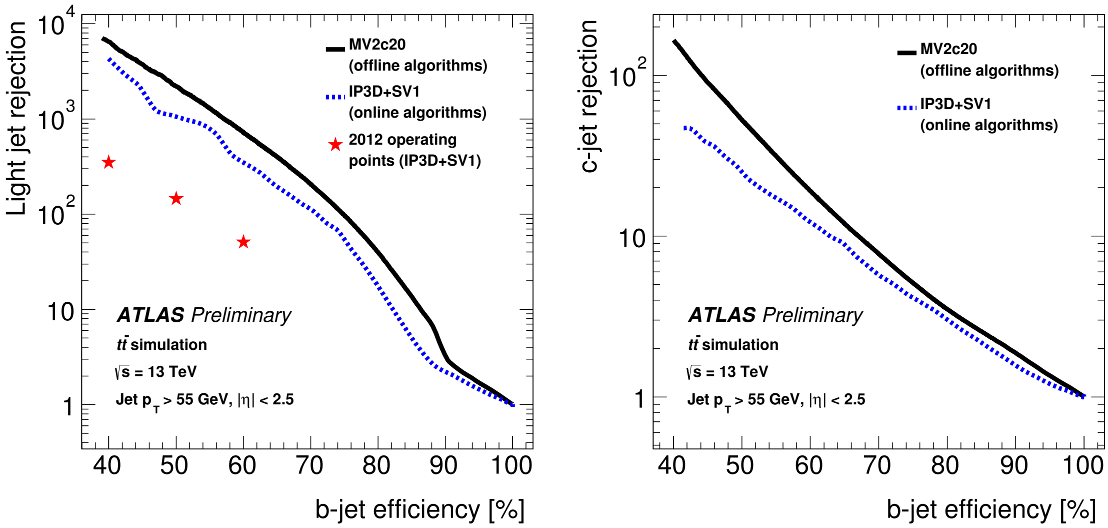

Figure 2: The expected online performance in terms of light-jet rejection (left) and c-jet rejection (right) of the MV2c20 tagger (solid black line) is shown together with the expected performance of the IP3D+SV1 tagger in Run 2 (dashed blue line) and the actual performance of the IP3D+SV1 tagger that was achieved during Run 1 (red star) [6].

[4]Pileup describes the interference of multiple proton collisions with the primary interaction. This can occur "in time" when the many protons in the same beam bunching collide and "out of time" when particles from a previous bunch crossing still affect the detector readout.

5. Summary

The overview and preliminary results of the new online b-tagging strategy and algorithms, designed to face the new LHC Run 2 challenges are presented. These results show the significant improvements in performance for Run 2. In particular, the adoption of new b-tagging algorithms results in a large improvement in tagging efficiency for similar levels of rejection.

References

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