PROCEEDINGS OF SCIENCE

Jet flavour tagging for the ATLAS Experiment

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The ability to identify jets stemming from the hadronisation of b- quarks (b-jets) is crucial for the physics program of ATLAS. The higher pileup conditions and the growing interest for measurements including c-jets and for searches in the high transverse momentum regime make the task more and more complex. The algorithms responsible for establishing the jet's flavour are evolving quickly, exploiting powerful multivariate and deep machine learning techniques. Since the primary input to any such algorithm consists of charged-particle tracks within the jet, the identification of jets from heavy-flavor decays depends strongly on the tracking efficiency and resolution and the robustness of the track-jet association logic. Flavour-tagging techniques in ATLAS will be reviewed, presenting the state-of-the-art in terms of algorithms, with focus on the capability to reconstruct and select the relevant tracks produced in the ATLAS Inner Detector.

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1. A brief introduction to b-tagging

Jet flavour tagging is the set of algorithms designed to discriminate different flavours of jets, i.e. jets initiated by b, c or gluons and light quarks. The identification of jets from b-quarks plays an important role in various contexts, like Higgs production, top production and several new physics scenarios. B-tagging relies on some important typical feature of B hadrons, that allows discriminating b-quark initiated jets from other jet flavors: in particular, B hadrons have long lifetime ($\sim$ 1.5 ps, corresponding to $\sim$ 3 mm flight length), high mass ($\sim$ 5 GeV), high decay multiplicity, and typically decay in D hadrons. As a result, b-tagging algorithms implemented in the ATLAS [1] can be divided in two categories: IP-based and SV-based. The first category heavily relies on the use of the impact parameter (IP) of the decay products of B-hadrons as a typical signature that is used for the tagging, the second category of taggers focuses on the reconstruction of the displaced decay vertex of the B, which is denoted as secondary vertex (SV) separated from the vertex where the primary proton-proton collision takes place. Among the IP-based algorithms, IP2D and IP3D use a discriminant which is built from the signed-IP, for b,c and light jets. RNNIP (a recurrent neural network) and DIPS (which uses Deep Sets NN architecture) take into consideration, in addition to the impact parameters, also other properties of the tracks associated to jets. SV-based algorithms try to reconstruct the displaced vertex, and use SV-derived quantities for discriminating different flavours of jets. Two SV-based algorithms are in use at the moment in the ATLAS offline software: inclusive secondary vertex finding, (SSVF) and JetFitter (reconstructing the entire B to D chain). High-level taggers combine information coming from low-level taggers and use NNs to maximize performance; they are: DL1 (using IP3D), DL1r (using RNNIP) and DL1mu (using in addition to IP2D and IP3D an algorithm specialized in the identification of soft muons). DL1r is the current baseline tagger of the ATLAS offline software in use for the analysis of Run-2 data.

2. b-tagging performance

B-tagging algorithms are trained on simulated data; their performance is extensively studied with MC simulations. Results show that the task of b-quark identification is increasingly difficult at high jet p_T: the flavour tagging efficiency decreases and shows significant dependence on the modeling in simulation. Two are the main effects playing a role in this performance degradation:
1. Hadron simulation: highly boosted charged B/D hadrons may produce a few hits in the detector which are associated as spurious hits to the decay tracks. This effect spoils the track resolution and reduces the efficiency of the vertex reconstruction.
2. Jet modeling: different models of fragmentation and hadronization influence the estimated performance, especially at high p_T.

The nominal simulation does not include the interactions of B hadrons with the inner detector, therefore it does not handle the rare occurrence of spurious hits from B hadrons affecting the reconstruction of their decay products. In the nominal simulation only particles from B/D hadron decays are propagated through the detector materials. A dedicated simulation (quasi-stable model) taking into account EM interactions of B/D hadrons allows establishing the effect on the track reconstruction of the decay products of the B hadron. The left plot of Figure 1 shows that in simulations where B/D hadrons are propagated in the detector materials a performance loss on

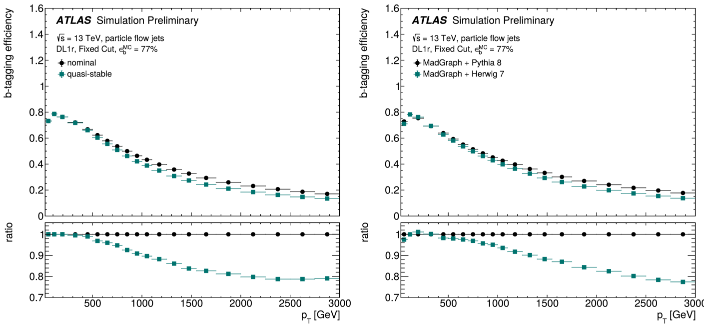

Figure 1: Left - the nominal and quasi-stable simulation of tracks differ in how the interaction of tracks with the detector is emulated, with an effect on b-tagging performance, especially at high p_T. Right - two different models of the fragmentation process are considered here, together with their effect of b-tagging performance. The plots are taken from [4].

b-tagging, especially at high p_T, is obtained: however, a dedicated training of DL1r can reduce the actual impact in performance, as the tagger was trained on nominal MC simulations. In the plot on the right of Figure (1) the b-tagging efficiency is compared for two simulations based on two different models of fragmentation and hadronization. As it can be seen, different fragmentation models lead to differences in the estimated efficiency as large as 30% when the transverse momentum approaches 3 TeV. In order to further understand the origin of the performance degradation, a detailed study of track composition of b jets was carried out. These differences arise in all cases from the difficulty of reconstructing tracks or associating them to the correct jet that emerges in the dense environment of high p_T jets and high pileup events.

3. B jets track composition

The track composition of jets has been studied as a function of the jet p_T. In Figures (2) tracks are divided in different categories, namely: pile up (tracks coming from vertices other than the primary, or from previous events), fakes (poorly reconstructed tracks), GEANT (tracks coming from the interactions of particles with the material of the inner detector), fragmentation (tracks from fragmentation and hadronization) and B/D tracks (good reconstructed decay products from B and D hadrons). In Figure (2) (top) the average number of tracks is shown at low p_T (left) and high p_T (right). It's evident how fragmentation tracks become more important in the high p_T region, with a significant impact on performance. At the same time the number of B/D tracks decreases due to failures of the tracking or track association algorithms in the difficult conditions of high pt jets. In Figure (2) (bottom) the fraction of tracks used as input by the IPxD algorithms (left) and associated to the secondary vertex by SV1 (right) is shown against the jet p_T. In both cases the relative fraction of tracks within the jet is shown (therefore the different contributions sum to 1 for each pt interval). IP-based algorithms do a pre-selection of tracks: as a result, the amount of pile up is dramatically decreased while a high number of B/D tracks is accepted. However, fragmentation tracks are still contributing substantially to the input of IP-based algorithms. The tracks used by SV1 are determined by a different pre-selection and by the vertex reconstruction, with the aim of

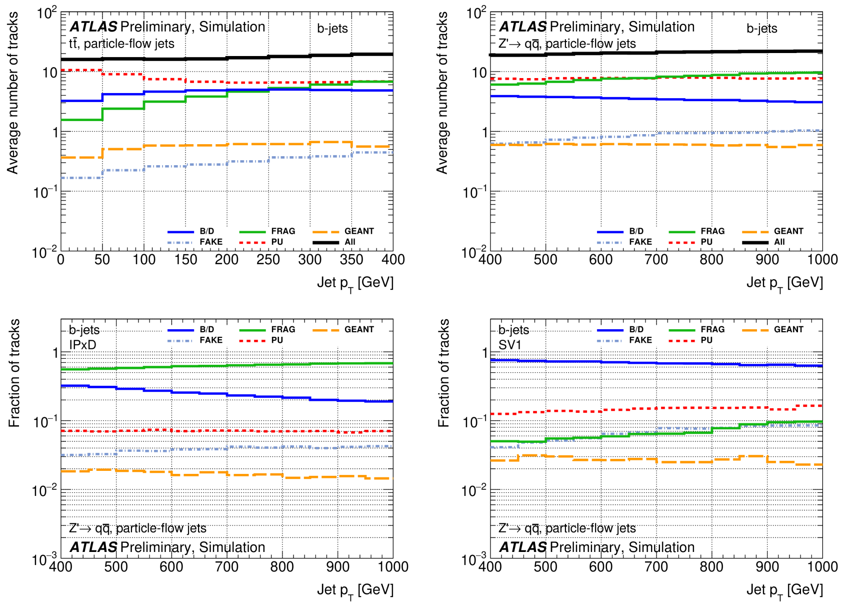

Figure 2: Track composition of b-jets at low p_T (top left) and high p_T (top right) is shown, together with the relative fraction of tracks in b-jets for tracks used by IPxD algorithms (*i.e.* IP2D, IP3D, RNNIP and DIPS) (bottom left) and SV1 (bottom right plot). The plots are taken from [5].

discarding tracks coming directly from the primary vertex. The result is a very efficient reduction of noisy tracks, including fragmentation ones.

4. The future of b-tagging

New versions of flavour tagging algorithms are under validations and others algorithms are being developed, addressing also the difficulties of the high p_T regime. The strategy to achieve higher efficiency can consider looking more extensively at the track content of jets. For example, the new IP-based tagger, DIPS [6], in preparation for Run 3 operation (where the average number of interactions per bunch crossing will be higher than in Run 2), is shown to reach a better rejection of light-jets when a pretty loose track selection is applied.

References

[1] ATLAS Collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider*, JINST 3 (2008) S08003

[2] ATLAS Collaboration, *ATLAS b-jet identification performance and efficiency measurement with $t\bar{t}$ events in pp collisions at $\sqrt{s}$ = 13 TeV*, Eur. Phys. J. C 79 (2019) 970.

[3] ATLAS Collaboration, *Expected performance of the 2019 ATLAS b-taggers*, FTAG-2019-005.

[4] ATLAS Collaboration, *Simulation-based extrapolation of b-tagging calibrations towards high transverse momenta in the ATLAS experiment*, ATL-PHYS-PUB-2021-003.

[5] ATLAS Collaboration, *Simulated flavour composition of tracks processed by the ATLAS b-tagging algorithms applied to particle flow jets*, FTAG-2021-003.

[6] ATLAS Collaboration, *Deep Sets based Neural Networks for Impact Parameter Flavour Tagging in ATLAS*, ATL-PHYS-PUB-2020-014.