Tagging b-jets in ATLAS

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The ability to identify jets containing b-hadrons is important for the high-p_T physics program of the ATLAS experiment at the LHC. This is in particular useful to select very pure top quark samples or for studying Standard Model or supersymmetric Higgs bosons which couple preferably to heavy objects. After a review of the algorithms used to identify b-jets, their anticipated performance is discussed as well as the impact of various critical ingredients such as the residual misalignments in the tracker. The prospects to measure the b-tagging performance in the first few hundreds of pb^{-1} of data with di-jet and $t\bar{t}$ events are presented. Finally two different physics use cases of b-tagging are summarised.

1 b-tagging algorithms in ATLAS

Bottom jets possess several characteristic properties that can be utilised to separate them from jets coming from the hadronisation of lighter quarks. The most important property is the relatively long lifetime of b-hadrons of about 1.5 ps. This leads to a measurable flight length of a few millimeters before their subsequent decay. The decay of the b-hadrons at a displaced secondary vertex can be identified inclusively by measuring the impact parameters (IP) of tracks coming from the decay, that is the distance from the point of closest approach of the track to the interaction vertex. The IP is a signed quantity, which is positive if the point of closest approach lies upstream with respect to the jet direction and negative in the other case. Apart from that, a secondary vertex can also be reconstructed explicitly. The various tagging methods studied in ATLAS can be divided into two main classes: the *spatial taggers* comprise methods that utilise lifetime information like impact parameters and decay vertices; the *soft-lepton taggers* are based on the reconstruction of the lepton in case the b-hadron decays semi-leptonically. These leptons have a sizable tranverse momentum as well as a large transverse momentum relative to the jet axis (p_T^{rel}). Detailed information on the presented results and b-tagging in ATLAS can be found in the chapter on b-tagging in [1] and references therein.
Apart from a few simple algorithms all tagging methods rely on a likelihood ratio to build a discriminating variable, called jet weight, for the separation of b-jets, c-jets and other jets. In the following only the separation between b-jets and light-jets is considered for simplicity. All jets having a jet weight above a certain cut value are then tagged as b-jets. This cut value determines the b-tagging efficiency ϵ_b, defined as the fraction of true b-jets that are tagged as b-jets. It also determines the rejection rate of light-jets R_u, defined as the inverse of the fraction of true light-jets that are falsely tagged. For a given cut on the weight the rejection of light jets as well as the efficiency, in general, strongly depend on η and p_T of the jet (c.f. Fig. 1).
A brief description of some of the ATLAS b-tagging algorithms follows. The *JetProb* algorithm uses the negative side of the transverse IP significance distribution as obtained from prompt tracks to calculate the probability of compatibility of the tracks with the primary vertex. More

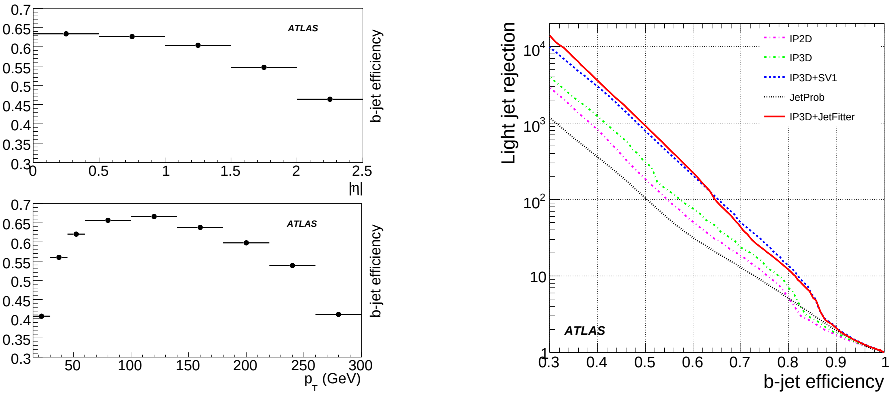

Figure 1: Left: b-tagging efficiency obtained with the IP3D+SV1 algorithm operating at a fixed cut on the b-tagging weight for $t\bar{t}$ events versus jet $|\eta|$ and p_{T} respectively [1]. Right: Rejection of light jets versus b-jet efficiency for $t\bar{t}$ events and for various tagging algorithms [1].

sophisticated tagging algorithms utilise the distribution of the IP significance as calculated in the transverse plane (*IP2D*) and in addition in the longitudinal projection (*IP3D*). One secondary-vertex tagger (*SV1/2*) fits inclusive secondary vertices and builds the jet weight from several one or more-dimensional variable distributions like e.g. the vertex mass. The tagger with the best single performance (*JetFitter*) fits the decay chain of b-hadrons, i.e. it fits a common b/c-hadron flight direction along with the position of additional vertices on it. The jet weight is calculated similarly to *SV1/2*, but taking different decay topologies into account.
Two soft-lepton tagger approaches are pursued in ATLAS. One uses soft muons and one or two dimensional reference histograms of the muons p_{T} and the muons $p_{\mathrm{T}}^{\mathrm{rel}}$. The other uses electrons and relies on the challenging identification of soft electrons inside jets.

2 Performance in Monte Carlo simulations

The performance of the tagging methods is estimated on Monte Carlo simulated events. For the following results $t\bar{t}$ events were used. A snapshot of the expected light jet rejection as a function of the efficiency can be found in Fig. 1 for the spatial taggers. One can expect $R_u \sim 30$ for the *JetProb* tagger and up to $R_u \sim 200$ for the sophisticated *JetFitter* algorithm at a typical b-tagging efficiency of $\epsilon_b = 60\%$. The soft muon tagger for example gives $R_u \sim 300$ at $\epsilon_b = 10\%$, where ϵ_b includes semi-leptonic branching fractions.
An effort has been made to reach a realistic understanding of critical aspects of b-tagging. The studies summarised above were done assuming a perfect knowledge of all misalignments. More realistic studies take residual misalignments into account as well as the process of realignment including systematic uncertainties. Recent studies indicate a possible degradation of the light jet rejection of up to $\sim 30\%$ at most for fixed ϵ_b. Further degradations in rejection are seen in studies including pile-up events (~ 5 minimum bias events are expected at an instantaneous luminosity of $2 \cdot 10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$), where in a few percent of the cases a wrong primary vertex is reconstructed leading, among other things, to an artificial shift in the longitudinal IP and finally to a loss in rejection of $\sim 30 - 40\%$ for *IP3D* and *IP3D+SV1*. The taggers that take only the transverse impact parameter into account are minimally affected by pile-up however.

3 Prospects for performance measurements

It will be necessary to calibrate the b-tagging methods on data. This means that one has to measure the tagging efficiency as well as the rejection rate. Due to the dependence on p_{T} and η it is desirable to perform the calibration in bins of those variables. In addition one would also like to measure the reference histograms with data. For the efficiency measurement several methods have been studied in ATLAS that make use of either di-jet or $t\bar{t}$ events.
The $p_{\mathrm{T}}^{\mathrm{rel}}$ method is one approach that uses events with jets that include non-isolated muons. Templates of the muon $p_{\mathrm{T}}^{\mathrm{rel}}$ as obtained from simulated and reconstructed b-, c- and light-jets passing basic selection criteria are fitted to the measured distribution before and after applying the respective tagger, which preferably is a spatial tagger. By counting the number of muon jets before and after the tagging, the efficiency ϵ_b can be estimated. It was shown that an integrated luminosity of $\sim 50\,\mathrm{pb}^{-1}$ is sufficient to derive detailed calibration curves in p_{T} or η with a relative precision on ϵ_b of about 6%.
There are several methods that make use of $t\bar{t}$ events. One is an event counting method, that measures the average b-tagging efficiency and the cross section of $t\bar{t}$ production in the lepton+jets or the dilepton channel at the same time, by counting the number of events with 1, 2 or 3 tagged jets. With $\sim 100\,\mathrm{pb}^{-1}$ of data a relative precision on ϵ_b of $\sim (2.7(\mathrm{stat.}) \pm 3.4(\mathrm{sys.}))\%$ can be reached in the lepton+jets channel.

4 Physics use cases

There are various examples of use cases where b-tagging is a critical ingredient. One is the search for a Standard Model Higgs boson in the $t\bar{t}H(H \to b\bar{b})$ channel. Here b-tagging can be used to reduce or even eliminate large backgrounds like $t\bar{t}j\bar{j}$ or W+jets. For example the $t\bar{t}j\bar{j}$ background is reduced by two orders of magnitude by using b-tagging. Another example is the top quark mass measurement. There the highest precision can be reached in the $t\bar{t}$ lepton+jets channel by requiring two b-tagged jets using the hadronically decaying top as the mass estimator. Assuming a jet energy scale uncertainty of the order of one percent, a precision of 1 GeV can be reached with an integrated luminosity of $1\,\mathrm{fb}^{-1}$. A complementary approach relying on b-tagging infers the top quark mass from the mean transverse decay length of b-hadrons coming from the top decays. Here the uncertainty due to the jet energy scale is negligible.

5 Conclusion

Various algorithms for tagging b-jets have been studied in detail in ATLAS. The spectrum covers simple, robust taggers as well as sophisticated taggers, that make use of as much information as possible from the b-hadron decay chain. Several approaches for calibrating b-tagging algorithms with data were shown to be realisable with a few $100\,\mathrm{pb}^{-1}$ of data. b-tagging is essential for many physics analyses, like Higgs boson searches or top quark mass measurements.

References

[1] The ATLAS Collaboration, Expected Performance of the ATLAS Experiment, Detector, Trigger and Physics, CERN-OPEN-2008-020, Geneva, 2008.