A new Soft Muon Tagger for ATLAS Run 2

based on *"Optimisation and performance studies of the ATLAS b-tagging algorithms for the 2017-18 LHC run"*

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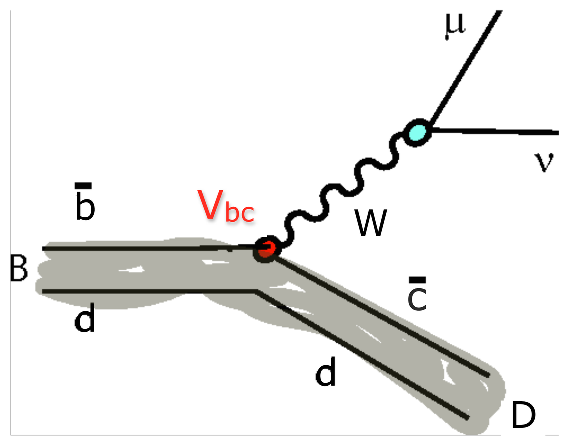
Basic Principles

The Soft Muon Tagger (SMT) is an algorithm devoted to the identification of b-jets by exploiting the presence of reconstructed muons coming from semileptonic decays of heavy-flavour hadrons. These muons usually have a sizeable transverse momentum, as well as a large transverse momentum relative to the jet axis, and their presence is enhanced in b-jets due to the significant semileptonic decay branching ratio of b hadrons (BR(b → μ ν X) + BR(b → c → μ ν X) ≈ 21%). The SMT tagging efficiency is limited by the semileptonic branching ratio, but the response of this algorithm is independent of impact parameter- and vertex-based taggers; therefore the SMT information can be combined with the latter as additional input to high level b-taggers.



Selection and Composition

The development of a SMT algorithm in ATLAS has been performed using MC simulation samples of $t\bar{t}$ events produced in proton-proton collisions with a centre-of-mass-energy of 13 TeV. The SMT tagger is based on calorimetric jets and **combined muons**, i.e. muons candidates with matching tracks reconstructed in both the **Inner Detector** and **Muon Spectrometer** systems.

Jets are required to satisfy the following requirements:

- $p_T > 20$ GeV
- $|\eta| < 2.5$
- cut on Jet Vertex Tagger algorithm (JVT) output in order to suppress jets originating from pile-up interactions

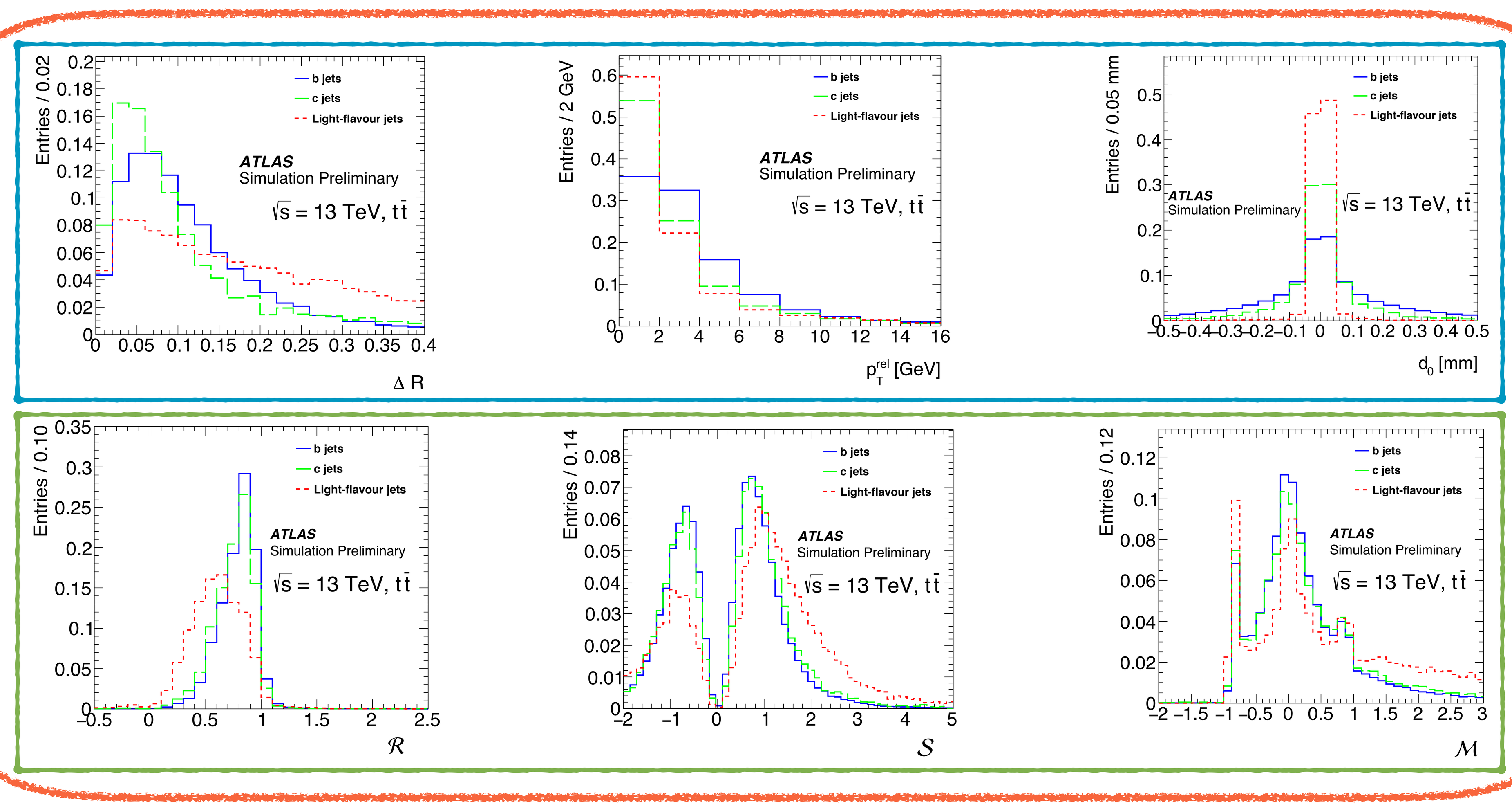
Muons are associated to the closest jet by requiring a **ΔR < 0.4** match and are required to have

- $p_T > 5$ GeV
- $|\eta| < 2.5$
- $d_0 < 4$ mm

The fraction of **b-jets** in the $t\bar{t}$ MC sample with a reconstructed muon passing the requirements listed above is **~12%.** In **light jets** there are three main background sources that give rise to muon candidates passing these requirements:

- **prompt muons** from the W boson decays randomly associated to the jet (~1% contamination)
- muons coming from the **decay in flight of light hadrons**, mostly pions and kaons (~1% contamination)
- **energetic hadrons** ("punch-through") travel through the calorimeter system and reach the Muon Spectrometer (< 0.1% contamination)

Input Variables



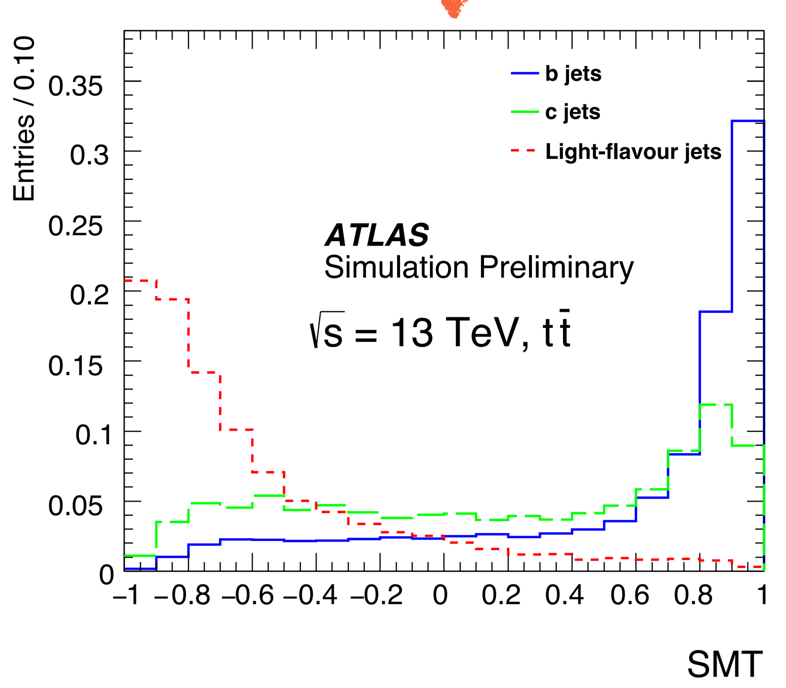
A Boosted Decision Tree (BDT) is used to separate muons from b-decays from all other sources of muon candidates. For this purpose three properties of the muon with respect to the b-decay are exploited:

- ΔR : angular distance between the muon and the associated jet
- $p_{\mathrm{T}}^{\mathrm{rel}}$: orthogonal projection of the muon p_T onto the jet axis
- d_0 : muon impact parameter measured with respect to the interaction primary vertex

as well as three properties of the muon track:

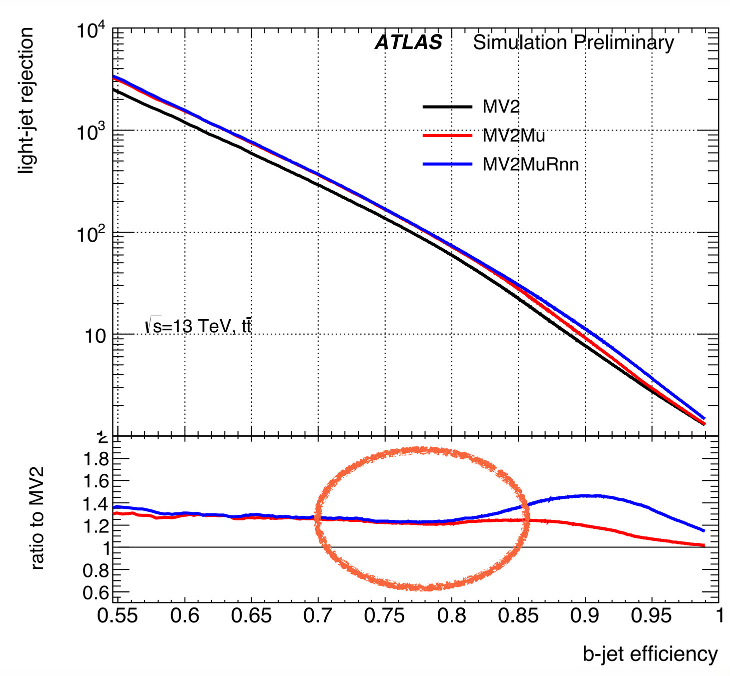
- $\mathcal{R} = \frac{(q/p)_{\mathrm{ID}}}{(q/p)_{\mathrm{MS}}}$: ratio between the track momentum measured in the Muon Spectrometer and the momentum measured in the Inner Detector
- $\mathcal{S} = q \times \sum_i \frac{\Delta\phi^i_{\mathrm{scat}}}{\sigma_{\Delta\phi^i_{\mathrm{scat}}}}$: the sum of scattering angle significances over all adjacent hits along the Inner Detector track times the muon charge
- $\mathcal{M} = \frac{p_{\mathrm{ID}} - p_{\mathrm{MS}}^{\mathrm{extr}}}{\sigma_{E_{\mathrm{loss}}}}$: the difference between the momentum measured in the Inner Detector and the momentum measured in the Muon Spectrometer plus the energy loss in the calorimeters, divided by the uncertainty on the energy loss in the calorimeters

SMT Output



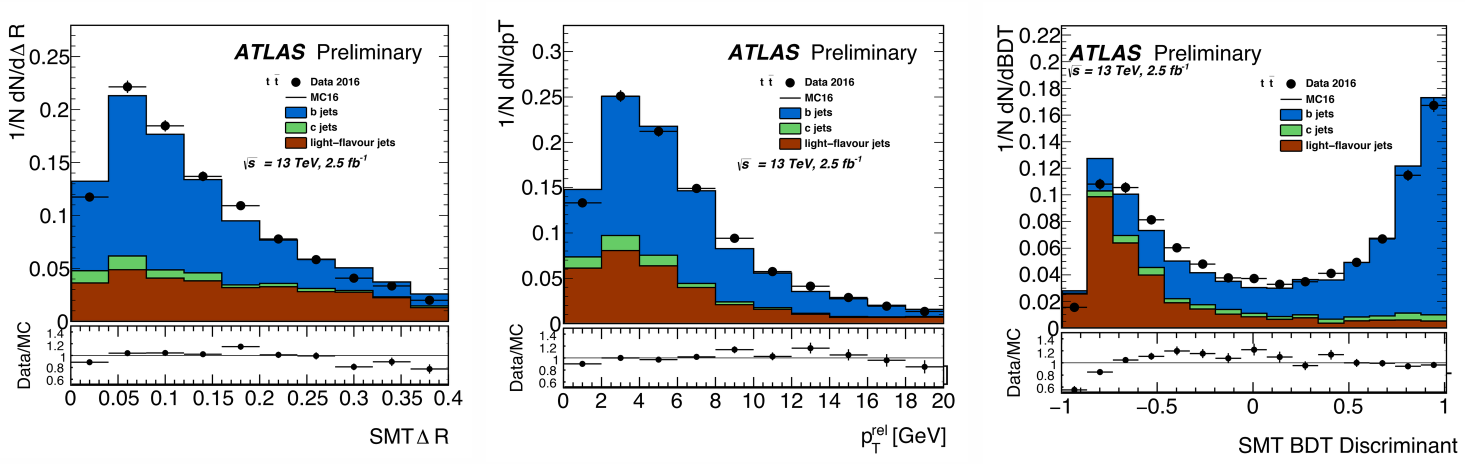
The combination of these six discriminating variables into a gradient BDT results in the SMT response; a cut at -0.15 on the final discriminant corresponds to an expected inclusive **b-jet** tagging efficiency of **10%** and an expected corresponding **light-jet** mistag efficiency of **0.2%** in $t\bar{t}$ events.

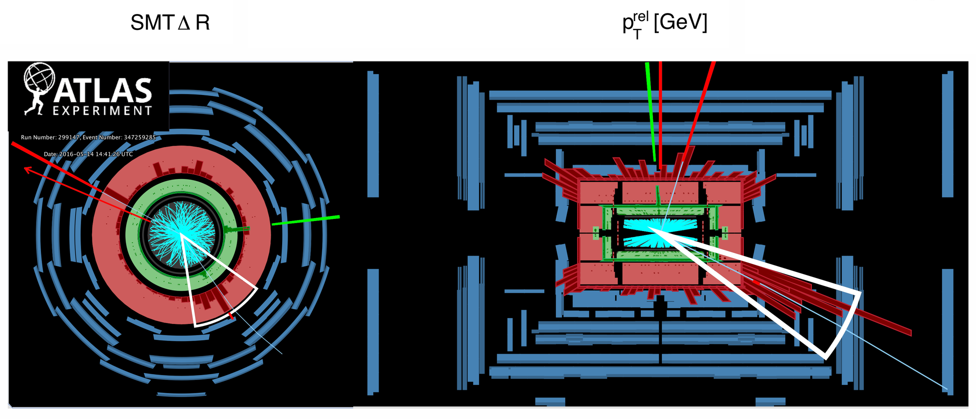
Implementation in MV2



The **MV2** b-tagging algorithm combines 24 input variables based on properties of impact parameter, secondary vertex and weak decay topology algorithms into a BDT. Among the variants of the MV2 taggers a new option has been developed, including in addition the SMT output ("**MV2Mu**"), and added for the 2017 data-taking campaign. The implementation of the SMT output itself as an additional input variable leads to a **20-25% improvement in light-jet rejection** in the 70-85% b-jet efficiency range (relevant for most of the physics analyses).

Modelling of Inputs and Output





Data/MC comparisons, not including any systematic uncertainty, are performed on a data set corresponding to a total integrated luminosity of **2.5 fb^{-1}** requiring:

- an opposite charge sign *e*-μ pair
- leading lepton p_T >25 (20) GeV for electrons (muons) and subleading lepton p_T > 15 GeV
- invariant mass of the dilepton pair > 10 GeV
- between two and seven jets passing the selection
- subleading jet is required to be identified as a b-jet using the MV2 discriminant at a working point with an identification efficiency of 77% and the other selected jets are used to study the flavour tagging algorithm response

In this region, enriched with $t\bar{t}$ and Wt events, an overall **good agreement** is observed between data and MC simulation for SMT input variables, here relative p_T and ΔR are shown, as well as for the final BDT discriminant.

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