Real-time flavour tagging selection in ATLAS

C. Bertella, on behalf of ATLAS Collaboration
Johannes Gutenberg University Mainz

http://atlas.ch

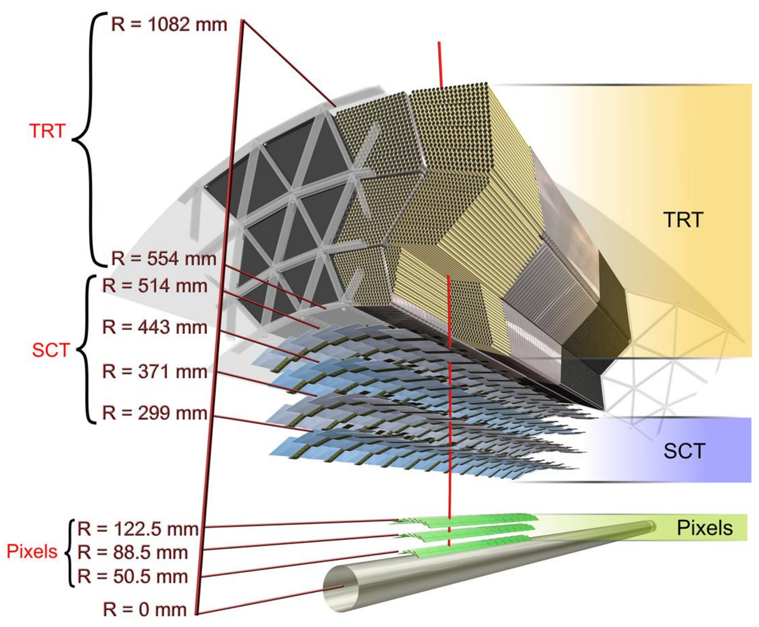
Physics Motivation

A trigger system able to perform real-time track reconstruction and identify jets originating from the b-quark hadronization allows to reject an important fraction of uninteresting background events, keeping most of the signal events. This ability is crucial for physics analyses characterized by the presence in the final state of high multiplicity of jets and b-jets, but without high p_T leptons. The overwhelming multi-jet background could be easily reduced by using real-time b-tagging while keeping the trigger rate under control. The most interesting physics signatures which could benefit from the b-jet trigger are $t\bar{t}$ signatures (fully hadronic or semileptonic with a τ lepton channels), VBF and associated producion (with a vector boson W/Z or with top quarks) of SM Higgs boson with $H \to b\bar{b}$ and Supersymmetric scenario ($bH \to b\bar{b}b$, associated production with a b-quark).

ATLAS detector

The ATLAS detector is a multi-purpose particle physics apparatus with a forward - backward symmetric cylindrical geometry, divided in different subsystems [1]

- Inner Detector (ID): reconstructs charged particle trajectories and measures their momentum in $|\text{eta}| < 2.5$. It is immersed in a magnetic field with $B = 2$ T. It has an excellent momentum resolution and reconstruction efficiency which together provide the capability to identify secondary vertices formed by the hadronization of b-quarks.
  - Insertable B-Layer (IBL): 448 pixel sensors of (ϕ, z) 50×250 μm^2 size. Located at $R = 3.2$ cm from the beam line
  - Pixel detector: 3 layers and 3 disks of silicon-based pixels of 50×400 μm^2 size
  - SemiConductor Tracker (SCT): 4 layers and 9 disks of stereo silicon strips of 80 μm size
  - Transition Radiation Tracker (TRT): straw drift tubes, tube diameter 4 mm

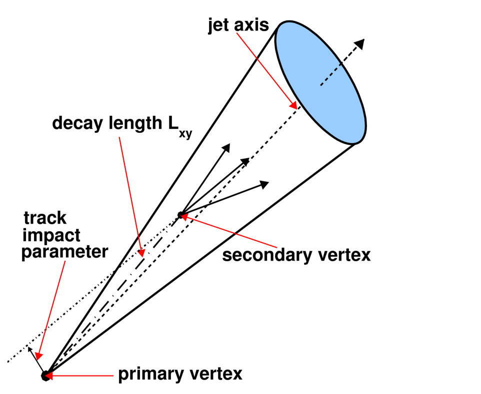


- Calorimeters: the electromagnetic calorimeter identifies electrons and photons and measures their energy, the hadronic calorimeter identifies jets formed by the hadronization of quarks
- Muon System: designed with two sets of detectors; one providing precision hit measurements (e.g. drift tubes) and the other fast trigger information (e.g. resistive plate chambers).

How b-tagging works

Jets originating from the hadronization of b-quarks ("b-jets") can be identified thanks to the peculiar production and decay properties of the b-hadrons.

1. b-hadrons have a relative long lifetime (~ 1.5 ps)
   - as a consequence they typically travel several millimeters before decaying
   - it results in a displaced vertex (SV) and high impact parameter d_0
2. high decay multiplicity
3. hard fraction function: most of the jet energy goes into the b-hadron decays



The impact parameter and the secodary/tertiary veterx information are used to discriminate between b-jets from gluon jets.

Run I vs Run II

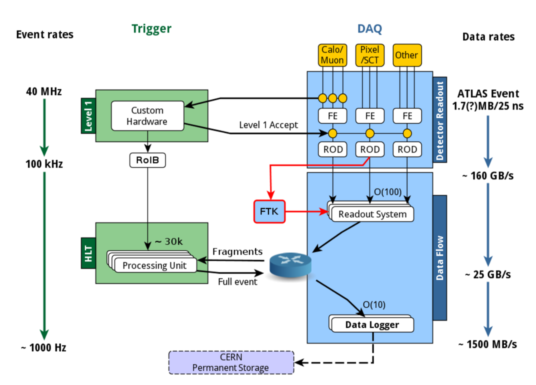
The trigger system in Run I was divided in 3 levels:

- Level1 (L1): hardware-based using custom-built electronics; used calorimeter and muon information with coarse granularity to select Region of Interest (RoI)
- Level2 (L2): processed data from all sub-detectors at full granularity but in RoIs identified by L1. Access to ID allows track reconstruction.
- Event Filter (EF): guided by the L2 results, it had the ability to access all sub-detector data at full granularity.

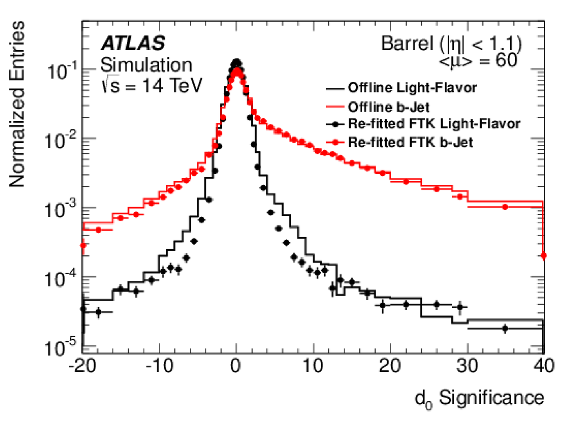
Jets are reconstructed at L1, L2 and EF. Tracking information for b-tagging is available at L2 and EF.

Major upgrades of the trigger system for Run II to cope with the increased centre-of-mass energy, increased luminosity and pile-up. A few highlights relevant to the flavour tagging triggers:

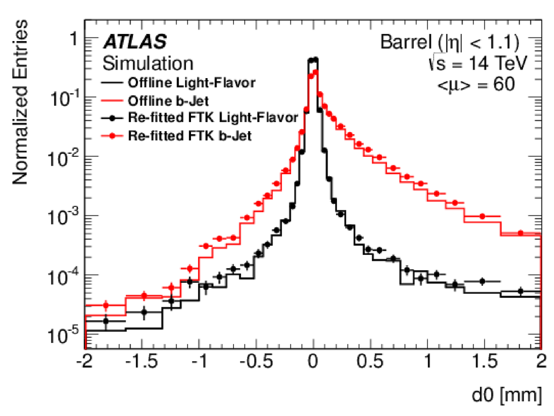
- New hardware component included in L1 Trigger: topological trigger processor (L1Topo) [2]
  - performs real-time event selection using algorithms based on topological variables, such as angular correlation among objects (ΔR, $\Delta\phi$), invariant mass, etc.
    - possible to match muon and jet already at L1



- Read out system upgrade
- L2 and EF farms merged in a unique HLT farm to match with network evolution; reduced latency since no packing and transporting information from L2 to EF is anymore needed
- Offline b-tagging algorithms directly at the HLT level
  - reconstruct the b- to c-hadron decay chain under the hypothesis that their vertices are approximately aligned on a single flight line (JetFitter)
  - implemet the same offline multi-variate techniques



- Adding Fast TracKer (FTK) [3]
  - receives all data from the pixel and silicon strip detectors
  - finds and reconstructs charged track candidates using pattern matching to pre-processed data
    - tracking information available after L1
    - track quality can be improved at HLT by refitting pre-existing patterns

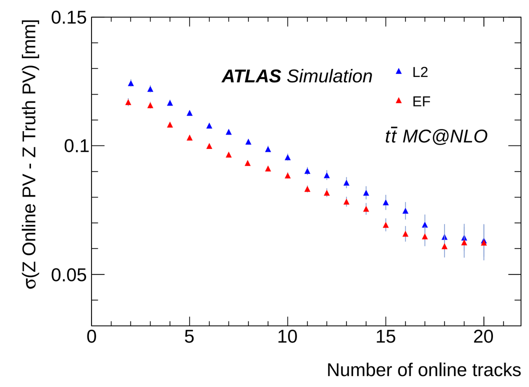


- **Installation due to start in autumn 2015, full $|\eta|$ coverage by the end of 2016**

Run I Performance

The correct reconstruction of the primary vertex is crucial for all the b-tagging algorithms:

- z position is measured for each bunch crossing using a sliding window algorithm that counts the number of tracks around each z value
- x and y coordinates of the PV are obtained by an average for several bunch crossings sharing the same running conditions
  - vertexing done in every RoI using all the tracks reconstructed in the RoI

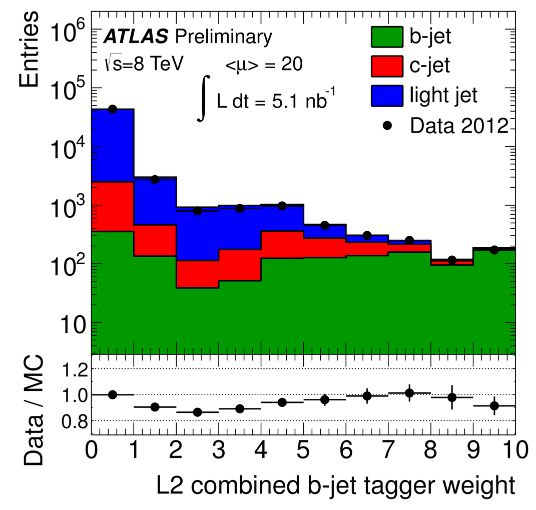


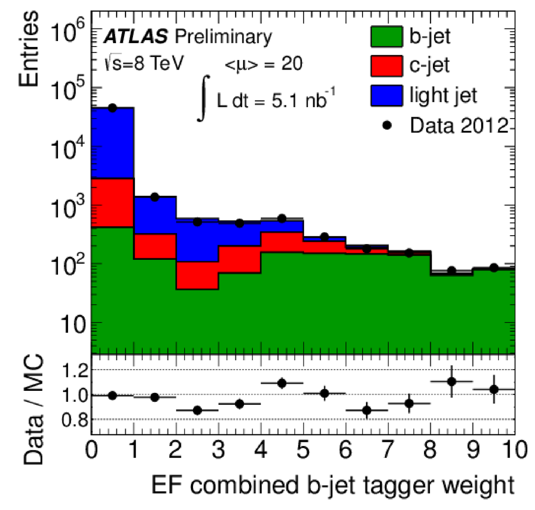
During the 2012 data taking a combination of two likelihood-based algorithms, one exploiting the impact parameter significance distribution (IP3D) and the other the secondary vertex properties (SV1), were used.

- IP3D tagger: uses a likelihood ratio technique

$$\mathcal{L}_R = \prod_{k=0}^{N_{trk}} \frac{\mathcal{L}_b(S_{xy,k}, S_{z,k})}{\mathcal{L}_{light}(S_{xy,k}, S_{z,k})}$$

  where $\mathcal{L}_b(S_{xy,k}, S_{z,k})$ and $\mathcal{L}_{light}(S_{xy,k}, S_{z,k})$ are the two-dimensional likelihood functions for b and light flavour derived using the transverse $(S_{xy,k})$ and longitudinal $(S_{xy,k})$ impact parameter significance.
- SV1 tagger: exploits 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 two-track vertices.





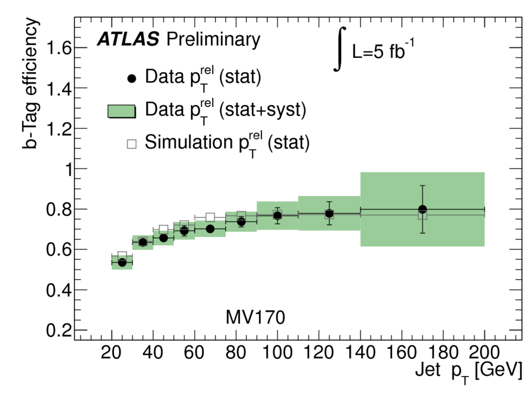
The jet combined tagger weight is calculated from prescaled L2 and EF tracks in L2 and EF jets with $p_T > 55$ GeV and $|\eta| < 2.5$ using for the combination of the impact parameter significance and the secondary vertex likelihood-based taggers.

Working Point	b-tag Efficiency	l-reject. L2	l-reject. EF
loose	60%	16	51
medium	50%	40	145
tight	40%	60	350

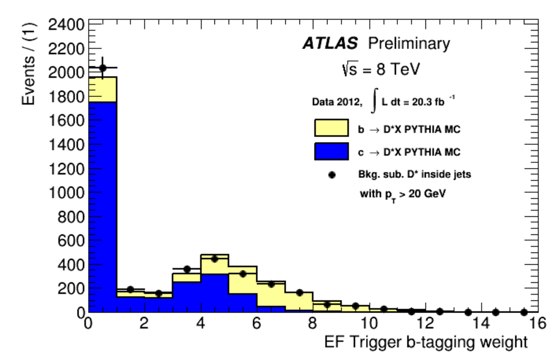
Calibration

To provide correct modeling of the tagging rates, scale factor are derived from data as a function of p_T and $|\eta|$ and then applied to simulation.

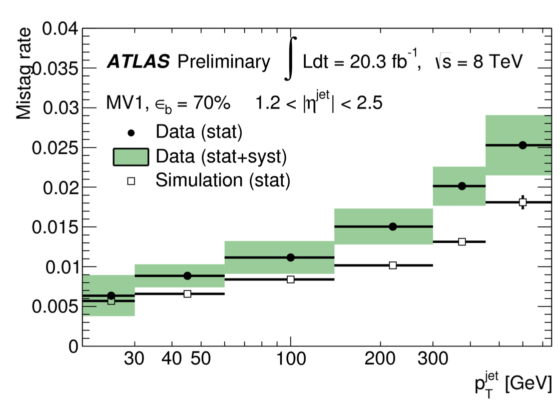
- b-tagging efficiency: the efficiency to tag a jet originating from a b-quark is computed using the p_T^{rel} method which exploits the different properties of muons embedded in b-jets and light-jets (muon-jets). The muon-jet sample offers the advantage of being enriched in heavy-flavour jets since 20% of b-hadrons decay into muons [4].



- c-tagging efficiency: the measurement makes use of the D^* method which exploits exclusive charm meson decays within a jet such as $D^{*+} \to D^0(\to K\pi^+)\pi^+$ to provide a sample enriched in charm content [5]



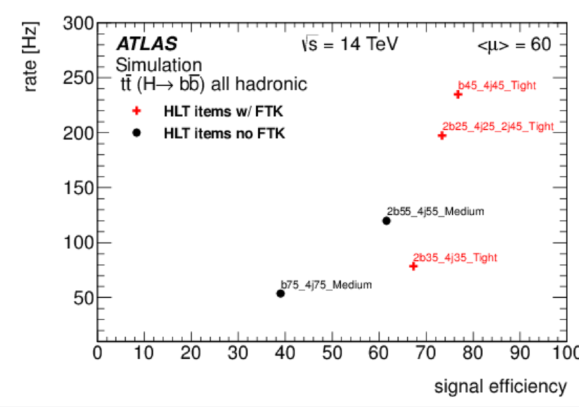
- mistag rate: the probability of mistakenly tagging a jet originating from a light flavour parton as a b-jet is estimated with the negative tag method which measures the negative tag rate by reverting the selections of the discriminant parameters (lifetime sign the impact parameter of the tracks and decay length significance of SV) [5]



b-tagging prospects at 13 TeV

The possibility to trigger on b-jets will be crucial for several analyses of Run II data. Thanks to the real time tagging many physics signals, contaminated from a high multi-jet production of light quarks and gluons, can be efficiently selected. For the LHC Run II, **more sophisticated b-jet triggers are implemented thanks to the merged HLT and the ability to use complex offline tagging algorithms directly at the HLT level**, such as multi-variate combinations of properties sensitive to the jet flavours. Using **common algorithms online and offline will improve the trigger performance, the correlation between online and offline** and simplify the calibration procedure.

In Run II, the FTK will be incorporated into the ATLAS trigger system, providing the possibility to find and reconstruct tracks in the ID for events that satisfy the L1 trigger. This opens up the possibility of performing b-tagging on multi-jet triggers at a higher rate than currently possible and therefore be sensitive to trigger on lower momentum b-quarks than previously possible.



References

[1] JINST 3 S08003. [2] arXiv:1406.4316. [3] CERN-LHCC-2013-007. [4] ATLAS-CONF-2012-43. [5] ATLAS-CONF-2014-046.