Real-time flavor tagging selection in ATLAS

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Physics motivations

The ATLAS experiment employs a sophisticated trigger system, capable of real-time track reconstruction to reject most of the events containing uninteresting background collisions while preserving as much as possible the interesting physics signals.

Triggering on jets originating from the hadronization of b-quarks, b-jets, allows ATLAS to collect interesting events with multi-jet topology, while rejecting most of the large background. This is crucial for many physics analyses characterized by several b-jets in the final state and by the absence of high p_T leptons.

By using this class of trigger, the large multi-jet background can be substantially reduced without the need of increasing the jet p_T thresholds to keep the rate to sustainable values. b-jet triggers are essential for physics analysis which have large jet multiplicity and b-quarks in the final state, such as : fully hadronic tt, tt with hadronic tau in the final state [1]; VBF H (H→bb); fully hadronic ttH; supersymmetric bH->bbb.

[1]: Eur. Phys. J. C, 73 3 (2013) 2328
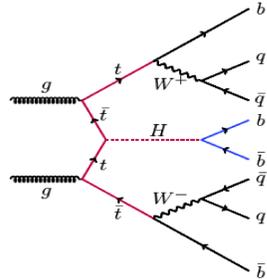
The ATLAS detector

The ATLAS detector is a multi-purpose particle physics apparatus with a forward–backward symmetric cylindrical geometry, divided into different subsystems.

Inner Detector (ID): immersed in a magnetic field with B = 2 T, it reconstructs charged particle trajectories and measures their momentum. It has an acceptance of $|\eta|$ < 2.5 and has excellent performance in the momentum resolution and reconstruction efficiency together with capability to identify secondary vertices formed by the hadronization of b-quarks. It is composed of different subsystems:

IBL:
Ready in 2015; 448 pixel sensors; pixel size (ϕ, z) 50 x 250 μm^2.
Located at R = 3.2 cm from the beam line.

Pixel detector:
3 layers and 3 disks of silicon-based pixels ; pixel size 50 x 400 μm^2.
Spatial resolution Rϕ = 16 μm, z = 66 μm.

**SemiConductor Tracker** (SCT)
4 layers and 9 disks of stereo silicon strips ; strip size 80 μm.

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.

The Muon System: consists of detectors providing precision hit measurements (e.g. drift tubes) and fast trigger information (e.g. resistive plate chambers).
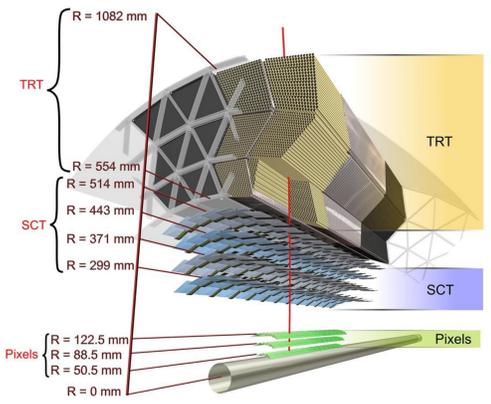
ATLAS Inner Detector layout.
IBL not yet incorporated.

Trigger evolution

The ATLAS trigger system consist of three levels:

Level 1 (L1) :
It is a hardware trigger implemented in custom-built electronics. It uses the calorimeters and muon spectrometer with coarse granularity to select Regions of Interest (RoI), which are analysed by the following subsequent levels.
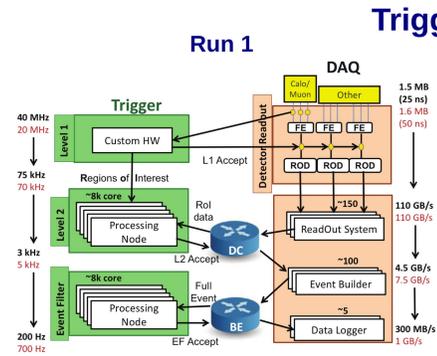
Level 2 (L2) :
It processes data from all sub-detectors at full granularity but only in limited detector RoIs seeded by L1. Access to ID allows track reconstruction.
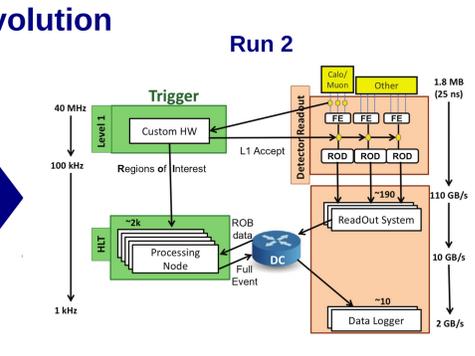
Event filter (EF) :
Guided by L2 result it has the ability to access all sub-detectors data at full granularity.

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

Run 1

Run 2

Major updates:
- L1 Calorimeter Trigger, inclusion of new algorithms for event selection based on topological variables, i.e. depending on angular correlation between objects, like ΔR and invariant mass.
- Read Out System upgrade to sustain increased rate.
- L2, Event Builder & EF farms become a unique HLT farm to match with network evolution and have automatically balanced distribution of computing resources.
- Reduced latency since there is no need to pack and transport informations of the accepted events from L2 to the EF.
- Addition of Fast TracKer ID hardware-based tracking finding after L1. It will be installed in late 2015.

The upgrade provides ATLAS with a robust configuration for higher luminosity running, enabling the experiment to take full advantage of the accelerator upgrades.

How b-tagging works

The identification of jets originating from the hadronization of b-quarks (b-tagging) is possible thanks to the peculiar properties of b-quark decays. The relatively long lifetime of B-hadrons – of the order of 1.5 ps – allows them to travel several millimetres before decaying.
Jets originating from b-mesons decay will be prone to be originated from a Secondary Vertex (SV), separated from the primary vertex where the hard process occurred. For these reasons tracks within a b-jet tend to have larger impact parameter (d_0) than the ones coming from the primary vertex.

Combination of secondary vertex properties and tracks informations has been proved to be an excellent discriminator between jets coming from the hadronization of b quarks and the ones coming from light quarks or gluons.
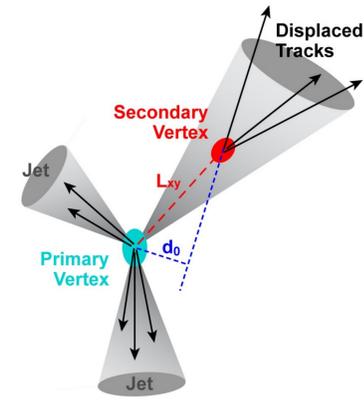
ATLAS online b-tagging algorithms at 8 TeV

A combination of two likelihood-based algorithms, exploiting the impact parameter significance distribution (IP3D) and the secondary vertex properties (SV1) were used during the 2012 data taking campaign for online b-tagging.
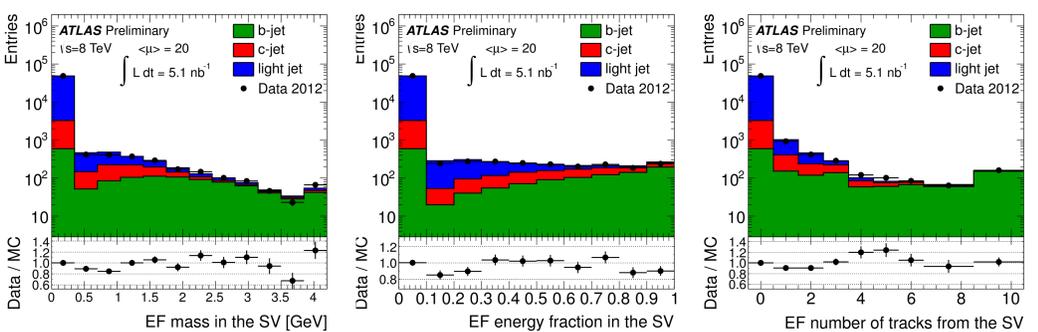
IP3D
The IP3D tagging algorithm uses a likelihood ratio technique in which input variables are compared to pre-defined distributions for both the b- and light jet hypotheses, obtained from Monte Carlo simulation. The discriminating variables used is the 2D distribution of transverse and longitudinal impact parameter significance $d_0/\sigma(d_0)$ of tracks within jets.
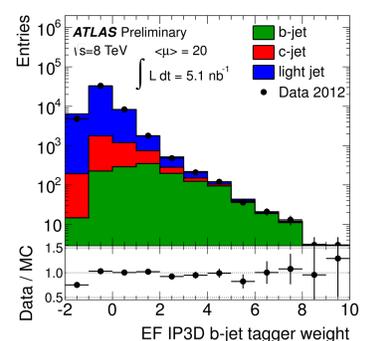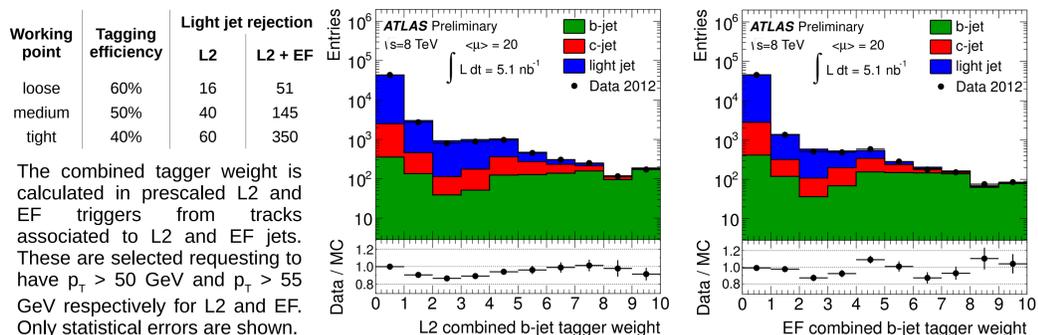
SV1
SV1 exploits secondary vertex properties: the invariant mass of all tracks associated to the vertex, the ratio of the sum of the energies of the tracks in the vertex to the sum of the energies of all tracks in the jet, and the number of tracks associated to the SV. It is different from the offline version that uses, instead of the latter variable, the number of two track vertices that can be formed with the tracks in the jet. In the figures shown the peaks at zero correspond to jets in which no secondary vertex could be reconstructed.

Thanks to the likelihood ratio method used for IP3D and SV1, the algorithms can be easily combined, the result is a combined tagger. The plots below show the jet weight distribution for this tagger, the table show the tagging efficiency and the light jet rejection for the used working points.

Working point	Tagging efficiency	Light jet rejection	
		L2	L2 + EF
loose	60%	16	51
medium	50%	41	145
tight	40%	60	350

The combined tagger weight is calculated in prescaled L2 and EF triggers from tracks associated to L2 and EF jets. These are selected requesting to have p_T > 50 GeV and p_T > 55 GeV respectively for L2 and EF. Only statistical errors are shown.

Calibrations

In order for online b-tagging to be used in physics analyses it is necessary to measure the difference in the performance between data and Monte Carlo simulation. In particular for the **b-tagging efficiency**, i.e., the efficiency with which a jet originating from a b-quark is tagged by a b-tagging algorithm, **c-tagging efficiency** and **mistag rate**, i.e., the probabilities of mistakenly b-tagging a jet originating from a c-quark or a light-flavour parton respectively. Calibration results are expressed in the form of p_T-binned scale factors to be applied to simulation to match the tagging rate observed in data.

B-tagging efficiency→p_T^{rel} method: This calibration technique exploits the different properties of muons embedded in b-jets and light-jets (muon-jets). The muon-jet sample offers advantage of being enriched in heavy flavour jets since ~20% of B-mesons decay into muons [1].

C-tagging efficiency→D* method: The fractional abundance of jets can be measured from data reconstructing exclusive charm meson decays within a jet, such as $D^{*+}→D^0(→K^- \pi^+)\pi^+$ and charge conjugated [2].

Mistag rate→Negative tag method: Light-flavour jets are mistakenly tagged as b-jets mainly because of the finite resolution of the ID and the presence of tracks stemming from displaced vertices from long-lived particles or material interactions. The negative tag rate is computed defining a negative version of the tagging algorithm which internally reverses the selections of the discriminant parameters [3].

[1]: ATLAS-CONF-2012-43, [2]: ATLAS-CONF-2012-39, [3]: ATLAS-CONF-2012-40
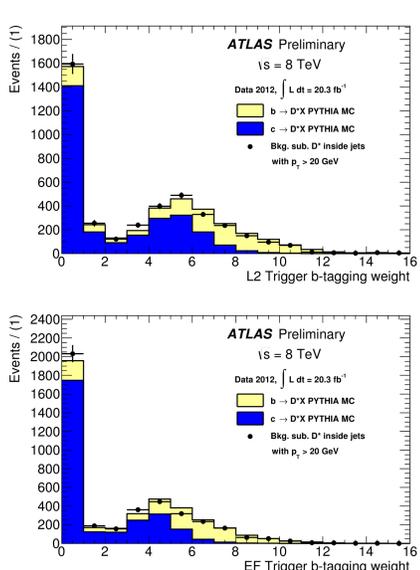
In the plots above it is shown a comparison between data and Monte Carlo simulation of the combined weight at L2 and EF in background subtracted D*+ events.

Prospects for Run 2

Triggering on b-jets is crucial for many analyses in the ATLAS run 2 physics programme. Given the large multi-jets production of light quarks and gluons, it is important that the ATLAS trigger efficiently select jets from b-quarks while providing a large rejection factor against light jets. ATLAS used ever-improving b-tagging algorithms at the trigger level in the data taking in 2011 and 2012 and calibrated these for data analysis. For the LHC Run II data, more advanced b-jet triggers will be used thanks to the merged HLT and the ability to use complex offline b-tagging algorithms directly to the HLT level.

In Run 2 the Fast TracKer (FTK), an electronics system that rapidly finds and reconstructs tracks in the inner-detector pixel and SCT layers for every event that passes the L1 trigger, will also be incorporated inside the ATLAS trigger system. Part of FTK will be installed in late 2015, it will give full η coverage by the end of 2016. FTK tracks, freed from the CPU constraints of L2 tracking, will be an important tool box for the ATLAS HLT, allowing it to have improved event selection. This opens up the possibility of doing b-tagging on multi-jet triggers at a higher rate than currently possible and could potentially give the ATLAS trigger sensitivity to models with lower momentum b-quarks than were previously accessible.