Trigger studies for W'→tb in the hadronic final state at ATLAS

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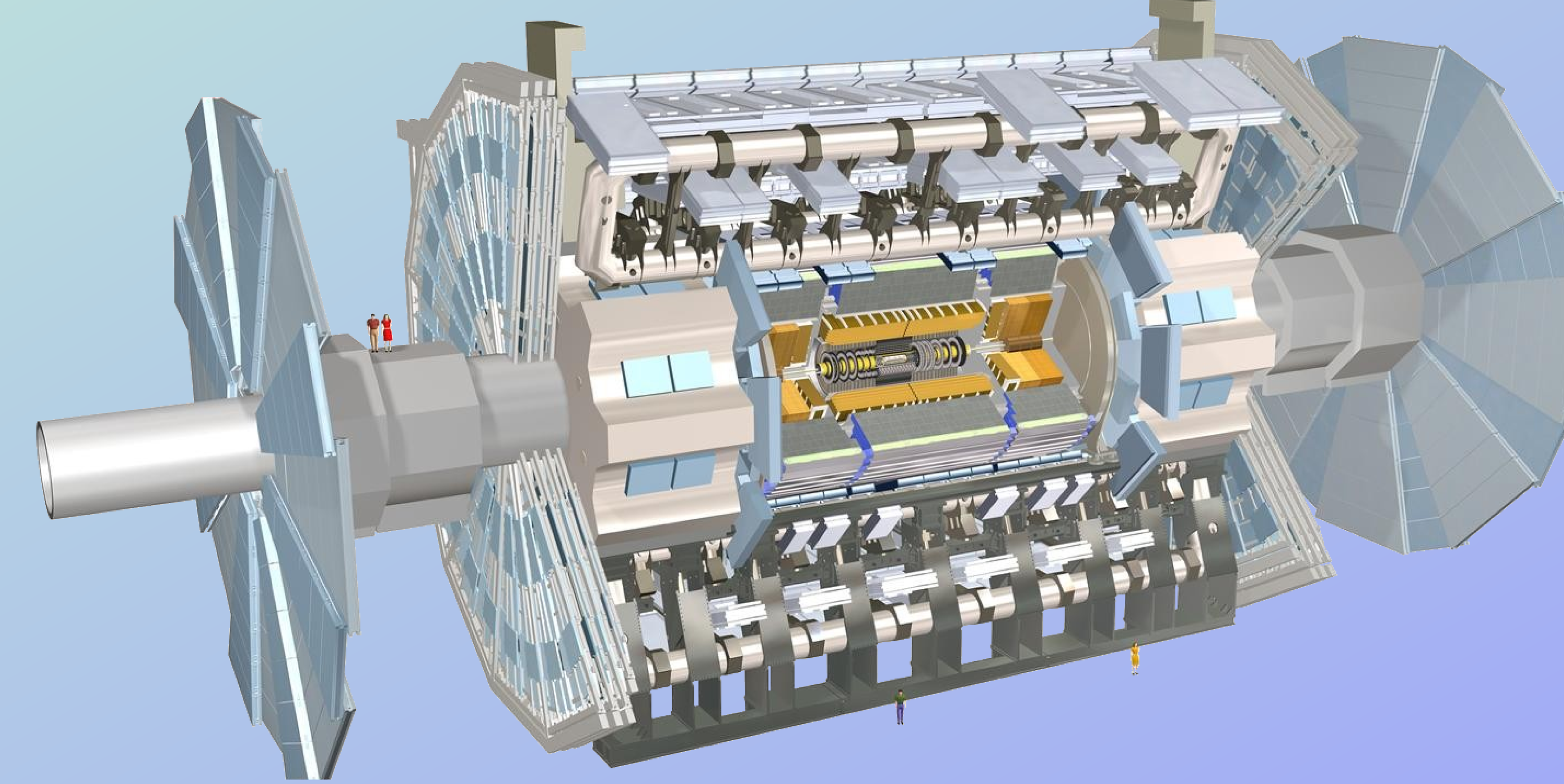
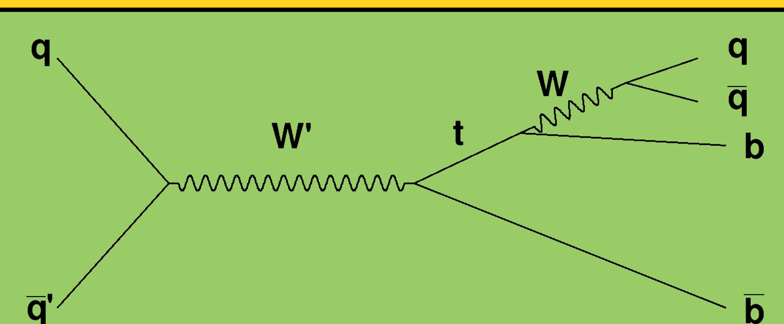
Abstract

The W' is a new heavy gauge boson predicted to exist by many "Beyond the Standard Model" theories. The search for W'→tb (W' into a top quark and a bottom quark) in the hadronic final state will be carried out by analyzing data gathered by the ATLAS detector during the Large Hadron Collider's 13 TeV run.

ATLAS uses a trigger system to select interesting events – ones more likely to represent new physics – from the overwhelming number of uninteresting ones. The W'→tb search will make use of these triggers, but the proposed triggers for the analysis need to be checked to ensure that they (1) do not introduce bias into the analysis method and (2) maintain or improve the range of energies where W'→tb events can be accepted with low systematic uncertainty. This trigger study uses QCD background data generated by a Monte Carlo simulation to investigate how much the choice of triggers in the W'→tb analysis effects systematic uncertainty in the estimation of contribution from background events in the analysis, namely from soft QCD multijet events.

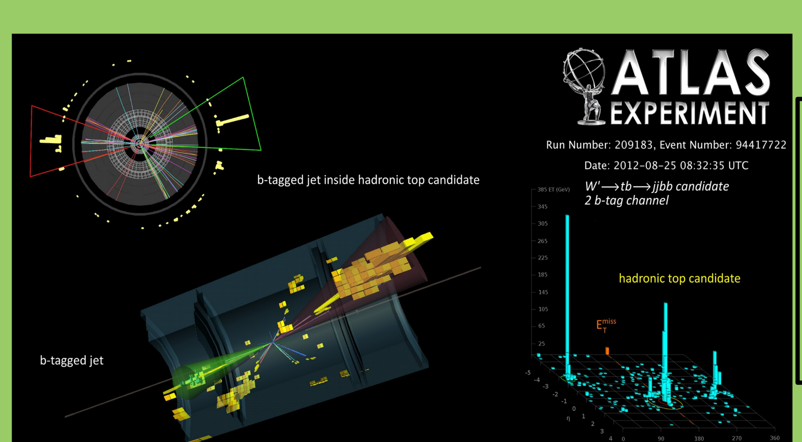


W'→tb Events



Feynman diagram representing the hadronic final state of W'→tb.

W' particles produced during proton-proton interactions inside ATLAS would have far too short a lifetime to be directly detected. The top and bottom quarks produced by the W' decay, too, would not last long enough to be detected. Instead, the roughly cone-shaped spray of particles (a "hadronic jet") that results from their hadronization would be detected in ATLAS's hadronic calorimeter. A W'→tb candidate event recorded by ATLAS during LHC run 1 at 8 TeV is illustrated below.



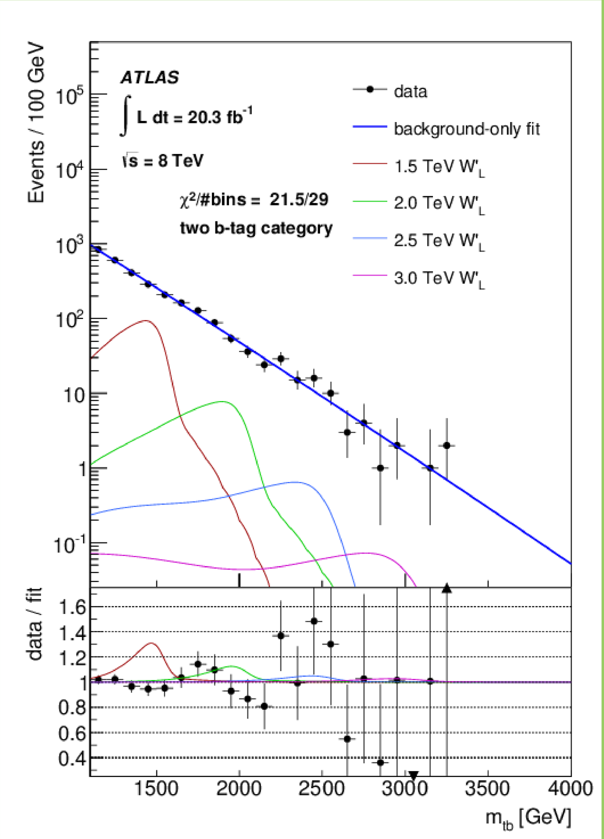
A candidate event for W'→tb: a top-tagged large radius hadronic jet and a b-tagged small radius hadronic jet with a large angle of separation between them.

W'→tb events need to be identified from among other dijet events. Two processes dominate the background in the W'→tb analysis: soft QCD multijet production and top-antitop production. Soft QCD processes are expected to contribute most of the background, about 99%. The second most contributing process, Top-antitop ($t\bar{t}$) production, is expected to contribute about 1%. Other processes are expected to contribute less than 1% to the background, making them insignificant. The ratio of the cross-sections (related to probability of the event happening) of background events and W'→tb events is about 10^6. By only considering higher energy events and events where the two jets are properly flavor-tagged (one is a t-jet and the other is a b-jet), most background events are excluded and this ratio is predicted to decrease to just 10^1.

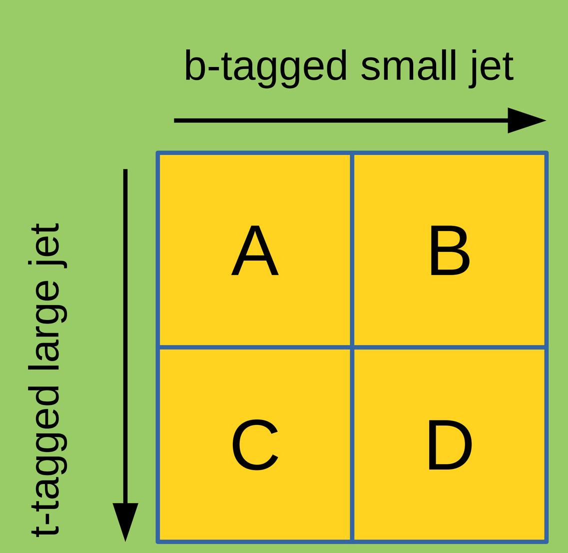
W'→tb Analysis

ATLAS generates so much data that it is only feasible to keep about 0.00001% of it. Bunch crossings happen in the detector at a rate of 40 MHz (once per 25 ns). The custom hardware that initially processes the data outputs at a rate of 100 kHz to computer farms that further process the data and save it at a rate of 600 Hz for later offline analysis. These initial processing steps make up ATLAS's trigger system, which is designed to reduce the rate that high-rate processes are recorded to make more room in the limited bandwidth for rarer processes of interest.

The ATLAS trigger system will be used in the W'→tb analysis to improve the ratio of signal events (W'→tb) to background events. The importance of reducing background can be seen here. More restrictive triggers will exclude more background events from the analysis, but move the x-axis of this plot to the right. This results in increased sensitivity to W' particles in general, but complete insensitivity to ones at lower mass.



A comparison of predicted W' signal to LHC run 1 data fitted to a background-only prediction. The absence of "bumps" in the data above the red and green curves indicates that W' particles were not observed at these energies. At higher energies, the background dominates the blue and pink curves so much that it is impossible to draw conclusions.



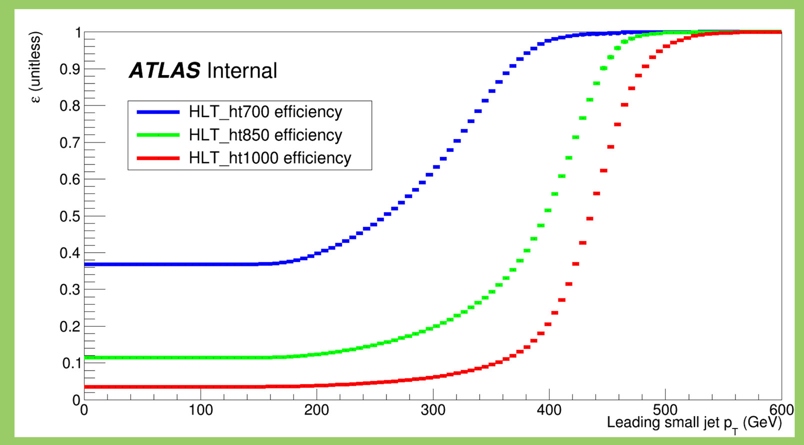
A data-driven method called the ABCD method is used to estimate the contribution of QCD multijet events to the total background. Requiring the event's large jet to fail top-tagging and/or the small jet to fail b-tagging allows the assignment of the event into one of three control regions: A, B, or C. These control regions are dominated by background multijet events. The orthogonality of the control regions allows them to be used to estimate the contribution of background multijet events in the signal region, D.

Trigger Study

This trigger study investigates how the choice of trigger affects the systematic uncertainty for contribution of background events in the W'→tb search. Soft QCD dijet events for this trigger study are provided by a Monte Carlo simulation. We investigated single jet p_T triggers (p_T is the component of the jet's momentum perpendicular to the LHC beam line), multijet p_T triggers, and H_T triggers ($H_T = \Sigma p_T$ for all jets in an event).

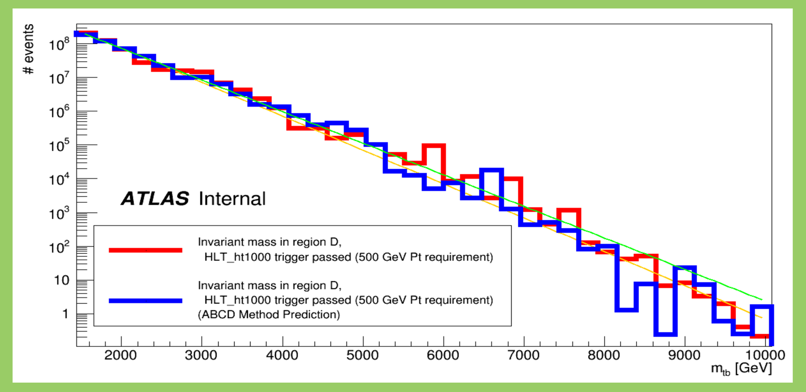
The triggers should cut at a precise value, rejecting events below that value and accepting events above that value. There is, however, some inefficiency that can be seen in the trigger's efficiency curve, or "turn-on" curve. These curves take the shape of a skewed cumulative distribution function.

Sample "turn-on" curves for the triggers HLT_ht700, HLT_ht850, and HLT_ht1000 showing the triggers' efficiencies as a function of the highest small jet p_T in each event. At high values of leading p_T 100% of events pass these triggers, and at low values only a fraction pass.



We generated these turn-on curves for each trigger investigated in the study. The points on the curve where 95% or more of events pass the trigger is taken to be the "trigger plateau". In this region, since the trigger's behavior is stable, we can investigate background contribution without introducing bias or instability from the trigger.

We used the start of the trigger plateau region for interesting triggers as a low-end jet p_T cut, and then classified the events passing this cut with the ABCD method. The invariant mass of each event's dijet system (m_{tb}) in the control regions is used to predict the shape of the dijet invariant mass distribution in region D, the signal region. This prediction is compared to the actual distribution for events classified in region D, and the two distributions are fitted to decaying exponential functions. The ABCD method does well in predicting the shape of the background distribution where these distributions are close, meaning the systematic uncertainty of the background estimation is reduced significantly at these values.



A sample dijet invariant mass distribution comparing the distribution in the signal region with the ABCD method's prediction. The ABCD method seems to have low systematic uncertainty for dijet systems with mass between 1500 GeV and 10000 GeV when this particular trigger (HLT_ht1000) is used.

References

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ATLAS image retrieved from *http://atlas.ch/photos/*
W'→tb event display image and background vs. signal plot from *https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/EXOT-2013-14/*

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