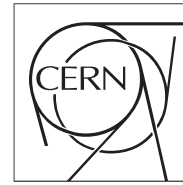


The Compact Muon Solenoid Experiment
Conference Report

Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland



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Commissioning ATLAS and CMS with top quarks

Bobby Samir Acharya, Francesca Cavallari, Gennaro Corcella, Riccardo Di Sipio, Giovanni Petrucciani on the behalf of the ATLAS and CMS collaborations

Abstract

The large $t\bar{t}$ production cross-section at the LHC suggests the use of top quark decays to calibrate several critical parts of the detectors, such as the trigger system, the jet energy scale and b-tagging.

The ATLAS and CMS experiments will both take advantage of these facts and a brief review of their capabilities is given.

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1 Introduction

Events in which top-quark pairs are produced will be extremely important at the LHC, as they will provide a unique environment to study physics within the Standard Model and beyond [1]. Final states in $t\bar{t}$ events are classified in three categories, according to the W -decay mode in top decay $t \rightarrow bW$: fully hadronic, semileptonic or fully leptonic. Semileptonic $t\bar{t}$ decays produce complex signatures within the detector, involving missing transverse energy, charged leptons, light-particle jets and b -jets. Therefore, in order to study these events accurately at the LHC, the understanding of all the parts of the detectors is mandatory. In particular, the following should be mastered:

- Trigger system;
- Lepton and jet reconstruction;
- Calculation of missing transverse energy;
- b -tagging.

Conversely, the top quark is an excellent instrument, thanks to the large $t\bar{t}$ cross-section at the LHC, $\sigma(t\bar{t}) \sim 830$ pb, more than 100 times larger than at the Tevatron accelerator [2]. Semileptonic $t\bar{t}$ events link all these items together and can therefore be used to make what is commonly referred to as an *in-situ* calibration.

2 Triggers

At the LHC collisions will happen with a frequency of up to 40 MHz, and this number has to be compared with the capabilities of the ATLAS and CMS mass storage systems of about 200 Hz. So, the trigger system of ATLAS and CMS has been designed to select one event out of 10 millions, when running at the highest design luminosity.

The ATLAS and CMS trigger systems both have a hardware-based level 1 and a software-based high-level trigger[3, 4]. Level 1 makes use of the muon detectors and calorimeters in order to identify particles, while higher levels perform a more refined reconstruction. In order to choose interesting events and reduce the output rate, the two experiments designed their trigger systems in two different ways.

ATLAS makes use of *Regions of Interest* (RoI), a technique that gives access to high-granularity information only for the regions flagged as interesting by the Level 1 Trigger. The CMS High Level Trigger can access the full detector readout, but it performs only the minimal amount of reconstruction needed to determine if an event has to be accepted or dropped. At the end of the process, both ATLAS and CMS trigger systems will write data with a frequency of about 100 Hz and a latency of few μs .

In the first days of data-taking, close attention will be paid to the study of the single-lepton triggers. In fact, a large number of important processes involve the production of at least one isolated charged lepton, and leptonic decays of top quarks are amongst these. Fig. 1 shows the efficiency of the level-1 single-lepton triggers in $t\bar{t}$ events, calculated with respect to the offline reconstruction.

Moreover, semileptonic events are triggered from jet triggers, too, giving the possibility to measure directly the efficiency of the leptonic triggers. Thus, the very large cross section of $t\bar{t}$ events can be successfully exploited to calibrate the triggers.

For example, a sample of events can be collected according to the offline selection defined in Tab. 1. Then, a sub-sample is extracted, containing only events that fired the single-lepton trigger. From this sub-sample, one can easily calculate the fraction of $t\bar{t}$ events that fired the jet trigger. This technique can be subsequently applied, e.g., to several jet triggers for each lepton trigger, leading to a very good determination of combined trigger efficiencies [4].

Top-quark production is also suitable to study other triggers, such as double-lepton (for full-leptonic decays), jet and missing- E_T triggers. In fact, two leptons give a very clean signature for triggering, albeit limited in statistics at the very beginning.

With early data, the fully hadronic channel is extremely challenging triggerwise, due to the large QCD background. Reasonably, this channel will be studied accurately in a subsequent phase of the experiment.

ATLAS and CMS will also estimate the single-lepton trigger efficiency as a function of its momentum from processes which do not involve top quarks, such as $Z \rightarrow ee / \mu\mu$. However, since the jet energy scale and underlying

event might be different between $Z \rightarrow ee$ and $t\bar{t}$ processes, it is clearly preferable to calculate efficiencies for $t\bar{t}$ events by using $t\bar{t}$ events themselves.

3 Jet Energy Scale

The cone algorithm for jet reconstruction, with a cone radius $R = 0.4$ or 0.5 , is commonly used both in ATLAS and CMS, since it provides a good compromise between energy reconstruction and angular resolution [5].

Due to a HCAL resolution lower than ATLAS, CMS found better results using the *particle flow*, a useful technique when dealing with low-granularity calorimeters. Preliminary studies show an overall efficiency similar to that of ATLAS.

The (mis)calibration of the Jet Energy Scale (JES) appears as an important source of systematic uncertainty on M_W and M_t . The *a priori* knowledge of jet-energy calibration is about 10%. The goal of 1 GeV error on M_t requires understanding the JES to 1%. The Jet Energy Scale can be evaluated using the method of p_T -balance applied to Z/γ +jets events. Here, the well reconstructed Z/γ transverse momentum can be balanced against the jets in the events, allowing a p_T -dependent jet calibration. These processes are also useful for the b -jet energy scale, when jets are tagged as b -jets.

However, as stated before, it would be better to measure the JES for $t\bar{t}$ events by means of $t\bar{t}$ events themselves, at least for two main reasons:

- $t\bar{t}$ selection cuts can lead to JES different from that of Z/γ +jets;
- the underlying event (UE) may be different for the two processes.

To this end one could exploit the $t \rightarrow Wb \rightarrow jjb$ decay chain, since it gives an identifiable $W \rightarrow jj$ sample (*in-situ* calibration). The jj invariant mass should of course yield the well-known W -boson mass.

ATLAS will determine the JES by studying the reconstructed M_W after the offline selection (as defined in Tab 2). Its impact, after varying the reconstructed jet energies by $\pm 1\%$, has been evaluated. Unfortunately, offline selection introduces a bias caused by the p_T -cut which is important near threshold [5]. To handle this problem, fitting techniques are applied to determine the jet-energy-scale factors as a function of the jet energy and pseudorapidity η .

Starting from the same principles, CMS will calculate M_W by combining the two jets. The light-quark jet energy is scaled by a global correction factor ΔC , chosen to fit the reconstructed W mass within the world average, as shown in Fig. 2. Studies show that the main sources of systematic uncertainty on ΔC are the pile-up and b -tag efficiency [6]. More refined techniques are under study, based on a kinematic fit of M_{bjj} in $t \rightarrow Wb \rightarrow jjb$ decays, so that one can also measure the b -JES.

4 b -tagging

Identification of b -jets is crucial in many analyses at the LHC, such as the searches for the Higgs boson, supersymmetry and other New Physics scenarios. Thus, to calibrate b -tagging algorithms, one would like to isolate a sample of b -jets as pure as possible.

Again, the large $t\bar{t}$ cross section offers the possibility of an *in-situ* calibration with several advantages, since almost every $t\bar{t}$ event contains two b -quarks. In fact, semileptonic $t\bar{t}$ events are identifiable *without b -tagging* and hence give a handle on b -tagging mechanisms [7]. With an integrated luminosity of 100/pb, several hundred events are expected. To gain more statistics, di-jet events could be used but for b -tagging calibration. However the b -tagging efficiency, - like the JES - is sample and analysis dependent. For this reason a measurement of the efficiency from top events themselves is preferable.

The default ATLAS b -tagger uses a likelihood algorithm weight w , constructed from the impact parameter and the secondary-vertex taggers. Choosing a threshold on the weight translates into an efficiency to recognize correctly the b -jets (ϵ_b) and to reject the jets originated from the lighter quarks ($R_{l-jets} = 1/\epsilon_{l-jets}$). As shown in Fig. 3, w is large for b -jets and low for light-jets, proving itself as a good quantity to distinguish b -jets from light-jets. For example, setting the cut $w > 6$, an overall efficiency $\epsilon_b = 63\%$ and light-jet rejection $R_{l-jets} = 250$ can be achieved [7].

In a recent CMS study an attempt was made to evaluate the b -tagging efficiency directly from data. In this study, a simple algorithm was used, mainly based on *track counting* and *track probability*. One can associate to each track inside the jet an impact parameter and a secondary vertex location. If these values are greater than their thresholds, the track is ‘counted’. Then, the jet is b -tagged if it contains more ‘counted’ tracks than a minimum. Tagging one of the b -jets hardly allows to have a rather pure b -jets sample from the other top and evaluate the performance of the b -tagging. However, this study shows that with 1fb^{-1} one can reach an uncertainty on the b -tagging efficiency of $\sim 5\%$.

Other strategies, such as the *soft lepton* method, are also under study.

Assuming that each selected event actually contains two b -jets, ϵ_b can be measured from the data themselves, counting the number of tagged jets as b -jets. To take into account mistagged events and backgrounds, a more refined likelihood function can be written, with ϵ_b and $R_{l\text{-jets}}$ as parameters.

Overall, the main sources of systematic uncertainty are light-jet rejection, JES, W +jets background contamination, and the uncertainty on the measurement of the top mass.

5 Conclusions

Top-quark events and, in particular, those with semileptonic decays, will be a powerful source of data for the measurement of trigger efficiencies, jet energy scale and b -tagging performance. Both ATLAS and CMS are developing methods and algorithms to capitalise on this opportunity.

$t\bar{t}$ events, especially semileptonic, allow one to trigger on both leptons and jets independently, thereby allowing the possibility to measure trigger efficiencies.

Moreover, the presence of W -bosons, light jets and b -jets in $t\bar{t}$ events, allows one to measure the JES for both light jets and b -jets. The goal of measuring the top-quark mass with an uncertainty of 1 GeV requires a 1% error on the JES, which can be achieved with at least 1/fb of data.

Since almost every decaying top quark produces a b quark, $t\bar{t}$ events supply a pure sample of b -jets, which could be used to calibrate the b -taggers. Much work is in progress to develop these techniques in preparation for the first data-taking.

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Isolated e or μ with $p_T > 20$ GeV
≥ 4 jets with $p_T > 40$ GeV
2 b -jets
$E_T^{\text{miss}} > 20$ GeV

Table 1: Offline selection cuts for semileptonic decays.

Isolated e or μ with $p_T > 20$ GeV
 ≥ 4 jets with $p_T > 40$ GeV
 2 b -jets
 $E_T^{\text{miss}} > 20$ GeV
 $M_{jjj} \sim M_t$

Table 2: Offline selection cuts for selecting a sample suitable for jet energy scale determination.

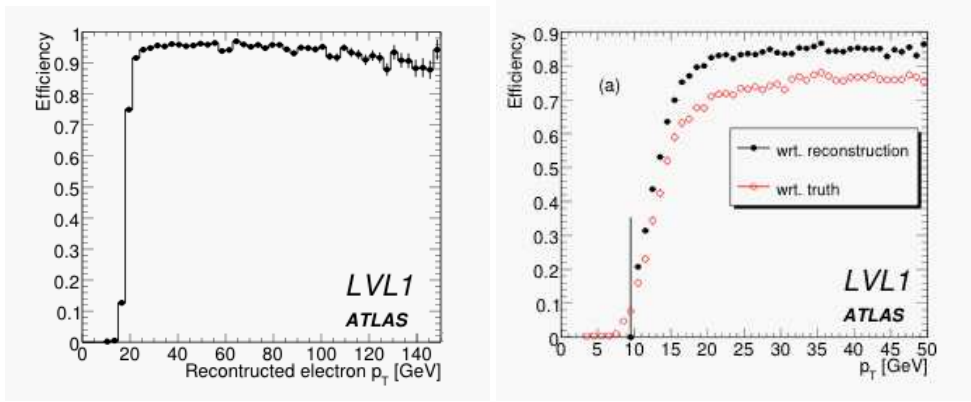


Figure 1: ATLAS Level-1 efficiencies for one-lepton trigger menu e251 (left) and mu20i (right). Efficiencies are calculated with respect to the offline reconstruction.

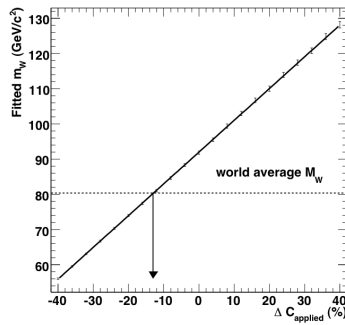


Figure 2: CMS will calculate JES by fitting the reconstructed M_W to the world average. Corrections are applied by multiplying M_W^{reco} by a constant term ΔC .

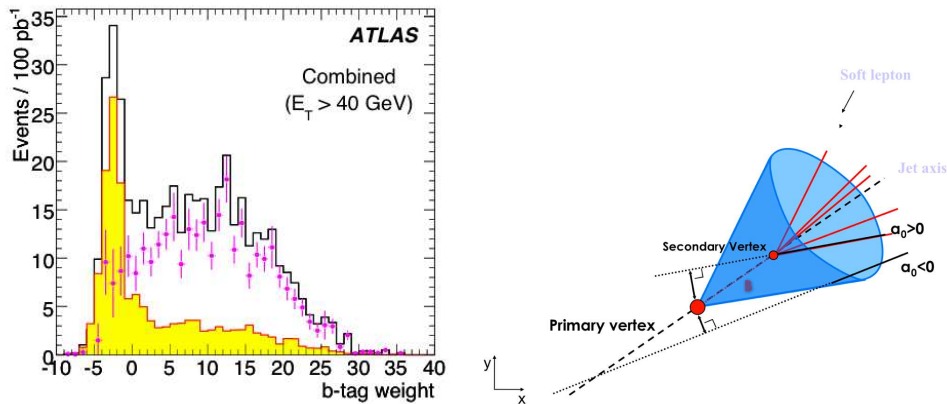


Figure 3: The ATLAS b -tagger weight w (left) is low for light jets and high for b -jets. A generic selection is made applying a cut $w > 6$. CMS will make use of track counting and track probability taggers (right).