

Top quark mass measurement with ATLAS

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The top quark mass measurement with ATLAS in the lepton ($l = e, \mu$) plus jets channel is summarized from the perspective of the first 1 fb^{-1} of data taking. Using the invariant mass of the three jets arising from the hadronic side as the estimator of the top quark mass, a precision of the order of 1 to 3.5 GeV on the top quark mass measurement should be achievable with 1 fb^{-1} of collected data, assuming a jet energy scale uncertainty of 1 to 5 %.

1. Introduction

With a mass close to the scale of the electroweak symmetry breaking, the top quark mass M_{top} is a particularly important parameter of the Standard Model (SM). For instance, we can test the consistency of any theory (SM and its extensions) and probe Physics beyond the SM by comparing the measurements of the electroweak precision observables with the theoretical predictions of the model under consideration. As a distinctive feature, the top quark mass enters quadratically in the W boson mass M_W while the dependence on the Higgs boson mass M_H is only logarithmic. Consequently, accurate measurements of both M_W and M_{top} are required to provide stringent theoretical constraints on M_H in order to test the consistency of the SM in the hypothesis of a SM Higgs boson discovery.

At the LHC, top quarks will be produced mainly in tt pair through the hard process $gg \rightarrow tt$ (90%) and $q\bar{q} \rightarrow tt$ (10%) with a cross section at the next to leading order of 833 pb. Therefore, about 800 000 tt pairs will be produced with the integrated luminosity of 1 fb^{-1} expected in 2009. This huge statistic available at the LHC will allow us to perform a direct top quark mass measurement by determining the peak of the invariant mass of the particles arising from the top quark decay. With a width $\Gamma \approx 1.5 \text{ GeV}$, roughly an order of magnitude greater than Γ_{QCD} , the top quark has such a short lifetime that it decays before hadronizing and almost exclusively through the mode $t \rightarrow Wb$. I summarize here the measurement of M_{top} in the lepton ($l = e, \mu$) plus jets channel, where one of the W bosons decays hadronically while the other one decays leptonically (the analysis is detailed in [1]). This channel is the most promising one since it constitutes the best compromise between a high branching ratio and a high signal over background ratio, the lepton of the final state allowing a good rejection of the QCD background.

2. Event selection and background

The major source of physical background (summarized in Table 1) are single top events and W + jets production with leptonic W boson decay. An analysis performed on fast simulation has shown that backgrounds from QCD and bb production are negligible after the leptonic cuts (isolated lepton, p_T, E_T).

All particles forming the tt final state are required to lie within $|\eta| \leq 2.5$. In order to reduce the QCD background and the tt fully hadronic and di-lepton processes, we require E_T higher than 20 GeV and exactly one isolated lepton ($l = e, \mu$) with $p_T \geq 20 \text{ GeV}$. To reduce the W + jets background, exactly 2 b-tagged jets are required with $p_T \geq 40 \text{ GeV}$. Finally, we require at least two light jets with $p_T \geq 40 \text{ GeV}$. This cut leads to an important loss of efficiency since only 34 % of W bosons with hadronic decay have both jets passing this requirement, but jets below 40 GeV are known to be less precisely calibrated. Moreover, 30 % of signal events have more than two light jets because of initial and final state radiation (ISR/FSR); therefore, we require at least two light jets (and not exactly two).

The efficiency of the selection with respect to l+ jets events is 5 % and, starting from a signal over background ratio very unfavorable, the successive cuts allow us to reach a signal over background ratio of 10 at this step of the reconstruction.

Table I: Number of remaining events for the main backgrounds to the semi-leptonic signal after the successive cuts.

Process	Number of events ($L = 1 \text{ fb}^{-1}$)	1 isolated lepton $p_T \geq 20 \text{ GeV}$ and $E_T \geq 20 \text{ GeV}$	4 jets $p_T \geq 40 \text{ GeV}$	2 b-jets $p_T \geq 40 \text{ GeV}$
Signal $' = e, \mu + \text{jets}$	313200	132380	43370	15780
W boson backgrounds	$9.5 \cdot 10^5$	154100	9450	200
all-jets (top pairs)	466 480	1 020	560	160
di-lepton (top pairs)	52 500	16 470	2 050	720
single top: t, W t and s channels	91 810	33 470	2 011	505

3. Hadronic W boson mass reconstruction

For the remaining events with more than two light jets in the final state, we have to find the two jets arising from the hadronically-decaying W boson. The hadronic W boson candidates are selected in a mass window of $\pm 30 \text{ GeV}$ around the peak value of the dijets distribution of events reconstructed with exactly two light jets (Fig. 1). We then perform an event by event χ^2 minimization for each possible way of pairing two light jets and choose the pair with the smallest χ^2 as the hadronic W boson candidate. The χ^2 formula contains a term which constrains the invariant mass of the two jets M_{jj} to the W boson mass and with from the Particle Data Group as follows:

$$\chi^2 = \frac{(M_{jj} - M_W^{\text{PDG}})^2}{(\Delta M_W^{\text{PDG}})^2} + \frac{(E_{j1} - E_1)^2}{\Delta E_1^2} + \frac{(E_{j2} - E_2)^2}{\Delta E_2^2} :$$

The main asset of this method is to reduce the systematic uncertainty due to the light jet energy scale since we perform an event by event in-situ rescaling of light jets by constraining the jet energies to their measured value within the jet energy resolution ΔE . Further on, only events with a hadronic W boson candidate within a mass window of $\pm 2 \Delta M_W^{\text{PDG}}$ ($\Delta M_W^{\text{PDG}} = 2.1 \text{ GeV}$) are kept.

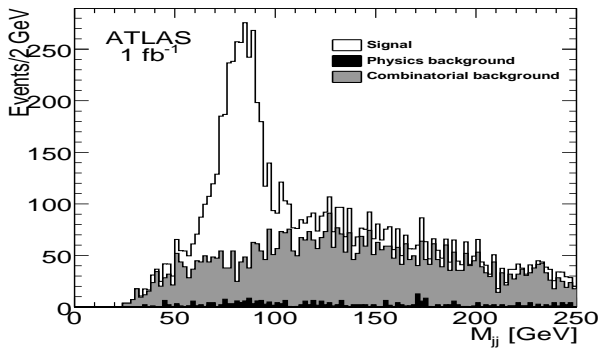


Figure 1: Invariant mass of light jet pairs for events with only two light jets.

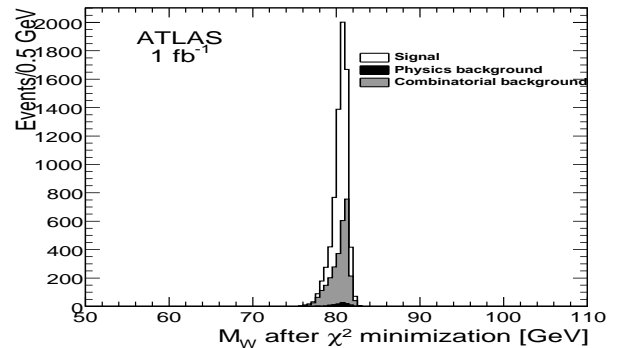


Figure 2: Hadronic W boson mass after the χ^2 minimization.

4. Top quark mass determination with the hadronic side

Once the hadronic W boson candidate is selected, we have to choose among the two b-jets the right one to be associated with the hadronic W boson in order to reconstruct the top quark mass. Several methods have been investigated and we obtain a better purity by picking the b-jet which is the closest to the hadronic W boson.

The final efficiency of the reconstruction with respect to $t\bar{t}$ jets events is $2.22 \pm 0.03\%$ with a top purity of $40.2 \pm 0.8\%$. The reconstructed top quark mass distribution is shown on Fig. 3; the fit is the sum of a Gaussian for the signal and a third degree polynomial for the combinatorial background. For a generated mass of 175 GeV , we reconstruct $M_{\text{top}} = 175.0 \pm 0.2 \text{ GeV}$ with a width equal to $11.6 \pm 0.2 \text{ GeV}$.

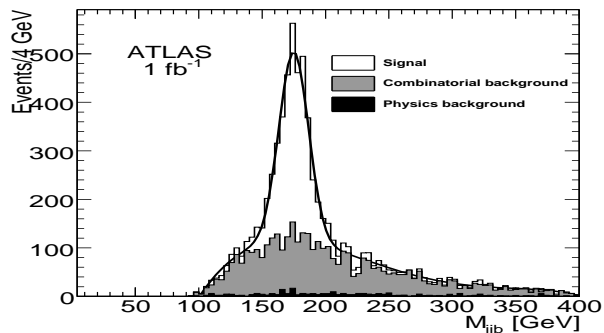


Figure 3: The hadronic top quark mass, M_{top} with a Gaussian and a third order polynomial, scaled to 1 fb^{-1} .

Systematic uncertainty	Shift on M_{top}
Light jet energy scale	$0.2 \text{ GeV} / \%$
b-jet energy scale	$0.7 \text{ GeV} / \%$
ISR /FSR	$\sim 0.3 \text{ GeV}$
b quark fragmentation	0.1 GeV
Background	negligible
Method	$0.1 \text{ to } 0.2 \text{ GeV}$

Table II: Systematic uncertainties on the top quark mass measurement in the semi-leptonic channel.

5. Systematic uncertainties

The statistical uncertainty on M_{top} will be quickly negligible at the LHC; with a few fb^{-1} of integrated luminosity, the experimental error on M_{top} will be dominated by the systematic uncertainties summarized in Table 2. Since M_{top} is measured as the invariant mass of three jets, the jet energy scale constitutes the main source of systematic uncertainties. Its incidence on the top quark mass measurement is estimated by multiplying separately the light jet and b-jet momenta by a rescaling factor without modifying E_T . The resulting top quark mass being linearly dependent on the rescaling factor, we can express the related uncertainty as a shift on M_{top} by percent of jet energy scale miscalibration. Note the reduced dependence on the light jet energy scale compared to the b-jet energy scale thanks to the W mass constraint in the 2^{nd} minimization.

6. Conclusion and perspectives

The statistical uncertainty being negligible at the LHC, the error on the top quark mass measurement will be dominated by the systematic uncertainties and a precision of the order of 1 to 3.5 GeV on M_{top} should be achievable with 1 fb^{-1} of collected data, assuming a jet energy scale uncertainty of 1 to 5%. Several studies have been performed using a relaxed requirement on the b-tagging to increase the efficiency during the commissioning phase of data taking. Even with one or no b-tagged jet, we still have a good signal over background ratio and, using a kinematic fit on the entire final state in order to decrease the combinatorial background, we should reach a precision on M_{top} of about 5 GeV for 100 pb^{-1} assuming a jet energy scale uncertainty of 5%. The development of other methods for the top quark mass measurement with ATLAS are in progress in the three different channels: the matrix element method, the template method and the b decay length method which exploits the correlation between M_{top} and the b quark momentum when the top quark decays at rest.

References

- [1] ATLAS Collaboration, Expected Performance of the ATLAS Experiment, Detector, Trigger and Physics, CERN-OPEN-2008-020, Geneva, 2008, to appear.