Early Measurement of the Top Quark Mass at the ATLAS Experiment

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When the Large Hadron Collider (LHC) will start colliding protons later this year, a first run of data taking at a centre-of-mass energy of 10 TeV (which will be increased to 14 TeV at a later stage) is planned to yield an integrated luminosity of $\int \mathcal{L}dt = 200\,\text{pb}^{-1}$. With a production cross section for top pairs of about 400 pb the LHC can be considered a "top quark factory" even at the lower beam energy in the first months, and will thus provide a great opportunity to study top quark physics.

With the first collisions at the LHC, the ATLAS detector will begin its operation as well. Naturally the commissioning and calibration of all its components will take some time to complete, and in the mean time high systematic uncertainties have to be assumed for the measurements.

The study shows that even under the conditions of the first run of the LHC a rediscovery of the top quark and an early determination of its mass is still possible. For this purpose a scenario with relatively low statistics ($\int \mathcal{L}dt = 100\,\text{pb}^{-1}$) and an uncertainty of 10% on the most important measurement – the jet energies and momenta – is considered; more sophisticated features of ATLAS detector, like bottom quark jet tagging and the determination of the missing transverse energy, are omitted as their performance for early data are unknown.

The determination of the top quark mass is performed in the semileptonic decay channel. Preselection cuts are applied for background suppression, requiring exactly four jets with high transverse momentum[1] and exactly one isolated electron or muon with $p_T > 20\,\text{GeV}$. To meet the challenge of low statistics, together with the high combinatorial background that arises from the difficulties of the event reconstruction without the use of b-tagging, an artificial neural network is used for the jet assignments in the reconstruction to achieve a better signal efficiency and background suppression than possible when relying on kinematic and geometric cuts. That way the signal significance is raised by over 30%, compared to a cut-based approach.

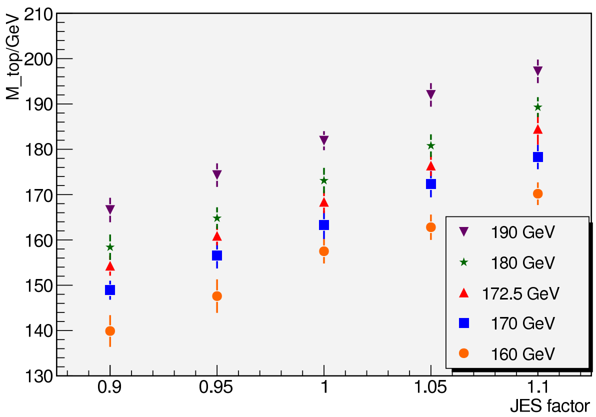

Fig. 1: Reconstructed 3-jet mass for different simulated top quark mass points and scaling factors for the Jet Energy Scale (JES)

The masses of the W boson and top quark from the hadronic decay are determined separately as the 2-jet and 3-jet masses in the hadronic decay, respectively (See Figure 1 for the reconstructed 3-jet masses). To cancel out a possible scaling factor on the jet energies and momenta in early data, the top quark mass is rescaled with the W boson mass given by the Particle Data Group, $m_{\text{W,PDG}} = 80.4\,\text{GeV}$. This is accomplished by calculation of m_{top} as

$$m_{\text{top}} = \frac{m_{3-\text{jet}}}{m_{2-\text{jet}}} \cdot m_{\text{W,PDG}}.$$

Figure 2 plots the top masses obtained by this procedure for several simulated top mass points and scaling factors applied to the Jet Energy Scale.

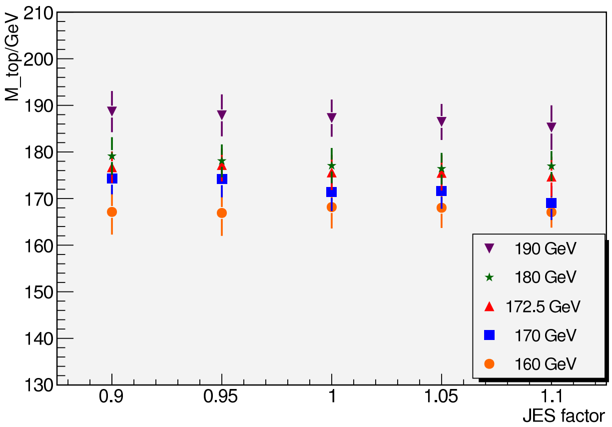

Fig. 2: Reconstructed and rescaled top quark mass for different simulated mass points and JES scaling factors

As a final step a calibration curve for m_{top} is given to compensate for systematic effects of the event selection and reconstruction process. The resulting uncertainty on the top quark mass when determined with this procedure, assuming an uncertainty of 10% on the Jet Energy Scale (JES) and an integrated luminosity of $100\,\text{pb}^{-1}$, is

$$\frac{\Delta m_{\text{top}}}{m_{\text{top}}} = \pm 3.6\%\,(\text{stat}) \pm 1.6\%\,(\text{JES}).$$

The statistical uncertainty outweighs the systematic uncertainty on the JES; in effect, for the first run of the LHC, the limiting factor on the precision of the measurement will be the amount of data taken rather than the calibration of the Jet Energy Scale[2].

It can be concluded that, in this scenario, a first measurement of the top quark mass is indeed possible with the first data taken at the ATLAS detector, and a precision of about 4% is achievable, providing a valuable test of our understanding of the detector.

[1] All four jets have $p_T > 25\,\text{GeV}$, of which at least one satifies $p_T > 40\,\text{GeV}$ and at least two more jets have $p_T > 30\,\text{GeV}$.

[2] However, the influence of other sources of systematic uncertainty, for example the cross section of the QCD multijet background and the electron fake rate, has to be estimated once the experiment is running.