Independent Measurement of the Top Quark Mass and the Light- and Bottom-Jet Energy Scales at Hadron Colliders

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At hadron-colliders, the measurement of the mass \( m_t \) of the top quark and the absolute energy scale \( S \) for calorimeter jets are closely linked. While the scale \( S \) for light jets can be calibrated with hadronic \( W \) decays in the same \( t\bar{t} \) events used to measure \( m_t \), the main remaining systematic uncertainty on \( m_t \) is so far due to differences between \( S \) and the scale \( S_b \) for \( b \) jets [1]. A novel measurement technique has now been developed that allows a simultaneous determination of \( m_t, S_j, S_b \), and the jet energy resolution \( R \) from \( t\bar{t} \) events [2].

It is assumed that the full calorimeter calibration up to constant scales \( S \) and \( S_b \) has been performed before this method is applied. Three estimators, \( m_t^{\text{reco}}, S_j^{\text{reco}}, \) and \( S_b^{\text{reco}} \), are calculated for each selected event. Functions are derived to describe the expected estimator distributions (templates) for any given set of assumed values of \( m_t, S_j, S_b, \) and \( R \). A comparison of the measured estimator distributions in the data with these fitted templates then yields the \( m_t, S_j, S_b, \) and \( R \) values and their uncertainties.

The method has been tested using \( t\bar{t} \) events in 14 TeV pp collisions generated at parton level with ALPGEN [3]. The energies of the final-state quarks have been smeared according to a Gaussian resolution whose width is set to \( \sigma(E) = R \sqrt{E} \) with constant \( R \). All jet energies are multiplied by a factor \( S_j \), and \( b \)-jet energies by another factor \( S_b \). Tests have been performed with various \( (m_t, S_j, S_b, R) \) parameter sets.

Standard \( t\bar{t} \) event selection criteria [2] are applied. In each event, assuming unambiguous \( b \)-jet identification, the estimator \( S_j^{\text{reco}} = \frac{m_{t,W}^{\text{reco}}}{m_W} \) is calculated from the known \( W \) mass \( m_W \) and the mass \( m_{t,W}^{\text{reco}} \) reconstructed from the smeared light-jet energies. A scan over \( S_b^{\text{reco}} \) values is performed. Given an assumed value of \( S_b^{\text{reco}} \), the reconstructed \( b \)-quark jet energies and momenta are scaled accordingly, and the missing transverse momentum is adjusted and taken as transverse momentum of the neutrino from the leptonic \( W \) decay. The longitudinal neutrino momentum \( p_z^{\nu} \) is then obtained from \( m_{t,W}^{\text{reco}} \), and the resulting top quark masses \( m_t^{\text{reco}} \) and \( m_{t,W}^{\text{reco}} \) of the top quarks with the leptonic/hadronic \( W \) decay are computed. If one finds \( m_t^{\text{reco}} = m_{t,W}^{\text{reco}} \), then this top quark mass and the corresponding \( S_b^{\text{reco}} \) value are taken as estimator values for the event. Events are only retained if exactly one solution with \( 0.5 < S_b^{\text{reco}} < 2.0 \) and \( 150 \text{ GeV} < m_t^{\text{reco}} < 200 \text{ GeV} \) is found.

After the preselection, events with a magnitude of the vector sum of \( b \)-quark jet transverse momenta of less than 50 GeV that yield poor independent information on the top quark mass and \( b \)-quark jet energy scale are rejected. Finally, the quantity \( \Delta^{\text{reco}} := \left| \frac{\partial m_t^{\text{reco}}}{\partial S_b^{\text{reco}}} \right| - \left| \frac{\partial m_{t,W}^{\text{reco}}}{\partial S_b^{\text{reco}}} \right| \) is obtained during the scan of \( S_b^{\text{reco}} \) values. Events with \( \Delta^{\text{reco}} < 30 \text{ GeV} \) have a degraded resolution and are rejected. The resulting \( S_b^{\text{reco}} \) estimator distributions for various choices of input parameters are shown in Figure 1 as an example.

![Figure 1: \( S_b^{\text{reco}} \) template when varying (left plot) the input \( S_j \) value, and (right plot) the input \( m_t \) value. The template parameterizations are overlaid.](http://example.com/figure1.png)

To test the method, pseudo-experiments are then performed using simulated events for various sets of input parameter values. Figure 2 shows results for the distributions of measured \( m_t, S_j, \) and \( S_b \) values. The correlation matrix between the four measured parameters is given by:

| \( m_t \) \( S_j \) \( S_b \) \( R \) |
|---|---|---|---|
| \( m_t \) | \(-0.09\) | \(-0.50\) | \(-0.22\) |
| \( S_j \) | \(-0.38\) | \(-0.11\) | \(-0.14\) |

**Fig. 2:** Pseudo-experiments: The correlation between \( m_t \) and \( S_b \) results (left plot), and that between \( S_j \) and \( S_b \) (right plot).

The parton-level tests of the method have been published [2] as a proof of principle. In the future, the method will be applied to fully simulated ATLAS events, and systematic uncertainties will be investigated.

**References**

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[2] F. Fiedler, Eur. Phys. J. C 53 (2008) 41 [arXiv:0706.1640 [hep-ex]].

[3] M. L. Mangano et al., JHEP 307 (2003) 1