Measuring the Top Quark Mass in the All-Jets Channel

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The top quark mass m_t is a key parameter of the Standard Model of particle physics, entering the electroweak fit and playing an important role in determining the stability of the electroweak vacuum. Improving the precision of its measurement therefore remains an important goal of the LHC physics program. This thesis project aims to measure m_t in the $\mathrm{t\bar{t}}$ all-jets final state using data recorded by the CMS detector during the LHC Run 2 data-taking period at a center-of-mass energy of $\sqrt{s} = 13$ TeV. The analysis extends the profile-likelihood approach recently applied with high precision in the lepton+jets channel to the all-jets channel for the first time.

In the all-jets channel, both W bosons decay hadronically, resulting in the largest branching fraction of all $\mathrm{t\bar{t}}$ decay modes but also a more challenging experimental signature than channels containing leptons. The absence of a lepton signature or significant missing transverse momentum requires dedicated multijet triggers, and the sizable QCD multijet background is challenging to model in simulation. Events are selected using requirements on H_T, jet multiplicity, and b-tagging. The offline preselection requires $H_\mathrm{T} \geq 450$ GeV, at least six jets with $p_\mathrm{T} \geq 40$ GeV and $|\eta| < 2.4$, and exactly two b-tagged jets among the six leading jets.

To improve the resolution of the reconstructed top-quark mass and identify the correct jet-parton assignment, a kinematic fit is applied to the six leading jets under the $\mathrm{t\bar{t}}$ hypothesis. The two W-boson masses are constrained to 80.4 GeV, while the top and antitop masses are required to be equal. All six physical jet permutations are tested, and the one with the lowest χ^2 is retained. A goodness-of-fit requirement of $P_\mathrm{gof} > 0.1$ substantially increases the fraction of correctly matched permutations from 7% to 50%, at the cost of removing roughly 90% of preselected events. An additional requirement on the angular separation of the two b jets, $\Delta R_{\mathrm{b\bar{b}}} > 2$, further suppresses the QCD multijet background, which is enhanced at small opening angles due to collimated $g \to \mathrm{b\bar{b}}$ splittings. Together, these requirements define the signal region used for the mass extraction.

The simulated QCD multijet events passing the full selection have large event weights, reducing the reliability of a purely simulation-based background prediction. The multijet background is therefore estimated directly from data using a control region. Events in this region are selected with a background trigger that does not include the b-tagging requirement of the signal trigger and are required to contain exactly zero b-tagged jets among the six leading jets, using a looser b-tagging working point. All remaining selection criteria are unchanged. For the kinematic fit in this region, two jets are assigned randomly as b-jet candidates. The initial multijet normalization is obtained from the difference between the observed data and the expected $\mathrm{t\bar{t}}$ yield in the signal region and is subsequently treated as a free parameter in the final fit.

Using this signal region, the top quark mass is extracted from a binned profile-likelihood fit, with systematic uncertainties incorporated directly as nuisance parameters and constrained simultaneously with m_{t}. The fitted top-quark mass $m_{\mathrm{t}}^{\mathrm{fit}}$ provides the dominant sensitivity to m_{t}. The average reconstructed W-boson mass, $m_{W_{\mathrm{avg}}}^{\mathrm{reco}}$, provides sensitivity to light-jet energy scale uncertainties, while the ratio of b-jet to light-jet p_{T}, R_{bq}^{reco}, is being investigated for its sensitivity to the b-jet energy scale. Different fit configurations combining one, two, or three observables are being investigated.

The analysis has been tested using Asimov data, and the leading systematic uncertainties have been identified. For a fit using only $m_{\mathrm{t}}^{\mathrm{fit}}$, the dominant impacts arise from top-quark recoil modeling, the b-jet energy response, the treatment of resonance decays in the color reconnection model, and final-state radiation. Including $m_{W_{\mathrm{avg}}}^{\mathrm{reco}}$ adds sensitivity to light-jet energy scale uncertainties and improves their constraint in the fit. The impact of including R_{bq}^{reco} is still under study. Remaining studies include finalizing the background shape modeling, evaluating the impact of limited template statistics, and validating the fit procedure with pseudo-experiments. These studies will establish the robustness of the fit and pave the way for its application to collision data.