Measurement of the top quark mass from leptonic observables in pp collisions

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A novel technique for measuring the top quark mass using only leptonic observables is discussed. Top and anti-top quark decays with one electron and one muon and at least one jet in the final state are selected in proton-proton collision data collected by the CMS experiment at a center-of-mass energy of 8 TeV, corresponding to an integrated luminosity of 19.7 fb^{-1}. Several variables are studied and the transverse momentum distribution of the charged lepton pair originated from the top quark decay is chosen to extract the top quark mass. The measurement is calibrated using simulated events.

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1. Introduction

The top quark mass (m_t) is a fundamental parameter of the standard model (SM) whose precise measurement can benefit the calculation of radiative corrections to several observables. The current m_t measurement methods exploit either the full kinematic reconstruction of top quark pair ($t\bar{t}$) events or alternative event topologies or observables that are sensitive to m_t variations. The latter can avoid intrinsic hadronization-related uncertainties and provide further understanding of the relation between the experimental results obtained for m_t and the mass parameters employed in theoretical calculations. In this report, we discuss a recent proposal to measure the top-quark mass from the kinematic properties of the dilepton system in $t\bar{t}$ events.

2. Top quark mass measurement

The observed distributions of the kinematic properties of the charged leptons depend on the dynamics of the top quark production and decay and can therefore be used to infer m_t, as recently proposed in [1].

The sensitivity to theoretical assumptions and experimental effects that may affect this measurement was studied by carrying out the analysis for a set of m_t-dependent observables reconstructed in the dilepton final state. The performance of the following kinematics was investigated separately: the transverse momentum, $p_T(l^+)$, and the energy, $E(l^+)$, of the positively-charged lepton; the transverse momentum $p_T(l^+l^-)$ and the invariant mass $M(\ell^+\ell^-)$ of the charged lepton pair; the scalar sum of the transverse momentum $p_T(l^+) + p_T(l^-)$ and the energies $E(l^+) + E(l^-)$ of the two charged leptons. Among all the aforementioned observables, $p_T(l^+l^-)$ is found to be the most robust against these effects and to be one of the most sensitive to m_t. Hence, the m_t measurement reported is based solely on the results obtained with this variable.

The analysis focuses in $t\bar{t}$ events with one isolated electron and muon in the final state and uses the full dataset, collected by the CMS experiment [2] in proton-proton collisions at $\sqrt{s} = 8\ TeV$, corresponding to an integrated luminosity of 19.7 fb^{-1}.

The m_t extraction is performed using the full shape of the distribution, and comparing the experimentally observed yields in individual bins with the prediction from fixed m_t hypothesis, ranging between 166.5 and 178.5 GeV, and using its first moments ($O^{(1)}, O^{(2)}$) and comparing those extracted from data with the expected in simulated events. After subtracting the background contribution from data and applying the simulation-based calibration, the first moments are translated as $m_t = 171.8 \pm 1.2$(stat) GeV ($m_t = 171.6 \pm 1.2$(stat) GeV). The shape analysis yields a value of $m_t = 171.7 \pm 1.1$(stat) GeV. The results are found to be in agreement with previous m_t measurements at CMS [3].

For each source of uncertainty, the size of the variation is estimated by using the alternative reconstructed prediction of the distribution to evaluate a difference in the moments of the distributions or in the estimator used to scan the m_t parameter (See Table 2). A detailed explanation of the sources of uncertainty can be found in [4].

The total experimental uncertainty is only limited by the lepton momentum scale calibration, while the dominant uncertainties stem from the modeling of top quark kinematics and the modeling of the hard process, which includes scale variations in the simulation, jet-to-parton matching, and

Source	Δm_t^{fit} [GeV]	$\Delta m_t^{O^{(1)}}$ [GeV]	$\Delta m_t^{O^{(2)}}$ [GeV]
μ_R/μ_F scales $t\bar{t}$	$\{^{+1.61}_{-2.29}$	$\{^{+1.70}_{-2.91}$	$\{^{+1.79}_{-2.71}$
ME-PS matching scale	$\{^{+0.91}_{-1.06}$	$\{^{+0.99}_{-0.99}$	$\{^{+1.08}_{-0.79}$
Parton density functions	± 0.35	± 0.38	± 0.37
Top quark p_T (p_T (t))	$+0.78$	$+0.85$	$+1.15$
Underlying event	± 0.82	± 0.56	± 0.57
Color reconnection	± 0.48	± 0.66	± 0.51
Signal modeling	± 1.29	± 0.71	± 0.61
Jet energy scale	± 0.05	± 0.05	± 0.05
Jet energy resolution	$< \pm 0.01$	$< \pm 0.01$	$< \pm 0.01$
Lepton energy scale	± 0.37	$\{^{+0.24}_{-0.48}$	$\{^{+0.22}_{-0.51}$
Lepton selection efficiency	± 0.04	± 0.08	± 0.08
b tagging	± 0.02	± 0.02	± 0.02
Misidentification efficiency	± 0.03	± 0.09	± 0.09
Pileup	± 0.16	± 0.24	± 0.27
Background normalization	± 0.33	± 0.45	± 0.35
Total systematic	$\mathbf{+2.68 - 3.09}$	$\mathbf{+2.57 - 3.42}$	$\mathbf{+2.72 - 3.14}$

Table 1: Summary of the systematic uncertainties for the different m_t measurements performed in this analysis [4].

matrix-element generator. However, is expected that the use of next-to-leading (NLO) simulation in future analyses will improve these effects.

3. Particle level correction

In order to allow direct comparison with different generators and theoretical predictions, particle-level distributions are reported for each of the aforementioned kinematic observables. An unfolding procedure is applied to correct the measured distributions for detector resolution effects which can lead to a migration of events across bin boundaries. The normalized unfolded distributions are reported in Fig. 1 and compared to predictions generated at different mass hypothesis ($m_t = 166.5, 172.5, 178.5$ GeV). Within the total uncertainties, good agreement is observed with respect to the nominal m_t=172.5 GeV - based simulation.

4. Conclusions

A novel alternative technique to measure the mass of the top quark in $e\mu$ final states, with at least one b jet, using the distribution of the transverse momentum of the charged lepton pair yields values of:

$$m_t = 171.8 \pm 1.2 \text{ (stat.)} {}^{+0.6}_{-0.7} \text{ (exp.)} {}^{+2.4}_{-3.3} \text{ (th.)} {}^{+0.9}_{-0.0} (p_T \text{ (t)}) \text{ GeV (first moment)}$$
$$m_t = 171.6 \pm 1.2 \text{ (stat.)} {}^{+0.5}_{-0.7} \text{ (exp.)} {}^{+2.4}_{-3.1} \text{ (th.)} {}^{+1.2}_{-0.0} (p_T \text{ (t)}) \text{ GeV (second moment)}$$
$$m_t = 171.7 \pm 1.1 \text{ (stat.)} \pm 0.5 \text{ (exp.)} {}^{+2.5}_{-3.1} \text{ (th.)} {}^{+0.8}_{-0.0} (p_T \text{ (t)}) \text{ GeV (shape analysis)}$$
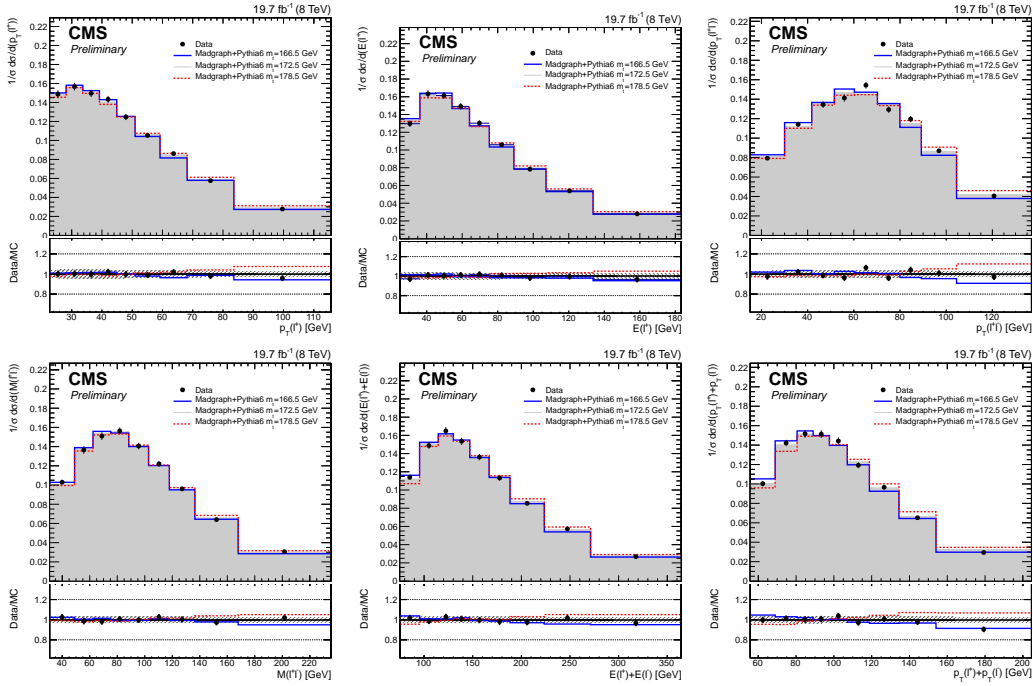
Figure 1: Normalized event yields at particle level for $t\bar{t}$ production, presented as a function of each of the kinematic distributions studied in this analysis [4]. The bottom panels show the ratio with respect to the nominal simulation generated at m_t=172.5 GeV with the hatched band representing the envelope of the statistical and systematic uncertainties.

With improved MC event generators at NLO it is expected that the theoretical uncertainties, such as the scale choice in QCD calculations, will be significantly reduced allowing direct comparisons with the original theory proposal [1].

References

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