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Prospects for the measurement of the top-quark mass with early ATLAS data

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Summary. — The prospects are presented for a top-quark mass, $m_{\rm top}$, measurement in the $t\bar{t} \to$ lepton+jets channel via the template method using early ATLAS data. Two variants of the template analysis are presented. A 1-dimensional template analysis which adopts the stabilized top-quark mass variable, $m_{\rm top}^{\rm stab}$, exploiting the event-by-event ratio of the reconstructed top-quark and W boson masses associated to the hadronically decaying top quark candidate, to minimize the impact of the jet energy scale, JES, uncertainty on $m_{\rm top}$. A 2-dimensional analysis which simultaneously extracts $m_{\rm top}$ and the JES from the data. The latter, making use of b-tagging, as well as of a kinematic fit of the decay products, offers a more precise determination of $m_{\rm top}$, while requiring a better understanding of the detector. The 1-d analysis is optimized for very first data with integrated luminosities, $\mathcal{L}_{\rm int}$, up to $100\,{\rm pb}^{-1}$; whereas the 2-d analysis is targeted at $\mathcal{L}_{\rm int}$ of $1\,{\rm fb}^{-1}$, the total integrated luminosity currently expected from the ongoing 2010-2011 LHC operations.

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PACS 14.65.Ha – Top quarks.

1. – Introduction

The top-quark mass is a fundamental parameter of the Standard Model, SM, of particle physics. It gives large contributions to electroweak radiative corrections which, when connected to precision electroweak measurements, can be used to derive constraints on the masses of the yet-unobserved Higgs boson, and of particles predicted by some SM extensions. The top quark mass has been measured using various techniques, and multiple decay channels by the Tevatron experiments. The present $m_{\rm top}$ world average value is $173.1 \pm 1.3\,{\rm GeV}$ [1].

Top pair production will be copious at the LHC: the corresponding cross sections are enhanced by factors of about 20 or 125 with respect to the Tevatron collider, for pp collisions at $\sqrt{s} = 7$ or $14\,{\rm TeV}$, respectively [2]. As a consequence, $m_{\rm top}$ results from LHC will also be soon limited by systematics. For early measurements, the golden channel is $t\bar{t} \to$ lepton+jets as it provides the best compromise of branching ratio and signal over background ratio (S/B). In this channel the complete detector capability is explored: the events contain many jets (two of which originate from b-quarks), one high p_T, isolated charged lepton, and missing transverse energy, $E_{\mathrm{T}}^{\mathrm{miss}}$, from the escaping neutrino.

In general m_{top} analyses, relying on the reconstruction of the hadronic top decays, suffer from the limited experimental knowledge of the jet energy scale, JES. In view of this difficulty, ATLAS explored two complementary measurement paths either aimed at being as independent of the JES as possible, which may be poorly known at the beginning of the data taking, or at determining the JES together with m_{top} [3]. The first scenario is realized by a 1-d analysis based on the stabilized top-quark mass, $m_{\mathrm{top}}^{\mathrm{stab}}$ defined as: $m_{\mathrm{top}}^{\mathrm{stab}} = \frac{m_{\mathrm{top}}^{\mathrm{reco}}}{m_{W}^{\mathrm{reco}}} \cdot m_W$ (with $m_W = 80.4\,\mathrm{GeV}$). The second, the 2-d analysis, simultaneously determines m_{top} and the JES, by combining $m_{\mathrm{top}}^{\mathrm{reco}}$ and m_{W}^{reco} information from the data. Both analyses utilize the template method to determine m_{top} from the measured top-quark mass distributions, and for the 2-d analysis by also exploiting the distribution of the measured invariant mass of the W boson. Signal templates are derived from the distributions of Monte Carlo $t\bar{t}$ events generated under different m_{top} assumptions in the range 160–190 GeV. For the 2-d analysis templates for different JES assumptions are also constructed. Background templates are derived in a similar way from the sum of all physics processes considered as background. Templates are parameterized by means of probability density functions, then used in an un-binned likelihood fit to the data, whose free parameters are the numbers of signal and background events, m_{top} (and the JES for the 2-d analysis). The method validation, as well as the linearity and sanity checks are performed using the pseudo-experiment technique.

2. – Selection of lepton+jets candidates and event reconstruction

In order to reduce the background contamination, different strategies are adopted for the 1-d and 2-d analyses. Starting from a common pre-selection requiring exactly one lepton (e, μ) with $p_T > 20\,\mathrm{GeV}$ within the detector acceptance, $E_{\mathrm{T}}^{\mathrm{miss}} > 20\,\mathrm{GeV}$, and at least 4 jets with $p_T > 20\,\mathrm{GeV}$, the 1-d analysis tightens the jet p_T requirements ($p_T > 75$, 40, 40 GeV for the three highest p_T jets), and imposes restrictions to the allowed range for m_{W}^{reco} ($\pm 25\,\mathrm{GeV}$ from the observed peak position). On the other hand, the 2-d analysis increases the p_T thresholds for all jets to 40 GeV, and requires the presence of at least two jets identified as originating from b-quarks. In the case of the 2-d analysis, jets are pre-calibrated using Monte Carlo based corrections to account for the light- to b-jet response differences. The expected signal yields, assuming SM cross sections at $\sqrt{s} = 10\,\mathrm{TeV}$, and $\mathcal{L}_{\mathrm{int}} = 100\,\mathrm{pb}^{-1}$, for the 1-d analysis correspond to 615 ± 3 (734 ± 3) events in the electron (muon) channel, with a S/B of 1.3 (1.4). With the same assumptions, the 2-d analysis selection provides 120 ± 1 signal events in the combined (e+μ) channel, and a S/B of 8.0.

The event reconstruction is limited to the hadronic top quark in the case of the 1-d analysis: jets belonging to the top candidate are chosen as the jet triplet whose 4-vector sum yields the maximum p_T. Within this triplet, the W boson is reconstructed as the pair of jets, in the top quark candidate rest-frame, closest in ΔR. The 2-d analysis, on the other hand, performs jet associations based on the results of a kinematic fit to the $t\bar{t}$ decay hypothesis. Inputs to the fit are the differences of the measured and fitted charged lepton and jet energies; the differences of m_{W}^{reco} and m_W, for the leptonic and hadronic W boson candidates; the differences of the (q, q, b) and (ℓ, ν, b) invariant masses and $m_{\mathrm{top}}^{\mathrm{reco}}$, for the leptonic and hadronic top-quark candidates, all normalized to the corresponding resolutions or widths.

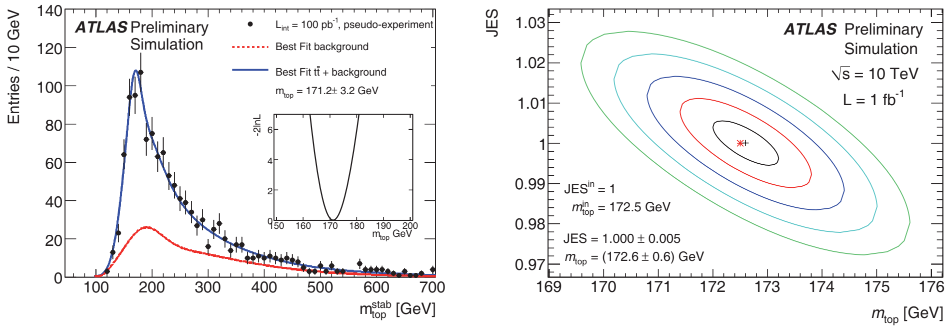

Fig. 1. – (Colour on-line) 1-d analysis (left): example fit in the muon channel to a pseudo-experiment generated assuming $m_{\text{top}} = 172.5\,\text{GeV}$ and $\mathcal{L}_{\text{int}} = 100\,\text{pb}^{-1}$. The inset shows the likelihood profile *vs.* m_{top}. 2-d analysis (right): result of the simultaneous determination of m_{top} and the JES ($\mathcal{L}_{\text{int}} = 1\,\text{fb}^{-1}$). The (red) star indicates the input parameter values, the (black) cross the fitted ones. The ellipses correspond to the n-σ statistical uncertainty contours.

3. – Results, expected uncertainties, and conclusions

Typical pseudo-experiment results for the 1-d ($\mathcal{L}_{\text{int}} = 100\,\text{pb}^{-1}$) and 2-d ($\mathcal{L}_{\text{int}} = 1\,\text{fb}^{-1}$) analyses are reported in fig. 1. For the 1-d analysis, assuming $\sqrt{s} = 10\,\text{TeV}$, the statistical uncertainty of the top-quark mass measurement in the electron or muon channel is expected to be about 10(3) GeV for $\mathcal{L}_{\text{int}} = 10(100)\,\text{pb}^{-1}$. Both channels give consistent results, and their combination leads to a statistical uncertainty of 2.0 GeV for $\mathcal{L}_{\text{int}} = 100\,\text{pb}^{-1}$. On the other hand, for the 2-d analysis the statistical uncertainty of m_{top} in the combined (e+μ) channel is expected to be of the order of 1.8(0.6) GeV, for $\mathcal{L}_{\text{int}} = 100\,\text{pb}^{-1}$ ($1\,\text{fb}^{-1}$). The total systematic uncertainty is still dominated by the residual light jet energy scale uncertainty (1-d analysis), and by the remaining difference between the energy scales of b-jets and light jets (both 1-d and 2-d analyses). The second largest contribution comes from uncertainties in the modeling of initial and final state radiation; in addition, background normalization and shape uncertainties provide significant contributions, in the case of the 1-d analysis. The total systematic uncertainty is estimated to be about 3.8 GeV for each 1-d analysis channel, and 2.0 GeV for the 2-d analysis.

The presented analyses are for many aspects complementary and in view of their application to data, the interplay between them will be a key ingredient for the timely commissioning of the more elaborate one.

REFERENCES

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