Electroweak precision observables (m_{W}, m_{top}) from ATLAS and CMS

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We present the latest ATLAS and CMS measurements of the top quark mass, the W boson mass, the effective Electroweak (EW) mixing angle and the on-shell EW mixing angle. In addition, the uncertainties for current and future measurements of EW parameters at hadron colliders are investigated.

1 Measurement of the forward-backward asymmetry

The forward-backward asymmetry in electron and muon pairs from Z/γ^* is measured [1] using the 7 TeV pp LHC collision data recorded with the ATLAS [2] detector in 2011 corresponding to an integrated luminosity of 4.8 fb^{-1}. The data are analysed over a range of dilepton invariant masses from 66 GeV to 1000 GeV in the central-central electron and muon channels, and up to 250 GeV in the central-forward electron channel. The latter includes events where one electron is reconstructed in the forward pseudorapidity range ($2.5 < |\eta| < 4.9$). The forward-backward asymmetry is measured separately for the three channels as a function of the dilepton invariant mass and unfolded for detector effects and final-state radiation. The detector level asymmetry values are used to extract the value of the leptonic effective weak mixing angle, $\sin^2\theta_{\mathrm{eff}}^{\mathrm{lept}}$, separately for the three data samples using a χ^2 minimization method. The results are in good agreement with each other and with measurements at e^+e^- colliders, at the Tevatron and by CMS and LHCb at the LHC, as can be seen in Figure 1 (left). Results from the electron and muon final states are combined, yielding $\sin^2\theta_{\mathrm{eff}}^{\mathrm{lept}} = 0.2308 \pm 0.0005\,(\mathrm{stat.}) \pm 0.0006\,(\mathrm{syst.}) \pm 0.0009\,(\mathrm{PDF})$. The dominant uncertainty comes from knowdlege of the PDFs.

2 W-like measurement of the Z boson mass

The standard model (SM) quantum corrections to the mass of the W boson, m_{W}, are dominated by contributions dependent on the masses of the top quark, m_{top}, and the Higgs boson mass, m_{H}, as well as the fine-structure constant α. Therefore, combining precise measurements of these three masses provides a critical test of the nature and consistency of the SM. After the discovery of the Higgs boson, a global electroweak fit predicts $m_{\mathrm{W}} = 80.358 \pm 0.008$ GeV, a result with an uncertainty smaller than that from the combination of all direct m_{W} measurements. This means that the mass of the W boson should be measured with a precision of 6 MeV or better, to be compared with the 15 MeV uncertainty of the current m_{W} world average. The analysis presented here by CMS [3,4] constitutes a milestone towards a high precision W mass measurement with $\mathrm{W} \to \mu\nu$ events. The study is made on the basis of a dimuon data sample collected by CMS at 7 TeV, corresponding to an integrated luminosity of 4.7 fb^{-1}. The muon momentum scale calibration has been improved by correcting the curvature of the muon tracks for small variations of the magnetic field, in addition of residual misalignment effects, and imperfect modelling of

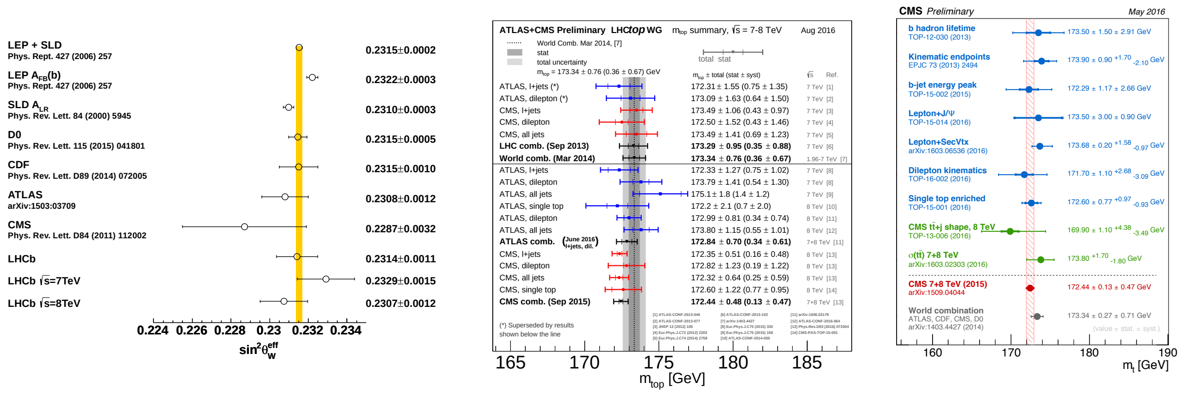

Figure 1 – (Left [5]) Comparison of the $\sin^2\theta_{\rm eff}^{\rm lept}$ results, including the most precise measurements from LEP, SLD, Tevatron and LHC. The combined LEP and SLD measurement is indicated by the vertical yellow band. (Center [6]) Summary of the ATLAS and CMS direct $m_{\rm top}$ measurements. The results are compared with the LHC and Tevatron+LHC $m_{\rm top}$ combinations. For each measurement, the statistical uncertainty includes the jet scale factor (JSF) and b-jet scale factor (bJSF) contributions (when applicable), while the sum of the remaining systematic uncertainties is reported separately. The JSF and bJSF contributions are statistical in nature and apply to analyses performing in-situ (top quark pair based) jet energy calibration procedures. The results below the line are results produced after the LHC and Tevatron+LHC combinations were performed. (Right [7]) Summary of Run-I CMS alternative $m_{\rm top}$ measurements.

the material resulting in different energy loss. This calibration has been done with the J/ψ and $\Upsilon(1S)$ resonances, and a closure test has been performed with Z+jets events, achieving a precision below 8 MeV. In addition, the hadronic recoil of the events has also been calibrated, achieving a precision good enough to pursue an accurate measurement of the W mass at the LHC, even in the presence of multiple interactions. As a proof of principle the analysis technique has been used to measure the mass of the Z boson after removing one of its decay muons, getting a result compatible with the world-average value.

3 Top mass

The mass of the top quark is an important parameter of the SM, and precise measurements provide critical inputs to fits of global electroweak parameters that, as mentioned in the previous section, help assess the internal consistency of the SM. In addition, the value of $m_{\rm top}$ affects the stability of the SM Higgs potential, which has cosmological implications.

3.1 Direct measurements

In the ATLAS paper [8] the top quark mass has been measured via a three-dimensional template method in the $t\bar{t} \to$ lepton + jets final state, and using a one-dimensional template in the $t\bar{t} \to$ dilepton channel. Both analyses are based on 7 TeV pp collision data corresponding to an integrated luminosity of 4.6 fb^{-1}. In the lepton+jets analysis $m_{\rm top}$ is determined together with a global jet energy scale factor and a residual b-to-light jet energy scale factor. A combination of the lepton+jets and dilepton results is performed using the BLUE technique, exploiting the full uncertainty breakdown, and taking into account the correlation of the measurements for all sources of the systematic uncertainty. The result is $m_{\rm top} = 172.99 \pm 0.48$ (stat.)± 0.78 (syst.) GeV. The total uncertainty of the combination corresponds to 0.91 GeV and is currently dominated by systematic uncertainties due to jet calibration and modelling of the $t\bar{t}$ events. In the ATLAS paper [9] the top quark mass is measured in the $t\bar{t} \to$ dilepton channel from about 20.2 fb^{-1} of 8 TeV proton-proton collision data recorded by the ATLAS detector at the LHC. Compared to the latest ATLAS measurement in this decay channel, the event selection is refined exploiting the average transverse momentum $p_{\rm T}$ of the lepton-b-jet pairs to enhance the fraction of correctly reconstructed events, thereby reducing the systematic uncertainties. Using the optimal point in terms of total uncertainty observed in a phase-space scan of this variable as an additional event selection criterion, the measured value of $m_{\rm top}$ is 172.99 ± 0.41 (stat.) $\pm\, 0.74$ (syst.) GeV, with a total uncertainty of 0.84 GeV. The precision is mainly limited by systematic uncertainties, mostly by the calibration of the jet energy scale. This measurement is combined with the aforementioned ATLAS results in the lepton+jets and dilepton channels from 7 TeV data. Using a dedicated mapping of uncertainty categories, the combination of the three measurements results in $m_{\rm top} = 172.84 \pm 0.34$ (stat.) $\pm\, 0.61$ (syst.) GeV, with a total uncertainty of 0.70 GeV, which means a relative precision of 0.4%. The result is mostly limited by the calibration of the jet energy scales and by the Monte Carlo modelling of signal events.

A new set of measurements of the top quark mass has been also presented by CMS [10], based on the data recorded by the CMS experiment at the LHC at 8 TeV during 2012, and corresponding to a luminosity of 19.7 fb^{-1}. The top quark mass has been measured in the lepton+jets, all-jets and dilepton decay channels, giving values of 172.35 ± 0.16 (stat.) $\pm\, 0.48$ (syst.) GeV, 172.32 ± 0.25 (stat.) $\pm\, 0.59$ (syst.) GeV, and 172.82 ± 0.19 (stat.) $\pm\, 1.22$ (syst.) GeV, respectively. Individually, these constitute the most precise measurements in each of the decay channels studied. When combined with the published CMS results at 7 TeV, a top quark mass measurement of 172.44 ± 0.13 (stat.) $\pm\, 0.47$ (syst.) GeV is obtained. This is the most precise measurement of $m_{\rm top}$ to date, with a total uncertainty of 0.48 GeV. These measurements use analysis techniques in which either $m_{\rm top}$ alone is determined or $m_{\rm top}$ and the overall jet energy scale factor are determined simultaneously. For the lepton+jets and the all-jets channels analyses have been based on the ideogram technique, which is a joint maximum likelihood fit that determines the top quark mass and the overall jet energy scale factor. While the ideogram technique provides the most precise measurements, it is not suitable for dilepton events where the presence of more than one neutrino introduces uncertainties in the use of the measured missing transverse energy. Instead, for the dilepton channel, the analytical matrix weighting technique has been used. The top quark mass has also been studied as a function of the event kinematical properties in the lepton+jets channel. No indication of a kinematical bias in the measurement is observed and the data are consistent with a range of predictions from current theoretical models of $\rm t\bar{t}$ production. Both ATLAS and CMS latest $m_{\rm top}$ direct measurements are summarized in Figure 1 (center).

3.2 Alternative measurements

In contrast to the $\rm t\bar{t}$ production via the strong interaction, in pp collisions at the LHC, top quarks can also be produced singly via the weak charged-current interactions, giving another possibility for measuring $m_{\rm top}$. In the ATLAS document [11] we present the first measurement of the top quark mass in a phase-space dominated by single top quarks produced via the weak interaction. The signal corresponds to a mix of topologies containing single top quarks produced in the t-channel and of $\rm t\bar{t}$ pairs, for which the total background fraction has been reduced to below 30% using a neural network based discriminant. Candidate events are selected in the lepton + missing energy + 2-jet channel, with exactly one of the jets required to be b-tagged, from 20.3 fb^{-1} of 8 TeV data. The measured $m_{\rm top}$ in the combined electron and muon channels is 172.2 ± 0.7 (stat.) $\pm\, 2.0$ (syst.) GeV, in good agreement with the measurements performed in $\rm t\bar{t}$ events. In a similar way, in the CMS document [12] the top quark mass is measured on 19.7 fb^{-1} of data collected at 8 TeV. The top quark is reconstructed from its decay $\rm t \to W^{+}b$, with the W boson decaying leptonically in the muon channel. Specific event topology and kinematic properties are used in order to enrich the sample in single top quark events in the t-channel, at the expense of top-quark pair production events. A fit to the reconstructed top invariant mass distribution yields $m_{\rm top} = 172.60 \pm 0.77$ (stat.) $\pm\, 0.97$ (syst.) GeV.

The top quark mass can also be measured from the inclusive cross section for $\rm t\bar{t}$ production. With this method the top quark mass scheme is unambiguously defined in the theoretical calculations, albeit it is less precise, due to a relatively weak sensitivity of the inclusive cross section to the top quark mass, as well as to the large uncertainties on the factorization and normalization scales and the proton PDF. In these ATLAS [13] and CMS [14] documents, $m_{\rm top}$ is extracted from a measurement of the normalized differential cross section for $\rm t\bar{t}$ production with at least one additional jet, as a function of the inverse of the invariant mass of the $\rm t\bar{t}$ + 1-jet system. This distribution is sensitive to $m_{\rm top}$ because the amount of gluon radiation depends on its value, with large effects in the phase-space region relatively close to the $\rm t\bar{t}$ + 1-jet production threshold. ATLAS uses 4.6 $\rm fb^{-1}$ of 7 TeV pp collision data. By looking at the lepton+jets channel with two b-tagged jets, the measured top quark pole mass is 173.7 ± 1.5 (stat.)±1.4 (syst.)$^{+1.0}_{-0.5}$ (theory) GeV. CMS uses 19.7 $\rm fb^{-1}$ of 8 TeV data. By looking at the dileptonic decay channels the measured top quark pole mass is 169.9 ± 1.1 (stat.)$^{+2.5}_{-3.1}$ (syst.)$^{+3.6}_{-1.6}$ (theory) GeV.

In the ATLAS document [15] the inclusive $\rm t\bar{t}$ production cross-section has been measured using 4.6 $\rm fb^{-1}$ at 7 TeV and 20.3 $\rm fb^{-1}$ at 8 TeV, in the $\rm e\mu$ decay channel with one and two b-tagged jets. This result has been used to determine the top quark pole mass via the dependence of the predicted cross-section on $m_{\rm top}^{\rm pole}$, giving a value of $172.9^{+2.5}_{-2.6}$ GeV. The same is done in the following CMS paper [16], using 5.0 $\rm fb^{-1}$ at 7 TeV and 19.7 $\rm fb^{-1}$ at 8 TeV. Looking also at the $\rm e\mu$ decay channel, CMS measures $m_{\rm top}^{\rm pole} = 173.8^{+1.7}_{-1.8}$ GeV. This is the most precise result found by CMS, when using the NNPDF3.0 PDF set.

In the CMS document [17] the top quark mass is extracted from a simultanoeus template fit to the invariant mass of the leading lepton-J/ψ candidate, in a sample enriched in top decays with $\rm b \to J/\psi + X \to \mu^+\mu^- + X$. This sample corresponds to 19.7 $\rm fb^{-1}$ pp collisions at 8 TeV. The method provides a top quark mass measurement of 173.5 ± 3.0 (stat.) $\pm\,0.9$ (syst.) GeV. A similar study has been presented by CMS [18] where the top quark mass is measured using only the kinematic properties of its charged decay products, showing minimal sensitivity to experimental sources of uncertainty. This result, together with all alternative top mass measurements, can be found in Figure 1 (right). Finally, in the CMS document [19] a novel technique for measuring the top quark mass using only leptonic observables is discussed, by analyzing top quark pair events with one electron, one muon and at least one jet in the final state, sleected from 19.7 $\rm fb^{-1}$ of 8 TeV pp data. The transverse momentum distribution of the charged lepton pair is chosen to extract the following top mass, 171.7 ± 1.1 (stat.) $\pm\,0.5$ (exp.)$^{+2.5}_{-3.1}$ (theory)$^{+0.8}_{-0.0}$ ($p_{\rm T}$) GeV.

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