Measurement of the W-boson mass in top-quark decays from tt-bar production in lepton and jets events in proton-proton collisions

Warda Al Saidi for the CMS Collaboration [*1]

[1]Supervisors: Dr. Martijn MULDERS and Markus Seidel
[1]Sultan Qaboos University, Collage of Science, Department of Physics, Box 36, Al-Khoud, Oman

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1 Abstract

A measurement is performed of the mass of the W-boson produced in top quarks events. CMS data was used and simulation samples from previous top studies in the CERN CMS group to develop this new analysis method. The measurement is based on $13TeV$ proton-proton collision data corresponding to and integrated luminosity of $35.9fb^{-1}$, the measured mass of the W-boson was found to be equal $m_w = 80.317 \pm 0.072(\text{stat}) \pm 1.315(syst) \pm 1.317(Total)GeV$ to and the measurement of the mass difference between the W+and W- bosons yields $m_{W+} - m_{W-} = 0.008 \pm 0.149(stat) \pm 0.488(syst) \pm 0.509(Total)GeV$. The results where compared with PDG, Tevatron's, LEP and ATLAS (2017).

2 Introduction

The European Organization for Nuclear Research (CERN) built the Large Hadron Collider (LHC), which is the world's largest and most powerful par-

*bntalsaid@gmail.com

ticle collider. The collider consist of four crossing points, around which are positioned seven detectors, each designed for certain kinds of research these include the general purpose detector a Toroidal LHC Apparatus (ATLAS) and Compact Muon Solenoid (CMS), ATLAS and CMS both aiming a peak luminosity of $L = 10^{34} cm^2 s^1$ for proton operation [1].

The Standard Model (SM) of elementary particles provides an accurate description of results from many accelerator and non-accelerator based experiments. The SM comprises quarks and leptons as the building blocks of matter, and describes their interactions through the exchange of force carriers: the photon for electromagnetic interactions, the W and Z bosons for weak interactions, and the gluons for strong interactions [2].

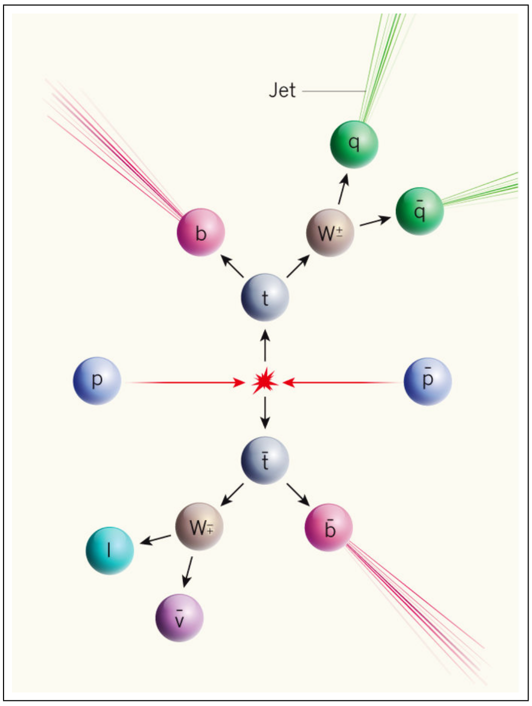

Figure 1: Diagram of semi-leptonic tt decay, consists of two quarks (jets), two b-quarks (b-jets), one charged lepton and one neutrino.

The top quark is one of six types of quarks predicted by the standard model of particle physics and the most massive among the observed elementary particle.The collisions of protons and antiprotons in the CMS, among many other possible reactions can produce a pair of top quarks, one top quark and one anti-top quark. The top quark produced primarily by the strong interaction, but can only decay through the weak force. It decays to a W boson and either a bottom quark (most frequently), a strange quark, or, on the rarest of occasions, a down quark besides jets as shown in figure1 [3].

3 Material and Method

The goal of this project is to measure the W boson mass by using the W bosons that are produced in the decays of top quarks. The work starts by a very basic event selection to select a pure sample of top pair events with one good lepton. The selections require one good lepton (muon or electron) and exactly 2 b-tagged jets and 2 non-b-tagged jets. The 2 jets are not b-tagged are assumed to originate from W boson decay used to measure the invariant mass of the W boson. The mass of the W boson is determined from fitting the histogram obtained from the code.
Monte Carlo simulation is used in this experiment since in High Energy Experiments when elementary particles collide in accelerators (for example) unstable particles are created; these particles decay quickly [4]. It is necessary to reconstruct an "image" of the event through measurements by complex detectors comprising many sub detectors. The Monte Carlo simulation role is to mimic what happens in the spectrometers to understand experimental conditions and performance. The fitted mass in Monte Carlo was used calibrate the analysis and to correct the result measured in data.

4 Results and discussion

The data sample used in this analysis was collected with the CMS detector in proton-proton collisions at the LHC at a center- of-mass energy of $\sqrt{s} = 13TeV$. The sample with all relevant detector systems operational corresponds to approximately $35.9fb^{-1}$ of integrated luminosity. Top-quark pair production where used from previous study in CMS, a program was produced to select events, figure2 shows W, W+ and W- histogram from tt-bar event the fitted data results shows that $m_W = 80.976 \pm 0.064GeV$, $m_{W+} = 80.969 \pm 0.094GeV$ and $m_{W-} = 80.910 \pm 0.093GeV$ respectively, while Monte Carlo results were $m_W = 81.059 \pm 0.033GeV$, $m_{W+} = 81.084 \pm 0.048GeV$and $m_{W-} = 81.033 \pm 0.049GeV$.

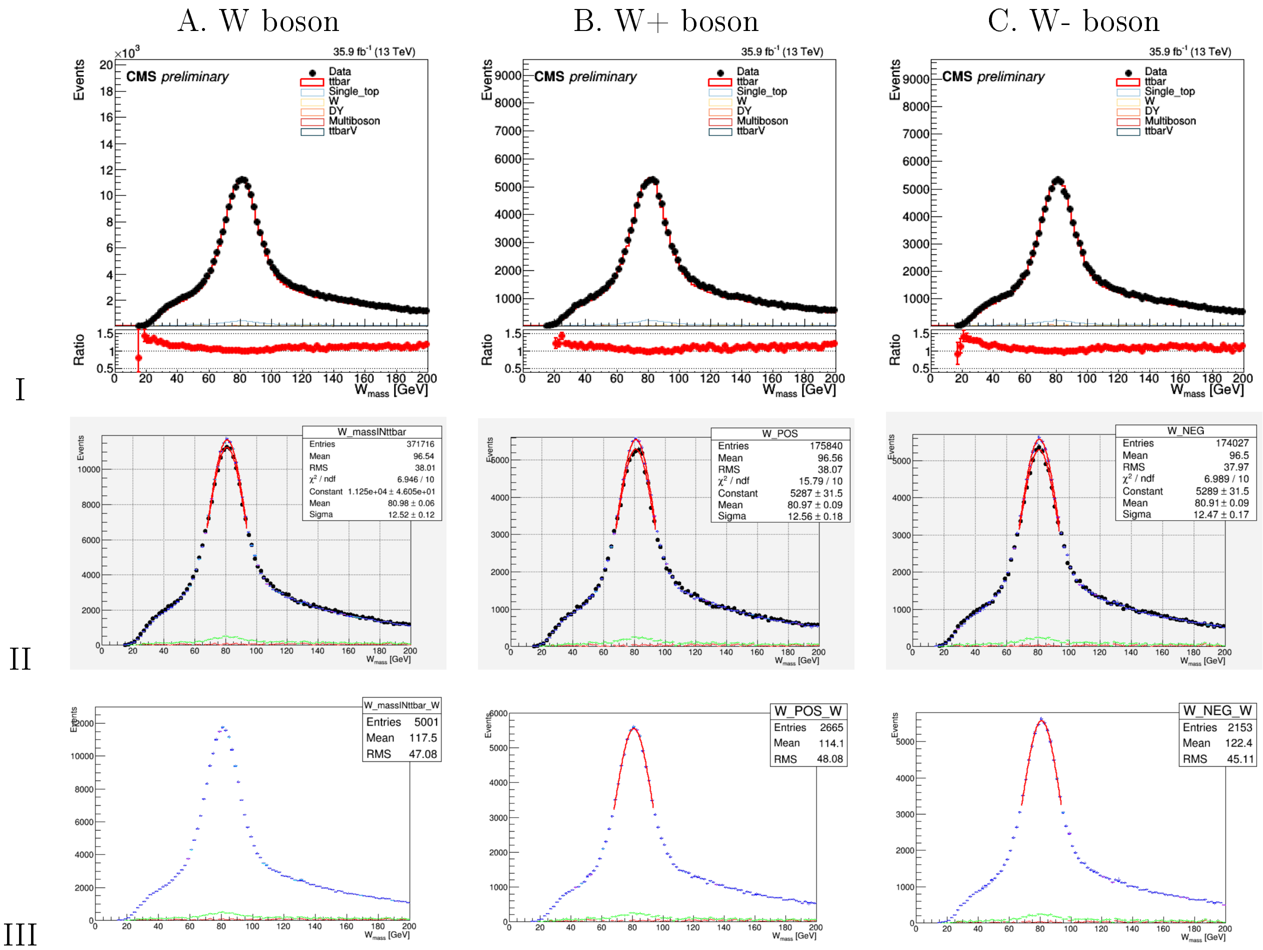

Figure 2: (A I) is the invariant mass of the W boson, (BI) and (CI) is the invariant mass of W+ and W – respectively. (AII, BII and CII) is a calibration of the invariant mass fit distribution with Monte Carlo technique for W, W+, W- respectively. (AIII,BIII and CIII) is the Monte Carlo simulation for W, W+ and W- respectively.

The corrected mass was found to be $80.317 \pm 0.072(stat)GeV$to and the measurement of the mass difference between the W+and W-bosons yields $m_{W+} - m_{W-} = 0.008 \pm 0.149(stat)GeV$. Results from the analysis were compared with PDG, Tevatron's, LEP and ATLAS (2017) for the difference between positive and negative W (Figure 3a) and for W mass (Figure 3b) along with the prediction of how the statistical error of W- boson mass will change after run 2 and HL-LHC. It is clear for the difference between positive and negative W that the error is currently better than the PDG ((Particle Data Group) error while ATLAS is less. In figure.3-b the statistical error is currently higher than Tevatron's, LEP and ATLAS (2017).

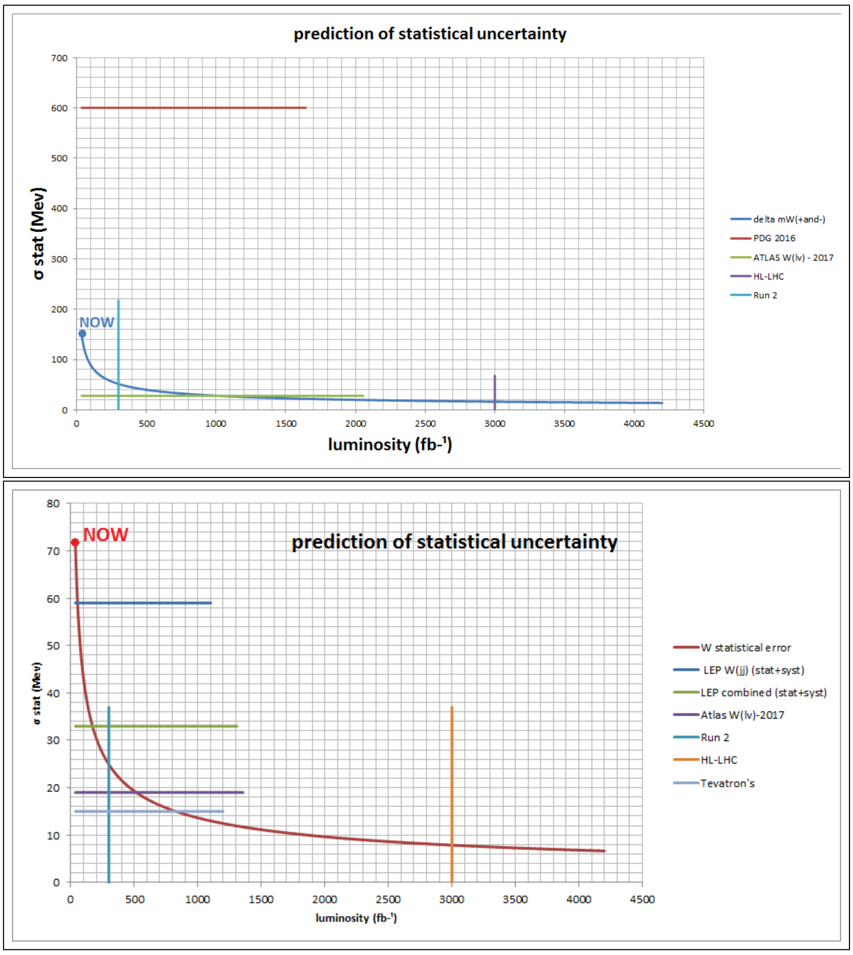

Figure 3: The statistical uncertainty compared with PDG, Tevatron's, LEP and ATLAS (2017). (a): for the difference between positive and negative W and (b). for the W mass..

The systematic uncertainties of the m_W measurements are listed in Table 1. Effects considered include QCD modeling, extra jets from initial state or final state radiation and colour reconnection. Jet energy calibration is not included but could be significant ($< 1\%$). The colour flip (CF) model assumes that the W boson is a colour octet not a colour singlet, this model is so extreme, and that we didn't include it in the total uncertainty. However, for the $m_{W+} - m_{W-}$ all systematic uncertainty are reduced. The measured mass of the W-boson was found to be equal $m_w = 80.317 \pm 0.072(stat) \pm 1.315(syst) \pm 1.317(Total) GeV$ to and the measurement of the mass difference between the W+and W-bosons yields $m_{W+} - m_{W-} = 0.008 \pm 0.149(stat) \pm 0.488(syst) \pm 0.509(Total) GeV$.

Source	$\Delta(M_W)[Gev]$	$\Delta(M_{W+} - M_{W-})[Gev]$
Generator used for b-hadron decay (evtgen)	0.135	0.178
Top mass	0.011	0.038
Decay width of top quark	0.016	0.055
Initial state radiation	0.019	0.049
final state radiation	1.143	0.258
different top mass value (m171v5)	0.081	0.078
Parton shower program (herwig)	0.337	0.016
matrix element radiation (hdamp)	0.023	0.070
Underlying events	0.037	0.213
Early residence decay (erdON)	0.392	0.035
Colour reconnection model (qcdBased)	0.356	0.259
Colour reconnection model (gluonMove)	0.040	0.116
Colour flip (CF) reconnection model*	2.562	0.276
Statistical uncertainty	0.072	0.149
Total systematic uncertainty without CF	1.315	0.488
Total uncertainty without CF	1.317	0.509

table 1: Systematic uncertainties of the W boson measurement of the$35.9 fb^{(-1)}$, data set

The measured value of the W boson mass is compared to other published results (Figure 4), including measurements from the LEP2 experiments ALEPH, DELPHI, L3, OPAL, Tevatron ,CDF and D0 [5], and ATLAS [6].The statistical and total uncertainties are only shown for CMS and ATLAS. On the other hand, other published results have the total uncertainty. The red vertical line indicates the value from the PDG, while the green line indicates the predicted W mass value from the electroweak fit. The first figure contains both statistical and full uncertainty while the second has only the statistical uncertainty. Figure 5 shows us the comparisons between the W+ and W- boson compared with CDF[7],ATLAS[6] and PDG.

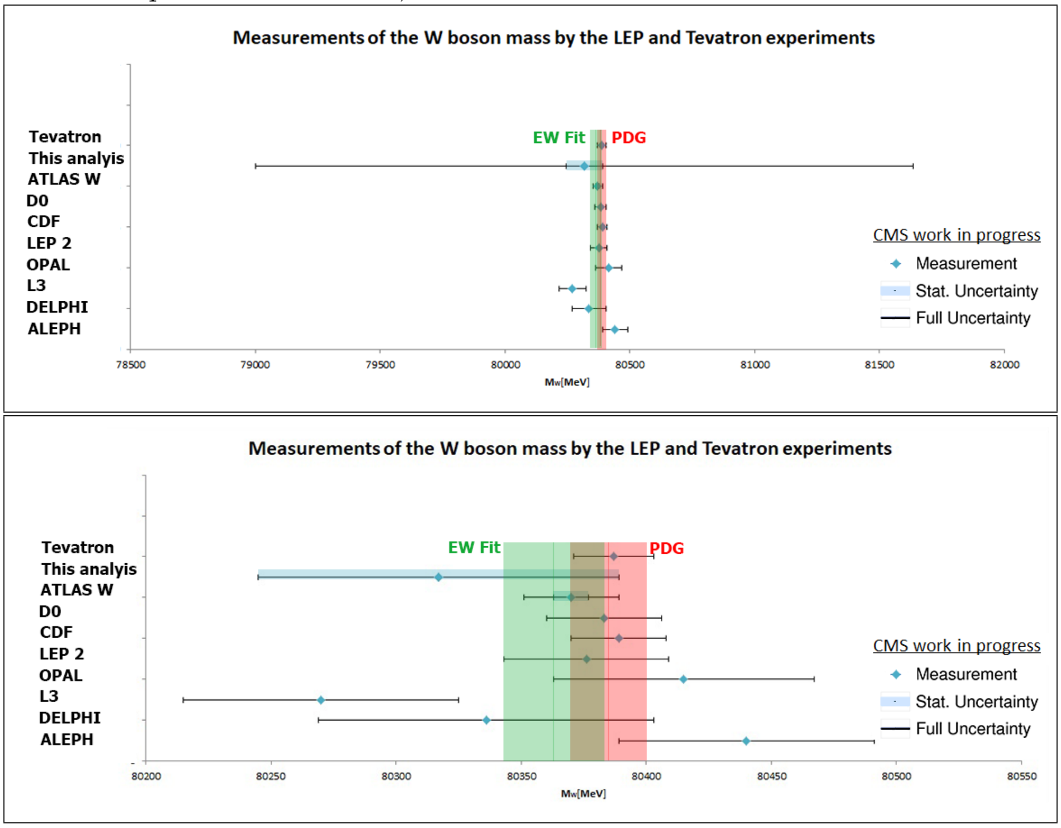

Figure 4: The measured value of W boson compared with other published results.

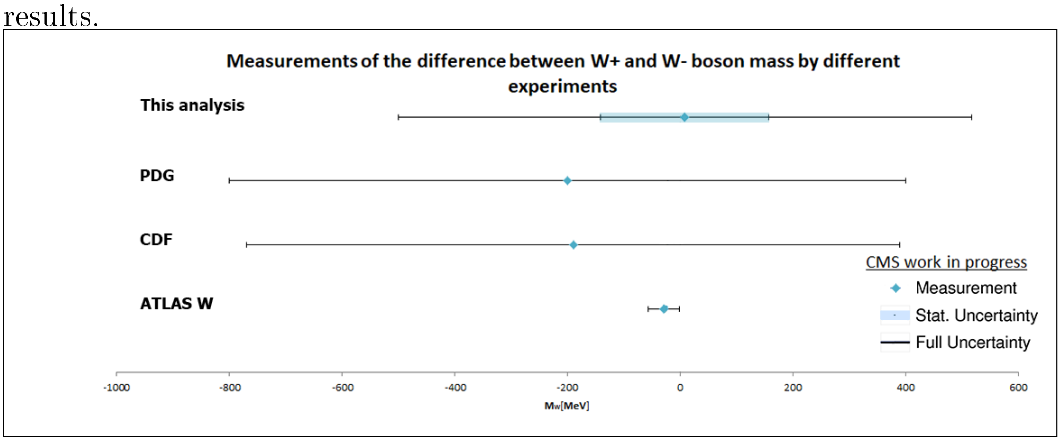

Figure 5: The measured value of W+ and W- boson compared with other published results.

5 Summary

This reports a measurement of the W-boson mass with the CMS detector, obtained from tt-bar events. The measurement is based on proton–proton collision data at a centre-of-mass energy of at 13 Tev the LHC, and corresponding to an integrated luminosity of $35.9fb^{-1}$. The measured value of W boson mass is $m_W = 80.317 \pm 0.072(stat) \pm 1.315(syst) \pm 1.317(Total)GeV$ and the measurement of the mass difference between the W+and W-bosons $m_{W+} - m_{W-} = 0.008 \pm 0.149(stat) \pm 0.488(syst) \pm 0.509(Total)GeV$.

6 References

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