W Mass Measurement at D0

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Abstract. Within the Standard Model (S.M) of particle physics the W boson mass is sensitive to the mass of the Higgs boson. The Higgs boson is the quantum of the Higgs field which generates the mass of elementary particles within the S.M.. Precision measurement of the W mass, top quark mass, and the Fermi coupling (G_F) allow one to constrain the allowed mass of the Higgs boson within this model. The D0 collaboration has determined the mass of the W boson to be 80.375 GeV +- 0.023 GeV [1] by combining two measurements (of 4.3 and 1 inverse femtobarn/s) where the identified W decayed to an electron and a neutrino after being produced at the Tevatron (proton-antiproton collisions at 1.96 TeV in the centre of mass frame).

1. Introduction

The S.M. has proven to be an accurate description of nature, and stood as the theoretical description of our observations for far longer than expected. There are some fundamental questions which the S.M. does not address like neutrino mass, and a quantum description of gravity. Precision measurements of standard model parameters which are expected to be most sensitive to new physics are good avenues in which to probe for the onset of previously undiscovered phenomena in order to determine the underlying full description of existence.

A crucial piece to the S.M. is the scalar Higgs field responsible for dynamically generating the masses of elementary particles. A necessary result of the Higgs mechanism being a valid description is the existence of a scalar Higgs boson. The ATLAS and CMS collaborations at CERN have recently shown the existence of a new particle with properties which, while mainly unknown, are thus far consistent with that of the Higgs boson. Prior to these observations measurements of the W Mass were used to constrain the available parameter space for the Higgs boson to be found. Now that there is a candidate particle, increasing the precision with which we can predict the mass of the Higgs boson will contribute to verifying whether or not the discovered particle is consistent with the S.M. Higgs boson, or is a sign of something new.

2. Relationship between the W and Higgs Boson Masses

[1] Work done at Northwestern University, as part of the D0 collaboration, and with funding by the National Research Foundation of South Africa

The S.M. does not predict the mass of the W boson. It does predict the relationship between the mass of the W boson and other measureable quantities [2]. Using the relationship:

$$m_W = \sqrt{\frac{\pi\alpha}{2G_F}} \frac{1}{\sin\theta_w} \bullet \frac{1}{\sqrt{1-\Delta r}} \quad (1)$$

Where α, θ_w, and G_F are all well measured quantities, and the term Δr contains radiative corrections to the W mass which are dominated by the interactions with the top quark and the Higgs boson. This enables one to derive a relationship between the masses of the W boson, top quark, and Higgs Boson. Armed with this relationship and measurements of the masses of the top quark and the W Boson one can determine the allowed range of masses for the S.M. Higgs Boson

3. Apparatus

3.1. The Tevatron

The Tevatron was a proton -- antiproton collider at a centre of mass energy of 1.98 TeV which ceased operation in 2011 and was responsible, amongst many other feats, for the discovery of the top quark in 1995. The result shown uses 5.3 fb^{-1} of data collected between 2001 and 2009 [1].

3.2. The upgraded D0 detector [3]

The D0 Detector consists of an inner tracking volume (silicon, and scintillating fibres) within a magnetic field. This is surrounded by 3 liquid argon calorimeters, one for the central region covering $|\eta| < 1.05$, and two end caps extending coverage to ± 2.3 in η for this analysis. Outside of this lies the muon subsystem which is ignored in this analysis. For full technical details please refer to ref. [3]

4. Measurement Strategy

Once produced a W boson decays instantaneously decays to quarks or leptons. Due to the excellent performance of the D0 detector with respect to electron identification and energy determination we determine the mass of the W boson by examining events where the W boson has decayed to an electron (positron) and an antineutrino (neutrino). For the remainder of this text the term electron should be understood to be an inclusive term for both electrons and positrons, and the term neutrino, similarly to include anti-neutrinos since we make no charge distinction in this analysis.

4.1. Observables sensitive to the W Boson Mass

Since the neutrino escapes undetected it is impossible to reconstruct the invariant mass peak of the W boson. Additionally since the W boson is produced by an interaction between the quark constituents of the proton we do not know the initial energy and momentum of the system in the longitudinal direction (along the beam). We do know that the transverse momentum vector ($\mathbf{p_T}$) of the incoming system is zero. Measuring the total transverse momentum of the event we attribute the difference between the incoming and outgoing momenta (called the MET) to the momentum carried away by the neutrino.

We make use of three predictable distributions which are sensitive to the mass of the W boson, namely: The transverse momentum of the electron $p_T(e)$ shown in Figure 1.,the MET, and the transverse mass m_T shown in Figure 2 and defined below:

$$m_T^2 = (E_T(e) + MET)^2 - \left(\overrightarrow{p_T}(e) + \overrightarrow{MET}\right)^2 \quad (2)$$

Each of these distributions are sensitive to different effects as shown in figures 1 and 2 where the black line shows the distributions with no detector effects and W bosons produced at rest. The yellow histogram shows how each distribution changes when one uses a realistic model for the transverse momentum distribution of the produced W bosons, one notices that the transverse mass is insensitive to this effect. The red points show the change in these distributions when a realistic model of detector smearing is used. The transverse momentum distribution of the electron is insensitive to detector resolution effects. The MET suffers from the resolution effects of the recoil system (sensitive to detector resolution), and the initial transverse momentum of the W boson and as such is used as a cross check not a contributor to the final mass determination.

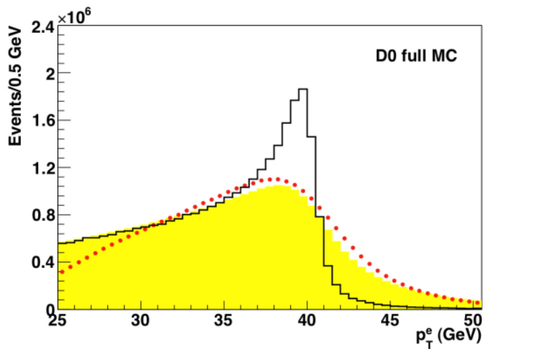

Figure 1. Transverse momentum distribution of the electron decay products of a W boson under assumptions described in the text

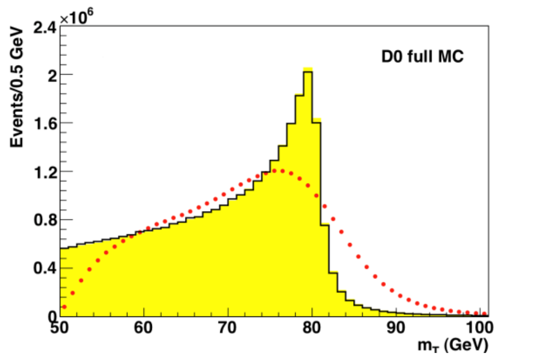

Figure 2. Transverse mass distribution of W boson events under various assumptions as described in the text.

4.2. Determining the W Boson Mass

We make use of the RESBOS [4] event generator coupled with the CTEQ6.6 parton distribution functions [5] to produce a large samples of W boson events which decay in the electron channel, the Pythia generator to describe the remnants of the proton antiproton system, the PHOTOS[6] to describe the effect of photon radiation from the electron to generate a realistic description of a W boson event with the correct kinematics. We pair this with a realistic fast description of the D0 detector including efficiencies, response, and electronic noise to provide templates of the variables described above for a range of different values of the W boson mass. Using a maximum likelihood method we find the distributions which most closely resemble the data and assign the mass value used to generate that template as the mass of the W Boson.

Our ability to calibrate the detector, as well as determine the parameters for our fast simulation of the detector response is due to the excellent work done at LEP [7] to measure the properties of the Z boson which we rely on heavily.

4.3. Backgrounds

There are three significant sources of backgrounds which are added to the templates for comparison to the data.

- Di-jet events where a jet is misidentified as an electron, which introduces a large MET due to the incorrect application of the electron calibration.
- Events where a Z boson is produced and decays to 2 electrons, but one is lost in a crack.
- Events where the W boson decays first to a tau lepton and neutrino, the tau then decays to an electron.

The background from the tau decay channel is determined from RESBOS, the other contributions are determined by studying the data.

5. Uncertainties

A proper description of the systematic uncertainties is beyond the scope of this note. They are determined by varying the relevant parameters in our model up and down by 1 and 2 standard deviations from their optimal values. Correlations are accounted for. The dominant uncertainty is from the determination of the electron energy scale which depends on the Z boson yield and will be reduced with a larger data sample. (Although D0 is no longer taking data more data than used here has been collected)

6. Result

We have measured the mass of the W boson to be 80.375 ± 0.023 GeV by combining two individual measurements of the W boson mass. Figure 3 (4) shows the best fit template and background estimation compared to the data for the transverse mass (electron transverse momentum) distribution, along with the chi value for each point.

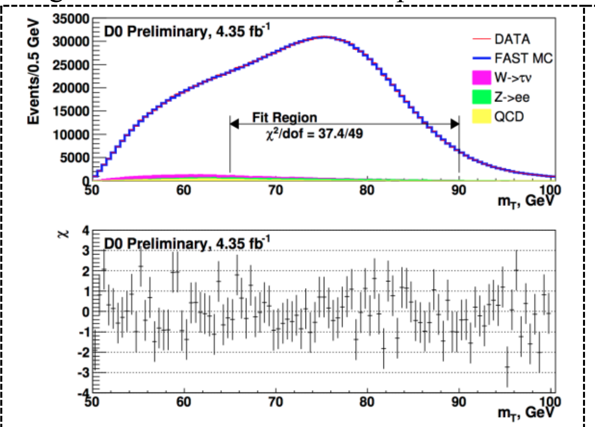

Figure 3. best fit template and background estimation compared to the data for the transverse mass distribution, along with the chi value for each point..

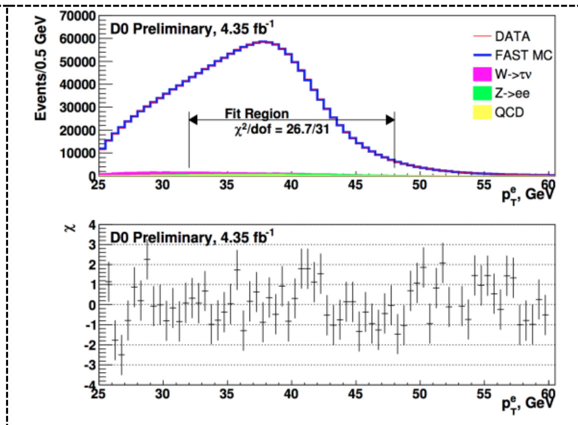

Figure 4. best fit template and background estimation compared to the data for the electron transverse momentum distribution, along with the chi value for each point.

This is consistent with previous measurements and when combined with similar work by the CDF[8] collaboration leads to a new world average value of 80.385 ± 0.015 GeV. Figure 4 shows a comparison of the world average to previous measurements.

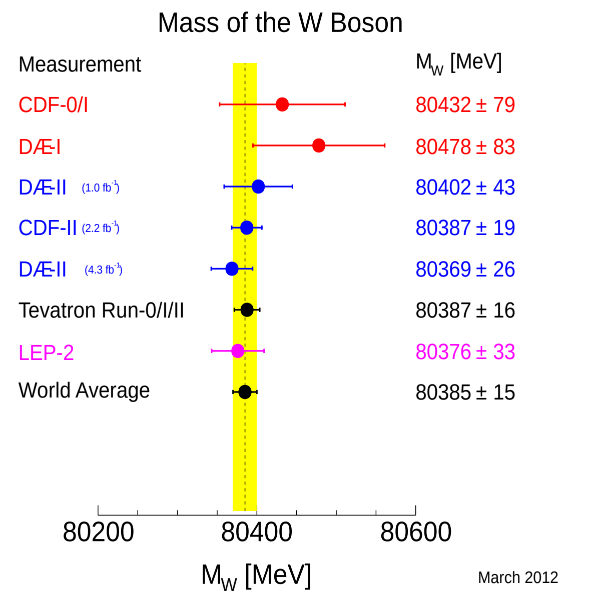

Figure 5. The current world average mass of the W Boson (dashed line) and uncertainty (yellow band) compared to measurements from LEP and the Tevatron [9].

References

[1] V. M. Abazov et al. (D0 Collaboration), *Phys. Rev. Lett. 108*, 151804 (2012)

[2] F. Jegerlehner, M. Y. .Kalmykov and O. Veretin, *Nucl. Phys. B 641*, 285 (2002)

[3] V.M. Abazov et al. (D0 Collaboration), *Nucl. Instrum. Methods in Phys. Res.* A565, 463 (2006).

[4] C. Balazs and C.P. Yuan, *Phys. Rev. D56*, p. 5558-5583(1997).
G. A. Ladinsky and C.-P. Yuan, The nonperturbative regime in QCD resummation for gauge boson production at hadron colliders, *Phys. Rev. D50*, 4239 (1994).
C. Balazs and C.-P. Yuan, Soft gluon effects on lepton pairs at hadron colliders, *Phys. Rev. D56*, 5558 (1997).

[5] P. M. Nadolsky et al., *Phys. Rev. D* 78, 013004 (2008).

[6] P. Golonka and Z. Was, PHOTOS Monte Carlo: A Precision tool for QED corrections in Z and W decays, *Eur. Phys. J. C*45, 97 (2006)

[7] The ALEPH, DELPHI, L3, OPAL, SLD Collaborations, the LEP Electroweak Working Group, the SLD Electroweak and Heavy Flavour Groups, *Phys. Rep. 427* Nos. 5-6, 257 (2006).

[8] T. Aaltonen *et al.* (CDF Collaboration), *Phys. Rev. Lett. 108*, 151803 (2012)

[9] The LEP Electroweak Working Group