Latest Electroweak Results from CDF

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Abstract. The latest results in electroweak physics from proton anti-proton collisions at the Fermilab Tevatron recorded by the CDF detector are presented. The results provide constraints on parton distribution functions, the mass of the Higgs boson and beyond the Standard Model physics.

1. Introduction
Electroweak physics studies the properties and interactions of the electroweak gauge bosons: the $W$, $Z$ and photon. $W$ and $Z$ particles are being produced at a prodigious rate in proton anti-proton collisions at a centre of mass energy of 1.96 TeV at the Fermilab Tevatron. The CDF detector has already recorded around 6 million $W$ and 600,000 $Z$ bosons and before the end of data-taking in 2011 will have accumulated samples that will be twice those anticipated from the first LHC running period (1 fb$^{-1}$ of integrated luminosity at $\sqrt{s} = 7$ TeV). These large data samples allow the electroweak sector to be probed to high accuracy. Measurements of the rapidity distributions of $W$ and $Z$ bosons are providing precise constraints on the parton distribution functions (PDFs) and a study of di-boson production ($WW$, $ZZ$, $WZ$, $W\gamma$, $Z\gamma$) and searches for rare decay modes e.g. $W \rightarrow \pi\gamma$ are providing stringent constraints on physics beyond the Standard Model (SM). A precise measurement of the mass, $M_W$, of the $W$ boson (in conjunction with that of the top-quark) allows one to predict the mass of the Higgs boson which presently points to a light Higgs boson. The results presented in the following sections are from 3–5 fb$^{-1}$ of integrated luminosity. At the time of writing CDF is analysing datasets of $\sim 7$ fb$^{-1}$ and is expected to accumulate $\sim 10$ fb$^{-1}$ before the scheduled end of the Tevatron programme in September 2011 and as such significant further improvements in the precision and scope with which the electroweak sector can be probed are expected.

2. PDF Constraints
Precise PDFs are necessary to make robust predictions of the SM background and new physics at all colliders, but particularly the LHC. The LHC will ultimately provide some of the measurements that constrain PDFs but at present the constraints predominantly come from HERA (and fixed-target) deep-inelastic data, HERA/Tevatron jet-data and Drell-Yan data both from the Tevatron and at lower centre of mass energy experiments. The rapidity, $Y_Z$, of the $Z$ from a Drell-Yan event is given by $Y_Z = 0.5 \ln \left( \frac{x_p}{x_F} \right)$ where $x_p(x_F)$ is the momentum fraction of the quarks in the proton (anti-proton) participating in the Drell-Yan process. At large values of $|Y_Z|$ one thus simultaneously probes the high-$x$ and low-$x$ structure of the proton which are the regions of greatest PDF uncertainty. The $u$-valence distribution is already well constrained by $F_2$ data and consequently the latest CDF $Z$ rapidity data [1] allows a robust determination of the
3. Di-boson Cross Sections and Anomalous Gauge Couplings

The study of di-bosons at the Tevatron is interesting for two reasons. Firstly beyond the SM (BSM) physics would likely manifest itself in anomalous couplings resulting in enhanced production rates and secondly di-boson production are generally backgrounds to the Higgs signal.

The lepton decay channels present the cleanest mode of identifying di-bosons, albeit at the expense of a small branching fraction. CDF has recently remeasured [10] the $W$W cross section in the leptonic decay mode and obtained $\sigma_{WW} = 12.1^{+1.8}_{-1.7}$ pb in good agreement with the SM prediction [11] of $11.7 \pm 0.7$ pb. It has also obtained limits (for $\Lambda = 1.5$ TeV) on the anomalous couplings: $\lambda_Z < 0.16, \Delta g_1^Z < 0.34$ and $\Delta h^Z < 0.72$. CDF has also observed the $ZZ$ signature in the leptonic mode with a significance of greater than $5\sigma$ for the first time, allowing a cross section of $\sigma_{ZZ} = 1.56^{+0.5}_{-0.66}$ (stat.) $\pm 0.25$ (syst.) pb to be determined which again is in good agreement with the SM prediction of $1.4 \pm 0.1$ pb [11].

In the recent analyses the emphasis has been to identify $WZ/ZZ/WW$ decays where one of the bosons decays hadronically. CDF has used two different selection methods for this purpose: the first requires $H_T$ and two jets and is a cut-based analysis and the second requires a charged lepton, $H_T$ and two jets and is a log-likelihood based analysis. The second selection clearly precludes the $ZZ$ mode. In both cases signals of $\sim 1,500$ events are observed with significances in excess of $5\sigma$ with cross sections in good agreement with the SM. For example the cut based analysis measures a cross section of $18.0 \pm 2.8$ (stat.) $\pm 2.6$ (syst.) pb compared to the SM
prediction of $16.8 \pm 0.5$ pb. The successful demonstration from the di-boson samples that $W$ and $Z$ bosons can be successfully identified from the hadronic decay mode is particularly valuable in the context of Higgs searches since the application of the same techniques can be used to enhance the number of possible signal events.

A search for anomalous couplings has also recently been performed in the $Z\gamma$ channel where such couplings would enhance the rate of high $E_T$ photons. A search in the region of $E_T^Z > 40$ GeV resulted in 91 events with a background $\ll 1$ compared to a SM expectation of 89 events. Limits on anomalous couplings ($h_3, h_4$) which physically correspond to anomalous electric-dipole and magnetic-quadrupole moments of the $Z$ have been determined to be: $|h_3| < 0.037$, $|h_4| < 0.0017$ which are already significantly better than the LEP limits and which are expected to improve by approximately a factor of two when the $Z \rightarrow \nu\bar{\nu}$ channel is incorporated into the analysis.

4. Beyond the Standard Model Constraints
In addition to the analysis of di-bosons, the large number of single $Z$ and single $W$ events can be used to probe for BSM physics. A measurement of the forward backward asymmetry of the decay leptons from $Z$ decays ($A_{FB}$) is sensitive to the presence of new $Z$ bosons and the rare decay $W \rightarrow \pi\gamma$ is expected to be enhanced in the presence of BSM interactions. CDF has measured $A_{FB}$ up to masses of 500 GeV/$c^2$ using 4.1 fb$^{-1}$ of integrated luminosity and found excellent agreement with the SM which will subsequently be exploited to measure $\sin \theta_W$ to a precision that, with the full Tevatron dataset ($\sim 10$ fb$^{-1}$), should eclipse the LEP measurement. In the SM the branching ratio for the rare decay $W \rightarrow \pi\gamma$ is $\sim 10^{-6} - 10^{-8}$ and is expected to be enhanced by BSM interactions. No evidence for a significant enhancement has been observed from 4.3 fb$^{-1}$ of integrated luminosity and an upper limit (at 95% confidence level) of $6.4 \times 10^{-5}$ has been placed on the branching fraction.

5. Outlook
The Tevatron is performing extremely well and is presently delivering integrated luminosities in excess of 50 pb$^{-1}$ per week and is expected to deliver 10 fb$^{-1}$ before the nominal end of the run in September 2011. This will result in electroweak samples far larger than those expected from the first LHC run and significant improvements over the analyses presented here are to be expected with increases by factors of at least two in statistical precision across all analyses which are for the most part still statistically limited. CDF expects to measure the $W$ mass to a precision of better 20 MeV/$c^2$ which in conjunction with a top mass measured to 1 GeV and the central values remaining the same offers the tantalising prospect of establishing an upper limit on the Higgs mass (at 95% confidence level) below the LEP2 direct search limit of 114 GeV/$c^2$. Anomalous couplings and rare decays will be probed with increased precisions and improved PDF constraints are expected as the theoretical treatment is refined. The future for electroweak physics at CDF is a rosy one.

Acknowledgments
I would like to thank the organizers of the Lake Louise Institute for a supremely well organized, stimulating and enjoyable conference in an stunning location and my congratulations to the host nation in winning the Ice Hockey Olympic gold medal. I would also like to thank the STFC for their financial support that enabled me to present results at this conference.

References


