PROCEEDINGS OF SCIENCE

Is it possible to reach $\Delta M_W \leq 10$ MeV at the LHC?*

M.W. Krasny[1], **F. Dydak**[2], **F. Fayette**[1], **W. Płaczek**[3], **and A. Siódmok**[4†]
[1] *LPNHE, Universités Paris VI et VII and CNRS–IN2P3, Paris, France*
[2] *CERN, Geneva, Switzerland*
[3] *Institute of Physics, Jagiellonian University, Cracow, Poland*
[4] *Institut für Theoretische Physik, Karlsruhe Institute of Technology, Karlsruhe Germany*
E-mail: Andrzej.Siodmok@cern.ch

At the LHC, the measurement of the W mass with a precision of $\mathscr{O}(10)$ MeV is both mandatory and difficult. In the analysis strategies proposed so far, shortcuts have been made that are justified for proton–antiproton collisions at the Tevatron, but not for proton–proton collisions at the LHC. The root of the problem lies in the inadequate knowledge of parton density functions of the proton. It is argued that in order to reach a 10 MeV precision for the W mass, more precise parton density functions of the proton are needed, and an LHC-specific analysis strategy ought to be pursued. Proposals are made on both issues. This paper is an abbreviated version of [1].

35th International Conference of High Energy Physics - ICHEP2010,
July 22-28, 2010
Paris France

*Work in part supported by the cooperation programme between the French IN2P3 and Polish, COPIN Laboratories No. 05-116, and by the EU Marie Curie Research Training Network grant No. MRTN-CT-2006-035505
†Speaker.

PoS(ICHEP 2010)091

1. Introduction

The relation between Fermi coupling constant G_F, the fine-structure constant, the Z and W bosons masses (M_W, M_Z) is a cornerstone of the Electroweak Standard Model (SM). Among these independent input parameters of the Electroweak SM, the M_W is by one order of magnitude less precise than M_Z that is one before last. The Z mass is well measured to ± 2.1 MeV [2], while M_W is measured at the Tevatron to ± 31 MeV [3][1]. Therefore, the measurement of the W mass at the LHC with a precision of $\mathcal{O}(10)$ MeV is *per se* important, and even more important if the Higgs boson will not be found.

2. Measurement of the W mass at the LHC

In previous analyses, it was claimed that an M_W precision of 10 MeV or better will be obtained at the LHC [4, 5]. Here we show that shortcuts have been made that are not justified, and hence the claimed measurement precision is much too optimistic. The reason is that the analysis of $p_{T,l}$ spectra from leptonic W and Z boson decays in $p\bar{p}$ collisions at the Tevatron—that served as template for the respective analyses at the LHC—benefits from symmetry properties that are absent in pp collisions at the LHC. In particular, at LHC the difference in the rates and the momentum spectra of charged leptons from W^+ and W^- decays renders a common analysis of leptons with positive and negative charge questionable. Therefore, M_{W^+} and M_{W^-} have to be separately determined or equivalently, like used in this paper, the average $(M_{W^+} + M_{W^-})/2 = M_W$ and the difference $M_{W^+} - M_{W^-}$ of the masses.

In presented studies as an example LHC detector, ATLAS is chosen. Charged leptons from W and Z decays are accepted with $p_T > 20$ GeV/c and $|\eta| < 2.5$. The event statistics correspond to an integrated luminosity of 10 fb^{-1}. Both the electron and muon decay channels of W and Z are considered. In pp as well as in $p\bar{p}$ collisions, M_W is determined by the Jacobian peak in the p_T spectrum of charged leptons from $W \to l\nu$ decays. From a fit of the Jacobian peaks in the p_T distributions and by calibrating with the known Z mass, the W^+ and W^- masses are determined.

3. A biased W mass

It is advocated and widely believed that the proton PDFs are precise enough not to pose a limitation for LHC data analysis. For example, the u_v and d_v PDFs are claimed to be precise to 2% [6]. Why then differ the CTEQ [7] and MSTW [8] proton PDFs by much more than 2%, as shown in Ref. [8], although they stem largely from the same input data? In our studies we use a 5% error of the PDFs of the u and d quarks which appears more realistic. The present experimental uncertainty of the PDF of the c quark is at the 10% level[2] and the b quark is at the 20% level, see Ref. [8]. The above uncertainties of PDFs are incorporated in the simulation of p_T spectra from W^+, W^- and Z leptonic decays. This simulation uses the LHAPDF package [9] of PDFs, and PYTHIA 6.4 [10] for the modelling of the QCD/QED initial-state parton shower and its hadronization; the transverse momentum k_T of quarks and antiquarks is the one incorporated in

[1] The ultimate W mass error at the Tevatron may be as low as ± 15 MeV.

[2] Theoretical calculations of heavy-quark PDFs from the gluon PDF are claimed to have a smaller error margin.

PYTHIA. The tool for event generation is WINHAC 1.31 [13, 11, 12], a Monte Carlo generator for single W production in hadronic collisions, and subsequent leptonic decay. WINHAC includes also neutral-current processes with γ and Z bosons in the intermediate state.

Tables below list the biases of M_W and of $M_{W^+} - M_{W^-}$ caused by compensating changes of the PDFs of quarks of the 1st family[3] and 2nd family (Table 1), as well as caused by changes of the PDF of the b quark (Table 2).

	ΔM_W	$\Delta[(M_{W^+} - M_{W^-})]$		ΔM_W	$\Delta[(M_{W^+} - M_{W^-})]$
$u_v^{bias} = 1.05\,u_v$ $d_v^{bias} = d_v - 0.05\,u_v$	$+79$ MeV	$+115$ MeV	$c^{bias} = 0.9\,c$ $s^{bias} = s + 0.1\,c$	$+148$ MeV	$+17$ MeV
$u_v^{bias} = 0.95\,u_v$ $d_v^{bias} = d_v + 0.05\,u_v$	-64 MeV	-139 MeV	$c^{bias} = 1.1\,c$ $s^{bias} = s - 0.1\,c$	-111 MeV	-11 MeV

Table 1: Biases from uncertainties in the 1st and 2nd quarks families.

	ΔM_W
$b^{bias} = 1.2\,b$	$+42$ MeV
$b^{bias} = 0.8\,b$	-39 MeV

Table 2: Biases from uncertainties in the 3rd quark family.

The conclusion is, when allowing for compensating PDF changes and a realistic PDF error margin, that there is no way to obtain M_W with a precision at the 10 MeV level with the currently available proton PDFs.

4. Conclusion

A considerably better knowledge of the $u_v - d_v$, $s - c$, and b parton density functions (PDFs) of the proton[4] than available today is needed, together with an LHC-specific measurement and analysis programme. No improvement of the current precision of the W mass measurement is expected unless special experimental efforts are made to obtain the missing high-precision PDFs. Two possible ways forward are presented in [1, 15, 16]. One is to complement the pp programme of the LHC with a deuteron–deuteron collision programme. Another is to obtain missing input from a new high-precision muon–nucleon scattering experiment, and to analyze these data coherently with LHC pp and Tevatron $p\bar{p}$ data.

References

[1] M. W. Krasny, F. Dydak, F. Fayette, W. Placzek and A. Siodmok, Eur. Phys. J. C **69** (2010) 379 [arXiv:1004.2597 [hep-ex]].

[3] The differences $M_{W^+} - M_{W^-}$ are taken from Ref. [14].

[4] Throughout this paper, PDFs refer to the proton.

[2] C. Amsler *et al.* (Particle Data Group), Phys. Lett. **B667** (2008) 1

[3] The Tevatron Electroweak Working Group, Updated Combination of CDF and D0 results for the Mass of the W Boson, FERMILAB–TM–2439–E, arXiv: 0908.1374 [hep-ex]

[4] ATLAS Detector and Physics Performance, Report ATLAS TDR 15 (CERN/LHCC 99-15); N. Besson *et al.* (ATLAS Collaboration), Eur. Phys. J. **C57** (2008) 627, arXiv: hep-ex/0805.2093; N. Besson (for the ATLAS Collaboration), presentation at the Int. Europhysics Conference on High Energy Physics (EPS–HEP2009), Cracow (Poland), July 2009

[5] V. Buge *et al.* (CMS Collaboration), J. Phys. **G34** (2007) 995

[6] J. Stirling, MSTW2008: Parton distributions for the LHC, Seminar given at CERN on 18 February, 2009

[7] P.M.Nadolsky *et al.*, Phys. Rev. **D 78** (2008) 013004, arXiv:0802.0007 [hep-ph]

[8] A.D. Martin *et al.*, Parton distributions for the LHC, arXiv:0901.0002v2 [hep-ph]

[9] M.R. Whalley, D. Bourilkov, and R.C. Group, arXiv: hep-ph/0508110

[10] T. Sjostrand, S. Mrenna, and P. Skands, JHEP **05** (2006) 26

[11] W. Płaczek and S. Jadach, http://cern.ch/placzek/winhac

[12] W. Płaczek, WINHAC–the Monte Carlo event generator for single W-boson production in hadronic collisions, PoS (EPS-HEP 2009) 340, arXiv: 0911.0572 [hep-ph]

[13] W. Płaczek and S. Jadach, Eur. Phys. J. **C 29** (2003) 325

[14] F. Fayette *et al.*, Eur. Phys. J. **C63** (2009) 33, arXiv:0812.2571

[15] M. W. Krasny, F. Fayette, W. Placzek and A. Siodmok *et al.*, Eur. Phys. J. **C51**, 607 (2007), hep-ph/0702251

[16] F. Dydak, M. W. Krasny, and R. Voss, Document CERN-SPSC-2009-028 / CERN-LHCC-2009-014