Electroweak physics at the LHC

J Berryhill[1] **and A Oh**[2]

[1] Fermi National Accelerator Laboratory, Batavia, IL, USA

[2] School of Physics and Astronomy, University of Manchester, Manchester, UK

Abstract. The Large Hadron Collider (LHC) has completed in 2012 its first running phase and the experiments have collected data sets of pp collisions at center-of-mass energies of 7 and 8 TeV with an integrated luminosity of about 5 fb^{-1}and 20 fb^{-1}, respectively. Analyses of these data sets have produced a rich set of results in the electroweak sector of the standard model. This article reviews the status of electroweak measurements of the ATLAS and CMS experiments at the LHC and discusses phenomenological developments in the electroweak sector.

PACS numbers: 12.15.-y, 12.60.Cn, 14.70.-e

Submitted to: *J. Phys. G: Nucl. Part. Phys.*

1. Introduction

1.1. Motivation to study the electroweak sector

1.2. Electroweak physics at hadron colliders

1.3. LHC physics program

1.4. Electroweak challenges for Run 2 and beyond

2. Theory overview and recent developments

2.1. PDF and electroweak observables (V+jets, ϕ^*)

2.2. Electroweak NLO corrections

2.3. Anomalous gauge couplings and effective field theory

2.4. Oblique corrections, constructed observables

3. Inclusive boson production

3.1. Drell-Yan production

ATLAS high-mass Drell–Yan 7 TeV [1]
ATLAS low-mass Drell-Yan 7 TeV [2]
ATLAS Z PT 7 TeV [3]
ATLAS Z phistar 7 TeV [4]
CMS Drell–Yan 7 TeV [5]
CMS Drell–Yan 8 TeV [6]
CMS angular coefficients 8 TeV [7]
CMS Z PT and rapidity 8 TeV [8]

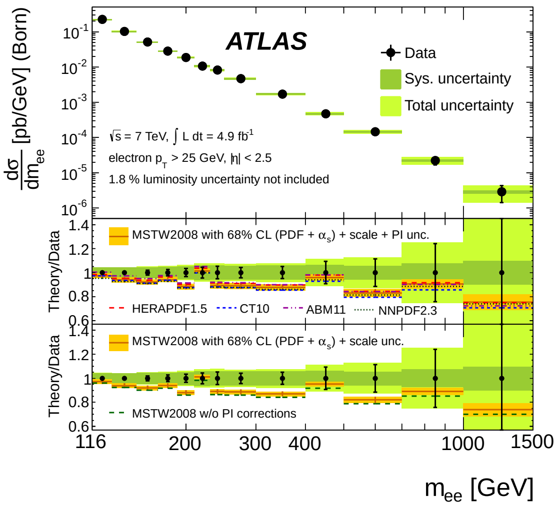

Figure 1. Measured differential cross-section at the Born level within the fiducial region (electron $p_{\mathrm{T}} > 25$ GeV and $|\eta| < 2.5$) with statistical, systematic, and combined statistical and systematic (total) uncertainties, excluding the 1.8% uncertainty on the luminosity. The measurement is compared to FEWZ 3.1 calculations at NNLO QCD with NLO electroweak corrections using the G_μ electroweak parameter scheme. The predictions include an additional small correction from single-boson production in which the final-state charged lepton radiates a real W or Z boson. On the left, in the upper ratio plot, the photon-induced (PI) corrections have been added to the predictions obtained from the MSTW2008, HERAPDF1.5, CT10, ABM11 and NNPDF2.3 NNLO PDFs, and for the MSTW2008 prediction the total uncertainty band arising from the PDF, α_s, renormalisation and factorisation scale, and photon-induced uncertainties is drawn. The lower ratio plot shows the influence of the photon-induced corrections on the MSTW2008 prediction, the uncertainty band including only the PDF, α_s and scale uncertainties. On the right, the results are shown for a restricted range of m_{ee}.

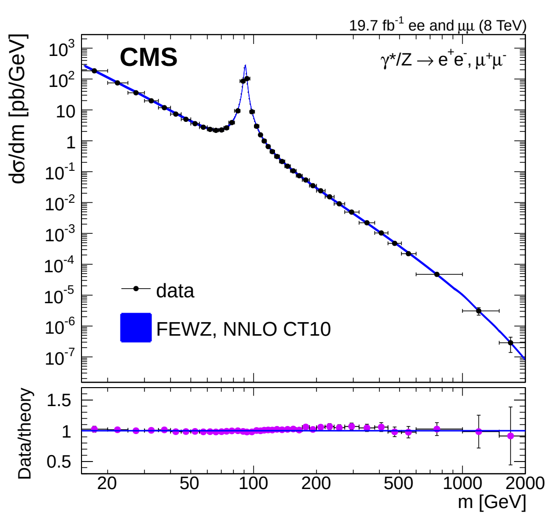

Figure 2.

3.2. Inclusive di-boson production

ATLAS $W^{\pm}\gamma$ $Z\gamma$ 7 TeV [9]
CMS $W^{\pm}\gamma/Z\gamma$ 7 TeV [10]
CMS $Z(\nu\bar{\nu})\gamma$ 7 TeV [11]
CMS $Z\gamma$ 8 TeV [12]
ATLAS simultaneous tt/WW/Z cross section 7 TeV [13]
ATLAS WW 7 TeV [14]
ATLAS WW+WZ cross section 7 TeV [15]
ATLAS WW 8 TeV [16]
CMS WW2l2n 7 TeV [17]
CMS WWlnjj 7 TeV [18]
CMS WW/ZZ 8 TeV [19]
CMS WW2l2n 8 TeV(CMS-PAS-SMP-14-016, to be published)
ATLAS WZ 7 TeV [20]
CMS VZ 8 TeV [21]
CMS WZ at 7+8 TeV(CMS-PAS-SMP-12-006, to be published)

3.2.1. ZZ production lala

The production of ZZ in proton-proton collisions has been one of the first di-boson processes measured at the LHC. The SM process is and an important and irreducible background to resonance searches and Higgs production. The production at leading order is dominated by quark anti-quark annihilation in the t and u-channel, whereas the s-channel process is forbidden in the SM (see also Figure 3). The gluon fusion process contributes about 6% to the total production cross section.

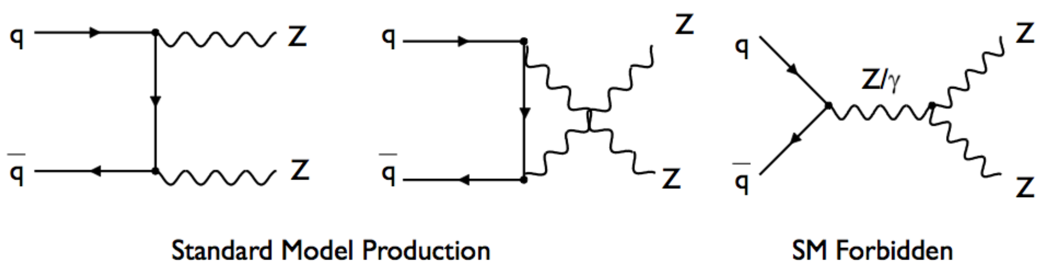

Figure 3. Leading order Feynman diagrams of ZZ production in the dominant $q\bar{q}$ channel. The ZZ production via the s-channel is not allowed in the SM.

Precision measurements use the leptonic decay modes of the Z to reduce the impact of QCD backgrounds. The four lepton final state provides an almost background free signature, at the expense of a relatively small branching ratio $BR(ZZ) \to \ell^+\ell^-\ell^+\ell^- = 0.101^2 \cdot \frac{4}{9} = 0.0045$ [?]. The di-lepton and missing energy channel can exploit the one order of magnitude higher branching ratio of $BR(ZZ \to \ell^+\ell^-\nu\bar{\nu}) = 0.101 \cdot 0.20 \cdot 2 \cdot \frac{2}{3} = 0.0269$,

The ATLAS collaboration has published results on the 7 TeV data-set in the $\ell^+\ell^-\ell^+\ell^-$ and $\ell^+\ell^-\nu\bar{\nu}$ final state [22]. The CMS collaboration has analysed the full 7 and 8 TeV data sets in both the $\ell^+\ell^-\ell^+\ell^-$ [24, 23] and $\ell^+\ell^-\nu\bar{\nu}$ final state [25].

Theoretical predictions for ZZ production are available at NLO in α_s [?]. In addition, electroweak corrections at NLO have been calculated [?, ?].

The event selection for the $\ell^+\ell^-\ell^+\ell^-$ final state requires exactly four leptons fulfilling a set of cuts on kinematic quantities. ATLAS and CMS use similar criteria as listed in detail in Table **??**. While ATLAS uses $l = e, \mu$, CMS includes also $Z \to \tau^+\tau^-$ with subsequent hadronic and leptonic τ decays. ATLAS uses in addition forward leptons outside the ID tracker to increase the acceptance by 6% for electrons and 10% for muons.

Besides the total cross section for the $pp \to ZZ$ production process, both experiments measure also fiducial and differential cross sections, and provide limits on anomalous neutral triple gauge boson couplings.

3.3. Inclusive tri-boson production

ATLAS $W\gamma\gamma$ [26]
CMS WVgamma 8 TeV [27]

4. Exclusive boson production

4.1. Exclusive single boson production, vector-boson fusion

ATLAS VBF Z 7 TeV [28]
CMS VBF Z 7 TeV [29]
CMS VBF Z 8 TeV [30]

4.2. Exclusive di-boson production, vector-boson scattering

ATLAS SSWW 8 TeV [31]
CMS WWexcl 7 TeV [32]
CMS SSWW 8 TeV [33]

5. Electroweak (precision) tests of the standard model

5.1. Test of tri-boson vertex

ATLAS Wgamma Zgamma 7 TeV [9]
ATLAS WW 7 TeV [14]
ATLAS WW+WZ cross section 7 TeV [15]
ATLAS WZ 7 TeV [20]
ATLAS ZZ4l,ZZ2l2v 7 TeV [22]
CMS ZZ4l 8 TeV [23]
CMS ZZ4l 7 TeV [24]
CMS WW2l2n 7 TeV [17]
CMS WWlnjj 7 TeV [18]
CMS WW2l2n 8 TeV(CMS-PAS-SMP-14-016, to be published)
CMS $W^{\pm}\gamma/Z\gamma$ 7 TeV [10]
CMS Znngamma 7 TeV [11]
CMS $Z\gamma$ 8 TeV [12]
CMS $ZZ \to \ell^{\pm}\ell^{-}\nu\bar{\nu}$ 7+8 TeV [25]

5.2. Test of tetra-boson vertex

ATLAS $W\gamma\gamma$ 8 TeV [26]
ATLAS SSWW 8 TeV [31]
CMS WVgamma 8 TeV [27]
CMS WWexcl 7 TeV [32]
CMS SSWW 8 TeV [33]

5.3. Z AFB and sin thetaW

ATLAS weak mixing angle [34]

CMS weak mixing angle [35]

CMS Drell–Yan AFB 7 TeV [36]

CMS Drell–Yan AFB 8 TeV, g_1^Z, κ^Z, λ^Z(CMS-PAS-SMP-14-004, to be published)

5.4. W mass

6. Summary

ATLAS [37] CDF [38] CMS [39] D0 [40] LHCb [41]

CDF Z asymmetry muon [42] CDF Z asymmetry electron [43] CDF W mass PRD [44] CDF W mass PRL [45]

D0 W asymmetry electron [46] D0 W asymmetry muon [47] D0 W mass PRD [48] D0 W mass PRL [49]

CDF+D0 W mass combination [50]

Snowmass electroweak [51]

Wmass PDF [52]

Acknowledgments

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