PROCEEDINGS OF SCIENCE

W^+W^-+ dijet to next-to-leading order in QCD

Raoul Röntsch
Rudolf Peierls Centre for Theoretical Physics, 1 Keble Road, University of Oxford, UK
Email: r.rontsch1@physics.ox.ac.uk

I present the calculation of the production of a W-boson pair in association with two jets at the Tevatron and LHC, performed to next-to-leading order in QCD. This is an important background in Higgs boson production, whether it occurs through gluon fusion or weak boson fusion. In this calculation, the W-bosons decay leptonically and all spin correlations are included. Although we find that the NLO QCD corrections modify the results for the default scale choice by only around 10-20%, we also see that they are responsible for a drastic decrease in the scale uncertainty associated with the results. For this reason, the NLO calculation allows for much greater accuracy in Higgs searches.

The 2011 Europhysics Conference on High Energy Physics-HEP 2011,
July 21-27, 2011
Grenoble, Rhône-Alpes France

 http://pos.sissa.it/

PoS(EPS-HEP2011)324

1. Introduction

The study of the hadronic production of a pair of W-bosons in association with two jets is well-motivated. The primary motivation is that, if the Higgs bosons has a mass $m_H \gtrsim 130$ GeV, then its dominant decay is into a W^+W^- pair. In this case, the production of W-bosons is an important background. Higgs production in association with two jets accounts for about 10% of total Higgs production via gluon fusion. If the Higgs is produced through weak boson fusion (WBF), then two jets are present even at leading order (LO). In either case, the production of a pair of W^+W^-+ dijet is an important background which should be well understood.

A secondary, more technical motivation is the challenge of computing the next-to-leading order (NLO) corrections to a $2 \to 4$ process in which there are two colourless particles. The on-shell method of D-dimensional generalised unitarity [1, 2], combined with the OPP subtraction scheme [3], provides a framework in which virtual amplitudes can be computed. However, these methods rely heavily on the use of colour ordering. The computation of $pp(p\bar{p}) \to W^+W^- + 2$ jets in ref. [4] demonstrated that they can be extended to processes involving more than one colourless particle; this report follows closely from this reference.

2. Results

2.1 Tevatron

We begin by considering the production of W^+W^-+ dijet at the Tevatron, with the W-bosons decaying leptonically. We use cuts based on the Tevatron and LHC Higgs boson searches [5]. The hardest lepton is required to have $p_{T,l_1} > 20$ GeV and $|\eta_{l_1}| < 0.8$, and the other lepton to have $p_{T,l_2} > 10$ GeV and $|\eta_{l_2}| < 1.1$. The invariant mass of the lepton system is required to satisfy $m_{ll} >$ 16 GeV, and a cut related to the missing energy is also imposed: $\not{E}_\perp^{\text{spec}} = \not{E}_\perp \sin[\min(\Delta\phi, \frac{\pi}{2})] > 25$ GeV. Jets are defined using the k_T-algorithm with $R > 0.4$, and are required to have $p_{T,j} > 15$ GeV and $|\eta_j| < 2.5$. Lepton isolation is also imposed: a jet within $R = 0.4$ of a lepton must have $p_{T,j} < 0.1 p_{T,l}$.

At LO, the cross-section for the production of a W-pair and two jets at the Tevatron using the above cuts is $\sigma_{\text{LO}} = 2.5 \pm 0.9$ fb. At NLO, the cross-section is $\sigma_{\text{NLO}} = 2.0 \pm 0.1$ fb. The uncertainty shown is obtained by changing the factorisation and renormalisation scale (which we set equal to one another) between $\frac{M_W}{2}$ and $2M_W$. The scale uncertainty decreases by almost an order of magnitude once the NLO corrections are included (see the left-hand plot in Fig. 1). In Ref. [6], the Higgs production through gluon fusion with the above cuts is given as 0.2 fb (with a large uncertainty), which is a factor of around 4 smaller than the LO scale uncertainty in the background. The situation improves once NLO corrections are included, although the scale uncertainty of the background at NLO is still comparable to the signal cross-section.

2.2 LHC

Next, we consider the production of W^+W^-+ dijet at the LHC with a centre-of-mass energy $\sqrt{s} = 7$ TeV. We use cuts inspired by top physics analyses at the LHC [7, 8]. We require all leptons to have $p_{T,l} > 20$ GeV and $|\eta_l| < 2.4$ and both jets to have $p_{T,j} > 30$ GeV and $|\eta_j| < 3.2$. Missing

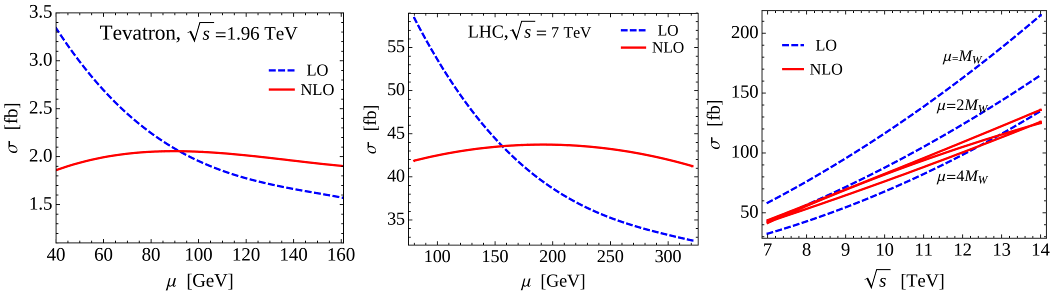

Figure 1: On the left and in the centre is shown the dependence on renormalisation and factorisation scale of the cross-section for $p\bar{p}(pp) \to \mu^+\nu_\mu e^-\bar{\nu}_e$ at the Tevatron and 7 TeV run at the LHC, respectively. The right plot shows the dependence of the cross-section on the centre-of-mass energy at the LHC, for three different values of the scale.

transverse momentum is required to satisfy $p_{T,\text{miss}} > 30$ GeV. Jets are reconstructed using the anti-k_T algorithm with $R > 0.4$ [9].

We find a cross-section of $\sigma_{\text{LO}} = 46 \pm 13$ fb at LO, which decreases by about 10% to $\sigma_{\text{NLO}} = 43 \pm 1$ fb at NLO. Again, the scale uncertainty has decreased from close to 30% at LO to around 2% at NLO (see the central plot in Fig. 1). Despite the high number of weak interactions occurring, the cross-section is still large enough to allow this process to be recorded in the current data set.

In the right-hand plot in Fig. 1, we see that the NLO cross-section has a close to linear dependence on the centre-of-mass energy. Furthermore, the scale at which NLO corrections are minimised increases from $\mu \simeq 2M_W$ at $\sqrt{s} = 7$ TeV to $\mu \simeq 4M_W$ at $\sqrt{s} = 14$ TeV. This shows the need to compute NLO corrections explicitly, as the K-factor depends not only on the scale but also on the centre-of-mass energy.

Discrimination between Higgs signal and W-pair background can be achieved using distributions. In particular, W-bosons created through the decay of a scalar Higgs have anti-correlated spins, producing charged leptons with a small opening angle. Background W-boson pairs tend to decay into back-to-back charged leptons. Looking at the distribution of the opening angle between the leptons, $\phi_{e^-\mu^+}$, or related distributions like the invariant mass of the charged lepton pair $m^2_{e^-\mu^+} = 2E_{e^-}E_{\mu^+}(1 - \cos\phi_{e^-\mu^+})$ can enable us to distinguish between signal and background [10].

Another distribution of interest is the rapidity difference between the two hardest jets, $\Delta\eta_{j1,j2}$. The background distribution peaks at $\Delta\eta_{j1,j2} \simeq 0$, while the signal distribution depends on the manner in which the Higgs is created. A Higgs created through gluon fusion results in a central peak similar to the background, whereas a Higgs created through WBF results in a distribution peaked at large values of $|\Delta\eta_{j1,j2}|$ [6].

As with the cross-sections, NLO QCD corrections to the distributions greatly reduce the scale uncertainty (see Fig. 2). This should lead to a greater accuracy in distinguishing between signal and background, and hence in greater discovery capabilities at the Tevatron and LHC.

3. Conclusion

I have presented results for the NLO calculation of the hadronic production of W^+W^- + dijet. Generalised unitarity provides an efficient framework in which to compute NLO corrections to this

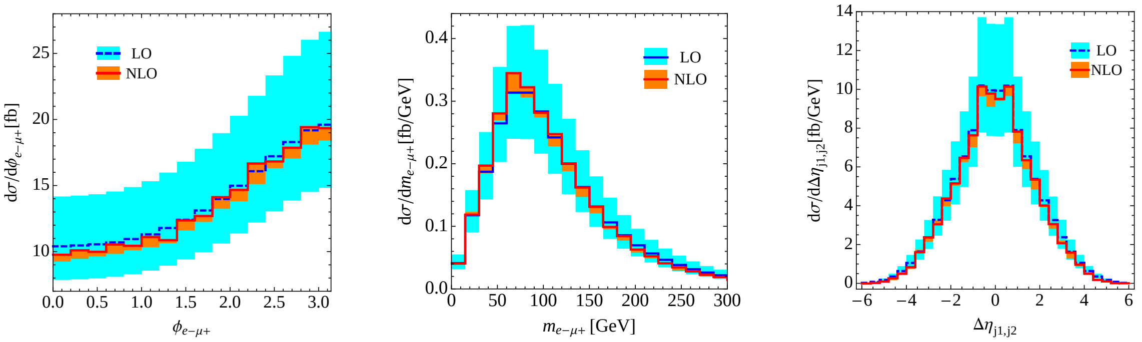

Figure 2: Distributions of the lepton opening angle, the invariant mass of the charged leptons, and the rapidity difference between the two hardest jets for the process $pp \to \mu^+ \nu_\mu e^- \bar{\nu}_e$ at the 7 TeV LHC.

process, which includes two colourless particles. I have shown that the NLO corrections affect the cross-sections at the level of around 10% at the LHC and 20% at the Tevatron, and significantly decrease the scale uncertainty associated with the results. This emphasises the need for NLO calculations to backgrounds to new physics processes at the LHC.

Acknowledgments

I thank the organisers of the EPS HEP 2011 for an exciting and stimulating conference, and the convenors of the QCD parallel session in particular. This report is based on work done in collaboration with Tom Melia, Kirill Melnikov and Giulia Zanderighi and published in ref. [4].

References

[1] R. K. Ellis, W. T. Giele, and Z. Kunszt, *JHEP* **03** (2008) 003, [arXiv:0708.2398].

[2] W. T. Giele, Z. Kunszt, and K. Melnikov, *JHEP* **04** (2008) 049, [arXiv:0801.2237].

[3] G. Ossola, C. G. Papadopoulos, and R. Pittau, *Nucl. Phys.* **B763** (2007) 147–169, [hep-ph/0609007].

[4] T. Melia, K. Melnikov, R. Röntsch, and G. Zanderighi, *Phys.Rev.* **D83** (2011) 114043, [hep-ph/0609007].

[5] **CDF Collaboration**, CDF note 9887.

[6] J. M. Campbell, R. K. Ellis, and C. Williams, *Phys. Rev.* **D81** (2010) 074023, [arXiv:1001.4495].

[7] **ATLAS Collaboration**, G. Aad *et. al.*, arXiv:1012.1792.

[8] **CMS Collaboration**, V. Khachatryan *et. al.*, *Phys.Lett.* **B695** (2011) 424–443, [arXiv:1010.5994].

[9] M. Cacciari, G. P. Salam, and G. Soyez, *JHEP* **04** (2008) 063, [arXiv:0802.1189].

[10] G. Klamke and D. Zeppenfeld, *JHEP* **04** (2007) 052, [hep-ph/0703202].