Note on doubly charged Higgs boson pair production at hadron colliders

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(Received 8 September 2003; published 30 December 2003)

We analyze the next-to-leading order QCD corrections to the production of doubly charged Higgs particles at hadron colliders in extensions of the standard model with Higgs isospin triplets. At both the Fermilab Tevatron and the CERN Large Hadron Collider (LHC), these corrections are found to be moderate in size increasing the cross sections by about 20–30 %. The residual theoretical uncertainties are of the order of 10–15 % which is sufficient for experimental searches for these particles at the Tevatron and LHC.

DOI: 10.1103/PhysRevD.68.117701 PACS number(s): 14.80.Cp, 12.38.Bx, 13.60.Hb

I. INTRODUCTION

Exotic extensions of the Higgs sector involving higher isospin multiplets naturally predict the existence of doubly charged Higgs bosons $\Delta^{\pm\pm}$. Particular examples are left-right symmetric models [1]. However, higher Higgs multiplets are generally severely constrained by the ρ parameter which is unity at the tree level. In order to satisfy these constraints, very particular Higgs representations have to be chosen or fine-tuning is required between different Higgs multiplets. The simplest options allowed by the ρ parameter are Higgs multiplets without neutral states or representations containing neutral states with a very small vacuum expectation value. Left-right symmetric models predict the appearance of a left- and a right-handed Higgs triplet, both with hypercharge $|Y|=2$ [1]. If the vacuum expectation values of the neutral members vanish, the doubly charged components $\Delta^{\pm\pm}$ do not couple to $W^\pm W^\pm$ pairs. In this case the dominant doubly charged Higgs boson production process at hadron colliders is pair production via $q\bar{q}\to\gamma^*,Z^*\to\Delta^{++}\Delta^{--}$ [2]. The cross section of this production mode only depends on the electroweak quantum numbers and the mass of the doubly charged Higgs states and not on further details of the model. Doubly charged Higgs bosons have been searched for at the CERN e^+e^- LEP collider via the related process $e^+e^-\to\gamma^*,Z^*\to\Delta^{++}\Delta^{--}$ resulting in a lower mass bound $M_\Delta \gtrsim 98.5$ GeV within supersymmetric left-right symmetric models [3]. Present searches at the Fermilab Tevatron cannot impose any mass limits yet, but this will improve with increasing statistics [4].

II. QCD CORRECTIONS TO THE PRODUCTION PROCESSES

At hadron colliders, the lowest order partonic cross section for doubly charged Higgs boson pair production is given by

$$\hat{\sigma}_{\rm LO}(q\bar{q}\to\Delta^{++}\Delta^{--}) = \frac{\pi\alpha^2}{9Q^2}\beta^3\left[e_q^2e_\Delta^2+\frac{e_qe_\Delta v_qv_\Delta(1-M_Z^2/Q^2)+(v_q^2+a_q^2)v_\Delta^2}{(1-M_Z^2/Q^2)^2+M_Z^2\Gamma_Z^2/Q^4}\right] \quad (1)$$

with $v_q=(2I_{3q}-4e_qs_W^2)/(2s_Wc_W)$, $a_q=2I_{3q}/(2s_Wc_W)$ and $v_\Delta=(2I_{3\Delta}-2e_\Delta s_W^2)/(2s_Wc_W)$, where I_{3q} ($I_{3\Delta}$) denotes the third isospin component and $e_q(e_\Delta)$ the electric charge of the quark q (doubly charged Higgs boson Δ^{--}) and $s_W=\sin\theta_W, c_W=\cos\theta_W$. Q^2 is the squared partonic center-of-mass (c.m.) energy, α the QED coupling evaluated at the scale Q, M_Z the Z boson mass, and Γ_Z the Z boson width. The Higgs velocity is defined as $\beta=\sqrt{1-4M_\Delta^2/Q^2}$.

The hadronic cross sections can be obtained from convoluting the partonic cross section with the corresponding (anti)quark densities of the (anti)protons

$$\sigma_{LO}(p\overset{(-)}{p}\to\Delta^{++}\Delta^{--}) = \int_{\tau_0}^1 d\tau \sum_q \frac{d\mathcal{L}^{q\bar{q}}}{d\tau}\hat{\sigma}_{LO}(Q^2=\tau s) \quad (2)$$

where $\tau_0=4M_\Delta^2/s$ with s being the total hadronic c.m. energy squared, and $\mathcal{L}^{q\bar{q}}$ denotes the $q\bar{q}$ parton luminosity.

The standard QCD corrections, with virtual gluon exchange, gluon emission and quark emission, are identical to the corresponding corrections to the Drell-Yan process [5]. They modify the lowest order cross section in the following way:

$$\sigma=\sigma_{LO}+\Delta\sigma_{q\bar{q}}+\Delta\sigma_{qg}$$

$$\Delta\sigma_{q\bar{q}}=\frac{\alpha_s(\mu_R)}{\pi}\int_{\tau_0}^1 d\tau\sum_q\frac{d\mathcal{L}^{q\bar{q}}}{d\tau}\times\int_{\tau_0/\tau}^1 dz\,\hat{\sigma}_{LO}(Q^2=\tau z s)\,\omega_{q\bar{q}}(z)$$

$$\Delta\sigma_{qg}=\frac{\alpha_s(\mu_R)}{\pi}\int_{\tau_0}^1 d\tau\sum_{q,\bar{q}}\frac{d\mathcal{L}^{qg}}{d\tau}\times\int_{\tau_0/\tau}^1 dz\,\hat{\sigma}_{LO}(Q^2=\tau z s)\,\omega_{qg}(z) \quad (3)$$

with the coefficient functions [5]

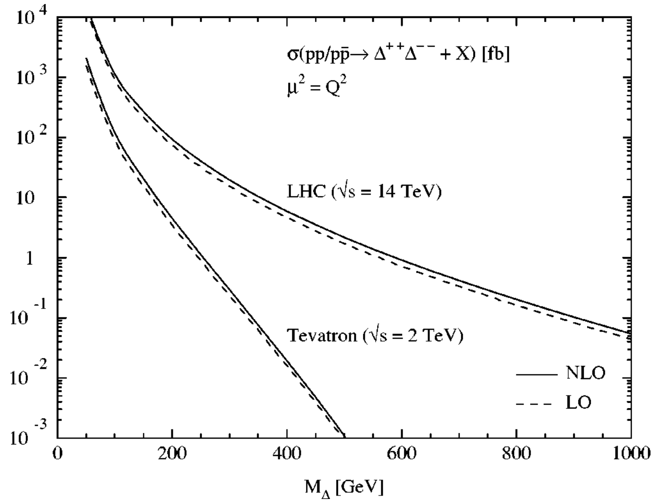

FIG. 1. Production cross sections of doubly charged Higgs boson pair production at the Tevatron and the LHC. The doubly charged Higgs bosons Δ^{--} carry $I_{3\Delta}=-1$ as the third isospin component. CTEQ6L1 (CTEQ6M) parton densities [7] have been used at LO (NLO).

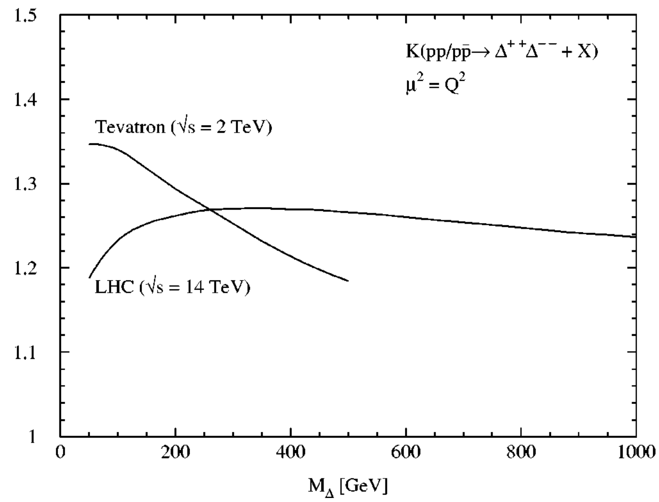

FIG. 2. K factors of doubly charged Higgs boson pair production at the Tevatron and the LHC. The parameters are the same as in Fig. 1. The curve for the Tevatron has been truncated at $M_\Delta=500$ GeV, because the cross section is too small above and thus phenomenologically irrelevant.

$$\omega_{q\bar{q}}(z)=-P_{qq}(z)\log\frac{\mu_F^2}{\tau s}+\frac{4}{3}\left\{\left[\frac{\pi^2}{3}-4\right]\times\delta(1-z)+2(1+z^2)\left(\frac{\log(1-z)}{1-z}\right)_+\right\}$$

$$\omega_{qg}(z)=-\frac{1}{2}P_{qg}(z)\log\left(\frac{\mu_F^2}{(1-z)^2\tau s}\right)+\frac{1}{8}\{1+6z-7z^2\} \qquad (4)$$

where μ_F denotes the factorization scale, μ_R the renormalization scale and P_{qq}, P_{qg} the well-known DGLAP splitting functions, which are given by [6]

$$P_{qq}(z)=\frac{4}{3}\left\{\frac{1+z^2}{(1-z)_+}+\frac{3}{2}\delta(1-z)\right\}$$

$$P_{qg}(z)=\frac{1}{2}\{z^2+(1-z)^2\}. \qquad (5)$$

III. NUMERICAL RESULTS

Our numerical results will be presented using CTEQ6L1 (CTEQ6M) parton densities [7] at (next-to-)leading order with the strong coupling α_s adjusted accordingly, i.e. $\alpha_s^{LO}(M_Z)=0.130, \alpha_s^{NLO}(M_Z)=0.118$. The electroweak quantum numbers of the doubly charged Higgs boson Δ^{--} have been chosen to be $I_{3\Delta}=-1$ and $e_\Delta=-2$. Figure 1 shows the total cross sections at the LHC and the Tevatron in leading and next-to-leading order as a function of the charged Higgs boson mass M_Δ. The renormalization/factorization scale has been chosen as $\mu_F^2=\mu_R^2=Q^2$ which is the natural scale choice for Drell-Yan-like processes. The QCD corrections increase the cross sections by 20–30 % and are thus of moderate size. This can explicitly be inferred from Fig. 2, where the K factors, defined as the ratio $K=\sigma_{NLO}/\sigma_{LO}$, are depicted for the Tevatron and the LHC. The curve for the Tevatron is truncated at $M_\Delta=500$ GeV, since the cross section becomes too small above. The residual renormalization and factorization scale dependence at NLO amounts to about 5–10 % and serves as an estimate of the theoretical uncertainties. They are of the order of the known NNLO corrections [8] which amount to about 5–10 %. They have not been included in our analysis. The uncertainties of the parton densities have to be added resulting in a total theoretical uncertainty of about 10–15 %.

IV. CONCLUSIONS

In this Brief Report we have analyzed doubly charged Higgs boson pair production at the Tevatron and the LHC at NLO QCD. The NLO corrections increase the cross sections by about 20–30 % and reduce the residual renormalization/factorization scale dependence to 5–10 %. The total theoretical uncertainties including the errors of the parton densities can be estimated to be 10–15 %. This accuracy is sufficient for doubly charged Higgs boson searches at the Tevatron and LHC.

ACKNOWLEDGMENTS

We are grateful to S. Lammel for drawing our attention to this topic. We thank P.M. Zerwas for carefully reading the manuscript. This work has been supported in part by the Swiss Bundesamt für Bildung und Wissenschaft and by the European Union under contract HPRN-CT-2000-00149.

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