I will briefly review the status of higher-order calculations for top-quark observables, comment on the need for improvements, discuss some of the recent theoretical advances, and present a few examples to highlight the role of top-quark observables in searches for signals of physics beyond the Standard Model.

1. THE MANY FACETS OF TOP QUARK PHYSICS

The study of top-quark properties and dynamics provides a unique window to the mechanism of electroweak symmetry breaking (EWSB). The large mass of the top quark suggests that it plays a special role in EWSB, and that new physics connected to EWSB may be found first through precision studies of top-quark observables. Deviations of experimental measurements from the SM predictions, including electroweak (EW) and QCD corrections, could indicate new non-standard top production or decay mechanisms. Since the top quark immediately decays before it hadronizes or flips its spin, it provides an excellent testing ground for perturbative QCD. Moreover, information about spin correlation and polarization, imprinted by the production process, is preserved, and can be measured in angular distributions of top-decay products, providing another way to search for deviations from the SM expectation.

The precise measurement of the top-quark mass ($m_t$) allows for improved bounds on the mass of the Standard Model (SM) Higgs boson ($M_H$), which is presently constrained to be smaller than 185 GeV (95% C.L.) [1]. Measuring precisely the properties of the top quark and studying its dynamics therefore is an important goal at the Tevatron Run II, LHC and ILC. To fully exploit the potential of these colliders for precision top-quark physics, it is crucial that predictions for top-quark observables are under theoretical control and include higher-order corrections within the SM and beyond. In the following, I will briefly describe some theory aspects of top-quark physics relevant to the Tevatron, LHC and ILC. For detailed reviews of theoretical and experimental results please see, e.g., Refs. [2, 3, 4, 5, 6] (as well as presentations in this session).

2. TOTAL PRODUCTION CROSS SECTIONS: $t\bar{t}$ AND SINGLE TOP

The total top-pair production cross section ($\sigma_{t\bar{t}}$) is presently measured at the Tevatron 1 with a relative uncertainty of $\Delta_{t\bar{t}}/\sigma_{t\bar{t}} = 9(11)\%$ (CDF [3] (D0 [4])) (with $L = 2.8(0.9) \text{ fb}^{-1}$). While QCD predictions [3, 10, 11] and measurements of $\sigma_{t\bar{t}}$ agree within their respective uncertainties, recent detailed studies [3, 10, 11] of the theoretical uncertainties of presently available state-of-the-art QCD calculations show that further theoretical improvements will be necessary in order to match (or better exceed) the anticipated future experimental precision, as illustrated in Table I. For instance at the LHC, the goal is to measure $\sigma_{t\bar{t}}$ ultimately with a relative uncertainty of $\approx 5\%$. All presently available QCD predictions for the total cross sections of the strong $t\bar{t}$ production processes, $q\bar{q} \rightarrow t\bar{t}$ and $gg \rightarrow t\bar{t}$, include the complete fixed-order next-to-leading-order (NLO) corrections [12] and next-to-leading-logarithmic (NLL) contributions due to soft gluon radiation at the $t\bar{t}$ threshold resummed to all orders [13]. However, as illustrated in Table I and also pointed out in Ref. [14], the next-to-next-to-leading-order (NNLO) QCD corrections are needed. Without having a full NNLO calculation at hand, recent advances aim to extract partial NNLO contributions [5, 11] (labeled NNLO approx. in Table I) from an expansion of the threshold-resummed results at next-to-next-to-leading logarithmic (NNLL) accuracy. The residual theoretical uncertainty of these predictions due to missing higher-order

---

1 See www-cdf.fnal.gov and www-d0.fnal.gov for most recent results from the CDF and D0 collaborations, respectively.
Table I: Theoretical uncertainties of state-of-the-art QCD predictions for $\sigma_{t\bar{t}}$ at the Tevatron ($\sqrt{s} = 1.96$ TeV) and the LHC (with $m_t = 171$ GeV) due to scale dependence and PDF uncertainties. The total uncertainties have been calculated by adding the scale and PDF uncertainties (and in case of Ref. [11] also the kinematic uncertainties) in quadrature.

|                  | Tevatron | MRST2006nlo | CTEQ6.5/6.6M |
|------------------|----------|-------------|--------------|
| $\Delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}}[\%]$ | scale    | PDF         | total        |
| NLO+NLL [10]    | +4.7     | +5.7        | +4.7,+7.5,+8.8 |
| NNLO approx. [9] | 3        | 6           | 3,6,8       |
| NNLO approx. [11]| +0.4,-3  | +3.2,+5.6   | +0.4,-3,+7.5,+8.7 |
| LHC             |          |             |              |
| NLO+NLL [10]    | +8.5     | +8.5        | +8.5,3,+8.6 |
| NNLO approx. [9] | 3        | 4           | 3,4,6       |

corrections is estimated by varying the renormalization and factorization scales as shown in Table I. The PDF uncertainty is also provided for two sets of PDFs, MRST2006nlo [27] and CTEQ6.5 (or CTEQ6.6M) [15]. For a complete fixed-order NNLO calculation of $\sigma_{t\bar{t}}$ one needs the leading-order $2 \to 4$ parton scattering process, the $2 \to 3$ process at NLO, the NLO $2 \to 2$ process squared, virtual 2-loop corrections to the $2 \to 2$ process, a treatment of soft and collinear singularities at NNLO (see, e.g., Refs. [10, 17]), and last but not least NNLO PDFs. The 2-loop virtual QCD corrections to $q\bar{q} \to t\bar{t}$ have been evaluated numerically in Ref. [18]. An analytic result for 2-loop fermion loops in $q\bar{q} \to t\bar{t}$ has been provided as well [19]. Results for two-loop corrections to both $q\bar{q} \to t\bar{t}$ and $gg \to t\bar{t}$ have been obtained in the limit $s, |t|, |u| \gg m_t^2$ in Refs. [20, 21]. NNLO $O(\alpha_s^4)$ one-loop squared corrections to both production processes $q\bar{q} \to t\bar{t}$ [22] and $gg \to t\bar{t}$ [23, 24] with full mass dependence have been finalized recently. The $t\bar{t}$+jet cross section at NLO QCD is provided in Refs. [25, 26]. For a complete consistent NNLO calculation NNLO PDFs are needed. MRST2006 [27] uses NNLO evolution kernels [28, 29] and NNLO QCD predictions for Drell-Yan cross sections [30]. SM EW radiative corrections to $\sigma_{t\bar{t}}$ have been studied at NLO in Refs. [31, 32, 33, 34, 35, 36, 37, 38, 39]. While they are known to only have a small impact on $\sigma_{t\bar{t}}$ ($\approx 1 - 2\%$), EW corrections can significantly affect top-quark distributions at high energies due to the occurrence of large EW Sudakov-like logarithms [37]. SUSY EW [40, 41, 42, 43, 44] and SUSY QCD [44, 45, 46, 47, 48, 49] one-loop corrections have been calculated for both $q\bar{q} \to t\bar{t}$ and $gg \to t\bar{t}$. Supersymmetric particles in loops can affect $\sigma_{t\bar{t}}$ by up to $\approx 6\%$ [44]. More interesting observables to observe such effects are kinematic distributions and asymmetries as will be discussed in Section 1.4.9. The total cross section for single top-quark production ($\sigma_t$) has been measured only recently at the Tevatron [50, 51], providing a first direct measurement of $V_{tb}$. Single top production can play an important role at the LHC in identifying and discriminating between different new physics models [52, 53], since they can have different, model-specific effects on the three production processes, $s$-channel and $t$-channel (dominant at both the Tevatron and the LHC) $tq$ production, and associated $tW$ production. The NLO QCD corrections to these processes are known for both an on-shell top quark [54] and including the top-quark decay [55]. Improved QCD predictions for $\sigma_t$ also include NLL threshold resummation effects [56, 57, 58], resulting in a residual theoretical uncertainty of $\Delta\sigma_t/\sigma_t \approx 4 - 5\%$ as shown in Table I. Complete one-loop EW corrections to the $t$-channel production process have been studied in Ref. [60] and only have a modest effect on $\sigma_t$ (a few percent at the LHC). Genuine SUSY effects, at least within mSUGRA, affect $\sigma_t$ ($t$-channel) at the LHC by at most $1\%$ [59, 61].

3. TOP QUARK MASS

The impressively precise top-mass measurement at the Tevatron ($\Delta m_t^{\text{exp}}/m_t^{\text{exp}} = 0.7\%$ [61]) and future high-precision measurements at the LHC and the ILC require a theoretically stable mass definition in a suitable renor-
Table II: Predictions for $\sigma_t$ at the Tevatron ($\sqrt{s}=1.96$ TeV) and the LHC (with $m_t = 171.4$ GeV and MRST2004nnlo) including scale, PDF, and $\Delta m_t$ uncertainties \[57, 58\]. The NNLO approximate results include the exact NLO QCD cross sections and an expansion of NLL resummed soft gluon corrections through NNNLO. For comparison, the NNLO approximate result for $\sigma_{tt}$ from Ref. \[11\] including scale, kinematics and PDF uncertainties is also provided.

| $\sigma_t$ [pb] | Tevatron | LHC |
|----------------|----------|-----|
| $t$-channel (NNNLO approx.) | $1.15 \pm 0.07$ | $150 \pm 6$ |
| $s$-channel (NNNLO approx.) | $0.54 \pm 0.04$ | $7.8 \pm 0.7 \pm 0.6$ |
| $t\bar{t}$ mode (NNLO/NNNLO approx.) | $0.14 \pm 0.03$ | $43.5 \pm 4.8$ |
| $\sigma_{tt}$ (NNLO approx., $m_t=172$ GeV)[pb] | $7.80 \pm 0.39 \pm 0.45$ | $968 \pm 80 \pm 52$ |

The determination of top-quark properties (mass, spin, charge), searches for signals of non-SM physics, such as anomalous couplings, FCNC, CP and parity-violating interactions, new $t\bar{t}$ resonances, and background studies to
Higgs and new physics searches, require good theoretical control of kinematic distributions in top-quark production and decay. Figure 1, for instance, illustrates the importance of controlling backgrounds [71] and theoretical uncertainties [65] in the tail of the $M_{t\bar{t}}$ distribution in the search of new $t\bar{t}$ resonances at the LHC. For inclusive observables, such as $\sigma_{t\bar{t}}$, and $M_{t\bar{t}}, p_T$ distributions, predictions with on-shell top quarks usually are sufficient. But for the study of spin correlations and polarization asymmetries the top-quark decay needs to be included. The NLO QCD corrections to $t\bar{t}$ production and decay at hadron colliders have been calculated by using the narrow-width approximation including spin correlations between the $t$ and $\bar{t}$ [72, 73]. Asymmetries are especially interesting tools in the search for non-SM physics, since they are usually small in the SM. For instance, within the SM the forward-backward charge asymmetry in $t\bar{t}$ production, recently measured at the Tevatron [74], is zero at tree-level and small ($\approx +5\%$) [75, 76] when induced by QCD interference effects between initial and final-state gluon radiation. The large theoretical uncertainty ($\approx 30\%$) [75, 76] of this prediction is considerably reduced when NLL threshold resummation of soft gluon radiation is taken into account [77]. In $t\bar{t}$+jet production at the Tevatron the NLO QCD corrections reduce the forward-backward charge asymmetry from $-7\%$ to $1.5 \pm 1.5\%$ [25]. At the Tevatron, the impact of non-SM physics, such as tree-level axial couplings of the gluon, can result in charge asymmetries as large as $-13\%$ [78], for instance. Also parity-violating asymmetries in the production of left and right-handed top quarks have the potential to provide a clean signal of non-SM physics: QCD preserves parity and the SM induced asymmetries are too small to be observable, at least at the Tevatron $p_T$ collider [79, 80]. The produced top quarks decay almost entirely into a bottom quark and a $W$ boson before they can hadronize [81] or flip their spins. The spin correlation of the top-pair system will therefore be preserved and can be measured by studying angular distributions of the decay products [82]. To measure spin correlations and asymmetries at the Tevatron and the LHC, higher-order corrections to polarized $t\bar{t}$ production need to be known as well: The NLO QCD and EW corrections to polarized $t\bar{t}$ production have been calculated in Refs. [72, 73, 83, 84] and Refs. [32, 33, 79, 80, 85], respectively. The effects of SUSY QCD and SUSY EW one-loop corrections to polarized $t\bar{t}$ production at hadron colliders have been studied in Ref. [41, 80] and Ref. [79, 87], respectively. They have been found to be promising, but further more realistic studies are needed, including top-quark decays, in order to determine whether these effects will be observable at the LHC.

5. CONCLUSIONS

There has been a lot of activity and many advances in every aspect of accurately predicting and modeling top-quark observables at hadron and $e^+e^-$ colliders of which only a small subset could be presented here. Observables in top-
pair and single-top production at hadron colliders are known at NLO QCD and NLO EW both within the SM and the minimal supersymmetric SM, and resummation techniques have been successfully employed to deal with logarithmic enhanced corrections. A complete fixed-order NNLO QCD calculation for $\sigma_{t\bar{t}}$ is needed and the calculation of many of the necessary building blocks has been completed. The applicability of new results for a well-defined $m_t$ extraction at the ILC to the LHC is under investigation and the potential of alternative observables for a precise $m_t$ measurements at hadron colliders, such as $\sigma_{t\bar{t}}$ and $d\sigma/dM_{t\bar{t}}$, are being studied. Theoretically stable top-mass definitions are needed to match the experimental precision of $m_t$ measurements at hadron and $e^+e^-$ colliders. Theoretically stable top-mass definitions are needed to match the experimental precision of $m_t$ measurements at hadron colliders, such as $\sigma_{t\bar{t}}$ and $d\sigma/dM_{t\bar{t}}$, are being studied. Theoretically stable top-mass definitions are needed to match the experimental precision of $m_t$ measurements at hadron colliders, such as $\sigma_{t\bar{t}}$ and $d\sigma/dM_{t\bar{t}}$, are being studied.

Acknowledgments

Work of D. W. supported by National Science Foundation grant no. NSF-PHY-0456681 and no. NSF-PHY-0547564.

References

[1] J. Alcaraz et al. [ALEPH, DELPHI, L3 and OPAL Collaborations and the LEP EW Working Group], arXiv:0712.0929 [hep-ex]; Summer 2008 update obtained from lepewwg.web.cern.ch/LEPEWWG.

[2] W. Bernreuther, J. Phys. G 35, 083001 (2008) arXiv:0805.1333 [hep-ph].

[3] R. Kehoe, M. Narain and A. Kumar, Int. J. Mod. Phys. A 23, 353 (2008) arXiv:0712.2733 [hep-ex].

[4] C. E. Gerber et al. [TeV4LHC-Top and Electroweak Working Group], arXiv:0705.3251 [hep-ph].

[5] T. Abe et al. [American Linear Collider Working Group], in Proc. of the APS/DPF/DPB Summer Study on the Future of Particle Physics (Snowmass 2001) ed. N. Graf, arXiv:hep-ex/0106057.

[6] M. Beneke et al., arXiv:hep-ph/0003033.

[7] T. Aaltonen et al. [CDF Collaboration], Phys. Rev. D 76, 072009 (2007) arXiv:0706.3790 [hep-ex]; update taken from CDF note 9448.

[8] V. M. Abazov et al. [D0 Collaboration], Phys. Rev. Lett. 100, 192004 (2008) arXiv:0803.2779 [hep-ex].

[9] S. Moch and P. Uwer, Phys. Rev. D 78, 034003 (2008) arXiv:0704.1476 [hep-ph].

[10] M. Cacciari, S. Frixione, M. L. Mangano, P. Nason and G. Ridolfi, JHEP 0809, 127 (2008) arXiv:0804.2800 [hep-ph].

[11] N. Kidonakis and R. Vogt, arXiv:0805.3844 [hep-ph].

[12] P. Nason, S. Dawson and R. K. Ellis, Nucl. Phys. B 303, 607 (1988); P. Nason, S. Dawson and R. K. Ellis, Nucl. Phys. B 327, 49 (1989) [Erratum-ibid. B 335, 260 (1990)]; W. Beenakker, H. Kuijf, W. L. van Neerven and J. Smith, Phys. Rev. D 40, 54 (1989); W. Beenakker, W. L. van Neerven, R. Meng, G. A. Schuler and J. Smith, Nucl. Phys. B 351, 507 (1991); M. L. Mangano, P. Nason and G. Ridolfi, Nucl. Phys. B 373, 295 (1992).

[13] N. Kidonakis and R. Vogt, arXiv:0805.3844 [hep-ph].

[14] P. Nason, S. Dawson and R. K. Ellis, Nucl. Phys. B 303, 607 (1988); P. Nason, S. Dawson and R. K. Ellis, Nucl. Phys. B 327, 49 (1989) [Erratum-ibid. B 335, 260 (1990)]; W. Beenakker, H. Kuijf, W. L. van Neerven and J. Smith, Phys. Rev. D 40, 54 (1989); W. Beenakker, W. L. van Neerven, R. Meng, G. A. Schuler and J. Smith, Nucl. Phys. B 351, 507 (1991); M. L. Mangano, P. Nason and G. Ridolfi, Nucl. Phys. B 373, 295 (1992).

[15] G. Sterman, Nucl. Phys. B 281, 310 (1987); E. Laenen, J. Smith and W. L. van Neerven, Phys. Lett. B 321, 254 (1994) arXiv:hep-ph/9310233; S. Catani, M. L. Mangano, P. Nason and L. Trentadue, Nucl. Phys. B 478, 273 (1996) arXiv:hep-ph/9604351; E. L. Berger and H. Contopanagos, Phys. Rev. D 54, 3085 (1996) arXiv:hep-ph/9604326; N. Kidonakis and G. Sterman, Nucl. Phys. B 505, 321 (1997) arXiv:hep-ph/9705234; R. Boneciani, S. Catani, M. L. Mangano and P. Nason, Nucl. Phys. B 529, 424 (1998) [Erratum-ibid. B 803, 234 (2008)] arXiv:hep-ph/9801375; N. Kidonakis, E. Laenen, S. Moch and R. Vogt, Phys. Rev. D 64, 114001 (2001) arXiv:hep-ph/0105041.
[14] Z. Bern et al. [NLO Multileg Working Group], arXiv:0803.0494 [hep-ph].
[15] P. M. Nadolsky et al., Phys. Rev. D 78, 013004 (2008) arXiv:0802.0007 [hep-ph].
[16] A. Gehrmann-De Ridder, T. Gehrmann and E. W. N. Glover, JHEP 0509, 056 (2005) arXiv:hep-ph/0505111.
[17] A. Daleo, T. Gehrmann and D. Maitre, JHEP 0704, 016 (2007) arXiv:hep-ph/0612257.
[18] M. Czakon, Phys. Lett. B 664, 307 (2008) arXiv:0803.1400 [hep-ph].
[19] R. Bonciani, A. Ferroglia, T. Gehrmann, D. Maitre and C. Studerus, JHEP 0807, 129 (2008) arXiv:0806.2301 [hep-ph].
[20] M. Czakon, A. Mitov and S. Moch, Phys. Lett. B 651, 147 (2007) arXiv:0705.1975 [hep-ph].
[21] M. Czakon, A. Mitov and S. Moch, Nucl. Phys. B 798, 210 (2008) arXiv:0707.4139 [hep-ph].
[22] J. G. Korner, Z. Mereshashvili and M. Rogal, Phys. Rev. D 77, 094011 (2008) arXiv:0802.0106 [hep-ph].
[23] B. Kniehl, J. G. Korner, Z. Mereshashvili and M. Rogal, arXiv:0809.3980 [hep-ph].
[24] C. Anastasiou and S. M. Aybat, arXiv:0809.1355 [hep-ph].
[25] S. Dittmaier, P. Uwer and S. Weinzierl, Phys. Rev. Lett. 98, 262002 (2007) arXiv:hep-ph/0703120.
[26] S. Dittmaier, P. Uwer and S. Weinzierl, arXiv:0810.0452 [hep-ph].
[27] A. D. Martin, W. J. Stirling, R. S. Thorne and G. Watt, Phys. Lett. B 664, 307 (2008) arXiv:0803.1400 [hep-ph].
[28] A. M. Mitov and S. Moch, Nucl. Phys. B 798, 210 (2008) arXiv:0707.4139 [hep-ph].
[29] J. G. Korner, Z. Mereshashvili and M. Rogal, Phys. Rev. D 77, 094011 (2008) arXiv:0802.0106 [hep-ph].
[30] M. Czakon, A. Mitov and S. Moch, Nucl. Phys. B 798, 101 (2008) arXiv:0707.4139 [hep-ph].
[31] A. D. Martin, W. J. Stirling, R. S. Thorne and G. Watt, Phys. Lett. B 652, 292 (2007) arXiv:0706.0459 [hep-ph].
[32] S. Dittmaier, P. Uwer and S. Weinzierl, arXiv:0810.0452 [hep-ph].
[33] C. Anastasiou, L. J. Dixon, K. Melnikov and F. Petriello, Phys. Rev. D 69, 094008 (2004) arXiv:hep-ph/0312266.
[34] W. Beenakker, A. Denner, W. Hollik, R. Mertig, T. Sack and D. Wackeroth, Nucl. Phys. B 411, 343 (1994).
[35] C. Kao, G. A. Ladinsky and C. P. Yuan, Int. J. Mod. Phys. A 12, 1341 (1997).
[36] W. Bernreuther, M. Fuecker and Z. G. Si, Phys. Lett. B 633, 54 (2006) arXiv:hep-ph/0508091.
[37] J. H. Kühn, A. Scharf and P. Uwer, Eur. Phys. J. C 45, 139 (2006) arXiv:hep-ph/0508092.
[38] S. Moretti, M. R. Nolten and D. A. Ross, Phys. Lett. B 639, 513 (2006) [Erratum-ibid. B 660, 607 (2008)] arXiv:hep-ph/0603083.
[39] S. Moretti, M. R. Nolten and D. A. Ross, Nucl. Phys. B 759, 50 (2006) arXiv:hep-ph/0606201.
[40] J. H. Kühn, A. Scharf and P. Uwer, Eur. Phys. J. C 51, 37 (2007) arXiv:hep-ph/0610335.
[41] W. Hollik and M. Kollar, Phys. Rev. D 77, 014008 (2008) arXiv:0708.1697 [hep-ph].
[42] W. Bernreuther, M. Fuecker and Z. G. Si, arXiv:0808.1142 [hep-ph].
[43] J. M. Yang and C. S. Li, Phys. Rev. D 54, 4380 (1996) arXiv:hep-ph/9603442.
[44] J. M. Yang and C. S. Li, Phys. Rev. D 52, 1541 (1995) [Erratum-ibid. D 54, 3671 (1996)].
[45] J. Kim, J. L. Lopez, D. V. Nanopoulos and R. Rangarajan, Phys. Rev. D 54, 4364 (1996) arXiv:hep-ph/9605419.
[46] W. Hollik, W. M. Mosle and D. Wackeroth, Nucl. Phys. B 516, 29 (1998) arXiv:hep-ph/9706218.
[47] D. A. Ross and M. Wiebusch, JHEP 0711, 041 (2007) arXiv:0707.4402 [hep-ph].
[48] S. Alam, K. Hagiwara, S. Matsumoto, K. Hagiwara and S. Matsumoto, Phys. Rev. D 55, 1307 (1997) arXiv:hep-ph/9607466.
[49] Z. Sullivan, Phys. Rev. D 56, 451 (1997) arXiv:hep-ph/9611302.
[50] H. Y. Zhou and C. S. Li, Phys. Rev. D 55, 4421 (1997).
[51] Z. H. Yu, H. Pietschmann, W. G. Ma, L. Han and J. Yi, Eur. Phys. J. C 9, 463 (1999) arXiv:hep-ph/9804331.
[52] S. Berge, W. Hollik, W. M. Mosle and D. Wackeroth, Phys. Rev. D 76, 034016 (2007) arXiv:hep-ph/0703016.
[53] T. Aaltonen et al. [CDF Collaboration], arXiv:0809.2581 [hep-ex].
[54] V. M. Abazov et al. [D0 Collaboration], Phys. Rev. Lett. 98, 181802 (2007) arXiv:hep-ex/0612052.
[55] T. M. P. Tait and C. P. P. Yuan, Phys. Rev. D 63, 014018 (2001) arXiv:hep-ph/0007298.
[56] Q. H. Cao, J. Wudka and C. P. Yuan, Phys. Lett. B 658, 50 (2007) arXiv:0704.2809 [hep-ph].
[57] G. Bordes and B. van Eijk, Nucl. Phys. B 435, 23 (1995); W. T. Giele, S. Keller and E. Laenen, Phys. Lett. B 372, 141 (1996) arXiv:hep-ph/9511449; M. C. Smith and S. Willenbrock, Phys. Rev. D 54, 6696 (1996) arXiv:hep-ph/9604223; T. Stelzer, Z. Sullivan and S. Willenbrock, Phys. Rev. D 56, 5919 (1997) arXiv:hep-ph/9705398; T. Stelzer, Z. Sullivan and S. Willenbrock, Phys. Rev. D 58, 094021 (1998).
[arXiv:hep-ph/9807340]; B. W. Harris, E. Laenen, L. Phaf, Z. Sullivan and S. Weinzierl, Phys. Rev. D 66, 054024 (2002) [arXiv:hep-ph/0207055]; S. Zhu, Phys. Lett. B 524, 283 (2002) [Erratum-ibid. B 537, 351 (2002)].

J. Campbell, R. K. Ellis and F. Tramontano, Phys. Rev. D 70, 094012 (2004) [arXiv:hep-ph/0408158]; Q. H. Cao and C. P. Yuan, Phys. Rev. D 71, 054024 (2005) [arXiv:hep-ph/0408180]; Q. H. Cao, R. Schwienhorst and C. P. Yuan, Phys. Rev. D 71, 054023 (2005) [arXiv:hep-ph/0409040]; J. Campbell and F. Tramontano, Nucl. Phys. B 726, 109 (2005) [arXiv:hep-ph/0506289].

S. Zhu, Phys. Lett. B 524, 283 (2002) [Erratum-ibid. B 537, 351 (2002)].

J. Campbell, R. K. Ellis and F. Tramontano, Phys. Rev. D 70, 054012 (2004) [arXiv:hep-ph/0408158]; Q. H. Cao and C. P. Yuan, Phys. Rev. D 71, 054022 (2005) [arXiv:hep-ph/0408203]; Q. H. Cao, R. Schwienhorst, J. A. Benitez, R. Brock and C. P. Yuan, Phys. Rev. D 72, 094027 (2005) [arXiv:hep-ph/0504230]; J. Campbell and F. Tramontano, Nucl. Phys. B 726, 109 (2005) [arXiv:hep-ph/0506289].

S. Zhu, Phys. Lett. B 524, 283 (2002) [Erratum-ibid. B 537, 351 (2002)].

The Tevatron Electroweak Working Group and CDF Collaboration and D0 Collaboration, arXiv:0808.1089 [hep-ex].