Measuring the top-quark Yukawa coupling at hadron colliders via $t\bar{t}h, h \to W^+W^-$

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We study the signal and backgrounds for the process $t\bar{t}h, h \to W^+W^-$ at the CERN Large Hadron Collider (LHC) and a 100 TeV Very Large Hadron Collider (VLHC). Signals are studied in two-, three-, and four-lepton final states. We find a statistical uncertainty in the top-quark Yukawa coupling at the LHC of 16%, 8%, 12% for $m_h = 130, 160, 190$ GeV, respectively. The statistical uncertainty at the VLHC is likely to be negligible in comparison with the systematic uncertainty.

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I. INTRODUCTION

One of the primary quests of present and future colliders is the search for the Higgs boson. Precision electroweak data [1] and direct searches at the CERN e^+e^- collider LEP [2] indicate that the mass of the standard-model Higgs boson lies in the range 114 GeV $< m_h \lesssim 200$ GeV. Such a Higgs boson may be discovered in Run II of the Fermilab Tevatron [3], and it cannot escape the CERN Large Hadron Collider (LHC) [4,5].

Once a Higgs boson is discovered, it will be important to measure its couplings to other particles to establish whether these couplings are those of a standard-model Higgs boson, or those of a Higgs boson from an extended Higgs sector, such as a two-Higgs-doublet model. For example, the minimal supersymmetric standard model requires the presence of two Higgs doublets to cancel gauge anomalies and to generate masses for both up- and down-type quarks [3]. There are many other models that employ an extended Higgs sector as well [6]. The coupling of the Higgs boson to other particles will be measured by studying the various production processes and decay modes of the Higgs boson [4,7].

In this paper we study the feasibility of measuring the Yukawa coupling of the Higgs boson to the top quark via the associated production of the Higgs boson with a top-quark pair ($t\bar{t}h$) [8,9], followed by the decay $h \to W^+W^-$ [10–12],[1] as shown in Fig. 1.[2] In the standard model, this decay mode has a branching ratio in excess of 10% for $m_h \gtrsim 120$ GeV, and is the dominant decay mode of the Higgs boson for $m_h \gtrsim 135$ GeV [3]. We study this process at the LHC ($\sqrt{s} = 14$ TeV) with low-luminosity ($\mathcal{L} = 10^{33}$ cm^{-2} s^{-1}), high-luminosity ($\mathcal{L} = 10^{34}$ cm^{-2} s^{-1}), and super-high-luminosity ($\mathcal{L} = 10^{35}$ cm^{-2} s^{-1}) [14]. We also consider a $\sqrt{s} = 100$ TeV Very Large Hadron Collider (VLHC) in order to judge the merits of increased energy. We omit a study at the Tevatron since, even with 30 fb^{-1} of integrated luminosity and before the application of any cuts, the number of signal events is less than unity once branching ratios are included.

Let us compare the measurement of the top-quark Yukawa coupling via $t\bar{t}h, h \to W^+W^-$ with other methods for measuring this Yukawa coupling. A less direct way to measure the top-quark Yukawa coupling at a hadron collider is to produce the Higgs boson via gluon fusion [15]. In the standard model this process is dominated by a top-quark loop, but if there are other heavy colored particles that couple to the Higgs boson (such as squarks), they too contribute to the amplitude, complicating the extraction of the top-quark Yukawa coupling. The process $gg \to h, h \to W^+W^-$, will be accessible at the LHC [4,16–18], and perhaps also at the Tevatron [19,20], for some range of Higgs-boson masses. The ratio of $gg \to h, h \to W^+W^-$ and $t\bar{t}h, h \to W^+W^-$ is potentially a good probe of additional contributions to the $gg \to h$ amplitude beyond that of the top quark, as $BR(h \to W^+W^-)$ and many systematic uncertainties cancel.

An e^+e^- linear collider of sufficient energy and luminosity could also measure the top-quark Yukawa coupling via

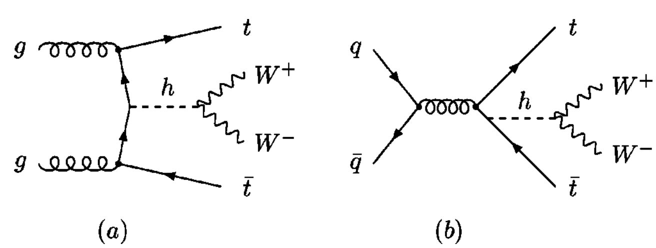

FIG. 1. Representative Feynman diagrams for associated production of the Higgs boson and a $t\bar{t}$ pair, followed by the decay $h \to W^+W^-$: (a) $gg \to t\bar{t}h$ (eight diagrams); (b) $q\bar{q} \to t\bar{t}h$ (two diagrams).

[1]For $m_h \leq 2M_W$, one or both of the W bosons is virtual.
[2]This process was first considered in Ref. [13].

TABLE I. Total cross section (fb) for $t\bar{t}h, h\rightarrow W^+W^-$ at the LHC and a VLHC of $\sqrt{s}=100$ TeV.

	$\sigma(t\bar{t}h)BR(h\rightarrow W^+W^-)$		
m_h(GeV)	130	160	190
LHC	110	180	90
VLHC	6800	12200	6700

$t\bar{t}h, h\rightarrow W^+W^-$. A machine of energy somewhat greater than m_h+2m_t would be required in order to overcome the phase space suppression near threshold. In particular, a $\sqrt{s}=500$ GeV machine would not be adequate for Higgs-boson masses above 130 GeV. We are not aware of any studies of this process at a linear collider.

For a Higgs boson of mass $\lesssim 135$ GeV, the dominant decay mode is $h\rightarrow b\bar{b}$. Such is the case for the lightest Higgs boson of the minimal supersymmetric standard model, which has a mass less than about 130 GeV [3,21–23]. The measurement of the top-quark Yukawa coupling via $t\bar{t}h$ in this decay mode at the LHC has been studied elsewhere [4,24–26].[3] If the Higgs-boson mass lies in the range of approximately 125–145 GeV, it has a significant branching ratio to both $b\bar{b}$ and W^+W^-, so both decays are potentially observable. The ratio of $t\bar{t}h, h\rightarrow b\bar{b}$ and $t\bar{t}h, h\rightarrow W^+W^-$ is potentially a good measure of the ratio of the Yukawa coupling of the b quark and the coupling of the Higgs boson to W bosons, as $\sigma(t\bar{t}h)$ and many systematic uncertainties cancel. The measurement of the top-quark Yukawa coupling via $t\bar{t}h, h\rightarrow b\bar{b}$ at an e^+e^- linear collider has been studied elsewhere [28,29].

In Sec. II we discuss the signal for $t\bar{t}h, h\rightarrow W^+W^-$, as well as the backgrounds. We consider final states with two, three, and four leptons. In Sec. III we discuss the details of the calculations. In Sec. IV we present the numerical results for the number of signal and background events and discuss uncertainties. We draw conclusions in Sec. V.

II. SIGNAL AND BACKGROUNDS

The extraction of the top-quark Yukawa coupling from a measurement of the cross section for $t\bar{t}h, h\rightarrow W^+W^-$ requires knowledge of $BR(h\rightarrow W^+W^-)$. Unfortunately, there is no known way to extract this branching ratio from measurements at the LHC in a model-independent way. However, by making a set of mild assumptions, $BR(h\rightarrow W^+W^-)$ can be extracted from measurements at the LHC with an accuracy of about 10–20 %, depending on the Higgs-boson mass [7]. Alternatively, one could simply assume that this branching ratio equals its standard-model value. This is internally consistent, since this branching ratio is insensitive to the top-quark Yukawa coupling (for $m_h<2m_t$).

[3]This process might also be accessible at the Tevatron [27], but only a crude measurement of the Yukawa coupling could potentially be made.

TABLE II. Cuts applied to simulate the acceptance of the detector at the LHC at low luminosity and at high luminosity (in parentheses). The high-luminosity cuts are also used for the VLHC.

j	$p_T>15(30)$ GeV	$\|\eta\|<4.5$
b	$p_T>15(30)$ GeV	$\|\eta\|<2.5$
l	$p_T>10$ GeV	$\|\eta\|<2.5$
Trigger lepton: $p_T>20(30)$ GeV		
$\Delta R_{ij}>0.4$		

The total cross section for $t\bar{t}h, h\rightarrow W^+W^-$ is given in Table I for a variety of Higgs-boson masses. In the standard model, the top quark decays via $t\rightarrow W^+b$ with a branching ratio of almost unity, so the final state is $W^+W^-W^+W^-b\bar{b}$. This can be divided into different cases, depending on how many W bosons decay leptonically. To reduce backgrounds that do not contain top quarks, we require that both b jets are tagged, with a single-b-tag efficiency $\epsilon_b=60\%$ (50% at high luminosity).[4] We also include a lepton identification and reconstruction efficiency $\epsilon_l=85\%$. We do not require that either of the top quarks are reconstructed, since the principal backgrounds also contain top quarks. For a similar reason, we do not require any missing transverse momentum. We also do not require that the Higgs boson be reconstructed, which would be difficult due to the loss of neutrinos from leptonic W decays. A trigger lepton of $p_T>20$ GeV (30 GeV at high luminosity) is required. The cuts made to simulate the acceptance of the detector are given in Table II.

We consider three different cases for the final state, depending on whether there are two, three, or four leptonic decays of the W bosons in the signal $W^+W^-W^+W^-b\bar{b}$. Each case is discussed separately in Secs. II A–II C, along with the dominant backgrounds, which are shown in Fig. 2. In Sec. II D we argue that nonresonant backgrounds are small.

A. $l^{\pm}l^{\pm}$

First consider the case where two W bosons decay leptonically. The signal consists of[5] $2l+2b+4j$. To eliminate the background $t\bar{t}+4j$, we require that the leptons have the same sign. The dominant backgrounds are as follows.

$t\bar{t}W^{\pm}jj$, where the W decays leptonically and the top quark of the same sign decays semileptonically. The two jets are produced via QCD. We require that the invariant mass of these two jets lie within 25 GeV of the W mass (there are also two jets from W decay, which automatically satisfy this requirement). This captures most of the signal events.

$t\bar{t}l^+l^-jj$, where one lepton is missed, and the top quark of the same sign as the detected lepton decays semileptonically. A lepton is considered missed if it has $p_T<10$ GeV or

[4]Since we require two b tags, any improvement in the b-tagging efficiency would be magnified.

[5]We use the symbol j to denote a gluon or a light quark (u,d,s,c).

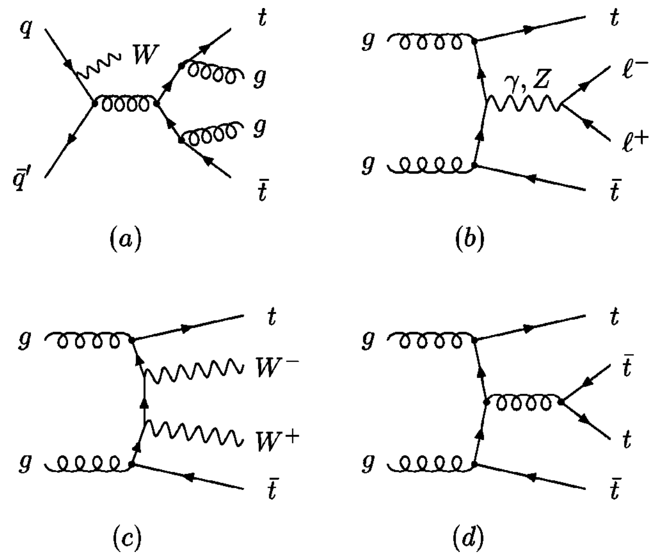

FIG. 2. Representative Feynman diagrams for the dominant backgrounds to $t\bar{t}h, h\to W^+W^-$: (a) $t\bar{t}W^{\pm}jj$; (b) $t\bar{t}l^+l^-$; (c) $t\bar{t}W^+W^-$; (d) $t\bar{t}t\bar{t}$.

$|\eta|>2.5$.[6] The two jets are produced via QCD, and are treated in the same way as in the previous background.

$t\bar{t}W^+W^-$, where one W decays leptonically and a top quark of the same sign decays semileptonically.

$t\bar{t}t\bar{t}$, where the leptons come from the semileptonic decay of same-sign top quarks. We demand that two and only two jets are b tagged. We accept events with four or more non-b-tagged jets.

B. 3l

Next consider the case where three W bosons decay leptonically. The signal is $3l+2b+2j$. Similar backgrounds are present as in the two-lepton case.

$t\bar{t}W^{\pm}jj$, where the W and both top quarks decay semileptonically. The two jets are produced via QCD. We require that the invariant mass of these two jets lie within 25 GeV of the W mass (there are also two jets from W decay, which automatically satisfy this requirement). This captures most of the signal events.

$t\bar{t}l^+l^-$, where both leptons are detected and one of the top quarks decays semileptonically. We suppress this background by requiring that there are no same-flavor, opposite-sign dileptons within 10 GeV of the Z mass.

$t\bar{t}W^+W^-$, where both W's decay leptonically and one top quark decays semileptonically, or both top quarks decay semileptonically and one W decays leptonically.

$t\bar{t}t\bar{t}$, where three of the top quarks decay semileptonically. We demand that two and only two jets are b tagged. We accept events with two or more non-b-tagged jets.

[6]If the missed lepton has $1\ \mathrm{GeV} < p_T < 10\ \mathrm{GeV}$ and is within a cone of $\Delta R<0.2$ from a detected lepton, then the detected lepton does not pass the isolation criteria and the event is rejected.

C. 4l

Finally, consider the case where all four W bosons decay leptonically. The signal is $4l+2b$. The same backgrounds are present as in the three-lepton case, with the exception of $t\bar{t}W^{\pm}jj$.

$t\bar{t}l^+l^-$, where both leptons are detected and both top quarks decay semileptonically. We suppress this background by requiring that there are no same-flavor, opposite-sign dileptons within 10 GeV of the Z mass.

$t\bar{t}W^+W^-$, where both W's decay leptonically and both top quarks decay semileptonically.

$t\bar{t}t\bar{t}$, where all four top quarks decay semileptonically. We demand that two and only two jets are b tagged. We accept events with zero or more non-b-tagged jets.

D. Non-resonant backgrounds

There will also be backgrounds from processes not involving top quarks, such as non-resonant $W^{\pm}W^{\pm}+6j$ and $W^{\pm}l^+l^-+6j$ (with one of the leptons missed) in the $l^{\pm}l^{\pm}$ final state, and $W^{\pm}l^+l^-+4j$ in the $3l$ final state. We expect such backgrounds to be small due to the requirement of double b tagging. This either forces two of the jets to be b quarks (which suppresses the cross section), or two jets to be mistagged as b quarks. A light quark or gluon will fake a b with a probability of less than 1%, so this latter possibility is also suppressed. To support this argument, consider $t\bar{t}$ production with one hadronic and one semileptonic top decay. With double b tagging, there is no significant background (including $W^{\pm}+4j$) [25]. We conclude that the dominant source of events with leptons and two b-tagged jets are those containing top quarks.

Requiring one or more b tags instead of two yields a significant increase in the number of signal events. However, non-resonant backgrounds such as those described above may become significant. We refrain from pursuing such an analysis in this paper.

III. CALCULATIONS

All calculations are performed at leading order with the code MADGRAPH [30], using the CTEQ4L parton distribution functions [31] and $\alpha_s(M_Z)=0.119$ with one-loop running.[7] We use a top-quark mass of 175 GeV. The code HDECAY (Version 2.0) [32] is used to calculate $BR(h\to W^+W^-)$, except for $m_h>2M_W$, where HDECAY uses the narrow-width approximation for the W bosons. We find that $\Gamma(h\to l\bar{\nu}\bar{l}\nu)$ is less than the narrow-width approximation

[7]The factorization and renormalization scales are chosen as follows: (i) for $t\bar{t}h$, $\mu_F=\mu_R=(2m_t+m_h)/2$; (ii) for $t\bar{t}W^{\pm}jj$, $\mu_F=(2m_t+M_W)/2$, $\mu_R=\mu_F$ for two factors of α_s and p_T of each radiated jet for each of the other two factors; (iii) for $t\bar{t}l^+l^-$, $\mu_F=\mu_R=(2m_t+m_{ll})/2$; (iv) for $t\bar{t}W^+W^-$, $\mu_F=\mu_R=m_t+M_W$; (v) for $t\bar{t}t\bar{t}$, $\mu_F=\mu_R=2m_t$. For $t\bar{t}h$, the one-loop running top-quark Yukawa coupling is evaluated at $\mu_R=m_h$.

TABLE III. The number of signal and background events in 30 fb^{-1} of integrated luminosity at the LHC for $t\bar{t}h, h\to W^+W^-$ in the two-, three-, and four-lepton final states. The low-luminosity cuts of Table II are applied. The background $t\bar{t}l^+l^-$ has two additional jets in the dilepton case only. Throughout the table, l denotes a summation over e and μ. B is the total number of background events.

	$t\bar{t}h$			Backgrounds				
m_h(GeV)	130	160	190	$t\bar{t}W^\pm jj$	$t\bar{t}l^+l^-(jj)$	$t\bar{t}W^+W^-$	$t\bar{t}t\bar{t}$	B
$2l$	6.4	15	8.3	10	1.9	0.86	1.6	14
$3l$	3.8	8.8	4.7	2.4	4.9	0.49	0.75	8.5
$4l$	0.38	0.67	0.34	—	0.67	0.036	0.009	0.72

$\Gamma(h\to W^+W^-)BR(W^-\to l\bar{\nu})BR(W^+\to \bar{l}\nu)$, by as much as 9% near threshold. For $m_h=130,160,190$ GeV, $BR(h\to W^+W^-)=30,92,79\%$, respectively.

Spin correlations between production and decay processes are maintained in all calculations. The top quarks are generated on-shell, but the W bosons can be off shell.

There are subtleties in the calculation of the background $t\bar{t}l^+l^-jj$ where one lepton is missed, and the top quark of the same sign as the detected lepton decays semileptonically. First, one must take care to implement the top-quark width in a manner than ensures gauge invariance of the amplitude. We use the "overall factor scheme" [33]. Second, the lepton mass must be maintained in the calculation to regulate the divergence when the missed lepton is collinear with an observed lepton.[8] We used the muon mass to perform the calculation; to obtain the result for electrons, we scale the cross section by a factor $\ln(m_\mu/m_e)$ since the divergence is logarithmic. This avoids problems with gauge invariance at very low dilepton invariant mass. Third, we approximate $t\bar{t}l^+l^-jj$ by calculating $t\bar{t}l^+l^-$ with all particles decaying to final-state quarks and leptons, and then multiplying by the ratio $t\bar{t}l^+l^-jj/t\bar{t}l^+l^-$. Rather than calculating this ratio, we approximate it as being equal to the ratio $t\bar{t}W^\pm jj/t\bar{t}W^\pm$ (which we calculate with all particles decaying to final-state quarks and leptons), since these two ratios entail QCD radiation from very similar subprocesses.

In the $t\bar{t}t\bar{t}$ background we demand two and only two b-tagged jets. This helps reduce this background, which has four b quarks in the final state. If only two of these b quarks are within the acceptance of the detector, we multiply by ϵ_b^2; if three are within the acceptance, we multiply by $3\epsilon_b^2(1-\epsilon_b)$; and if all four are within the acceptance, we multiply by $6\epsilon_b^2(1-\epsilon_b)^2$.

IV. RESULTS

The number of signal and background events with 30 fb^{-1} of integrated luminosity (three years at $\mathcal{L}=10^{33}\,\text{cm}^{-2}\,\text{s}^{-1}$) at the LHC are given in Table III for $m_h=130,160,190$ GeV. The low-luminosity cuts of Table II have been applied. The two-, three-, and four-lepton final states are considered individually. In each case, the signal-to-background ratio is of order unity, but the number of signal events is not large. The dominant backgrounds are $t\bar{t}W^\pm jj$ and $t\bar{t}l^+l^-$; the background $t\bar{t}W^+W^-$ is comparatively small,[9] and $t\bar{t}t\bar{t}$ is negligible.

We give in Table IV the number of signal and background events with 300 fb^{-1} of integrated luminosity (three years at $\mathcal{L}=10^{34}\,\text{cm}^{-2}\,\text{s}^{-1}$) at the LHC. The high-luminosity cuts of Table II have been applied. The number of events is increased due to the factor of ten increase in integrated luminosity, but this is partially compensated by the decreased acceptance. Another factor of ten increase is potentially available at a super-high-luminosity LHC (3000 fb^{-1} of integrated luminosity), assuming the same cuts can be used.

Table V gives the number of events at a 100 TeV VLHC with 300 fb^{-1} of integrated luminosity.[10] The high-luminosity cuts of Table II have been applied. The increased-energy results in many more events than at the LHC with the same integrated luminosity. The signal-to-background ratio remains of order unity. All four sources of background are comparable at the VLHC.

There are three sources of uncertainty in the extraction of the top-quark Yukawa coupling from the measured cross section: statistical, systematic, and theoretical. The statistical uncertainty in the measured cross section is $\sqrt{S+B}/S$, where S and B are the number of signal and background events, respectively. Since the cross section is proportional to the square of the Yukawa coupling, the statistical uncertainty in the measurement of the Yukawa coupling is half that of the cross section. We show in Figs. 3 and 4 the statistical uncertainty $\delta y_t/y_t$ at the low- and high-luminosity LHC, respectively. The statistical uncertainty from the two- and three-lepton final states are given separately, as well as the statistical uncertainty from the sum of the two channels, combined in quadrature. The statistical uncertainty in the four-lepton final state is much greater due to the dearth of signal events. Combining the low- and high-luminosity runs at the LHC in quadrature yields a statistical uncertainty in

[8]This is only relevant if the missed lepton has $p_T<1$ GeV; otherwise, the observed lepton does not pass the isolation cut mentioned in a previous footnote.

[9]The background $t\bar{t}W^\pm Z$ is less than or comparable to $t\bar{t}W^+W^-$, so we neglect it.

[10]Preliminary results for the VLHC were reported in Ref. [34].

TABLE IV. Same as Table III, except the high-luminosity cuts of Table II are applied, and 300 fb^{-1} of integrated luminosity are collected at the LHC.

	$t\bar{t}h$			Backgrounds				
m_h(GeV)	130	160	190	$t\bar{t}W^{\pm}jj$	$t\bar{t}l^{+}l^{-}(jj)$	$t\bar{t}W^{+}W^{-}$	$t\bar{t}t\bar{t}$	B
2l	8.1	24	16	19	3.2	2.1	4.2	29
3l	12	27	16	4.6	17	1.8	3.6	27
4l	2.1	3.8	2.0	—	3.9	0.21	0.20	4.3

the measurement of the Yukawa coupling of 16%,8%,12% for $m_h = 130,160,190$ GeV, respectively.

The dominant systematic uncertainty arises from our ability to measure and calculate the backgrounds. Since the signal is not separated from the backgrounds by kinematics, an accurate knowledge of the backgrounds is essential. It is beyond the scope of this work to attempt to estimate the systematic uncertainty in the measurement of the backgrounds; an uncertainty of 20% or less is desired in order to match the statistical uncertainty.

The dominant background in the three- and four-lepton final states is $t\bar{t}l^{+}l^{-}$. This background could be estimated by measuring $t\bar{t}Z, Z\rightarrow l^{+}l^{-}$, and extrapolating away from the Z resonance. This background is absent altogether if all opposite-sign leptons are of different flavor (e.g., $\mu^{+}\mu^{+}e^{-}$ or $\mu^{+}\mu^{+}e^{-}e^{-}$), but the number of events of this type is sufficiently small that the statistical uncertainty in the cross section increases when one considers only these events.

The dominant background in the two-lepton final state is $t\bar{t}W^{\pm}jj$. It is likely that our calculation overestimates this background because, using the cuts of Table II, each of the two jets can lie near the soft and collinear regions of phase space where perturbation theory overshoots the true cross section [35]. This background could be estimated by measuring the cross section for $W^{\pm}jj$ invariant masses far from the Higgs boson mass, and then extrapolating. This is nontrivial, as it assumes that one can correctly identify the $W^{\pm}jj$ system with good efficiency.

The theoretical uncertainty stems from the uncertainty in the subprocess cross section $gg,q\bar{q}\rightarrow t\bar{t}h$ and the uncertainty in the parton distribution functions. The subprocess cross section has been calculated at next-to-leading order in the strong interaction [36]. The dependence of the cross section on the common factorization and renormalization scales is relatively mild at the LHC, varying by about 10% as the scale is varied from half to twice its central value of $\mu_R = \mu_F = (2m_t + m_h)/2$. The largest uncertainty in the parton distribution functions is from the gluons. The gluon-gluon luminosity is known to about 10% accuracy at the LHC [37], and will be measured via $gg\rightarrow t\bar{t}$. Hence the total theoretical uncertainty in the cross section is about 15%. This is adequate in comparison with the statistical uncertainty.

The statistical uncertainty at the super-high-luminosity LHC (SLHC) is a factor $1/\sqrt{10}$ less than at the high-luminosity LHC, assuming the same cuts can be used. This yields a statistical uncertainty in the measurement of the Yukawa coupling of 7%,3%,5% for $m_h = 130,160,190$ GeV, respectively. This is small compared with the likely systematic uncertainty. Thus the measurement of the top-quark Yukawa coupling at the SLHC would be limited almost entirely by the systematic uncertainty.

The statistical uncertainty in $\delta y_t/y_t$ at the VLHC from the sum of the two- and three-lepton final states is 3.3%,1.6%,2.2% for $m_h = 130,160,190$ GeV, respectively. This is negligible compared with the likely systematic uncertainty.

The background $t\bar{t}t\bar{t}$ is negligible at the LHC, but it is significant at the VLHC; it is the largest background in the two-lepton final state, and one of the two largest backgrounds in the three-lepton final state. This background has two additional jets in the final state compared with the signal, so it could be reduced by vetoing events with extra jets. For example, vetoing events with two extra jets (but not one) reduces the $t\bar{t}t\bar{t}$ background at the VLHC to 500, 170, 21 in the two-, three, and four-lepton final states, respectively. While this does not decrease the statistical uncertainty (which is negligible in any case), it may be relevant to control the systematic uncertainty.

The process $t\bar{t}h, h\rightarrow ZZ$ may also be accessible at the VLHC. If both Z bosons decay leptonically, the Higgs-boson mass could be reconstructed, which would reduce the backgrounds.

TABLE V. Same as Table IV, except at the VLHC ($\sqrt{s} = 100$ TeV). The high-luminosity cuts of Table II are applied, and 300 fb^{-1} of integrated luminosity are collected.

	$t\bar{t}h$			Backgrounds				
m_h(GeV)	130	160	190	$t\bar{t}W^{\pm}jj$	$t\bar{t}l^{+}l^{-}(jj)$	$t\bar{t}W^{+}W^{-}$	$t\bar{t}t\bar{t}$	B
2l	370	1100	840	440	360	140	1065	2005
3l	500	1200	780	100	640	130	640	1510
4l	85	160	91	—	140	15	72	227

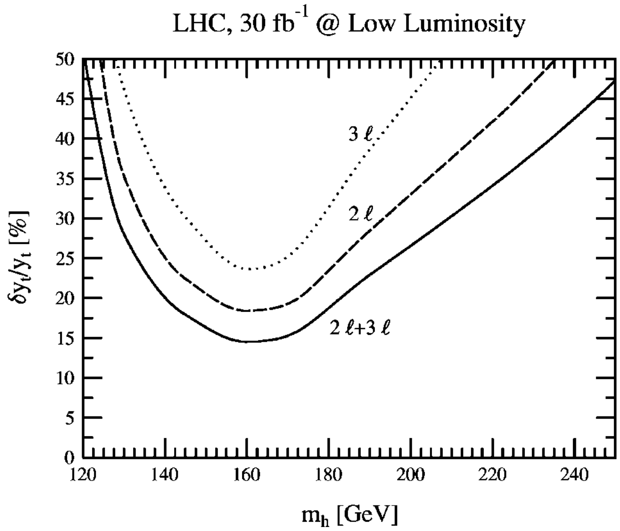

FIG. 3. The statistical uncertainty in the top-quark Yukawa coupling, $\delta y_t/y_t$, from $t\bar{t}h, h\to W^+W^-$ at the low-luminosity LHC (30 fb^{-1} of integrated luminosity). Results for the two- and three-lepton final states, as well as their sum, are shown.

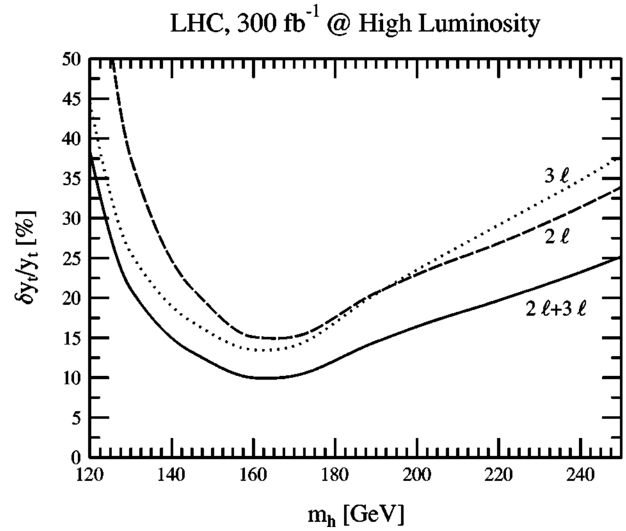

FIG. 4. Same as Fig. 3, but at the high-luminosity LHC (300 fb^{-1} of integrated luminosity).

V. CONCLUSIONS

We have studied the measurement of the top-quark Yukawa coupling to the Higgs boson via $t\bar{t}h, h\to W^+W^-$ at the LHC. A signal is available in the two- and three-lepton final states, and the signal to background ratio is of order unity. Combining both channels, and assuming 30 fb^{-1} of integrated luminosity at low luminosity and 300 fb^{-1} at high luminosity, we find a statistical uncertainty in the measurement of the Yukawa coupling $\delta y_t/y_t$ of 16%, 8%, 12% for $m_h = 130, 160, 190$ GeV, respectively.

The statistical uncertainty in the Yukawa coupling would be negligible at a 100 TeV VLHC. Thus the uncertainty in the Yukawa coupling would be dominated by the systematic uncertainty.

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