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Anomalous $W^+W^-t\bar{t}$ Couplings at the LC[1]

Timothy M. P. Tait[2]

HEP Division, Argonne National Lab
9700 South Cass Avenue, Argonne, IL 60439 USA[3]

Abstract. We study production of $t\bar{t}$ via W^+W^--fusion, including the relevant backgrounds at the proposed Linear Collider (an $e^+ e^-$ collider with $\sqrt{S} = 1.5$ TeV) in the context of a *Higgsless* Standard Model (HSM), i.e. a nonlinear $\mathrm{SU(2)}_L \times \mathrm{U(1)}_Y$ chiral Lagrangian, including dimension five $W^+W^-t\bar{t}$ interactions. Deviation from the HSM predictions can be used to constrain the coefficients of these operators to an order of 10^{-1} (divided by the cut-off scale $\Lambda = 3.1$ TeV) with a 95% C.L..

One of the deep mysteries with which we are confronted today in particle physics is the mechanism of the electroweak symmetry breaking (EWSB). While the fundamental Higgs mechanism postulated by the Standard Model (SM) currently provides an excellent description of all experimental data, the Higgs itself has defied discovery. This leads us to explore other probes of the EWSB sector, such as deviations in the couplings of known particles from SM predictions, induced by the underlying EWSB physics.

The top quark, as the only quark whose mass is of the same order as the EWSB scale, $v \sim 246$ GeV, provides a natural laboratory in which to search for these nonstandard effects. In fact, the large top mass may be a clue that top plays an essential role in the EWSB, and a detailed study of its properties may prove to be the only way to unravel the true nature of the EWSB dynamics. It is important that these interactions be studied exhaustively and model-independently, since without a deep understanding of the underlying physics it is impossible to know what to expect.

In this talk we address how one can use the process $W^+W^- \to t\bar{t}$ at a high energy e^+e^- collider (which we assume to have center-of-mass energy $\sqrt{S} = 1.5$ TeV with a data sample of 200 fb^{-1}) to probe several parameters of a generic effective theory in which the electroweak symmetry is broken, but no assumptions about

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[2] Electronic address: tait@anl.gov
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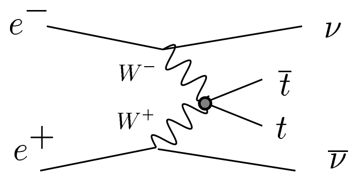

FIGURE 1. Diagrams for $e^+e^- \to \nu_e\bar{\nu}_e t\bar{t}$ through anomalous $W^+W^-t\bar{t}$ couplings.

how the breaking occurs are imposed. We show that non-standard interactions of $\mathcal{O}(10^{-1})$ are tested by this process [1]. Our model-independent results, in the context of a nonlinear realization of the electroweak (EW) gauge symmetry [2] are complimentary to studies based on specific models [3], upon parameterizations with linear realizations of the EW symmetry [4], studies which include generic scalar bosons [5], as well as to studies at hadron colliders based on single top production [6]. If there is new physics associated with the EWSB present in this channel, it could be discovered in this way, and we would know what some of the properties an underlying theory would have to possess in order to explain the observed deviation. Similarly, if no effect is discovered, we effectively constrain any theory of new physics which contributes to this process.

Our dimension five interactions are part of the electroweak chiral Lagrangian, which realizes the EW gauge symmetry nonlinearly. This parameterization is most appropriate for a theory in which the underlying EWSB dynamics is strong, and there is effectively no Higgs boson at low energies, and thus our setting can be thought of as the *Higgsless* Standard Model (HSM). As was studied in Ref. [7], there are fourteen dimension five operators which contribute to $W^+W^-t\bar{t}$ scattering in this context, however only seven of them contribute to the leading behavior in E, the energy of the $t\bar{t}$ system. These seven operators may be further classified by their Lorentz structure as either scalar operators, contributing only to S-wave $W_L^+W_L^- \to t\bar{t}$ scattering, as tensor operators contributing to P-wave scattering, and one operator which contains both structures. Thus, without loss of generality, we restrict our attention to one dimension 5 operator of each type, contributing at leading order in E,

$$\mathcal{L}^5_{eff} = \frac{a_1}{\Lambda}\bar{t}tW^+_\mu W^{-\mu} + \frac{a_2}{\Lambda}i\bar{t}\sigma^{\mu\nu}tW^+_\mu W^-_\nu \ , \tag{1}$$

where a_1 and a_2 parameterize the strength of the S-wave and P-wave operators, respectively, and are expected from naive dimensional analysis to be order 1 when the cut-off of the theory is $\Lambda = 4\pi v = 3.1$ TeV [8]. In our discussion below, we set $\Lambda = 3.1$ TeV and discuss how well one may constrain a_1 and a_2 for this assumed value of Λ.

We perform detailed Monte Carlo simulations of the process $e^+e^- \to \nu_e\bar{\nu}_e t\bar{t}$, including the exact $2 \to 4$ tree level matrix elements. The HSM contains 19 Feynman diagrams for this process, and our new physics that we wish to probe contributes up to two extra diagrams, as shown in Fig. 1, one for each operator under study.

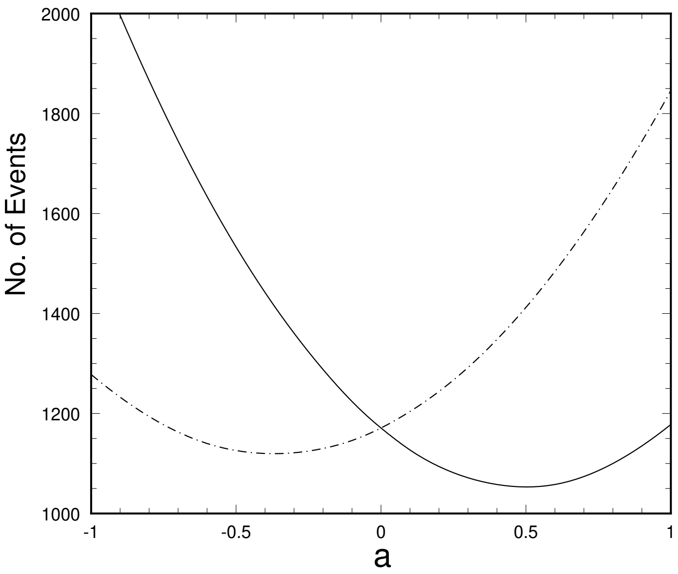

FIGURE 2. Number of W^+W^- fusion $t\bar{t}$ pairs as a function of the anomalous couplings a_1 (solid line) and a_2 (dash-dot line). The point $a_1 = a_2 = 0$ corresponds to the prediction of the *Higgsless* SM.

Assuming that the new physics contributions are small compared to the HSM rates, our dominant signal will arise from the interference between the HSM graphs, and ones containing the new physics operators in Eq. 1.

Our experimental signature is taken to be a $t\bar{t}$ pair, and missing transverse energy ($\not{E}_T$) from the neutrinos in the final state. We also consider the dominant background to this process, $e^+e^- \to t\bar{t}\gamma$, where the photon is missed because it falls outside of the detector coverage (assumed to be 0.15 rad about the beam axis), thus faking missing E_T. We impose the restriction that the t and $\bar{t}$ each have transverse momentum $p_T \geq 20$ GeV and rapidity $|y| \leq 2$ in order to be observable. In addition, we find that we can suppress the fake background by requiring the p_T of the $t\bar{t}$ pair to also be larger than 20 GeV, because the fake rate produces photons which tend to be collinear with the incoming electrons. After imposing these cuts, we are left with cross sections of 4 fb (assuming $a_1 = a_2 = 0$) for $e^+e^- \to t\bar{t}\nu\bar{\nu}$ and 1.8 fb for $e^+e^- \to t\bar{t}\gamma$. The fake background may be further reduced, by polarizing the e^- and/or e^+ beam, because in the signal $W^+W^- \to t\bar{t}$ process the W bosons only couple to left- (right-handed) fermions (anti-fermions), whereas the fake process is dominated by initial state radiation which couples to both polarizations.

We now allow a_1 and a_2 to be non-zero, and derive 95% confidence level (C.L.) constraints on these parameters. The simplest thing one can do is to count the number of $W^+W^- \to t\bar{t}$ events. The dependence on a_1 and a_2 is shown in Fig. 2. Note that because the primary influence of the new physics operators is through an interference effect, the event rate can actually be smaller than the HSM prediction. Requiring that no 95% C.L. deviation is observed restricts $-0.13 \leq a_1 \leq 0.18$ and $-0.9 \leq a_2 \leq 0.2$.

One may improve these constraints by noting that the new physics operators result in modified kinematic distributions for the produced top quarks. In particular, we have found that both the rapidity of the $t\bar{t}$ system, $y_{t\bar{t}}$, and the rapidity gap between the t and $\bar{t}$, $y_t - y_{\bar{t}}$, are sensitive to the presence of the anomalous $W^+W^-t\bar{t}$ operators. In particular, the tensor operator (a_2) tends to shift the t and $\bar{t}$ rapidities in the opposite directions from the HSM predictions, and thus the rapidity gap distribution is especially effective at revealing the presence of such a P-wave new physics effect. We quantify the deviation of a given measured distribution compared to the HSM prediction by the χ^2 deviation,

$$\chi^2 = \Sigma_{j=1}^{K} \frac{(N_j^A - N_j^{HSM})^2}{N_j^{HSM}}, \tag{2}$$

and find that for an integrated luminosity of $L = 200\,\mathrm{fb}^{-1}$, it is optimal to use 3 equally sized bins in the region $-0.6 \leq y_{t\bar{t}} \leq 0.6$, and 4 bins for the $y_t - y_{\bar{t}}$ analysis (in the region $0 \leq y_t - y_{\bar{t}} \leq 2$). Applying the χ^2 analysis improves the constraints to $-0.10 \leq a_1 \leq 0.12$ from $\chi^2(y_{t\bar{t}})$ and $-0.3 \leq a_2 \leq 0.2$ from $\chi^2(y_t - y_{\bar{t}})$. The fact that the two operators are more evident in two different distributions could also be used to disentangle one from the other, should a deviation in the total rate be observed. We have also examined the polarizations of the t and $\bar{t}$ and found that some improvement in sensitivity is possible if these polarizations are also measured [1].

In conclusion, we have found that in models in which the EWSB is a result underlying strong dynamics, the process $W^+W^- \to t\bar{t}$ at a high energy linear collider is a powerful test of several operators which may be present in the low energy effective theory, and may provide useful information in divining the true nature of the EWSB.

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REFERENCES

1. F. Larios, Tim Tait, C.–P. Yuan, Phys. Rev. **D57**, 3106 (1998), [hep-ph/9709316].
2. R.D. Peccei, X. Zhang, Nucl. Phys.**B337**, 269 (1990); Nucl. Phys. **B349**, 305 (1991); E. Malkawi, C.–P. Yuan, Phys. Rev. **D50**, 4462 (1994), [hep-ph/9405322].
3. E. R. Morales, M.E. Peskin, SLAC-PUB-8251, Presented at LCWS 99, Sitges, Barcelona, Spain, 28 Apr - 5 May 1999, [hep-ph/9909383].
4. T. Huang, Presented at ICHEP 2000, Osaka, Japan, 27 Jul - 2 Aug 2000, [hep-ph/0009047].
5. T. Han, Y.J. Kim, A. Likhoded, G. Valencia, Nucl. Phys. **B593**, 415 (2001), [hep-ph/0005306].
6. D.O. Carlson, Ehab Malkawi, C.–P. Yuan, Phys. Lett. **B337**, 145 (1994), [hep-ph/9405277]; Tim Tait, C.–P. Yuan, hep-ph/9710372; Phys. Rev. **D63**, 014018 (2001), [hep-ph/0007298].
7. F. Larios, C.–P. Yuan, Phys. Rev. **D55**, 7218 (1997).
8. A. Manohar, H. Georgi, Nucl. Phys. **B234**, 189 (1984).