SEARCH FOR NEW PHYSICS THROUGH $e^-e^+ \to t\bar{t}$ *

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(Received March 4, 1998)

If all new particles are too heavy to be directly produced in the future Colliders, then the long sought New Physics (NP) could only appear in the form of new interactions, beyond those of the Standard Model (SM). Many of the processes that could be used to study these interactions, have already been discussed in the literature. Here, I first briefly discuss the list of all not yet excluded CP conserving such interactions, realized as SU(3)×SU(2)×U(1) gauge invariant dim = 6 operators affecting the Higgs and the quarks of the third family. Subsequently, I concentrate on the $\gamma t\bar{t}$ and $Zt\bar{t}$ vertices generated by NP, and on the possibility to study them by using various spin asymmetries accessible in $e^-e^+ \to t\bar{t}$, for polarized and unpolarized beams. It is found that these asymmetries can fully determine the form of the $\gamma t\bar{t}$ and $Zt\bar{t}$ couplings.

PACS numbers: 14.65.Ha, 12.15.Ji, 13.38.Dg, 14.70.Hp

1. Introduction

The work I am presenting here was done in collaboration with F. Renard, J. Layssac, D. Papadamou and M. Kuroda. It addresses the logical possibility that in the future Colliders there would be no new particles discovered, apart from a standard-like Higgs boson. In such case, the only possibly observable NP effect, would be induced by new interactions, beyond those expected in the SM. If the scale of NP is sufficiently high, the NP interactions could appear as SU(3)×SU(2)×U(1) gauge invariant dim = 6 operators, affecting the various particles present in SM [1].

Since the Higgs is the most fascinating and mysterious of all fields appearing in SM, it seems quite plausible to assume that it is also the source of

* Presented at the Cracow Epiphany Conference on Spin Effects in Particle Physics and Tempus Workshop, Cracow, Poland, January 9-11, 1998.

NP. In such a case the above list of the NP induced operators [1], could be considerably reduced by assuming that it only involves the Higgs, the quarks of the third family (for which SM suggests that they have the strongest affinity to Higgs), and of course the gauge bosons inevitably introduced whenever derivatives enter. The CP conserving such operators have been listed in [2, 3], while the CP violating ones have appeared in [4, 5]. Below, we restrict ourselves only to the CP conserving NP operators.

In the present talk we investigate the extent to which polarization effects in $e^-e^+ \to t\bar{t}$ and the top decay amplitude $t \to bW$, can be used to study these NP operators. We only consider their dominant contributions, which can only appear as modifications of the γtt, Ztt and Wtb vertices. These arise either at tree level, or (in case this is vanishing), at the 1-loop level; where it is sufficient to retain only the leading-log part, whenever it is enhanced by a positive power of m_t [6].

2. The new physics operators

We first turn to the purely bosonic CP conserving operators [7]. Discarding all operators that give strongly constrained tree level contributions to LEP1 observables, we end up with the operators

$$\mathcal{O}_W = \frac{1}{3!}\left(\overrightarrow{W}_\mu{}^\nu \times \overrightarrow{W}_\nu{}^\lambda\right)\cdot \overrightarrow{W}_\lambda{}^\mu , \tag{1}$$

$$\mathcal{O}_{W\Phi} = i\,(D_\mu\Phi)^\dagger \overrightarrow{\tau}\cdot \overrightarrow{W}^{\mu\nu}(D_\nu\Phi)\,, \tag{2}$$

$$\mathcal{O}_{B\Phi} = i\,(D_\mu\Phi)^\dagger B^{\mu\nu}(D_\nu\Phi)\,, \tag{3}$$

$$\mathcal{O}_{WW} = (\Phi^\dagger\Phi)\,\overrightarrow{W}^{\mu\nu}\cdot\overrightarrow{W}_{\mu\nu}\,, \tag{4}$$

$$\mathcal{O}_{BB} = (\Phi^\dagger\Phi)B^{\mu\nu}\,B_{\mu\nu}\,, \tag{5}$$

$$\mathcal{O}_G = \frac{1}{3!}\,f_{ijk}\,G^{i\mu\nu}G^j_{\nu\lambda}G^{k\lambda}{}_\mu\,, \tag{6}$$

$$\overline{\mathcal{O}}_{DG} = 2\,(D_\mu\overrightarrow{G}^{\mu\rho})(D^\nu\overrightarrow{G}_{\nu\rho})\,, \tag{7}$$

$$\mathcal{O}_{GG} = (\Phi^\dagger\Phi)\,\overrightarrow{G}^{\mu\nu}\cdot\overrightarrow{G}_{\mu\nu}\,, \tag{8}$$

$$\mathcal{O}_{\Phi 2} = 4\,\partial_\mu(\Phi^\dagger\Phi)\partial^\mu(\Phi^\dagger\Phi)\,, \tag{9}$$

$$\mathcal{O}_{\Phi 3} = 8\,(\Phi^\dagger\Phi)^3\,. \tag{10}$$

The effective Lagrangian describing the NP contributions from these operators may be written as

$$\begin{aligned}\mathcal{L}_{\rm bos} = {} & \lambda_W\frac{g}{M_W^2}\mathcal{O}_W + f_W\frac{g}{2M_W^2}\mathcal{O}_{W\Phi} + f_B\frac{g'}{2M_W^2}\mathcal{O}_{B\Phi} \\ & + \frac{d}{v^2}\,\mathcal{O}_{WW} + \frac{d_B}{v^2}\,\mathcal{O}_{BB} + \frac{f_{\Phi 2}}{v^2}\mathcal{O}_{\Phi 2} + \frac{d_G}{v^2}\,\mathcal{O}_{GG}\,.\end{aligned} \tag{11}$$

Unitarity considerations relate any non vanishing of these NP couplings, to the corresponding Λ_{NP} scale where it may be generated. This Λ_{NP} scale is uniquely determined by unitarity, and does not depend on the normalization chosen to define the NP coupling. Thus, using unitarity, we express the sensitivity limits to the various NP scales defined in a physically appealing way. Referring to [8, 9], these relations are

$$|\lambda_W| \simeq 19\ \frac{M_W^2}{\Lambda_{NP}^2}\,, \qquad |f_B| \simeq 98\ \frac{M_W^2}{\Lambda_{NP}^2}\,, \qquad |f_W| \simeq 31\ \frac{M_W^2}{\Lambda_{NP}^2}\,, \tag{12}$$

$$\begin{aligned}
d &\simeq \frac{104.5\ \left(\frac{M_W}{\Lambda_{NP}}\right)^2}{1+6.5\left(\frac{M_W}{\Lambda_{NP}}\right)} \quad \text{for } d>0\,,\\
d &\simeq -\frac{104.5\ \left(\frac{M_W}{\Lambda_{NP}}\right)^2}{1-4\left(\frac{M_W}{\Lambda_{NP}}\right)} \quad \text{for } \ d<0\,, \qquad (13)\\
d_B &\simeq \frac{195.8\ \left(\frac{M_W}{\Lambda_{NP}}\right)^2}{1+200\left(\frac{M_W}{\Lambda_{NP}}\right)^2} \quad \text{for } d_B>0\,,\\
d_B &\simeq -\frac{195.8\ \left(\frac{M_W}{\Lambda_{NP}}\right)^2}{1+50\left(\frac{M_W}{\Lambda_{NP}}\right)^2} \quad \text{for } \ d_B<0\,, \qquad (14)
\end{aligned}$$

while for $\mathcal{O}_{\Phi 2}$ we refer to [9], and to [10] for $\mathcal{O}_{GG}$.

The operators in (1), (3) are best studied through $e^-e^+ \to W^-W^+$ at LEP2 and linear e^-e^+, $\mu^-\mu^+$ colliders [11,12]. Gauge and Higgs production in the $\gamma\gamma$ Collider, can give further information on $\mathcal{O}_W$, $\mathcal{O}_{W\Phi}$, $\mathcal{O}_{B\Phi}$, as well as on $\mathcal{O}_{WW}$ and $\mathcal{O}_{BB}$. Important constraints on $\mathcal{O}_G$ and $\mathcal{O}_{DG}$ could arise by dijet and multi jet production at the upgraded Tevatron and LHC [13], while $\mathcal{O}_{GG}$ will need the study the Higgs production at a hadron collider.

NP contributions from the bosonic operators to the γtt, Ztt and Wtb vertices, studied through $e^-e^+ \to t\bar{t}$, only appear 1-loop level. Thus, *e.g.* the dominant contribution from $\mathcal{O}_{\Phi 2}$ gives a purely axial Ztt and a left-handed Wtb coupling; while $\sigma_{\mu\nu}$ couplings for Ztt and γtt arise from $\mathcal{O}_{WW}$ and $\mathcal{O}_{BB}$ [6].

The NP operators containing quarks of the third family are divided into three classes [2,14]. Class 1 contains the operators involving t_R, Class 2 those not involving t_R; while in Class 3 we put all operators involving covariant derivatives of gauge boson field strengths and related to the currents through

the equations of motion. The **Class 1** operators, for the study of which the process $e^-e^+ \to t\bar{t}$ is most suited, are

A1) Four-quark operators

$$\mathcal{O}_{qt} = (\bar{q}_L t_R)(\bar{t}_R q_L)\,, \tag{15}$$

$$\mathcal{O}^{(8)}_{qt} = (\bar{q}_L \overrightarrow{\lambda} t_R)(\bar{t}_R \overrightarrow{\lambda} q_L)\,, \tag{16}$$

$$\mathcal{O}_{tt} = \frac{1}{2}(\bar{t}_R\gamma_\mu t_R)(\bar{t}_R\gamma^\mu t_R)\,, \tag{17}$$

$$\mathcal{O}_{tb} = (\bar{t}_R\gamma_\mu t_R)(\bar{b}_R\gamma^\mu b_R)\,, \tag{18}$$

$$\mathcal{O}^{(8)}_{tb} = (\bar{t}_R\gamma_\mu \overrightarrow{\lambda} t_R)(\bar{b}_R\gamma^\mu \overrightarrow{\lambda} b_R)\,, \tag{19}$$

$$\begin{aligned}\mathcal{O}_{qq} = {} & (\bar{t}_R t_L)(\bar{b}_R b_L) + (\bar{t}_L t_R)(\bar{b}_L b_R) \\ & -(\bar{t}_R b_L)(\bar{b}_R t_L) - (\bar{b}_L t_R)(\bar{t}_L b_R)\,,\end{aligned} \tag{20}$$

$$\begin{aligned}\mathcal{O}^{(8)}_{qq} = {} & (\bar{t}_R \overrightarrow{\lambda} t_L)(\bar{b}_R \overrightarrow{\lambda} b_L) + (\bar{t}_L \overrightarrow{\lambda} t_R)(\bar{b}_L \overrightarrow{\lambda} b_R) \\ & -(\bar{t}_R \overrightarrow{\lambda} b_L)(\bar{b}_R \overrightarrow{\lambda} t_L) - (\bar{b}_L \overrightarrow{\lambda} t_R)(\bar{t}_L \overrightarrow{\lambda} b_R)\,.\end{aligned} \tag{21}$$

B1) Two-quark operators.

$$\mathcal{O}_{t1} = (\Phi^\dagger\Phi)(\bar{q}_L t_R\widetilde{\Phi} + \bar{t}_R\widetilde{\Phi}^\dagger q_L)\,, \tag{22}$$

$$\mathcal{O}_{t2} = i\left[\Phi^\dagger(D_\mu\Phi) - (D_\mu\Phi^\dagger)\Phi\right](\bar{t}_R\gamma^\mu t_R)\,, \tag{23}$$

$$\mathcal{O}_{t3} = i\,(\widetilde{\Phi}^\dagger D_\mu\Phi)(\bar{t}_R\gamma^\mu b_R) - i\,(D_\mu\Phi^\dagger\widetilde{\Phi})(\bar{b}_R\gamma^\mu t_R)\,, \tag{24}$$

$$\mathcal{O}_{Dt} = (\bar{q}_L D_\mu t_R)D^\mu\widetilde{\Phi} + D^\mu\widetilde{\Phi}^\dagger(\overline{D_\mu t_R}\; q_L)\,, \tag{25}$$

$$\mathcal{O}_{tW\Phi} = (\bar{q}_L\sigma^{\mu\nu}\overrightarrow{\tau} t_R)\widetilde{\Phi}\cdot\overrightarrow{W}_{\mu\nu} + \widetilde{\Phi}^\dagger(\bar{t}_R\sigma^{\mu\nu}\overrightarrow{\tau} q_L)\cdot\overrightarrow{W}_{\mu\nu}\quad, \tag{26}$$

$$\mathcal{O}_{tB\Phi} = (\bar{q}_L\sigma^{\mu\nu} t_R)\widetilde{\Phi}B_{\mu\nu} + \widetilde{\Phi}^\dagger(\bar{t}_R\sigma^{\mu\nu} q_L)B_{\mu\nu}\,, \tag{27}$$

$$\mathcal{O}_{tG\Phi} = \left[(\bar{q}_L\sigma^{\mu\nu}\lambda^a t_R)\widetilde{\Phi} + \widetilde{\Phi}^\dagger(\bar{t}_R\sigma^{\mu\nu}\lambda^a q_L)\right]G^a_{\mu\nu}\,, \tag{28}$$

while the corresponding NP effective Lagrangian is written as

$$\mathcal{L}_{\rm top} = \sum_i \frac{f_i}{m_t^2}\,\mathcal{O}_i\,. \tag{29}$$

None of the Class 1 operators is strongly constrained by presently existing measurements. The unitarity constraints, relating in a normalization-independent way, these NP couplings to the corresponding Λ_{NP} scales, are given in [2].

TABLE I

Sensitivity limits for 1 free parameter, polarized/unpolarized cases

Operator	$\sqrt{s} = 0.5$ TeV	$\sqrt{s} = 1$ TeV	$\sqrt{s} = 2$ TeV	other constraints
$\mathcal{O}_{qt}$	0.53/1.62 (0.98)/(0.56)	0.26/0.53 (1.41)/(0.99)	0.18/0.31 (1.68)/(1.29)	-0.14 ± 0.07
$\mathcal{O}_{qt}^{(8)}$	0.10/0.30 (2.47)/(1.42)	0.049/0.099 (3.55)/(2.49)	0.034/0.057 (4.24)/(3.26)	-0.027 ± 0.013
$\mathcal{O}_{tt}$	0.064/0.11 (3.00)/(2.32)	0.017/0.039 (5.87)/(3.85)	0.010/0.026 (7.46)/(4.70)	—
$\mathcal{O}_{tb}$	0.14/0.36 (2.33)/(1.46)	0.043/0.11 (4.24)/(2.64)	0.027/0.071 (5.30)/(3.30)	-0.13 ± 0.06
$\mathcal{O}_{t2}$	0.010/0.023 (11.57)/(7.60)	0.0090/0.018 (12.18)/(8.62)	0.0089/0.017 (12.24)/(8.75)	0.01; 0.14 ± 0.07
$\mathcal{O}_{Dt}$	0.039/0.093 (2.84)/(1.85)	0.011/0.018 (5.27)/(4.15)	0.0052/0.0071 (7.84)/(6.68)	0.03; -0.06 ± 0.03
$\mathcal{O}_{tW\Phi}$	0.0010/0.0021 (42.67)/(29.97)	0.00067/0.0010 (53.14)/(42.73)	0.00043/0.00056 (66.16)/(58.10)	0.014
$\mathcal{O}_{tB\Phi}$	0.0011/0.0027 (41.63)/(26.52)	0.00079/0.0015 (48.82)/(36.11)	0.00060/0.0012 (55.89)/(39.80)	0.013
$\mathcal{O}_{tG\Phi}$	0.027/0.029 (7.86)/(7.30)	0.023/0.025 (9.08)/(8.54)	0.045/0.047 (4.71)/(4.52)	—
$\mathcal{O}_{W}$	0.065/0.13 (1.37)/(0.95)	0.021/0.045 (2.38)/(1.65)	0.014/0.030 (2.95)/(2.02)	$0.1^{(c)}$
$\mathcal{O}_{W\Phi}$	0.11/0.22 (1.35)/(0.94)	0.036/0.075 (2.35)/(1.63)	0.023/0.050 (2.91)/(1.99)	0.1
$\mathcal{O}_{B\Phi}$	0.071/0.14 ((2.98)/(2.09)	0.020/0.043 (5.66)/(3.81)	0.012/0.028 (7.14)/(4.76)	0.1
$\mathcal{O}_{WW}$	0.28/0.56 (1.56)/(1.10)	0.29/0.45 (1.52)/(1.22)	0.51/0.66 (1.15)/(1.01)	0.015
$\mathcal{O}_{BB}$	0.32/0.78 (1.99)/(1.27)	0.37/0.69 (1.83)/(1.35)	0.77/1.53 (1.27)/(0.91)	0.05
$\mathcal{O}_{\Phi 2}$	0.57/0.68	0.68/0.81	1.74/2.08	0.01

Among the 14 operators in (15, 28), only $\mathcal{O}_{t2}$, $\mathcal{O}_{Dt}$, $\mathcal{O}_{tW\Phi}$ and $\mathcal{O}_{tB\Phi}$ give tree level contributions to the gauge vertices. 1-loop γtt and Ztt contributions of the V and A type are induced by $\mathcal{O}_{qt}$, $\mathcal{O}_{qt}^{(8)}$ $\mathcal{O}_{tt}$ and $\mathcal{O}_{tb}$; while $\sigma_{\mu\nu}$ couplings arise from $\mathcal{O}_{tG\Phi}$, $\mathcal{O}_{qq}$ and $\mathcal{O}_{qq}^{(8)}$ [6]. The sensitivity of $e^-e^+ \to t\bar{t}$ to these operators is discussed in Table I.

3. Observables

As already stated, within our approximations, the only relevant NP effects induced by the above operators, are expressed as contributions to the γtt, Ztt and Wtb vertices. If CP is conserved, the $Vt\bar{t}$ ($V=\gamma,\ Z$) vertex is written as [6, 15–17]

$$-i\varepsilon_\mu^V J_V^\mu = -ie_V\varepsilon_\mu^V \bar{u}_t(p)\left[\gamma^\mu d_1^V(q^2)+\gamma^\mu\gamma^5 d_2^V(q^2)+(p-p')^\mu\frac{d_3^V(q^2)}{m_t}\right]v_{\bar{t}}(p')\,, \tag{30}$$

where the normalization is determined by $e_\gamma \equiv e$ and $e_Z \equiv e/(2s_W c_W)$, while d_i^V are in general q^2 dependent form factors. Similarly the $t(p_t)\to W^+(p_W)b(p_b)$ amplitude is written as

$$\begin{aligned}-i\varepsilon_\mu^{W*}J_W^\mu &= -i\frac{gV_{tb}^*}{2\sqrt{2}}\varepsilon_\mu^{W*}\bar{u}_b(p_b)\\ &\times\left[\gamma^\mu d_1^W+\gamma^\mu\gamma^5 d_2^W+(p_t+p_b)^\mu d_3^W+(p_t+p_b)^\mu\gamma^5 d_4^W\right]u_t(p_t)\,.\end{aligned} \tag{31}$$

We consider the case where $t\bar{t}$ are produced in $e^-e^+\to t\bar{t}$, and subsequently one of them decays semileptonicly; say *e.g.*, $t\to bW\to bl^+\nu$, while $\bar{t}$ decays purely hadronicly. The $e^-e^+\to t\bar{t}$ amplitude at a scattering angle θ, for L or R polarized e^- beam, determines the density matrix $\rho^{L,R}_{\tau\tau'}(\theta)$ of the produced t quark, which contains all possible information on the production mechanism and NP expressed through the six couplings (d_j^γ, d_j^Z).

The subsequent decay $t\to bW\to bl^+\nu$ is determined by the decay functions $\mathcal{R}_{\tau\tau'}$ which contain all NP dynamical information coming from the four d_i^W couplings; and depend also on the three Euler angles $(\varphi_1,\vartheta_1,\psi_1)$ determining the top decay plane in its rest frame, as well as on the angle θ_l describing the angular distribution of l^+ in the top decay plane.

We thus have [6])

$$\frac{d\sigma^{L,R}(e^-e^+\to bl^+\nu)}{d\cos\theta d\varphi_1 d\cos\vartheta_1 d\psi_1 d\cos\theta_l}\sim\rho^{L,R}_{\tau\tau'}(\theta)\cdot\mathcal{R}_{\tau\tau'}(\varphi_1,\vartheta_1,\psi_1,\theta_l)\,, \tag{32}$$

where the upper index describes the longitudinal polarization e^- beam. Eqs (32) may be written as

$$\begin{aligned}\rho^{L,R}_{\tau_1\tau_2}\cdot\mathcal{R}_{\tau_1\tau_2} &= \frac{1}{2}\,(\rho_{++}+\rho_{--})^{L,R}(\mathcal{R}_{++}+\mathcal{R}_{--})\\ &+\ \frac{1}{2}(\rho_{++}-\rho_{--})^{L,R}(\mathcal{R}_{++}-\mathcal{R}_{--})\\ &+\ \rho^{L,R}_{+-}(\mathcal{R}_{+-}+\mathcal{R}_{-+})\,,\end{aligned} \tag{33}$$

in which the three terms in the r.h.s. of (33), called respectively A, H and T terms, can be separated by averaging (32) in the Euler-angle space, using the weights [6, 15]

$$A \sim (\rho_{++} + \rho_{--})^{L,R} \longleftarrow 1 \cdot d\varphi_1 d\cos\vartheta_1 d\psi_1 \,, \tag{34}$$

$$H \sim (\rho_{++} - \rho_{--})^{L,R} \longleftarrow (\cos\psi_1 + r\sin\psi_1) \cdot d\varphi_1 d\cos\vartheta_1 d\psi_1 \,, \tag{35}$$

$$\begin{aligned} T \sim \rho_{+-}^{L,R} \longleftarrow & \Big\{ (\cos\psi_1 \sin\varphi_1 \cos\vartheta_1 - \sin\psi_1 \sin\varphi_1) \\ & + r(\sin\psi_1 \cos\varphi_1 \cos\vartheta_1 + \cos\psi_1 \sin\varphi_1) \Big\} \\ & \times d\varphi_1 d\cos\vartheta_1 d\psi_1 \,, \end{aligned} \tag{36}$$

where we choose

$$r \equiv \frac{3\pi m_t M_W}{4(m_t^2 - 2M_W^2)} \,, \tag{37}$$

so that to maximize the statistical significance of the results.

Integrating further over $\cos\theta$, we can then construct from (34)–(36) θ_l-asymmetries supplying information on the top decay NP. Unfortunately, to first order in the NP couplings, these asymmetries only measure the combination $d_3^W + d_4^W$; while the t width is to the same order only sensitive to $(d_1^W - d_2^W)^{NP}$. Thus, as far as the NP affecting the t decay is concerned, this method can at most provide two independent constraints on the four possible d_i^W couplings.

If instead we integrate (34)–(36) over θ_l, then the $\rho_{\tau\tau'}^{L\pm R}$ in the r.h.s. of (34)–(36) are determined as functions od θ, so that

$$\begin{aligned} (\rho_{++} + \rho_{--})^{L\pm R} = & \; 2e^4 \Big[\sin^2\theta \left(\frac{4m_t^2}{s} \right) A_1^{L\pm R} \\ & + (1 + \cos^2\theta) A_2^{L\pm R} - 4\beta_t \cos\theta A_3^{L\pm R} \Big], \end{aligned} \tag{38}$$

$$(\rho_{++} - \rho_{--})^{L\pm R} = 4e^4 [(1 + \cos^2\theta)\ \beta_t B_1^{L\pm R} - \cos\theta B_2^{L\pm R}] \,, \tag{39}$$

$$\rho_{+-}^{L\pm R} = e^4 \left(\frac{4m_t}{\sqrt{s}} \right) \sin\theta \left[C_1^{L\pm R} - \cos\theta\ \beta_t C_2^{L\pm R} \right] \quad , \tag{40}$$

with β_t being the top velocity, and $A_j^{L\pm R}$, $B_j^{L\pm R}$, $C_j^{L\pm R}$ depending only on the production dynamics.

To first order in NP, we have $B_2^{L\pm R} \simeq A_2^{L\mp R}$ and $B_1^{L\pm R} \simeq A_3^{L\mp R}$, which through (38)–(40) means that in the case of polarized beams, we can construct 11 different asymmetries, as well as measuring the overall magnitude

of the θ integrated three independent ρ_{ij}^{L+R} matrix elements, *i.e.* 14 independent observables are accessible. In the case of unpolarized beams we can measure instead 4 asymmetries and in addition the three independent ρ_{ij}^{L+R} matrix elements as above; *i.e.* 7 independent observables.

4. Results and Conclusions

Defining the NP contribution to the γtt and Ztt couplings by (30) and

$$\overline{d}_j^V \;=\; d_j^V - d_j^{V,SM} \tag{41}$$

we construct the $1\,\sigma$ ellipsoid in the 6-parameter $\overline{d}_j^\gamma,\ \overline{d}_i^Z$ space, assuming only statistical uncertainties for the various angular asymmetries, but reducing the overall number of event by a factor of 18% due to branching ratios, reconstruction of events and efficiencies [15, 18]. In addition for the measurement of the integrated ρ_{++}^{L+R}, ρ_{--}^{L+R} and ρ_{+-}^{L+R} matrix elements we consider two cases with additional uncertainties; (a) $\sim 2\%$, (b) 20% [15]. The e^-e^+ luminosity is taken $\mathcal{L} = 80\text{fb}^{-1}(\text{s/TeV}^2)$. In Figs 1–3 we present the results for the projection of the 6-parameter ellipsoid to various 2-parameter subspaces. The left half of the figures is always for polarized beams, while the right for unpolarized ones.

Finally in Table I, we give the sensitivity limits in the case that only one of the above defined operators contributes at a time, for a 0.5, 1 or 2 TeV Collider. In each case, the sensitivity limits are translated to lower bounds on the corresponding Λ_{NP} scales, using unitarity.

The conclusions reached through the above analysis are:

- The top-spin characteristics of the $e^-e^+ \to t\bar{t} \to (bl^+\nu)\bar{t}$ production process analyses powerfully the NP contributions to the γtt and Ztt vertices. A sufficient number of observables exist to constrain all NP couplings.

- Contrary to what happens in the W^+W^- production case, increasing the Collider energy does not always increase the sensitivity to NP. Among the couplings defined in (30), it is mainly for the d_3^γ and d_3^Z couplings, that the sensitivity increases with energy.

- For the $t \to bW$ decay, sensitivities are appreciable only for the combinations $(d_3^W + d_4^W)^{NP}$ and $(d_1^W - d_2^W)^{NP}$.

- From the fact the magnitudes of the left and right ellipses in many cases in Figs 1–3 are rather similar, we conclude that $e^{\pm}$ polarization is generally <u>not</u> very important.

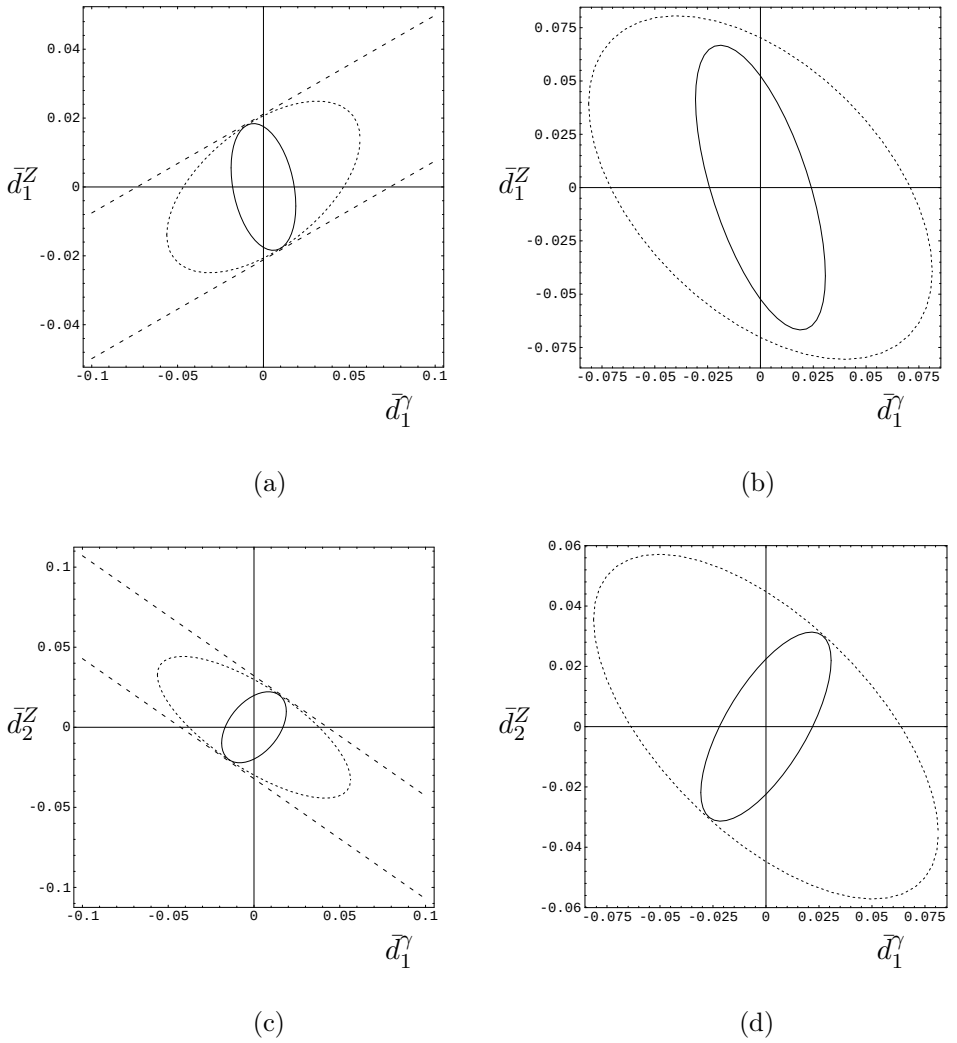


Fig. 1. Observability limits in the 6-parameter case; with polarized beams (a) (c), with unpolarized beams (b) (d); from asymmetries alone (- - - -), from asymmetries and the 3 integrated ρ_{ij}^{L+R} matrix elements with a normalization uncertainty of 2% (.....), 20% (———).

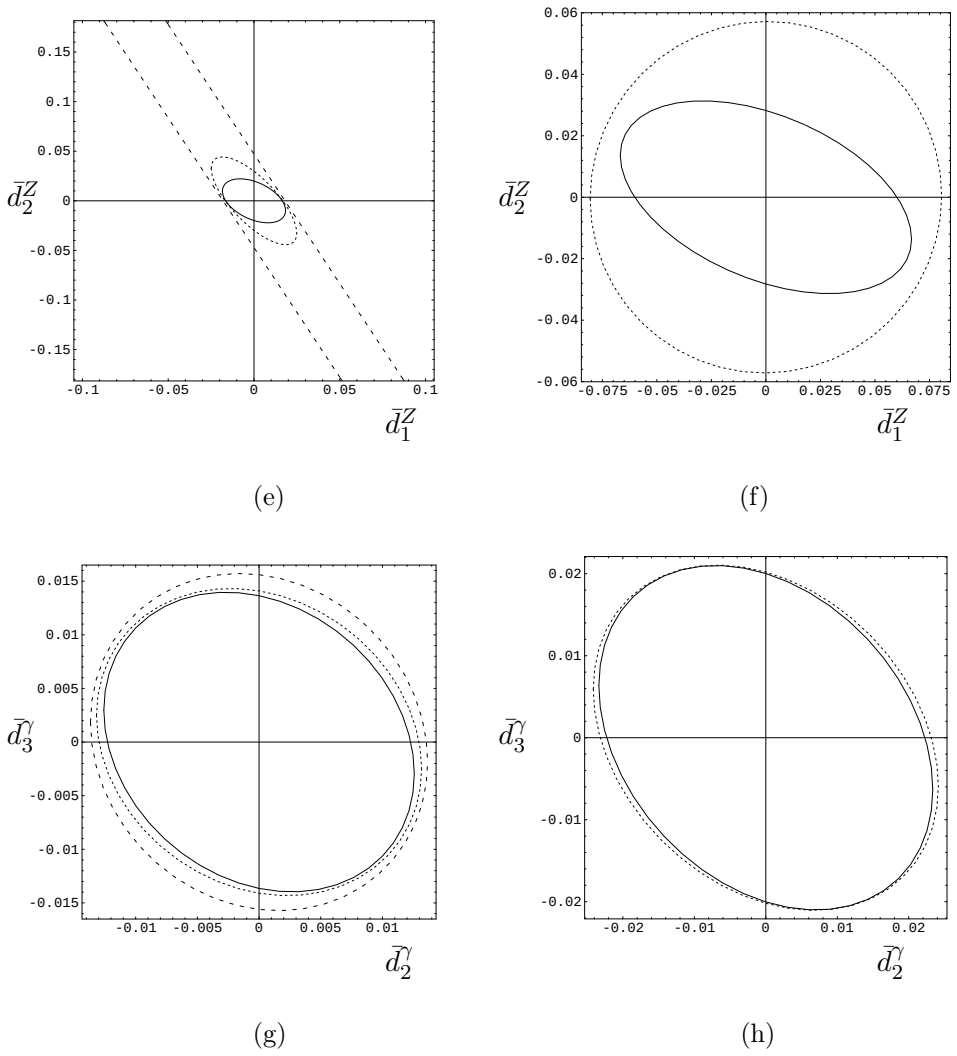


Fig. 2. Observability limits in the 6-parameter case; with polarized beams (e) (g), with unpolarized beams (f) (h); from asymmetries alone (- - - -), from asymmetries and the 3 integrated ρ_{ij}^{L+R} matrix elements with a normalization uncertainty of 2% (.....), 20% (————-).

- Dynamical models suggest that processes like $e^-e^+ \to t\bar{t}$, as well as $e^-e^+ \to HZ$, $H\gamma$ or $\gamma\gamma \to HZ$, are more promisings than $e^-e^+ \to W^-W^+$, for detecting New Physics, in the case that no new particles are produced in the future Colliders [2].

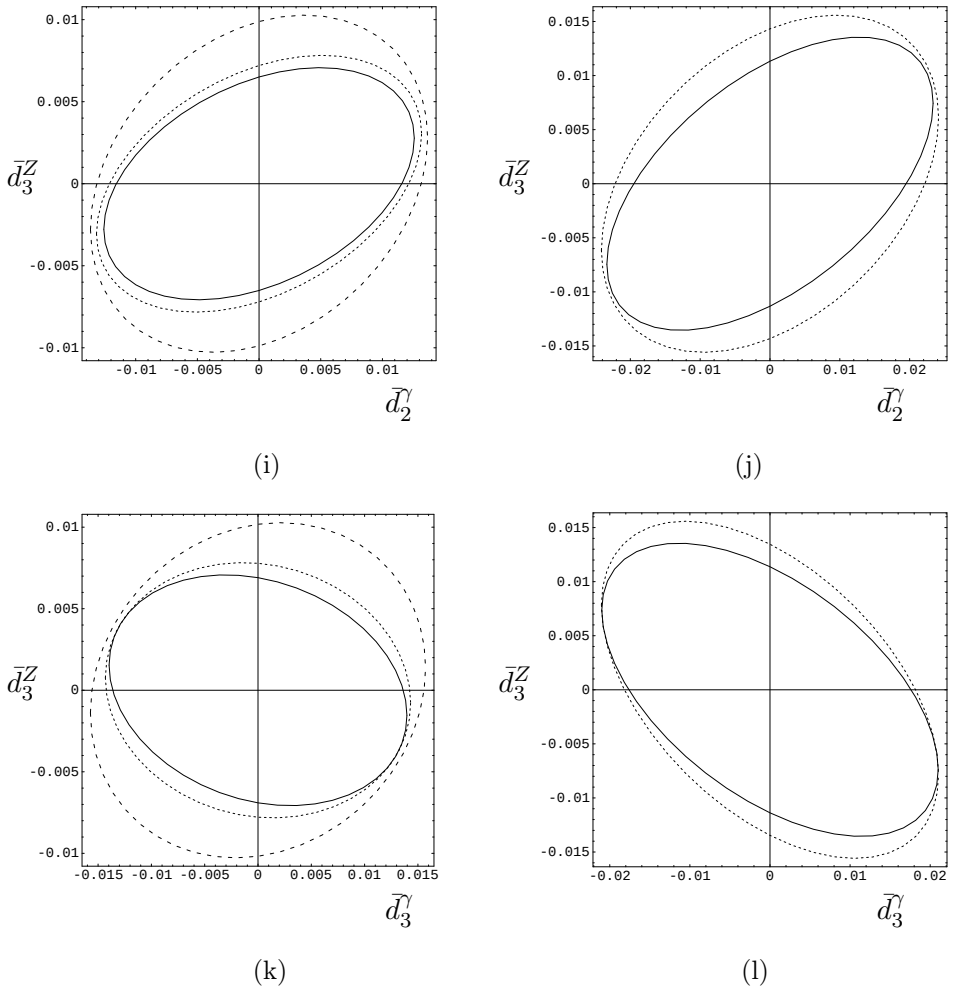


Fig. 3. Observability limits in the 6-parameter case; with polarized beams (i) (k), with unpolarized beams (j) (l); from asymmetries alone (- - - -), from asymmetries and the 3 integrated ρ_{ij}^{L+R} matrix elements with a normalization uncertainty of 2% (.....), 20% (————-).

REFERENCES

[1] W. Buchmüller, D. Wyler, *Nucl. Phys.* **B268**, 621 (1986); C.J.C. Burgess, H.J. Schnitzer, *Nucl. Phys.* **B228**, 454 (1983); C.N. Leung, S.T. Love, S. Rao *Z. Phys.* **C31**, 433 (1986).

[2] G.J. Gounaris, D.T. Papadamou, F.M. Renard, *Z. Phys.* **C76**, 333 (1997), hep-ph/9609437.

[3] K. Whisnant, J.M. Yang, B.-L. Young, X. Zhang, *Phys. Rev.* **D56**, 467 (1997), hep-ph/9702305.

[4] K.J.M. Yang, B.-L. Young, *Phys. Rev.* **D56**, 5907 (1997).

[5] K. Hagiwara, M.L. Stong *Z. Phys.* **C92**, 99 (1994); G.J. Gounaris, G. Tsirigoti, *Phys. Rev.* **D56**, 3030 (1997).

[6] G.J. Gounaris, M. Kuroda, F.M.Renard, *Phys. Rev.* **D54**, 6861 (1996).

[7] K.Hagiwara *et al.*, *Phys. Lett.* **B283**, 353 (1992);*Phys. Rev.* **D48**, 2182 (1993).

[8] G.J. Gounaris, J. Layssac, F.M. Renard, *Phys. Lett.* **B332**, 146 (1994); G.J. Gounaris, J. Layssac, J.E. Paschalis, F.M. Renard, *Z. Phys.* **C66**, 619 (1995); G.J. Gounaris, F.M. Renard, G. Tsirigoti, *Phys. Lett.* **B350**, 212 (1995).

[9] G. Gounaris, F.M. Renard, N.D. Vlachos, *Nucl. Phys.* **B459**, 51 (1996).

[10] G.J. Gounaris, J. Layssac, F.M. Renard, in preparation.

[11] Physics at LEP2, Yellow Report CERN 96-01, vol.1,2 edited by G. Altarelli, T. Sjötrand and F. Zwirner.

[12] E. Accomando *et al.*, DESY 97-10, hep-ph/9705442, to appear in Phys. Reports; e^+e^- Collisions at TeV Energies: The Physcis Potential, DESY 92-123A, 92-123B, 93-123C, 96-123D, P.M. Zerwas (ed).

[13] E.H. Simmons, *Phys. Lett.* **B226**, 132 (1989); *Phys. Lett.* **B246**, 471 (1990); H. Dreiner, A. Duff, D. Zeppenfeld, *Phys. Lett.* **B282**, 441 (1992); G.J. Gounaris, D.T. Papadamou, F.M. Renard, hep-ph/9711399.

[14] G.J. Gounaris, F.M.Renard, C.Verzegnassi, *Phys. Rev.* **D52**, 451 (1995).

[15] G.J. Gounaris, J. Layssac, F.M. Renard, hep-ph/9612335, *Phys. Rev.* **D55**, 5786 (1997).

[16] For a review, see *e.g.*, J.H. Kühn, TTP96-18 (1996); F. Larios, E. Malkawi, C.-P. Yuan, MSUHEP-60922, hep-ph/9609482; D.O. Carlson, C.-P. Yuan, MSUHEP-50823, 1995; C.-P. Yuan hep-ph/9604434.

[17] R.D. Peccei, X. Zhang, *Nucl. Phys.* **B337**, 269 (1990); R.D. Peccei, S. Peris, X. Zhang, *Nucl. Phys.* **B349**, 305 (1991); E. Malkawi, C.-P. Yuan, *Phys. Rev.* **D52**, 472 (1995); F. Larios, C.-P. Yuan, hep-ph/9606397.

[18] R. Frey, talk given at Conf. on Phys. and Exp. with Linear Colliders, Morioka-Appi, Japan (1995), OREXP 96-04.