

Anomalous $\gamma\gamma H$ and $Z\gamma H$ couplings from the process $e\gamma \rightarrow eH$

E. Gabrielli ^{1 *}, V.A. Ilyin ² and B. Mele ³.

¹ Departamento de Física Teórica, Universidad Autónoma, Madrid, Spain

² Institute of Nuclear Physics, Moscow State University, Russia

³ INFN, Sezione di Roma 1, and Dipartimento di Fisica, University “La Sapienza”, Rome, Italy

Abstract

The bounds on the anomalous contributions to the $\gamma\gamma H$ and $Z\gamma H$ vertices that can be obtained via the process $e\gamma \rightarrow eH$ are discussed through a model independent analysis based on $SU(2) \times U(1)$ invariant operators of $dim = 6$. A light Higgs mass of $m_H = 120$ GeV and center-of-mass energies of $\sqrt{s} = 500$ GeV and $\sqrt{s} = 1500$ GeV are assumed. The process $e\gamma \rightarrow eH$ is shown to provide an excellent way to strongly constraint both the CP-even and CP-odd anomalous contributions in the $\gamma\gamma H$ and $Z\gamma H$ couplings.

1 Introduction

Once the Higgs boson will be discovered, the next linear e^+e^- colliders with centre-of-mass (c.m.) energy $\sqrt{s} \simeq (300 \div 2000)$ GeV and integrated luminosity $\mathcal{O}(100)$ fb⁻¹ will allow an accurate determination of its mass, some couplings and parity properties [1, 2]. Among other couplings, the interaction of the Higgs scalar with the neutral electroweak gauge bosons, γ and Z , are particularly interesting. Indeed, an accurate determination of these couplings will allow to test some delicate feature of the Standard Model: the relation between the spontaneous symmetry breaking mechanism and the electroweak mixing of the two gauge groups $SU(2)$ and $U(1)$. In this respect, three vertices could be measured, ZZH , $\gamma\gamma H$ and $Z\gamma H$. In the SM the ZZH vertex stands at the tree level, while the other two are generated at one-loop. Therefore these last ones are particularly interesting, also because the effective $\gamma\gamma H$ and $Z\gamma H$ couplings could be sensitive to the contributions of new particles circulating in the loop.

Here, we consider the case of a light Higgs boson, that is with $M_Z \lesssim m_H \lesssim 140$ GeV. For this range of mass, a measurement of the $\gamma\gamma H$ coupling should be possible by the determination of the BR for the decay $H \rightarrow \gamma\gamma$, such as in the discovery channel $gg \rightarrow H \rightarrow \gamma\gamma$ at the next large

*Talk given at the Workshop on next e^+e^- Linear Colliders, Oxford, England, 20-23rd March, 1999.

hadron collider LHC (see, for instance, [3]). Furthermore, at future photon-photon colliders[†], the precise measurement of the $\gamma\gamma H$ vertex is achieved at the resonant production of the Higgs particle, $\gamma\gamma \rightarrow H$. To this end, the capability of tuning the $\gamma\gamma$ c.m. energy on the Higgs mass, through a good degree of the photons monochromaticity, will be crucial for not diluting too much the $\gamma\gamma \rightarrow H$ resonant cross section over the c.m. energy spectrum.

Measuring the $Z\gamma H$ vertex is in general a more complicated task. One possibility to test this vertex is given by the $H \rightarrow \gamma Z$ decay. Unfortunately this decay suffers the problem to have a small rate and moreover, due to the main Z decays, the signal is affected by large backgrounds.

Another possibility of measuring the $Z\gamma H$ vertex is given by collision processes. At electron-positron colliders, the corresponding channels are $e^+e^- \rightarrow \gamma H$ and $e^+e^- \rightarrow ZH$. The reaction $e^+e^- \rightarrow \gamma H$ has been extensively studied in the literature [6, 7, 8]. Unfortunately the $e^+e^- \rightarrow H\gamma$ channel suffers from small rates which are further depleted at large energies by the $1/s$ behavior of the dominant s-channel diagrams. The crossed process, the one-loop Higgs production in electron-photon collisions through $e\gamma \rightarrow eH$, was analysed in [9, 10, 11]. This channel turns out to be a golden place where to test both the $\gamma\gamma H$ and $Z\gamma H$ one-loop couplings with high statistics, without requiring a fine tuning of the c.m. energy. Indeed, the total rate of this reaction is rather high [9]. In particular, for m_H up to about 400 GeV, one finds $\sigma > 1$ fb. If no kinematical cuts are imposed, then the main contribution to the cross section is given by the $\gamma\gamma H$ vertex. On the contrary the $Z\gamma H$ vertex contribution is depleted by the Z propagator. Nevertheless, the $Z\gamma H$ vertex effects can be extracted from $e\gamma \rightarrow eH$ by implementing a suitable strategy to reduce the $\gamma\gamma H$ vertex contribution [9]. This strategy requires a final electron tagged at large angle together with a transverse momentum cut $p_T^e > 100$ GeV. The main irreducible background to the process $e\gamma \rightarrow eH \rightarrow e b \bar{b}$ comes from the channel $e\gamma \rightarrow e b \bar{b}$. However, a proper cut on the angles $\theta_{b(c)-beam}$ (between each b quark direction and both the beams) can reduce the signal and background at a comparable level. Then, with a luminosity of 100 fb^{-1} , at $\sqrt{s} = 500 \text{ GeV}$, one expects an accuracy as good as about 10% on the measurement of the $Z\gamma H$ effects assuming the validity of Standard Model [9].

Here, we present the prospects of the $e\gamma \rightarrow eH$ reaction in setting experimental bounds on the value of the anomalous $\gamma\gamma H$ and $Z\gamma H$ couplings [12]. Some preliminary results have been presented in [13], too (see also [14]). For this analysis we use a model independent approach, where $dim = 6$ $SU(2) \times U(1)$ invariant operators are added to the SM Lagrangian. In realistic models extending the SM, these operators contribute in some definite combinations. However, if one discusses the bounds on the possible deviations from the SM one-loop Higgs vertices, this approach can give some general insight into the problem. These anomalous operators contribute to the three vertices $\gamma\gamma H$, $Z\gamma H$ and ZZH , with only the first two involved in the $e\gamma \rightarrow eH$ reaction.

[†]Two further options are presently considered for a high-energy e^+e^- linear collider, where one or both the initial e^+/e^- beams are replaced by photon beams induced by Compton backscattering of laser light on the high-energy electron beams [4]. Then, the initial real photons could be to a good degree monochromatic, and have energy and luminosity comparable to the ones of the parent electron beam [5].

We show that the reaction $e\gamma \rightarrow eH$ has an excellent potential in bounding both the vertices $\gamma\gamma H$ and $Z\gamma H$. While in the case of $\gamma\gamma H$, it is complementary to the resonant $\gamma\gamma \rightarrow H$ reaction, $e\gamma \rightarrow eH$ offers a unique possibility to investigate possible anomalies in the $Z\gamma H$ vertices.

2 Anomalous vertices

We consider the possibility that the new physics affects the bosonic sector of the SM through low energy effective operators of $dim = 6$. We restrict our analysis to the set of operators that contribute to the $e\gamma \rightarrow eH$ amplitude via anomalous couplings to the $\gamma\gamma H$ and $Z\gamma H$ vertices. This set is divided in two pairs of $dim = 6$ operators[‡], CP-even and CP-odd respectively, giving anomalous contributions to the process $e\gamma \rightarrow eH$. In terms of these operators the most general lagrangian is given by

$$\mathcal{L}^{eff} = d \cdot \mathcal{O}_{UW} + d_B \cdot \mathcal{O}_{UB} + \bar{d} \cdot \bar{\mathcal{O}}_{UW} + \bar{d}_B \cdot \bar{\mathcal{O}}_{UB}, \quad (1)$$

$$\mathcal{O}_{UW} = \frac{1}{v^2} \left(|\Phi|^2 - \frac{v^2}{2} \right) \cdot W^{i\mu\nu} W_{\mu\nu}^i, \quad \mathcal{O}_{UB} = \frac{1}{v^2} \left(|\Phi|^2 - \frac{v^2}{2} \right) \cdot B^{\mu\nu} B_{\mu\nu}, \quad (2)$$

$$\bar{\mathcal{O}}_{UW} = \frac{1}{v^2} |\Phi|^2 \cdot W^{i\mu\nu} \tilde{W}_{\mu\nu}^i, \quad \bar{\mathcal{O}}_{UB} = \frac{1}{v^2} |\Phi|^2 \cdot B^{\mu\nu} \tilde{B}_{\mu\nu}, \quad (3)$$

where $\tilde{W}_{\mu\nu}^i = \epsilon_{\mu\nu\mu'\nu'} \cdot W^{i\mu'\nu'}$ and $\tilde{B}_{\mu\nu} = \epsilon_{\mu\nu\mu'\nu'} \cdot B^{\mu'\nu'}$. In these formulas, Φ is the Higgs doublet and v is the electroweak vacuum expectation value. Finally, the $\gamma\gamma H$ and $Z\gamma H$ anomalous terms contributions to the helicity amplitudes of $e\gamma \rightarrow eH$ are given by:

$$M_{anom}(\sigma, \lambda) = M^{\gamma\gamma}(\sigma, \lambda) + M^{\gamma Z}(\sigma, \lambda), \quad (4)$$

where

$$\begin{aligned} M^{\gamma\gamma}(\sigma, \lambda) &= \frac{4\pi\alpha}{M_Z(-t)} \sqrt{-\frac{t}{2}} \{d_{\gamma\gamma}[(u-s) - \sigma\lambda(u+s) - i\bar{d}_{\gamma\gamma}[\lambda(u-s) + \sigma(u+s)]]\}, \\ M^{\gamma Z}(\sigma, \lambda) &= \frac{4\pi\alpha(-g_e^\sigma)}{M_Z(M_Z^2 - t)} \sqrt{-\frac{t}{2}} \{d_{\gamma Z}[(u-s) - \sigma\lambda(u+s) - i\bar{d}_{\gamma Z}[\lambda(u-s) + \sigma(u+s)]]\}. \end{aligned} \quad (5)$$

Here, s , t and u are the Mandelstam kinematical variables (defined as in [9]), $\sigma/2 = \pm 1/2$ and $\lambda = \pm 1$ are the electron and photon helicities, respectively. The Z charge of electron is denoted

[‡]We assume that $SU(2) \times U(1)$ local gauge invariance of the Standard Model should be valid as well as so-called custodial symmetry of the gauge and Higgs sectors present in the Standard Model [15]

as g_e^σ . The anomalous couplings d, d_B (CP-even) and \bar{d}, \bar{d}_B (CP-odd) contribute to the $\gamma\gamma H$, ZZH , and $Z\gamma H$ interactions in the combinations

$$\begin{aligned} d_{\gamma\gamma} &= \tan\theta_W d + (\tan\theta_W)^{-1} d_B, & d_{\gamma Z} &= d - d_B \\ d_{ZZ} &= (\tan\theta_W)^{-1} d + \tan\theta_W d_B, \\ \bar{d}_{\gamma\gamma} &= \tan\theta_W \bar{d} + (\tan\theta_W)^{-1} \bar{d}_B, & \bar{d}_{\gamma Z} &= \bar{d} - \bar{d}_B \\ \bar{d}_{ZZ} &= (\tan\theta_W)^{-1} \bar{d} + \tan\theta_W \bar{d}_B, \end{aligned} \tag{6}$$

where θ_W is the Weinberg angle (we assume $\sin^2\theta_W = 0.2247$)[§].

3 Bounds on anomalous $\gamma\gamma H$ and $Z\gamma H$ couplings

In this section, we present the numerical results for the bounds on the anomalous couplings d, d_B and \bar{d}, \bar{d}_B which are obtained from the $e\gamma \rightarrow eH$ process.[¶] These bounds have been computed by using the requirement that no deviation from the SM cross section is observed at the 95% CL. In particular, we have [12]:

$$N^{\text{anom}}(\kappa) < 1.96 \cdot \sqrt{N^{\text{tot}}(\kappa)}, \quad \kappa = d, d_B, \bar{d}, \bar{d}_B, \tag{7}$$

$$N^{\text{tot}}(\kappa) = \mathcal{L}_{\text{int}} \cdot [\sigma_S(\kappa) + \sigma_B], \quad N^{\text{anom}}(\kappa) = \mathcal{L}_{\text{int}} \cdot [\sigma_S(\kappa) - \sigma_S(0)]. \tag{8}$$

where \mathcal{L}_{int} is the integrated luminosity, N^{tot} and N^{anom} denote respectively the total number of observed events and the anomalous number of events deviating from the expected SM predictions for the signal. By $\sigma_S(\kappa)$ we mean the cross section of the signal reaction $e\gamma \rightarrow eH \rightarrow ebb$ with the anomalous contributions. $\sigma_S(0)$ is the SM cross section. By σ_B we denote the total cross section of the background processes $e\gamma \rightarrow ebb$, $e\gamma \rightarrow ecc$ (with 10% probability of misidentifying a c quark into a b quark).

In table [1], we report the main results for the bounds on the anomalous couplings. The bounds are obtained for $m_H = 120$ GeV, at $\sqrt{s} = 500$ GeV (with $\mathcal{L}_{\text{int}} = 100$ fb⁻¹) and $\sqrt{s} = 1500$ GeV (with $\mathcal{L}_{\text{int}} = 1000$ fb⁻¹), and for different electron-beam polarizations, $P_e = 0, 1, -1$. We assume that for each bound the only contribution is given by the corresponding anomalous coupling, switching-off the other three anomalous contributions. A more complete analysis for the bounds on the $d, d_B, \bar{d}, \bar{d}_B$ and $d_{\gamma\gamma}, d_{\gamma Z}, \bar{d}_{\gamma\gamma}, \bar{d}_{\gamma Z}$ couplings can be found in [12], where the correlations between pairs of different anomalous contributions have been studied.

From the results of tables [1] we draw the following conclusions:

- The strongest bounds on the CP-even couplings at $\sqrt{s} = 500$ GeV are at the level of $|d| \lesssim 6 \times 10^{-4}$, obtained at $P_e = -1$, and $|d_B| \lesssim 2.5 \times 10^{-4}$ (with no cut on p_T^e), not

[§]The adopted values for the other physical parameters of the SM are described in [9].

[¶]Most of the results presented in this work were obtained with the help of CompHEP package [16].

depending on the e polarization. At $\sqrt{s} = 1500$ GeV, one has $|d| \lesssim 1.7 \times 10^{-4}$, obtained at $P_e = -1$ and $p_T^e > 100$ GeV, and $|d_B| \lesssim 1 \times 10^{-4}$ (with no cut on p_T^e), not depending on the e polarization.

- The strongest bounds on the CP-odd couplings at $\sqrt{s} = 500$ GeV are $|\bar{d}| \lesssim 3 \times 10^{-3}$ and $|\bar{d}_B| \lesssim 1 \times 10^{-3}$, which are obtained for $P_e = -1$ and $P_e = 1$, respectively. These bounds are quite insensitive to the cuts on p_T^e . At $\sqrt{s} = 1500$ GeV, one has $|\bar{d}| \lesssim 1.0 \times 10^{-3}$ for $P_e = -1$, with $p_T^e > 100$ GeV, and $|\bar{d}_B| \lesssim 3 \times 10^{-4}$, for $P_e = 1$, with $p_T^e > 100$ GeV.

It is interesting to compare these results with other bounds obtained in literature from different processes at future linear colliders. In particular, the processes $e^+e^- \rightarrow HZ$ and $\gamma\gamma \rightarrow H$ have been studied for a e^+e^- collider at $\sqrt{s} = 1$ TeV and with 80 fb^{-1} by Gounaris et al.. From $e^+e^- \rightarrow HZ$, they get $|d| \lesssim 5 \times 10^{-3}$, $|d_B| \lesssim 2.5 \times 10^{-3}$, $|\bar{d}| \lesssim 5 \times 10^{-3}$ and $|\bar{d}_B| \lesssim 2.5 \times 10^{-3}$ [17]. The process $\gamma\gamma \rightarrow H$ can do a bit better and reach the values $|d| \lesssim 1 \times 10^{-3}$, $|d_B| \lesssim 3 \times 10^{-4}$, $|\bar{d}| \lesssim 4 \times 10^{-3}$ and $|\bar{d}_B| \lesssim 1.3 \times 10^{-3}$, assuming a particular photon energy spectrum [18]. These analysis assume a precision of the measured production rate equal to $1/\sqrt{N}$ (with N the total number of events), and neglect possible backgrounds. In order to set the comparative potential of our process with respect to these two processes in bounding the parameters d , d_B , \bar{d} , \bar{d}_B , we assumed $\sqrt{s} = 0.9$ TeV and (conservatively) a luminosity of 25 fb^{-1} in $e\gamma \rightarrow eH$. We then neglected any background, and assumed a precision equal to $1/\sqrt{N}$. In the case $P_e = 0$ and $p_T^e > 0$, we get $|d| \lesssim 5 \times 10^{-4}$, $|d_B| \lesssim 2 \times 10^{-4}$, $|\bar{d}| \lesssim 2 \times 10^{-3}$ and $|\bar{d}_B| \lesssim 8 \times 10^{-4}$.

This analysis confirms the excellent potential of the process $e\gamma \rightarrow eH$.

Following the conventions of reference [19], one can convert our constraints into upper limits for the *new physics* scale Λ that can be explored through $e\gamma \rightarrow eH$ with $\sqrt{s} \simeq 1.5$ TeV and 10^3 fb^{-1} :

$$\begin{aligned}
|d| \lesssim 1.7 \times 10^{-4} &\rightarrow \left| \frac{f_{WW}}{\Lambda^2} \right| \lesssim 0.026 \text{ TeV}^{-2} \\
|d_B| \lesssim 1.0 \times 10^{-4} &\rightarrow \left| \frac{f_{BB}}{\Lambda^2} \right| \lesssim 0.015 \text{ TeV}^{-2} \\
|\bar{d}| \lesssim 1.0 \times 10^{-3} &\rightarrow \left| \frac{\bar{f}_{WW}}{\Lambda^2} \right| \lesssim 0.15 \text{ TeV}^{-2} \\
|\bar{d}_B| \lesssim 3.0 \times 10^{-4} &\rightarrow \left| \frac{\bar{f}_{WW}}{\Lambda^2} \right| \lesssim 0.046 \text{ TeV}^{-2}
\end{aligned} \tag{9}$$

For $f_i \sim 1$ one can explore energy scales up to about 6, 8, 2.6 and about 4.5 TeV, respectively. At $\sqrt{s} \simeq 500$ GeV and 10^2 fb^{-1} , the corresponding constraints on the couplings are a factor 2 or 3 weaker than above (reflecting into energy scales Λ lower by a factor 1.4 or 1.7, respectively), mainly because of the smaller integrated luminosity assumed.

	$\sqrt{S} = 500\text{GeV}$	$\sqrt{S} = 500 \text{ GeV}$	$\sqrt{S} = 1500\text{GeV}$	$\sqrt{S} = 1500 \text{ GeV}$
$P_e = 0$	$p_T^e > 0$	$p_T^e > 100 \text{ GeV}$	$p_T^e > 0$	$p_T^e > 100 \text{ GeV}$
$d \times 10^3$	(-0.73, 0.76)	(-1.2, 1.3)	(-0.24, 0.25)	(-0.25, 0.25)
$d_B \times 10^3$	(-0.25, 0.26)	(-0.70, 3.3)	(-0.10, 0.10)	(-0.17, 0.21)
$\bar{d} \times 10^3$	(-3.2, 3.3)	(-3.6, 3.7)	(-1.5, 1.5)	(-1.2, 1.2)
$\bar{d}_B \times 10^3$	(-1.1, 1.1)	(-1.5, 1.5)	(-5.6, 5.6)	(-0.52, 0.53)
$P_e = 1$	$p_T^e > 0$	$p_T^e > 100 \text{ GeV}$	$p_T^e > 0$	$p_T^e > 100 \text{ GeV}$
$d \times 10^3$	(-0.89, 0.94)	(-10, 25)	(-0.4, 0.4)	(-3.3, 17)
$d_B \times 10^3$	(-0.24, 0.26)	(-0.65, 1.4)	(-0.11, 0.12)	(-0.19, 0.49)
$\bar{d} \times 10^3$	(-3.9, 3.9)	(-15, 15)	(-2.5, 2.7)	(-9.3, 8.1)
$\bar{d}_B \times 10^3$	(-0.97, 0.96)	(-0.97, 0.97)	(-4.5, 4.7)	(-0.31, 0.31)
$P_e = -1$	$p_T^e > 0$	$p_T^e > 100 \text{ GeV}$	$p_T^e > 0$	$p_T^e > 100 \text{ GeV}$
$d \times 10^3$	(-0.63, 0.66)	(-0.83, 0.83)	(-0.18, 0.18)	(-0.16, 0.17)
$d_B \times 10^3$	(-0.25, 0.26)	(-0.67, 0.66)	(-0.093, 0.094)	(-0.14, 0.14)
$\bar{d} \times 10^3$	(-3.1, 3.2)	(-2.9, 3.1)	(-1.2, 1.2)	(-0.96, 0.98)
$\bar{d}_B \times 10^3$	(-1.2, 1.2)	(-2.3, 2.4)	(-0.69, 0.71)	(-0.88, 0.90)

Table 1: Bounds on the CP-even d , d_B and CP-odd \bar{d} , \bar{d}_B anomalous couplings, for $\sqrt{S} = 500 \text{ GeV}$ and $\sqrt{S} = 1500 \text{ GeV}$, e -beam polarizations $P_e = 0, 1, -1$, and for $p_T^e > 0$ and $p_T^e > 100 \text{ GeV}$. In the case of $\sqrt{S} = 500 \text{ GeV}$ and $p_T^e > 100 \text{ GeV}$, a cut on the final electron angle $\theta_e < 90^\circ$ is applied.

Acknowledgements

E.G. acknowledges the financial support of the TMR network project ref. FMRX-CT96-0090 and partial financial support from the CICYT project ref. AEN97-1678. V.I. was partly supported by the joint RFBR-DFG grant 99-02-04011.

References

- [1] *Physics and Experiments with e^+e^- Linear Colliders*, ed. Miyamoto A., Fujii Y., Matsui T. and Iwata S., Singapore: World Sci., 1996.
- [2] Proceedings, *Conceptual Design of a 500 GeV e^+e^- Linear Collider with Integrated X-Ray Laser Facility*, ed. Sjöstrand T. and Zerwas P., DESY 79-048, ECFA-97-181, 1997; Accomando E. et al., Phys. Rep. **299** (1998) 1.
- [3] ATLAS Technical Design Report, CERN/LHCC/99-15, 1999.

- [4] Ginzburg I.F. et al., *Nucl.Instr. Methods* **205**, 47 (1983); **219**, 5 (1984);
Telnov V.I., *Nucl.Instr. Methods* **A294**, 72 (1990).
- [5] Brinkmann R. et al., *An Interaction Region for $\gamma\gamma$ and $e\gamma$ collisions at TESLA/SBLC*,
Nucl. Instrum. Meth. **A406**, 13 (1998).
- [6] Barroso A., Pulido J., and Romao J.C., *Nucl. Phys.* **B267**, 509 (1985); **B272**, 693 (1986).
- [7] Abbasabadi A. et al., *Phys. Rev.* **D52**, 3919 (1995).
- [8] Djouadi A. et al., *Nucl. Phys.* **B491**, 68 (1997).
- [9] Gabrielli E., Ilyin V.A., and Mele B., *Phys. Rev.* **D56**, 5945 (1997); *erratum-ibid* **D58**,
119902 (1998);
- [10] Gabrielli E., Ilyin V.A., and Mele B., in “ e^+e^- Linear Colliders: Physics and Detectors
Studies”, Report DESY-97-123E, p.405.
- [11] Cotti U., Diaz-Cruz J.L., Toscano J.J, *Phys. Lett. B* **404**, 308 (1997).
- [12] Gabrielli E., Ilyin V.A. and Mele B., hep-ph/9902362, to appear in *Phys. Rev. D* (1999).
- [13] Gabrielli E., Ilyin V.A., and Mele B., in: ”Beyond the Standard Model V” (Proc. Fifth
Conference, Balholm, Norway April-May 1997), ed. G.Eigen, P.Osland and B.Stugu, AIP,
N.-Y., 1997, p.506, hep-ph/9709351; in: Proc. Int. Europhysics Conf on HEP (Jerusalem,
Israel, August 1997), ed. D.Lellouch, G.Mikenberg and E.Rabinovoci, Springer, Berlin
Heidelberg, 1999, p.1163, hep-ph/9712285.
- [14] Banin A.T., Ginzburg I.F., Ivanov I.P., *Phys. Rev.* **D59**, 115001, 1999.
- [15] Buchmüller W., and Wyler D., *Nucl. Phys.* **B268**, 621 (1986).
Hagiwara K. et al., *Phys. Rev.* **D48**, 2182 (1993); *Phys. Lett.* **B318**, 155 (1993).
Gounaris G.J. et al., *Nucl. Phys.* **B459**, 51 (1996).
- [16] Baikov P.A. et al., *High Energy Physics and Quantum Field Theory*, ed. Levtchenko B.
and Savrin V., Moscow, hep-ph/9701412;
Boos E.E et al., SNUTP-94-116, 1994, hep-ph/9503280.
- [17] Hagiwara K. and Stong M.L., *Z. Phys.* **C62** 99 (1994).
Gounaris G.J., Renard F.M. and Vlachos N.D. *Nucl. Phys.* **B459** 51 (1996).
- [18] Gounaris G.J. and Renard F.M., *Z. Phys.* **C69** 513 (1996).
- [19] Gounaris G.J. and Renard F.M., *Phys. Rev.* **D59**, 113015, 1999.