

# STUDY ON THE SINGLE- $W$ PRODUCTION AT LEP ENERGIES \*

T. TSUKAMOTO

Department of Physics, Saga University, Saga 840, Japan

*(Received January 14, 1997)*

We present a study of single- $W$  production ( $e^+e^- \rightarrow e^-\bar{\nu}_e W^+$ ) as a new probe of the anomalous couplings at the LEP energy region. The cross-section measurement of the single- $W$  process is found to give complementary bounds on the anomalous couplings to those obtained from  $W$ -pair analysis at LEP2.

PACS numbers: 14.70. Fm

## 1. Introduction

The non-abelian self couplings of gauge bosons are the most direct consequences of the  $SU(2) \times U(1)$  gauge symmetry and a direct confirmation of Triple Gauge boson Couplings (TGC) is one of the most important subjects at LEP2. Most studies up-to now have focused on the process  $e^+e^- \rightarrow W^+W^-$ . Although this process is anticipated to give a good sensitivity to the anomalous couplings, it suffers from the disadvantage that one cannot disentangle the effects of  $WW\gamma$  and  $WWZ$  couplings. Especially, the gauge cancellations between  $\gamma$ ,  $Z^0$  and  $\nu$  exchange graphs are still not fully operative at LEP2, hence, only the interference effects between different TGCs dominate.

One way to avoid such complications is to use the channels which is only sensitive to the  $WW\gamma$  coupling. Recently we have proposed a new probe of the  $WW\gamma$  vertex using  $e^+e^- \rightarrow e^-\bar{\nu}_e W^+$  process where the electron escapes down the beam pipe [2]. In this report, we give a brief summary of the characteristics of the single- $W$  production and present the anticipated sensitivity to the anomalous TGCs.

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\* Presented at the Cracow International Symposium on Radiative Corrections to the Standard Model, Cracow, Poland, 1-5 August 1996.

## 2. Single- $W$ production and its signature

Figure 1 shows a gauge invariant set of  $t$ -channel diagrams involved in  $e^+e^- \rightarrow e^-\bar{\nu}_e\mu^+\nu_\mu$ . Among them, the  $\gamma$ - $W$  process (the first row) give the dominant contribution. Even below the  $WW$  threshold, a significant contribution is expected from the  $\gamma$ - $W$ - $W$  diagram (the second graph).

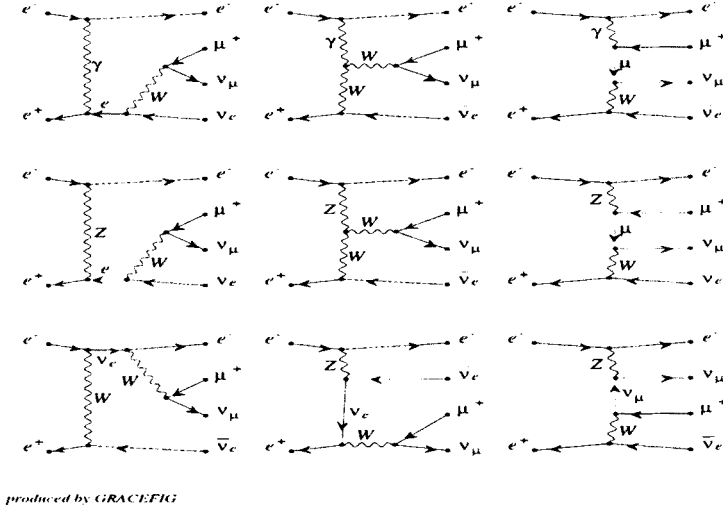


Fig. 1. The  $t$ -channel diagrams of the  $e^+e^- \rightarrow e^-\bar{\nu}_e\mu^+\nu_\mu$  process.

The contribution of the  $t$ -channel can be enhanced by requiring the outgoing electron to be within a small angle. To calculate the cross-section with this requirement, special care has to be taken of the following points: (1) the matrix element needs to keep even the electron mass finite throughout the calculation to avoid a singularity at small electron polar angle ( $\theta_{e-}$ ), (2) the gauge violating term due to the introduction of the finite width of  $W$  is found to blow up at small  $\theta_{e-}$  [3], and stops one from obtaining reliable cross-section as a result. This problem can, however, be avoided by several methods [4, 5] and the results of each scheme are found to be consistent [5].

Here we use a four-fermion generator “grc4f” [6] for the calculation. In this package, all the fermion masses are properly taken into account and the gauge violation due to the finite width of the  $W$  is cured [4]. One can thus perform a cross-section calculation reliably even without a cut on the electron polar angle.

We mainly focus on the  $e^+e^- \rightarrow e^-\bar{\nu}_e\mu^+\nu_\mu$  process in this report since the signature is very clean from an experimental point of view. To discriminate single- $W$  from  $WW$ , we introduce “single- $W$  cuts”:  $\theta_{e-} < 35$  mrad,  $|\cos\theta_{\mu+}| < 0.95$  and  $P_\mu > 20$  GeV. The resulting event signature is high

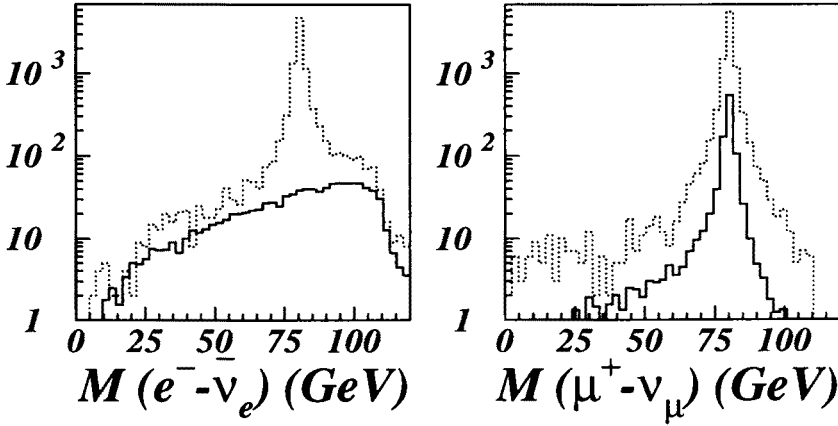


Fig. 2.  $M(e^- - \bar{\nu}_e)$  and  $M(\mu^+ - \nu_\mu)$  distributions for  $e^+e^- \rightarrow e^- \bar{\nu}_e \mu^+ \nu_\mu$  process with no cut (dotted line) and single- $W$  cuts (solid line).

$P_t$  “single muon”. As is seen in figure 2, double resonant contribution is clearly suppressed while keeping single- $W$ .

The total cross-section of the single- $W$  process with  $e\nu\mu\nu$  final state is shown in Table I. One can observe “single muon” events from single- $W$  production with modest luminosity at LEP2.

TABLE I

Cross-section of single- $W$  process with  $e\nu\mu\nu$  final state

$E_{\text{cm}}$ (GeV)	161	176	188	192
$\sigma$ (fb)	28	39	50	54

### 3. Anomalous couplings

To test the triple gauge boson coupling, we use the following effective Lagrangian [8] assuming both  $C$  and  $P$  conservation:

$$i\mathcal{L}_{eff}^{WWV} = g_{WWV} \left[ g_1^V \left( W_{\mu\nu}^\dagger W^\mu V^\nu - W_\mu^\dagger V_\nu W^{\mu\nu} \right) + \kappa_V W_\mu^\dagger W_\nu V^{\mu\nu} + \frac{\lambda_V}{m_W^2} W_{\rho\nu}^\dagger W_\nu^\mu V^{\rho\nu} \right], \quad (1)$$

where  $V = \gamma$  or  $Z$ , and the overall couplings are  $g_{WW\gamma} = e$ ,  $g_{WWZ} = e \cot \theta_W$ ,  $W_{\mu\nu} = \partial_\mu W_\nu - \partial_\nu W_\mu$  and  $V_{\mu\nu} = \partial_\mu V_\nu - \partial_\nu V_\mu$ .

Since  $g_1^\gamma$  is required to be 1 by electromagnetic gauge invariance, deviations from the Standard Model are defined as 5 parameters:

$$\Delta g_1^Z \equiv (g_1^Z - 1), \quad \Delta \kappa_\gamma \equiv (\kappa_\gamma - 1), \quad \Delta \kappa_Z \equiv (\kappa_Z - 1), \quad \lambda_\gamma, \quad \lambda_Z. \quad (2)$$

The anomalous TGCs are already severely constrained by low energy data [9]. The parameters in equation (2) are no longer independent each other in order to protect low energy observables from acquiring discrepancies with the experimental data [10]. In case the  $SU(2)_L \times U(1)_Y$  gauge symmetry is realized linearly, only three of the five couplings are found to be independent [9, 10]. As a result, the  $WWZ$  couplings are related to the  $WW\gamma$  ones with the equations:

$$\Delta\kappa_\gamma = -\cot^2\theta_W \cdot (\Delta\kappa_Z - \Delta g_1^Z), \quad \lambda_\gamma = \lambda_Z. \quad (3)$$

The anticipated best sensitivity from the  $W$ -pair analysis at LEP2 are inferred based on this relation, which are found to be [1]:  $\Delta\kappa_\gamma = 0.06$ ,  $\lambda_\gamma = 0.04$  and  $\Delta g_1^Z = 0.02$ .

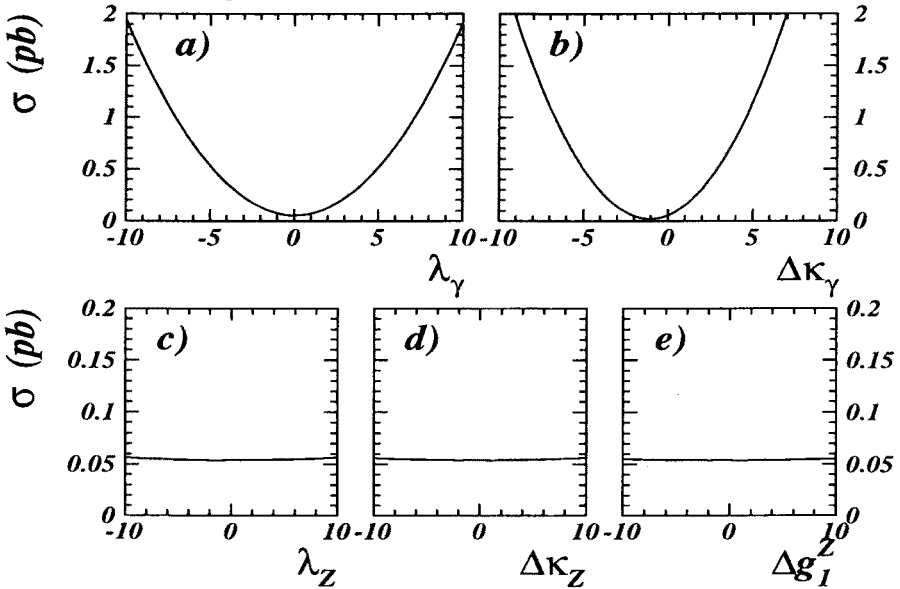


Fig. 3. Variation of the cross-section for the single- $W$  process ( $e\nu\mu\nu$ ). Note that the vertical scales are expanded for  $Z$ -related couplings (c-e).

In contrast to the  $W$ -pair production, the observable of the single- $W$  process is less sensitive to these relations since the contribution from the  $WWZ$  vertex diagram for single- $W$  process is very small at LEP energies. We demonstrate the variation of the cross-section at  $E_{\text{cm}} = 192$  GeV as a function of each anomalous coupling in figure 3. The cross-section depends only marginally on  $WWZ$  related couplings while we see a large sensitivity to  $WW\gamma$  ones. This orthogonal feature against  $WWZ$  couplings not only helps to extract anomalous  $WW\gamma$  couplings alone but also constrain  $WWZ$  couplings once the  $W$ -pair analysis restricts the parameter space along equation (3).

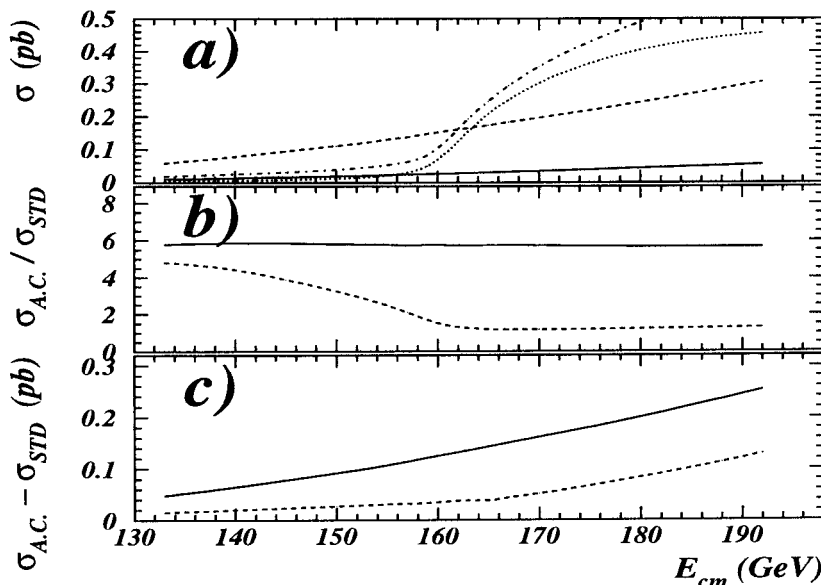


Fig. 4. The enhancement of the cross-section due to the anomalous couplings as a function of  $E_{\text{cm}}$ .

Figure 4a), b) and c) illustrate a specific sensitivity to the anomalous coupling as a function of  $E_{\text{cm}}$ . In figure 4a), the solid line corresponds to the Standard Model cross-section with “single- $W$ ” cut. If we assume anomalous couplings to be  $\Delta\kappa_\gamma = -\cot^2\theta_W \cdot \Delta\kappa_Z = 2$ , we get a significantly larger cross-section (dashed line). Also in the figure, the ratio of two cases (b) and the difference between two (c) are shown as a function of  $E_{\text{cm}}$ . The enhancement factor of about 6 is expected, which is in marked contrast to  $W$ -pair production since the measurement of the  $WW$  total cross-section is not sensitive to the anomalous coupling around the LEP energy region. We give the sensitivity for  $W$ -pair production as dashed lines in figure 4-b) and c), where the “canonical cuts” [11] are made to enhance  $WW$  contribution. The  $W$ -pair case is much less sensitive than the single- $W$  case.

The anticipated sensitivity based on 1-parameter fit for the anomalous couplings are;  $-0.4 < \Delta\kappa_\gamma < 0.3$  and  $-0.9 < \lambda_\gamma < 1.0$ , at 95% C.L., where  $E_{\text{cm}} = 192$  GeV and  $\int \mathcal{L} dt = 500 \text{ pb}^{-1}$  are assumed. We emphasize that one can improve the limits further by including other leptonic and hadronic channels. The hadronic channel is especially very attractive because of its large cross-section ( $\sim 350 \text{ fb}$  at  $E_{\text{cm}} = 192$  GeV). Single- $W$  process is, in general, more sensitive to  $\Delta\kappa_\gamma$  than to  $\lambda_\gamma$ . Although the anticipated bound on  $\lambda_\gamma$  will not be attractive ( $\sim 0.6$ ), the sensitivity of  $|\Delta\kappa_\gamma| \sim 0.1$  is expected with  $\int \mathcal{L} dt = 500 \text{ pb}^{-1}$  which is comparable to that will be obtained from  $W$ -pair studies [1].

#### 4. Conclusion

We have for the first time presented the TGC studies making use of single- $W$  production at the LEP energy region. The cross-section measurement of this process are found to give good sensitivities to the anomalous couplings, in particular to  $\Delta\kappa_\gamma$ .

We emphasize that the precise study of the  $WW\gamma$  vertex from  $e^+e^- \rightarrow e^-\bar{\nu}_e W^+$  process is important to disentangle the complex effects coming from  $WW\gamma$  and  $WWZ$  vertices which will be obtained from  $W$ -pair production analyses. In this sense, the bounds from single- $W$  process are complementary to  $W$ -pair ones.

The author would like to thank Minami-Tateya theory group of KEK for their physics discussions and technical help in grc4f system. This work was supported in part by Japan Society for Promotion of Science under Fellowship for Research Program at Centres of Excellence Abroad.

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