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W^+W^+ Production as a Sensitive Test of Three-Vector-Boson Couplings at SSC and LHC [1]

Hong-Yi Zhou and Yu-Ping Kuang

China Center of Advanced Science and Technology (World Laboratory),

P.O.Box 8730,Beijing 100080,China,

and Institute of Modern Physics and Department of Physics,

Tsinghua University,Beijing 100084,China [2]

ABSTRACT

W^+W^+ production cross-sections at SSC and LHC are studied with the consideration of anomalous three-vector-boson couplings $\Delta\kappa_\gamma = \kappa_\gamma - 1$ and $\Delta\kappa_Z = \kappa_Z - 1$. It is shown that the effects of these anomalous couplings are measurable even if they are as small as $O(10^{-3}) - O(10^{-2})$.

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[2] Mailing address

The prediction of the Standard Model (SM) for the three-vector-boson couplings $WW\gamma$ and WWZ have not yet been tested with significant precision. It is important to test these couplings since any observed deviation could provide some hints of new physics beyond the SM. The vector-boson self-couplings in the SM are fixed by the $SU(2)_L \times U(1)_Y$ gauge structure. As an anomalous coupling, one can add to the SM couplings an extra term[1][2]:

$$\Delta\mathcal{L} = -ig_V(\kappa_V - 1)W^\dagger_\mu W_\nu V^{\mu\nu} , \tag{1}$$

where W^μ is the W^- field, V^μ stands for the photon or the Z field, $V^{\mu\nu} \equiv \partial^\mu V^\nu - \partial^\nu V^\mu$, $g_\gamma = g\sin\theta_W$ and $g_Z = g\cos\theta_W$. The SM values of κ_V are $\kappa_\gamma = \kappa_Z = 1$. The deviation $\Delta\kappa_Z = \kappa_Z - 1$ violates the gauge coupling relation between the 3-vector-boson and the 4-vector-boson couplings, so that we expect that it may give rise to considerable effects at very high energies.

There have been various studies of the detection of $\Delta\kappa_V$. It is shown that effect of $\Delta\kappa_V \geq O(10^{-1})$ in $e^+e^- \to W^+W^-$ can be detected at LEP II [1], and the same sensitivity can be obtained at SSC and LHC through the processes $pp \to W^\pm\gamma X$[3] and $pp \to W^\pm ZX$[4] .

In this letter, we calculate the cross-sections of W^+W^+ productions at SSC and LHC considering the anomalous couplings $\Delta\kappa_\gamma$ and $\Delta\kappa_Z$. W^+W^+ production is advantageous in studying strongly interacting longitudial vector boson (W_L) scatterings since the backgrounds from the SM (no qq, gg annihilation backgrounds) are small [5][6]. In the usual studies, the self-couplings of the vector bosons are assumed to be the the SM couplings, and the corrections to W_LW_L scattering amplitude come from the exchanges of heavy quanta(e.g. heavy Higgs boson etc.). Here we also assume that there are no exchanges of light quanta like the light Higgs boson etc. Then the corrections to the W_LW_L scattering amplitudes come mainly from the anomalous three-vector-boson couplings $\Delta\kappa_\gamma$ and $\Delta\kappa_Z$ since the contribution from the heavy quanta exchange is much smaller. Since

$\Delta\kappa_V$ induces unitarity violation at high energy, there must be limitations on them. The s-wave amplitude of $W_L^+W_L^+$ scattering is

$$a_0 = -\frac{s}{16\pi v^2} - \frac{2s^2}{3\pi v^4}(\cos^2\theta_W \Delta\kappa_Z + \sin^2\theta_W \Delta\kappa_\gamma), \tag{2}$$

where $v = 246\ GeV$. We require $|a_0| \leq 1$ at $1\ TeV$ and find that the limitations are

$$\begin{aligned} &-9.7\times10^{-3} \leq \Delta\kappa_V \leq 4.9\times10^{-3}\ ,\ \ for\ \ \Delta\kappa_\gamma = \Delta\kappa_Z = \Delta\kappa_V\ , \\ &-1.3\times10^{-2} \leq \Delta\kappa_Z \leq 6.3\times10^{-3}\ ,\ \ for\ \ \Delta\kappa_\gamma = 0\ , \\ &-4.2\times10^{-2} \leq \Delta\kappa_\gamma \leq 2.1\times10^{-2}\ ,\ \ for\ \ \Delta\kappa_Z = 0\ . \end{aligned} \tag{3}$$

Equation (3) shows that if there are no anomalous four-vector-boson couplings, the anomalous three-vector-boson couplings $\Delta\kappa_\gamma$ and $\Delta\kappa_Z$ should be at most of the order of 10^{-3} – 10^{-2}. Therefore they can neither be detected at LEP II through the W^+W^- production, nor be detected at SSC and LHC through the $W^\pm\gamma$ and $W^\pm Z$ productions. We shall show that one can detect these small anomalous couplings through W^+W^+ productions at SSC and LHC.

We calculate the full tree level electroweak process $q_1q_2 \to q_3q_4W^+W^+$ in three cases: (a) $\Delta\kappa_\gamma = \Delta\kappa_Z$, (b) $\Delta\kappa_\gamma \neq 0$, $\Delta\kappa_Z = 0$, (c) $\Delta\kappa_\gamma = 0$, $\Delta\kappa_Z \neq 0$. It has been shown in Ref.[5] that the backgrounds from gluon exchange process in $q_1q_2 \to q_3q_4W^+W^+$ and the $W^+t\bar{t}$ production can be efficiently suppressed by taking the following cuts:

$$\begin{aligned} &0.5\,TeV < M_{WW} < 1.0\,TeV,\ \ |y_W| < 1.5, \\ &No\ jet\ with\ p_T(j) > 60\,GeV,\ \ |\eta(j)| < 3.0\ . \end{aligned} \tag{4}$$

Although one can not reconstruct W^+ in its leptonic decay mode, one can use an equivalent lepton cuts to achieve the cuts on W^+ [5]. With the cuts given in (4), the only important background to the anomalous coupling signal is the production of W^+W^+ from the electoweak process $q_1q_2 \to q_3q_4W^+W^+$ with the SM couplings $\kappa_\gamma = \kappa_Z = 1$. In our calculation, we use the computing program PAPAGENO version 3.33[7] , and the parton distribution functions are taken to be the EHLQ Set II[8] ($\Lambda = 290\ MeV$) with $Q^2 = M_W^2$.

The background cross-sections at SSC and LHC are:

$$\begin{aligned} &SSC(\sqrt{s} = 40\,TeV):\ \ \sigma_B = 22.4\ fb\ , \\ &LHC(\sqrt{s} = 16\,TeV):\ \ \sigma_B = 3.48\ fb\ . \end{aligned} \tag{5}$$

Since the anomalous couplings $\Delta\kappa_\gamma$ and $\Delta\kappa_Z$ contribute to the $W_L^+W_L^+$ production cross-section with a $M^2_{W_L^+W_L^+}$ dependence[9][4], they influence mainly on $W_L^+W_L^+$ productions at very high energies. We list in TABLE I–III the $W_L^+W_L^+$ production cross-sections for the three cases stated above. The ratio $\sigma(\kappa_V)/\sigma(1) \equiv \frac{\sigma_{LL}(\kappa_V)-\sigma_{LL}(1)+\sigma_B}{\sigma_B}$ indicates the percentage of the change of cross-section induced by $\Delta\kappa_V$. The curves of $\sigma(\kappa_V)/\sigma(1)$ versus $\Delta\kappa_V$ are shown in Fig.1 (A)–(F). The $W_L^+W_L^+$ invariant mass distributions of $W_L^+W_L^+$ productions for $\Delta\kappa_\gamma = \Delta\kappa_Z$ case are given in Fig.2 (A)–(D). If we assume that 50% change of cross-section from the SM coupling background is detectable, then we obtain the following detectable regions of $\Delta\kappa_\gamma$ and $\Delta\kappa_Z$:

$$\begin{aligned} &LHC\ : \\ &\kappa_V = \kappa_\gamma = \kappa_Z\ ,\ \ \Delta\kappa_V \geq 1.3\times10^{-3},\ \ -4.8\times10^{-3} \leq \Delta\kappa_V \leq -2.2\times10^{-3}\ , \\ &\kappa_Z = 1.000\ ,\ \ \Delta\kappa_\gamma \geq 5.7\times10^{-3},\ \ -2.1\times10^{-2} \leq \Delta\kappa_\gamma \leq -9.6\times10^{-3}\ , \\ &\kappa_\gamma = 1.000\ ,\ \ \Delta\kappa_Z \geq 1.7\times10^{-3},\ \ -6.2\times10^{-3} \leq \Delta\kappa_Z \leq -2.9\times10^{-3}\ ; \end{aligned} \tag{6}$$

$$\begin{aligned} &SSC\ : \\ &\kappa_V = \kappa_\gamma = \kappa_Z\ ,\ \ \Delta\kappa_V \geq 1.4\times10^{-3},\ \ -4.7\times10^{-3} \leq \Delta\kappa_V \leq -2.4\times10^{-3}\ , \\ &\kappa_Z = 1.000\ ,\ \ \Delta\kappa_\gamma \geq 6.0\times10^{-3},\ \ -2.0\times10^{-2} \leq \Delta\kappa_\gamma \leq -1.1\times10^{-2}\ , \\ &\kappa_\gamma = 1.000\ ,\ \ \Delta\kappa_Z \geq 1.9\times10^{-3},\ \ -6.1\times10^{-3} \leq \Delta\kappa_Z \leq -3.0\times10^{-3}\ ; \end{aligned} \tag{7}$$

If we further assume that there are about 30% systematic error of calculation and detection, then one needs a statistical error less than 40% to have the error of total cross-section $\leq 50\%$. To have statistical error $\leq 40\%$ with 95% C.L., more than $(1.96/0.4)^2 = 24$ events are needed. Assuming SSC and LHC have yearly integrated luminosities of $10pb^{-1}$ and $100pb^{-1}$, respectively, $BR(W^+W^+ \to l^+\nu l^+\nu) = 5\%$, we find that it needs about two years running at SSC and one and half years running at LHC .

We have assumed that there is no light quanta (like light Higgs boson) exchange in our calculations. If there is a light Higgs exchange as in the SM, then $W_L^+W_L^+$ scattering is weakly interacting. The anomalous couplings will then enhance the W^+W^+ production cross-section significantly as if $W_L^+W_L^+$ is strongly interacting, and this enhancement is observable. We conclude that W^+W^+ production is a good process for obtaining anomalous three-vector-boson coupling information. Its sensitivity to $\Delta\kappa_\gamma$ and $\Delta\kappa_Z$ is about an order of magnitude better than the known processes like $W^\pm\gamma$ and $W^\pm Z$ productions at SSC and LHC.

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References

[1] K.Hagiwara et al., Nucl. Phys. B**282**, 253(1987).

[2] E.N.Argyres et al., Phys. Lett. B**272**,431 (1991); *ibid.* B**280**, 324(1992).

[3] G.L.Kane, J.Vidal and C.-P.Yuan, Phys. Rev. D**39**, 2617(1989).

[4] D.Zeppenfeld and S.Willenbrock, Phys. Rev. D**37**, 1775(1988).

[5] V.Barger et al., Phys. Rev. D**42**, 3052(1990).

[6] M.S.Berger and M.S.Chanowitz, Phys. Lett. B**263**, 509(1991); *ibid.* B**267**, 416(1991).

[7] I.Hinchliffe, private communications.

[8] E.Eichten, I.Hinchliffe, K.Lane, and C.Quigg, Rev.Mod.Phys. **56**,579(1984).

[9] M.Kuroda et al., Nucl. Phys. B**299**,7 (1988); U. Baur and D. Zeppenfeld, Phys. Lett. B**201**, 383(1988); Y.Nir, Phys. Lett. B**209**, 523(1988).

TABLE I $W_L^+W_L^+$ production cross-sections at SSC and LHC when $\kappa_\gamma = \kappa_Z$.

$\sigma(\kappa_Z)/\sigma(1) \equiv \frac{\sigma_{LL}(\kappa_Z)-\sigma_{LL}(1)+\sigma_B}{\sigma_B}$

	SSC		LHC	
$\Delta\kappa_\gamma = \Delta\kappa_Z$	$\sigma_{LL}(fb)$	$\sigma(\kappa_Z)/\sigma(1)$	$\sigma_{LL}(fb)$	$\sigma(\kappa_Z)/\sigma(1)$
0.005	68.1	3.47	11.8	3.69
0.002	31.1	1.77	5.26	1.81
0.000	13.8	1.00	2.45	1.00
−0.002	4.34	0.58	0.82	0.53
−0.005	3.91	0.56	0.61	0.47
−0.008	18.8	1.22	2.99	1.16
−0.011	50.2	2.63	7.95	2.58

TABLE II $W_L^+W_L^+$ production cross-sections at SSC and LHC when $\kappa_Z = 1.000$.

$\sigma(\kappa_\gamma)/\sigma(1) \equiv \frac{\sigma_{LL}(\kappa_\gamma)-\sigma_{LL}(1)+\sigma_B}{\sigma_B}$

	SSC		LHC	
$\Delta\kappa_\gamma$	$\sigma_{LL}(fb)$	$\sigma(\kappa_\gamma)/\sigma(1)$	$\sigma_{LL}(fb)$	$\sigma(\kappa_\gamma)/\sigma(1)$
0.008	29.3	1.69	5.10	1.76
0.005	23.0	1.41	4.01	1.45
0.002	17.4	1.16	3.02	1.16
0.000	13.8	1.00	2.45	1.00
−0.005	7.17	0.70	1.35	0.68
−0.010	3.29	0.53	0.64	0.48
−0.020	2.92	0.51	0.49	0.44
−0.030	12.3	0.93	1.91	0.84
−0.040	30.0	1.72	4.76	1.66

TABLE III $W_L^+W_L^+$ production cross-sections at SSC and LHC when $\kappa_\gamma = 1.000$.

$\sigma(\kappa_Z)/\sigma(1) \equiv \frac{\sigma_{LL}(\kappa_Z)-\sigma_{LL}(1)+\sigma_B}{\sigma_B}$

	SSC		LHC	
$\Delta\kappa_Z$	$\sigma_{LL}(fb)$	$\sigma(\kappa_Z)/\sigma(1)$	$\sigma_{LL}(fb)$	$\sigma(\kappa_Z)/\sigma(1)$
0.005	52.0	2.71	8.87	2.84
0.003	32.6	1.84	5.79	1.96
0.002	26.0	1.54	4.52	1.59
0.000	13.8	1.00	2.45	1.00
−0.004	2.27	0.49	0.45	0.42
−0.008	7.63	0.72	1.20	0.64
−0.012	28.2	1.64	4.54	1.60
−0.016	65.8	3.32	10.6	3.34

FIGURE CAPTIONS:

Fig.1 (A): $\sigma(\kappa_Z)/\sigma(1) \sim \kappa_Z$ relation at SSC when $\kappa_\gamma = \kappa_Z$.

Fig.1 (B): $\sigma(\kappa_\gamma)/\sigma(1) \sim \kappa_\gamma$ relation at SSC when $\kappa_Z = 1.000$.

Fig.1 (C): $\sigma(\kappa_Z)/\sigma(1) \sim \kappa_Z$ relation at SSC when $\kappa_\gamma = 1.000$.

Fig.1 (D): $\sigma(\kappa_Z)/\sigma(1) \sim \kappa_Z$ relation at LHC when $\kappa_\gamma = \kappa_Z$.

Fig.1 (E): $\sigma(\kappa_\gamma)/\sigma(1) \sim \kappa_\gamma$ relation at LHC when $\kappa_Z = 1.000$.

Fig.1 (F): $\sigma(\kappa_Z)/\sigma(1) \sim \kappa_Z$ relation at LHC when $\kappa_\gamma = 1.000$.

Fig.2 (A) $W_L^+W_L^+$ invariant mass distributions of $W_L^+W_L^+$ productions at SSC with $\kappa_\gamma = \kappa_Z = 1.000, 1.002, 1.005$.

Fig.2 (B) $W_L^+W_L^+$ invariant mass distributions of $W_L^+W_L^+$ productions at SSC with $\kappa_\gamma = \kappa_Z = 1.000, 0.998, 0.995, 0.992, 0.989$.

Fig.2 (C) $W_L^+W_L^+$ invariant mass distributions of $W_L^+W_L^+$ productions at LHC with $\kappa_\gamma = \kappa_Z = 1.000, 1.002, 1.005$.

Fig.2 (D) $W_L^+W_L^+$ invariant mass distributions of $W_L^+W_L^+$ productions at LHC with $\kappa_\gamma = \kappa_Z = 1.000, 0.998, 0.995, 0.992, 0.989$.

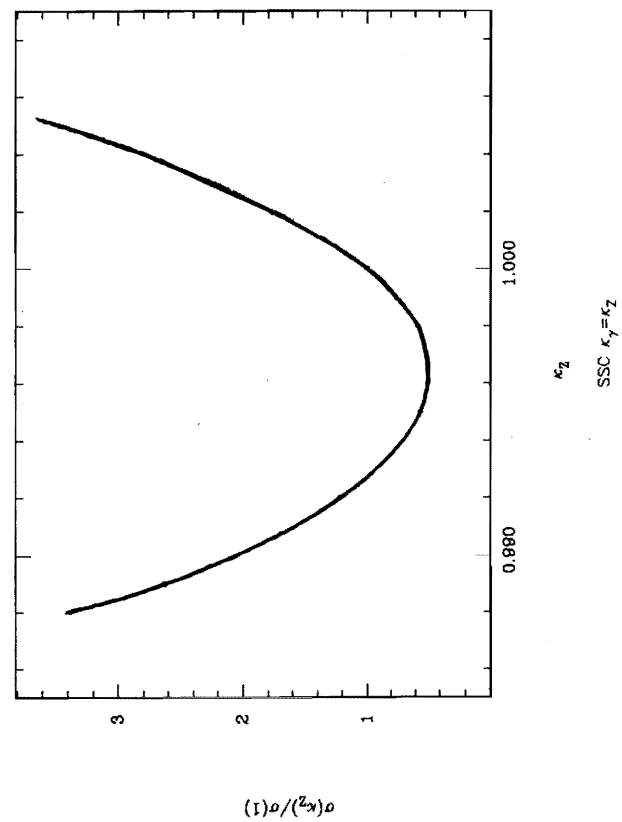


Fig.1 (A)

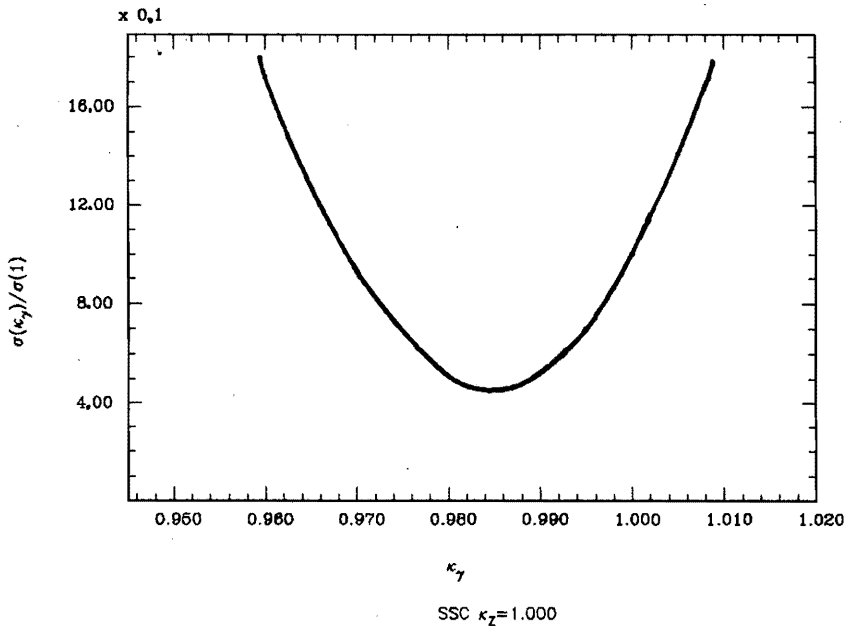

x 0.1
16.00
12.00
8.00
4.00
σ(κγ)/σ(1)
0.950
0.960
0.970
0.980
0.990
1.000
1.010
1.020
κγ
SSC κZ=1.000

Fig.1 (B)

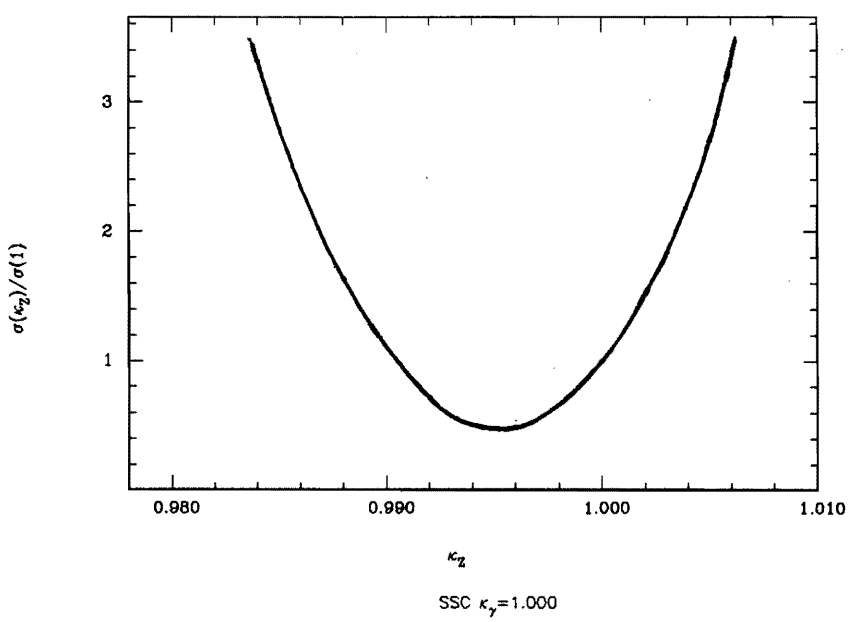

3
2
1
σ(κZ)/σ(1)
0.980
0.990
1.000
1.010
κZ
SSC κγ=1.000

Fig.1 (C)

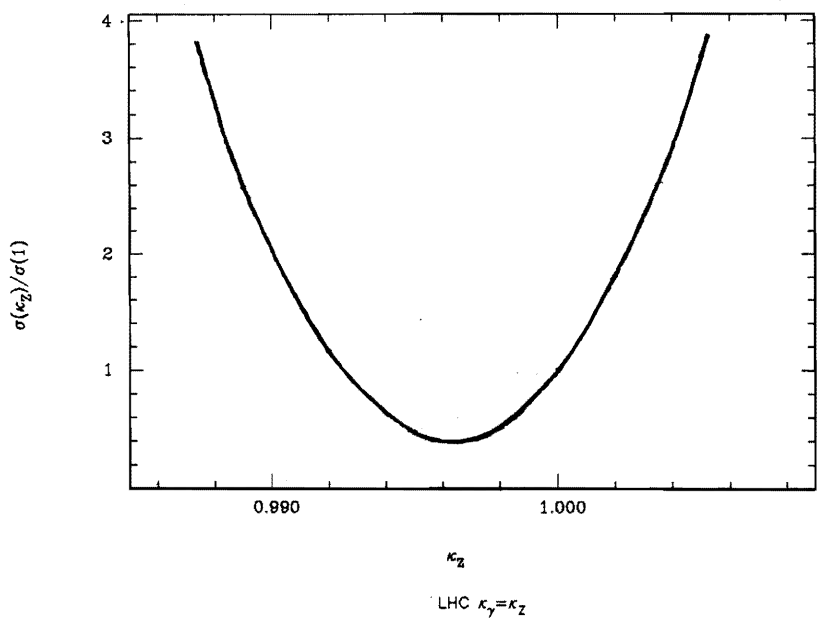

4
3
2
1
$\sigma(\kappa_Z)/\sigma(1)$
0.990
1.000
κ_Z
LHC $\kappa_\gamma=\kappa_Z$

Fig.1 (D)

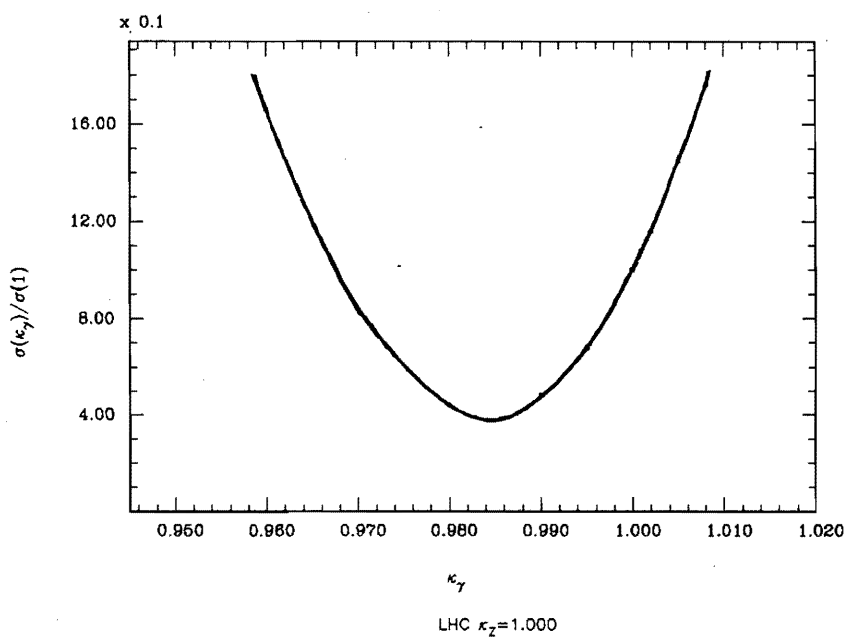
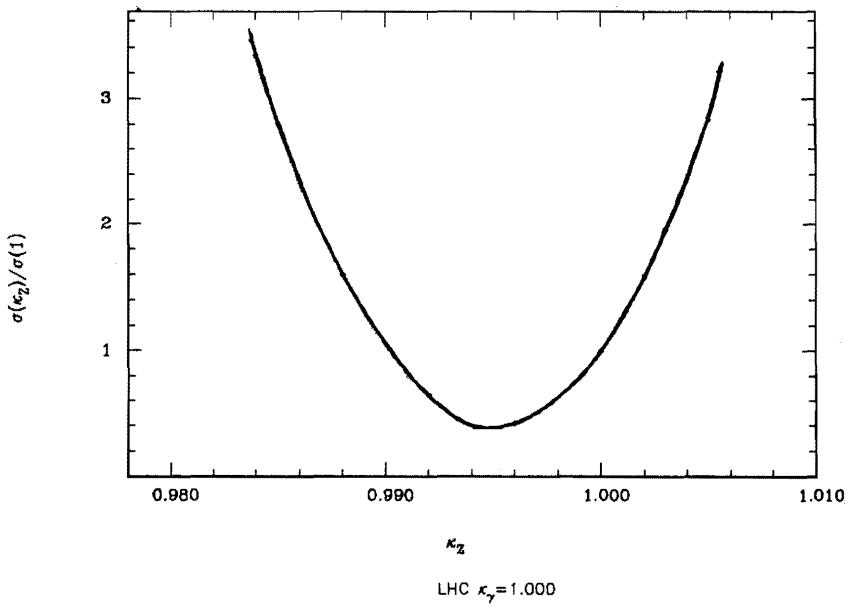

x 0.1
16.00
12.00
8.00
4.00
$\sigma(\kappa_\gamma)/\sigma(1)$
0.950
0.960
0.970
0.980
0.990
1.000
1.010
1.020
κ_γ
LHC κ_Z=1.000

Fig.1 (E)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2
1
$\sigma(\kappa_Z)/\sigma(1)$
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0.990
1.000
1.010
κ_Z
LHC κ_γ=1.000

Fig.1 (F)

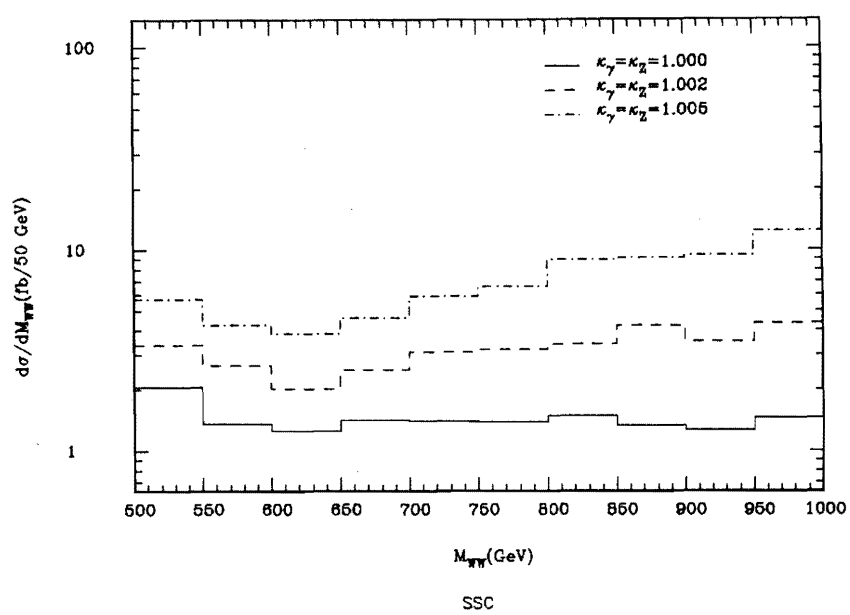

100
10
1
$d\sigma/dM_{WW}$(fb/50 GeV)
$\kappa_\gamma=\kappa_Z=1.000$
$\kappa_\gamma=\kappa_Z=1.002$
$\kappa_\gamma=\kappa_Z=1.005$
500
550
600
650
700
750
800
850
900
950
1000
M_{WW}(GeV)
SSC

Fig.2 (A)

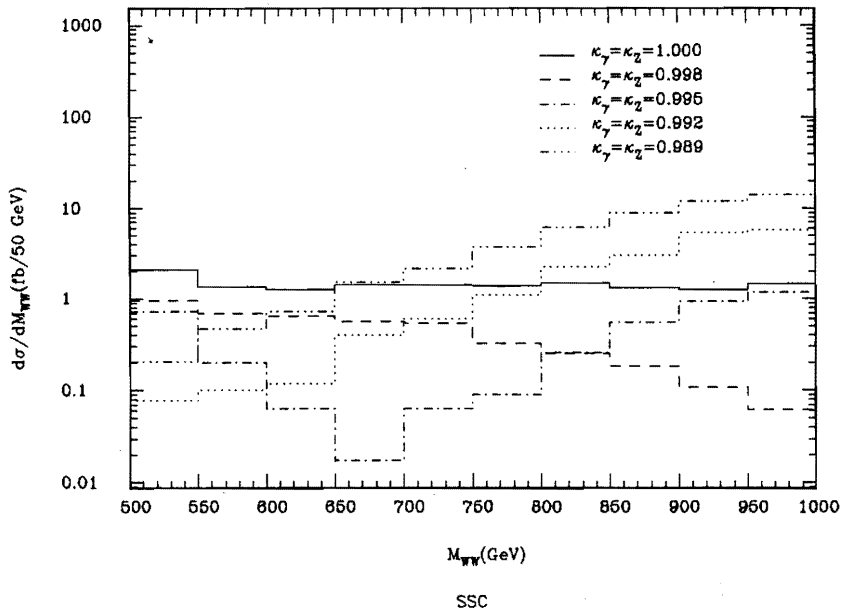

$\kappa_\gamma=\kappa_Z=1.000$
$\kappa_\gamma=\kappa_Z=0.998$
$\kappa_\gamma=\kappa_Z=0.995$
$\kappa_\gamma=\kappa_Z=0.992$
$\kappa_\gamma=\kappa_Z=0.989$
$d\sigma/dM_{WW}$(fb/50 GeV)
1000
100
10
1
0.1
0.01
500 550 600 650 700 750 800 850 900 950 1000
M_{WW}(GeV)
SSC

Fig.2 (B)

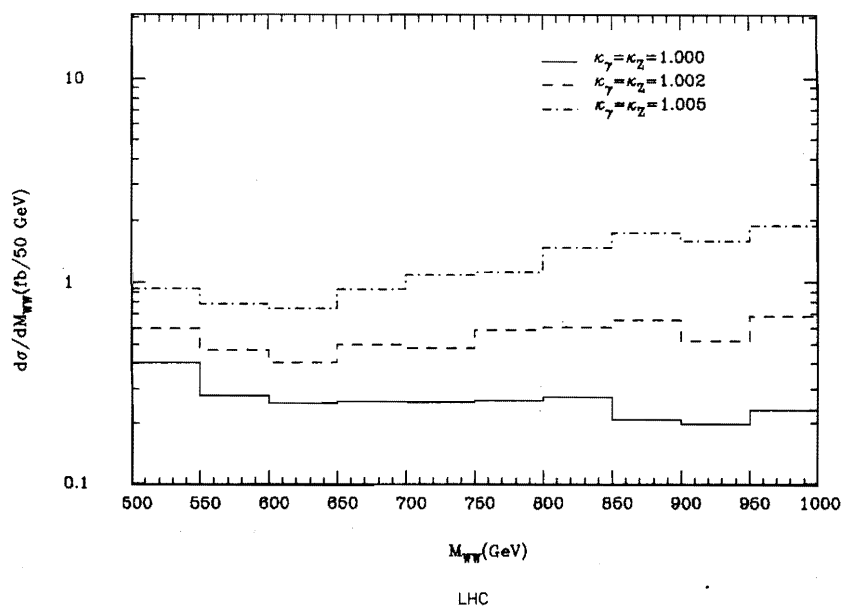
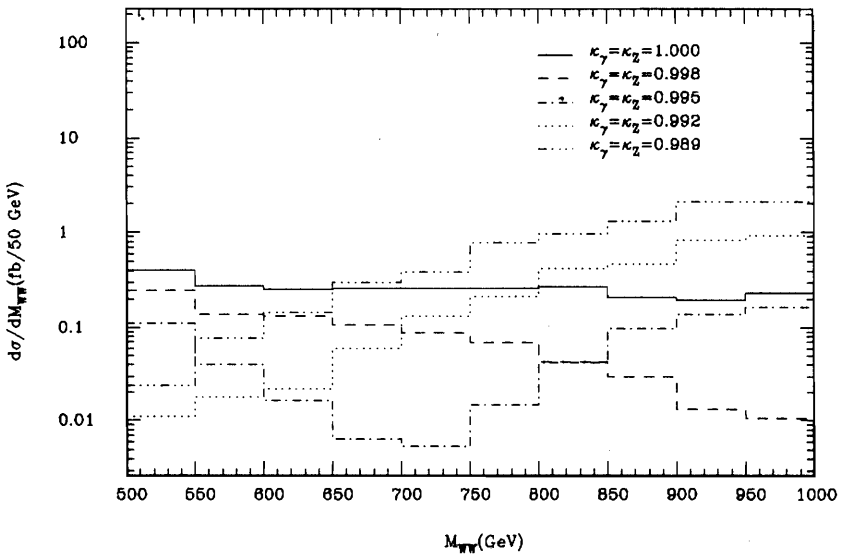

$\kappa_\gamma=\kappa_Z=1.000$
$\kappa_\gamma=\kappa_Z=1.002$
$\kappa_\gamma=\kappa_Z=1.005$
$d\sigma/dM_{WW}$(fb/50 GeV)
10
1
0.1
500 550 600 650 700 750 800 850 900 950 1000
M_{WW}(GeV)
LHC

Fig.2 (C)


100
10
1
0.1
0.01
dσ/dM_WW(fb/50 GeV)
κ_γ=κ_Z=1.000
κ_γ=κ_Z=0.998
κ_γ=κ_Z=0.995
κ_γ=κ_Z=0.992
κ_γ=κ_Z=0.989
500
550
600
650
700
750
800
850
900
950
1000
M_WW(GeV)

LHC

Fig.2 (D)