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Supersymmetric Electroweak Radiative Corrections To $e^+e^- \to W^+W^-$

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Abstract

In this short note we summarize some of the work of our thesis, which is also reported elsewhere in detail. We have examined the one loop quantum corrections to the W pair production in the electron positron annihilation in the context of supersymmetric electroweak theory. We have adopted the On Mass Shell Renormalization scheme of Sakakibara and previously demonstrated the consistency of this scheme. The relevant analytic results are written out. A complete computer program for these corrections has been developed. This program has been checked in several ways to ensure against errors over the life of the calculation where many subtle cancellations are involved. The major aim of our work was to calculate the Supersymmetric Quantum Flavor Dynamics (SQFD] one loop radiative corrections to the process $e^+e^- \to W^+W^-$. The addition of the particles due to Supersymmetry [SUSY] tend to increase the amount of one loop corrections on the order of 8%. With an accurate measurement at LEP II, one can, in principle, detect such a deviation away from the Standard Model [SM].

Introduction

Supersymmetry is one the most elegant extensions to the standard model. It solves the hierarchy problem, one of the main drawbacks of the grand unified theories, by introducing a fermion-boson symmetry. It is precisely this beautiful property of supersymmetry which provides a hope of unifying all forces of nature*, and also allows forces and matter to be treated on the same footing. As a consequence of the fermi-bose symmetry, many new degrees of freedom corresponding to supersymmetric partners [s-p] of the standard model particles are predicted by the theory. However, aesthetically appealing a theory might be, it must stand the test of the experiment. Therefore it is of crucial interest to explore

*We mean generalizations of global SUSY such as supergravity and supertring theories.

all the phenomenological implications of supersymmetric theories in order to confront experiments.

A lot of work has been done on supersymmetric [1-5]. The effect of supersymmetry on the physical properties such as g-2 of leptons [6], the two-photon decay width of Higgs boson [7], the magnetic and quadrupole [8,9] moments of the W-boson has received some attention. Radiative corrections in N=1 supersymmetry, given in context of neutral scattering, have been given by Grifols et al. [10] and Schwarzer [11] and for $e^+e^-\mu^+\mu^-$ by Lynn [12]. In reference [10], no mention is made of the renormalization scheme adopted. Schwarzer [11] adopts the MS scheme and find the dependence of the electroweak parameters on supersymmetric effects to be small; for example a 0.002 increase is found in the value of $\sin^2\theta_w(\mu)$ at a scale $\mu = M_w^2$ and a small decrease, of the order of few MeV's in the predicted gauge-boson masses. A good review of the phenomenology and work on radiative corrections both in and beyond the standard model may be found in [2]. We have reported our calculation of the one loop radiative corrections to the process $e^+e^- \to W^+W^-$ in the supersymmetric Salam-Weinberg or Quantum Flavor Dynamics [QFD] model in [9,13-16].

The purpose of this short note is to summarize the results of our calculation of the one loop radiative corrections to the process $e^+e^- \to W^+W^-$ in the Supersymmetric Electroweak model [9,13-16].

Motivations

We now outline some reasons or motivating factors which led us to examine the one loop radiative corrections in context of SQFD:
1. QFD has been experimentally tested and LEP I energy [or the center of mass energy [ECM] near the Z resonance]. However LEP I does not test the three or four vector vertices which are the central features of the electroweak model. LEP II on the other hand will scan teh energy range near W pair production.
2. The question aries if the W is a fundamental or a composite particle. This point is related to the Higgs particle, which has eluded detection up to LEP I energy. If the W is a composite particle then will the compositeness be manifest in the energy range range 100-300 GeV?
3. Another relevant question is: if new particles, i.e. SUSY particles, exist in the energy range 50-300 GeV, can they induce measurable effects at teh LEP II energies? Thus far LEP I energies haev allowedl experimentalists to put lower mass limits on the SUSY particles.
4. As the SM is successful in the realm up to Z mass scale, so is quantum electrodynamics [QED] succesful in its realm. Yet QED is still embedded in a larger group structure i.e. the elctroweak gauge group $\mathrm{SU}(2)_L \times U(1)_Y$. One is lead to suspect that due to physical reasons, such as number of generations, fermion masses, origin of CKM matrix elements, that the SM is not the end of the story and it must be embedded in a larger symmetry group. So the relevant practical question is not if the SM will breakdown but when does it breakdown?

The question then aries: will it breakdown at the W pair production threshold? One expects that at LEP II energies there will not be an explicit breakdown but some hints might be there which will signal new physics in the energy range 200 GeV - 1 TeV. The one TeV scale is suggested in the context of the supersymmetric theories [2].

With these considerations in mind we undertook to calculate the one loop radiative corrections to the process $e^+e^- \to W^+W^-$ in the context of SQFD [9,13,16]. We have adopted the on mass shell scheme of Sakakibara [17] and previously demonstrated the consistency of the scheme.

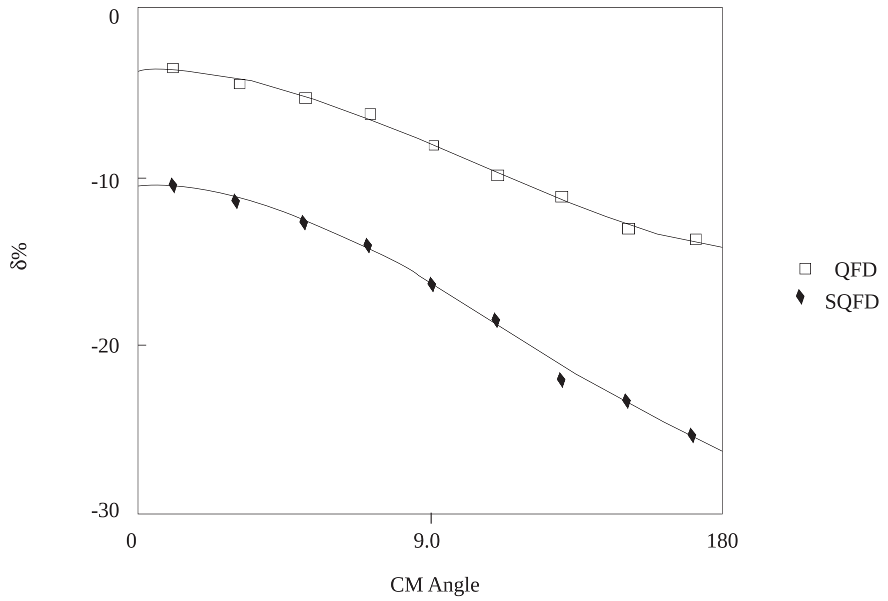

Figure 1. The percentage one loop radiative corrections to the lowest order cross section compared for QFD and SQFD, the Higgs mass and top masses are 50 GeV and 100 GeV respectively. The photon cutoff is here taken as a=0.1.

Results and Conclusions

We now turn to the discussion of the actual contribution of the SUSY particles to the one loop differential cross section. To this end we sum up all the contributions due to the one loop supersymmetric radiative corrections. The numerical results are listed in Table 1. We note that the $\bigcirc$ denotes the one loop contributions due to the self-energy insertions and the wave function renormalization terms. The Δ is likewise a shorthand for the contributions arising from the vertex corrections. Finally, $\Box$ stands for the contributions due to the box diagrams.

The fractional contribution of one loop radiative corrections in SQFD can be obtained by adding the contributions due to the SUSY particles in Table 1 to the SM virtual and real radiative corrections. The results are given in Tables 2 and 3 for two values of photon cutoff respectively. In Table 1 the photon cutoff parameter a is taken to be 0.1, likewise in Table 2 a=0.05. δ denotes the percentage radiative corrections with respect to the SM Born value. We note that the center of mass energy [ECM] is 200 GeV for all the results reported in this note.

Table 1. The additional virtual one loop radiative corrections in pb for ECM=200 GeV due to the addition of the supersymmetric particles.

$\theta(deg)$	$(\frac{d\sigma}{d\cos\theta})_1^{\bigcirc}$	$(\frac{d\sigma}{d\cos\theta})_1^{\Delta}$	$(\frac{d\sigma}{d\cos\theta})_1^{\Box}$	$(\frac{d\sigma}{d\cos\theta})_1^{Total}$
10	-9.2337	-1.8838	+0.2842	-10.8333
30	-6.2351	-1.0077	-0.3435	-7.5863
50	-3.3755	-0.4449	-0.5927	-4.4131
70	-1.8386	-0.1602	-0.6985	-2.6973
90	-1.0709	-0.0252	-0.5744	-1.6705
110	-0.6689	+0.0333	-0.5215	-1.1571
130	-0.4413	-0.1277	-0.4723	-1.0413
150	-0.3121	-0.0349	-0.4330	-0.7800
170	-0.2499	+0.0063	-0.5213	-0.7649

The SUSY particles tend to increase the absolute magnitude of the percentage one loop corrections relative to the SM radiative corrections. The reason for this is straightforward. The contribution from the SUSY virtual loop corrections comes with the opposite sign to the opposite sign to the virtual loop corrections generated by the standard model particles. Bearing in mind that bremsstrahlung comes with the opposite sign to the SM virtual corrections, there is an overall increase in magnitude of the percentage corrections in the context of SQFD. In Figs. 1 and 2 we have compared our results for QFD and SQFD. It is easily observed from these figures that three is almost a constant increase or enhancement of approximately 6.7% relative to the SM result. This relative enhancement gradually increases with CM angle so that at $\theta = 170^\circ$ it rises to approximately to 11.7%.

An interesting question that naturally ariess is what happens if the masses of all the SUSY partners of the SM particles are taken to be larger than the W mass? The result for this case is shown in Fig. 3. It can be seen from Fig. 3 that δ is reduced in the forward direction and increased in he backward direction and there is an overall greater variation of δ compared to the other case of s-p masses, shown in Figs. 1 and 2, and also shown in Fig. 3 for the shake of comparison. We note that the actual numerical values of the mass spectrum for the SUSY particles that we have utilized for both cases is listed in [14] and [16].

In conclusion we find that our results for the QFD one loop radiative corrections to the process $e^+e^- \rightarrow W^+W^-$ garee with those given by Veltman [18] on the order of 0.5%-1.5% of δ and on the order of 0.6%-10% of δ with Bohm et al. [19]. For the benefit of the reader we list below the explicit numerical comparison of the percentage one loop corrections between our work and that reported by Bohm et al. [19] for the same values of parameters used by the latter in the context of QFD. [We note that by "Our" we mean M. K. Sundaresan, P. Kalyniak and the author]:

Table 2. The percentage loop radiative corrections to the lowest order differential cross section of SQFD. The photon cutoff is taken to be $\alpha = 0.1$. ECM=200 GeV.

$\theta(deg)$ -	$(\frac{d\sigma}{d\cos\theta})_1^{virtual}$ pb	$(\frac{d\sigma}{d\cos\theta})_1^{real}$ pb	δ^{total} %
10	+17.7465	-34.2446	-10.6021
30	+11.7357	-24.0332	-11.4999
50	+6.2352	-13.8036	-12.7495
70	+3.3099	-8.1109	-14.3160
90	+1.8547	-5.1752	-16.1520
110	+1.0790	-3.5939	-18.3075
130	+0.5324	-2.6759	-21.7037
150	+0.3570	-2.1297	-23.2023
170	+0.2057	-1.8633	-25.2129

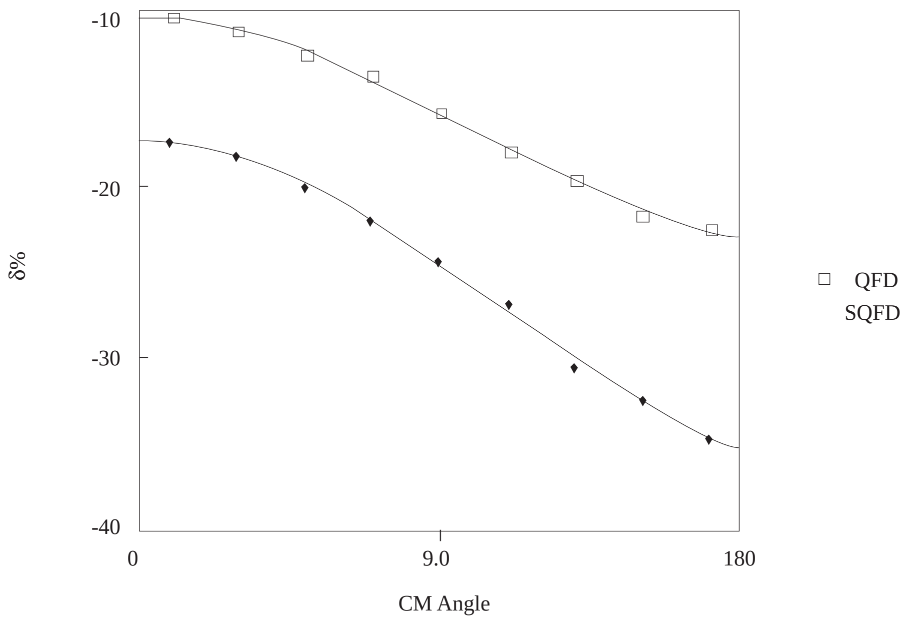

Figure 2. The percentage one loop radiative corrections to the lowest order cross section compared for QFD and SQFD, the Higgs mass and top masses are 50 GeV and 100 GeV respectively. The photon cutoff is here taken as a=0.05.

θ	θ of Bohm et al. [19]	Our δ [9]
10°	-4.29%	-3.87%
90°	-7.24%	-7.20%
170°	-10.04%	-10.68%

Table 3. The percentage one loop radiative corrections to the lowest order differential cross section of SQFD. The photon cutoff is taken to be $\alpha = 0.1$. ECM=200 GeV.

$\theta(deg)$ -	$(\frac{d\sigma}{d\cos\theta})_1^{virtual}$ pb	$(\frac{d\sigma}{d\cos\theta})_1^{real}$ pb	δ^{total} %
10	+17.7465	-45.5995	-17.8990
30	+12.0792	-31.9715	-18.6021
50	+6.2352	-18.3357	-20.3842
70	+3.3099	-10.7547	-22.1994
90	+1.8547	-6.8497	-24.2973
110	+1.0790	-4.7488	-26.7147
130	+0.5324	-3.5308	-30.3599
150	+0.3570	-2.8071	-32.0685
170	+0.2057	-2.4546	-34.2069

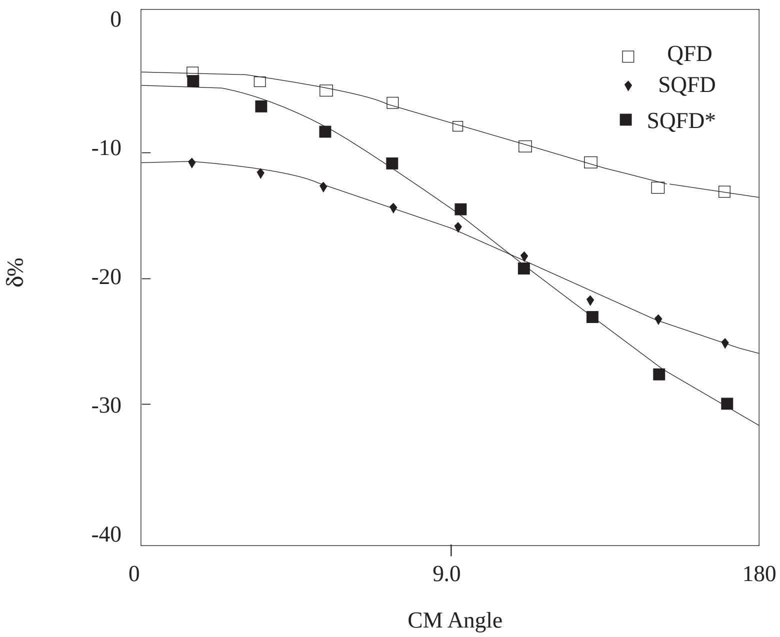

Figure 3. The percentage one loop radiative corrections to the lowest order cross section compared for the two cases of SUSY particles masses. SQFD* is the case when most of the S-P masses are above the W boson mass. The photon cutoff is here taken as a=0.1.

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References

[1] G. Altarelli et al., Editors: Z Physics at LEP I, II and III Cern 89-08 (1989).

[2] H. E. Haber and G. L. Kane, Phys. Repts, 117 (1985)

[3] J. F. Gunion et al., Higgs Hunter's Guide, Addison Wesley Publishing Company, (1990).

[4] A. Bohm and W. Hoogland, Editors: ECFA Workshop on LEP 200, Cern 87-08, (1987).

[5] V. Barger and R. Phillips, Collider Physics, Addison Wesley Publishing Company, (1987).

[6] J. Baily et al., Nucl. Phys. B, 150 (1979).

[7] R. Bates et al., Phys. Rev. D, 34 (1986) 172; ibid P. Kalyniak, Phys. Rev. D, 33 (1986)

[8] S. Alam, Phys. Rev. D, 39 (1989) and references therein.

[9] S. Alam, Ph.D Thesis **The One Loop Radiative Corrections to the W pair production in electron-positron annhilation in the Supersymmetric extension of the Salam-Weinberg model of the electroweak interactions,** Herzberg Laboratories for Physics, Physics Department, Carleton University, Ottawa, Canada, 1992.

[10] J. A. Grifols, Nucl. Phys. B, 253 (1985) 47.

[11] K. Schwarzer, Oxford preprint 40/84, 1984.

[12] B. W. Lynn, Slac-Pub-3358, June (1984) T/E.

[13] S. Alam, J. Sc & Tech. Peshawar, 17 (1993) 81.

[14] S. Alam, Phys. Rev. D, 50 (1994) 124.

[15] S. Alam, Phys. Rev. D, 50 (1994) 148.

[16] S. Alam, Phys. Rev. D, 50 (1994) 174.

[17] S. Sakakibara, Phys. Rev. D, 24 (1981) 1149.

[18] M. Lemoine and M. Veltman, Nucl. Phys. B, 169 (1980) 445.

[19] M. Bohm et al., Nucl. Phys. B, 304 (1988) 463.