Single W Production Associated with SUSY Particles in Longitudinally Polarized e^+e^- Collisions

M. JIMBO

Department of Physics, Rikkyo University, Tokyo 171, JAPAN

Abstract – We investigate the single W production associated with sleptons in longitudinally polarized e^+e^- beams. The polarized cross-sections and the angular distributions of W^- are calculated for charged sleptons in left-handed and right-handed multiplets. It is shown that the cross-sections for spin-1 configurations of e^+e^- beams are sensitive to the mass spectrum of SUSY particles in the sub-TeV region, and considerably large in the TeV region.

The search for supersymmetric (SUSY) particles will be one of the most important pursuits at the present and future colliders. As has been noted in a previous paper [1], the polarized electron and positron beams are useful to obtain the information of the masses of SUSY particles. As the energy of future machines increases, however, higher masses of SUSY particles become accessible. Thus at the next stage of the verification of SUSY, we have to consider the test for the framework of the standard $\mathrm{SU(2)_L \times U(1)_Y}$ gauge theory itself with SUSY particles.

The investigation of the triple vertex couplings of the gauge bosons γWW and Z^0WW is the most serious test for the structure of the standard model. For the charged massive vector bosons, in general, the cross-section for the tree-level pair production violates unitarity owing to the longitudinal polarization state. In the standard gauge model, the ingenious cancellation mechanism works among the dangerous diagrams [2,3]. In this context the processes $e^+e^- \to W^+W^-$ [4] and $p\bar{p} \to W^+W^-$ [5] have been analyzed for the proposed $\mathrm{LEP_{200}}$ and for the Tevatron. The possibility of probing the Z^0WW couplings in $Z^0 \to Wff'$ has also been studied in the standard gauge model [6] and with the deviation from the gauge couplings [7]. As for single W production, $e^+e^- \to W^-\nu e^+$ has been studied from the Z^0-region to the W-pair threshold [8]. At the e^+e^- colliders

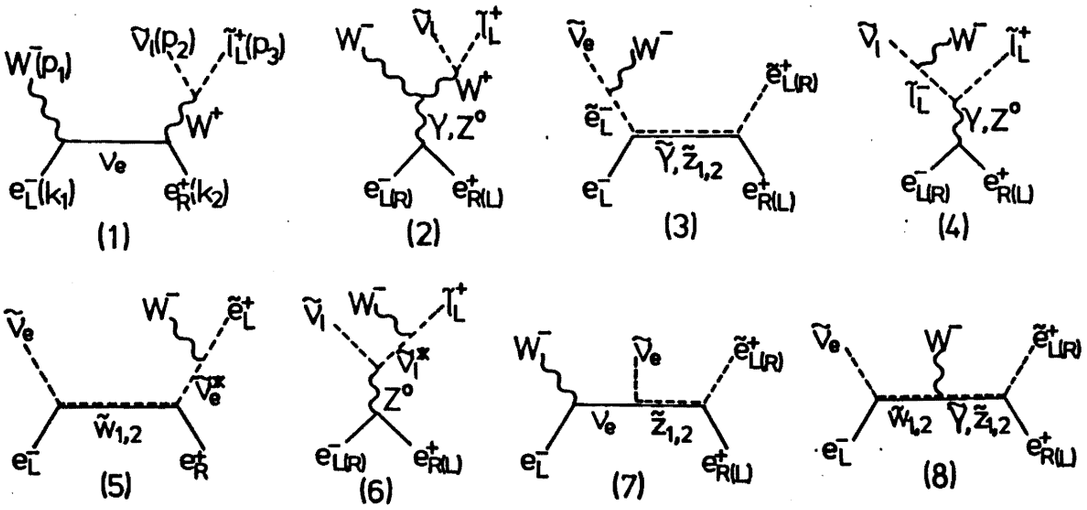

Fig. 1. Feynman diagrams for $e^-(k_1) + e^+(k_2) \to W^-(p_1) + \tilde{\nu}_l(p_2) + \tilde{l}^+(p_3)$.

in the TeV region such as CLIC [9], single W production associated with SUSY particles will have to be considered for completeness.

In this paper, we investigate one of the processes of the single W production,

$$e^-(k_1) + e^+(k_2) \to W^-(p_1) + \tilde{\nu}_l(p_2) + \tilde{l}^+(p_3), \tag{1}$$

in longitudinally polarized beams, through the diagrams of fig. 1. Here $\tilde{\nu}_l$ and $\tilde{l}^+$ denote sneutrinos and charged sleptons, the SUSY partners of corresponding leptons. It is shown that the cross-sections for spin-1 configurations of e^+e^- beams are sensitive to the mass spectrum of SUSY particles in the sub-TeV region, and considerably large in the TeV region.

The polarized cross-sections are denoted by $\sigma_{\lambda,\lambda'}$ for the helicity states of electron ($\lambda = \pm 1$) and those of positron ($\lambda' = \pm 1$). For the high-energy limit ($\sqrt{s} \gg m_e$), these cross-sections are replaced by those for the chiral states of electron and positron ($\lambda, \lambda' : +1 \to$ R and $-1 \to$ L). Since not all the diagrams in fig. 1 contribute to the cross-sections $\sigma_{\lambda,\lambda'}$, the contributed ones are listed in

TABLE I. – Contents of polarized cross-sections

	$e^-e^+ \to W^-\tilde{\nu}_e\tilde{e}^+$	$e^-e^+ \to W^-\tilde{\nu}_\mu\tilde{\mu}^+$
L-slepton		
$\sigma_{\rm RR}$	[forbidden]	[forbidden]
$\sigma_{\rm RL}$	$\lvert M(2)+M(4)+M(6)\rvert^2$	$\lvert M(2)+M(4)+M(6)\rvert^2$
$\sigma_{\rm LR}$	$\lvert M(1)+\cdots+M(8)\rvert^2$	$\lvert M(1)+M(2)+M(4)+M(6)\rvert^2$
$\sigma_{\rm LL}$	[forbidden]	[forbidden]
R-slepton		
$\sigma_{\rm RR}$	[forbidden]	[forbidden]
$\sigma_{\rm RL}$	[forbidden]	[forbidden]
$\sigma_{\rm LR}$	[forbidden]	[forbidden]
$\sigma_{\rm LL}$	$\lvert M(3)+M(7)+M(8)\rvert^2$	[forbidden]

table I. The heading 'L-slepton' ('R-slepton') means the production of $\tilde{l}_{\rm L}^+$ ($\tilde{l}_{\rm R}^+$), which is the SUSY partner of the left- (right-) handed charged lepton.

We employ a minimal model of supergravity (SUGRA) GUT [10], for separating the essential part of SUSY phenomenology from the effects due to exotics as in superstring-inspired SUGRA GUTs. The input parameters adopted in numerical calculation are taken so that $\alpha_{\rm em}(m_W) = 1/128, \sin^2\theta_W(m_W) = 0.22$ and $m_{Z^0} = 93$ GeV. With this choice, the mass formula for sleptons [1] is

$$\begin{aligned} M\tilde{l}_{\rm R} &= [{m_0}^2 + 0.16{m_{1/2}}^2]^{1/2}, \\ M\tilde{l}_{\rm L} &= [{m_0}^2 + 0.58{m_{1/2}}^2]^{1/2}, \end{aligned} \tag{3}$$

with $M\tilde{\gamma} = 0.47 m_{1/2}$. The mass parameters m_0 and $m_{1/2}$ come from soft SUSY-breaking terms have to be chosen to definite values for numerical calculation. We take two mass sets as in table II with $M\tilde{\gamma} = 10$ and 20 GeV by setting $M\tilde{l}_{\rm R} = 36$ GeV in accordance with the lightest mass set in ref. [1], and setting $M\tilde{\nu}_l = M\tilde{l}_{\rm L}$. It is memorable that the real W-pair production is kinematically allowed only for the mass set I.

In fig. 2 we show the integrated cross-sections $\sigma_{\lambda,\lambda'}$ versus the total energy $\sqrt{s}$. The cut condition, $|\cos\theta| \leq 0.985$, is taken here. The cross-section $\sigma_{\rm RL}$

TABLE II. – Mass sets (in GeV)

	$M\tilde{\gamma}$	$M\tilde{l}_R$	$M\tilde{l}_L$	$M\tilde{\nu}_l$	$M\tilde{z}_2$	$M\tilde{z}_1$	$M\tilde{w}_2$	$M\tilde{w}_1$
I	10	36	38	38	86	101	74	91
II	20	36	45	45	79	109	67	101

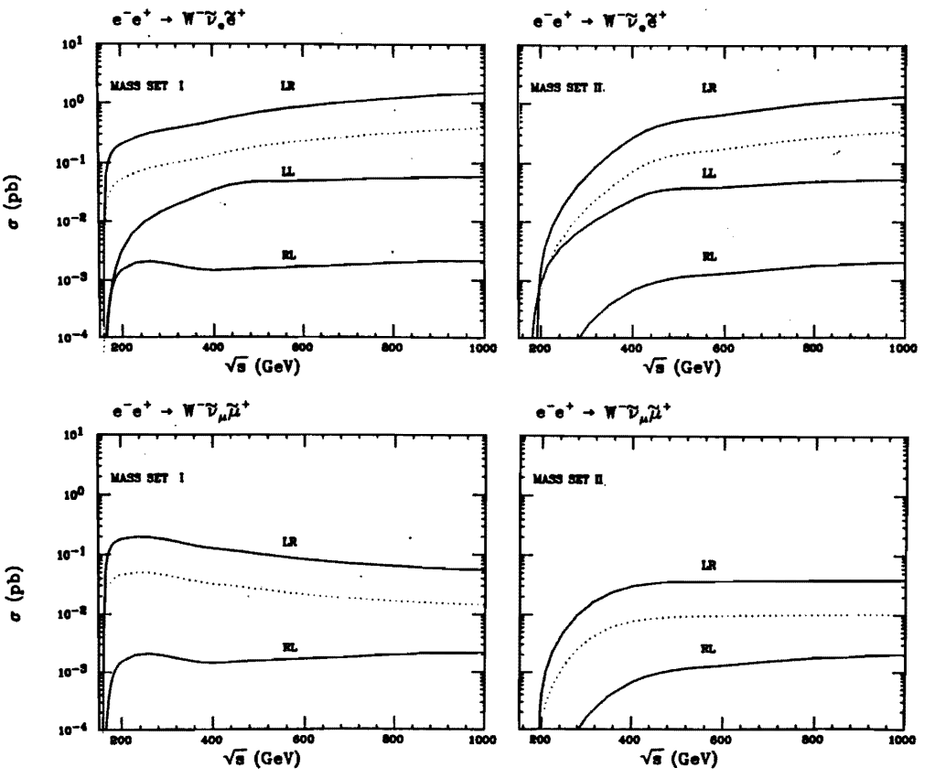

Fig. 2. Integrated cross-sections $\sigma_{\lambda,\lambda'}$ versus total energy $\sqrt{s}$.

of selectron production is equal to that of smuon production due to the same value in masses of sleptons for the different generations. The cross-section $\sigma_{\rm LR}$ of selectron production differ from that of smuon production owing to the four diagrams (3), (5), (7) and (8). The contribution of the annihilation processes in general becomes smaller with the increase of $\sqrt{s}$. The $W^-"W^+"$ (real and/or virtual) production through the diagram (2), however, is controled by the triple

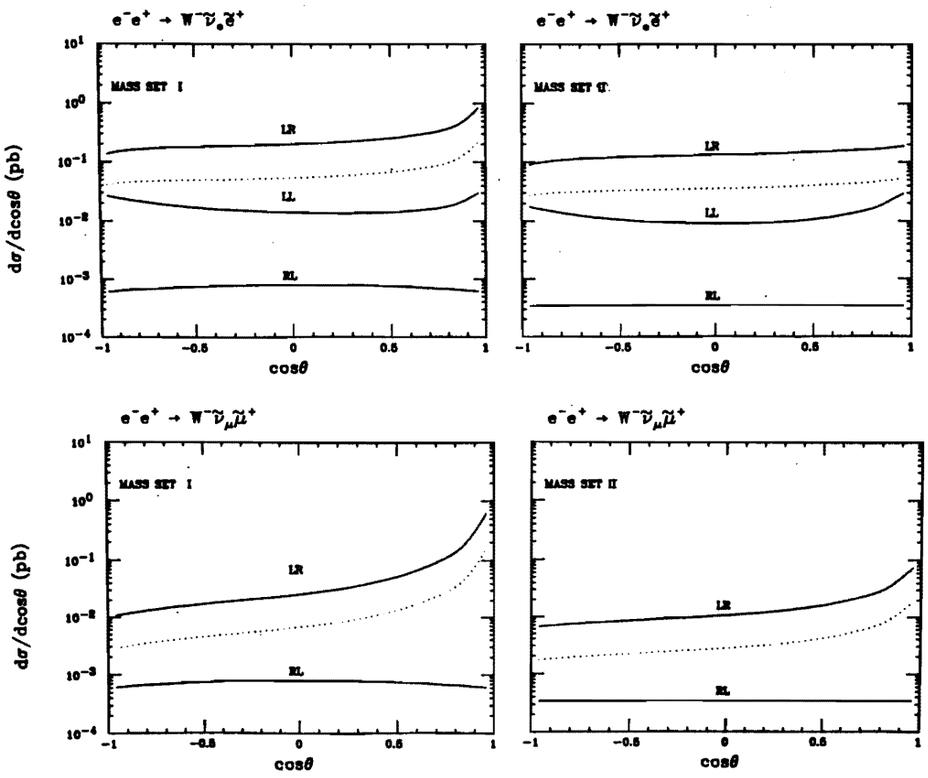

Fig. 3. Angular distributions of $W^-, d\sigma_{\lambda,\lambda'}/d\cos\theta$ at $\sqrt{s} = 400$ GeV.

gauge coupling. It is found that the cancellation mechanism works well between the γWW process and the Z^0WW one in the cross-section $\sigma_{\rm RL}$. On the other hand, the contribution of the diagram (1), another W^-"W^+" production, cancels that of the diagram (2) in the cross-section $\sigma_{\rm LR}$. Consequently, $\sigma_{\rm RL}$ is much smaller than $\sigma_{\rm LR}$. The differences of $\sigma_{\rm LR}$ and $\sigma_{\rm RL}$ among two mass sets are determined by the distinct threshold behavior in the LEP$_{200}$ region. At $\sqrt{s} = 1$ TeV, the cross-sections become insensitive to the mass spectrum, and compete with those of the standard process $e^+e^- \to W^-\nu e^+$. It is notable that only the L-sleptons could be produced for the spin-1 configurations of e^+e^- beams. On the other hand, $\sigma_{\rm LL}$ occurs only for the R-selectron production. This cross-section is constant in the sub-TeV region, and insensitive to the mass spectrum.

In fig. 3 we illustrate the dependence of angular distributions of W^- upon the mass spectrum at $\sqrt{s} = 400$ GeV. The angular distributions are sensitive to the mass spectrum at this energy. For the RL-polarization, the angular distributions are completely symmetric with the reflection of the longitudinal W^- production. On the other hand, $d\sigma_{\rm LR}/d\cos\theta$'s are forward-backward asymmetric owing to the transverse W^- production at this energy. It is found that those become flatter with the increase of $\sqrt{s}$ due to the dominance of the longitudinal W^- production. Thus the equivalence theorem [2] would be successful in the SUSY processes. The angular distribution $d\sigma_{\rm LL}/d\cos\theta$ is peculiar to the R-selectron production and is insensitive to the mass spectrum in the whole region.

We have calculated the cross-sections and the angular distributions for the single W^- production associated with sleptons in longitudinally polarized e^+e^- beams. It is found that the cross-sections and the angular distributions of W^- are sensitive to the mass spectrum of SUSY particles provided the e^+e^- beams are in the spin-1 configurations in the sub-TeV region. The behavior of the cross-sections reflects the gauge cancellation mechanism and the scalar nature of sleptons. The rate is comparable with that of the standard single W^- production in the TeV region. Although the angular distributions are different between the standard and the SUSY processes, the signature is the charged lepton and di-jet with missing energy-momentum in both processes. At any rate, we believe that the SUSY processes will be major background ones for the standard ones in the single W production at the future TeV-region colliders.

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