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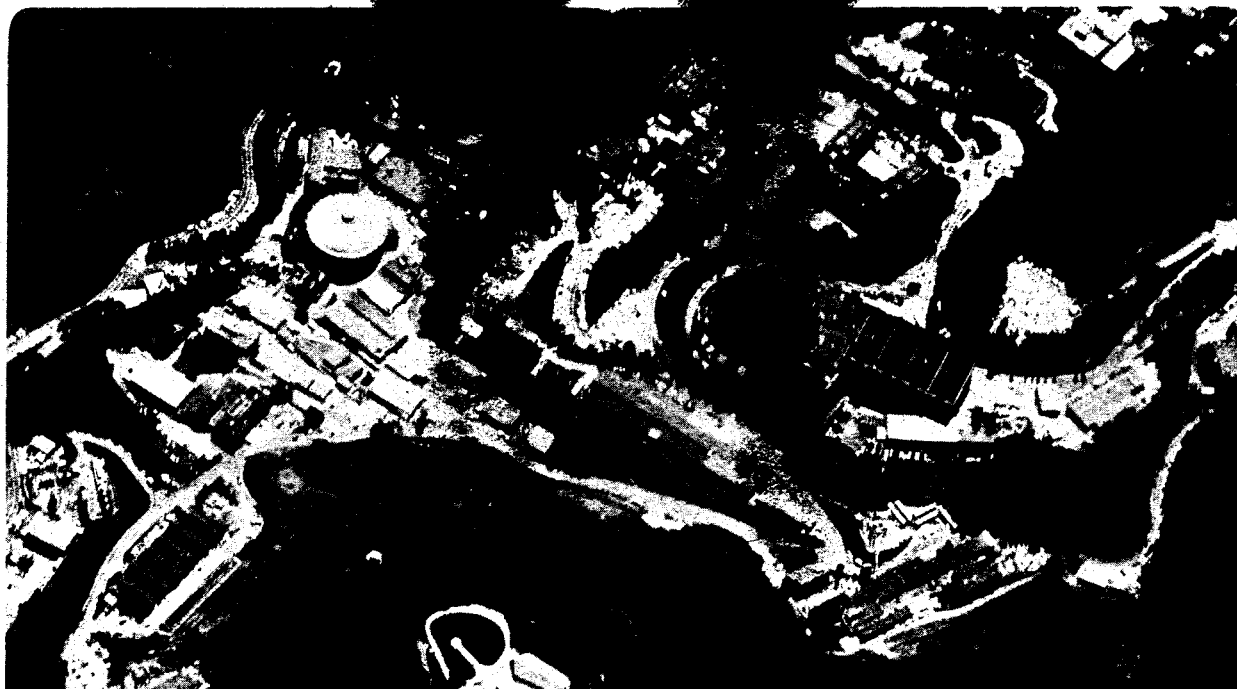
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PRODUCTION OF SINGLE W BOSONS IN e^+e^- COLLISIONS

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ABSTRACT

The cross section for single W production in e^+e^- collisions below the two W threshold is computed with an arbitrary W magnetic moment.

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The now standard Glashow-Weinberg-Salam (GWS) model of weak and electromagnetic interactions has had many successes, notably the prediction of the recently detected W and Z bosons. One as yet untested aspect of the theory is the self interaction of the gauge bosons. There is very little freedom to adjust the form of these couplings: in the GWS model the WW γ coupling corresponding to the vertex shown in Fig. 1 is given by

$$ie[g_{\rho\nu}(p+p')_\mu + g_{\rho\mu}(\lambda q - p)_\nu + g_{\mu\nu}(-p' - \lambda q)_\rho]$$

with $\lambda = 1$. The gyromagnetic ratio of the W is $1 + \lambda$, while its electric quadrupole moment is $-e\lambda/M_W^2$. Note that for a charged vector particle "minimally" coupled to the photon, $\lambda = 0$.¹

A probe of the value of λ is provided by single W production in e^+e^- collisions at energies below the two W threshold. This process has been studied by a number of people. Choban² calculated the cross section for energies $\sqrt{s} \gg M_W$ as a function of λ , and our leading term agrees with his result. Ellis and Gaillard³ cite a result for $\lambda = 1$ which differs from ours. Berends and West⁴ have made a numerical estimate of the cross section for $\lambda = 0$, and our results are roughly in agreement with theirs.

Below the two W threshold the dominant contribution to $e^+e^- \rightarrow W^-e^+\nu$ is due to the two diagrams shown in Fig. 2. If the positron is scattered at a small angle the photon propagator becomes large, so that the cross section has a logarithmic singularity in the forward direction, and one may be able to tag the process cleanly by observing the positron.

We have used the Weizsäcker-Williams⁵ approximation to find this cross section by first calculating the cross section $\sigma'(s_{e\gamma})$ for the process $e^-\gamma \rightarrow W^-\nu$. The total cross section for this process is (to lowest order in α and neglecting m_e),

$$\begin{aligned} \sigma'(s_{e\gamma}) = \frac{G\alpha}{4\sqrt{2}} & \left[(\lambda - 1)^2(1 + 4\log \bar{s}) + 32\lambda \right. \\ & - \left(\frac{1}{\bar{s}} \right) (\lambda^2(4\log \bar{s} + 2) + \lambda(40\log \bar{s} + 12) + 20\log \bar{s} - 22) \\ & + \left(\frac{1}{\bar{s}} \right)^2 (\lambda^2 - 18\lambda + 33 - 32\log \bar{s}) \\ & \left. - \left(\frac{1}{\bar{s}} \right)^3 (32\log \bar{s} + 56) \right] \end{aligned}$$

where $\bar{s} = \frac{s_{e\gamma}}{M_W^2}$. The Weizsäcker-Williams approximation then gives

$$\frac{d\sigma(s)}{d\cos\theta} = \int_{M_W^2/s}^1 dy \frac{1 + (1-y)^2}{y \left[1 - \cos\theta + \frac{2m_e^2}{s} \left(\frac{y}{1-y} \right)^2 \right]} \sigma'(ys)$$

for the cross section for $e^+e^- \rightarrow W^-e^+\nu$. The result of this integration is

$$\begin{aligned} \sigma = \frac{\alpha^2 G}{64\sqrt{2}\pi} f \times & \left[8(\lambda - 1)^2 \log^2 \bar{s} - 8(\lambda^2 - 18\lambda + 1) \log \bar{s} - 11\lambda^2 - 362\lambda - \frac{323}{9} \right. \\ & + \left(\frac{1}{\bar{s}} \right) (8(\lambda^2 + 10\lambda + 5) \log^2 \bar{s} + 16(\lambda^2 + 8\lambda - 3) \log \bar{s} + 12\lambda^2 + 488\lambda + \frac{68}{3}) \\ & - \left(\frac{1}{\bar{s}} \right)^2 (32 \log^2 \bar{s} - 2(\lambda^2 - 18\lambda + 1) \log \bar{s} + \lambda^2 + 126\lambda + 289) \\ & \left. - \left(\frac{1}{\bar{s}} \right)^3 \left(\frac{128}{3} \log \bar{s} + \frac{1088}{9} \right) \right] \end{aligned}$$

where, for $s \gg m_e^2$, we have $f \simeq \log \frac{s}{m_e^2}$ for the total cross section, or $f \simeq \log \frac{1 - \cos \theta_2}{1 - \cos \theta_1}$ for scattering of the positron at $\frac{m_e}{\sqrt{s}} \ll \theta_1 < \theta < \theta_2$.

Figure 3 shows the total cross section as a function of λ for several values of \sqrt{s} expected to be available at LEP I, and the total cross section as a function of \sqrt{s} for $\lambda = -1, 0, 1$. At relatively low energy the minimum of σ occurs near $\lambda = 0$; at high energy one observes that the minimum moves to $\lambda = 1$, reflecting the gauge theory cancellation of the leading term. One promising observation is that at low energy the cross section is rapidly varying around $\lambda \sim 1$, changing by about a factor of three from $\lambda = 0$ to $\lambda = 1$ at $\sqrt{s} = 140$ GeV. Unfortunately, if tagging of the positron is necessary, the cross section at 140 GeV and $\lambda = 1$ is only about $2 \times 10^{-38} \text{ cm}^2$. Including W^+ production ($e^+e^- \rightarrow W^+e^-\bar{\nu}$) doubles this value, but even with an integrated luminosity of 10^{39} cm^{-2} this still yields only about 40 events. The total cross section with no tagging is about a factor of 5 greater than this, giving about 200 events. Even with only 40 events, though, one should be able to distinguish $\lambda = 0$ from $\lambda = 1$.

We conclude that running at the highest LEP I energy should yield a sensitivity to λ competitive with or better than that which could be attained in moderate energy hadron colliders by studying inclusive $W\gamma$ production.⁶

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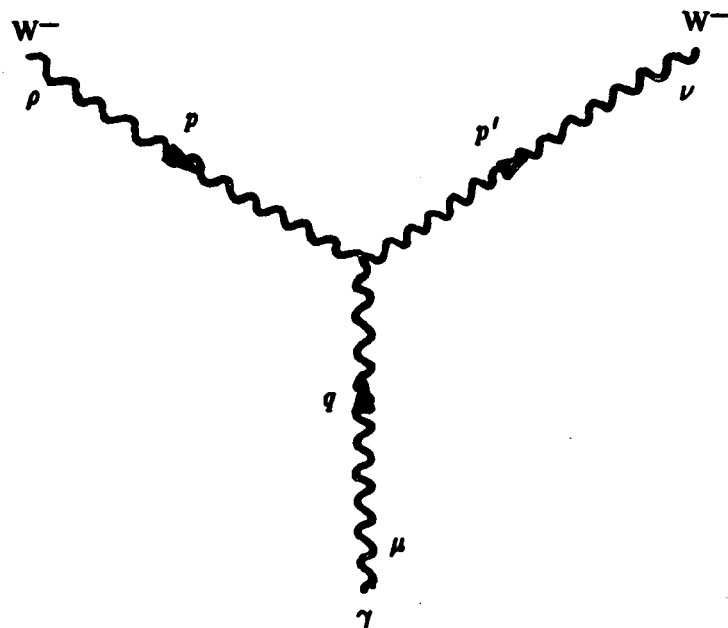


Figure 1

$WW\gamma$ vertex

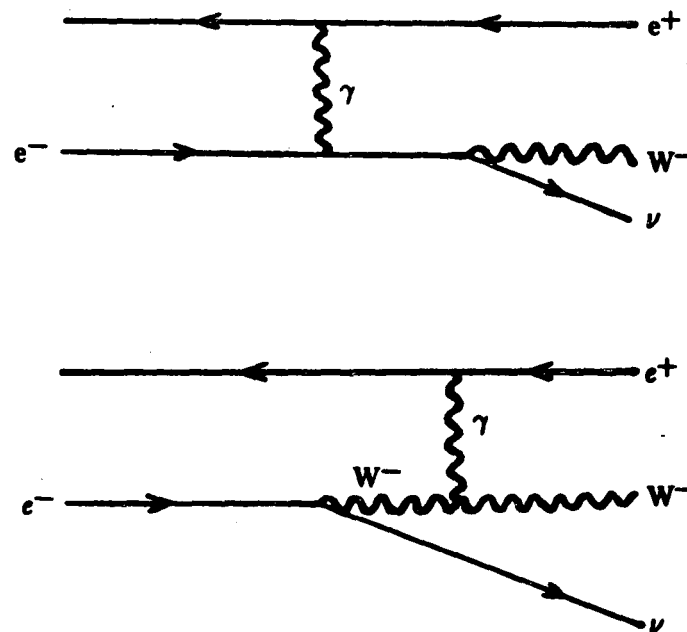
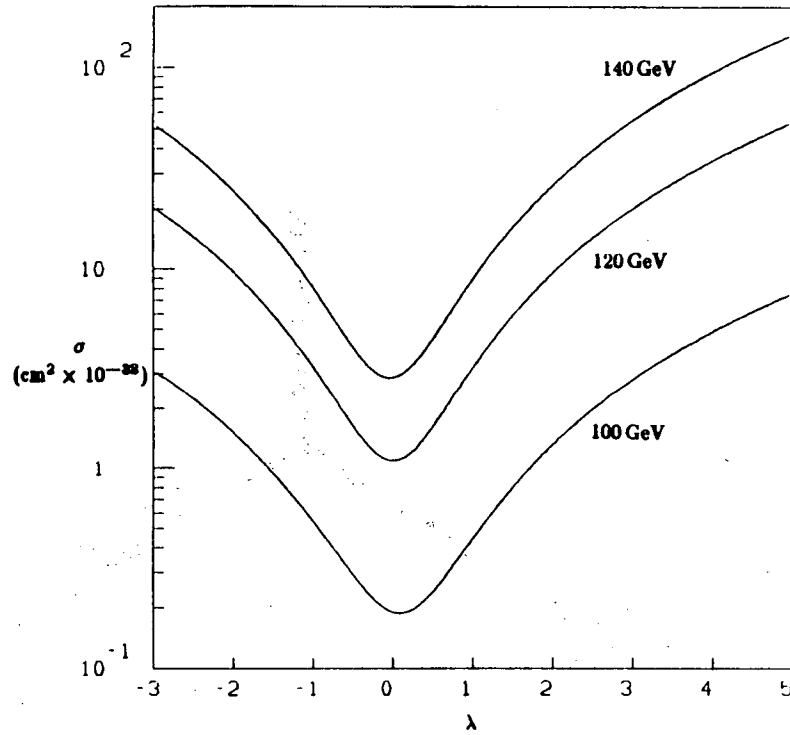
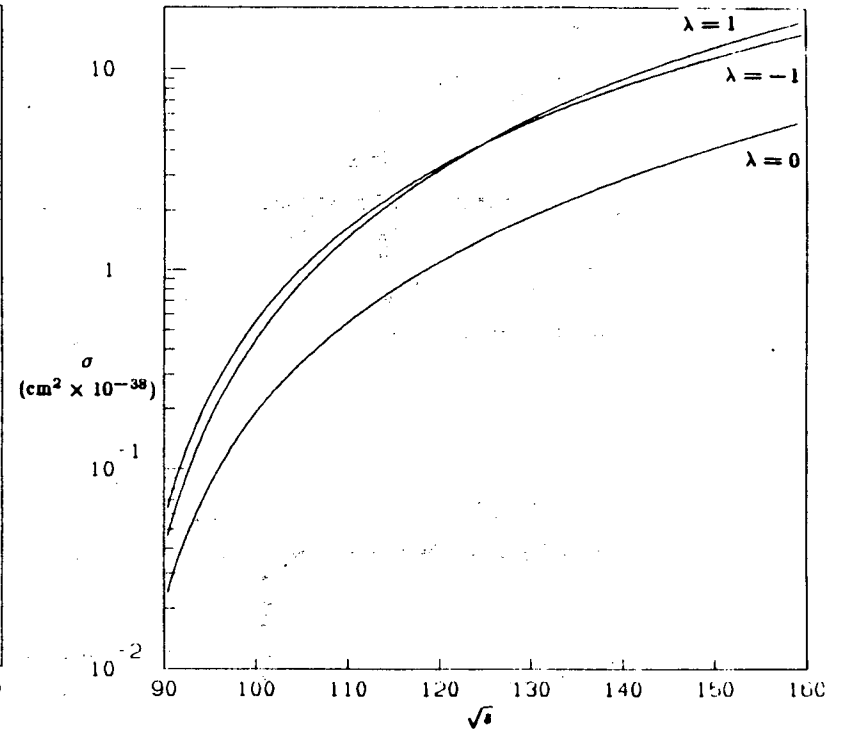


Figure 2

Dominant contributions to $e^+e^- \rightarrow e^+W^-\nu$ below the $2W$ threshold.



(a) total cross section vs. λ



(b) total cross section vs. \sqrt{s}

Figure 3

Cross section for $e^+e^- \rightarrow e^+W^-\nu$ ($M_W = 83 \text{ GeV}$)

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