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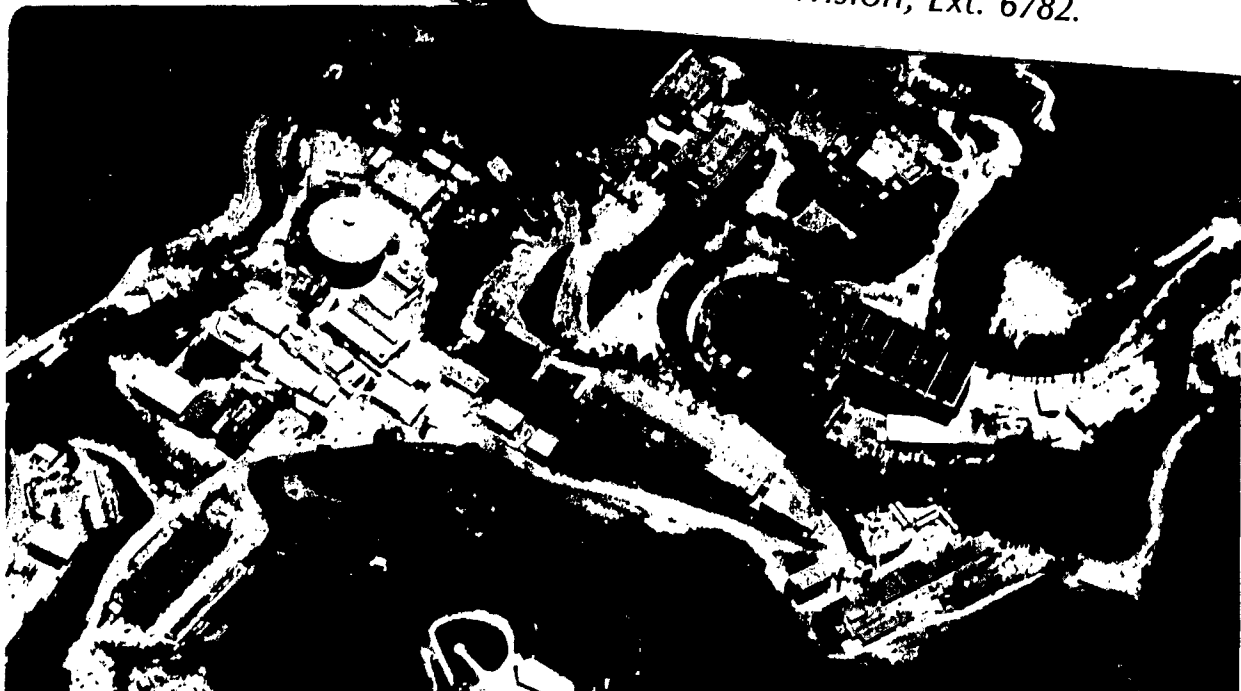
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August 1982

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VECTOR MESON BACKGROUNDS AT HIGH ENERGY $e\bar{e}$ MACHINES*

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To appear in The Proceedings of the Elementary Particle
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*

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This note presents cross sections for $e\bar{e} \rightarrow W^+W^-$, ZZ , $Z\gamma$ at high energies. The first of these is available in the LEP reports and elsewhere,^{1,2} but the remaining two seem to be unavailable.[†] These cross-sections represent a background to potentially interesting physics on mass scales of order 1 TeV. They are large due to t channel lepton exchange diagrams. Higgs diagrams are neglected; they are zero if the electron mass is set to zero. The graphs of Fig. 1 give for $e^-e^+ \rightarrow W^+W^-$

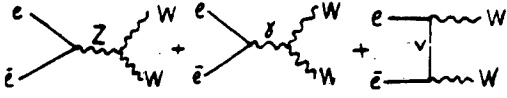


Fig. 1

$$\frac{d\sigma(e^-e^+ \rightarrow W^+W^-)}{d\Omega} = \frac{\alpha^2}{32\sin^4\theta_W} \frac{\beta}{s} \sum_1 A_1$$

$$A_1 = \frac{2}{a} + \frac{\sin^2\theta}{2} \left[\left(\frac{s}{K}\right)^2 + \frac{1}{4a} \right] \beta^2$$

$$A_2 = \beta^2 \left(\frac{16}{a} + \left(\frac{1}{a^2} - \frac{4}{a} + 12 \right) \sin^2\theta \right) (\sin^4\theta_W + 2 \frac{s}{s-M_Z^2})$$

$$\times \sin^2\theta_W \left(\frac{1}{4} - \sin^2\theta_W \right) + \left(\frac{s}{s-M_Z^2} \right)^2 \left(\sin^4\theta_W - \frac{1}{2} \sin^2\theta_W + \frac{1}{8} \right)$$

$$A_3 = \left[16(1 + M_W^2/K^2) + 8\beta^2/a + \frac{\beta^2 \sin^2\theta}{2} \left(\frac{1}{a^2} - \frac{2}{a} - \frac{4s}{K^2} \right) \right]$$

$$\times \left((\sin^2\theta_W - 1/2) \left(\frac{s}{s-M_Z^2} \right) - \sin^2\theta_W \right)$$

$$a = M_W^2/s \quad K^2 = M_W^2 - s/2 + \frac{sE}{2} \cos\theta$$

$\beta = \sqrt{1-4a}$ and θ is the angle between the e^+ and W^+ . Those of Fig. 2 give for $e\bar{e} \rightarrow ZZ$

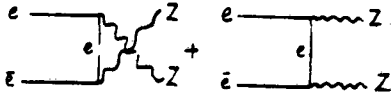


Fig. 2

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2}{512 \sin^4\theta_W \cos^4\theta_W} \frac{(s/4 - M_Z^2)^{1/2}}{s\sqrt{s} t^2}$$

$$\times \left[1 + 6(1 - 4 \sin^2\theta_W)^2 + (1 - 4 \sin^2\theta_W)^4 \right]$$

$$\times \left[-2t^4 - 4st^3 + 8M_Z^2 t^3 - 3s^2 t^2 + 8M_Z^2 s t^2 - 14M_Z^4 t^2 \right.$$

$$\left. - s^3 t + 2M_Z^2 s^2 t - 6M_Z^4 s t + 12M_Z^6 t - M_Z^4 s^2 \right.$$

$$\left. + 4M_Z^6 s - 4M_Z^8 \right] / (t + s - 2M_Z^2)^2$$

where $s = 4E^2$
 $t = -2E(E - p \cos\theta) + M_Z^2$
 $p = (s/4 - M_Z^2)^{1/2}$

and those of Fig. 3 give for $e\bar{e} \rightarrow Z\gamma$.

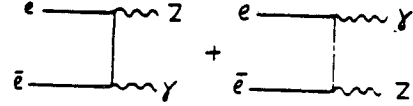


Fig. 3

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2 (s - M_Z^2) [1 + (1 - 4 \sin^2\theta_W)^2]}{32 \sin^2\theta_W \cos^2\theta_W s^2 t (s + t - M_Z^2)}$$

$$\times [-2t^2 - 2st + 2M_Z^2 t - s^2 - M_Z^4]$$

where now

$$t = - \frac{(s - M_Z^2)}{\sqrt{s}} [E - p_e \cos\theta]$$

here p_e is the electron (or positron) momentum. It is necessary to keep the electron mass (M_e) in the denominator to protect the mass singularity at $\cos\theta = \pm 1$. The cross-sections are shown in Figure 4 as a function of angle in units of the point cross section

$R = \frac{4\pi\alpha^2}{3s}$ at $\sqrt{s} = 750$ GeV and for $\sin^2\theta_W = 0.22$. The ZZ and $Z\gamma$ cross-sections are symmetrical about $\theta = \pi/2$.

The W^+W^- is not.

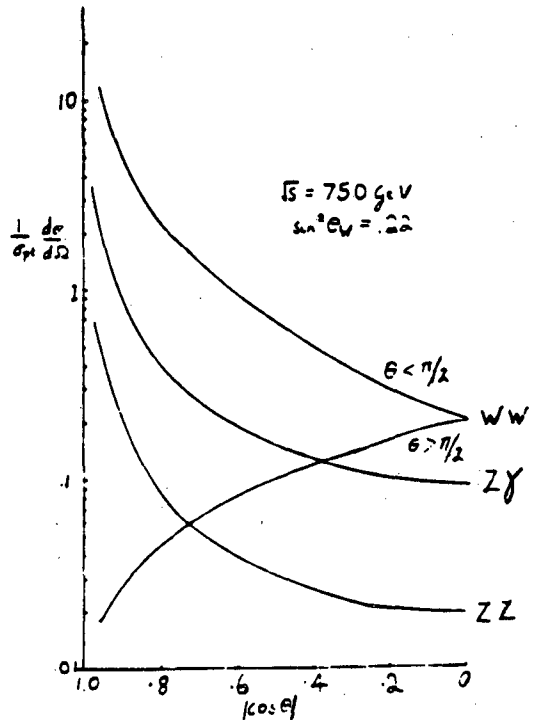


Fig. 4

[†] Beware of the typographical error in LEP version. The correct formula is given in Ref. 2.

The cross-section peaks near $\theta = 0$ due the presence of the t channel diagrams. The peaking is most severe for the Z γ rate where the singularity is protected only by the electron mass.

Figure 5 the integrated cross section

$$\sigma_{\text{INT}} = \int_{-\theta}^{\theta} d\phi d(\cos\theta) \frac{d\sigma}{d\Omega}$$

is shown.

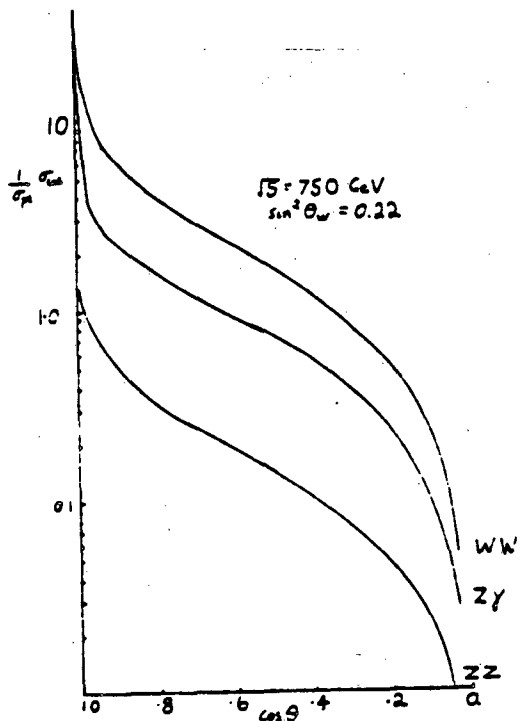


Fig. 5

The relevant formulae are

$$\sigma_{\text{INT}}(W^+W^-) = \frac{\pi\alpha^2}{16 \sin^2\theta_W} \frac{\beta}{s} \sum_{i=1}^3 A_i$$

$$A_1 = \frac{4 \cos\theta}{a} + \beta^2 \left(\frac{\cos\theta}{4a^2} (1 - \frac{\cos^2\theta}{3}) \right)$$

$$+ s^2 \left[\left(1 - \frac{v^2}{u^2}\right) \frac{\cos\theta}{v^2 - u^2 \cos^2\theta} - \frac{\cos\theta}{u^2} + \frac{v}{u^3} L \right]$$

$$A_2 = 2E^2 \cos\theta \left(\frac{16}{a} + \left(\frac{1}{2} - \frac{4}{a} + 12\right) (1 - \frac{\cos^2\theta}{3}) \right)$$

$$\times \left[\sin^4\theta_W + \left(\frac{s}{s-M_Z^2}\right)^2 \left(\sin^4\theta_W - \frac{1}{2} \sin^2\theta_W + \frac{1}{8} \right) \right.$$

$$\left. + 2 \sin^2\theta_W \left(\frac{1}{4} - \sin^2\theta_W \right) \frac{s}{s-M_Z^2} \right]$$

$$A_3 = \left((\sin^2\theta_W - \frac{1}{2}) \frac{s}{s-M_Z^2} - \sin^2\theta_W \right) \times \left[16 \left(2 \cos\theta + \frac{M_W^2}{u} \right) \right.$$

$$\left. + \frac{16\beta^2 \cos\theta}{a} + \beta^2 \cos\theta \left(1 - \frac{\cos^2\theta}{3} \right) \left(\frac{1}{2} - \frac{2}{a} \right) \right.$$

$$\left. - 2sE^2 \left((1 - v^2/u^2) \frac{1}{v} + 2u \cos\theta/v^2 \right) \right]$$

$$u = \frac{s\beta}{2}, v = M_W^2 - \frac{s}{2}$$

$$L = \log \left(\frac{v + u \cos\theta}{v - u \cos\theta} \right), a = M_W^2/s, \beta = \sqrt{1 - 4a}$$

$$\sigma_{\text{INT}}(ee + ZZ) = \frac{\alpha^2 \pi}{64 \sin^4\theta_W \cos^4\theta_W s \sqrt{s}}$$

$$\times [1 + 6(1 - 4 \sin^2\theta_W)^2 + (1 - 4 \sin^2\theta_W)^4]$$

$$\times \left\{ \frac{2(M_Z^4 + s^2/4)}{(2M_Z^2 - s)\sqrt{s}} \log \left[\frac{p\sqrt{s}(2M_Z^2 - s) - \cos\theta[2M_Z^2s - s^2/2]}{p\sqrt{s}(2M_Z^2 - s) + \cos\theta[2M_Z^2s - s^2/2]} \right] \right.$$

$$\left. - p \cos\theta - \frac{p \cos\theta M_Z^4}{M_Z^4 - sM_Z^2 + s^2/4 + \cos^2\theta[sM_Z^2 - s^2/4]} \right\},$$

$$\text{where } p^2 = s/4 - M_Z^2.$$

$$\sigma_{\text{INT}}(ee + Z\gamma) = \frac{\alpha^2 \pi [1 + (1 - 4 \sin^2\theta_W)^2]}{4 s^2 \sin^2\theta_W \cos^2\theta_W}$$

$$\times \left[-(s - M_Z^2) \cos\theta + \frac{(M_Z^4 + s^2)}{(s - M_Z^2)} \log \left[\frac{\sqrt{s} + 2p_e \cos\theta}{\sqrt{s} - 2p_e \cos\theta} \right] \right],$$

$$\text{where } p_e^2 = s/4 - M_e^2.$$

The total rates of W^+W^- and $Z\gamma$ are very large (24 and 31 units of R respectively at $\sqrt{s} = 750$ GeV), but are strongly forward peaked. A cut of $|\cos\theta| < .8$ reduces them considerably (to 4.1 and 1.6 units of R respectively). The ZZ rate is rather small. This is accidental; it is caused by $\sin^2\theta_W$ being close to 1/4. If $\sin^2\theta_W$ were $\frac{1}{2}$ the ZZ rate would increase by a factor of 8. Given the angular cuts the rates appear to be small enough not to present a serious background at high energies.

REFERENCES

1. Physics with Very High Energy $e\bar{e}$ Colliding Beams, CERN 76-18.
2. W. Alles, Ch. Boyer, A. J. Buras, Nucl. Phys. **B117**, 125(1977).

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