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VECTOR MESON BACKGROUNDS AT HIGH ENERGY ee MACHINES

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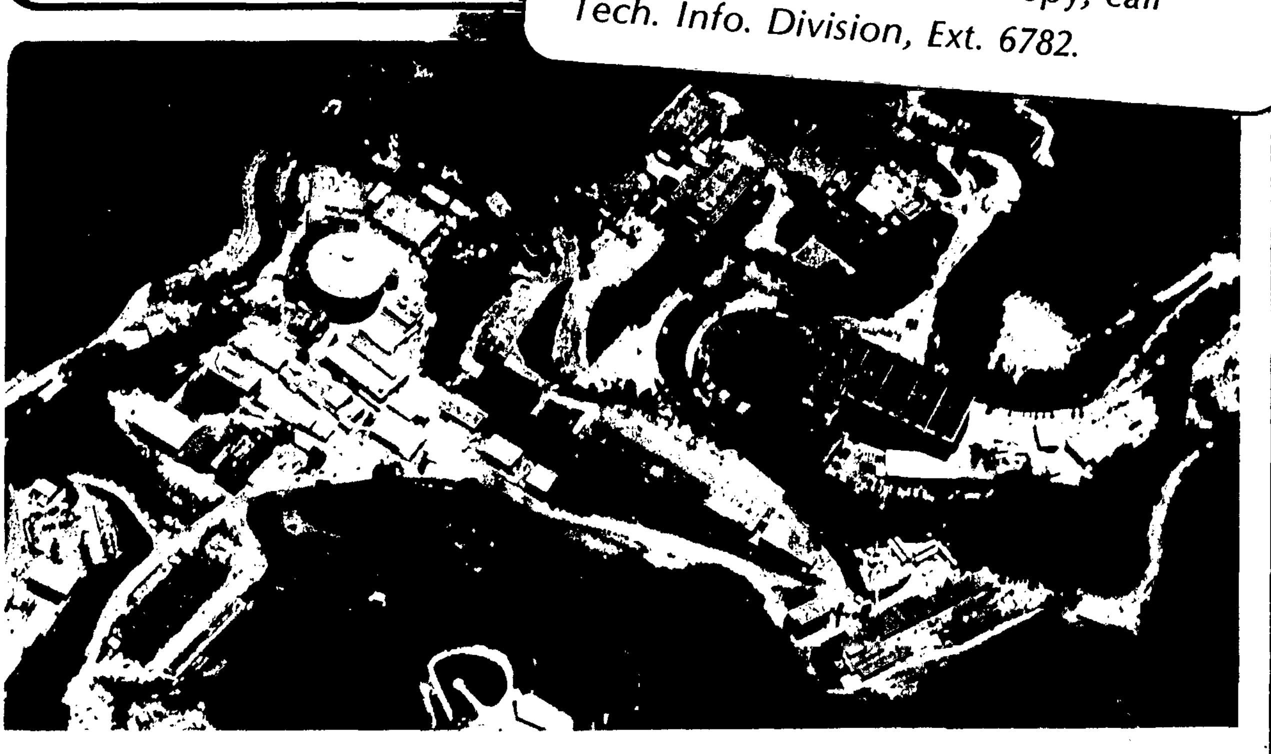

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This note presents cross sections for $e\bar{e} \to W^-W^+$, ZZ, $Z\gamma$ at high energies. The first of these is available in the LEP reports and elsewhere,[1,2] but the remaining two seem to be unavailable.† These cross-sections represent a background 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 $e^-e \to W^+W^-$

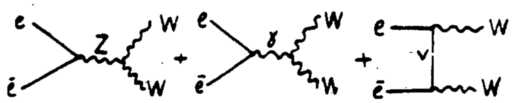

Fig. 1

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

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

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

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

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

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

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

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

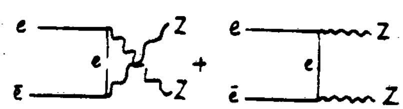

Fig. 2

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

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

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

$$- s^3t + 2M_Z^2s^2t - 6M_Z^4st + 12M_Z^6t - M_Z^4s^2$$

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

† Beware of the typographical error in LEP version. The correct formula is given in Ref. 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 $e\bar{e} \to Z\gamma$.

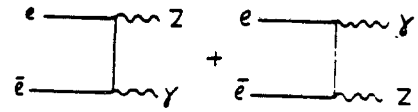

Fig. 3

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

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

where now

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

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.

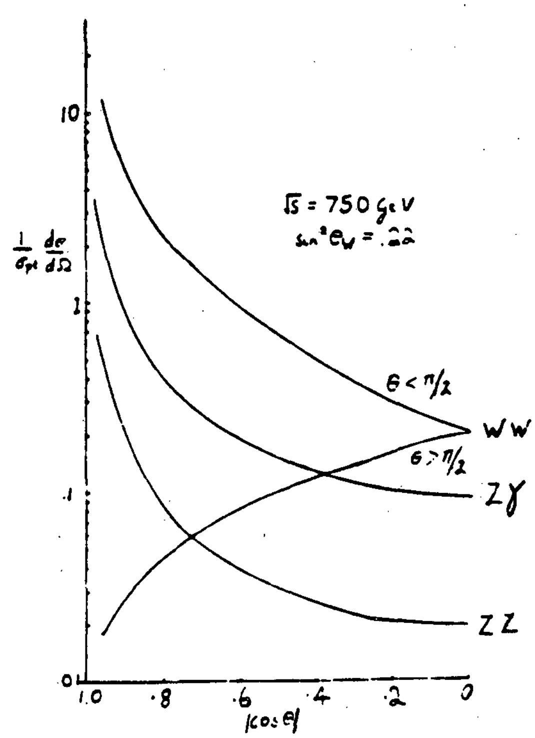

Fig. 4

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

Figure 5 the integrated cross section

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

is shown.

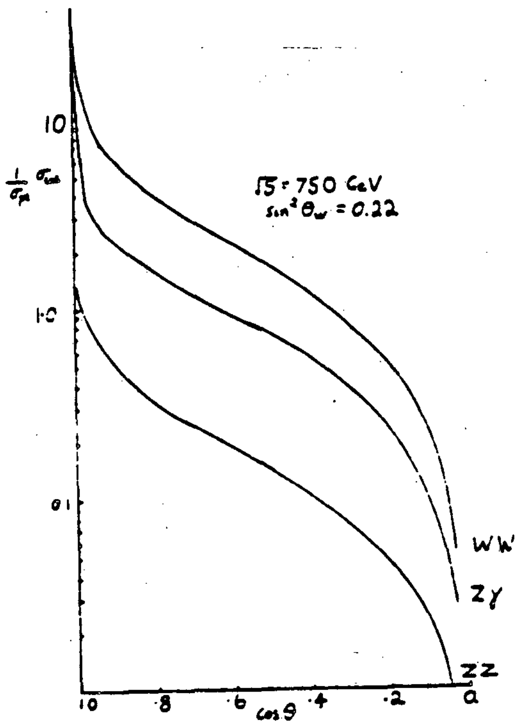

Fig. 5

The relevant formulae are

$$\sigma_{INT}(W^+W^-) = \frac{\pi\alpha^2}{16 \sin^2\theta_W} \frac{\beta}{s} \sum_i A_i$$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

where $p^2 = s/4 - M_Z^2$.

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

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

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.

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2. W. Alles, Ch. Boyer, A. J. Buras, Nucl. Phys. B117, 125(1977).

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