TRANSVERSE LUMINOSITY AND THE EFFECTIVE W APPROXIMATION

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Summary

We present a comparison of the cross sections for W pair production in pp collisions arising from the subprocess $WW \to WW$ with different assumptions about the polarization of the initial W's. Working in the effective W approximation, we supplement earlier treatments which included only longitudinally polarized W's by presenting results for the case when all polarization states and their corresponding luminosities are taken into account. At SSC energies, the transverse polarization states make a negligible contribution near the Higgs peak, although they do contribute significantly to the continuum.

Effective W Approximation

The 'effective W approximation' is a calculational technique which utilizes the notion that a sufficiently energetic fermion can dissociate into a fermion-gauge boson pair with a calculable probability. The gauge bosons can in turn initiate interactions with other particles they may encounter. This picture is known to be extremely useful in two-photon physics,[1] and it is natural to contemplate extending the idea to the massive gauge bosons of the Standard Model.[2] The extension, which requires a treatment of the longitudinal polarization state, has been completed[3] and applied to a number of processes involving the production of heavy particles.[4] Generally, comparisons of the effective W approximation treatment with complete Feynman diagram calculations have been quite satisfactory.[4,5]

These comparisons, however, have always made use of the simplest version of the effective W approximation; namely, the assumption that the longitudinal polarization state of the initial W (or W's) makes the dominant contribution. For the production of a Higgs boson by gauge boson fusion, this is known to be the case.[6] In general, the validity of this particular assumption should be tested.

Structure Functions and WW Scattering

The effective W approximation is implemented by using structure functions which describe the probability that a quark contains a gauge boson.[3] If $F_L(x)$ denotes the distribution of longitudinally polarized W's in a quark, and $F_T(x)$ the corresponding distribution of transversely polarized W's, then the effective W approximation gives

$$F_L(x) = \frac{\alpha_W}{4\pi}\,\frac{(1-x)}{x}\,,$$

$$F_T(x) = \frac{\alpha_W}{8\pi}\,\frac{1+(1-x)^2}{x}\,\ln\left(\frac{P_\perp^2}{m_W^2}\right).$$

Here, $\alpha_W = \alpha/\sin^2\theta_W$, where θ_W is the weak mixing angle, and $P_\perp$ is the maximum transverse momentum in the W scattering process. For the process under consideration - W pair production by WW scattering - we choose $P_\perp^2$ to be m_{WW}^2.

At the constituent level, the WW mass distribution can be computed using

$$\frac{d\hat{\sigma}}{d\,m_{WW}^2} = \frac{1}{\hat{s}}\int_{\hat{\tau}}^{1}\frac{dx}{x}\,F_\lambda(x)\,F_{\lambda'}\left(\frac{\hat{\tau}}{x}\right)\hat{\sigma}_{\lambda\lambda'}(m_{WW}^2),$$

where $\sqrt{\hat{s}}$ is the quark-quark center of mass energy and $\hat{\tau} = m_{WW}^2/\hat{s}$. The constituent level scattering process is illustrated in Fig. 1 and the diagrams included in the calculation of the WW scattering cross section $\hat{\sigma}(m_{WW}^2)$ are given in Fig. 2.

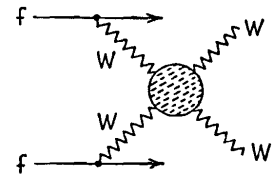

Fig. 1. Constituent level representation of the effective W approximation to WW scattering.

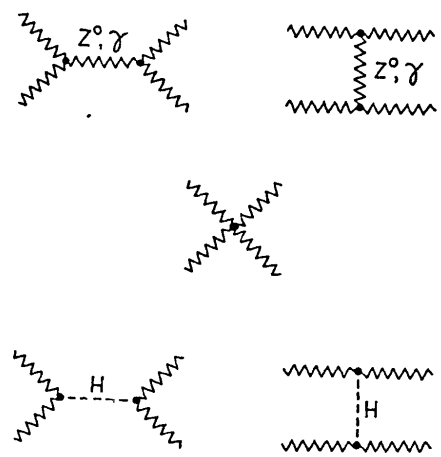

Fig. 2. Feynman diagrams included in the effective W approximation.

To complete the calculation for W pair production in pp collisions, it is necessary to fold the constituent level expression with the appropriate quark distribution functions. For pp center of mass energy $\sqrt{s}$, this folding process leads to the WW mass distribution

$$\frac{d\sigma}{d\,m_{WW}^2} = \frac{1}{s}\int_{m_{WW}^2/s}^{1}\frac{d\tau}{\tau}\int_{-\eta}^{\eta} dy\; q_a(\sqrt{\tau}\,e^{y})\,q_b(\sqrt{\tau}\,e^{-y})$$

$$\times\int_{-\hat{\eta}}^{\hat{\eta}} d\hat{y}\; F_\lambda(\sqrt{\hat{\tau}}\,e^{\hat{y}})\,F_{\lambda'}(\sqrt{\hat{\tau}}\,e^{-\hat{y}})\,\hat{\sigma}_{\lambda\lambda'}(m_{WW}^2),$$

where $\eta = \ln(1/\sqrt{\tau})$, $\hat{\eta} = \ln(1/\sqrt{\hat{\tau}})$, $q_a(x)$ and $q_b(x)$ are quark distribution functions, $\hat{s} = \tau s$ and there are no rapidity cuts on the individual W's.

To assess the importance of the luminosity associated with the W's transverse degrees of freedom, we have computed the cross section for W pair production at an SSC energy $\sqrt{s} = 40$ TeV. Figure 3 illustrates the contribution to W pair production from WW scattering assuming a Higgs mass of 0.5 TeV. Notice that in the vicinity of the Higgs peak there is very little effect from the transverse luminosity. This is illustrated in more detail in Fig. 4. For large invariant mass of the WW pair, the difference between the purely longitudinal luminosity and the complete calculation is quite substantial, though still small compared to the background from $q\bar{q}$ annihilation.

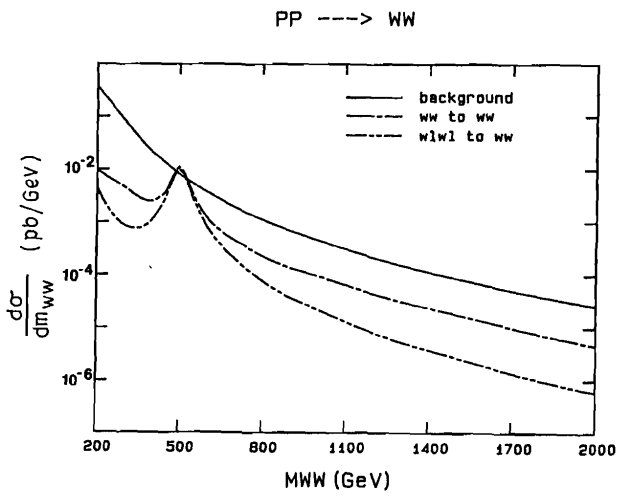

Fig. 3. Cross section for $pp \to W^+W^-$ at $\sqrt{s} = 40$ TeV. Here, both W's have rapidity <1.5 and $m_H = 0.5$ TeV. The solid curve labeled background is $q\bar{q} \to W^+W^-$, the dash-dot curve is the contribution to WW scattering from all polarizations of initial W's, and the dash-dot-dot curve is the contribution from longitudinal initial W's only.

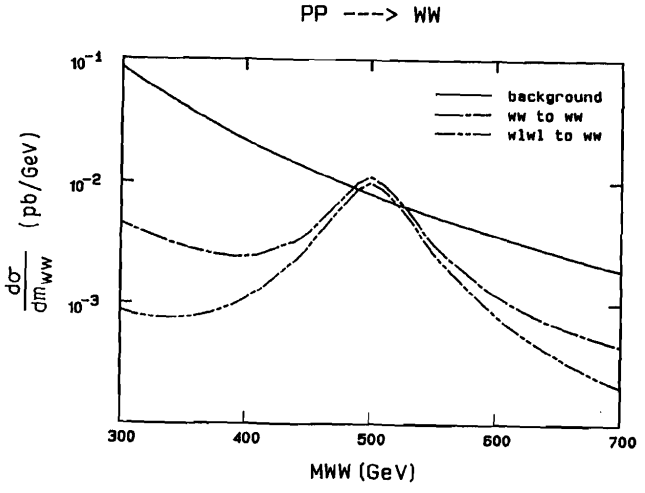

Fig. 4. Expanded view of the Higgs peak in the preceding figure.

Conclusions

Understanding the Higgs sector of the Standard Model remains an important challenge to the physics community. According to current ideas,[7] the Higgs particle is either relatively light on the weak interaction scale and W self interactions correspondingly weak, or the Higgs is quite massive implying strong WW interactions. In either case, it is important to have a convenient calculational technique with which to investigate W-pair physics. The effective W approximation provides such a tool. It is accurate and often simpler to use when the perturbative regime is valid. Moreover, should WW interactions become strong at SSC energies the technique could provide a useful alternative to perturbation theory.

Acknowledgments

Conversations with J.F. Gunion, G.L. Kane and W.-K. Tung are greatfully acknowledged. This research was supported in part by the National Science Foundation under grant PHY-86-05967.

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