GLUONIC PRODUCTION OF W^+W^- AND Z^0Z^0 AT THE SSC

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Summary

We present results for the direct production of W and Z pairs by gluon fusion. The relevant box diagrams of the Standard Model are estimated by their s-channel discontinuities, which can be evaluated exactly in terms of elementary functions. Our conclusion is that gauge-boson pair production by this mechanism will be significant at SSC energies, but will not be so large as to preclude discovery of the Higgs.

Introduction

We investigate the gluonic production of intermediate vector boson pairs, $gg \to W^+W^-$ and $gg \to Z^0Z^0$, using the Standard Model in the lowest order of perturbation theory. The relevant Feynman diagrams are the box diagrams shown in Fig. 1. These diagrams are significant because they will provide both coherent and incoherent background in the search for Higgs production at the SSC, especially those Higgs produced by the gluon fusion mechanism[1] of Fig. 2. In addition, observing the box diagram would provide a useful experimental test of the Standard Model at the one-loop level, and would provide a measurement of the gluon structure function.

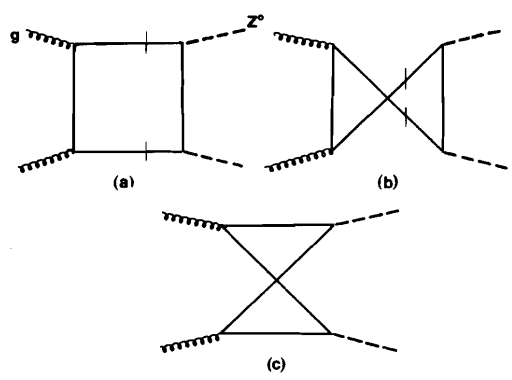


Fig. 1. Box diagrams for $gg \to Z^0Z^0$.

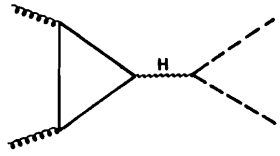


Fig.2. Higgs production by gluon fusion.

The box diagram mechanism for $gg \to Z^0Z^0$ is higher order in α_s than the production from quark anti-quark annihilation, $q\bar{q} \to Z^0Z^0$. It can nevertheless be important for several reasons: (1) the luminosity function for gg interactions is much larger than that for $q\bar{q}$ interactions at the SSC energy of $\sqrt{s} = 40$ TeV, where rather small Feynman x is involved; (2) the box diagram amplitudes include a coherent sum over colors and flavors of the quark in the loop; (3) $q\bar{q}$ annihilation produces mainly transversely polarized W's and Z's, which can be suppressed by kinematic cuts on the decay products to enhance the predominantly longitudinal W's and Z's from Higgs decay; and (4) the box diagram can show itself by quantum mechanical interference with the Higgs, assuming the Higgs mass lies above or not too far below Z^0Z^0 threshold.

Outline of the Amplitude Calculation

To make a first estimate of the box diagrams, we compute in this paper the s-channel discontinuities of the graphs in Fig. 1. This greatly simplifies the calculation, since it reduces the four-dimensional integral over the loop momentum to a two-dimensional integral over the direction of one of the quarks in the $q\bar{q}$ center of mass. These integrals can be evaluated explicitly in terms of logarithms. The discontinuity approximation may provide a good estimate of the magnitudes involved. However, diagram 1c does not contribute at all in the discontinuity approximation. Together with portions of the non-discontinuity parts of diagrams 1a and 1b, it is a separate gauge-invariant entity which could cause the full amplitude to be unrelated to the discontinuity approximation - even if that approximation is supplemented by derivative dispersion relations.[2] Work on evaluating the full diagrams is in progress. It may be possible to take over the results of Ll. Ametller, et.al.[3], which use off-shell photon photon scattering amplitudes.

In this paper, we discuss in detail only Z^0Z^0 production, since this is the crucial channel for "gold-plated" detection of a Higgs boson. Production of W^+W^- will be similar, except that its amplitude contains additional terms in which the quark flavor changes at the $q\bar{q}$ W corners of the box diagram. When the full diagrams are calculated, one can imagine finding a modest enhancement factor like $\log(m_t/m_b)$ from this mass change.

For longitudinally polarized Z^0's, our result for the discontinuity function corresponding to equal gluon helicities takes the form

$$C(0,0;\lambda,\lambda) = \frac{g^2}{\cos^2\theta_W}\,\frac{\alpha_s}{\pi}\,\frac{4\mu^2}{\beta^2 s M^2}\,\{[4M^4 A^2 + (s-2M^2)^2 B^2]I - (s-2M^2) \times [M^4 A^2 + (\mu^2\beta^2 s + M^4) B^2] \times (I(p,r) + I(p,\ell))\},$$

where M is the Z^0 mass, β its velocity, μ is the quark mass and the Z^0-quark coupling is written $\gamma_\mu(A + B\gamma_5)$. The integrals I and I(p,r) are

$$I = \int \frac{d^4k\, \delta(k^2 + \mu^2)\, \delta\left((p + q - k)^2 + \mu^2\right)}{-2p \cdot k},$$

$$I(p,r) = \int \frac{d^4k\, \delta(k^2 + \mu^2)\, \delta\left((p + q - k)^2 + \mu^2\right)}{(-2p \cdot k)(-2r \cdot k - M^2)},$$

which can be evaluated to give

$$I = \frac{\pi}{2s} \ln\left(\frac{1 + \beta'}{1 - \beta'}\right),$$

$$I(p,r) = \frac{\pi}{2sD} \ln\left[\frac{(F - D + H)(F - D - H)}{(F + D + H)(F + D - H)}\right],$$

with β' denoting the quark velocity and

$$F = \frac{1}{2}\beta'(\beta s + t - u)$$

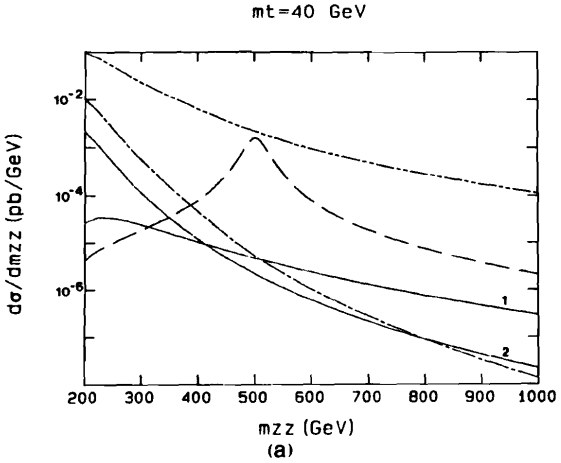
$$H = \frac{1}{2}s(1 + \beta) - M^2$$

$$D = \left[t^2 + \frac{4\mu^2}{s}(tu - M^4)\right]^{1/2}.$$

$I(p,\ell)$ is obtained from I(p,r) by interchanging t and u. Notice that $C(0,0;\lambda,\lambda)$ contains a factor of μ^2, which is discussed below. The discontinuity function for opposite helicities involves the same set of integrals.

We restrict consideration to longitudinally polarized Z^0, since this is the important channel for $H \to Z^0Z^0$. The cross section for equal-helicity gluons (which can interfere with Higgs) is quite sensitive to the assumed mass of the top quark. This reflects the fact that the lowest-order quark exchange amplitude for $gg \to q\bar{q}$ vanishes in the limit of zero quark mass when the helicities of the gluons are the same. Hence, in this limit, the box diagram also vanishes in our discontinuity (on-shell quark) approximation. The amplitude rises with quark mass until that mass is so large that threshold effects come into play.

Predicted cross sections for Z^0Z^0 production in $p\bar{p}$ scattering at the standard SSC energy of $\sqrt{s} = 40$ TeV are shown in Fig. 3. We have assumed Duke and Owens set 1 for the structure functions,[4] and imposed a rapidity cut of $|y| < 1.5$ for both Z^0's. Figure 3 also shows predicted contributions from Higgs production via the triangle diagram (Fig. 2) for a Higgs mass of 500 GeV. The effect on the line shape of the Higgs due to interference with the box diagram background is potentially very interesting, but we do not include this effect in Fig. 3 because it is also likely to be sensitive to our discontinuity approximation.



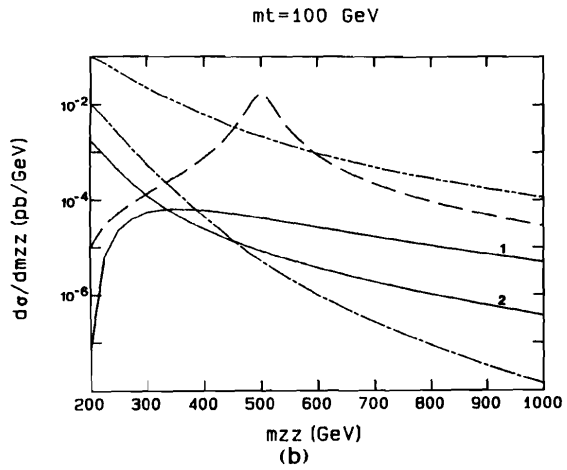


Fig. 3. Cross sections for Z^0 pair production. Figures (a) and (b) correspond to top quark masses of 40 GeV and 100 GeV, respectively. The solid curves labeled 1 and 2 are the box diagram discontinuity estimates for equal and unequal gluon helicities. The dashed curve represents Z^0 pair production by the gluon fusion mechanism of Fig. 2 with a Higgs mass of 500 GeV, the dash-dot curve is $q\bar{q} \to Z^0_L Z^0_L$ and the dash-dot-dot curve corresponds to $q\bar{q} \to Z^0Z^0$.

Conclusion

Our principal conclusion is that the box diagram contribution to Z^0Z^0 production will be significant at the proposed SSC, but will not be so large as to preclude discovery of the Higgs. It may actually increase the visibility of the Higgs signal as a result of the interference effect on the line shape. A full calculation of the box diagrams necessary to complete this subject is currently in progress.

Acknowledgment

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