Search for High Mass Photon Pairs in $p\overline{p} \rightarrow \gamma\gamma jj$ Events at $\sqrt{s} = 1.8$ TeV

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Abstract

A search for new physics in the channel $p\overline{p} \rightarrow \gamma\gamma jj$ has been studied. In some extended Higgs models, a light neutral scalar Higgs boson is produced with suppressed couplings to fermions and standard model(SM) strength couplings to vector bosons(bosonic Higgs), thus enhancing the $H \rightarrow \gamma\gamma$ channel.We required one photon in the event with $E_T^{\gamma} > 20\,\mathrm{GeV}$, $|\eta^{\gamma}| < 1.1$ or $1.5 < |\eta^{\gamma}| < 2.0$ and a second photon with $E_T^{\gamma} > 15\,\mathrm{GeV}$, $|\eta^{\gamma}| < 1.1$ or $1.5 < |\eta^{\gamma}| < 2.25$. Additionally, we required one hadronic jet in the event with $E_T^{jet} > 20\,\mathrm{GeV}$, $|\eta^{jet}| < 2.0$ and a second hadronic jet with $E_T^{jet} > 15\,\mathrm{GeV}$, $|\eta^{jet}| < 2.25$. The photons are required to have a $\sum \vec{E}_T(\gamma) \geq 10$ GeV, and likewise the jets are required to have a $\sum \vec{E}_T(jet) \geq 10$ GeV. The final $M_{\gamma\gamma}$ distribution is consistent with background and no resonance is observed. A 90(95)% C.L. upper limit cross section vs $M_{\gamma\gamma}$ is calculated, which ranges from 0.6(0.7) pb^{-1} for $M_{\gamma\gamma} = 60GeV/c^2$ to 0.3(0.4) pb^{-1} for $M_{\gamma\gamma} = 130GeV/c^2$. With standard model coupling strengths between the bosonic Higgs and vector bosons, a 90(95)% C.L. bosonic Higgs lower mass limit is set at 86(81) GeV/c^2.

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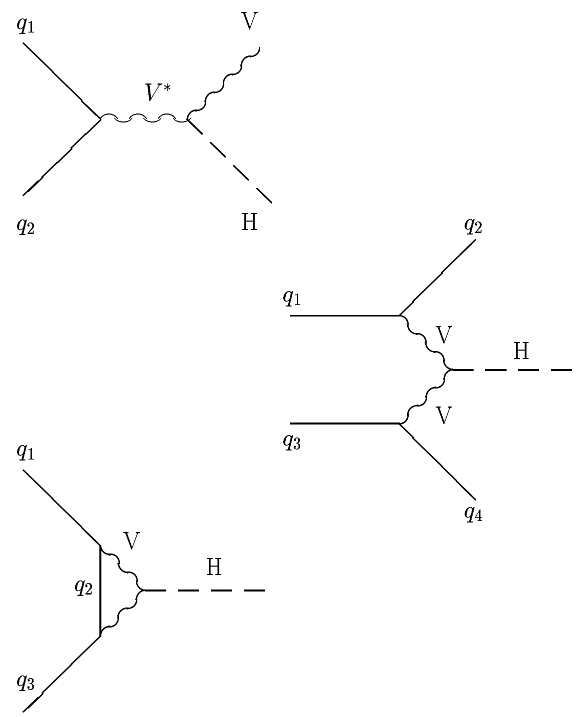

FIG. 1. Production diagrams for the bosonic Higgs. The first diagram is the radiated Higgs channel, the second diagram is the vector boson fusion channel, and the third diagram is a one loop single Higgs production. The radiated Higgs channel is the most detectable, and will be studied exclusively.

I. INTRODUCTION

Some extended Higgs models predict a light neutral scalar Higgs that has suppressed couplings to fermions, but standard model strength couplings to vector bosons(bosonic Higgs) [1–6]. The strongest constraints on any extended Higgs model is the ρ parameter ($\rho = M_W^2/M_Z^2 cos^2\theta_W$). The extended models must preserve $\rho \approx 1$, since experimentally $\rho = 1.0004 \pm 0.0022 \pm 0.002$ [7]. The most promising model is discussed by A.G. Akeryod [1,2], which produces a light neutral scalar bosonic Higgs naturally(no fine tuning) and conserves $\rho = 1$. As expected, the decay channels of the bosonic Higgs are much different from the minimal standard model(SM) Higgs. Since the fermion decay channels are suppressed, the decay of the bosonic Higgs with mass less than $2M_W$ is not dominated by $H \rightarrow b\bar{b}$. At tree level the bosonic Higgs decays only to W^*W^* and Z^*Z^* vector bosons (where '*' denotes off the mass shell). At the one loop level the bosonic Higgs decays predominantly into two photons. The one loop W boson mediated $H \rightarrow \gamma\gamma$ channel is competitive, for bosonic Higgs masses less than 90 GeV/c^2, with the tree level decays due to the vector bosons being considerably off the mass shell. Three possible Higgs production diagrams in $p\bar{p}$ collisions are shown in figure 1. The most detectable production mode is the radiated Higgs channel, where an off mass shell W or Z vector boson is produced and radiates a Higgs boson. Vector boson fusion has the same event topology, but the production cross section is five to ten times smaller, and will be disregarded. The summed HW and HZ cross sections range from a couple of picobarns at $M_H = 60$ GeV/c^2 to several hundred femtobarns at $M_H = 100$ GeV/c^2. We expect sensitivity in the $\gamma\gamma jj$ final state, where the bosons decay

$H \rightarrow \gamma\gamma$ and $W/Z \rightarrow jj$, up to a mass of 85 GeV/c^2. The present mass limit on a bosonic Higgs is 60 GeV/c^2 from LEP1 [8,9].

II. DATA SELECTION

The events are selected with the DØ detector [10] during the 1992-1996 Tevatron Run and represents an integrated luminosity of 101.2 $\pm$ 5.5 pb^{-1}. The triggers require two em clusters within the electromagnetic(EM) calorimeter with a transverse energy greater than 12 GeV. The event selection criteria are optimized using an 80 GeV/c^2 Higgs sample and a QCD multijet sample. The event requirements are:

- **Event Requirement**
  - ▷ vertex position within 75 cm of $Z_{det} = 0$,
- **Photon Requirements**
  - ▷ one γ with $E_T^\gamma \geq 20$ GeV and $\mid \eta_\gamma \mid \leq 2.0$,
  - ▷ second γ with $E_T^\gamma \geq 15$ GeV and $\mid \eta_\gamma \mid \leq 2.25$,
  - ▷ $\sum \vec{E}_T(\gamma) \geq 10$ GeV,
  - ▷ $\chi^2_\gamma \leq 100$,
  - ▷ EMF $\geq$ .96,
  - ▷ ISOL $\leq$ 2 GeV,
  - ▷ no 'hits' in drift chamber between vertex and γ's calorimeter shower,
- **Jet Requirements**
  - ▷ jets consistent with hadronic showers,
  - ▷ one jet with $E_T^{jet} \geq 20\ GeV$ and$\mid \eta_{jet} \mid \leq 2.0$,
  - ▷ second jet with $E_T^{jet} \geq 15\ GeV$ and$\mid \eta_{jet} \mid \leq 2.25$,
  - ▷ $\sum \vec{E}_T(jet) \geq 10$ GeV,
  - ▷ $dR_{\gamma jet} \geq 0.7$,
  - ▷ $40 \leq M_{jj} \leq 150\ GeV/c^2$,

where $\eta = -ln\ tan(\theta/2)$, dR is a cone defined as $dR = \sqrt{(\triangle\eta)^2 + (\triangle\phi)^2}$, EMF $= E_{EM}(dR = 0.2)/(E_{EM}(dR = 0.2) + E_{Hadronic}(dR = 0.2))$, ISOL$=(E_T(dR = 0.4) - E_T(dR = 0.2))$, and χ^2 is an EM shower shape quantity with χ^2-like behavior.

The offline selection criteria, especially the energy isolation requirement and the 'no-hits' tracking cut on the γ remove much of the QCD multijet background. Further, the E_T, η, and $\sum \vec{E}_T$ selections optimize the differences between Higgs events and QCD events; Higgs events are more central than QCD events. The diphoton and dijet invariant mass distributions of the seven events that pass these selection criteria are shown in Figure 2.

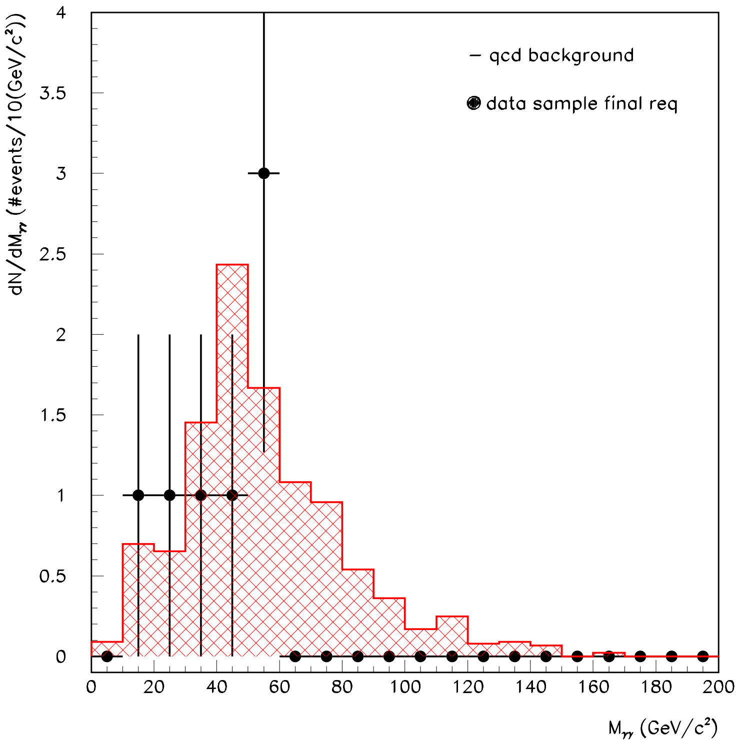

FIG. 2. Diphoton mass distribution with the final event requirements. The QCD background is calculated using a data-based method. The error on the data is statistical. The systematic error on the background is from the normalization procedure and is 38%.

III. BACKGROUND

The dominant background in the $\gamma\gamma jj$ channel is QCD multijet events, where two jets mimic two photons. During the jet fragmentation process, π^0 and η mesons are produced and will promptly decay into multiple photons. If the mesons have a E_T greater than about 10 GeV they will coalesce and mimic a single photon. The handle on these events comes from the longitudinal shower profile. The meson's multi-photons generally shower sooner in the electromagnetic calorimeter than a single photon would. A thorough study of em candidates' longitudinal shower shape has been completed to estimate the jet misidentification rate [11]. The probability for a jet to fragment into an isolated photon(P($j \to$ "γ")) is of the order of a few times 10^{-4}. P($j \to$ "γ") is small, but the multijet cross section is so very large that this background is still significant. A rough Monte Carlo estimate of the expected number of QCD multijet events is,

$$N(\gamma\gamma jj) = \{\sigma(prod) \times A\} L_{int} \{P(jet \to \text{“}\gamma''\text{)}\}^2$$

$$N(\gamma\gamma jj) = (4.0 \times 10^5 pb)(100pb^{-1})(2.5 \times 10^{-7})$$

$$N(\gamma\gamma jj) = 10 \pm 4 \ events,$$

where σ is the production cross section, L_{int} is the integrated luminosity, 'A' is the acceptance of a $\gamma\gamma jj$ event, and $P(jet \rightarrow$ "γ") is the probability for a jet to fragment into an isolated photon. The $\sigma \cdot A$ is estimated from PYTHIA5.7 , and P($jet \rightarrow$ "γ") was carefully calculated [11].

The second, and much smaller, source of background is single and double direct photon production. The number of events expected is small due to the direct photon production's low probability of producing high E_T jets. The expected number of events for all direct photon production is N($\gamma\gamma jj$)=0.1 ± 0.05 events. This was estimated using PYTHIA5.7 and a careful calculation of the probability for high E_T jets to be produced in direct photon events [12]. The direct photon channels are small sources of background and are ignored.

Other sources of background would be the $Z \rightarrow e^+e^-$ + 2jet, $W\gamma \rightarrow e^\pm\nu\gamma$ + 2jet where a track is lost by the electron, and $t\bar{t} \rightarrow e^+e^-\nu\nu$ + 2jet where both the tracks are lost. With the no 'hits' in drift chamber between vertex and γ's calorimeter shower requirement, the electron sources of background are greatly reduced [12], $N_{electron} = 0.1 \pm 0.05$ events.

The QCD multijet background $M_{\gamma\gamma}$ is estimated using a data-based method. The data-based method uses the same event requirements, but requires either photon candidate to fail an EMF, ISOL, or χ^2 requirement. This will give a QCD enriched sample, since the photon candidate is likely a π^0 or η meson. Similarly, a $M_{\gamma\gamma}$ distribution is calculated and the background is normalized to the LEP Higgs mass excluded region of the data sample, i.e. both ensembles have the same number of events for $M_{\gamma\gamma} \leq 60\ GeV/c^2$ (Fig.2). The expected number of QCD events are N_{QCD}=10.5 ± 4.0 events, while seven events are observed. For a $M_{\gamma\gamma}$ mass greater than $60 GeV/c^2$, N_{QCD}=3.5 ± 1.3 events are expected, while zero are seen. Further, the data-based background estimate is consistent with the Monte Carlo estimated number of N^{MC}_{QCD}=10 ± 4.

IV. SIGNAL EFFICIENCY AND HIGGS MASS LIMIT

Monte Carlo (MC) is essential for calculating the signal efficiences for $\gamma\gamma jj$ events. Initially $p\bar{p} \rightarrow HW$ and $p\bar{p} \rightarrow HZ$ events are generated using PYTHIA5.7, in which internal decay channel switches force the decays $H \rightarrow \gamma\gamma$ and $W/Z \rightarrow q\prime q$ exclusively. PYTHIA is a leading order event generator that correctly models all spin effects of the decaying W,Z, and H particles. The structure function used is CTEQ3M , but using several other structure functions very little change is seen. Seven ensembles of 5000 events each are generated, with Higgs masses of 60, 70, 80, 90, 100, 110, and 150 GeV/c^2. The events are then detector simulated and event reconstructed.

The final event requirements are applied to the seven HW/HZ samples. A diphoton invariant mass is calculated and histogramed for every event that passes. The signal efficiency for each Higgs-mass sample is calculated by making a gaussian fit to the diphoton invariant mass distribution. A mass width is extracted from the fit; here a 4σ $M_{\gamma\gamma}$ window is used, and the number of events are integrated and simply divided by the number generated (Fig. 3).

A preliminary 90% and 95% confidence level cross section limit vs $M_{\gamma\gamma}$ was calculated (Fig. 4). The limit is calculated using a Bayesian approach [13]. The calculation incorporates the error associated with the efficiency uncertainty, luminosity uncertainty, and background

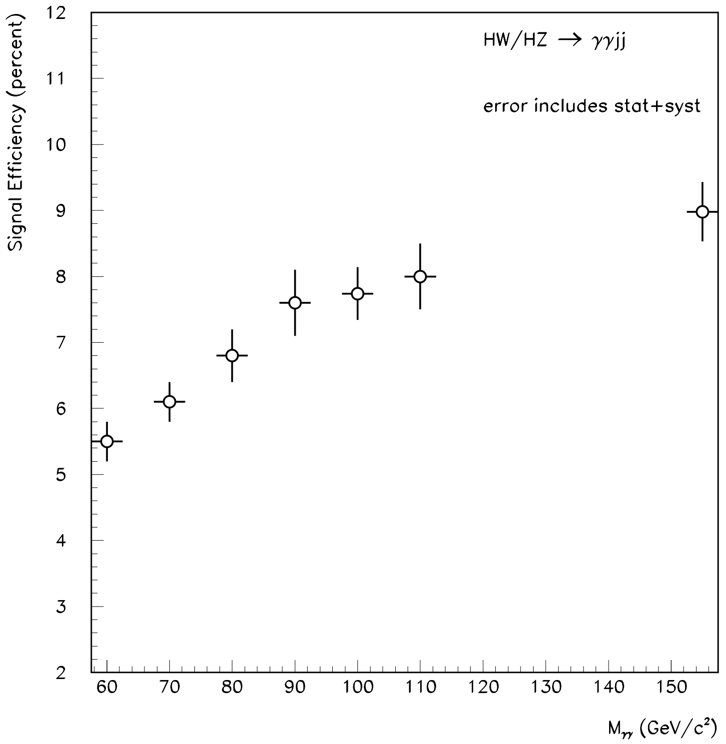

FIG. 3. The efficiency ranges from 5.5% to 9%. The error displayed on the efficiency is statistical, and is of the order of 5%.

expectation uncertainty. The calculated limit assumes all error sources are uncorrelated, which is generally true. The bosonic Higgs cross section is overlaid onto the cross section limit plot. The cross section and branching fractions are taken from [8]. A 90(95)% C.L. bosonic Higgs lower mass limit of 86(81) GeV/c^2 is set. A general 90(95)% C.L. upper limit production cross section is calculated which ranges from 0.6(0.7) pb for $M_{\gamma\gamma} = 60GeV/c^2$ to 0.3(0.4) pb for $M_{\gamma\gamma} = 130GeV/c^2$.

V. CONCLUSIONS

A search for new physics in the $p\bar{p} \rightarrow \gamma\gamma jj$ has been completed. Seven events are seen in the entire ensemble with zero events seen with $M_{\gamma\gamma} \geq 60\ GeV/c^2$, while 3.5 ± 1.3 events of QCD are expected. A 90(95)% C.L. bosonic Higgs lower mass limit of 86(81) GeV/c^2 is set, using standard model coupling strengths between the Higgs and the vector bosons. A general 90(95)% C.L. upper limit production cross section is calculated which ranges from 0.6(0.7) pb for $M_{\gamma\gamma} = 60GeV/c^2$ to 0.3(0.4) pb for $M_{\gamma\gamma} = 130GeV/c^2$.

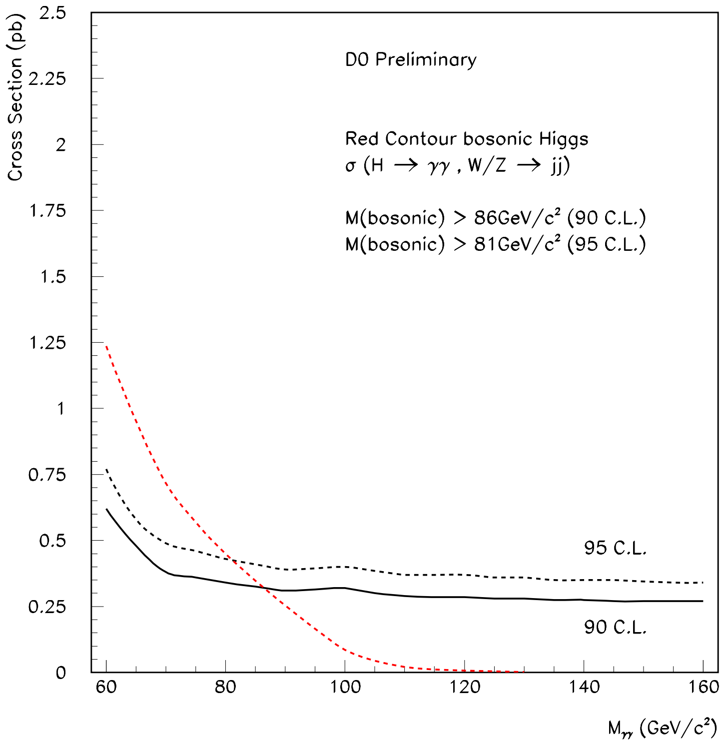

FIG. 4. The bosonic Higgs cross section is from reference 8. The 90% and 95% C.L. lower mass limit of 86 GeV/c^2 and 80 GeV/c^2 respectively is set for the bosonic Higgs.

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