LBL-34232
UC-414

# Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

## Physics Division

Presented at the Hadron Collider Workshop,
Argonne, Illionois, June 2–5, 1993,
and to be published in the Proceedings

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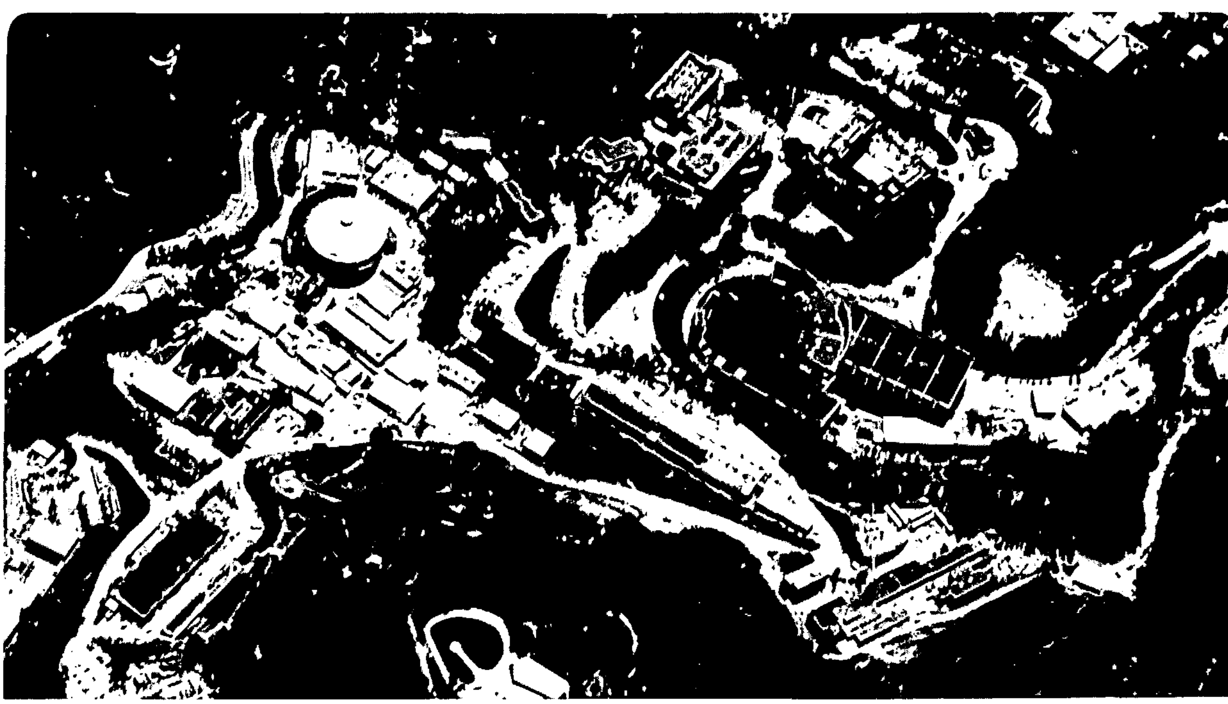
B. Bailey and D. Graudenz

August 1993





**Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098**

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August 15, 1993

FSU–HEP–930815
LBL–34232

# Signal and Background in NLO QCD for the Search of the Intermediate Mass Higgs Boson at the SSC *

B. Bailey
*Department of Physics, B-159, Florida State University*
*Tallahassee, Florida 32306*

D. Graudenz ‡
*Theoretical Physics Group, Lawrence Berkeley Laboratory, University of California*
*1 Cyclotron Road, Berkeley, California 94720*

**Abstract**

The signal and background for the search of the Standard Model Higgs boson in the intermediate mass range 80 GeV $< m_H < 2M_Z$ is studied based on calculations of the cross sections in next-to-leading order QCD perturbation theory for the production of the Higgs boson via gluon-gluon fusion and for the hadronic two-photon production. The method of Monte-Carlo integration allows the application of realistic cuts ($p_T$, rapidity, photon isolation) to the cross section. Results are given for the K-factors of the signal and the background. It turns out that the NLO corrections improve the situation for a Higgs boson mass in the range of 80–120 GeV. Furthermore, the influence of a cut on the transverse momentum of the additional jet produced in the processes gg $\rightarrow$ Hg, gq $\rightarrow$ Hq, q$\overline{\text{q}}$ $\rightarrow$ Hg is compared to a similar cut for the background.

**This work was supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, Division of High Energy Physics of the U.S. Department of Energy under Contract DE-AC03-76SF00098.*

‡*supported by Max Kade Foundation, New York*

## 1. Introduction

In the Standard Model, the electroweak symmetry breaking is achieved by a weak isodoublet scalar field. If the mass associated with this field is small enough, a real physical particle, the Higgs boson, should be observable experimentally. LEP has set a lower bound on the Higgs mass of $m_H > 57$ GeV [1]. LEP II, with a center of mass energy of 180 Gev, will be able to improve this limit to 90 Gev [2]. If $m_H > 90$ GeV, high energy colliders such as the SSC will be required to extend the search.

The dominant production mechanism at hadron colliders for a Higgs mass up to 700 GeV is the gluon gluon fusion process $gg \to H$ [3]. The dominant decay mode depends on the Higgs mass. If the Higgs particle is heavy ($m_H > 2m_Z$), then the four lepton decay mode, $H \to ZZ \to 4l$, will be observable [3]. For a Higgs mass in the intermediate mass region (80 GeV $< m_H < 2M_Z$), QCD backgrounds overwhelm the main decay mode $H \to b\bar{b}$ and the rare processes $H \to ZZ^*$ and $H \to \gamma\gamma$ become the decay modes of choice [4]. The decay $H \to ZZ^*$ occurs at observable rates for $m_H > 130$ GeV and $H \to \gamma\gamma$ occurs at observable rates for the entire intermediate mass region. The two photon decay mode is plagued by a large background [5] and therefore the detection of the inclusive process $pp \to H \to \gamma\gamma$ will require detectors with excellent $\gamma\gamma$ mass resolution [6].

Alternative production mechanisms which eliminate the large two photon background by the inclusion of a final state lepton have been studied [7, 8, 9, 10]. These production mechanisms include associated $W\ H$, or $t\bar{t}\ H$ production with $H \to \gamma\gamma$. Including cuts, the expected number of such events per year at the SSC, assuming $\sqrt{s} = 40$ TeV and a luminosity of 10 $fb^{-1}$, is $\sim 20$. By comparison, for $m_H = 140$ GeV the expected number of $pp \to H \to \gamma\gamma$ events per year is $\sim 700$. The Higgs can be discovered via the $l\gamma\gamma$ signal but confirmation of the discovery in the $\gamma\gamma$ channel would provide a margin of certainty. Because of the experimental difficulties the $\gamma\gamma$ channel requires precise knowledge of the two photon signal and background.

The aim of this paper is to provide a comparison of the signal and background to Higgs production in the intermediate mass region including the next-to-leading order (NLO) QCD corrections. For the Higgs production process via gluon-gluon fusion the NLO corrections have been obtained in [11, 12] and for the background process with a photon pair in the final state in [13]. The photon pair production calculation was performed in a Monte Carlo environment allowing a thorough study of the effect of various kinematic and isolation cuts on the two photon background. In order to make useful comparisons between signal and background, the signal $pp \to H \to \gamma\gamma$ was recalculated using the Monte Carlo formalism.

The rest of this paper is organized as follows. In Section 2, details of the calculation are discussed. In Section 3 numerical results are presented. The results are summarized in Section 4.

## 2. Signal and Background Cross Sections

The Monte Carlo formalism for NLO calculations has been described in detail in

Refs. [13, 14]. The explicit details for the two photon calculation can be found in Ref. [13] and will not be repeated here. The NLO Monte Carlo calculation of the signal $pp \to H$ proceeds in a similar manner.

The leading order (LO) signal in the pole approximation consists of the Born process $pp \to H$ followed by the decay $H \to \gamma\gamma$. The Higgs decay is calculated in the Higgs center-of-mass frame and then boosted into the hadron-hadron center-of-mass frame. The Higgs branching fractions are calculated as per Ref. [3]. Including the $\mathcal{O}(\alpha_s)$ corrections to the Born process [11, 12] we obtain the NLO signal. The Feynman diagrams in Fig. 1 show the LO and some generic NLO corrections to the process $pp \to H$. The matrix element is calculated in the approximation of a top quark with infinite mass. The "K-factor" NLO/Born in this limit is then multiplied by the Born term for a finite top quark mass. This procedure yields an excellent approximation to the general case, even for top quark masses above threshold [12].

The two photon background consists of several contributions: Born, gluon box, single- and double-photon fragmentation processes, and the $\mathcal{O}(\alpha_s)$ corrections to the Born process. The gluon box is an $\mathcal{O}(\alpha^2\alpha_s^2)$ process but due to the large gluon luminosity it cannot be neglected. For the remainder of this paper the LO background contribution will be defined as LO = Born + box + single fragmentation + double fragmentation and NLO = LO + $\mathcal{O}(\alpha_s)$ corrections to the Born process. A list of some of the contributing diagrams is given in Fig. 2.

## 3. Numerical Results

Unless otherwise stated the following input parameters are used for this calculation: CTEQ1M parton distributions [15], the two-loop expression for $\alpha_s(Q^2)$, $Q^2 = p_{T_\gamma}^2$, and $m_t = 140$ GeV. Additionally, the following cuts utilized in studies by the GEM and SDC collaborations [6] are used: $p_{T_\gamma} > 20$ GeV, $|y_\gamma| < 2.5$, $|\cos\theta^*| < 0.7$, isolation cone $R \equiv \sqrt{\Delta y^2 + \Delta\phi^2} = 0.7$, and hadronic energy inside of isolation cone $< 4$ GeV.

Defining a $K$-factor as $K$ = NLO/LO, Fig. 3 (a) shows the variation of this correction factor with the photon-pair mass (i.e. Higgs mass) using GEM/SDC cuts.

The solid curve denotes the variation for the signal and the dashed curve for the background. Specific values for the signal and the background may be found in Tab. 1. Fig. 3 (a) shows that the situation for a light Higgs (80 GeV $< m_H <$ 100 GeV) may be better than previously assumed. In this region the $K$-factor for the background is decreasing while the $K$-factor for the signal is increasing for decreasing Higgs mass. The effect of this behavior on the significance $S$ ($S = s/\sqrt{b}$, where $s$ is the signal and $b$ is the background) of the signal can be seen in Fig. 3 (b) which shows the ratio of QCD corrected significance to the leading-log significance. For the light mass region this curve implies that the discovery time may be reduced by up to a factor of 1.4, and for the rest of the mass region by a factor $\sim 1.3$.

Finally, the effect of $p_T$ cuts on the additional jet for the signal and the background is considered. Cross sections for the process $pp \to H +$jet have been studied in [16]. Fig. 4 shows the NLO cross section for Higgs production depending on the Higgs mass

Table 1: Signal (fb) and background (fb/GeV) at $\sqrt{s} = 40$ TeV with GEM/SDC cuts. $K_S$ and $K_B$ are the K-factors for signal and background, respectively.

| $m_H$ | $\sigma_{LO}(pp \to H \to \gamma\gamma)$ | $\sigma_{NLO}(pp \to H \to \gamma\gamma)$ | $K_S$ | $\frac{d\sigma_{LO}(pp\to\gamma\gamma)}{dM_{\gamma\gamma}}$ | $\frac{d\sigma_{NLO}(pp\to\gamma\gamma)}{dM_{\gamma\gamma}}$ | $K_B$ |
|---|---|---|---|---|---|---|
| 80 | 39 | 67 | 1.72 | 761 | 1121 | 1.47 |
| 90 | 49 | 82 | 1.67 | 496 | 780 | 1.57 |
| 100 | 59 | 100 | 1.69 | 340 | 522 | 1.54 |
| 110 | 70 | 117 | 1.67 | 237 | 377 | 1.59 |
| 120 | 76 | 125 | 1.64 | 173 | 283 | 1.64 |
| 130 | 72 | 117 | 1.63 | 128 | 212 | 1.66 |
| 140 | 57 | 93 | 1.63 | 98 | 163 | 1.66 |
| 150 | 37 | 60 | 1.62 | 75 | 127 | 1.69 |
| 160 | 7 | 12 | 1.71 | 60 | 103 | 1.72 |

with an additional cut of 20 GeV on the $p_T$ of the produced jet. The branching ratio $H \to \gamma\gamma$ is not included. The renormalisation and factorization scales are $m_H^2$.

Clearly, a substantial fraction of Higgs particles is accompanied by a jet with a $p_T$ larger than 20 GeV. For a Higgs mass of 100 GeV, Fig. 5 shows the cross section in $p_T$ bins (for $p_T > 20$ GeV). In the bin 70 GeV$< p_T <$100 GeV, the integrated cross section is still 10 pb. The virtual correction is of the order of 50% of the Born term [11, 12], and this part of the cross section (together with the Born term) does not give rise to a high-$p_T$-jet. Can the detection or rejection of an additional jet help to disentangle signal and background?

It turns out that the requirement of a high-$p_T$-jet reduces the signal too much to be useful. The influence of a jet veto is shown in Fig. 6 for (a) the signal $pp \to H \to \gamma\gamma$ and (b) the background $pp \to \gamma\gamma$. Although the reduction of the background is larger than the reduction of the signal by these cuts, the significance $s/\sqrt{b}$ is found to be smaller than in the case without cuts, because the absolute rate of the signal is reduced substantially.

## 4. Summary and Conclusions

Results have been presented, at the NLO level, for the signal and background in the intermediate mass region. The $K$-factors and the significance of the signal were found to depend on the mass of the Higgs boson and the cuts implemented. The QCD corrections imply that the discovery time for the intermediate mass Higgs boson could be reduced by a factor of 1.3 to 1.4. Additional cuts on the transverse momentum of the produced jets in NLO do not improve the situation.

## 5. Acknowledgments

This research was supported in part by the U. S. Department of Energy under contract numbers DE-FG05-87ER40319 and DE-AC03-76SF00098. The authors would like to thank I. Hinchliffe, J. Womersley and R. Zhu for useful discussions.

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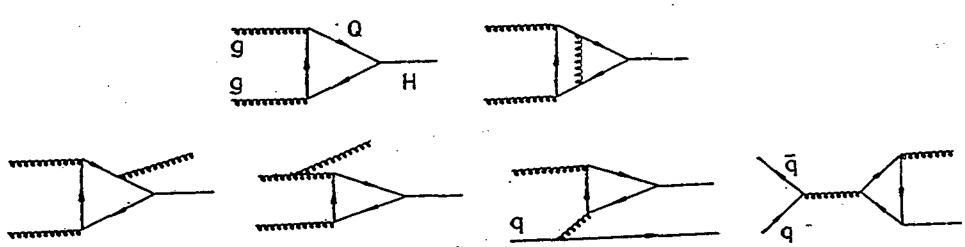


Figure 1: Feynman diagrams of the Born term and QCD corrections to the process $gg \to H$.

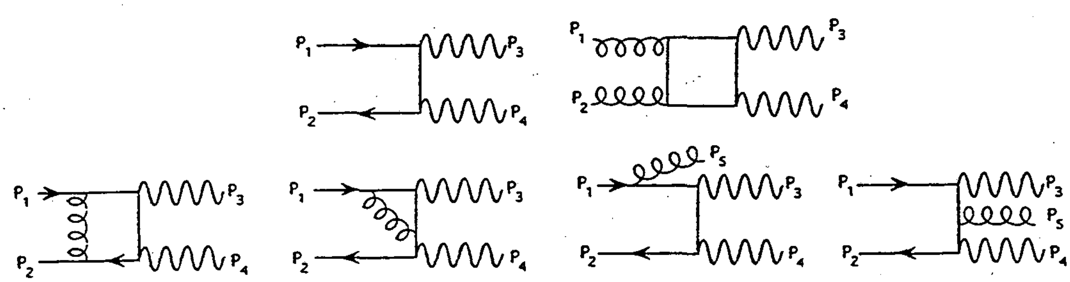


Figure 2: Feynman diagrams of the LO and NLO contributions to the two photon background process.

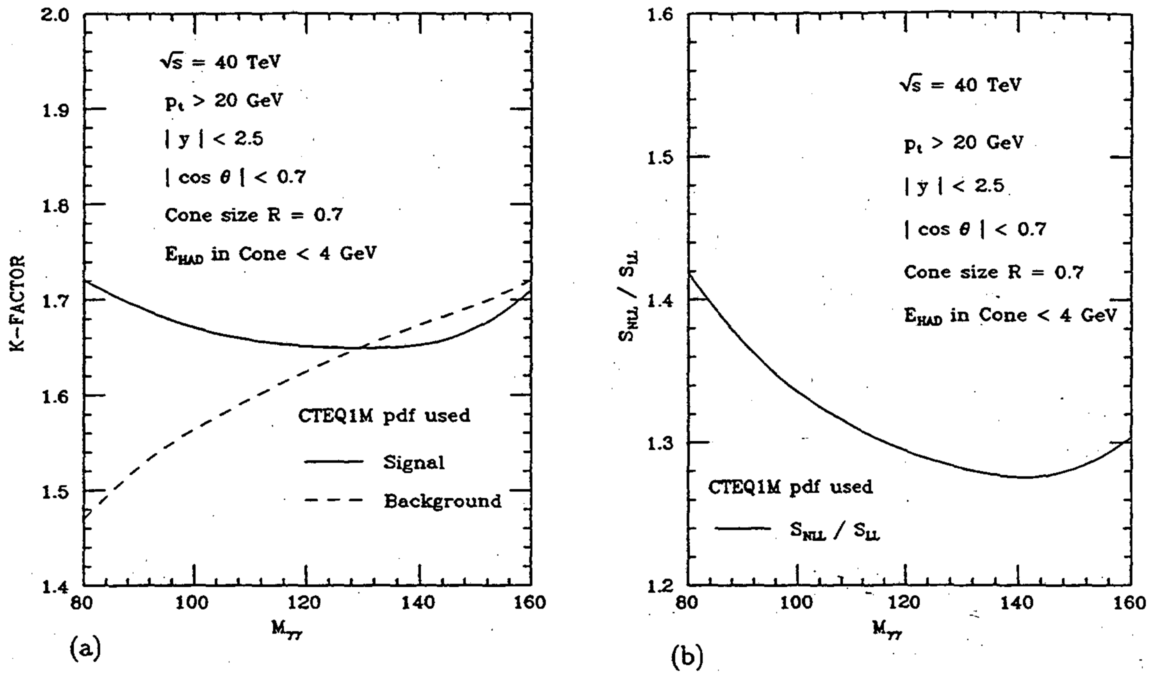


Figure 3: (a) $K$-factor for the signal and background at $\sqrt{s} = 40$ TeV using GEM/SDC cuts, (b) ratio NLO significance to LO significance.

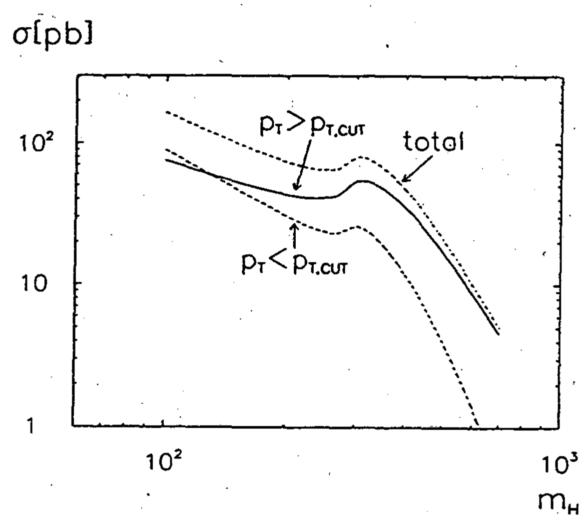


Figure 4: NLO cross section $pp \to H + X$, $p_{T,\mathrm{CUT}}$=20 GeV.

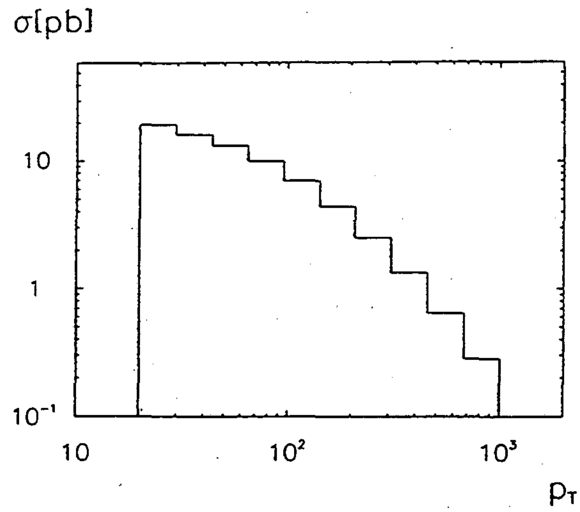


Figure 5: $p_T$ spectrum of the produced jet in the process $pp \to H + \text{jet}$

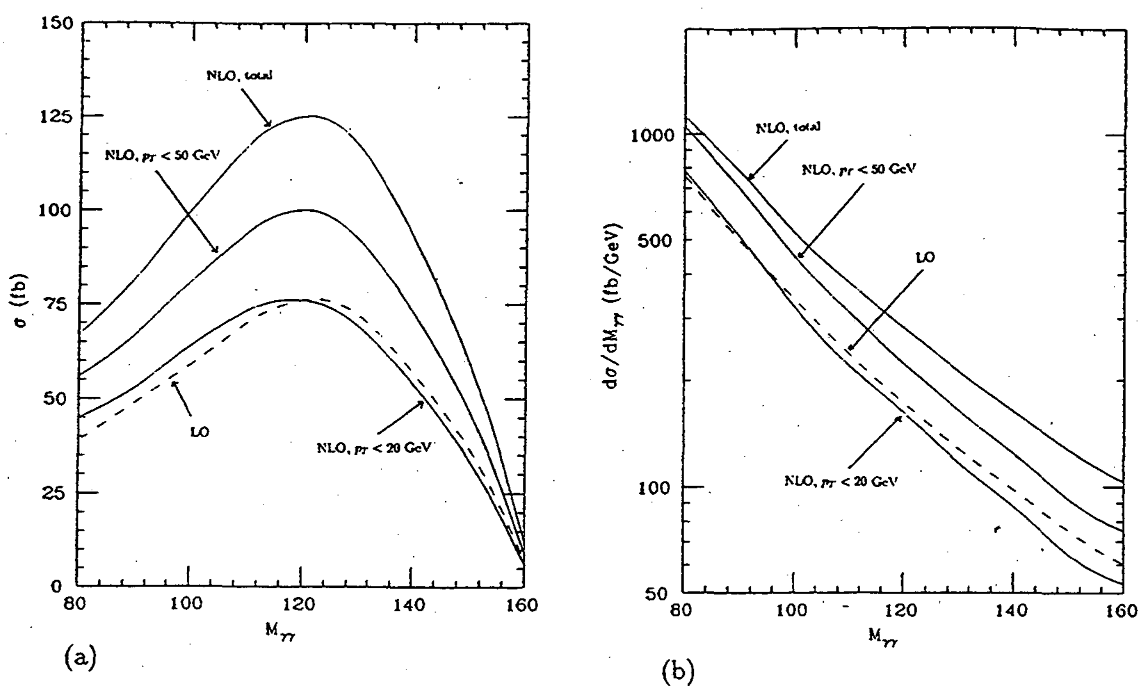


Figure 6: (a) Signal $pp \to H \to \gamma\gamma$, (b) background $pp \to \gamma\gamma$; LO (dashed lines), NLO (full lines).