SEARCH FOR SM HIGGS SIGNALS AT LHC *

R. STRÖHMER

LMU München, Sektion Physik
Am Coulombwall 1, 85748 Garching, Germany

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Both the ATLAS and CMS collaborations have developed search strategies (which are quite similar) to find a Standard Model Higgs boson at the LHC. This paper describes the basic concepts of them, it is mostly based on the Technical Proposals of the two experiments ATLAS (Technical Proposal CERN/LHC/94-43 (15.Dez 1994) and Technical Proposal CMS Collaoration CERN/LHC/94-38 (15.Dez 1994)). After combining the different channels both experiments will be able to see a SM Higgs boson in the range of 80 GeV/c^2 > m_H > 1000 GeV/c^2 with at least 5σ significances after collecting an integrated luminosity of $10^5 pb^{-1}$.

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1. Introduction

The LHC is a Hadron Collider which will be built inside the existing LEP tunnel (with a circumference of 27 km) at CERN in Geneva. At LHC protons will collide on protons with a center of mass energy of 14 TeV and a bunch crossing rate of 25 ns. The start of data taking is planed for the year 2005. The design luminosity of LHC is $\mathcal{L} = 10^{34}\mathrm{cm}^{-1}s^{-1}$. This corresponds to an integrated luminosity of $10^5 pb^{-1}$ per year (100 days with design luminosity and full efficiency) At this luminosity one will have 23 minimal bias events per crossing. It is foreseen that LHC will start with an initial luminosity of $\mathcal{L} = 10^{33}\mathrm{cm}^{-1}s^{-1}$, this corresponds to an integrated luminosity of $3 \times 10^4 pb^{-1}$ in 3 years and to 2.3 minimal bias events per crossing.

One important purpose of LHC is to find the Higgs particle. The current lower limit for the SM Higgs boson form the combination of the 4 LEP experiments is 77 GeV/c^2 [3]. The limit is expected to improve to about 90

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GeV at the end of the LEP 2 program. The triviality bound predicts that a SM Higgs boson should be lighter than ≈ 1 TeV. Electroweak precision measurements favor low values for the Higgs mass [4]. ($m_H = 115^{+116}_{-66}\mathrm{GeV}/c^2$)

In the range of $m_H \leq 130$ GeV/c^2, the decay $H \to b\bar{b}$ dominates but it is experimentally difficult to separate it from the background. The decay $H \to \gamma\gamma$ which has a branching ratio of $\mathcal{O}(10^{-3})$ yields the best Signal/$\sqrt{\text{Background}}$ ratio. For 130 GeV/$c^2 \leq m_H \leq 700$ GeV/c^2 the decay $H \to ZZ \to llll$ gives the best significance. For higher Higgs masses the discovery potential can be increased by also looking into the decays $H \to ZZ, WW \to lljj$, $ll\nu\nu$, $l\nu jj$ which have higher branching ratios.

The Born-level prediction for the Higgs production cross section are increased by QCD corrections by a factor of $K_f = 1.5$. However, similar corrections have not been calculated for all background processes. Because of this, in the following, a K-factor of $K_f = 1$ will be used. This gives a conservative estimate of the significance as long as the QCD corrections for the background are smaller than $1.5^2 = 2.25$. The discovery potential as a function of the Higgs mass are presented in figure 2 in the conclusions.

2. Search for a Higgs boson with 80 GeV/c^2 < m_H < 130 GeV/c^2

In the mass region of 80 GeV/$c^2 \leq m_H \leq 130$ GeV/c^2, the most promising search channel is $H \to \gamma\gamma$. In this mass region, one has: $\sigma \times Br \sim 40fb$ ($K_f = 1$). In order to select the events, one requires two photons with $p_T^1 > 40$ GeV/c and $p_T^2 > 25$ GeV/c and with $|\eta| < 2.5$. This reduces the background from the prompt two photon production. ATLAS requires in addition $p_T/(p_T^1 + p_T^2) < 0.7$ which reduces the background from $qg \to q\gamma \to q\gamma\gamma$ with an Bremsstrahlungs-photon. After this cuts $\sim 150fb$/GeV background from $gg, qq \to \gamma\gamma$ and $\sim 50fb$/GeV background from $gq \to q\gamma\gamma$ remain. In this Higgs mass range, the width of the mass peak is completely dominated by the experimental resolution. To see a significant peak over the continuous background, it is important to have a good mass resolution.

Two components enter into the mass resolution for $H \to \gamma\gamma$, the energy resolution for the two photons and the angular resolutions between the two photons. The energy resolution can be parametrized as:

$$\frac{\Delta E}{E} = \frac{a}{\sqrt{E}} \bigoplus \frac{b}{E} \bigoplus c\,.$$

The stochastic term a is due to fluctuations in the shower development. The term b is due to electronic noise and pile-up from the minimal bias events. There contribution to ΔE is independent of the shower energy. The constant term c is due to the precision of the calibration of the Calorimeter channels. In order to measure the angle between the two photons, one has to know the primary vertex at which the Higgs boson decayed into the two photons. The interaction region has a size of $\Delta z \times \Delta x \times \Delta y = 5.3$ cm $\times$ $(15\mu m)^2$. In order to separate the Higgs vertex in an event from the vertices from minimal bias events, the fact that the Higgs vertex has on average 30% more tracks from charged particles can be utilizing, but this is only feasible for low luminosity. It is also possible to use the position of the shower in 3 calorimeter layers to extrapolate the z position of the photon at the primary vertex. This yields a precision of $\Delta z = 2$cm. The total mass resolution is $\Delta m_{\gamma\gamma} = 1.4$ GeV$/c^2$ for ATLAS and $\Delta m_{\gamma\gamma} = 0.9$ GeV$/c^2$ for CMS.

In addition too the irreducible background from real photons, one has a reducible background from misidentifying Jets as photons. The Jet-γ cross section is $\sim 2 \times 10^2$ times larger than the $\gamma\gamma$ continuum and the Jet-Jet cross section is $\sim 2 \times 10^6$ times larger. This backgrounds can be reduced below the level of the irreducible backgrounds by using the shower shape in the electro-magnetic calorimeter, the activity in the hadron calorimeter and a pre shower detector to veto on $\pi^0 \to \gamma\gamma$ decays. For $m_H \approx m_{Z^0}$ one has in addition to veto on tracks pointing to the cluster in the electro magnetic calorimeter to suppress the $Z^0 \to e^+e^-$ decays. (The $Z^0 \to e^+e^-$ rate is 2.5×10^4 times larger than the $H^0 \to \gamma\gamma$ rate.) Figure 1 shows the expected signal $m_H = 120$ GeV$/c^2$ and $10^5 pb^{-1}$.

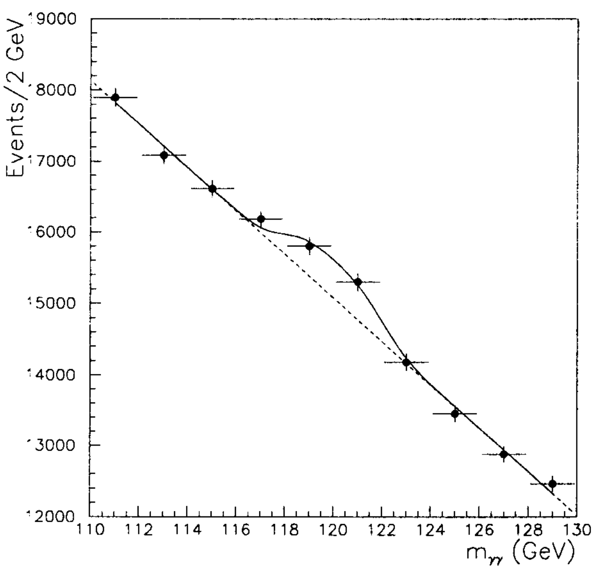

Fig. 1. Expected signal for $m_H = 120$ GeV$/c^2$ and$10^5 pb^{-1}$.

The Higgs boson is often produced in association with a W or with at $t\bar{t}$ pair. One can use this in a further analysis by requiring in addition to the two photons a lepton (electron or muon) with $|\eta^l| < 2.4$ and $p_T^l > 20$ GeV/c. This reduces the signal drasticly but it improves the signal/background ratio to better than 1. One also can use the lepton to find the primary vertex which improves the angular resolution.

The $H \to b\bar{b}$ decays can be used in a search if one also looks for the W or $t\bar{t}$ which can be produced in association with the Higgs boson. The considered channels are $WH \to lbb$ (which has a resonant background from WZ) and $t\bar{t}H \to lbbb$ (from the WWbbbb). The b-Jet are either tagged by leptons from semileptonic decays of the b-quark (or the c-quark in cascade decays) or by vertex tags. The b-Hadrons have a lifetime of $\mathcal{O}(10^{-12}s)$ hence the decay products come form a secondary vertex which is separated form the primary vertex. One expects tagging efficiency of $\epsilon \sim 50\%$ while suppressing non b-Jets by a reduction factor $R \sim 100$. Because of the hadronisation effect and the not complete reconstruction of the b-Jet the peak in the m_{bb} spectrum is about 20 GeV/c^2 below m_H. This means one has to use large Monte Carlo corrections to extract the Higgs mass from this channel.

3. Search for a Higgs boson with 130 GeV/$c^2 < m_H < 700$ GeV/c^2

In this mass region, the gold plated channel $H \to ZZ^*, ZZ \to llll$ can be used to search for the Higgs boson. The kinematic cuts to select the 4 leptons (electron or muon pairs) are:
CMS e: $p_t^1 > 20$ GeV/c^2, $p_t^2 > 15$ GeV/c^2, $p_t^{3,4} > 10$ GeV/c^2, $|\eta| < 2.5$.
CMS μ: $p_t^1 > 20$ GeV/c^2, $p_t^2 > 10$ GeV/c^2, $p_t^{3,4} > 5$ GeV/c^2, $|\eta| < 2.4$.
ATLAS e or μ: $p_t^1 > 20$ GeV/c^2, $p_t^2 > 20$ GeV/c^2, $p_t^{3,4} > 7$ GeV/c^2, $|\eta| < 2.5$.
The four lepton mass resolution is $\Delta m_{llll}/m_{llll} \approx 1\% - 2\%$ and the Z^0 mass resolution is $\Delta m_{Z^0} \approx 2$ GeV/c^2.

For $H \to ZZ^* \to llll$ the main backgrounds are ZZ^*, $Z\gamma^*$ continuum events and $t\bar{t}$, $Zb\bar{b}$ decays. To reduce the background, one requires one l^+l^- pair with $m_{ll} = m_{Z^0} \pm 4$ GeV/c^2 and the second pair with $m_{ll} > 20$ GeV/c^2. A pair of leptons are two leptons of the same flavor (electron or muon) with opposite charge. The second cut suppresses background events where two leptons come from the decay of the same b ($b \to l^-\nu c$, $c \to l^+\nu s$). Both the $t\bar{t}$ and the $Zb\bar{b}$ contain at least two leptons from b decays. These leptons are not isolated one therefore requires that no track with $p_t > 2.5$ GeV/c is close ($\Delta R < 0.3$) to the leptons. The high threshold of 2.5 GeV/c ensures that random overlap with minimal bias events doesn't reduce the signal efficiency too much. ATLAS also uses the fact that the leptons from the

Higgs boson decay come from the primary vertex whereas the leptons from the b decays come from a secondary vertex. A cut on the impact parameter (the closest distance of the extrapolated track to the beam axis) which is over 80% efficient, reduces, for low luminosities, the $t\bar{t}$ background by a factor of 20 and the $Zb\bar{b}$ background by a factor of 12. For high luminosities which make the impact parameter measurement much more difficult (because of the higher occupancy of the inner detectors), the reduction factors are still 7 and 5.

For the $H \to ZZ \to llll$, the only significant background is from the irreducible ZZ continuum production. To select the signal, one requires two l^+l^- pairs with $m_{ll} = m_{Z^0} \pm 6$ GeV$/c^2$.

4. Search for a Higgs boson with 700 GeV$/c^2 < m_H < 1$ TeV$/c^2$

Above $\sim$ 500 GeV$/c^2$, the significance for the 4 lepton channel starts to drop because of the reduced production cross section and the increased natural Higgs width. To compensate for this, one can look into the decay $H \to ZZ \to ll\nu\nu$ which has a 6 times larger branching ratio than $H \to ZZ \to llll$. The signature for such events are a lepton pair with $m_{ll} \approx m_{Z^0}$ and missing transverse energy. In the missing transverse energy distribution, the signal gives a broad Jacobian peak at about 300 GeV. For missing transverse energies above 250 GeV, the dominant background are the ZZ continuum events which have a similar shape in the missing transverse energy distribution as the signal. This makes it essential to know the absolute level of the background with good accuracy.

The channels $H \to WW \to l\nu jj$ and $H \to ZZ \to lljj$ have a 150 times larger branching ratio than $H \to ZZ \to llll$. The search strategies here is to demand one or two leptons and to reconstruct the $W/Z \to jj$ in the region of $|\eta| < 2$. To reduce the background, one vetos on additional jets with $|\eta| < 2$ and one requires two extra Jets with $2 < |\eta| < 5$. The requirement of the two extra jets in the forward region can be made because a large fraction of the Higgs bosons in this mass range are produced through fusion processes $qq \to qqH$ in which the two quarks are boosted in the forward direction.

5. Conclusions

Figure 2 shows the discovery potential of the ATLAS detector for SM Higgs. The significances are based on an integrated luminosity of $\mathcal{L} = 10^5 pb^{-1}$ taken in 3 years of low luminosity and one year at high luminosity. One can see that a Higgs boson with 80 GeV/c^2 $< m_H <$ 1 TeV/c^2 can be discovered with a significance of more than 5 σ. One sees the dip in the significance at about 170 GeV/c^2 which is due to the reduced branching ratio $H \to ZZ^*$ in the range where the decay into real WW pairs is possible but the decay in real ZZ pairs is still not possible.

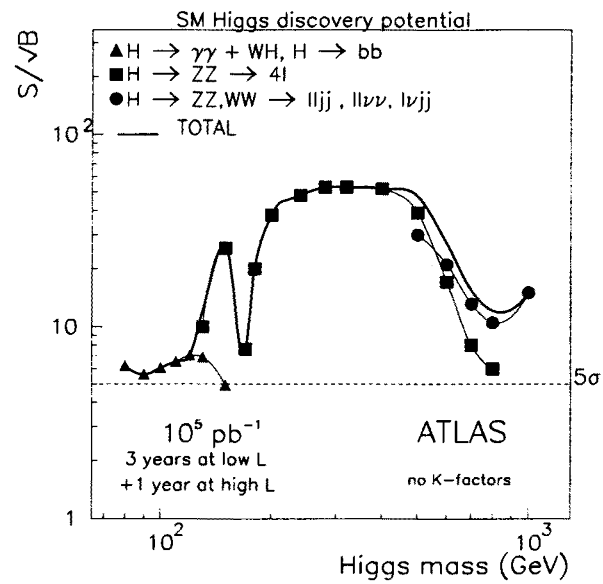

Fig. 2. ATLAS discovery potential.

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