BALKAN PHYSICS LETTERS
© Bogazici University Press 29 October 2008
BPL, **8** (2), pp. 105 - 109 (2000)

SEARCH FOR THE STANDARD MODEL $H \rightarrow \gamma\gamma$ DECAYS WITH THE ATLAS DETECTOR AT LHC

J.-F. Marchand on behalf of the ATLAS collaboration,
Laboratoire d'Annecy-le-Vieux de Physique des Particules LAPP,
IN2P3/CNRS, Université de Savoie, France

(received 2 January 2000 ; accepted 21 March 2000)

Abstract. - A light Standard Model Higgs boson, with mass between 114 and ≈150 GeV, is favored by precise measurements of electroweak radiative corrections and other theory predictions. One of the most important channels to search for this particle in this mass region is the decay $H \rightarrow \gamma\gamma$. We investigate the ATLAS discovery potential for a light Higgs boson in the two photon decay mode. In addition to the inclusive analysis we consider also the reconstruction of diphoton systems produced in association with jets. The studies are based on a realistic detector simulation of Monte Carlo signal and background events.

ATL-PHYS-PROC-2008-065
26 November 2008

The $H \rightarrow \gamma\gamma$ decay mode is one of the most promising discovery channels for the Standard Model Higgs boson in low mass region ($114 < m_{\mathrm{H}} < 150$ GeV). Despite the small branching ratio ($2.2 \cdot 10^{-2}$ for $m_H = 120$ GeV) this channel has a simple signature and a very good mass resolution (≈1.5 GeV). With respect to previous studies several new aspects have been considered: QCD high order corrections (for inclusive analysis), contributions of reducible background fragmentation from hard partons to photons and the reconstruction of diphoton systems produced in association with jets in addition to the inclusive analysis. Finally significance results computed with a maximum likelihood fit are compared to results obtained by event counting. All the results presented are based on a realistic detector simulation of Monte Carlo signal and background events.

The Higgs boson is mainly produced by the gluon fusion process via a heavy top quark loop and by Vector Boson Fusion (VBF). The advantage of the VBF process is the appearance of forward jets. Production in association with W, Z or $t\bar{t}$ pair is also considered; it allows an increase in the signal to background ratio despite limited statistics. The decay to two photons proceeds through loops with W bosons or top quarks. The background processes can be split into two categories: The irreducible background, coming from the production of two isolated photons and the reducible background, coming from events with at least one fake photon (for instance jets faking photons).

Photons are reconstructed from electromagnetic clusters whose size depends on where the cluster is located and whether the photon is converted or not. The cluster position is corrected for known systematic biases and the energy is reconstructed using longitudinal weights to correct for energy loss in front of the calorimeter, longitudinal leakage and energy loss outside the cluster. Unconverted and converted photons use different weights. A good photon identification is mandatory to reduce the background from jets faking photons (reducible background) below the irreducible background. A cut-based method using shower shape parameters is applied: The middle layer of the electromagnetic calorimeter and the hadronic calorimeter are used to reject jets using wide showers and the fine segmentation of the first compartment of the electromagnetic calorimeter is used to separate photons from neutral pions. A track based isolation is also used to remove some jets faking photons.

Monte Carlo studies have shown that 57% of $H \rightarrow \gamma\gamma$ events have at least one true conversion with a radius below 800mm (corresponding to the last position where we can reconstruct a track in the detector) therefore it is really important to recover converted photons. Two kinds of converted photons are used: Double track conversions which are reconstructed by a vertexing algorithm using two tracks with opposite charges as input and single track conversions (conversions for which only one of the two tracks has been reconstructed). The separation between a primary electron and a conversion electron is done using the first pixel layer. The conversion reconstruction efficiency is almost 66.4% for conversions with radius below 400mm and with the reconstruction software used for this analysis (fig. 1).

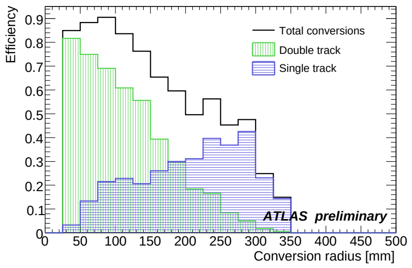

Figure 1: Conversion reconstruction efficiency

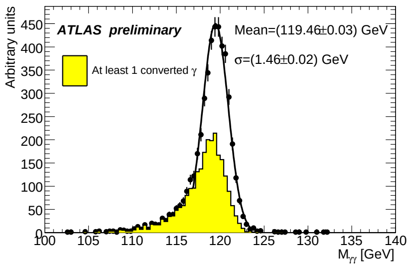

Figure 2: Invariant diphoton mass distribution for $m_H = 120$ GeV

A precise measurement of the primary vertex position and of photon directions is very important for the Higgs mass resolution. The photon direction is measured by an iterative method using a linear fit and exploiting the multi-layer structure of the electromagnetic calorimeter, the position of the conversion vertex when possible and the position of the primary vertex reconstructed by the inner detector. The addition of the primary vertex gives the best Higgs boson position accuracy, with a Gaussian width of 0.07mm (the distribution exhibits large tails 8mm RMS when reconstructed primary vertex is not used).

The invariant mass of diphoton pairs is determined from an asymmetric Gaussian fit ($[-2\sigma, +3\sigma]$, fig. 2). The relative mass resolution σ_m/m is close to 1.2% degrading by a few percent when $10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ pileup is added.

The inclusive analysis refers to the search for a resonance in events with at least two photon candidates in the central detector region excluding the transition region between barrel and end cap ($0 < |\eta| < 1.37$ and $1.52 < |\eta| < 2.37$). Leading and sub-leading photons candidates are required to have a transverse momentum above 40 and 25 GeV respectively.

For the Higgs boson plus one jet analysis, at least two photons in the same detector region are mandatory with transverse momenta higher than 45 and 25 GeV and at least one hadronic jet with a transverse momentum higher than 20 GeV in $|\eta| < 5$ is also mandatory. Finally a cut on the invariant mass of the diphoton and the leading jet is applied ($m_{\gamma\gamma\mathrm{jet}} > 350$ GeV).

For the Higgs boson plus two jets analysis, the two photons are asked to have transverse momenta higher than 50 and 25 GeV and have to be in the same detector region. At least two hadronic jets are mandatory with transverse momenta higher than 40 and 20 GeV and in $|\eta| < 5$. As the pseudorapidity gap and invariant mass of signal jets tend to be significantly larger than those expected for background processes, we also apply the following cuts: $\Delta\eta_{jj} > 3.6$ and $m_{jj} > 500$ GeV. The photons are required to be between the tagging jets and a central jet veto is applied: $p_T > 20$ GeV, $|\eta| < 3.2$.

The expected cross-sections are presented in the table 1 (diphoton searches in association with missing transverse momentum and charged leptons are also added) and the diphoton invariant mass spectra are shown on figure 3 for inclusive analysis, for H+1jet analysis and for H+2jets analysis.

	Inclusive	H+1jet	H+2jets	H+$E_T{}^{\mathrm{miss}}$+1 lepton	H+$E_T{}^{\mathrm{miss}}$
σ_{sig}	25.4 fb	4.0 fb	0.97 fb	0.126 fb	0.072 fb
σ_{bkg}	947 fb	49 fb	1.95 fb	0.075 fb	0.036 fb

Table 1: Expected cross-sections for $m_H = 120$ GeV within a mass window of $m_{\gamma\gamma}$ of ± 2 GeV around 120 GeV

An unbinned extended multivariate maximum likelihood fit is performed: It takes the advantage of discrimination information from the kinematics and topological properties of the $H \rightarrow \gamma\gamma$ decays. The transverse momentum of the Higgs boson and the photon decay angle in the Higgs boson rest frame with respect to the Higgs boson lab flight direction $|cos\theta^*|$ are used in addition to the invariant diphoton mass. Different categories are used to split data into subsets in order to separate sub-populations of events with different properties. This categorization gives a finer grained description of the data, increases the significance and reduces the biases from the correlation:

therefore it improves the accuracy of the likelihood model. Three η categories, two categories for converted photons and unconverted photons and three higgs production categories are used: H+0, 1 or 2 jets.

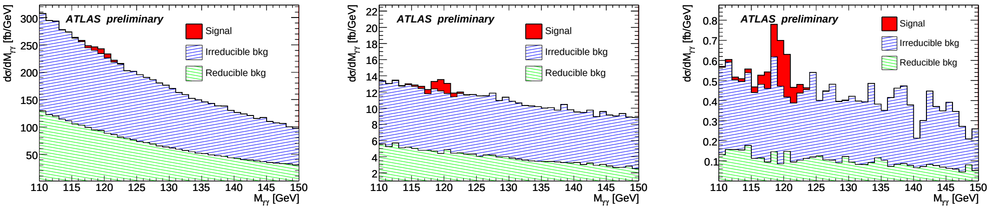

Figure 3: Diphoton invariant mass spectrum in terms on the cross-section in fb (from left to right: Inclusive, H+1jet and H+2jets)

The expected signal significances for 10 fb^{-1} of integrated luminosity are summarized in table 2 using an event counting method. The combined significance (sum in quadrature of H+0, not inclusive, H+1jet and H+2jets) is almost 25% higher than the significance obtained only with inclusive analysis while the significance increases by 40% with respect to inclusive analysis using the combined likelihood fit with fixed Higgs mass (see table 2).

	Event counting		Using combined fit	
m_H (GeV)	Inclusive	Combined	Floating mass	Fixed mass
120	2.6	3.3	2.8	3.6
130	2.8	3.5	3.4	4.2
140	2.5	3.0	3.2	4.0

Table 2: Expected signal significances for 10 fb^{-1} of integrated luminosity

To conclude, the impact of the detector performance on $H \to \gamma\gamma$ has been evaluated using a full detector simulation and the feasibility of the search for a Standard Model Higgs boson via the $H \to \gamma\gamma$ channel has been confirmed. Inclusive analysis and diphoton in association with jets have been studied and a combined analysis has been done, improving the significance by ≈25% with respect to inclusive analysis. The use of an unbinned maximum-likelihood fit has been studied to enhance the expected sensitivity and the gain is ≈40% with respect to inclusive analysis. Finally, a 5σ discovery should be possible with integrated luminosity of 20-30 fb^{-1} but some work will be needed to understand the detector performance with early data.

REFERENCES

[1] ATLAS Collaboration, Expected Performance of the ATLAS Experiment, Detector, Trigger and Physics, CERN-OPEN-2008-020, Geneva, 2008, to appear