

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

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A light Standard Model Higgs boson, with mass between 114.4 and ≈ 150 GeV, is favored by electroweak fits and direct searches. 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, missing E_T or missing E_T plus leptons. The studies are based on a realistic detector simulation of Monte Carlo signal and background events.

Recent 95% Confidence Level exclusion limits from the CDF and D0 experiments¹ ($m_H \notin [160, 170]$ GeV) together with the LEP limit² $m_H > 114.4$ GeV and theory predictions emphasize the importance of the low mass region for the Higgs searches. 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, between 114.4 and 150 GeV. Despite the small branching ratio (2.2×10^{-3} for $m_H = 120$ GeV) this channel has a simple signature and the invariant mass can be reconstructed with a very good mass resolution (≈ 1.5 GeV). With respect to previous studies several new aspects are 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. The detector performance issues relevant to the search have been evaluated using a realistic detector simulation.

The Higgs boson is mainly produced by the gluon fusion process via a top quark loop and by Vector Boson Fusion (VBF). The peculiarity of the VBF process is the appearance of forward

jets, with a large rapidity gap and no activity in the central rapidity region, which can be used to enhance the sensitivity. Production in association with W , Z or $t\bar{t}$ pair is also considered; dedicated analyses allow us to increase 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 QCD 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 calibration constants to correct for energy loss in front of the calorimeter, longitudinal leakage and energy loss outside the cluster. 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 with high energy pions and 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. Details on the electromagnetic calorimeter calibration, photon reconstruction, including the conversions and the rejection are presented and discussed in ^{3,4}.

Monte Carlo studies have shown that 57% of $H \rightarrow \gamma\gamma$ events have at least one conversion with a radius below 800 mm (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 400 mm and with the reconstruction software used for this analysis (Fig. 1).

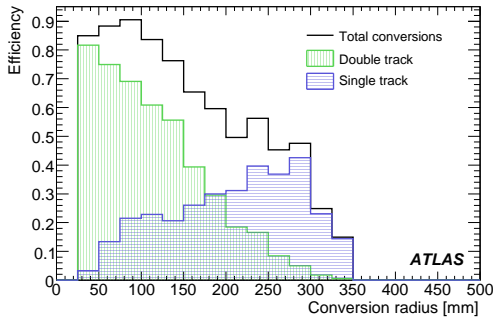


Figure 1: Conversion reconstruction efficiency as a function of the conversion radius.

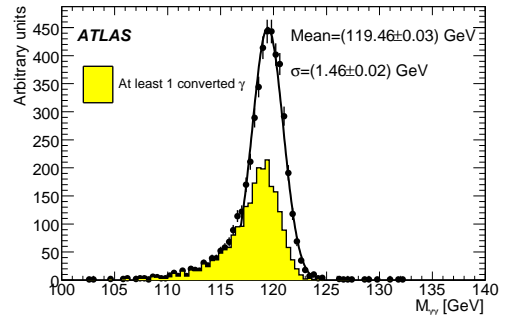


Figure 2: Invariant diphoton mass distribution for a Higgs boson with $m_H = 120$ GeV.

A precise measurement of the photon direction is very important for the accurate Higgs mass reconstruction. 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 and the position of the primary vertex reconstructed by the inner detector when possible. The addition of the primary vertex gives the best photon angle determination accuracy, with a Gaussian width of 0.07 mm (the distribution exhibits large tails with RMS of 8 mm when reconstructed primary vertex is not used) but its identification is not always possible at high luminosity.

The invariant mass of photon pairs is determined from an asymmetric Gaussian fit (in the $[-2\sigma, +3\sigma]$ range, Fig.2). The relative mass resolution σ_m/m is close to 1.2% degrading by a few

percent when additional soft proton-proton collisions corresponding to $10^{33}\text{cm}^{-2}\text{s}^{-1}$ luminosity are added.

The inclusive analysis refers to the search for a resonance in events with at least two photon candidates in the η region $0 < |\eta| < 1.37$ and $1.52 < |\eta| < 2.37$, which excludes the transition region between barrel and end cap. 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 fiducial region are required with transverse momenta greater than 45 and 25 GeV and at least one hadronic jet with a transverse momentum higher than 20 GeV in $|\eta| < 5$ is also required. Finally a cut on the invariant mass of the diphoton and the leading jet is applied ($m_{\gamma\gamma\text{jet}} > 350$ GeV).

For the Higgs boson plus two jets analysis (optimized for VBF processes), the two photons are asked to have transverse momenta higher than 50 and 25 GeV and have to be in the same fiducial region. At least two hadronic jets are required 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: $\Delta\eta_{\text{jj}} > 3.6$ and $m_{\text{jj}} > 500$ GeV. The photons are required to be between the tagging jets and a central jet veto is applied: $p_{\text{T}} > 20$ GeV, $|\eta| < 3.2$.

The Higgs boson plus missing E_{T} (plus lepton) requires at least two photons with transverse momenta higher than 60 and 30 GeV in the same detector region. The missing E_{T} must be greater than 80 GeV for the $H + E_{\text{T}}^{\text{miss}}$ analysis and 30 GeV for the $H + E_{\text{T}}^{\text{miss}} + \ell$ analysis. For the latter analysis, the transverse momentum of the most energetic isolated lepton (electron or muon) must be higher than 30 GeV. When an electron is reconstructed, events are rejected if the invariant mass of the electron and each of the photons is close to the Z mass ($[80, 100]$ GeV).

The expected cross-sections after event selection are presented in the Table 1 and the diphoton invariant mass spectra are shown on Fig. 3. Details on the event selection and the results found with these analyses are reported in⁴.

	Inclusive	H+1jet	H+2jets	H+ $E_{\text{T}}^{\text{miss}}$ +1 lepton	H+ $E_{\text{T}}^{\text{miss}}$
σ_{sig}	25.4 fb	4.0 fb	0.97 fb	0.126 fb	0.073 fb
σ_{bkg}	947 fb	49 fb	1.95 fb	0.075 fb	0.036 fb

Table 1: Expected cross-sections after event selection for $m_H = 120$ GeV within a mass window of $m_{\gamma\gamma}$ of 1.4σ around 120 GeV.

Three η categories and three Higgs production categories (H+0, 1 or 2 jets) are combined using an unbinned extended multivariate maximum likelihood fit. Additional discriminating power is gained considering the difference in the kinematics and topological properties between signal and background events. 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. Data are split into different categories 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.

The expected signal significances for 10fb^{-1} of integrated luminosity are summarized in Table 2 using an event counting method. The combined significance (sum in quadrature of H+0 exclusive, H+1jet exclusive and H+2jets) is almost 25% higher than the significance obtained only with the inclusive analysis while the significance increases by 40% with respect to the in-

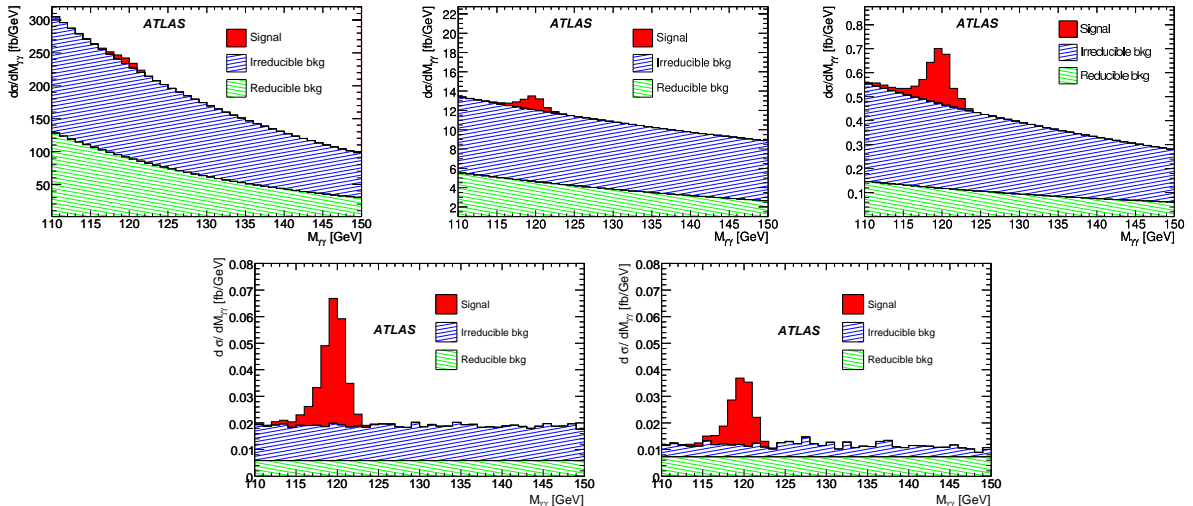


Figure 3: Diphoton invariant mass spectrum as obtained after the event selection from the inclusive analysis, $H+1\text{jet}$, $H+2\text{jets}$, $H+E_T^{\text{miss}}+\text{lepton}$ and $H+E_T^{\text{miss}}$ (from top to bottom and from left to right).

m_H (GeV)	Event counting		Using combined fit	
	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.

clusive analysis using the combined likelihood fit with fixed Higgs mass (see Table 2).

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

References

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