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STUDY OF THE H $\rightarrow \gamma\gamma$ DECAY WITH THE ATLAS DETECTOR

LEONARDO CARMINATI
on behalf of the ATLAS collaboration
INFN and Università degli Studi di Milano
via G. Celoria 16, 20122 Milano, Italy
E-mail: leonardo.carminati@mi.infn.it

The Standard Model Higgs boson discovery potential in the two photons decay channel with the ATLAS detector is reviewed in the $\simeq$ 115 - 140 GeV mass range. A signal significance above 5σ can be achieved with 100 fb^{-1} of integrated luminosity in a conservative approach in which leading order cross sections are used for both signals and backgrounds

1 Introduction

The H $\rightarrow \gamma\gamma$ is a promising discovery channel for a Standard Model Higgs boson in the $115 < m_H < 140$ GeV mass range at the LHC. It is a rare decay mode with a branching ratio at the level of 10^{-3} and a small production cross section of the order of $\sim$ 50 fb. The total Higgs boson production cross-section takes contribution from various subprocesses: in the mentioned mass range the gluon-gluon fusion is the dominant process. Small contributions come from VBF and $t\bar{t}$H associated production. The final state consists of two high-p$_T$ photons (p$_T \sim 50$ GeV) with invariant mass compatible with the Higgs boson mass. Despite the simple signature this is the most challenging channel for the performance of the ATLAS electromagnetic calorimeters: excellent energy and angular resolutions are needed to observe the narrow mass peak above the irreducible prompt $\gamma\gamma$ continuum and a powerful particle identification capability is required to reject the large QCD jet background.

2 Background rejection

The search of the H$\rightarrow \gamma\gamma$ signal at the LHC has to deal with two sources of background: the *irrebucible background*, which is due to direct QCD genuine photons pair production and the *reducible background*, which consists of jets that fake photons in the calorimeters. At the leading order the irreducible $\gamma\gamma$ QCD pairs are produced via the Born ($q\bar{q} \rightarrow \gamma\gamma$), box ($gg \rightarrow \gamma\gamma$) and quark bremsstrahlung ($qg \rightarrow q\gamma \rightarrow q\gamma\gamma$): the production cross section for the sum of the Born and box processes is of the order of 0.7 pb/GeV in the two photons mass range around 120 GeV. It has been shown ([1]) that, after isolation cuts, the quark bremsstrahlung contribution amounts to 50 % of the combined Box+Born, approximately indipendent of $m_{\gamma\gamma}$.
The reducible background comes from jet-jet and γ-jet events in which one or both jets are misidentified as photons: since the production cross-sections for these

processes are many order of magnitude larger than the signal cross section, an excellent γ/jet discrimination is required. In the ATLAS detector, the photon/jet separation essentially relies on the information from the hadronic and electromagnetic calorimeters: the leakage of the electromagnetic showers into the hadronic calorimeter and the shower shapes in the η and ϕ directions as well as the shower widths in the second sampling of the electromagnetic calorimeters can be used in the discrimination. After applying the cuts in the hadronic calorimeter and in the second sampling of the electromagnetic calorimeter only jets with little hadronic activity and narrow showers survive: the most dangerous consist of single or multiple hard π^0 decaying to two photons. The fine granularity of the strips compartment of the electromagnetic calorimeter can be exploited in order to reject these jets by looking for substructures within one shower in the η direction and by analysing the shower shape. The photon identification cuts have been optimized for converted and uncoverted photons separately, using the information from the Inner Detector: a track veto has also been applied. It has been shown ([5], [4]) that a jet rejection factor greater than 3000 can obtained for $E_T > 40$ GeV with a photon efficiency of ~ 80 % almost flat in η and p_T. After applying the full photon identification cuts the residual jet-jet and γ-jet backgrounds are found to be at the level of 15 % and 20 % respectively of the total irreducible background on the full relevant Higgs mass range.

3 Invariant mass reconstruction

A large number of $H \to \gamma\gamma$ events with different Higgs boson masses have been generated using PYTHIA 5.7 and the CTEQ2L structure function parametrization while the full ATLAS detector response has been simulated using the GEANT3 package. The effect of the electronic noise and pileup in the electromagnetic calorimeters has been included in the simulations for both low (10^{33} cm^{-2}s^{-1}) and high luminosity (10^{34} cm^{-2}s^{-1}) conditions. The impact of photon conversions on the mass resolution and on the signal reconstruction efficiency has thus been realistically evaluated since the fraction of events with a least one converted photons is $\sim 46\%$. The converted γ's are expected to be tagged in the tracker with an efficiency of $\sim 80\%$ approximately indipendent of p_T and η in the regions of interest.
The energy of unconverted and converted photons is reconstructed using different cluster sizes: referring to the middle layer granularity of the electromagnetic calorimeter ($\Delta\eta \times \Delta\phi = 0.025 \times 0.025$) a 3x5 and 3x7 cluster sizes have been used for unconverted and converted photons respectively: these cluster dimensions were found to be the optimal compromise between intrinsic resolution and sensitivity to pileup and electronic noises, which increases with larger cluster areas. A presampler, placed in front of the calorimeter, is used to correct for the energy lost in the upstream material.
Simple kinematic cuts which optimise the significance of the signal approximately over the considered mass range have been applied: the photon candidates were required to have a $p_T^1 > 40$ and $p_T^2 > 25$ GeV respectively and to be in the pseudorapidity range $|\eta| < 2.4$. Events with one or both photons in the barrel/endcap

electromagnetic calorimeters transition region ($\eta \sim 1.5$)) in an interval of $\Delta\eta = 0.15$ were rejected.
The direction of each photon is reconstructed exploiting the longitudinal segmentation of the electromagnetic calorimeter: the best estimation of the η position is calculated with a least squares fit method using the different measurements provided by the calorimeter compartments. The direction reconstruction takes advantages essentially from the fine granularity of the first compartment which is made of narrow strips ($\Delta\eta = 0.003$). In the H$\to \gamma\gamma$ events the primary vertex is reconstructed by properly weighting the two vertices estimations from both photons: the precision on the vertex measurement from the calorimeter alone, averaged over the full pseudorapidity coverage is 1.3 cm. Moreover, when a γ converts in the tracker, the position of the conversion is also used to increase the lever arm for pointing, leading to a better vertex reconstruction.
In low luminosity conditions the primary vertex can be reconstructed from the associated tracks by the Inner Detector with a $\sigma_z = 40\mu$m ([6]): in the presented analysis the vertex measurement from the tracker has been included in the low luminosity results while in the high luminosity case a conservative approach has been adopted and only the information from the calorimeters has been used.
The invariant mass of the two photons has been reconstructed and a 0.7 % contribution for the global constant term, as confirmed from recent testbeam data ([2], [3]) has been added: a summary of some relevant numbers for the case of 100 fb^{-1} of integrated luminosity in high luminosity conditions are reported in table 1.

Higgs mass (GeV)	**100**	**120**	**130**	**140**
Mass resolution (GeV)	1.31	1.43	1.55	1.66
Acceptance	0.44	0.51	0.53	0.55
Signal events	1045	1283	1186	973
Background events	56459	39400	33700	28250

Table 1. Resolutions, acceptances, expected number of signal and background events in the selected $\pm1.4\sigma$ mass window for H $\to \gamma\gamma$ decays as a function of m$_H$ for 100 fb^{-1} of integrated luminosity in high luminosity conditions.

4 Discovery potential

The expected H $\to \gamma\gamma$ signal significance, defined for each mass point as $S/\sqrt{B}$ where S and B are the expected number of accepted signal and background events in the choosen mass window of $\pm$ 1.4 σ_m are reported in figure 1 for an integrated luminosity of 30 and 100 fb-1: the first integrated luminosity will be collected in three years of LHC operation in the low luminosity phase and the second in one year at high luminosity. The contributions from the irreducible and reducible backgrounds are accounted in these estimates but NLO contributions are not included.

It can be noticed that in a conservative leading order approach (no K-factors) a Standard Model Higgs boson can be discovered with a significance greater than

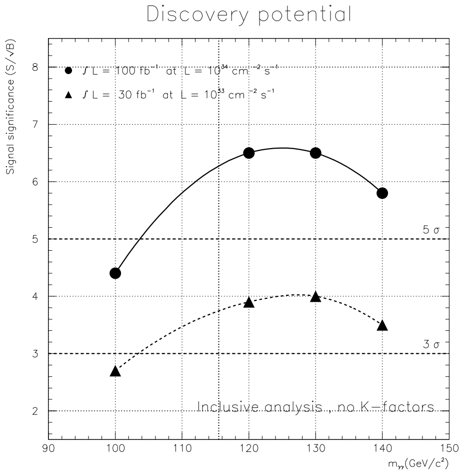

Figure 1. Sensitivity for the discovery of a Standard Model Higgs boson in the $\gamma\gamma$ channel for inclusive analysis as a function of the Higgs mass for an integrated luminosity of 30 and 100 fb^{-1} (no K-factors included).

5σ in the $115 \simeq m_H \simeq 140$ GeV mass range for an integrated luminosity of 100 fb^{-1}. Recently the detector layout has been slightly changed and the estimation of the luminosity in the first phase of the LHC has been updated to $2 \cdot 10^{33}$ cm^{-2} s^{-1} More recent analysis on new full detector simulations based on PYTHIA 6.203 and CTEQ5L structure functions confirm the presented results.
Recent theoretical calculations ([7], [8]) on the background allow a complete study of the channel at the NLO: a K-factor of $\sim$ 2 for the signal and $\sim$ 1.7 for the background have been computed so that a considerable increase of the signal significance is expected, although with large uncertainties. Analyses including NLO calculation are still ongoing. Promising results have been recently obtained on exclusive analysis such as VBF ([10]) and H+jet(s) ([9]): final studies on combined results are also in progress.

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