Standard Model Higgs Boson Properties with ATLAS.

William Murray on behalf of the ATLAS collaboration

STFC RAL, Harwell Science and Innovation Campus, Didcot, UK
E-mail: bill.murray@stfc.ac.uk

The observation of the Higgs Boson by the ATLAS experiment will be a key point in the exploration of LHC physics, but the analysis will not be complete until the properties of the particle have been established. This note attempts to explore which parameters can be measured and with what precision.
1. Introduction

The search for Higgs Bosons is one of the most compelling tasks for the LHC. The design of the ATLAS and CMS detectors was guided by the desire to discover - or exclude - this particle. The result seems to be that given sufficient data there is sensitivity to the Standard Model Higgs in at least two channels for all relevant masses [1]. The purpose of this note is to interpret those conclusions in terms of the measurements of the Higgs boson properties, as a step towards determining whether a new resonance observed is in fact the Standard Model Higgs boson.

The combination of search results and the electroweak fits [2] now indicate a Higgs boson mass between 114.4 GeV and 140 GeV at 95% CL; for the current discussion the region below 130 GeV will be regarded as low mass, and from 130 GeV up to 170 GeV is intermediate mass. The ATLAS sensitivity to this region, with 10 fb$^{-1}$, is shown in Fig 1.

![Figure 1](image_url)

**Figure 1:** The expected significance contributed by various search channels as a function of the Higgs boson mass for 10 fb$^{-1}$.

2. Mass

Within the framework of the Standard Model the Higgs boson mass will test the electroweak fits, but for this purpose a very precise determination is not particularly required. Stronger requirements come from the desire to define its decay modes, but even these should be easily surpassable. However, extensions such as supersymmetry make precise predictions of this quantity in terms of other unknown parameters, and it can then become of great interest.

For a low mass Higgs boson, the mass resolution is dominated by $H \rightarrow \gamma\gamma$. The typical event mass resolution, see Fig 2, is 1.5 to 1.7 GeV, and therefore the error is expected to be dominated by the photon energy scale, which is around 0.5% but improving with knowledge of the detector [1].

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Figure 2: The mass distributions expected in the $H \to \gamma\gamma$ (left) and $H \to ZZ$ (right) channels for Higgs boson masses of 120 and 150 GeV respectively.

In the intermediate mass region the $H \to ZZ$ channel produces the best measurement of the mass, with a resolution of 2 to 2.5 GeV. Again, the resulting error on the Higgs mass will be of the order of the lepton energy scale error which is 0.5% to 0.2% or better [1].

3. Couplings

The multitude of channels contributing to the Higgs discovery will allow information on their relative couplings to be extracted. Figure 1 gives a guideline as to the precision with which the rate in each channel might be determinable. It can be seen that for both low and intermediate masses there is a contribution both from gluon fusion ($\gamma\gamma$, 4l, $WW\,0j$) and from VBF dominated process ($\tau\tau$, $WW\,2j$), which means that the relative couplings to the top quark and W boson will be accessible via production. This is particularly straightforward in the case of the $WW$ decay mode where both production modes are presented separately in the figure, but is also true in, for example, $\gamma\gamma$. These production and decay channels give information on the coupling to the particle concerned except gluon fusion and photonic decay, which proceed by loops dominated by the top quark and W boson.

The $ttH, H \to bb$ process, where the expected mass distribution for a 120 GeV signal is shown in Fig 3, represents a considerable experimental challenge, but would provide a useful control on the overall cross-section through the dominant decay mode if the Higgs boson does indeed have a low mass. Although this is unlikely to be a discovery channel, if the mass is provided it should be possible to obtain a measurement which would allow the proportionality of the fermionic coupling to the mass can be tested.

The absolute values of Higgs boson couplings will not be available without making additional theoretical assumptions, unless the width can be measured. A global fit to all the channels including information from production and decay will be required. One procedure [3] is to limit the W and Z coupling to less than 5% above their Standard Model values. This produces sensitivity as shown in Fig 4 (right); around 20-30% on the $t$, $\tau$, $W$ and $Z$ and somewhat worse on the $b$ for a low mass Higgs boson.
4. Lifetime and Quantum Numbers

The lifetime of the Higgs boson in this mass region is around $10^{-22}$ seconds, which is not measurable through flight length, nor does it produce a width which is experimentally accessible to ATLAS unless the mass is well above the vector boson on-shell threshold. On the other hand, the charge will be established to be zero through the detection mode rather easily.

The observation of a Higgs boson produced in gluon fusion or photon decay shows the spin is integral and not unity. The $ZZ$ decay angular distribution will exclude the higher spin states convincingly. The parity can also be determined from $ZZ$ decay with around 60 $fb^{-1}$ [4], and VBF [5] should also be sensitive.

References


