SM Higgs properties measurement at ATLAS

William Murray, on behalf of the ATLAS collaboration

STFC RAL, Harwell Science and Innovation Campus, Didcot, Oxon. OX11 0QX, UK

Abstract. The discovery of a new particle in the Higgs searches being prepared for LHC will not guarantee that the Standard Model Higgs boson has been seen. This paper discusses the possibilities for measuring the spin, parity and couplings of the particle, under the assumption that it does in fact behave like the Standard Model Higgs.

The key question, which cannot alas be answered, is: if it looks like a dog, and barks like a dog, how much of the DNA must we analyse to be sure that it is a dog?

Keywords: Higgs, properties, spin, couplings, lifetime
PACS: 14.80.Bn

ATL-PHYS-PROC-2009-078
12 August 2009

THE SCENARIO ENVISAGED

One of the highest priorities for ATLAS at the LHC will be the discovery (or falsification) of the Higgs Boson. The luminosity required for this will depend upon the Higgs boson mass and the detector performance. In this note we consider what properties of the Higgs boson can be established, assuming that a particle like the Standard Model Higgs boson has been seen and that 30 fb^{-1} or more of data are available.

Current data [1, 2, 3] suggest that the Standard Model Higgs lies between 114 and 160 GeV, and probably rather close to the lower limit. The analyses described here divide roughly by whether or not the Higgs Boson, in this range, lies above or below 130 GeV in mass. In the upper region searches for $H \to WW$ and $H \to ZZ^*$ dominate the results, while in the lower region they are progressively suplanted by $H \to \gamma\gamma$ and $H \to \tau\tau$ modes. $H \to b\bar{b}$ is a difficult, but important, addition.

There are four significant production modes, which in descending order of rate are gluon fusion, vector boson fusion, vector boson associated production, and top quark associated production. Each mode should ultimately be measured, providing distinct information on the relative production rates.

HIGGS MASS MEASUREMENT

The mass measurement depends upon the mass itself. Assuming, that a particle with properties close to the Standard Model Higgs boson has been found, then the measurement of that mass is most accurately performed by the ZZ^* channel, which contributes for masses above around 125 GeV, and the $\gamma\gamma$ mode below about 140 GeV.

The resolution in the $ZZ^* \to l^+l^-l^+l^-$ mode is 2 to 2.5 GeV per event, depending upon mass and chanel (e, μ), giving a statistical error of 0.4 GeV or better from 30 fb^{-1} for most of the mass range considered. The expected distribution for m_H=150 GeV is shown in Fig. 1 (left). The systematic errors are dominated by the lepton energy scale

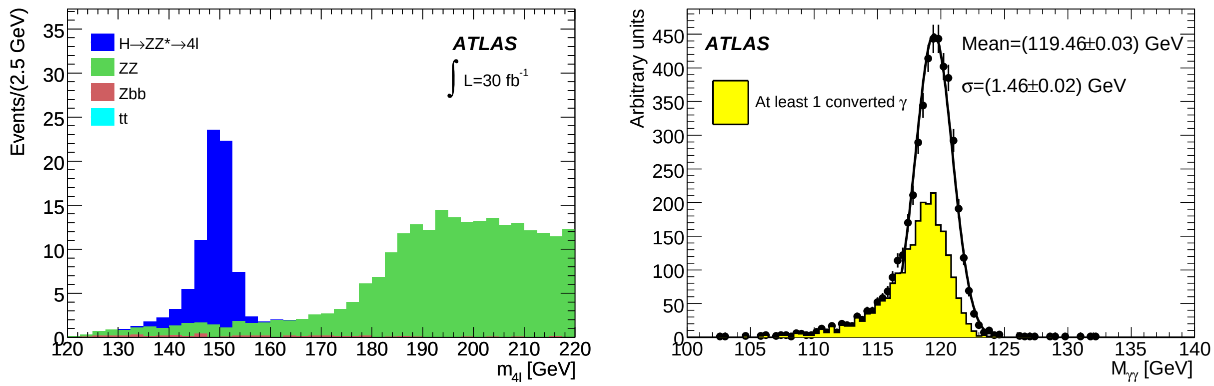

FIGURE 1. The expected mass distribution in the ZZ^* channel (left) and the mass resolution in the $H \rightarrow \gamma\gamma$ channel (right).

uncertainty of 0.5% to 0.2% or better, and are thus likely to be a significant concern. They will be controlled in many ways, including the use of the known Z peak in the $Z \rightarrow l^+l^-$ decay.

In the $\gamma\gamma$ channel the mass resolution is around 1.5 GeV, dependent upon the understanding of photon conversions in the material of the ATLAS tracker (Fig 1 right). The systematic error will be more difficult than in the leptonic channels as the calibration is not directly applicable, and will be of order 0.5% or better. It is likely to dominate the resulting precision on the Higgs boson mass.

The electroweak fits constrain the Higgs mass only to of order 30%; thus a measurement at the level of 10% is sufficient to test the standard model. However, in minimal supersymmetry the mass of the lightest Higgs boson can be predicated in terms of the other model parameters, and a precision at least equal to that on the top quark mass is desirable. These goals should be achieved.

COUPLINGS

The total width of the Higgs boson varies between 4 MeV at 115 GeV to 300 MeV at 160 GeV. These will be too small to be measurable at ATLAS, but an upper limit should still be derived. Similarly, the lifetime is unobservable, consistency with zero of the lifetime can be checked in ZZ^*, WW^* and $\tau\tau$ modes.

Much more information can however be obtained from the measured branching ratios. ATLAS has many search channels and Fig 2 shows the sensitivity with which the most prominent of them would be sensitive to a Standard Model Higgs boson as a function of its mass. This gives a guide to the precision which could be achieved with this luminosity. It is gratifying to notice that there are always three channels giving at least two sigma from 160 GeV down to 130 GeV.

To give specific examples: for a 160 GeV Higgs the WW decay dominates, and it should be possible to access it in gluon fusion, vector boson fusion, and both associated modes. However, the other decay modes are suppressed, with the ZZ^* in gluon fusion being the most important other observable channel. In contrast, for a 120 GeV Higgs boson, the rare $\gamma\gamma$ mode which will provide information on all the production processes, but requiring more data than the aforementioned WW. It will be accompanied by VBF $H \rightarrow \tau\tau$, and probably Higgs to $b\bar{b}$ via one or both of the associated production processes.

Thus several different products of production times branching ratio can be measured, and from these information on the fundamental couplings can be extracted. However, absolute couplings cannot be established without imposing some theoretical assumptions, as the total width is not measurable. One approach [4], is to limit the HWW and HZZ couplings are less than or equal to their Standard Model values. The results of this can be seen in figure 2.

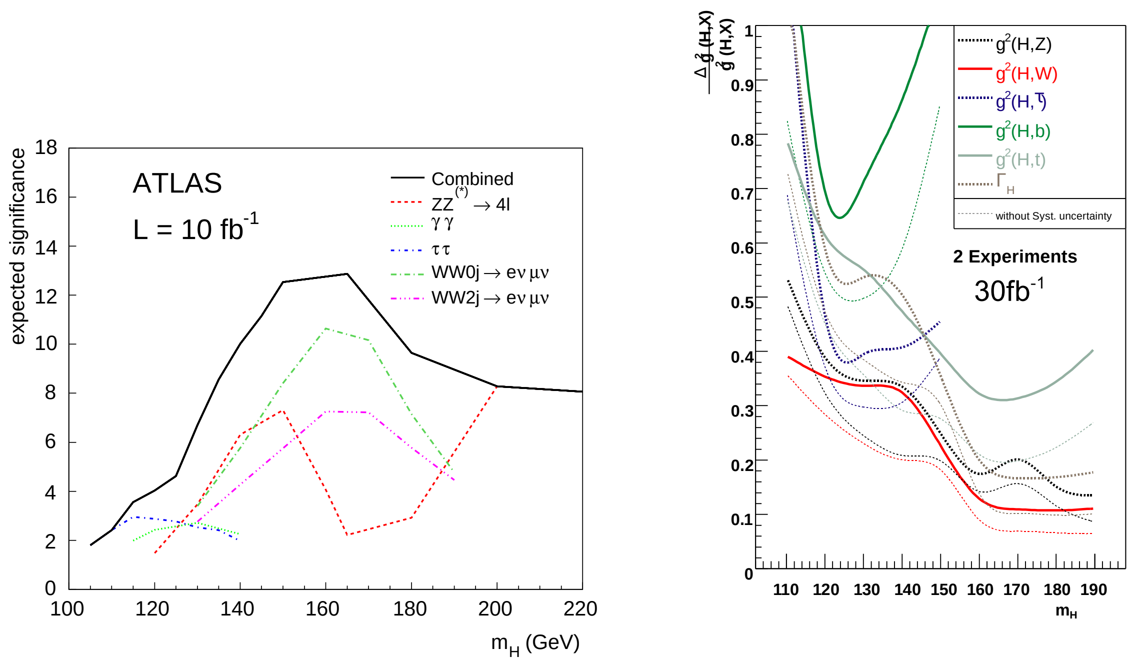

FIGURE 2. The expected significance from the more important ATLAS Higgs search channels (left), and the precision which can be achieved in the measurement of the Higgs couplings (right).

The conclusion is that couplings to W, Z, t and τ can be extracted with precision of order 40%, while the b quark coupling has an error of 60% when two experiments with 30 fb^{-1} are combined. These numbers will improve with larger datasets.

Note that the measurement of the $t\bar{t}H \rightarrow t\bar{t}b\bar{b}$ process is important for this derivation. The most recent ATLAS study [5] expected a significance of order only 0.5 σ from 30 fb^{-1}; much lower than assumed in Fig 2 (right). The analysis of $H \rightarrow b\bar{b}$ will be suplemented by the addition of the production channels WH and ZH, which are under development.

The self-couplings of the Higgs, accessed through HH production, are a particular challenge for LHC experiments [6]. This is sometimes advanced as a motivation for the SLHC, but this needs justification.

SPIN AND PARITY

The spinless nature of the Higgs boson is unique, and should be verified. The channels used for its observation will instantly prove that the spin is integral (and, incidentally, show it to be chargeless and colourless). Furthermore the likely observation of the two-photon decay mode will further remove the possibility of a spin one particle. However, verification of the spin zero parity plus nature must be done.

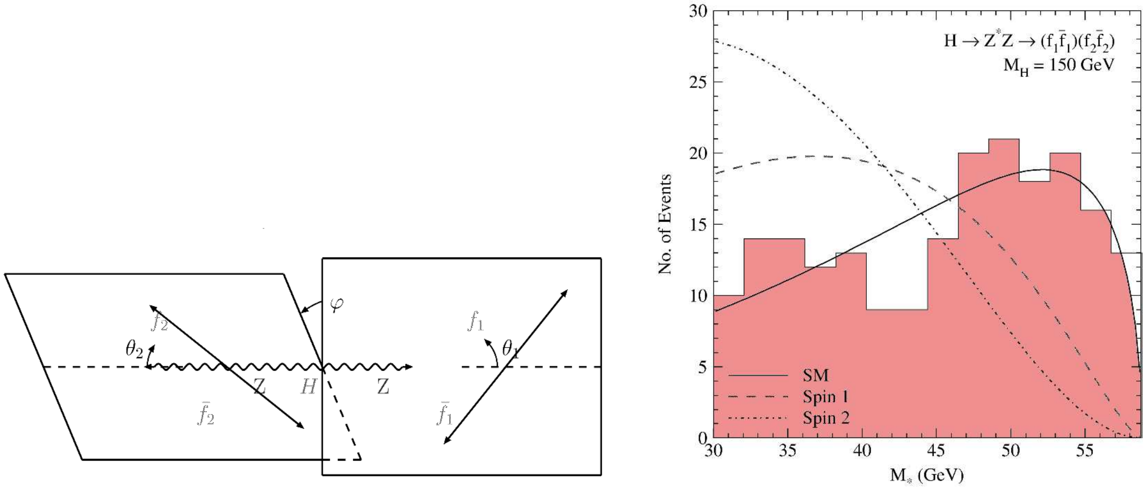

FIGURE 3. The angles used to spin-analyse the ZZ^* channel (left) and the mass distribution of the off-shell boson (right). Plots are from [7].

The ZZ^* channel is especially suitable for this extraction. In particular the decay angles of the Z bosons allow the extraction of both spin and parity. This has been studied mostly for on-shell ZZ production, suggesting a high degree of separation is possible for 100 fb^{-1}[8]. For the lower Higgs masses currently expected the mass distribution, as shown in Fig. 3, also has an important role to play.

Furthermore the spin and parity can also be extracted from the VBF process, which also sensitive to large CP odd or even couplings in addition to the Standard Model ones with only 10 fb^{-1}[9].

REFERENCES

1. ALEPH, DELPHI, L3, and OPAL, *Phys. Lett. B* **565**, 61–75 (2003).
2. V. Büscher, “Experimental searches for Higgs Bosons at the Tevatron,” 2009.
3. H. Flächer, M. Goebel, J. Haller, A. Höcker, K. Mönig, and J. Stelzer, *Eur. Phys. J. C* **60**, 543 (2009).
4. M. Duhrssen, S. Heinemeyer, H. Logan, D. Rainwater, G. Weiglein, and Z. Zeppenfeld, *Phys. Rev. D* **70**, 113009 (2004).
5. ATLAS, Expected performance of the atlas experiment : Detector, trigger and physics, Tech. Rep. CERN-OPEN-2008-020 (2008).
6. U. Baur, T. Plehn, and D. Rainwater, *Phys. Rev. D* **68**, 033301 (2003).
7. S. Y. Choi, D. J. Miller, M. M. Mühelleitner, and P. Zerwas., *Physics Letters B* **553**, 61–71 (2003).
8. C. P. Buszello, I. Fleck, P. Marquard, and J. J. van der Bij, *Eur. Phys. J C* **32**, 209–219 (2004).
9. C. Ruwiedel, M. Schumacher., and N. Wermes, *Eur. Phy. J C* **51**, 385–414 (2007).