ATLAS discovery potential for Higgs bosons beyond the Standard Model

Markus Warsinsky for the ATLAS collaboration

Institut für Kern- und Teilchenphysik, TU Dresden, 01062 Dresden, Germany.

E-mail: Markus.Warsinsky@physik.tu-dresden.de

Abstract. This article describes the potential of the ATLAS experiment at the LHC to discover Higgs bosons in Beyond the Standard Model (BSM) scenarios. Two examples are discussed. First the discovery potential for Higgs bosons in the Minimal Supersymmetric Standard Model (MSSM) is evaluated. At least one Higgs boson can be observed for the whole accessible parameter space. Second the case of invisibly decaying Higgs bosons is discussed. A Higgs boson with a large branching ratio into invisible particles can also be discovered.

ATL-PHYS-CONF-2007-010
24 September 2007

1. Introduction

The ATLAS experiment at the LHC is due to start data taking in 2008. One of the primary goals of the experiment is to search for the Higgs boson. However, if there is physics beyond the Standard Model (SM), the Higgs sector could be altered significantly thus requiring different search strategies. In this article the cases of the Minimal Supersymmetric Standard Model (MSSM) and of invisibly decaying Higgs bosons are discussed.

2. MSSM Higgs bosons

Low scale supersymmetry is considered to be one of the most promising theories introducing physics beyond the SM. The MSSM adds a supersymmetric partner to each SM field. SUSY-particles are expected to have masses of $\mathcal{O}(1\,\mathrm{TeV})$ and below, making most of them accessible at the LHC. In addition the MSSM requires two complex Higgs field doublets. If CP is conserved this leads to five physical Higgs bosons, h and H ($CP = +1$), A ($CP = -1$), and two charged Higgs bosons, $H^{\pm}$. At tree level the MSSM Higgs sector is described by two parameters, usually chosen to be the ratio of the vacuum expectation values of the two Higgs doublets, $\tan\beta$, and the mass of the pseudoscalar Higgs boson M_A. Loop corrections, mainly from the $t/\tilde{t}$-sector introduce sensitivity to five additional parameters and to the mass of the top-quark. Representative benchmark scenarios [1] have been introduced, where only $\tan\beta$ and M_A are varied and the other parameters are fixed. One of them is the M_h^{max} scenario, which was designed to give the maximal mass for the lightest Higgs boson leading to the most conservative exclusion bounds from LEP [2]. The CPX scenario [3] was designed to maximize CP-violation in the Higgs sector. In this scenario, the CP-eigenstates given above mix into mass-eigenstates H_1, H_2 and H_3. The scan is then done in the $M_{H^{\pm}}$-$\tan\beta$-plane.

The discovery potential reported here is obtained from a set of Monte-Carlo studies of searches for the SM Higgs boson and dedicated MSSM analyses. For neutral Higgs bosons the following channels have been included (ϕ stands for a neutral Higgs boson mass eigenstate): Vector Boson

Fusion ($qq \to qq\phi$) with $\phi \to \tau\tau, WW, \gamma\gamma$ [4, 5], top-associated production with $\phi \to bb$ [6], b-associated production with $\phi \to \mu\mu$ [7, 8] and $\phi \to \tau\tau$ [9–11], gluon-gluon-fusion with $\phi \to \gamma\gamma/ZZ \to 4\ell/WW \to \ell\nu\ell\nu$, gauge-boson-associated production with $\phi \to \gamma\gamma/bb/WW \to \ell\nu\ell\nu$, $H/A \to tt$, $H \to hh \to \gamma\gamma bb$ and $A \to Zh \to \ell\ell bb$ (all from [12]). For charged Higgs bosons $gb \to tH^{\pm}, H^{\pm} \to \tau\nu$ [13] and $tt \to tH^{\pm}b, H^{\pm} \to \tau\nu$ [14] contribute. Key performance numbers have been obtained from a full simulation of the ATLAS detector, but signal efficiencies and background expectations are estimated from a fast simulation. Systematic uncertainties are not yet included. Masses and couplings of the MSSM Higgs bosons have been calculated using the FeynHiggs program [15], the production cross sections have been taken from [16–19] after having been modified for differences between MSSM and SM couplings. More detail can be found in [20–22]. The discovery potential at the 5σ level is similar in all benchmark scenarios. It is shown exemplarily assuming an integrated luminosity of 300 fb^{-1} in Figure 1 for the M_h^{max} scenario and in Figure 2 for the CPX scenario. In almost all of the parameter space that is

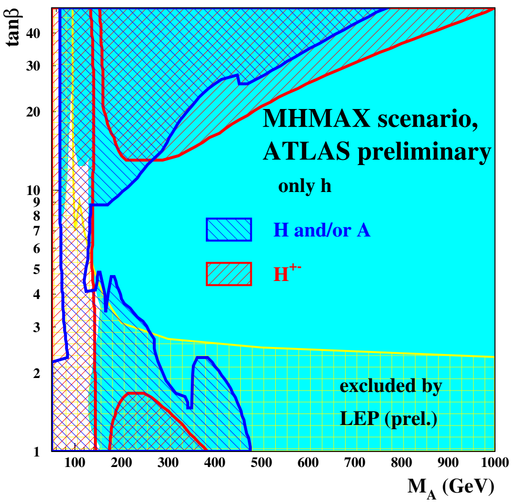

Figure 1. ATLAS discovery potential for Higgs bosons of the MSSM in the M_h^{max} scenario for 300 fb^{-1} (from [20]).

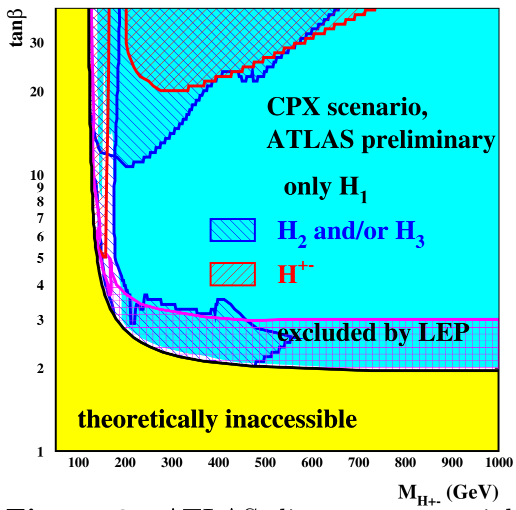

Figure 2. ATLAS discovery potential for Higgs bosons of the MSSM in the CPX scenario for 300 fb^{-1} (from [22]).

not excluded by LEP [2] at least one Higgs boson can be discovered. Only in the CPX scenario a small region corresponding to $M_{H^{\pm}} \approx 150$ GeV and $\tan\beta \approx 5$ is not covered by the current analyses [22]. For a large part of the parameter space more than one Higgs boson can be discovered. A new analysis on charged Higgs boson production [23] closes the gap at high $\tan\beta$ and $M_A \approx M_{\text{top}}$. In the remaining region of intermediate $\tan\beta$ only the lightest Higgs boson will be in reach. It will be difficult to distinguish it from a SM Higgs boson on measurements of the ratio of branching fractions into different final states in the same production process [20]. Updated analyses for b-associated production of MSSM Higgs bosons in the $\mu\mu$ [24, 25] and $\tau\tau$ [26] final states have not yet been included in this combination.

3. Invisible Higgs Decays

In many extensions of the SM, e.g. [27, 28], the branching ratio of the Higgs boson into undetectable particles can be enhanced. In the context of searches for invisibly decaying Higgs bosons the sensitivity is given with respect to $\xi^2 = \text{BR}(H \to \textit{invisible}) \cdot \sigma_{\text{prod}}/\sigma_{\text{prod}}^{\text{SM}}$. A sensitivity to $\xi^2 < 1$ means that one can observe this invisible Higgs decay with Standard Model cross sections, while for $\xi^2 > 1$ an enhanced cross section is necessary. MC studies have been performed of invisible Higgs decays in top-associated ($t\bar{t}H$, all hadronic and 1 lepton final states) [29,30] and gauge boson associated ($ZH, Z \to ee$ or $\mu\mu$) production [31,32], and in Vector

Boson Fusion (VBF, $qq \to qqH$) [33]. The overall discovery potential is shown in Figure 3 [31] for an integrated luminosity of $30\,\text{fb}^{-1}$. Only the VBF topology is sensitive to $\xi^2 < 1$ for all Higgs boson masses considered. At low masses also the ZH and $t\bar{t}H$ production mechanisms provide some sensitivity. In case of evidence for an invisibly decaying resonance it would be necessary to observe it in different channels in order to establish it as a Higgs boson.

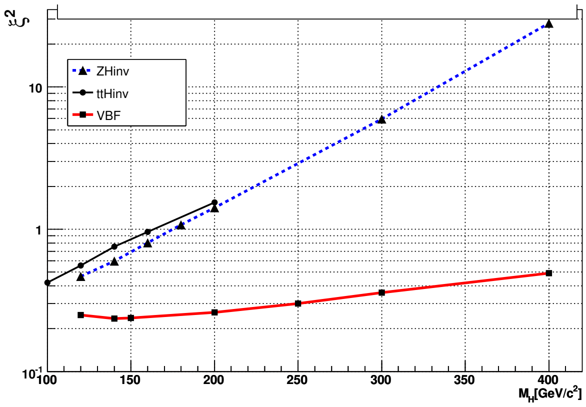

Figure 3. ATLAS sensitivity at the 95% CL to a Higgs boson with a branching ratio of ξ^2 to invisible final states assuming SM-like production cross sections for an integrated luminosity of $30\,\text{fb}^{-1}$ [31]. Red (gray) solid line: VBF ($qq \to qqH$), blue (black) dashed line: ZH, black solid line: $t\bar{t}H$).

Acknowledgments

I want to thank all ATLAS collaborators, especially Markus Schumacher, for helpful discussions.

4. References

[1] Carena M S, Heinemeyer S, Wagner C E M and Weiglein G 2003 *Eur. Phys. J.* C **26** 601.
[2] [LEP Higgs Working Group] 2001 *Preprint* hep-ex/0107030, LHWG Note 2001-04.
[3] Carena M S, Ellis J R, Pilaftsis A and Wagner C E M 2000 *Phys. Lett.* B **495** 155.
[4] Asai S *et al* 2004 *Eur. Phys. J.* C **32S2** 19.
[5] Cranmer K, Mellado B, Quayle W and Wu Sau Lan 2003 *Atlas Note* ATL-PHYS-2003-036.
[6] Cammin J and Schumacher M 2003 *Atlas Note* ATL-PHYS-2003-024.
[7] Cavalli D and Bosatelli P 2000 *Atlas Note* ATL-PHYS-2000-001.
[8] Gonzales S, Ros E and Vos M A 2002 *Atlas Note* ATL-PHYS-2002-021.
[9] Cavalli D and Resconi S 2000 *Atlas Note* ATL-PHYS-2000-005.
[10] Cavalli D and Negri G 2003 *Atlas Note* ATL-PHYS-2003-009.
[11] Thomas J 2003 *Atlas Note* ATL-PHYS-2003-003.
[12] ATLAS Collaboration 1999 CERN-LHCC-99-15.
[13] Assamagan K A, Coadou Y and Deandrea A 2002 *Eur. Phys. J. direct* C **4** 9.
[14] Biscarat C and Dosil M 2003 *Atlas Note* ATL-PHYS-2003-038.
[15] Heinemeyer S 2006 *Int. J. Mod. Phys.* A **21** 2659 and references therein.
[16] Spira M 1998 *Fortsch. Phys.* **46** (1998) 203.
[17] Plehn T 2003 *Phys. Rev.* D **67** 014018.
[18] Sjostrand T 1994 *Comput. Phys. Commun.* **82** 74.
[19] Sjostrand T *et al* 2001 *Comput. Phys. Commun.* **135** 238.
[20] Schumacher M 2004 *Preprint* hep-ph/0410112.
[21] Buscher V and Jakobs K 2005 *Int. J. Mod. Phys.* A **20** 2523.
[22] Accomando E *et al* 2006 *Preprint* hep-ph/0608079, CERN-2006-009.
[23] Mohn B, Flechl M and Alwall J 2007 *Atlas Note* ATL-PHYS-PUB-2007-006.
[24] Gentile S, Bilokon H, Chiarella V and Nicoletti G 2007 *Preprint* arXiv:0705.2801 [hep-ex].
[25] Kourkoumelis C, Fassouliotis D, Nikolopoulos K and Milosavljevic M 2006 *Atlas Note* ATL-PHYS-PUB-2006-030.
[26] Szymocha T 2006 *Atlas Note* ATL-PHYS-PUB-2006-010.
[27] Binoth T and van der Bij J J 1997 *Z. Phys.* C **75** 17.
[28] Belotsky K, Fargion D, Khlopov M, Konoplich R and Shibaev K 2003 *Phys. Rev.* D **68** 054027.
[29] Kersevan B P, Malawski M and Richter-Was E 2003 *Eur. Phys. J.* C **29** 541.
[30] Schroff D *et al*, ATLAS note in preparation.
[31] Meisel F, Dührssen M, Heldmann M and Jakobs K 2006 *Atlas Note* ATL-PHYS-PUB-2006-009.
[32] Gagnon P 2005 *Atlas Note* ATL-PHYS-PUB-2005-011.
[33] Di Girolamo B and Neukermans L 2003 *Atlas Note* ATL-PHYS-2003-006.