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THE STANDARD MODEL HIGGS BOSON AT LHC: RECENT DEVELOPMENTS

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Abstract

The search for the Higgs boson is one of the most important tasks of two multi-purpose experiments: CMS and ATLAS. Both experiments are expected to start taking data in 2008, when the LHC begins its operation at 14 TeV. The most recent results from the CMS and ATLAS Standard Model Higgs boson discovery potential are presented, obtained using the most recent full simulation and reconstruction software as well as with detailed treatment of systematic uncertainties. Results show that the whole Standard Model Higgs boson mass range will be covered with about $\sim 10 fb^{-1}$.

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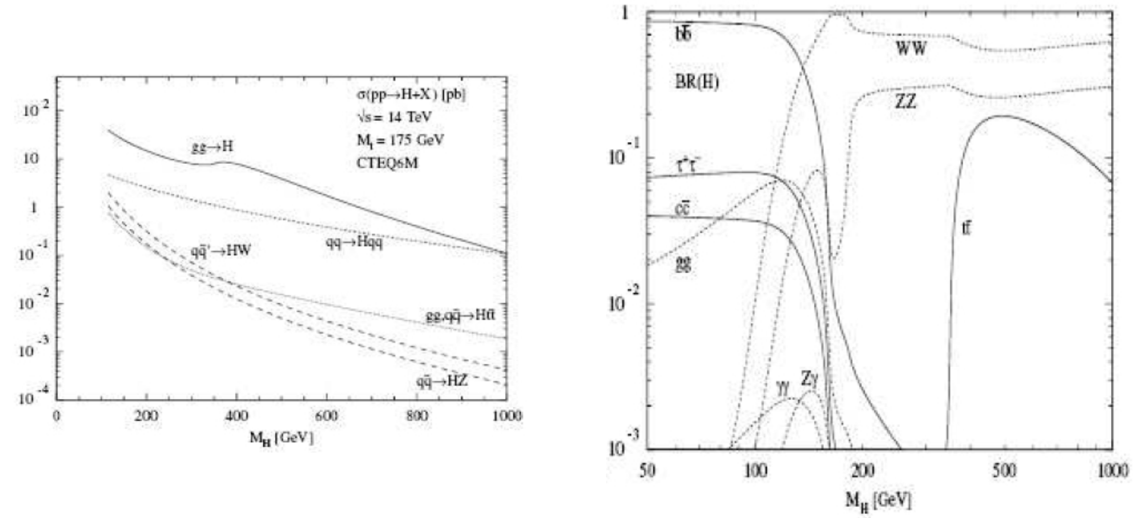

Figure 1: **Left:** Higgs production cross sections at the LHC for the various production mechanisms as a function of the Higgs mass. The full QCD-corrected results for the gluon fusion $gg \to H$, vector-boson fusion $qq \to VVqq \to Hqq$, vector-boson bremsstrahlung $q\bar{q} \to V^* \to HV$ and associated production $gg, q\bar{q} \to Ht\bar{t}$ are shown. **Right:** Branching ratios of the dominant decay modes of the SM Higgs particle. All relevant higher-order corrections are taken into account.

There are four main experiments at the Large Hadron proton-proton Collider (LHC) [1] at CERN [2], two of them are general purpose detectors: CMS (Compact Muon Solenoid) [3] and ATLAS [4] (A Toroidal Lhc ApparatuS). One of the most important tasks for these experiments is to search for the Higgs boson, the last missing piece of the Standard Model (SM) that is still not confirmed experimentally.

1 The Standard Model Higgs boson production and decay

The main production channels for the SM Higgs boson are: gluon fusion via top loop, vector boson (W/Z) fusion, W/Z associated production, $t\bar{t}$ fusion. The production cross section at the LHC as a function of the the Higgs boson mass is shown in Fig. 1 [5] (right). In the Higgs boson search analyses, NLO corrections for signal and background processes were used when available. At LHC, 14 TeV proton-proton collider, the dominant production mechanism is gluon fusion, whereas at Tevatron, proton-anti-proton 2 TeV collider, the most relevant mechanism is W/Z associated production, see e.g. Ref. [6].

The Higgs decay modes (see Fig. 1, left plot) can be divided into two different mass ranges. For $M_H \leq 135\text{GeV}/c^2$ the Higgs boson mainly decays into $b\bar{b}$ and $\tau^+\tau^-$ pairs with branching ratios of about 85% and 8% respectively. Both $b\bar{b}$ and $\tau^+\tau^-$ Higgs boson decay modes (as well as modes into $c\bar{c}$ and gluon pairs) are [almost] impossible for discovery due to overwhelming background level. The most useful Higgs decays in this mass range at the LHC is the decay into photon pairs. It reaches a branching fraction of up to 2×10^{-3}. Its importance lies in the clean environment and controllable background, which makes it an important discovery channel for small Higgs boson masses.

For Higgs masses above 135 GeV/c^2 the main decay modes are those into WW and ZZ pairs. These are very important discovery channels, in particular $\mathrm{H} \to \mathrm{ZZ}^{(*)} \to 4\mu$ is called the "golden mode" for its very clean (4 muons) final state, which provides a low/medium integrated luminosity level for discovery of the Higgs boson for all possible Higgs boson masses in consideration ($\sim 115 - 600\text{GeV}/c^2$).

2 Searches for the SM Higgs boson

This section discusses the detailed analyses available for many of the SM Higgs boson production and decay channels from both CMS and ATLAS collaborations. They include:

- inclusive $H \to \gamma\gamma$ [7, 8],
- inclusive $H \to WW/ZZ$ [9, 10],

- qqH production mode with Higgs decaying into $\tau\tau, \gamma\gamma, WW/ZZ$ [11, 12],
- W/Z+H production mode with Higgs decaying into $\gamma\gamma, WW$ [13],
- $t\bar{t}H$ production mode with Higgs decaying into $b\bar{b}, \gamma\gamma$ [14, 15].

2.1 Inclusive $H \to \gamma\gamma$

The distinct feature of this analysis is the assignment of a weight to every event depending on the "quality" of reconstructed photon candidates. One can find the signal-background spectrum for different photon categories in Fig. 2 [16]. There is a clear gain in exploiting this feature: getting the most for significance from events with less background contamination. This analysis also took advantage of optimizing the signal vs. background significance via Neural Network techniques, which decreased the integrated luminosity level needed for 5σ discovery roughly by factor of 2.

2.2 Inclusive $H \to ZZ$

In the $\mathrm{H} \to \mathrm{ZZ}^{(*)} \to 4\mu$ analysis counting and Log-Likelihood ratio techniques were used as well as genetic algorithm techniques [17] to optimize the outcome of the analysis, which led to $M_{4\mu}$-dynamic cuts and about 1σ improvement in terms of signal to background significance all over the $M_{4\mu}$ spectrum. Effort was made to make analysis as close as possible to "as one would do it with real data": lepton reconstruction and isolation techniques from data were developed and tested.

A detailed study of systematic uncertainties was performed in this and many other analyses by CMS and ATLAS. Some of the main systematic uncertainties come from the major background cross sections (for many analyses) and NLO k-factors as well as possible contribution from unaccounted backgrounds (including processes, which become important when fake leptons, for example, are taken into account). Also estimations were made to rescale the local excess of significance due to the fact that we look for a narrow resonance in a broad range of M_H.

2.3 Inclusive $H \to WW$

In $H \to \gamma\gamma$ analysis, one uses sidebands of huge, but smooth background in $M_{\gamma\gamma}$-spectrum; the, inclusive $H \to WW$ analysis uses control regions in phase space where signal "contamination" is minimized (see Fig. 3 [16], top). Signal and irreducible WW background events were also re-weighted with dynamic NLO k-factors (for p_T^{WW} distribution) in order to properly calculate the discovery potential for this important channel (the procedure is proposed in Ref. [18] and it improves significance considerably).

2.4 Vector boson fusion $H \to WW$

As in the previous one, this analysis is also a counting experiment and uses signal and control parts of phase space for the discovery region and background control (see Fig. 3 [12], bottom). The advantage in this analysis is the ability to tag two additional forward jets.

2.5 Discovery reach summary

Figure 4 (left) [16] shows the signal significance as a function of the Higgs boson mass for 30 fb^{-1} of integrated luminosity for the different Higgs boson production and decay channels with CMS. Similar results for ATLAS are shown on Fig. 4 (right) [12].

Figure 5 (left) [16] shows the integrated luminosity needed for the 5σ discovery of the inclusive Higgs boson production $\mathrm{pp} \to \mathrm{H} + \mathrm{X}$ with the Higgs boson decay modes $\mathrm{H} \to \gamma\gamma$, $\mathrm{H} \to \mathrm{ZZ} \to 4\ell$, and $\mathrm{H} \to \mathrm{WW} \to 2\ell 2\nu$ – the three front runners among all possible decay channels. $\mathrm{H} \to \gamma\gamma$ dominates the discovery reach up to $m_H \sim 130 \mathrm{GeV}/c^2$, similarly $\mathrm{H} \to \mathrm{WW} \to 2\ell 2\nu$ dominates for $\sim 150 - 180$ GeV and $\mathrm{H} \to \mathrm{ZZ} \to 4\ell$ – in the rest of the possible Higgs boson masses. Figure 5 (right) shows the Higgs boson mass measurements precision, $\Delta M_H/M_H$, as a function of the Higgs boson mass for 30 fb^{-1} of integrated luminosity for the different Higgs boson production and decay channels with CMS.

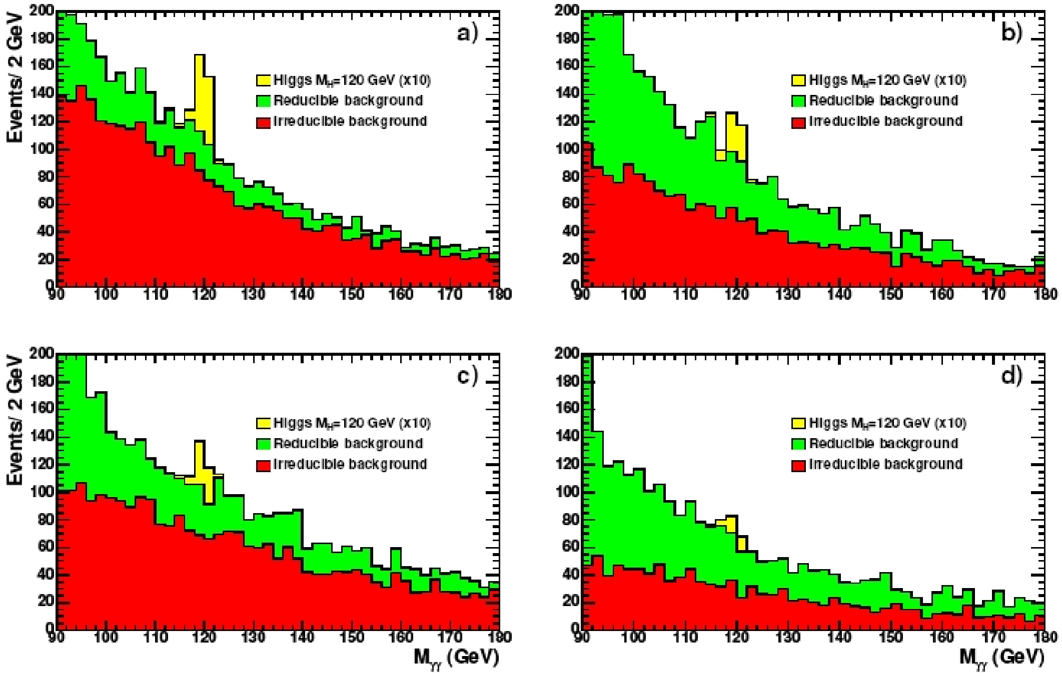

Figure 2: **Inclusive $H \to \gamma\gamma$ analysis.** Invariant mass spectrum for four photon categories. Events are normalized to an integrated luminosity of $1fb^{-1}$ and the Higgs signal, shown for different masses, is scaled by a factor 10.

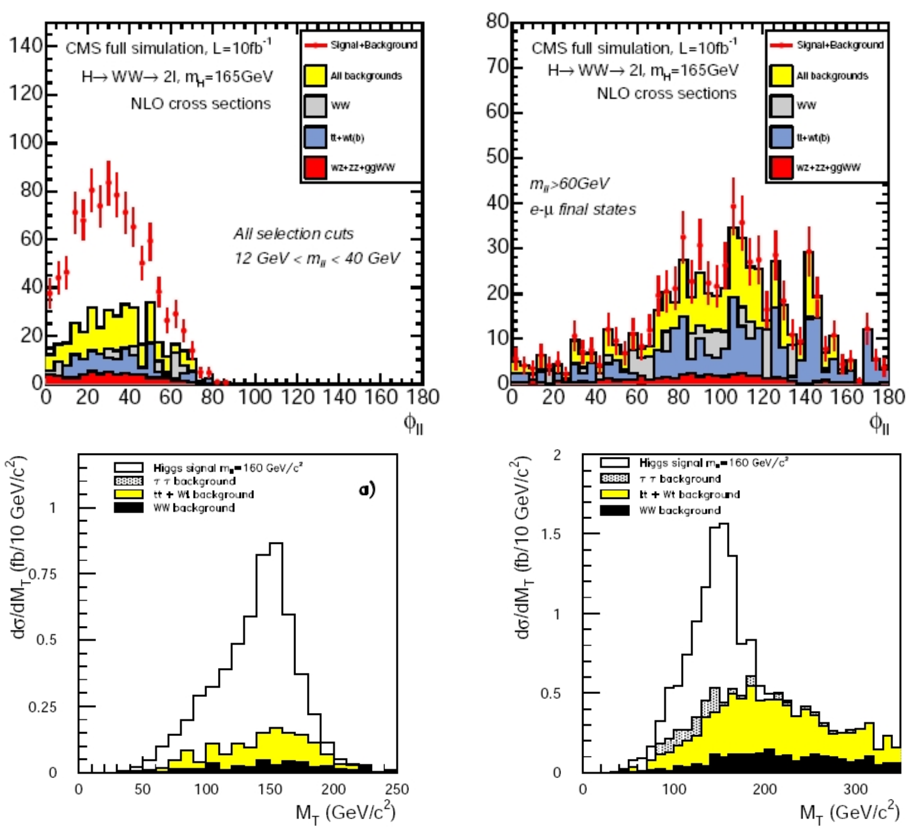

Figure 3: **Inclusive $H \to WW$ analysis. Top:** The angle between the leptons in the transverse plane is shown for the signal and the different backgrounds and a luminosity of 10fb^{-1}, left plot is for the signal cuts and right plot is for the WW background normalization region where all signal cuts are applied, except the one on the lepton invariant mass. **VBF $H \to WW$ analysis. Bottom:** Distribution of the transverse mass M_T for Higgs boson masses of 160 GeV$/c^2$ is shown (left - is for "signal-like" part of the phase space, and right - is for "background-like" part of the phase space).

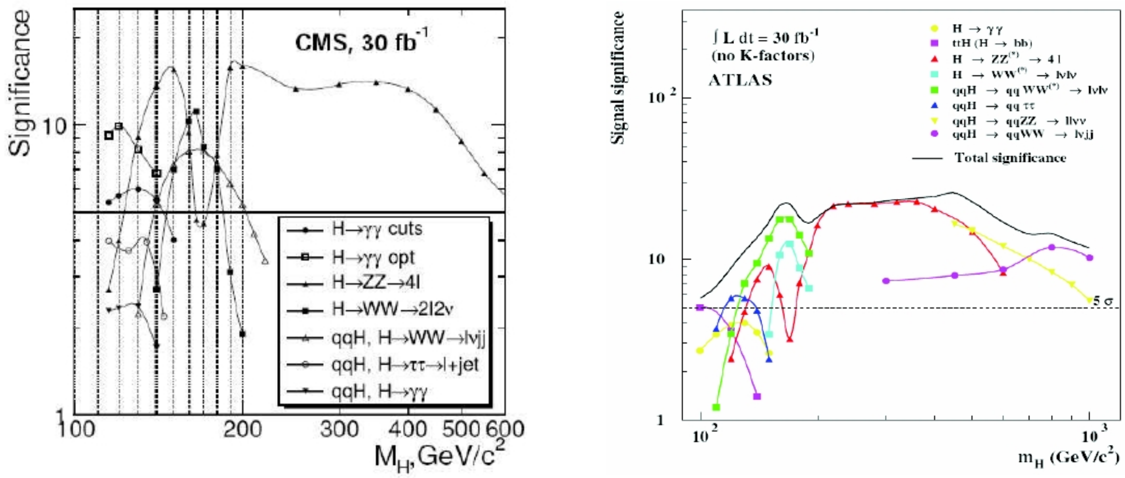

Figure 4: **Left:** The signal significance as a function of the Higgs boson mass for 30 fb^{-1} of the integrated luminosity is shown for the different Higgs boson production and decay channels for analyses with CMS. **Right:** The corresponding summary plot for ATLAS is shown. The difference in reach curves mainly comes from NLO vs. LO cross sections and full simulation vs. fast simulation for CMS vs. ATLAS results. (There is an update expected for ATLAS official results.)

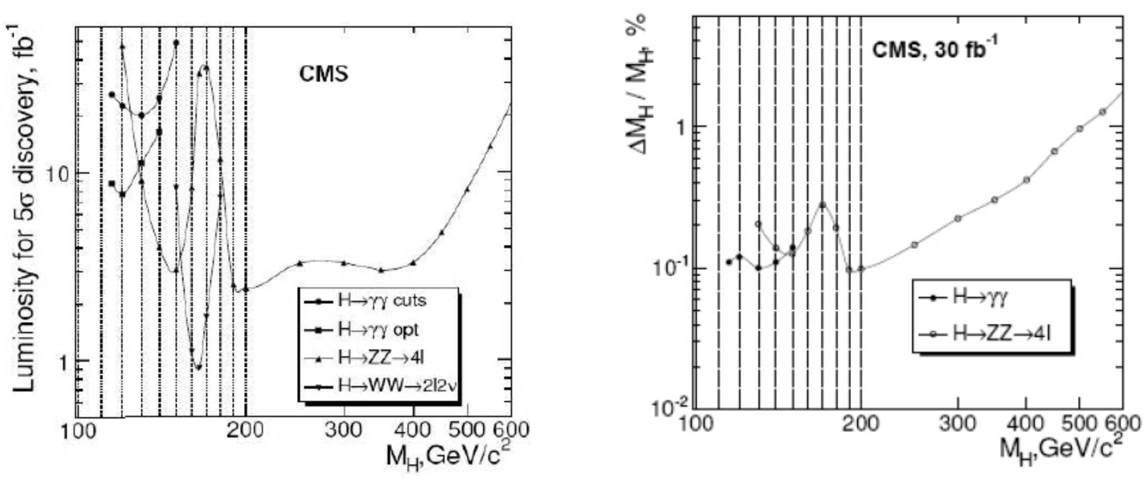

Figure 5: **Left:** The integrated luminosity needed for the 5σ discovery of the inclusive Higgs boson production $\mathrm{pp} \rightarrow \mathrm{H{+}X}$ is shown for the Higgs boson decay modes $\mathrm{H} \rightarrow \gamma\gamma$, $\mathrm{H} \rightarrow \mathrm{ZZ} \rightarrow 4\ell$, and $\mathrm{H} \rightarrow \mathrm{WW} \rightarrow 2\ell 2\nu$. **Right:** Higgs boson mass measurements precision as a function of the Higgs boson mass for 30 fb^{-1} of the integrated luminosity is shown for the different Higgs boson production and decay channels for analyses with CMS.

3 Summary

Both collaborations, CMS and ATLAS, show that discoveries may be expected already at integrated luminosity, about $1fb^{-1}$. The SM Higgs boson, if it exists, is expected to be discovered by the time we reach $L \approx 10fb^{-1}$. By the time we get $L \approx 30fb^{-1}$ we should be able to measure the Higgs boson mass with precision of about 0.1%.

References

[1] LHC Project, *http://lhc.web.cern.ch/lhc/*, *http://lhc-machine-outreach.web.cern.ch/lhc-machine-outreach/lhc_in_pictures.htm*

[2] CERN, *http://www.cern.ch/*

[3] CMS Collaboration, *http://cms.cern.ch/*

[4] ATLAS Collaboration, *http://atlas.web.cern.ch/Atlas/index.html*

[5] M. Spira and P. Zerwas *Electroweak symmetry breaking and Higgs physics*, CERN-TH-97-379, DESY-97-261, Dec 1997. 69pp. hep-ph/9803257

[6] M. Spira *Higgs boson production and decay at the Tevatron*, DESY-98-159, Oct 1998. 12pp. hep-ph/9810289

[7] Pieri M. et al., *Inclusive Search for the Higgs Boson in the $H \to \gamma\gamma$ Channel*, CMS Note 2006/112.

[8] L. Carminati (on behalf of ATLAS collaboration), *Search for a Standard Model Higgs boson in the $H \to \gamma\gamma$ channel with the ATLAS detector*, ATL-PHYS-CONF-2006-018 (and references therein).

[9] G. Davatz et al., *Standard Model Higgs Discovery Potential of CMS in $H \to WW \to l\nu l\nu$ Channel*, CMS Note 2006/047.

[10] S. Abdullin et al., *Search Strategy for the Standard Model Higgs Boson in the* $\mathrm{H} \to \mathrm{ZZ}^{(*)} \to 4\mu$ *Decay Channel using $M(4\mu)$-Dependent Cuts*, CMS Note 2006/122; S. Baffioni et al., *Discovery Potential for the SM Higgs Boson in the* $\mathrm{H} \to \mathrm{ZZ}^{(*)} \to 4e$ *Decay Channel*, CMS Note 2006/115; D. Futyan et al., *Search for the Standard Model Higgs Boson in the Two-Electron and Two-Muon Final State with CMS*, CMS Note 2006/136.

[11] M. Dubinin et al., *Vector Boson Fusion Production with $H \to \gamma\gamma$*, CMS Note 2006/097; S. Kunori et al., *Search for a Standard Model Higgs Boson in CMS via Vector Boson Fusion in the $H \to WW \to l\nu l\nu$ Channel*, CMS NOTE 2006/091; H. Pi et al., *Search for Standard Model Higgs Boson via Vector Boson Fusion in the $H \to W^+W^- \to l^{\pm}\nu jj$ with 120 ¡ m_H ¡ 250 GeV/c^2*, CMS Note 2006/092; C. Foudas et al., *Observation of the Standard Model Higgs boson via $H \to \tau\tau \to lepton + jet$ Channel*, CMS Note 2006/088.

[12] S. Asai et al., *Prospects for the Search for a Standard Model Higgs Boson in ATLAS using Vector Boson Fusion*, Eur.Phys.J. C32S2 (2004) 19-54, hep-ph/0402254.

[13] M. Lethuillier et al., *Search for a Neutral Higgs Boson with WH/ZH, $H \to \gamma\gamma$*, CMS Note 2006/110; C. Delaere *Study of associated WH production with $H \to WW^*$ in the 3 leptons final state*, CMS Note 2006/053.

[14] S. Cucciarelli et al., *Search for $H \to b\bar{b}$ in Association with a ttbar Pair at CMS*, CMS Note 2006/119.

[15] Cammin J. et al., *The ATLAS discovery potential for the channel $t\bar{t}H$, $H \to b\bar{b}$*, ATLAS-PHYS-2003-024.

[16] M.Della Negra, A. Petrilli, A. Ball, L. Foa et al., *CMS Physics Technical Design Report, volume II*, J. Phys. G: Nucl. Part. Phys., vol34 (2007), 995-1579.

[17] S. Abdullin, A. Drozdetskiy et al., *GARCON: Genetic Algorithm for Rectangular Cuts OptimizatioN. User's manual for version 2.0*, hep-ph/0605143, http://drozdets.home.cern.ch/drozdets/home/genetic/

[18] G. Davatz et al., *Effective K-factors for $gg \to H \to WW \to l\nu l\nu$ at the LHC*, JHEP 0405 (2004) 009, arXiv:hep-ph/0402218v2