

ATLAS and CMS experiments at the Large Hadron Collider discover a Higgs-like new boson

XinChou Lou^{1,2}

¹*Division for Experimental Physics, The Institute of High Energy of Physics, Chinese Academy of Sciences, Beijing 100049, China*

²*Department of Physics, University of Texas at Dallas, Richardson, TX 75083-0688, USA*

E-mail: xinchou@utdallas.edu

Received August 28, 2012; accepted September 3, 2012

1 News about the Higgs

On July 4, 2012, with the full anticipation of physicists and the general public around the world, the ATLAS and CMS experiments working at the Large Hadron Collider (LHC) released their latest preliminary results in the search for the Higgs particle, in a joint seminar presented at the European Lab for Particle Physics (CERN) in Geneva, Switzerland. Both experiments announced the observation of a new boson with a mass in the range of 125–126 GeV. The new particle is consistent with the long-sought Higgs boson, although much research work remains to be done before a firm confirmation of the discovery of the Higgs boson can be made. The seminar speakers representing these experiments are their respective spokespersons:

“We observe in our data clear signs of a new particle, at the level of 5 sigma, in the mass region around 126 GeV. The outstanding performance of the LHC and ATLAS and the huge efforts of many people have brought us to this exciting stage,” said ATLAS experiment spokesperson Fabiola Gianotti, *“but a little more time is needed to prepare these results for publication.”*

“The results are preliminary but the 5 sigma signal at around 125 GeV we are seeing is dramatic. This is indeed a new particle. We know it must be a boson and it’s the heaviest boson ever found,” said CMS experiment spokesperson Joe Incandela. *“The implications are very significant and it is precisely for this reason that we must be extremely diligent in all of our studies and cross-checks.”*

The seminar was simultaneously webcast over the internet and reached many destinations, including: Melbourne, where physicists gathered for this year’s International Conference on High Energy Physics; Beijing, where Chinese physicists at the Institute of High Energy Physics active on the LHC experiments shared the joy

of the discovery with Chinese journalists and faculty at Peking University celebrated the event with a large group of students; and Hefei, where physicists at the University of Science and Technology of China watched the CERN seminar live and held a discussion session to explain to the public what the Higgs is and the significance of this current discovery.

The ATLAS [1] and CMS [2] papers providing the details of the analyses behind the results which were presented at the July 4 CERN announcement, as well as including additional decay modes, were submitted to *Physics Letter B* for publication on July 31.

2 Standard model Higgs and previous searches

The Higgs mechanism can be traced back to the early 1960s when several physicists independently proposed an energy field which persists along after the Big Bang [3]. The Higgs field would resist the motion of particles moving through it. Such inertia caused by the Higgs field defines the mass of a particle, and as a result elementary particles acquire their masses; the amount of the mass is directly related to how strongly a particle interacts with the energy field. The spontaneous symmetry breaking of the underlying local symmetry and thus the mass asymmetry among the elementary particles can be explained. In the Standard Model (SM) of elementary particles, the Higgs field is an $SU(2)$ doublet, a complex spinor with four real components. After symmetry breaking, three of the four degrees of freedom in the Higgs field mix with the W^+ , W^- and Z bosons which have all been observed in experiments; while the one remaining degree of freedom becomes the Higgs boson — a new scalar particle.

The SM Higgs boson is a crucial piece which has eluded experimental detection for several decades. Detecting the SM Higgs boson has been the primary physics objective of many major high energy accelerators: The Stanford

Linear Collider (SLC), Large Electron Positron collider (LEP) at CERN, the Tevatron at the Fermilab, and the LHC at CERN.

Searches have been pursued by several experiments through global fits to precision electroweak results. Indirect limits on the SM Higgs boson mass of less than 158 GeV at 95% confidence level have been obtained [4]. Direct searches at LEP have excluded the SM Higgs up to 114.4 GeV at 95% CL [5].

Both the ATLAS and CMS Collaborations reported excesses of events in their 2010, 2011 datasets of proton-proton collisions at the center-of-mass energy $\sqrt{s} = 7$ TeV at the LHC, which were compatible with SM Higgs boson production and decay in the mass region 124–126 GeV, with significances of 2.9 and 3.1 standard sigma's (σ), respectively [6, 7]. The CDF and DØ experiments at the Tevatron have also recently reported a broad excess in the mass region 120–135 GeV; using the existing LHC constraints, the observed local significances for $m_H = 125$ GeV are 2.7σ for CDF [8], 1.1σ for DØ [9] and 2.8σ for their combination [10].

3 Observations by ATLAS and CMS at LHC

Though the searches for the SM Higgs prior to the July 4, 2012 seminar at CERN collectively show evidence for a new particle around 124–126 GeV, the statistical significance falls short of 5σ , a threshold commonly adopted by HEP experiments to decide if an observation can be claimed.

On July 31, 2012, the results from ATLAS and CMS have become final, and have been submitted for publication in *Physics Letter B* [1, 2]. The observations reported in the papers submitted are based on the search for the SM Higgs performed in the final states $\gamma\gamma$, ZZ , W^+W^- , $\tau^+\tau^-$, and b quark pairs. The ATLAS significance of observation is thus increased to 5.9σ by including the W^+W^- channel. Note the choice of the journal: it is a European Journal. This is not surprising as the experiments are Europe based.

The ATLAS results (Fig. 1), based on 4.8 fb^{-1} collected at $\sqrt{s} = 7$ TeV in 2011 and 5.8 fb^{-1} collected at $\sqrt{s} = 8$ TeV in 2012, establish clear evidence for the production of a neutral boson with a measured mass of 126.0 ± 0.4 (stat.) ± 0.4 (sys.) GeV. “This observation, which has a significance of 5.9 standard deviations, corresponding to a background fluctuation probability of 1.7×10^{-9} , is compatible with the production and decay of the Standard Model Higgs boson”, the ATLAS paper reports.

For the CMS observation (Fig. 2), up to 5.1 fb^{-1} at 7 TeV and 5.3 fb^{-1} at 8 TeV of data have been analyzed. “An excess of events is observed above the expected background, a local significance of 5.0 standard deviations, at a mass near 125 GeV, signaling the

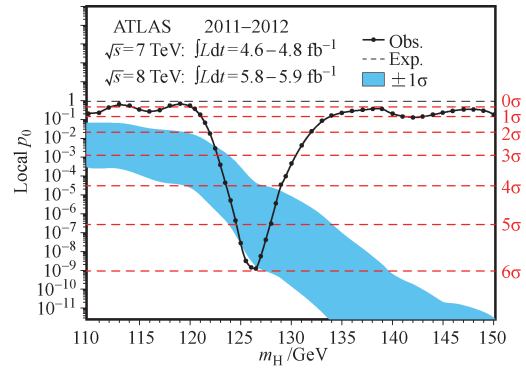


Fig. 1 The ATLAS Higgs analysis [1]. The observed (solid) local p_0 as a function of the Higgs mass in the low mass range. The dashed curve shows the expected local p_0 under the hypothesis of an SM Higgs boson signal at that mass with its $\pm 1\sigma$ band. The horizontal dashed lines indicate the p -values corresponding to significances of 1σ to 6σ .

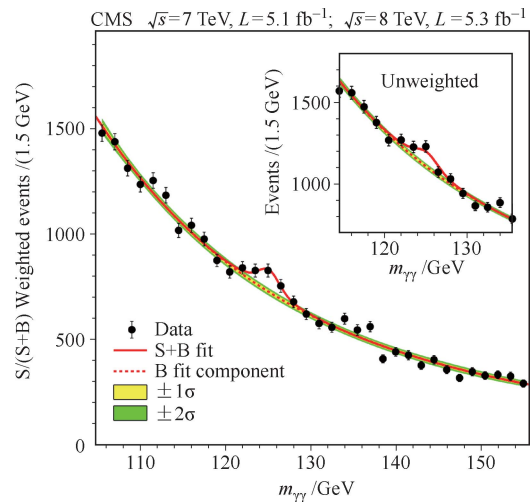


Fig. 2 CMS Higgs to $\gamma\gamma$ analysis [2]. The $\gamma\gamma$ invariant mass distribution with each event weighted by the Signal/(Signal+Background) value of its category. The lines represent the fitted background and signal, and the colored bands represent the $\pm 1\sigma$ and $\pm 2\sigma$ uncertainties on the background estimate. The inset shows the central part of the unweighted invariant mass distribution.

production of a new particle. The expected significance for a standard model Higgs boson of that mass is 5.8 standard deviations. The excess is most significant in the two decay modes with the best mass resolution, $\gamma\gamma$ and ZZ ; a fit to these signals gives a mass of 125.3 ± 0.4 (stat.) ± 0.5 (syst.) GeV. The decay to two photons indicates that the new particle is a boson with spin different from one”, according to the manuscript submitted.

4 What more to expect from LHC experiments?

Almost lost among the excitement of the new discovery was CERN’s announcement that the 2012 LHC proton run would be extended. This is a result of a meeting between CERN management and representatives from the LHC and the experiments (Alice, ATLAS, CMS and

LHCb) where the merits of increasing the data target were discussed. The extra seven weeks of proton run would allow the luminosity goal to reach 20 fb^{-1} from the original 15 fb^{-1} , to give the ATLAS and CMS experiments “a good supply of data to work on during the LHC first long shut-down as well as allow them to make progress in determining the properties of the new particle.” [11] According to the new schedule, proton running will continue until December 16. After the Christmas stop LHC will switch to proton-ion run on January 18, 2013 and will end on February 10, 2013, after which the LHC will undergo a 18-month shutdown to be upgraded for the run at 8 TeV. During that period the LHC experiment will also upgrade their detector components to get ready for higher energy and higher intensity LHC operation.

5 Impact of observation on future of a linear e^+e^- collider

It has been argued that a linear electron positron collider may be best suited for the detailed study of the Higgs boson after its discovery at the LHC. The Higgs program at a linear collider will be well positioned to examine: the mass, the spin, and the parity of the Higgs boson; its coupling to gauge bosons; decay modes; total width; and the Yukawa coupling to the top quark. These will provide precision test of the Standard Model and also permit searches for new physics through the Higgs boson.

The Japanese Subcommittee on Future Projects of High Energy Physics reported in February, 2012 that “should a new particle such as a Higgs boson with a mass below approximately 1 TeV be confirmed at LHC, Japan should take the leadership role in an early realization of an e^+e^- linear collider. In particular, if the particle is light, experiments at low collision energy should be started at the earliest possible time. In parallel, continuous studies on new physics should be pursued for both LHC and the upgraded LHC version. Should the energy scale of new particles/physics be higher, accelerator R&D should be strengthened in order to realize the necessary collision energy.” [12]

A group of Chinese high energy physicists and accelerator experts gathered in Beijing during May 29–30, 2012 to discuss the Chinese participation in the International Linear Collider (ILC) program. The workshop participants support participation in the ILC and decided to strengthen ILC research activities and actively pursue critical ILC accelerator and detector technologies [13].

6 Outlook

By the end of the year, the ATLAS and the CMS experiments are each expected to have collected 20 fb^{-1} of data at 8 TeV. With the additional data they will attempt

to verify that the new particle is indeed the SM Higgs boson. Efforts will be made to understand the nature of the particle, its coupling to various final states, and searches for new physics associated with this particle. The LHC shut-down and upgrade will take approximately 18 months, after which the LHC will come back gradually to reach the designed center of mass energy of 14 TeV. The Higgs study at the LHC will continue for a very long period of time. The electron positron linear collider may well be built in Asia to study the Higgs couplings in fine details. The discovery announced on July 4, 2012 has likely paved the way for a very exciting and rich physics program at the LHC and at a future international linear collider.

Acknowledgements The author thanks Dr. Kendall Reeves for Valuable comments on this article.

References and notes

1. ATLAS Collaboration, arXiv:1207.7214v1 [hep-ex], 2012, submitted to Phys. Lett. B
2. CMS Collaboration, arXiv:1207.7235v1 [hep-ex], 2012, Submitted to Phys. Lett. B
3. See for example, F. Englert and R. Brout, Broken symmetry and the mass of gauge vector mesons, Phys. Rev. Lett., 1964, 13: 321; P. W. Higgs, Broken symmetries, massless particles and gauge fields, Phys. Lett., 1964, 12: 132; P. W. Higgs, Broken symmetries and the masses of gauge bosons, Phys. Rev. Lett., 1964, 13: 508; G. S. Guralnik, C. R. Hagen, and T. W. B. Kibble, Global conservation laws and massless particles, Phys. Rev. Lett., 1964, 13: 585; P. W. Higgs, Spontaneous symmetry breakdown without massless bosons, Phys. Rev., 1966, 145: 1156; and T. W. B. Kibble, Symmetry breaking in non-Abelian gauge theories, Phys. Rev., 1967, 155: 1554
4. ALEPH, CDF, DØ, DELPHI, L3, OPAL, SLD Collaborations, the LEP Electroweak Working Group, the Tevatron Electroweak Working Group, and the SLD electroweak and heavy flavor groups, CERN-PH-EP-2010-095 (2010), arXiv:1012.2367 [hep-ex]
5. ALEPH, DELPHI, L3 and OPAL Collaborations, The LEP Working Group for Higgs boson searches, Phys. Lett. B, 2003, 565: 61
6. ATLAS Collaboration, arXiv:1207.0319 [hep-ex], 2012, accepted by Phys. Rev. D
7. CMS Collaboration, Phys. Lett. B, 2012, 710: 26
8. T. Aaltonen, et al. [CDF Collaboration], arXiv:1207.1707 [hep-ex], 2012, submitted to Phys. Rev. Lett.
9. V. M. Abazov, et al. [DØ Collaboration], arXiv:1207.6631v1 [hep-ex], 2012, submitted to Phys. Rev. Lett.
10. CDF Collaboration, DØ Collaboration, arXiv:1207.6436 [hep-ex], 2012, submitted to Phys. Rev. Lett.
11. CERN Courier, August 23, 2012
12. The final report of the subcommittee on future projects of high energy physics, February 11, 2012, http://www.jahep.org/office/doc/201202_hecsb_subreport.pdf
13. Second Workshop on Linear Colliders, Beijing, May 29–30, 2012, http://www.ihep.cas.cn/xwdt/gnwxw/201206/t20120601_3588896.html