



Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC[☆]

CMS Collaboration[★]

CERN, Switzerland

This paper is dedicated to the memory of our colleagues who worked on CMS but have since passed away. In recognition of their many contributions to the achievement of this observation.

ARTICLE INFO

Article history:

Received 31 July 2012

Received in revised form 9 August 2012

Accepted 11 August 2012

Available online 18 August 2012

Editor: W.-D. Schlatter

Keywords:

CMS

Physics

Higgs

ABSTRACT

Results are presented from searches for the standard model Higgs boson in proton–proton collisions at $\sqrt{s} = 7$ and 8 TeV in the Compact Muon Solenoid experiment at the LHC, using data samples corresponding to integrated luminosities of up to 5.1 fb^{-1} at 7 TeV and 5.3 fb^{-1} at 8 TeV. The search is performed in five decay modes: $\gamma\gamma$, ZZ , W^+W^- , $\tau^+\tau^-$, and $b\bar{b}$. An excess of events is observed above the expected background, with a local significance of 5.0 standard deviations, at a mass near 125 GeV, signalling the 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 $125.3 \pm 0.4(\text{stat.}) \pm 0.5(\text{syst.}) \text{ GeV}$. The decay to two photons indicates that the new particle is a boson with spin different from one.

2012 CERN. Published by Elsevier B.V. Open access under CC BY-NC-ND license.

1. Introduction

The standard model (SM) of elementary particles provides a remarkably accurate description of results from many accelerator and non-accelerator based experiments. The SM comprises quarks and leptons as the building blocks of matter, and describes their interactions through the exchange of force carriers: the photon for electromagnetic interactions, the W and Z bosons for weak interactions, and the gluons for strong interactions. The electromagnetic and weak interactions are unified in the electroweak theory. Although the predictions of the SM have been extensively confirmed, the question of how the W and Z gauge bosons acquire mass whilst the photon remains massless is still open.

Nearly fifty years ago it was proposed [1–6] that spontaneous symmetry breaking in gauge theories could be achieved through the introduction of a scalar field. Applying this mechanism to the electroweak theory [7–9] through a complex scalar doublet field leads to the generation of the W and Z masses, and to the prediction of the existence of the SM Higgs boson (H). The scalar field also gives mass to the fundamental fermions through the Yukawa interaction. The mass m_H of the SM Higgs boson is not predicted by theory. However, general considerations [10–13] suggest that

m_H should be smaller than $\sim 1 \text{ TeV}$, while precision electroweak measurements imply that $m_H < 152 \text{ GeV}$ at 95% confidence level (CL) [14]. Over the past twenty years, direct searches for the Higgs boson have been carried out at the LEP collider, leading to a lower bound of $m_H > 114.4 \text{ GeV}$ at 95% CL [15], and at the Tevatron proton–antiproton collider, excluding the mass range 162–166 GeV at 95% CL [16] and detecting an excess of events, recently reported in [17–19], in the range 120–135 GeV.

The discovery or exclusion of the SM Higgs boson is one of the primary scientific goals of the Large Hadron Collider (LHC) [20]. Previous direct searches at the LHC were based on data from proton–proton collisions corresponding to an integrated luminosity of 5 fb^{-1} collected at a centre-of-mass energy $\sqrt{s} = 7 \text{ TeV}$. The CMS experiment excluded at 95% CL a range of masses from 127 to 600 GeV [21]. The ATLAS experiment excluded at 95% CL the ranges 111.4–116.6, 119.4–122.1 and 129.2–541 GeV [22]. Within the remaining allowed mass region, an excess of events near 125 GeV was reported by both experiments. In 2012 the proton–proton centre-of-mass energy was increased to 8 TeV and by the end of June an additional integrated luminosity of more than 5 fb^{-1} had been recorded by each of these experiments, thereby enhancing significantly the sensitivity of the search for the Higgs boson.

This Letter reports the results of a search for the SM Higgs boson using samples collected by the CMS experiment, comprising data recorded at $\sqrt{s} = 7$ and 8 TeV. The search is performed in

[☆] © CERN for the benefit of the CMS Collaboration.

[★] E-mail address: cms-publication-committee-chair@cern.ch.

- [108] C. Anastasiou, K. Melnikov, F. Petriello, Nucl. Phys. B 724 (2005) 197, <http://dx.doi.org/10.1016/j.nuclphysb.2005.06.036>.
- [109] C. Anastasiou, S. Bucherer, Z. Kunszt, JHEP 0910 (2009) 068, <http://dx.doi.org/10.1088/1126-6708/2009/10/068>.
- [110] S. Gieseke, D. Grellscheid, K. Hamilton, A. Ribon, P. Richardson, et al., Herwig++ 2.0 Release Note, arXiv:hep-ph/0609306, 2006.
- [111] J. Alwall, P. Demin, S. de Visscher, R. Frederix, M. Herquet, et al., JHEP 0709 (2007) 028, arXiv:0706.2334, <http://dx.doi.org/10.1088/1126-6708/2007/09/028>.
- [112] ATLAS and CMS Collaborations, LHC Higgs Combination Group, Procedure for the LHC Higgs boson search combination in Summer 2011, Tech. Rep. ATL-PHYS-PUB 2011-11, CMS NOTE 2011/005, 2011, <http://cdsweb.cern.ch/record/1379837>.
- [113] T. Junk, Nucl. Instrum. Meth. A 434 (1999) 435, [http://dx.doi.org/10.1016/S0168-9002\(99\)00498-2](http://dx.doi.org/10.1016/S0168-9002(99)00498-2).
- [114] A.L. Read, J. Phys. G 28 (2002) 2693, <http://dx.doi.org/10.1088/0954-3899/28/10/313>.
- [115] E. Gross, O. Vitells, Eur. Phys. J. C 70 (2010) 525, arXiv:1005.1891, <http://dx.doi.org/10.1140/epjc/s10052-010-1470-8>.
- [116] G. Cowan, K. Cranmer, E. Gross, O. Vitells, Eur. Phys. J. C 71 (2011) 1554, arXiv:1007.1727, <http://dx.doi.org/10.1140/epjc/s10052-011-1554-0>.
- [117] L. Moneta, K. Belasco, K. Cranmer, S. Kreiss, et al., in: 13th Int. Workshop on Advanced Computing and Analysis Techniques in Physics Research (ACAT2010), 2010, PoS ACAT:057, arXiv:1009.1003, http://pos.sissa.it/archive/conferences/093/057/ACAT2010_057.pdf.
- [118] C.J. Seez, T.S. Virdee, L. Di Lella, R.H. Kleiss, Z. Kunszt, W.J. Stirling, in: G. Jarlskog, D. Rein (Eds.), Proceedings of the Large Hadron Collider Workshop, Aachen, Germany, 1990, p. 474, CERN 90-10-V-2/ECFA 90-133-V-2, <http://cdsweb.cern.ch/record/220524>.
- [119] B.P. Roe, H.-J. Yang, J. Zhu, Y. Liu, I. Stancu, et al., Nucl. Instrum. Meth. A 543 (2005) 577, <http://dx.doi.org/10.1016/j.nima.2004.12.018>.
- [120] H. Voss, A. Höcker, J. Stelzer, F. Tegenfeldt, in: XI Int. Workshop on Advanced Computing and Analysis Techniques in Physics Research, 2007, PoS ACAT:040, arXiv:physics/0703039, http://pos.sissa.it/archive/conferences/050/040/ACAT_040.pdf.
- [121] R.J. Barlow, J. Comp. Phys. 72 (1987) 202, [http://dx.doi.org/10.1016/0021-9991\(87\)90078-7](http://dx.doi.org/10.1016/0021-9991(87)90078-7).
- [122] M. Della Negra, D. Froidevaux, K. Jakobs, R. Kinnunen, R. Kleiss, A. Nisati, T. Sjöstrand, in: G. Jarlskog, D. Rein (Eds.), Proceedings of the Large Hadron Collider Workshop, Aachen, Germany, 1990, p. 509, CERN 90-10-V-2/ECFA 90-133-V-2, <http://cdsweb.cern.ch/record/215298>.
- [123] N. Cabibbo, A. Maksymowicz, Phys. Rev. B 137 (1965) 438, <http://dx.doi.org/10.1103/PhysRev.137.B438>, also Erratum, <http://dx.doi.org/10.1103/PhysRev.168.1926>.
- [124] Y. Gao, A.V. Gritsan, Z. Guo, K. Melnikov, M. Schulze, et al., Phys. Rev. D 81 (2010) 075022, arXiv:1001.3396, <http://dx.doi.org/10.1103/PhysRevD.81.075022>.
- [125] A. De Rujula, J. Lykken, M. Pierini, C. Rogan, M. Spiropulu, Phys. Rev. D 82 (2010) 013003, arXiv:1001.5300, <http://dx.doi.org/10.1103/PhysRevD.82.013003>.
- [126] S. Chatrchyan, et al., JHEP 1204 (2012) 036, arXiv:1202.1416, [http://dx.doi.org/10.1007/JHEP04\(2012\)036](http://dx.doi.org/10.1007/JHEP04(2012)036).
- [127] S.Y. Choi, D.J. Miller, M.M. Muhlleitner, P.M. Zerwas, Phys. Lett. B 553 (2003) 61, arXiv:hep-ph/0210077, [http://dx.doi.org/10.1016/S0370-2693\(02\)03191-X](http://dx.doi.org/10.1016/S0370-2693(02)03191-X).
- [128] S. Chatrchyan, et al., JHEP 1110 (2011) 132, [http://dx.doi.org/10.1007/JHEP10\(2011\)132](http://dx.doi.org/10.1007/JHEP10(2011)132).
- [129] V.D. Barger, G. Bhattacharya, T. Han, B.A. Kniehl, Phys. Rev. D 43 (1991) 779, <http://dx.doi.org/10.1103/PhysRevD.43.779>.
- [130] M. Dittmar, H.K. Dreiner, Phys. Rev. D 55 (1997) 167, arXiv:hep-ph/9608317, <http://dx.doi.org/10.1103/PhysRevD.55.167>.
- [131] S. Chatrchyan, et al., JINST 7 (2011) P01001, <http://dx.doi.org/10.1088/1748-0221/7/01/P01001>.
- [132] S. Chatrchyan, et al., Phys. Rev. Lett. 106 (2011) 231801, arXiv:1104.1619, <http://dx.doi.org/10.1103/PhysRevLett.106.231801>.
- [133] A. Denner, S. Dittmaier, S. Kallweit, A. Muck, JHEP 1203 (2012) 075, arXiv:1112.5142, [http://dx.doi.org/10.1007/JHEP03\(2012\)075](http://dx.doi.org/10.1007/JHEP03(2012)075).
- [134] J. Gallicchio, M.D. Schwartz, Phys. Rev. Lett. 105 (2010) 022001, arXiv:1001.5027, <http://dx.doi.org/10.1103/PhysRevLett.105.022001>.
- [135] L.D. Landau, Dokl. Akad. Nauk 60 (1948) 207.
- [136] C.N. Yang, Phys. Rev. 77 (1950) 242, <http://dx.doi.org/10.1103/PhysRev.77.242>.

CMS Collaboration

S. Chatrchyan, V. Khachatryan, A.M. Sirunyan, A. Tumasyan

Yerevan Physics Institute, Yerevan, Armenia

W. Adam, E. Aguilo, T. Bergauer, M. Dragicevic, J. Erö, C. Fabjan¹, M. Friedl, R. Frühwirth¹, V.M. Ghete, J. Hammer, M. Hoch, N. Hörmann, J. Hrubec, M. Jeitler¹, W. Kiesenhofer, V. Knünz, M. Krammer¹, I. Krätschmer, D. Liko, W. Majerotto, I. Mikulec, M. Pernicka[†], B. Rahbaran, C. Rohringer, H. Rohringer, R. Schöffbeck, J. Strauss, F. Szoncsó, A. Taurok, W. Waltenberger, G. Walzel, E. Widl, C.-E. Wulz¹

Institut für Hochenergiephysik der OeAW, Wien, Austria

V. Chekhovsky, I. Emelianchik, A. Litomin, V. Makarenko, V. Mossolov, N. Shumeiko, A. Solin, R. Stefanovitch, J. Suarez Gonzalez

National Centre for Particle and High Energy Physics, Minsk, Belarus

A. Fedorov, M. Korzhik, O. Missevitch, R. Zuyevski

Research Institute for Nuclear Problems, Minsk, Belarus

M. Bansal, S. Bansal, W. Beaumont, T. Cornelis, E.A. De Wolf, D. Druzhkin, X. Janssen, S. Luyckx, L. Mucibello, S. Ochesanu, B. Roland, R. Rougny, M. Selvaggi, Z. Staykova, H. Van Haevermaet, P. Van Mechelen, N. Van Remortel, A. Van Spilbeeck

Universiteit Antwerpen, Antwerpen, Belgium

F. Blekman, S. Blyweert, J. D'Hondt, O. Devroede, R. Gonzalez Suarez, R. Goorens, A. Kalogeropoulos, M. Maes, A. Olbrechts, S. Tavernier, W. Van Doninck, L. Van Lancker, P. Van Mulders, G.P. Van Onsem, I. Villella

Vrije Universiteit Brussel, Brussel, Belgium

C. Albajar, G. Codispoti, J.F. de Trocóniz

Universidad Autónoma de Madrid, Madrid, Spain

H. Brun, J. Cuevas, J. Fernandez Menendez, S. Folgueras, I. Gonzalez Caballero, L. Lloret Iglesias, J. Piedra Gomez

Universidad de Oviedo, Oviedo, Spain

J.A. Brochero Cifuentes, I.J. Cabrillo, A. Calderon, S.H. Chuang, J. Duarte Campderros, M. Felcini³⁸, M. Fernandez, G. Gomez, J. Gonzalez Sanchez, A. Graziano, C. Jorda, A. Lopez Virto, J. Marco, R. Marco, C. Martinez Rivero, F. Matorras, F.J. Munoz Sanchez, T. Rodrigo, A.Y. Rodríguez-Marrero, A. Ruiz-Jimeno, L. Scodellaro, M. Sobron Sanudo, I. Vila, R. Vilar Cortabitarte

Instituto de Física de Cantabria (IFCA), CSIC-Universidad de Cantabria, Santander, Spain

D. Abbaneo, P. Aspell, E. Auffray, G. Auzinger, M. Bachtis, J. Baechler, P. Baillon, A.H. Ball, D. Barney, J.F. Benitez, C. Bernet⁶, W. Bialas, G. Bianchi, P. Bloch, A. Bocci, A. Bonato, C. Botta, H. Breuker, D. Campi, T. Camporesi, E. Cano, G. Cerminara, A. Charkiewicz, T. Christiansen, J.A. Coarasa Perez, B. Curé, D. D'Enterria, A. Dabrowski, J. Daguin, A. De Roeck, S. Di Guida, M. Dobson, N. Dupont-Sagorin, A. Elliott-Peisert, M. Eppard, B. Frisch, W. Funk, A. Gaddi, M. Gastal, G. Georgiou, H. Gerwig, M. Giffels, D. Gigi, K. Gill, D. Giordano, M. Girone, M. Giunta, F. Glege, R. Gomez-Reino Garrido, P. Govoni, S. Gowdy, R. Guida, J. Gutleber, M. Hansen, P. Harris, C. Hartl, J. Harvey, B. Hegner, A. Hinzmann, A. Honma, V. Innocente, P. Janot, K. Kaadze, E. Karavakis, K. Kloukinas, K. Kousouris, P. Lecoq, Y.-J. Lee, P. Lenzi, R. Loos, C. Lourenço, N. Magini, T. Mäki, M. Malberti, L. Malgeri, M. Mannelli, A. Marchioro, J. Marques Pinho Noite, L. Masetti, F. Meijers, S. Mersi, E. Meschi, L. Moneta, M.U. Mozer, M. Mulders, P. Musella, A. Onnela, T. Orimoto, L. Orsini, J.A. Osborne, E. Palencia Cortezon, E. Perez, L. Perrozzi, P. Petagna, A. Petrilli, A. Petrucci, A. Pfeiffer, M. Pierini, M. Pimiä, D. Piparo, G. Polese, H. Postema, L. Quertenmont, A. Racz, W. Reece, D. Ricci, J. Rodrigues Antunes, G. Rolandi³⁹, C. Rovelli⁴⁰, M. Rovere, V. Ryjov, H. Sakulin, D. Samyn, F. Santanastasio, C. Schäfer, C. Schwick, A. Sciaba, I. Segoni, S. Sekmen, A. Sharma, P. Siegrist, P. Silva, M. Simon, P. Sphicas^{*,41}, D. Spiga, B.G. Taylor, P. Tropea, J. Troska, A. Tsiros, F. Vasey, L. Veillet, G.I. Veres²⁰, P. Vichoudis, J.R. Vlimant, P. Wertelaers, H.K. Wöhri, S.D. Worm⁴², W.D. Zeuner

CERN, European Organization for Nuclear Research, Geneva, Switzerland

W. Bertl, K. Deiters, W. Erdmann, D. Feichtinger, K. Gabathuler, R. Horisberger, Q. Ingram, H.C. Kaestli, S. König, D. Kotlinski, U. Langenegger, B. Meier, F. Meier, D. Renker, T. Rohe, T. Sakhelashvili⁴³

Paul Scherrer Institut, Villigen, Switzerland

L. Bäni, F. Behner, B. Betev, B. Blau, P. Bortignon, M.A. Buchmann, B. Casal, N. Chanon, Z. Chen, D.R. Da Silva Di Calafiori, S. Dambach⁴⁴, G. Davatz, A. Deisher, G. Dissertori, M. Dittmar, L. Djambazov, M. Donegà, M. Dünser, C. Eggel⁴⁴, J. Eugster, G. Faber, K. Freudenreich, C. Grab, W. Hintz, D. Hits, H. Hofer, O. Holme, I. Horvath, P. Lecomte, W. Lustermann, C. Marchica⁴⁴, A.C. Marini, P. Martinez Ruiz del Arbol, N. Mohr, F. Moortgat, C. Nägeli⁴⁴, P. Nef, F. Nessi-Tedaldi, F. Pandolfi, L. Pape, F. Pauss, M. Peruzzi, T. Punz, F.J. Ronga, U. Röser, M. Rossini, L. Sala, A.K. Sanchez, M.-C. Sawley, D. Schinzel, A. Starodumov⁴⁵, B. Stieger, H. Suter, M. Takahashi, L. Tauscher[†], A. Thea, K. Theofilatos, D. Treille, P. Trüb⁴⁴, S. Udriot, C. Urscheler, G. Viertel, H.P. von Gunten, R. Wallny, H.A. Weber, L. Wehrli, J. Weng, S. Zelepoukine⁴⁶

Institute for Particle Physics, ETH Zurich, Zurich, Switzerland

C. Amsler⁴⁷, V. Chiochia, S. De Visscher, C. Favaro, M. Ivova Rikova, B. Millan Mejias, P. Otiougova, P. Robmann, H. Snoek, S. Tuppiti, M. Verzetti

Universität Zürich, Zurich, Switzerland