The CMS experiment at the Large Hadron Collider

Ted Kolberg (Florida State University) July 26th, 2017









8 October 2013



The Nobel Prize 2013

Nobelpriset 2013

The Nobel Prize in Physics 2013



François Englert Université Libre de Bruxelles, Belgium



Peter W. Higgs University of Edinburgh, UK

"För den teoreliska upptäckten av en mekanism som bidrar till förståelsen av massans ursprung hos subatomära partiklar, och som nyligen, genom upptäckten av den förutsagda fundamentala partikeln, bokräftats av ATLAS- och CMS-experimenten vid CERN:s accelerator LHC."

"For the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider."

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EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)



CERN-PH-FP/2012-220 2013/01/29

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

The CMS Collaboration

Abstract

Results are presented from searches for the standard model Higgs boson in protonproton 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 $5.1 \,\text{fb}^{-1}$ at 7 TeV and $5.3 \,\text{fb}^{-1}$ at 8 TeV. The search is performed in five decay modes: $\gamma \gamma$, ZZ, W⁺W⁻, $\tau^+ \tau^-$, and bb. 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 ± 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.

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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. Schölbeck, 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. Emeliantchik, 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. Zuyeuski

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 Universiteù Brussel, Brussel, Belgium

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	48 OMS Collaboration / Mysics Leners 8 716 (2012) 30-61	
	D. Boutigny, D. Mercier	
	Contro de Calud de Datiliai National de Physique Nodativ ni de Aprilgue de Pariliado, CNE(NEP3, Viltor Isano, Fanos, Viltor Isano, Fanos	
	G. Baulieu, S. Beauceron, N. Beaupere, M. Bedjidian, O. Bondu, G. Boudoul, S. Brochet, J. Chasserat, R. Chierici ⁵ , C. Combaret, D. Contardo, P. Depasse, H. El Marnouni, J. Fay, S. Gascon, N. Giraud, M. Gouzevitch, R. Haroutunian, B. Ille, T. Kurca, M. Lethuillier, N. Lumb, H. Mathez, L. Mirabito, S. Perrites, L. Sgandurra, V. Sordini, Y. Tschudi, M. Vander Doncki, P. Verdler, S. Virei	
CMS Collaboration	Université de jyon, Université Claude Bernard Lyon I, CNRS-INCPR, Institut de Physique Nuclétaire de Lyon, Valleurbanne, France	
	V. Roinishvili, L. Ru-ua	
	E. Andronikusivili Inskine of Physics, Academy of Science, Tolibi, Sewgin	
S, Chatrchyan, V. Kha	N. Amaglobeli, I. Bagaturia, B. Chiladze, R. Kvatadze, D. Lomidze, R. Sharidze, Z. Tsamalaidze ¹⁵	
Yerevan Physics Institute, Yerevan, An	Institute of High Energy Ayutics and Informatization, Thilid State Informity, Thilid, Gorgia	
W. Adam, E. Aguilo, I J. Hammer, M. Hoch, I. Krätschmer, D. Liko	R. Adolphi, G. Anagnostou, C. Autermann, S. Beranek, K. Brauer, W. Braunschweig, B. Calpas, M. Edelhoff, L. Feld, N. Heracleous, O. Hindrichs, R. Jussen, W. Karpinski, K. Klein, K. Lübelsmeyer, J. Merz, A. Ostapchuk, D. Pandoulas, A. Perieanu, F. Raupach, J. Sammet, S. Schael, D. Schmitt, A. Schultz von Dratzig, R. Siedling, D. Sprenger, H. Weber, B. Wittmer, M. Wlochal, V. Zhukov ¹⁶ (2000) Assert University J. Physicanon Institut, Acom, Lerman.	.M. Ghete, mer ⁻¹ , Rohringer,
R. Schölbeck, J. Strau	M. Ata, P. Biallass, J. Caudron, E. Dietz-Laursonn, D. Duchardt, M. Erdmann, R. Fischer, A. Güth,	z ¹
Institut für Hochenergiephysik der Oe	T. Hebbeker, C. Heidemarn, G. Hilgers, K. Hoepfrer, C. Hof, T. Klimkovich, D. Klingebiel, P. Kreuzer, C. Magass, M. Merschmeyer, A. Meyer, M. Olschewski, P. Papacz, B. Philipps, H. Pieta, H. Feithler, S.A. Schmitz, L. Sonnenschein, M. Sowa, J. Steggemann, D. Teyssier, M. Weber	
V. Chekhovsky, I. Em	BMTH Auchen University. III. Physicalischen Institut A, Achen, Gemany	۱.
R. Stefanovitch, J. Sua	M. Bontenackels, V. Cherepanov, Y. Erdogan, G. Hügge, H. Geenen, M. Geisler, W. Haj Ahmad, F. Hoehle,	
National Centre for Particle and High	R. Kargell, T. Kress, Y. Kuessel, J. Lingemann ⁵ , A. Nowark, L. Perchalla, O. Pooth, P. Sauerland, A. Stahl, M.H. Zoeller	
A. Fedorov, M. Korzh	PATE Archen University III. Dynikolischen Institut II, Archen, Corneray	
Research Institute for Nuclear Problem	M. Aldaya Martin, J. Behr, W. Behrenhoff, U. Behrens, M. Bergholz ¹⁷ , A. Bethani, K. Borras, A. Burgmeier, A. Cakir, L. Caligans, A. Campbell, E. Castro, F. Costanza, D. Dammann, C. Diez Pardos, G. Eckerin, D. Eckstein, A. Flossdorf, G. Flucke, A. Geiser, I. Clushkov, P. Goettlicher, A. Grebenvuk, P. Gunnellini,	
M. Bansal, S. Bansal, L. Mucibello, S. Oche P. Van Mechelen, N. V Universiteit Antwerper, Autwerper, F	 S. Habib, J. Hauk, G. Hellwig, H. Jung, M. Kasemann, P. Katsas, C. Kleinwort, H. Kluge, A. Knutssen, M. Krämer, D. Krücker, E. Kuznetsova, W. Lange, B. Lewendel, W. Lohmann¹⁷, B. Lutz, R. Mankel, I. Marfin, M. Marienfeld, L-A. Nelzer-Pellmann, A.B. Meyer, J. Mnich, C. Muhl, A. Mussgiller, S. Naumann-Emme, O. Novgorodova, J. Olzem, A. Parenti, H. Perrey, A. Petrukhin, D. Pitzl, A. Raspereza, P.M. Ribeiro Gipriano, C. Riedl, E. Ron, C. Rosemann, M. Rosin, J. Salfeld-Nebgen, R. Schmidt¹⁷, T. Schoerner-Sadenius, N. Sen, A. Spiridonov, M. Stein, J. Tomaszewska, D. Volyanskyy, R. Walsh, C. Wissing, C. Youngman 	kx, ;
E Plakman S. Physics	Deutschen Elektronen-Synchrotron, Hamburg Germany	moules
M. Maes, A. Olbrecht I. Villella	 V. Blobel, J. Draeger, H. Enderk, J. Erfle, U. Gebbert, M. Görner, T. Hermanns, R.S. Höing, K. Kaschube, G. Kaussen, H. Kirschenmann, R. Klarner, J. Lange, B. Nura, F. Nowak, T. Peiffer, N. Fietsch, D. Rathjens, C. Sander, H. Schertler, P. Schleper, F. Schlieckau, A. Schmidt, M. Schröder, T. Schum, M. Seidel, J. Sibille¹⁸, V. Sola, H. Stadie, G. Steirbrück, J. Thomsen, L. Vanelderen 	n Onsem,
Vrije Universiteit Brussel, Brussel, Beh	Thisersity of Kamburg Kemburg Germany	

C. Barth, J. Bauer, J. Berger, P. Blüm, C. Böser, V. Buege, Z.Y. Chen, S. Chowdhury, T. Chwalek, D. Daeuwel, W. De Boer, A. Descroix, A. Dierlamm, G. Dirkes, M. Fahrer, M. Feindt, U. Felzmann, M. Frey, A. Furgeri,



(MS Collaboration / Hysics Letters B 716 (2012) 30-61 N. Godinovic, D. Lelas, R. Plestina⁶, D. Polic, I. Puljak⁵ D. B Technical University of Split. Split. Croatia Other a G. B. Z. Antunovic, M. Kovac R. C. Mineraly of Split. Split. Courier MG 5, Pt V. Brigljevic, S. Duric, K. Kadija, J. Luetic, S. Morovic Ohieri Astilate Rasjer Soslevis Zagreb Groatia CMS Collaboration V. R. A. Attikis, M. Galanti, G. Mavromanolakis, J. Mousa, C. Nicolaou, F. Ptochos, P.A. Razis Education Deliversity of Cyprus, Messie, Cyprus S. Chatrchyan, V. Kha_{N A M. Finger, M. Finger Jr.} Yerevan Physics Institute, Verevan, An¹⁰⁰⁰⁰⁰ Chates University, Inque, Cieck Aquatic W. Adam, E. Aguilo, ^{R. Al} J. Hammer, M. Hoch, ^{A. St} Astrony of Straft Second and Petrology of the feet Benefit of Says, Easter Reveals of Barry Barles, Gene Store te, I. Krätschmer, D. Likt and A. Hektor, M. Kadastik, K. Kannike, M. Müntel, M. Raidal, I., Rebane, A. Strumia, A. Tiko er, R. Schölbeck, J. Strau M. A. Nederal Instance of Overlied Replaces of Replaying Tables, Second Institut für Hochenergiephysik der De C. M. P. Eerola, G. Fedi, M. Voutilainen S.A.¹ Department of Physics, University of Related, Reinted, Extend V. Chekhovsky, I. Em man E. Anttila, J. Härkönen, A. Heikkinen, V. Karimäki, H.M. Katajisto, R. Kinnunen, M.J. Kortelainen, A. Fedorov, M. Korzh K. Banzuzi, A. Karjalainen, A. Korpela, T. Tuuva Research Institute for Nuclear Problem A. G. Lapsenners Intends of Technology Lapsenners, Soland D, E M. Anfreville, M. Besancon, S. Choudhury, M. Dejardin, D. Denegri, B. Fabbro, J.L. Faure, F. Ferri, M. Anfreville, M. Besancon, S. Choudhury, M. Dejardin, D. Denegri, B. Fabbro, J.L. Faure, F. Ferri, M. Bansal, S. Bansal, M. K. S. Ganjour, F.X. Gentir, A. Givernaud, P. Gras, G. Hamel de Monchenault, P. Jarry, F. Kircher, M.C. Lemaire, L. Mucibello, S. Oche, I. M. E. Locci, J. Malcles, I. Mandjavidze, A. Nayak, J.P. Pansart, J. Rander, J.M. Reymond, A. Rosowsky, S. Ni, I. Shreyber, M. Titov, P. Verrecchia P. Van Mechelen, N. 1849. 1849 184 (1945 actor, 64 art Yorn, Brear T. Sc Universiteit Antworpen, Autworpen, & C. W. J. Badier, S. Baffioni, F. Beaudette, E. Becheva, I., Benhabib, I., Bianchini, M., Bluj 13, C. Broutin, P. Busson, nemet M. Cerutti, D. Chamont, C. Charlot, N. Daci, T. Dahms, M. Dalchenko, L. Dobrzynski, Y. Geerebaert, F. Blekman, S. Blywee R. Granier de Cassagnac, M. Haguerrauer, F. Heannan, S. Blywee N. Bl M. Nguyen, C. Ochando, P. Paganini, T. Romanteau, D. Sabes, R. Salerno, A. Sartirana, Y. Sirois, R, Granier de Cassagnac, M, Haguenauer, P, Hennion, G, Millerer, P, Miné, C, Mironov, I,N, Naranjo, M. Maes, A. Olbrecht G.K C. Thiebaux, C. Veelken, A. Zabi n, C.Sa I. Villella Inharcraite Leptines, Rington, Ecole Philoschnique, MOPA, CMRS, Reinbaco, France I. Sil Vrije Universiteù Brussel, Brussel, Behrmann, J.-L. Agram 14, J. Andrea, A. Besson, D. Bloch, D. Bodin, J.-M. Brom, M. Cardaci, F.C. Chaberr, C. Collard, E, Conte ¹⁴, F, Drouhin ¹⁴, C, Ferro, J.-C, Fontaine ¹⁴, D, Gelé, U, Goerlach, C, Goerzmann, L, Gross, D, Huss, P. Juillot, E. Kieller, A.-C. Le Bihan, J. Pansanel, Y. Patois, P. Van Hove W. E

Institut Rendelsciptionite Robert Conten, Université de Strasbourg, Dateenteé de Roue Alexa Malhause, (MRS/MOP), Strasbourg, France



48 OMS Collaboration / Hwsics Letters B 716 (2012) 30-61 in a state of interesting in matter in particular D, B CMN Callaboration / Rhysics Letters 8 716 (2012) 30-63 Charles 1 B. Betchart, A. Bodek, H. Budd, Y.S. Chung, R. Covarelli, P. de Barbaro, R. Demina, Y. Eshaq, T. Ferbel, A. Garcia-Bellido, G. Ginther, P. Goldenzweig, Y. Gotra, J. Han, A. Harel, S. Korjenevski, D.C. Miner, R, Class D. Orbaker, W. Sakumoto, P. Slattery, D. Vishnevskiy, M. Zielinski MC S. Pt V University of Reductor, Reductor, USA Uhiers A A. Bhatti, R. Ciesielski, I., Demortier, K. Goulianos, G. Lungu, S. Malik, C. Mesropian CMS Collaboration V. R / The Rocksfeller University, New York, USA 6.min a S. Chatrchyan, V. Kha_{N.A.N} S. Arora, A. Barker, J.P. Chou, C. Contreras-Campana, E. Contreras-Campana, D. Duggan, D. Ferencek, Y. Gershtein, R. Gray, E. Halkiadakis, D. Hidas, A. Lath, S. Panwalkar, M. Park, R. Patel, V. Rekovic, Yerevan Physics Institute, Yerevan, Ant Institute of J. Robles, K. Rose, S. Salur, S. Schnetzer, C. Seitz, S. Somalwar, R. Stone, S. Thomas W. Adam, E. Aguilo, 1L Fe A Rugers the State University of New Jersey. Recording, USA J. Hammer, M. Hoch, A. St. & G. Cerizza, M. Hollingsworth, G. Ragghianti, S. Spanier, Z.C. Yang, A. York I. Krätschmer, D. Like and A thinking of Senarous Kumite 104 R. Schölbeck, J. Strau M. A. M. O. Bouhali, R. Eusebi, W. Flanagan, J. Gilmore, T. Kamon 68, V. Khotilovich, R. Montalvo, C.N. Nguyen, Institut für Hochenergiephysik der De T. Ho C. M P I. Osipenkov, Y. Pakhotin, A. Perlolf, J. Roe, A. Safonov, T. Sakuma, S. Sengupta, I. Suarez, A. Tatarinov, D. Toback S.A. 1 n Texas 46M University, College Starlar, USA V. Chekhovsky, I. Em man R. Stefanovitch, J. Sua M. B. N. Akchurin, J. Damgov, C. Dragoiu, P.R. Dudero, C. Jeong, K. Kovitanggoon, S.W. Lee, T. Libeiro, Y. Roh, RUK: E A. Sill, I. Volobouev, R. Wigmans National Centre for Particle and High MH A Texas Tech University, Inbbook, USA A. Fedorov, M. Korzh ^B E. Appelt, A.G. Delannoy, D. Engh, C. Florez, W. Gabella, S. Greene, A. Gurrola, W. Johns, P. Kurt, Research Institute for Nuclear Problem A. G. 4 C. Maguire, A. Melo, M. Sharma, P. Sheldon, B. Snook, S. Tuo, J. Velkovska D, E **Manderick Deiversity, Reducing 198** S. 14 M. Bansal, S. Bansal, M. K. E D. Andelin, M.W. Arenton, M. Balazs, S. Boutle, S. Conetti, B. Cox, B. Francis, J. Goodell, R. Hirosky, S. N. I. A. Ledovskoy, C. Lin, C. Neu, D. Phillips II, J. Wood L. Mucibello, S. Oche LM P. Van Mechelen, N. V.P.M. In Conversity of Virginia, Charlaneeville, USA T. Sc Universiteit Antwerpen, Autwerpen, & C.W.J., S., Gollapinni, R., Harr, P.E., Karchin, C., Kottachchi Kankanamge Don, P. Lamichhane, M., Mattson, Date A. C. Milstène, A. Sakharov F. Blekman, S. Blywee Wayne State University, Detroit, USA M. Maes, A. Olbrecht G.K. M. Anderson, D. Belknap, J.N. Bellinger, L. Borrello, D. Bradley, D. Carlsmith, M. Cepeda, I. Crotty⁵, C.S. I. Villella J. Sit " S. Dasu, F. Feyzi, E. Friis, T. Gorski, L. Gray, K.S. Grogg, M. Grothe, R. Hall-Wilton, M. Herndon, A. Hervé, Wrije Universite's Brussel, Brussel, Belt Interes J. P. Klabbers, J. Klukas, J. Lackey, A. Lanaro, C. Lazaridis, J. Leonard, R. Loveless, S. Lusin⁵, E. M. Magrans de Abril, W. Maier, A. Mohapatra, I. Ojalvo, F. Palmonari, G.A. Pierro, D. Reeder, I. Ross, C. Ba F. A. Savin, W.H. Smith, J. Swanson, D. Wenman W. E ^b Deiversity of Wisconsin, Medison, IISA



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De Favereau De Jeneret, C. Delaere, P. Demin, T. du Pree, Verseur Physics Institute, Yerevort, An¹ Institute</sup>, G. Alver, D. Favart, L. Forthomme, A. Giammanco², G. Grégoire, J. Hollar, V. Lemaitre, J. Liao, O. Militaru, J. Bribles, G. Alver, D. Favart, L. Forthomme, A. Giammanco², G. Grégoire, J. Hollar, V. Lemaitre, J. Liao, O. Militaru, Yerevan Physics Institute, Yerevan, Ant^{Institut} a J. Robles, G. Alver, D. Fazart, L. Forthomme, A. Gammanco, G. Gregorius, J. Wizan Garcia R, Al A Rargers, the State Network 1 Universit? Catholique de Louvain, Louvain-lo-Neuve, leigium W. Adam, E. Aguilo, 14 Fe J. Hammer, M. Hoch, A. St. & G. Cerizza A. Anast N. Beliy, T. Caebergs, E. Daubie, G.H. Hammad I. Krätschmer, D. Like must a thinking of ten M, Schur Universit de Mont, Mont, Betgam R. Schölbeck, J. Strau M. A ... O. Bouhal Multivision G.A. Alves, L. Brito, M. Correa Martin Junior, T. Martins, M.E. Pol, M.H.G. Souza Institut für Hochenergiephysik der Ge M, Plant W.L. Aldá Júnior, W. Carvalho, A. Custódio, E.M. Da Costa, D. De Jesus Damiao, C. De Oliveira Martins, SA: n TeaseAfM (http://www.gov.carvaino, A. Custouio, E.M. Da Cota, D. De Jose Ballin, V. Oguri, W.L. Prado Da Silva, Ballin, F. Ballin, M. Plane W.L. Alda Junior, W. Carvaino, A. Custouio, E.M. Da Cota, D. De Jose Ballin, V. Oguri, W.L. Prado Da Silva, Ballin, F. Ballin, M. Plane W.L. Alda Junior, W. Carvaino, A. Custouio, E.M. Da Cota, D. De Jose Ballin, V. Oguri, W.L. Prado Da Silva, Ballin, F. Ballin, M. Plane W.L. Alda Junior, W. Carvaino, A. Custouio, E.M. Da Cota, D. De Jose Ballin, V. Oguri, W.L. Prado Da Silva, Ballin, F. Ballin, J. S. Fonseca De Souza, D. Matos Figueiredo, L. Mundim, H. Nogima, V. Oguri, W.L. Prado Da Silva, Ballin, F. Ballin, M. Santoro, A. Sznajder, A. Vilela Pereira V. Chekhovsky, I. Em man R. Stefanovitch, J. Sua M. B. N. Akchui B. Bylsn Universitede do Estado do Rio de Janeiro, Rio de Janeiro, Brazil National Centre for Particle and High R. K: E A. Sill, I. V. C. Vuosa MH. 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Pavlov, P. Petkov Universiteit Antwerpen, Autwerpen, & C, W J. S. Gollapi E. Alago. University of Sofia, Sofia, Bulgaria Data A C, Milster L, Gutay F. Blekman, S. Blywei R. P. Merkt J.G. Bian, G.M. Chen, H.S. Chen, K.L. He, C.L. Jiang, W.S. Li, D. Lang, X. Zhang, Z. Zhang, P. Merkt J.G. Bian, G.M. Chen, H.S. Chen, K.L. He, C.H. Jiang, W.G. Li, D. Liang, S. Liang, X. Meng, G. Sun, H.S. Sun, M. Maes, A. Olbrecht G.K. C C.S. M. Anden M.R. Zhao, Z. Zhu J. Sit " S. Dasu, F S. Gurag Institute of High Energy Physics, Beijing, Chine Vrije Universiten Brussel, Brussel, Behrmanner, J. P. Klabben C. Asawatangtrakuldee, Y. Ban, J. Cai, S. Guo, Y. Guo, W. Li, H.T. Liu, S. Liu, Y. Mao, S.J. Qian, H. Teng, E M. Magra 1 D. Wang, Y.L. Ye, L. Zhang, B. Zhu, W. Zou C. B. F. A. Savin, A. Adair. State KryLab. of Nacl. Phys. and Tech., Peking University, Beijing, China * Detwenty of Wis B.P. Padl C. Avila, J.P. Gomez, B. Gomez Moreno, A.E. Osorio Oliveros, J.C. Sanabria Nice University Universidad de Los Andes, Bogsta, Colombia



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Fazart, R. Cavanaugh, M.H. Chung, O. Evdokimov, E.J. Carcia-Solis, L. Gauthier, C.E. Gerber, D.J. Hofman, R. Cavanaugh, M.H. Chung, O. Evdokimov, E.J. Carcia-Solis, L. Gauthier, C.E. Gerber, D.J. Hofman, R. Cavanaugh, M.H. Chung, O. Evdokimov, E.J. Carcia-Solis, L. Gauthier, C.E. Gerber, D.J. Hofman, R. Cavanaugh, M.H. Chung, O. Evdokimov, E.J. Carcia-Solis, L. Gauthier, C.E. Gerber, D.J. Hofman, R. Cavanaugh, M.H. Chung, O. Evdokimov, E.J. Carcia-Solis, L. Gauthier, C.E. Gerber, D.J. Hofman, R. Cavanaugh, M.H. Chung, O. Evdokimov, E.J. Carcia-Solis, L. Gauthier, C.E. Cerber, D.J. Hofman, R. Cavanaugh, M.H. Chung, O. Evdokimov, E.J. Carcia-Solis, L. Gauthier, C.E. Cerber, D.J. Hofman, R. Cavanaugh, M.H. Chung, O. Evdokimov, E.J. Carcia-Solis, L. Gauthier, C.E. Cerber, D.J. Hofman, R. Cavanaugh, M.H. Chung, O. Evdokimov, E.J. Carcia-Solis, L. Gauthier, C.E. Cerber, D.J. Hofman, R. Cavanaugh, M.H. Chung, O. Evdokimov, E.J. Carcia-Solis, L. Gauthier, C.E. Cerber, D.J. Hofman, R. 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Albayrak, A.S. Ayan, B. Eilki 64, W. Clarida, P. Debbins, F. Duru, F.D. Ingram, E. McCliment, J.-P. Merlo, H. Mermerkaya 65, A. Mestvirishvili, M.J. Miller, A. Moeller, J. Nachtman, R. Schölbeck, J. Strau MAN O. Bouhal G.A. Alve C.R. Newsom, E. Norbeck, J. Olson, Y. Cnel, F. Ozok ⁶⁶, I. Schmidt, S. Sen, P. Tan, E. Tiras, J. Wetzel, Institut für Hochenergiephysik der Oe T. Ho C. M. P S.A. n L. Osipenk I., Anton Genov Busilein T. Yetkin, K. Yi D. Toback D.J. Karr M. Plane W.L. Aldi V. Chekhovsky, I. Em and F. Transford (and F. Tr R. Stefanovitch, J. Sua M. B. N. Akchur B. Bylsm Unterstated Jude cliquins University Balance 184 National Centre for Particle and High R. K: E A. Sill, I. V. C. Vuosa MH. A Texas Tech Univer Tech Univer Tech University Serrer S.M. Liett S. Sanders, R. Stringer, G. Tinti, J.S. Wood, V. Zhukova A. Fedorov, M. Korzh Research Institute for Nucleur Problem A. G. ¹⁴ C. Maguir D. E. M. A. G. ¹⁴ C. Maguir D. E. S. H. S. H. S. H. S. H. S. H. S. H. Saka, R. Trayan I. 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Fahn, Y. Kim, M. Klute, K. Krajczar⁶⁷, A. Levin, P.D. Luckey, T. Ma, S. Nahn, C. Paus, J. Sit ⁴ S. Dasu, F. S. Gurag ^{busineer High}, M. Goncharov, K.A. Fahn, Y. Kim, M. Klute, K. Krajczar⁶⁷, A. Levin, P.D. Luckey, T. Ma, S. Nahn, C. Paus, D. Ralph, C. Roland, G. Roland, M. Rudolph, G.S.F. Stephans, F. Stöckli, K. Sumorok, K. Sung, D. Velicanu, Vrije Universiteit Brussel, Brussel, Behrinners J. P. Klabbei Robertson C. Asawa E.A. Wenger, R. Wolf, B. Wyslouch, M. Yang, Y. Yilmaz, A.S. Yoon, M. Zanetti E M, Magra D. Wang, Mussechusetts Institute of Technology, Combridge, UM C. B. F. A. Savin, ' A. Adair, Sure Replated W. E. B. P. Padli D. Bailleux, S.I. Cooper, P. Cushman, B. Dahmes, A. De Benedetti, R. Egelard, G. Franzoni, A. Gude, B. P. Padli D. Bailleux, S.I. Cooper, P. Cushman, B. Dahmes, A. De Benedetti, R. Egelard, G. Franzoni, A. Gude, B. P. Padli D. Bailleux, S.I. Cooper, P. Cushman, B. Dahmes, A. De Benedetti, R. Egelard, G. Franzoni, A. Gude, B. P. Padli D. Bailleux, S.I. 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Kubota, J. Mans, N. Pastika, R. Rusack, A. Singovsky, N. Tambe, J. Turkewitz And University University of Minnesota, Minnespolis USA



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      W. Adam, E. Aguilo, J. Fe A
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                                                                                                                                                                                                                                                                                                                                                                                                                                                      SD, Worm<sup>42</sup>, W.D, Zeuner
                                                                                                                                                                                                                                                                                                                                                                                                                                                        CIRN, European Organization for Nuclear Research, Geneva, Switzerland

    Liniversiteit Antwerpen, Autwerpen, & C. W. J. S. Gollapi E. Alago
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                                                                                                                                                                                                                                                                                                                                                                                                                                                      J. Weng, S. Zelepoukine 46
                                                                                                                                                                                                                                                                                                                                                                                                                                                        Institute for Particle Physics, ETU Zurich, Zurica, Switzerland
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G. Ha
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Universition Zurich, Zurich, Switzmione



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 S. Chatrchyan, V. Kha<sub>N,A,K</sub>
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J. Bribles
G. Alver, D. Favart, R. Carlo M. Paul
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  Yerevan Physics Institute, Yerevan, An Institut o J. Robles, G. Alver, D. Pavart, R. Ca. M. Pau Bund University National J. Bund P. Bu
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  W. Adam, E. Aguilo, L. Fe A
J. Hammer, M. Hoch, A. St A
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R. Schölbeck, J. Strau

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  National Centre for Particle and High R. K. E A. Sill, I. V. C. Vuosa
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   A. Fedorov, M. Korzh
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M. Bansal, S. Bansal, M. K.S.
L. Mucibello, S. Oche I. M. E.
S. Ni, L.
A. Ledovs J.E. Ram
M. Bansal, S. Rither S. Ni, L.
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Universiteit Antwerper, Autwerper, E C.W.J.

F. Blekman, S. Blywei

M. Maes, A. Olbrecht, G.K.

I. Villella

Wige Universiteit Brussel, Brussel, Beth marks

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                                                                                                                                                                                                                                                                                                              M. Don V. Krychkine, A. Levine, V. Petrov, A. Ryabov, R. Ryutin, A. Sobol, V. Talov, L. Tourtchanovitch, S. Troshin,
                                                                                                                                                                                                                                                                                                              H. Hofe N. Tyurin, A. Uzurian, A. Volkov
                                                                                                                                                                                                                                                                                                             P. Mart State Research Center of RussianFederation, Institute for High Energy Physics, Provine, Russia
                                                                                           C. Bi P A, Savin, ' A, Adair
W. E A Savin, ' A, Adair
B.P. Padl B.P. Padl C. Avila, J. Hugo C. Petruc J.r. Co
B.P. Padl C. Avila, J. Hugo C. Petruc J.r. Co
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                                                                                                                                                                                                                                                                                                             D. Treil
                                                                                                                                                                                                                                                                                                                                      University of Belgrade Faculty of Physics and Vinco Institute of Nuclear Sciences, Belgrade, Serbia
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                                                                                                                                                                                                                                                          University of Ca
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~3000 authors × 2 experiments a spectrum of the content of the con









What do all these people do?

- How to make a new particle
- Building a particle detector
- Operating a detector
- Understanding the detector
- Analyzing the data & making a discovery









$E = mc^2$



























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Tools of the trade




Particle accelerators/colliders





CMS



21 m long × 15 m diameter 14000t wt. 3.8 T magnetic field

Our detector — CMS



.840 n 21 m long × 15 m diameter 14000t wt atons

An LHC event





CMS Experiment at the LHC, CERN Data recorded: 2012-May-13 20:08:14.621490 GMT Run/Event: 194108 / 564224000

CMS detector components







Semiconductor

р

n

1. dope Si (or Ge) to create a diode



depletion region

Cherenkov

Readout

Scintillator



Semiconductor



- 1. dope Si (or Ge) to create a diode
- 2. apply reverse bias; no current flows

Cherenkov

Readout

Scintillator



Semiconductor



- 1. dope Si (or Ge) to create a diode
- 2. apply reverse bias; no current flows
- 3. charged particle passes through; creates e/h pairs

Cherenkov

Scintillator



Semiconductor



- 1. dope Si (or Ge) to create a diode
- 2. apply reverse bias; no current flows
- 3. charged particle passes through; creates e/h pairs
- 4. current pulse is produced

Readout

Scintillator



Semiconductor

choose a material with energy levels separated by visible wavelength

Scintillator





Semiconductor



- choose a material with energy levels separated by visible wavelength
- 2. charged particle passes through; transfers energy to atoms in material

Scintillator



Semiconductor



- choose a material with energy levels separated by visible wavelength
- charged particle passes through; transfers energy to atoms in material

excited atom decays; emits a photon

Scintillator





Semiconductor



- choose a material with energy levels separated by visible wavelength
- charged particle passes through; transfers energy to atoms in material
 - excited atom decays; emits a photon
- photodetector measures the photon and produces a current

Scintillator







1. choose an optically clear material with a known index of refraction

Scintillator







- choose an optically clear material with a known index of refraction
 - relativistic particle travels through with speed c/n < v < c









- choose an optically clear material with a known index of refraction
 - relativistic particle travels through with speed c/n < v < c



Cherenkov radiation is produced with characteristic cone angle relative to speed of particle







- 1. choose an optically clear material with a known index of refraction
 - relativistic particle travels through with speed c/n < v < c
 - Cherenkov radiation is produced with characteristic cone angle relative to speed of particle
 - photodetectors around edges image this cone







detectors produce a small amount of current







- 1. detectors produce a small amount of current
- 2. pass it through an amplifier to make it measurable







- 1. detectors produce a small amount of current
- 2. pass it through an amplifier to make it measurable
 - amplifier output is passed to an ADC which converts to digital data





57



- 1. detectors produce a small amount of current
- 2. pass it through an amplifier to make it measurable
 - amplifier output is passed to an ADC which converts to digital data
 - store events in FIFO and wait for readout decision







- 1. detectors produce a small amount of current
- 2. pass it through an amplifier to make it measurable
 - amplifier output is passed to an ADC which converts to digital data
 - store events in FIFO and wait for readout decision
- 5. save for analysis!



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So what does everyone do?



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- Remember the 3000 authors on the Higgs discovery paper.
- What does everyone do?
- Use FSU as an example...

FSU CMS group







A. Ackert, T. Adams, A. Askew, V. Hagopian, S. Hagopian, K.F. Johnson, T. Kolberg, G. Martinez, T. Perry, H. Prosper, A. Saha, A. Santra, R. Yohay

Academic faculty — at any given time, some of the faculty are retired, or working part or all of their time on other things (teaching, university administration, ...)

PhD scientists and postdocs — most are working full time on CMS

PhD students — some are working part time while taking classes, writing their doctoral thesis, etc.

To be an author, you have to work on the experiment for at least a year, and help pay into a common fund which keeps the lights on, etc. As a very rough rule of thumb, about half of the authors might be actively working on CMS at any given moment.

Only a few of us worked 'directly' on the Higgs discovery. What is everyone else doing?

Understanding the detector



- Discovering a particle like the Higgs requires a very good understanding of how the detector responds to different kinds of events.
- At any given time, CMS physicists are constantly updating and refining many performance studies which quantify how well the detector is working.
- These numbers change as the experimental conditions evolve, the software algorithms used to analyze the data are improved, and the detector hardware ages and is upgraded. So it is a constant struggle to stay up to date.
- The next few slides illustrate an example of a performance measurement...



Transverse mass of W events







[JINST 10 (02) 2015 P02006]





- Building detectors
- Developing electronic systems for readout
- Working on the physical plant of the experiment and taking shifts
- Distributed computing and writing software

Detector development





Detector development





Electronics development





Installation & operations





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Large Hadron Collider turns on 'data tap'

By Paul Rincon Science editor, BBC News website

C 3 June 2015 | Science & Environment



The CMS experiment team celebrated when the first collisions occurred
Marketable skills









- Adding together all the activities needed to discover a particle like the Higgs, the huge size of the collaboration starts to look rather small!
- We could do more if we had more resources...
- CMS experiment at the LHC is an exciting place and time to do physics.