Higgs@PDG

STATUS OF HIGGS BOSON PHYSICS

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HEP with a Higgs boson

" If you don't have the ball, you cannot score"

Now the PDG has the ball

H^0 $\quad J = 0$

In the following H^0 refers to the signal that has been discovered in the Higgs searches. Whereas the observed signal is labeled as a spin 0 particle and is called a Higgs Boson, the detailed properties of H^0 and its role in the context of electroweak symmetry breaking need to be further clarified. These issues are addressed by the measurements listed below.

Concerning mass limits and cross section limits that have been obtained in the searches for neutral and charged Higgs bosons, see the sections "Searches for Neutral Higgs Bosons" and "Searches for Charged Higgs Bosons ($H^{\pm}$ and $H^{\pm\pm}$)", respectively.

H^0 MASS

A combination of the results from ATLAS and CMS, where a recent unpublished result from CMS is used, yields an average value of 125.6 ± 0.3 GeV, see the review on "Status of Higgs Boson Physics."

VALUE (GeV)	*DOCUMENT ID*	*TECN*	*COMMENT*
125.7±0.4 OUR AVERAGE			
$125.5 \pm 0.2^{+0.5}_{-0.6}$	[1,2] AAD 13AK	ATLS	pp, 7 and 8 TeV
$125.8 \pm 0.4 \pm 0.4$	[1,3] CHATRCHYAN 13J	CMS	pp, 7 and 8 TeV

In ~~football~~ as in watchmaking, talent and elegance mean nothing without rigor and precision.
Higgs Physics

Lionel Messi, 2014

11. STATUS OF HIGGS BOSON PHYSICS

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I. Introduction

The observation by ATLAS [1] and CMS [2] of a new boson with a mass of approximately 125 GeV decaying into $\gamma\gamma$, WW and ZZ bosons and the subsequent studies of the properties of this particle is a milestone in the understanding of the mechanism that breaks electroweak symmetry and generates the masses of the known elementary particles[1], one of the most fundamental problems in particle physics.

In the Standard Model, the mechanism of electroweak symmetry breaking (EWSB) [3] provides a general framework to keep untouched the structure of the gauge interactions at high energy and still generate the observed masses of the W and Z gauge bosons by means of charged and neutral Goldstone bosons that manifest themselves as the longitudinal components of the gauge bosons. The discovery of ATLAS and CMS now strongly suggests that these three Goldstone bosons combine with an extra (elementary) scalar boson to form a weak doublet.

This picture matches very well with the Standard Model (SM) [4] which describes the electroweak interactions by a gauge field theory invariant under the $SU(2)_L \times U(1)_Y$ symmetry group. In the SM, the EWSB mechanism posits a self-interacting complex doublet of scalar fields, and the renormalizable interactions are arranged such

[1] In the case of neutrinos, it is possible that the EWSB mechanism plays only a partial role in generating the observed neutrino masses, with additional contributions at a higher scale via the so called see-saw mechanism.

Higgs @ PDG 2014

- **53 double-column printed pages**
- **32 figures**
- **18 tables**
- **500 References**
- **> 50'000 downloads**

- SM Higgs: sections II, III, IV
- New Physics models with a light Higgs boson: section V

Status in 2014 ⟶ 2015 Updates

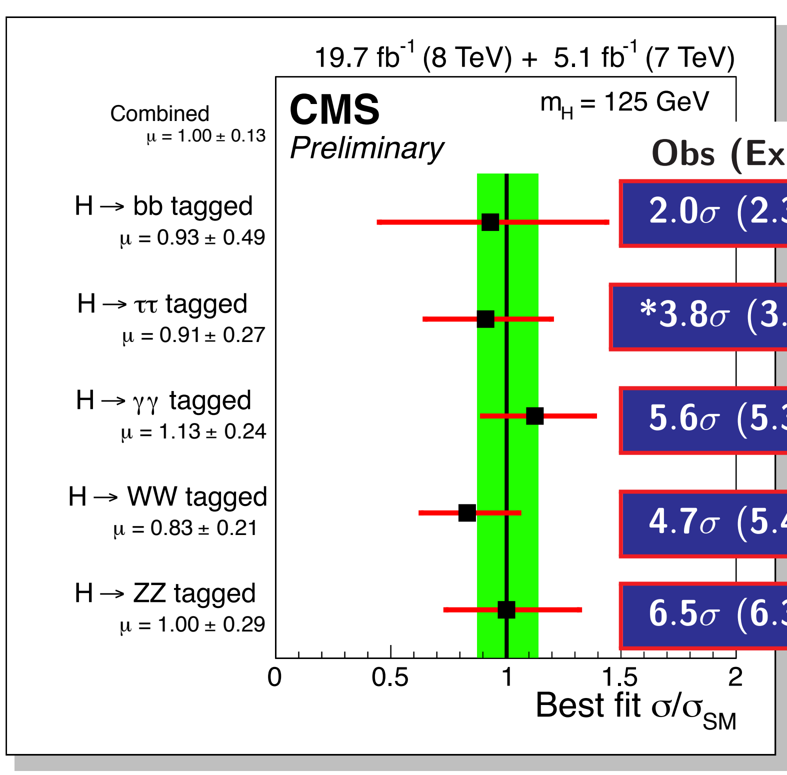
PDG 2014 edition

	$\gamma\gamma$	ZZ (4ℓ)	WW ($\ell\nu\ell\nu$)	$\tau\tau$	W/Z(bb)	Combination
ATLAS						
μ (at 125.5 GeV)	$1.55^{+0.33}_{-0.28}$	$1.43^{+0.40}_{-0.35}$	$0.99^{+0.31}_{-0.28}$	$1.4^{+0.5}_{-0.4}$	0.2±0.7	1.3±0.2
Z Exp.	4.1	4.4	3.8	4.1	1.4	–
Z Obs.	7.4	6.6	3.8	3.2	0.3	–
Mass (GeV)	126.8±0.2±0.7	124.3±0.5±0.5	–	–	–	125.5±0.2±0.6
Reference	[119]	[119]	[119]	[133]	[138]	[119]
CMS						
μ (at 125.7 GeV)	0.77±0.27	0.92±0.28	0.68±0.20	1.10±0.41 0.87±0.29*	1.15±0.62	0.80±0.14
Z Exp.	3.9	7.1	5.3	2.6 (3.6*)	2.2	–
Z Obs.	3.2	6.7	3.9	2.8 (3.4*)	2.0	–
Mass (GeV)	125.4±0.5±0.6	125.8±0.5±0.2				125.7±0.3±0.3
Reference	[120]	[121]	[127]	[131,132]	[137]	[124]
Tevatron						
μ (at 125 GeV)	$6.0^{+3.4}_{-3.1}$	–	0.9±0.8	$1.7^{+2.3}_{-1.7}$	1.6±0.7	1.4±0.6
Reference	[108]		[108]	[108]	[108]	[108]

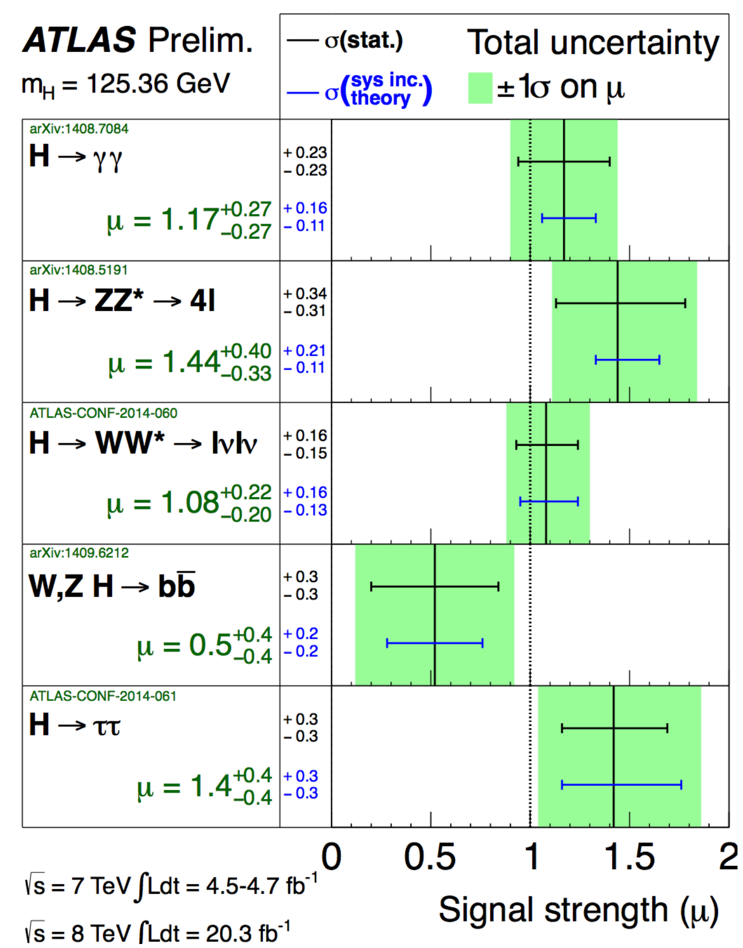
ICHEP'14

★ "seen" ☆ "tried"	H→bb̄	H→ττ	H→WW	H→ZZ	H→γγ	H→Z(*)γ	H→inv.	H→μμ	H→cc̄ H→HH
ggH		★	★	★	★	☆		☆	
VBF	☆	★	★	☆	★	☆	☆	☆	
VH	★	☆	☆	☆	☆		☆		
ttH	☆	☆	☆		☆				

CMS updates



ATLAS updates



"What will be new and different in the 2015 edition?"

- **LHC Run I Legacy Results**

  No new 13 TeV results but CMS/ATLAS final legacy results on full Run-1 data

  Finalization of all ttH channels (including multi-lepton channels)

  Constraints on Spin/Parity

	ATLAS limits	CMS limits	CMS sig. strengths
$t\bar{t}(H \to \gamma\gamma)$	<5.3 (6.4)	<5.4 (5.5)	$\mu = -0.2^{+2.4}_{-1.9}$
$t\bar{t}(H \to b\bar{b})$	<13.1 (10.5)‡	<4.5 (3.7)*	$\mu = 1.0^{+1.9}_{-2.0}$
$t\bar{t}(H \to 4\ell)$	–	<6.8 (8.8)	$\mu = -4.8^{+5.0}_{-1.2}$
$t\bar{t}(H \to 3\ell)$	–	<6.7 (3.8)	$\mu = 2.7^{+2.2}_{-1.8}$
$t\bar{t}(H \to SS2\ell)$	–	<9.1 (3.4)	$\mu = 5.3^{+2.2}_{-1.8}$
$t\bar{t}(H \to \tau^+\tau^-)$	–	<12.9 (14.2)	$\mu = -1.4^{+6.3}_{-5.5}$
Combination	–	<4.3 (1.8)	$\mu = 2.5^{+1.1}_{-1.0}$

- **Combination**

  Published combination of Higgs properties

  ATLAS+CMS combination of Higgs properties (mass, signal strengths, couplings…)

- **Rare Decay Channels**

  $\gamma\gamma^*$, invisible

  $h \to J/\Psi+\gamma$ as a measurement of the charm Yukawa coupling

- **Flavor violating channels**

  $h \to \tau\mu$

  $t \to hc$

"What will be new and different in the 2015 edition?"

- **Rare production channels**

  th

  h+boosted jet

- **Double-Higgs production**

  $gg \rightarrow hh$

  $WW \rightarrow hh$

- **Kinematical distributions**

  Differential cross sections in ZZ and $\gamma\gamma$ channels

  off-shell couplings and EFT interpretation (rather than bound on width)

  interferometry in $\gamma\gamma$ channel

- **BSM Higgs Searches**

How did we handle the previous recommendations?

“ The Higgs review should be **rewritten in a very substantial way** as soon as possible, and no later than the 2013 update following the publication of final results from ATLAS and CMS on the full 7 and 8 TeV datasets. The focus should be on the SM Higgs and its properties.”

- **All New: We rewrote the review completely**

- **SM Higgs: We devoted 1/2 of the review: Sections II, III and IV to the SM-like Higgs**

Properties, production mechanisms and decay rates.

Description of SM Higgs boson analysis channels

General theoretical framework to analyze deviations of Higgs properties from SM predictions

- **New Physics models with a light Higgs boson: Section V**

SUSY extensions (incl. new sources of CP violation),
Non-SUSY extensions with an elementary Higgs,
Composite Higgs models
Searches for additional Higgs bosons

How did we handle the previous recommendations?

"On the experimental side, we suggest reorganizing the review to include first a summary of the status before July 4 (a condensation of the present section), and then detailing the data that has subsequently been collected."

- **We have ~ a page of the status prior to July 4th, 2012, the rest is on new analyses**
- We are considering to shorten the details of the discovery analyses in the 2015 edition (refer to 2014 edition)

"On the theory side, the focus should be changed to reflect the transition to a precision measurement era. The data should be interpreted in a model-independent manner (with analogy to the S and T variables of electroweak precision tests, which would parameterize both the tree-level structure of the theory and the loop-induced effects). This would provide a guide to future measurements."

- **We show the interpretation of data in terms of the EFT approach (Section IV).**
This allows to evaluate deviations of the Higgs couplings from its SM values (SM coupling modifiers) in an as much as possible model independent manner

- **We present likelihood contours of global fits in terms of pairs of SM coupling modifiers under some assumptions for the rest of them.**

- **We present a general framework to study the spin and parity quantum numbers of the newly discovered particle The most general tensor structure is used for the three possible spin hypotheses of spin 0, spin 1 and spin 2, as well as for probing CP mixture.**

Can we make it shorter?

- **Need to cover new exp. results**
- **TH vs EXP**

  separated or kept together?

  We all agree is better to keep them together.

  More useful, coherent. More work, but the hardest part already done

- **What could be removed:**

  large description of the analyses part? Refer to the 2014 edition for details?

  narrative about the discovery? Already quite succinct!

  pre-LHC bounds? Already quite succinct too, but could refer to the 2014 edition

- **What could be improved:**

  expand the EFT part?
  balance susy and compositeness parts while keeping them concise