Higgs combination results from ATLAS and CMS

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Higgs Search in Belgium
Louvain-la-Neuve

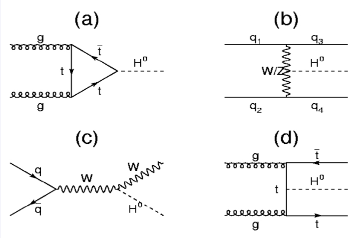
Outline

1. Introduction
2. Exclusion and p-values
3. Mass and signal strength
4. Compatibility with SM Higgs couplings

Higgs boson in the SM

- Result of spontaneous symmetry breaking
- Mass to gauge bosons + unitarity at high energy
- Mass to fermions through Yukawa

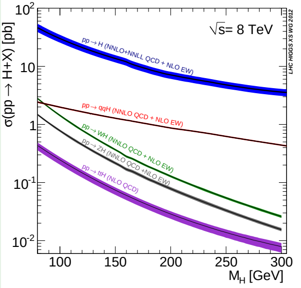
Production @ LHC

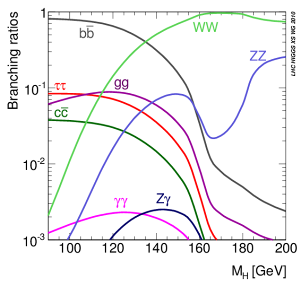


- **a:** Gluon fusion
- **b:** VBF
- **c:** W/Z associated
- **d:** $t\bar{t}$ associated

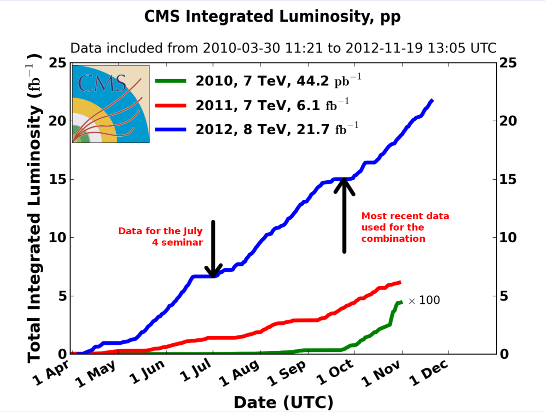
cross-section and BR

- Mass is a free parameter of the SM
- Couples to gauge bosons and elementary fermions
- Coupling strength proportional to mass
- total XS$\times$BR: few fb - few pb

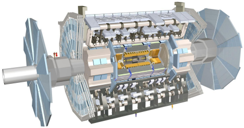


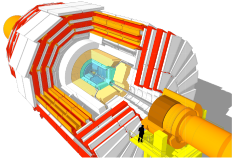


The collider and detectors



- LHC is colliding proton-proton beams since 2009
- Collisions @ 7 TeV in 2010 and 2011
- Collisions @ 8 TeV in 2012
- Up to 15/30 interactions per beam collission in 2011/2012
- O(10^5) decays of H(125)$\rightarrow b\bar{b}$
- O(10^2) decays of H(125)$\rightarrow \gamma\gamma$
- CMS and ATLAS:
  - general purpose detectors at LHC
  - well suited for all SM H decays





Search channels overview

- The Higgs search is done in all channels sensitive for low-mass SM Higgs decays and 2 high-mass sensitive channels
- Every decay analysis is combination of many analyses optimized separately for best sensitivity
- Some analyses tag the specific production mode to increase sensitivity
- Most ATLAS results (except the total signal strength) uses only 5+5 fb^{-1}
- Most CMS analyses use full 17-18 fb^{-1} dataset except
  - $\gamma\gamma$ uses only 5+5 fb^{-1}
  - $t\bar{t}H \to t\bar{t}b\bar{b}$ uses only 2011 data
  - $VH \to V\tau^+\tau^-$ uses only 2011 data in
  - $WH \to WWW$ uses 5+5 fb^{-1}

Decay	untagged	VBF	VH	$t\bar{t}$H	remarks
H$\to \gamma\gamma$	✓	✓			excellent mass resolution + sensitivity low mass, low BR
H$\to b\bar{b}$			✓	CMS only	high BR, huge background low mass
H$\to \tau^+\tau^-$	✓	✓	✓		moderate BR, complex final states low mass
H$\to W^+W^-$	✓	✓	CMS only		high BR, lepton final states no peak, low+high mass
H$\to ZZ$	✓				very low BR, clean signature excelent peak, low+high mass

Statistical combination methodology

Based on the approach agreed by ATLAS and CMS in
http://cdsweb.cern.ch/record/1379837

Likelihood

$$\mathcal{L}(\mathrm{data}|\mu \cdot s + b, \theta) = \mathcal{P}(\mathrm{data}|\mu \cdot s + b, \theta) \cdot p(\tilde{\theta}|\theta)$$

- $\mathcal{P}$ . . . Product of probabilities over all channels and all bins (or all events)
- $p(\tilde{\theta}|\theta)$ . . . Probability of observing measured value $\tilde{\theta}$ of nuissance parameter θ

Limits

$$\textbf{Test statistics: } q_\mu = -2\ln \frac{\mathcal{L}(\mathrm{obs}|\mu \cdot s + b, \hat{\theta}_\mu)}{\mathcal{L}(\mathrm{obs}|\hat{\mu} \cdot s + b, \hat{\theta})}$$

- $\mathcal{L}(\mathrm{obs}|\hat{\mu} \cdot s + b, \hat{\theta})$ . . . global maximal likelihood
- $\mathcal{L}(\mathrm{obs}|\mu \cdot s + b, \hat{\theta}_\mu)$ . . . maximal likelihood for fixed value μ

Signal strength $\mu \cdot s$ is excluded at $1 - \alpha$ confidence level if

$$\mathrm{CL_s} = \frac{P(q_\mu \geq q_\mu^{\mathrm{obs}}|\mu \cdot s + b)}{P(q_\mu \geq q_\mu^{\mathrm{obs}}|b)} \leq \alpha$$

Statistical combination methodology

Based on the approach agreed by ATLAS and CMS in
http://cdsweb.cern.ch/record/1379837

Excess of events

Test statistics: $q_0 = -2\ln\frac{\mathcal{L}(\mathrm{obs}|b,\hat{\theta}_0)}{\mathcal{L}(\mathrm{obs}|\hat{\mu}\cdot s+b,\hat{\theta})}$

- p-value: $p_0 = \mathrm{P}(q_0 \geq q_0^{\mathrm{obs}}|b)$
- significance Z: $p_0 = \int_Z^\infty \frac{1}{\sqrt{2\pi}} e^{-\frac{x^2}{2}}\,\mathrm{d}x$

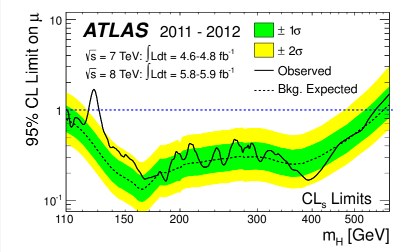
Signal model parameters

Test statistics: $q(a) = -2\ln\frac{\mathcal{L}(\mathrm{obs}|s(a)+b,\hat{\theta}_a)}{\mathcal{L}(\mathrm{obs}|s(\hat{a})+b,\hat{\theta})}$

- The 68% (95%) CL on a given parameter of interest a_i: $q(a_i) = 1(3.84)$
- For 2D contours, The 68% (95%) CL on a given parameter of interest a_i: $q(a_i, a_j) = 2.3(6)$

Exclusion of the SM Higgs boson

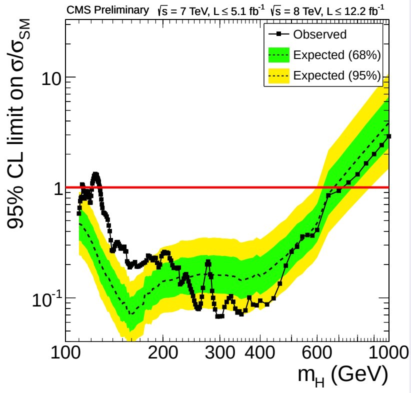
ATLAS



- Expected exclusion: 110 - 582 GeV
- Observed exclusion: 111 - 122 GeV and 131 - 559 GeV
- 113–114, 117–121, 132–527 GeV:

  SM Higgs excluded by > 99% CL

CMS



- Expected exclusion: 110 - 650 GeV
- Observed exclusion: 110 - 112 GeV, 114-120 GeV and 129 - 700 GeV
- 130-600 GeV:

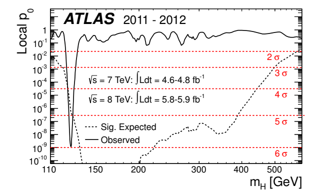
  SM Higgs excluded by > 99.9% CL

Significance of the observation

Probabibility of background fluctuation

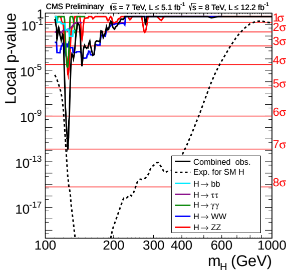
- $5\sigma : 5.73 \times 10^{-7}$
- $6\sigma : 1.97 \times 10^{-9}$
- $7\sigma : 2.56 \times 10^{-12}$

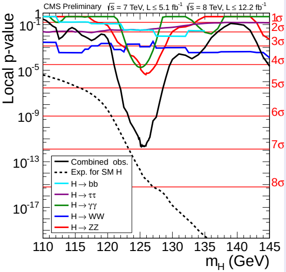
ATLAS



- Largest significance of excess is **6.0** σ **@126.5 GeV**
- Expected excess for SM Higgs@126.5 GeV is **4.9** σ

CMS





- Largest significance of excess is **6.9** σ **@125.8 GeV**
- Expected excess for SM Higgs@125.8 GeV is **7.8** σ
- $ZZ + \gamma\gamma$ combination has excess 5.8σ (expected 5.7σ)

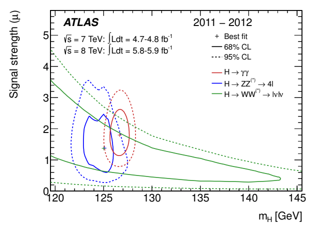
Mass of the new state

Method

- Use $H \to ZZ \to 4l$ and $H \to \gamma\gamma$ channels
- Assume that excess in both channels is due to single particle $\Rightarrow$ common mass m_X
- Test statistics $q(m_X)$, channel signal strengths independent

ATLAS

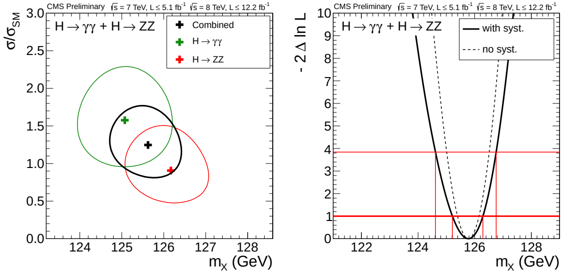
$\mathbf{126.0} \pm \mathbf{0.4}(\text{stat}) \pm \mathbf{0.4}(\text{sys})\mathbf{GeV}$



- 2D contours of $q(\mu, m_X)$

CMS

$\mathbf{125.8} \pm \mathbf{0.4}(\text{stat}) \pm \mathbf{0.4}(\text{sys})\mathbf{GeV}$



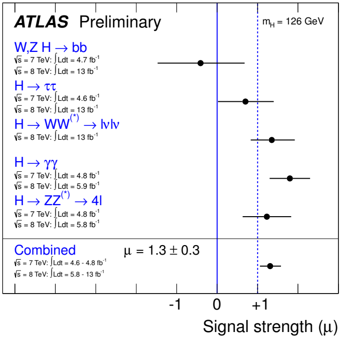
- untagged and VBF-tagged $\gamma\gamma$ separately
- consistent with 1 particle

SM compatibility: signal strength

Method

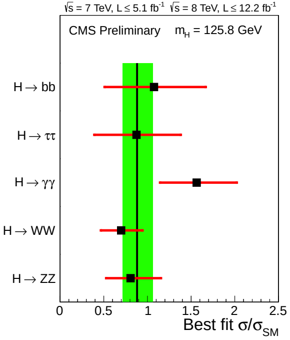
- Use all channels
- Test statistics q_μ, $\hat{\mu} = \sigma/\sigma_{\mathrm{SM}}$

ATLAS



$\hat{\mu} = \mathbf{1.3 \pm 0.3}$ for $m_H = 126.0$ GeV

CMS

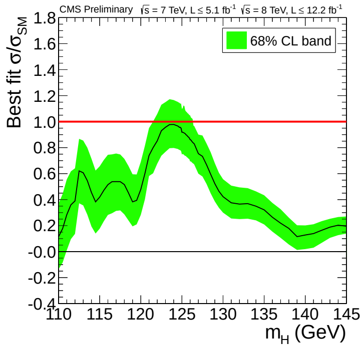


$\hat{\mu} = \mathbf{0.88 \pm 0.21}$ for $m_H = 125.8$ GeV

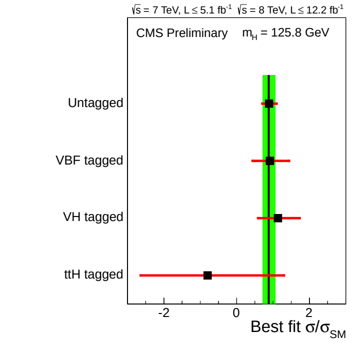
Both CMS and ATLAS measurements consistent with SM ($\mu = 1$)

CMS signal strength: details

- Results as a function of mass/by production mode tag
- Production tag never 100% pure
- Negative $\hat{\mu}$ means deficit of events w.r.t. expected SM background
- No evidence against SM Higgs hypothesis



- χ^2/n.d.f = 8.7/11
- P($\chi^2 > 8.7$| n.d.f=11)=0.65

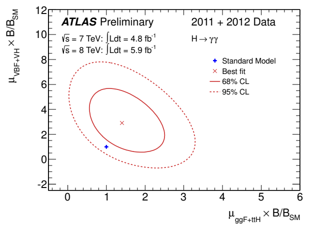


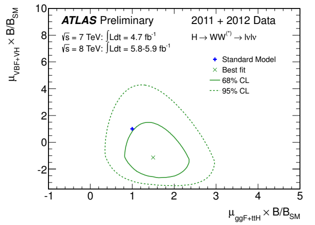
- χ^2/n.d.f = 1.3/4
- P($\chi^2 > 1.3$| n.d.f=4)=0.86

SM compatibility: 2D signal strength

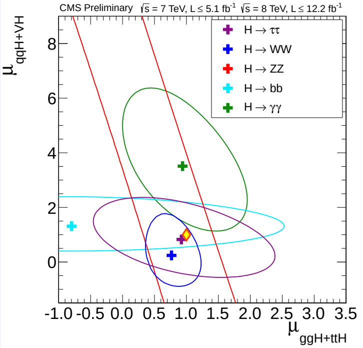
- Test statistics $q(\mu_{\mathrm{ggH+ttH}}, \mu_{\mathrm{qqH+VH}})$, 2 + 2 production modes grouped together
- Decays as in SM

ATLAS





CMS



In $H \to ZZ$ the production mechanisms are not specifically targeted

Compatibility of couplings

Scaling factors

$$N(xx \to H \to yy) \sim \sigma(xx \to H) \cdot \mathcal{B}(H \to yy) \sim \frac{\Gamma_{xx}\Gamma_{yy}}{\Gamma_{\mathrm{tot}}}$$

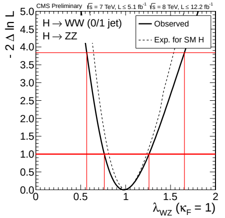
- 8 **independent** parameters relevant for current searches
- Γ_{ZZ}, Γ_{WW}, $\Gamma_{\tau\tau}$, Γ_{bb}, $\Gamma_{\gamma\gamma}$, Γ_{gg}, Γ_{tt}, Γ_{tot}
- Not possible to extract those parameters at the moment
- **Scaling factors for couplings:** $\mathbf{g_i} = \kappa_\mathbf{i} \cdot \mathbf{g_i}^{\mathrm{SM}}$
- Introducing Γ_{BSM}

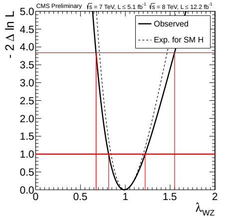
- Following slides are **compatibility tests**, not measurements
- Significant deviation of κ's from 1 would mean BSM physics
  - Re-fit of event yields in particular BSM framework will be also needed

Custodial symmetry

Testing $\lambda_{WZ} = \kappa_W/\kappa_Z$, κ_Z and κ_f

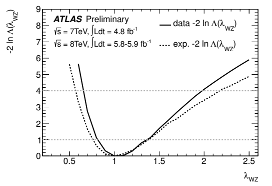
CMS





1. use $gg \rightarrow H \rightarrow WW/ZZ$
   - nearly model independent
   - fit for λ_{WZ} and κ_Z, $\kappa_f = 1$
   - $\lambda_{WZ} \in [0.57, 1.65]$@ 95% CL
2. use all channels
   - model independent (uniform κ_f)
   - fit for λ_{WZ}, κ_Z and κ_f, $\Gamma_{\mathrm{BSM}} = 0$
   - $\lambda_{WZ} \in [0.67, 1.55]$@ 95% CL

ATLAS



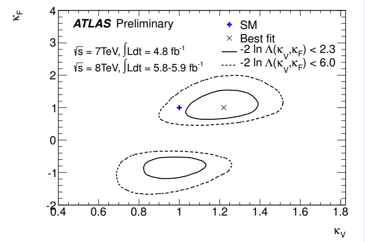
- All chanels
- fitting λ_{WZ}, κ_Z and κ_f
- $\lambda_{WZ} = 1.07^{+0.35}_{-0.27}$
- $\kappa_{ZZ} = \kappa_Z^2/\kappa_{\mathrm{tot}} = 1.3^{+0.9}_{-0.6}$
- $\lambda_{fZ} = \kappa_f/\kappa_Z \in [-1.1, -0.5] \cup [0.6, 1.2]$@ 68% CL

- Data are consistent with custodial symmetry
- Further CMS tests assume $\kappa_W = \kappa_Z = \kappa_V$

Couplings to fermions and W/Z: 2D contours

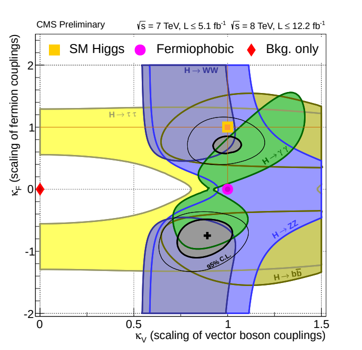
- Assume common scaling factors for fermion and W/Z couplings: κ_f, κ_V
- $\Gamma_{\mathrm{BSM}} = 0$
- $\Gamma_{gg} \sim \kappa_f^2$
- $\Gamma_{\gamma\gamma} \sim |\alpha\kappa_V + \beta\kappa_f|^2$ (W and t loop)$\Rightarrow$ $\gamma\gamma$ sensitive to relative sign of κ_V and κ_f

ATLAS



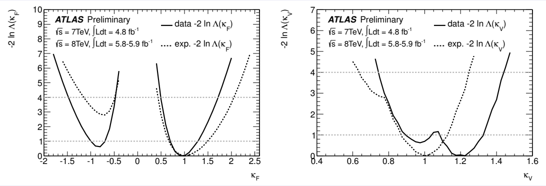
$(\kappa_V, \kappa_f) = (1, 1)$ within CL 95% defined by data

CMS



Couplings to fermions and W/Z: 1D scans

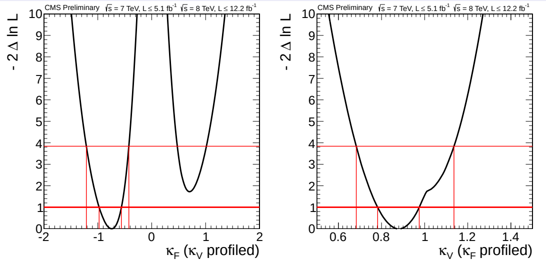
ATLAS



1 parameter fit, other profiled

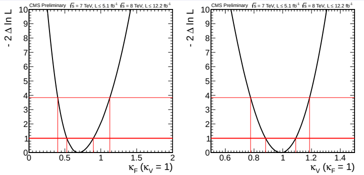
- $\kappa_f \in [-1.5, -0.5] \cup [0.5, 1.7]$ @ 95% CL
- $\kappa_V \in [0.7, 1.4]$ @ 95% CL

CMS



1 parameter fit, other set to SM value (1) and required $\kappa_f > 0$

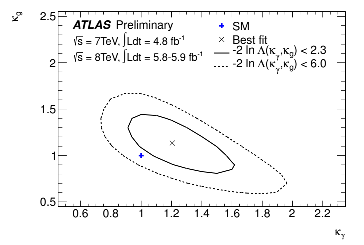
- $\kappa_f \in [0.4, 1.12]$ @ 95% CL
- $\kappa_V \in [0.78, 1.19]$ @ 95% CL



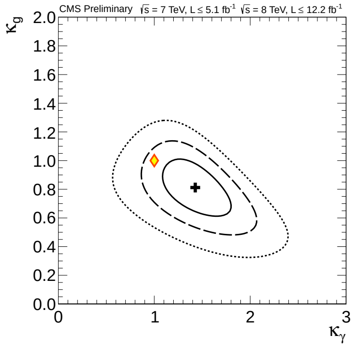
New physics in the loops: κ_g and κ_γ

- Loop diagrams sensistive to new particles, κ_g and κ_γ allow contributions from new particles
- $\Gamma_{\rm BSM} = 0$, all other $\kappa_i = 1$

ATLAS



CMS



ATLAS @68% CL

$\kappa_g = 1.1^{+0.2}_{-0.3}$

$\kappa_\gamma = 1.2^{+0.3}_{-0.1}$

CMS @95% CL

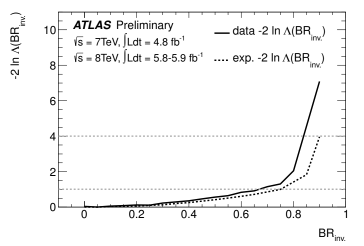
$\kappa_g = 0.81^{+0.26}_{-0.26}$

$\kappa_\gamma = 1.43^{+0.49}_{-0.45}$

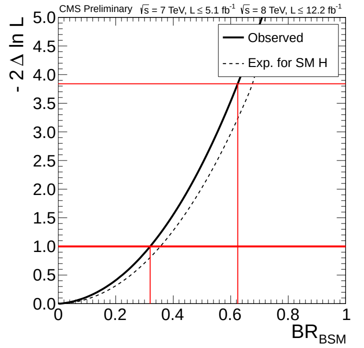
Non SM Higgs decays

- Assume tree-level couplings are SM
- fit for $\Gamma_{\rm BSM}$, κ_γ and κ_g

ATLAS



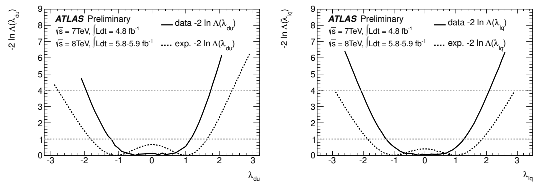
CMS



ATLAS @95% CL	CMS @95% CL
$\Gamma_{\rm BSM}/\Gamma_{\rm tot} < 0.84$	$\Gamma_{\rm BSM}/\Gamma_{\rm tot} < 0.62$

Fermion coupling asymmetries

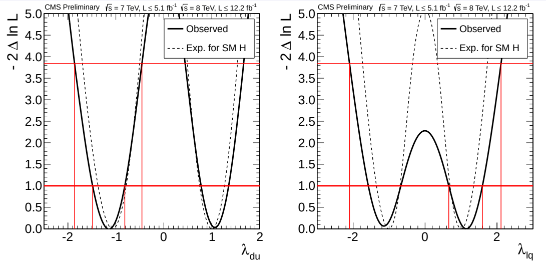
ATLAS



Dominated by low sensitivity in $H \to \tau\tau$ and $H \to bb$

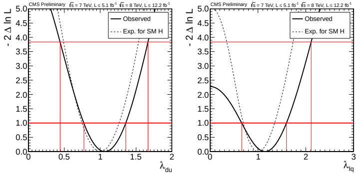
- $\lambda_{du} = \kappa_d/\kappa_u \in [-2.0, 1.8]$ @ 95% CL
- $\lambda_{lq} = \kappa_l/\kappa_q \in [-2.1, 2.1]$ @ 95% CL

CMS



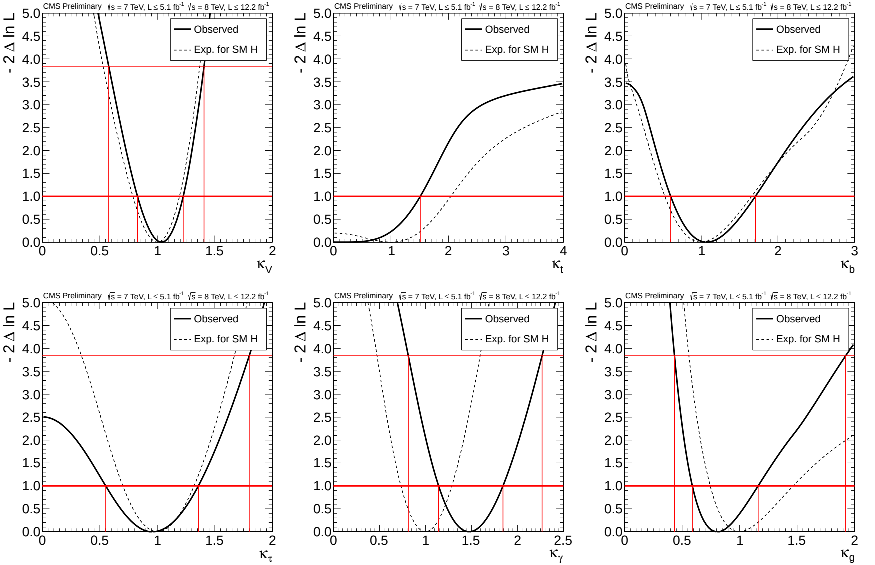
Results for $\lambda_{du} > 0$ and $\lambda_{lq} > 0$

- $\lambda_{du} = \kappa_d/\kappa_u \in [0.45, 1.66]$ @ 95% CL
- $\lambda_{lq} = \kappa_l/\kappa_q \in [0.00, 2.11]$ @ 95% CL

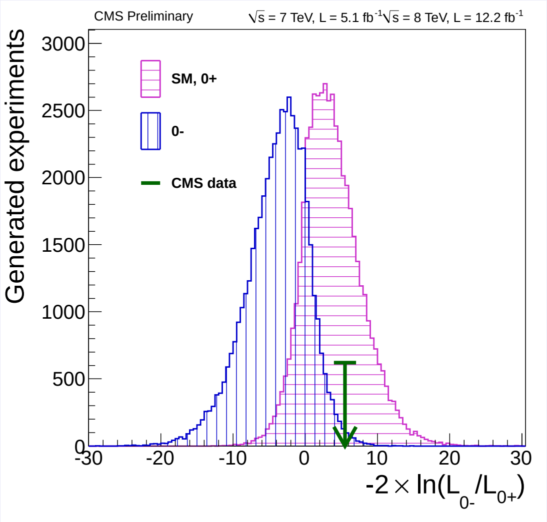


C6 model @ CMS

- Assume 6 independent parameters: κ_V, κ_t, κ_b, κ_τ, κ_γ, κ_g; $\Gamma_{\rm BSM} = 0$



Testing of J^P



- Decay to $\gamma\gamma \Rightarrow J = 1$ disfavoured
- Parity tested in $H \to ZZ \to 4l$
- Assume SM x-section in both hypotheses
- maximize independently
- Assuming J=0, data disfavours 0^- pseudoscalar at 97.6% CL
- Need more data to sort out J=2 from J=0

Summary

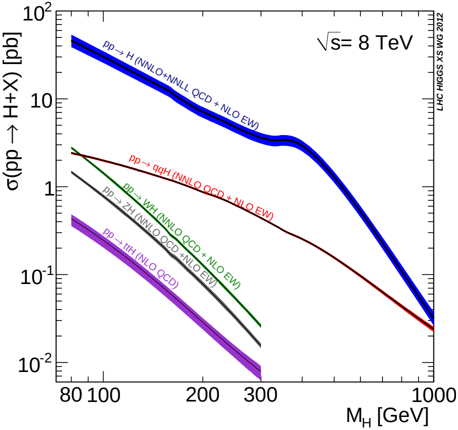
- Boson at 126 GeV does not go away (significance 6.9σ now), otherwise excluded up to 700 GeV
- mass is around 126 GeV, with 0.5 % precision
- No statistically significant anomalies from the SM predictions observed in any decay channels at both experiments
- Spin is not 1 and 100% pure 0^- boson not likely
- Discovered boson should be treated as a background in all other searches

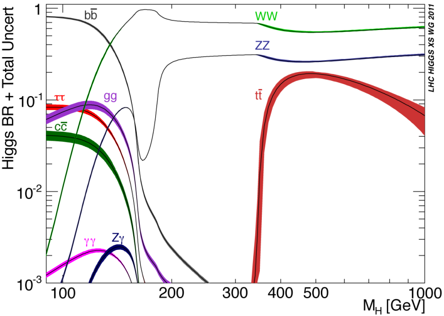
Additional material

References

- ATLAS exclusions, p-value and mass: Phys. Lett. B 716 (2012) 1-29
- ATLAS signal strength: ATLAS-CONF-2012-162
- ATLAS coupling properties: ATLAS-CONF-2012-127
- CMS Higgs combinations: CMS PAS HIG-12-045
- Procedure for the LHC Higgs boson search combination in Summer 2011: ATL-PHYS-PUB 2011-11, CMS NOTE 2011/005
- Higgs cross-sections and BR's: CERN Yellow Report

Higgs cross-section and BR





ATLAS channels in combination (signal strength)

Higgs Boson Decay	Subsequent Decay	Sub-Channels	$\int L\,dt$ [fb^{-1}]	Ref.
		2011 $\sqrt{s}$ =7 TeV		
$H \to ZZ^{(*)}$	4ℓ	$\{4e, 2e2\mu, 2\mu 2e, 4\mu\}$	4.8	[1]
$H \to \gamma\gamma$	–	10 categories $\{p_{\mathrm{Tt}} \otimes \eta_\gamma \otimes \text{conversion}\} \oplus \{\text{2-jet}\}$	4.8	[1]
$H \to \tau\tau$	$\tau_{\mathrm{lep}}\tau_{\mathrm{lep}}$	$\{e\mu\} \otimes \{\text{0-jet}\} \oplus \{\ell\ell\} \otimes \{\text{1-jet, 2-jet}, p_{\mathrm{T},\tau\tau} > 100\text{ GeV}, VH\}$	4.6	[4]
	$\tau_{\mathrm{lep}}\tau_{\mathrm{had}}$	$\{e, \mu\} \otimes \{\text{0-jet, 1-jet}, p_{\mathrm{T},\tau\tau} > 100\text{ GeV, 2-jet}\}$	4.6	
	$\tau_{\mathrm{had}}\tau_{\mathrm{had}}$	$\{\text{1-jet, 2-jet}\}$	4.6	
$VH \to Vbb$	$Z \to \nu\nu$	$E_{\mathrm{T}}^{\mathrm{miss}} \in \{120-160, 160-200, \geq 200\text{ GeV}\} \otimes \{\text{2-jet, 3-jet}\}$	4.6	[5]
	$W \to \ell\nu$	$p_{\mathrm{T}}^{W} \in \{< 50, 50-100, 100-150, 150-200, \geq 200\text{ GeV}\}$	4.7	
	$Z \to \ell\ell$	$p_{\mathrm{T}}^{Z} \in \{< 50, 50-100, 100-150, 150-200, \geq 200\text{ GeV}\}$	4.7	
		2012 $\sqrt{s}$ =8 TeV		
$H \to ZZ^{(*)}$	4ℓ	$\{4e, 2e2\mu, 2\mu 2e, 4\mu\}$	5.8	[1]
$H \to \gamma\gamma$	–	10 categories $\{p_{\mathrm{Tt}} \otimes \eta_\gamma \otimes \text{conversion}\} \oplus \{\text{2-jet}\}$	5.9	[1]
$H \to WW^{(*)}$	$e\nu\mu\nu$	$\{e\mu, \mu e\} \otimes \{\text{0-jet, 1-jet}\}$	13	[6]
$H \to \tau\tau$	$\tau_{\mathrm{lep}}\tau_{\mathrm{lep}}$	$\{\ell\ell\} \otimes \{\text{1-jet, 2-jet}, p_{\mathrm{T},\tau\tau} > 100\text{ GeV}, VH\}$	13	[4]
	$\tau_{\mathrm{lep}}\tau_{\mathrm{had}}$	$\{e, \mu\} \otimes \{\text{0-jet, 1-jet}, p_{\mathrm{T},\tau\tau} > 100\text{ GeV, 2-jet}\}$	13	
	$\tau_{\mathrm{had}}\tau_{\mathrm{had}}$	$\{\text{1-jet, 2-jet}\}$	13	
$VH \to Vbb$	$Z \to \nu\nu$	$E_{\mathrm{T}}^{\mathrm{miss}} \in \{120-160, 160-200, \geq 200\text{ GeV}\} \otimes \{\text{2-jet, 3-jet}\}$	13	[5]
	$W \to \ell\nu$	$p_{\mathrm{T}}^{W} \in \{< 50, 50-100, 100-150, 150-200, \geq 200\text{ GeV}\}$	13	
	$Z \to \ell\ell$	$p_{\mathrm{T}}^{Z} \in \{< 50, 50-100, 100-150, 150-200, \geq 200\text{ GeV}\}$	13	

ATLAS channels in combination (coupling compatibility tests)

Higgs Boson Decay	Subsequent Decay	Sub-Channels	$\int L\,dt$ [fb^{-1}]	Ref.
		2011 $\sqrt{s}$ =7 TeV		
$H \to ZZ^{(*)}$	4ℓ	$\{4e, 2e2\mu, 2\mu 2e, 4\mu\}$	4.8	[10]
$H \to \gamma\gamma$	–	10 categories $\{p_{Tt} \otimes \eta_\gamma \otimes \text{conversion}\} \oplus \{\text{2-jet}\}$	4.8	[11]
$H \to WW^{(*)}$	$\ell\nu\ell\nu$	$\{ee, e\mu, \mu\mu\} \otimes \{\text{0-jet, 1-jet, 2-jet}\} \otimes \{\text{low, high pile-up}\}$	4.7	[12]
$H \to \tau\tau$	$\tau_{lep}\tau_{lep}$	$\{e\mu\} \otimes \{\text{0-jet}\} \oplus \{\ell\ell\} \otimes \{\text{1-jet, 2-jet}, VH\}$	4.7	[13]
	$\tau_{lep}\tau_{had}$	$\{e,\mu\} \otimes \{\text{0-jet}\} \otimes \{E_T^{miss} < 20\text{ GeV}, E_T^{miss} \geq 20\text{ GeV}\} \oplus \{e,\mu\} \otimes \{\text{1-jet}\} \oplus \{\ell\} \otimes \{\text{2-jet}\}$	4.7	
	$\tau_{had}\tau_{had}$	$\{\text{1-jet}\}$	4.7	
$VH \to Vbb$	$Z \to \nu\nu$	$E_T^{miss} \in \{120-160, 160-200, \geq 200\text{ GeV}\}$	4.6	[14]
	$W \to \ell\nu$	$p_T^W \in \{< 50, 50-100, 100-200, \geq 200\text{ GeV}\}$	4.7	
	$Z \to \ell\ell$	$p_T^Z \in \{< 50, 50-100, 100-200, \geq 200\text{ GeV}\}$	4.7	
		2012 $\sqrt{s}$ =8 TeV		
$H \to ZZ^{(*)}$	4ℓ	$\{4e, 2e2\mu, 2\mu 2e, 4\mu\}$	5.8	[10]
$H \to \gamma\gamma$	–	10 categories $\{p_{Tt} \otimes \eta_\gamma \otimes \text{conversion}\} \oplus \{\text{2-jet}\}$	5.9	[11]
$H \to WW^{(*)}$	$e\nu\mu\nu$	$\{e\mu, \mu e\} \otimes \{\text{0-jet, 1-jet, 2-jet}\}$	5.8	[15]

CMS channels in combination

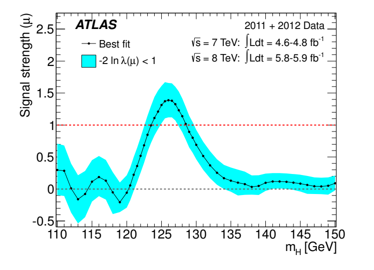
H decay	H prod	Analyses: Exclusive final states	No. of channels	m_H range (GeV)	m_H resolution	Lumi (fb^{-1}) 7 TeV	Lumi (fb^{-1}) 8 TeV
$\gamma\gamma$	untagged	$\gamma\gamma$ (4 diphoton classes)	4	110–150	1-2%	5.1	5.3
	VBF-tag	$\gamma\gamma + (jj)_{VBF}$ (low or high m_{jj} for 8 TeV)	1 or 2	110–150	1-2%	5.1	5.3
bb	VH-tag	($\nu\nu$, ee, $\mu\mu$, $e\nu$, $\mu\nu$ with 2 b-jets) $\times$ (low or high p_T^V or loose b-tag)	10 or 13	110–135	10%	5.0	12.1
	ttH-tag	(ℓ with 4,5,$\geq$6 jets) $\times$ (3,$\geq$4 b-tags); (ℓ with 6 jets with 2 b-tags); ($\ell\ell$ with 2 or $\geq$3 b-tagged jets)	9	110–140		5.0	-
$H \to \tau\tau$	1-jet	($e\tau_h$, $\mu\tau_h$, $e\mu$, $\mu\mu$) $\times$ (low or high p_T^τ) and $\tau_h\tau_h$	9	110–145	20%	4.9	12.1
	VBF-tag	($e\tau_h$, $\mu\tau_h$, $e\mu$, $\mu\mu$, $\tau_h\tau_h$) $+ (jj)_{VBF}$	5	110–145	20%	4.9	12.1
	ZH-tag	(ee, $\mu\mu$) $\times$ ($\tau_h\tau_h$, $e\tau_h$, $\mu\tau_h$, $e\mu$)	8	110–160		5.0	-
	WH-tag	$\tau_h ee$, $\tau_h\mu\mu$, $\tau_h e\mu$	3	110–140		4.9	-
$WW \to \ell\nu qq$	untagged	($e\nu$, $\mu\nu$) $\times$ ($(jj)_W$ with 0 or 1 jets)	4	170–600		5.0	12.1
$WW \to \ell\nu\ell\nu$	0/1-jets	(DF or SF dileptons) $\times$ (0 or 1 jets)	4	110–600	20%	4.9	12.1
$WW \to \ell\nu\ell\nu$	VBF-tag	$\ell\nu\ell\nu + (jj)_{VBF}$ (DF or SF dileptons for 8 TeV)	1 or 2	110–600	20%	4.9	12.1
$WW \to \ell\nu\ell\nu$	WH-tag	$3\ell 3\nu$	1	110–200		4.9	5.1
$ZZ \to 4\ell$	inclusive	$4e$, 4μ, $2e2\mu$	3	110–1000	1-2%	5.0	12.2
$ZZ \to 2\ell 2\tau$	inclusive	(ee, $\mu\mu$) $\times$ ($\tau_h\tau_h$, $e\tau_h$, $\mu\tau_h$, $e\mu$)	8	180–1000	10-15%	5.0	12.2

SM compatibility: signal strength

Remarks

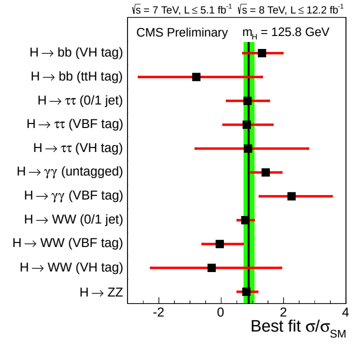
- ATLAS result from discovery paper
- CMS detailed result split by decay mode and production tag

ATLAS



$\hat{\mu} = \mathbf{1.4} \pm \mathbf{0.3}$ for $m_H = 126.0$ GeV

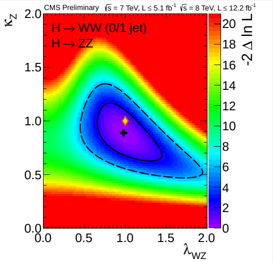
CMS



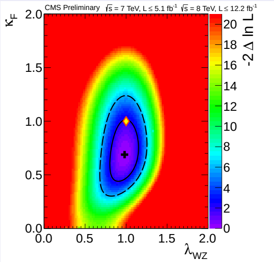
$\hat{\mu} = \mathbf{0.88} \pm \mathbf{0.21}$ for $m_H = 125.8$ GeV

Custodial symmetry test: CMS 2D likelihoods

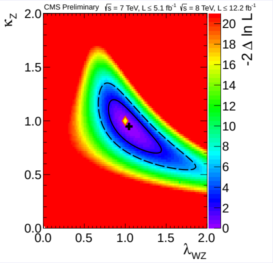
test 1



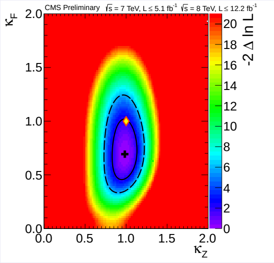
test 2, κ_Z profiled



test 2, κ_f profiled

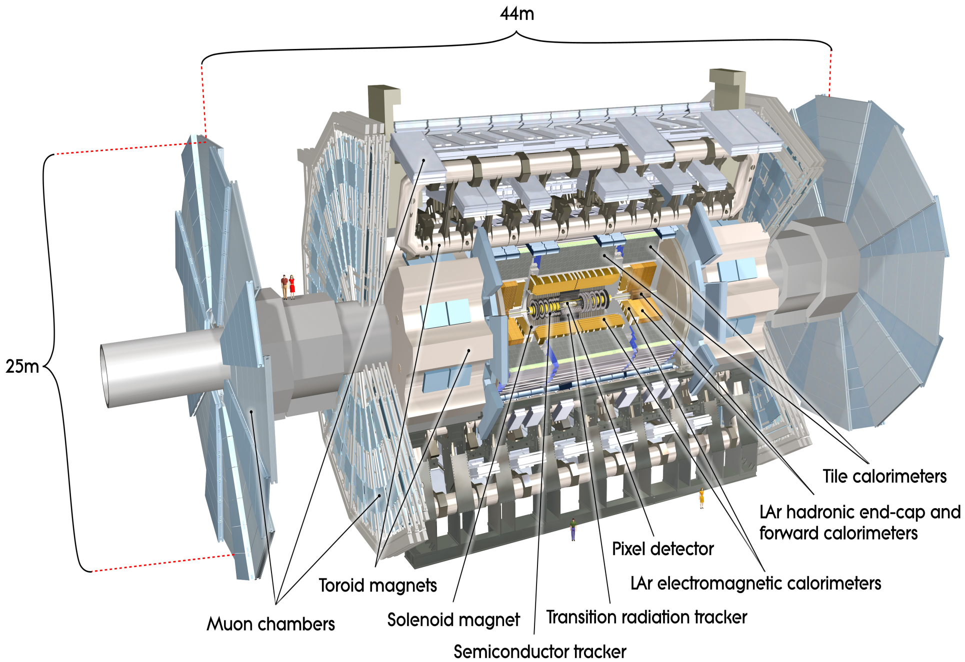


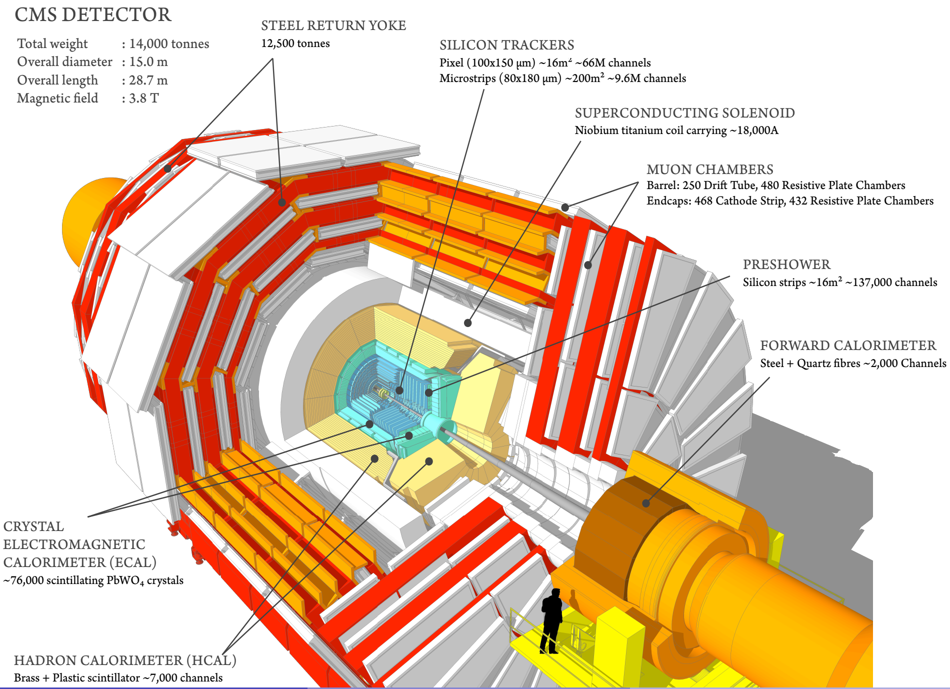
test 2, λ_{WZ} profiled



Summary of CMS compatibility tests

Model parameters	Assessed scaling factors (95% CL intervals)		Comments
$\lambda_{\mathrm{WZ}}, \kappa_{\mathrm{Z}}$	λ_{WZ}	[0.57,1.65]	Ratio of couplings to W and Z; ZZ and WW(0/1jet) channels only
$\lambda_{\mathrm{WZ}}, \kappa_{\mathrm{Z}}, \kappa_f$	λ_{WZ}	[0.67,1.55]	Ratio of couplings to W and Z
κ_{V}	κ_{V}	[0.78,1.19]	Couplings to W/Z-bosons (V); $\kappa_f = 1$
κ_f	κ_f	[0.40,1.12]	Couplings to fermions (f); $\kappa_{\mathrm{V}} = 1$
κ_γ, κ_g	κ_γ	[0.98,1.92]	Couplings to photons (γ) and gluons (g)
	κ_g	[0.55,1.07]	(loop-induced couplings)
$\mathcal{B}(\mathrm{H} \to \mathrm{BSM}), \kappa_\gamma, \kappa_g$	$\mathcal{B}(\mathrm{H} \to \mathrm{BSM})$	[0.00,0.62]	Branching ratio for decays to BSM particles
$\lambda_{\mathrm{du}}, \kappa_{\mathrm{V}}, \kappa_{\mathrm{u}}$	λ_{du}	[0.45,1.66]	Ratio of couplings to down and up-type fermions
$\lambda_{\ell\mathrm{q}}, \kappa_{\mathrm{V}}, \kappa_{\mathrm{q}}$	$\lambda_{\ell\mathrm{q}}$	[0.00,2.11]	Ratio of couplings to leptons and quarks
$\kappa_{\mathrm{V}}, \kappa_b, \kappa_\tau, \kappa_t, \kappa_g, \kappa_\gamma$	κ_{V}	[0.58,1.41]	Couplings to W/Z-bosons (V)
	κ_b	not constrained	Couplings to down-type quarks (b)
	κ_τ	[0.00,1.80]	Couplings to charged leptons (τ)
	κ_t	not constrained	Couplings to top-type quarks (t)
	κ_g	[0.43,1.92]	Effective couplings to gluons (g)
	κ_γ	[0.81,2.27]	Effective couplings to photons (γ)


44m
25m
Tile calorimeters
LAr hadronic end-cap and forward calorimeters
Pixel detector
LAr electromagnetic calorimeters
Toroid magnets
Muon chambers
Solenoid magnet
Transition radiation tracker
Semiconductor tracker


CMS DETECTOR
Total weight : 14,000 tonnes
Overall diameter : 15.0 m
Overall length : 28.7 m
Magnetic field : 3.8 T
STEEL RETURN YOKE
12,500 tonnes
SILICON TRACKERS
Pixel (100x150 μm) ~16m^2 ~66M channels
Microstrips (80x180 μm) ~200m^2 ~9.6M channels
SUPERCONDUCTING SOLENOID
Niobium titanium coil carrying ~18,000A
MUON CHAMBERS
Barrel: 250 Drift Tube, 480 Resistive Plate Chambers
Endcaps: 468 Cathode Strip, 432 Resistive Plate Chambers
PRESHOWER
Silicon strips ~16m^2 ~137,000 channels
FORWARD CALORIMETER
Steel + Quartz fibres ~2,000 Channels
CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)
~76,000 scintillating $PbWO_4$ crystals
HADRON CALORIMETER (HCAL)
Brass + Plastic scintillator ~7,000 channels