中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

Higgs Boson
Couplings and Properties at LHC

Roko Pleština
CMS collaboration

Physics Seminar, PNPI, Gatchina,
23 June 2015

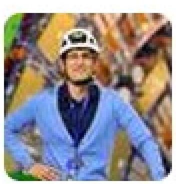
Petersburg
Nuclear
Physics
Institute

Roko Plestina @rplestina · 7m

#Run2 has started. Looking forward to #NewPhysics. Congratulations to all the people involved.

Roko Plestina @rplestina · 7m

What have we learned about the #Higgs so far? Time to remind ourselves...

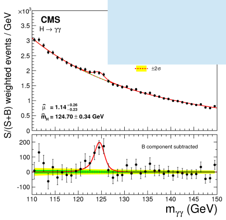


Roko Plestina @rplestina · 2m

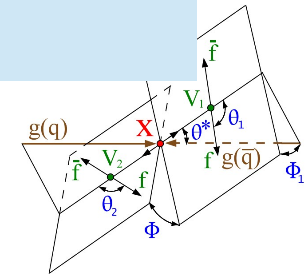
Thanks for seminar opportunity on this prestigious institution #PNPI. You must be very proud being major actors in the line of #discovery.

Is this the Standard Model Higgs?

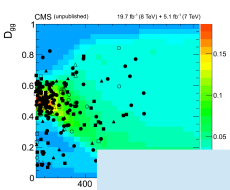
Measurment of Higgs Mass



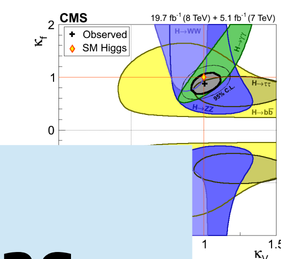
Higgs Decay Tensor Structure



The Standard Model Higgs Boson



Measurment of Higgs Decay Width



Higgs Coupling Strenght

For the hot summer afternoon ...

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Combined Measurement of the Higgs Boson Mass in pp Collisions at $\sqrt{s} = 7$ and 8 TeV with the ATLAS and CMS Experiments

G. Aad *et al.* (ATLAS Collaboration, CMS Collaboration)
Phys. Rev. Lett. **114**, 191803 – Published 14 May 2015

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-PH-EP/2013-037
2014/07/29

CMS-HIG-14-002

Constraints on the Higgs boson width from off-shell production and decay to Z-boson pairs

The CMS Collaboration*

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-PH-EP/2013-037
2015/06/16

CMS-HIG-14-009

Precise determination of the mass of the Higgs boson and tests of compatibility of its couplings with the standard model predictions using proton collisions at 7 and 8 TeV

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-PH-EP/2014-265
2014/11/14

CMS-HIG-14-018

Constraints on the spin-parity and anomalous HVV couplings of the Higgs boson in proton collisions at 7 and 8 TeV

The CMS Collaboration*

ATLAS NOTE

ATLAS-CONF-2015-007

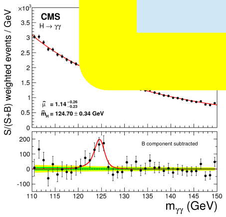
18th March 2015

Measurements of the Higgs boson production and decay rates and coupling strengths using pp collision data at $\sqrt{s} = 7$ and 8 TeV in the ATLAS experiment

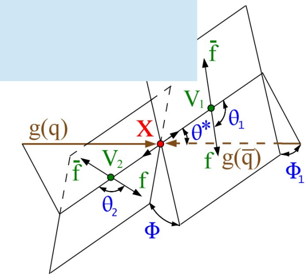
The ATLAS Collaboration

Mass as a free parameter…

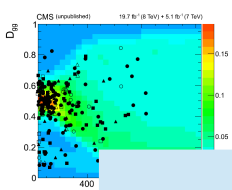
Measurement of Higgs Mass



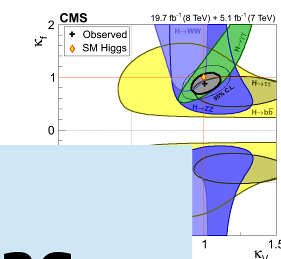
Higgs Decay Tensor Structure



The Standard Model Higgs Boson



Measurement of Higgs Decay Width



Higgs Coupling Strenght

Higgs boson mass at CMS

Analysis with good mass resolution

Using only analysis with **good mass resolution** and with **fully reconstructed** final state:

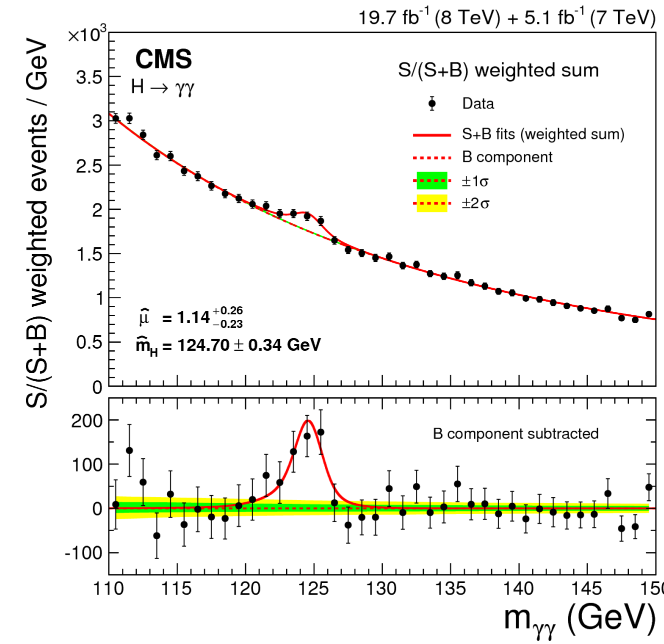
- $H \to ZZ^\star \to 4l$
- $H \to \gamma\gamma$

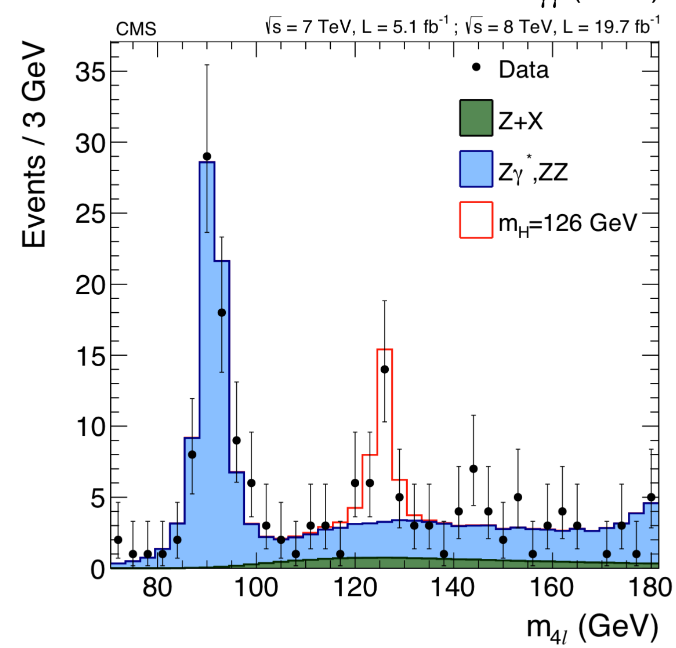
$H \to \gamma\gamma$

- Two isolated, high p_T photons
- Events categorized by $m_{\gamma\gamma}$ resolution, kinematics and production mode
- Same as measurement of the couplings
- Simultaneous S+B fit to all categories
- Background from fit to data
- Analytic signal model accounting for data/MC corrections and associated uncertainties

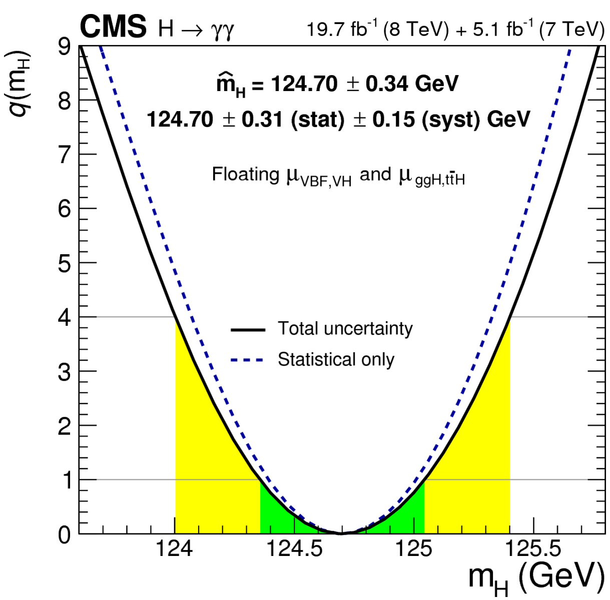
$H \to ZZ^\star \to 4l$

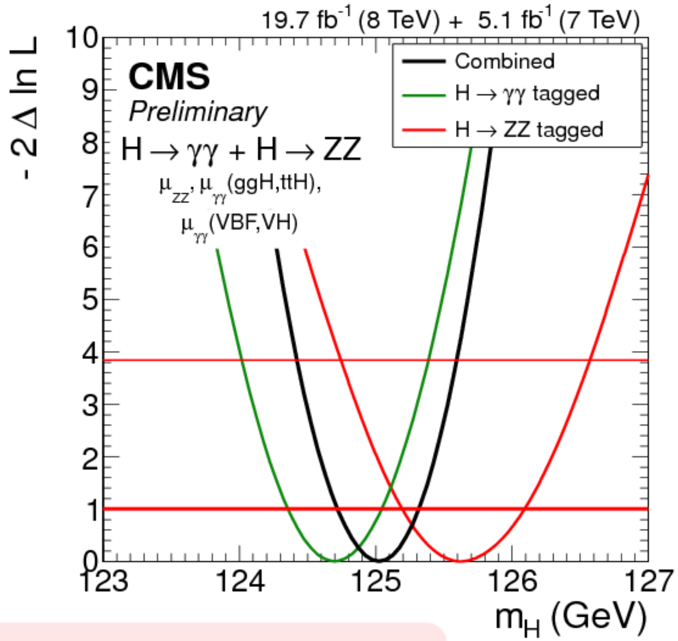
- Four isolated leptons
- Only lepton flavor categorization (4e, 4μ , 2e2μ)
- Unbinned maximum likelihood fit
- Use m_{4l} vs kin. discriminant (KD) for S/B separation
- Use information on event-by-event mass resolution

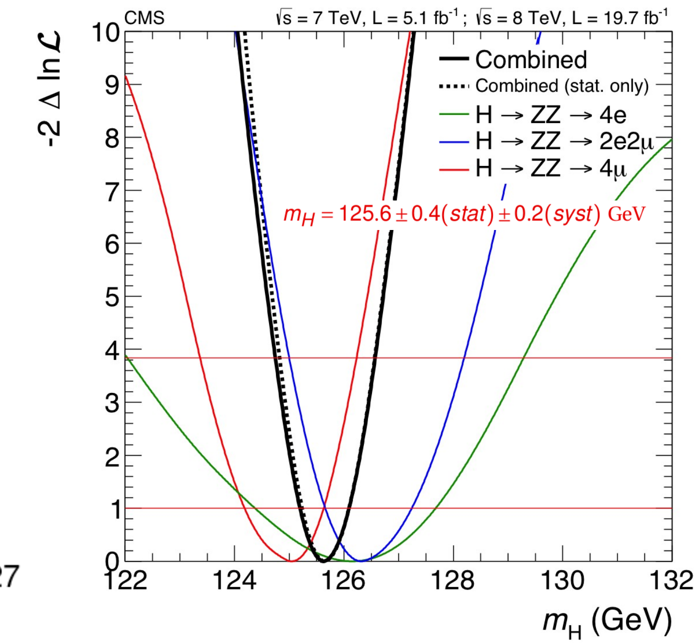




Higgs boson mass at CMS

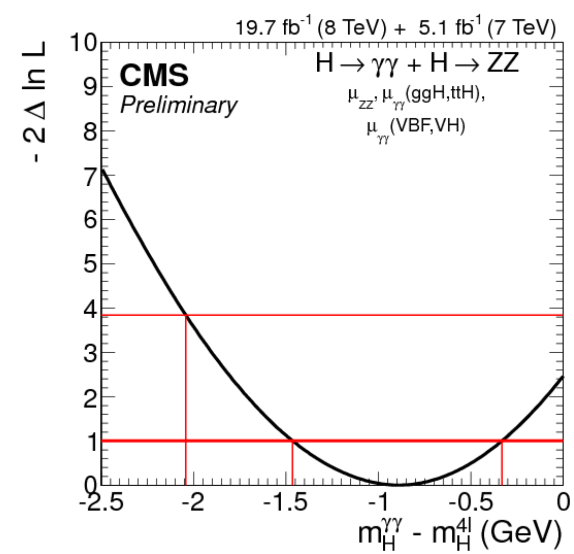




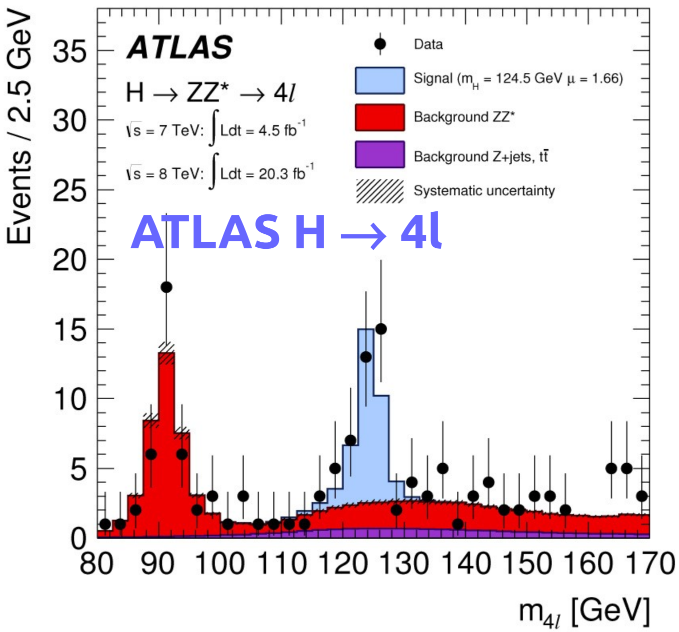


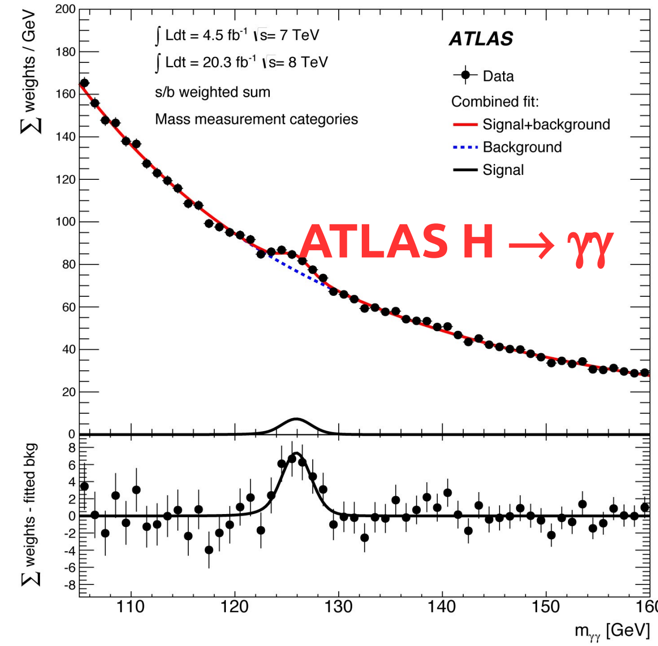
$$m_H = 125.03^{+0.26}_{-0.27}(stat.)^{+0.13}_{-0.15}(syst.)\ \mathrm{GeV}$$

- Reduce model dependence of the mass estimate by allowing signal strengths of Higgs production mechanisms to float independently
- $H \to \gamma\gamma$ and $H \to ZZ^\star \to 4l$ results compatible at the 1.6σ level
- Statistical uncertainty still dominates the measurement (wait for Run2)



ATLAS+CMS Higgs mass combination





Combination of ATLAS and CMS mass measurements in

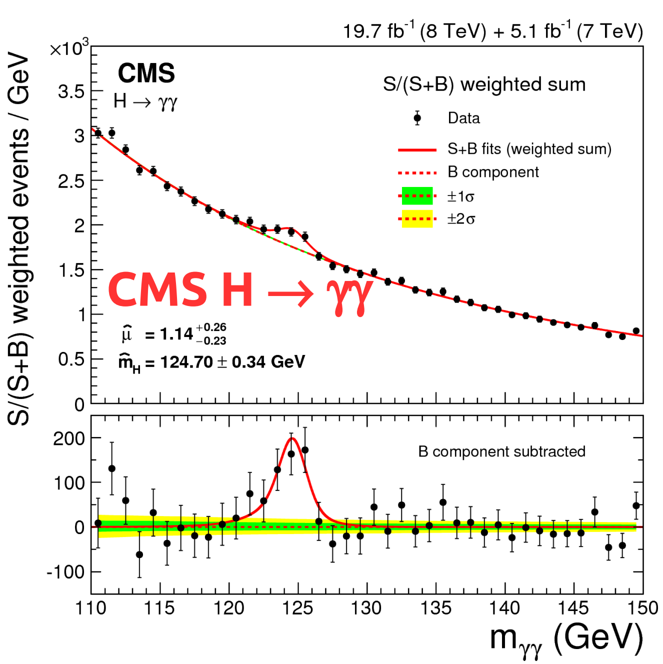
- $H \to \gamma\gamma$
- $H \to 4l$

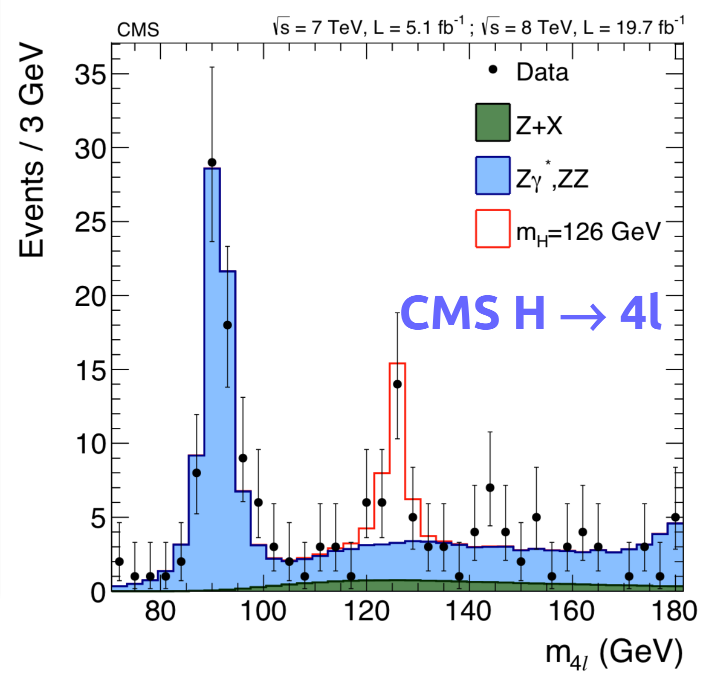
Agnostic to the signal yields

3 signal strength parameter μ for

- $gg \to H \to \gamma\gamma$
- VBF $H \to \gamma\gamma$
- $H \to 4l$

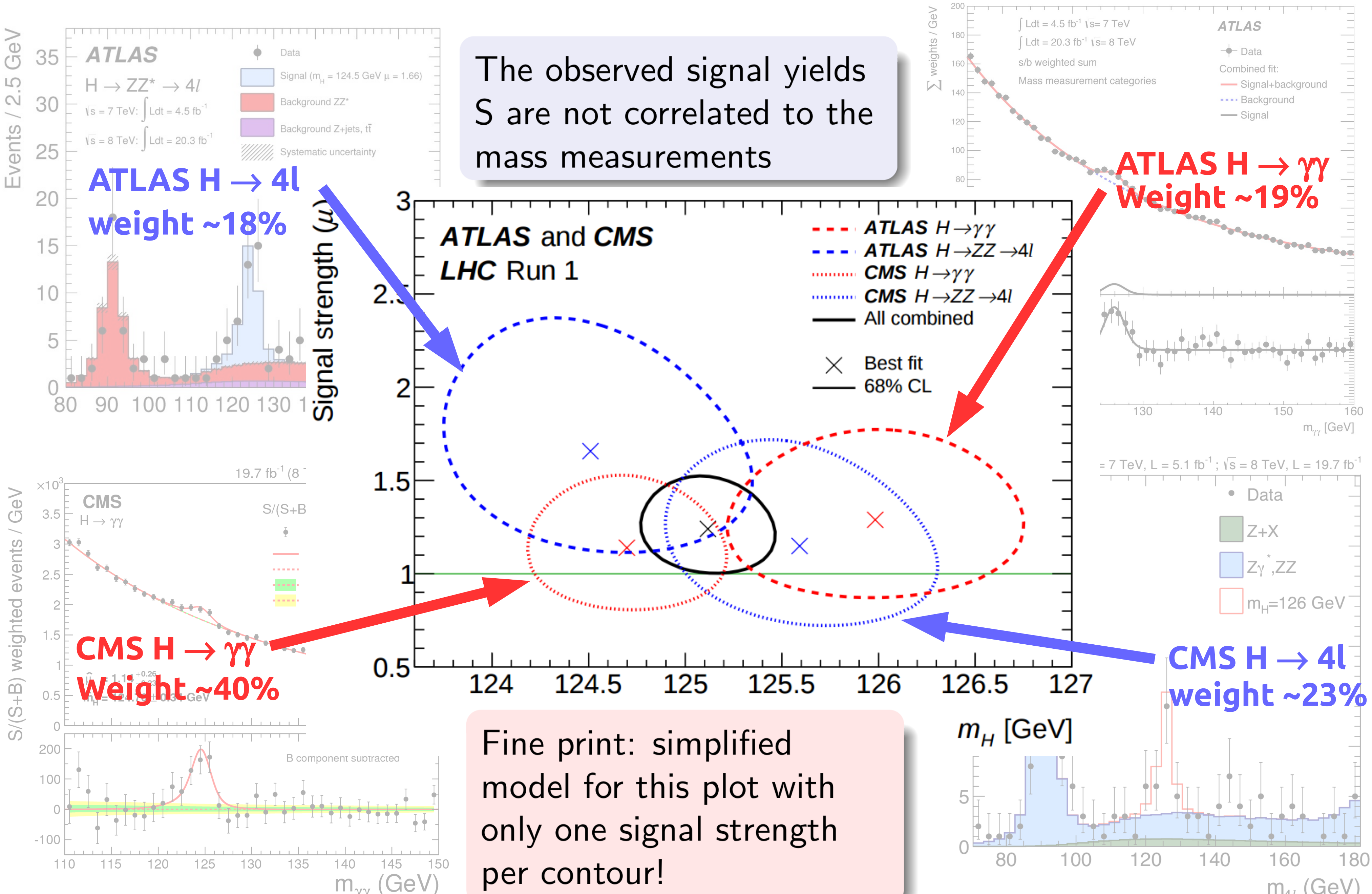
simultaneously determined from data (profiled)





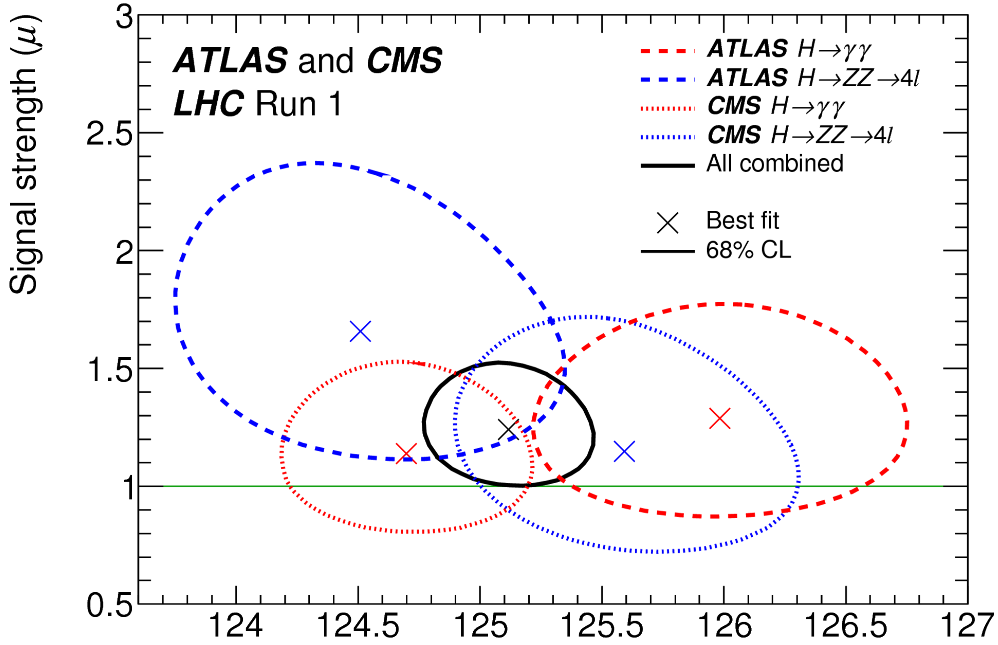
ATLAS+CMS Higgs mass combination

The observed signal yields S are not correlated to the mass measurements



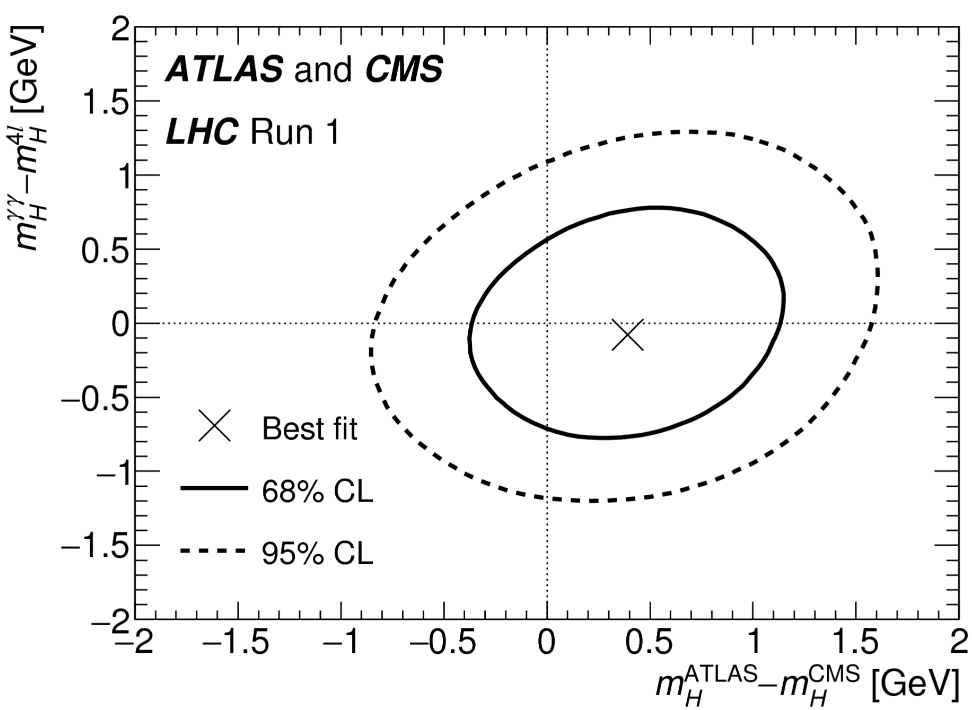
Fine print: simplified model for this plot with only one signal strength per contour!

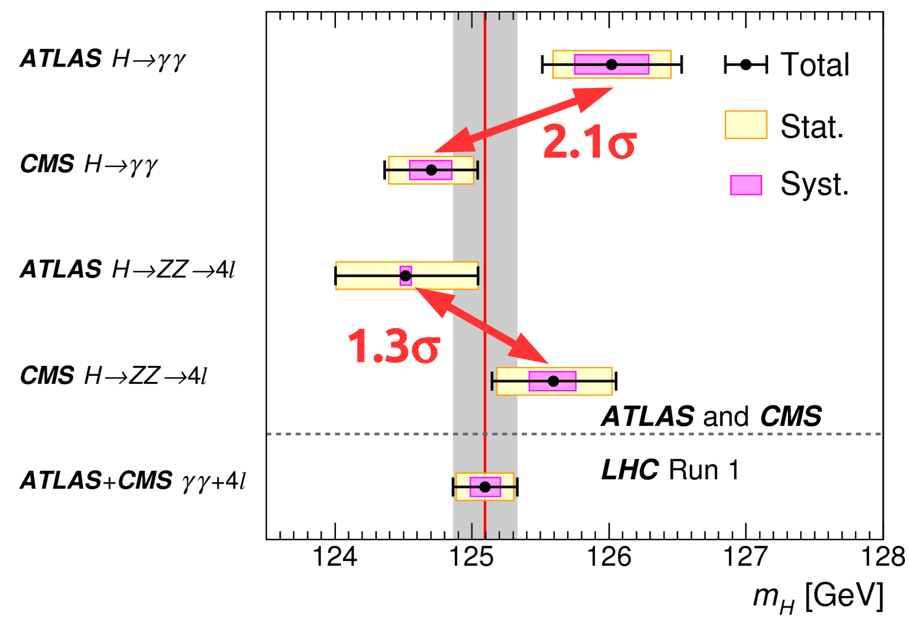
ATLAS+CMS Higgs mass combination



After combining the mass measurements in the $H \to \gamma\gamma$ and the $H \to 4l$ channel and in ATLAS and CMS are very compatible with each other.

Tension only within the experiments

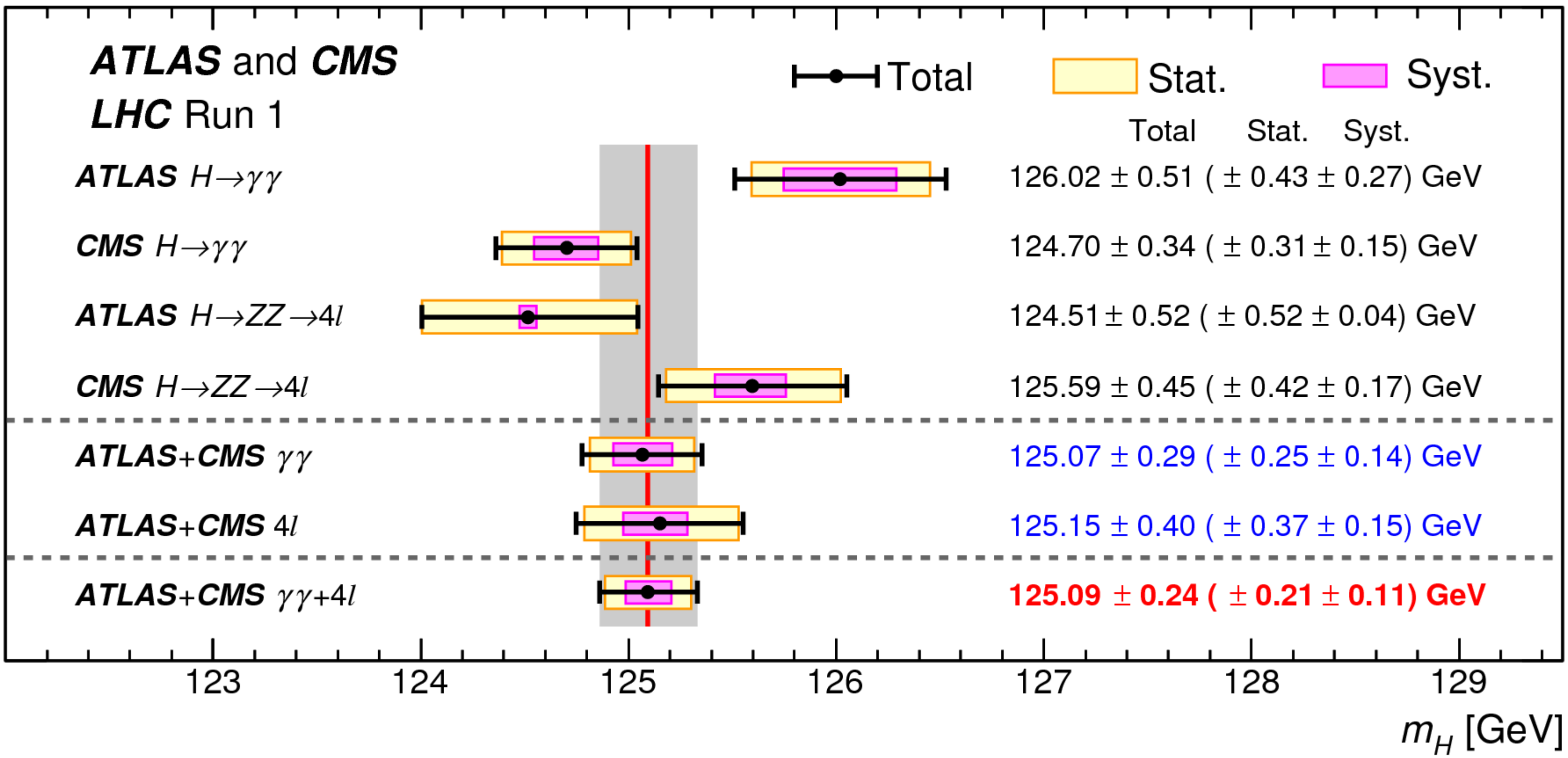




ATLAS+CMS Higgs mass combination – results

$$m_H = 125.09 \pm 0.24 \text{ GeV}$$
$$= 125.09 \pm 0.21 \text{ (stat.)} \pm 0.11 \text{ (syst.) GeV}$$

0.19% precision

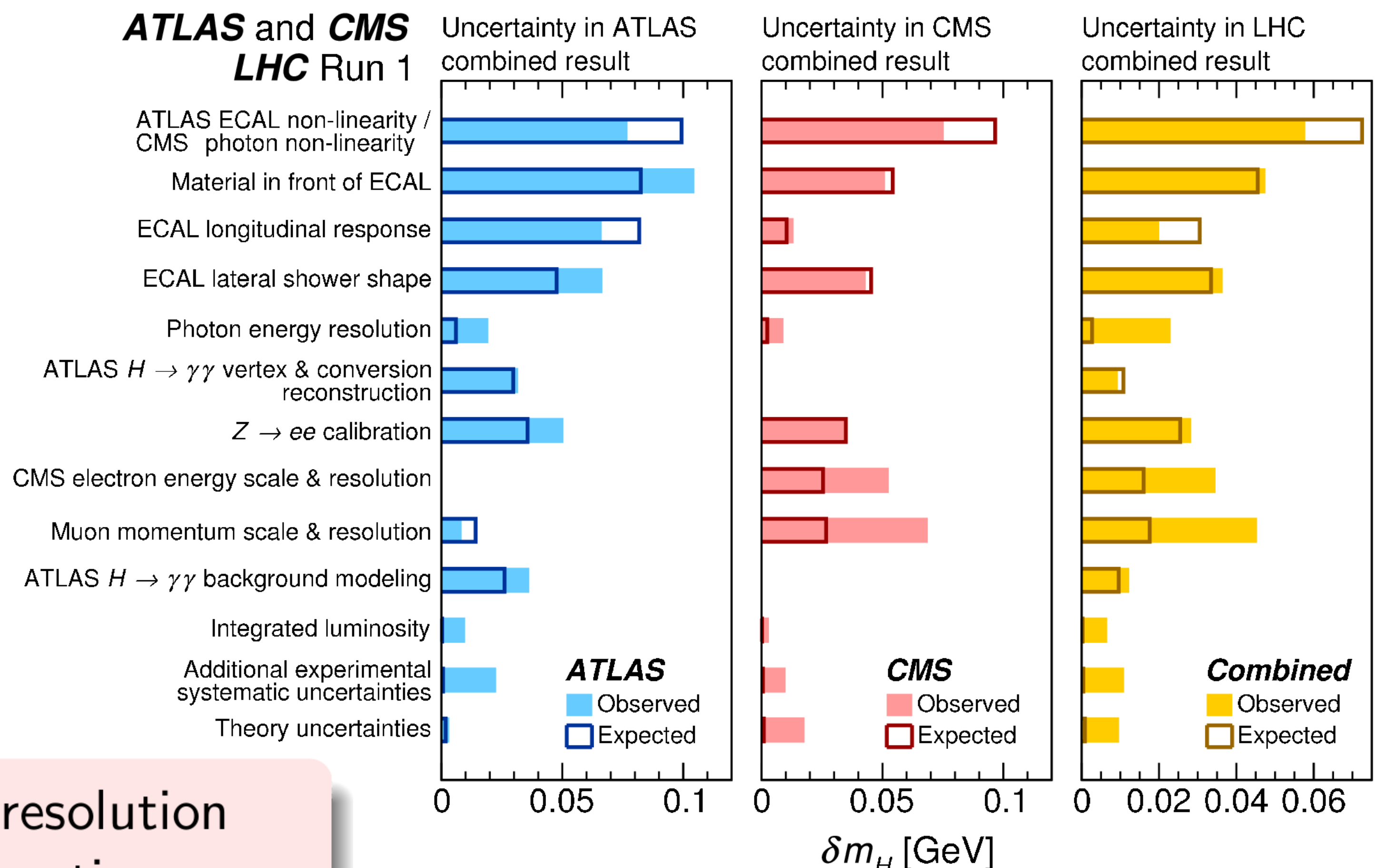


4 measurements are compatible with the combined mass to 7-10% level (p-value)

ATLAS+CMS Higgs mass combination – systematics

- Measurement still dominated by the statistical uncertainties
- Special effort to check systematic uncertainties

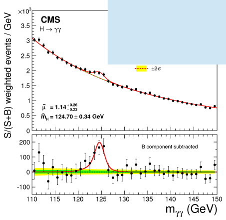
$$m_H = 125.09 \pm 0.21\ (\text{stat.}) \pm 0.11\ (\text{scale}) \pm 0.02\ (\text{other}) \pm 0.01\ (\text{theory})\ \text{GeV}$$



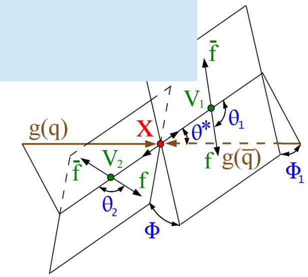
Energy scale and resolution dominate systematics.

Getting Handle on the Width...

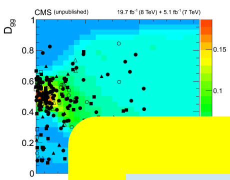
Measurement of Higgs Mass



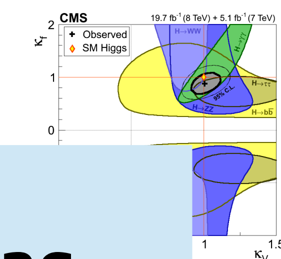
Higgs Decay Tensor Structure



The Standard Model Higgs Boson



Measuement of Higgs Decay Width



Higgs Coupling Strenght

Higgs boson width from offshell production

F. Caola, K. Melnikov (Phys. Rev. D88 2013)
J. Campbell et al. (arXiv:1311.3589)

$$\frac{d\sigma_{gg\to H\to ZZ}}{dm^2_{ZZ}} \propto g^2_{ggH} g^2_{HZZ} \frac{F(m_{ZZ})}{(m^2_{ZZ} - m^2_H)^2 + m^2_H \Gamma^2_H}$$

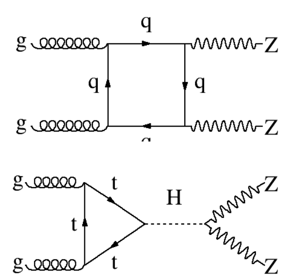
$$\sigma^{on-peak}_{gg\to H\to ZZ} \propto \frac{g^2_{ggH} g^2_{HZZ}}{\Gamma_H}$$

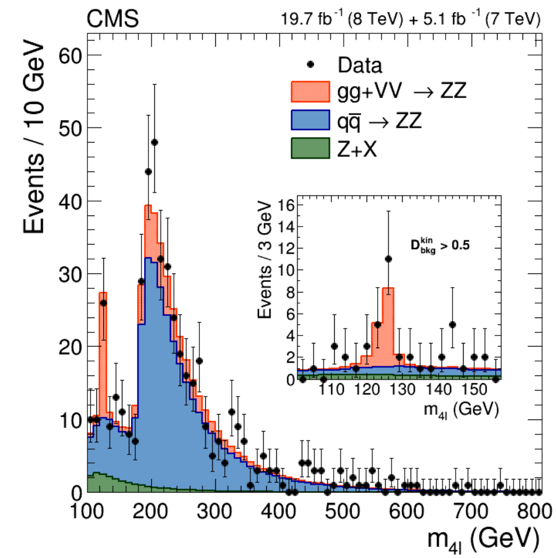
$$\sigma^{off-peak}_{gg\to H\to ZZ} \propto g^2_{ggH} g^2_{HZZ}$$

on-shell: $m_{ZZ} \approx m_H$
off-shell: $m_{ZZ} - m_H >> \Gamma_H$

On-shell/Off-shell ratio

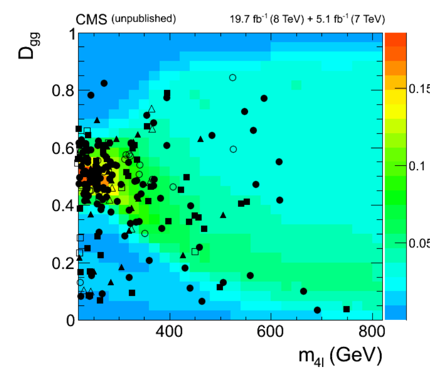
- SM predicts $\Gamma_{tot} = 4.2$ MeV, direct measurement yields $\Gamma_{tot} = 3.4$ GeV, 3 orders of magnitude
- Γ_H can indirectly be extracted from On-shell/Off-shell ratio
- Mild model dependence — works for BSM models if the ratio is not altered by new physics (i.e. top loop still dominates in ggH)
- Signal - background destructive interference through fermion box diagrams

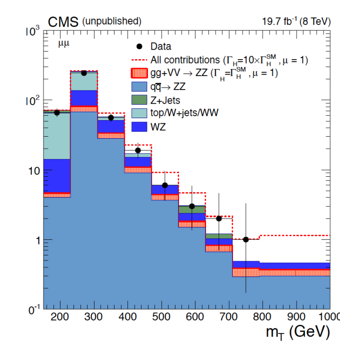


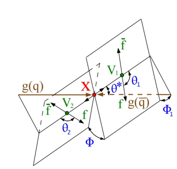


Analysis

- The $H \to ZZ^\star \to 4l$ analysis uses the m_{4l} distribution near the peak and above the ZZ production threshold as well as a kinematic discriminant to separate the Higgs boson production from the ZZ continuum background
- The $H \to ZZ^\star \to 2l2\nu$ analysis relies on the transverse mass or missing transverse energy distributions, depending on the jet categories.







$$\mathcal{D}_{gg} \equiv \frac{\mathcal{P}_{gg}}{\mathcal{P}_{gg} + \mathcal{P}_{q\bar{q}}} = \left[1 + \frac{\mathcal{P}^{q\bar{q}}_{bkg}}{a \times \mathcal{P}^{gg}_{sig} + \sqrt{a} \times \mathcal{P}^{gg}_{int} + \mathcal{P}^{gg}_{bkg}}\right]^{-1}$$

$$m^2_T = \left[\sqrt{p_{T,\ell\ell}{}^2 + m_{\ell\ell}{}^2} + \sqrt{E^{miss}_T{}^2 + m_{\ell\ell}{}^2}\right]^2 - \left[\vec{p}_{T,\ell\ell} + \vec{E}^{miss}_T\right]^2$$

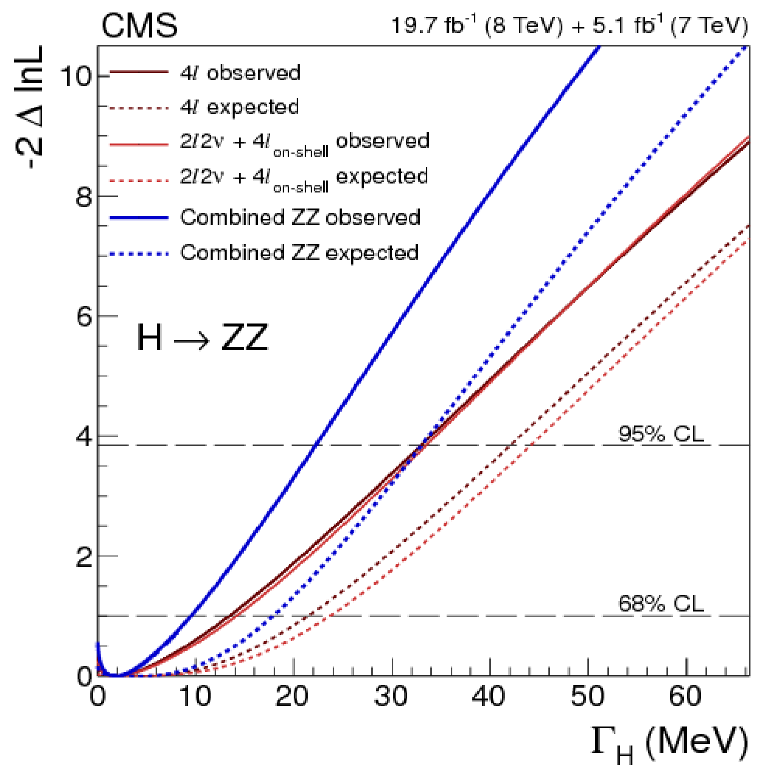
[10.1103/PhysRevD.89.092007, 10.1140/epjc/s10052-013-2469-8]

Higgs boson width from offshell production

Likelihood fits

3 parameters are unconstrained in the likelihood fit:

- μ_{ggH} and μ_{VBF} : Signal strength scale w.r.t SM prediction (driven by the on-shell analysis — 4l analysis dominates)
- Γ_H/Γ_0 : Higgs width scal w.r.t SM prediction (Γ_H extracted from the off-shell analysis)



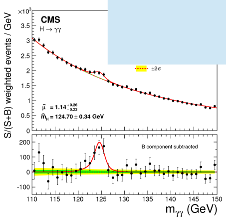
Γ_H Measurement

- expected: $\Gamma_H = 4.2^{+13.5}_{-4.2}$ MeV
- measured: $\Gamma_H = 1.8^{+7.7}_{-1.8}$ MeV

Γ_H 95% limits

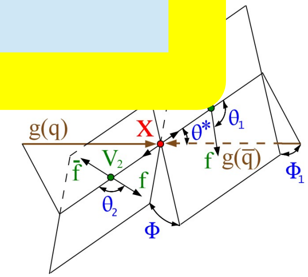
- expected: 33 MeV
- measured: 22 MeV

Which Spin? Which Parity? Mixture?

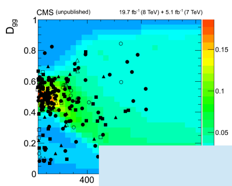


Measurment of Higgs Mass

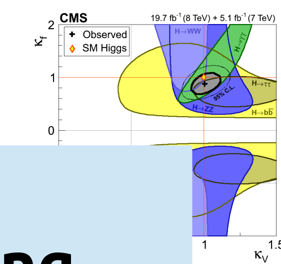
Higgs Decay Tensor Structure



The Standard Model Higgs Boson

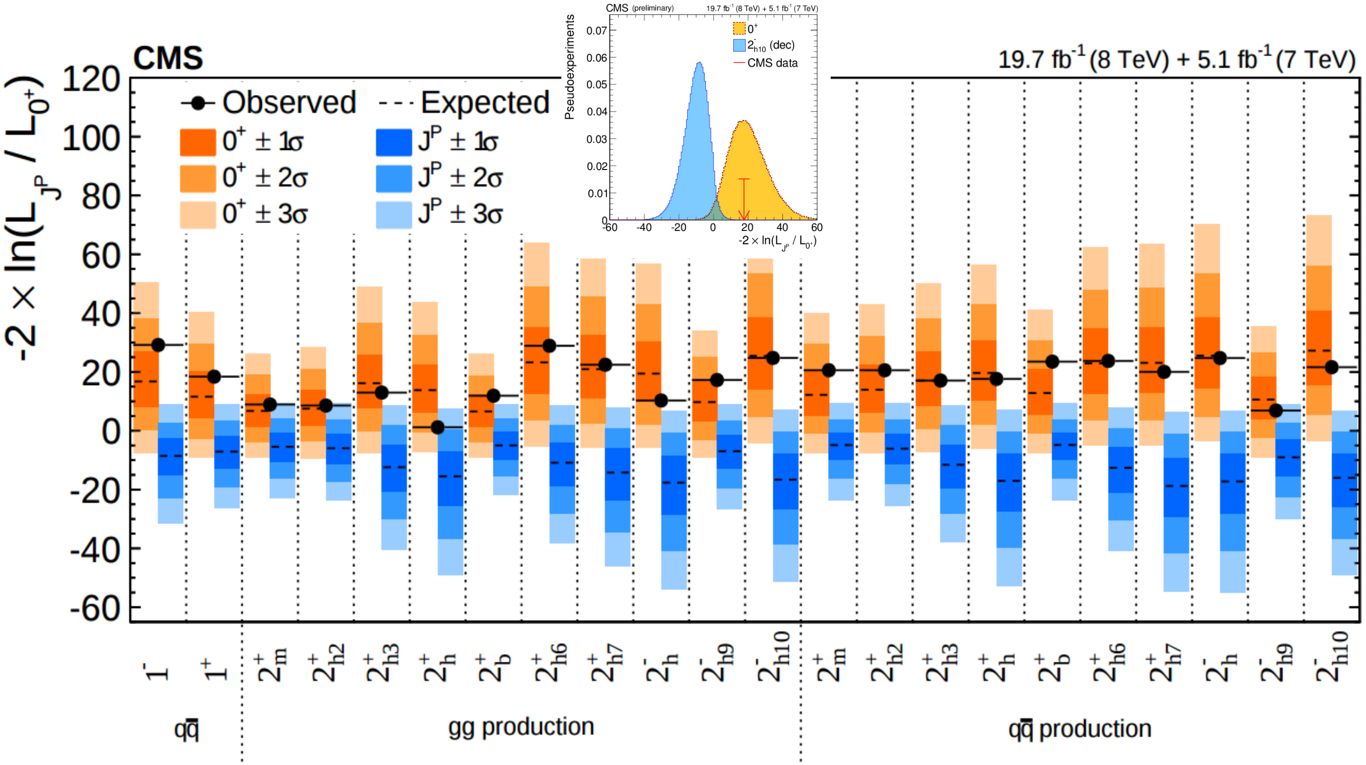


Measurment of Higgs Decay Width

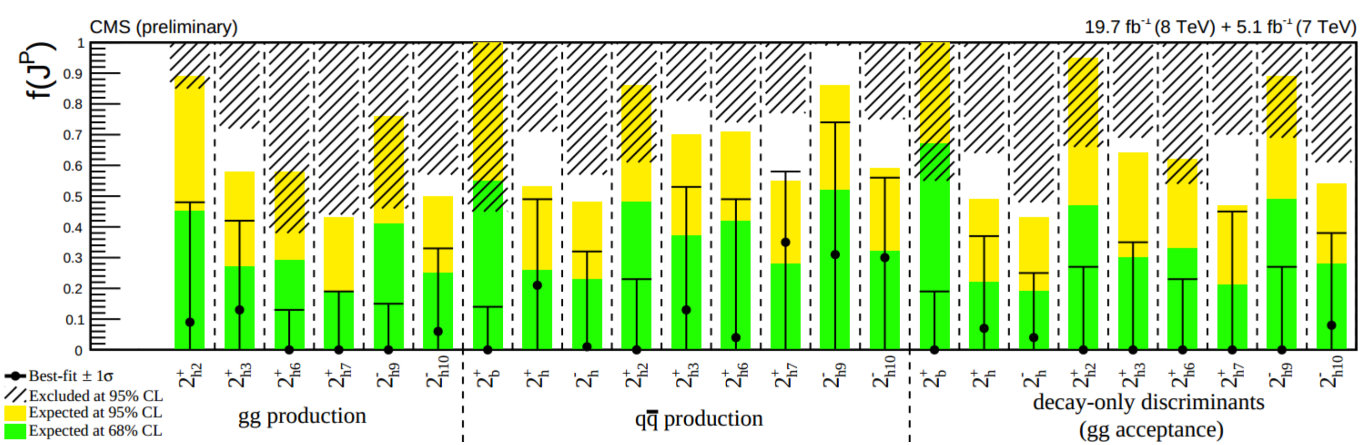


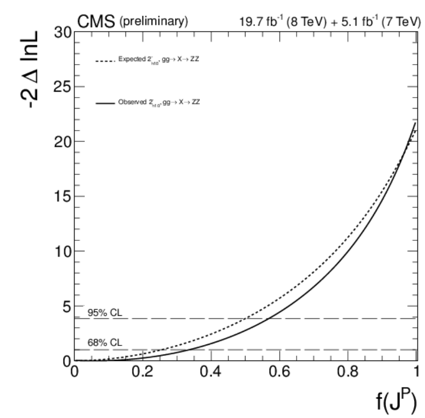
Higgs Coupling Strenght

Higgs spin and parity – spin 1 and 2



- Combination of ZZ+WW channels excludes all pure alternative models at 99.9 % CL
- Case of nearly degenerated states — testing for mixture of SM Higgs (0^+) and spin 1 or 2 models





Higgs spin and parity – spin 0

$$A(\mathrm{HV_1V_2}) \sim \left[a_1^{\mathrm{V_1V_2}} + \frac{\kappa_1^{\mathrm{V_1V_2}} q_{\mathrm{V1}}^2 + \kappa_2^{\mathrm{V_1V_2}} q_{\mathrm{V2}}^2}{\left(\Lambda_1^{\mathrm{V_1V_2}}\right)^2} \right] m_{\mathrm{V}}^2 \epsilon_{\mathrm{V1}}^* \epsilon_{\mathrm{V2}}^* + a_2^{\mathrm{V_1V_2}} f_{\mu\nu}^{*(\mathrm{V_1})} f^{*(\mathrm{V_2}),\mu\nu} + a_3^{\mathrm{V_1V_2}} f_{\mu\nu}^{*(\mathrm{V_1})} \tilde{f}^{*(\mathrm{V_2}),\mu\nu}$$

Λ_1 term
leading momentum expansion

a_2 term
CP even state

a_3 term
CP odd state

Phenomenology of HVV interactions

Interaction between a spin 0 Higgs and two gauge bosons V_1, V_2 (Z, W, γ, g):

- Expansion up to q^2
- assume small anomalous couplings — q^4 and h.o. not considered

Analysis strategy

- Use sensitive channels $H \to ZZ$ and $H \to WW$
- Test exotic spin-parity states using hypothesis testing
- Measure tensor structure parameters using likelihood fits

$$f_{a2} = \frac{|a_2|^2\sigma_2}{|a_1|^2\sigma_1 + |a_2|^2\sigma_2 + |a_3|^2\sigma_3 + \tilde{\sigma}_{\Lambda_1}/\left(\Lambda_1\right)^4}$$

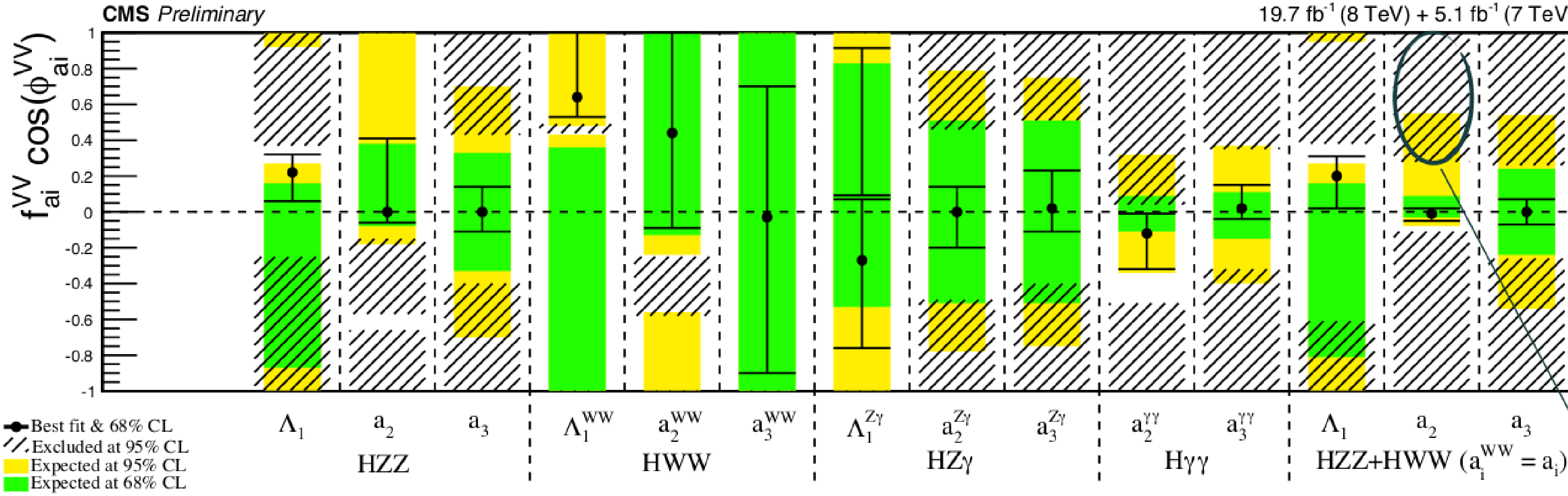
SM values

	a_1	q^2/Λ_1^2	a_2	a_3
HZZ(WW)	2	$10^{-3} - 10^{-2}$	$10^{-3} - 10^{-2}$	$< 10^{-10}$
HZγ	-	$10^{-3} - 10^{-2}$	$\sim$ 0.0035	$< 10^{-10}$
H$\gamma\gamma$	-	-	$\sim$ -0.004	$< 10^{-10}$

Interaction	Anomalous coupling	Coupling phase	Effective fraction	Translation constant
HZZ	Λ_1	$\phi_{\Lambda 1}$	$f_{\Lambda 1}$	$\sigma_1/\tilde{\sigma}_{\Lambda 1} = 1.45 \times 10^{-8}\,\mathrm{GeV}^{-4}$
	a_2	ϕ_{a2}	f_{a2}	$\sigma_1/\sigma_2 = 2.68$
	a_3	ϕ_{a3}	f_{a3}	$\sigma_1/\sigma_3 = 6.36$
HWW	Λ_1^{WW}	$\phi_{\Lambda 1}^{\mathrm{WW}}$	$f_{\Lambda 1}^{\mathrm{WW}}$	$\sigma_1^{\mathrm{WW}}/\tilde{\sigma}_{\Lambda 1}^{\mathrm{WW}} = 1.87 \times 10^{-8}\,\mathrm{GeV}^{-4}$
	a_2^{WW}	ϕ_{a2}^{WW}	f_{a2}^{WW}	$\sigma_1^{\mathrm{WW}}/\sigma_2^{\mathrm{WW}} = 1.25$
	a_3^{WW}	ϕ_{a3}^{WW}	f_{a3}^{WW}	$\sigma_1^{\mathrm{WW}}/\sigma_3^{\mathrm{WW}} = 3.01$
HZγ	$\Lambda_1^{Z\gamma}$	$\phi_{\Lambda 1}^{Z\gamma}$	$f_{\Lambda 1}^{Z\gamma}$	$\sigma_1/\tilde{\sigma}_{\Lambda 1}^{Z\gamma} = 5.76 \times 10^{-9}\,\mathrm{GeV}^{-4}$
	$a_2^{Z\gamma}$	$\phi_{a2}^{Z\gamma}$	$f_{a2}^{Z\gamma}$	$\sigma_1/\sigma_2^{Z\gamma} = 22.4 \times 10^{-4}$
	$a_3^{Z\gamma}$	$\phi_{a3}^{Z\gamma}$	$f_{a3}^{Z\gamma}$	$\sigma_1/\sigma_3^{Z\gamma} = 27.2 \times 10^{-4}$
H$\gamma\gamma$	$a_2^{\gamma\gamma}$	$\phi_{a2}^{\gamma\gamma}$	$f_{a2}^{\gamma\gamma}$	$\sigma_1/\sigma_2^{\gamma\gamma} = 28.2 \times 10^{-4}$
	$a_3^{\gamma\gamma}$	$\phi_{a3}^{\gamma\gamma}$	$f_{a3}^{\gamma\gamma}$	$\sigma_1/\sigma_3^{\gamma\gamma} = 28.8 \times 10^{-4}$

[Phys.Rev.Lett. 110 (2013) 081803, Phys.Rev. D89 (2014) 092007, CMS-PAS-HIG-14-014]

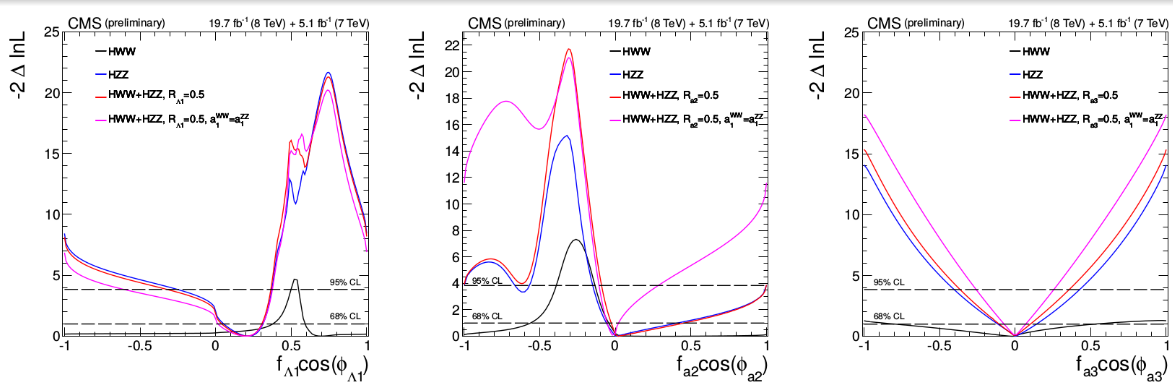
Higgs spin and parity – spin 0

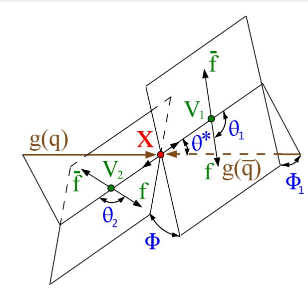


Likelihood fits

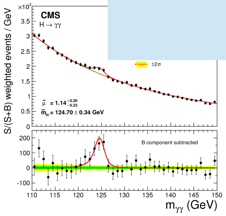
- Use suitable Kinematic Discriminants for each measurement
- Construct multidimensional signal and background pdf templates from discriminants
- Perform likelihood function scans over complex couplings ratios (exotic/SM)

Region not excluded in either *HZZ* or *HWW*. Constraint from *HZZ – HWW* correlation

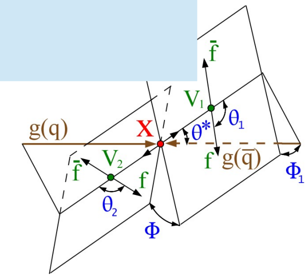




Does It Couple to Particles as It Should?

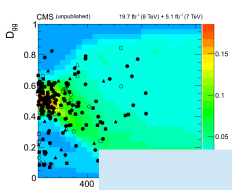


Measurment of Higgs Mass

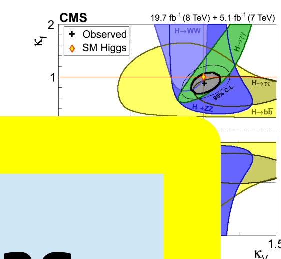


Higgs Decay Tensor Structure

The Standard Model Higgs Boson



Measurment of Higgs Decay Width



Higgs Coupling Strenght

Higgs signatures entering combinations

	H→γγ	H→ZZ	H→WW	H→ττ	H→bb	H→Zγ	H→μμ
gg→H	ATLAS CMS	ATLAS CMS	ATLAS CMS	ATLAS CMS		ATLAS CMS	ATLAS CMS
VBF	ATLAS CMS	ATLAS CMS	ATLAS CMS	ATLAS CMS		ATLAS CMS	ATLAS CMS
VH	ATLAS CMS	ATLAS CMS	ATLAS CMS	- CMS	ATLAS CMS	ATLAS CMS	- CMS
ttH	ATLAS CMS	ATLAS CMS	ATLAS CMS	ATLAS CMS	ATLAS CMS		

ATLAS

$M_H = 125.36$ GeV

CMS

$M_H = 125.02$ GeV

CMS-PAS-HIG-14-009

207 subcategories,
2519 nuisance parameters

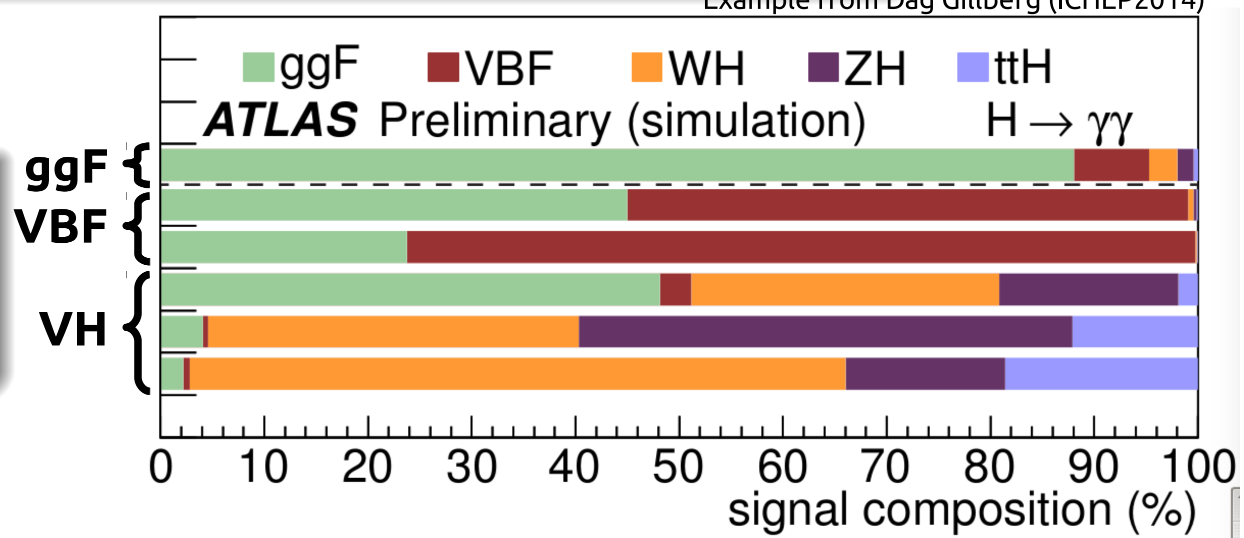
Analysis categorization to increase sensitivity

- Different S/B and production mode/decay compositions
- Allows to extract Higgs couplings to different particles

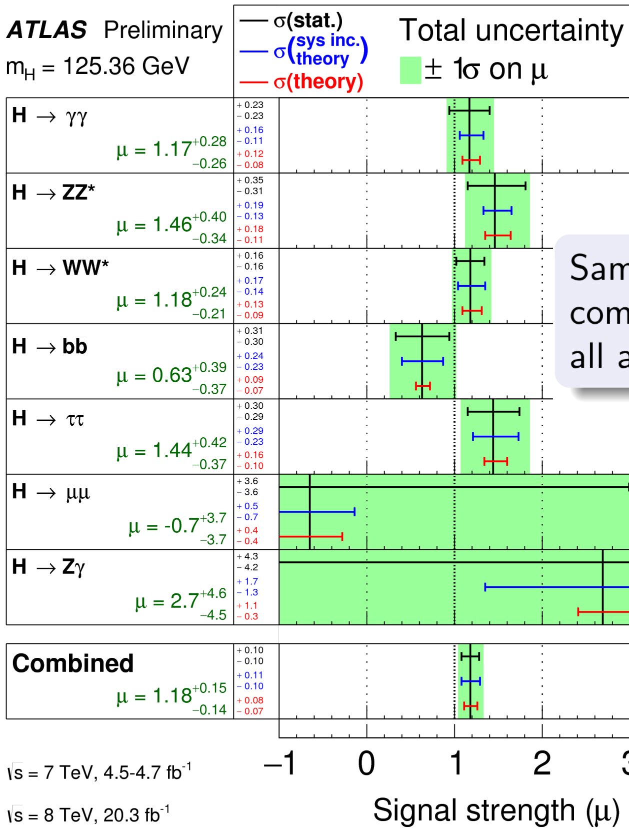
Tags are never 100% pure

e.g. VBF-tagged events are expected to contain 20-50% gg→H, depending on the analysis and subcategory

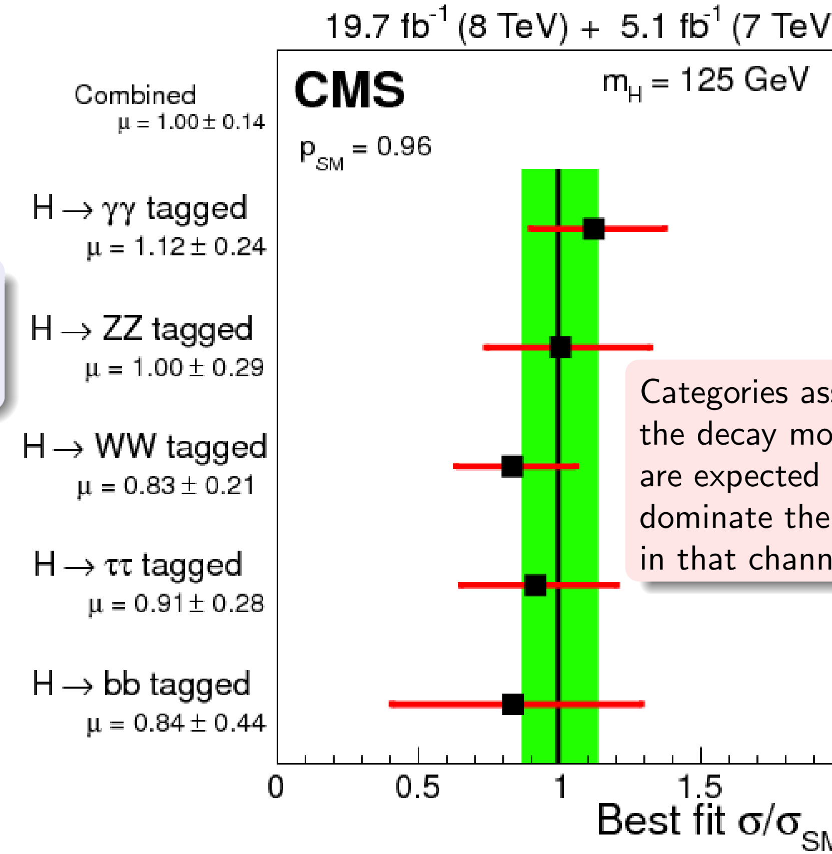
Example from Dag Gillberg (ICHEP2014)



Signal strength – grouped by decay mode



Same decay channel combined together for all analyses

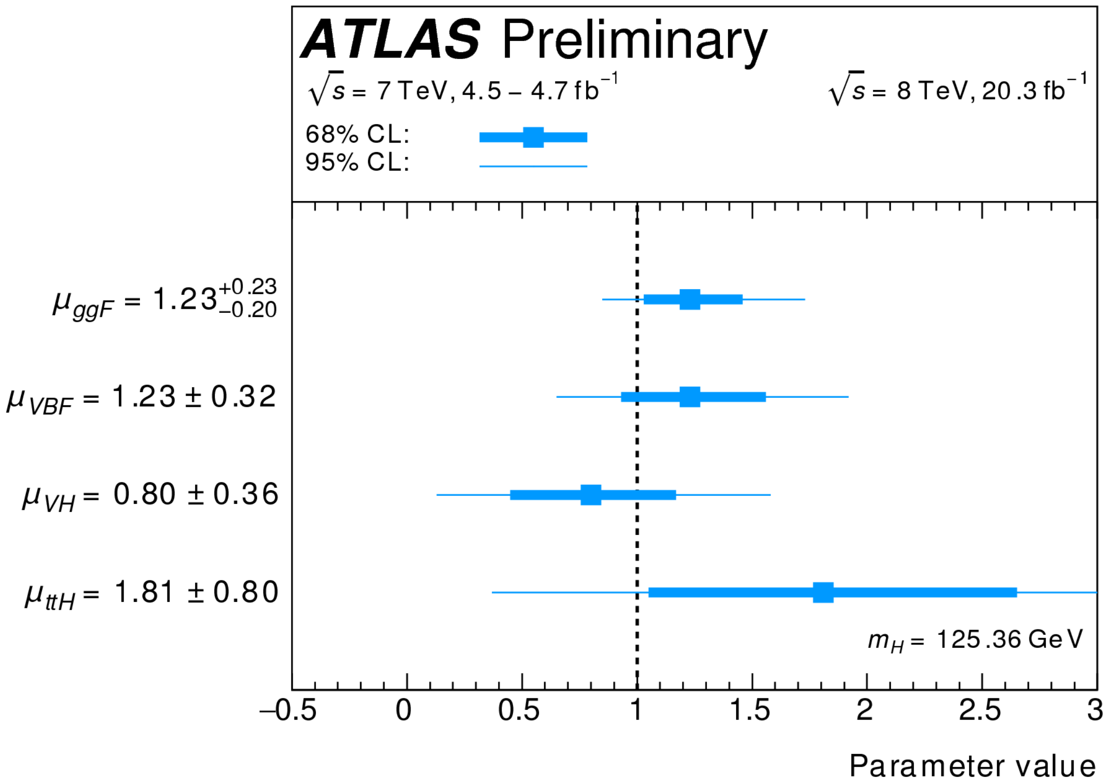


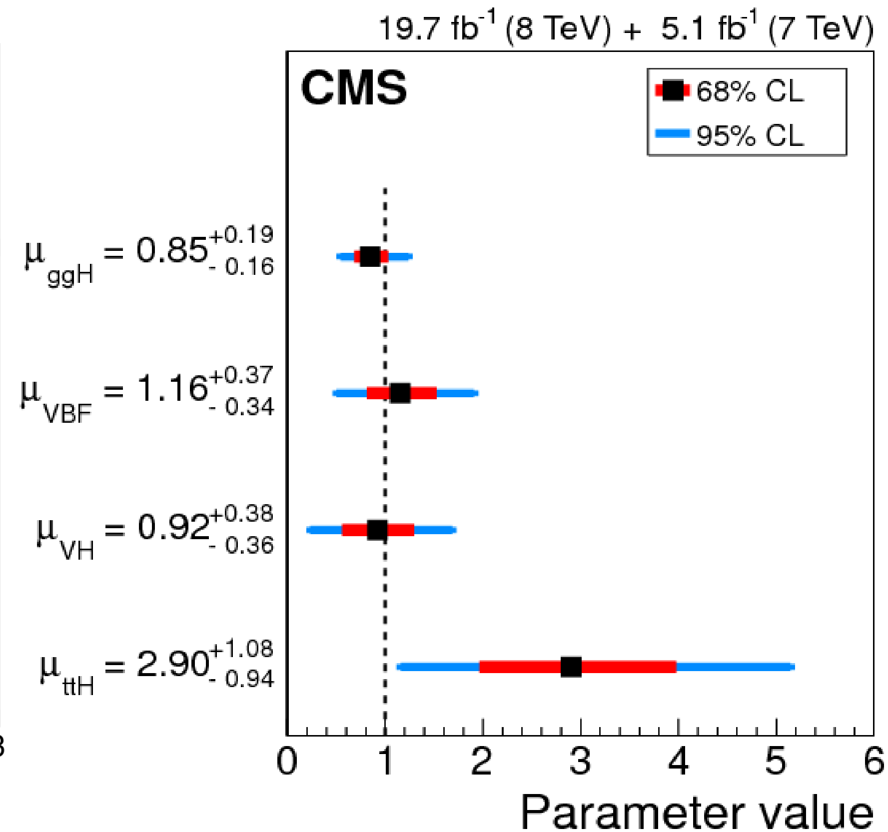
Categories assigned to the decay mode group are expected to dominate the sensitivity in that channel for SM

Decay mode groups

- Assumed SM fractions of production cross sections
- Overall signal strength ATLAS: $1.18 \pm 0.10(stat.)^{+0.08}_{-0.07}(theo.) \pm 0.07(syst.)$
- Overall signal strength CMS: $1.00 \pm 0.09(stat.)^{+0.08}_{-0.07}(theo.) \pm 0.07(syst.)$
- *Theoretical* uncertainty includes QCD scales, PDF+α_S, UEPS, and BR

Signal strength – grouped by production mode

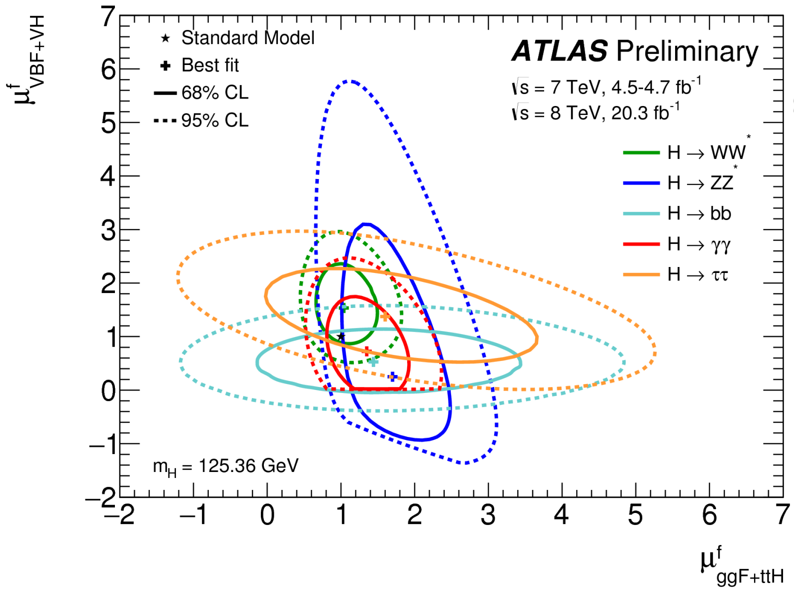


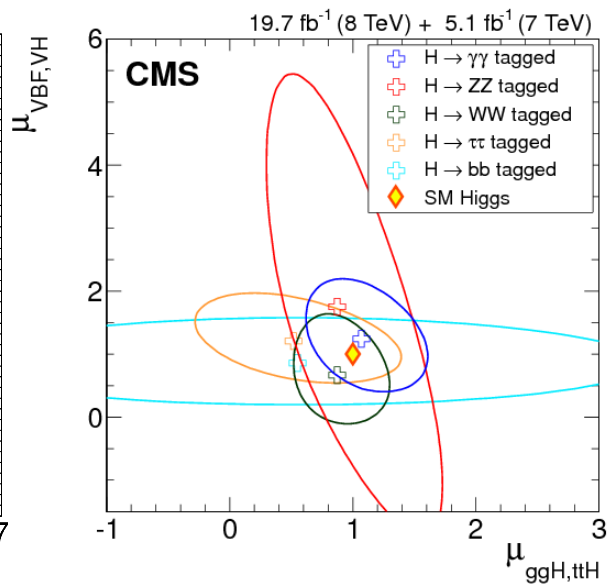


Production mode groups

- Assumed SM branching fractions to factor out the signal strengths from production modes
- Excess 2σ in ttH — interesting

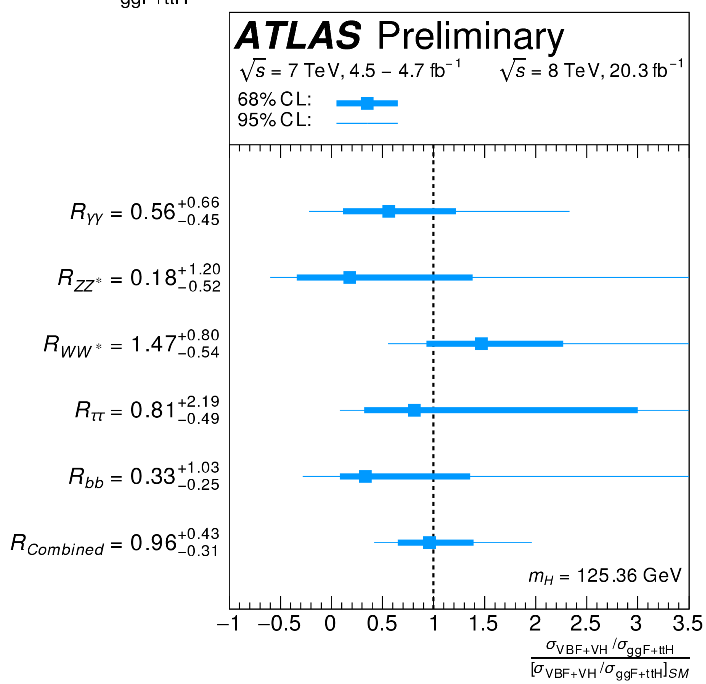
Signal strength – couplings to bosons and fermions

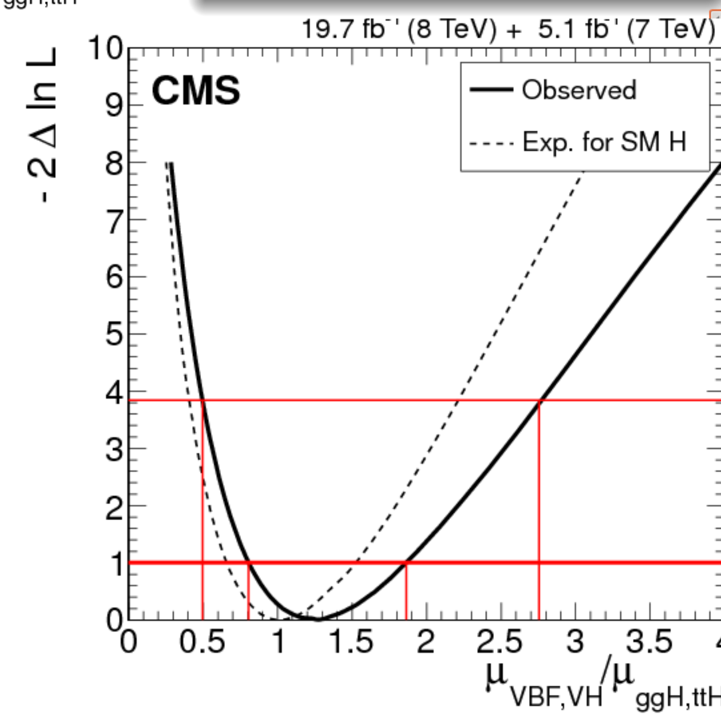




- Look at signal strengths of different Higgs production mechanisms
- $(ggF + ttH)$ scale mostly with fermionic Higgs couplings
- $(VBF + VH)$ scale mostly with bosonic Higgs couplings

- The ratio of $\mu_{VBF,VH}$ and $\mu_{ggH,ttH}$ measured in each decay mode group
- The branching fractions cancel out in each channel and the results of the different channels can be combined





κ-framework for coupling measurements

Prescription from LHCHXSWG [arXiv:1307.1347]

Production modes

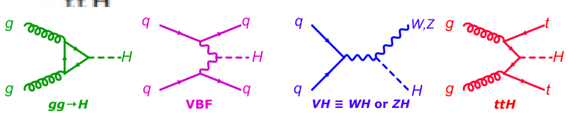
$$\frac{\sigma_{\mathrm{ggH}}}{\sigma^{\mathrm{SM}}_{\mathrm{ggH}}} = \begin{cases} \kappa_g^2(\kappa_b, \kappa_t, m_H) \\ \kappa_g^2 \end{cases}$$

$$\frac{\sigma_{\mathrm{VBF}}}{\sigma^{\mathrm{SM}}_{\mathrm{VBF}}} = \kappa^2_{\mathrm{VBF}}(\kappa_W, \kappa_Z, m_H)$$

$$\frac{\sigma_{\mathrm{WH}}}{\sigma^{\mathrm{SM}}_{\mathrm{WH}}} = \kappa_W^2$$

$$\frac{\sigma_{\mathrm{ZH}}}{\sigma^{\mathrm{SM}}_{\mathrm{ZH}}} = \kappa_Z^2$$

$$\frac{\sigma_{t\bar{t}H}}{\sigma^{\mathrm{SM}}_{t\bar{t}H}} = \kappa_t^2$$



Detectable decay modes

$$\frac{\Gamma_{WW^{(*)}}}{\Gamma^{\mathrm{SM}}_{WW^{(*)}}} = \kappa_W^2$$

$$\frac{\Gamma_{ZZ^{(*)}}}{\Gamma^{\mathrm{SM}}_{ZZ^{(*)}}} = \kappa_Z^2$$

$$\frac{\Gamma_{b\bar{b}}}{\Gamma^{\mathrm{SM}}_{b\bar{b}}} = \kappa_b^2$$

$$\frac{\Gamma_{\tau^-\tau^+}}{\Gamma^{\mathrm{SM}}_{\tau^-\tau^+}} = \kappa_\tau^2$$

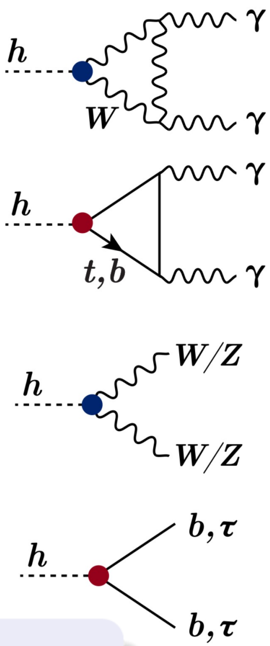
$$\frac{\Gamma_{\gamma\gamma}}{\Gamma^{\mathrm{SM}}_{\gamma\gamma}} = \begin{cases} \kappa_\gamma^2(\kappa_b, \kappa_t, \kappa_\tau, \kappa_W, m_H) \\ \kappa_\gamma^2 \end{cases}$$

$$\frac{\Gamma_{t\bar{t}}}{\Gamma^{\mathrm{SM}}_{t\bar{t}}} = \kappa_t^2$$

$$\frac{\Gamma_{gg}}{\Gamma^{\mathrm{SM}}_{gg}} : \text{see Section 3.1.2}$$

$$\frac{\Gamma_{\mu^-\mu^+}}{\Gamma^{\mathrm{SM}}_{\mu^-\mu^+}} = \kappa_\tau^2$$

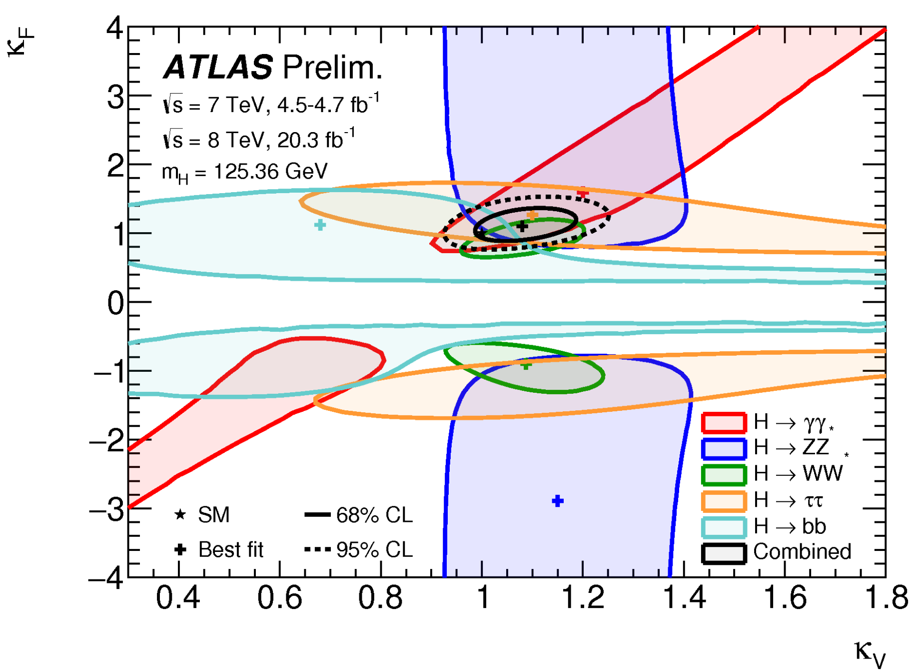
Deviations from SM parametrized using κ multipliers (SM $\kappa = 1$)

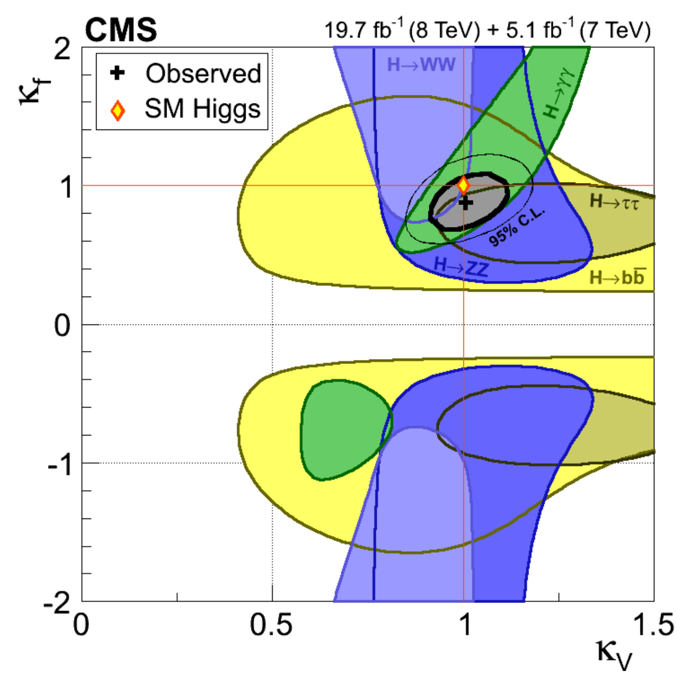


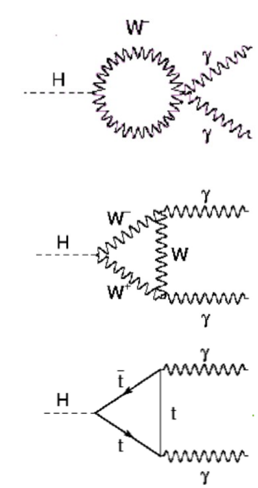
- Simplest parametrization of Higgs-couplings deviations from SM
- Assume kinematics are unchanged
- Motivated only for small scalar deviations from SM
- Assume single, narrow and CP-even resonance (SM tensor structure)
- Assume zero-width approximation is valid: $\sigma \times BR(i \to H \to f) = \frac{\sigma_i \times \Gamma_f}{\Gamma_H}$
- κ allows for more direct access to couplings as μ contains complex convolution of production and decay

Couplings to vector bosons and fermions

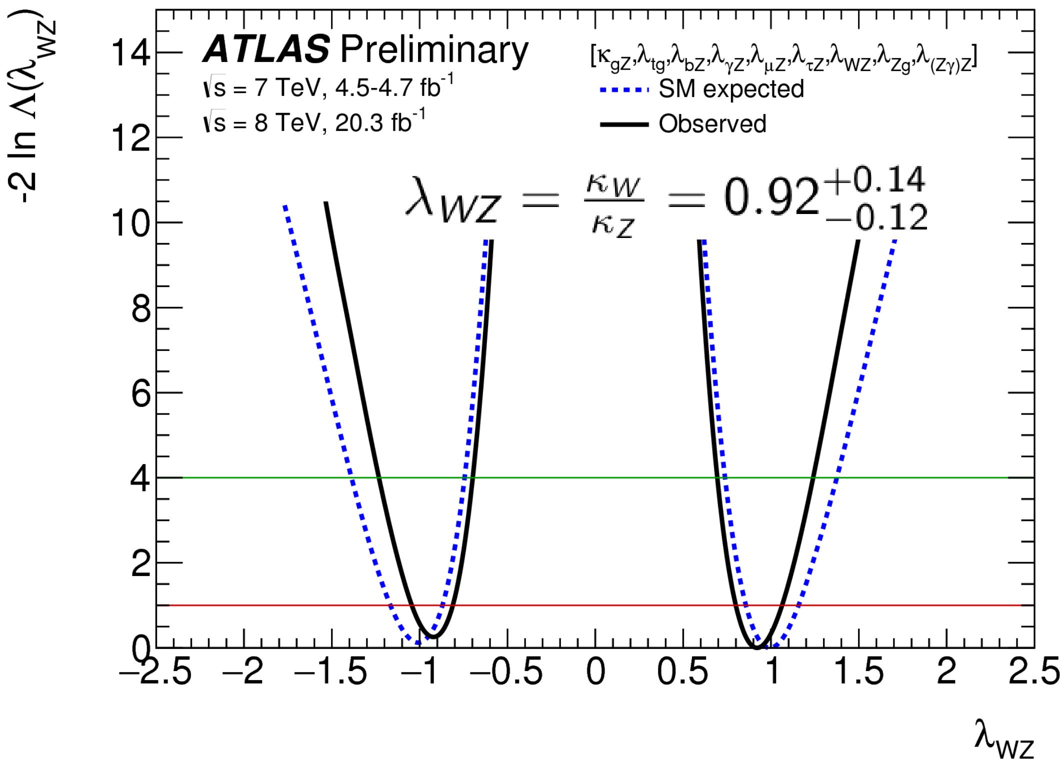
- Map vector-boson and fermionic couplings into κ_V ($\kappa_W = \kappa_Z$) and κ_f ($\kappa_b = \kappa_t = \kappa_\tau$) plane
- κ_γ and κ_g effective couplings due to loops
- $H \to \gamma\gamma$ loops sensitive to relative sign of couplings to W and top: $\kappa_\gamma^2 = |1.28\kappa_W - 0.28\kappa_t|^2$
- κ_F sign ambiguity resolved from the interference in $H \to \gamma\gamma$, tH, $gg \to ZH$
- No BSM particle contributions in the total width nor in loops
- Individual channels converge on the SM quadrant and agree well with each other and the SM within uncertainties

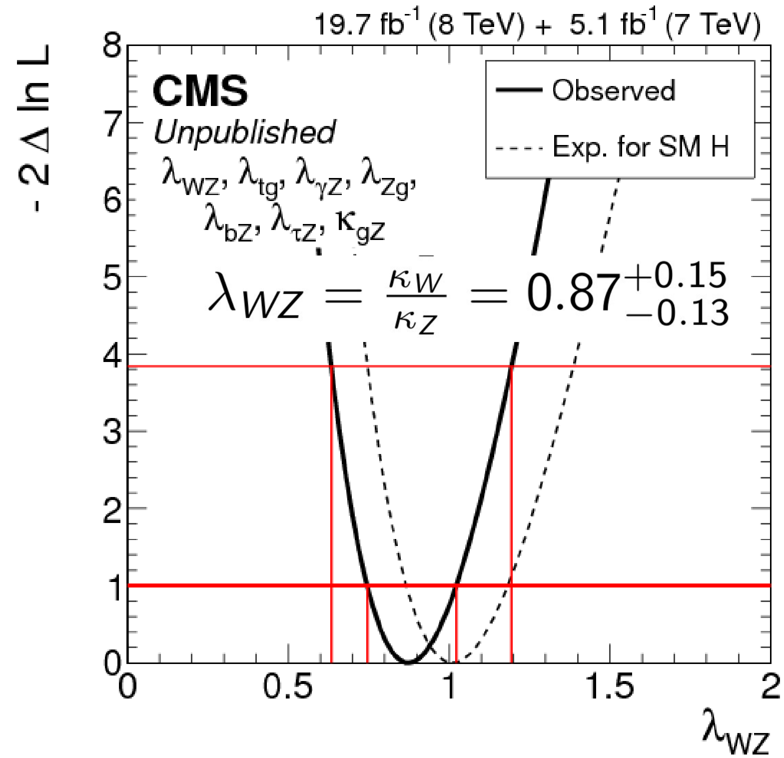






Custodial symmetry



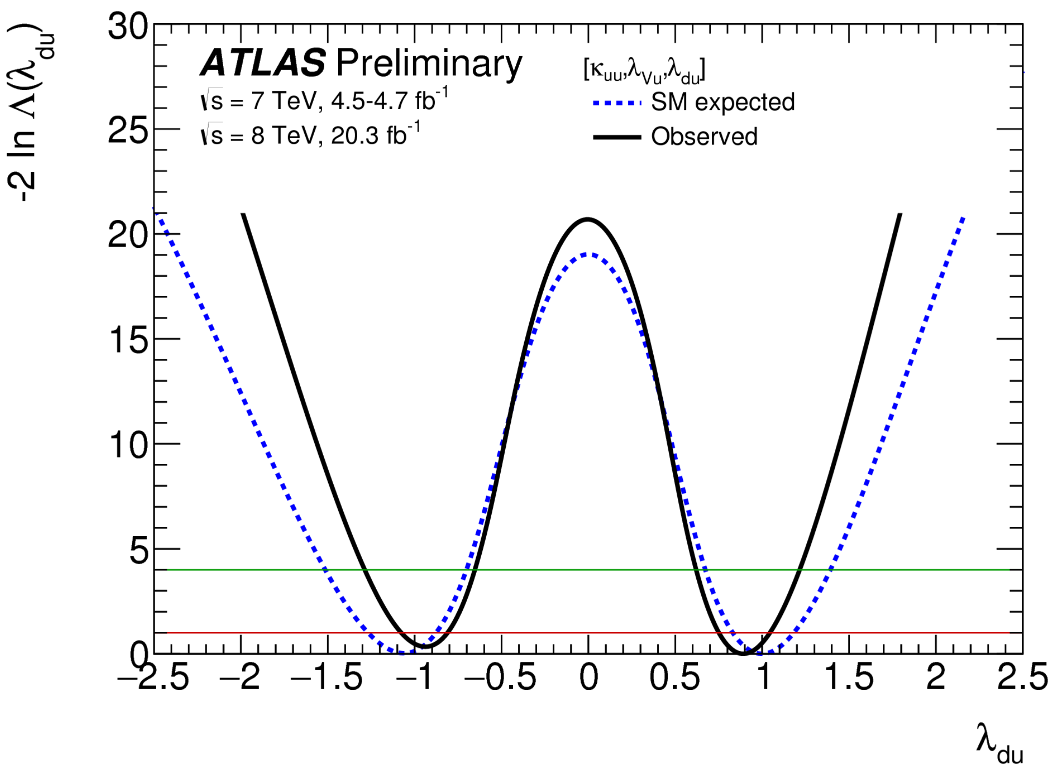


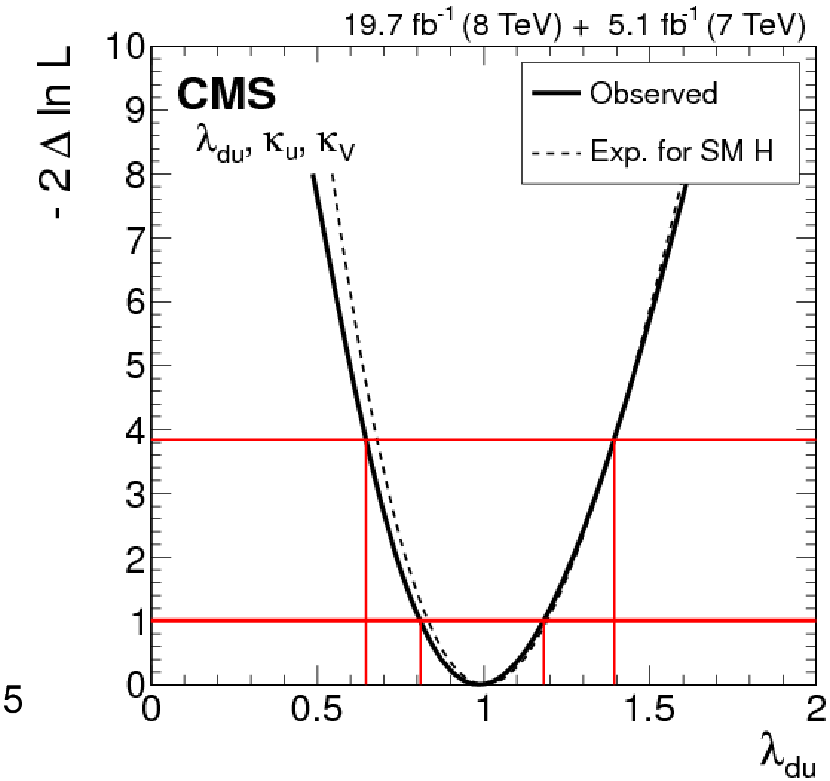
- Custodial symmetry imposes the SM couplings ratio between W and Z Higgs couplings
- $\rho = 1$ measured to high precision at LEP and Tevatron sets also tight bounds [arXiv:1012.2367]
- ATLAS: The fit is sensitive to the relative sign (interference) between the W and top-coupling (tH) and the Z and top-coupling ($gg \to ZH$)
- No deviation $\to$ treat Z and W as V

Custodial Symmetry

- The SM Higgs sector symmetry $SU(2)_L \times SU(2)_R \to SU(2)_{L+R}$ (due to Higgs *vev*)
- Result: m_W/m_Z , and their couplings to the Higgs, g_W/g_Z , protected against large radiative corrections

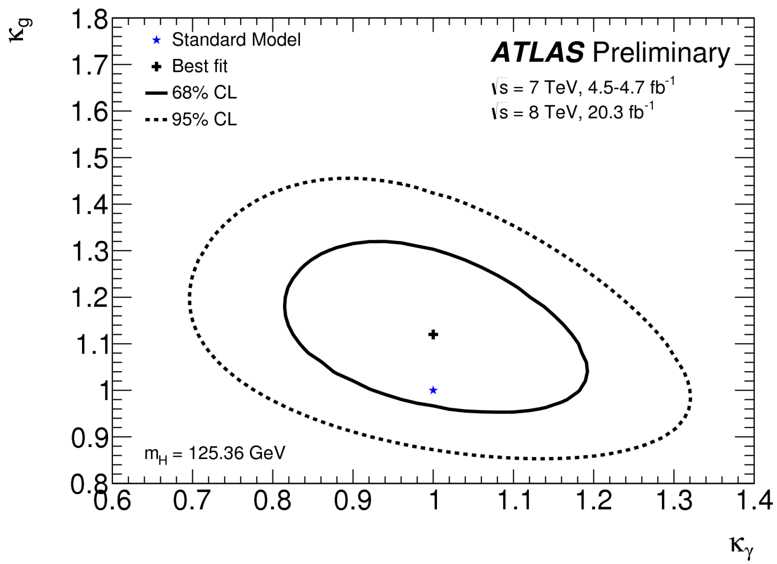
Up vs Down type couplings to fermions

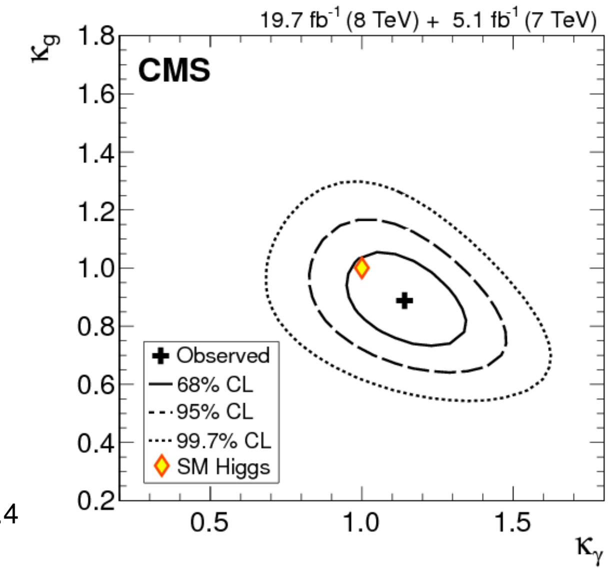




- Several doublet models (e.g. MSSM) predict different Higgs couplings to up and down-type fermions
- One multiplier for up-type fermions: $\kappa_u = \kappa_t$, and one for of down-type $\kappa_d = \kappa_b = \kappa_\tau = \kappa_\mu$
- Model almost insensitive to the relative sign of $\kappa_u$and κ_d — the interference of the b and t loops in the $gg \to H$ induces a tiny asymmetry
- CMS assumes $\Gamma_{BSM} = 0$

New physics in loops – couplings κ_g vs κ_γ

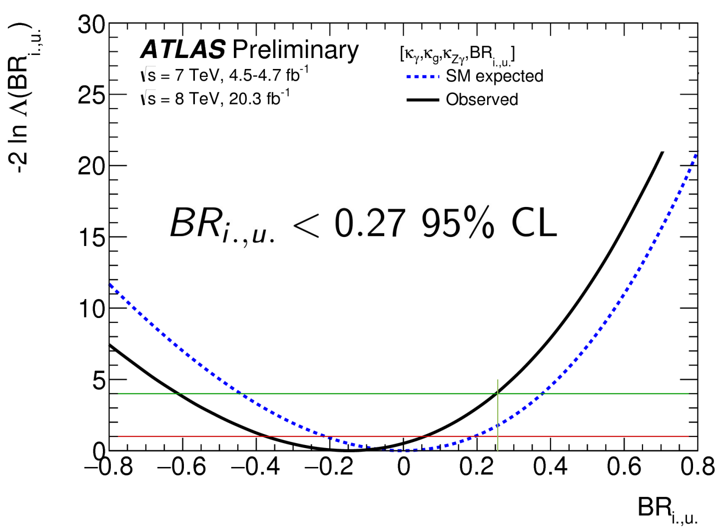


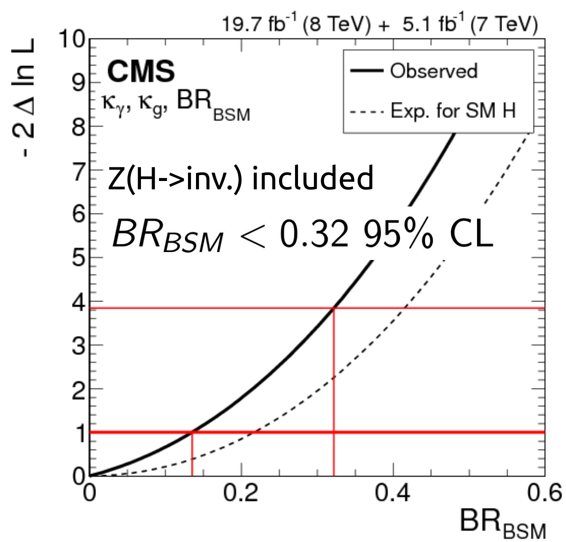


- New particles can potentially hide in the loop-mediated couplings ($H\gamma\gamma$, ggH and $HZ\gamma$)
- The photons and gluons are treated tree-level effective couplings

$BR_{BSM} = 0$

- Tree-level Coupling to SM particles as in SM: $\kappa_b = \kappa_W = \kappa_Z = \kappa_\tau = \kappa_t = 1$
- κ_γ and κ_g are sensitive to new particles

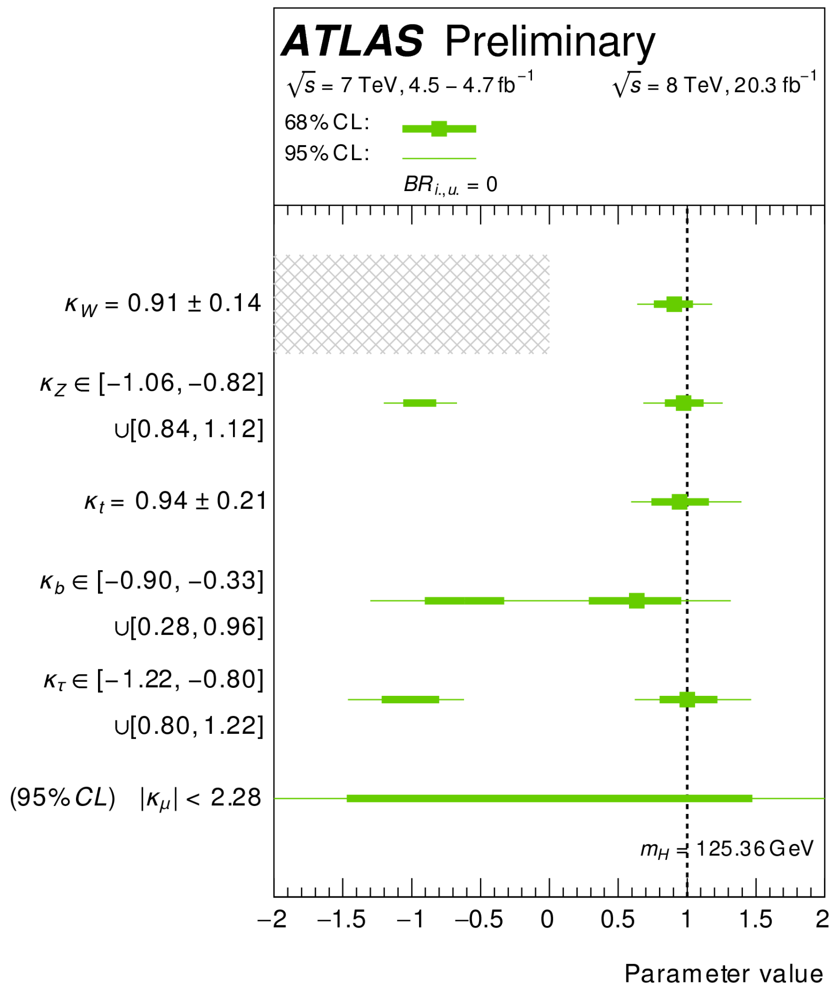


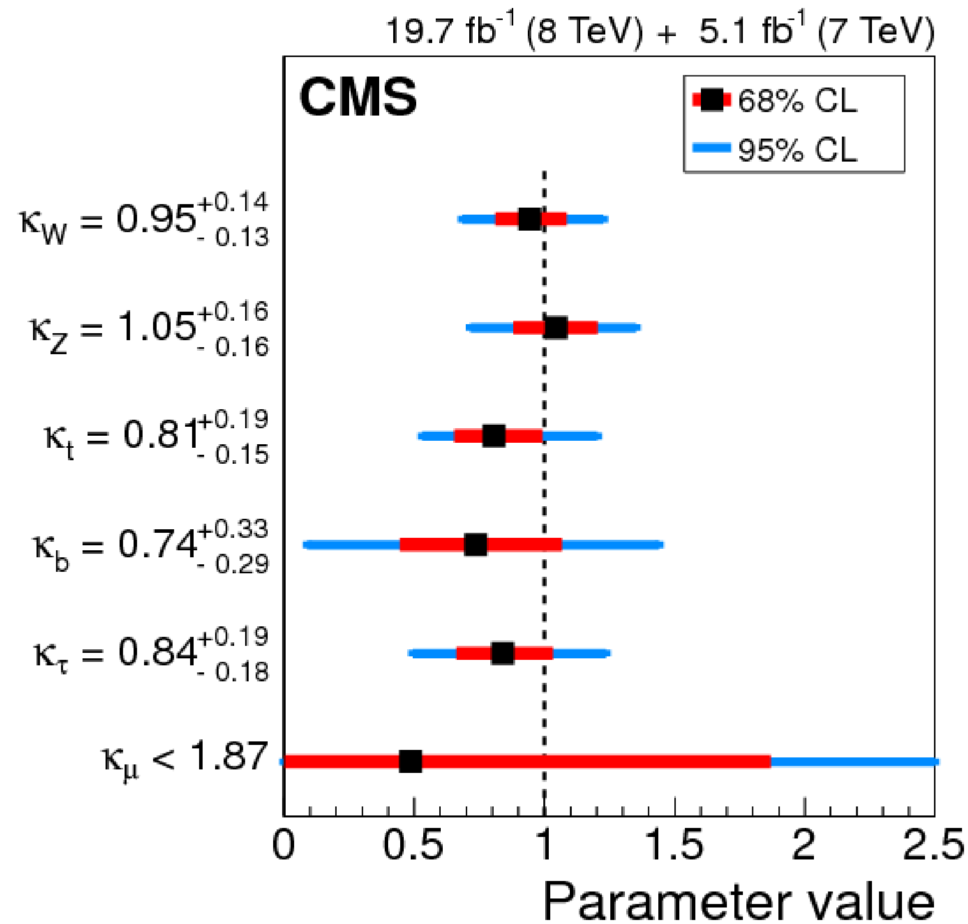


BR_{BSM} unconstrained

- New particles can contribute to the total width
- Allow total width to scale as $1/(1 - BR_{BSM})$

Generic model with SM width and loops

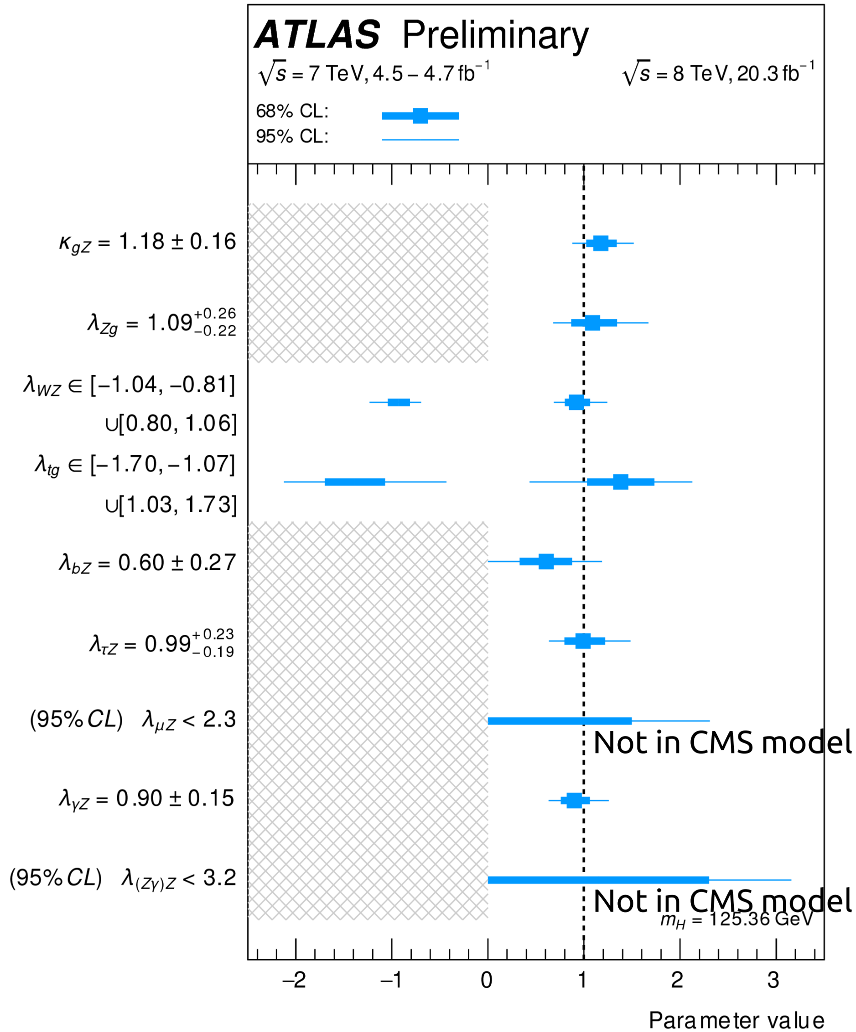


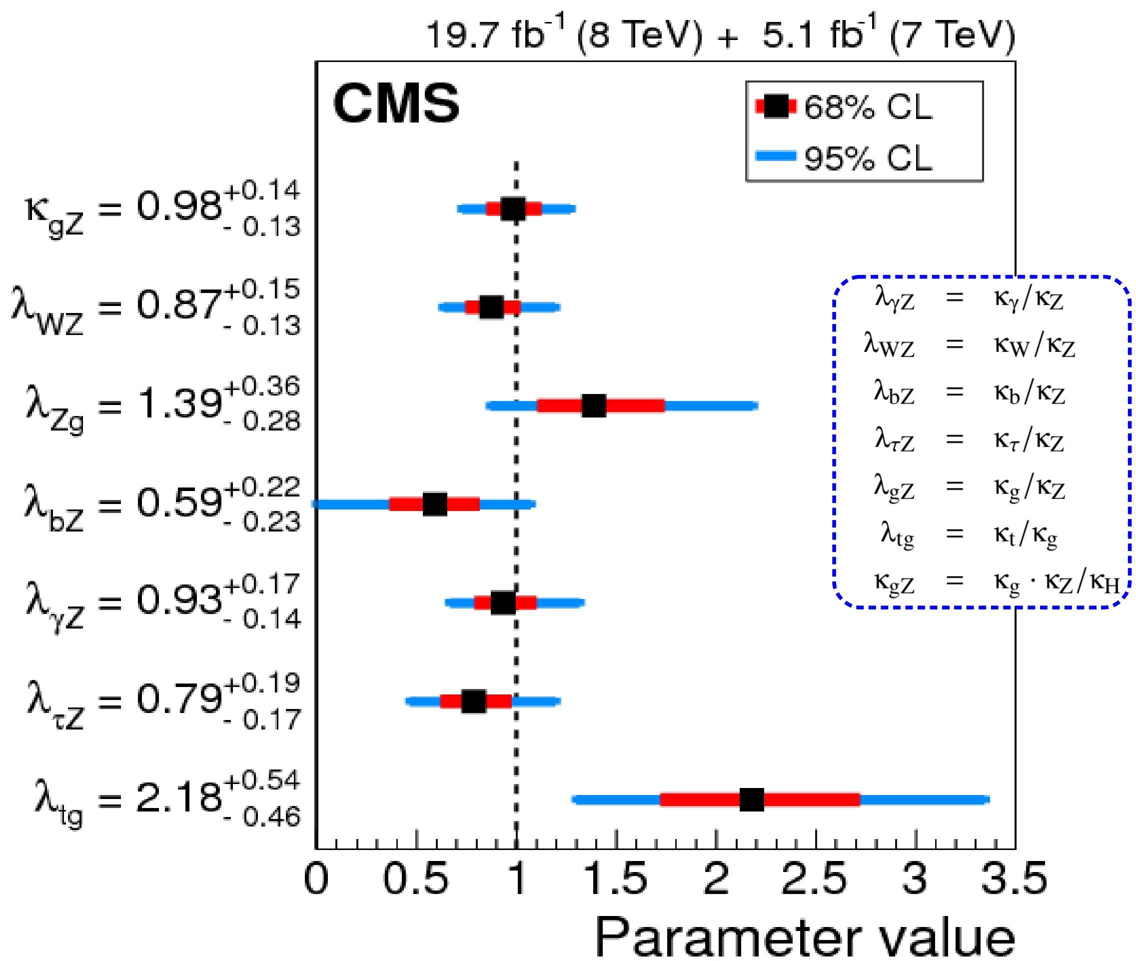


SM particles in loops and SM total width

- The couplings scale factors to W, Z, t, b and τ treated independently
- The SM particle content in case of $gg \to H$ production, $H \to \gamma\gamma$ decay
- The total width Γ_H assumed to be SM

Generic model with unconstrained width and loops





Allowing deviations in vertex loop couplings and the total width

- All gauge and third generation fermion effective couplings are floated
- Allowing for invisible or undetectable widths

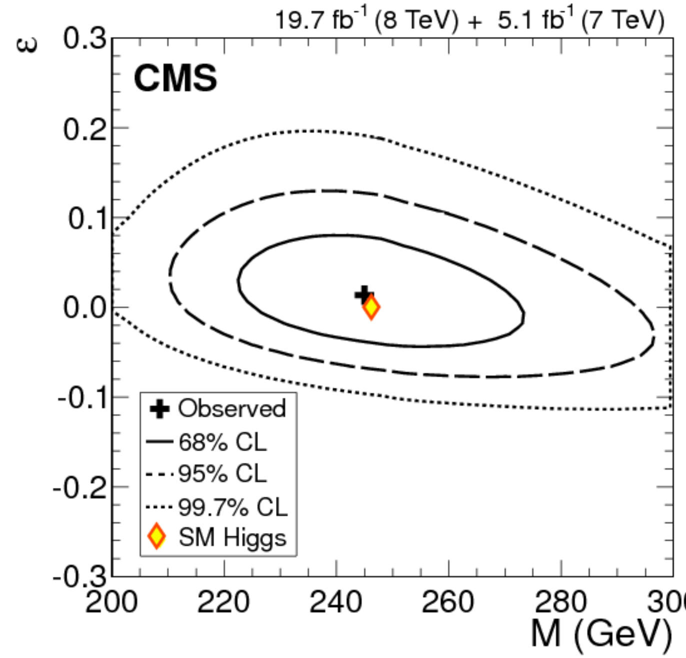
Scaling of couplings vs. particle mass

[J. Ellis and T. You, arXiv:1207.1693]

Generic M and ϵ model

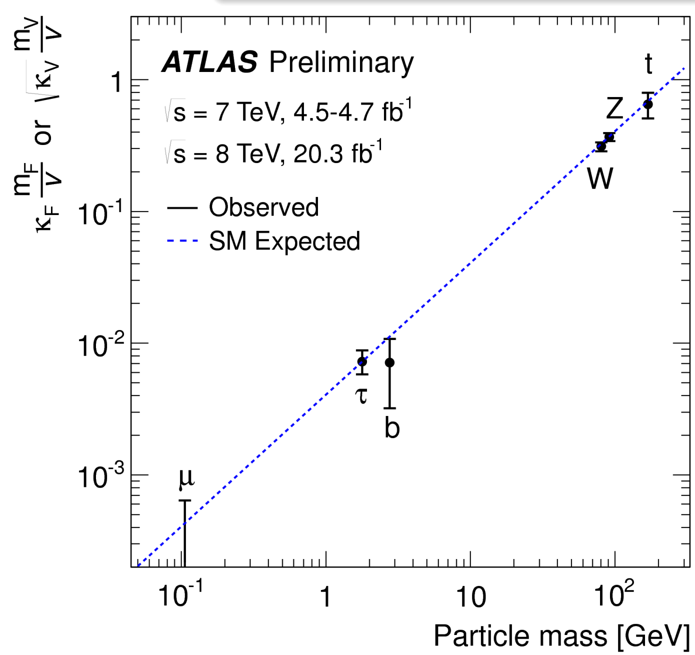
Parametrized in terms of a mass scaling parameter ϵ and a *vev* parameter M:

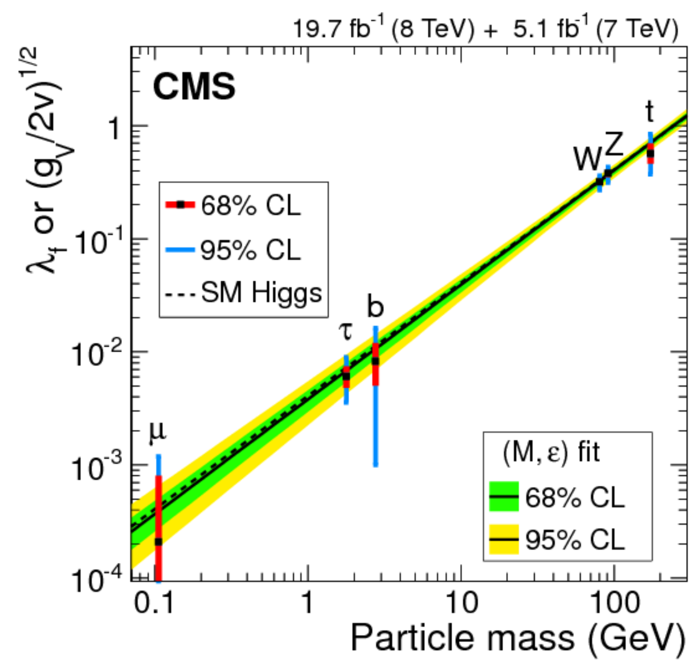
- $\kappa_f = vev \cdot \frac{m_f^{\epsilon}}{M^{1+\epsilon}}$
- $\kappa_V = vev \cdot \frac{m_V^{2\epsilon}}{M^{1+2\epsilon}}$



Standard Model

$vev = 246$ GeV and $\kappa_f = \kappa_V = 1$ recovered for $M = vev$ and $\epsilon = 0$





$$\lambda = \kappa_f \frac{m_f}{vev}$$

$$\left(\frac{g_V}{2vev}\right)^{1/2} = \kappa_V^{1/2} \frac{m_V}{vev}$$

Conclusions and Prospects

- First combination of ATLAS and CMS Higgs boson mass measurement ($m_H = 125.09 \pm 0.24$ GeV) — statistical uncertainty still dominates
- Higgs width measurement boosted to the realm of SM expectation using off-shell production ($\Gamma_H < 22$ MeV)
- Excluded at $> 99\%$ CL models with Higgs boson of spin-1 and spin-2
- Set stringent limits on effective fractions and phases from spin-0 tensor structure allowing for mixture of multiple spin-0 models
- Higgs boson couplings to fermions and bosons measured in different production and decay categories
- Both experiments performed a search for deviations from the Higgs coupling to SM particles using a tree-level motivated benchmark models from LHCHXSWG
- Indirect measurements set moderate limits (30%) on couplings to BSM particles $B(H \to invisible)$

Overall consistency with Standard Model with the backdoor left slightly open for some fresh air to enter.

Conclusions and Prospects

Hopefully Near Future

- With 10 fb^{-1} by the end of 2015 we have equivalent of Run1 data — $\sigma_{ggH}(13\ TeV) \sim 2.5 \times \sigma_{ggH}(8\ TeV)$
- Having 20 fb^{-1} would decrease the statistical uncertainties by 2 times — goes below systematic uncertainty
- Statistical and systematic uncertainties comparable — great effort put on decreasing systematics by both, experiments and theory
- ATLAS+CMS combination for couplings in preparation for the summer conferences

Спасибо!

- Special thanks to
  - Ekaterina Kuznetsova
  - Victor Kim
  - Victor Murzin
  - Alexey Ivanov
  - Those behind the scene…