ATLAS+CMS Higgs run 1 Combinations

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on behalf of the ATLAS and CMS collaborations

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Institut Lagrange de Paris

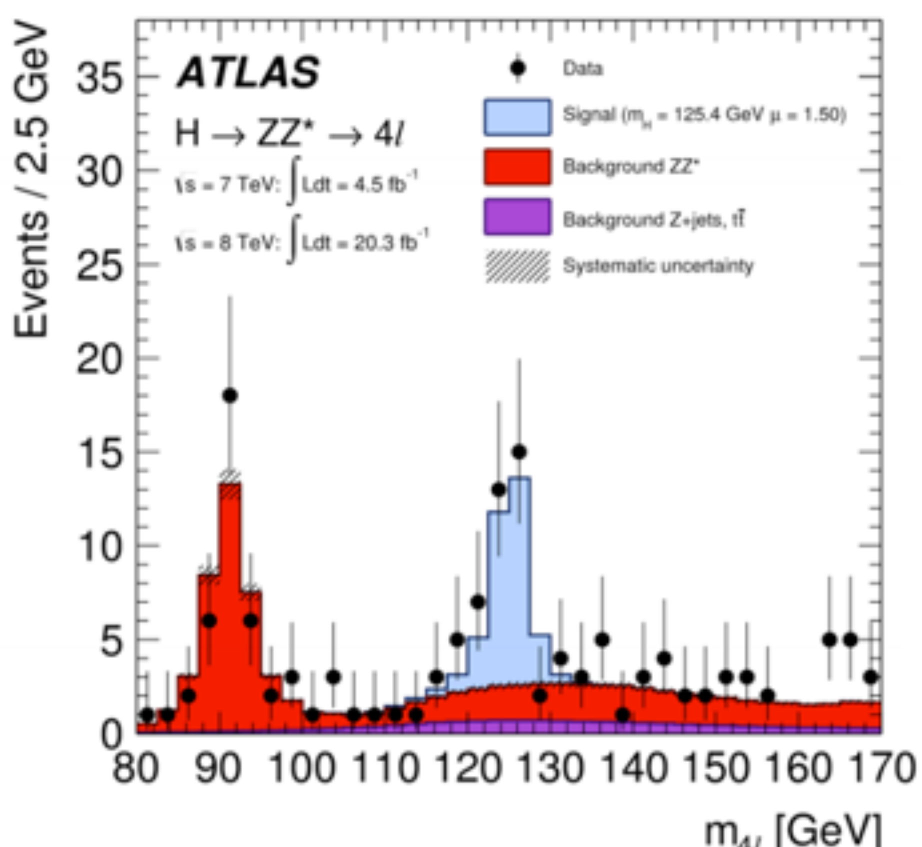
LPNHE PARIS

Outline

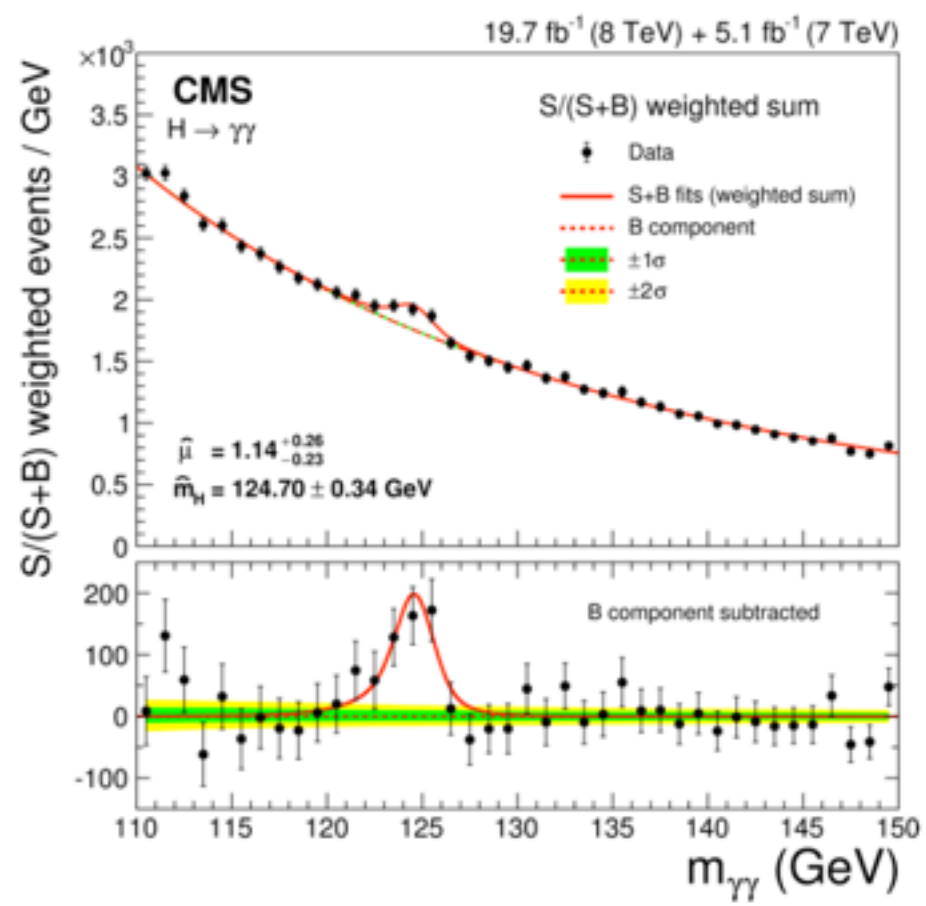
- Higgs boson mass measurement ⇒ Completing the SM predictions
- Experimental inputs and combination procedure
- Most generic parametrisation
- Signal strengths for the production and decay modes
- Measurement of the coupling modifiers
- Up/down-type fermion and lepton/quark asymmetries
- Effective scaling factors and constrains on BR for BSM decay modes
- Conclusions

Measurement of the Higgs boson mass

- Higgs mass is the only parameter unconstrained by SM
- Crucial in SM prediction of production and decay modes
- Measurement based on $H \rightarrow ZZ^* \rightarrow 4l$ and $H \rightarrow \gamma\gamma$ final states, for which invariant mass can be reconstructed with high precision



Phys. Rev. D 90, 052004 (2014)

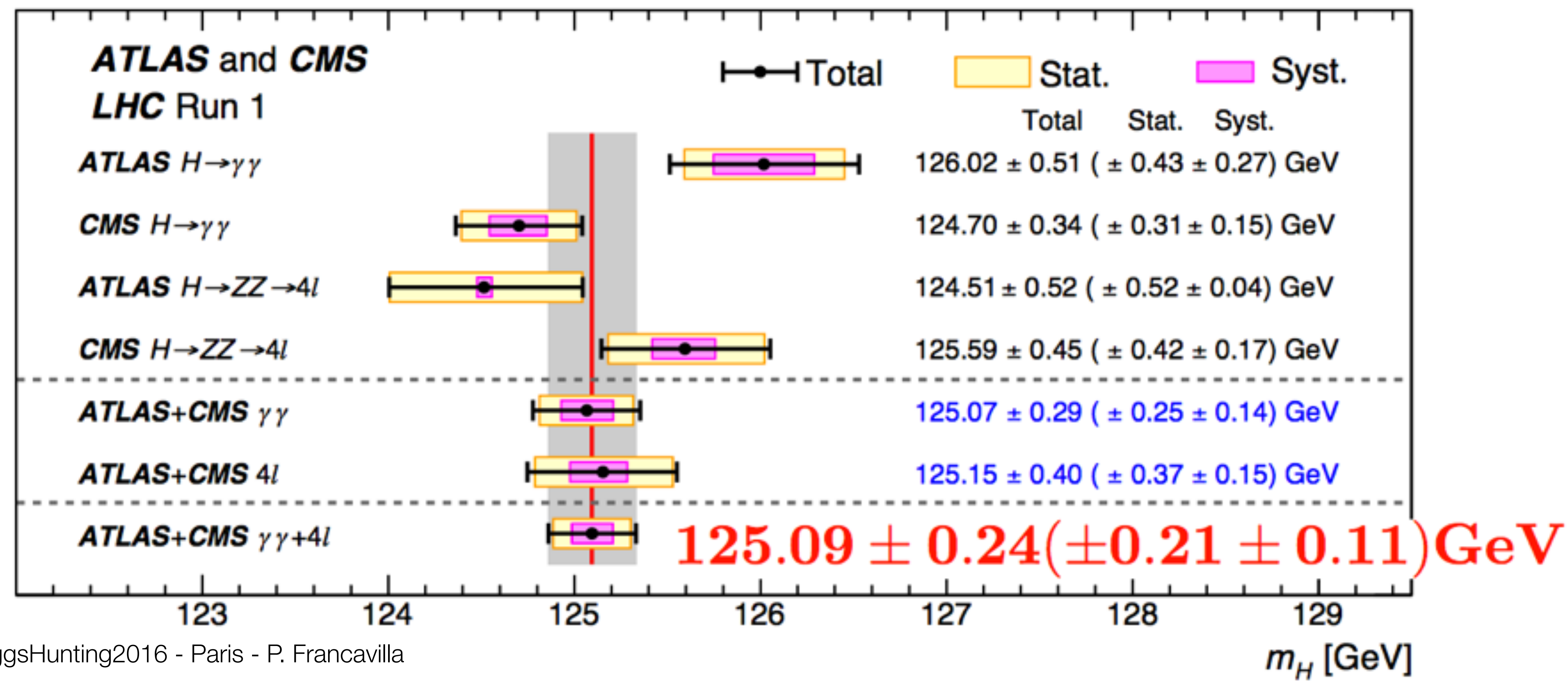


Eur. Phys. J. C 74 (2014) 3076

Phys. Rev. Lett. 114, 191803 (2015)

Measurement of the Higgs boson mass

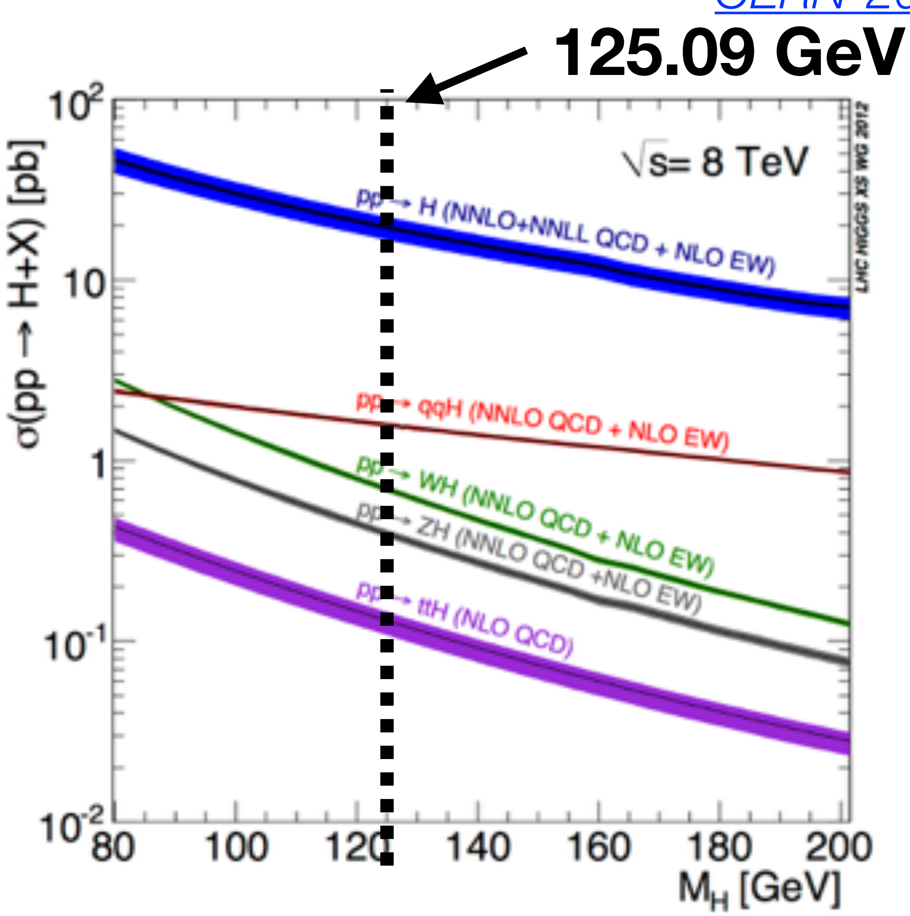
- Mass of Higgs boson measured with <0.2% precision
- MH = 125.09 ± 0.24 GeV [±0.21 (stat.) ±0.11(syst.)]
- Dominant systematics: energy or momentum scale and resolution for γ,e,μ

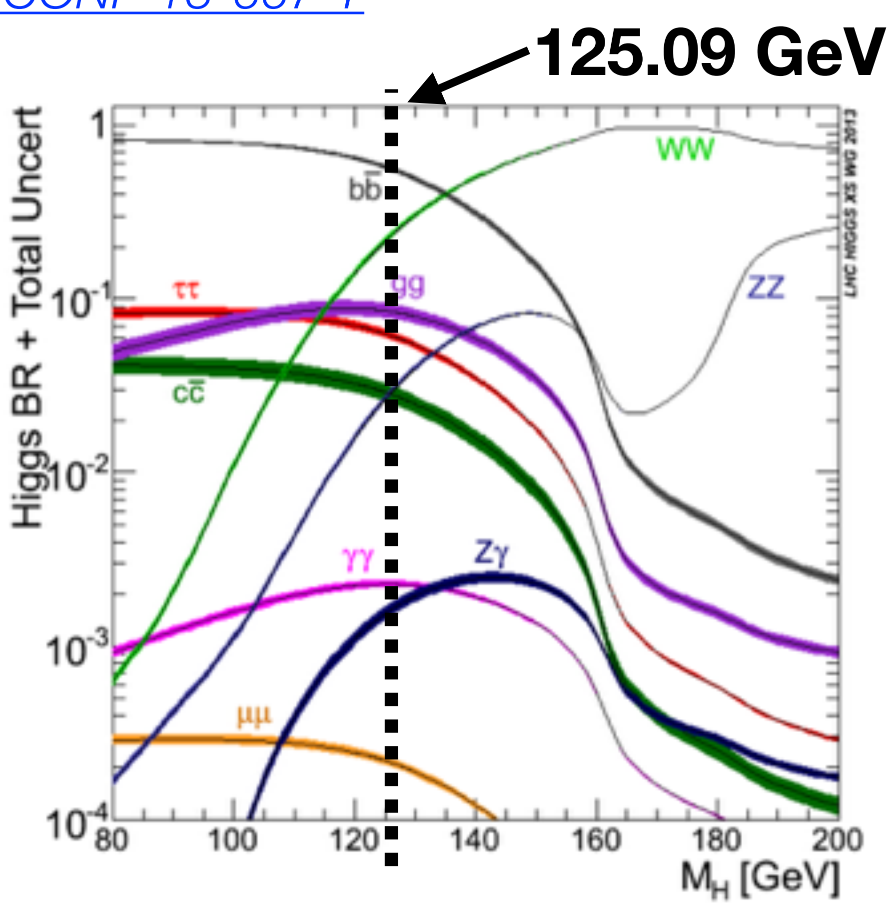


Knowing the mass….

- SM predictions for production mode cross sections and decay BR fully determined

CERN-2013-004, FERMILAB-CONF-13-667-T





- Combining measurements and searchers by ATLAS and CMS collaborations published in 17 individual publications

Analysis - Measurements in ATLAS and CMS

- Integrated luminosities per experiment: **~5 fb^{-1} at $\sqrt{s}$ = 7 TeV ~20 fb^{-1} at $\sqrt{s}$ = 8 TeV**
- **Why combining?**
  Doubling statistical power in measuring the Higgs boson production and decay rates
  Checks for tensions between experiments that are supposed to probe the same particle

Channel	References for individual publications		Signal strength [μ] from results in this paper (Section 5.2)		Signal significance [σ]	
	ATLAS	CMS	ATLAS	CMS	ATLAS	CMS
$H \to \gamma\gamma$	[91]	[92]	$1.14\,^{+0.27}_{-0.25}$ $\left(^{+0.26}_{-0.24}\right)$	$1.11\,^{+0.25}_{-0.23}$ $\left(^{+0.23}_{-0.21}\right)$	5.0 (4.6)	5.6 (5.1)
$H \to ZZ$	[93]	[94]	$1.52\,^{+0.40}_{-0.34}$ $\left(^{+0.32}_{-0.27}\right)$	$1.04\,^{+0.32}_{-0.26}$ $\left(^{+0.30}_{-0.25}\right)$	7.6 (5.6)	7.0 (6.8)
$H \to WW$	[95, 96]	[97]	$1.22\,^{+0.23}_{-0.21}$ $\left(^{+0.21}_{-0.20}\right)$	$0.90\,^{+0.23}_{-0.21}$ $\left(^{+0.23}_{-0.20}\right)$	6.8 (5.8)	4.8 (5.6)
$H \to \tau\tau$	[98]	[99]	$1.41\,^{+0.40}_{-0.36}$ $\left(^{+0.37}_{-0.33}\right)$	$0.88\,^{+0.30}_{-0.28}$ $\left(^{+0.31}_{-0.29}\right)$	4.4 (3.3)	3.4 (3.7)
$H \to bb$	[100]	[101]	$0.62\,^{+0.37}_{-0.37}$ $\left(^{+0.39}_{-0.37}\right)$	$0.81\,^{+0.45}_{-0.43}$ $\left(^{+0.45}_{-0.43}\right)$	1.7 (2.7)	2.0 (2.5)
$H \to \mu\mu$	[102]	[103]	$-0.6\,^{+3.6}_{-3.6}$ $\left(^{+3.6}_{-3.6}\right)$	$0.9\,^{+3.6}_{-3.5}$ $\left(^{+3.3}_{-3.2}\right)$		
ttH production	[77, 104, 105]	[107]	$1.9\,^{+0.8}_{-0.7}$ $\left(^{+0.7}_{-0.7}\right)$	$2.9\,^{+1.0}_{-0.9}$ $\left(^{+0.9}_{-0.8}\right)$	2.7 (1.6)	3.6 (1.3)

off-shell analyses not in combination

	Untagged	VBF	VH	ttH
H→γγ	✓	✓	✓	✓
H→ZZ→4l	✓	✓	✓	✓
H→WW→2l2ν	✓	✓	✓	✓
H→ττ	✓	✓	✓	✓
H→bb			✓	✓
H→μμ	✓	✓		
H→Zγ	in ATLAS combination			
H→inv	in CMS combination			

overwhelming multijet BKG

not yet in combination

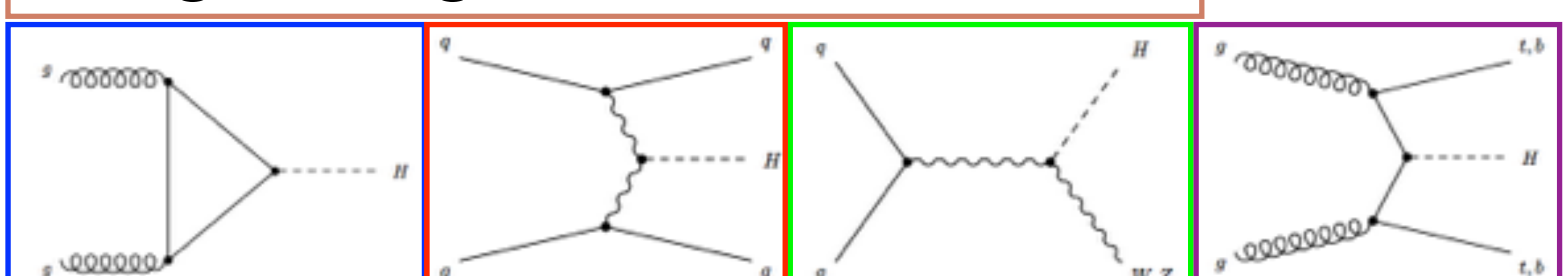
extremely low $\sigma_i \times B^{\mu\mu}$

From single channel, to combined results

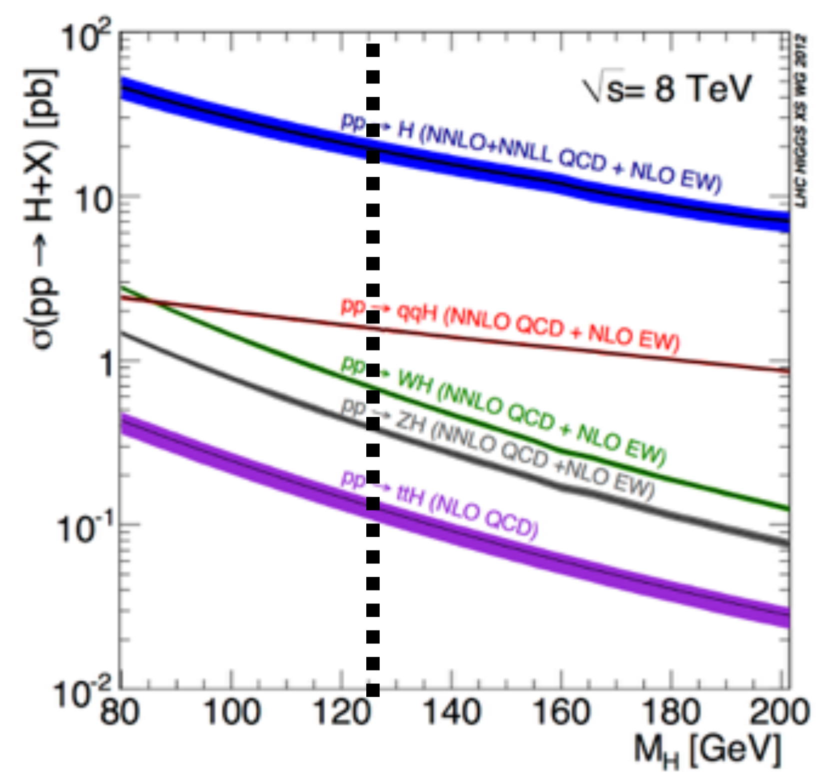
- To **enhance the sensitivity**, the experimental analysis uses **event categories(k) also based on multi variate techniques**
  - **Sensitivity to different production modes**

$$n_{\text{signal}}(k) = \mathcal{L}(k) \cdot \sum_i \sum_f \left\{ \boxed{\sigma_i \cdot} A_i^{f,\text{SM}}(k) \cdot \varepsilon_i^f(k) \cdot \text{B}^f \right\}$$

Inclusive SM cross-section for production mode *i* i.e. gluon-gluon fusion



SM Predictions



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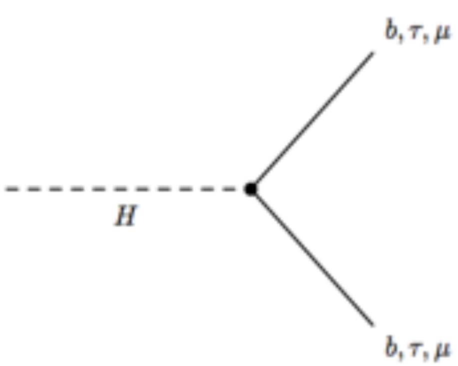
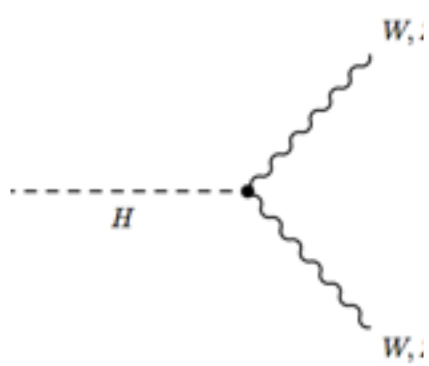
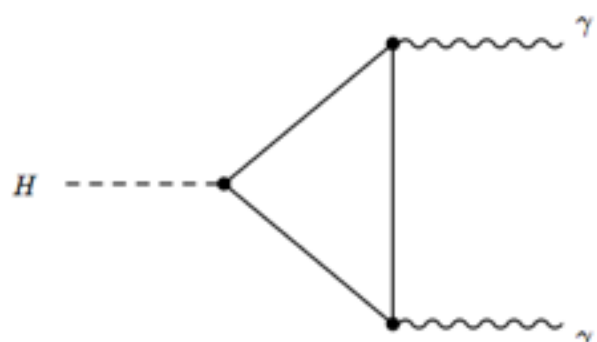
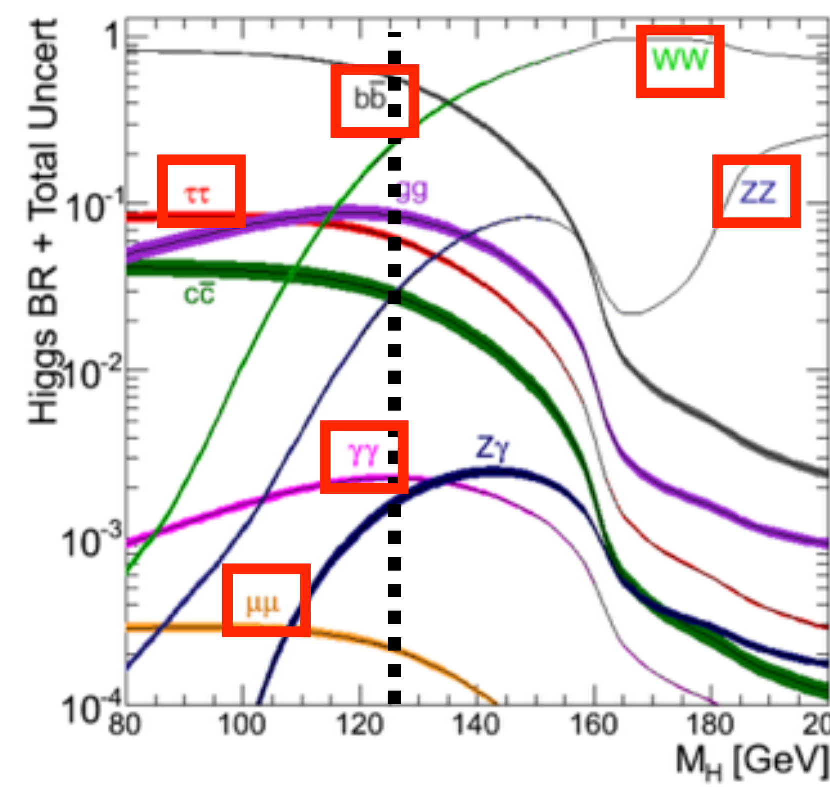
Branching Fractions
i.e.: H→ZZ







SM Predictions



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Acceptances and efficiencies, from MC assuming SM

Production process	Event generator	
	ATLAS	CMS
ggF	Powheg [79–83]	Powheg
VBF	Powheg	Powheg
WH	Pythia8 [84]	Pythia6.4 [85]
ZH ($qq \to ZH$ or $qg \to ZH$)	Pythia8	Pythia6.4
$ggZH$ ($gg \to ZH$)	Powheg	See text
ttH	Powhel [87]	Pythia6.4
tHq ($qb \to tHq$)	MadGraph [89]	aMC@NLO [78]
tHW ($gb \to tHW$)	aMC@NLO	aMC@NLO
bbH	Pythia8	Pythia6.4, aMC@NLO

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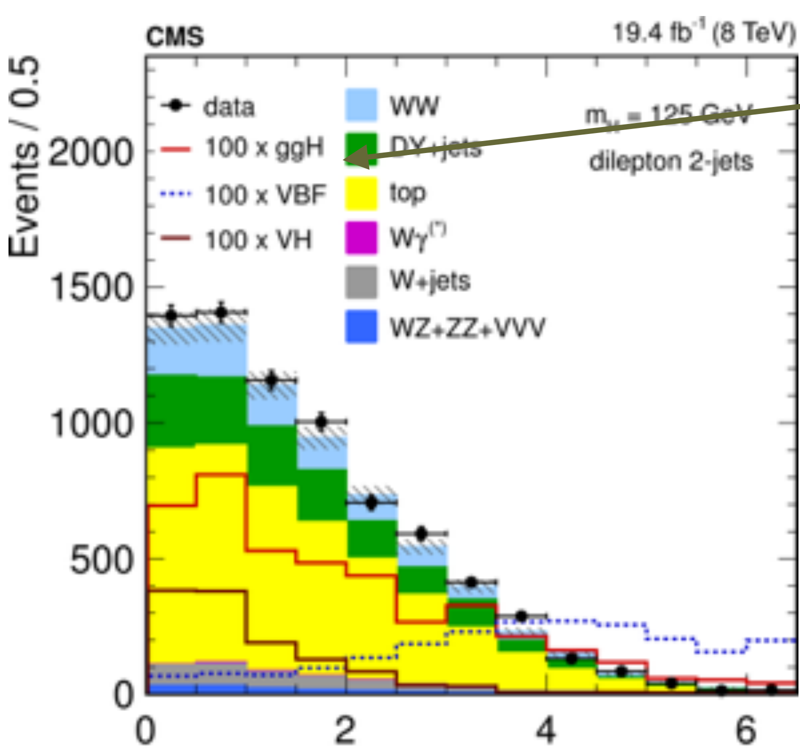

[JHEP 01 (2014) 096](#)

Example: ttH, H→multilepton

	Higgs boson decay mode			
Category	WW^*	$\tau\tau$	ZZ^*	Other
$2\ell 0\tau_{\text{had}}$	80%	15%	3%	2%
3ℓ	74%	15%	7%	4%
$2\ell 1\tau_{\text{had}}$	35%	62%	2%	1%
4ℓ	69%	14%	14%	4%
$1\ell 2\tau_{\text{had}}$	4%	93%	0%	3%

[Physics Letters B 749 (2015) 519-541](#)

From single channel, to combined results

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Full combination: **~600 signal regions & control regions**

Grand total of ~4200 nuisance parameters:

related to (systematic) uncertainties

Correlation scheme: strategy of nuisance parameters a delicate and complicated task (would deserve a separate talk)

From single channel, to combined results

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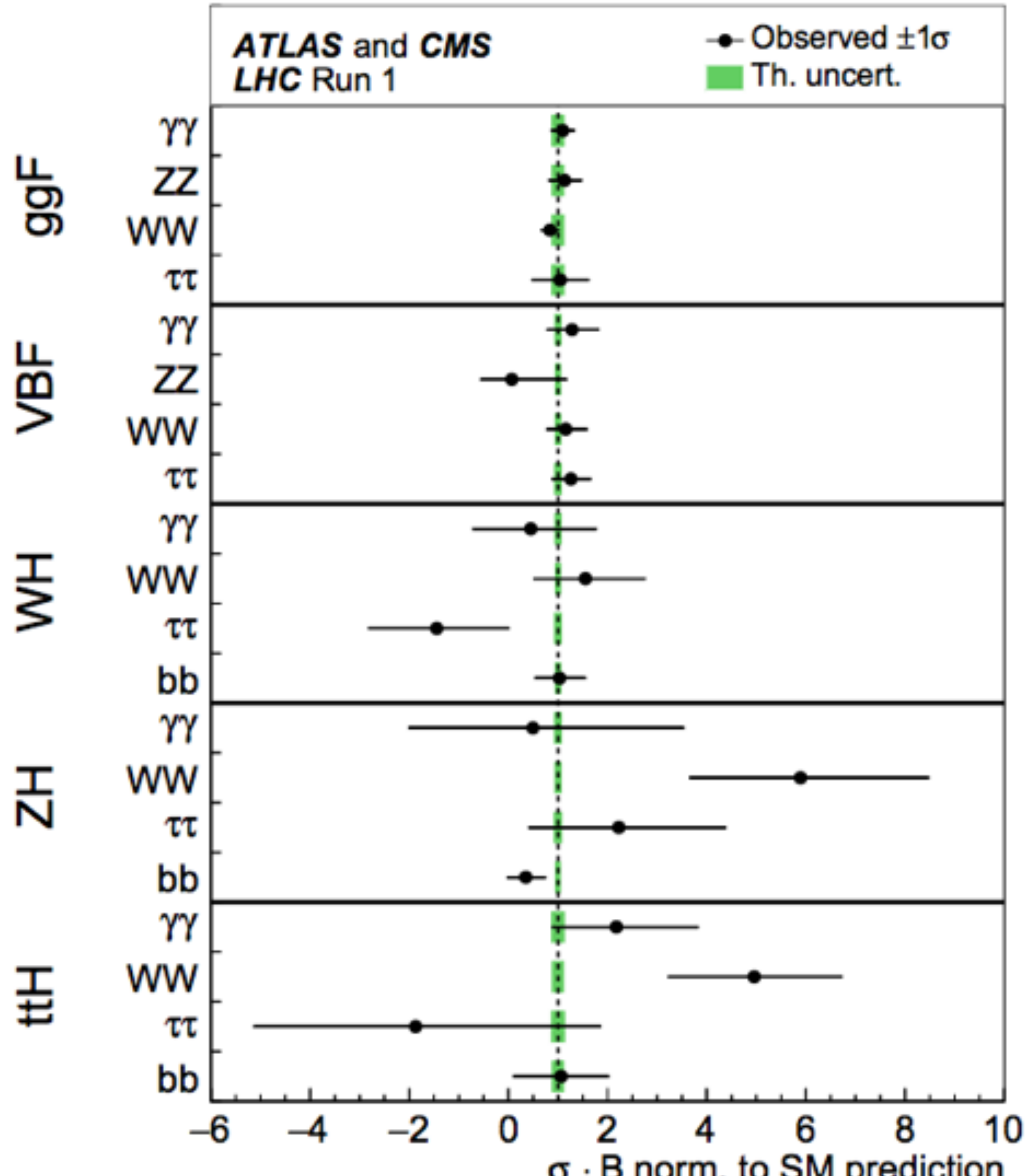
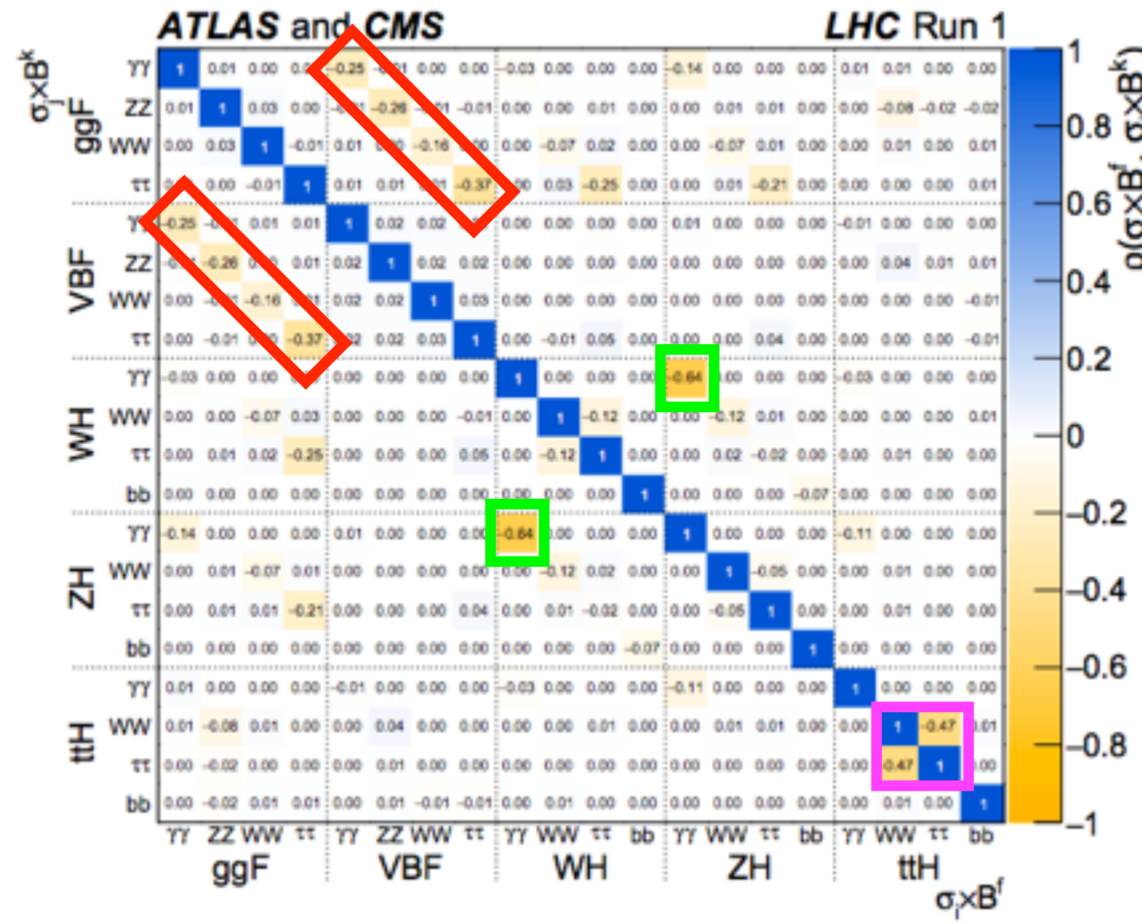
  - **What to measure?**
  - **To reduce as much as possible the assumptions on the SM nature of the Higgs boson, we can measure σ_i B^f. SM assumption only on A ε and σ_i(7TeV)/σ_i(8TeV)**

Cross Sections times Branching Ratios



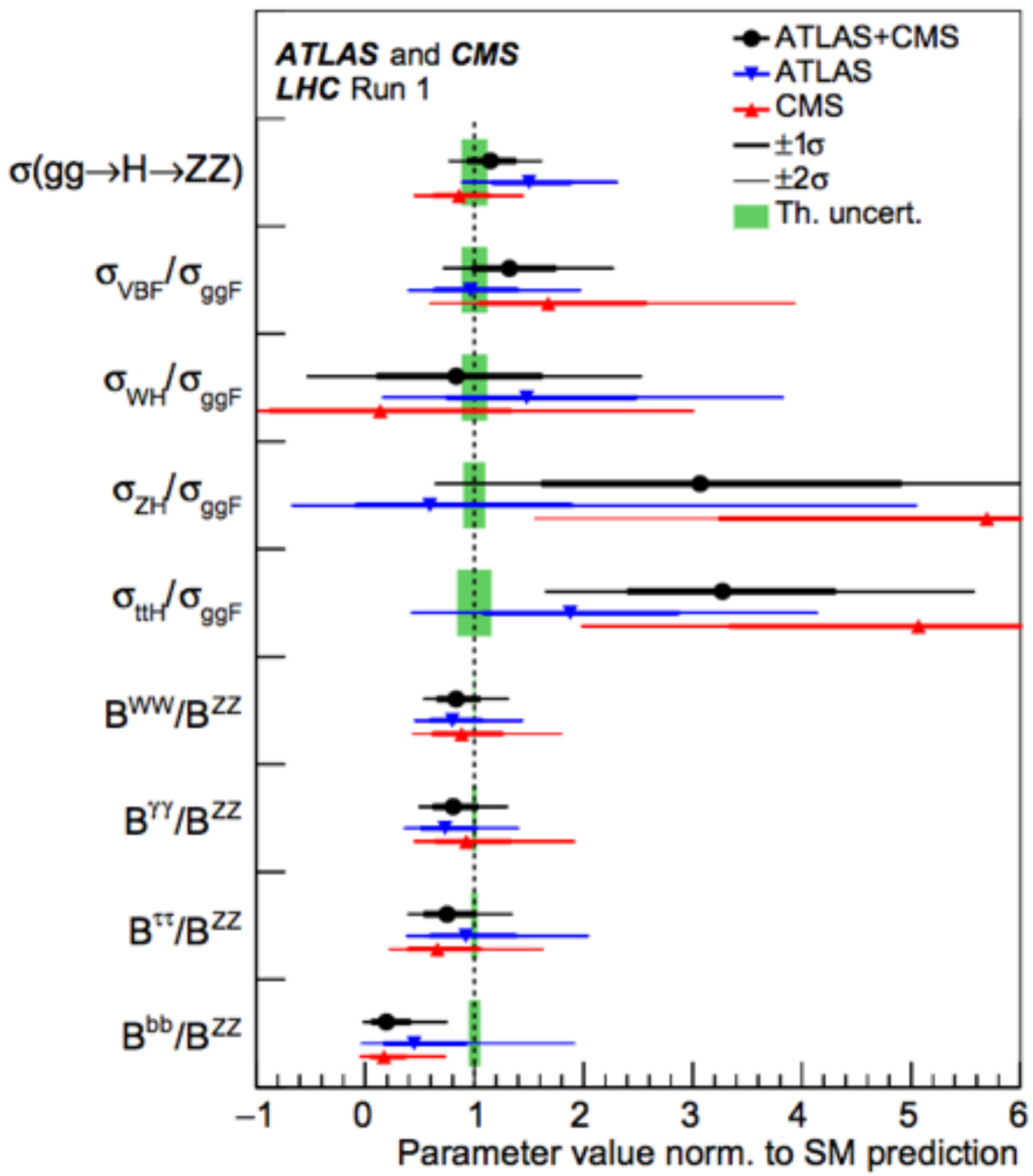


- As expected, correlations due to signal **mix** of **production modes** in the analysis categories:
  - ggF VS VBF (in 2-jet selections) or WH VS ZH (V→hadrons) in H→γγ;

and **decay modes**:

- ττ VS WW in ttH (in multileptons)

Ratios of production Cross Sections and BR



- Measuring ratios of production cross sections and BR

$$\sigma_i \cdot \mathrm{B}^f = \sigma(gg \to H \to ZZ) \cdot \left(\frac{\sigma_i}{\sigma_{ggF}}\right) \cdot \left(\frac{\mathrm{B}^f}{\mathrm{B}^{ZZ}}\right)$$

- No additional SM assumption on these measurements
- p-value(SM) = 16% (~1σ)

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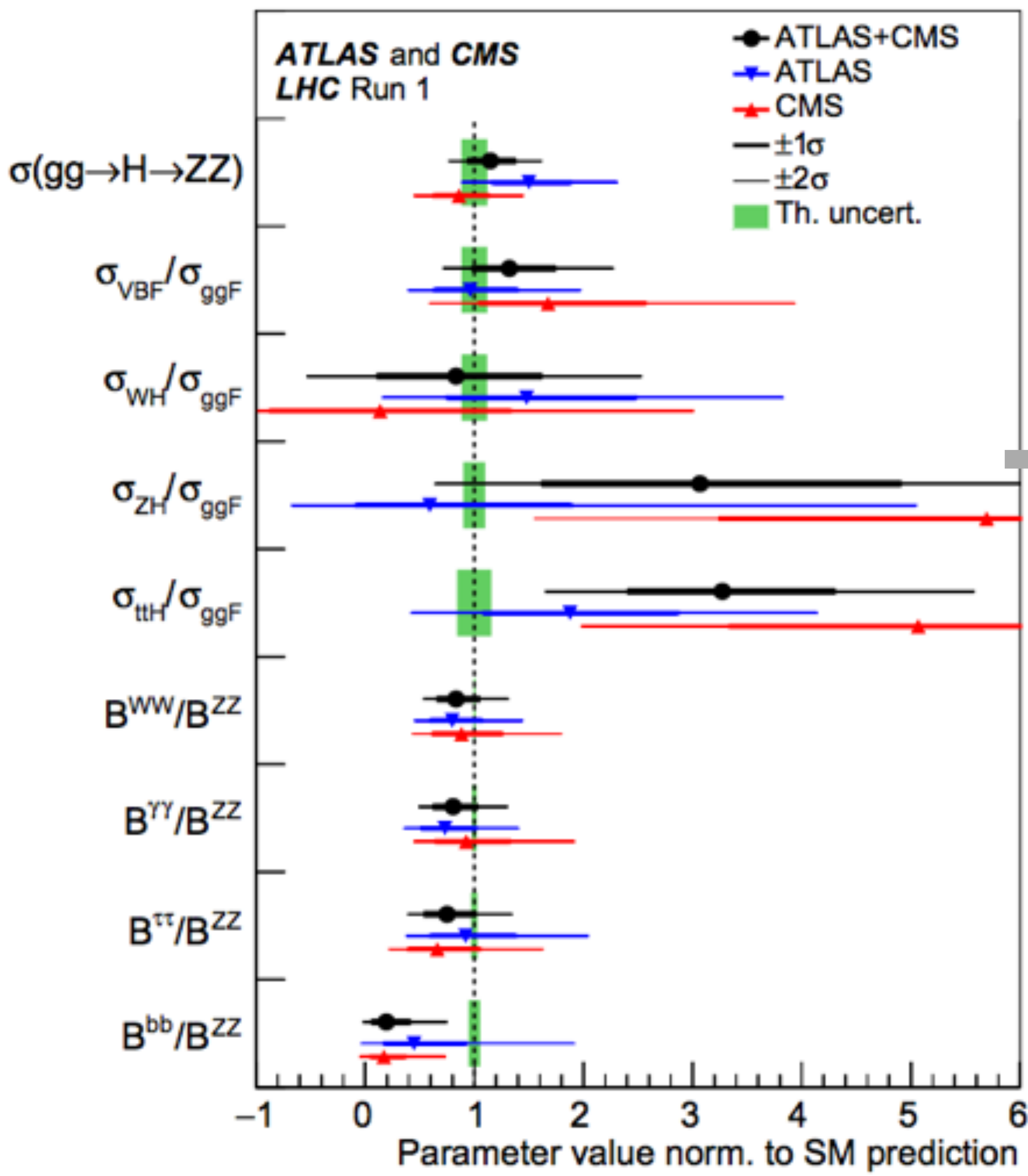

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- σ_{ZH}/σ_{ggF} ~3, mainly due to ZH, H → WW

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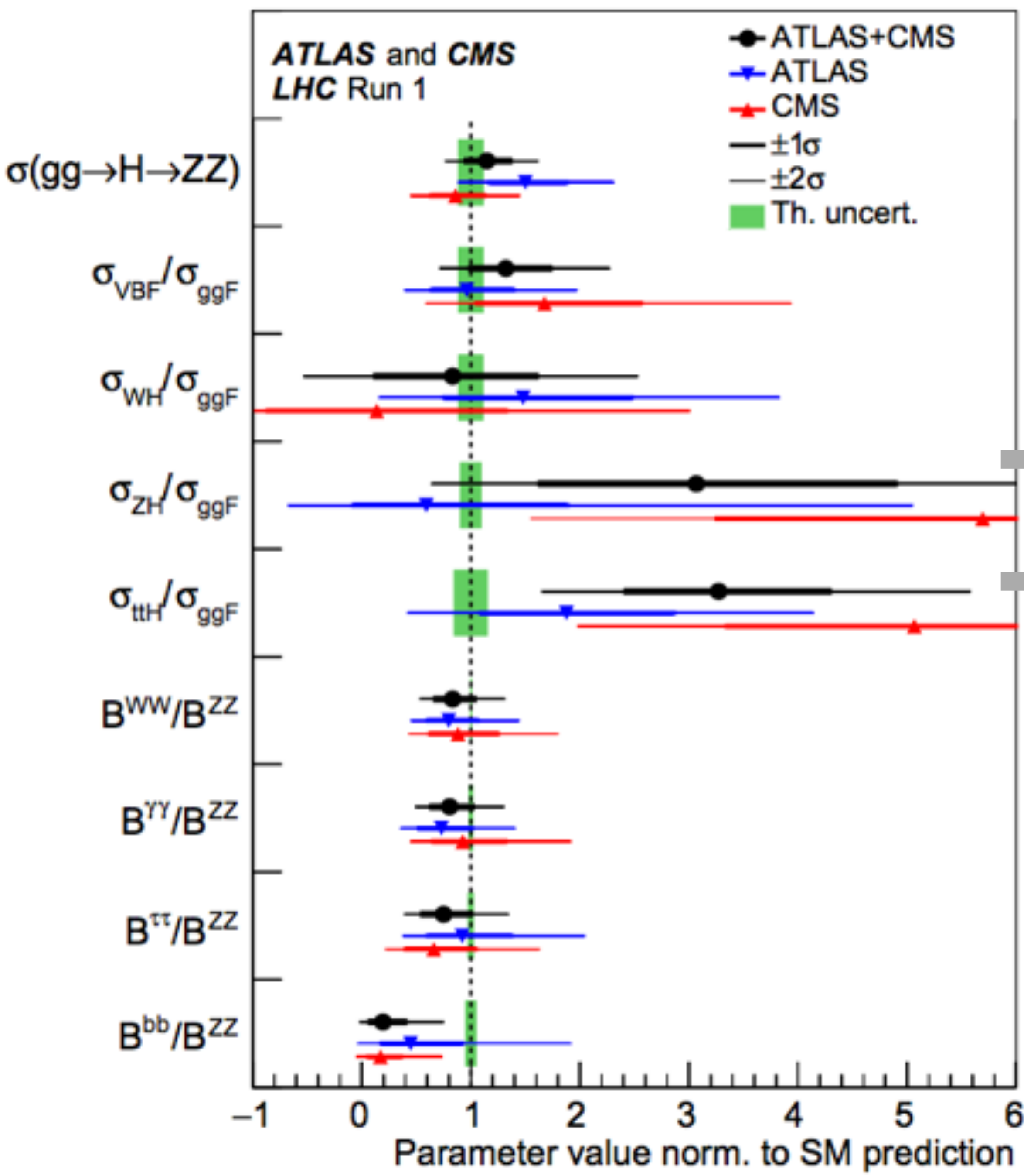

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- $\sigma_{ttH}/\sigma_{ggF}$ ~3σ excess with respect to SM due to ttH, H → multi lepton: WW/ττ/(ZZ)

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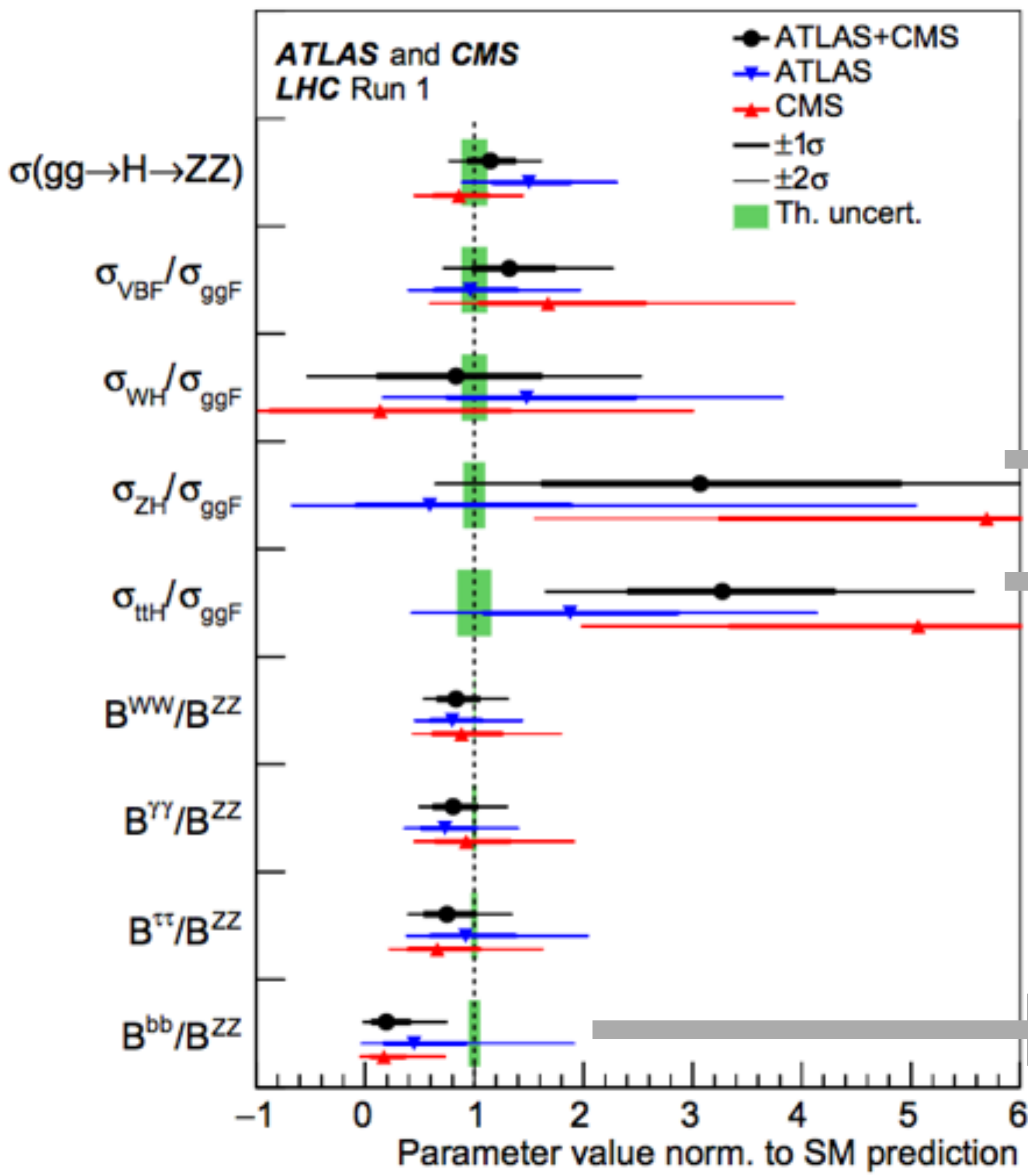

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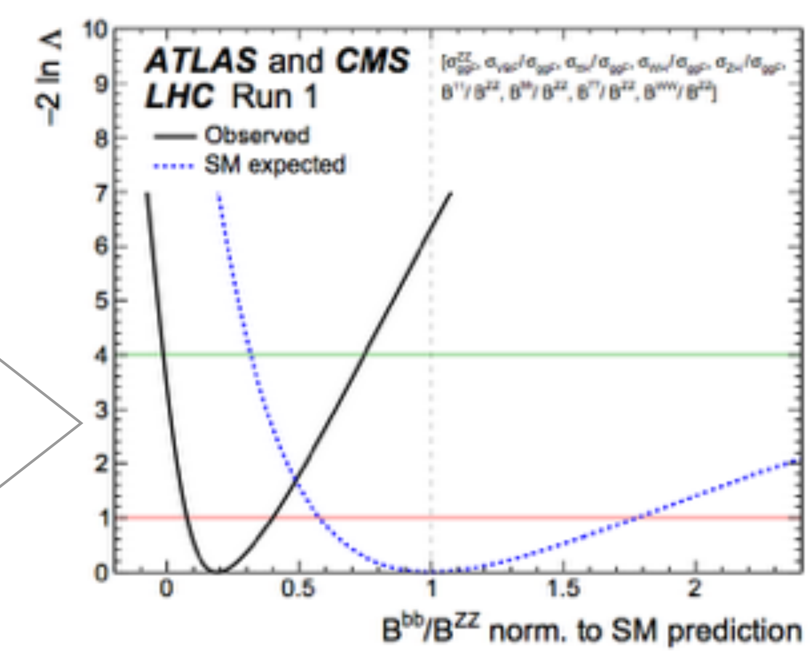
High ZH, H ➞ WW ,
High ttH, H ➞ multi lept
Low ZH, H ➞ bb
contribute to…

- B^{bb}/B^{ZZ} :
deficit ~ 2.5σ
with respect to SM



Signal strengths

- Measurements of signal strengths μ for each production mode and for each decay mode by fixing the relative B^f or the σ_i to the SM prediction.

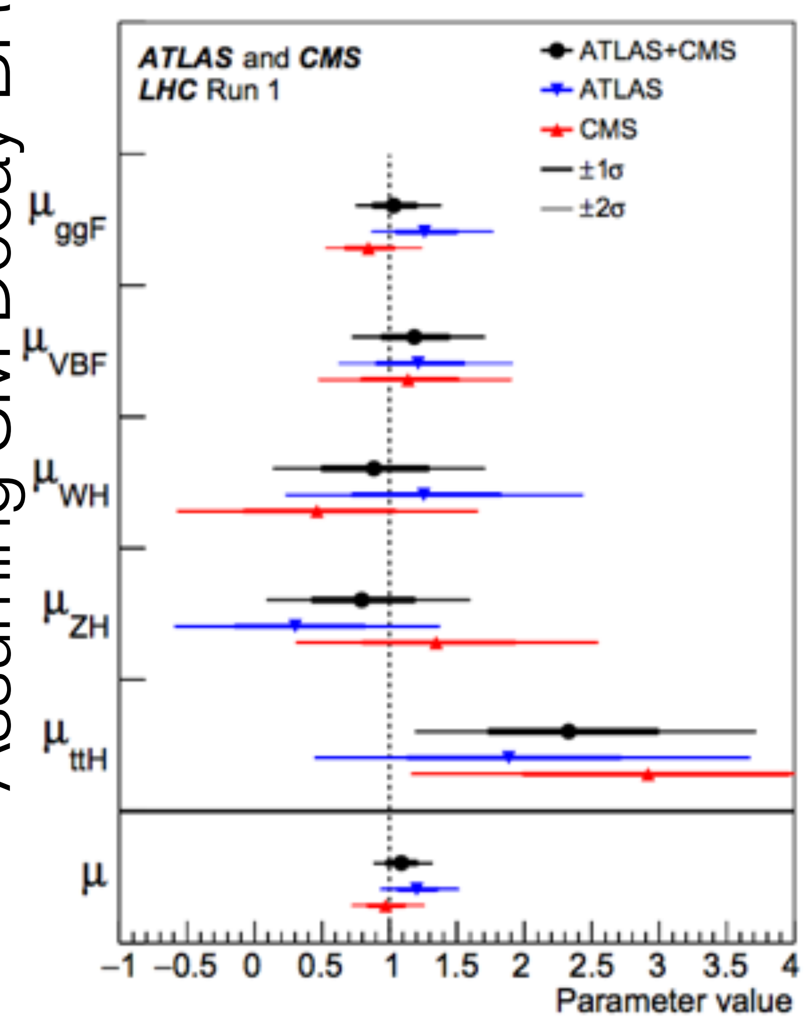
$$n_{\text{signal}}(k) = \mathcal{L}(k) \cdot \sum_i \sum_f \mu_i \mu^f \left\{ \sigma_i^{\text{SM}} \cdot A_i^{f,\text{SM}}(k) \cdot \varepsilon_i^f(k) \cdot \text{B}^f_{\text{SM}} \right\}$$

Production process	Measured significance (σ)	Expected significance (σ)
VBF	5.4	4.6
WH	2.4	2.7
ZH	2.3	2.9
VH	3.5	4.2
ttH	4.4	2.0
Decay channel		
$H \to \tau\tau$	5.5	5.0
$H \to bb$	2.6	3.7

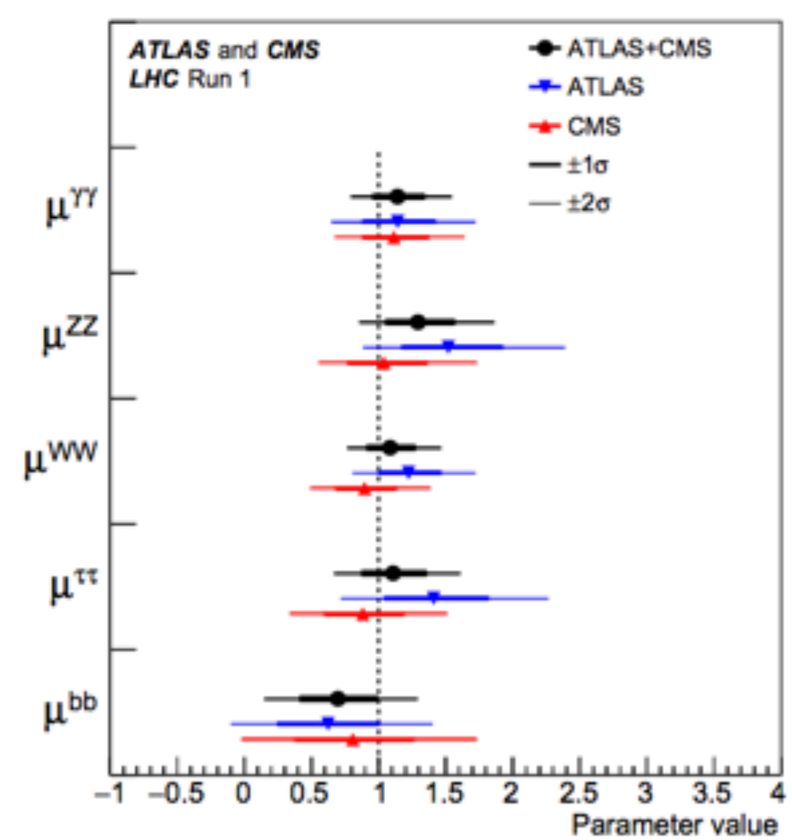
- By fixing all the B^f and σ_i to the SM prediction, and allowing for only one global signal strength, one gets:

$$\mu = 1.09^{+0.11}_{-0.10} = 1.09^{+0.07}_{-0.07}\,(\text{stat})\,^{+0.04}_{-0.04}\,(\text{expt})\,^{+0.03}_{-0.03}\,(\text{thbgd})^{+0.07}_{-0.06}\,(\text{thsig}),$$

Assuming SM Decay BR



Assuming SM Production XS



$$\sigma_i \cdot \mathrm{B}^f = \frac{\sigma_i(\vec{\kappa}) \cdot \Gamma^f(\vec{\kappa})}{\Gamma_H}$$

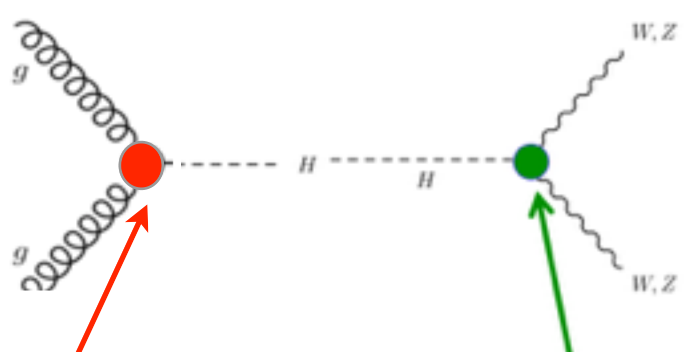
Coupling modifiers

$$\kappa_j^2 = \sigma_j / \sigma_j^{\mathrm{SM}} \quad \text{or} \quad \kappa_j^2 = \Gamma^j / \Gamma^j_{\mathrm{SM}}$$

- Information on Higgs couplings with the other particles using the κ framework
- σ^{SM}_j and Γ^j_{SM} are calculated using the status of art theoretical SM predictions
  - recovered with κ=1
- NLO QCD corrections essentially factorise with respect to κ rescaling, used where there is a non-trivial relationship between κ and σi , Γf

Example: ggF→H→WW (or ZZ)

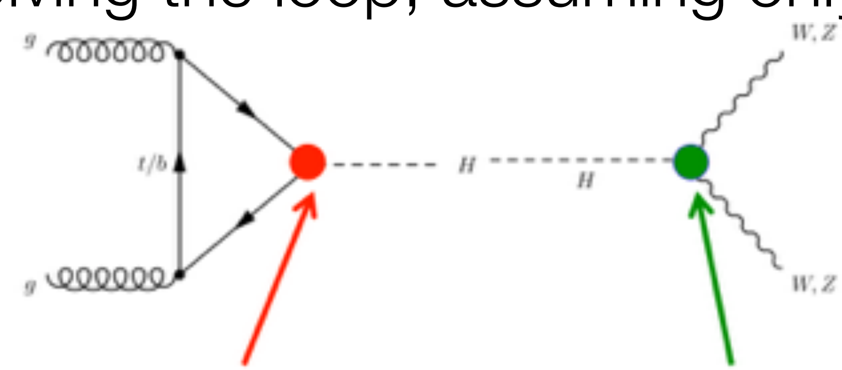
Effective κ



$\sigma_{ggF} = \kappa_g^2\ \sigma_{ggF}(SM)$ $\Gamma_{W,Z} = \kappa^2_{W,Z}\Gamma_{W,Z}(SM)$

or

Resolving the loop, assuming only SM



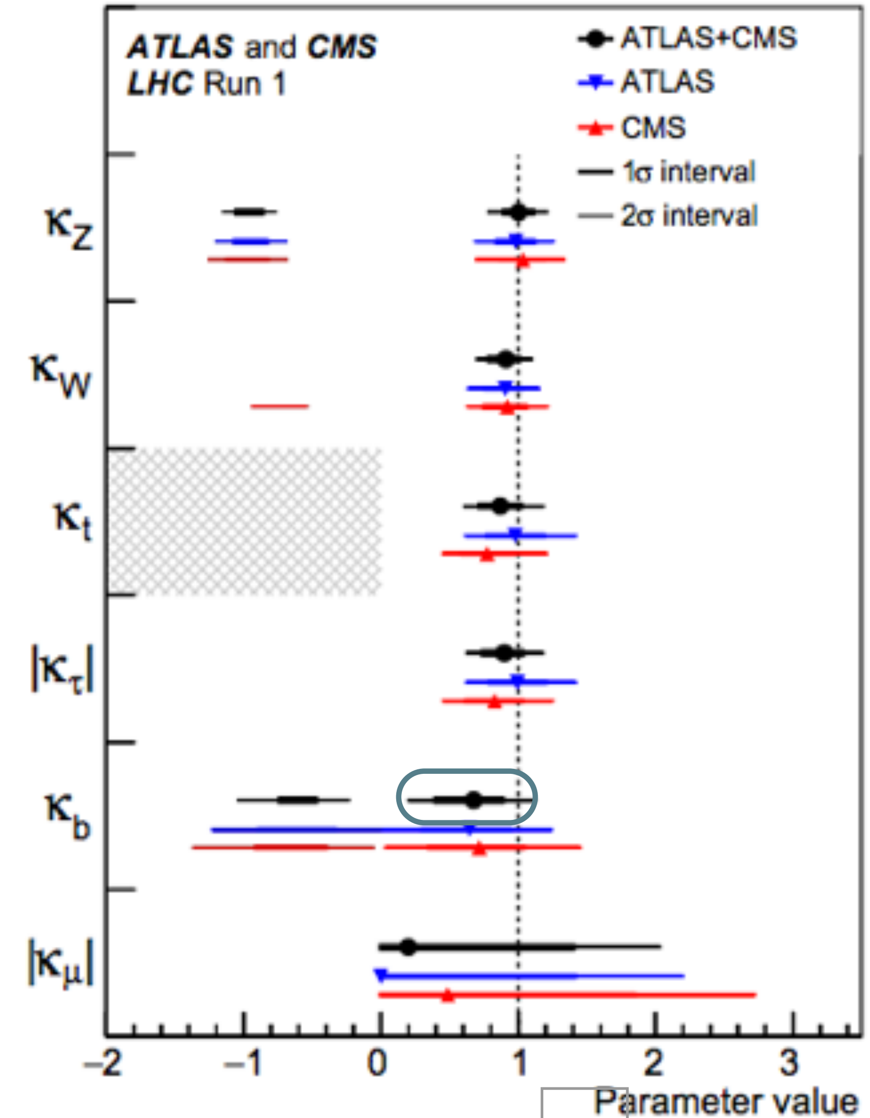
$\sigma_{ggF} = (1.06\ \kappa_t^2 + 0.01\kappa_b^2 - 0.07\kappa_b\kappa_t)\ \sigma_{ggF}(SM)$ $\Gamma_{W,Z} = \kappa^2_{W,Z}\Gamma_{W,Z}(SM)$

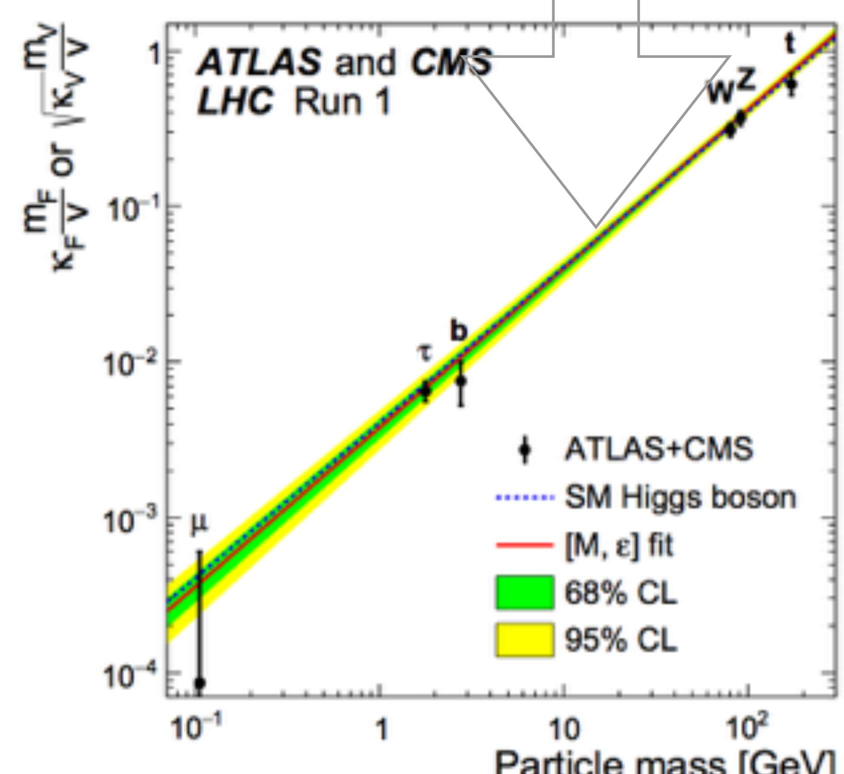
- and Γ_H?
  - Option 1: assume only SM decay modes $\Gamma_H = \sum_j \mathrm{B}^j_{\mathrm{SM}}\kappa_j^2 \cdot \Gamma_H^{\mathrm{SM}}$
  - Option2: allow for an additional branching fractions in BSM $\Gamma_H = \dfrac{\sum_j \mathrm{B}^j_{\mathrm{SM}}\kappa_j^2 \cdot \Gamma_H^{\mathrm{SM}}}{1 - \mathrm{B}_{\mathrm{BSM}}}$

Resolving the loops and assuming coupling with only SM particles

- **Interferences** help to resolve the sign (*NB:* κ_τ and κ_μ)
- *NB:* in this fit model, low measured value of **κb reduces total width Γ_H => all κ_i measured low**

Production	Loops	Interference	Resolved scaling factor
$\sigma(ggF)$	✓	t–b	$1.06 \cdot \kappa_t^2 + 0.01 \cdot \kappa_b^2 - 0.07 \cdot \kappa_t\kappa_b$
$\sigma(VBF)$	–	–	$0.74 \cdot \kappa_W^2 + 0.26 \cdot \kappa_Z^2$
$\sigma(WH)$	–	–	κ_W^2
$\sigma(qq/qg \to ZH)$	–	–	κ_Z^2
$\sigma(gg \to ZH)$	✓	t–Z	$2.27 \cdot \kappa_Z^2 + 0.37 \cdot \kappa_t^2 - 1.64 \cdot \kappa_Z\kappa_t$
$\sigma(ttH)$	–	–	κ_t^2
$\sigma(gb \to tHW)$	–	t–W	$1.84 \cdot \kappa_t^2 + 1.57 \cdot \kappa_W^2 - 2.41 \cdot \kappa_t\kappa_W$
$\sigma(qq/qb \to tHq)$	–	t–W	$3.40 \cdot \kappa_t^2 + 3.56 \cdot \kappa_W^2 - 5.96 \cdot \kappa_t\kappa_W$
$\sigma(bbH)$	–	–	κ_b^2
Partial decay width			
Γ^{ZZ}	–	–	κ_Z^2
Γ^{WW}	–	–	κ_W^2
$\Gamma^{\gamma\gamma}$	✓	t–W	$1.59 \cdot \kappa_W^2 + 0.07 \cdot \kappa_t^2 - 0.66 \cdot \kappa_W\kappa_t$
$\Gamma^{\tau\tau}$	–	–	κ_τ^2
Γ^{bb}	–	–	κ_b^2
$\Gamma^{\mu\mu}$	–	–	κ_μ^2
Total width ($B_{BSM} = 0$)			
Γ_H	✓	–	$0.57 \cdot \kappa_b^2 + 0.22 \cdot \kappa_W^2 + 0.09 \cdot \kappa_g^2 +$ $0.06 \cdot \kappa_\tau^2 + 0.03 \cdot \kappa_Z^2 + 0.03 \cdot \kappa_c^2 +$ $0.0023 \cdot \kappa_\gamma^2 + 0.0016 \cdot \kappa_{(Z\gamma)}^2 +$ $0.0001 \cdot \kappa_s^2 + 0.00022 \cdot \kappa_\mu^2$

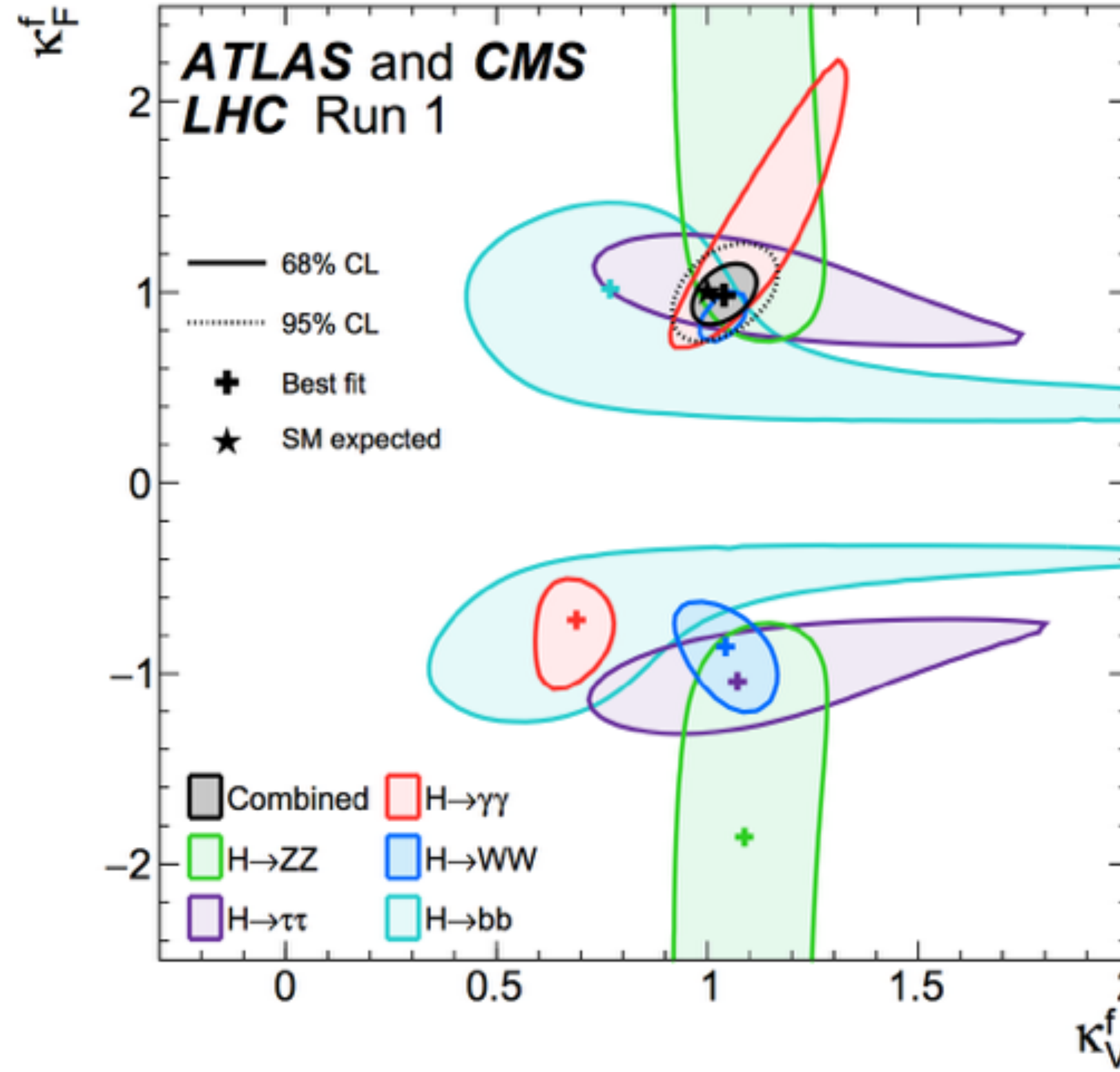




Fermions and bosons

- Testing the intrinsic difference between couplings to
  - W/Z: EW Symmetry Breaking $\kappa_Z = \kappa_W = \kappa_V$
  - fermions: Yukawa couplings $\kappa_t = \kappa_\tau = \kappa_b = \kappa_F$
- Sensitivity to the relative sign between κ_V and κ_F through interference terms
- Large asymmetry between the positive and negative coupling ratios for H→γγ

$\Gamma^{\gamma\gamma}$ t–W $1.59 \cdot \kappa_W^2 + 0.07 \cdot \kappa_t^2 - 0.66 \cdot \kappa_W \kappa_t$



- Fits on individual channels have slight preference for negative κ_F
- Combined result converges to positive κ_F

up/down-type fermion and lepton/quark asymmetries

Asymmetries in Higgs couplings

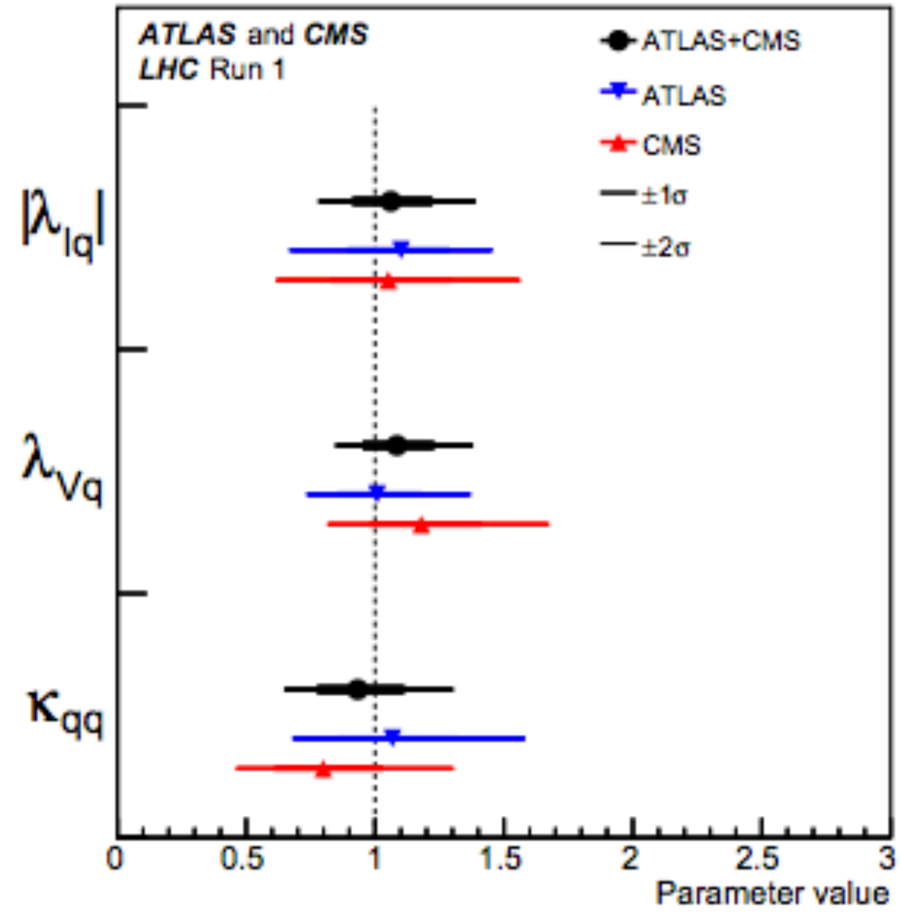
- between up-type and down-type fermion
- between lepton and quark

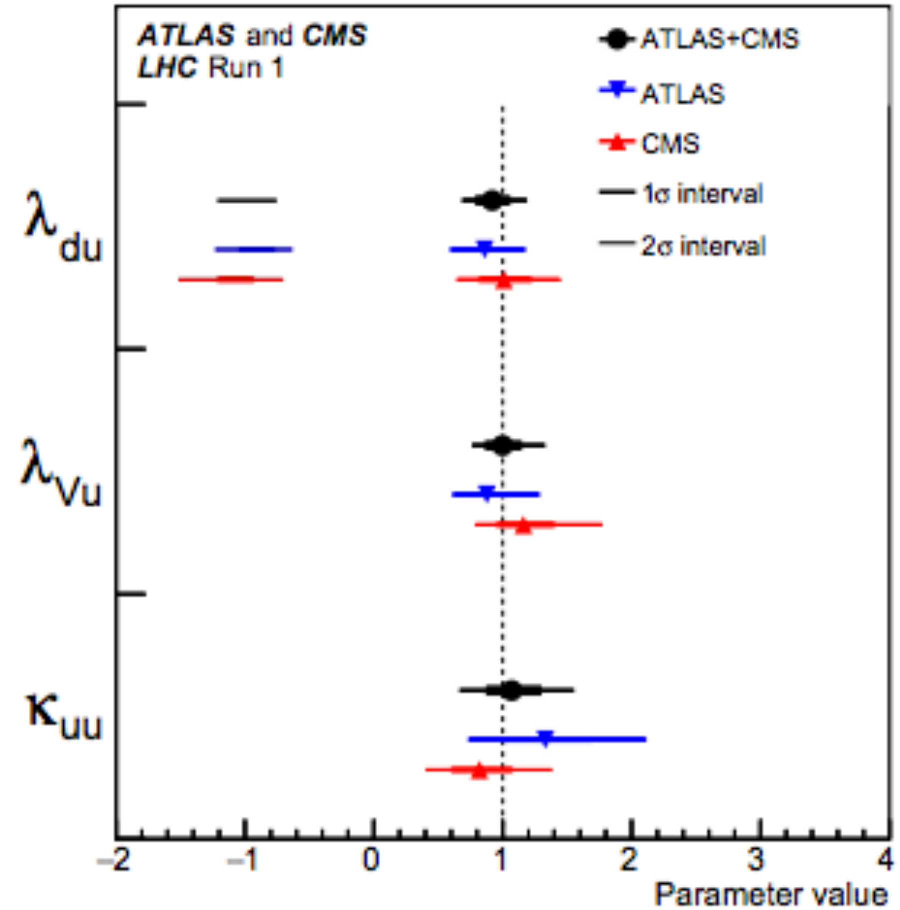
predicted by several BSM physics models (notably 2HDM)

Parameterise model in terms of ratios of coupling strength modifiers

$$\lambda_{du} = \kappa_d/\kappa_u$$
$$\lambda_{Vu} = \kappa_V/\kappa_u$$
$$\kappa_{uu} = \kappa_u \cdot \kappa_u/\kappa_H.$$

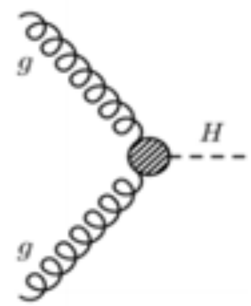
$$\lambda_{\ell q} = \kappa_\ell/\kappa_q$$
$$\lambda_{Vq} = \kappa_V/\kappa_q$$
$$\kappa_{qq} = \kappa_q \cdot \kappa_q/\kappa_H$$





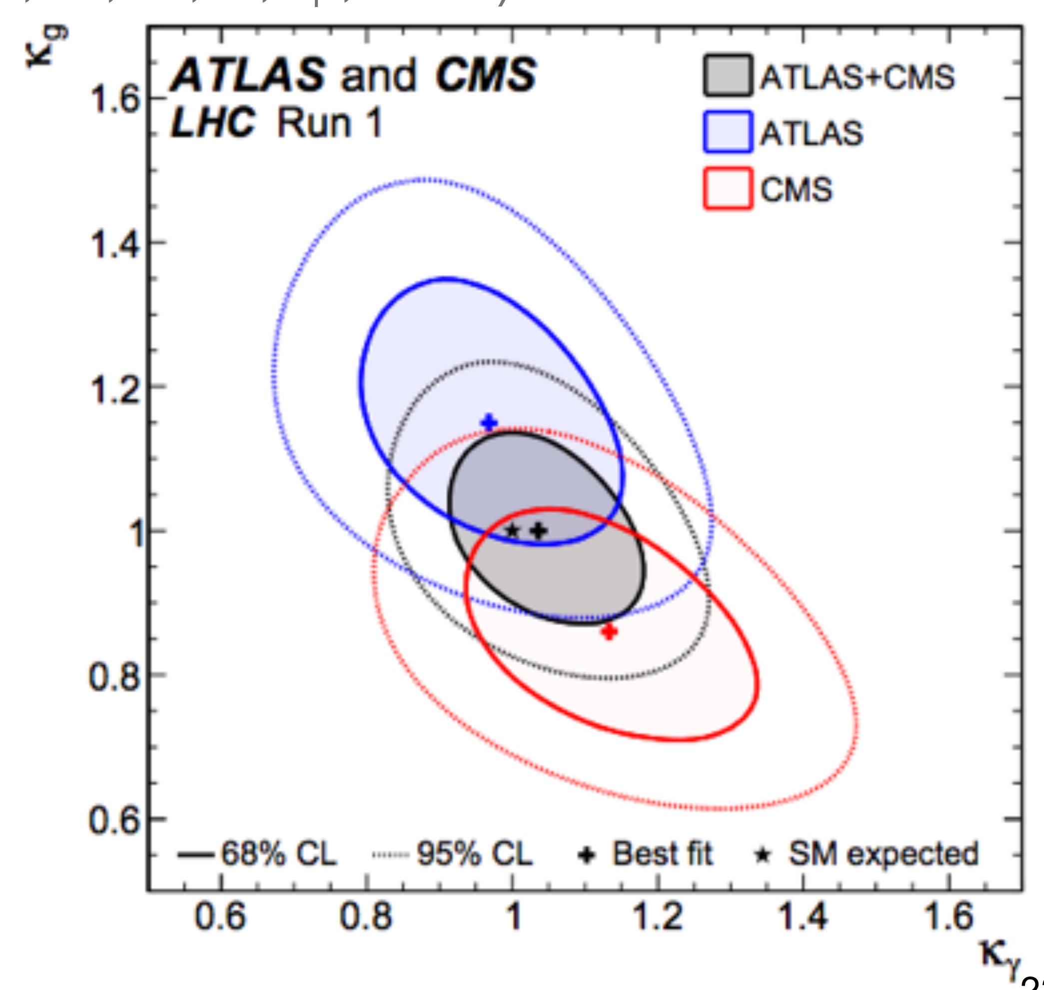
Effective couplings and BSM BR

- What if we have new particles in the loops?
- Specific fit not resolving the loops, but use effective couplings κ_g and κ_γ



Production	Loops	Interference	Effective scaling factor
$\sigma(ggF)$	✓	t–b	κ_g^2
Partial decay width			
$\Gamma^{\gamma\gamma}$	✓	t–W	κ_γ^2

- Fix all tree-level Higgs couplings to SM (κ_W,κ_Z,κ_b,κ_t,κ_μ,κ_τ=1) and B_{BSM}=0



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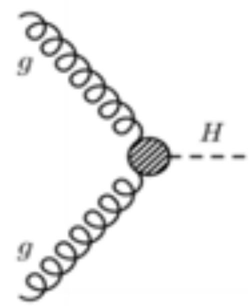

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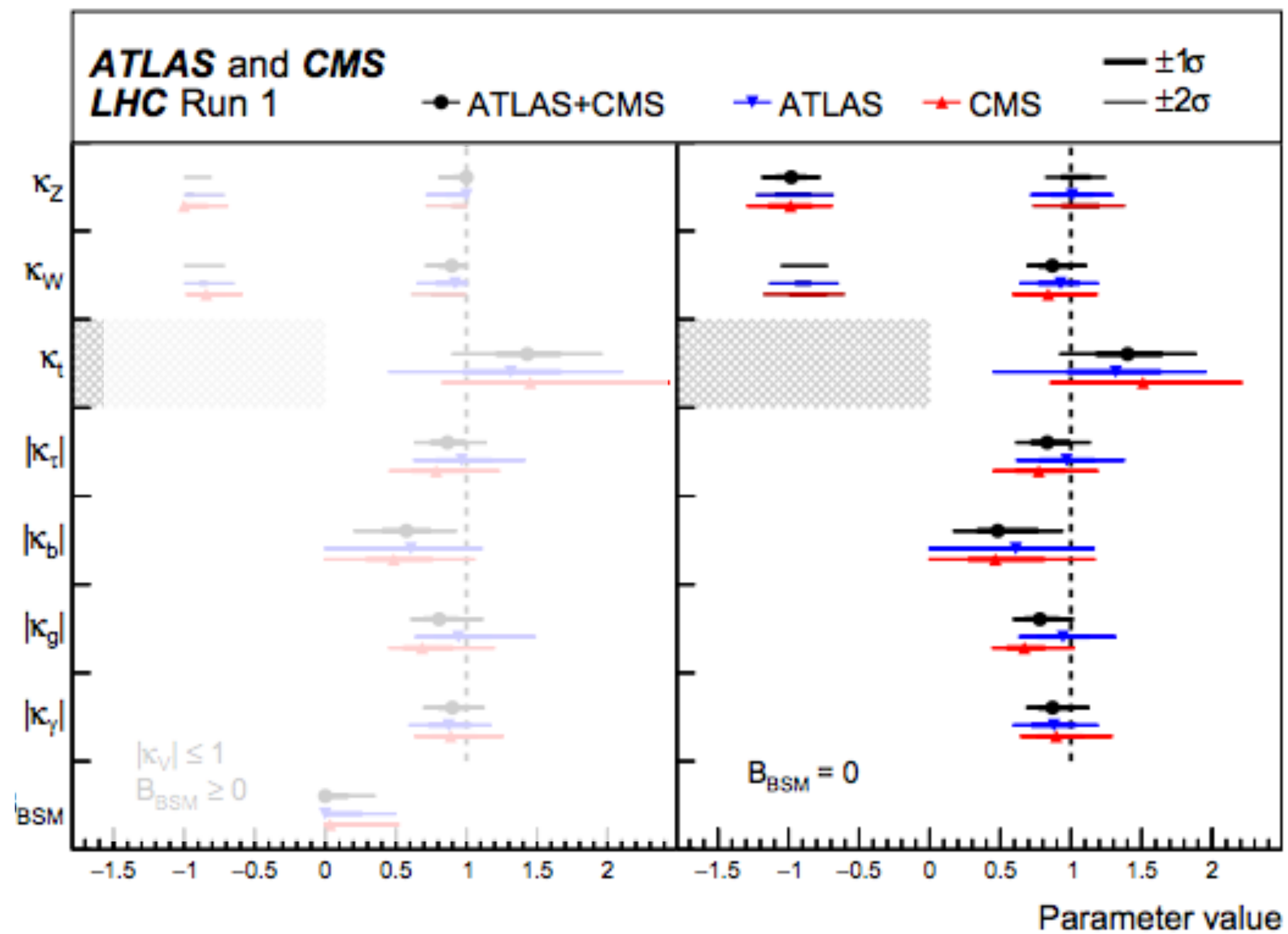
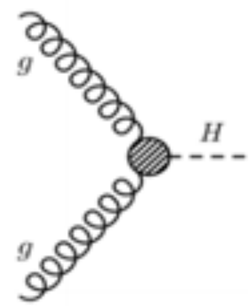


Effective couplings and BSM BR

- What if we have new particles in the loops?
- Specific fit not resolving the loops, but use effective couplings κg and κγ
- And if the Higgs boson decays in some other mode we did not detect yet?
  - Constrain $B_{BSM} \geq 0$ and $|\kappa_V| \leq 1$



Production	Loops	Interference	Effective scaling factor
$\sigma(ggF)$	✓	t–b	κ_g^2
Partial decay width			
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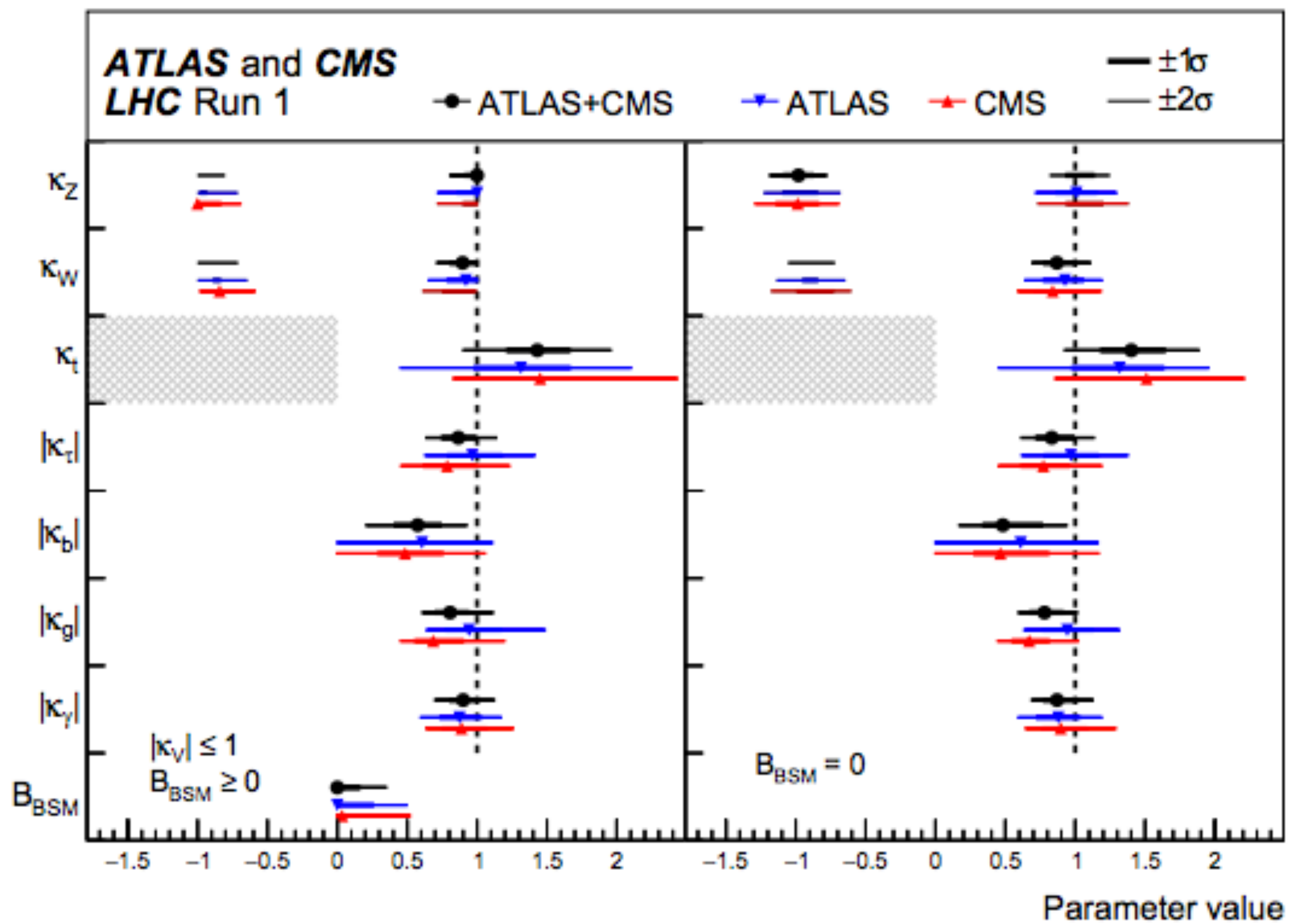
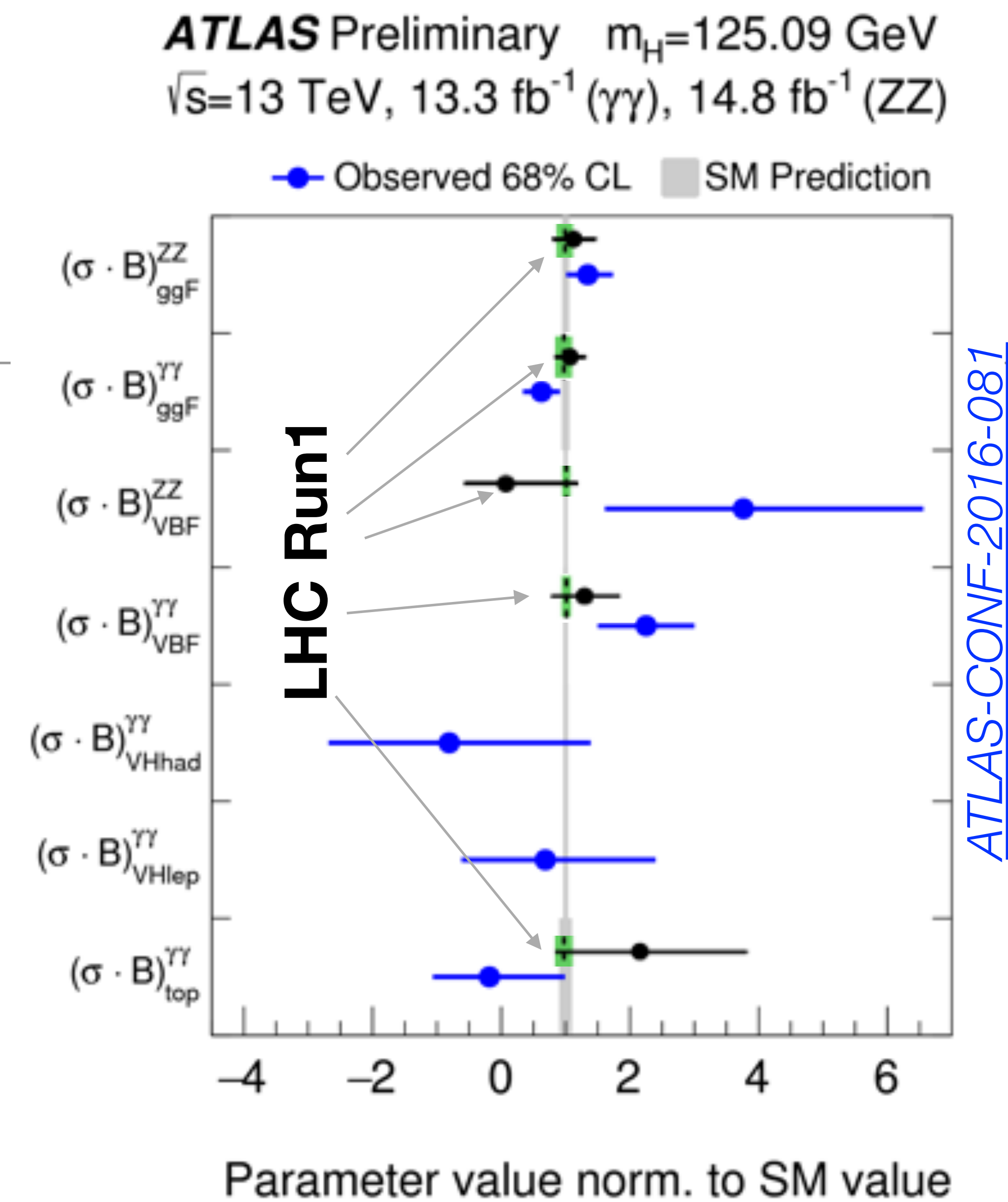


Conclusions

- ATLAS and CMS Higgs boson mass and coupling results have been combined
- Higgs to ττ and VBF production established at more than 5σ level
- The most precise results on Higgs production and decay and constraints on its couplings have been obtained at O(10%) precision
- All results are consistent with the SM predictions within uncertainties: SM p-value of all combined fits in range 10%-88%



- **SM still resists!**
- **Precision will be improved during the coming years…**
- **…but we have giants with solid shoulders to stay on, while seeing further with the coming data.**

Backup

SM Predictions

Production process	Cross section [pb] $\sqrt{s} = 7$ TeV	Cross section [pb] $\sqrt{s} = 8$ TeV	Order of calculation
ggF	15.0 ± 1.6	19.2 ± 2.0	NNLO(QCD) + NLO(EW)
VBF	1.22 ± 0.03	1.58 ± 0.04	NLO(QCD+EW) + APPROX. NNLO(QCD)
WH	0.577 ± 0.016	0.703 ± 0.018	NNLO(QCD) + NLO(EW)
ZH	0.334 ± 0.013	0.414 ± 0.016	NNLO(QCD) + NLO(EW)
$[ggZH]$	0.023 ± 0.007	0.032 ± 0.010	NLO(QCD)
ttH	0.086 ± 0.009	0.129 ± 0.014	NLO(QCD)
tH	0.012 ± 0.001	0.018 ± 0.001	NLO(QCD)
bbH	0.156 ± 0.021	0.203 ± 0.028	5FS NNLO(QCD) + 4FS NLO(QCD)
Total	17.4 ± 1.6	22.3 ± 2.0	

Decay mode	Branching fraction [%]
$H \to bb$	57.5 ± 1.9
$H \to WW$	21.6 ± 0.9
$H \to gg$	8.56 ± 0.86
$H \to \tau\tau$	6.30 ± 0.36
$H \to cc$	2.90 ± 0.35
$H \to ZZ$	2.67 ± 0.11
$H \to \gamma\gamma$	0.228 ± 0.011
$H \to Z\gamma$	0.155 ± 0.014
$H \to \mu\mu$	0.022 ± 0.001

1 or more Higgs Bosons?

- What if we have more particles?
- if they couple in different way, ranking of matrix here is bigger than 1.
- Testing it with test statistics

$$q_\lambda = -2\ln \frac{L(\text{data}|\lambda_i^j = \hat{\lambda}_i, \hat{\mu}_{ggF}^j)}{L(\text{data}|\hat{\lambda}_i^j, \hat{\mu}'^j_{ggF})},$$

p-value 1 boson: (29±2)%,

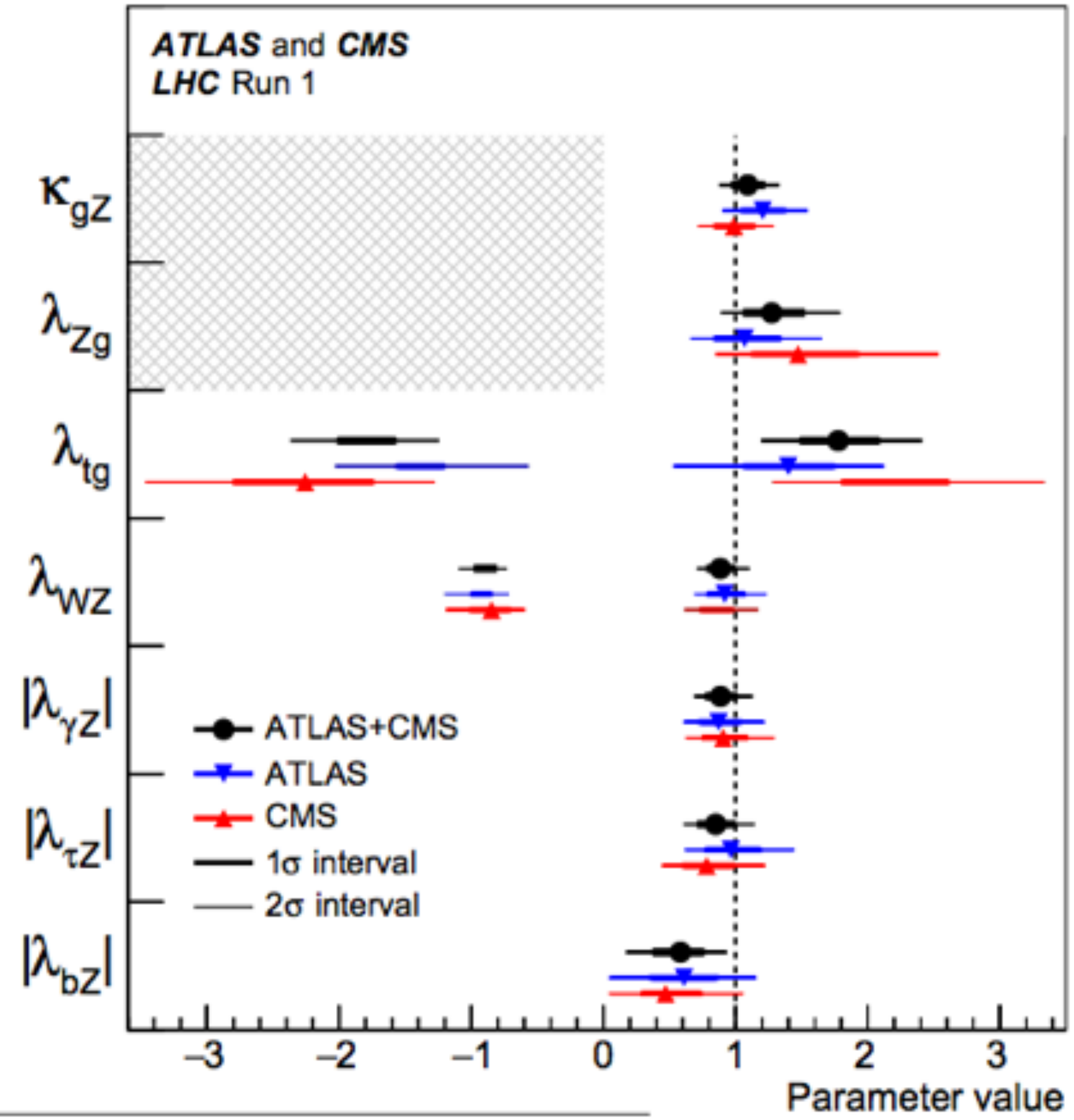
General matrix parameterisation: rank($\mathcal{M}$) = 5

	$H\to\gamma\gamma$	$H\to ZZ$	$H\to WW$	$H\to\tau\tau$	$H\to bb$
ggF	$\mu_{ggF}^{\gamma\gamma}$	μ_{ggF}^{ZZ}	μ_{ggF}^{WW}	$\mu_{ggF}^{\tau\tau}$	μ_{ggF}^{bb}
VBF	$\lambda_{VBF}^{\gamma\gamma}\mu_{ggF}^{\gamma\gamma}$	$\lambda_{VBF}^{ZZ}\mu_{ggF}^{ZZ}$	$\lambda_{VBF}^{WW}\mu_{ggF}^{WW}$	$\lambda_{VBF}^{\tau\tau}\mu_{ggF}^{\tau\tau}$	$\lambda_{VBF}^{bb}\mu_{ggF}^{bb}$
WH	$\lambda_{WH}^{\gamma\gamma}\mu_{ggF}^{\gamma\gamma}$	$\lambda_{WH}^{ZZ}\mu_{ggF}^{ZZ}$	$\lambda_{WH}^{WW}\mu_{ggF}^{WW}$	$\lambda_{WH}^{\tau\tau}\mu_{ggF}^{\tau\tau}$	$\lambda_{WH}^{bb}\mu_{ggF}^{bb}$
ZH	$\lambda_{ZH}^{\gamma\gamma}\mu_{ggF}^{\gamma\gamma}$	$\lambda_{ZH}^{ZZ}\mu_{ggF}^{ZZ}$	$\lambda_{ZH}^{WW}\mu_{ggF}^{WW}$	$\lambda_{ZH}^{\tau\tau}\mu_{ggF}^{\tau\tau}$	$\lambda_{ZH}^{bb}\mu_{ggF}^{bb}$
ttH	$\lambda_{ttH}^{\gamma\gamma}\mu_{ggF}^{\gamma\gamma}$	$\lambda_{ttH}^{ZZ}\mu_{ggF}^{ZZ}$	$\lambda_{ttH}^{WW}\mu_{ggF}^{WW}$	$\lambda_{ttH}^{\tau\tau}\mu_{ggF}^{\tau\tau}$	$\lambda_{ttH}^{bb}\mu_{ggF}^{bb}$

Single-state matrix parameterisation: rank($\mathcal{M}$) = 1

	$H\to\gamma\gamma$	$H\to ZZ$	$H\to WW$	$H\to\tau\tau$	$H\to bb$
ggF	$\mu_{ggF}^{\gamma\gamma}$	μ_{ggF}^{ZZ}	μ_{ggF}^{WW}	$\mu_{ggF}^{\tau\tau}$	μ_{ggF}^{bb}
VBF	$\lambda_{VBF}\mu_{ggF}^{\gamma\gamma}$	$\lambda_{VBF}\mu_{ggF}^{ZZ}$	$\lambda_{VBF}\mu_{ggF}^{WW}$	$\lambda_{VBF}\mu_{ggF}^{\tau\tau}$	$\lambda_{VBF}\mu_{ggF}^{bb}$
WH	$\lambda_{WH}\mu_{ggF}^{\gamma\gamma}$	$\lambda_{WH}\mu_{ggF}^{ZZ}$	$\lambda_{WH}\mu_{ggF}^{WW}$	$\lambda_{WH}\mu_{ggF}^{\tau\tau}$	$\lambda_{WH}\mu_{ggF}^{bb}$
ZH	$\lambda_{ZH}\mu_{ggF}^{\gamma\gamma}$	$\lambda_{ZH}\mu_{ggF}^{ZZ}$	$\lambda_{ZH}\mu_{ggF}^{WW}$	$\lambda_{ZH}\mu_{ggF}^{\tau\tau}$	$\lambda_{ZH}\mu_{ggF}^{bb}$
ttH	$\lambda_{ttH}\mu_{ggF}^{\gamma\gamma}$	$\lambda_{ttH}\mu_{ggF}^{ZZ}$	$\lambda_{ttH}\mu_{ggF}^{WW}$	$\lambda_{ttH}\mu_{ggF}^{\tau\tau}$	$\lambda_{ttH}\mu_{ggF}^{bb}$

Most generic parametrisation



σ and B ratio parameterisation	Coupling modifier ratio parameterisation
$\sigma(gg \to H \to ZZ)$	$\kappa_{gZ} = \kappa_g \cdot \kappa_Z / \kappa_H$
$\sigma_{\mathrm{VBF}}/\sigma_{gg\mathrm{F}}$	
$\sigma_{WH}/\sigma_{gg\mathrm{F}}$	
$\sigma_{ZH}/\sigma_{gg\mathrm{F}}$	$\lambda_{Zg} = \kappa_Z / \kappa_g$
$\sigma_{ttH}/\sigma_{gg\mathrm{F}}$	$\lambda_{tg} = \kappa_t / \kappa_g$
$\mathrm{B}^{WW}/\mathrm{B}^{ZZ}$	$\lambda_{WZ} = \kappa_W / \kappa_Z$
$\mathrm{B}^{\gamma\gamma}/\mathrm{B}^{ZZ}$	$\lambda_{\gamma Z} = \kappa_\gamma / \kappa_Z$
$\mathrm{B}^{\tau\tau}/\mathrm{B}^{ZZ}$	$\lambda_{\tau Z} = \kappa_\tau / \kappa_Z$
$\mathrm{B}^{bb}/\mathrm{B}^{ZZ}$	$\lambda_{bZ} = \kappa_b / \kappa_Z$

Fitting the couplings

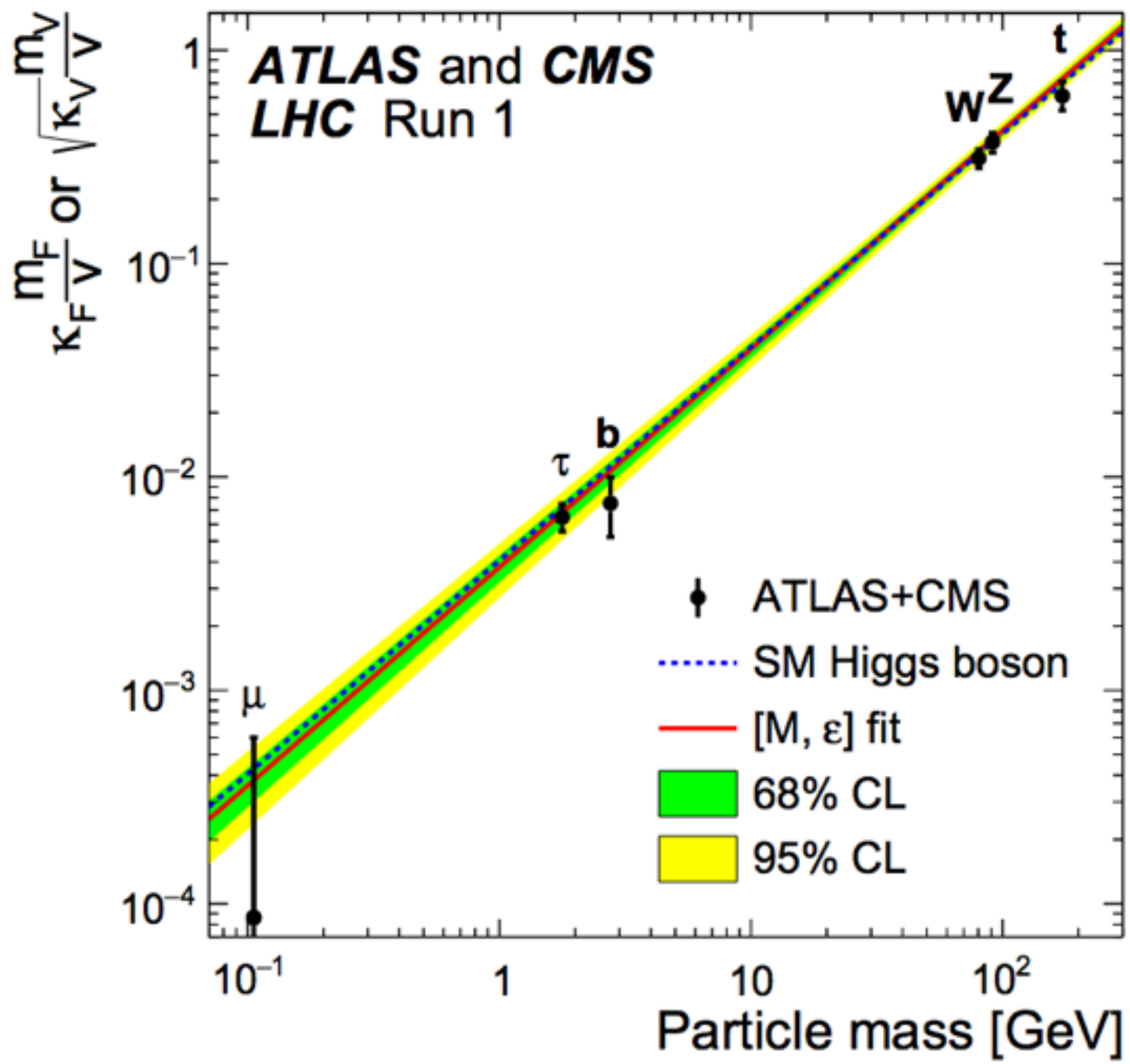
- following 1303.3879

$$\kappa_{F,i} = v \cdot m_{F,i}^{\epsilon}/M^{1+\epsilon}$$

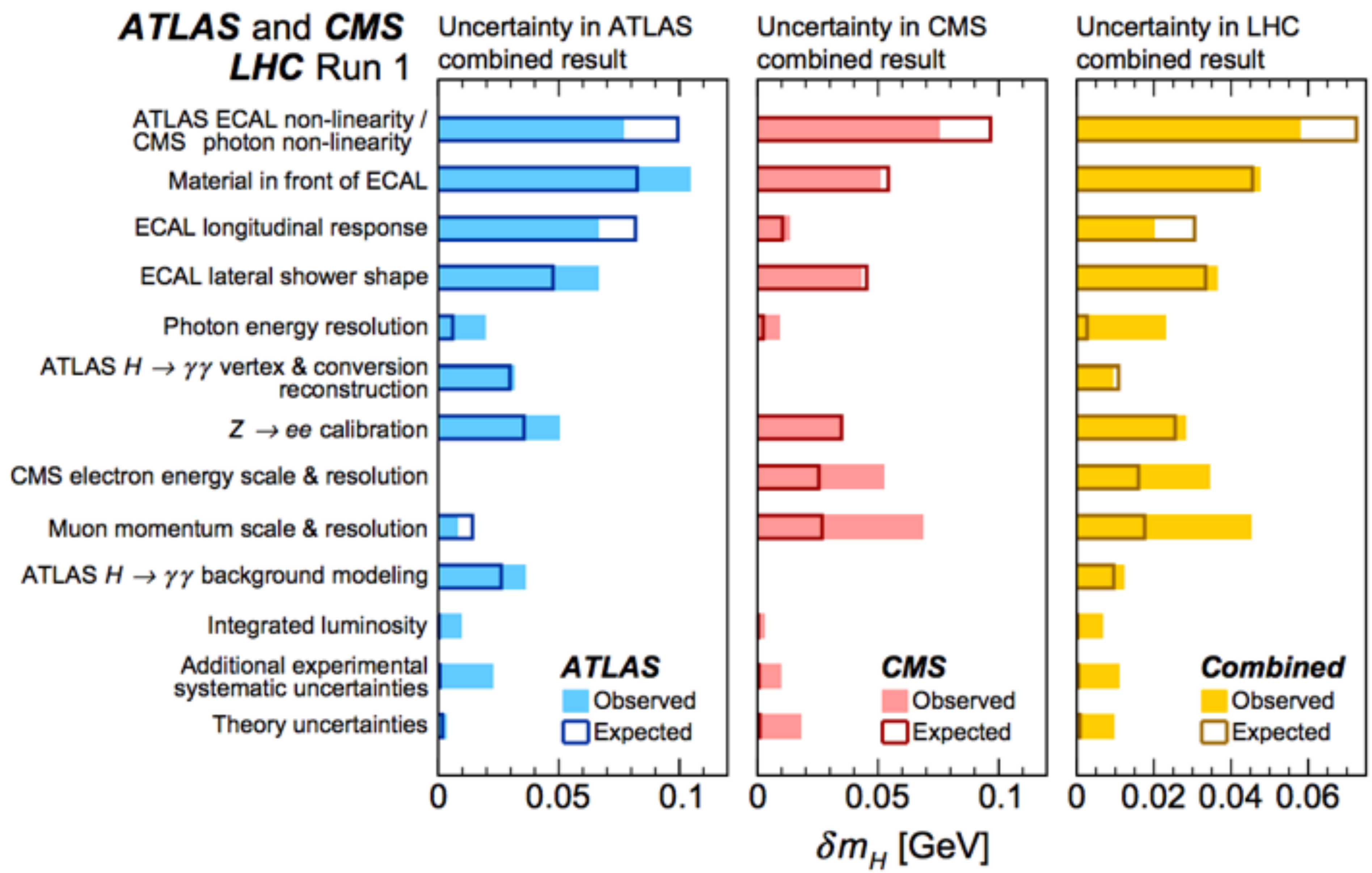
$$\kappa_{V,i} = v \cdot m_{V,i}^{2\epsilon}/M^{1+2\epsilon}$$

$$\epsilon = 0.023^{+0.029}_{-0.027}$$

$$\bar{M} = 233^{+13}_{-12}\ \text{GeV}$$



Systematics in the mass determination



Systematic Correlation

- Correlation strategy of nuisance parameters a delicate and complicated task
  - Detector systematic uncertainties à follow strategy of ATLAS and CMS internal combinations (generally correlated within, not between experiments)
  - Signal theory uncertainties (QCD scales, PDF, UEPS) on inclusive cross-sections generally correlated between experiments.
  - Signal theory uncertainties on acceptance and selection efficiency are uncorrelated between experiments, as these are small and estimation procedures are generally different.
  - PDF uncertainties on signal cross-sections uncorrelated between channels, except WH/ZH = correlated (effect of ignoring other correlations is ≤1%)
  - No correlations assumed between Higgs BRs (except for WW/ZZ).
- Effect of ignoring correlations shown to be generally small, except for a few specific measurements, in which case full correlation structure is retained