Measurements of higgs couplings at CMS

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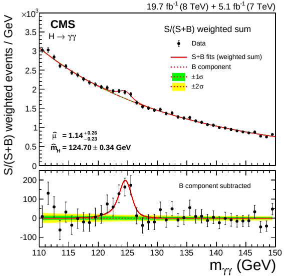
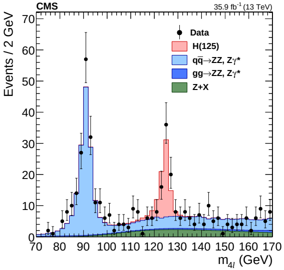
May 7, 2018

Introduction

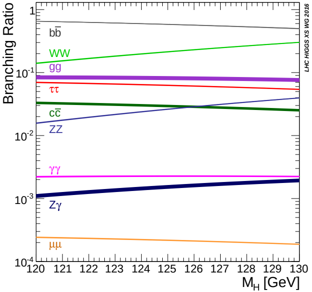
- Higgs boson discovered in 2012 by both CMS and ATLAS
- Properties already measured with Run 1 dataset:
  - $\rightarrow$ 5 fb^{-1} at $\sqrt{S} = 7$TeV + 20 fb^{-1} at $\sqrt{S} = 8$TeV
  - $\rightarrow$ coupling uncertainty order $\sim$ 20 %
    $\rightarrow$ statistically limited
  - $\rightarrow$ agreement with SM predictions
- Improved precision with 2016 Run 2 dataset: 35.9 fb^{-1} at $\sqrt{S} = 13$ TeV
  - $\rightarrow$ larger dataset
  - $\rightarrow$ more precise theory predictions
    $\rightarrow$ lower systematic uncertainty
- Possible to spot BSM physics in coupling precision measurements

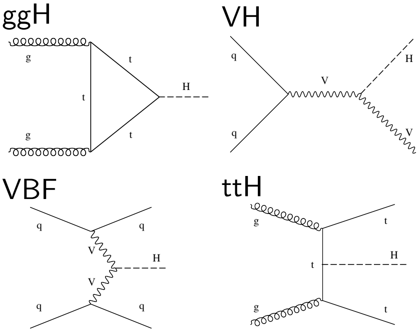




SM Higgs boson @ LHC

- Production processes @ 13 TeV
  - → gluons fusion 87.3 %
  - → VBF 6.8 %
  - → VH (V=W/Z) 4.1 %
  - → ttH 0.9 %





- Main decay modes
  - → ZZ
  - → $\gamma\gamma$
  - → WW
  - → $b\bar{b}$
  - → $\tau\tau$
  - → $\mu\mu$
  - → $Z\gamma$

Signal Strength and k-framework

- Define **signal strength** (μ) as:

$$\mu_i = \frac{\sigma_i}{(\sigma_i)_{SM}} \qquad \mu^f = \frac{BR^f}{(BR^f)_{SM}}$$

- **k-factors: modifier of SM amplitudes** $\rightarrow$ simplest parametrization of deviations from SM
  - $\rightarrow$ assume same kinematics as SM
  - $\rightarrow$ possible different parametrizations to account for BSM contribution

$$\sigma_i = k_i^2 \cdot \sigma_i^{SM} \qquad \Gamma_i = k_f^2 \cdot \Gamma_f^{SM}$$

$$k_H^2 = \sum_j BR_j^{SM} k_j^2 \qquad \Gamma_H = \frac{k_H^2 \cdot \Gamma_H^{SM}}{1 - BR_{BSM}}$$

k = 1 $\rightarrow$ recover SM

- Parametrize μ in terms of k
  - $\rightarrow$ probe different assumptions on relations among k factors

$$\mu_i^f = \frac{k_i^2 \cdot k_f^2}{k_H^2}$$

- k_H account for change in total width
  - $\rightarrow$ treated either as independent parameter or combination of other k factors

Run 1 ATLAS-CMS combination results

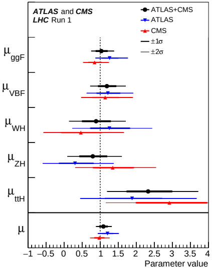
https://doi.org/10.1007/JHEP08(2016)045

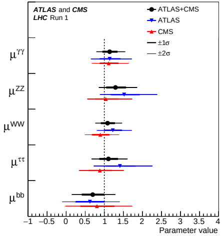
- **ATLAS and CMS combined measurement** with full Run 1 dataset (5 fb^{-1} @ 7 TeV and 20 fb^{-1} @ 8 TeV)

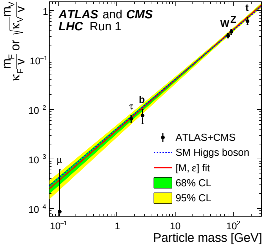
- Most constrained parametrization: μ scaling **all production processes**:

$$\mu = 1.09^{+0.11}_{-0.10} = 1.17^{+0.07}_{-0.07}(stat)^{+0.04}_{-0.04}(exp.\ syst.)^{+0.03}_{-0.03}(th.\ bkg\ syst.)^{+0.07}_{-0.06}(th.\ sig.\ syst)$$

Consider a **different μ per production process and decay mode**:







- All measurements in **agreement with SM predictions** within the uncertainties

CMS Run 2 measurements

CMS PAS HIG-17-031

- 2016 LHC Run2 dataset: $\mathcal{L} = 35.9\ \text{fb}^{-1}$ at $\sqrt{S} = 13$ TeV
- **Combination of several analysis** aiming at different production processes and decay modes

	ggF	VBF	VH	ttH
ZZ	✔	✔	✔	✔
$\gamma\gamma$	✔	✔	✔	✔
WW	✔	✔	✔	✔
bb	✔		✔	✔
$\tau\tau$	✔	✔		✔
$\mu\mu$	✔	✔		

- Sizable precision **gain from larger dataset**
- **Reduction of theory systematic uncertainty**

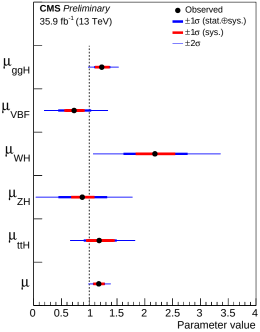
Signal Stregth

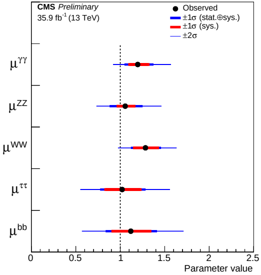
- Overall signal strength:

$$\mu = 1.17^{+0.10}_{-0.10} = 1.17^{+0.06}_{-0.06}(stat)^{+0.06}_{-0.05}(sig.th)^{+0.06}_{-0.06}(other\ sys.)$$

- Consider different μ for different production and decay modes

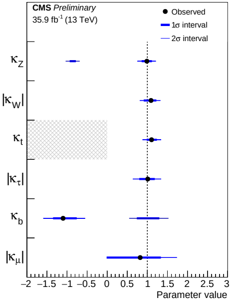
- $\mu_{\mathbf{ggF}}$ **∼ 30 % more precise** than in Run 1 ATLAS-CMS combination
- $\mu_{\mathbf{ttH}}$ **∼ 50% more precise** than in Run 1 ATLAS-CMS combination

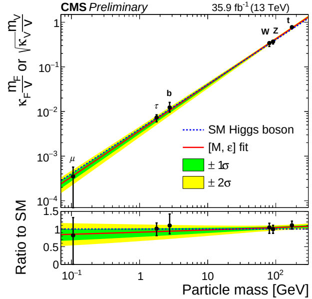




Coupling measurements: resolved loops

- Measurements interpretated within the k-framework
- **Assume no BSM contributions** in ggH and H$\rightarrow\gamma\gamma$ loops
  $\rightarrow$ express loops in terms of SM coupling modifiers
- Sensitive to relative sign of couplings

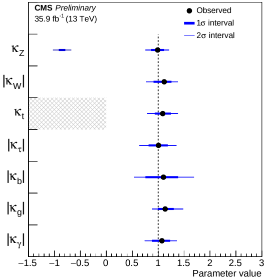


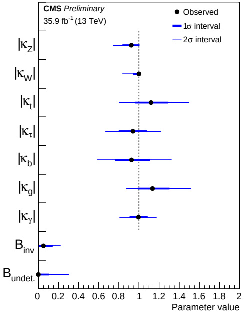


- Precision on coupling ranging from $\sim$ 10% to $\sim$ 30% (k_b)

- Consider effective k-factors for ggH and H$\rightarrow \gamma\gamma$ loops
  $\rightarrow$ **allow possible BSM contribution in the loops**
- Two models concerning BSM branching fractions:
  - $\rightarrow$ $BR_{BSM} = 0$ (BSM contribution only in loops)
  - $\rightarrow$ BR_{inv} and BR_{und} left floating (constraint: $|k_W|,|k_Z| \leq 1$)

    BR_{und}: decays in final states not included in the combination

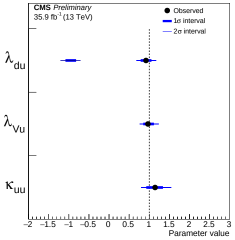




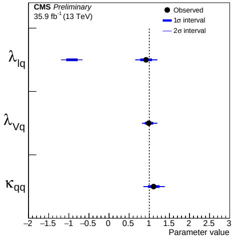
- $B_{inv} < 0.22$ at 95% C.L.
- In both cases agreement with SM

Example of constraints on BSM theories

- Extended Higgs sector predicted by BSM theories → **possible non universality of Higgs boson couplings to up and down like fermions**



- $\lambda_{ij} = k_i/k_j$
- Parametrize Higgs coupling to fermions with **different k-factors for up and down type fermions**



- Consider **different modifiers for quarks** (k_q) and **leptons** (k_l)
- **Measurements compatible with SM**

Summary

- The CMS measurements of the Higgs boson couplings with the 2016 dataset, $\mathcal{L} = 35.9\ \text{fb}^{-1}$, in the combination of several production and decay channels have been presented
- The signal strength for either production channels or decay modes have been measured
  - $\rightarrow$ overall total signal strength $\mu = 1.17^{+0.10}_{-0.10}$
- The Higgs boson couplings have been measured within the k-framework under different assumptions
  - $\rightarrow$ Achieved $\sim 10\%$ precision on the best measured Higgs boson couplings
  - $\rightarrow$ Higgs boson branching ratio to invisible particles constrained $< 22\ \%$ at 95% CL
- All the measurements are compatible within the uncertainties with the SM predictions

Additional Material

Run 1 ATLAS-CMS combination: signal strength table

Production process	ATLAS+CMS	ATLAS	CMS
μ_{ggF}	$1.03\,^{+0.16}_{-0.14}$ $\left(^{+0.16}_{-0.14}\right)$	$1.26\,^{+0.23}_{-0.20}$ $\left(^{+0.21}_{-0.18}\right)$	$0.84\,^{+0.18}_{-0.16}$ $\left(^{+0.20}_{-0.17}\right)$
μ_{VBF}	$1.18\,^{+0.25}_{-0.23}$ $\left(^{+0.24}_{-0.23}\right)$	$1.21\,^{+0.33}_{-0.30}$ $\left(^{+0.32}_{-0.29}\right)$	$1.14\,^{+0.37}_{-0.34}$ $\left(^{+0.36}_{-0.34}\right)$
μ_{WH}	$0.89\,^{+0.40}_{-0.38}$ $\left(^{+0.41}_{-0.39}\right)$	$1.25\,^{+0.56}_{-0.52}$ $\left(^{+0.56}_{-0.53}\right)$	$0.46\,^{+0.57}_{-0.53}$ $\left(^{+0.60}_{-0.57}\right)$
μ_{ZH}	$0.79\,^{+0.38}_{-0.36}$ $\left(^{+0.39}_{-0.36}\right)$	$0.30\,^{+0.51}_{-0.45}$ $\left(^{+0.55}_{-0.51}\right)$	$1.35\,^{+0.58}_{-0.54}$ $\left(^{+0.55}_{-0.51}\right)$
μ_{ttH}	$2.3\,^{+0.7}_{-0.6}$ $\left(^{+0.5}_{-0.5}\right)$	$1.9\,^{+0.8}_{-0.7}$ $\left(^{+0.7}_{-0.7}\right)$	$2.9\,^{+1.0}_{-0.9}$ $\left(^{+0.9}_{-0.8}\right)$

Decay channel	ATLAS+CMS	ATLAS	CMS
$\mu^{\gamma\gamma}$	$1.14\,^{+0.19}_{-0.18}$ $\left(^{+0.18}_{-0.17}\right)$	$1.14\,^{+0.27}_{-0.25}$ $\left(^{+0.26}_{-0.24}\right)$	$1.11\,^{+0.25}_{-0.23}$ $\left(^{+0.23}_{-0.21}\right)$
μ^{ZZ}	$1.29\,^{+0.26}_{-0.23}$ $\left(^{+0.23}_{-0.20}\right)$	$1.52\,^{+0.40}_{-0.34}$ $\left(^{+0.32}_{-0.27}\right)$	$1.04\,^{+0.32}_{-0.26}$ $\left(^{+0.30}_{-0.25}\right)$
μ^{WW}	$1.09\,^{+0.18}_{-0.16}$ $\left(^{+0.16}_{-0.15}\right)$	$1.22\,^{+0.23}_{-0.21}$ $\left(^{+0.21}_{-0.20}\right)$	$0.90\,^{+0.23}_{-0.21}$ $\left(^{+0.23}_{-0.20}\right)$
$\mu^{\tau\tau}$	$1.11\,^{+0.24}_{-0.22}$ $\left(^{+0.24}_{-0.22}\right)$	$1.41\,^{+0.40}_{-0.36}$ $\left(^{+0.37}_{-0.33}\right)$	$0.88\,^{+0.30}_{-0.28}$ $\left(^{+0.31}_{-0.29}\right)$
μ^{bb}	$0.70\,^{+0.29}_{-0.27}$ $\left(^{+0.29}_{-0.28}\right)$	$0.62\,^{+0.37}_{-0.37}$ $\left(^{+0.39}_{-0.37}\right)$	$0.81\,^{+0.45}_{-0.43}$ $\left(^{+0.45}_{-0.43}\right)$
$\mu^{\mu\mu}$	$0.1\,^{+2.5}_{-2.5}$ $\left(^{+2.4}_{-2.3}\right)$	$-0.6\,^{+3.6}_{-3.6}$ $\left(^{+3.6}_{-3.6}\right)$	$0.9\,^{+3.6}_{-3.5}$ $\left(^{+3.3}_{-3.2}\right)$

Run 1 ATLAS-CMS combination: couplings table

Parameter	ATLAS+CMS Measured	ATLAS+CMS Expected uncertainty	ATLAS Measured	CMS Measured
κ_Z	1.00 $[-1.05, -0.86] \cup [0.90, 1.11]$	$[-1.00, -0.88] \cup [0.90, 1.10]$	0.98 $[-1.07, -0.83] \cup [0.84, 1.12]$	1.03 $[-1.11, -0.83] \cup [0.87, 1.19]$
κ_W	$0.91^{+0.10}_{-0.12}$	$^{+0.10}_{-0.11}$	$0.91^{+0.12}_{-0.15}$	$0.92^{+0.14}_{-0.17}$
κ_t	$0.87^{+0.15}_{-0.15}$	$^{+0.15}_{-0.18}$	$0.98^{+0.21}_{-0.20}$	$0.77^{+0.20}_{-0.18}$
$\lvert\kappa_\tau\rvert$	$0.90^{+0.14}_{-0.16}$	$^{+0.15}_{-0.14}$	$0.99^{+0.20}_{-0.20}$	$0.83^{+0.20}_{-0.21}$
κ_b	0.67 $[-0.73, -0.47] \cup [0.40, 0.89]$	$[-1.24, -0.76] \cup [0.74, 1.24]$	0.64 $[-0.89, -0.33] \cup [0.30, 0.94]$	0.71 $[-0.91, -0.40] \cup [0.35, 1.04]$
$\lvert\kappa_\mu\rvert$	$0.2^{+1.2}$	$^{+0.9}$	$0.0^{+1.4}$	$0.5^{+1.4}$

Parameter	ATLAS+CMS Measured	ATLAS+CMS Expected uncertainty	ATLAS Measured	CMS Measured
Parameterisation assuming $\lvert\kappa_V\rvert \leq 1$ and $B_{BSM} \geq 0$				
κ_Z	1.00 $[0.92, 1.00]$	$[-1.00, -0.89] \cup [0.89, 1.00]$	1.00 $[-0.97, -0.94] \cup [0.86, 1.00]$	-1.00 $[-1.00, -0.84] \cup [0.90, 1.00]$
κ_W	0.90 $[0.81, 0.99]$	$[-1.00, -0.90] \cup [0.89, 1.00]$	0.92 $[-0.88, -0.84] \cup [0.79, 1.00]$	-0.84 $[-1.00, -0.71] \cup [0.76, 0.98]$
κ_t	$1.43^{+0.23}_{-0.22}$	$^{+0.27}_{-0.32}$	$1.31^{+0.35}_{-0.33}$	$1.45^{+0.42}_{-0.32}$
$\lvert\kappa_\tau\rvert$	$0.87^{+0.12}_{-0.11}$	$^{+0.14}_{-0.15}$	$0.97^{+0.21}_{-0.17}$	$0.79^{+0.20}_{-0.16}$
$\lvert\kappa_b\rvert$	$0.57^{+0.16}_{-0.16}$	$^{+0.19}_{-0.23}$	$0.61^{+0.24}_{-0.26}$	$0.49^{+0.26}_{-0.19}$
$\lvert\kappa_g\rvert$	$0.81^{+0.13}_{-0.10}$	$^{+0.17}_{-0.14}$	$0.94^{+0.23}_{-0.16}$	$0.69^{+0.21}_{-0.13}$
$\lvert\kappa_\gamma\rvert$	$0.90^{+0.10}_{-0.09}$	$^{+0.10}_{-0.12}$	$0.87^{+0.15}_{-0.14}$	$0.89^{+0.17}_{-0.13}$
B_{BSM}	$0.00^{+0.16}$	$^{+0.19}$	$0.00^{+0.25}$	$0.03^{+0.26}$
Parameterisation assuming $B_{BSM} = 0$				
κ_Z	-0.98 $[-1.08, -0.88] \cup [0.94, 1.13]$	$[-1.01, -0.87] \cup [0.89, 1.11]$	1.01 $[-1.09, -0.85] \cup [0.87, 1.15]$	-0.99 $[-1.14, -0.84] \cup [0.94, 1.19]$
κ_W	0.87 $[0.78, 1.00]$	$[-1.08, -0.90] \cup [0.88, 1.11]$	0.92 $[-0.94, -0.85] \cup [0.78, 1.05]$	0.84 $[-0.99, -0.74] \cup [0.71, 1.01]$
κ_t	$1.40^{+0.24}_{-0.21}$	$^{+0.26}_{-0.39}$	$1.32^{+0.31}_{-0.33}$	$1.51^{+0.33}_{-0.32}$
$\lvert\kappa_\tau\rvert$	$0.84^{+0.15}_{-0.11}$	$^{+0.16}_{-0.15}$	$0.97^{+0.19}_{-0.19}$	$0.77^{+0.18}_{-0.15}$
$\lvert\kappa_b\rvert$	$0.49^{+0.27}_{-0.15}$	$^{+0.25}_{-0.28}$	$0.61^{+0.26}_{-0.31}$	$0.47^{+0.34}_{-0.19}$
$\lvert\kappa_g\rvert$	$0.78^{+0.13}_{-0.10}$	$^{+0.17}_{-0.14}$	$0.94^{+0.18}_{-0.17}$	$0.67^{+0.14}_{-0.12}$
$\lvert\kappa_\gamma\rvert$	$0.87^{+0.14}_{-0.09}$	$^{+0.12}_{-0.13}$	$0.88^{+0.15}_{-0.15}$	$0.89^{+0.19}_{-0.13}$

CMS Run 2 combination analysis

Production and decay tags		Expected tagged signal fraction	Number of categories	Mass resolution
$H \to \gamma\gamma$, Section ??				
	Untagged	74-91% ggH	4	
	VBF	51-80% VBF	3	
	VH hadronic	25% WH, 15% ZH	1	
$\gamma\gamma$	WH leptonic	64-83% WH	2	$\approx$1-2%
	ZH leptonic	98% ZH	1	
	VH p_T^{miss}	59% VH	1	
	ttH	80-89% ttH, $\approx$8% tH	2	
$H \to ZZ^{(*)} \to 4\ell$, Section ??				
	Untagged	$\approx$95% ggH	3	
	VBF 1, 2-jet	$\approx$11-47% VBF	6	
4μ, $2e2\mu/2\mu 2e$, 4e	VH hadronic	$\approx$13% WH, $\approx$10% ZH	3	$\approx$1-2%
	VH leptonic	$\approx$46% WH	3	
	VH p_T^{miss}	$\approx$56% ZH	3	
	ttH	$\approx$71% ttH	3	
$H \to WW^{(*)} \to \ell\nu\ell\nu$, Section ??				
$e\mu/\mu e$	ggH 0, 1, 2-jet	$\approx$55-92% ggH, up to $\approx$15% $H \to \tau\tau$	17	
	VBF 2-jet	$\approx$47% VBF, up to $\approx$25% $H \to \tau\tau$	2	
$ee+\mu\mu$	ggH 0, 1-jet	$\approx$84-94% ggH	6	$\approx$20%
$e\mu$+jj	VH 2-jet	22% VH, 21% $H \to \tau\tau$	1	
3ℓ	WH leptonic	$\approx$80% WH, up to 19% $H \to \tau\tau$	2	
4ℓ	ZH leptonic	85-90% ZH, up to 14% $H \to \tau\tau$	2	
$H \to \tau\tau$, Section ??				
	0-jet	$\approx$70-98% ggH, 29% $H \to WW$ in $e\mu$	4	
$e\mu$, $e\tau_h$, $\mu\tau_h$, $\tau_h\tau_h$	VBF	$\approx$35-60% VBF, 42% $H \to WW$ in $e\mu$	4	$\approx$10-20%
	Boosted	$\approx$48-83% ggH, 43% $H \to WW$ in $e\mu$	4	
VH production with $H \to bb$, Section ??				
$Z(\nu\nu)$bb	ZH leptonic	$\approx$100% VH, 85% ZH	1	
$W(\ell\nu)$bb	WH leptonic	$\approx$100% VH, $\approx$97% WH	2	$\approx$10%
$Z(\ell\ell)$bb	Low $p_T(V)$ ZH leptonic	$\approx$100% ZH, of which $\approx$20% ggZH	2	
	High $p_T(V)$ ZH leptonic	$\approx$100% ZH, of which $\approx$36% ggZH	2	
Boosted H Production with $H \to bb$, Section ??				
$H \to bb$	$p_T(H)$ bins	$\approx$72-79% ggH	6	$\approx$10%
ttH production with $H \to$ leptons, Section ??				
	2ℓss	$WW/\tau\tau \approx 4.5$, $\approx$5% tH	10	
	3ℓ	$WW : \tau\tau : ZZ \approx 15 : 4 : 1$, $\approx$5% tH	4	
$H \to WW, \tau\tau, ZZ$	4ℓ	$WW : \tau\tau : ZZ \approx 6 : 1 : 1$, $\approx$3% tH	1	
	$1\ell+2\tau_h$	96% ttH with $H \to \tau\tau$, $\approx$6% tH	1	
	$2\ell ss+1\tau_h$	$\tau\tau : WW \approx 5 : 4$, $\approx$5% tH	2	
	$3\ell+1\tau_h$	$\tau\tau : WW : ZZ \approx 11 : 7 : 1$, $\approx$3% tH	1	
ttH production with $H \to bb$, Section ??				
	$t\bar{t} \to$ jets	$\approx$83-97% ttH with $H \to bb$	6	
$H \to bb$	$t\bar{t} \to 1\ell$+jets	$\approx$65-95% ttH with $H \to bb$, up to 20% $H \to WW$	18	
	$t\bar{t} \to 2\ell$+jets	$\approx$84-96% ttH with $H \to bb$	3	
$H \to \mu\mu$, Section ??				
$\mu\mu$	S/B bins	56-96% ggH, 1-42% VBF	15	$\approx$1-2%
Search for invisible H decays, Section ??				
	VBF	52% VBF, 48% ggH	1	
$H \to$ inv.	ggH + $\geq$ 1 jet	80% ggH, 9% VBF	1	
	VH hadronic	54% VH, 39% ggH	1	
	ZH leptonic	$\approx$100% ZH, of which 21% ggZH	1	

Run 2: signal strength table

Production process																			
ggH				VBF				WH				ZH				ttH			
Best fit value	Uncertainty	Stat.	Syst.	Best fit value	Uncertainty	Stat.	Syst.	Best fit value	Uncertainty	Stat.	Syst.	Best fit value	Uncertainty	Stat.	Syst.	Best fit value	Uncertainty	Stat.	Syst.
1.23	$^{+0.14}_{-0.13}$	$^{+0.08}_{-0.08}$	$^{+0.12}_{-0.10}$	0.73	$^{+0.30}_{-0.27}$	$^{+0.24}_{-0.23}$	$^{+0.17}_{-0.15}$	2.18	$^{+0.58}_{-0.55}$	$^{+0.46}_{-0.45}$	$^{+0.34}_{-0.32}$	0.87	$^{+0.44}_{-0.42}$	$^{+0.39}_{-0.38}$	$^{+0.20}_{-0.18}$	1.18	$^{+0.31}_{-0.27}$	$^{+0.16}_{-0.16}$	$^{+0.26}_{-0.21}$
	$(^{+0.11}_{-0.11})$	$(^{+0.07}_{-0.07})$	$(^{+0.09}_{-0.08})$		$(^{+0.29}_{-0.27})$	$(^{+0.24}_{-0.23})$	$(^{+0.16}_{-0.15})$		$(^{+0.53}_{-0.51})$	$(^{+0.43}_{-0.42})$	$(^{+0.30}_{-0.29})$		$(^{+0.42}_{-0.40})$	$(^{+0.38}_{-0.37})$	$(^{+0.19}_{-0.17})$		$(^{+0.28}_{-0.25})$	$(^{+0.16}_{-0.16})$	$(^{+0.23}_{-0.20})$

Decay mode																			
$H \to bb$				$H \to \tau\tau$				$H \to WW$				$H \to ZZ$				$H \to \gamma\gamma$			
Best fit value	Uncertainty	Stat.	Syst.	Best fit value	Uncertainty	Stat.	Syst.	Best fit value	Uncertainty	Stat.	Syst.	Best fit value	Uncertainty	Stat.	Syst.	Best fit value	Uncertainty	Stat.	Syst.
1.12	$^{+0.29}_{-0.28}$	$^{+0.19}_{-0.19}$	$^{+0.22}_{-0.20}$	1.02	$^{+0.26}_{-0.24}$	$^{+0.15}_{-0.15}$	$^{+0.21}_{-0.19}$	1.28	$^{+0.17}_{-0.16}$	$^{+0.09}_{-0.09}$	$^{+0.14}_{-0.13}$	1.06	$^{+0.19}_{-0.17}$	$^{+0.16}_{-0.15}$	$^{+0.10}_{-0.08}$	1.20	$^{+0.17}_{-0.14}$	$^{+0.12}_{-0.11}$	$^{+0.12}_{-0.09}$
	$(^{+0.28}_{-0.27})$	$(^{+0.19}_{-0.18})$	$(^{+0.21}_{-0.20})$		$(^{+0.24}_{-0.23})$	$(^{+0.15}_{-0.14})$	$(^{+0.19}_{-0.17})$		$(^{+0.14}_{-0.13})$	$(^{+0.09}_{-0.09})$	$(^{+0.11}_{-0.10})$		$(^{+0.18}_{-0.16})$	$(^{+0.15}_{-0.14})$	$(^{+0.10}_{-0.08})$		$(^{+0.14}_{-0.12})$	$(^{+0.10}_{-0.10})$	$(^{+0.09}_{-0.07})$

Production	Loops	Interference	Effective scaling factor	Resolved scaling factor
$\sigma(\mathrm{ggH})$	✓	$\mathrm{b}-\mathrm{t}$	κ_g^2	$1.04\cdot\kappa_\mathrm{t}^2+0.002\cdot\kappa_\mathrm{b}^2-0.038\cdot\kappa_\mathrm{t}\kappa_\mathrm{b}$
$\sigma(\mathrm{VBF})$	–	–		$0.73\cdot\kappa_\mathrm{W}^2+0.27\cdot\kappa_\mathrm{Z}^2$
$\sigma(\mathrm{WH})$	–	–		κ_W^2
$\sigma(\mathrm{qq/qg}\to\mathrm{ZH})$	–	–		κ_Z^2
$\sigma(\mathrm{gg}\to\mathrm{ZH})$	✓	$\mathrm{Z}-\mathrm{t}$		$2.46\cdot\kappa_\mathrm{Z}^2+0.47\cdot\kappa_\mathrm{t}^2-1.94\cdot\kappa_\mathrm{Z}\kappa_\mathrm{t}$
$\sigma(\mathrm{ttH})$	–	–		κ_t^2
$\sigma(\mathrm{gb}\to\mathrm{WtH})$	–	$\mathrm{W}-\mathrm{t}$		$2.91\cdot\kappa_\mathrm{t}^2+2.40\cdot\kappa_\mathrm{W}^2-4.22\cdot\kappa_\mathrm{t}\kappa_\mathrm{W}$
$\sigma(\mathrm{qb}\to\mathrm{tHq})$	–	$\mathrm{W}-\mathrm{t}$		$2.63\cdot\kappa_\mathrm{t}^2+3.58\cdot\kappa_\mathrm{W}^2-5.21\cdot\kappa_\mathrm{t}\kappa_\mathrm{W}$
$\sigma(\mathrm{bbH})$	–	–		κ_b^2
Partial decay width				
Γ^{ZZ}	–	–		κ_Z^2
Γ^{WW}	–	–		κ_W^2
$\Gamma^{\gamma\gamma}$	✓	$\mathrm{W}-\mathrm{t}$	κ_γ^2	$1.59\cdot\kappa_\mathrm{W}^2+0.07\cdot\kappa_\mathrm{t}^2-0.67\cdot\kappa_\mathrm{W}\kappa_\mathrm{t}$
$\Gamma^{\tau\tau}$	–	–		κ_τ^2
Γ^{bb}	–	–		κ_b^2
$\Gamma^{\mu\mu}$	–	–		κ_μ^2
Total width for $\mathrm{BR_{BSM}}=0$				
Γ_H	✓	–	κ_H^2	$0.58\cdot\kappa_\mathrm{b}^2+0.22\cdot\kappa_\mathrm{W}^2+0.08\cdot\kappa_\mathrm{g}^2+$ $+0.06\cdot\kappa_\tau^2+0.026\cdot\kappa_\mathrm{Z}^2+0.029\cdot\kappa_\mathrm{c}^2+$ $+0.0023\cdot\kappa_\gamma^2+0.0015\cdot\kappa_{\mathrm{Z}\gamma}^2+$ $+0.00025\cdot\kappa_\mathrm{s}^2+0.00022\cdot\kappa_\mu^2$

CMS Run 2 resolved loops: couplings table

Parameter											
κ_W				κ_Z				κ_t			
Best fit value		Uncertainty Stat.	Syst.	Best fit value		Uncertainty Stat.	Syst.	Best fit value		Uncertainty Stat.	Syst.
1.09	$^{+0.12}_{-0.17}$	$^{+0.08}_{-0.16}$	$^{+0.09}_{-0.04}$	0.99	$^{+0.11}_{-0.12}$	$^{+0.09}_{-0.10}$	$^{+0.07}_{-0.07}$	1.11	$^{+0.12}_{-0.11}$	$^{+0.08}_{-0.07}$	$^{+0.09}_{-0.08}$
	$\left(^{+0.11}_{-0.10}\right)$	$\left(^{+0.08}_{-0.08}\right)$	$\left(^{+0.06}_{-0.06}\right)$		$\left(^{+0.11}_{-0.11}\right)$	$\left(^{+0.09}_{-0.09}\right)$	$\left(^{+0.06}_{-0.06}\right)$		$\left(^{+0.11}_{-0.12}\right)$	$\left(^{+0.07}_{-0.08}\right)$	$\left(^{+0.09}_{-0.09}\right)$

Parameter											
κ_b				κ_τ				κ_μ			
Best fit value		Uncertainty Stat.	Syst.	Best fit value		Uncertainty Stat.	Syst.	Best fit value		Uncertainty Stat.	Syst.
−1.10	$^{+0.33}_{-0.24}$	$^{+0.29}_{-0.16}$	$^{+0.15}_{-0.17}$	1.01	$^{+0.16}_{-0.20}$	$^{+0.11}_{-0.17}$	$^{+0.12}_{-0.10}$	0.82	$^{+0.50}_{-0.82}$	$^{+0.49}_{-0.82}$	$^{+0.11}_{-0.00}$
	$\left(^{+0.23}_{-0.22}\right)$	$\left(^{+0.16}_{-0.15}\right)$	$\left(^{+0.16}_{-0.16}\right)$		$\left(^{+0.17}_{-0.15}\right)$	$\left(^{+0.12}_{-0.10}\right)$	$\left(^{+0.12}_{-0.11}\right)$		$\left(^{+0.45}_{-1.01}\right)$	$\left(^{+0.44}_{-1.00}\right)$	$\left(^{+0.07}_{-0.11}\right)$

CMS Run 2 effective loops: couplings table

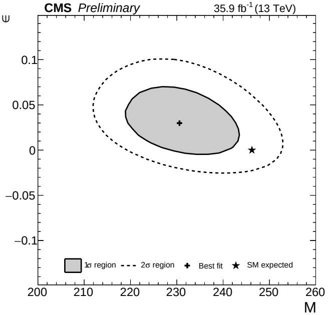
$BR_{inv.} = 0$				$BR_{inv.} > 0, \kappa_V < 1$			
		Uncertainty				Uncertainty	
Parameter	Best fit	Stat.	Syst.	Parameter	Best fit	Stat.	Syst.
κ_Z	$0.99^{+0.11}_{-0.11}$ $\left(^{+0.11}_{-0.11}\right)$	$^{+0.09}_{-0.09}$ $\left(^{+0.09}_{-0.09}\right)$	$^{+0.06}_{-0.06}$ $\left(^{+0.06}_{-0.06}\right)$	κ_Z	$0.89^{+0.09}_{-0.08}$ $\left(^{+0.00}_{-0.11}\right)$	$^{+0.07}_{-0.07}$ $\left(^{+0.00}_{-0.09}\right)$	$^{+0.05}_{-0.04}$ $\left(^{+0.00}_{-0.06}\right)$
κ_W	$1.12^{+0.13}_{-0.19}$ $\left(^{+0.12}_{-0.12}\right)$	$^{+0.10}_{-0.18}$ $\left(^{+0.09}_{-0.09}\right)$	$^{+0.08}_{-0.07}$ $\left(^{+0.07}_{-0.07}\right)$	κ_W	$1.00^{+0.00}_{-0.05}$ $\left(^{+0.00}_{-0.12}\right)$	$^{+0.00}_{-0.04}$ $\left(^{+0.00}_{-0.09}\right)$	$^{+0.00}_{-0.02}$ $\left(^{+0.00}_{-0.07}\right)$
κ_t	$1.09^{+0.14}_{-0.14}$ $\left(^{+0.14}_{-0.15}\right)$	$^{+0.08}_{-0.08}$ $\left(^{+0.08}_{-0.09}\right)$	$^{+0.12}_{-0.12}$ $\left(^{+0.12}_{-0.12}\right)$	κ_t	$1.12^{+0.17}_{-0.16}$ $\left(^{+0.18}_{-0.15}\right)$	$^{+0.09}_{-0.09}$ $\left(^{+0.13}_{-0.09}\right)$	$^{+0.14}_{-0.13}$ $\left(^{+0.12}_{-0.12}\right)$
κ_τ	$1.01^{+0.17}_{-0.18}$ $\left(^{+0.16}_{-0.15}\right)$	$^{+0.11}_{-0.15}$ $\left(^{+0.11}_{-0.11}\right)$	$^{+0.12}_{-0.09}$ $\left(^{+0.11}_{-0.11}\right)$	κ_τ	$0.91^{+0.13}_{-0.13}$ $\left(^{+0.14}_{-0.15}\right)$	$^{+0.08}_{-0.08}$ $\left(^{+0.09}_{-0.11}\right)$	$^{+0.11}_{-0.10}$ $\left(^{+0.11}_{-0.11}\right)$
κ_b	$1.10^{+0.27}_{-0.33}$ $\left(^{+0.25}_{-0.23}\right)$	$^{+0.19}_{-0.30}$ $\left(^{+0.19}_{-0.17}\right)$	$^{+0.19}_{-0.14}$ $\left(^{+0.17}_{-0.15}\right)$	κ_b	$0.91^{+0.19}_{-0.16}$ $\left(^{+0.18}_{-0.23}\right)$	$^{+0.12}_{-0.11}$ $\left(^{+0.13}_{-0.17}\right)$	$^{+0.14}_{-0.11}$ $\left(^{+0.13}_{-0.15}\right)$
κ_g	$1.14^{+0.15}_{-0.13}$ $\left(^{+0.14}_{-0.12}\right)$	$^{+0.10}_{-0.09}$ $\left(^{+0.10}_{-0.09}\right)$	$^{+0.11}_{-0.09}$ $\left(^{+0.10}_{-0.09}\right)$	κ_g	$1.17^{+0.18}_{-0.14}$ $\left(^{+0.17}_{-0.12}\right)$	$^{+0.11}_{-0.10}$ $\left(^{+0.13}_{-0.09}\right)$	$^{+0.14}_{-0.11}$ $\left(^{+0.10}_{-0.09}\right)$
κ_γ	$1.07^{+0.15}_{-0.18}$ $\left(^{+0.12}_{-0.12}\right)$	$^{+0.10}_{-0.17}$ $\left(^{+0.10}_{-0.10}\right)$	$^{+0.11}_{-0.07}$ $\left(^{+0.07}_{-0.07}\right)$	κ_γ	$0.96^{+0.09}_{-0.08}$ $\left(^{+0.08}_{-0.12}\right)$	$^{+0.06}_{-0.06}$ $\left(^{+0.07}_{-0.09}\right)$	$^{+0.07}_{-0.05}$ $\left(^{+0.05}_{-0.07}\right)$
				$BR_{inv.}$	$0.04^{+0.09}_{+0.00}$ $\left(^{+0.08}_{+0.00}\right)$	$^{+0.03}_{-0.03}$ $\left(^{+0.04}_{-0.00}\right)$	$^{+0.08}_{-0.00}$ $\left(^{+0.07}_{-0.00}\right)$
				$BR_{undet.}$	$0.00^{+0.09}_{+0.00}$ $\left(^{+0.20}_{+0.00}\right)$	$^{+0.08}_{-0.00}$ $\left(^{+0.17}_{-0.00}\right)$	$^{+0.03}_{-0.00}$ $\left(^{+0.11}_{-0.00}\right)$

Additional coupling parametrization

- Relate masses of particles to the relative k factors through M and ϵ:

$$k_f = v\ m_f^{\epsilon}/M^{1+\epsilon} \qquad k_V = v\ m_V^{2\epsilon}/M^{1+2\epsilon}$$

with v = 246.22 GeV is the SM Higgs boson vacuum expectation value
$(M,\epsilon) = (v,0) \rightarrow$ recover SM



CMS Run 2 Constraint on Higgs boson width

- Reinterpratete effective coupling parametrization to contraint Γ_H^{SM}:

$$\frac{\Gamma_H}{\Gamma_H^{SM}} = \frac{k_H}{1 - (BR_{und} + BRinv)}$$