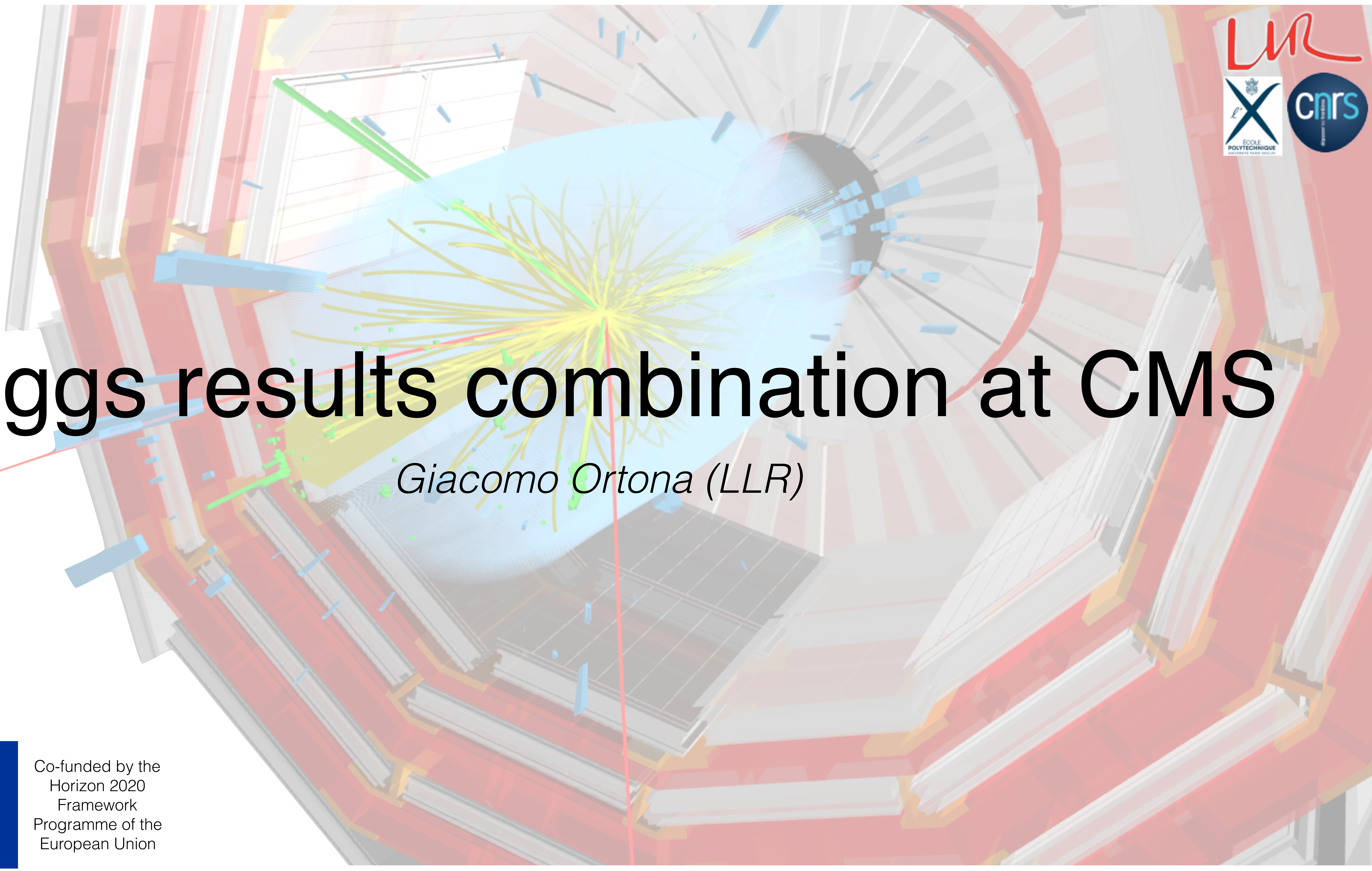


Higgs results combination at CMS

Giacomo Ortona (LLR)

Co-funded by the Horizon 2020 Framework Programme of the European Union

Introduction

Previous combination was the Run1 legacy CMS+ATLAS combination

- ~40fb-1 combined statistics
- Huge effort from the cross-experiments group

All main single Higgs analyses in CMS have completed their analysis of 2016 data

- 2016 statistics is close to Run1
- We should be able to improve on the combined Run1 results

Complex task:

- 5 production modes x 5 (+1) decay modes (+invisible)
- 11 analyses

	ggF	VBF	VH	ttH
H→ZZ→4l	•	•	•	•
H→γγ	•	•	•	•
H→WW	•	•	•	•
H→bb	•		•	•
H→ττ	•	•		•
H→μμ	•	•		
H→inv	•	•	•	

H→ZZ→4l	HIG-16-041	JHEP 11 (2017) 047
H→γγ	HIG-16-040	
H→WW	HIG-16-042	
VH→bb	HIG-16-044	PLB 780 (2018) 501
H→ττ	HIG-16-043	PLB 779 (2018) 283
H→μμ	HIG-17-019	
Boosted H→bb	HIG-17-010	PRL 120 (2018) 071802
ttH→WW/ZZ/ττ	HIG-17-018	
ttH→bb (leptonic)	HIG-17-026	
ttH→bb (hadronic)	HIG-17-022	
H→inv	HIG-17-023	

Signal strengths

Signal strengths, μ

Parameters scale cross sections and BRs relative to SM

$$\mu_i = \frac{\sigma_i}{\sigma_i^{\mathrm{SM}}} \qquad \mu^f = \frac{\mathrm{BR}^f}{\mathrm{BR}^f_{\mathrm{SM}}}.$$

Scaling of generic i → H → f process

$$\mu_i^f \equiv \frac{\sigma_i \cdot \mathrm{BR}^f}{(\sigma_i \cdot \mathrm{BR}^f)_{\mathrm{SM}}} = \mu_i \times \mu^f$$

Most immediate quantity: ratio of observed “rate” with respect to the expected results

Production: ratio of cross-sections

Decay: ratio of branching fractions

Many systematic uncertainties and theory assumptions cancel out in the ratio

- Easy to interpret
- Deviation from SM immediately visible
- Can decouple production and decay mechanisms
- Only effects modifying the absolute normalisation are visible, no sensitivity to shapes

No immediate relation with the width, each signal strength is independent from each other, but possible reinterpretation in the k-framework

K-framework

Couplings, κ

Parameters scale cross sections and partial widths relative to SM

$$\kappa_j^2 = \sigma_j / \sigma_j^{\mathrm{SM}} \qquad \kappa_j^2 = \Gamma_j / \Gamma_j^{\mathrm{SM}}$$

$$\sigma_i \cdot \mathrm{BR}^f = \frac{\sigma_i \cdot \Gamma_f}{\Gamma_{\mathrm{H}}},$$

Total width determined as

$$\Gamma_{\mathrm{H}} = \frac{\kappa_H^2 \cdot \Gamma_H^{\mathrm{SM}}}{1 - \mathrm{BR}_{\mathrm{BSM}}}$$

Where

$$\kappa_H^2 = \sum_j \mathrm{BR}^j_{\mathrm{SM}} \kappa_j^2$$

At first, signal strengths μ (ratio of observed cross-section to SM predictions)

- Good to verify H(125) properties and to check compatibility with SM
- Not ideal parametrization when introducing NP

Second step, K-framework:

- Disentangles production and decay mechanisms. Notation $k_f = \{k_t, k_b, k_\tau\}$; $k_V = \{k_W, k_Z\}$
- Effective coupling modifiers for processes with loops (k_g, k_γ, k_H…)
- Also possible to describe as coupling modifier ratios $\lambda_{ij} = \kappa_i / \kappa_j$
- Production processes: ggF, VBF, WH, ZH, ttH
- Decay channels: HZZ,WW,$\gamma\gamma$,$\tau\tau$,bb,$\mu\mu$

Can be used to estimate the Higgs width

Next steps: PseudoObservables, cross-sections…

Fiducial and Simplified template cross-section

Fiducial cross-section

- Optimized for maximal theoretical independence
- Fiducial in Higgs decay
- Smallest acceptance corrections
- Simple signal cuts
- “Exact” fiducial volume
- Targeted object definitions
- Agnostic to production mode

Can be done with single and differential distributions

Only feasible in HZZ,$H\gamma\gamma$,HWW

Combination not straightforward

Simplified templates cross section

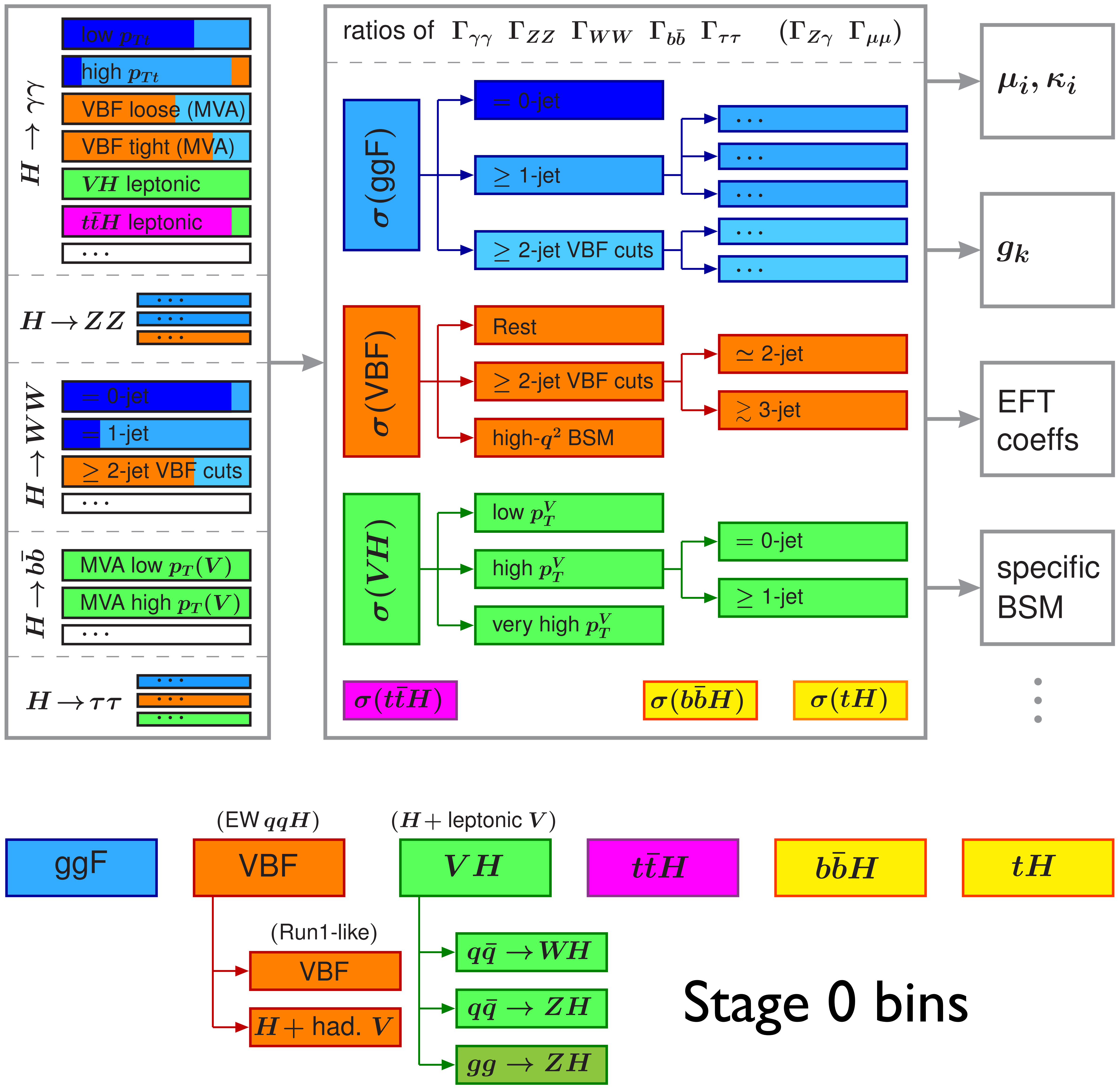
- Target maximum sensitivity, while keeping theoretical dependence as small as possible
- Cross section split by production mode
- Cross section divided in **exclusive** regions of phase space (bins)
- Larger acceptance corrections
- Abstracted fiducial volumes
- Inclusive in Higgs decay
- Allows complex event selections, categorisation

Common abstracted object definitions

Can be done in all decay modes

Explicitly designed for combination

Fiducial and Simplified template cross-section



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Common abstracted object definitions

Can be done in all decay modes

Explicitly designed for combination

Overview

Tricky business

- 11 analyses
- 265 event categories
- 5500+ nuisance parameters
- Including both shape and yield systematics
- All in one fit in one go!

Need Common description of signal

- All gluon fusion signals scaled/weighted to match NNLOPS predictions
- Use WG1 interim ggH uncertainty scheme

Need common treatment of correlated systematic uncertainties

- Carefully check correlations

Production and decay tags		Expected tagged signal fraction	Number of categories	Mass resolution
$H \to \gamma\gamma$, Section ??				
$\gamma\gamma$	Untagged	74-91% ggH	4	≈1-2%
	VBF	51-80% VBF	3	
	VH hadronic	25% WH, 15% ZH	1	
	WH leptonic	64-83% WH	2	
	ZH leptonic	98% ZH	1	
	VH p_T^{miss}	59% VH	1	
	ttH	80-89% ttH, ≈8% tH	2	
$H \to ZZ^{(*)} \to 4\ell$, Section ??				
4μ, $2e2\mu/2\mu2e$, $4e$	Untagged	≈95% ggH	3	≈1-2%
	VBF 1, 2-jet	≈11-47% VBF	6	
	VH hadronic	≈13% WH, ≈10% ZH	3	
	VH leptonic	≈46% WH	3	
	VH p_T^{miss}	≈56% ZH	3	
	ttH	≈71% ttH	3	
$H \to WW^{(*)} \to \ell\nu\ell\nu$, Section ??				
$e\mu/\mu e$	ggH 0, 1, 2-jet	≈55-92% ggH, up to ≈15% $H \to \tau\tau$	17	≈20%
	VBF 2-jet	≈47% VBF, up to ≈25% $H \to \tau\tau$	2	
$ee+\mu\mu$	ggH 0, 1-jet	≈84-94% ggH	6	
$e\mu$+jj	VH 2-jet	22% VH, 21% $H \to \tau\tau$	1	
3ℓ	WH leptonic	≈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 ??				
$e\mu$, $e\tau_h$, $\mu\tau_h$, $\tau_h\tau_h$	0-jet	≈70-98% ggH, 29% $H \to WW$ in $e\mu$	4	≈10-20%
	VBF	≈35-60% VBF, 42% $H \to WW$ in $e\mu$	4	
	Boosted	≈48-83% ggH, 43% $H \to WW$ in $e\mu$	4	
VH production with $H \to bb$, Section ??				
$Z(\nu\nu)bb$	ZH leptonic	≈100% VH, 85% ZH	1	≈10%
$W(\ell\nu)bb$	WH leptonic	≈100% VH, ≈97% WH	2	
$Z(\ell\ell)bb$	Low $p_T(V)$ ZH leptonic	≈100% ZH, of which ≈20% ggZH	2	
	High $p_T(V)$ ZH leptonic	≈100% ZH, of which ≈36% ggZH	2	
Boosted H Production with $H \to bb$, Section ??				
$H \to bb$	$p_T(H)$ bins	≈72-79% ggH	6	≈10%
ttH production with $H \to$ leptons, Section ??				
$H \to WW, \tau\tau, ZZ$	2ℓss	$WW/\tau\tau \approx 4.5$, ≈5% tH	10	
	3ℓ	$WW : \tau\tau : ZZ \approx 15 : 4 : 1$, ≈5% tH	4	
	4ℓ	$WW : \tau\tau : ZZ \approx 6 : 1 : 1$, ≈3% tH	1	
	$1\ell+2\tau_h$	96% ttH with $H \to \tau\tau$, ≈6% tH	1	
	2ℓss$+1\tau_h$	$\tau\tau : WW \approx 5 : 4$, ≈5% tH	2	
	$3\ell+1\tau_h$	$\tau\tau : WW : ZZ \approx 11 : 7 : 1$, ≈3% tH	1	
ttH production with $H \to bb$, Section ??				
$H \to bb$	$t\bar{t} \to$ jets	≈83-97% ttH with $H \to bb$	6	
	$t\bar{t} \to 1\ell$+jets	≈65-95% ttH with $H \to bb$, up to 20% $H \to WW$	18	
	$t\bar{t} \to 2\ell$+jets	≈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	≈1-2%
Search for invisible H decays, Section ??				
$H \to$ inv.	VBF	52% VBF, 48% ggH	1	
	ggH + ≥ 1 jet	80% ggH, 9% VBF	1	
	VH hadronic	54% VH, 39% ggH	1	
	ZH leptonic	≈100% ZH, of which 21% ggZH	1	

Systematic uncertainties

Signal theory uncertainties

- Systematic uncertainties on cross section due to QCD scale and PDFs correlated, as are those on branching ratios due to partial width uncertainties
- UE/PS uncertainties also correlated

Background theory uncertainties:

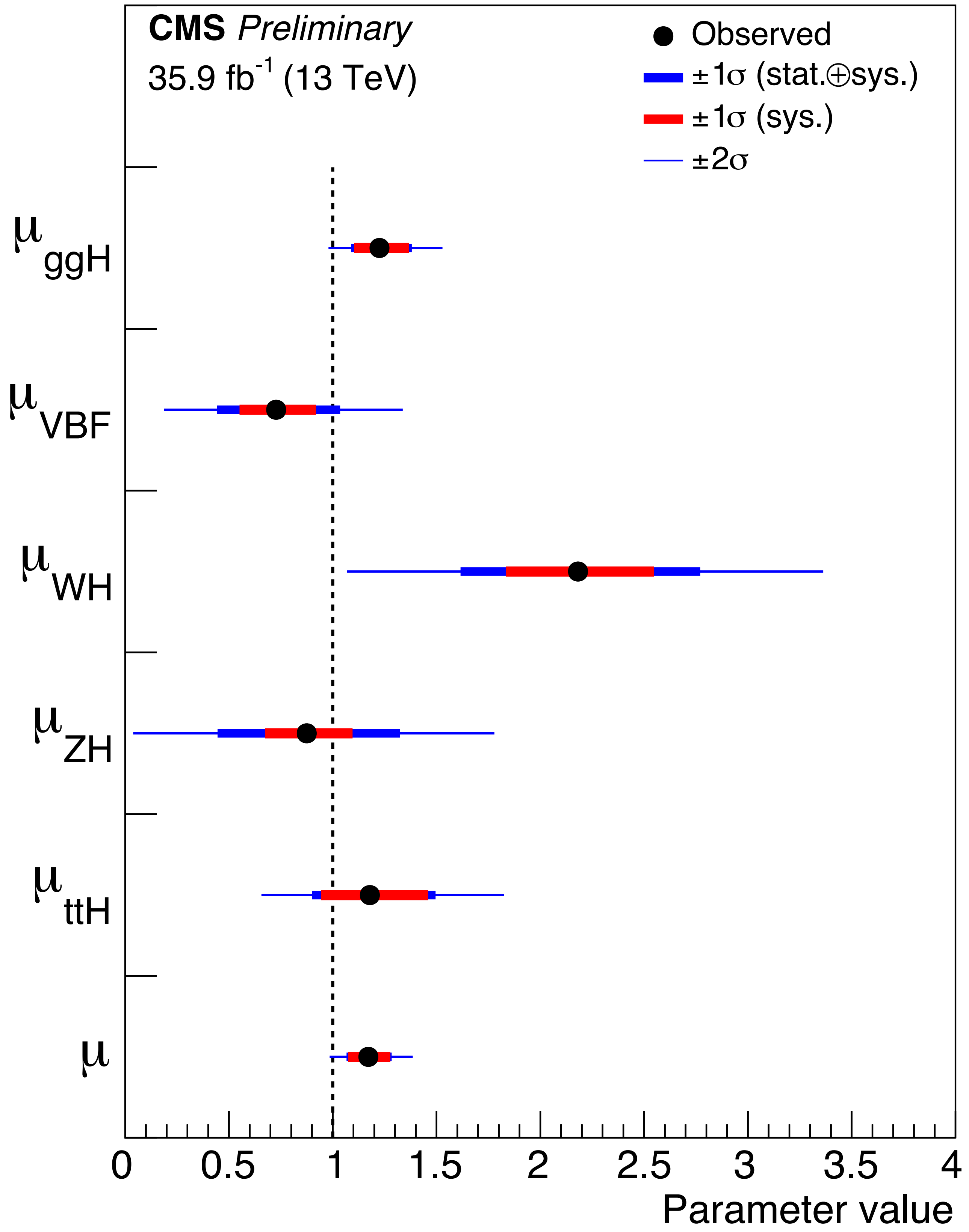
- When backgrounds are normalised from MC correlate uncertainties on cross section
- E.g. tt+HF correlated between ttH→bb hadronic and leptonic analyses

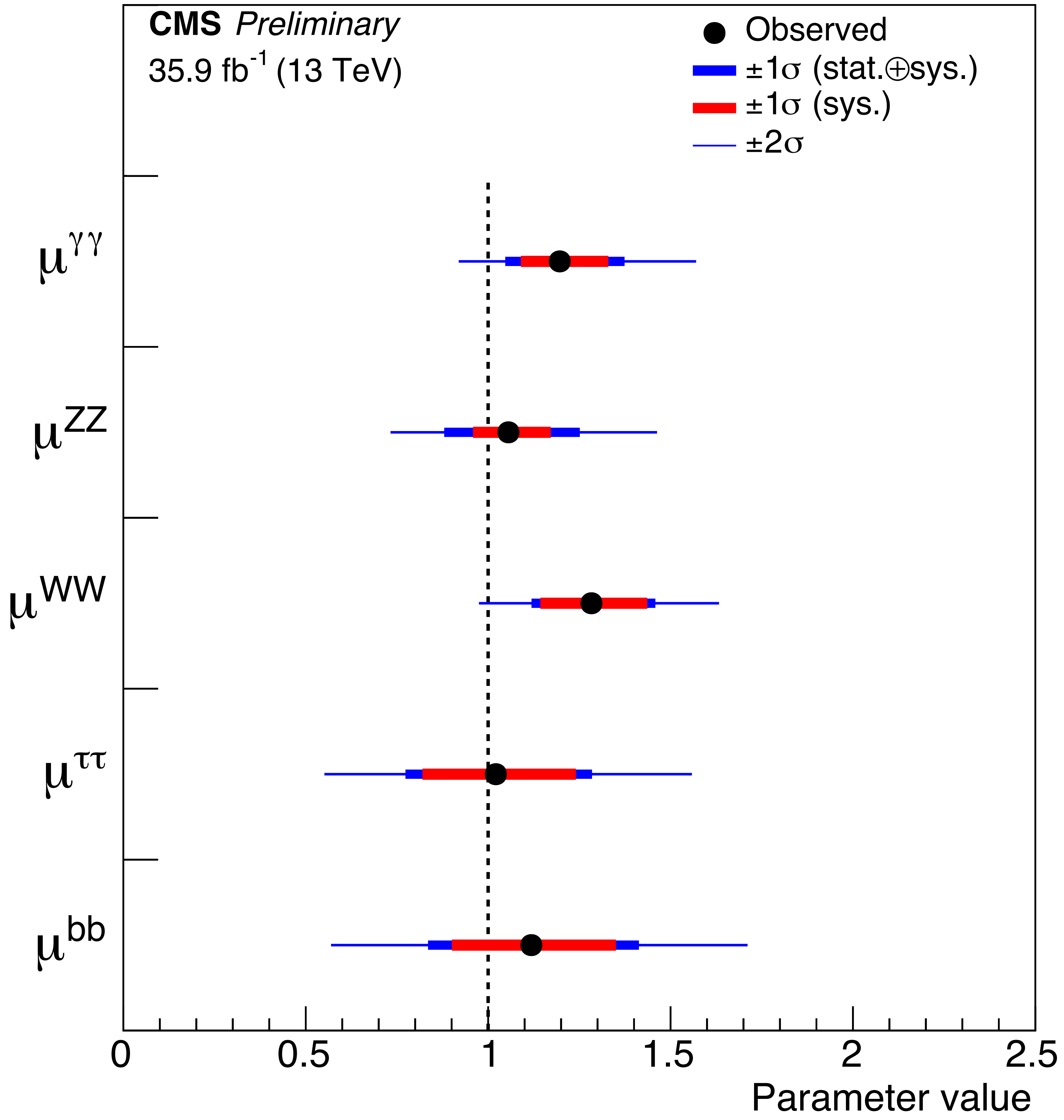
Correlation of experimental uncertainties:

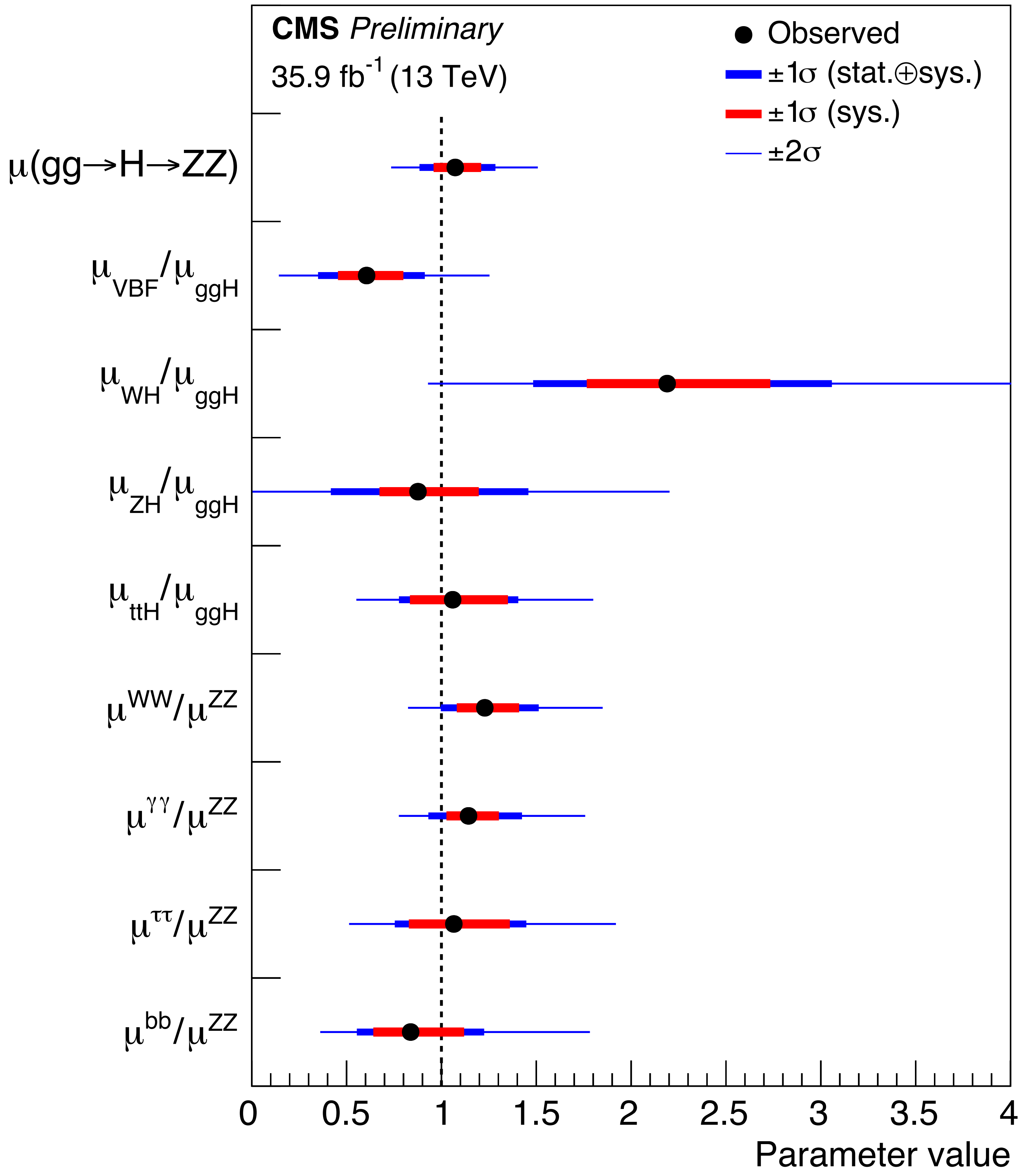
- Luminosity, pileup reweighting, JES, b-tagging (when from the same physic modelling)
- b-tagging: similar to JES, some use split sources, others single parameters
- Lepton efficiencies: generally not correlated - analyses use different triggers, working points and kinematic selections

Signal strengths (I)

note: bbH scales with ggH, tH with ttH







30% improvement on precision for ggH production

50% improvement in ttH makes ttH observation finally feasible!

Ratios normalised to gg→H→ZZ (to reduce uncertainties)

Signal strengths (II)

Most general parametrisation: product of production x decay signal strength with all parameters floating

- 5x5 matrix μ_i={ggH, VBF, WH, ZH, ttH} x μ^f={γγ, ZZ, WW, bb, ττ}
- 22/25 measurements available (H$\mu\mu$ is coming)

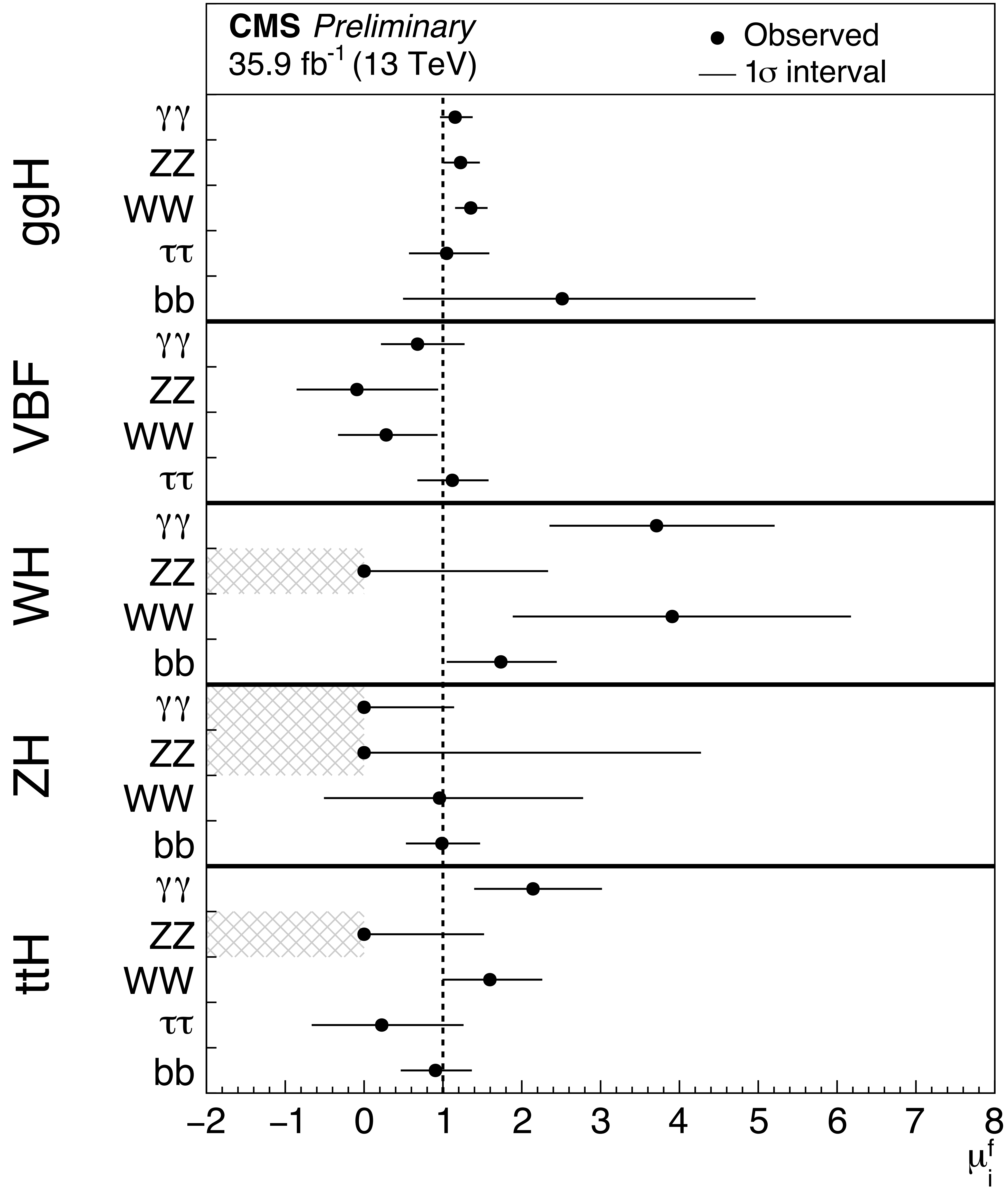
Different interpretations possible by applying constraints on μ_i, μ^f, i.e. STXS, ratios of cross sections

Global signal strength: μ=1.17±0.10

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

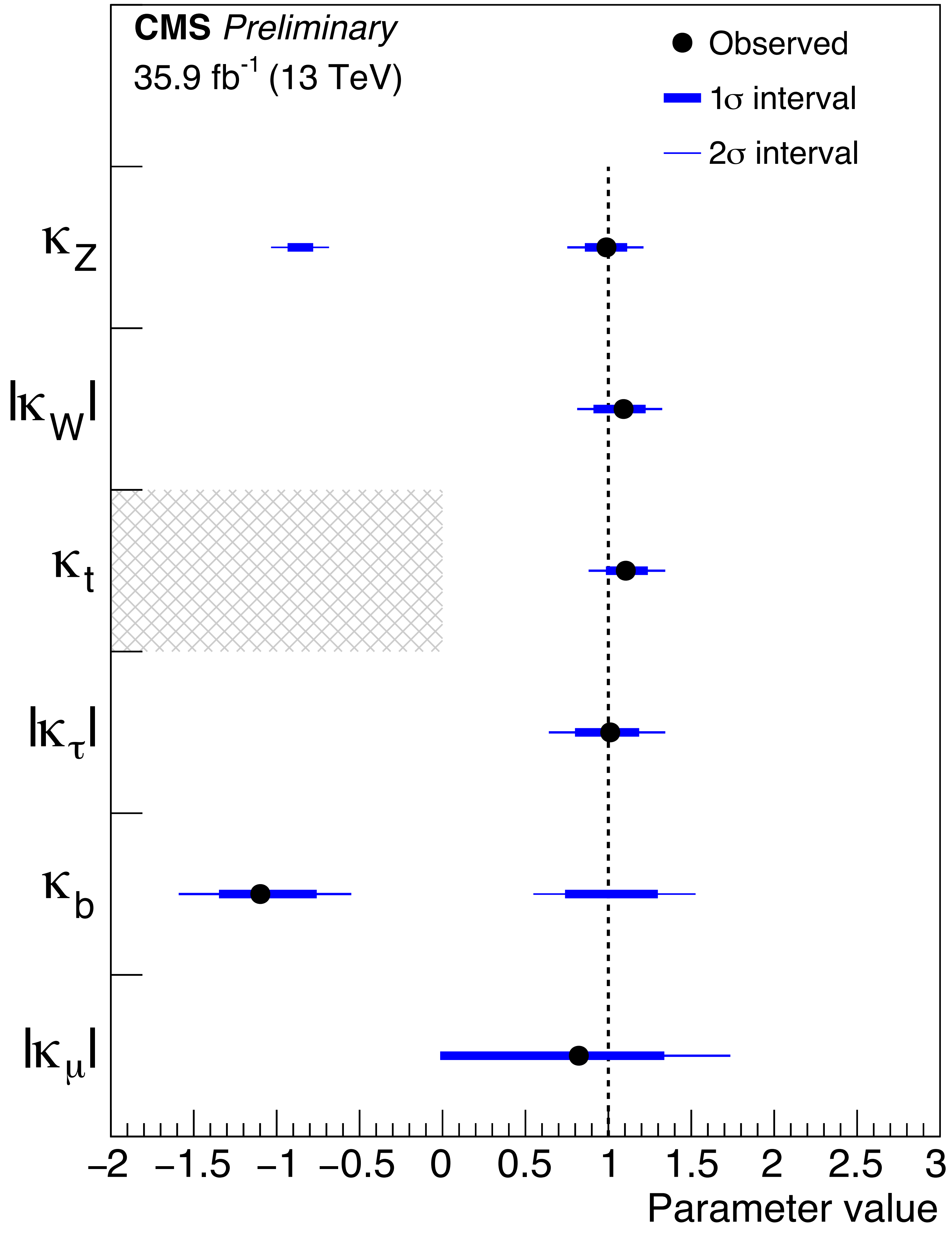
c.f. Run 1 CMS+ATLAS: $\mu = 1.09^{+0.11}_{-0.10} = 1.09^{+0.07}_{-0.07}(\text{stat})^{+0.07}_{-0.06}(\text{sig. th.})^{+0.05}_{-0.05}(\text{other sys.})$

Picture consistent with SM expectations

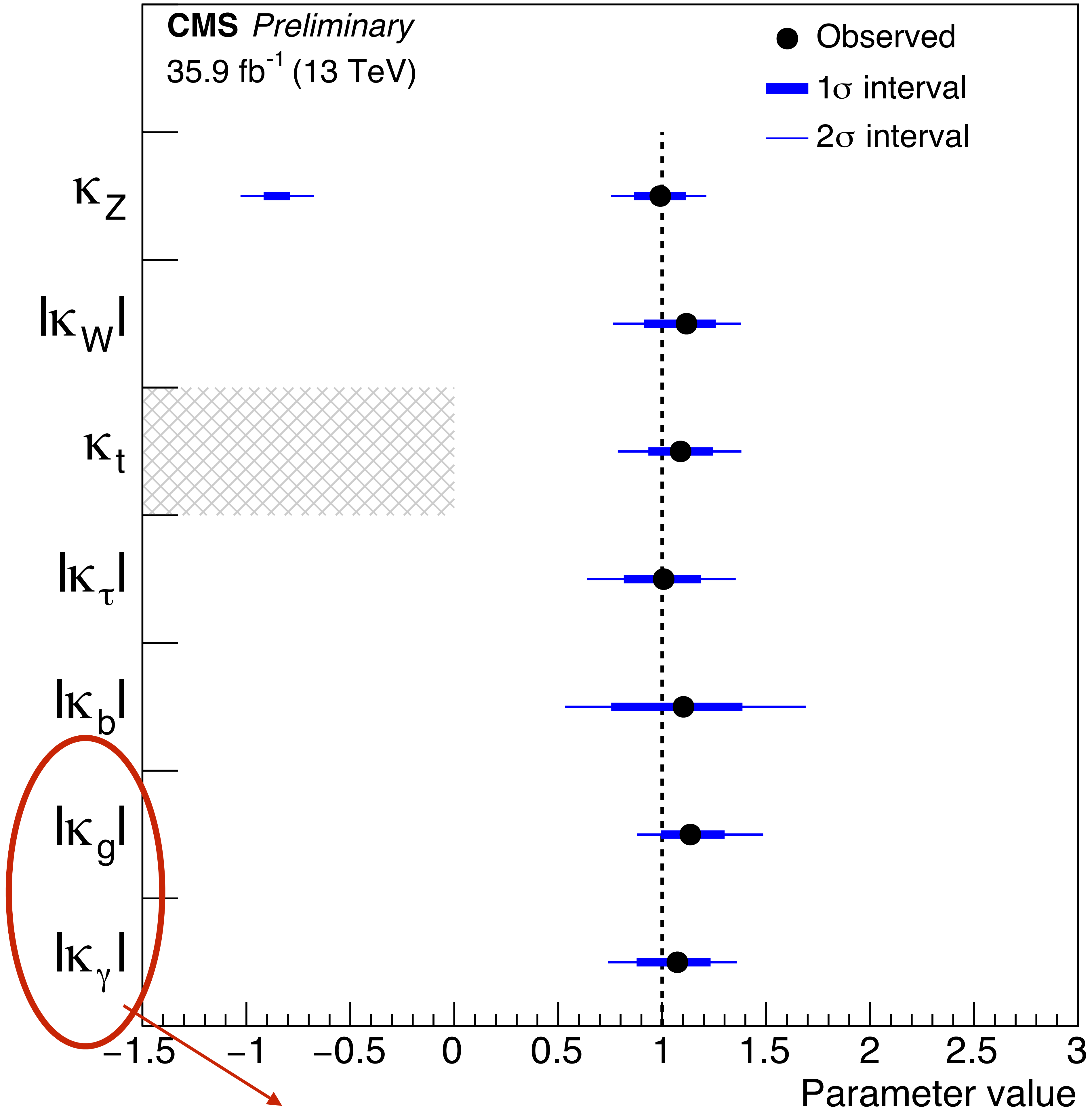


Coupling modifiers

Resolved g/γ loops, k-framework

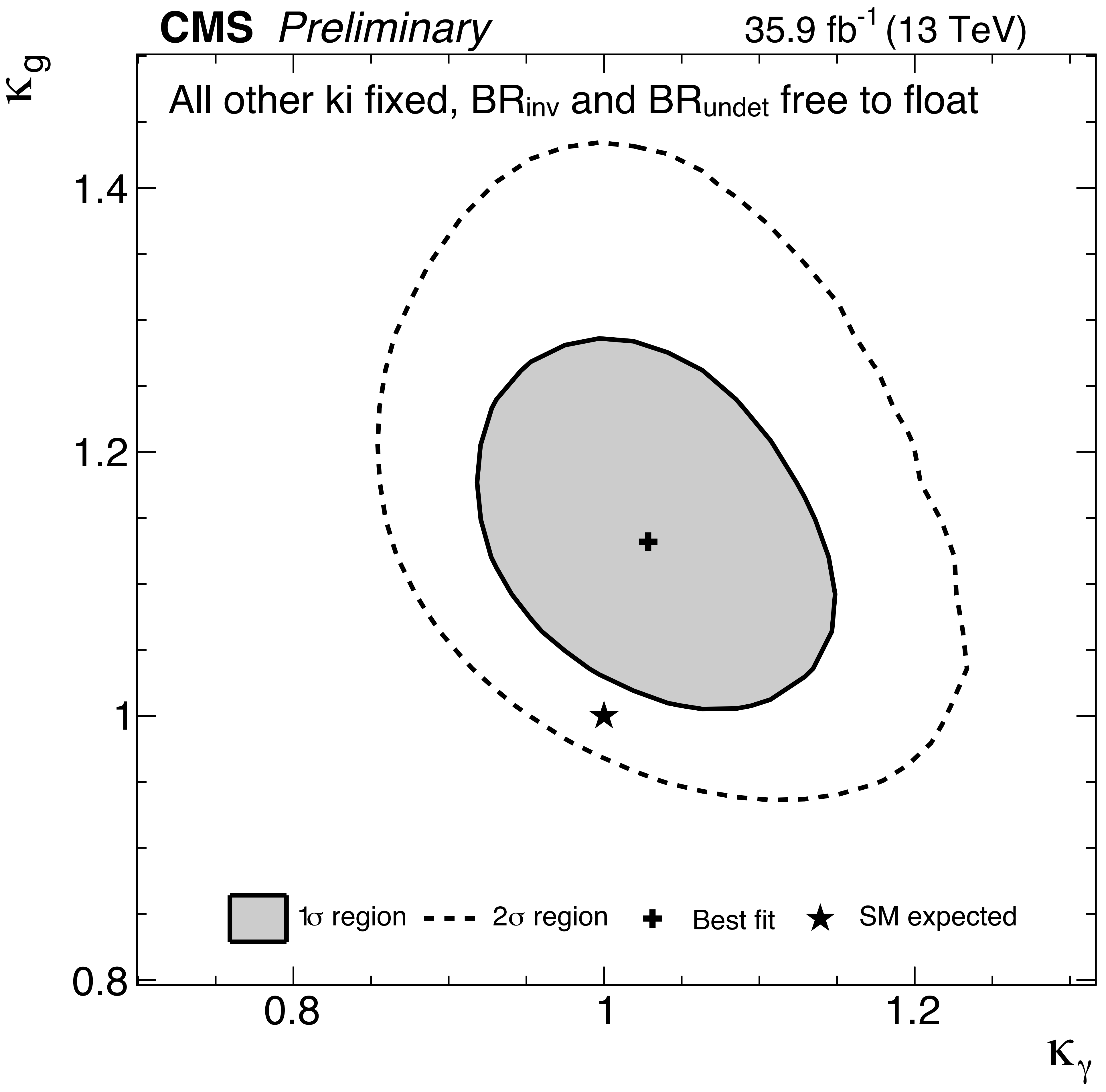


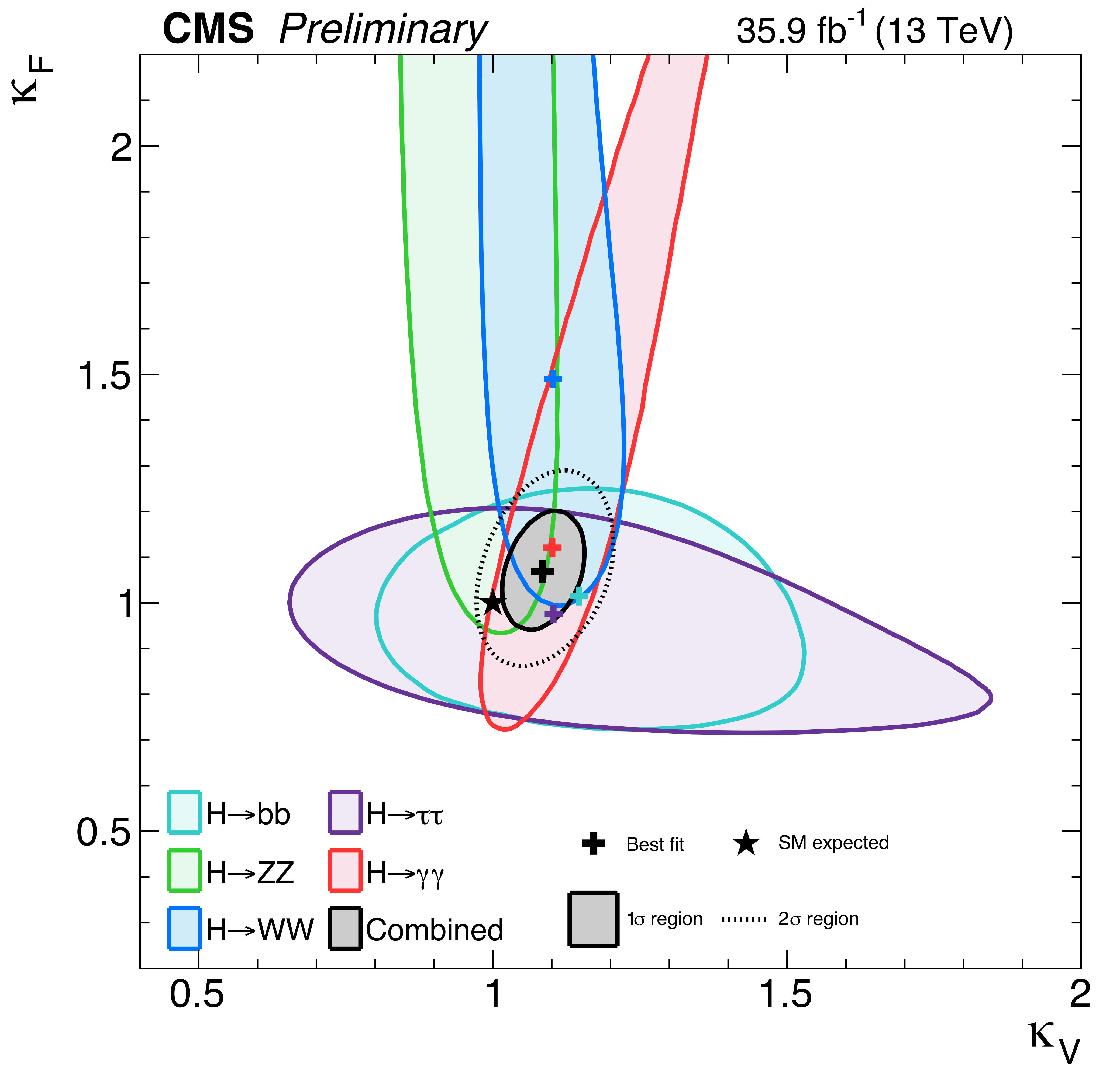
- Interference between processes, scaling can be sensitive to the relative sign of the k
- If possible, let k be negative (depends on the model)
- $k_b<0$ slightly favoured in the resolved model



Unresolved g/γ loops

Multidimensional scans in the k-space





2 parameters (k_V,K_F) or 10 parameters model (k^i_V, k^i_F)

Compatible results. Negative quadrant already excluded at Run 1

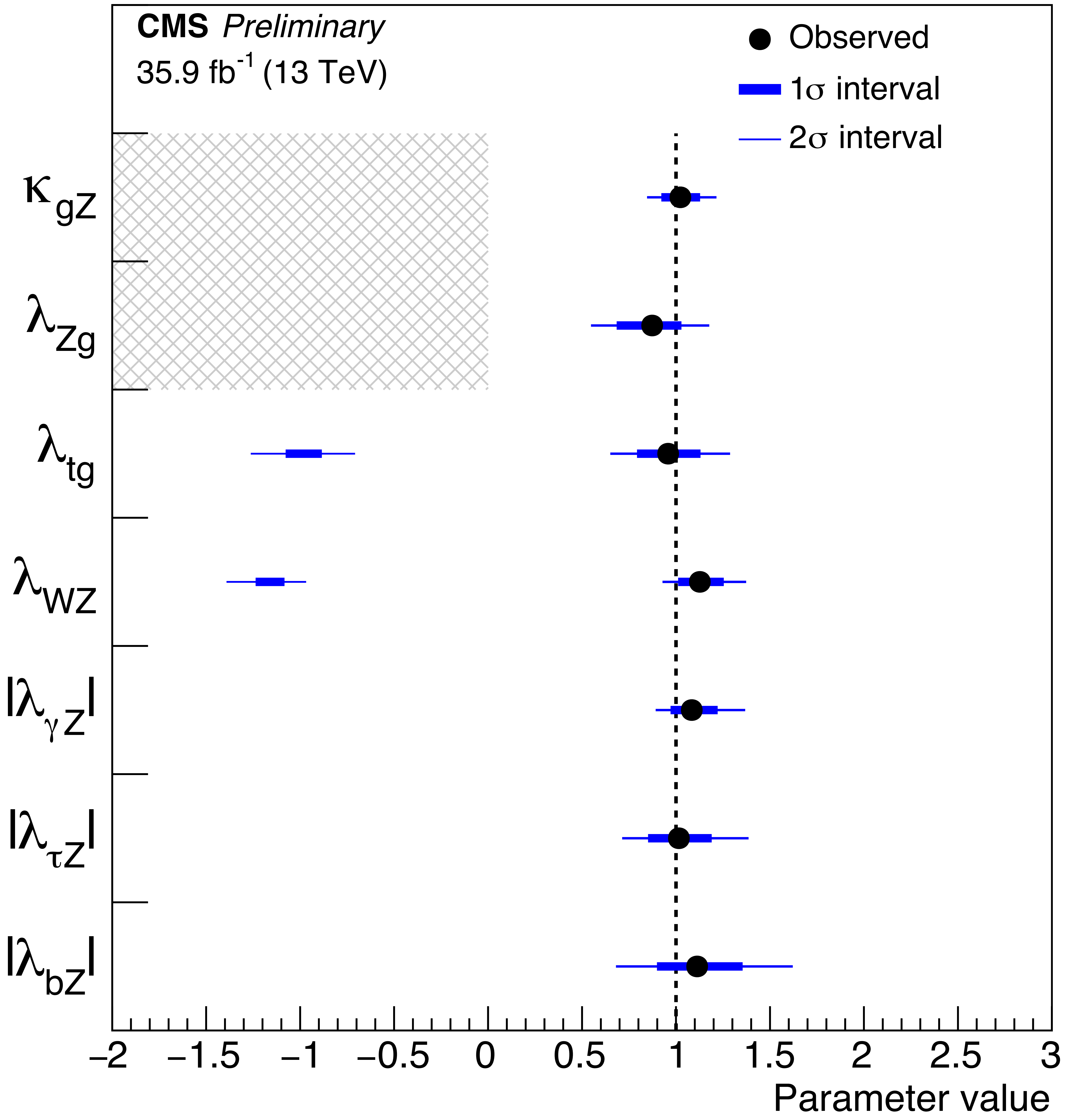
Ratios of coupling modifiers

Same concept as the ratio of signal strengths

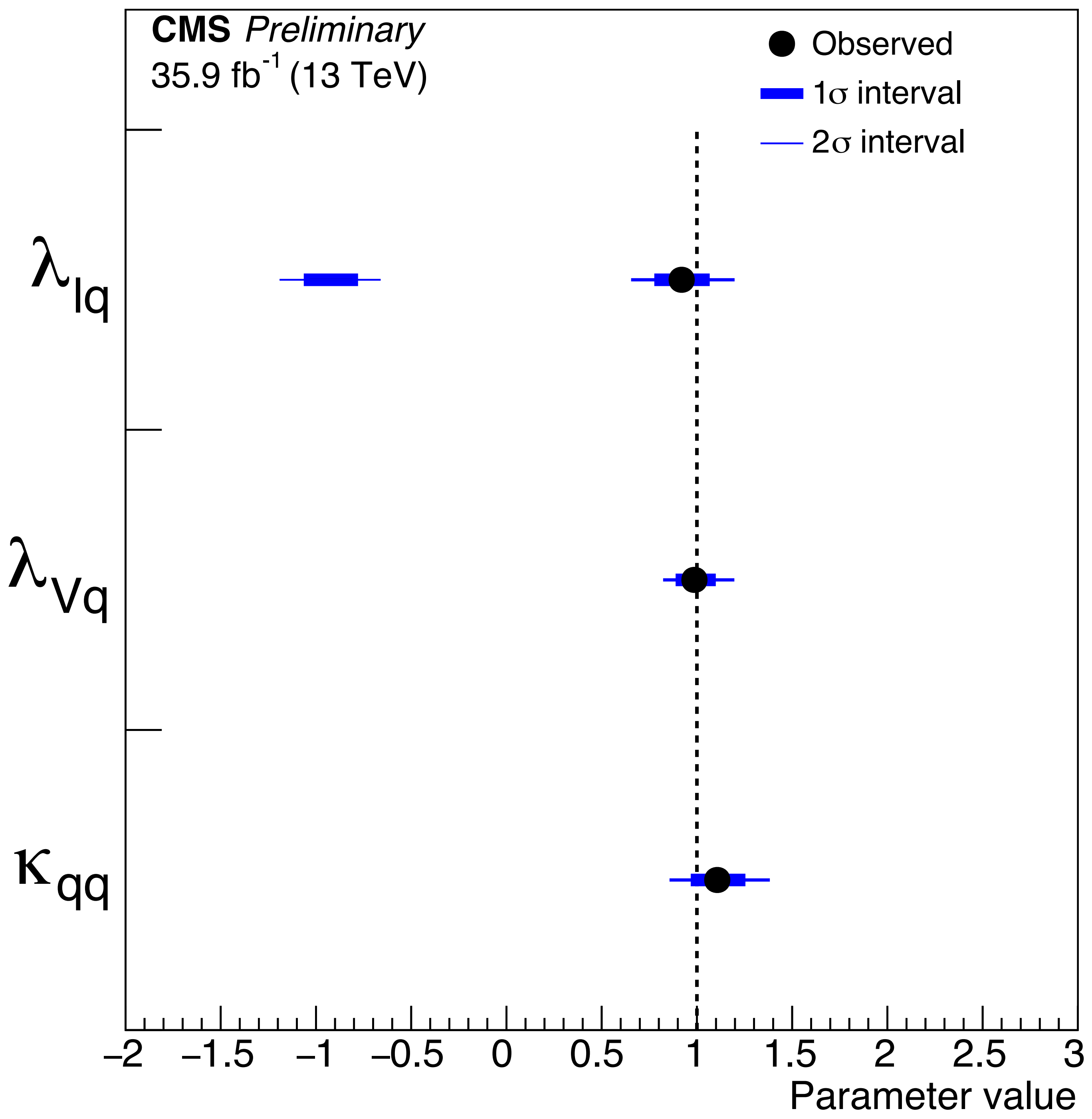
- Use the ratio to reduce the uncertainties on the measurement

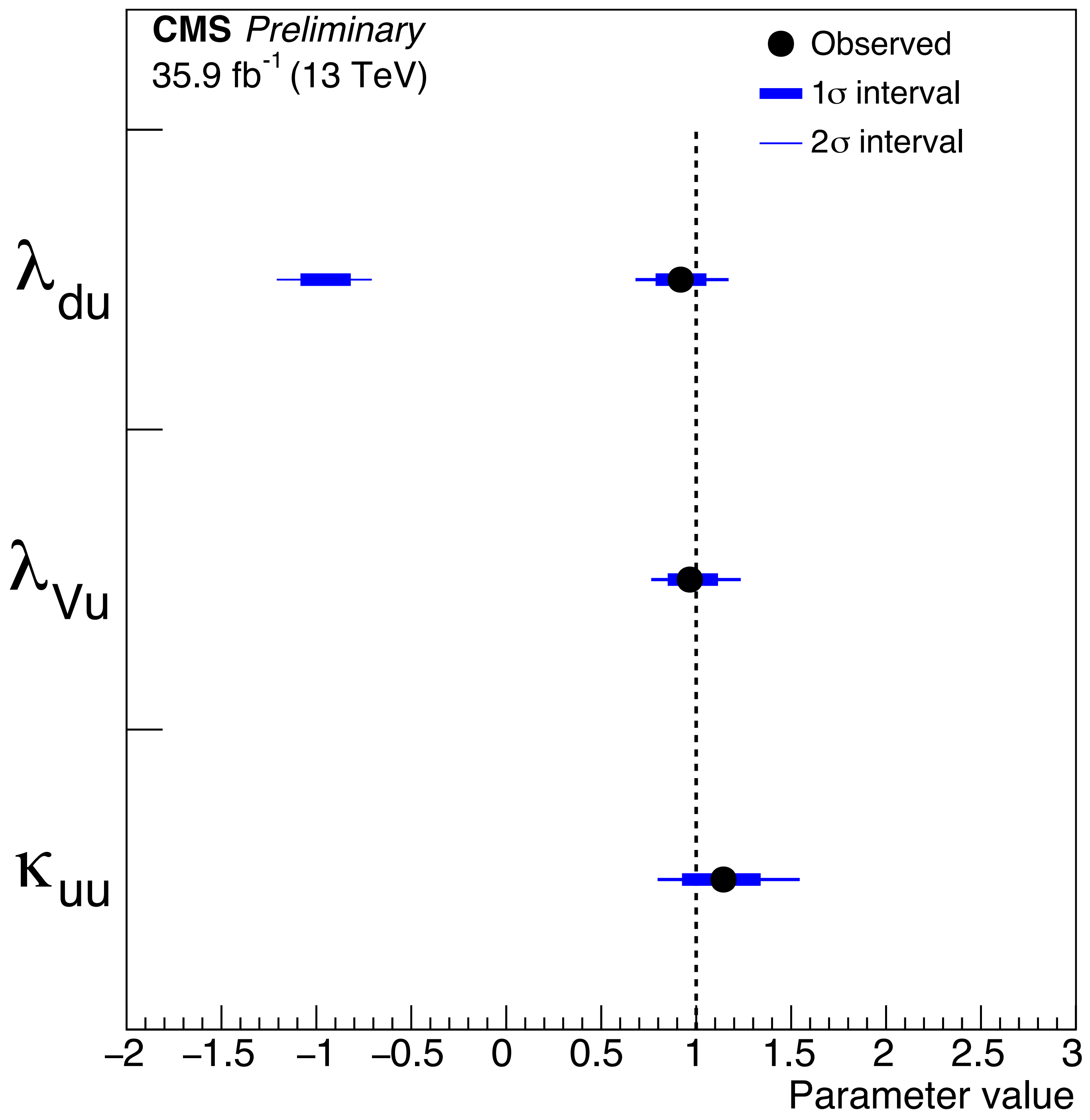
- Reference value: $k_{gZ} = k_g * k_Z/k_H$

Parameter	Best fit	Uncertainty Stat.	Uncertainty Syst.	Parameter	Best fit	Uncertainty Stat.	Uncertainty Syst.
κ_{gZ}	$1.02^{+0.09}_{-0.09}\left(^{+0.09}_{-0.09}\right)$	$^{+0.07}_{-0.07}\left(^{+0.07}_{-0.07}\right)$	$^{+0.05}_{-0.05}\left(^{+0.05}_{-0.05}\right)$	$\lambda_{\gamma Z}$	$1.08^{+0.12}_{-0.10}\left(^{+0.10}_{-0.09}\right)$	$^{+0.10}_{-0.09}\left(^{+0.09}_{-0.08}\right)$	$^{+0.07}_{-0.05}\left(^{+0.05}_{-0.04}\right)$
λ_{WZ}	$1.13^{+0.11}_{-0.10}\left(^{+0.11}_{-0.09}\right)$	$^{+0.09}_{-0.08}\left(^{+0.09}_{-0.08}\right)$	$^{+0.06}_{-0.06}\left(^{+0.06}_{-0.05}\right)$	λ_{bZ}	$1.11^{+0.23}_{-0.20}\left(^{+0.22}_{-0.19}\right)$	$^{+0.17}_{-0.17}\left(^{+0.16}_{-0.14}\right)$	$^{+0.16}_{-0.11}\left(^{+0.14}_{-0.13}\right)$
λ_{tg}	$0.96^{+0.16}_{-0.15}\left(^{+0.17}_{-0.16}\right)$	$^{+0.10}_{-0.10}\left(^{+0.11}_{-0.11}\right)$	$^{+0.13}_{-0.12}\left(^{+0.13}_{-0.12}\right)$	$\lambda_{\tau Z}$	$1.02^{+0.16}_{-0.15}\left(^{+0.16}_{-0.14}\right)$	$^{+0.11}_{-0.10}\left(^{+0.11}_{-0.10}\right)$	$^{+0.12}_{-0.11}\left(^{+0.11}_{-0.10}\right)$
λ_{Zg}	$0.87^{+0.14}_{-0.17}\left(^{+0.17}_{-0.16}\right)$	$^{+0.11}_{-0.15}\left(^{+0.13}_{-0.13}\right)$	$^{+0.09}_{-0.09}\left(^{+0.11}_{-0.09}\right)$			-	



Coupling to leptons and fermions



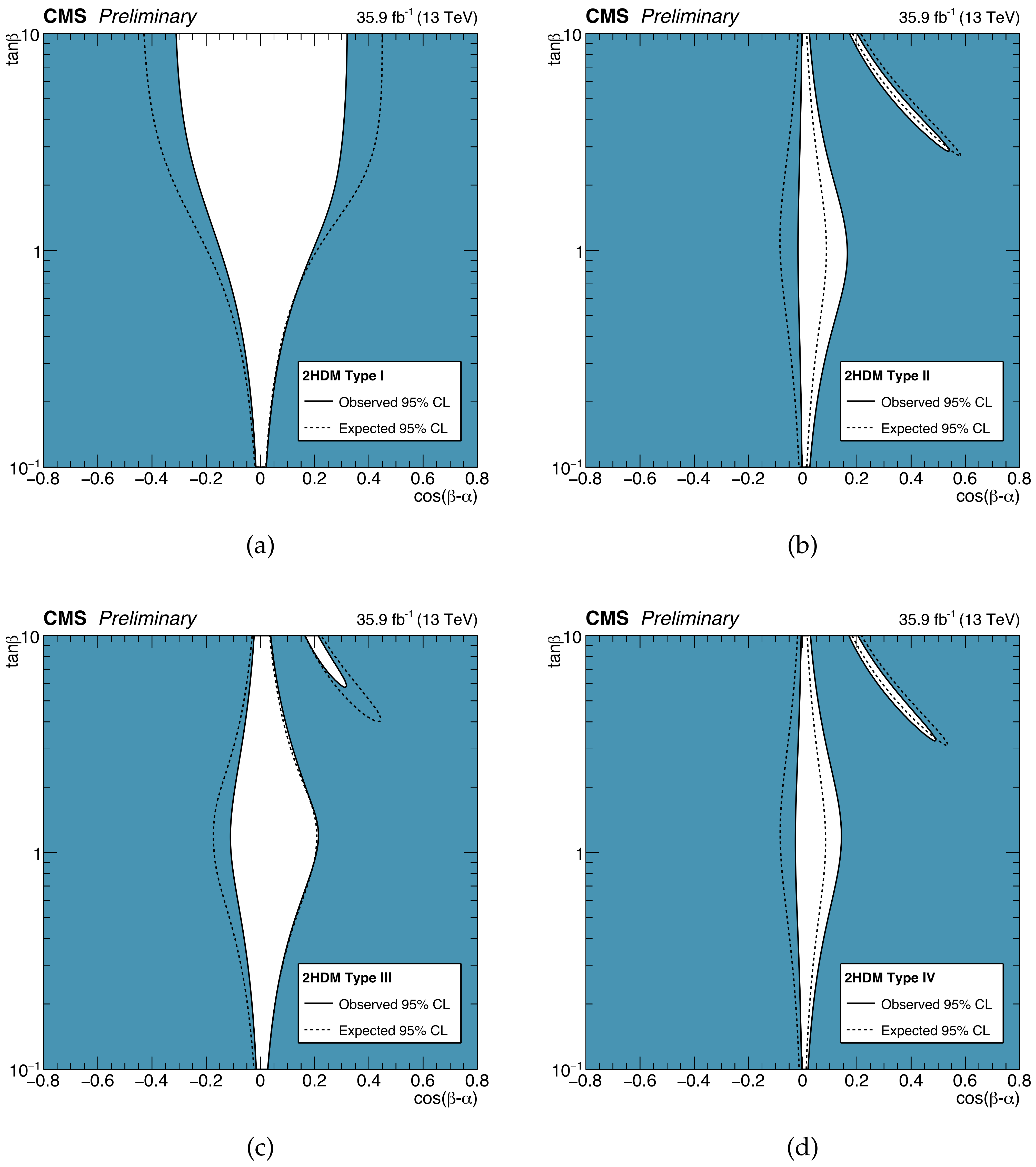


Test for SM deviations in the ratio between up/down quarks or in the ratio of the couplings between fermions and leptons

No deviations observed

The same structure can be used to test hMSSM/2HDM models

BSM models: 2HDM/hMSSM

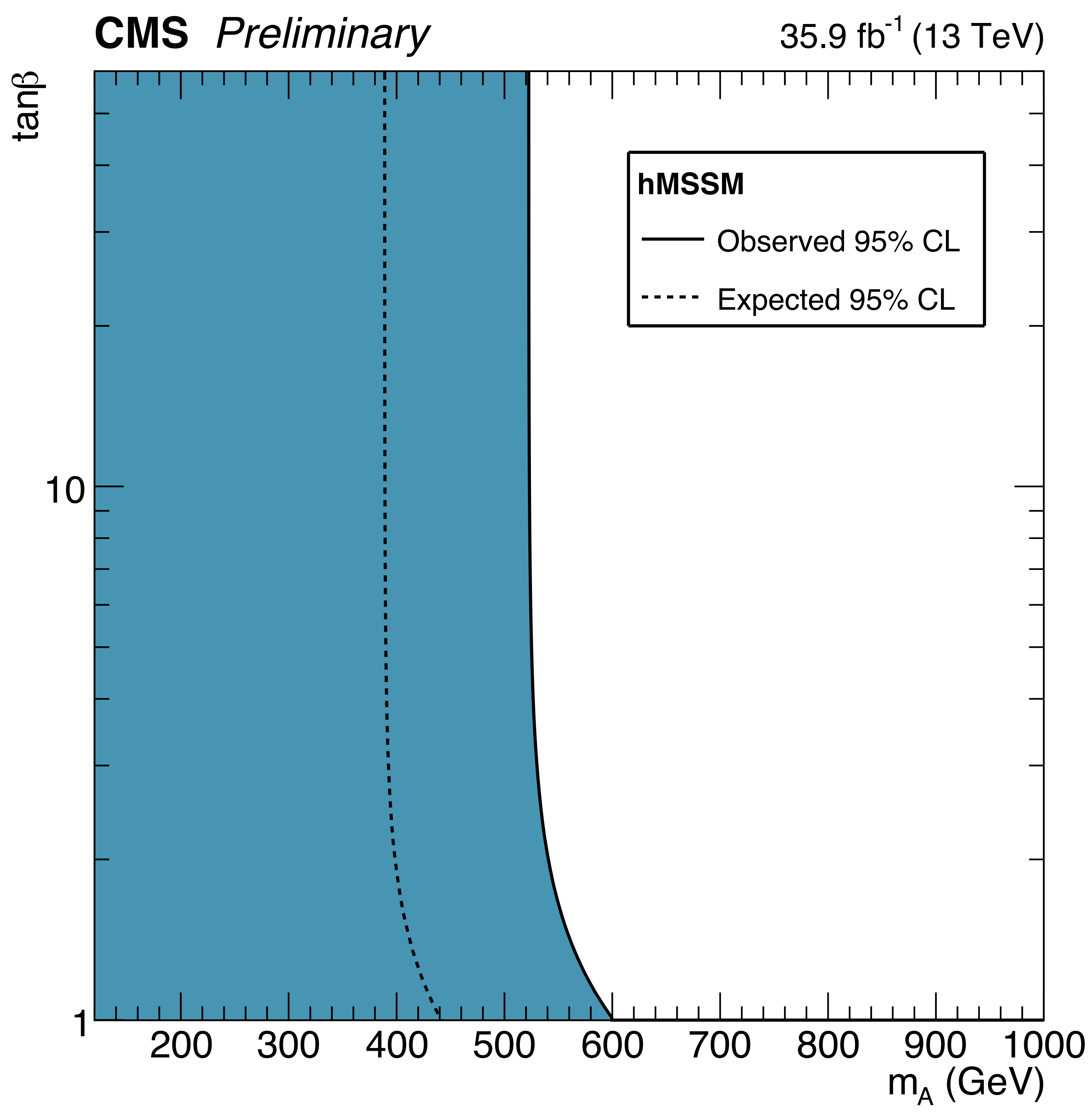


	2HDM				hMSSM
	type I	type II	Type III	Type IV	
κ_V	$\sin(\beta-\alpha)$	$\sin(\beta-\alpha)$	$\sin(\beta-\alpha)$	$\sin(\beta-\alpha)$	$\frac{s_d+s_u\tan\beta}{\sqrt{1+\tan^2\beta}}$
κ_u	$\cos(\alpha)/\sin(\beta)$	$\cos(\alpha)/\sin(\beta)$	$\cos(\alpha)/\sin(\beta)$	$\cos(\alpha)/\sin(\beta)$	$s_u\frac{\sqrt{1+\tan^2\beta}}{\tan\beta}$
κ_d	$\cos(\alpha)/\sin(\beta)$	$-\sin(\alpha)/\cos(\beta)$	$\cos(\alpha)/\sin(\beta)$	$-\sin(\alpha)/\cos(\beta)$	$s_d\sqrt{1+\tan^2\beta}$
κ_ℓ	$\cos(\alpha)/\sin(\beta)$	$-\sin(\alpha)/\cos(\beta)$	$-\sin(\alpha)/\cos(\beta)$	$\cos(\alpha)/\sin(\beta)$	$s_d\sqrt{1+\tan^2\beta}$

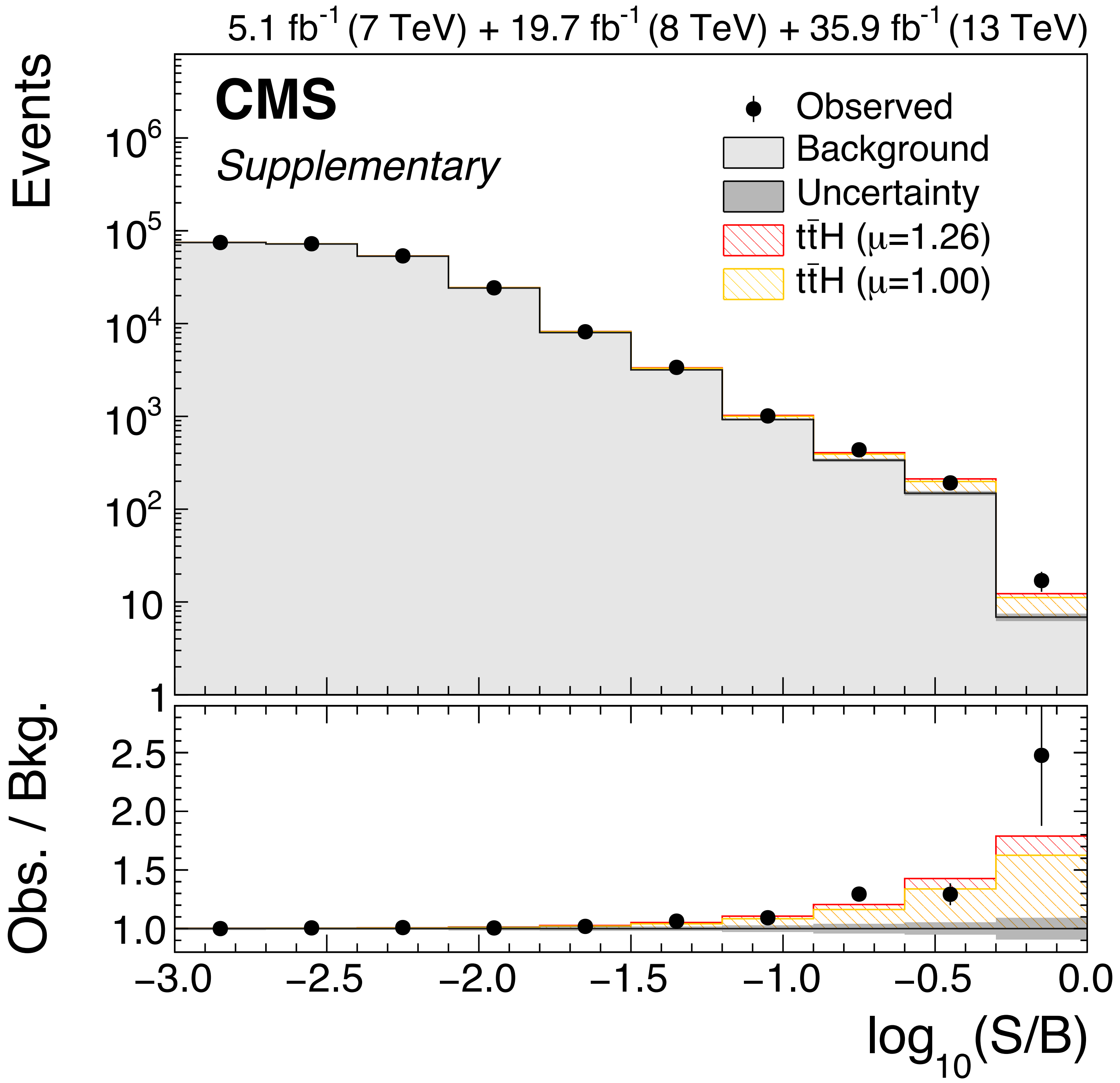
Translate 2HDM parameters to couplings and use a 3D likelihood function in $\{\lambda_{du}, \lambda_{Vu}, \kappa_{uu}\}$ or $\{\lambda_{lq}, \lambda_{Vq}, \kappa_{qq}\}$

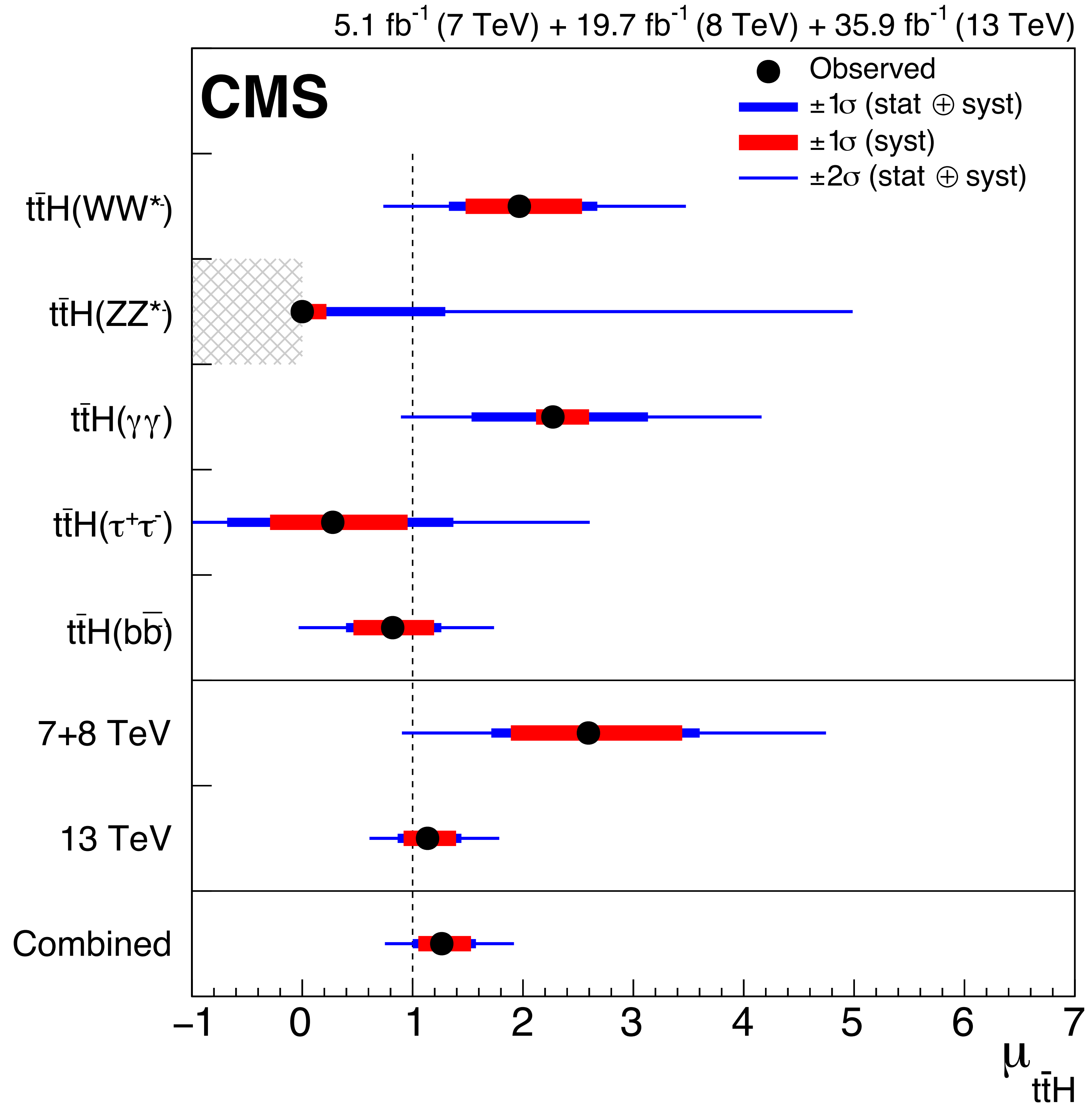
Lobe in 2HDM due to allowed $k_d<0$ values

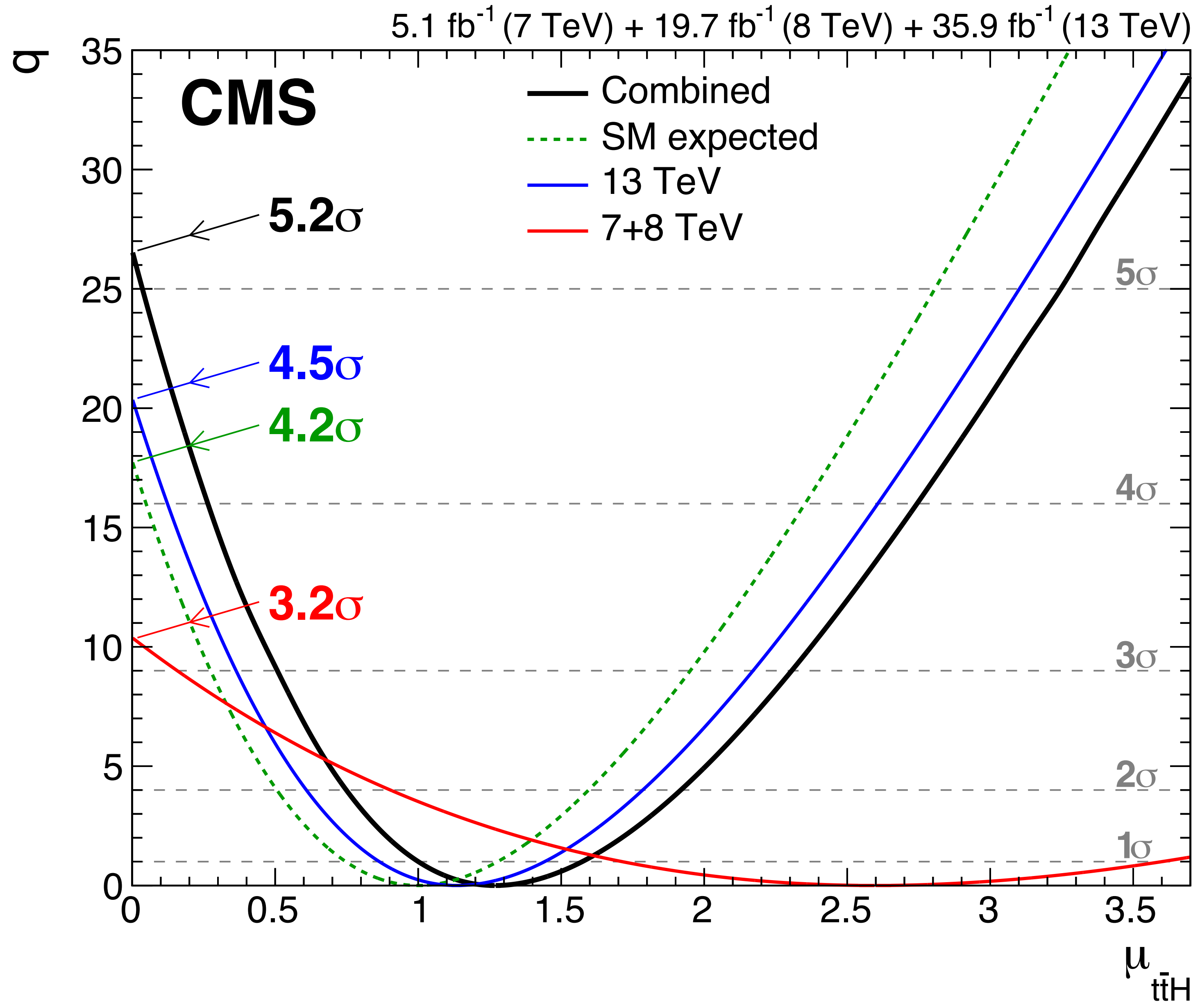
Significant improvement in hMSSM exclusion



ttH observation



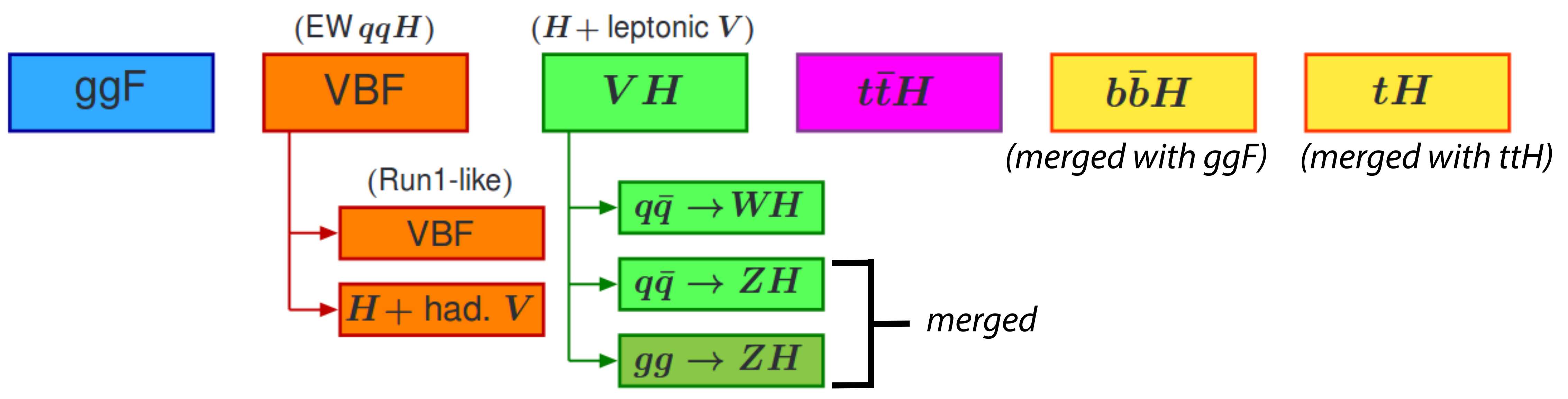


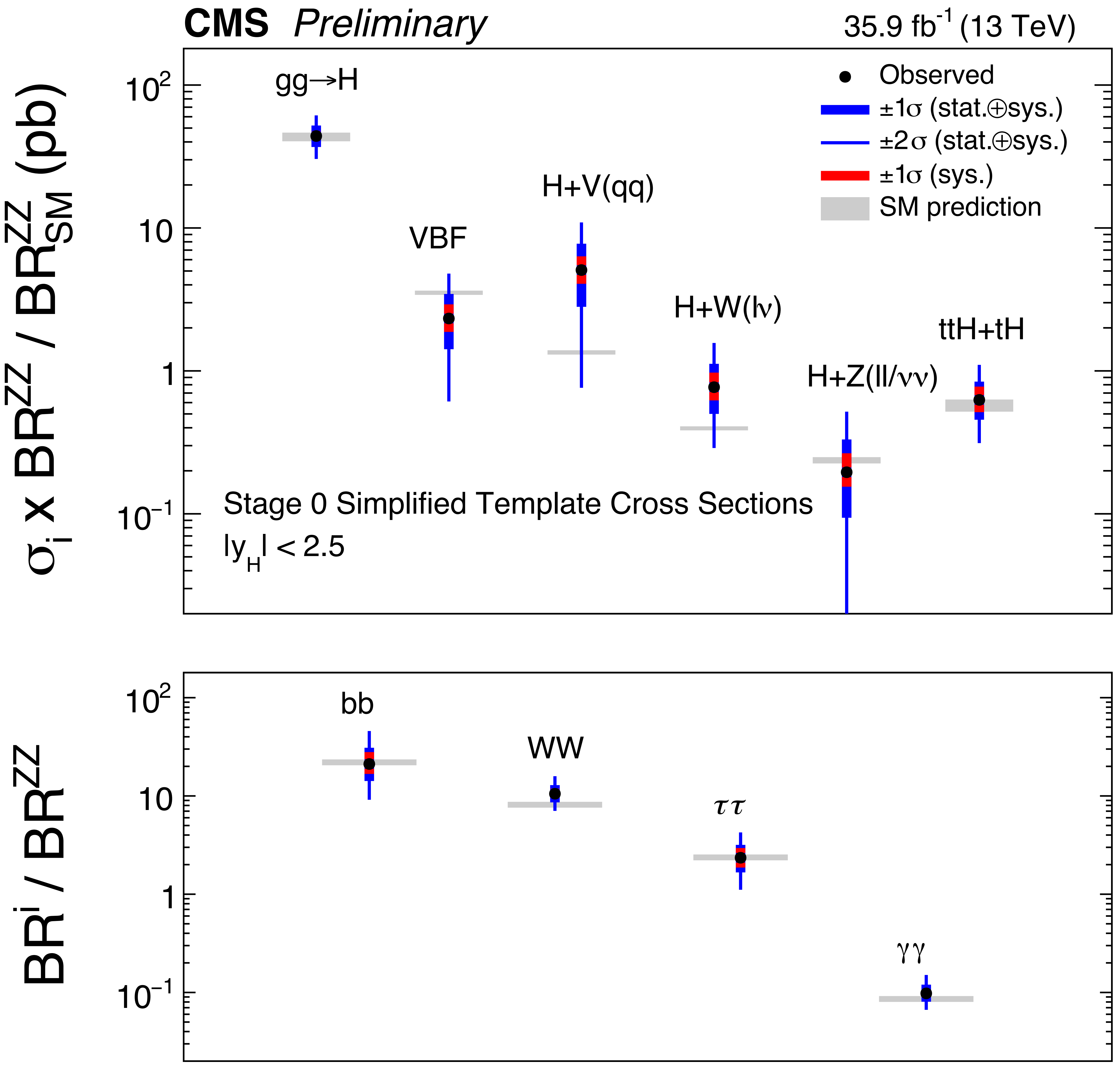


- Combination of Run1 and Run2 results (7+8+13TeV)
- Several Higgs decay (WW, ZZ, $\gamma\gamma$, ττ, bb) covered in multiple final states
- Slight over fluctuation in all 3 datasets, most evident in the high sensitivity region

$\mu_{ttH}=1.26^{+0.31}_{-0.26}$ corresponding to **5.2σ observed** (4.2σ expected)

Simplified Template Cross Section



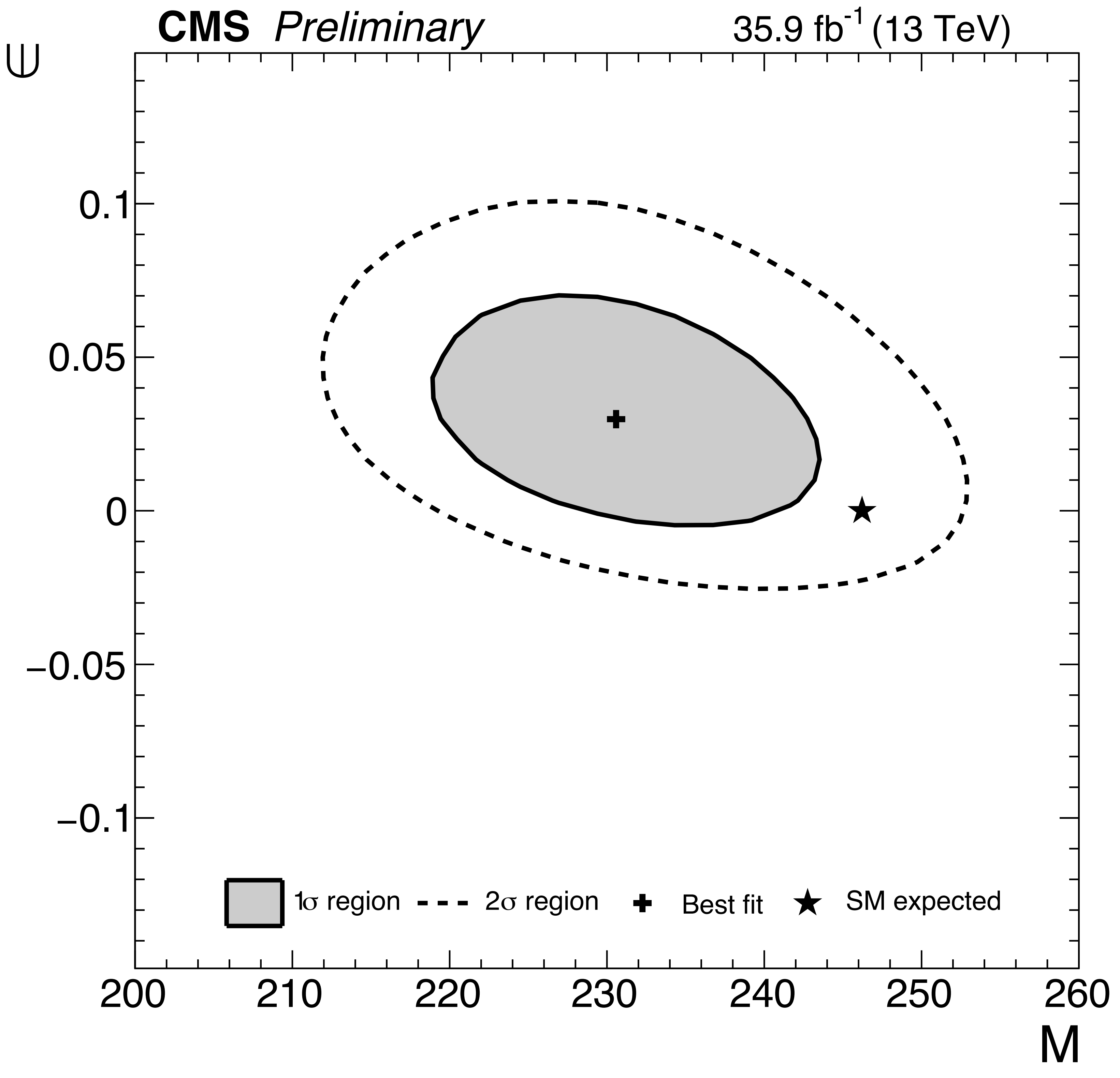


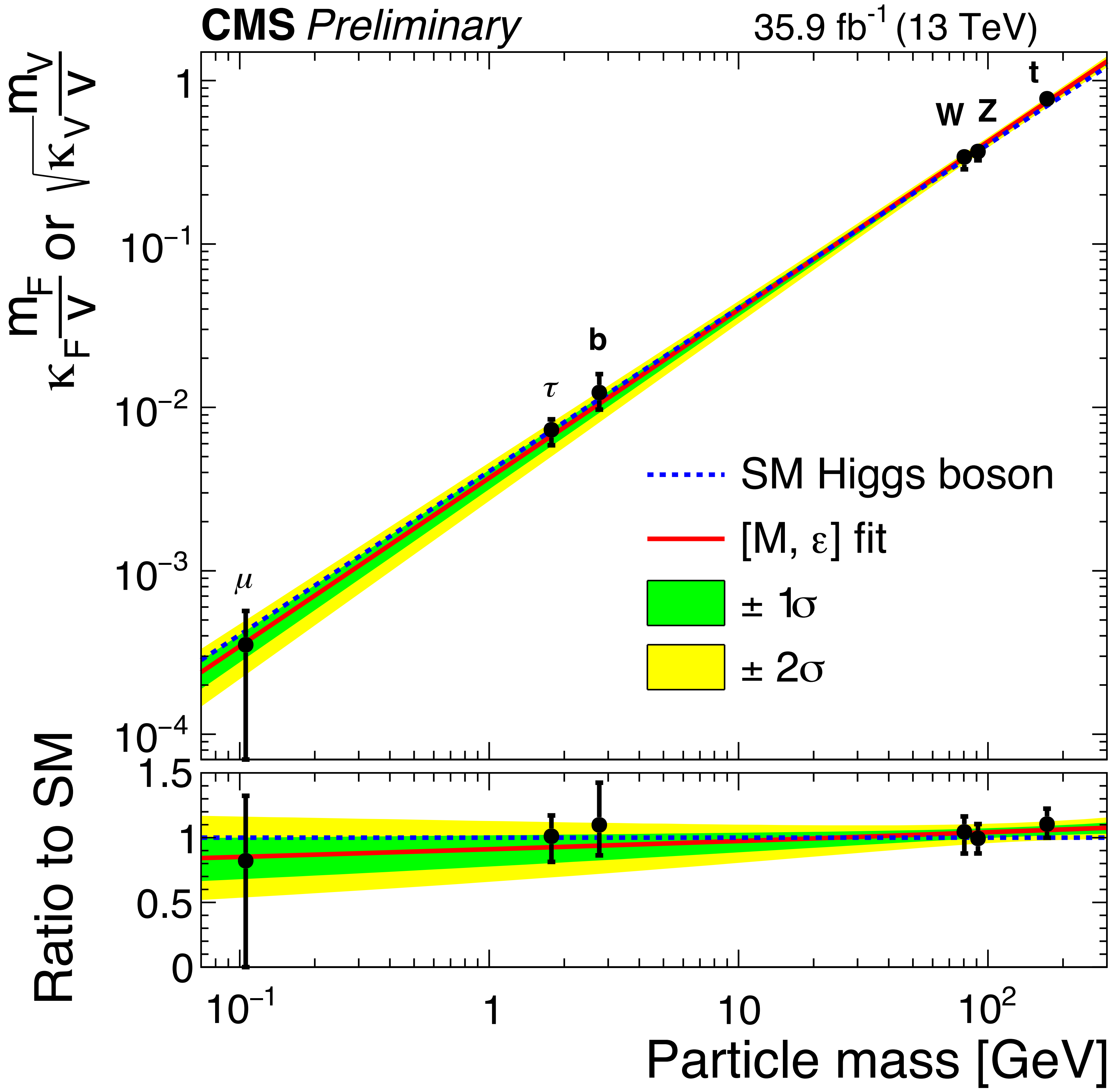
Good agreement between stage-0 prediction and observation, both in production and decay rates

Statistics not yet sufficient to perform a stage-1 combination

Mass scaling model

$$\kappa_{F,i} = v\frac{m_{F,i}^{\epsilon}}{M^{1+\epsilon}} \qquad \kappa_{V,i} = v\frac{m_{V,i}^{2\epsilon}}{M^{1+2\epsilon}}$$





- Resolved loops model used for the scaling.

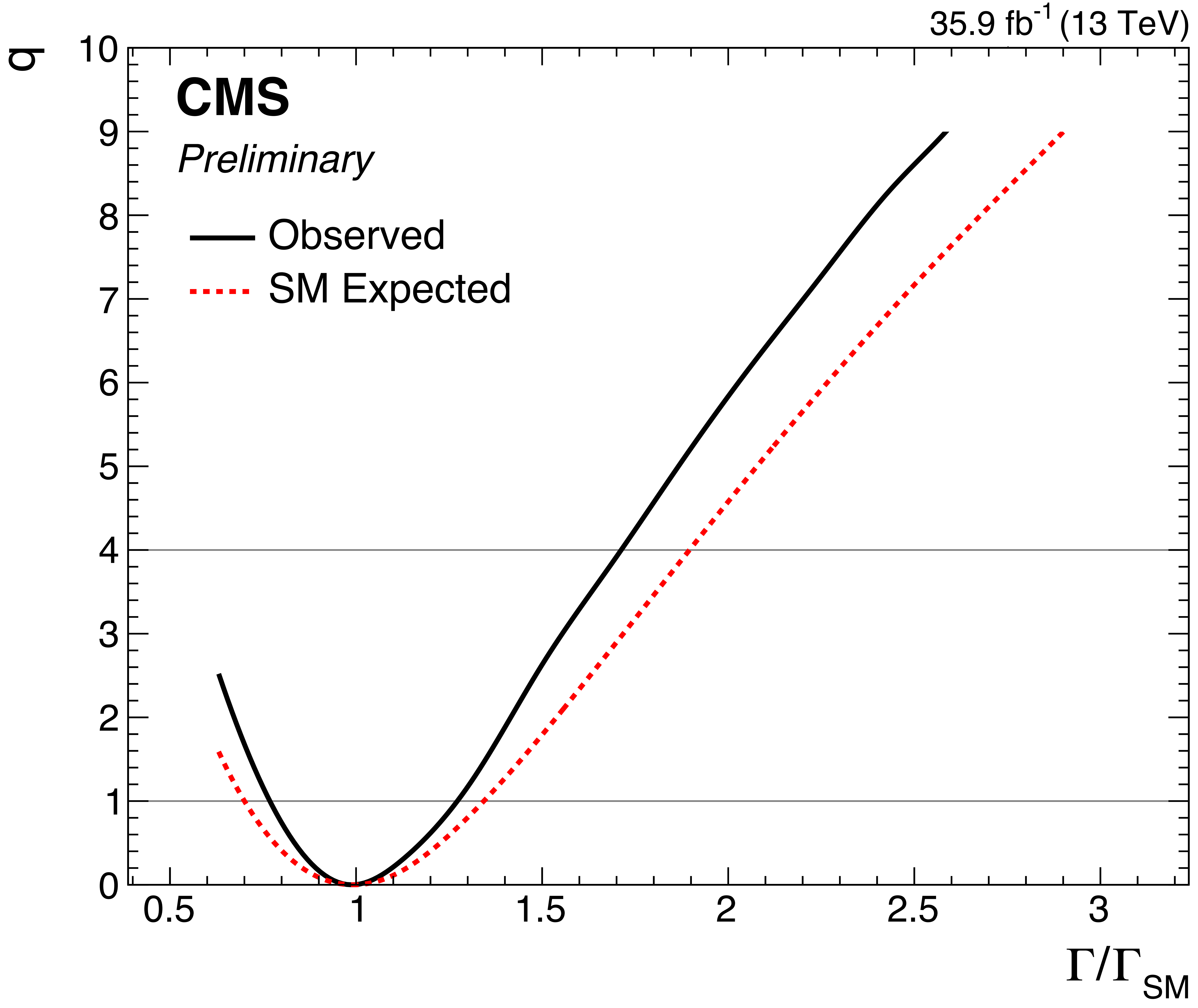
Higgs Width

Best fit: $\Gamma/\Gamma_{SM} = 0.98^{+0.29}_{-0.22}$

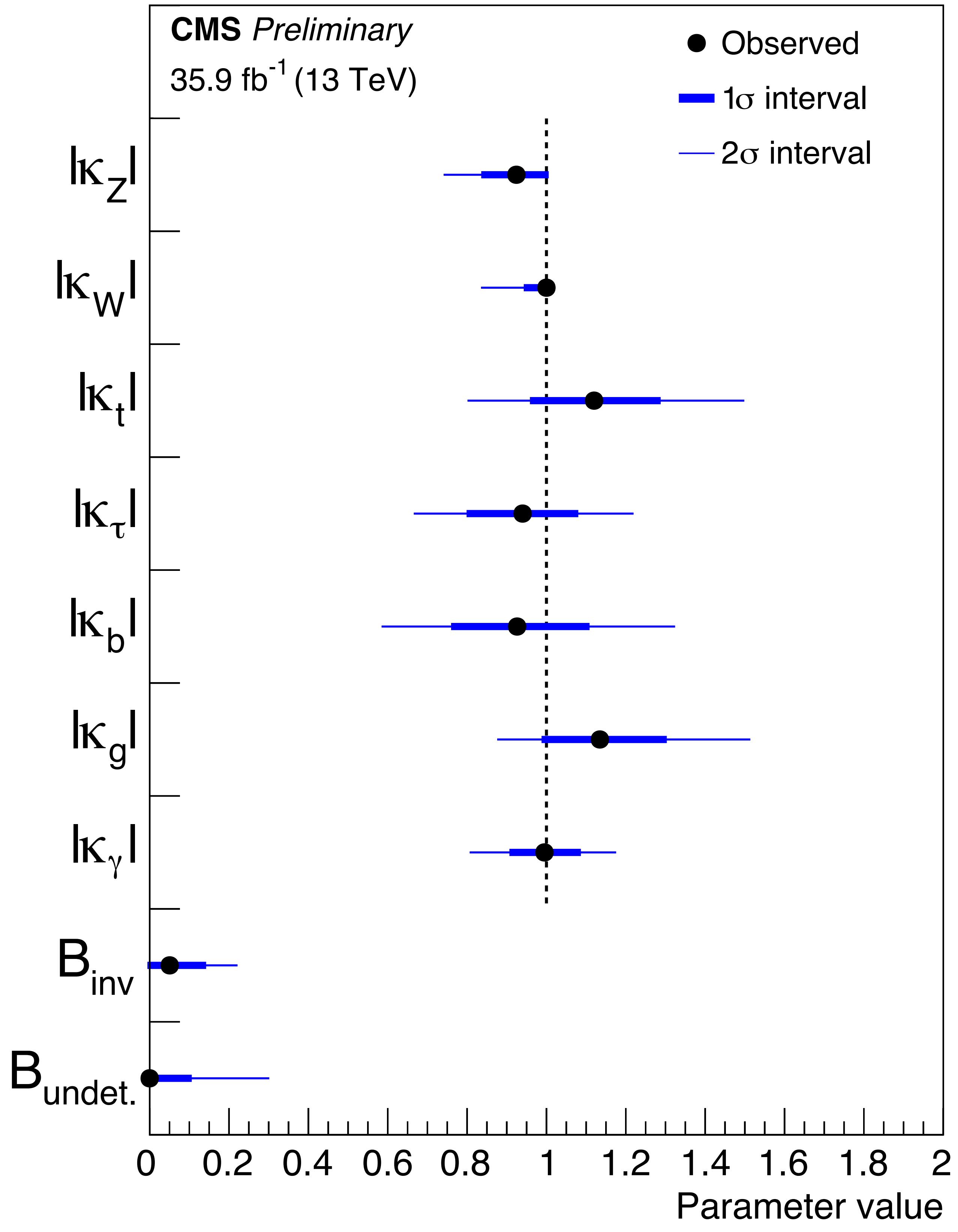
Unresolved model with effective gluon and photon couplings

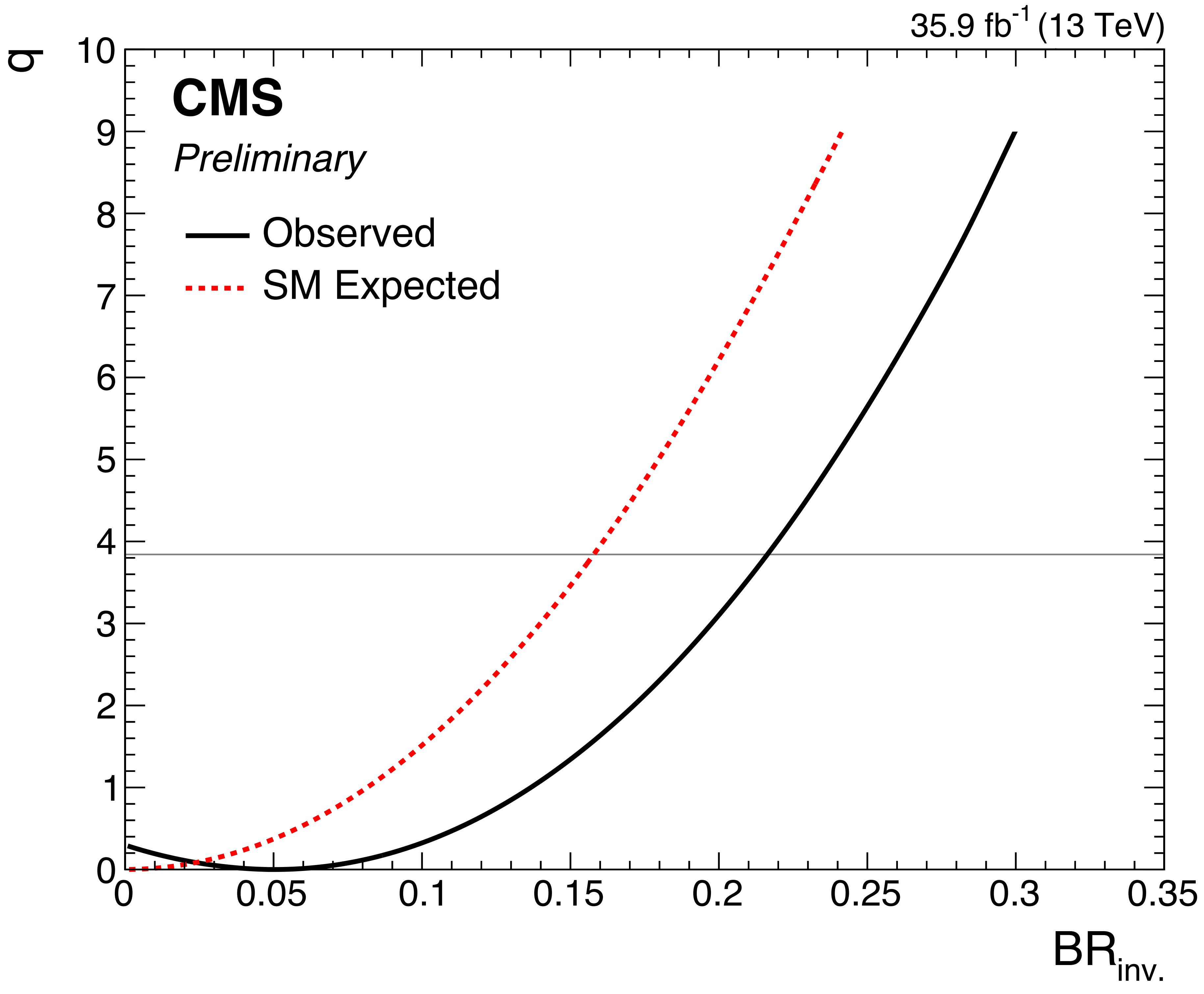
Dominated by experimental resolution

Not competitive with indirect measurements (off-shell), but more general

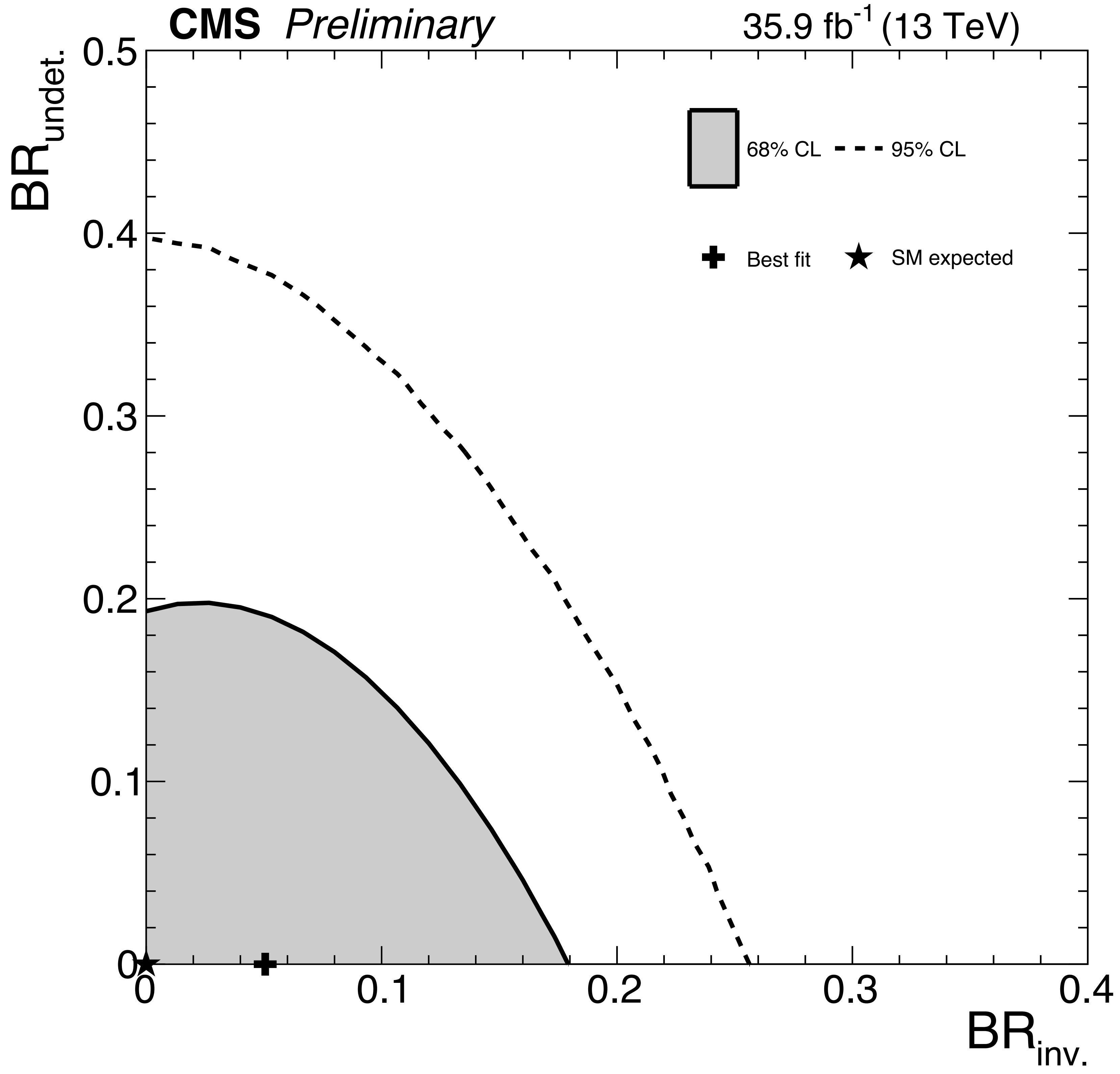


BSM models: Higgs to invisible





Assumption: |kV|<1



Without H_{inv} channel: BR_{BSM} < **0.31** (0.38) observed (expected) [*compare to LHC run1 < 0.34 (0.39)*]

Including H_{inv}:

- BR_{inv} < **0.22** (0.16) observed (expected)
- BR_{undet} < **0.29** (0.38) observed (expected)

Conclusions

The full combination of 2016 CMS single Higgs results has been presented
Results reported in HIG-17-031

Most precise measurement of Higgs properties available

Ever more results included in the combination (width, STXS, hMSSM)

No significant discrepancies observed with respect to expectations

Statistical precision at the level of theory and systematic uncertainties

We are readying for the legacy Run2 combination with ATLAS

BACKUP

Co-funded by the
Horizon 2020
Framework
Programme of the
European Union

Signal strengths

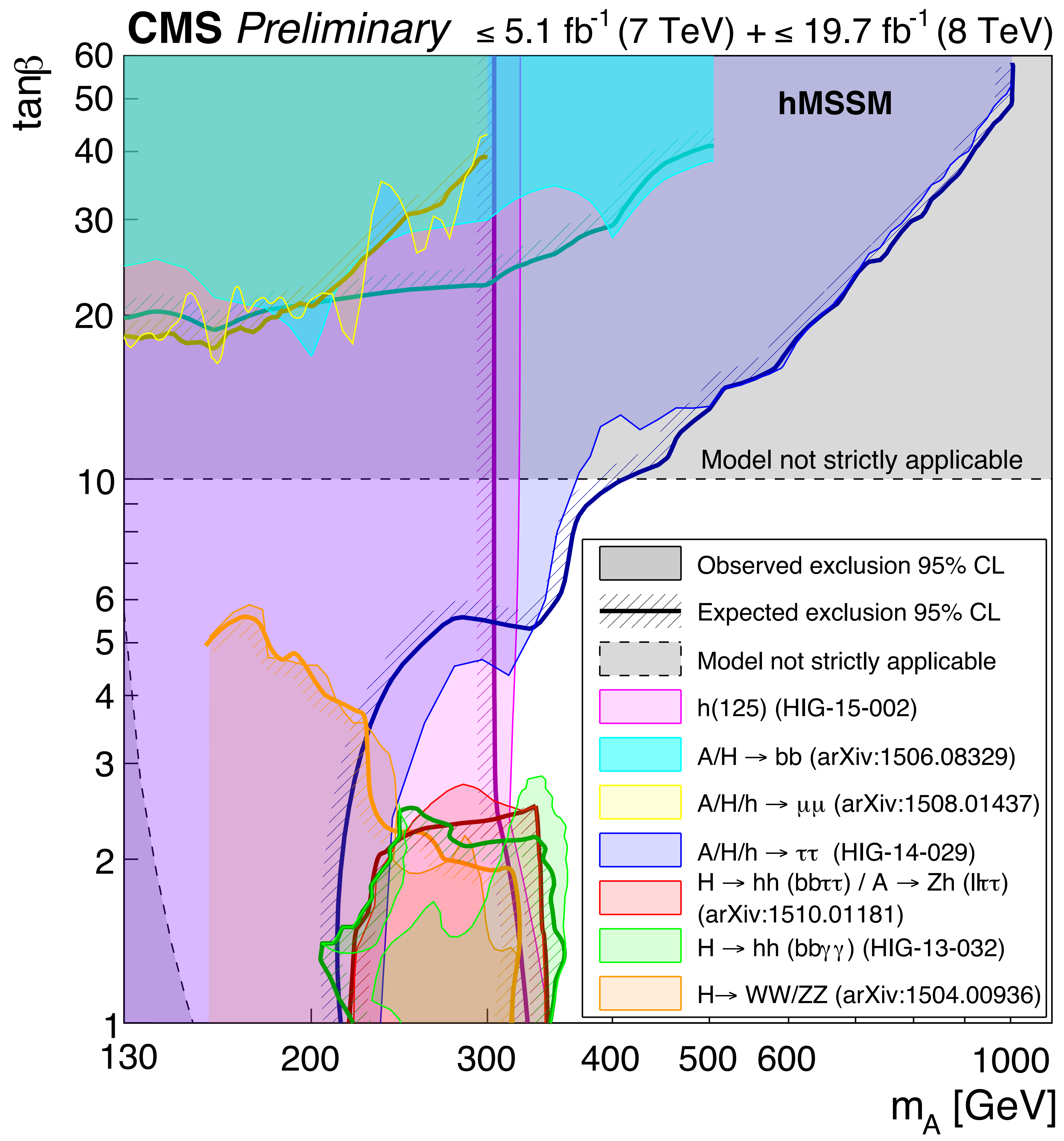
Production process	Best fit value	Uncertainty Stat.	Uncertainty Syst.
ggH	$1.23^{+0.14}_{-0.13}$ $\left(^{+0.11}_{-0.11}\right)$	$^{+0.08}_{-0.08}$ $\left(^{+0.07}_{-0.07}\right)$	$^{+0.12}_{-0.10}$ $\left(^{+0.09}_{-0.08}\right)$
VBF	$0.73^{+0.30}_{-0.27}$ $\left(^{+0.29}_{-0.27}\right)$	$^{+0.24}_{-0.23}$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

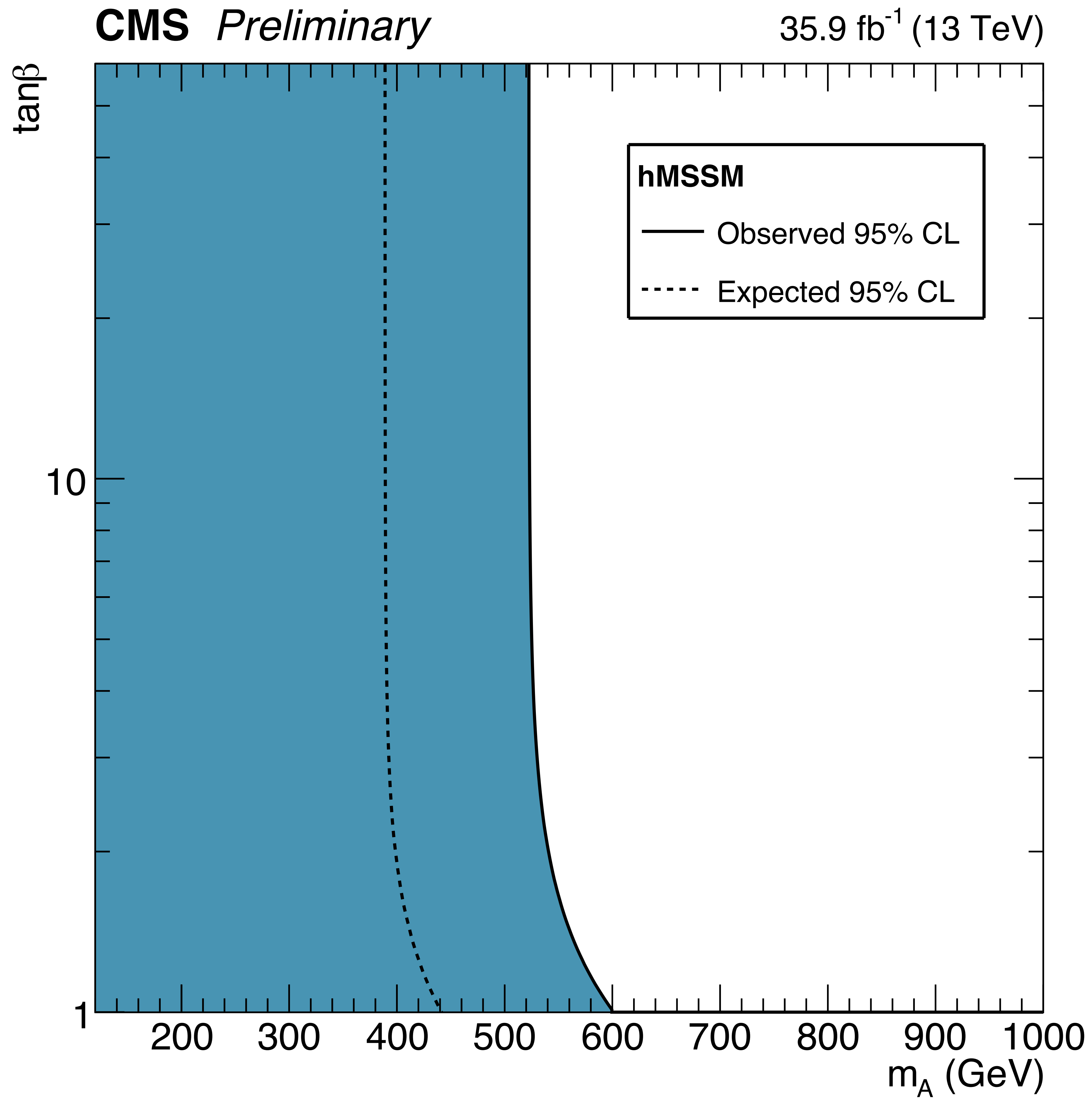
Decay mode	Best fit value	Uncertainty Stat.	Uncertainty Syst.
$H \to bb$	$1.12^{+0.29}_{-0.28}$ $\left(^{+0.28}_{-0.27}\right)$	$^{+0.19}_{-0.19}$ $\left(^{+0.19}_{-0.18}\right)$	$^{+0.22}_{-0.20}$ $\left(^{+0.21}_{-0.20}\right)$
$H \to \tau\tau$	$1.02^{+0.26}_{-0.24}$ $\left(^{+0.24}_{-0.23}\right)$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

Signal strengths

Production process	Decay mode														
	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.
$H \rightarrow bb$	$2.51\,^{+2.44}_{-2.01}$ $\left(^{+2.06}_{-1.86}\right)$	$^{+1.96}_{-1.92}$ $\left(^{+1.86}_{-1.83}\right)$	$^{+1.46}_{-0.59}$ $\left(^{+0.89}_{-0.33}\right)$	– (–)			$1.73\,^{+0.70}_{-0.68}$ $\left(^{+0.69}_{-0.67}\right)$	$^{+0.53}_{-0.51}$ $\left(^{+0.53}_{-0.51}\right)$	$^{+0.46}_{-0.44}$ $\left(^{+0.45}_{-0.44}\right)$	$0.99\,^{+0.48}_{-0.45}$ $\left(^{+0.46}_{-0.44}\right)$	$^{+0.41}_{-0.40}$ $\left(^{+0.40}_{-0.39}\right)$	$^{+0.23}_{-0.20}$ $\left(^{+0.23}_{-0.20}\right)$	$0.91\,^{+0.45}_{-0.43}$ $\left(^{+0.44}_{-0.42}\right)$	$^{+0.24}_{-0.24}$ $\left(^{+0.24}_{-0.23}\right)$	$^{+0.38}_{-0.36}$ $\left(^{+0.37}_{-0.35}\right)$
$H \rightarrow \tau\tau$	$1.05\,^{+0.53}_{-0.47}$ $\left(^{+0.45}_{-0.41}\right)$	$^{+0.25}_{-0.25}$ $\left(^{+0.23}_{-0.23}\right)$	$^{+0.47}_{-0.40}$ $\left(^{+0.38}_{-0.34}\right)$	$1.12\,^{+0.45}_{-0.43}$ $\left(^{+0.45}_{-0.43}\right)$	$^{+0.37}_{-0.35}$ $\left(^{+0.37}_{-0.35}\right)$	$^{+0.25}_{-0.25}$ $\left(^{+0.25}_{-0.24}\right)$	– (–)			– (–)			$0.22\,^{+1.03}_{-0.88}$ $\left(^{+0.98}_{-0.87}\right)$	$^{+0.80}_{-0.71}$ $\left(^{+0.80}_{-0.73}\right)$	$^{+0.65}_{-0.52}$ $\left(^{+0.56}_{-0.47}\right)$
$H \rightarrow WW$	$1.35\,^{+0.20}_{-0.19}$ $\left(^{+0.17}_{-0.16}\right)$	$^{+0.12}_{-0.12}$ $\left(^{+0.10}_{-0.10}\right)$	$^{+0.17}_{-0.15}$ $\left(^{+0.13}_{-0.12}\right)$	$0.28\,^{+0.64}_{-0.60}$ $\left(^{+0.63}_{-0.58}\right)$	$^{+0.58}_{-0.53}$ $\left(^{+0.57}_{-0.53}\right)$	$^{+0.28}_{-0.28}$ $\left(^{+0.26}_{-0.25}\right)$	$3.91\,^{+2.26}_{-2.01}$ $\left(^{+1.47}_{-1.19}\right)$	$^{+1.89}_{-1.72}$ $\left(^{+1.32}_{-1.06}\right)$	$^{+1.24}_{-1.05}$ $\left(^{+0.64}_{-0.54}\right)$	$0.96\,^{+1.81}_{-1.46}$ $\left(^{+1.67}_{-1.37}\right)$	$^{+1.74}_{-1.44}$ $\left(^{+1.61}_{-1.35}\right)$	$^{+0.51}_{-0.22}$ $\left(^{+0.45}_{-0.20}\right)$	$1.60\,^{+0.66}_{-0.59}$ $\left(^{+0.56}_{-0.53}\right)$	$^{+0.40}_{-0.39}$ $\left(^{+0.38}_{-0.38}\right)$	$^{+0.52}_{-0.45}$ $\left(^{+0.41}_{-0.38}\right)$
$H \rightarrow ZZ$	$1.22\,^{+0.24}_{-0.21}$ $\left(^{+0.22}_{-0.20}\right)$	$^{+0.20}_{-0.19}$ $\left(^{+0.20}_{-0.19}\right)$	$^{+0.12}_{-0.10}$ $\left(^{+0.10}_{-0.07}\right)$	$-0.09\,^{+1.02}_{-0.76}$ $\left(^{+1.27}_{-0.99}\right)$	$^{+1.00}_{-0.72}$ $\left(^{+1.25}_{-0.97}\right)$	$^{+0.21}_{-0.22}$ $\left(^{+0.24}_{-0.21}\right)$	$0.00\,^{+2.32}_{+0.00}$ $\left(^{+4.45}_{-0.99}\right)$	$^{+2.31}_{-0.00}$ $\left(^{+4.41}_{-0.99}\right)$	$^{+0.28}_{-0.00}$ $\left(^{+0.57}_{-0.00}\right)$	$0.00\,^{+4.26}_{+0.00}$ $\left(^{+7.58}_{-0.99}\right)$	$^{+4.19}_{-0.00}$ $\left(^{+7.46}_{-0.99}\right)$	$^{+0.81}_{-0.00}$ $\left(^{+1.33}_{-0.00}\right)$	$0.00\,^{+1.51}_{+0.00}$ $\left(^{+2.95}_{-0.99}\right)$	$^{+1.48}_{-0.00}$ $\left(^{+2.89}_{-0.99}\right)$	$^{+0.31}_{-0.00}$ $\left(^{+0.59}_{-0.00}\right)$
$H \rightarrow \gamma\gamma$	$1.15\,^{+0.21}_{-0.18}$ $\left(^{+0.17}_{-0.16}\right)$	$^{+0.17}_{-0.15}$ $\left(^{+0.14}_{-0.14}\right)$	$^{+0.13}_{-0.10}$ $\left(^{+0.11}_{-0.08}\right)$	$0.68\,^{+0.59}_{-0.45}$ $\left(^{+0.59}_{-0.48}\right)$	$^{+0.49}_{-0.42}$ $\left(^{+0.48}_{-0.43}\right)$	$^{+0.32}_{-0.18}$ $\left(^{+0.34}_{-0.21}\right)$	$3.71\,^{+1.49}_{-1.35}$ $\left(^{+1.29}_{-1.16}\right)$	$^{+1.45}_{-1.33}$ $\left(^{+1.28}_{-1.16}\right)$	$^{+0.35}_{-0.23}$ $\left(^{+0.13}_{-0.06}\right)$	$0.00\,^{+1.13}_{+0.00}$ $\left(^{+2.52}_{-1.04}\right)$	$^{+1.13}_{-0.00}$ $\left(^{+2.50}_{-1.04}\right)$	$^{+0.09}_{-0.00}$ $\left(^{+0.24}_{-0.00}\right)$	$2.14\,^{+0.87}_{-0.74}$ $\left(^{+0.72}_{-0.62}\right)$	$^{+0.81}_{-0.72}$ $\left(^{+0.71}_{-0.62}\right)$	$^{+0.31}_{-0.14}$ $\left(^{+0.15}_{-0.06}\right)$

hMSSM


CMS Preliminary ≤ 5.1 fb-1 (7 TeV) + ≤ 19.7 fb-1 (8 TeV)
hMSSM
Model not strictly applicable
Observed exclusion 95% CL
Expected exclusion 95% CL
Model not strictly applicable
h(125) (HIG-15-002)
A/H → bb (arXiv:1506.08329)
A/H/h → μμ (arXiv:1508.01437)
A/H/h → ττ (HIG-14-029)
H → hh (bbττ) / A → Zh (llττ) (arXiv:1510.01181)
H → hh (bbγγ) (HIG-13-032)
H→ WW/ZZ (arXiv:1504.00936)
tanβ
m_A [GeV]


CMS Preliminary
35.9 fb-1 (13 TeV)
hMSSM
Observed 95% CL
Expected 95% CL
tanβ
m_A (GeV)