Measurement of the Properties of the New (Higgs) Boson

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On behalf of the CMS Collaboration

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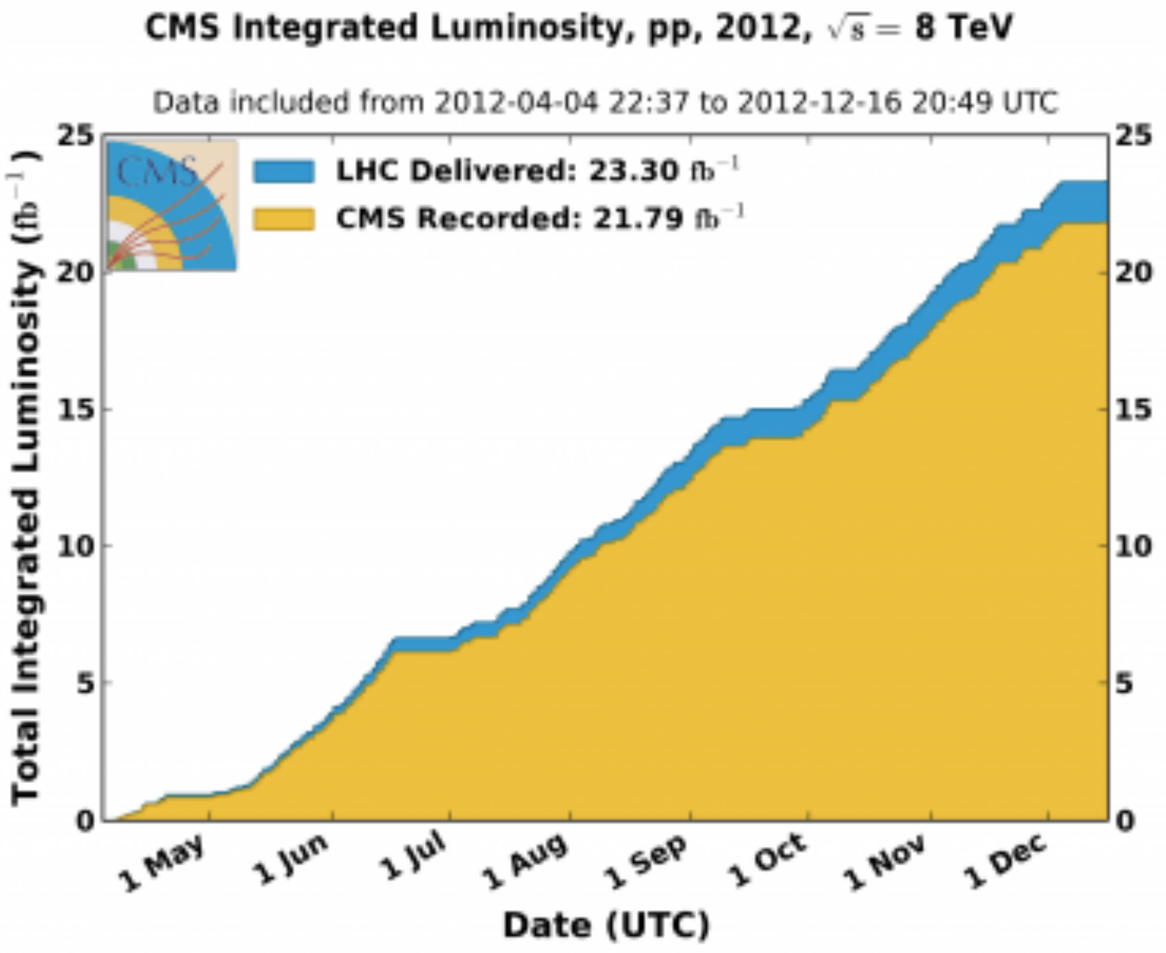


Combination Inputs

The following Higgs signatures have been explored at CMS:

Decay tag	incl.(ggH)	VBF tag	VH tag	ttH tag
H→ZZ	✔	✔		
H→γγ	✔	✔	✔	✔
H→WW	✔	✔	✔	✔
H→ττ	✔	✔	✔	✔
H→bb		✓	✔	✔
H→Zγ	✓	✓		
H→μμ	✓	✓		
H→inv.		✓	✓	

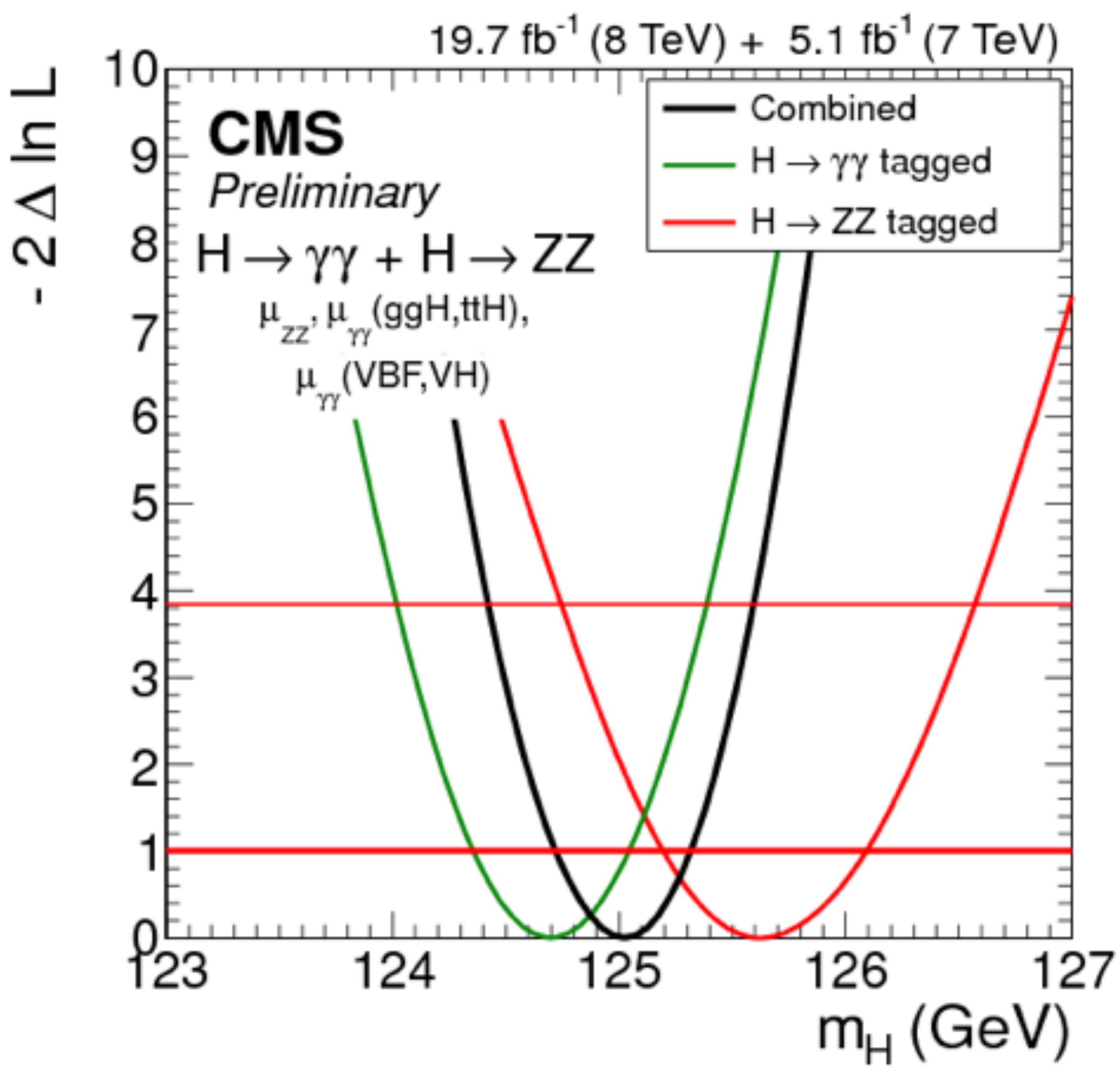
✔ Used in the NEW combination CMS-PAS-HIG-14-009

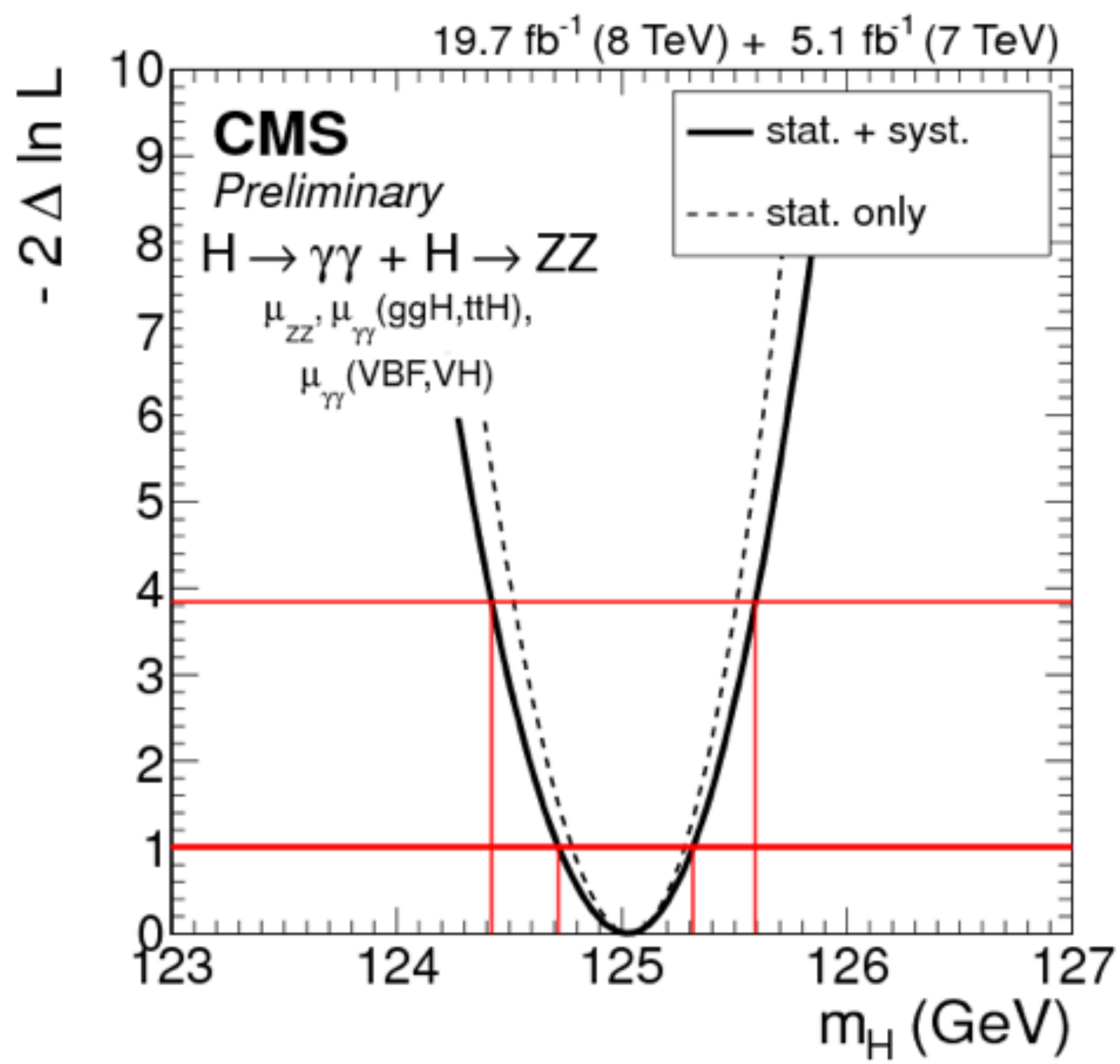
Difference from individual Higgs Analysis

1. Change in the value of m_H for which the significance of H → ZZ & H → WW analysis were done
2. Inclusion of channels from $t\bar{t}H$ analysis for various decay modes
3. Treating H → WW as part of the signal rather than background in H → $\tau\tau$ analysis

Mass of Higgs Boson

Measured the best-fit value of the **mass** of the new boson and its uncertainty with the $H \rightarrow \gamma\gamma$ and $H \rightarrow ZZ \rightarrow 4l$ channels



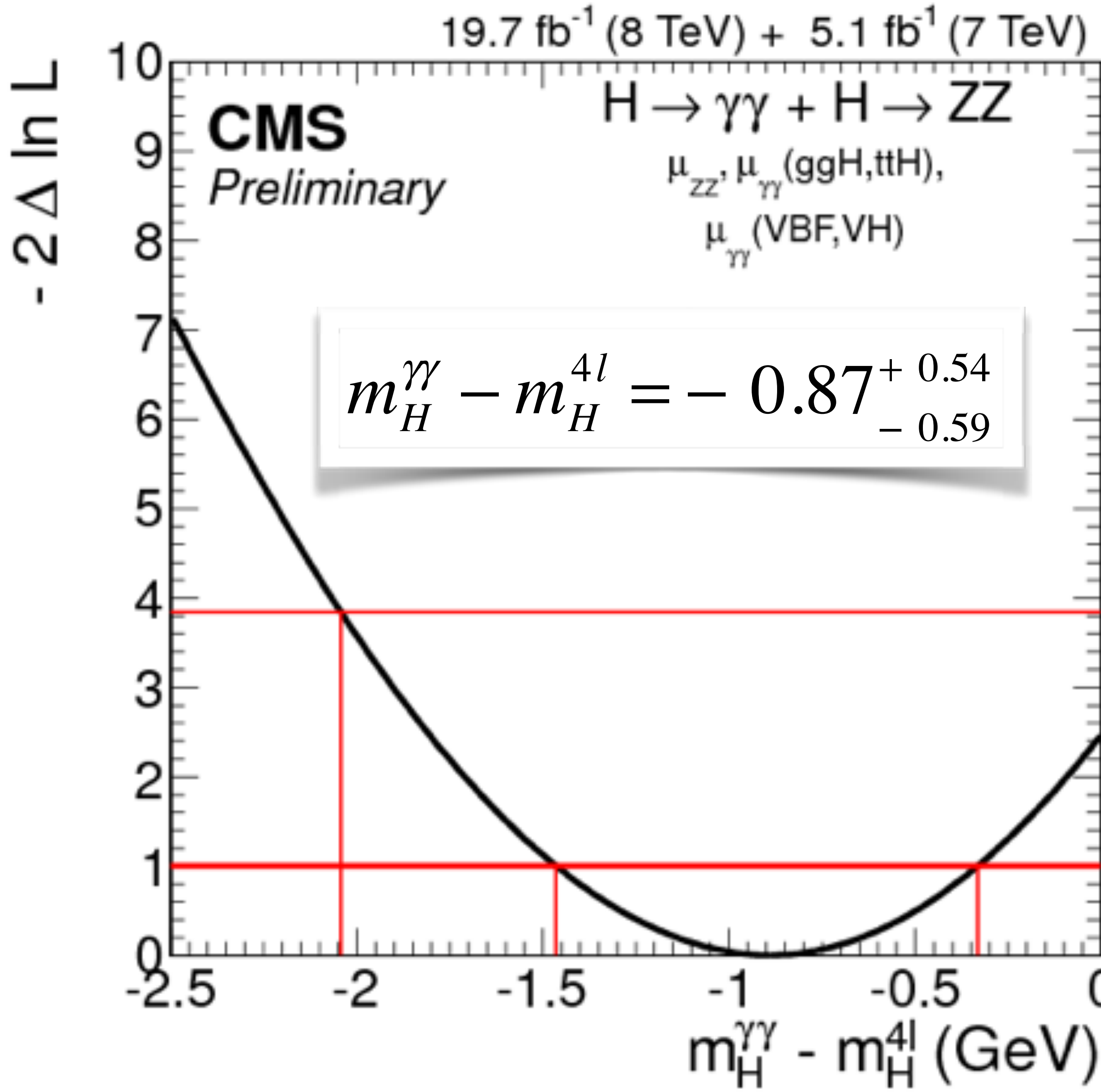


$$m_H = 125.03^{+0.29}_{-0.31}\,GeV$$

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

Difference in Mass Measurement

To check the compatibility of mass measurement of two analysis with each other



1.6σ at $\Delta m_H = 0$

Excess for m_H = 125 GeV

After measuring the mass at 125 GeV and fixing m_H, observed and expected significances for different decay modes were evaluated

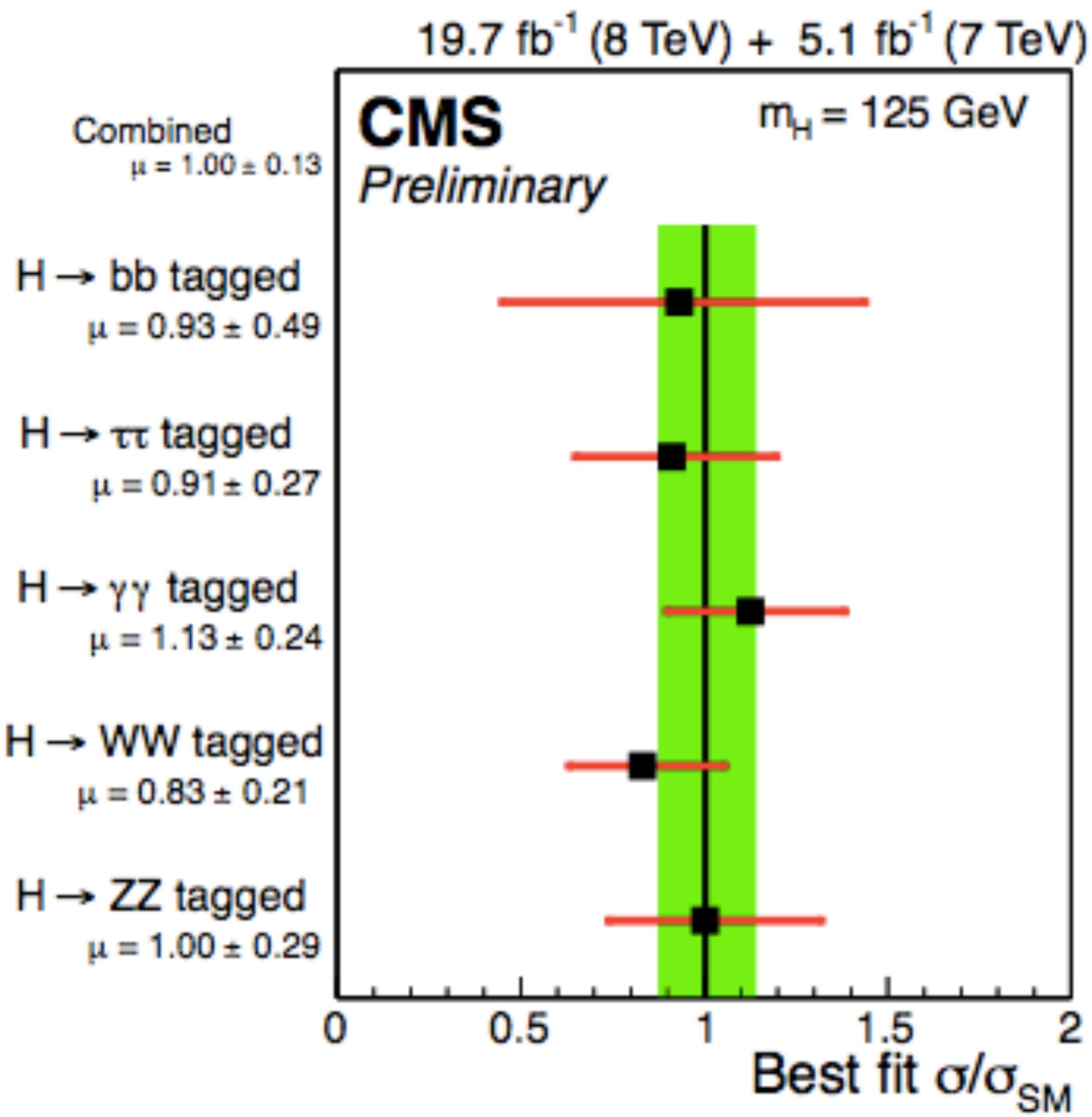
Channel	Observed σ	Expected σ
$H \to ZZ$	6.5	6.3
$H \to \gamma\gamma$	5.6	5.3
$H \to WW$ (t)	4.7	5.4
$H \to WW$	4.3	5.4
$H \to \tau\tau$ (t)	3.8	3.9
$H \to \tau\tau$	3.9	3.9
$H \to bb$ (t)	2.0	2.3
$H \to bb$	2.1	2.3

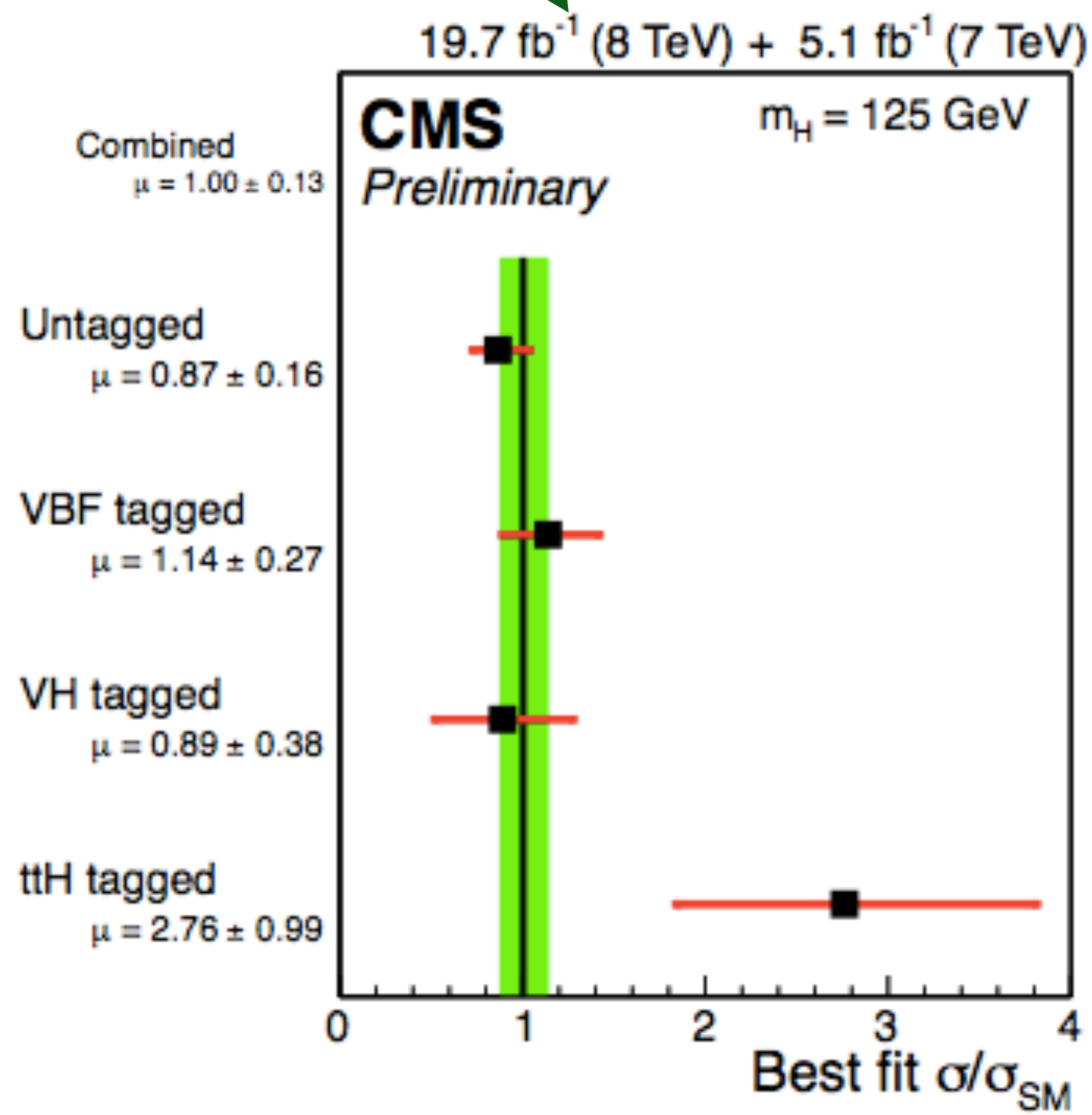
(t) implies $t\bar{t}H$ production mode is included

Signal Strength

The 68% CL region for the signal strength divided into different

Decay Modes & Production Tags

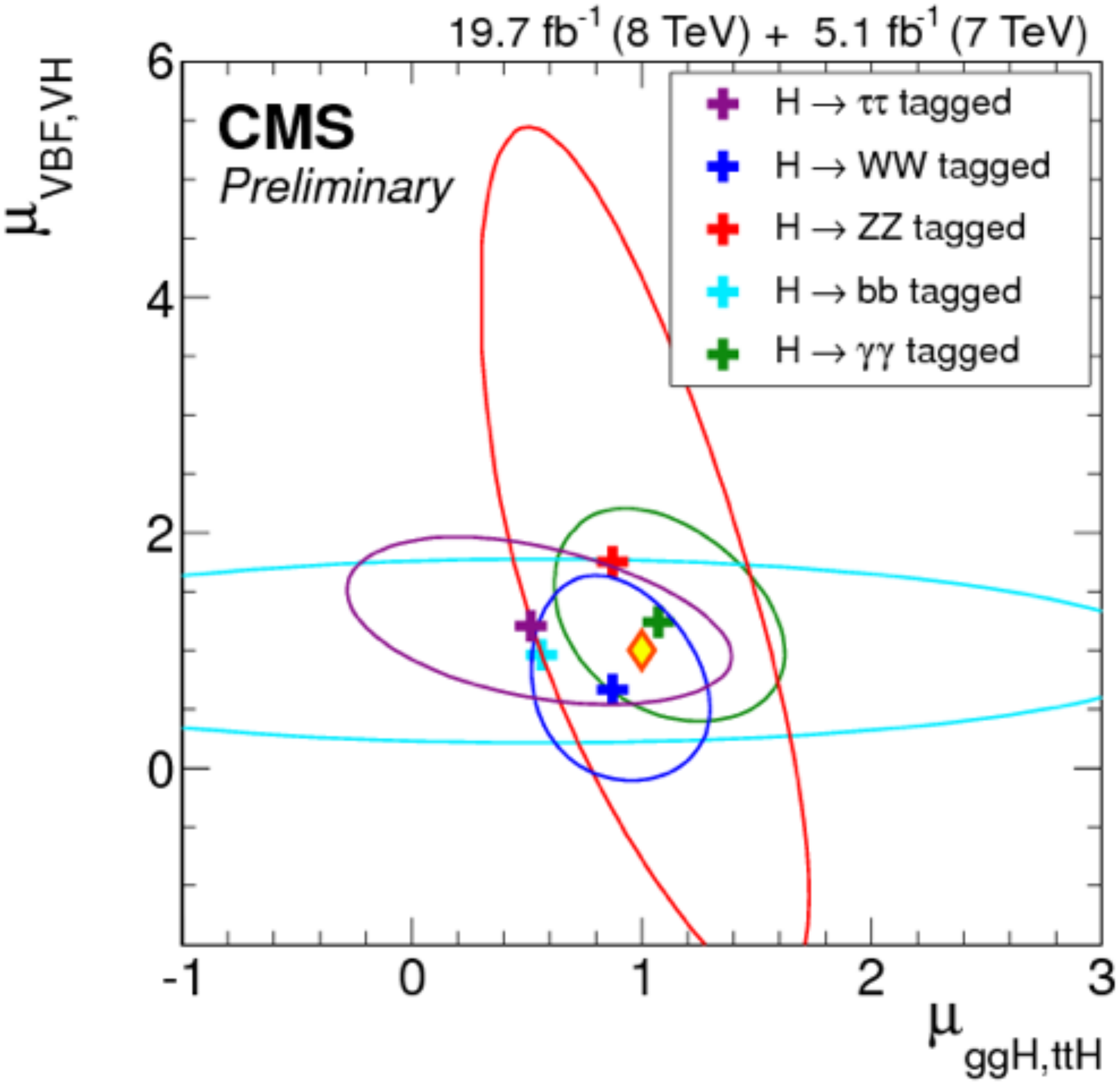


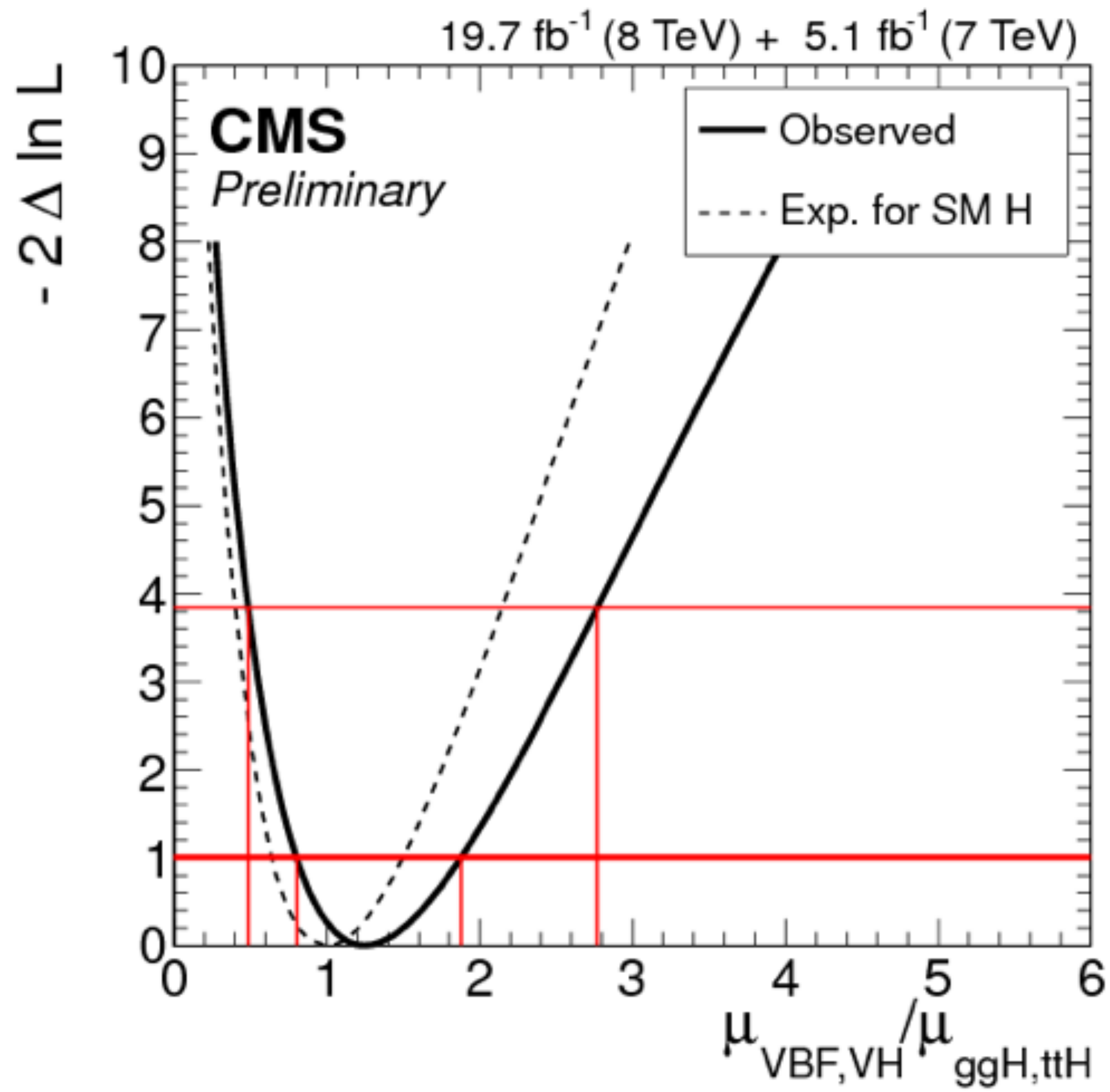


Overall Signal Strength

$$\mu = 1.00 \pm 0.09\ (stat.)\ {}^{+0.08}_{-0.07}\ (theo.) \pm 0.07\ (syst.)$$

Signal Strength





Best-fit results for the relative strengths of the couplings to the vector boson and fermions corresponding to different decay modes

The branching fractions cancel out in each channel and the results of the different channels can be combined

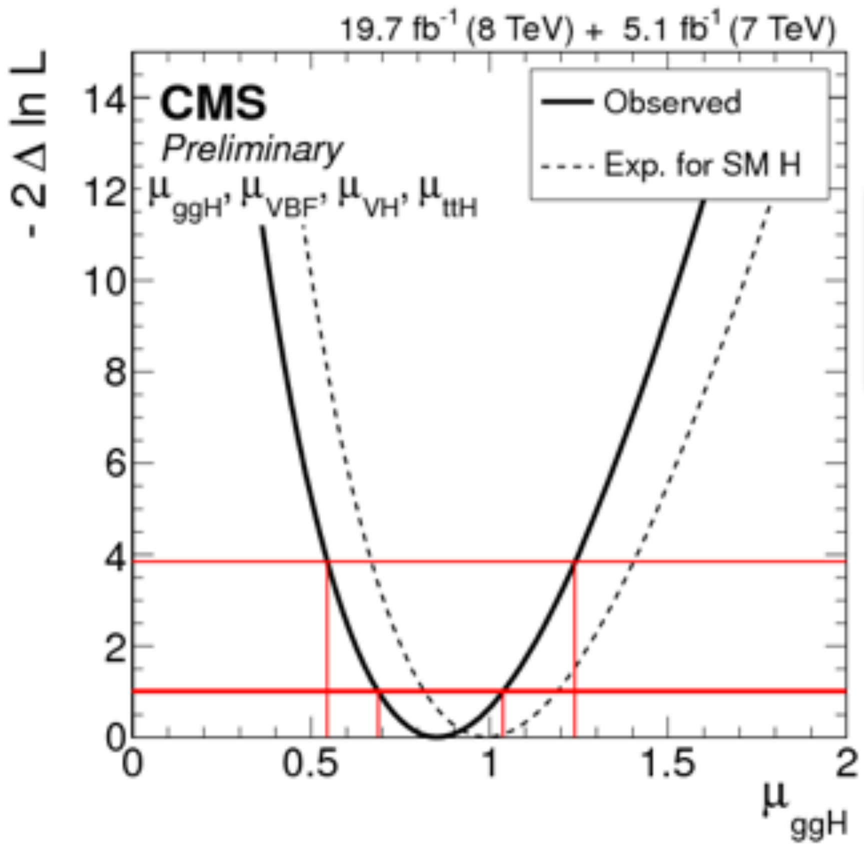
Combined best fit

$\mu_{VBF,VH}/\mu_{ggH,ttH}$: $1.25\ ^{+0.63}_{-0.45}$ $(1.00\ ^{+0.49}_{-0.35})$

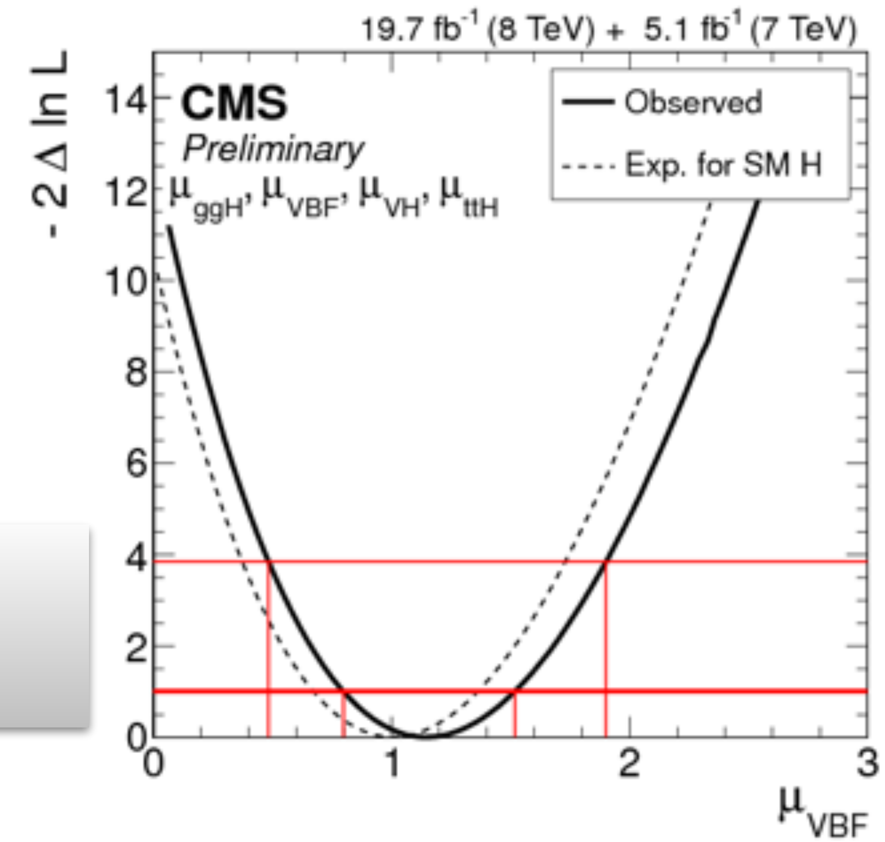
Production Modes

Independent signal strengths corresponding to the four main production processes

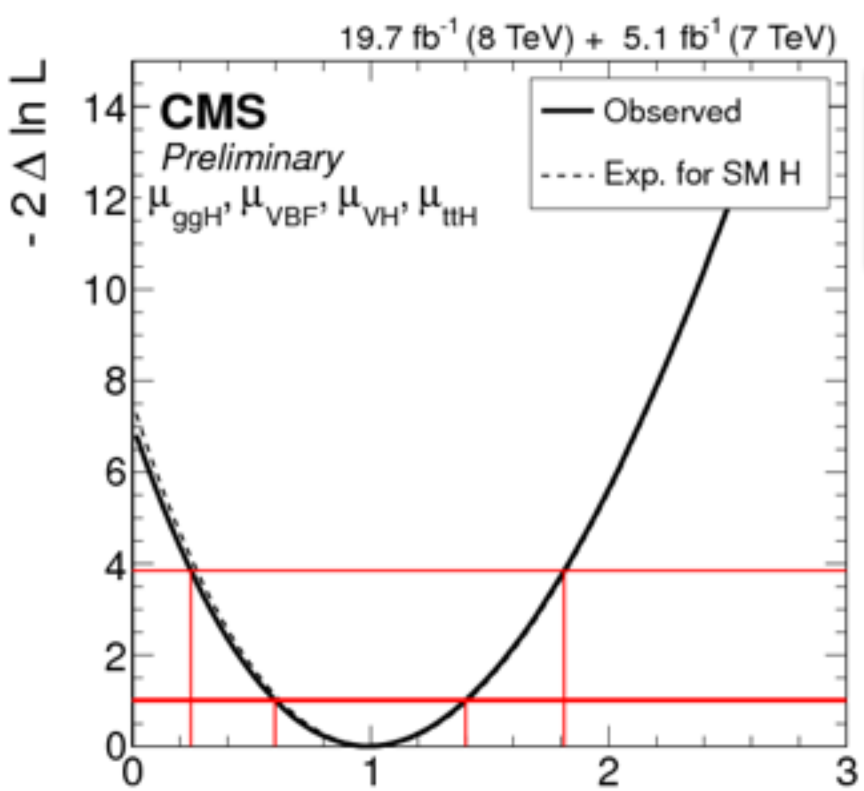
Best-fit Values



$0.85^{+0.19}_{-0.17}$

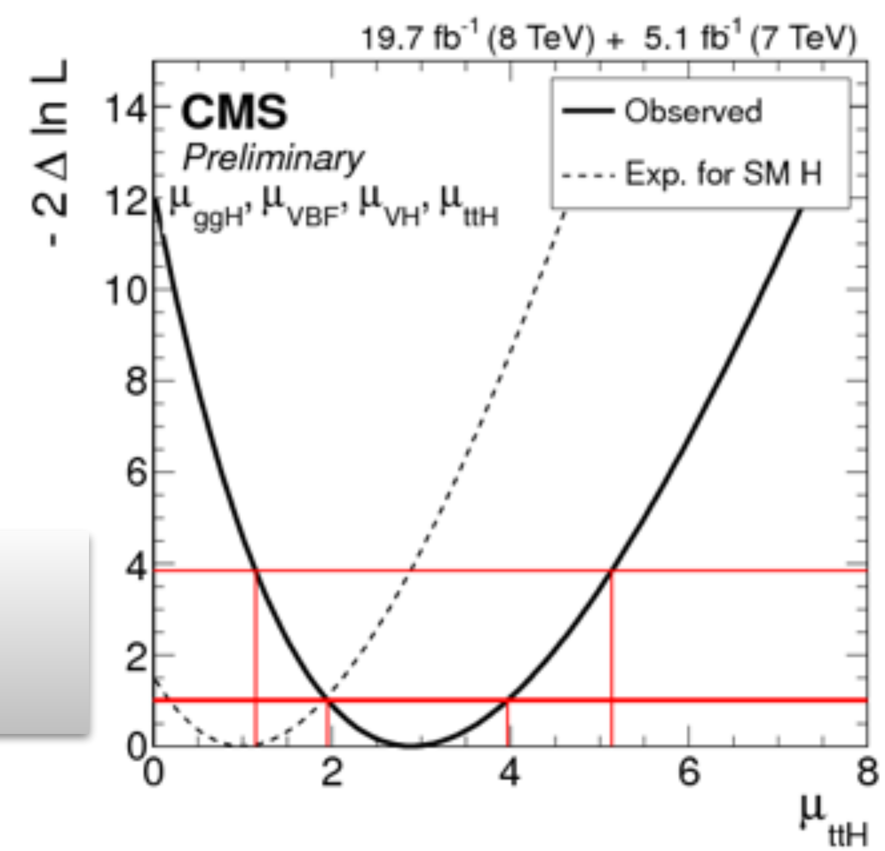


$1.15^{+0.37}_{-0.35}$



μ_{VH}

$1.00^{+0.40}_{-0.40}$



$2.93^{+1.04}_{-0.97}$

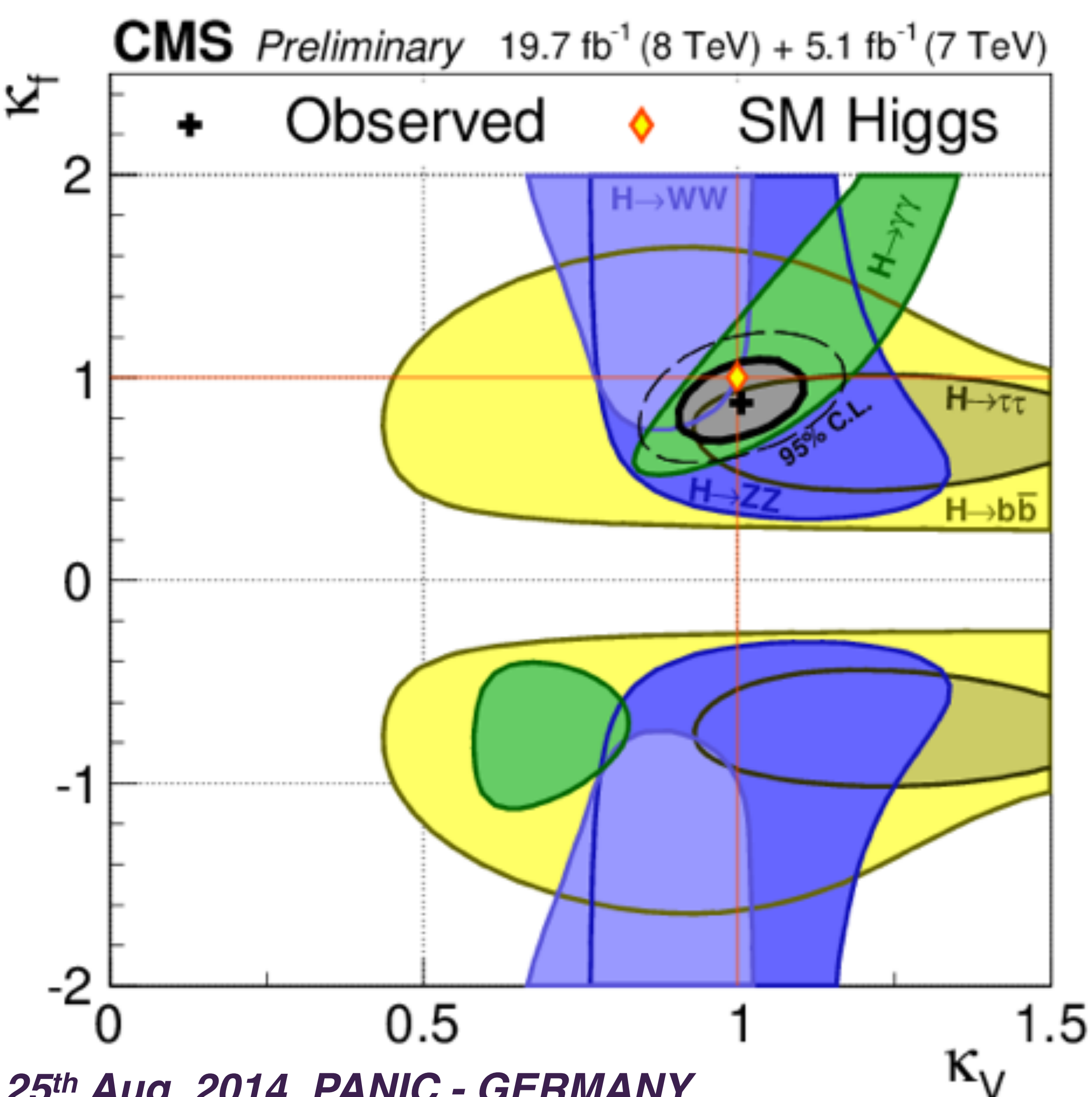
Coupling to Fermions & Bosons

Map vectorial and fermionic couplings into two scale factors, κ_V and κ_f

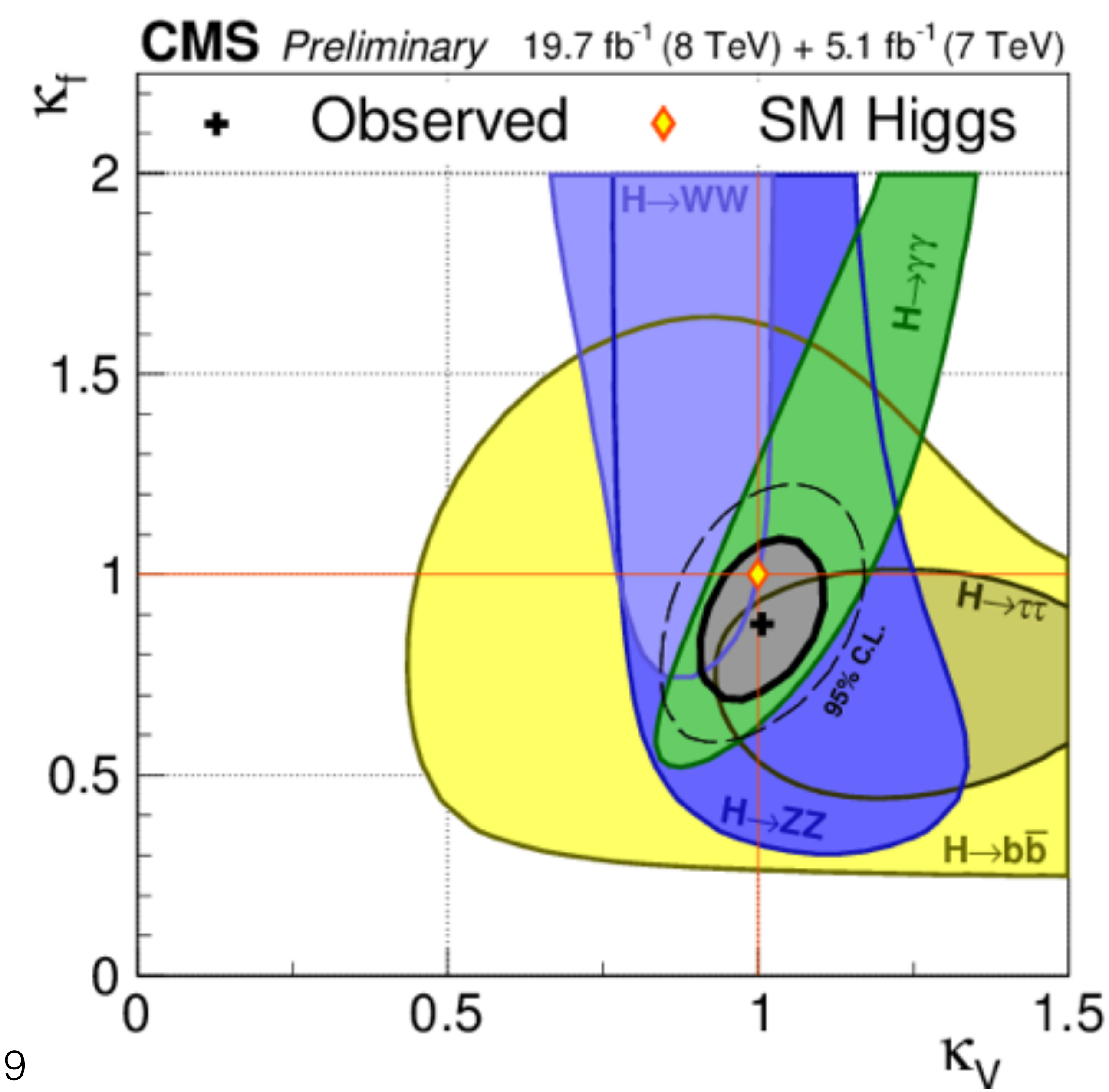
2D scan for individual channels and overall combination

Yellow Diamond shows the SM point (1,1)

Two quadrants

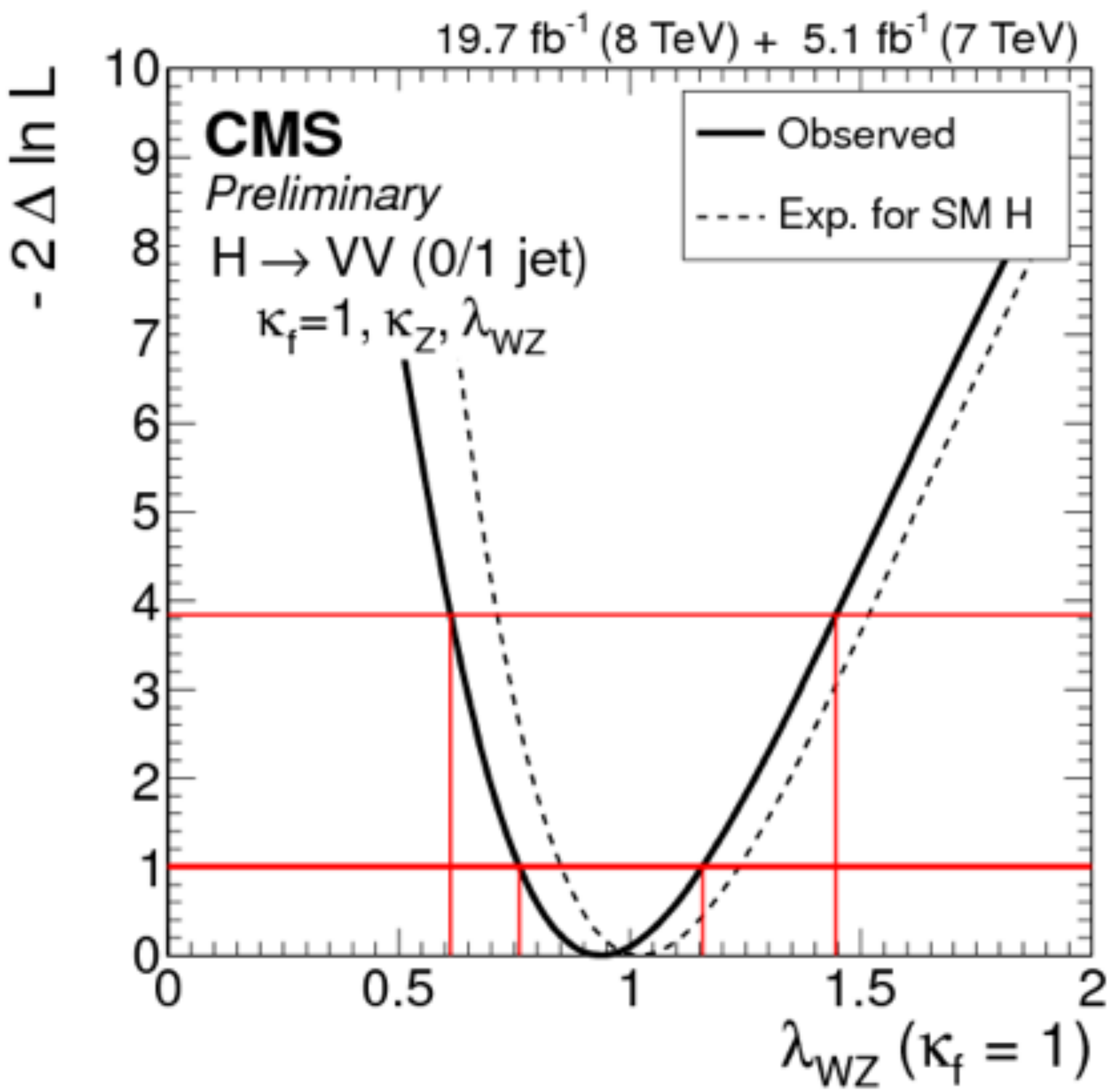


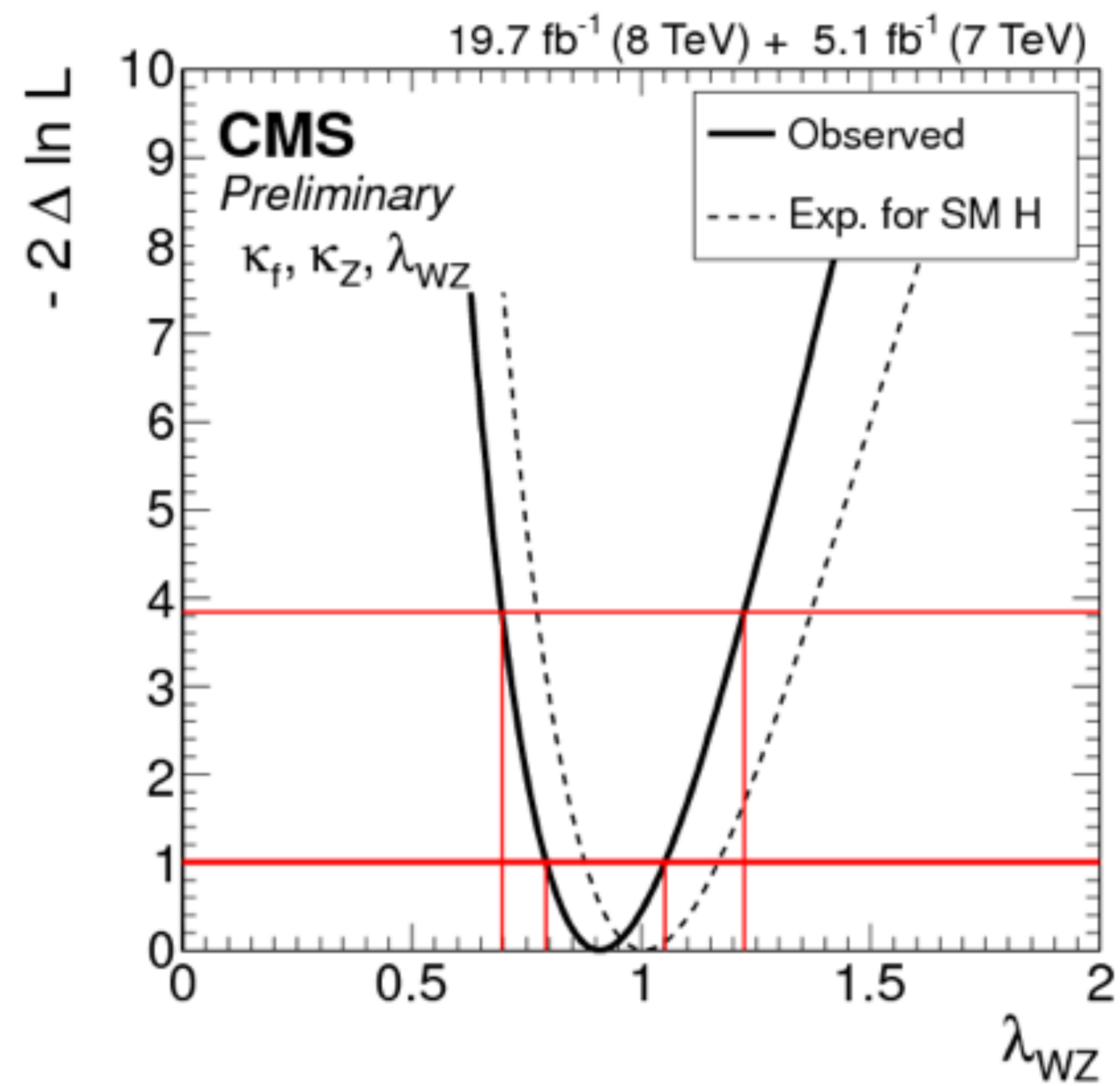
One quadrant



Custodial Symmetry

κ_W and κ_Z are used to denote the SM Higgs couplings to W and Z bosons and we check their ratio for any violation of custodial symmetry





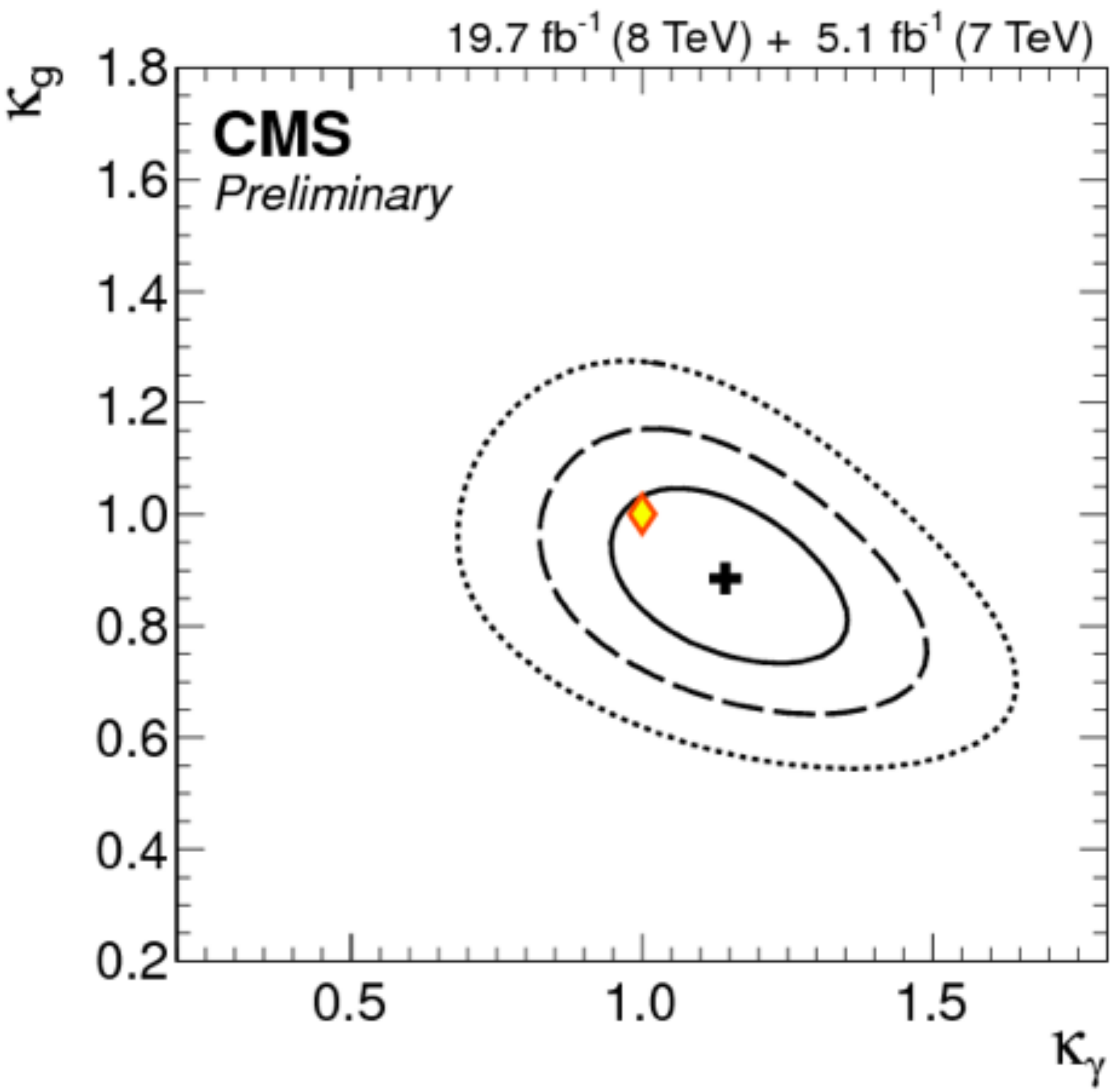
$$\lambda_{WZ} = \frac{\kappa_W}{\kappa_Z} = 0.94\,^{+0.22}_{-0.18}$$

$$\lambda_{WZ} = \frac{\kappa_W}{\kappa_Z} = 0.91\,^{+0.14}_{-0.12}$$

➡ We can treat **Z** and **W** together as **V**

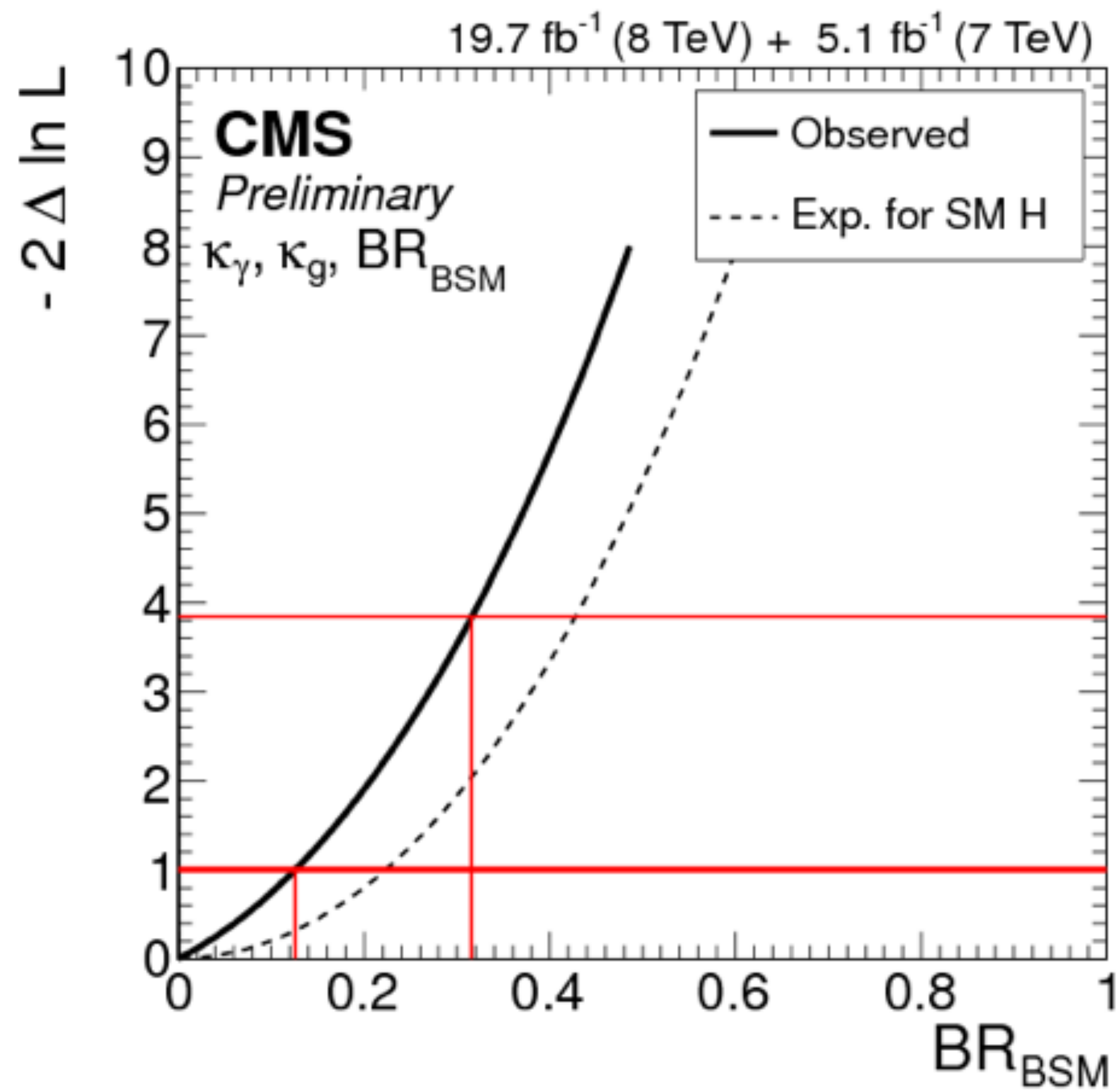
New Physics Model

Parameters κ_γ and κ_g were scanned to get best-fit value at (1.14, 0.88) having (1, 1) within 95% CL.



New particles can contribute to the total width

Allowed total width to scale as $1/(1\text{-}BR_{BSM})$

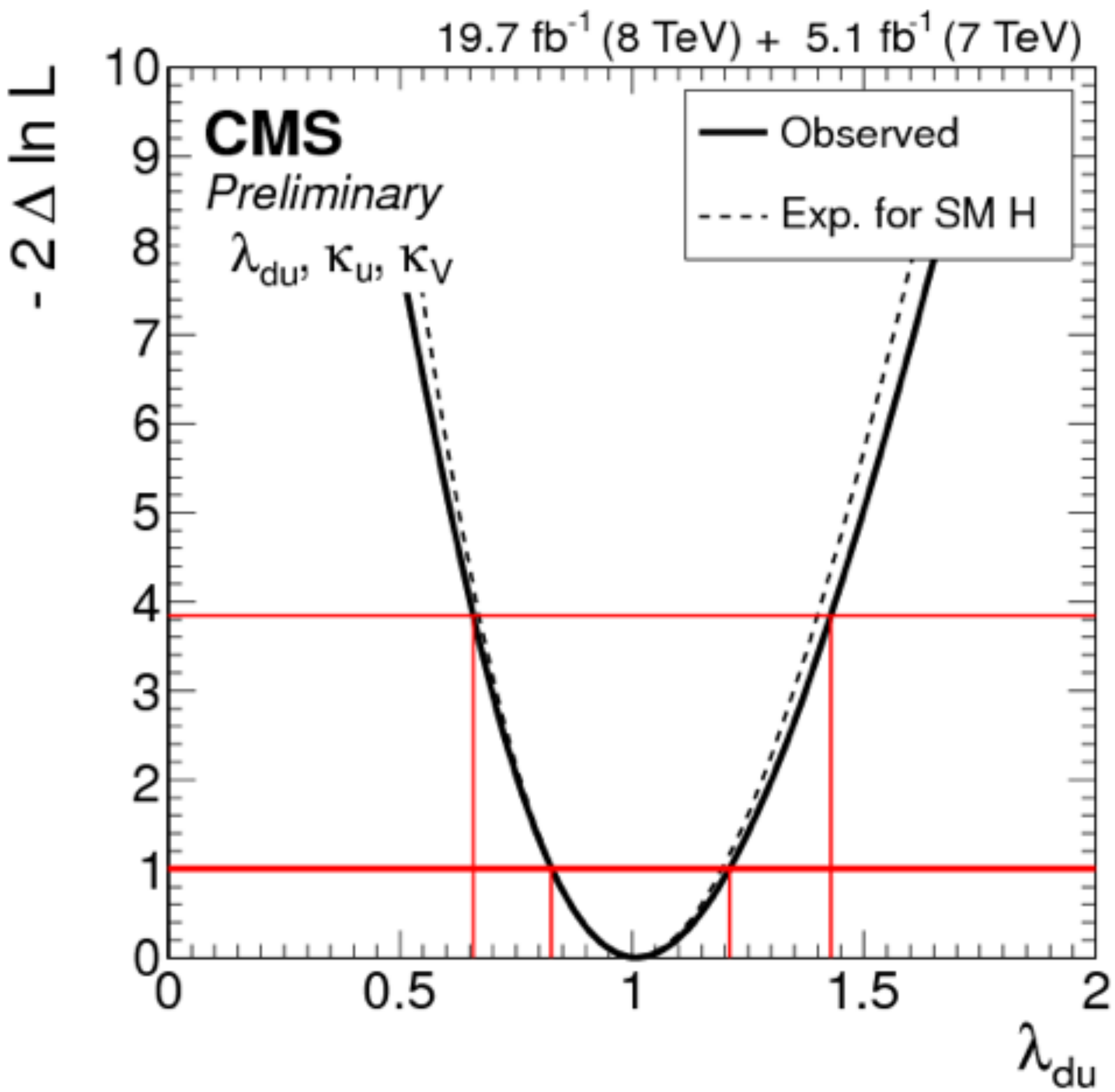


Asymmetry of Coupling to Fermions

1D scans wrt coupling modifier

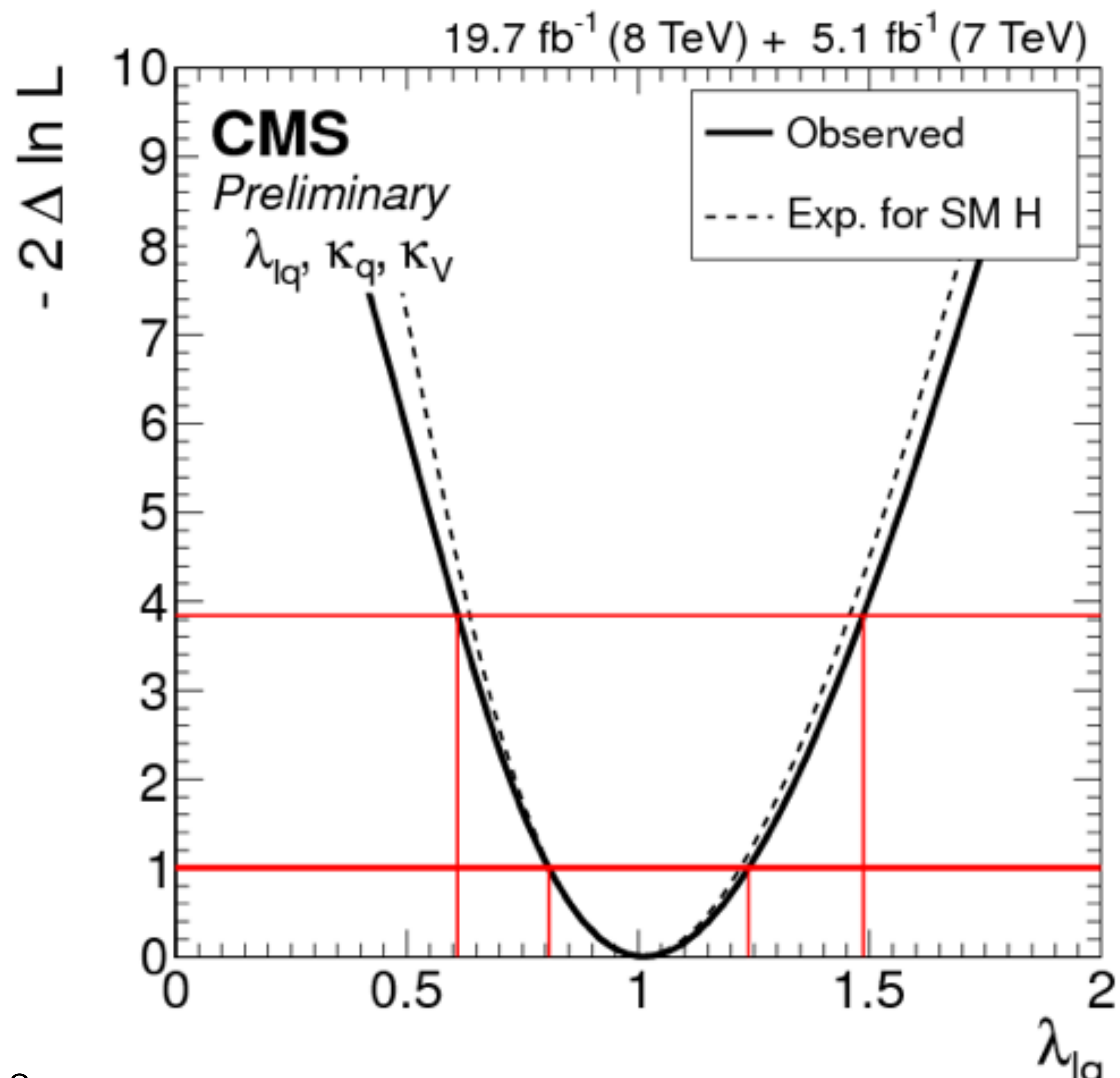
Up-type vs Down-type

$$\lambda_{du} = \frac{\kappa_d}{\kappa_u} = 1.01\,^{+0.20}_{-0.19}$$



Leptons vs Quarks

$$\lambda_{lq} = \frac{\kappa_l}{\kappa_q} = 1.02\,^{+0.22}_{-0.21}$$



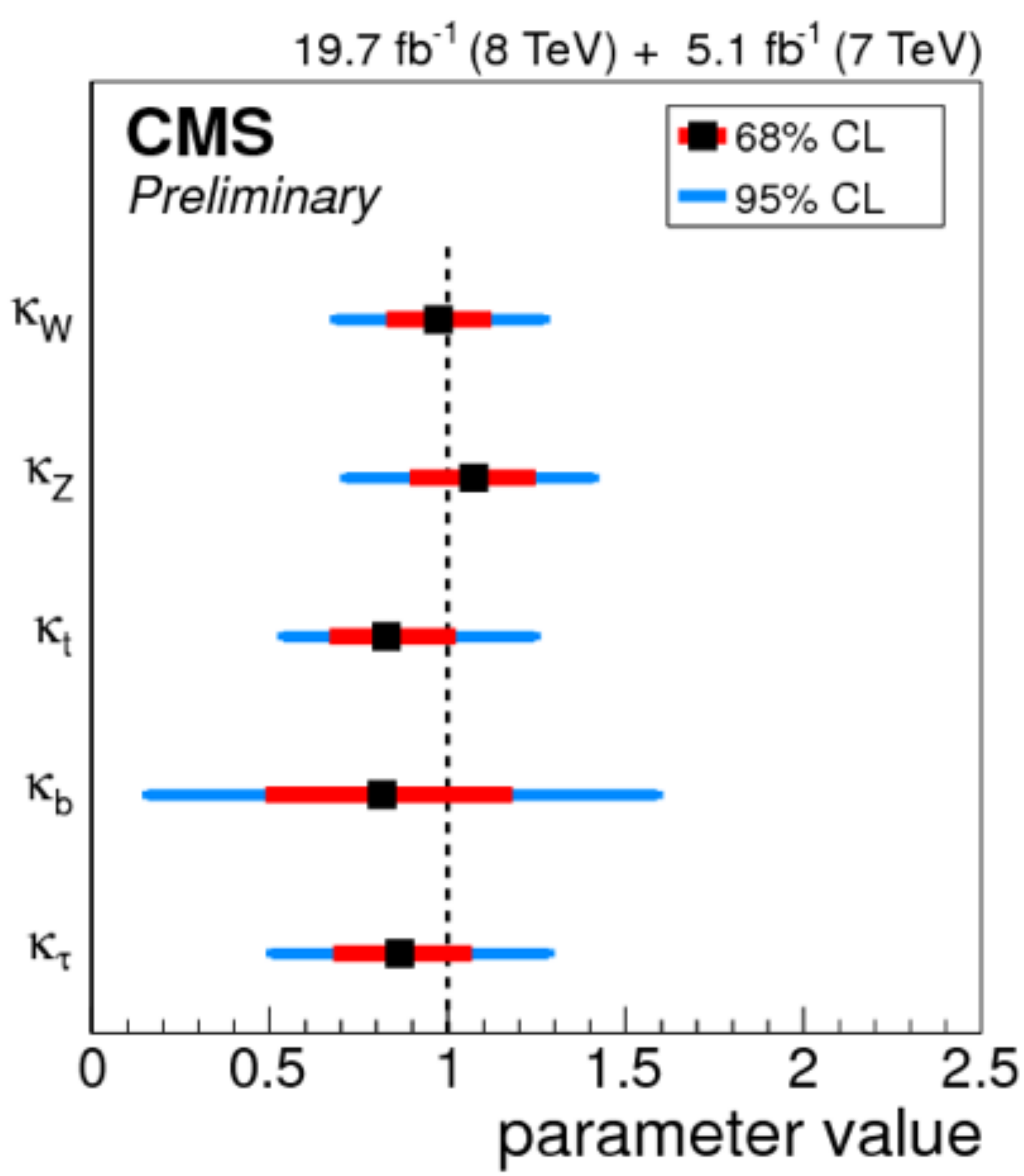
Coupling vs Particle Mass

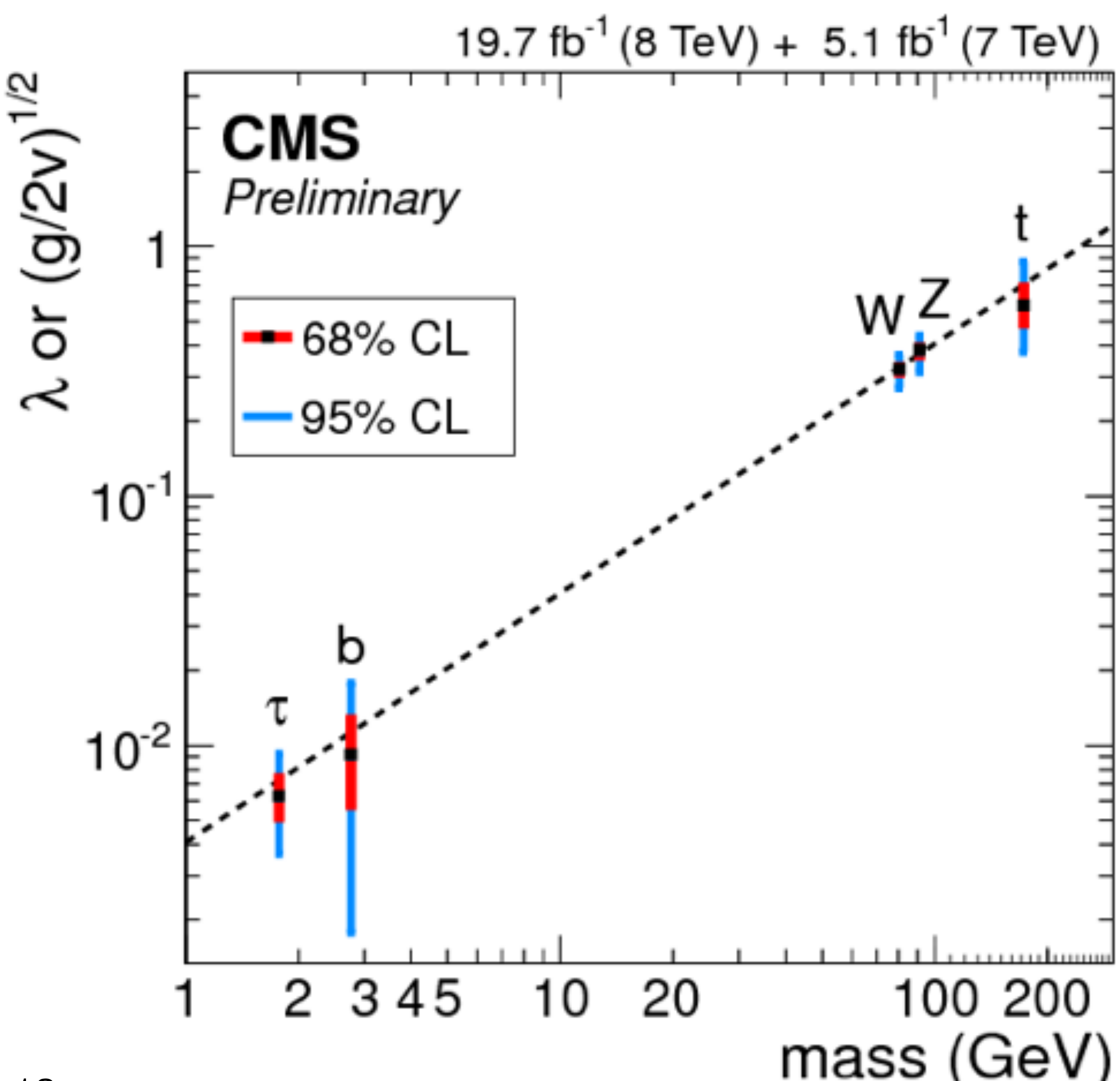
Test of generic five-parameter model, assuming SM structure for loops

κ_t denotes the scale factor for couplings of Up-type quarks;

κ_b denotes the scale factor for couplings of Down-type quarks; and

κ_τ denotes the scale factor for all the charged leptons





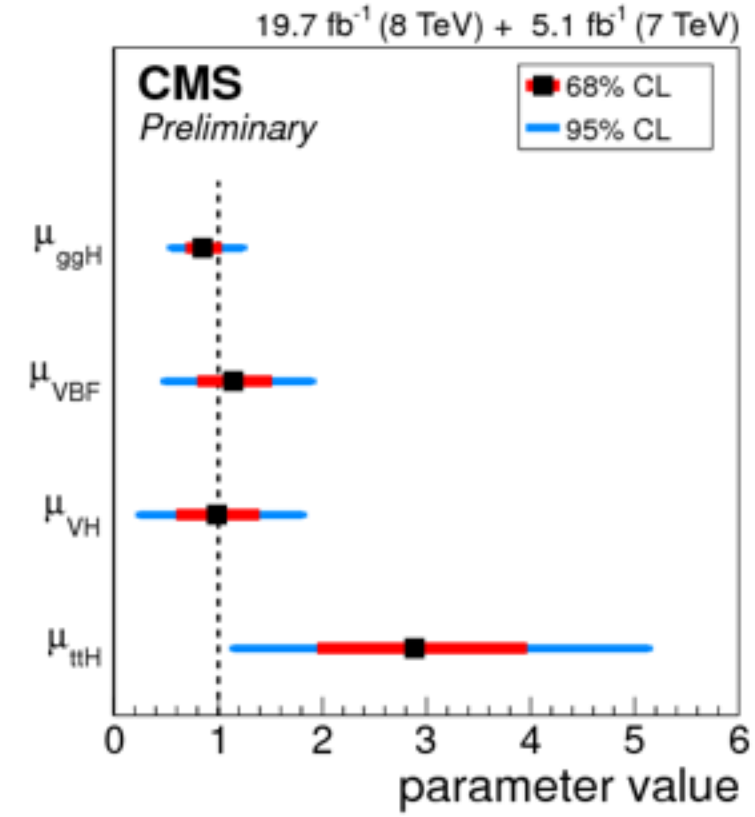
Summary

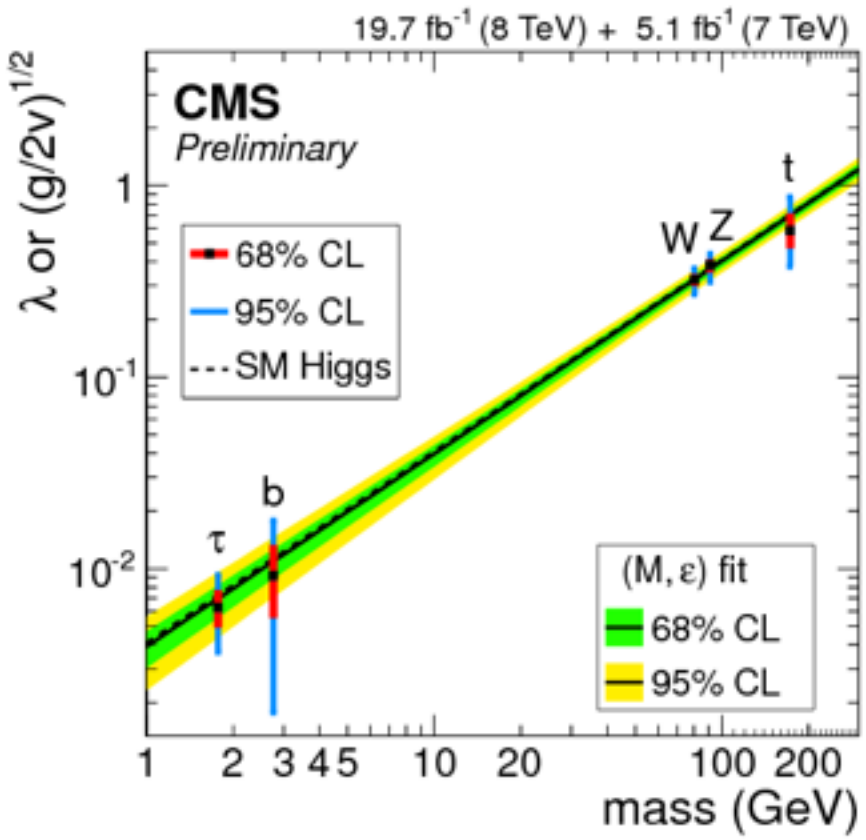
- **Very precise Higgs mass measurement has been done with the current available dataset**

- **Compatibility tests show no significant deviation from SM expectation**

- **Results are compatible with the SM Higgs boson**

- ***Limited Statistics*: Run 2 will shed some more light with more compatibility tests on their way**





Additional Information

Combination Technique

I. To find *p*-values & Significance

- To quantify the presence of an excess of events over what is expected for the background, we use the test statistics *q*, where the likelihood appearing in the numerator is for the background only hypothesis :

$$q_0 = -2\ln\frac{L(obs\,|\,b,\hat{\theta}_0)}{L(obs\,|\,\hat{\mu}.s+b,\hat{\theta})}$$

where, s : signal expected under SM Higgs hypothesis
μ : signal strength modifier
b : backgrounds
q : nuisance parameters describing systematics uncertainties

- The value θ_0 maximises the likelihood in the numerator under the background only hypothesis, while μ and θ define the point at which the likelihood reaches its global maximum.

- Local *p*-value is defined as the probability under the background-only hypothesis, to obtain a value q_0 at least as large as that observed in the data, q_0^{data}:

$$p_0 = P(q_0 \geq q_0^{data}\,|\,b)$$

- The local significance *z* of a signal-like excess is then computed using one-sided Gaussian tail:

$$p_0 = \int_z^{+\infty}\frac{1}{\sqrt{2\pi}}\exp(-x^2/2)dx$$

Combination Technique

II. To extract signal model parameter

- Signal model parameters *a* are evaluated from a scan of the profile likelihood ratio *q(a)*.

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

- The parameters **â** and that maximise the likelihood, $L(obs\,|\,s(\hat{a}) + b,\ \theta) = L_{max}$ are called the best-fit set.

- For 68% CL parameter of interest *a* are evaluated from $q(a_i) = 1$ and $q(a_i, a_j) = 2.30$ & for 95% CL as $q(a_i) = 3.84$ and $q(a_i, a_j) = 6.99$ for 1-D and 2-D respectively, with all other unconstrained model parameter treated in the same way as the nuisance parameters.

- Overall statistical methodology for combination was developed by the ATLAS & CMS Collaborations in context of **LHC Higgs Combination Group.**

Signal Strength