Higgs Couplings 2013
14-16 October 2013, Freiburg

Higgs Couplings results from CMS

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for the CMS Collaboration

Overview

- The latest CMS Combination was performed on the Moriond '13 dataset:
  - Released as preliminary PAS HIG-13-005
  - Full 2011 + 2012 luminosity used for all analyses except Hbb, VBF HWW (HCP) and ttH (ICHEP)
- The main results presented in this talk will be from that combination, but some updates from individual channels will be mentioned

Signatures explored at CMS

	incl. (ggH)	VBF tag	VH tags	ttH tag
bb		✔	✔	✔
ττ	✔	✔	✔	✔
WW	✔	✔	✔ (3ℓ, Vjj)	✔
ZZ	✔	✔	(✔)	(✔)
γγ	✔	✔	✔	✔
Zγ	✔	✔		
μμ	✔	✔		
invis.		✔	✔	

✔ = full 8 TeV dataset analyzed, often full 7 TeV too

(✔) = signal yield is however dominated by other production modes (VH) or decay modes (ttH)

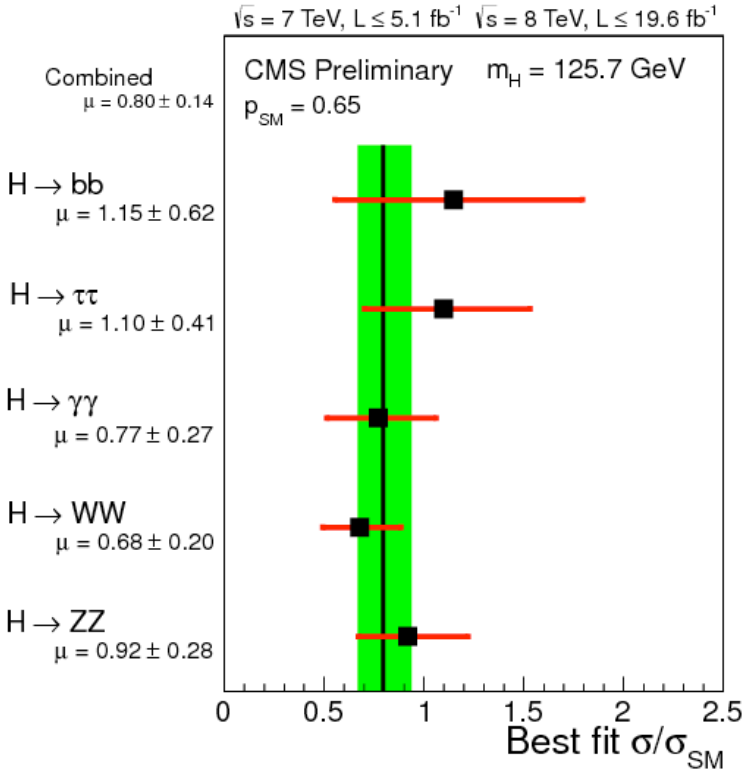
Moriond '13 combination

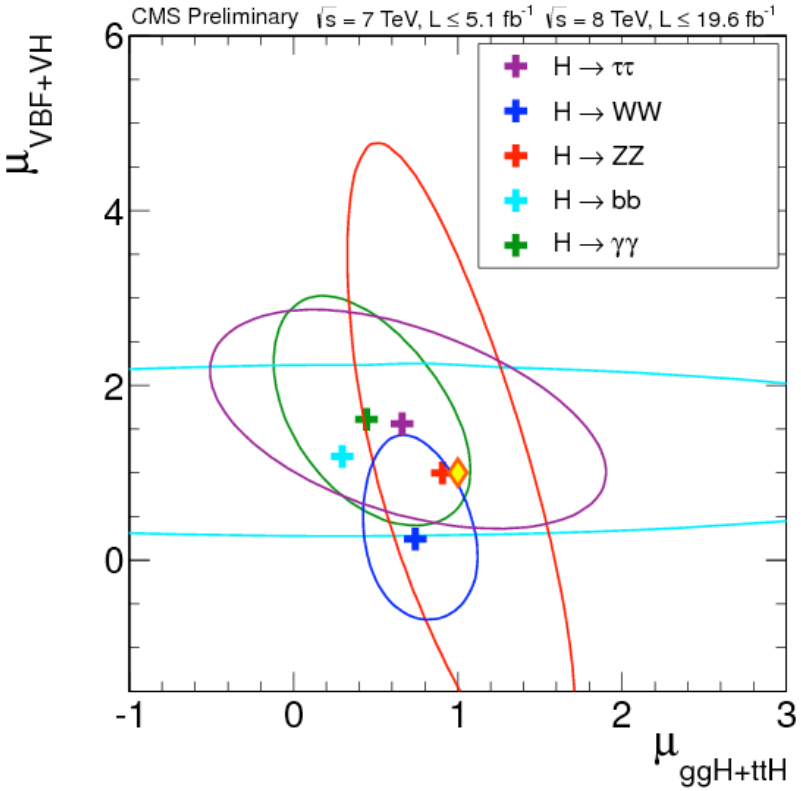
	incl. (ggH)	VBF tag	VH tags	ttH tag
bb			✓ (5+12 fb^{-1})	✓ (5+5 fb^{-1})
ττ	✔	✔	✔	
WW	✔	✓ (5+12 fb^{-1})	✔ (3ℓ only)	
ZZ	✔	✔	(✔)	
γγ	✔	✔	✔	
Zγ	✔			
μμ				
invis.				

✔= full 8 TeV dataset analyzed, often full 7 TeV too.

Signal strength results

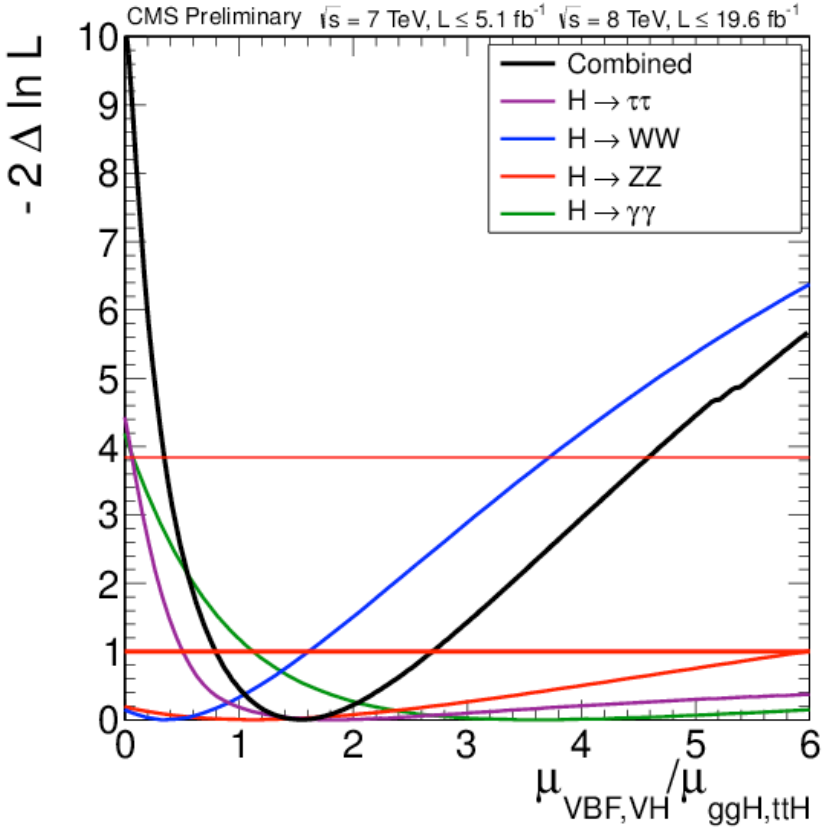
- Results from the individual modes close to the SM Higgs predictions: can probe the couplings by expanding around that reference point.

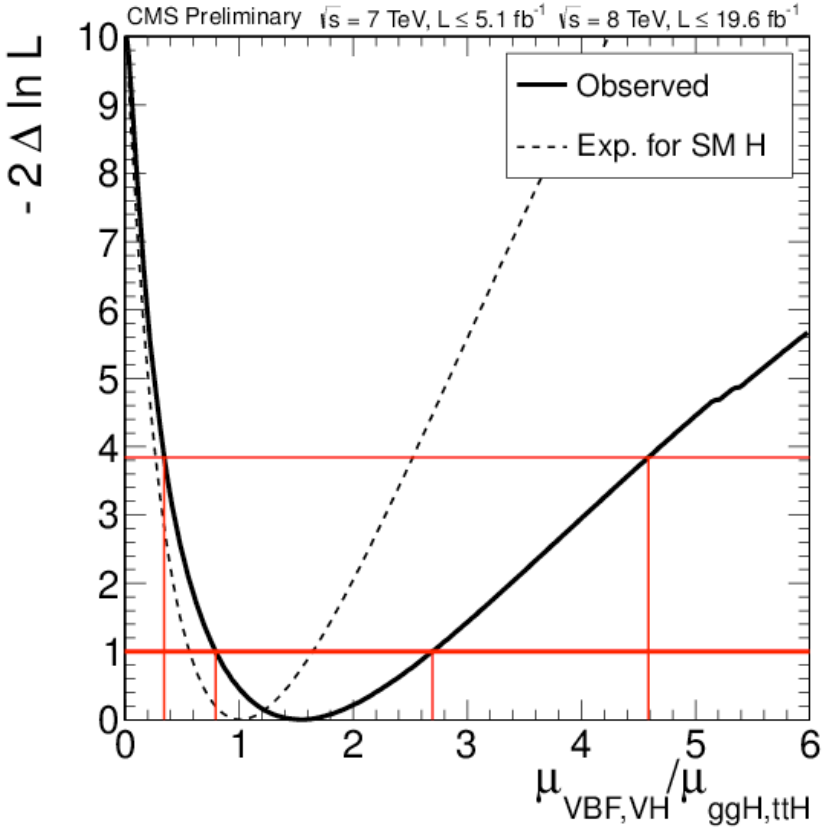




μ(VBF+VH)/μ(ggH) ratio

- Alternative presentation of μ(V) vs μ(F)
- In this case, it is possible to combine results as the V/F ratio is independent from the BR's





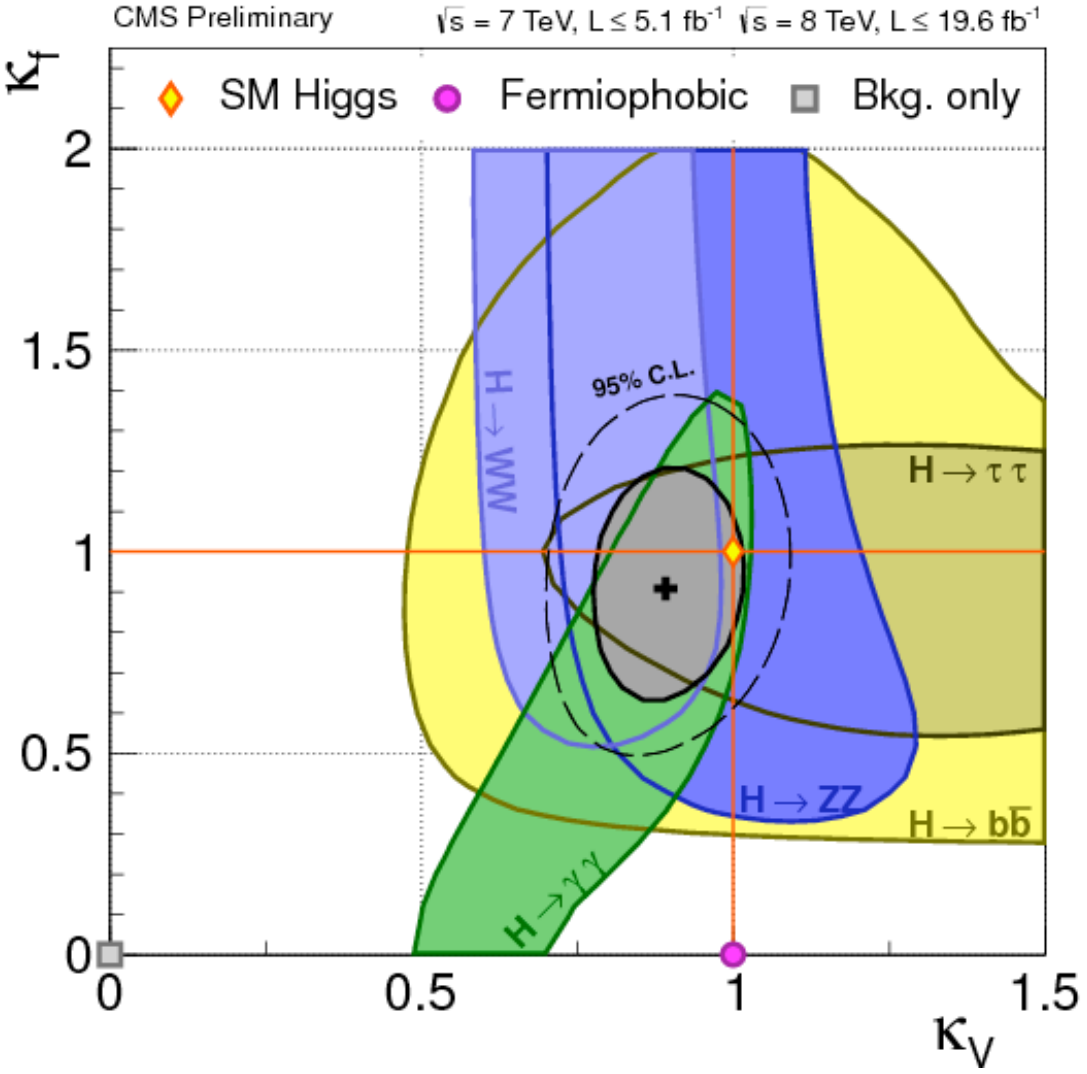
Couplings

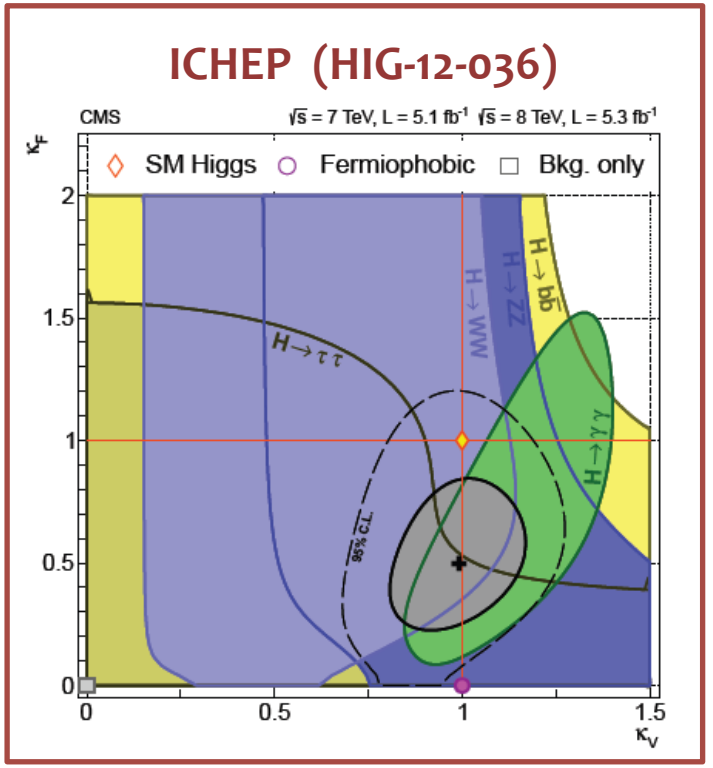
- More properly defined as *searches for deviations from the SM Predictions in the scalar couplings* (LHC XSWG, arxiv:1209.0040)
  - Define a set of parameters for the models
  - Scale the SM production cross sections and the partial widths of the SM decays as function of those parameters.
  - BSM decays , when allowed in the models, scale down the BRs of all SM decays uniformly.

Couplings: outline

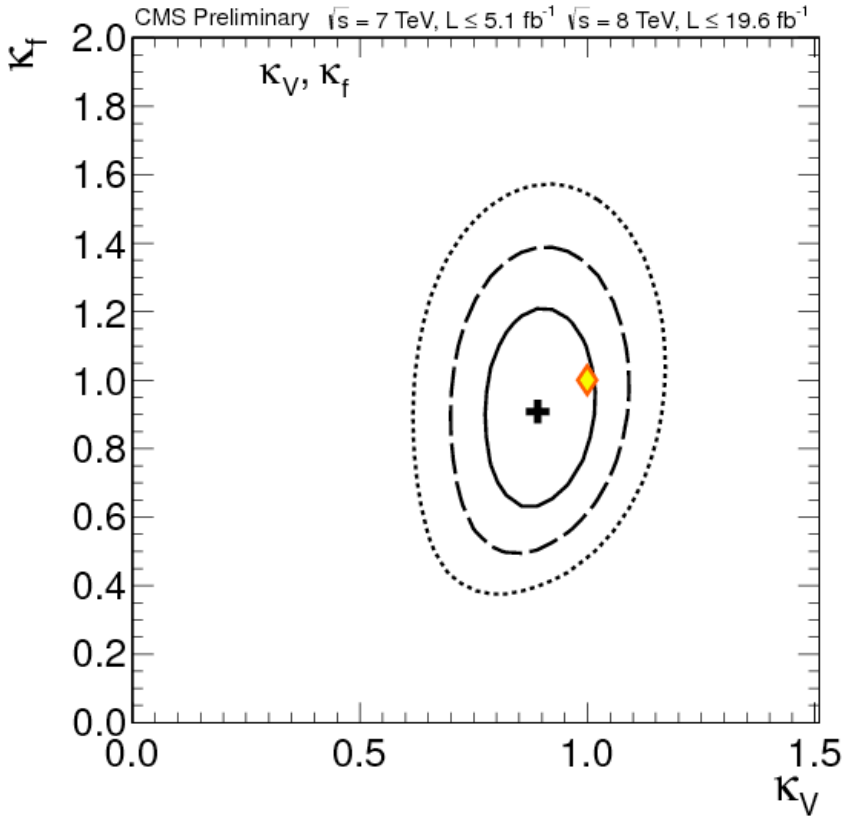
- LHC XS WG benchmark models:
  - Fermion vs Vector boson couplings: $\kappa_V\, \kappa_f$
  - Search for asymmetries: λ_{WZ}, λ_{du}, λ_{lq}
  - Search for new physics in loops: $\kappa_g\, \kappa_\gamma\, BR_{BSM}$
- Simultaneous fit of all couplings (also w/ indirect limit on BR_{BSM} from $\kappa_V \leq 1$)
- Couplings vs particle mass
- 2D limits in $\kappa_\gamma\, \kappa_{Z\gamma}$

Couplings: κ_V, κ_f

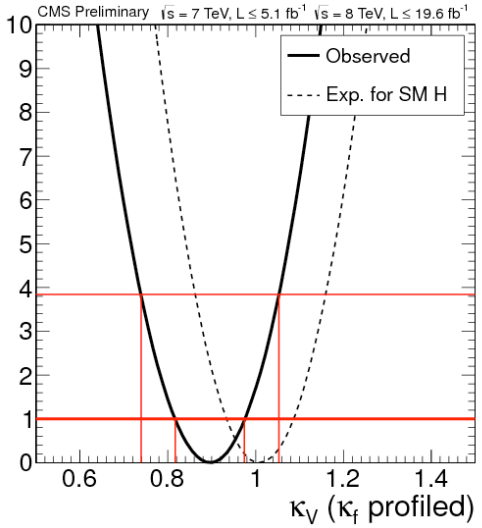




Couplings: κ_V, κ_f

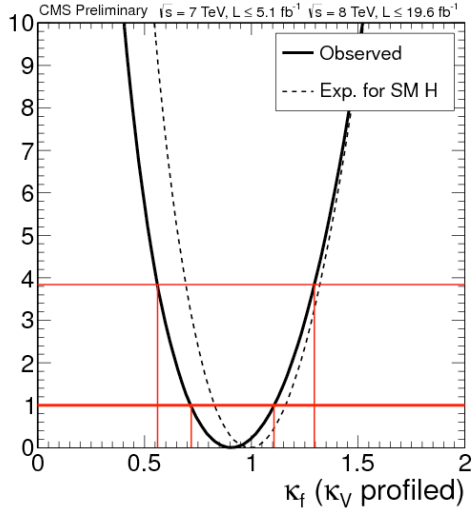


W/Z bosons



[0.81, 0.97] @ 1σ
[0.73, 1.05] @ 95%

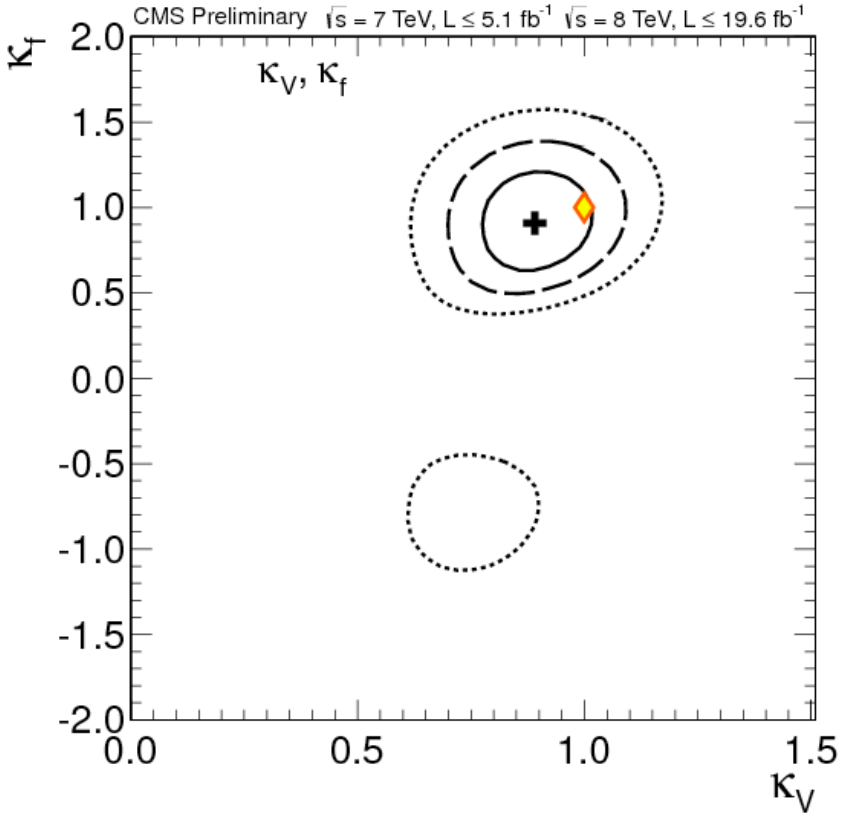
Fermions

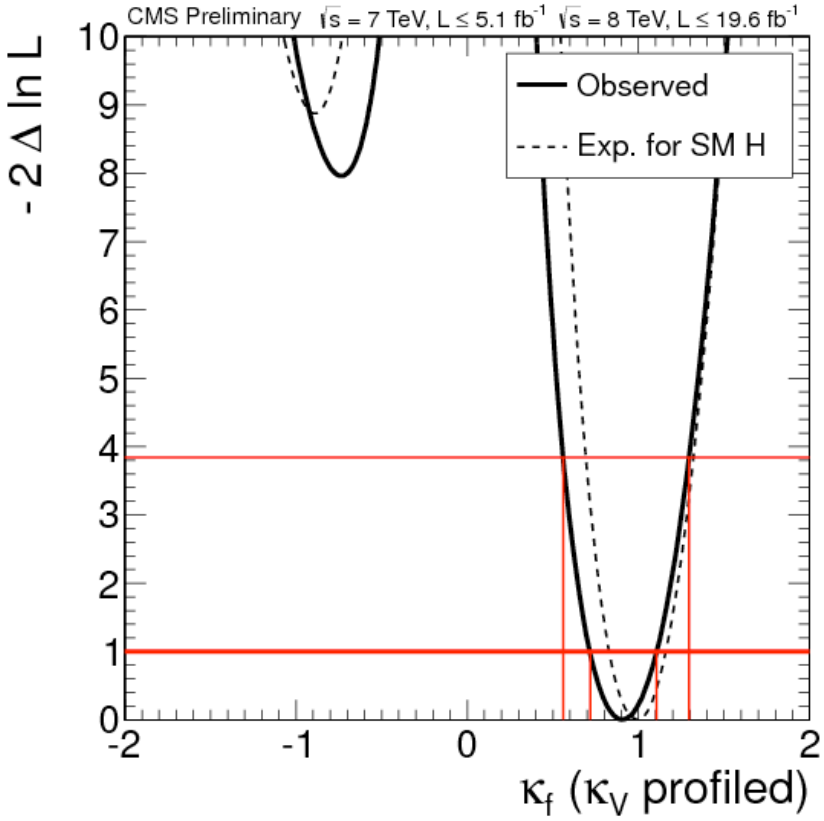


[0.71, 1.11] @ 1σ
[0.55, 1.31] @ 95%

- Good compatibility with SM hypothesis seen.

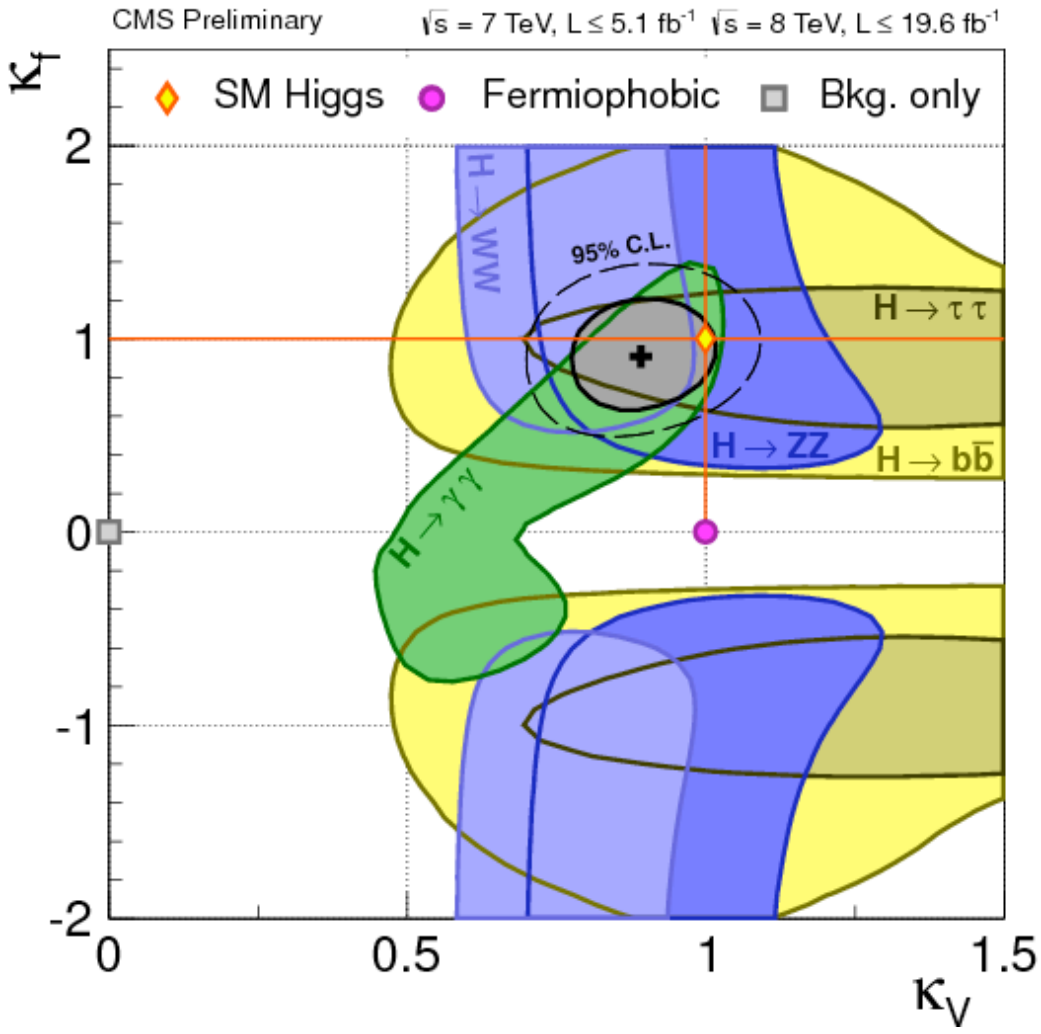
κ_V, κ_f: prefer positive couplings





- Anomalous $\kappa_F < 0$ disfavoured at about 2.7σ for κ_V profiled (and even more strongly if assuming $\kappa_V = 1$)

$\kappa_f > 0$: teamwork explained



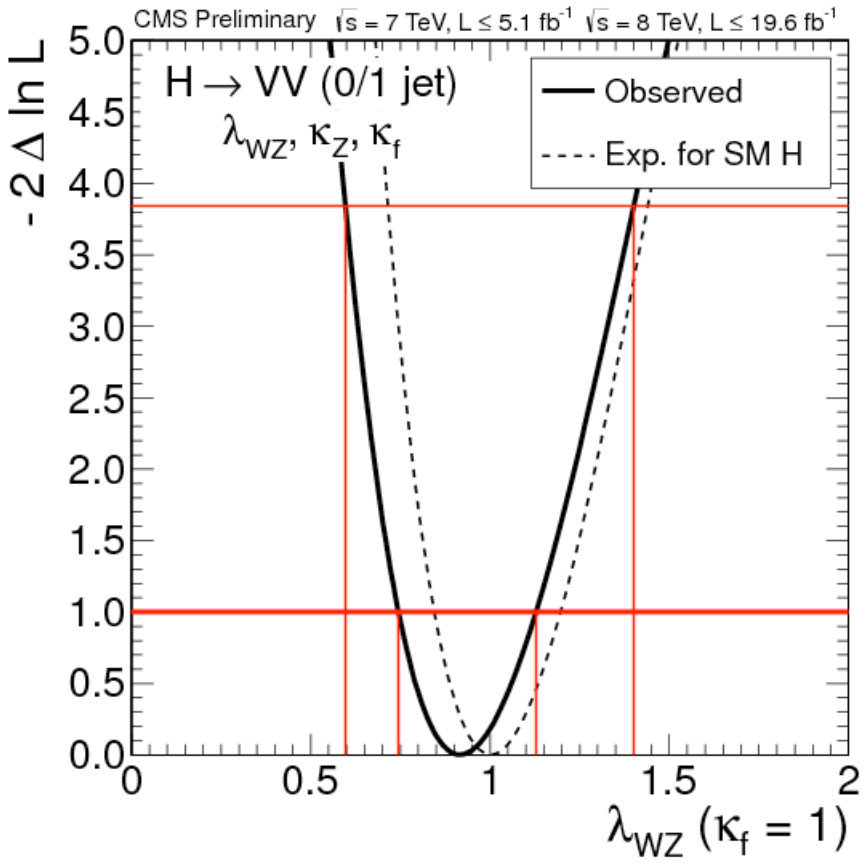
Exclusion of $\kappa_f < 0$ joint from combination of:

- VV modes: $\kappa_V > 0.7$
- ττ boosted: $|\kappa_f| \sim 1$ (ττ VBF sensitive to κ_V)
- γγ: reject $(\kappa_V, \kappa_f) = (+1,-1)$ as it would imply BR(γγ) ~2.3*SM

However, this is just one benchmark model; other tests for $\kappa_f < 0$ (e.g. tH) still interesting as probes of different BSM physics.

Custodial symmetry

Only 0/1 jet ZZ, WW. κ_F fixed to SM



[0.75,1.13] @ 68% CL
[0.60,1.40] @ 95% CL

Most direct test of the ratio of W/Z couplings from event yields in 0/1 jet categories.
(production is dominated by ggH for both channels)

$$\mu_{WW} \sim (\lambda_{WZ}\,\kappa_Z)^2$$
$$\mu_{ZZ} \sim \kappa_Z^2$$

κ_Z^2 can absorbe also any deviation in $\sigma(ggH)$ or Γ_{tot}

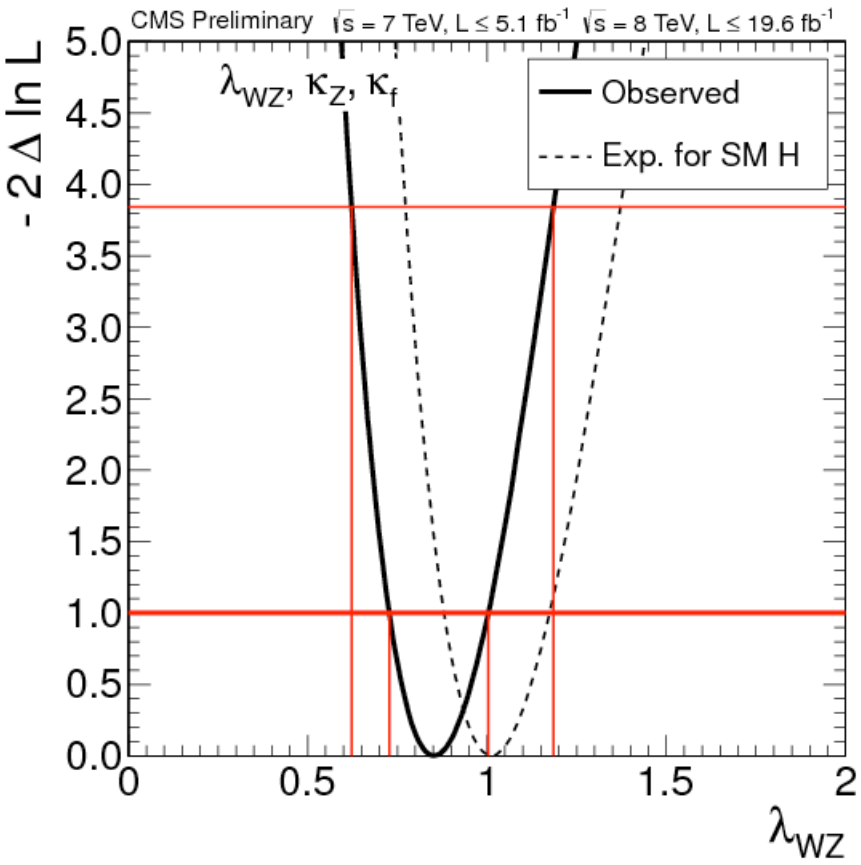
Custodial symmetry

Full combination can exploit information from:

- WH/ZH tagged modes
- VBF production cross section, as Ws and Z's have different weight.
- BR(γγ), sensitive to κ_W

In this case, floating also κ_f (affects σ(ggH) and Γ_{tot})

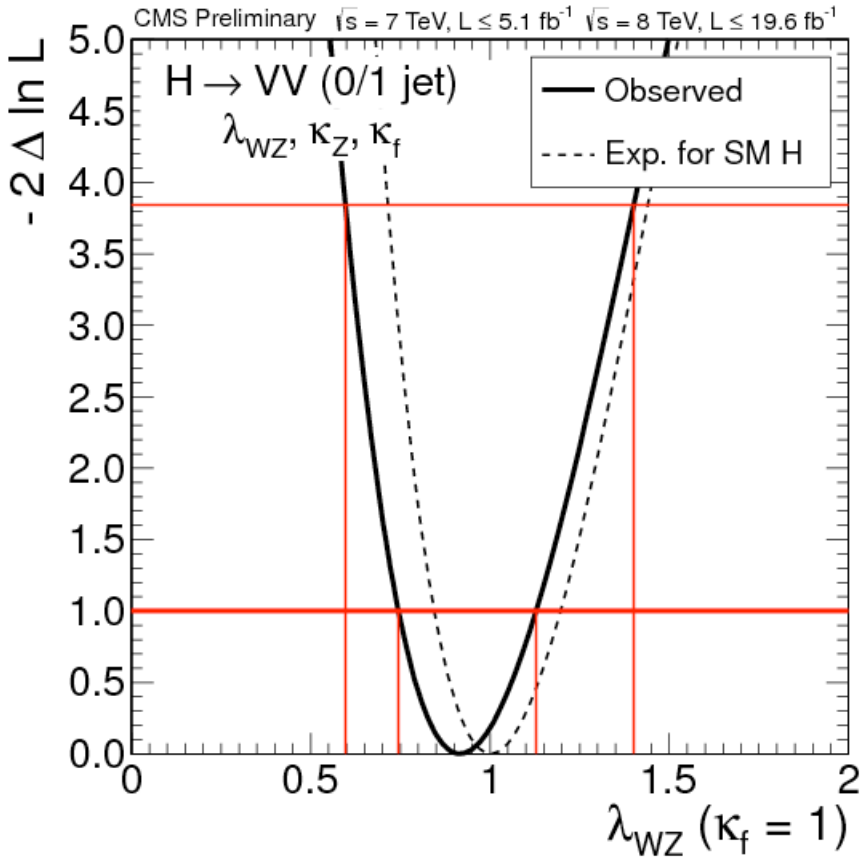
All channels. κ_F profiled.



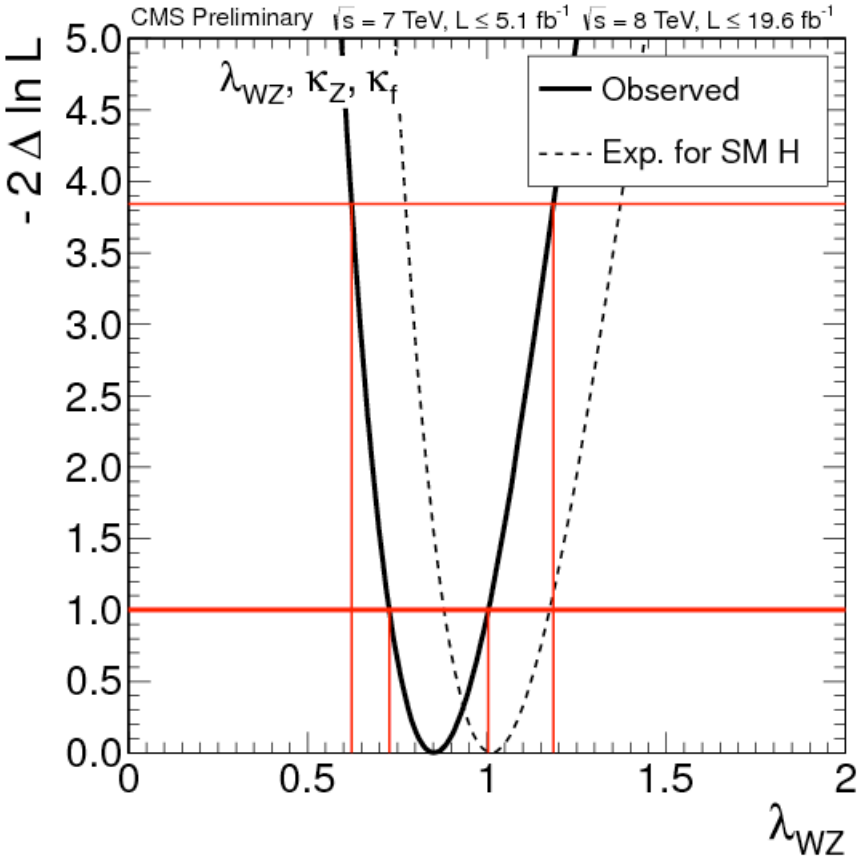
[0.73,1.00] @ 68% CL
[0.62,1.19] @ 95% CL

Custodial symmetry

Only 0/1 jet ZZ, WW. κ_F fixed to SM



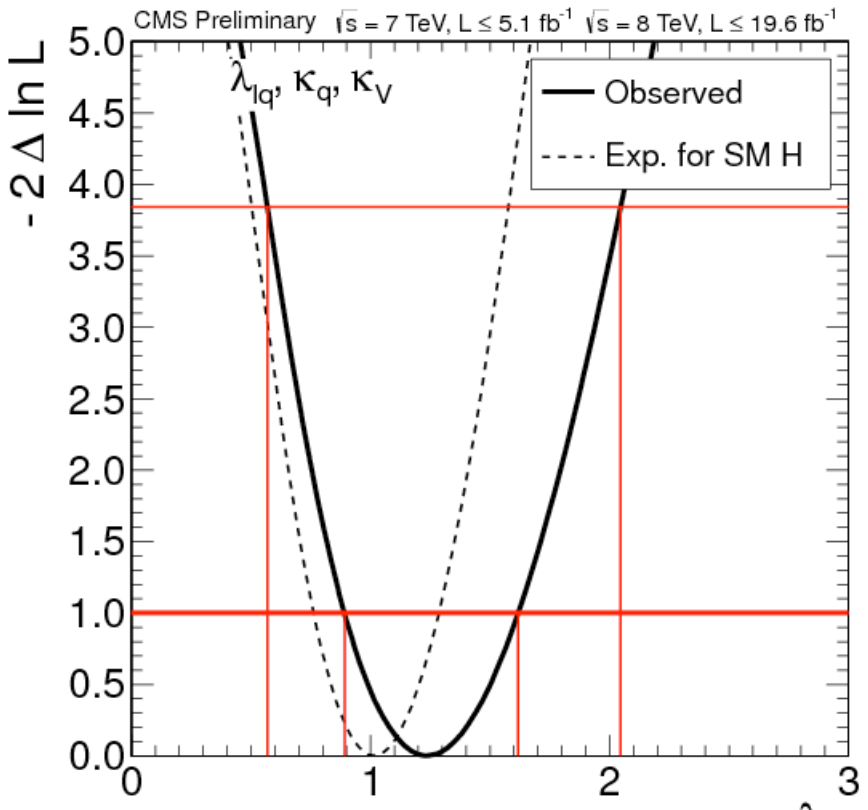
All channels. κ_F profiled.



- Consistent results with the two approaches.

Fermion universality

Leptons vs Quarks



[0.89,1.62] @ 68% CL
[0.57,2.05] @ 95% CL

3 parameter model

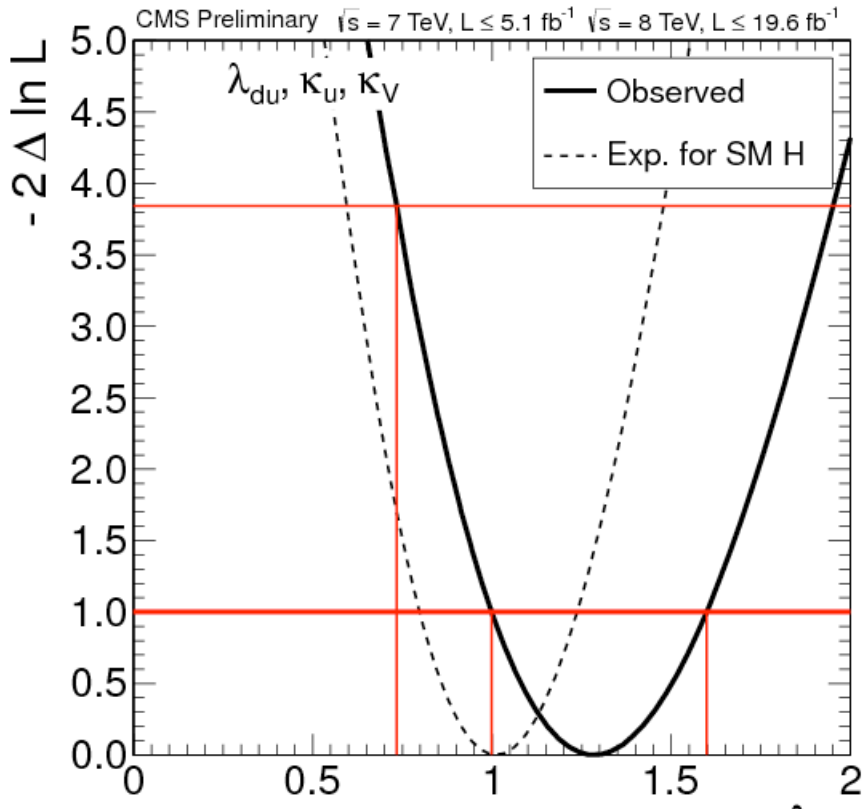
- **κ_V**: scales W, Z couplings, and also most of BR(γγ).
- **κ_q**: quark couplings, and so also σ(ggH) & $\Gamma_{tot} \sim \Gamma_{bb}$
- **λ_{lq}** := κ_l/κ_q, coupling to τ

Deviation of λ_{lq} from unity expected in some 2HDM.

Measure $\lambda_{lq} > 1$ since μ(ττ) is larger than the average.

Fermion universality

Up- vs Down-type Fermions



[1.00,1.60] @ 68% CL
[0.74,1.95] @ 95% CL

3 parameter model

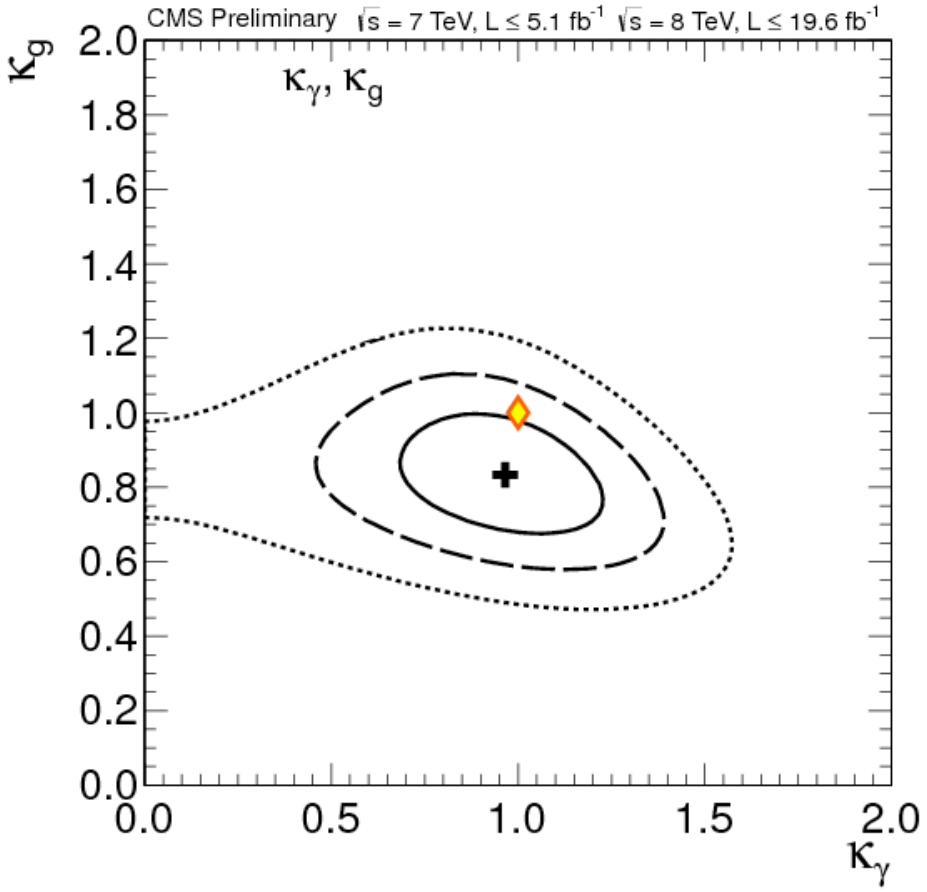
- **κ_V**: as previous model.
- **κ_u**: top quark coupling, mainly through σ(ggH).
- **λ_{du}** := κ_d/κ_u, coupling to τ and b (and so also Γ_{tot})

Motivated by MSSM-like Higgs sectors.

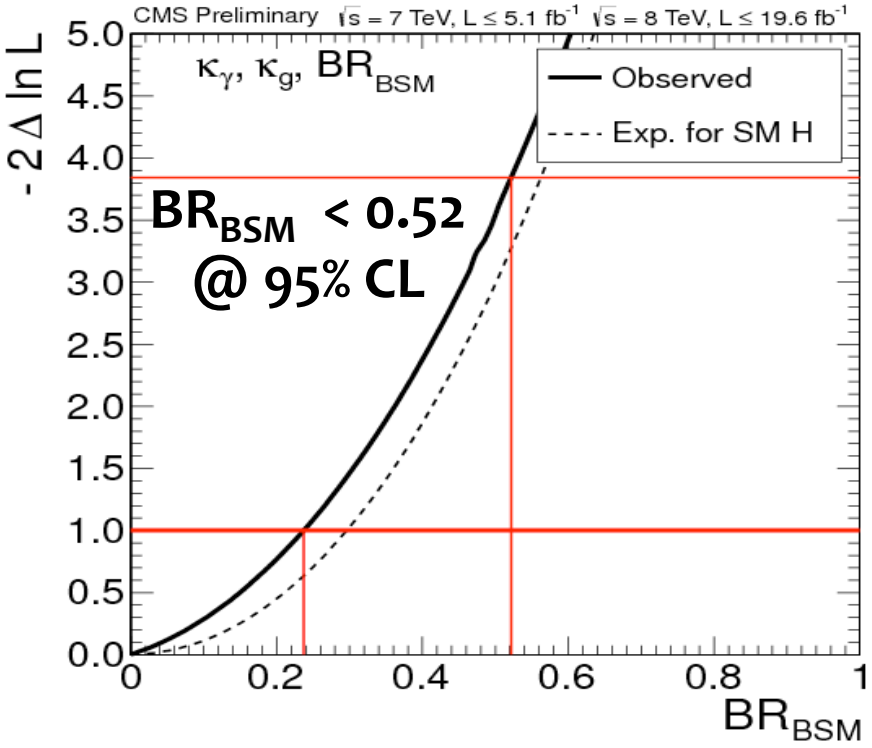
$\lambda_{du} > 1$ driven by low VV, γγ yields compared to bb, ττ

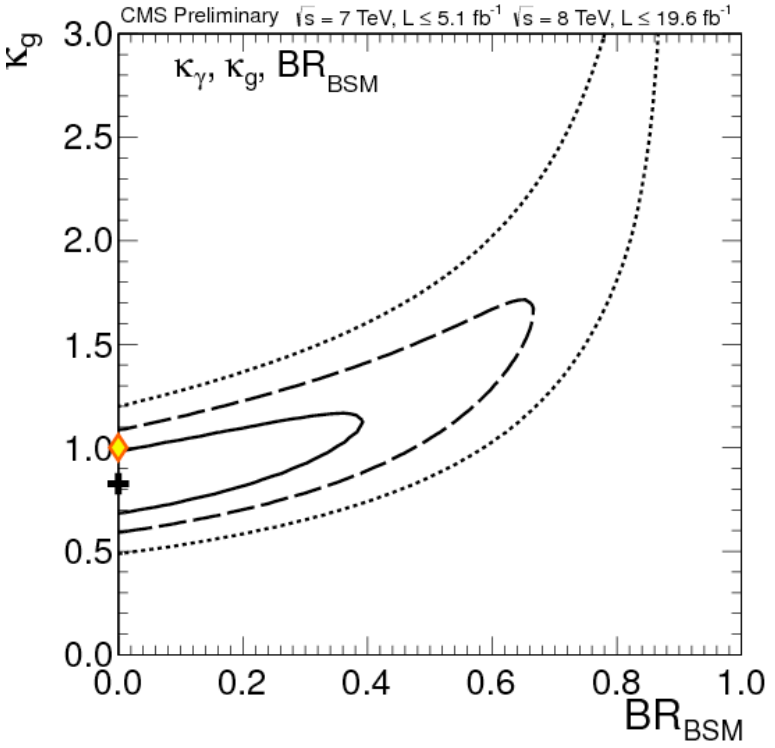
Search for new physics in loops

- Effective couplings to gluons and photons in good agreement with SM predicitons.
- Note best fit $\kappa_\gamma \sim 1$, with $\kappa_g < 1$, in line with $\mu < 1$ in VV modes as well.



Search for new physics in decays



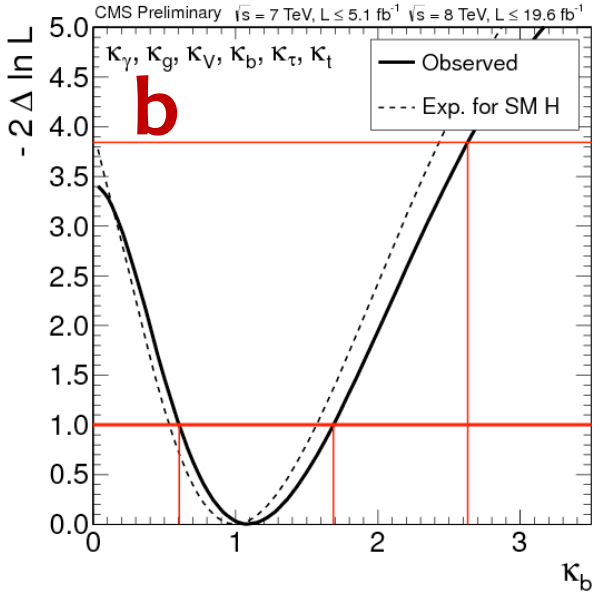


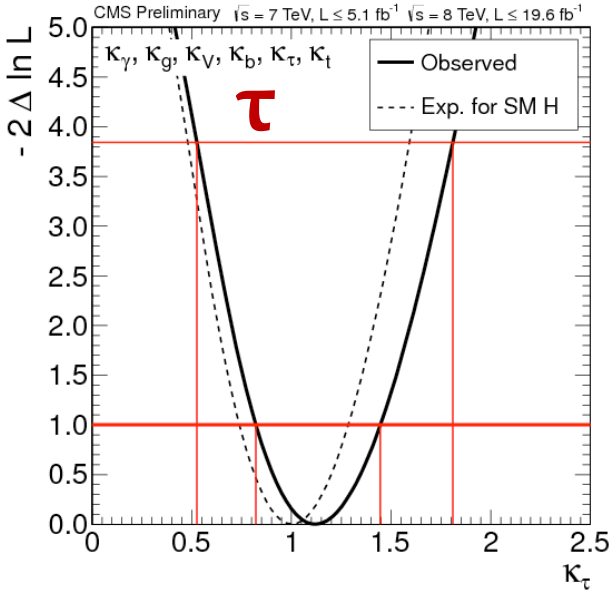
- Constrain total width from observed σ·BR's assuming SM tree-level couplings (but loop-induced couplings free)
- Degeneracy of BR_{BSM} with gluon coupling from σ(gg→H)
- Note: not using direct searches of H→invisible for this

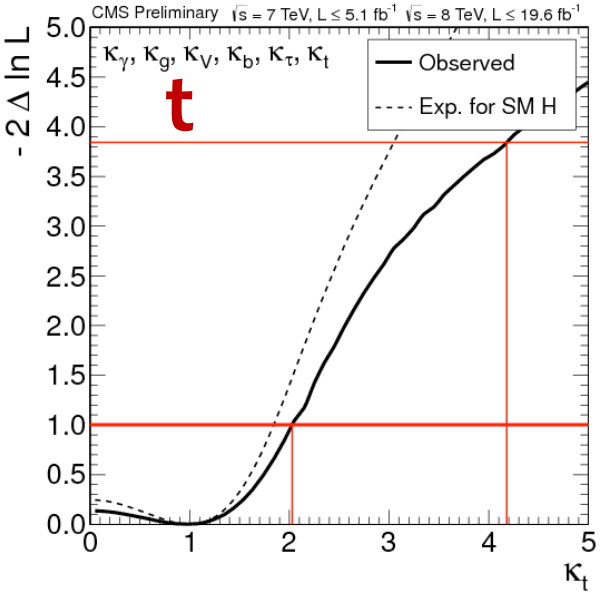
Fit six couplings at once

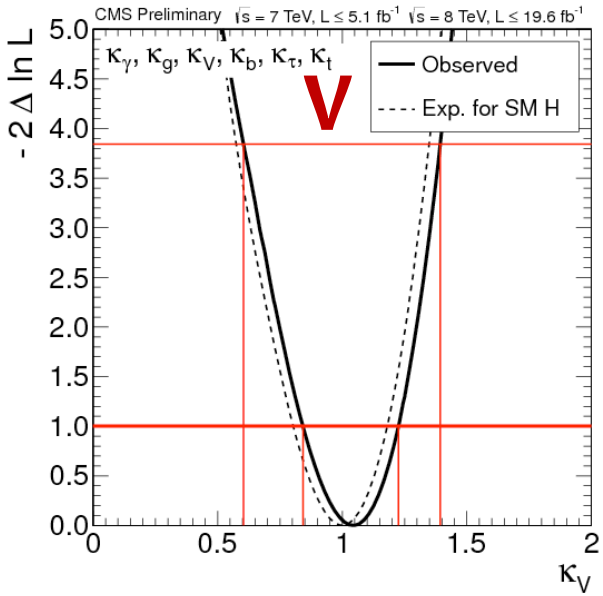
- General parameterization with 6 couplings, and the following assumptions:
  - Custodial symmetry: $\kappa_W = \kappa_Z =: \kappa_V$
  - Charm quark coupling scaling as top quark one (and similar ones for rarer decays like μ, s, …)
  - No BSM decays. If there were, they would just scale down all measured κ by $\sqrt{1-BR_{BSM}}$ i.e. in models with BSM decays this assumption is just a choice of coordinates in a space with (N+1)-dimensions of which 1 is not measured.

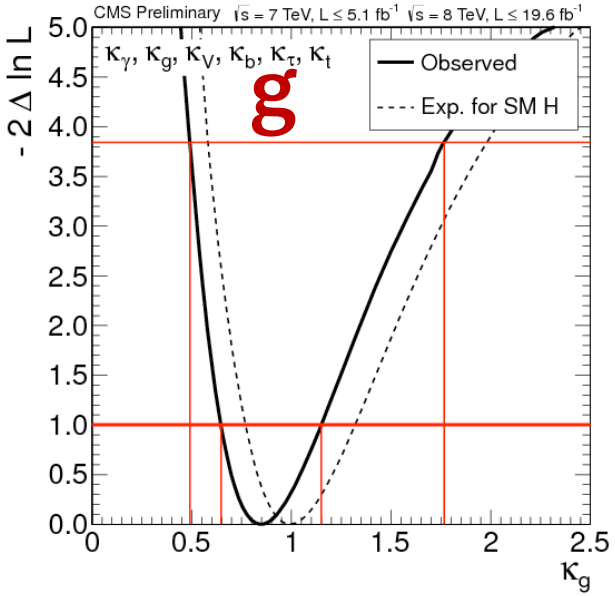
Fit six couplings at once

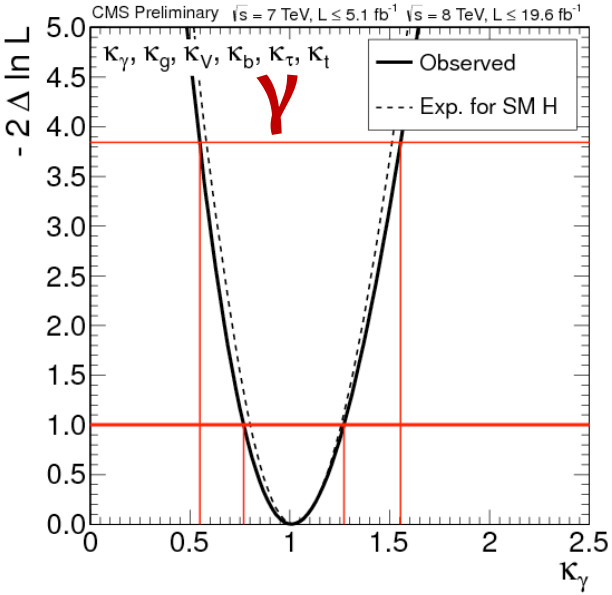












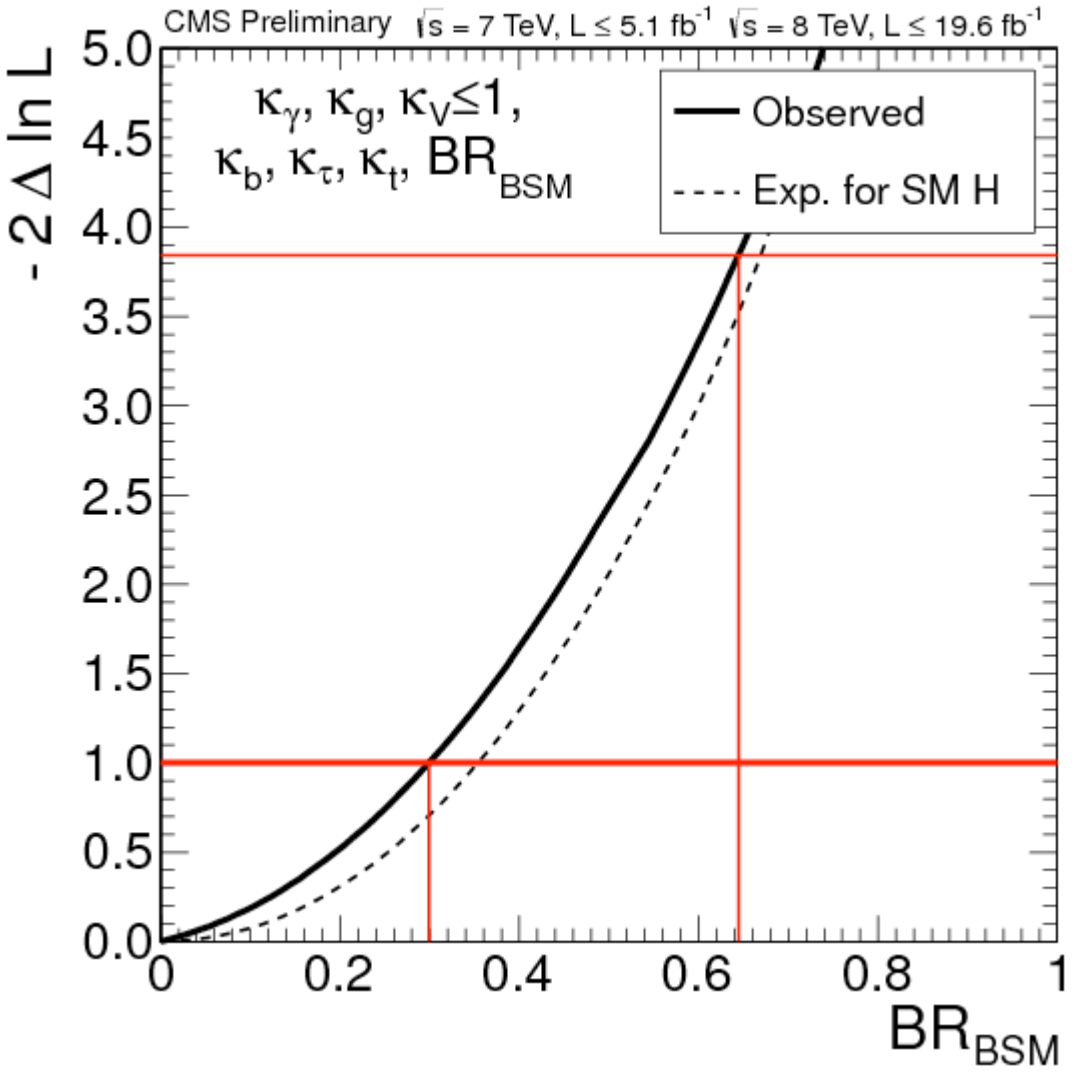
Total width with free couplings

- If no assumption is made, all couplings are degenerate with the total width:
  - All $\sigma \cdot BR$ scale as $\kappa^4 / (\kappa^2 \Gamma_{SM} + \Gamma_{BSM})$
- However, in most EWSB models $\kappa_V \leq 1$
- If that constraint is imposed, one can put an upper limit on the total width with no other assumption on the other couplings.
- Direct H→invis searches not used in this fit. Note that in the general scenario they can only provide a lower bound ($BR_{BSM} \geq BR_{Inv}$)

Total width with free couplings

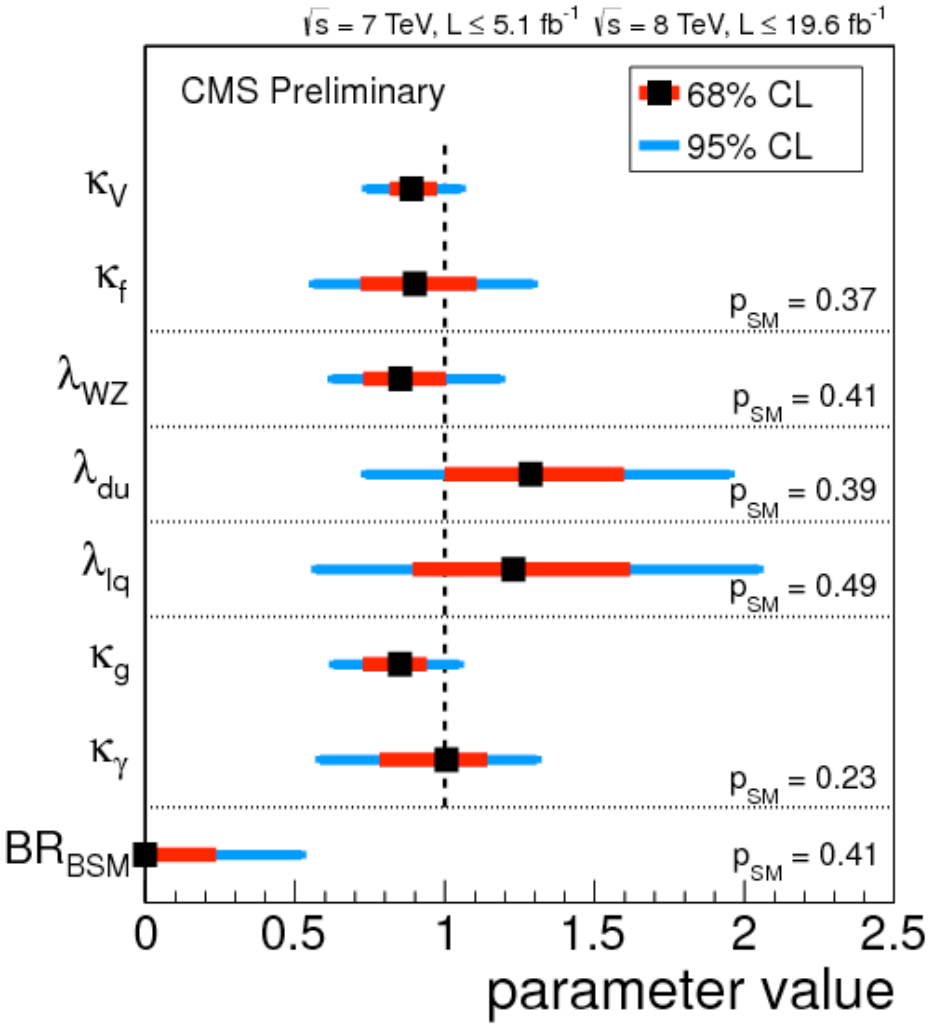
- Upper limit to BSM decays imposing $\kappa_V \leq 1$:

BR_{BSM} < 0.64 @ 95% CL



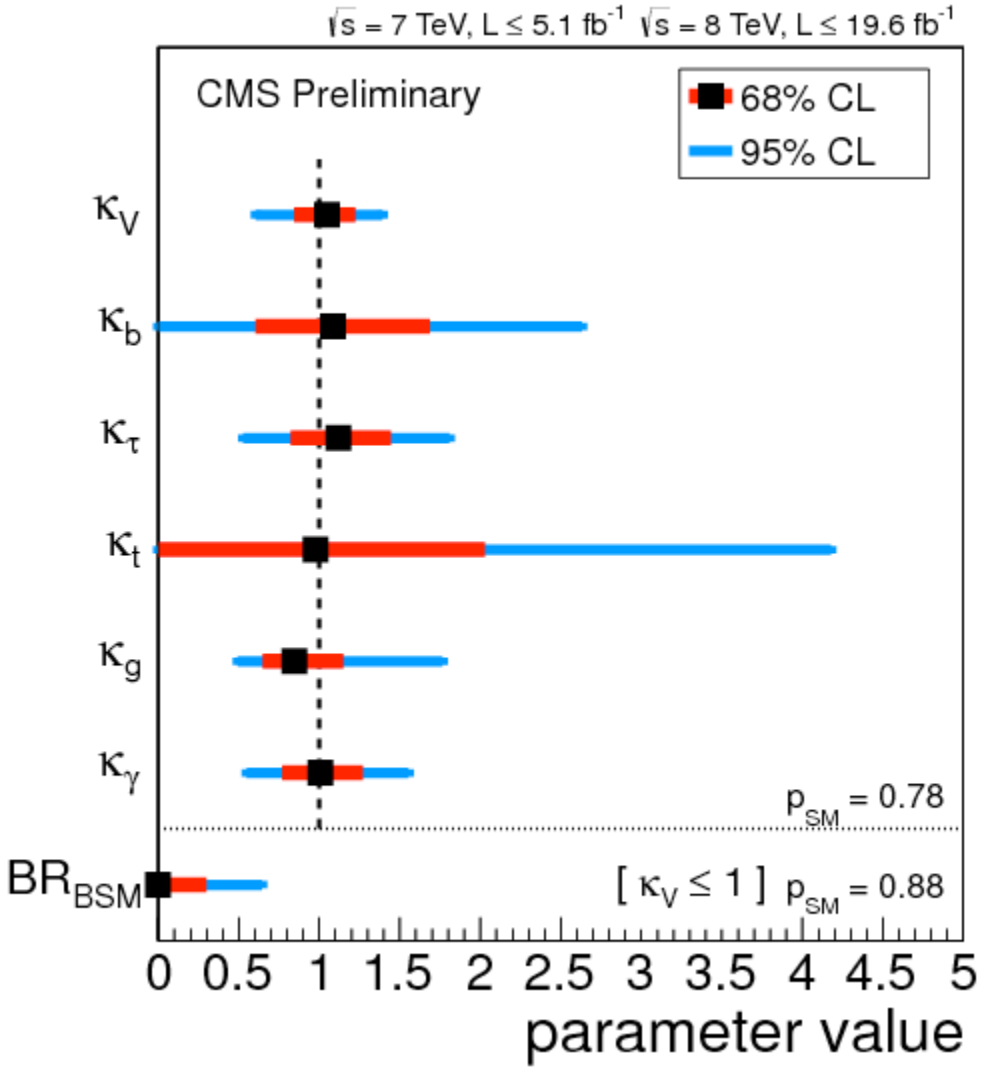
Summary of coupling results

- **Results for all the LHC XS WG models**
- Each block of points corresponds to fits from one model, all on the same data.
- Approximate p-vals of SM H hypothesis given for each test



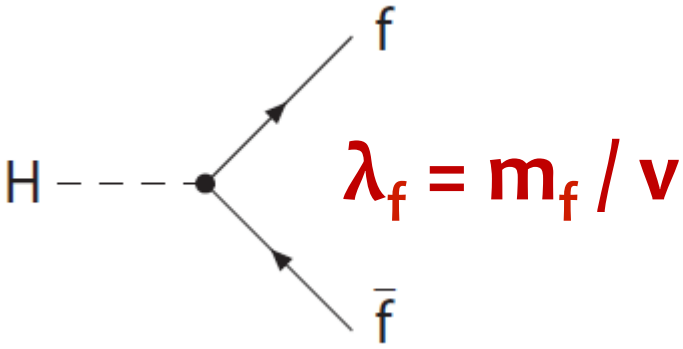
Summary of coupling results

- **Results for generic fit of all couplings**
- First 6 paramaters all from the same simultaneous fit (but uncertainties are correlated)
- Last is BR_{BSM} from fit with $\kappa_V \leq 1$ constraint

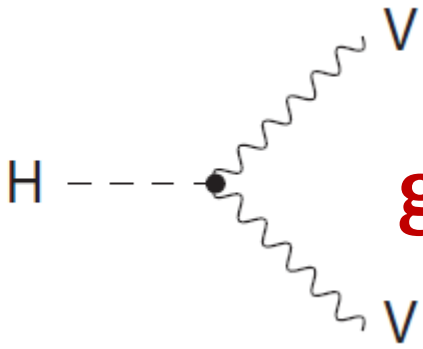


Couplings vs mass

- We usually say "the Higgs boson couplings are proportional to the masses of the particles"
- More precisely, Feynman rules have



$\lambda_f = m_f / v$



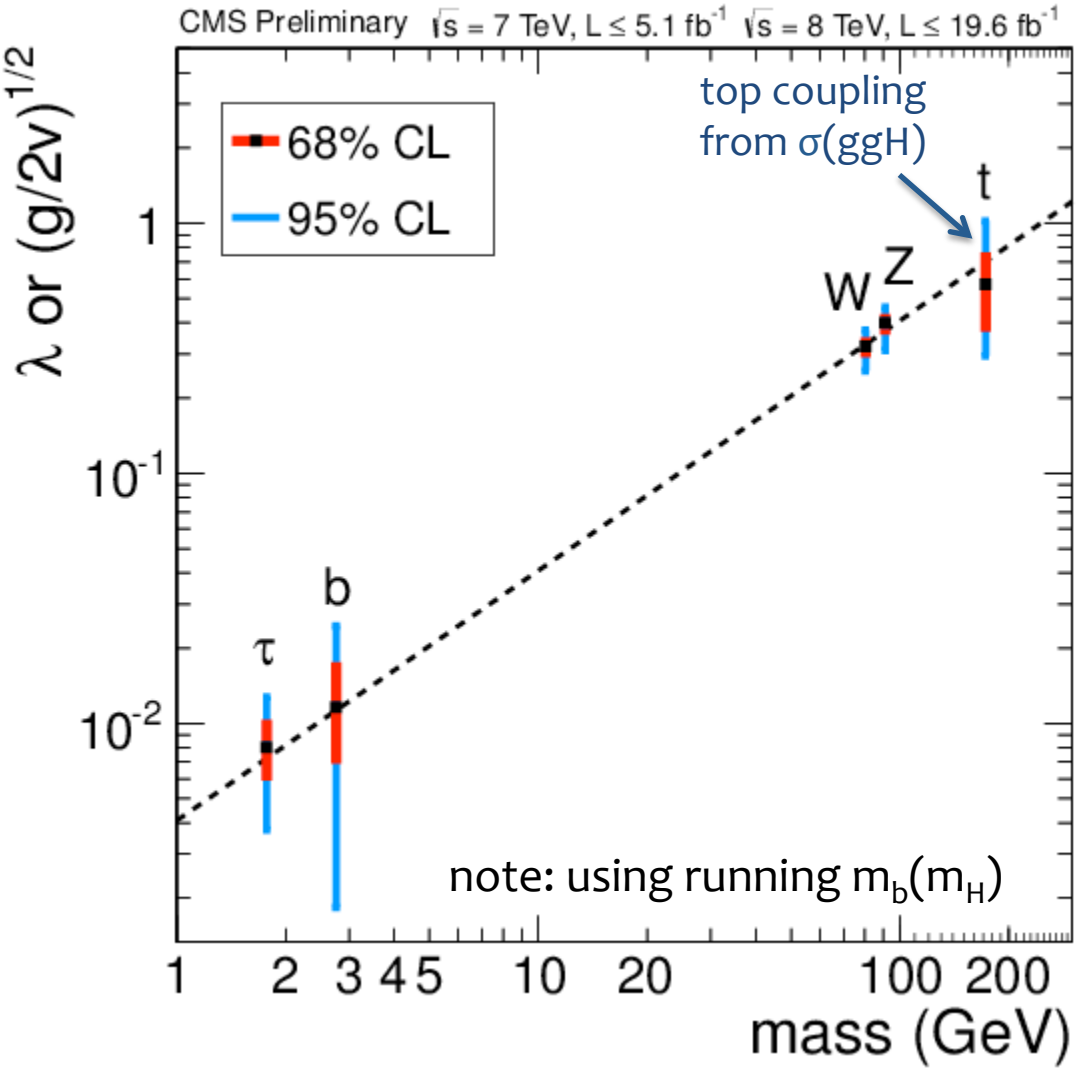
$g_V = 2\, m_V^2 / v$

- Make a summary plot with all "couplings" linear in mass using λ_f and sqrt(g_v/2v)

[e.g. Giardino et al, arXiv:1303.3570]

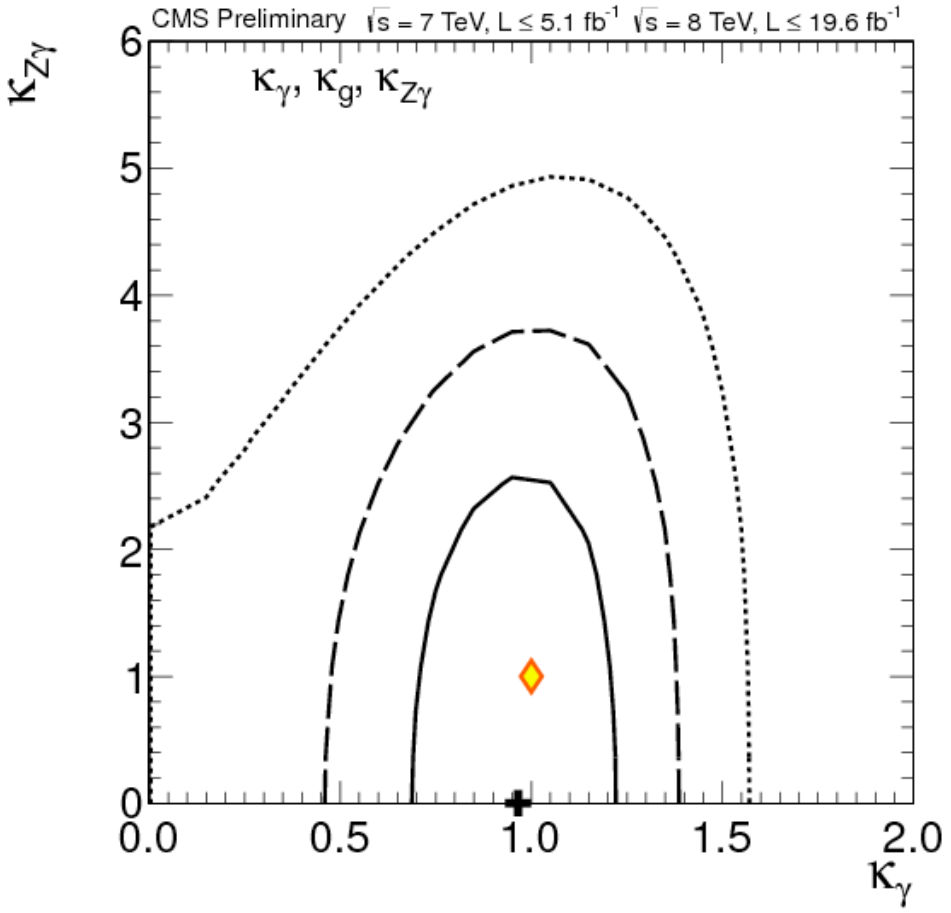
Couplings vs mass

- Perform fit to full CMS combination, resolving gluon and photon loops in terms of tree-level couplings.
- Define couplings from the kappa's:
  $\lambda_f = \kappa_f m_f / v$
  $g_v = 2 \kappa_V m_V^2 / v$



Limits on γ vs Zγ couplings

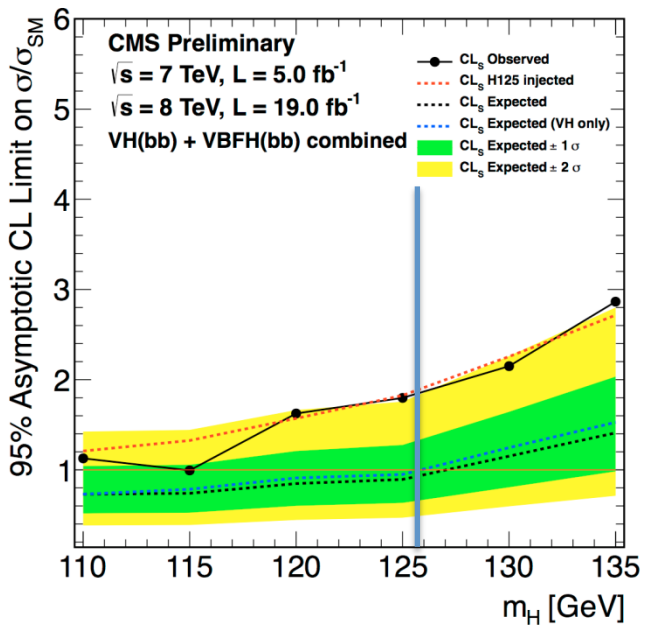
- Search for BSM in loops (gg, γγ, Zγ)
- Assume all other tree-level couplings to be as in SM.
- Set limits on κ_γ, $\kappa_{Z\gamma}$ plane profiling κ_g
- Interesting for some BSM scenarios like composite Higgs.

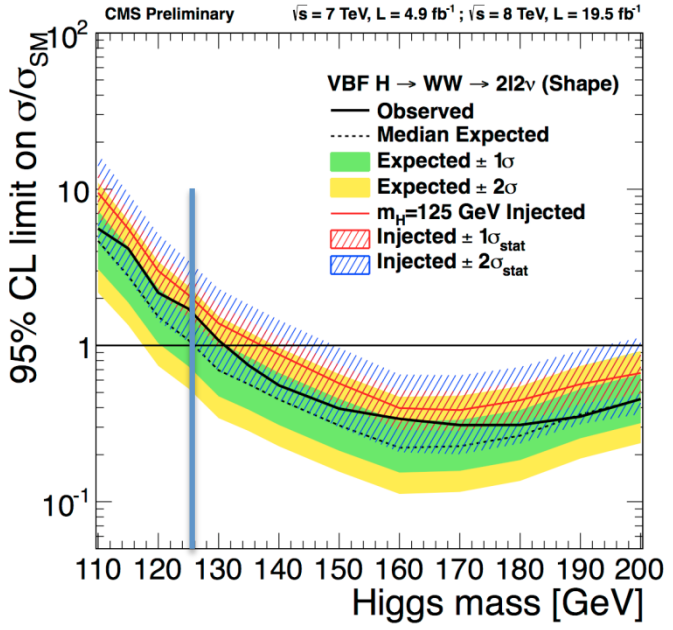


Beyond Moriond'13: core

New Run I results bringing in more precision:

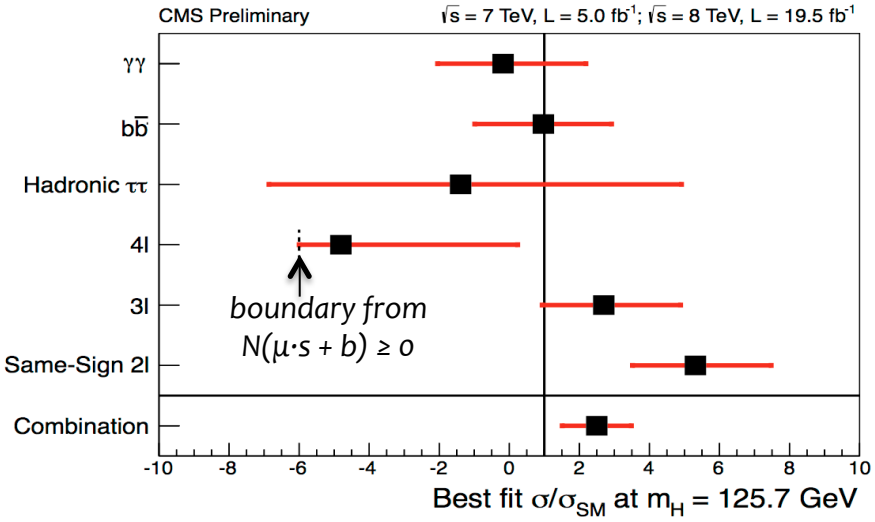
- H→bb: VH with full luminosity (**20% better**), and new VBF result (**1.4×SM** sensitivity on μ)
- VBF H→WW with full luminosity, and improved analysis: **30% better sensitivity**.

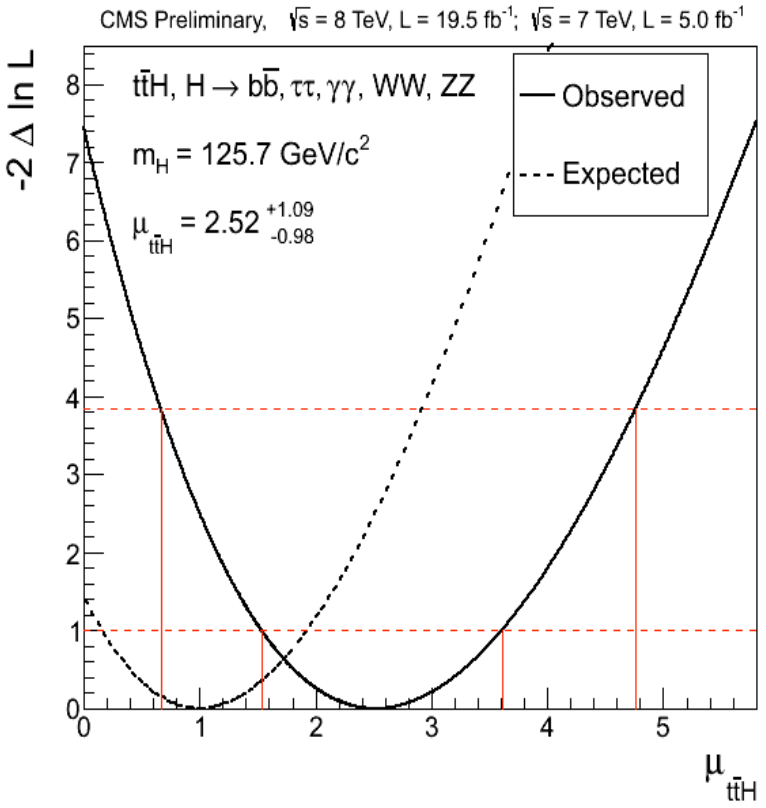




Beyond Moriond'13: top

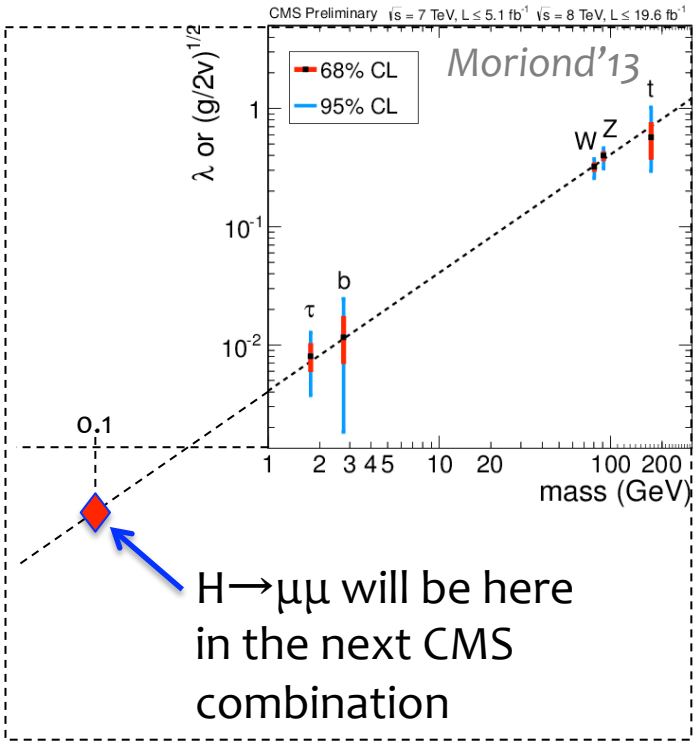
- ttH: full luminosity analyzed in bb, γγ, $\tau_h\tau_h$, and multi-lepton final states: **reached 1×SM sensitivity on μ(ttH)!** (was 2.6×SM at Moriond'13)





Beyond Moriond'13: rare

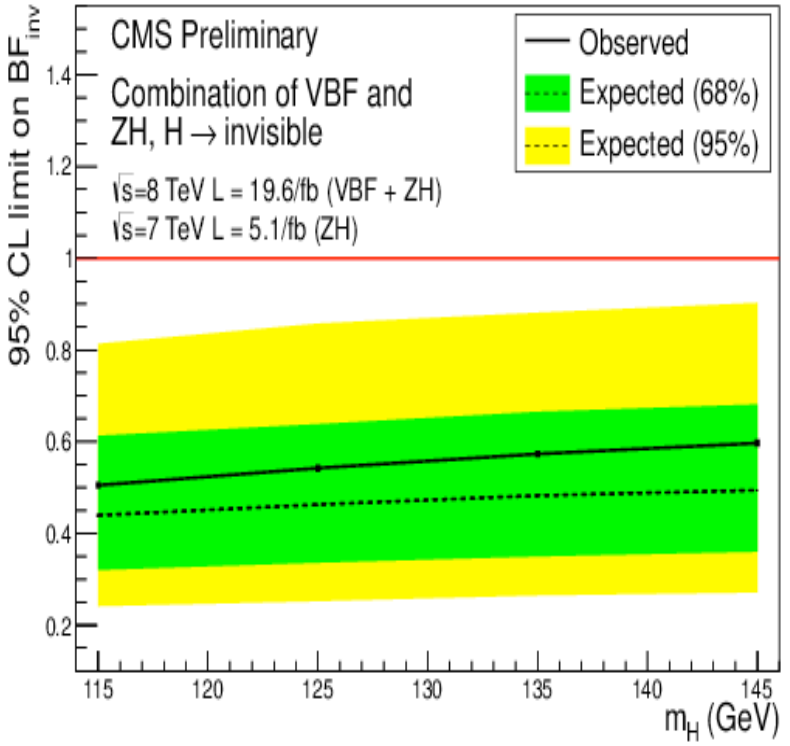
- Progress also in rare Higgs boson decays:
  - Zγ including VBF-tag: 20% better sensitivity compared to the Moriond 2013 result
  - H→μμ, inclusive + VBF: **~3×SM sensitivity on μ.** i.e. in absolute terms BR(μμ) to 1% of BR(ττ)



Beyond Moriond'13: invisible

Two new analyses: ZH ($Z \to \ell\ell$) and VBF

- Combined 95% upper limit on BR($H \to inv$):
  - Observed 54%
  - Expected 46%
- Will allow for combined fit with no κ_V constraint and assuming instead $BR_{BSM} = BR(H \to inv)$



Conclusions

- Comprehensive set of Higgs coupling fits done for the Moriond'13 dataset at CMS.
  - No significant deviation from SM predictions observed within the uncertainties (10-100%)
- Since then, many new analyses have been performed, and all updated to full dataset.
  - Significant gain in sensitivity in many modes, will be visible in the next CMS combination
  - The SM Higgs predictions look quite solid

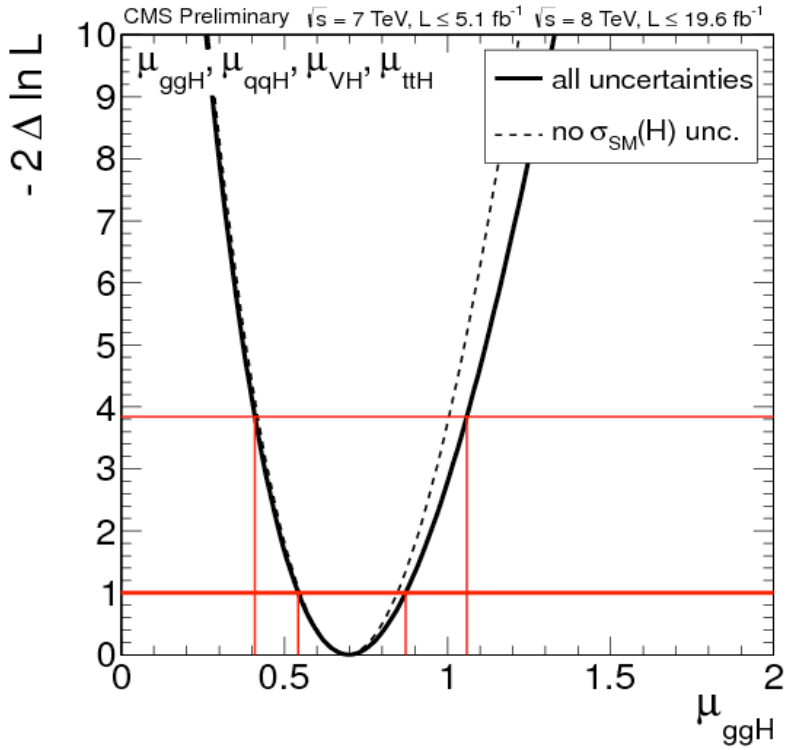
"I don't know anyone, beside scientists, who is thrilled when discovering that he is wrong, and disappointed when everything works as expected"

Providing the Likelihood?

- The real likelihood function is a too nasty beast: needs dedicated C++ code, O(1000) nuisance parameters, slow to evaluate, ...
- We could provide profiled likelihoods in the $\mu_{VBF,VH} - \mu_{ggH,ttH}$ plane for each search.
  - Allows building an *approximate* likelihood for any model with $\kappa_W = \kappa_Z$ and $\kappa_{qqH} = \kappa_{VH}$
  - Correlations of experimental uncertainties are small if we don't split channels too finely
  - Other options could be discussed if there's genuine interest, but are harder to realize.

Theoretical uncertainties

- Current measurements are still dominated by experimental uncertainies even for μ(ggH)
- Theory uncertainties can't be fully factored out in general (e.g. there are uncertainties on backgrounds, acceptances, ..)
- So far using log-normal prescription for THUs.
- For next results will evaluate also DFD pdf, or any other new and agreed-upon prescription.



$$\mu_{ggH} = 0.69\ ^{+0.15\ +0.09}_{-0.14\ -0.05}$$

THU on $\sigma_{SM}(ggH)$