Higgs combination/properties at CMS

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Chicago 2012 Workshop on LHC Physics 12-14 November 2012

Channels going into combination

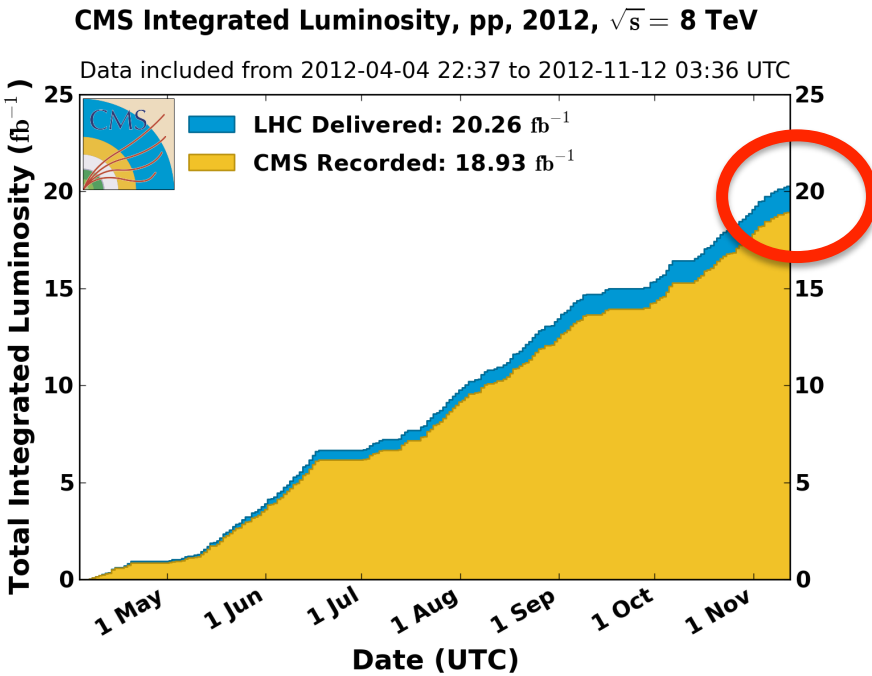
- **Low mass (110-150 GeV)**

	untagged	VBF-tag	VH-tag	ttH-tag
γγ	✔	✔		
bb			✔	✔
ττ	✔	✔	✔	
WW(lνlν)	✔	✔	✔	
ZZ(4l)	✔			

- **High mass**
  - WW(lνlν)
  - WW(lνjj)
  - ZZ(4l), **now up to 1 TeV**
  - ZZ(2l2q) and ZZ(2l2ν) not used (not ready with the new treatment of the Higgs boson mass line shape for large m_H)

Luminosity used (low-mass channels)

Channels		Luminosity (fb^{-1})	
decay	prod. tags	7 TeV	8 TeV
γγ	untagged	5.1	5.3
	VBF	5.1	5.3
bb	VH	5.0	**12.1**
	ttH	5.0	-
ττ	1-jet	4.9	**12.1**
	VBF	4.9	**12.1**
	VH	5.0	-
WW (2l2ν)	0/1-jets	4.9	**12.1**
	VBF	4.9	**12.1**
	VH	4.9	5.1
ZZ (4l)	inclusive	5.0	**12.2**



Expect 25 fb^{-1} (8 TeV) by the end of the year

NB: tags are never 100% pure
(e.g. VBF-tagged events are expected to contain 20-50% gg->H, depending on the analysis and sub-category)

Flow of results

- Setting aside the observed excess near mass 125 GeV, what can we say about where the SM Higgs boson cannot be?
- What is the significance of the excess near 125 GeV?
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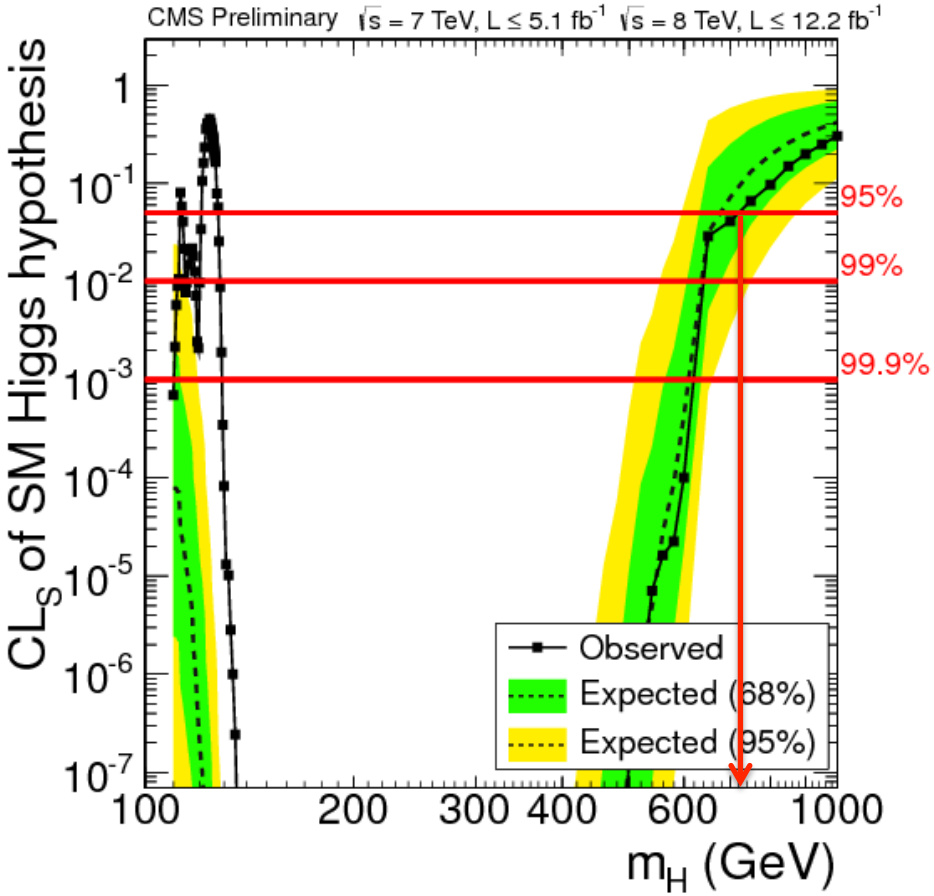
Where the SM Higgs boson is not



Exclusion at high mass is up 700 GeV at 95% CL

The void between 130 and 600 GeV at >99.9% CL

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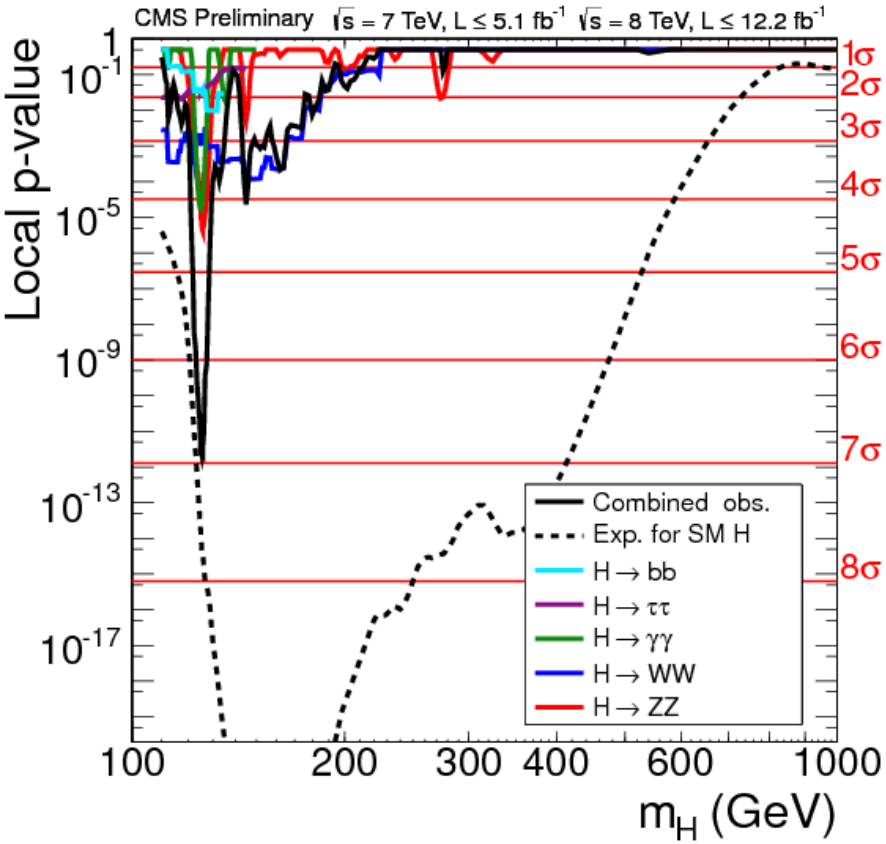
Excess near 125 GeV and elsewhere

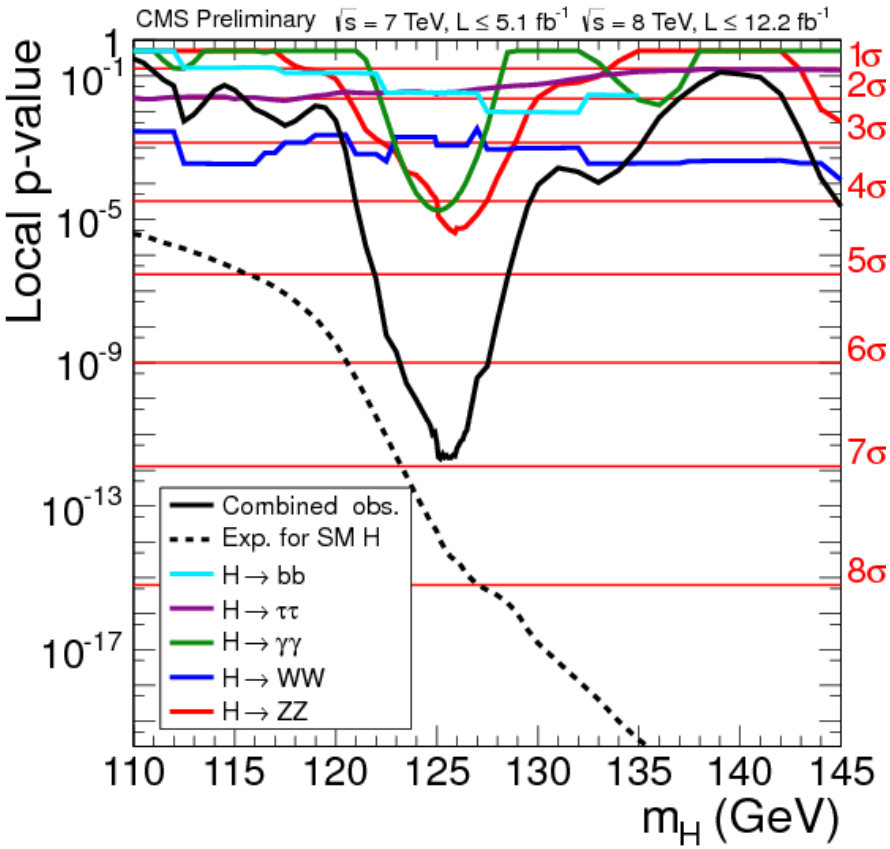


The excess near 125 GeV

- does not go away
- its significance is now 6.9σ
- broad 3σ bump from WW (low mass resolution ≈30 GeV)

Not much out there anywhere else

Excess near 125 GeV: closer look



Good mass resolution (γγ, 4l):

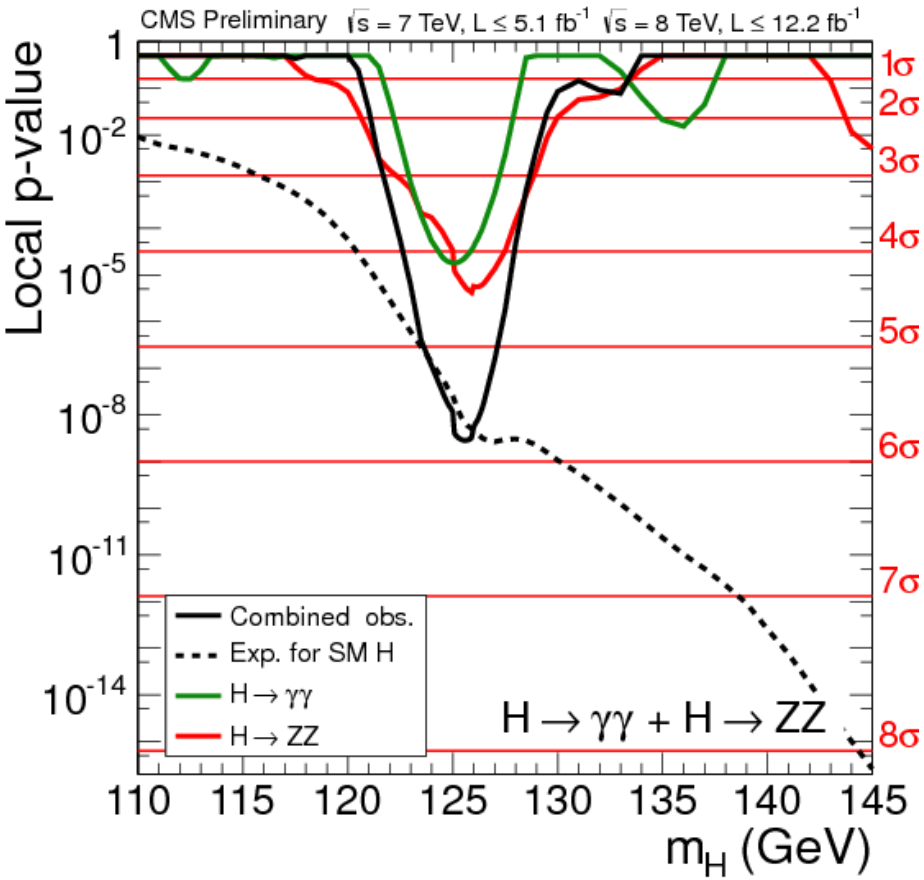
- very localized excesses
- about 4σ each
- line up near 125 GeV

Poor mass resolution channels:

- WW: about 3σ excess
- ττ, bb: about 2σ excess each

NB: m_H point of the maximum significance is indicative of the mass, but not a mass measurement

Excess near 125 GeV: closer look



Good mass resolution (γγ, 4l):

- very localized excesses
- about 4σ each
- line up near 125 GeV
- **almost 6σ, combined**

NB: m_H point of the maximum significance is indicative of the mass, but not a mass measurement

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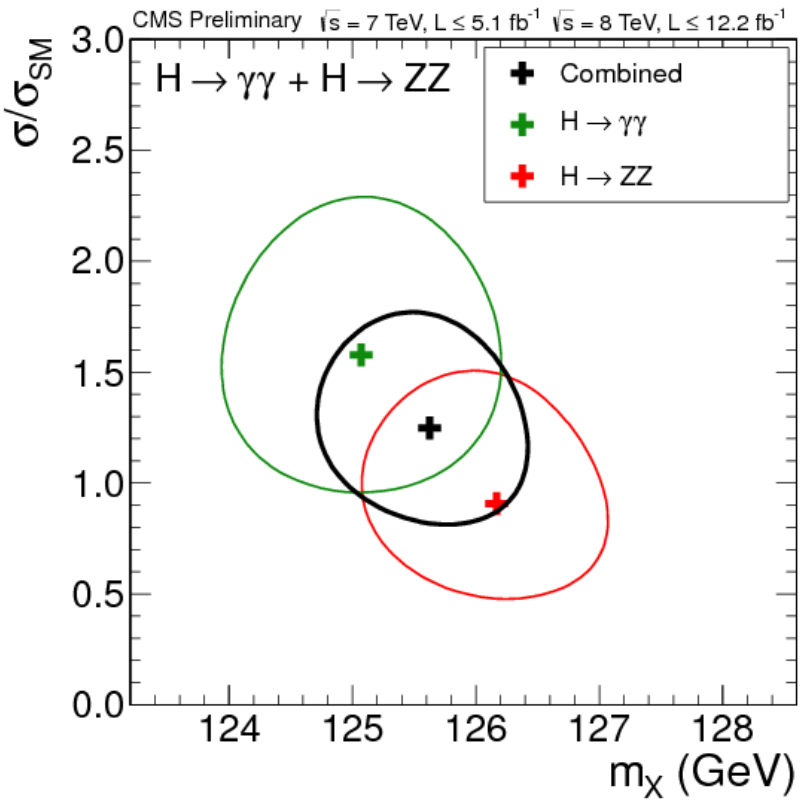
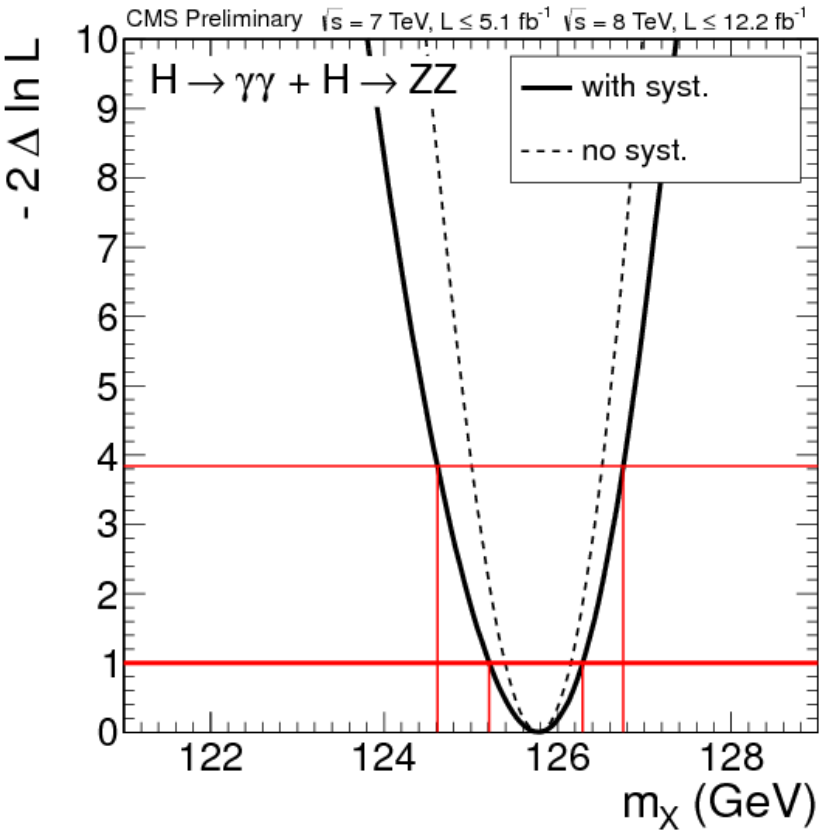
Mass measurement: preliminaries



- Two channels with good mass resolution
  - γγ (relative rates for VBF and gg->H contributions are SM-like)
  - inclusive ZZ(4l)
- **Results are consistent with one particle → can combine**
- Black curve:
  - example of the SM-Higgs-like combination with a **common mass** and a **common signal strength**

Mass measurement: final result



Assume one particle.

Allow for three **independent** signal yields (not tied by SM):

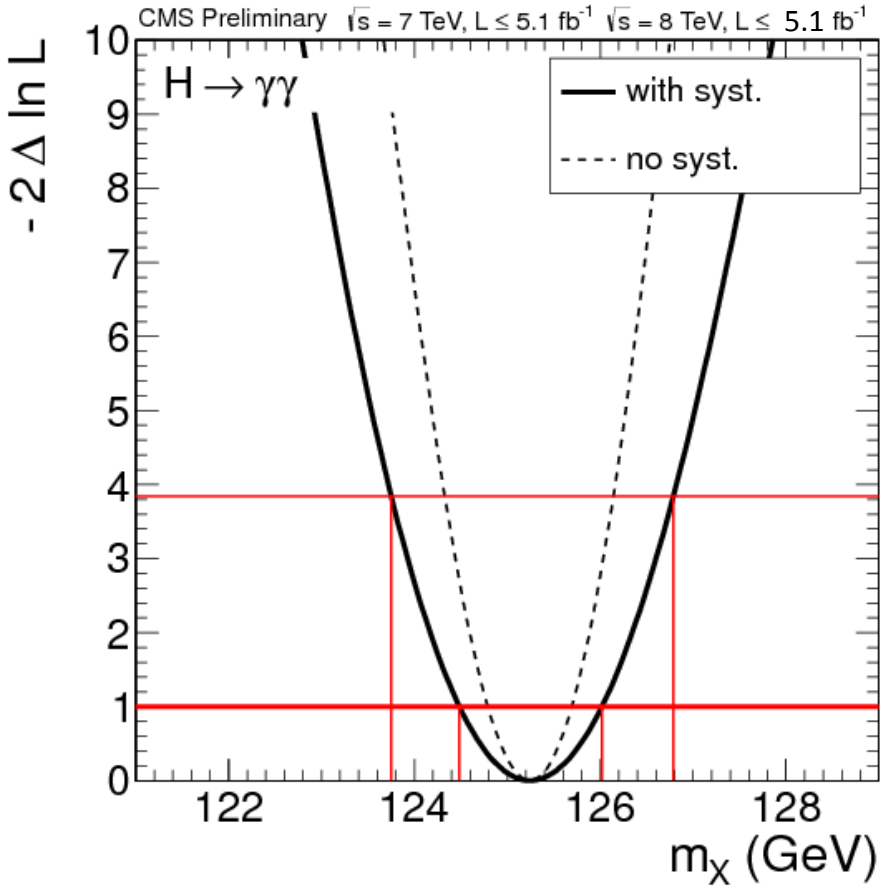
- untagged γγ
- VBF-tagged γγ
- inclusive ZZ(4l)

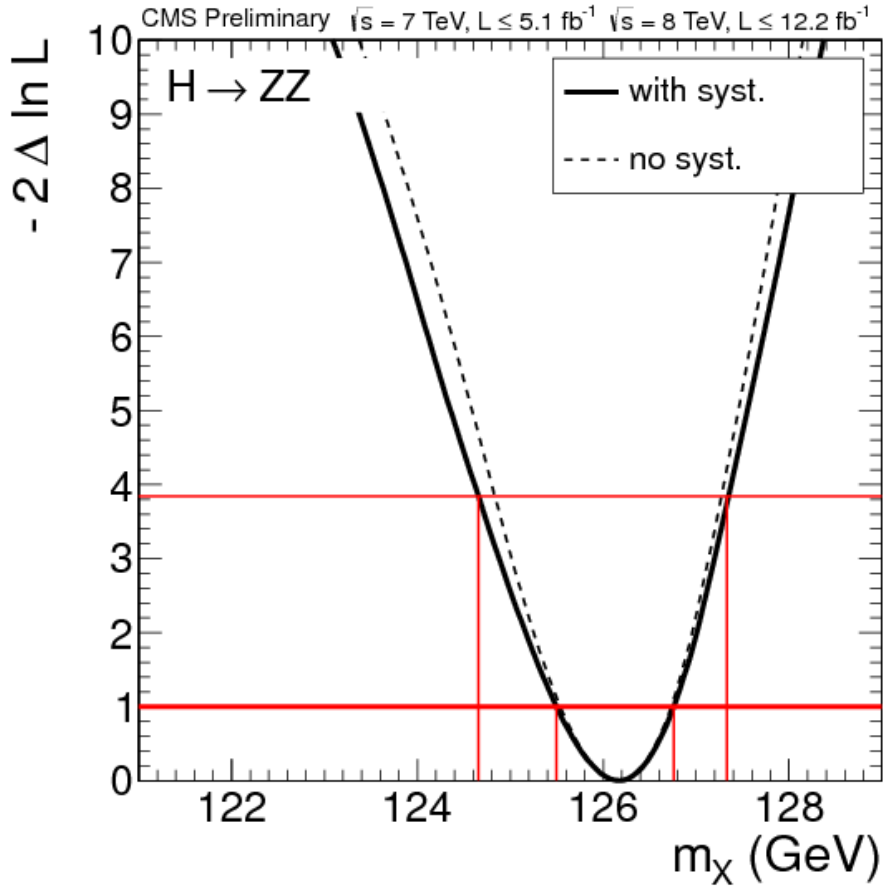
Fit for a common mass:

m_X = 125.8 ± 0.6 GeV (±0.5%)

= 125.8 ± 0.4(stat) ± 0.4(syst) GeV

Side note: mass fits for γγ and 4l





NB: The 4l channel now gives overall the most accurate measurement.
The error in 4l channels is dominated by statistics
(systematic error in 4l is 0.2%; 0.1% in the 4μ-channel)

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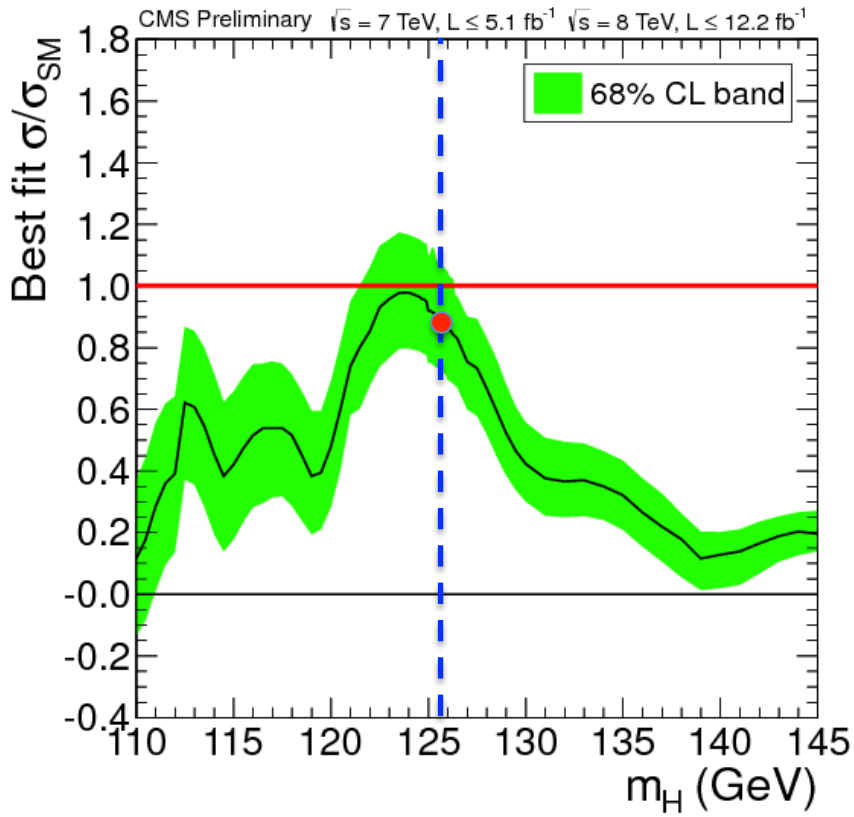
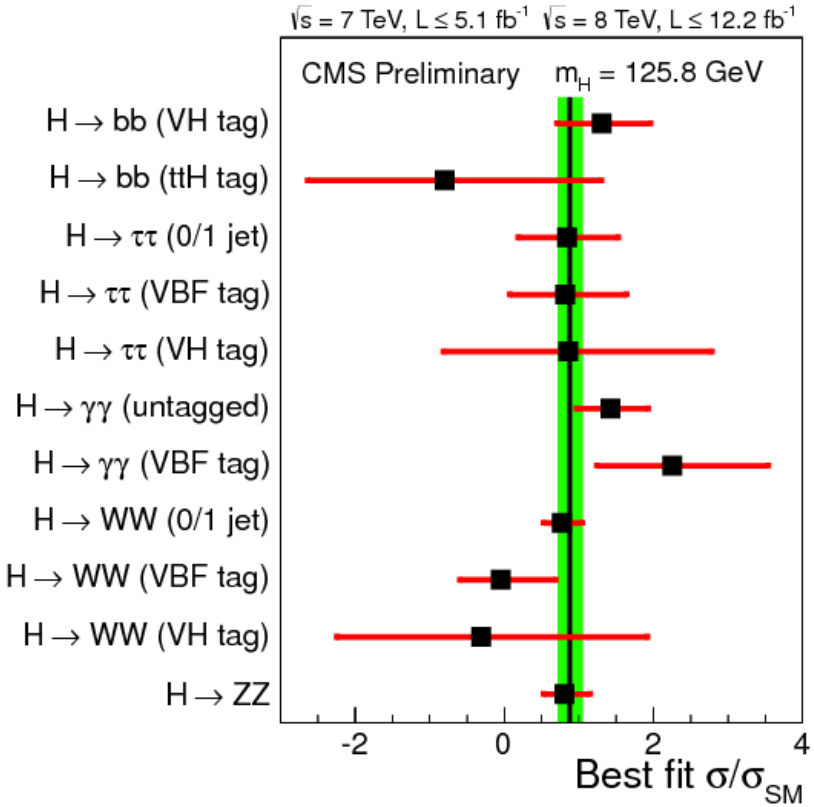
Overall signal strength



- **Best-fit signal strength** (common scale factor for expected signal event yields in all channels): **μ = 0.88 ± 0.21**
- This is the simplest (highly constrained) compatibility test of the excess seen in data with the SM Higgs boson
- Results are consistent with the SM Higgs boson

Self-consistency by search channel (1)



Sub-combinations grouped by (production tag) × (decay mode)

NB: VBF-tagged channels have large gg->H contributions

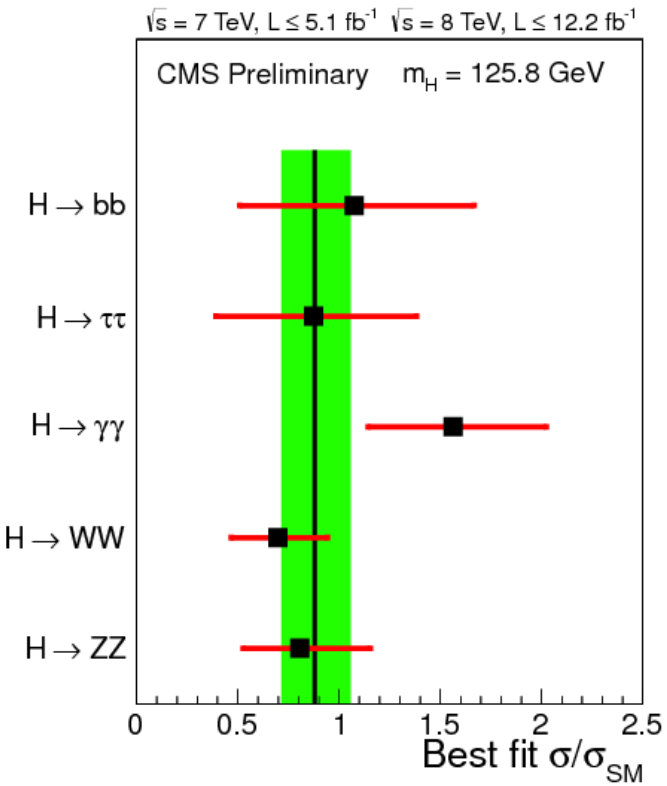
Consistency with the SM Higgs:

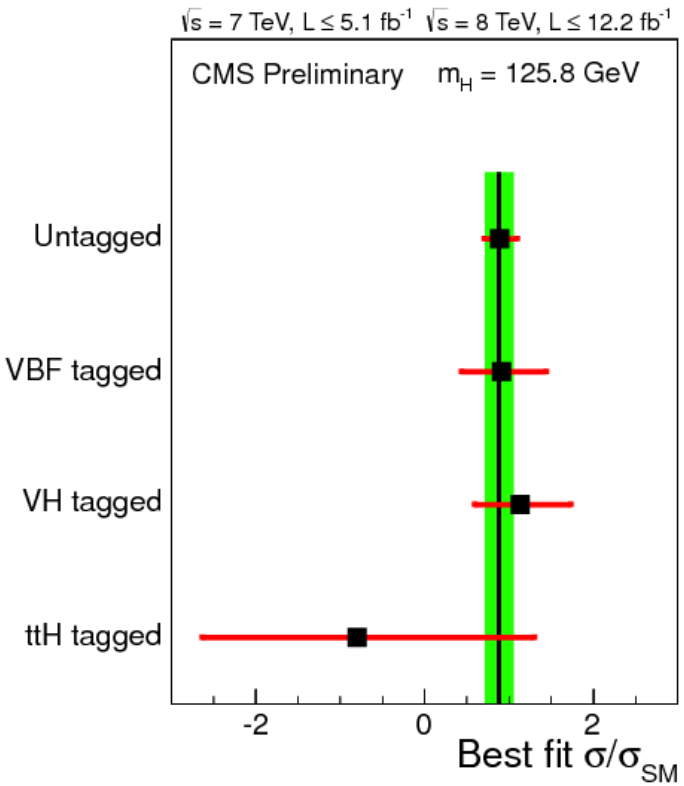
χ^2 / ndf = 8.7 / 11

asymptotic $P(\chi^2>8.7|ndf=11) = 0.65$

pseudo-experiments: P = 0.48

Self-consistency by search channel (2)





χ^2 / ndf = 4.3 / 5

asymptotic $P(\chi^2>8.7|ndf=11) = 0.51$

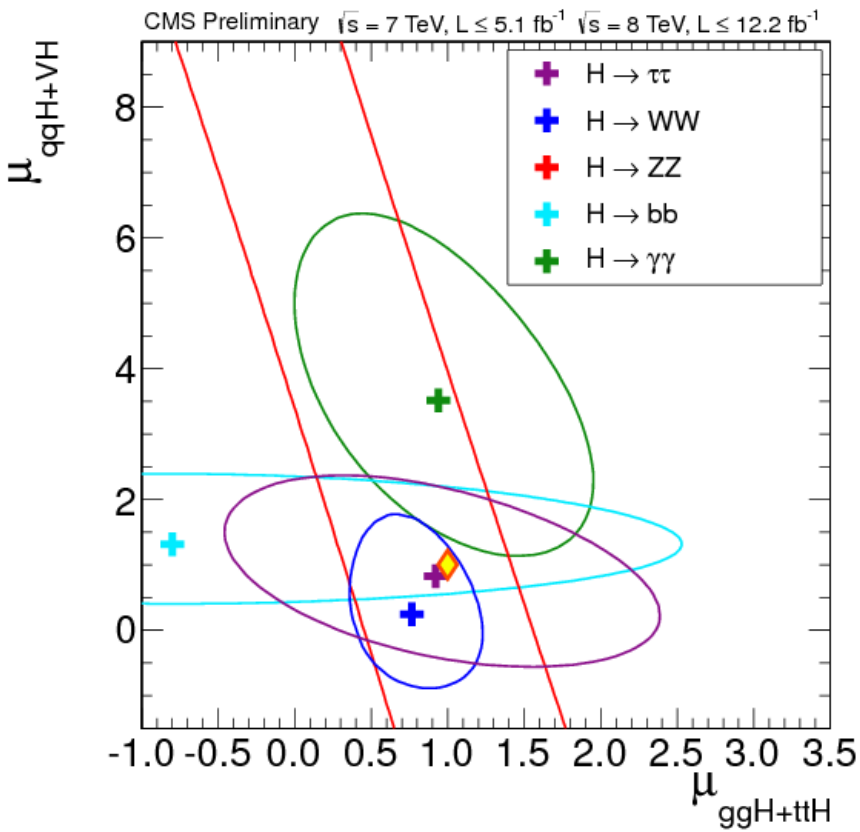
pseudo-experiments: P = 0.54

χ^2 / ndf = 1.3 / 4

asymptotic $P(\chi^2>8.7|ndf=11) = 0.86$

pseudo-experiments: P = 0.87

Self-consistency by search channel (3)



Another look…

Two signal strengths in **each of 5 decay channels**:

- one related to **fermion-coupling** induced production mechanisms
- another---to **W/Z-coupling** induced production mechanisms
- $\mu = (CS \times BR) / (CS \times BR)_{SM}$

NB: these results for 5 channels cannot be combined by construction

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Production x Decay parameterization

8 independent parameters to describe all currently relevant decays and production mechanisms:

- Γ_{ZZ}
- Γ_{WW}
- $\Gamma_{\tau\tau}$
- Γ_{bb}
- $\Gamma_{\gamma\gamma}$ (loop induced)
- Γ_{gg} (loop induced)
- Γ_{tt}
- Γ_{TOT} (including H → "invisible")

$$N(xx \to H \to yy) \sim \sigma(xx \to H) \cdot \mathcal{B}(H \to yy) \sim \frac{\Gamma_{xx}\Gamma_{yy}}{\Gamma_{tot}}$$

	untagged	VBF-tag	VH-tag	ttH-tag
γγ	✔	✔		
bb			✔	✔
ττ	✔	✔	✔	
WW(lvlv)	✔	✔	✔	
ZZ(4l)	✔			

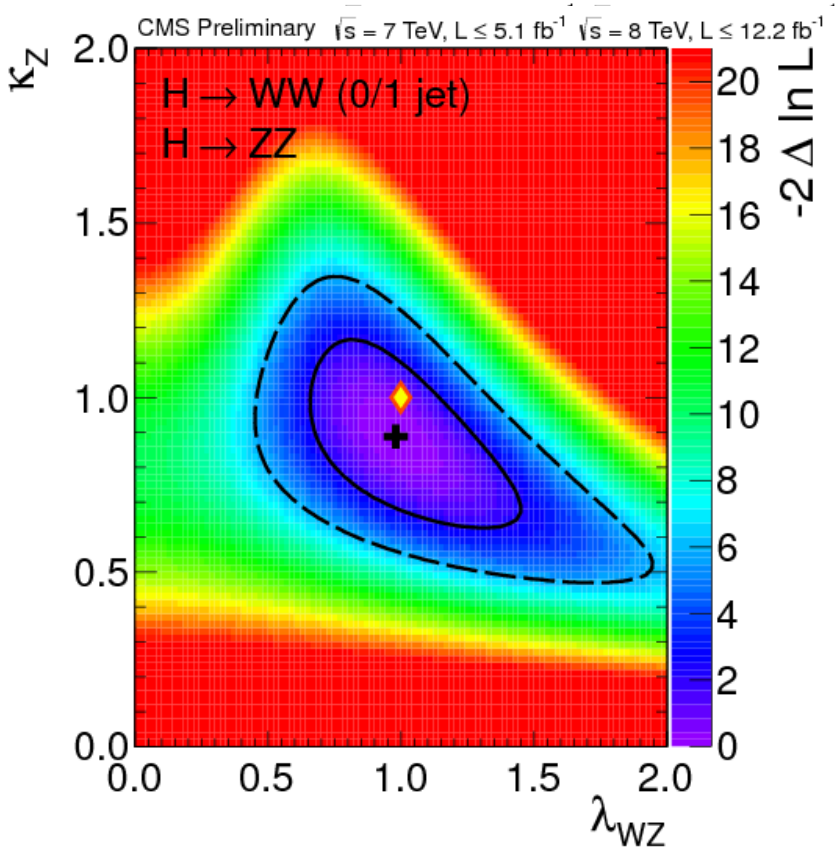
Couplings compatibility tests

- Extraction of all 8 parameters is too early with the current data

- Instead, we go after coupling compatibility tests:
  - assume SM Higgs couplings
  - introduce **a limited number of scaling factor** for:
    - couplings (κ): $g = \kappa \bullet g_{SM}$
    - or ratios of couplings (λ)
  - also can add and probe BR(BSM)

- **These are <u>compatibility tests</u>, not measurements of couplings:**
  - In SM, couplings are not free parameters
  - Any significant deviation of scale factors from 1 would
    - imply new physics beyond SM
    - require a re-fit of event yields in in the framework of particular BSM models

Custodial symmetry (test 1)

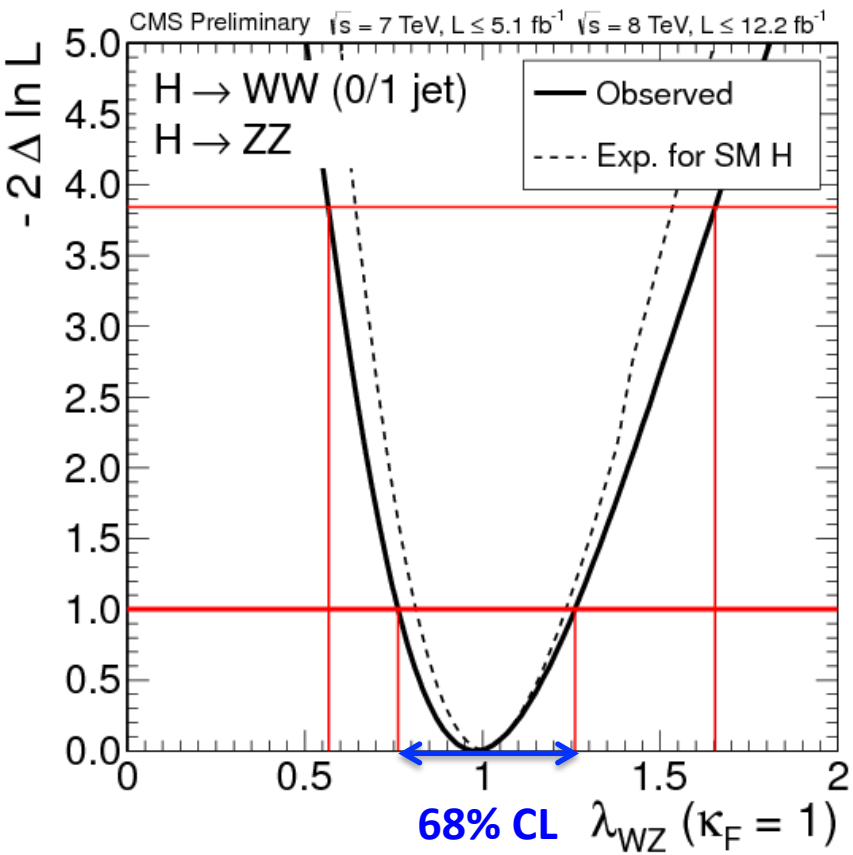


Custodial symmetry: in SM, the ratio of couplings to W and Z bosons is almost not affected by loop corrections

Compatibility test No.1:

- use un-tagged WW and ZZ channels
- the ratio of signal yields: $\sim g_W^2 / g_Z^2 = \lambda_{WZ}^2$
- Assume SM coupling to fermions (κ_F=1); dependence on this assumption is weak
- **Fit for: κ_Z , λ_{WZ}**

Custodial symmetry (test 1)



95% CL

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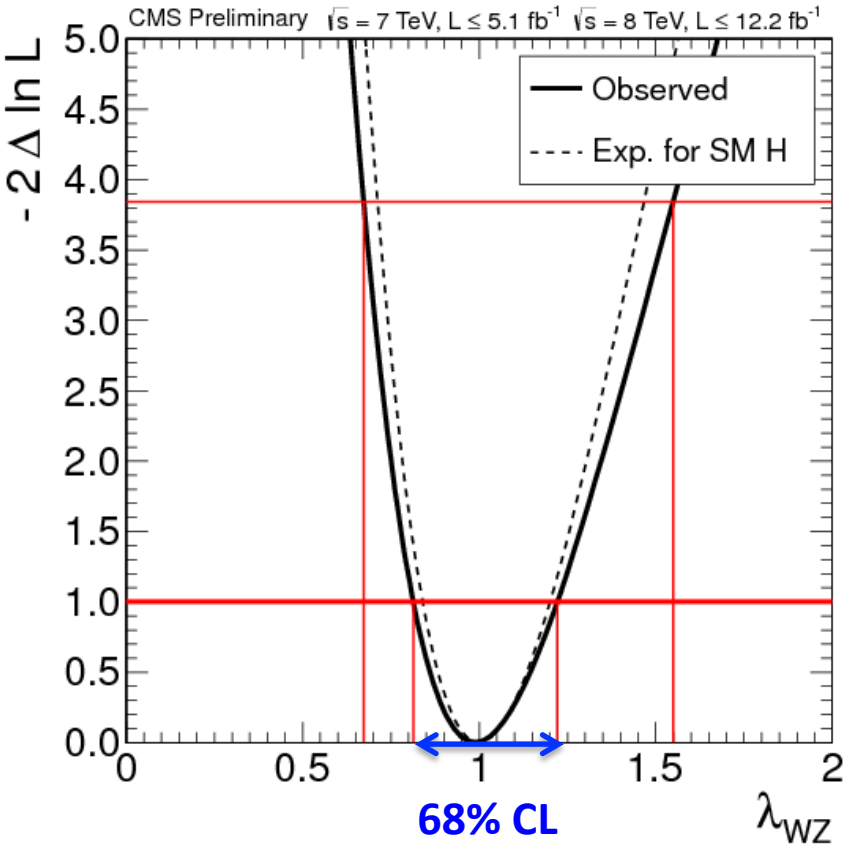
Custodial symmetry (test 2)



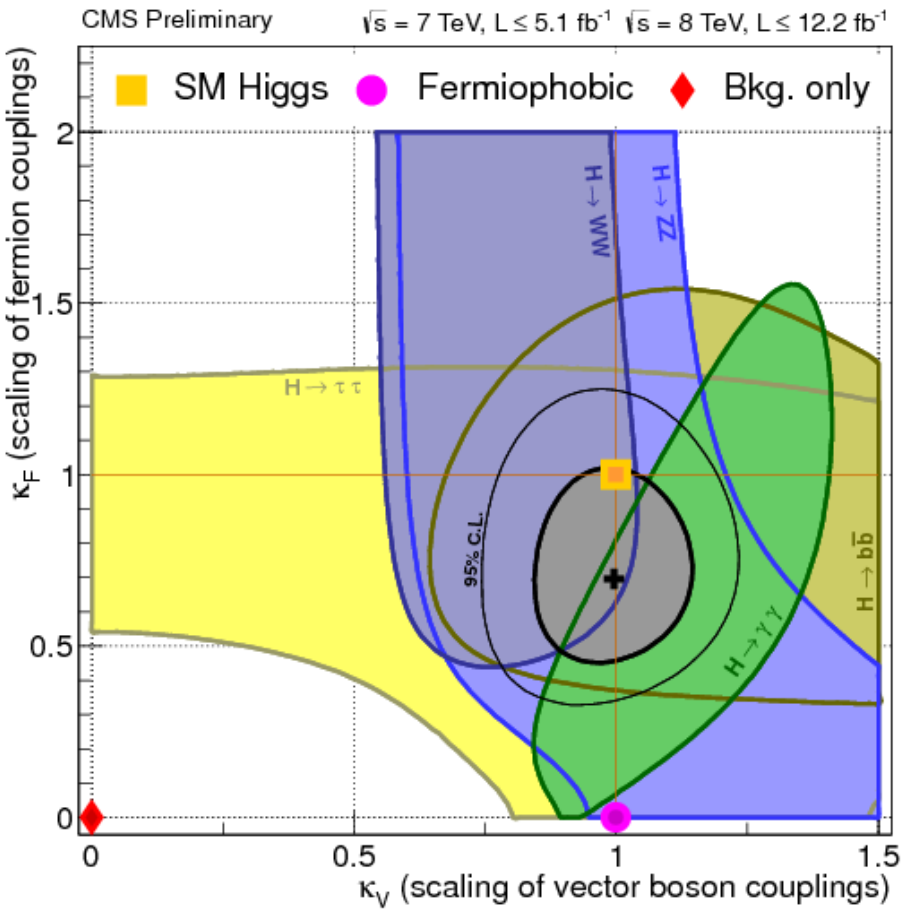
Compatibility test No.2:

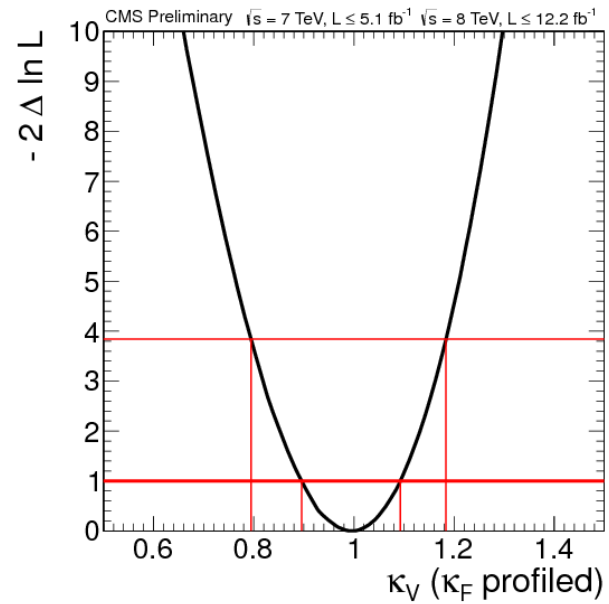
- use all channels
- Assume common scale factor for couplings to fermions (κ_F)
- **Fit for: κ_Z , λ_{WZ} , κ_F**

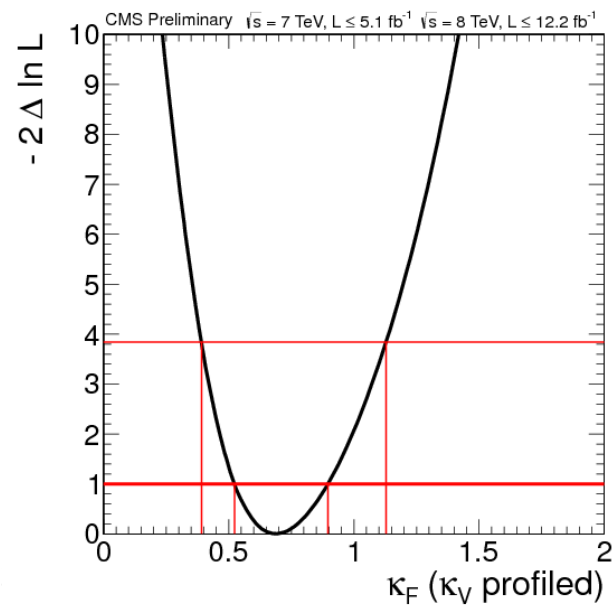
Data consistent with the custodial symmetry

Further we assume: $\kappa_Z = \kappa_W = \kappa_V$

Two parameters: κ_V and κ_F

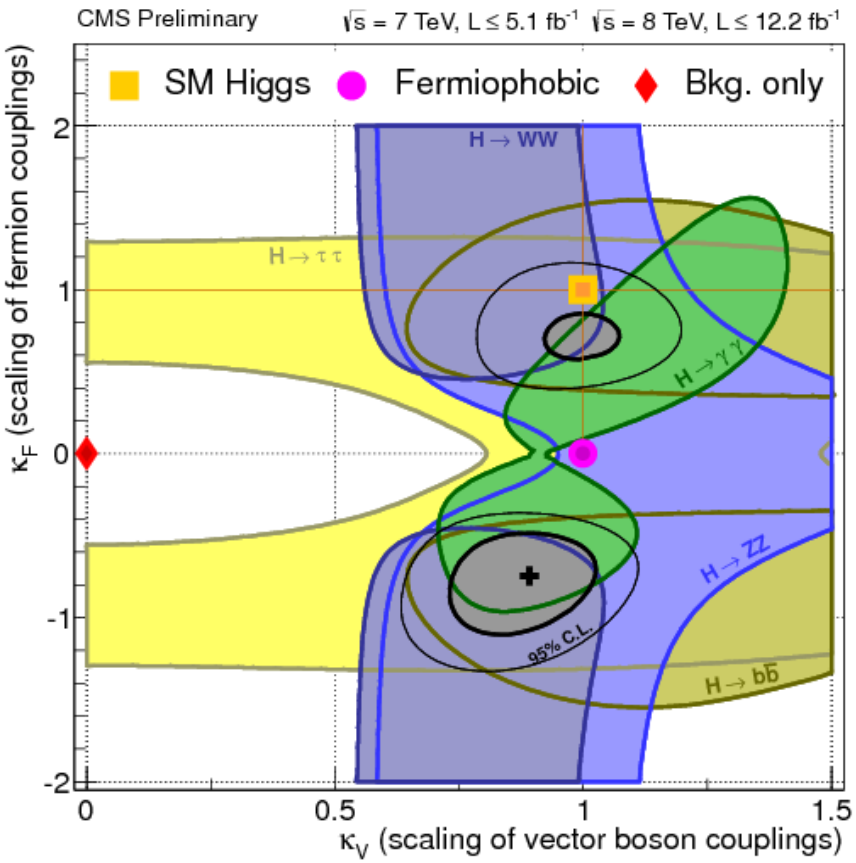






Data are consistent with (κ_V; κ_F)=(1; 1)

Two parameters: κ_V and κ_F



Fit in two quadrants

H -> (W and t loops) -> γγ

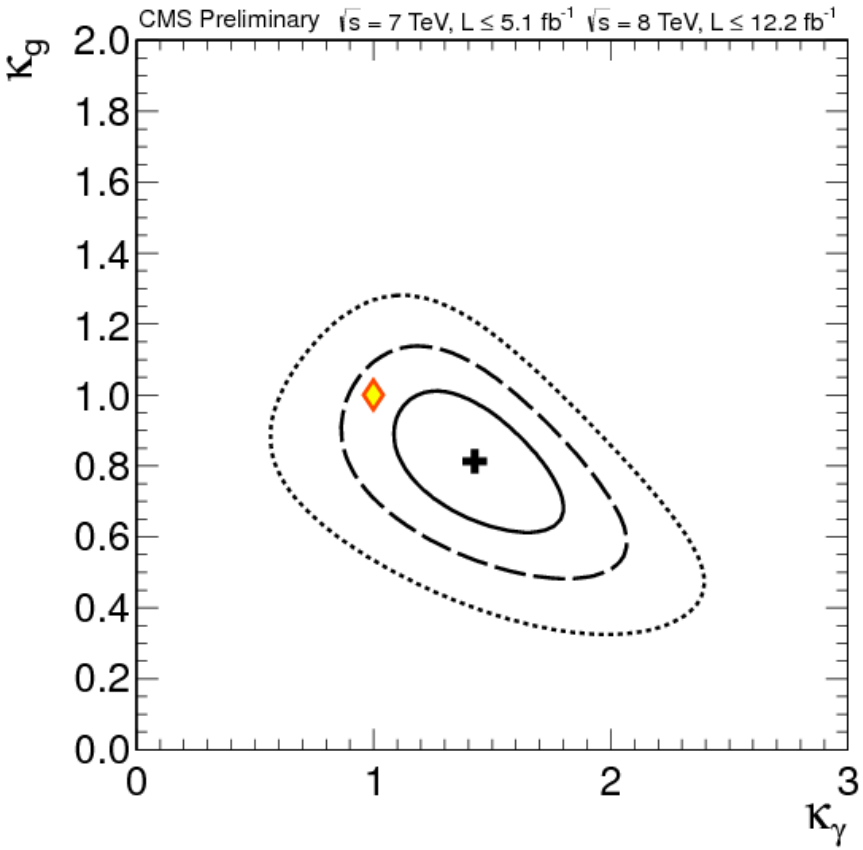
- sensitive to relative sign of couplings to W and top
- relative sign of W and top loop amplitudes is negative

Slight excess in H→γγ makes the fit prefer (+;-) quadrant

to make positive interference between W and top loops

Data remains consistent with $(\kappa_V; \kappa_F) = (1; 1)$

Look for new physics in loops: κ_g and κ_γ

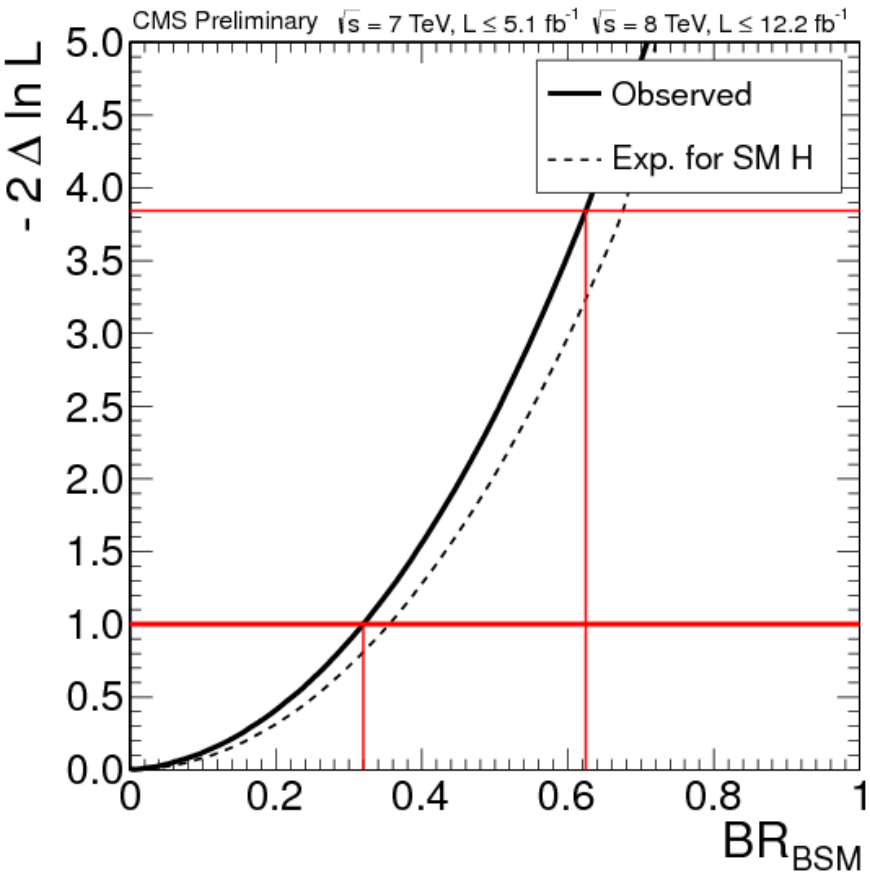


Two parameter fit

- use all channels
- Assume tree-level couplings = SM
- Assume BR(BSM)=0
- **Fit for: κ_γ , κ_g**

Data are consistent with (κ_γ; κ_g)=(1; 1)

Look for new physics: BR(BSM), κ_g , κ_γ



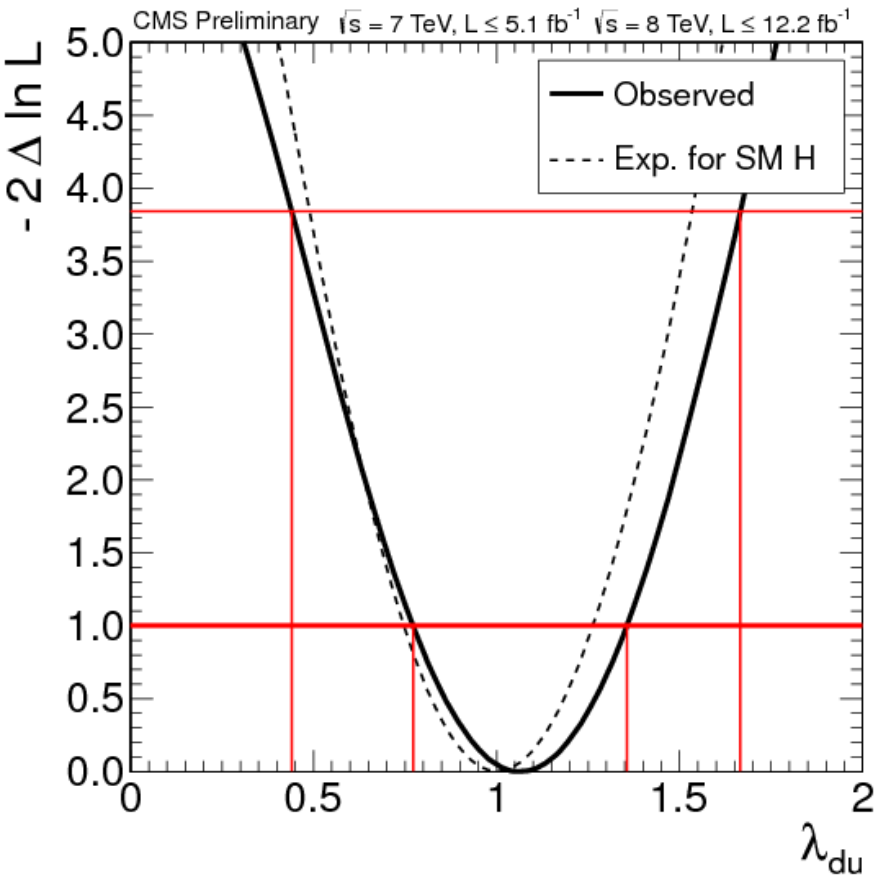
Three parameter fit

- use all channels
- Assume tree-level couplings = SM
- Allow for BR(BSM) ≠ 0
- **Fit for: BR("invisible"), κ_γ , κ_g**

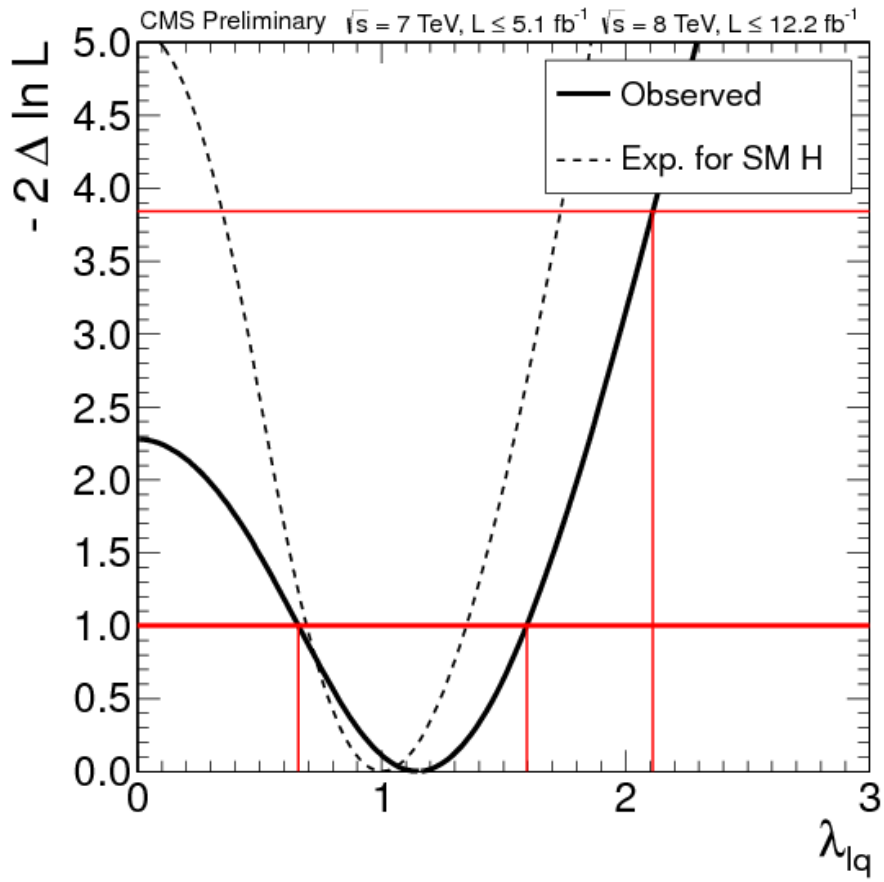
BR(BSM) < 0.62 at 95% CL

Asymmetry of couplings to fermions

Ratio of coupling between down- and up-fermions



Ratio of coupling between leptons and quarks

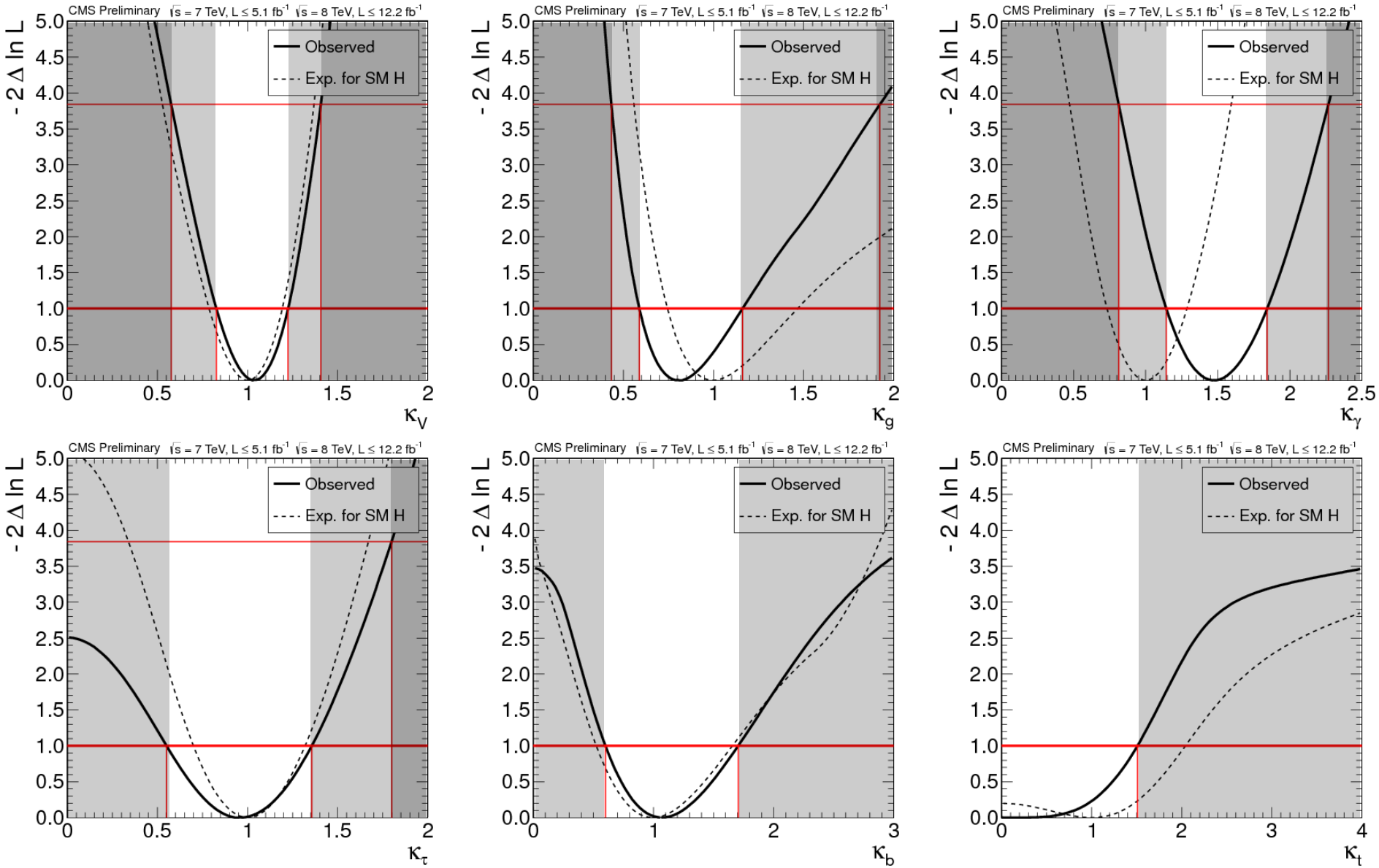


C6 model (almost a measurement)

8 independent parameters to describe all currently relevant decays and production mechanisms:

- Γ_{ZZ} → κ_V
- Γ_{WW}
- $\Gamma_{\tau\tau}$ → κ_τ
- Γ_{bb} → κ_b
- $\Gamma_{\gamma\gamma}$ (loop induced) → κ_γ
- Γ_{gg} (loop induced) → κ_g
- Γ_{tt} → κ_t
- Γ_{TOT} ~~(including H → "invisible")~~ → **assume BR(BSM)=0**
- Assume couplings to the 1st, 2nd, 3rd generations are modified the same way

C6 model results



Couplings compatibility: summary

Model parameters	Assessed scaling factors (95% CL intervals)		Comments
λ_{wz}, κ_z	λ_{wz}	[0.57,1.65]	Ratio of couplings to W and Z; ZZ and WW(0/1jet) channels only
$\lambda_{wz}, \kappa_z, \kappa_f$	λ_{wz}	[0.67,1.55]	Ratio of couplings to W and Z
κ_v	κ_v	[0.78,1.19]	Couplings to W/Z-bosons (V); $\kappa_f = 1$
κ_f	κ_f	[0.40,1.12]	Couplings to fermions (f); $\kappa_v = 1$
κ_γ, κ_g	κ_γ κ_g	[0.98,1.92] [0.55,1.07]	Couplings to photons (γ) and gluons (g) (loop-induced couplings)
$\mathcal{B}(H \to BSM), \kappa_\gamma, \kappa_g$	$\mathcal{B}(H \to BSM)$	[0.00,0.62]	Branching ratio for decays to BSM particles
$\lambda_{du}, \kappa_v, \kappa_u$	λ_{du}	[0.45,1.66]	Ratio of couplings to down and up-type fermions
$\lambda_{\ell q}, \kappa_v, \kappa_q$	$\lambda_{\ell q}$	[0.00,2.11]	Ratio of couplings to leptons and quarks
$\kappa_v, \kappa_b, \kappa_\tau, \kappa_t, \kappa_g, \kappa_\gamma$	κ_v κ_b κ_τ κ_t κ_g κ_γ	[0.58,1.41] not constrained [0.00,1.80] not constrained [0.43,1.92] [0.81,2.27]	Couplings to W/Z-bosons (V) Couplings to down-type quarks (b) Couplings to charged leptons (τ) Couplings to top-type quarks (t) Effective couplings to gluons (g) Effective couplings to photons (γ)

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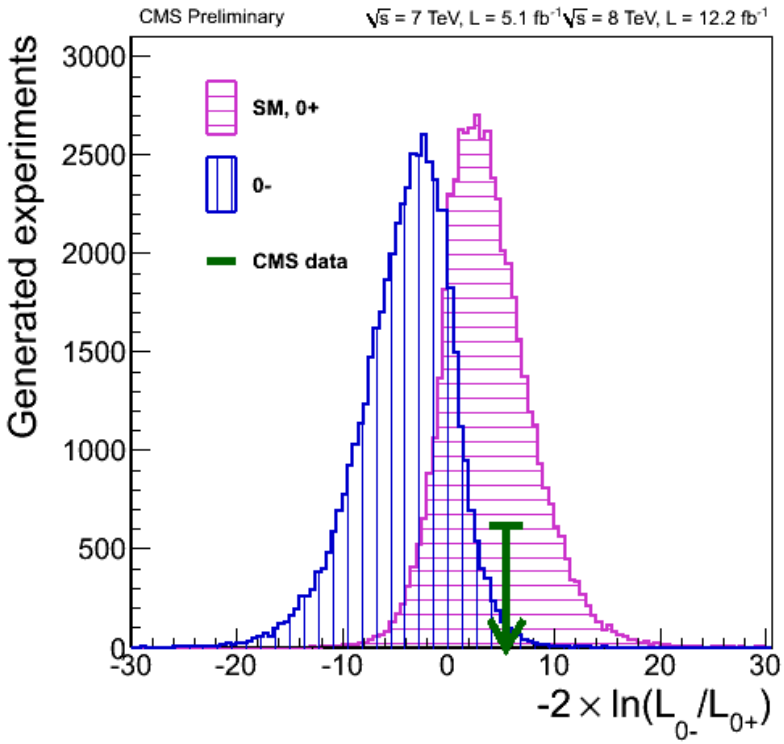
J^{CP}



- Observed decays (γγ, 4l, etc):
  boson
- Observed X→γγ:
  J ≠ 1 [Landau-Yang theorem]
- Lepton correlations in ZZ→4l:
  X can't be 100% 0^-
- Sorting out J=2 from J=0:
  - need more data;
  - many channels can contribute:
    ZZ→4l, WW→lνlν, VBF jets, mass(VH)

Summary

- **With more data, the boson near 125 GeV does not go away:**
  significance is now 6.9 (we can stop looking at it now)

- **Mass: 125.8 ± 0.6 GeV** (or ±0.5%)

- **SM Higgs boson couplings compatibility tests:**
  no statistically significant anomalies in event yields for different channels

- **J^{CP}:**

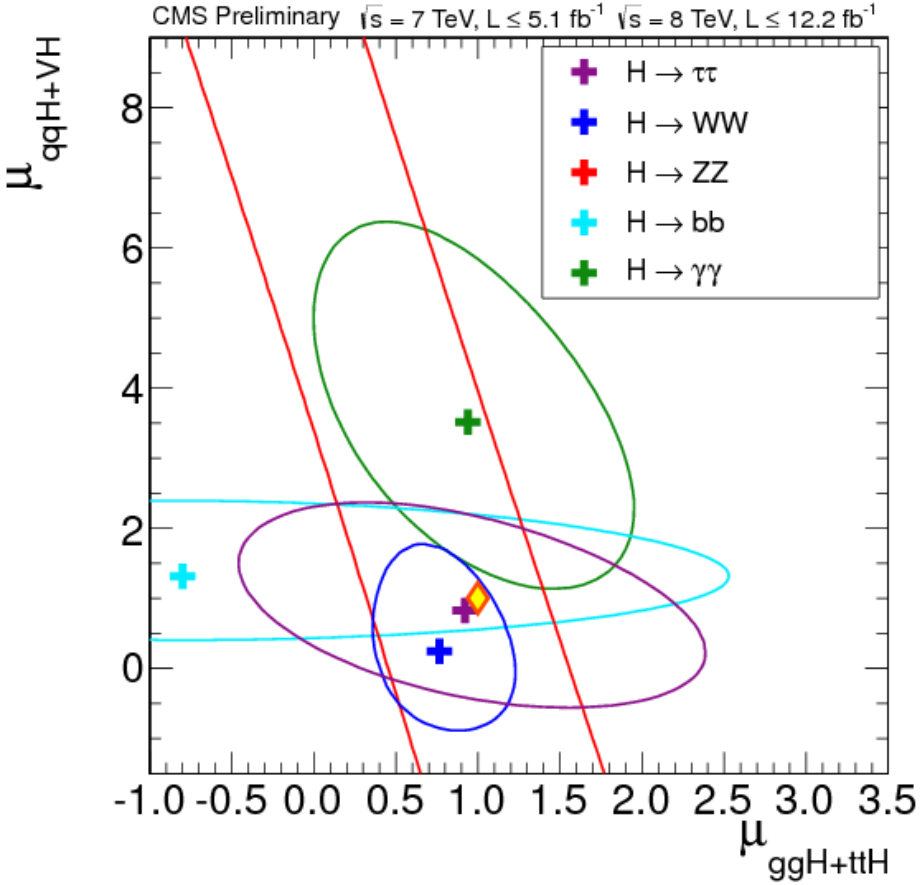
  $J \neq 1$

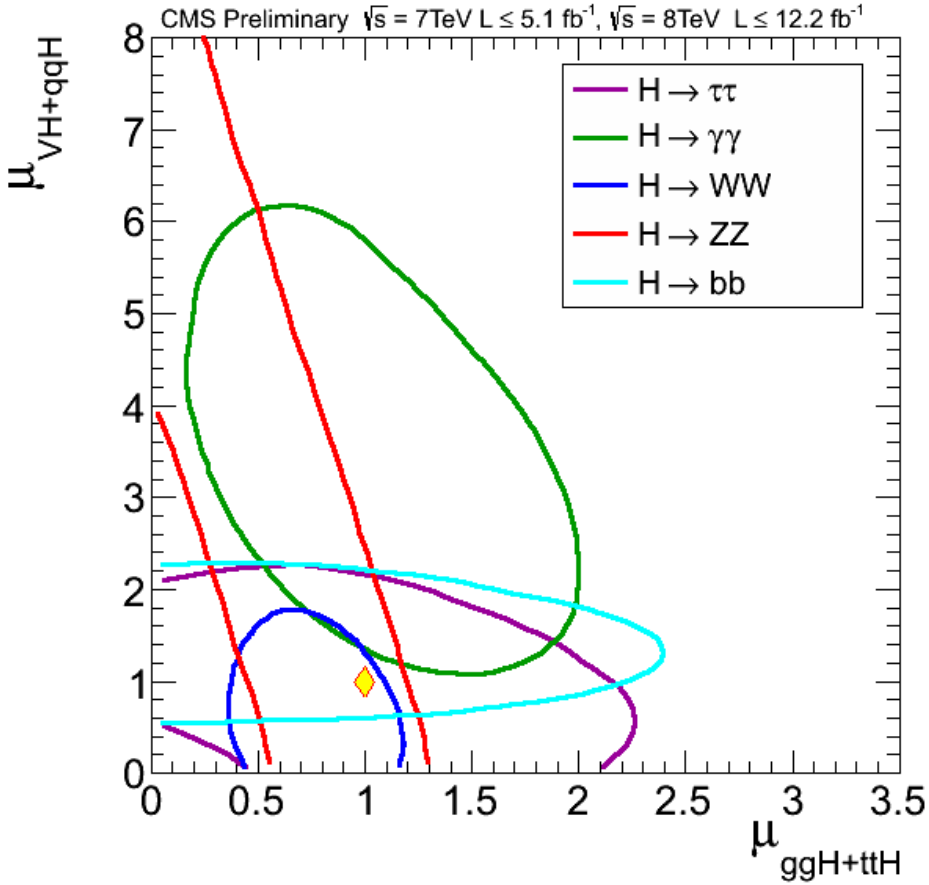
  100% pure 0^- not likely

- **Time has come to treat the discovered boson as a part of the background model in all searches, including searches for a second Higgs-like boson**

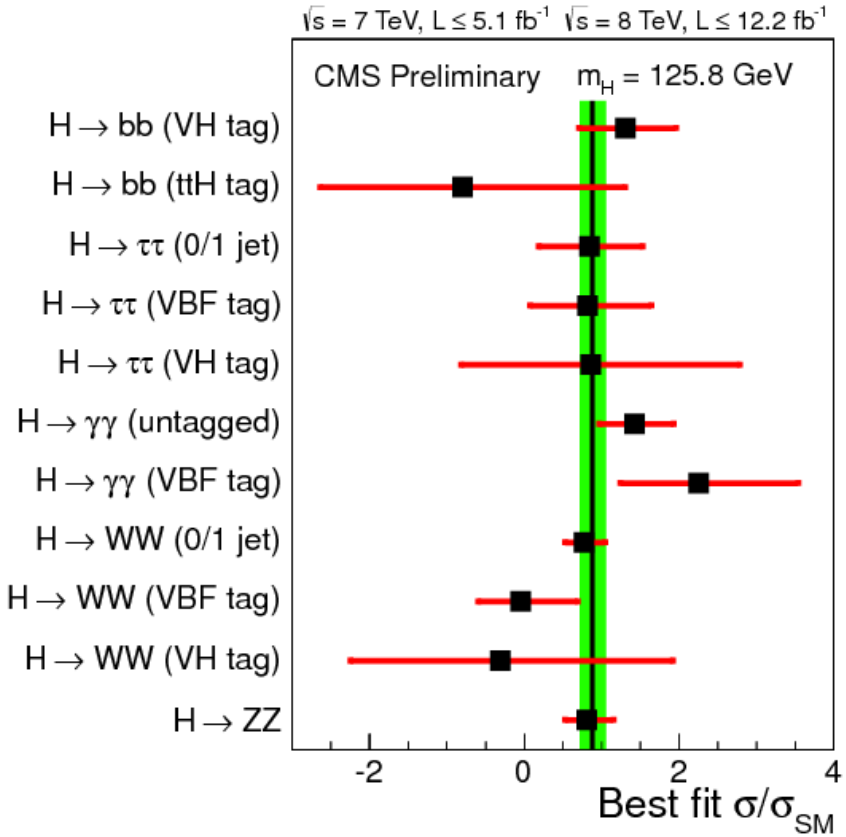
Back-up slides

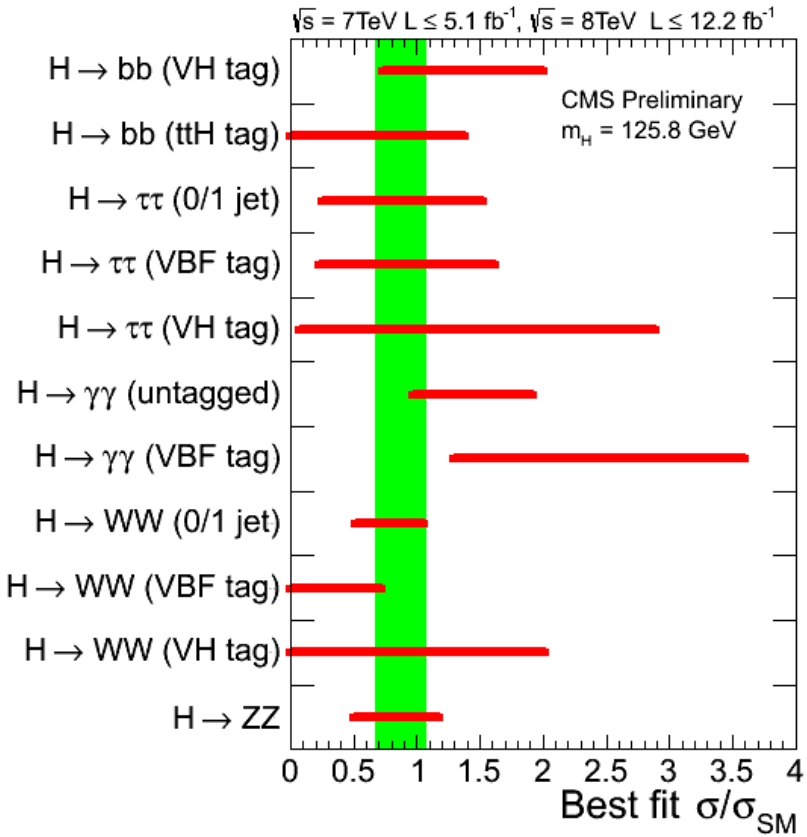
Likelihood scan <--> Feldman-Cousins



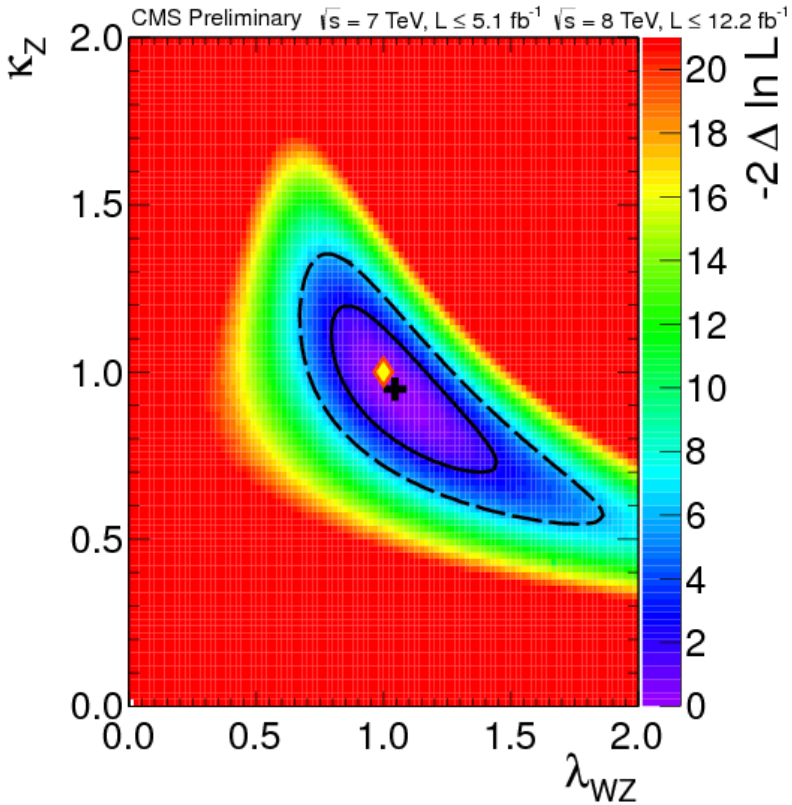


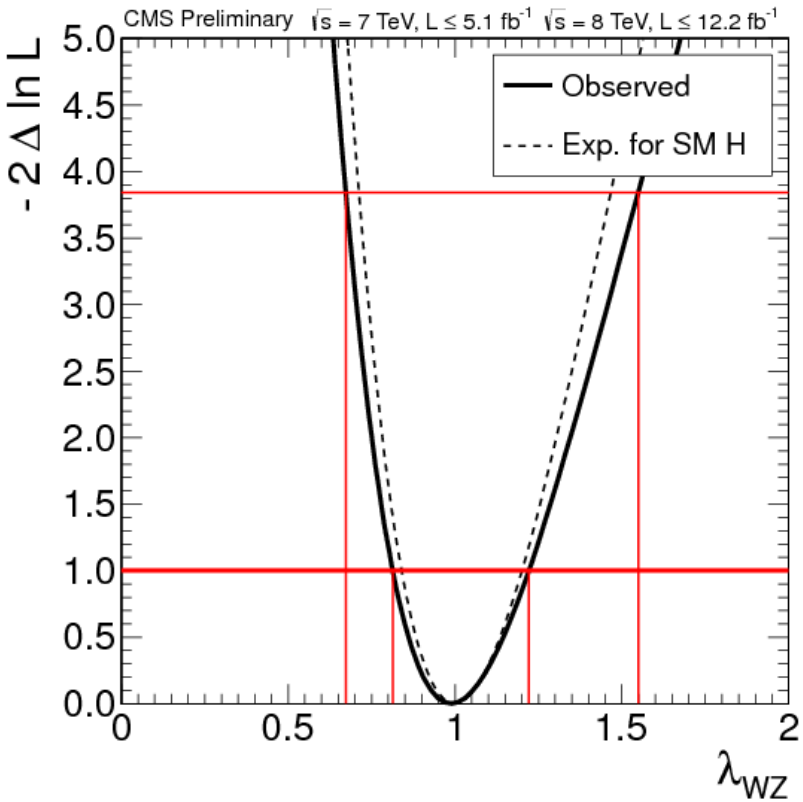
Likelihood scan <--> Feldman-Cousins





Custodial symmetry (2)





BR for “invisible” decays