Property Measurements of the Higgs-like boson at CMS

Jonathan Hays
On behalf
of the CMS collaboration
Kruger 2012

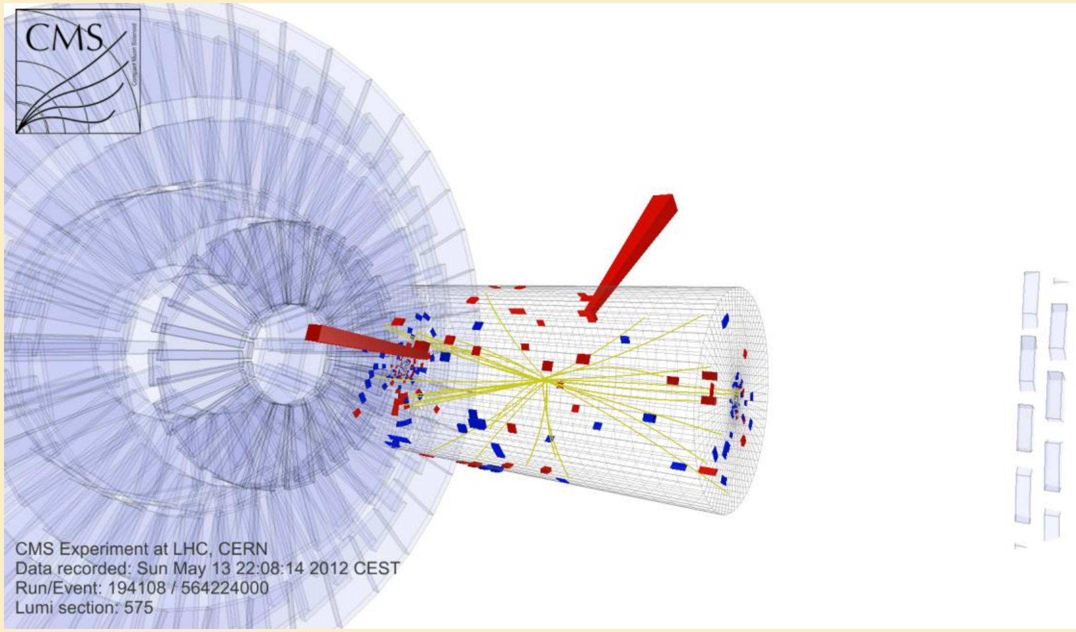
Overview

Introduction

Mass

Couplings

Spin-parity

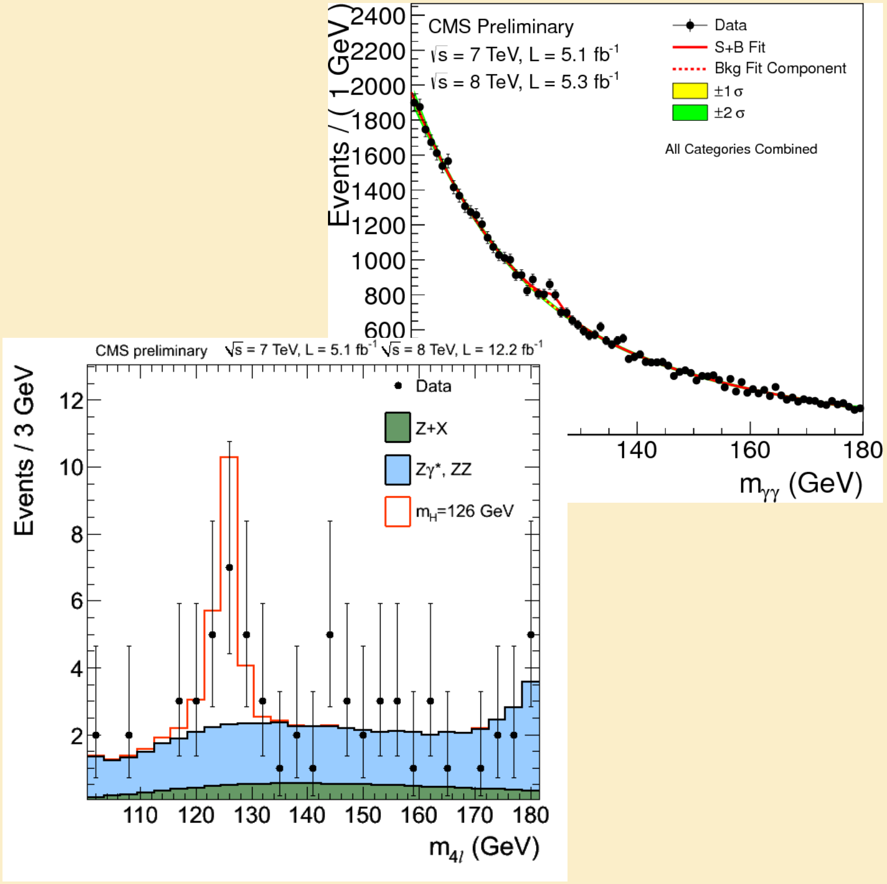


Introduction

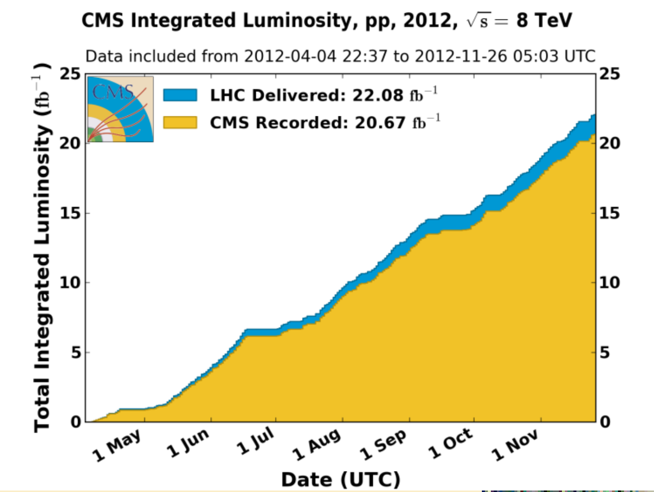
Both ATLAS and CMS observe a new boson around 126 GeV with most sensitivity in WW, ZZ, and γγ decays

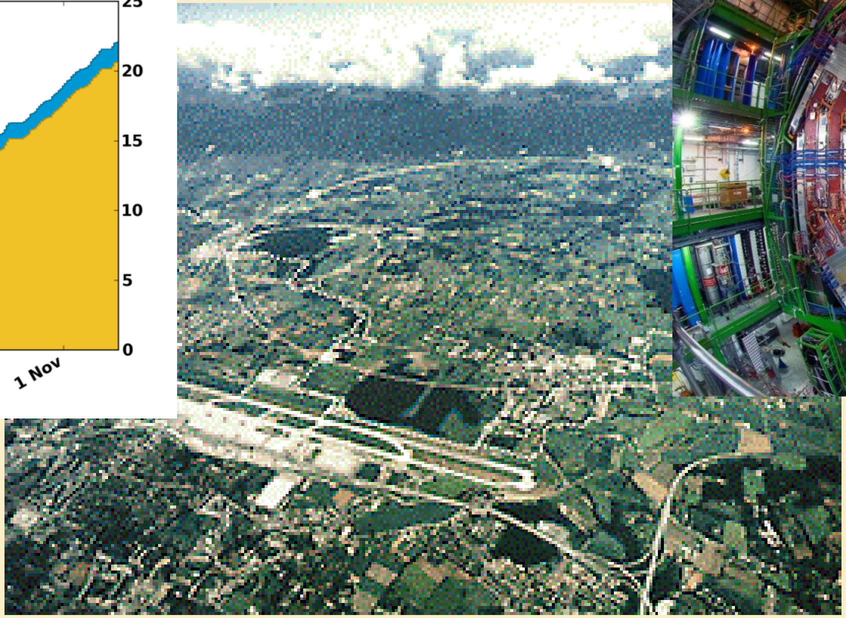
Question now is: what have we found?

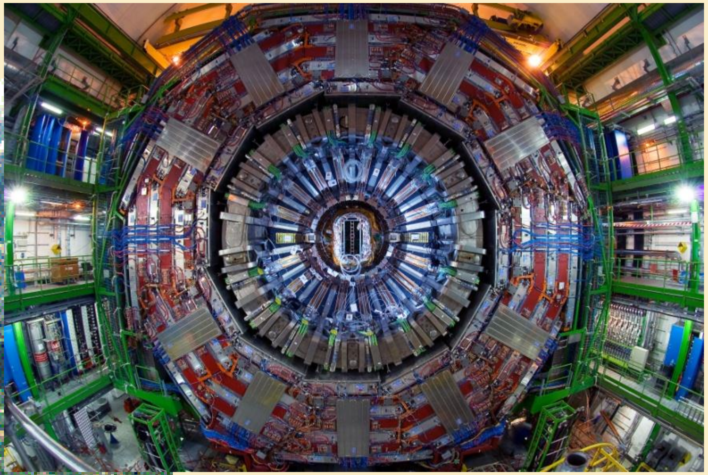
Only with careful measurements of properties will the answer be found:
mass, yields, distributions



Introduction

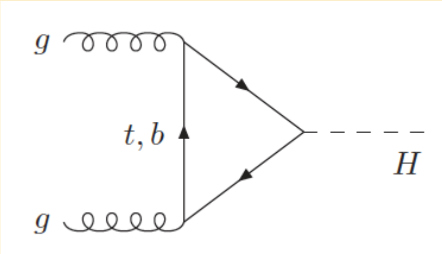


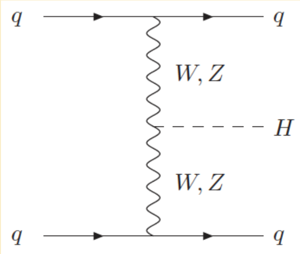


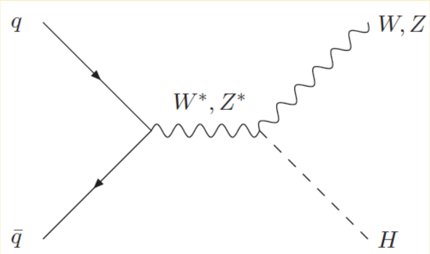


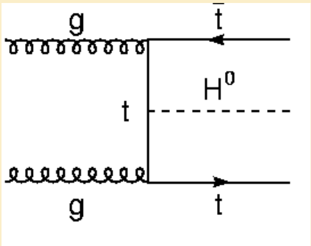
Very successful running through 2012. Over 20fb^{-1} recorded so far at 8TeV
A big thank you to everyone who made things come together so well!

Production and decay

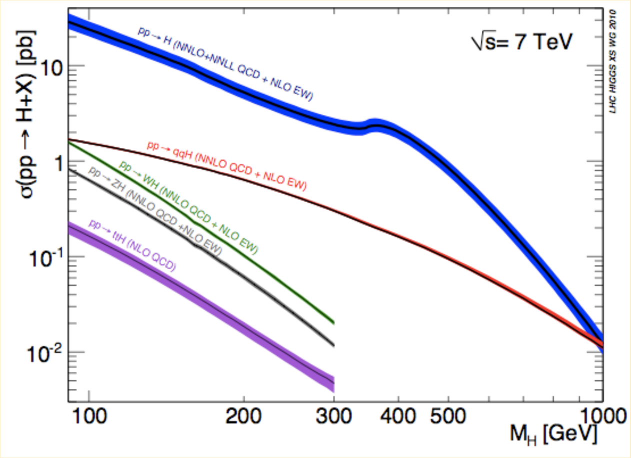




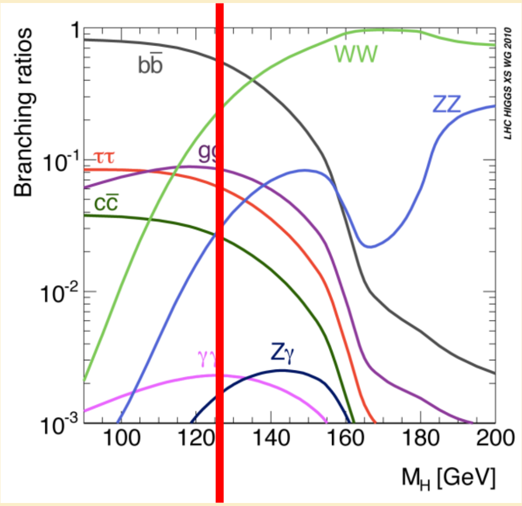




4 production modes, 5 main decay modes



	None	VBF	VH	ttH
γγ	✓	✓	(✓)	
ZZ	✓			
WW	✓	✓	✓	
ττ	✓	✓	✓	
bb			✓	✓



Most channels updated with $12fb^{-1}$ 8 TeV data, some still with ICHEP result

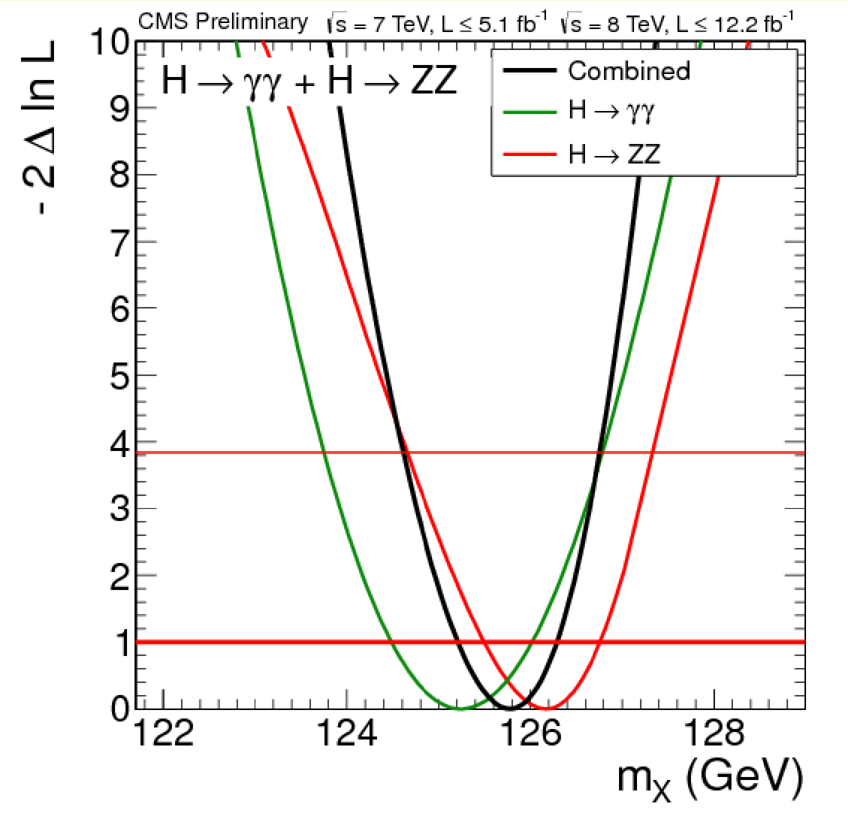
Mass

γ γ and ZZ high resolution channels provide a measurement of boson mass

assume single particle of mass m_X

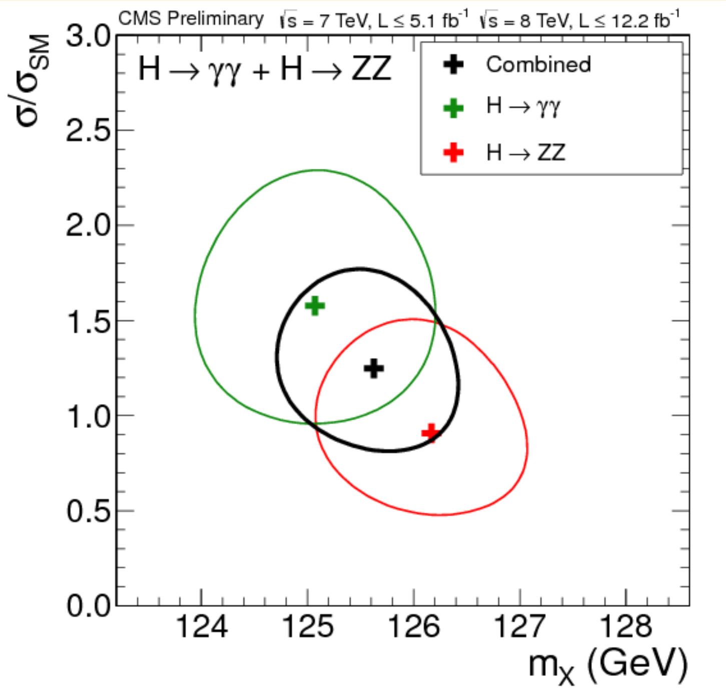
Reduced model dependence:
Individual signal strengths from each channel – profiled like other nuisances

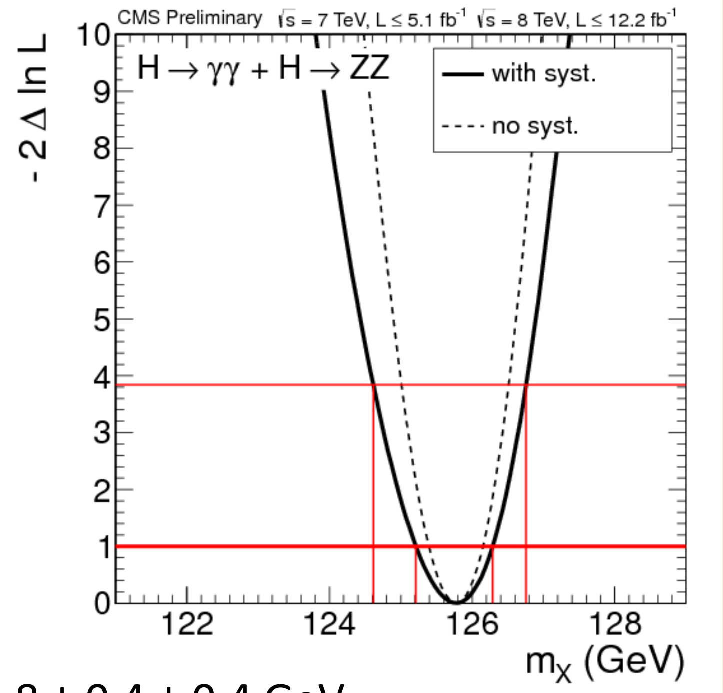
Use this in couplings studies:
some mass dependence



Mass

2D scan with 68% CL limits





$m_X = 125.8 \pm 0.4 \pm 0.4$ GeV

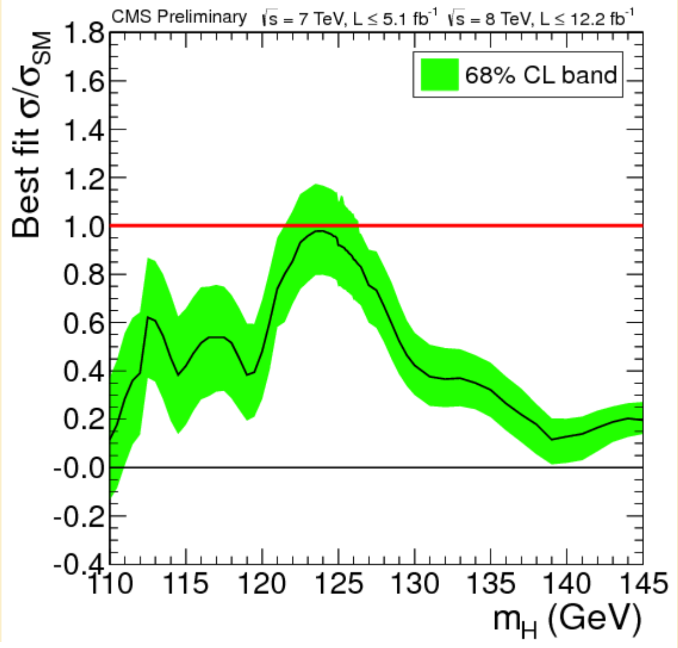
1D scan with and without systematics

Fixing signal strengths to SM gives result compatible to within 0.1 GeV

Global signal strength

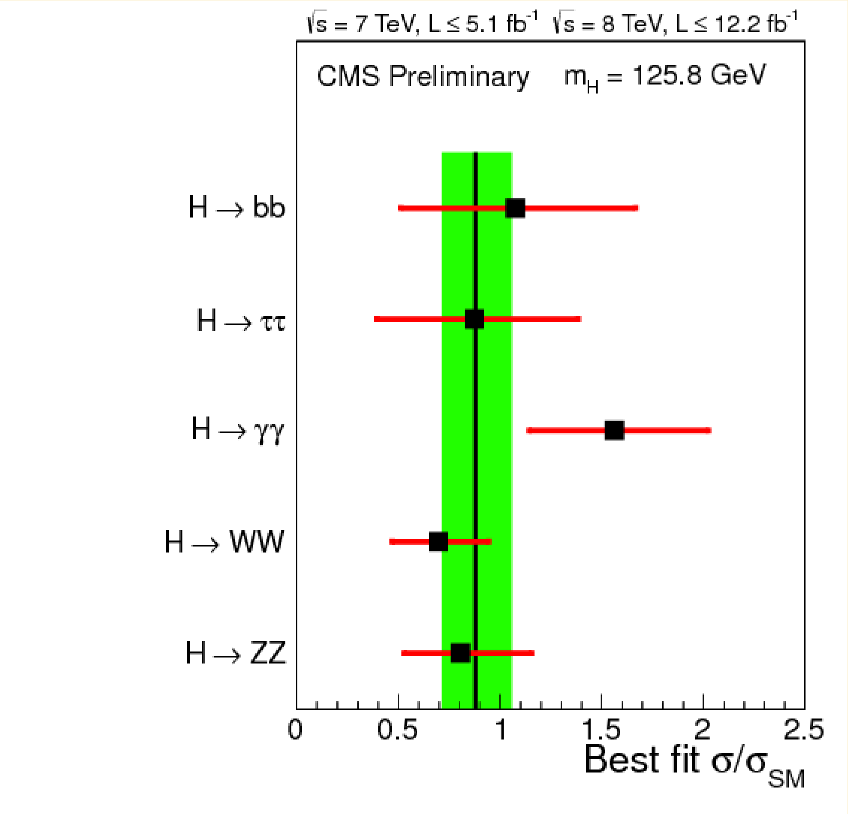
Simplest scaling:
Fix relative rates to SM and scale with 1 parameter

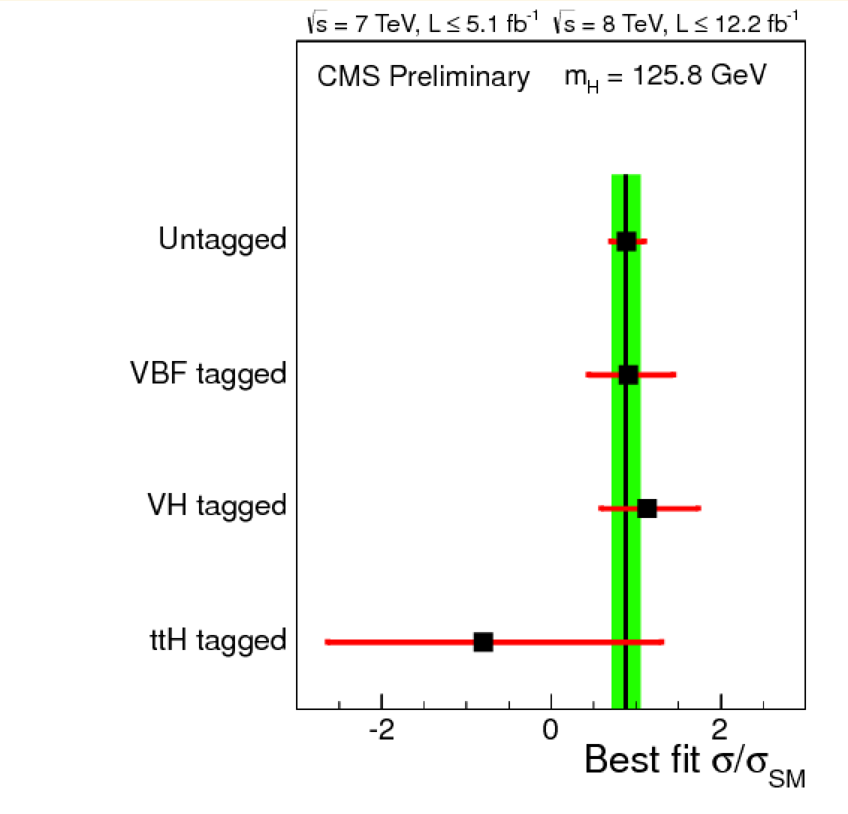
Compatible with SM predictions



$\mu = 0.88 \pm 0.21$ @ $m_X = 125.8$ GeV

Decay and production

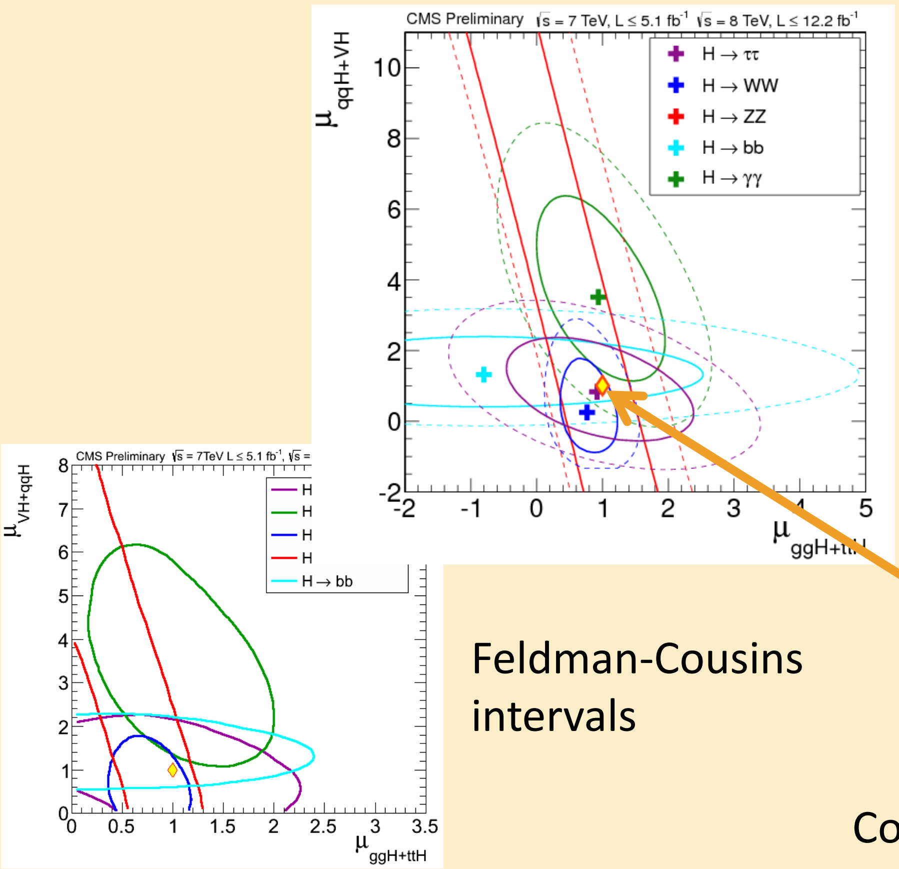




All decay modes see evidence of signal, all consistent with SM

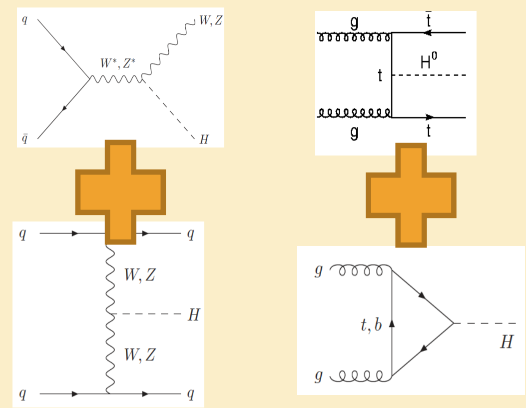
By production mode

68% and 95% CL bounds



Feldman-Cousins intervals

Sub-combinations by production mode:

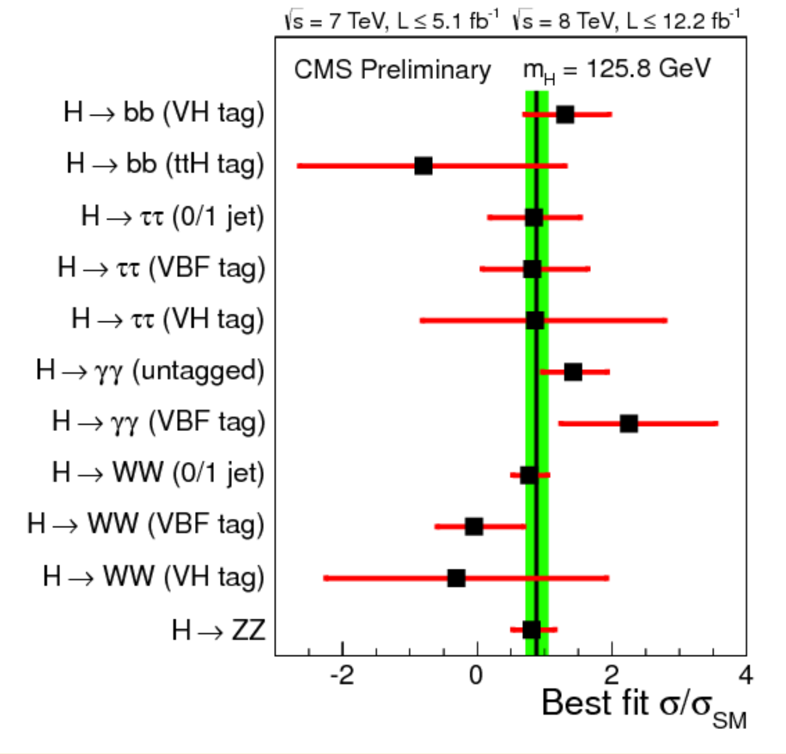


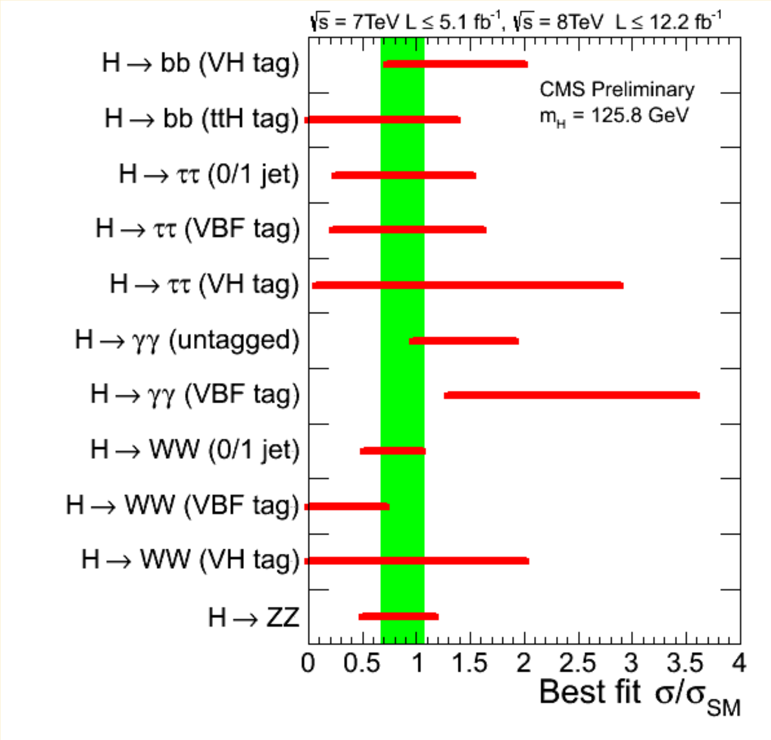
Fit for 2 signal strengths in 5 different decay modes

Compatible with standard model (1,1)

By channel

Fit each channel separately for signal strength





Feldman-Cousins intervals

Compatible with SM predictions

Parameterisations

Largely use parameterisations from interim framework from LHCHXSWG
arXiv:1209.0040

$$(\sigma \cdot \mathrm{BR})(ii \to \mathrm{H} \to ff) = \frac{\sigma_{ii} \cdot \Gamma_{ff}}{\Gamma_{\mathrm{H}}}$$

Production modes

$$\frac{\sigma_{\mathrm{ggH}}}{\sigma^{\mathrm{SM}}_{\mathrm{ggH}}} = \begin{cases} \kappa^2_{\mathrm{g}}(\kappa_{\mathrm{b}}, \kappa_{\mathrm{t}}, m_{\mathrm{H}}) \\ \kappa^2_{\mathrm{g}} \end{cases}$$

$$\frac{\sigma_{\mathrm{VBF}}}{\sigma^{\mathrm{SM}}_{\mathrm{VBF}}} = \kappa^2_{\mathrm{VBF}}(\kappa_{\mathrm{W}}, \kappa_{\mathrm{Z}}, m_{\mathrm{H}})$$

$$\frac{\sigma_{\mathrm{WH}}}{\sigma^{\mathrm{SM}}_{\mathrm{WH}}} = \kappa^2_{\mathrm{W}}$$

$$\frac{\sigma_{\mathrm{ZH}}}{\sigma^{\mathrm{SM}}_{\mathrm{ZH}}} = \kappa^2_{\mathrm{Z}}$$

$$\frac{\sigma_{\mathrm{t\bar{t}H}}}{\sigma^{\mathrm{SM}}_{\mathrm{t\bar{t}H}}} = \kappa^2_{\mathrm{t}}$$

Assume all signals near 126 come from a single resonance of zero width, with SM-like coupling structure

Total width = sum of all decays widths (+ invisible)

Decay modes

$$\frac{\Gamma_{\mathrm{WW}^{(*)}}}{\Gamma^{\mathrm{SM}}_{\mathrm{WW}^{(*)}}} = \kappa^2_{\mathrm{W}}$$

$$\frac{\Gamma_{\mathrm{ZZ}^{(*)}}}{\Gamma^{\mathrm{SM}}_{\mathrm{ZZ}^{(*)}}} = \kappa^2_{\mathrm{Z}}$$

$$\frac{\Gamma_{\mathrm{b\bar{b}}}}{\Gamma^{\mathrm{SM}}_{\mathrm{b\bar{b}}}} = \kappa^2_{\mathrm{b}}$$

$$\frac{\Gamma_{\tau^-\tau^+}}{\Gamma^{\mathrm{SM}}_{\tau^-\tau^+}} = \kappa^2_{\tau}$$

$$\frac{\Gamma_{\gamma\gamma}}{\Gamma^{\mathrm{SM}}_{\gamma\gamma}} = \begin{cases} \kappa^2_{\gamma}(\kappa_{\mathrm{b}}, \kappa_{\mathrm{t}}, \kappa_{\tau}, \kappa_{\mathrm{W}}, m_{\mathrm{H}}) \\ \kappa^2_{\gamma} \end{cases}$$

$$\frac{\Gamma_{\mathrm{Z}\gamma}}{\Gamma^{\mathrm{SM}}_{\mathrm{Z}\gamma}} = \begin{cases} \kappa^2_{(\mathrm{Z}\gamma)}(\kappa_{\mathrm{b}}, \kappa_{\mathrm{t}}, \kappa_{\tau}, \kappa_{\mathrm{W}}, m_{\mathrm{H}}) \\ \kappa^2_{(\mathrm{Z}\gamma)} \end{cases}$$

Parameterisations

Largely use parameterisations from interim framework from LHCHXSWG arXiv:1209.0040

$$(\sigma \cdot \mathrm{BR})\,(ii \to \mathrm{H} \to ff) = \frac{\sigma_{ii} \cdot \Gamma_{ff}}{\Gamma_{\mathrm{H}}}$$

Assume all signals near 126 come from a single resonance of zero width, with SM-like coupling structure

Total width = sum of all decays widths (+ invisible)

Production modes

$$\frac{\sigma_{\mathrm{ggH}}}{\sigma^{\mathrm{SM}}_{\mathrm{ggH}}} = \begin{cases} \kappa_g^2(\kappa_b, \kappa_t, m_H) \\ \kappa_g^2 \end{cases}$$

$$\frac{\sigma_{\mathrm{VBF}}}{\sigma^{\mathrm{SM}}_{\mathrm{VBF}}} = \kappa^2_{\mathrm{VBF}}(\kappa_W, \kappa_Z, m_H)$$

$$\frac{\sigma_{\mathrm{WH}}}{\sigma^{\mathrm{SM}}_{\mathrm{WH}}} = \kappa_W^2$$

$$\frac{\sigma_{\mathrm{ZH}}}{\sigma^{\mathrm{SM}}_{\mathrm{ZH}}} = \kappa_Z^2$$

$$\frac{\sigma_{t\bar{t}H}}{\sigma^{\mathrm{SM}}_{t\bar{t}H}} = \kappa_t^2$$

Factors involving loops

Decay modes

$$\frac{\Gamma_{WW^{(*)}}}{\Gamma^{\mathrm{SM}}_{WW^{(*)}}} = \kappa_W^2$$

$$\frac{\Gamma_{ZZ^{(*)}}}{\Gamma^{\mathrm{SM}}_{ZZ^{(*)}}} = \kappa_Z^2$$

$$\frac{\Gamma_{b\bar{b}}}{\Gamma^{\mathrm{SM}}_{b\bar{b}}} = \kappa_b^2$$

$$\frac{\Gamma_{\tau^-\tau^+}}{\Gamma^{\mathrm{SM}}_{\tau^-\tau^+}} = \kappa_\tau^2$$

$$\frac{\Gamma_{\gamma\gamma}}{\Gamma^{\mathrm{SM}}_{\gamma\gamma}} = \begin{cases} \kappa_\gamma^2(\kappa_b, \kappa_t, \kappa_\tau, \kappa_W, m_H) \\ \kappa_\gamma^2 \end{cases}$$

$$\frac{\Gamma_{Z\gamma}}{\Gamma^{\mathrm{SM}}_{Z\gamma}} = \begin{cases} \kappa_{(Z\gamma)}^2(\kappa_b, \kappa_t, \kappa_\tau, \kappa_W, m_H) \\ \kappa_{(Z\gamma)}^2 \end{cases}$$

e.g. can insert BSM physics here. Interference terms can also bring linear dependence on κ

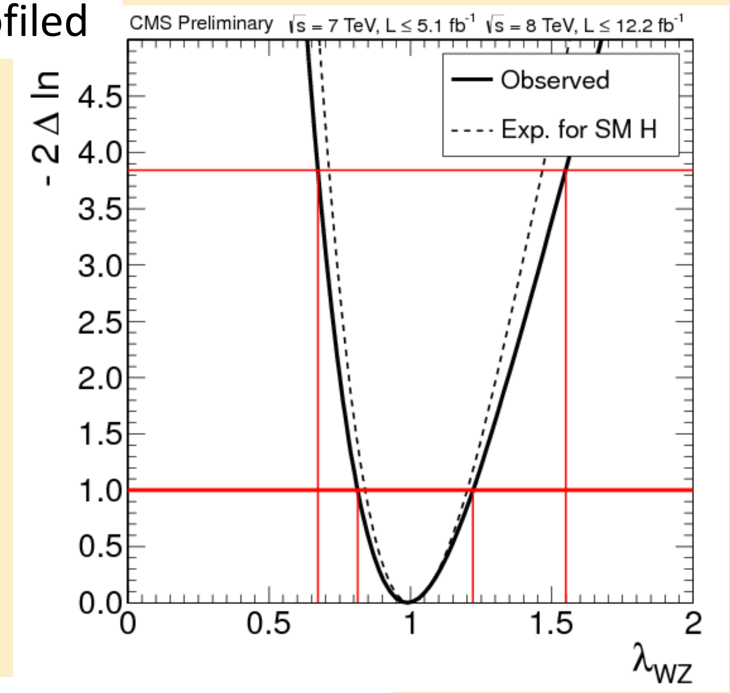
Custodial Symmetry

Approximate symmetry of SM

$$\lambda_{WZ} = \frac{\kappa_W}{\kappa_Z} \backsimeq 1(\mathrm{SM})$$

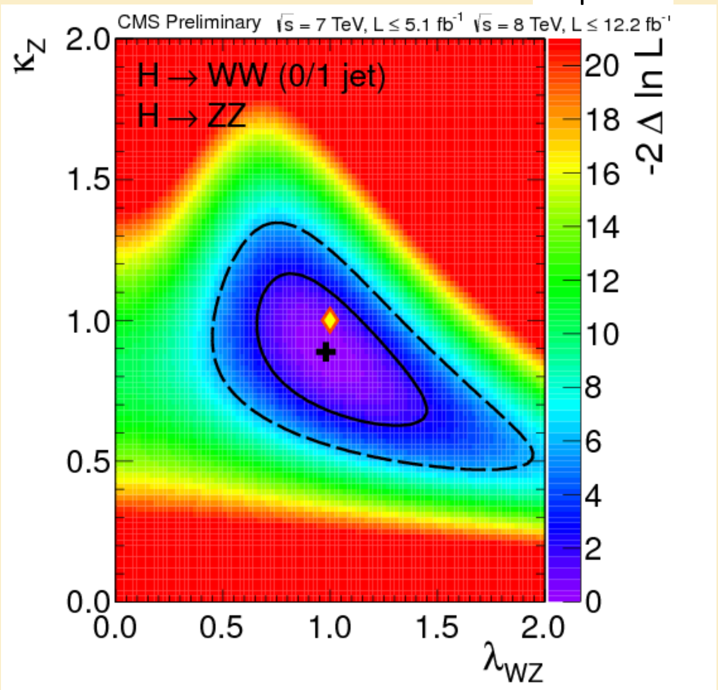
Parameters: λ_{WZ}, κ_Z, κ_F

κ_Z, κ_F profiled



95% CI [0.67,1.55]

κ_F =1



Compatible with SM predictions

Fermion and Vector Couplings

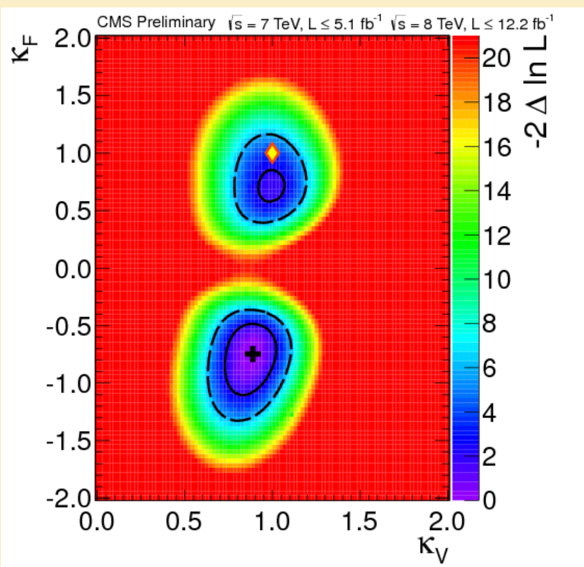
Assume common fermion and common vector boson couplings

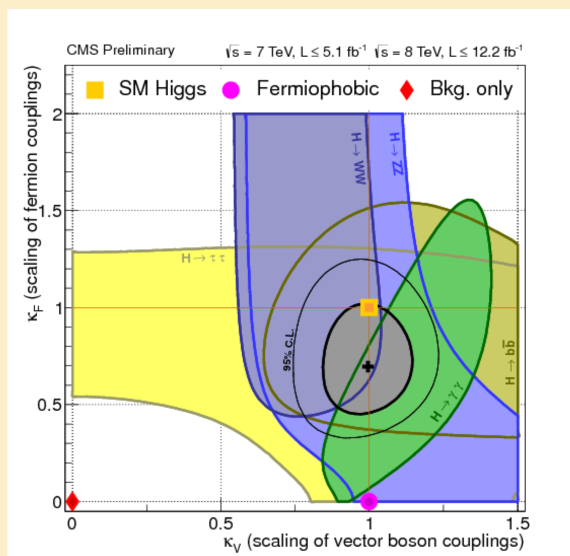
Parameters: κ_V, κ_F

Boson and fermion scaling assuming no invisible or undetectable widths

Free parameters: $\kappa_V (= \kappa_W = \kappa_Z)$, $\kappa_f (= \kappa_t = \kappa_b = \kappa_\tau)$.

	$H \to \gamma\gamma$	$H \to ZZ^{(*)}$	$H \to WW^{(*)}$	$H \to b\bar{b}$	$H \to \tau^-\tau^+$
ggH $t\bar{t}H$	$\frac{\kappa_f^2 \cdot \kappa_\gamma^2(\kappa_f,\kappa_f,\kappa_f,\kappa_V)}{\kappa_H^2(\kappa_i)}$	$\frac{\kappa_f^2 \cdot \kappa_V^2}{\kappa_H^2(\kappa_i)}$		$\frac{\kappa_f^2 \cdot \kappa_f^2}{\kappa_H^2(\kappa_i)}$	
VBF WH ZH	$\frac{\kappa_V^2 \cdot \kappa_\gamma^2(\kappa_f,\kappa_f,\kappa_f,\kappa_V)}{\kappa_H^2(\kappa_i)}$	$\frac{\kappa_V^2 \cdot \kappa_V^2}{\kappa_H^2(\kappa_i)}$		$\frac{\kappa_V^2 \cdot \kappa_f^2}{\kappa_H^2(\kappa_i)}$	





$$\Gamma_{\gamma\gamma} \backsim |\alpha\kappa_F + \beta\kappa_V|^2$$

photon loop could give access to relative sign

Compatible with SM

Fermion and Vector Couplings

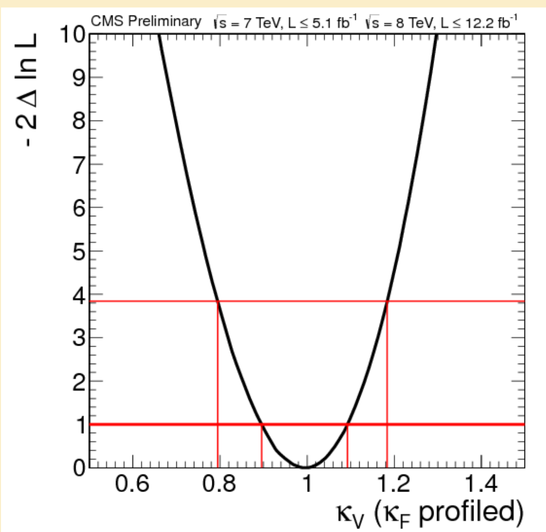
Assume common fermion and common vector boson couplings

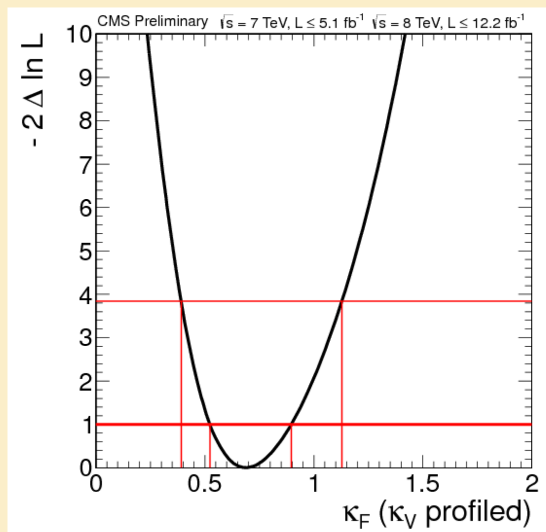
Parameters: κ_V, κ_F

Boson and fermion scaling assuming no invisible or undetectable widths

Free parameters: $\kappa_V (= \kappa_W = \kappa_Z)$, $\kappa_f (= \kappa_t = \kappa_b = \kappa_\tau)$.

	$H \to \gamma\gamma$	$H \to ZZ^{(*)}$, $H \to WW^{(*)}$	$H \to b\bar{b}$, $H \to \tau^-\tau^+$
ggH $t\bar{t}H$	$\frac{\kappa_f^2 \cdot \kappa_\gamma^2(\kappa_f,\kappa_f,\kappa_f,\kappa_V)}{\kappa_H^2(\kappa_i)}$	$\frac{\kappa_f^2 \cdot \kappa_V^2}{\kappa_H^2(\kappa_i)}$	$\frac{\kappa_f^2 \cdot \kappa_f^2}{\kappa_H^2(\kappa_i)}$
VBF WH ZH	$\frac{\kappa_V^2 \cdot \kappa_\gamma^2(\kappa_f,\kappa_f,\kappa_f,\kappa_V)}{\kappa_H^2(\kappa_i)}$	$\frac{\kappa_V^2 \cdot \kappa_V^2}{\kappa_H^2(\kappa_i)}$	$\frac{\kappa_V^2 \cdot \kappa_f^2}{\kappa_H^2(\kappa_i)}$





Can also look at individual parameter, profiling the other

Clearly favours non-zero values

Compatible with SM

Asymmetry in fermion couplings

Some BSM modify couplings for up-type fermions relative to down-type

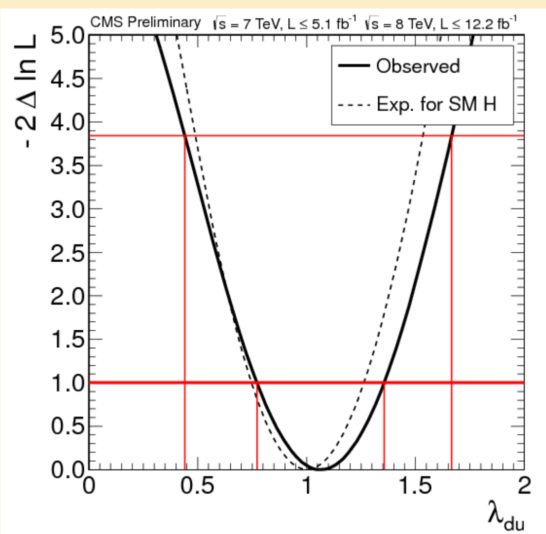
$\lambda_{du} = \kappa_d/\kappa_u$, assume λ_{WZ}=1

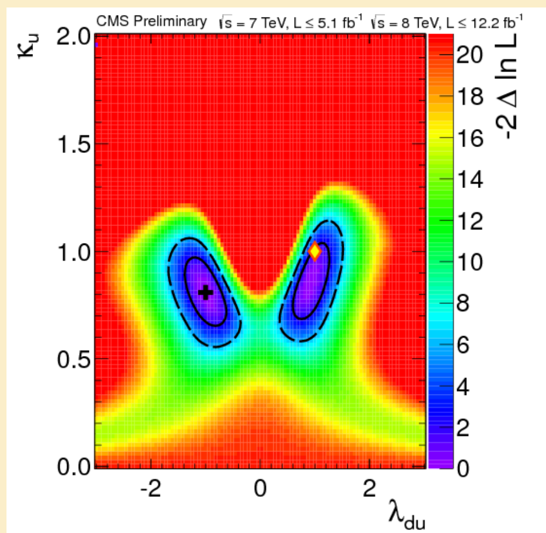
Parameters are: $\lambda_{du}, \kappa_u, \kappa_V$

Probing up-type and down-type fermion symmetry assuming no invisible or undetectable widths

Free parameters: $\kappa_V (= \kappa_Z = \kappa_W), \lambda_{du} (= \kappa_d/\kappa_u), \kappa_u (= \kappa_t)$.

	$H \to \gamma\gamma$	$H \to ZZ^{(*)}$	$H \to WW^{(*)}$	$H \to b\bar{b}$	$H \to \tau^-\tau^+$
ggH	$\frac{\kappa_g^2(\kappa_u\lambda_{du},\kappa_u)\cdot\kappa_\gamma^2(\kappa_u\lambda_{du},\kappa_u,\kappa_u\lambda_{du},\kappa_V)}{\kappa_H^2(\kappa_i)}$	$\frac{\kappa_g^2(\kappa_u\lambda_{du},\kappa_u)\cdot\kappa_V^2}{\kappa_H^2(\kappa_i)}$		$\frac{\kappa_g^2(\kappa_u\lambda_{du},\kappa_u)\cdot(\kappa_u\lambda_{du})^2}{\kappa_H^2(\kappa_i)}$	
$t\bar{t}H$	$\frac{\kappa_u^2\cdot\kappa_\gamma^2(\kappa_u\lambda_{du},\kappa_u,\kappa_u\lambda_{du},\kappa_V)}{\kappa_H^2(\kappa_i)}$	$\frac{\kappa_u^2\cdot\kappa_V^2}{\kappa_H^2(\kappa_i)}$		$\frac{\kappa_u^2\cdot(\kappa_u\lambda_{du})^2}{\kappa_H^2(\kappa_i)}$	
VBF WH ZH	$\frac{\kappa_V^2\cdot\kappa_\gamma^2(\kappa_u\lambda_{du},\kappa_u,\kappa_u\lambda_{du},\kappa_V)}{\kappa_H^2(\kappa_i)}$	$\frac{\kappa_V^2\cdot\kappa_V^2}{\kappa_H^2(\kappa_i)}$		$\frac{\kappa_V^2\cdot(\kappa_u\lambda_{du})^2}{\kappa_H^2(\kappa_i)}$	





Loops give access to sign

Data currently favour –ve but not significantly so

Compatible with SM

Asymmetry in fermion couplings

Some BSM modify couplings for leptons relative to quarks

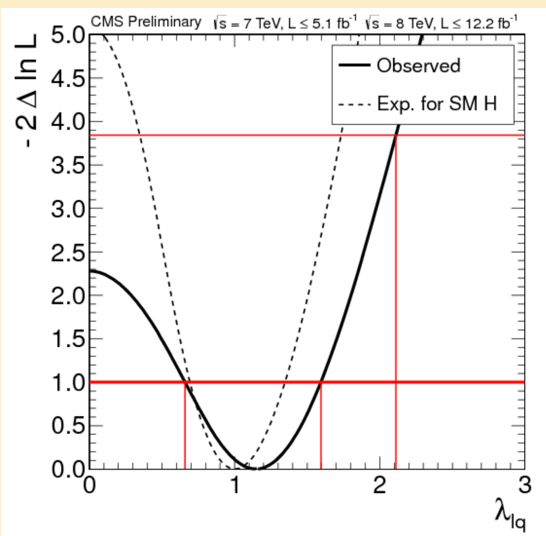
$\lambda_{lq} = \kappa_l/\kappa_q$, assume $\lambda_{WZ}=1$

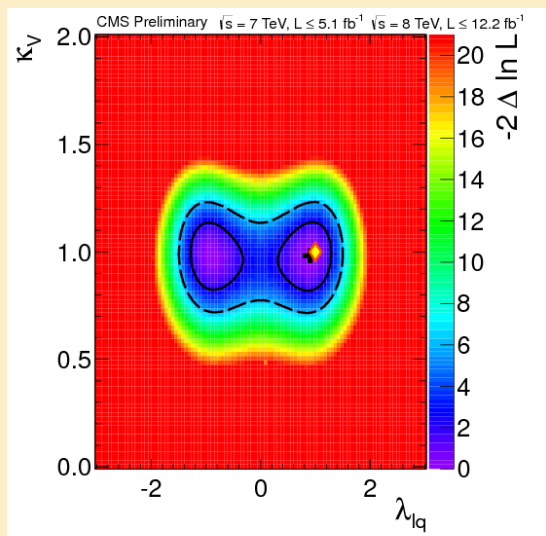
Parameters are: $\lambda_{lq}, \kappa_q, \kappa_V$

Probing quark and lepton fermion symmetry assuming no invisible or undetectable widths

Free parameters: $\kappa_V (= \kappa_Z = \kappa_W)$, $\lambda_{lq} (= \kappa_l/\kappa_q)$, $\kappa_q (= \kappa_t = \kappa_b)$.

	$H \to \gamma\gamma$	$H \to ZZ^{(*)}$ / $H \to WW^{(*)}$	$H \to b\bar{b}$	$H \to \tau^-\tau^+$
ggH $t\bar{t}H$	$\frac{\kappa_q^2 \cdot \kappa_\gamma^2(\kappa_q,\kappa_q,\kappa_q\lambda_{lq},\kappa_V)}{\kappa_H^2(\kappa_i)}$	$\frac{\kappa_q^2 \cdot \kappa_V^2}{\kappa_H^2(\kappa_i)}$	$\frac{\kappa_q^2 \cdot \kappa_q^2}{\kappa_H^2(\kappa_i)}$	$\frac{\kappa_q^2 \cdot (\kappa_q\lambda_{lq})^2}{\kappa_H^2(\kappa_i)}$
VBF WH ZH	$\frac{\kappa_V^2 \cdot \kappa_\gamma^2(\kappa_q,\kappa_q,\kappa_q\lambda_{lq},\kappa_V)}{\kappa_H^2(\kappa_i)}$	$\frac{\kappa_V^2 \cdot \kappa_V^2}{\kappa_H^2(\kappa_i)}$	$\frac{\kappa_V^2 \cdot \kappa_q^2}{\kappa_H^2(\kappa_i)}$	$\frac{\kappa_V^2 \cdot (\kappa_q\lambda_{lq})^2}{\kappa_H^2(\kappa_i)}$



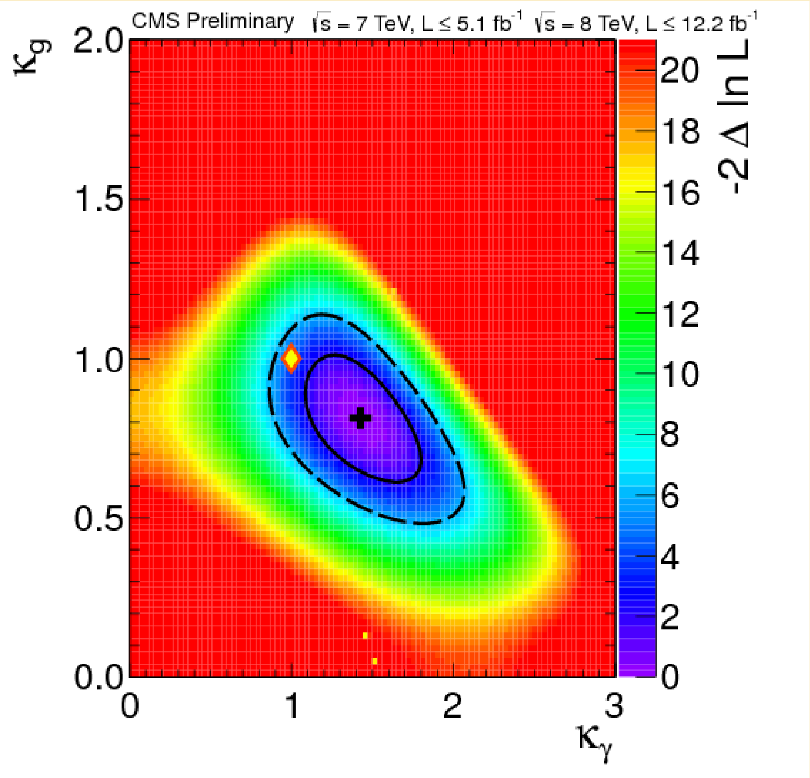


Best fit SM-like but $\kappa_l = 0$ not excluded at 95% CL

Compatible with SM

BSM in Loops

BSM can significantly alter phenomenology even if Higgs sector largely same with new particles in loops



Don't resolve gluon and photon loops just treat as free parameters

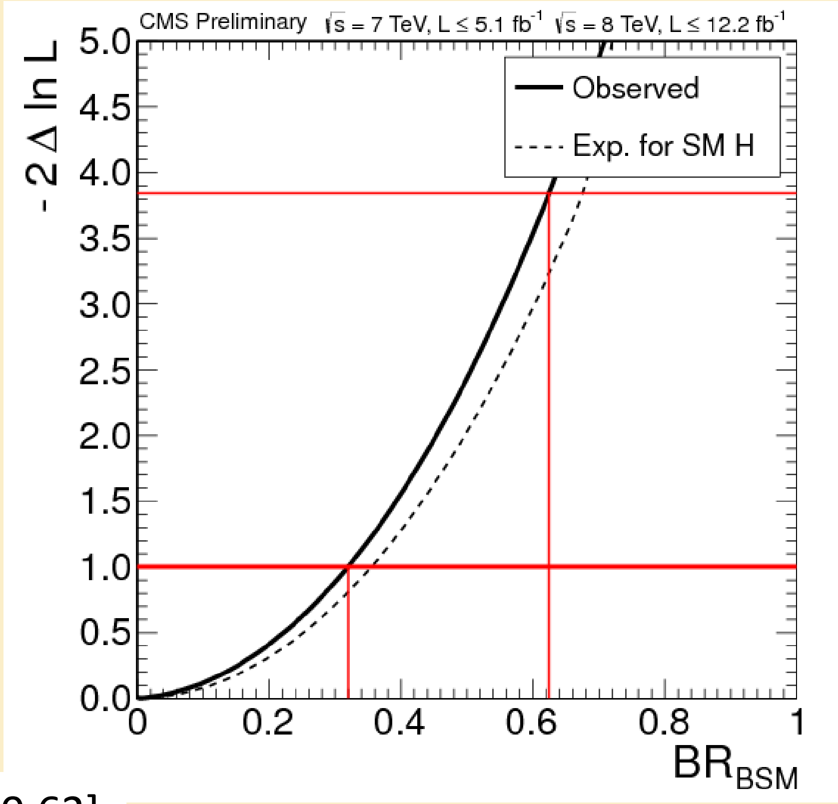
2D scan in $(\kappa_\gamma, \kappa_g)$ profiling everything else with $\Gamma_{BSM}=0$

Best fit: (1.43, 0.81)
κ_γ 95% CI [0.98,1.92]
κ_g 95% CI [0.55,1.07]

Compatible with SM

BSM in loops

BSM can significantly alter phenomenology even if Higgs sector largely same with new particles in loops



Investigate potential $\Gamma_{BSM} \neq 0$

κ_γ, κ_g free parameters as before
But now profile and allow non-zero decay to BSM particles

BR(BSM) [0.00,0.62]

Compatible with SM

Generic C6 search

Examine individual couplings assuming custodial symmetry and not resolving loops

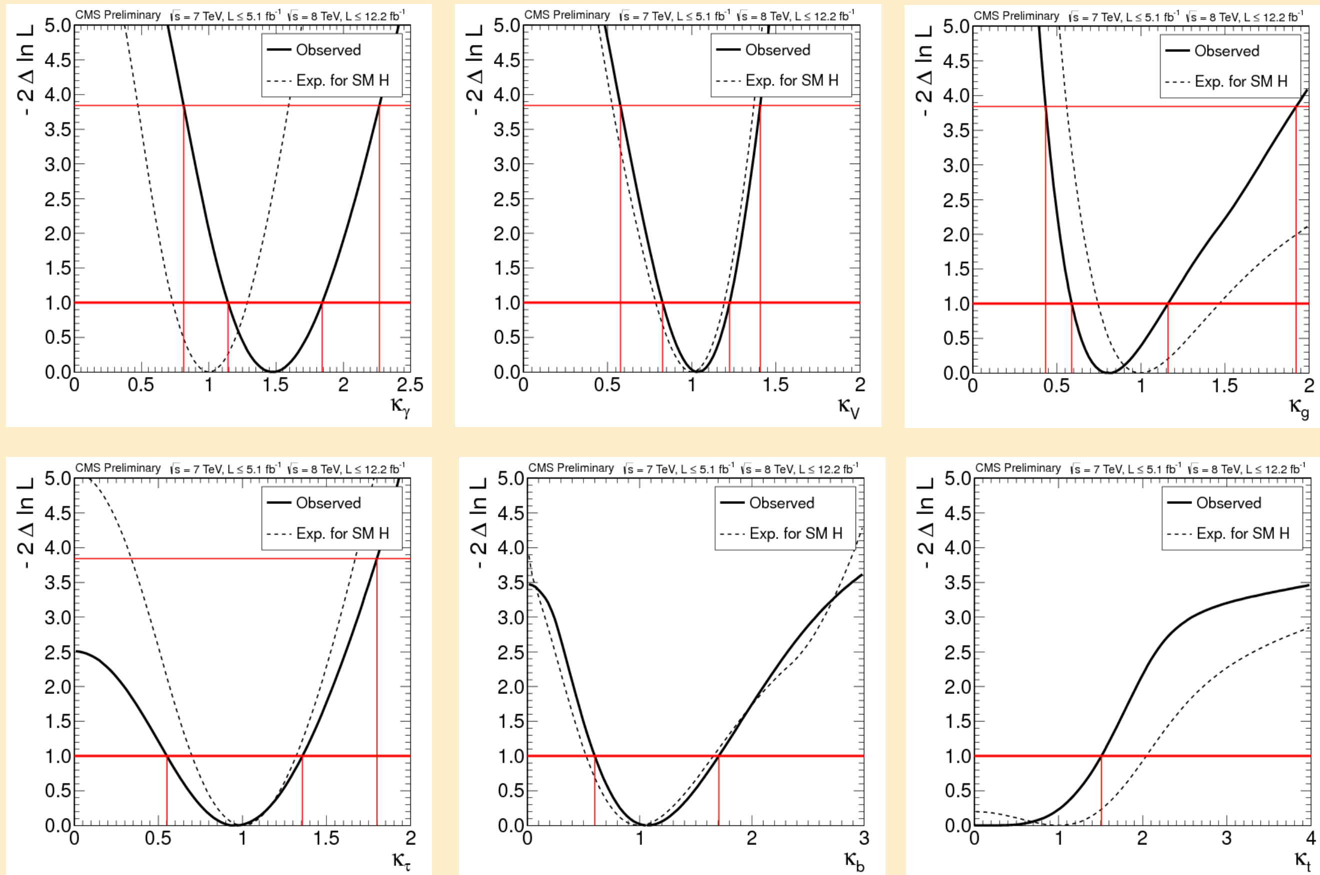
Leaves 6 parameters:

κ_γ, κ_V, κ_g, κ_τ, κ_b, κ_t

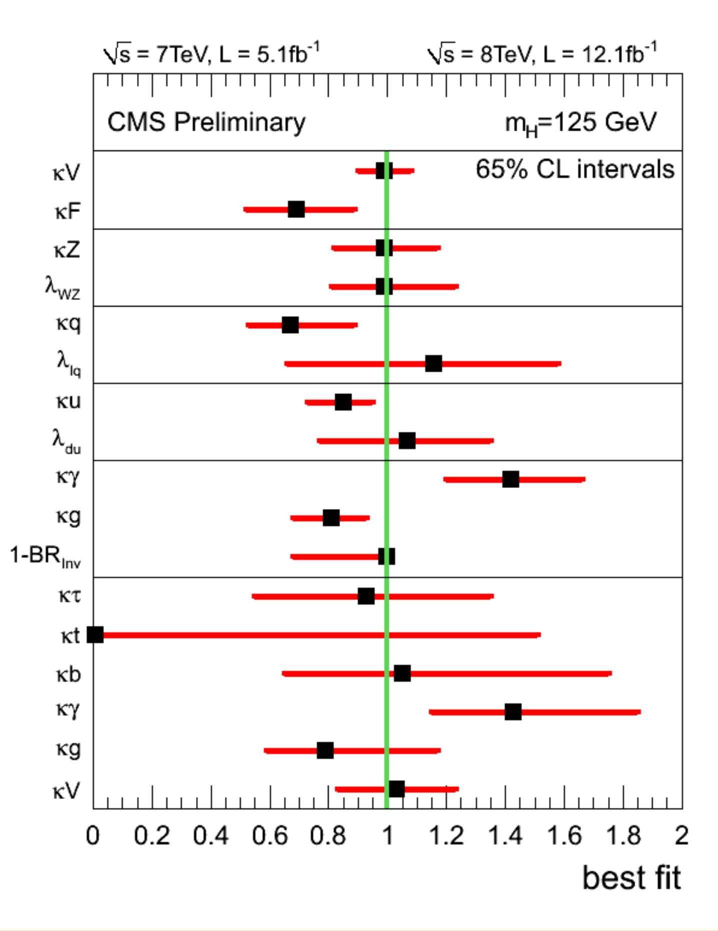
Fit one, profile others

Looks largely SM-like

Some constraint even with 6 parameters



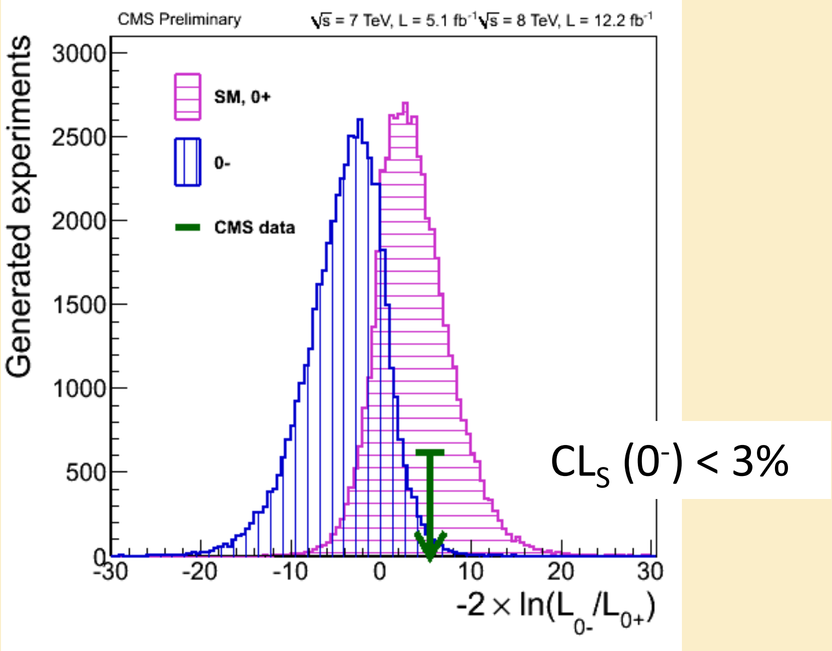
Couplings summary



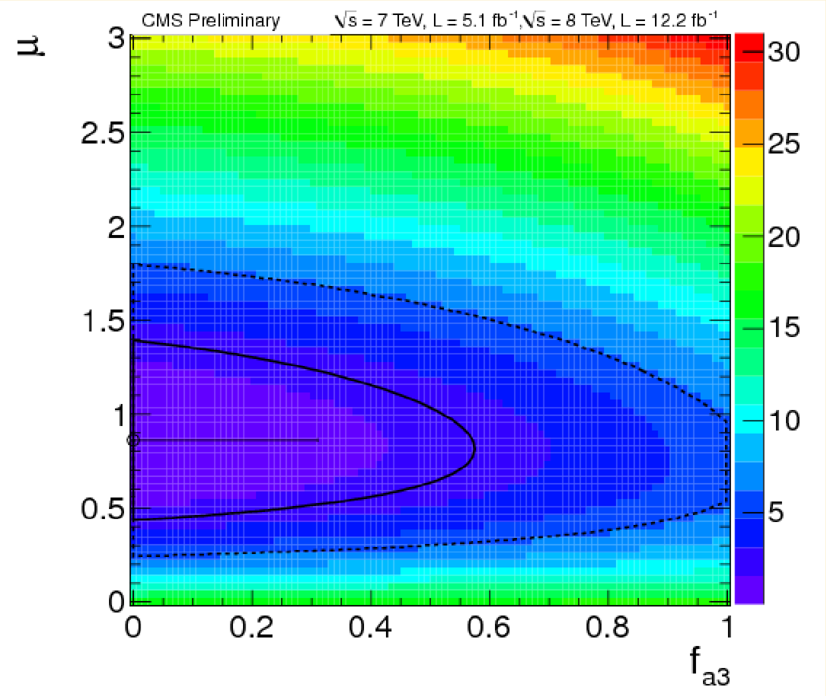
Model parameters	Assessed scaling factors (95% CL intervals)	
λ_{WZ}, κ_Z	λ_{WZ}	[0.57,1.65]
$\lambda_{WZ}, \kappa_Z, \kappa_f$	λ_{WZ}	[0.67,1.55]
κ_V	κ_V	[0.78,1.19]
κ_f	κ_f	[0.40,1.12]
κ_γ, κ_g	κ_γ	[0.98,1.92]
	κ_g	[0.55,1.07]
$\mathcal{B}(H \to BSM), \kappa_\gamma, \kappa_g$	$\mathcal{B}(H \to BSM)$	[0.00,0.62]
$\lambda_{du}, \kappa_V, \kappa_u$	λ_{du}	[0.45,1.66]
$\lambda_{\ell q}, \kappa_V, \kappa_q$	$\lambda_{\ell q}$	[0.00,2.11]
$\kappa_V, \kappa_b, \kappa_\tau, \kappa_t, \kappa_g, \kappa_\gamma$	κ_V	[0.58,1.41]
	κ_b	not constrained
	κ_τ	[0.00,1.80]
	κ_t	not constrained
	κ_g	[0.43,1.92]
	κ_γ	[0.81,2.27]

Spin-parity: 0^+ versus 0^-

Angular analysis based on ZZ search
Test statistic: $q = \log(L(B+0^+)/L(B+0^-))$



Throw 50k toys for each hypothesis



Can also construct a likelihood with overall scale and parameters sensitive to each species

Conclusions

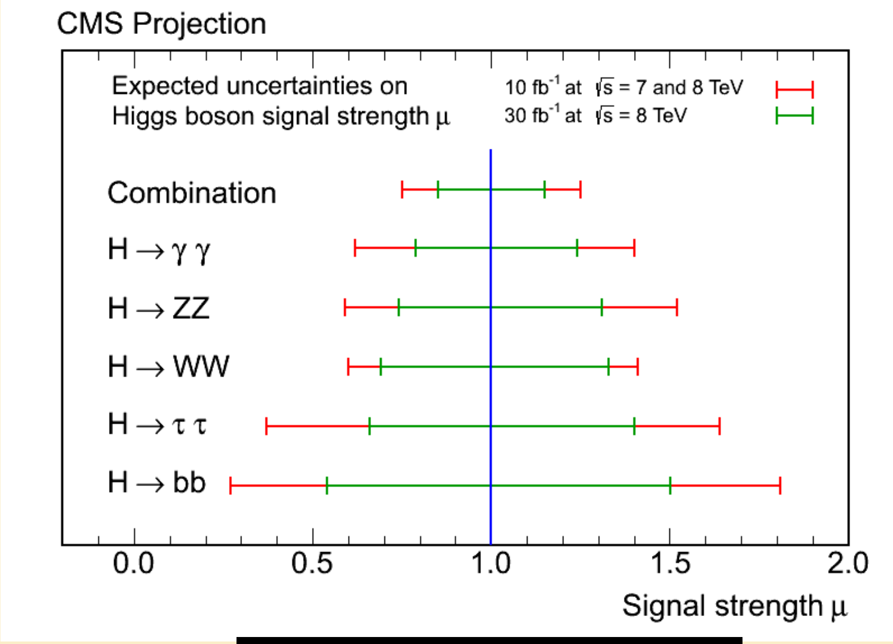
With more data and improved analyses CMS making significant tests of the new boson

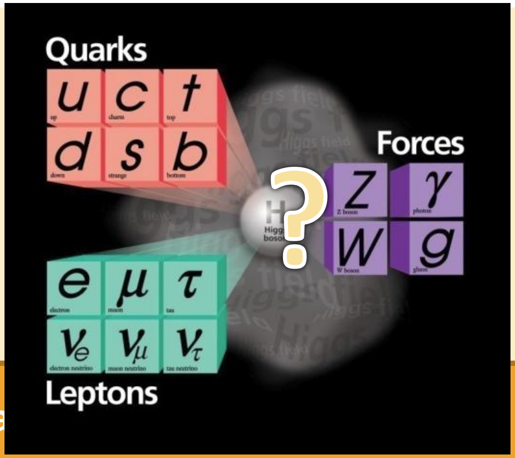
No significant deviations seen
– looks SM like

Benchmark parameterisations used to probe for small deviations of couplings from SM

Assuming spin-0 angular analysis disfavours 0^-

More data needed!





Data

Standard Model

Canonical elephant

Other Models

SUSY Elephants?

Exotics

Conclusions

With more data and improved analyses CMS making significant tests of the new boson

No significant deviations seen
– looks SM like

Benchmark parameterisations used to probe for small deviations of couplings from SM

Assuming spin-0 angular analysis disfavours 0^-

More data needed!