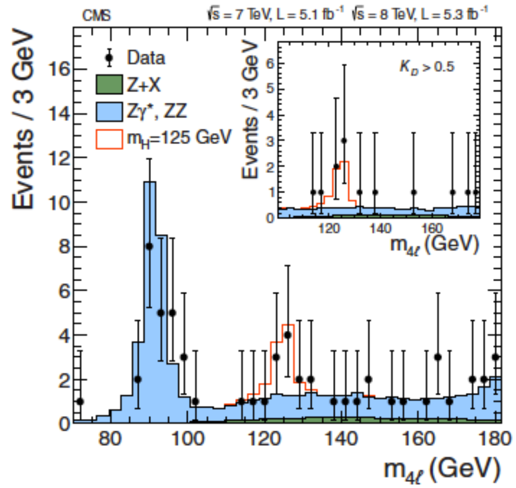
19th International Symposium on Particle, Strings and Cosmology (PASCOS)
19-26th November 2013, Taipei (Taiwan)

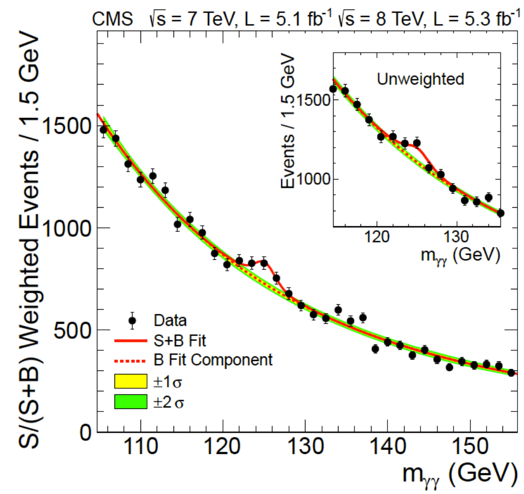
Higgs properties with CMS

Roberto Castello (UC Louvain CP3, FNRS)
on behalf of CMS collaboration

Anatomy of the excess

4^{th} July 2012:
5.1 (7TeV) + 5.3 (8TeV) /fb





CMS coll. , Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC, arXiv:1207.7235

Is it the SM Higgs boson foreseen by the BEH mechanism?

Which mass?

Which spin?

Is it *the only*?

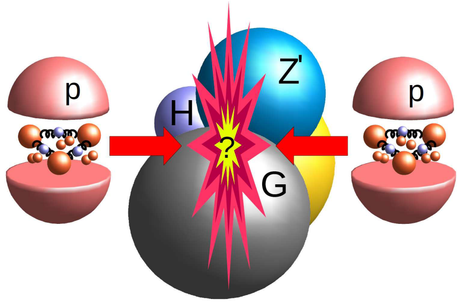
Is it decaying into ZZ and γγ ?

Does it couple with bosons/fermions?

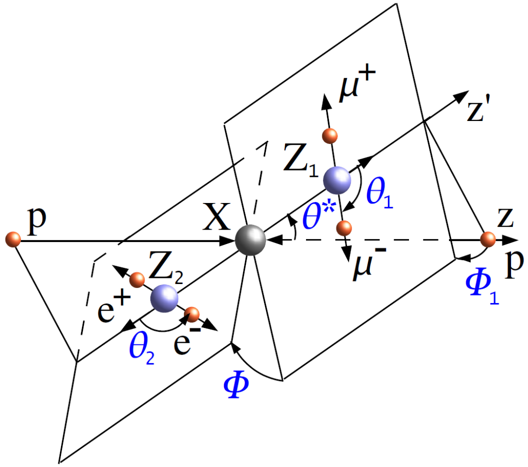
Is custodial symmetry (g_W/g_Z) kept?

- Significance of the excess and its mass (5.1+19.6 fb^{-1})

- Compatibility with SM hypothesis
  - Signal strength
  - Production mechanisms



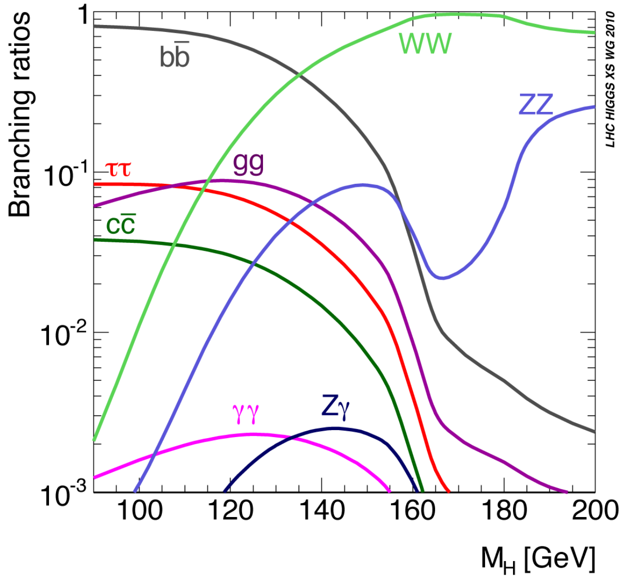
- Compatibility with SM couplings
  - Fermion/bosons
  - Custodial symmetry
  - Presence of BSM particles



- Test of different spin-parity hypothesis
  - Scalar, pseudo-scalar, spin-2..
  - Exploiting kinematic of bosonic channel H→VV

Reference: *CMS Physics Analysis Summary HIG-13-005, HIG-13-002*

- SM Higgs production mode: *gg-fusion* dominates at LHC (p-p)
- Concerning SM Higgs decays at *low* masses:
  - H→ bb is the favored decay mode, but large QCD background
  - Excellent resolution from H→ZZ and H→γγ
- Measured by *p-value*: probability of fluctuations under bkg-only hypothesis

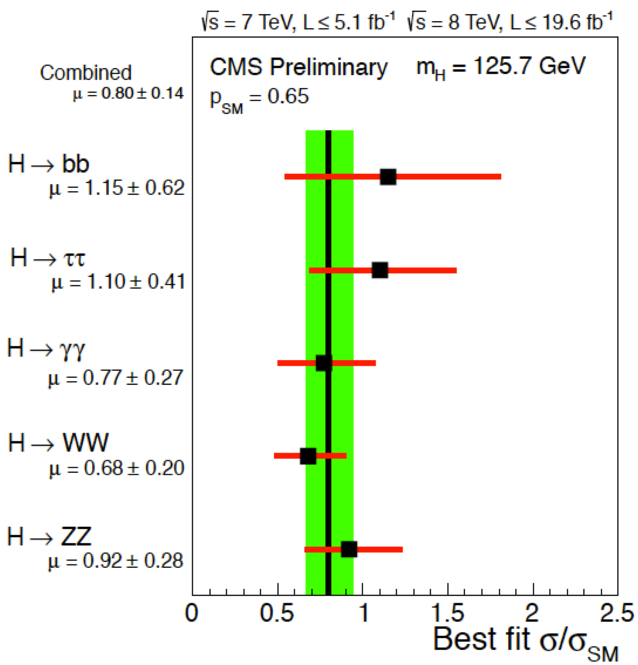


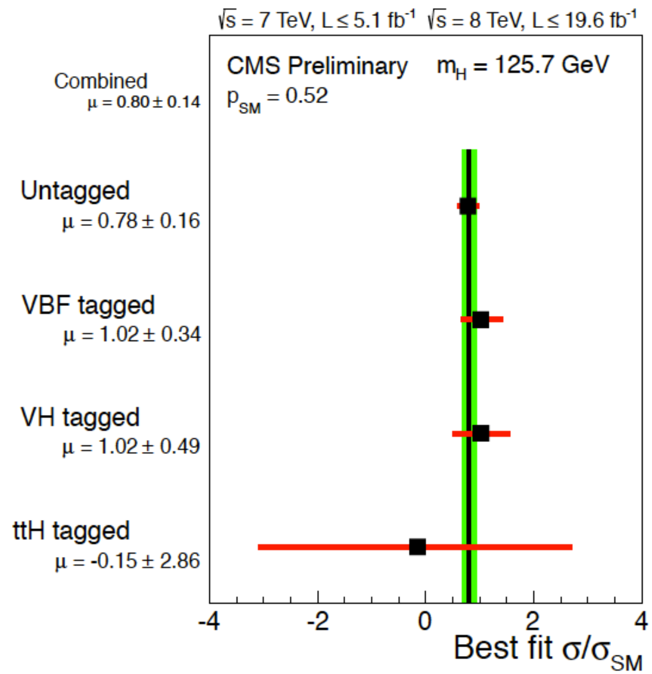
Channel	Expected	Observed
ZZ	7.1σ	6.7σ
$\gamma\gamma$	3.9σ	3.2σ
WW	5.3σ	3.9σ
bb	2.2σ	2.0σ
$\tau\tau$	2.6σ	2.8σ
$(bb+\tau\tau)$	3.4σ	3.4σ

In this session: *G.Cerati, Higgs decaying into bosons at CMS and P. Azzurri, Higgs decaying into fermions at CMS*

Compatibility with SM: *signal strength*

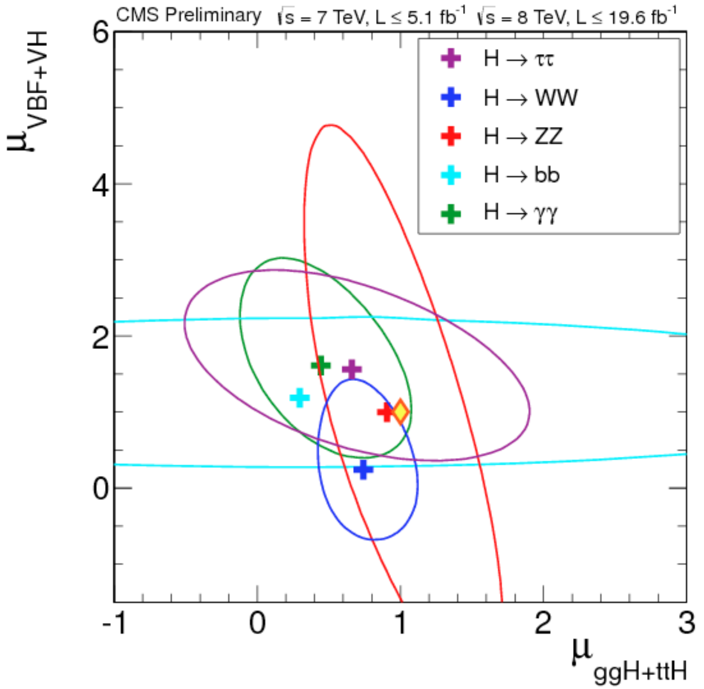
- Defined to accommodate deviations from SM: $\boldsymbol{N = \mu \times \sigma_{SM} \times BR_{SM} \times A \times \varepsilon \times L}$
- Categorized by decay/production mechanism (but contamination possible)

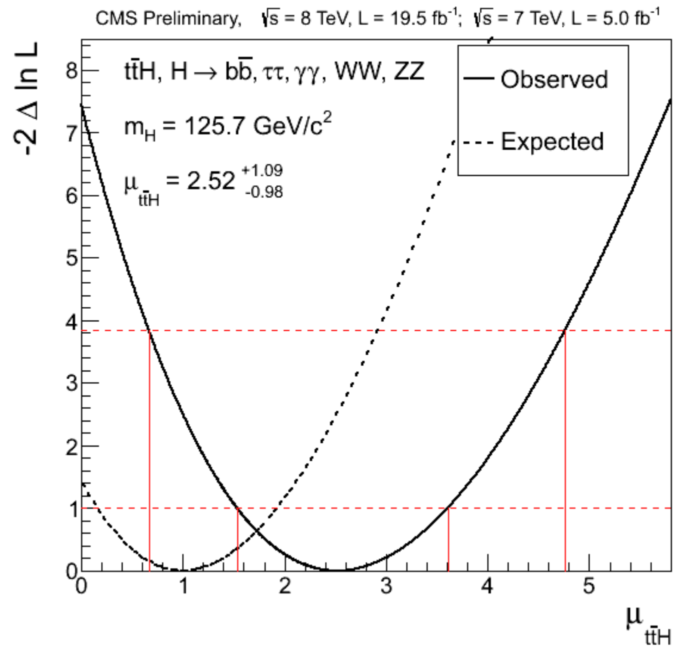




Overall best fit μ =0.80± 0.14 for m_H=125.7 GeV

- Categorizing the signal strength according to the production mechanism
- *Untagged* channels → *g-g* fusion. *Tagged channels* → sensitive to the others

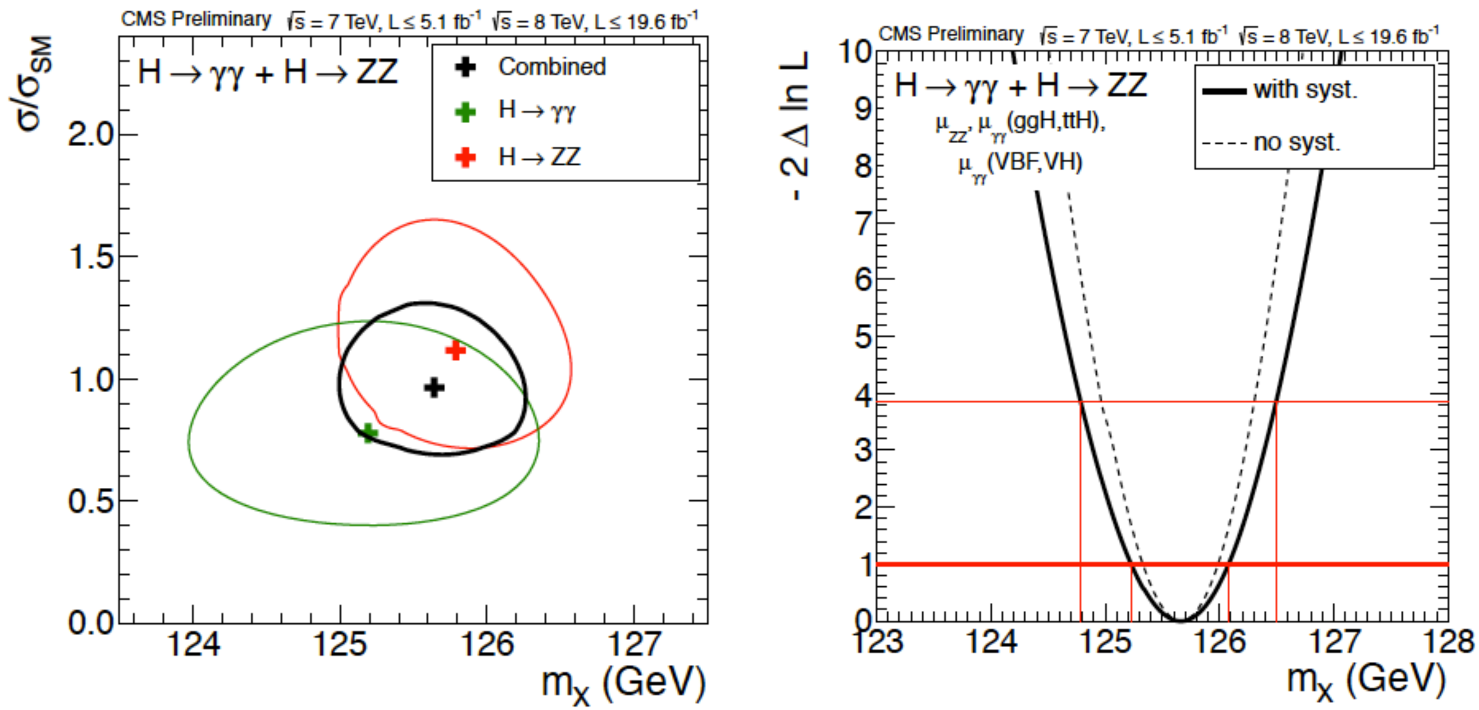




- NEW ttH: full luminosity analyzed in bb, γγ, ττ and multileptonic final state:
  - 1xSM sensitivity on μ(ttH)

Excellent compatibility with SM

- Exploiting the excellent mass resolution of H→ZZ→4l and H→ γγ decays
- Model-independent: 3 μ independent modifiers for production mechanisms



m_{higgs} = 125.7 ± 0.3 (stat.) ± 0.3 (syst.) GeV

Probing the couplings

- Boson in BEH mechanism should couple to both fermions & bosons
- Search for deviations from the SM predictions in the scalar couplings

LHC x-sec WG, arXiv:1209.0040

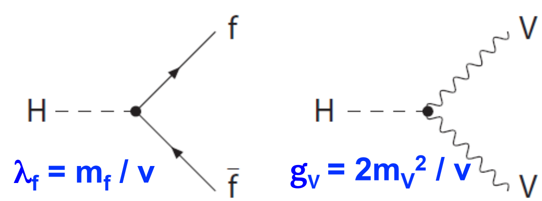
$$\sigma \times BR = \sigma \times \Gamma_i / \Gamma_{tot}$$

Allowing modified couplings: $\Gamma_i \sim (k_i\, c_i)^2$

i = V, W,Z, f, l, q, t, b, …

Accommodating BSM decays: $\Gamma_{tot} = \Sigma\, \Gamma_{ii} + \Gamma_{BSM}$

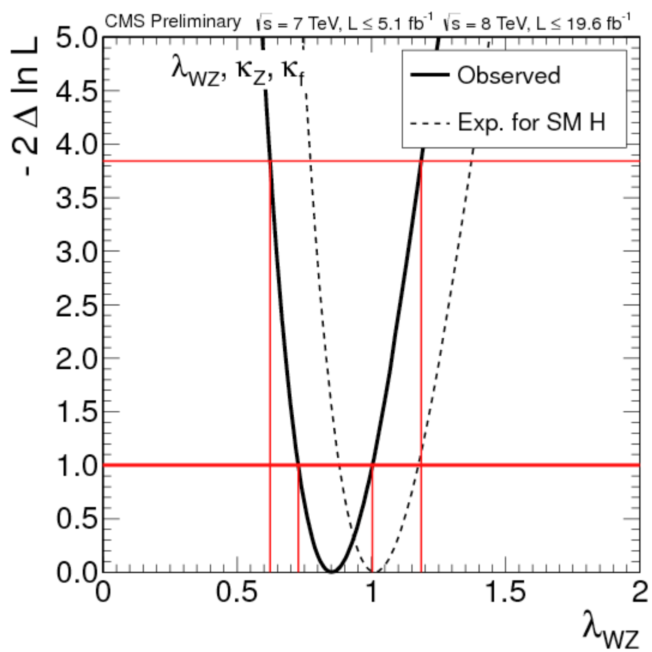
- Testing model fitting couplings independently: allowing two, five or six k_i
- Evidence of BSM processes in loops (i.e. $gg \rightarrow H$, $H \rightarrow \gamma\gamma$) + custodial symmetry
- Couplings vs mass: proving the proportionality



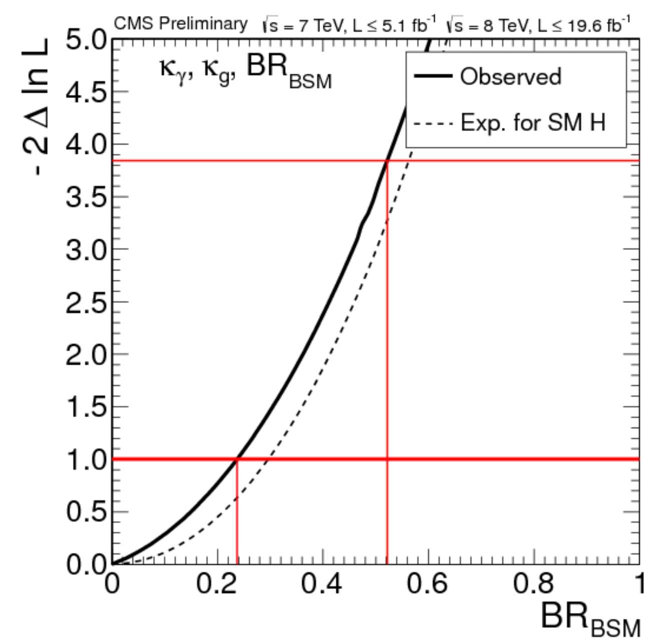
Custodial symmetry and hints for BSM physics

- Global $SU(2)_{L+R}$ symmetry introduces a relation between W and Z masses
- Testing the custodial symmetry by looking at Z and W couplings, $\lambda_{WZ}=k_W/k_Z$
- Looking for BSM physics in decays and loops (k_γ and k_g)

All channels. k_Z and κ_f profiled

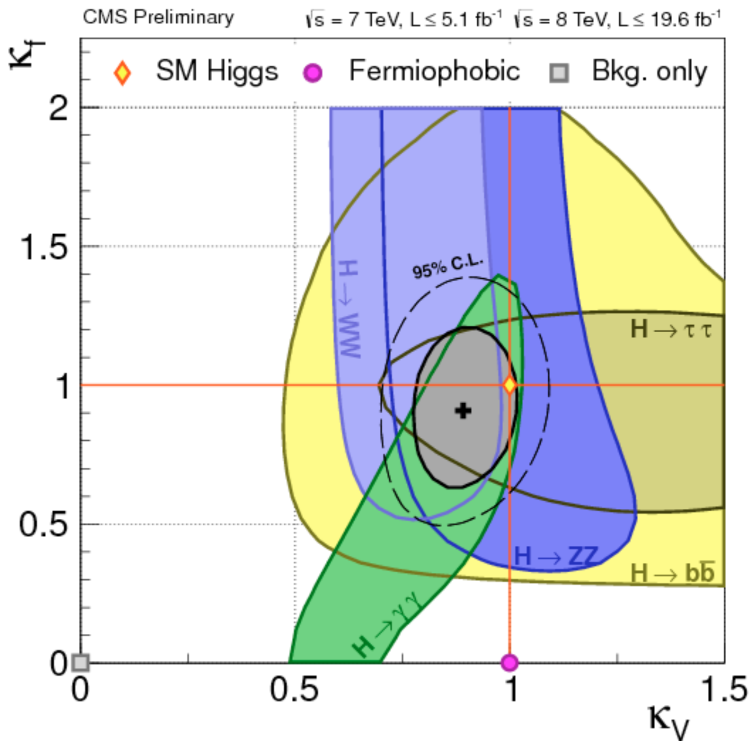


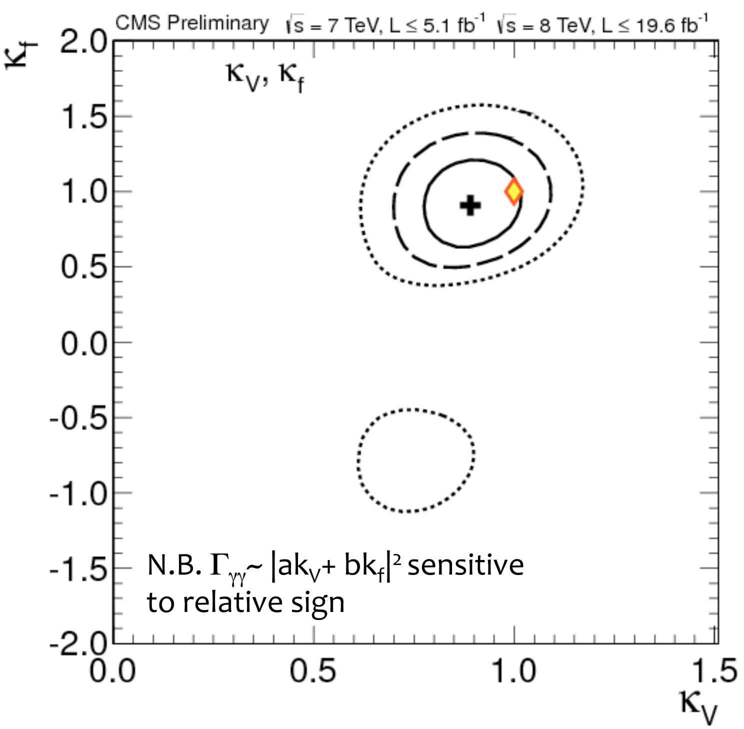
κ_γ and k_g profiled, k_i =1, as in SM



$\lambda_{WZ} \in [0.62, 1.19]$ and $BR_{BSM} \in [0, 0.52]$ at 95% CL

- Grouping together vector boson and fermion couplings (as initial test)
- Assuming: $\mathbf{k_V} = k_W = k_Z$, $\mathbf{k_f} = k_t = k_b = k_\tau = k_g$ and $\boldsymbol{\Gamma_{BSM}=0}$

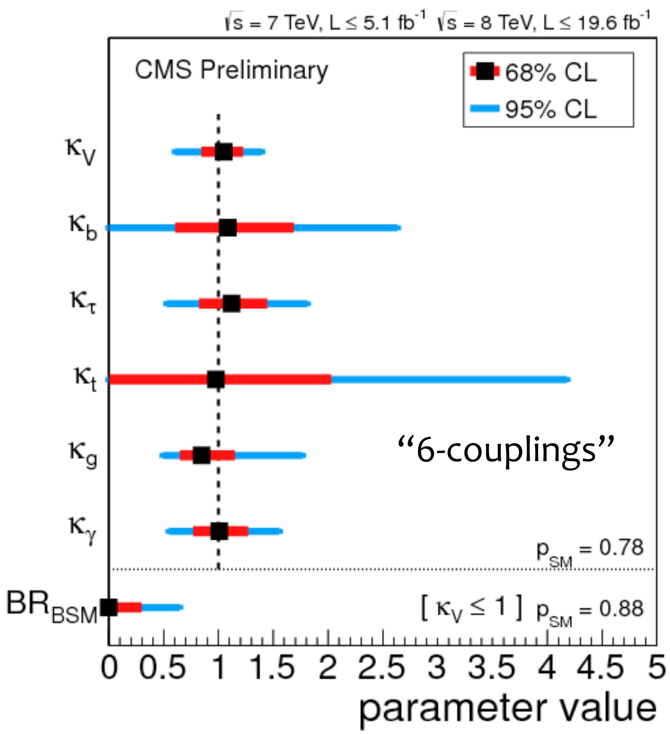


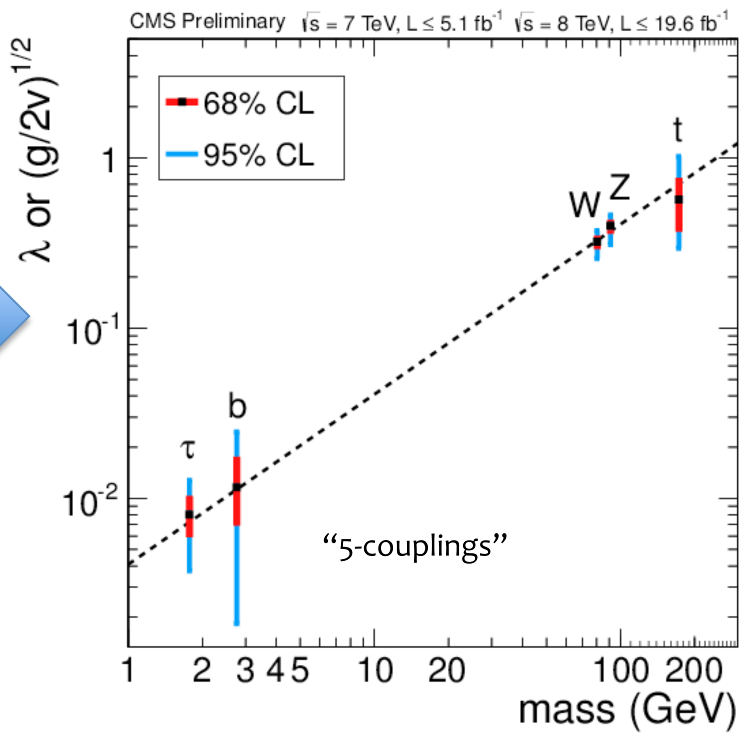


N.B. $\Gamma_{\gamma\gamma} \sim |ak_V + bk_f|^2$ sensitive to relative sign

Best fit compatible with predicted SM couplings, preferring positive couplings

- Fitting independent couplings, assuming:
  - For 6-coupling model: $k_W = k_Z$, $k_{d,s,b}$, $k_{u,c,t}$, $k_{e,\mu,\tau}$, κ_γ , k_g ,
  - For 5-coupling model: as 6C but $\Gamma_{BSM} = 0$ (k_γ , k_g as in SM) and $k_W \neq k_Z$

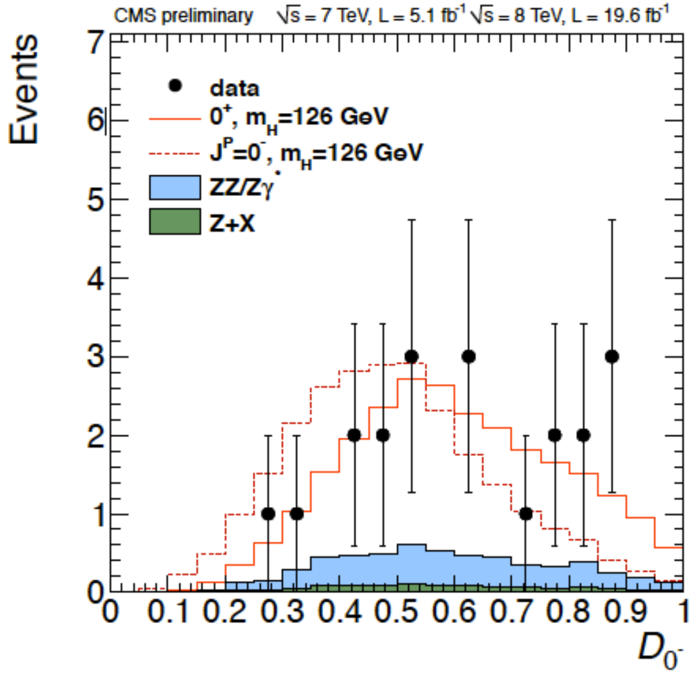


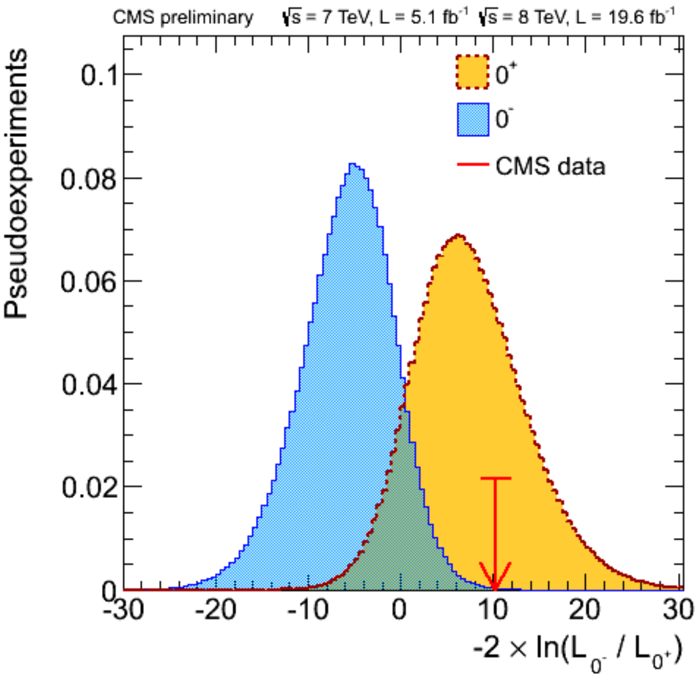


No significant deviation from SM and Yukawa couplings very well reproduced

Parity: H→ZZ→4l

- Exploiting matrix-element based discriminator (*D*) based on production and decay angles and Z masses
- Statistical test using the likelihood ratio of the two alternative hypotheses

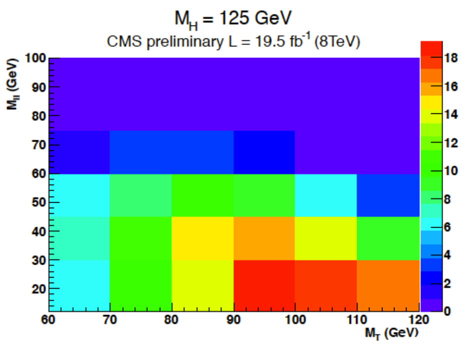


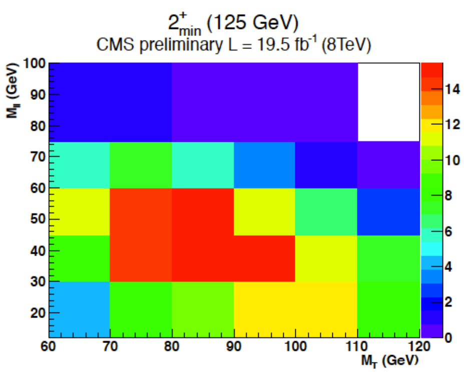


Pure pseudoscalar hypothesis excluded at 99.8% (CLs criterion)

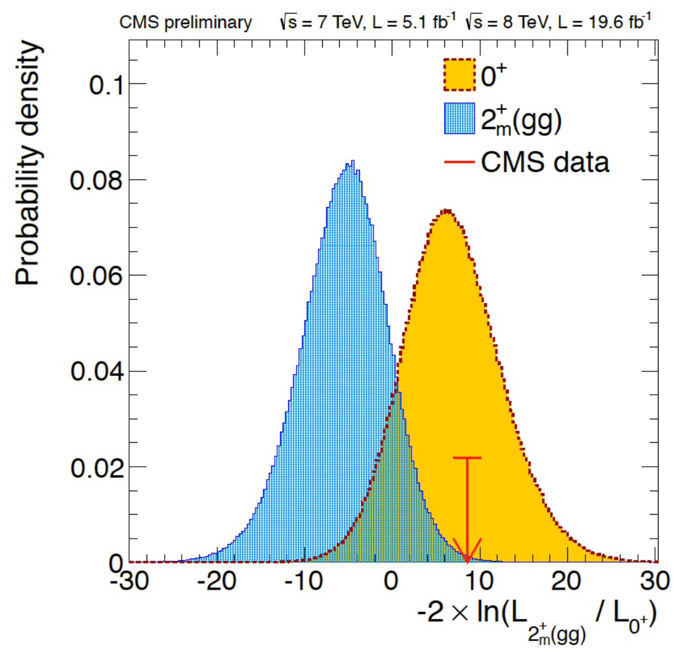
The case of spin-2: H→ZZ and H→WW

- H→ZZ alone already disfavors most of representative alternatives (0^-, 1^+, 1^-)
- Using H→ WW to discriminate from spin-2 hypo: 2-D [M_{ll}, M_T] distribution



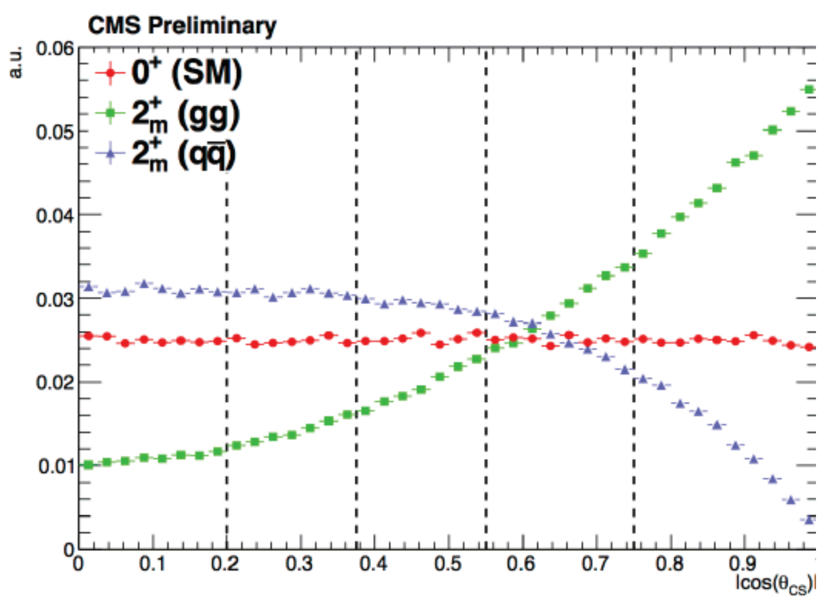


H→ZZ and H→WW combined

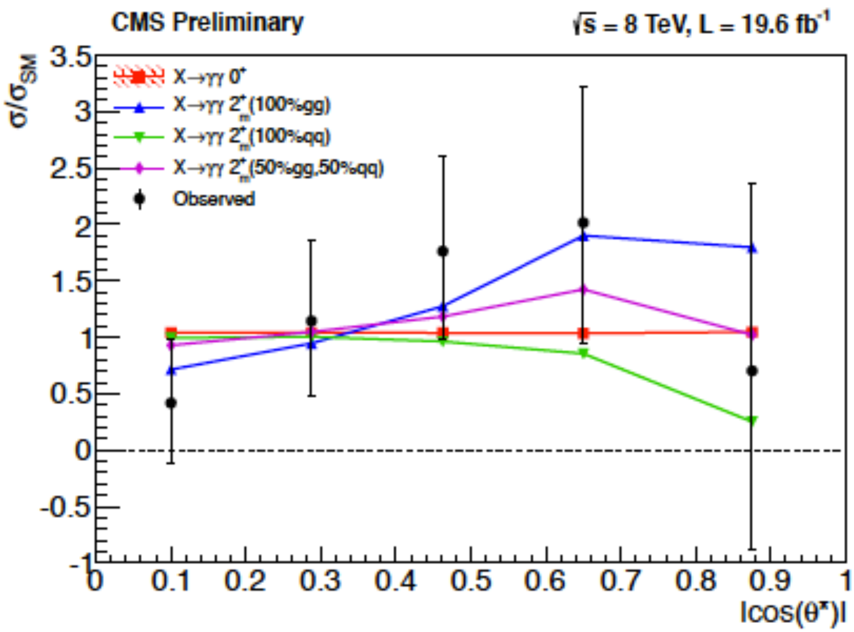


Combining : gg → 2^+_m → VV excluded at 99.4% (CLs criterion)

- For spin-1: excluded at 3.2σ (existence of H → γγ, i.e. Landau-Yang)
- For spin-2: $\cos^2\theta^*$ (decay angle relative to the beam axis) as discriminant, analysis of $m_{\gamma\gamma}$ and $\cos\theta^*$



But discriminating power reduced after sel. cuts



No significant discrimination reached (yet)

Conclusions

- Properties of new observed particle studied using 7 TeV + 8 TeV dataset:
  - it is a boson
  - mass, couplings to SM, J^P…

- Observed Higgs properties are broadly consistent with the Standard Model predictions within the present uncertainties
- Significative gain in sensitivity in many modes: visible in next combination
- Plan to extend spin and parity tests to fermion decays (e.g. V+X(bb))
- Additional data post-LS1 will increase the precision of these results

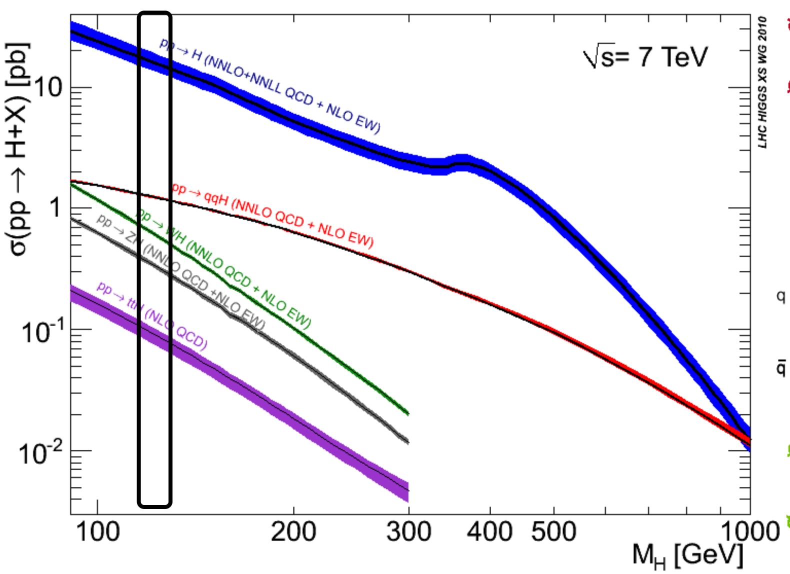
Standard Model Higgs still looks quite solid.
Then, "*no news is good news*" ?

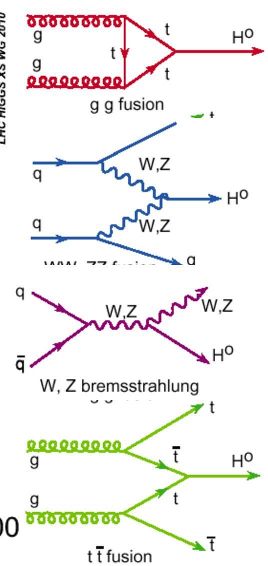
Stay tuned.

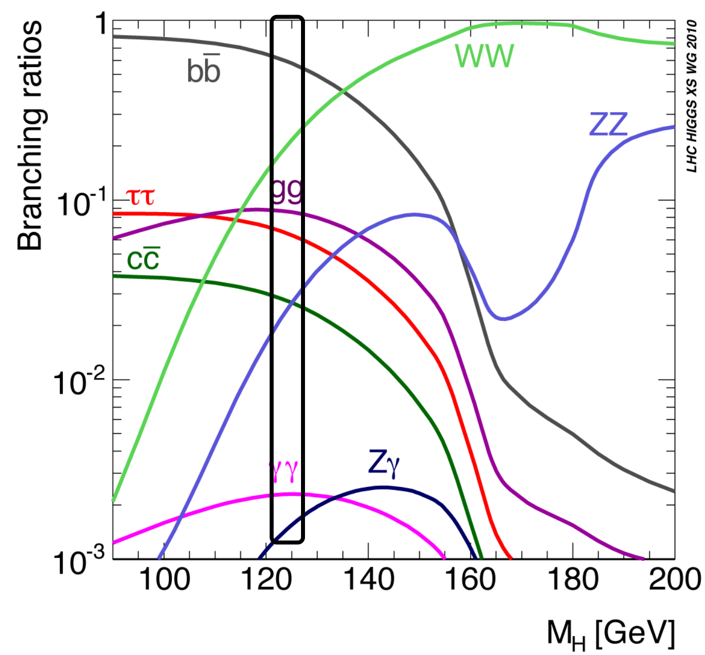
BACKUP

The SM scalar boson production and decay modes at LHC

- Gluon fusion production mode dominates at *p-p* Large Hadron Collider
- H→ bb is the favored decay mode, but suppressed by large QCD
  - $\boldsymbol{\sigma}_{bb}$(QCD) ~ 10^7 $\boldsymbol{\sigma}$**x**BR(H->bb)







Likelihood of observing n_i events for a given value of μ_i (no syst unc.) in presence of background, b_i

$$Poisson(n_i \mid \mu_i s_i + b_i) = \frac{\prod_{k=1}^{Nbins} (\mu_i s_i + b_i)^{n_i}}{n_i!} e^{-\mu_i s_i - b_i}$$

$$L_{max} = L(obs \mid \hat{\mu} s_i + b_i; \hat{\theta})$$

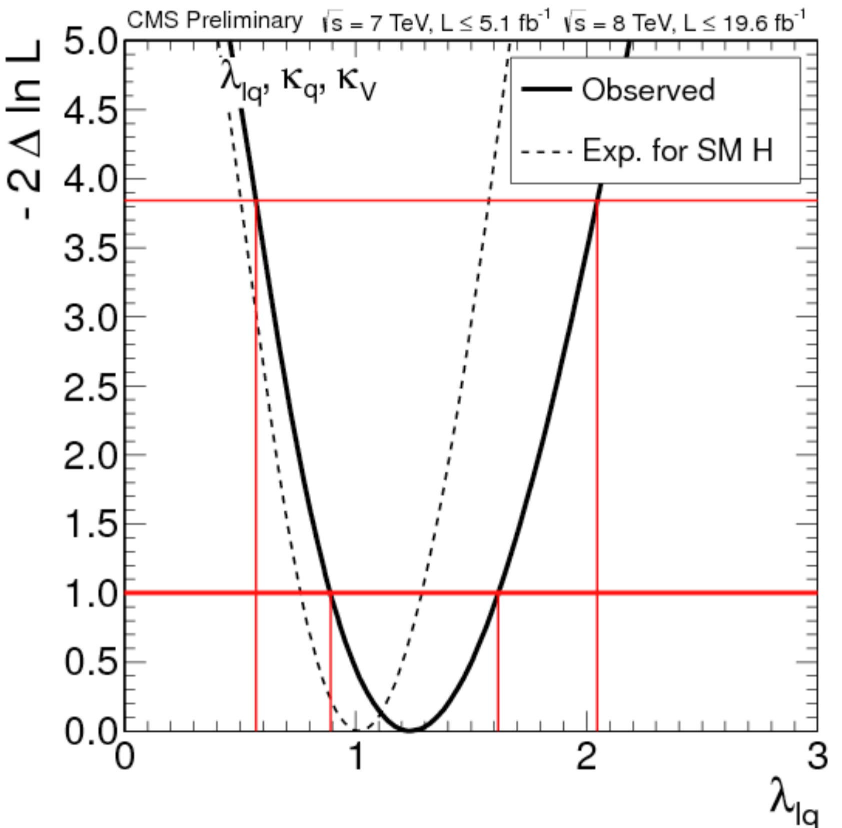
Nuisance profiling: evaluating L at a given μ_i, fixing all nuisances to the values that maximize $L(\mu_i)$.

p-value: probability probability to obtain a value q_0 at least as large as the one observed in data, q_{obs} , under the background-only hypothesis

$$q_0 = -2 \ln \frac{\mathcal{L}(\text{obs} \mid b, \hat{\theta}_0)}{\mathcal{L}(\text{obs} \mid \hat{\mu} \cdot s + b, \hat{\theta})},$$

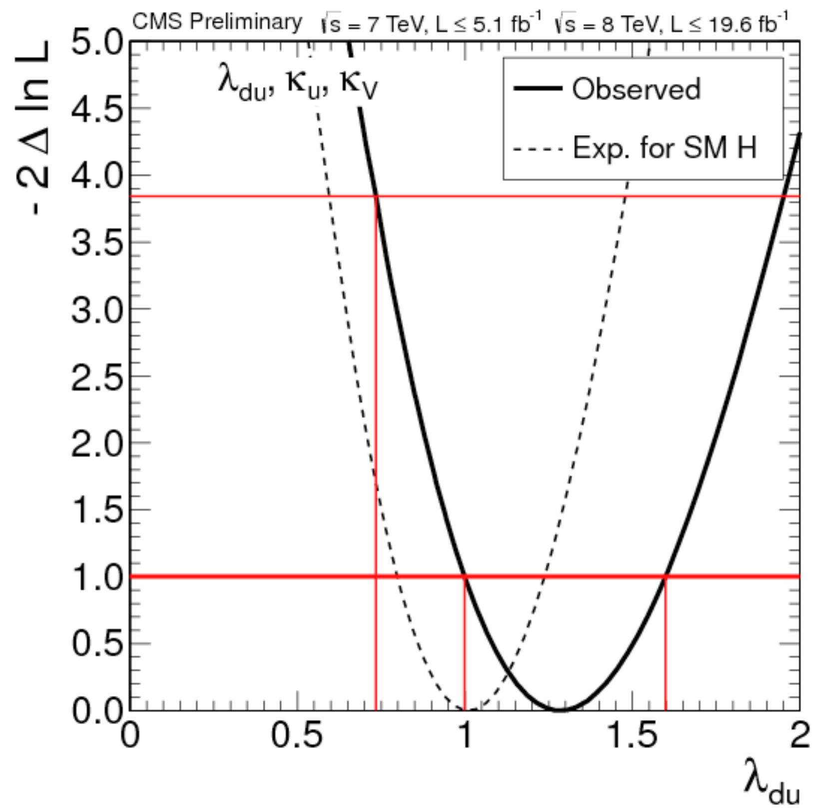
Testing fermion universality

Leptons VS quarks (2HDM)



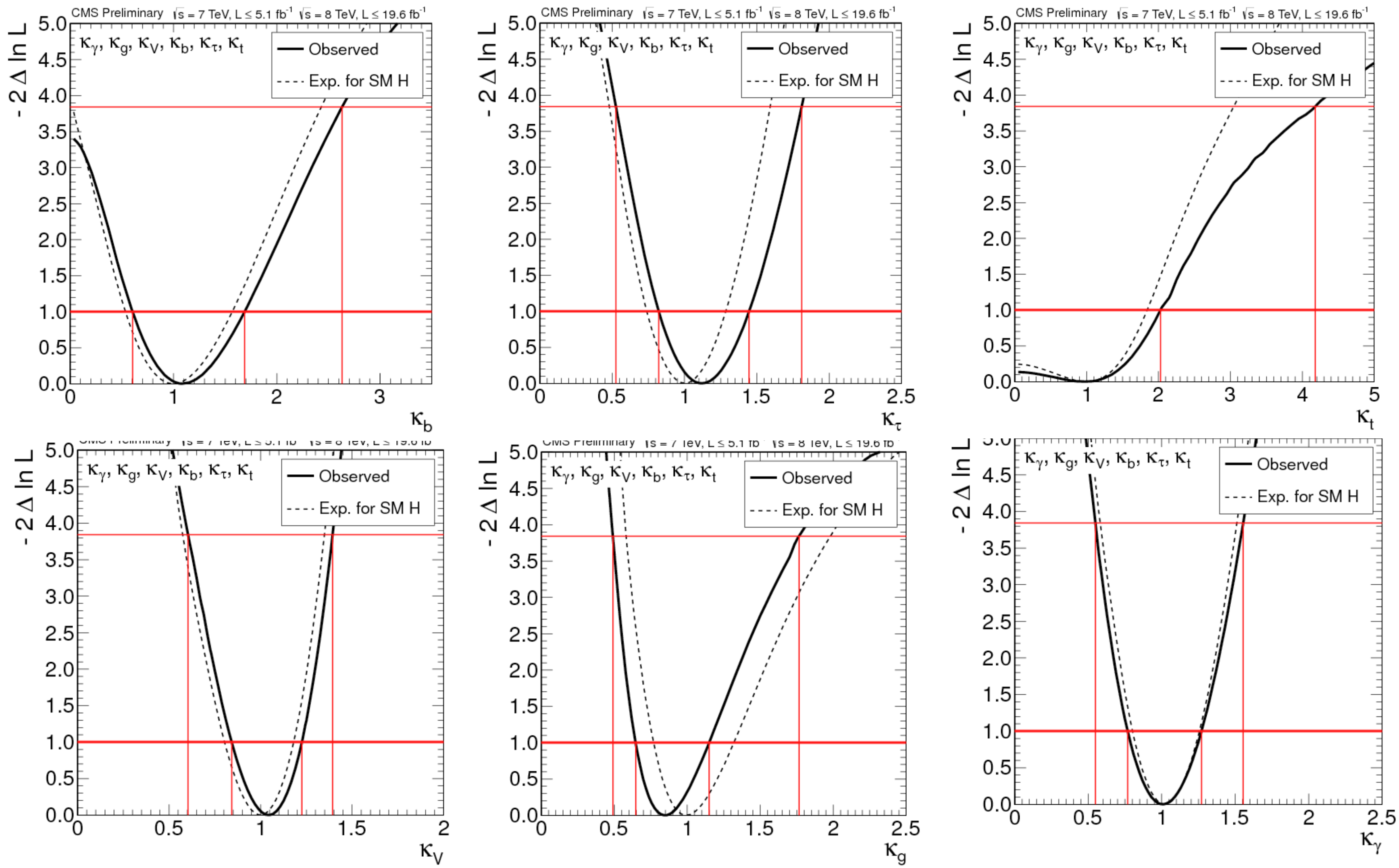
$\lambda_{lq} \in [0.57, 2.05]$ at 95% CL

U- quark VS d-quarks (MSSM)



$\lambda_{du} \in [0.74, 1.95]$ at 95% CL

Fitting six couplings at once: detailed results



Synoptic view of different spin model tests

- Results of spin hypothesis test for m_H=125.7 GeV using kinematic in H→ZZ

J^P	production	expect (μ=1)	obs. 0^+	obs. J^P	CL_s
0^-	$gg \rightarrow X$	2.6σ (2.8σ)	-0.5σ	3.3σ	0.16%
0_h^+	$gg \rightarrow X$	1.7σ (1.8σ)	0.0σ	1.7σ	8.1%
2_m^+	$gg \rightarrow X$	1.8σ (1.9σ)	-0.8σ	2.7σ	1.5%
2_m^+	$q\bar{q} \rightarrow X$	1.7σ (1.9σ)	-1.8σ	4.0σ	$<$0.1%
1^-	$q\bar{q} \rightarrow X$	2.8σ (3.1σ)	-1.4σ	$>4.0\sigma$	$<$0.1%
1^+	$q\bar{q} \rightarrow X$	2.3σ (2.6σ)	-1.7σ	$>4.0\sigma$	$<$0.1%