Spin parity of the Higgs-like boson

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(heavily stolen from the *Moriond* Talk of Dr. Chen)

https://indico.in2p3.fr/conferenceOtherViews.py?view=standard&confId=7411

+ CMS PAS HIG-13-002, HIG-13-005

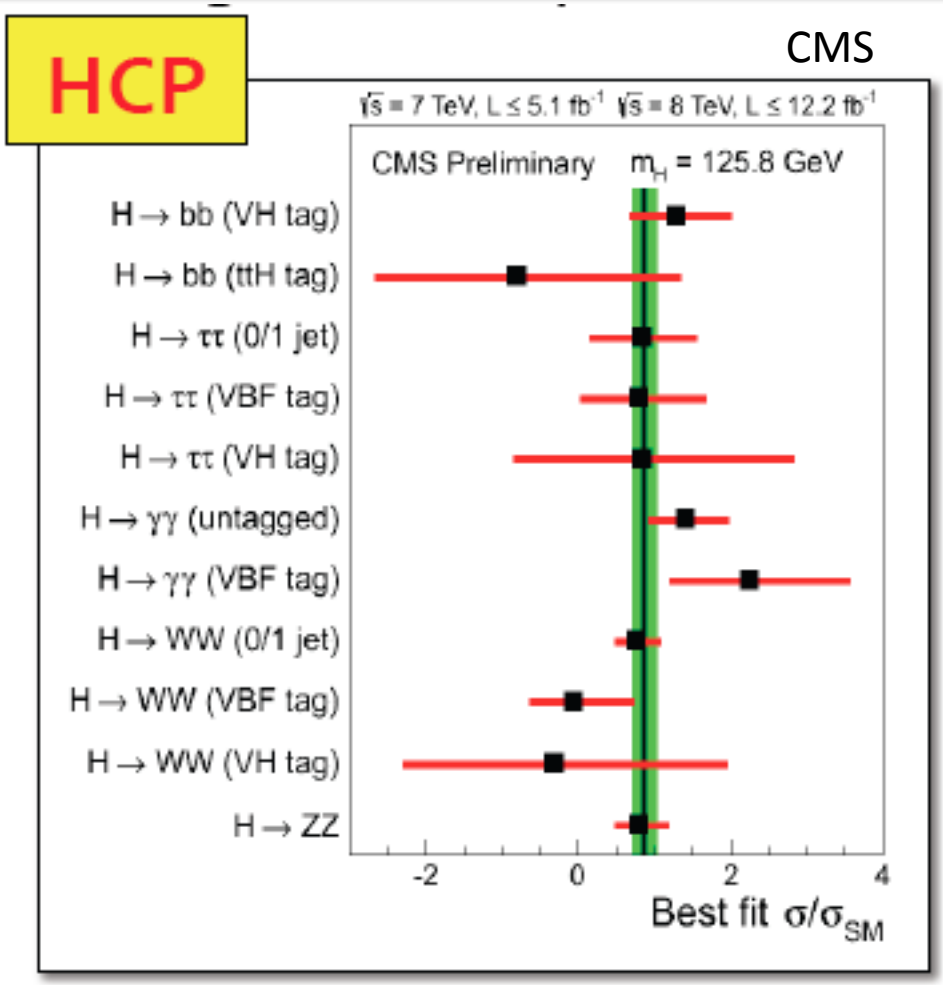
Signal strengths

- Given the mass, properties of the SM Higgs boson are all known theoretically
- Proceed to test data whether it is compatible with SM prediction on various properties
  - signal strengths
  - spin parity
  - couplings
- Overall signal strength (common scale factor for expected signal event yields all channels): $\mu = 0.88 + 0.21$
- Sub-combinations grouped by

`(production tag) x (decay mode)`

$\chi^2/ndf = 8.7/11$

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



Results are consistent with the SM Higgs boson

Introduction

- What can the spin of the "new found" particle be?

Spin of the decaying boson	Allowed decay channel for a boson with given spin value			
	photons	ZZ or WW	taus	b quarks
Spin 0	yes	yes	yes	yes
Spin 1	no	yes	yes	yes
Spin 2	yes	yes	no	yes
Observed?	yes	yes	Unknown yet	Unknown yet

➢ That's why it is very important to observe Higgs in ττ channel – which will rule out for it to have a spin of 2

Spin Parity

- So far we know the observed particle (assuming just one particle)
  - X is a boson (decays to γγ, 4l etc)
  - X can not be spin 1 (decays to γγ + Landau-Yang theorem)
  - X can not be 100% 0^- (from 4l correlations) PRL **110**, 081803 (2013)

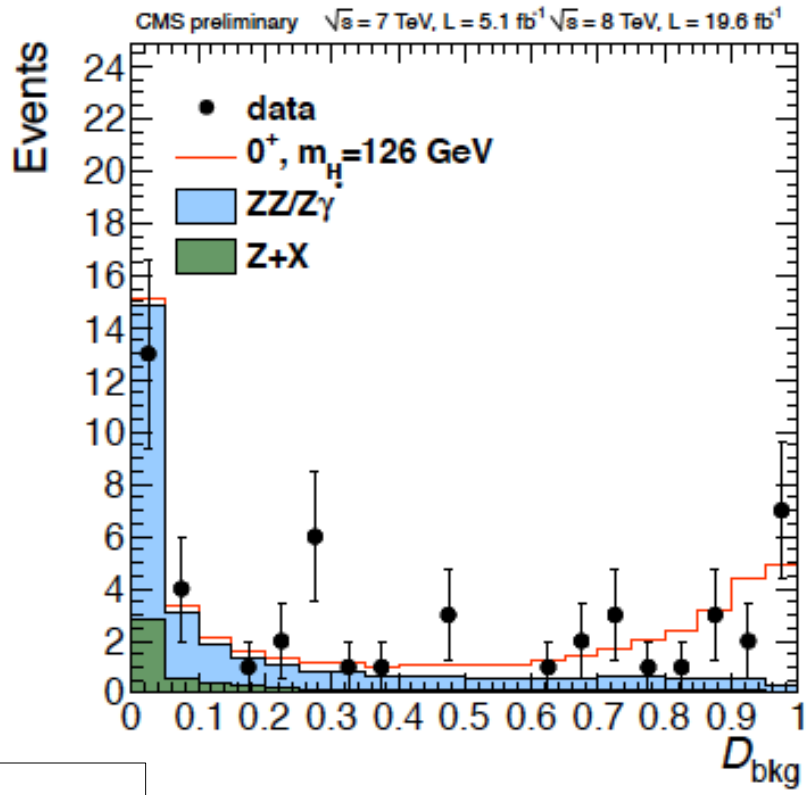
- Further tests in 4l and WW(lνlν) channels with full data on a few reasonably well motivated J^P hypothesis ("pure" states only) w.r.t. SM Higgs boson

J^P	production	comment	expect (μ=1)	obs. 0^+	obs. J^P	CL_s
0^-	$gg \to X$	pseudoscalar	2.6σ (2.8σ)	0.5σ	3.3σ	0.16%
0^+_h	$gg \to X$	higher dim operators	1.7σ (1.8σ)	0.0σ	1.7σ	8.1%
2^+_{mgg}	$gg \to X$	minimal couplings	1.8σ (1.9σ)	0.8σ	2.7σ	1.5%
$2^+_{mq\bar{q}}$	$q\bar{q} \to X$	minimal couplings	1.7σ (1.9σ)	1.8σ	4.0σ	<0.1%
1^-	$q\bar{q} \to X$	exotic vector	2.8σ (3.1σ)	1.4σ	$>4.0\sigma$	<0.1%
1^+	$q\bar{q} \to X$	exotic pseudovector	2.3σ (2.6σ)	1.7σ	$>4.0\sigma$	<0.1%

NB: testing spin-1 hypothesis makes sense if the excesses come from more than one particle

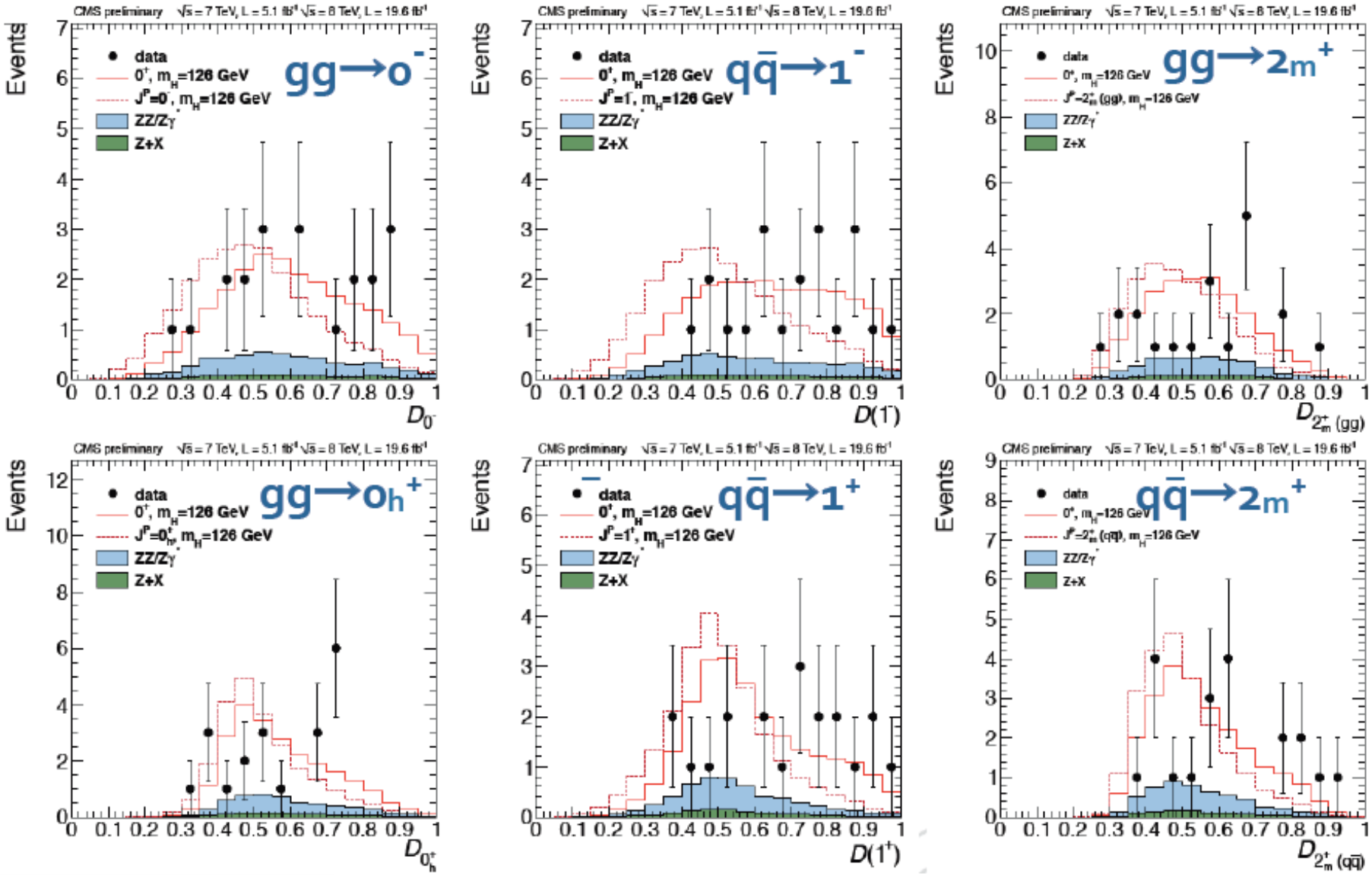
Matrix Element approach in 4l

- Build two discriminant based on the complete Leading-Order MEs
  - D_{bkg} to separate signal from background (ME combined with pdf(m_{4l})
  - D_{JP} to separate the SM Higgs boson from alternative J^P hypothesis
- Exploit fully the (D_{bkg}, D_{JP}) – plane in statistical analysis

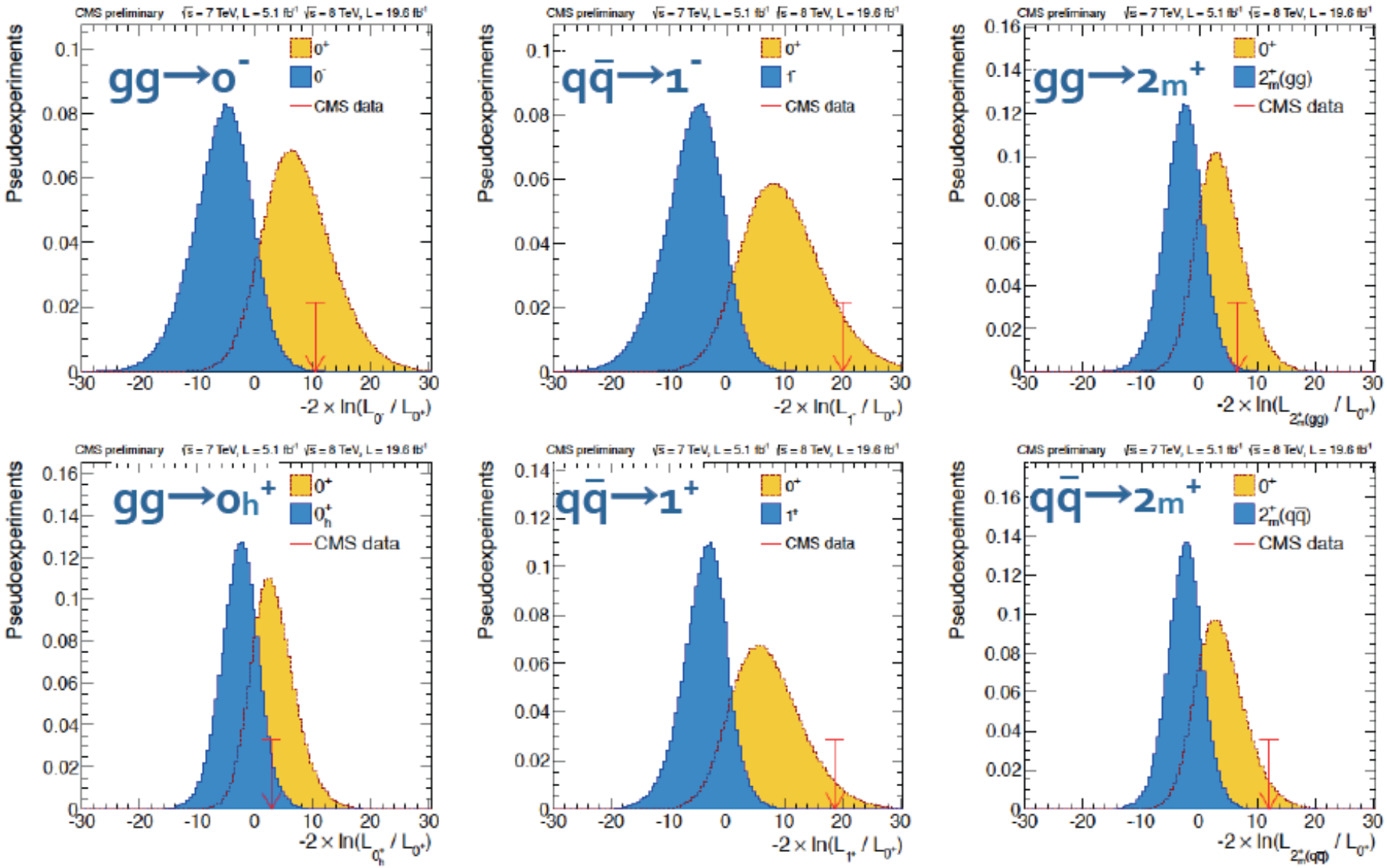


$$\mathcal{D}_{J^P} = \frac{\mathcal{P}_{\rm SM}}{\mathcal{P}_{\rm SM} + \mathcal{P}_{J^P}} = \left[1 + \frac{\mathcal{P}_{J^P}(m_{Z_1}, m_{Z_2}, \vec{\Omega}|m_{4\ell})}{\mathcal{P}_{\rm SM}(m_{Z_1}, m_{Z_2}, \vec{\Omega}|m_{4\ell})}\right]^{-1}$$

DJP distributions (with D_{bkg}>0.5)



Spin-parity : test statistics

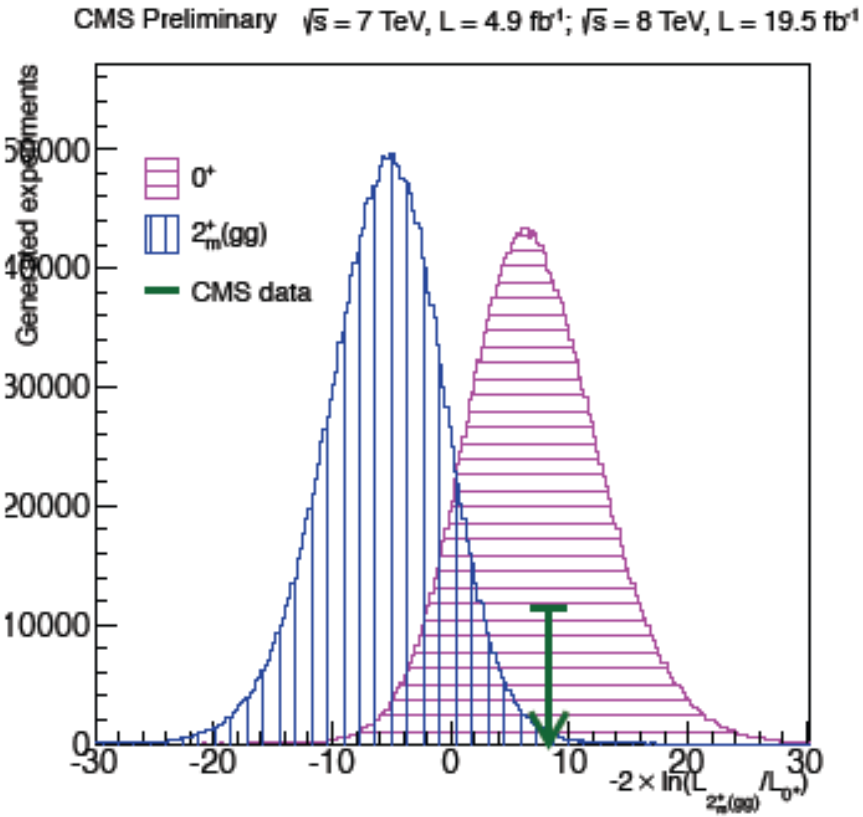


Spin-parity: results

	Expected [σ]		Observed (μ from data)		
	μ=1	μ from data	P(q > Obs | alternative) [σ]	P(q > Obs | SM Higgs) [σ]	CLs [%]
$gg \rightarrow 0^-$	2.8	2.6	3.3	-0.5	0.16
$gg \rightarrow 0_h^+$	1.8	1.7	1.7	+0.0	8.1
$q\bar{q} \rightarrow 1^+$	2.6	2.3	> 4.0	-1.7	< 0.1
$q\bar{q} \rightarrow 1^-$	3.1	2.8	> 4.0	-1.4	< 0.1
$gg \rightarrow 2_m^+$	1.9	1.8	2.7	-0.8	1.5
$q\bar{q} \rightarrow 2_m^+$	1.9	1.7	4.0	-1.8	< 0.1

- The studied pseudo-scalar, spin-1 and spin-2 models are excluded at 95% CL or higher

D_{JP} distributions (with D_{bkg}>0.5)



case	expected	observed
assuming $\sigma/\sigma_{SM} = 1$		
0^+	1.9	0.9
2^+_m	2.4	1.3
assuming pre-fit σ/σ_{SM} from data		
0^+	1.5	0.5
2^+_m	1.8	1.3

- Expected separation is at the 2-σ level
- Data is consistent with both hypothesis and slightly favoring 0^+

Coupling compatibility tests

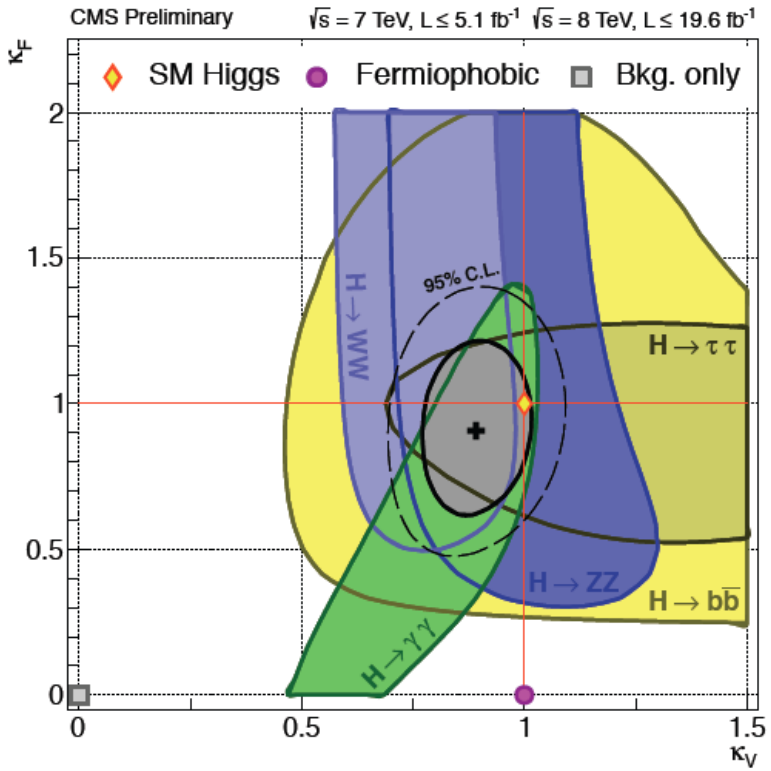
- 8 independent parameters (Γ_{ZZ}, Γ_{WW}, $\Gamma_{\tau\tau}$, Γ_{bb}, $\Gamma_{\gamma\gamma}$, Γ_{gg}, Γ_{tt} and Γ_{TOT}) to describe all currently relevant decays and production mechanisms

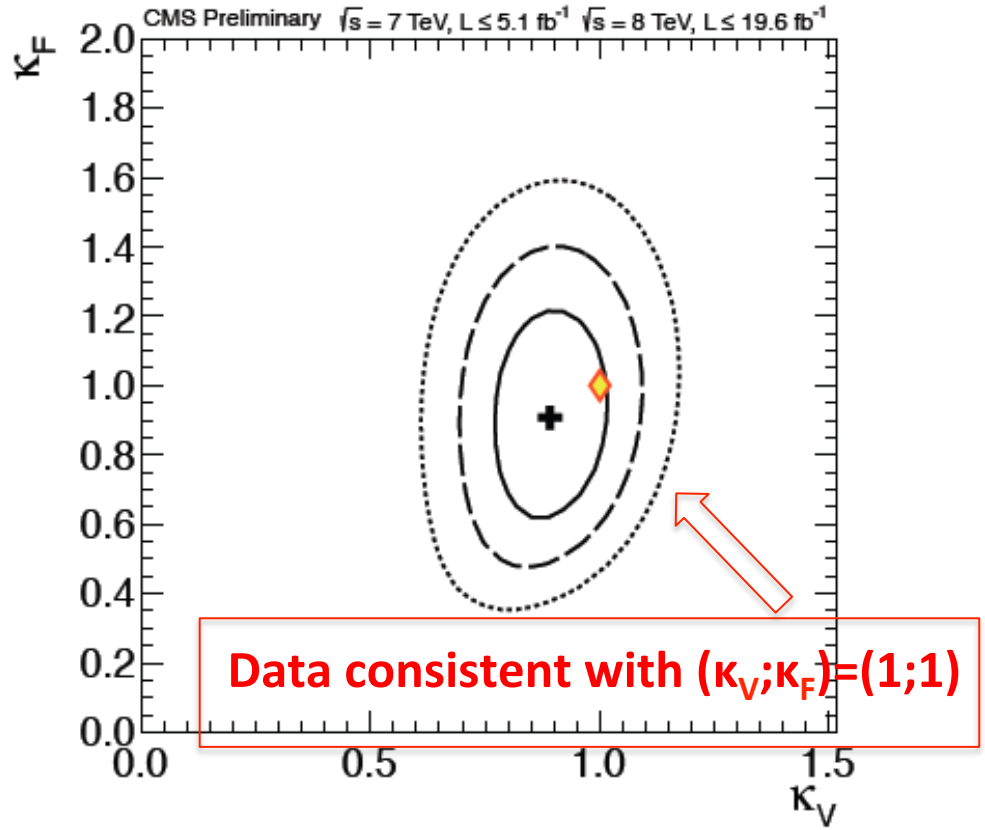
$$N(xx\text{->}H\text{->}yy) \sim \sigma(xx\text{->}H).B(H\text{->}yy) \sim (\Gamma_{xx}\,\Gamma_{yy} / \Gamma_{tot})$$

- Extraction of all 8 parameters is <u>too early</u> with the current data

- Instead, we go after couplings compatibility tests
  - assume SM Higgs couplings
  - introduce a limited number of scaling factors (κ, λ) for couplings and ratio of couplings

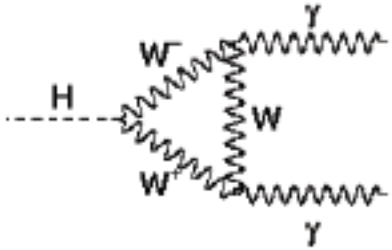
κ_V and κ_F

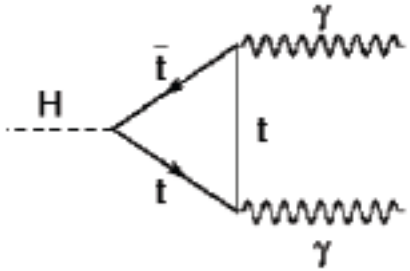




- A map vectorial and fermionic couplings into 2 scale factors, κ_V and κ_F

  H->(W and t loops)->γγ





Conclusions

- Data is consistent with SM 0^+ and disfavoring following pure states:
  - pseudo –scalar
  - vector and pseudo-vector
  - spin 2 resonances with minimal couplings

“Higgs-like” -> “Higgs”

Back up

How the CL_s Exclusion Limit is obtained

- The distribution of $q = -2\ln(\mathcal{L}_{J^P}/\mathcal{L}_{SM})$ is examined with generated samples of background and signal of 7 types (SM 0^+ and 6 J^P) for m_H = 126 GeV
- Likelihoods $\mathcal{L}$ are calculated with the signal rates allowed to float independently for each signal type and the nuisance parameters are treated as independent.
- Adjust the relative expected yield distributions in the different channels in alternative J^P hypotheses which differ from SM due to kinematics and detector effects.
- Expected distributions are generated with the cross section for each type of signal determined from the fit to data.
- Consistent results when the expected distributions are generated with the signal event yields according to SM expectation.