Combination and Standard Model Scalar Boson Properties in CMS

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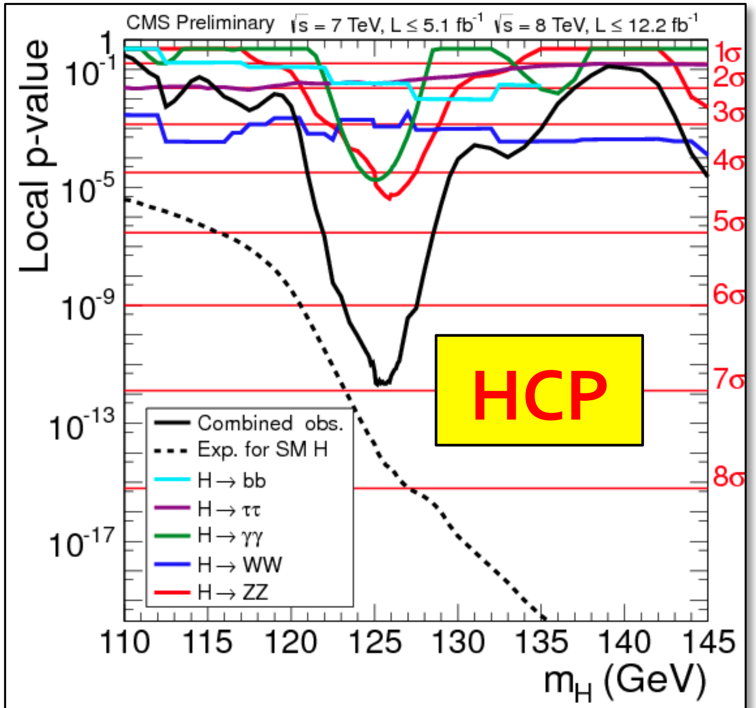
On behalf of the CMS collaboration

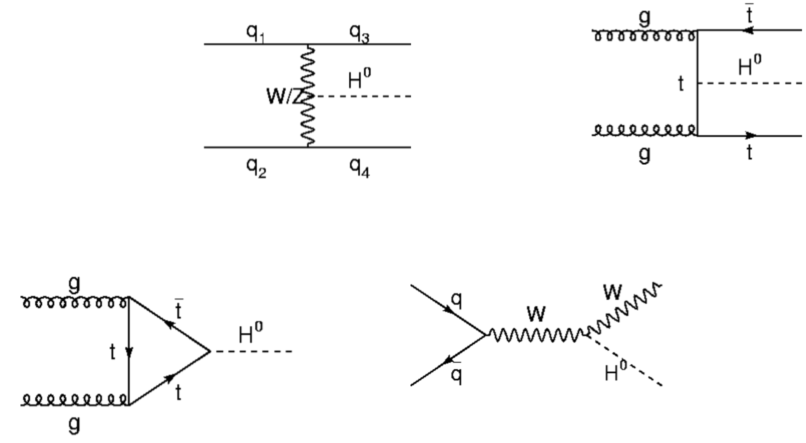
Rencontres de Moriond EW, La Thuile, 2-9 March 2013

What went in the combination



No update on combination since HCP

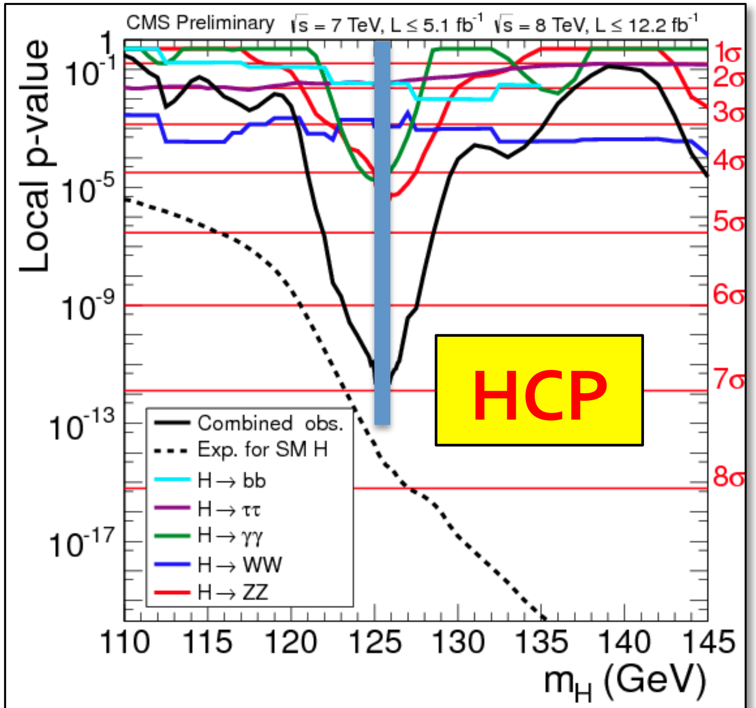
But some analyses updated with full 2011+2012 data
(e.g. WW(lνlν), ZZ(4l) and ττ …
presented in previous CMS talks)

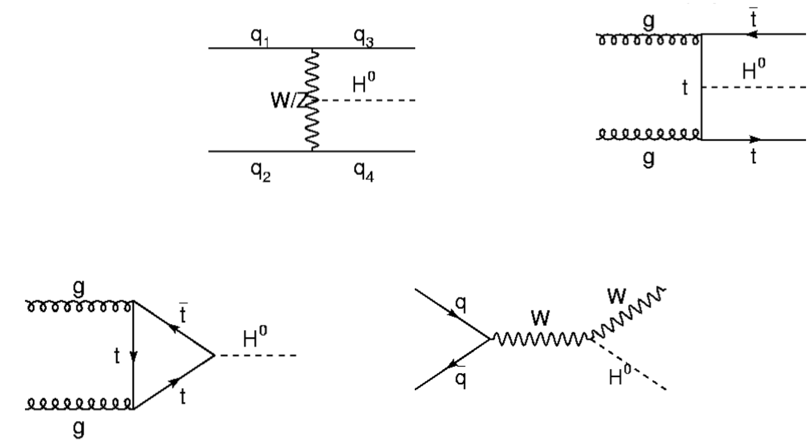


	un-tagged	VBF-tag	VH-tag	ttH-tag
γγ	✔	✔		
bb			✔	✔
ττ	✔	✔	✔	
WW(lνlν)	✔	✔	✔	
ZZ(4l)	✔			

For low-mass

What went in the combination





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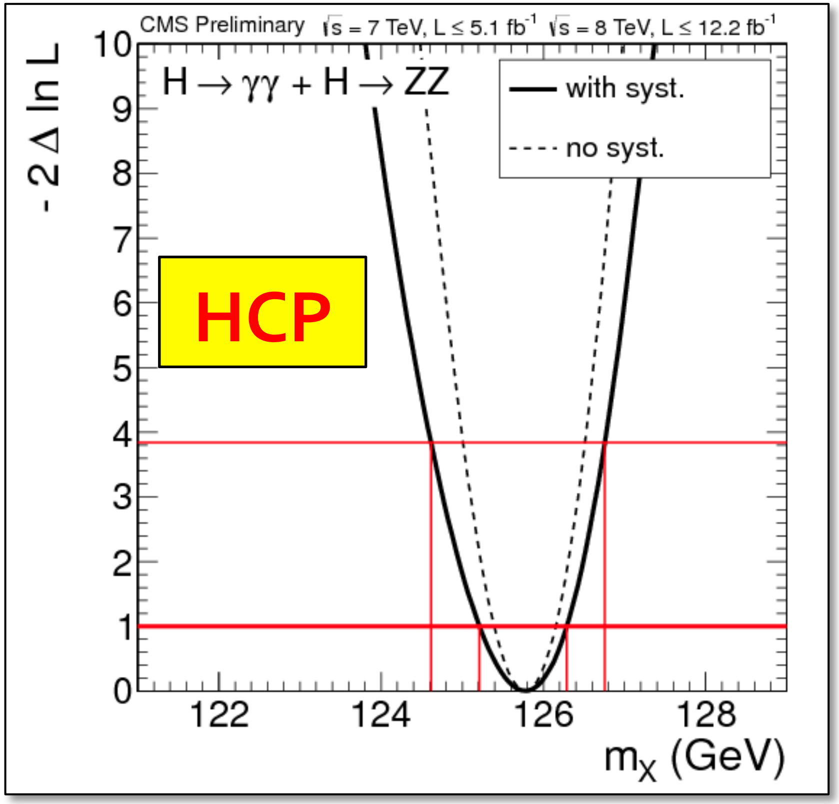
But some analyses updated with full 2011+2012 data (e.g. WW(lvlv), ZZ(4l) and ττ … presented in previous CMS talks)

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

For low-mass

Mass measurement

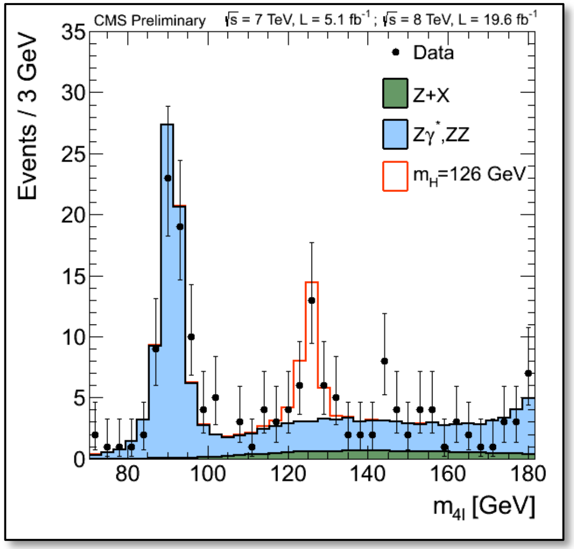


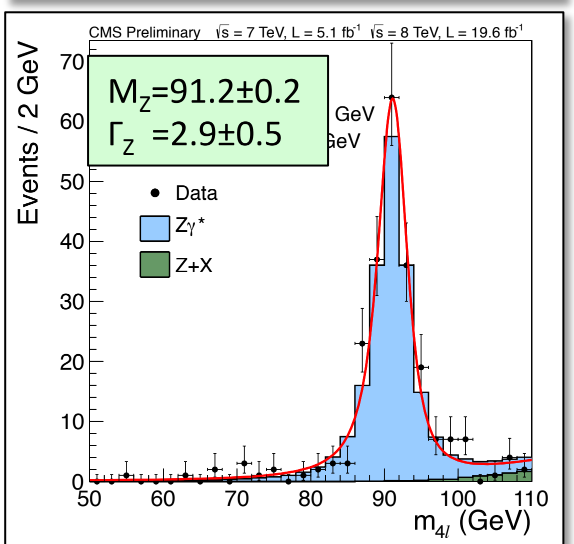
- Assume one particle, use two channels with good mass resolution: γγ and ZZ(4l)
- Allow for three independent signal yields (not tied by SM)
  - ggH (also ttH) ➔ γγ
  - VBF (also VH) ➔ γγ
  - inclusive ZZ (4l)
- Fit for a common mass:

m_x = 125.8 ± 0.6 GeV (±0.5%)
= 125.8 ± 0.4(stat) ±0.4(syst) GeV

PRL. 110, 081803 (2013)

Update on mass in ZZ(4l)

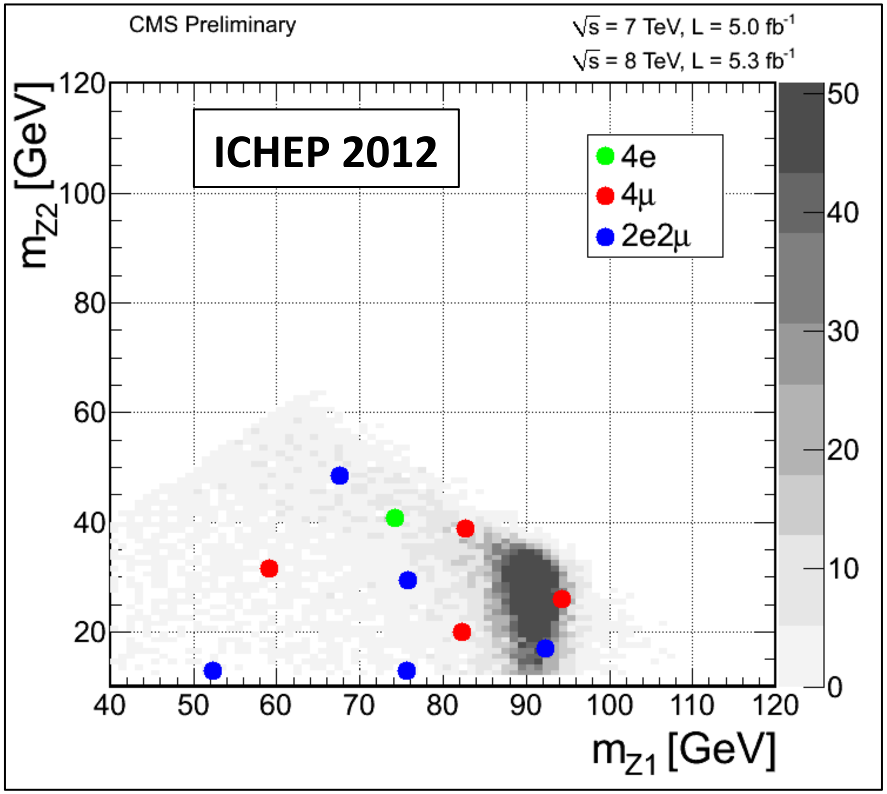


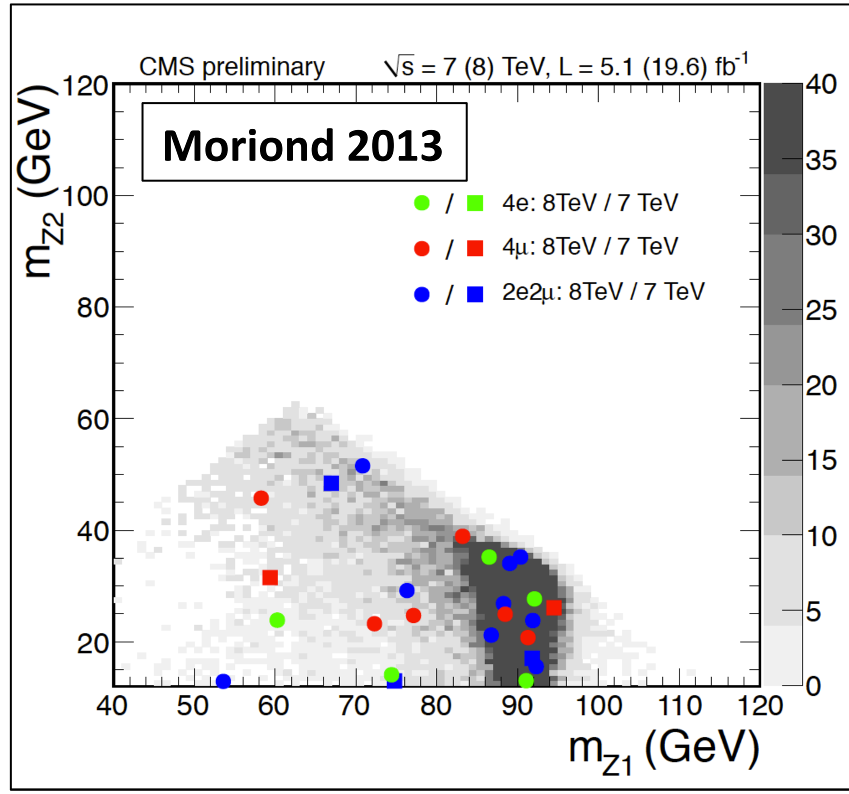


Bottom plot is made with relaxed m_{Z2} cut (12->4 GeV)

- Validation with Z→4l peak
  - derive mass and width
  - excellent agreement with PDG values
- The 4l channel now gives overall the most accurate measurement
  - **125.8±0.5(stat)±0.2(syst) GeV**
  - was 126.2±0.6(stat)±0.2(syst)
- Expect to contribute more in the combination
- The uncertainty in 4l channels still dominated by statistics (systematics error in 4e is 0.3% and 0.1% in 4μ)

m_{Z1} vs m_{Z2} in 4l channel





- Follow-up to the question raised this morning
- There was a clear statistical fluctuation that is filling in

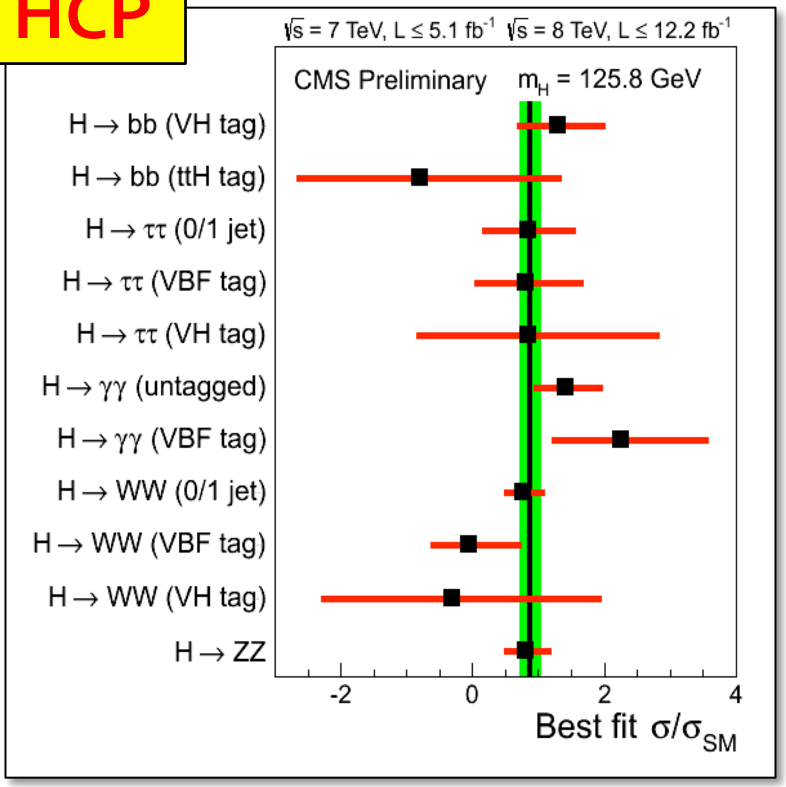
Check the compatibility with SM

- Given the mass, properties of the SM Higgs boson are all known theoretically
- Proceed to test data whether it's compatible with SM prediction on various properties
  - signal strengths
  - spin parity
  - couplings

Signal strengths

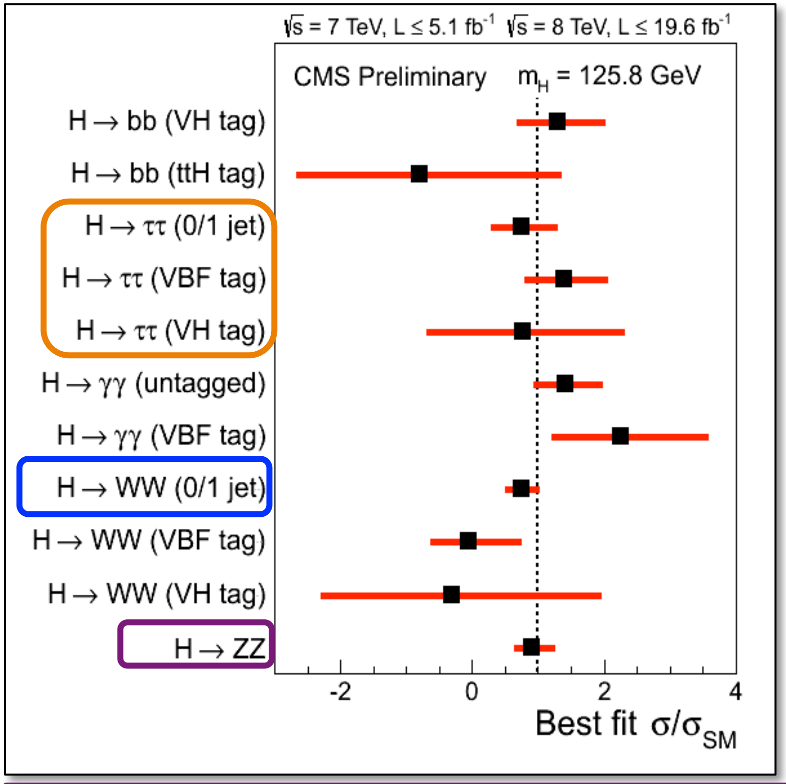
- Overall signal strength (common scale factor for expected signal event yields in all channels): μ=0.88 ± 0.21

HCP



- Sub-combinations grouped by (production tag) × (decay mode)
  - χ^2/ndf = 8.7/11
  - P(χ^2>8.7|ndf=11)=0.65
- Results are consistent with the SM Higgs boson

Signal strengths



New updates on some modes preliminary with full 2011+2012 data

New results are compatible with the SM Higgs boson

$H \rightarrow ZZ$(0/1 jet) : $0.84^{+0.32}_{-0.26}$

$H \rightarrow ZZ$(dijet tag): $1.22^{+0.84}_{-0.57}$

Spin parity (new)

Spin parity

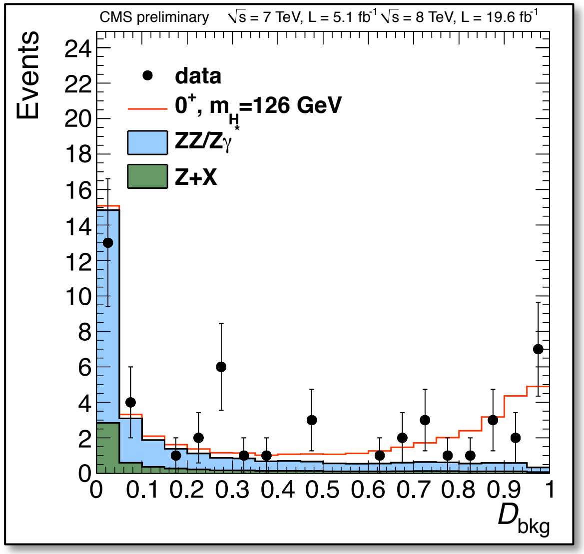
- So far, we know the observed particle (assuming just one particle)
  - X is a boson (decays to γγ, 4l, etc.)
  - X can't be spin 1 (decays to γγ + Landau-Yang theorem)
  - X can't be 100% 0- (from 4l correlations) PRL. 110, 081803 (2013)
- Further tests in 4l and WW(lvlv) channels with full data on a few reasonably well motivated J^P hypotheses ("pure" states only) w.r.t. SM Higgs boson

J^P	production	description
0^+	$gg \to X$	SM Higgs boson
0^-	$gg \to X$	pseudoscalar
0_h^+	$gg \to X$	BSM scalar with higher dim operators (decay amplitude)
2_{mgg}^+	$gg \to X$	KK Graviton-like with minimal couplings
$2_{mq\bar{q}}^+$	$q\bar{q} \to X$	KK Graviton-like with minimal couplings
1^-	$q\bar{q} \to X$	exotic vector
1^+	$q\bar{q} \to X$	exotic pseudovector

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

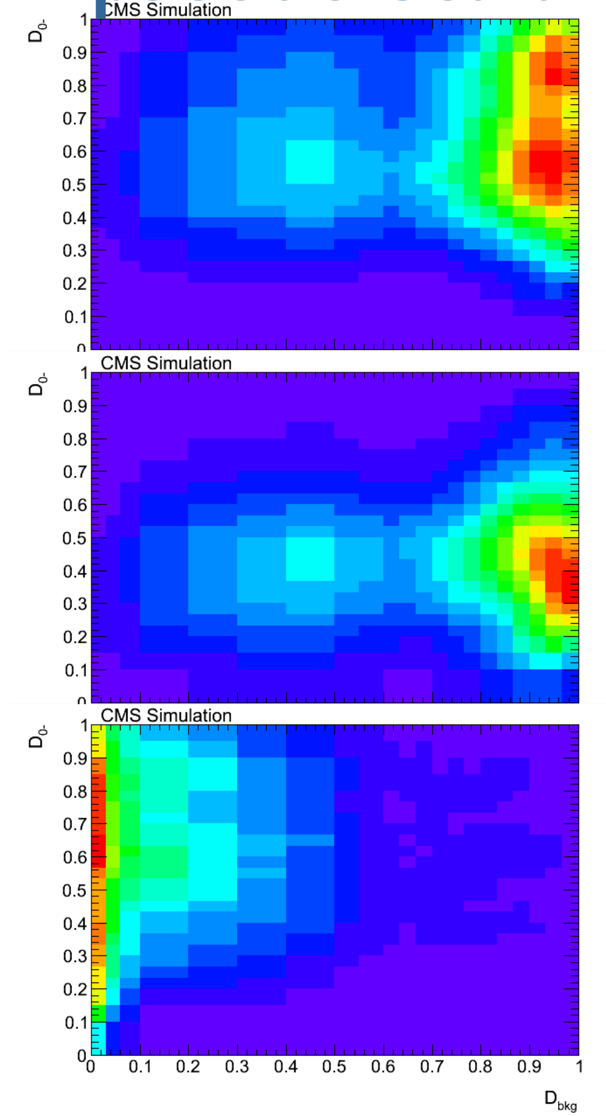
Matrix Element approach in 4l

- Build two discriminants based on the complete Leading-Order MEs
  - D_{bkg} to separate signal from background (ME combined with pdf(m4l))
  - D_{JP} to separate the SM Higgs boson from alternative J^P hypothesis
- Exploit fully the (D_{bkg}, D_{JP})-plane in statistical analysis

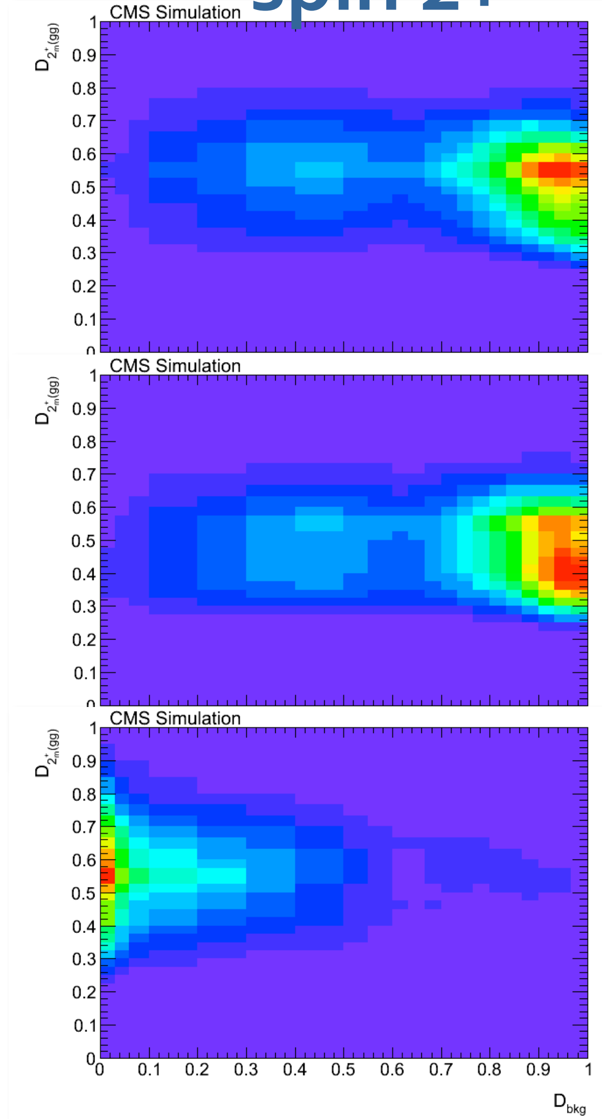


Templates for hypotheses test

pseudo-scalar



spin 2+

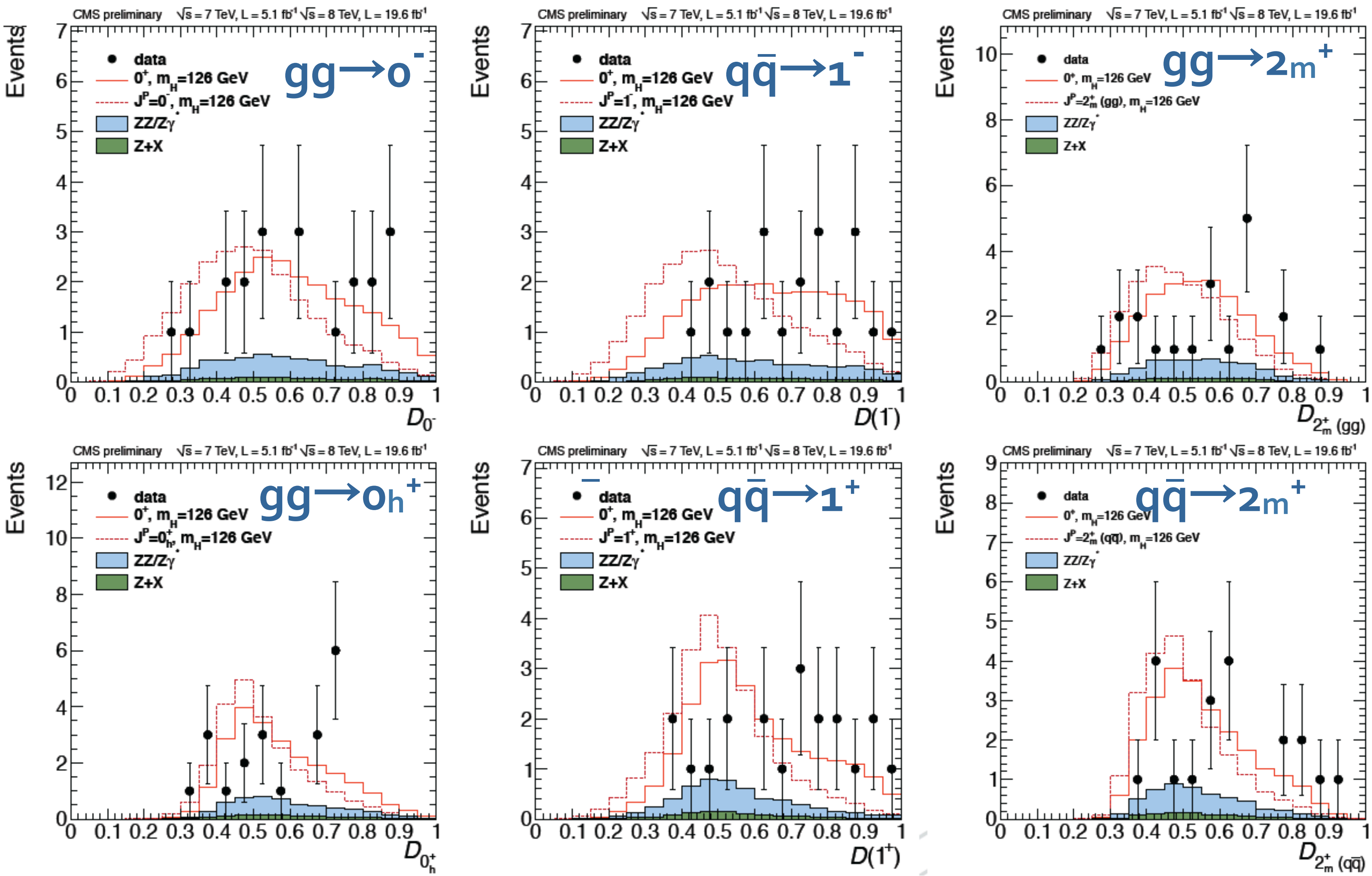


$gg \rightarrow$ SM Higgs

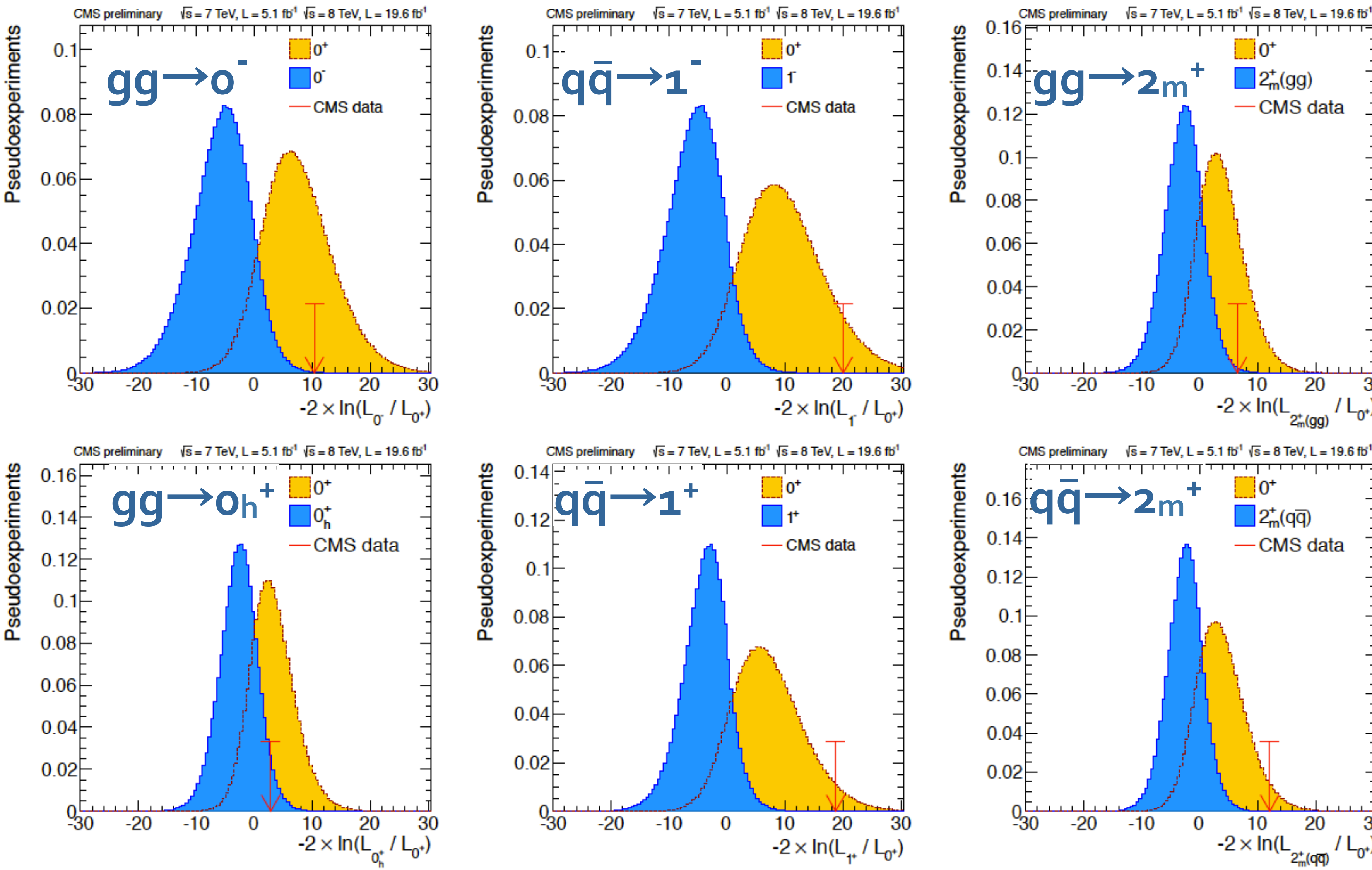
Alternative hypothesis

$qq \rightarrow ZZ$

D_{JP} 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

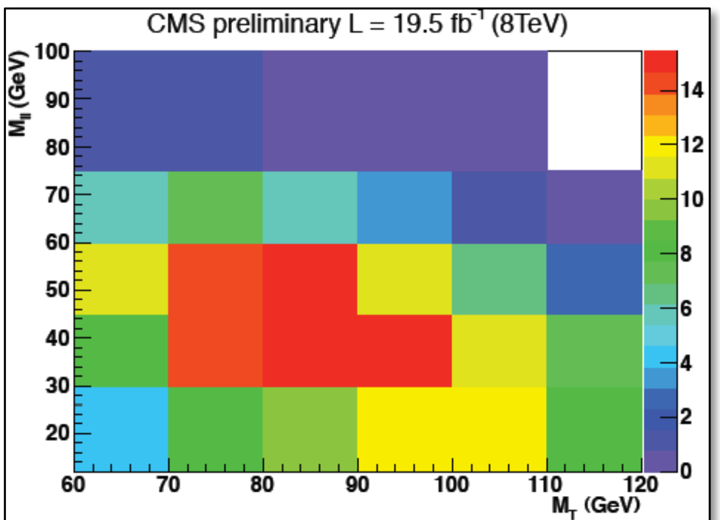
Assuming spin-0, fitting for CP-odd contribution gives

$f_{a3} = 0.00^{+0.23}_{-0.00}$ (more in backup)

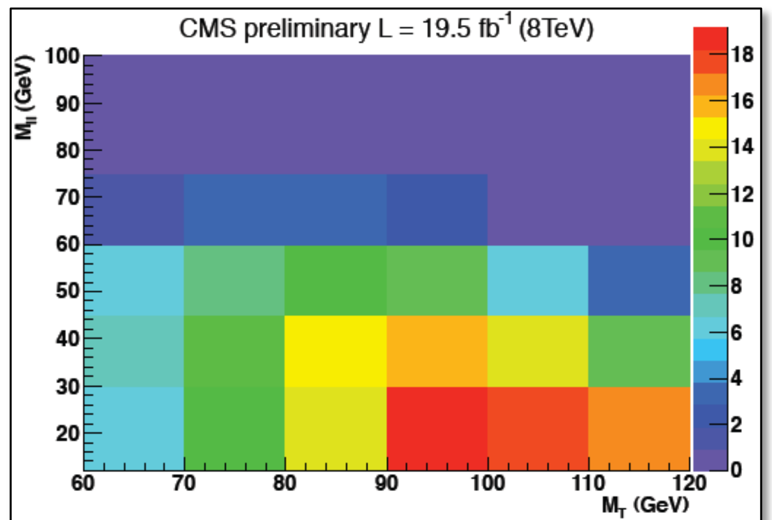
The studied pseudo-scalar, spin-1 and spin-2 models are excluded at 95% CL or higher

Brand new: spin in WW(lvlv)

- Only different-flavor 0/1 jet channels (shape-based analysis)
- Exploit the (transverse invariant mass, dilepton mass)-plane
- Tested model: spin-2 resonance with minimal coupling (gluon-fusion production mode)

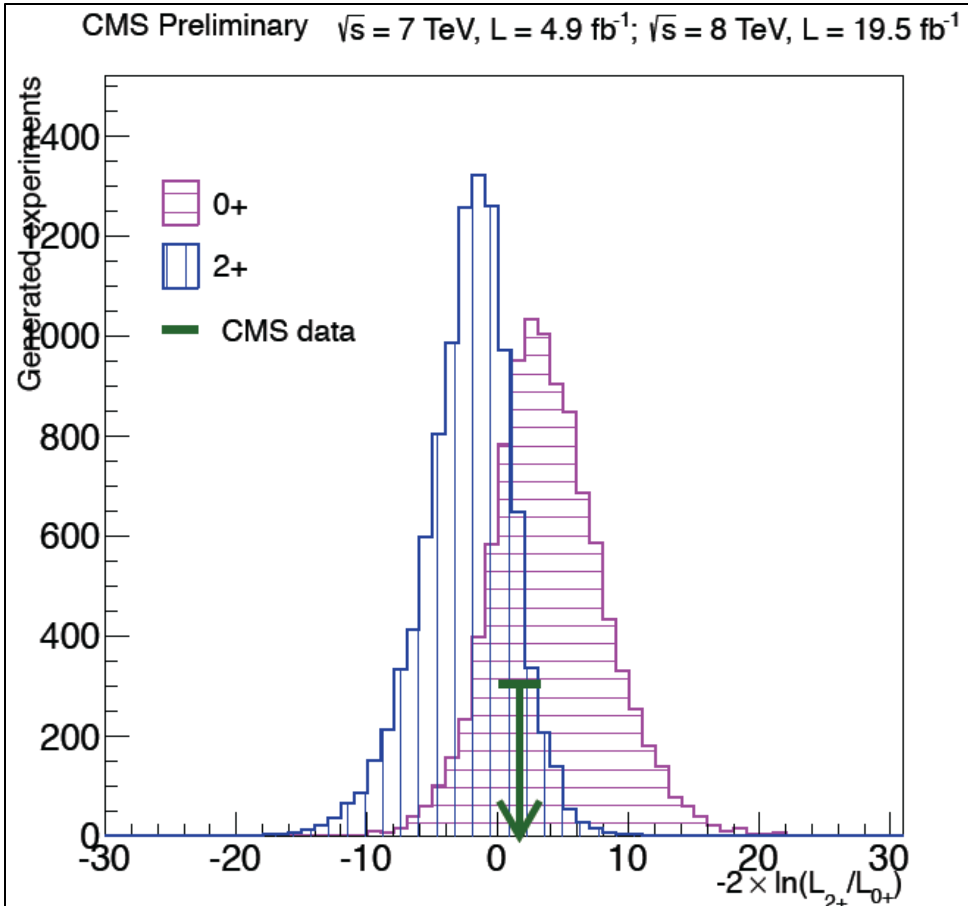


Spin-2 Hypothesis



SM Hypothesis

Brand new: spin in WW(lνlν)



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 hypotheses and slightly favoring 0+

Couplings compatibility tests (not updated since HCP)

Assumptions:

- single resonance
- zero-width
- no modification of the tensor structure

Couplings compatibility tests

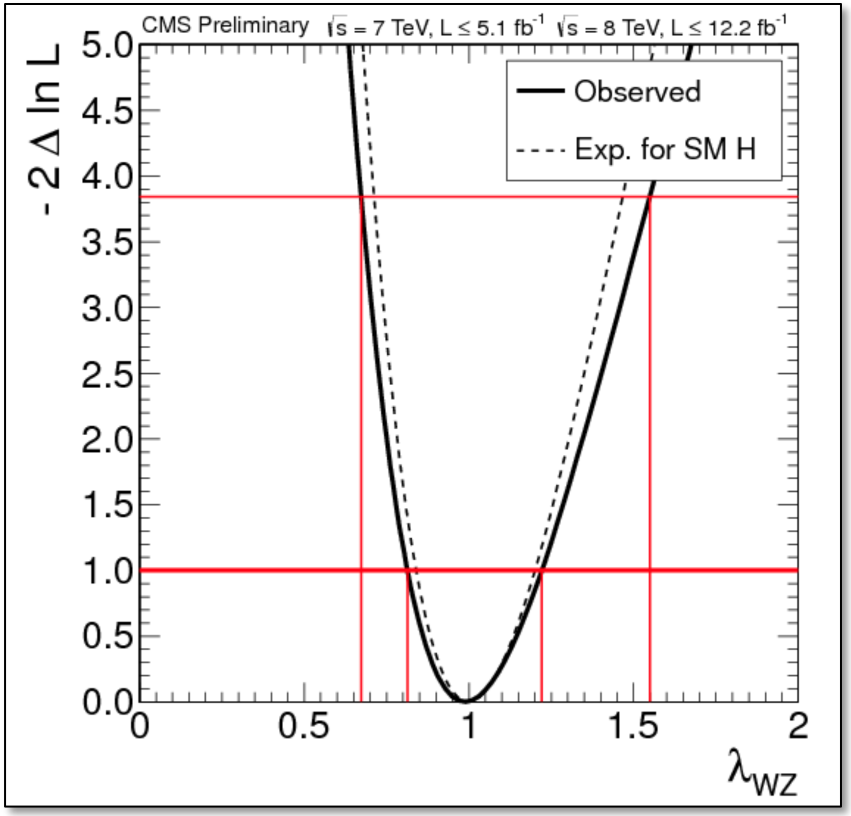
- 8 independent parameters ($\Gamma_{ZZ}, \Gamma_{WW}, \Gamma_{\tau\tau}, \Gamma_{bb}, \Gamma_{\gamma\gamma}, \Gamma_{gg}, \Gamma_{tt}$ and Γ_{TOT}) to describe all currently relevant decays and production mechanisms

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

- Extraction of all 8 parameters is too early 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

Custodial symmetry

HCP



- In SM, the ratio of couplings to W and Z bosons is almost not affected by loop corrections

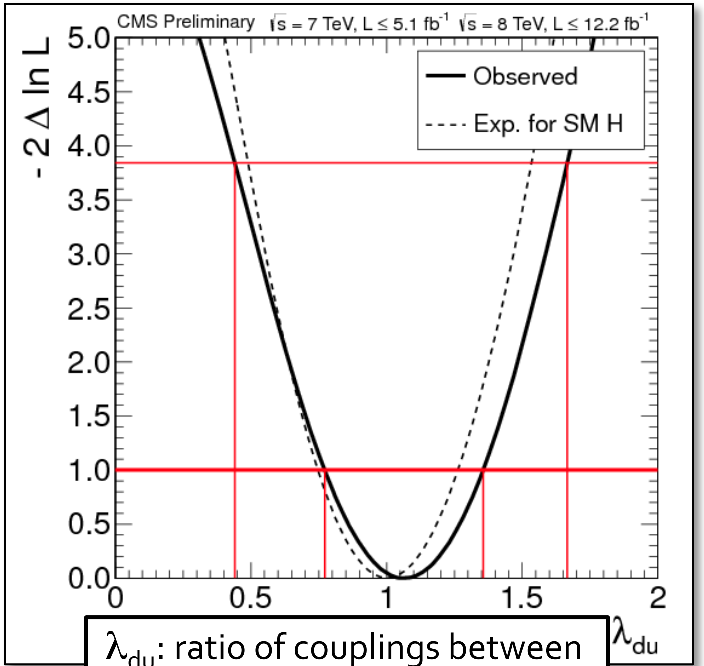
Data consistent with the custodial symmetry

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

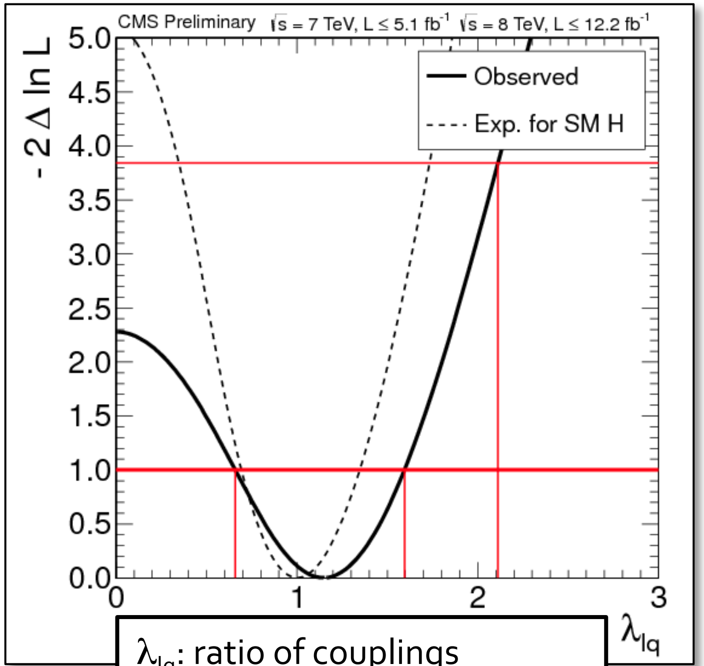
Asymmetry of couplings to fermions

HCP

- In MSSM, couplings to **up/down** fermions are modified
- In more generic 2-Higgs Doublet models, one can also alter relative couplings to **leptons and quarks**



λ_{du}: ratio of couplings between down- and up-fermions

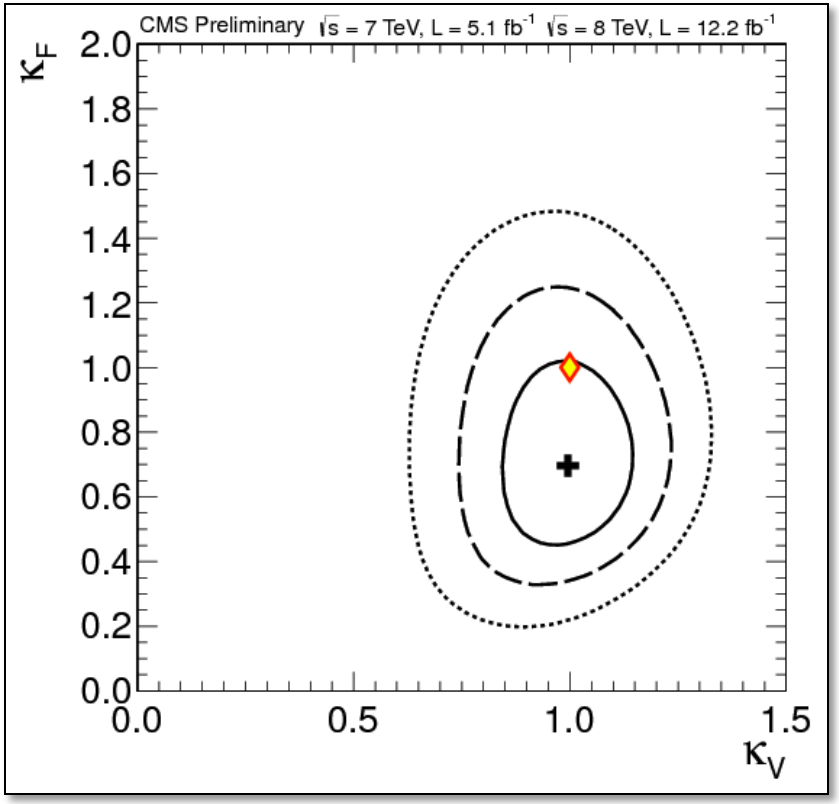


λ_{lq}: ratio of couplings between leptons and quarks

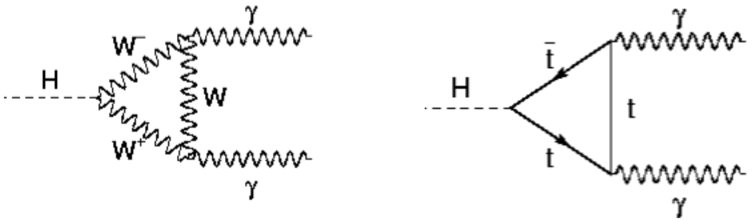
Both ratios are consistent with 1

κ_V and κ_F

HCP



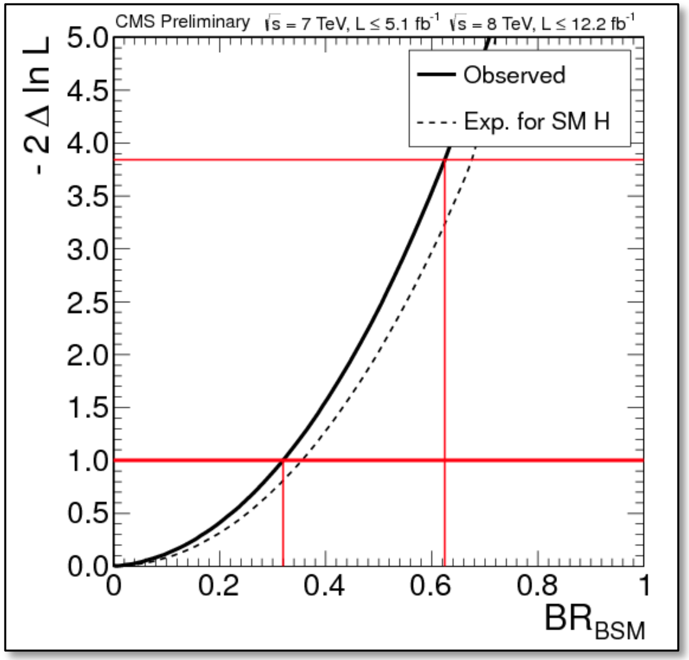
- Map vectorial and fermionic couplings into two scale factors, κ_V and κ_F
- H→(W and t loops)→γγ



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

Look for new physics in loops

HCP



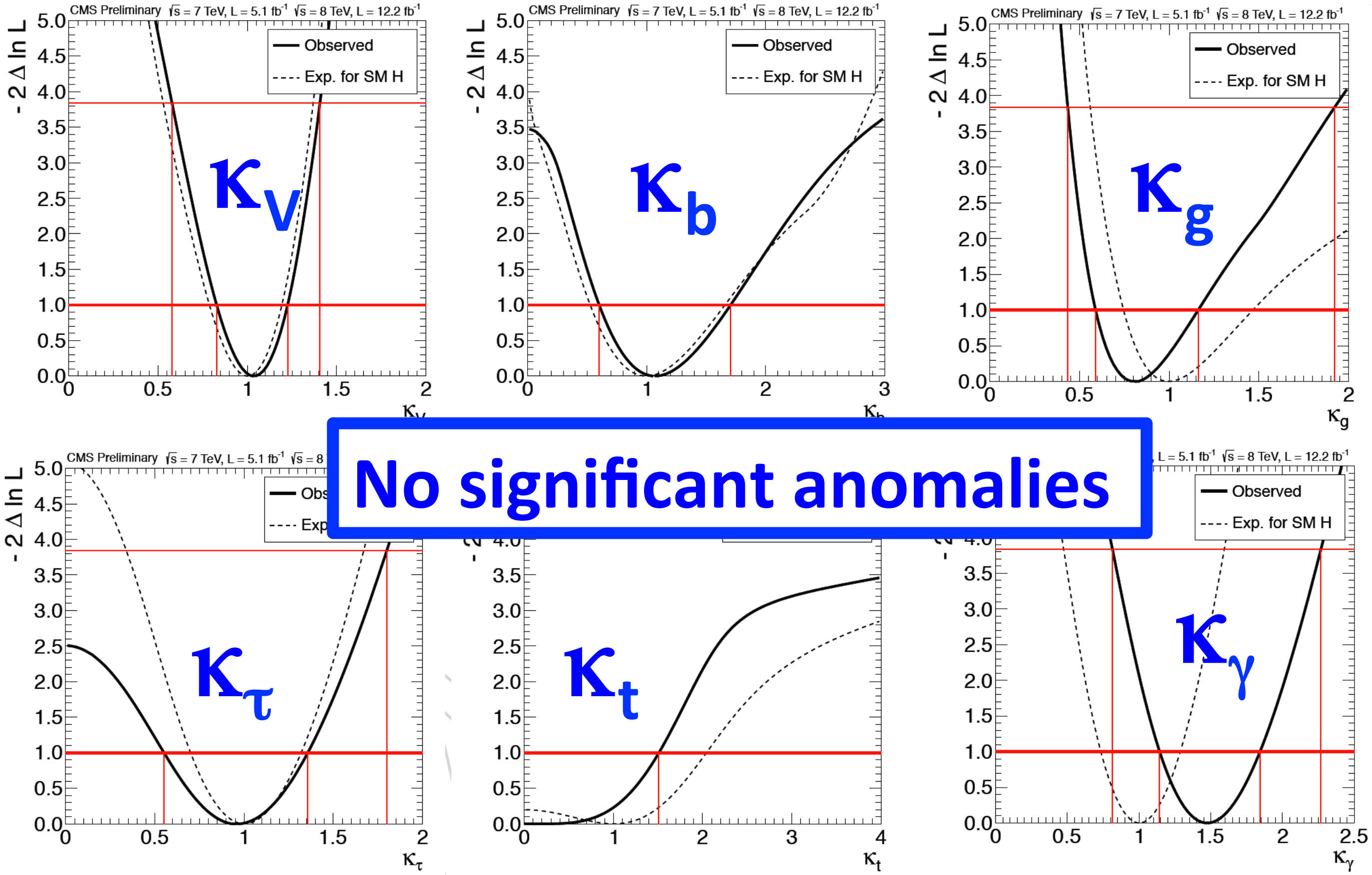
- New particles can
  - hide in the loop-mediated couplings
  - contribute to the total width
- Allow total width to scale as $1/(1\text{-}BR_{BSM})$

No sign of new physics

C6 model

HCP

- Assuming custodial symmetry and $BR_{BSM}=0$
- End up with 6 scale factors: $\kappa_V, \kappa_t, \kappa_b, \kappa_\tau, \kappa_g, \kappa_\gamma$
- Fit individually each of those, while profiling the others



No significant anomalies

Summary

- Mass of the observed boson: 125.8 ± 0.6 GeV
- Coupling compatibility test: consistent with SM prediction, no significant anomalies
- Data is consistent with SM 0+ and disfavoring the following pure states:
  - pseudo-scalar
  - vector and pseudo-vector
  - spin-2 resonances with minimal couplings
- 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
- More results are coming, **stay tuned**!

Many thanks !

More information is available at

CMS-PAS-HIG-12-045

CMS-PAS-HIG-13-002

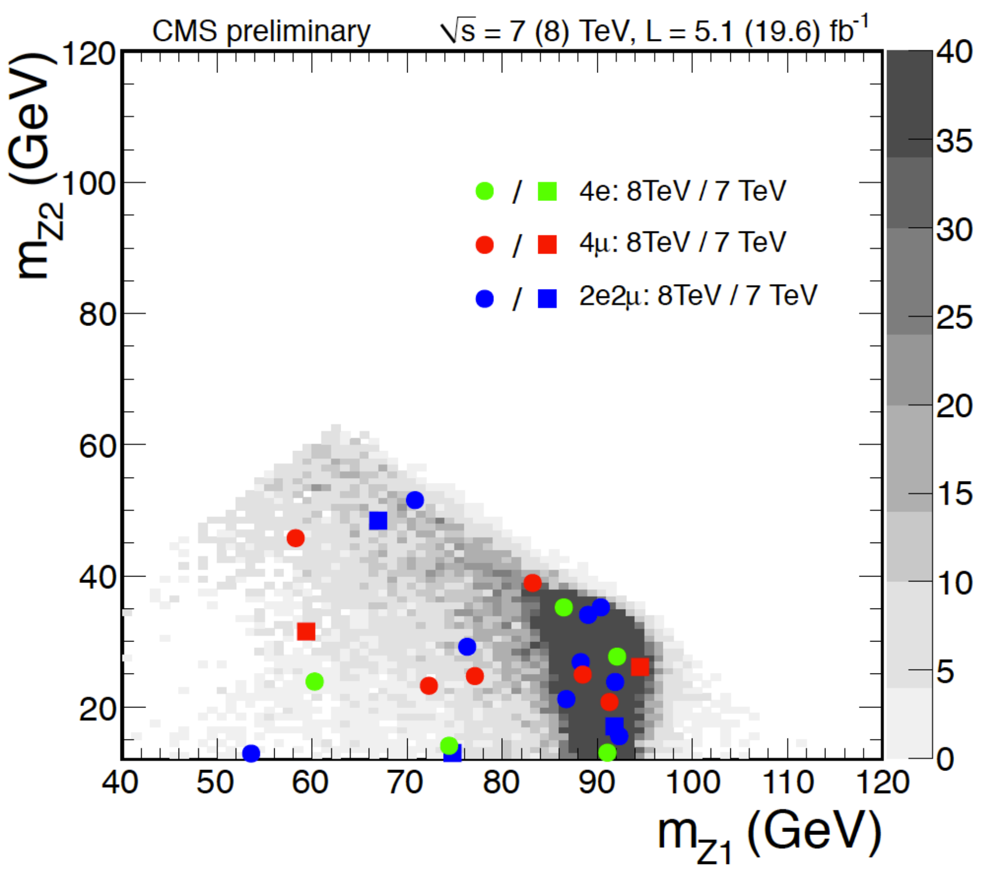
CMS-PAS-HIG-13-003

CMS-PAS-HIG-13-004

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIG

Additional materials

m_{Z1} vs m_{Z2} with m_{4l} in (121.5,130.5)



Distribution of the reconstructed mass of the second lepton pair (MZ2) versus the reconstructed mass of the first lepton pair (MZ1) for the 4e, 4μ, and 2e2μ final states. Shaded histograms represent the expectations for a signal with m_H=126 GeV.The measurements are presented for the sum of the data collected at √s = 7 TeV and √s = 8 TeV.

HCP combination input

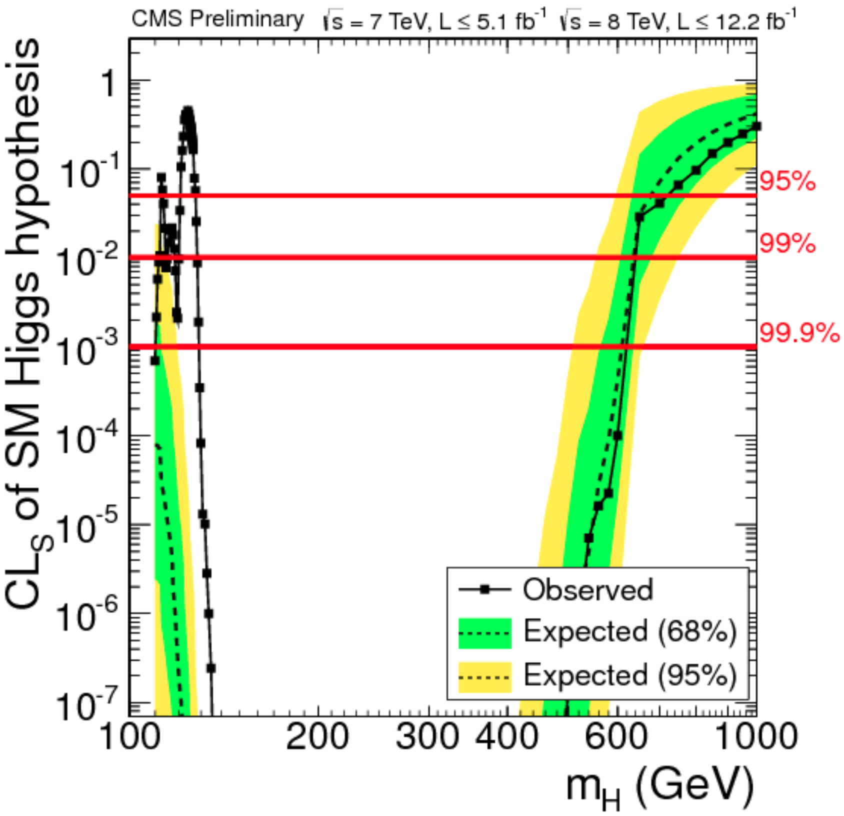
Higgs decay mode	Higgs production mechanism	Mass range [GeV]	Data used		Mass resolution	Used in the combination
			7 TeV [fb^{-1}]	8 TeV [fb^{-1}]		
γγ	Untag (~gg) VBF-tag	110 – 150 110 – 150	5.1 5.1	5.3 5.3	1–2% 1–2%	✔ ✔
bb	VH-tag ttH-tag	110 – 135 110 – 140	5.0 5.0	12.1 –	10% –	✔ ✔
ττ	1-jet (~gg) VBF-tag ZH-tag WH-tag	110 – 145 110 – 145 110 – 160 110 – 140	4.9 4.9 5.0 4.9	12.1 12.1 – –	20% 20% – –	✔ ✔ ✔ ✔
ZZ → 4l ZZ → 2l2τ ZZ → 2l2ν ZZ → lljj	Inclusive Inclusive Inclusive Inclusive	110 –1000 180 –1000 200 – 600 120 – 600	5.0 5.0 4.7 4.7	12.2 12.2 5.0 –	1–2% 10–15% – –	✔ ✔
WW → 2l2ν WW → lνjj	0/1-jets (~gg) VBF-tag WH-tag Untag (~gg)	110 – 600 110 – 600 110 – 200 170 – 600	4.9 4.9 4.9 5.0	12.1 12.1 5.1 12.1	20% 20% – –	✔ ✔ ✔ ✔

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)

What we excluded

HCP



High mass channels:

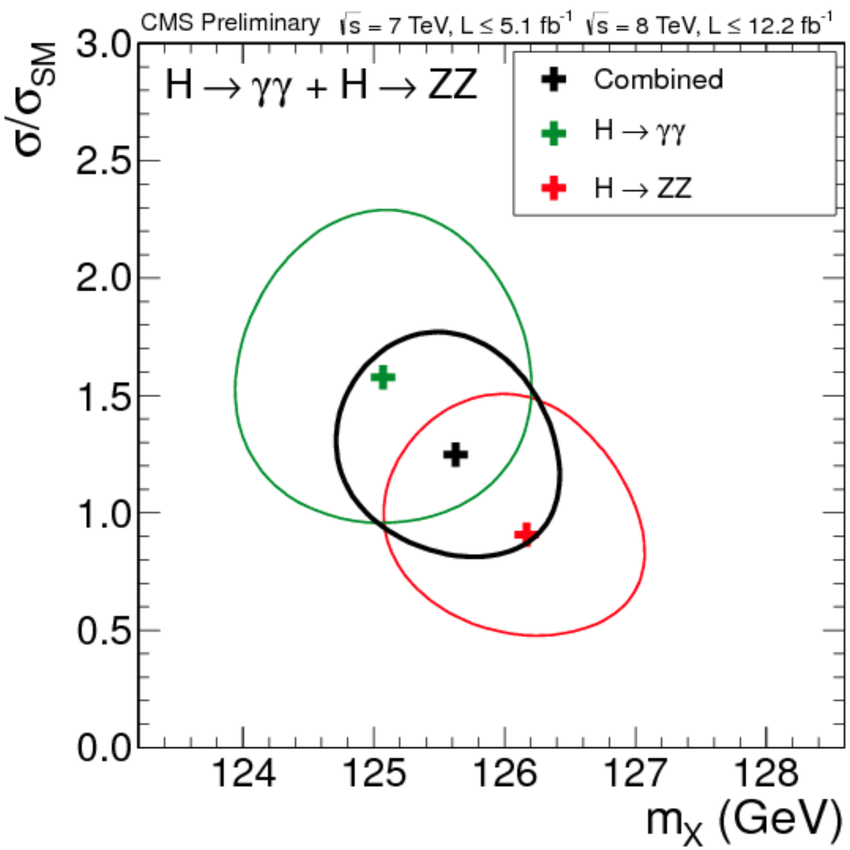
- WW(lvlv)
- WW(lvlq)
- ZZ(4l) up to 1 TeV

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

The void between 130 and 600 GeV at 99.9% CL

Mass measurement

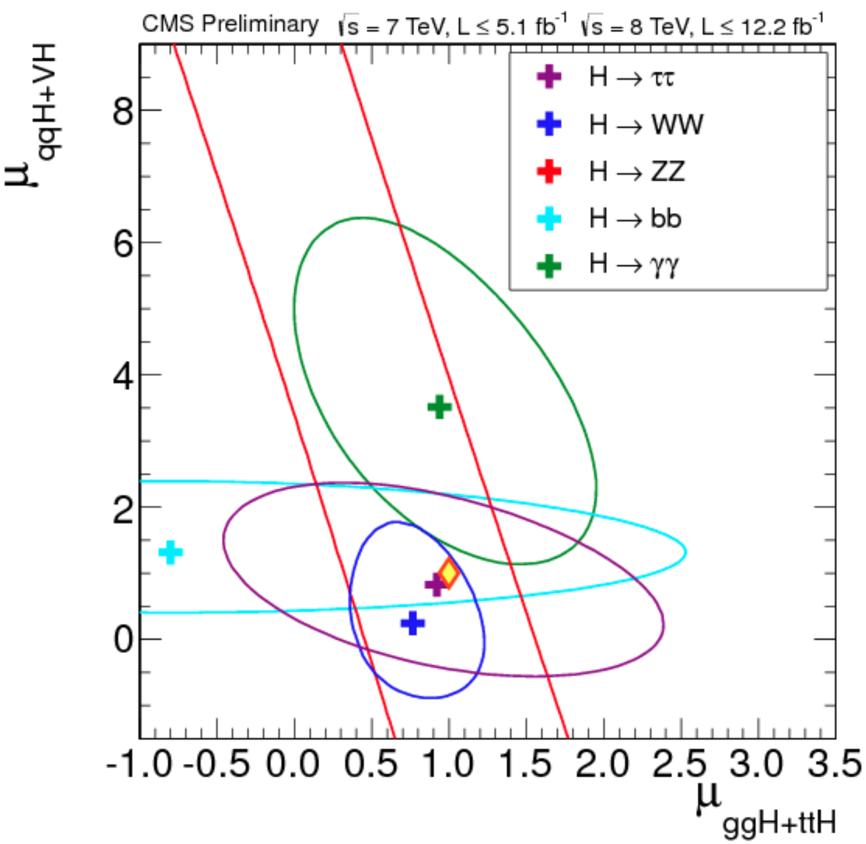
HCP



- 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

Self-consistency by search channel

HCP



- 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
  - μ=(CS x BR)/(CS x BR)$_{SM}$

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

Discriminants in 4l

- Build two discriminants based on the complete Leading-Order MEs
  - one to separate signal from background, combined with mass information → D_{bkg}

$$D_{\rm BKG} = \left[1 + c_{\rm bkg} \cdot \frac{|\mathcal{M}_{\rm BKG}(\vec{p}_i)|^2 \cdot pdf(m_{4\ell}|{\rm BKG})}{|\mathcal{M}_{\rm Higgs}(\vec{p}_i)|^2 \cdot pdf(m_{4\ell}|{\rm Higgs})}\right]^{-1}$$

  - another ME discriminant D_{JP} to separate the SM Higgs from J^P hypothesis

$$D_{\rm J^P} = \left[1 + c_{\rm J^P} \cdot \frac{|\mathcal{M}_{\rm J^P}(\vec{p}_i)|^2}{|\mathcal{M}_{\rm Higgs}(\vec{p}_i)|^2}\right]^{-1}$$

Fit for CP-odd contribution

- Perform a fit for the fraction f_{a3} of a CP-odd contribution in the observed peak

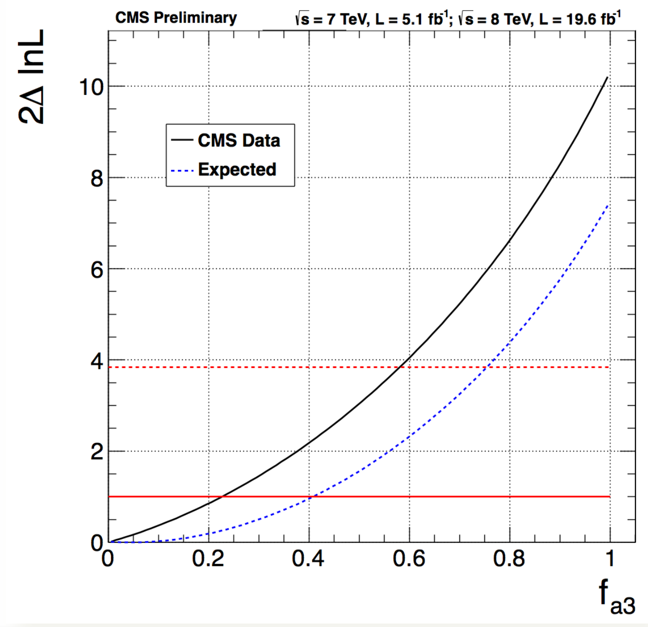
$$f_{a3} = \frac{|A_3^2|}{|A_1^2| + |A_3^2|}$$

$$A(X \to VV) = v^{-1} \epsilon_1^{*\mu} \epsilon_2^{*\nu} \left(a_1 g_{\mu\nu} m_H^2 + a_2 q_\mu q_\nu + a_3 \epsilon_{\mu\nu\alpha\beta} q_1^\alpha q_2^\beta \right) = A_1 + A_2 + A_3$$

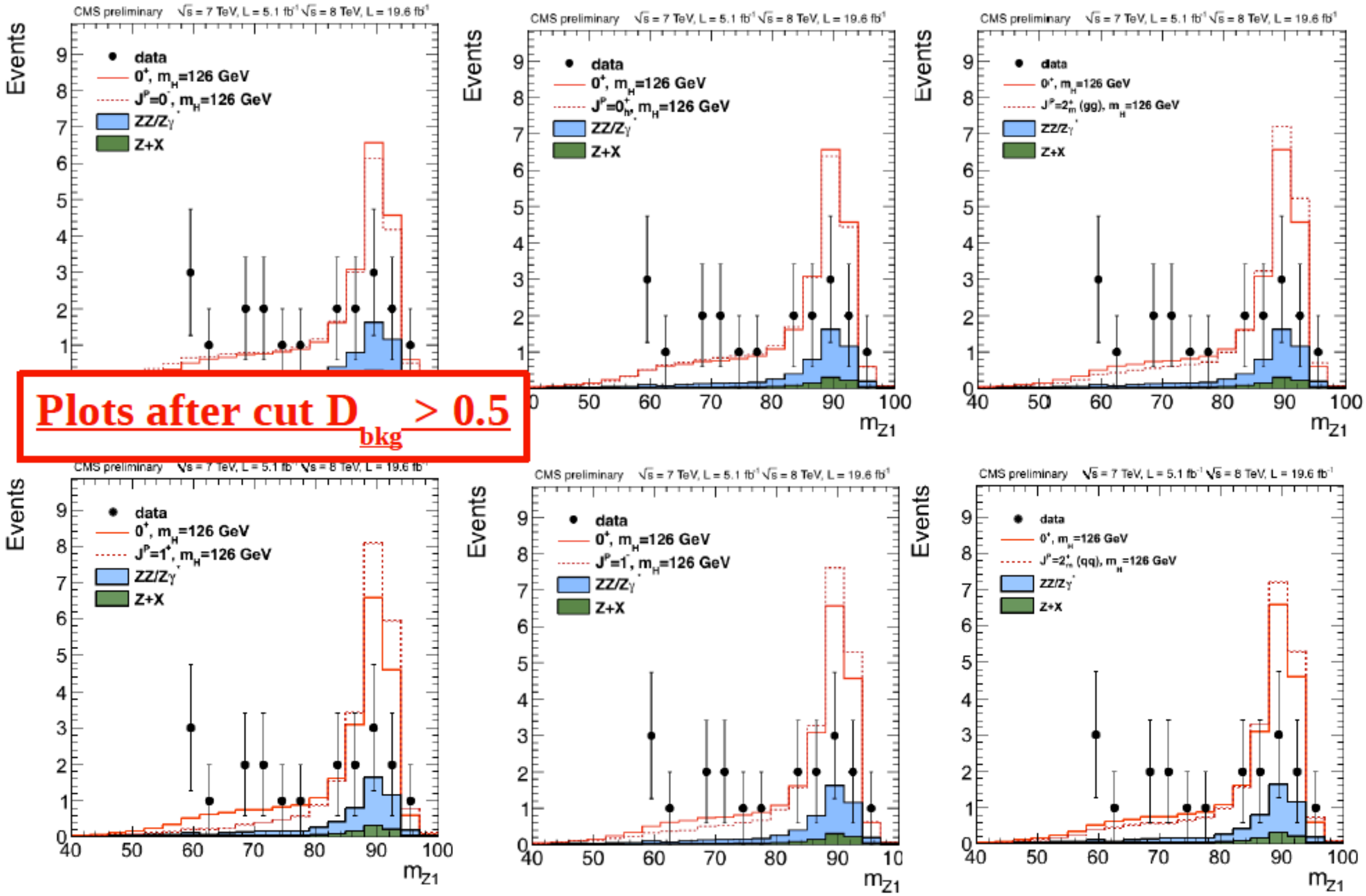
(A2 contribution assumed to be 0)

  - decays of state 0_m^+ governed by the A1 amplitude
  - decays of state 0^- governed by A3 amplitude

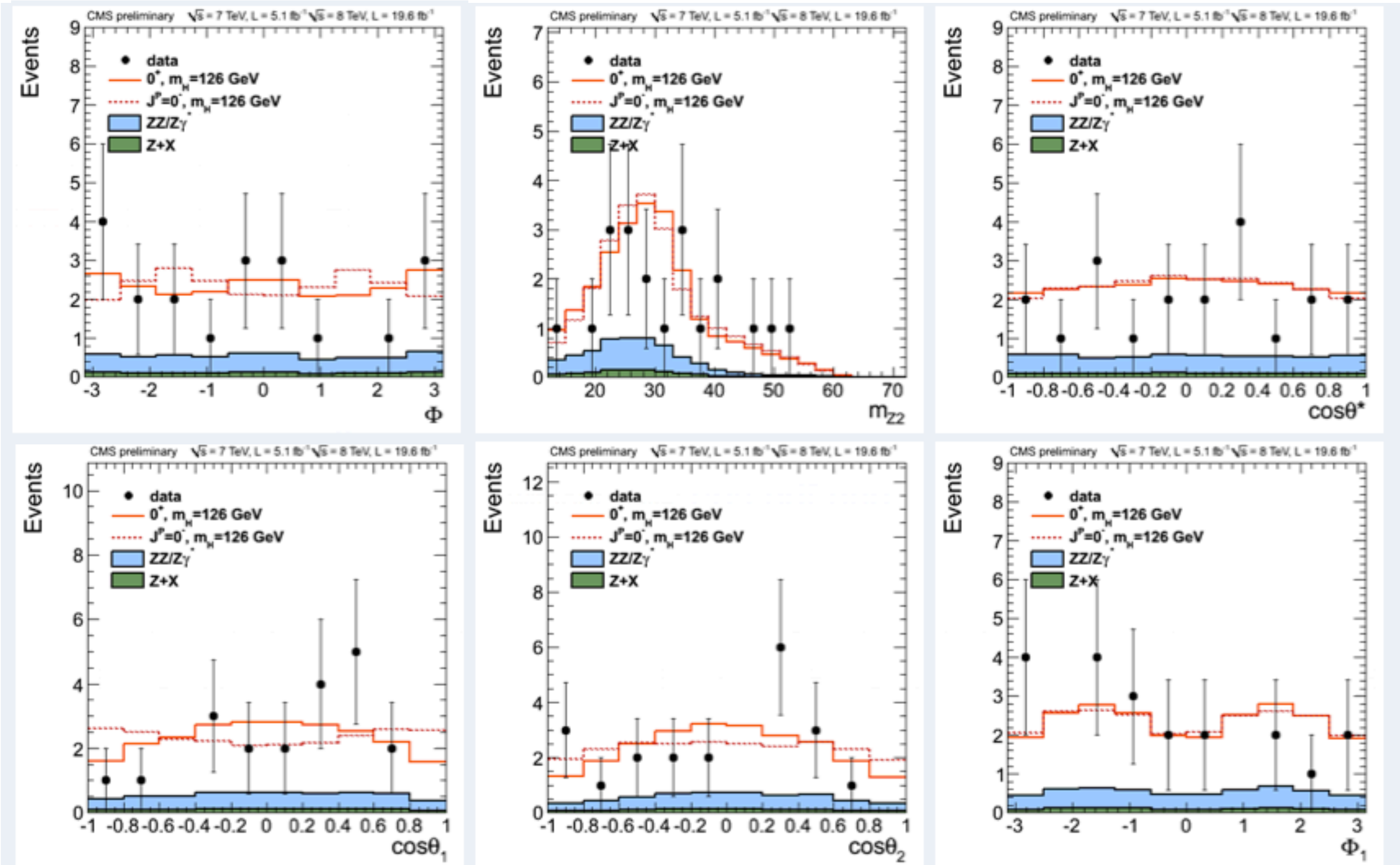
- Take separate templates for SM Higgs (A1) and 0- (A3) states and fit the data for the ratio between the two states
- Measurement of the f_{a3} fraction in data: $f_{a3} = 0.00^{+0.23}_{-0.00}$, or equivalently $f_{a3} < 0.58$ @ 95% CL



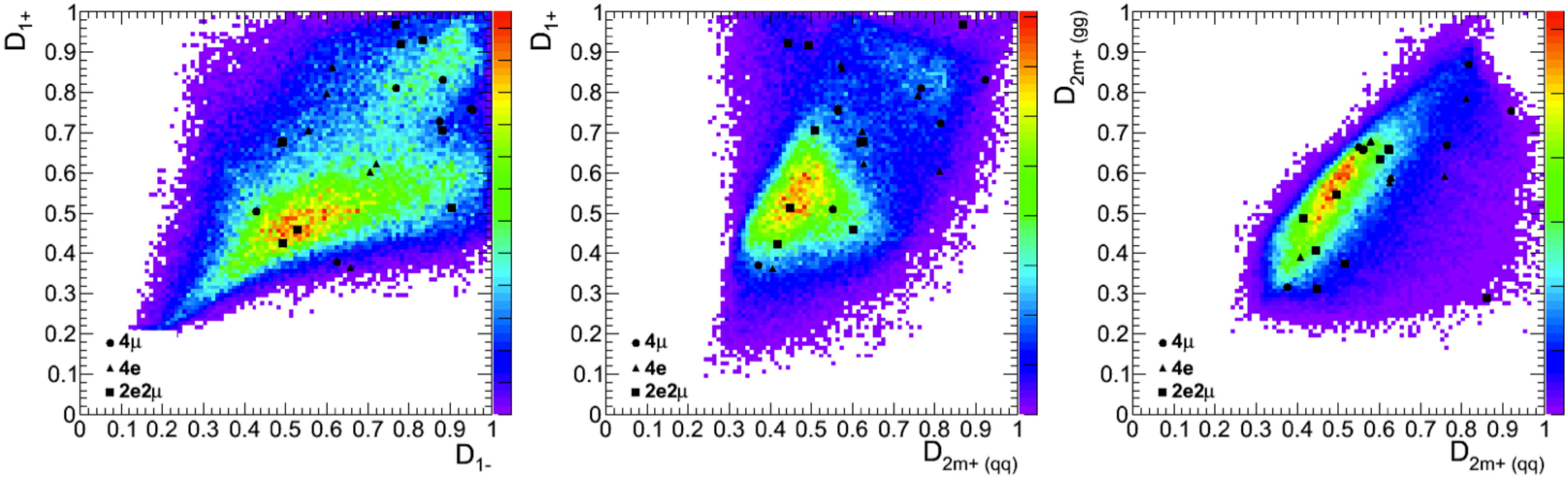
m_{Z1} for SM and other J^P



4l kinematics (with D_{bkg}>0.5)



Correlations btw discriminants D_{JP}



- Correlation between two D_{JP} with a requirement $D_{bkg} > 0.5$: D_{1+} vs D_{1-} (left), D_{1+} vs D_{2+qq} (center), and D_{1+} vs D_{2+qq} (right). Distributions of data (points) and expectations for signal are shown
- gg spin2+, qq spin2+: correlated by same decay angles
- qq spin1+, qq spin2+ : production angles and their correlations

Scattering amplitude assuming spin-0

arXiv:1208.4018 [hep-ph]

$$A(X \to V_1 V_2) = v^{-1} \left(g_1^{(0)} m_V^2 \epsilon_1^* \epsilon_2^* + g_2^{(0)} f_{\mu\nu}^{*(1)} f^{*(2),\mu\nu} + g_3^{(0)} f^{*(1),\mu\nu} f_{\mu\alpha}^{*(2)} \frac{q_\nu q^\alpha}{\Lambda^2} + g_4^{(0)} f_{\mu\nu}^{*(1)} \tilde{f}^{*(2),\mu\nu} \right)$$

scenario	X production	$X \to VV$ decay	comments
0_m^+	$gg \to X$	$g_1^{(0)} \neq 0$ in Eq. (9)	SM Higgs boson scalar
0_h^+	$gg \to X$	$g_2^{(0)} \neq 0$ in Eq. (9)	scalar with higher-dimension operators
0^-	$gg \to X$	$g_4^{(0)} \neq 0$ in Eq. (9)	pseudo-scalar

Therefore, terms with $g_1^{(0)}$ in $A(X \to V_1 V_2)$ are associated with dimension-three operators in the Lagrangian, terms with $g_2^{(0)}$ and $g_4^{(0)}$ with dimension-five, and terms with $g_3^{(0)}$ with dimension seven.

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}
  - $\Gamma_{\gamma\gamma}$
  - Γ_{gg}
  - Γ_{tt}
  - Γ_{TOT}(including H→ " invisible ")

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

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

Coupling scale factors

Production modes

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

$$\frac{\sigma_{VBF}}{\sigma_{VBF}^{SM}} = \kappa_{VBF}^2(\kappa_W, \kappa_Z, m_H)$$

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

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

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

Detectable decay modes

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

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

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

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

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

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

Undetectable decay modes

$$\frac{\Gamma_{t\bar{t}}}{\Gamma_{t\bar{t}}^{SM}} = \kappa_t^2$$

$$\frac{\Gamma_{gg}}{\Gamma_{gg}^{SM}} : \text{see Section 3.1.2}$$

$$\frac{\Gamma_{c\bar{c}}}{\Gamma_{c\bar{c}}^{SM}} = \kappa_t^2$$

$$\frac{\Gamma_{s\bar{s}}}{\Gamma_{s\bar{s}}^{SM}} = \kappa_b^2$$

$$\frac{\Gamma_{\mu^-\mu^+}}{\Gamma_{\mu^-\mu^+}^{SM}} = \kappa_\tau^2$$

Scale factors for loops

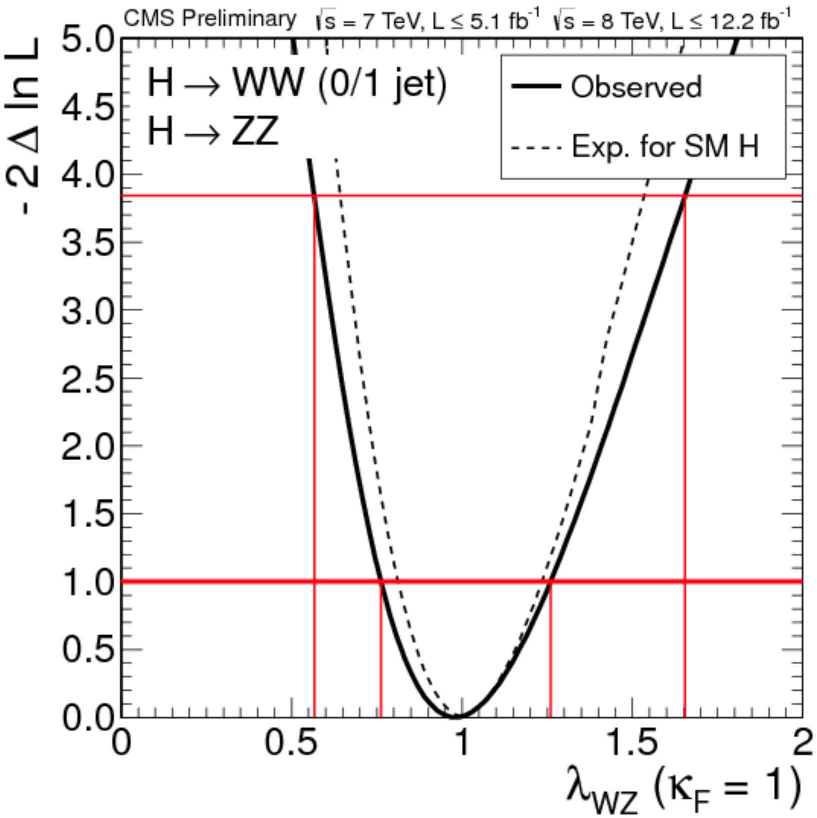
- In the case of coupling via loops scale factors are functions of the other scale factors
- Example: the gluon fusion cross section scaling:

$$\kappa_g^2(\kappa_t,\kappa_b,M_H) = \frac{\kappa_t^2 \cdot \sigma_{ggH}^{tt} + \kappa_b^2 \cdot \sigma_{ggH}^{bb} + \kappa_t\kappa_b \cdot \sigma_{ggH}^{tb}}{\sigma_{ggH}^{tt} + \sigma_{ggH}^{bb} + \sigma_{ggH}^{tb}}$$

- Where $\sigma_{ggH}^{tt,bb}$ is the square of the top and bottom contributions and σ_{ggH}^{tb} is the square of the interference terms
  - Interference term is negative for M_H<200 GeV
- Similar expressions implemented for other loops ($\gamma\gamma$, $Z\gamma$)
  - VBF is also expressed as combination of κ_W and κ_Z
- Alternatively the dependency on other scale factors can be discarded and treat the loop scale factor as additional free parameter

Custodial symmetry

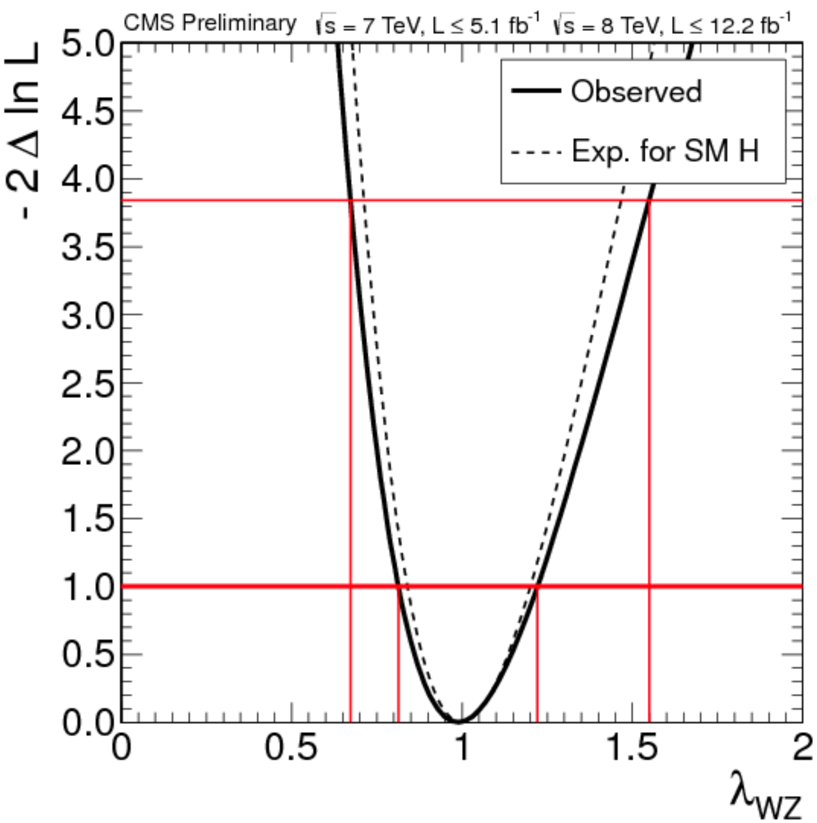
HCP



- 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: ~$g^2_W/g^2_Z=\lambda^2_{WZ}$
  - assume SM coupling to fermions (κ_F=1); dependence on this assumption is weak
  - Fit for: κ_Z , λ_{WZ}

Custodial symmetry

HCP



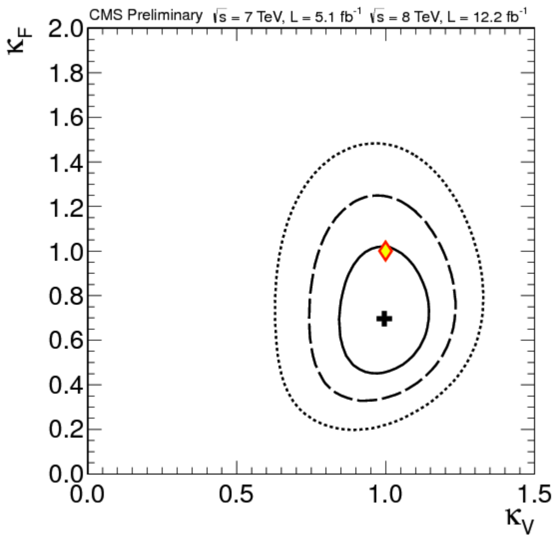
- Custodial symmetry: in SM, the ratio of couplings to W and Z bosons is almost not affected by loop corrections
- Compatibility test :
  - assume common scale factor for couplings to fermions (κ_F)
  - Fit for: κ_Z, λ_{WZ}, κ_F

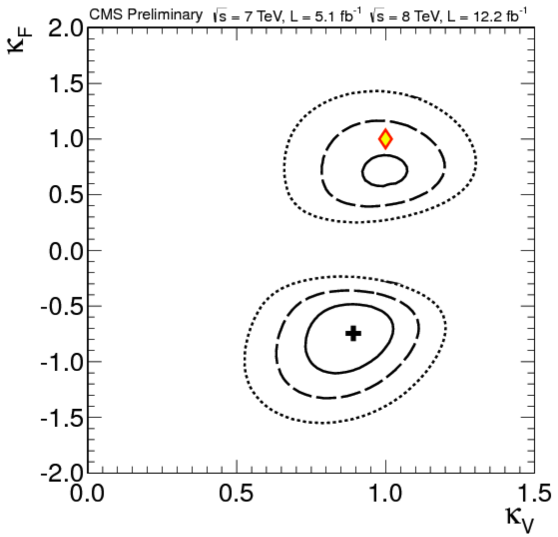
Data consistent with the custodial symmetry

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

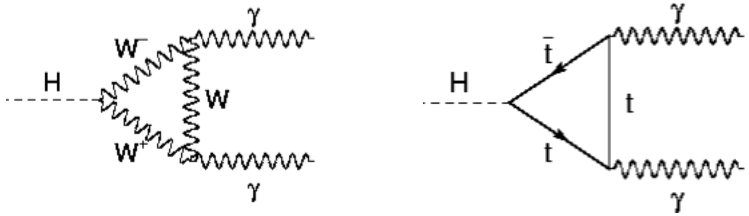
Two parameters: κ_V and κ_F

HCP





- Map vectorial and fermionic couplings into two scale factors, κ_V and κ_F
- H→(W and t loops)→γγ

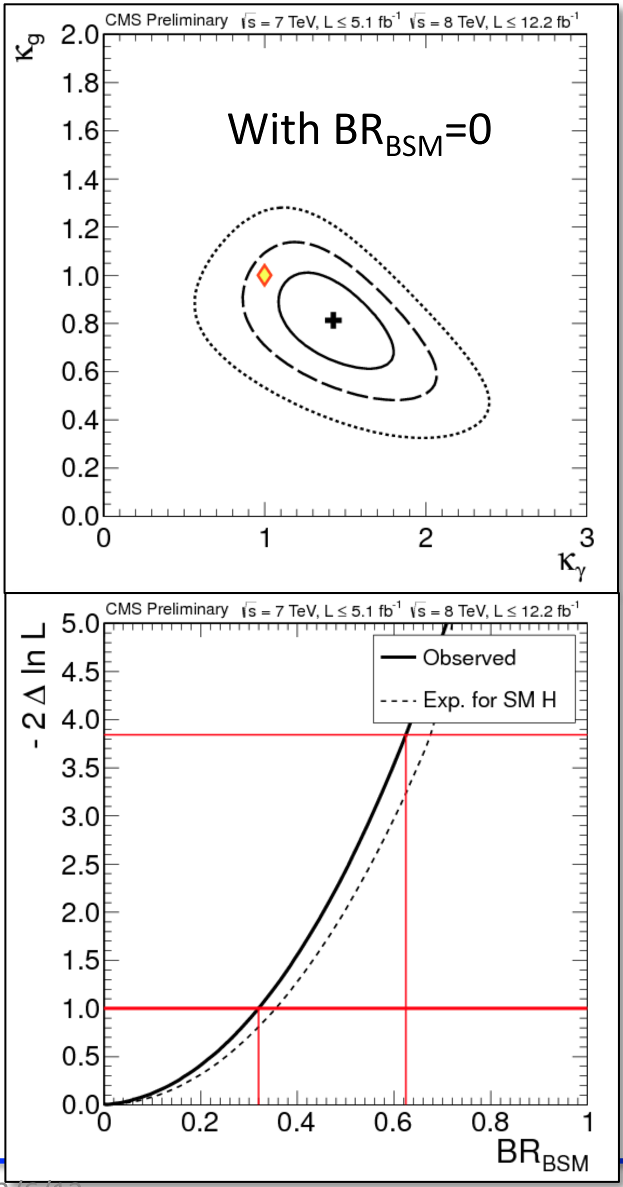


  - sensitive to relative sign of couplings to W and top
  - relative sign of W and top loop amplitudes is negative
- Slight excess in H→γγ makes the fit prefer (+;-) quadrant
  - to make positive interference between W and top loops

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

Look for new physics in loops

HCP



- New particles can
  - hide in the loop-mediated couplings
  - contribute to the total width
- Parameterize the photon and the gluon loops with effective scale factors (κ_γ,κ_g)
- In addition, allow total width to scale as $1/(1-Br_{inv})$

No sign of new physics

Couplings compatibility: summary

HCP

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	[0.98,1.92]	Couplings to photons (γ) and gluons (g)
	κ_g	[0.55,1.07]	(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	[0.58,1.41]	Couplings to W/Z-bosons (V)
	κ_b	not constrained	Couplings to down-type quarks (b)
	κ_τ	[0.00,1.80]	Couplings to charged leptons (τ)
	κ_t	not constrained	Couplings to top-type quarks (t)
	κ_g	[0.43,1.92]	Effective couplings to gluons (g)
	κ_γ	[0.81,2.27]	Effective couplings to photons (γ)

No significant deviation from the SM couplings

Test statistics

Signal model parameters a (signal strength modifier μ can be one of them) are evaluated from a scan of the profile likelihood ratio $q(a)$:

$$q(a) = -2 \ln \frac{\mathcal{L}(\text{obs} \,|\, s(a) + b, \hat{\theta}_a)}{\mathcal{L}(\text{obs} \,|\, s(\hat{a}) + b, \hat{\theta})}, \tag{6}$$

Parameters $\hat{a}$ and $\hat{\theta}$ that maximize the likelihood, $\mathcal{L}(\text{obs} \,|\, s(\hat{a}) + b, \hat{\theta}) = \mathcal{L}_{\text{max}}$, are called the best-fit set. The 68% (95%) CL on a given parameter of interest a_i is evaluated from $q(a_i) = 1$ (3.84) with all other unconstrained model parameters treated in the same way as the nuisance parameters. The 2D 68% (95%) CL contours for pairs of parameters are derived from $q(a_i, a_j) = 2.3$ (6). One should keep in mind that boundaries of 2D confidence regions projected on either parameter axis are not identical to the 1D confidence interval for that parameter.