HIGGS SEARCHES & PROPERTY MEASUREMENTS

CMS at LHC
HXSWG 7

A. David (LIP, Lisboa) for the CMS Collaboration

What to expect

- This talk focuses on:
  - The low mass range and the object residing therein.
  - The picture arising from combining all search channels.

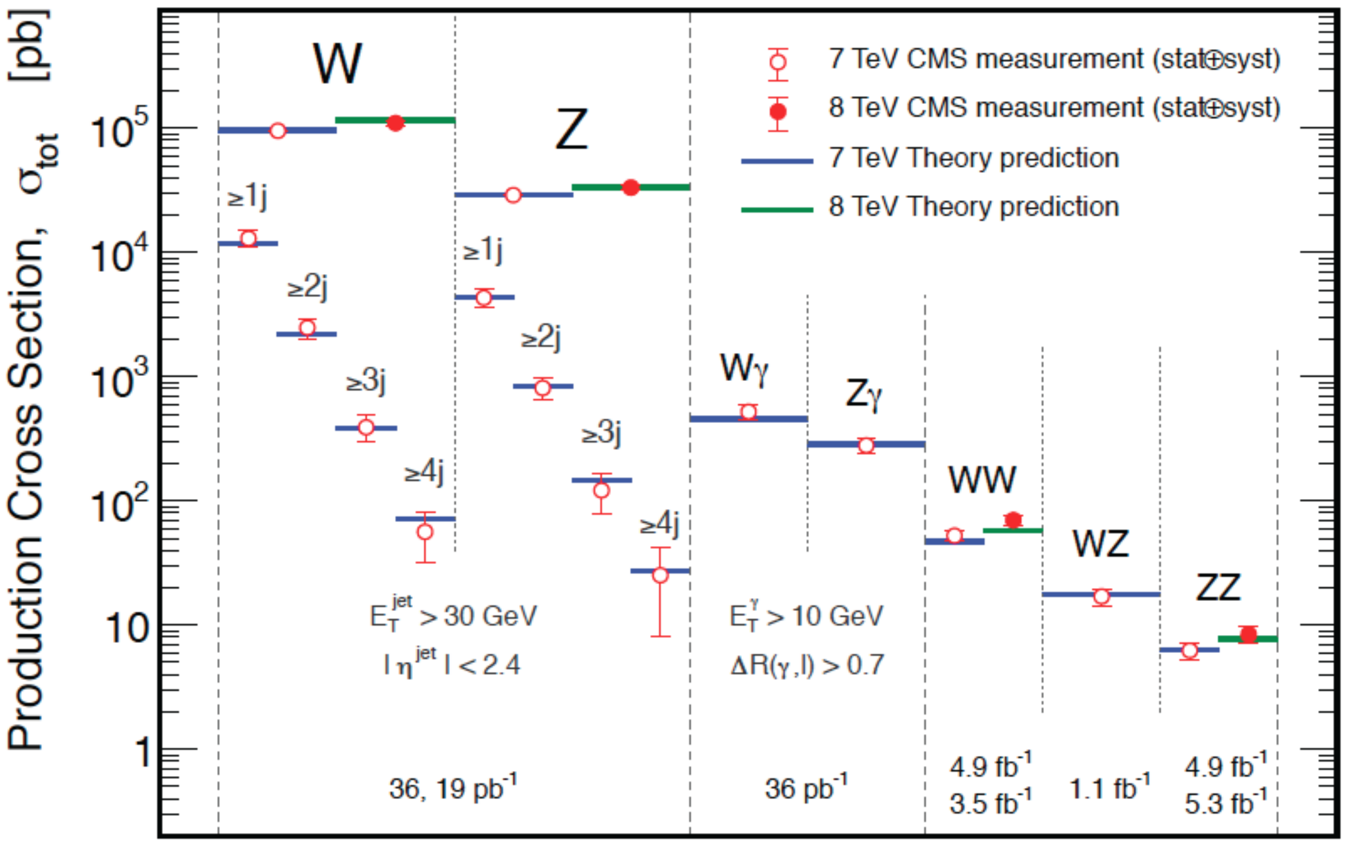
- Overview:
  - What happened since July 4.
  - The "big five".
  - Combined results.
  - Properties (fits, fits, fits,…)

fit ² | fit |
noun
a sudden uncontrollable outbreak of intense emotion, laughter, coughing, or other action or activity: *in **a fit of** temper* | *he got coughing fits.*
• a sudden attack of convulsions and/or loss of consciousness, typical of epilepsy and some other medical conditions: *he thought she was **having a fit** .*

A tribute to those doing SM calculations

[SMP-12-005, 007, 011, 013, 014] [arXiv:1210.3844]

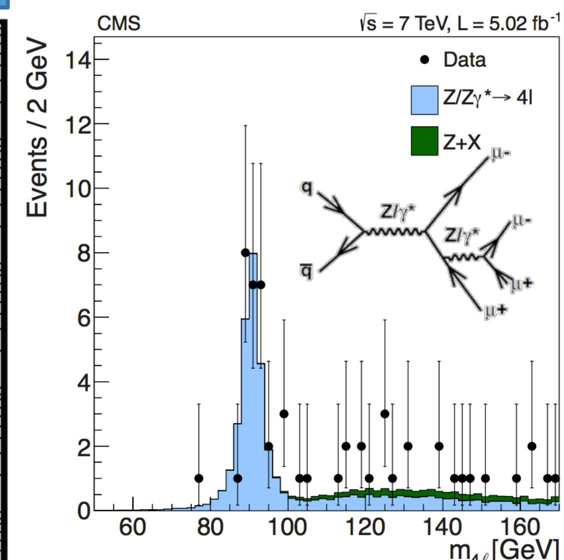
Single- and multi-boson production measurements



JHEP10(2011)132
JHEP01(2012)010
CMS-PAS-SMP-12-011 (W/Z 8 TeV)

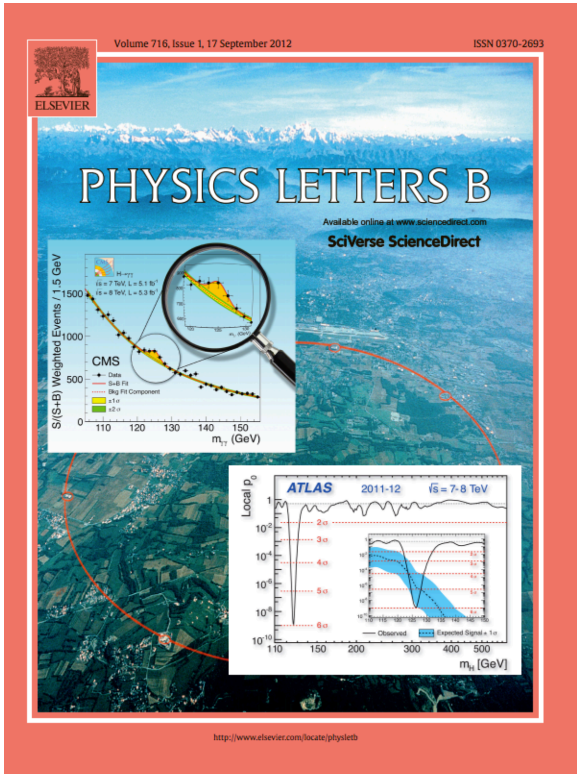
PLB701(2011)535

CMS-PAS-EWK-11-010 (WZ)
CMS-PAS-SMP-12-005,
007, 013, 014 (WW ZZ)



$Z \rightarrow 4\ell$ decay
9.7 σ observation

Looking up to a new boson

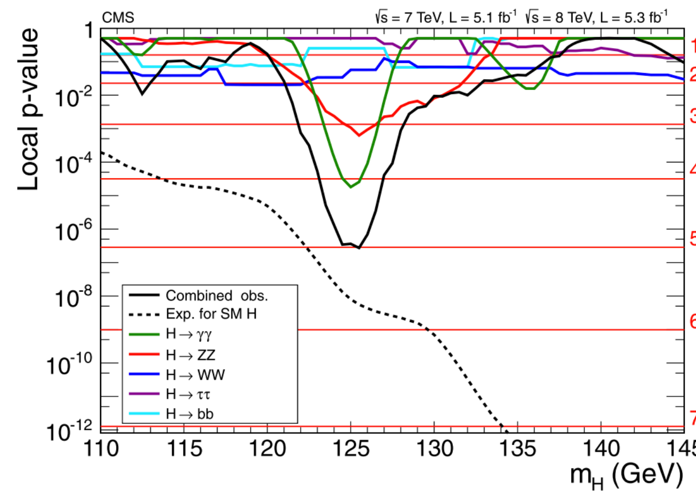


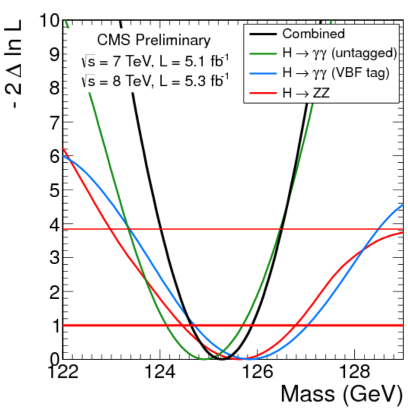
Higgsdependence day recap

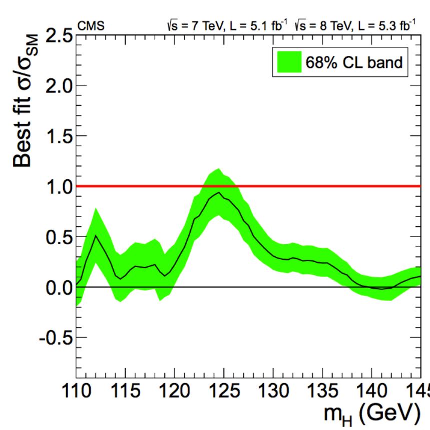
[arXiv:1207.7235][HIG-12-020]

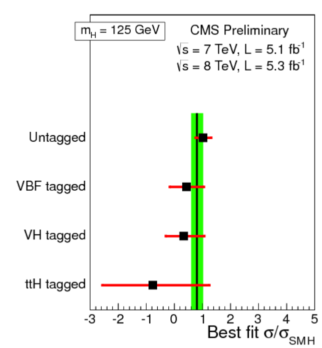
- 5.0 σ observed.
- m_X = 125.3 ±0.6 GeV.
- At 125 GeV:
  - σ/σ_{SM} = 0.80 ±0.20.
  - "Couplings" compatible with SM.
- ***"More data is needed…"***

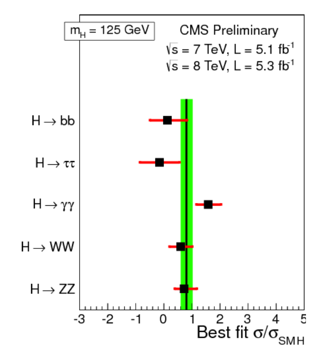
Decay mode	Production tagging	No. of subchannels	m_H range (GeV)	Int. Lum. (fb^{-1}) 7 TeV	8 TeV
$\gamma\gamma$	untagged dijet (VBF)	4 1 or 2	110–150	5.1	5.3
ZZ	untagged	3	110–600	5.1	5.3
WW	untagged dijet (VBF)	4 1 or 2	110–600	4.9	5.1
$\tau\tau$	untagged dijet (VBF)	16 4	110–145	4.9	5.1
bb	lepton, E_T^{miss} (VH)	10	110–135	5.0	5.1

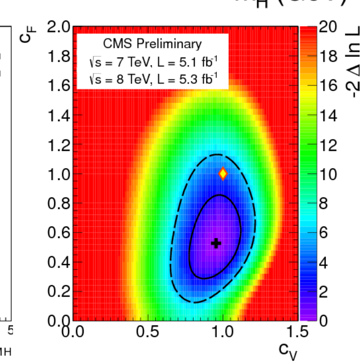












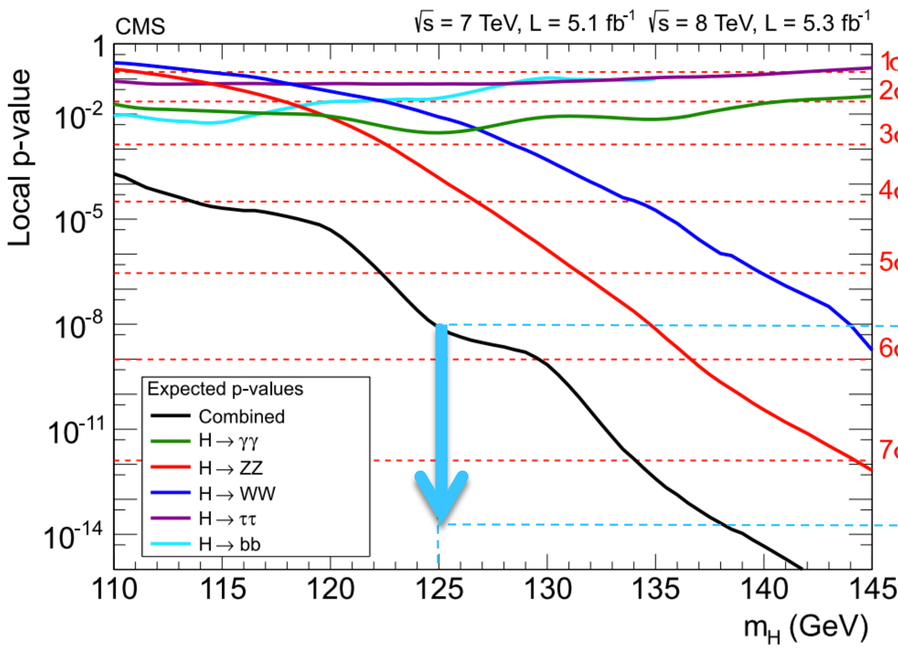
LHC delivered more data, as needed

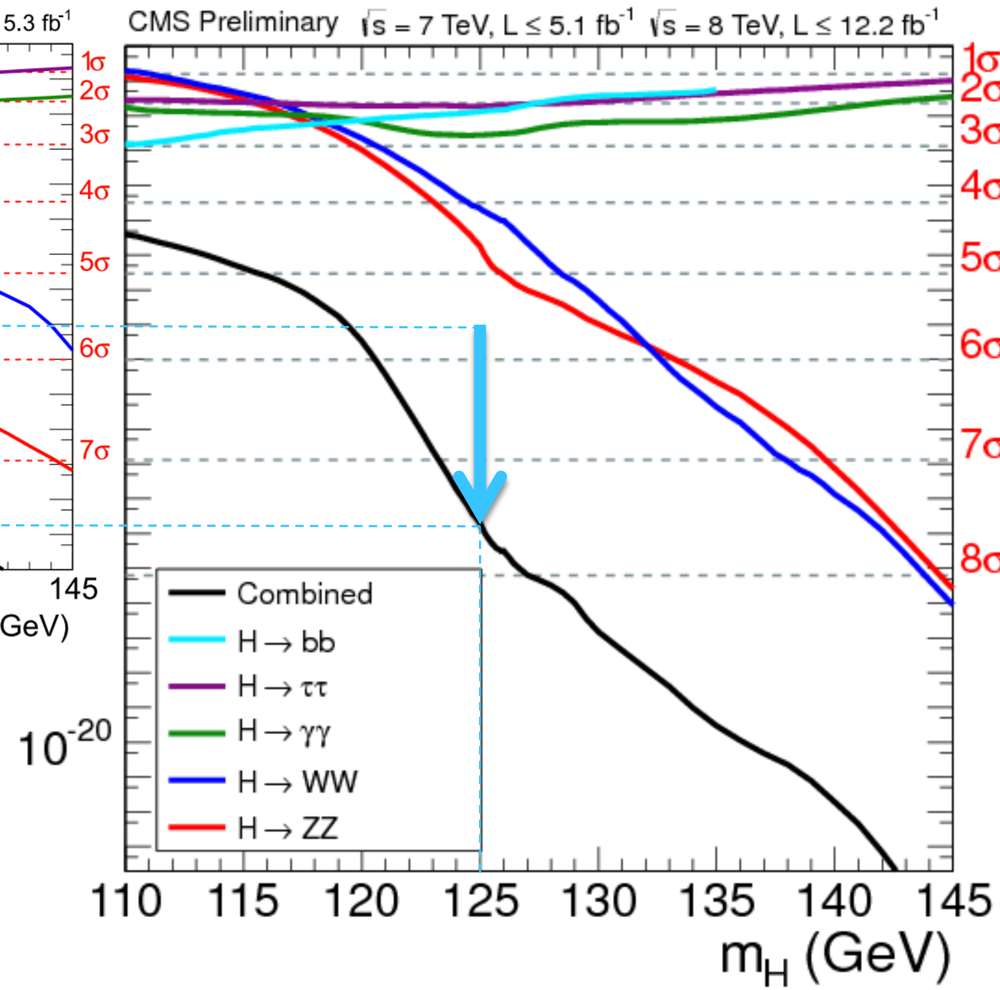
- Reloaded most channels with 2x more 8 TeV data.
- Extended high mass search range to 1000 GeV.
- Multiple other analysis improvements.

H decay	H prod	No. of channels	m_H range (GeV)	m_H resolution	Lumi (fb^{-1}) 7 TeV	8 TeV
$\gamma\gamma$	untagged	4	110–150	1-2%	5.1	5.3
	VBF-tag	1 or 2	110–150	1-2%	5.1	5.3
bb	VH-tag	10 or 13	110–135	10%	5.0	12.1
	ttH-tag	9	110–140		5.0	-
$H \to \tau\tau$	1-jet	9	110–145	20%	4.9	12.1
	VBF-tag	5	110–145	20%	4.9	12.1
	ZH-tag	8	110–160		5.0	-
	WH-tag	3	110–140		4.9	-
$WW \to \ell\nu qq$	untagged	4	170–600		5.0	12.1
$WW \to \ell\nu\ell\nu$	0/1-jets	4	110–600	20%	4.9	12.1
$WW \to \ell\nu\ell\nu$	VBF-tag	1 or 2	110–600	20%	4.9	12.1
$WW \to \ell\nu\ell\nu$	WH-tag	1	110–200		4.9	5.1
$ZZ \to 4\ell$	inclusive	3	110–1000	1-2%	5.0	12.2
$ZZ \to 2\ell 2\tau$	inclusive	8	180–1000	10-15%	5.0	12.2

What to expect from the changes

[arXiv:1207.7235][HIG-12-045]

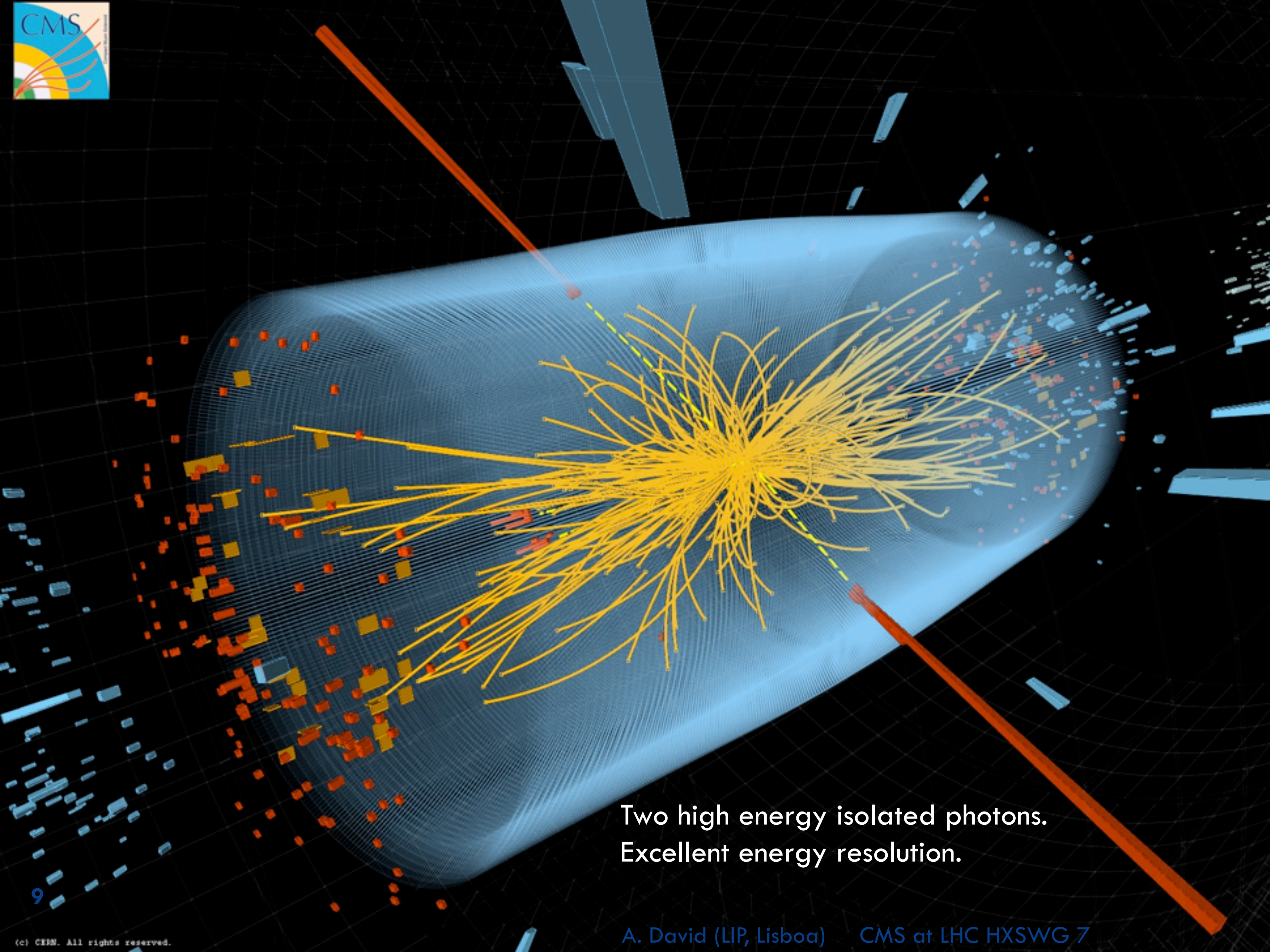




- **From 5.8 σ to 7.8 σ.**
  - Dealing with infinitesimal p-values…

You are here


√s = 7 TeV, L ≤ 5.1 fb-1 √s = 8 TeV, L ≤ 12.2 fb-1
CMS Preliminary
mH = 125.8 GeV
Here be fermions ?
Here be bosons ?
-2
0
2
4
Best fit σ/σSM

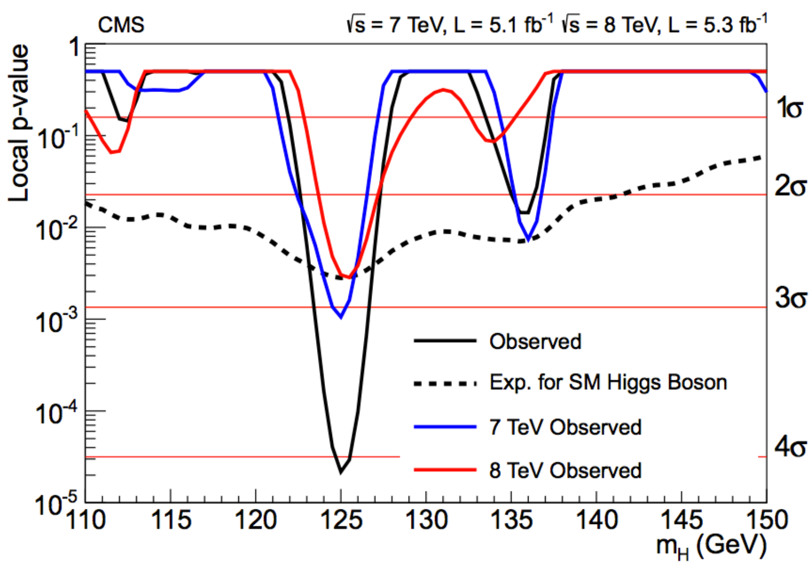


Two high energy isolated photons.
Excellent energy resolution.

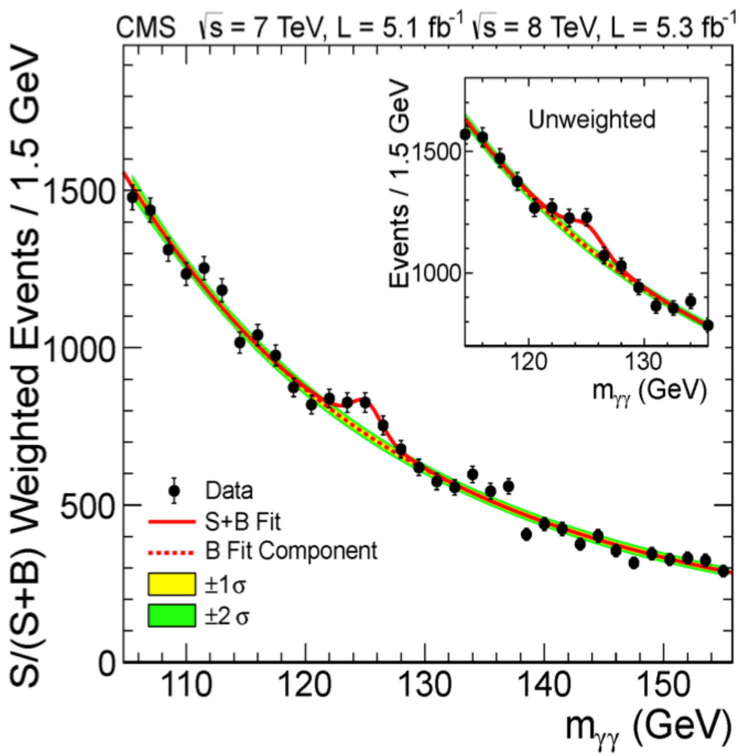
H→ $\gamma\gamma$

Evidence for

Global significance > 3.2 σ



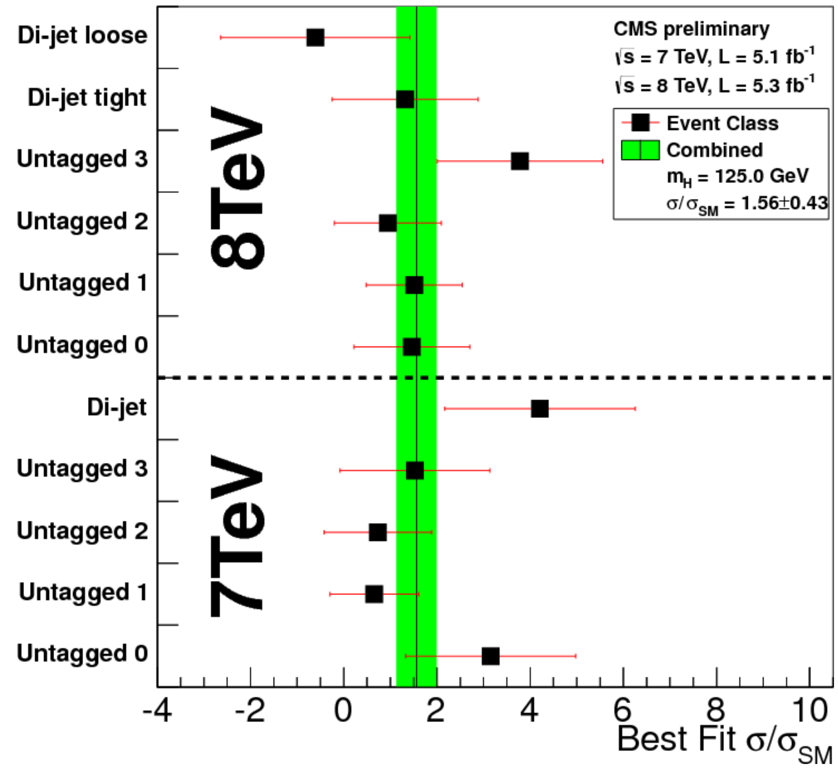
Combined data



H→ $\gamma\gamma$

- Channel breakdown:
  - Untagged:
    - Mass resolution.
    - S/B.
  - Di-jet tag:
    - VBF topology.

- For m_H = 125 GeV:
  - **4.1 σ obs.** (2.8 σ exp.).
  - **σ / σ_{SM} = 1.56 ±0.43.**



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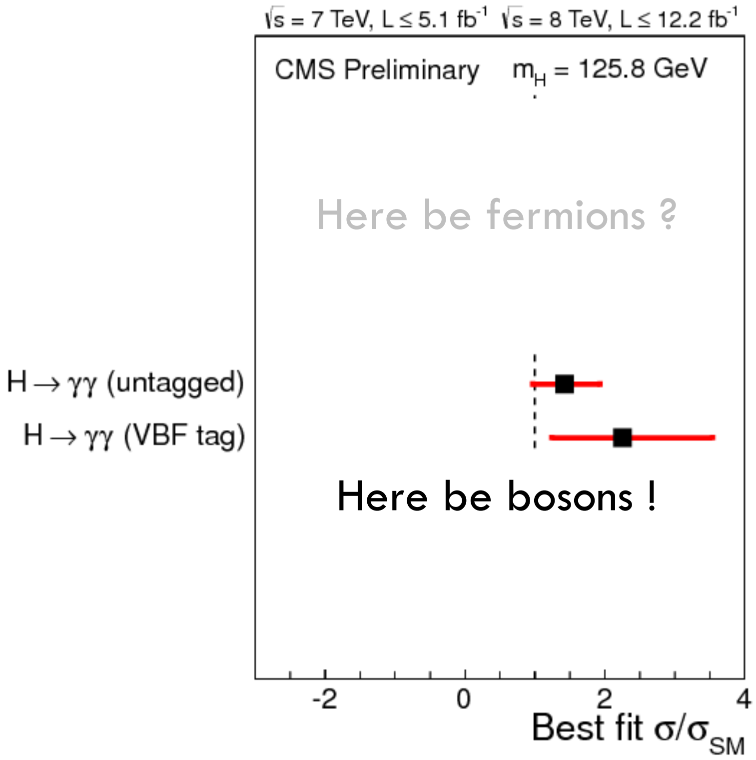

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CMS Preliminary
m_H = 125.8 GeV
Here be fermions ?
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-2
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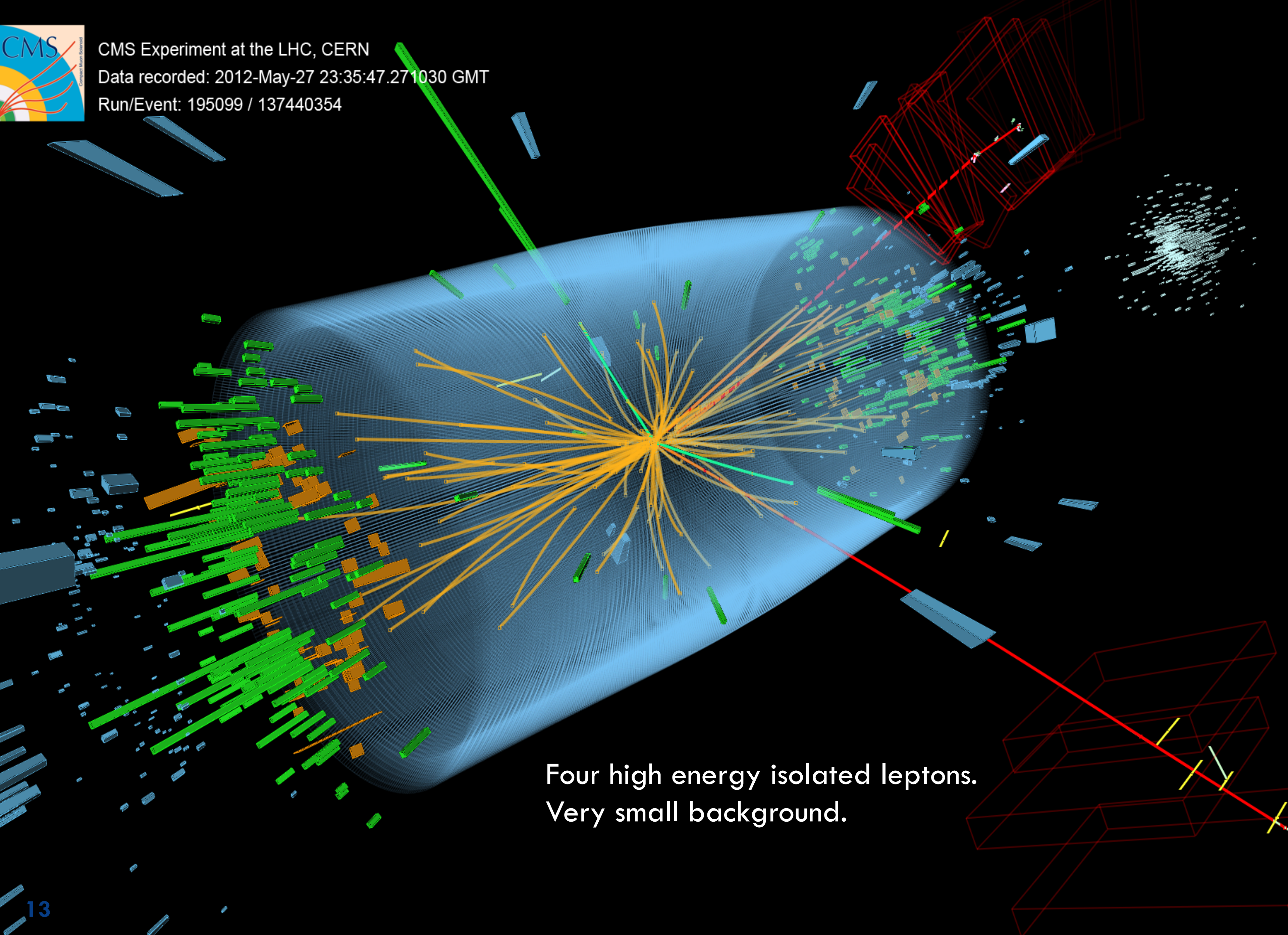
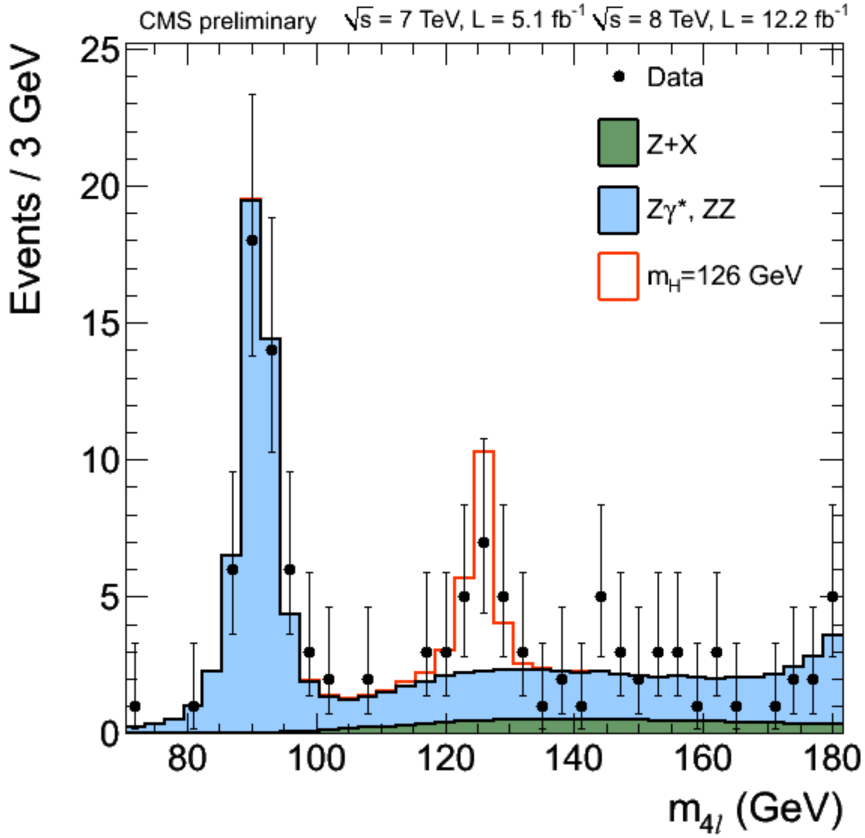
Best fit σ/σ_{SM}

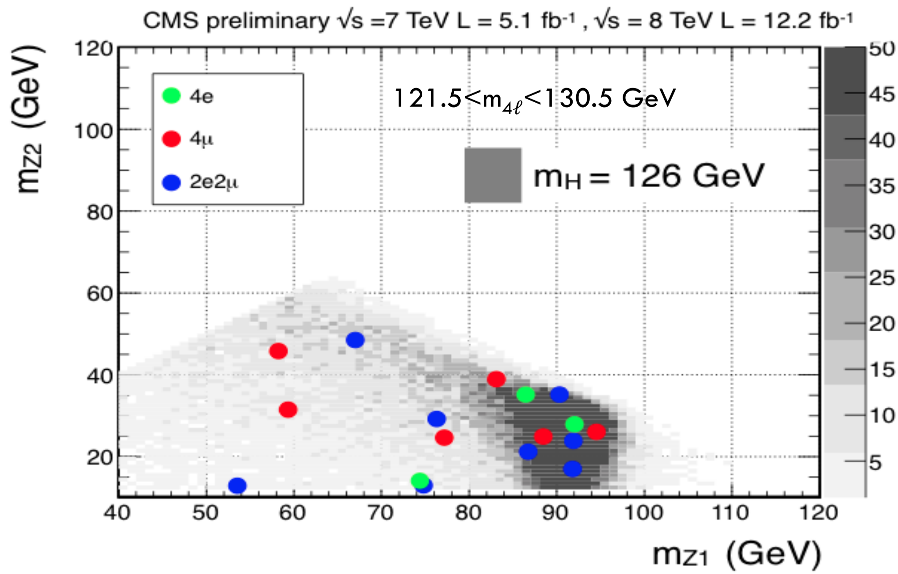


Four high energy isolated leptons.
Very small background.

H→Z*Z*→4ℓ

[HIG-12-041]

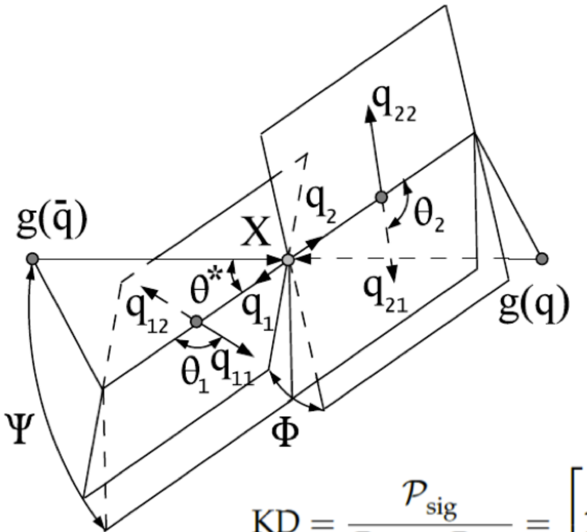




- Clearer peak around 126 GeV.
- $m(Z_1)$ vs $m(Z_2)$ clustering around SMH expectation.

$H \rightarrow Z^{*}Z^{*} \rightarrow 4\ell$

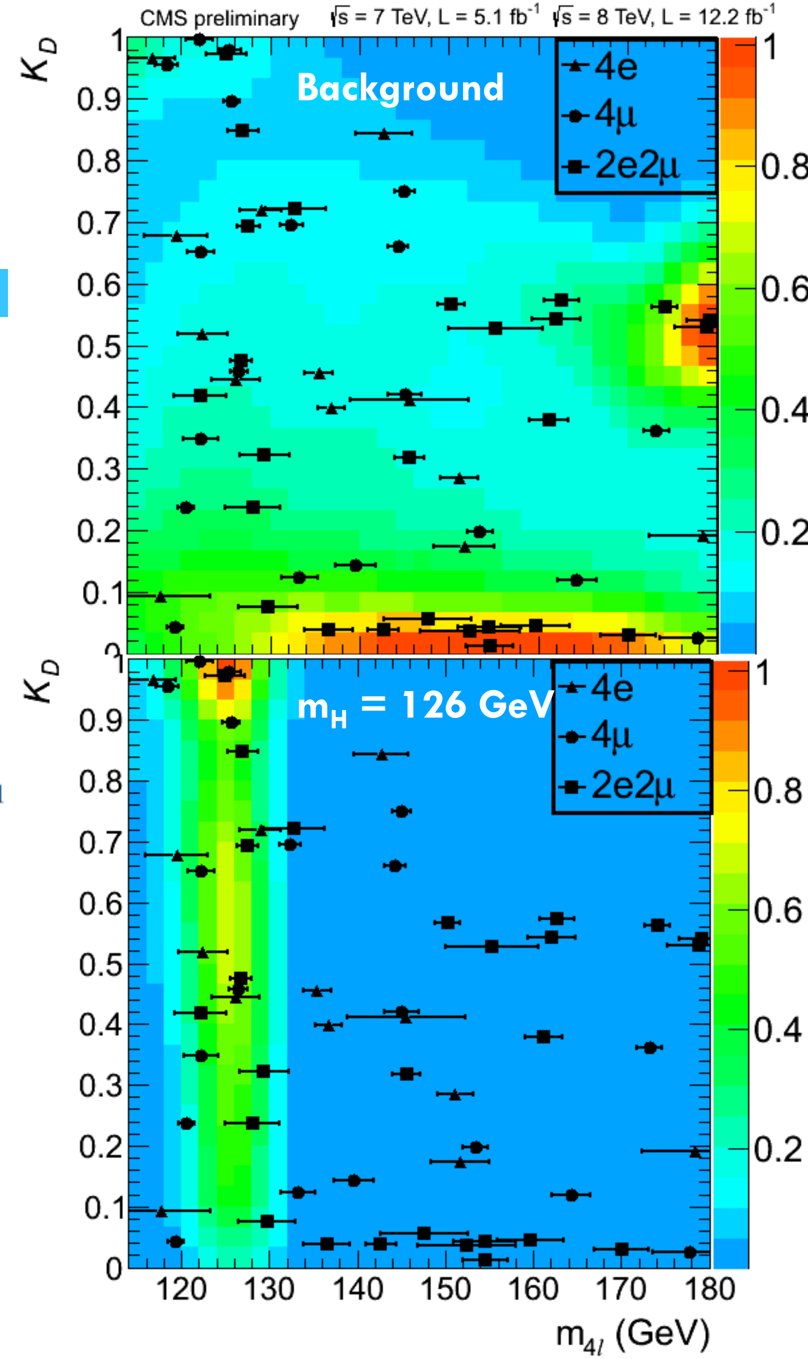
 [HIG-12-041]



$$\mathrm{KD} = \frac{\mathcal{P}_{\mathrm{sig}}}{\mathcal{P}_{\mathrm{sig}} + \mathcal{P}_{\mathrm{bkg}}} = \left[1 + \frac{\mathcal{P}_{\mathrm{bkg}}(m_1, m_2, \vec{\Omega}|m_{4\ell})}{\mathcal{P}_{\mathrm{sig}}(m_1, m_2, \vec{\Omega}|m_{4\ell})}\right]^{-1}$$

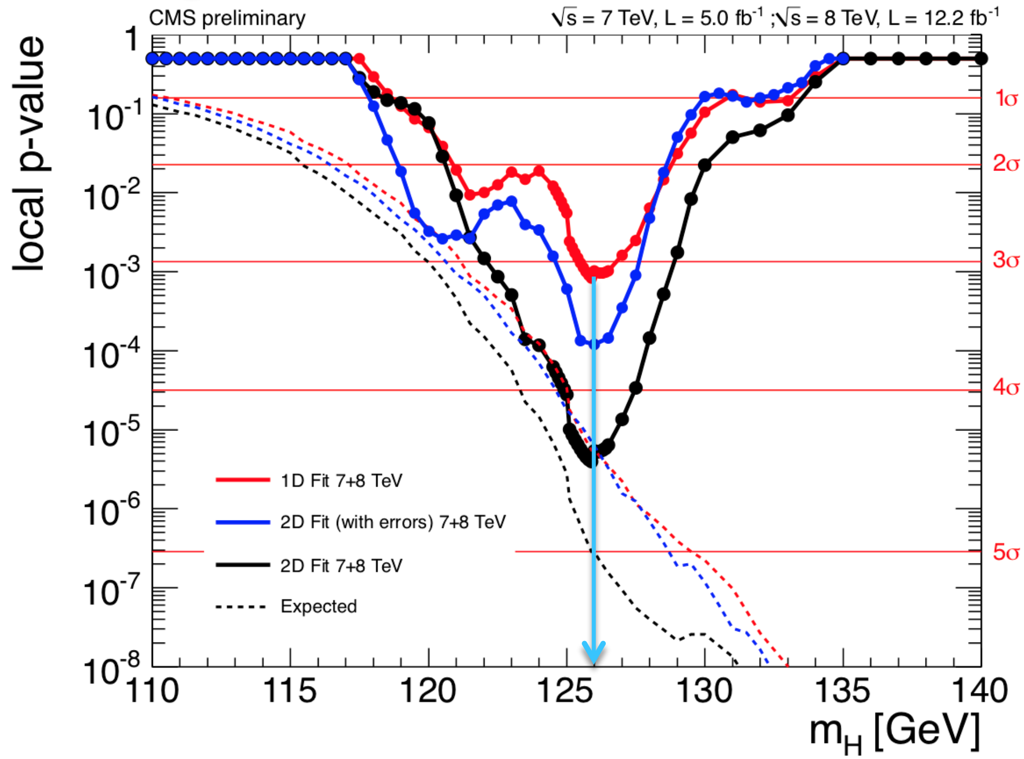
$$\vec{\Omega} = \{\theta^*, \Phi_1, \theta_1, \theta_2, \Phi\}$$

- 2D fit including angles and momenta improves sensitivity.



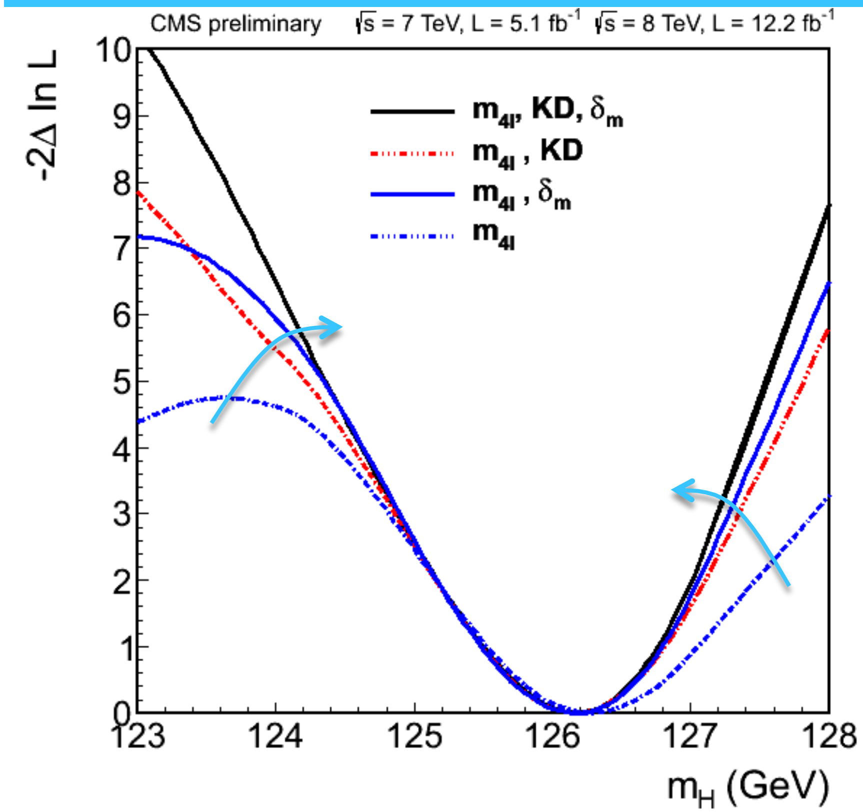
$H \to Z^*Z^* \to 4\ell$

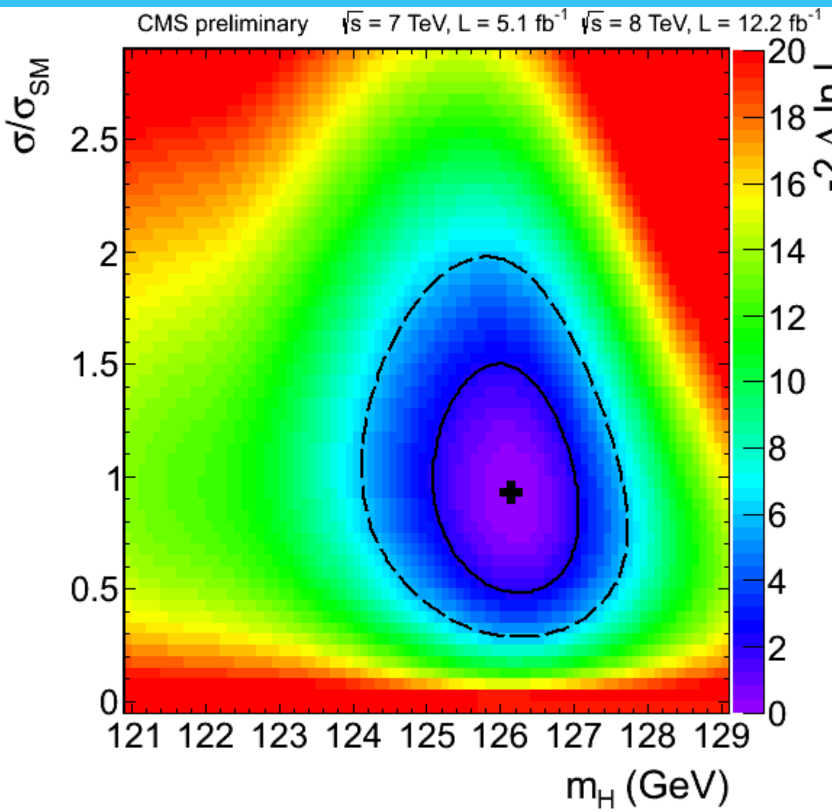
Evidence for



- For m_H = 126 GeV:
  - **4.5 σ obs.** (5.0 exp.).
  - σ / σ_{SM} **= 0.80$^{+0.35}_{-0.28}$.**

$H \to Z^*Z^* \to 4\ell$

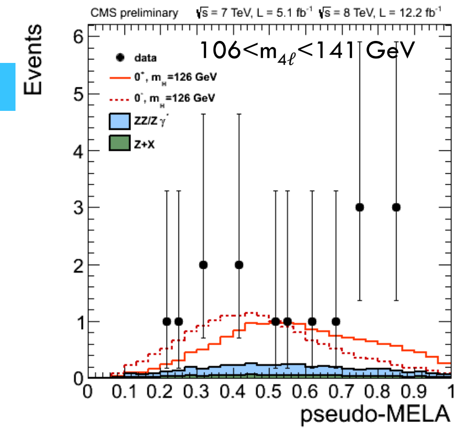




- 3D fit using $m_{4\ell}$, angles, and event-by-event $m_{4\ell}$ uncertainties:
  - $m_X = 126.2 \pm 0.6\text{(stat)} \pm 0.2\text{(syst)}$ GeV.

H→Z*Z*→4ℓ: parity specialist

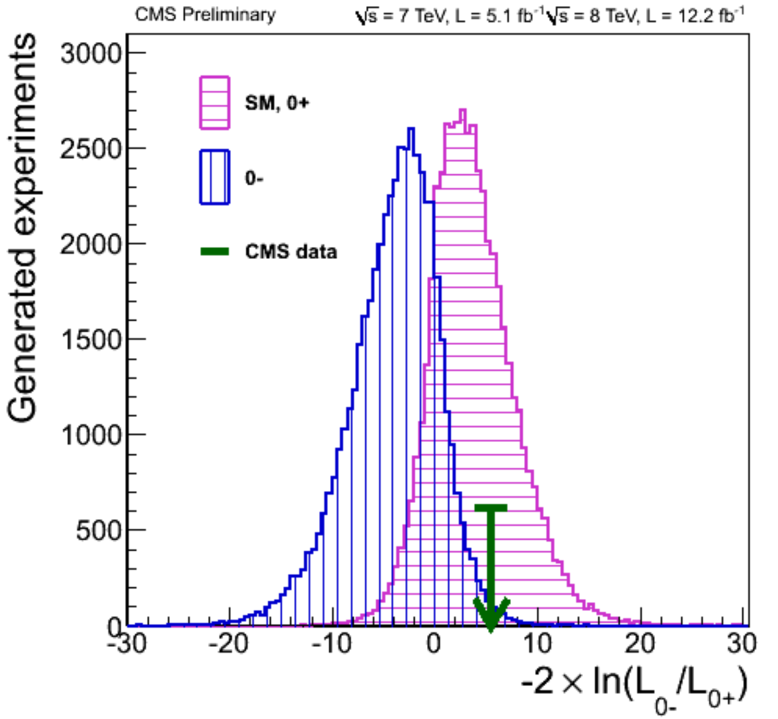
[HIG-12-041]



- Build same kind of angular discriminant:

$$\mathcal{D}_{J^P} = \frac{\mathcal{P}_{\rm SM}}{\mathcal{P}_{\rm SM}+\mathcal{P}_{J^P}} = \left[1+\frac{\mathcal{P}_{J^P}(m_1,m_2,\vec{\Omega}|m_{4\ell})}{\mathcal{P}_{\rm SM}(m_1,m_2,\vec{\Omega}|m_{4\ell})}\right]^{-1}$$

- Test **BG+SMH (0^+)** against **BG+pseudoscalar (0^-)**:
  - 0^- hypothesis disfavored with CL_S value of 2.4%.



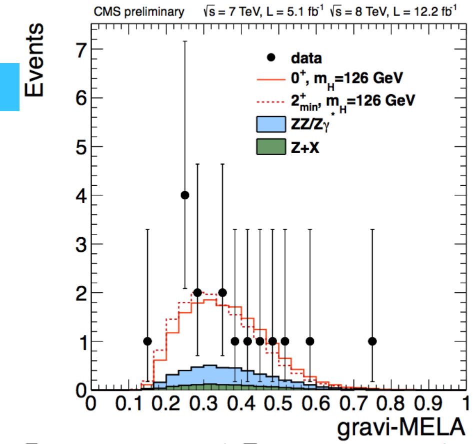
$H \to Z^*Z^* \to 4\ell$: spin tryout

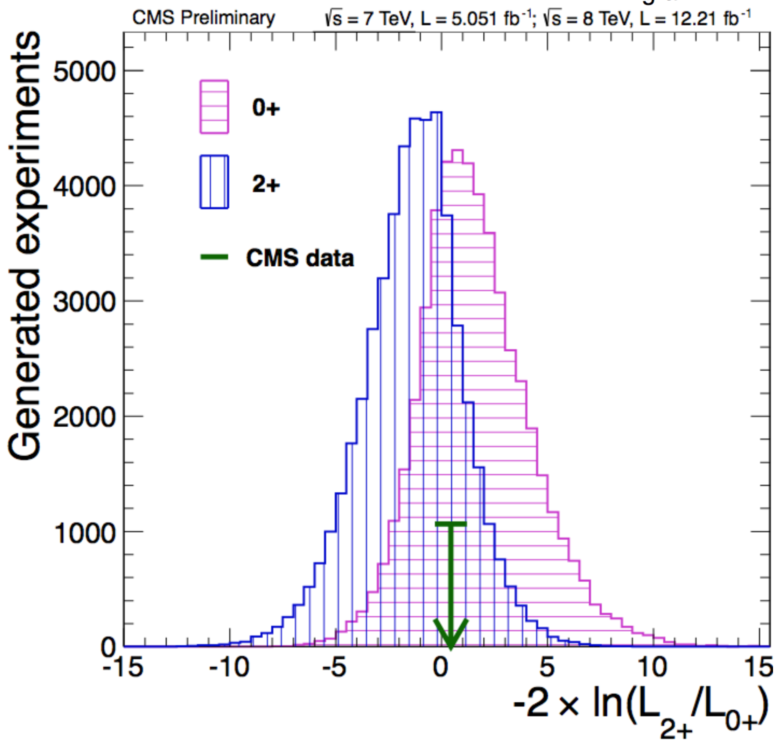
[HIG-12-041]

- Build same kind of angular discriminant:

$$\mathcal{D}_{J^P} = \frac{\mathcal{P}_{\rm SM}}{\mathcal{P}_{\rm SM} + \mathcal{P}_{J^P}} = \left[1 + \frac{\mathcal{P}_{J^P}(m_1, m_2, \vec{\Omega} | m_{4\ell})}{\mathcal{P}_{\rm SM}(m_1, m_2, \vec{\Omega} | m_{4\ell})}\right]^{-1}$$

- Test **BG+SMH (0^+)** against **BG+graviton-like ($2^+{}_m$):**
  - Too early to tell.





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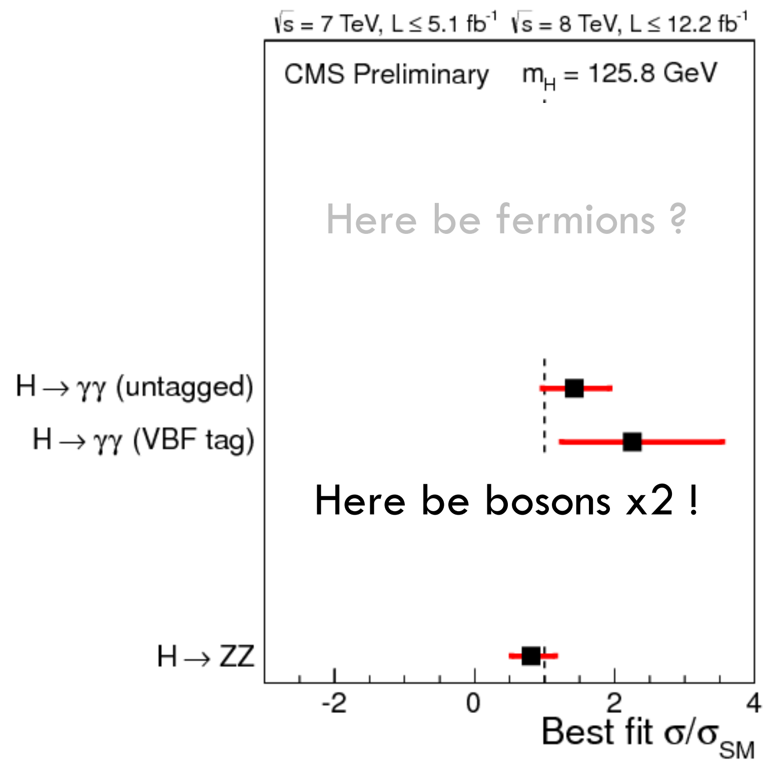


√s = 7 TeV, L ≤ 5.1 fb⁻¹ √s = 8 TeV, L ≤ 12.2 fb⁻¹
CMS Preliminary m_H = 125.8 GeV
Here be fermions ?
H → γγ (untagged)
H → γγ (VBF tag)
Here be bosons x2 !
H → ZZ
-2
0
2
4
Best fit σ/σ_{SM}

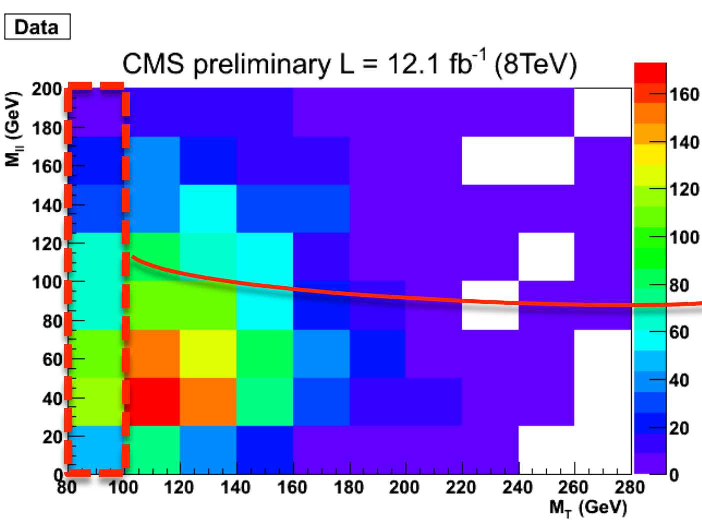
$H \to W^*W^* \to 2\ell 2\nu$

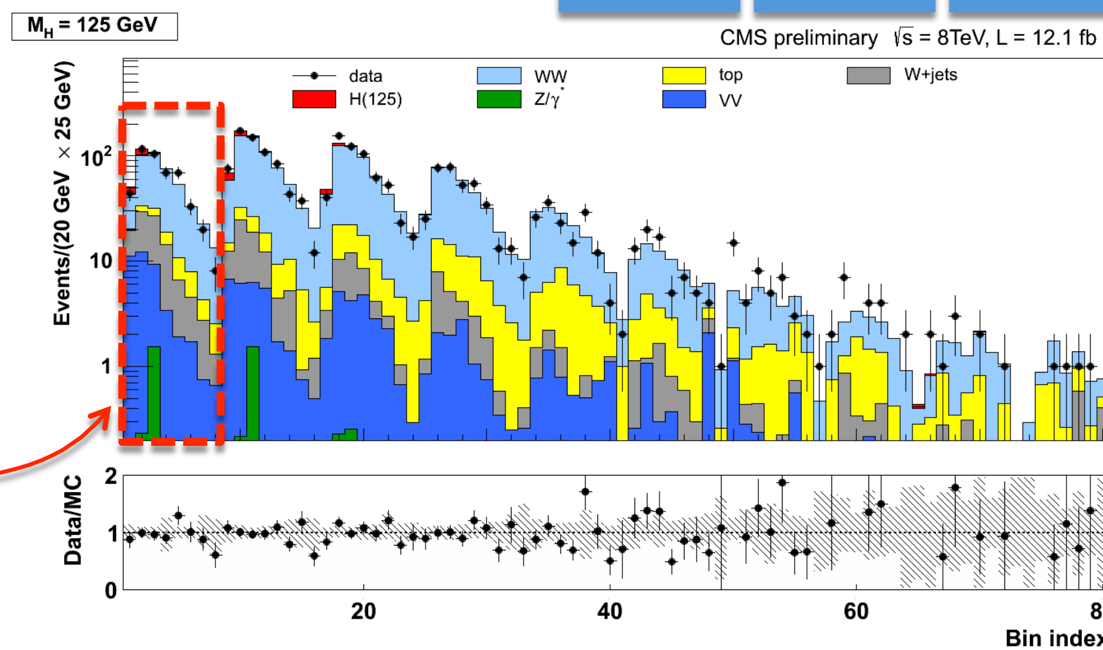
[HIG-12-042]

- Different flavor and same flavor analyses.
  - Shape analysis only in DF and 8 TeV.
- Optimized VBF selection.
- $m_{\ell\ell}$ vs m_T shape.
  - DF 0-jet example:

Different flavor		
0-jets shape	1-jet shape	2-jets VBF

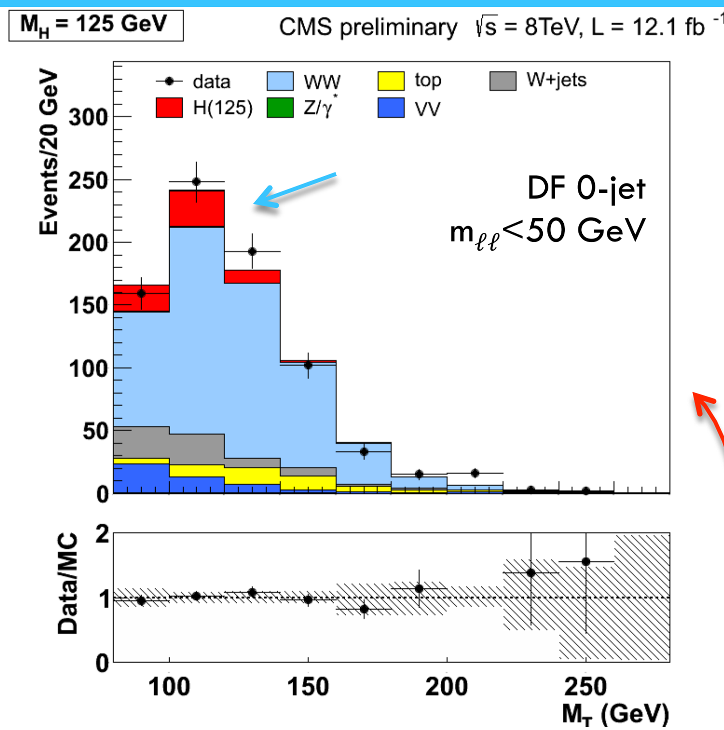
Same flavor		
0-jets	1-jet	2-jets VBF

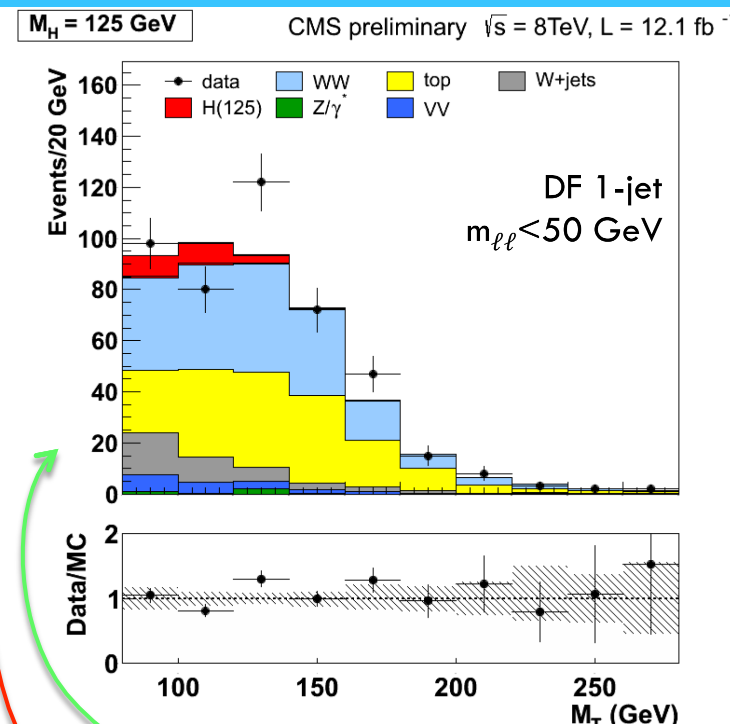


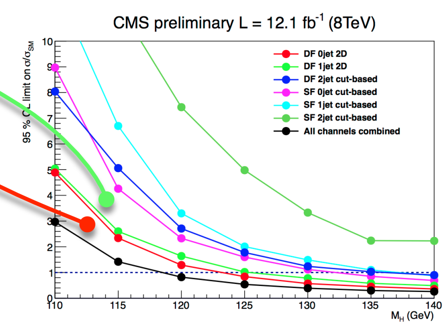


$H \to W^{*}W^{*} \to 2\ell 2\nu$

[HIG-12-042]



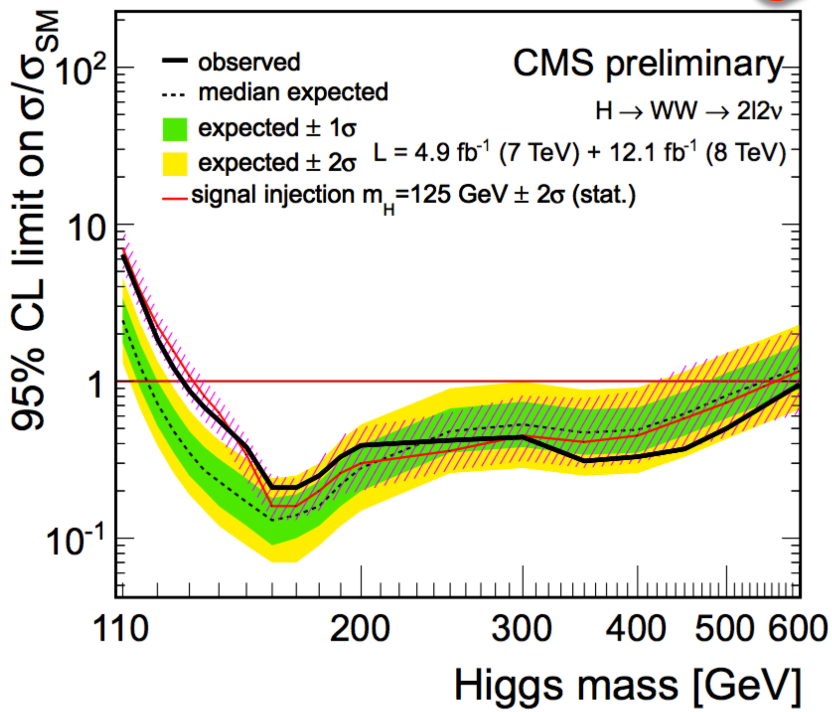


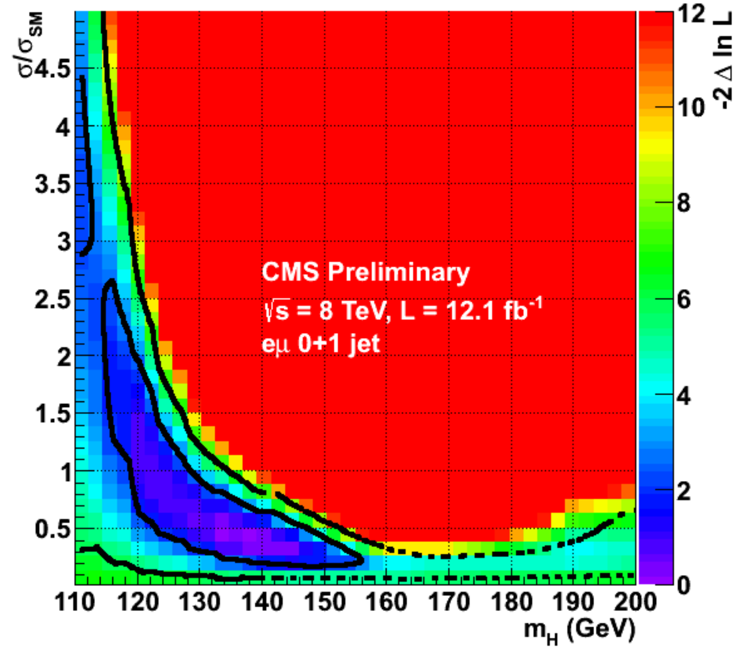


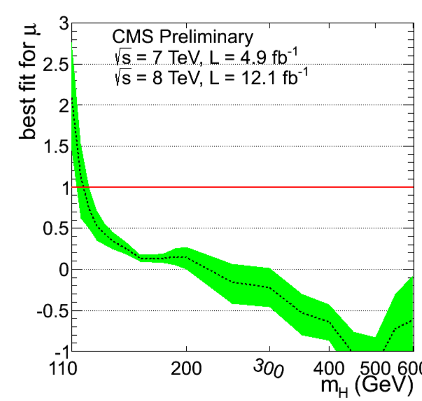
- Clear signal after projecting the two most sensitive channels.

$H \rightarrow W^*W^* \rightarrow 2\ell 2\nu$

Evidence for

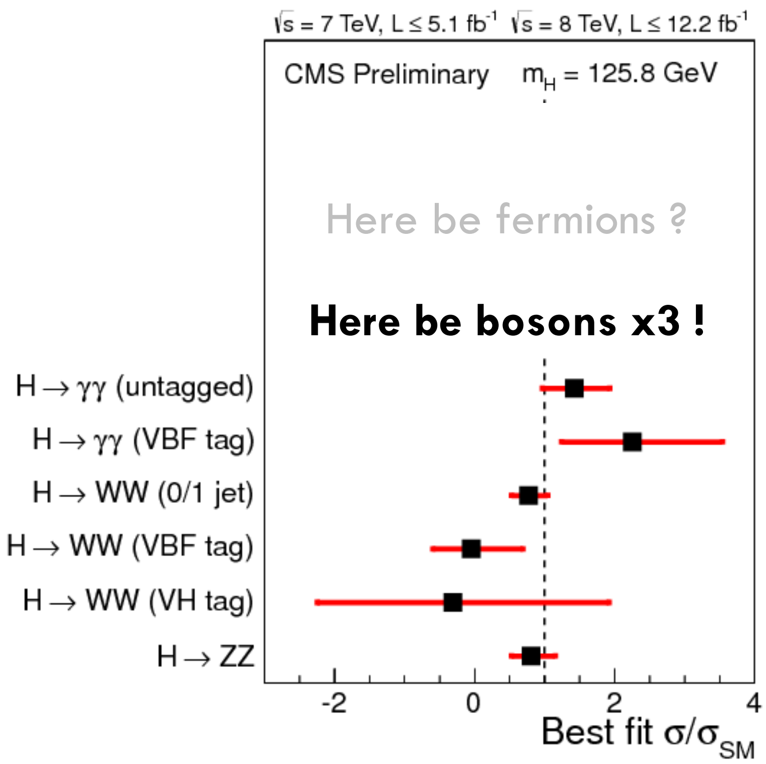






- For $m_H = 125$ GeV:
  - **3.1 σ obs.** (4.1 σ exp.).
  - $\boldsymbol{\sigma / \sigma_{SM} = 0.74 \pm 0.25}$.

You are here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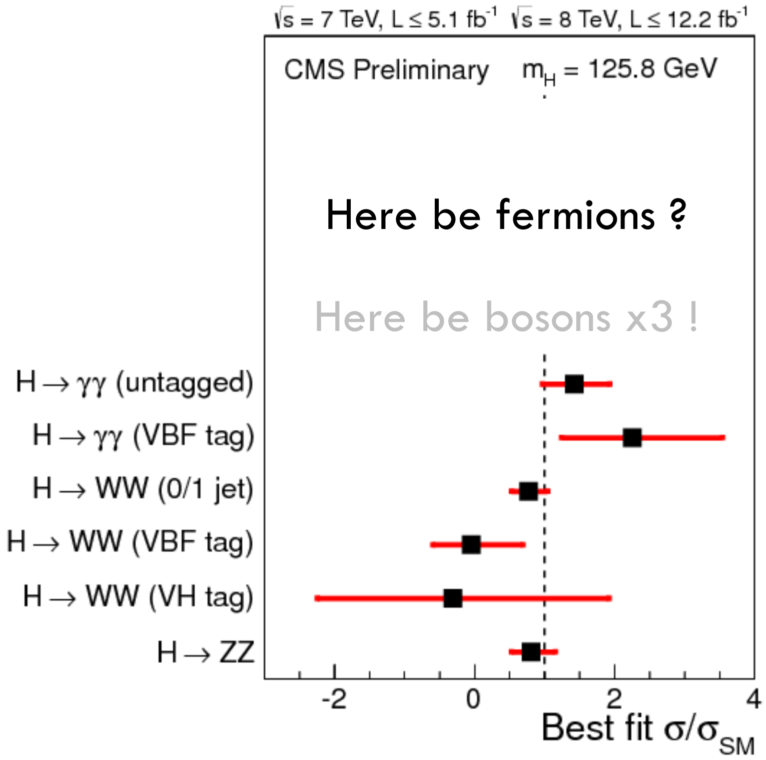
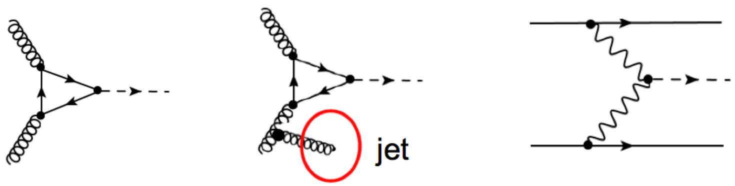
H → γγ (VBF tag)
H → WW (0/1 jet)
H → WW (VBF tag)
H → WW (VH tag)
H → ZZ
-2
0
2
4
Best fit σ/σSM

You are here

- How about fermions ?
  - Not clear on July 4.



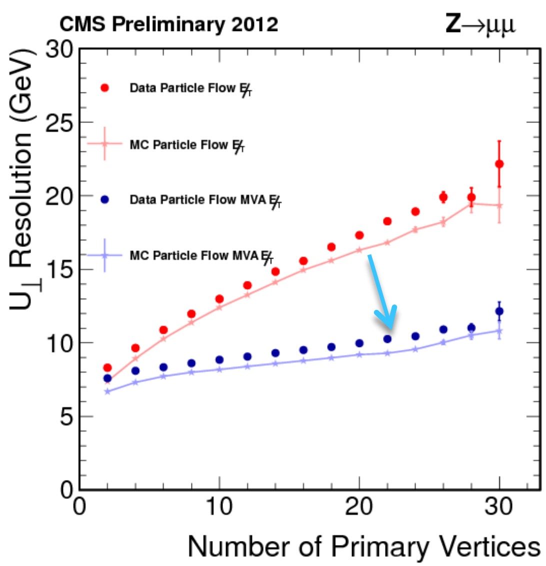
H⟶ τ τ

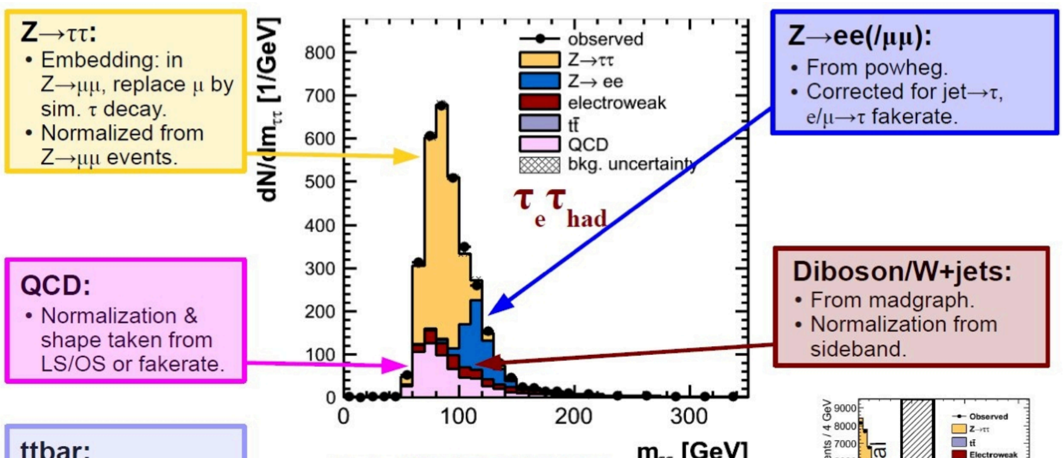


[HIG-12-043][HIG-12-051]

- **τ (e, μ , τ $_h$)^2 p$_T$ categories.**
  - 0-jet constrains backgrounds.
- Additional exclusive modes.
- **MVA MET and τ $_h$ added.**

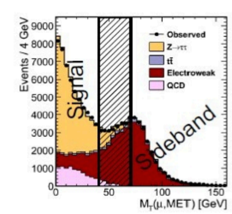
0-jets **BG**	1-jet High τ p$_T$	2-jets **VBF**
	1-jet Low τ p$_T$	**VH**





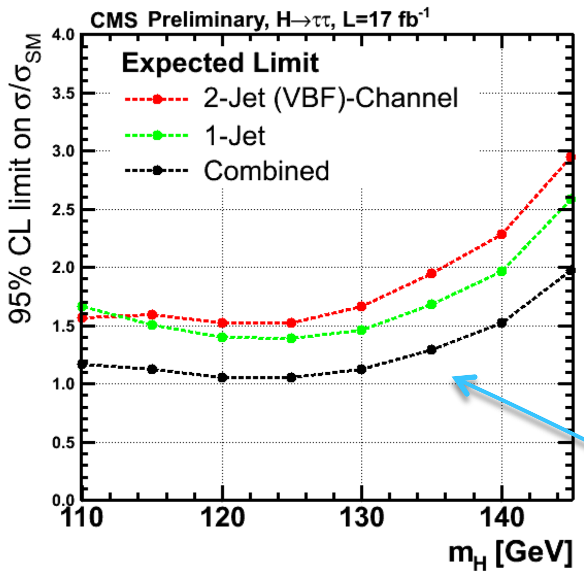
ttbar:
- From madgraph.
- Normalization from sideband.

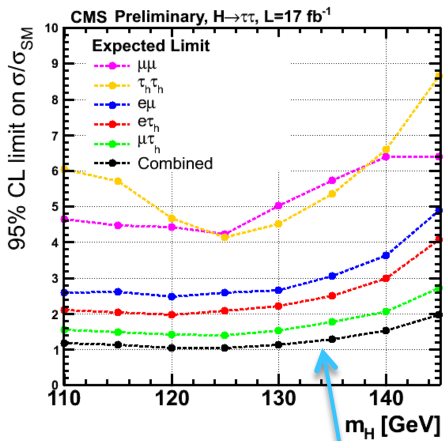
- Select isolated leptons.
- Restrict $\not{E}_T$ (supp. W+jets, ttbar).
- Discriminate signal from background based on m$_{\tau\tau}$.

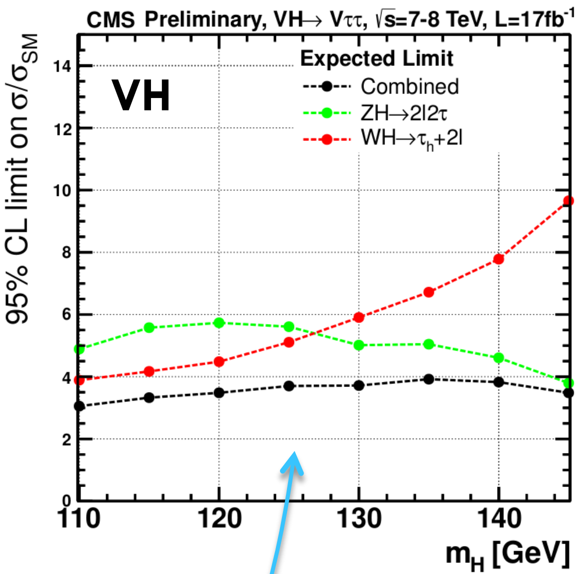


H→ τ τ

[HIG-12-043][HIG-12-051]



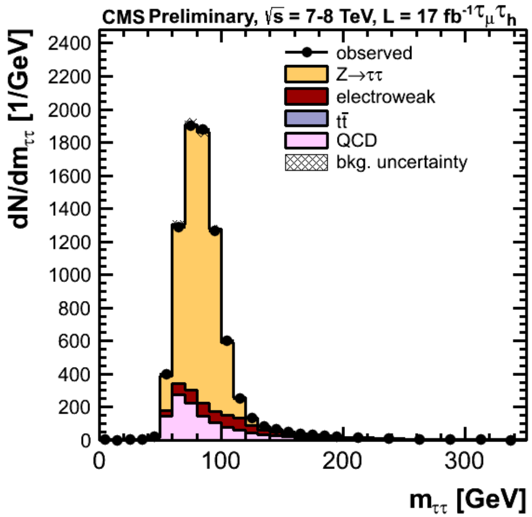


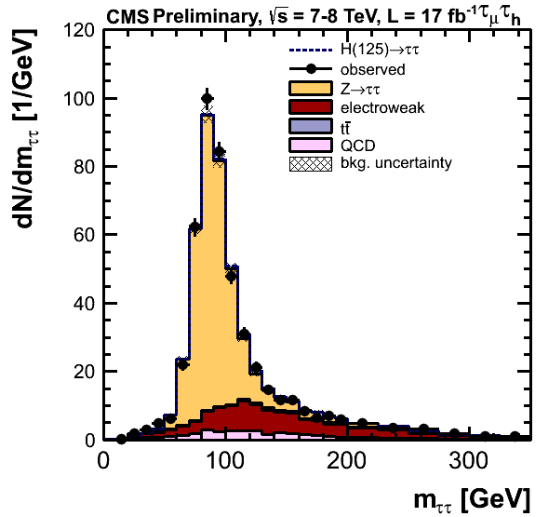


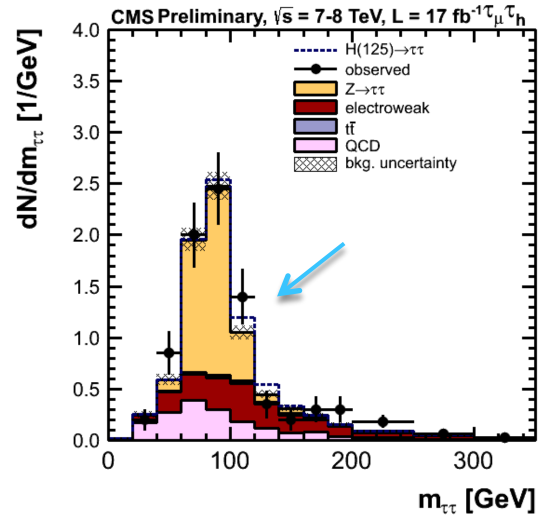
- **Expected performance:**
  - 1-jet and 2-jet on par.
    - Driven by $\tau_\mu \tau_h$ and $\tau_e \tau_h$.
  - Additional power from VH analysis.

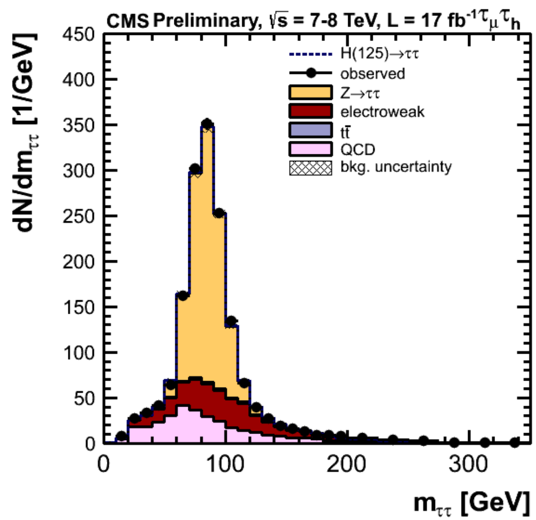
$H \rightarrow \tau_{\mu} \tau_{h}$

[HIG-12-043]









0-jets
BG

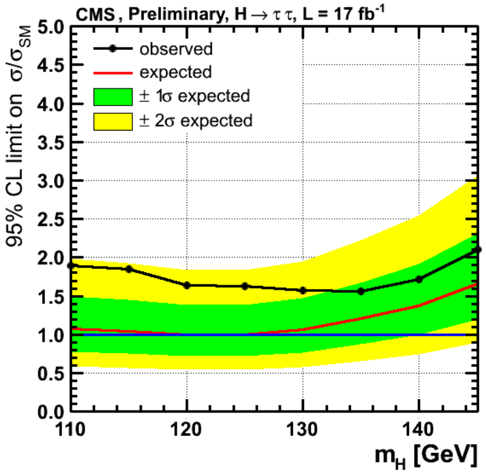
1-jet
High τ p_T

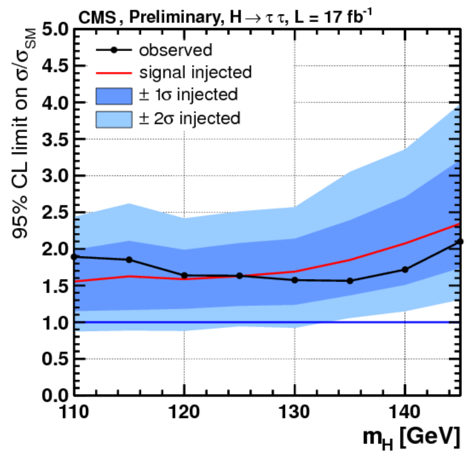
2-jets
VBF

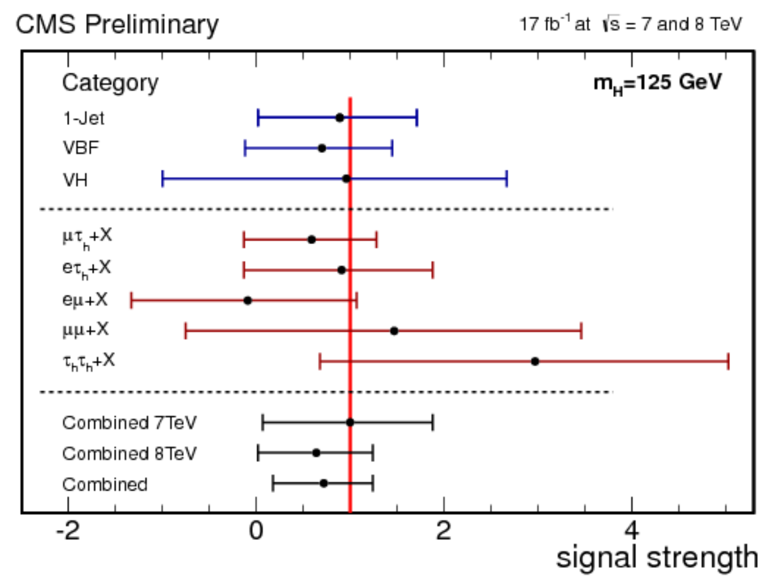
1-jet
Low τ p_T

H→ $\tau\ \tau$

[HIG-12-043][HIG-12-051]



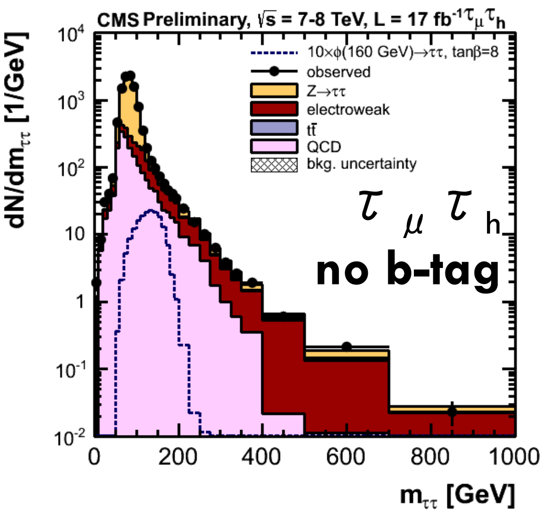


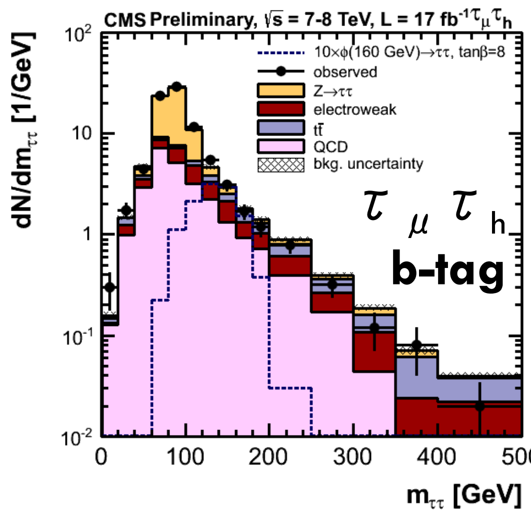


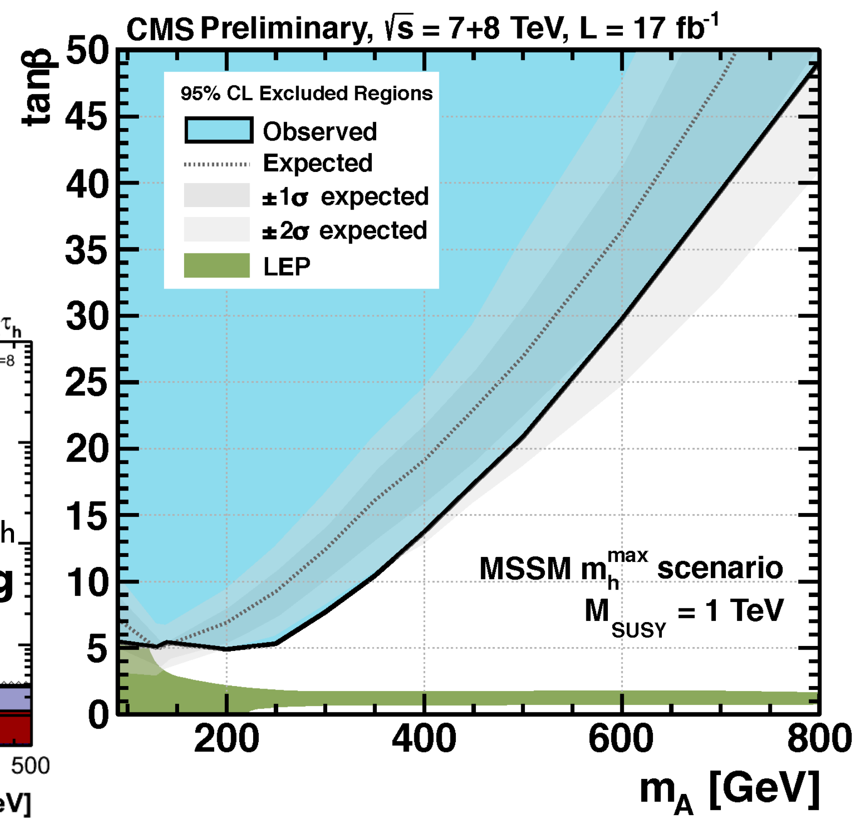
- Sensitivity ~1x SM.
  - Injecting SMH at 125 GeV gives good agreement.
- For $m_H = 125$ GeV:
  - **1.50 σ obs.** (2.45 σ exp.).
  - σ / σ_{SM} **= 0.7 ±0.5.**

H→ τ τ : MSSM specialist

- Further categorize SM search on b-tag.
- **Limits in m_h^{max} scenario.**

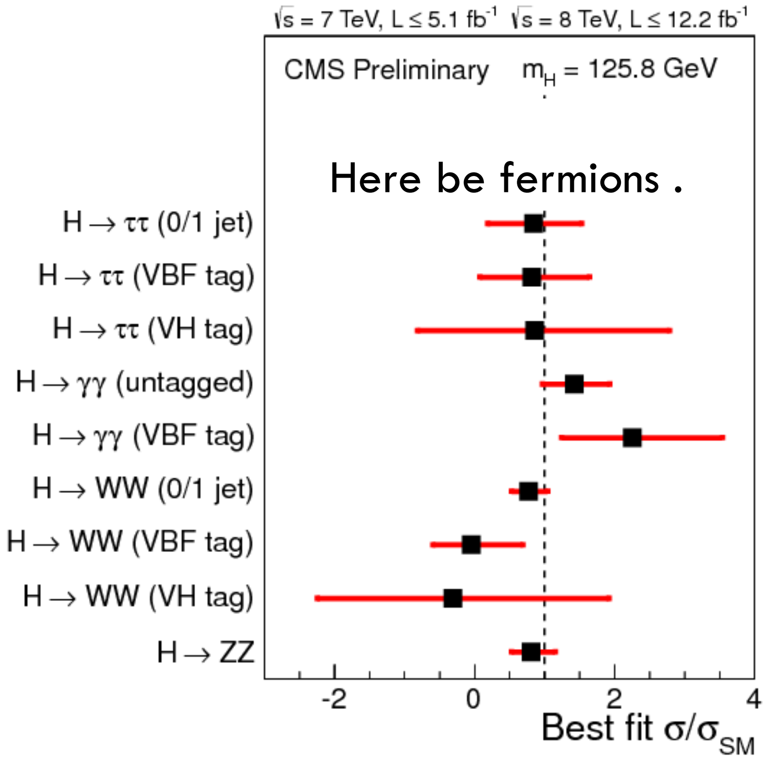






You are here

- How about fermions ?
  - Not clear on July 4.
- Hints in H→ $\tau\ \tau$.



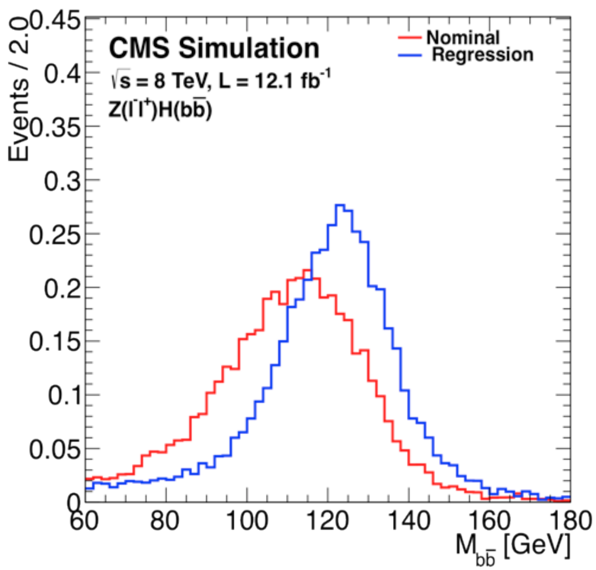
Here be bosons x3 !

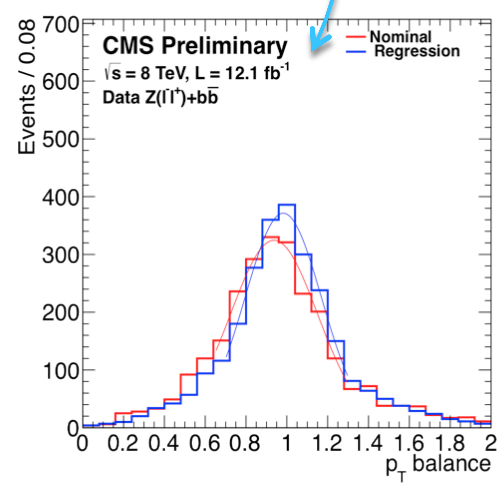
VH→Vbb

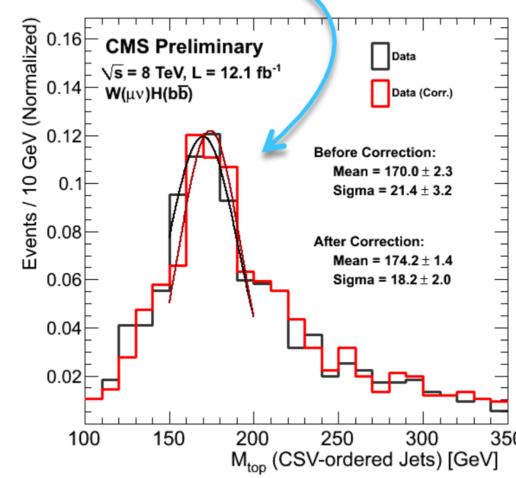
[HIG-12-044]

- Use five leptonic decays of the V.
  - Times 2 categories based on $p_T(V)$.
- **B-jet energy regression: improved mass resolution.**
  - Better $Z(\ell\ell)$+bb p_T balance.
  - Better top mass reconstruction.

Z(ν ν) x2	Z(ee) x2	W(e ν) x2
	Z(μ μ) x2	**W(μ ν)** x2

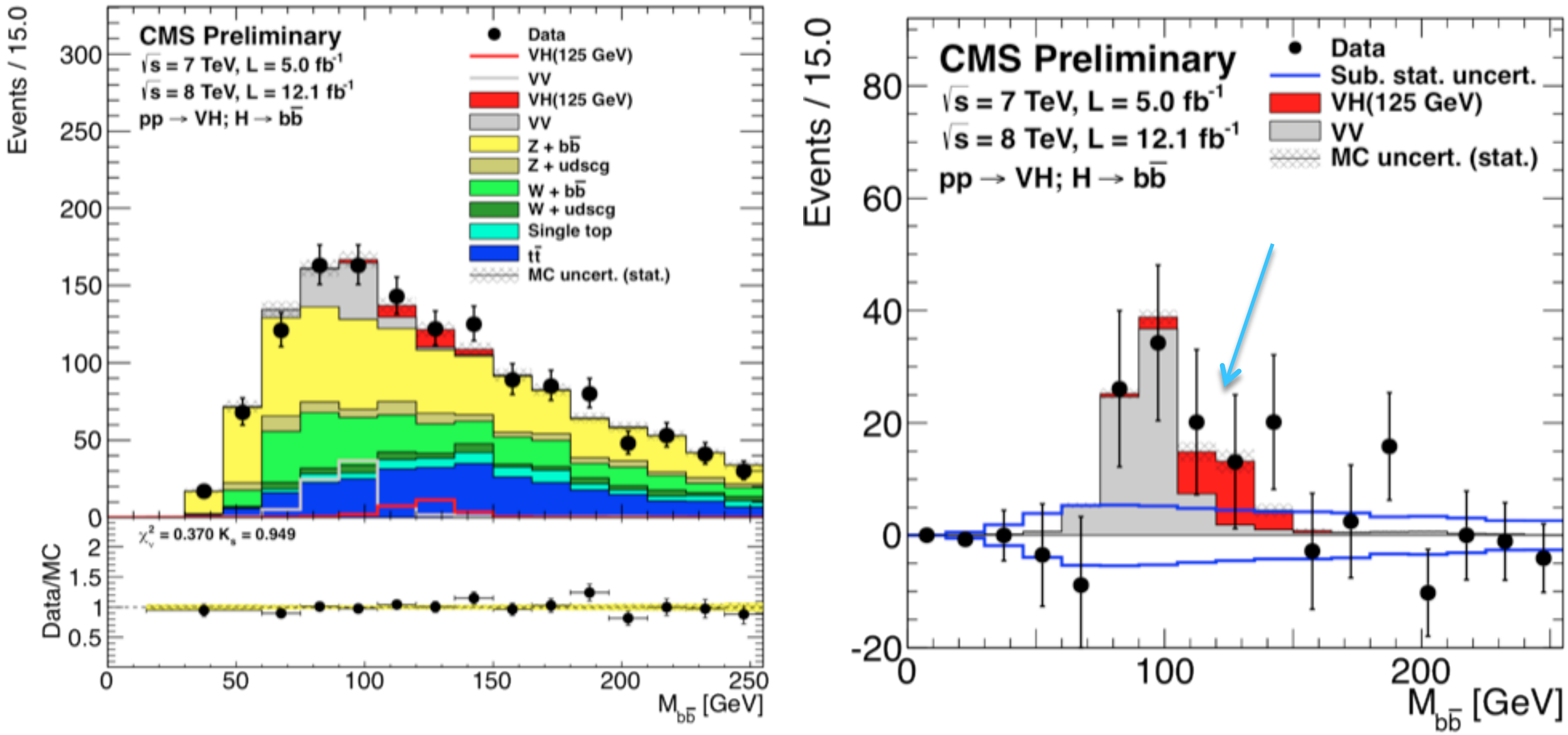






VH→Vbb

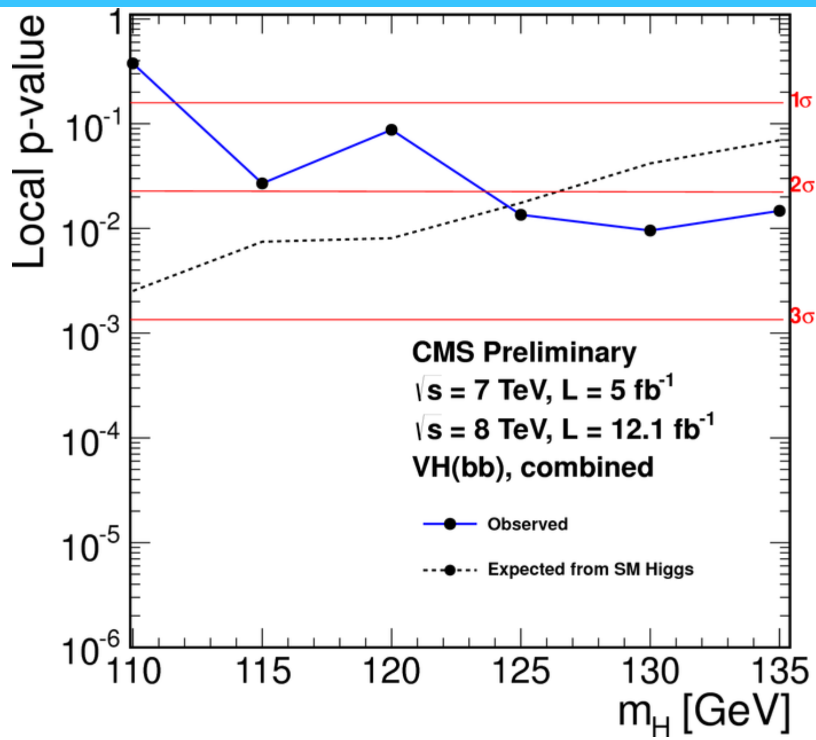
 [HIG-12-044]

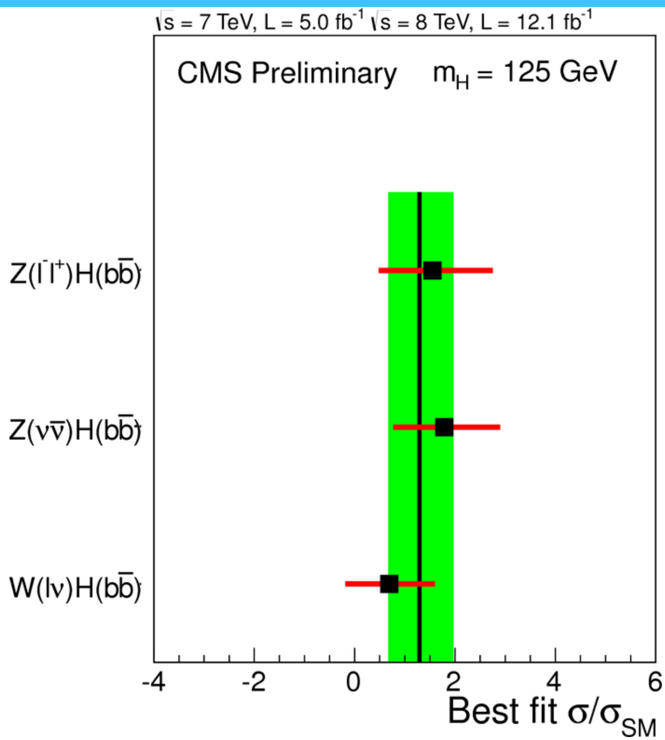


- VV signal in place and **hints of excess** in region of interest.

VH→Vbb

[HIG-12-044]



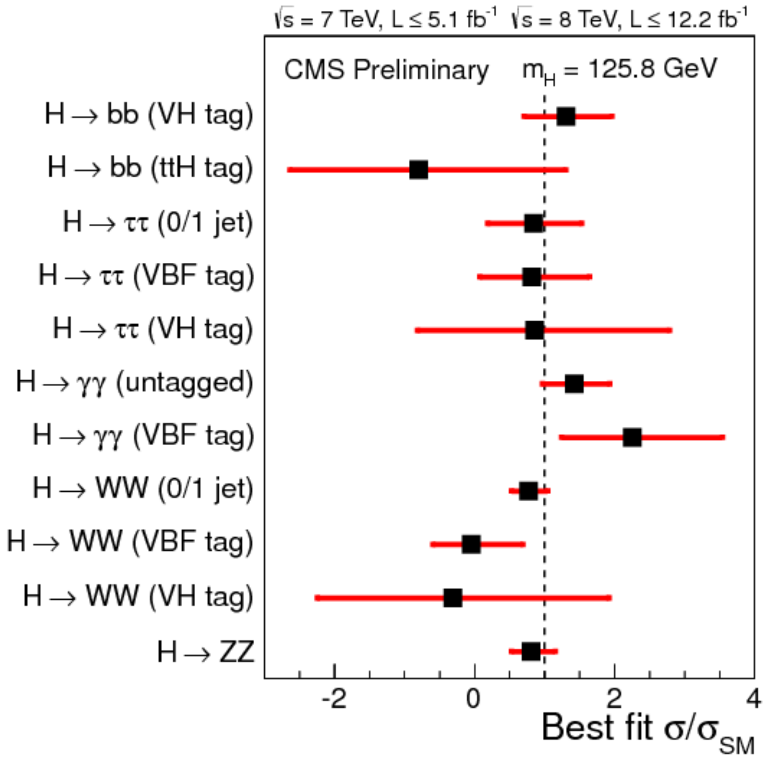


- For $m_H = 125$ GeV:
  - **2.2σ obs.**
  - **$\sigma/\sigma_{SM} = 1.3^{+0.7}_{-0.6}$.**

You are here

- How about fermions ?
  - Not clear on July 4.
- Hints in H→ τ τ .
- …and in H→bb.
- So what's the bigger picture ?

Here be fermions x2 .



Here be bosons x3 !

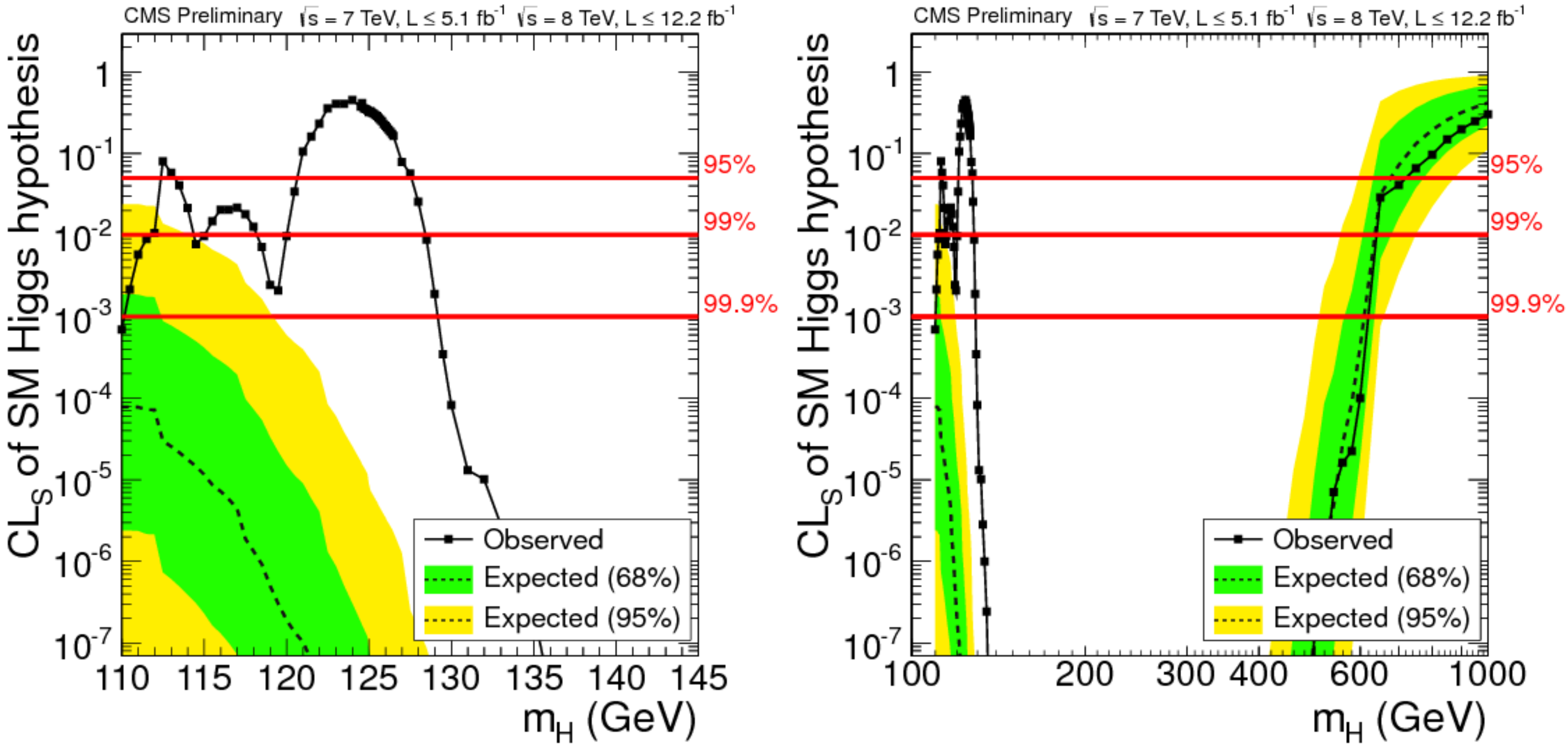
Onwards to…

the Juicy stuff®

>>> a cocktail for success

Exclusion

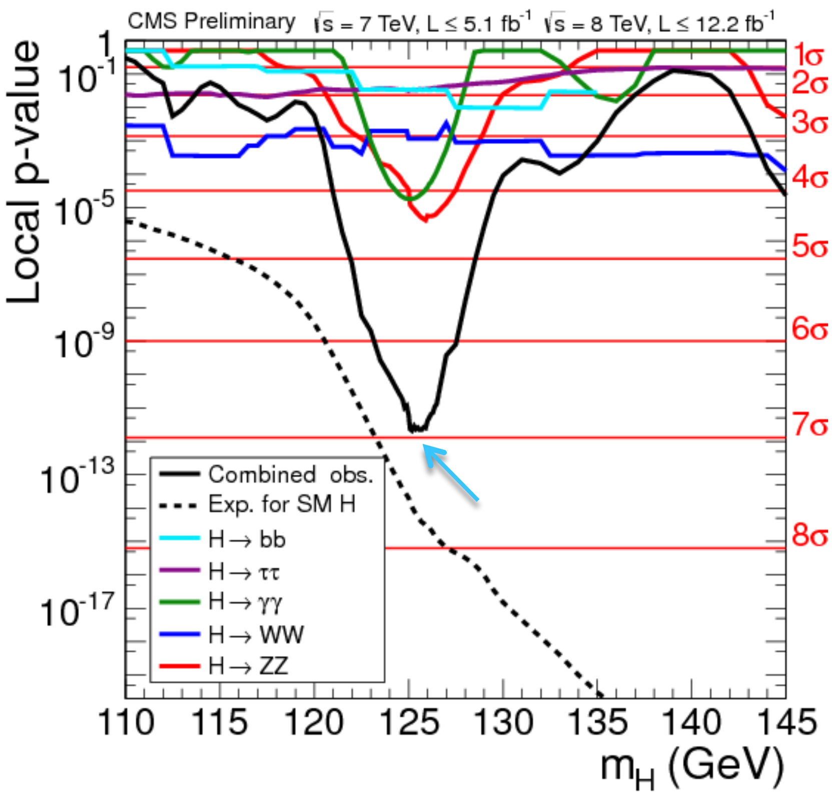
[HIG-12-045]

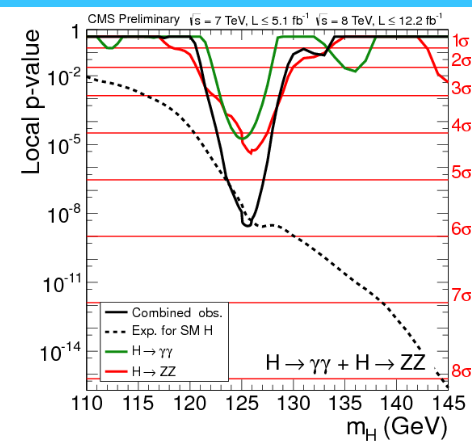


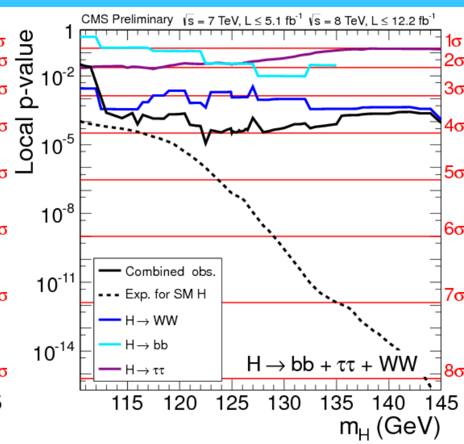
- Small blip at 113 GeV in LEP-excluded range.
- In high mass range: **m_H > 700 GeV (95% CL)**

Incompatibility with background

[HIG-12-045]





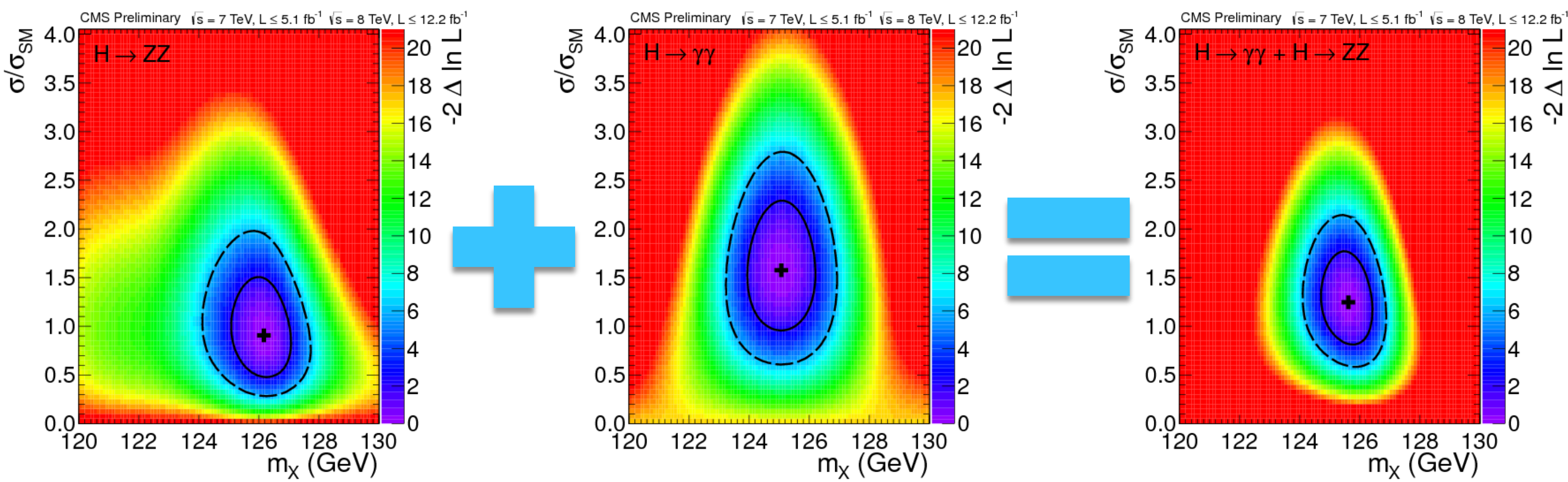


Decay mode or combination	Expected (σ)	Observed (σ)
ZZ	5.0	4.4
$\gamma\gamma$	2.8	4.0
WW	4.3	3.0
bb	2.2	1.8
$\tau\tau$	2.1	1.8
$\gamma\gamma$ + ZZ	5.7	5.8
$\gamma\gamma$ + ZZ + WW + $\tau\tau$ + bb	7.8	6.9

- **Significance flat between 125 and 126 GeV.**
  - Driven by **ZZ**+ $\gamma\gamma$,
    but substantial contribution from **bb** + $\tau\tau$ + **WW**.

Mass measurement

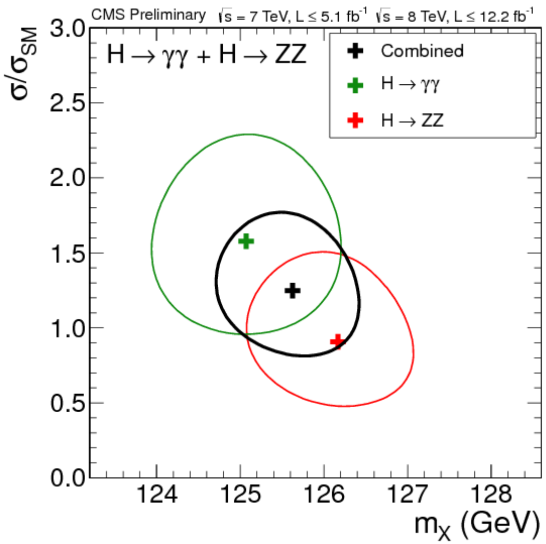
[HIG-12-045]

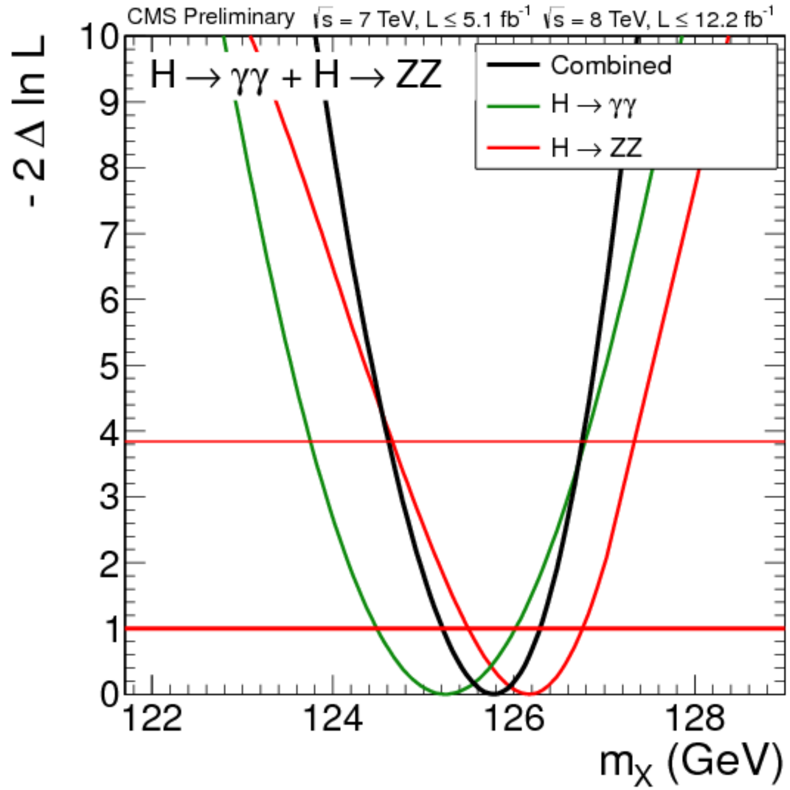


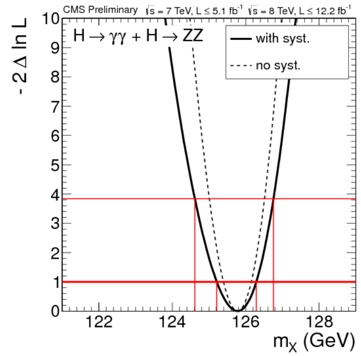
- Good complementarity in the μ vs m_H plane.
- **m_X = 125.8 ±0.4(stat.) ±0.4(syst.) GeV.**

Mass measurement

[HIG-12-045]





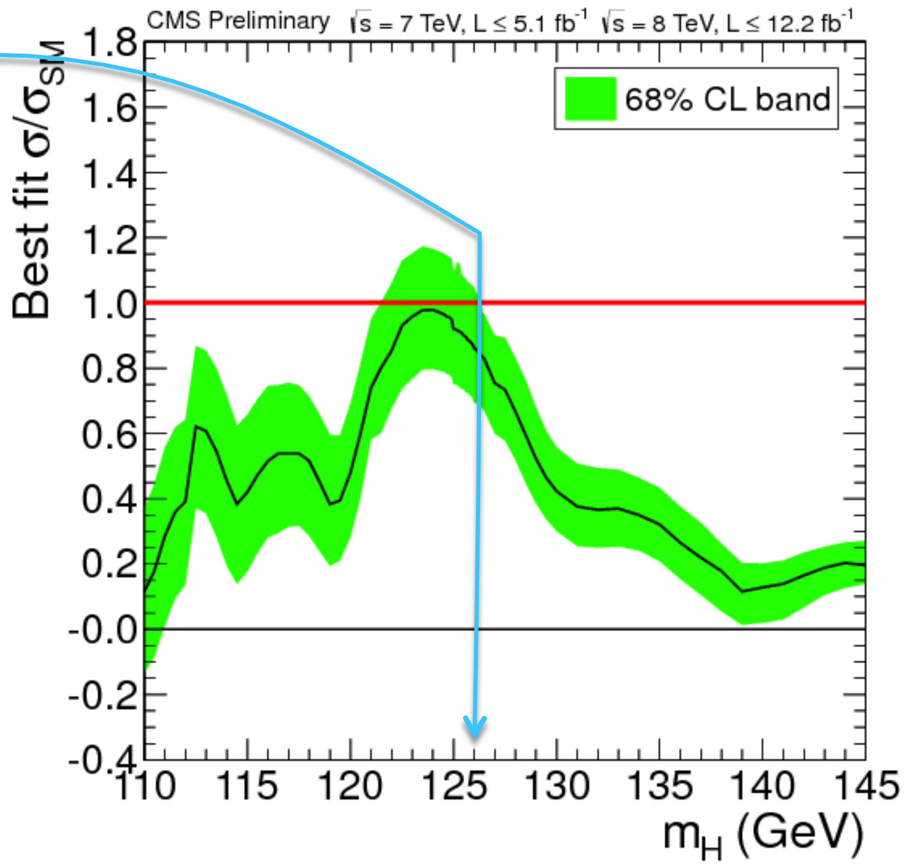


- Profile $\mu_{(ggH+ttH)}$ and $\mu_{(VBF+VH)}$ separately in $\gamma\gamma$.
- **m_X = 125.8 ±0.4(stat.) ±0.4(syst.) GeV.**

Signal strength

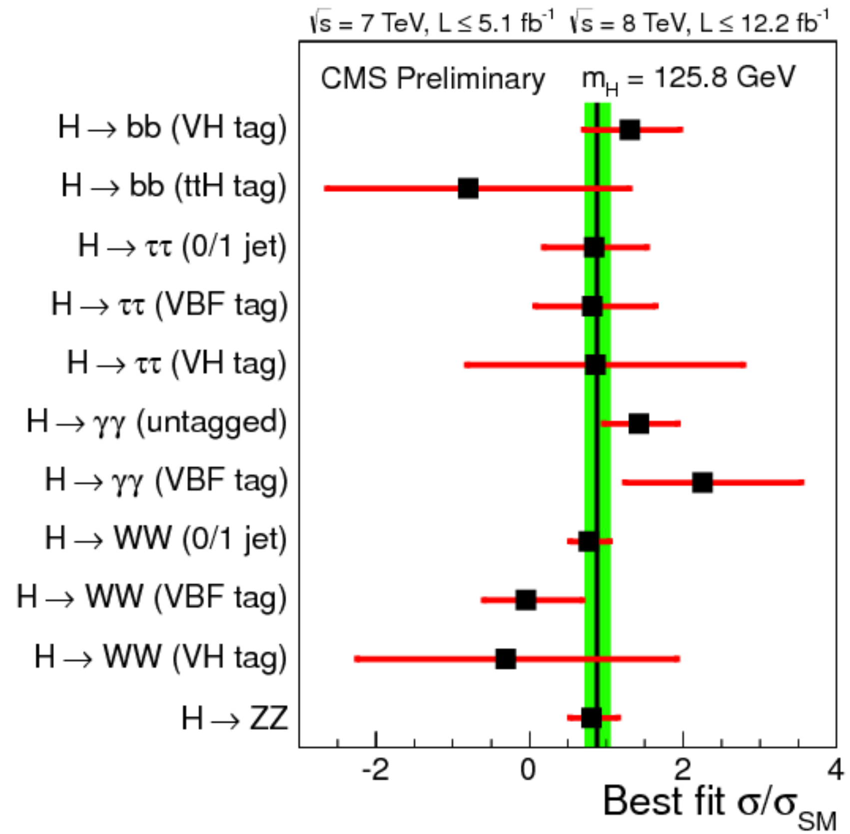
[HIG-12-045]

- At m_H = 125.8 GeV:
  - σ / σ_{SM} **= 0.88 ±0.21.**



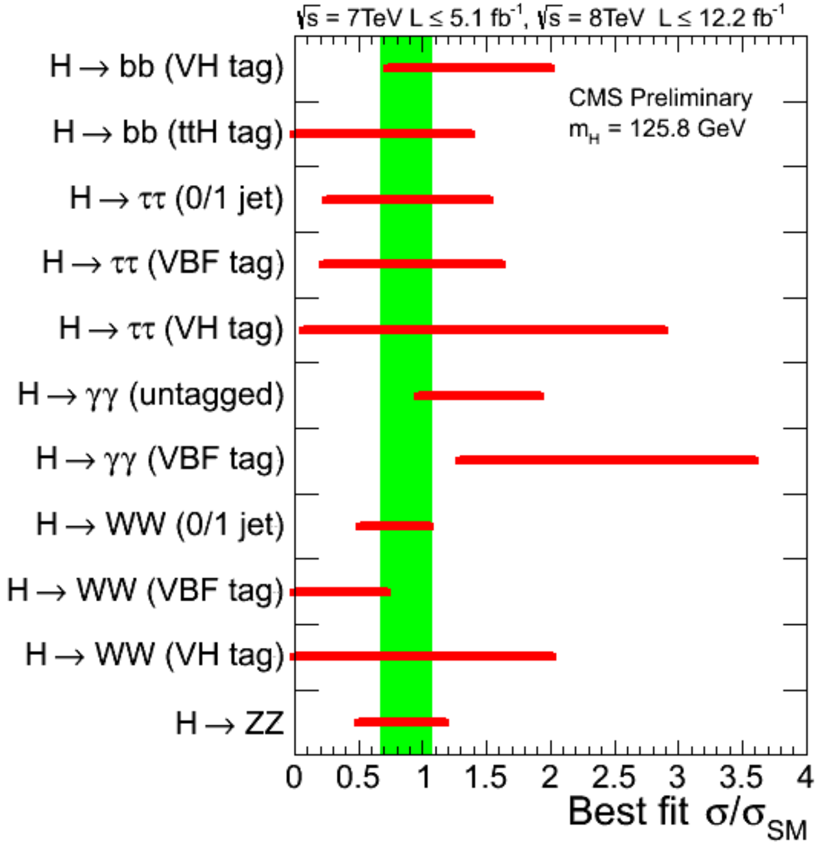
Signal strength compatibility

- At m_H = 125.8 GeV:
  - σ / σ_{SM} **= 0.88 ±0.21.**
- **Channels:**
  - χ^2/ndf = 8.7 / 11
  - p-value:
    - Asymptotic: 65%.
    - Toys: 46%.



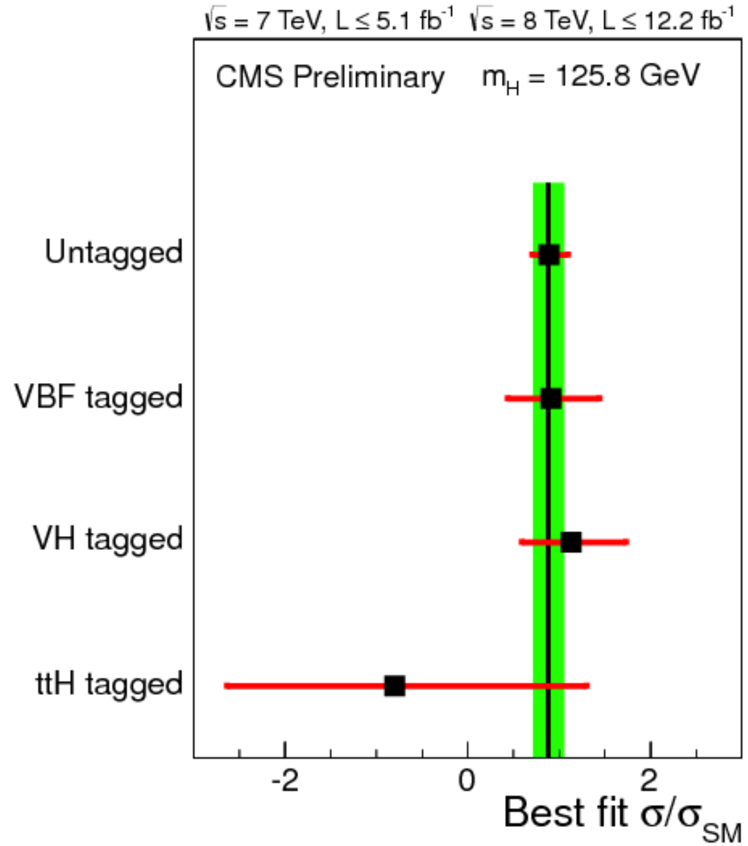
Signal strength compatibility

- At m_H = 125.8 GeV:
  - σ / σ_{SM} **= 0.88 ±0.21.**
- **Channels:**
  - Feldman-Cousins construction, same results.



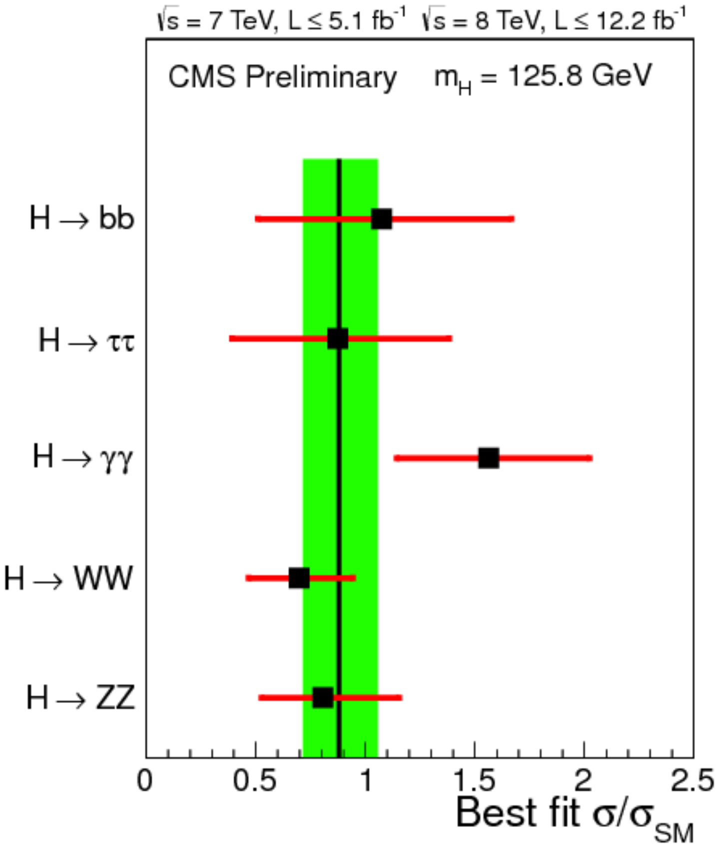
Signal strength compatibility

- At m_H = 125.8 GeV:
  - σ/σ_{SM} **= 0.88 ±0.21.**
- **Production modes:**
  - $\chi^2/\text{ndf} = 1.3\ /\ 4$
  - p-value:
    - Asymptotic: 86%.
    - Toys: 87%.



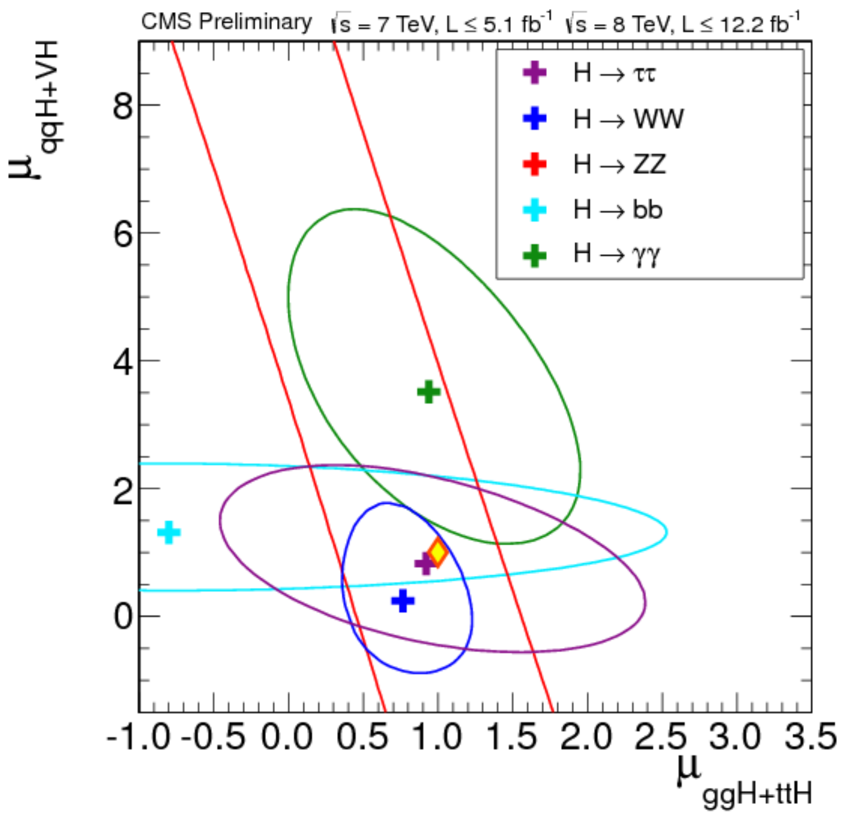
Signal strength compatibility

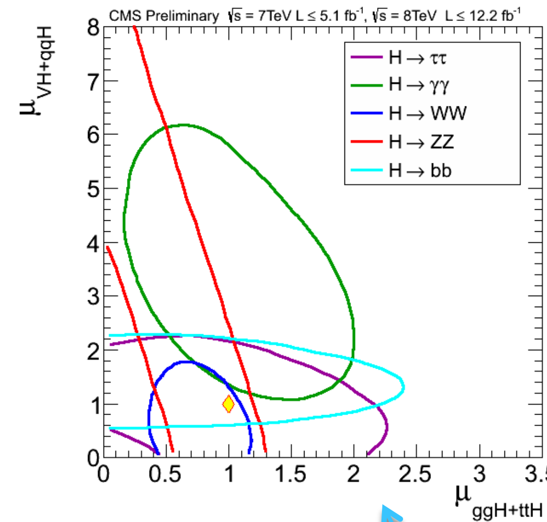
- At $m_H = 125.8$ GeV:
  - $\sigma / \sigma_{SM} = 0.88 \pm 0.21$.
- **Decay modes:**
  - $\chi^2/\text{ndf} = 4.3 / 5$
  - p-value:
    - Asymptotic: 51%.
    - Toys: 54%.



Scaling production modes

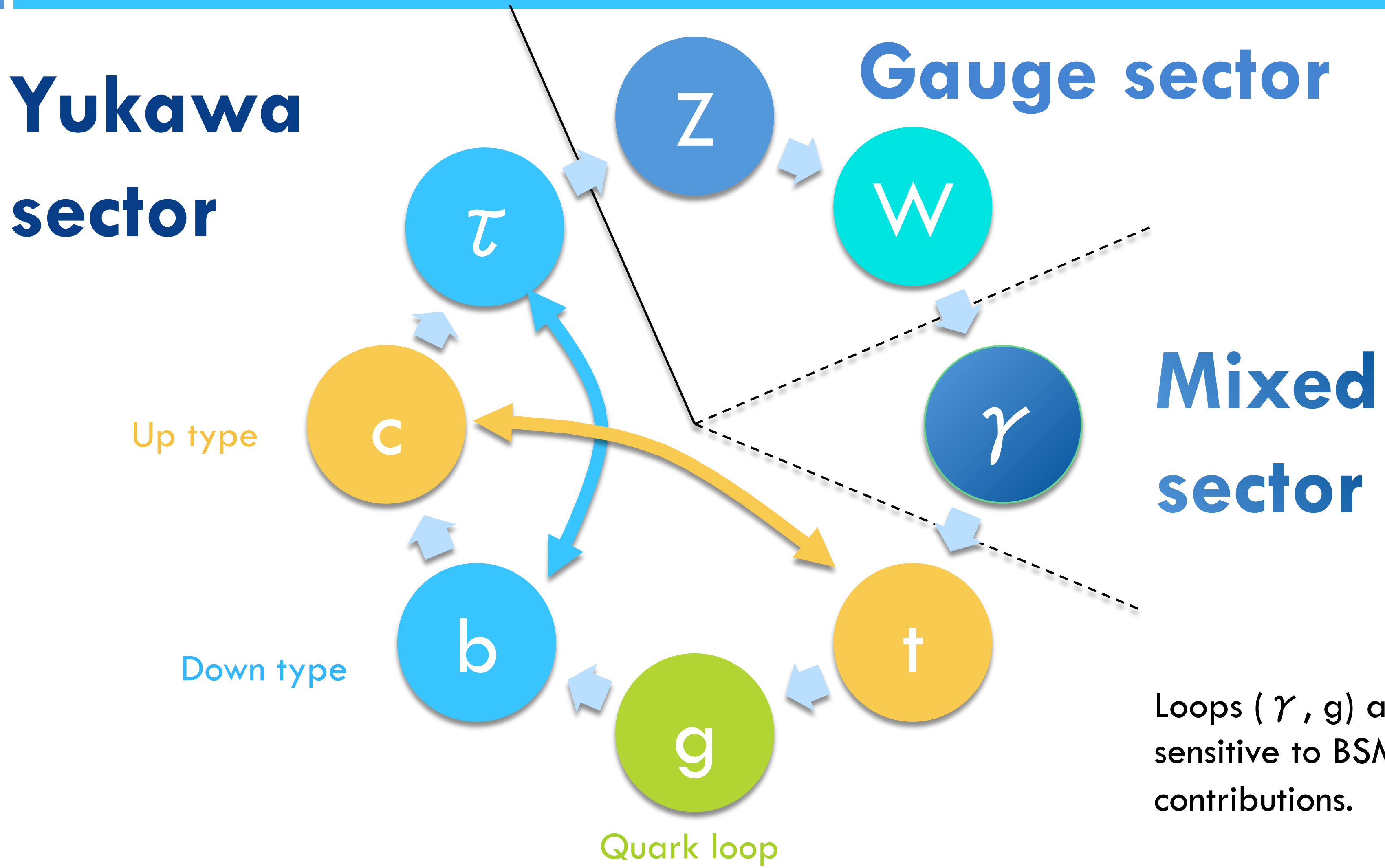
[HIG-12-045]





- Fit for $\mu_{ggH+ttH}$ and μ_{VBF+VH} separately in each decay mode.
  - **Comprehensive compatibility with SMH.**
  - Cross-check with Feldman-Cousins construction, same conclusions.

Scalar coupling structures



Loops (γ , g) are sensitive to BSM contributions.

Scalar coupling deviations framework

[arXiv:1209.0040]

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

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

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

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

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

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

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

Currently undetectable decay modes

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

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

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

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

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

Total width

$$\frac{\Gamma_H}{\Gamma_H^{SM}} = \begin{cases} \kappa_H^2(\kappa_i, m_H) \\ \kappa_H^2 \end{cases}$$

Custodial symmetry

[arXiv:1209.0040]

Probing custodial symmetry assuming no invisible or undetectable widths

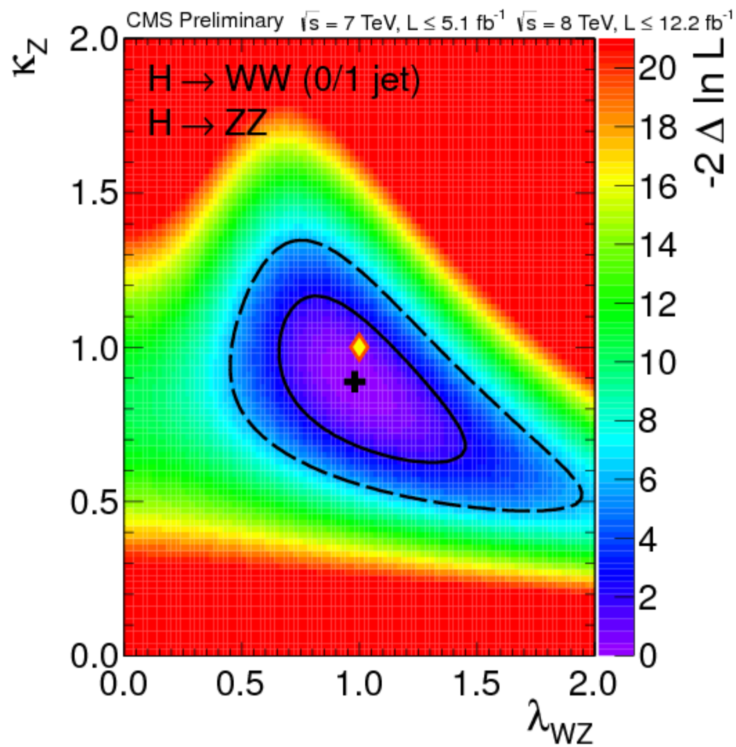
Free parameters: $\kappa_Z, \lambda_{WZ} (= \kappa_W/\kappa_Z), \kappa_f (= \kappa_t = \kappa_b = \kappa_\tau)$.

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

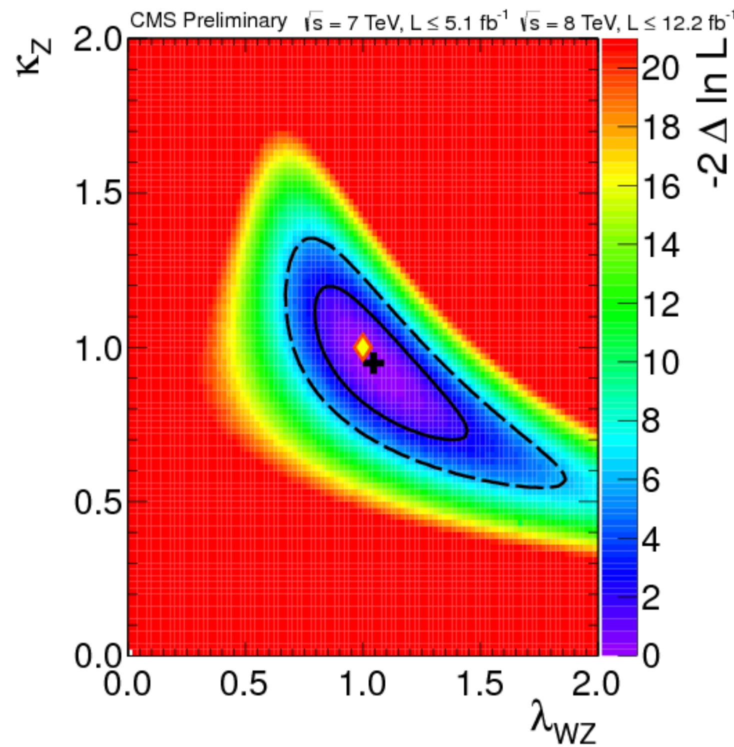
Custodial symmetry

[HIG-12-045]

$WW_{(0/1\ jet)}$ and ZZ events
+ $\kappa_F = 1$ as for SMH



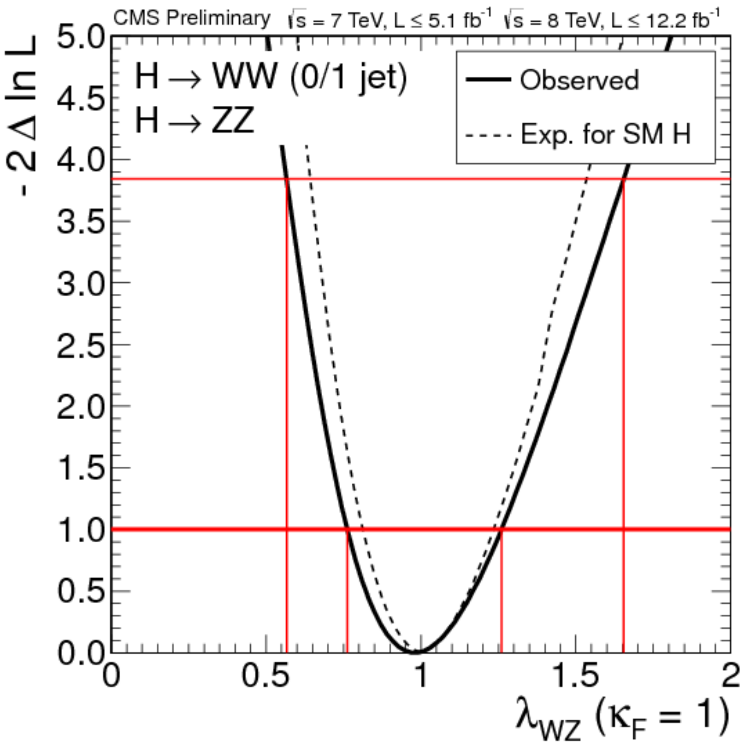
All channels, profiling κ_F



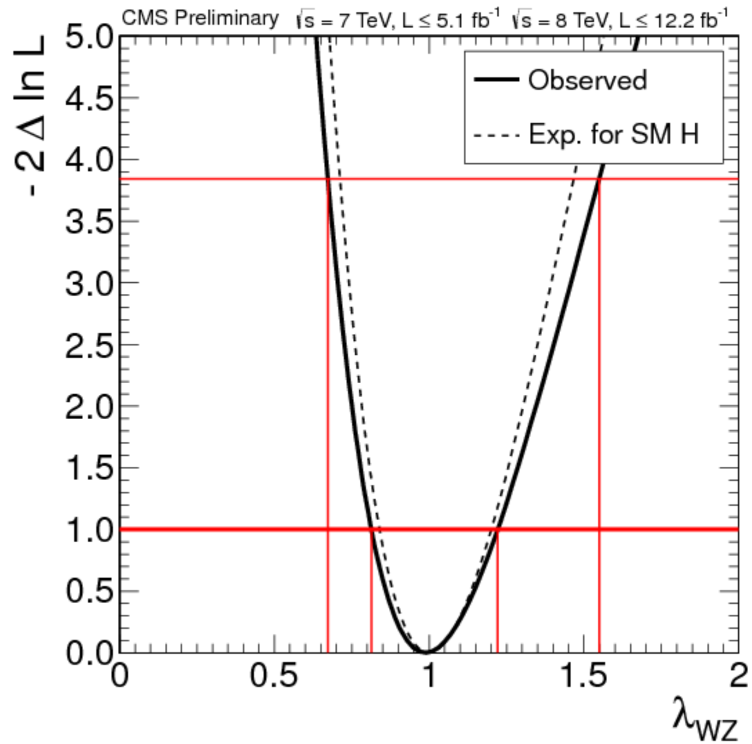
Custodial symmetry

[HIG-12-045]

$WW_{(0/1\ jet)}$ and ZZ events + $\kappa_F = 1$ as for SMH + profile κ_Z.



All channels, profiling κ_F, κ_Z.
λ_{WZ} in [0.68—1.55] 95%CL.



Weak bosons and fermions

[arXiv:1209.0040]

Boson and fermion scaling assuming no invisible or undetectable widths

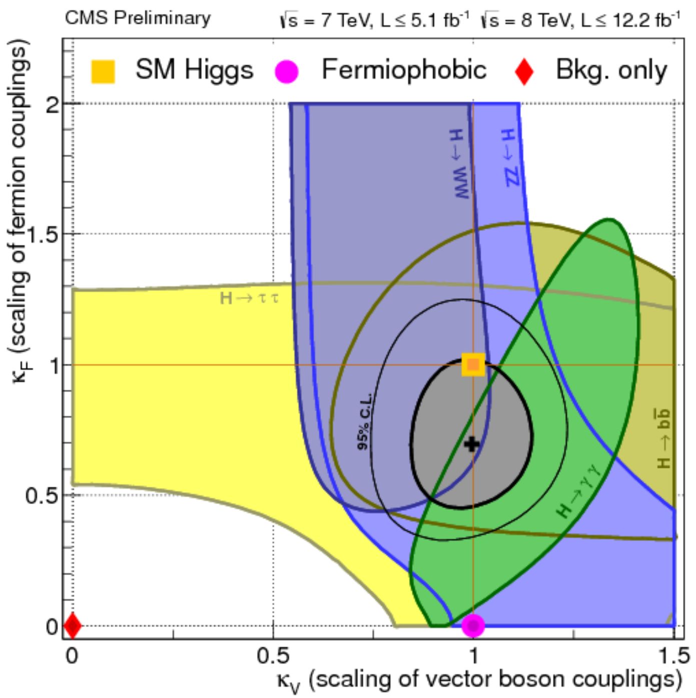
Free parameters: $\kappa_V (= \kappa_W = \kappa_Z), \kappa_f (= \kappa_t = \kappa_b = \kappa_\tau)$.

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

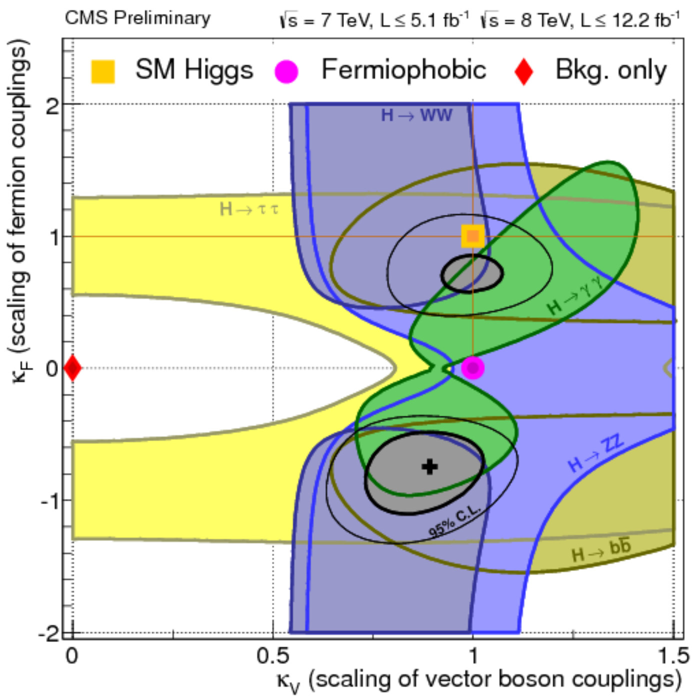
Weak bosons and fermions

 [HIG-12-045]

SM quadrant only



Both quadrants



Looking for new particles

[arXiv:1209.0040]

Probing loop structure assuming no invisible or undetectable widths

Free parameters: κ_g, κ_γ.

	$H \to \gamma\gamma$	$H \to ZZ^{(*)}$	$H \to WW^{(*)}$	$H \to b\bar{b}$	$H \to \tau^-\tau^+$
ggH	$\frac{\kappa_g^2 \cdot \kappa_\gamma^2}{\kappa_H^2(\kappa_i)}$			$\frac{\kappa_g^2}{\kappa_H^2(\kappa_i)}$	
$t\bar{t}H$, VBF, WH, ZH	$\frac{\kappa_\gamma^2}{\kappa_H^2(\kappa_i)}$			$\frac{1}{\kappa_H^2(\kappa_i)}$	

Probing loop structure allowing for invisible or undetectable widths

Free parameters: $\kappa_g, \kappa_\gamma, BR_{inv.,undet.}$.

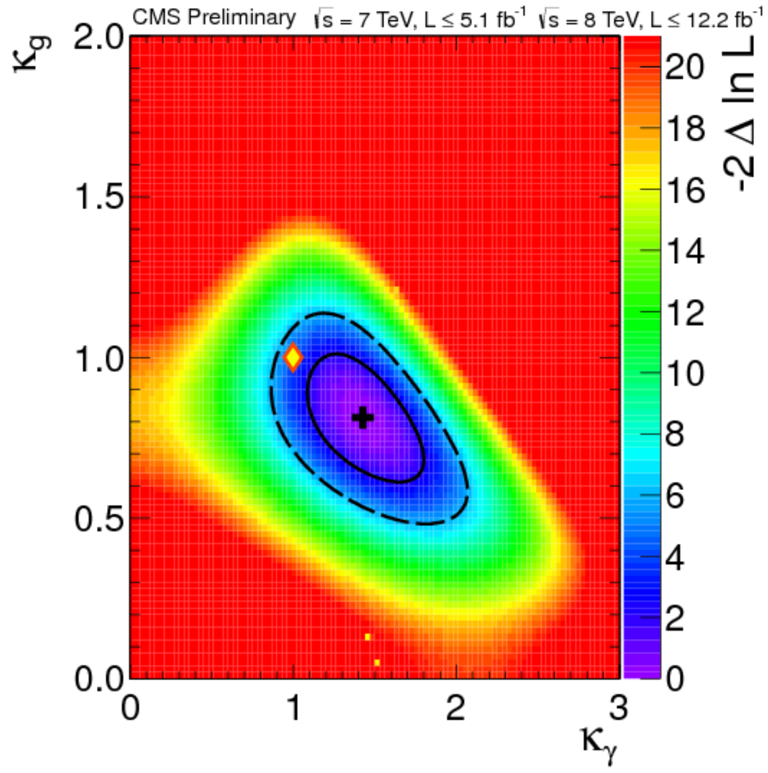
	$H \to \gamma\gamma$	$H \to ZZ^{(*)}$	$H \to WW^{(*)}$	$H \to b\bar{b}$	$H \to \tau^-\tau^+$
ggH	$\frac{\kappa_g^2 \cdot \kappa_\gamma^2}{\kappa_H^2(\kappa_i)/(1-BR_{inv.,undet.})}$			$\frac{\kappa_g^2}{\kappa_H^2(\kappa_i)/(1-BR_{inv.,undet.})}$	
$t\bar{t}H$, VBF, WH, ZH	$\frac{\kappa_\gamma^2}{\kappa_H^2(\kappa_i)/(1-BR_{inv.,undet.})}$			$\frac{1}{\kappa_H^2(\kappa_i)/(1-BR_{inv.,undet.})}$	

$$\kappa_i^2 = \Gamma_{ii}/\Gamma_{ii}^{SM}$$

Loops

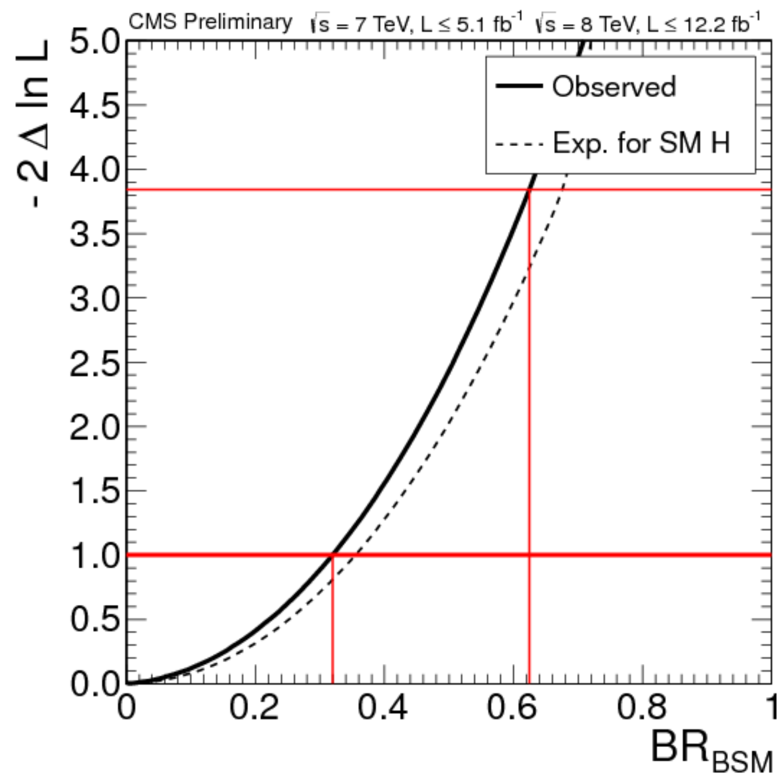
[HIG-12-045]

- Scale couplings to gluons (photons) effectively: κ_g, κ_γ.
- Everything else as in SM.



Loops and new contributions

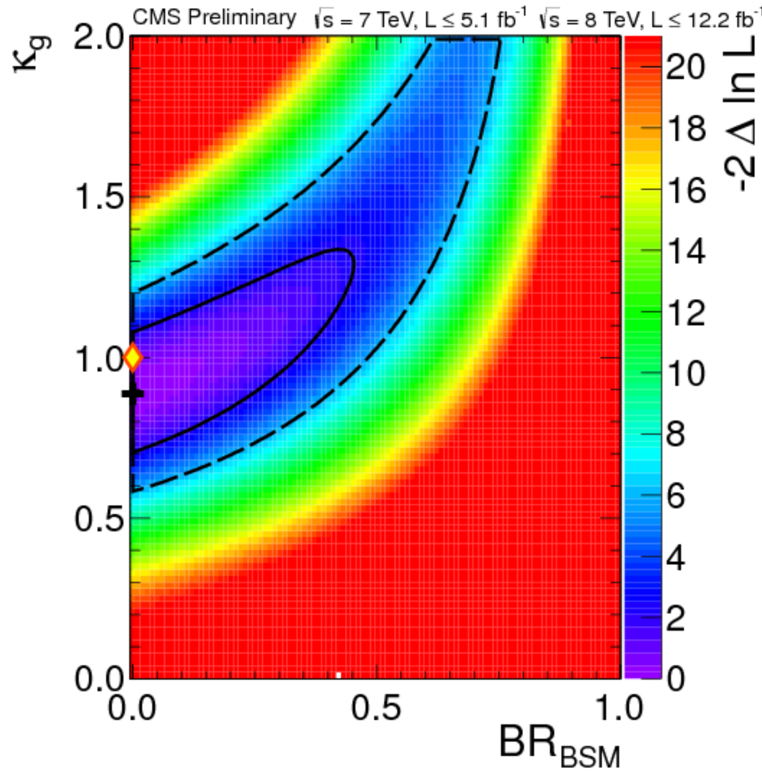
- Scale couplings to gluons (photons) effectively: κ_g, κ_γ.
- Additionally, allow total width to change by 1 / (1 - $\mathbf{BR_{BSM}}$).



Loops and new contributions

[HIG-12-045]

- Scale couplings to gluons (photons) effectively: κ_g, κ_γ.
- Additionally, allow total width to change by $1 / (1 - \mathrm{BR}_{\mathrm{BSM}})$.
- Demonstration that the LHC cannot measure the total width.



Probing possible 2HDM

[arXiv:1209.0040]

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	$\frac{\kappa_V^2\cdot\kappa_\gamma^2(\kappa_u\lambda_{du},\kappa_u,\kappa_u\lambda_{du},\kappa_V)}{\kappa_H^2(\kappa_i)}$	$\frac{\kappa_V^2\cdot\kappa_V^2}{\kappa_H^2(\kappa_i)}$		$\frac{\kappa_V^2\cdot(\kappa_u\lambda_{du})^2}{\kappa_H^2(\kappa_i)}$	

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

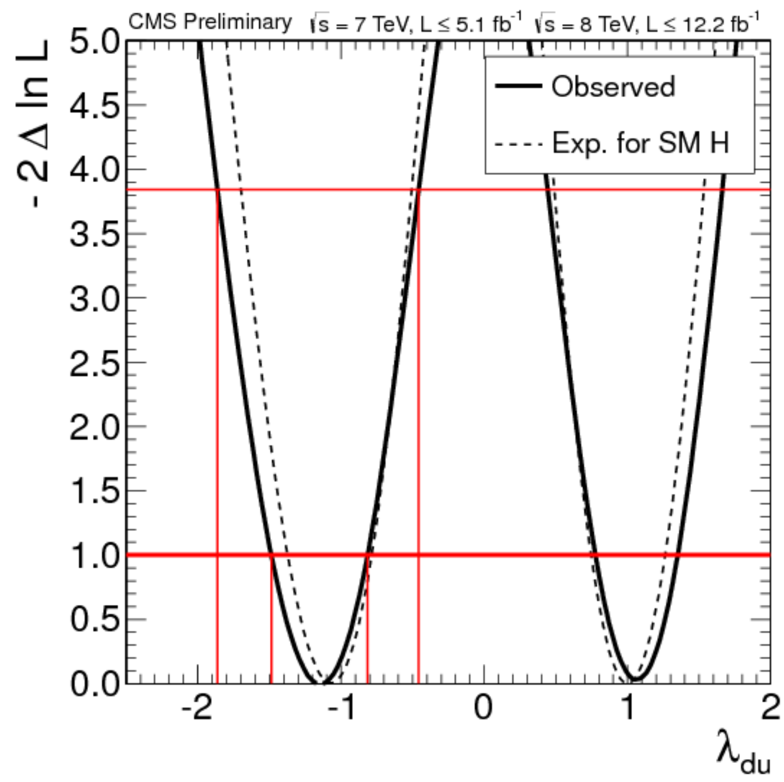
Free parameters: $\kappa_V (= \kappa_Z = \kappa_W), \lambda_{lq} (= \kappa_l/\kappa_q), \kappa_q (= \kappa_t = \kappa_b)$.

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

Up-type vs down-type fermions

[HIG-12-045]

- κ_V, κ_u, $\lambda_{du} = \kappa_d / \kappa_u$
- Data says only that sign(κ_u) = - sign(λ_{du}).
- **Note how λ_{du} = 0 is very disfavored.**



Up-type vs down-type fermions

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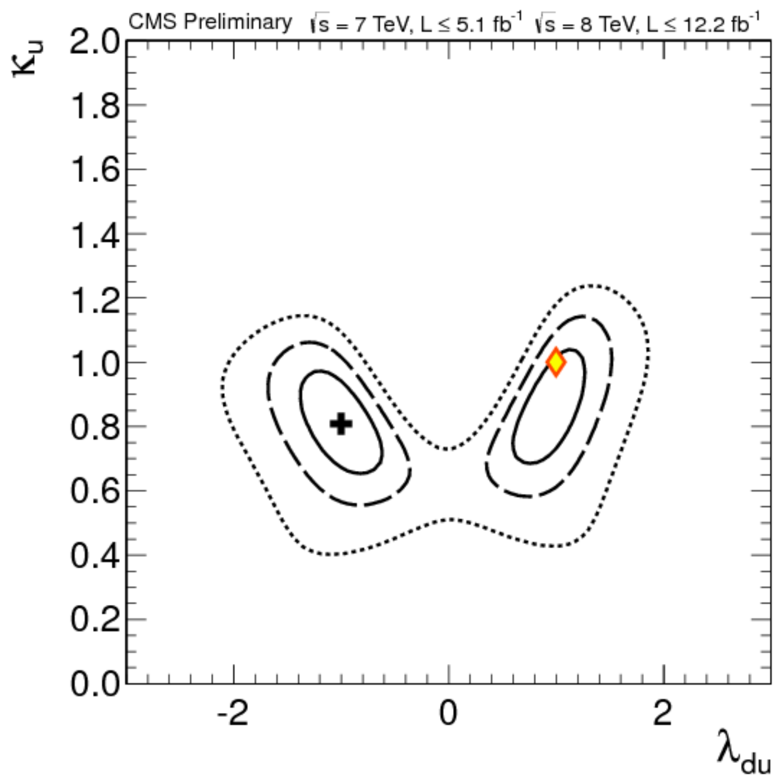

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$t\bar{t}H$	$\frac{\kappa_u^2\cdot\kappa_\gamma^2(\kappa_u\lambda_{du},\kappa_u,\kappa_u\lambda_{du},\kappa_V)}{\kappa_H^2(\kappa_i)}$	$\frac{\kappa_u^2\cdot\kappa_V^2}{\kappa_H^2(\kappa_i)}$		$\frac{\kappa_u^2\cdot(\kappa_u\lambda_{du})^2}{\kappa_H^2(\kappa_i)}$	
VBF WH ZH	$\frac{\kappa_V^2\cdot\kappa_\gamma^2(\kappa_u\lambda_{du},\kappa_u,\kappa_u\lambda_{du},\kappa_V)}{\kappa_H^2(\kappa_i)}$	$\frac{\kappa_V^2\cdot\kappa_V^2}{\kappa_H^2(\kappa_i)}$		$\frac{\kappa_V^2\cdot(\kappa_u\lambda_{du})^2}{\kappa_H^2(\kappa_i)}$	

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 $t\bar{t}H$	$\frac{\kappa_q^2\cdot\kappa_\gamma^2(\kappa_q,\kappa_q,\kappa_q\lambda_{lq},\kappa_V)}{\kappa_H^2(\kappa_i)}$	$\frac{\kappa_q^2\cdot\kappa_V^2}{\kappa_H^2(\kappa_i)}$		$\frac{\kappa_q^2\cdot\kappa_q^2}{\kappa_H^2(\kappa_i)}$	$\frac{\kappa_q^2\cdot(\kappa_q\lambda_{lq})^2}{\kappa_H^2(\kappa_i)}$
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Quarks vs leptons

[HIG-12-045]

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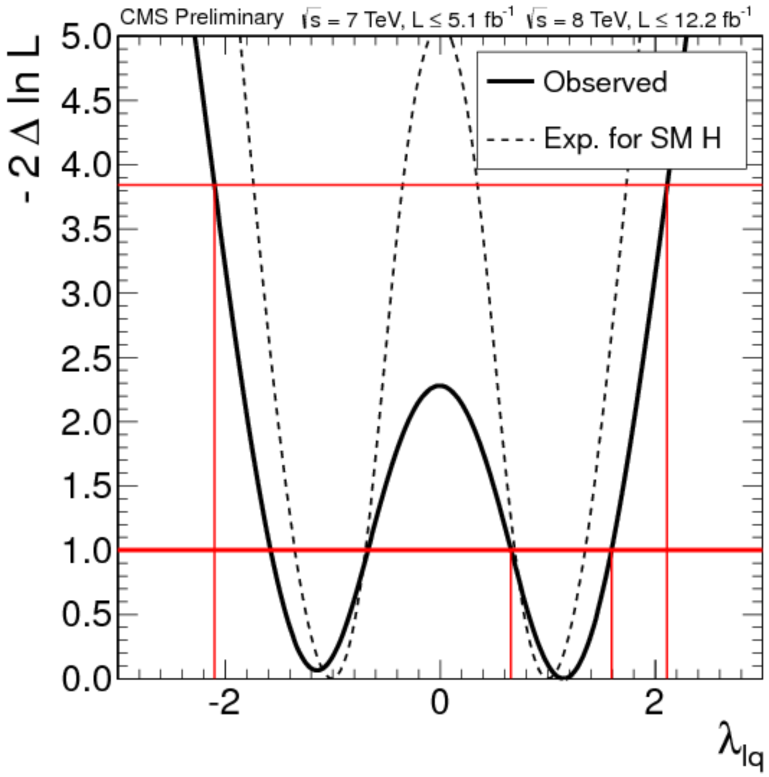
- **Note how $\lambda_{lq} = 0$ is disfavored.**



Quarks vs leptons

[HIG-12-045]

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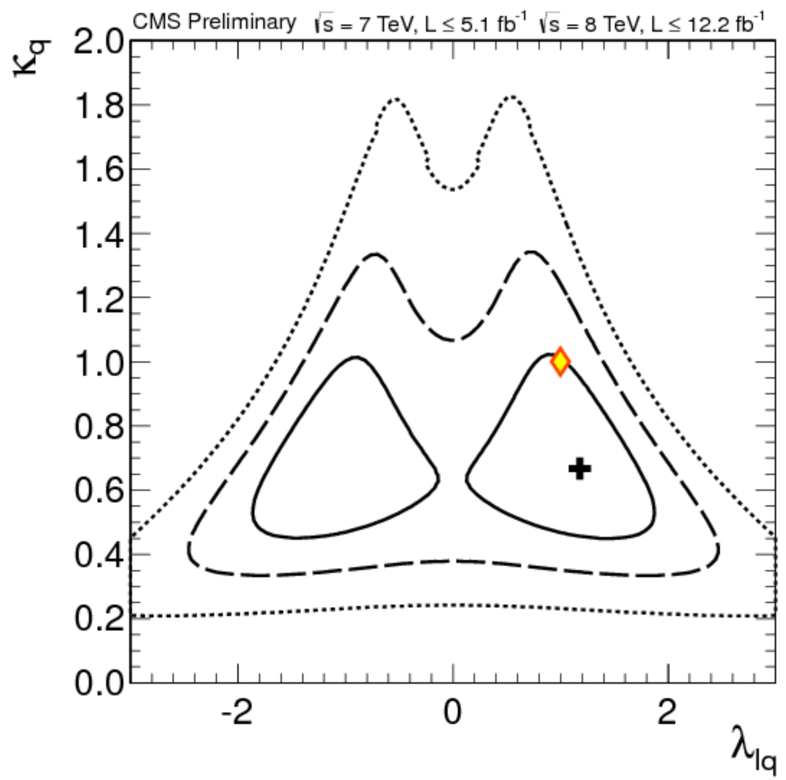


Pushing the data to the limit

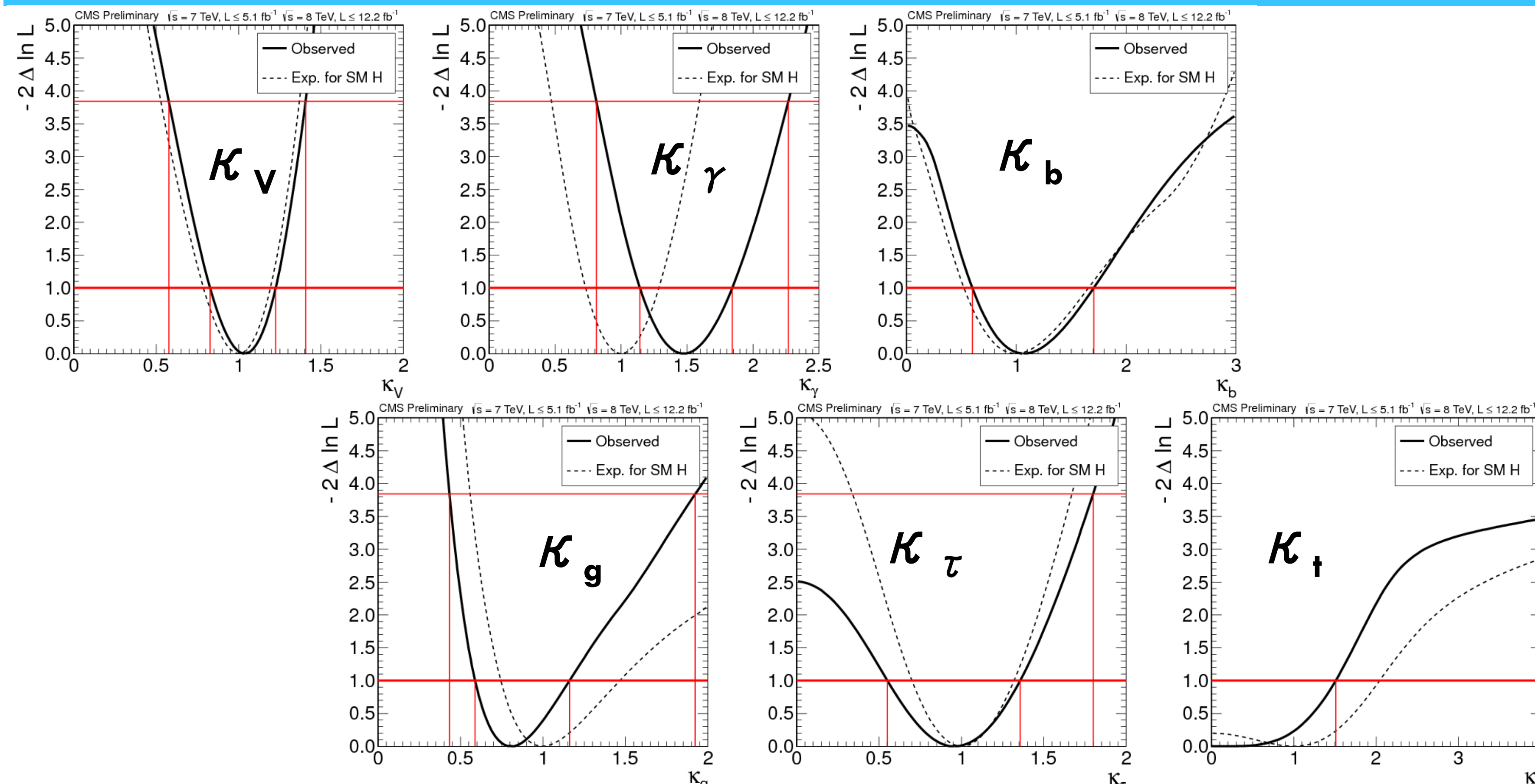
[HIG-12-045]

- Custodial symmetry:
  κ_V.
- Fermions split:
  κ_b, κ_t, κ_τ
- Effective loops:
  κ_γ, κ_g.
- SMH full width.

- Not explicitly a LHC HXSWG benchmark.
- **Good check of how far the data can go.**

Pushing the data to the limit

[HIG-12-045]

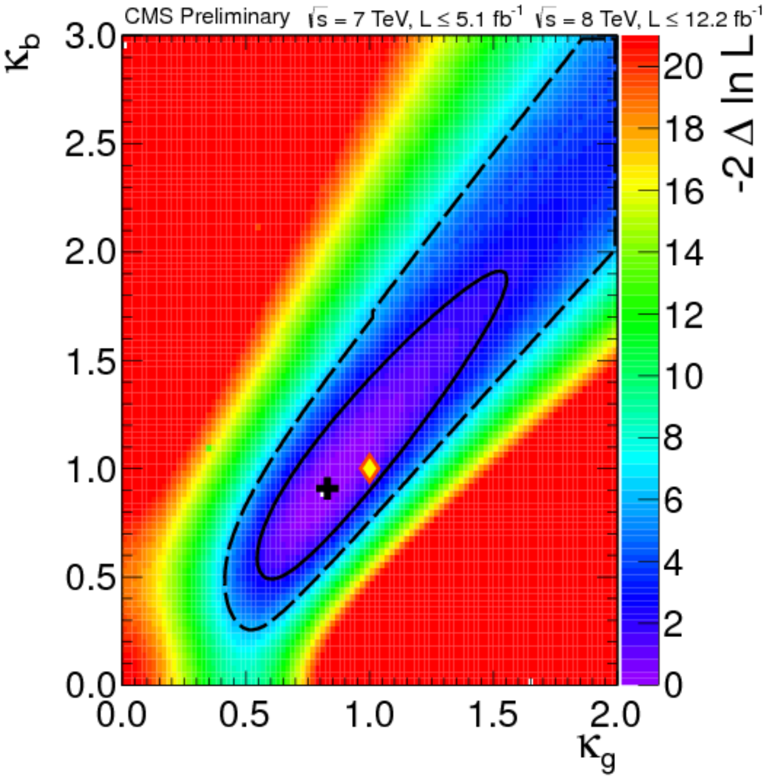


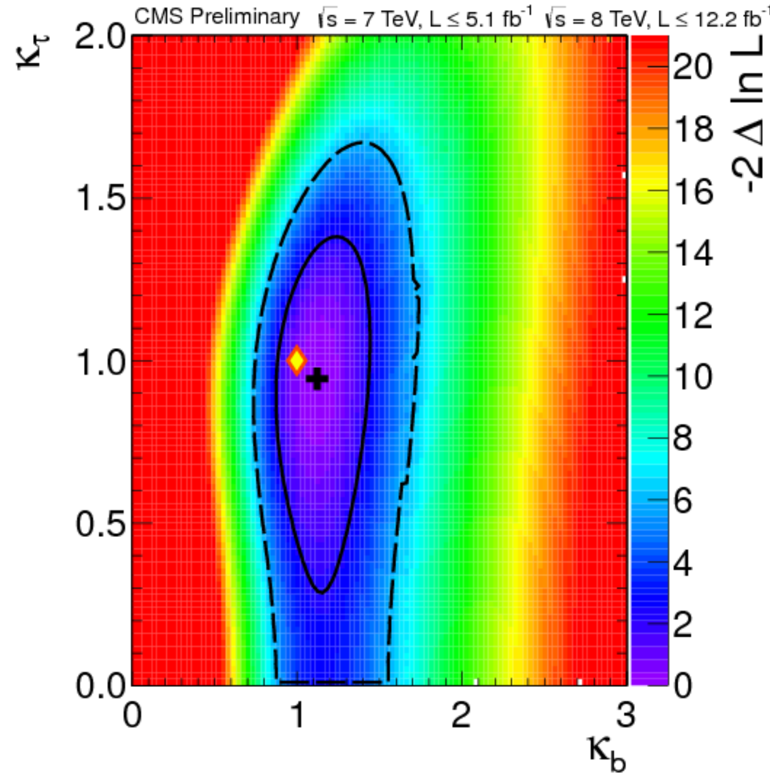
Best constrained → **Least constrained**

- Profiling over the other 5 parameters, all as expected.

Pushing the data to the limit

[HIG-12-045]



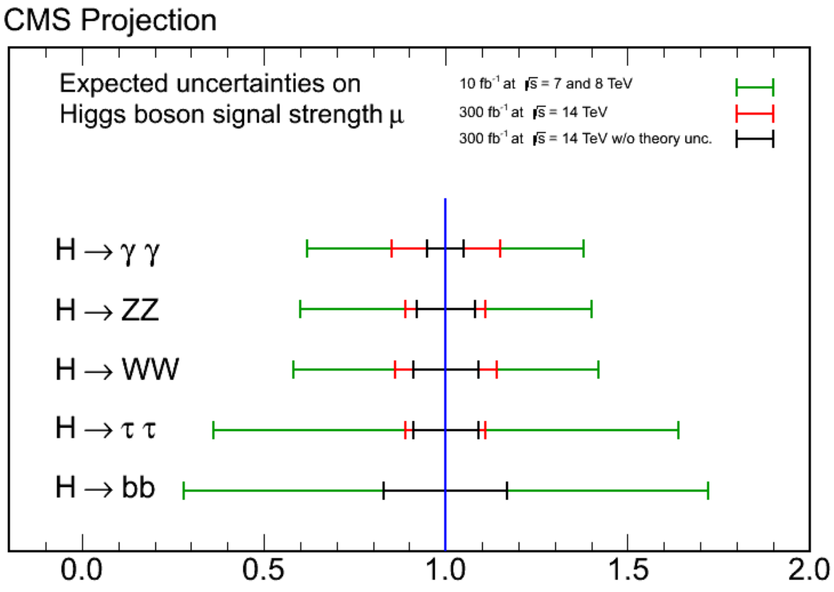


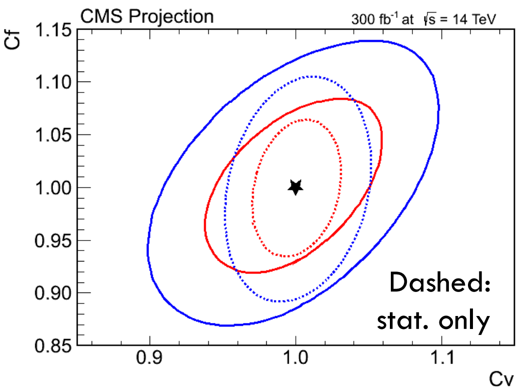
- **Some interesting correlations** profiling over the other 4 parameters.
  - κ_b and κ_g correlated via the SMH total width.
  - Relative power of the observations in $\tau\tau$ and bb.

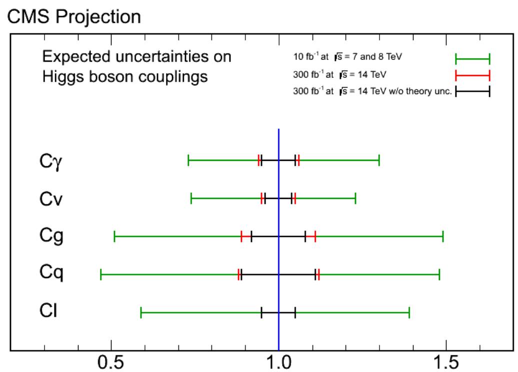
Looking forward

[http://goo.gl/TweX8]

- Projections for 300/fb at 14 TeV.
  - Vast improvements over present datasets.
  - **Space for theory improvements in $\gamma\gamma$ and WW.**
- **Also new analyses:**
  - Self-coupling.
  - $\mu\mu$.

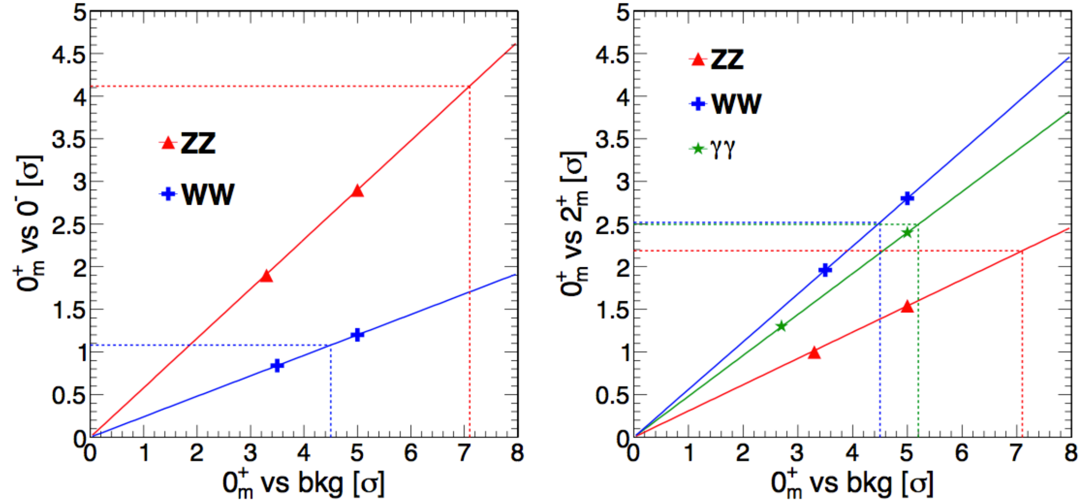






Spin prospects

[arXiv:1208.4018]

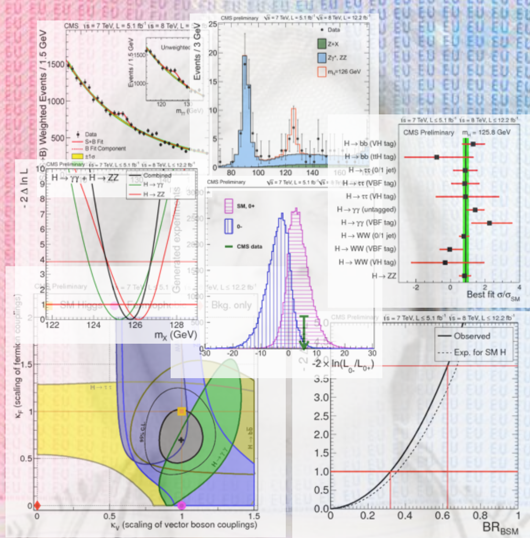


scenario	$X \to ZZ$	$X \to WW$	$X \to \gamma\gamma$	combined
0_m^+ vs bkg	7.1	4.5	5.2	9.9σ
0_m^+ vs 0^-	4.1	1.1	0.0	4.2σ
0_m^+ vs 2_m^+	2.2	2.5	2.5	4.2σ

- Simplified analyses assuming 5+30/fb.
- **Looking forward to J^{CP} discussion this afternoon.**

RESIDENCE PERMIT

ZU1234567



NAME

Massive Boson X

DATE OF ENTRY IN CMS

July 2012

PARENTS

Gluons (others possible)

CHILDREN

ZZ, $\gamma\gamma$, and WW

(possibly also bb, $\tau\tau$)

RELATIVE STRENGTH

0.88 ±0.21

WEIGHT

125.8 ±0.6 GeV

PARITY

0^- disfavored (CL_S 2.4%)

SPIN

Too early to tell

CUSTODIAL SYMMETRY

$\lambda_{WZ} \in$ **[0.68–1.55]** (95%CL)

OTHER COUPLINGS

All within 1σ from SMH

(2σ if $\gamma\gamma$ drives)

2HDM STATUS

Disfavored: $|\lambda_{du}|\neq 0$, $|\lambda_{lq}|\neq 0$

Massi X

HOLDER'S SIGNATURE

UK RESIDENCE PERMIT

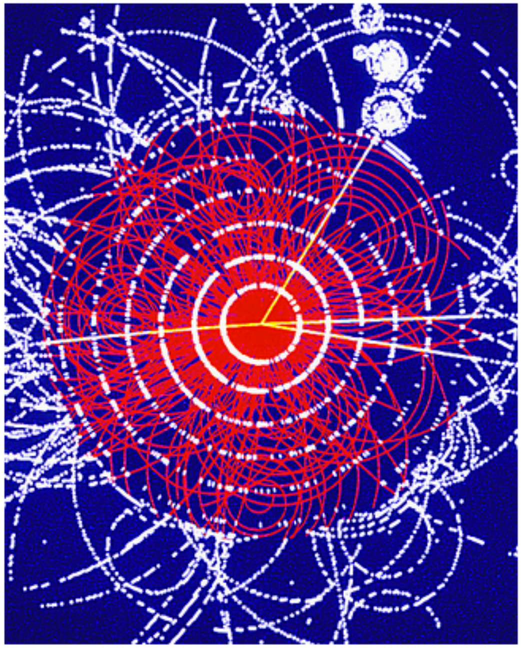
Who Should Be TIME's Person of the Year 2012?

As always, TIME's editors will choose the Person of the Year, but that doesn't mean readers shouldn't have their say. Cast your vote for the person you think most influenced the news this year for better or worse. Voting closes at 11:59 p.m. on Dec. 12, and the winner will be announced on Dec. 14.

THE CANDIDATES

The Higgs Boson

By Jeffrey Kluger | Monday, Nov. 26, 2012



SSPL/GETTY IMAGES

Simulation of a Higgs-Boson decaying into four muons, CERN, 1990.

What do you think?

Should **The Higgs Boson** be TIME's Person of the Year 2012?

Definitely No Way

VOTE

Take a moment to thank this little particle for all the work it does, because without it, you'd be just inchoate energy without so much as a bit of mass. What's more, the same would be true for the entire universe. It was in the 1960s that Scottish physicist Peter Higgs first posited the existence of a particle that causes energy to make the jump to matter. But it was not until last summer that a team of researchers at Europe's Large Hadron Collider — Rolf Heuer, Joseph Incandela and Fabiola Gianotti — at last sealed the deal and in so doing finally fully confirmed Einstein's general theory of relativity. The Higgs — as particles do — immediately decayed to more-fundamental particles, but the scientists would surely be happy to collect any honors or awards in its stead.

Photos: Step inside the Large Hadron Collider.

WHO SHOULD BE TIME'S PERSON OF THE YEAR 2012?

The Candidates

Video

Poll Results

PAST PERSONS OF THE YEAR

2011: The Protester

2010: Facebook's Mark Zuckerberg

2009: Ben Bernanke

2008: Barack Obama

Most Read | Most Emailed

1 Who Should Be TIME's Person of the Year 2012?

2 LIFE Behind the Picture: The Photo That Changed the Face of AIDS

3 Nativity-Scene Battles: Score One for the Atheists

4 The $7 Cup of Starbucks: A Logical Extension of the Coffee Chain's Long-Term Strategy

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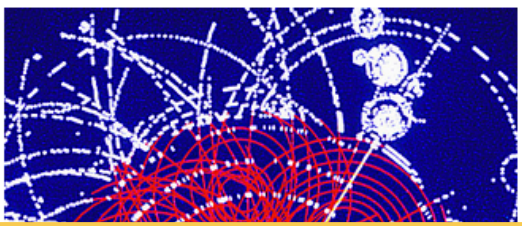

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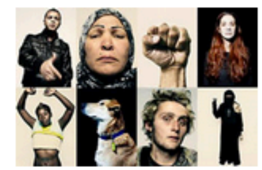

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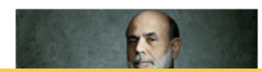
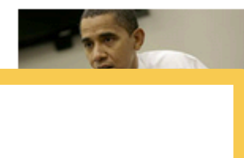
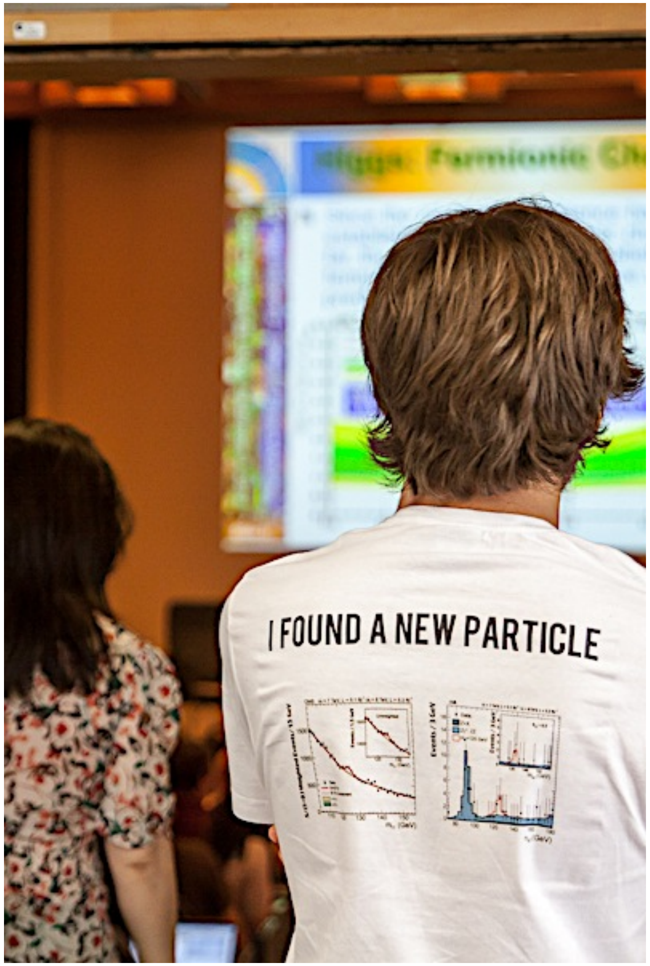
2010: Facebook's Mark Zuckerberg





Conclusions



- **Major update of CMS Higgs searches.**
  - Signal appearing in all main channels.
- **Big picture unfailingly consistent with SMH:**
  - Per channel, final state, or production mode.
  - No significant deviations of scalar couplings.
  - Parity hypothesis test disfavors 0^-.
  - More work (and data) needed for spin assignment.
- **CMS is working hard to leave no stone unturned.**
  - Looking forward to surprises.
  - The future looks promising for further characterization.

For discussion

Combination details

HCP 2012 combination details

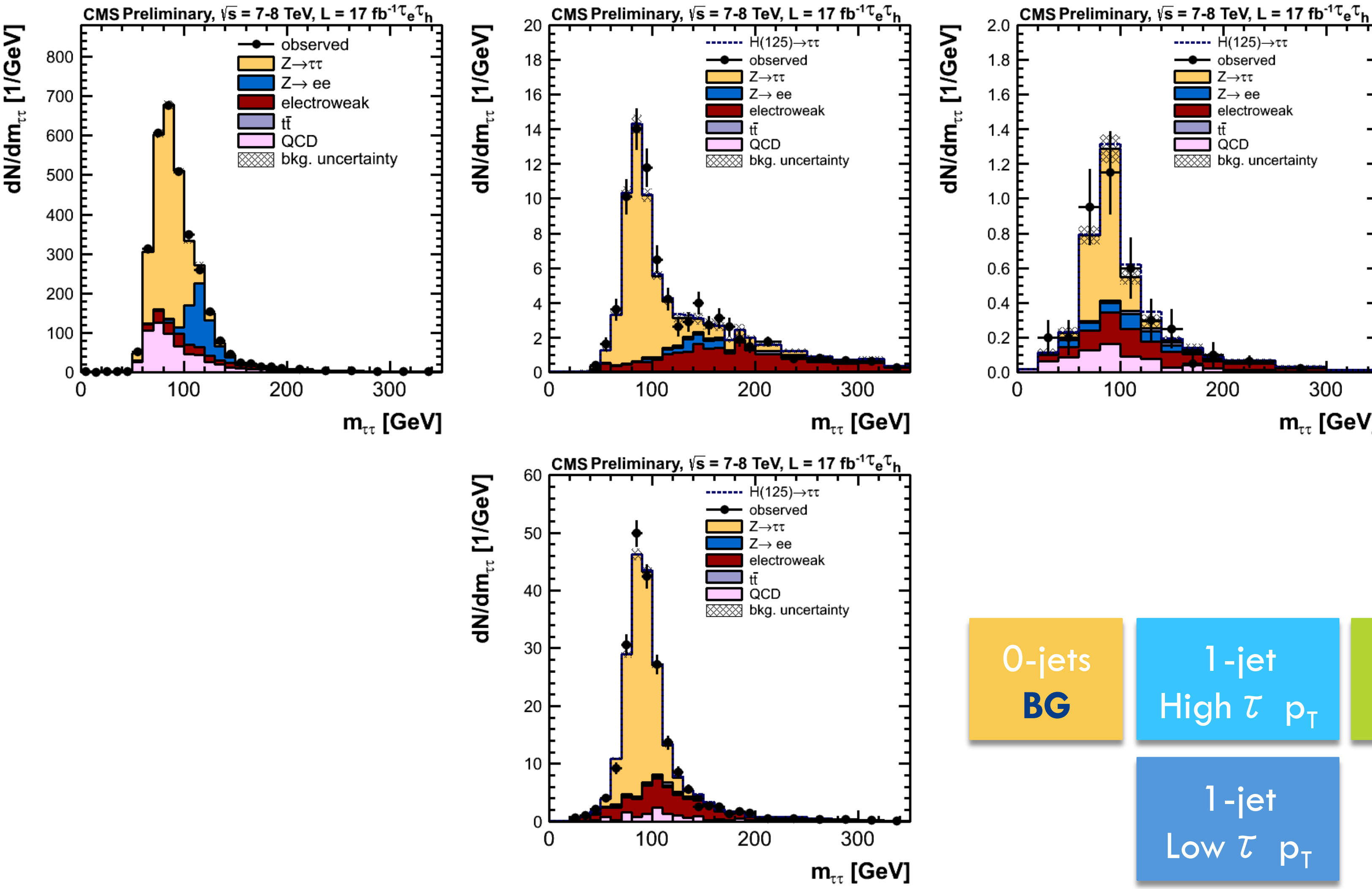
[HIG-12-045]

H decay	H prod	Analyses Exclusive final states	No. of channels	m_H range (GeV)	m_H resolution	Lumi (fb^{-1}) 7 TeV	Lumi (fb^{-1}) 8 TeV
$\gamma\gamma$	untagged	$\gamma\gamma$ (4 diphoton classes)	4	110–150	1-2%	5.1	5.3
	VBF-tag	$\gamma\gamma + (jj)_{VBF}$ (low or high m_{jj} for 8 TeV)	1 or 2	110–150	1-2%	5.1	5.3
bb	VH-tag	($\nu\nu$, ee, $\mu\mu$, $e\nu$, $\mu\nu$ with 2 b-jets)$\times$ (low or high p_T^V or loose b-tag)	10 or 13	110–135	10%	5.0	12.1
	ttH-tag	(ℓ with 4,5,$\geq$6 jets) $\times$ (3,$\geq$4 b-tags); (ℓ with 6 jets with 2 b-tags); ($\ell\ell$ with 2 or $\geq$3 b-tagged jets)	9	110–140		5.0	-
$H \rightarrow \tau\tau$	1-jet	($e\tau_h$, $\mu\tau_h$, $e\mu$, $\mu\mu$)$\times$ (low or high p_T^τ) and $\tau_h\tau_h$	9	110–145	20%	4.9	12.1
	VBF-tag	($e\tau_h$, $\mu\tau_h$, $e\mu$, $\mu\mu$, $\tau_h\tau_h$) + $(jj)_{VBF}$	5	110–145	20%	4.9	12.1
	ZH-tag	(ee, $\mu\mu$) $\times$ ($\tau_h\tau_h$, $e\tau_h$, $\mu\tau_h$, $e\mu$)	8	110–160		5.0	-
	WH-tag	$\tau_h ee$, $\tau_h\mu\mu$, $\tau_h e\mu$	3	110–140		4.9	-
$WW \rightarrow \ell\nu qq$	untagged	($e\nu$, $\mu\nu$)$\times$($(jj)_W$ with 0 or 1 jets)	4	170–600		5.0	12.1
$WW \rightarrow \ell\nu\ell\nu$	0/1-jets	(DF or SF dileptons) $\times$ (0 or 1 jets)	4	110–600	20%	4.9	12.1
$WW \rightarrow \ell\nu\ell\nu$	VBF-tag	$\ell\nu\ell\nu + (jj)_{VBF}$ (DF or SF dileptons for 8 TeV)	1 or 2	110–600	20%	4.9	12.1
$WW \rightarrow \ell\nu\ell\nu$	WH-tag	$3\ell 3\nu$	1	110–200		4.9	5.1
$ZZ \rightarrow 4\ell$	inclusive	$4e$, 4μ, $2e2\mu$	3	110–1000	1-2%	5.0	12.2
$ZZ \rightarrow 2\ell 2\tau$	inclusive	(ee, $\mu\mu$) $\times$ ($\tau_h\tau_h$, $e\tau_h$, $\mu\tau_h$, $e\mu$)	8	180–1000	10-15%	5.0	12.2

$H \rightarrow \tau\tau$ details

H→ $\tau_e \tau_h$

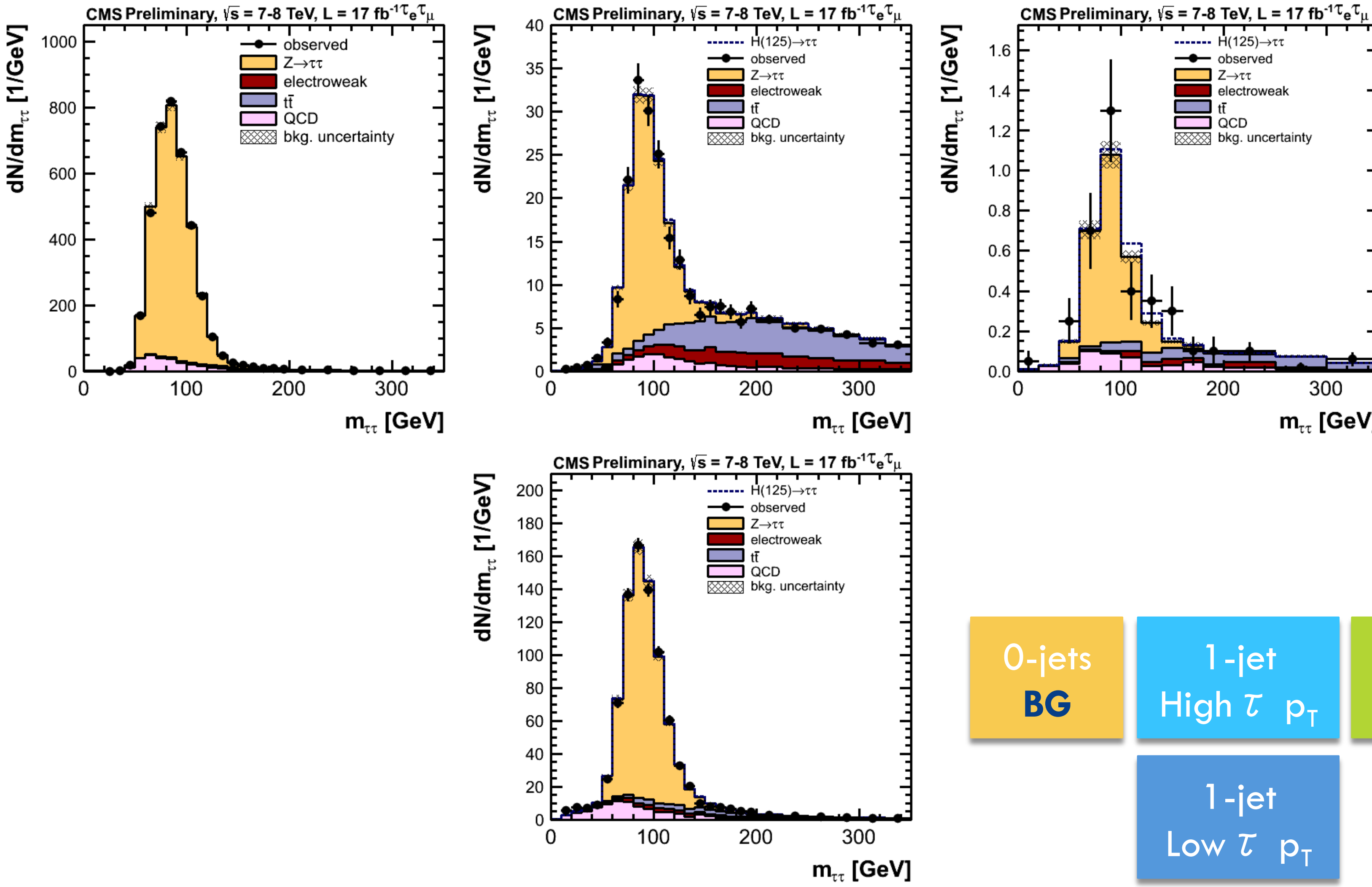
[HIG-12-043]



0-jets **BG**	1-jet High τ p_T	2-jets **VBF**
	1-jet Low τ p_T	

H→ $\tau_e \tau_\mu$

[HIG-12-043]



0-jets **BG**

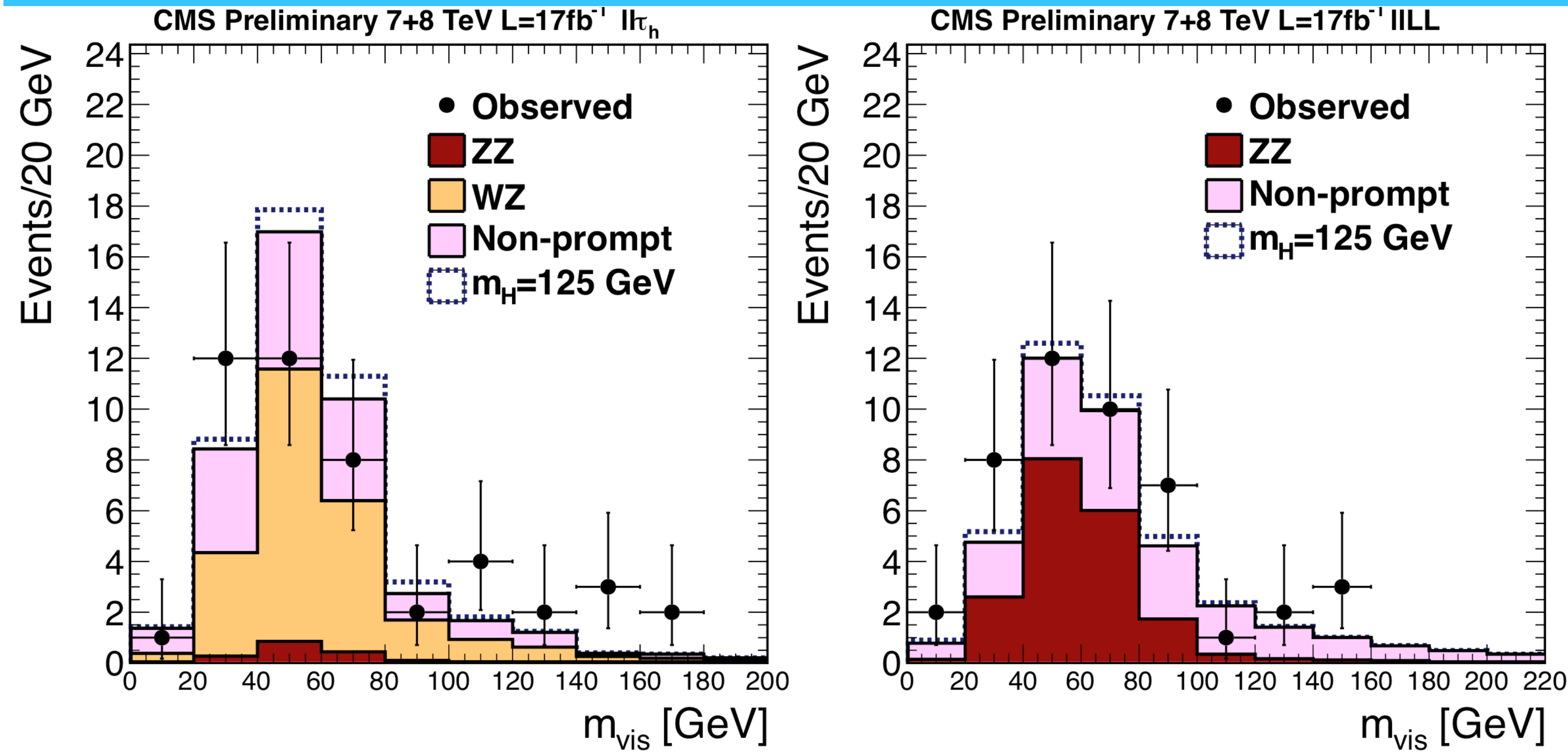
1-jet High τ p_T

2-jets **VBF**

1-jet Low τ p_T

VH→V $\tau\tau$

[HIG-12-051]



- $\ell\ell = \{e, \mu\}$
- $LL = \{\tau_e\tau_\mu, \tau_e\tau_h, \tau_\mu\tau_h, \tau_h\tau_h\}$

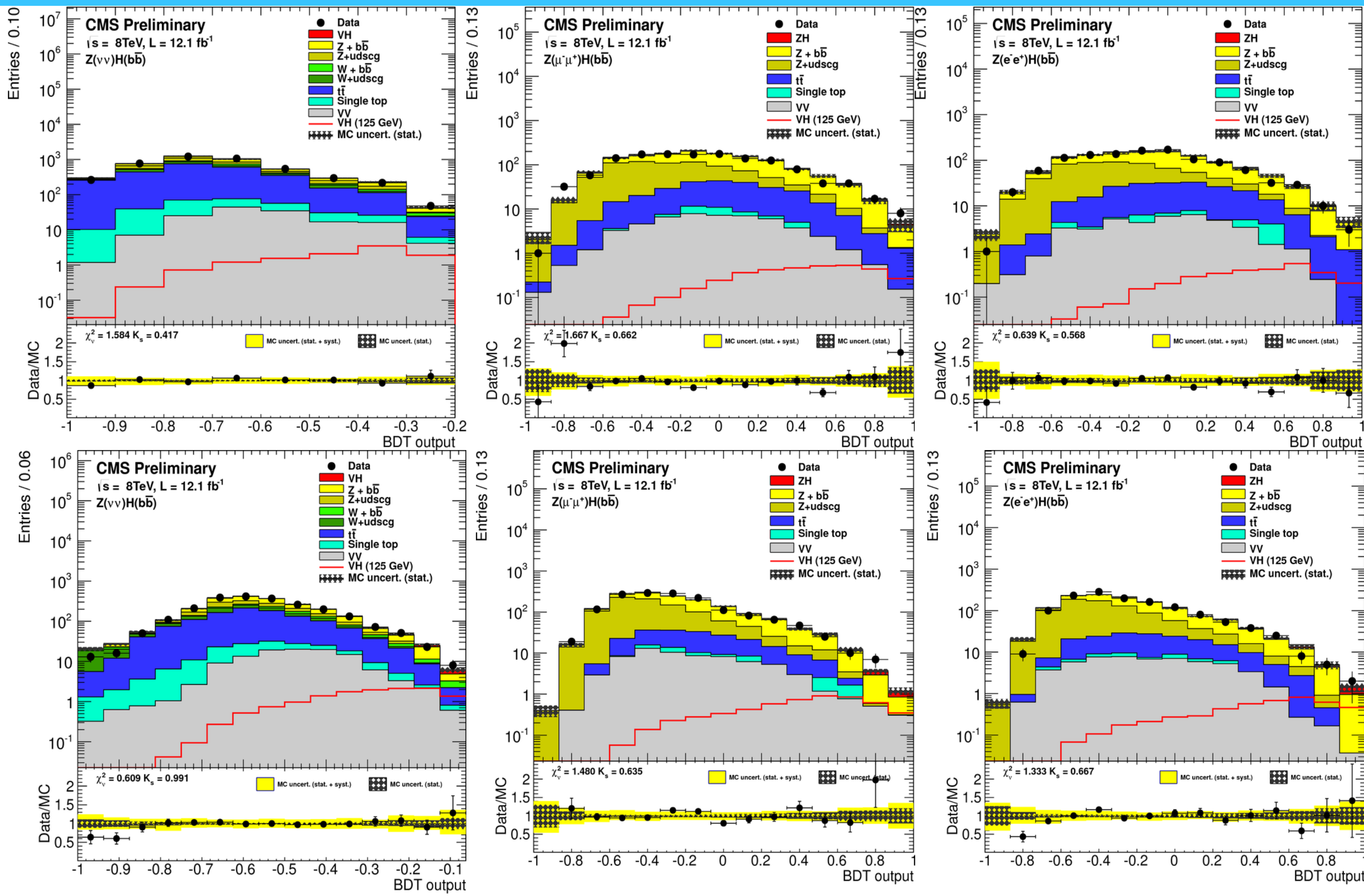
H→bb details

ZH→Zbb

[HIG-12-044]

Low $p_T(V)$

High $p_T(V)$

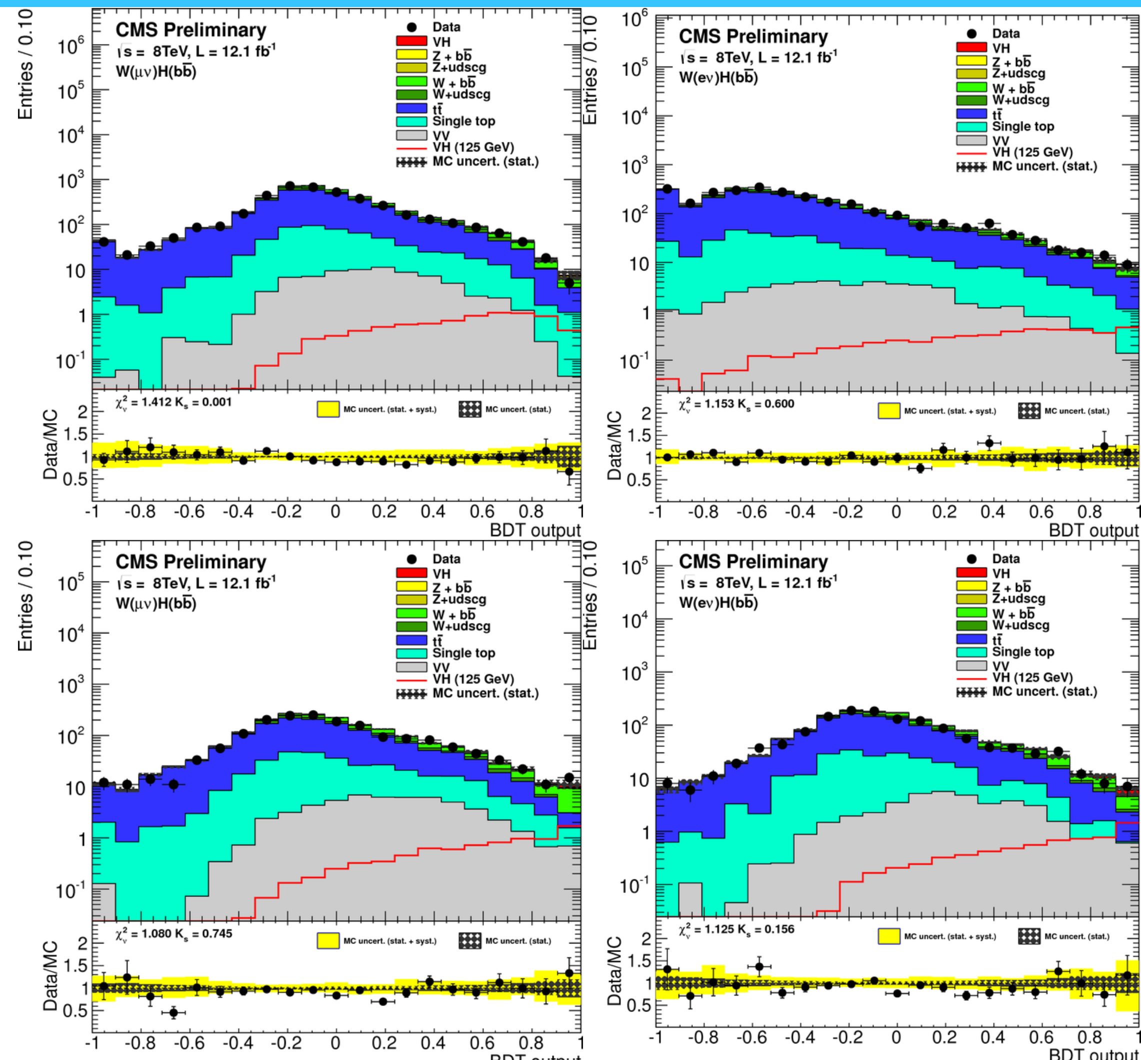


WH→Wbb

[HIG-12-044]

Low $p_T(V)$

High $p_T(V)$



VH→Vbb looser b-tag

[HIG-12-044]