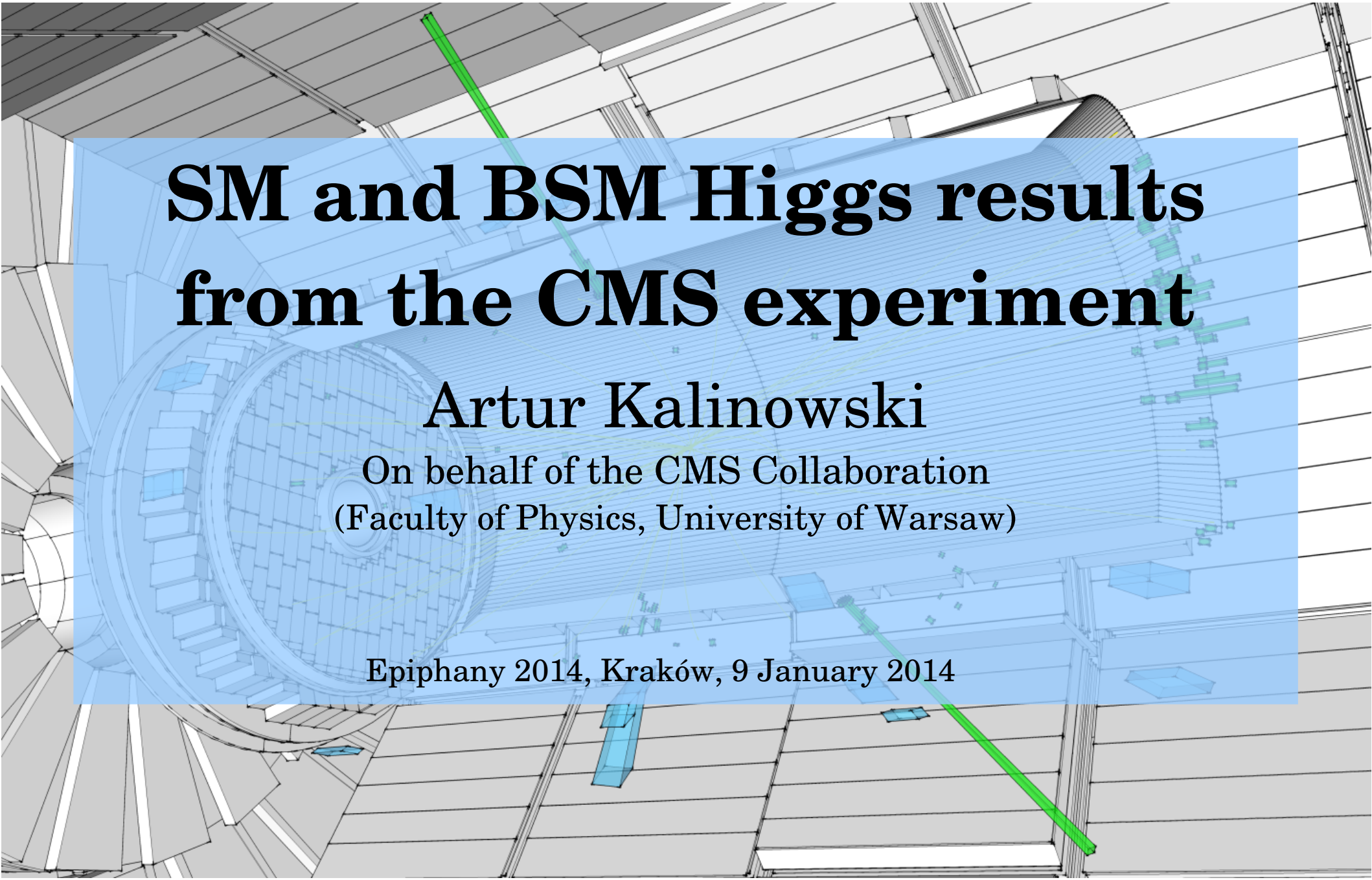


SM and BSM Higgs results from the CMS experiment

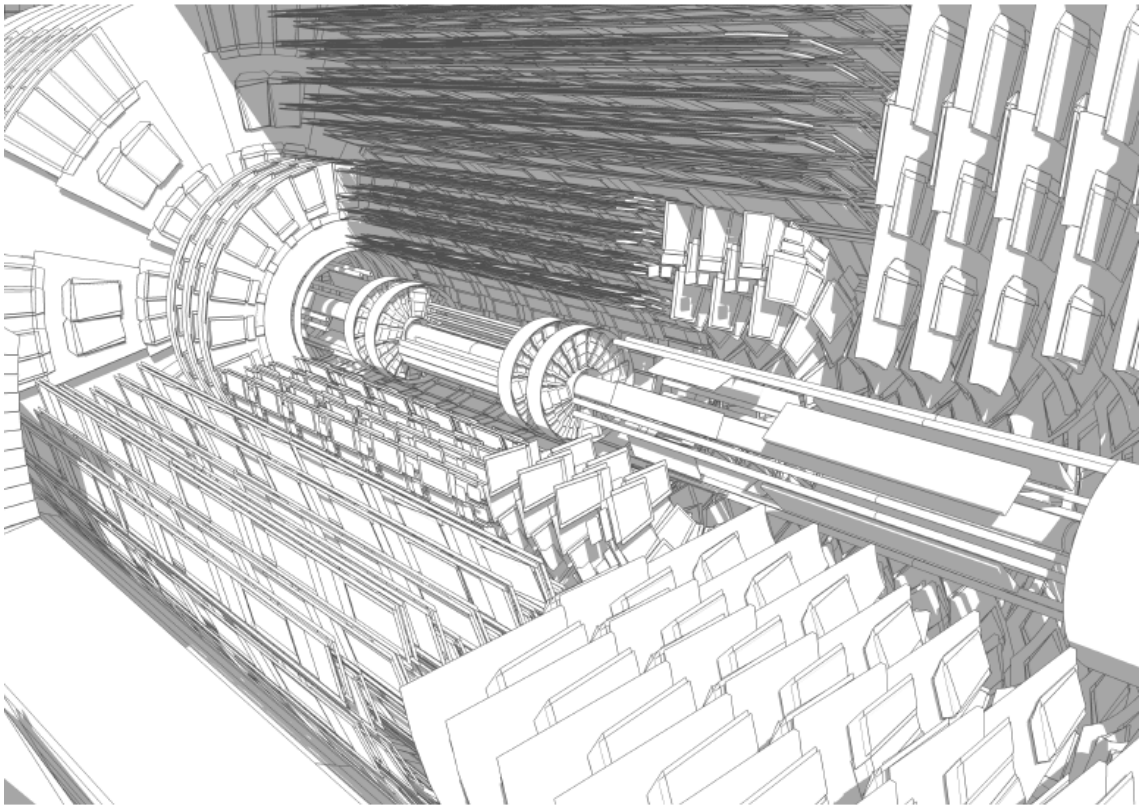
Artur Kalinowski

On behalf of the CMS Collaboration

(Faculty of Physics, University of Warsaw)

Epiphany 2014, Kraków, 9 January 2014

Outline



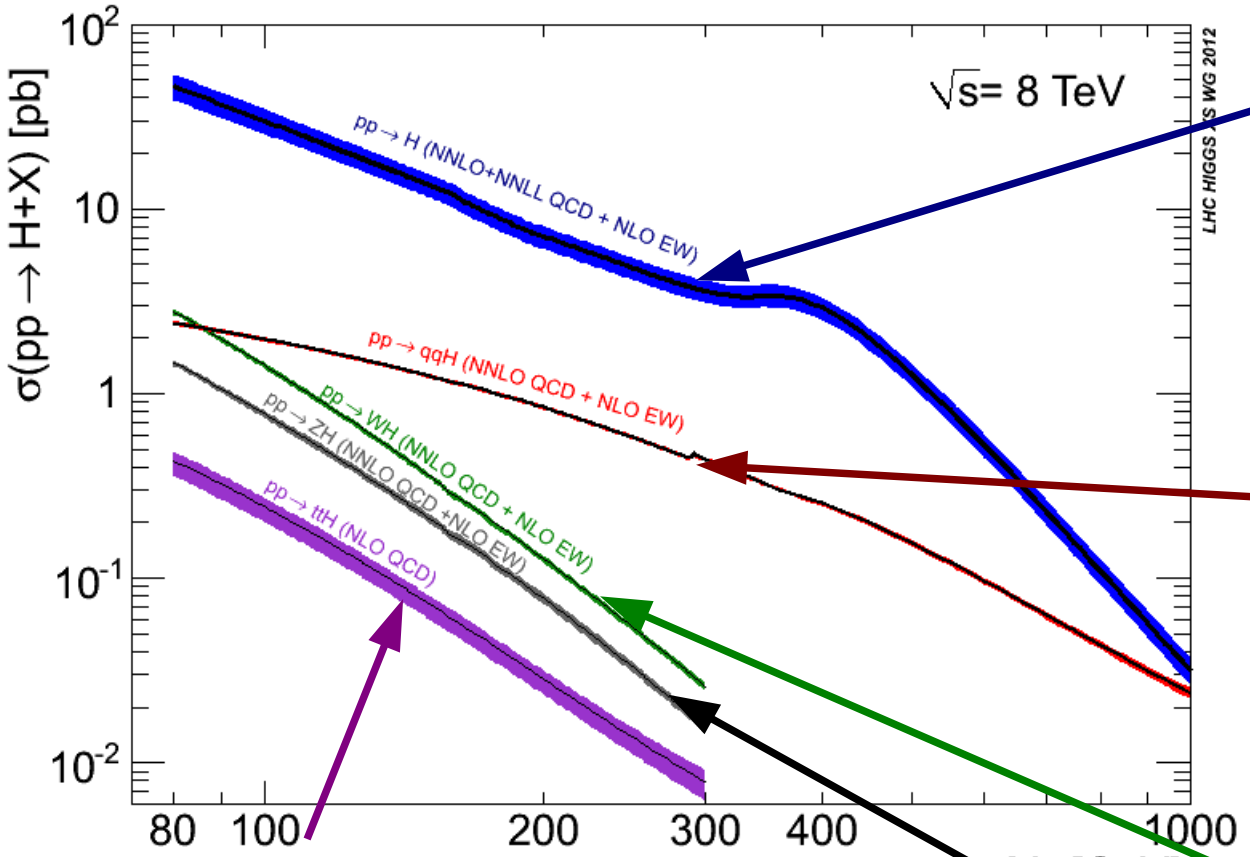
The SM hypothesis:

- Review of couplings
- Review of quantum numbers
- Mass estimation

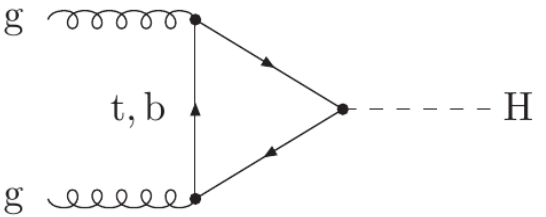
a BSM: a MSSM example:

- Recent results for neutral Higgs bosons

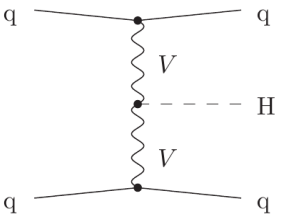
SM Higgs production modes at LHC



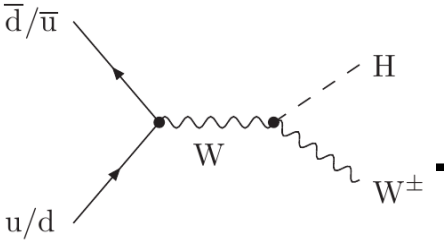
• dominating production mode: gluon-gluon fusion gg→H: $\sigma(m_H=125)=19.27$ pb



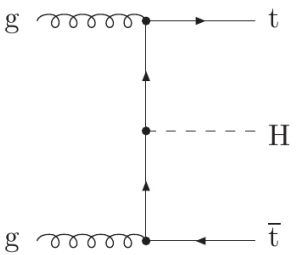
• next is Vector Boson Fusion (VBF) qq→qqH: $\sigma(m_H=125)=1.578$ pb



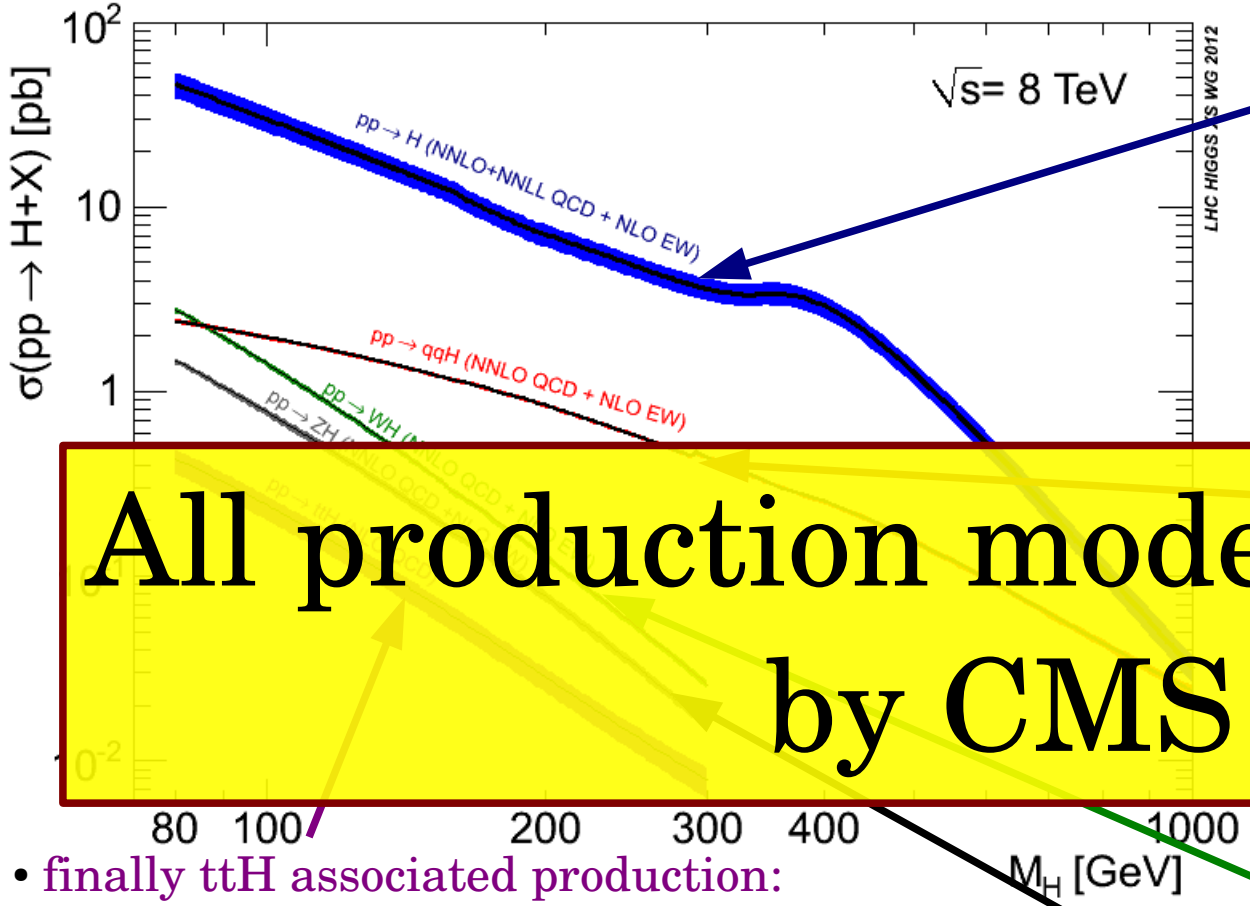
• then is VH associated production: qq'→WH $\sigma(m_H=125)=0.70$ pb and qq→ZH $\sigma(m_H=125)=0.42$ pb



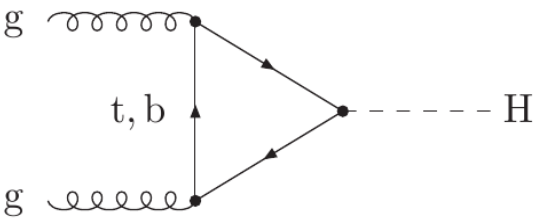
• finally ttH associated production: qq→ttH $\sigma(m_H=125)=0.13$ pb



SM Higgs production modes at LHC

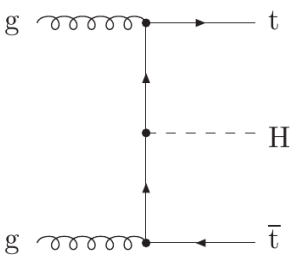


• dominating production mode: gluon-gluon fusion gg→H: $\sigma(m_H=125)=19.27$ pb

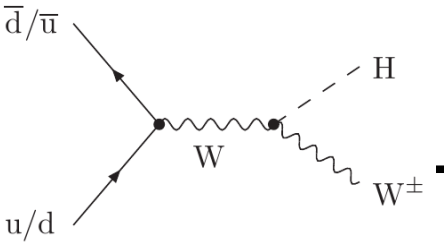


All production modes exploited by CMS

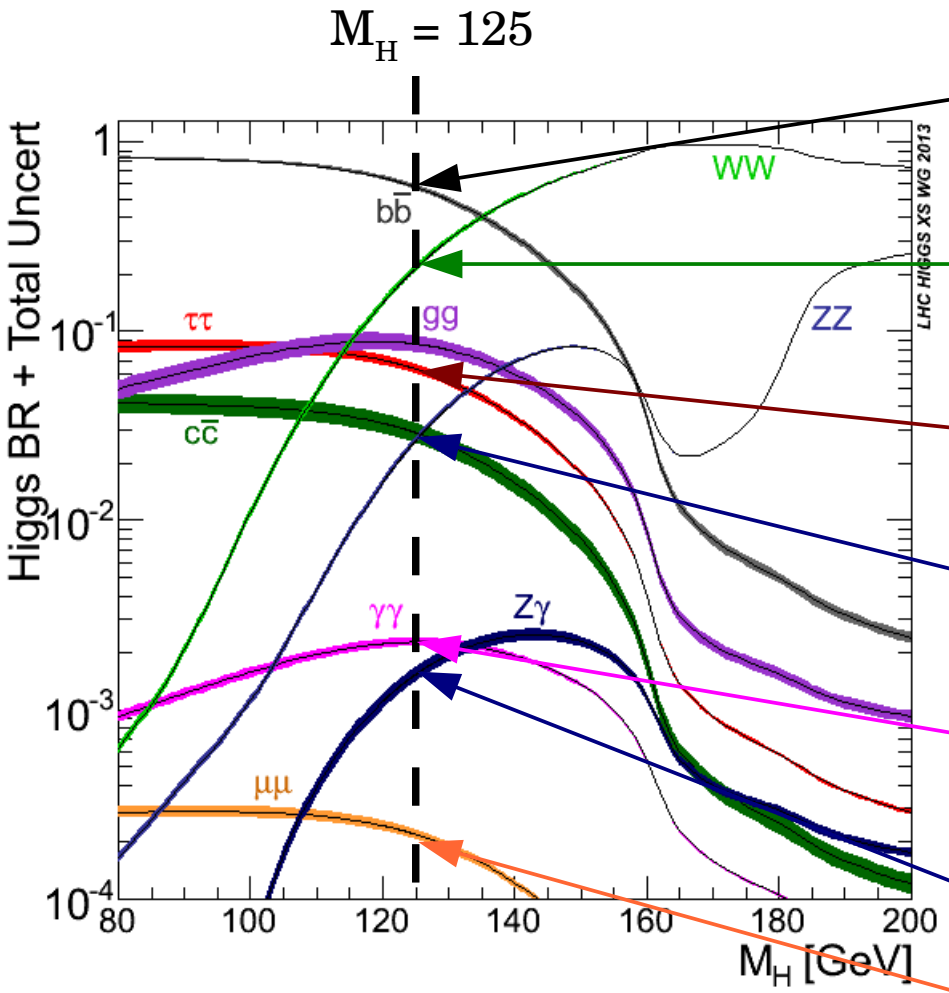
• finally ttH associated production: qq→ttH $\sigma(m_H=125)=0.13$ pb



• then is VH associated production: qq'→WH $\sigma(m_H=125)=0.70$ pb and qq→ZH $\sigma(m_H=125)=0.42$ pb



SM Higgs decays



VH(bb) (arXiv:1310.3687),
ttH(bb) (CMS-PAS-HIG-13-019)

H→WW→2l2υ (**UPDATED**, arXiv:1312.1129)

H→ττ (**UPDATED**, CMS-PAS-HIG-13-004)

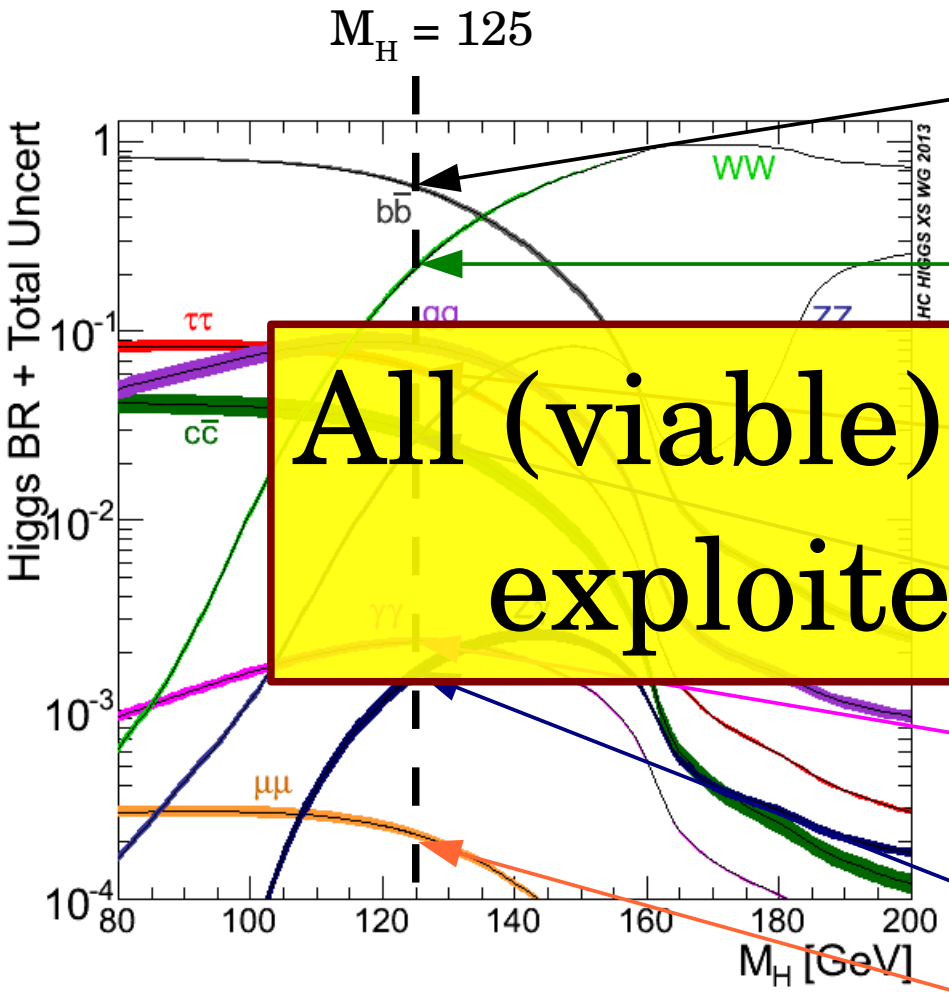
H→ZZ$^{(*)}$→4l (**UPDATED,** arXiv:1312.5353)

H→γγ (**UPDATED**, CMS-PAS-HIG-13-016)

H→Zγ (arXiv:1307.5515)

H→μμ (**UPDATED**, CMS-PAS-HIG-13-007)

SM Higgs decays



VH(bb) (arXiv:1310.3687),
ttH(bb) (CMS-PAS-HIG-13-019)

H→WW→2l2υ (**UPDATED**, arXiv:1312.1129)

All (viable) decay modes exploited by CMS

H→γγ (**UPDATED**, CMS-PAS-HIG-13-016)

H→Zγ (arXiv:1307.5515)

H→μμ (**UPDATED**, CMS-PAS-HIG-13-007)

Coupling to τ

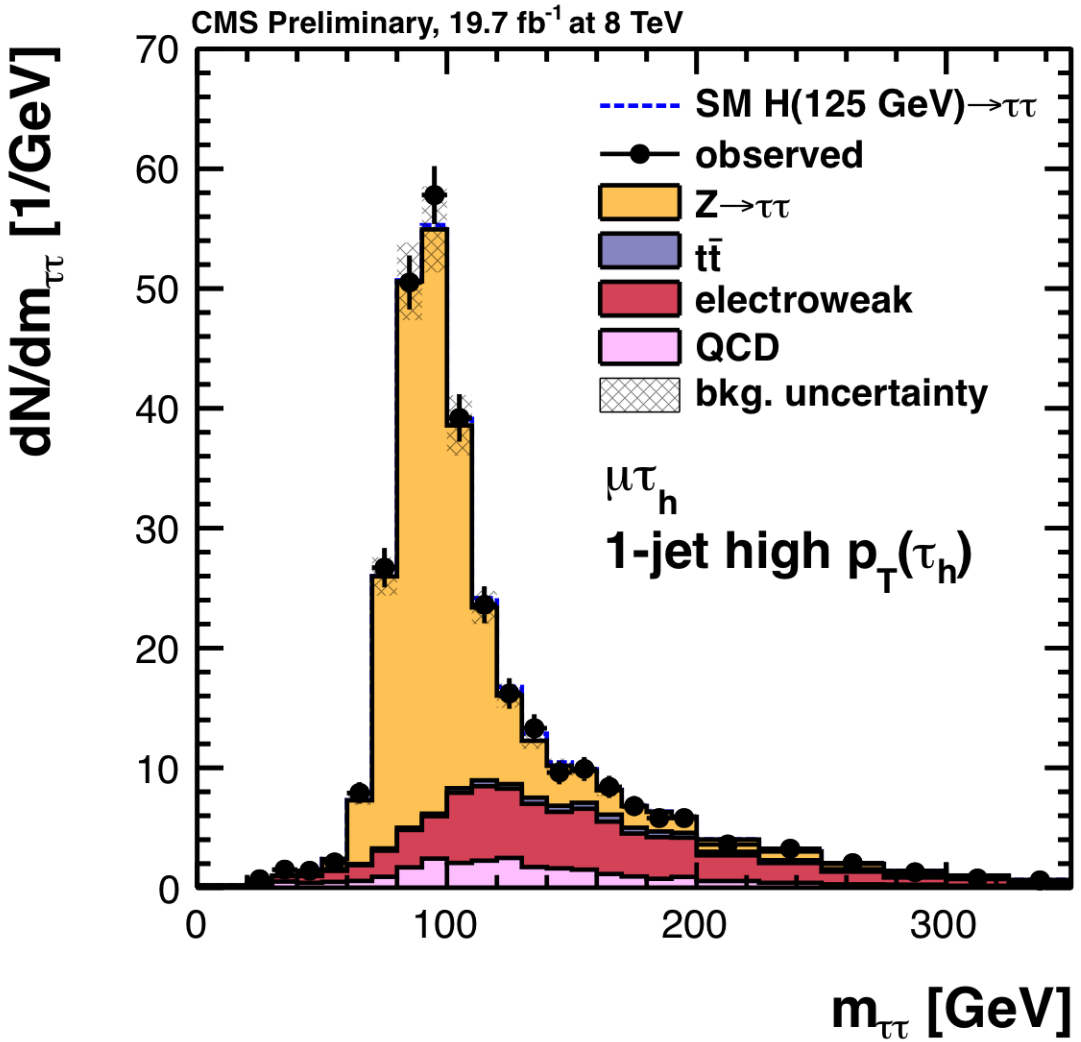
- $\mu\tau_h$, $e\tau_h$, $\tau_h\tau_h$, $e\mu$, $\mu\mu$, ee tau pair decays considered

- events split into 0-jet ($gg \rightarrow H$), 1 jet ($gg \rightarrow H+j$) and 2-jet (VBF) categories

- some categories further split into two based on τ_h p_T

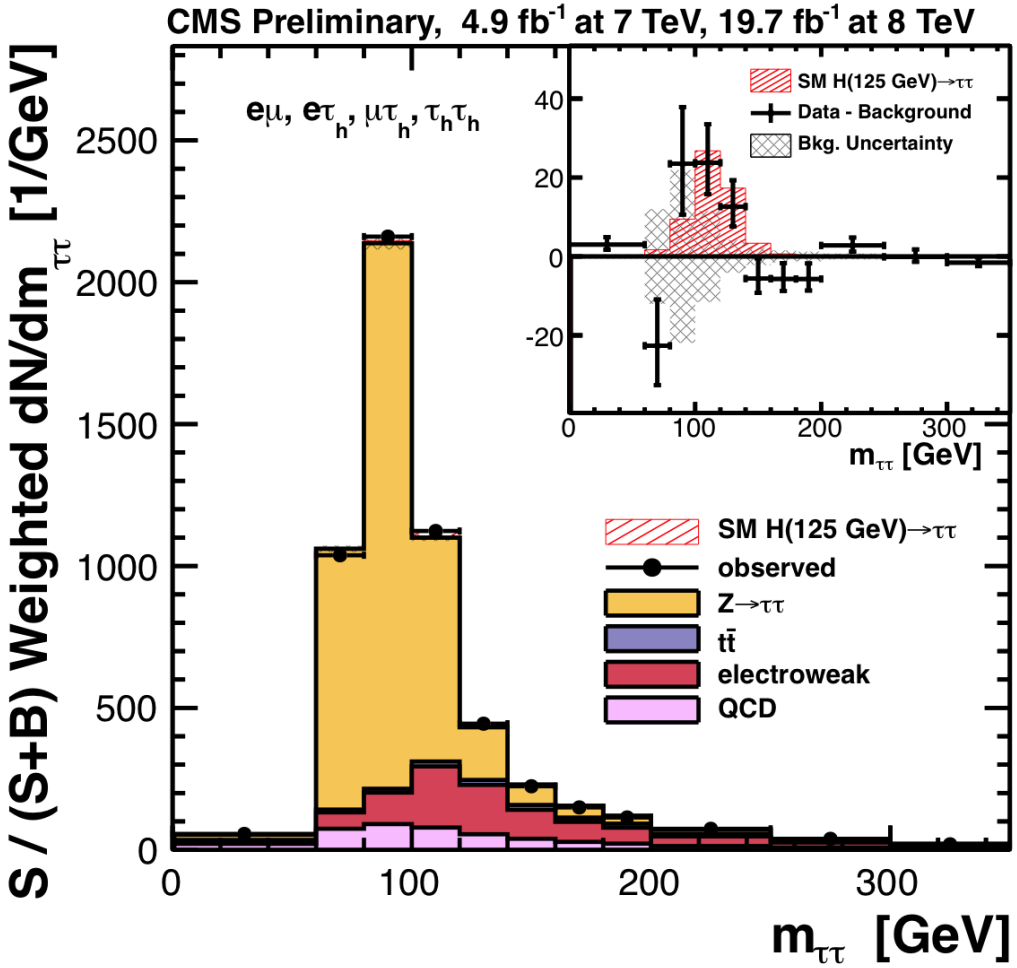
- VBF category further split into loose/tight

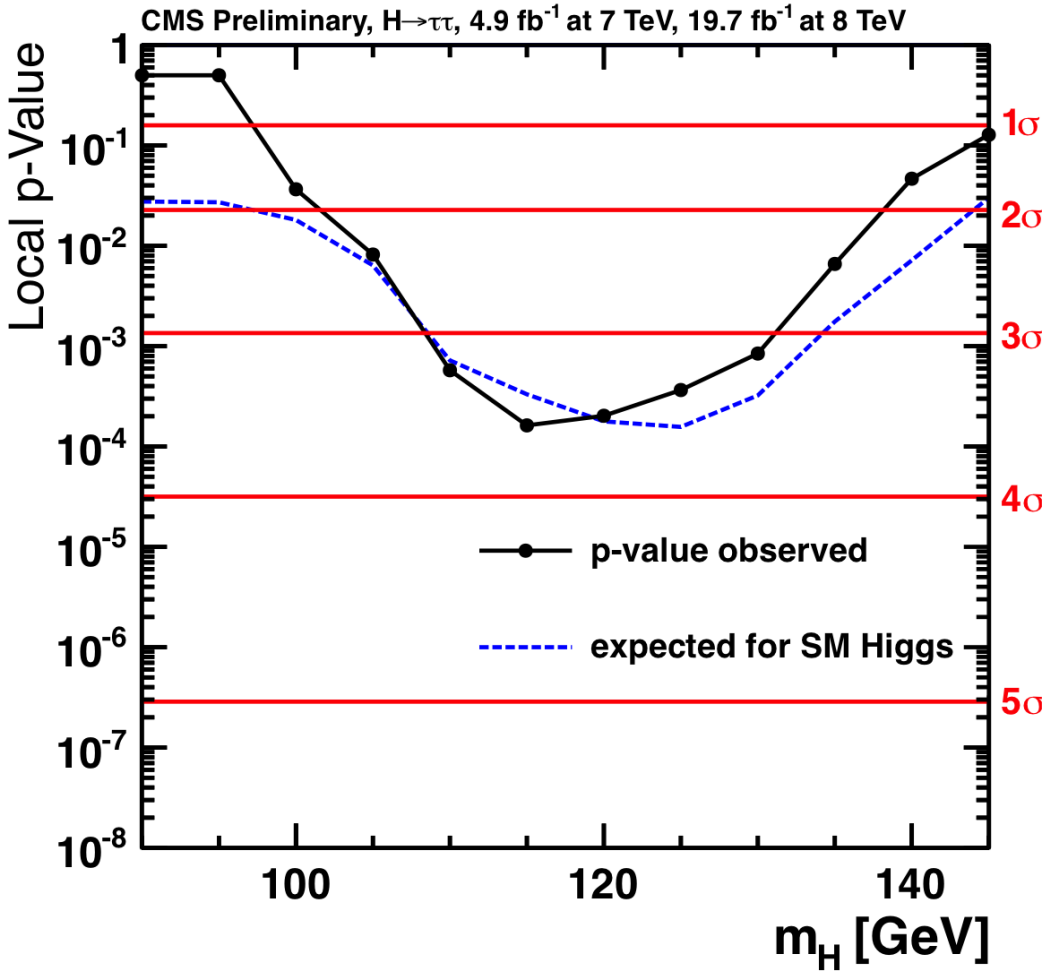
- full mass reconstructed with likelihood approach



- main background estimated from data

Coupling to τ



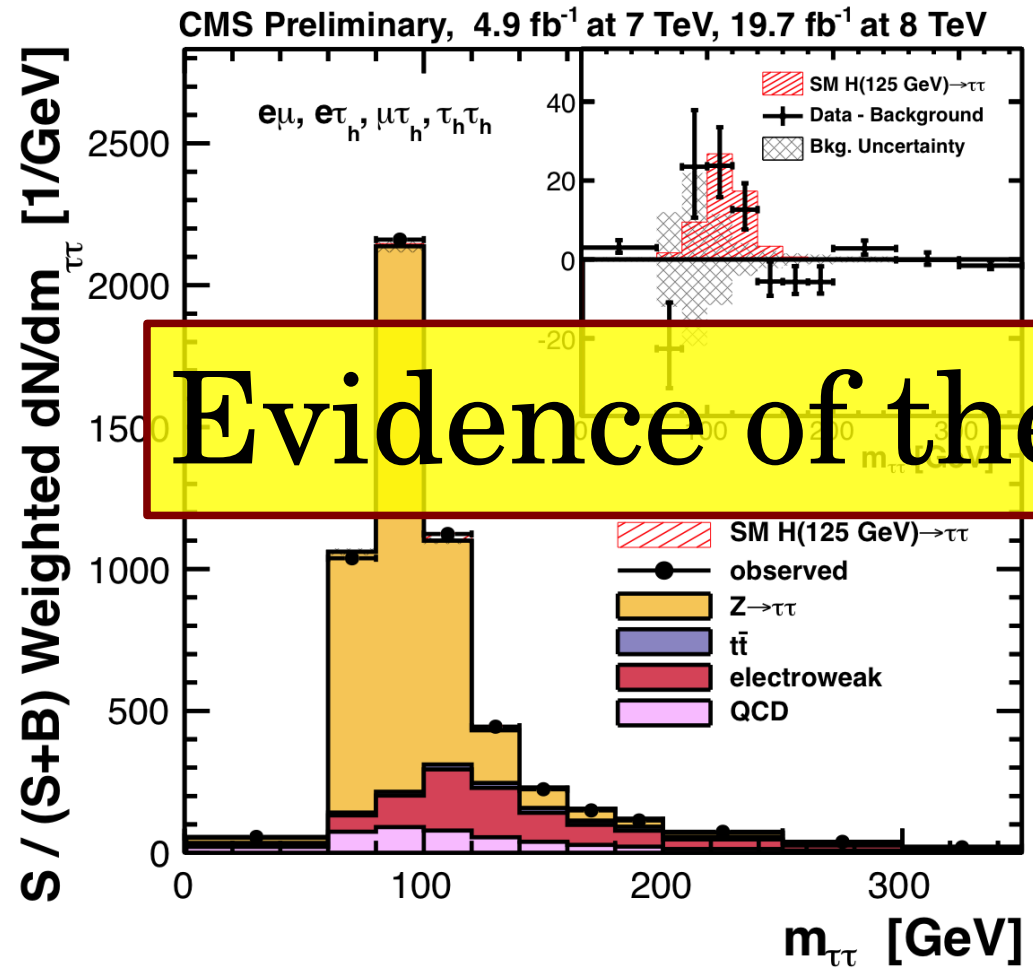


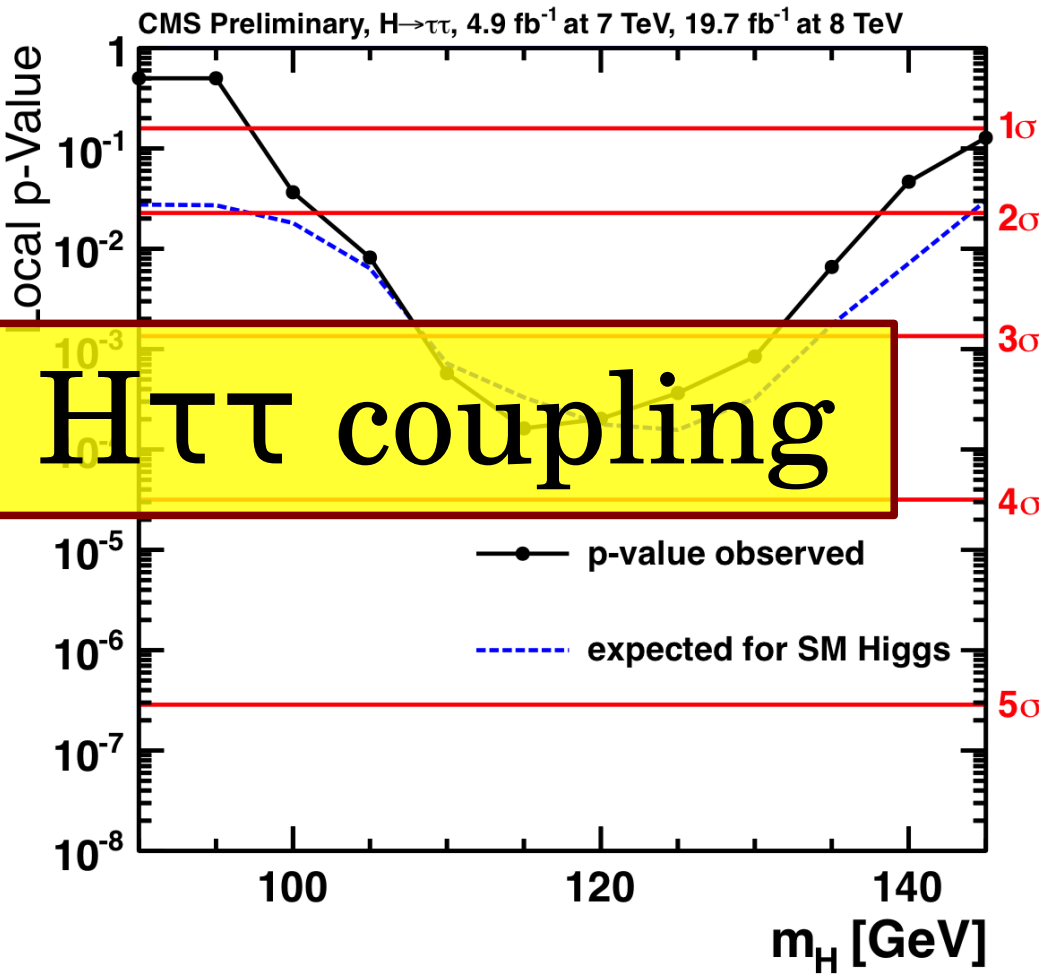
Observed **p-value at 125 GeV corresponds to 3.4σ**

μ(at 125 GeV) = 0.87 ± 0.29, $m_{best\ fit} = 115^{+8}_{-2}$ GeV

$\mu = \sigma_{fit}/\sigma_{SM}$

Coupling to τ





Evidence of the Hττ coupling

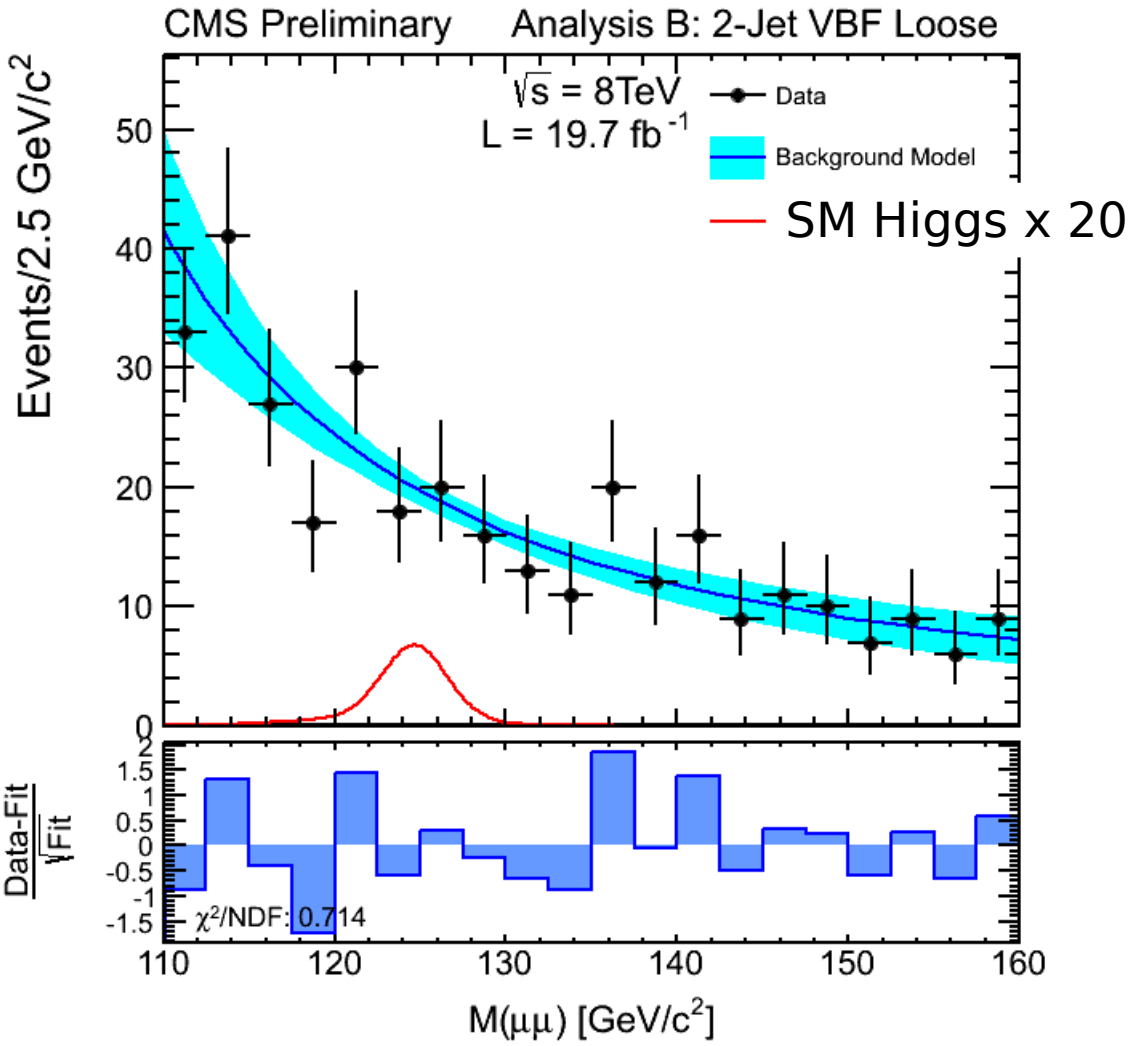
Observed **p-value at 125 GeV corresponds to 3.4σ**

μ(at 125 GeV) = 0.87 ± 0.29, $m_{best\ fit} = 115^{+8}_{-2}$ GeV

$\mu = \sigma_{fit}/\sigma_{SM}$

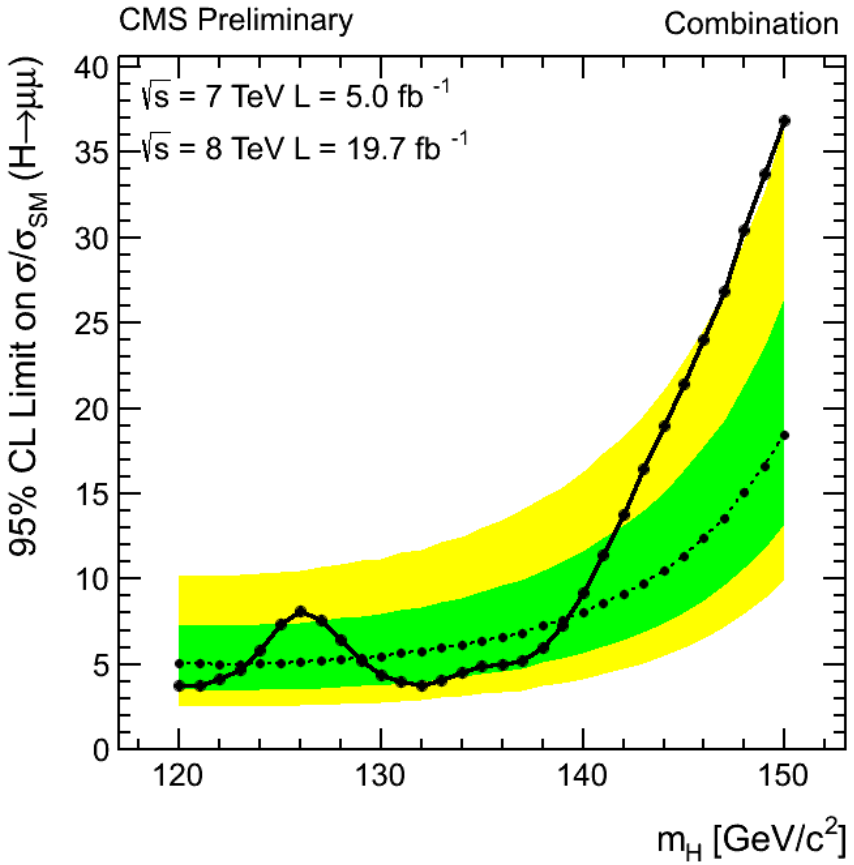
Coupling to μ

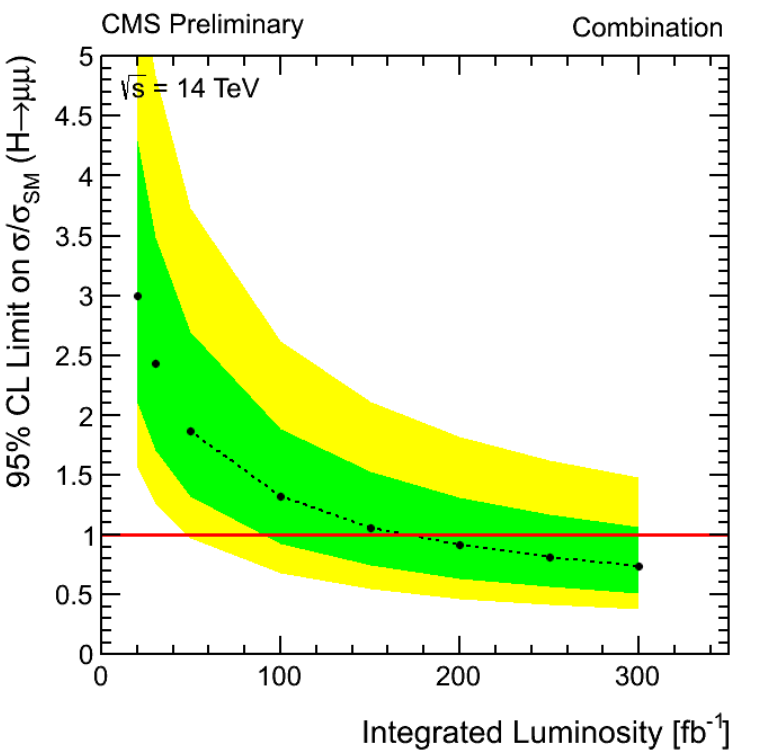
- extremely rare in SM: $BR(H(125)\rightarrow\mu\mu)=2\bullet10^{-4}$
- two independent analyses
- events split into 0-jet (gg→H), 1 jet (gg→H+j) and 2-jet (VBF) categories
- some categories further split into two based on $p_T(\mu\mu)$
- VBF category further split into loose/tight

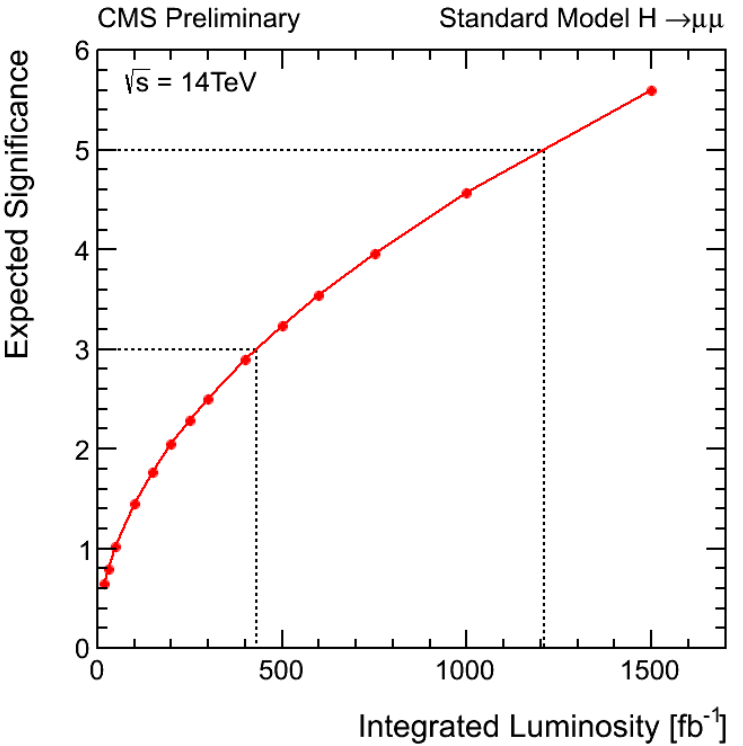


- Signal extracted by simultaneous fit of signal and background shapes

Coupling to μ

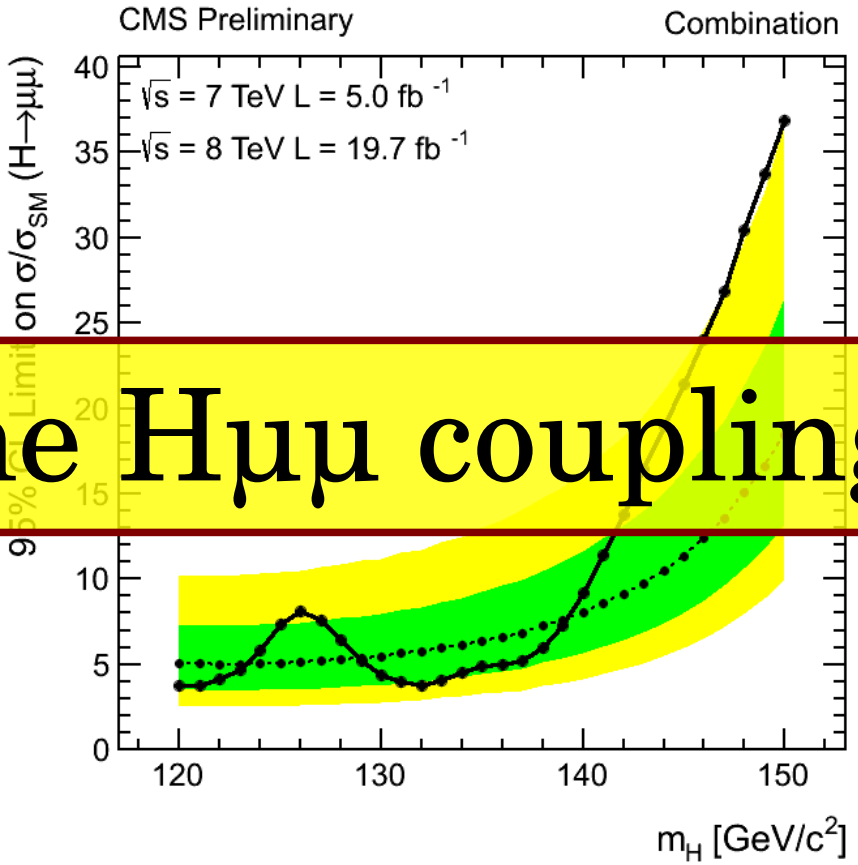


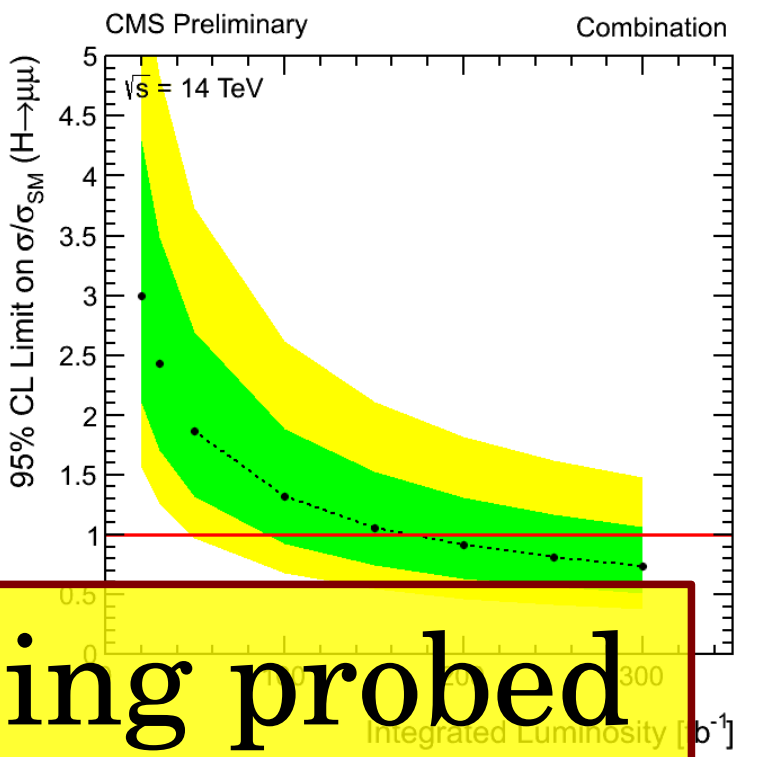




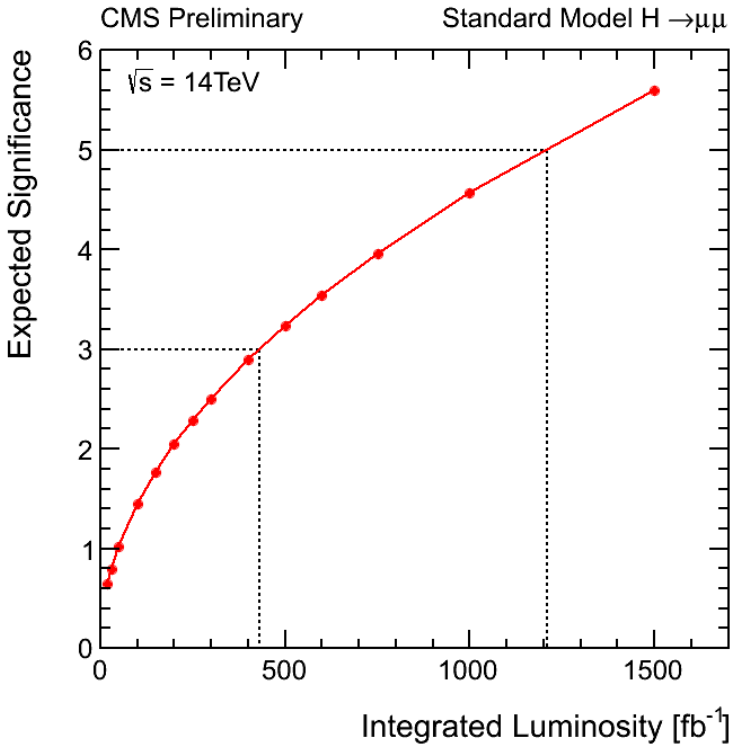
- Observed (expected) exclusion on σ/σ_{SM} at 125 is 7.4 (5.1)
- 175 fb^{-1}@ 14 TeV necessary to exclude SM
- 450 fb^{-1}@ 14 TeV necessary to reach 3σ

Coupling to μ





The Hμμ coupling being probed



- Observed (expected) exclusion on σ/σ_{SM} at 125 is 7.4 (5.1)

- 175 fb^{-1}@ 14 TeV necessary to exclude SM
- 450 fb^{-1}@ 14 TeV necessary to reach 3σ

Coupling to bottom

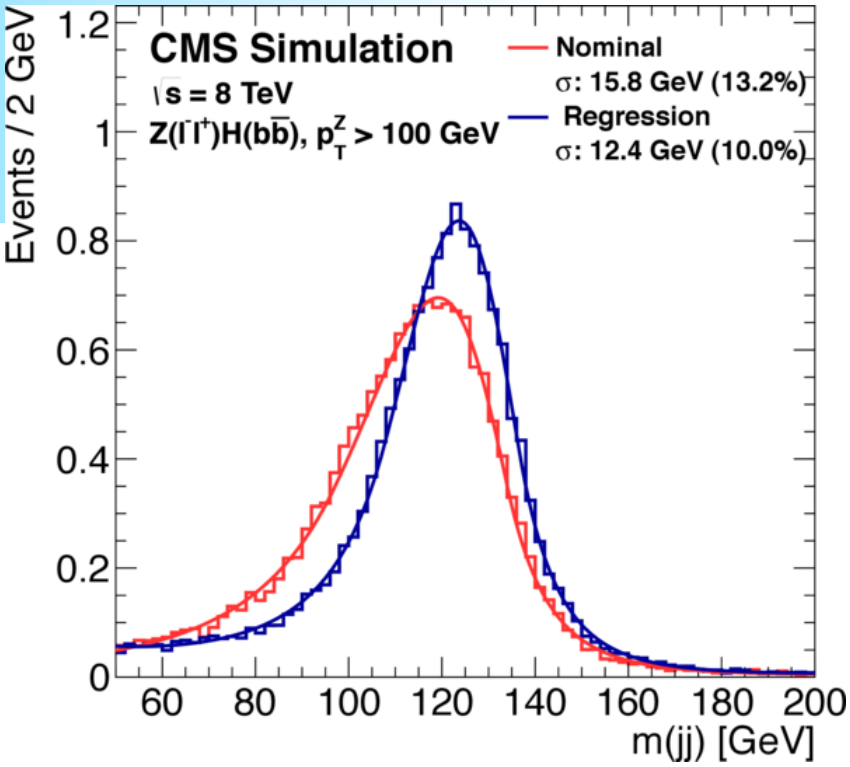
•VH production modes provides a signal selection handle

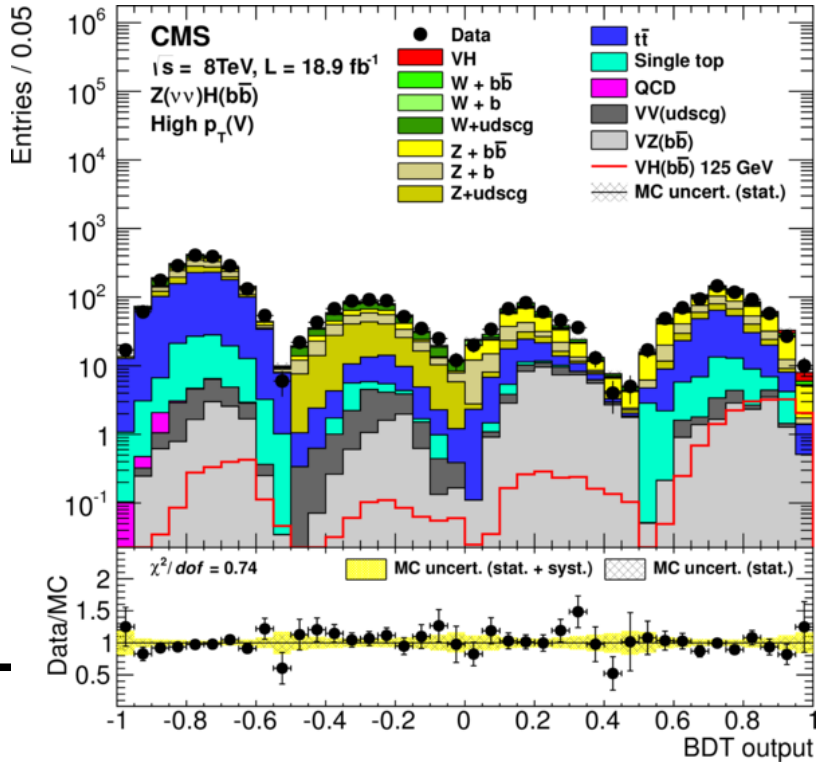
• BDT regression used to improve bb mass resolution to 10%

• BTD trained on $p_T(j_1,j_2,jj)$, m_{bb}, b-tag discriminator, topology used

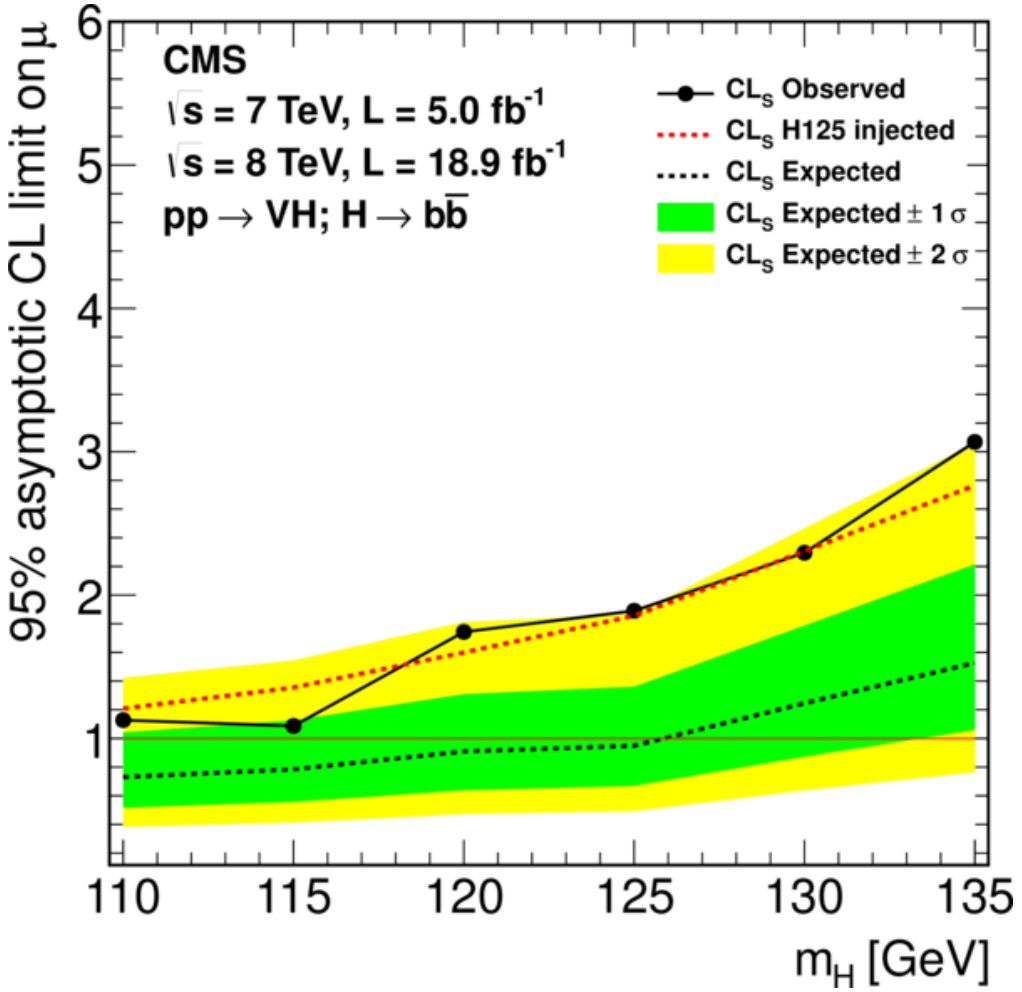
• four categories enriched in tt, V+jets, dibosons, and VH defined

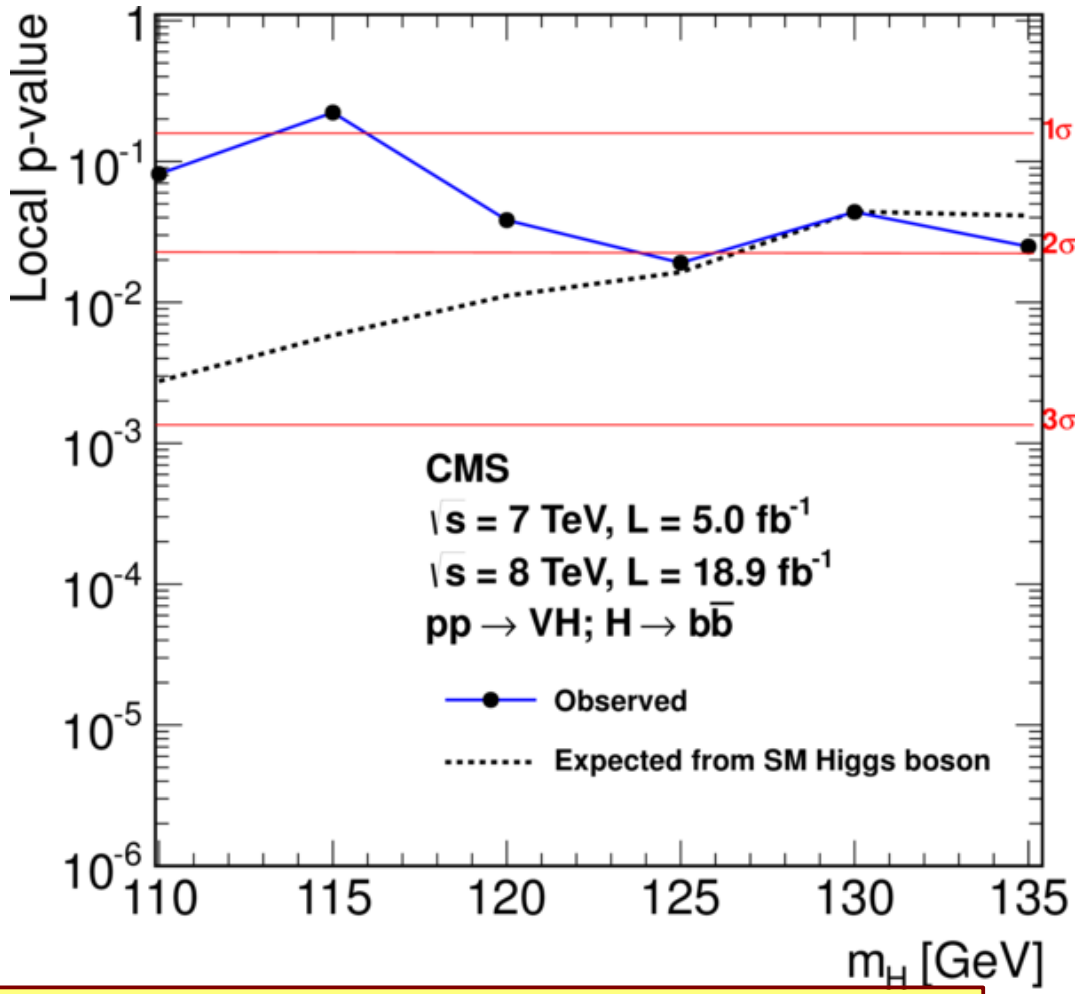
• signal extracted by simultaneous fit to BDT signal and background shape in all categories (cross check with fit to m_{bb})





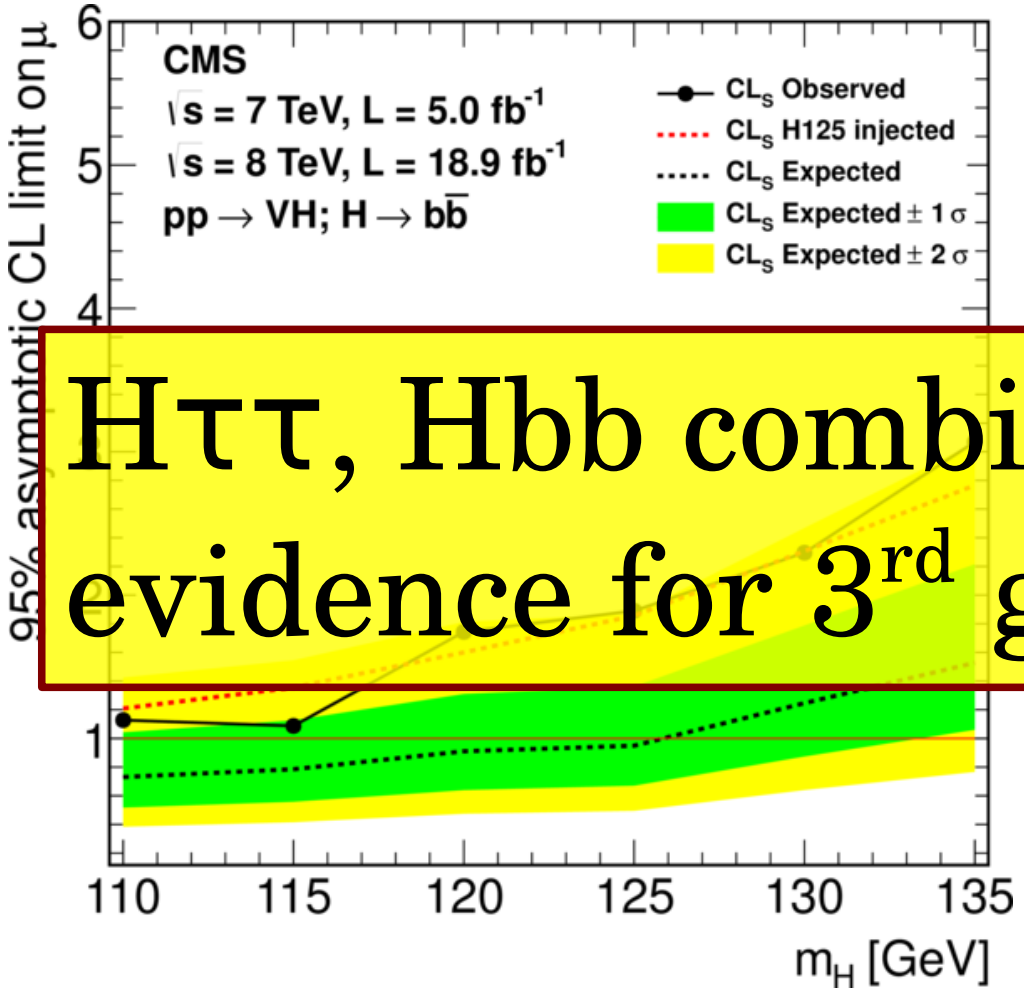
Coupling to bottom

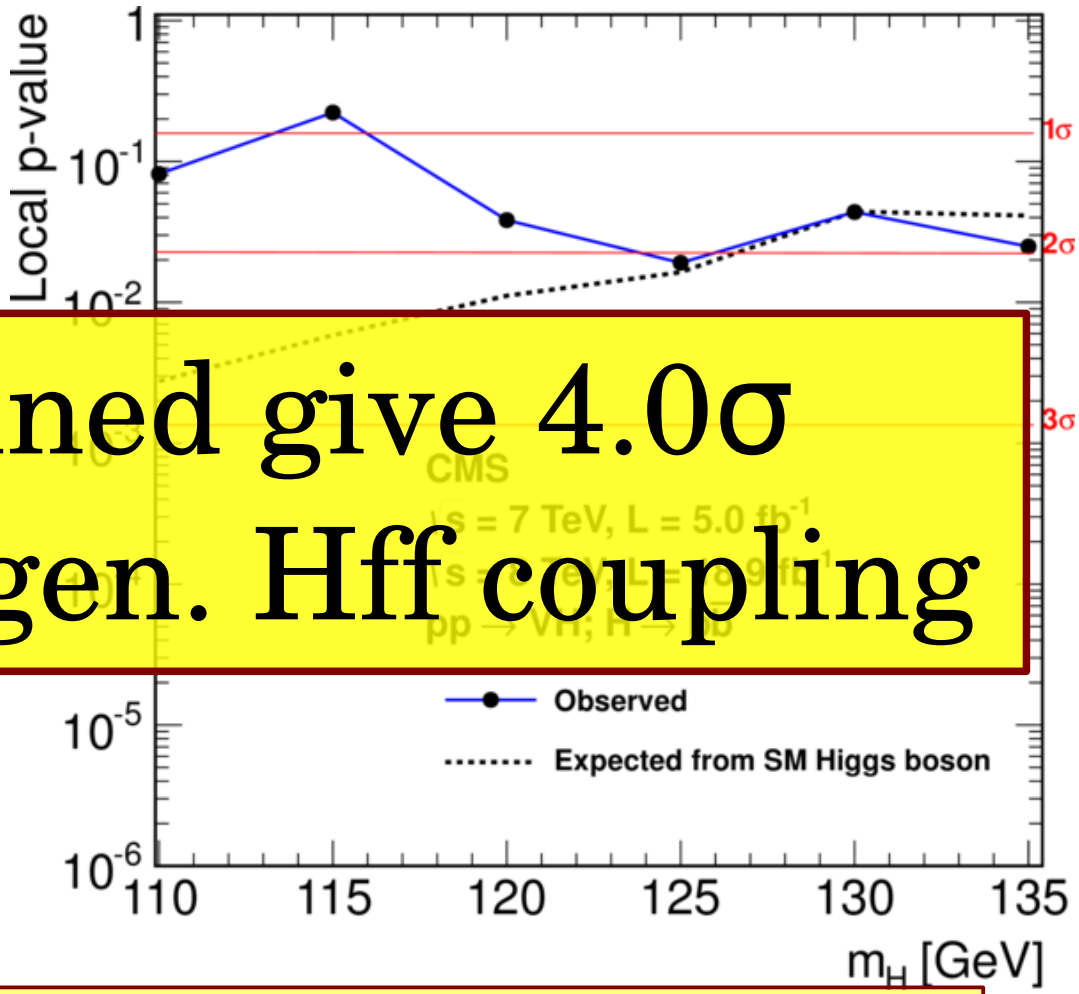




- 2.1 σ excess observed at 125 GeV
- the signal strength corresponding to this excess μ =1.0±0.5

Coupling to bottom





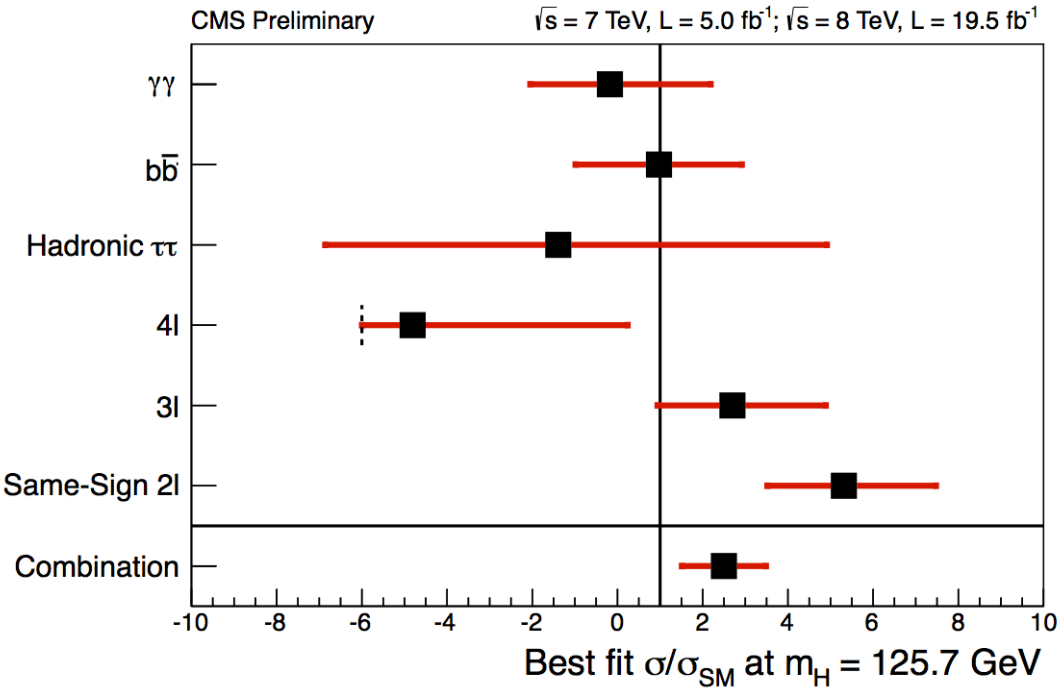
Hττ, Hbb combined give 4.0σ evidence for 3rd gen. Hff coupling

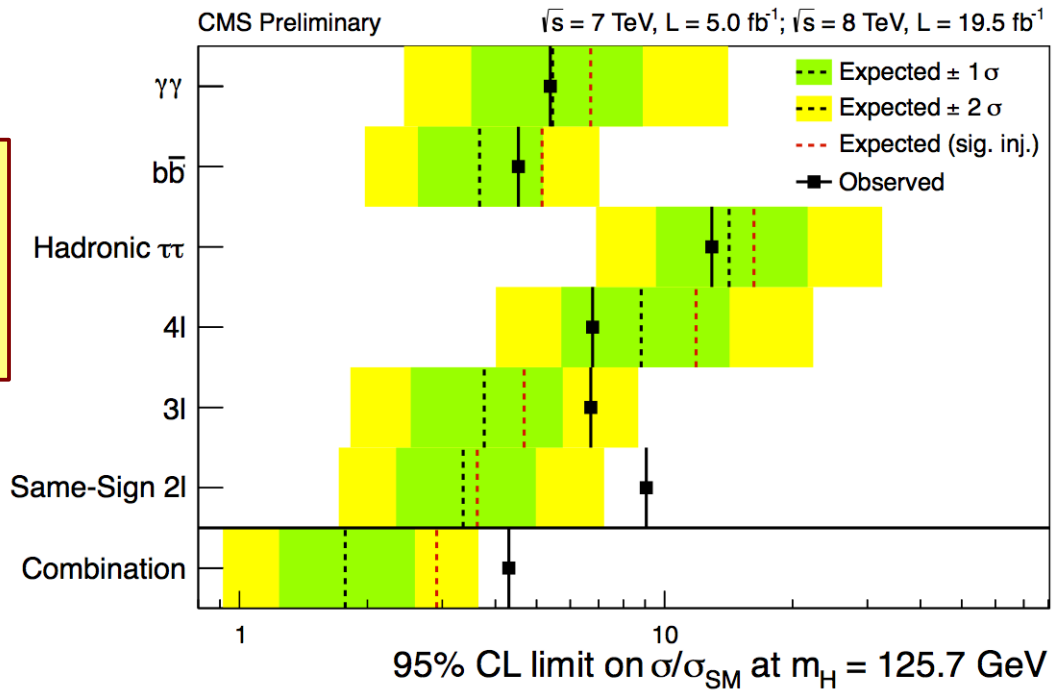
- 2.1 σ excess observed at 125 GeV
- the signal strength corresponding to this excess μ =1.0±0.5

Coupling to top

- tree coupling to top probed in ttH production mode
- combination of many decay modes: $\gamma\gamma$, $\tau\tau$, bb, WW, ZZ
- a simultaneous fit for signal and background is performed using the MVA output distributions
- signal like excess observed with μ(at 125.7 GeV) = $2.5^{+1.1}_{-1.0}$ – compatible with SM within 2σ

$\mu = \sigma_{fit}/\sigma_{SM}$





VV analyses

WW

- discovery mode: $2l2\nu$
- broad peak in $m_T(l,MET)$
- m_H optimised selection used
- shape-based or event counting analysis uses depending on leptons flavour and number of jets

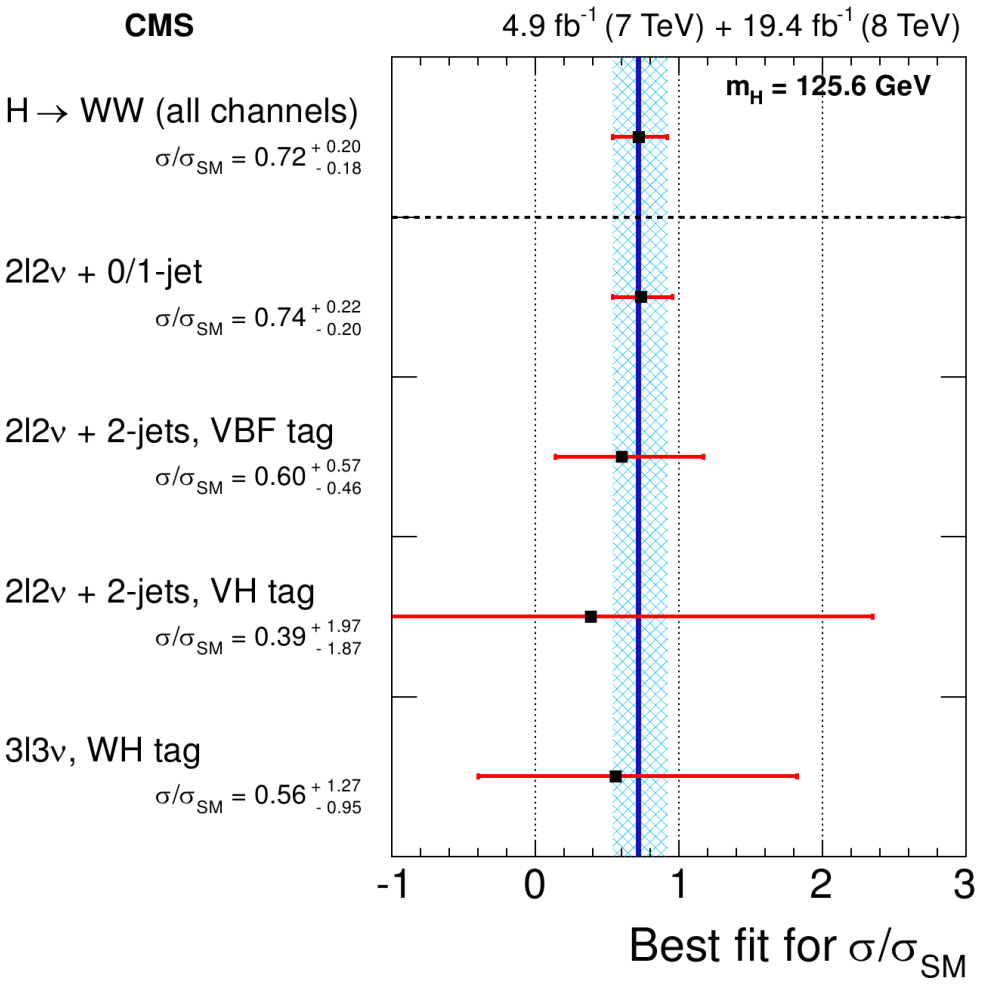
ZZ

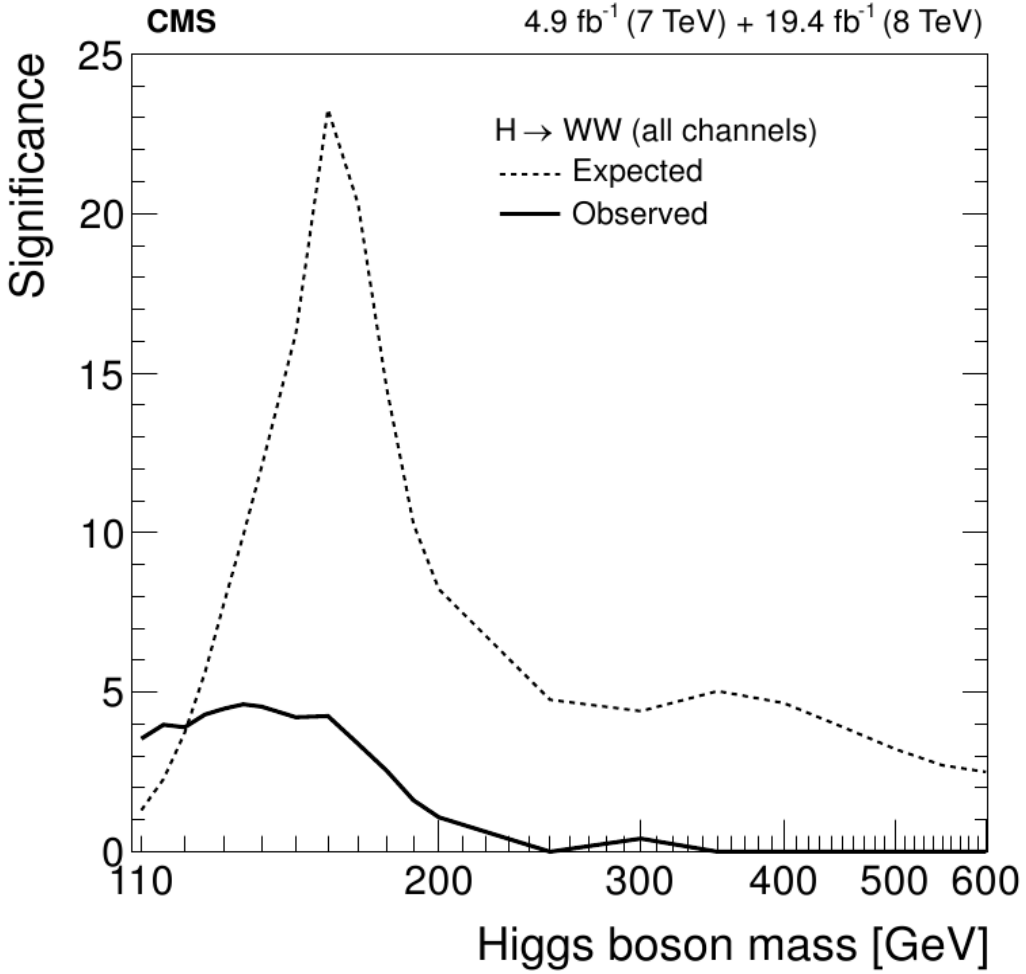
- discovery mode: 4μ, 4e, 2e2μ
- narrow peak in m_{4l}
- very low BR → low p_T lepton ID
- FSR recovery improves $\sigma(m_{4l})$
- event-by-event m_{4l} uncertainty used
- signal extraction with 3D fit: mass, matrix element angular analysis (MELA), p_T^{4l}

γγ

- narrow peak in $m_{\gamma\gamma}$, $\sigma(m_{\gamma\gamma}) \sim 1 - 2\ \%$
- huge nonresonant background – precisely estimated from sidebands
- two analysis flavours: cut-based and MVA

Coupling to W

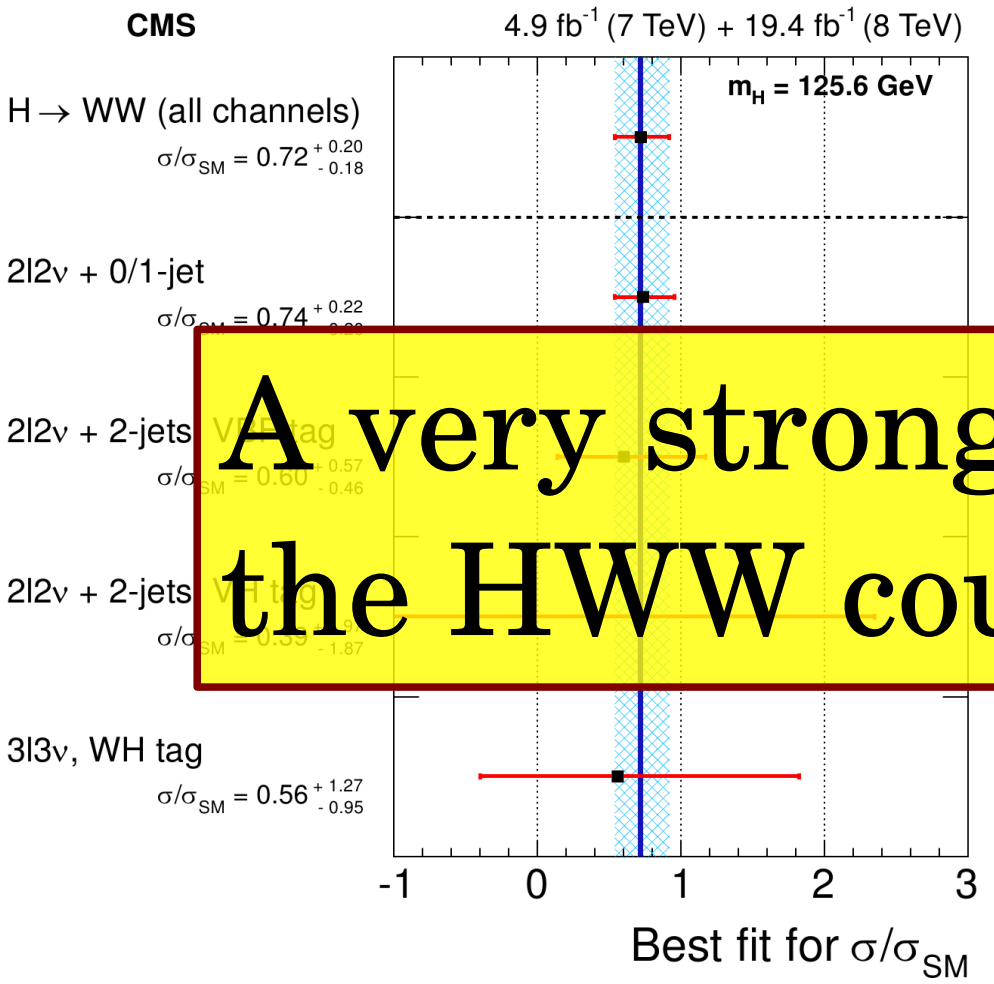


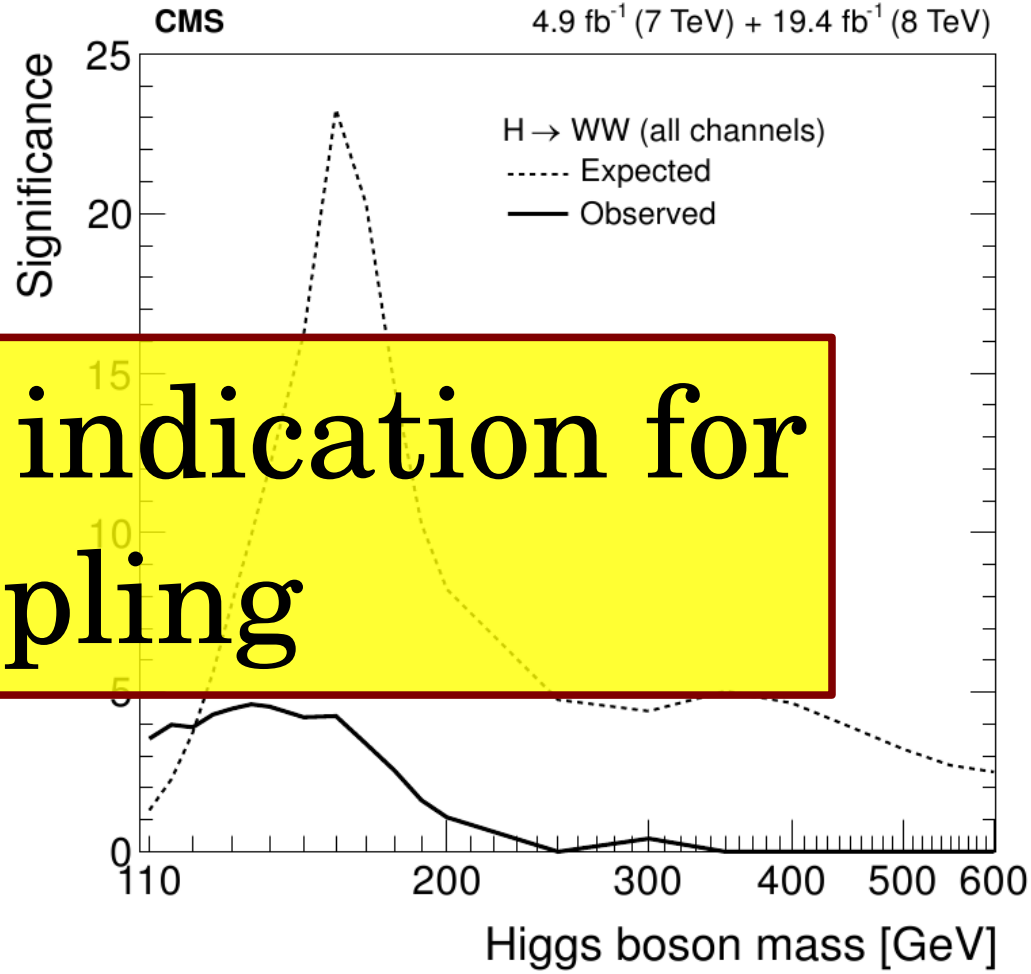


- 4.3 σ excess observed at 125.6 GeV
- the signal strength is $\mu = 0.72^{+0.20}_{-0.18}$

$\mu = \sigma_{fit}/\sigma_{SM}$

Coupling to W



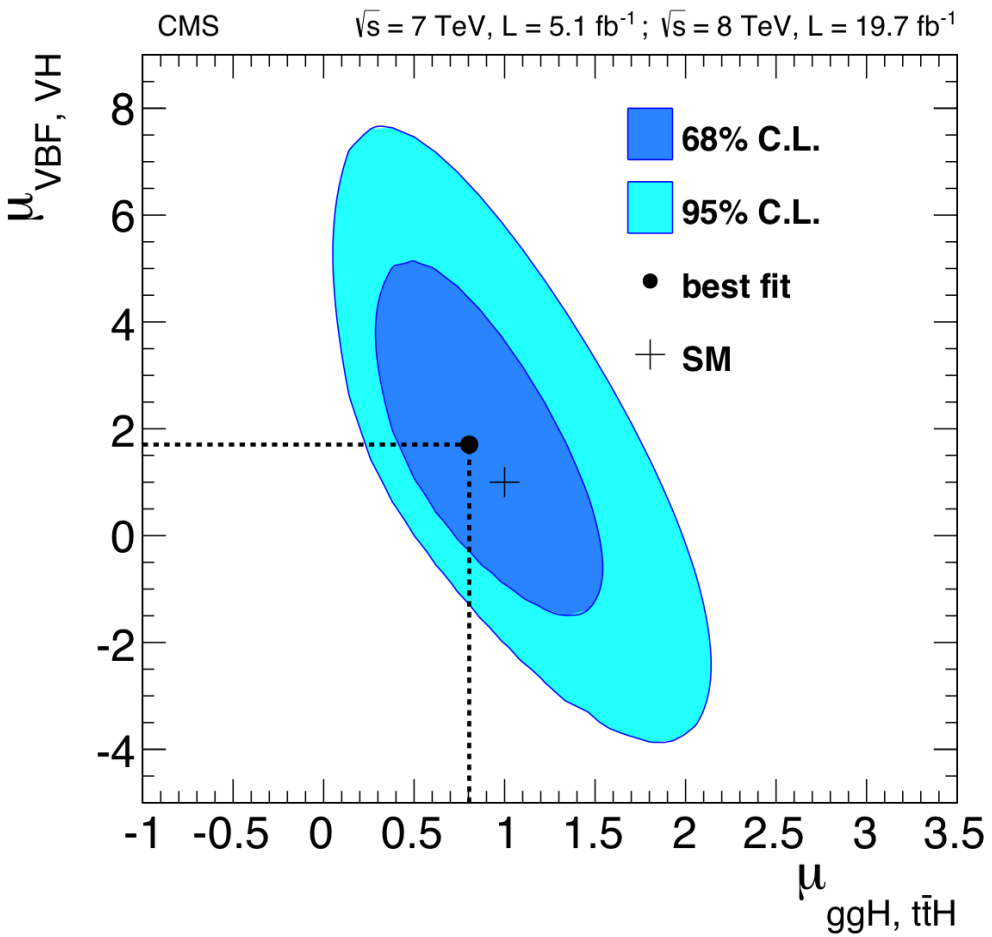


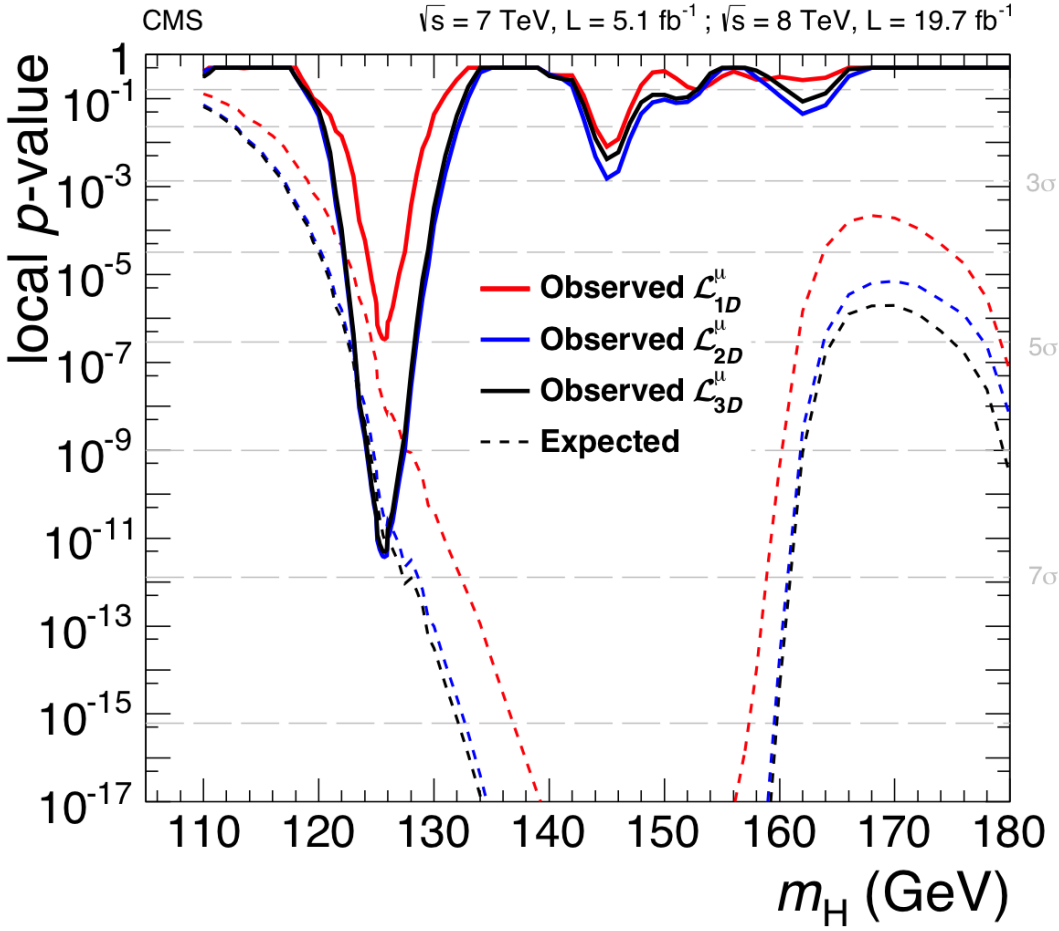
A very strong indication for the HWW coupling

- 4.3 σ excess observed at 125.6 GeV
- the signal strength is $\mu = 0.72^{+0.20}_{-0.18}$

$\mu = \sigma_{fit}/\sigma_{SM}$

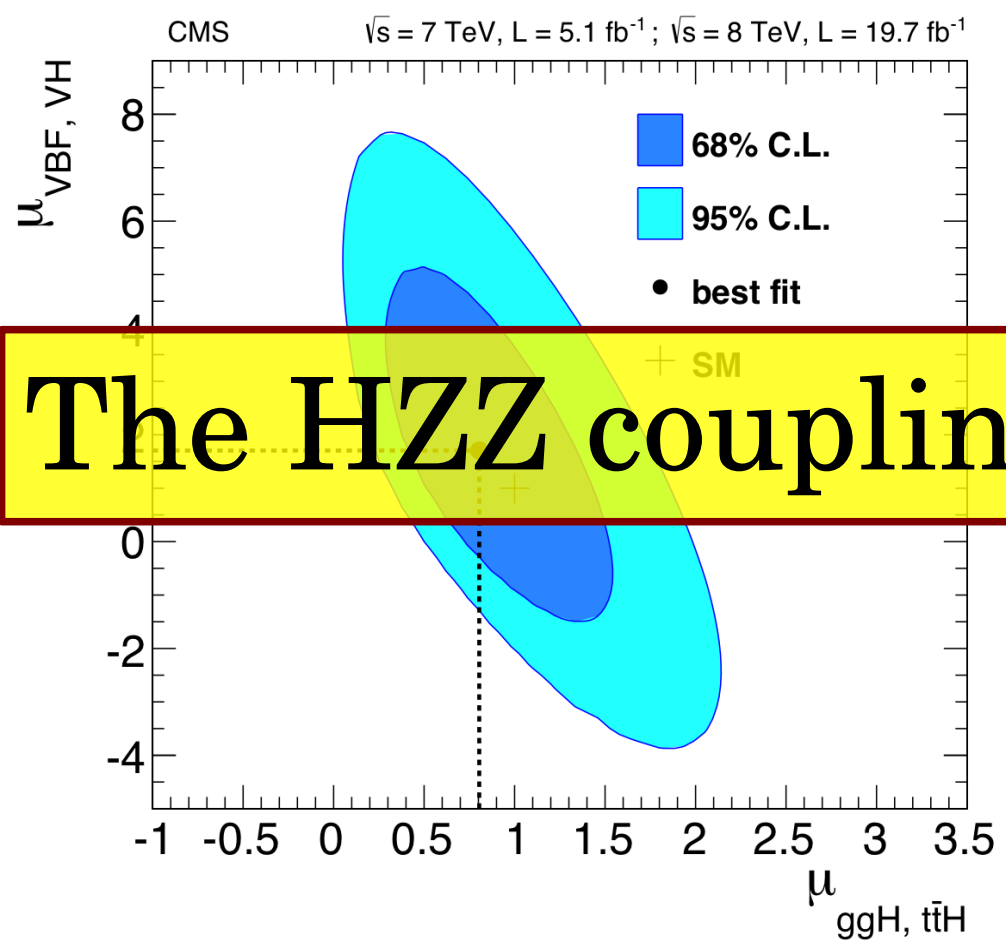
Coupling to Z

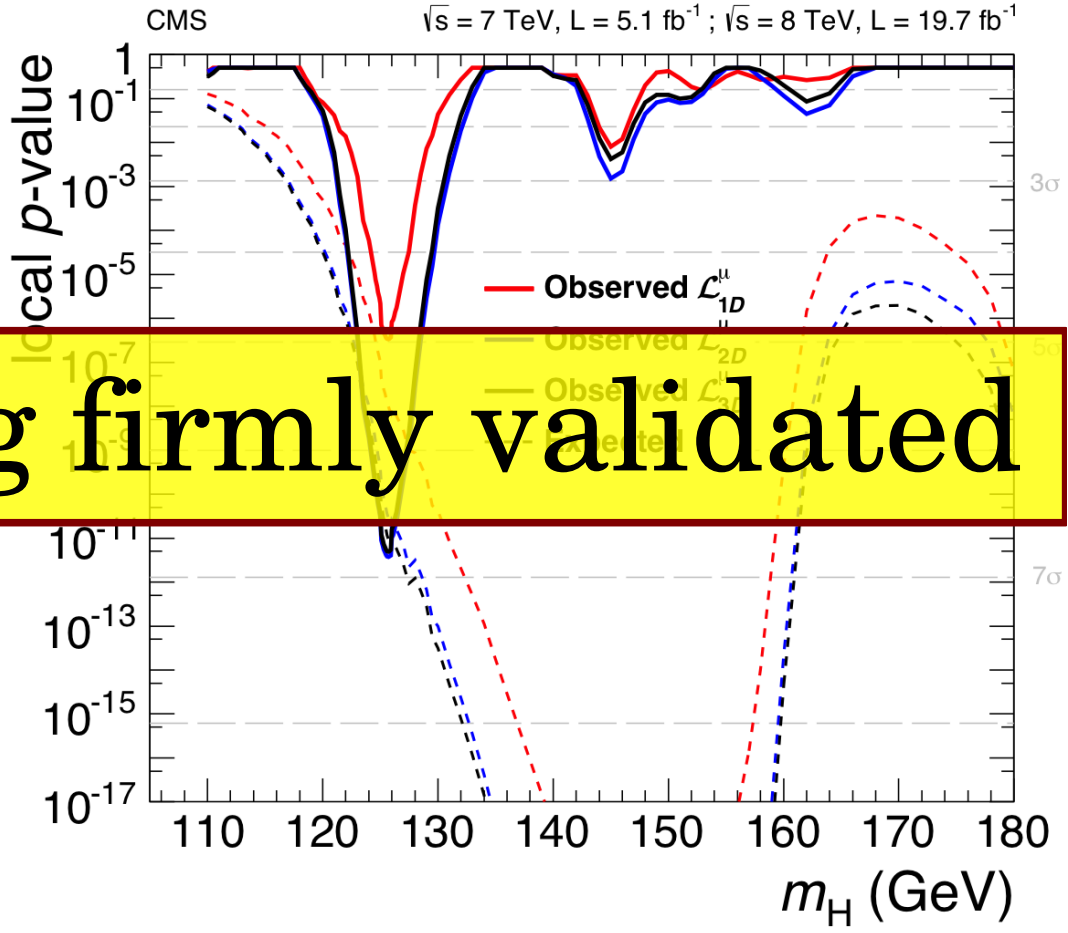




- signal observed at 125.6±0.4(stat)±0.2 (syst) GeV at 6.8 σ
- the signal strength is $\mu = 0.93^{+0.26}_{-0.23}(\text{stat})\ ^{+0.13}_{-0.09}(\text{syst})$

Coupling to Z

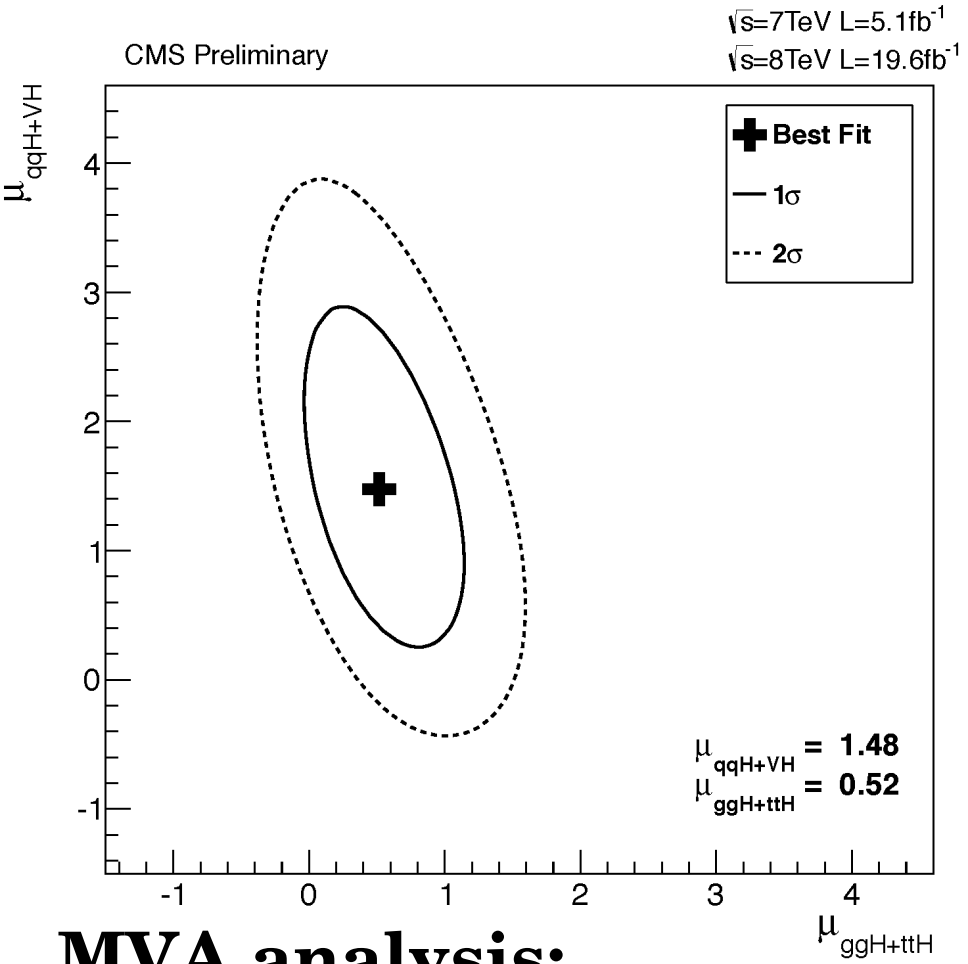


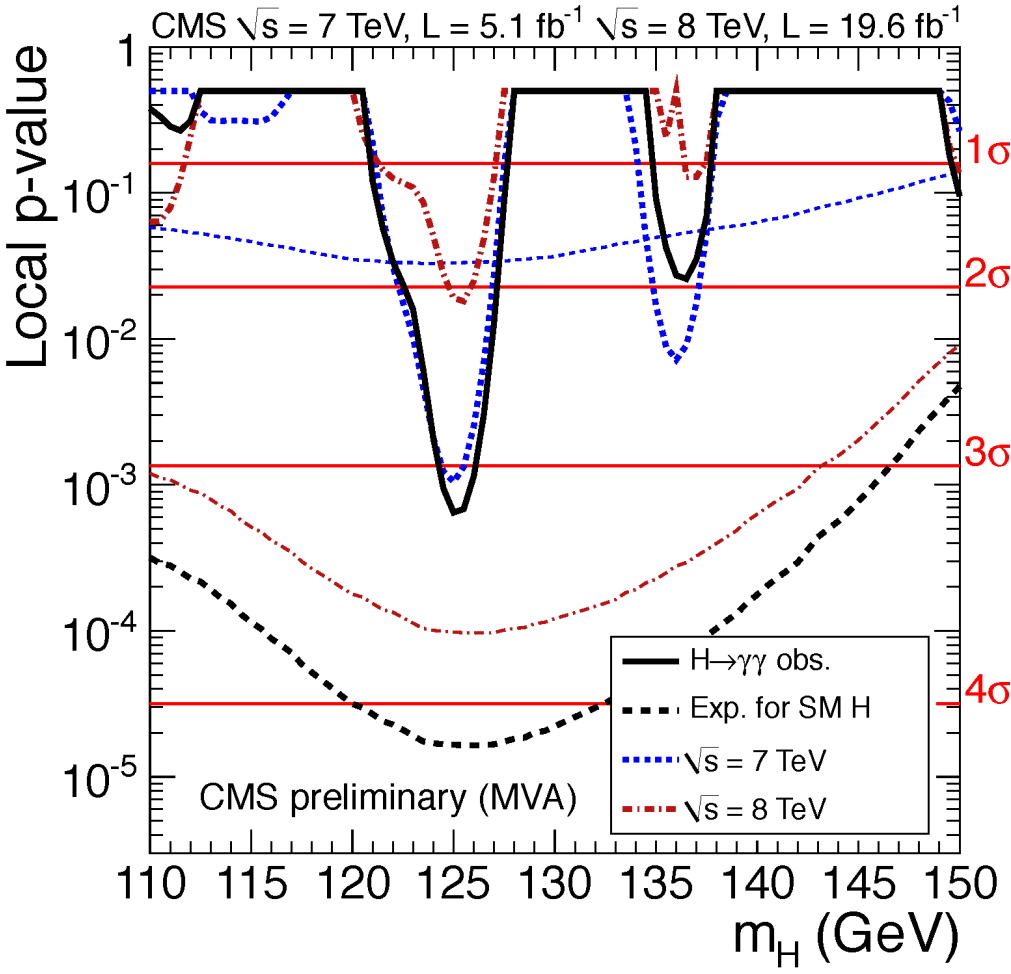


The HZZ coupling firmly validated

- signal observed at 125.6±0.4(stat)±0.2 (syst) GeV at 6.8 σ
- the signal strength is $\mu = 0.93^{+0.26}_{-0.23}(\text{stat})\ ^{+0.13}_{-0.09}(\text{syst})$

Coupling to γ

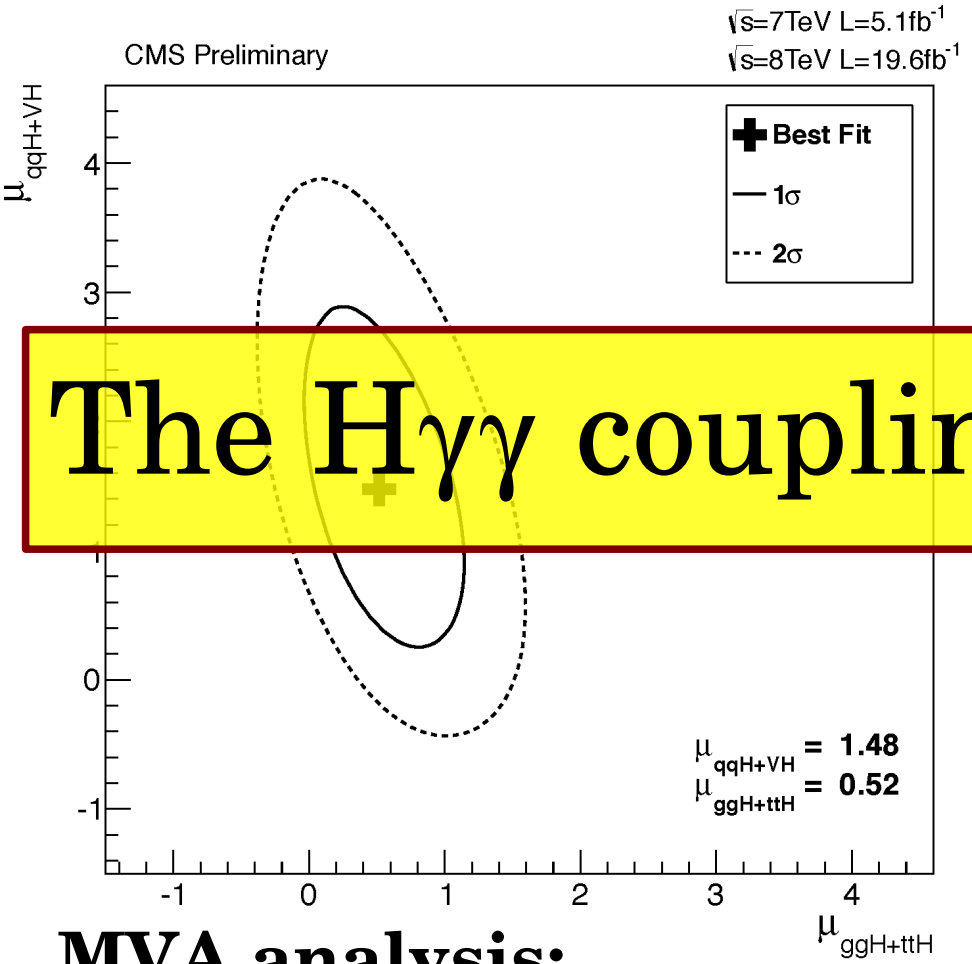


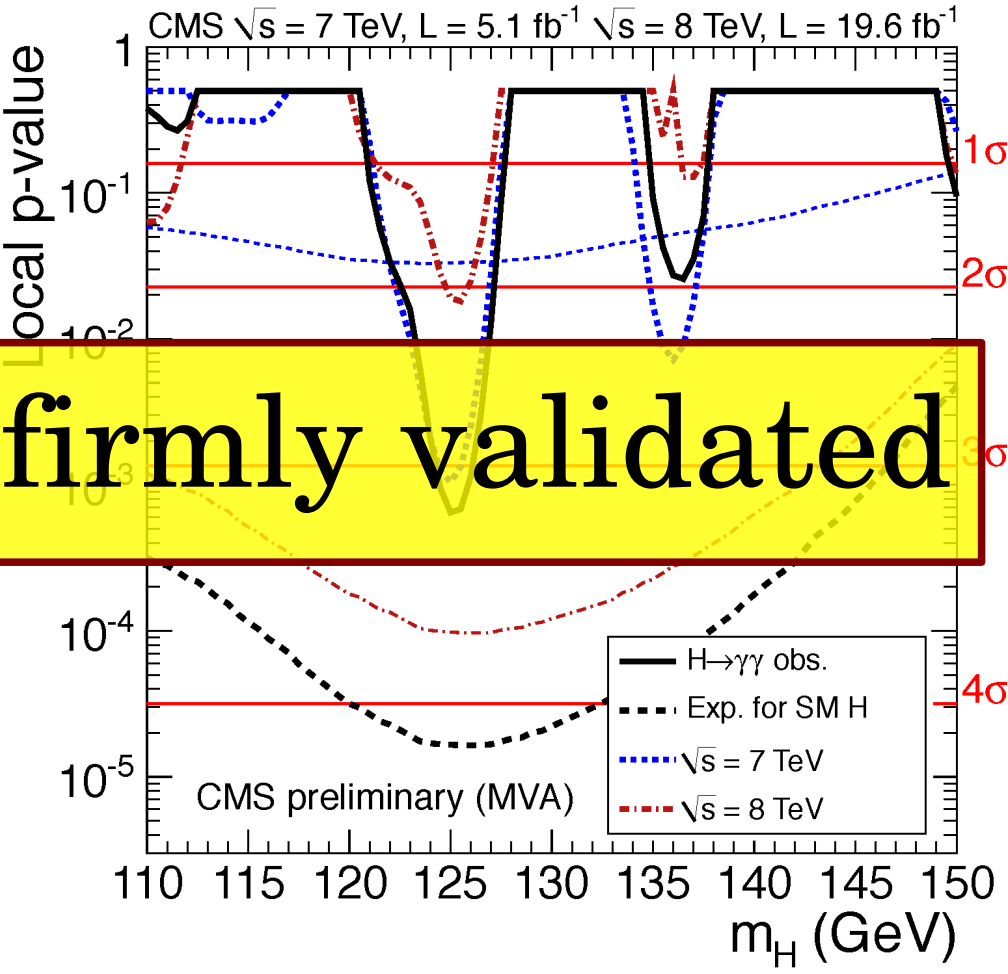


MVA analysis:

- 3.2 σ signal observed at 125.4±0.5(stat)±0.6 (syst) GeV
- the fitted signal strength is $\mu = 0.78^{+0.28}_{-0.26}$

Coupling to γ



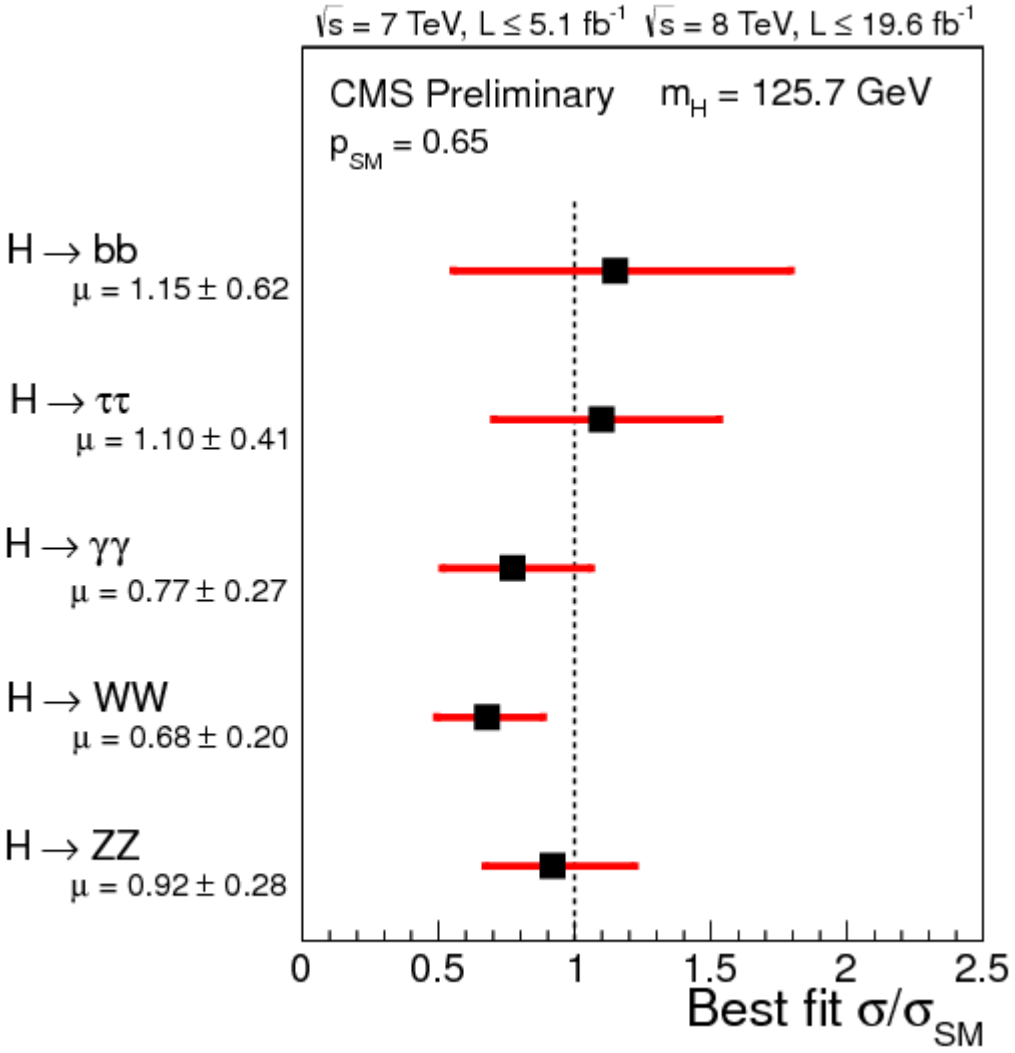


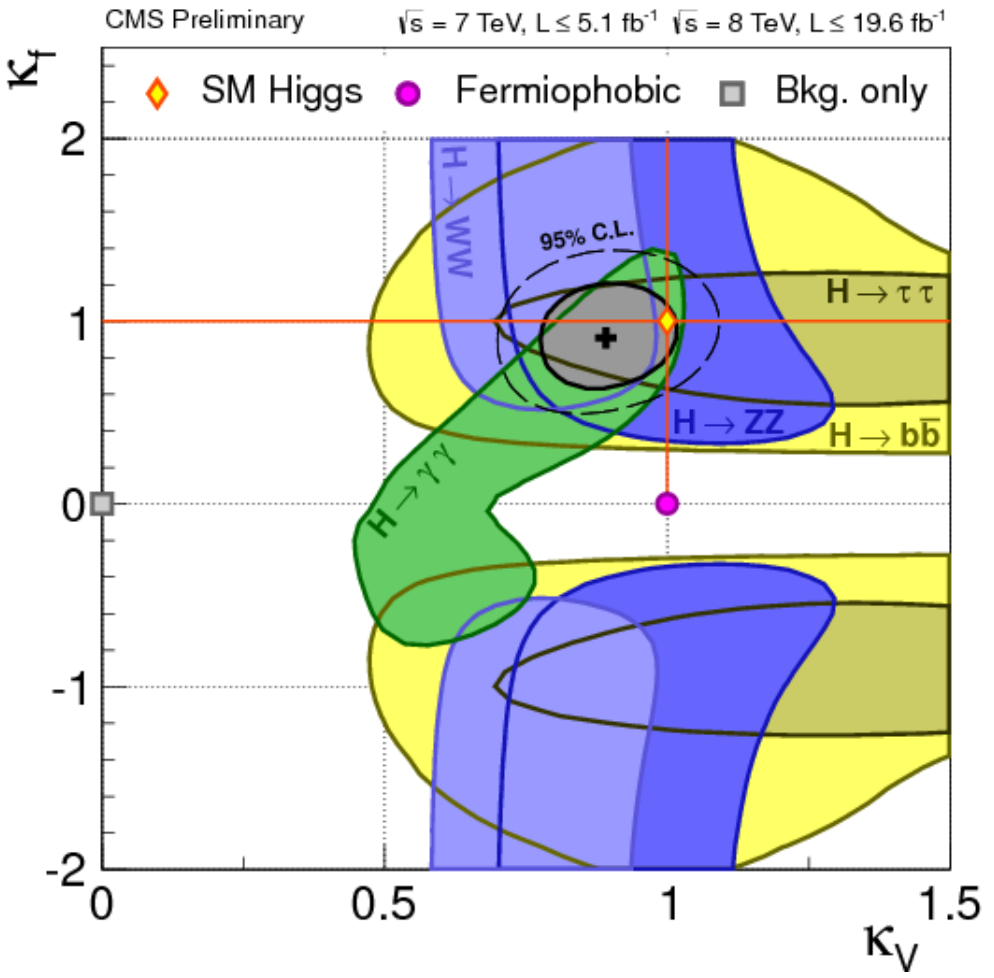
The Hγγ coupling firmly validated

MVA analysis:

- 3.2 σ signal observed at 125.4±0.5(stat)±0.6 (syst) GeV
- the fitted signal strength is $\mu = 0.78^{+0.28}_{-0.26}$

Couplings combination



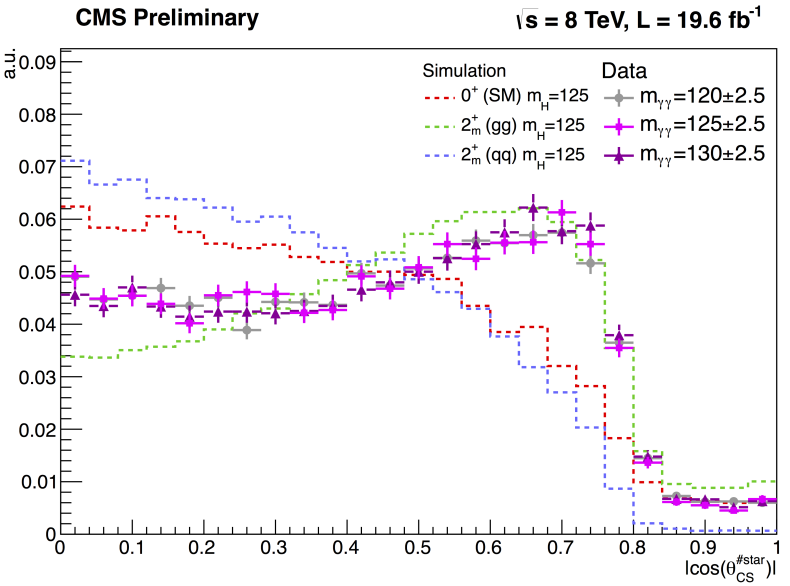


All measured couplings agree with SM within 2 σ

Spin and Parity (selected results)

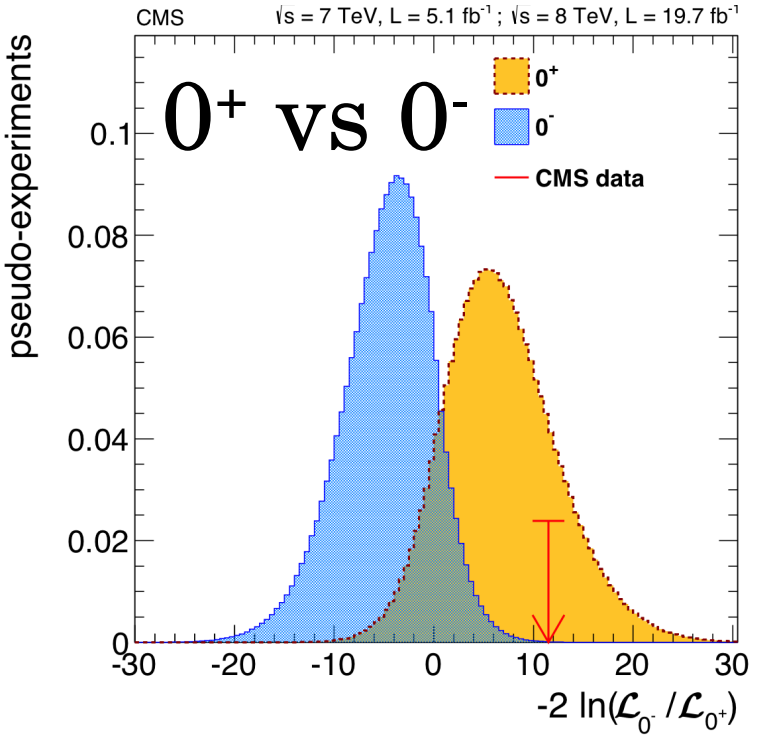
$\gamma\gamma$: angle between photons in Colin-Sapers frame

the data are compatible with 0^+
still the spin-2 cannot be excluded



ZZ: different spin/parity models assumed for MELA analysis

data is consistent with 0^+ hypothesis



Spin and Parity (selected results)

$\gamma\gamma$: angle between photons in Colin-Sapers frame

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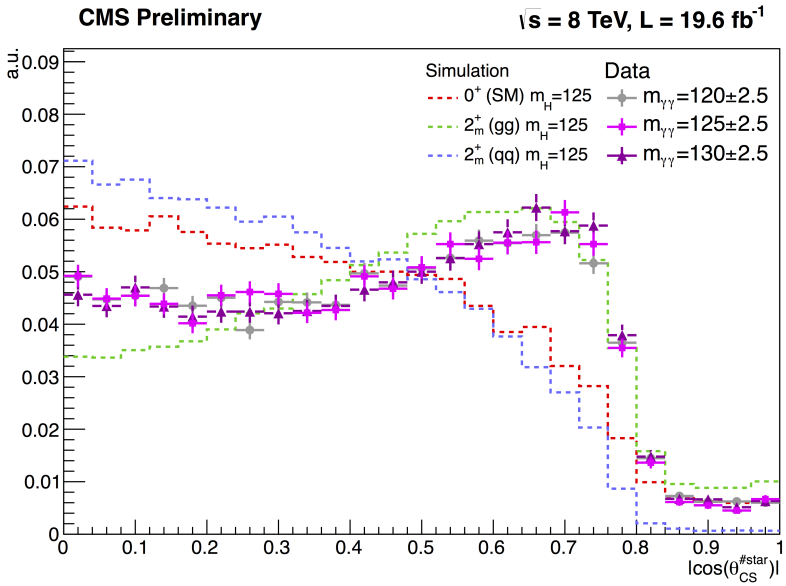
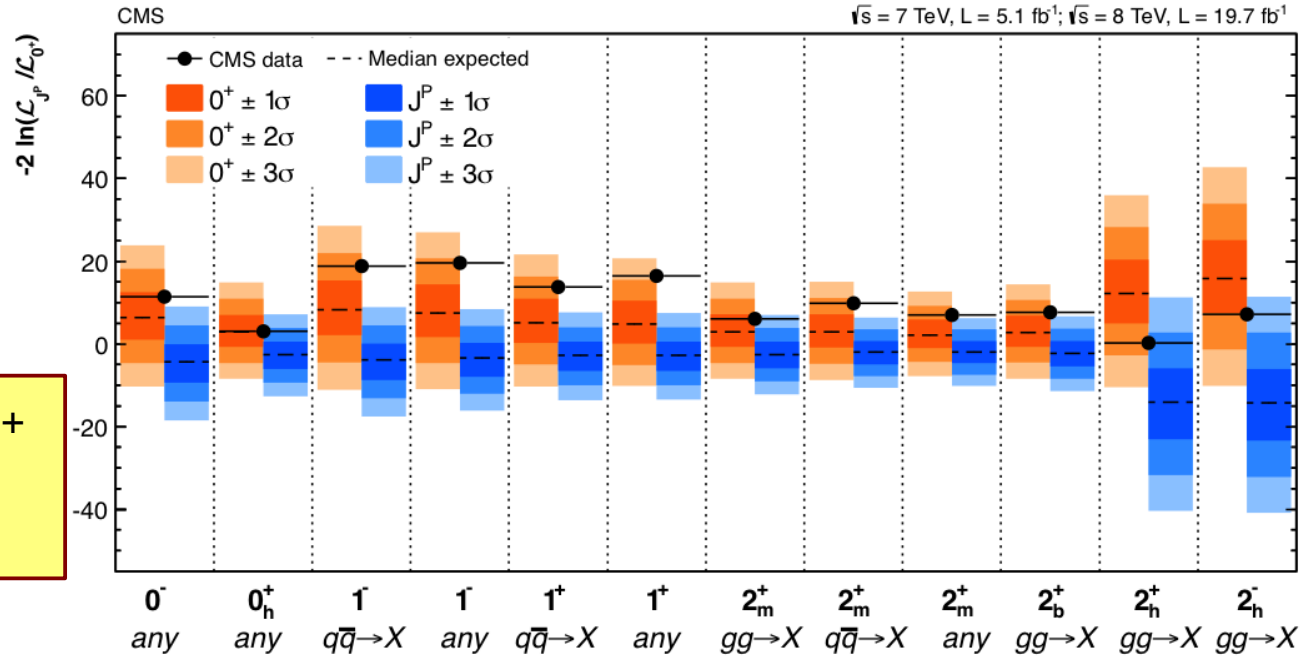
still the spin-2 cannot be excluded



ZZ: different spin/parity models assumed for MELA analysis

data is consistent with 0^+ hypothesis

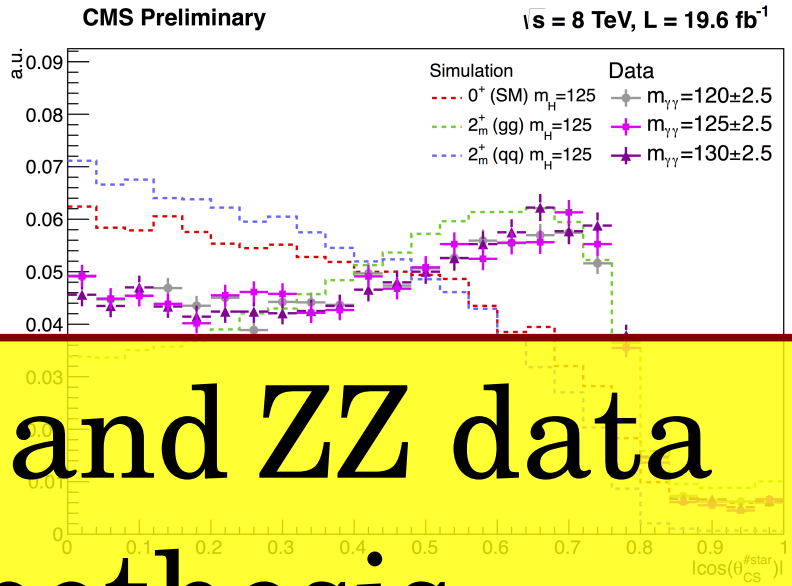


Spin and Parity (selected results)

γγ: angle between photons in Colin-Sapers frame

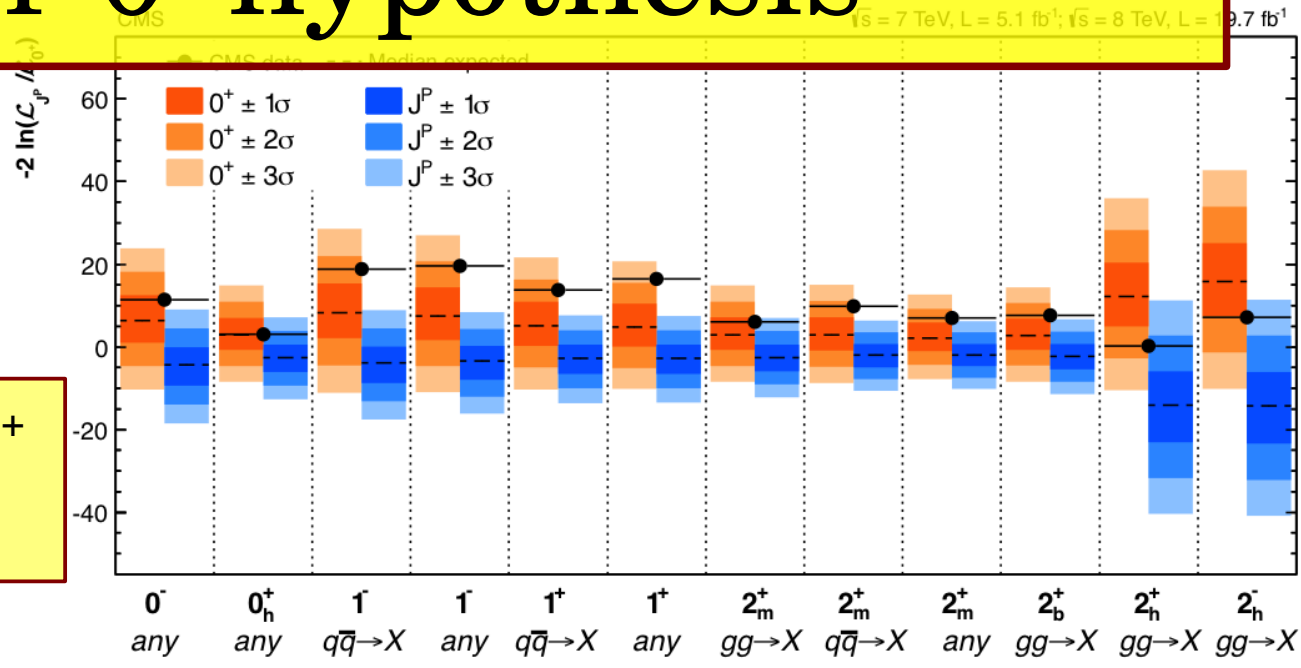
the data are compatible with 0⁺

still the spin-2 cannot be excluded



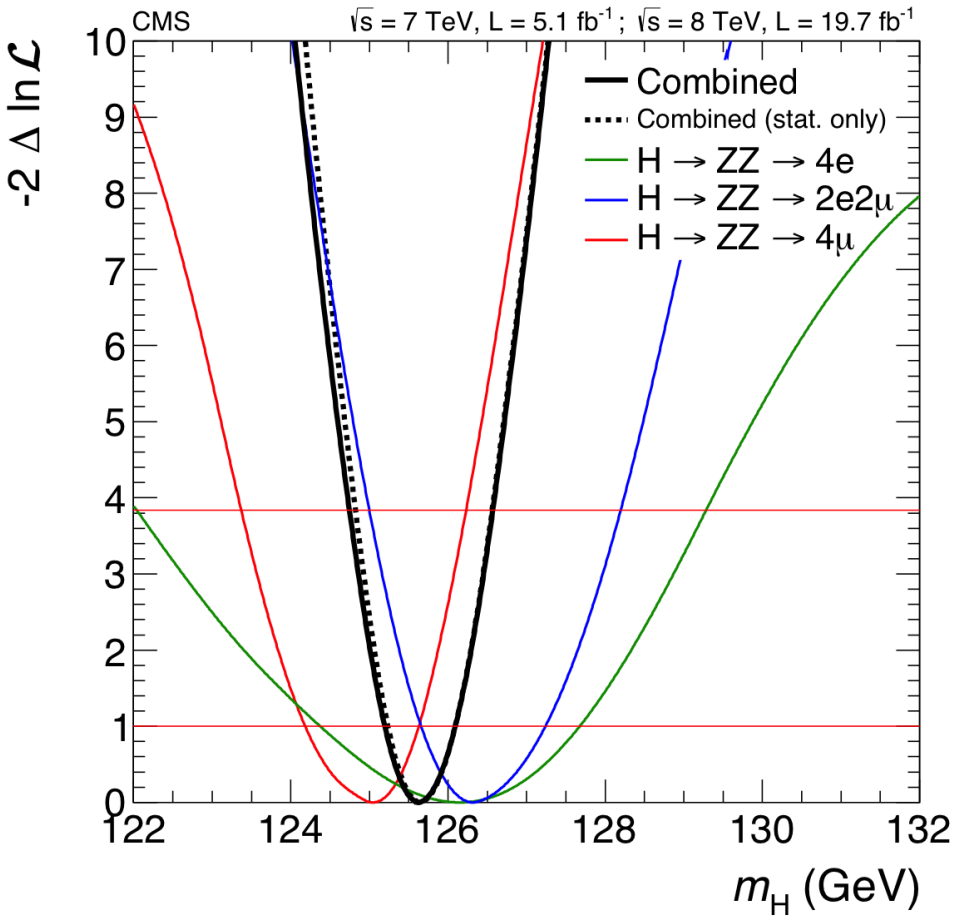
WW (not shown here) and ZZ data disfavor 0⁻ hypothesis

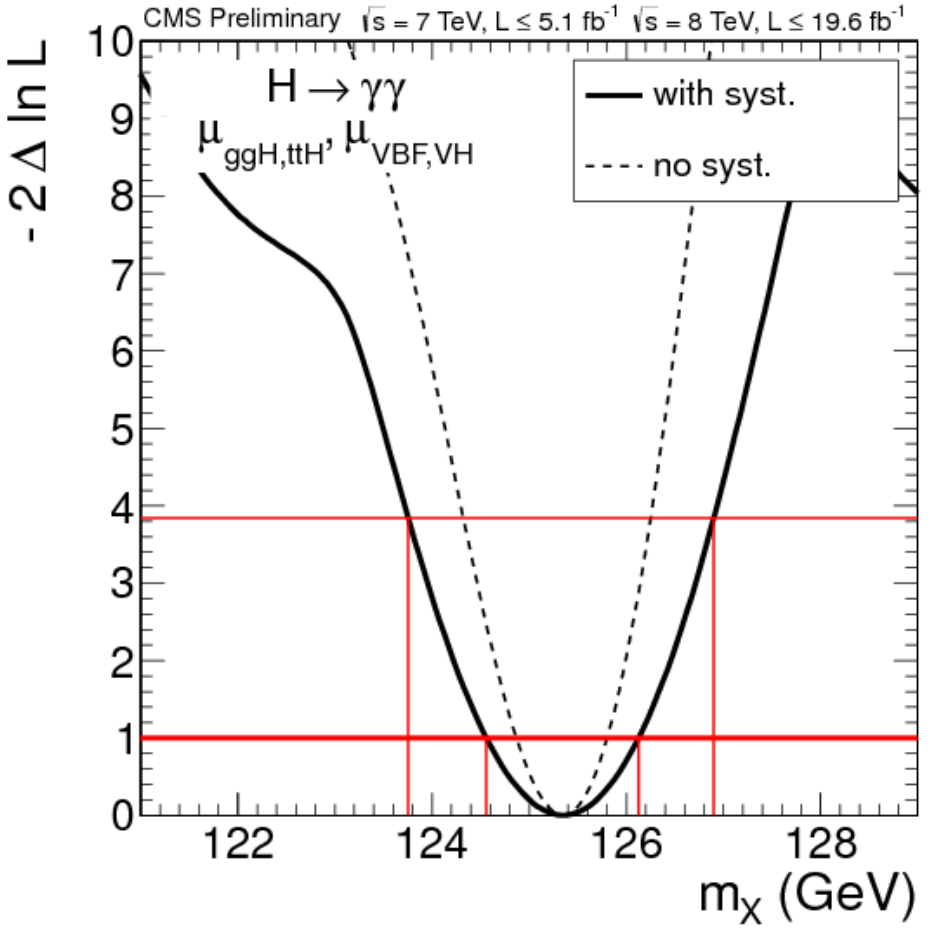
ZZ: different spin/parity models assumed for MELA analysis



data is consistent with 0⁺ hypothesis

Mass





Mass estimated for two precise search channels:

H→ZZ→4l: $m_H = 125.6 \pm 0.4\,(\text{stat.}) \pm 0.2\,(\text{syst.})$

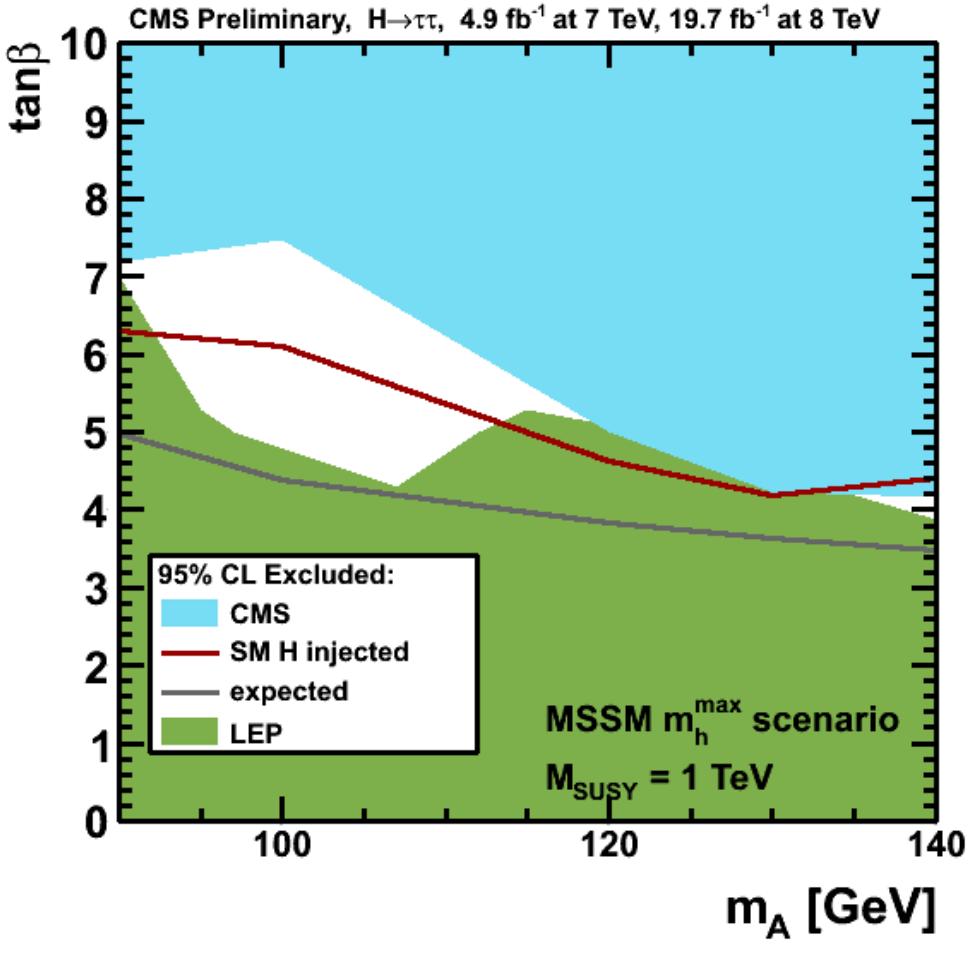
H→γγ: $m_H = 125.4 \pm 0.5(\text{stat.}) \pm 0.6(\text{syst.})$.

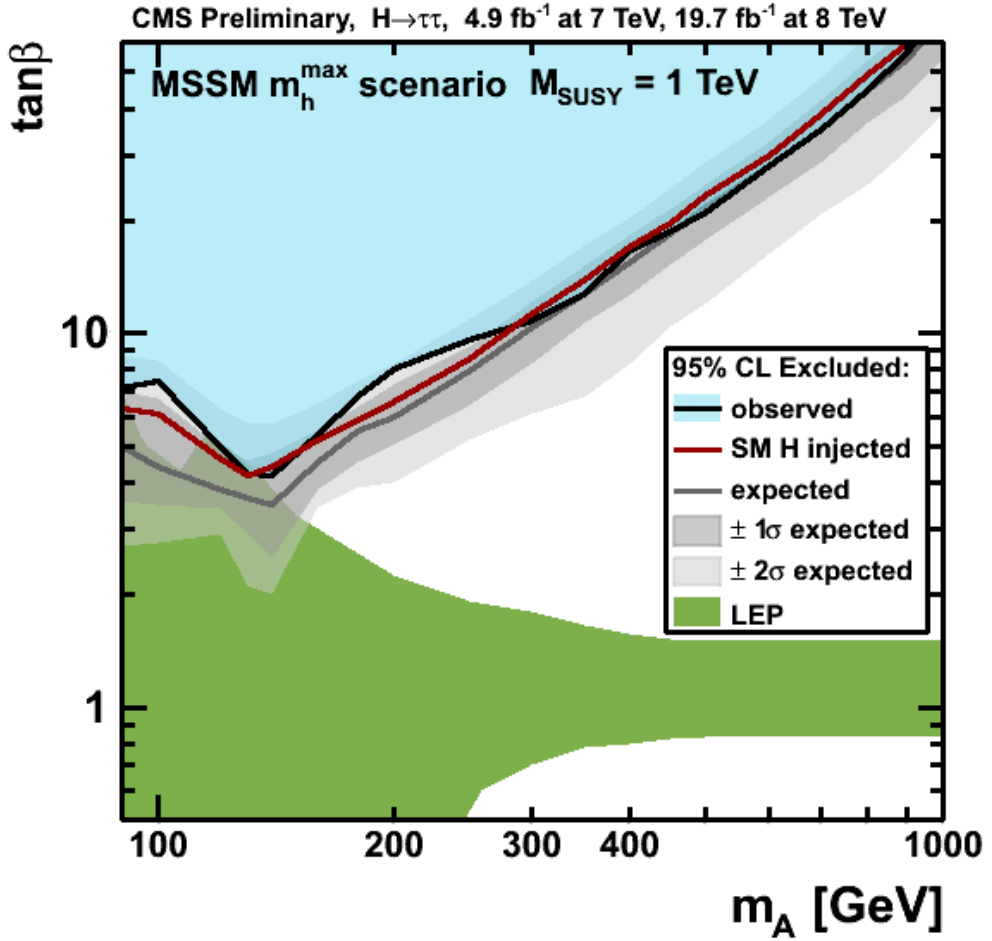
Combined: $m_H = 125.7 \pm 0.3(\text{stat.}) \pm 0.3(\text{syst.})$

MSSM searches (neutral)

- $\mu\tau_h$, $e\tau_h$, $\tau_h\tau_h$, $e\mu$, $\mu\mu$ tau pair decays considered

- events split into No-B-Tag ($gg \rightarrow H$) and B-Tag ($gg \rightarrow bbH$)





- full mass reconstructed with likelihood approach

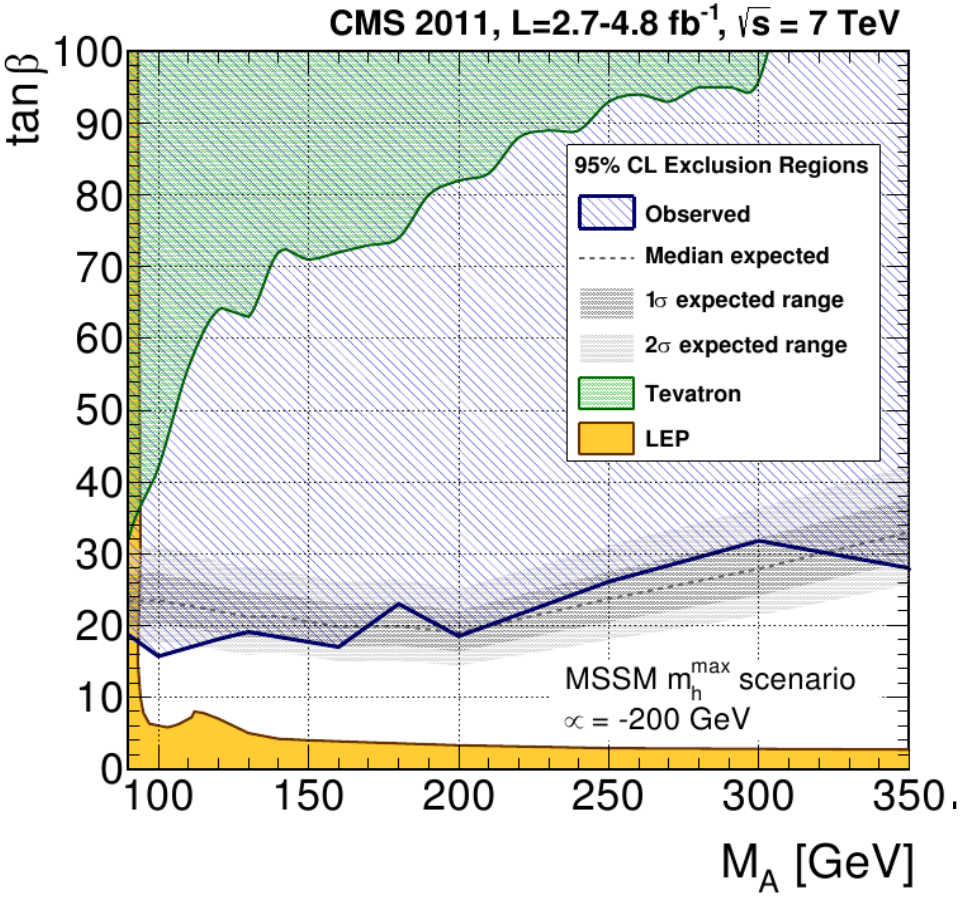
- no MSSM signal observed

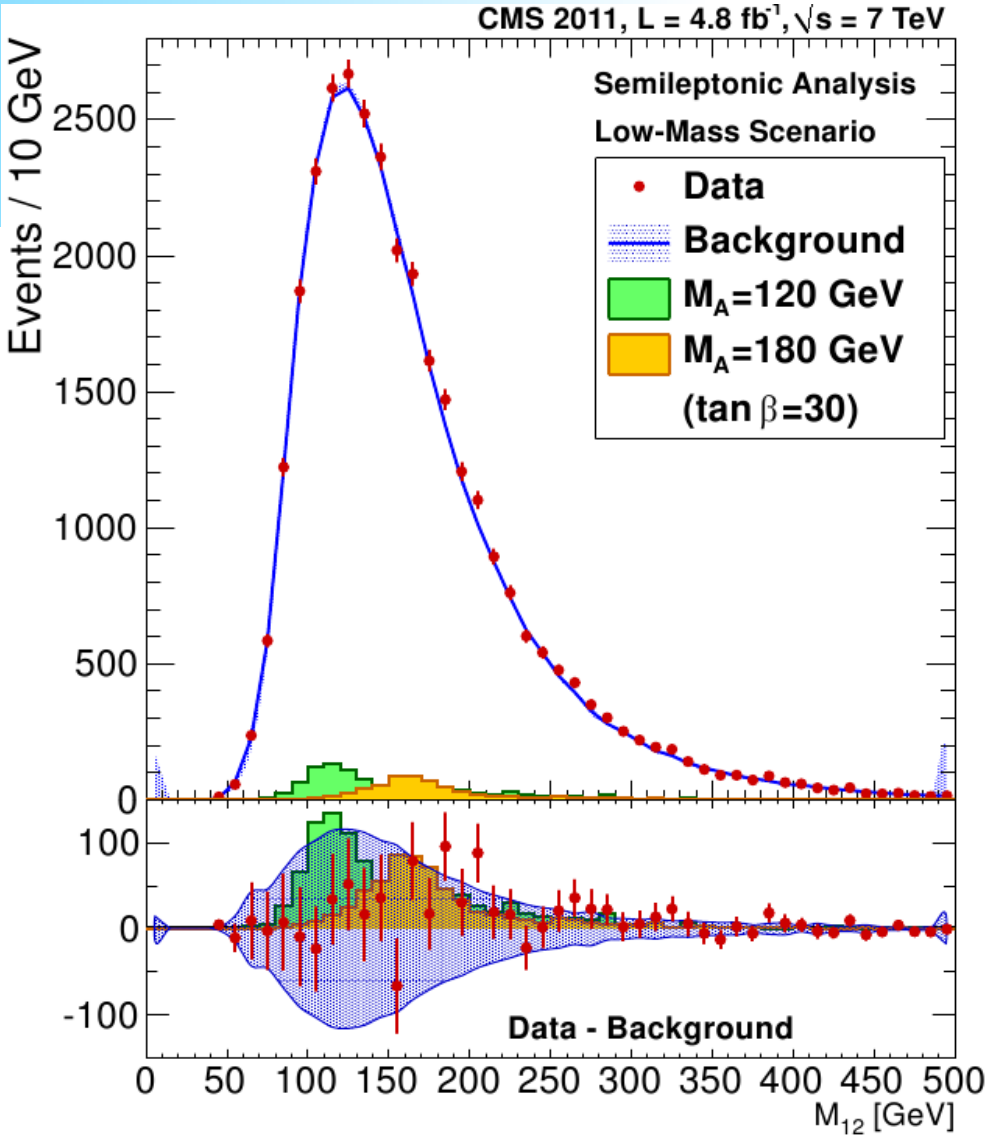
MSSM searches (neutral)

• three b-jets events considered, targeting bH(→bb) and bbH(→bb)

• all-hadronic and semileptonic

•(with an additional non-isolated muon) categories considered





• peak in the invariant mass distribution of the two leading b analyzed

• no MSSM signal observed

Conclusions

- The CMS Collaboration analysed 5.1(19.6) fb^{-1} of data collected at $\sqrt{s}$ =7(8) TeV in search for SM Higgs boson using number of decay and production modes
- **More than 5σ excess was observed in HZZ. Other modes are compatible with SM expectations**
- **Measured spin and parity are compatible with 0^+ of SM Higgs boson, although spin admixture still cannot be excluded**
- **No sign of BSM signal was observed**

References

- CMS detector: JINST 3:S08004,2008
  http://iopscience.iop.org/1748-0221/3/08/S08004

- Handbook of LHC Higgs Cross Sections: 3. Higgs Properties
  http://arxiv.org/abs/1307.1347

- Search for the standard-model Higgs boson decaying to ττ in non VH channels
  CMS-PAS-HIG-13-004

- Search for the standard model Higgs boson in the μ+μ− decay channel in pp collisions at √s = 7 and 8 TeV
  CMS-PAS-HIG-13-007

References

- Search for the standard model Higgs boson produced in association with a W or a Z boson and decaying to bottom quarks
  http://arxiv.org/abs/arXiv:1310.3687

- Search for the standard model Higgs boson produced in vector boson fusion, and decaying to bottom quarks
  CMS-PAS-HIG-13-011

- Combination of Search Results for Higgs Boson Production in Association with a Top-Quark Pair
  TWiki page, CMS-PAS-HIG-13-020, CMS-PAS-HIG-13-019, CMS-PAS-HIG-13-015, CMS-PAS-HIG-12-025

- Measurement of the standard model Higgs boson decaying to a W-boson pair in leptonic final states at $\sqrt{s}$ = 7 and 8 TeV
  http://arxiv.org/abs/1312.1129

References

- Measurement of the properties of a Higgs boson in the four-lepton final state
  http://arxiv.org/abs/1312.5353

- Updated measurements of the Higgs-like boson at 125 GeV in the two photon decay channel
  CMS-PAS-HIG-13-001

- Measurements of the properties of the new boson with a mass near 125 GeV
  CMS-PAS-HIG-13-005

- Search for Neutral MSSM Higgs Bosons Decaying to Tau Pairs in pp Collisions
  CMS-PAS-HIG-13-021

- Search for a Higgs boson produced in association with b quarks and decaying into a b-quark pair
  http://arxiv.org/abs/1302.2892