# Higgs coupling to bosons in CMS

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on behalf of the CMS collaboration

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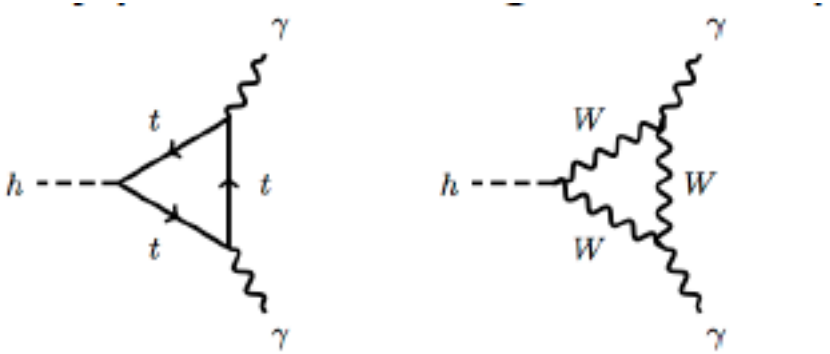
# Outline

- This talk will cover the results of Higgs-to-boson couplings on CMS Run-1 data including
  - **Higgs to γγ**
  - **Higgs to WW**
  - **Higgs to ZZ to four leptons (lepton = e, μ)**
  - **Higgs combination**

# Reference

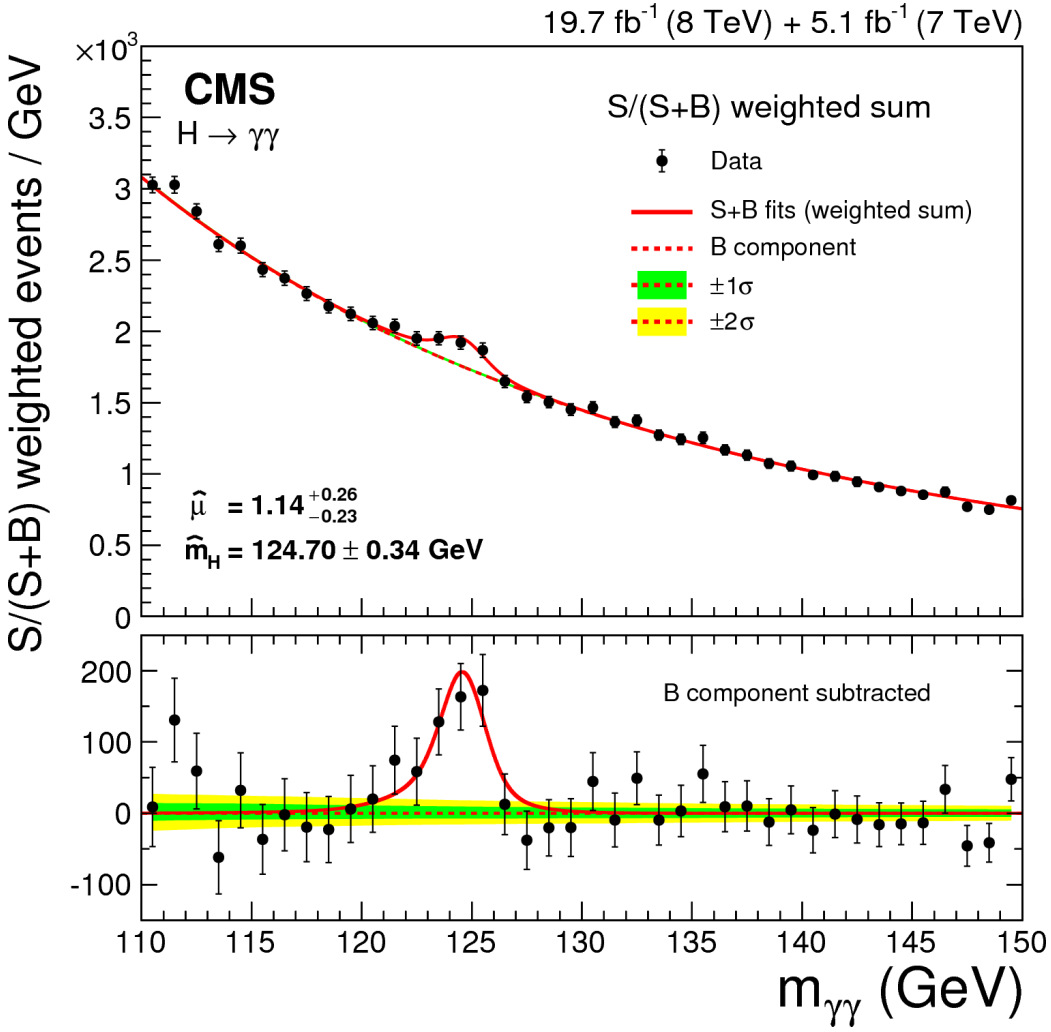
- **Higgs to γγ**
  Eur. Phys. J. C, 74, 3076 (2014)
- **Higgs to WW**
  JHEP, 01, 096 (2014)
- **Higgs to ZZ to four leptons (lepton = e, μ)**
  Phys. Rev. D, 89, 092007
- **Higgs combination**
  CMS-HIG-14-009, submitted to Eur. Phys. J. C

# Higgs to γγ




Higgs to γγ sensitive to Vector Bosons and top coupling in both production and decay.

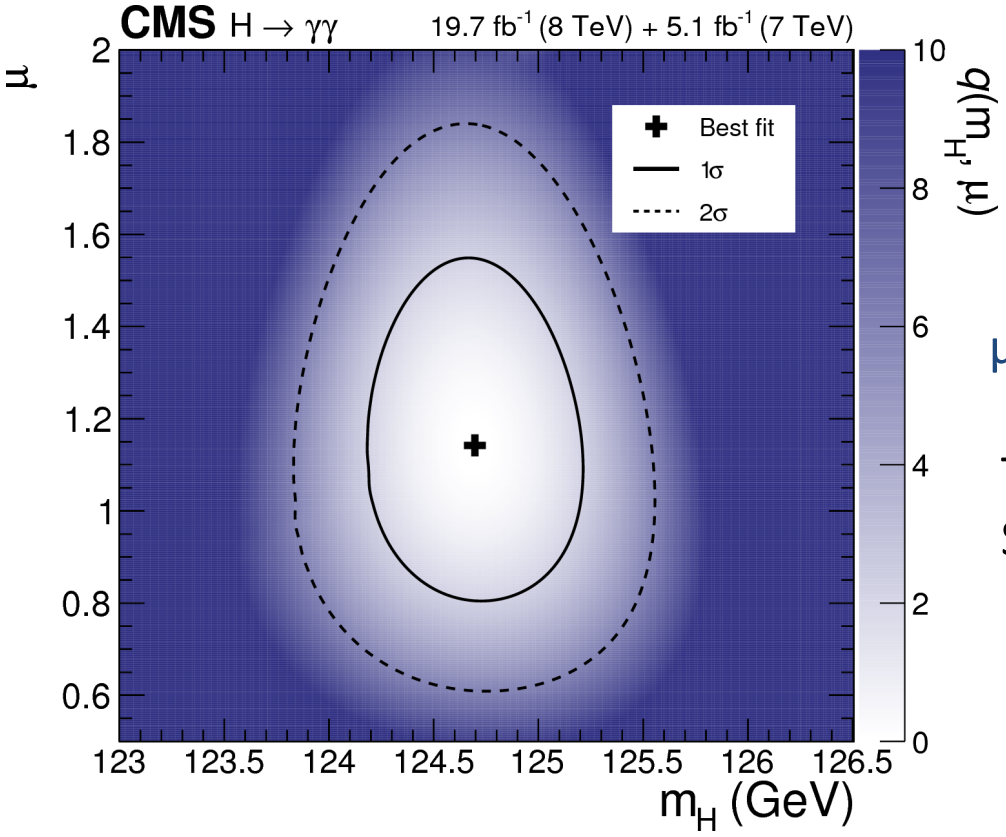
# Analysis strategy




- Require two isolated, high pT photons
- Events are classified to tag different production modes
- Untagged events are classified according to MVA categorization

Left plot:
diphoton mass spectrum weighted by the ratio S/(S + B) in each event class

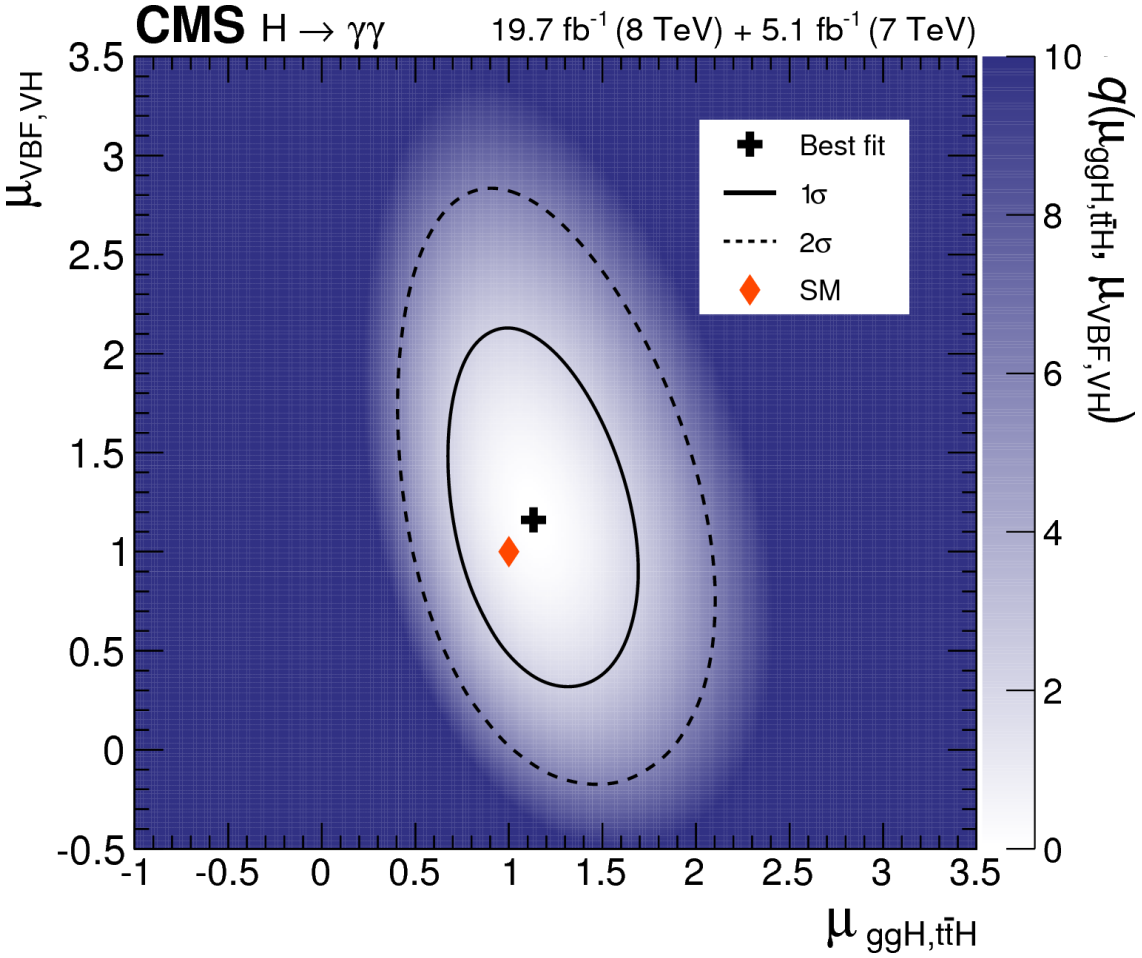
# Results of signal strength




$\mu = 1.14\ ^{+0.26}_{-0.23}$ at $m_H$ = 124.7GeV

The signal strength is compatible with SM prediction within 1σ band.

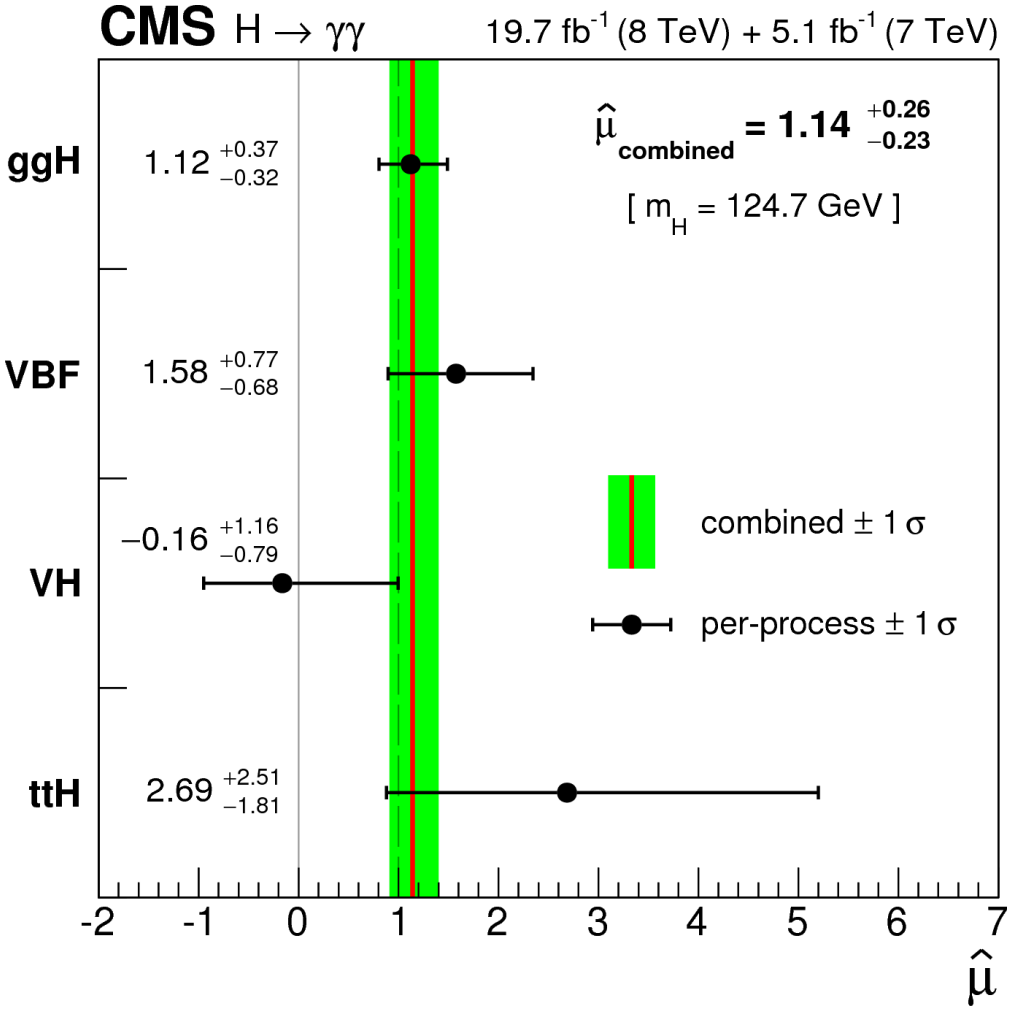
# Results of signal strength



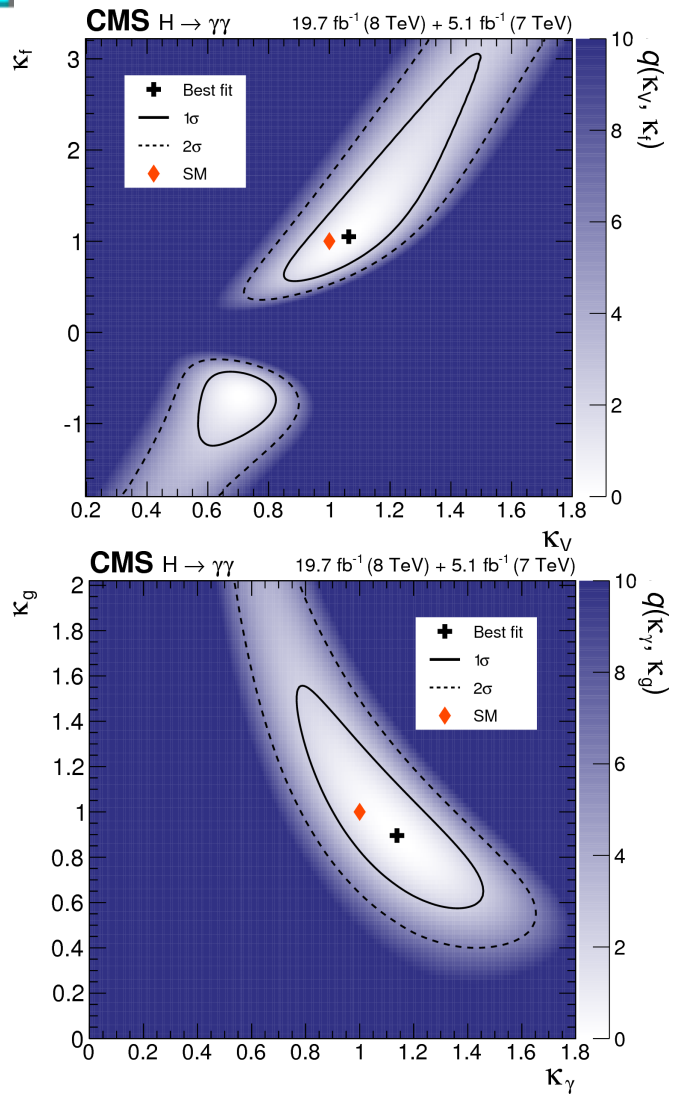

Likelihood contours on the signal strengths associated with fermions and vector bosons.

The results are compatible with SM prediction within 1σ band.

# Results of signal strength



# Results of coupling studies




Likelihood contours on the coupling modifiers associated with fermions ($\kappa_f$) and vector bosons ($\kappa_V$) in the upper plot,

with gluons ($\kappa_g$) and photons ($\kappa_\gamma$) in the upper plot,

The best-fits are compatible with SM prediction within 1σ band.

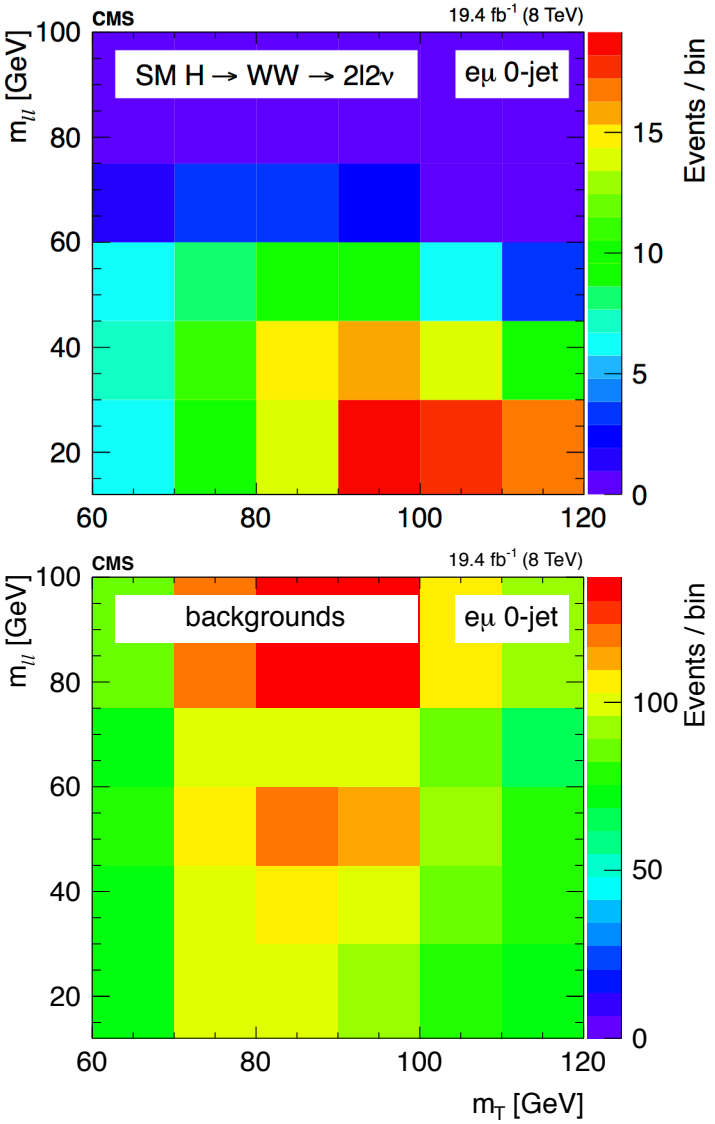
# Higgs to WW

# Analysis strategy :
## final states with two charged leptons

- Analysis uses 2D shape analysis in $m_{ll}$-$m_T$ plane as base line.
  (Cut-based analysis as cross check)

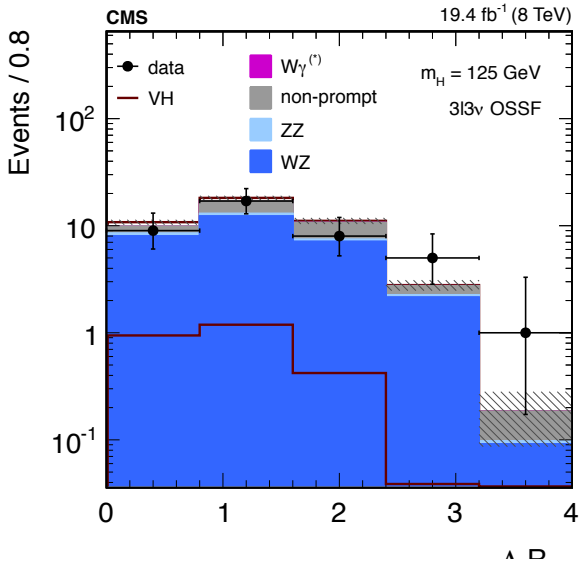
$$M_T = \sqrt{2 p_T^{\ell\ell} E_T^{miss} \cos(\Delta\phi_{\ell\ell} - E_T^{miss})}$$

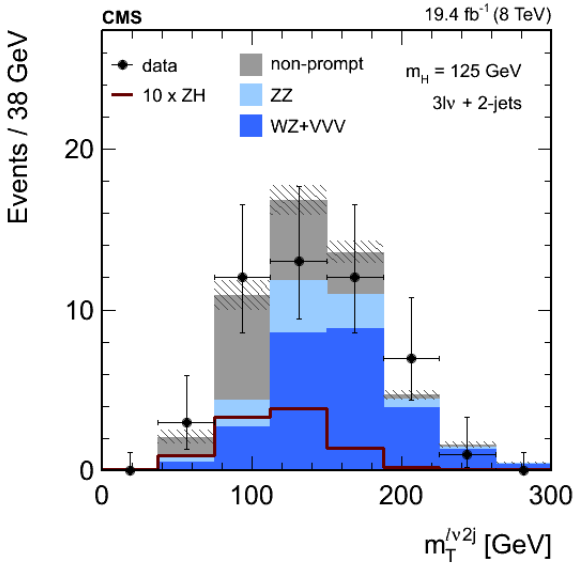
- Event are categorized into
  - The zero-jet and one-jet ggH
  - The two-jet VBF tag
  - The two-jet VH tag



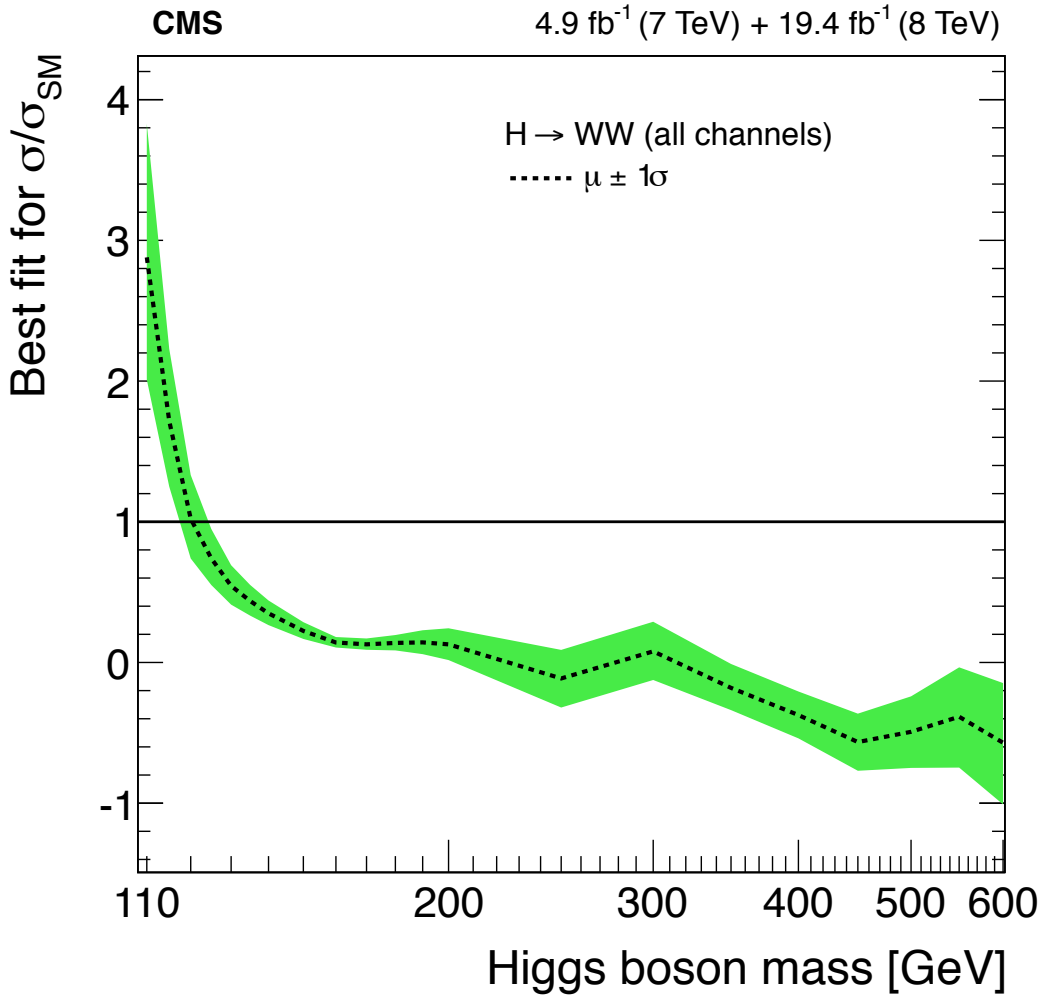
# Analysis strategy :
## final states with three charged leptons

- Associated production
- Backgrounds:
  WZ->3lv, ZZ->4l, tri-bosons, Z+γ
- Split into categories based on lepton charge and flavor to tag WH and ZH signal signature
- Shape-based analysis
  $\Delta R_{l+l-}$ as discriminator for WH(3l3v)
  $m_{T,lvjj}$ for ZH (3lv+2 jets)



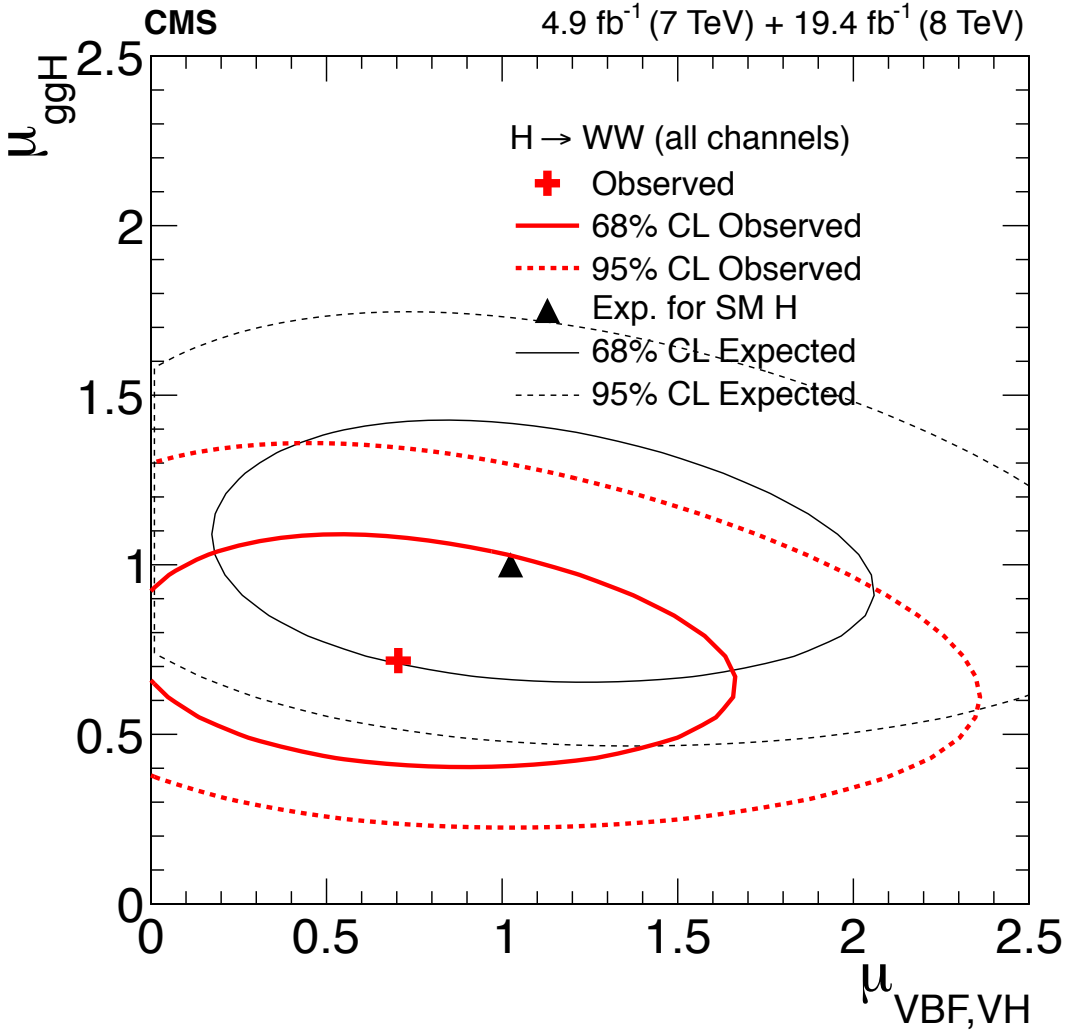
# Results of signal strength




Signal strength as a function of $m_H$ with all channels combined:

$\mu = 0.72^{+0.20}_{-0.18}$ at $m_H$ = 125.6 GeV with observed (expected) significance 4.3 (5.8)

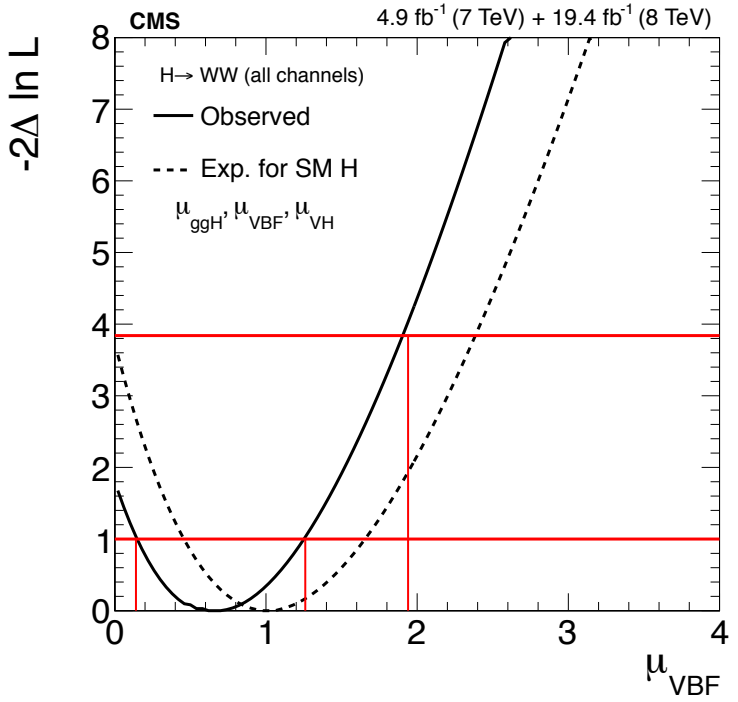
# Results of signal strength

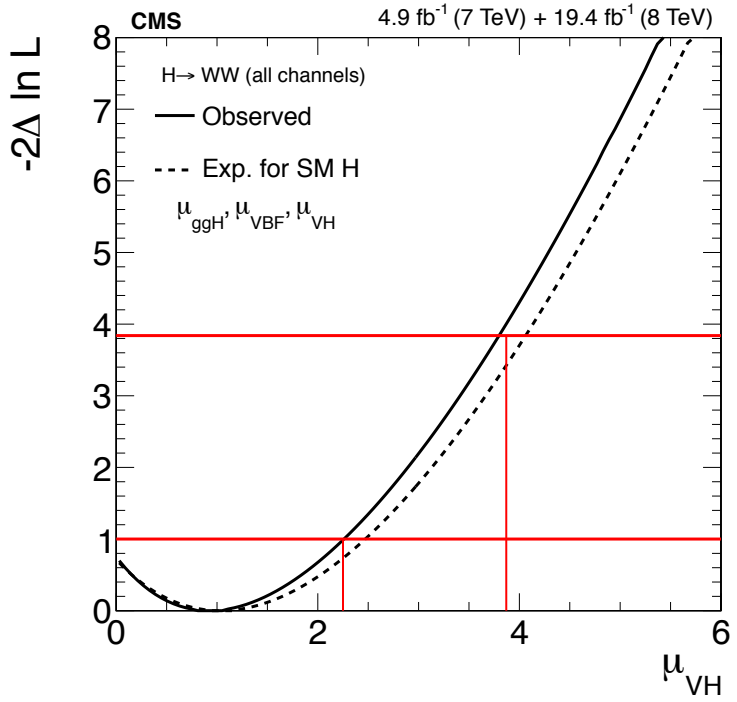



Likelihood contours on the signal strength associated with fermions and vector bosons.

The results are compatible with SM prediction within 1σ band.

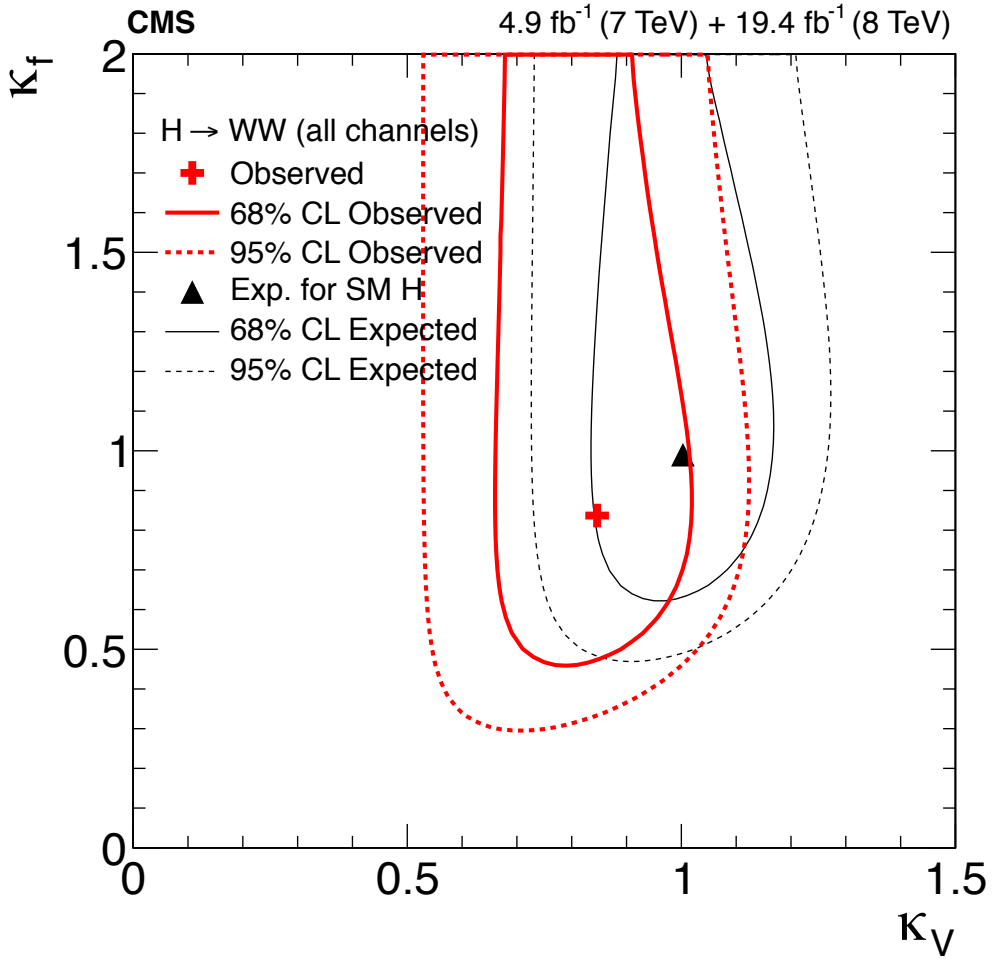
# Results of signal strength




Results of likelihood scan of signal strengths for VBF and VH while the other production modes are profiled with $m_H$ = 125.6GeV. The observed results are compatible with SM prediction.

# Results of coupling studies

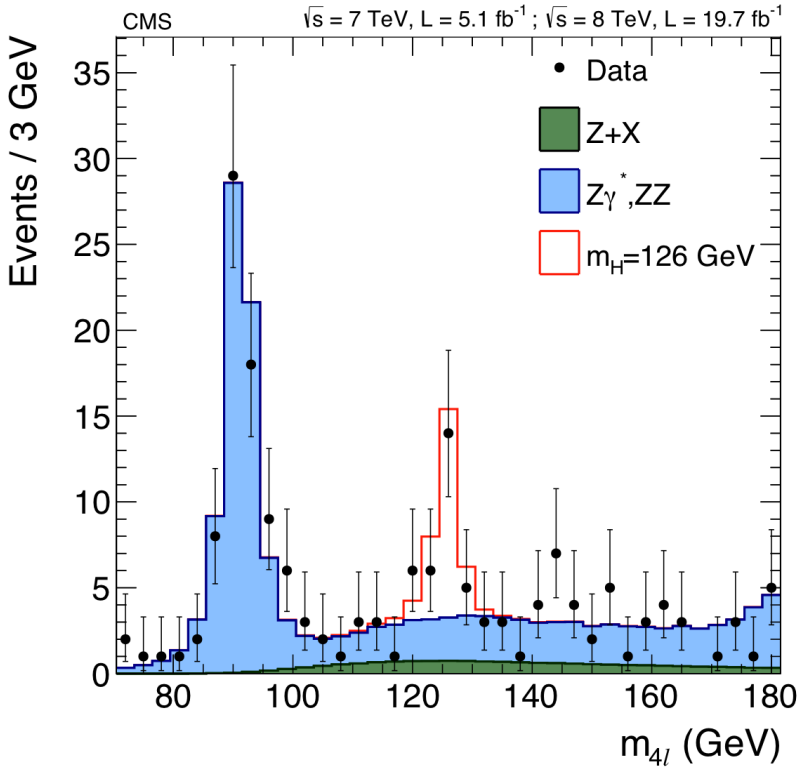



Likelihood contours on the coupling modifiers associated with fermions ($\kappa_f$) and vector bosons ($\kappa_V$) at $m_H$ = 125.6GeV

The results are compatible with SM prediction within 1σ band.

# Higgs to ZZ to four leptons

# Analysis strategy



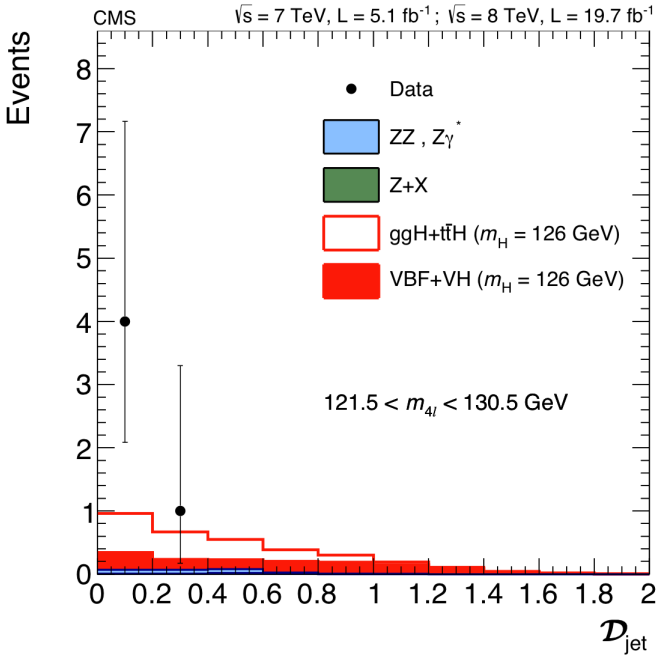

- Four isolated leptons grouped into 2e2μ, 4e and 4μ final states
- Kinematic discriminator(KD) used to enhance S/B separation
- Events are categorized into 0/1-jet and di-jet

# VBF tagging

- Study different production mechanisms for the Standard Model(SM) Higgs-like boson:

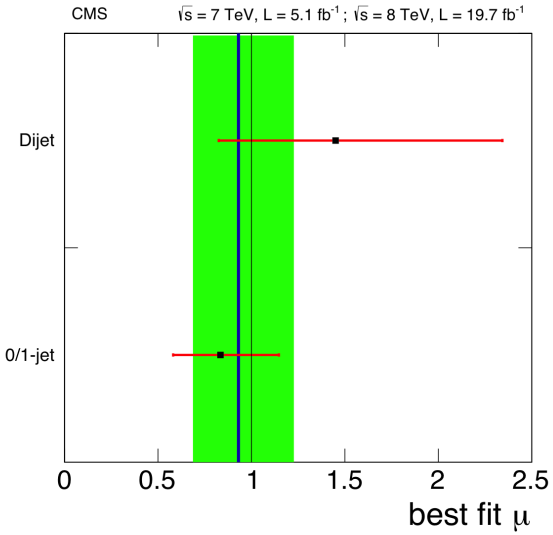
No VBF-like ($V_D$>0.5) events are observed.
( 3.3 expected for 126GeV, where 0.86 from VBF )

| |
|---|
| Di-jet tagged: two jets, linear discriminant $V_D$ from $\|\Delta\eta jj\|$ and mjj (about 20% signal from VBF) |
| Un-tagged: 0/1 jet, uses $pT_{4l+\gamma}$/m4l as additional discriminant (about 5% signal from VBF) |



# Results of signal strength

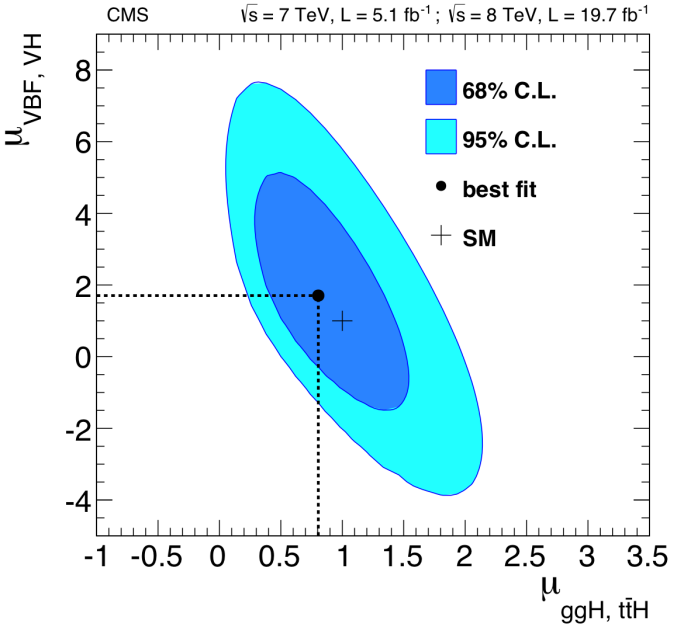
- $\mu = 0.93^{+0.30}_{-0.24}$ at $m_H$=125.6GeV
- The signal strength is measured for both di-jet-tagged and untagged cases. Results are consistent with each other.




- The signal strength (modifiers) associated with vector bosons $\mu_V$ and fermions in production $\mu_F$ are measured to be :

  $\mu_V$: $+1.7^{+2.2}_{-2.1}$ (68%)

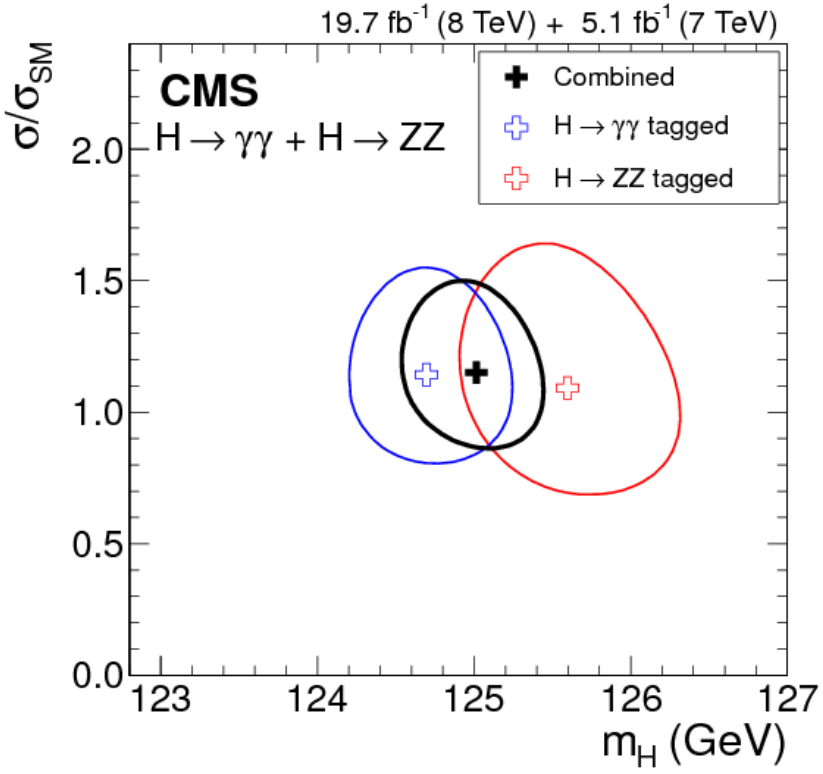
  $\mu_F$: $+0.8^{+0.5}_{-0.4}$ (68%)



# Coupling results from CMS Higgs combination

# Mass measurement compatibility

- Do **Higgs to γγ** and **Higgs to ZZ to four leptons** observe the same particle?



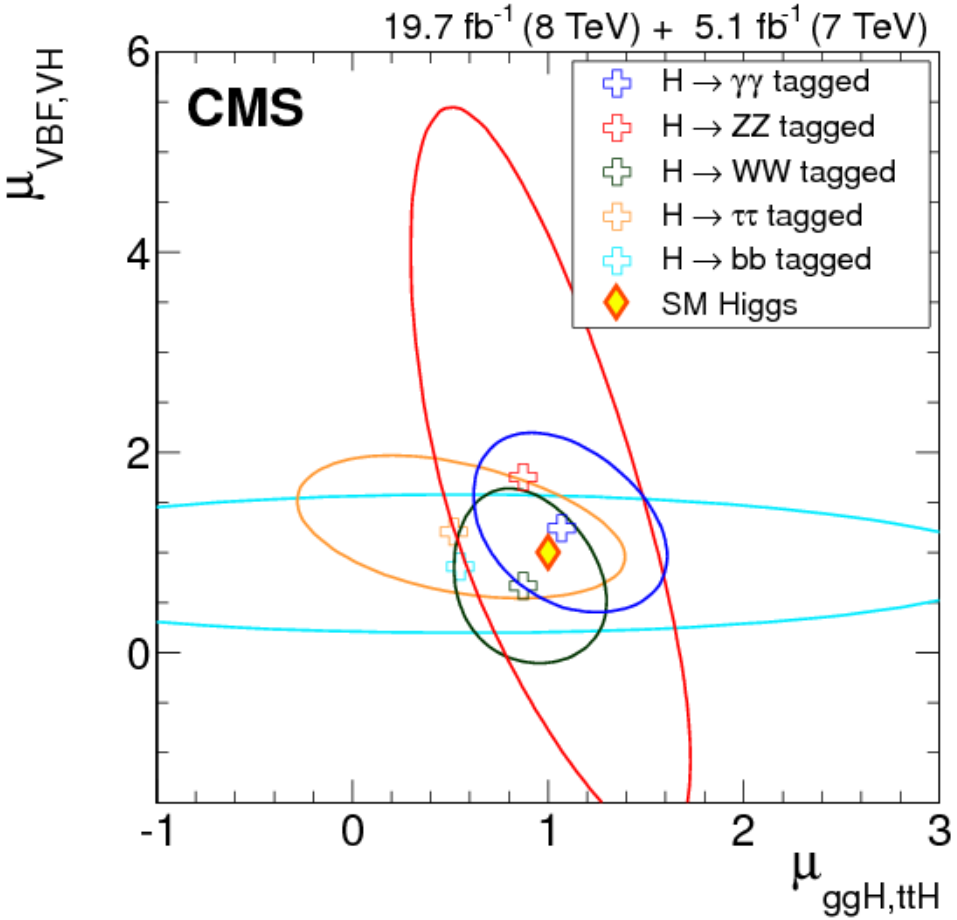

H->γγ : $124.70\ ^{+0.31}_{-0.31}(\text{stat})\ ^{+0.15}_{-0.15}(\text{syst})$ GeV

H->ZZ->4l : $125.6\ ^{+0.43}_{-0.41}(\text{stat})\ ^{+0.16}_{-0.18}(\text{syst})$ GeV

Combined : $125.02\ ^{+0.26}_{-0.27}(\text{stat})\ ^{+0.14}_{-0.15}(\text{syst})$ GeV

Higgs mass results from other less sensitive channels (WW,ττ) are compatible with the combination results.

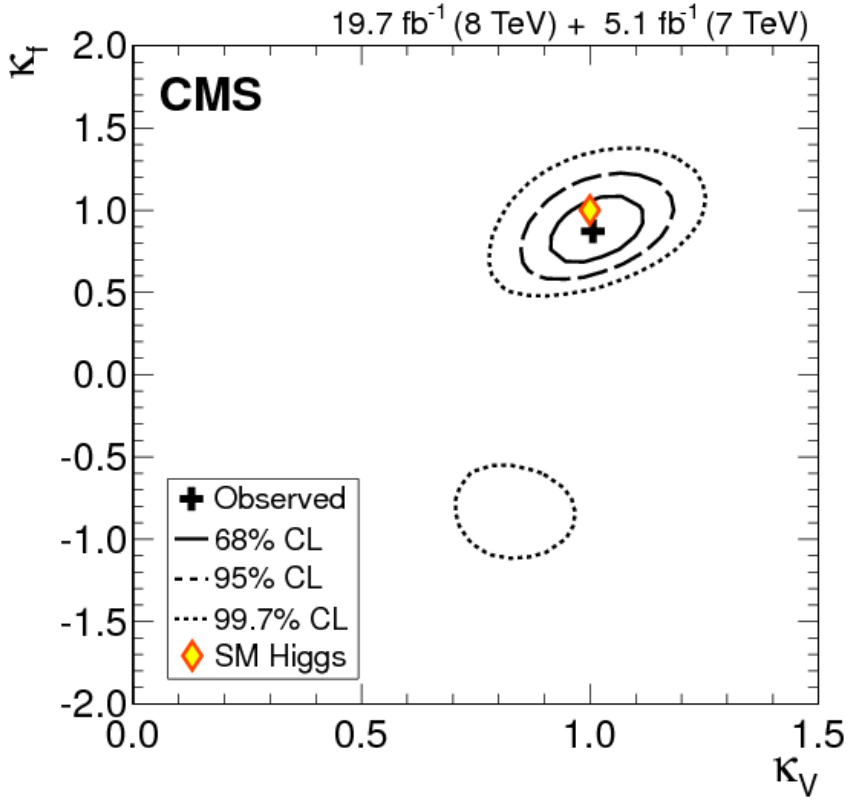
# Results of signal strength:




Results from different channels are compatcible with SM prediction.

Combined best fit $\mu_{VBF,VH}/\mu_{ggH,ttH}$ is $1.25^{+0.62}_{-0.44}$ $(1.00^{+0.49}_{-0.35})$ Observed (expected)

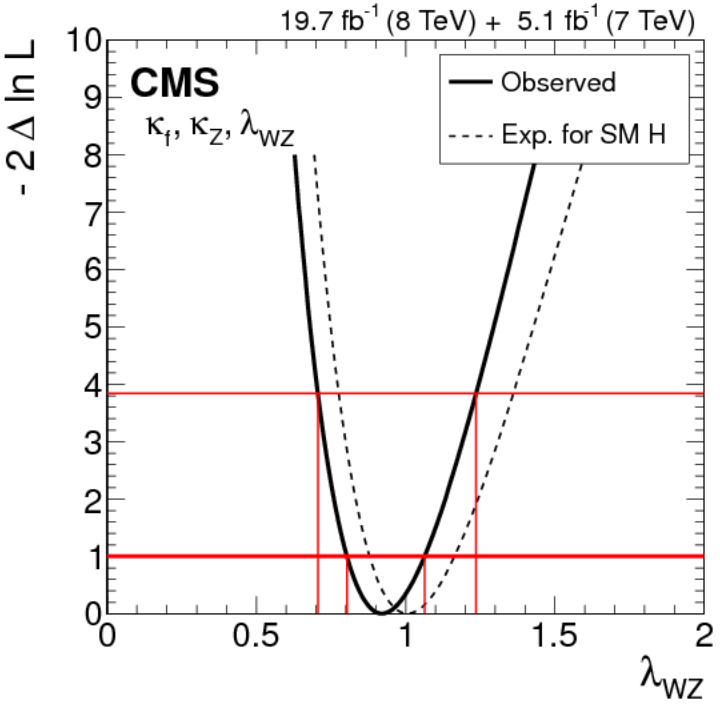
# Coupling results :

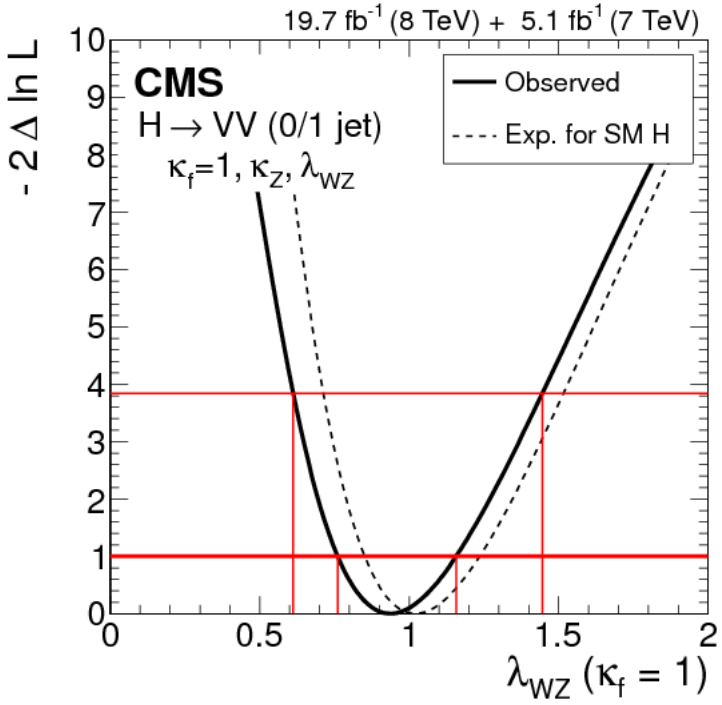



Likelihood contours on the coupling modifiers associated with fermions ($\kappa_f$) and vector bosons ($\kappa_V$).

Observation is consistent with SM prediction in 1σ band

# Custodial symmetry



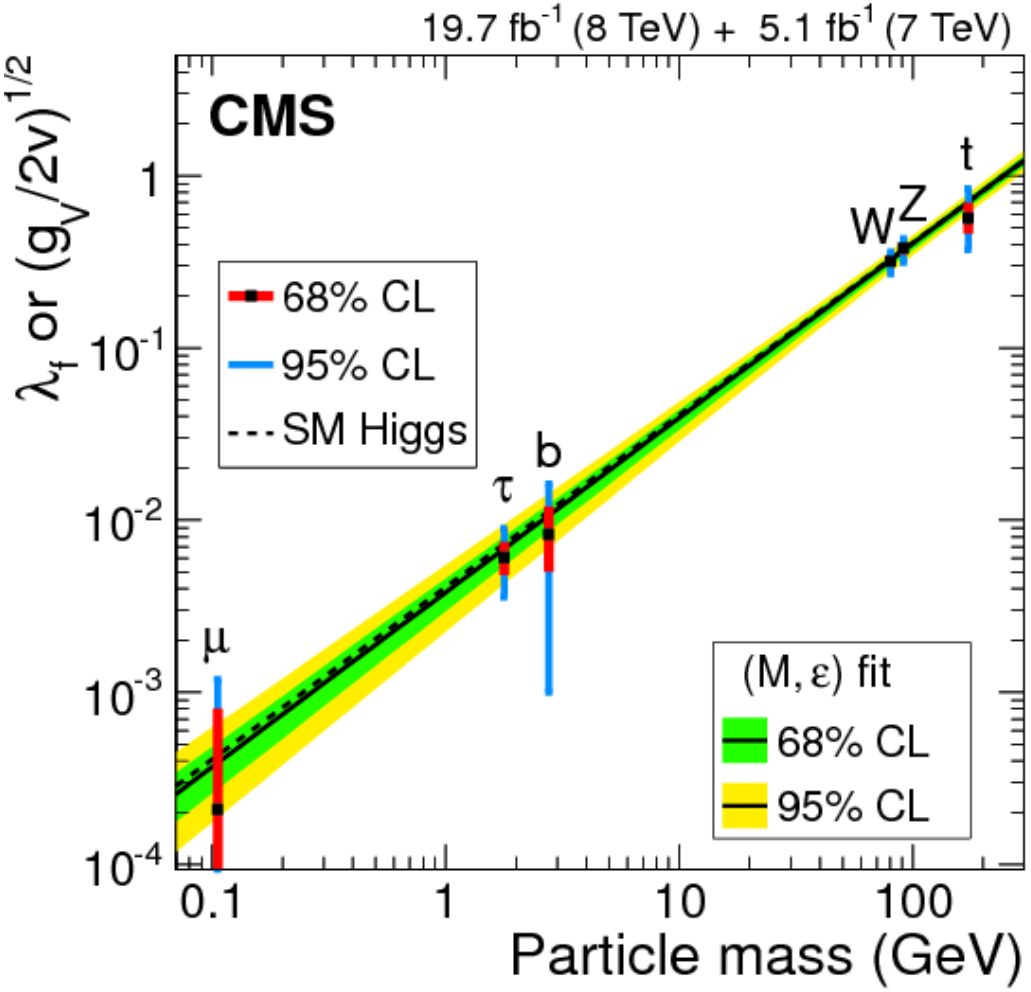




The ratio between W and Z coupling modifier $\lambda_{WZ}$

$\lambda_{WZ} = 0.92^{+0.14}_{-0.12}$ $\lambda_{WZ} = 0.94^{+0.22}_{-0.18}$ ($\kappa_f$ =1),

is consistent with SM prediction.

# Summary of the fits for deviations in the coupling




Coupling for the generic five-parameter model including effective loop couplings, expressed as function of the particle mass.

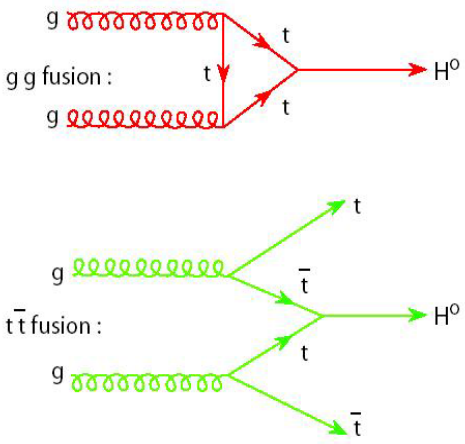
Fermions :
the values of the fitted Yukawa couplings
Bosons:
the square-root of the coupling for the **hVV** vertex divided by twice the vacuum expectation value of the Higgs boson.

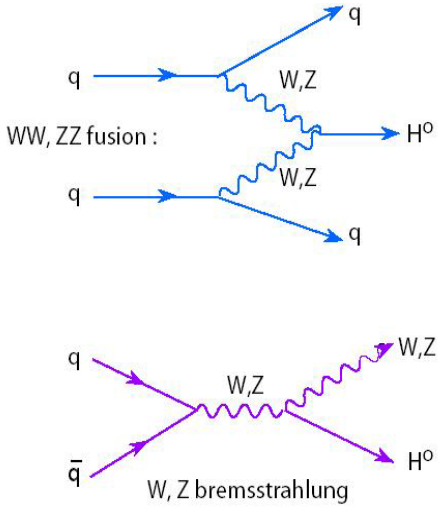
# Summary

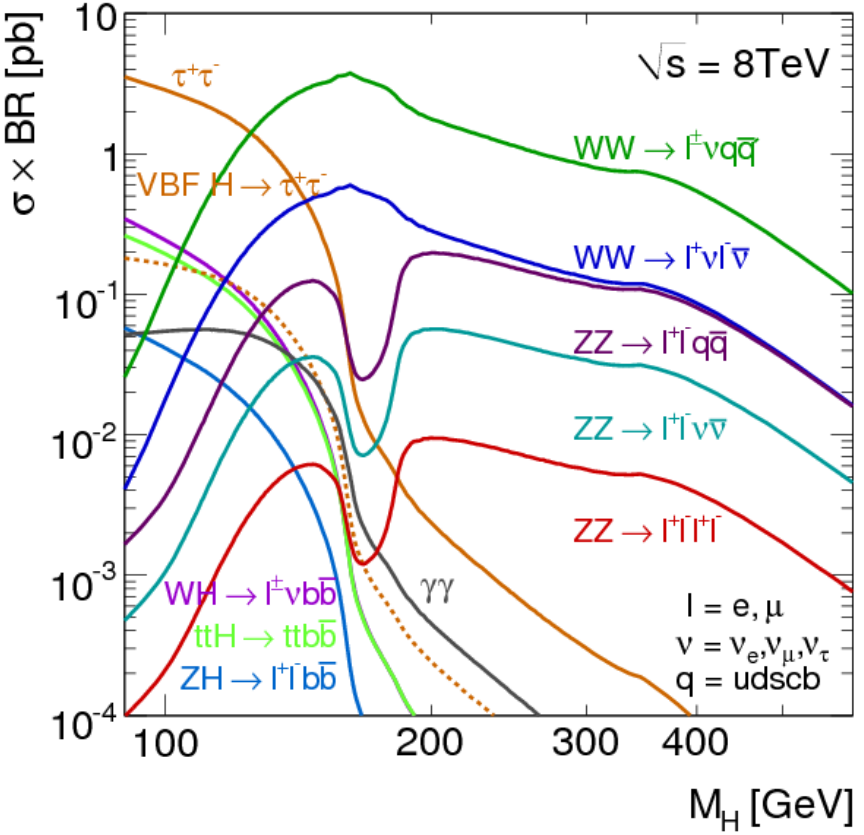
- Higgs couplings to bosons are studies using CMS Run-1 data.
- The signal strength, coupling modifiers for bosons are compatible with SM prediction for both individual analysis and combination. Overall signal strength in each channel is
  - H->γγ : $\mu = 1.14^{+0.26}_{-0.23}$ at $m_H$ = 124.7 GeV
  - H->WW : $\mu = 0.72^{+0.20}_{-0.18}$ at $m_H$ = 125.6 GeV
  - H->ZZ->4l : $\mu = 0.93^{+0.30}_{-0.24}$ at $m_H$ = 125.6 GeV
- The observed coupling symmetry between W and Z bosons is consistent with SM prediction.
  The correlation between coupling and W/Z mass is consistent with SM prediction.

# Back up

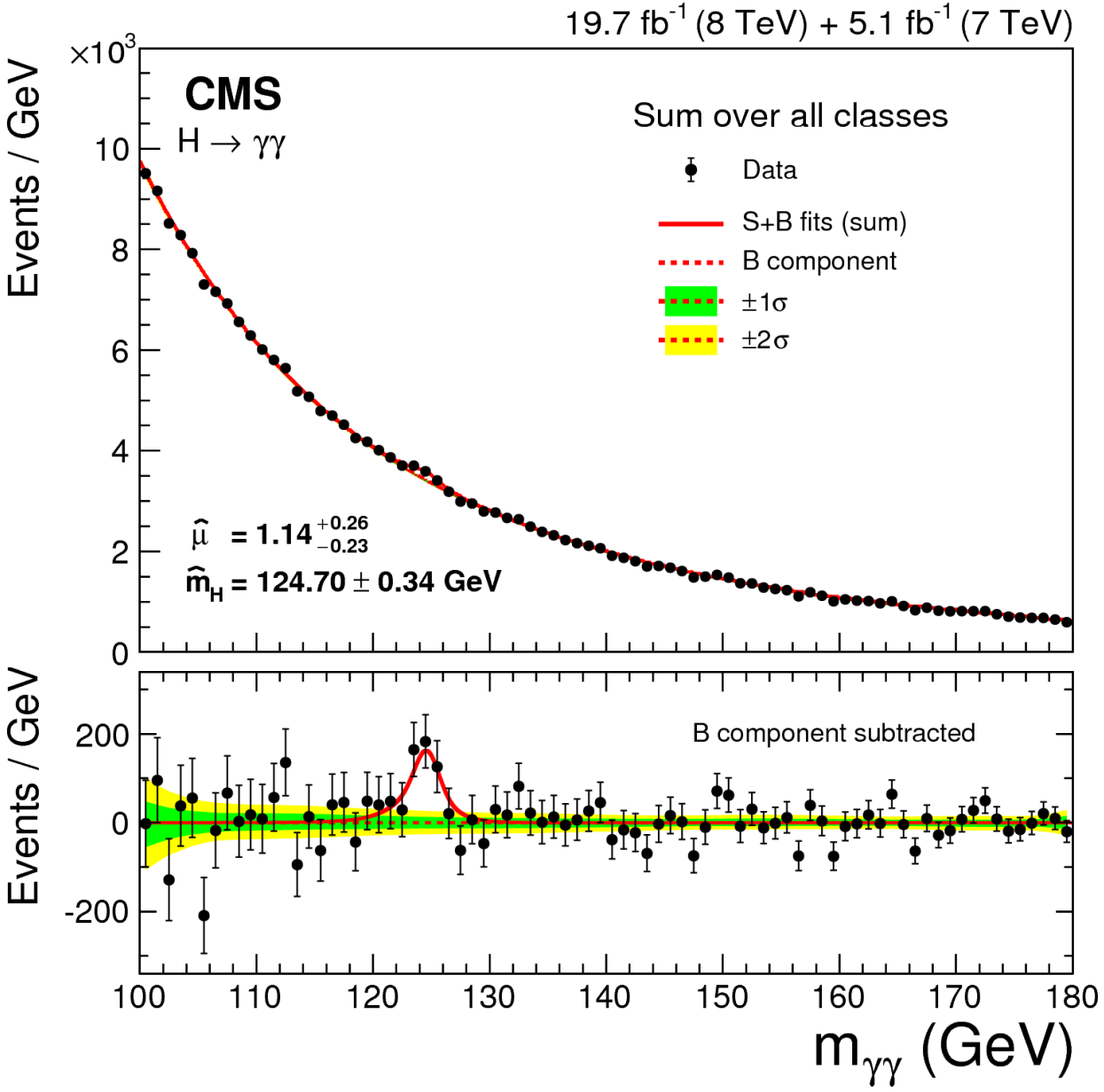
# Production mechanisms and σxBR

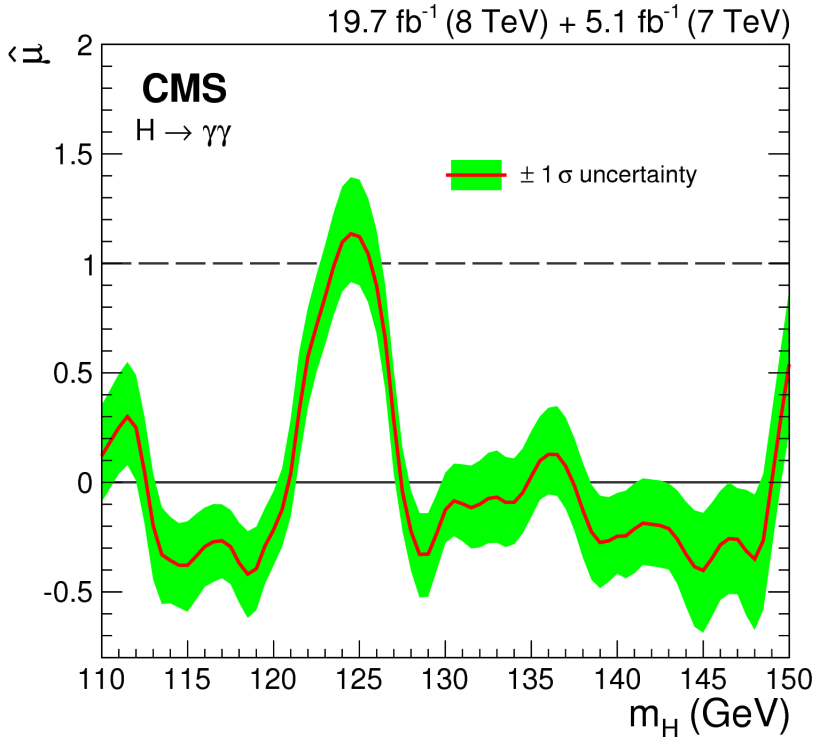


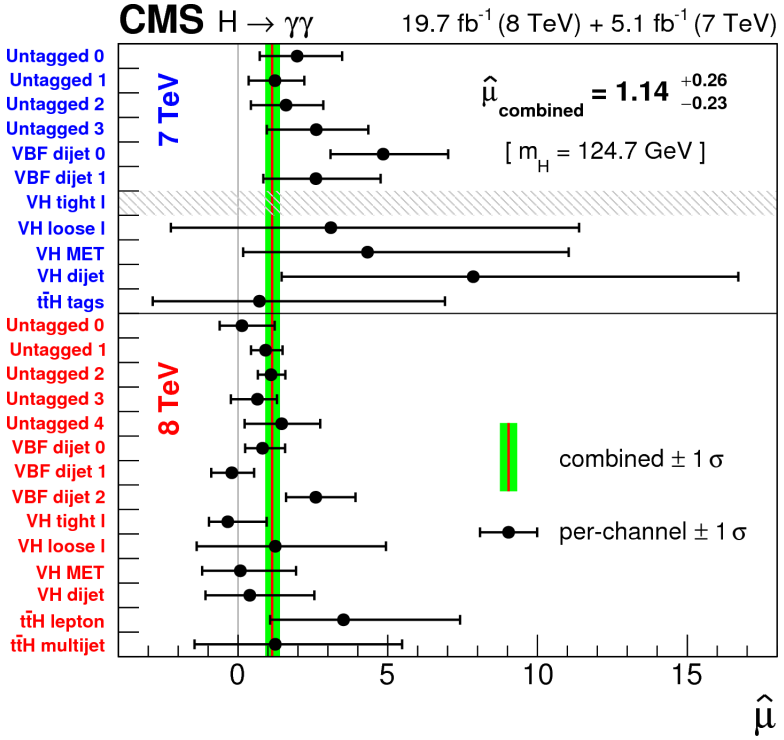



# Higgs to γγ

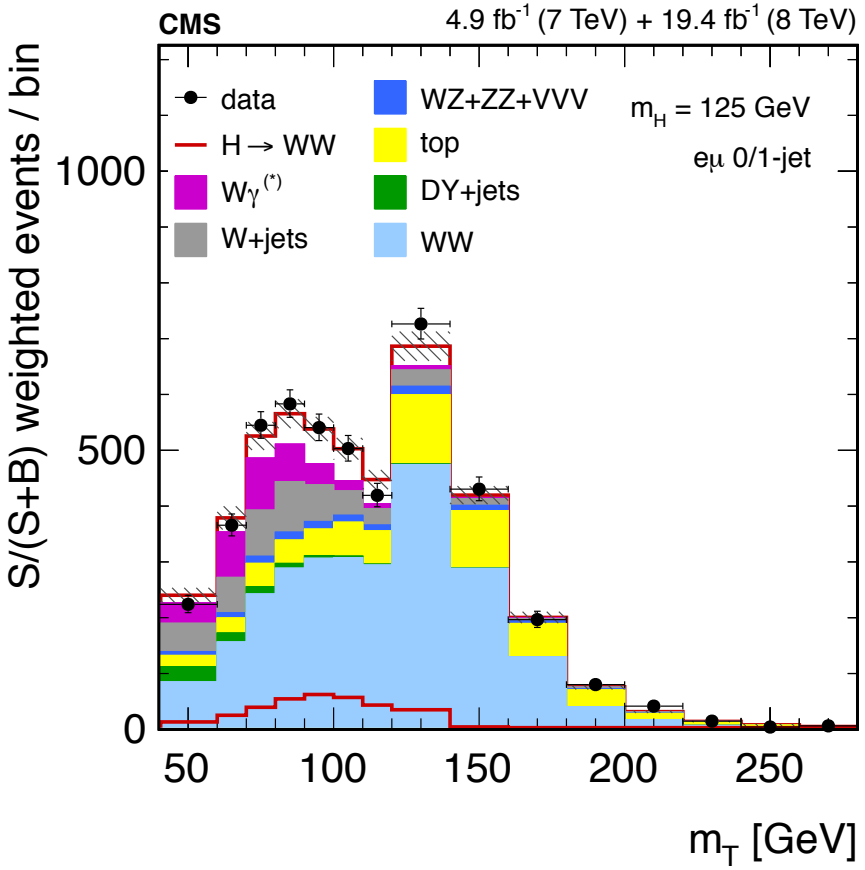

19.7 fb-1 (8 TeV) + 5.1 fb-1 (7 TeV)
CMS
H → γγ
Sum over all classes
Data
S+B fits (sum)
B component
±1σ
±2σ
×10³
Events / GeV
μ̂ = 1.14 +0.26 −0.23
m̂H = 124.70 ± 0.34 GeV
B component subtracted
Events / GeV
mγγ (GeV)

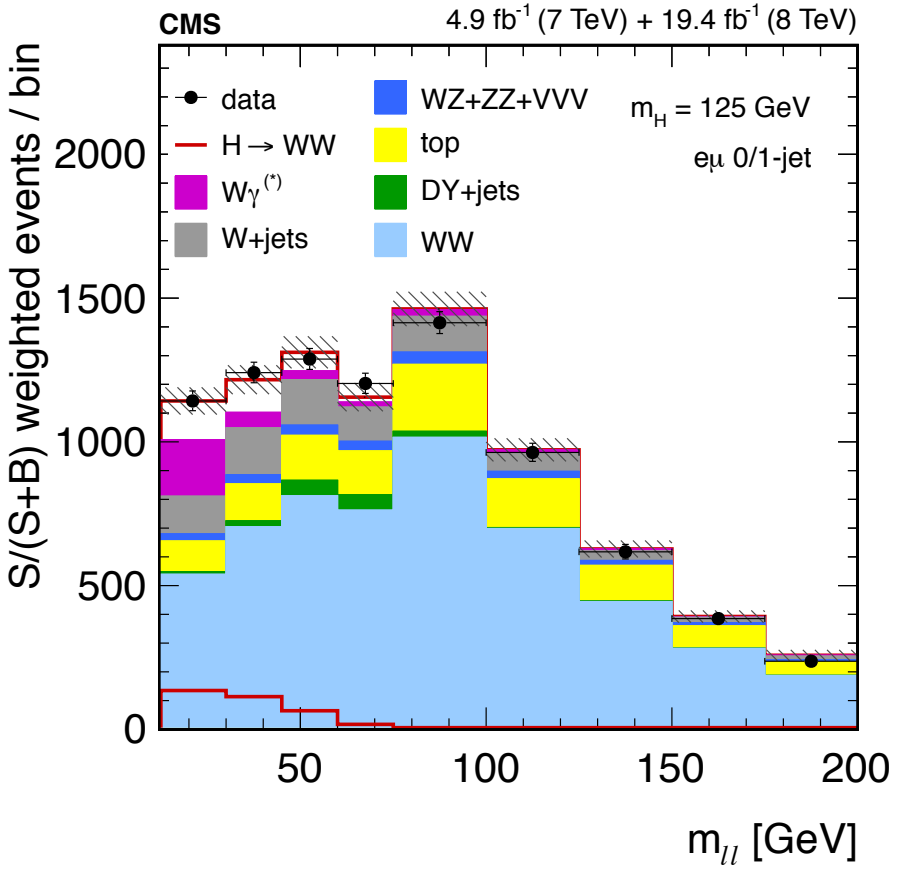

19.7 fb-1 (8 TeV) + 5.1 fb-1 (7 TeV)
CMS
H → γγ
± 1 σ uncertainty
μ
2
1.5
1
0.5
0
-0.5
110
115
120
125
130
135
140
145
150
mH (GeV)


CMS H → γγ
19.7 fb-1 (8 TeV) + 5.1 fb-1 (7 TeV)
Untagged 0
Untagged 1
Untagged 2
Untagged 3
VBF dijet 0
VBF dijet 1
VH tight l
VH loose l
VH MET
VH dijet
tt̄H tags
Untagged 0
Untagged 1
Untagged 2
Untagged 3
Untagged 4
VBF dijet 0
VBF dijet 1
VBF dijet 2
VH tight l
VH loose l
VH MET
VH dijet
tt̄H lepton
tt̄H multijet
7 TeV
8 TeV
μ̂combined = 1.14 +0.26 −0.23
[ mH = 124.7 GeV ]
combined ± 1 σ
per-channel ± 1 σ
0
5
10
15
μ̂

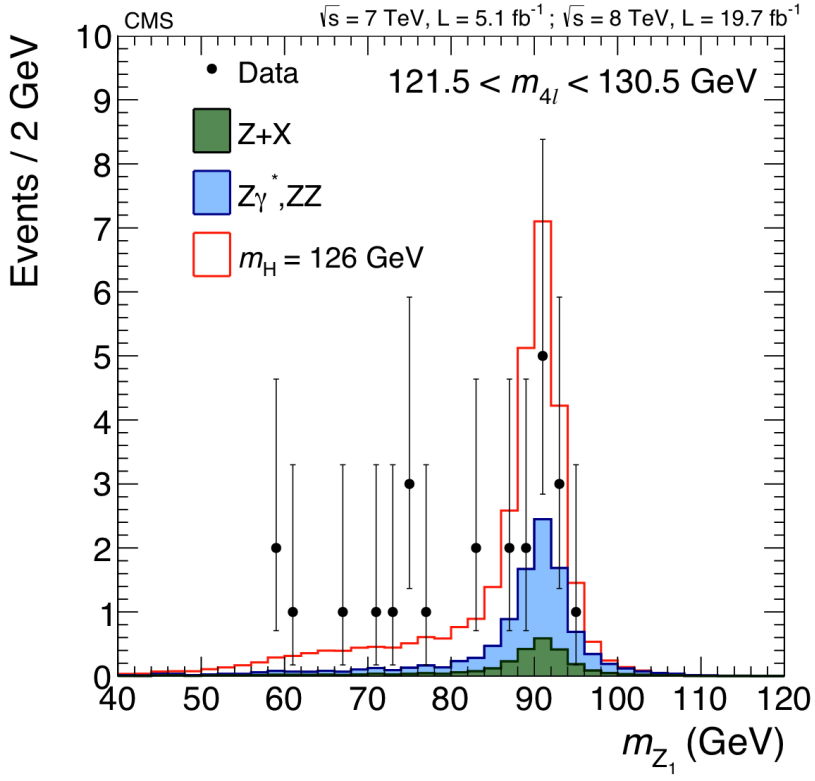
# Higgs to WW

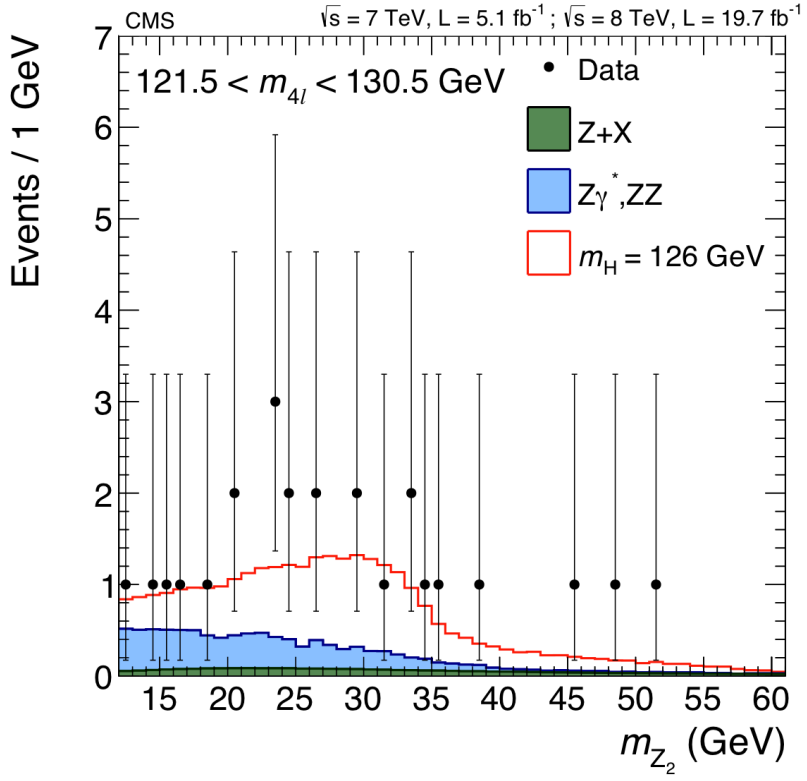
# Two charged lepton : 1D distribution



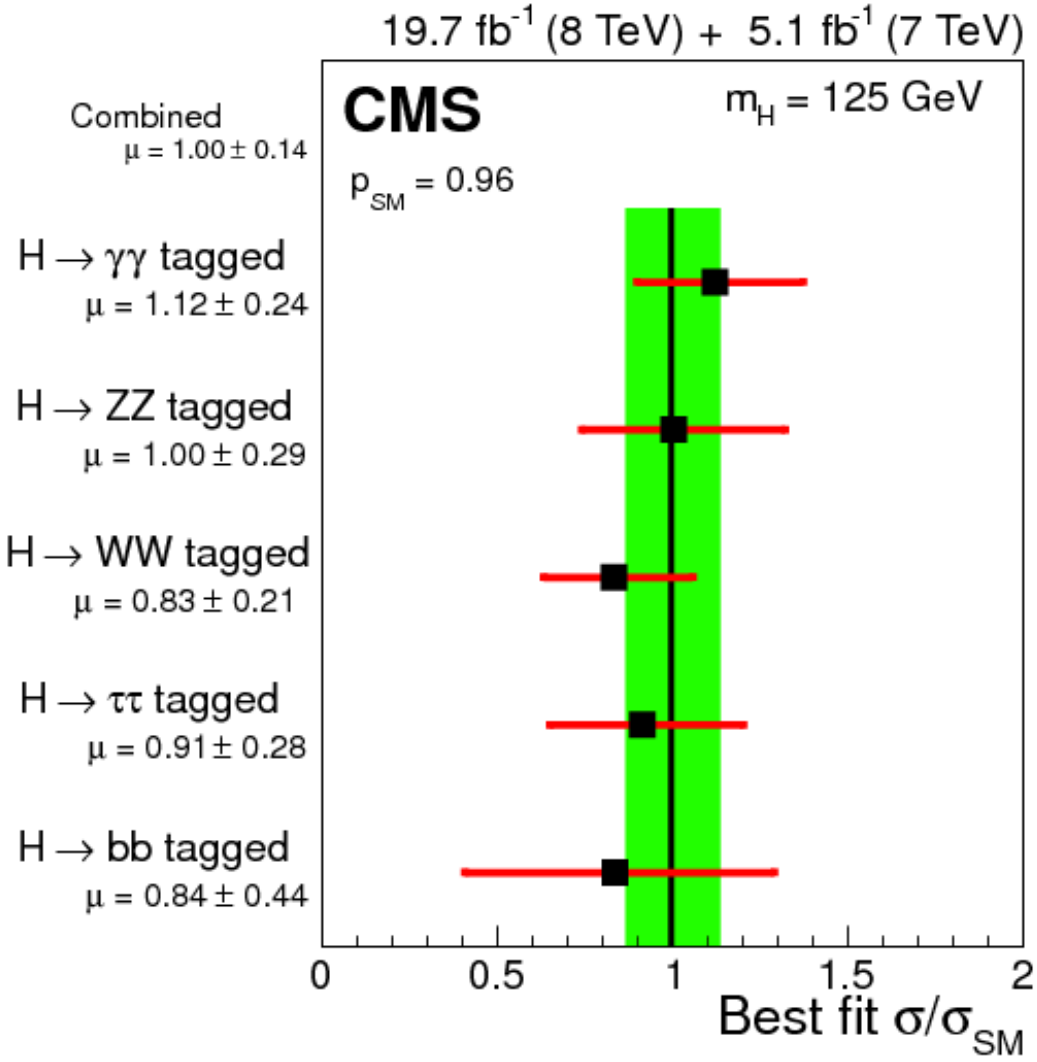



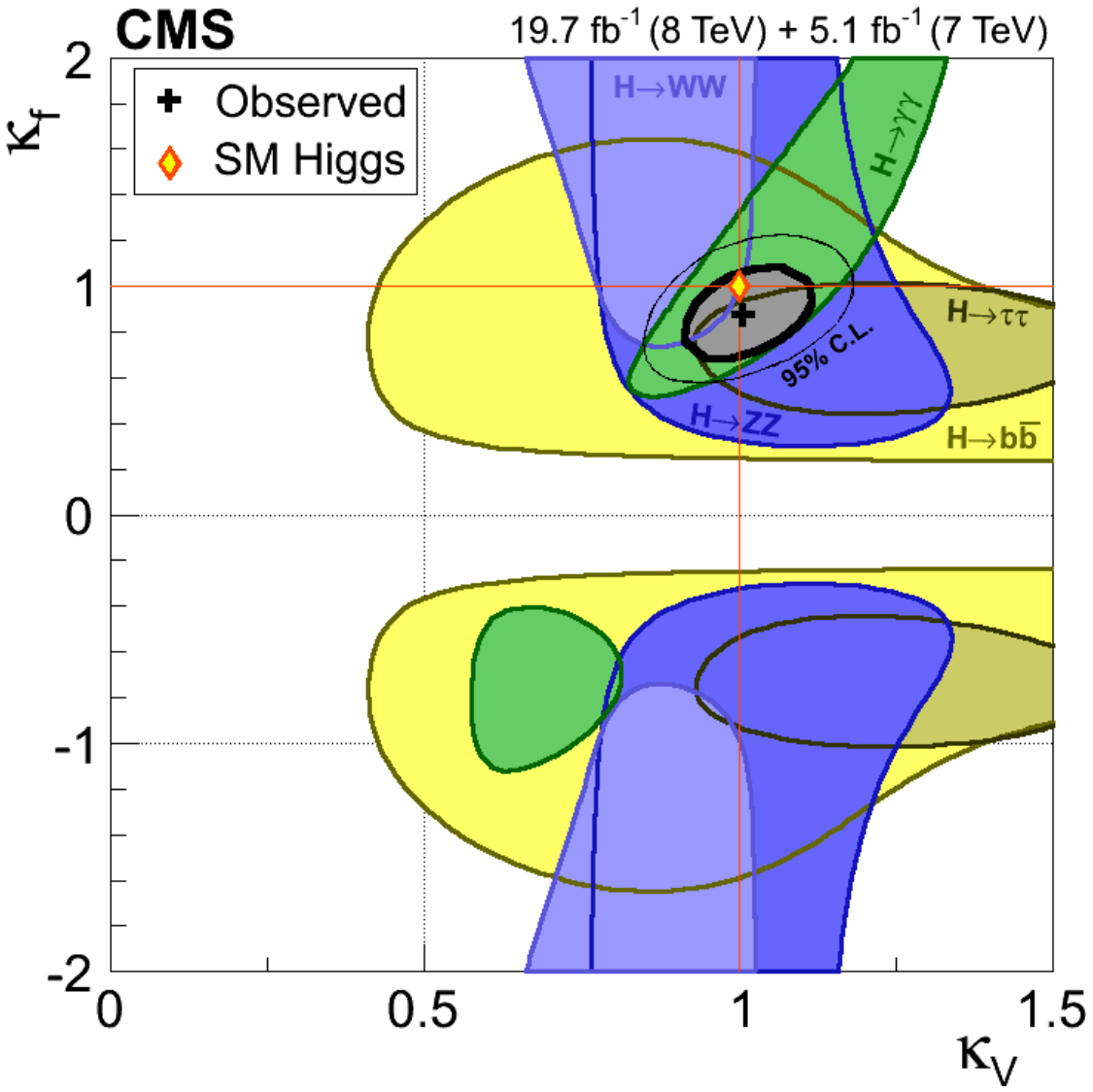
# Higgs to ZZ to four leptons


CMS
√s = 7 TeV, L = 5.1 fb-1 ; √s = 8 TeV, L = 19.7 fb-1
Data
121.5 < m4l < 130.5 GeV
Z+X
Zγ*,ZZ
mH = 126 GeV
Events / 2 GeV
mZ1 (GeV)


CMS
√s = 7 TeV, L = 5.1 fb-1 ; √s = 8 TeV, L = 19.7 fb-1
121.5 < m4l < 130.5 GeV
Data
Z+X
Zγ*,ZZ
mH = 126 GeV
Events / 1 GeV
mZ2 (GeV)

# Higgs combination


19.7 fb-1 (8 TeV) + 5.1 fb-1 (7 TeV)
CMS
mH = 125 GeV
pSM = 0.96
Combined
μ = 1.00 ± 0.14
H → γγ tagged
μ = 1.12 ± 0.24
H → ZZ tagged
μ = 1.00 ± 0.29
H → WW tagged
μ = 0.83 ± 0.21
H → ττ tagged
μ = 0.91 ± 0.28
H → bb tagged
μ = 0.84 ± 0.44
0
0.5
1
1.5
2
Best fit σ/σSM


CMS
19.7 fb-1 (8 TeV) + 5.1 fb-1 (7 TeV)
Observed
SM Higgs
H→WW
H→γγ
H→ττ
H→bb̄
H→ZZ
95% C.L.
κf
κV
2
1
0
-1
-2
0
0.5
1
1.5