Measurements of the SM Higgs properties with Run2 data in the bosonic channels

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On behalf of the CMS Collaboration

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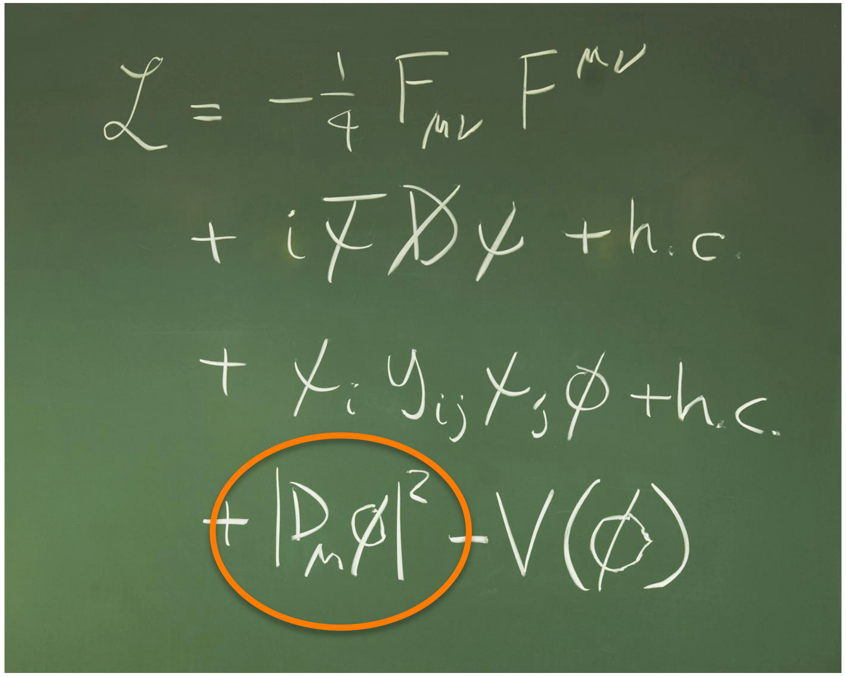
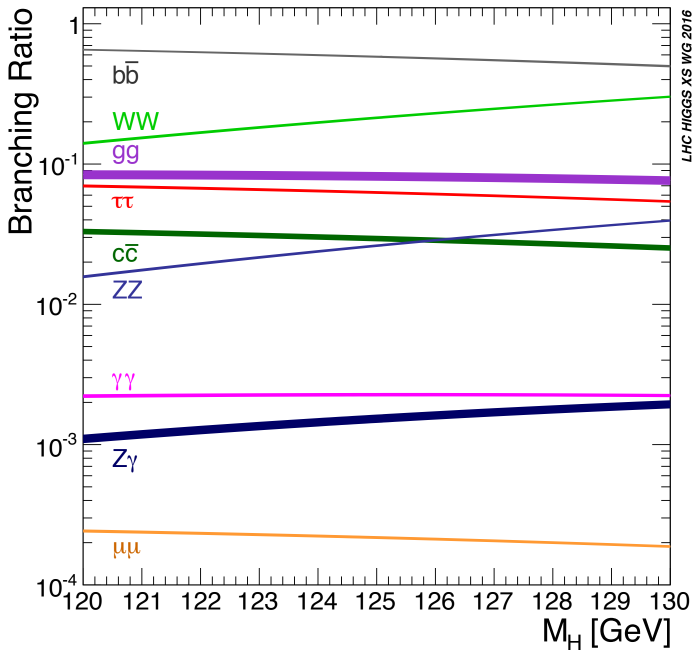
DIS 2018

16-20 April 2018, Kobe, Japan

The SM Higgs boson





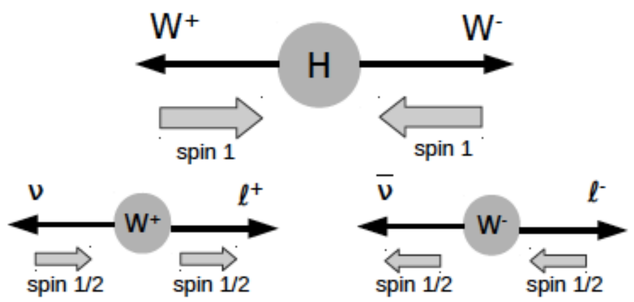
Recent results from CMS reported here, all based on 2016 data:

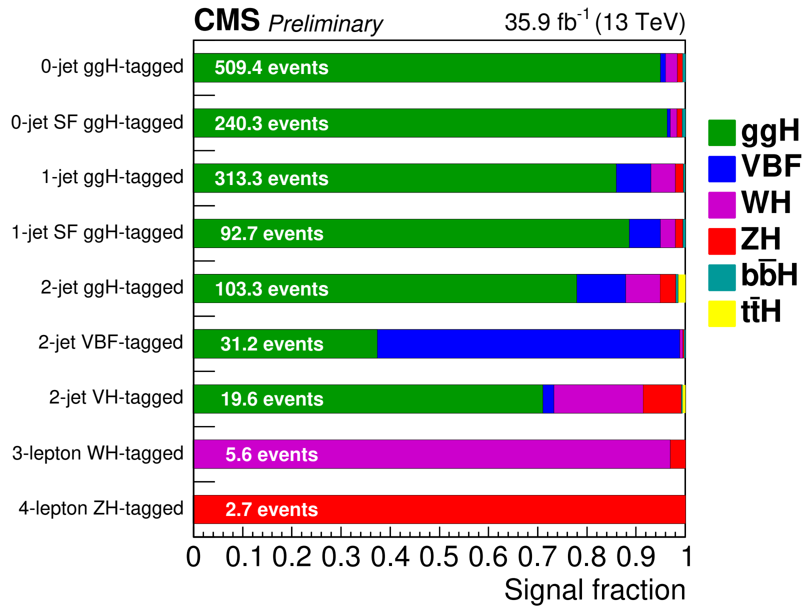
- Higgs in WW* (HIG-16-042, very recent result)
- Higgs in ZZ* (HIG-16-041, JHEP 11 (2017) 047)
- Higgs in γγ (HIG-16-040, arXiv:1804.01716 submitted last week)
- Higgs in llγ (HIG-17-007, very recent result, see Chia-Ming Kuo's talk)

Higgs into WW

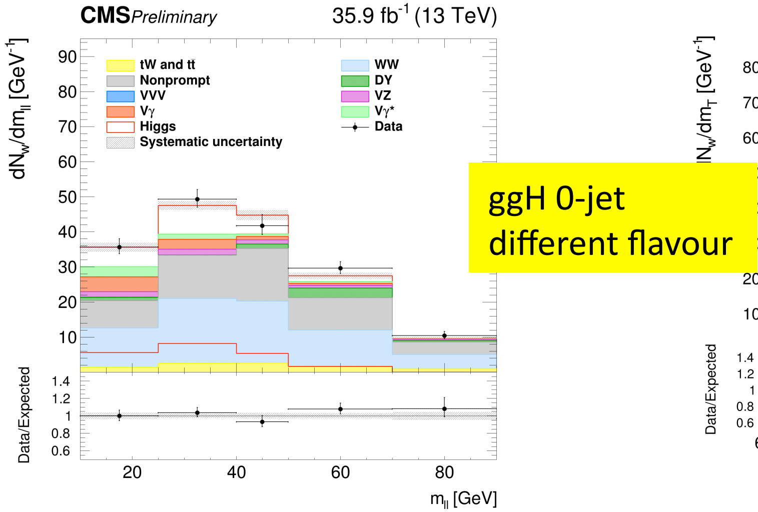
HIG-16-042

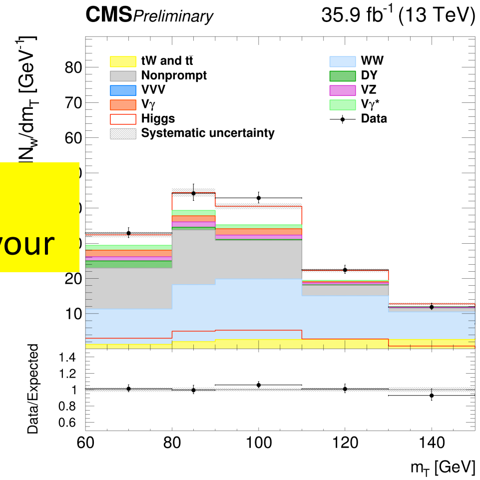
- High BR but poor mass resolution
- two opposite signs lepton (eμ, ee, μμ), missing p_T and additional jets/leptons targetting also VBF, VH
- main backgrounds are top in eμ, DY in same-flavour categories, W+jets. Data-driven estimations
- WW as irreducible background
- exploit spin 0 of Higgs for H->WW, where leptons are emitted closer, to suppress the backgrounds

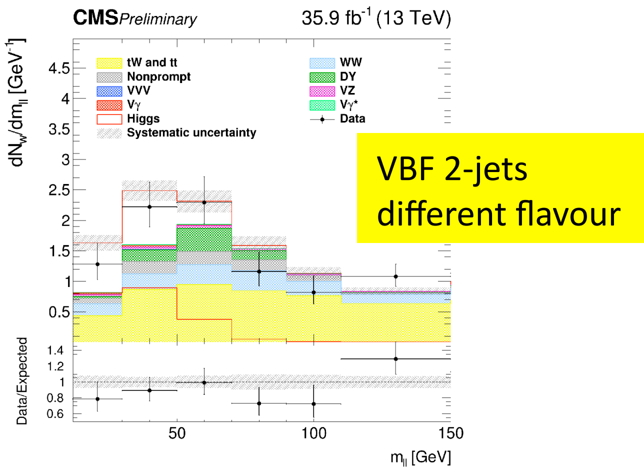


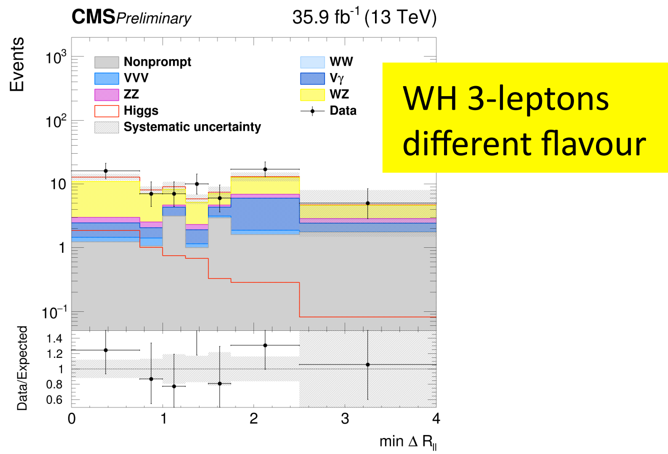


Higgs into WW



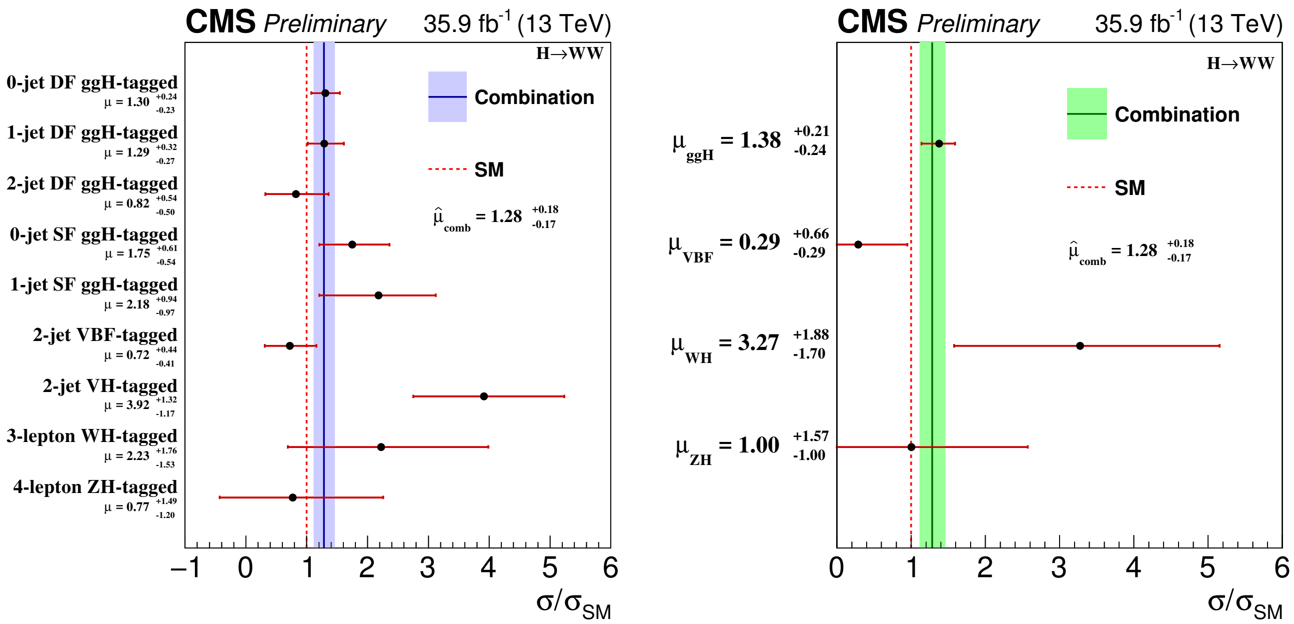






Signal extracted from 2D fit to m_{ll} and m_T (ggH) , from m_{ll} (VBF) or ΔR_{ll} (WH)

Higgs into WW



(a) (b)

- Main experimental systematics: data-driven background estimations, lepton efficiencies
- Best fit value from a simultaneous fit to all categories with m_H=125.09:

$$\widehat{\mu} = 1.28 \pm 0.10(stat.)^{+0.11}_{-0.11}(syst.)^{+0.10}_{-0.07}(theo.)$$

- **Observed** (Expected) significance **9.1** (7.1) sigma, first observation in CMS alone

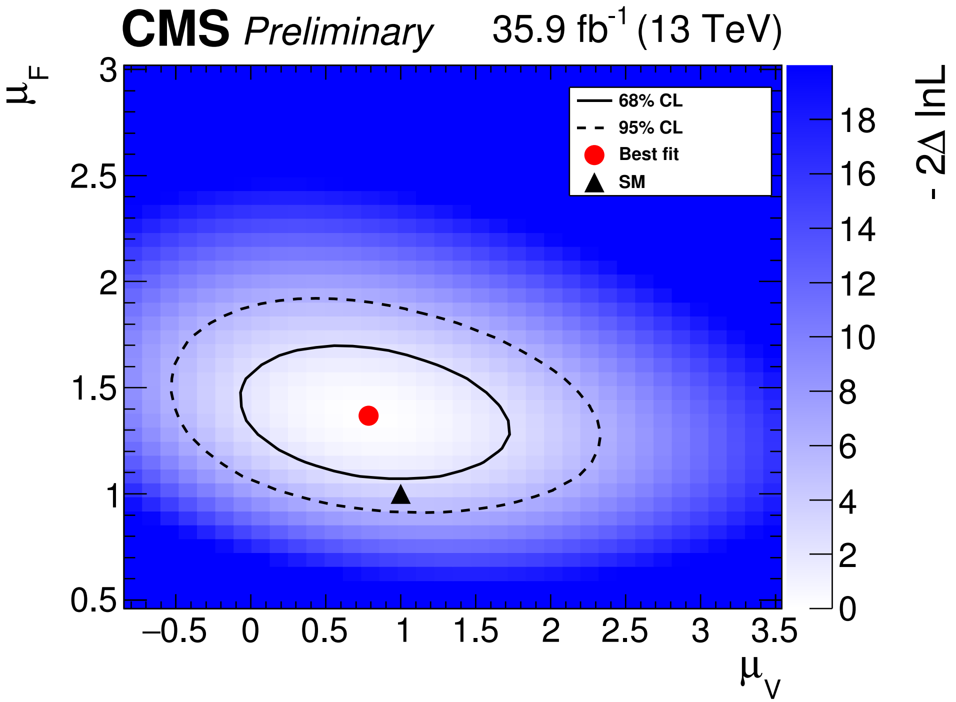
Higgs into WW

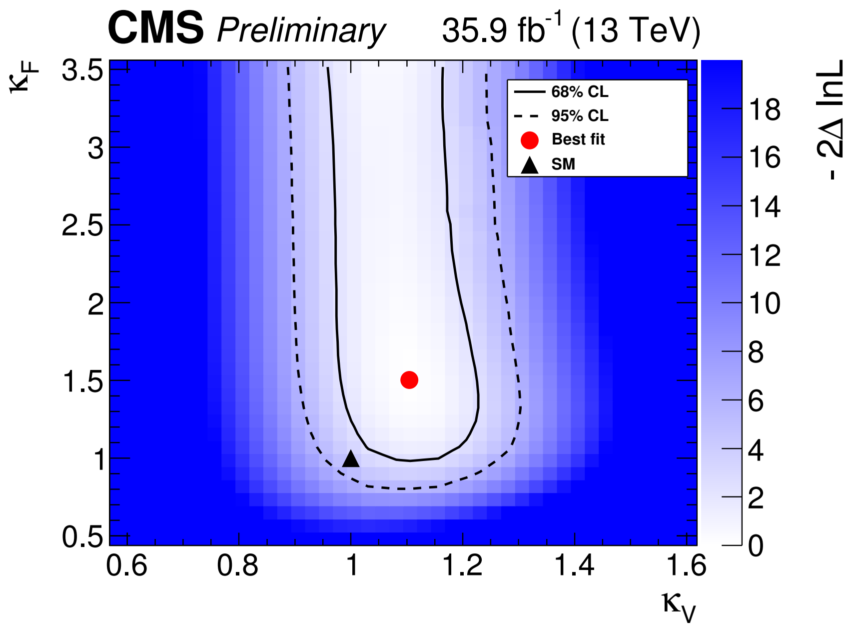
μ_V vs $\mu_{F,}$ separating production processes driven by vector boson coupling (VBF, VH) vs fermion coupling (ggF, ttH)

Fit in the k-framework:

$$\sigma \times \mathcal{B}(X \to H \to WW) = \kappa_i^2 \frac{\kappa_V^2}{\kappa_H^2} \sigma_{SM} \times \mathcal{B}_{SM}(X \to H \to WW)$$

k_F for ggH, ttH, bbH, k_V for VBF, VH

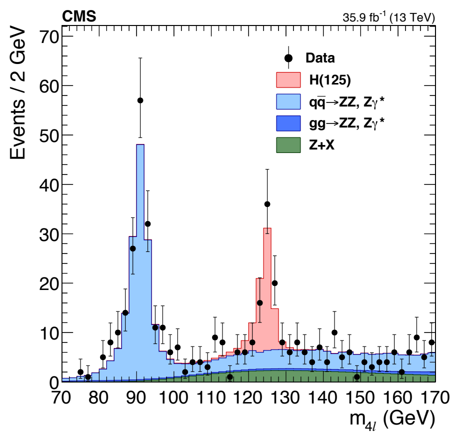


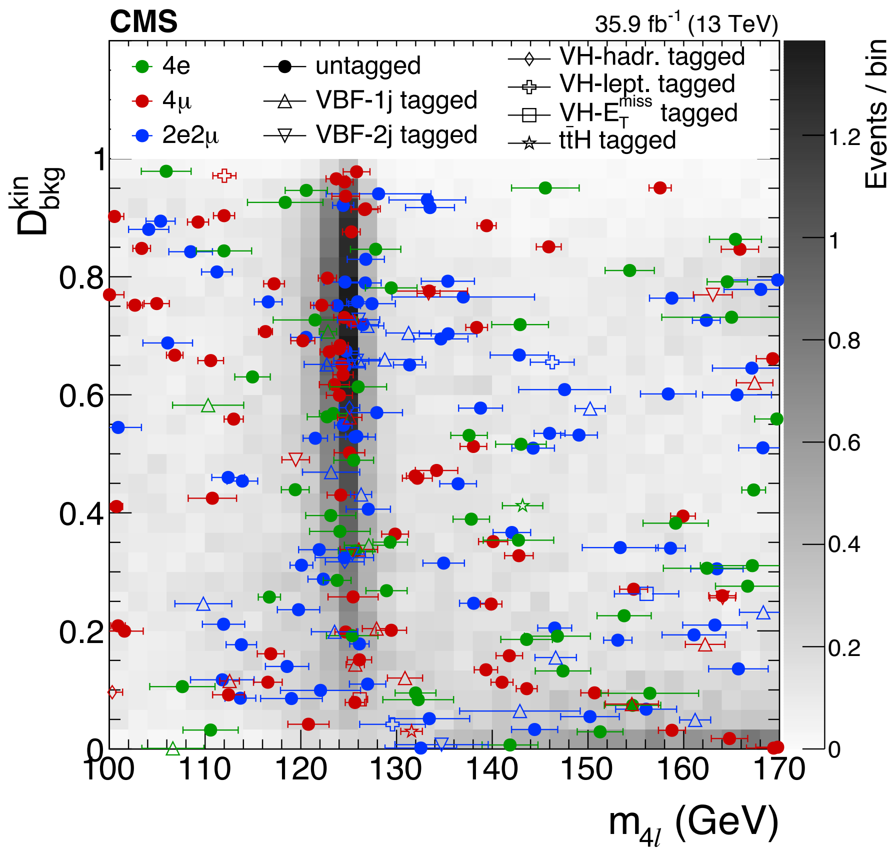


Higgs into ZZ

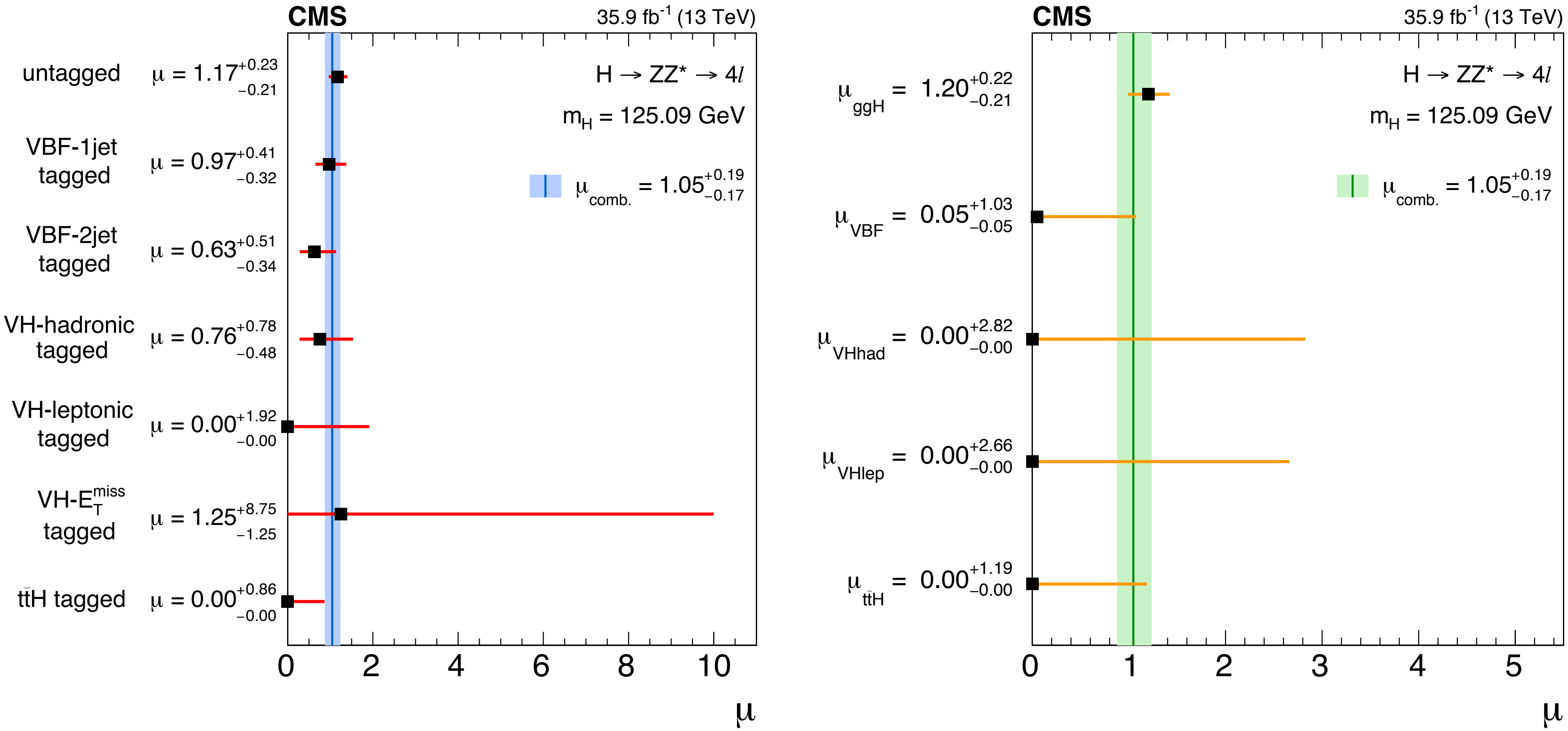
HIG-16-041
JHEP 11 (2017) 047

- Good mass resolution, best S/B, but low statistics
- 7 different categories targetting ggH, VBF, VH, ttH
- signal extracted from 2D fit of m_{4l} and kinematic discriminant
- Dominant experimental uncertainties: lepton efficiencies and luminosity
- Dominant theoretical: ggH prediction and migrations among categories





Higgs into ZZ



$\mu = 1.05^{+0.15}_{-0.14}(stat.)^{+0.11}_{-0.09}(syst.)$

at m_H= 125.09 GeV (Run 1 combination)

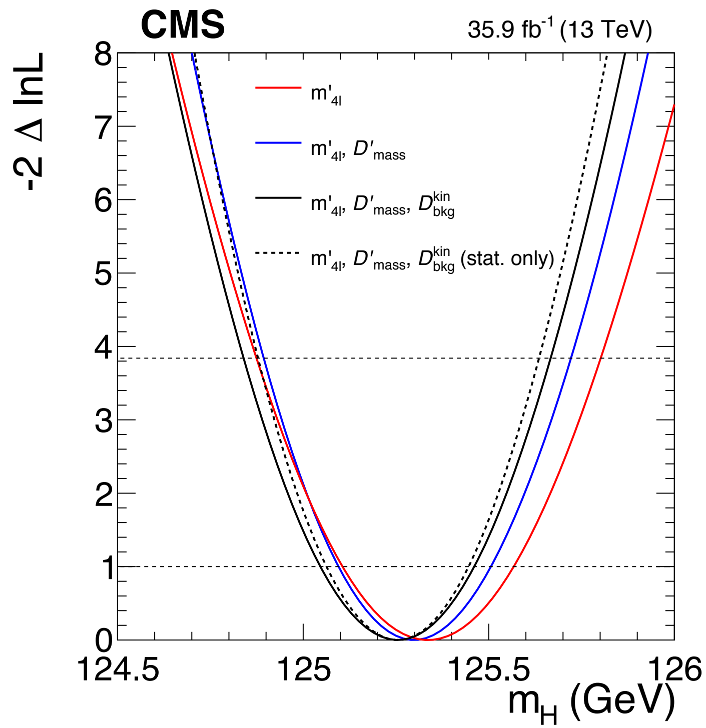
Higgs into ZZ

No $m(Z_1)$ constraint	3D: $\mathcal{L}(m_{4\ell}, \mathcal{D}_{\text{mass}}, \mathcal{D}_{\text{bkg}}^{\text{kin}})$	2D: $\mathcal{L}(m_{4\ell}, \mathcal{D}_{\text{mass}})$	1D: $\mathcal{L}(m_{4\ell})$
Expected m_H uncertainty change	+8.1%	+11%	+21%
Observed m_H (GeV)	125.28±0.22	125.36±0.24	125.39±0.25
With $m(Z_1)$ constraint	3D: $\mathcal{L}(m'_{4\ell}, \mathcal{D}'_{\text{mass}}, \mathcal{D}_{\text{bkg}}^{\text{kin}})$	2D: $\mathcal{L}(m'_{4\ell}, \mathcal{D}'_{\text{mass}})$	1D: $\mathcal{L}(m'_{4\ell})$
Expected m_H uncertainty change	—	+3.2%	+11%
Observed m_H (GeV)	125.26±0.21	125.30±0.21	125.34±0.23

- World's most precise mass measurement in a 3D fit, constraining the highest m_{ll} (Z_1) to be equal to m_Z.
- Systematic error dominated by the lepton energy scale.

m_H= 125.26±0.20 (stat.) ±0.08 (syst.) GeV
= 125.26 ± 0.21 GeV (CMS, 2016 data)

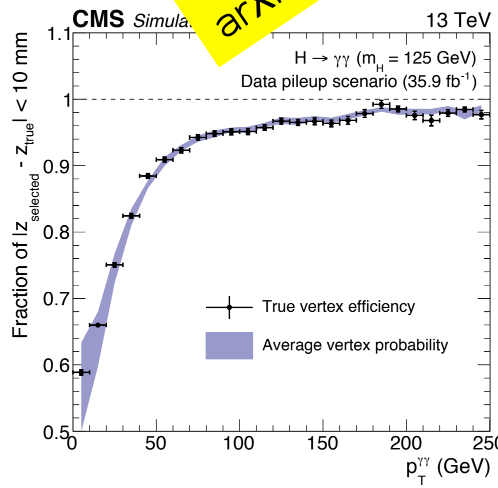
m_H= 125.09 ± 0.21 (stat.)± 0.11 (syst.) GeV
(Run 1 legacy ATLAS+CMS combination)

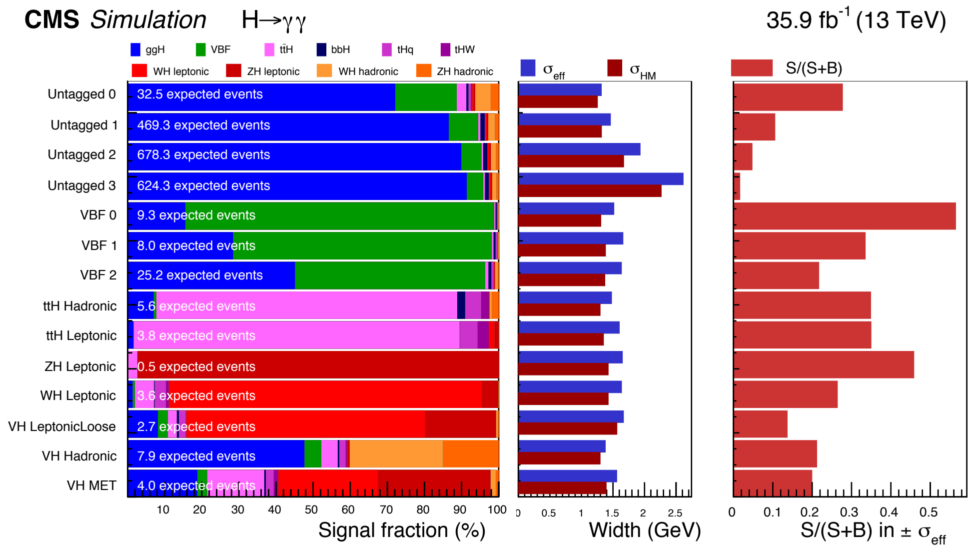


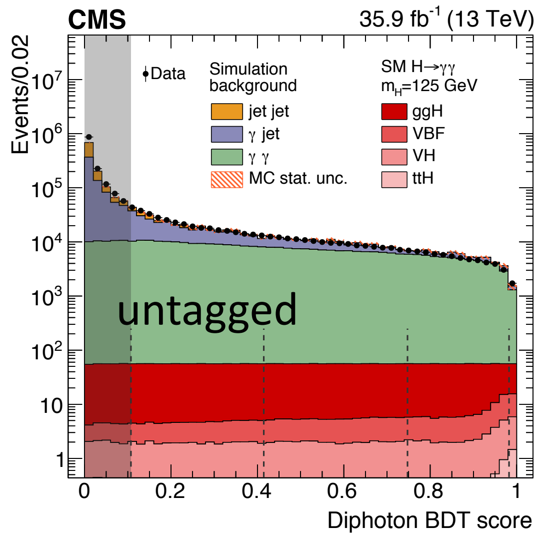
Higgs into γγ

HIG-16-040
arXiv:1804.02716

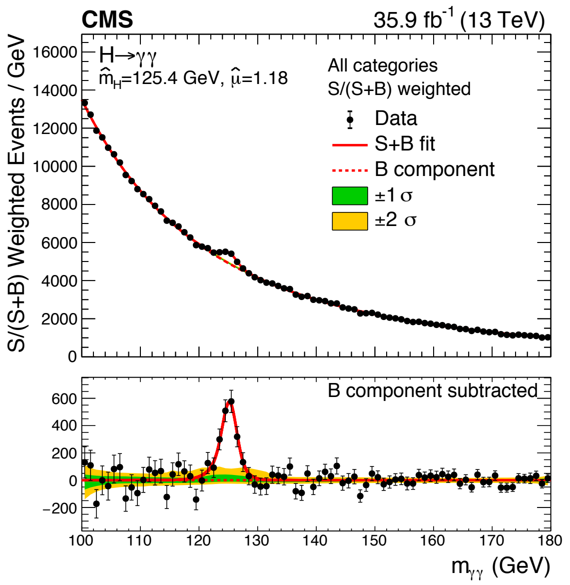
- High statistics and mass resolution
- BDT for the identification of prompt photons
- Multivariate regression technique to determined the energy of the photon, calibration with Z->ee events
- BDT for the vertex assignment
- Event categories targetting different production modes and using a dedicated diphoton BDT

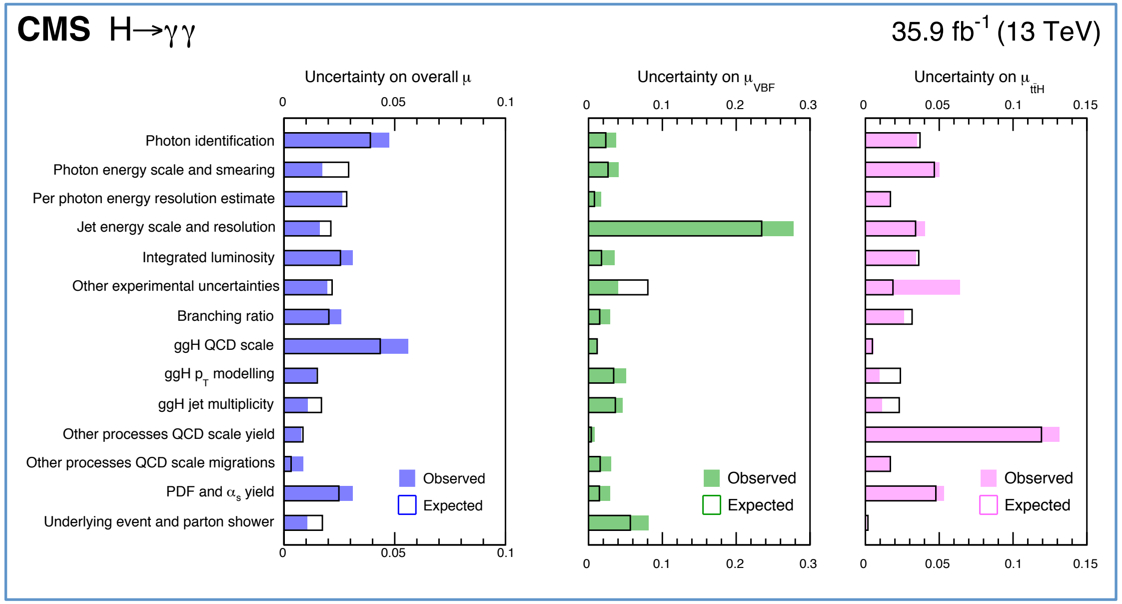






Higgs into γγ

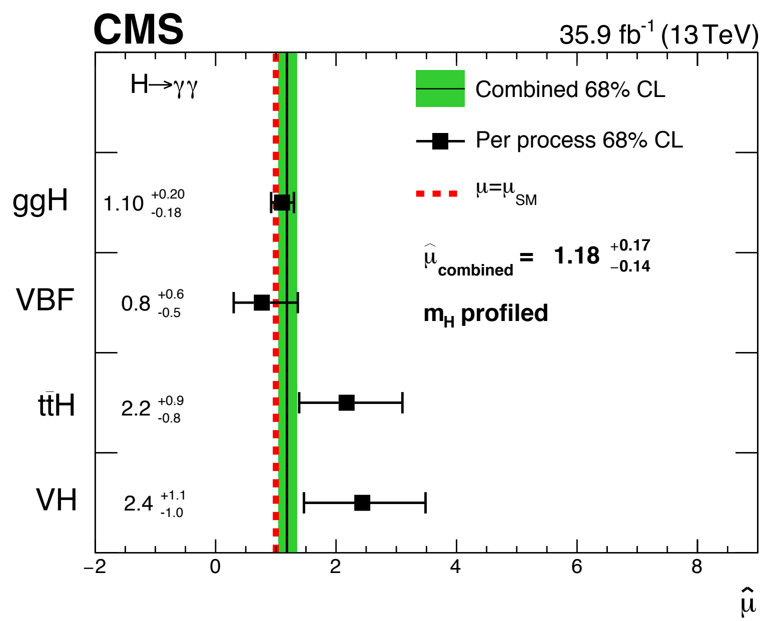


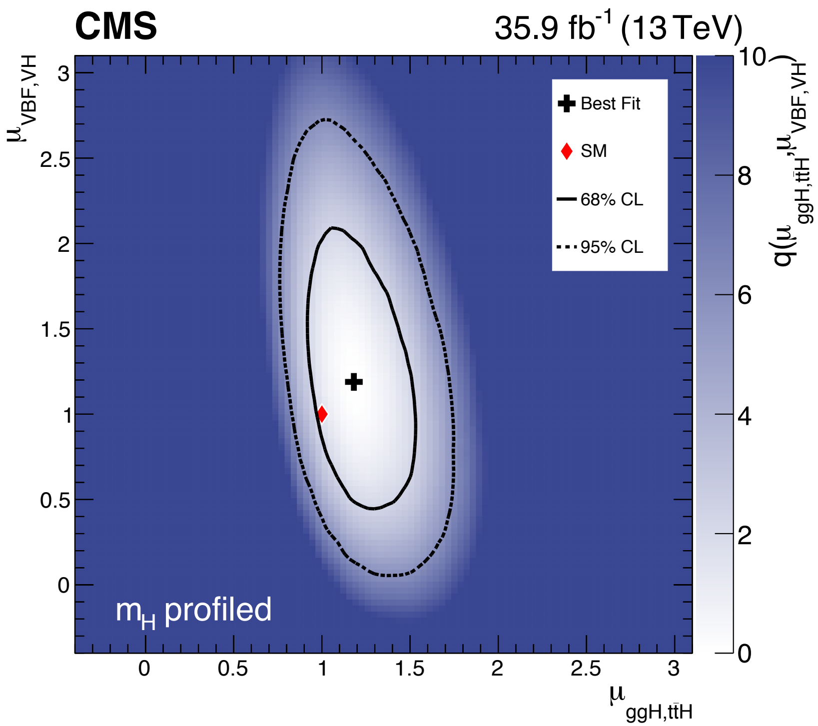


Distribution for all categories summed weighted for their sensitivity

Dominant uncertainties:
- photon shower shape modelling and energy scale
- luminosity
- jet energy scale (especially for VBF)
- QCD theory (scale and BR)

Higgs into γγ





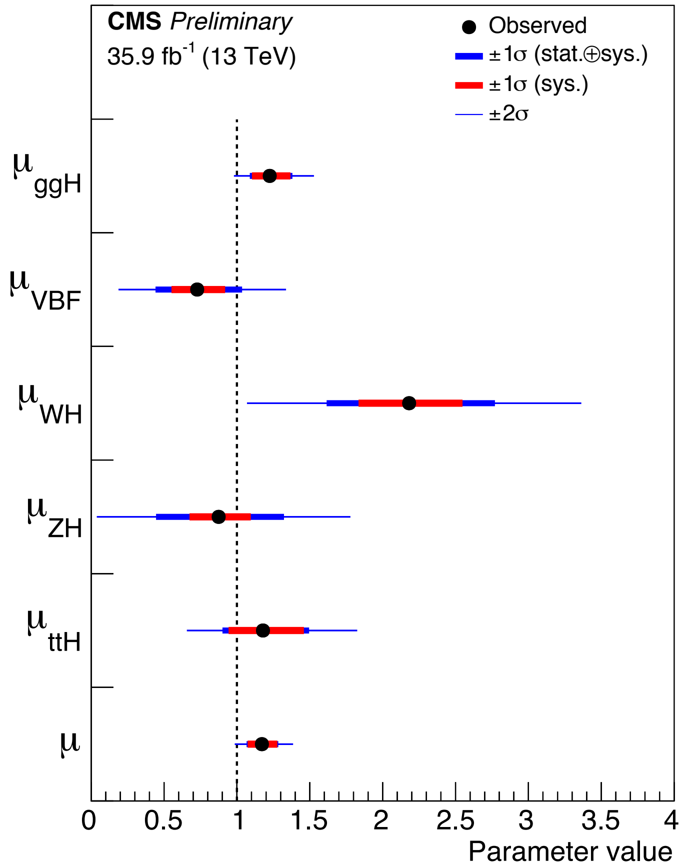
Simultaneous ML fit to m(γγ) in all categories with a single μ and m_H free:

$$\mu = 1.18^{+0.12}_{-0.11}(stat.)^{+0.09}_{-0.07}(syst.)^{+0.07}_{-0.06}(theo.)$$

Conclusions

- **H -> WW:**
  - Observation of H in WW in CMS alone and precise measurement of couplings to fermions and bosons
- **H->ZZ and H-> γγ:**
  - more and more precision in couplings
  - (differential/STXS) cross sections (see G. Ortona's talk)
  - currently most precise mass measurement is in the CMS ZZ channel, m_H=125.26 ± 0.21 GeV

These 3 results included in the overall combination (ggH ~ 11%, VBF~ 41%) →



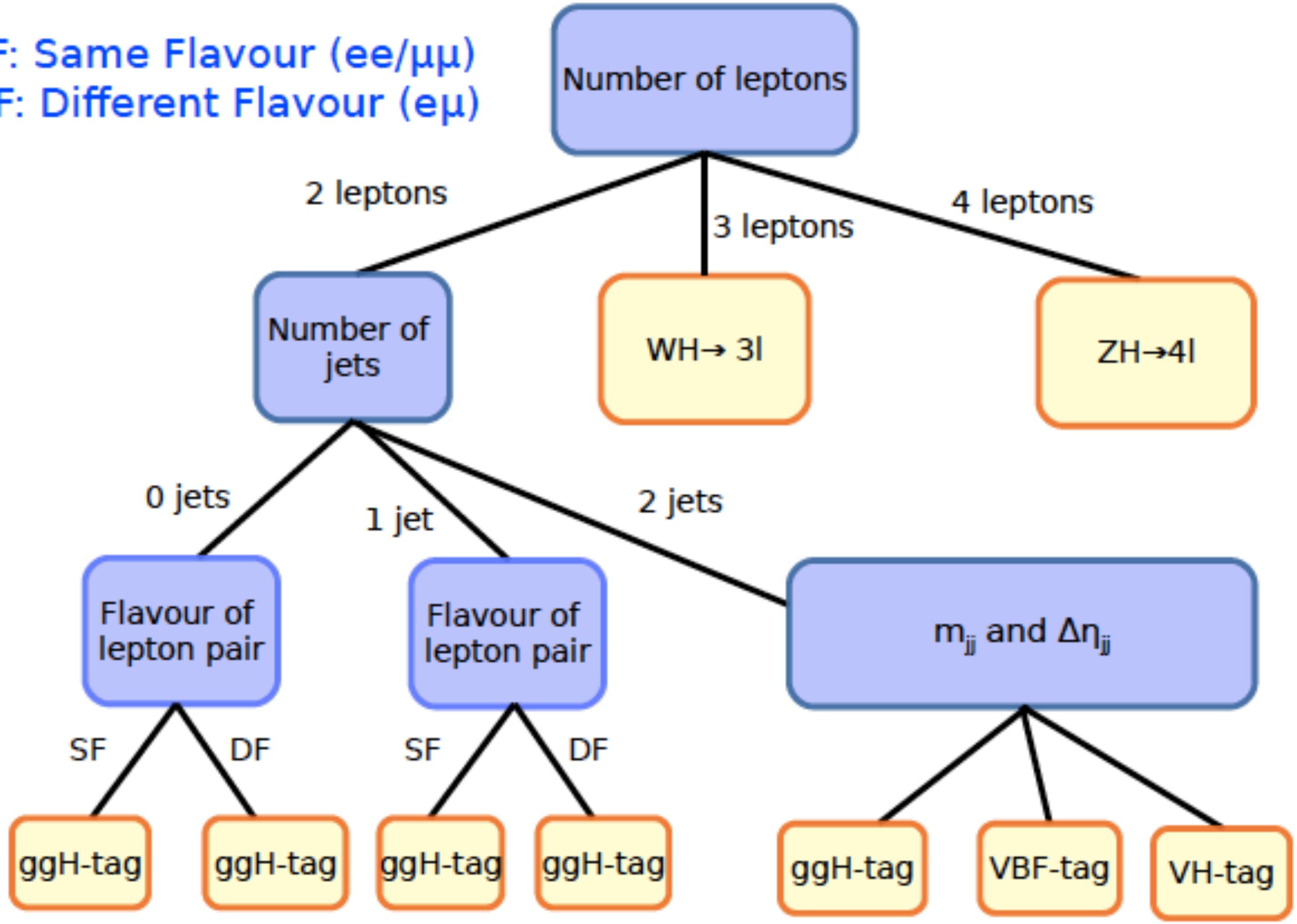
$$\mu = 1.17^{+0.10}_{-0.10}$$

- Rare decays **H-> γ*γ and H->Zγ**

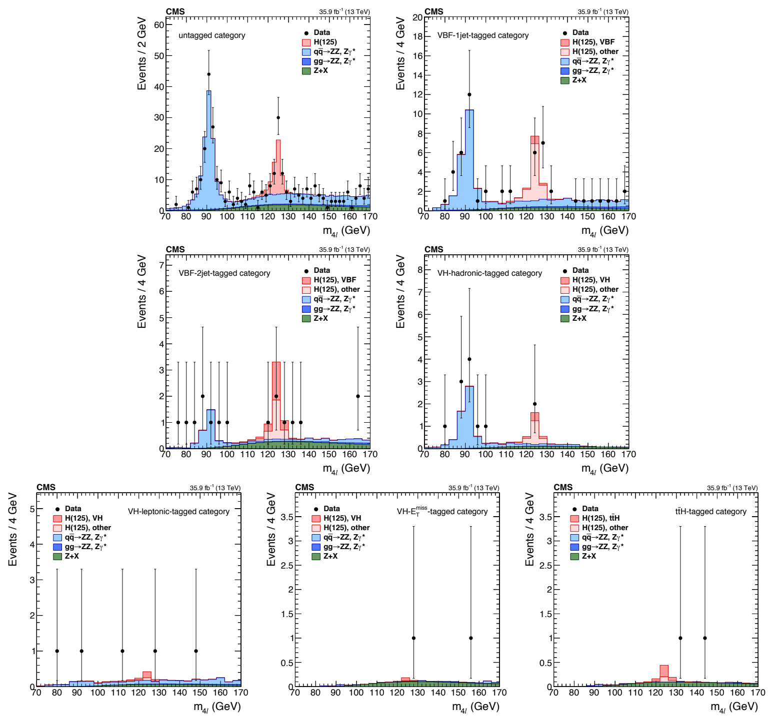
Backup

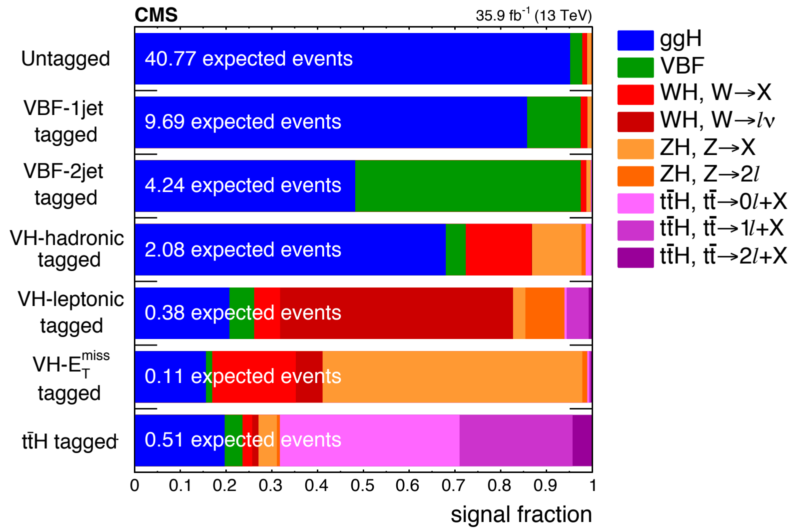
H into WW

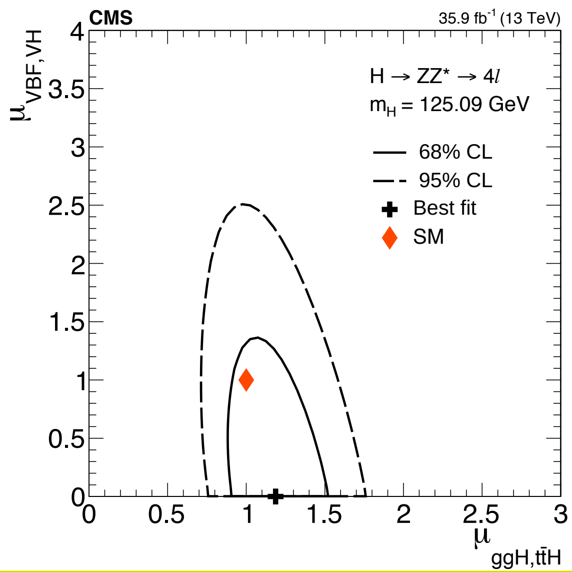
SF: Same Flavour (ee/μμ)
DF: Different Flavour (eμ)



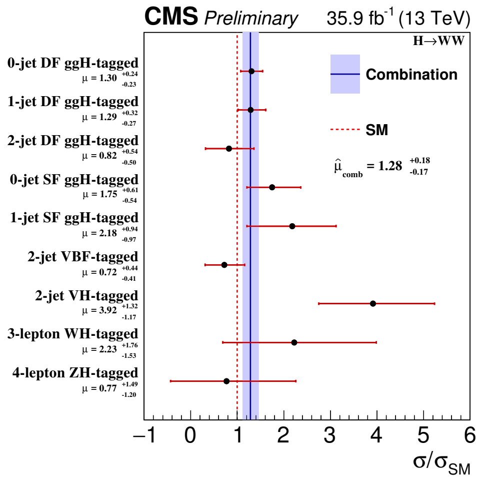
Higgs into ZZ



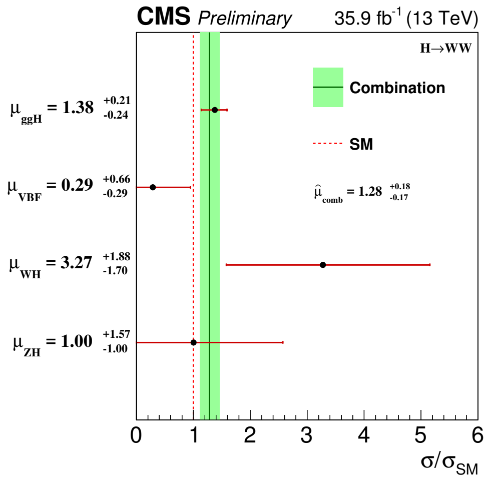




Couplings

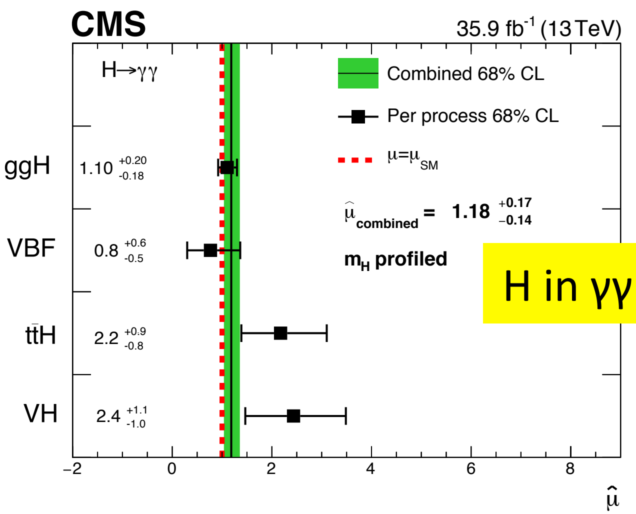


(a)

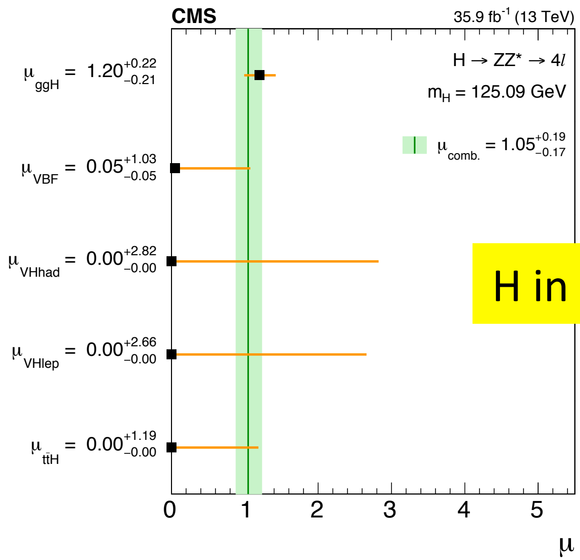


(b)

H in WW



H in γγ



H in ZZ

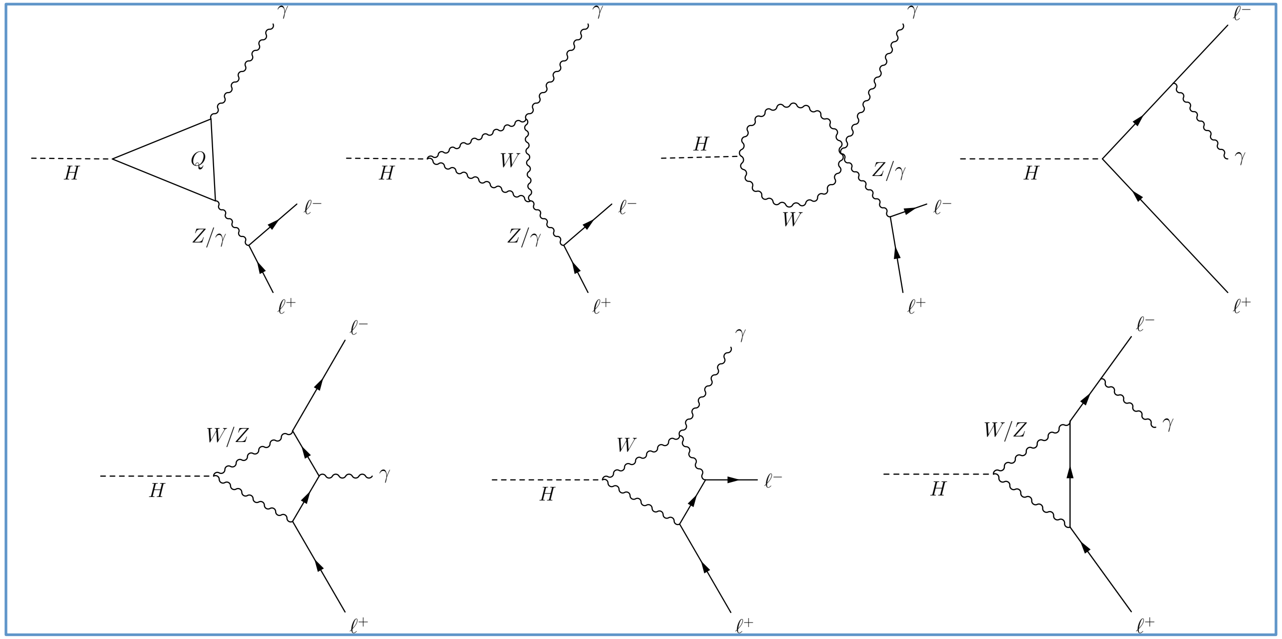
Couplings

Production	Loops	Interference	Effective scaling factor	Resolved scaling factor
$\sigma(\text{ggH})$	✓	b − t	κ_g^2	$1.04 \cdot \kappa_t^2 + 0.002 \cdot \kappa_b^2 - 0.038 \cdot \kappa_t \kappa_b$
$\sigma(\text{VBF})$	–	–		$0.73 \cdot \kappa_W^2 + 0.27 \cdot \kappa_Z^2$
$\sigma(\text{WH})$	–	–		κ_W^2
$\sigma(\text{qq/qg} \to \text{ZH})$	–	–		κ_Z^2
$\sigma(\text{gg} \to \text{ZH})$	✓	Z − t		$2.46 \cdot \kappa_Z^2 + 0.47 \cdot \kappa_t^2 - 1.94 \cdot \kappa_Z \kappa_t$
$\sigma(\text{ttH})$	–	–		κ_t^2
$\sigma(\text{gb} \to \text{WtH})$	–	W − t		$2.91 \cdot \kappa_t^2 + 2.40 \cdot \kappa_W^2 - 4.22 \cdot \kappa_t \kappa_W$
$\sigma(\text{qb} \to \text{tHq})$	–	W − t		$2.63 \cdot \kappa_t^2 + 3.58 \cdot \kappa_W^2 - 5.21 \cdot \kappa_t \kappa_W$
$\sigma(\text{bbH})$	–	–		κ_b^2
Partial decay width				
Γ^{ZZ}	–	–		κ_Z^2
Γ^{WW}	–	–		κ_W^2
$\Gamma^{\gamma\gamma}$	✓	W − t	κ_γ^2	$1.59 \cdot \kappa_W^2 + 0.07 \cdot \kappa_t^2 - 0.67 \cdot \kappa_W \kappa_t$
$\Gamma^{\tau\tau}$	–	–		κ_τ^2
Γ^{bb}	–	–		κ_b^2
$\Gamma^{\mu\mu}$	–	–		κ_μ^2
Total width for $\text{BR}_{\text{BSM}} = 0$				
Γ_H	✓	–	κ_H^2	$0.58 \cdot \kappa_b^2 + 0.22 \cdot \kappa_W^2 + 0.08 \cdot \kappa_g^2 +$ $+ 0.06 \cdot \kappa_\tau^2 + 0.026 \cdot \kappa_Z^2 + 0.029 \cdot \kappa_c^2 +$ $+ 0.0023 \cdot \kappa_\gamma^2 + 0.0015 \cdot \kappa_{Z\gamma}^2 +$ $+ 0.00025 \cdot \kappa_s^2 + 0.00022 \cdot \kappa_\mu^2$

Higgs into llγ

HIG-17-007
new

- Rare decay
- Diagrams contributing and BRs:



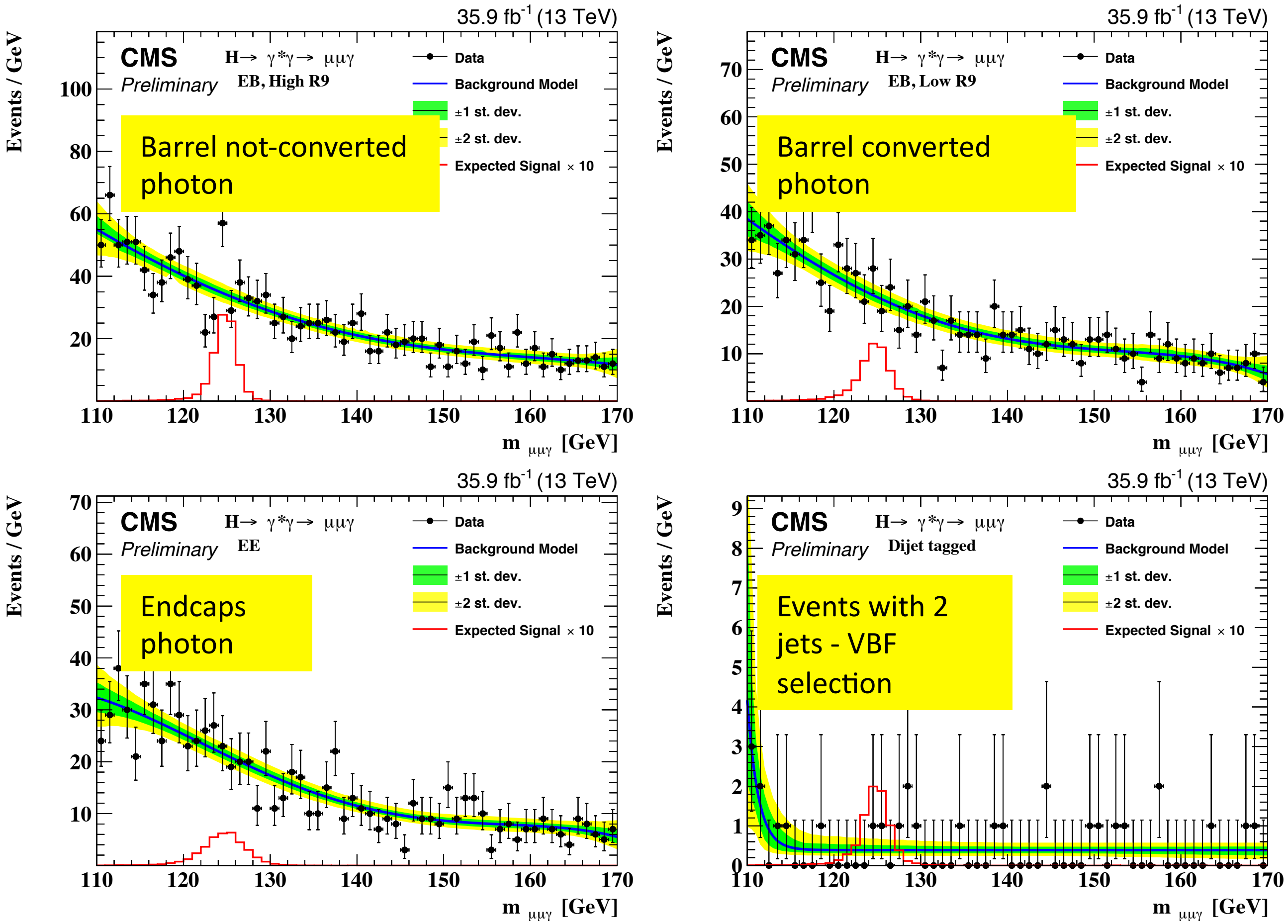
$$\frac{\Gamma(H \to \gamma^* \gamma \to \mu\mu\gamma)}{\Gamma(H \to \gamma\gamma)} = (1.69 \pm 0.25)\%,$$

$$\frac{\Gamma(H \to Z\gamma \to \ell\ell\gamma)}{\Gamma(H \to \gamma\gamma)} = (2.27 \pm 0.34)\%$$

- Signature is a pair of opposite-sign muons or electrons and a photon. The two processes H->Zγ and H->γ*γ interfere and are experimentally separated in the selection via a cut on m_{ll}.

Higgs into llγ

the 4 categories in γ*γ:



γ*γ

- m_{ll}< 50 GeV
- only the muon channel
- split in 4 categories with different sensitivity

Zγ

- m_{ll}> 50 GeV,
- e and μ channels
- categories for VBF, VH, boosted, untagged

Higgs into llγ

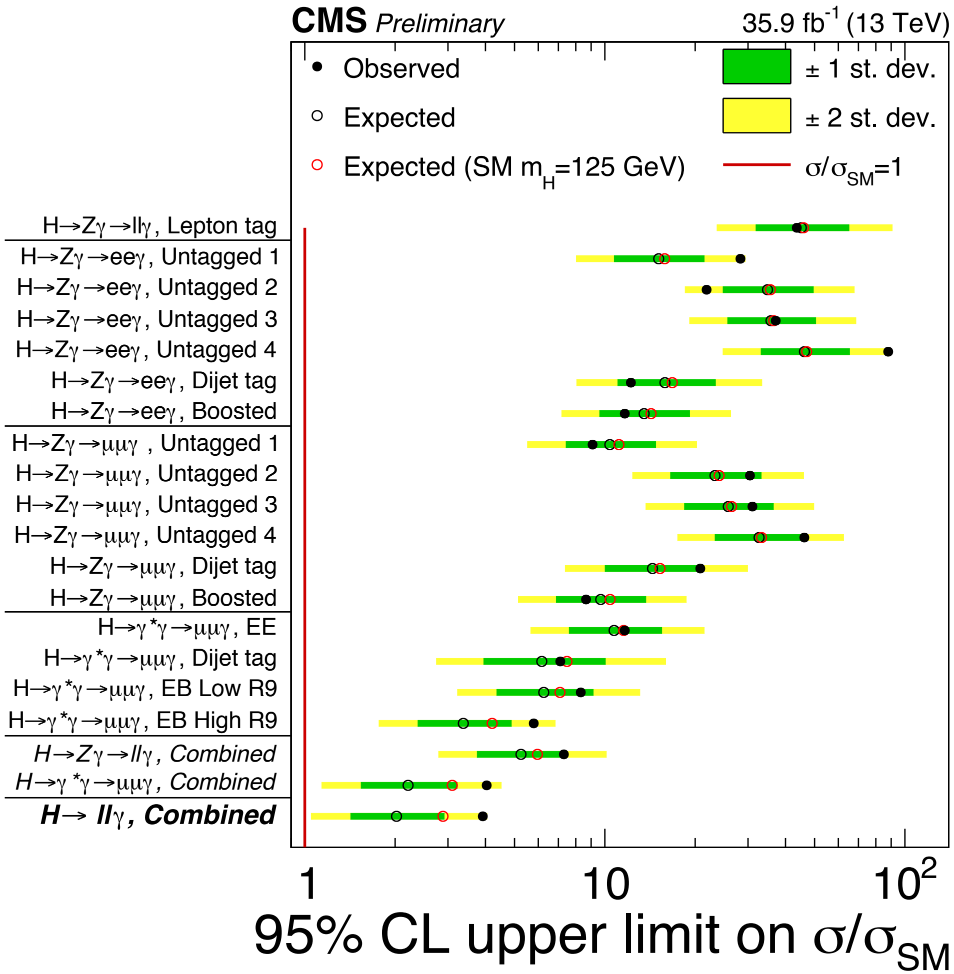
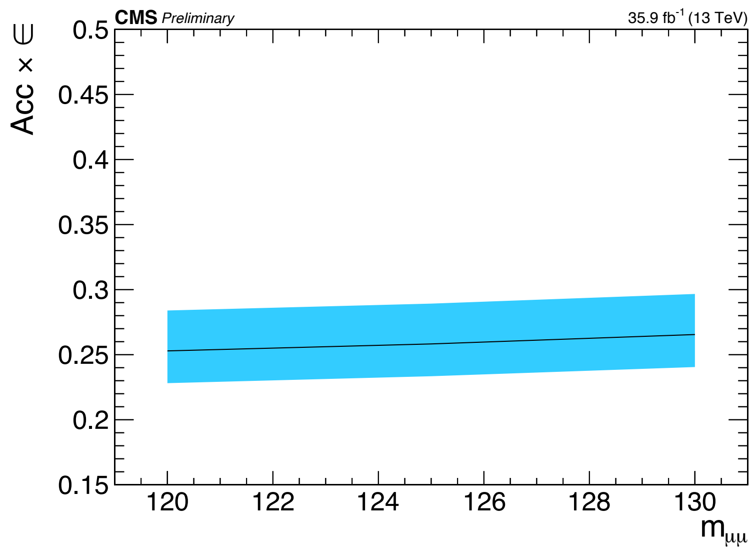


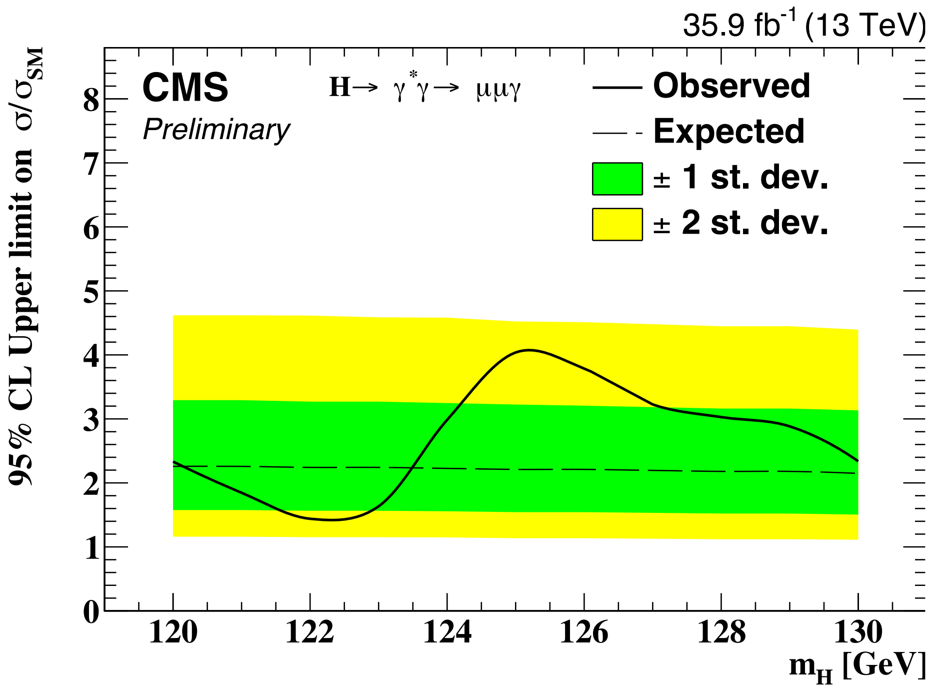
Table 3: Fit function chosen as a result of the bias study used in the analysis.

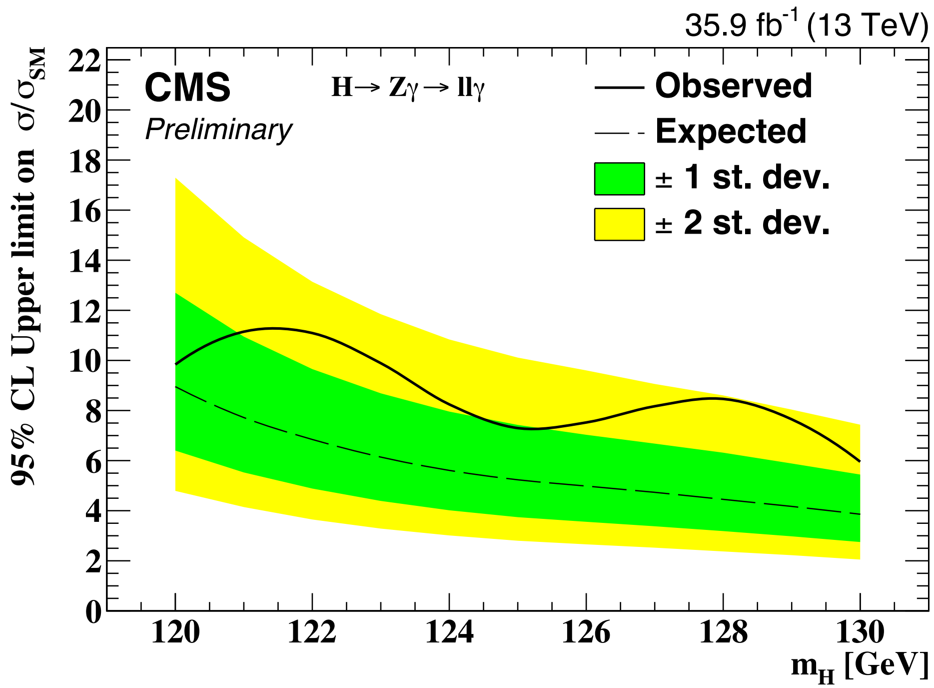
$m_{\ell\ell}$	Category	Best fit function
< 50 GeV	EB - low R_9	Bernstein of order 4
	EB - high R_9	Bernstein of order 4
	EE	Bernstein of order 4
	Dijet tag	Exponential of order 2
> 50 GeV	Untagged 1	Bernstein of order 4
	Untagged 2	Bernstein of order 5
	Untagged 3	Bernstein of order 4
	Untagged 4	Bernstein of order 4
	Dijet tag	Power law of order 1
	Boosted tag	Bernstein of order 3
	Lepton tag	Power law of order 1



Higgs into llγ

Upper limits at 95% CL on Higgs production X BR for the two channels:





Combined **observed** (expected) upper limit: **3.9** (2.0) X SM expectation for a 125 GeV mass
p-value for background-only hypothesis: 0.02, ~ 2 sigma