H(125) decay to bosons at CMS

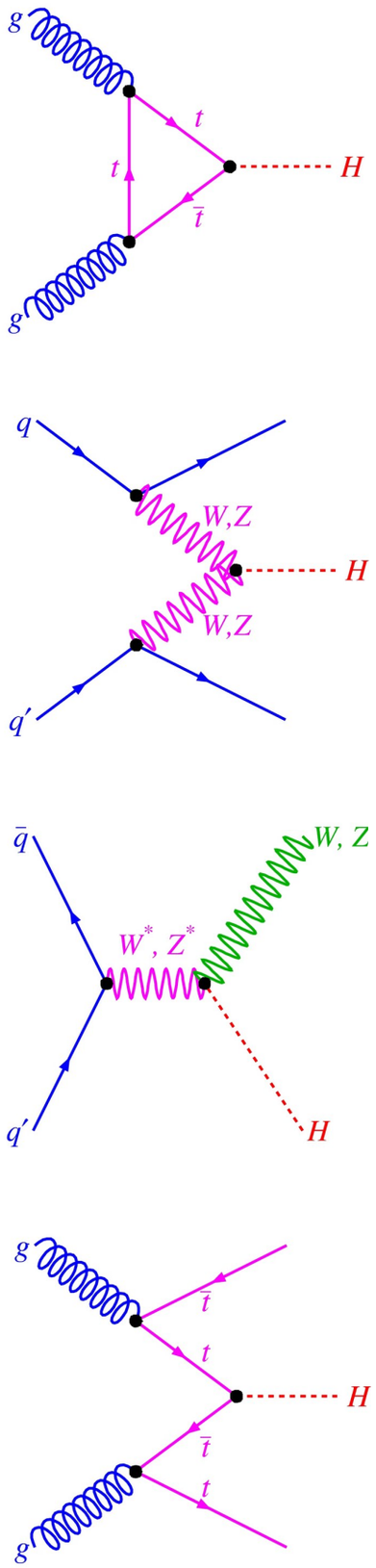
Jónatan Piedra, on behalf of the CMS Collaboration
IFCA (CSIC - Universidad de Cantabria)

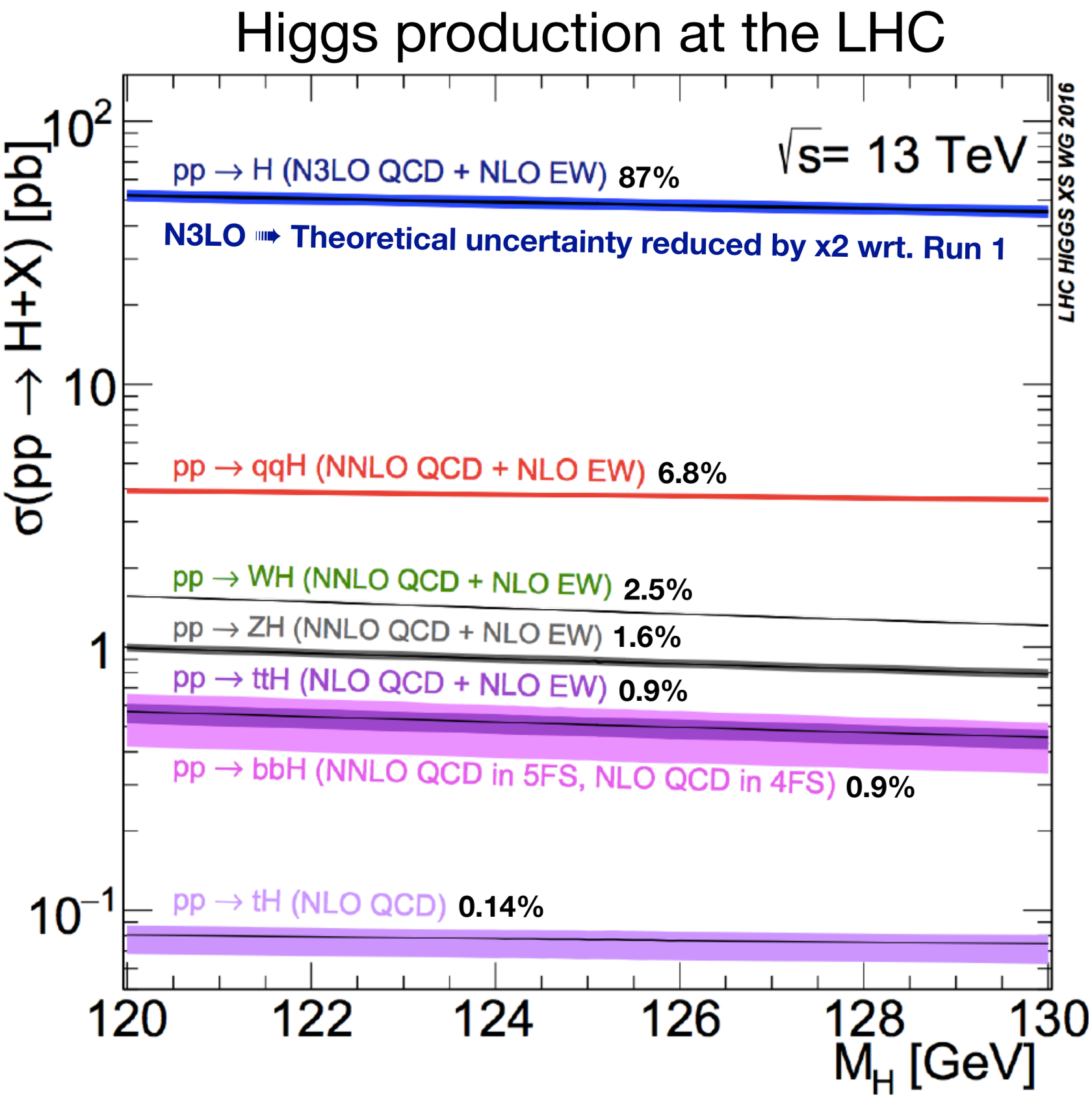
Higgs Hunting
July 24th 2017, Orsay-Paris, France

Higgs results covered in this talk

HIG-16-041	H → ZZ → 4 lepton ***properties***	35.9 fb^{-1}	submitted to JHEP
HIG-17-011	H → ZZ → 4 lepton ***anomalous couplings***	38.6 fb^{-1}	submitted to PLB
HIG-16-033	H → ZZ → 4 lepton ***width***	12.9 fb^{-1}	
HIG-16-040	H → γγ ***properties***	35.9 fb^{-1}	
HIG-17-015	H → γγ ***cross sections***	35.9 fb^{-1}	
HIG-16-021	H → WW ***measurements***	15.2 fb^{-1}	NEW

https://arxiv.org/abs/1610.07922
https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHXSWG



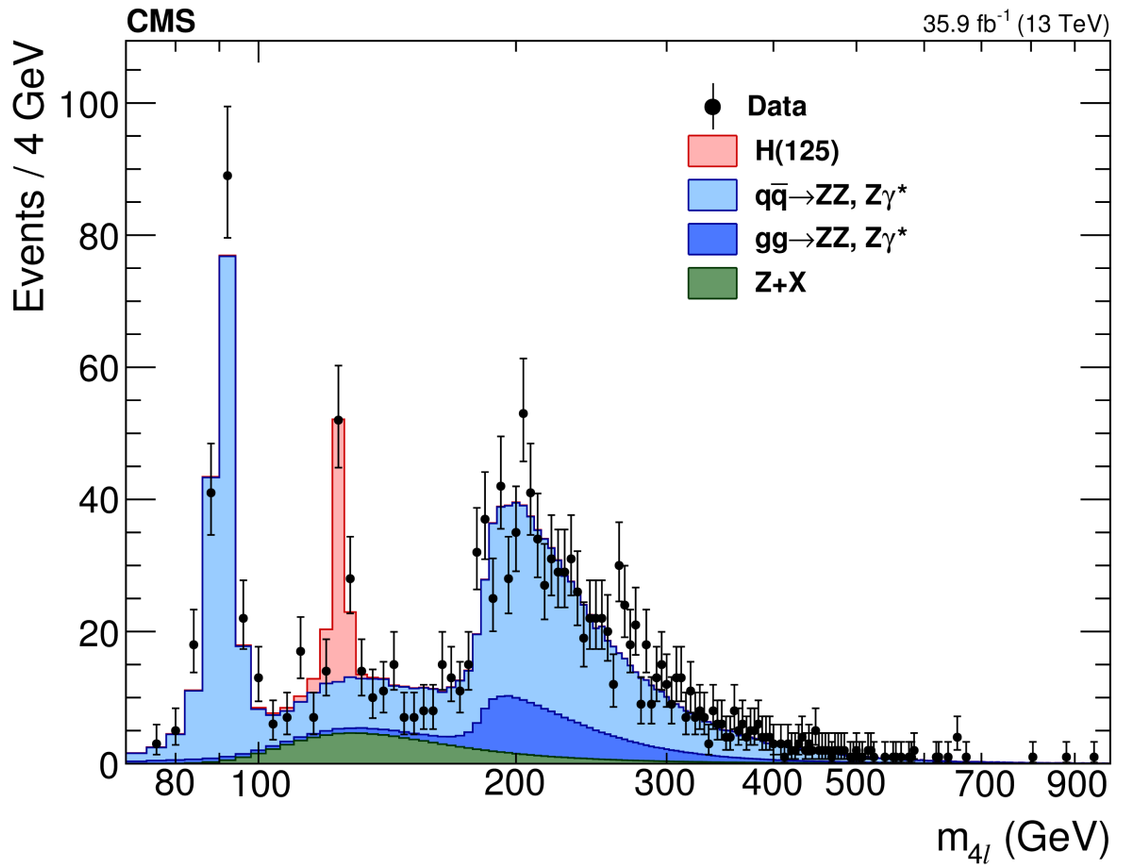


H → ZZ* → 4 lepton ***properties*** *and* ***anomalous couplings***

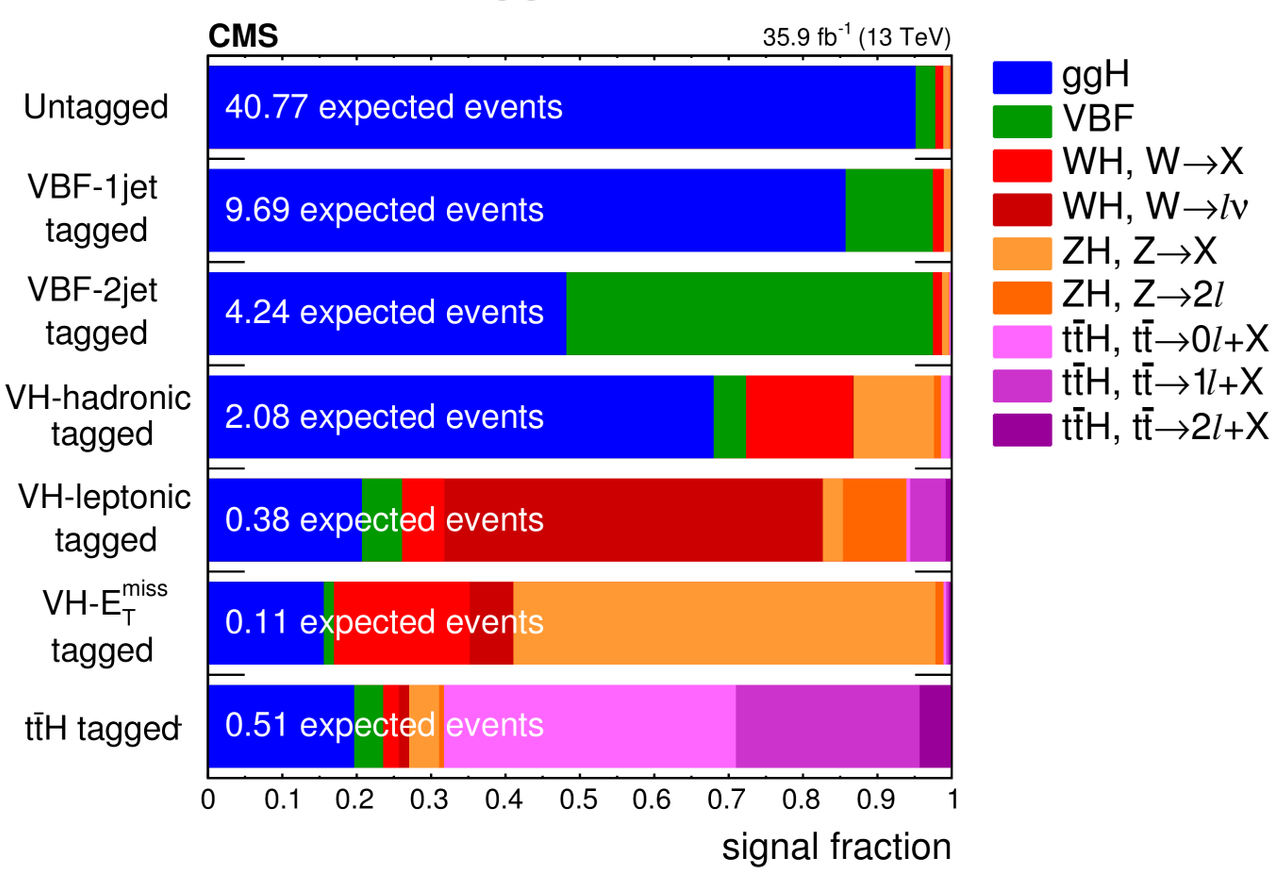
HIG-16-041

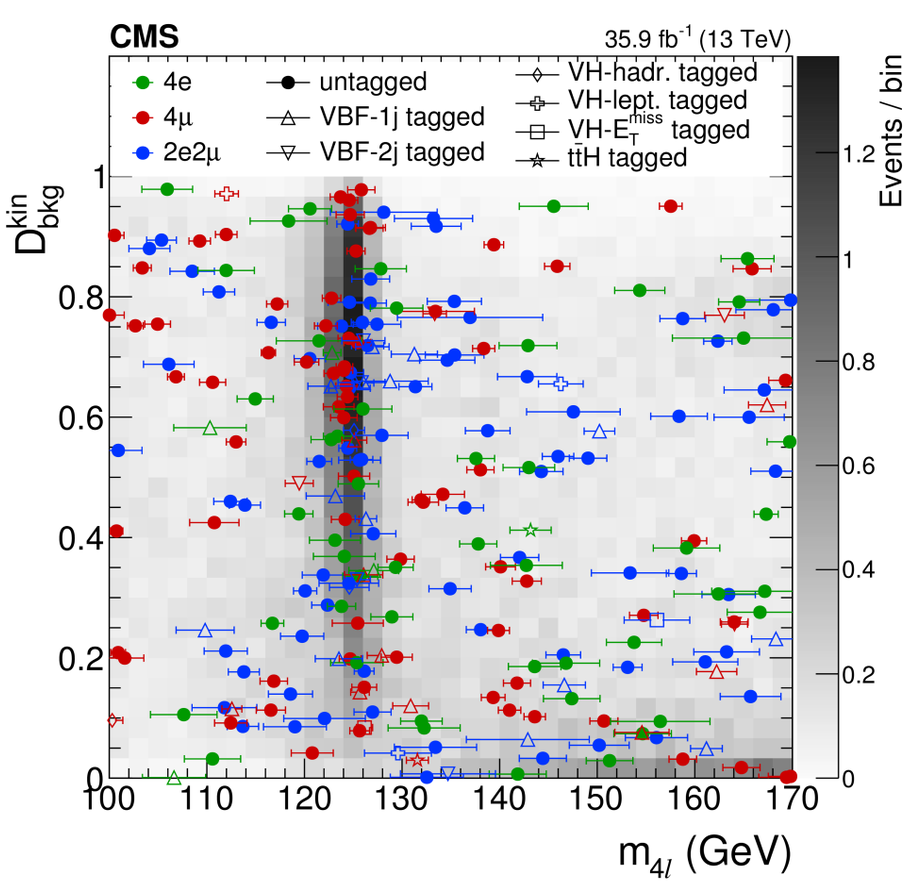
What is my production mode?

H → ZZ has high resolution and large S/B. **An event categorization is performed based on the different production modes** (number of leptons, jets, b-jets and MET) and ME based discriminants sensitive to signal and background kinematics



7 exclusive categories
for the main Higgs production modes

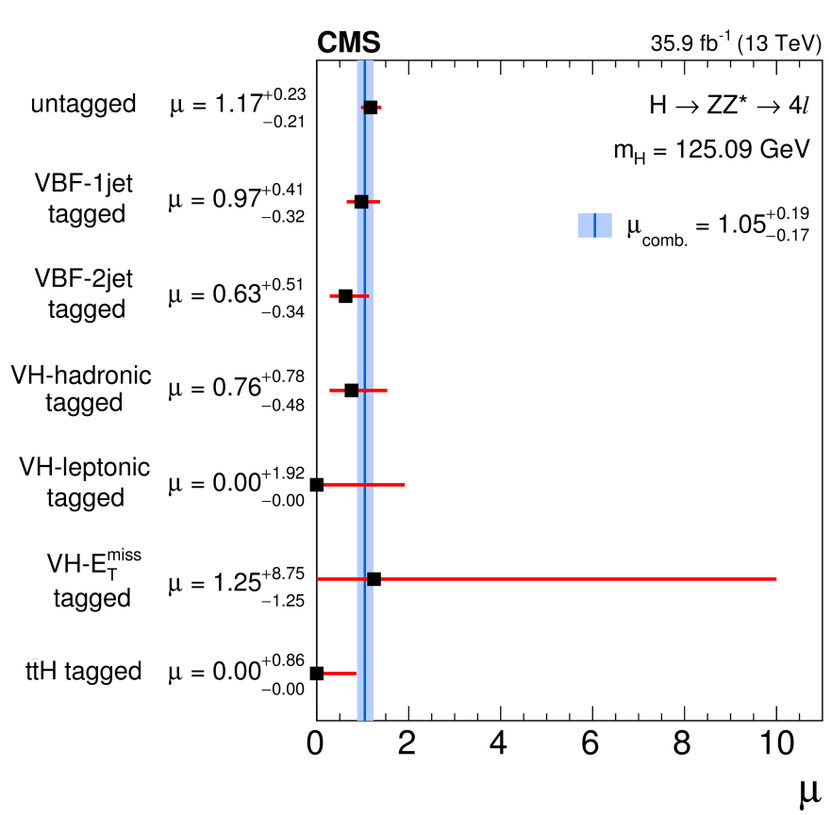




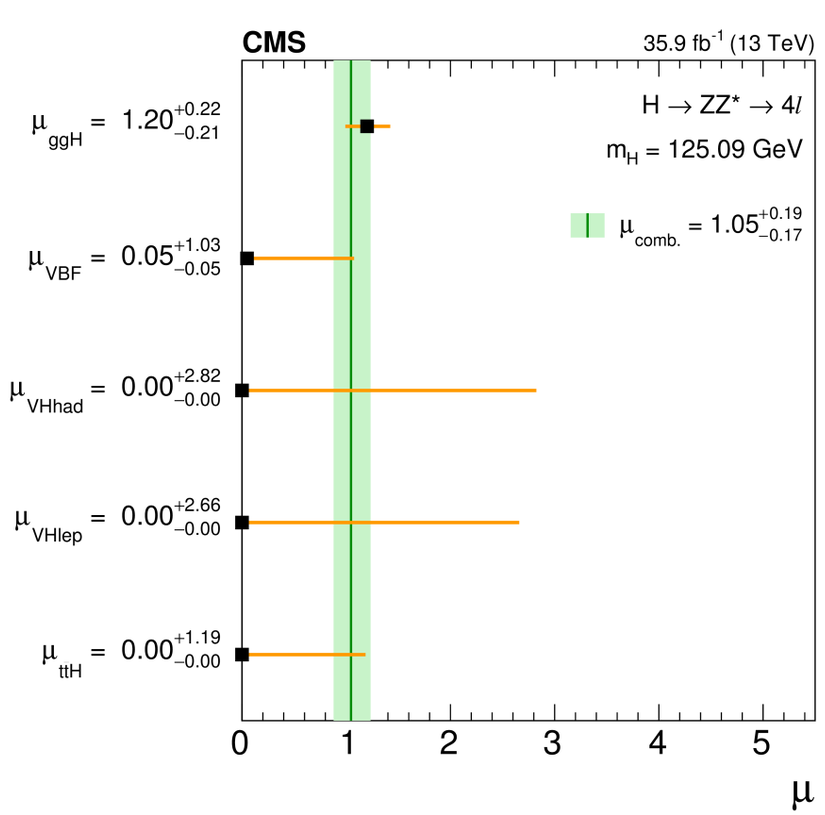
How about my signal strength?

The signal strength μ is extracted from a 2D (D_{bkg}^{kin} and m_{4l}) simultaneous fit on all categories. The main theoretical uncertainties are removed in the simplified template cross sections (STXS, arXiv:1610.07922)

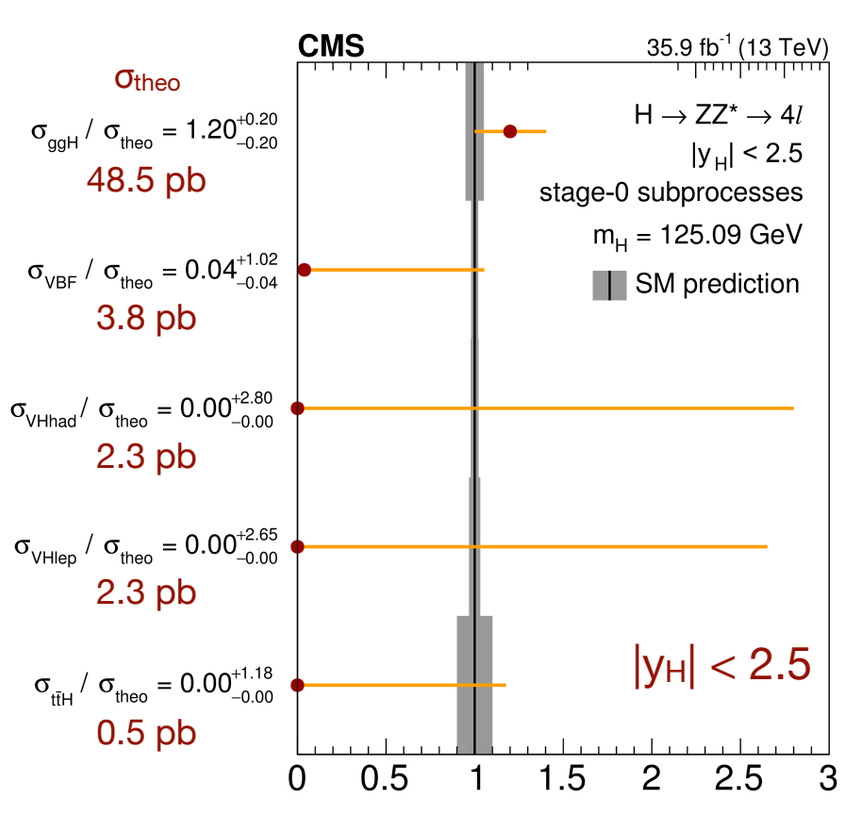
$$\mu = 1.05\ ^{+0.15}_{-0.14}\ \text{(stat.)}\ ^{+0.11}_{-0.09}\ \text{(syst.)}$$



categories



production modes



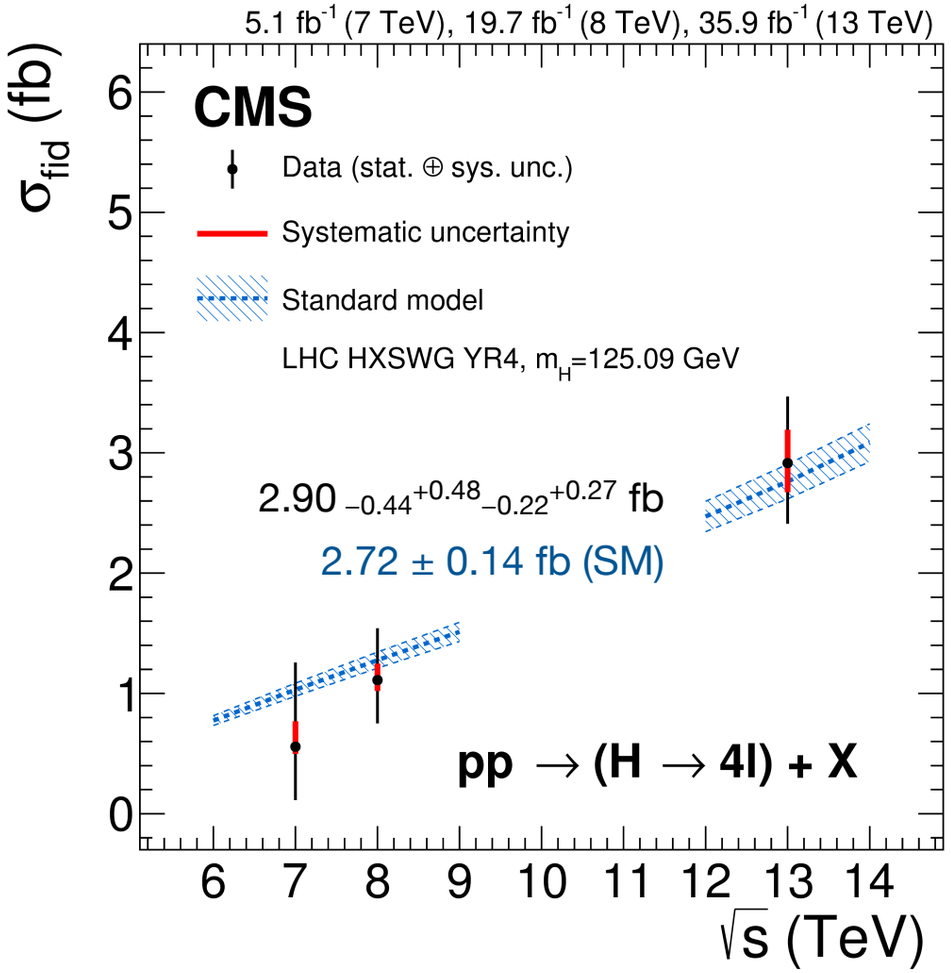
simplified cross sections

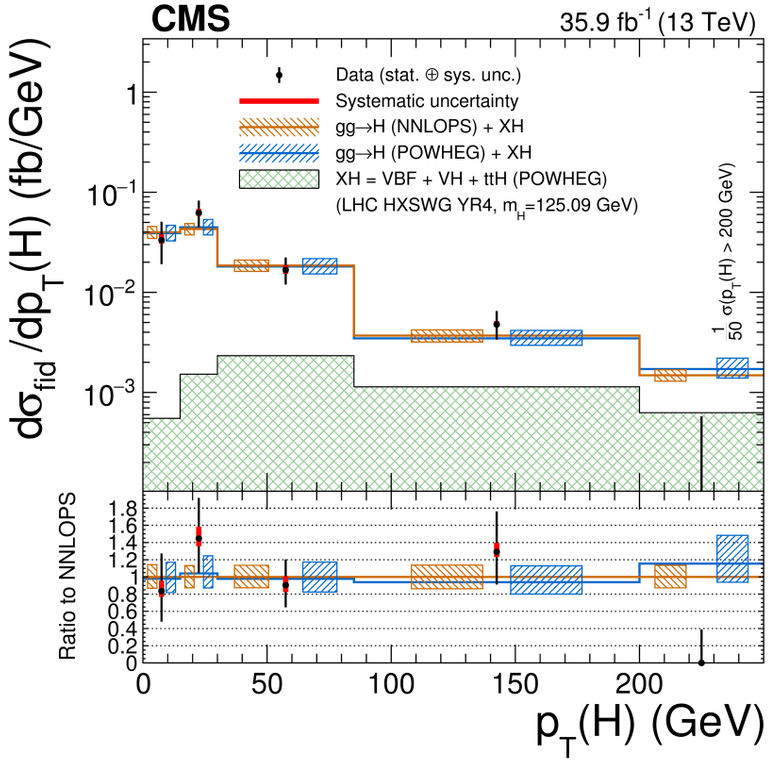
Fiducial and differential cross sections

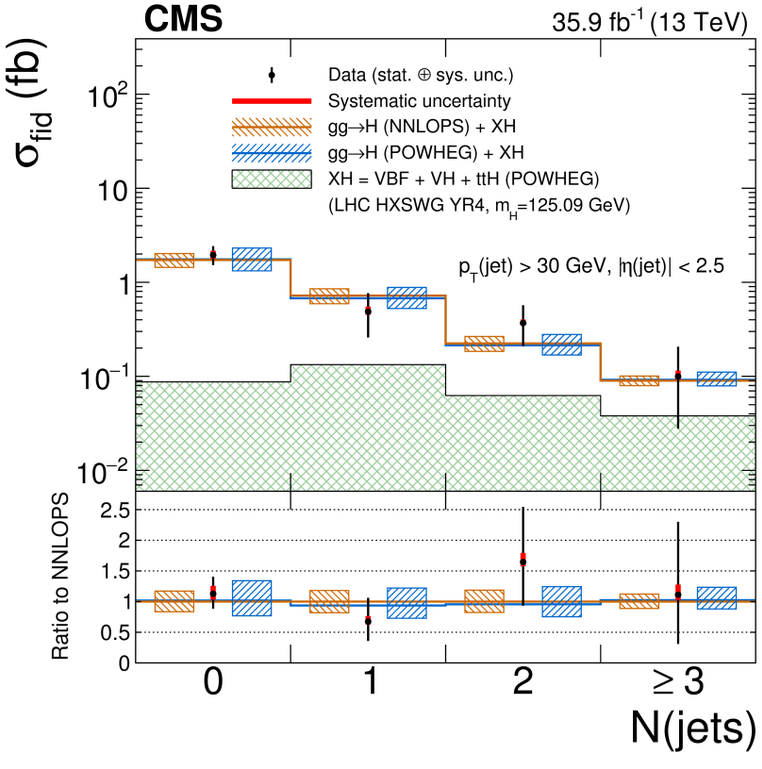
HIG-16-041

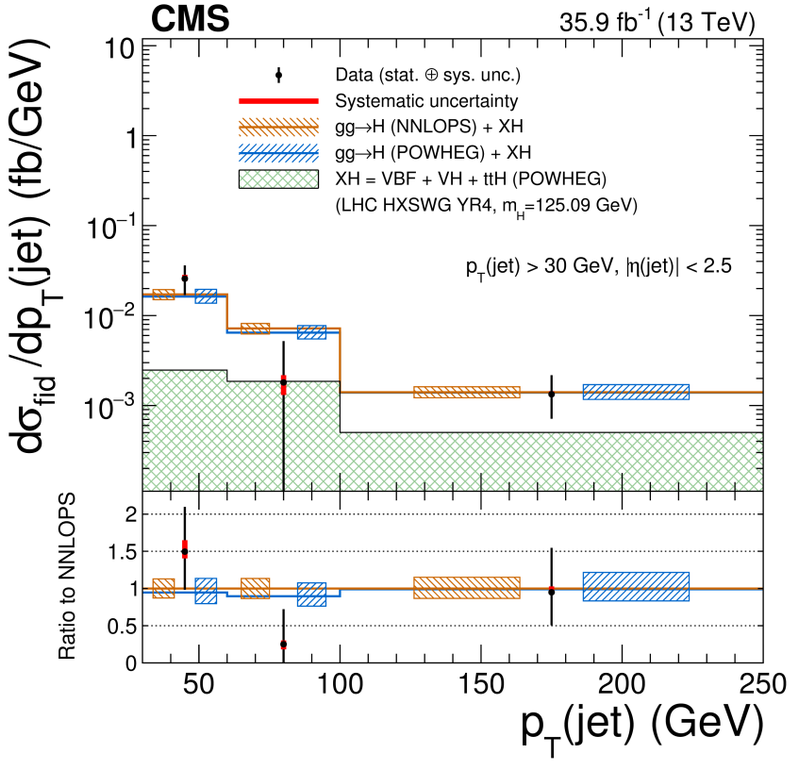
Minimal model dependence, **the integrated fiducial cross section is extracted from m_{4l} inclusive (no event categorization) maximum likelihood fit**, in good agreement with the N3LO ggH prediction

Differential measurements of p_T(H), N(jets) and p_T(jet), with lepton ID efficiencies as the main systematic uncertainty









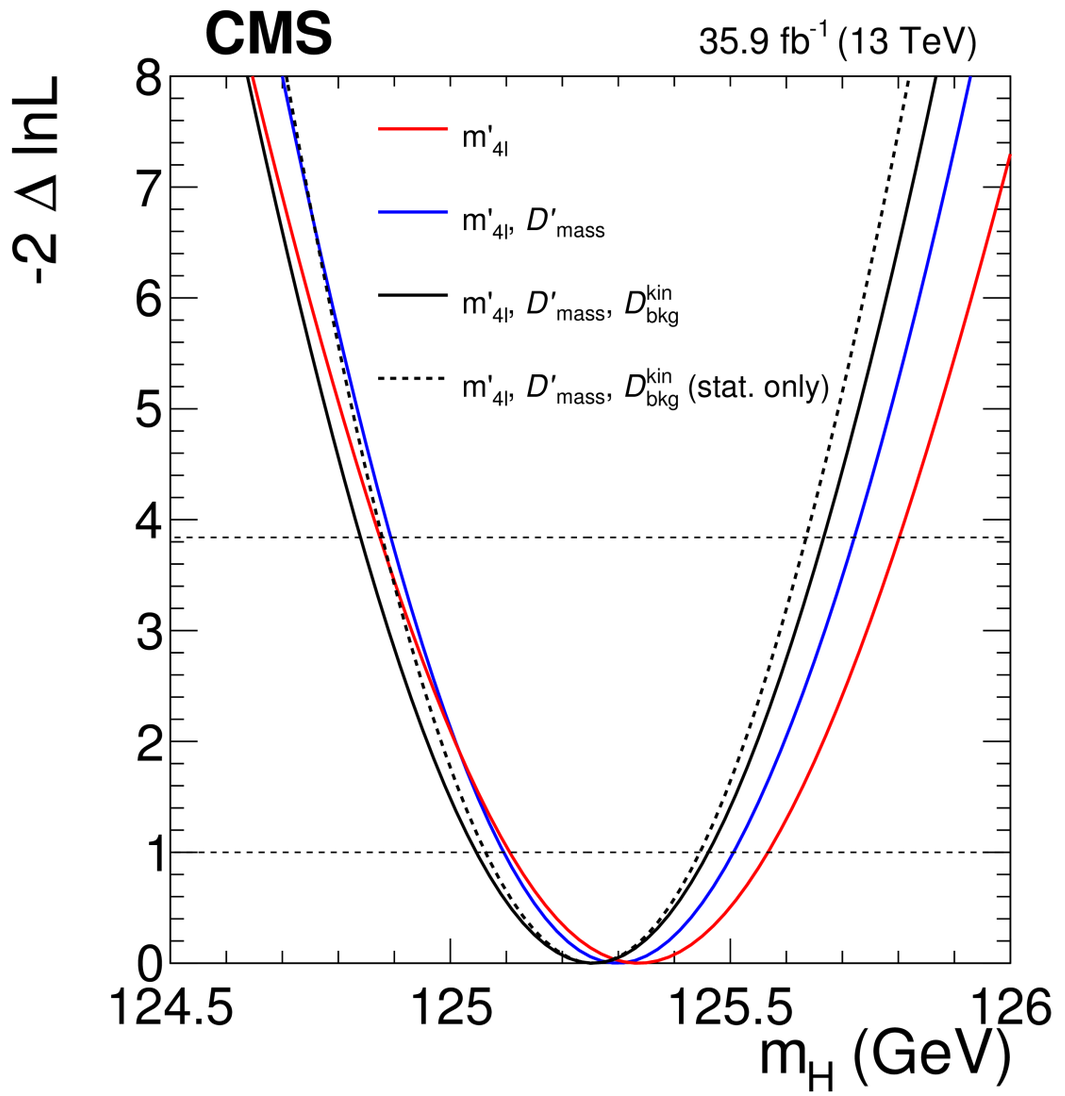
Give me the mass

And I'll give you precise details of my properties. Or you can estimate the mass from the cross section, together with N3LO theory predictions

We perform a 3D fit, using a constraint on the first Z mass

m_H = 125.26 ± 0.20 (stat.) ± 0.08 (syst.) GeV

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



No $m(Z_1)$ constraint	3D: $\mathcal{L}(m_{4l}, \mathcal{D}_{\text{mass}}, \mathcal{D}^{\text{kin}}_{\text{bkg}})$	2D: $\mathcal{L}(m_{4l}, \mathcal{D}_{\text{mass}})$	1D: $\mathcal{L}(m_{4l})$
Expected m_{H} uncertainty change	+8.1%	+11.2%	+21%
Observed m_{H} (GeV)	125.28±0.22	125.36±0.24	125.39±0.25

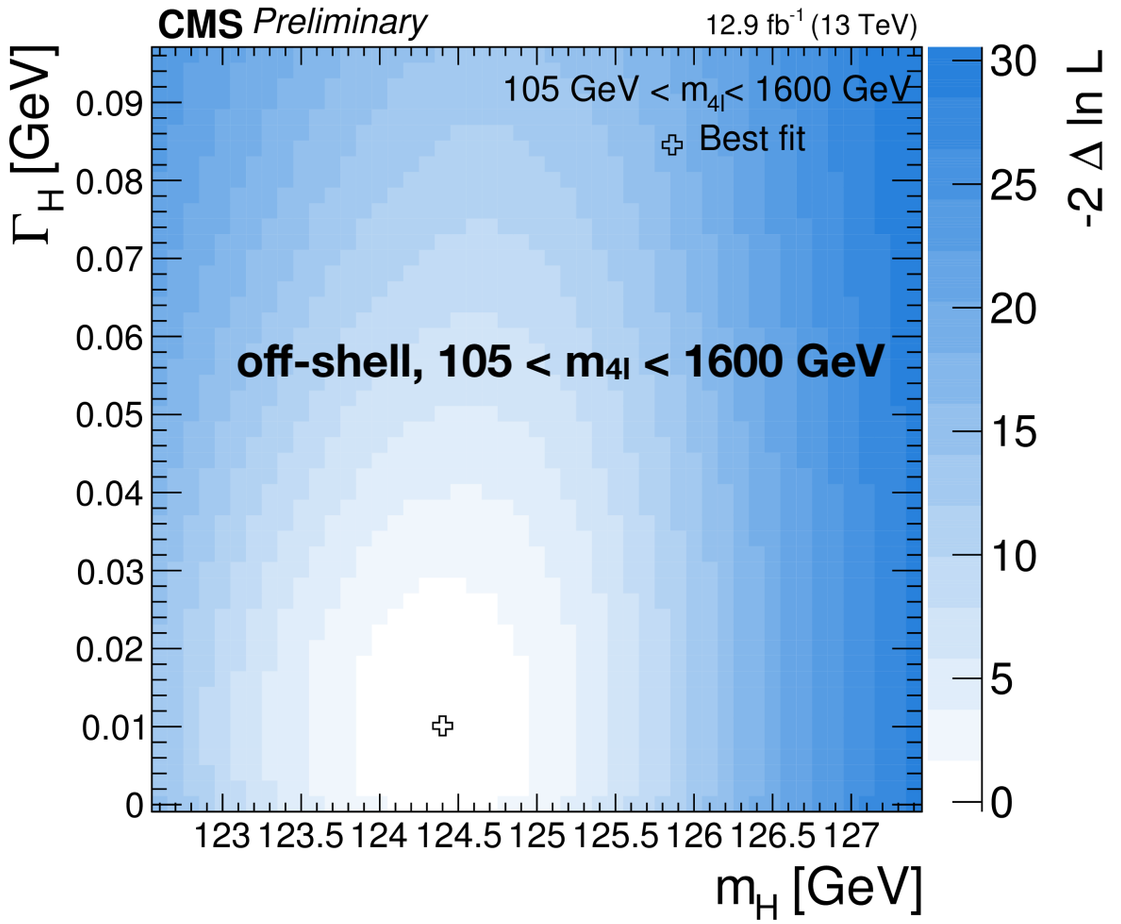
With $m(Z_1)$ constraint	3D: $\mathcal{L}(m'_{4l}, \mathcal{D}'_{\text{mass}}, \mathcal{D}^{\text{kin}}_{\text{bkg}})$	2D: $\mathcal{L}(m'_{4l}, \mathcal{D}'_{\text{mass}})$	1D: $\mathcal{L}(m'_{4l})$
Expected m_{H} uncertainty change	—	+3.2%	+10.7%
Observed m_{H} (GeV)	125.26±0.21	125.30±0.21	125.34±0.23

H^0 decay width

HIG-16-033
HIG-16-041

1D (m_{4l}) unbinned fit performed

Off-shell width is two orders of magnitude more precise than on-shell, assuming in the off-shell no BSM particles nor interactions affecting the Higgs coupling at either production or decay

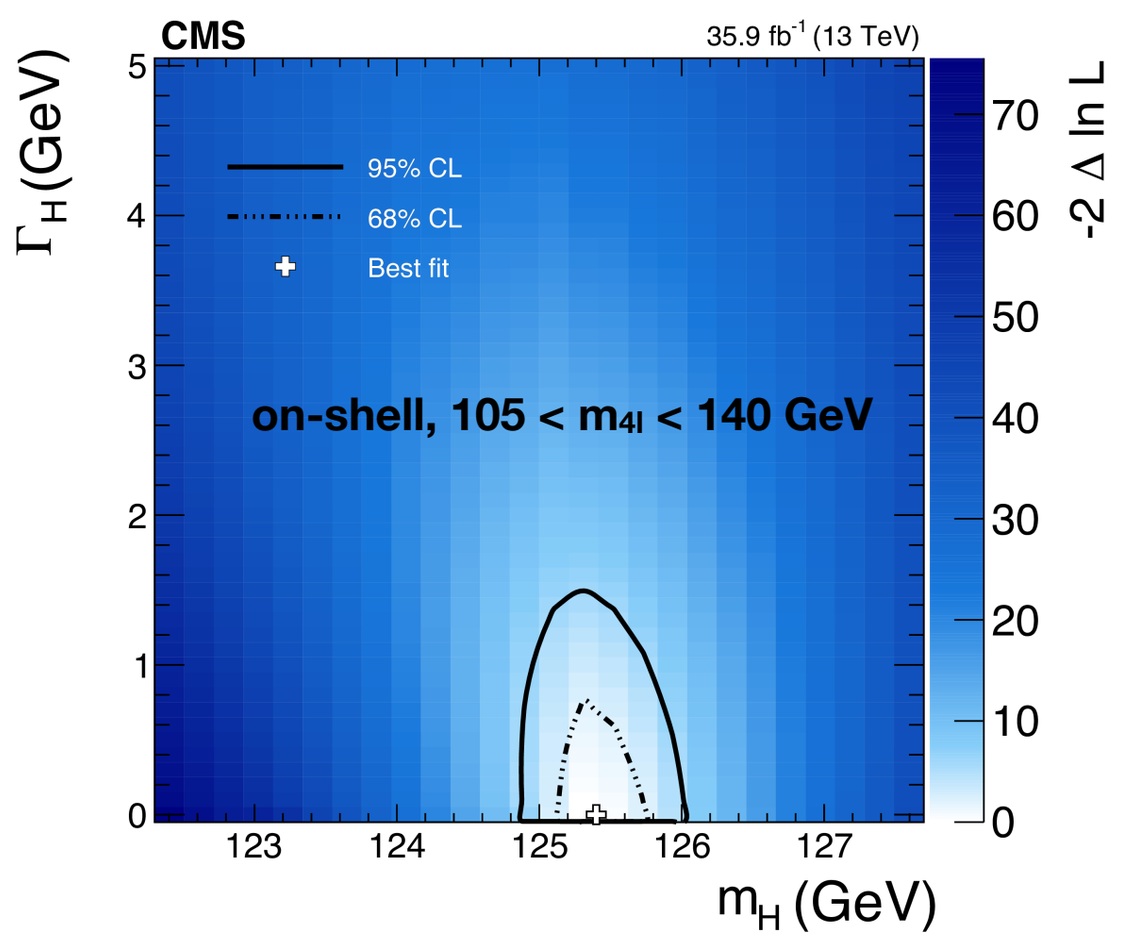


off-shell Γ_H < 41 MeV (HIG-16-033)

On-shell width precision limited by the four-lepton invariant mass resolution, sensitive to a width of about 1 GeV. Under these conditions interference between signal and background is important and has been included

on-shell Γ_H < 1.1 GeV (HIG-16-041)

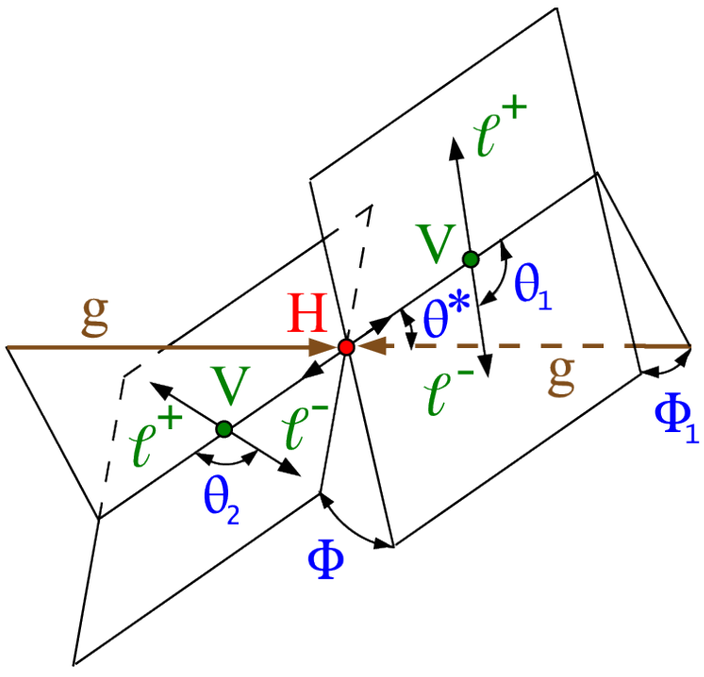
m_H precision does not depend on the m_{4l} range

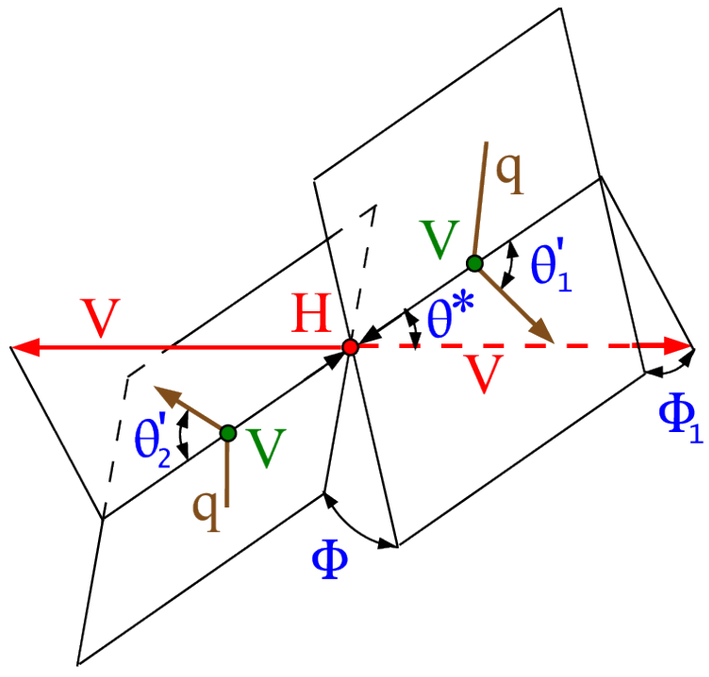


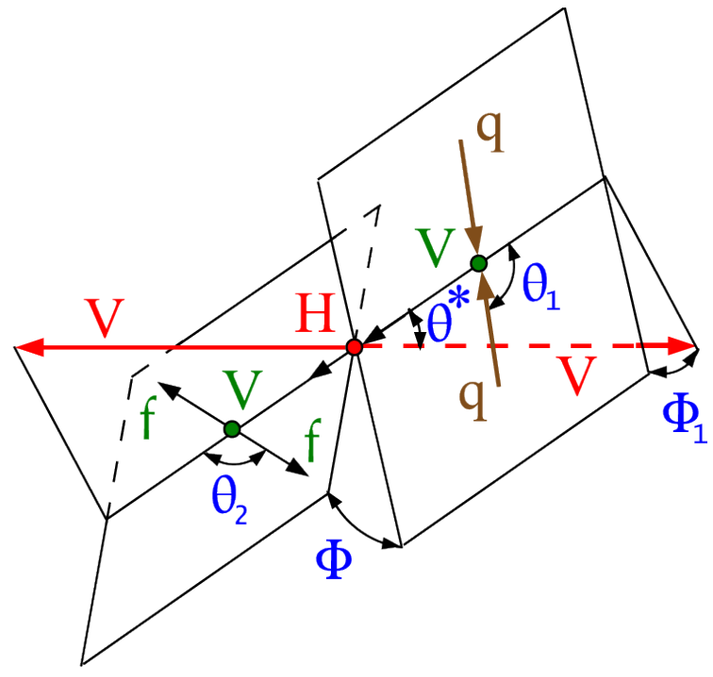
Anomalous HVV couplings

Using a ME likelihood to simultaneously analyze the H → 4l decay and associated production with two quarks, in the VBF, VH and gluon fusion categories, **we measure the product of effective cross-section ratios f_{ai} and phases Φ_{ai} sensitive to anomalous Higgs interactions**

$$A(\mathrm{HVV}) \sim \left[a_1^{\mathrm{VV}} + \frac{\kappa_1^{\mathrm{VV}} q_1^2 + \kappa_2^{\mathrm{VV}} q_2^2}{\left(\Lambda_1^{\mathrm{VV}}\right)^2}\right] m_{\mathrm{V1}}^2 \epsilon_{\mathrm{V1}}^* \epsilon_{\mathrm{V2}}^* + a_2^{\mathrm{VV}} f_{\mu\nu}^{*(1)} f^{*(2),\mu\nu} + a_3^{\mathrm{VV}} f_{\mu\nu}^{*(1)} \tilde{f}^{*(2),\mu\nu}$$







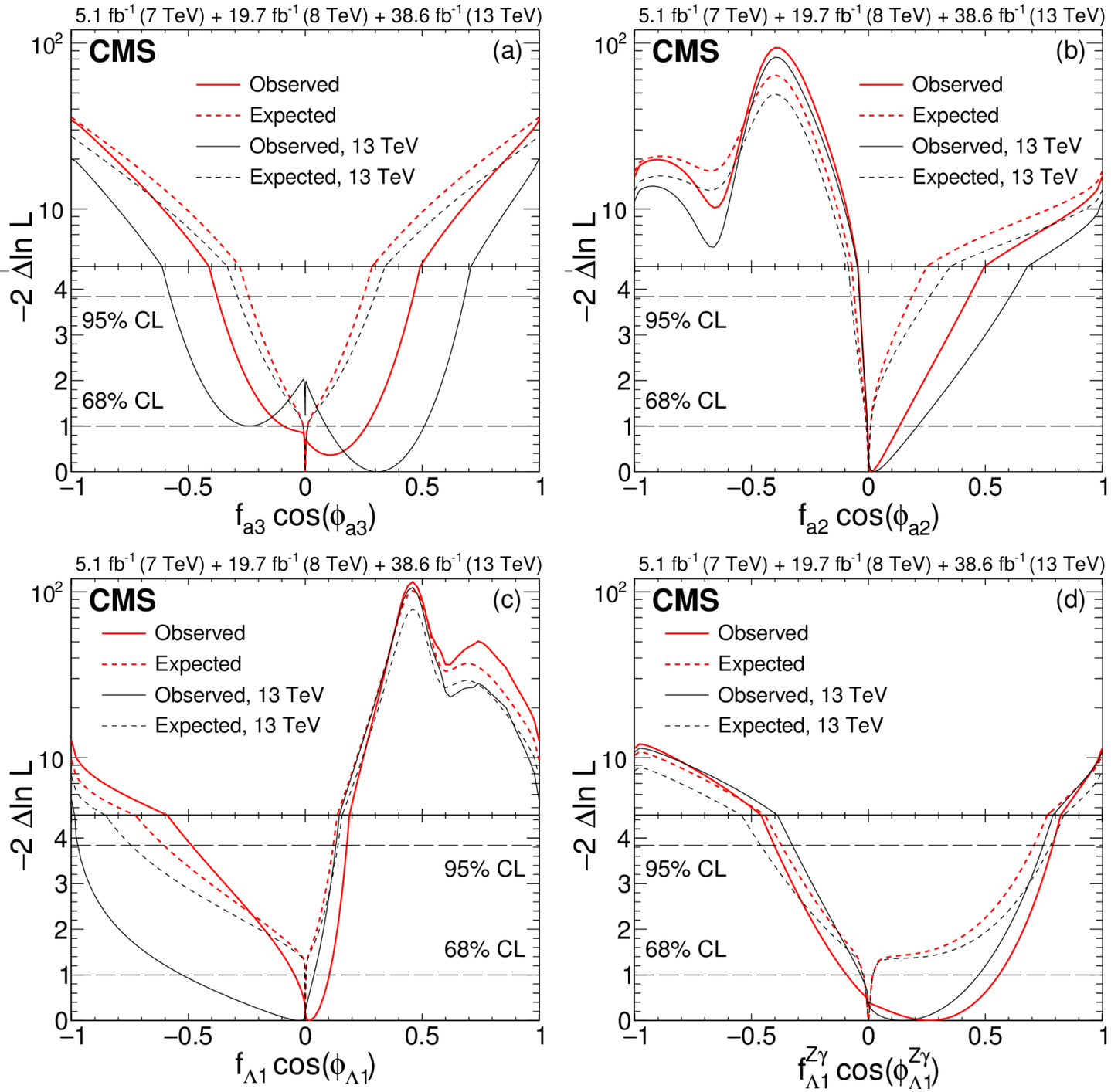
Anomalous couplings

HIG-17-011

No deviations from the SM are observed

Improved 68% CL constraints thanks to the inclusion of production information

Improvement in the 95% CL constraints with respect to Run 1 mostly due to the ×4 signal yield increase



Parameter	Observed	Expected
$f_{a3}\cos(\phi_{a3})$	$0.00^{+0.26}_{-0.09}$ $[-0.38, 0.46]$	$0.000^{+0.010}_{-0.010}$ $[-0.25, 0.25]$
$f_{a2}\cos(\phi_{a2})$	$0.01^{+0.12}_{-0.02}$ $[-0.04, 0.43]$	$0.000^{+0.009}_{-0.008}$ $[-0.06, 0.19]$
$f_{\Lambda1}\cos(\phi_{\Lambda1})$	$0.02^{+0.08}_{-0.06}$ $[-0.49, 0.18]$	$0.000^{+0.003}_{-0.002}$ $[-0.60, 0.12]$
$f_{\Lambda1}^{Z\gamma}\cos(\phi_{\Lambda1}^{Z\gamma})$	$0.26^{+0.30}_{-0.35}$ $[-0.40, 0.79]$	$0.000^{+0.019}_{-0.022}$ $[-0.37, 0.71]$

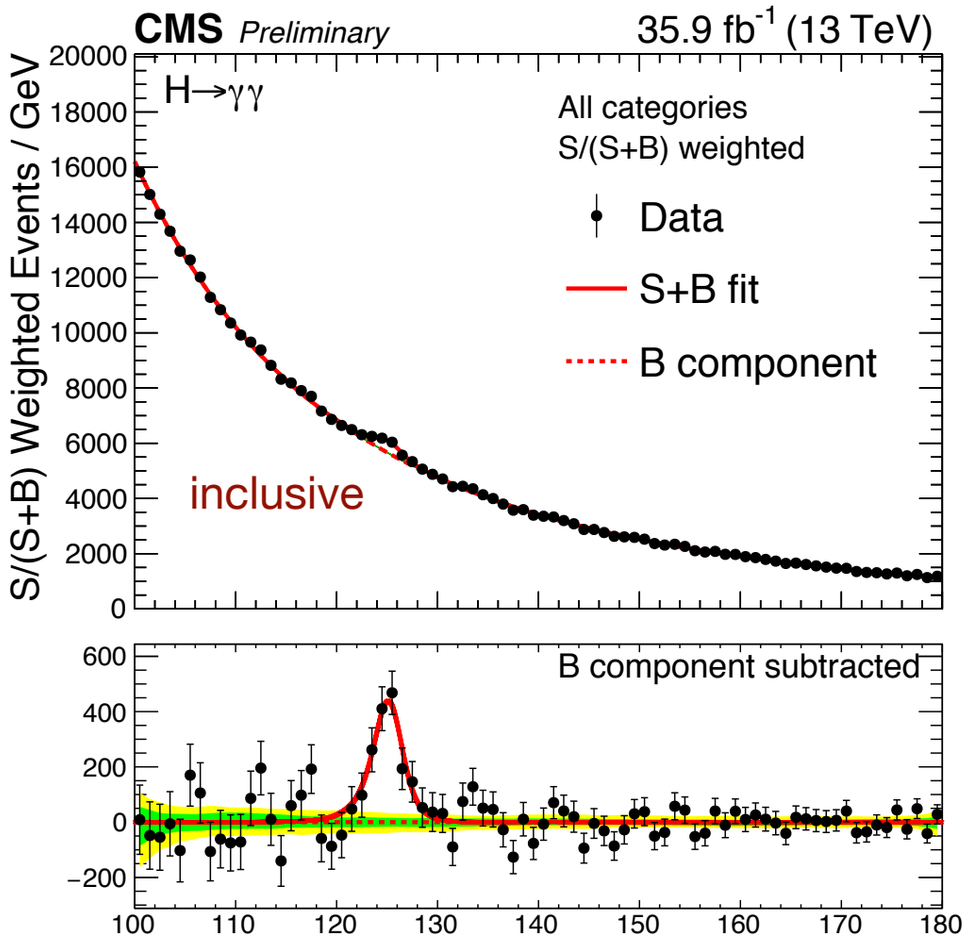
$H \rightarrow \gamma\gamma$ ***properties*** *and* ***cross sections***

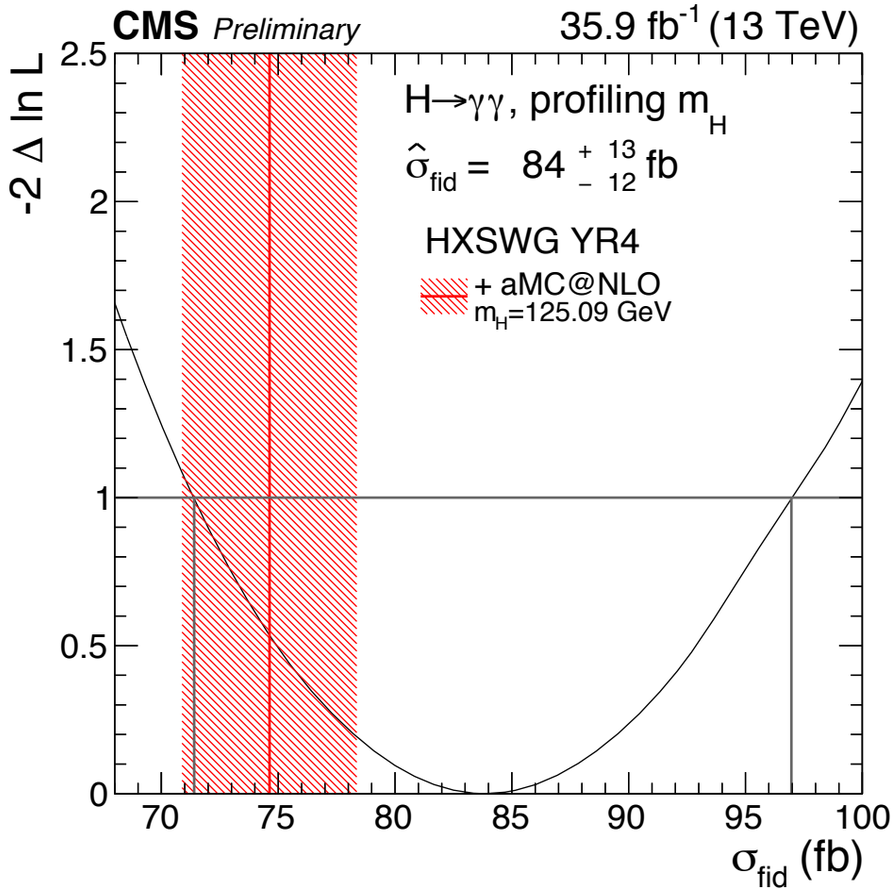
Fiducial cross section

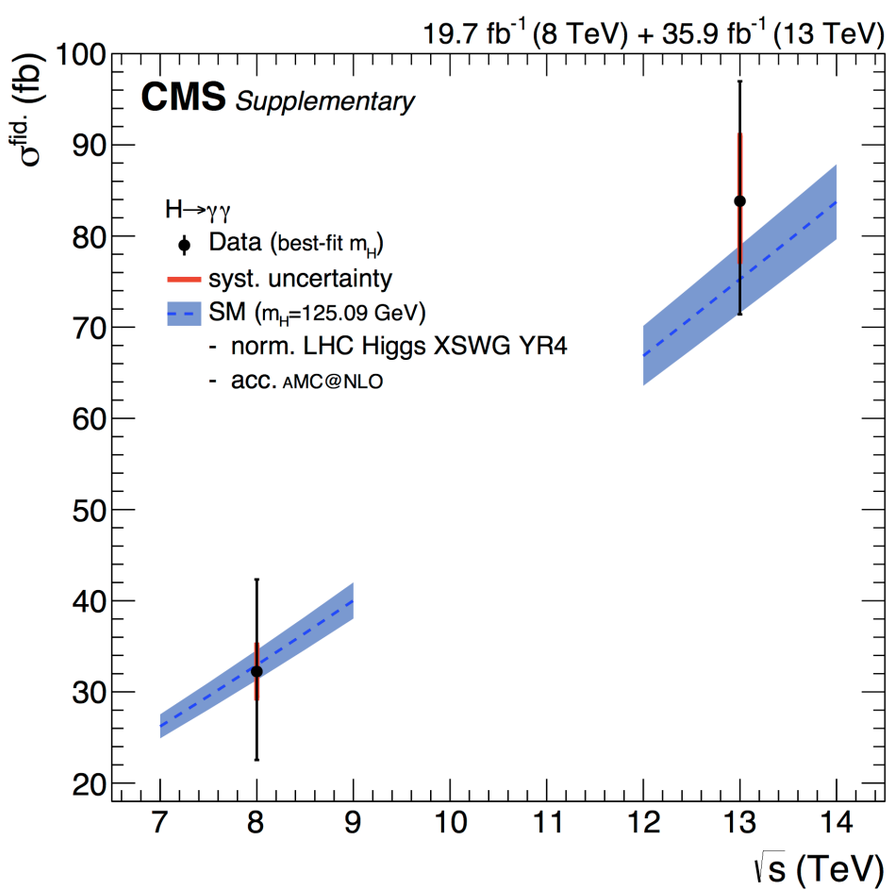
Define three categories based on the estimated relative mass resolution. **Fit $m_{\gamma\gamma}$ simultaneously for all categories**

$$\sigma_{fid} = 84 \pm 11 \text{ (stat.)} \pm 7 \text{ (syst.) fb}$$

σ_{fid} = 75 ± 4 fb (SM)

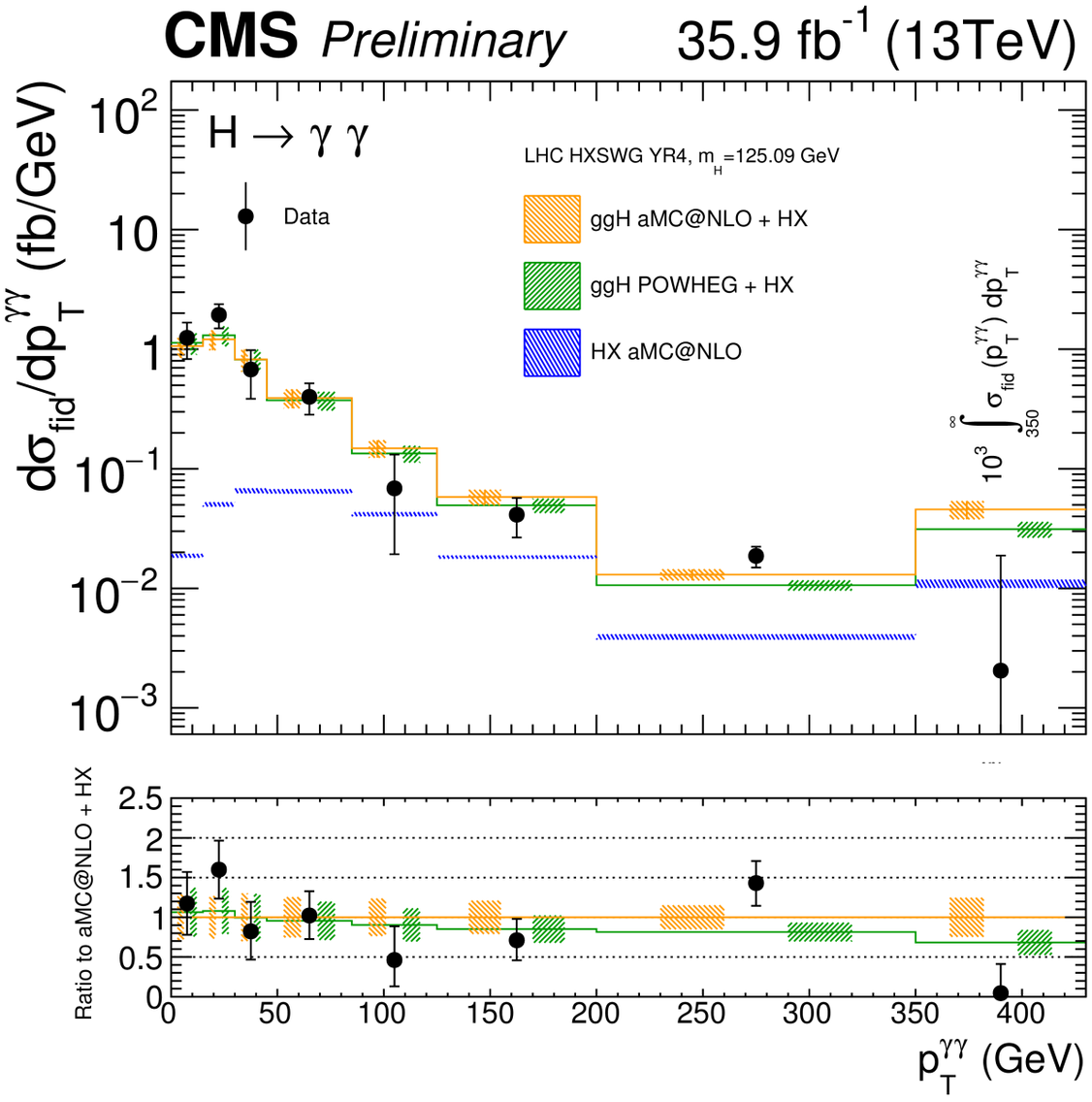


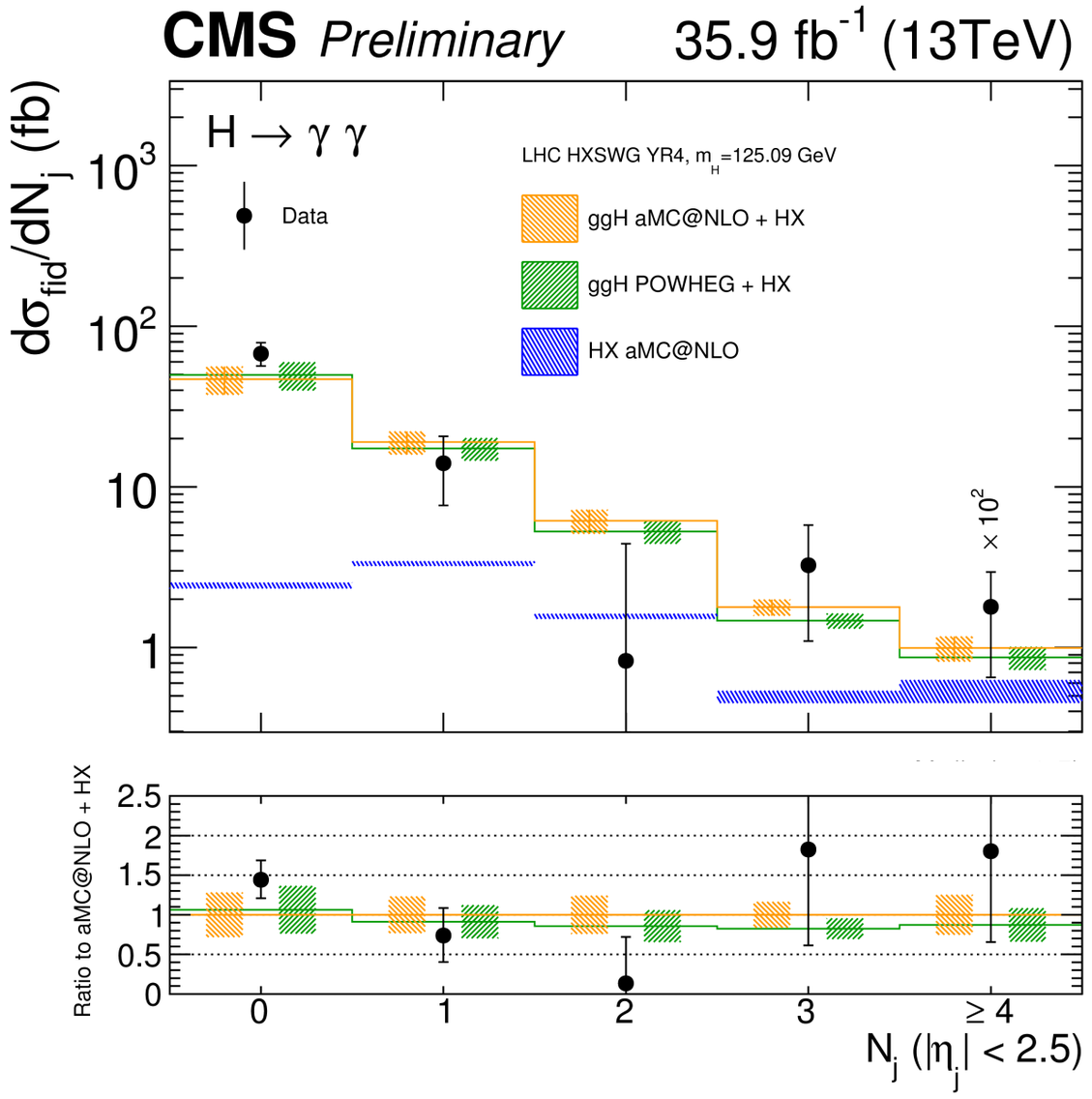




Most precise fiducial cross section to date

Differential measurements



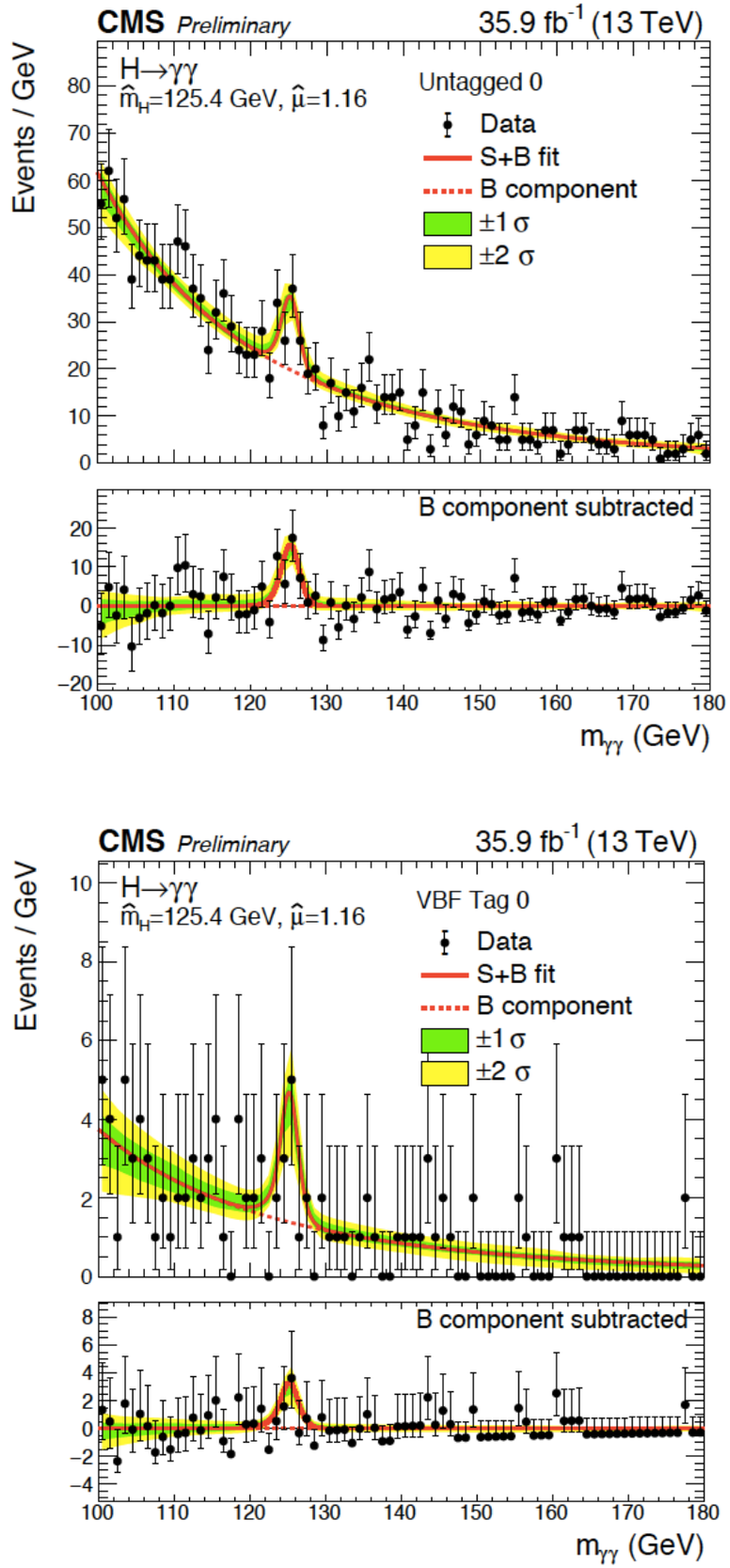


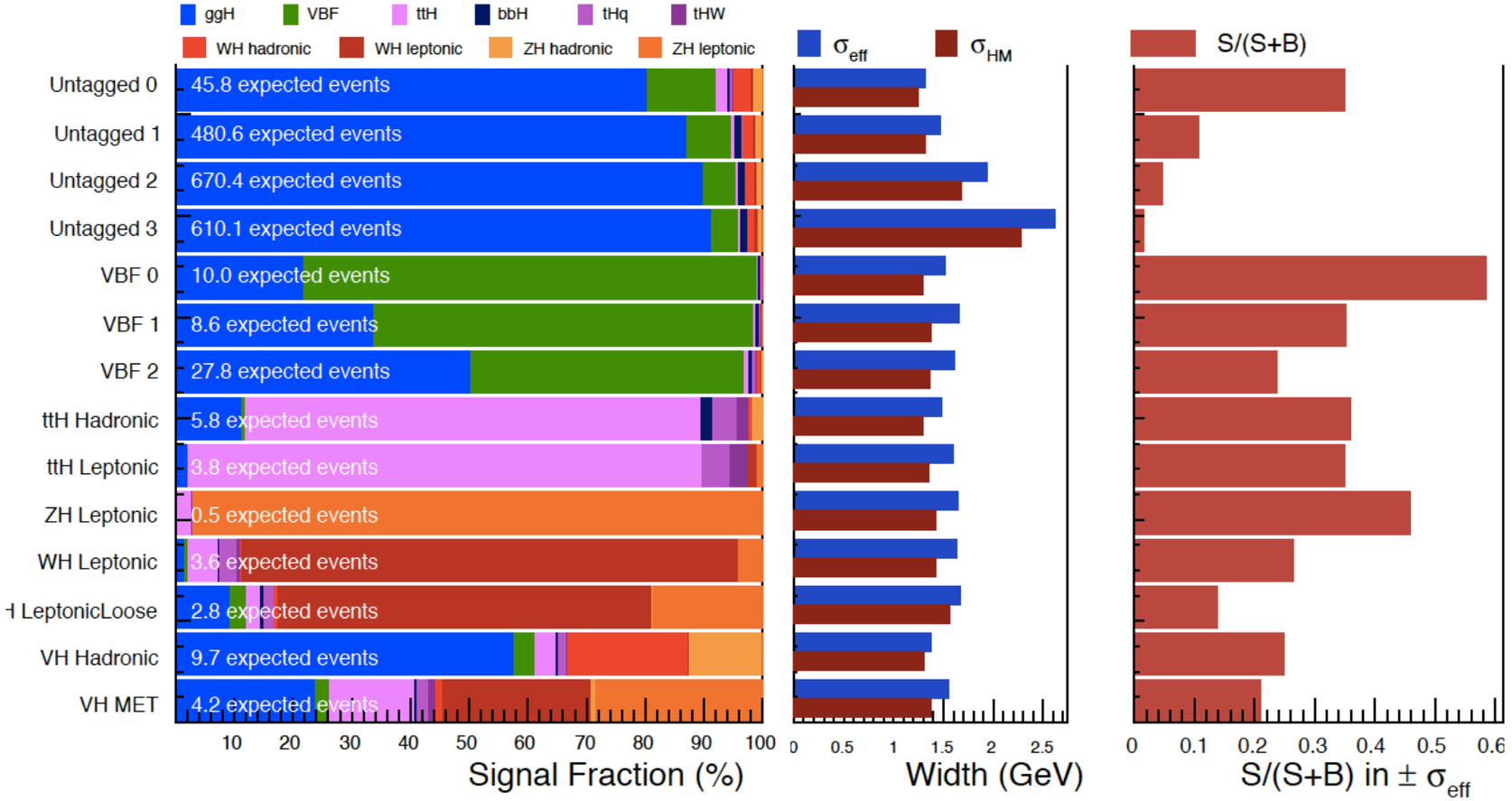
Can probe BSM at high p_T

Can be used to test perturbative QCD calculations

H → γγ *properties*

Standard preselection $p_{T1}/m_{\gamma\gamma} > 0.33$, $p_{T2}/m_{\gamma\gamma} > 0.25$, $100 < m_{\gamma\gamma} < 180$ GeV. **Events are classified according to mass resolution and S/B in the VBF, VH, ttH and gluon fusion categories**

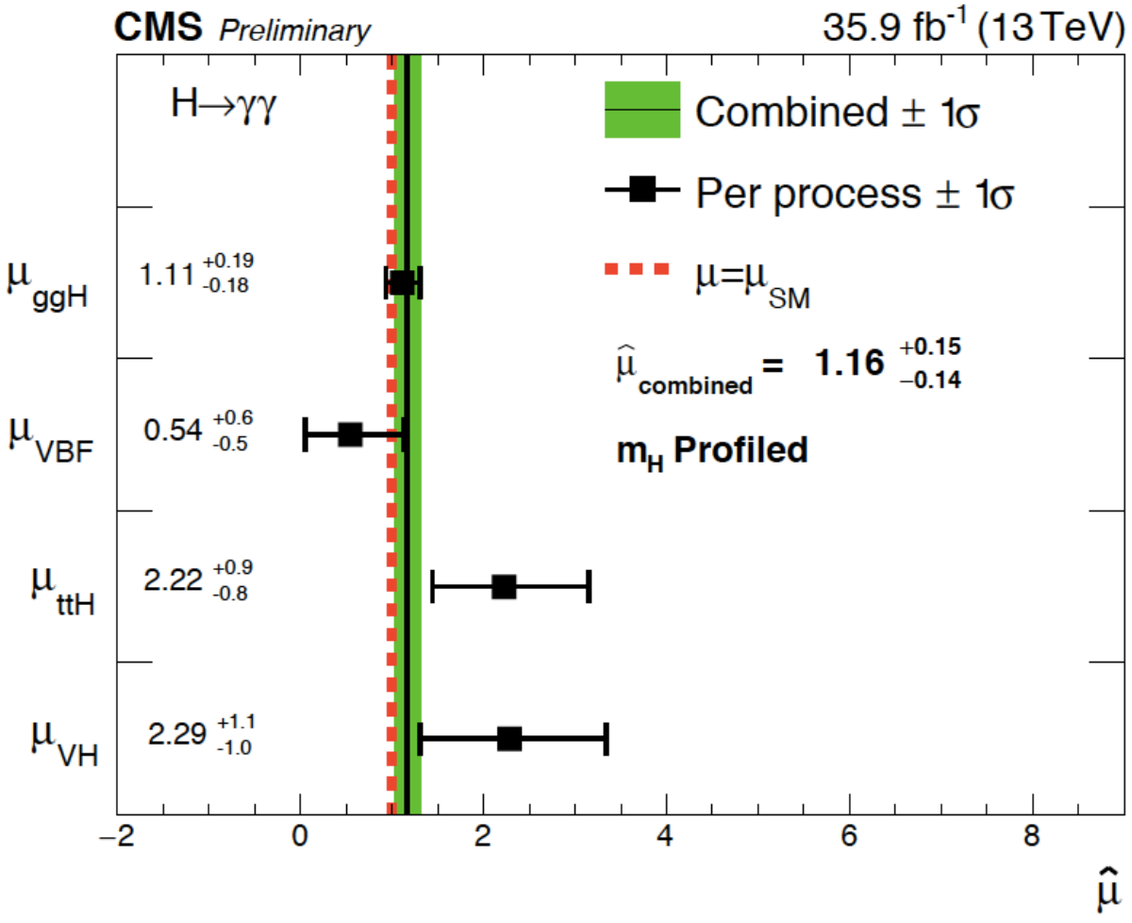


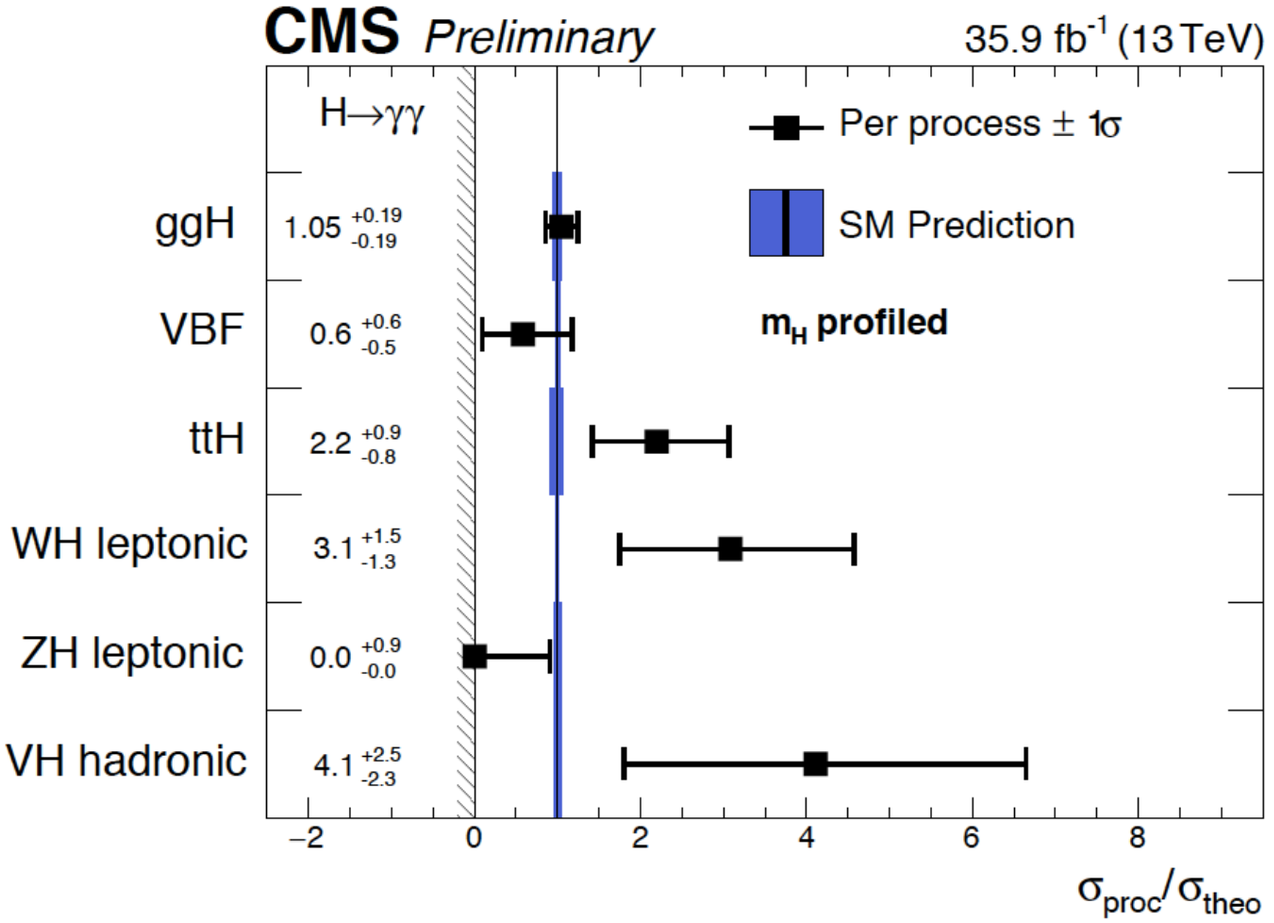


Measuring the signal strength

A likelihood scan of the signal strength is performed, profiling all other nuisances including the Higgs mass. In addition, cross section ratios for each process are measured in the Stage 0 Higgs Simplified Template Cross Section (STXS) framework

$$\mu = \sigma/\sigma_{SM} = 1.16\ ^{+0.11}_{-0.10}\ (\text{stat.})\ ^{+0.09}_{-0.08}\ (\text{syst.})\ ^{+0.06}_{-0.05}\ (\text{theo.})$$

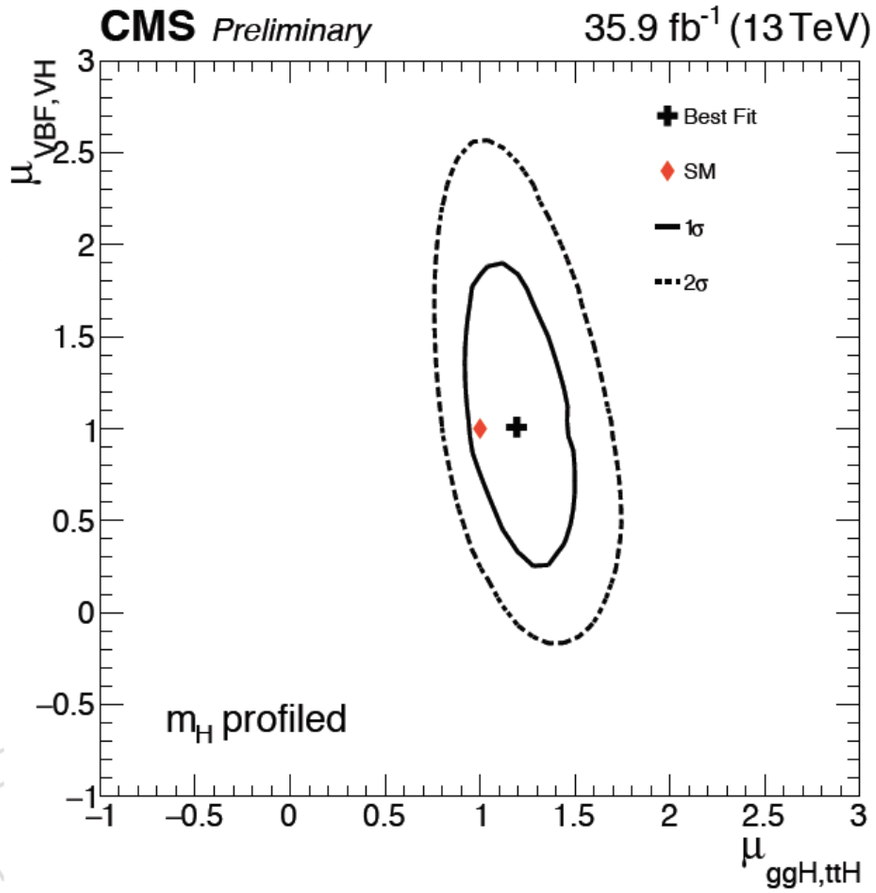


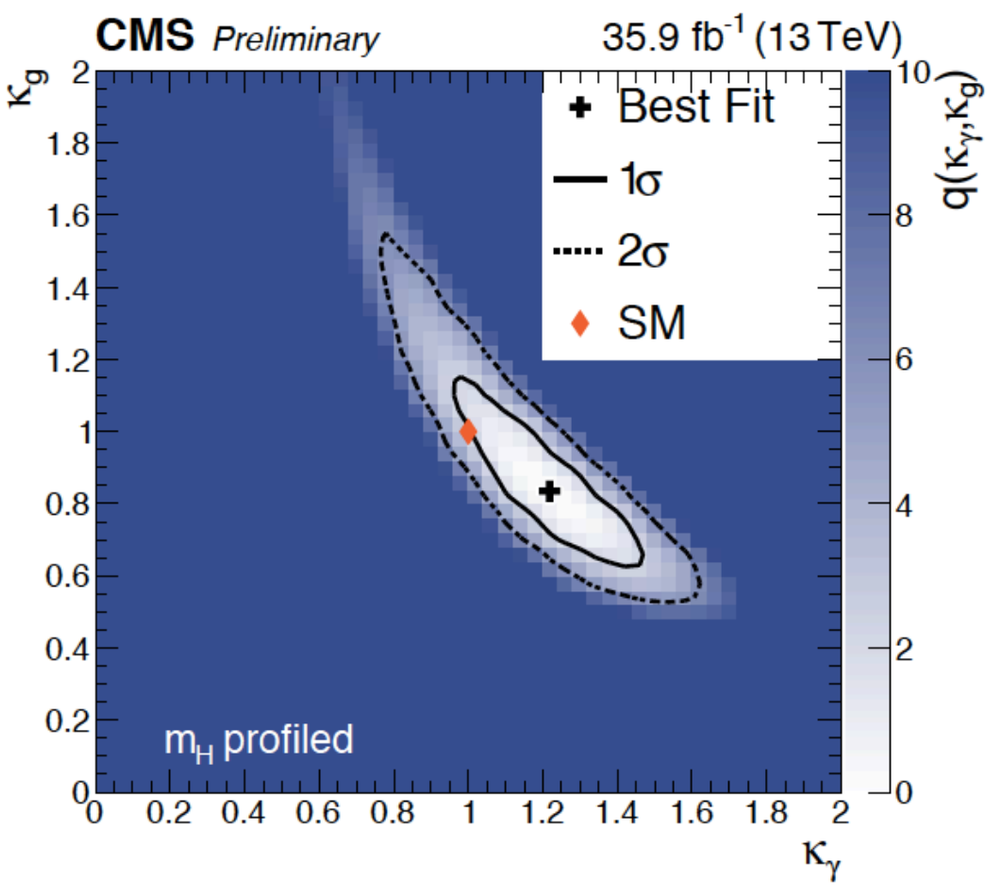


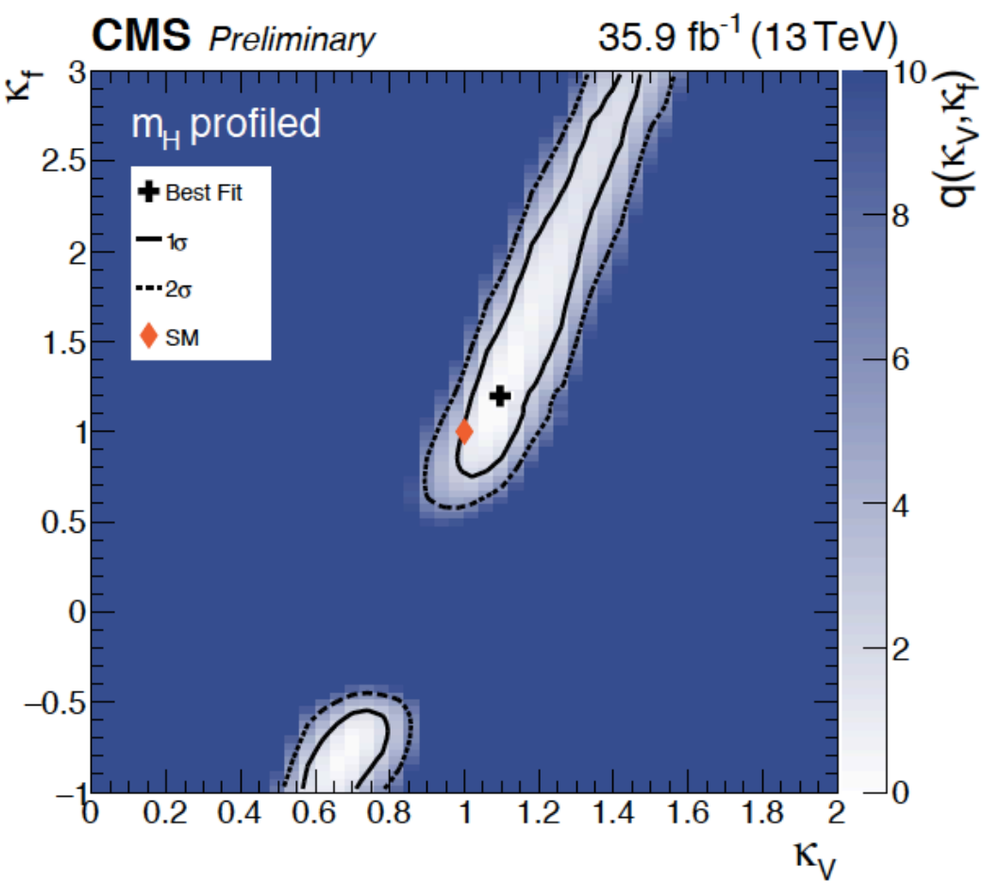
2D likelihood scans

Signal strength for fermionic production modes (ggH and ttH) vs. signal strength for vector boson production modes (VBF, ZH, WH)

Coupling modifiers to gluons and photons k_g vs. k_γ (left) and coupling modifiers to fermions and bosons k_f vs. k_V (right)





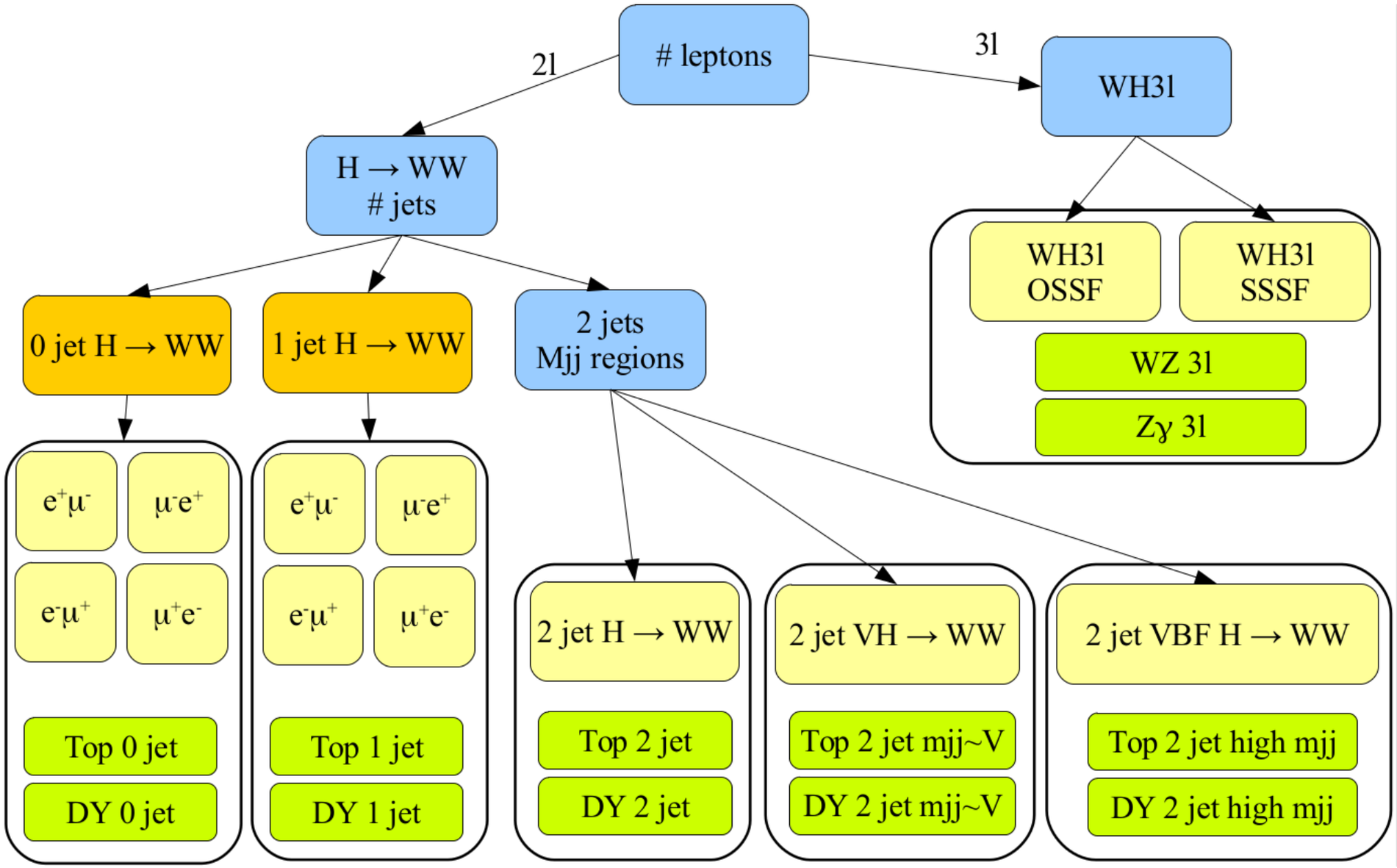


H → WW → 2l 2ν

measurements

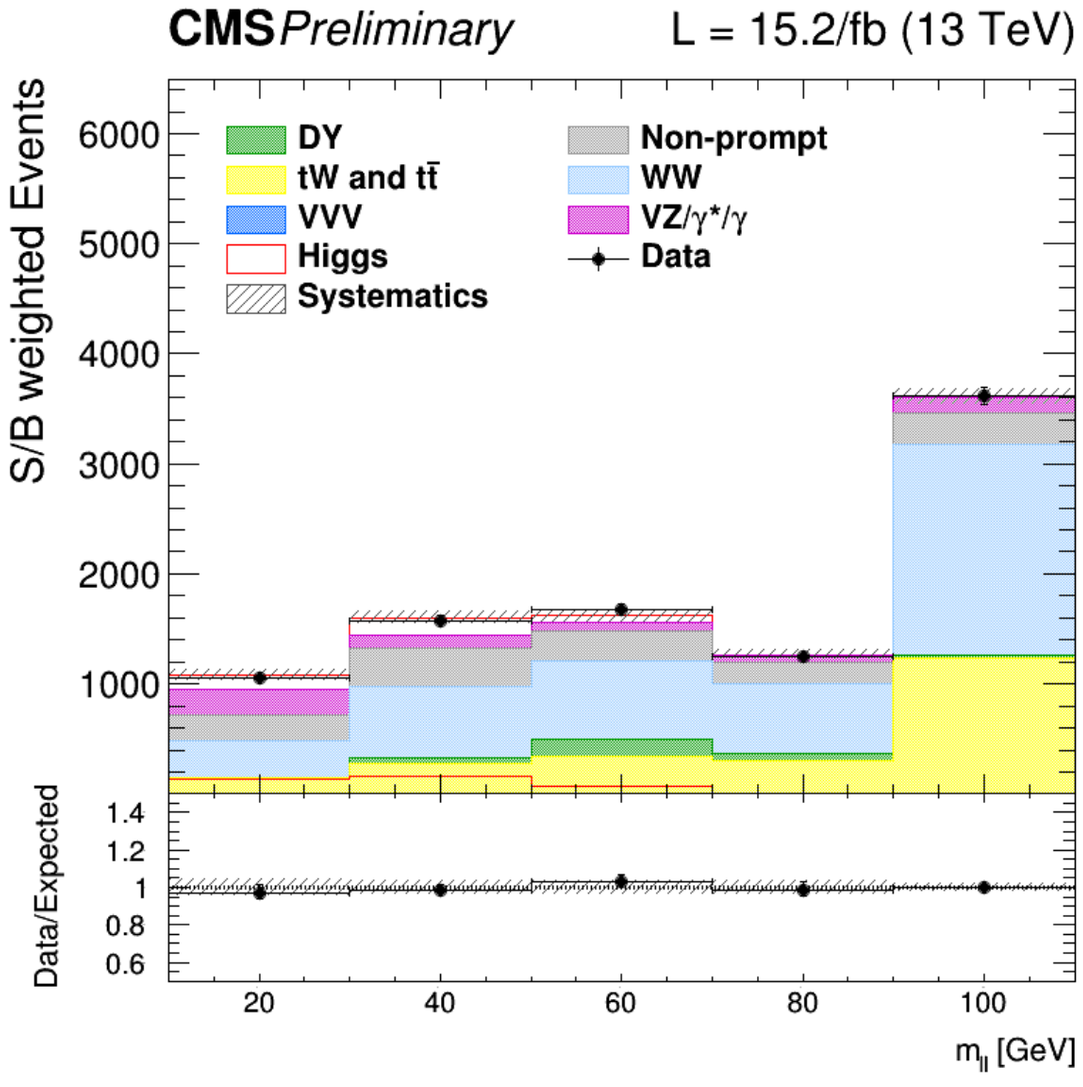
Divide et impera

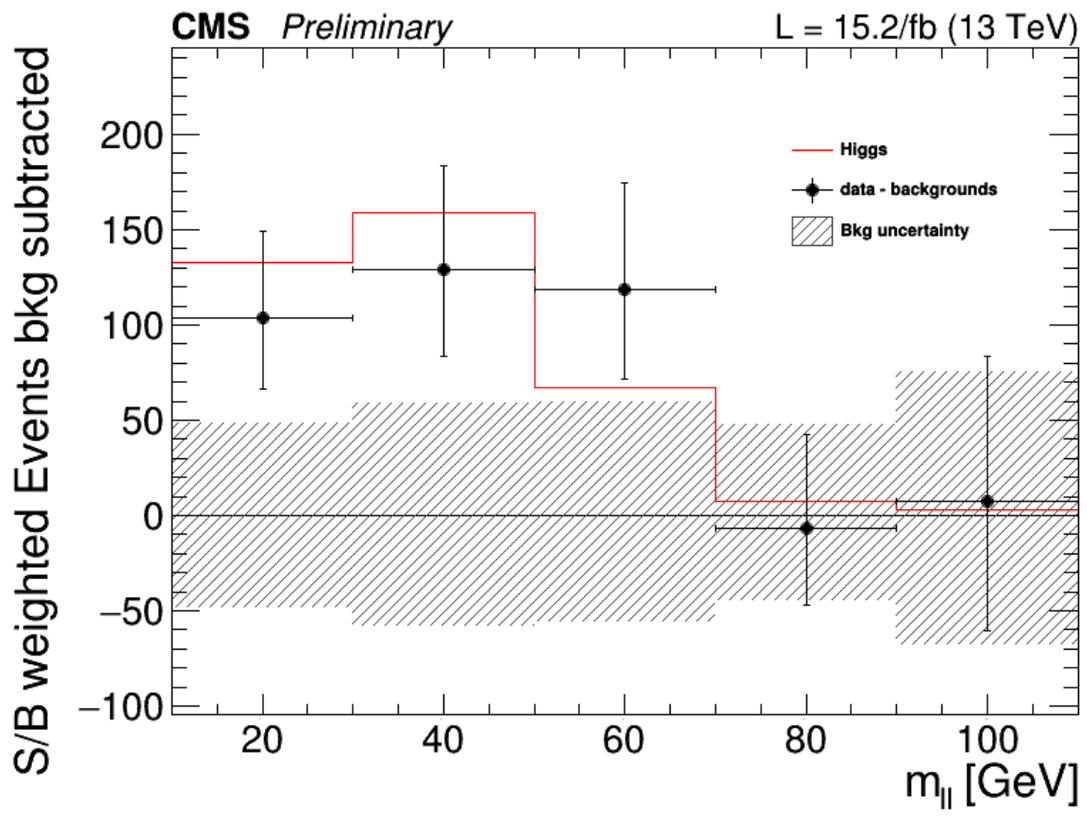
Analysis performed on 2.3 fb^{-1} (2015) + 12.9 fb^{-1} (2016) in the different flavour (eμ) topology. **With the DY contamination strongly reduced, the main backgrounds are top and WW**



Getting there

Weighted and combined dilepton invariant mass for the 0, 1 and 2 jet categories



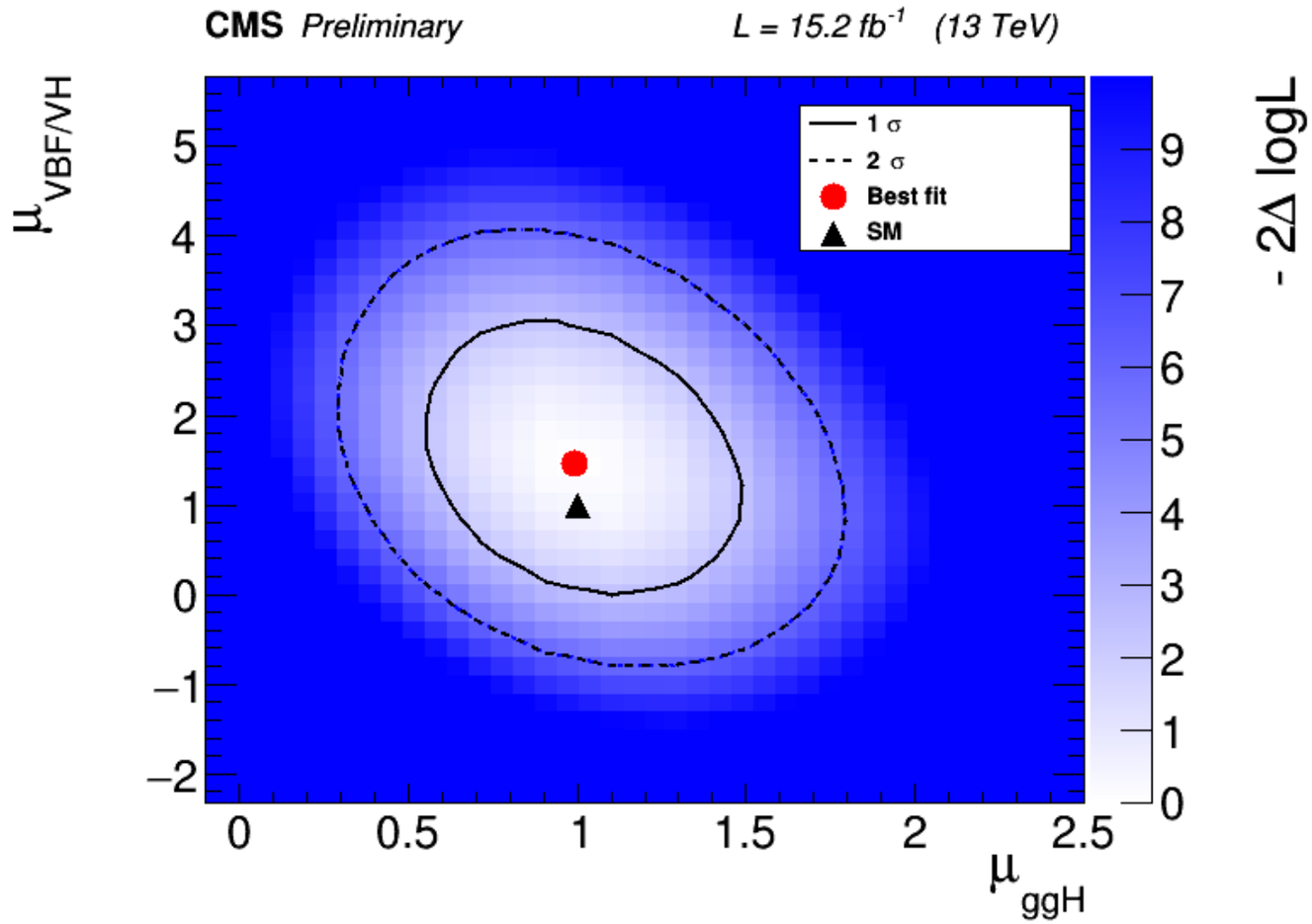


HWW significance and signal strength

The combined signal strength is

1.05 ± 0.26 (0.25 stat. ⊕ 0.03 theory ⊕ 0.07 syst.)

category	significance	$\sigma/\sigma_{\mathrm{SM}}$
0-jet	2.7 (2.9)	$0.9\ ^{+0.4}_{-0.3}$
1-jet	2.1 (2.5)	$1.1\ ^{+0.4}_{-0.4}$
2-jet	2.0 (1.0)	$1.3\ ^{+1.0}_{-1.0}$
VBF 2-jet	2.2 (1.5)	$1.4\ ^{+0.8}_{-0.8}$
VH 2-jet	1.0 (0.4)	$2.1\ ^{+2.3}_{-2.2}$
WH 3-lep	0.0 (0.5)	$-1.4\ ^{+1.5}_{-1.5}$
combination	4.3 (4.1)	$1.05\ ^{+0.27}_{-0.25}$



July 24th conclusions

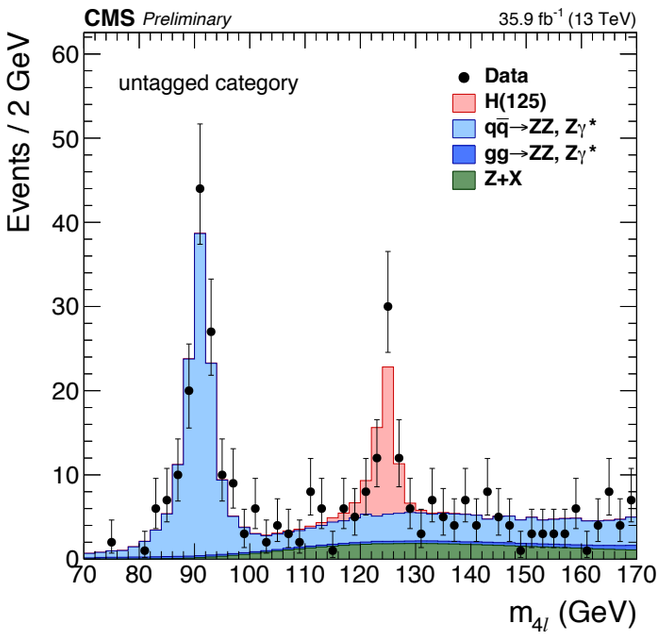
Improved H → ZZ, γγ and WW sensitivity by splitting events in different categories, based on resolution, production modes and S/B

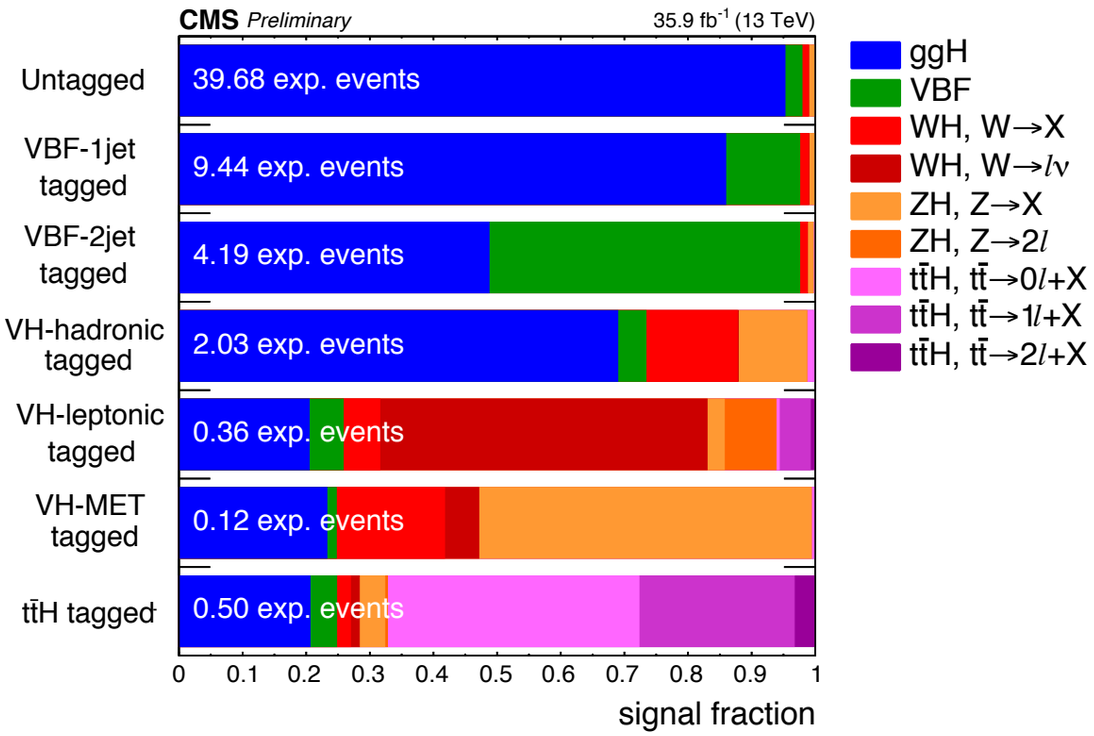
CMS has analyzed up to 38.6 fb^{-1} of pp collisions at 13 TeV, measuring Higgs properties like fiducial and differential cross sections, mass, width and coupling constants

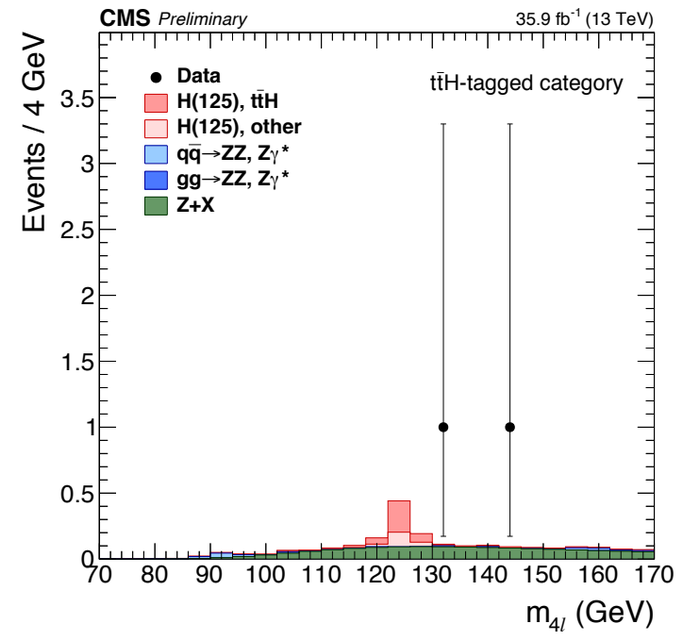
The challenge for the ongoing Run 2 is high precision Higgs Physics, with an expected luminosity above 100/fb and more than 50 pileup interactions per event

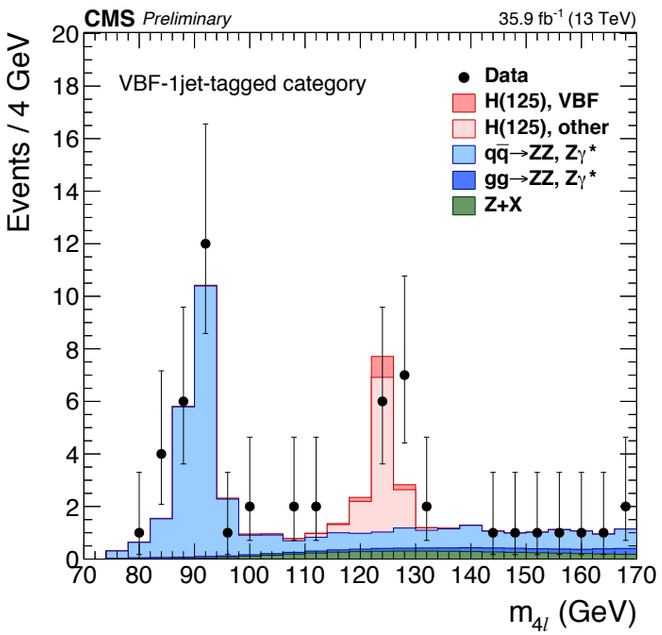

HF-S90
TYPE I (NORMAL) POSITION
NORMAL BIAS 120μs EQ
SONY
B
NR ON OFF
B

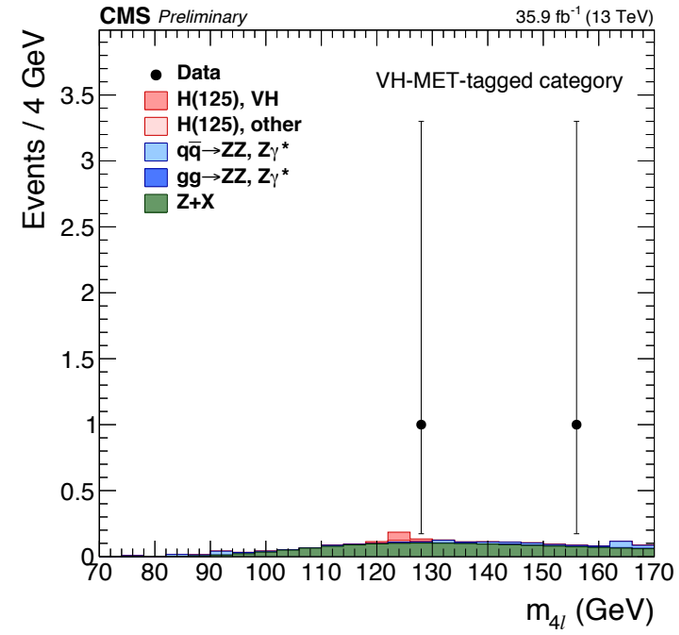
HIG-16-041

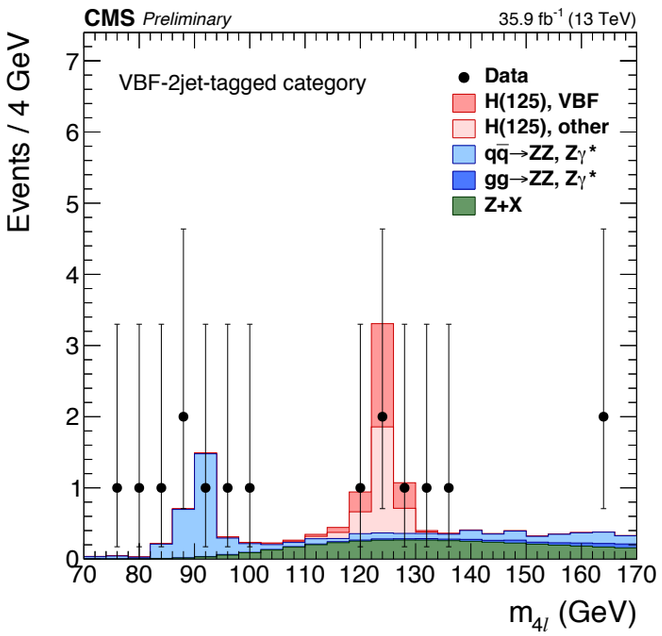

CMS Preliminary
35.9 fb-1 (13 TeV)
untagged category
Data
H(125)
qq̄→ZZ, Zγ*
gg→ZZ, Zγ*
Z+X
Events / 2 GeV
m4l (GeV)

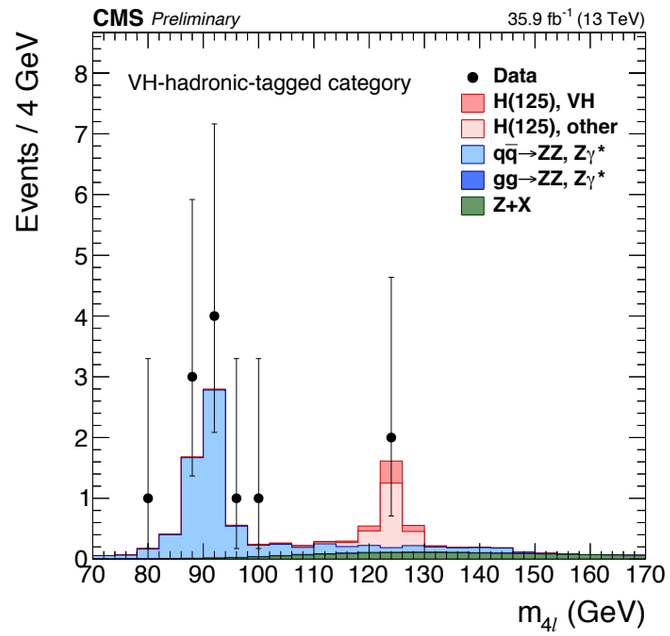

CMS Preliminary
35.9 fb-1 (13 TeV)
Untagged
39.68 exp. events
VBF-1jet tagged
9.44 exp. events
VBF-2jet tagged
4.19 exp. events
VH-hadronic tagged
2.03 exp. events
VH-leptonic tagged
0.36 exp. events
VH-MET tagged
0.12 exp. events
ttH tagged
0.50 exp. events
signal fraction
ggH
VBF
WH, W→X
WH, W→lν
ZH, Z→X
ZH, Z→2l
ttH, tt→0l+X
ttH, tt→1l+X
ttH, tt→2l+X

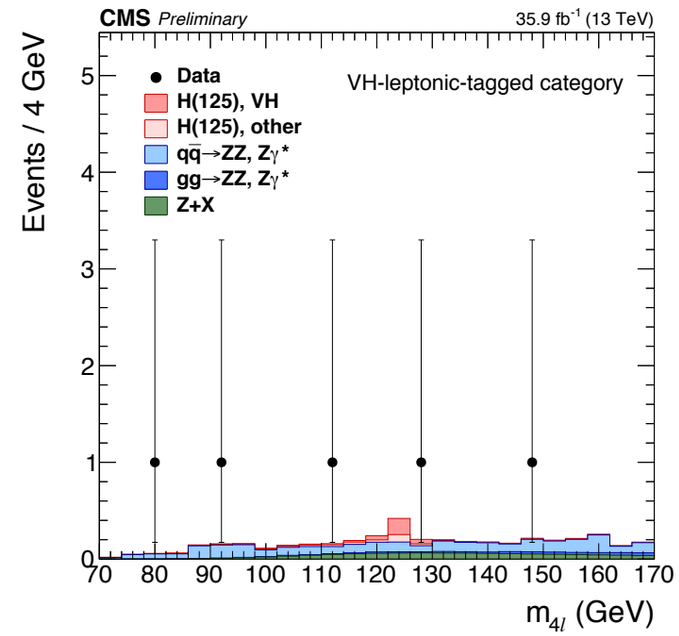

CMS Preliminary
35.9 fb-1 (13 TeV)
ttH-tagged category
Data
H(125), ttH
H(125), other
qq̄→ZZ, Zγ*
gg→ZZ, Zγ*
Z+X
Events / 4 GeV
m4l (GeV)


CMS Preliminary
35.9 fb-1 (13 TeV)
VBF-1jet-tagged category
Data
H(125), VBF
H(125), other
qq̄→ZZ, Zγ*
gg→ZZ, Zγ*
Z+X
Events / 4 GeV
m4l (GeV)


CMS Preliminary
35.9 fb-1 (13 TeV)
VH-MET-tagged category
Data
H(125), VH
H(125), other
qq̄→ZZ, Zγ*
gg→ZZ, Zγ*
Z+X
Events / 4 GeV
m4l (GeV)


CMS Preliminary
35.9 fb-1 (13 TeV)
VBF-2jet-tagged category
Data
H(125), VBF
H(125), other
qq̄→ZZ, Zγ*
gg→ZZ, Zγ*
Z+X
Events / 4 GeV
m4l (GeV)


CMS Preliminary
35.9 fb-1 (13 TeV)
VH-hadronic-tagged category
Data
H(125), VH
H(125), other
qq̄→ZZ, Zγ*
gg→ZZ, Zγ*
Z+X
Events / 4 GeV
m4l (GeV)


CMS Preliminary
35.9 fb-1 (13 TeV)
VH-leptonic-tagged category
Data
H(125), VH
H(125), other
qq̄→ZZ, Zγ*
gg→ZZ, Zγ*
Z+X
Events / 4 GeV
m4l (GeV)

Signal strengths

document	decay	luminosity	μ
HIG-16-041	H → ZZ → 4 lepton	35.9 fb^{-1}	**$1.05\ ^{+0.19}_{-0.17}$**
HIG-16-040	H → γγ	35.9 fb^{-1}	**$1.16\ ^{+0.15}_{-0.14}$**
HIG-16-021	H → WW	15.2 fb^{-1}	**$1.05\ ^{+0.27}_{-0.25}$**