Higgs measurements in high resolution channels with CMS

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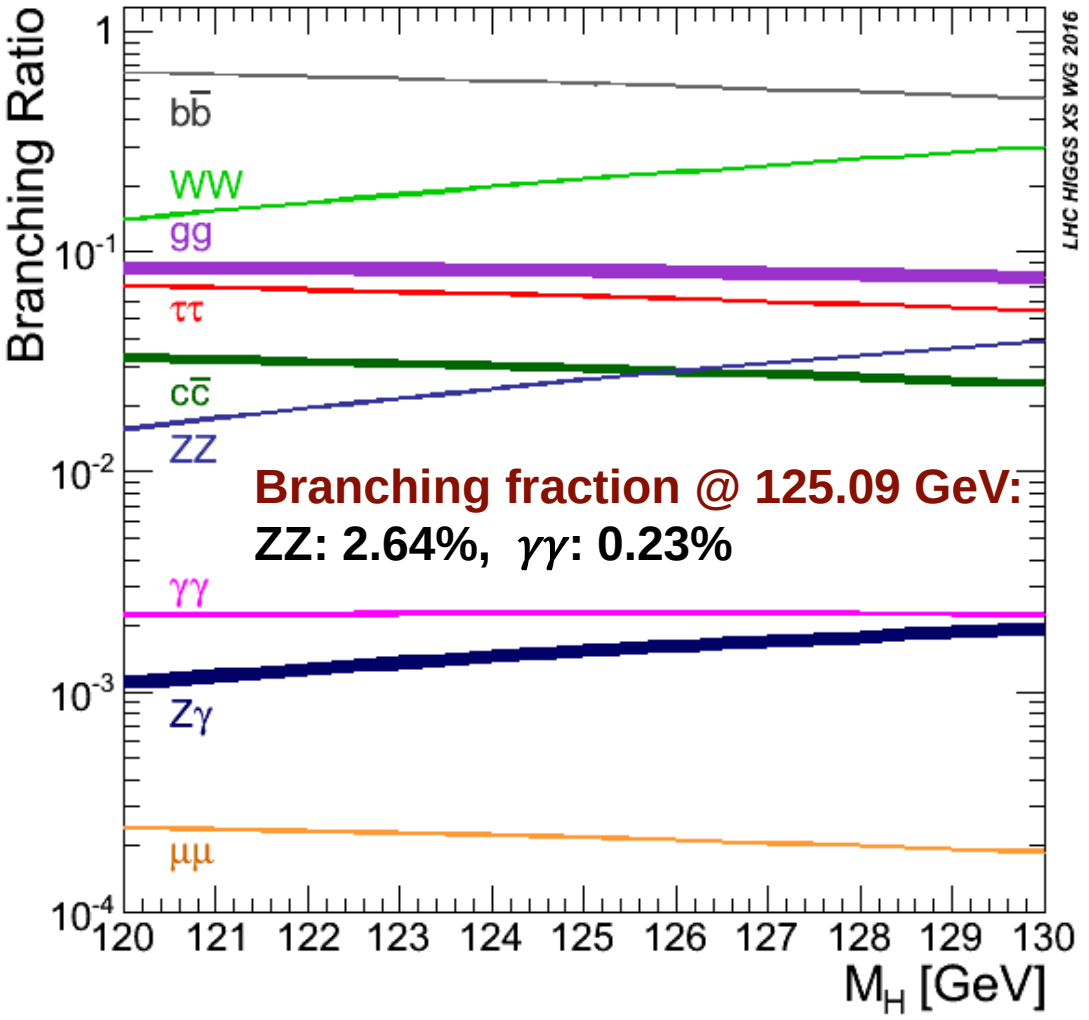
Higgs channels in this talk

- **Include latest results from the high resolution channels at CMS**
  - $H \to ZZ^* \to 4\ell$: **CMS-PAS-HIG-16-041 and CMS-PAS-HIG-17-011 (**anomalous coupling**)**
  - $H \to \gamma\gamma$: **CMS-PAS-HIG-16-040 (New for LHCP2017!) and CMS-PAS-HIG-17-015** (differential fiducial cross-section**)**
- **Will not cover results from $H \to Z(\to 2\ell)\gamma$ (Run 1 result only) and $H \to \mu\mu$: rare decays**



https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHXSWG

$H \rightarrow ZZ^* \rightarrow 4l$

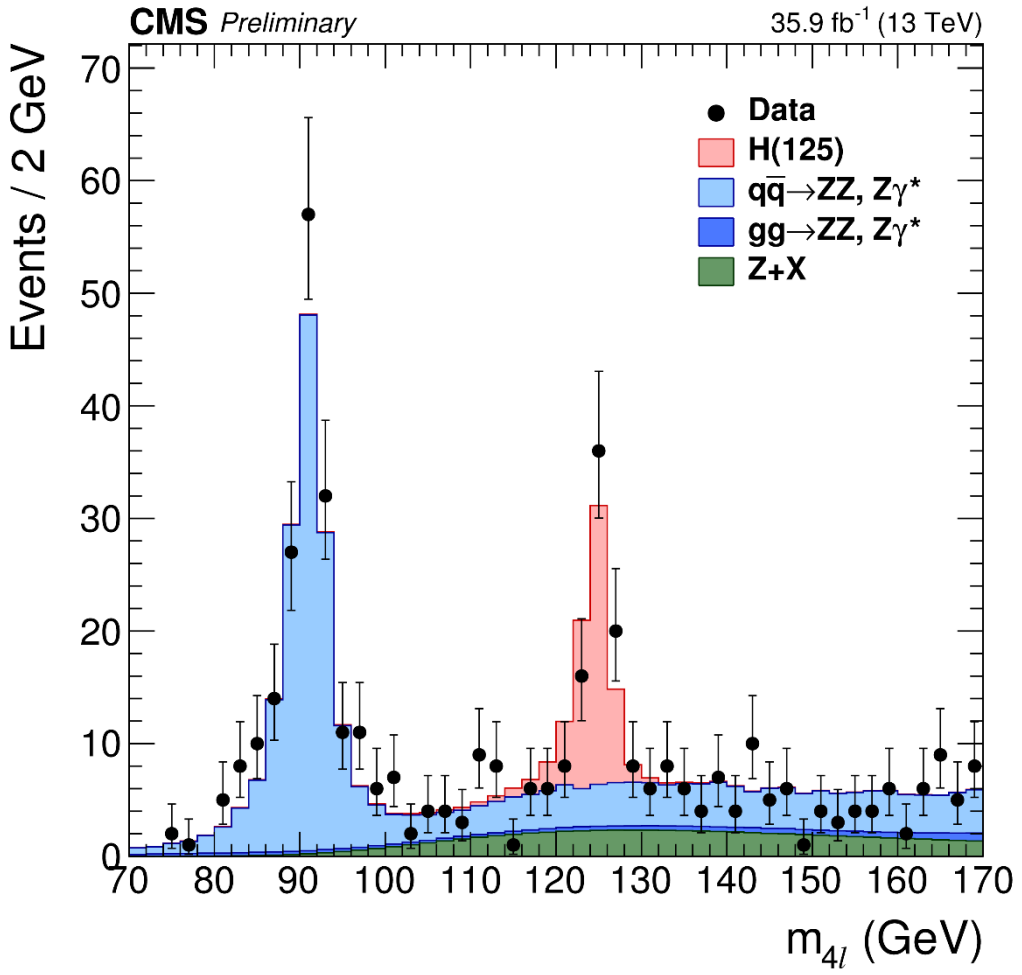
CMS-PAS-HIG-16-041

➢ Signal signature

- **4 isolated leptons** (e,μ) with excellent momentum resolution: **two pairs of same flavour, opposite sign leptons** (4e, 4μ, 2e2μ or 2μ2e)
- Fully reconstructed mass peak
- Large S/B ratio (>2:1)

➢ Backgrounds

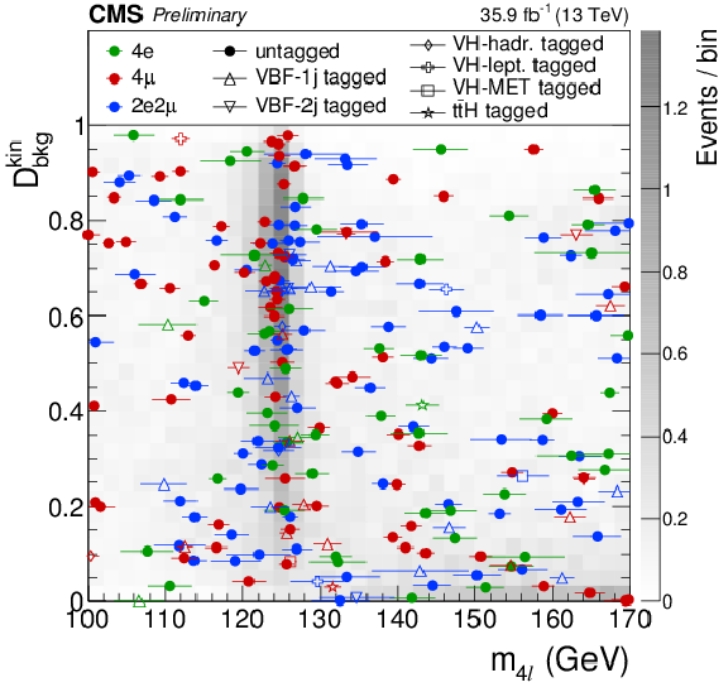
- **SM ZZ*** (main background, irreducible) estimated from MC
- **Z+X**: fakes from Z+jets, Z+bb, ttbar, ... (reducible) estimated from data-driven methods

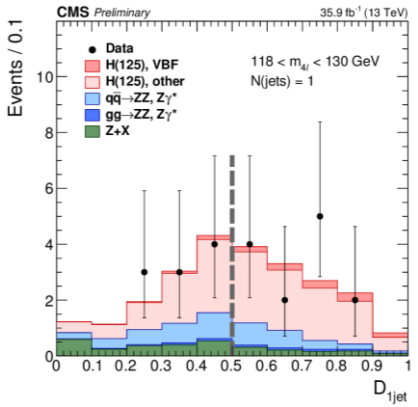


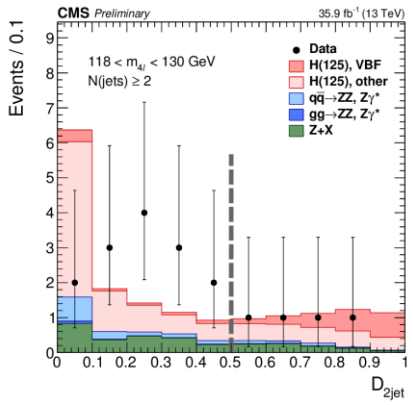
$H \rightarrow ZZ^* \rightarrow 4l$: Analysis strategy

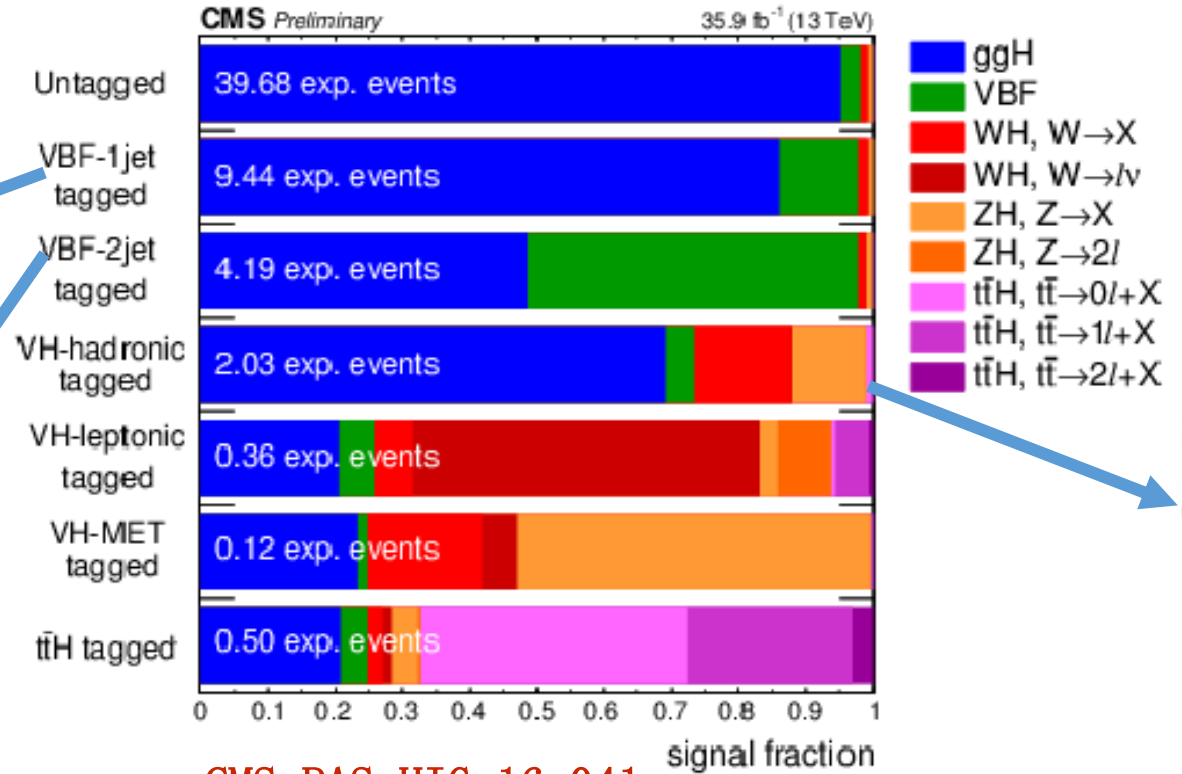
- Events are split into seven categories according to Higgs productions modes to increase sensitivity, based on number of leptons, number of (b-) jets, missing energy and selections on kinematic discriminants ($\mathcal{D}^{kin}_{bkg}$)

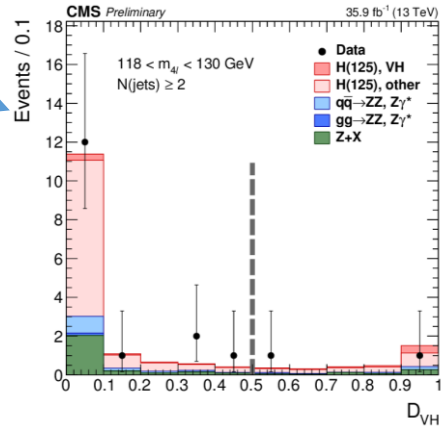
- Additional discriminants (D_{1jet}, D_{2jet} and D_{VH} = max (D_{WH}, D_{ZH}), >0.5) are calculated for the selection of VBF and VH-hadronic tagged events







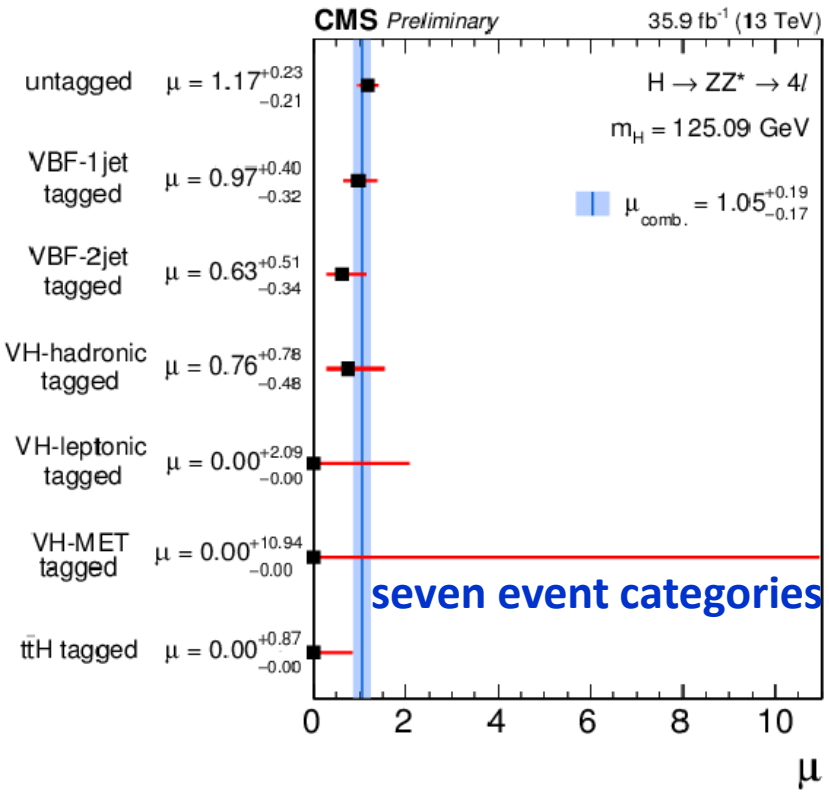


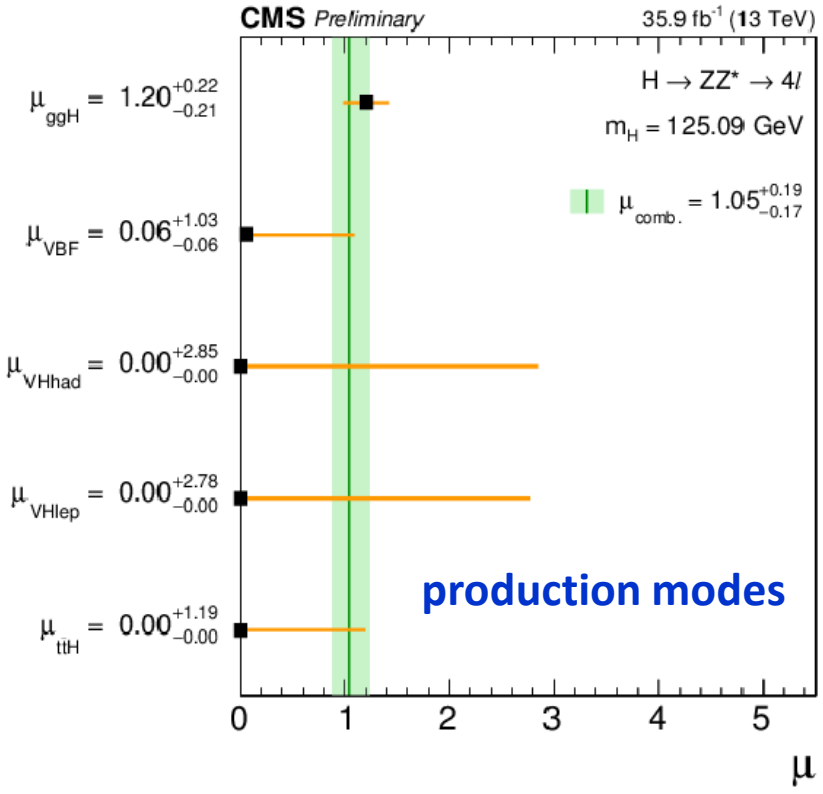


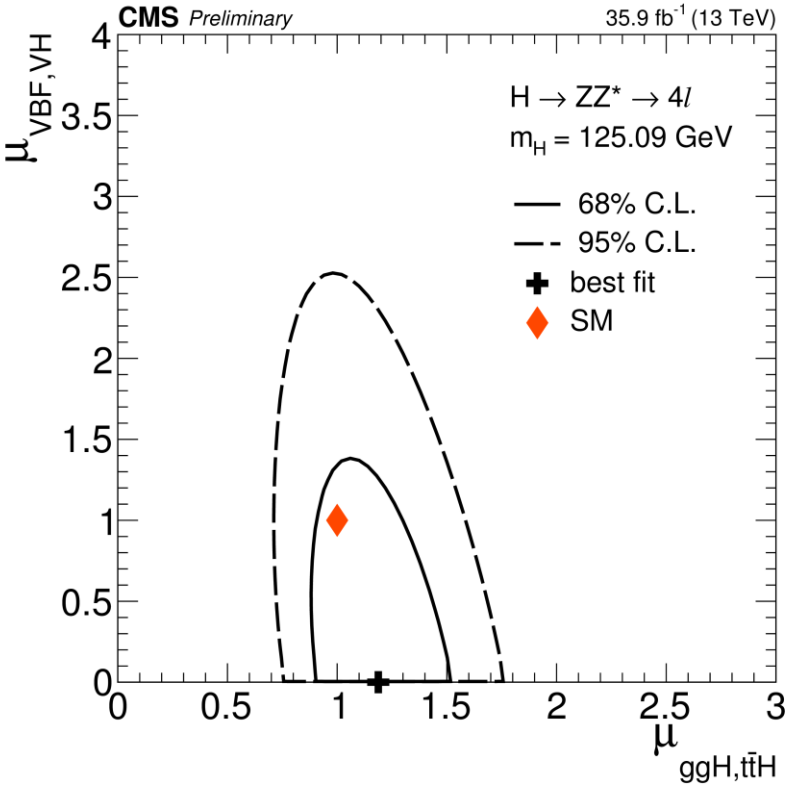
CMS-PAS-HIG-16-041

$H \rightarrow ZZ^* \rightarrow 4l$: Signal strength

- **Signal strength ($\mu = \sigma/\sigma_{SM}$) extracted with 2D** $\mathcal{L}_{2D}(m_{4\ell}, \mathcal{D}^{kin}_{bkg}) = \mathcal{L}(m_{4\ell})\mathcal{L}(\mathcal{D}^{kin}_{bkg}|m_{4\ell})$







At m_H = 125.09 GeV, combined result:

$$\mu = \sigma/\sigma_{SM} = 1.05^{+0.15}_{-0.14}(\text{stat.})^{+0.11}_{-0.09}(\text{sys.}) = 1.05^{+0.19}_{-0.17}$$

CMS-PAS-HIG-16-041

Measured signal strength with fermions and bosons in 2D scan:

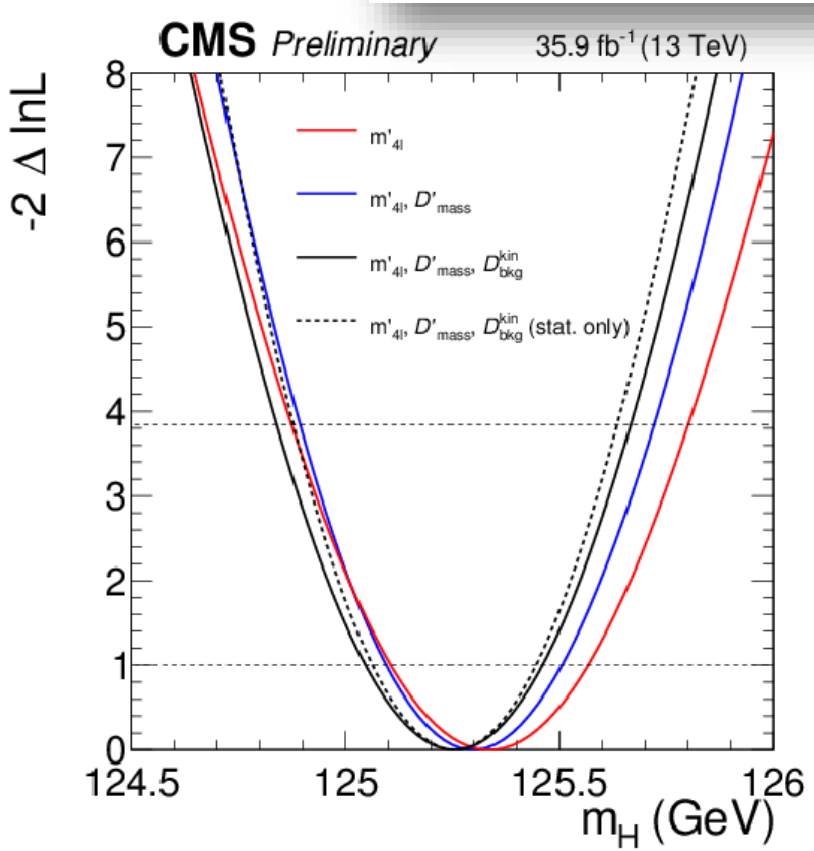
$$\mu_{ggH,ttH} = 1.20^{+0.35}_{-0.31}$$

$$\mu_{VBF,VH} = 0.00^{+1.37}_{-0.00}$$

$H \rightarrow ZZ^* \rightarrow 4l$: Mass and Width

- **Mass measurement is based on 3D fit** : $\mathcal{L}(m_{4\ell}, \mathcal{D}_{\text{mass}}, \mathcal{D}^{\text{kin}}_{\text{bkg}})$ invariant mass, expected uncertainty on mass and the discriminant
  - The on-shell Z is mass constrained
  - Systematic uncertainty dominated by uncertainty in the lepton momentum scale

$$125.26 \pm 0.20(\text{stat.}) \pm 0.08(\text{sys.}) \text{ GeV}$$



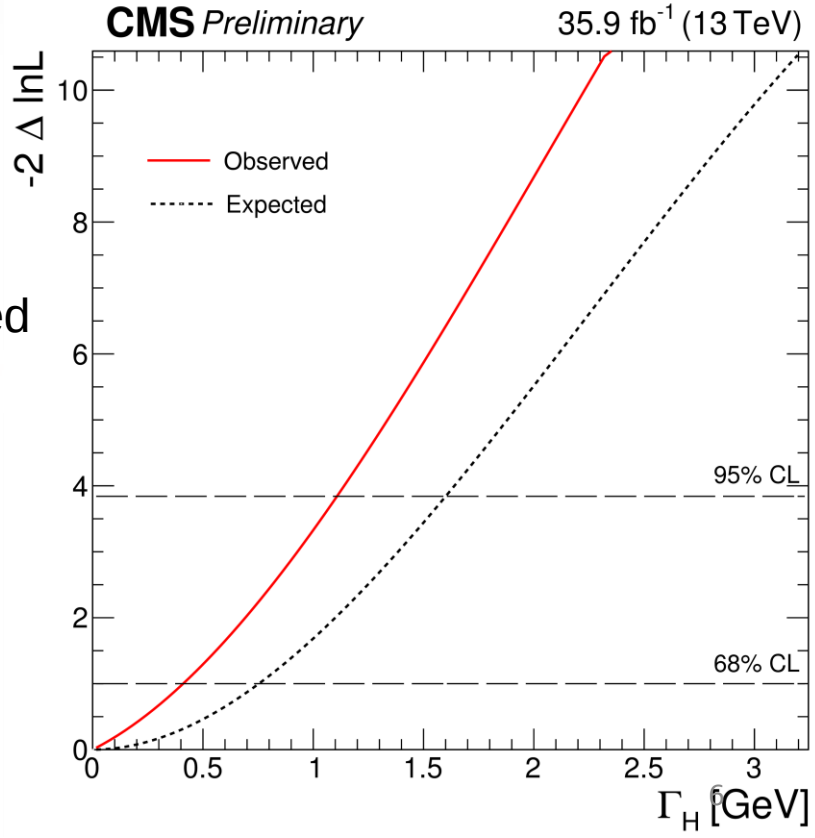
Run1 ATLAS+CMS combined

125.09 ± 0.24 (± 0.21 ± 0.11) GeV

CMS-PAS-HIG-16-041

- **Width measurement using on-shell production**

If m_H floated, Γ_H **< 1.1 GeV** @ 95% CL



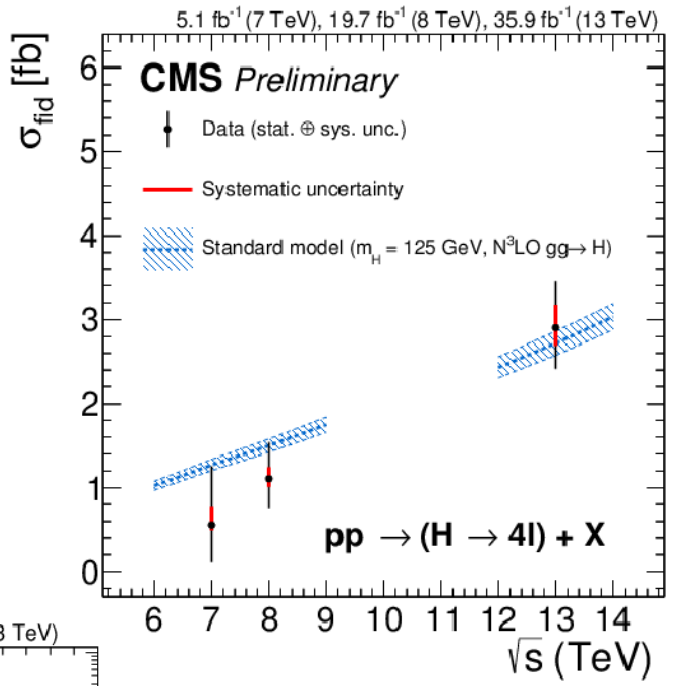
$H \rightarrow ZZ^* \rightarrow 4l$: Differential and fiducial cross section

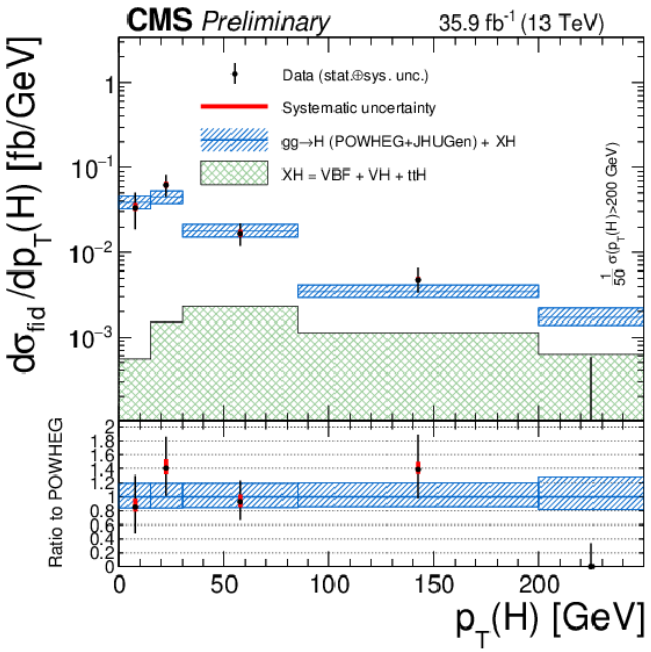
- Cross sections measured in **fiducial phase space** to maximize model independence
- Signal extracted using a 1D m(4ℓ) fit

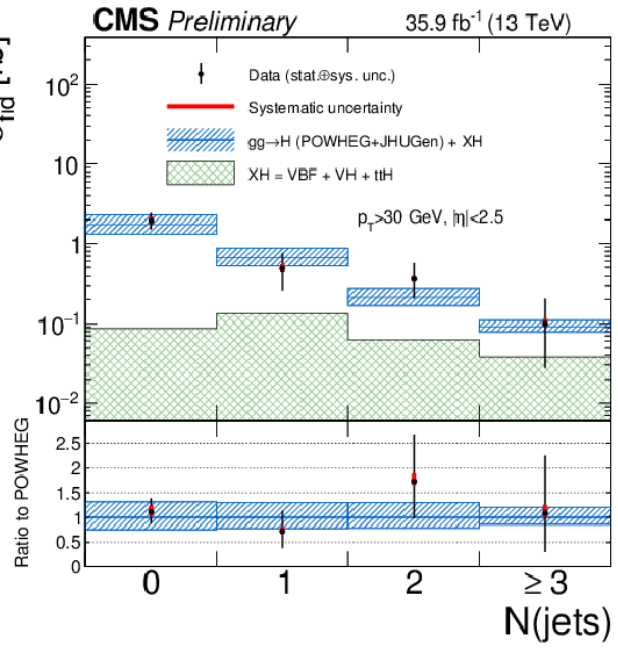
$$\sigma_{fid} = 2.90^{+0.48}_{-0.44}(stat)^{+0.27}_{-0.22}(sys)\ fb$$

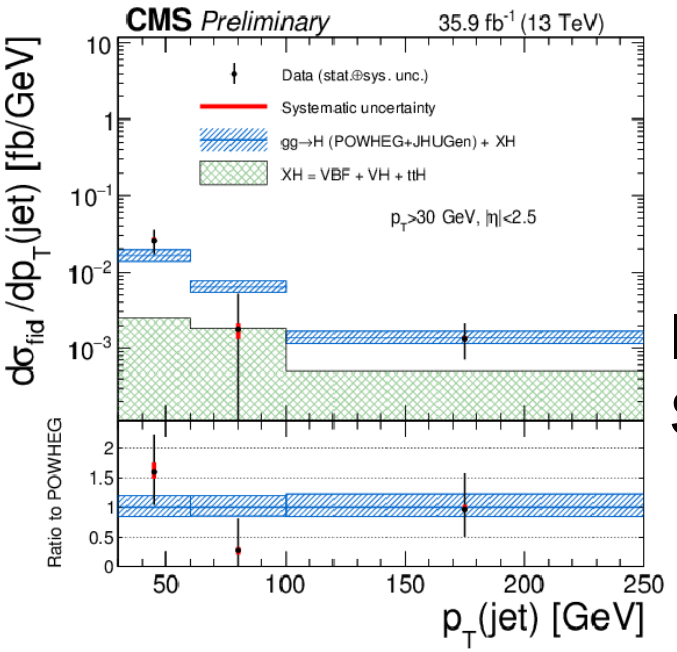
$$\sigma^{SM}_{fid} = 2.72 \pm 0.14\ fb$$

- **Differential cross sections** measured for pT(H), N(jets), and pT(jet), compared with predictions from powheg (NLO)









CMS-PAS-HIG-16-041

In agreement with SM predictions

$H \to ZZ^* \to 4l$: Anomalous couplings

- **Same lepton selections** as cross section measurement
- **Three event categories because of less statistics : VBF and VH selected using dedicated discriminators with** production kinematics **(New in Run 2), and untagged**
- **Discriminants** to suppress background, to separate BSM and SM, and to isolate interference of BSM and SM (Ω - up to 13 observables)

$$\mathcal{D}_{\rm bkg} = \frac{\mathcal{P}_{\rm SM}(\vec{\Omega})}{\mathcal{P}_{\rm SM}(\vec{\Omega}) + \mathcal{P}_{\rm bkg}(\vec{\Omega})} \qquad \mathcal{D}_{\rm BSM} = \frac{\mathcal{P}_{\rm SM}(\vec{\Omega})}{\mathcal{P}_{\rm SM}(\vec{\Omega}) + \mathcal{P}_{\rm BSM}(\vec{\Omega})} \qquad \mathcal{D}_{\rm int} = \frac{\mathcal{P}^{\rm int}_{\rm SM-BSM}(\vec{\Omega})}{\mathcal{P}_{\rm SM}(\vec{\Omega}) + \mathcal{P}_{\rm BSM}(\vec{\Omega})}$$

- **Effective cross-section ratios f_{ai} and coupling phases ϕ_{ai} :** allowed 68% CL (central values with uncertainties) and 95% CL (ranges in square brackets) intervals

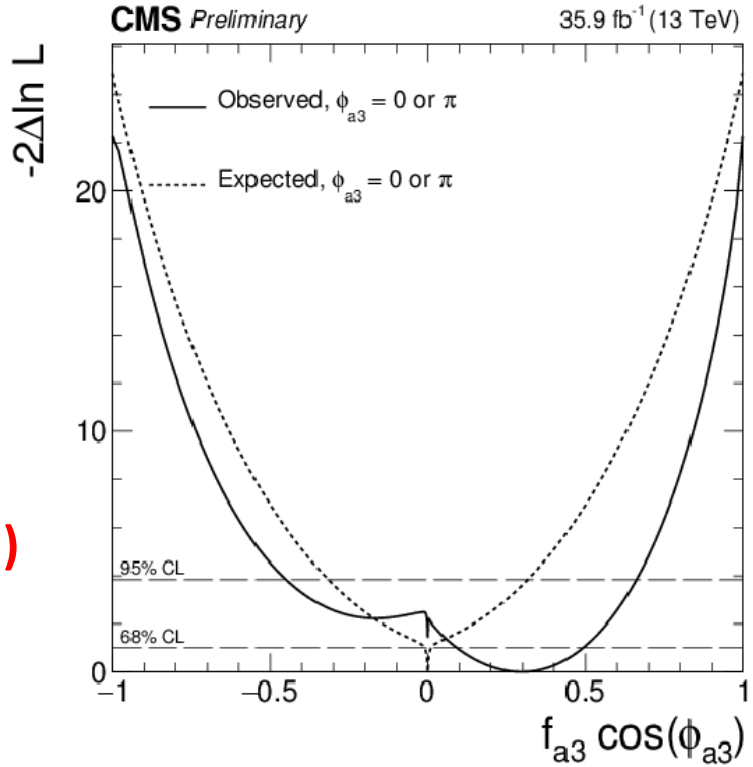
f_{ai}=0 (1) indicates pure SM (BSM)

Parameter	Observed	Expected
$f_{a3}\cos(\phi_{a3})$	$0.30^{+0.19}_{-0.21}$ $[-0.45, 0.66]$	$0.000^{+0.017}_{-0.017}$ $[-0.32, 0.32]$
$f_{a2}\cos(\phi_{a2})$	$0.04^{+0.19}_{-0.04}$ $[-0.69, -0.64] \cup [-0.04, 0.64]$	$0.000^{+0.015}_{-0.014}$ $[-0.08, 0.29]$
$f_{\Lambda 1}\cos(\phi_{\Lambda 1})$	$0.00^{+0.06}_{-0.33}$ $[-0.92, 0.15]$	$0.000^{+0.014}_{-0.014}$ $[-0.79, 0.15]$
$f^{Z\gamma}_{\Lambda 1}\cos(\phi^{Z\gamma}_{\Lambda 1})$	$0.16^{+0.36}_{-0.25}$ $[-0.43, 0.80]$	$0.000^{+0.020}_{-0.024}$ $[-0.49, 0.80]$

Scattering amplitude describing the interaction between a spin-0 H boson and two spin 1 gauge bosons VV

$$A = \frac{1}{v}\left[\text{SM}\ a_1^{VV} + \text{leading momentum expansion}\ \frac{\kappa_1^{VV} q_1^2 + \kappa_2^{VV} q_2^2}{(\Lambda_1^{VV})^2} + \frac{\kappa_3^{VV}(q_1+q_2)^2}{(\Lambda_Q^{VV})^2}\right] m_{V1}^2 \epsilon_{V1}^* \epsilon_{V2}^* + \text{higher order cp-even}\ a_2^{VV} f_{\mu\nu}^{*(1)} f^{*(2),\mu\nu} + \text{cp-odd}\ a_3^{VV} f_{\mu\nu}^{*(1)} \tilde{f}^{*(2),\mu\nu}$$

CMS-PAS-HIG-17-011

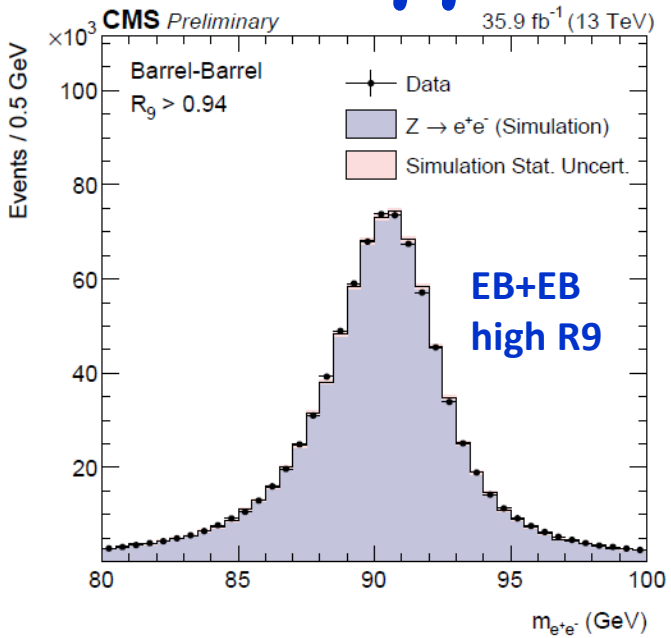


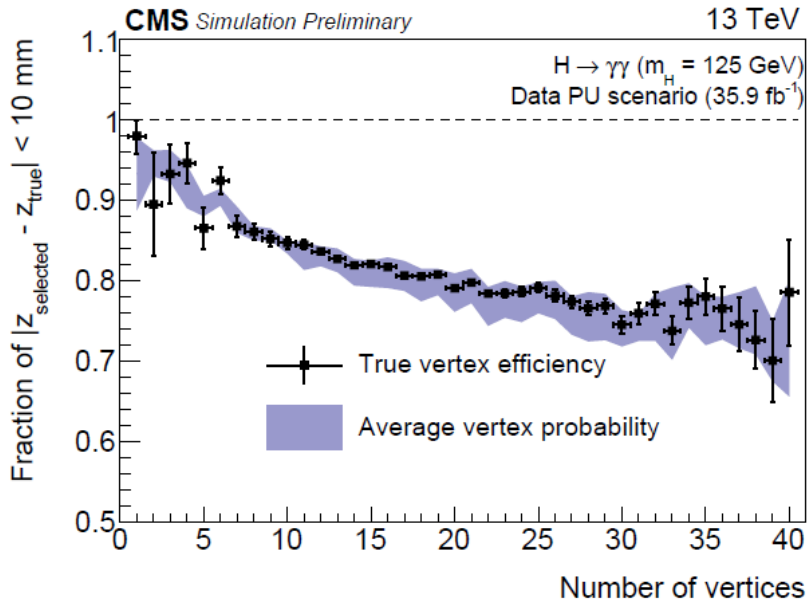
Distribution of the decay discriminant for CP-violation has small forward-backward asymmetry, which results in this preference at +0.3

Results consistent with SM

H→γγ

- Signal signature
  - Two isolated and high ET photons
  - Final state **fully reconstructed** with **high resolution**
  - Mass resolution : **σ~ 1-2% $m_{\gamma\gamma}$**





- Large backgrounds
  - **Continuum γγ (irreducible)**
  - Fakes from **γ+jet/jet+jet** (reducible)

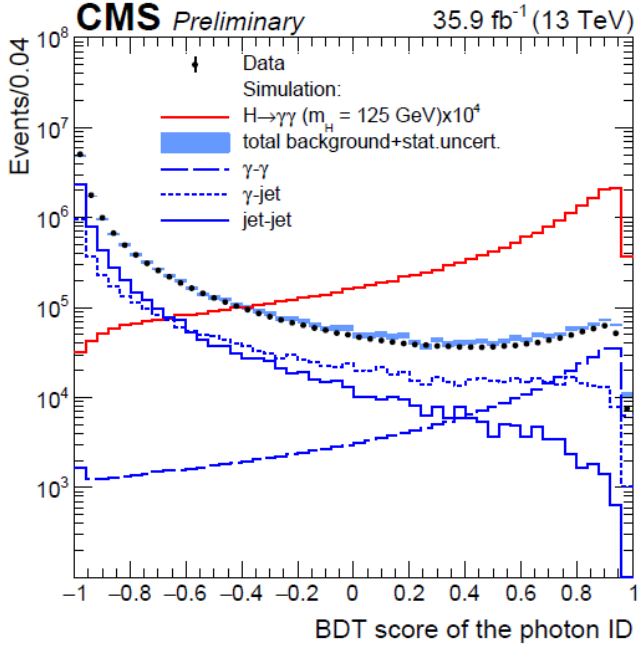
- **Photon energy**: well calibrated and corrected, with **Z→ee peak** used as reference

$$m_{\gamma\gamma} = \sqrt{2E_1E_2(1-\cos\theta)}$$

- **Primary vertex**: BDT for selection; Within 1cm → negligible impact on resolution.

$$m_{\gamma\gamma} = \sqrt{2E_1E_2(1-\cos\theta)}$$

- **Photon ID**: BDT discriminates real/fake photons from jet fragment

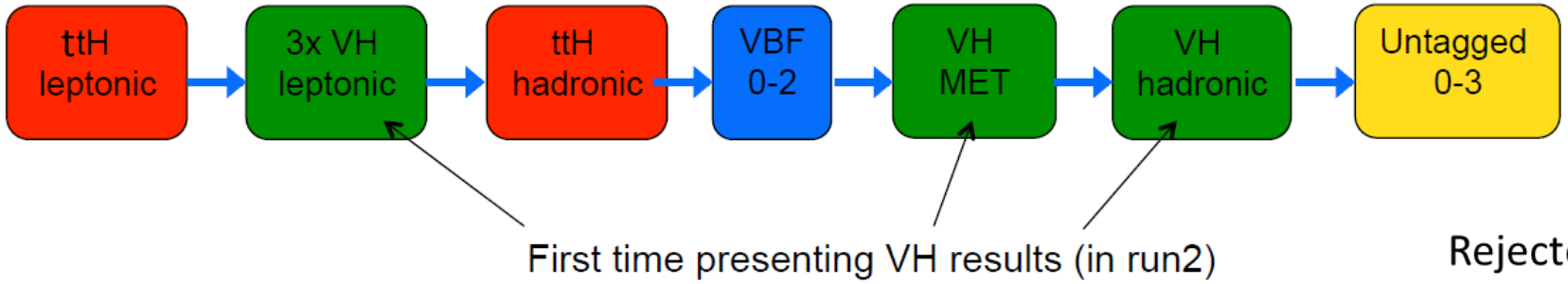


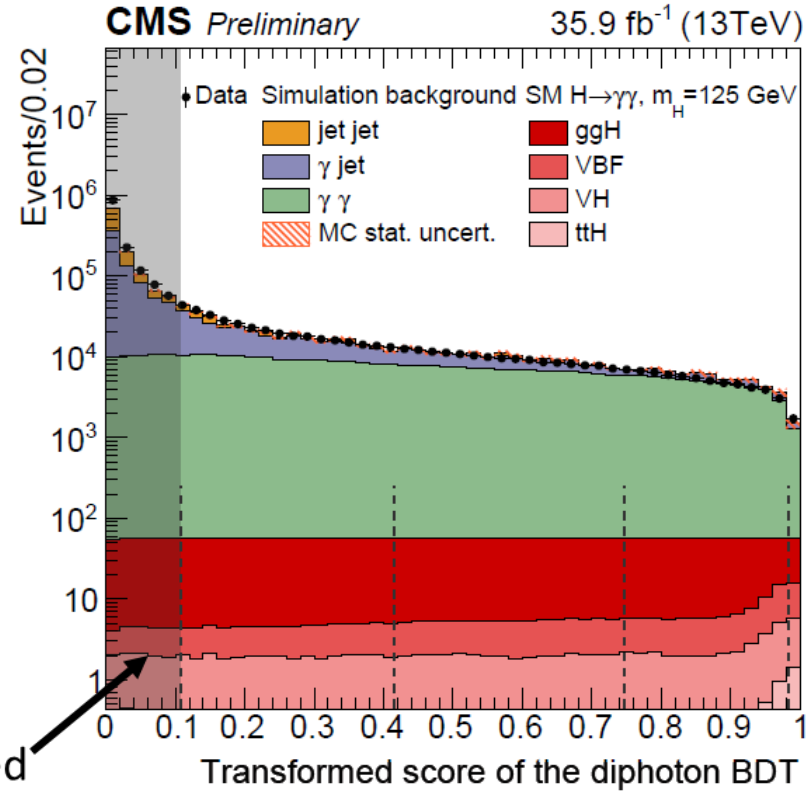
CMS-PAS-HIG-16-040

H→γγ : Analysis strategy

- **Event tagging**: events are sorted into **14 categories** depending on **Higgs production modes** and kinematics, to improve the analysis sensitivity
- Top fusion (**ttH**): cut-based ***leptonic*** and mva-based ***hadronic*** (2cats)
- **VH**: **new in 2017**, cut-based and split into ***leptonic, hadronic, MET*** (5cats)
- **VBF**: dijet + diphoton BDTs with categories based on significance (3cats)
- **Untagged**: split by ***diphoton BDT score***, correspond to different S/B and invariant mass resolutions (4cats)

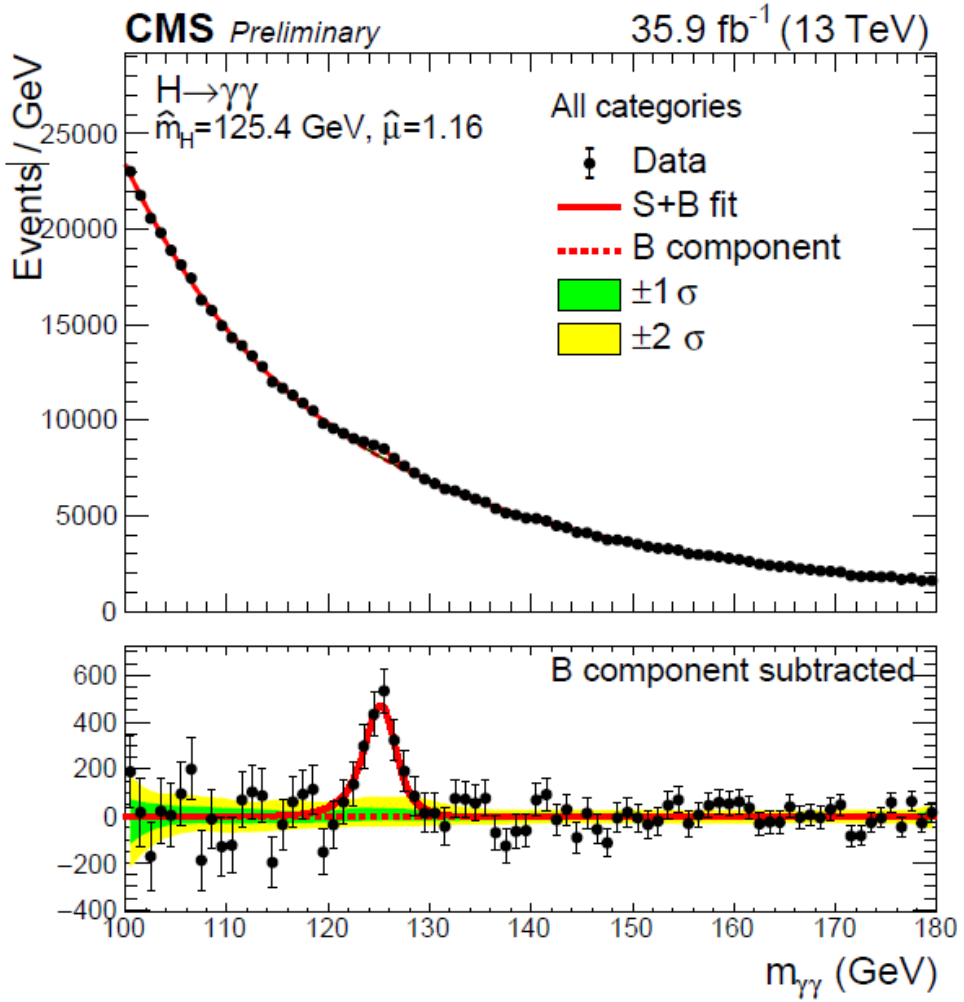
CMS-PAS-HIG-16-040



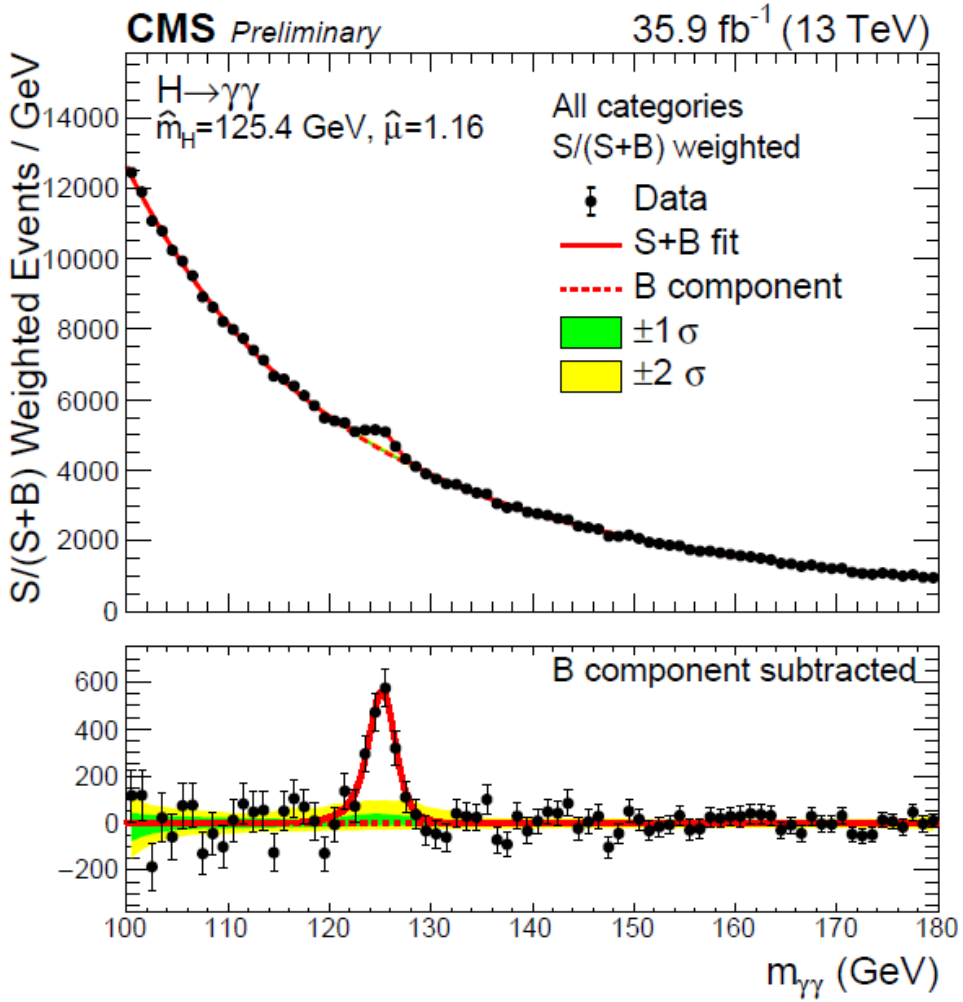


H→γγ : Mass distributions

All categories



All categories (weighted by their sensitivity)



CMS-PAS-HIG-16-040

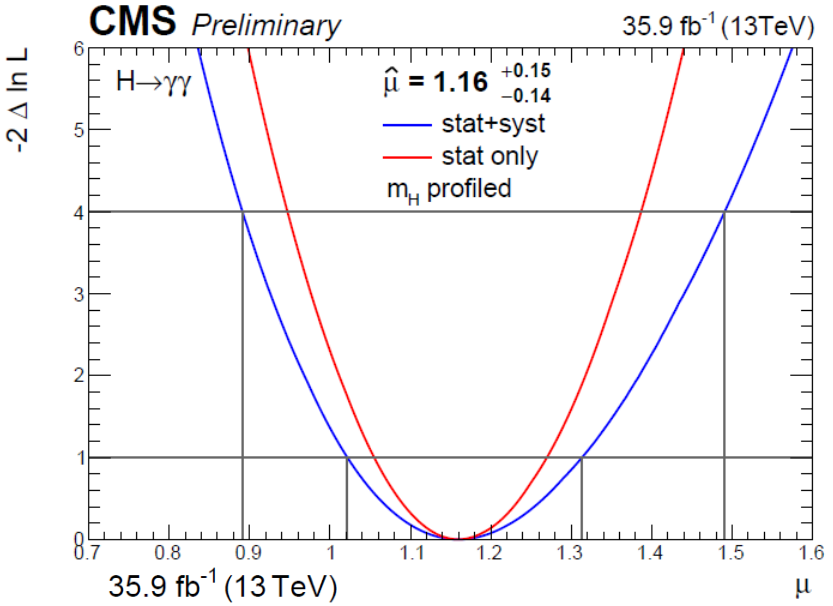
H→γγ : Signal strength

- Overall signal strength

$$\mu = 1.16^{+0.15}_{-0.14}(stat+syst) = 1.16^{+0.11}_{-0.10}(stat.)^{+0.09}_{-0.08}(syst.)^{+0.06}_{-0.05}(theo.)$$

- Production mechanism **signal strengths** are SM-consistent

- **Signal strengths** measured in bosonic and fermionic parts are also SM-consistent



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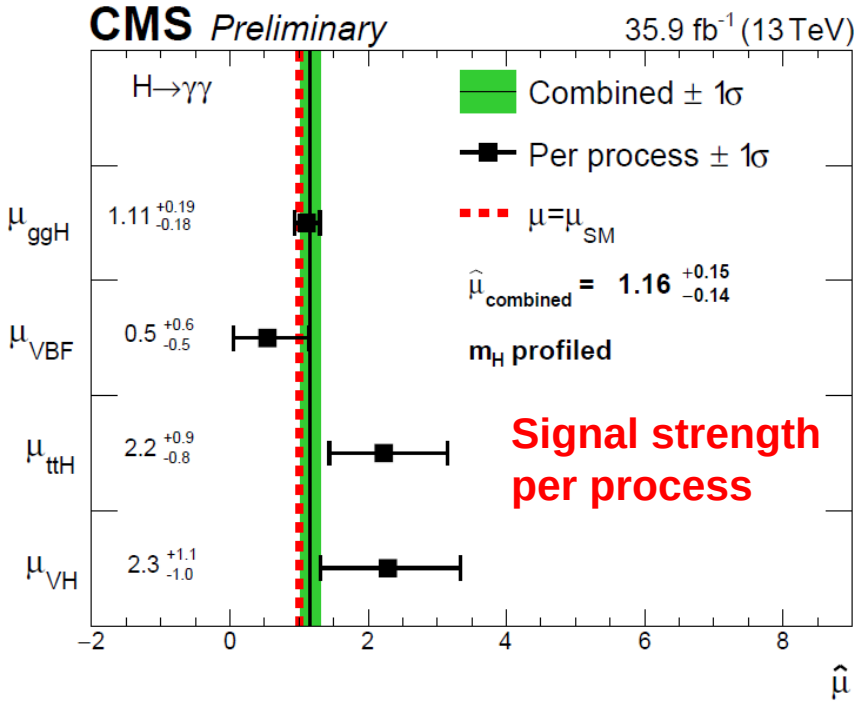
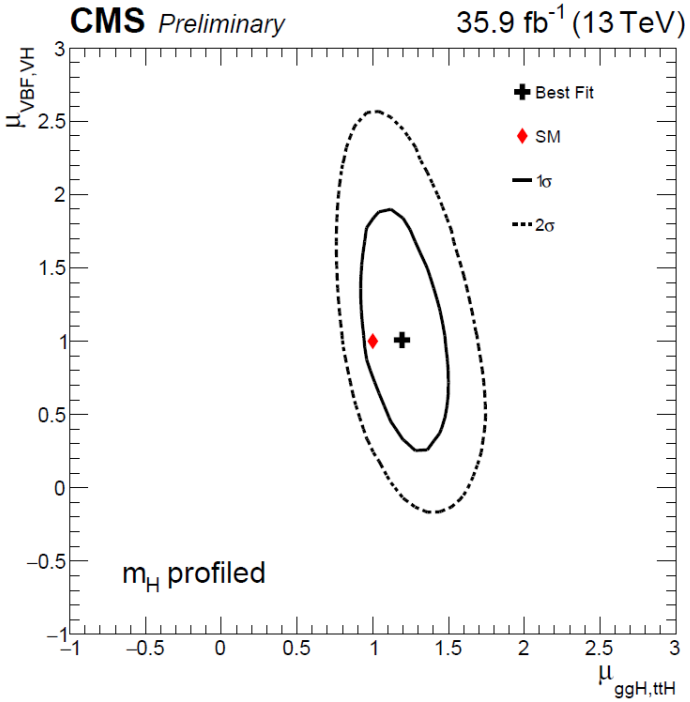


Significance
Observed(Expected)

VBF **1.1σ (1.9σ)**

ttH **3.3σ (1.5σ)**

VH **2.4σ (1.2 σ)**

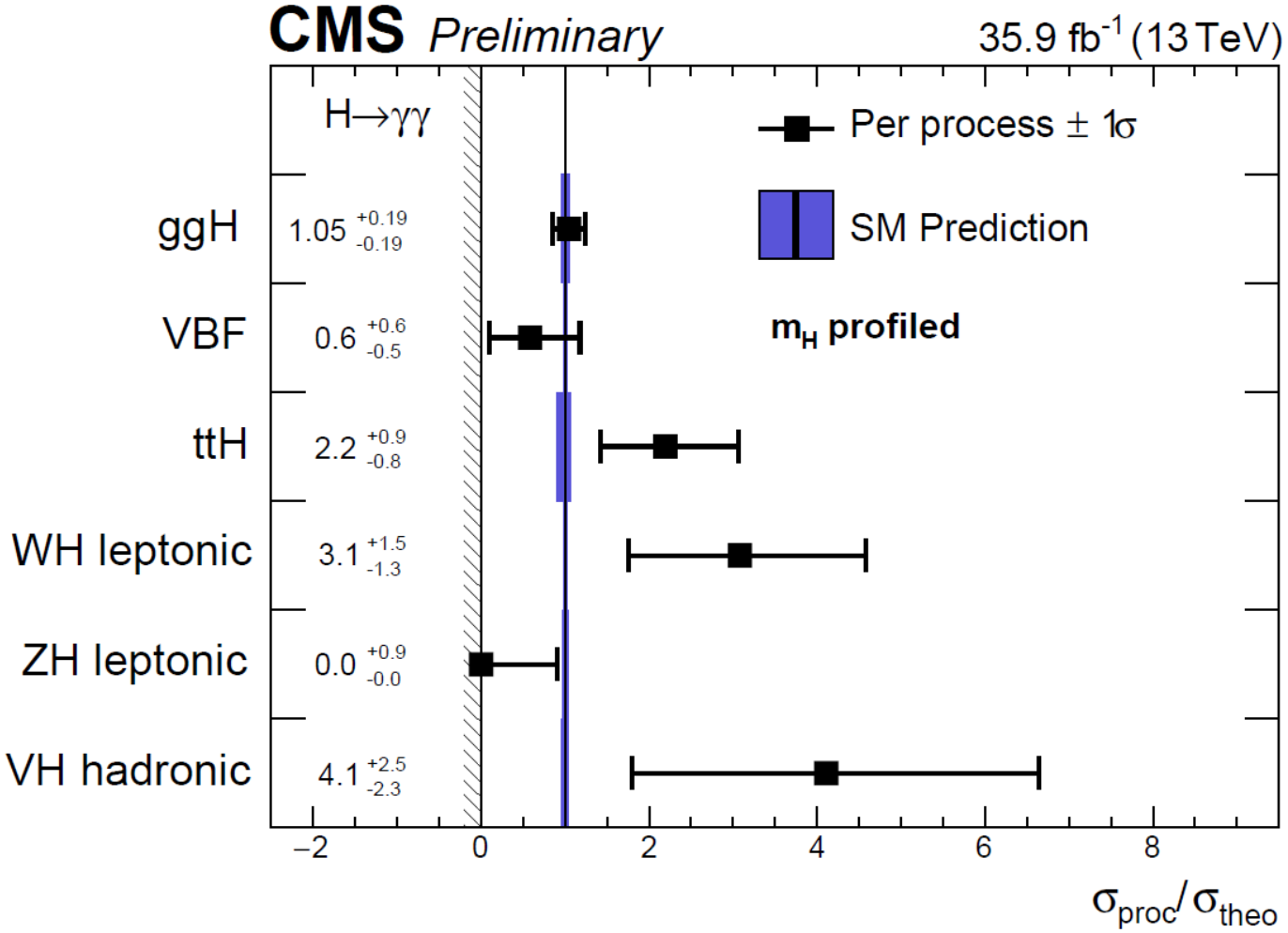


$$\mu_{ggH,t\bar{t}H} = 1.19^{+0.20}_{-0.18}$$

$$\mu_{VBF,VH} = 1.01^{+0.57}_{-0.51}$$

H→γγ : cross section

Cross section ratios measured for each process in the Higgs Simplified Template Cross Section (STXS) framework, for profiled m_H, compared to the SM expectation and its uncertainties



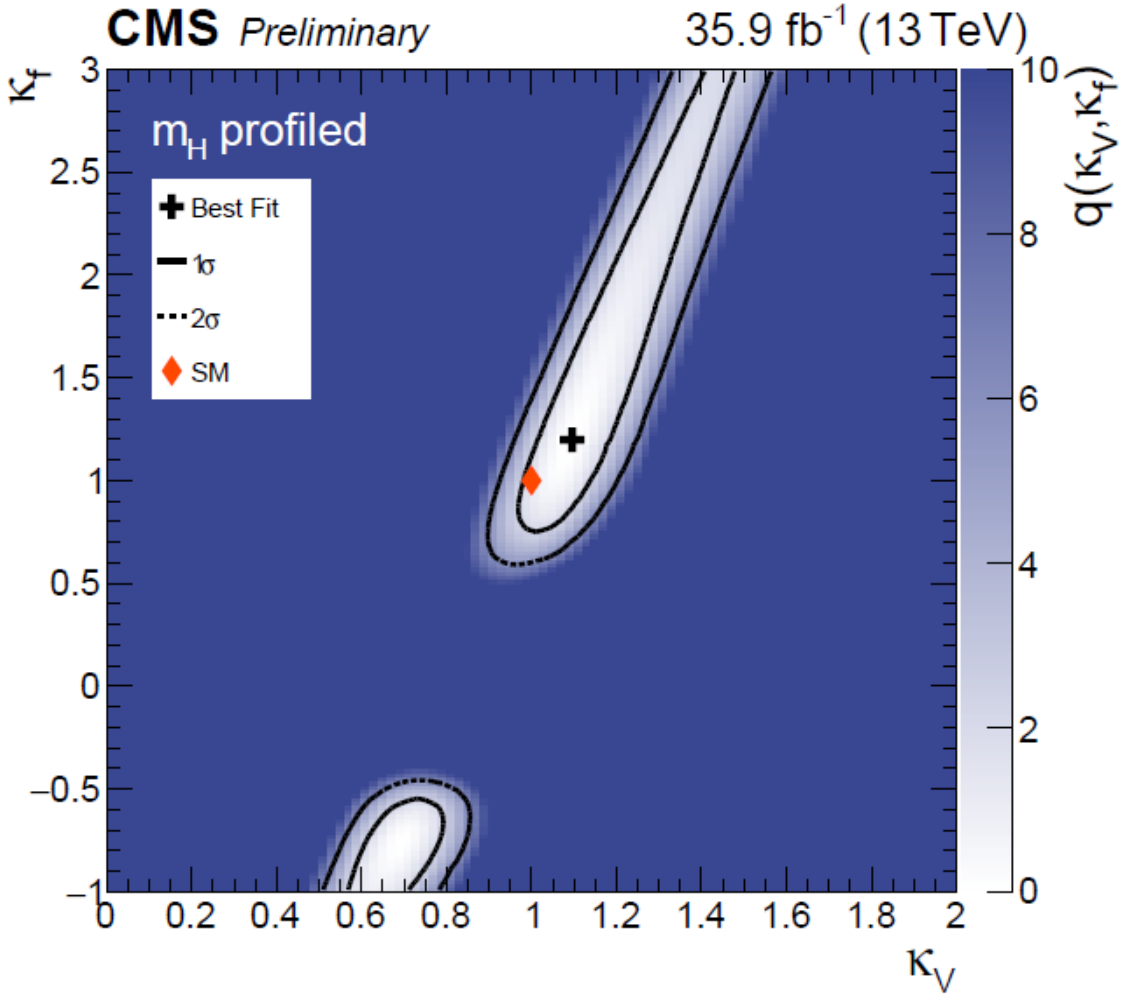
CMS-PAS-HIG-16-040

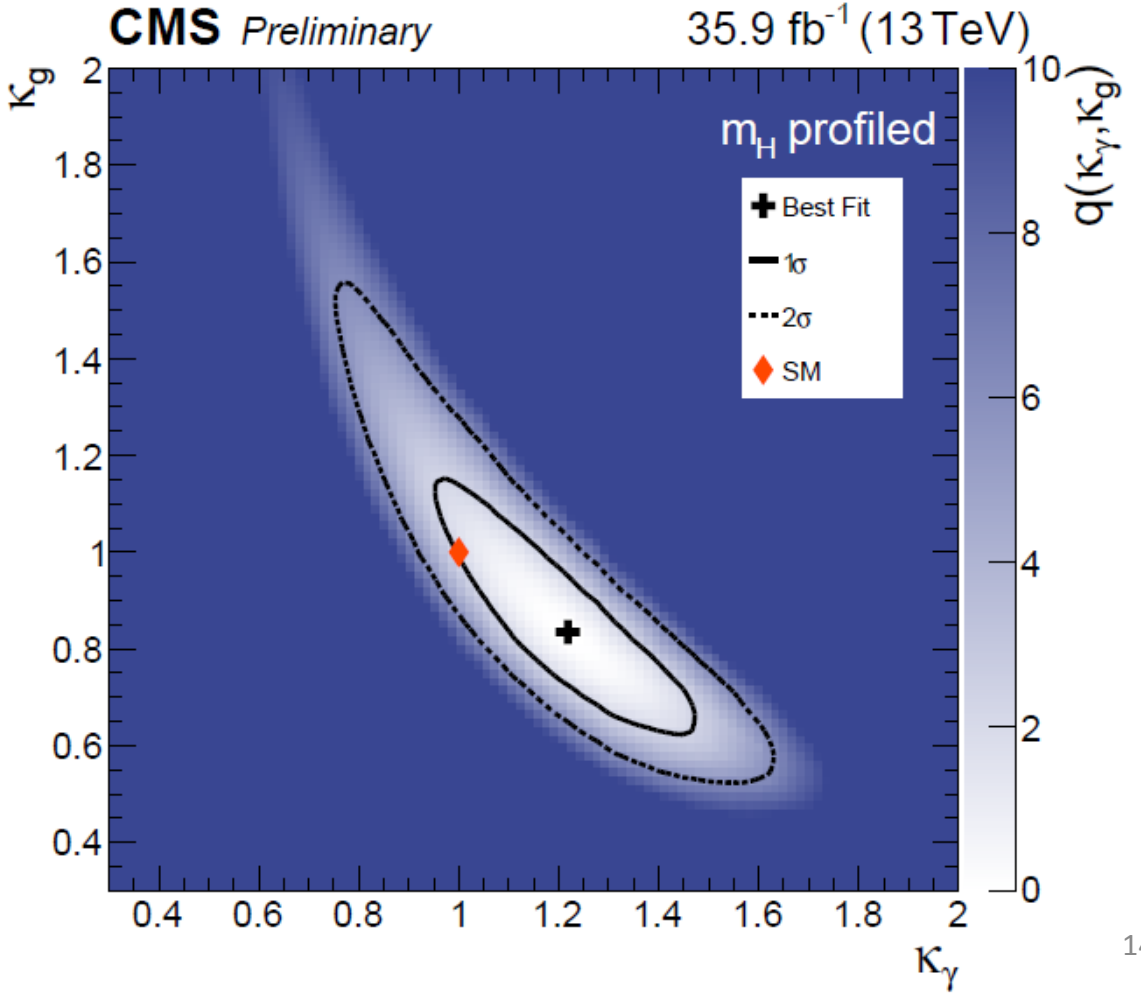
H→γγ : Coupling constants

Measurements of **coupling modifiers** to **vector bosons** and **fermions** (k_V, k_f) and to **photons** and **gluons** (k_γ, k_g)

Compatible with SM

CMS-PAS-HIG-16-040





H→γγ : Fiducial cross section

- **3 untagged event categories** based on **expected mass resolution**

- **Results**: **most precise fiducial measurement so far**

CMS-PAS-HIG-17-015

$$\hat{\sigma}_{\text{fiducial}} = 84 \pm 11\ (\text{stat}) \pm 7\ (\text{syst})\ \text{fb}$$

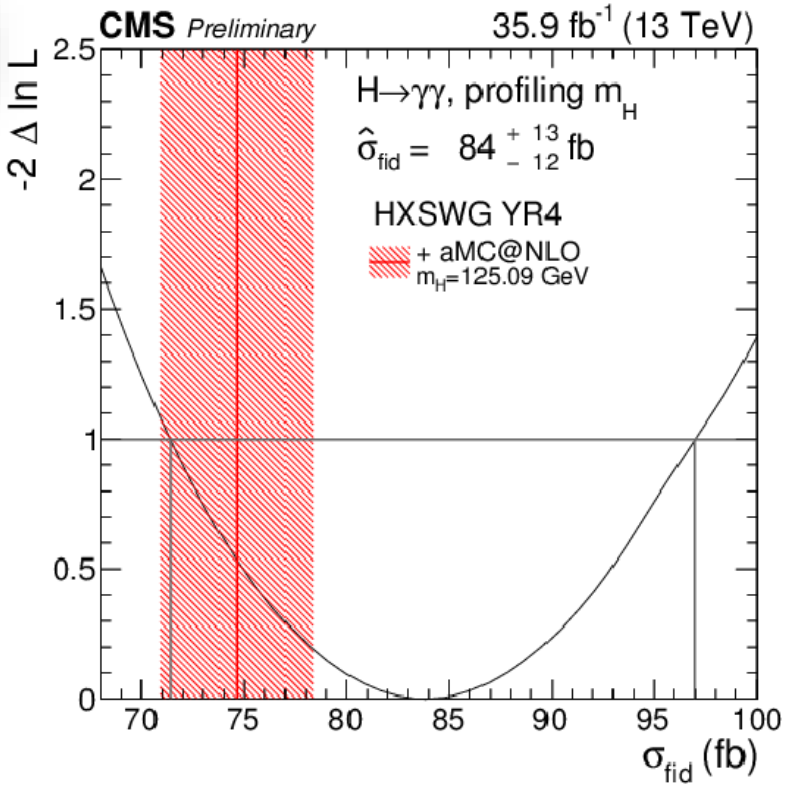
$$\sigma^{theory}_{\text{fiducial}} = 75^{+4}_{-4}\,\text{fb}$$

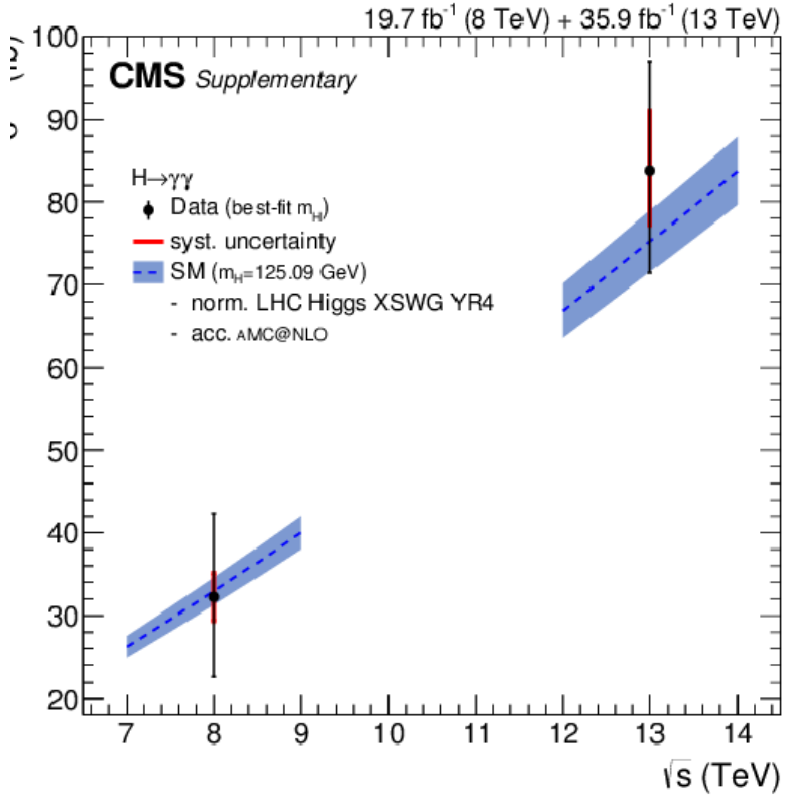
Fiducial volume:

$p_{T1}/m_{\gamma\gamma} < 1/3$, $p_{T2}/m_{\gamma\gamma} < 1/4$

$|\eta_{1,2}| < 2.5$

$\text{Iso}_{\text{gen}1,2} < 10$ GeV ($\Delta R=0.3$)

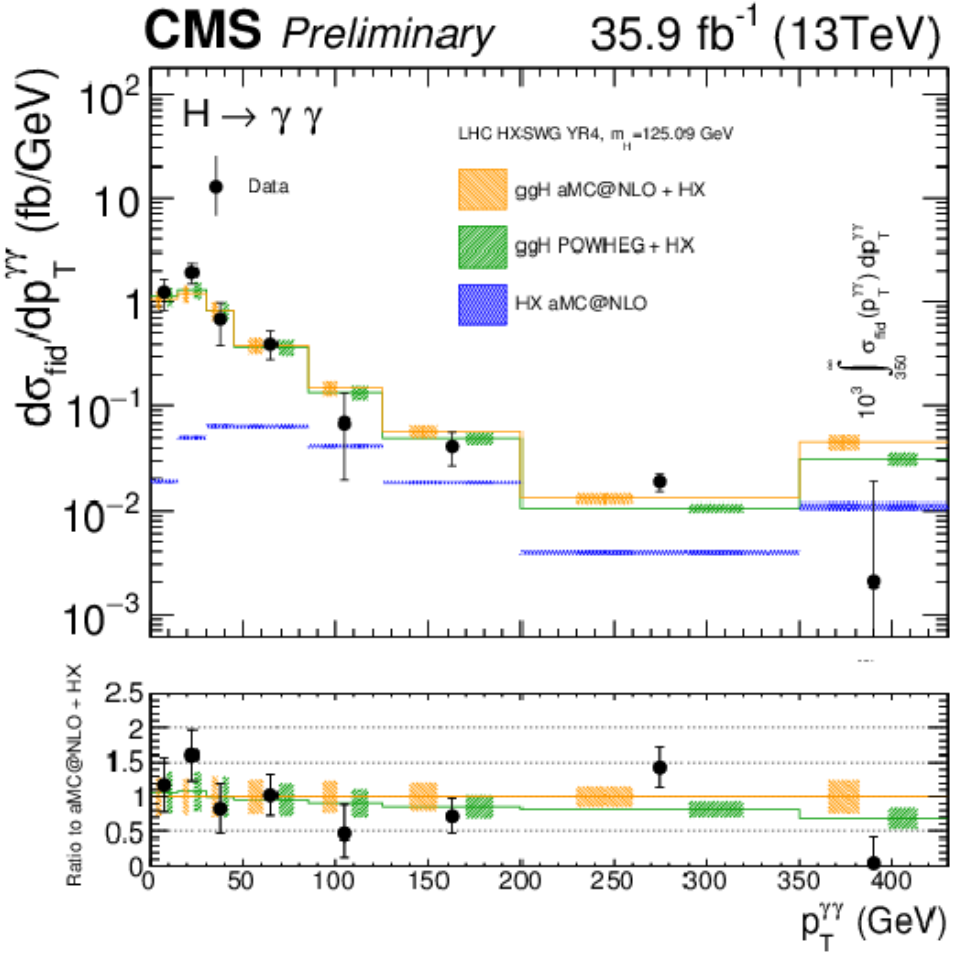


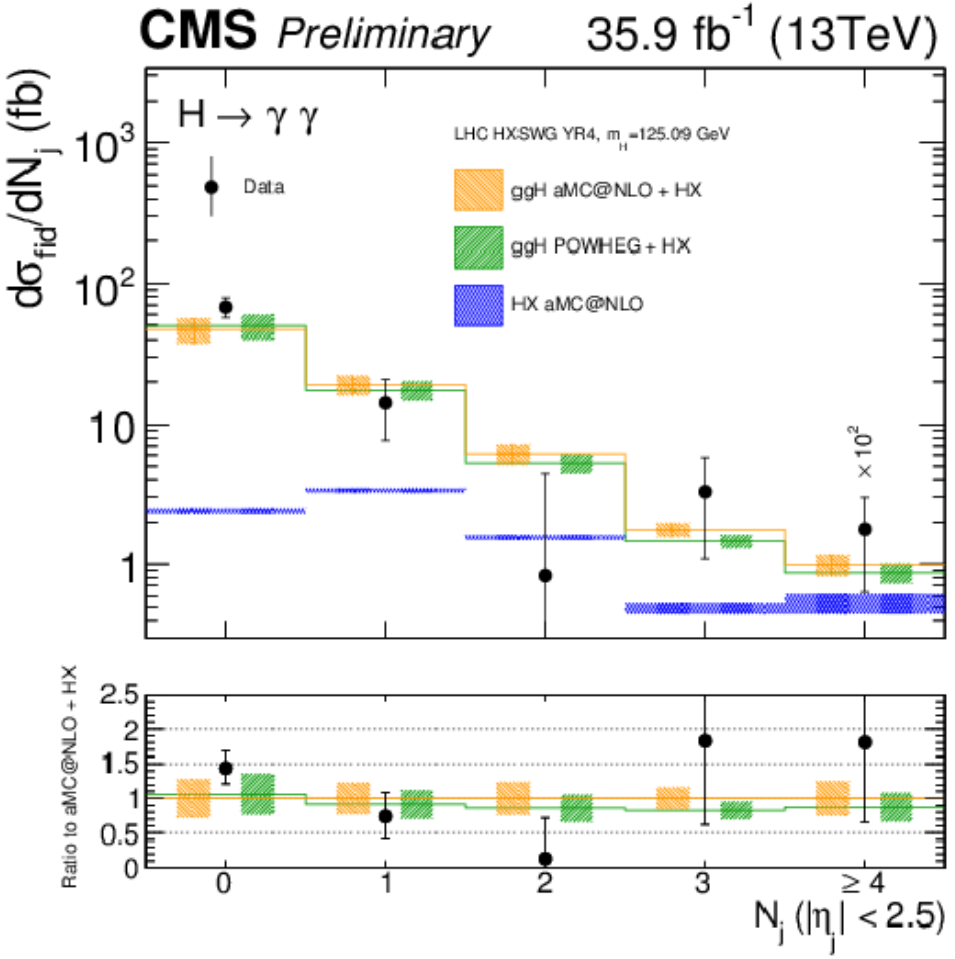


H→γγ : Differential fiducial cross section

- **Differential fiducial cross sections** are measured for **pT(γγ)** and **N(jets)**, compared with predictions from MADGRAPH aMC@NLO, **ggH powheg** + **other modes (VBF+VH+ttH, "HX")** **from MADGRAPH aMC@NLO**

CMS-PAS-HIG-17-015

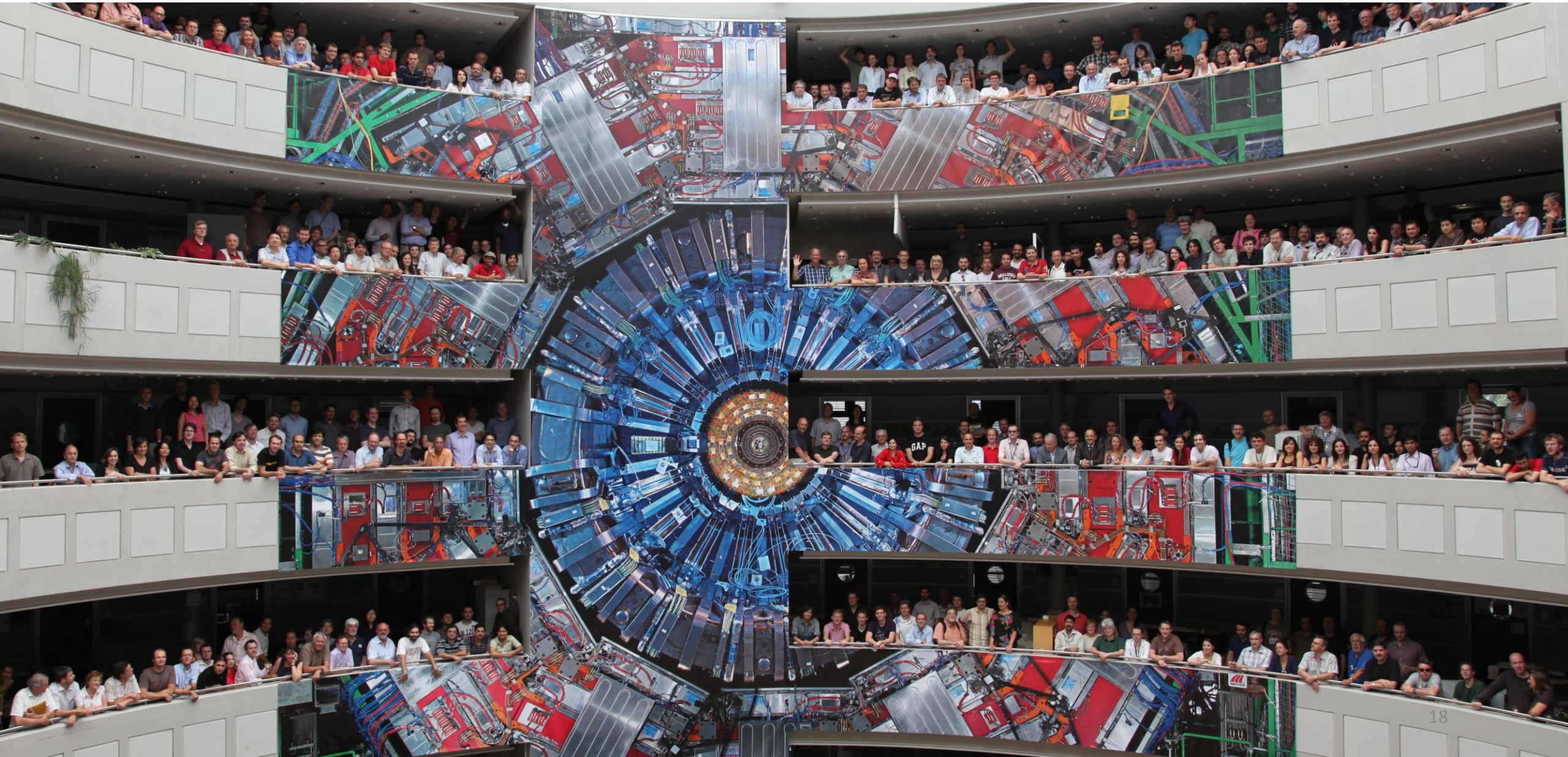




Summary and outlook

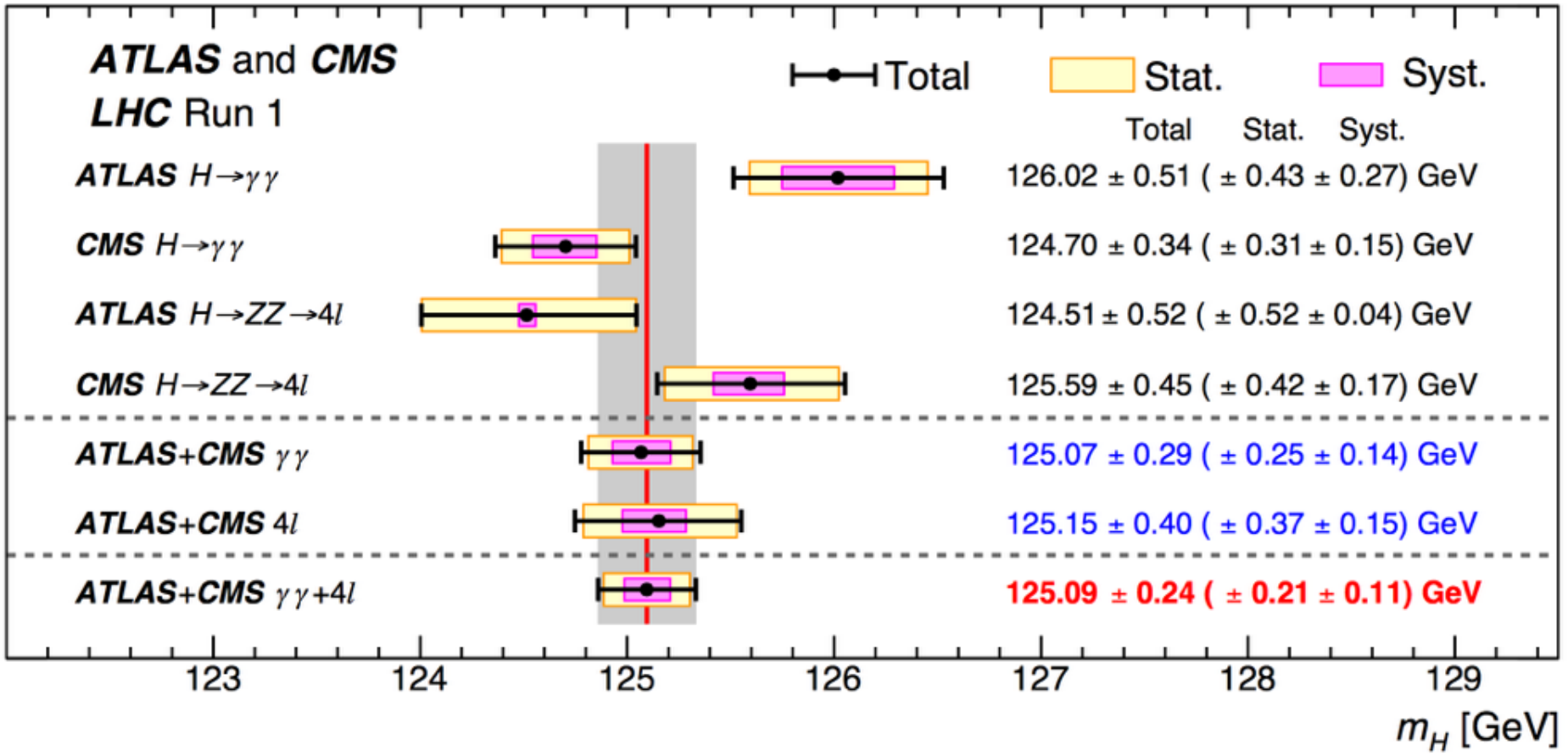
- Latest results of Higgs measurements with $H \to ZZ^* \to 4\ell$ and $H \to \gamma\gamma$ from Run 2 data (~36 fb^{-1}) collected by CMS detector at 13 TeV are presented
- Precision of its mass measured from $H \to ZZ^* \to 4\ell$ is a little better than the combined ATLAS+CMS result in Run1
- Measurements of its properties are largely compatible with SM expectations
- Results are still statistically limited
- Expected > 100 fb^{-1} to be delivered by the end of Run2
  – improve precision on the measurements

Thanks for your attention!



Backup slides

Mass : Run 1 combination



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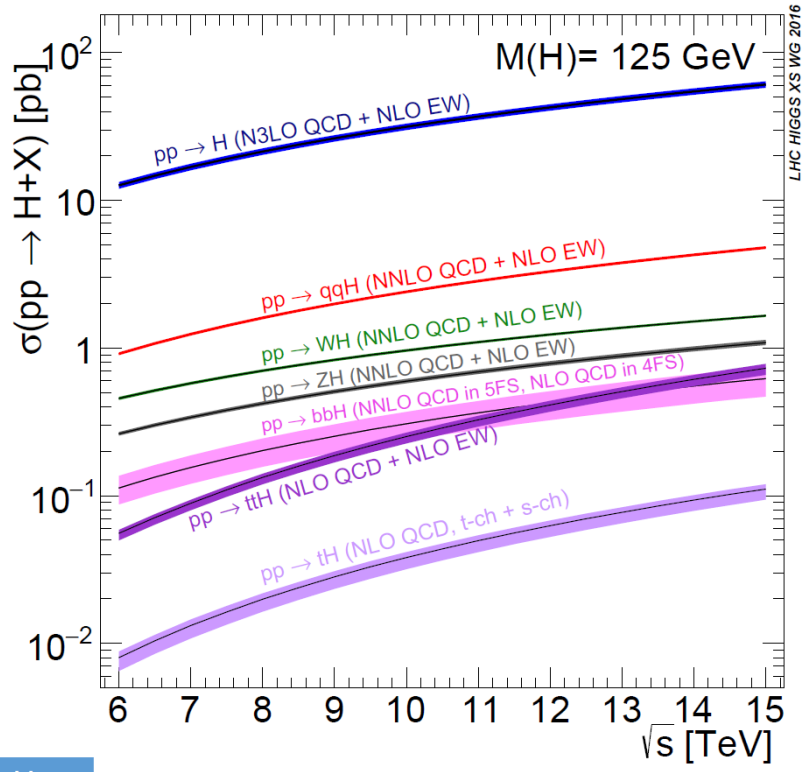
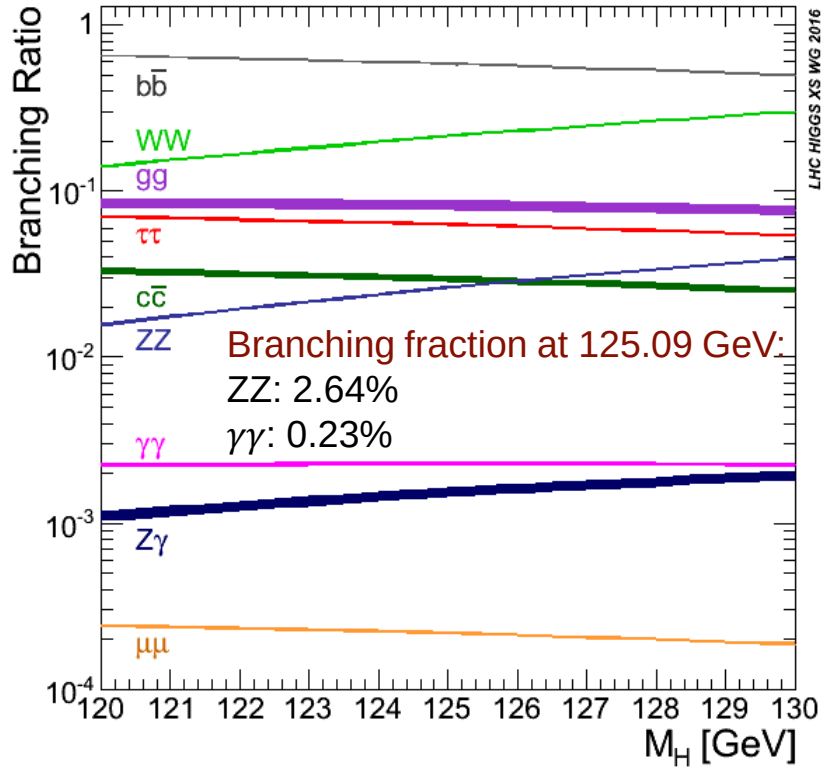
Higgs production and decays at LHC

- Cross sections are increased by ~2.3 except for ttH 3.8 from 8 TeV to 13 TeV
- More than 100 fb^{-1} is expected in Run 2 : ~25 fb^{-1} in Run 1
- We expect 10 times more the BEH scalar events than Run 1

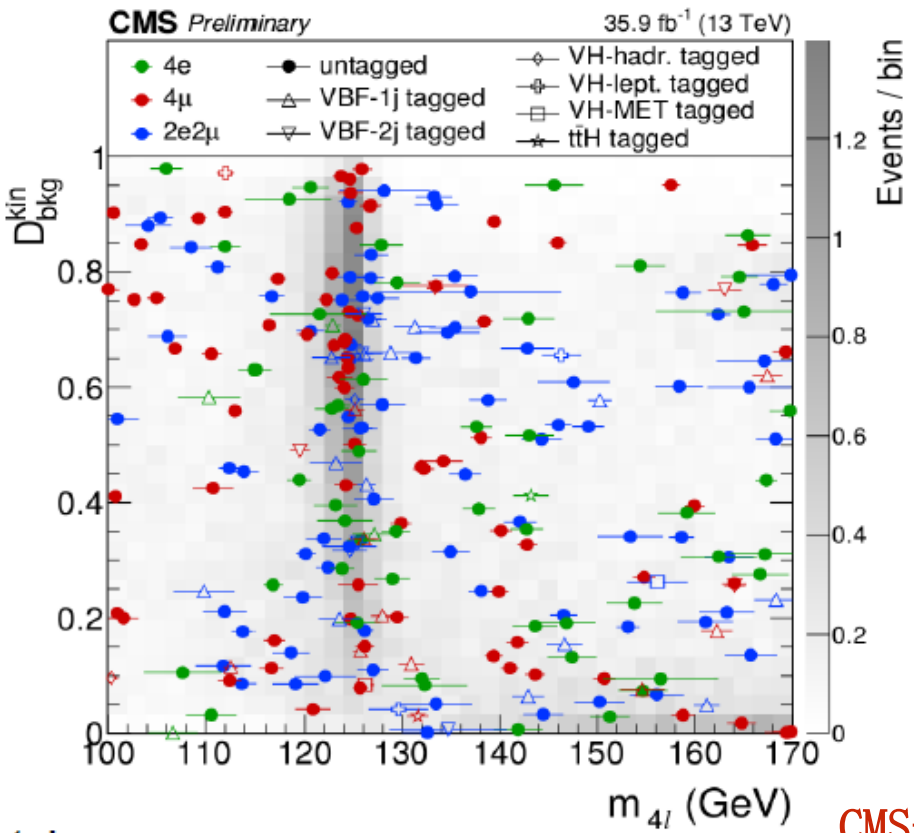


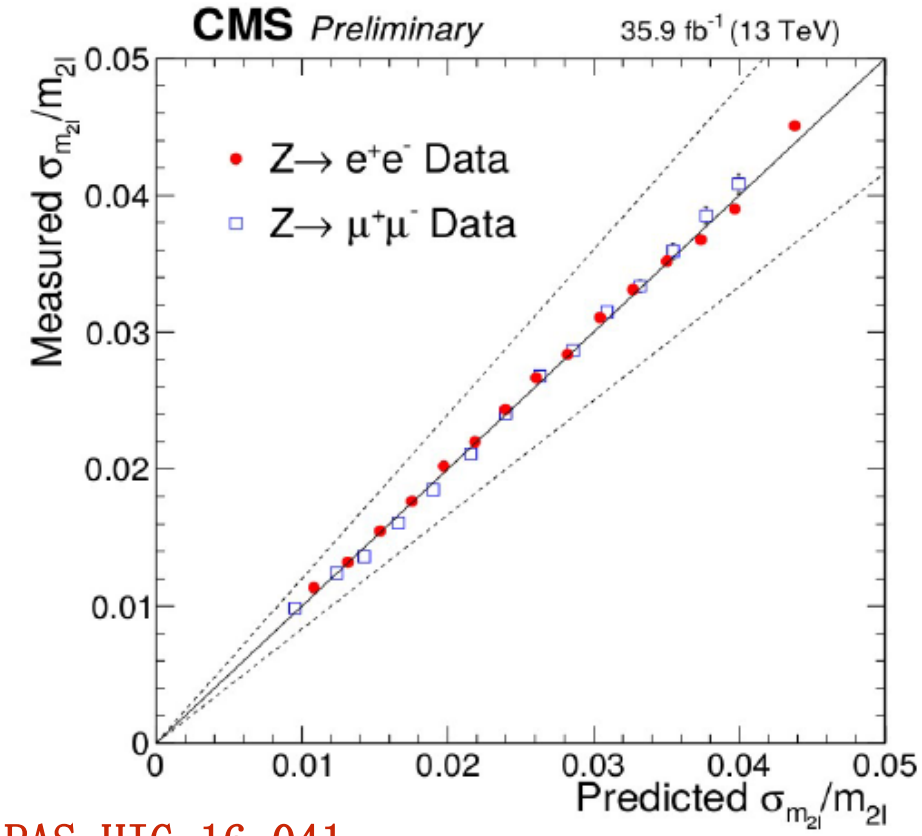


Cross section [pb] @125.09 GeV	ggF	VBF	WH	ZH	ttH	bbH
8 TeV	21.39	1.600	0.701	0.4199	0.1326	0.2015
13 TeV	48.52	3.779	1.369	0.8824	0.5065	0.4863
Ratio	2.27	2.36	1.95	2.10	3.82	2.41

https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHXSWG

$H \rightarrow ZZ^* \rightarrow 4l$: **Observables**





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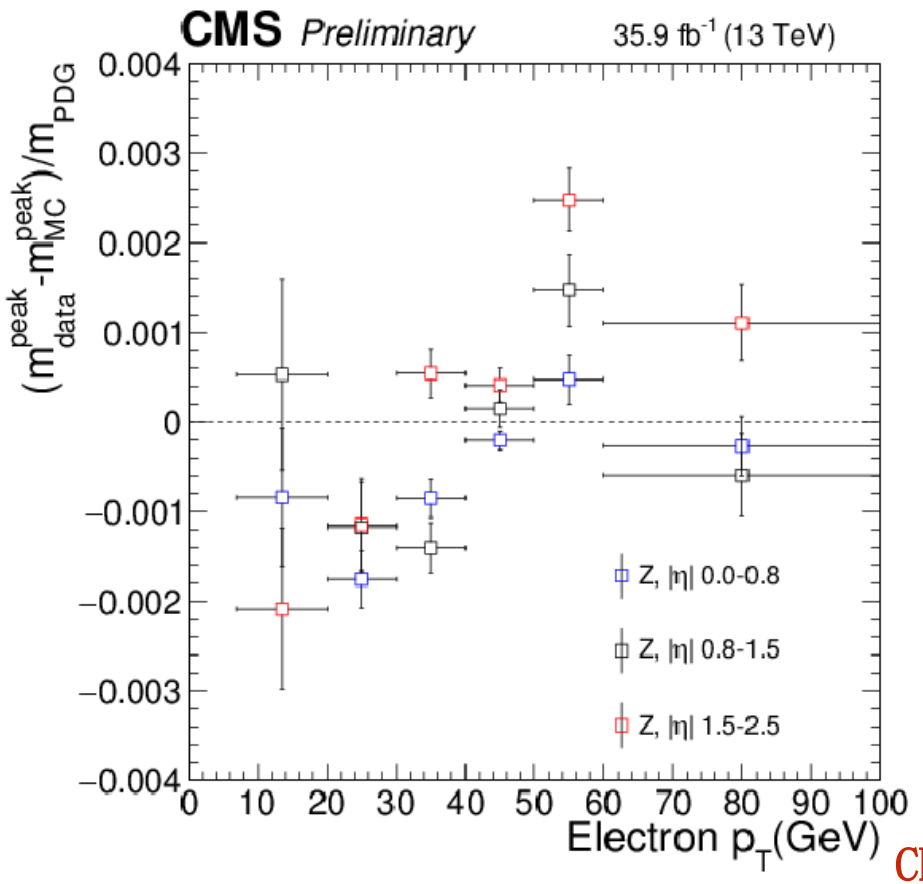
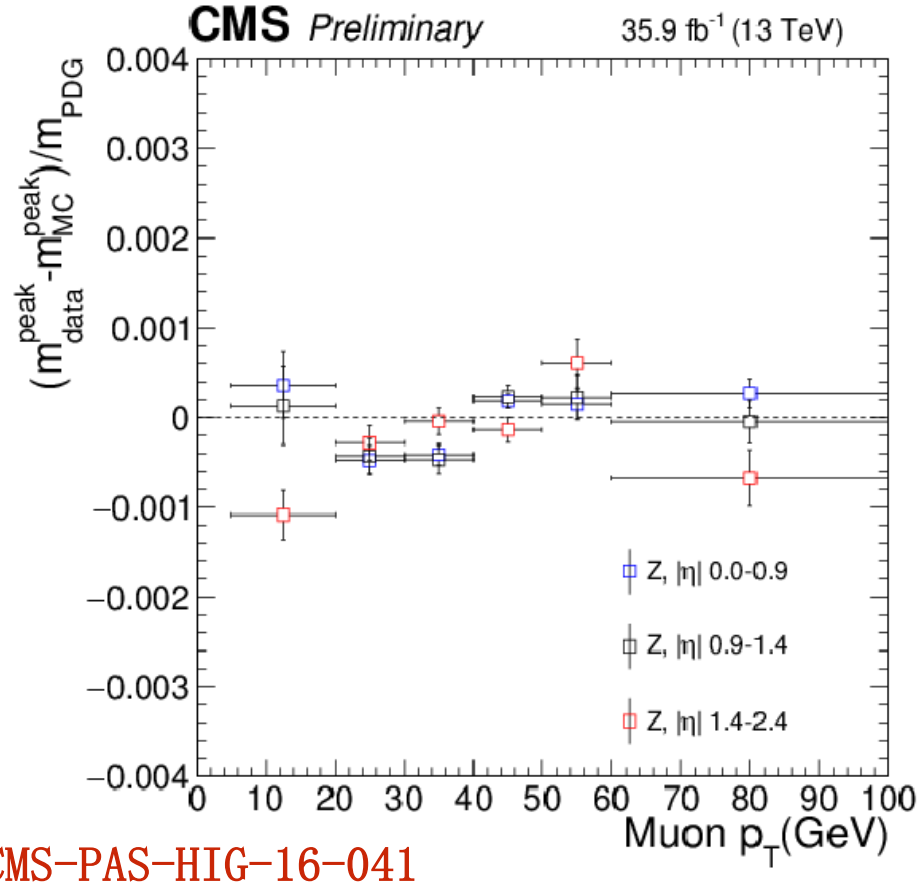
- 4 lepton invariant mass : m_{4l}
- Event-by-event mass uncertainty : $D_{mass} = \sigma_{m_{4l}} / m_{4l}$, propagated from individual lepton p_T resolution (Corrected in data/MC using Z → ll events)
- Matrix element kinematic discriminant: $\mathcal{D}^{kin}_{bkg} = \left[1 + \frac{\mathcal{P}^{q\bar{q}}_{bkg}(\vec{\Omega}^{H\to 4\ell} | m_{4\ell})}{\mathcal{P}^{gg}_{sig}(\vec{\Omega}^{H\to 4\ell} | m_{4\ell})} \right]^{-1}$

$H \rightarrow ZZ^* \rightarrow 4l$: Lepton energy scale uncertainty





Difference between the $Z \rightarrow \ell\ell$ mass peak positions in data and simulation normalized by the nominal Z boson mass obtained as a function of the pT and $|\eta|$ of one of the leptons regardless of the second for electrons (left) / muons (right).

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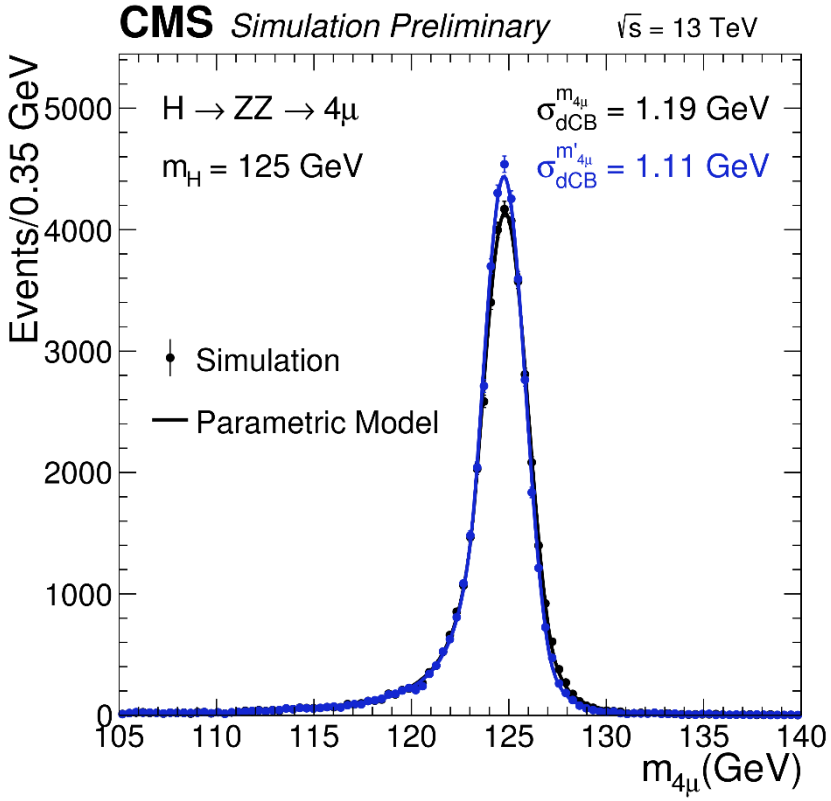
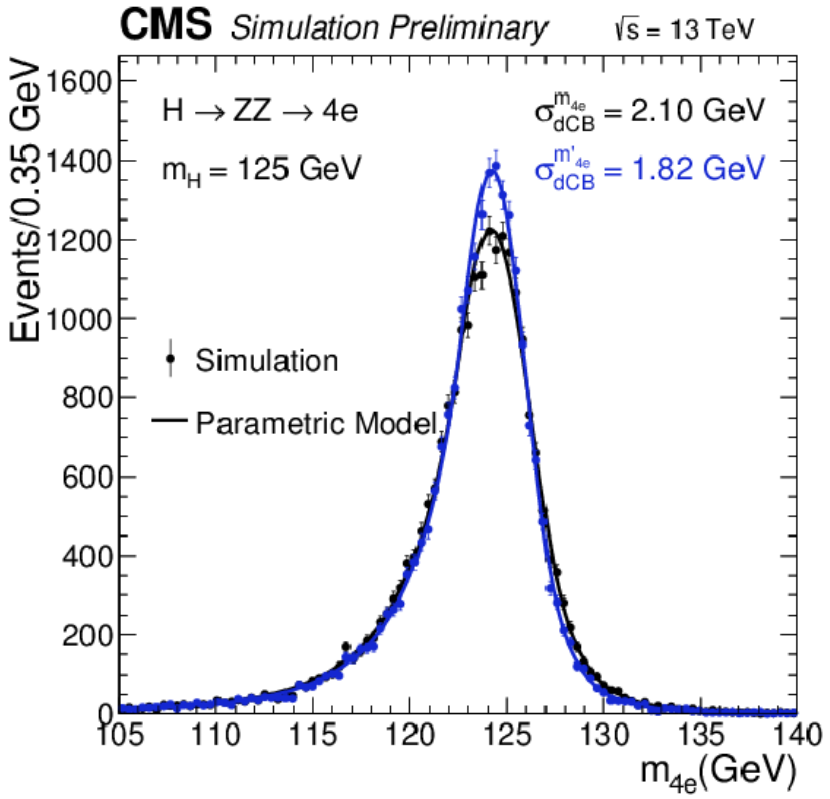
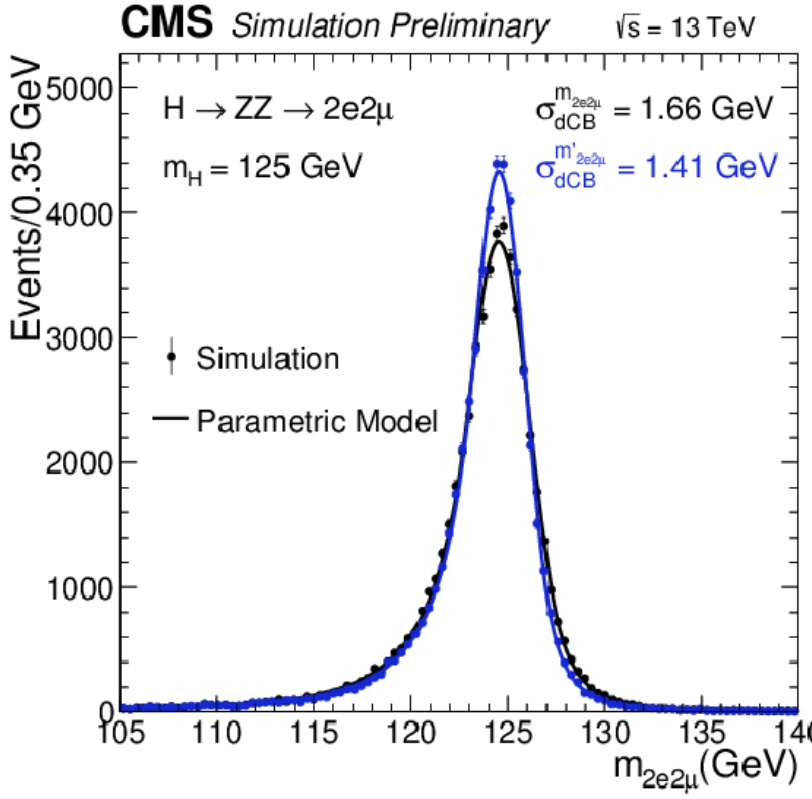
- Events are separated into categories based on the p_T and η of one of the two leptons in data/MC
- Fit di-lepton mass distributions to a Breit-Wigner parameterization convolved with a double-sided Crystal Ball (CB) function
- Extract offset in the measured peak position with respect to the nominal Z-boson mass
- Relative difference between data and simulation is propagated to the reconstructed four-lepton mass from simulated Higgs-boson events
- The uncertainty is determined to be 0.04% (0.3%) for the 4μ (4e) channels, respectively

$H \rightarrow ZZ^* \rightarrow 4l$: Mass resolution

With and without the kinematic refit using $m(Z_1)$ constraint





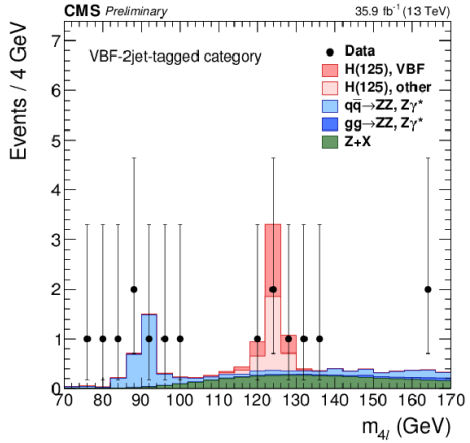


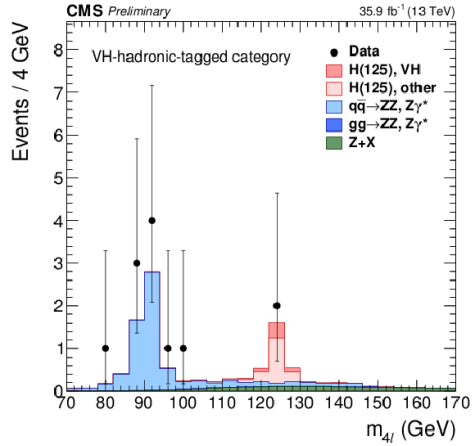
http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/HIG-16-041/index.html

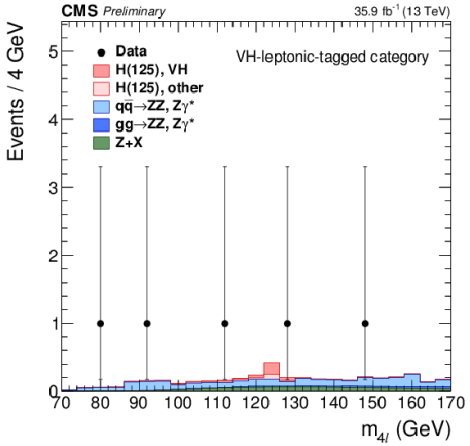
order

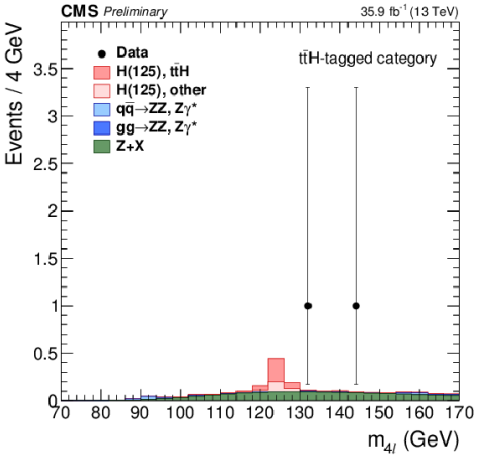
$H \to ZZ^* \to 4l$: categorization criteria

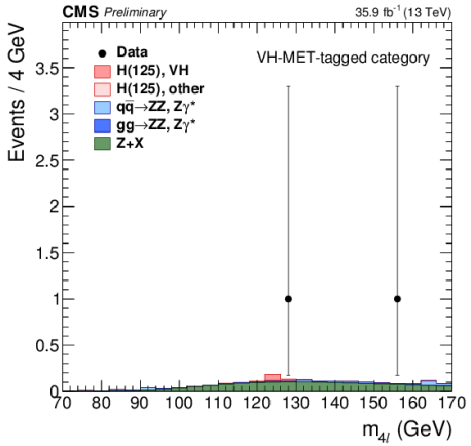
- **VBF-2jet-tagged category** requires exactly 4 leptons. In addition there must be either 2 or 3 jets of which at most 1 is b-tagged, or at least 4 jets and no b-tagged jets. Finally, $\mathcal{D}_{2\text{jet}} > 0.5$ is required.
- **VH-hadronic-tagged category** requires exactly 4 leptons. In addition there must be 2 or 3 jets, or at least 4 jets and no b-tagged jets. Finally, $\mathcal{D}_{\text{VH}} \equiv \max(\mathcal{D}_{\text{ZH}}, \mathcal{D}_{\text{WH}}) > 0.5$ is required.
- **VH-leptonic-tagged category** requires no more than 3 jets and no b-tagged jets in the event, and exactly 1 additional lepton or 1 additional pair of opposite sign same flavor leptons. This category also includes events with no jets and at least 1 additional lepton.
- **ttH-tagged category** requires at least 4 jets of which at least 1 is b-tagged, or at least 1 additional lepton.
- **VH-MET-tagged category** requires exactly 4 leptons, no more than 1 jet and E_T^{miss} greater than 100 GeV.
- **VBF-1jet-tagged category** requires exactly 4 leptons, exactly 1 jet and $\mathcal{D}_{1\text{jet}} > 0.5$.
- **Untagged category** consists of the remaining events.

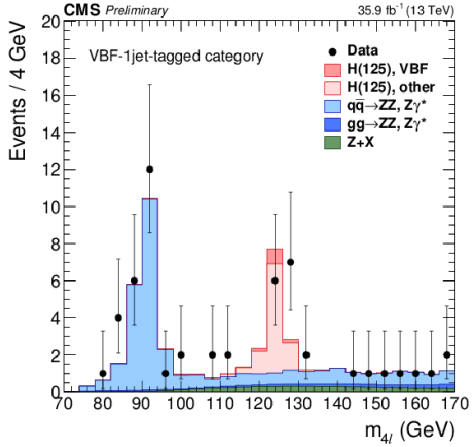


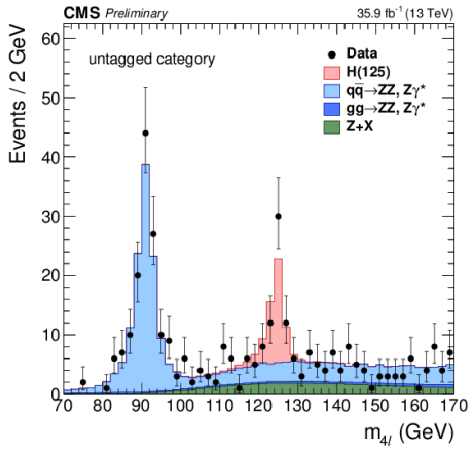












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$H \to ZZ^* \to 4l$: *Yields*

Channel	4e	4μ	$2e2\mu$	4ℓ
$q\bar{q} \to ZZ$	$192.7^{+18.6}_{-20.1}$	$360.2^{+24.9}_{-27.3}$	$471.0^{+32.6}_{-35.7}$	$1023.9^{+68.9}_{-76.0}$
$gg \to ZZ$	$41.2^{+6.3}_{-6.1}$	$69.0^{+9.5}_{-9.0}$	$101.7^{+14.0}_{-13.3}$	$211.8^{+28.9}_{-27.5}$
Z+X	$21.1^{+8.5}_{-10.4}$	$34.4^{+14.5}_{-13.2}$	$59.9^{+27.1}_{-25.0}$	$115.4^{+31.9}_{-30.1}$
Sum of backgrounds	$255.0^{+23.9}_{-25.1}$	$463.5^{+31.9}_{-33.7}$	$632.6^{+44.2}_{-46.1}$	$1351.1^{+85.8}_{-91.2}$
Signal ($m_H = 125$ GeV)	$12.0^{+1.3}_{-1.4}$	23.6 ± 2.1	30.0 ± 2.6	65.7 ± 5.6
Total expected	$267.0^{+24.9}_{-26.1}$	$487.1^{+33.1}_{-34.9}$	$662.6^{+45.7}_{-47.5}$	$1416.8^{+89.1}_{-94.3}$
Observed	293	505	681	1479

Mass>70 GeV

	Event category							
	Untagged	VBF-1j	VBF-2j	VH-hadr.	VH-lept.	VH-MET	$t\bar{t}H$	Inclusive
$gg \to H$	38.78	8.31	2.04	1.41	0.08	0.02	0.10	50.74
VBF	1.08	1.14	2.09	0.09	0.02	< 0.01	0.02	4.44
WH	0.43	0.14	0.05	0.30	0.21	0.03	0.02	1.18
ZH	0.41	0.11	0.04	0.24	0.04	0.07	0.02	0.93
$t\bar{t}H$	0.08	< 0.01	0.02	0.03	0.02	< 0.01	0.35	0.50
Signal	40.77	9.69	4.24	2.08	0.38	0.11	0.51	57.79
$q\bar{q} \to ZZ$	19.18	2.00	0.25	0.30	0.27	0.01	0.01	22.01
$gg \to ZZ$	1.67	0.31	0.05	0.02	0.04	0.01	< 0.01	2.09
Z+X	10.79	0.88	0.78	0.31	0.18	0.30	0.27	13.52
Total expected	72.41	12.88	5.32	2.71	0.86	0.43	0.79	95.41
Observed	73	13	4	2	1	1	0	94

Mass range 118-130GeV

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$H \rightarrow ZZ^* \rightarrow 4l$: *Fiducial phase space*

Requirements for the H $\rightarrow 4\ell$ fiducial phase space	
Lepton kinematics and isolation	
Leading lepton p_T	$p_T > 20$ GeV
Next-to-leading lepton p_T	$p_T > 10$ GeV
Additional electrons (muons) p_T	$p_T > 7(5)$ GeV
Pseudorapidity of electrons (muons)	$\lvert\eta\rvert < 2.5(2.4)$
Sum of scalar p_T of all stable particles within $\Delta R < 0.3$ from lepton	$< 0.35 \cdot p_T$
Event topology	
Existence of at least two same-flavor OS lepton pairs, where leptons satisfy criteria above	
Inv. mass of the Z_1 candidate	$40\,\text{GeV} < m_{Z_1} < 120\,\text{GeV}$
Inv. mass of the Z_2 candidate	$12\,\text{GeV} < m_{Z_2} < 120\,\text{GeV}$
Distance between selected four leptons	$\Delta R(\ell_i, \ell_j) > 0.02$ for any $i \neq j$
Inv. mass of any opposite sign lepton pair	$m_{\ell^+\ell'^-} > 4\,\text{GeV}$
Inv. mass of the selected four leptons	$105\,\text{GeV} < m_{4\ell} < 140\,\text{GeV}$

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H→γγ : Photon energy

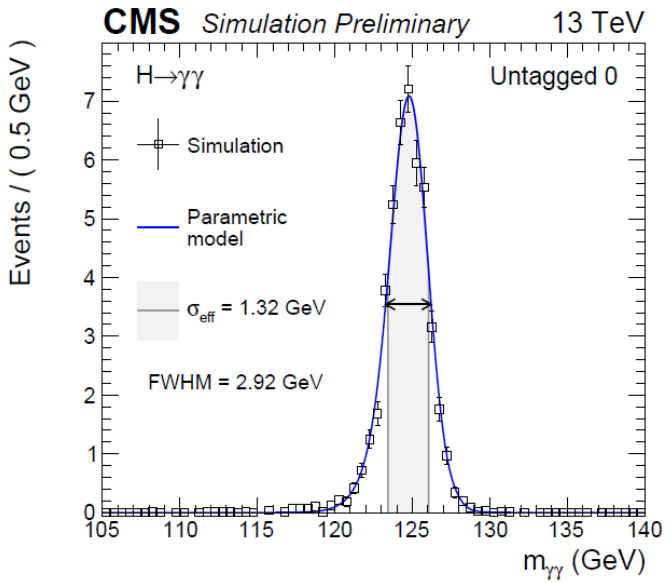
$$m_{\gamma\gamma} = \sqrt{2E_1E_2(1-\cos\theta)}$$

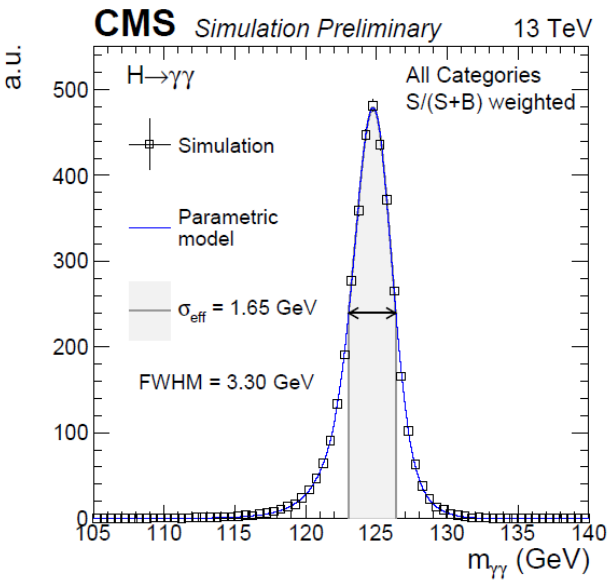
- **Electro-magnetic calorimeter response**
  - corrected for **change in time**
  - **inter-calibrated** to be uniform in η/ϕ
  - adjustment of **absolute scale**

- **Energy and its uncertainty** corrected for local and global shower containment: **regression targeting E_{true}/E_{reco}**

- **Scale vs time and resolution calibration:** **Z→ee peak** used as reference

- **Corrected energies and resolutions used in the analysis**





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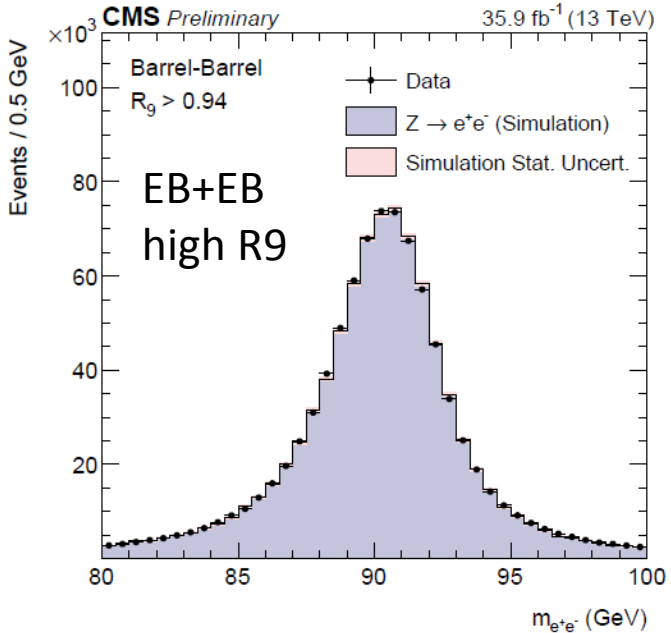
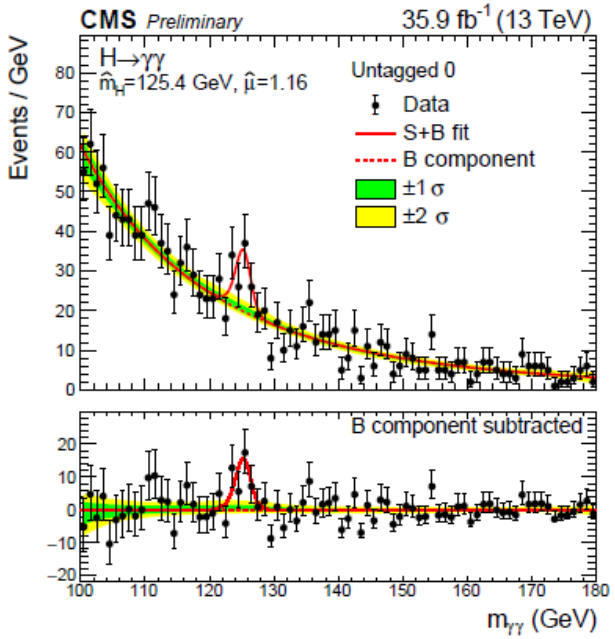
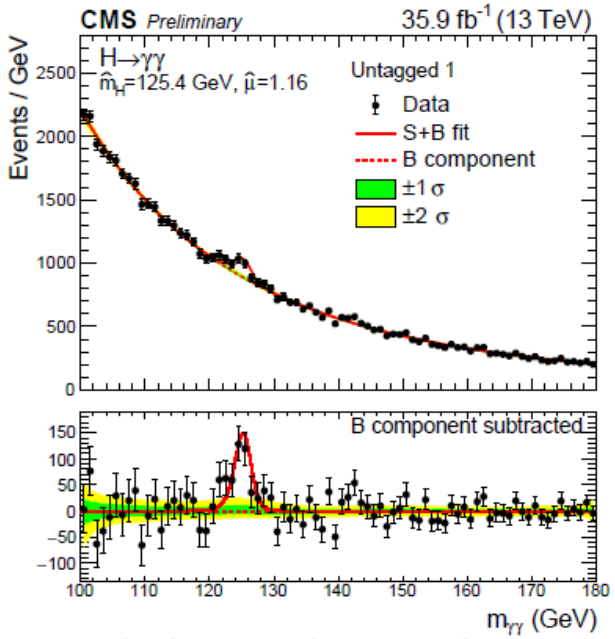
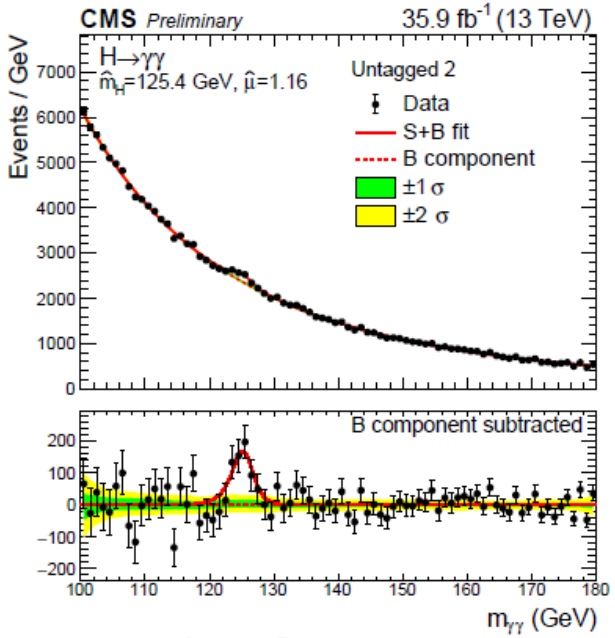


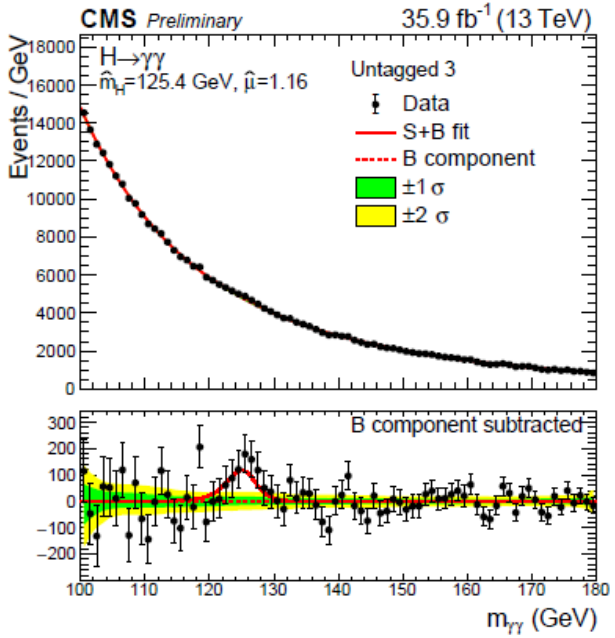
R9 and η dependent scaling and MC smearing

H→γγ : Untagged









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H→γγ : ttH

Objects

- **Jets**:
  - ak4PFCHS; pT>25 GeV; |η| <2.4
- **Bjets**:
  - PF CSV v2 (medium WP)
- **Muons**:
  - p_T>20 GeV; |η|<2.4; "tight muon"; miniIso<0.06
- **Electrons**:
  - p_T>20 GeV; |η|<2.5; 1.442<|η| <1.566; loose EGM ID

leptonic

$t\bar{t} \to bl\nu_l\bar{b}q\bar{q}'$ $t\bar{t} \to bl\nu_l\bar{b}l'\nu_{l'}$

- **Selection**
  - (sub)leading photon $p_T/M_{\gamma\gamma}$>0.5(.25)
  - At least 2 jets with ΔR(j, γ or l) >0.4
  - At least one b-tagged jet
  - At least 1 lepton ΔR(l,γ)>0.35
  - For electron: $|M_{e\gamma}-M_Z|$>5 GeV
  - diphoton mva > 0.107

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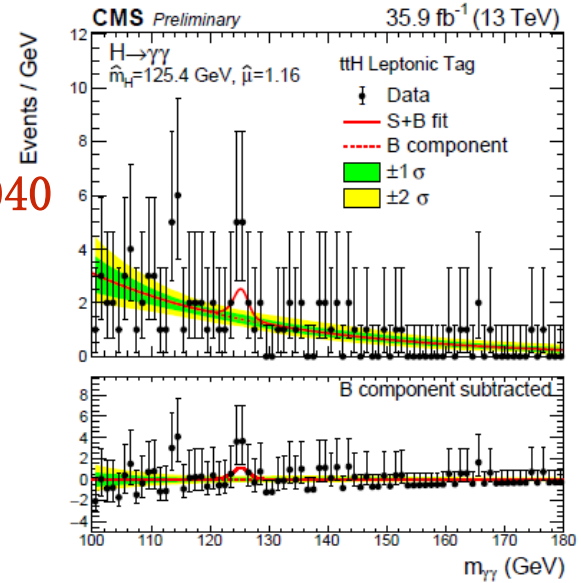
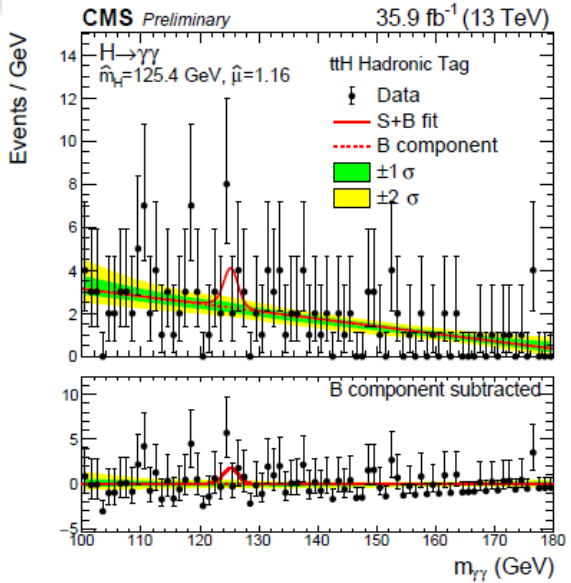


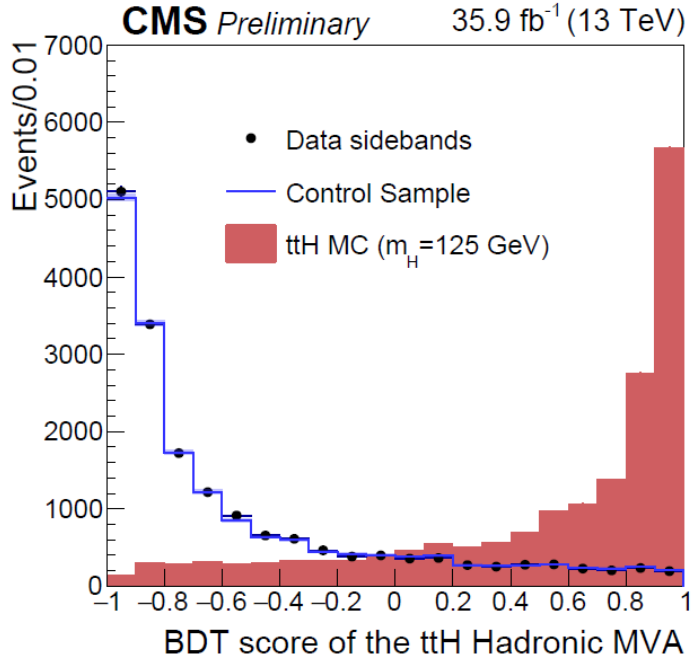


hadronic

$t\bar{t} \to bq\bar{q}'\bar{b}q\bar{q}'$

- **Preselection:**
  - at least 3 jets
  - at least 1 loose b-jet
- 2-d optimization of diphoton MVA and ttH MVA
  - diphoton MVA > 0.577
  - ttH MVA > 0.75

Cut-based strategy replaced with mva to improve μttH sensitivity



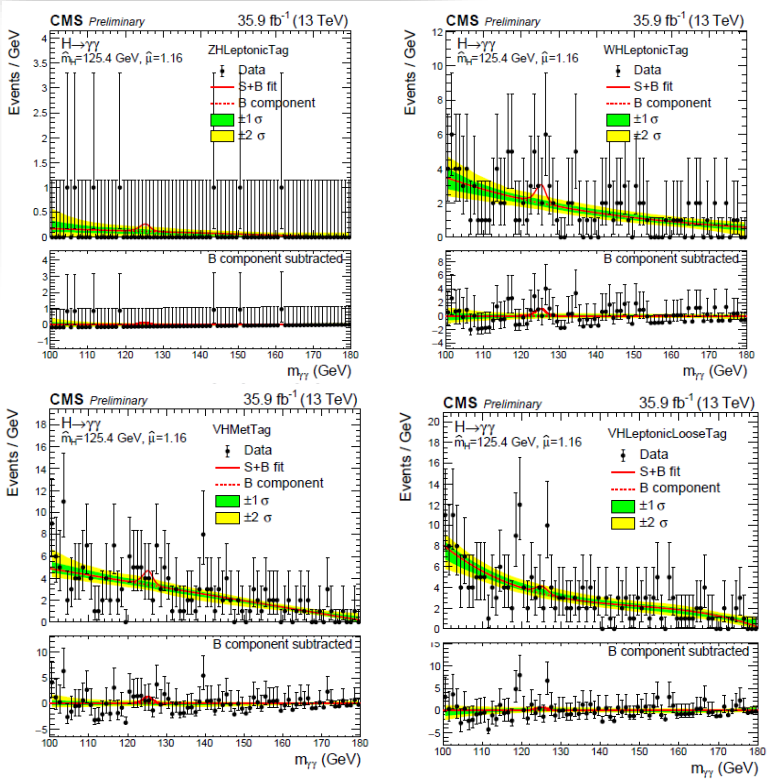
H→γγ : VH

3 VH leptonic categories $W \to l\nu$ or $Z \to l\bar{l}$

- **Muons**
  - p_T>20 GeV; |η|<2.4; "tight muon"; pf isolation < 0.25 (loose WP)
- **Electrons**
  - p_T>20 GeV; |η|<2.5; 1.442<|η|<1.566; loose EGM ID
- **Photons**
  - (sub)leading $p_T/m_{\gamma\gamma}$>0.375(0.25)

Diphoton MVA cuts were tuned

- **WH leptonic:**
  - one lepton:
  - p_T^{miss} > 45 GeV
  - ΔR(γ, l) >1.0
  - diphoton mva>0.28
  - <=2 jets
- **ZH leptonic:**
  - two leptons:
  - 70<m_{ll}<110 GeV
  - ΔR(γ, μ(e)) >0.5(1.0)
  - diphoton mva>0.107
- **VH leptonic loose:**
  - one lepton:
  - p_T^{miss} < 45 GeV
  - ΔR(γ, l) >1.0
  - diphoton mva>0.28
  - <=2 jets



MET category

- $W \to l\nu$ (lepton out of acceptance) or $Z \to \nu\nu$
  - p_T^{miss} > 85 GeV
  - Δφ(γγ, p_T^{miss}) >2.4
  - diphoton MVA > 0.790 (0.6 before flattening)

hadronic category W->jj or Z->jj

- **Photons**
  - (sub)leading $p_T/m_{\gamma\gamma}$>0.5(0.25)
  - $p_T^{\gamma\gamma}/m_{\gamma\gamma}$>1.0
- **Jets**
  - At least two jets
  - p_T > 40 GeV
  - |η| < 2.4
  - 60<m_{jj} < 120 GeV
  - |cosθ*| < 0.5

Diphoton MVA > 0.906

- before flattening (0.7)

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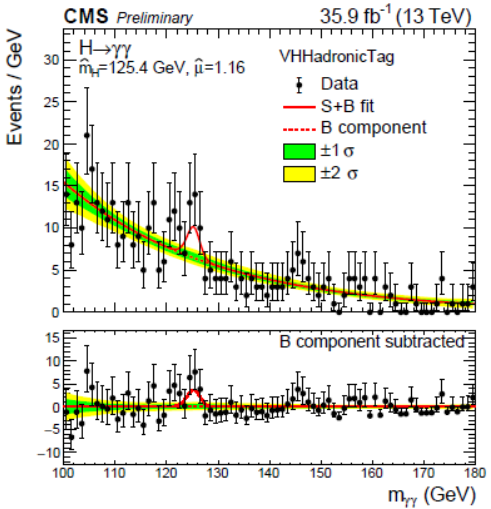

H→γγ : VBF Tag

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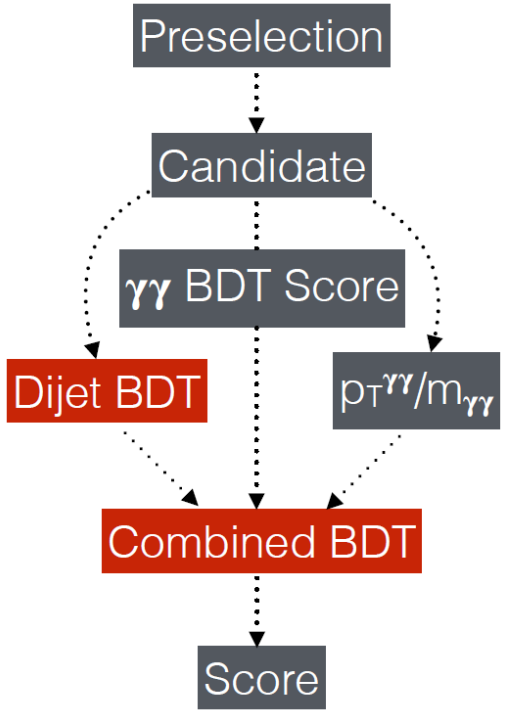
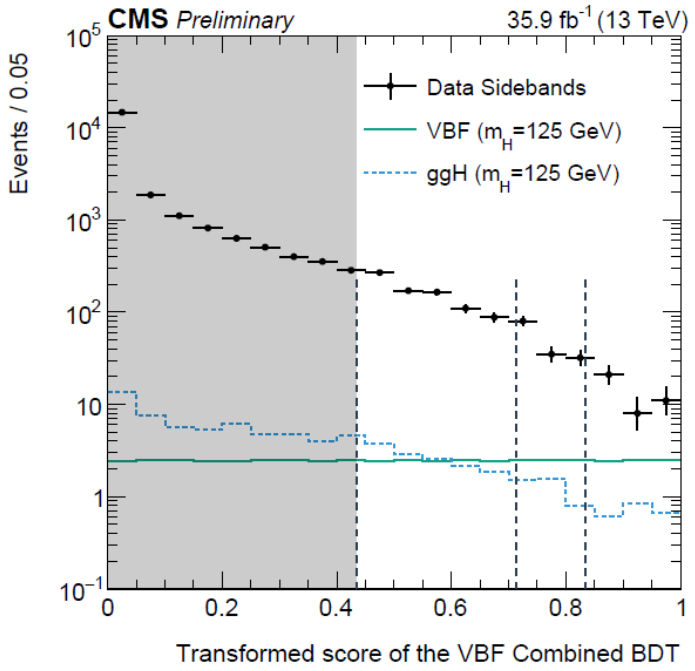
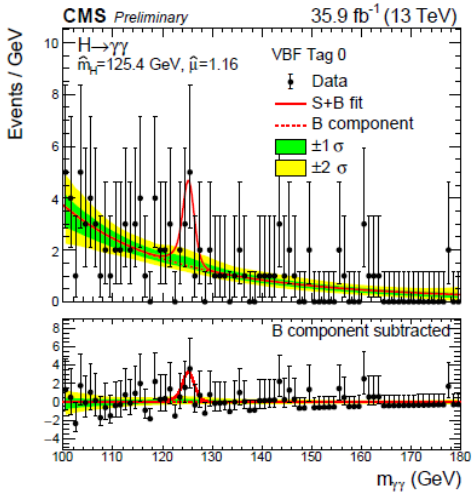
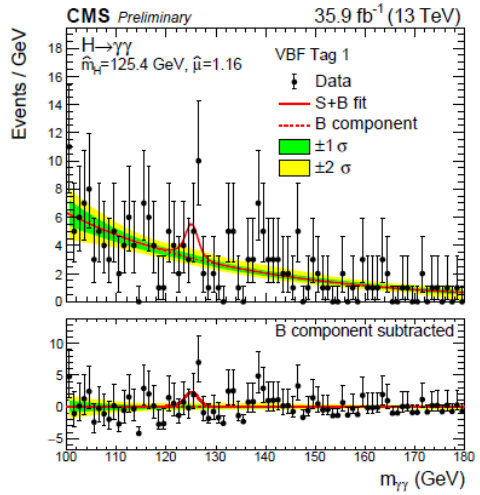
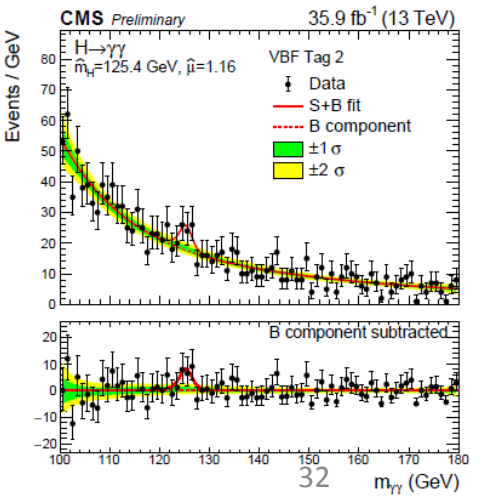
- Preselection (ICHEP): Two jets with pT_{j1}>30GeV, pT_{j2} >20GeV, |η|<4.7, m_{jj}>250GeV
- Main Structure: two parts, the Dijet BDT & Combined BDT
- Dijet BDT: separates VBF dijet from BG (incl. gluon fusion) using dijet kinematics
- Combined BDT: separates signal/BG diphotons using diphoton BDT, dijet BDT and scaled diphoton pT
- 3 VBF-tagged categories using the combined MVA with boundary optimisation: cuts on combined score are simultaneously optimised for max significance across all categories







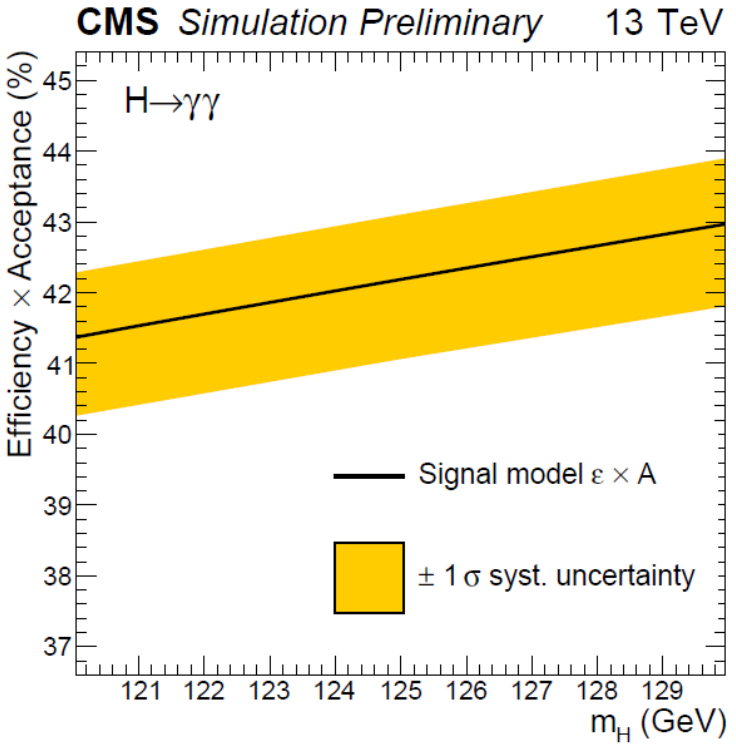




H→γγ : signal efficiency and expected Nevt

- Kinematic selection
  - Leading photon : $E_T / m_{\gamma\gamma} > 1/3$
  - Subleading photon : $E_T / m_{\gamma\gamma} > 1/4$
  - Photons $|\eta| < 2.5$

- Preselection to be tighter than HLT, selections on photon ID MVA and diphoton BDT

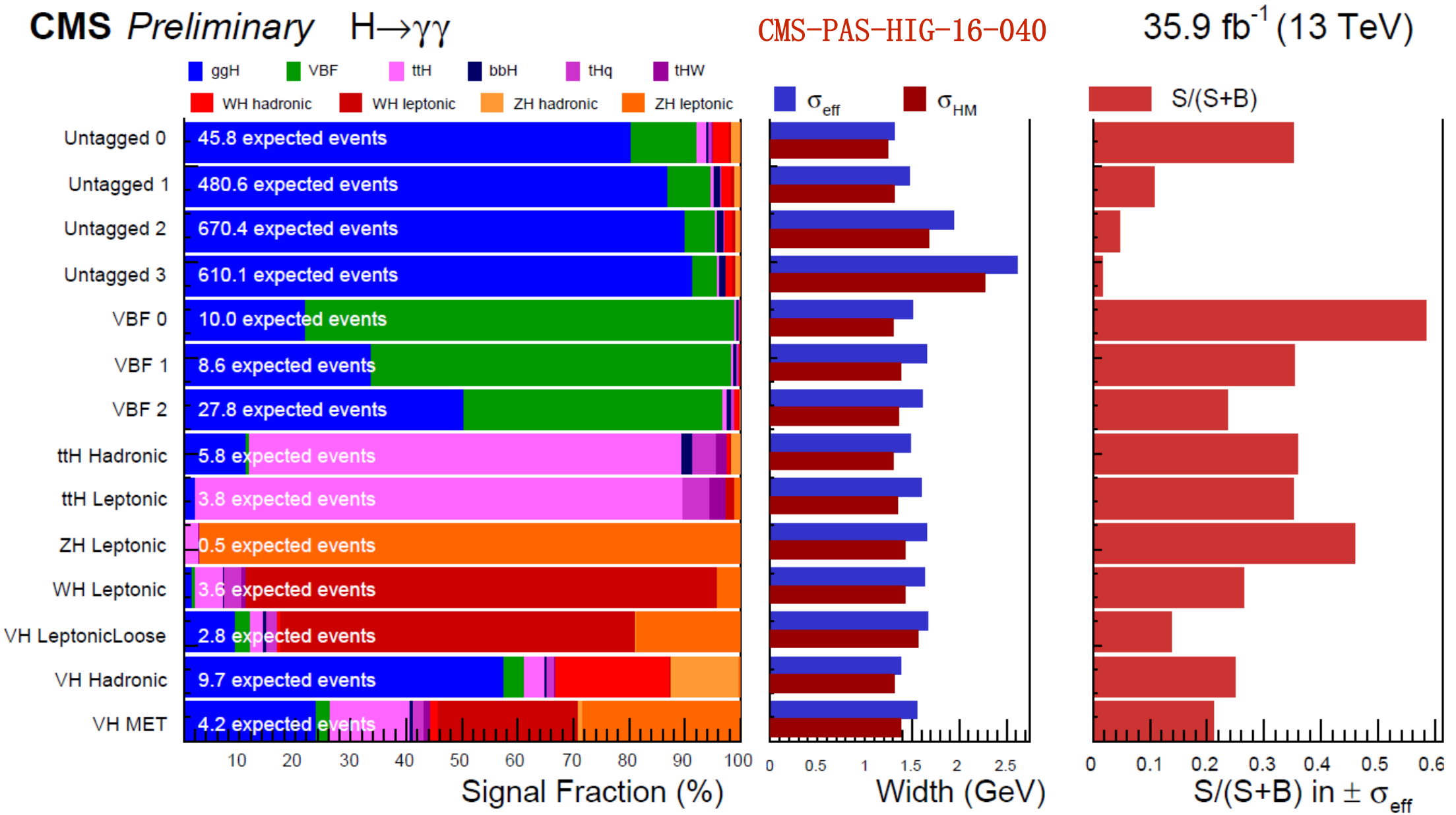


CMS-PAS-HIG-16-040

Event Categories	SM 125 GeV Higgs boson expected signal													Bkg
	Total	ggH	VBF	ttH	bbH	tHq	tHW	WH lep	ZH lep	WH had	ZH had	σ_{eff}	σ_{HM}	(GeV^{-1})
Untagged 0	45.83	80.19 %	11.75 %	1.83 %	0.40 %	0.47 %	0.22 %	0.41 %	0.19 %	2.96 %	1.58 %	1.32	1.24	21.92
Untagged 1	480.56	86.81 %	7.73 %	0.56 %	1.15 %	0.13 %	0.02 %	0.47 %	0.27 %	1.81 %	1.04 %	1.47	1.32	924.21
Untagged 2	670.45	89.76 %	5.48 %	0.44 %	1.18 %	0.08 %	0.01 %	0.51 %	0.34 %	1.40 %	0.81 %	1.94	1.68	2419.53
Untagged 3	610.07	91.13 %	4.51 %	0.48 %	1.07 %	0.07 %	0.01 %	0.55 %	0.30 %	1.21 %	0.69 %	2.62	2.28	4855.00
VBF 0	10.01	21.69 %	77.09 %	0.34 %	0.35 %	0.29 %	0.03 %	0.03 %	0.00 %	0.19 %	-0.01 %	1.51	1.30	1.60
VBF 1	8.64	33.58 %	64.64 %	0.39 %	0.52 %	0.36 %	0.04 %	0.13 %	0.03 %	0.24 %	0.07 %	1.66	1.38	3.25
VBF 2	27.76	50.14 %	46.46 %	0.81 %	0.73 %	0.53 %	0.07 %	0.20 %	0.06 %	0.71 %	0.27 %	1.61	1.36	18.89
ttH Hadronic	5.85	10.99 %	0.70 %	77.54 %	2.02 %	4.13 %	2.02 %	0.09 %	0.05 %	0.63 %	1.82 %	1.48	1.30	2.40
ttH Leptonic	3.81	1.90 %	0.05 %	87.48 %	0.08 %	4.73 %	3.04 %	1.53 %	1.15 %	0.02 %	0.02 %	1.60	1.35	1.50
ZH Leptonic	0.49	0.00 %	0.00 %	2.56 %	0.00 %	0.02 %	0.13 %	0.00 %	97.30 %	0.00 %	0.00 %	1.65	1.43	0.12
WH Leptonic	3.61	1.26 %	0.59 %	5.18 %	0.18 %	3.03 %	0.73 %	84.48 %	4.33 %	0.12 %	0.09 %	1.64	1.43	2.09
VH LeptonicLoose	2.75	9.16 %	2.70 %	2.34 %	0.57 %	1.81 %	0.13 %	63.62 %	18.87 %	0.56 %	0.23 %	1.67	1.56	3.50
VH Hadronic	9.69	57.38 %	3.68 %	3.61 %	0.35 %	1.39 %	0.27 %	0.17 %	0.42 %	20.47 %	12.26 %	1.38	1.31	7.22
VH Met	4.25	23.63 %	2.46 %	14.45 %	0.41 %	2.00 %	1.14 %	25.17 %	28.60 %	1.32 %	0.82 %	1.55	1.38	3.49
Total	1883.77	86.96 %	7.09 %	1.00 %	1.09 %	0.15 %	0.04 %	0.81 %	0.42 %	1.55 %	0.89 %	1.95	1.62	8264.73

Table 3: The expected number of signal events per category and the percentage breakdown per production mode in that category. The σ_{eff}, computed as the smallest interval containing 68.3% of the invariant mass distribution, and σ_{HM}, computed as the width of the distribution at half of its highest point divided by 2.35 are also shown as an estimate of the $m_{\gamma\gamma}$ resolution in that category. The expected number of background events per GeV around 125 GeV is also listed.

H→γγ : signal fractions



H→Zγ

PLB 726 (2013) 587-609

Rare decay

- SM: **BR(H→Zγ) = 0.1%**
- Similarity with **H→γγ**
- Sensitivity limited by $Z \to 2\ell$

7+8 TeV (24.6 fb^{-1})

- Search in Z(ee)+ γ and Z(μμ)+ γ final states
- 5 event cat's (jets, leptons, photon)
- Use invariant mass $\mathbf{m_{ll\gamma}}$
- Exclusion limit at 125 GeV:

  Observed: >**9.5 x BR$_{SM}$** @95%CL

  Expected: >10 x **BR$_{SM}$**