Flagship Measurements on the Higgs Boson and new physics searches at LHC

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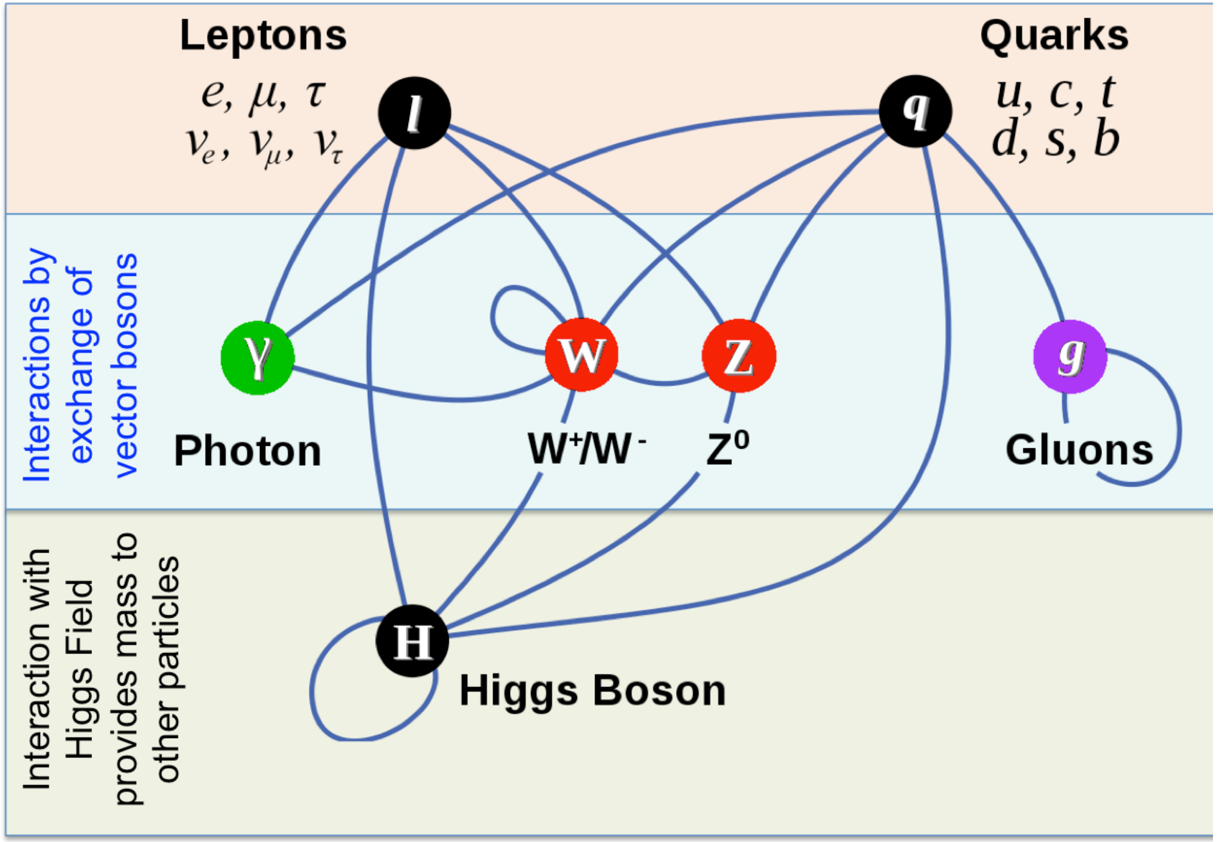
Outline

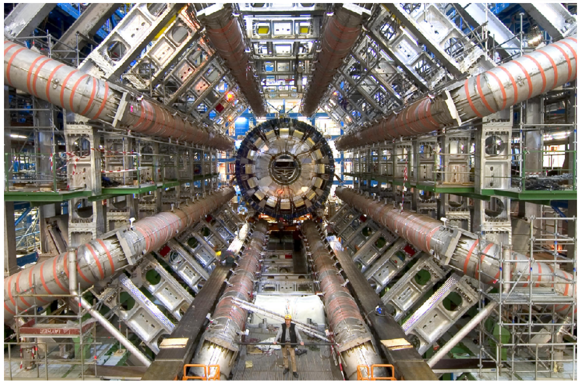
- **Accelerator and Detectors**
  - LHC
  - CMS and ATLAS

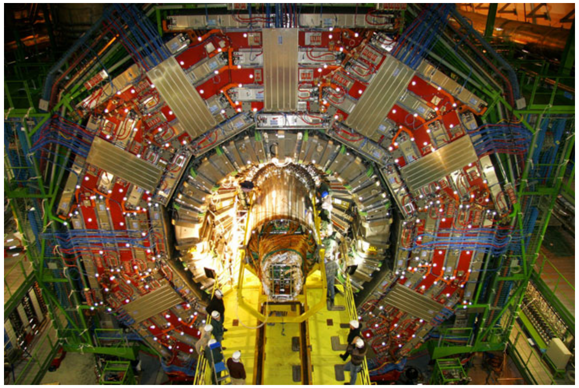
- **Study of Higgs Properties using ATLAS and CMS data**
  - Mass of Higgs
  - Production Mechanisms
  - Branching Fractions, Coupling
  - Cross Sections
    - Fiducial Cross Section
    - Differential Distributions

- **BSM Searches mediated by Higgs**

Higgs Boson...

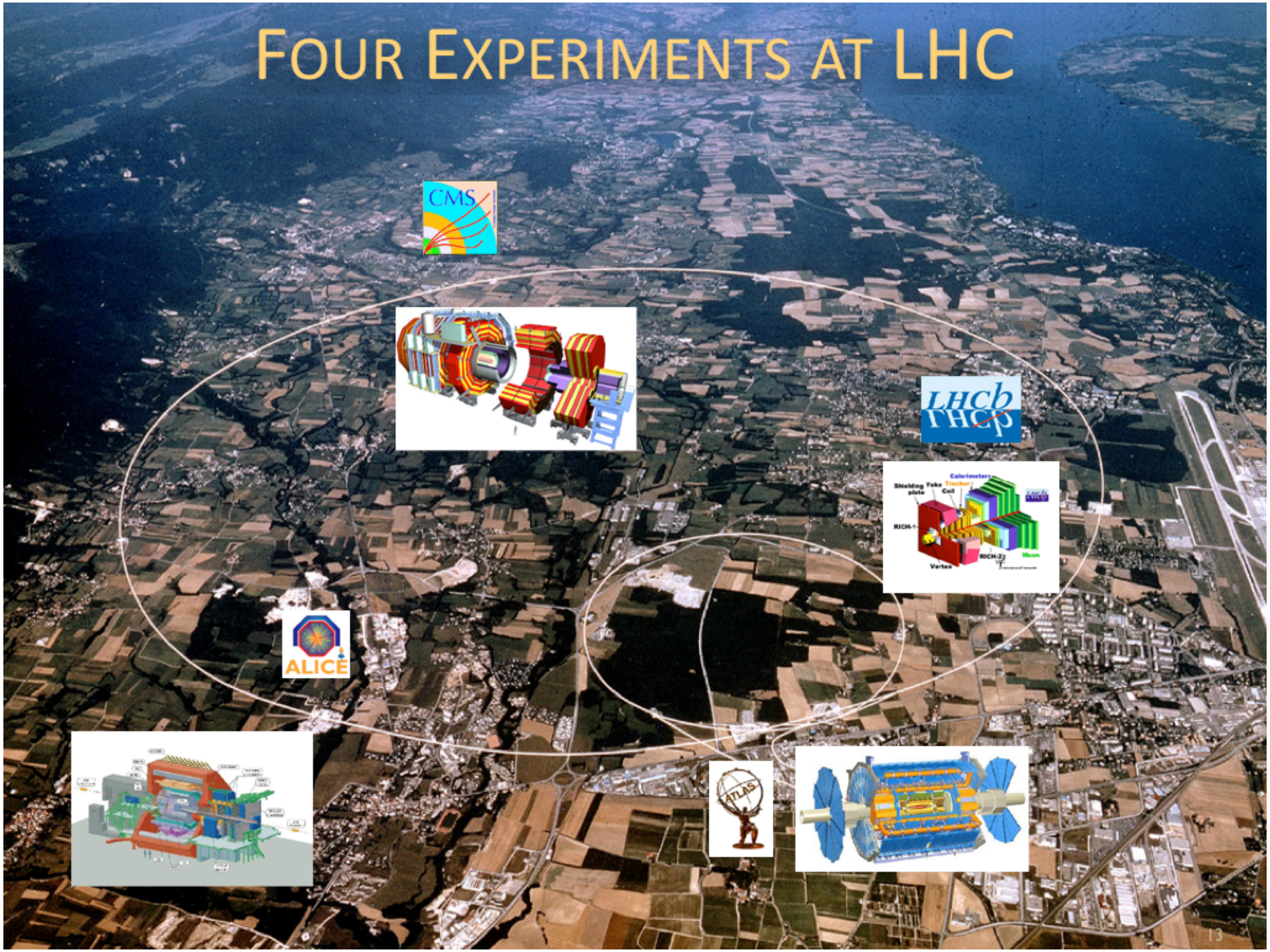






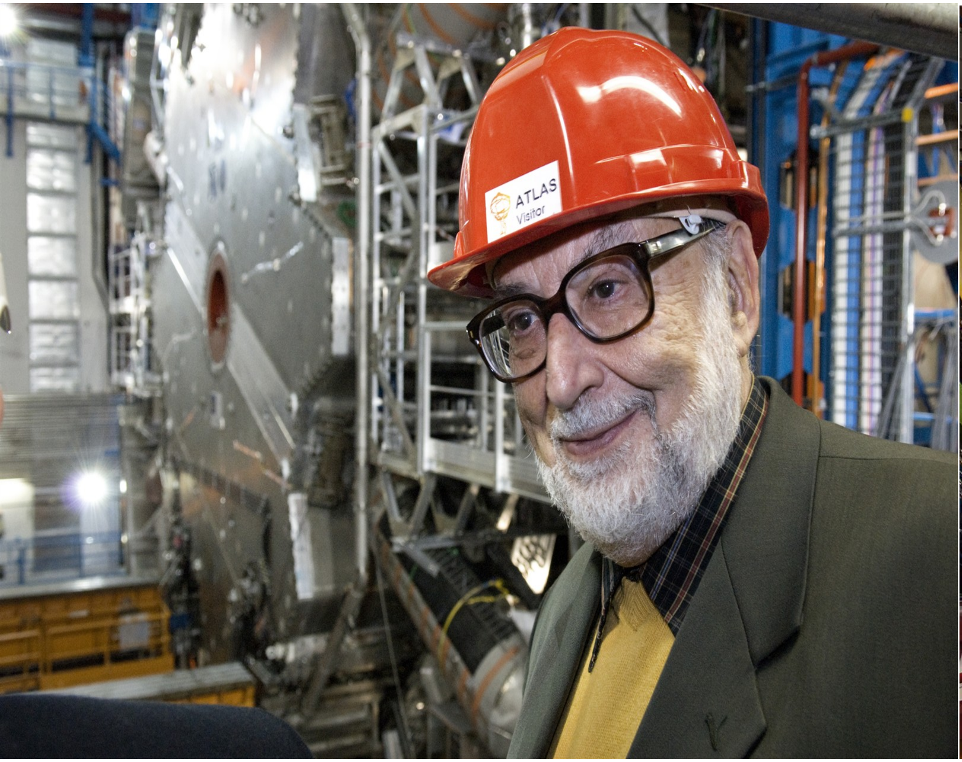
- Higgs Boson predicted in 1964
- Discovery of new boson by ATLAS and CMS detector announced in 2012 followed by its Higgs like nature confirmation in 2013
- Noble prize awarded for their predictions to P. Higgs and F. Englert in 2013

Detectors at LHC

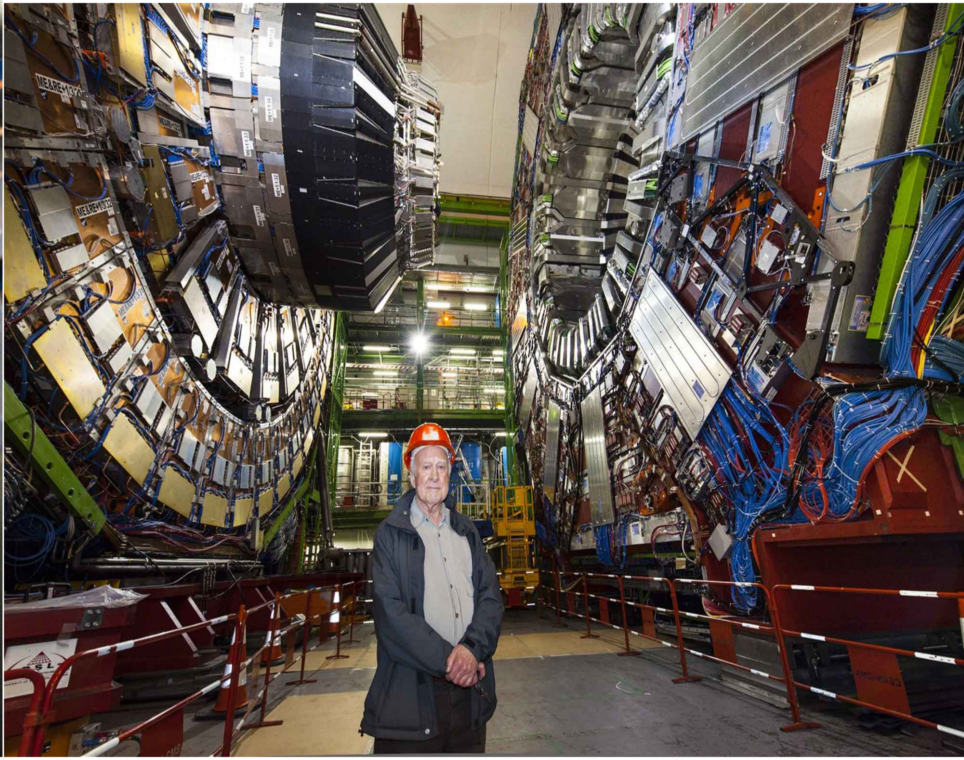


Accelerator (26.7 km)
pp collision Energy = 13000 GeV
No. Of bunch crossings per second 40 Millions

ATLAS and CMS Detectors at LHC

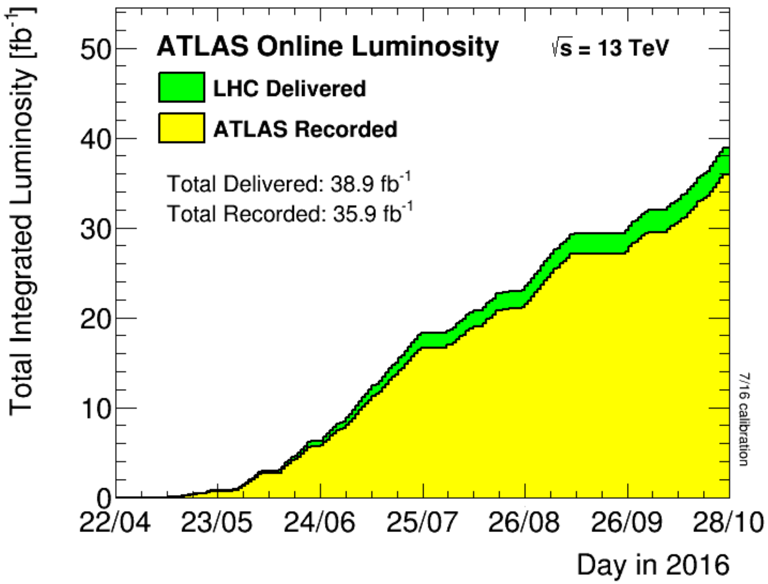


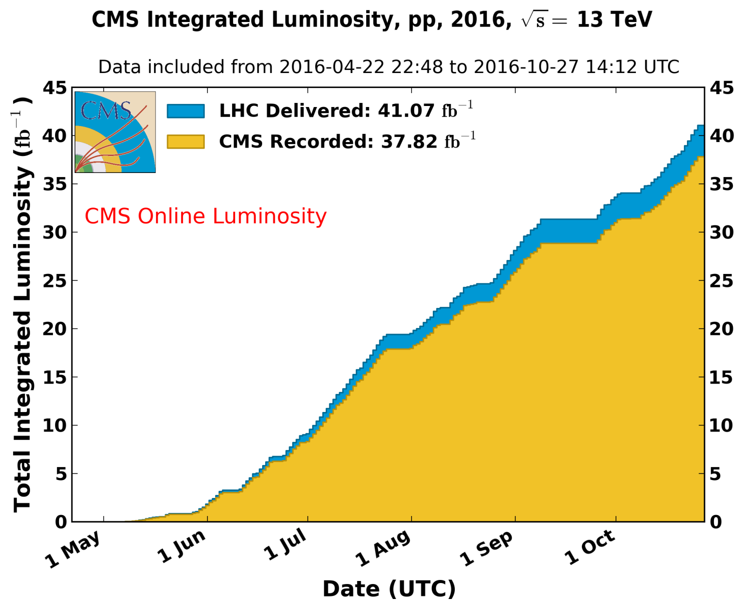
F. Englert @ ATLAS

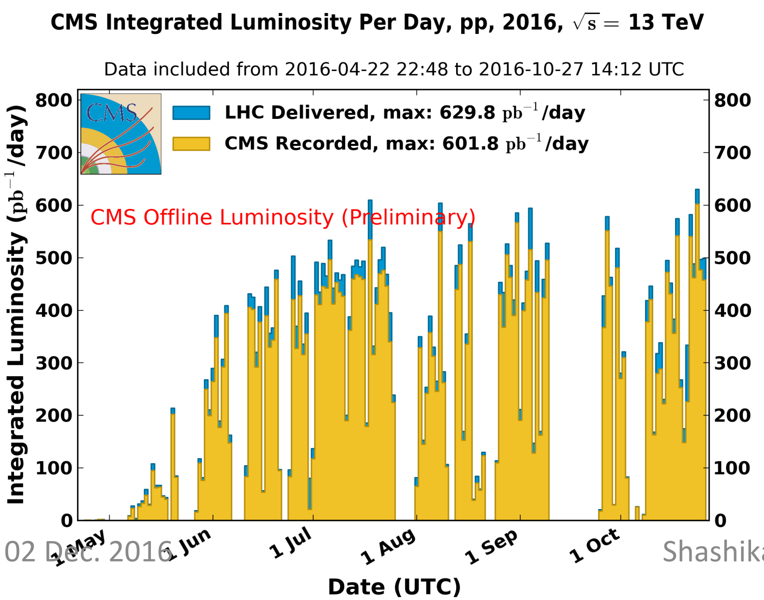


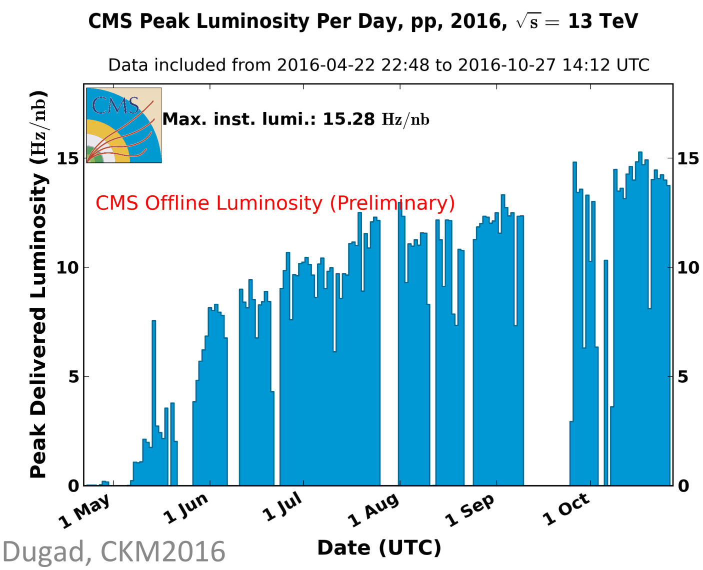
P. Higgs @ CMS

Outstanding Performance of LHC



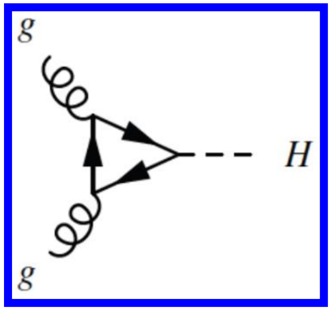




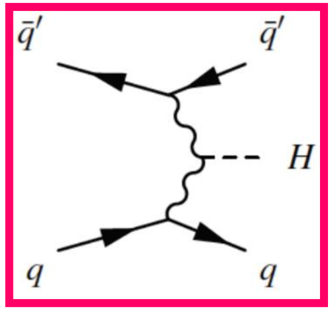


Analysis presented with ~ 1/3rd of the data

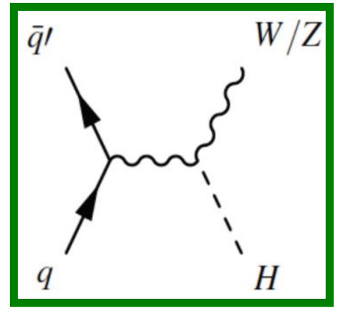
Higgs Production Mechanisms



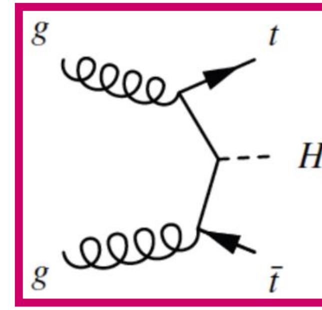
Gluon-Gluon Fusion
87.4%



Vector Boson Fusion
7.1%



W/ZH (Higgs-strahlung)
4.9%



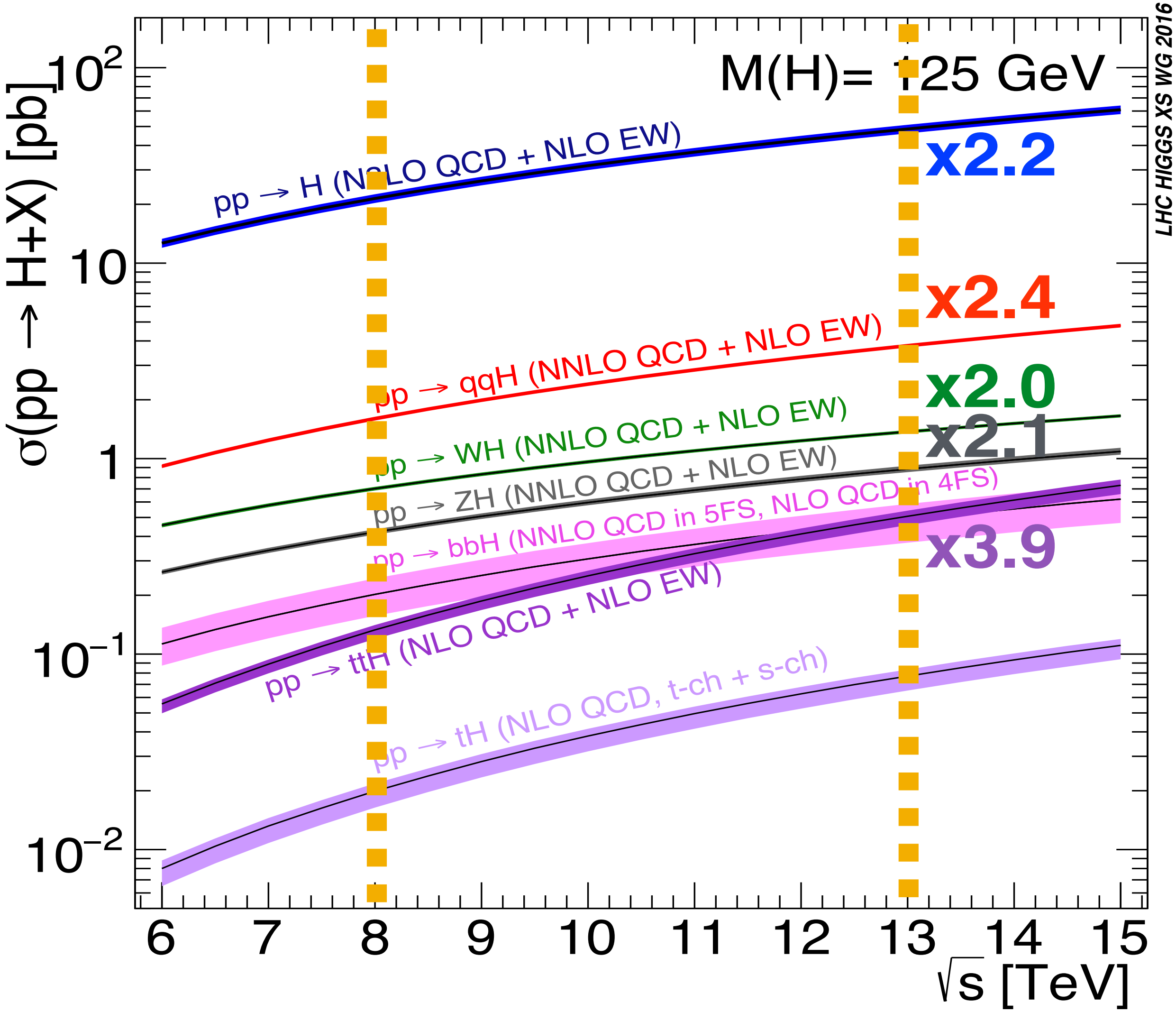
Top Fusion ($t\bar{t}H$)
0.6 %

$\sqrt{s}$	SM Higgs boson theoretical production cross-section in *pb* for $m_H = 125\ GeV$					
	ggF	VBF	WH	ZH	ttH	Total
7 TeV	$16.85^{+5.5\%}_{-7.7\%}$	$1.24^{+2.2\%}_{-2.2\%}$	$0.58^{+2.2\%}_{-2.3\%}$	$0.34^{+3.1\%}_{-2.8\%}$	$0.09^{+5.6\%}_{-10.0\%}$	19.1
8 TeV	$21.4^{+5.4\%}_{-7.6\%}$	$1.60^{+2.2\%}_{-2.2\%}$	$0.70^{+2.1\%}_{-2.2\%}$	$0.42^{+3.4\%}_{-2.9\%}$	$0.13^{+5.9\%}_{-10.1\%}$	24.25
13 TeV	$48.58^{+5.6\%}_{-7.4\%}$	$3.78^{+2.1\%}_{-2.1\%}$	$1.37^{+2.0\%}_{-2.0\%}$	$0.88^{+4.1\%}_{-3.5\%}$	$0.51^{+6.8\%}_{-9.8\%}$	55.12

	7 TeV	8 TeV	13 TeV
Luminosity (CMS+ATLAS)	~12 fb^{-1}	~45 fb^{-1}	~80 fb^{-1}
Cross Section	19.1 pb	24.3 pb	55.1 pb
# of Higgs (x 10^{6})	0.23	1.09	4.41

LHCHXSWG YR4 arXiv:1610.07922

Higgs Production Cross Sections



Higgs Decay Modes

Decay Mode	B.R. (%)	Effective B.R. (%)	Mass Resolution (%)	Detection Sensitivity (S/B)
H → ϒ ϒ	0.228	0.228	1-2	<1
H → Z Z^* → 4l	2.67	0.0136	1-2	>1
H → W W^* → 2l 2ν	21.6	1.01	30	<1
H → $\tau^+ \tau^-$	6.30	6.30	10-20	<1
H → $\mu^+ \mu^-$	0.022	0.022	1-2	<<1
H → b bbar	57.5	57.5	X	<<1
H → c cbar	2.90	2.90	X	X
H → g g	8.56	8.56	X	X

Fiducial Cross Section

- **Cross sections measured in a phase space covered by observations are sensitive to the kinematics of production, decay mechanism, detector acceptance etc.**

- **Theoretical calculations of cross sections (fiducial cross section) estimated at par with phase space covered by experimental data reduces systematic uncertainties on calculations**

$$\sigma^{tot} = \frac{N_S}{\mathcal{A}.\mathcal{C}.\mathcal{B}.\mathcal{L}_{int}}$$

$$\sigma^{fid}_{channel} = \frac{N_S}{\mathcal{C}.\mathcal{L}_{int}}$$

$\mathcal{A}$: kinematic and geometric acceptance in the fiducial volume

$\mathcal{B}$: Branching Fraction

C : detector correction factor (reco., trigger and identification efficiency, resolution etc.)

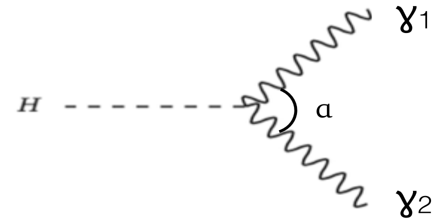
N_s : number of measured signal events (after background subtraction)

Coupling Strengths using H→ γ γ

Higgs →γ γ

Vertex ID

- **Vertex assignment crucial for di-photon mass resolution**
  - $|Z_{chosen} - Z_{true}| < 1$ cm



Photon ID

- **ATLAS:**
  - photon direction uses calorimeter data
  - Shower shape, isolation
  - $p_T(Y) > 25$ GeV, $|\eta(Y)| < 2.37$, excluding $1.37<|\eta(Y)|<1.52$
  - $p_T(Y_1) > 0.35m_{YY}$, $p_T(Y_2) > 0.25m_{YY}$
- **CMS:**
  - MVA based classifier to distinguish between prompt photons and fake photons
  - Shower shape, particle flow, isolation
  - $p_T(Y_1) > 30$ GeV, $p_T(Y_2) > 20$ GeV, $|\eta(Y)| < 2.5$),
  - excluding $1.44<|\eta(Y)|<1.57$, $p_T(Y_1) > 0.33\ m_{YY}$, $p_T(Y_2) > 0.25m_{YY}$
- **Di-photon mass:** $m_{\gamma\gamma} = \sqrt{2E_{\gamma 1}E_{\gamma 2}(1-\cos\alpha)}$

Backgrounds: Y-Y, Y-jet, jet-jet

Run 2: Di-photon mass distribution

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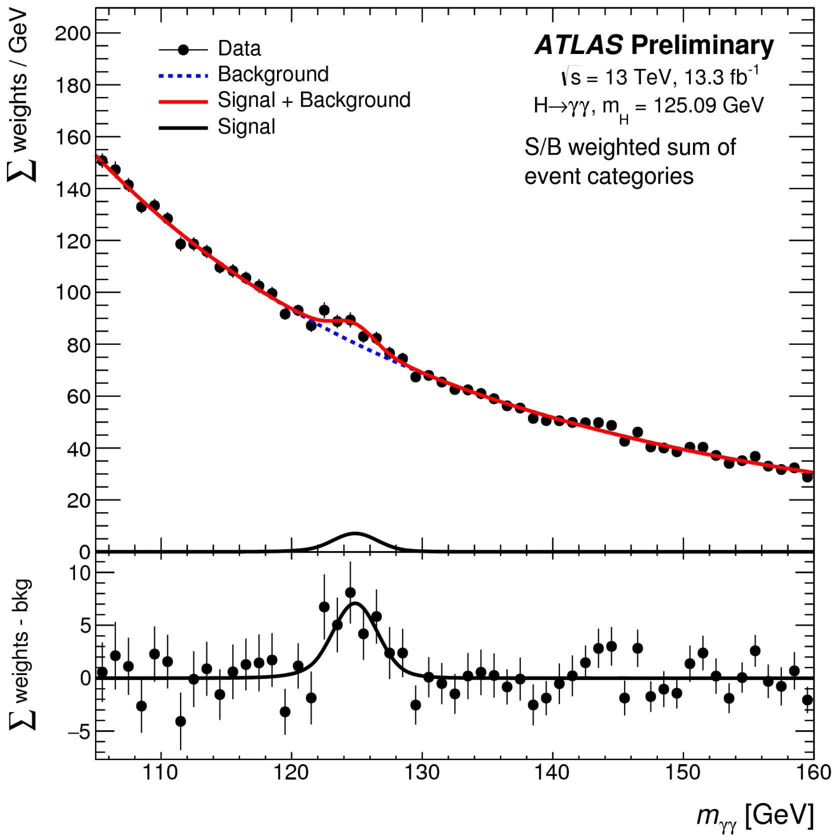
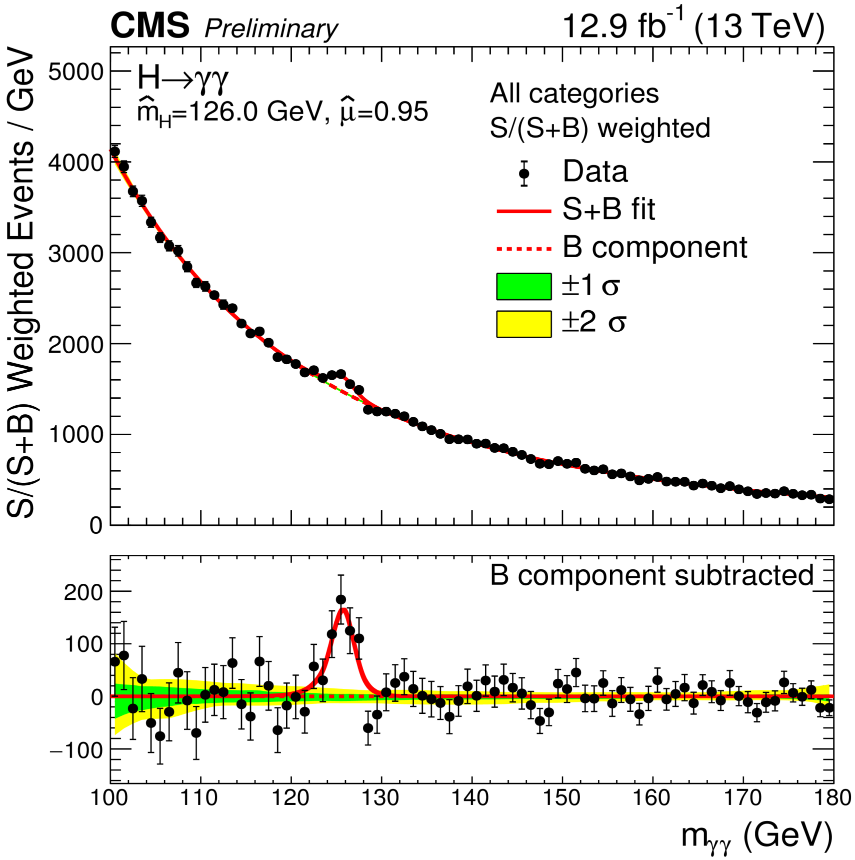


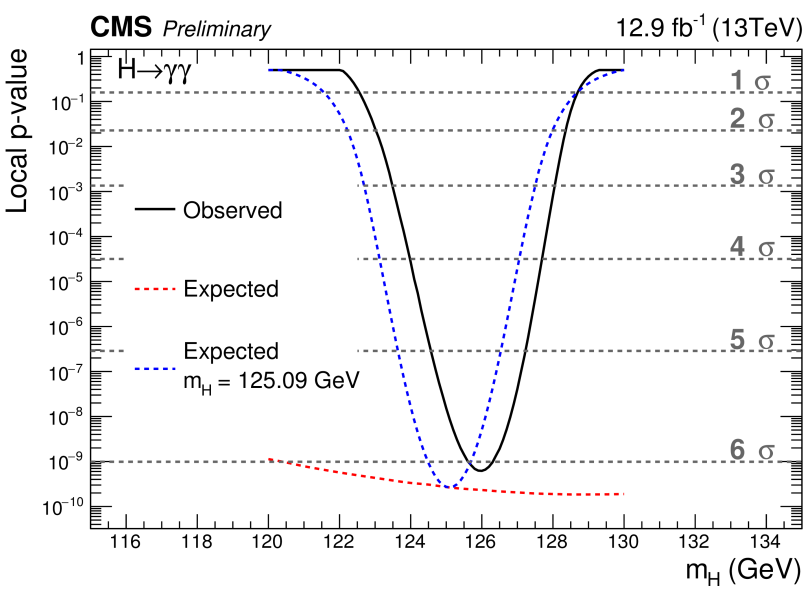


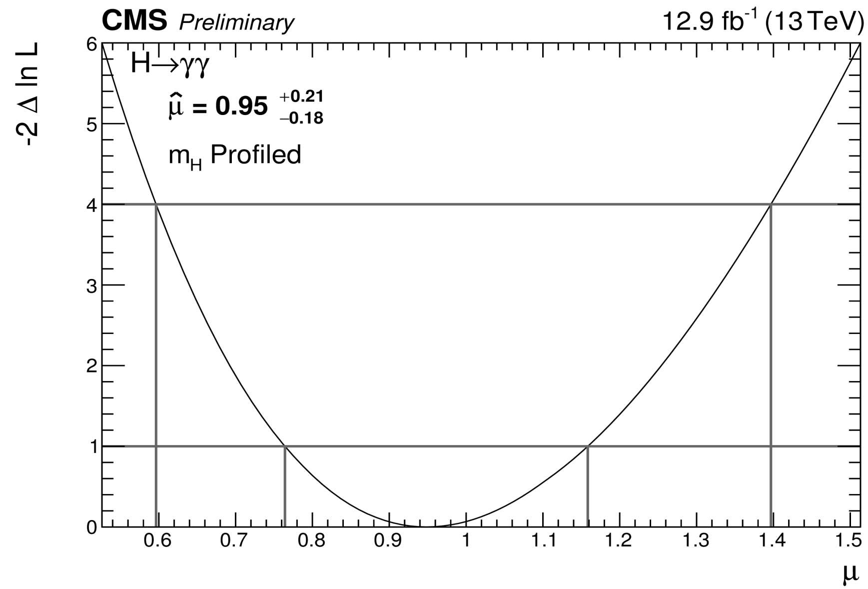
CMS-PAS-HIG-16-020

Systematic Errors dominated by photon energy scale, resolution and background bias

Run 2 CMS: p-value and Signal Strength for H→γ γ

CMS-PAS-HIG-16-020

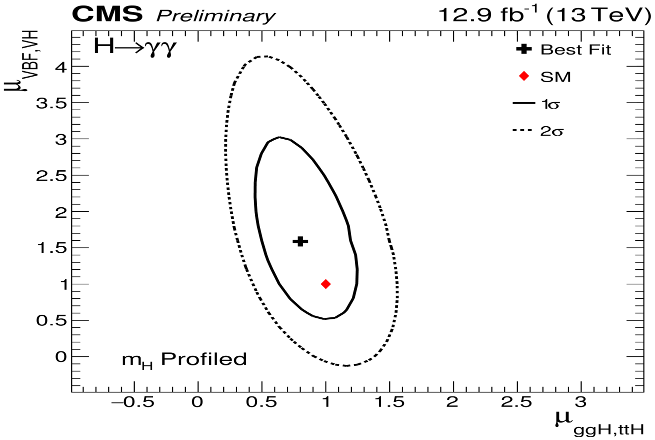




- **Observed significance 5.6σ (Expected: 6.2σ for the SM Higgs boson at m_H=125.09 GeV)**
- **The maximum observed significance is 6.1σ at m_H=126 GeV**
- **Observations consistent with Expected $(\sigma \times BR)_{SM}$**

$$\hat{\mu} = 0.95 \pm 0.20 = 0.95 \pm 0.17\,(\text{stat.})\,^{+0.10}_{-0.07}\,(\text{syst.})\,^{+0.08}_{-0.05}\,(\text{theo.}).$$

Fermionic and Bosonic Production Modes of H→γ γ



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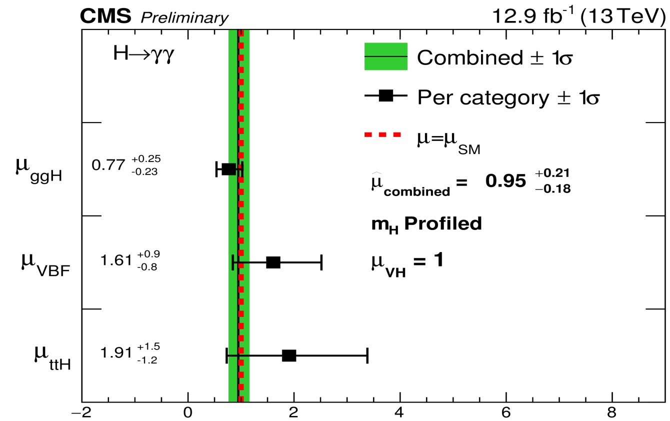

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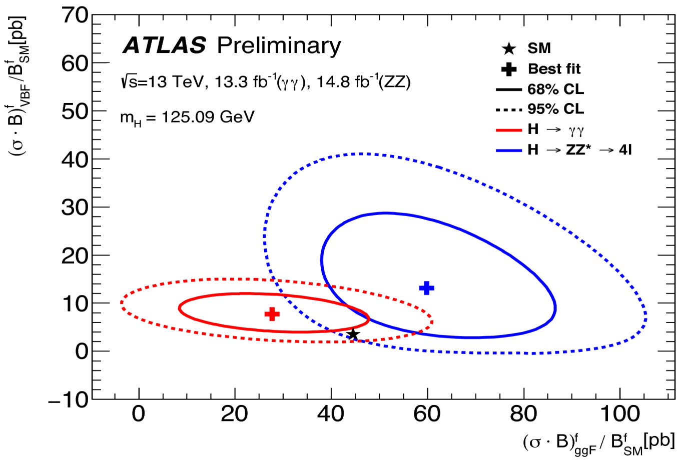
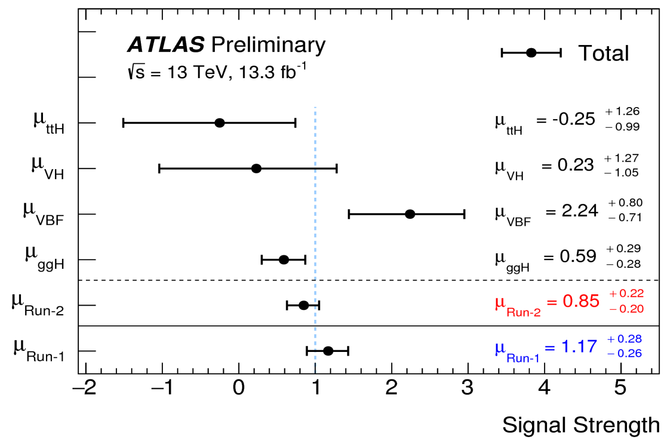


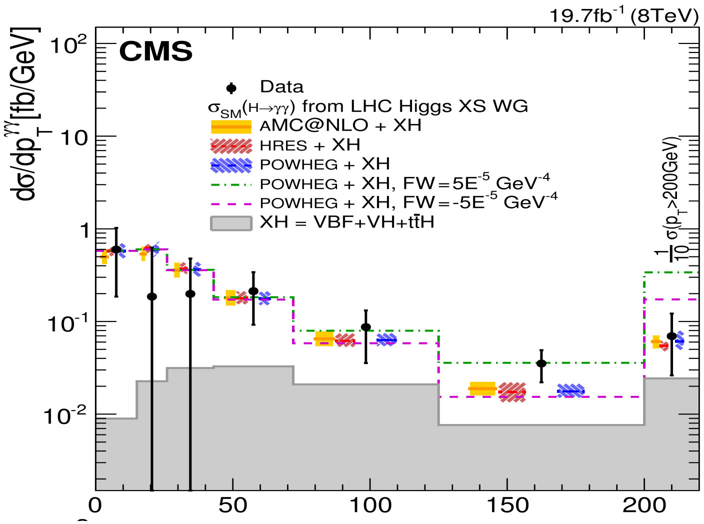


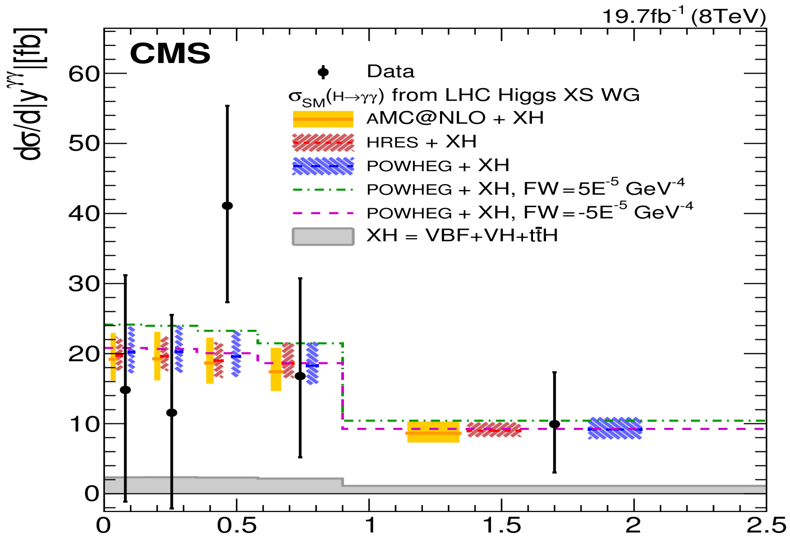
ATLAS-CONF-2016-067

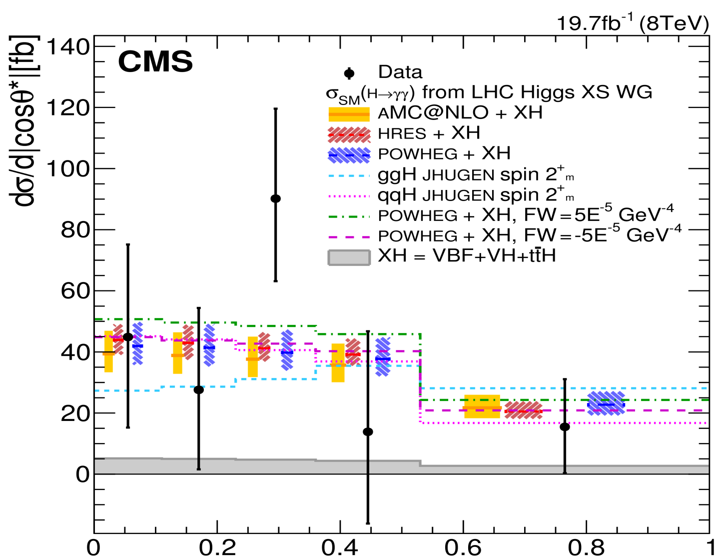
ATLAS: $R_{obs}=\sigma_{VBF}/\sigma_{ggF} = 0.25^{+0.15}_{-0.10}$ $R_{SM}=0.079\pm0.004$

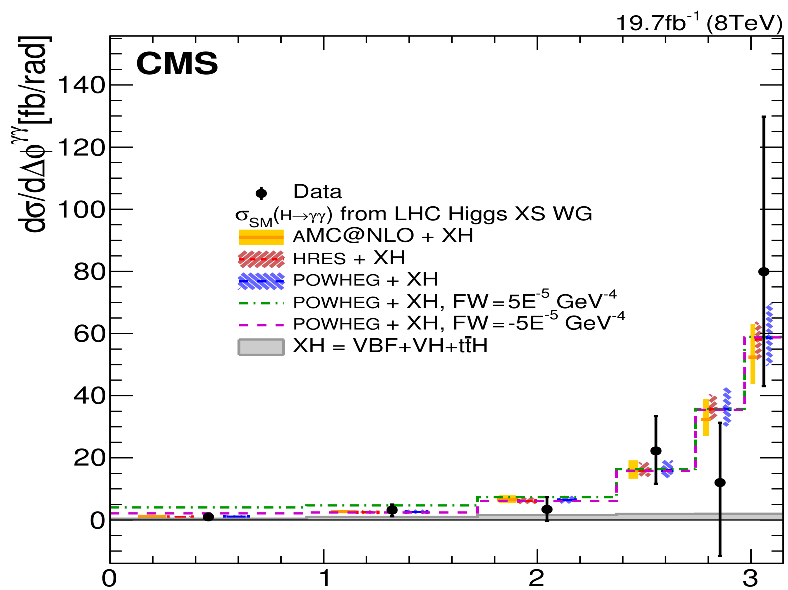
CMS: $\mu_{ggH,t\bar{t}H} = 0.80^{+0.14}_{-0.18}$ and $\mu_{VBF,VH} = 1.59^{+0.73}_{-0.45}$

CMS Run 1: Differential xSec for H→γ γ



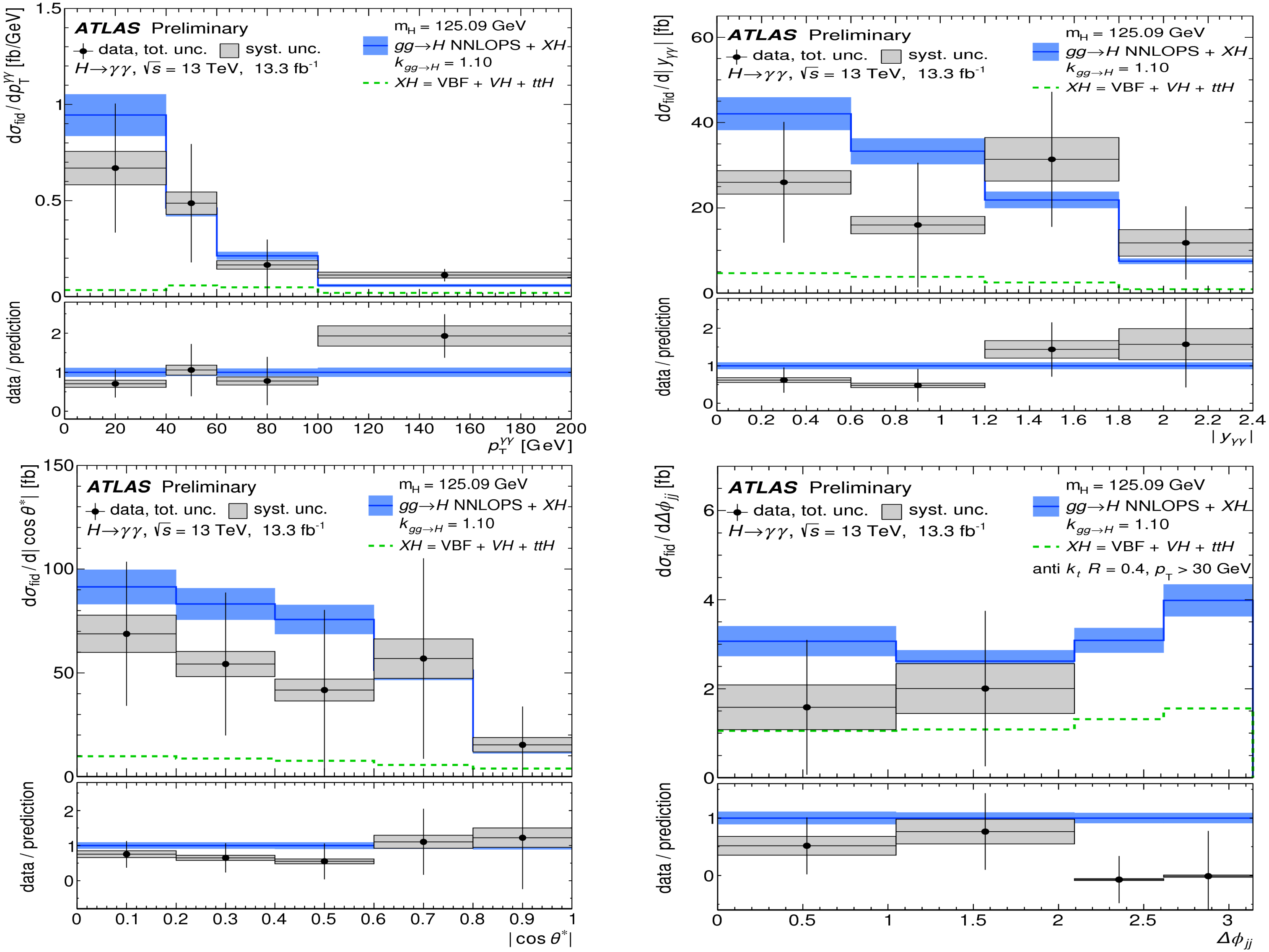






CMS-PAS-HIG-14-016 EPJC 76 (2016) 13

ATLAS Run 2: Differential xSec for H→γ γ



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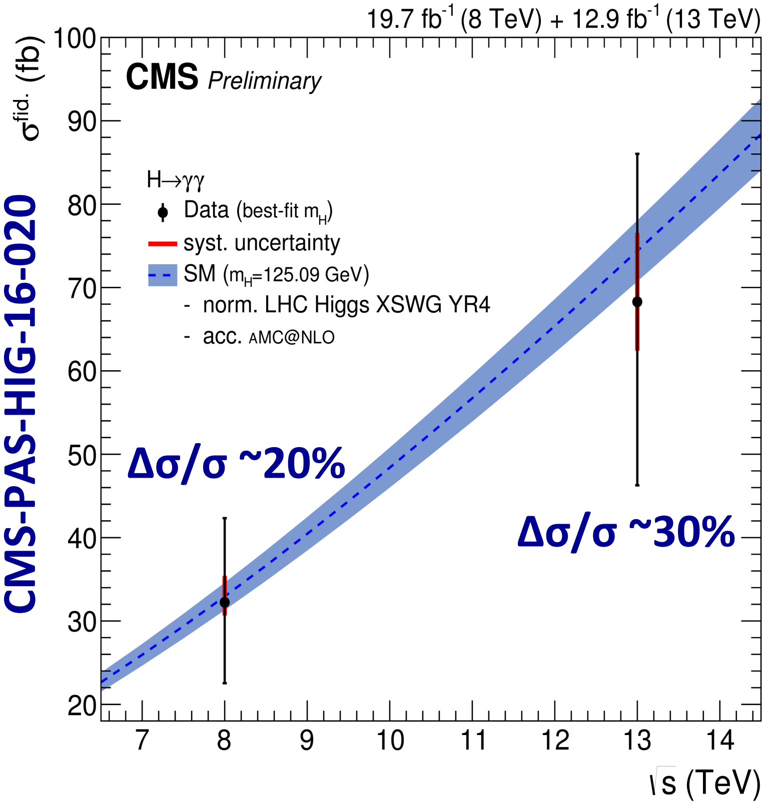
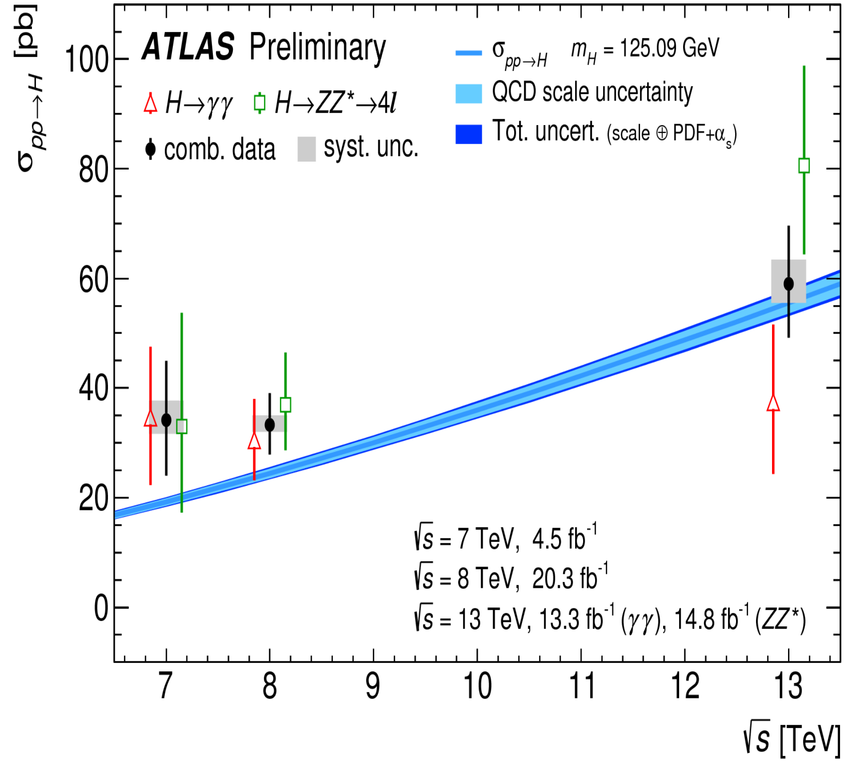
Fiducial Cross Section: $H \to \gamma\gamma$

CMS-PAS-HIG-16-020





ATLAS-CONF-2016-081

Measurements of fiducial cross section

13 TeV	Fiducial σ (fb)	SM prediction (fb)
ATLAS (13.3 fb^{-1})	43.2±14.9(stat)±4.9(syst)	$62.8^{+3.4}_{-4.4}$ (N^3LO+XH)
CMS (12.9 fb^{-1})	69^{+16}_{-22}(stat)$^{+8}_{-6}$(syst)	73.8±3.8

Coupling Strengths using H→ WW*, ZZ*

ATLAS, CMS: Selection Criteria's for H→ ZZ → 4l

Muons: $p_T > 5$ GeV, $\|\eta\| < 2.7$	Electrons: $p_T > 7$ GeV, $\|\eta\| < 2.47$
Leading pair:	SFOS lepton pair with smallest $\|m_Z - m_{\ell\ell}\|$
Sub-leading pair:	Remaining SFOS lepton pair with smallest $\|m_Z - m_{\ell\ell}\|$

Leading leptons $p_T > 20, 15, 10$ GeV
$50 < m_{12} < 106$ GeV; $12 < m_{34} < 115$ GeV
$\Delta R(\ell_i, \ell_j) > 0.1(0.2)$ for same(opposite)-flavour leptons
$m(\ell_i, \ell_j) > 5$ GeV for all SFOS lepton pairs
$115 < m_{4\ell} < 130$ GeV

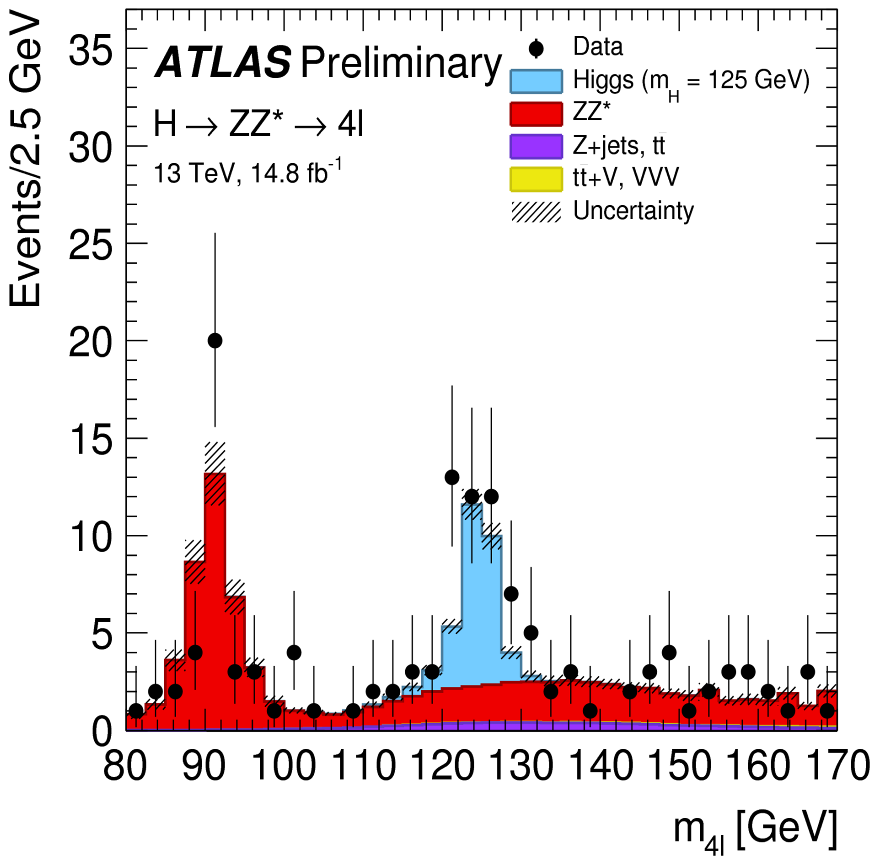
ATLAS

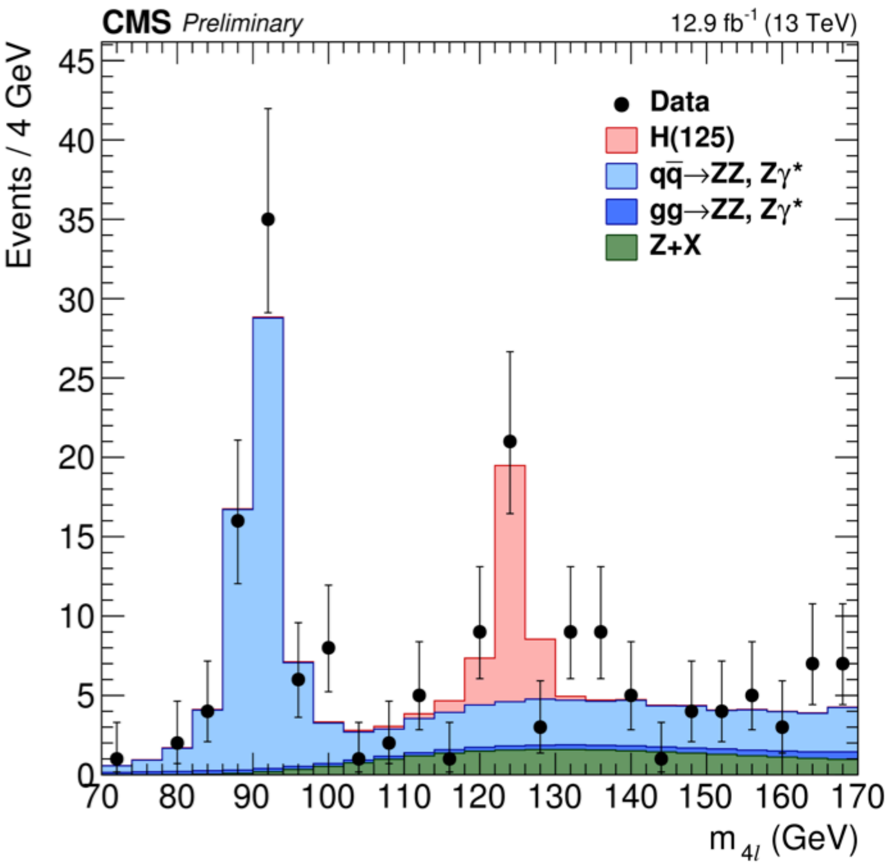
CMS

Requirements for the $H \to 4\ell$ 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)	$\|\eta\| < 2.5(2.4)$
Sum of scalar p_T of all stable particles within $\Delta R < 0.4$ from lepton	$< 0.4 \cdot p_T$
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	$105\,\text{GeV} < m_{4\ell} < 140\,\text{GeV}$

Run 2: $H \rightarrow ZZ^* \rightarrow 2\mu^+\mu^-, \mu^+\mu^-e^+e^-, 2e^+e^-$

ATLAS-CONF-2016-079





CMS-PAS-HIG-16-033

ATLAS

Expected Background: 9.7 ± 0.9

Observed Events: 44

CMS

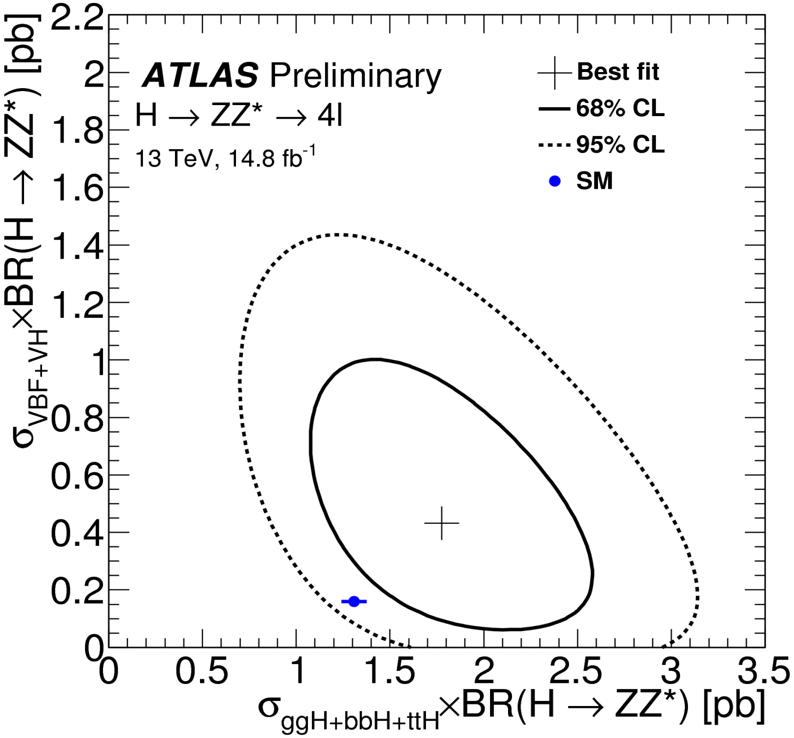
Expected Background: 13.8 ± 1.4

Observed Events: 33

Significance:6.4σ

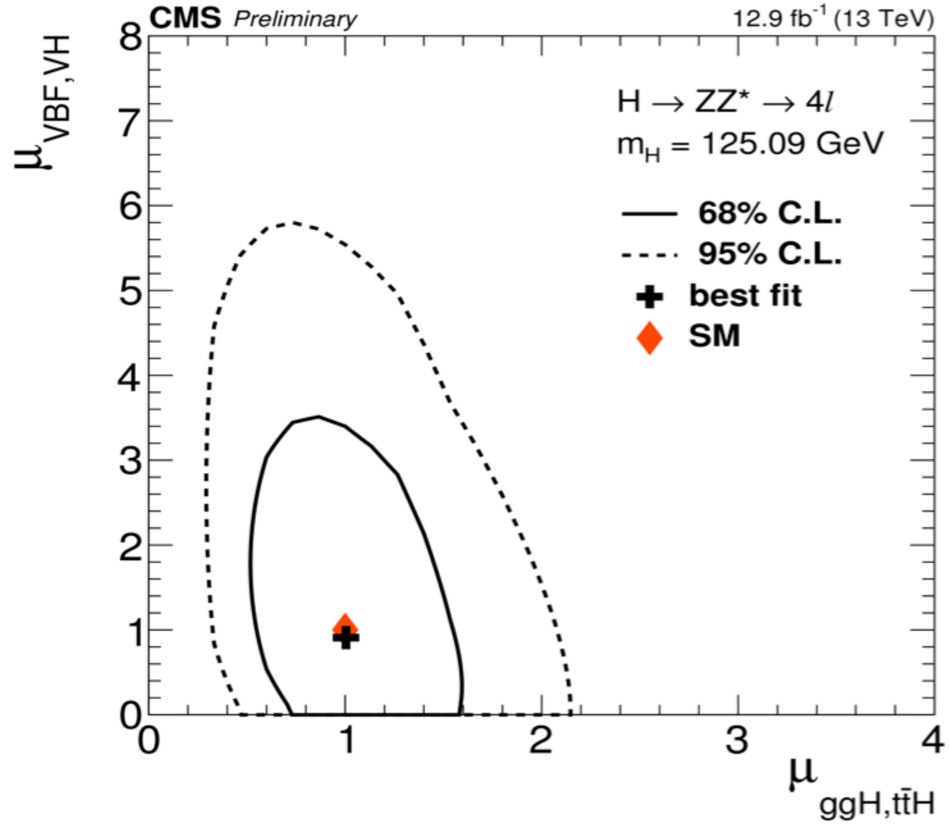
Fermionic and Bosonic Signal Strength using H→ZZ*→4l

ATLAS-CONF-2016-079



$$\sigma^{4\ell}_{\text{fid,comb}} = 4.54^{+1.02}_{-0.90}\ \text{fb}$$

$$\sigma_{\text{tot}} = 81^{+18}_{-16}\ \text{pb}$$

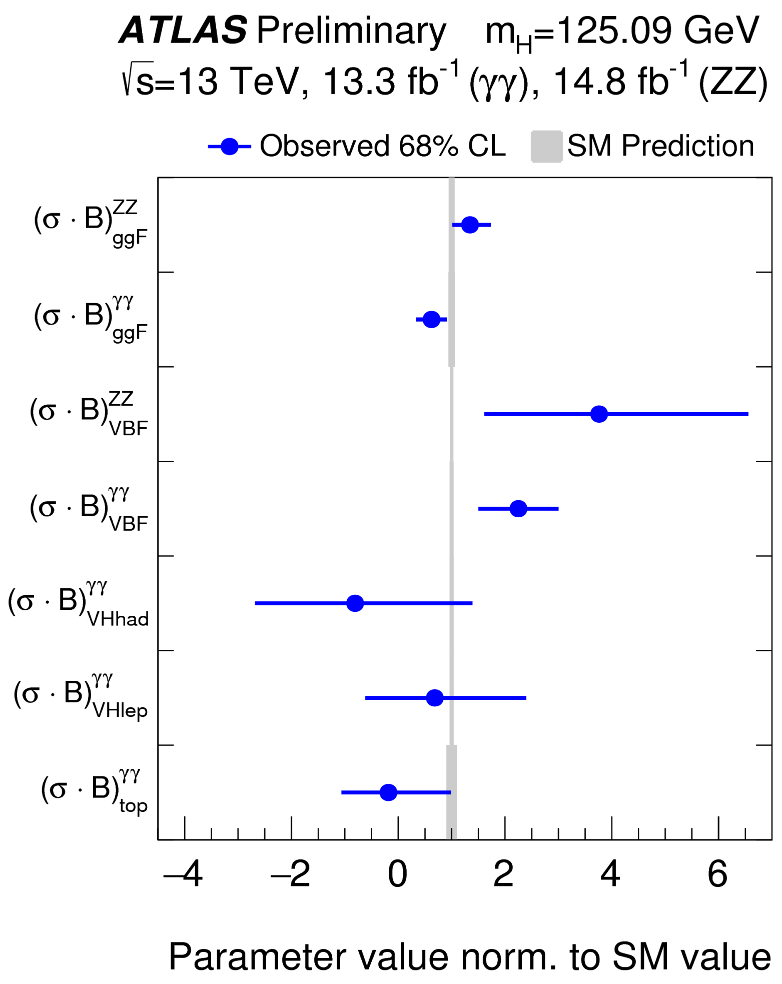


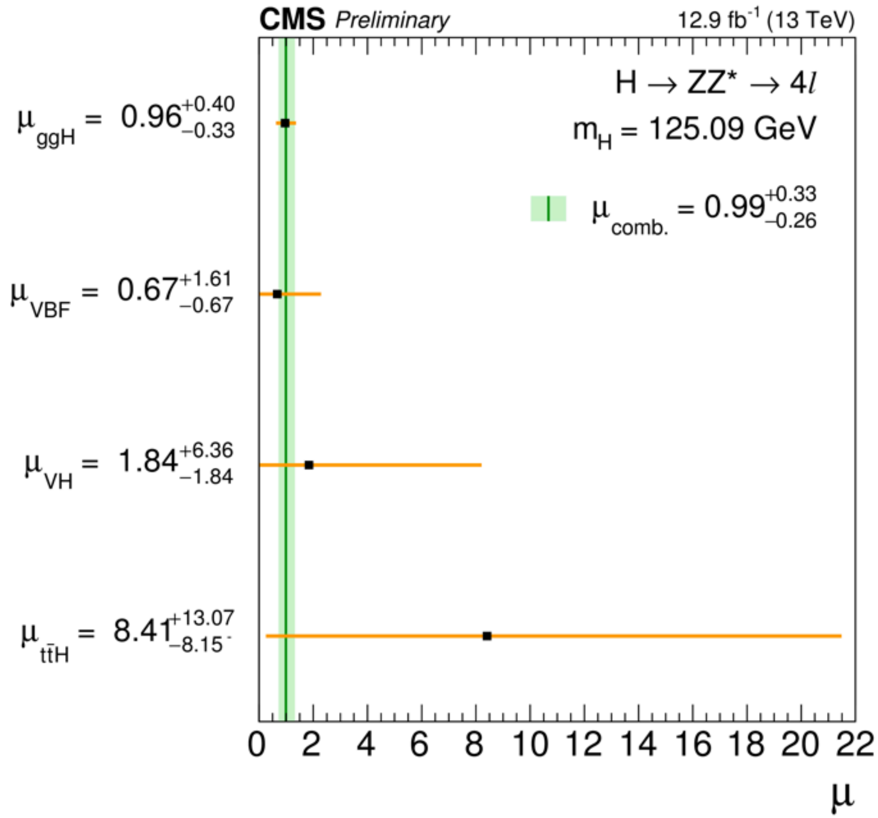
CMS-PAS-HIG-16-033

$$\mu_{\text{VBF,VH}} = 0.91^{+1.56}_{-0.91}$$
$$\mu_{\text{ggH},t\bar{t}\text{H}} = 1.00^{+0.39}_{-0.32}$$

Signal Strengths using H→ZZ*→4l

ATLAS-CONF-2016-081

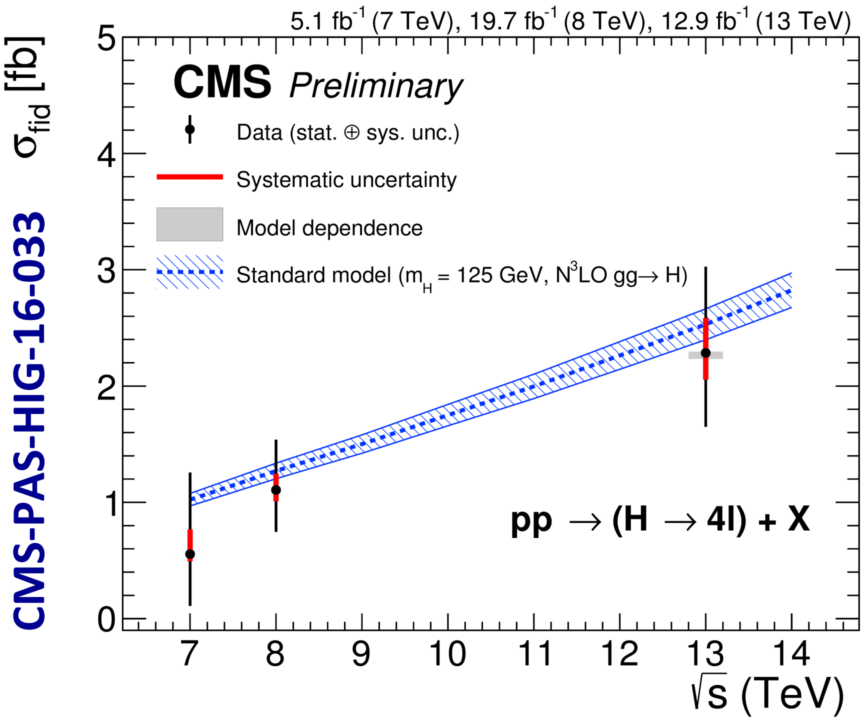


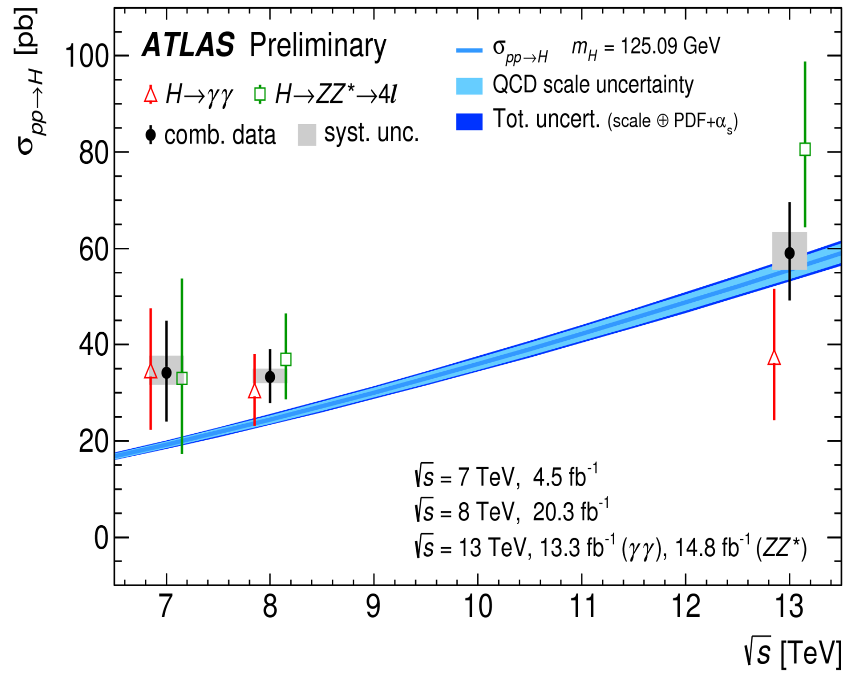


CMS-PAS-HIG-16-033

$H \rightarrow ZZ^* \rightarrow 2\mu^+\mu^-, \mu^+\mu^-e^+e^-, 2e^+e^-$

CMS-PAS-HIG-16-033





ATLAS-CONF-2016-081

CMS at 13 TeV

Observed $2.29^{+0.74}_{-0.64}$ (stat) $^{+0.30}_{-0.23}$ (syst) fb

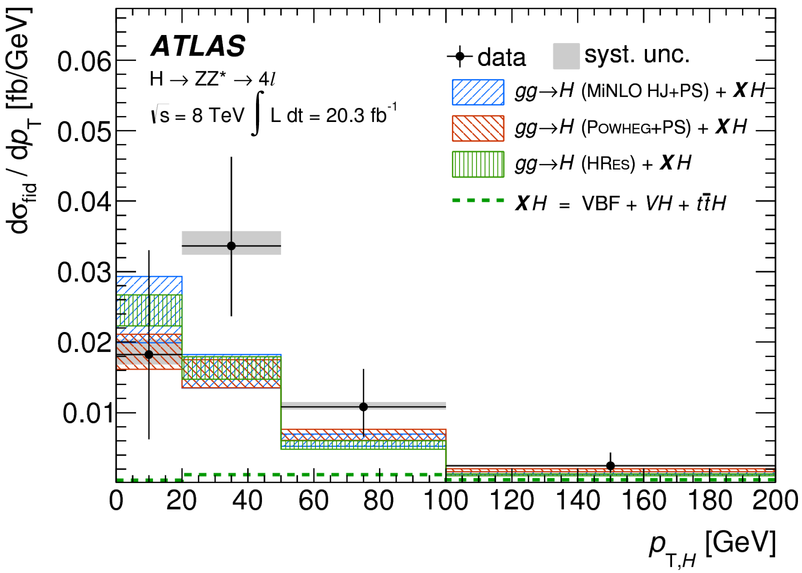
SM: 2.53 ± 0.13 fb

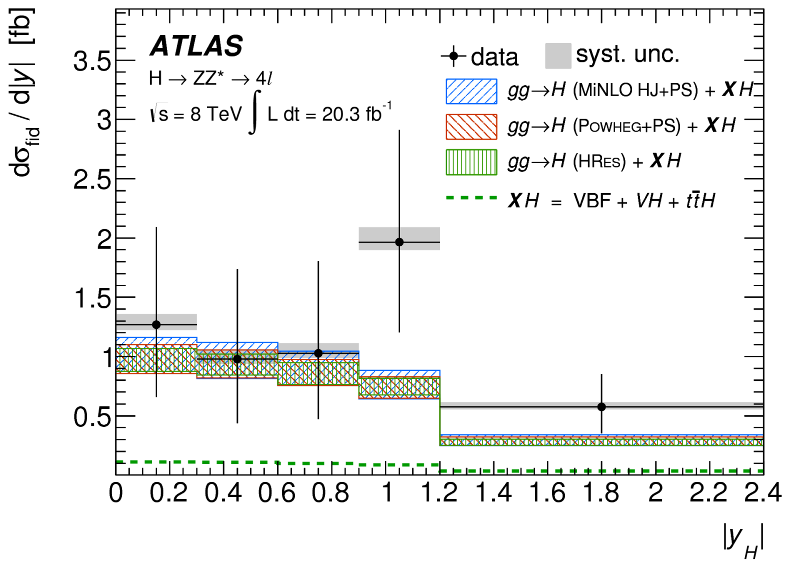
ATLAS at 13 TeV

Observed $59.0^{+9.7}_{-9.2}$ (stat) $^{+04.4}_{-3.5}$ (syst) pb

SM: $55.5^{+9.7}_{-9.2}$ fb

Run 1 ATLAS: Differential xSec for H→ZZ*, WW*





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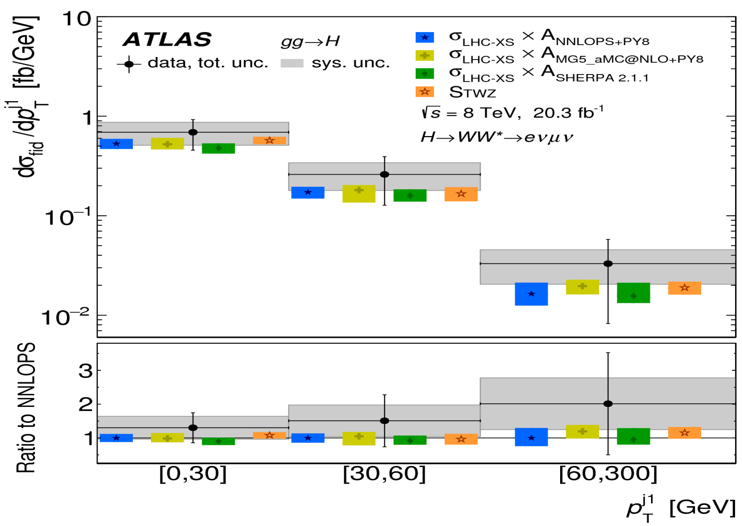
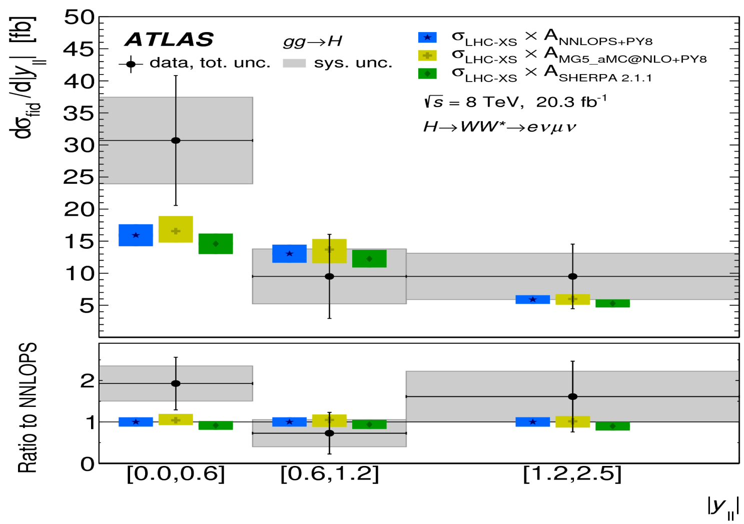
$\sigma^{\rm fid}_{\rm tot} = 2.11^{+0.53}_{-0.47}({\rm stat.}) \pm 0.08({\rm syst.})$ fb.

σ_{fid}(SM)= 1.3±0.13 fb





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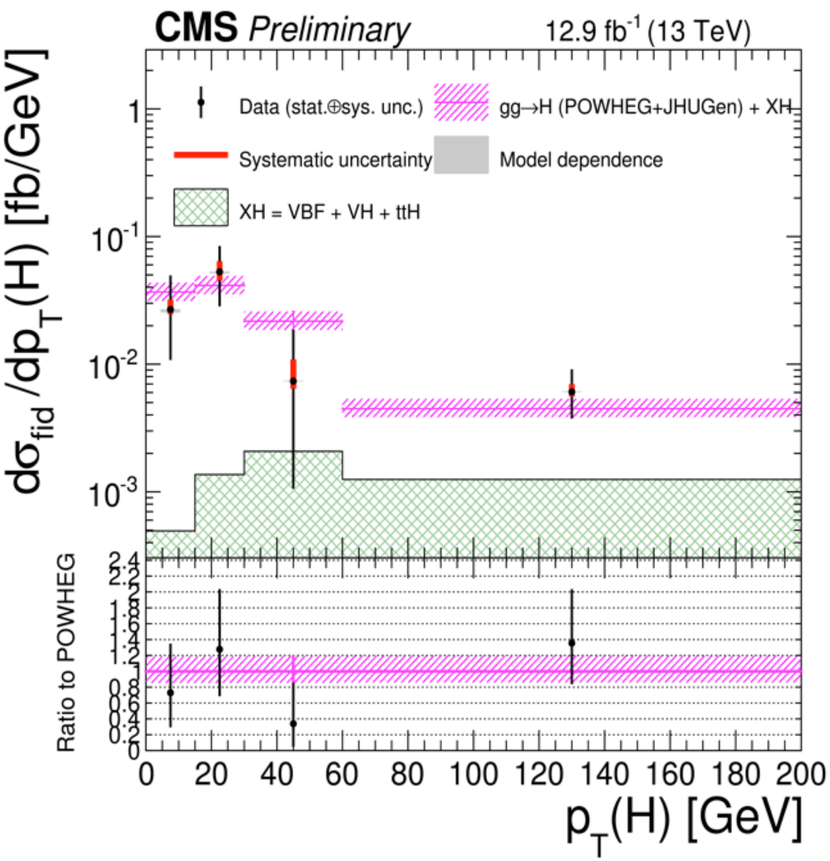
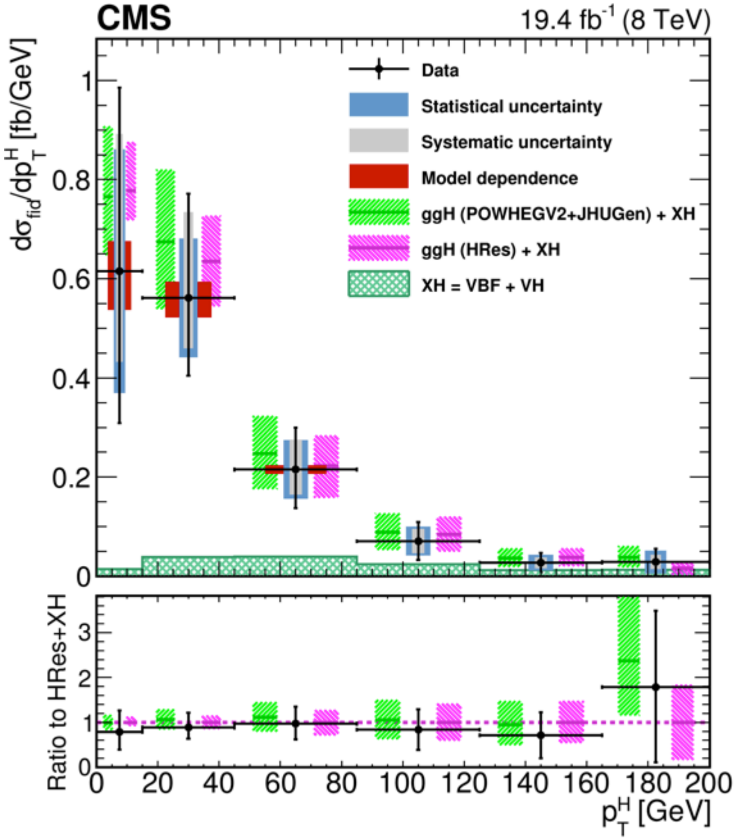
Differential xSec for $H \to ZZ^*$ and $H \to WW^*$

$H \to ZZ^*$: CMS-PAS-HIG-16-033





$H \to WW^*$: CMS-PAS-HIG-16-020

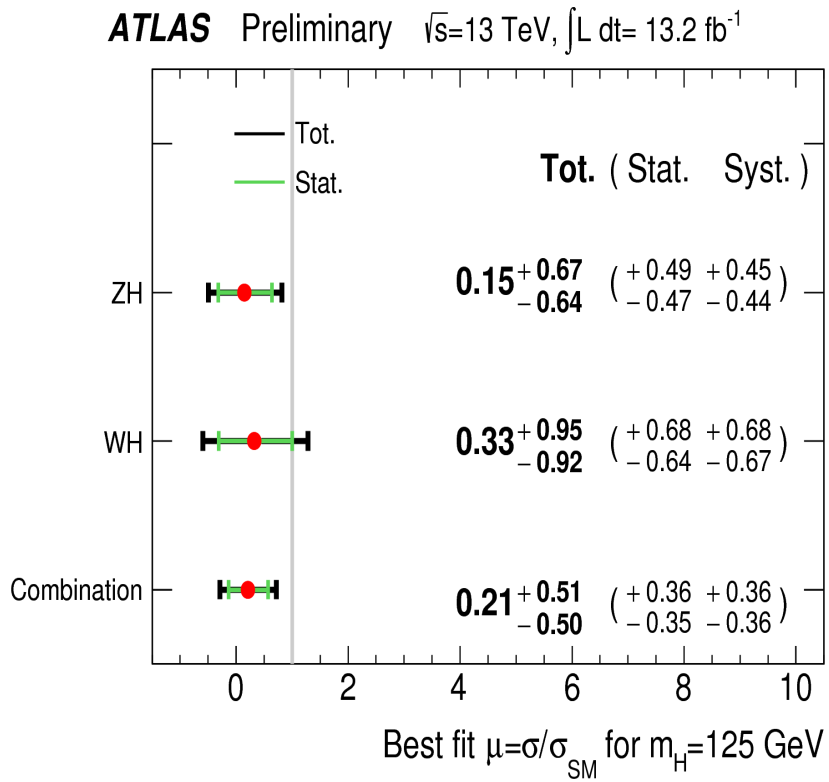
2015 data (2.3 fb^{-1}) data analyzed for $H \to WW^*$
ATLAS-CONF-2016-112

2016 data analysis for this channel is under progress

Run 2: H → b b

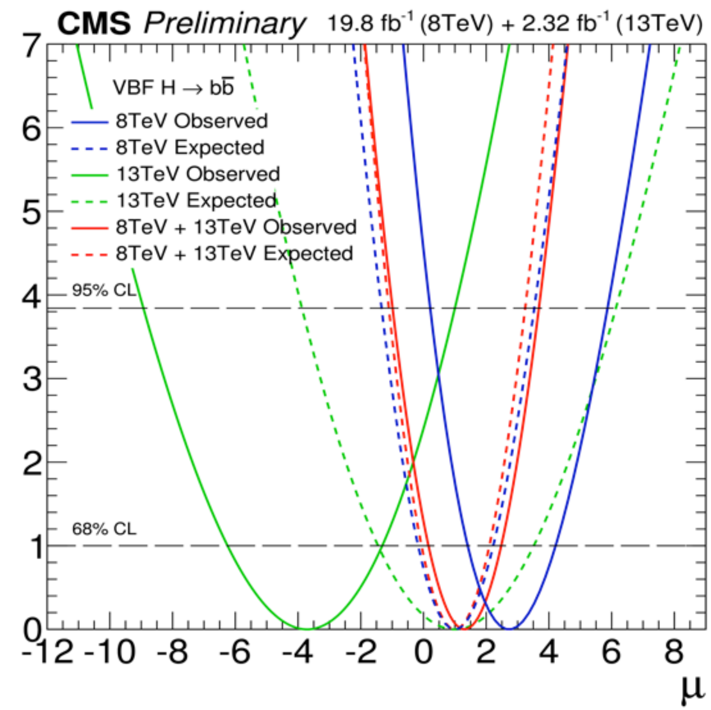
ATLAS: VH(→bb)

ATLAS-CONF-2016-091



CMS: VBF H(→bb)

CMS-PAS-HIG-16-003



CMS Run 1+2:

$\mu = 1.3^{+1.2}_{-1.1}$

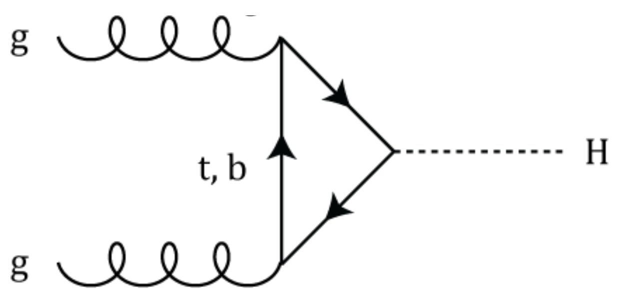
$\mu < 3.4$ at 95% CL

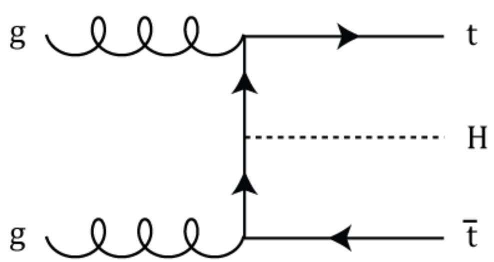
ttH ($H \rightarrow WW^*, ZZ^*, \tau^+\tau^-, \gamma\gamma$)

Probing ttH Production Mechanism

- **Probing Yukawa coupling between top and Higgs is very important**
  - via ggF with no BSM particles in the loop
  - ttH provides direct access at tree level, via associated production of ttbar
  - $\sigma_{13\ TeV}$(ttH) ~ 508 fb ~ 4$\sigma_{8\ TeV}$(ttH)

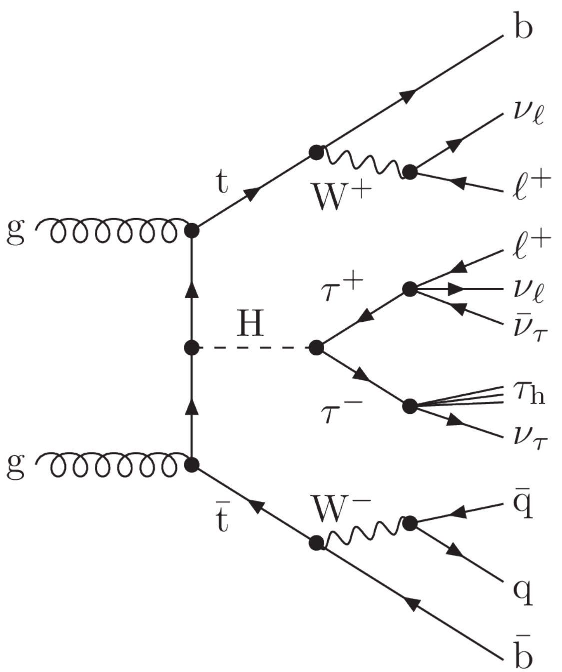
- **ttH(bb), ttH(W W*), ttH(Z Z*), ttH($\tau^+\tau^-$), ttH (→γγ) topologies targeted with multi-leptons, displaced b-jets etc. in final states**

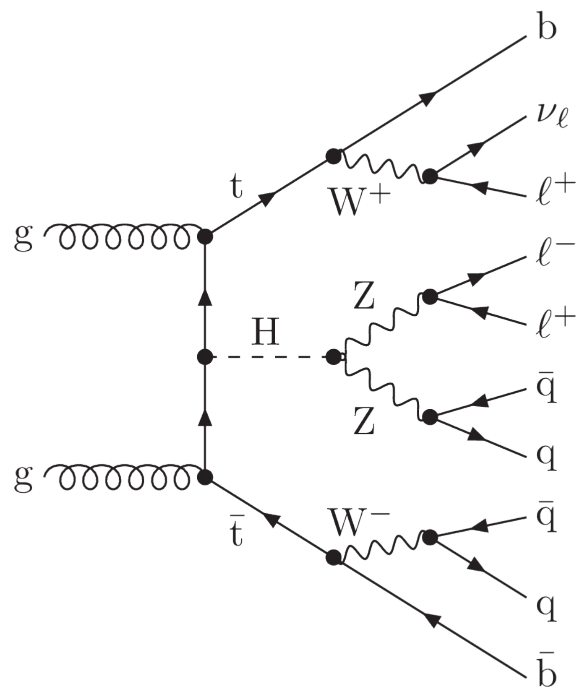


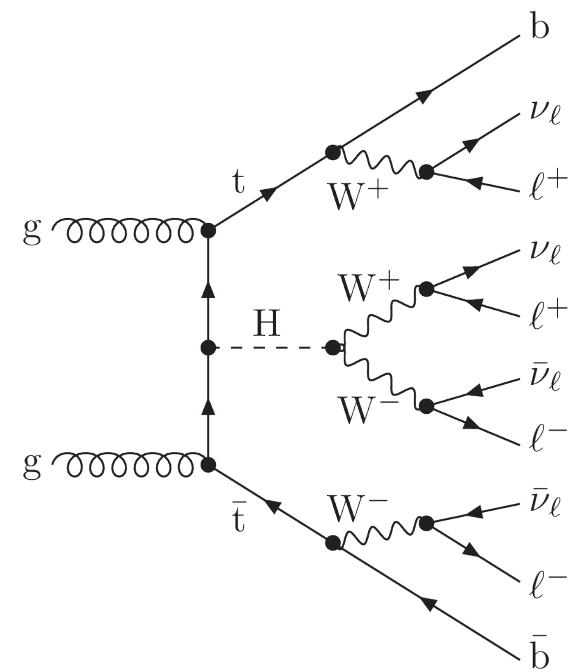


ttH → Multileptons + Jets

H → τ⁺τ⁻ (BF: 6.3%)	H → ZZ* (BF: 2.67%)	H → WW* (BF 21.6%)



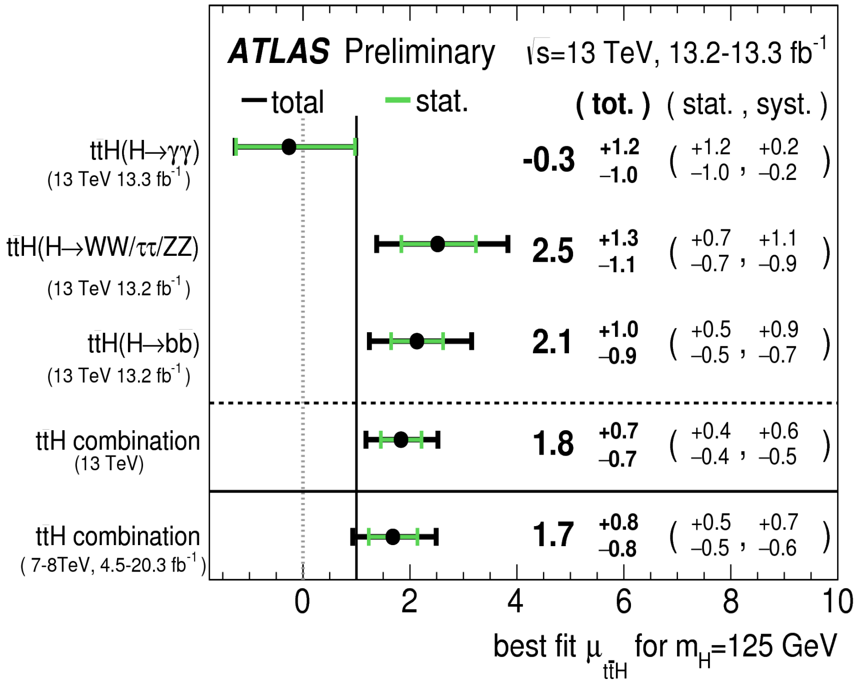


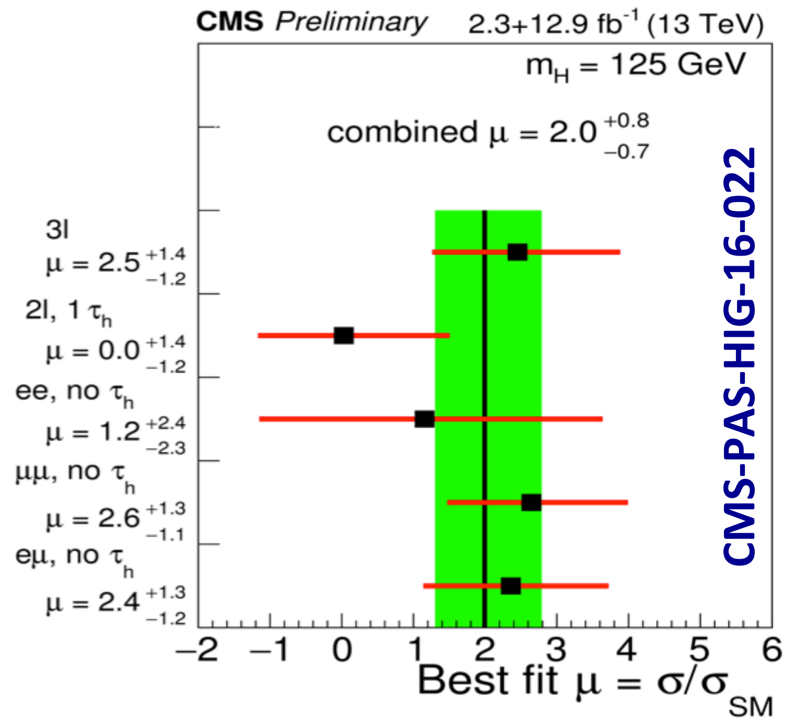


ttH Signal Strength

ttH (→bb), ttH (→ WW*), ttH (→ ZZ*), ttH (→ $\tau^+\tau^-$), ttH (→γγ) targeted

ATLAS-CONF-2016-068





CMS-PAS-HIG-16-022

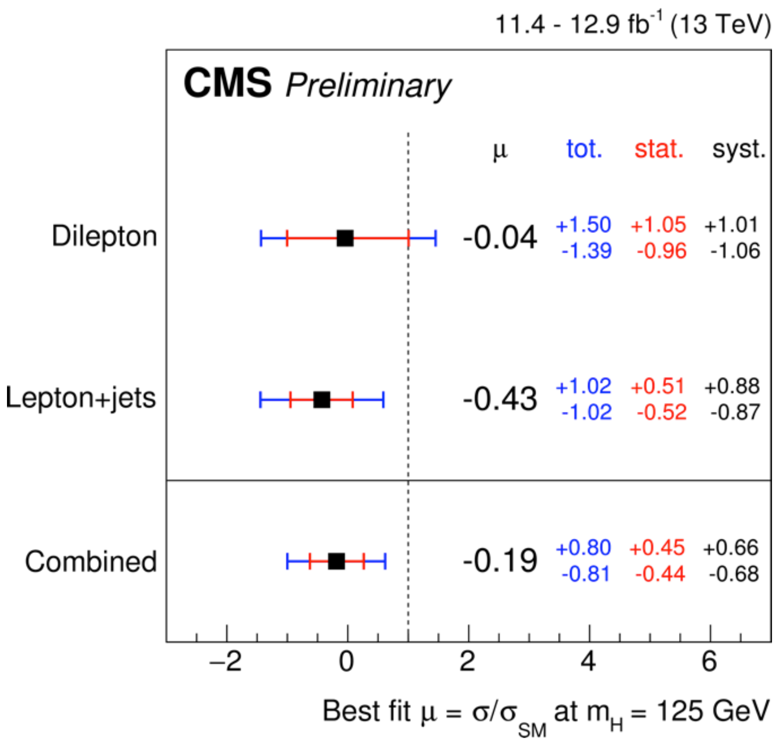
ATLAS Combined (7, 8, 13 TeV): $\mu=1.7^{+0.7}_{-0.8}$

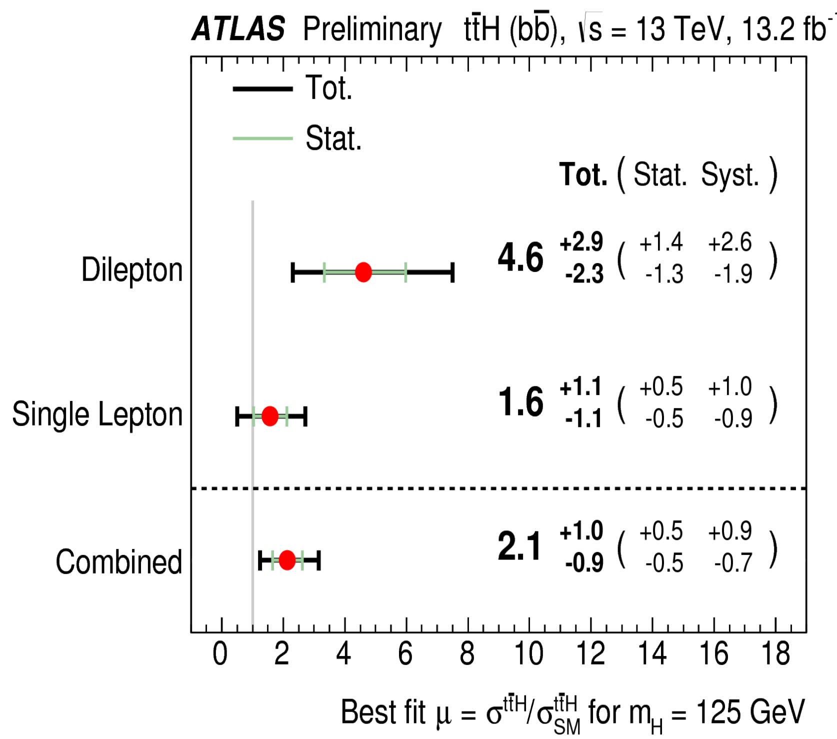
CMS: $\mu < 3.4$ at 95% CL

CMS: ttH(γγ) $\mu=1.9^{+1.5}_{-1.2}$

Run 2: ttH→bb Signal Strength

CMS-PAS-HIG-16-038





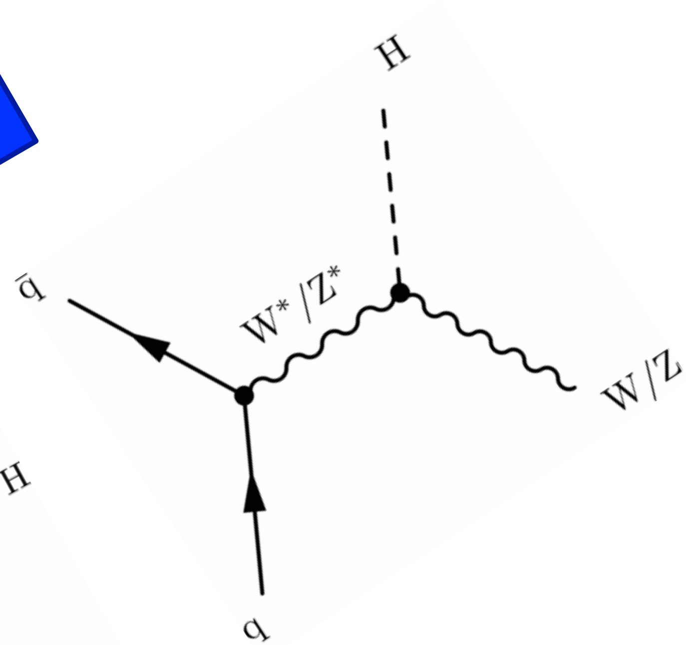
ATLAS-CONF-2016-080

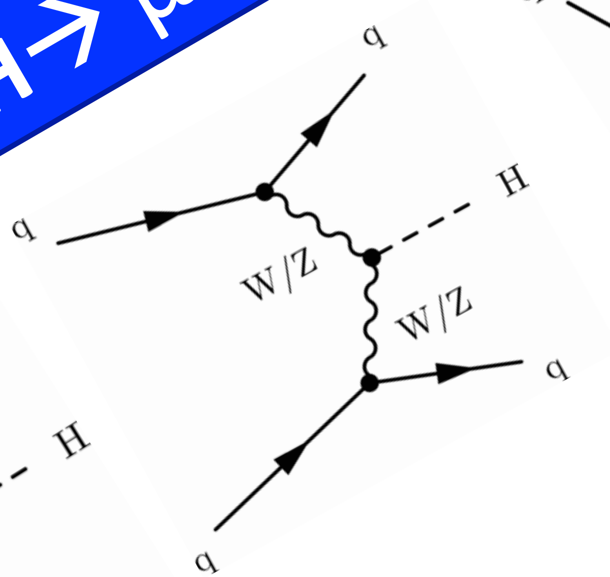
CMS: μ < 1.5 (1.7) at 95% CL

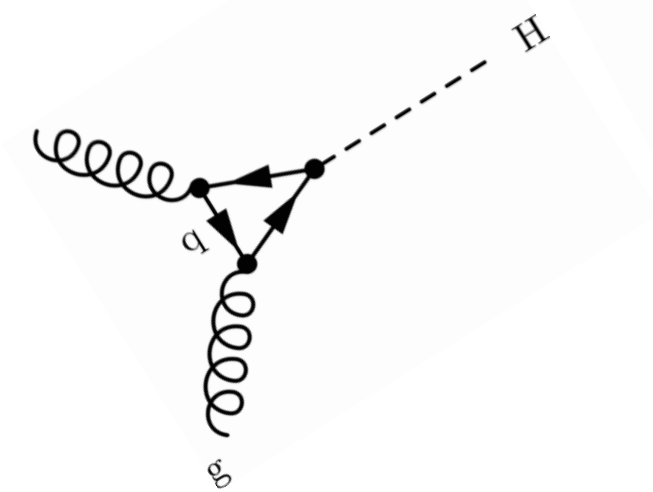
ATLAS: μ < 4.0 at 95% CL

$H \to \tau^+ \tau^-$

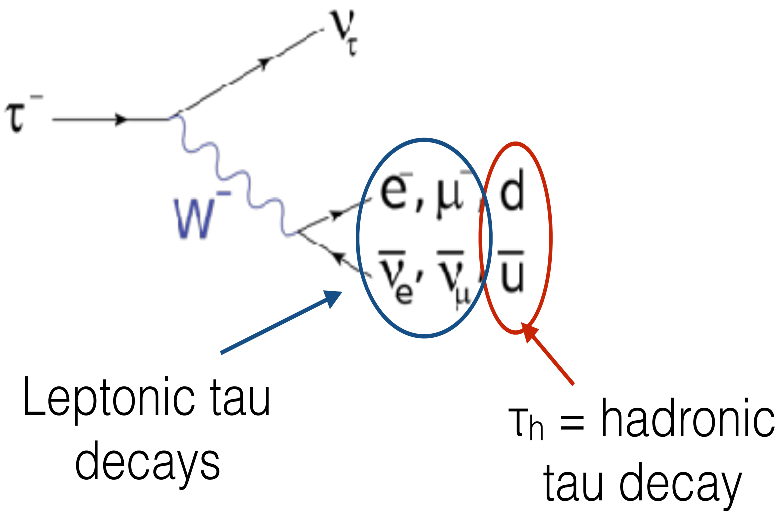
$H \to \mu^+ \mu^-$







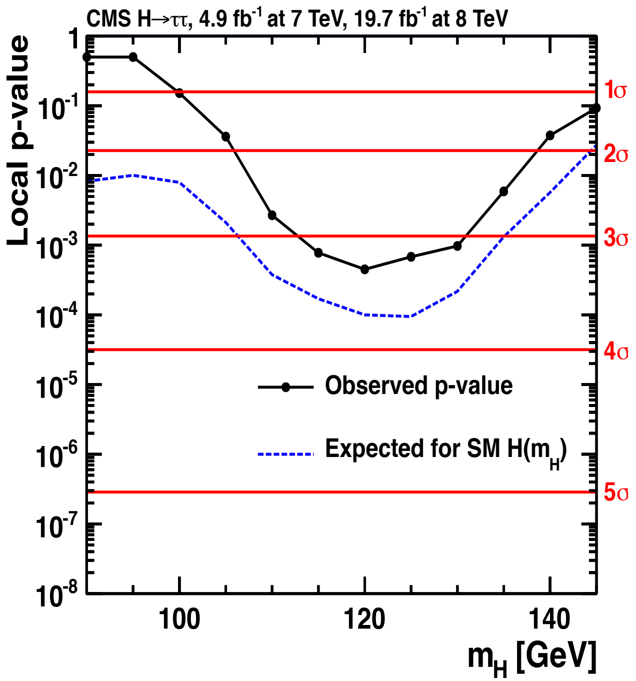
Higgs → $\tau^+ \tau^-$

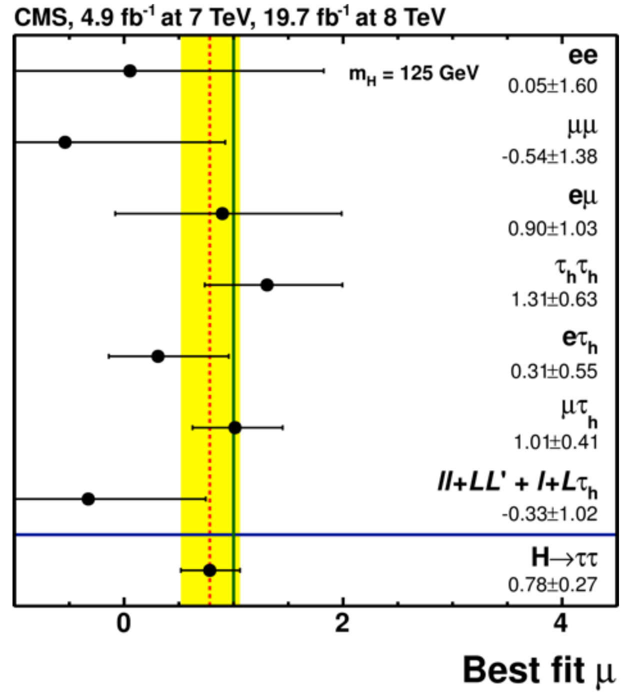


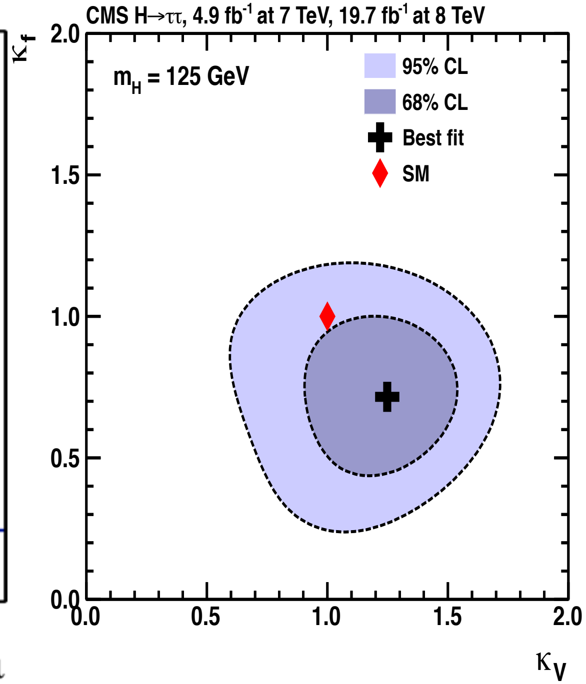
- SM Higgs has both; bosonic and fermionic coupling
- Higgs → $\tau^+ \tau^-$ is most sensitive fermionic decay channel of Higgs
- An important channel to test SM behavior of Higgs
- Possible final states of τ_{decay}
  - ee, μμ, eμ, $e\tau_h$, $\mu\tau_h$, $\tau_h\tau_h$

Run 1 CMS: Higgs → $\tau^+\tau^-$

JHEP 05 (2014) 104 CMS-PAS-HIG-13-004



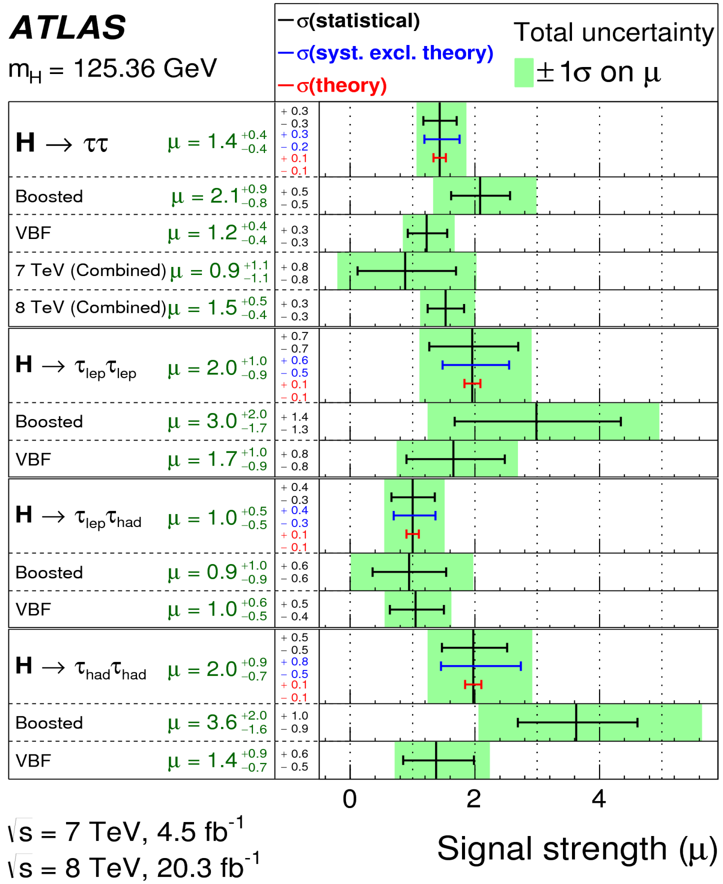




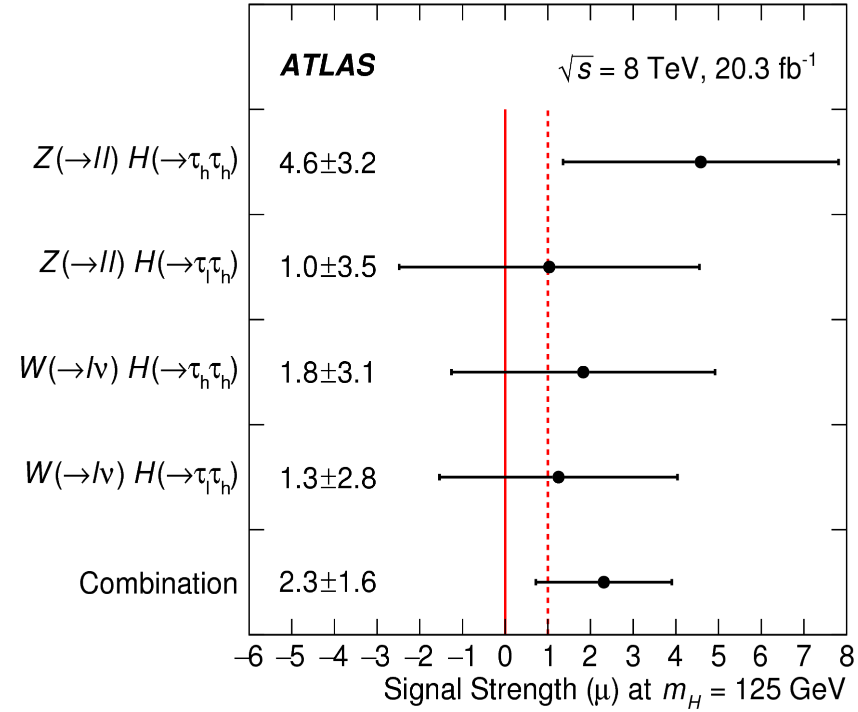
- > 3.2 σ evidence for H → $\tau^+\tau^-$ decays with CMS data
- > 5σ evidence for H → $\tau^+\tau^-$ decays with ATLAS and CMS data combined
- Run 2 data analysis under progress

Run 1 ATLAS: Higgs → $\tau^+\tau^-$

ATLAS: JHEP 04 (2015) 117



VH→ $\tau^+\tau^-$



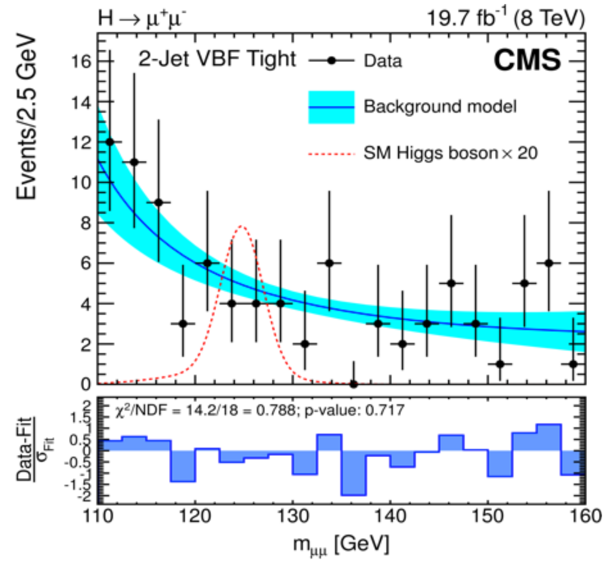
ATLAS: PRD 93, 092005 (2016)

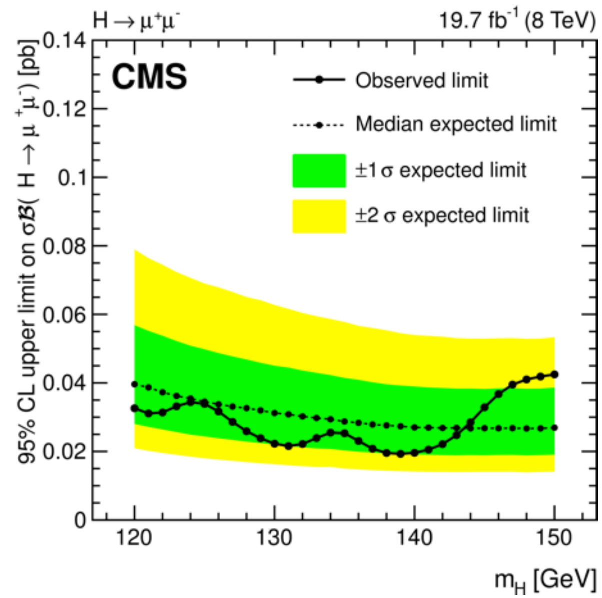
- **Evidence for H → ττ decays at 4.5σ (3.5σ expected) with ATLAS data**
- **Run 2 data analysis under progress**

$$\mu = 1.43^{+0.27}_{-0.26}(stat)^{+0.32}_{-0.25}(syst) \pm 0.09(theor)$$

Higgs → $\mu^+\mu^-$

- **A very rare decay in the SM (BF: 2.2×10^{-4})**
  - Probe Yukawa-coupling to 2nd generation fermions and mass dependence
  - Test of the Higgs coupling to leptons
- **Clean signature from dimuon final state**
- **Overwhelming irreducible background $Z/\gamma^* \to \mu\mu$**
- **Analysis strategy:**
  - Search for peak in di-muon mass spectrum over smoothly falling background
- **Categorize events according to VBF and ggF signature enriched**

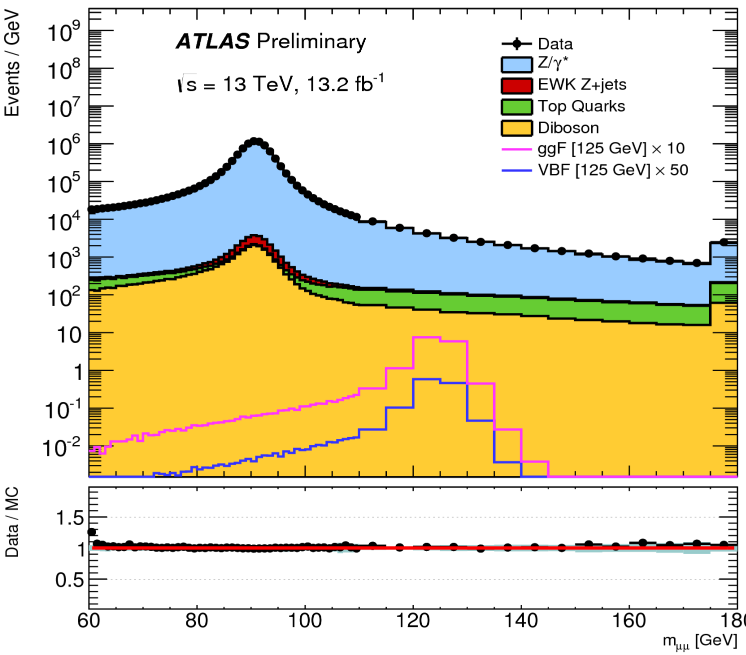


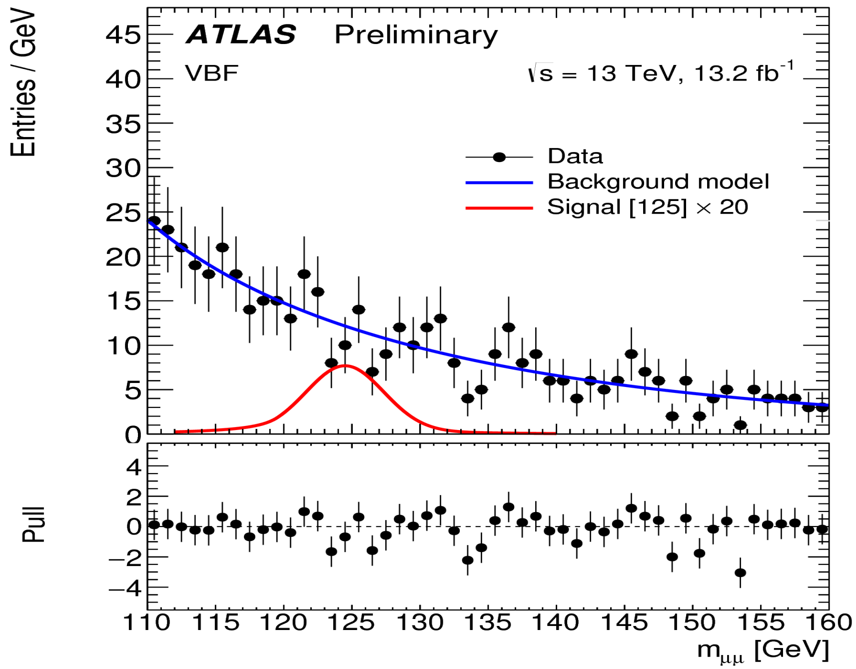


Run 1: $\mu < 7.4$ (6.4) @95%CL
PLB744 (2015), 184-207

Run 2 ATLAS: Higgs → $\mu^+\mu^-$

ATLAS-CONF-2016-041





ATLAS	Upper limit x SM (expected)
Run 1	7.1 (7.2)
Run 2	4.4 (5.5)
Combined Run 1 and Run 2	3.5 (4.5)

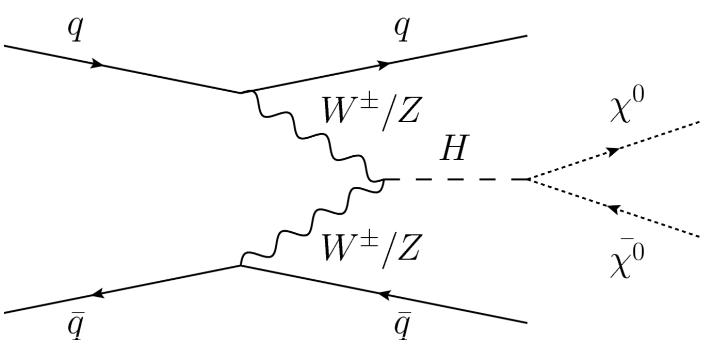
Search for Invisible Higgs

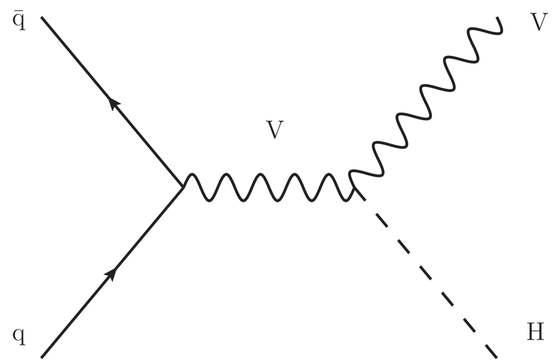
CMS-PAS-HIG-2016-016, EPJC 74 (2014) 2980

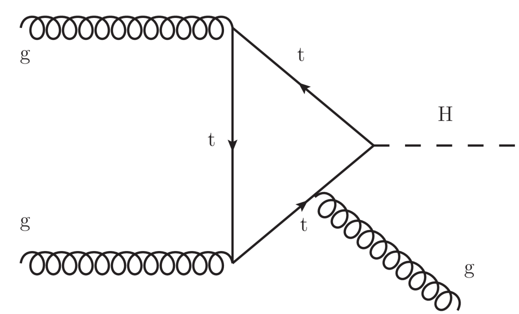
ATLAS: JHEP 01 (2016) 172

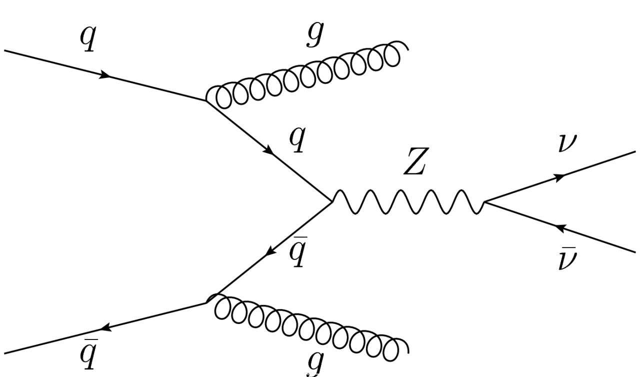
Direct Search for H → Invisible

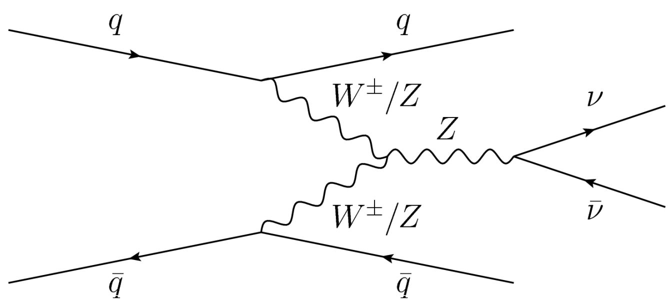
- **A standard model Higgs decaying to invisible particles**
  - **Higgs mediated Dark Matter**











Direct Search for H → Invisible

- **BF(→Invisible) → Width → Coupling →Cross Section for Higgs mediated DM production**

$$\Gamma_H^{\rm inv} = \frac{\mathrm{BF}(H \to \text{invisible})}{1 - \mathrm{BF}(H \to \text{invisible})} \times \Gamma_H$$

$$\Gamma^{\rm inv}_{H\to SS} = \frac{\lambda^2_{HSS} v^2 \beta_S}{64\pi m_H},$$

$$\Gamma^{\rm inv}_{H\to VV} = \frac{\lambda^2_{HVV} v^2 m_H^3 \beta_V}{256\pi m_V^4}\left(1 - 4\frac{m_V^2}{m_H^2} + 12\frac{m_V^4}{m_H^4}\right)$$

$$\Gamma^{\rm inv}_{H\to ff} = \frac{\lambda^2_{Hff} v^2 m_H \beta_f^3}{32\pi\Lambda^2},$$

$$\sigma^{\rm SI}_{SN} = \frac{\lambda^2_{HSS}}{16\pi m_H^4}\frac{m_N^4 f_N^2}{(m_S + m_N)^2},$$

$$\sigma^{\rm SI}_{VN} = \frac{\lambda^2_{HVV}}{16\pi m_H^4}\frac{m_N^4 f_N^2}{(m_V + m_N)^2},$$

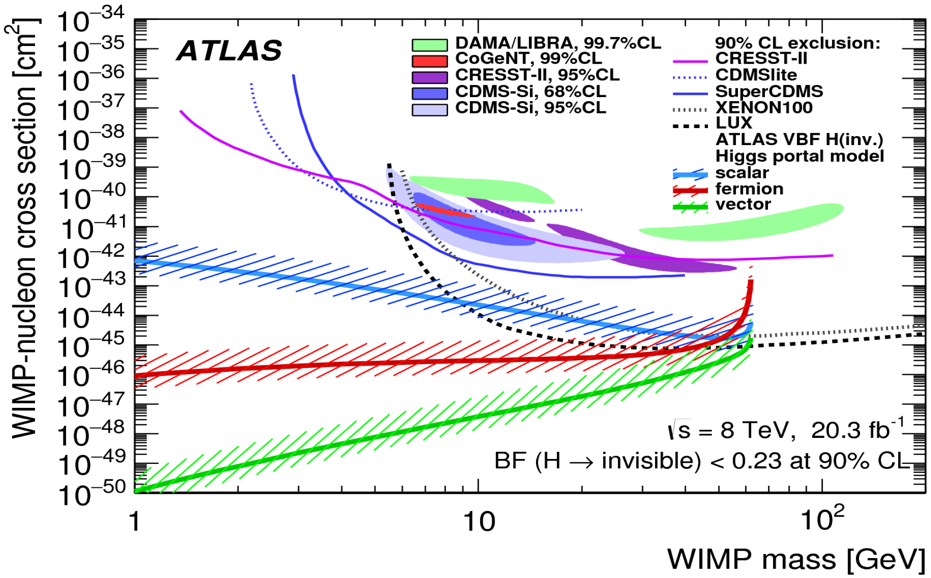
$$\sigma^{\rm SI}_{fN} = \frac{\lambda^2_{Hff}}{4\pi\Lambda^2 m_H^4}\frac{m_N^4 m_f^2 f_N^2}{(m_f + m_N)^2},$$

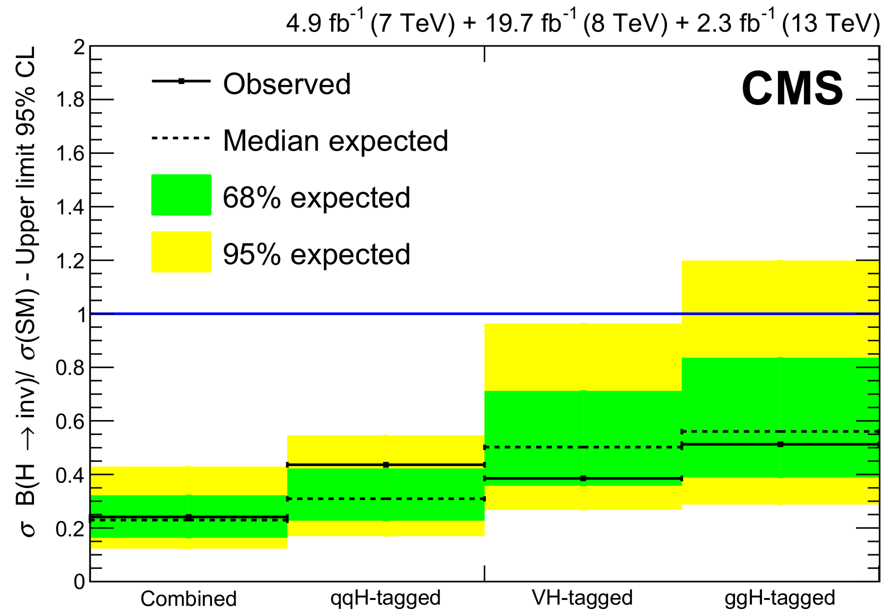
$$, \beta_\chi = \sqrt{1 - 4m_\chi^2/m_H^2}\ (\chi = S, V, f),$$

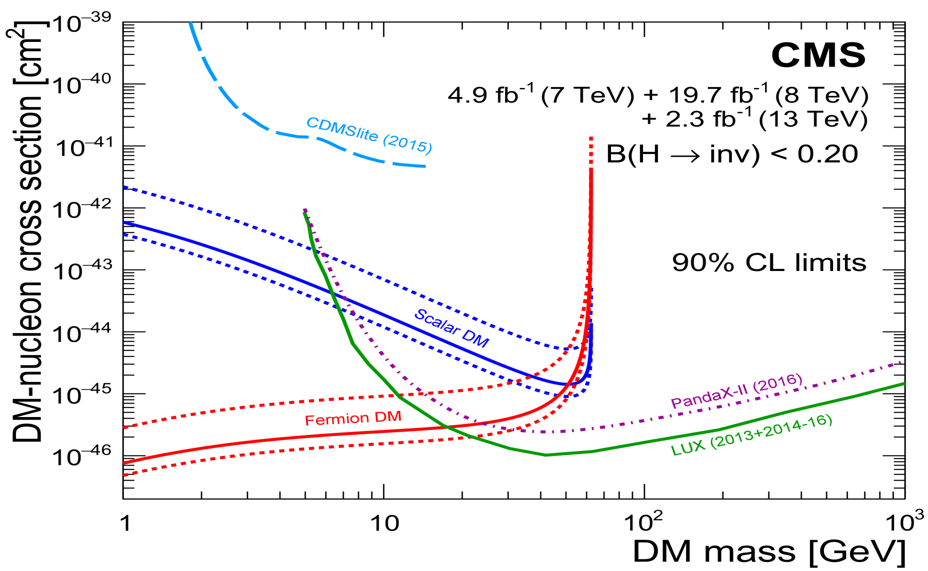
Table 11: Parameters in the Higgs-portal dark-matter model.

Vacuum expectation value	$v/\sqrt{2}$	174 GeV
Higgs boson mass	m_H	125 GeV
Higgs boson width	Γ_H	4.07 MeV
Nucleon mass	m_N	939 MeV
Higgs–nucleon coupling form factor	f_N	$0.33^{+0.30}_{-0.07}$

Direct Search for H → Invisible







CMS:

BF(H → Invisible) < 0.24 (0.23) at 95% CL

ATLAS:

BF(H → Invisible) < 0.23 at 95% CL

Search for Charged Higgs

$H^+ \rightarrow \tau^+ + \nu_\tau$

$H^+ \rightarrow c + b\text{-bar}$

$H^+ \rightarrow c + s\text{-bar}$

$H^+ \rightarrow t + b\text{-bar}$

ATLAS:

JHEP 03 (2015) 088

ATLAS-CONF-2016-088

ATLAS-CONF-2016-089

Phys. Lett. B 759 (2016) 555-574

Eur. Phys. J. C, 73 6 (2013) 2465

JHEP 11 (2015) 206

CMS:

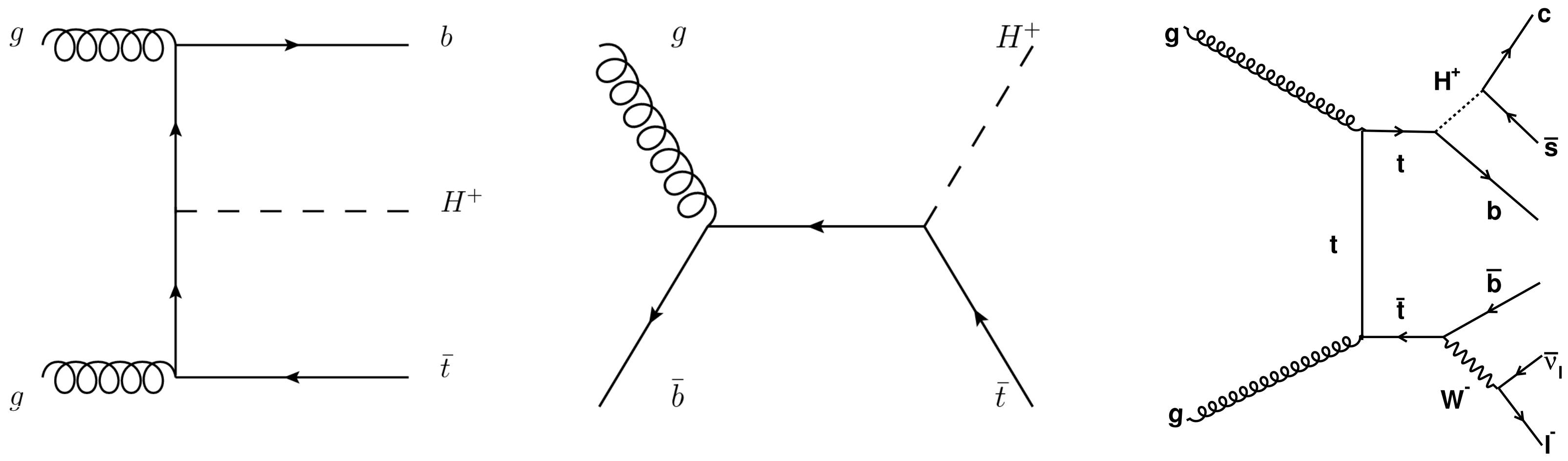
CMS-PAS-HIG-2016-030

CMS-PAS-HIG-2016-031

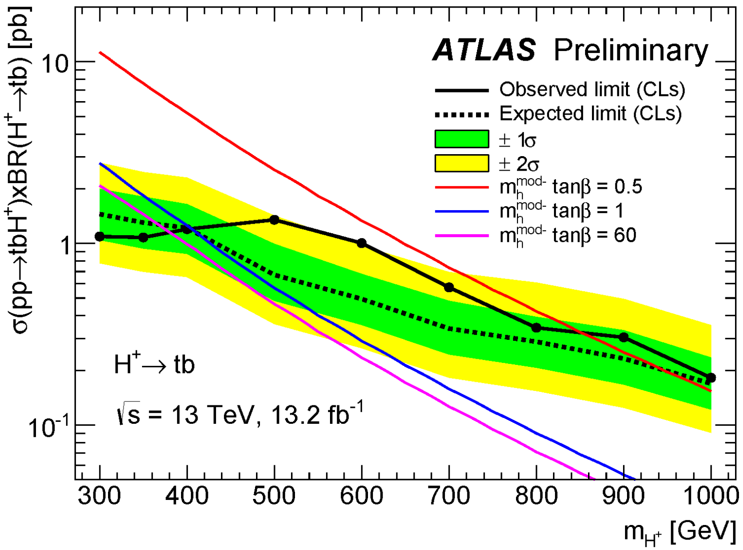
JHEP 12 (2015) 1

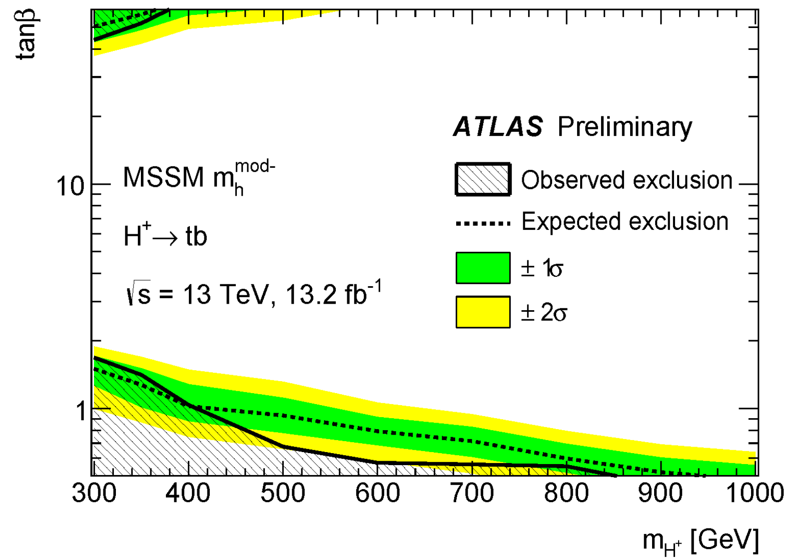
Search for Charged Higgs

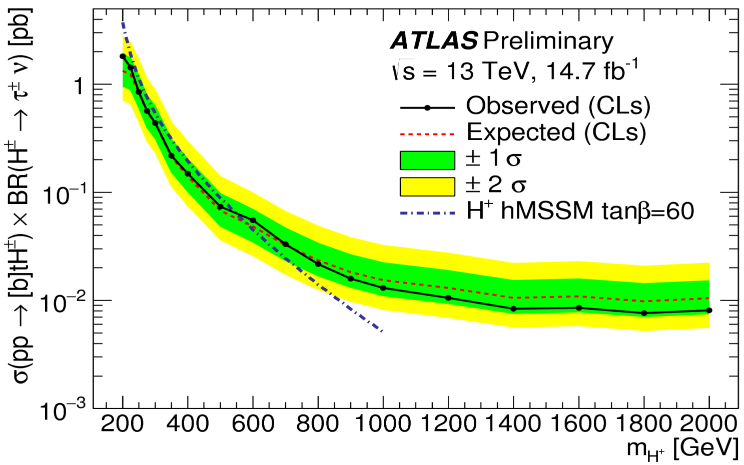
- **2 Higgs Doublet Model predicts 5 scalar Higgs boson (h, H, A, $H^{\pm}$)**
- **Charged Higgs can decay into $\tau\nu_{\tau}$, tb, cb, cs depending on the parameters of the model**
  - **Cos(β-α)→0 → dominant decay into $\tau\nu_{\tau}$**
  - **Type II 2HDM →dominant decay into tb**

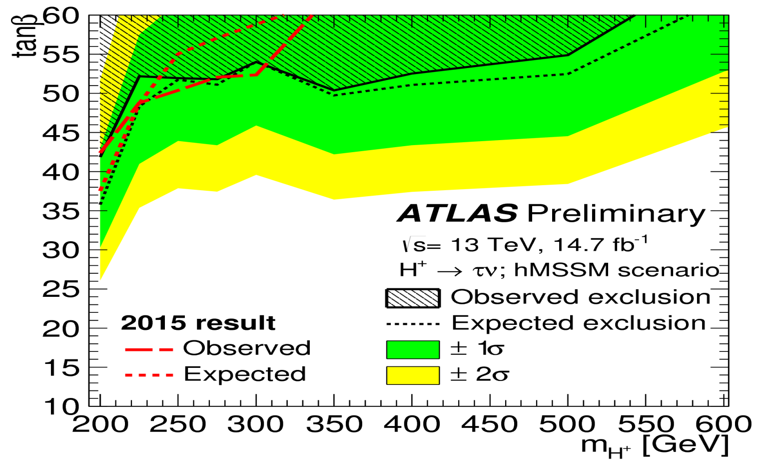


Search for Charged Higgs

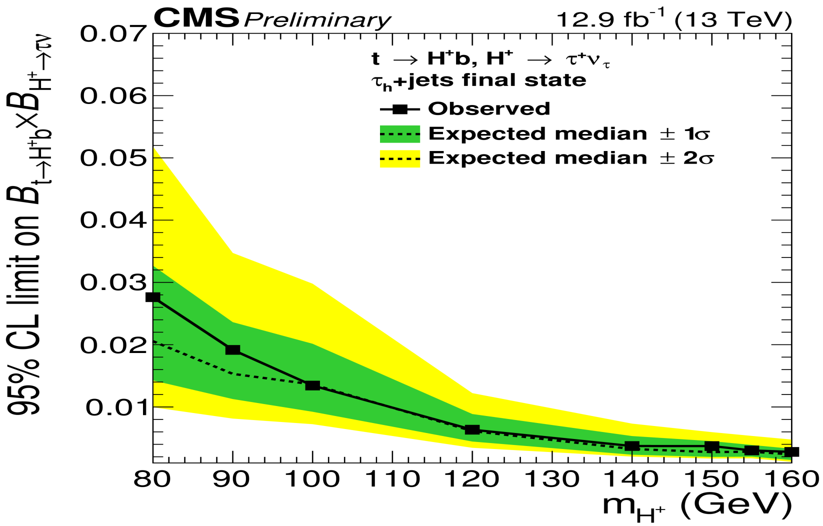


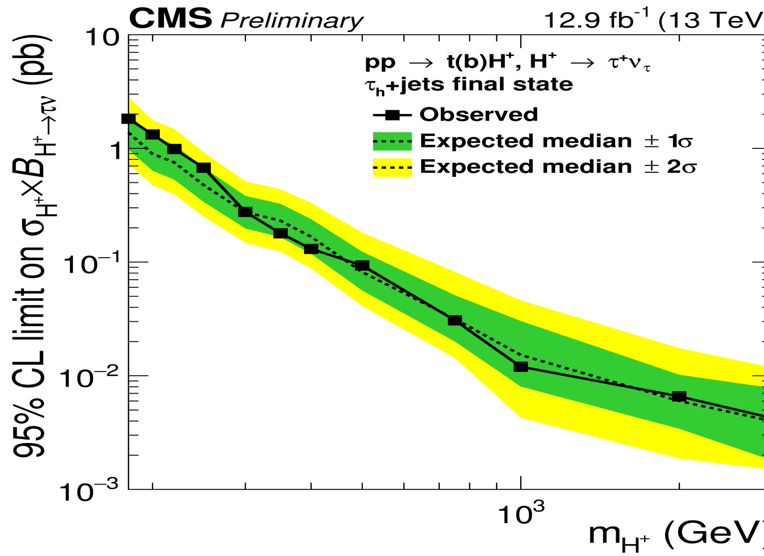


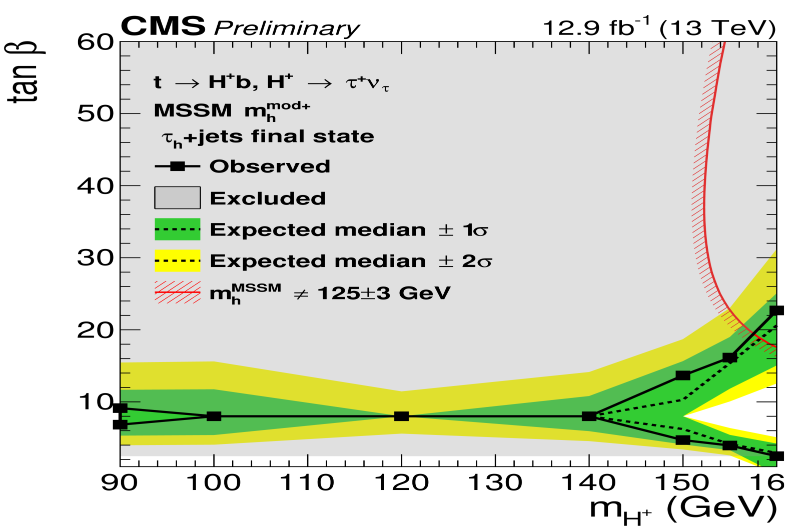


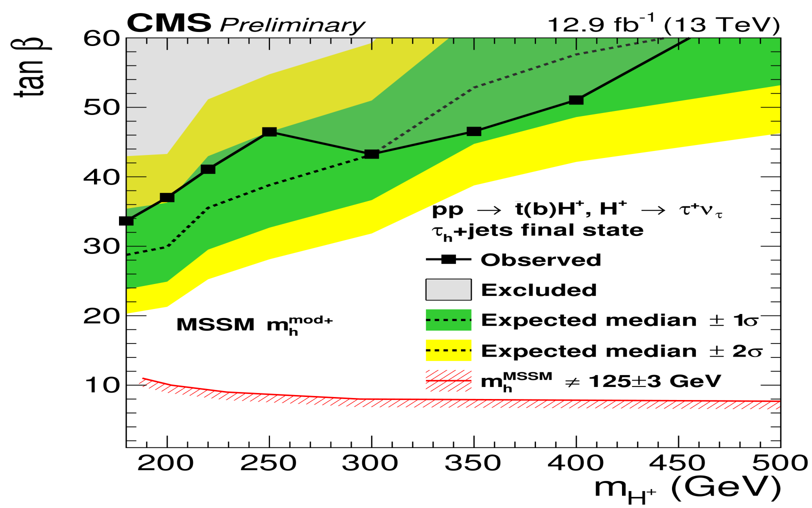


Search for Charged Higgs

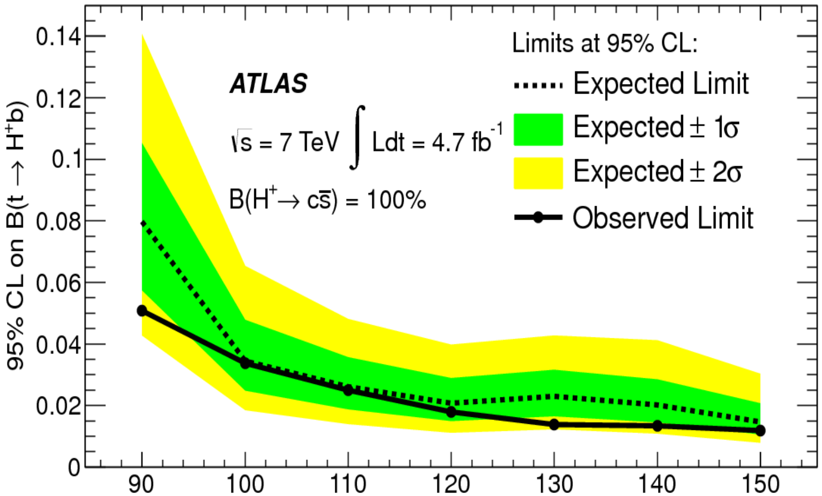


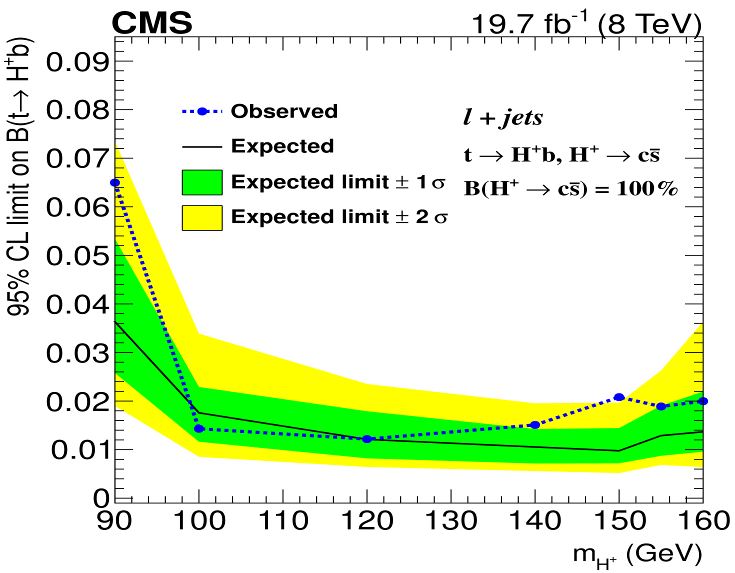


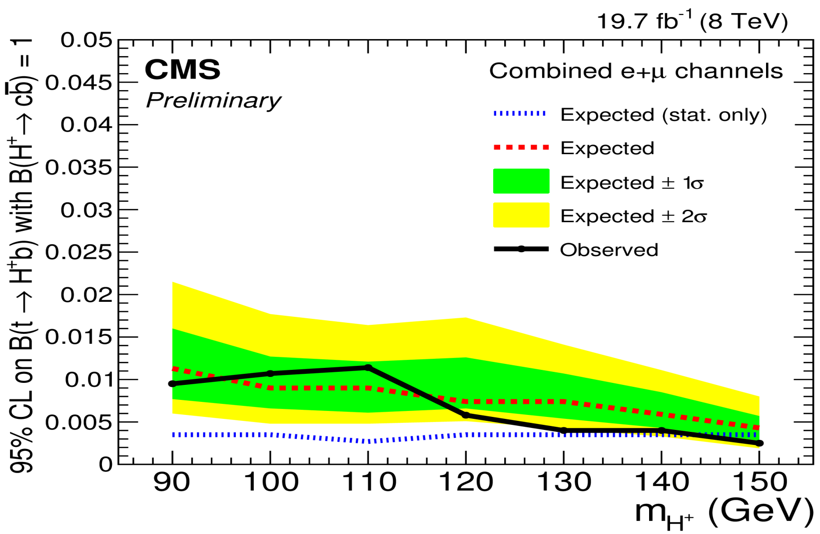




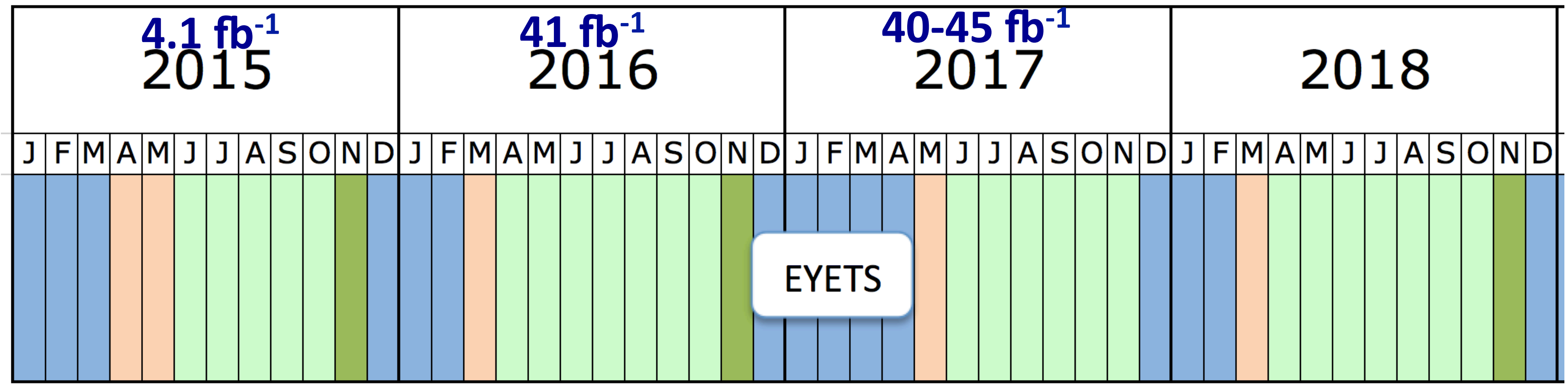
Search for Charged Higgs

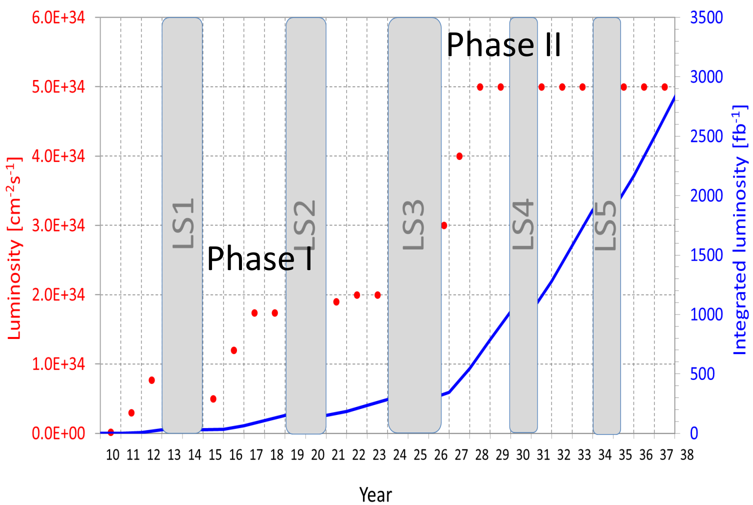




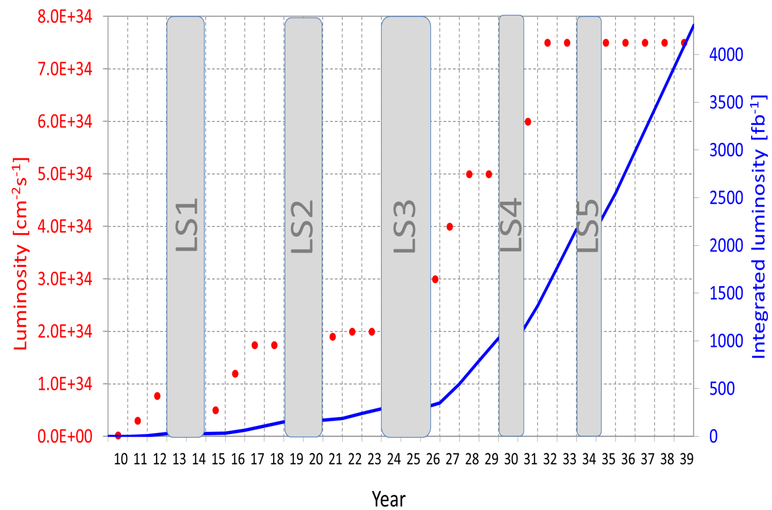


LHC @13 TeV Beyond 2016…





Nominal HL-LHC ≃ 140 p-p collisions/evt



Ultimate HL-LHC ≃ 200 p-p collisions/evt

Summary

- **Exploration of SM Higgs properties begun with Run-2 data**
- **Various Production mechanism and Decay modes of Higgs have been probed extensively using Run-2 data**
- **Results presented using ~1/3rd of 2016 (13 TeV) data**
- **Accurate measurements of BF, couplings, correlation between bosonic and fermionic coupling with more data from Run-2 would be accomplished**

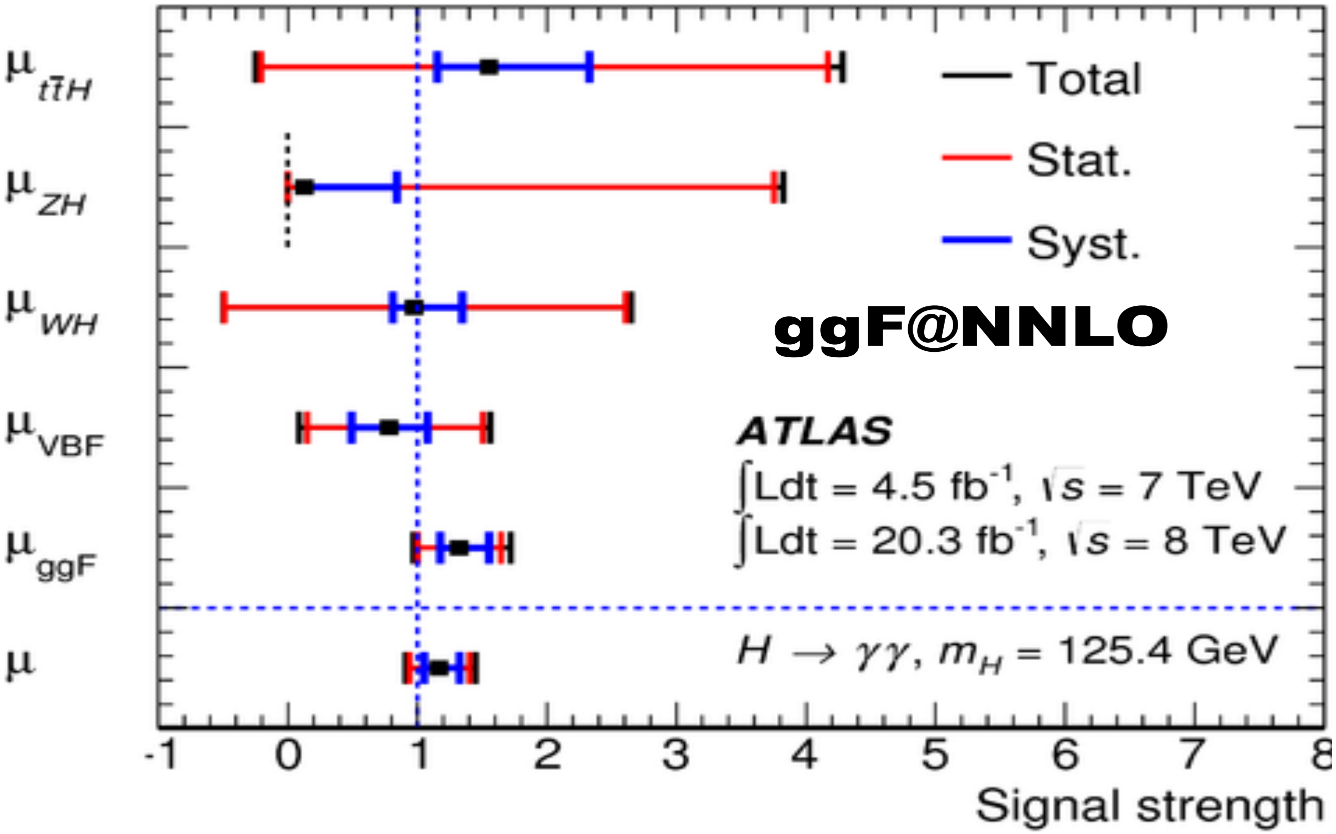
Additional Material

ATLAS+CMS Combined Run 1 Results

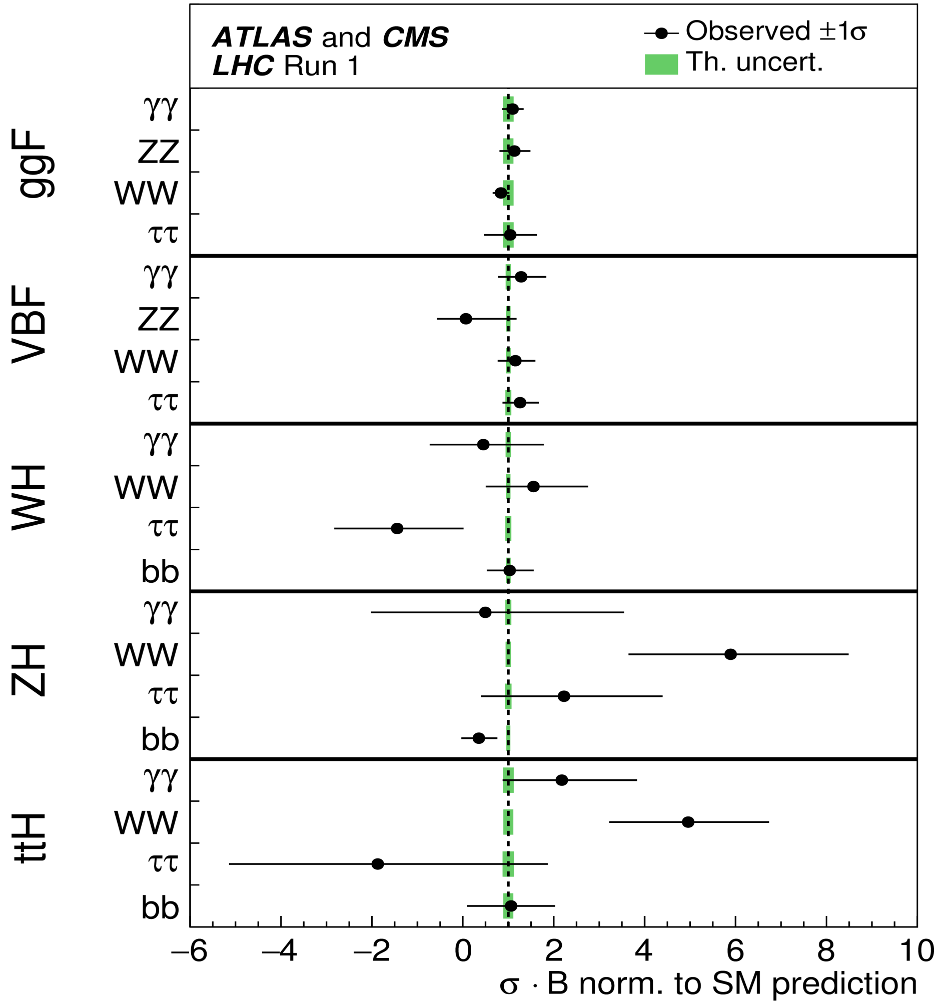
ATLAS_CONF_2015_014 CMS-PAS-HIG-15-002

JHEP 08 (2016) 045

Run 1 ATLAS: Signal Strength using H→γ γ



Run 1: Combined Coupling Strengths



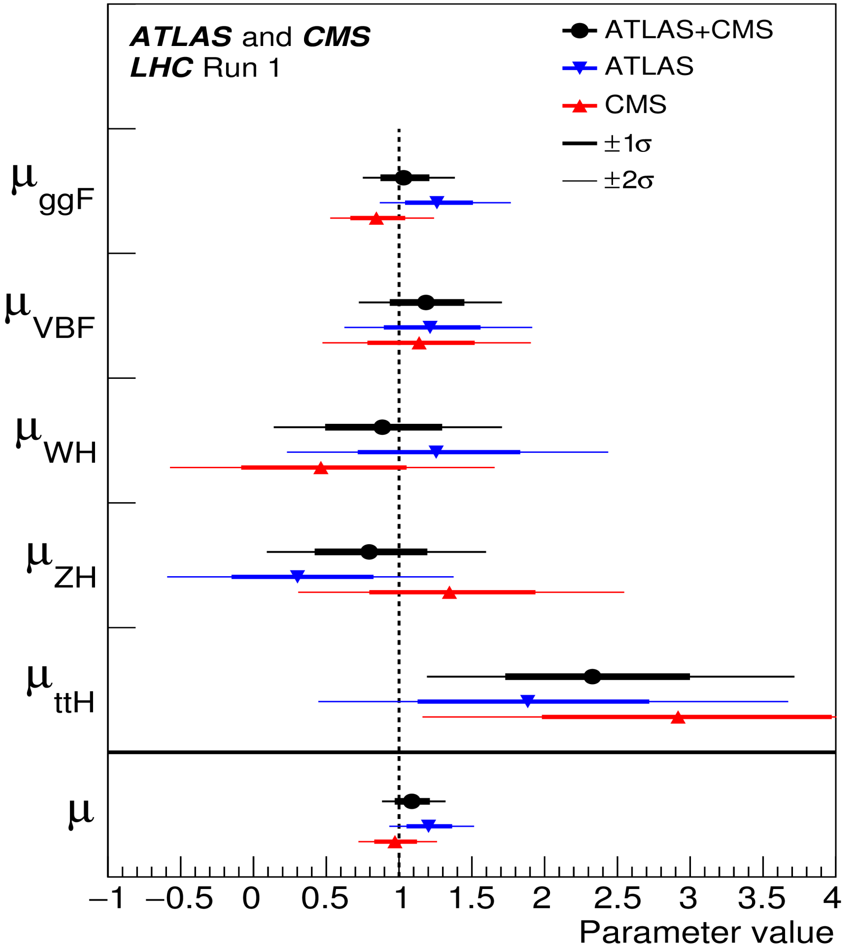
Mass: 125.09 ± 0.24 GeV

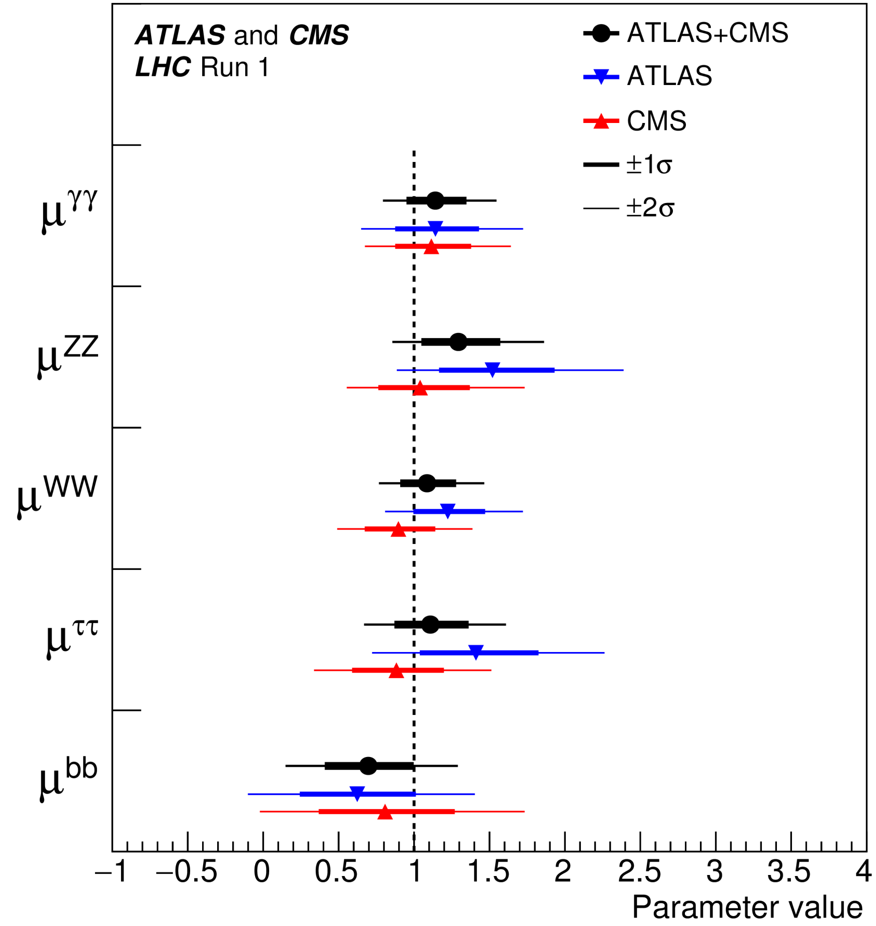
Spin: 0, Parity: Even

Consistency of SM expectation with μ=1 with a p-value of 40%

Mild excess in ttH and ZH production modes

Run 1: Production Mechanism and Decay Modes





ATLAS: $\mu=1.20^{+0.15}_{-0.14}$ CMS: $\mu=0.97^{+0.14}_{-0.13}$

Combined: $\mu=1.09^{+0.11}_{-0.10}$

Run 1 Relative Couplings

Reference channel:

- ggF → H → Z Z → 4l
- Small background
- Smallest uncertainties

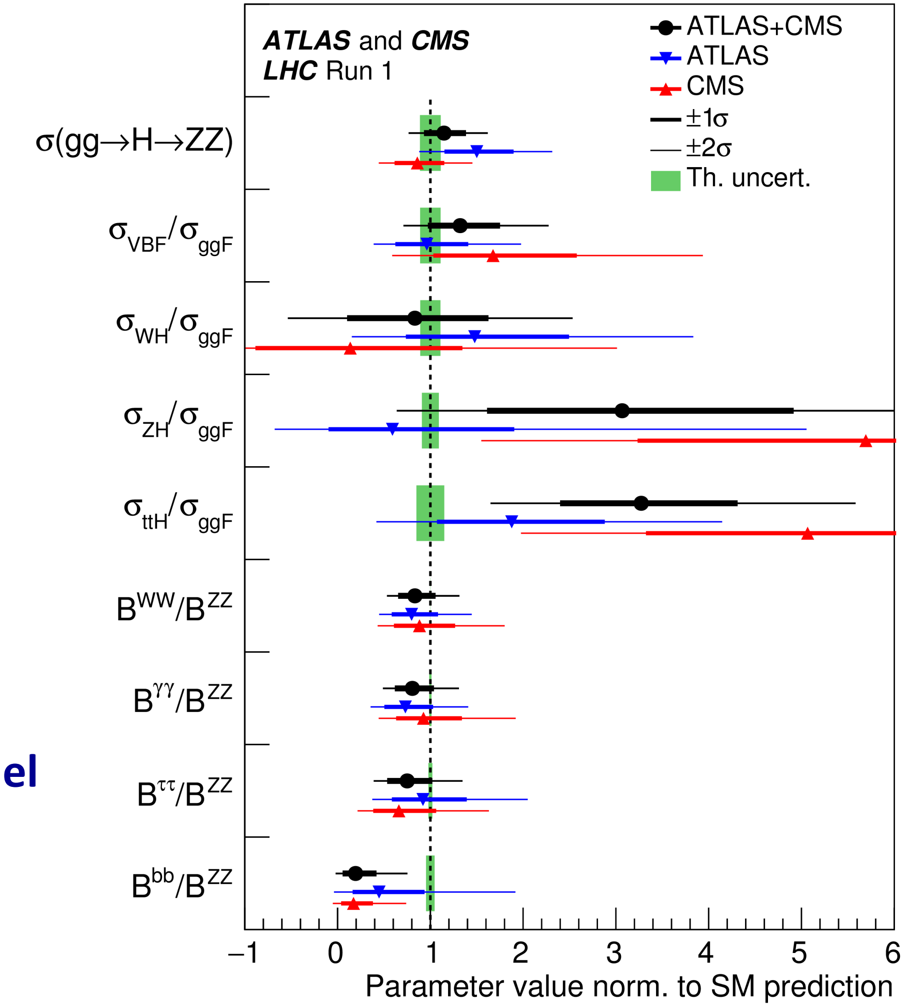
$$\frac{\sigma_{ttH}}{\sigma_{ggF}} = 3.3^{+1.0}_{-0.9}$$

$$\frac{\sigma_{ZH}}{\sigma_{ggF}} = 3.2^{+1.8}_{-1.4}$$

$$\frac{B^{bb}}{B^{ZZ}} = 0.19^{+0.21}_{-0.12}$$

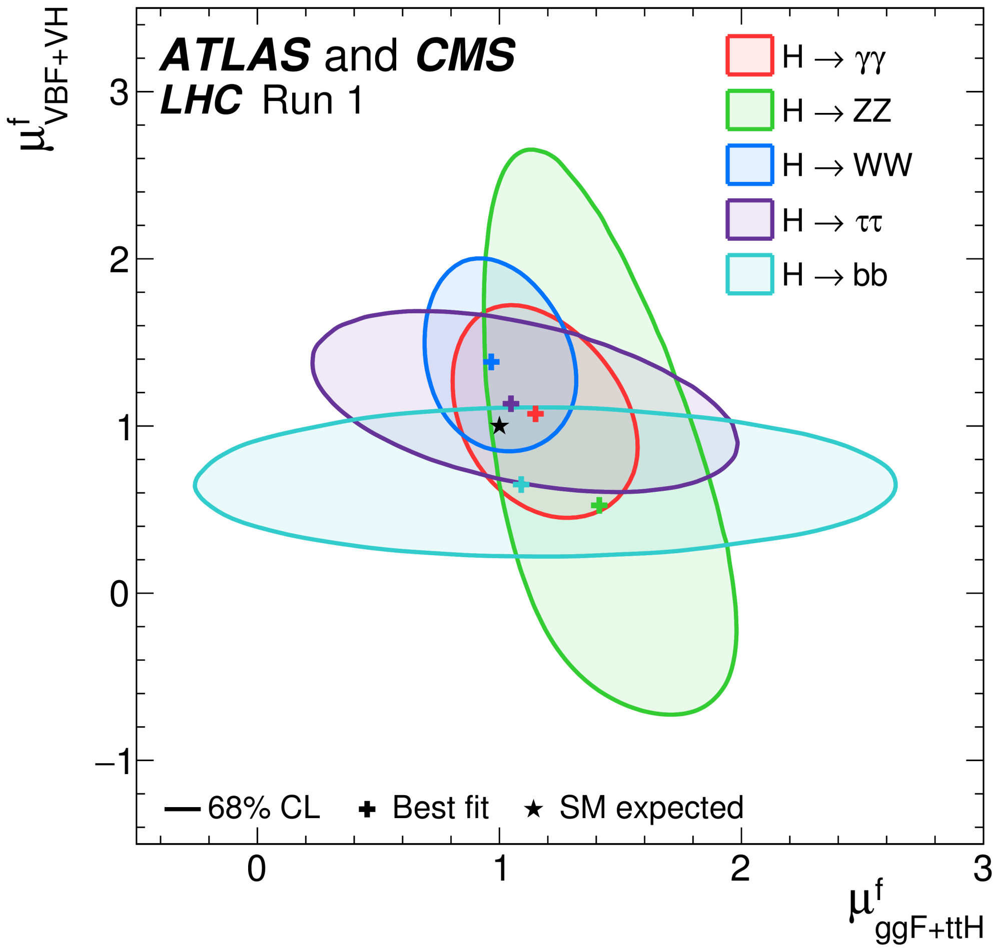
Mid excess in ttH in multi-lepton channel
Mild excess in ZH→WW
Deficit in VH→bb

Overall SM Compatibility: 16%



Run 1: Global Signal Strength

$$\mu_V/\mu_F = 1.09^{+0.36}_{-0.28}$$



H→gama gama *Angular Distribution*

$$|\cos\theta^*| = \frac{|\sinh(\Delta\eta^{\gamma\gamma})|}{\sqrt{1+\left(p_{\mathrm{T}}^{\gamma\gamma}/m_{\gamma\gamma}\right)^2}}\frac{2p_{\mathrm{T}}^{\gamma_1}p_{\mathrm{T}}^{\gamma_2}}{m_{\gamma\gamma}^2}$$