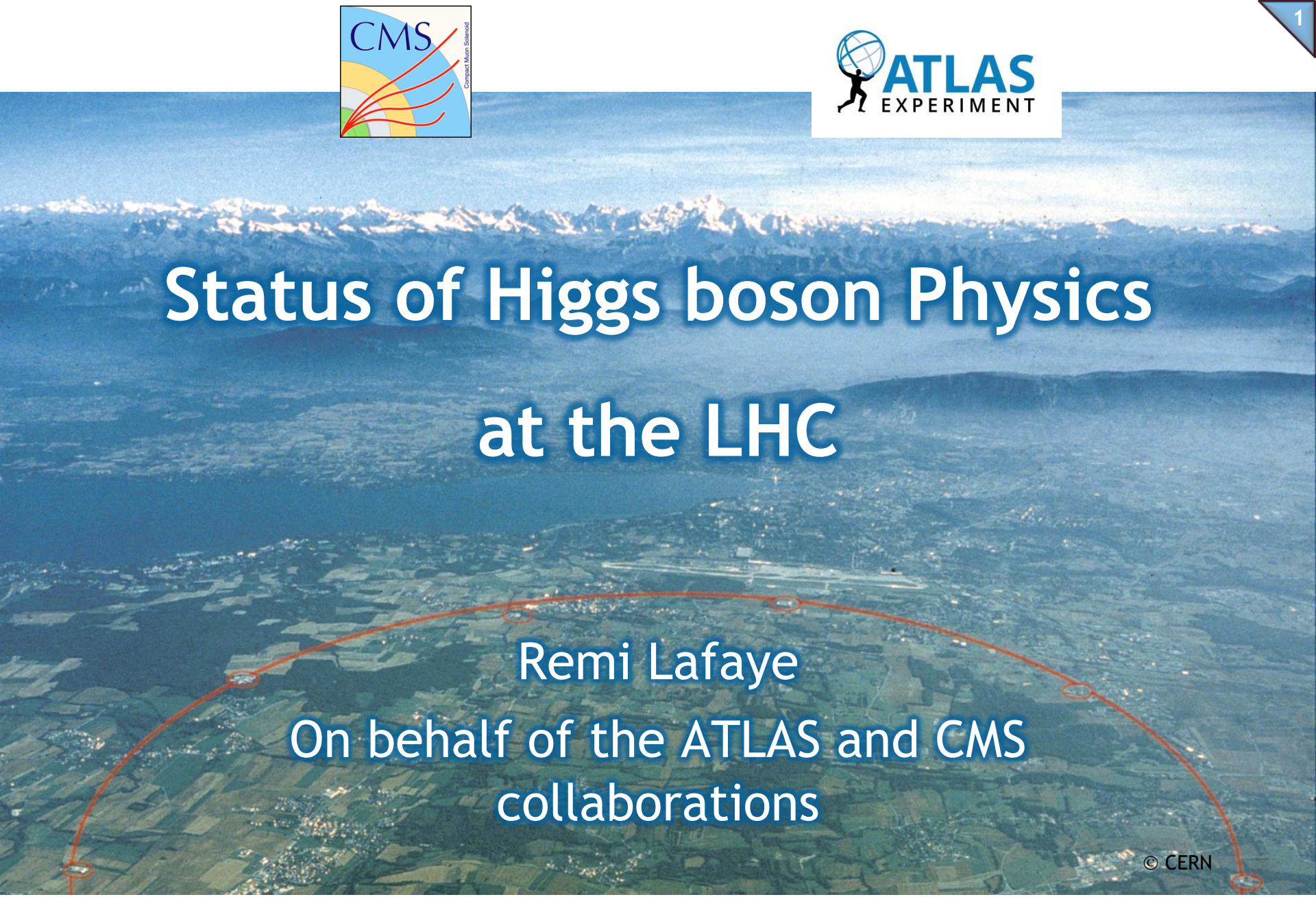


Status of Higgs boson Physics at the LHC

Remi Lafaye

On behalf of the ATLAS and CMS collaborations

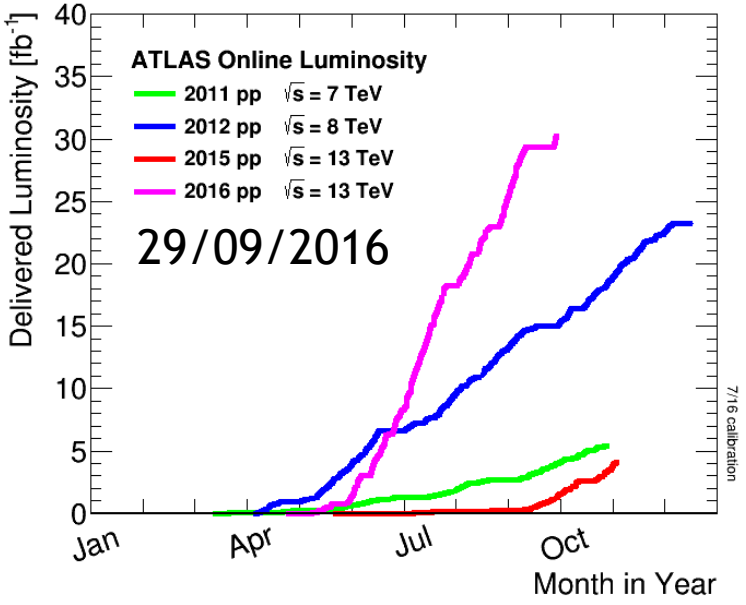
Rencontres du Vietnam, Quy-Nhon, September 29th 2016

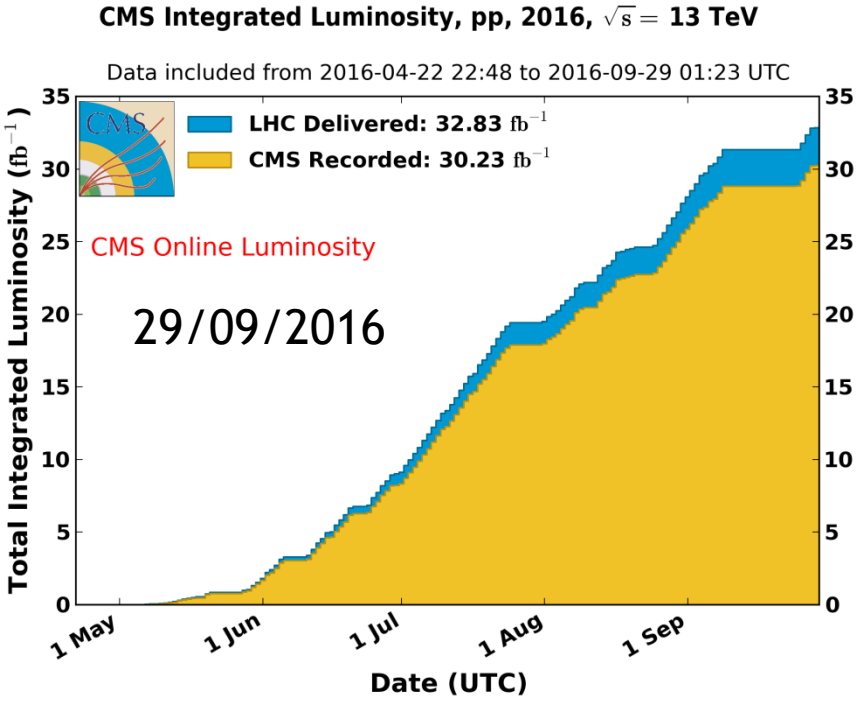
Higgs boson & partners at LHC

In 2012, after 1 ½ year of running at 7 & 8 TeV ATLAS and CMS announced the discovery of a Higgs boson at the LHC

With the run 1 data most accessible properties of the Higgs were measured and constraints were set on others

In 2015 and 2016 both experiments have collected up to now nearly 30 fb^{-1} of data at 13 TeV





To quote LHC team (2016): "No one is more surprised than we are "

Higgs boson at Run 1

m_H=125.09±0.21(stat.)±0.11(syst.) GeV (0.2% precision!)

Spin 0 and even parity from angular distributions

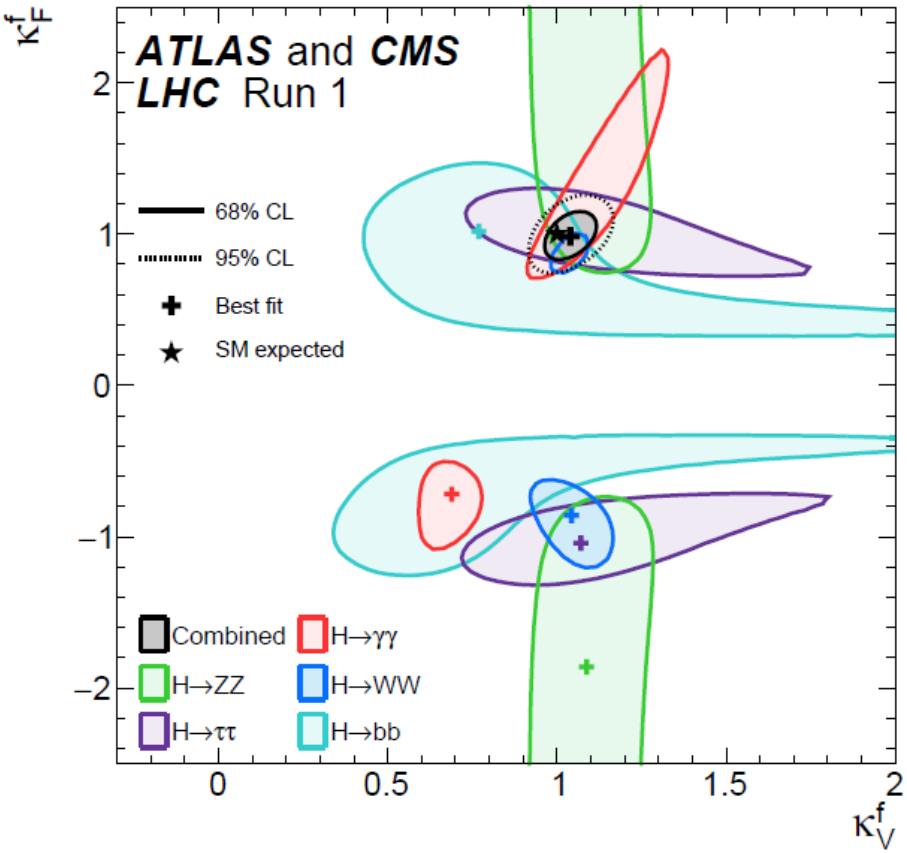
ggF precision close to NNLO+NNLL uncertainties (~15%)

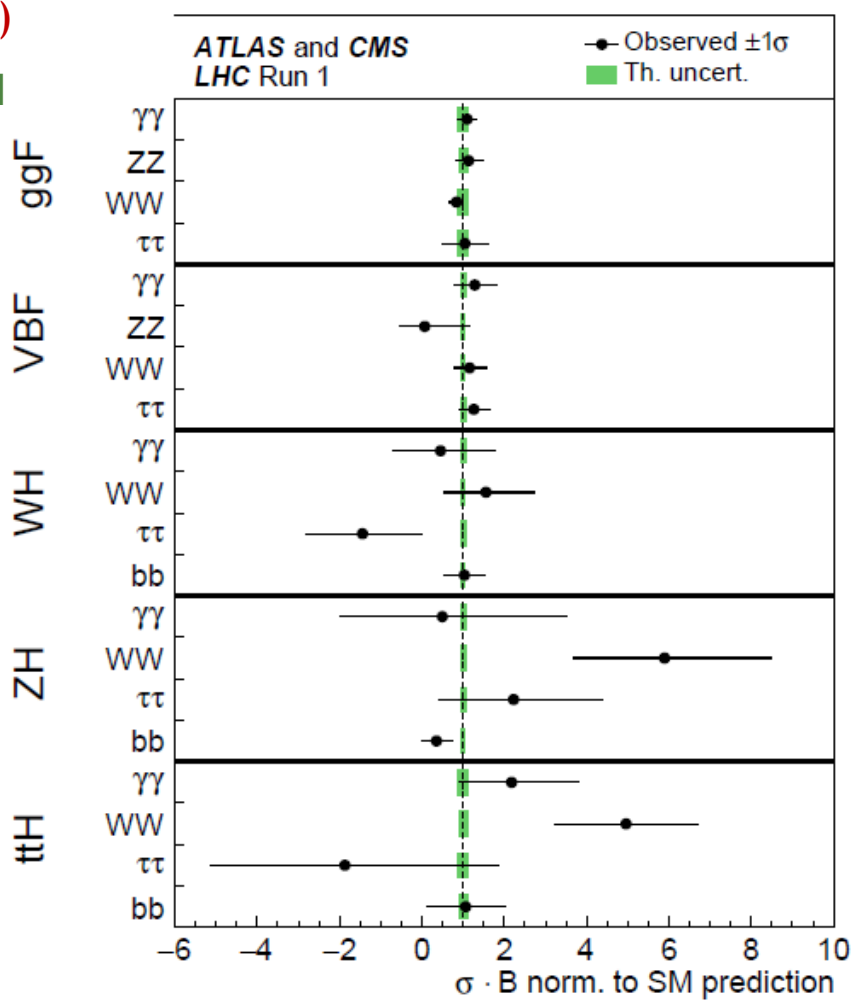
Consistent with SM for all parametrizations considered

Small excesses for ttH and ZH modes

Phys. Rev. Lett. 114, 191803

J. High Energy Phys. 08 (2016) 045





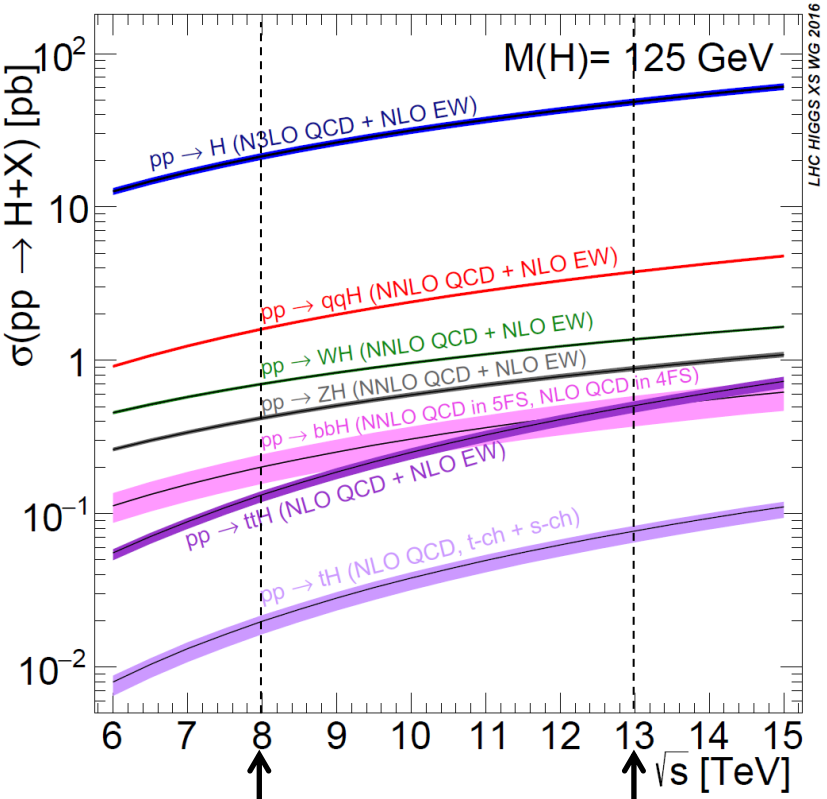
Combined signal yield 1.09±0.11

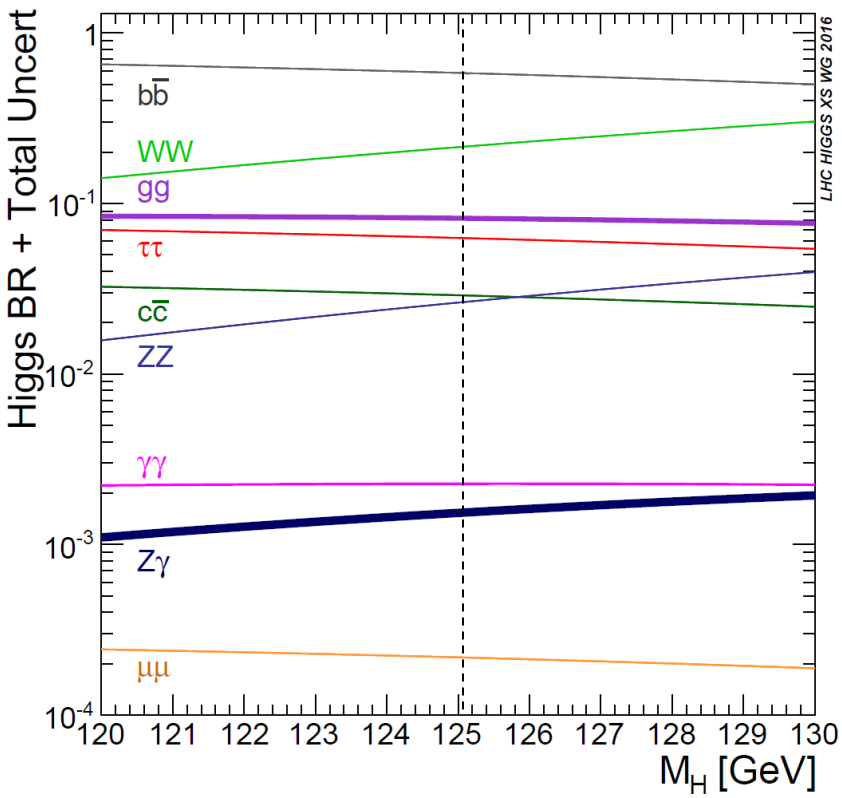
Higgs boson at Run 2

The run 2 dataset public results: ~3 fb^{-1} 2015 + ~13 fb^{-1} 2016 (in this talk)

The LHC already produced more Higgs bosons in run 2 than in run 1 !

Observed decay modes: $\gamma\gamma$, ZZ, WW, $\tau\tau$ (as of August 2016)





Total XS: 24.5 pb 55.6 pb

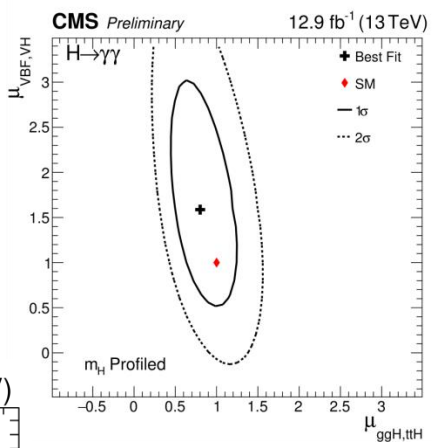
Higgs→γγ

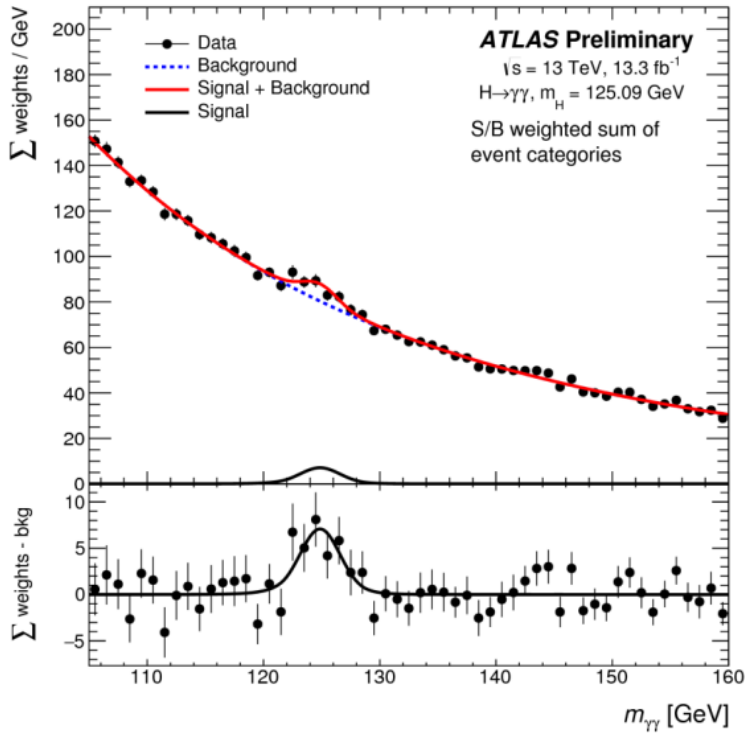
Event signature: 2 isolated photons

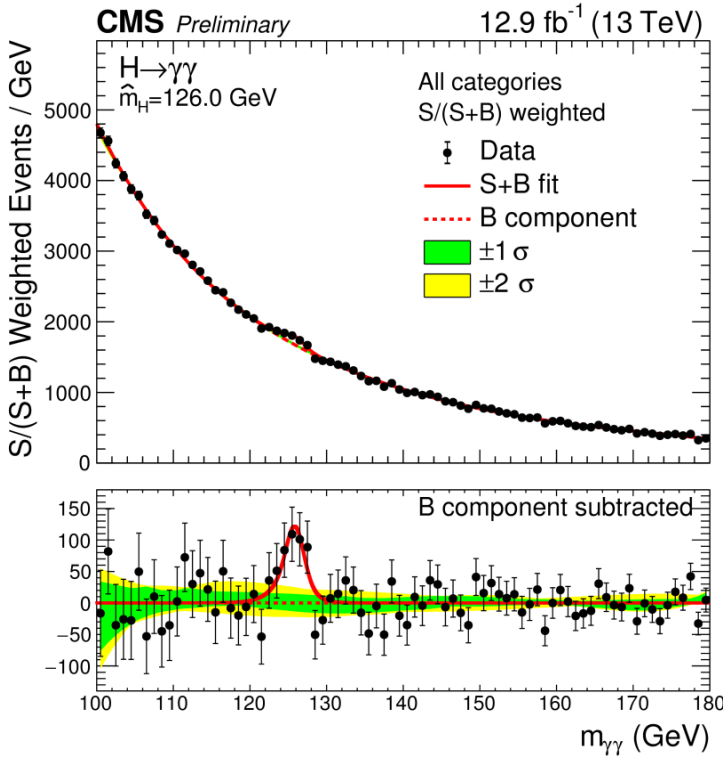
Large irreducible γγ background

Main reducible background: γ-jet + jet-jet (~20% of total bkg)

Signal extracted in different categories to increase significance







ATLAS-CONF-2016-067

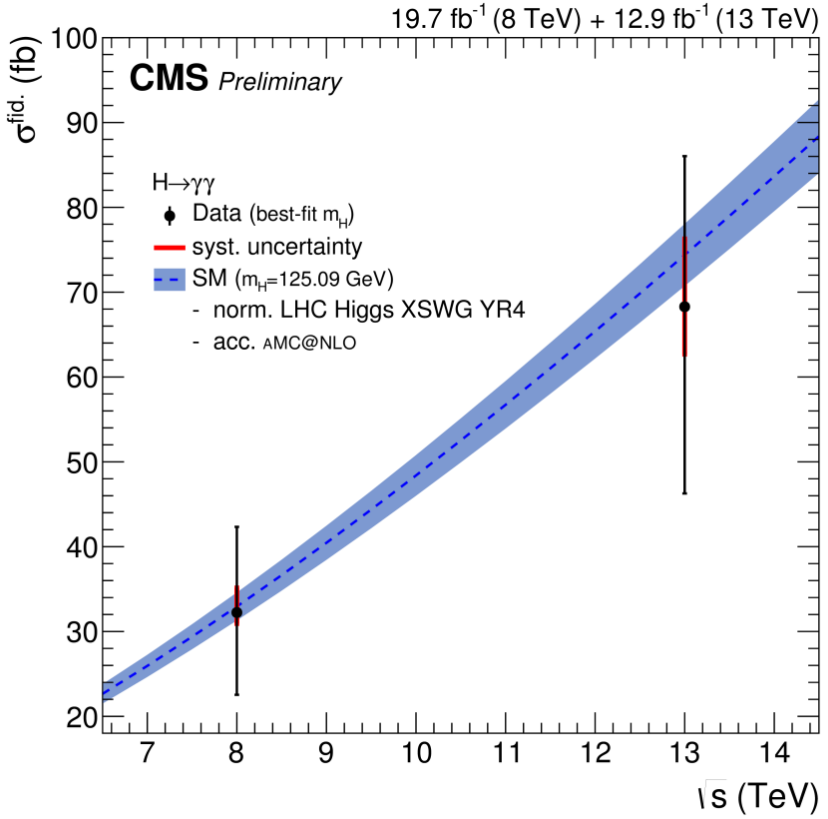
CMS-PAS-HIG-16-020

Higgs→γγ

Fiducial cross section:

$$\sigma_i = \frac{\nu_i^{sig}}{c_i \int L\,dt}$$

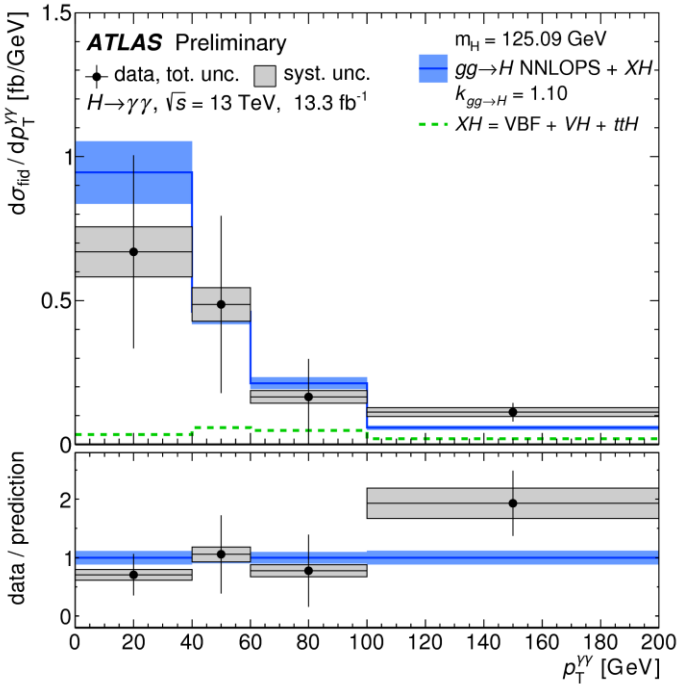
- Corrected for detector inefficiency and resolution
- To be used for comparison with computations with truth level corrections



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^{3}LO+XH)
CMS (12.9 fb^{-1})	69^{+16}_{-22}(stat)$^{+8}_{-6}$(syst)	73.8±3.8

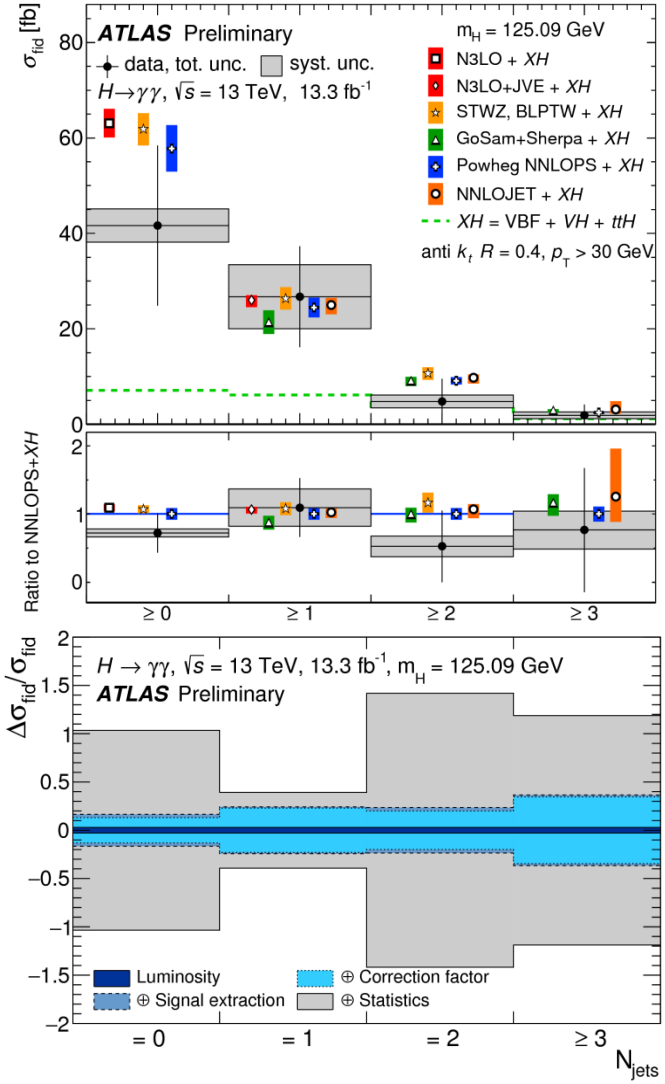
Higgs→γγ

Differential cross section:



NNLOPS normalized to N3LO, K_{ggH}=1.1

Worse agreement at high & low p_T



Stat. uncertainties dominate

Signal extraction: γ energy scale & **resolution**, signal & **bkg modelling**

Corr. factor: ID, calibration, efficiencies

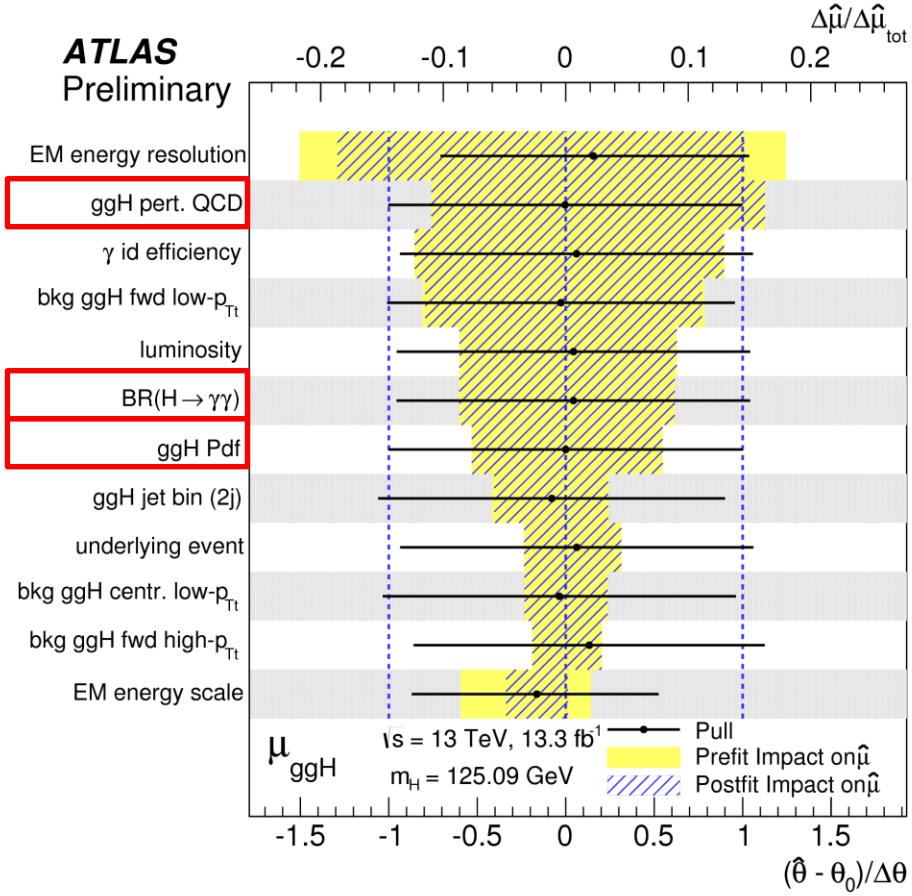
Jet energy calibration important in high jet activity regions

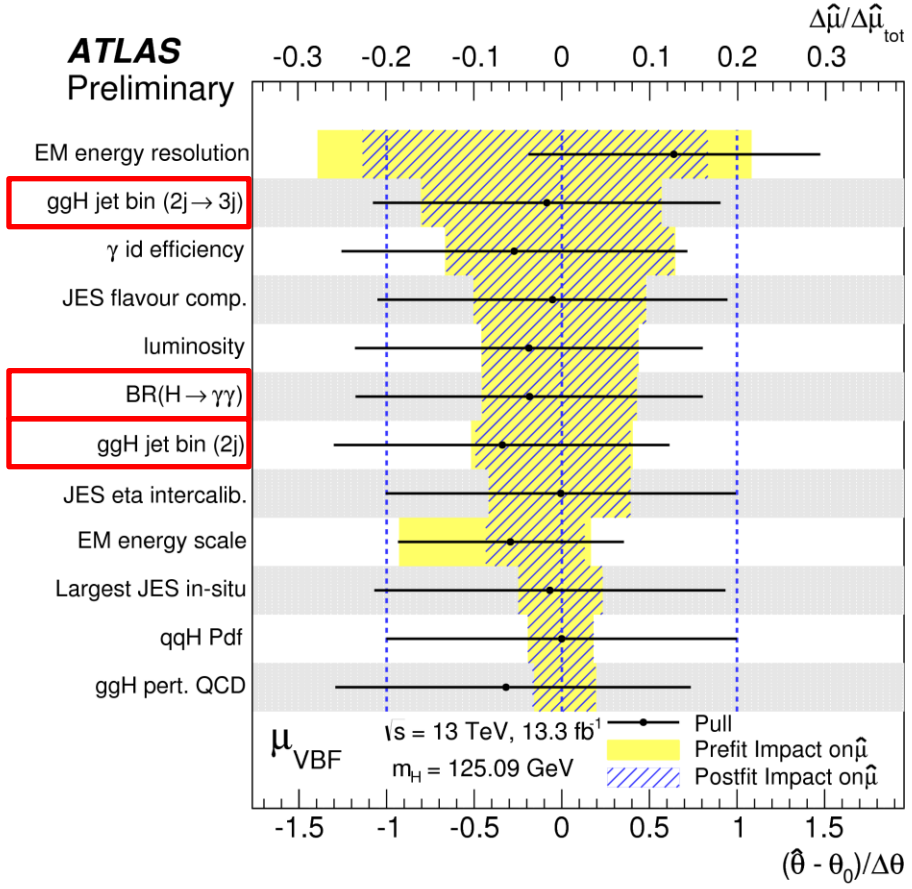
Higgs→γγ

γγ nuisance parameters ranking and pulls on signal strength

Impact on total uncertainty in % of total unc. (Yellow: pre-fit, Blue: post-fit)

Red: dominant theoretical uncertainties (but not for σ×BR tot.)





Higgs→γγ

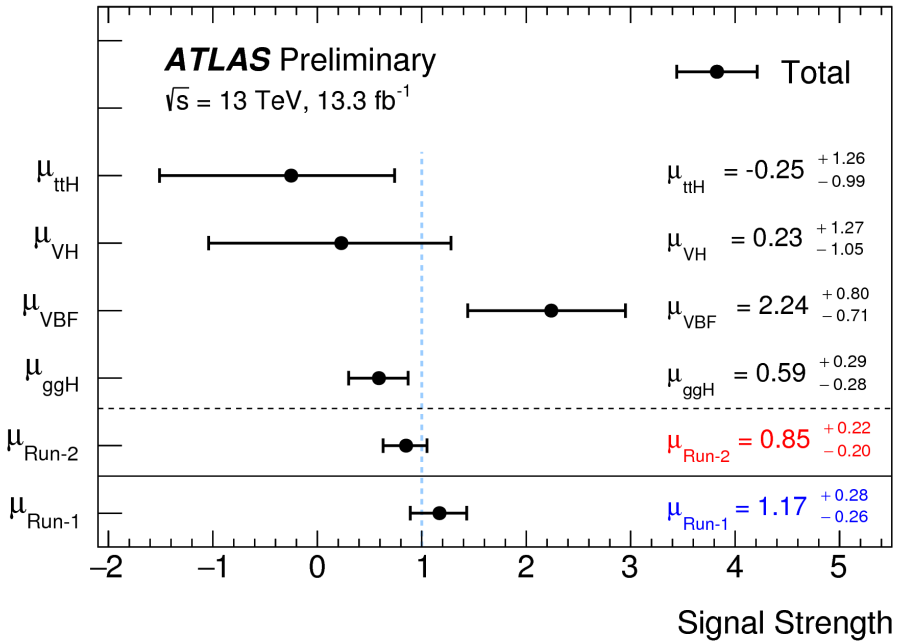
Signal strength & production

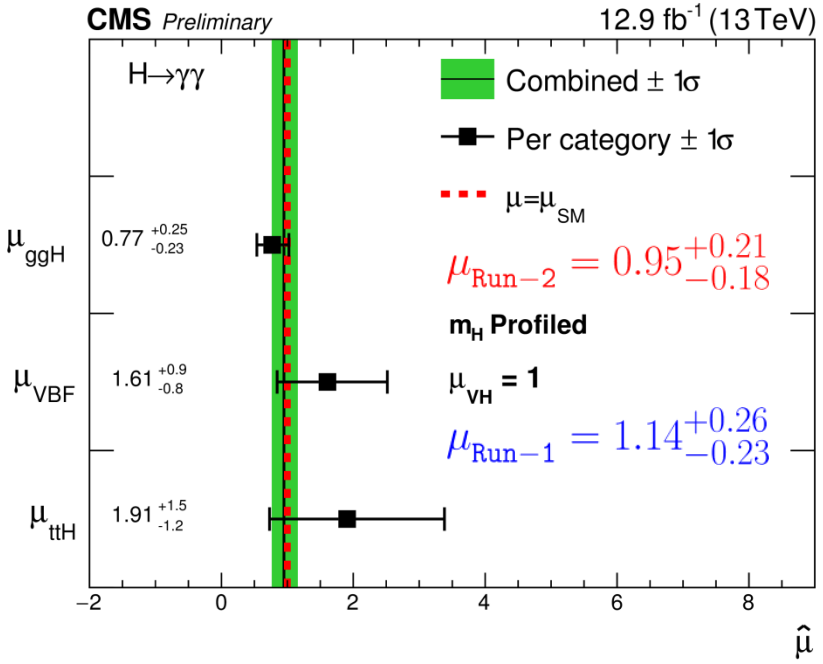
Different categories targeted at production modes: ggF, VBF, VH, ttH

Theoretical predictions using N3LO (QCD ggF)

Precision already similar to run-1

All results compatible with SM (uncertainties statistically dominated)





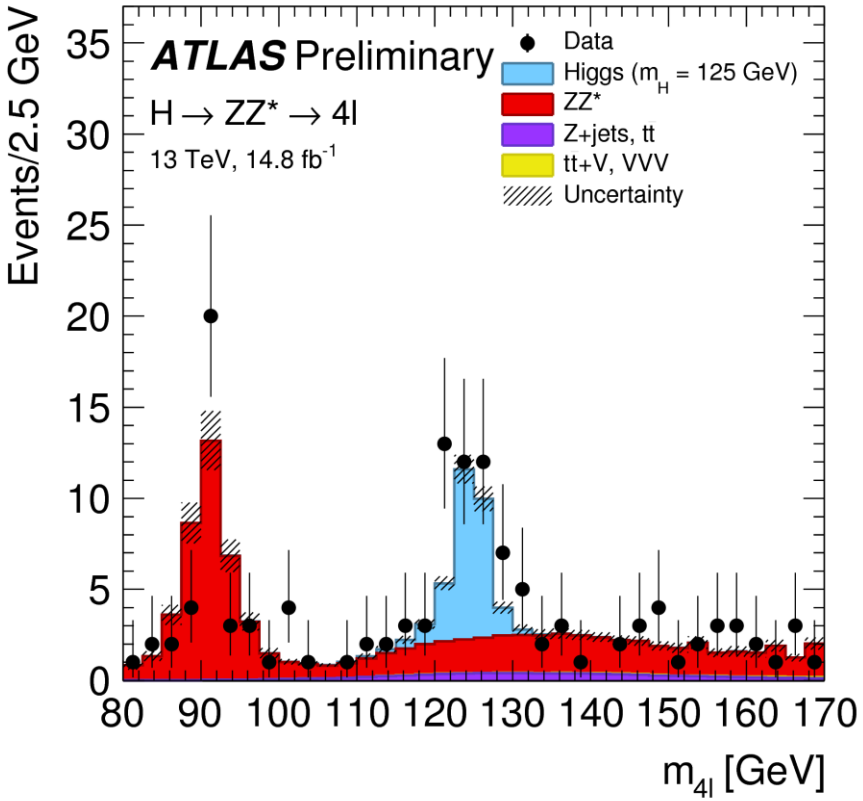
(Run-1 results use NNLO+NNLL QCD ggF)

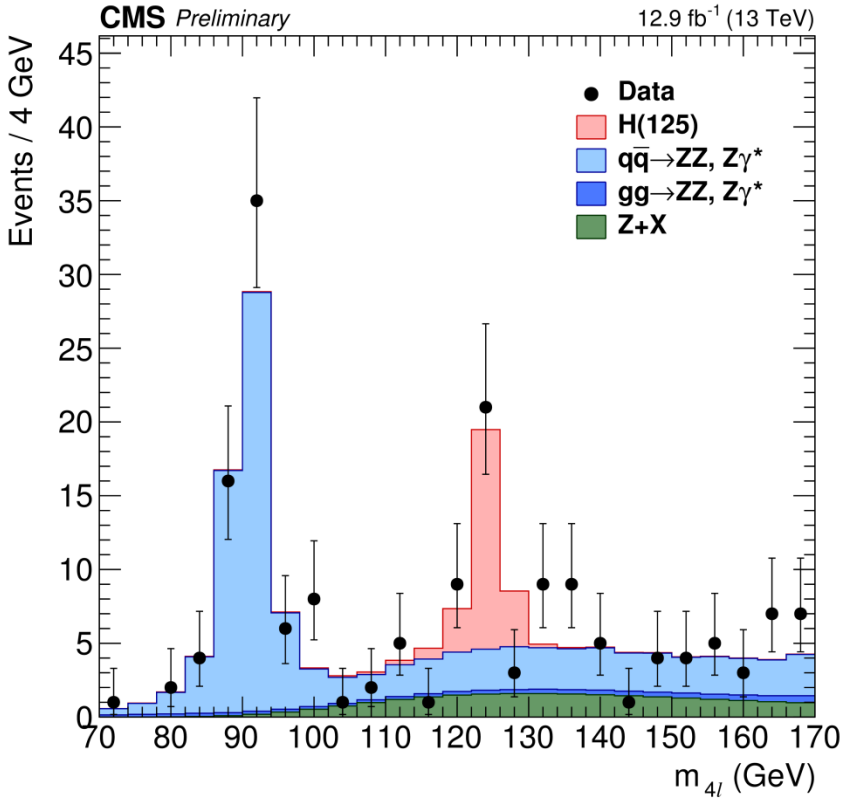
Higgs→ZZ*

Event signature: 2 pairs of same flavor isolated electrons or muons

Main background: ZZ, Z+X

Dominant systematics: luminosity and lepton ID + Isolation efficiency





ATLAS-CONF-2016-079

CMS-PAS-HIG-16-033

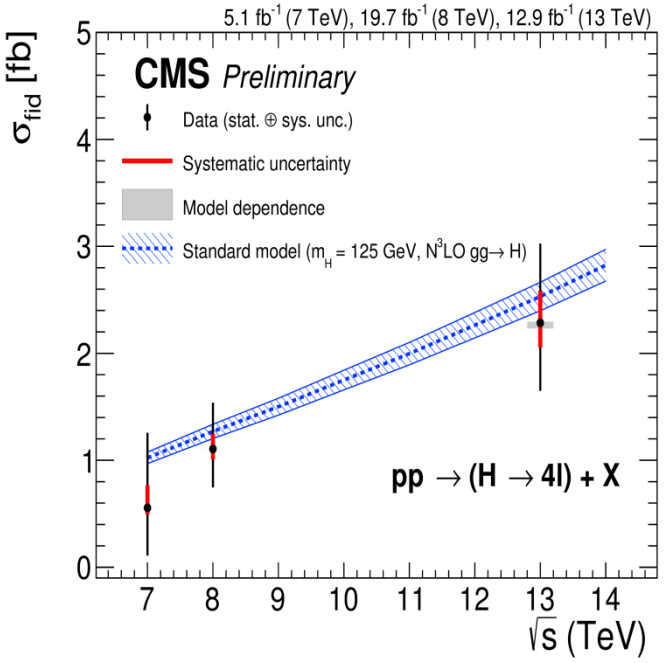
Higgs→ZZ*

Fiducial cross section:

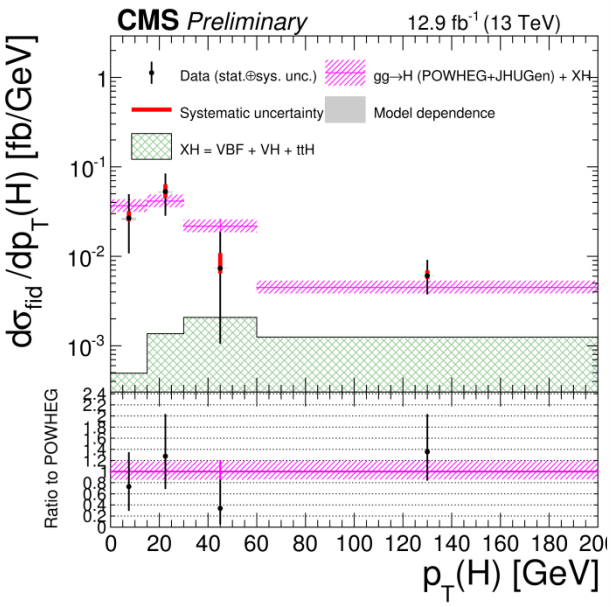
- Corrected for detector inefficiency and resolution
- To be used for comparison with computations with minimal corrections

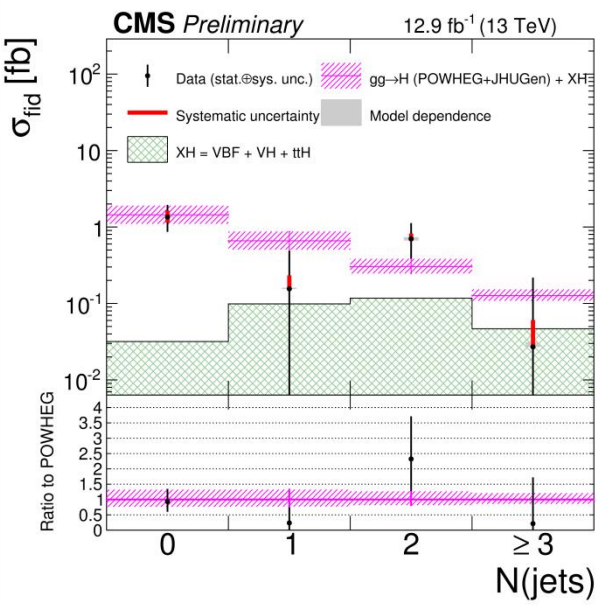
$$\sigma_i = \frac{\nu_i^{sig}}{c_i \int L\,dt}$$

13 TeV	Fiducial σ (fb)	SM prediction (fb)
ATLAS (14.8 fb^{-1})	$4.54^{+1.02}_{-0.90}$	$3.07^{+0.21}_{-0.25}$
CMS (12.9 fb^{-1})	$2.29^{+0.74}_{-0.64}(\text{stat})^{+0.30}_{-0.23}(\text{syst})$	2.53±0.13



Differential cross section:





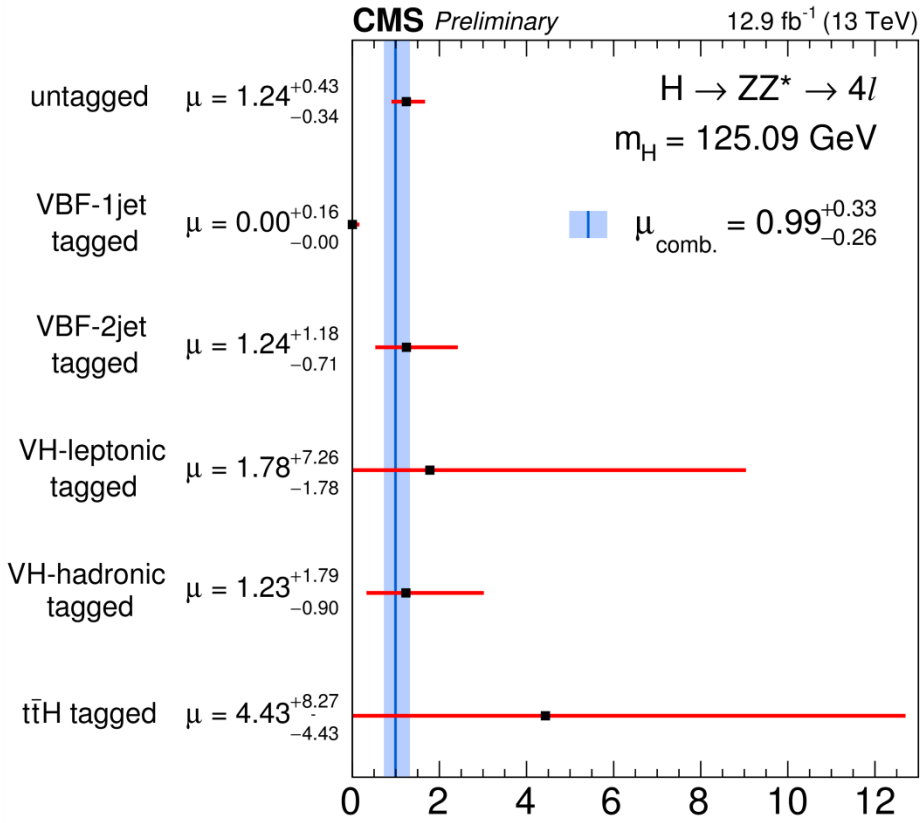
Higgs→ZZ*

Signal strength & production

Different categories targeted at production modes: ggF, VBF, VH, ttH

Precision already similar to run-1

All results compatible with SM (uncertainties statistically dominated)



CMS-PAS-HIG-16-033

ATLAS Run-1: $1.44\ ^{+0.40}_{-0.33}$

CMS Run-1: $0.93^{+0.29}_{-0.25}$

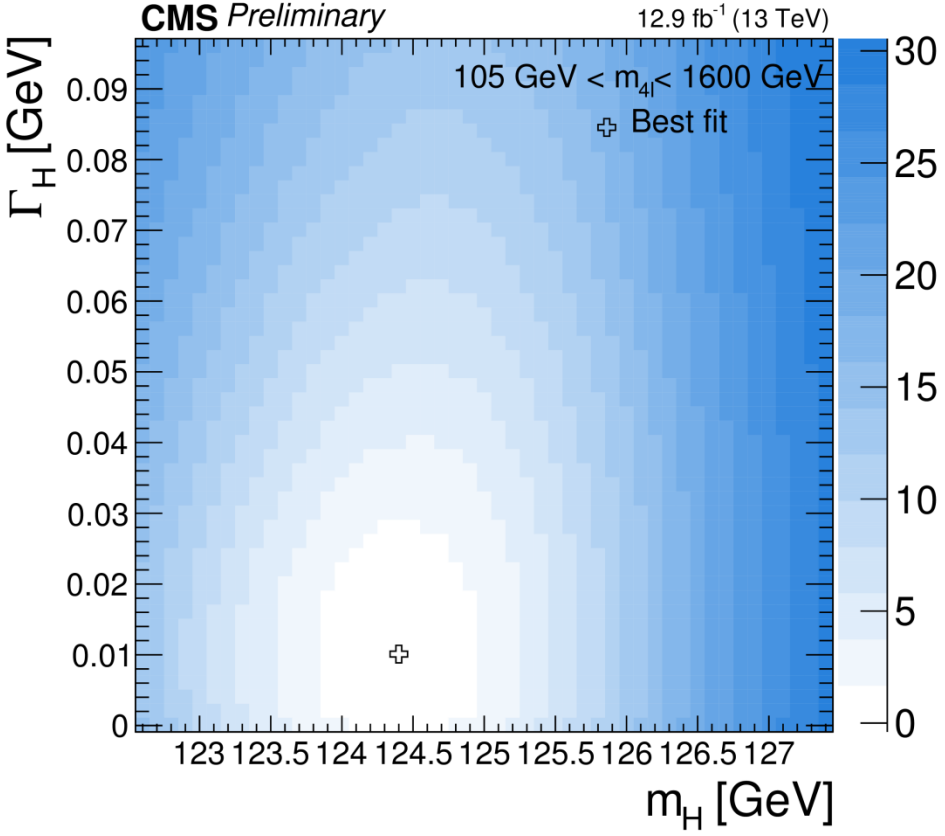
Higgs→ZZ*

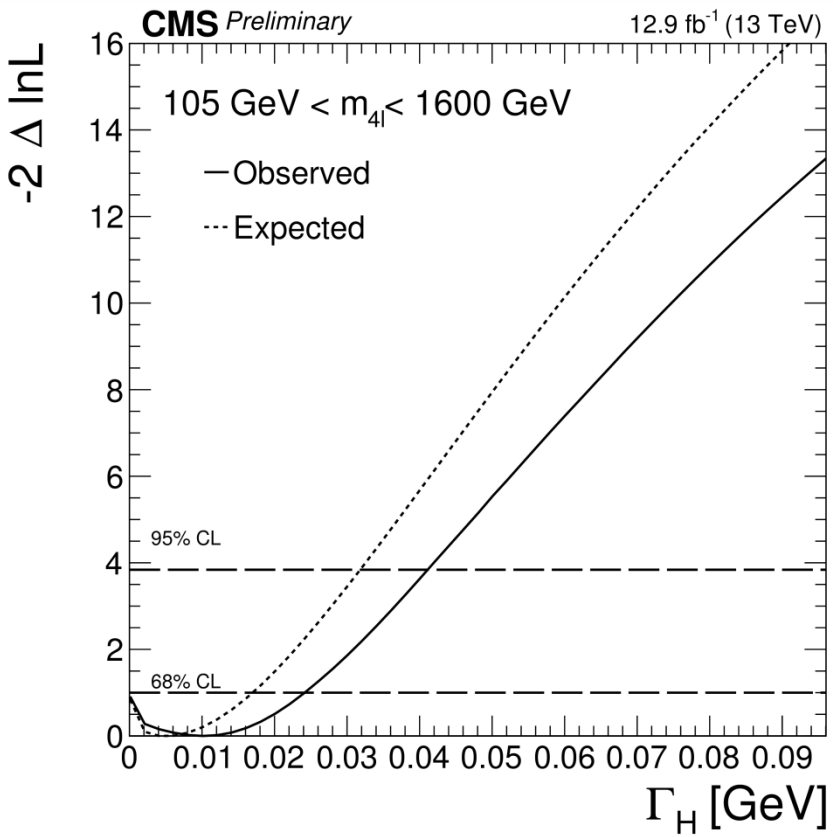
Measurement of the width from off-shell & on-shell regions

MCFM+JHUGEN+HNNLO framework includes interferences

Off-shell: Γ_H<41 (32) MeV

On-shell: Γ_H<3.9 (2.7) GeV(less assumptions on BSM contribution)



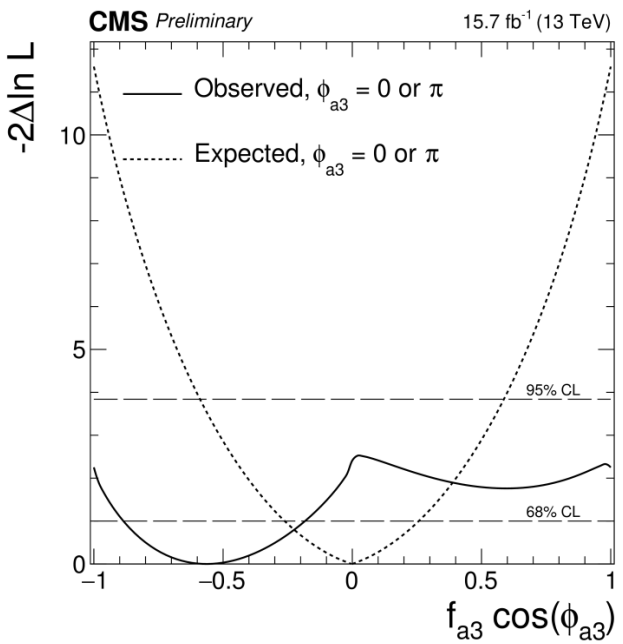


CMS-PAS-HIG-16-033

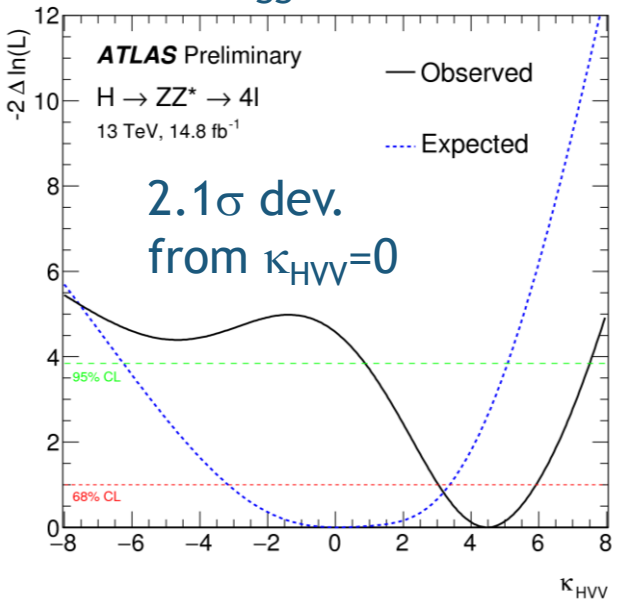
Higgs→ZZ*

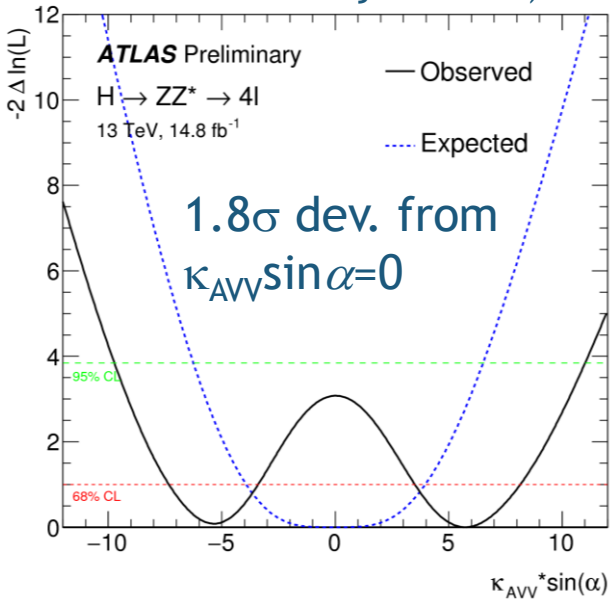
Constraints on HVV, AVV, sensitive to BSM interactions (production and decay)

Assume SM Higgs: scalar, spin 0, μ=1



Note: ggF fixed to SM can not accommodate for 2-jet excess)





f_{ai}: effective fractional cross sections w.r.t. tree level. $\cos(\phi_{ai}) = \pm 1$

Parameter	Observed	Expected	
$f_{a3}\cos(\phi_{a3})$	$-0.56^{+0.38}_{-0.32}$ $[-1.00, 1.00]$	$0.00^{+0.26}_{-0.26}$ $[-0.59, 0.59]$	(CP odd)
$f_{a2}\cos(\phi_{a2})$	$-0.06^{+0.06}_{-0.09}$ $[-0.22, 0.24]$	$0.00^{+0.24}_{-0.06}$ $[-0.15, 0.92]$	
$f_{\Lambda 1}\cos(\phi_{\Lambda 1})$	$-0.93^{+0.90}_{-0.16}$ $[-1.00, 0.10] \cup [0.77, 1.00]$	$0.00^{+0.13}_{-0.69}$ $[-1.00, 0.24] \cup [0.98, 1.00]$	

CMS-PAS-HIG-16-033

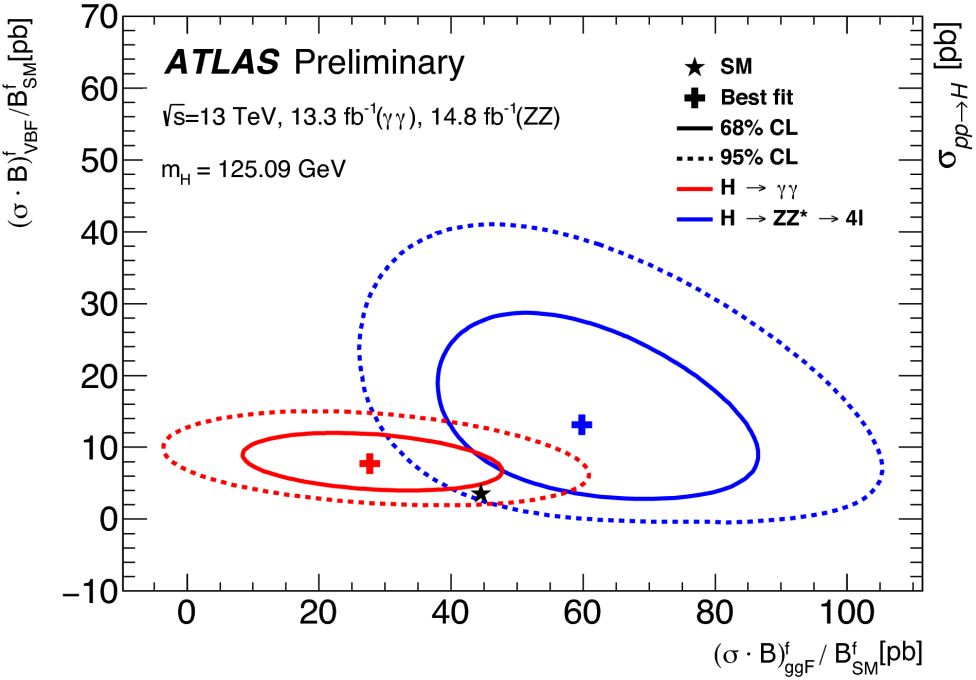
ATLAS-CONF-2016-079

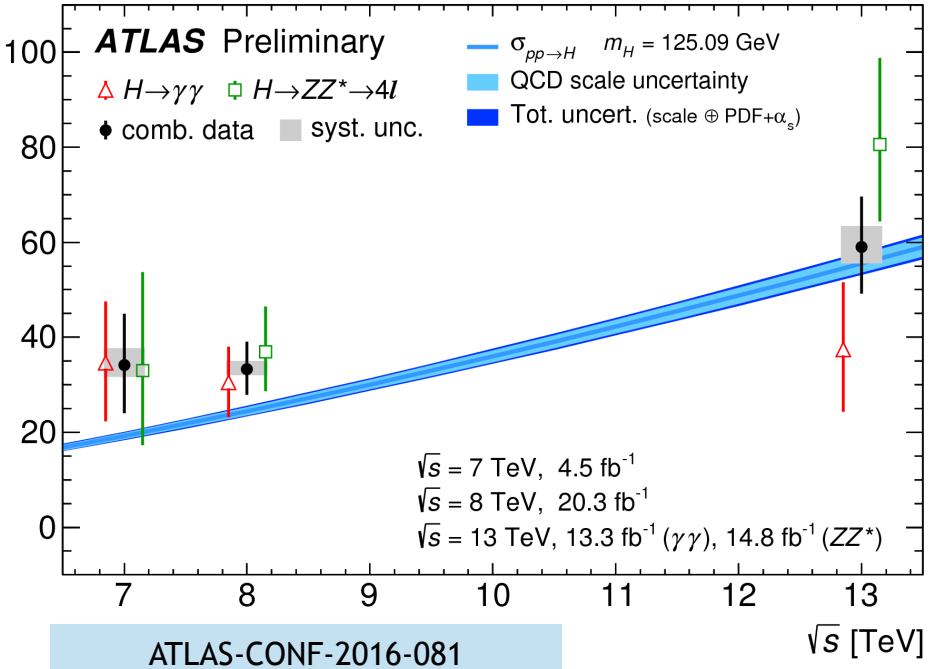
Combination of H→γγ & H→ZZ*

Event categorization optimized for production mode separation

Fiducial cross sections (from H→γγ & H→ZZ*) extrapolated to full acceptance

	Measurement at 13 TeV	SM prediction at 13 TeV
σ (pb)	$59.0^{+9.7}_{-9.2}(\text{stat})^{+4.4}_{-3.5}(\text{syst})$	$55.5^{+2.4}_{-3.4}$
μ	$1.13^{+0.18}_{-0.17}$	





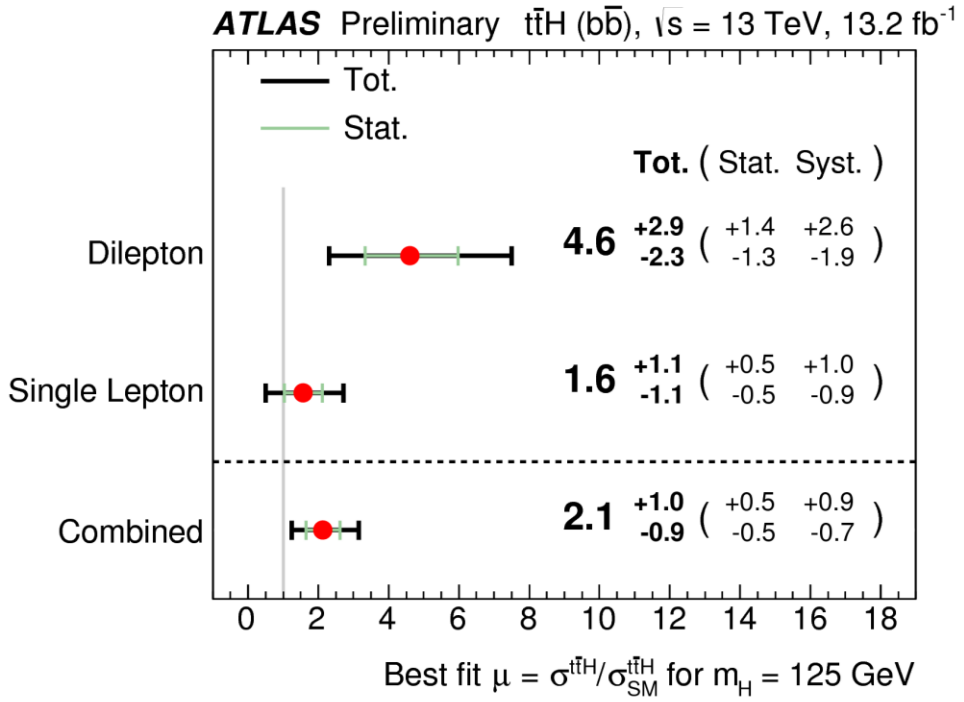
ATLAS-CONF-2016-081

ttH, H→bb

Direct probe to the top Yukawa coupling at LHC

Events categorized depending on amount of leptons, jets, b-jets

Dominant th. systematics: tt+HF & ttH modelling



ATLAS -CONF-2016-080

CMS *Preliminary* √s=13 TeV, 2.3 fb^{-1}

Channel	Best-fit μ	Observed UL	Expected UL
Lepton+jets	$-0.4^{+2.1}_{-2.1}$	4.0	$4.1^{+1.8}_{-1.2}$
Dilepton	$-4.7^{+3.7}_{-3.8}$	5.2	$7.7^{+3.6}_{-2.3}$
Combined	$-2.0^{+1.8}_{-1.8}$	2.6	$3.6^{+1.6}_{-1.1}$

CMS-PAS-HIG-16-004

ttH, H→WW, ZZ, ττ (multileptons)

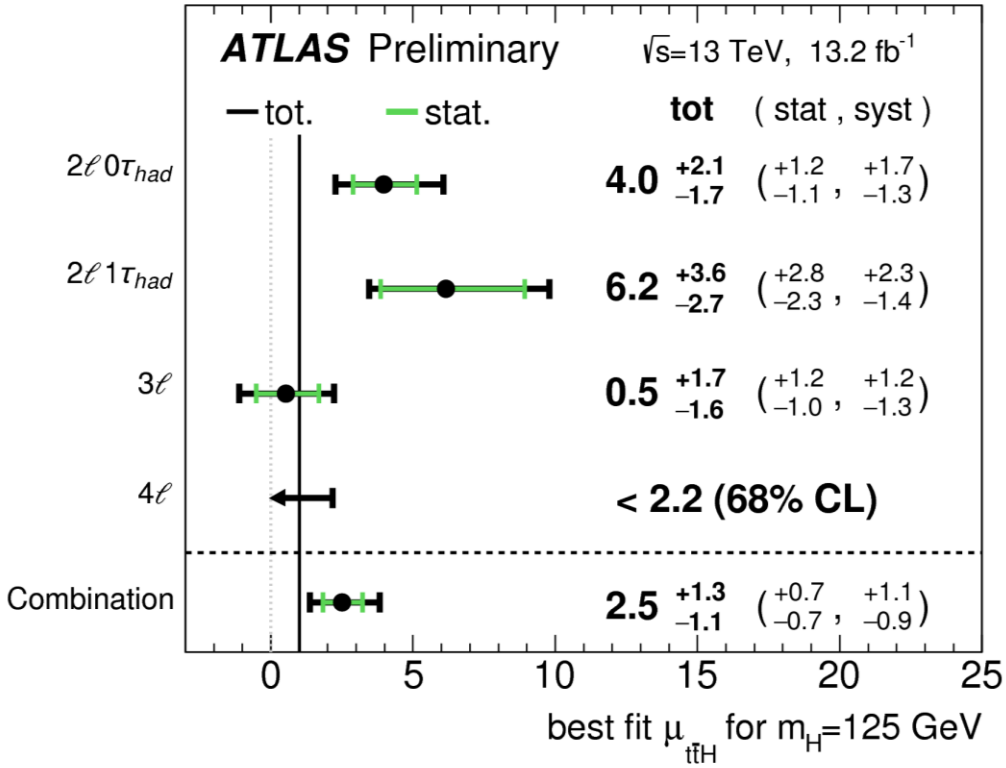
Focus on final states with clean signatures and low background

2 to 4 leptons, ≥2 jets, ≥1 b-jet

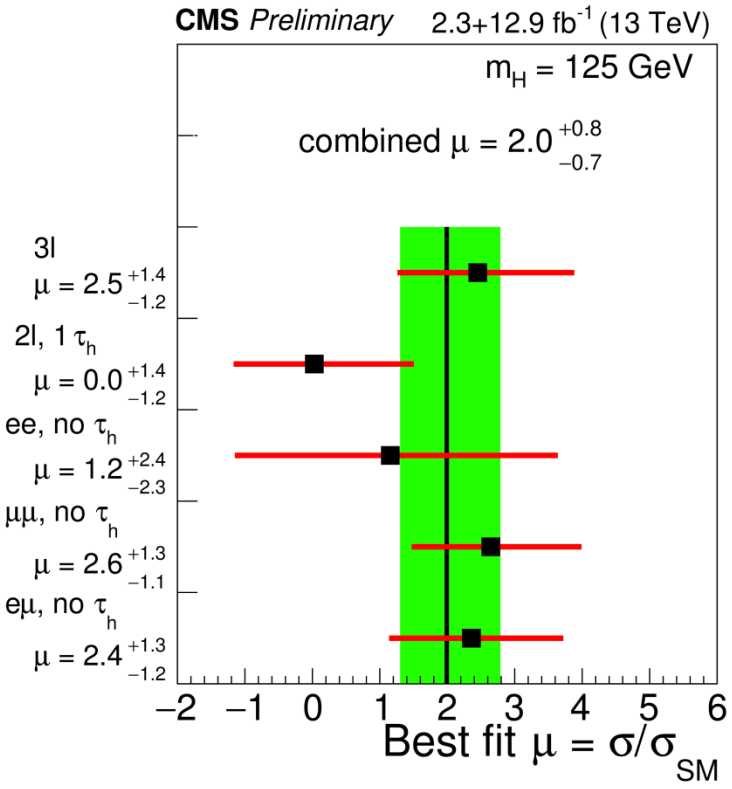
Dominant th. systematics: non-prompt lepton background pred.

(together with charge mis-id)

ATLAS -CONF-2016-058



CMS-PAS-HIG-16-022



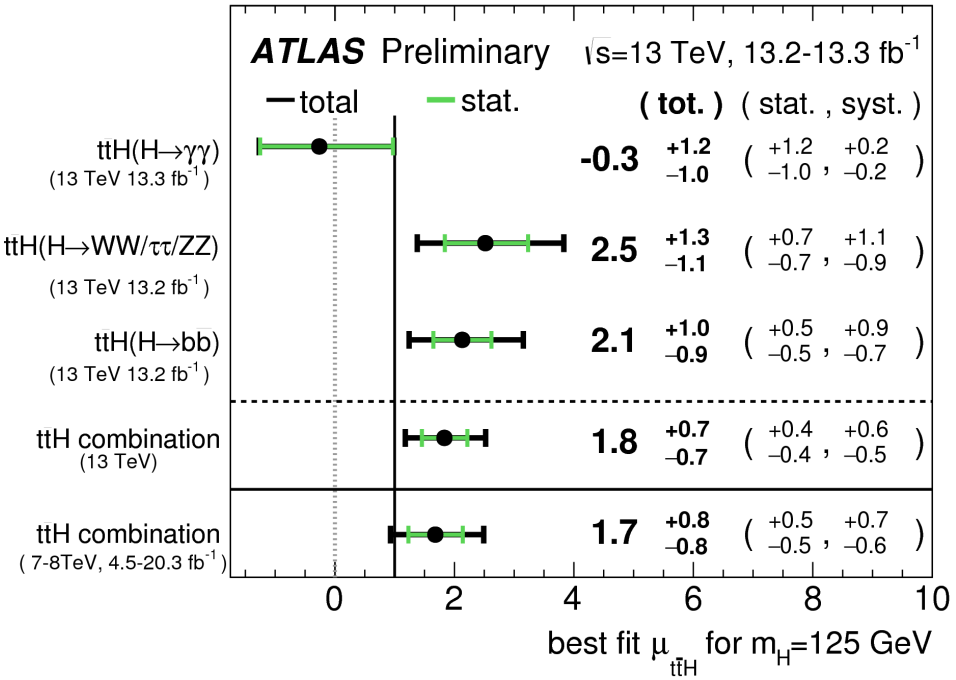
ttH cross sections are calculated at NLO QCD and NLO EW accuracies

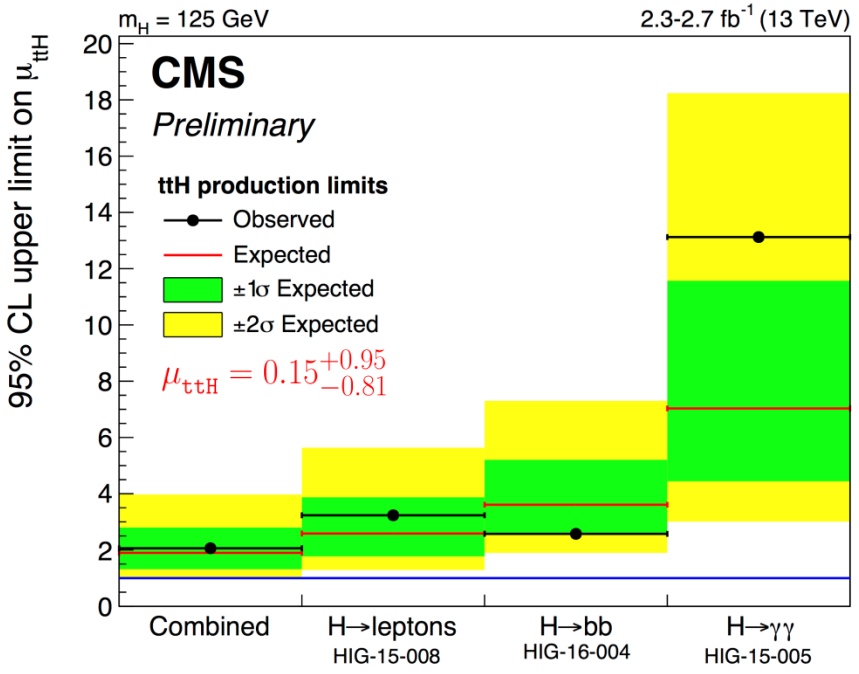
ttH combination

Combination of γγ, multileptons and bb analyses

Signal significance of 2.8σ (1.8σ expected) ATLAS Run-2

Run-1 ATLAS+CMS was 4.4σ (2.0σ)





ATLAS-CONF-2016-068

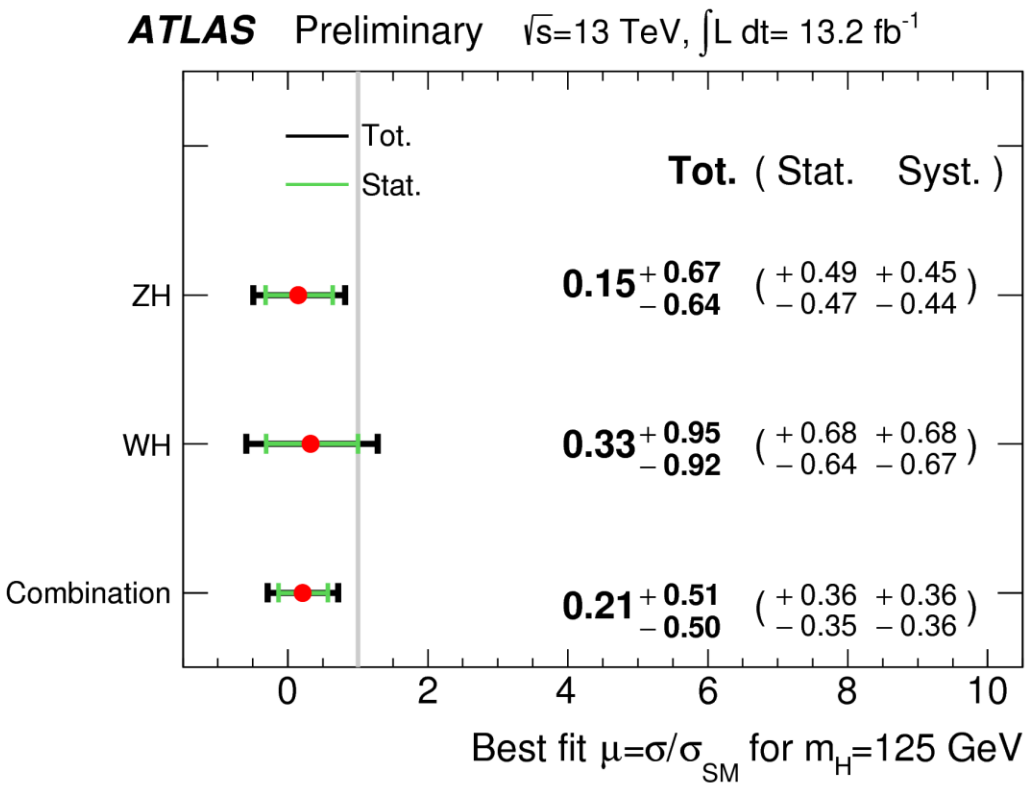
CMS Moriond 2016

VH, H→bb

Establishing Higgs coupling to b-quarks

Use leptonic decays of Z/W

Main th. Systematics: V+HF normalization



	Significance (expected)
ATLAS (13 TeV)	0.4σ (1.94σ)
ATLAS+CMS (8 TeV)	2.6σ (3.7σ)
Tevatron	2.8σ (1.5σ)

ATLAS-CONF-2016-091

J. High Energy Phys. 08 (2016) 045

Phys. Rev. Lett. 109, 071804

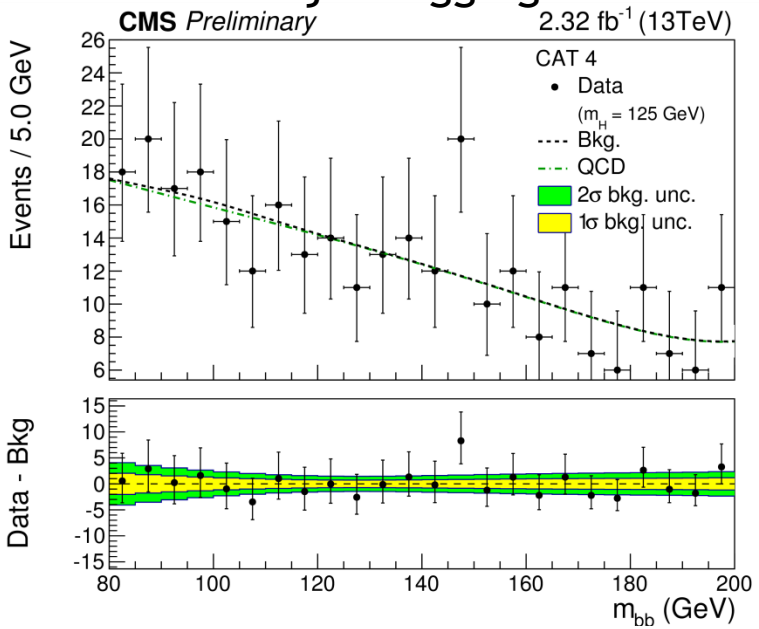
Phys. Rev. D 88, 052014

VBF, H→bb

VBF more difficult than VH

QCD bkg, No lepton

Use forward jet tagging

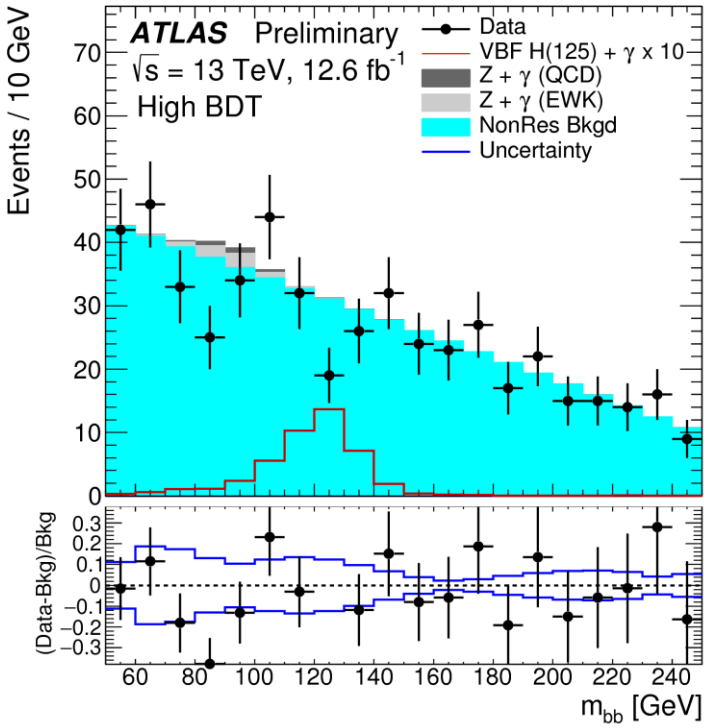


CMS	Upper limit x SM (expected)	Signal strength μ
Run 1	5.5 (2.5)	$2.8^{+1.6}_{-1.4}$
Run 2	3.0 (5.5)	$-3.7^{+2.4}_{-2.5}$
Run 2+1	3.4 (2.3)	$1.3^{+1.2}_{-1.1}$

CMS-PAS-HIG-16-003

Accompanying high energy γ (ATLAS)

Central-γ + 4-jet high level trigger



ATLAS	H(→bb) + γj	Z(→bb) + γj
Upper limit at 95% CL	4 x SM (expected 6 x SM)	2 x SM (expected 1.8 x SM)

ATLAS-CONF-2016-063

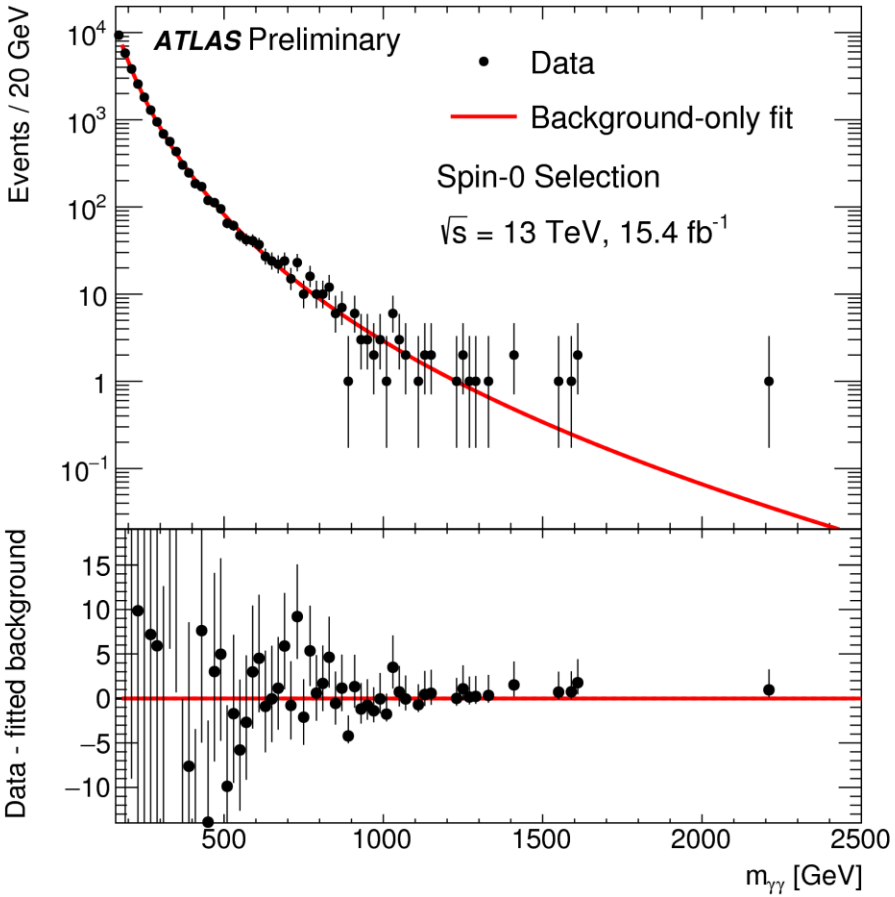
Beyond the SM Higgs: Heavy Higgs $\gamma\gamma$

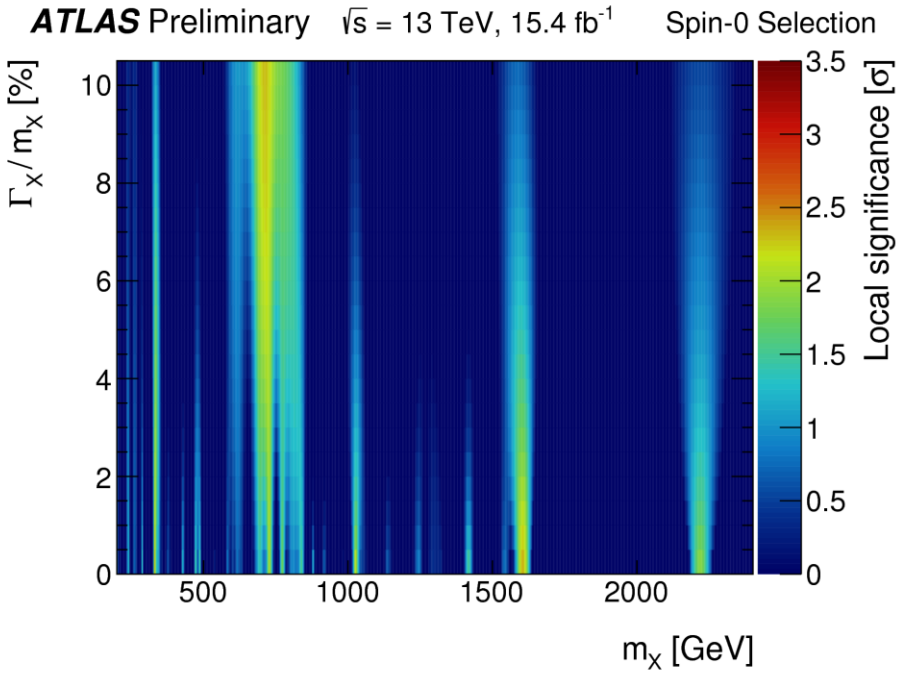
Extension of $\gamma\gamma$ channel analysis (spin-0)

ATLAS-CONF-2016-059

No significant excess observed in 2016 dataset

3.4σ for 2015 alone





With the higher pileup conditions of the 2016 data, more work is needed to complete the analysis in the extended acceptance of the spin-2 selection

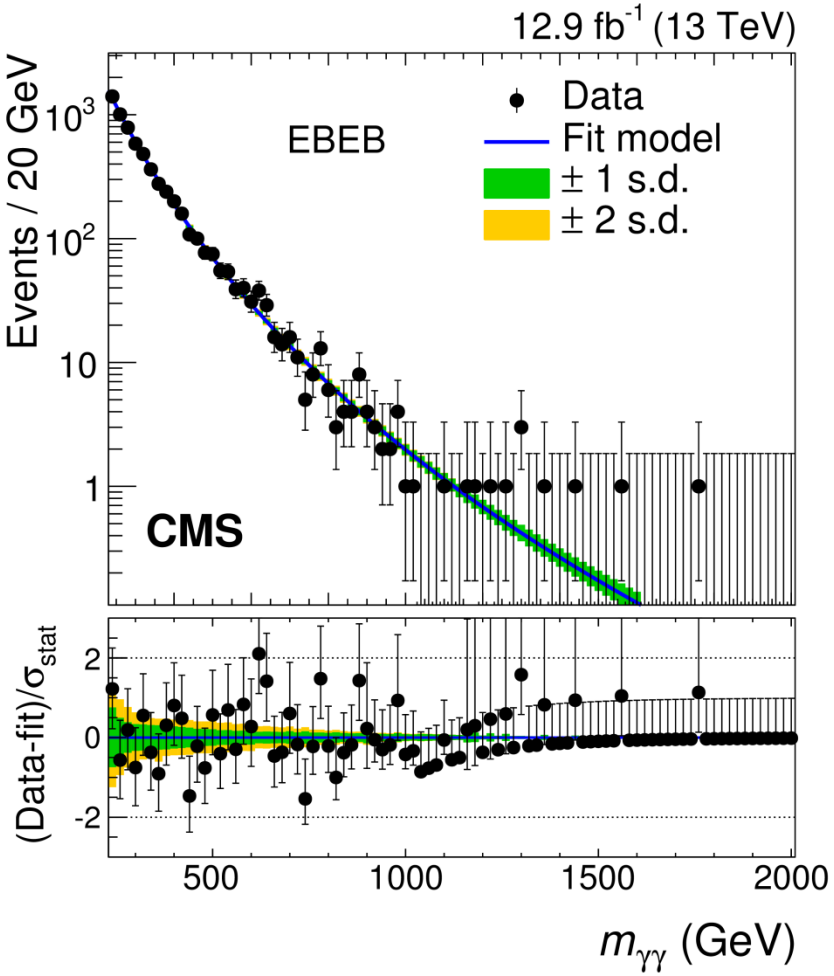
Beyond the SM Higgs: Heavy Higgs γγ

spin-0 + spin-2 search

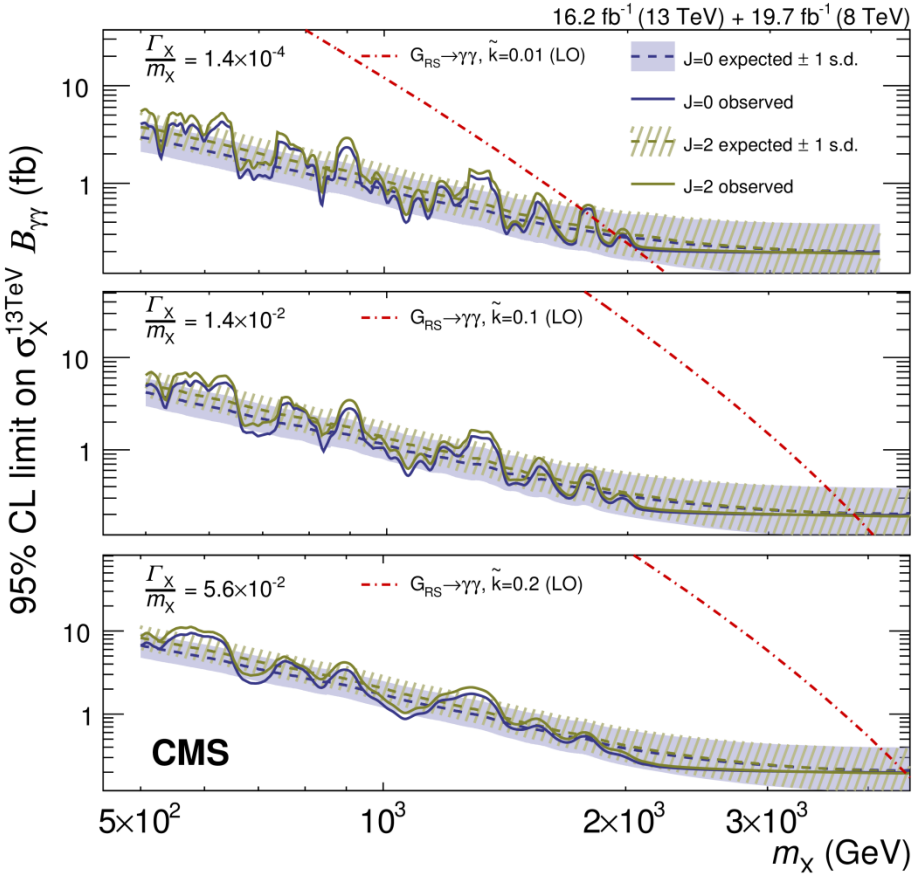
CMS-EXO-16-027

No significant excess observed in 2016 dataset

Limits derived from 2016+2015+2012 dataset



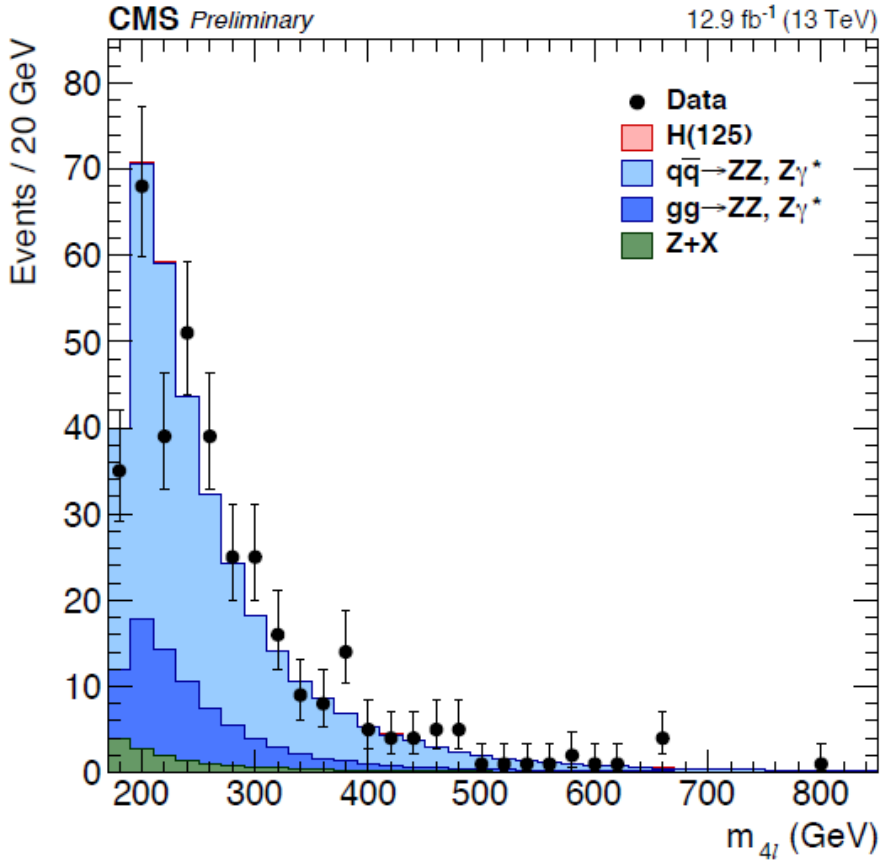
(+2012: 10% improvement at low masses)



Beyond the SM Higgs: Heavy Higgs ZZ

Extension of ZZ channel analyses

Assume ggF and VBF production modes



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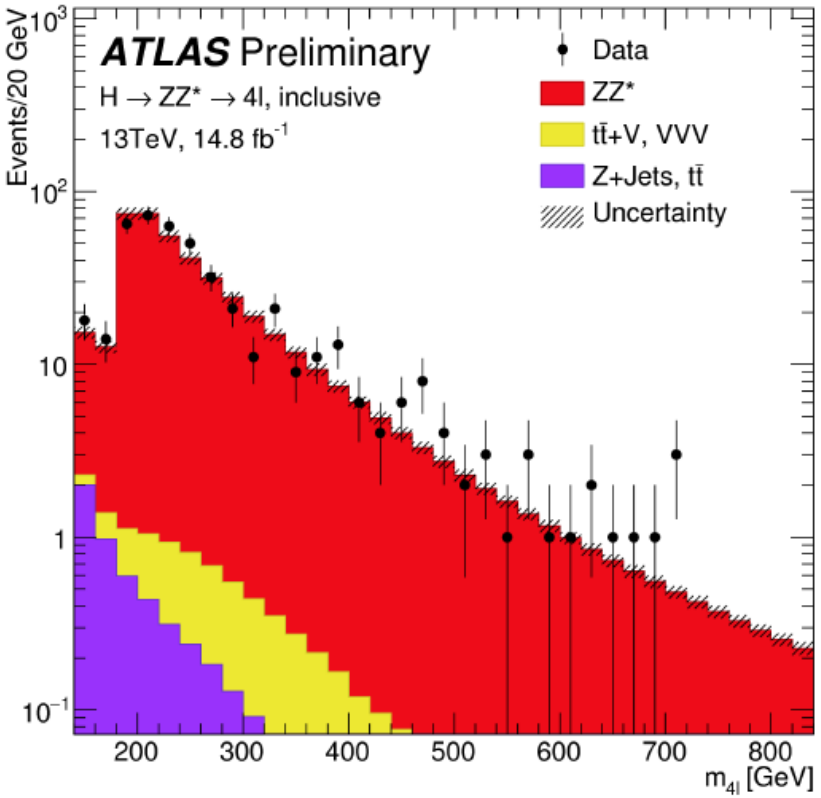
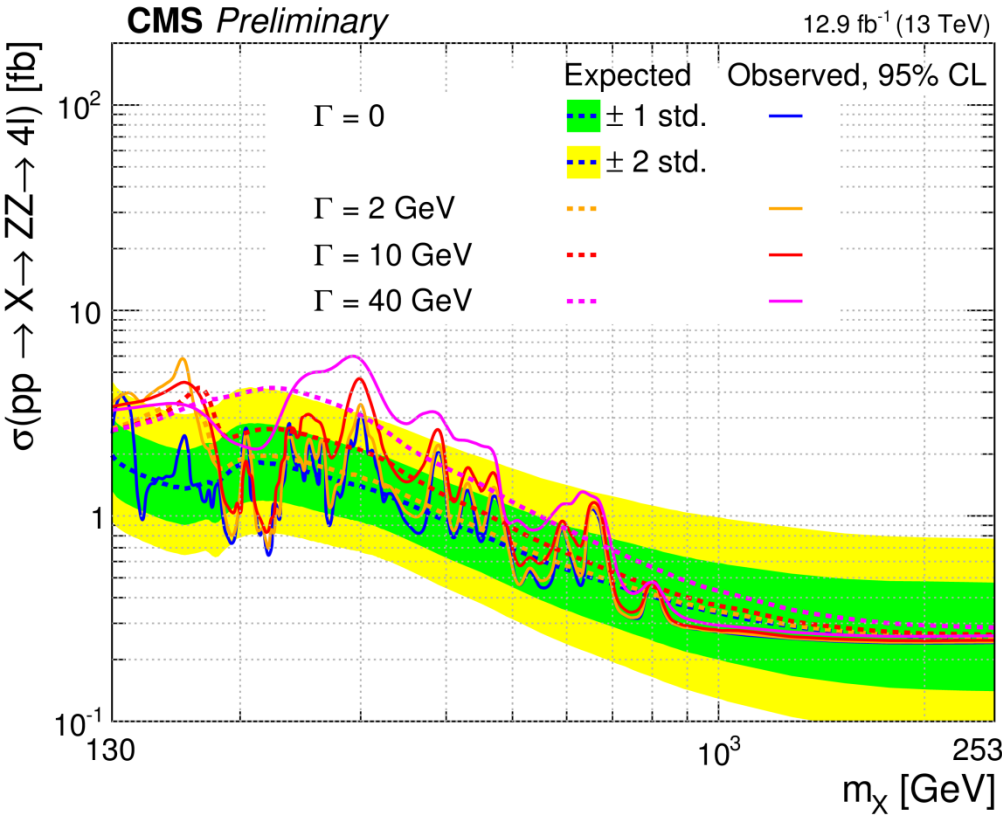


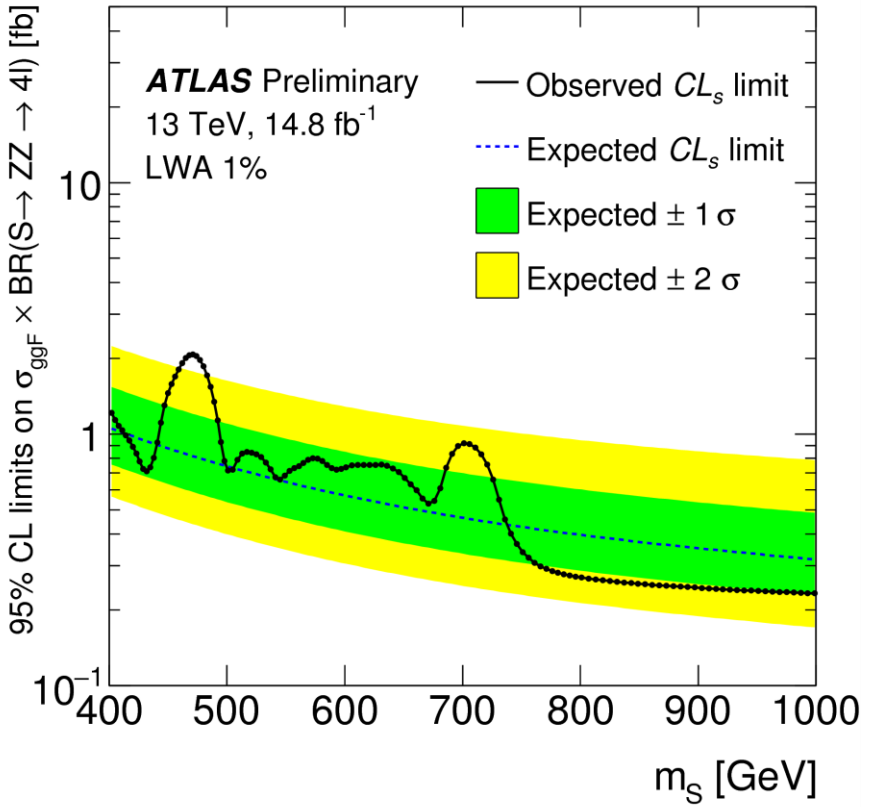
ATLAS-CONF-2016-079

Beyond the SM Higgs: Heavy Higgs ZZ

Assume ggF and VBF production modes

No hint for signal in 2016





CMS-PAS-HIG-16-033

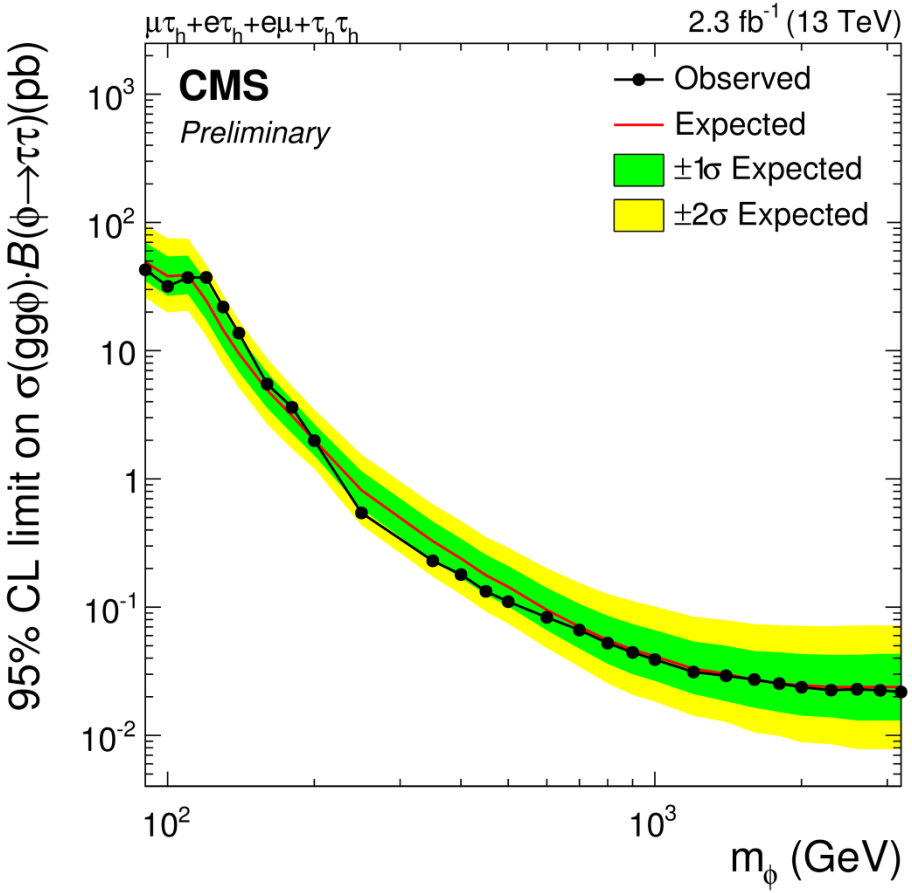
ATLAS-CONF-2016-079

Beyond the SM Higgs: Heavy Higgs ττ

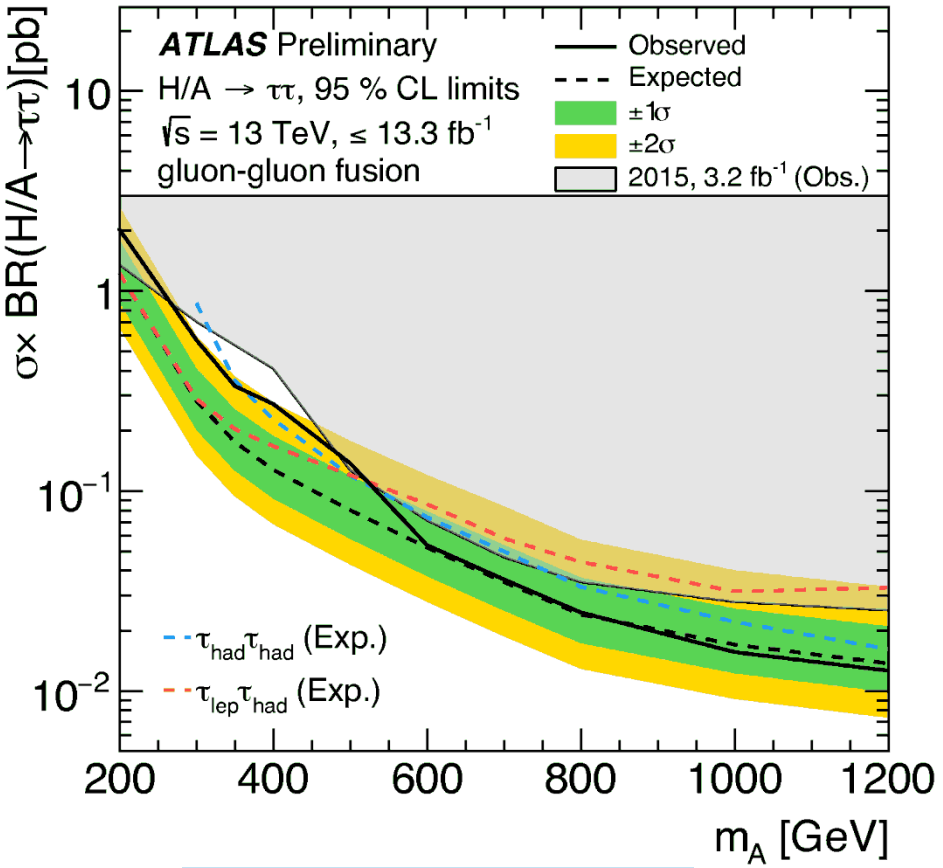
MSSM H/A→ ττ , direct production or associated with b-quarks (high tanβ)

e, μ, had. decays (CMS) at least one τ decaying hadronically (ATLAS)

Categories based on number of b-jets



CMS-PAS-HIG-16-006

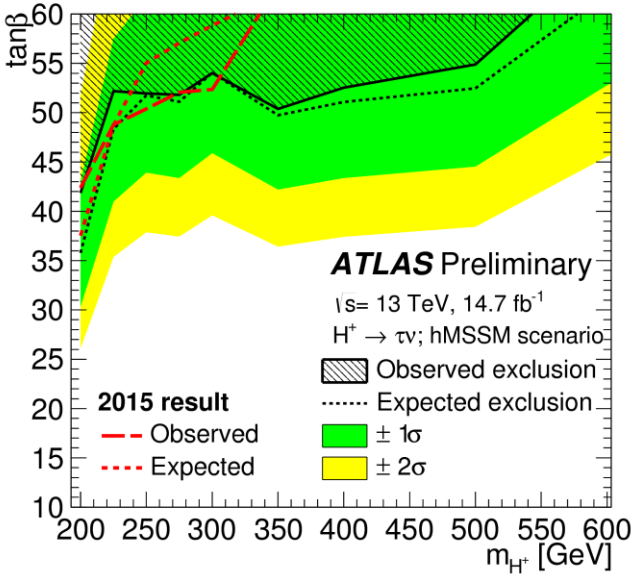


ATLAS-CONF-2016-085

Beyond the SM Higgs: Charged Higgs

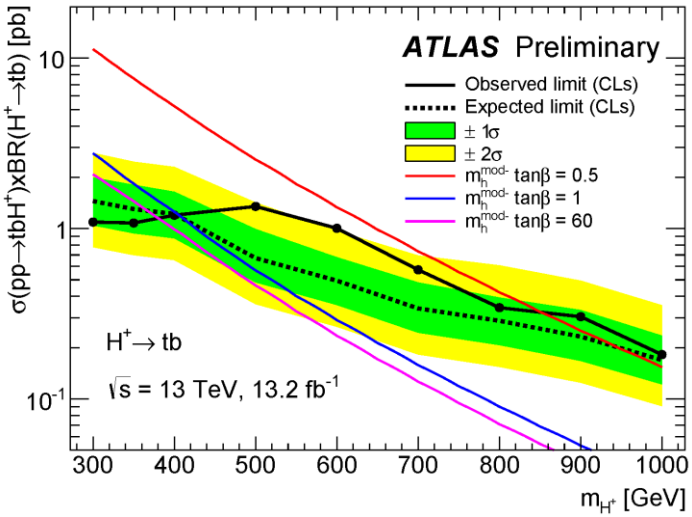
$H^{\pm} \rightarrow \tau\nu$ ATLAS-CONF-2016-088

Top associated production(τ_{lep}+jets)



$H^{\pm} \rightarrow tb$ ATLAS-CONF-2016-089

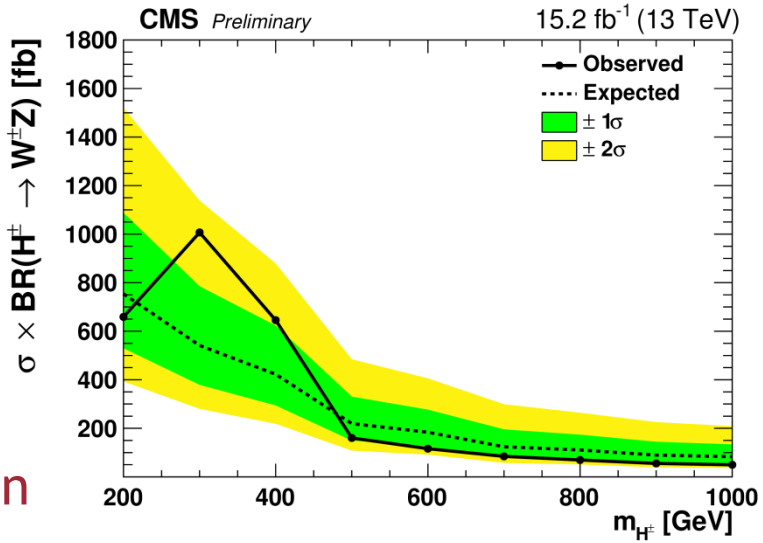
$pp \rightarrow tbH^{\pm}$ associated production



$H^{\pm} \rightarrow WZ$ CMS-PAS-HIG-16-027

3 leptons selection

(relevant for Higgs Triplet models, suppressed in 2HDM models)



No evidence of a charged Higgs boson

Beyond the SM Higgs: Higgs→Invisible

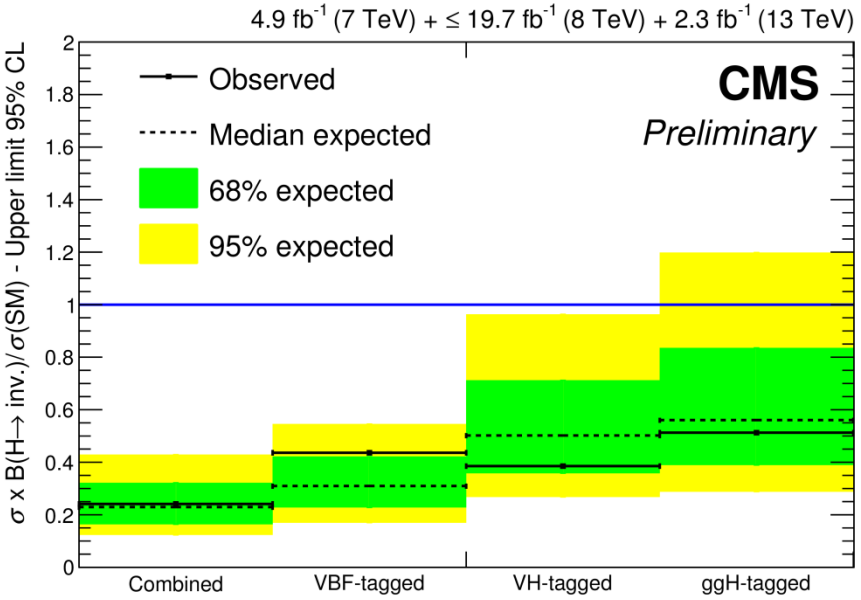
Constraint from Run-1: B(H→BSM)<34% @ 95% CL

CMS: Combine ggF, VBF, VH & 7, 13 TeV

Assume SM values for production mode ratios

VBF dominates sensitivity

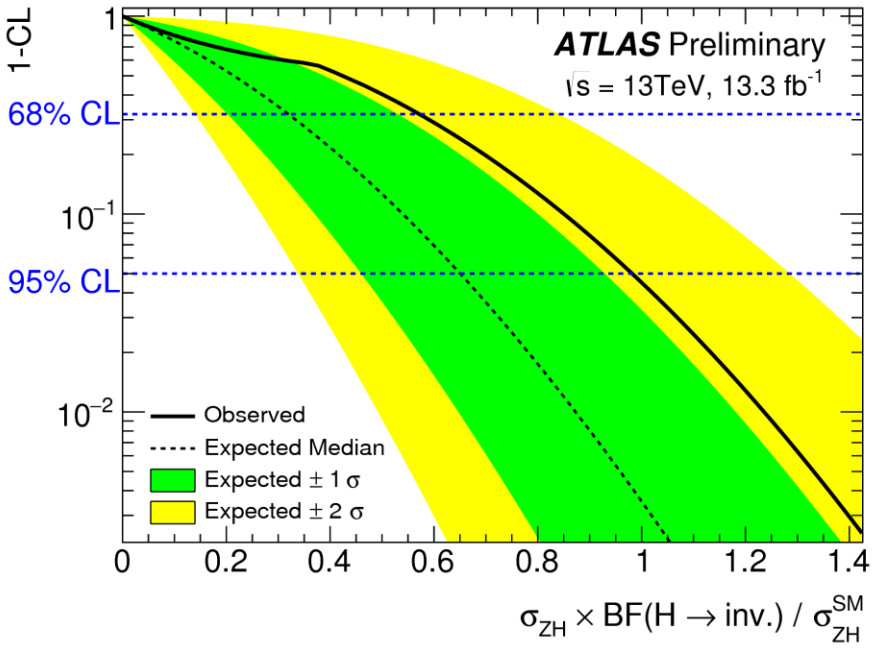
B(H→inv.)<0.24 (0.23) @ 95% CL



CMS-PAS-HIG-16-016

ATLAS: ZH→ll+inv

B(H→inv)<0.65 (0.98) @ 95% CL



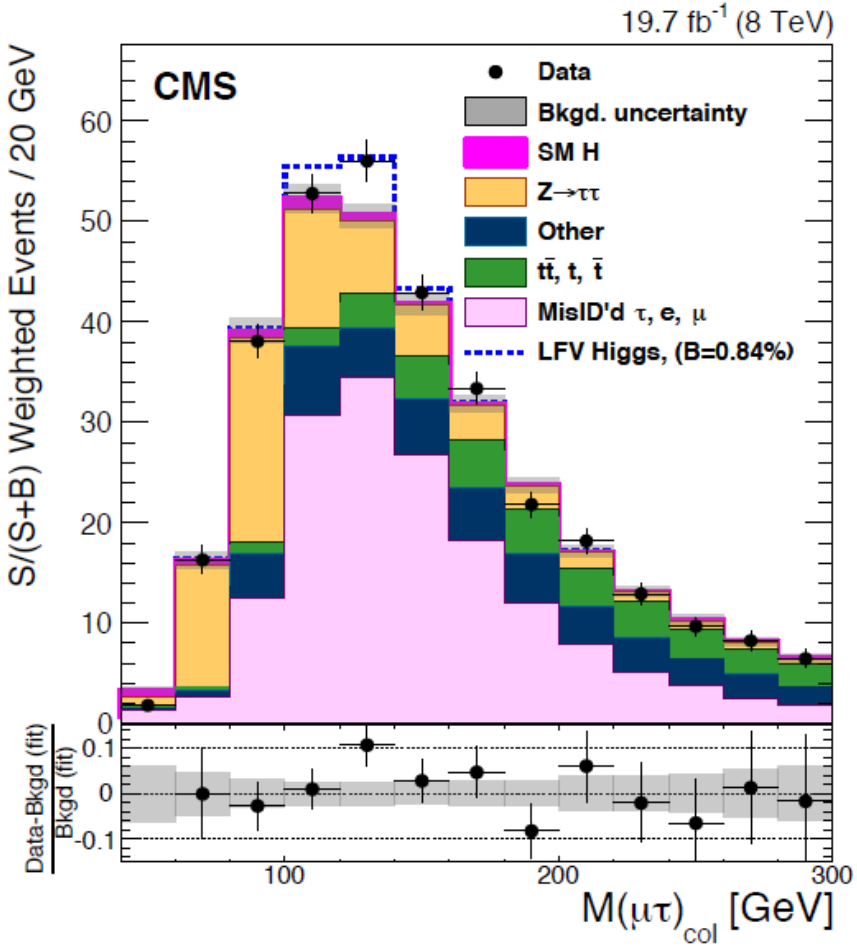
ATLAS-CONF-2016-056

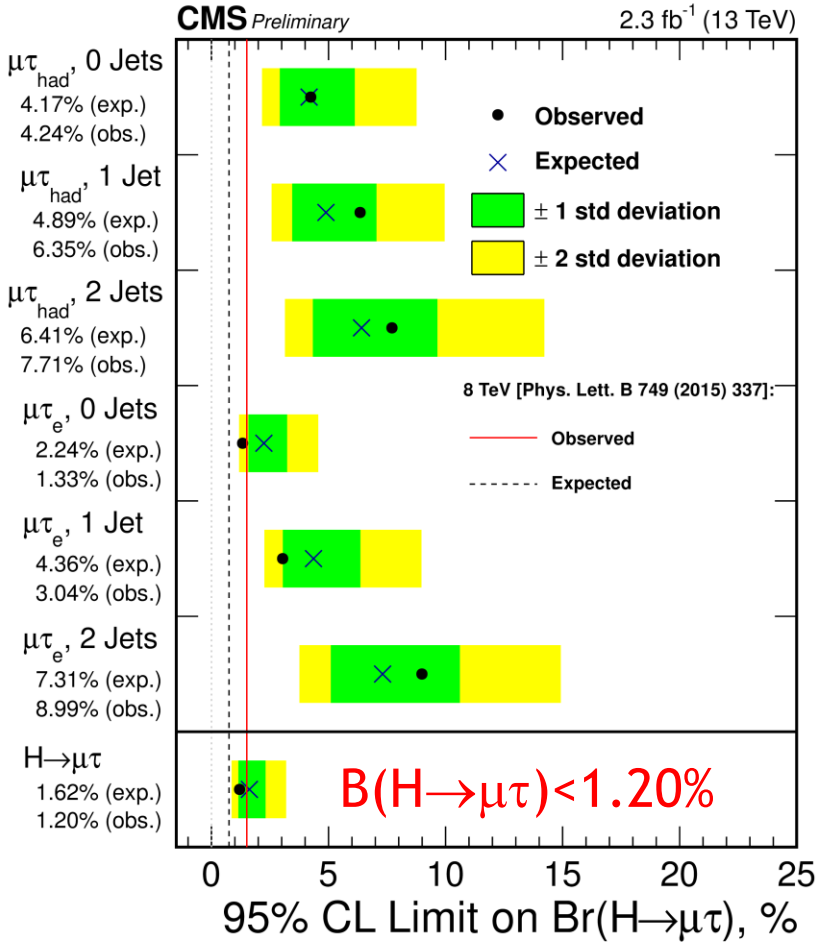
Beyond the SM Higgs: Lepton Flavor Violation

Small excess found by CMS in 8 TeV dataset for $H \to \mu\tau_{e,h}$

2015 data neither exclude nor confirm the excess

2016 data analysis in complete agreement with SM





CMS-PAS-HIG-16-005

Beyond (this talk) Higgs: Other topics

For more ATLAS+CMS Higgs results see:

From Monday parallel session

Higgs decays to meson+γ: Kostas' talk

Higgs Exotics decays: Chayanit's talk

Extended Higgs sector: Alice's talk

Invisible Higgs: Loan's talk

ttH: Nicolas' talk

Higgs pairs: Claudio's talk *tomorrow*

Summary

13 TeV data analyzed: 3 fb^{-1} 2015 + ~13 fb^{-1} 2016

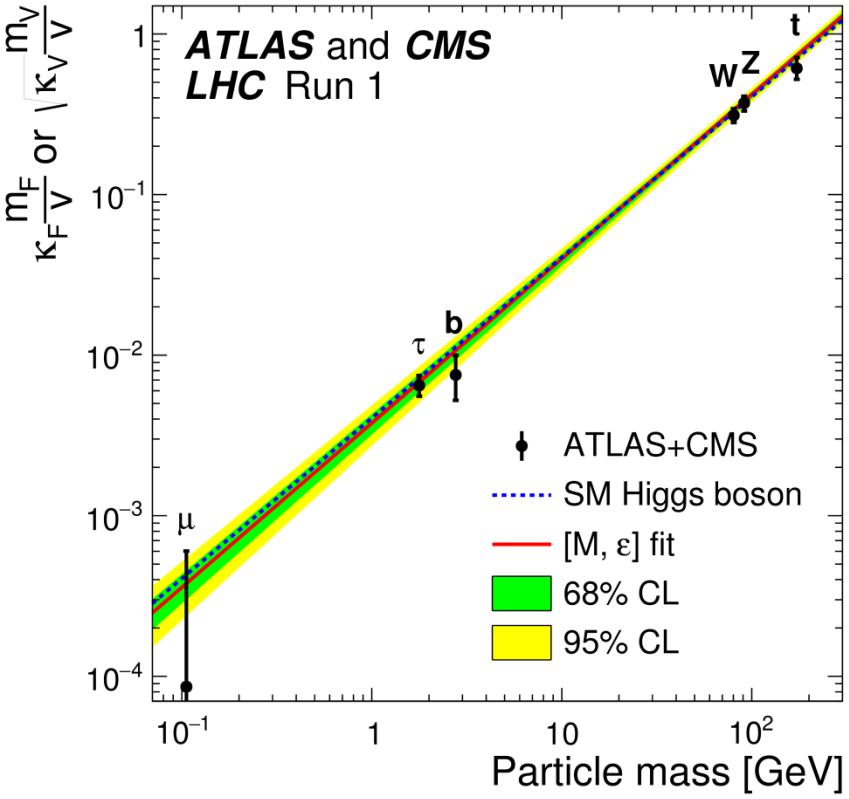
Observed Higgs is consistent with SM (so far)

Theoretical errors went down by a factor 2 since run-1 (ggF scale, gg PDF)

Precise Theory predictions are mandatory for Higgs precision measurements

30 fb^{-1} on tape for 2016

Wait for winter conferences for more Run-1+2 and ATLAS+CMS combinations



Backup slides

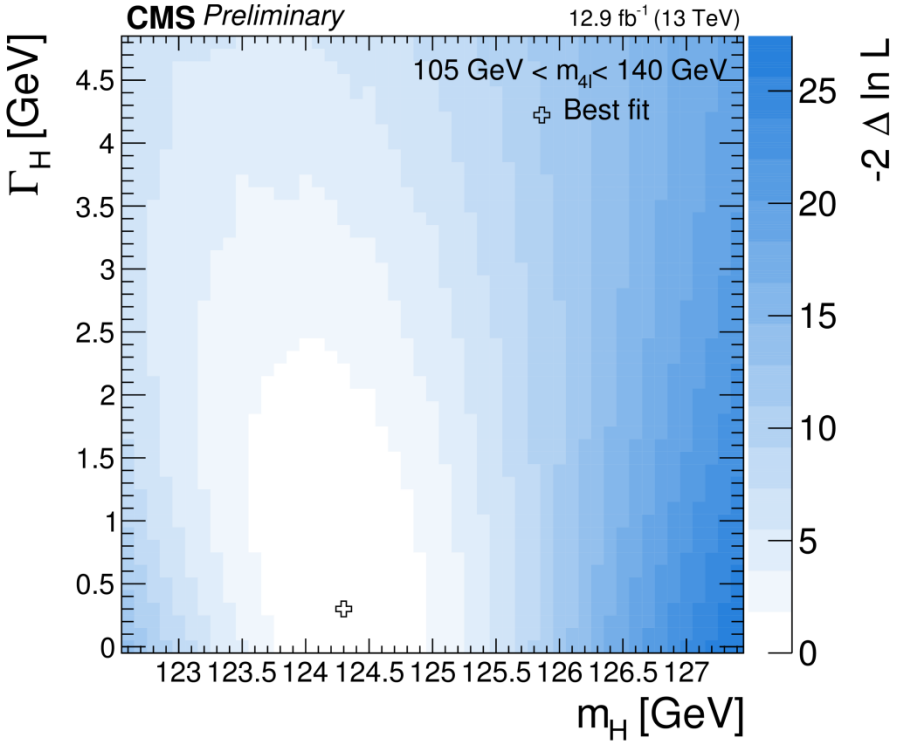
Higgs→ZZ*

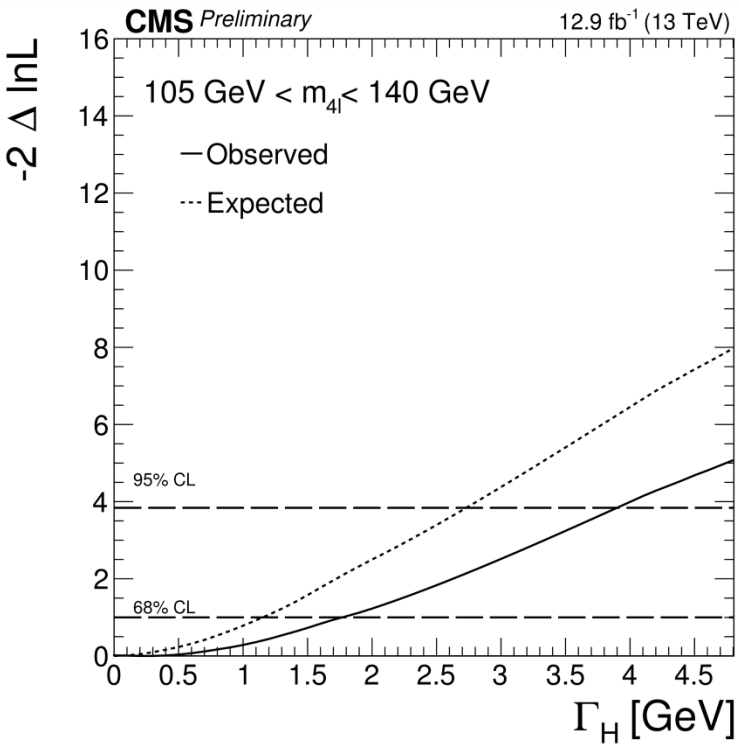
Measurement of the width from off-shell & on-shell regions

MCFM+JHUGEN+HNNLO framework includes interferences

Off-shell: Γ_H<41 (32) MeV

On-shell: Γ_H<3.9 (2.7) GeV(less assumptions on BSM contribution)





CMS-PAS-HIG-16-033