Higgs (SM and BSM) in ATLAS and CMS

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on behalf of the ATLAS and CMS collaborations

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Workshop on the Standard Model and Beyond

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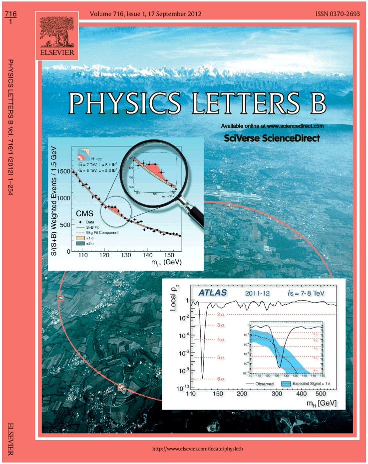
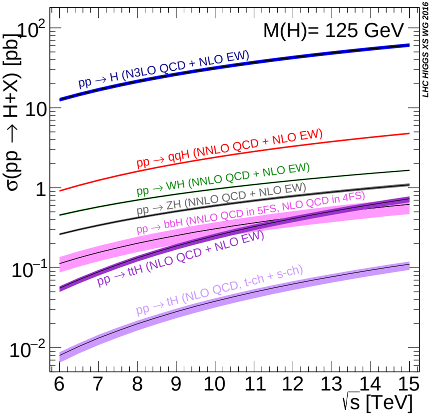
The Higgs boson entered history five years ago

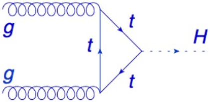
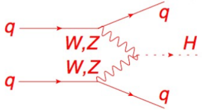
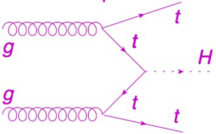
- 4 July 2012: ATLAS & CMS announce discovery of Higgs-like particle
  - ▸ Phys.Lett. B716 (2012) 1-29 and
    ▸ Phys.Lett. B716 (2012) 30-61
  - > 7300 citations each
- March 2013: several papers on properties
  - new particle IS “a Higgs boson”
- December 2013: Nobel Prize in physics to Englert&Higgs, “...which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN’s Large Hadron Collider”



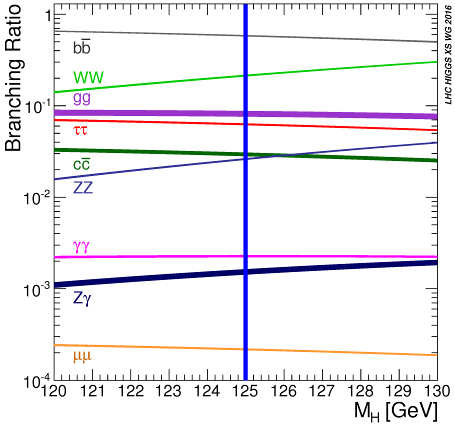
Higgs boson production @ LHC



- Factor 2–4 increase wrt Run 1 cross sections

Production mode	Higgs bosons produced in 2015–2016
gluon fusion 	**1.7M** (87%)
vector boson fusion (VBF) 	**137k** (7%)
associated prod. with W/Z 	**81k** (5%)
associated prod. with tt 	**18k** (0.6%)

Higgs boson decay



- $b\bar{b}$, $\tau\tau$: high yield, low S/B, coupling to fermions
- WW: high yield, low mass resolution
- $ZZ(4\ell)$, $\gamma\gamma$: high mass resolution (full decay reconstruction)
- $\mu\mu$: very small yield, 2^{nd} generation fermions

- Most Higgs boson decays accessible at LHC
- All predictions fixed once Higgs mass known
- Deviations $\Rightarrow$ clear sign of new physics!

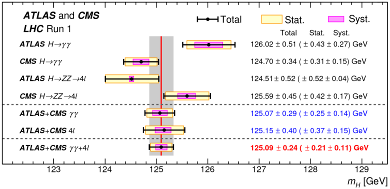
Run 1 legacy

- Mass determined to 0.2% precision (stats limited) ▸ PRL114(2015)191803
- Observation of gluon–gluon fusion and vector boson fusion ▸ JHEP08(2016)045
- Observation of bosonic decays: $H \to ZZ$, $H \to \gamma\gamma$, $H \to WW$
- Coupling to fermions not fully established:
  - $H \to \tau\tau$ observed via ATLAS+CMS combination
  - $H \to b\bar{b}$ below evidence
  - $t\bar{t}H$ not observed
- Production and decay rates measured to 20–60%
- Tests of spin/parity favour spin-0, CP-even

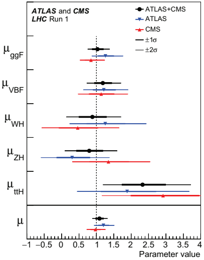
$$\mu = \frac{\sigma_{obs}}{\sigma_{SM}}$$

⇒ Very SM-like, need more precision

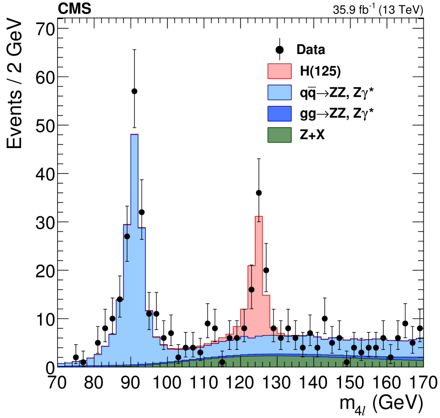
- Shown today: only new 2015+2016 Run 2 results



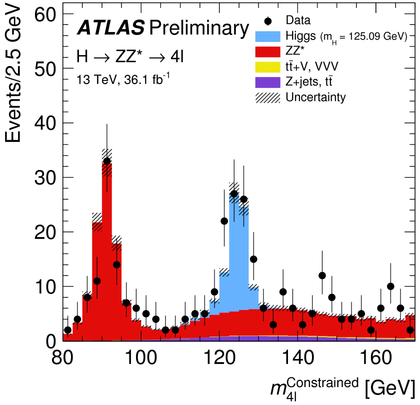
Production process	Measured significance (σ)
VBF	5.4
WH	2.4
ZH	2.3
VH	3.5
ttH	4.4
Decay channel	
$H \to \tau\tau$	5.5
$H \to bb$	2.6



arXiv:1706.09936



ATLAS-CONF-2017-043



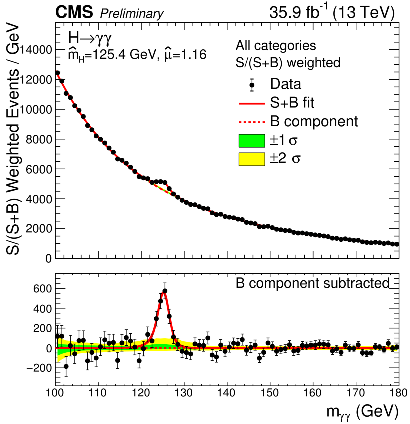
$$\mu = 1.05\,^{+0.15}_{-0.14}\,(\text{stat})\,^{+0.11}_{-0.09}\,(\text{syst})$$

$$\mu = 1.28^{+0.18}_{-0.17}(\text{stat.})^{+0.08}_{-0.06}(\text{exp.})^{+0.08}_{-0.06}(\text{th.})$$

- Uncertainty on μ reduced by factor $\sim$2 with respect to Run 1
- Starting to approach SM theory uncertainty

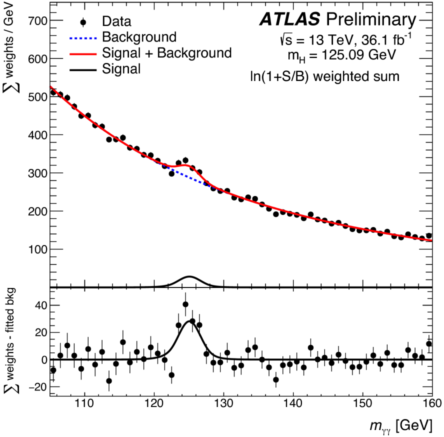
Discovery channel: $H \to \gamma\gamma$

CMS-PAS-HIG-16-040



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

ATLAS-CONF-2017-045



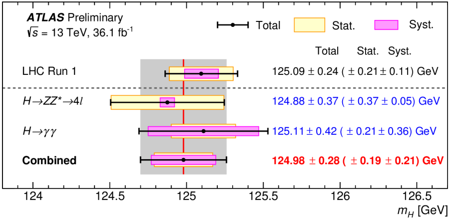
$$\mu = 0.99\,^{+0.14}_{-0.14} = 0.99\,^{+0.12}_{-0.11}\,(\text{stat.})\,^{+0.06}_{-0.05}\,(\text{exp.})\,^{+0.06}_{-0.05}\,(\text{theory})$$

- Precision similar to *ZZ* despite lower S/B
- Uncertainty on μ also reduced by factor $\sim$2 with respect to Run 1

ATLAS:

- $H \to \gamma\gamma$ and $H \to ZZ$ comb.
- Individual masses compatible to 0.4σ
- e/μ sub-channels also compatible
- $H \to \gamma\gamma$ systematically limited

ATLAS-CONF-2017-046

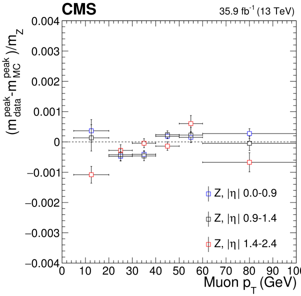


CMS:

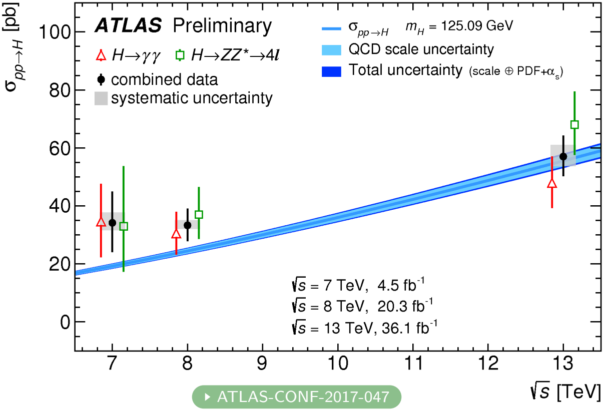
- $H \to ZZ$ only
- 3D fit to $m_{4\ell}$, mass uncertainty and ZZ background discriminator
- Kinematic fit to leading lepton pair 4-momenta $\Rightarrow$ $\sim$10% uncertainty improvement
- Single channel measurement competitive with ATLAS+CMS Run 1 combination

arXiv:1706.09936

$$125.26 \pm 0.20\,(\text{stat}) \pm 0.08\,(\text{syst})\ \text{GeV}$$



$H \to \gamma\gamma + H \to ZZ$ combination: inclusive XS

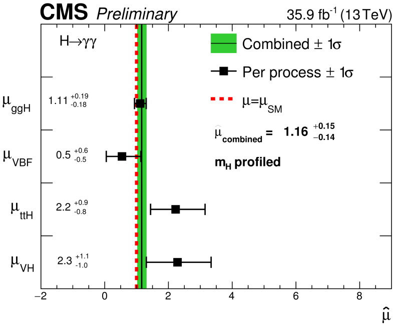


ATLAS-CONF-2017-047

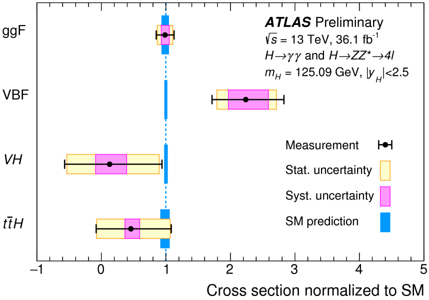
- Good agreement between SM prediction $55.6^{+2.4}_{-3.4}$ pb and observed total cross section $57.0^{+6.0}_{-5.9}$ (stat.) $^{+4.0}_{-3.3}$ (syst.) pb
- Uncertainties: experimental ∼12%, theory ∼5%
- Run 1 ⇒ Run 2: theory precision improved by factor 2 (*ggH* @ N^{3}LO QCD + PDF4LHC YR4 arXiv:1610.07922)

Cross section by production mode

CMS-PAS-HIG-16-040



ATLAS-CONF-2017-047



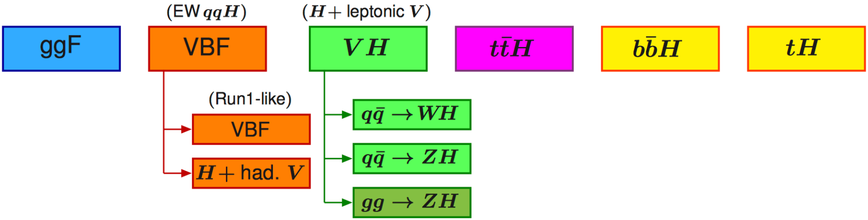
- Shown: signal strength $\mu_i = \frac{\sigma_i}{(\sigma_i)_{SM}}$ (assuming SM branching fractions)
- ggF very consistent with SM
- VBF excess in ATLAS (both $H \to \gamma\gamma$ and $H \to ZZ$): SM compatibility p-value 5%

Simplified template cross sections (STXS)

- Proposed in LHC Higgs cross section WG ▸ YR4 report arXiv:1610.07922
- Extend signal strength approach, splitting phase space into mutually exclusive "production bins", with $|y_H| < 2.5$
- Agreement between ATLAS, CMS and theorists on bin choices:
  - maximise experimental sensitivity
  - minimise dependence on theory assumptions

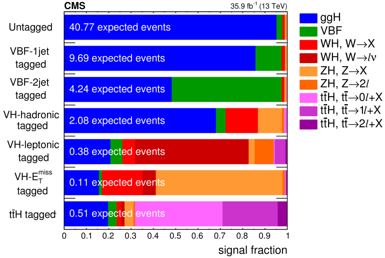
$\Rightarrow$ use experimental categories to measure cross sections in production bins

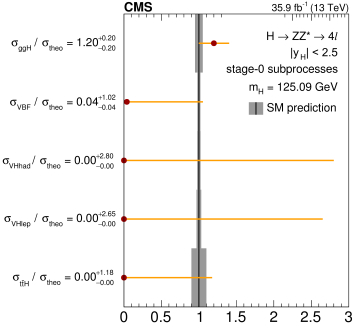
Stage $0^{(+)}$:



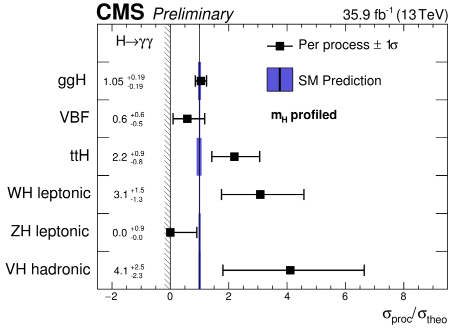
- Different contributions in different experimental categories

$H \to ZZ^* \to 4\ell$ ▸ arXiv:1706.09936



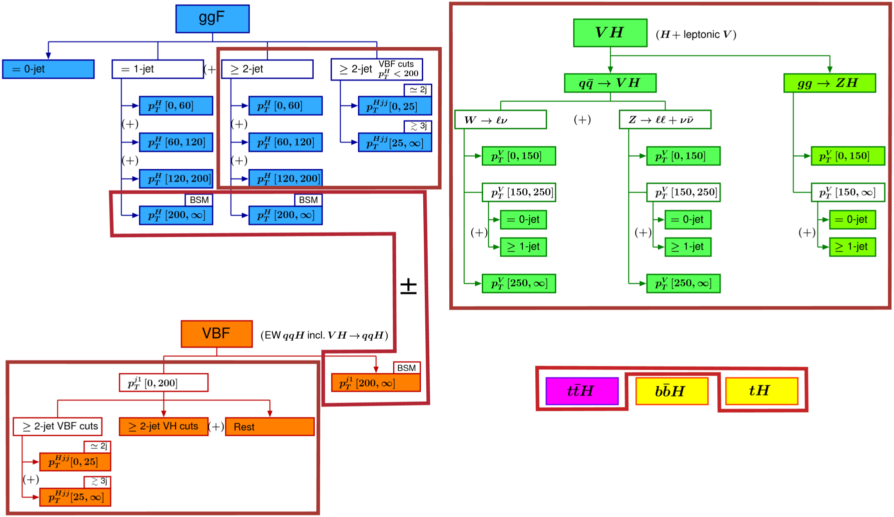


$H \to \gamma\gamma$ ▸ CMS-PAS-HIG-16-040



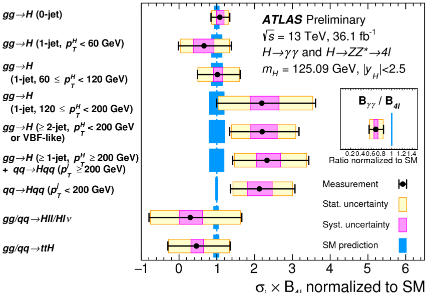
- Merge categories that are statistically limited

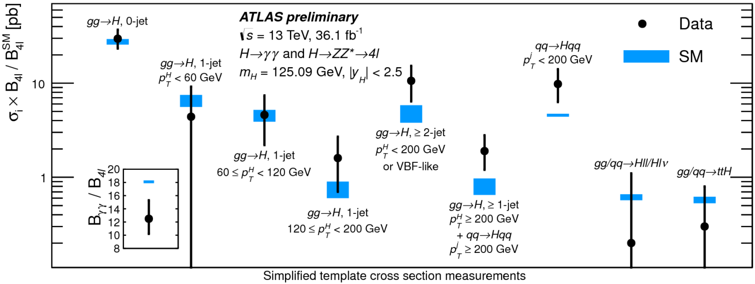
ATLAS-CONF-2017-047



STXS $H \to \gamma\gamma + H \to ZZ$

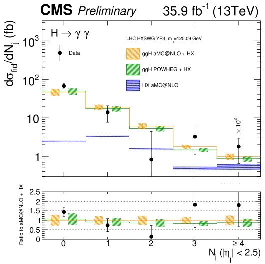
- MVA to separate production modes
- Both absolute and normalised to SM prediction
- Small excess seen in 2-jet events (both $H \to \gamma\gamma$ and $H \to ZZ$)



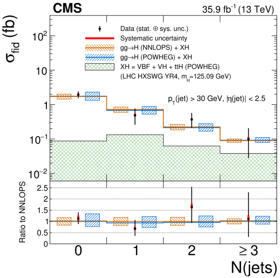


Differential measurements

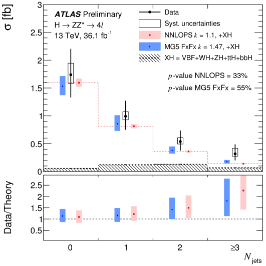
CMS-PAS-HIG-17-015



arXiv:1706.09936



ATLAS-CONF-2017-032



- Targeting ggF, with $H \to \gamma\gamma$ and $H \to ZZ$
- Njets: sensitive to production mode composition and gluon emission
- More and more differential variables being investigated: p_{T} of leading associated jet, $|y_{\gamma\gamma}|$, $|\Delta y_{\gamma\gamma}|$, $|\cos\theta^*|$, $m_{\ell^3\ell^4}$, ...

Large p_T sensitive to:

- perturbative QCD predictions
- new heavy particles coupling to the Higgs boson
- modifications of top Yukawa coupling

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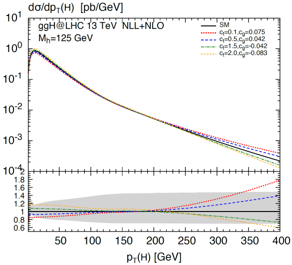
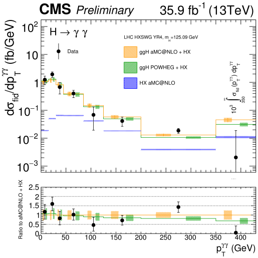


Differential measurements: Higgs boson p_T

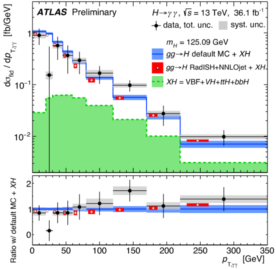
Large p_T sensitive to:

- perturbative QCD predictions
- new heavy particles coupling to the Higgs boson
- modifications of top Yukawa coupling

CMS-PAS-HIG-17-015



ATLAS-CONF-2017-045



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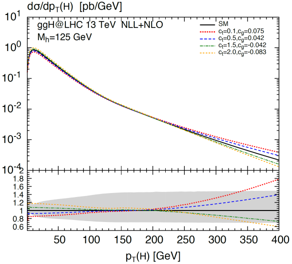

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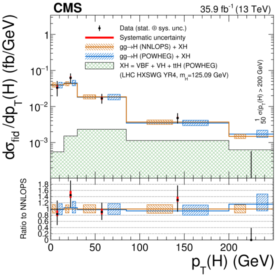

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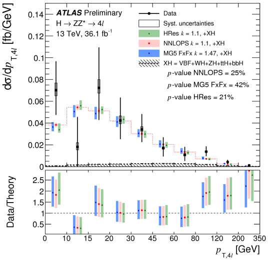
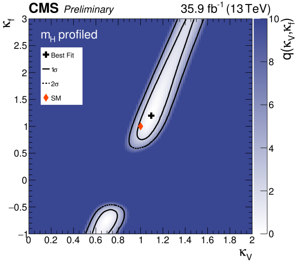


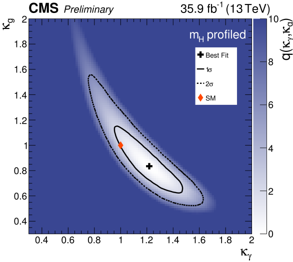
▸ YR3 arXiv:1307.1347

$$\sigma(i \to H \to f) = \kappa_i^2 \sigma_i^{SM} \frac{\kappa_f^2 \Gamma_f^{SM}}{\kappa_H^2 \Gamma_H^{SM}}$$

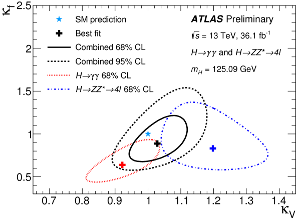
- κ's computed at LO in SM
- κ's other than those varied fixed to 1 (=SM)
- κ_f vs. κ_V: loops resolved (assume SM structure only)
- $\kappa_f < 0$ excluded at more than 95% CL
- κ_g vs. κ_γ: capture extra loop contributions $\Rightarrow$ could see new physics in loops
- Well compatible with SM

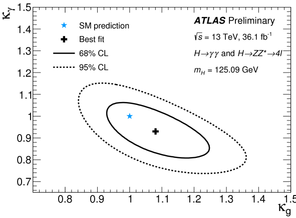
▸ CMS-PAS-HIG-16-040 $H \to \gamma\gamma$





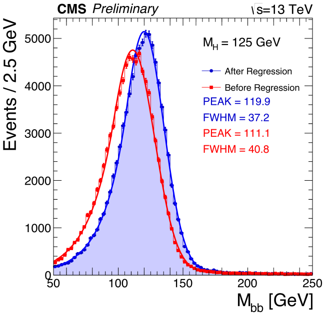
▸ ATLAS-CONF-2017-047 $H \to \gamma\gamma + H \to ZZ$



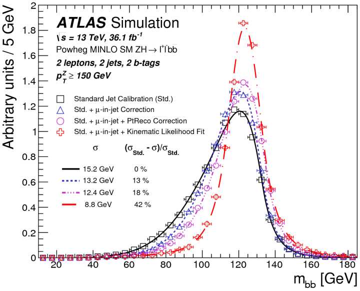


- $H \to b\bar{b}$ dominant Higgs boson decay mode (58%)
- Best accessible via $VH \to \ell\ell' b\bar{b}$ with $V = W, Z$, $\ell = e, \mu, \nu \Rightarrow 0/1/2$ charged leptons
- Tevatron's most sensitive channel (2.8σ) at 125 GeV PRL109(2012)071804
- Run 1: ATLAS+CMS 2.6σ (3.7σ expected) JHEP08(2016)045
- Just luminosity increase not enough: already systematics limited $\Rightarrow$ Hard work on objects, mass reconstruction, bkgd understanding, pileup handling, MVA (BDT in both ATLAS and CMS)

CMS-PAS-HIG-16-044



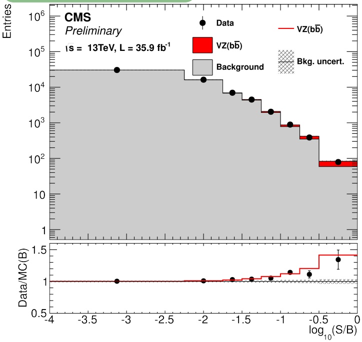
arXiv:1708.03299



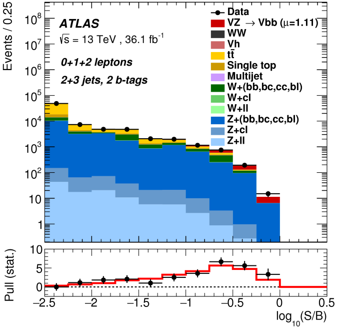
$VH(\to b\bar{b})$ validation: $VZ(\to b\bar{b})$

- Validation of performance and systematics understanding on $VZ(\to b\bar{b})$ with dedicated BDT

▸ CMS-PAS-HIG-16-044



▸ arXiv:1708.03299



- signal strength: $\mu_{VZ} = 1.02 \pm 0.22$
- significance: 5.0σ (4.9σ exp)

- signal strength: $\mu_{VZ} = 1.11^{+0.12}_{-0.11}(\text{stat.})^{+0.22}_{-0.19}(\text{syst.})$
- significance: 5.8σ (5.3σ exp)

CMS-PAS-HIG-16-044

arXiv:1708.03299

Run 2:

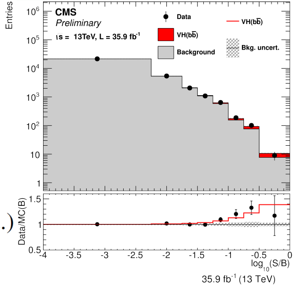
- ATLAS: 3.5σ (3.0σ exp)
- CMS: 3.3σ (2.8σ exp)

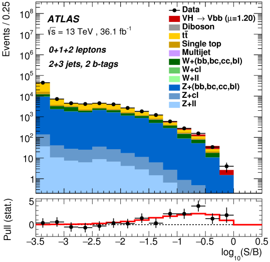
Run 1 + Run 2:

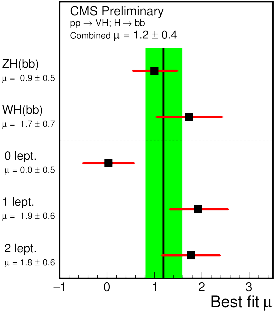
- ATLAS: 3.6σ (4.0σ exp)

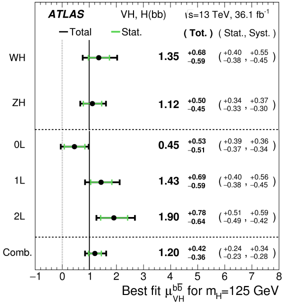
  $\mu = 0.90 \pm 0.18(\text{stat.})^{+0.21}_{-0.19}(\text{syst.})$
- CMS: 3.8σ (3.8σ exp)

  $\mu = 1.06^{+0.31}_{-0.29}$









$VH(\rightarrow b\bar{b})$ evidence

CMS-PAS-HIG-16-044 arXiv:1708.03299

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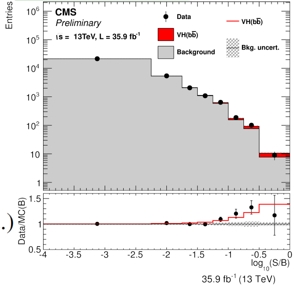
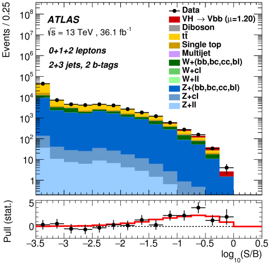
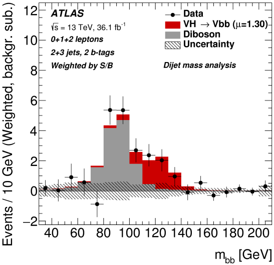
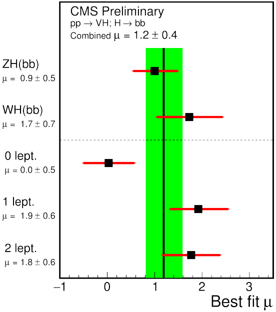
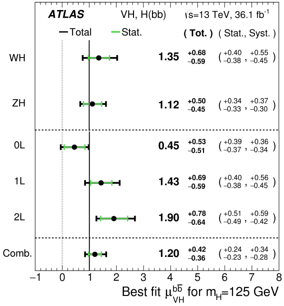


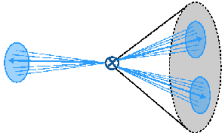


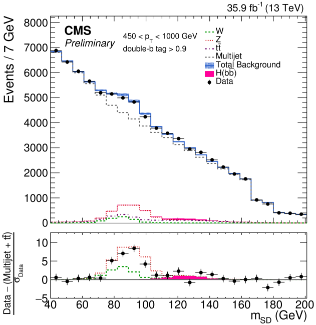


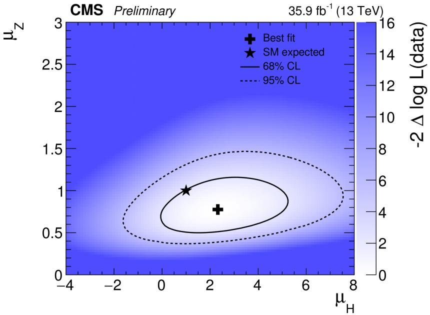




- Look for ggF with $H \to b\bar{b}$ in single large jet (double b-tagged), recoiling against high-p_T ISR jet
- $p_T(H) > 450$ GeV (background rejection, more sensitive to new physics)
- First observation of boosted $Z \to b\bar{b}$





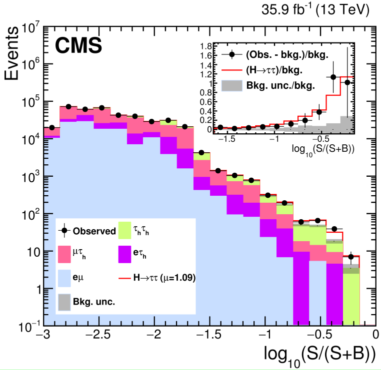


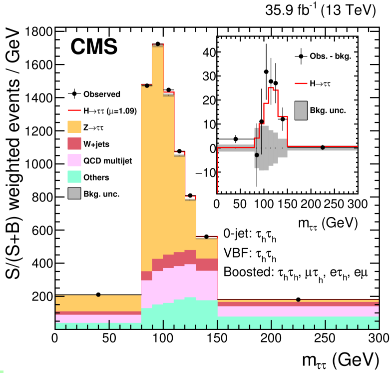
	H	H no p_T corrections	Z
Observed best fit	$\mu H = 2.3^{+1.8}_{-1.6}$	$\mu'_H = 3.2^{+2.2}_{-2.0}$	$\mu Z = 0.78^{+0.23}_{-0.19}$
Expected significance	0.7σ ($\mu H = 1$)	0.5σ ($\mu'_H = 1$)	5.8σ ($\mu_Z = 1$)
Observed significance	1.5σ	1.6σ	5.1σ

$H \to \tau\tau$ observation

arXiv:1708.00373

- Run 1: observation only via ATLAS+CMS combination (JHEP08(2016)045)
- Use $e\mu$, $e\tau_{\text{had}}$, $\mu\tau_{\text{had}}$, $\tau_{\text{had}}\tau_{\text{had}}$ decays, categorised in 0-jet, VBF (at least two jets with high m_{jj}, $\Delta\eta_{jj}$) and boosted (the rest)
- First single experiment observation of $H \to \tau\tau$





	μ	Obs.	Exp.
Run 2	$1.09^{+0.27}_{-0.26}$	4.9σ	4.7σ
Run 1&2	0.98 ± 0.18	5.9σ	5.9σ

(see A. de Maria for ATLAS)

Looking for $t\bar{t}H$

- Run 1 ATLAS+CMS combination: $\mu = 2.3^{+0.7}_{-0.6}$, 4.4σ (2.0σ expected)
- Already several single analyses around 2σ expected sensitivity
- More full Run 2 results expected soon
- Evidence in ML/$H \to \gamma\gamma$. Observation of $t\bar{t}H$ just around the corner?

13 fb^{-1} / 36 fb^{-1}	ATLAS μ	ATLAS obs (exp)	CMS μ	CMS obs (exp)
$H \to b\bar{b}$	$2.1^{+1.0}_{-0.9}$	2.3σ (1.2σ)	-0.2 ± 0.8	$< 0\sigma$
Multilepton	$2.5^{+1.3}_{-1.1}$	2.2σ (1.3σ)	1.5 ± 0.5	3.3σ (2.5σ)
$\tau_{\text{had}} + X$			$0.7^{+0.6}_{-0.5}$	1.4σ (1.8σ)
$H \to \gamma\gamma$	0.5 ± 0.6	1.0σ (1.8σ)	$2.2^{+0.9}_{-0.8}$	3.3σ (1.5σ)
$H \to ZZ$	< 6.9@95% CL	$\sim 0\sigma$	$0.0^{+1.2}_{-0.0}$	$< 0\sigma$

- ATLAS $H \to \gamma\gamma$ ATLAS-CONF-2017-045
- CMS $H \to \gamma\gamma$ CMS-PAS-HIG-16-040
- ATLAS $H \to ZZ$ ATLAS-CONF-2017-043
- CMS $H \to ZZ$ arXiv:1706.09936
- CMS $t\bar{t}H\tau$ CMS-PAS-HIG-17-003
- CMS $t\bar{t}H$ ML CMS-PAS-HIG-17-004
- CMS tH CMS-PAS-HIG-17-005

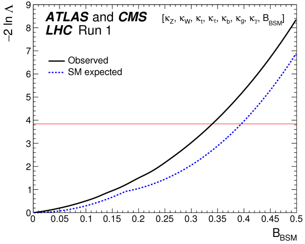
(see C. Wang for ATLAS 3ℓ)

Because one SM Higgs boson is not enough!

BSM Higgs scenarios

- Decays
  - From Run 1, branching fraction to BSM decays only constrained to $< 34\%$ at 95% CL (assuming $\kappa_V \leq 1$)
  - If new particles too heavy, deviations in Higgs decay properties may be only place showing signs of new physics
  - Could have enhanced decay rates to known modes, decay in forbidden channels (LFV), to BSM particles (undetected dark matter, light scalars, ...)

JHEP08(2016)045

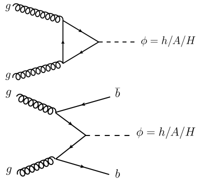


- Additional Higgs particles
  - only one Higgs doublet (SM) or more complex Higgs sector?
  - additional singlet: h, H
  - two Higgs doublet models (2HDM): h, H, A, $H^{\pm}$
  - two doublets + singlet model
  - SM doublet + triplet models: $H^{\pm\pm}$
- Heavy resonances decaying to SM Higgs boson(s)

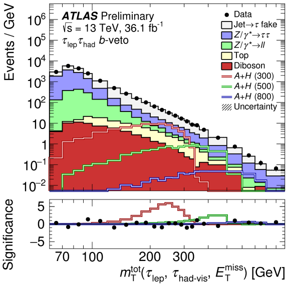
BSM $A/H \to \tau\tau$

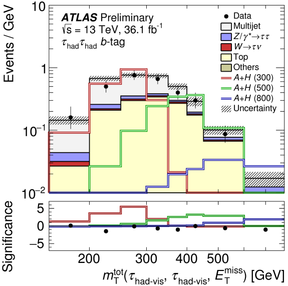
ATLAS-CONF-2017-050

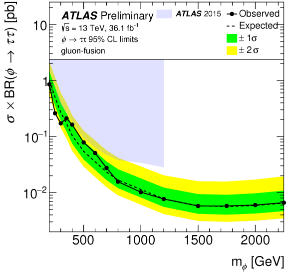
- In MSSM (and all 2HDM type II), enhanced heavy Higgs couplings to down-type fermions (τ, b) for large $\tan\beta$
- Target ggF (bbH) with b-jet veto (b-tag)

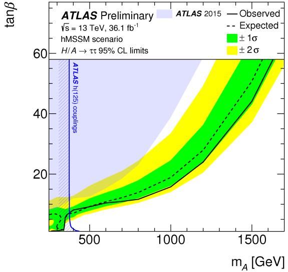


- Use $\tau_{lep}\tau_{had}$ and $\tau_{had}\tau_{had}$ channels
  - Measured in several scenarios (hMSSM, m_h^{mod+})



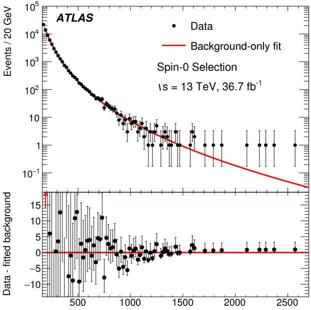


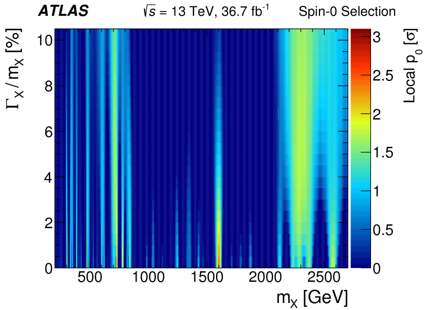


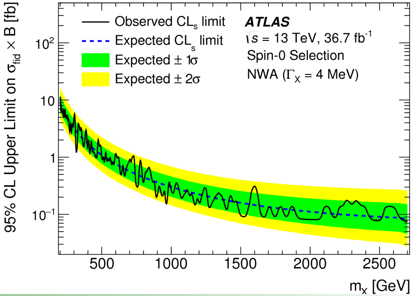


BSM $H \to \gamma\gamma$

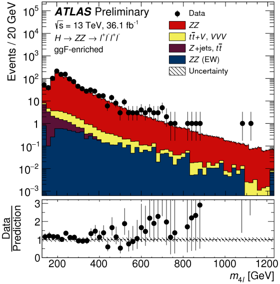
- During early Run 2, various high mass $\gamma\gamma$ excesses triggered high hopes for new physics
- Improved photon ID, calibration
- No serious excess in full dataset

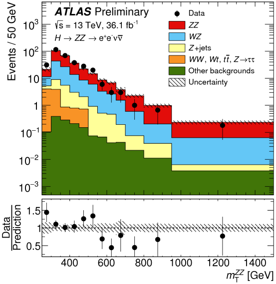


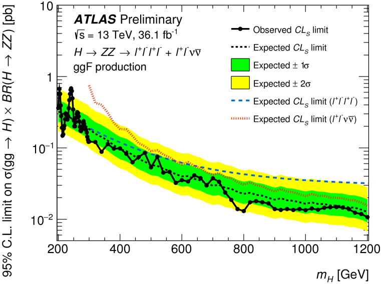


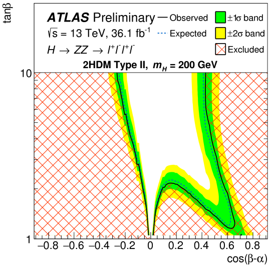


- $H \to ZZ \to 4\ell/\ell\ell\nu\nu$ (ggF and VBF)
- Two local excesses around 240 and 700 GeV (3.6σ local, 2.2σ global) in 4ℓ channel (700 GeV excluded by $\ell\ell\nu\nu$)
- Combined: mild excess around 700 GeV (2σ local, $< 1\sigma$ global)
- Interpreted in narrow and large width scenarios, 2HDM type I and II

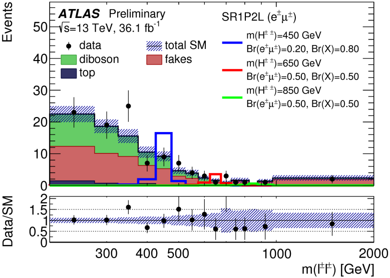


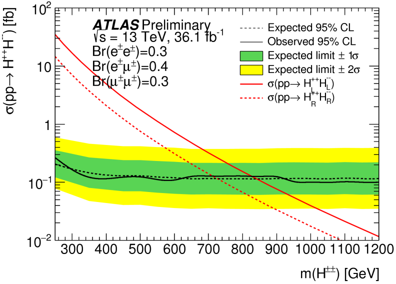


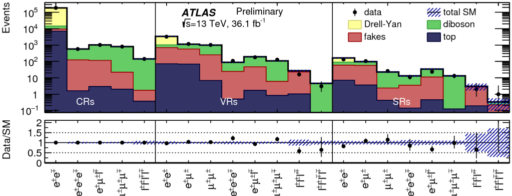




- No full 2015+2016 statistics analyses yet for charged Higgs bosons
- Only recent publication: CMS VBF fermiophobic $H^{\pm} \to WZ$ with 15.2 fb^{-1}
  ▸ arXiv:1705.02942
- Doubly charged Higgs ▸ ATLAS-CONF-2017-053
  - $H^{\pm\pm}H^{\mp\mp} \to \ell^{+}\ell^{+}\ell^{-}\ell^{-}$
  - $2/3/4\ell$ signal regions
  - No evidence of signal
  - Limits around 800 GeV, and still above 450 GeV with $Br(H^{\pm\pm} \to \ell^{\pm}\ell^{\pm}) = 10\%$







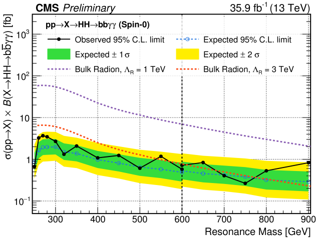
See also ▸ CMS-PAS-HIG-16-036

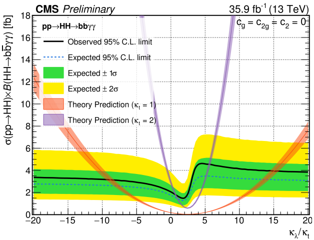
BSM $X \to HH$

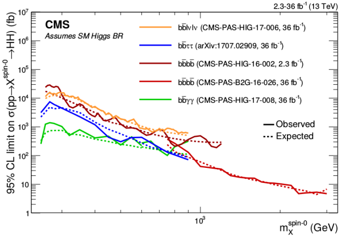
- Analysed many final states
- With 36 fb^{-1}:
  - $b\bar{b}\ell\nu\ell\nu$ ▸ arXiv:1708.04188
  - $b\bar{b}\tau\tau$ ▸ arXiv:1707.02909
  - $b\bar{b}\gamma\gamma$ ▸ CMS-PAS-HIG-17-008
  - $b\bar{b}b\bar{b}$ ▸ CMS-PAS-B2G-16-026
- Look for resonances

- And for SM non-resonant HH production:

3 / 13 / 36 /fb	σ/σ_{SM} 95% CL (exp) ATLAS	CMS
$b\bar{b}\ell\nu\ell\nu$		$< 79(89)$
$b\bar{b}\tau\tau$		$< 30(29)$
$b\bar{b}\gamma\gamma$	$< 117(161)$	$< 19(17)$
$b\bar{b}b\bar{b}$	$< 29(38)$	$< 342(308)$
$WW\gamma\gamma$	$< 747(386)$	

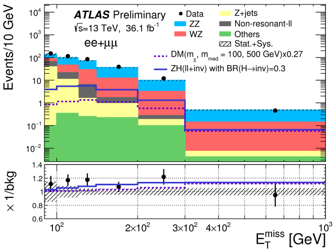


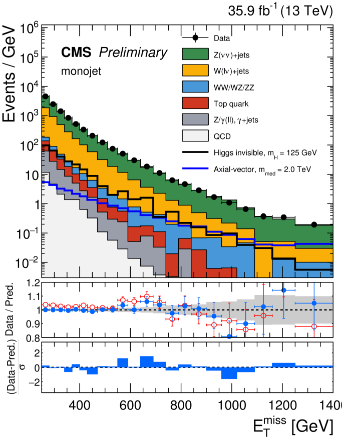




BSM Higgs to invisible

- Higgs decay to undetected dark matter
- Monojet: ggF + extra jet
- Requires good understanding of missing transverse momentum





BR 95% CL limit	Obs.	Exp.	
CMS $Z(\ell\ell)H$	$< 40\%$	$< 42\%$	▸ CMS-PAS-EXO-16-052
CMS Monojet	$< 74\%$	$< 57\%$	▸ CMS-PAS-EXO-16-048
CMS $V(\mathrm{had})H$	$< 49\%$	$< 45\%$	▸ CMS-PAS-EXO-16-048
ATLAS $Z(\ell\ell)H$	$< 67\%$	$< 39\%$	▸ ATLAS-CONF-2017-040

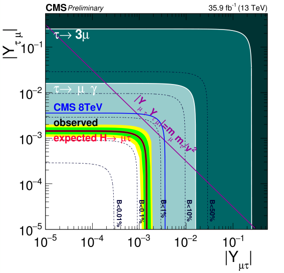
- ATLAS Run 1 VBF: 28% (31% exp) ▸ JHEP01(2016)172
- CMS 7/8/13 TeV (2.3 fb^{-1} only) combination: 24% (23% exp) ▸ JHEP02(2017)135

Anomalous couplings: flavour violation

Lepton flavour violation

CMS-PAS-HIG-17-001

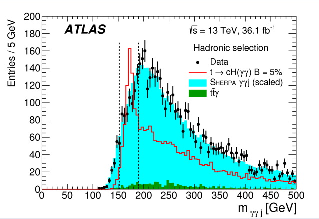
- FCNC highly suppressed in SM, bounds on $\mu \to e\gamma$ or $\mu \to 3e$ but not on $H \to e\tau$ or $H \to \mu\tau$
- No excess found (8 TeV 2.4σ excess excluded)
- Obs. (exp.) upper limits: $B(H \to \mu\tau) < 0.25(0.25)\%$ and $B(H \to e\tau) < 0.61(0.37)\%$ at 95% CL



Quark flavour violation

arXiv:1707.01404

- Search for $t \to qH(\to \gamma\gamma)$
- Reconstruct $m_{\gamma\gamma j}$
- Limits: $< 2.2 \times 10^{-3}$ for $t \to cH$, $< 2.4 \times 10^{-3}$ for $t \to uH$



Conclusions

- Higgs physics did not stop with 2012 discovery
- Particle very much SM Higgs-like
- New measurements with full 2015+2016 dataset ($\sim$36 fb^{-1} per experiment) well under way
  - increased statistics
  - improved analysis techniques
  - better theory calculations and generators

    $\Rightarrow$ most results now surpass Run 1
- Very rich research programme to look for possible deviations from SM predictions:
  - precision measurements of production cross sections and branching fractions
  - search for new Higgs bosons
  - Higgs bosons in new heavy resonance decays
- Many measurements still limited by end of Run 2: see HL-LHC prospects by L. Iconomidou-Fayard (ATLAS) and V. Rekovic (CMS)

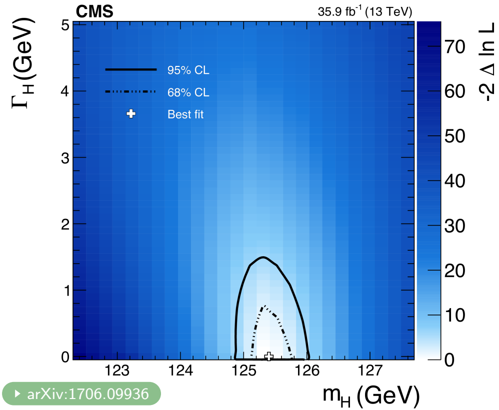
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HiggsPublicResults

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/Winter201713TeV

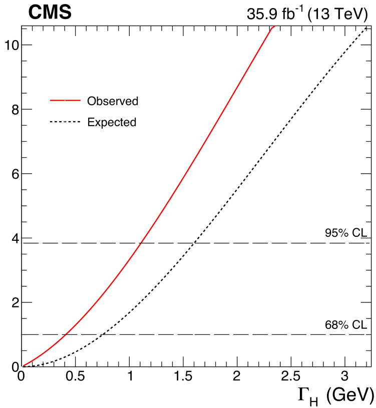
http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/HIG/

http://cms-results.web.cern.ch/cms-results/public-results/publications/HIG

Backup



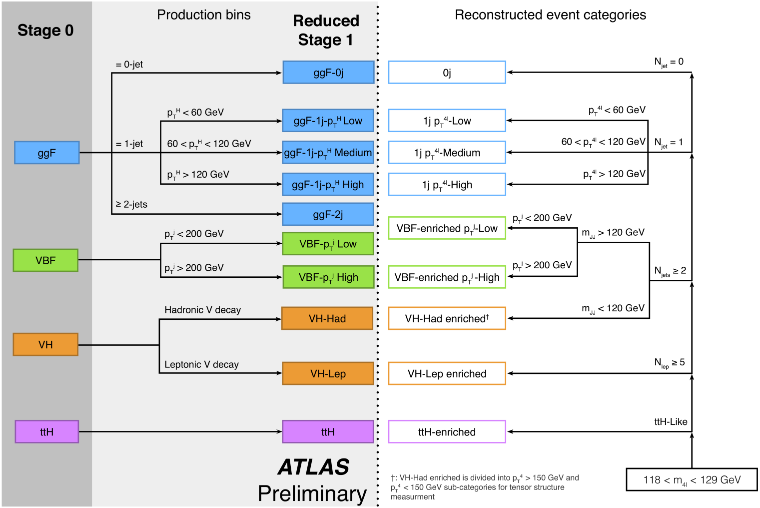
▸ arXiv:1706.09936



- Direct measurement with on-shell production, $105 < m_{4\ell} < 140$ GeV
- No assumption on BSM physics
- $\Gamma_H < 1.10$ GeV at 95% CL
- Limited by 4ℓ mass resolution (about 1 GeV)

- Match experimental categories with production bins

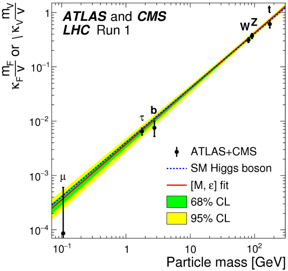
ex: $H \to ZZ^* \to 4\ell$ ATLAS-CONF-2017-043

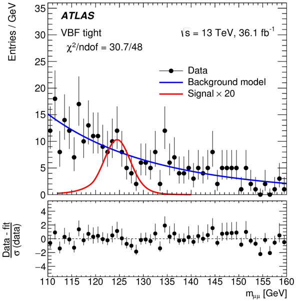


- Probe second generation fermion coupling
- Difficulty to see it: already sign that Higgs coupling to fermions correlated with mass
- Search for narrow $m_{\mu\mu}$ mass peak over continuum
- BDT to define two VBF regions and one ggF (split in six from $\mu\mu$ η and p_T)
- Completely driven by statistics (syst: 2.2%)

	μ	95% CL limit Obs.	Exp.
Run 2	-0.1 ± 1.5	$\mu < 3.0$	$\mu < 3.1$
Run 1&2	-0.1 ± 1.4	$\mu < 2.8$	$\mu < 2.9$

- ATLAS+CMS sensitivity $\sim 2\sigma$ by end of Run 2
- Other rare processes: $H \to Z\gamma$ ‣ arXiv:1708.00212, $H \to \rho\gamma$ and $H \to \phi\gamma$ ‣ ATLAS-CONF-2017-057

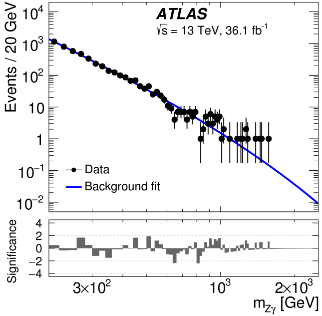


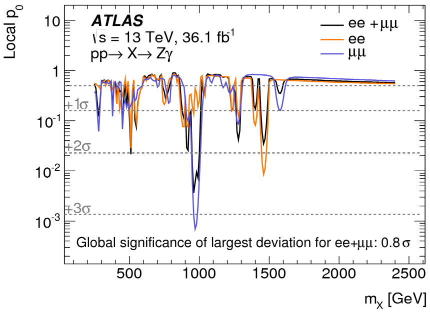


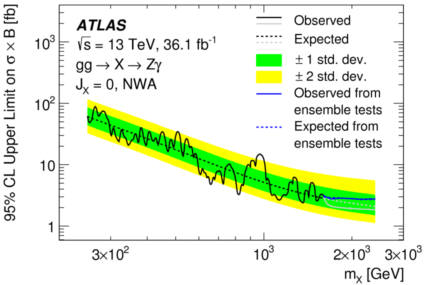
BSM $H \to Z\gamma$

arXiv:1708.00212

- No evidence for SM $H \to Z\gamma$ yet
- Upper limit: $\mu < 6.6$ @ 95% CL
- No excess at high mass



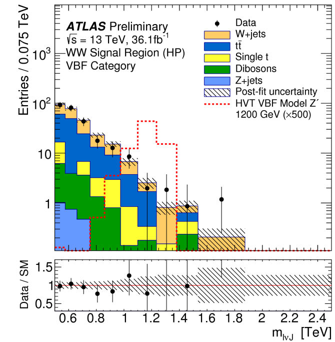


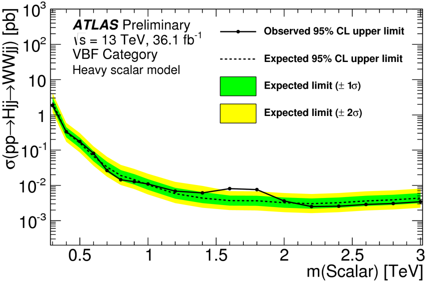


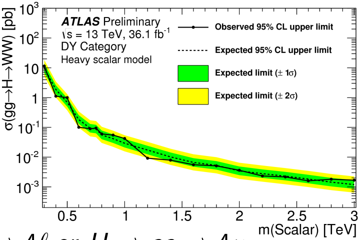
BSM $H \to WW$

ATLAS-CONF-2017-051

- $H \to WW \to \ell\nu qq$
- VBF and non-VBF selections
- Boosted (one large-R jet) and resolved (two small-R jets) analyses
- No excess
- Interpreted in narrow width scenario





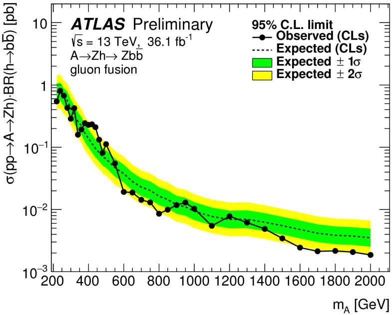


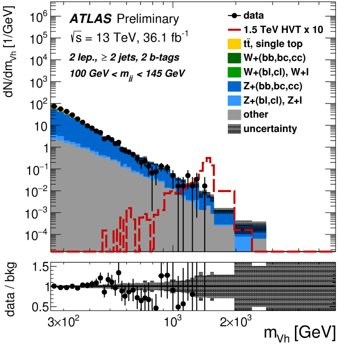
- Looking for more decays, e.g. $H \to Z_{(d)} Z_d \to 4\ell$ or $H \to aa \to 4\mu$

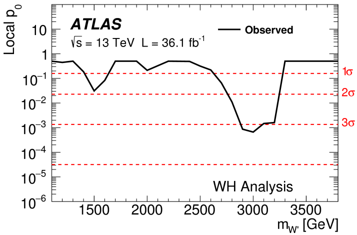
ATLAS-CONF-2017-042

BSM $X \to HV$

- $H \to b\bar{b}$
- $V \to \ell\ell, \ell\nu, \nu\nu$ ▸ ATLAS-CONF-2017-055 and $V \to q\bar{q}'$ ▸ arXiv:1707.06958
- Resolved ($V \to \ell\ell$ only) and boosted (both) analyses
- 3.3σ local excess (2.2σ global) in qq analysis



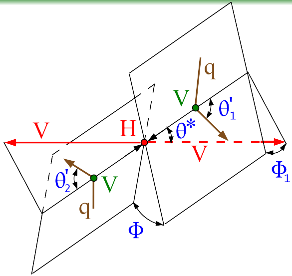




Anomalous HVV couplings

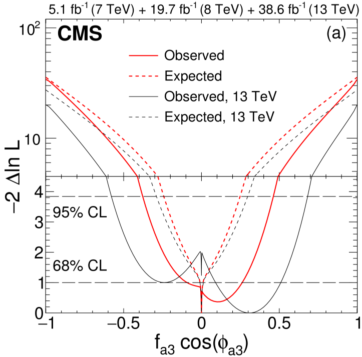
- Use both production and decay information about coupling
- Based on ME discriminators, including angular observables
- Use $H \to 4\ell$ in VBF, VH (with at least two jets) and ggF (not-VBF, not-VH) modes
- Fractional cross sections and phases:

$$f_{ai} = |a_i|^2\sigma_i \Big/ \sum |a_j|^2\sigma_j, \text{ and } \phi_{ai} = \arg\left(a_i/a_1\right)$$



- No deviation from SM

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



- See also ATLAS-CONF-2017-032 for limits on contact interactions within framework of pseudo-observables EPJC75(2015)341