

Measuring the SM Higgs properties with ATLAS at 13 TeV

Sarah Heim



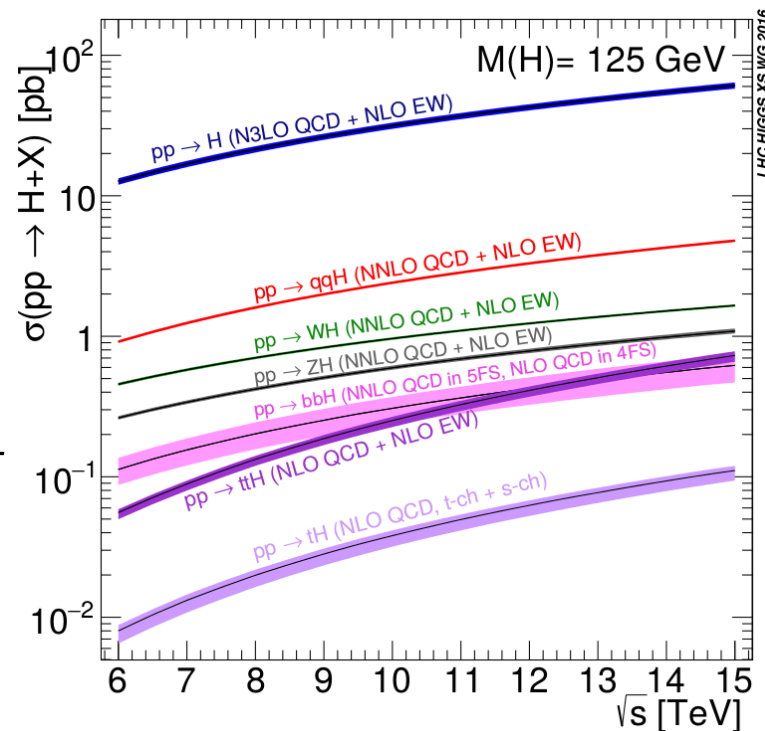
DESY LHC Physics discussions
November 14th, 2016

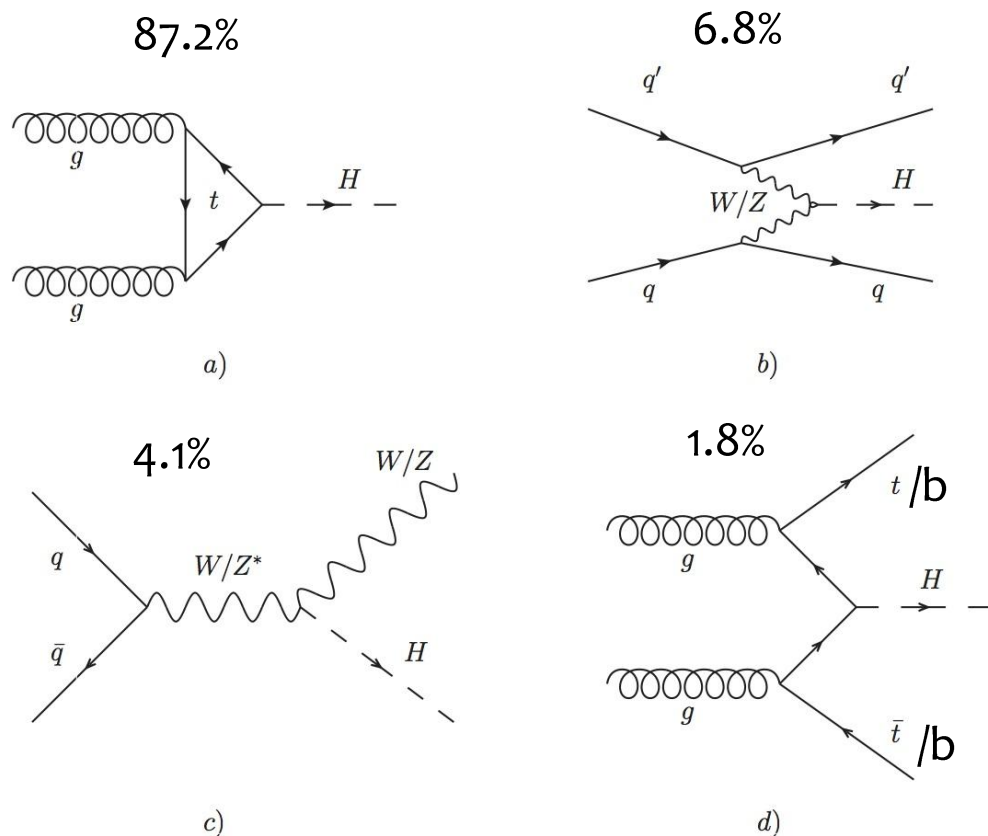


- Focus on ATLAS results with 2015/2016 data (ICHEP and later)
 - Comparisons with Run 1 results
- SM Higgs measurements (we re-discovered it at 13 TeV :))
 - See next talk for BSM
- Notes and links:
 - 4l: [ATLAS-CONF-2016-079](#)
 - $\gamma\gamma$: [ATLAS-CONF-2016-067](#)
 - 4l+ $\gamma\gamma$: [ATLAS-CONF-2016-081](#)
 - NEW! - WW: [ATLAS-CONF-2016-112](#)

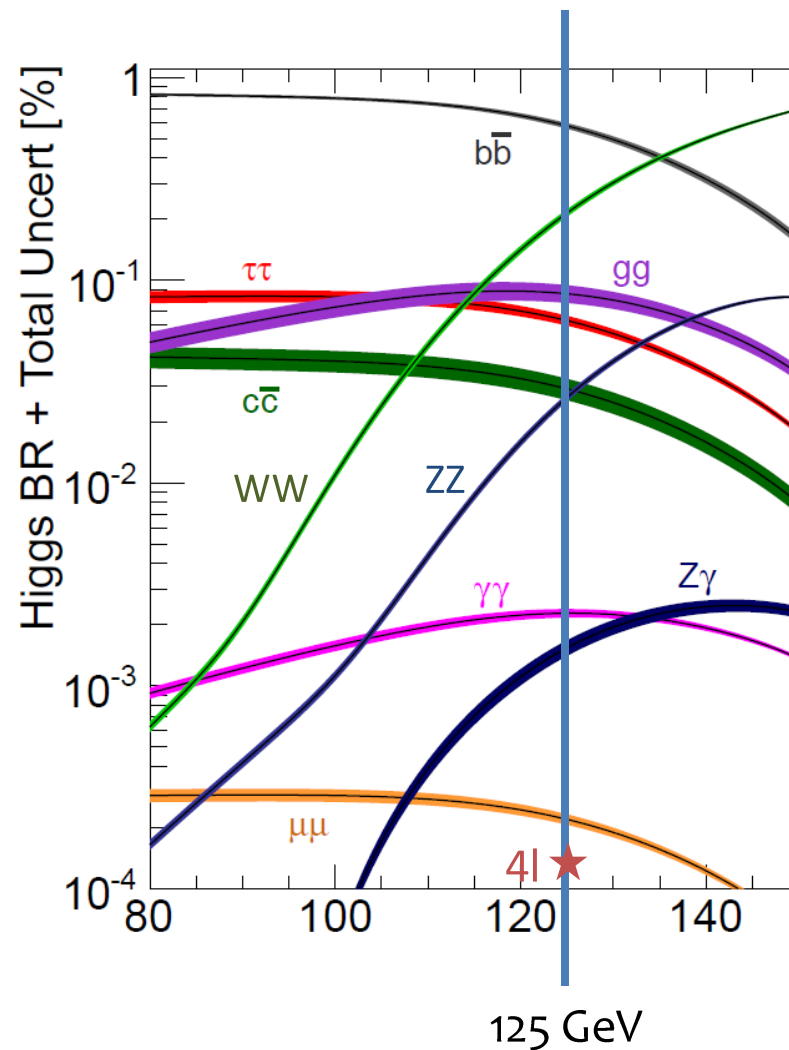
2016 Higgs results not covered here:

- ttH
- VH(bb), VBF(bb)+ γ

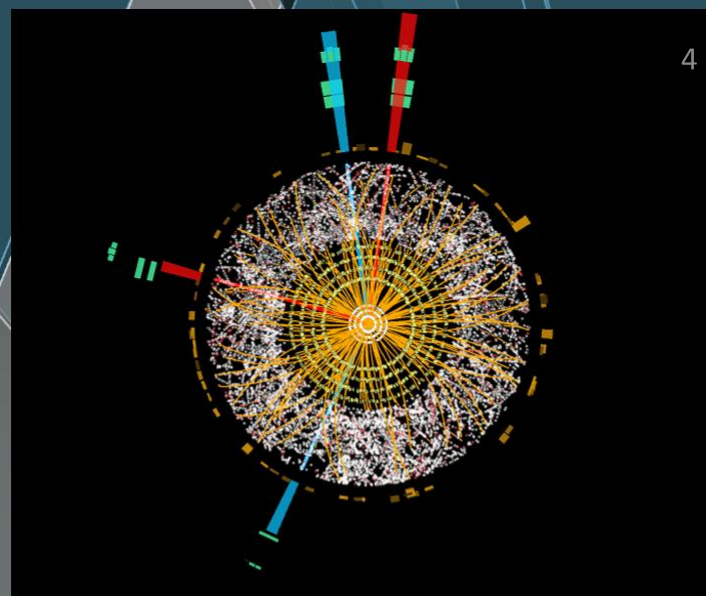
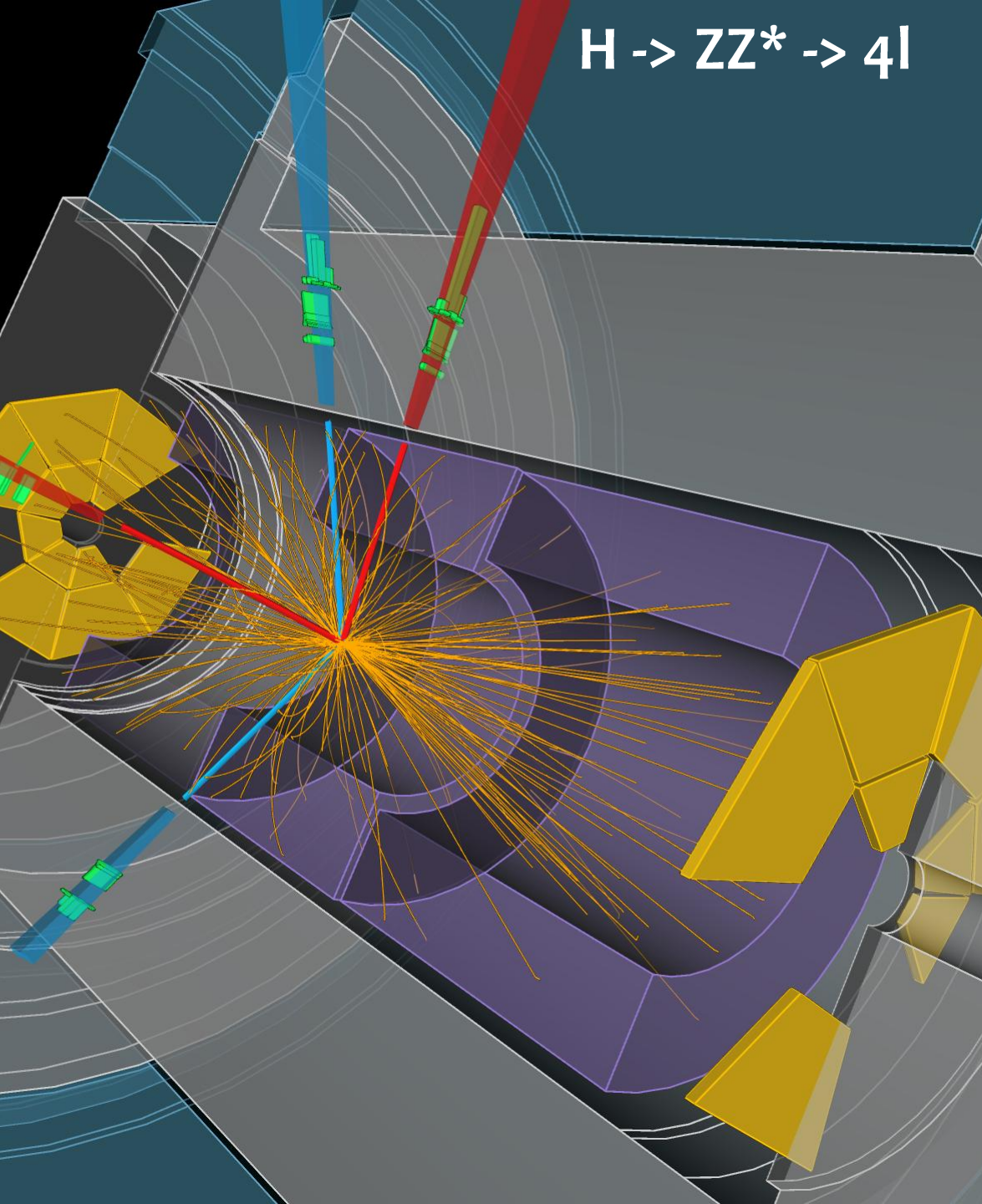




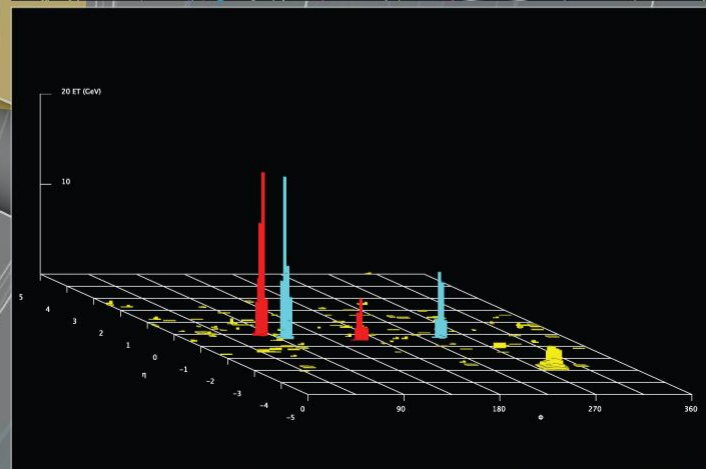
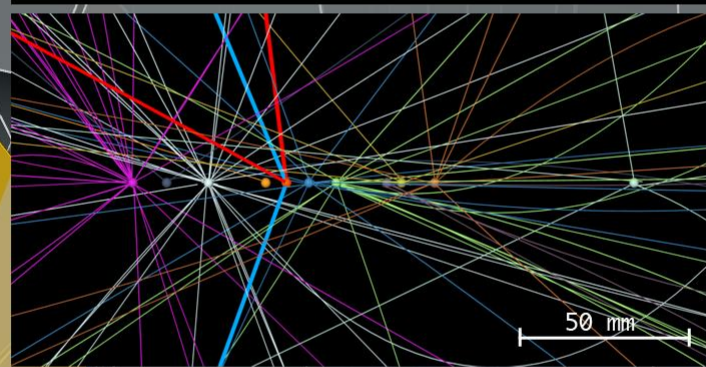
Production mode fractions for $m_H = 125$ GeV,
pp collisions at 13 TeV

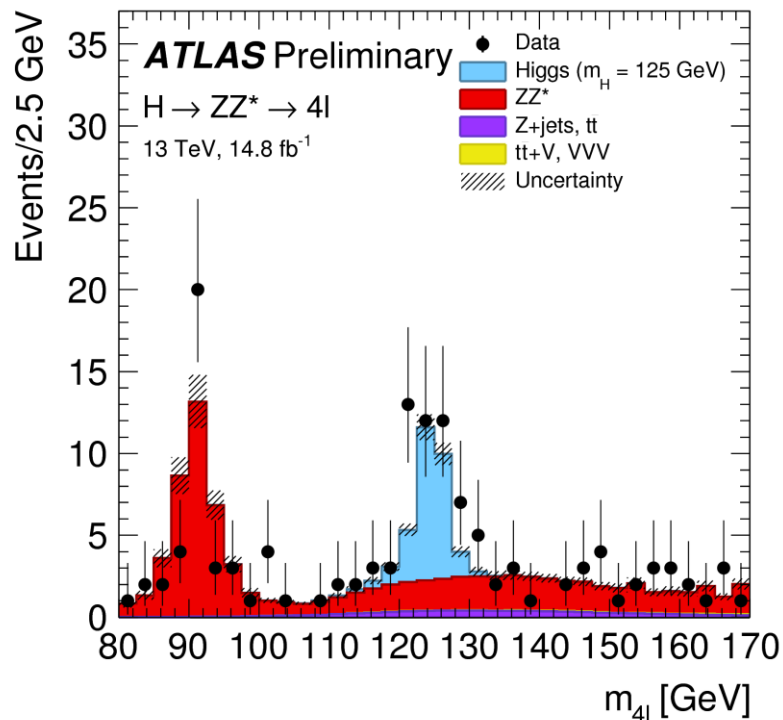


$H \rightarrow ZZ^* \rightarrow 4l$



4



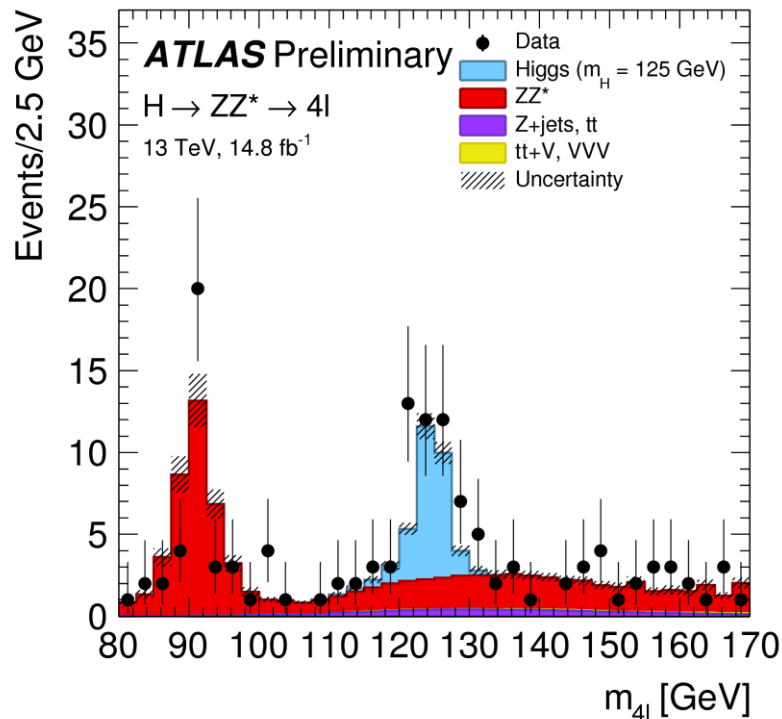


Event selection (acc*eff: 15 - 35%)

- 2 opposite sign, same flavor pairs
 - 4e, 4μ, 2e2μ
 - loose IDs, loose isolation
 - for 2016, lowest muon pt cut lowered from 6 to 5 GeV
- Z12 kinematically constrained to m_Z
- Cut on vertex compatibility of the 4 leptons

Background estimates

- qq $\rightarrow$ ZZ: Powheg, NNLO QCD, NLO EW mass dependent k-factors
- gg $\rightarrow$ ZZ: gg2VV, higher order k-factor
- Z+jets, top backgrounds: data-driven estimates in control regions, process dependent transfer factors to signal region



Events in mass window 118-129 GeV

Signal 22.3 ± 1.6

ZZ* 8.2 ± 0.8

Z+jets/ttbar/etc. 1.54 ± 0.18

Total expected 32.0 ± 1.8

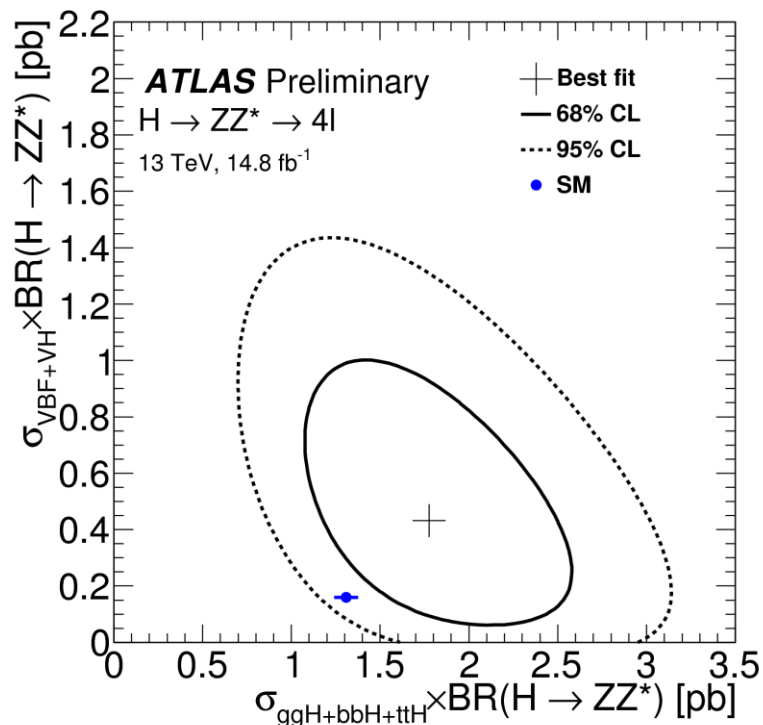
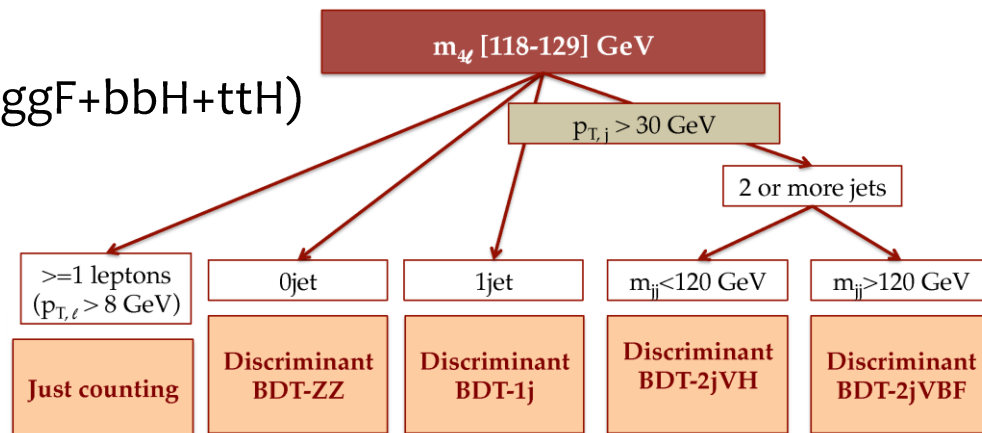
Observed 44

- Signal extraction by template fit to invariant mass (m_H fixed to 125.09 GeV)
- Unfolded to fiducial (and extrapolated to total) cross sections

	$\sigma(\text{fid})$ [fb]	$\sigma(\text{fid, SM})$ [fb]
ICHEP	$4.54 +1.02/-0.90$	$3.07 +0.21/-0.25$
Run 1(20.3 fb ⁻¹ , 8 TeV)	$2.11 +0.54/-0.48$	1.30 ± 0.13

- Split into final states (4e, 4μ, 2e2μ/2μ2e), no surprises

- Split the events into categories
- Use BDTs to improve purity
- Fit for $\sigma(\text{VH})$, $\sigma(\text{VBF})$ and $\sigma(\text{ggF+bbH+ttH})$



Cross section * BR(ZZ*)

	σ [pb]	$\sigma(\text{SM})$ [pb]
ggF	1.8 +0.49/-0.44	1.31 +/-0.07
VBF	0.37 +0.28/-0.21	0.100 +/-0.003
VH	0 +0.15	0.059 +/-0.002

Compatibility with the SM:

ggF+ttH+bbH – 1.1 σ , VBF+VH – 1.4 σ

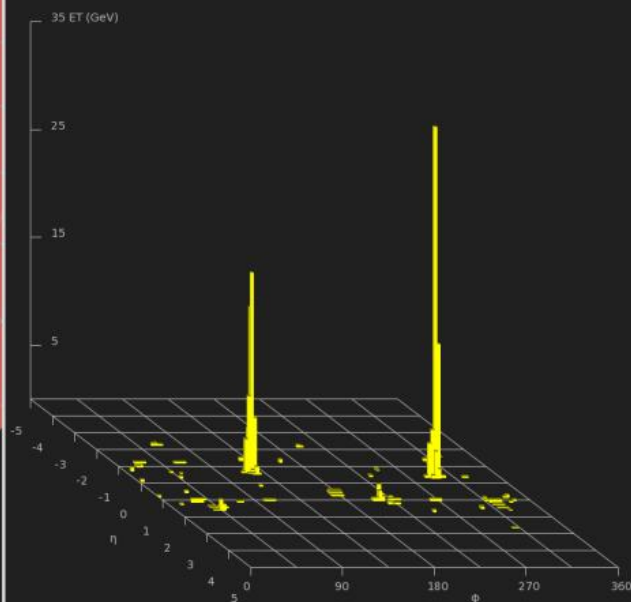
$H \rightarrow \gamma\gamma$



ATLAS
EXPERIMENT

Run Number: 191426, Event Number: 86694500

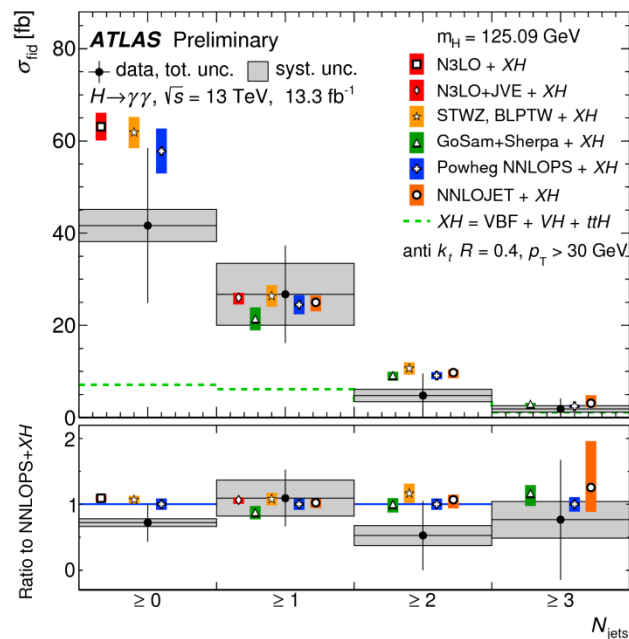
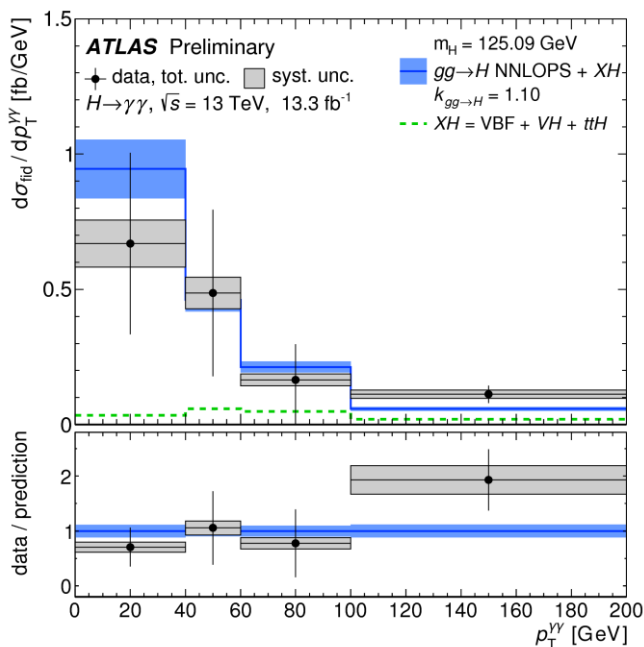
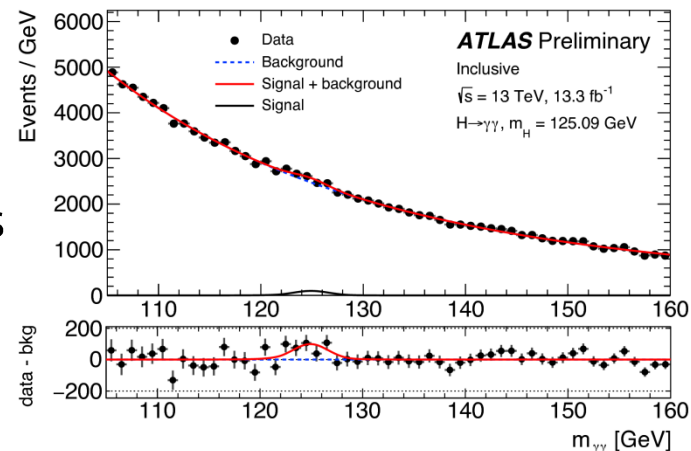
Date: 2011-10-22 15:30:29 UTC



- Signal extraction: fit to $m_{\gamma\gamma}$ distribution
(m_H fixed to 125.09 GeV)
- Unfolded with bin-by-bin correction factors
- Measured fiducial cross section:

$$\sigma(\text{fid}) = 43.2 \pm 14.9 (\text{stat}) \pm 4.9 (\text{sys}) \text{ fb}$$

$$\sigma(\text{fid, SM}) = 62.8 + 3.4/-4.4 \text{ fb}$$



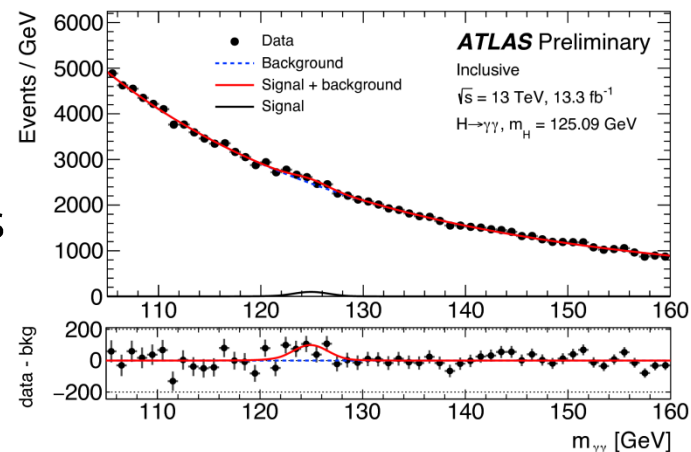


H → γγ, fiducial and differential cross sections 13.3 fb⁻¹ at 13 TeV¹⁰

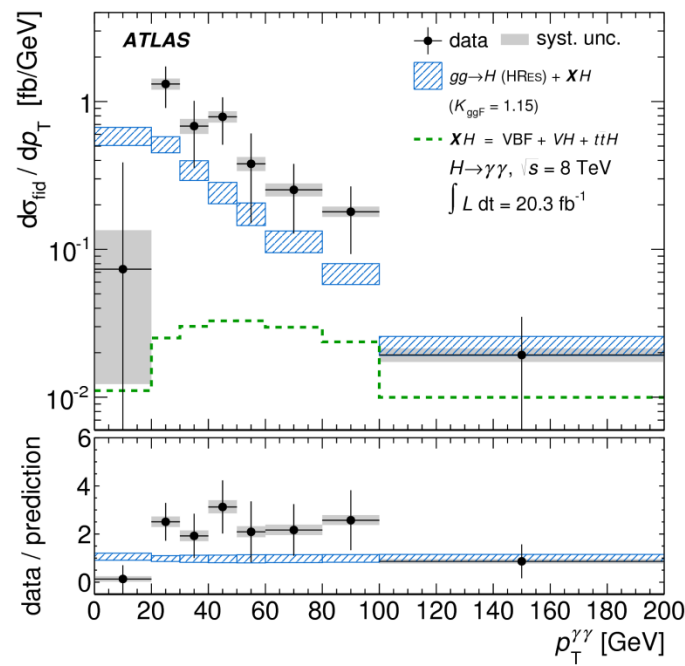
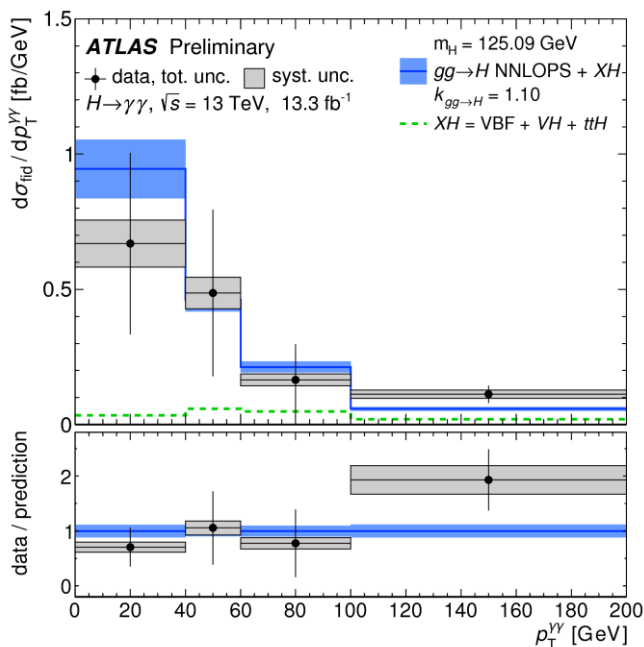
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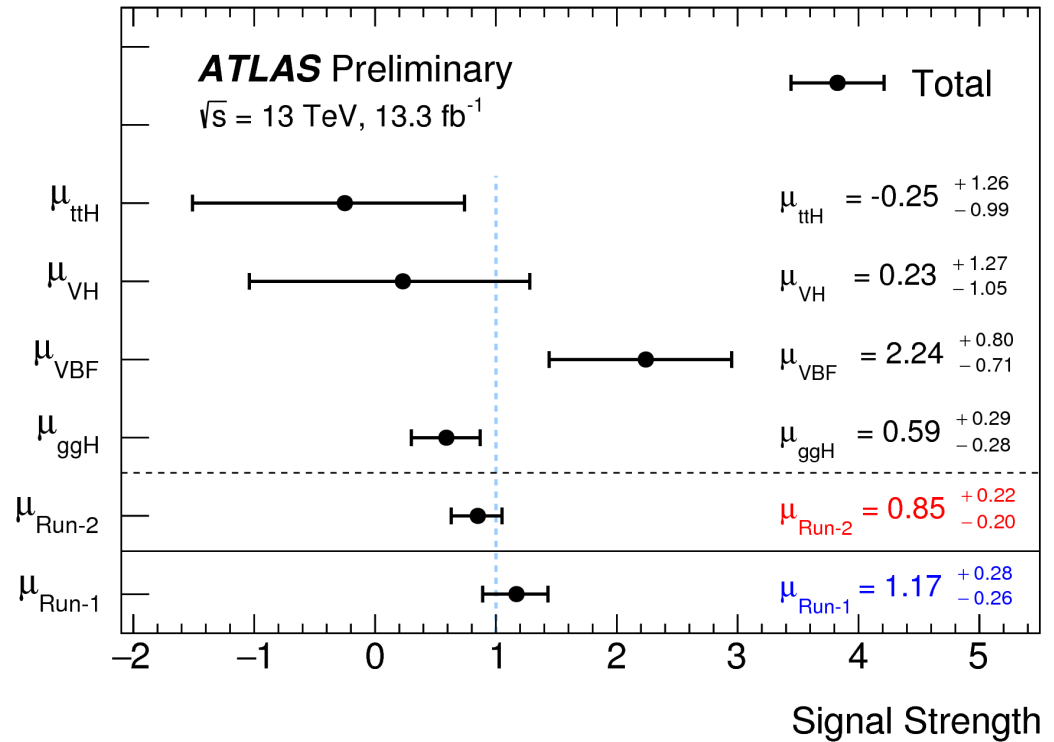
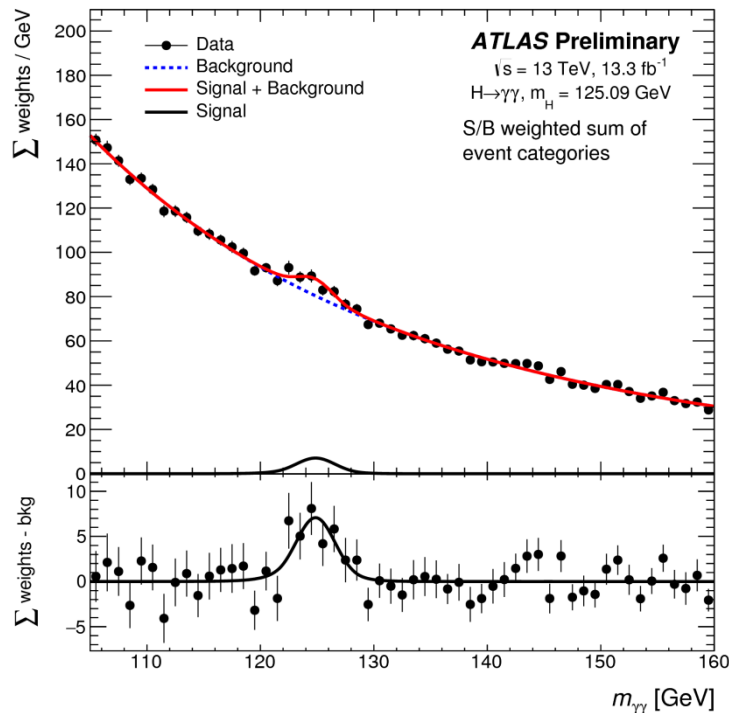
$$\sigma(\text{fid, SM}) = 62.8 + 3.4/-4.4 \text{ fb}$$



Run 1



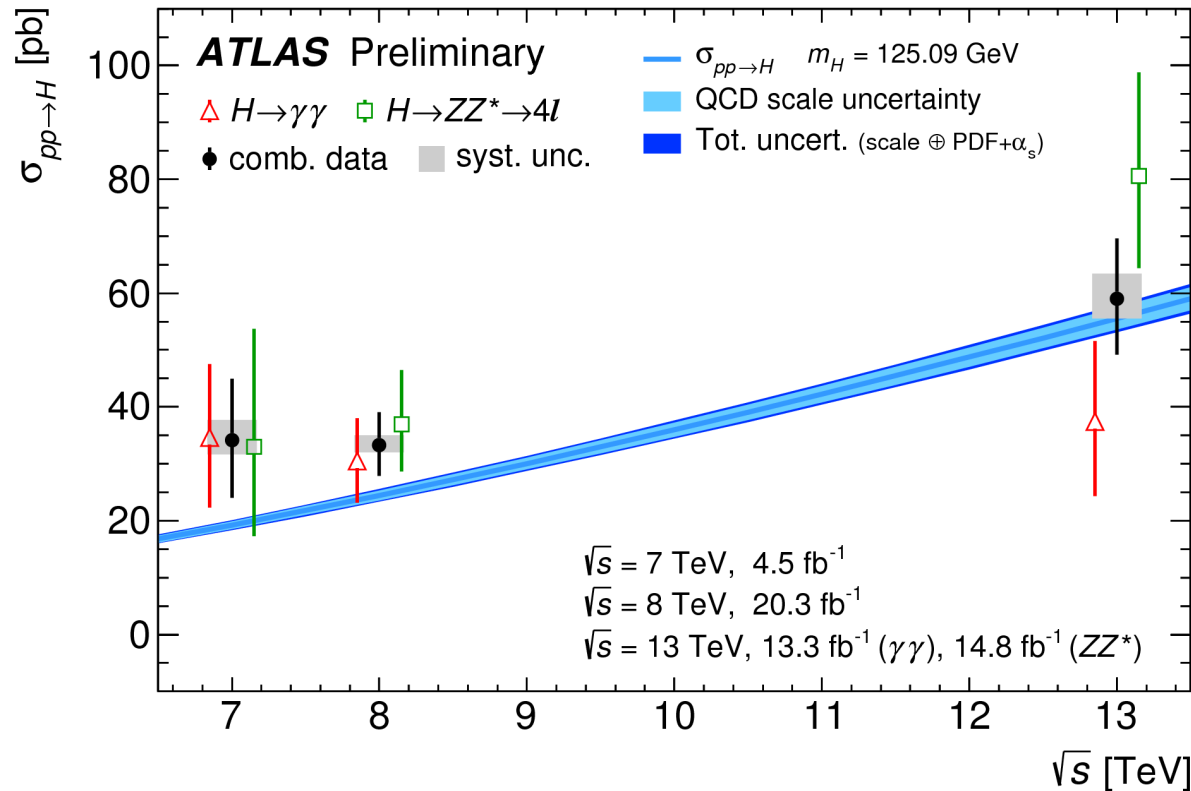
- Divide reconstructed events into 13 categories
- simultaneous fit to $m_{\gamma\gamma}$ in all categories



Results compatible with SM expectations

$H \rightarrow 4l + \gamma\gamma$ combination: total cross section

- Statistical significance of both channels similar
- Extrapolate to total cross sections with SM acceptance and BF

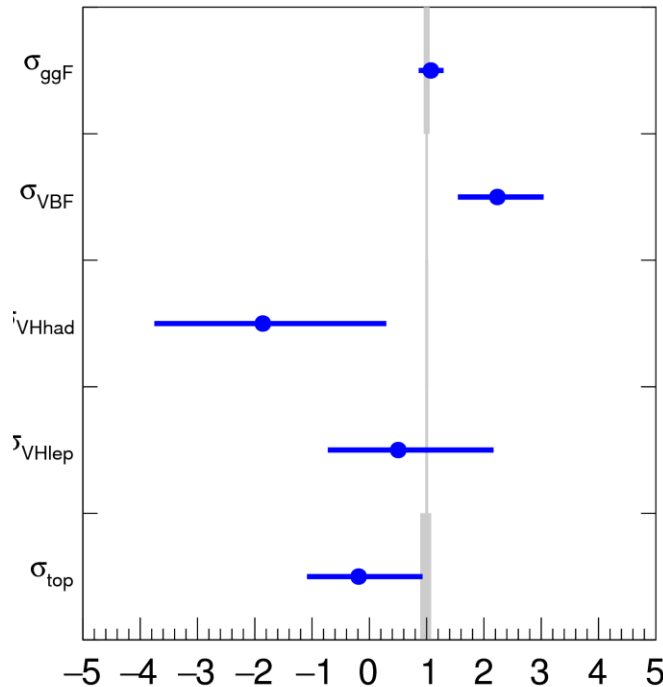
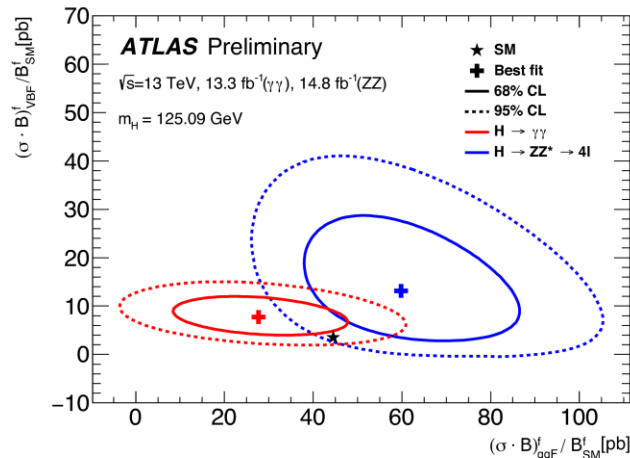


$\sim 10\sigma$

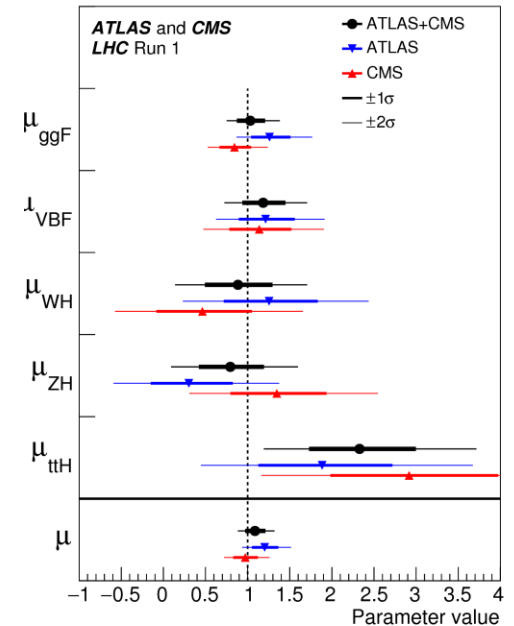
Results compatible
with SM
expectations

ATLAS Preliminary $m_H=125.09$ GeV
 $\sqrt{s}=13$ TeV, $13.3 \text{ fb}^{-1} (\gamma\gamma)$, $14.8 \text{ fb}^{-1} (ZZ)$

● Observed 68% CL ■ SM Prediction



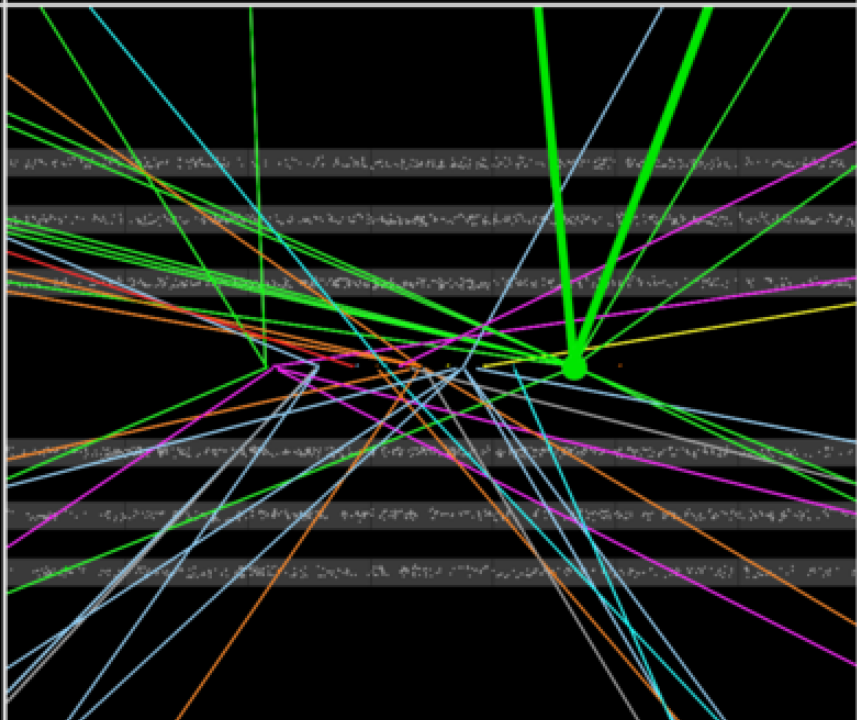
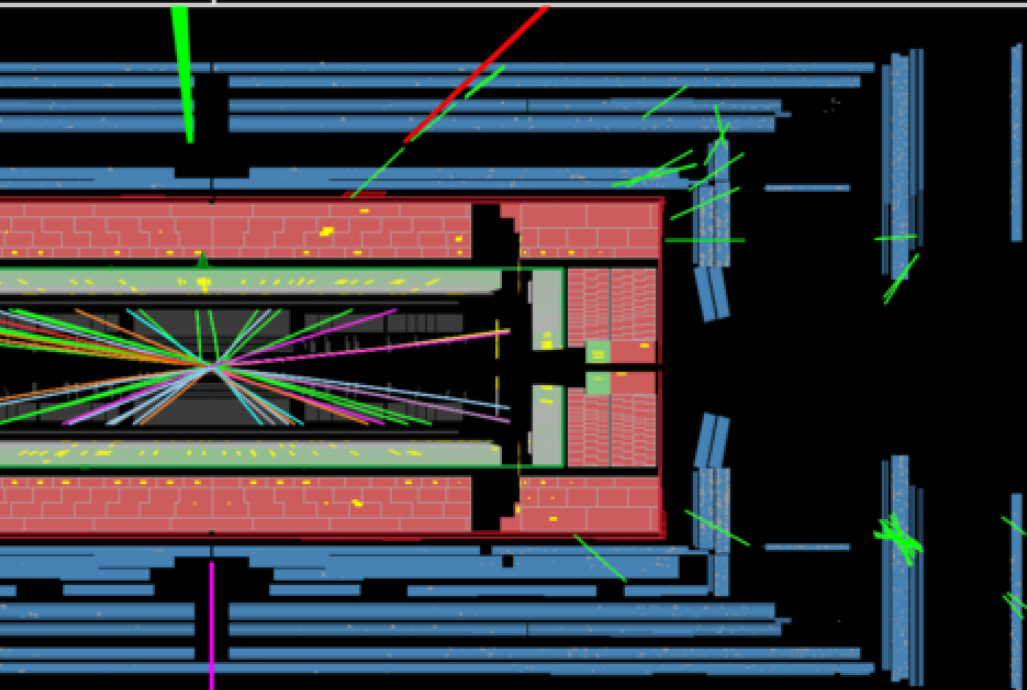
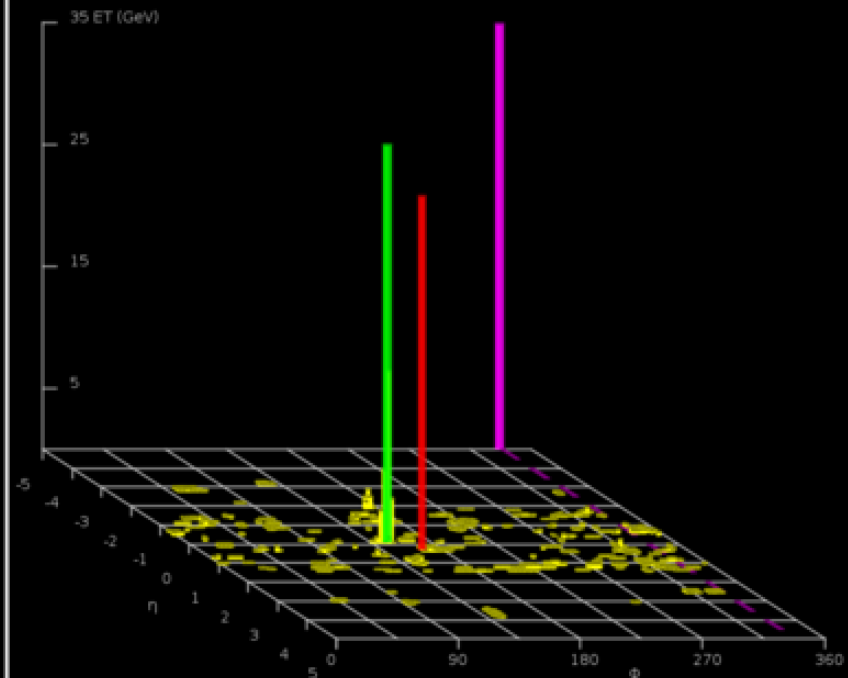
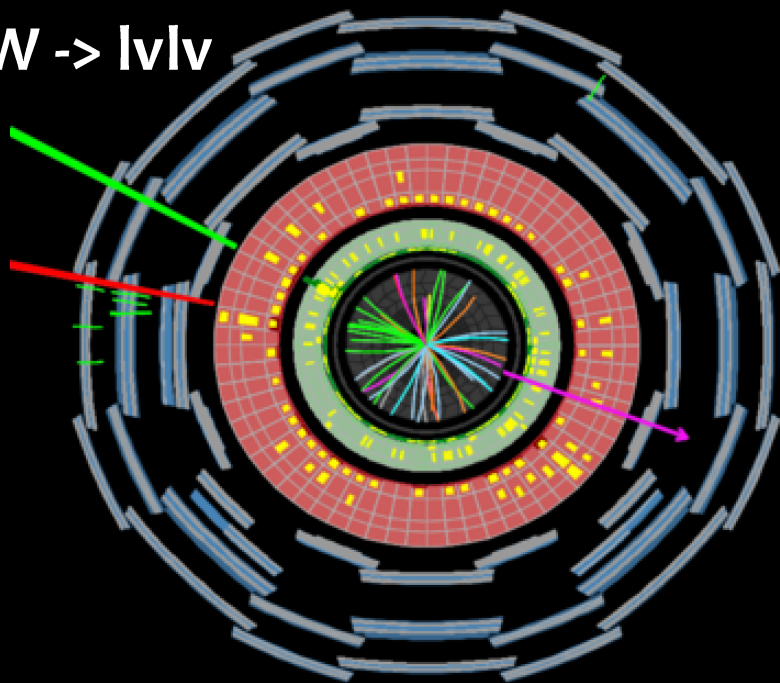
Run 1 (ATLAS+CMS,
 “all” decays,
 $m_H = 125.09$ GeV)



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Results compatible with SM expectations

$H \rightarrow WW \rightarrow l\nu l\nu$



New!

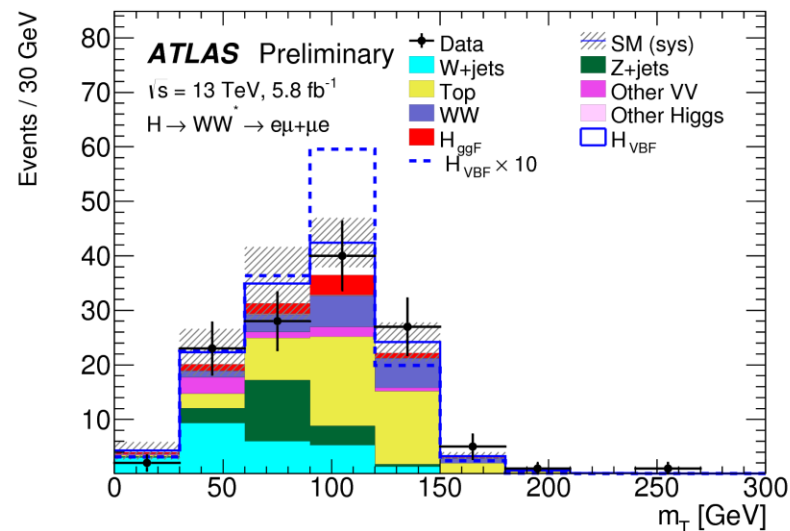
High BF, ~large backgrounds, final state not fully reconstructable
 -> very challenging analysis, performed here in VBF and WH channels

Signal extraction

- fit to signal and control region yields (BDT shape for VBF)
- assume $m_H = 125$ GeV

Main backgrounds

- top quarks (suppressed by b-jet veto),
 WW, Z → ττ, W+jets, ggF Higgs
- Estimated through control regions





VBF

- Select e/μ pair + 2 jets
- Central jet-, third and outside lepton veto
- 2 signal regions based on BDT score

$$\mu(\text{VBF}) = 1.7 \pm 0.8 \text{ (stat)} + 0.6 \pm 0.4 \text{ (sys)}$$

Run 1 (H → WW, m_H = 125.36 GeV):

$$\mu(\text{VBF}) = 1.27 \pm 0.44 \pm 0.40 \text{ (stat)} + 0.30 \pm 0.21 \text{ (sys)}$$

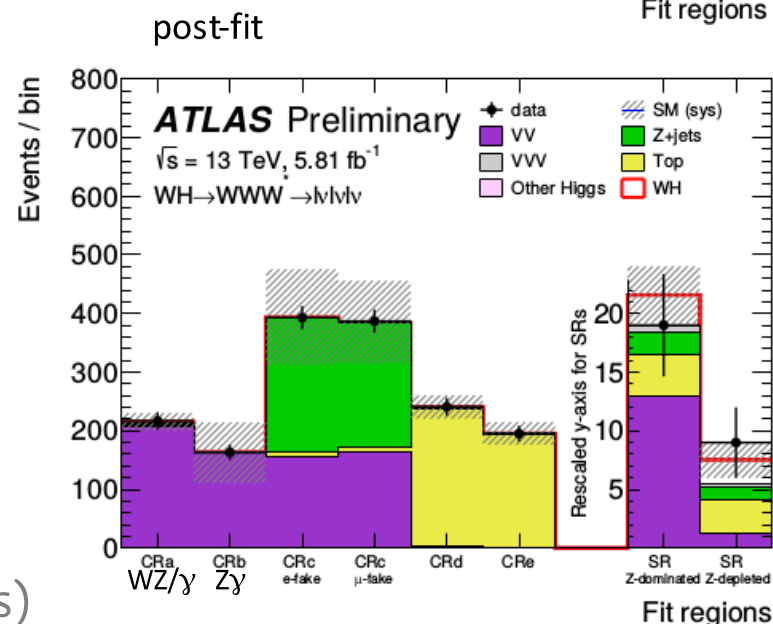
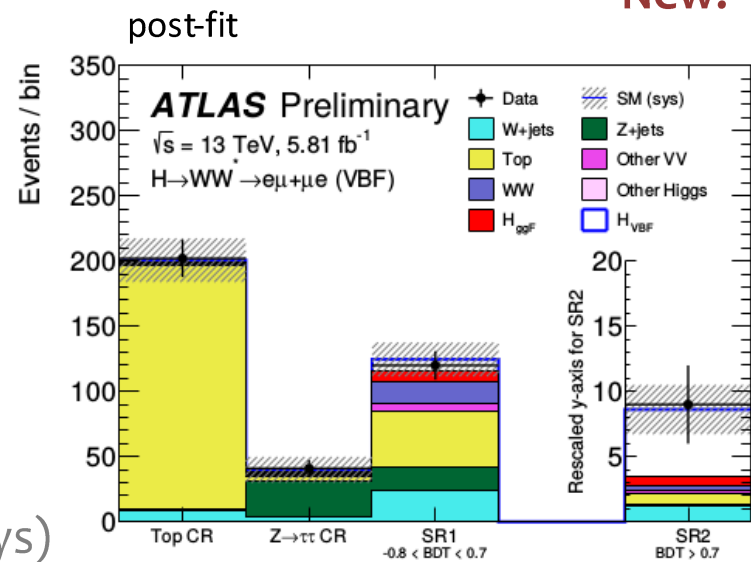
WH

- 3 leptons, q_{tot} = ±1, MET
- W+jets background negligible
- 2 signal regions

$$\mu(\text{WH}) = 3.2 \pm 3.7 \pm 3.2 \text{ (stat)} + 2.3 \pm 2.7 \text{ (sys)}$$

$$\text{Run 1: } \mu(\text{VH}) = 2.1 \pm 1.5 \pm 1.3 \text{ (stat)} + 1.2 \pm 0.8 \text{ (sys)}$$

New!



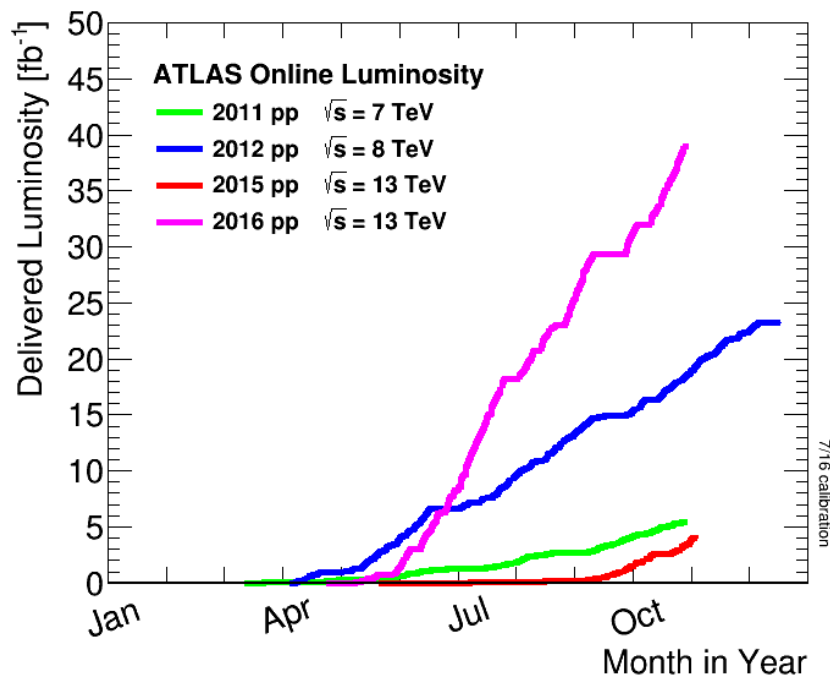


Rediscovered the Higgs boson in $\sqrt{s} = 13$ TeV collisions

- performed property measurements
- So far confirm the SM, no significant deviation
- But: many measurements still statistics limited

2016: collected data set at 13 TeV $\sim 38 \text{ fb}^{-1}$ (compared to $\sim 25 \text{ fb}^{-1}$ in Run 1)

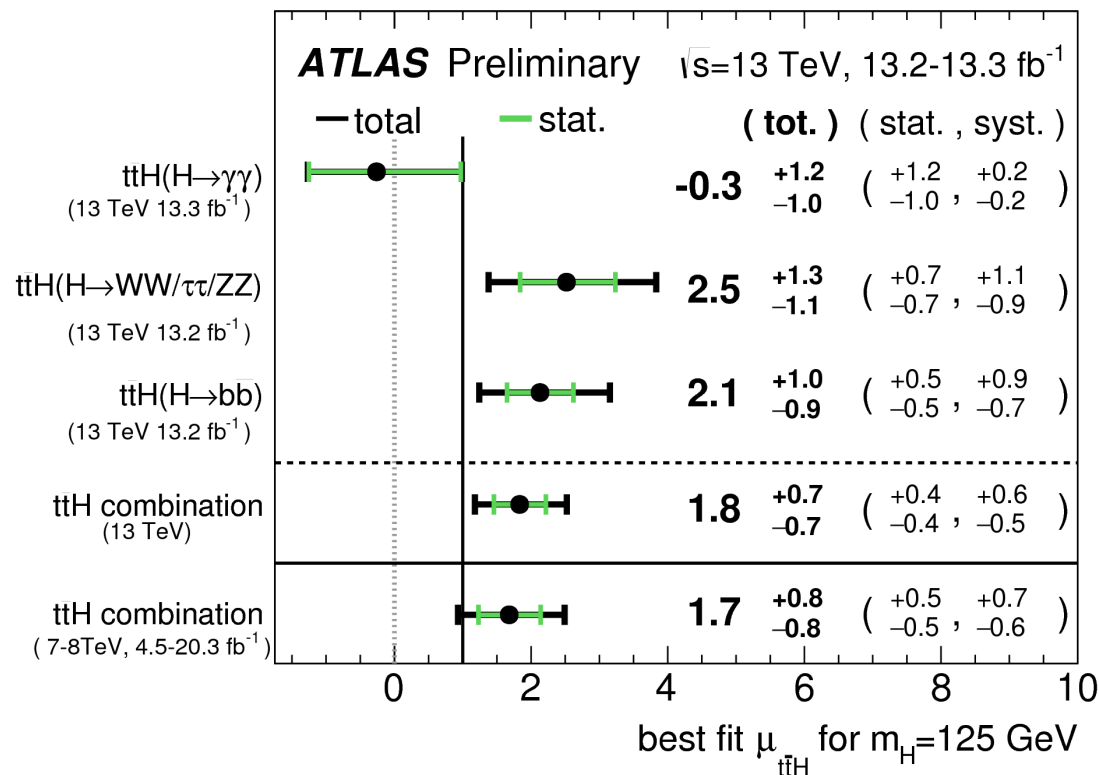
- the best is yet to come!







- combination of different Higgs decay channels
- including leptonic and hadronic top decays

2.8 σ (1.8 σ expected)1.5 σ expected

Large BF, large backgrounds → not doable in ggF → use VH (and VBF)

- Categorization into lepton and jet multiplicities
- BDT in each signal region
- $m_H = 125$ GeV

Main backgrounds: ttbar, V+heavy flavor pairs

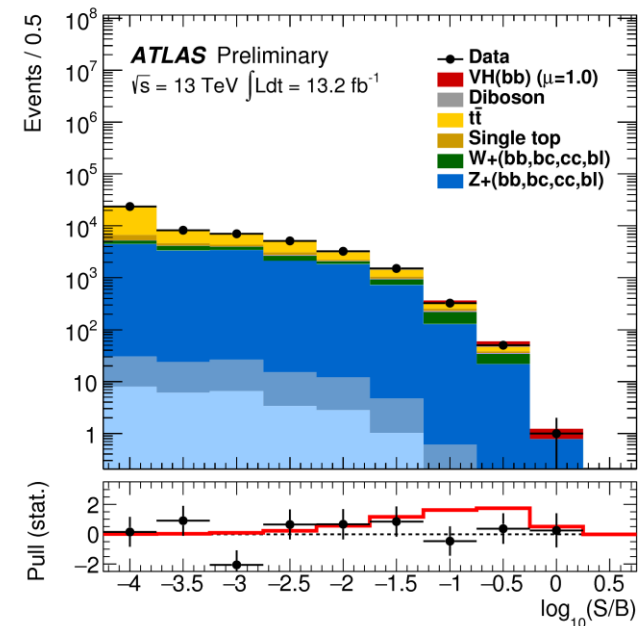
Result:

$$\mu(\text{VH}) = 0.21 + 0.36 / -0.35 \text{ (stat)} \pm 0.36 \text{ (sys)}$$

(observed significance: 0.42, expected: 1.94)

Run 1 (H → bb only, $m_H = 125.36$ GeV)

$$\mu(\text{VH}) = 0.52 \pm 0.32 \text{ (stat)} \pm 0.24 \text{ (sys)}$$





VBF

WH

Source	$\Delta\mu_{\text{VBF}}/\mu_{\text{VBF}} [\%]$
Statistical	+60 / -50
Fake factor, sample composition	+18 / -15
MC statistical	± 15
VBF generator	+14 / -5
WW generator	+11 / -7
QCD scale for ggF signal for $N_{\text{jet}} \geq 3$	+8 / -7
Jet energy resolution	+8 / -7
<i>b</i> -tagging	+8 / -6
Pile-up	+8 / -6
QCD scale for ggF signal for $N_{\text{jet}} \geq 2$	± 6
JES flavour composition	+6 / -4
WW renormalisation scale	± 5
Total systematic	+33 / -26
Total uncertainty	+70 / -50

Source	$\Delta\mu_{WH}/\mu_{WH} [\%]$
Statistical	+120 / -100
MC statistical	+60 / -70
Pile-up	+22 / -26
Jet energy resolution	+22 / -23
Top-quark generator	+17 / -20
<i>b</i> -tagging	+10 / -11
Top-quark PS/UE	+7 / -8
JES flavour comp.	+8 / -5
JES η intercalibration	+7 / -6
<i>WZ</i> / <i>W</i> γ^* generator	+7 / -6
Top-quark QCD scales	+6 / -7
<i>WZ</i> / <i>W</i> γ^* resum. scale	± 5
Total systematic	+70 / -80
Total uncertainty	+140 / -130

Higgs

Backgrounds

Mode	MC generator	$\sigma \cdot \mathcal{B}$ (pb)
ggF	POWHEG [13,14,15]+PYTHIA 8 [19]	$10.38^{+0.58}_{-0.77}$
VBF	POWHEG +PYTHIA 8	0.808 ± 0.021
WH	POWHEG +PYTHIA 8 (MiNLO [25])	0.293 ± 0.007
ZH	POWHEG +PYTHIA 8 (MiNLO)	$0.189^{+0.008}_{-0.007}$

Background	MC generator
$q\bar{q}/g \rightarrow llll, l\nu ll, l\nu l\nu$	SHERPA [16]
$gg \rightarrow llll, l\nu l\nu$	SHERPA
EW $llll, l\nu ll, l\nu l\nu$	SHERPA
$q\bar{q}/g \rightarrow WW, Z^{(*)}Z^{(*)} \rightarrow l\nu l\nu$	POWHEG +PYTHIA 8
$t\bar{t}, tW$	POWHEG +PYTHIA 6 [38]
$t\bar{t}W/Z, tZ$	MADGRAPH 5 [17]
$W\gamma, Z\gamma$	SHERPA
Z +jets	MADGRAPH 5
VBF $q\bar{q} \rightarrow (Z \rightarrow \tau\tau)q\bar{q}$	SHERPA
WWW, WWZ, ZZW, ZZZ	SHERPA

Variables used in the $H \rightarrow WW$ VBF BDT analysis

- properties of the $H \rightarrow WW^*$ decay: $\Delta\phi(l\bar{l})$, $m(l\bar{l})$, m_T
- properties of the VBF signature: Δy_{jj} , m_{jj} , $p_{T\text{tot}}$, $\text{Sum}(l, j) m_{lj}$, and $\eta(l, \text{centrality})$

