ATLAS SM HIGGS COMBINATION

Gen Steele, on behalf of the ATLAS collaboration. Higgs Hunting 2012.

Outline

- Statistical procedure used in separate channels and combined search
- Status of the search, pre July 4th
- Input channels, including updates
- Results

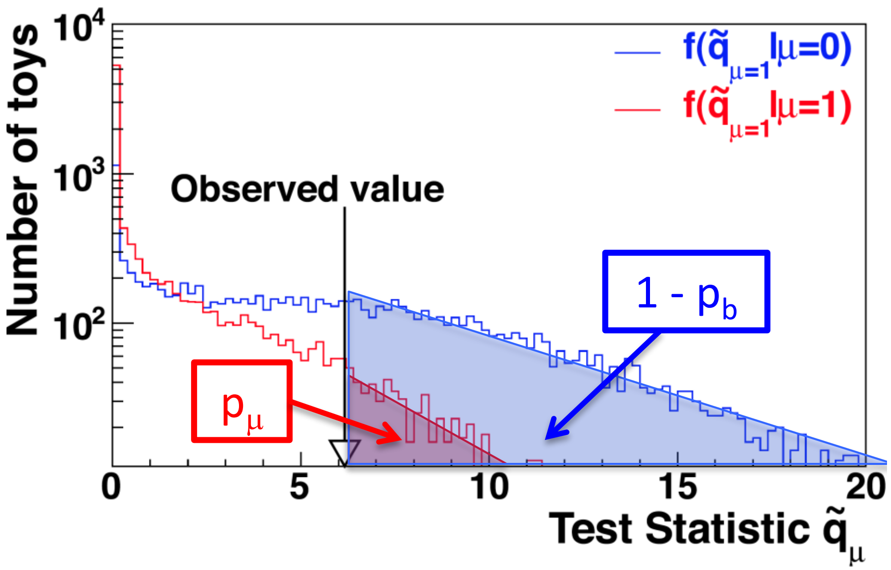
Statistics tools and techniques I

Based on the profile likelihood ratio, the test statistic used is:

$$\tilde{q}_\mu = -2\ln\frac{\mathcal{L}(\text{data}\mid\mu,\hat{\hat{\theta}}_\mu)}{\mathcal{L}(\text{data}\mid\hat{\mu},\hat{\theta})}$$

θ : all the nuisance parameters
μ : signal strength
$\hat{\mu},\hat{\theta}$: estimators for unconditional likelihood max.
$\hat{\hat{\theta}}_\mu$: max. likelihood estimator for given μ

with condition: $0 \le \hat{\mu} < \mu$



ATL-PHYS-PUB-2011-11 CMS NOTE-2011/005

95% confidence level on exclusion limits is found by adjusting μ until CLs=0.05

$$CL_s(\mu) = \frac{p_\mu}{1-p_b}$$

CLs is used to test the signal hypothesis.
Expected limits (and p0) are estimated using a representative (Asimov) dataset

Statistics tools and techniques II

p_0 tests the background hypothesis – i.e. quantifies the presence of a signal by showing the probability a fluctuation in the background could reproduce the same excess of events.

Using a test statistic defined as;

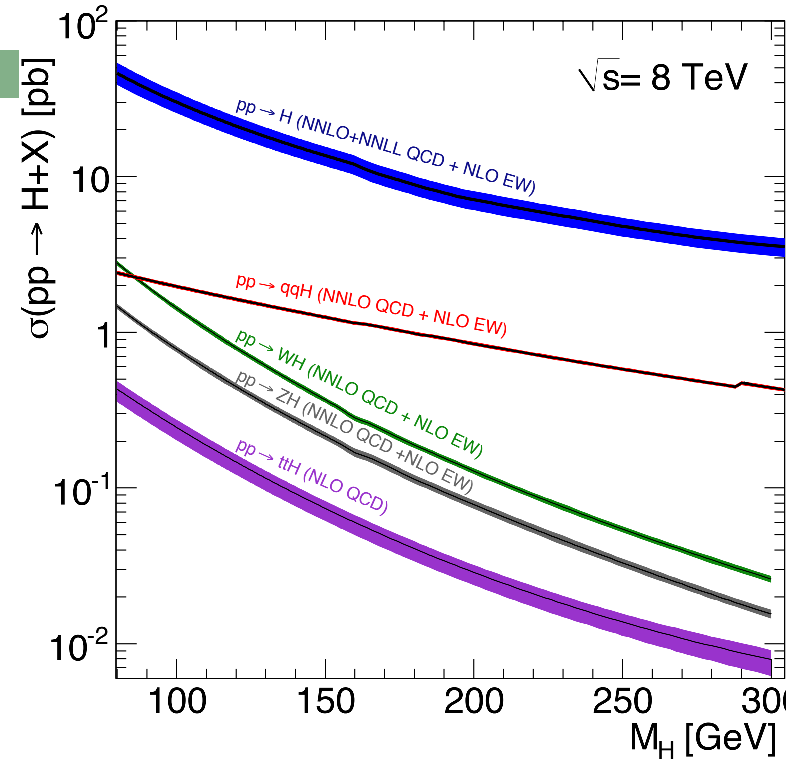
$$q_0 = -2 \ln \frac{\mathcal{L}(\mathrm{data} \mid 0, \hat{\hat{\theta}}_0)}{\mathcal{L}(\mathrm{data} \mid \hat{\mu}, \hat{\theta})}$$

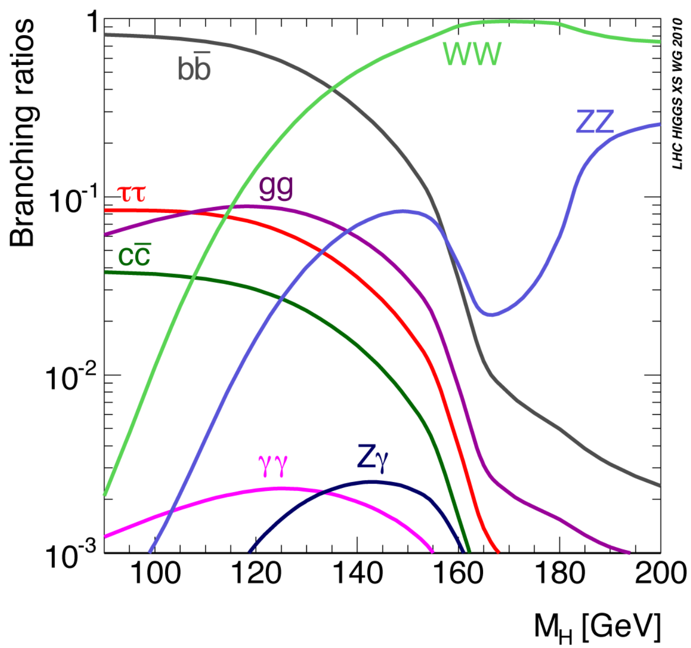
Calculate the p-value for the background-only hypothesis, $p_{0.}$
(Calculated for every mass point, => considered as a 'local' p-value.)

$\hat{\mu}$ is the best fit value of the signal strength, found by allowing parameters to float and minimising the test statistic. Colloquially $\hat{\mu}$ is known as 'the cyan band plot'.

SM Higgs production and decay modes.

- ATLAS searches for the SM Higgs in multiple channels
- Channels contribute differently over the m_H search region
- Sensitivity is maximised by combining channels

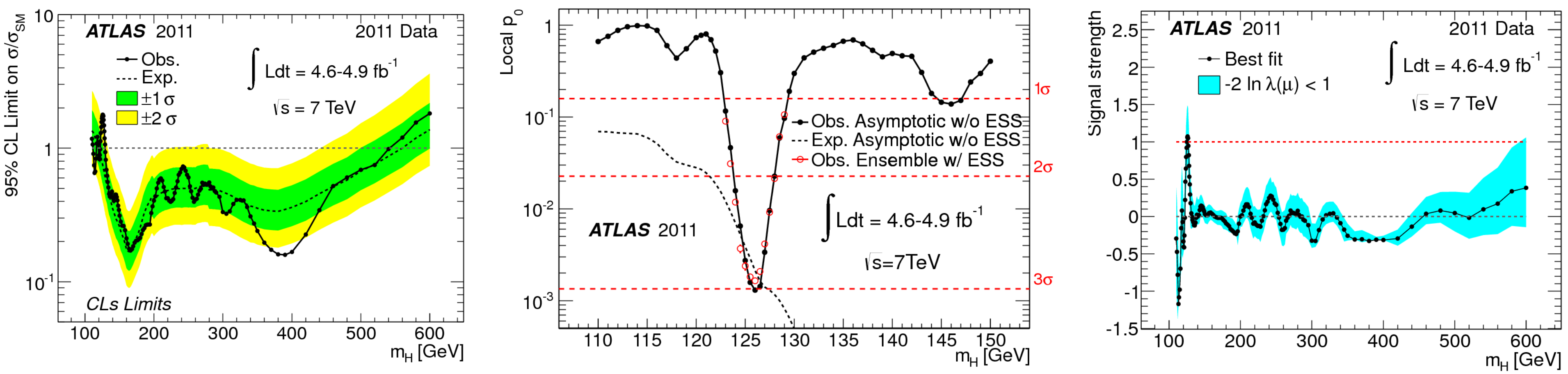




Increased SM Higgs production with 8 TeV data.

Backgrounds increase even more.

ATLAS 2011 data results



Combination of 2011 data representing an integrated luminosity of between 4.6-4.9 fb^{-1} per channel at a centre of mass energy of 7 TeV.

Excluded at 95% confidence level: 110.0 to 117.5, 118.5 to 122.5, and 129 to 539 GeV

Excess of events observed around m_H ~ 126 GeV with a local significance of 2.5σ.

Best fit signal strength shows that the excess is about 1 x SM production cross section.

Plots taken from: arXiv:1207.0319

Input channels used in summer 2012 combination

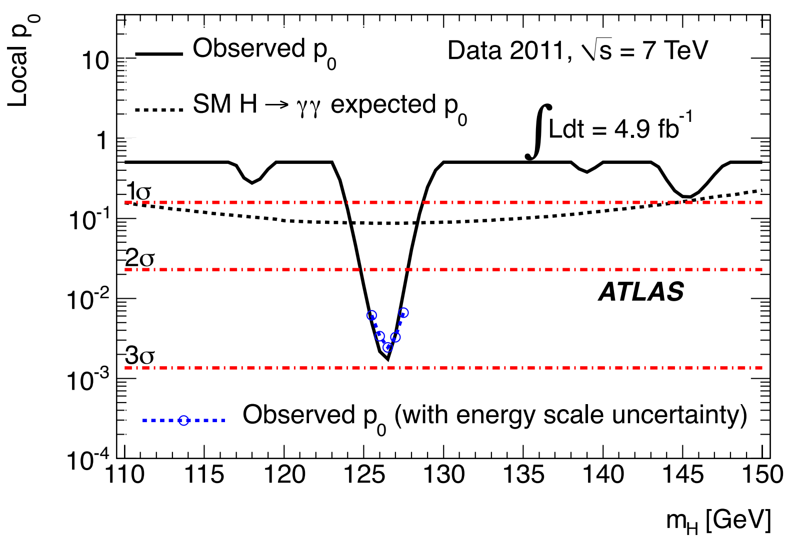
Higgs Decay	Subsequent Decay	Sub-Channels	m_H Range [GeV]	$\int L\,dt$ [fb^{-1}]
		2011 $\sqrt{s}$ =7 TeV		
$H \to \gamma\gamma$	–	9 sub-channels $\{p_{T_t} \otimes \eta_\gamma \otimes \text{conversion}\} \oplus \{\text{2-jets}\}$	110–150	4.8
$H \to ZZ^{(*)}$	$\ell\ell\ell'\ell'$	$\{4e, 2e2\mu, 2\mu 2e, 4\mu\}$	110–600	4.8
	$\ell\ell\nu\bar{\nu}$	$\{ee, \mu\mu\} \otimes \{\text{low, high pile-up}\}$	200–280–600	4.7
	$\ell\ell q\bar{q}$	$\{b\text{-tagged, untagged}\}$	200–300–600	4.7
$H \to WW^{(*)}$	$\ell\nu\ell\nu$	$\{ee, e\mu, \mu\mu\} \otimes \{\text{0-jets, 1-jet, 2-jets}\} \otimes \{\text{low, high pile-up}\}$	110–200–300–600	4.7
	$\ell\nu q\bar{q}'$	$\{e, \mu\} \otimes \{\text{0-jets, 1-jet, 2-jets}\}$	300–600	4.7
$H \to \tau^+\tau^-$	$\tau_{\text{lep}}\tau_{\text{lep}}$	$\{e\mu\} \otimes \{\text{0-jets}\} \oplus \{\ell\ell\} \otimes \{\text{1-jet, 2-jets}, VH\}$	110–150	4.7
	$\tau_{\text{lep}}\tau_{\text{had}}$	$\{e, \mu\} \otimes \{\text{0-jets}\} \otimes \{E_T^{\text{miss}} < 20\text{ GeV}, E_T^{\text{miss}} \geq 20\text{ GeV}\}$ $\oplus \{e, \mu\} \otimes \{\text{1-jet}\} \oplus \{\ell\} \otimes \{\text{2-jets}\}$	110–150	4.7
	$\tau_{\text{had}}\tau_{\text{had}}$	$\{\text{1-jet}\}$	110–150	4.7
$VH \to b\bar{b}$	$Z \to \nu\bar{\nu}$	$E_T^{\text{miss}} \in \{120 - 160, 160 - 200, \geq 200\text{ GeV}\}$	110-130	4.6
	$W \to \ell\nu$	$p_T^W \in \{< 50, 50 - 100, 100 - 200, \geq 200\text{ GeV}\}$	110-130	4.7
	$Z \to \ell\ell$	$p_T^Z \in \{< 50, 50 - 100, 100 - 200, \geq 200\text{ GeV}\}$	110-130	4.7
		2012 $\sqrt{s}$ =8 TeV		
$H \to \gamma\gamma$	–	9 sub-channels $\{p_{T_t} \otimes \eta_\gamma \otimes \text{conversion}\} \oplus \{\text{2-jets}\}$	110–150	5.9
$H \to ZZ^{(*)}$	$\ell\ell\ell'\ell'$	$\{4e, 2e2\mu, 2\mu 2e, 4\mu\}$	110–600	5.8

85 sub-channels in total go into this combination.

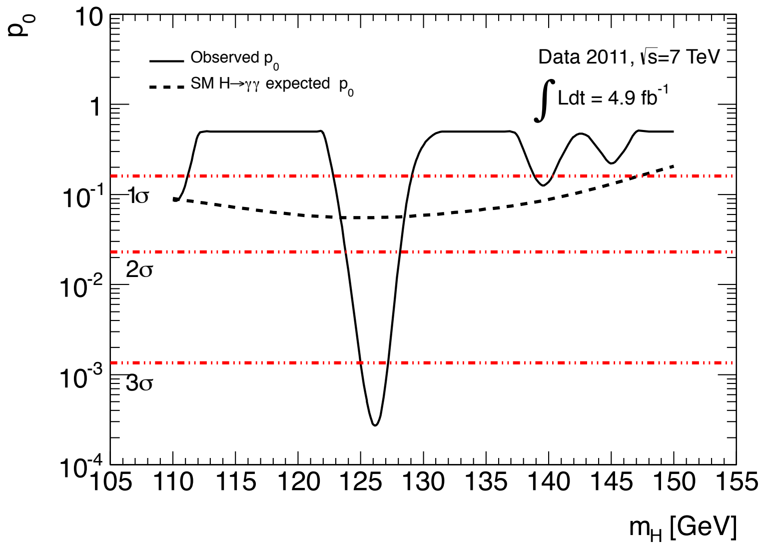
Additions and updates: H→γγ

- In 2011 data, photon identification based on NN combination of calorimeter shower shape variables.
- 2012 data photon identification uses re-optimized cuts.
- In both 2011 and 2012 analyses a 10th sub-channel has been added : 'VBF' which requires 2 jets well separated in pseudo-rapidity

January paper

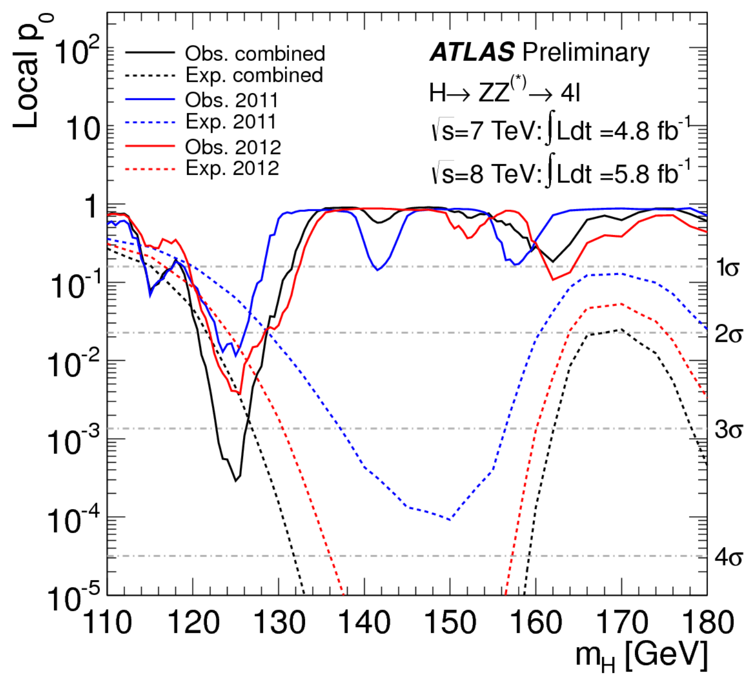


Summer update



Additions and updates: H→ZZ→ $\ell^+\ell^-\ell^+\ell^-$

- Improved electron reconstruction and identification.
- Kinematic selections optimized for a low mass Higgs
- Z mass constraint introduced to improve resolution.
  - Low mass events: Z required to be in 50-106 GeV window.
  - Higher mass events: both lepton pairs to pass this constraint.
  - Constraint leads to improvement in mass resolution of the order 10%

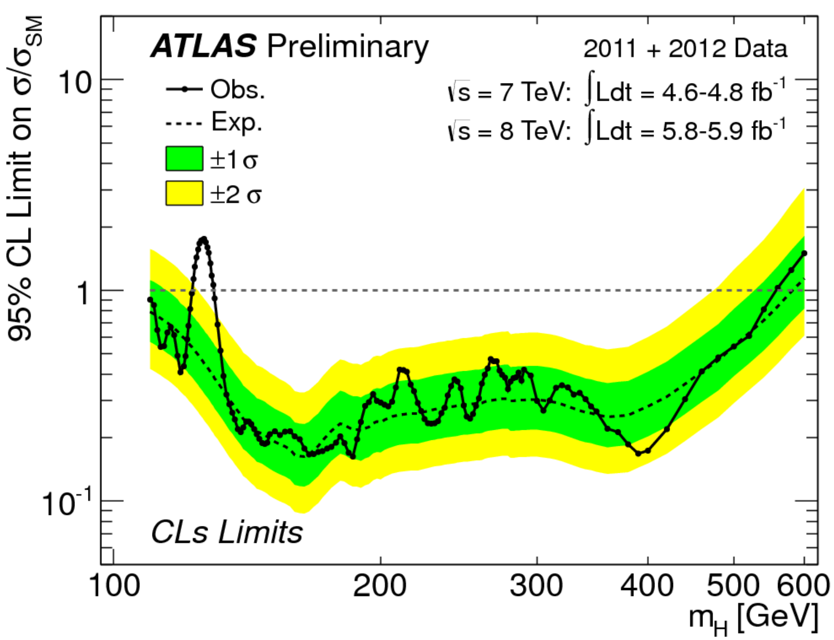


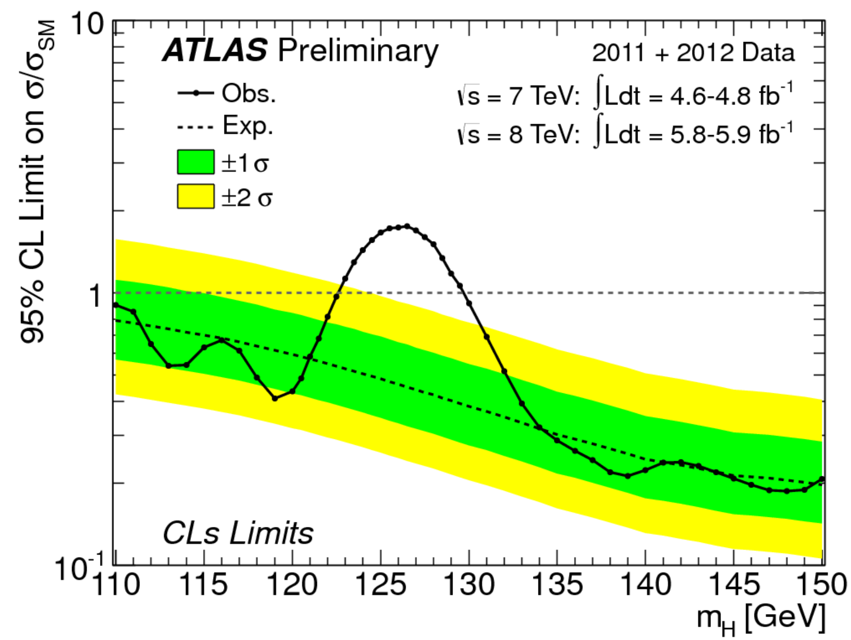
Systematic Uncertainties

- The same systematic uncertainty may affect more than one channel - correlated effects.
- Correlated systematics from:
  - Theoretical predictions e.g. production cross-sections
  - Luminosity
  - Detector uncertainty e.g. jet energy scale, b-tagging
- Analyses with 2012 and 2011 data:
  - In $\gamma\gamma$ channel all systematics are considered 100% correlated between years except luminosity
  - In *llll* channel all except luminosity and data-driven background normalizations are 100% correlated between years

Combination results - CLs.

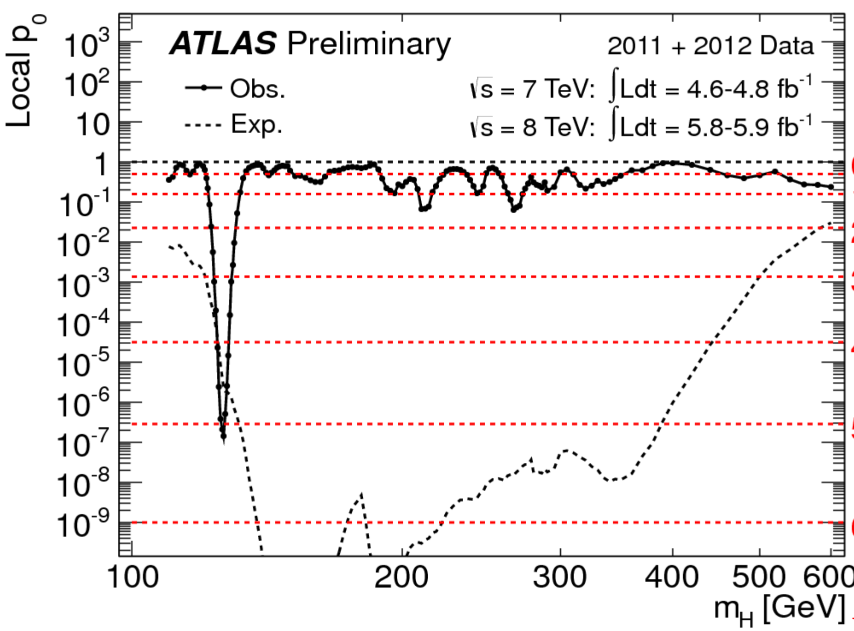
Expected exclusion: 110-582 GeV (calculated for background only hypothesis)
Observed exclusion: 110-122.6 & 129.7-558 GeV

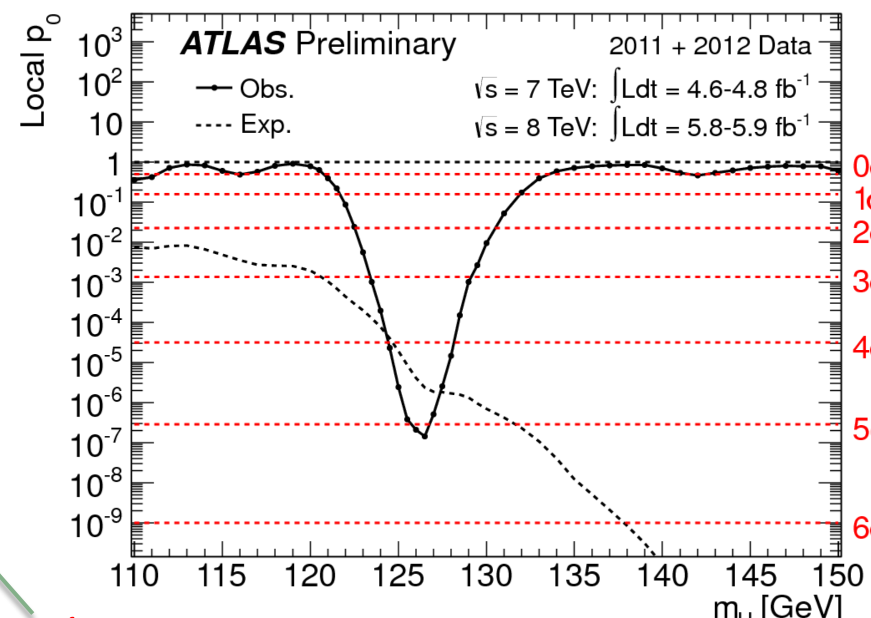




Combination results -p_0

- Maximum local significance (including energy scale systematics) = 5.0σ.
- Maximum local significance at m_H = 126.5 GeV
- Expected local significance here is 4.6σ (expected is calculated for signal +background hypothesis)
- Away from excess excellent agreement between data and background-only hypothesis

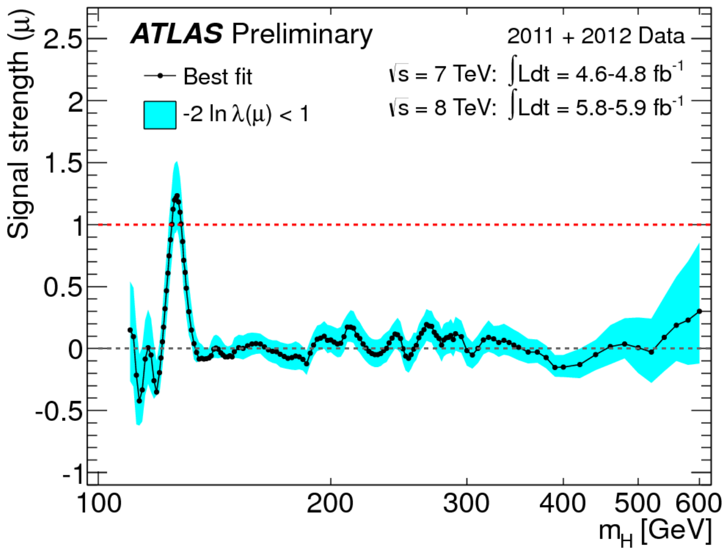


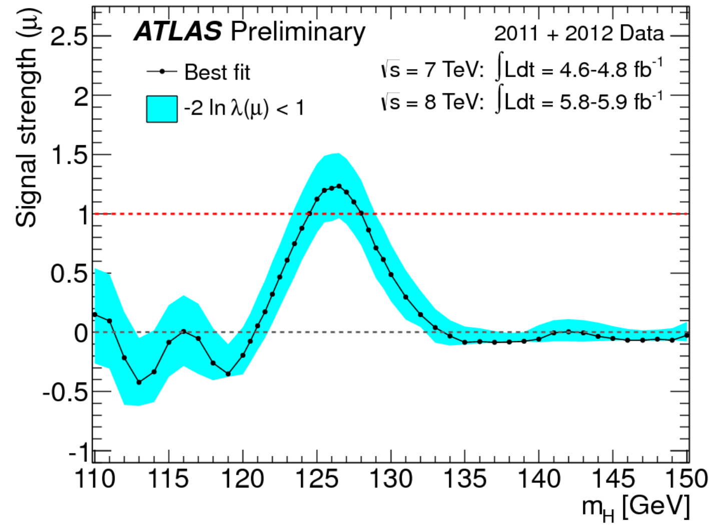


Local significance

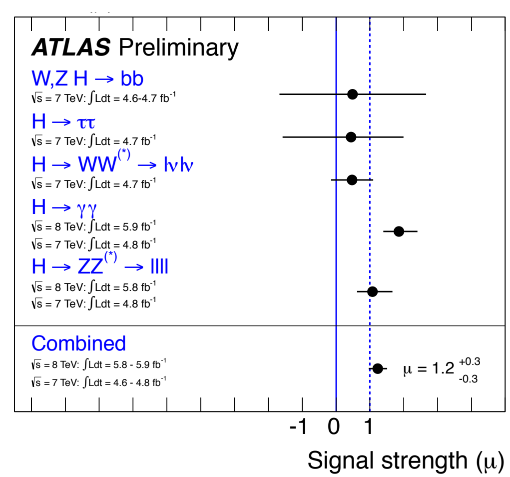
Combination results - $\hat{\mu}$

Best fit of the signal strength at $m_H = 126.5$ GeV: $\hat{\mu} = 1.2 \pm 0.3$

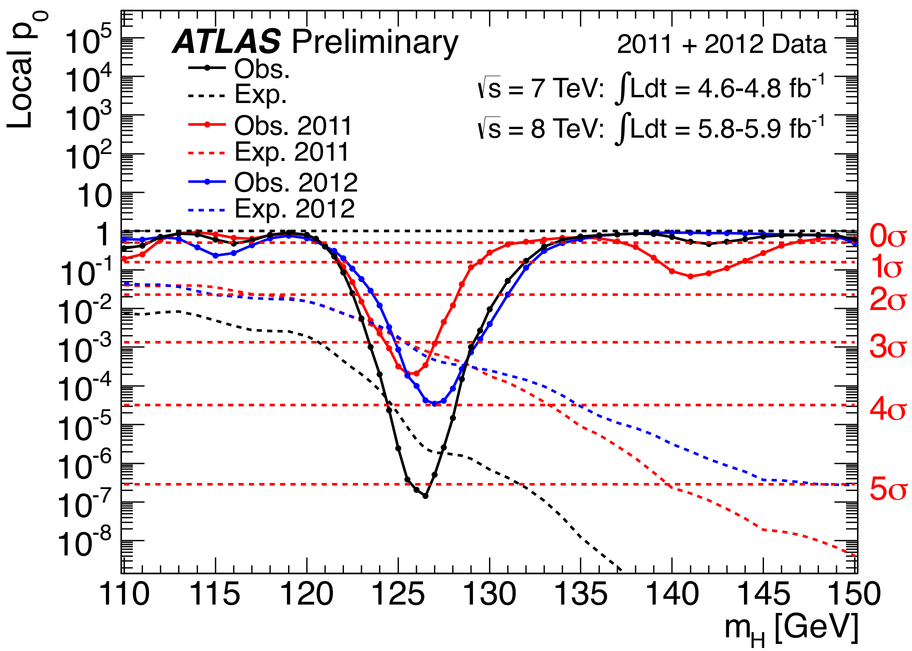


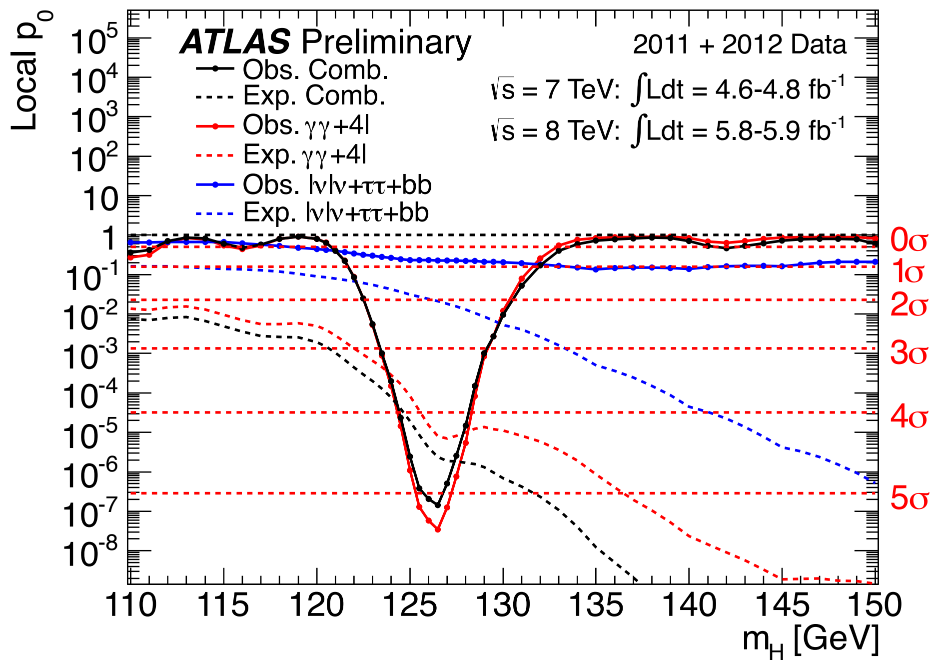


The best fit signal strength is slightly higher in H->γγ and H->ZZ->*llll* than in other channels but still consistent with the SM.



Combination results - by year/channel





- Similar expected significances

- High resolution channels drive sensitivity
- Other channels still important to investigate the nature of the signal

Combination results - contours

- Contours can be used to check the consistency of the global picture
- The test statistic is based on a 2D profile likelihood ratio, shown as a function of μ and m_H.

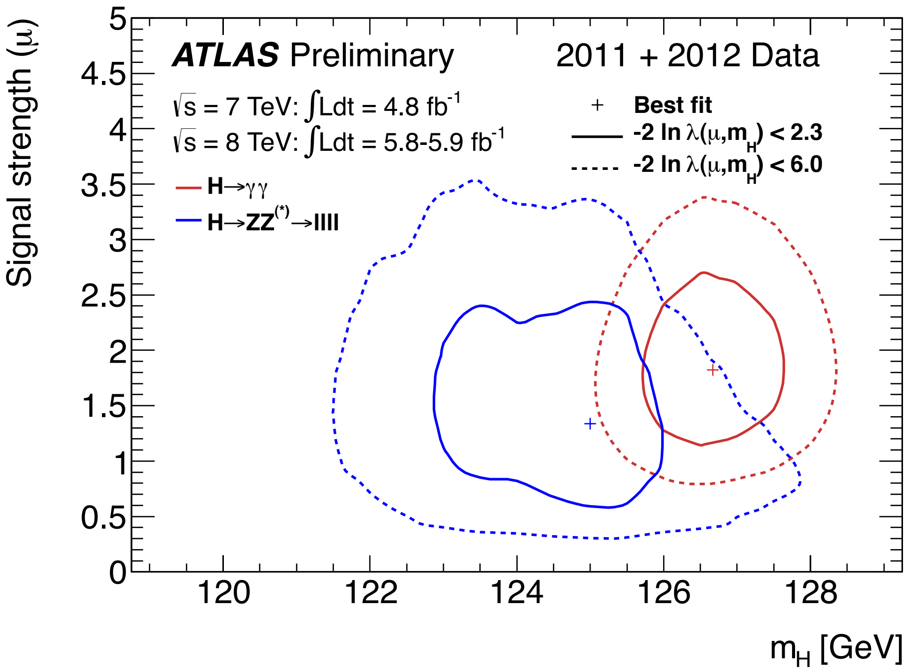
$$\lambda(\mu, m_H) = \frac{L(\mu, m_H, \hat{\hat{\theta}}(\mu, m_H))}{L(\hat{\mu}, \hat{m}_H, \hat{\theta})}$$

Without a strong signal, plots would be simply a horizontal line.

Curves show approximate ~68% (solid) and ~95% (dashed) confidence limits.

Cross marks best fit point.

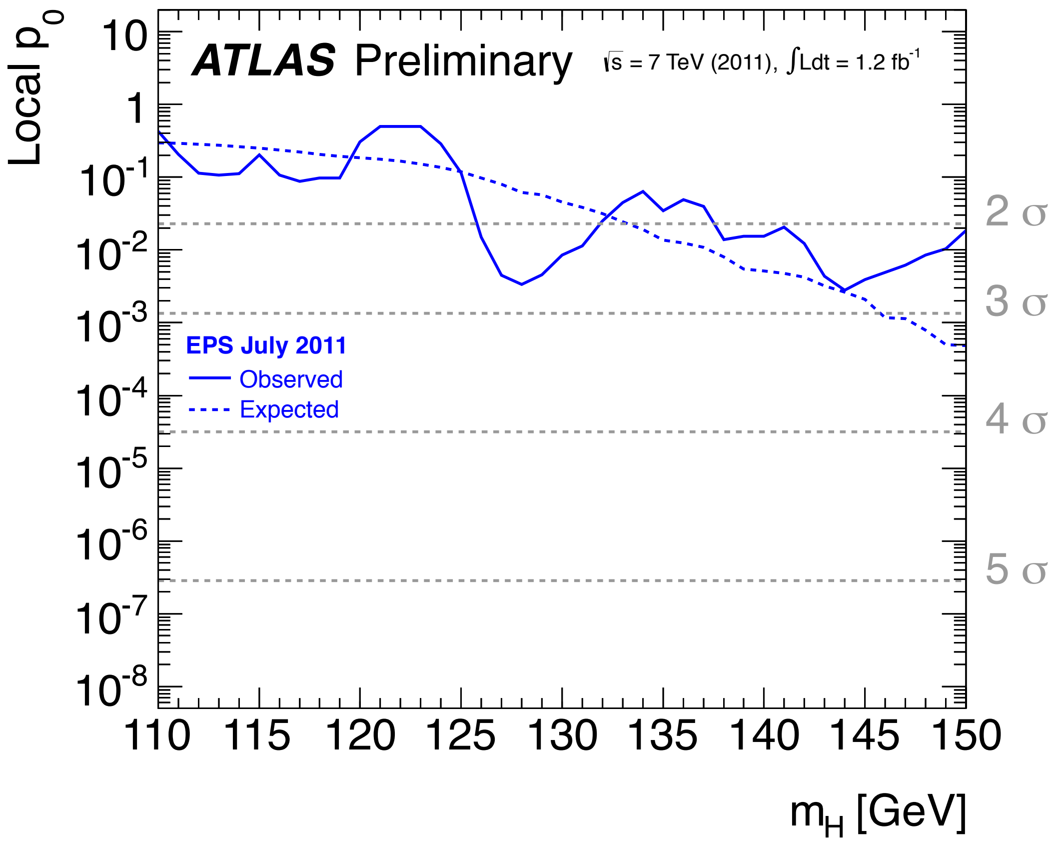
$\mu = 1$ on the y-axis represents the Standard Model.



Conclusions.

- ATLAS has performed a search for the SM Higgs over the mass region 110-600 GeV
- 12 channels total in combination
  - 2 channels: 7 & 8 TeV data, ~10.7 fb^{-1}
  - other channels: 7 TeV data, ~4.9 fb^{-1}
- observed an excess of events near m_H~126.5 GeV with a local significance of 5.0σ
- Fitted signal strength of 1.2±0.3
- More work to come…

Bump evolution



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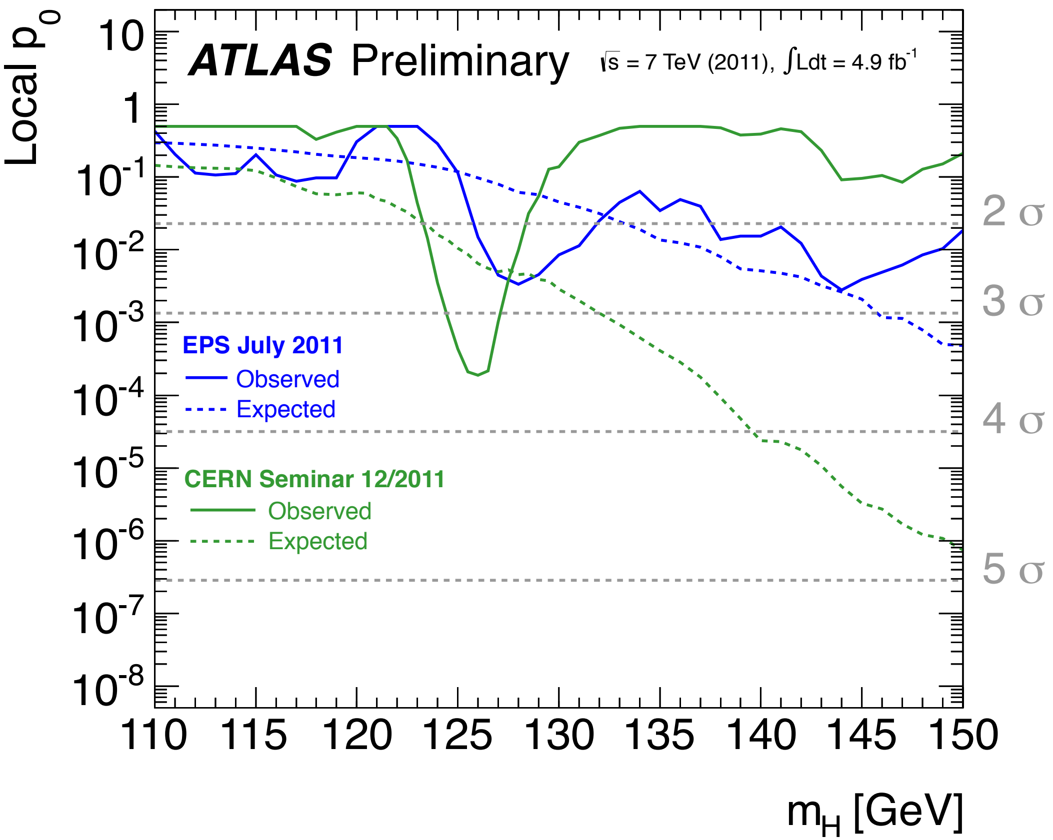

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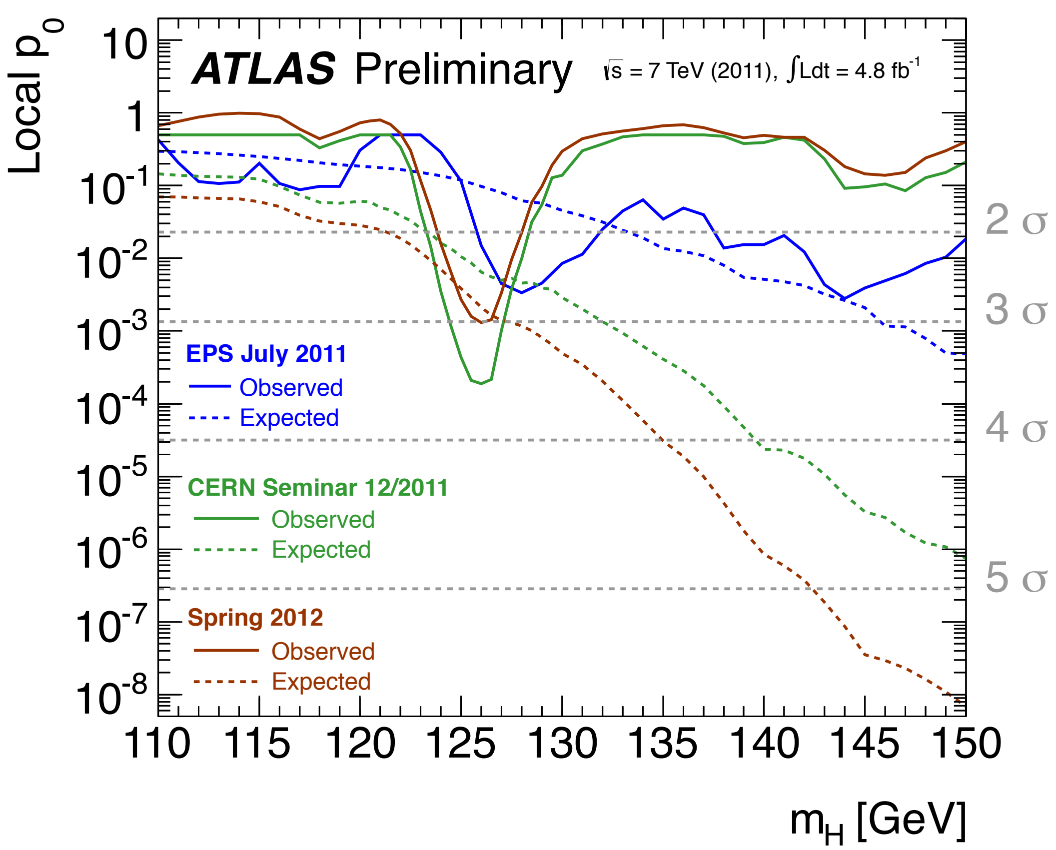

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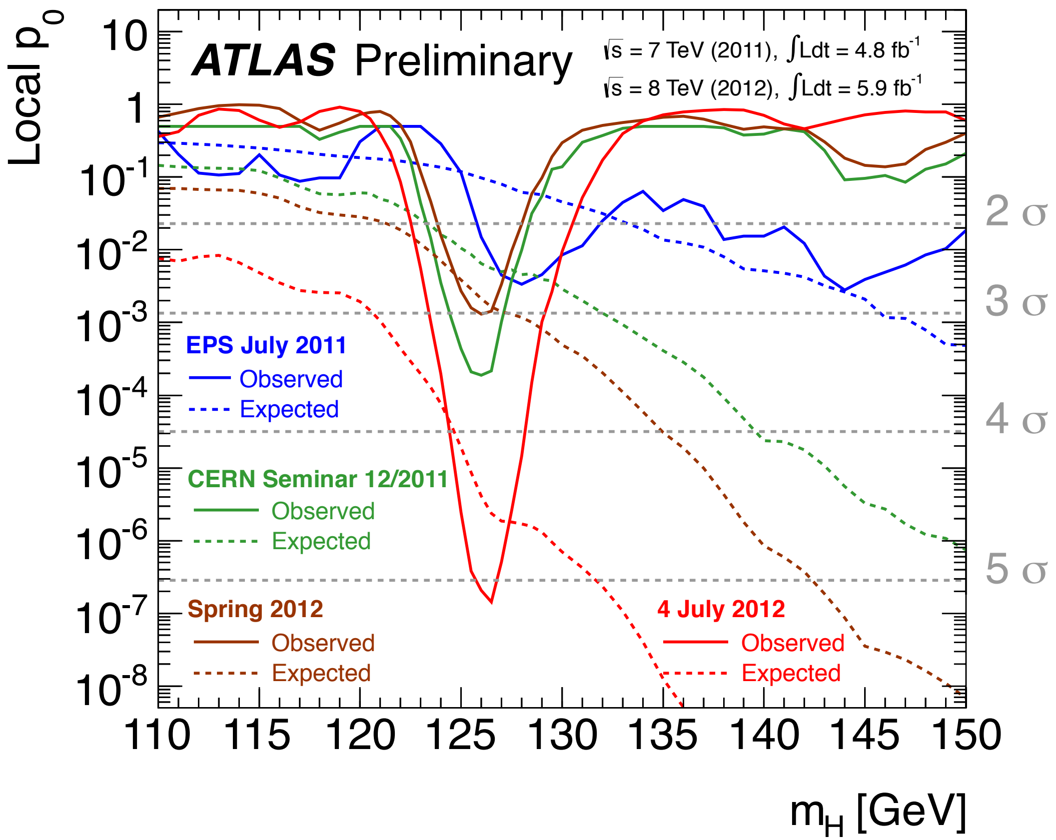

The happy news…

ATLAS and CMS

are pleased to announce the arrival of

a bouncing baby boson!!!

After a gestation period similar to an elephant, the proud parents are delighted by their latest discovery.

The name of the new boson will be confirmed once a bit more is known about baby.

More information on baby boson will come all in good time. Maybe they'll even end up with siblings.

Sample systematics - signal

	$H \to \tau^+\tau^-$		$H \to \gamma\gamma$	$H \to WW^{(*)}$		$H \to ZZ^{(*)}$		
	$\ell\tau_{had}3\nu$	$\tau_\ell\tau_\ell + jet$		$\ell\nu\ell\nu$	$\ell\nu qq$	$\ell\ell\ell\ell$	$\ell\ell\nu\nu$	$\ell\ell qq$
Luminosity	$^{+3.8}_{-3.6}$	$^{+3.8}_{-3.6}$	$^{+4.0}_{-3.8}$	$^{+3.8}_{-3.6}$	$^{+3.8}_{-3.6}$	$^{+3.9}_{-3.8}$	$^{+3.8}_{-3.6}$	$^{+3.8}_{-3.6}$
e/γ eff.	±3.5	±2.0	$^{+13.5}_{-11.9}$	±2.0	±0.9	±2.9	±1.2	±1.2
e/γ E. scale	$^{+1.3}_{-0.1}$	±0.3	-	±0.4	-	-	±0.7	±0.4
e/γ res.	-	$^{+0.2}_{-0.5}$	-	$^{+0.20}_{-0.05}$	-	-	±0.25	±0.1
μ eff.	±1.0	±2.0	-	-	±0.3	±0.16	±0.7	±0.5
μ res. Id.	-	$^{+0.2}_{-0.5}$	-	$^{+0.02}_{-0.04}$	-	-	±1.1	±1.1
μ res. MS.	-	-	-	$^{+0.04}_{+0.08}$	-	-	$^{+1.1}_{-1.0}$	±1.1
Jet/τ/MET E. scale	$^{+18.9}_{-16.4}$	$^{+3.4}_{-10.0}$	-	$^{+4.46}_{-6.47}$	$^{+18.4}_{-15.5}$	-	±1.6	±15.0
JER	-	±2.0	-	$^{+1.8}_{-1.7}$	$^{+9.0}_{-8.2}$	-	$^{+0.3}_{-0.0}$	$^{+4.0}_{-0.0}$
MET	-	$^{+4.4}_{-5.3}$	-	$^{+1.8}_{-1.7}$	-	-	-	-
b-tag eff.	-	-	-	±0.5	-	-	±0.3	±3.7
τ eff.	±9.1	-	-	-	-	-	-	

For a Higgs mass hypothesis of 120 GeV except for H->WW->lvqq, H->ZZ->llvv and H->ZZ->llqq which is for 300 GeV

Sample systematics - background

	$H \to \tau^+\tau^-$		$H \to \gamma\gamma$	$H \to WW^{(*)}$		$H \to ZZ^{(*)}$		
	$\ell\tau_{had}3\nu$	$\tau_\ell\tau_\ell + jet$		$\ell\nu\ell\nu$	$\ell\nu qq$	$\ell\ell\ell\ell$	$\ell\ell\nu\nu$	$\ell\ell qq$
Luminosity	$^{+3.0}_{-2.9}$	$^{+3.8}_{-3.6}$	-	±0.2	-	$^{+3.7}_{-3.6}$	$^{+2.4}_{-2.3}$	$^{+0.3}_{-0.2}$
e/γ eff.	±2.4	$^{+0.5}_{-1.6}$	-	±2.3	±0.8	±1.6	±0.8	±0.1
e/γ E. scale	$^{+0.9}_{-0.3}$	±0.8	-	$^{+0.2}_{-0.1}$	-	-	$^{+1.7}_{-1.6}$	±0.1
e/γ res.	-	$^{+0.3}_{-2.6}$	-	$^{+0.1}_{-0.0}$	-	-	±0.6	±0.2
μ eff.	±1.4	$^{+0.5}_{-1.6}$	-	-	±0.3	±0.1	±0.5	±0.03
μ res. Id.	-	$^{+0.3}_{-2.6}$	-	$^{-0.03}_{-0.06}$	-	-	$^{+1.7}_{-1.6}$	±0.2
μ res. MS.	-	-	-	$^{+0.00}_{-0.02}$	-	-	$^{+1.7}_{-1.6}$	±0.2
Jet/τ/MET E. scale	$^{+10.0}_{-8.9}$	$^{+7.0}_{-9.8}$	-	$^{+8.5}_{-10.4}$	-	-	$^{+6.9}_{-5.2}$	±1.0
JER	-	±2.5	-	$^{+3.3}_{-3.0}$	-	-	$^{+1.8}_{-0.0}$	$^{+0.3}_{-0.0}$
MET	-	$^{+0.4}_{-2.7}$	-	$^{+0.6}_{-0.5}$	-	-	-	-
b-tag eff.	-	-	-	±1.8	-	-	$^{+7.0}_{-5.5}$	±0.2
τ eff.	±7.2	-	-	-	-	-	-	