Observation of a New Particle in the Search for the Standard Model Higgs Boson with the ATLAS Detector at the LHC

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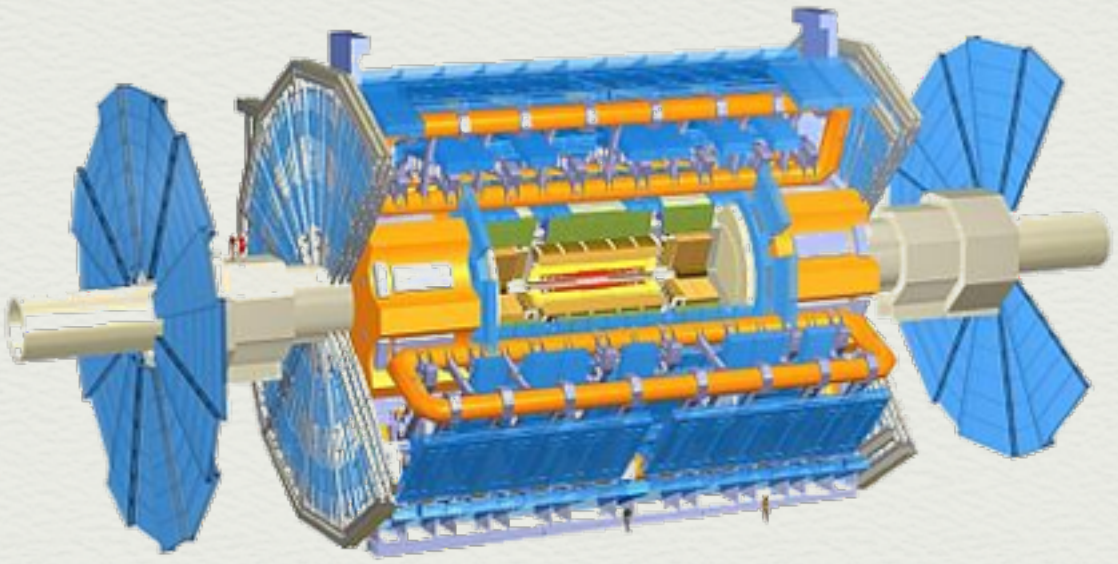
Outline

- Experiment
- Signal and background simulation samples
- Study of Higgs decays channels
  - $H \longrightarrow ZZ^{(*)} \longrightarrow 4l$ channel
  - $H \longrightarrow \gamma\gamma$ channel
  - $H \longrightarrow WW^{(*)} \longrightarrow e\nu\mu\nu$ channel
- Correlated systematic uncertainties
- Statistical procedure
- Results
- Conclusions

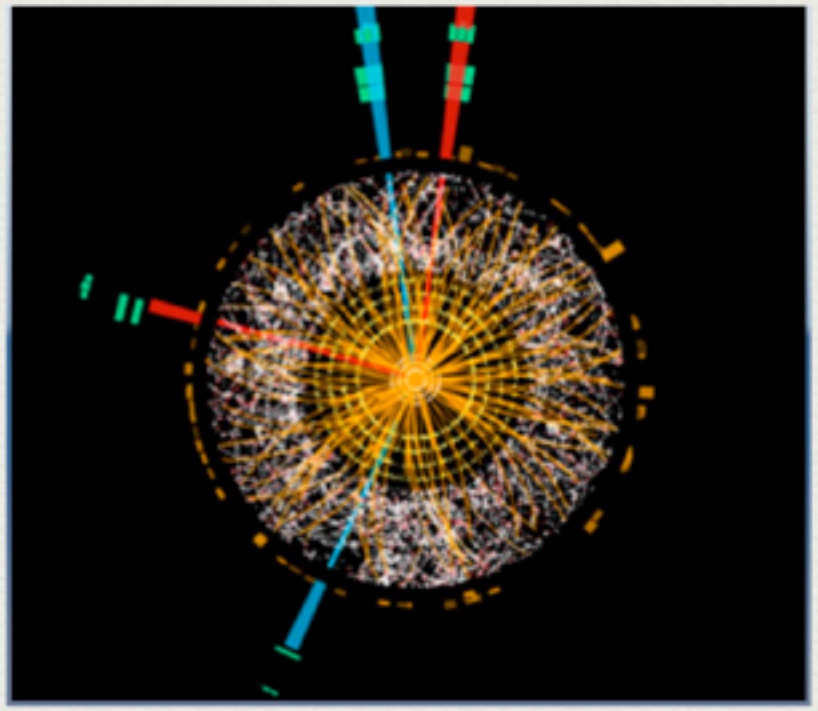
Experiment

LHC - Datasets used correspond to integrated luminosities of approximately 4.8 fb^{-1} collected at $\sqrt{s} = 7$ TeV in 2011 and 5.8 fb^{-1} at $\sqrt{s} = 8$ TeV in 2012



ATLAS - Some cuts in the electromagnetic calorimeter are applied (central barrel $|\eta| < 1.475$, and end-cap regions on either end of the detector $1.375 < |\eta| < 2.5$, for the outer wheel and $2.5 < |\eta| < 3.2$ for the inner wheel) in order to have more efficiency in the analysis

Experiment



Muon Spectrometer:

Magnet system:

Inner Detector:

Calorimeters:

Original data

Reconstruct every event

Data from the ATLAS are recovered to jets, photons ⟶ events

Experiment

The Higgs decays immediately, it is hard to particle detectors cannot detect it directly $\longrightarrow$ indirect detection of its decay

Reconstruct all the decay products as "Background" → Find the data that match the decay channel of Higgs → Get the properties of Higgs

Using simulations

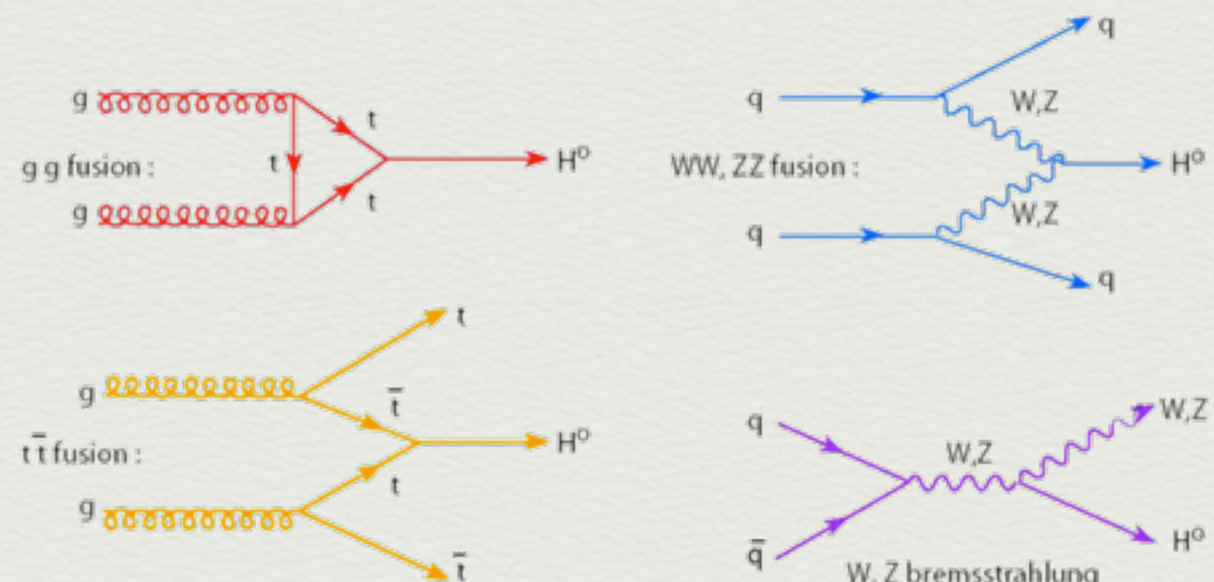
Statistical test if the result is convincing

Then... How to distinguish Higgs Boson?

Signal and background simulation samples

Cross section of production calculated up to:

- **ggF:** next-to-next-to-leading order (NNLO) in QCD , Next-to-leading order (NLO) in EW
- **VBF:** full QCD and EW: NLO and approximate NNLO in QCD
- **WH/ZH:** QCD: NNLO and EW: NLO
- **$t\bar{t}$H:** QCD: NLO



$t\bar{t}$H(small contribution) only in H ⟶ γγ channel

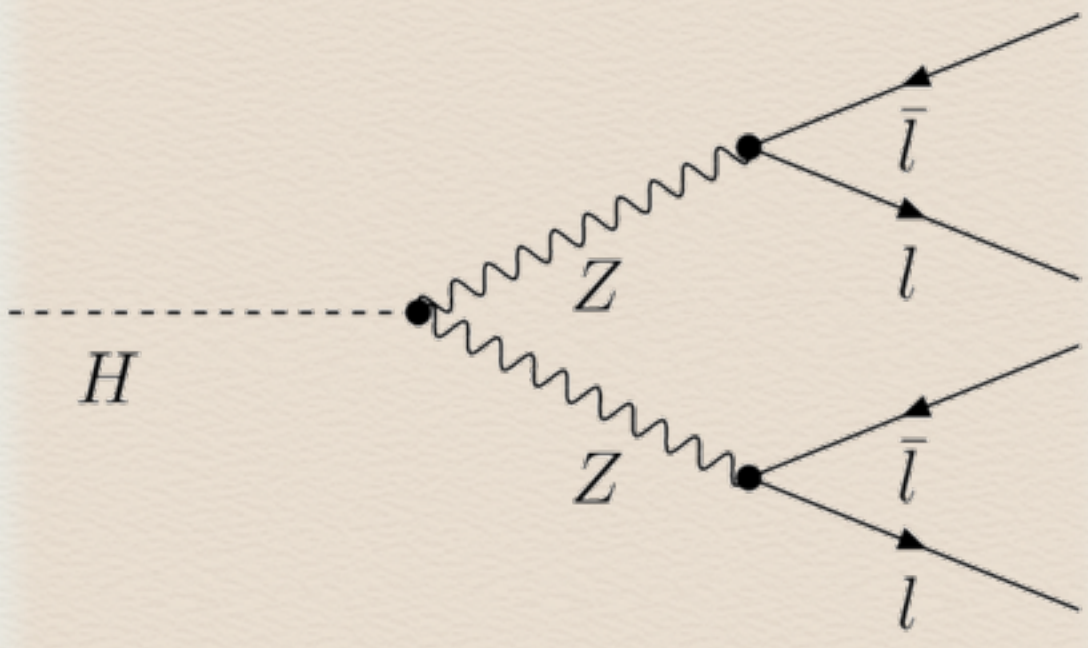
The following are used in simulation:

- The event generators: generated model signal and background processes in samples of Monte Carlo (MC) simulated events
- Parton distribution function (PDF) sets
- Acceptances and efficiencies (full simulations of the ATLAS)

- Total cross section for SM Higgs (m_H=125GeV), calculate 17.5 pb for √s = 7 TeV and 22.3 pb for √s = 8 TeV
- The branching ratios of the SM Higgs boson as a function of m_H , as well as their uncertainties HDECAY and PROPHECY4F program

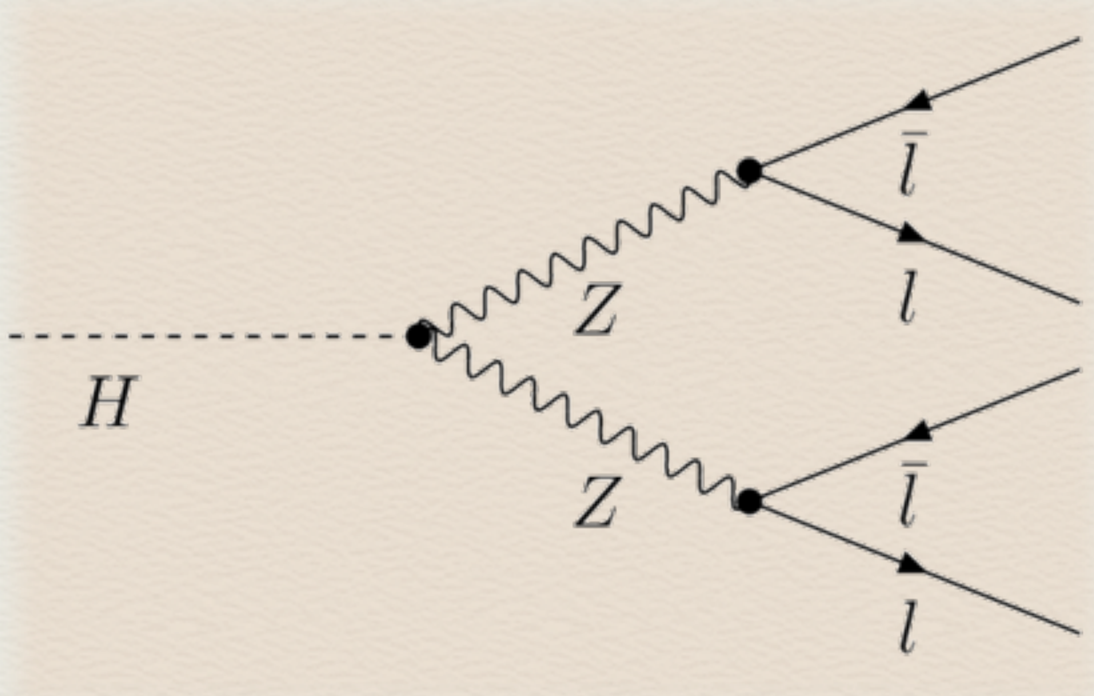
$H \longrightarrow ZZ^{(*)} \longrightarrow 4l$ channel

- This channel provides good sensitivity over 110-600 GeV
- Muons candidates are formed by matching reconstructed *inner tracking detector* (ID) tracks
- Electron candidates must have a well-reconstructed ID track pointing to an electromagnetic calorimeter cluster



$H \longrightarrow ZZ^{(*)} \longrightarrow 4l$ channel

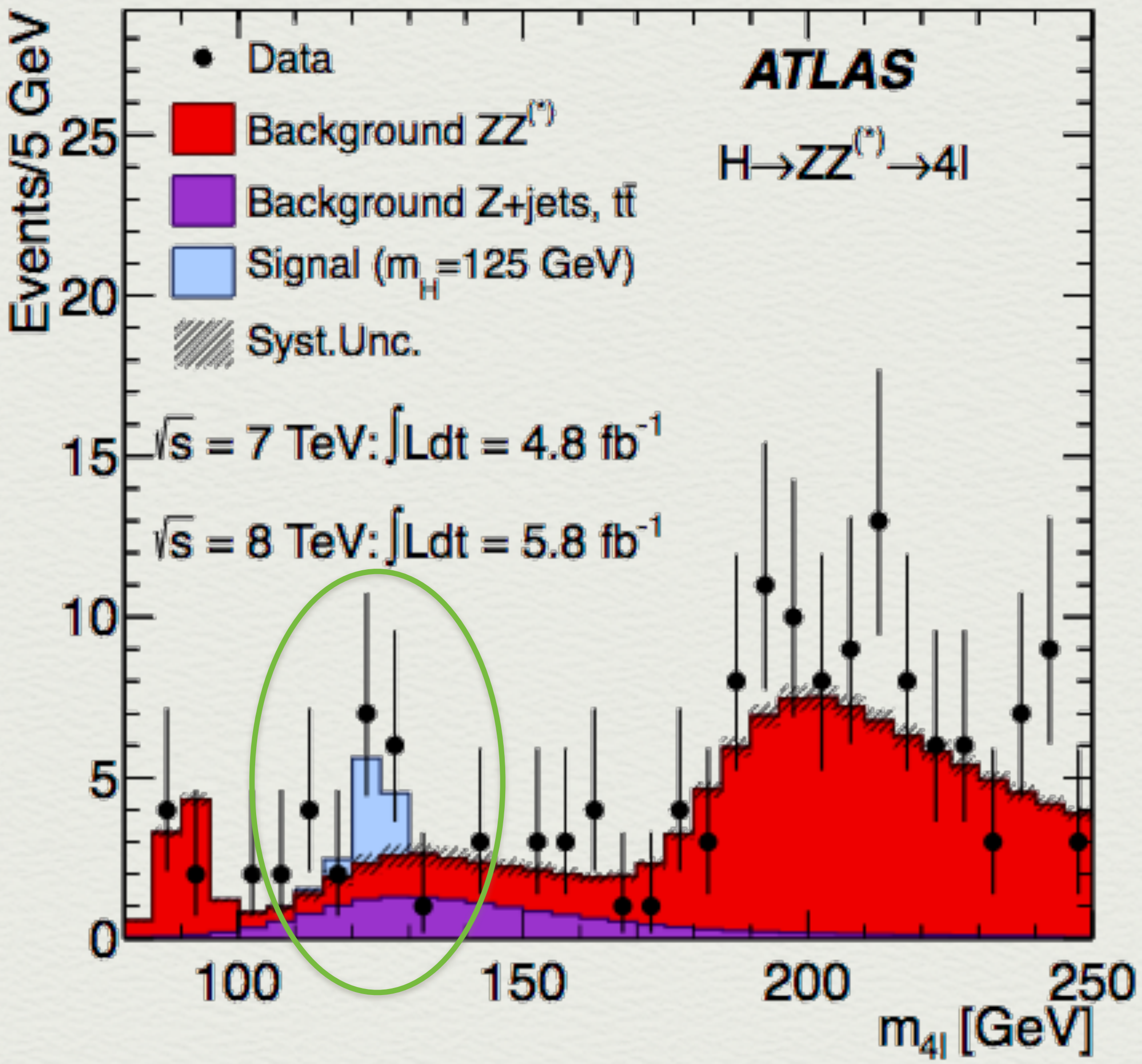
- The main sources of background are Z+jets (mostly $Zb\bar{b}$) and $t\bar{t}$ processes
- Also, there are some uncertainties:
  - On the integrated luminosities 1.8% (3.6%) for the 7 TeV data (for the 8 TeV)
  - On the lepton reconstruction and identification efficiencies
  - On the SM $ZZ^{(*)}$ background the uncertainty on the total yield due to the QCD scale uncertainty is ±5%



$H \longrightarrow ZZ^{(*)} \longrightarrow 4l$ channel

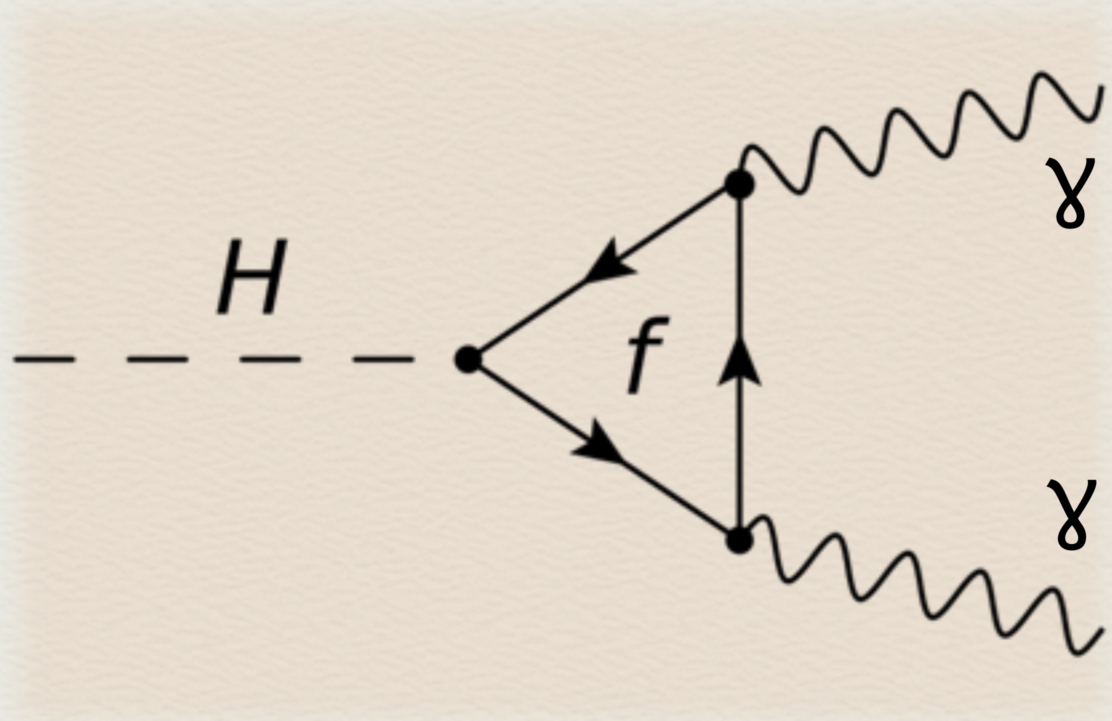
- The number of events near m_{4l} = 125 GeV

	Signal	$ZZ^{(*)}$	Z + jets, $t\bar{t}$	Observed
4μ	2.09 ± 0.30	1.12 ± 0.05	0.13 ± 0.04	6
$2e2\mu$/ $2\mu 2e$	2.29 ± 0.33	0.80 ± 0.05	1.27 ± 0.19	5
$4e$	0.90 ± 0.14	0.44 ± 0.04	1.09 ± 0.20	2



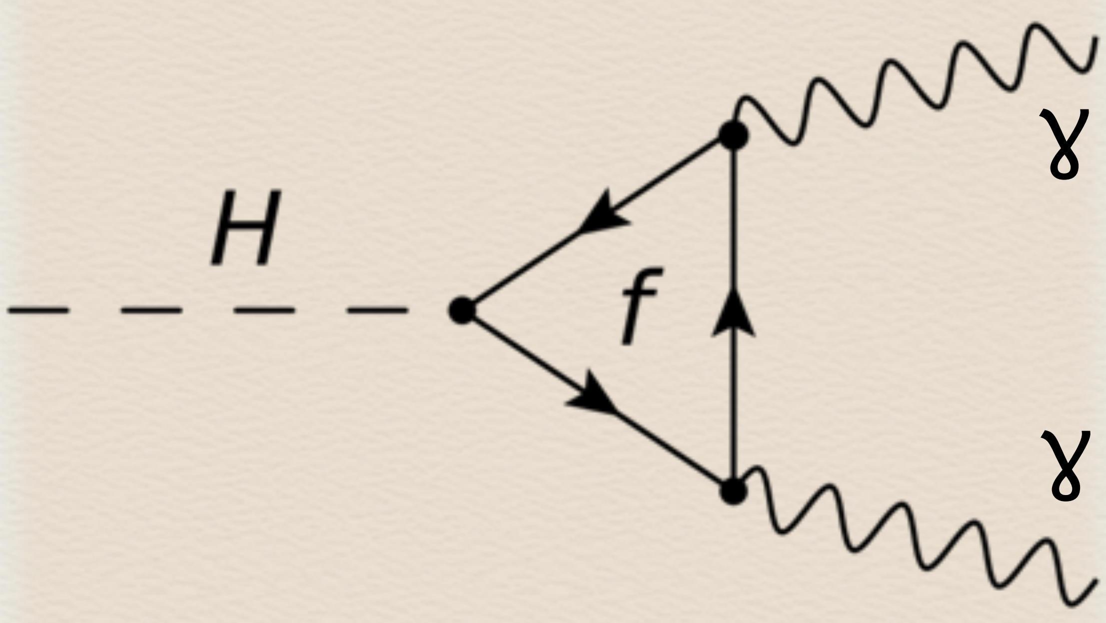
$H \longrightarrow \gamma\gamma$ channel

- This search is performed in the mass range between 110 GeV and 150 GeV
- Data are selected using a diphoton trigger
- Two photons with the highest E_T are taken
- Events are required to contain at least one reconstructed vertex with at least two associated tracks with $p_T > 0.4$ GeV, as well two photons candidates



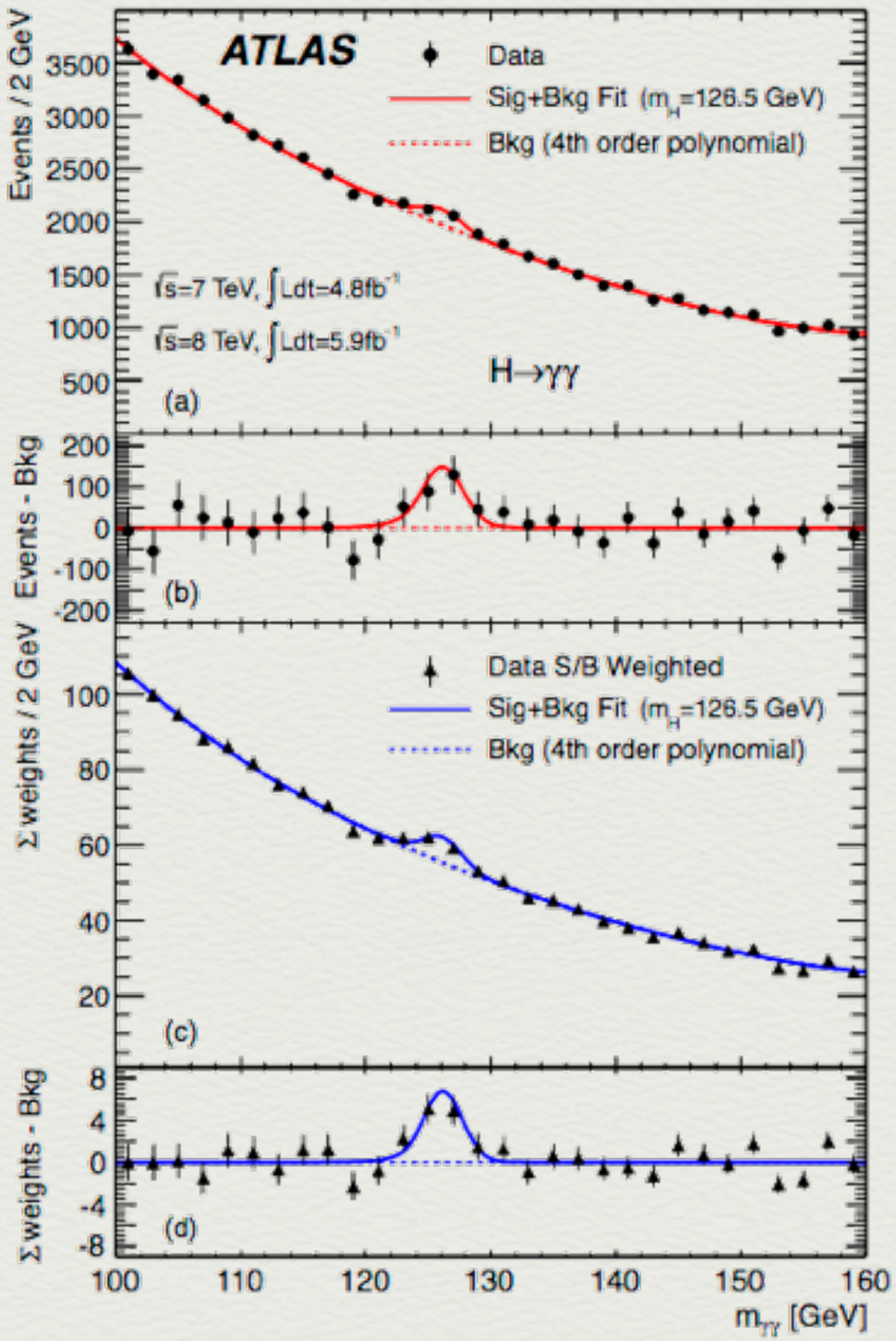
$H \longrightarrow \gamma\gamma$ channel

- Background is estimated from data by fitting the diphoton mass spectrum in the mass range 100-160 GeV
- The experimental uncertainty on the signal yield comes from the photon reconstruction and identification efficiency



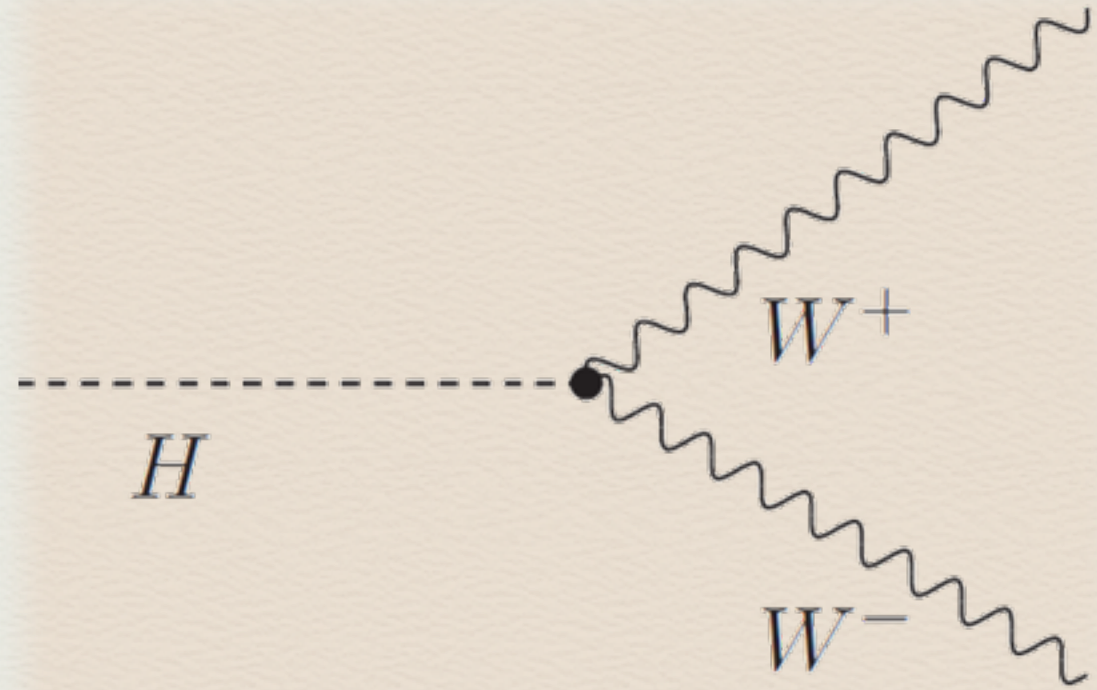
$H \longrightarrow \gamma\gamma$ channel

- There is an excess of events at $m_{\gamma\gamma}$ = 126.5 GeV
- This channel rejects a Higgs boson with spin 1
- Although this channel has a branching ratio very small it gives one of the most clear signals



$H \longrightarrow WW^{(*)} \longrightarrow e\nu\mu\nu$ channel

- Mass range between 110 GeV and 200 GeV
- The signature for this channel is two opposite-charge leptons
- Events are required to have large E_T^{miss}

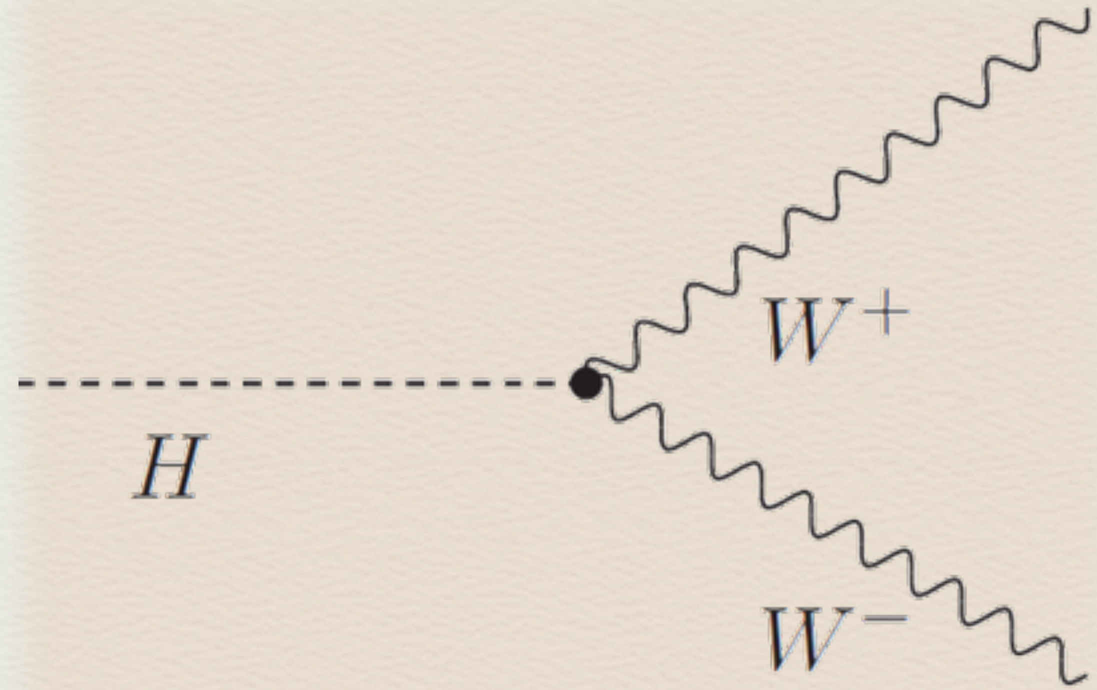


$$W^+ \rightarrow e^+ + \upsilon_e \quad \left(\mu^+ + \upsilon_\mu\right)$$

$$W^- \rightarrow \mu^- + \bar{\upsilon}_\mu \quad \left(e^- + \bar{\upsilon}_e\right)$$

$H \longrightarrow WW^{(*)} \longrightarrow e\nu\mu\nu$ channel

- The leading backgrounds are WW and top ($t\bar{t}$ and t)
- Bkg is estimated using partially data-driven techniques based on normalizing the MC predictions to the data in control regions dominated by the relevant background source
- The largest impact on the sensitivity of the search are the theoretical uncertainties associated with the signal



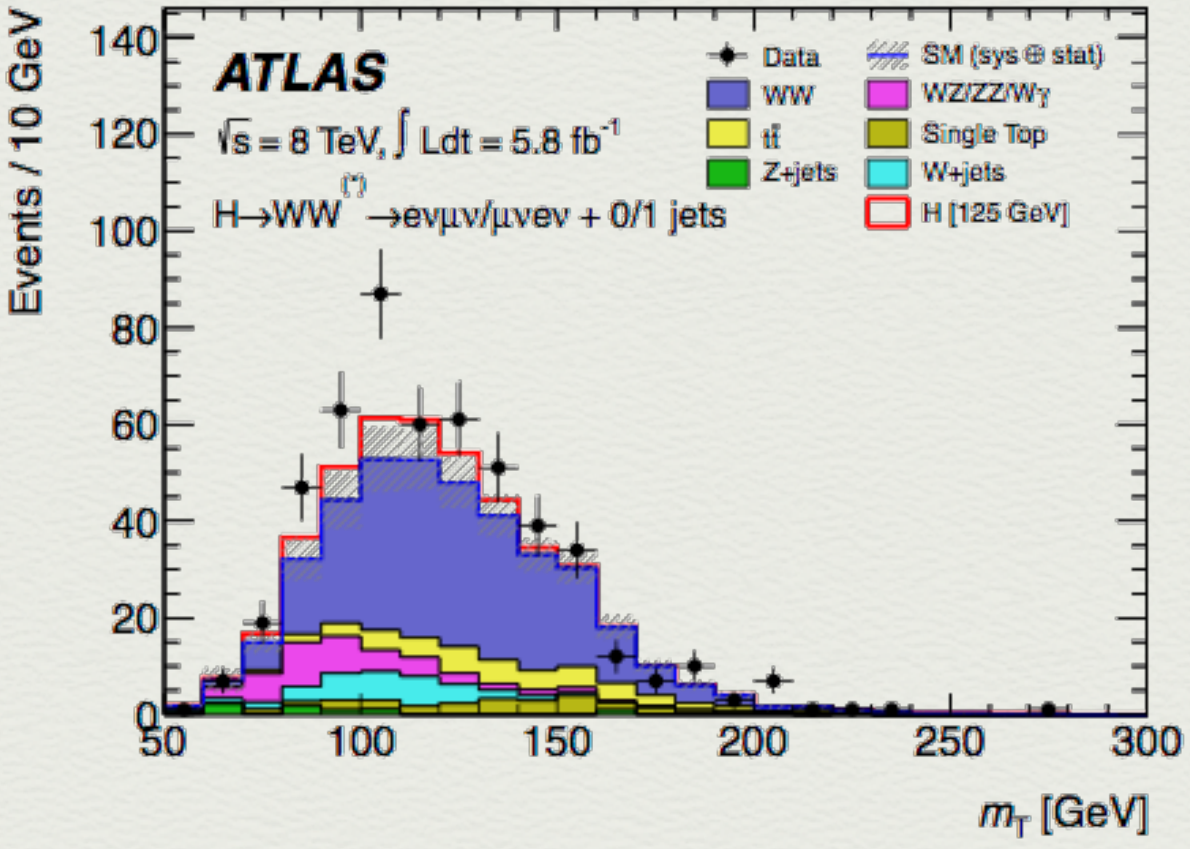
$$W^+ \rightarrow e^+ + \upsilon_e \quad \left(\mu^+ + \upsilon_\mu\right)$$

$$W^- \rightarrow \mu^- + \bar{\upsilon}_\mu \quad \left(e^- + \bar{\upsilon}_e\right)$$

$H \to WW^{(*)} \to e\nu\mu\nu$ channel

- Numbers of events of SM Higgs boson with m_H = 125 GeV were

	0-jet	1-jet	2-jet
Expected Signal	20 ± 4	5 ± 2	0.34 ± 0.07
Total Background	142 ± 16	26 ± 6	0.35 ± 0.18
Observed	185	38	0



Correlated systematic uncertainties

- Integrated luminosity: is considered as fully correlated among channels (±3.9% for the 7 TeV and ±3.6% for the 8 TeV data)
- Electron and photon trigger identification: the uncertainties are treated as fully correlated
- Muon reconstruction: the uncertainties affecting muons are separated into those related to the ID and MS, in order to obtain a better description of the correlated effects among channels
- Jet energy scale and missing transverse energy: negligible
- Theory uncertainties: correlated theoretical uncertainties affect mostly the signal predictions
- Sources of systematic uncertainty that affect both the 7 TeV and the 8 TeV data are taken as fully correlated
- The uncertainties on background estimates based on control samples in the data are considered uncorrelated between the 7 TeV and 8 TeV data.

Statistical procedure

Parameter

μ : global signal strength factor (0 := no, 1 := yes)

Evaluating the predicted Standard Model for the Higgs boson signal

→ Hypothesized values of μ: $\lambda(\mu)$

Likelihood function

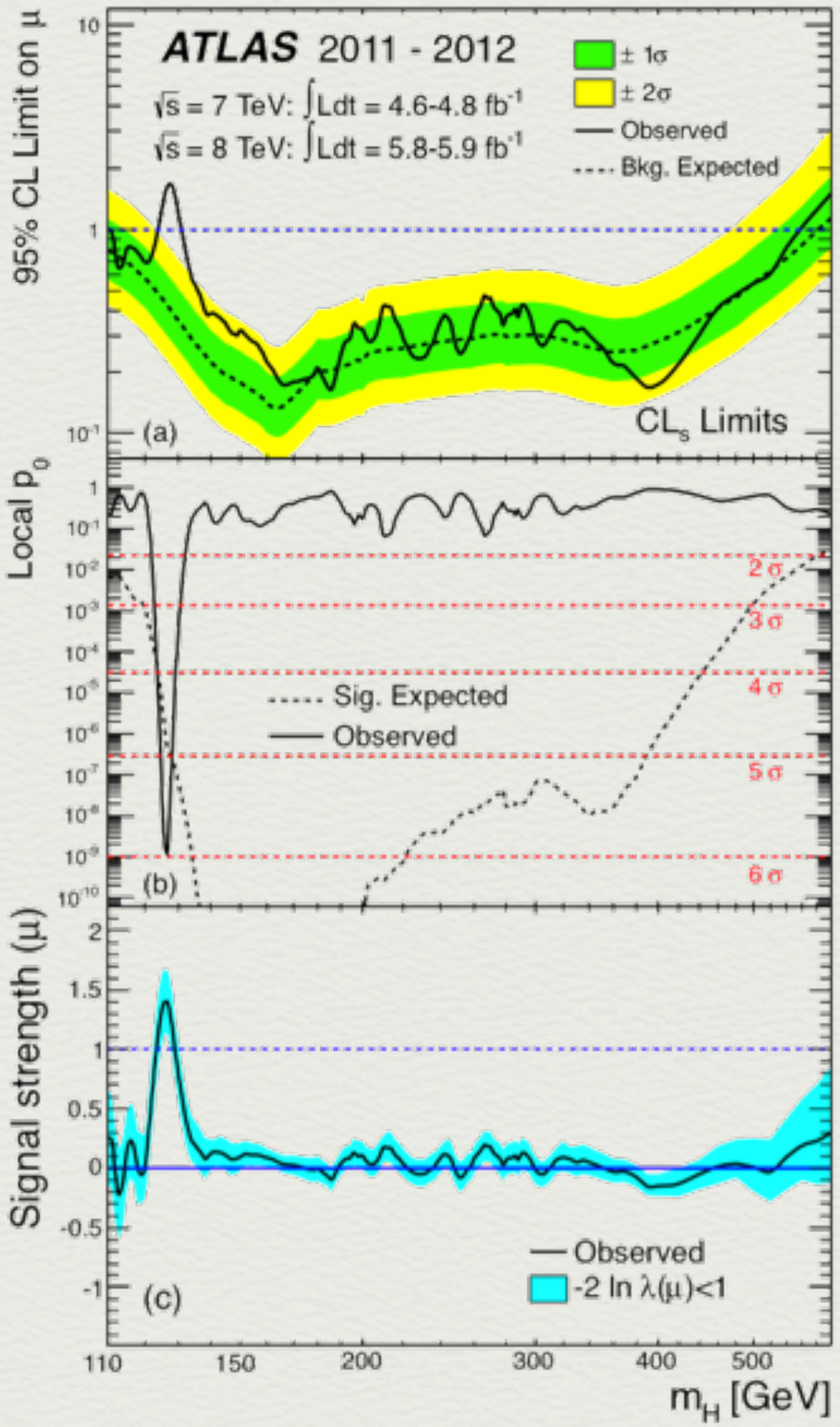
Local P_0

The probability that the background can produce a greater fluctuation

Tests Methods: CLs prescription

→ Excluded limits: CL 95%, if CLs 5%

Results

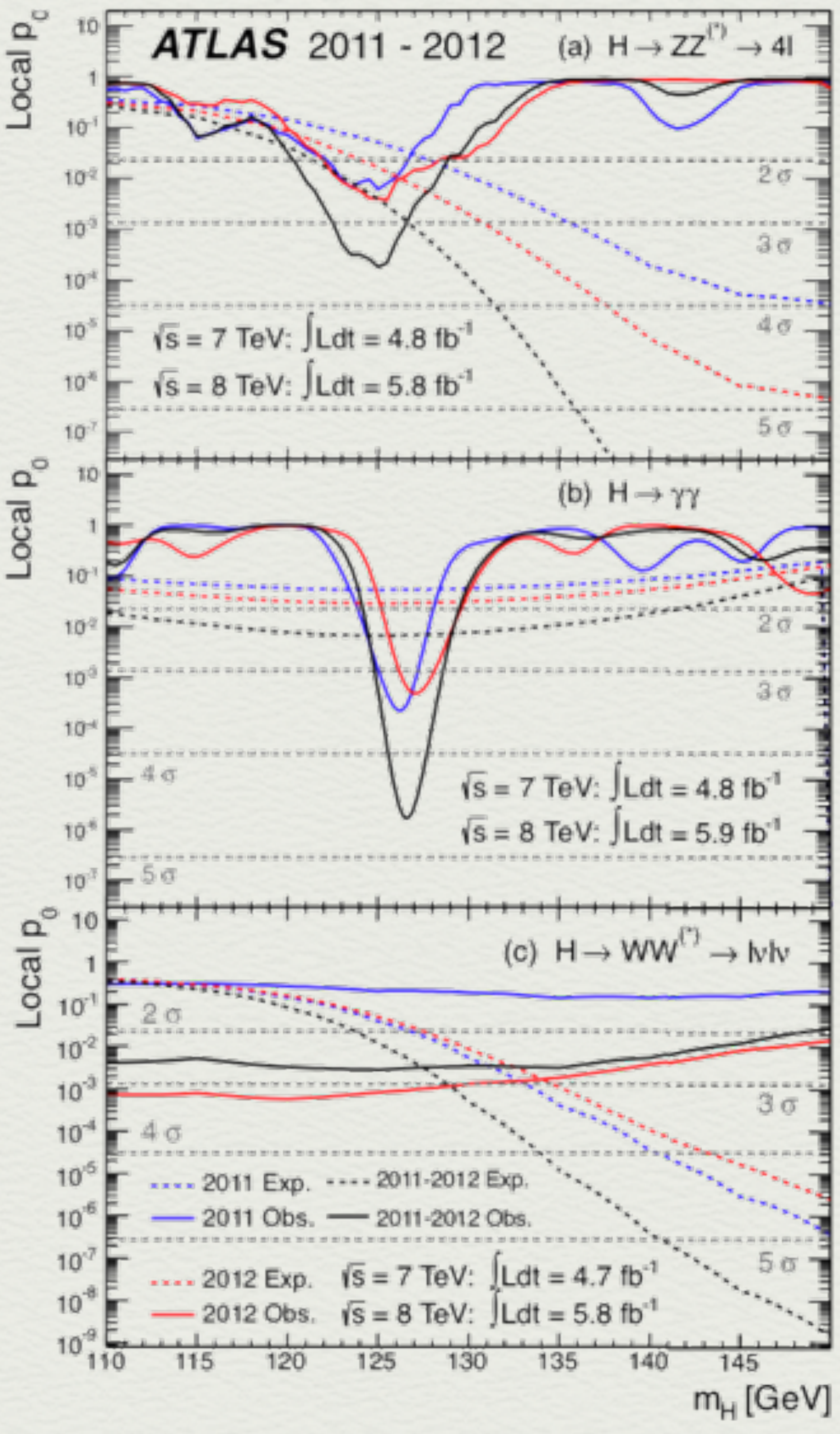


- The observed 95% CL exclusion regions are 111-122 GeV and 131-559 GeV
- Three regions are excluded at 99% CL, 113-114, 117-121 and 132-527 GeV

Results

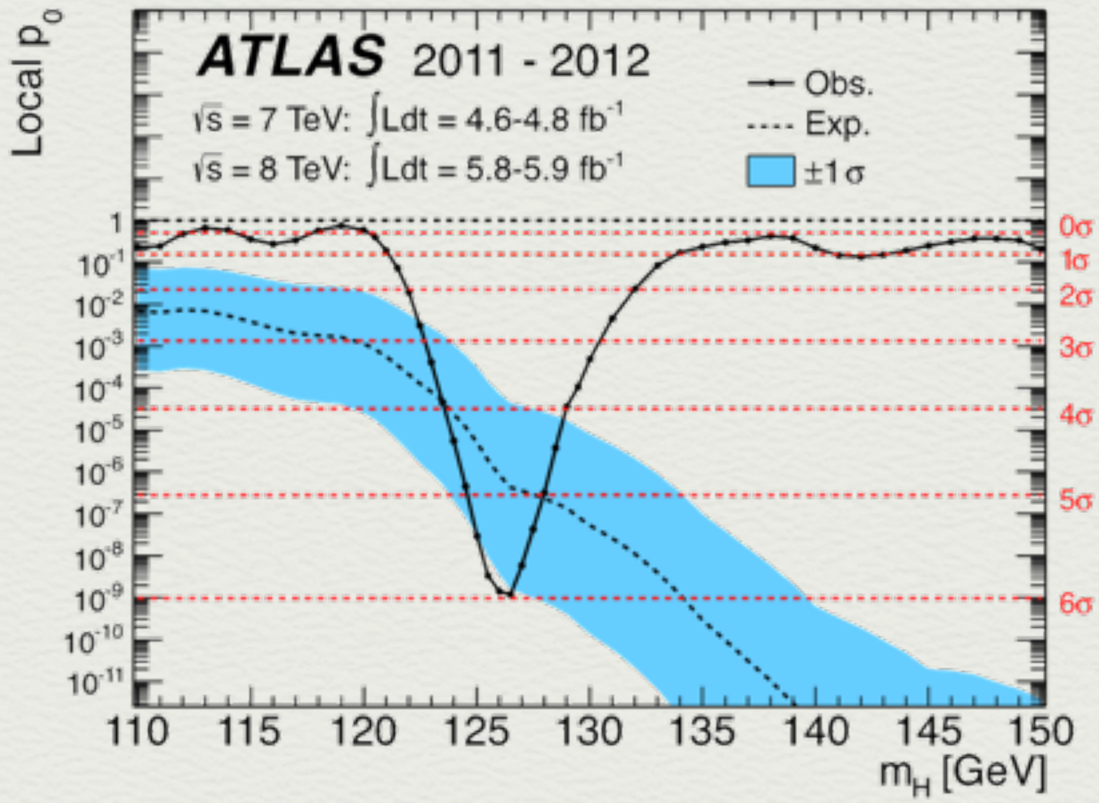
- An excess of events is observed near m_H = 126 GeV in the $H \longrightarrow ZZ^{(*)} \longrightarrow 4l$ and $H \longrightarrow \gamma\gamma$ channels

- These excesses are confirmed by the highly sensitive but low-resolution $H \longrightarrow WW^{(*)} \longrightarrow e\nu\mu\nu$ channel



Results

- The largest local significance for the combination of the 7 TeV and 8 TeV data is found for a SM Higgs boson hypothesis of m_H = 126.5 GeV, where it reaches 6.0 σ



Conclusions

- $H \longrightarrow ZZ^{(*)} \longrightarrow 4l$ channel has a high signal-to-background ratio (Golden channel)
- The Standard Model Higgs boson is excluded at 95% CL in the mass range 111-559 GeV, except for the narrow region 122-131 GeV
- In this last region, an excess of events with significance 5.9 σ (after taking into account some uncertainties), corresponding to $p_0 = 1.7 \cdot 10^{-9}$, is observed

Conclusions

- These results provide conclusive evidence for the discovery of a new particle with mass 126.0 ± 0.4 (stat) ± 0.4 (sys) GeV
- The signal strength parameter μ has the value 1.4 ± 0.3 at the fitted mass, which is consistent with the SM Higgs boson hypothesis μ = 1
- The observation in the diphoton channel disfavors the spin-1 hypothesis