Search for Low-Mass SM Higgs at ATLAS

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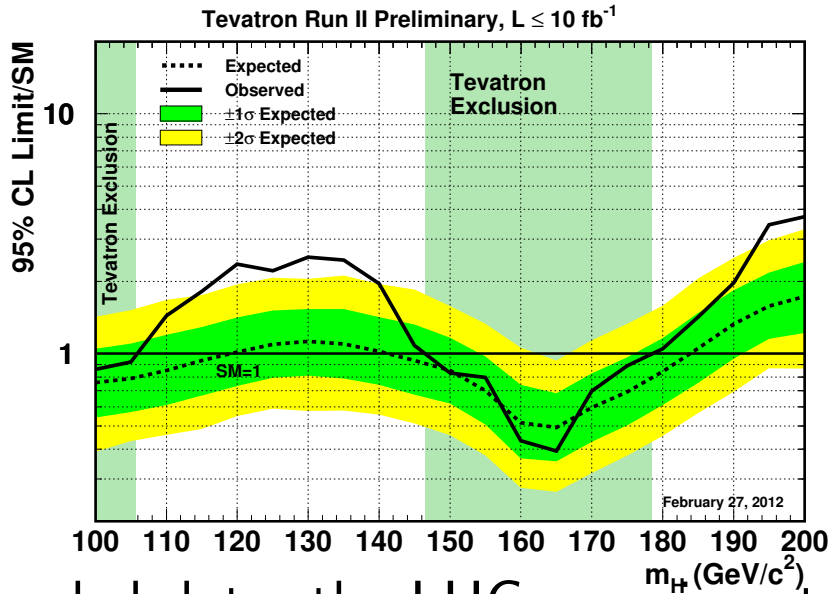
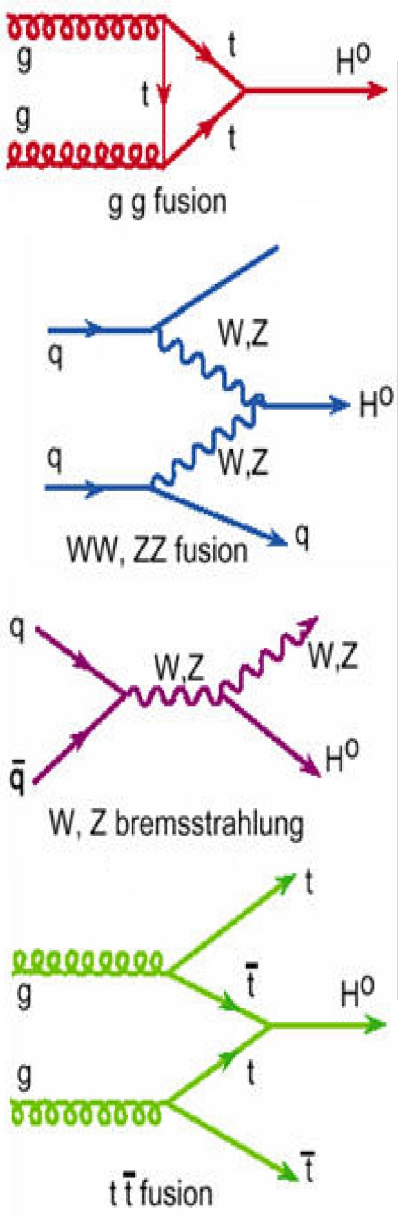
Introduction

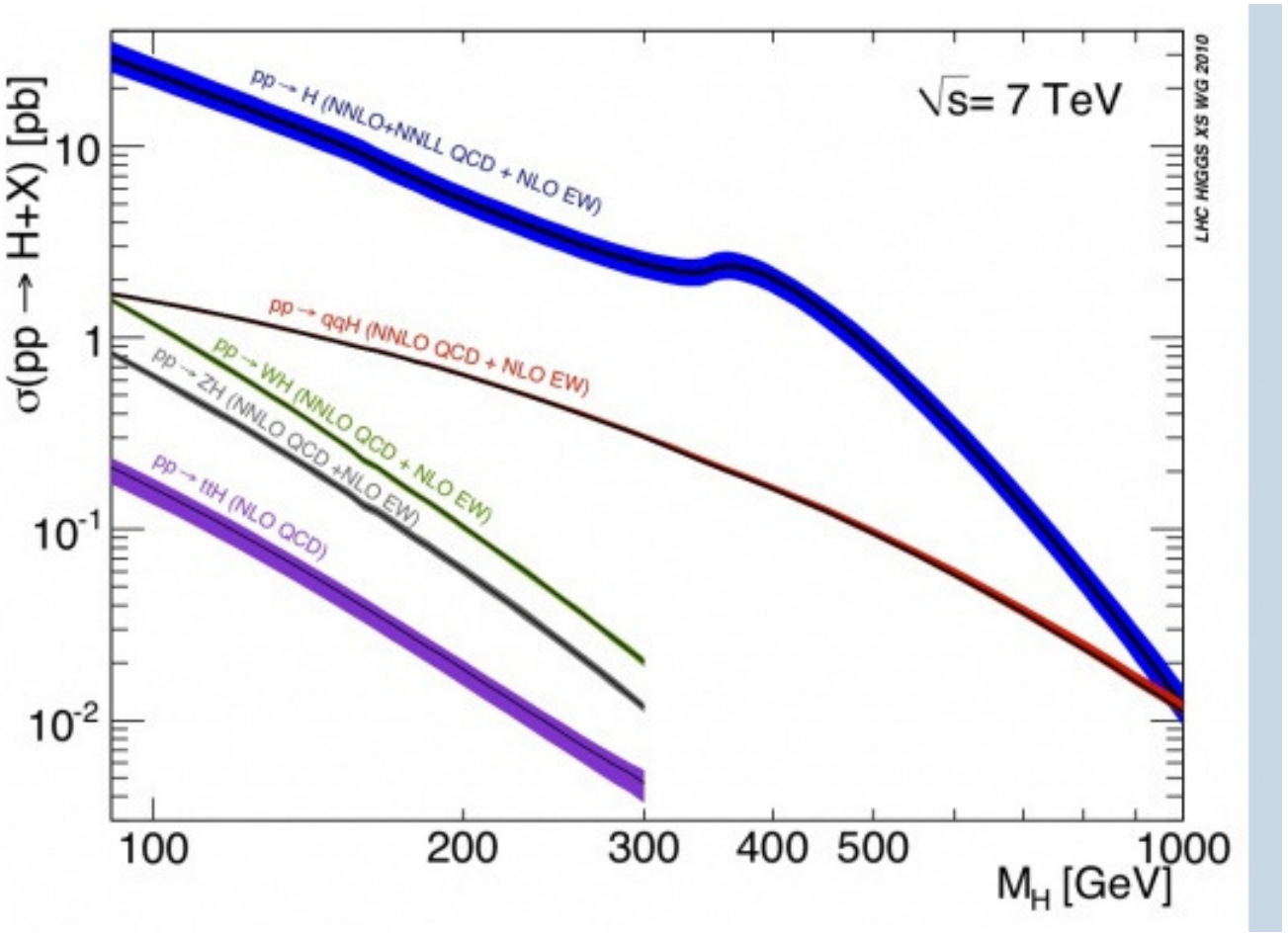
- The Higgs boson is the last missing particle predicted by the SM.
- The LEP experiments have excluded a SM Higgs boson with $m_H < 114.5$ GeV at 95% C.L.
- The Tevatron experiments have excluded the boson with $100 < m_H < 108$ GeV and $156 < m_H < 177$ GeV at 95% C.L.



- With 5 fb^{-1} of recorded data, the LHC experiments are looking for the Higgs boson and have reduced the mass range where it can still hide.

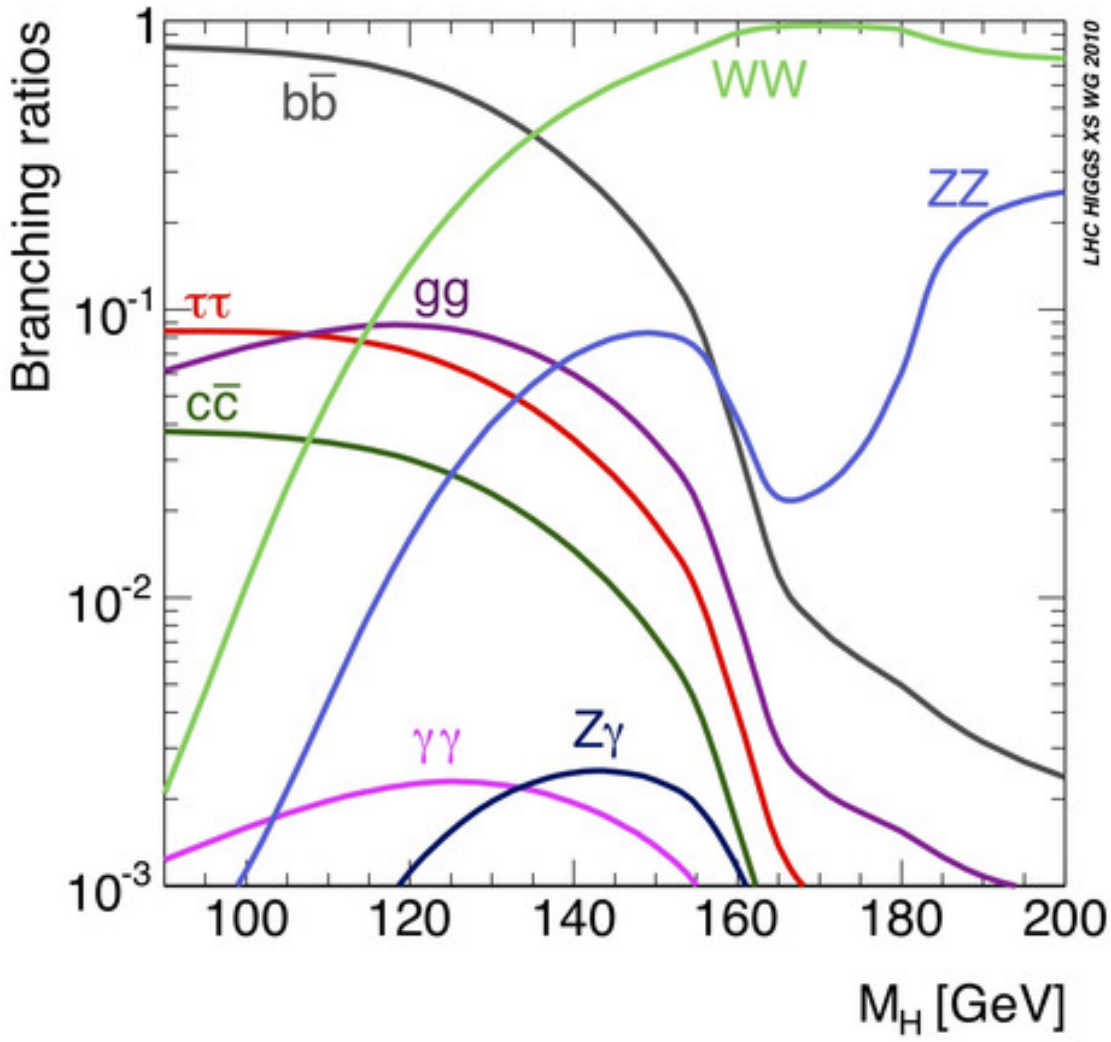
Higgs production





Cross-section of the Higgs boson production processes as a function of its mass.

Higgs decay

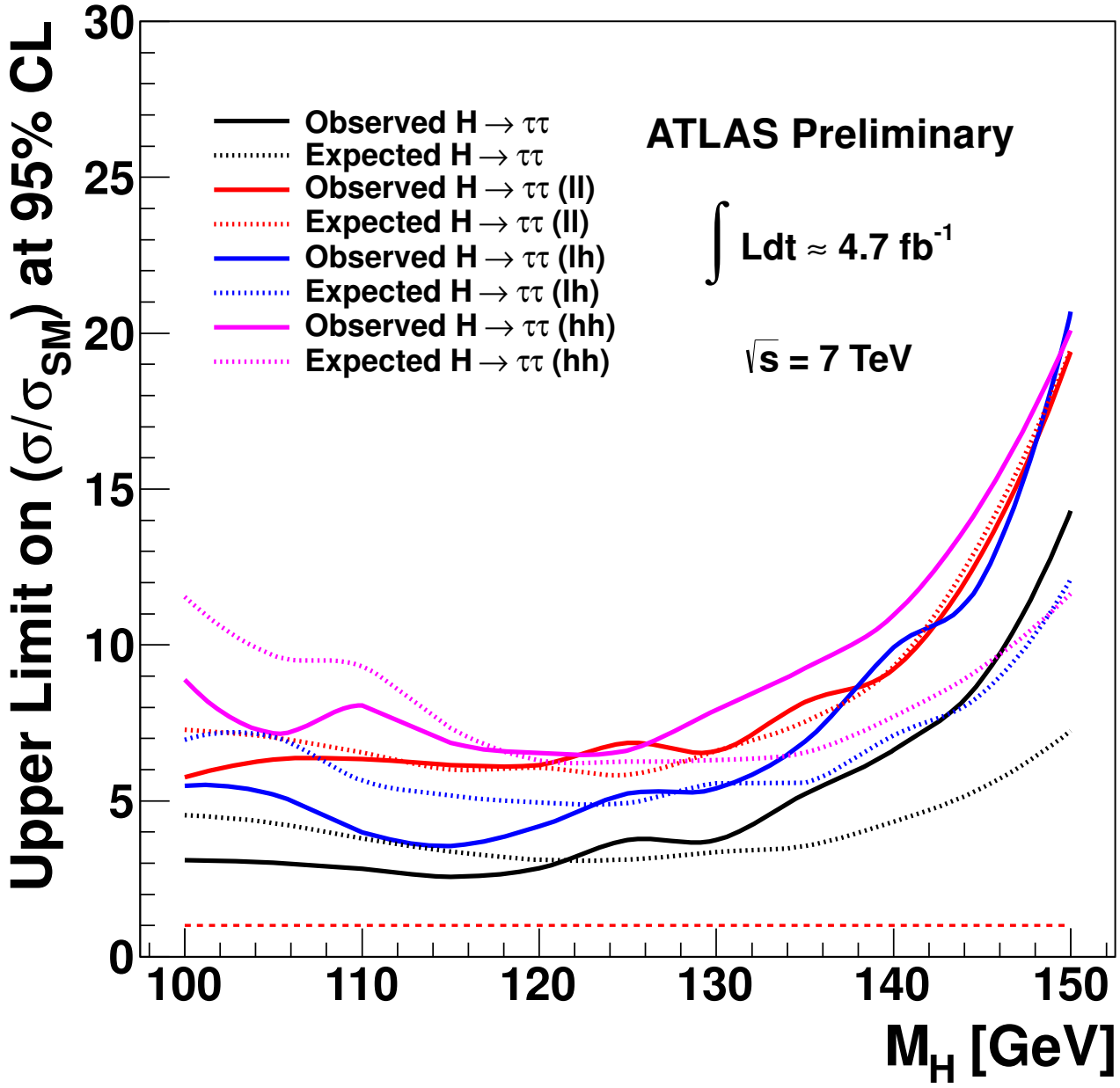


Branching ratio of the Higgs decay as a function of its mass.

$H \to \tau\tau$

- This channel is sensitive to $m_H \sim$ 110-140 GeV
- Lepton and hadronic decay of the τ leptons are considered :
  - $H \to \tau^+\tau^- \to \ell\ell 4\nu$
  - $H \to \tau^+\tau^- \to \ell\tau_{had} 3\nu$
  - $H \to \tau^+\tau^- \to \tau_{had}\tau_{had} 2\nu$
- The main background is $Z \to \tau\tau$. Other background contributions :
  - Z+jets
  - Top production
  - Diboson
  - Fake leptons production (especially in the $\tau_{had}\tau_{had}$ channels).
- The events are split according to their jet-multiplicity (different analysis cuts)

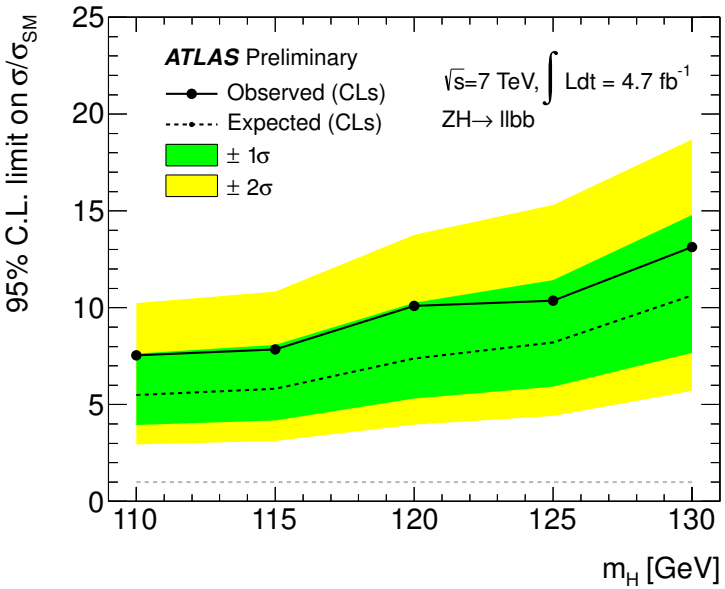
$H \to \tau\tau$

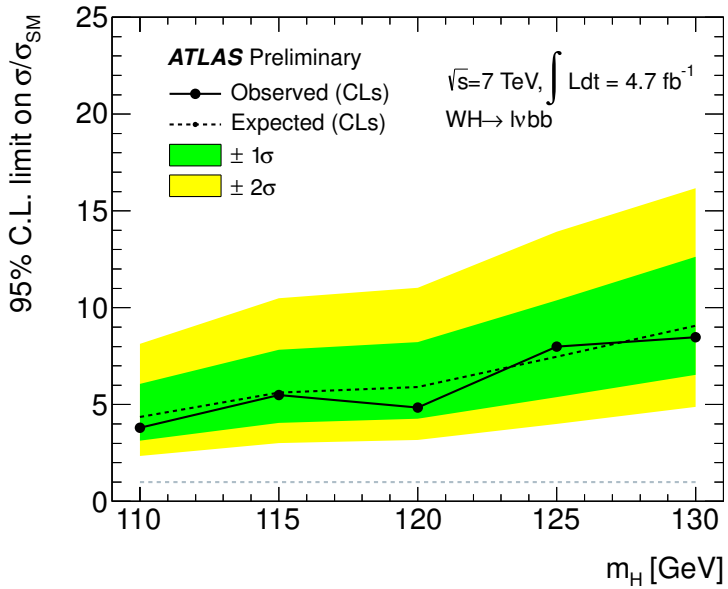

Observed H → ττ
Expected H → ττ
Observed H → ττ (ll)
Expected H → ττ (ll)
Observed H → ττ (lh)
Expected H → ττ (lh)
Observed H → ττ (hh)
Expected H → ττ (hh)
ATLAS Preliminary
∫ Ldt ≈ 4.7 fb-1
√s = 7 TeV
Upper Limit on (σ/σSM) at 95% CL
MH [GeV]
0
5
10
15
20
25
30
100
110
120
130
140
150

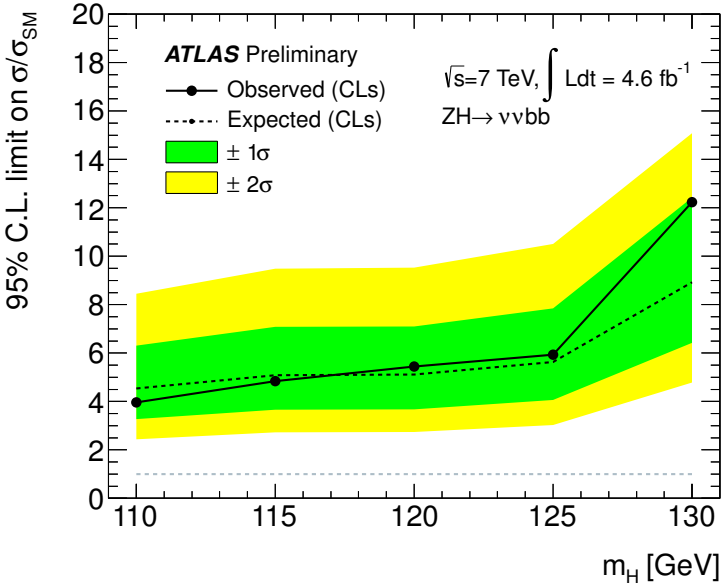
$Z/W\ H \to b\bar{b}$

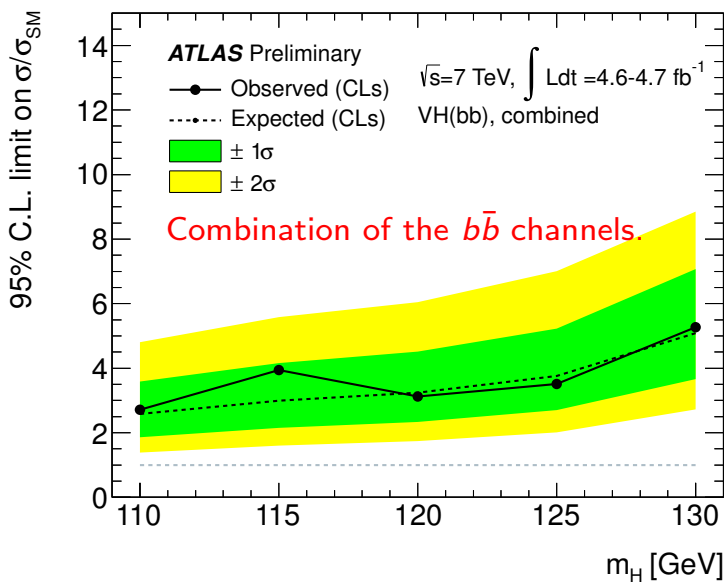
- Channel benefits from large branching ratio
- Very large QCD background : associated production with lepton requirement to reduce the background
- WH 2 times larger XS than ZH, but WH has more background
- Event selection :
  - ZH$\to \ell\ell$: exactly 2 leptons, Z mass cut, remove high Etmiss, two leading jets b-tagged
  - ZH$\to \nu\nu$: large Etmiss, p_T^{miss} requirement, lepton veto, 2 jets b-tagged
  - WH : exactly 1 lepton, $M_T > 25$ GeV, Etmiss cut, exactly 2 jets b-tagged
- Backgrounds :
  - ZH$\to \ell\ell b\bar{b}$: Z+jets is the main backgrounds, then comes top and dibosons
  - ZH$\to \nu\nu b\bar{b}$: Z+jets and top, but W+jets and dibosons are a bit smaller
  - WH$\to \ell\nu b\bar{b}$: top, W+jets, multijet (QCD) are the main backgrounds, then come dibosons

$Z/W\ H \to b\bar{b}$: limits per channel and combination



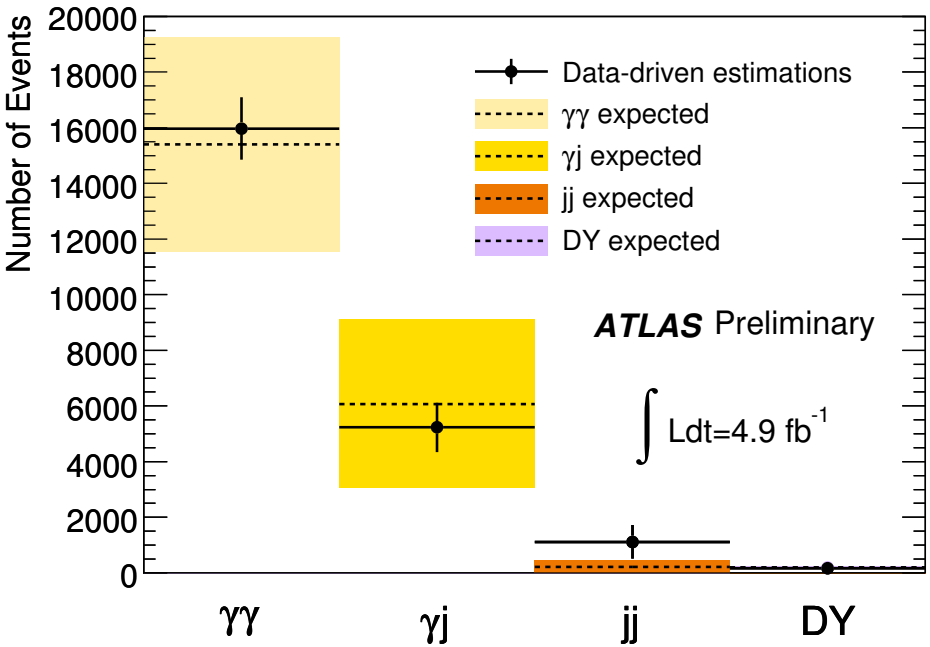






$H \to \gamma\gamma$ analysis

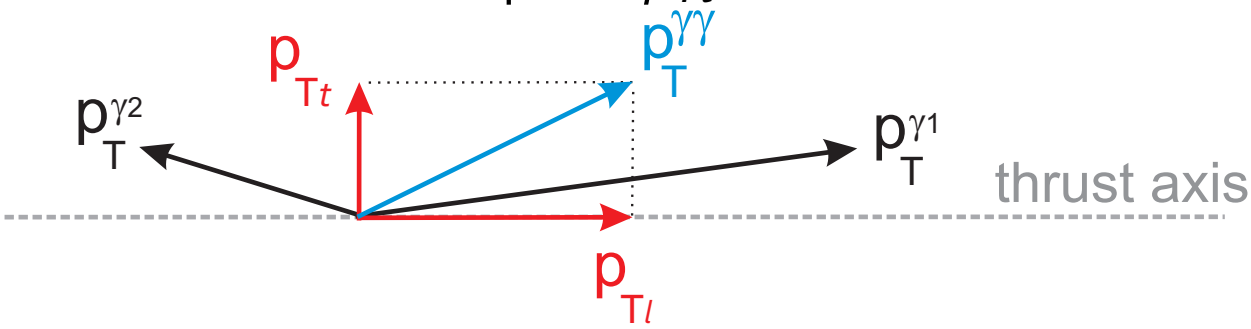
- $\gamma\gamma$ channel sensitive to $m_H \in [110 - 150]$ GeV
- benefits from good calorimeter resolution : 1.6 GeV for 120 GeV Signal
- 2 photons are required with $E_T^{\gamma 1} > 40$ GeV, $E_T^{\gamma 2} > 25$ GeV
- Main background : irreducible $\gamma\gamma$ (30 pb), reducible $\gamma - jet$ (200 nb) and $jet - jet$ (500 μb)
- Powerful $\gamma - jet$ separation used based on calorimeter shower-shape and isolation cuts



- Background composition from control samples by reversing isolation or identification criteria :
  Fraction of irreducible $\gamma\gamma$: (71$\pm$5)%

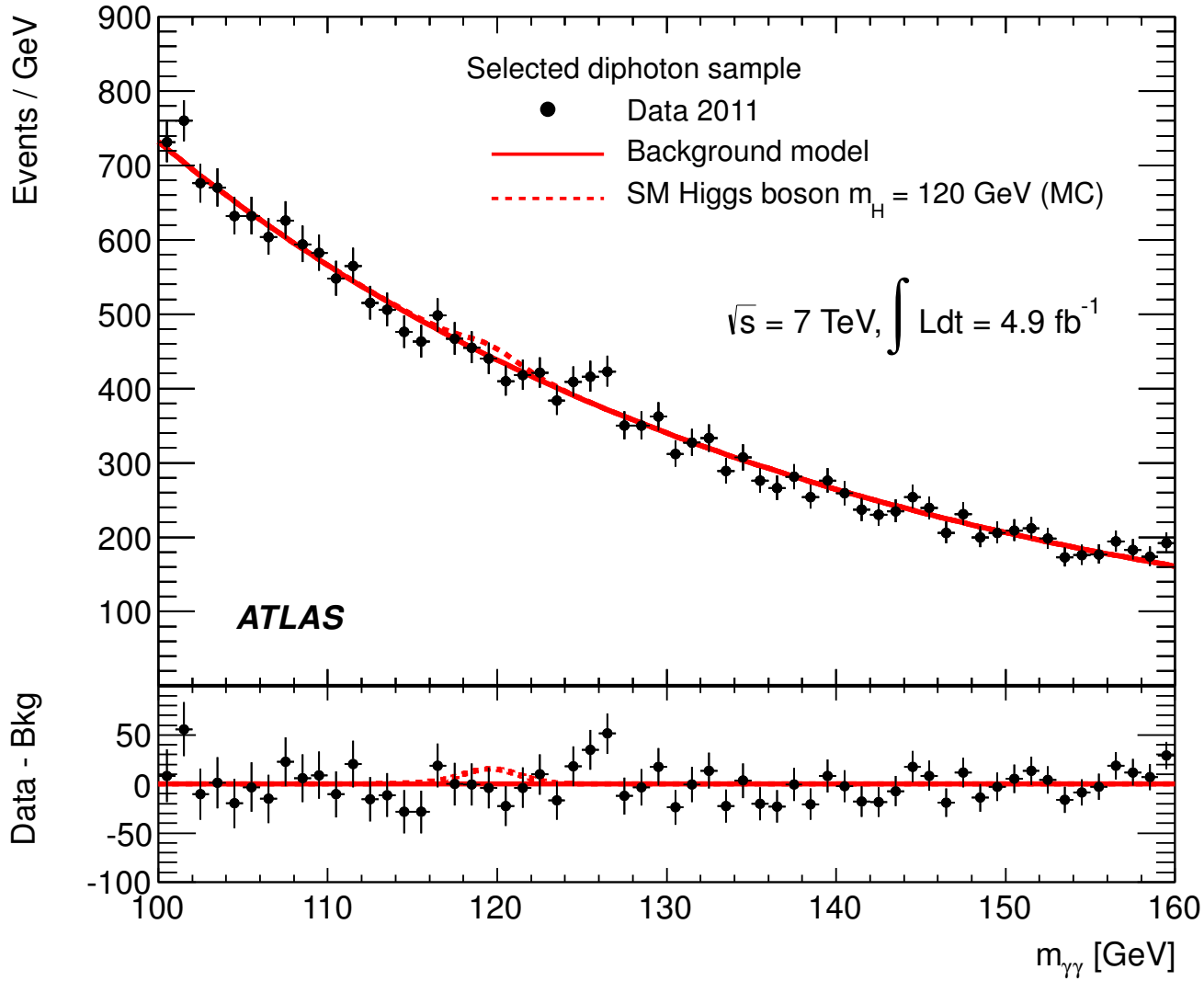
$H \to \gamma\gamma$ analysis

- 9 analysis categories (with different mass resolutions and signal-to-background ratio) to improve sensitivity depending on :
  - Conversion status
  - η (pseudo-rapidity) of the photons
  - The diphoton transverse momentum orthogonal to the diphoton thrust axis in the transverse plane p_{Tt}.



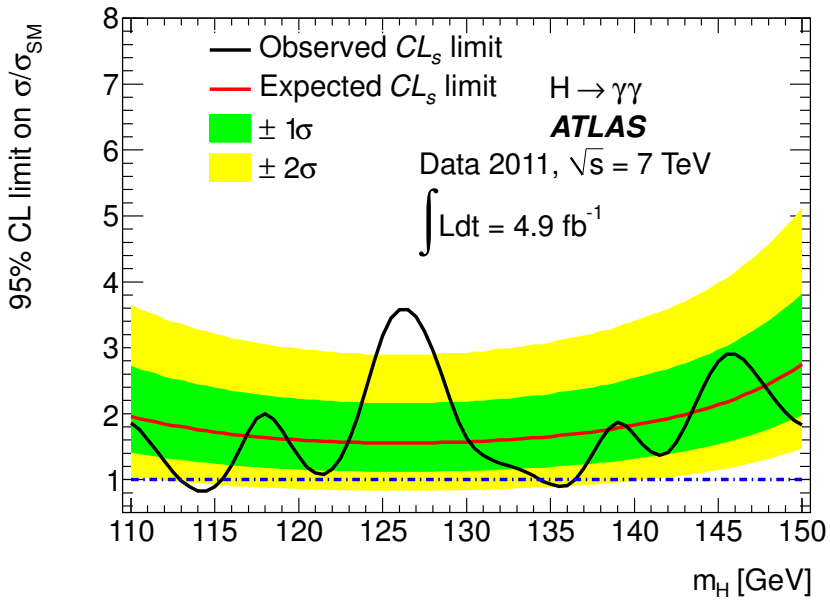
- Background estimation from fit to $m_{\gamma\gamma}$ spectrum :
  - Simultaneous fit to all 9 categories.
  - Exponential function, free slope and normalization.

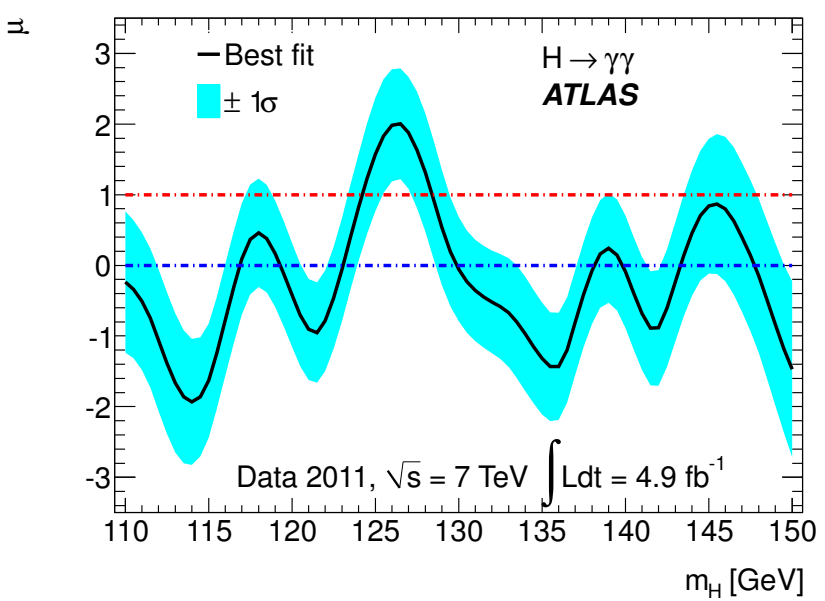
$H \to \gamma\gamma$ analysis



Invariant mass distribution for the 9-categories combined together.

$H \to \gamma\gamma$ results





Exclusion limit :

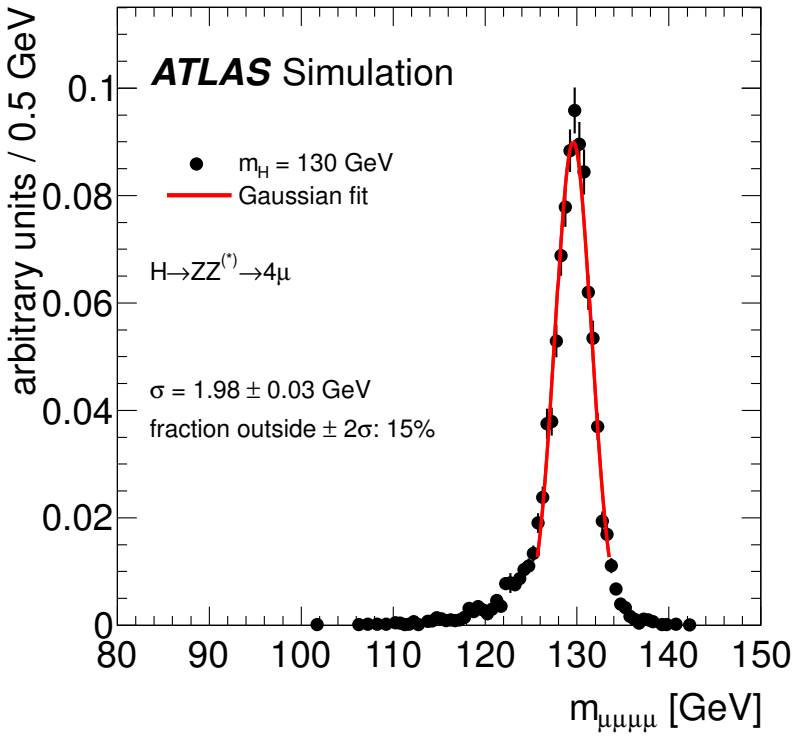
Observed exclusion in ranges [113,115] and [134.5,136] GeV

The best-fit signal strength $\mu = \sigma/\sigma_{SM}$ as a function of m_H.

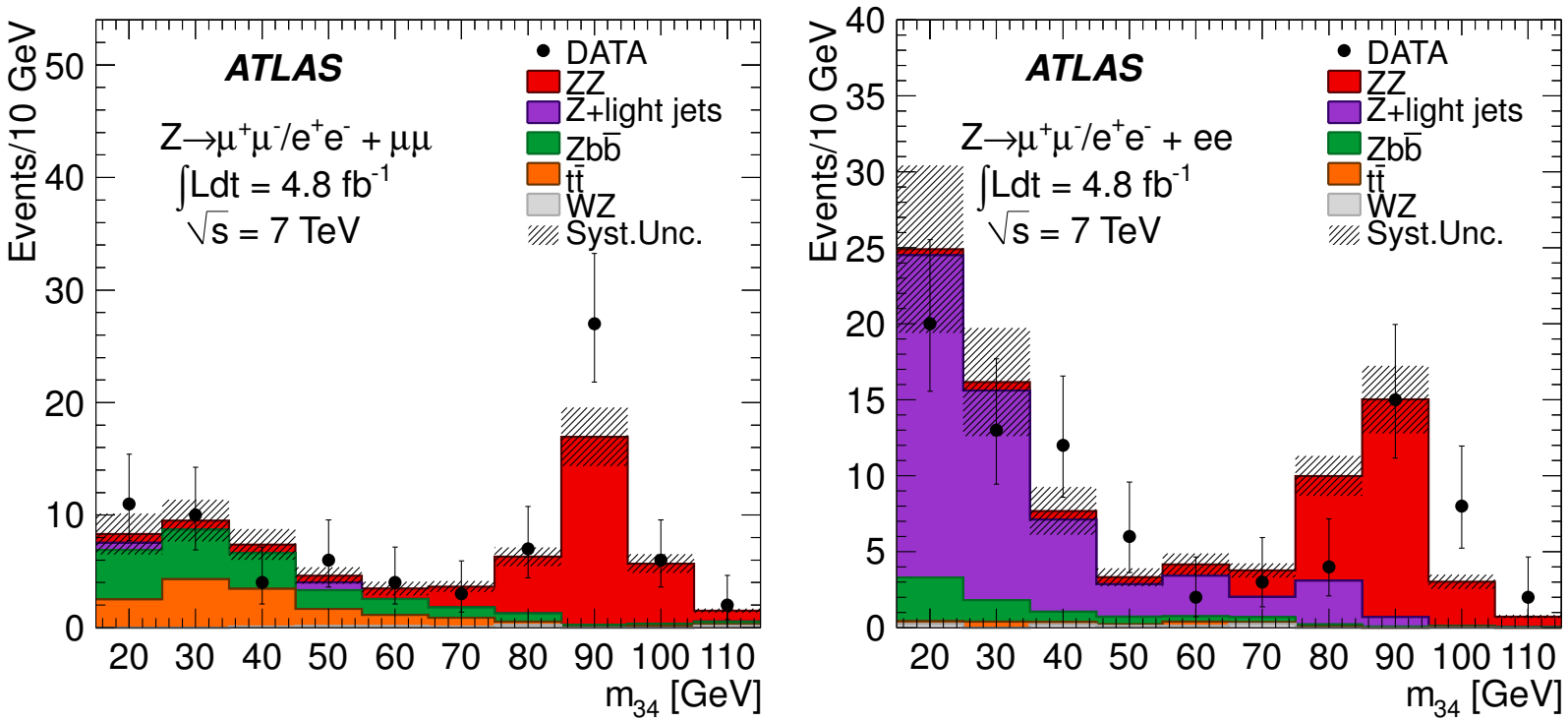
Largest excess of events observed at 126.5 GeV : Local significance: 2.8σ (1.5σ after the look-elsewhere-effect).

$H \to ZZ^* \to \ell\ell\ell\ell$

- Low branching ratio in the low mass region
- Sensitivity in low and high Higgs mass
- Benefits from good mass resolution (130 GeV: 1.5-2%)
- Backgrounds :
  - ZZ^* from simulation
  - $Z + jets$: control region without charge, isolation and impact parameter criteria on the second lepton pair.
  - $t\bar{t}$: $e^{\pm}\mu^{\mp}$ pair consistent with m_Z and two additional same-flavor leptons.

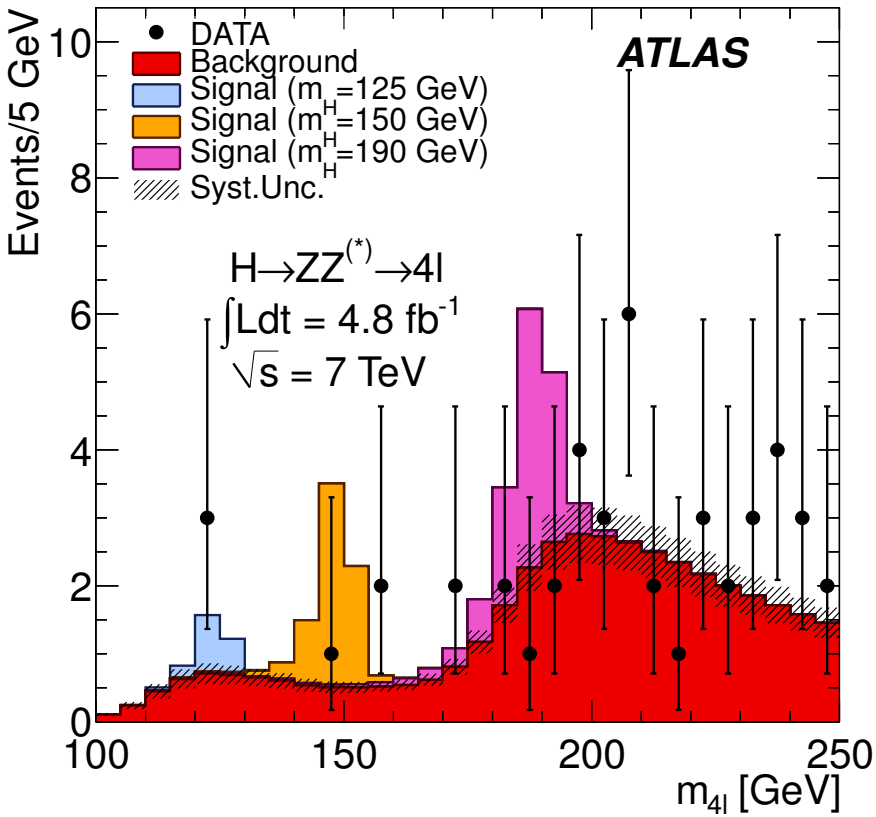


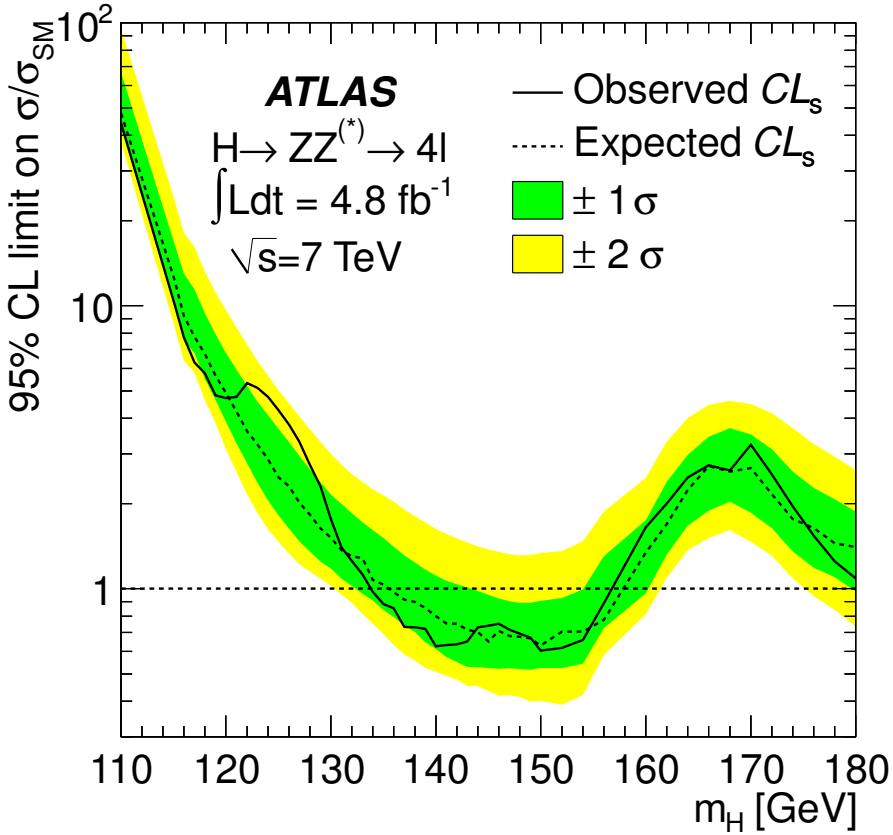
$H \to ZZ^* \to \ell\ell\ell\ell$: background estimation



Invariant mass of the 2 muons (2 electrons) in a control sample with $Z \to \ell\ell$ + 2 muons (2 electrons).

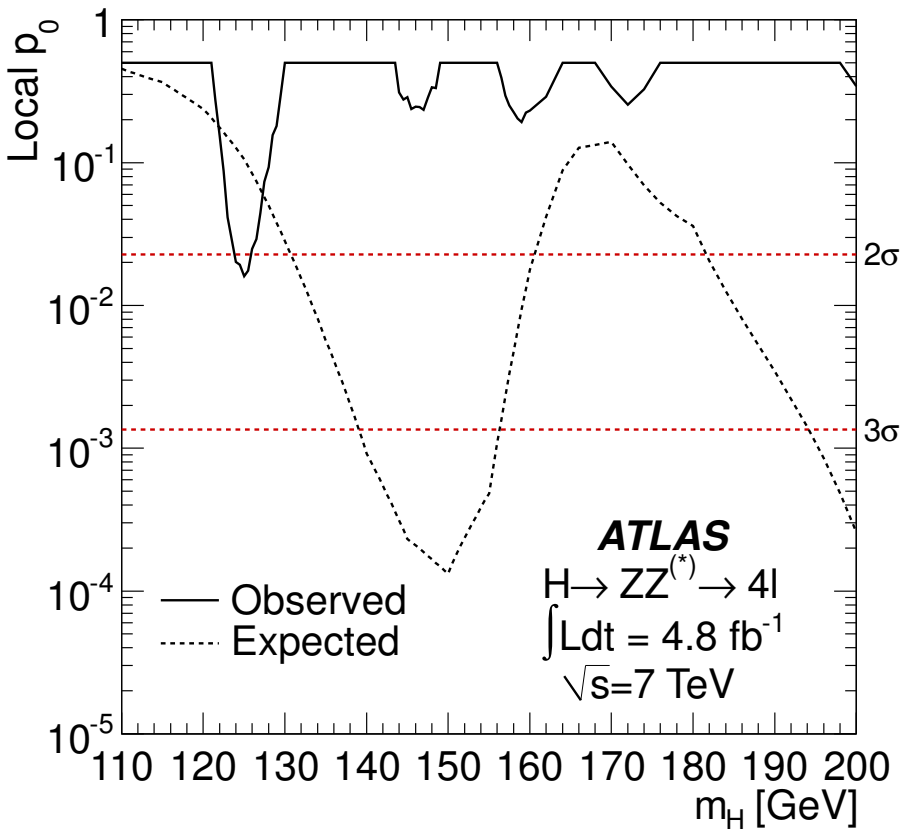
$H \to ZZ^* \to \ell\ell\ell\ell$: Results

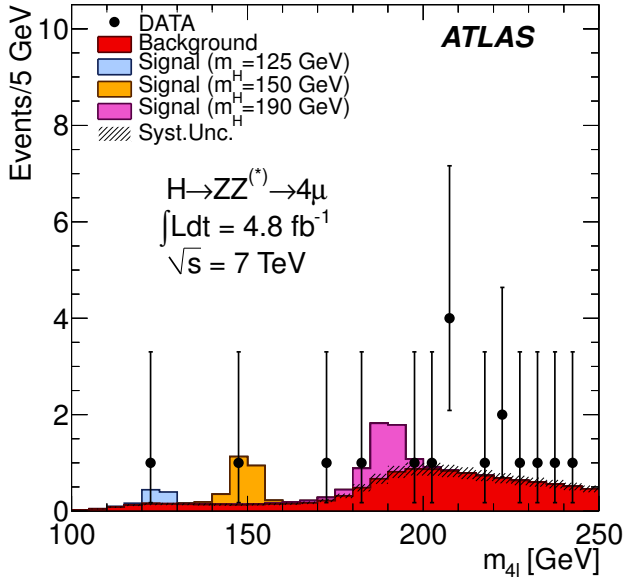


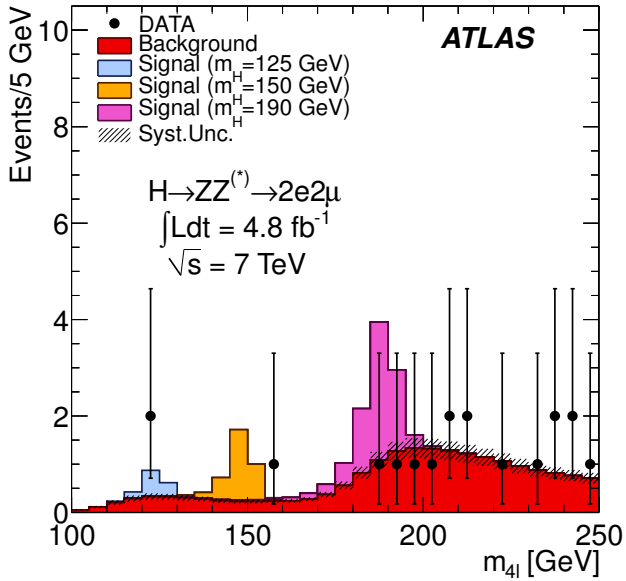


Observed exclusion at low mass : $m_H \in [134,156]$ GeV

$H \to ZZ^* \to \ell\ell\ell\ell$: Results







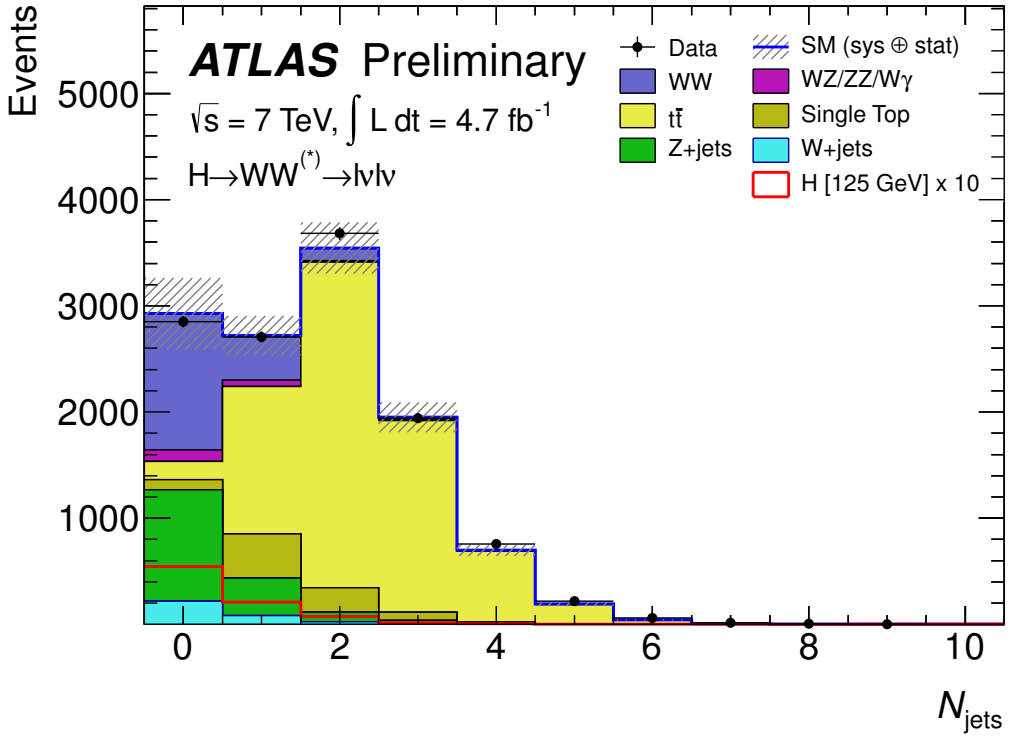
Excess of events observed at 125 GeV :
local significance of 2.1σ

$H \to WW^* \to \ell\nu\ell\nu$

- This channel is sensitive to $m_H \sim$ 120-180 GeV
- No mass reconstruction due to the neutrinos : use $m_T = \sqrt{(E_T^{\ell\ell} + E_T^{miss})^2 - |\vec{p}_T^{\ell\ell} + \vec{p}_T^{miss}|^2}$ with E_T^{miss} the missing transverse momemtum.
- Selection :
  - 2 isolated oppositely charged lepton ($p_T >$ 25, 15 GeV)
    Reduce W+jets and QCD background
  - Large missing energy and Z veto in case of same-flavor lepton pair
    Reduce Z background
  - $E_T^{miss\ rel} = E_T^{miss} * sin(\Delta\phi(\vec{p}_T^{\ell}, \vec{E}_T^{miss}))$, with closest lepton in ϕ
    Reduce fake missing energy
  - b-jet veto
    Reduce top background
  - $m_{\ell\ell}$ and $\Delta\phi_{\ell\ell}$ cuts
    Reduce SM WW background, $H \to WW$ produces polarized W bosons
  - Jet multiplicity dependent cut : $p_T^{\ell\ell}$, $\vec{p}_T^{tot}$
    Reduce Drell-Yan and soft QCD backgrounds

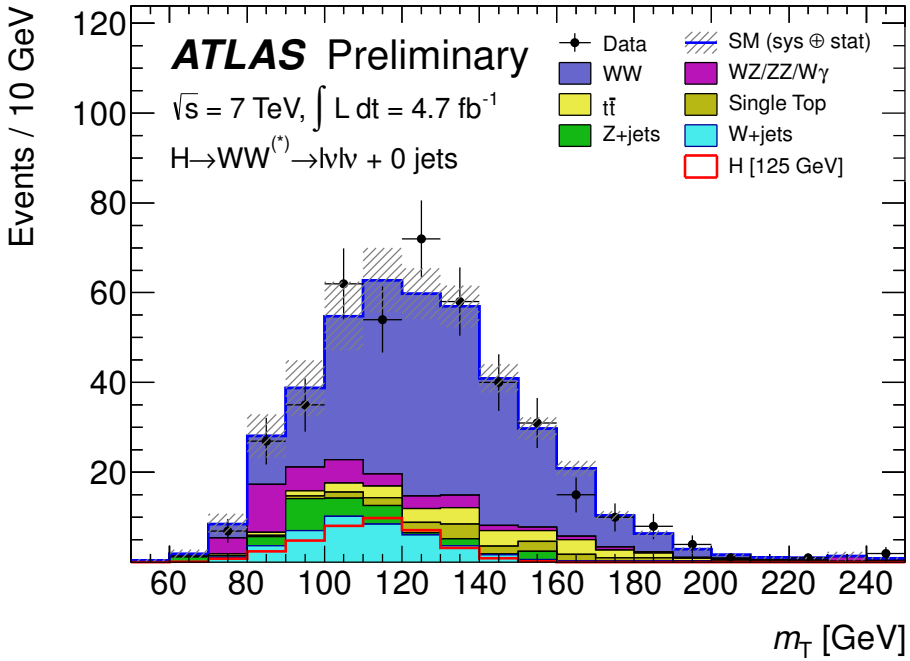
$H \to WW^* \to \ell\nu\ell\nu$: Background estimation

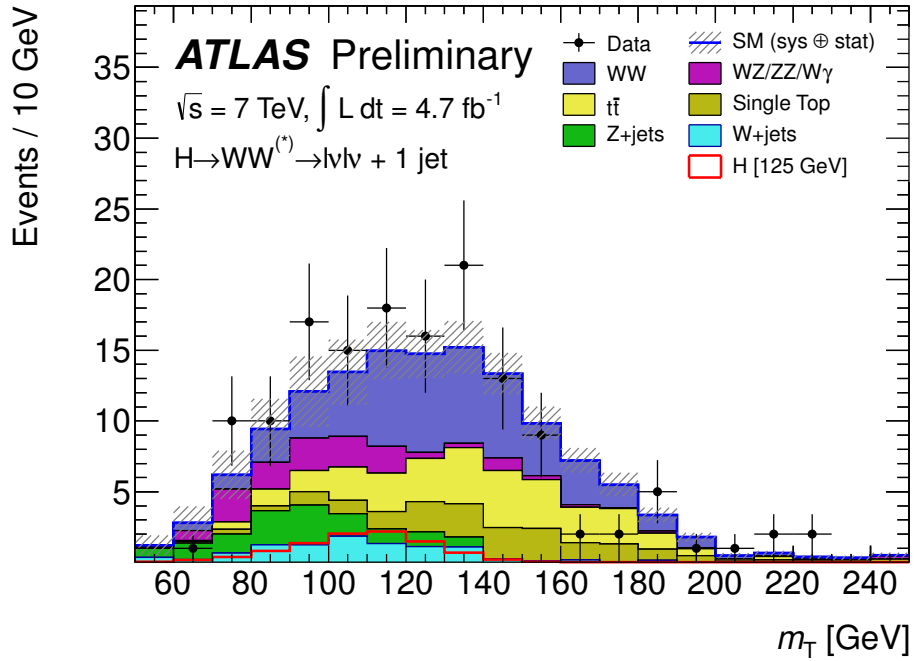
- WW : control sample with no $\Delta\phi_{\ell\ell}$ cut and reverse $m_{\ell\ell}$ cut.
- top : control sample by requesting b-tagged jet(s)
- Z+jets : control sample by reversing the Z-veto cut : $|m_{\ell\ell} - m_Z| < 15$ GeV
- W+jets : control sample by reversing identification cuts for one lepton



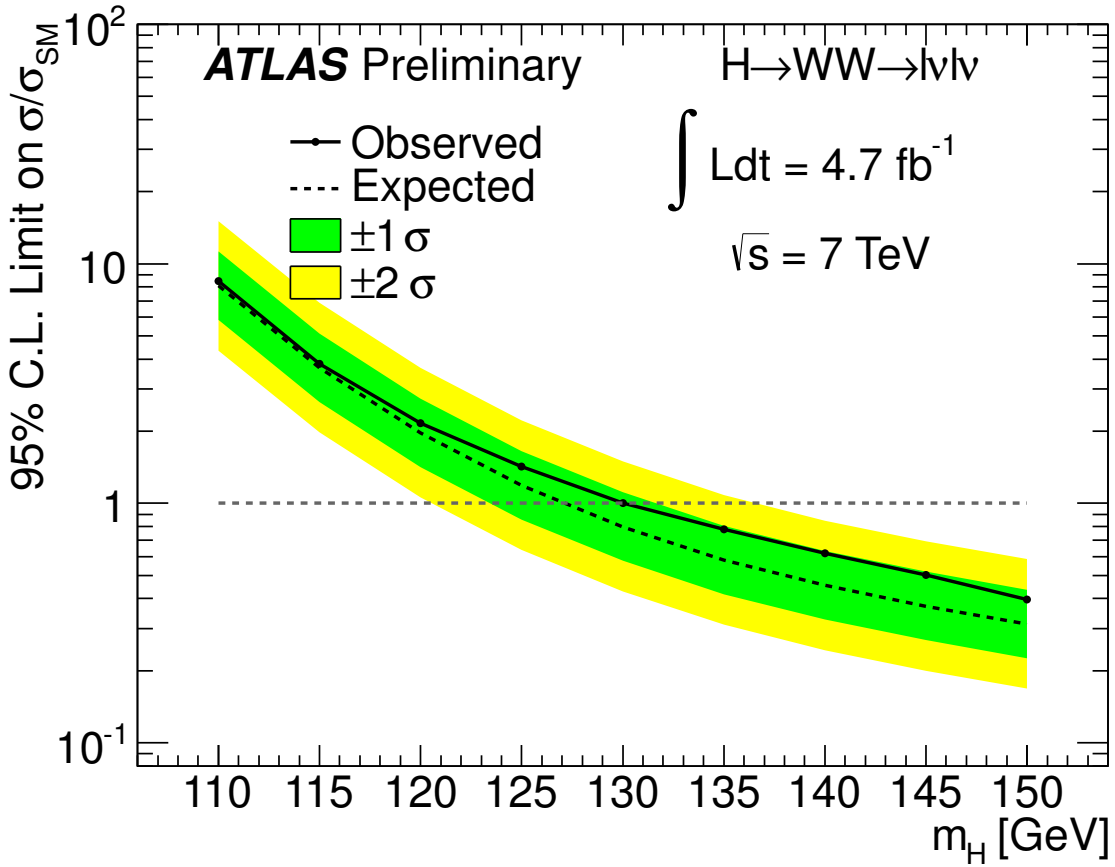
$H \to WW^* \to \ell\nu\ell\nu$: Analysis

- To improve the sensitivity, the analysis is divided according to:
  - Jet multiplicity :
    - 0 and 1 jet more sensitive to gluon-gluon fusion.
    - 2 jets more sensitive to VBF (vector boson fusion) production.
  - Lepton flavor : $e-e$, $e-\mu$, $\mu-\mu$: $e-\mu$ does not have Z background.





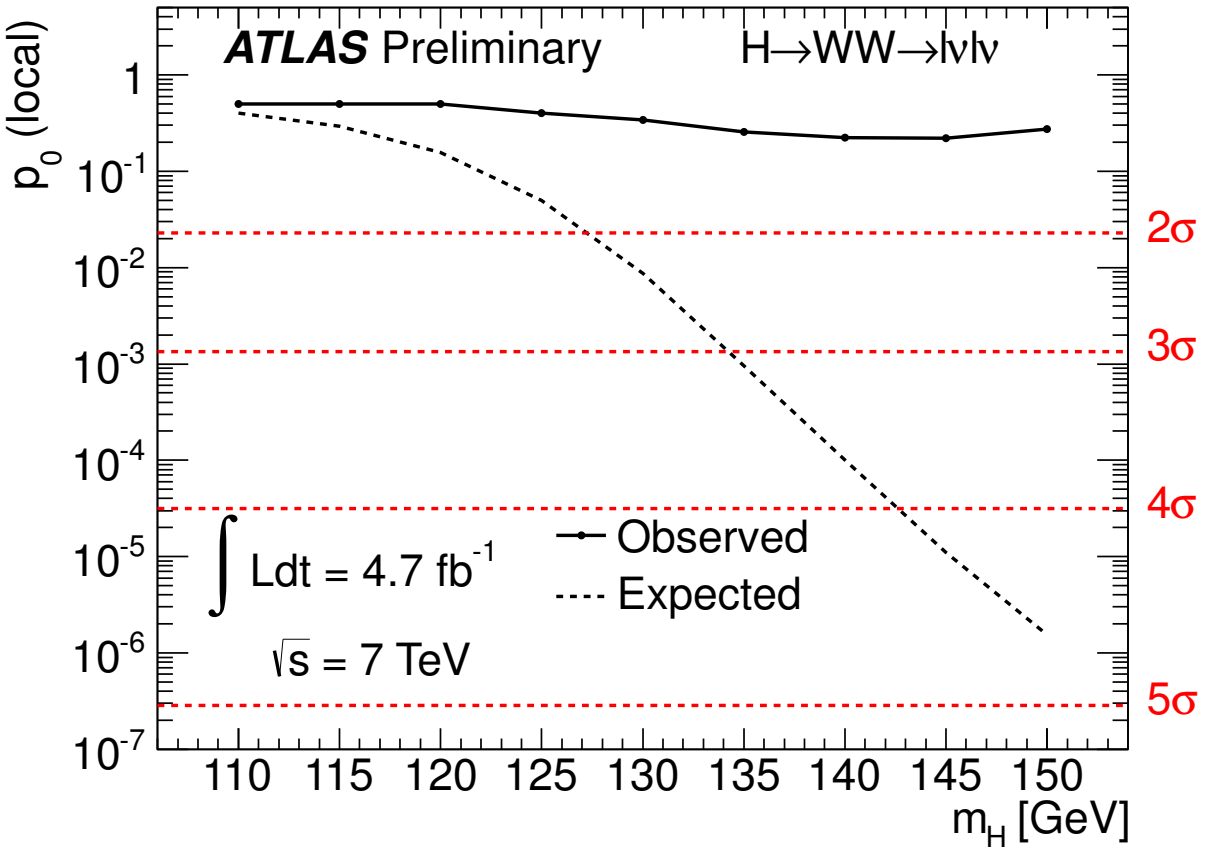
$H \to WW^* \to \ell\nu\ell\nu$: Results



95% C.L. exclusion of the SM higgs as a function of its mass.

Observed exclusion : $m_H \in$ [131,See S. Brunet's talk] GeV

$H \to WW^* \to \ell\nu\ell\nu$: Results

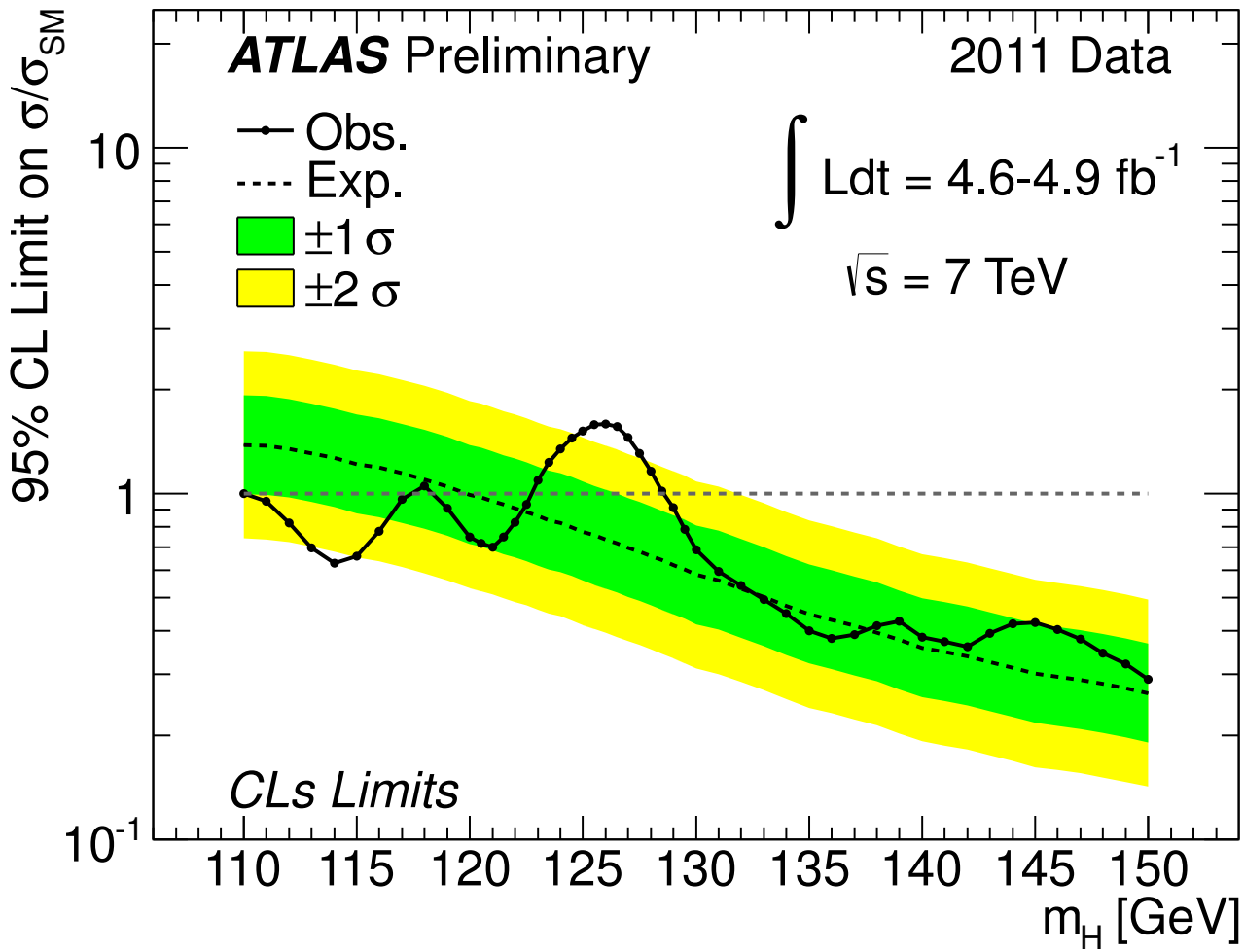


Local p-value as a function of the Higgs mass.

Combination of the channels

- The different channels are combined to set the limit on the SM Higgs boson :
  - Low mass channels : $H \to \gamma\gamma$, $H \to ZZ^* \to 4\ell$, $H \to WW^{(*)} \to \ell^+\nu\ell^-\bar{\nu}$, $H \to \tau\tau$, $VH \to b\bar{b}$
  - High mass channels : $H \to ZZ \to \ell^+\ell^- q\bar{q}$, $H \to ZZ \to \ell^+\ell^-\nu\bar{\nu}$, $H \to WW \to \ell\nu q\bar{q}$
- The combination procedure is based on the profile likelihood ratio test statistic :
  - Extracts the information on the signal strengh from the full likelihood
  - Takes into account the systematic uncertainties and their correlations
- Exclusion limits based on the CL_s method
- The exclusion is set on the ratio $\mu = \sigma/\sigma_{SM}$

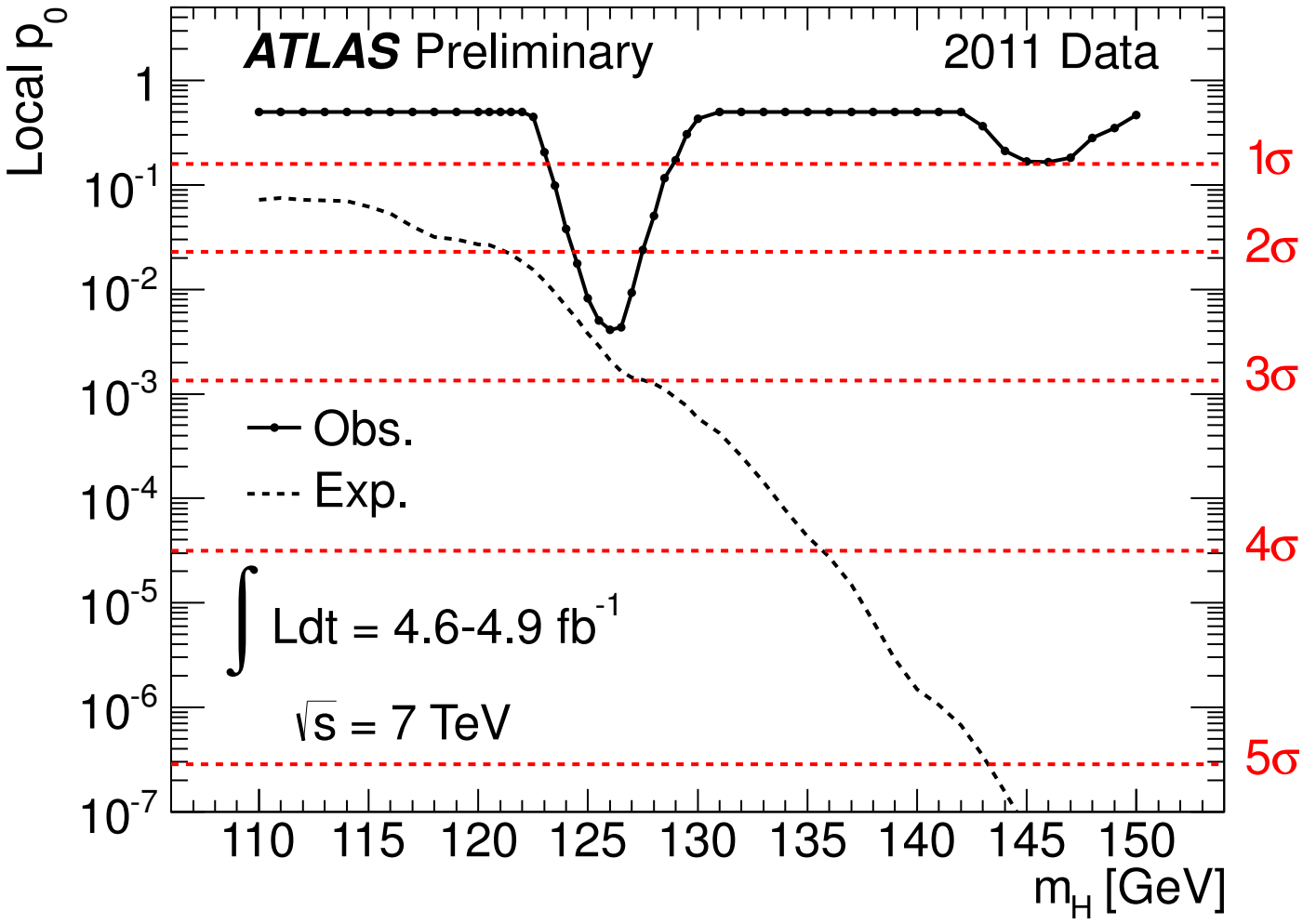
Combination of the channels



Expected exclusion at 95% C.L. : $m_H \in$ [119,See S. Brunet's talk] GeV

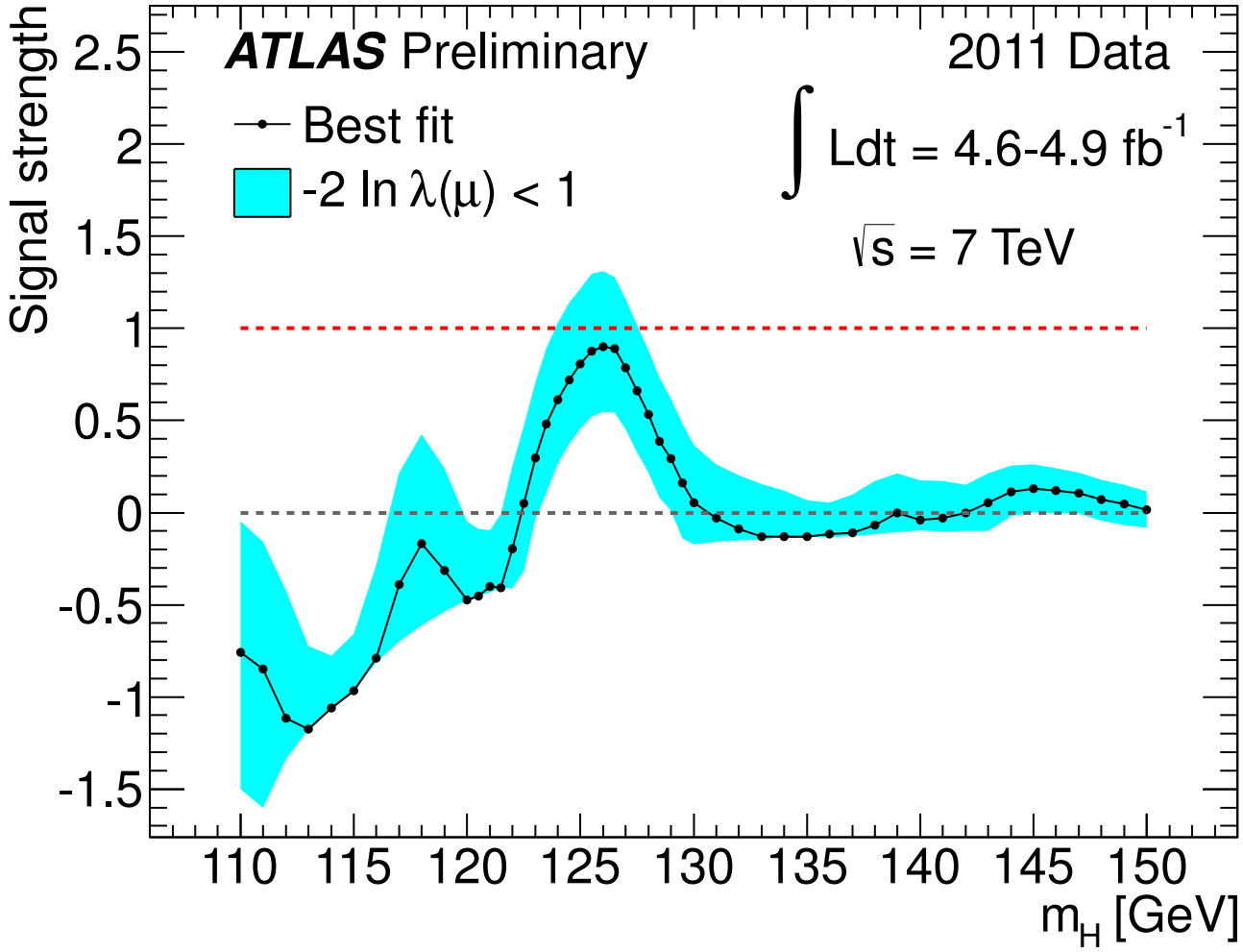
Observed exclusion : $m_H \in$ [110,117.5], [118.4,122.7], [128.6,See S. Brunet's talk] GeV

Combination of the channels



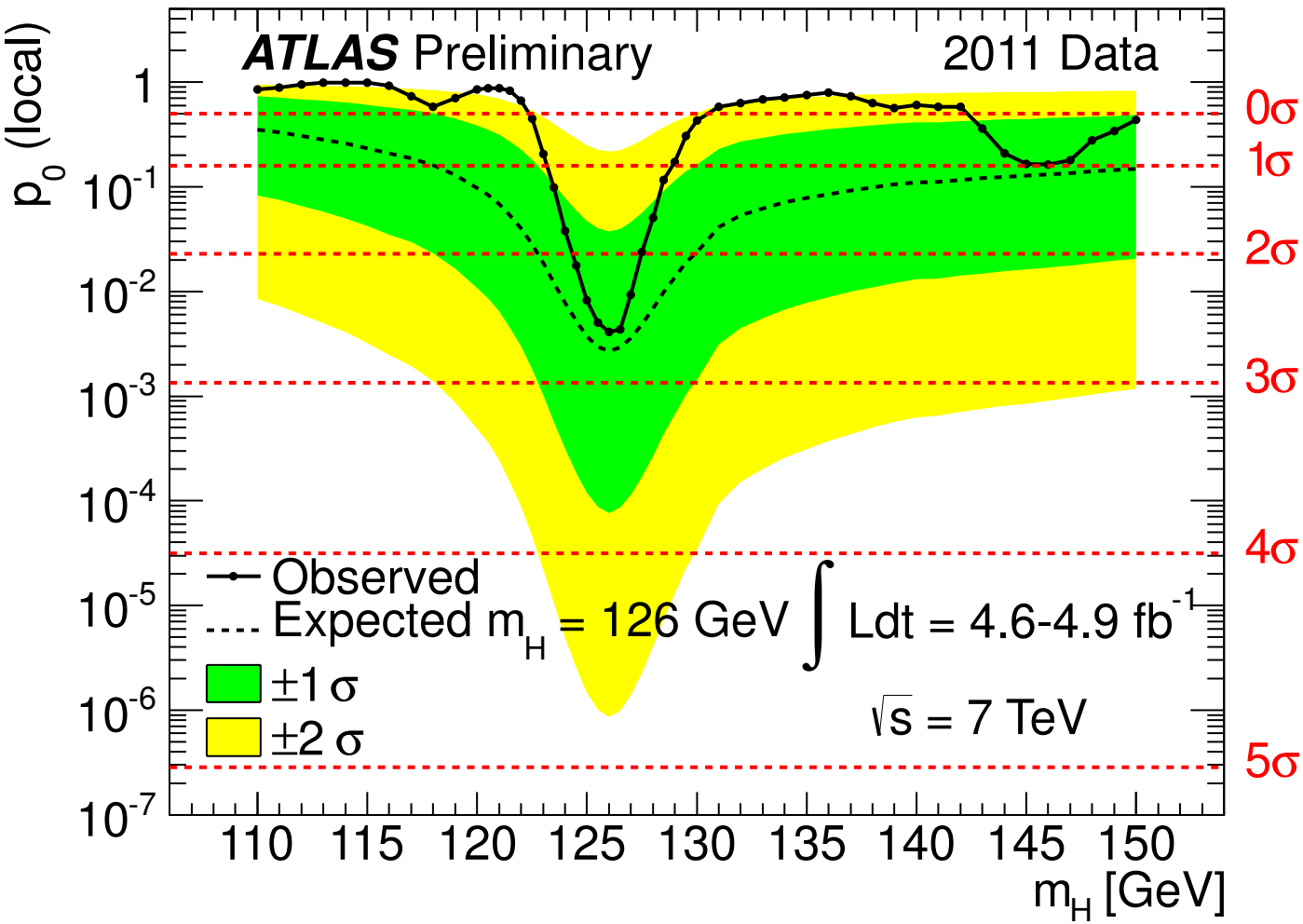
Consistency of the observed results with the background-only hypothesis.

Combination of the channels



The best-fit signal strength $\mu = \sigma/\sigma_{SM}$ as a function of the Higgs boson mass hypothesis.

Combination of the channels : injection plot



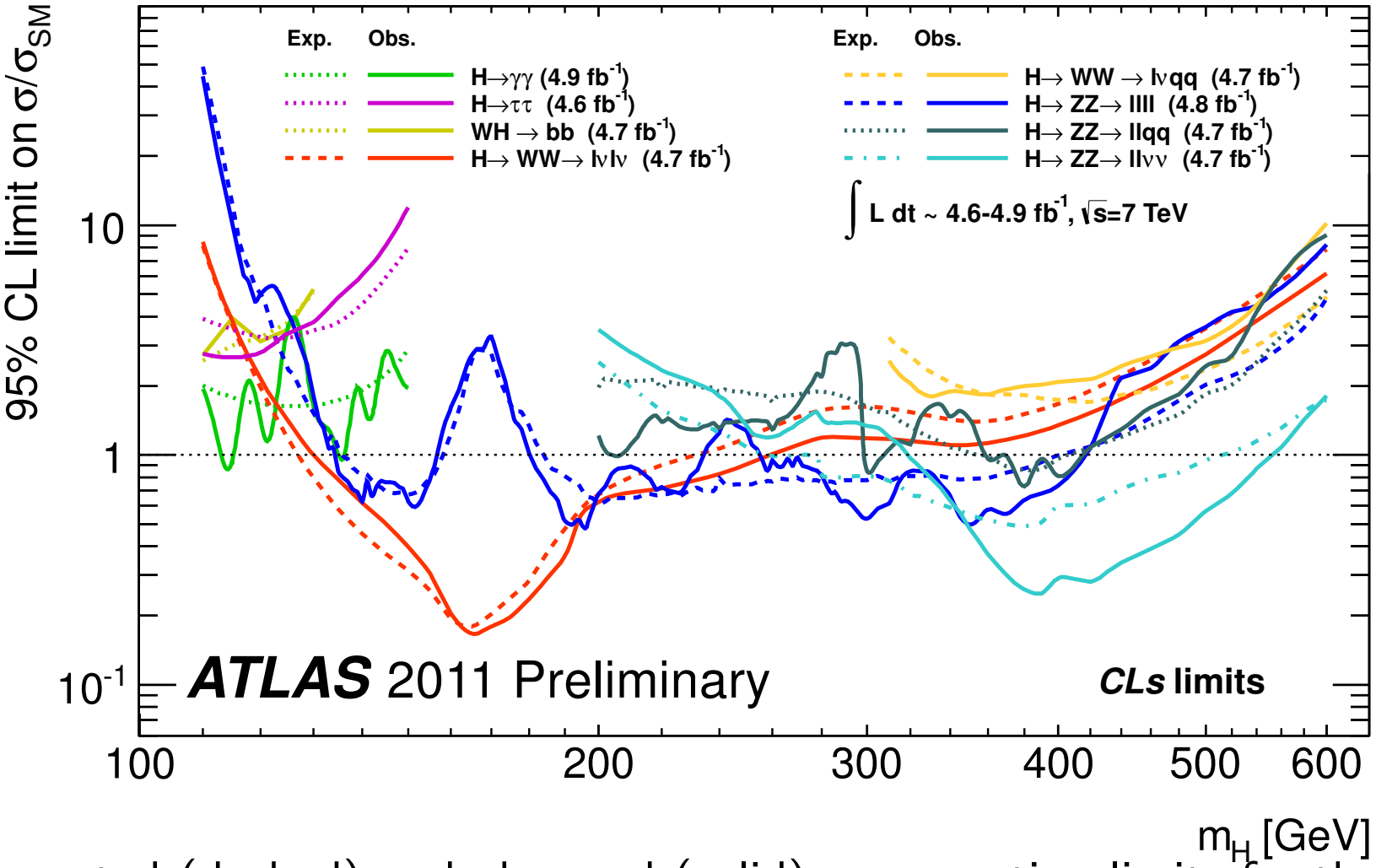
Combination of the channels

- An excess of events is observed $\sim$ 126 GeV with a local significance of 2.6 σ :
- The local significance of $H \to \gamma\gamma$: 2.8 σ
- The local significance of $H \to ZZ^* \to 4\ell$: 2.1 σ
- The local significance of $H \to WW^* \to \ell^+\nu\ell^-\bar{\nu}$: no excess.

Conclusions

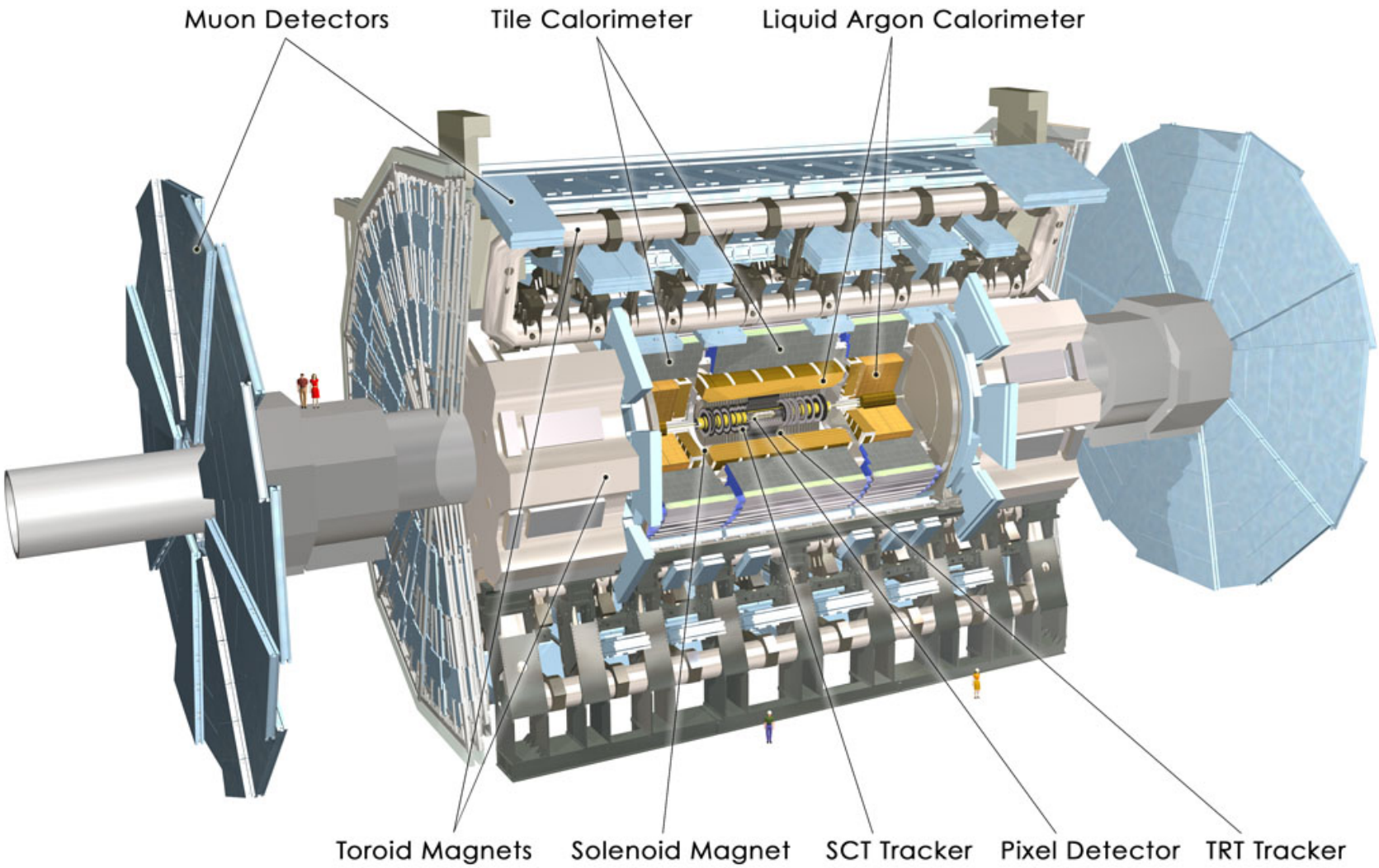
- We are in an exciting period for the Higgs searches
- Allowed SM higgs boson has been constrained to a tiny region : $m_H \in$ [117.5,118.4], [122.7,128.6] GeV
- In the low-mass region no exclusion was possible due to a moderate excess of observed events compared to the background only expectation.
- The excess is most compatible with the SM Higgs hypothesis around 126 GeV (2.6 σ measured with 2.8 σ expected). Statistical significance not large enough to distinguish signal from the background fluctuations (yet).

Backup



The expected (dashed) and observed (solid) cross-section limits for the individual search channels.

Backup : The Atlas detector



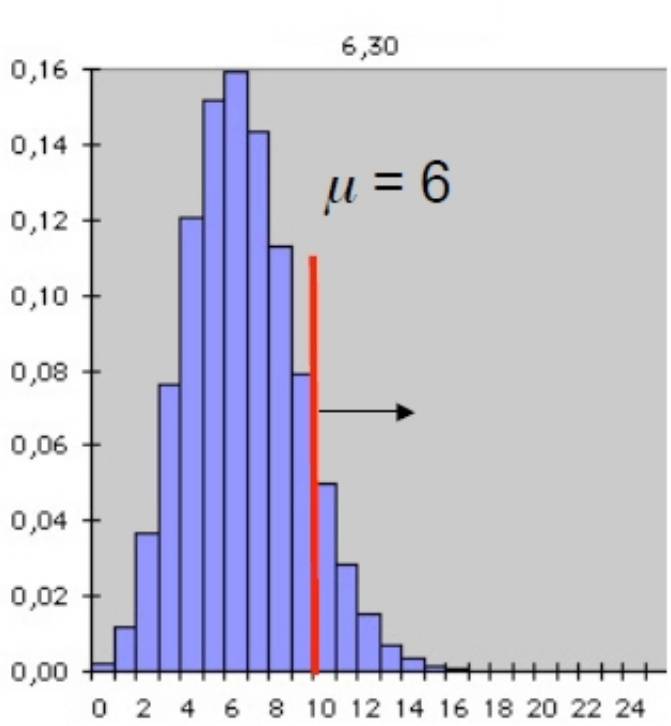
Backup : Test Statistics and p-values

Step 3: Run the experiment, get observed value of test statistic.

Step 4: Compute p-value

$p(n \geq n_{obs} | H_0)$

Example:
H_0: $b = \mu = 6$
$n_{obs} = 10$
p-value = 0.0839



A p-value is **not** the "probability H_0 is true"

But many often say that.

Statistics/Thomas R. Junk/TSI July 2009

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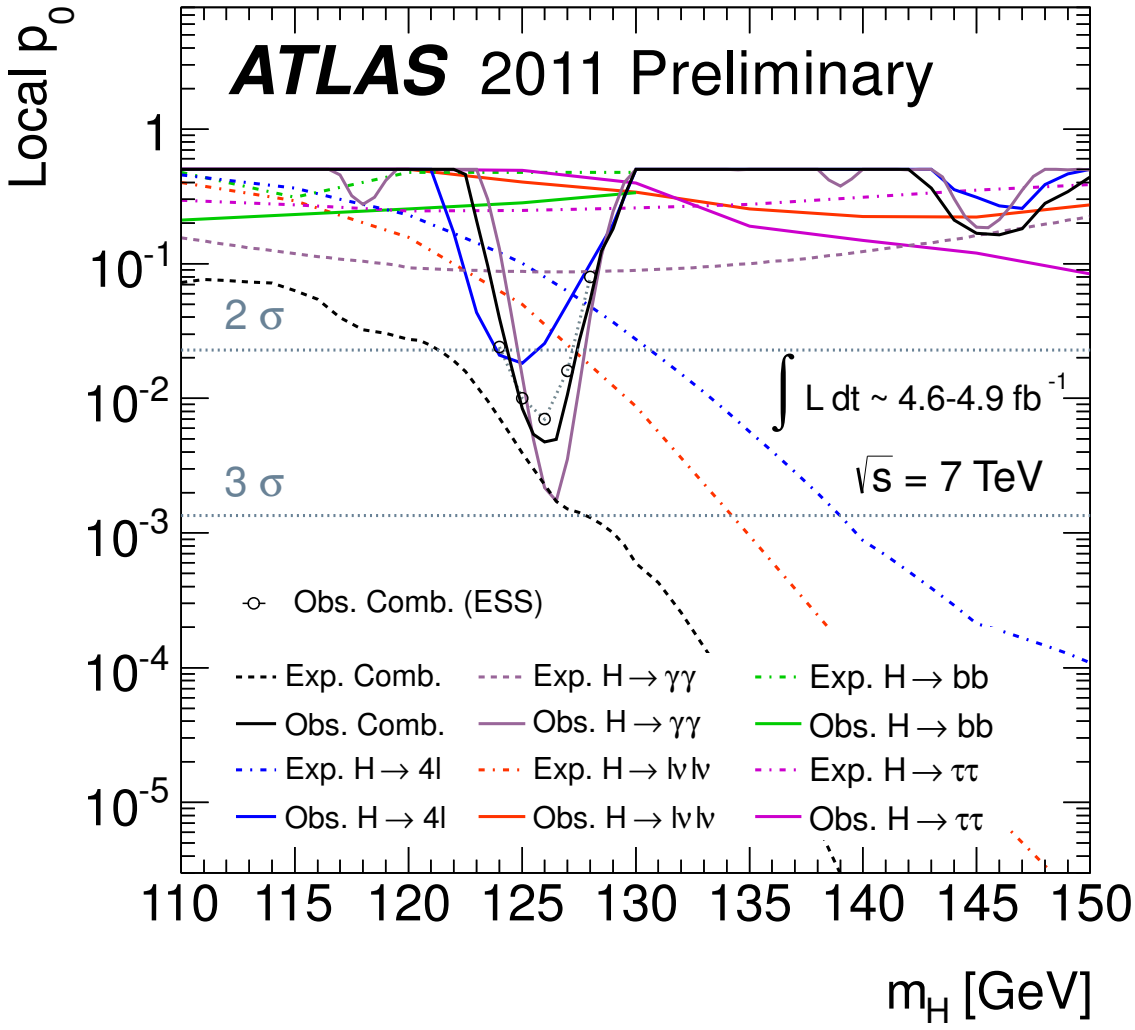
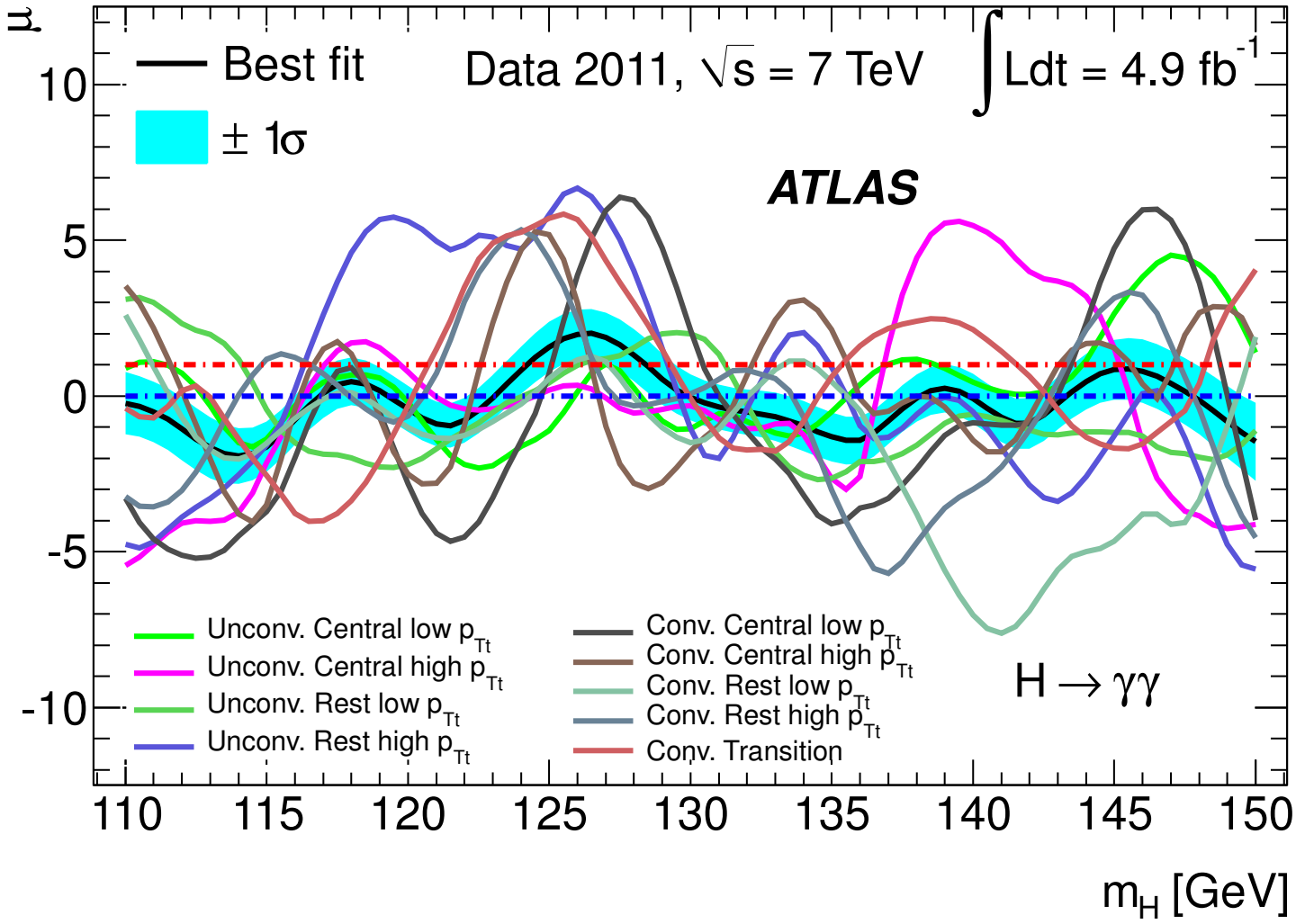
Backup : local probability p0

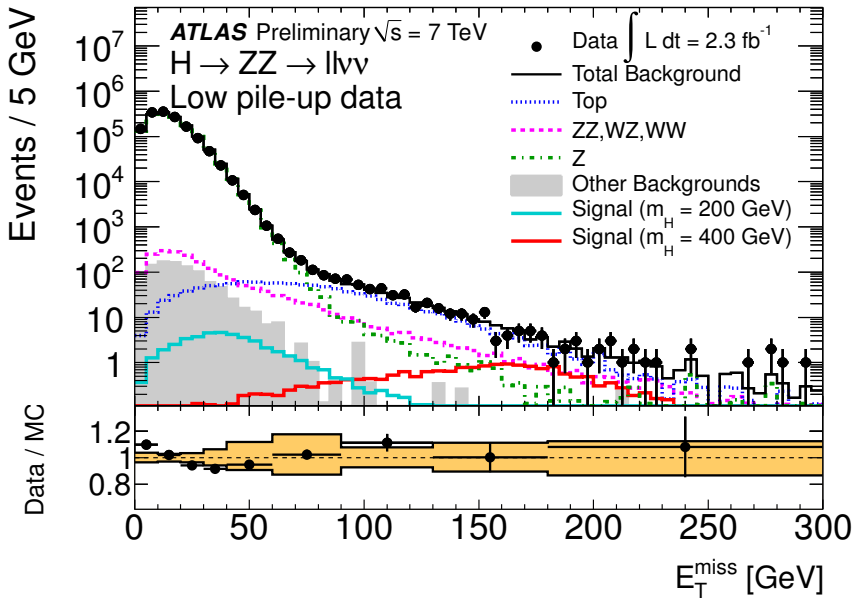


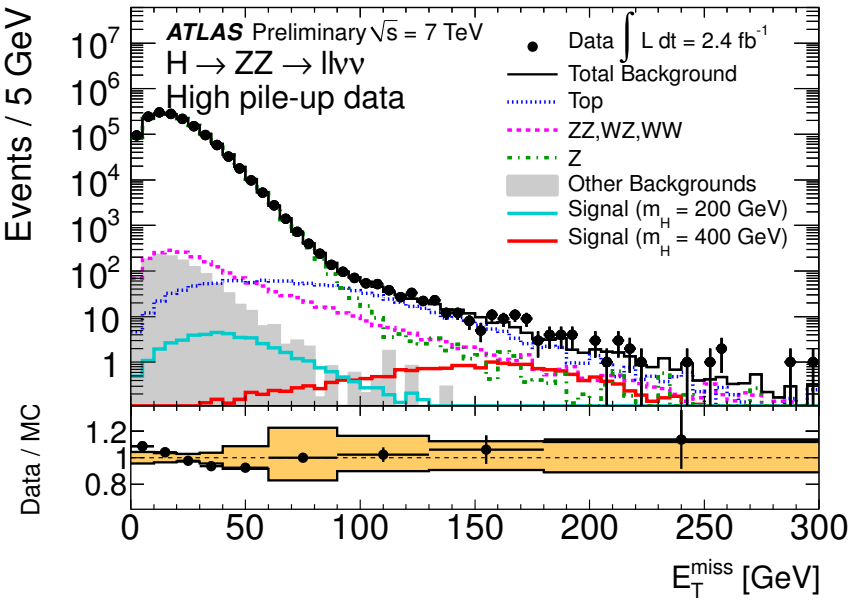
Backup : The best-fit signal strength for $H \to \gamma\gamma$



Backup : Pile-up effect

The $H \to ZZ$ is sensitive to the pile-up and has separated the analysis depending on the pile-up conditions.





Backup : References

"Search for the Standard Model Higgs boson in the diphoton decay channel with 4.9 fb-1 of pp collisions at sqrt(s)=7 TeV with ATLAS," arXiv:1202.1414 [hep-ex].

"Search for the Standard Model Higgs boson in the decay channel H->ZZ(*)->4l with 4.8 fb-1 of pp collision data at sqrt(s) = 7 TeV with ATLAS," arXiv:1202.1415 [hep-ex].

"Search for the Standard Model Higgs boson produced in association with a vector boson and decaying to a b-quark pair using up to 4.7 fb1 of pp collision data at s = 7 TeV with the ATLAS detector at the LHC" https://cdsweb.cern.ch/record/1429664

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