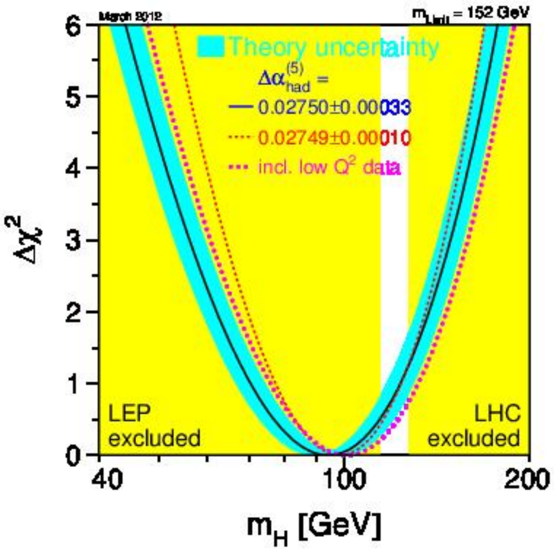
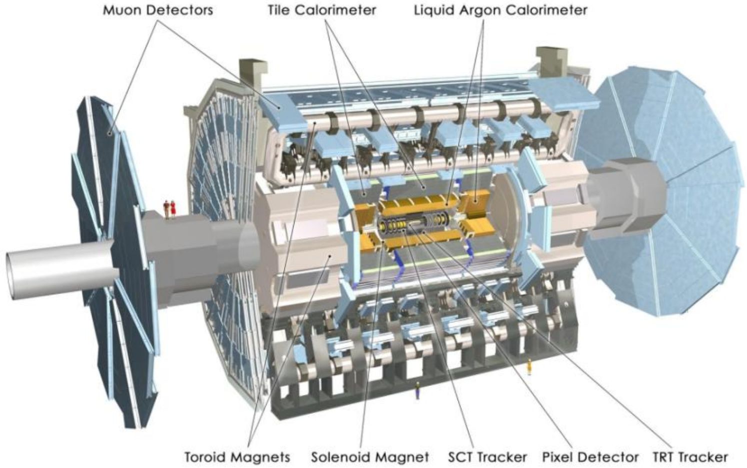
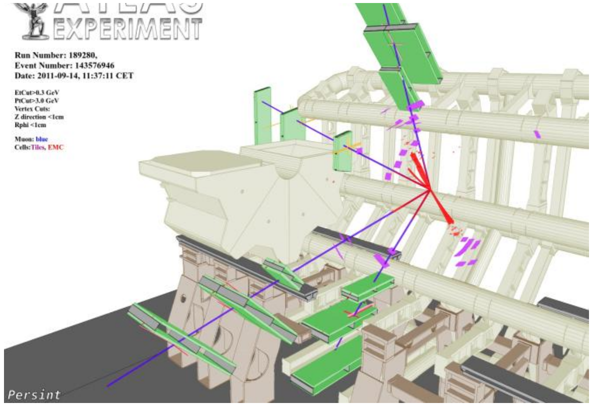
Current status of Higgs boson searches from ATLAS



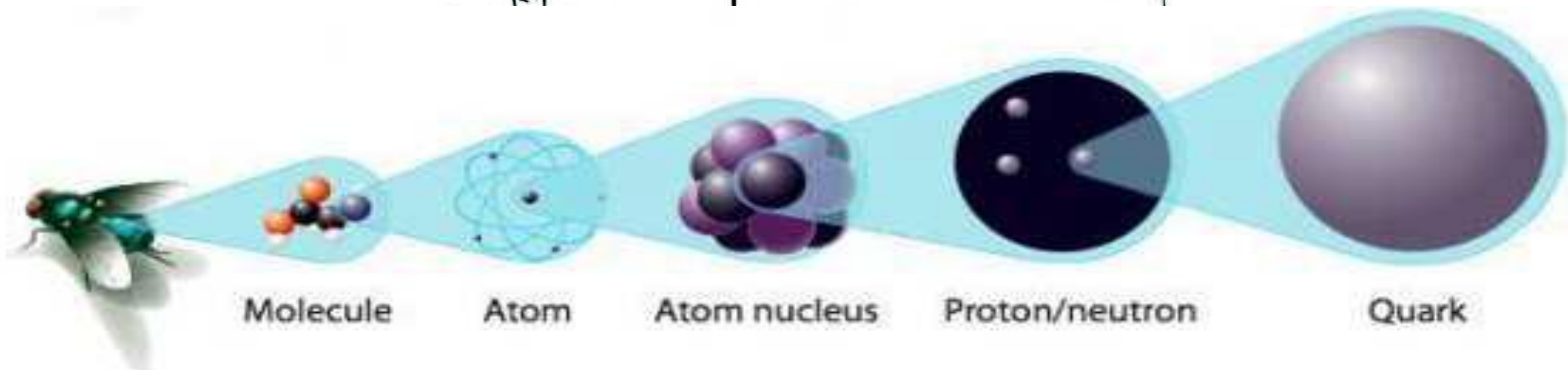




Introduction

- For 50 years now, particle phycisists have been searching for a particle called the Higgs boson.
  – Postulated to exist in the 1960’s to solve problems in the theory of elementary particles.
- The LHC at CERN was built primarily to give the final answer to the question of the Higgs boson existance.
  – During 2011 the experiments collected a lot of data and made significant progress towards this goal.
- In this talk I am going to try to explain the current results from the Higgs boson searches.
  – Will show why 2012 will be the year of the Higgs boson.

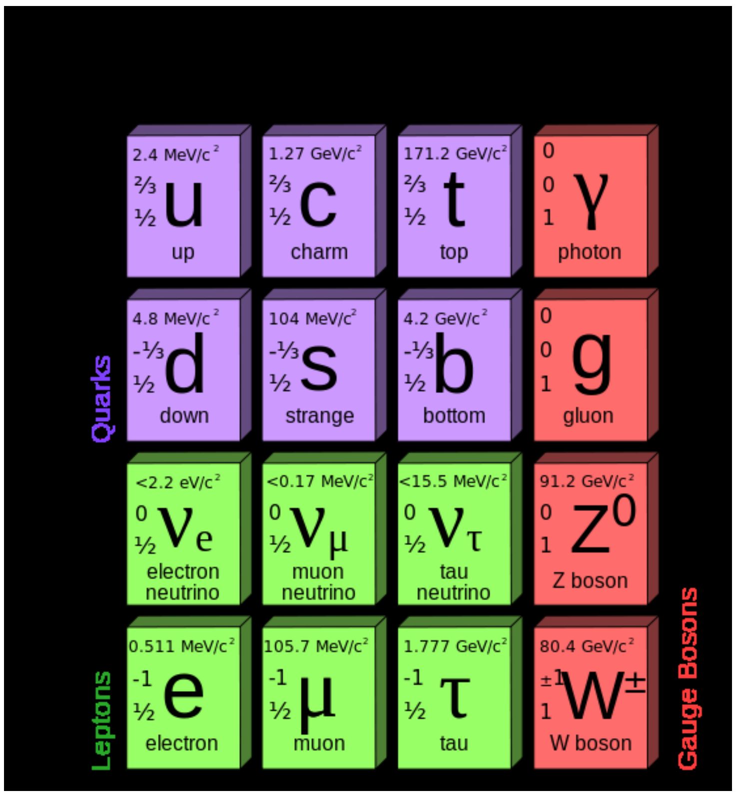
Particle Physics



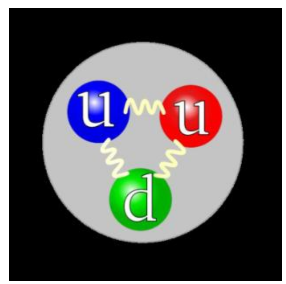
The Standard Model

- Describes the elementary particles and the forces that act between them (the motion of the particles).

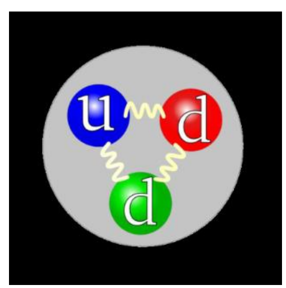
Particle content



proton



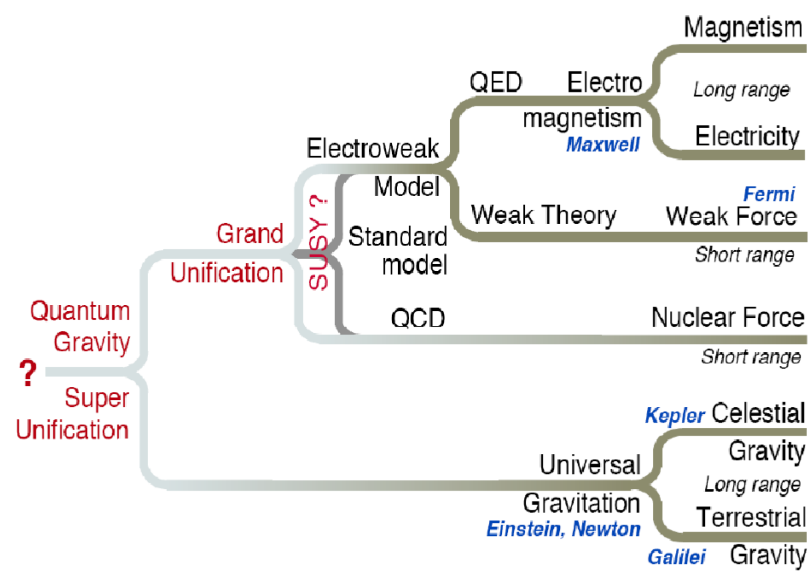
neutron



- Matter particles are spin-1/2 fermions.
  - First generation stable. Make up the atoms.
  - 2nd and 3rd generation heavier.
- The forces are mediated by spin-1 bosons.

The Forces

- We usually say that there are four forces in nature.
  - Dream of particle physics is to unify all forces into one single force. The unification will happen at a very high energy.
- The electromagnetic force, mediated by photons.
- The weak force, mediated by W and Z bosons. Responsible for radioactive decays.
- The strong force, mediated by gluons. Holds protons, neutrons and nuclei together.
- Gravity. There is no microscopic description of gravity.



The Higgs Boson

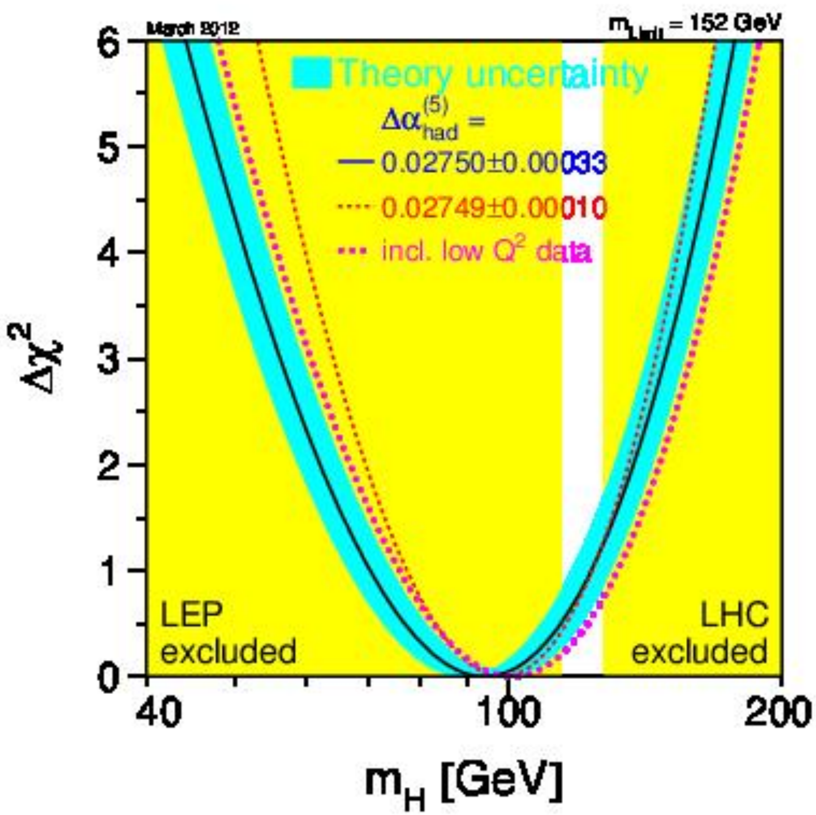
- The Higgs mechanism was proposed in the 1960's to solve many problems with the theory at the time.
  - Mass terms for particles give divergent results, unless a new field is introduced to cancel the divergencies.
- The mechanism also explain the electroweak unification. Field gives masses to W and Z bosons.
  - A new, neutral, spin-0 particle with particular couplings is also predicted to exist – the Higgs boson.
  - Fermions acquire mass through interactions with Higgs.
- Everything about the Higgs boson is predicted from theory, only the Higgs mass is a free parameter.
  - Masses less than 115 GeV excluded at LEP in 1990's.

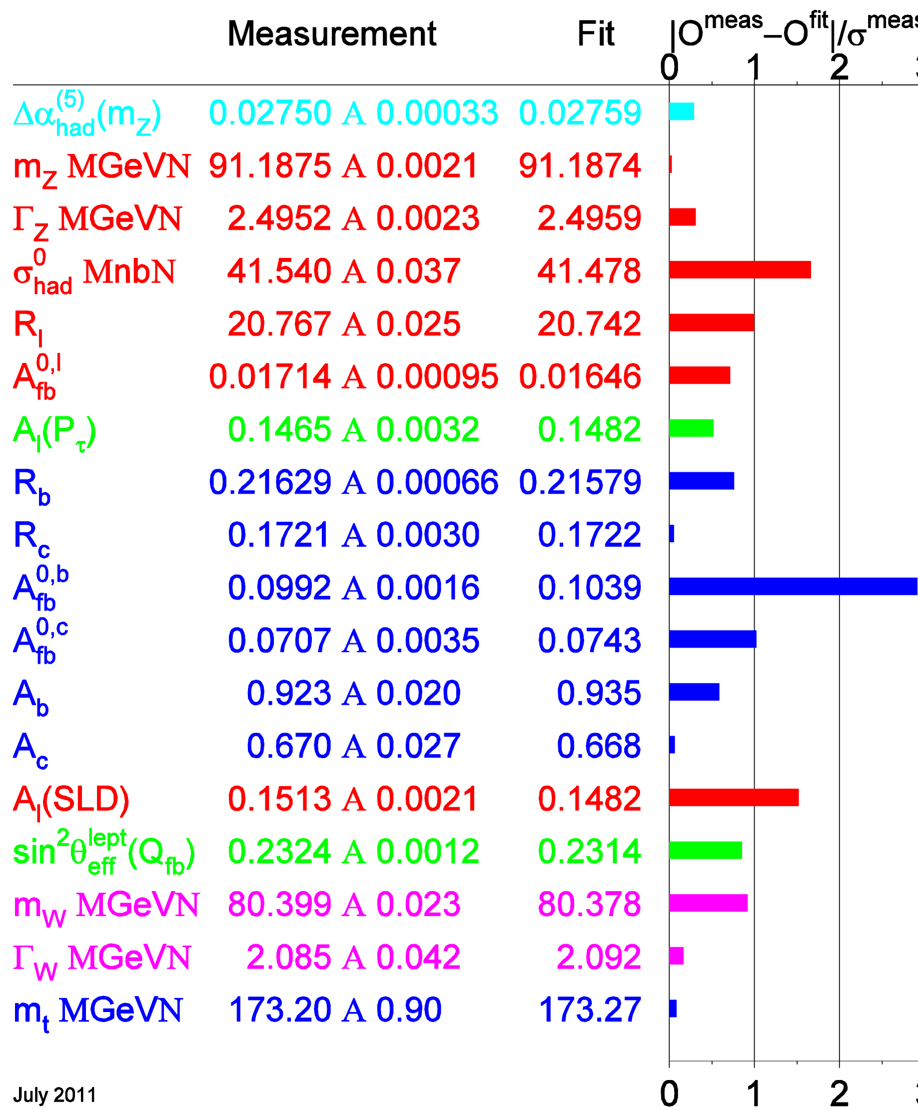
Electroweak Precision Observables

- LEP also showed that SM is a very succesful theory.
  - Precision measurements of the Z boson done with uncertainties on the level of a per mille.
- Tree-level (LO) calculations can be done exactly for the Z boson properties from the theory of QED.
  - Results differ from experiments by order of one percent.
  - Higher-order contributions need to be taken into account.
  - Directly probing the contribution of virtual particles. It turns out only the top quark and the Higgs boson matter.
- All LO results can be obtained from a set of three independent parameters of the SM, α, α_S and M_Z.
  - Higher-order corrections given by masses, M_t and M_H.

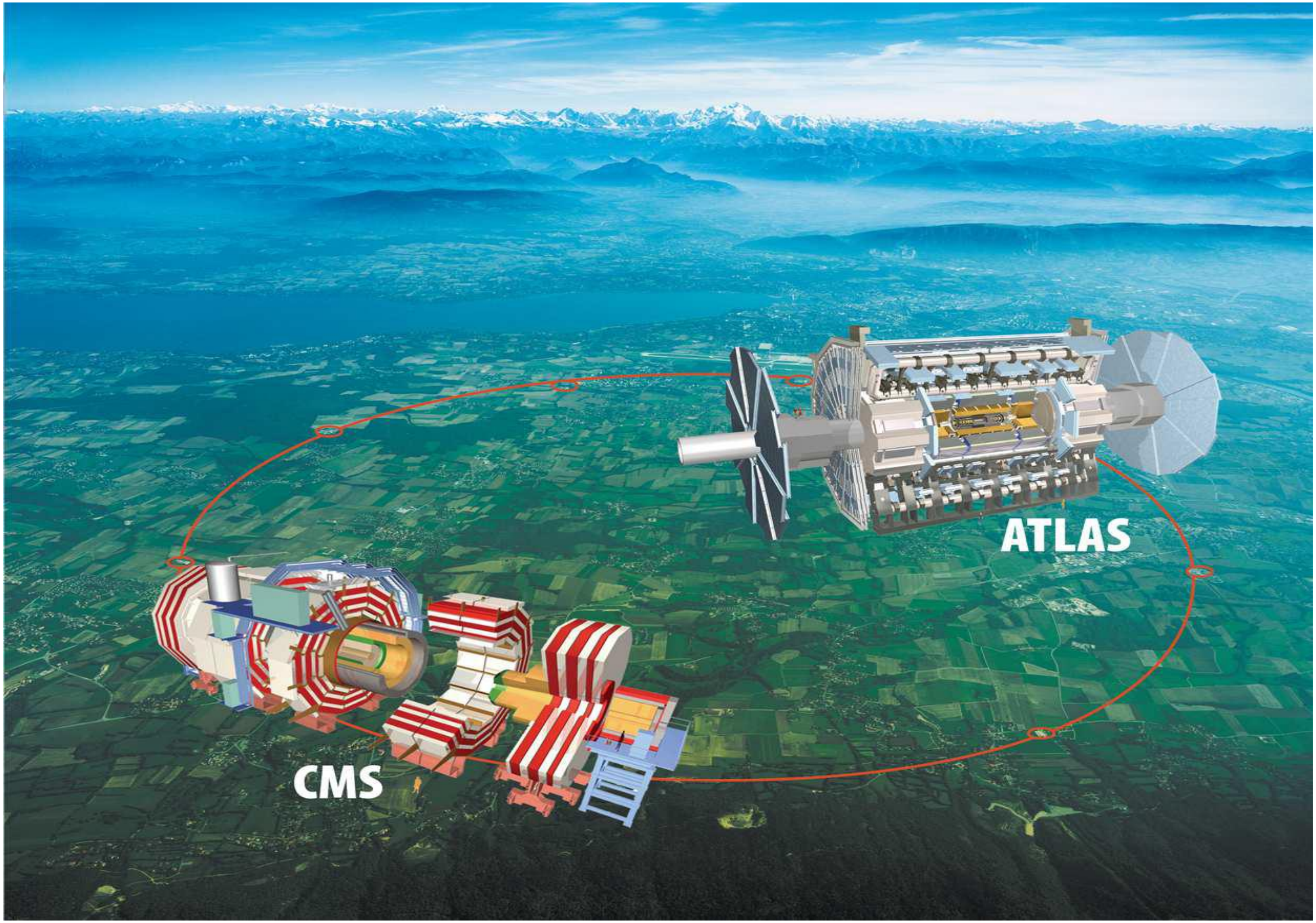
Electroweak Precision Observables

- 18 measurements. Fit with 5 parameters:
  - X^2/dof = 18.3/13.





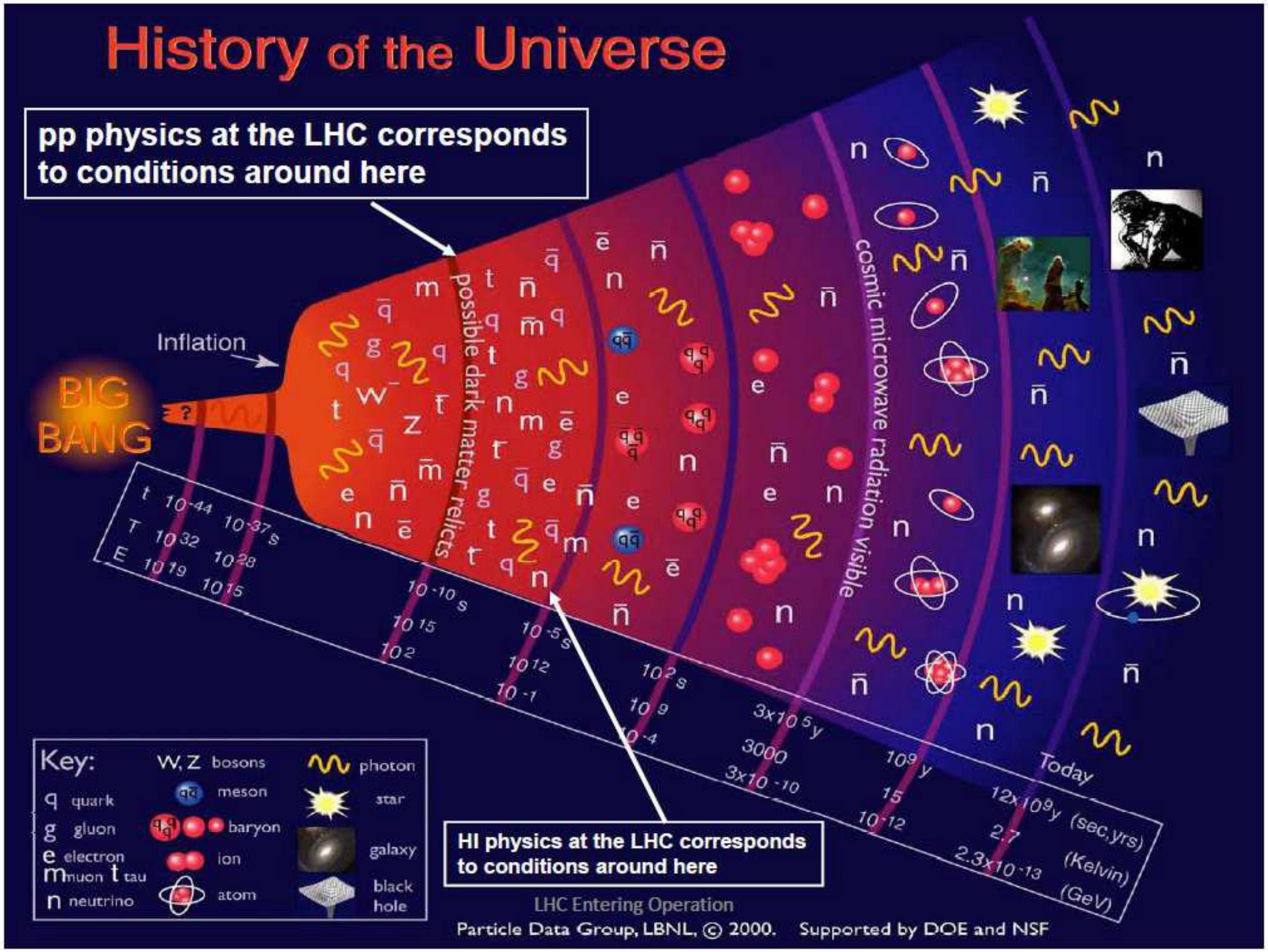
The Large Hadron Collider



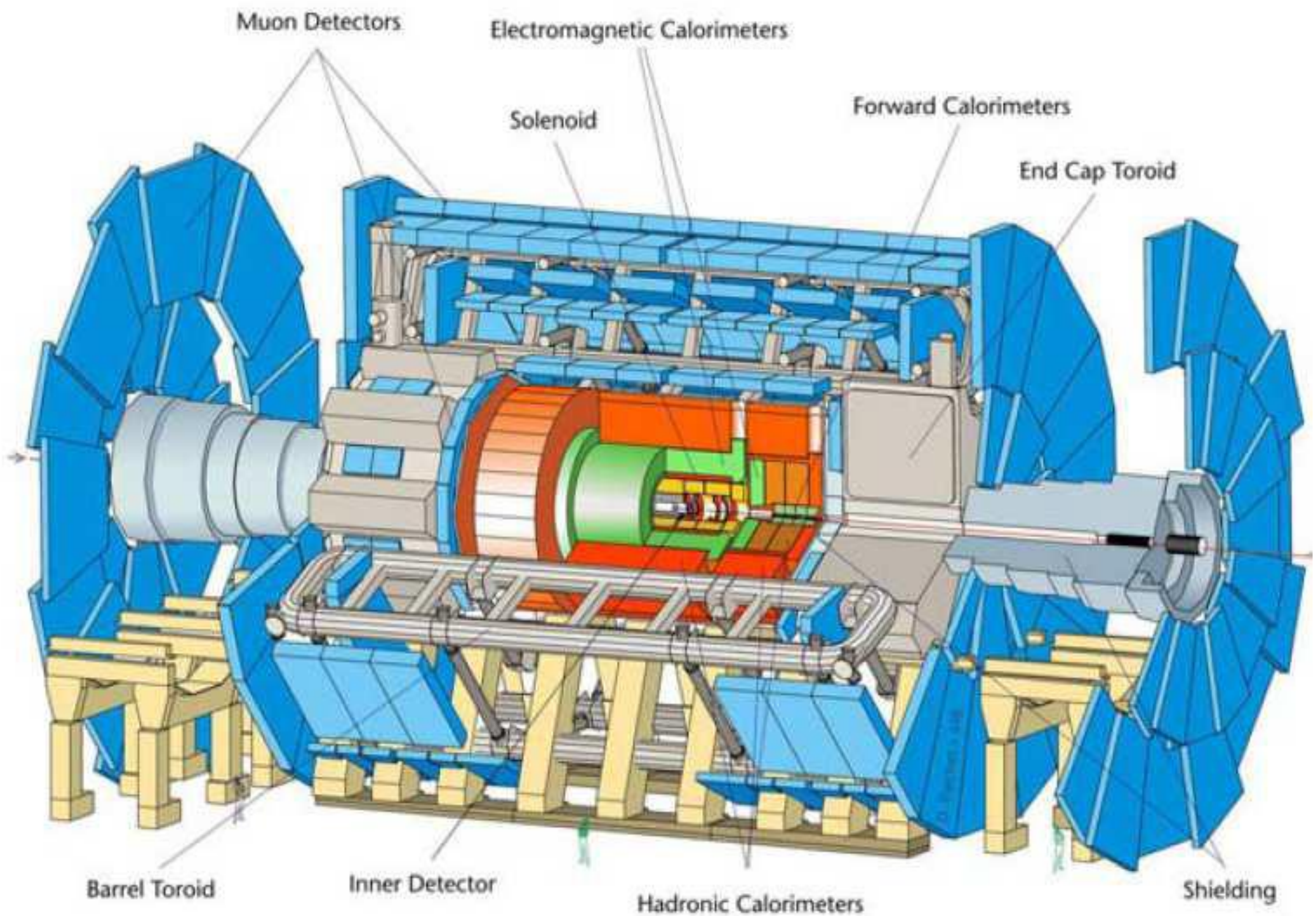
The LHC – a proton-proton collider

- Located outside of Geneva, Switzerland.
  - Circumference of 27 km, in a tunnel 100 m underground.
  - Has two main experiments, ATLAS and CMS.
- The LHC collides two beams of protons, each with an energy of 3.5 TeV. The design is 7 TeV per beam.
  - The proton rest mass is around 1 GeV. The energy of the protons is 3,500 times higher than this.
  - The proton speed is 99.9999991% of the speed of light.
- From the energy in the collisions, new, heavy and unstable particles can be created.
  - By detecting the decay products, the existance of the new particles can be inferred.

The LHC is Probing the Early Universe

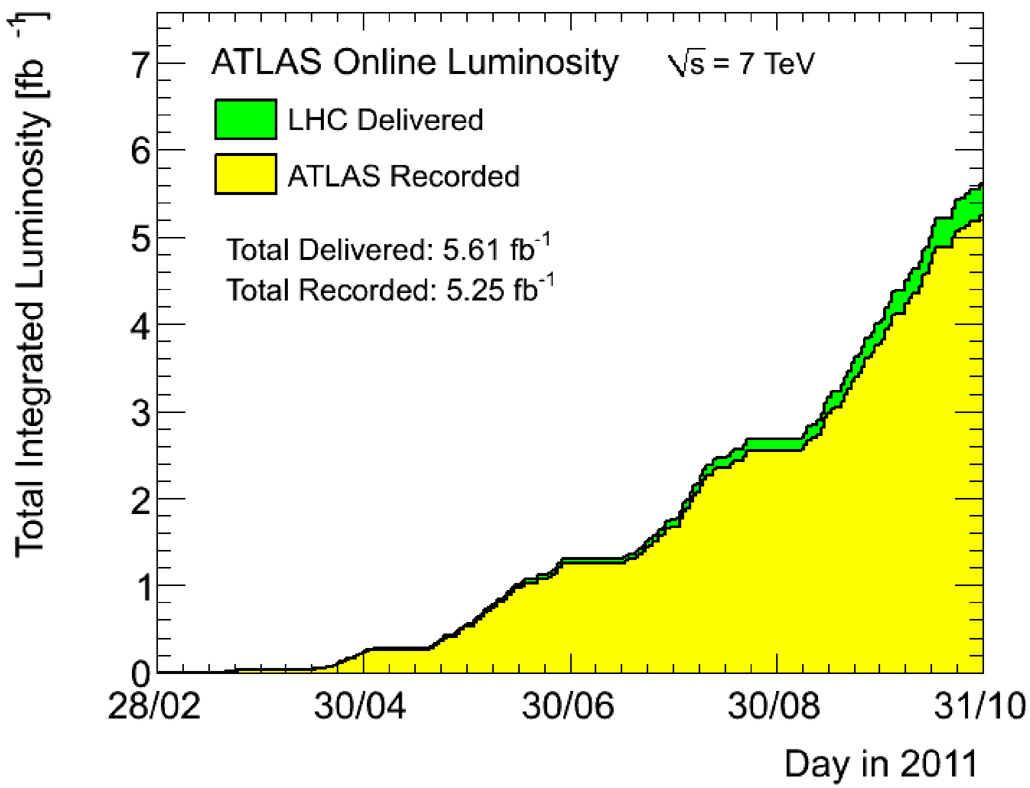


The ATLAS Detector



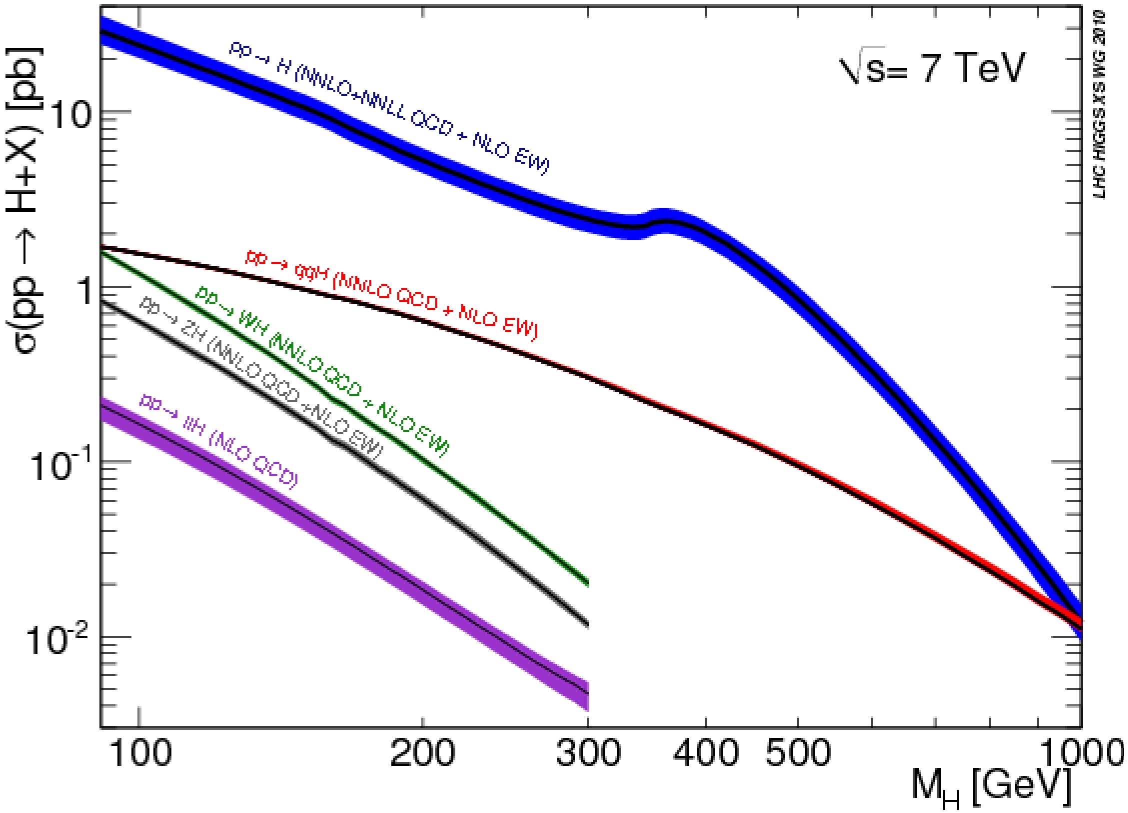
The Data Sample

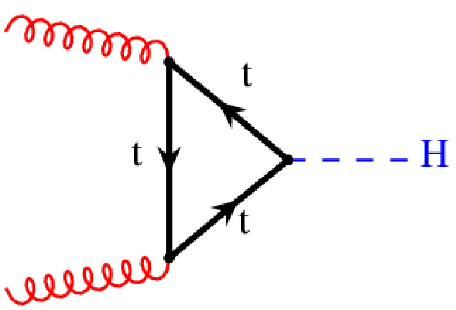
- The amount of collisions delivered by the LHC is measured in luminosity, L, with unit [fb^{-1}].
- $N = \sigma * L$.
- During 2011:
  - LHC delivered about 5 fb-1, or equivalently 5,000 pb^{-1}.
  - ATLAS recorded about 90% of it.

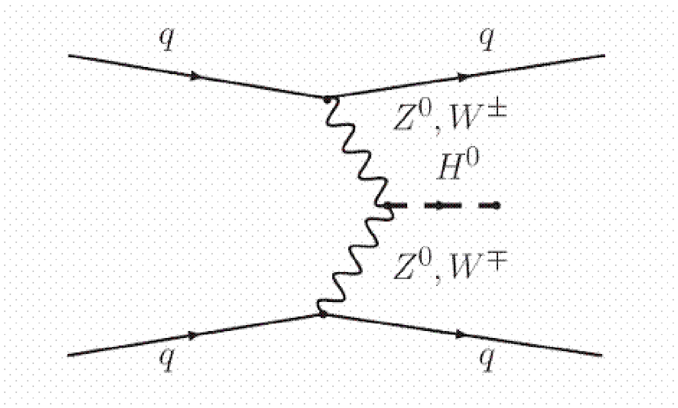


Higgs Boson Production at the LHC

- Total cross section, σ, at the LHC is 10^{11} pb.
  - A Higgs boson produced in 1 out of 10^{10} collisions.

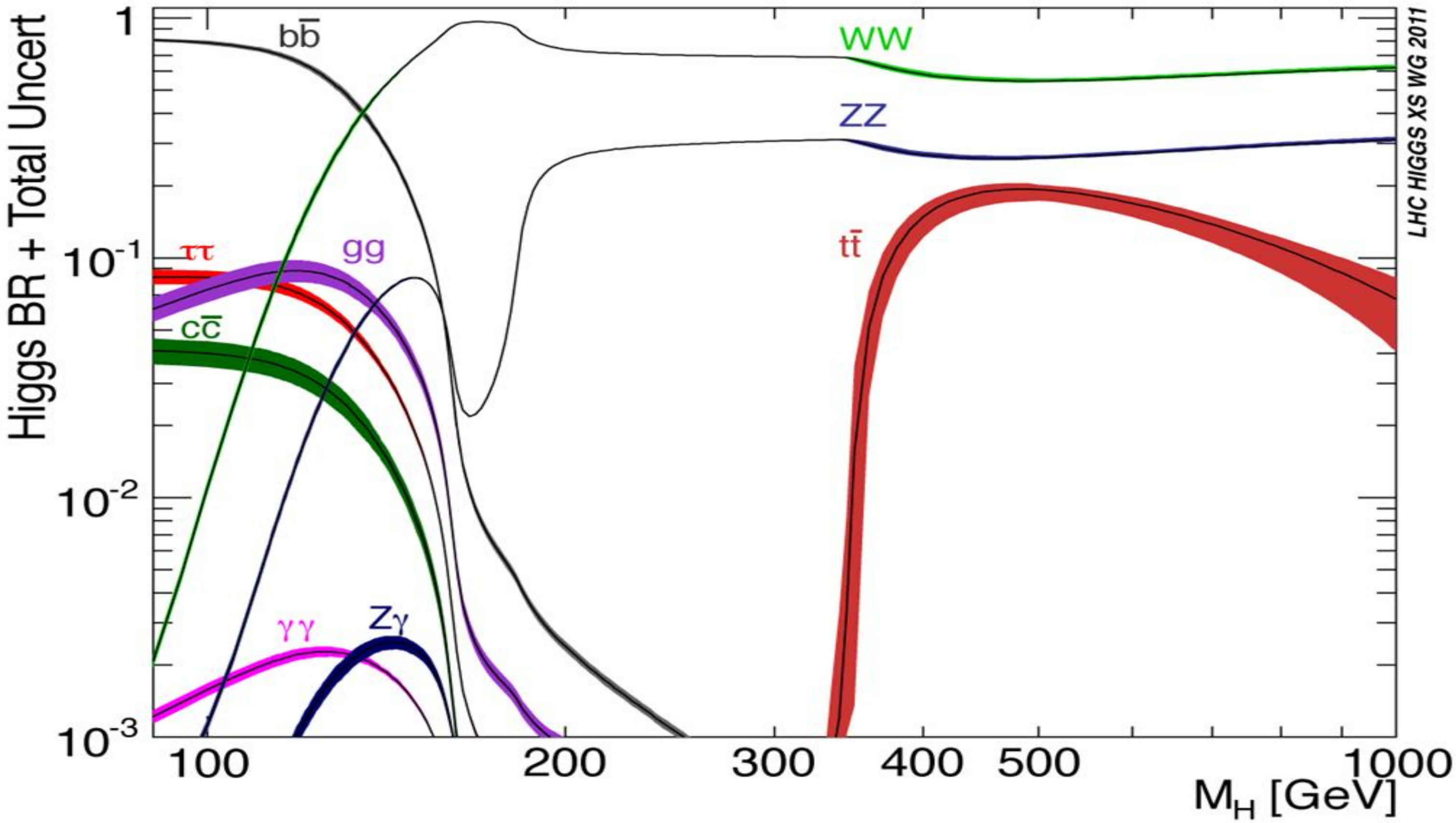






Higgs Boson Decays

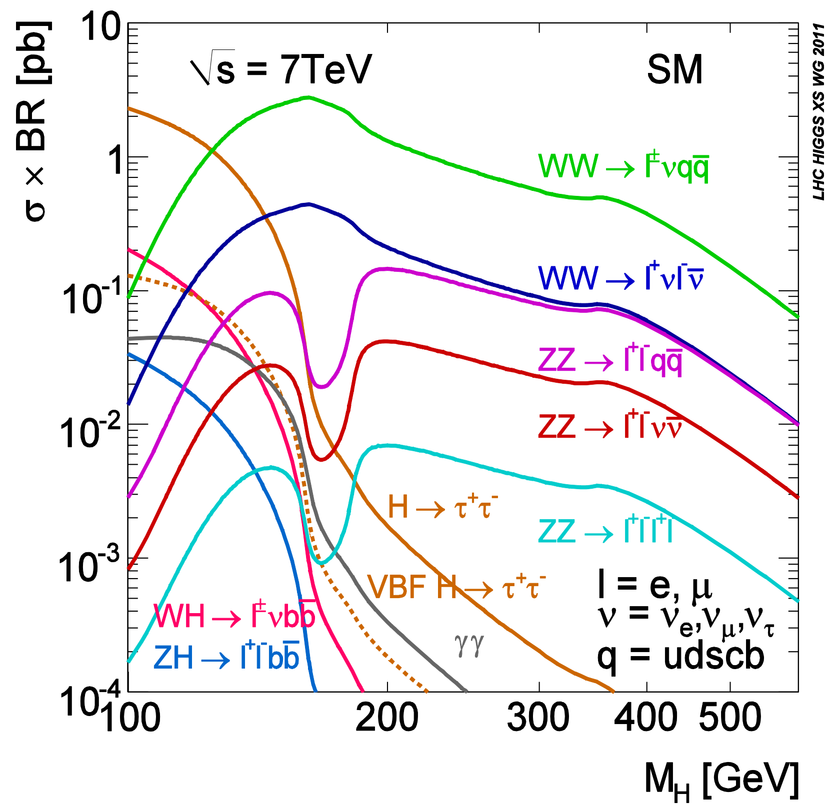
- Depending on the mass of the Higgs boson, it tends to decay to the heaviest available pair of particles.



Search Channels

- The decay probabilities of the Higgs boson and the background estimates have to be taken into account to determine the best search channels.

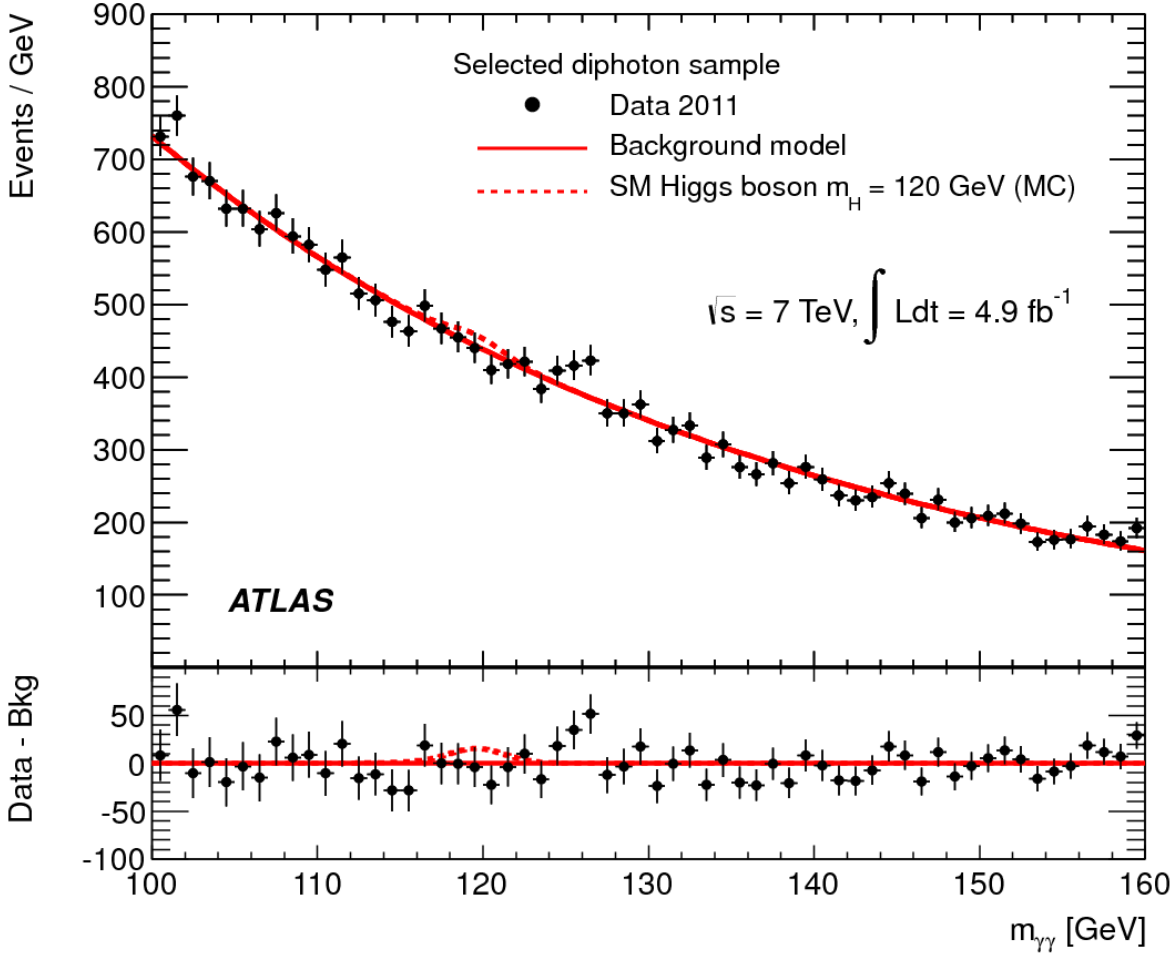
- Three main channels are:
  - The $H \rightarrow \gamma\gamma$ channel.
  - The $H \rightarrow ZZ \rightarrow 4\ell$ channel.
  - The $H \rightarrow WW \rightarrow \ell\nu\ell\nu$ channel.
- Other search channels possible, but of less importance.



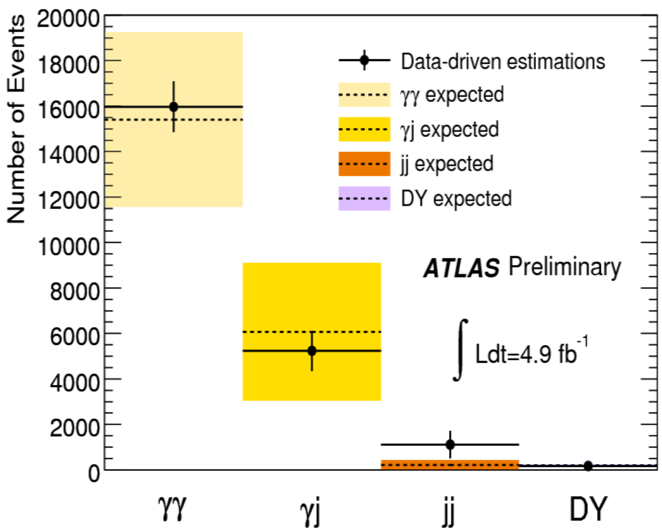
The H→γγ Channel

- Analysis selects two high energy, isolated photons.
  - All the decay products from the Higgs can be reconstructed, can look for a peak in the invariant mass spectrum.
  - Only a viable search channel for low Higgs boson masses.
- Main backgrounds come from production of two photons, γγ, from other sources. No mass prefered.
  - Smaller backgrounds come from misidentification of hadronic particles as photons, called γj and jj.
- Classifies events in 9 different categories, depending on the goodness of the events. For each category, look for a bump in the $m_{\gamma\gamma}$ spectra over background.

The H→γγ Channel

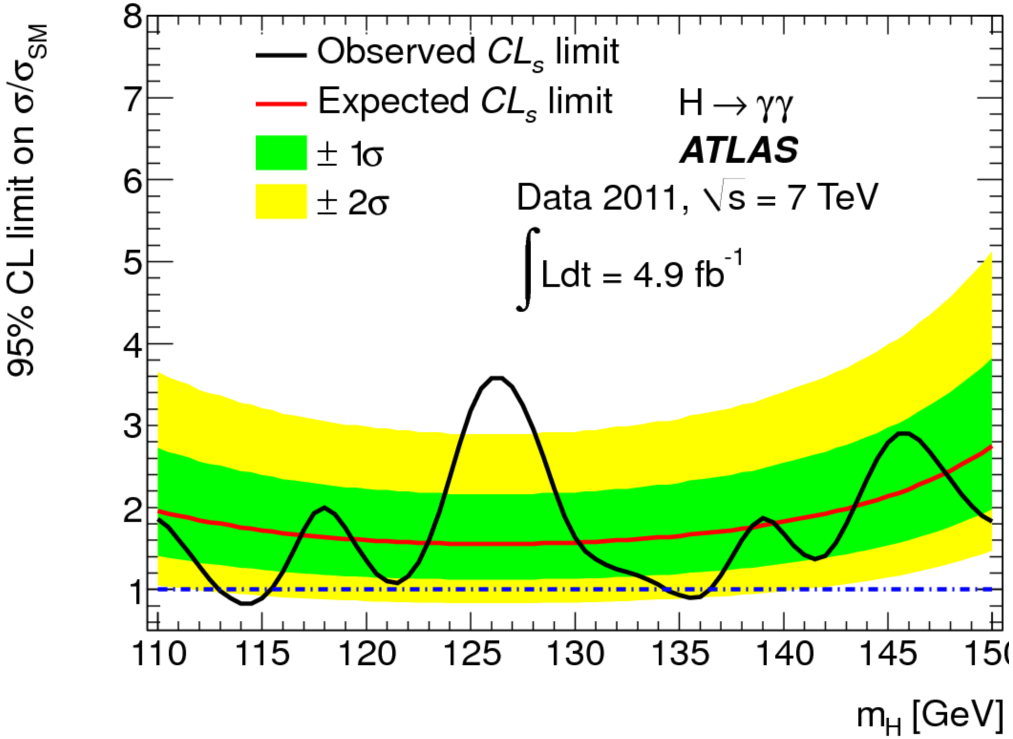


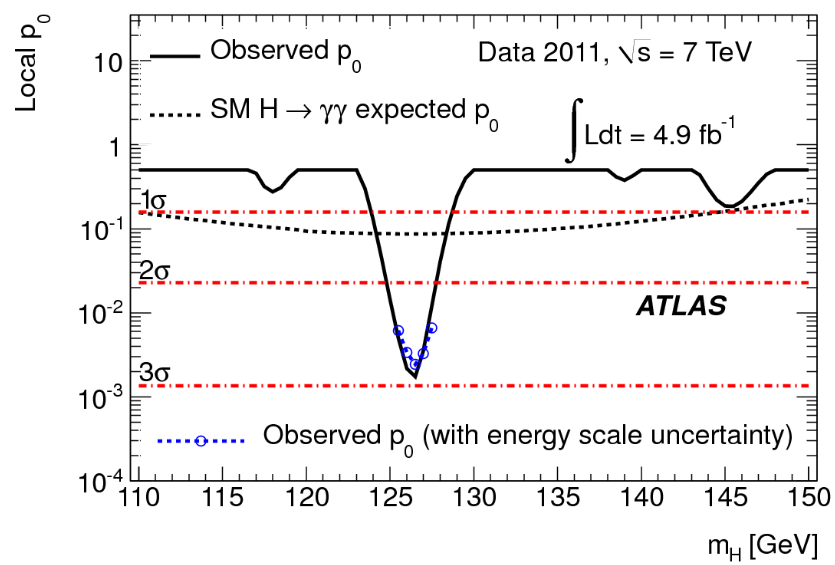
- Background fitted with exponential.
  - Largest excess at a mass of 126 GeV.



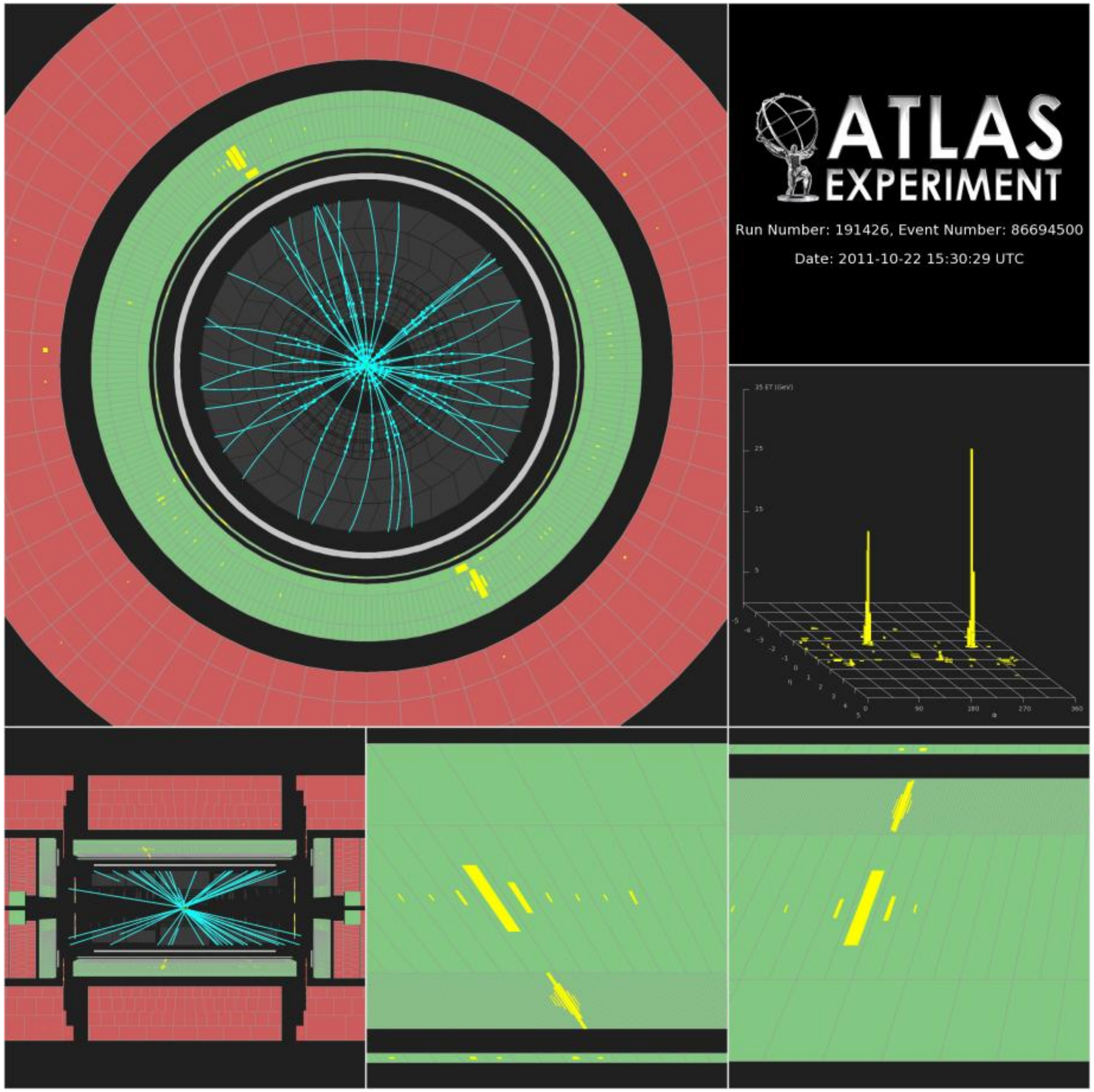
The H→γγ Channel

- Observed exclusion: 113-115 GeV, 134.5-136 GeV.
- Significance: 2.8σ local, 1.5σ global (entire range)

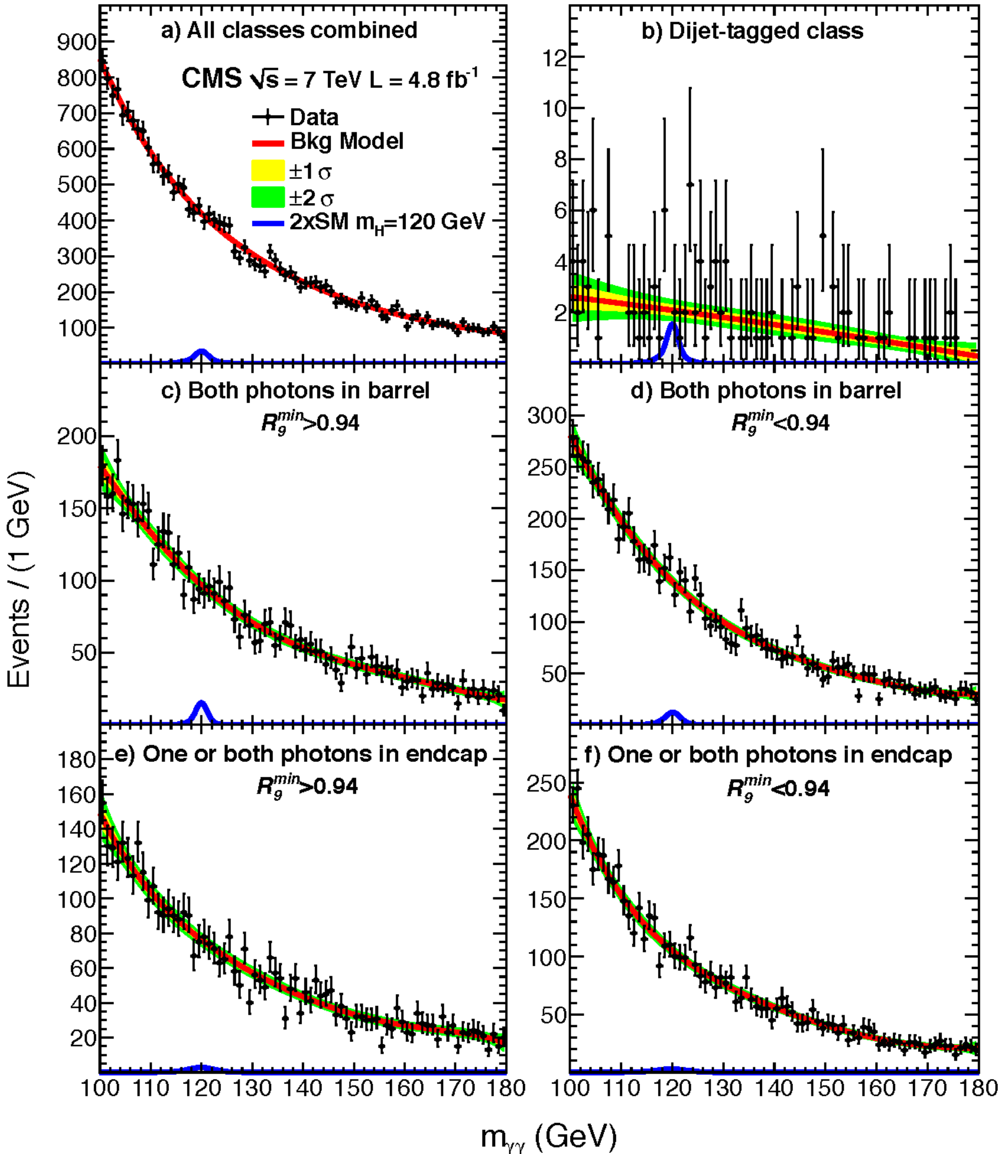


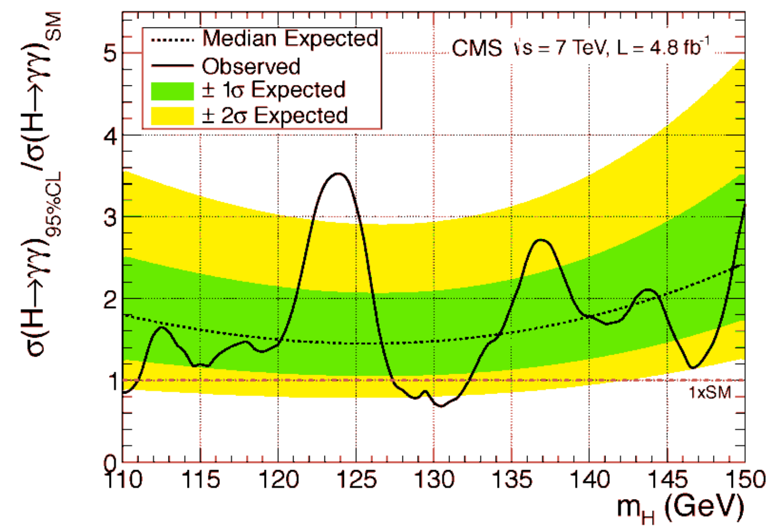


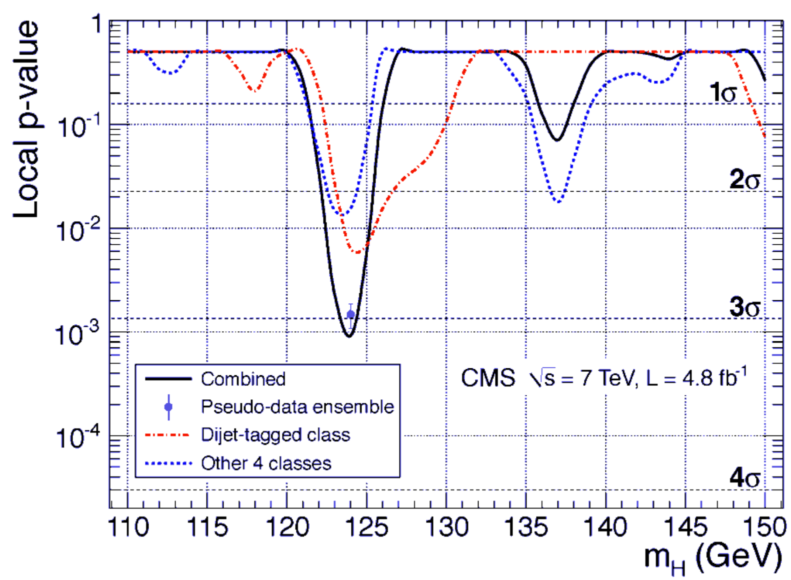
A Candidate Event



The H→γγ Channel from CMS



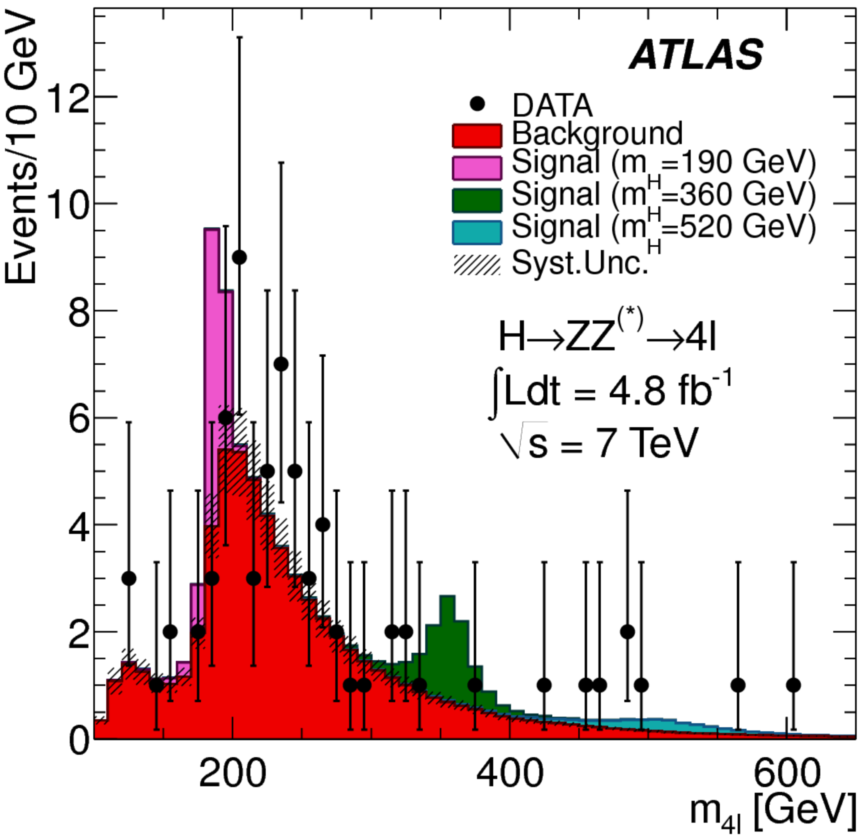


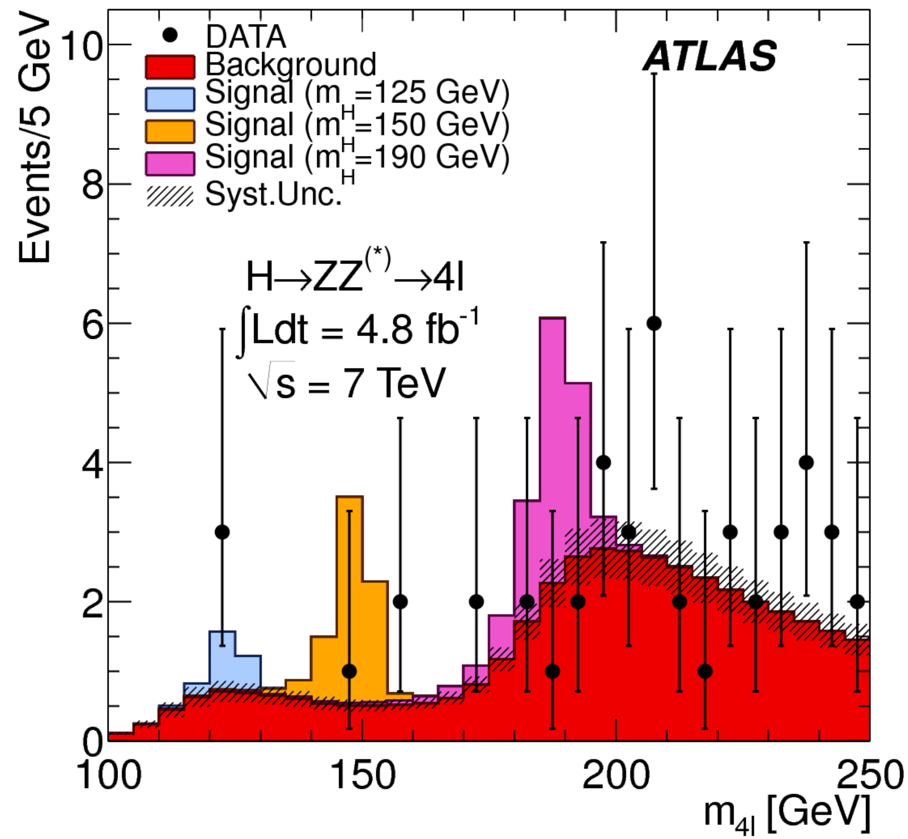


The $H \to ZZ \to 4\ell$ Channel

- The Higgs decays to two Z bosons. These in turn decays to a pair of like-flavor, opposite sign leptons.
  - Search for two pairs of electrons or muons.
  - Very little background, but also a small signal.
  - All decay products from the Higgs decay can be reconstructed, again search for a bump in invariant mass spectra of the four leptons over continous background.
- The $H \to ZZ \to 4\ell$ is a viable search channel for all Higgs masses. At high mass this is the golden channel.

The H→ZZ→4ℓ Channel

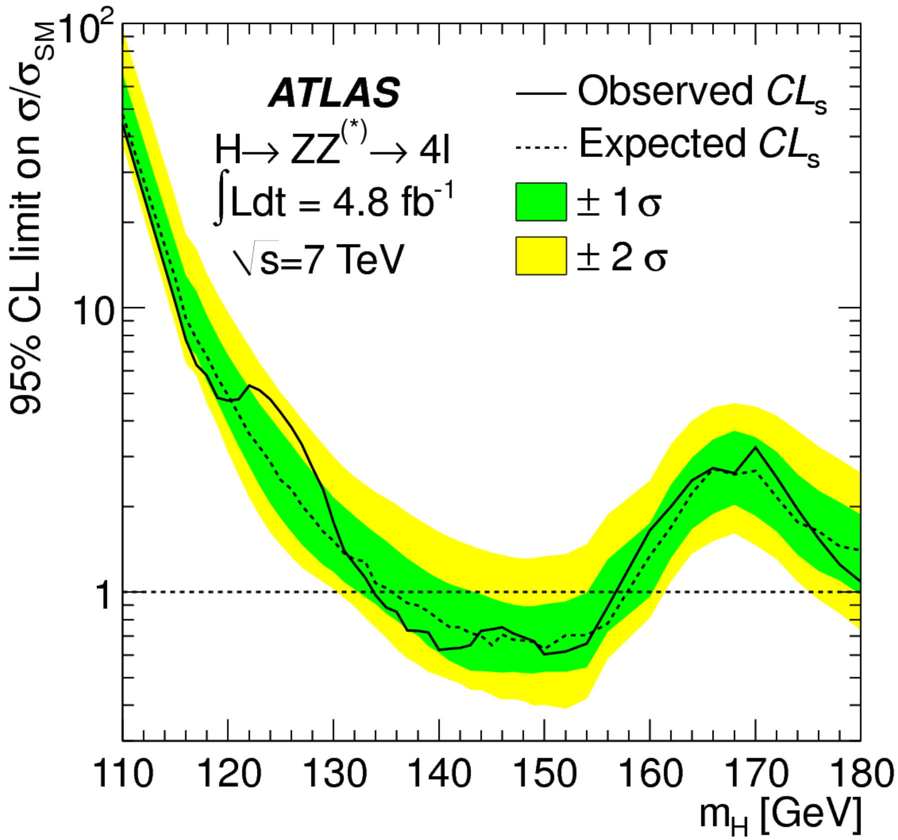


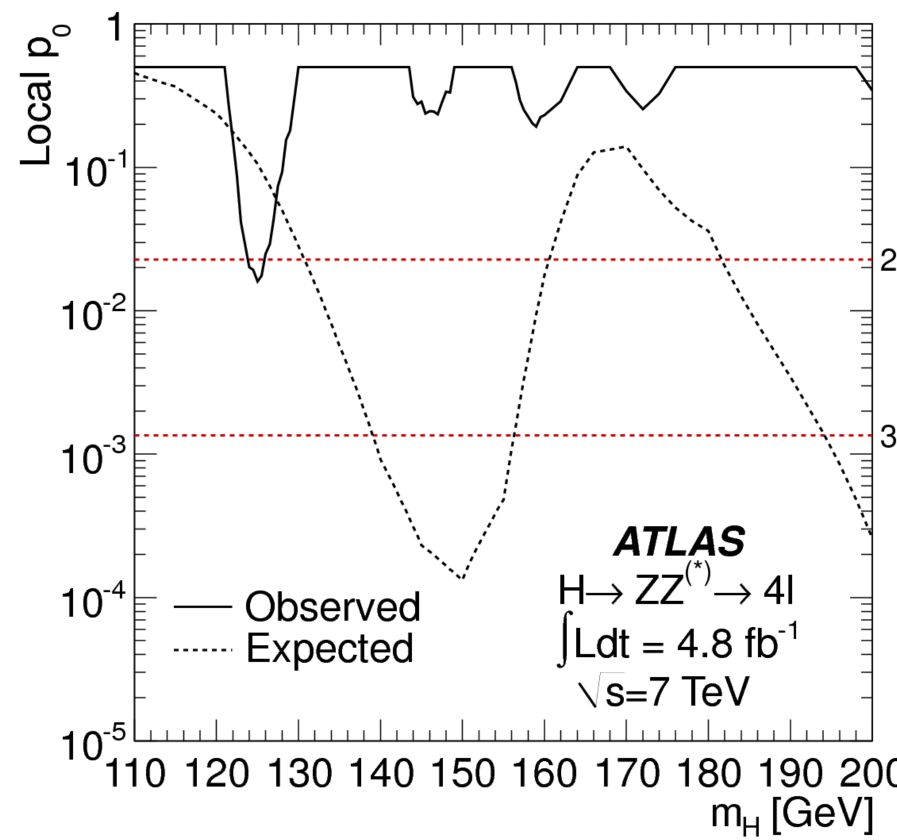


- Invariant mass spectra of the four leptons.

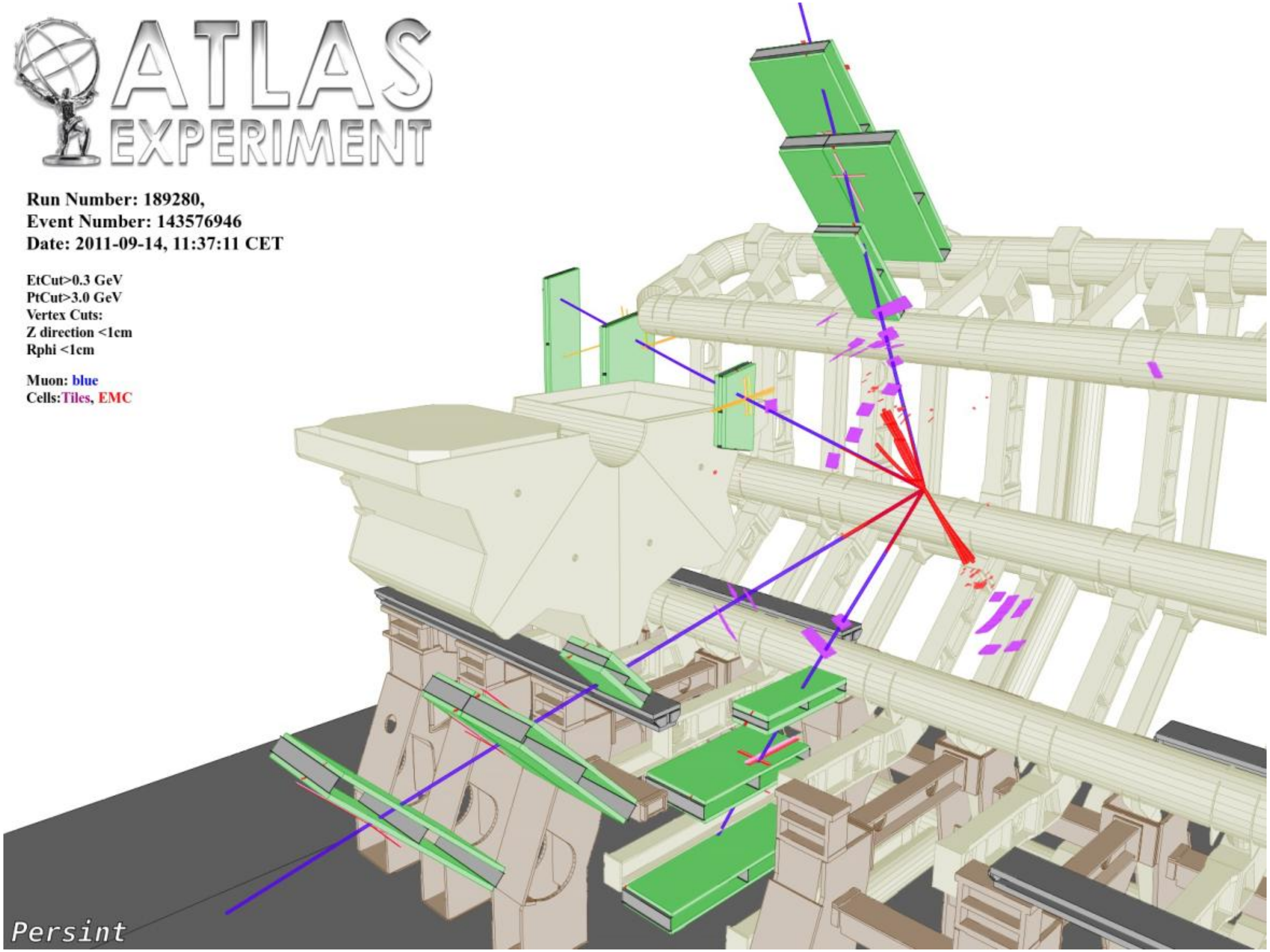
The H→ZZ→4ℓ Channel

- Exclusion: 134-156, 182-233, 256-265, 268-415 GeV.
- Largest excesses at m_H=125, 244 and 500 GeV, with local significances of 2.1σ, 2.2σ and 2.1σ.



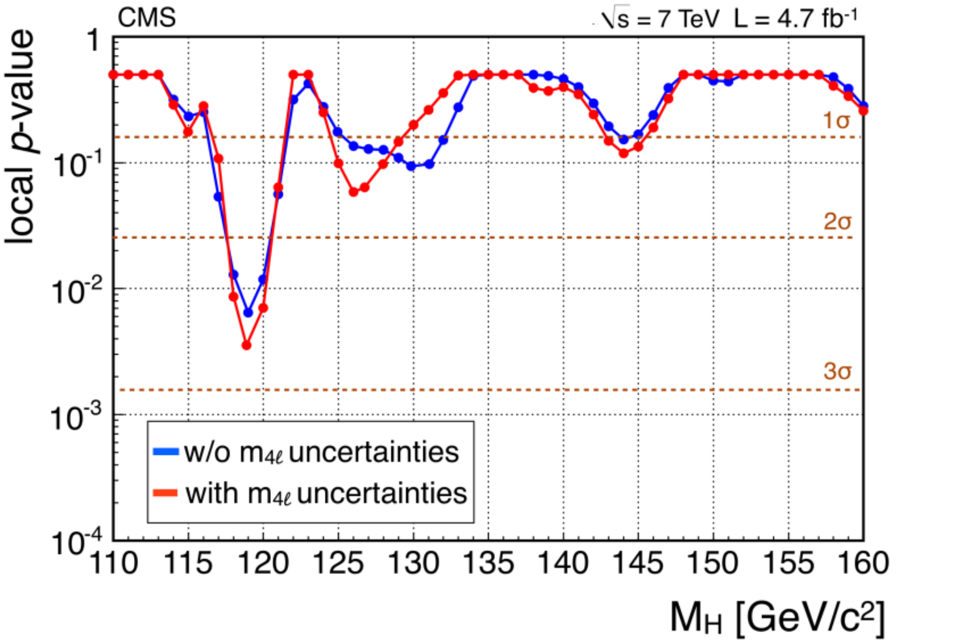


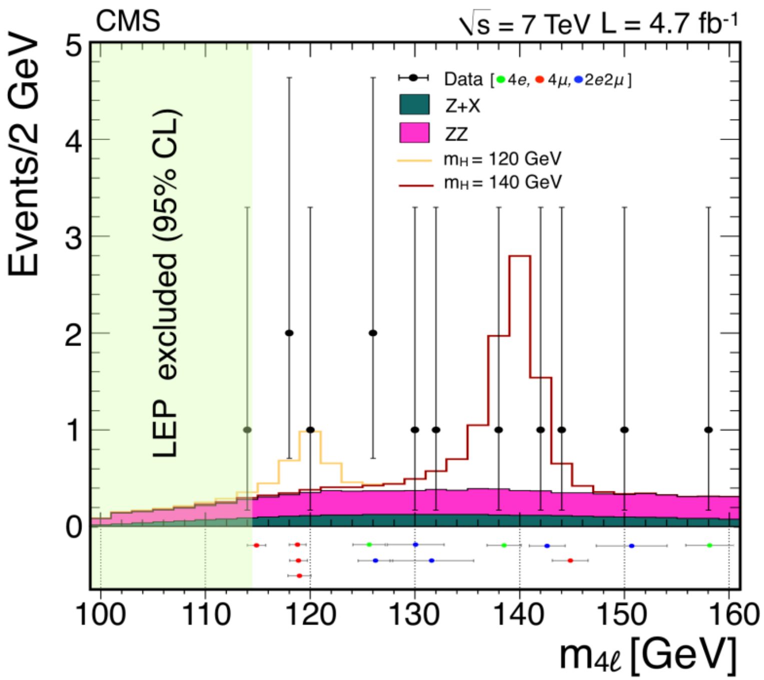
A Candidate Event

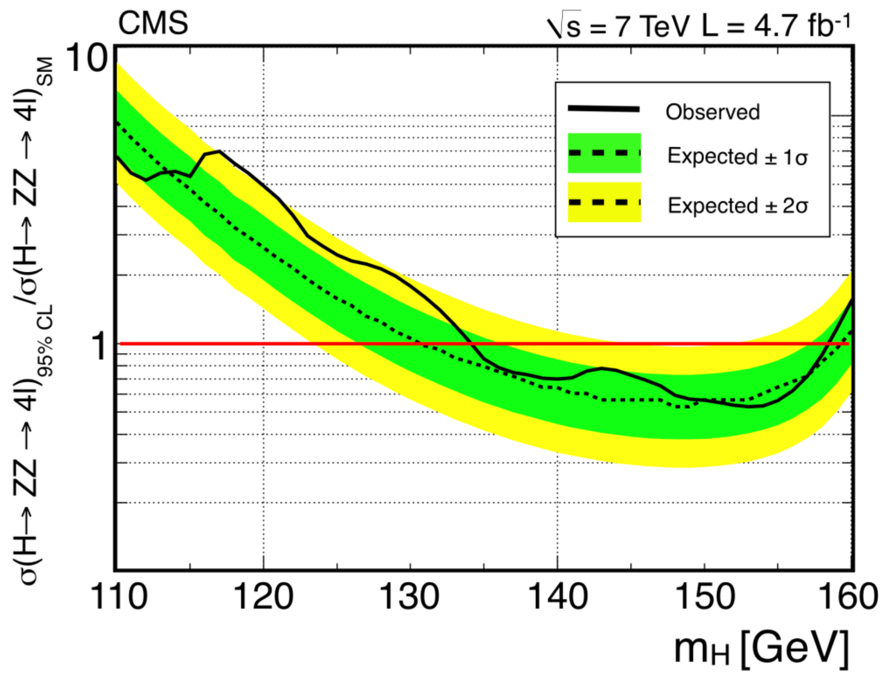


CMS Results

- The CMS analysis is very similar. Broad excess of events.

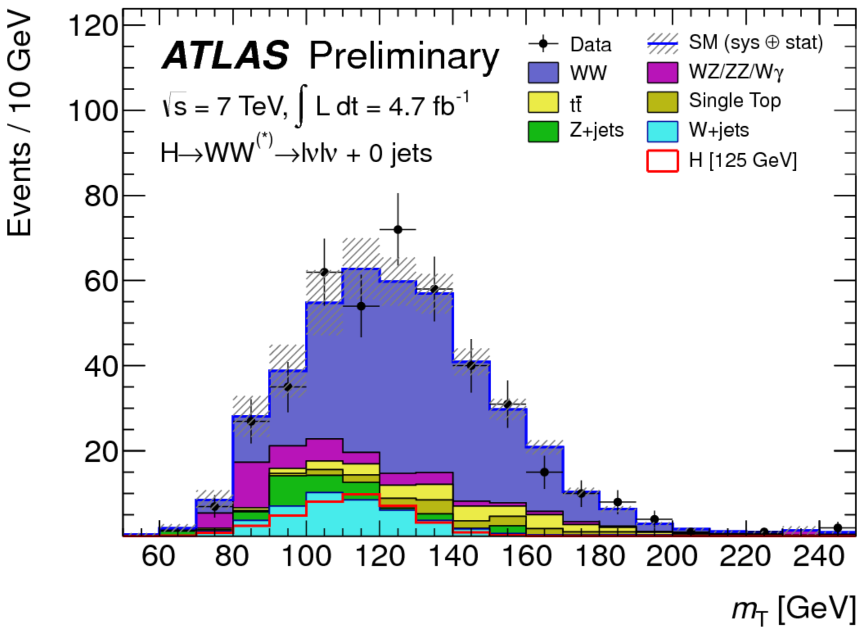


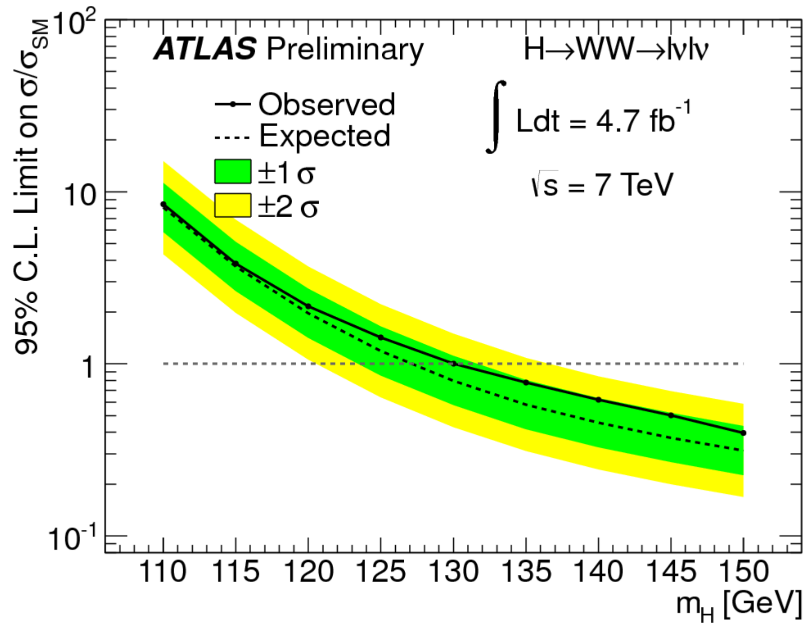




The H→WW→$\ell\nu\ell\nu$ Channel

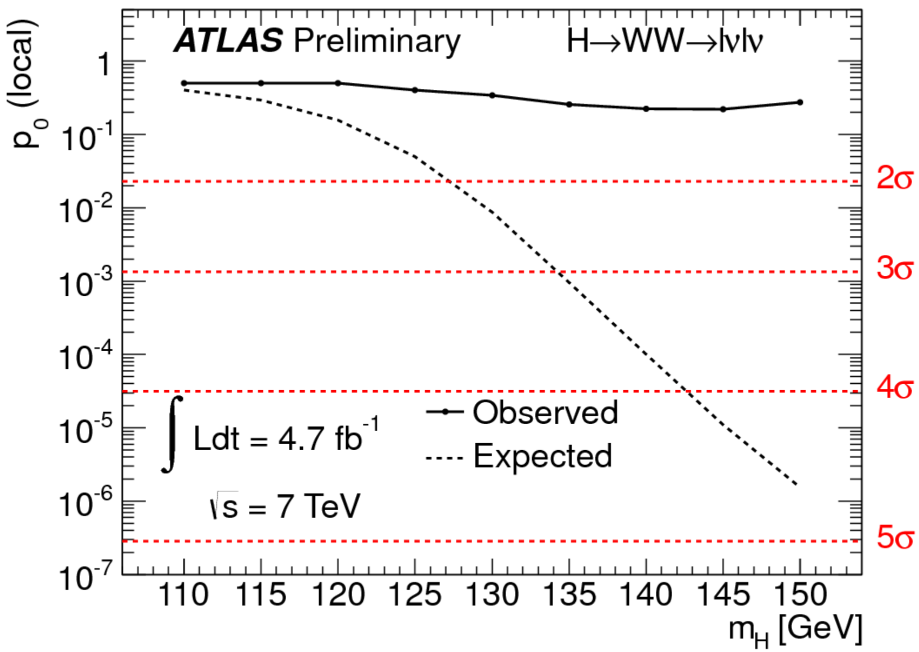
- The Higgs boson decays to two W bosons, these in turn decay to a lepton and a neutrino.
  - Neutrinos escape detection in the detector, can not reconstruct the invariant mass of the decay products.
  - No significant excess of events observed, exclude a mass range 130-260 GeV (expected exclusion 127-234 GeV).

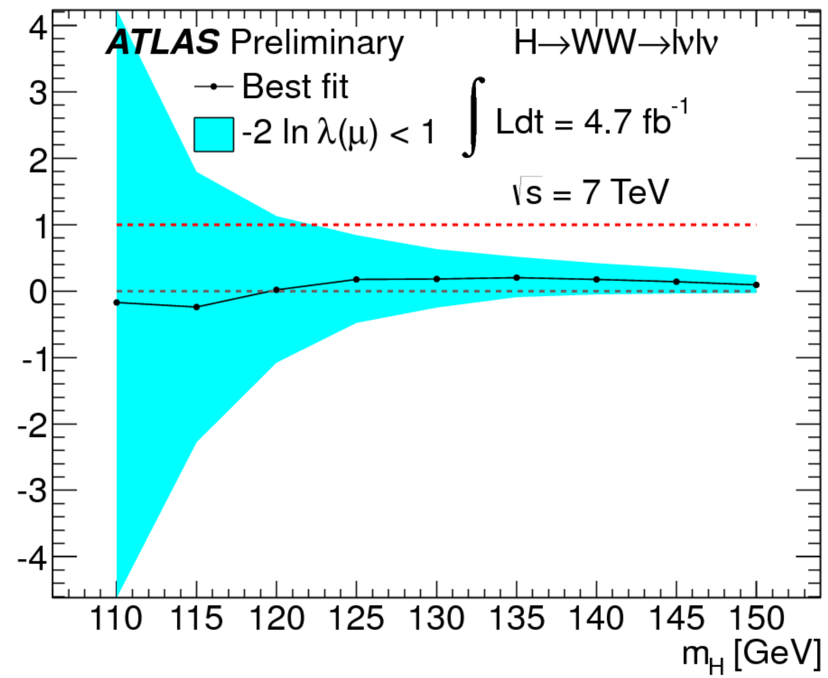




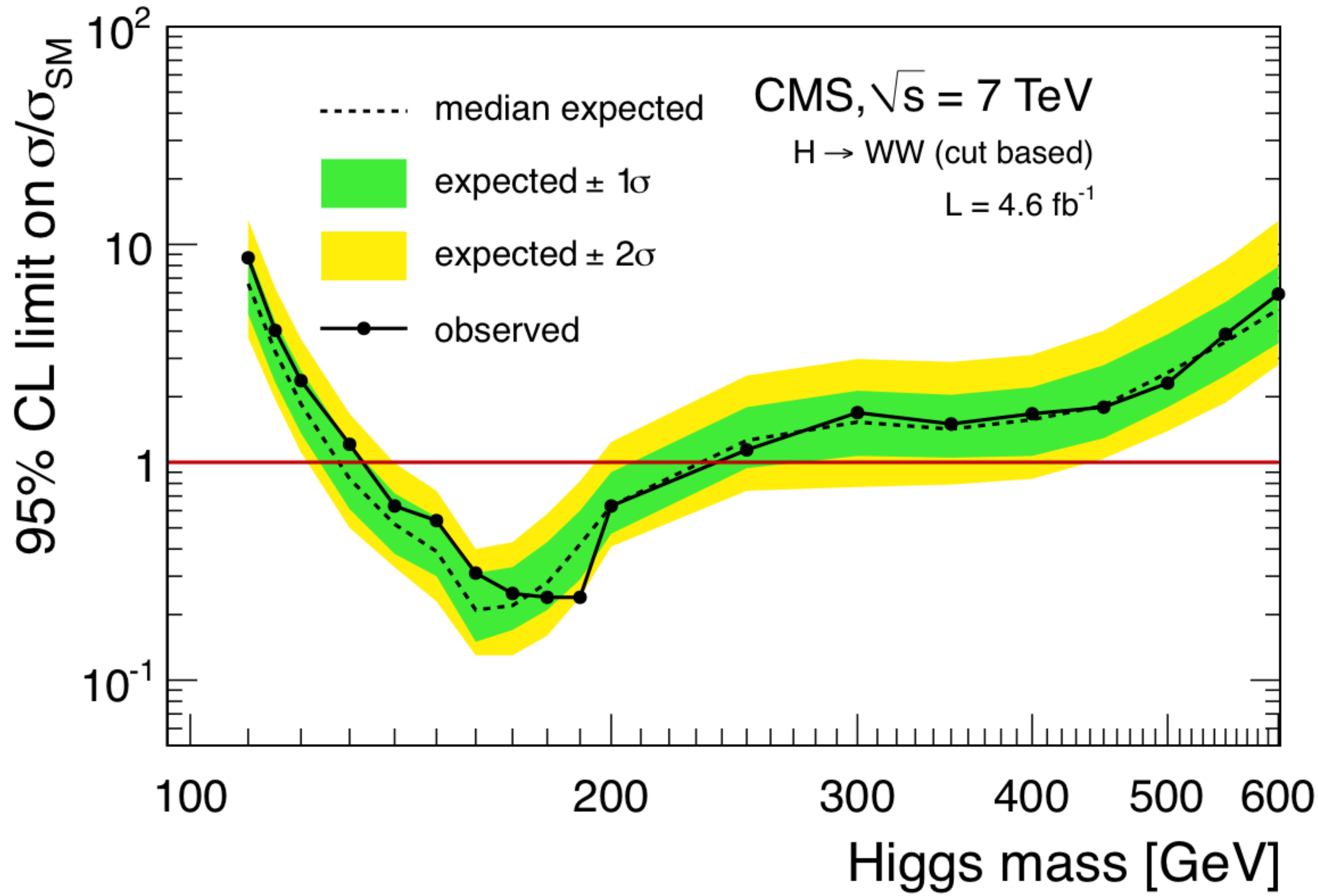
The H→WW→ℓνℓν Channel

- Looking at the significance of the excess, it is below what would be expected from a standard model H.



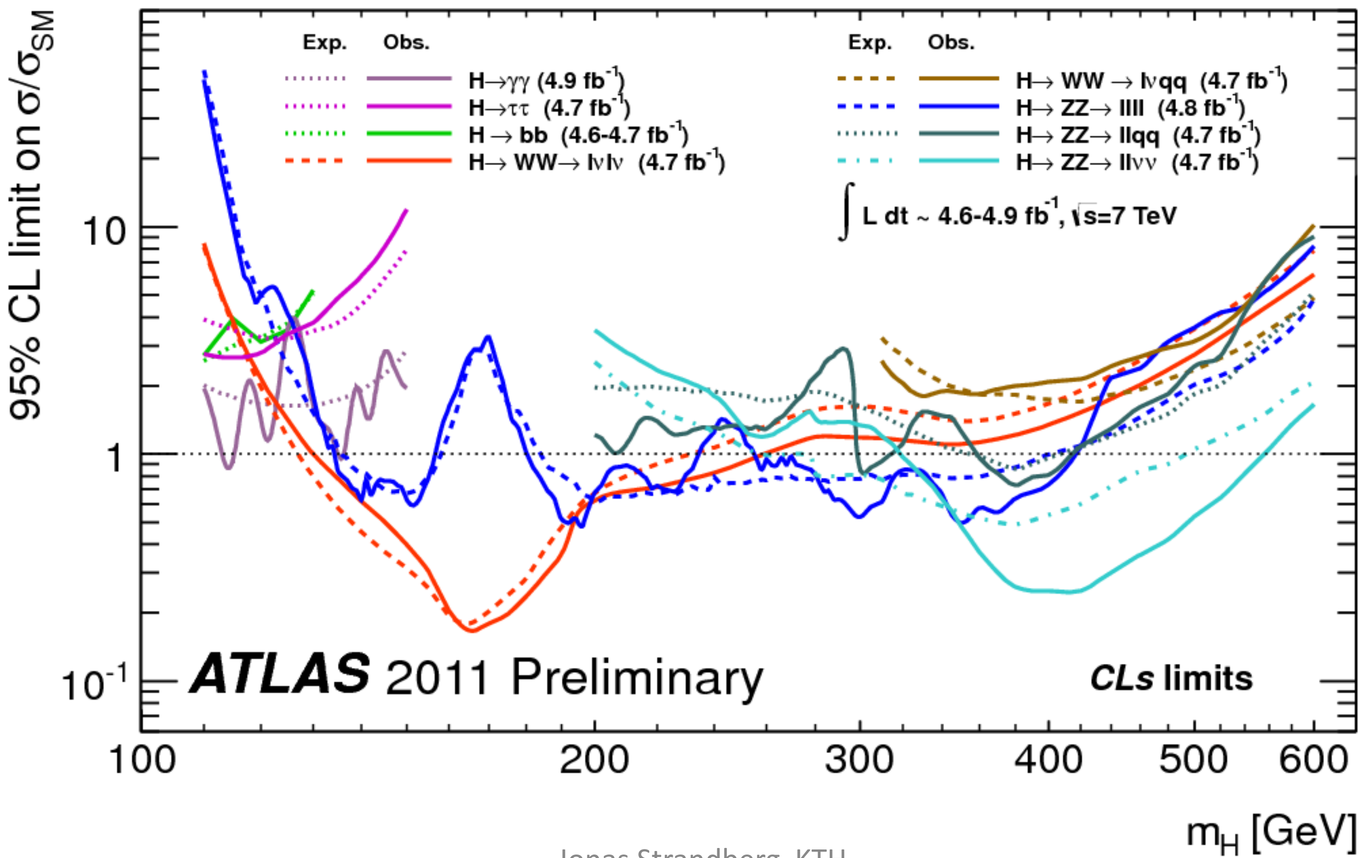


The CMS H→WW→ℓνℓν Result



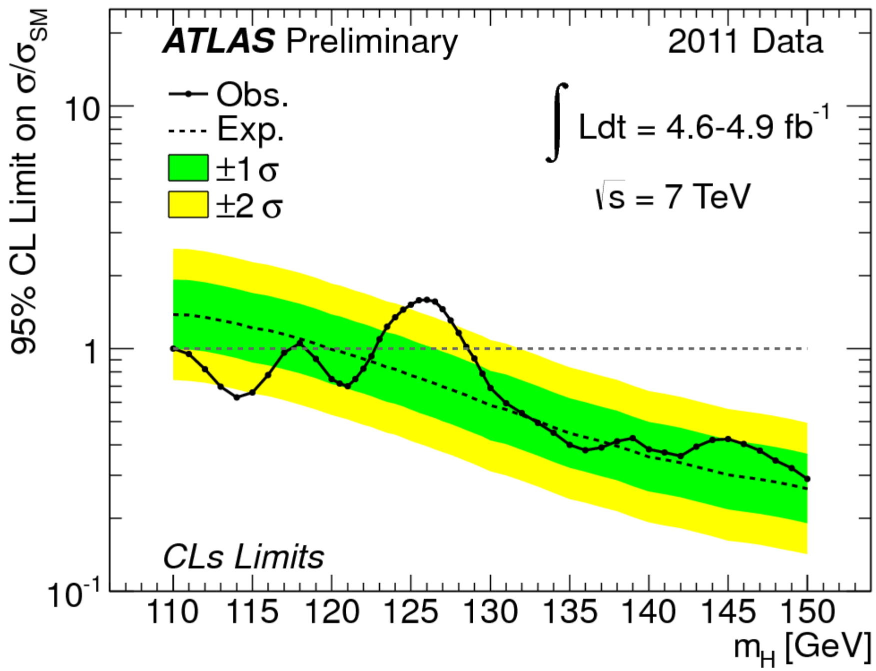
Limits from Other Search Channels

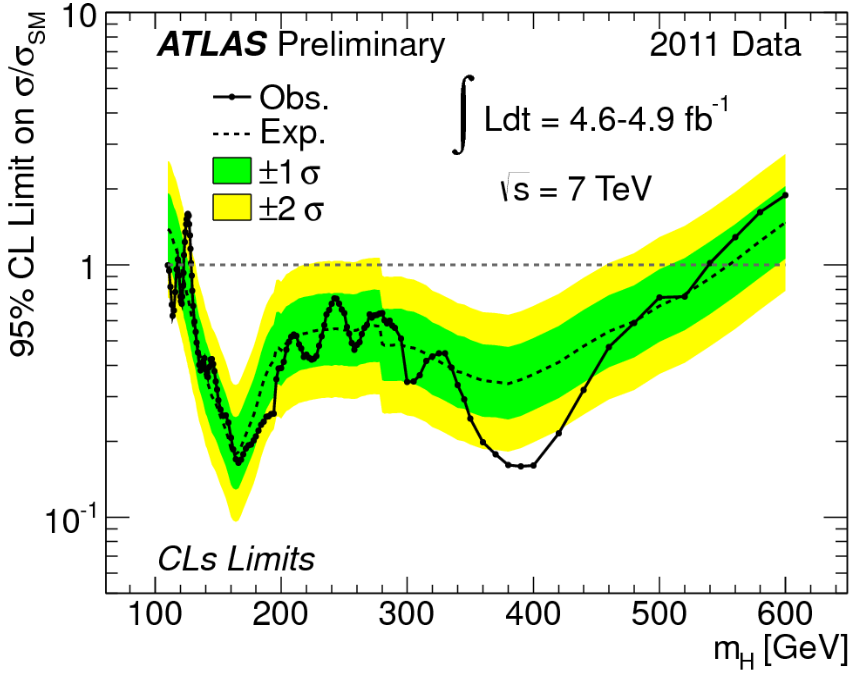
- Other search channels do contribute a little to the overall combined result from all channels.
  - But end result dominated by the three main channels.



Combined ATLAS Result

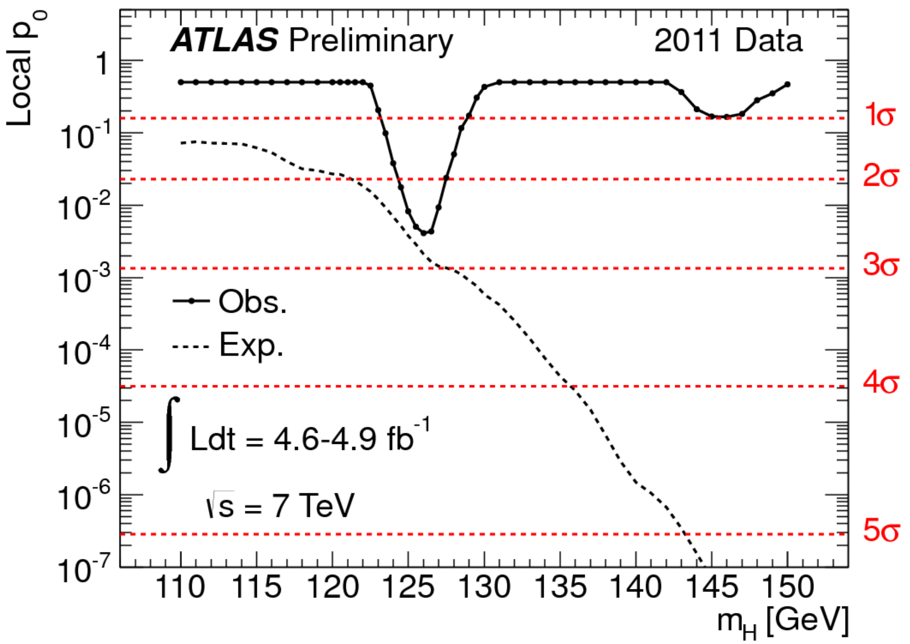
- Combining all channels almost excludes the Higgs.
- Observed exclusion: 110-117.5, 118.5-122.5, 129-539 GeV. CMS excludes 127-600 GeV.

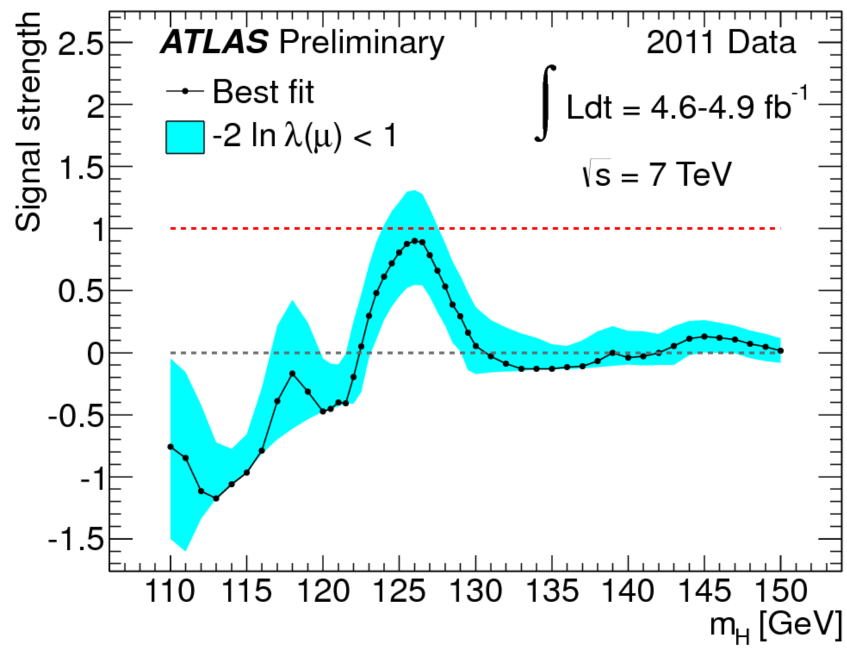




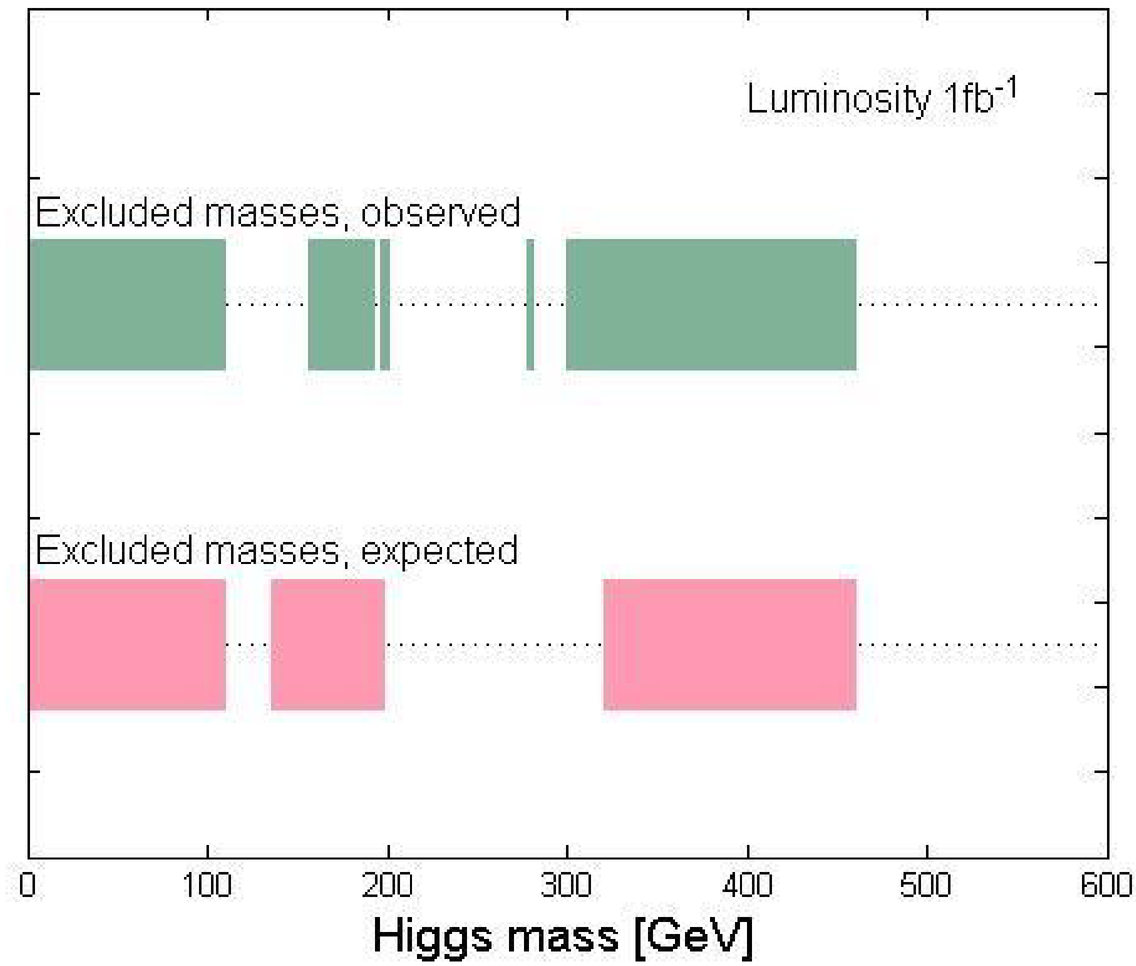
Combined Result

- Excess observed at a Higgs mass of 126 GeV from the $H \rightarrow \gamma\gamma$ and the $H \rightarrow ZZ \rightarrow 4\ell$ channels.
- Observed excess has a local signifcance of 2.5σ. CMS has excess of 2.1σ at a Higgs mass of 124 GeV.



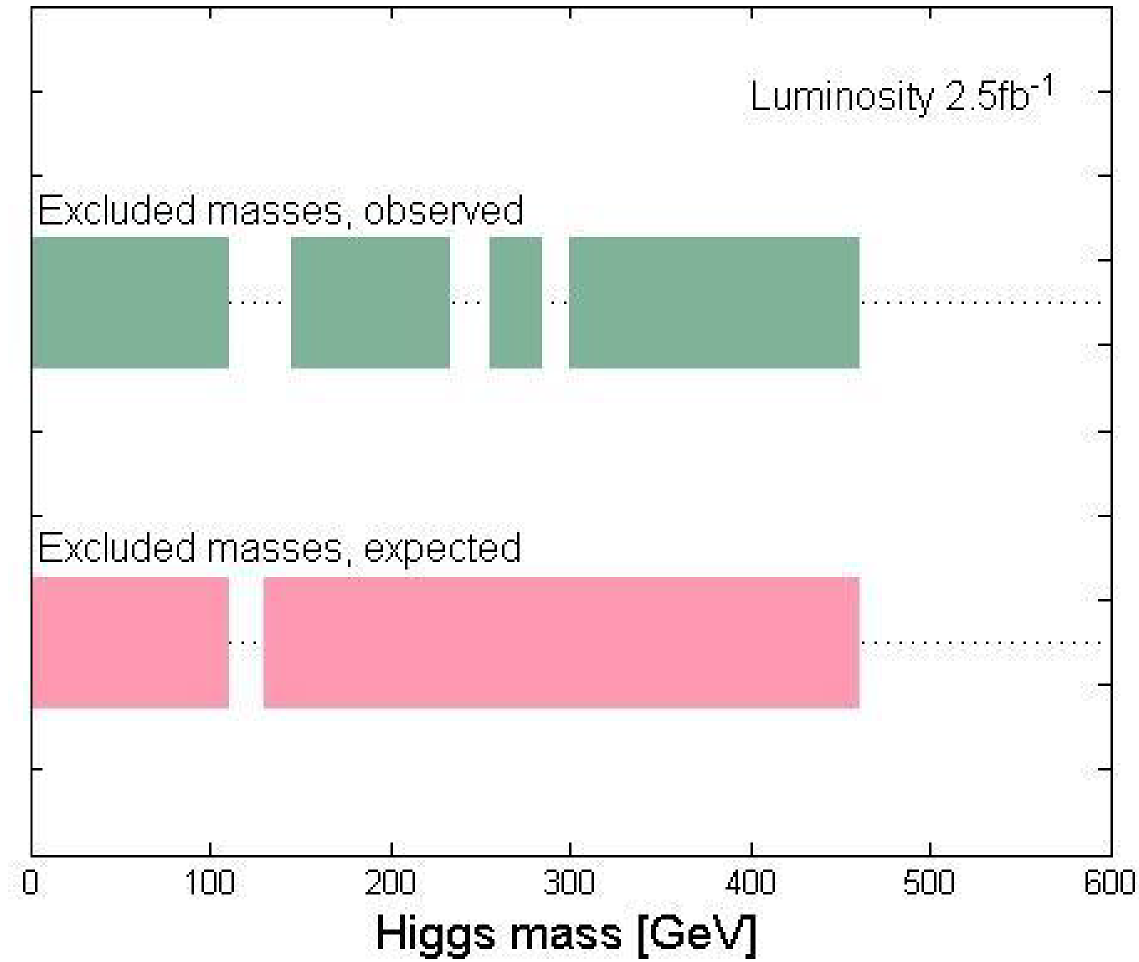


Student's interpretation of the Results



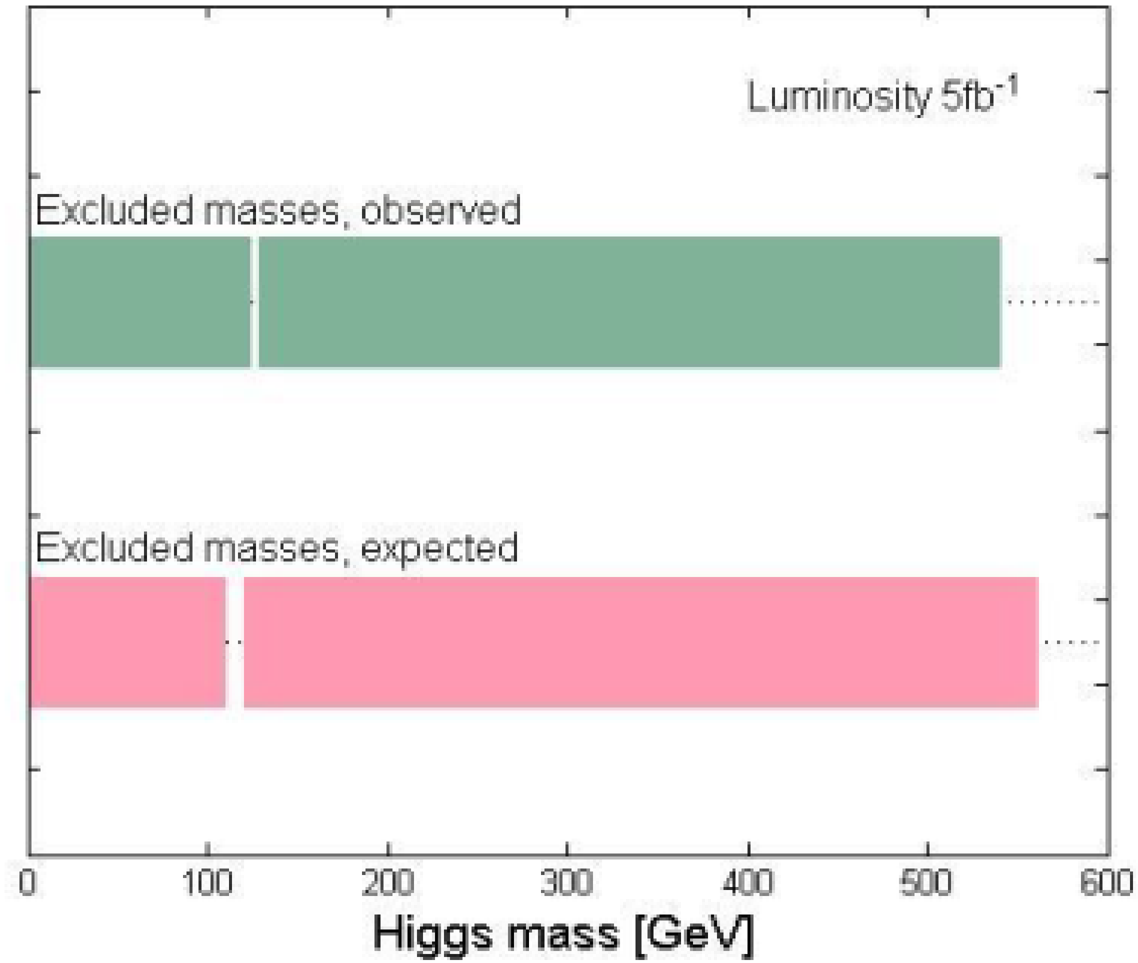
- ATLAS exclusion results with 1 fb-1, from July 2011.

Student's interpretation of the Results



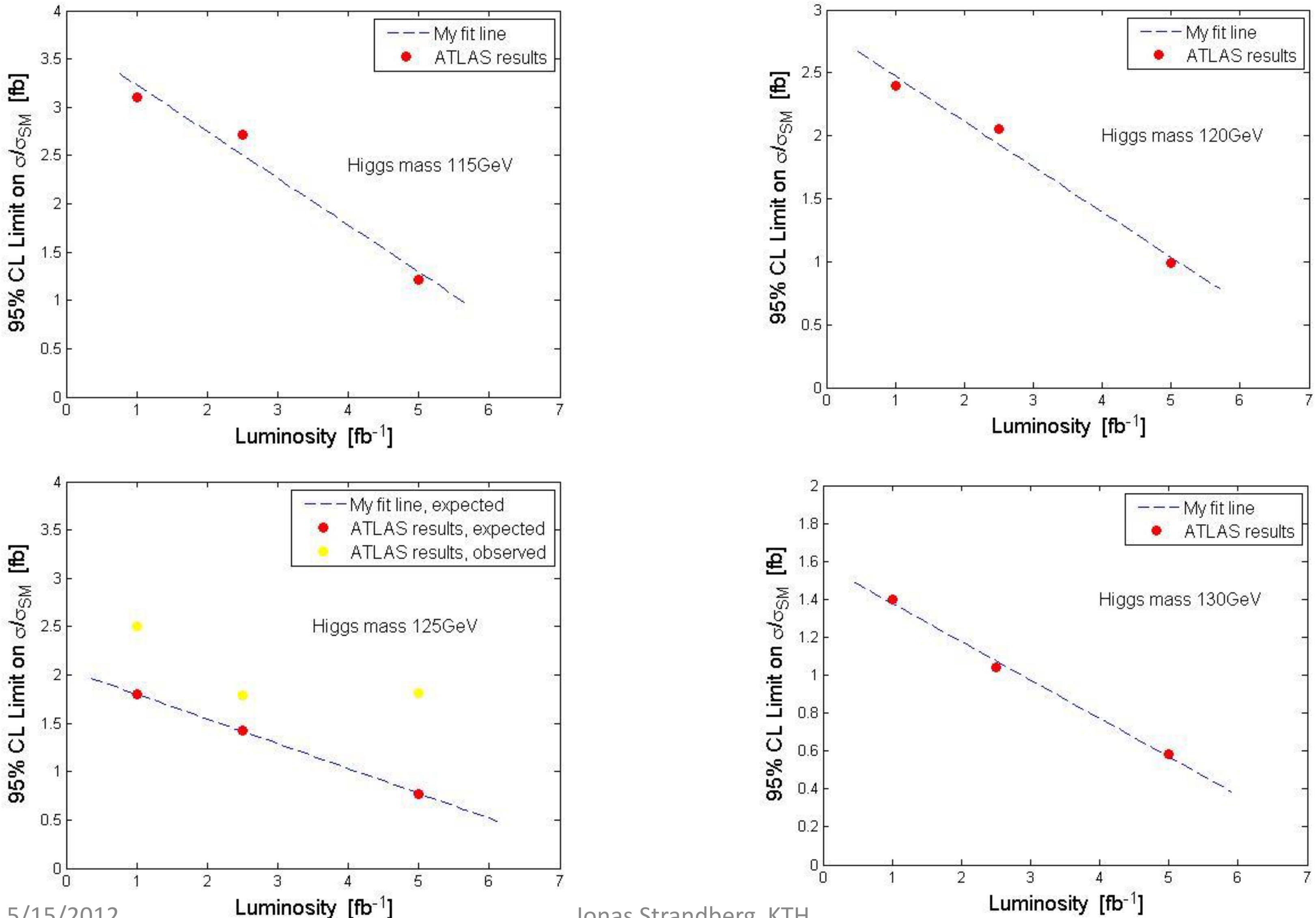
- ATLAS exclusion results with 2 fb-1, from Sept 2011.

Student's interpretation of the Results



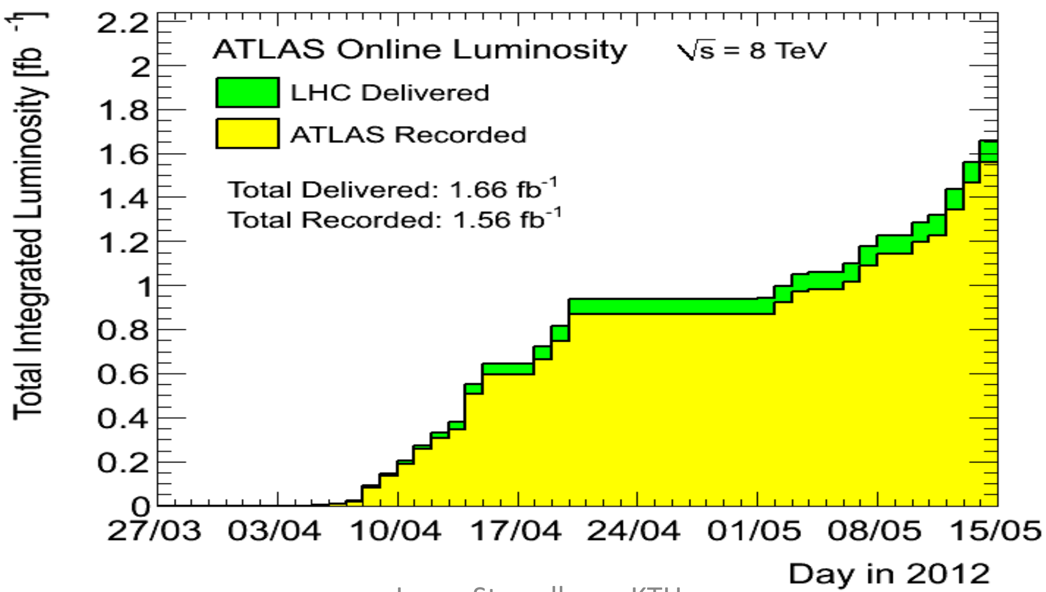
- ATLAS exclusion results with 5 fb-1, from Dec 2011.

Student's interpretation of the Results



The Results in 2012

- In 2012 the energy of the LHC was increased to 8 TeV.
- Data taking has already resumed in 2012. The LHC continue to perform excellently.
  - The goal is to collect at least 10 fb^{-1} in 2012.
  - This will surely be enough to close the book on the Higgs. First results expected at ICHEP in beginning of July.



Summary and Conclusions

- The latest results on the Higgs boson searches from ATLAS and CMS have been presented.
  - Only a small window of masses between 122 and 127 GeV is the only remaining ones that have not been excluded.
  - Even more exciting, there is close to a 3σ excess at a Higgs boson mass around 125 GeV.
- Results are not conclusive and perhaps not entirely consistent across different search channels.
- Data taking for 2012 at the LHC has already started and with the analysis of this years data we will learn whether the standard model Higgs boson exists.

Stay tuned for an exciting year in physics!