Combined Standard Model Higgs Boson Searches in pp Collisions at sqrt(s) = 7 TeV with the ATLAS Experiment at the LHC

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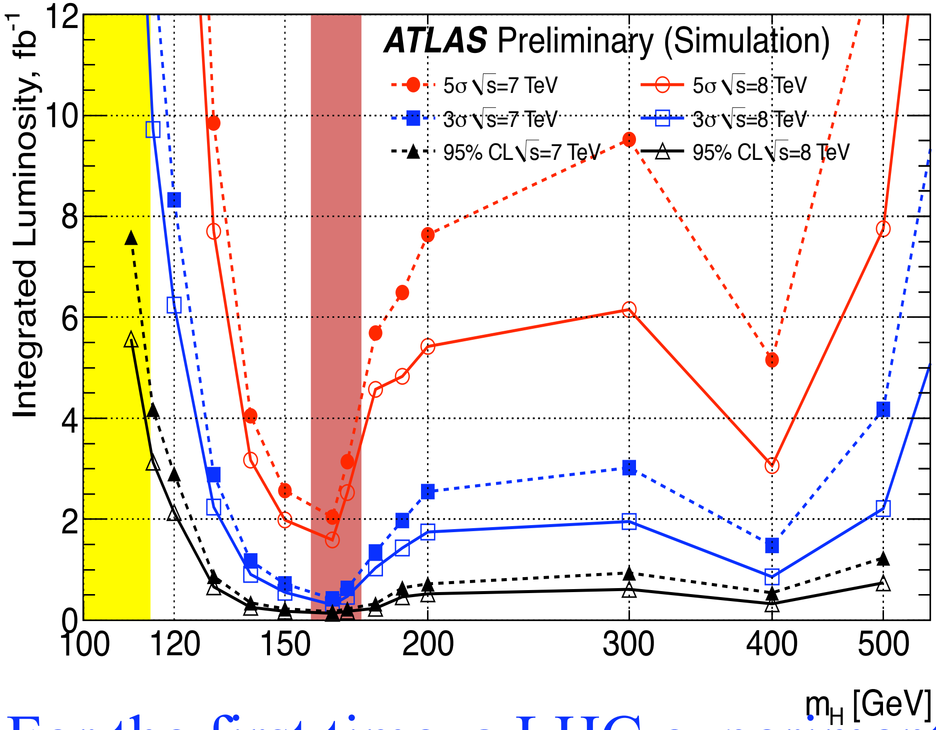
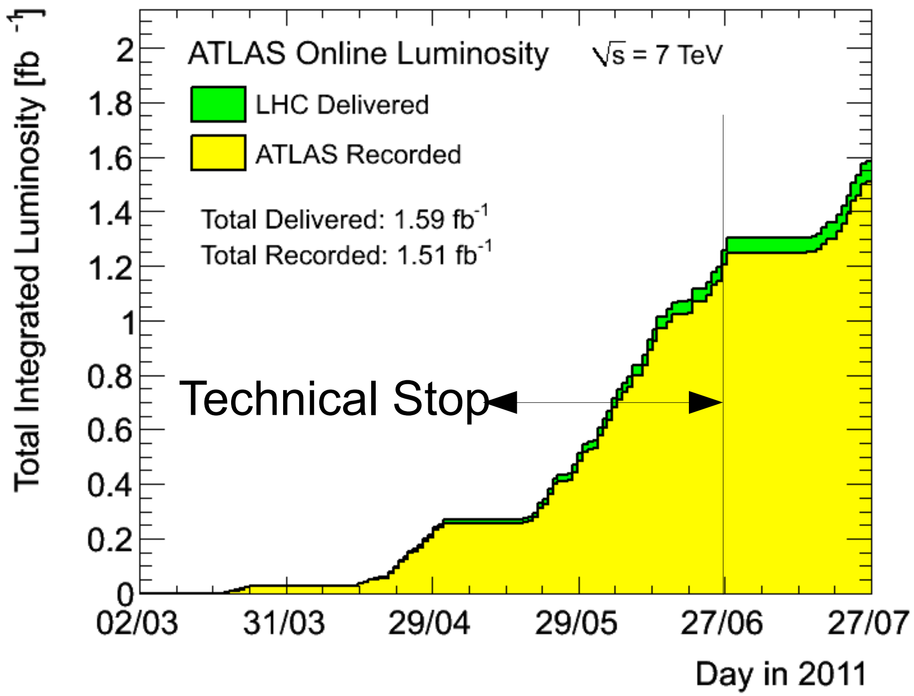
Introduction

The search for the Higgs Boson is one of the major goals of building LHC. To achieve this goal, a large amount of data is needed.

$1fb^{-1}$ is the first milestone

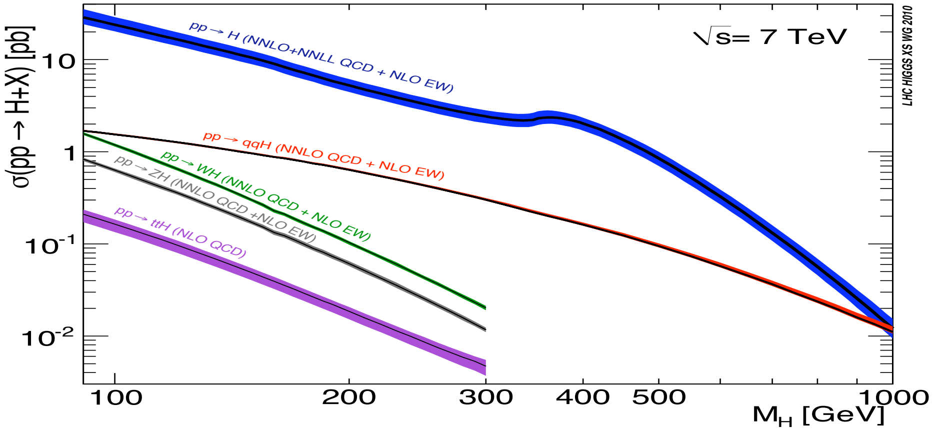
The LHC team has done a remarkable job for delivering about $1.2fb^{-1}$ data before the summer conference season.

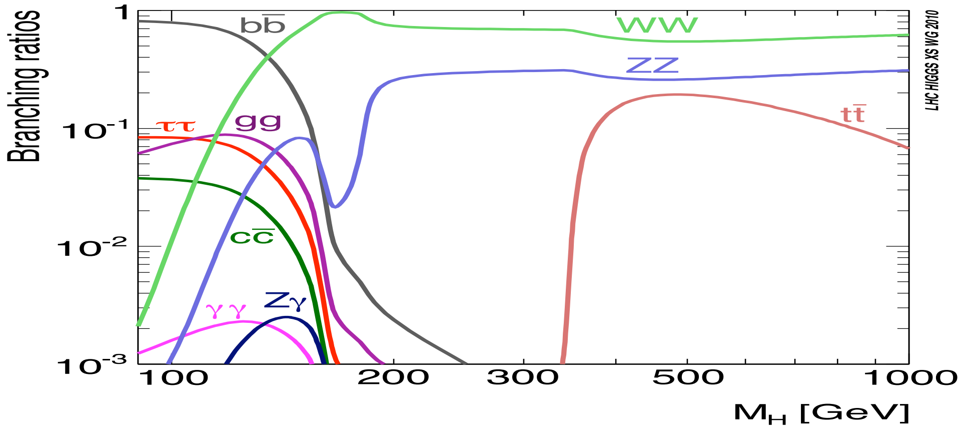


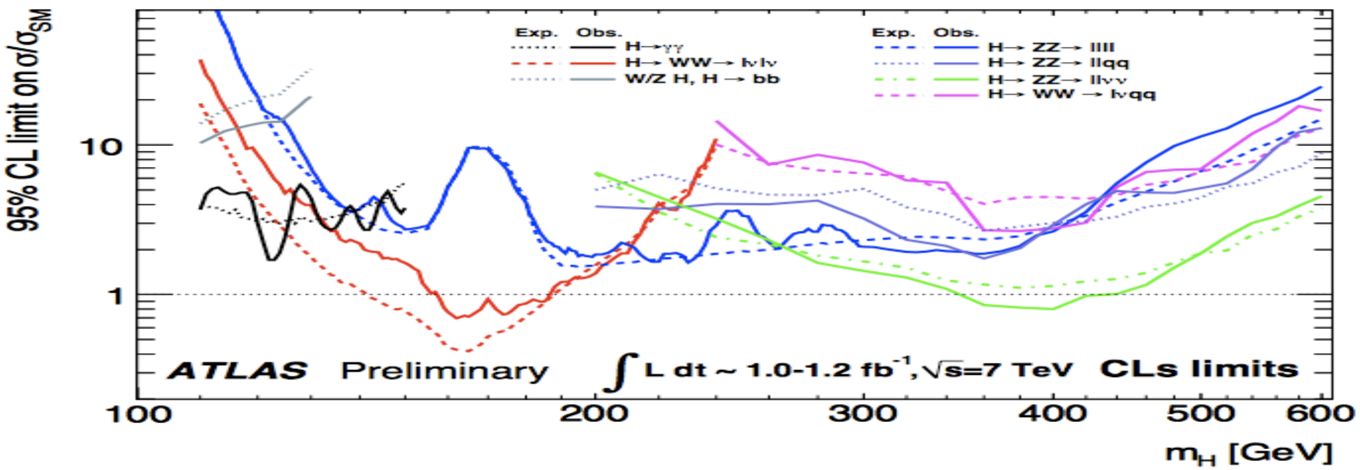


For the first time, a LHC experiment is in a position to tell us whether a Standard Model Higgs boson exists(at least in some mass range).

The Picture Before Combination





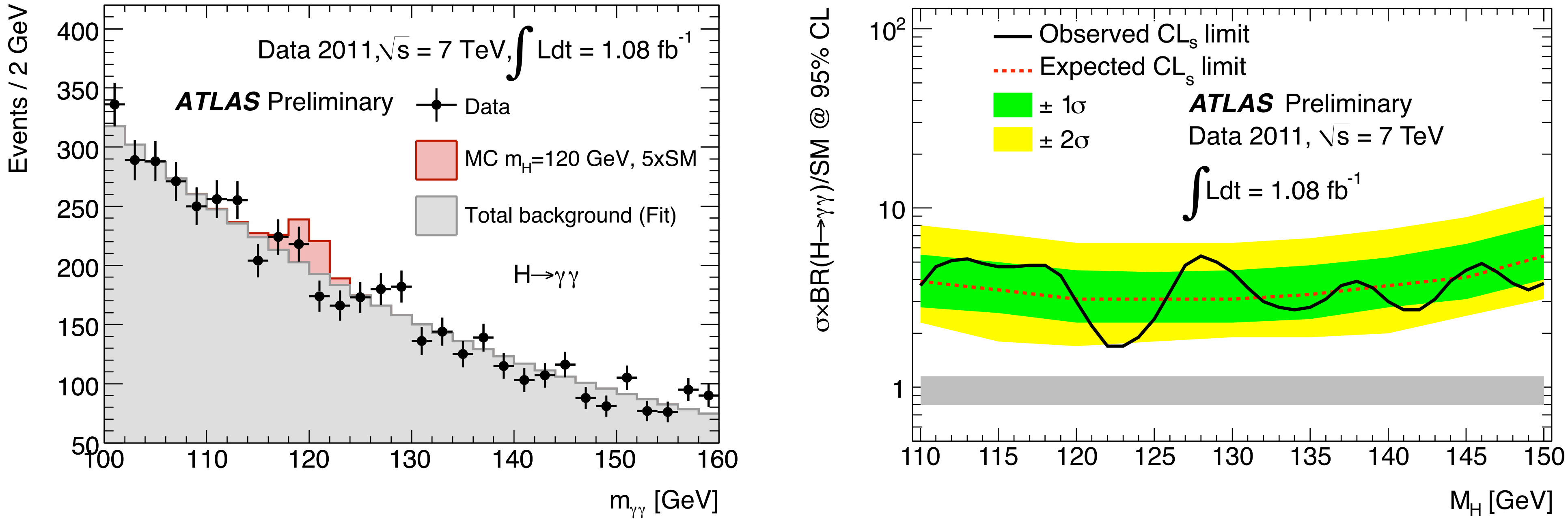


Seven individual channel search results are produced in a short time scale.

Higgs boson search is extended to mass range beyond 200GeV.

Among those searches, WW → lνlν or ZZ → llνν alone can exclude a SM Higgs boson in some mass ranges.

$H \rightarrow \gamma\gamma$

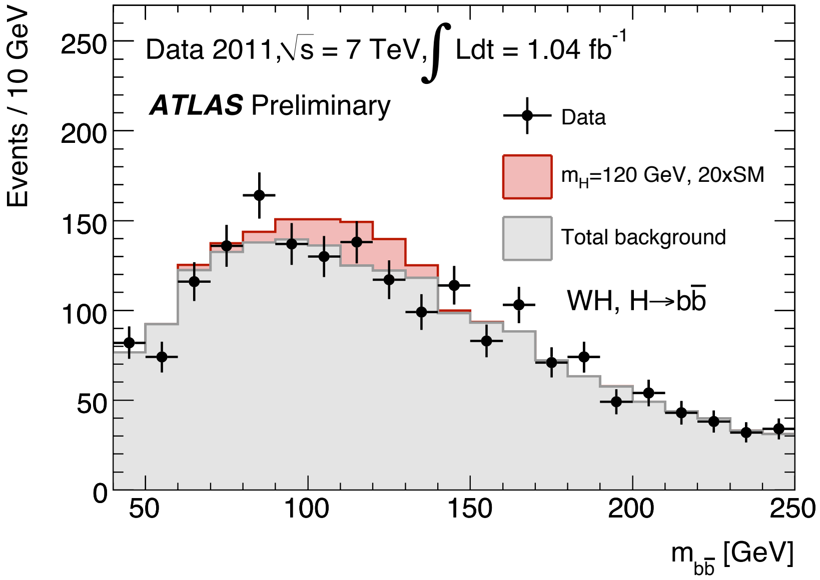


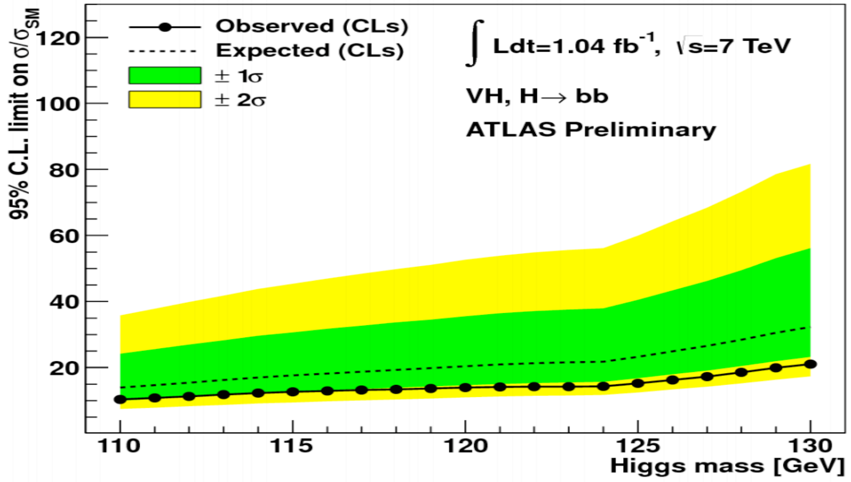
The dominant search channel in the low mass range (m_H<130GeV).

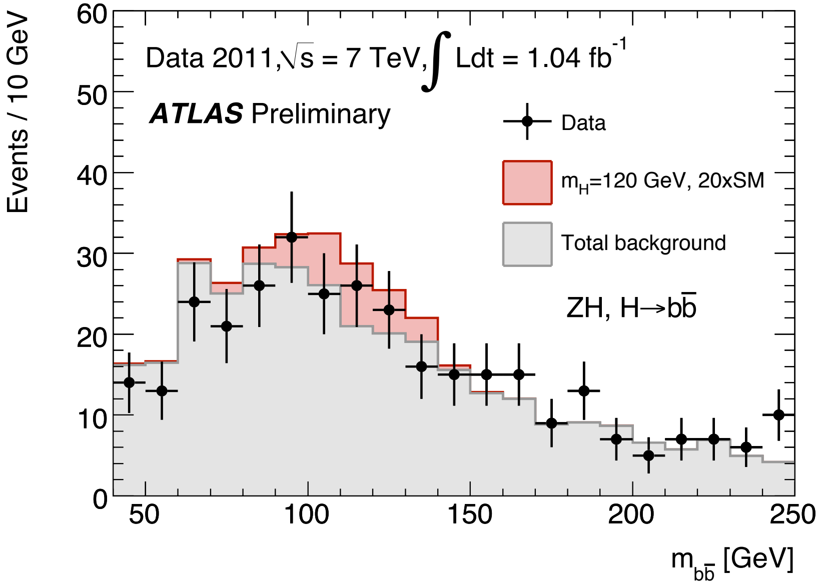
The expected limit is almost flat across the mass range.

2 to 6 X SM Higgs cross section is excluded.

VH → Vbbar







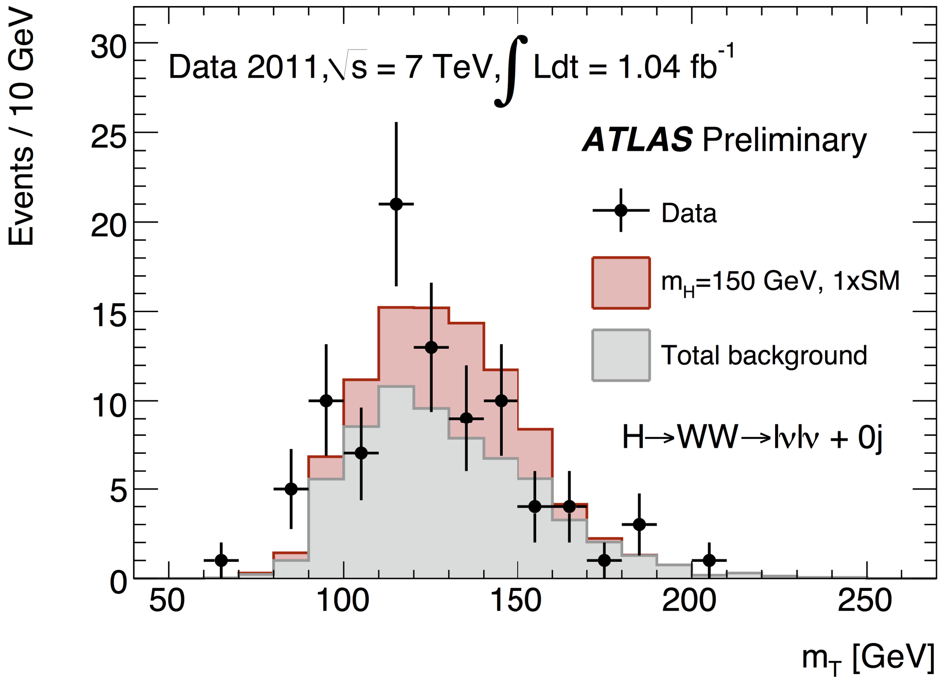
bbar is the dominant Higgs decay channel in mass region, but it suffers from large QCD backgrounds.

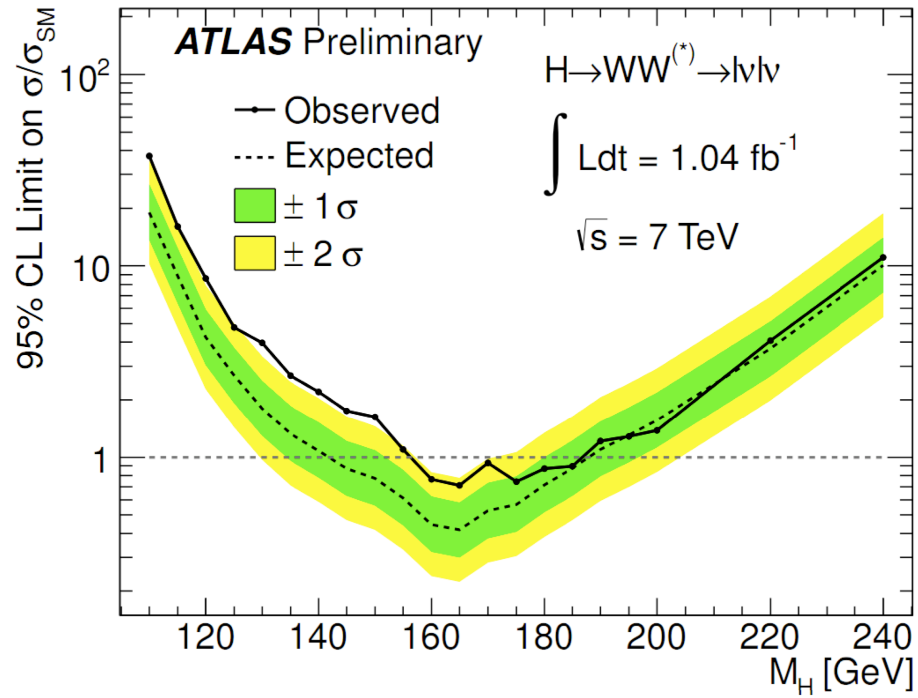
Expected sensitivity ~ 15 – 20 X SM expectation.

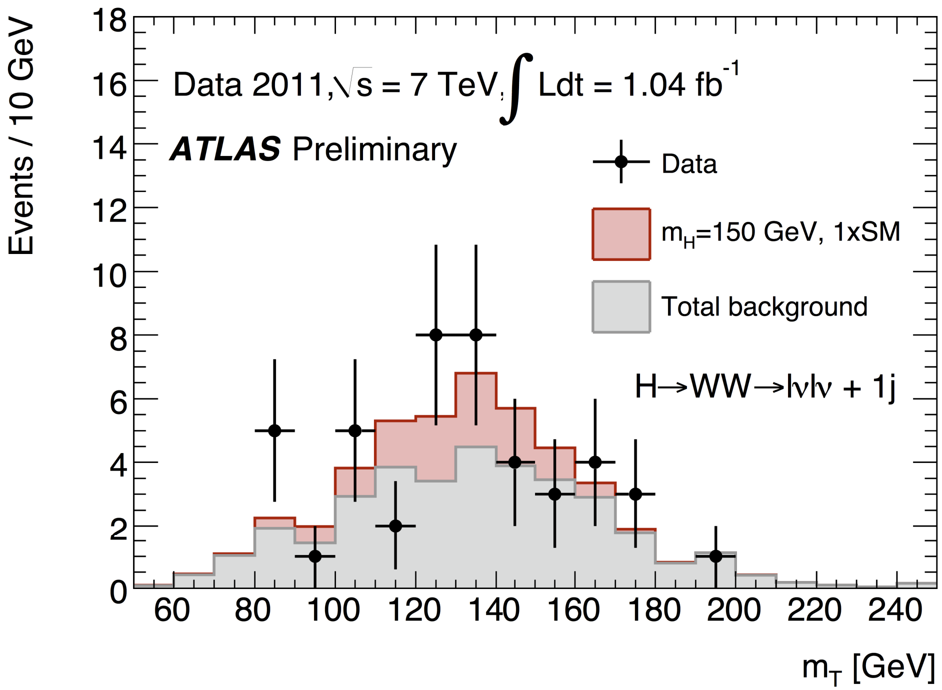
The current version of this analysis (VH) is an intermediate step toward a more inclusive analysis.

The signal mass peak is broad, and limit results in the mass range considered are strongly correlated.

H →WW → lνlν





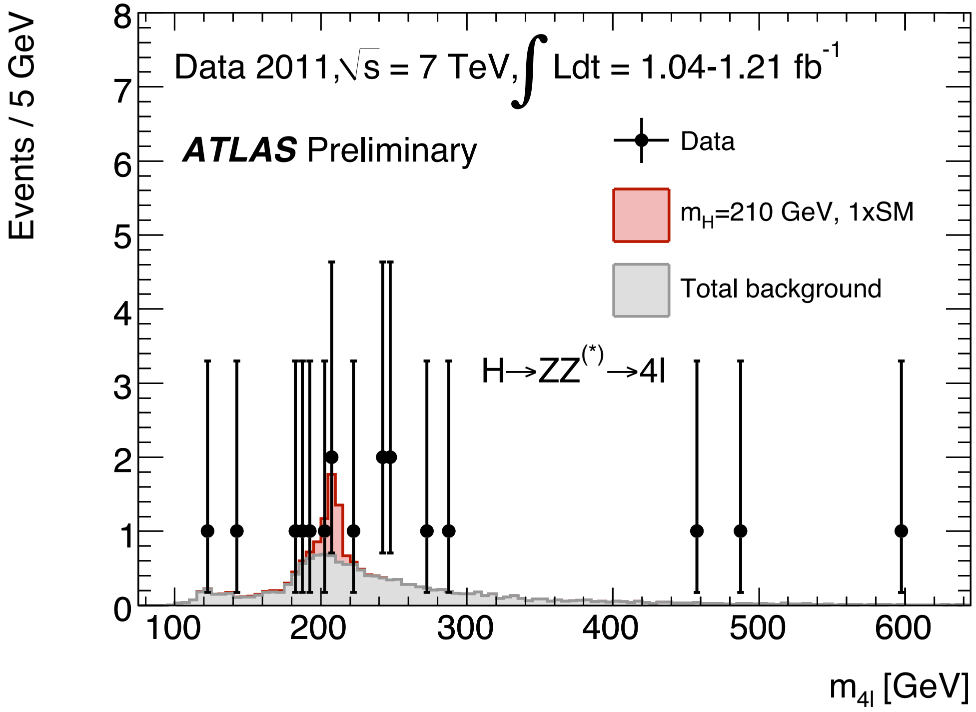


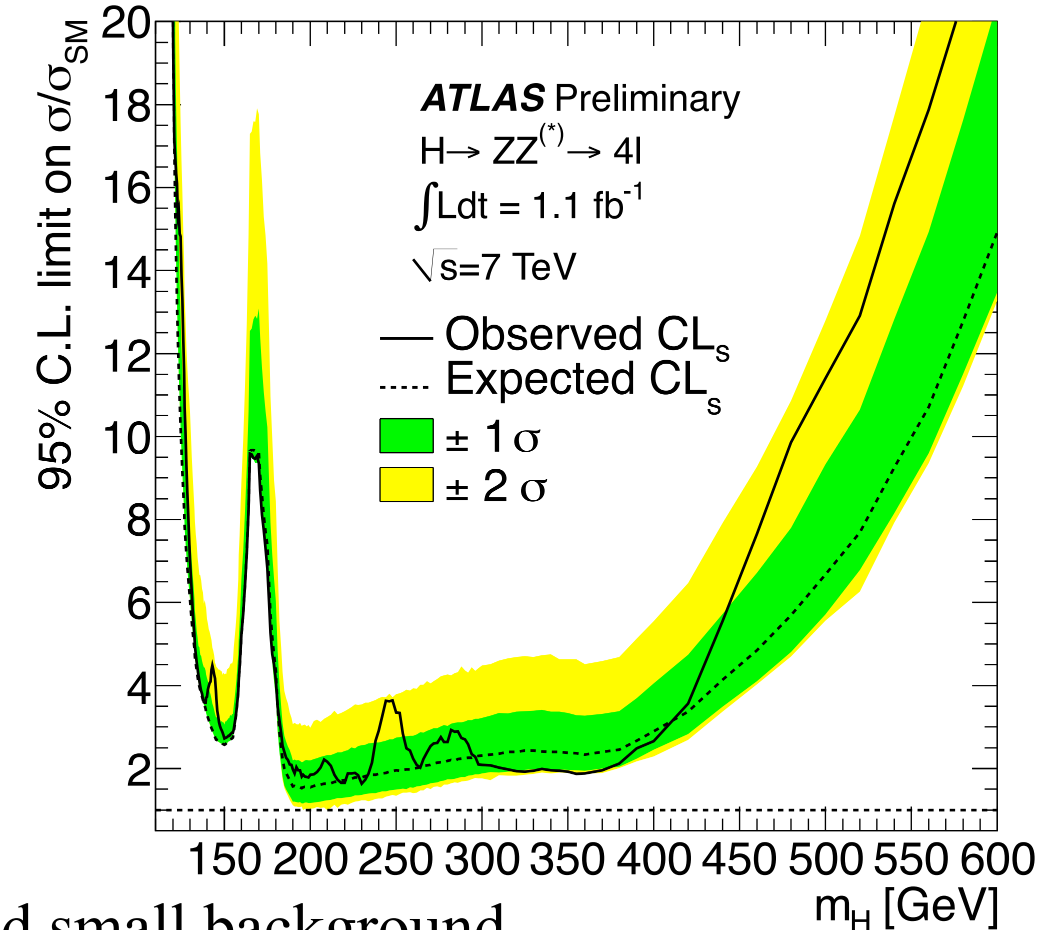
The most powerful channel in the intermediate mass range(130-200GeV).

A broad excess around 140GeV is observed, leading to a worse observed limit.

The transverse mass resolution is poor and limits at nearby mass points are correlated.

$H \rightarrow ZZ \rightarrow 4l$



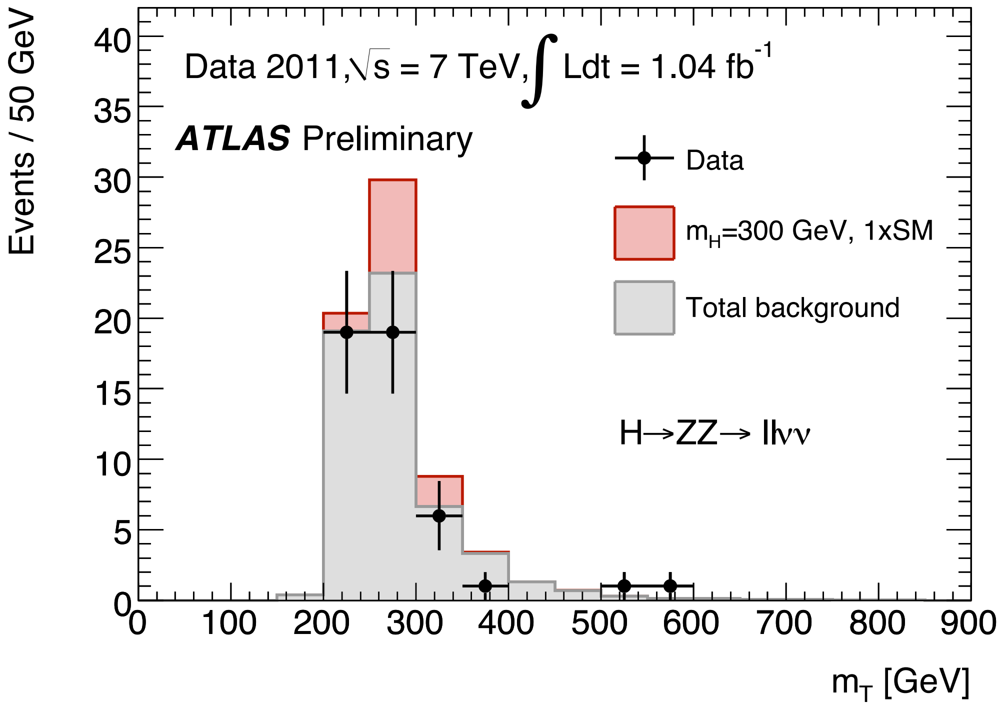


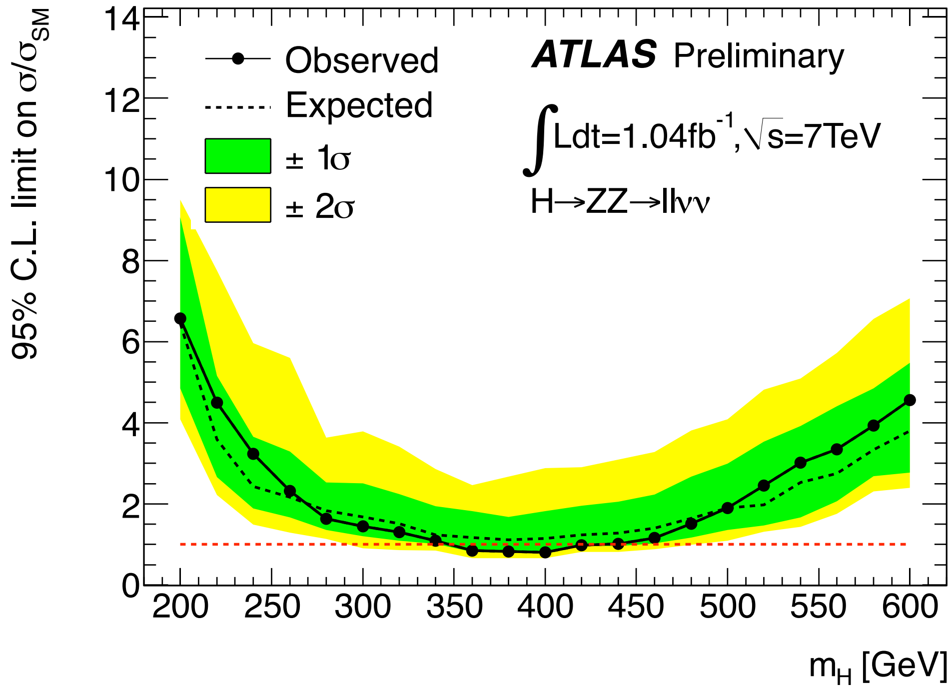
A channel with large S/B ratio and small background.

Any single candidate event would be very interesting.

It covers the full mass range, from 110GeV to 600GeV.

$H \to ZZ \to ll\nu\nu$

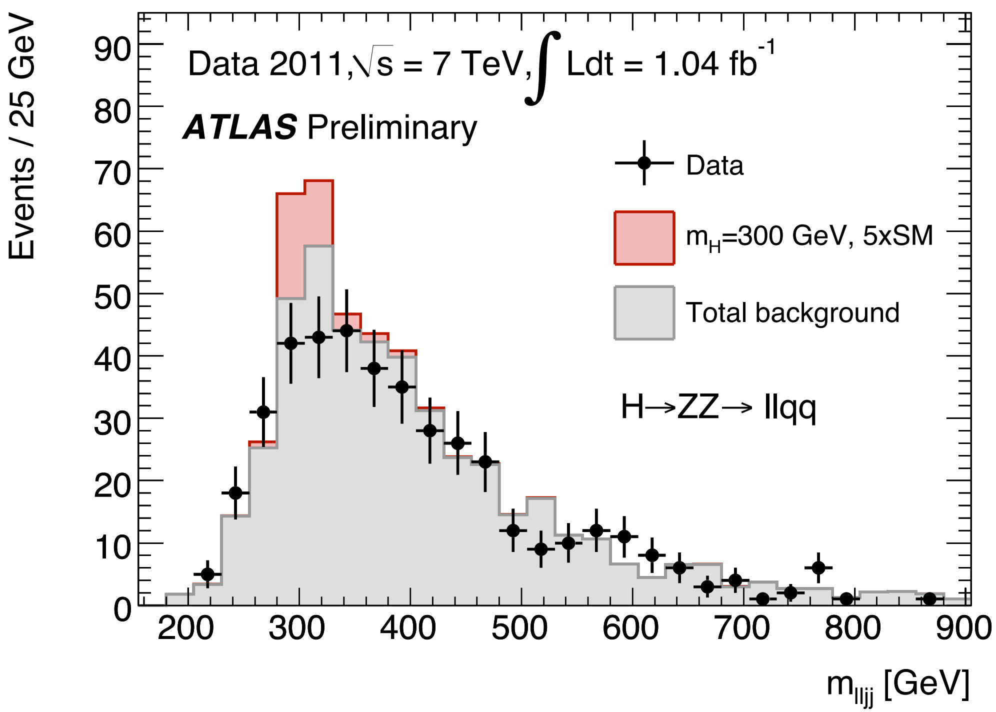


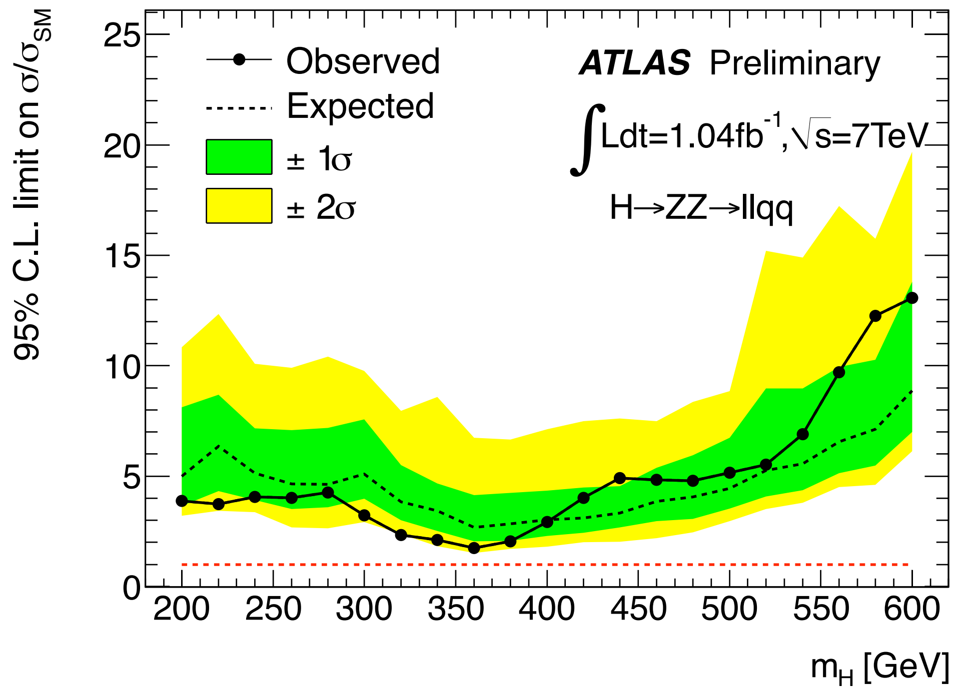


Most powerful channel in high mass range.

1X SM expectation is excluded ~ 380GeV.

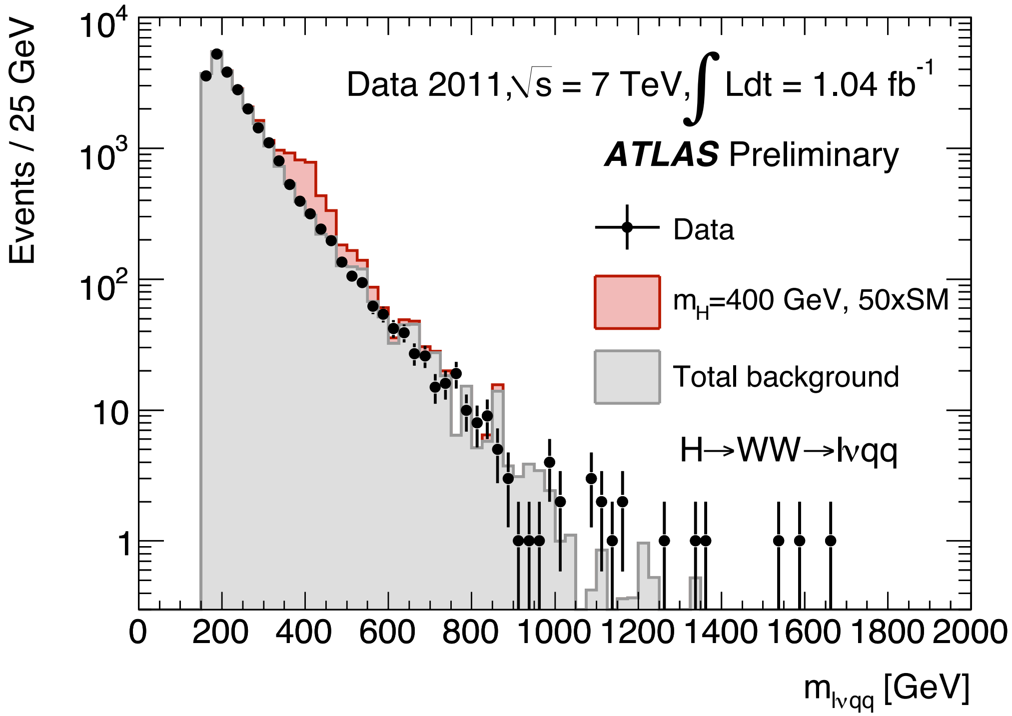
$H \to ZZ \to llqq$

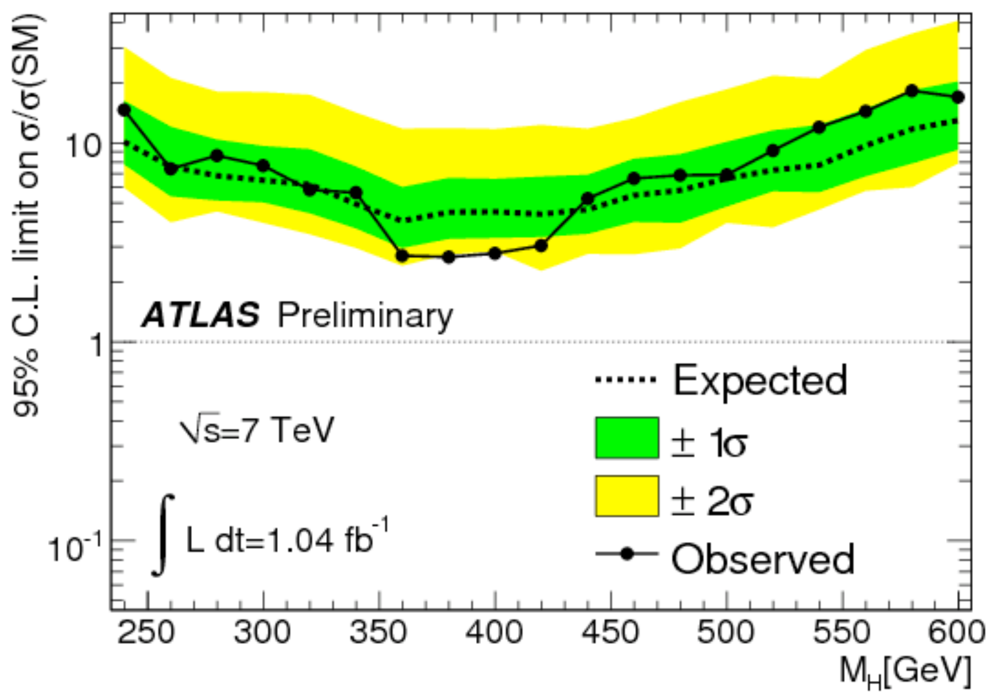




Less powerful than $H \to ZZ \to ll\nu\nu$ due to QCD backgrounds, but still contributes to sensitivity in high mass.

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





Large QCD backgrounds.

Provides additional sensitivity for high mass Higgs search.

A “Nano” Review of ATLAS Higgs Searches

Channel		btag (veto)	Jets	MET (GeV)	Shape	Mass Range (GeV/c^2)	Main backgrounds
γγ					M_{gg}	110-150	γγ (from sidebands)
WH		✓	2		M_{bb}	110-130	Top (3j - high M_{bb}) and W+jets (low M_{bb})
ZH		✓	2		M_{bb}	110-130	Z+jets (low M_{bb})
WW (lνlν)	0-jet		0	>30		110-240	WW (control region M_{ll})
	1-jet	veto	1	>30		110-240	Top (from reverse btag) and WW (M_{ll} CR)
WW (lνqq)	0-jet		0	>30	M_{WW}	200-600	W+jets (sidebands)
	1-jet	veto	1	>30	M_{WW}	200-600	W+jets (sidebands)
ZZ (llνν)		✓		>30	M_T	200-600	VV(from MC) and top (MC and checks)
ZZ (llqq)		✓	2	<50	M_{llqq}	200-600	Z+jets (from MC) and top (from MC)
ZZ (4l)		IP			M_{4l}	110-600	ZZ (from MC), Z+jets (MC) and top (CR)

All channels use invariant mass or transverse mass as discriminating variable.

JES and JER, lepton efficiency, luminosity and some background normalization predicted from MC are major systematic uncertainties shared among channels.

Statistical Procedure (1/2)

Build the combined likelihood function of all channels:

Parameter of interest: a cross-section scale factor: μ = σ / σSM
Systematics treated as *nuisance parameters.*
Correlate systematics shared among individual search channels.

Build the Test Statistic – The Profile Likelihood Ratio

$$\tilde{q}_\mu = -2 \ln \frac{\mathcal{L}(\text{data}|\mu, \hat{\theta}_\mu)}{\mathcal{L}(\text{data}|\hat{\mu}, \hat{\theta})}, \quad \text{with a constraint } 0 \leq \hat{\mu} \leq \mu$$

$\hat{\theta}_\mu$ refers to the conditional maximum likelihood estimators of θ

This is a one-sided test statistic that's used for upper-limits(μ=test value) and discovery(μ=0)

Statistical Procedure (2/2)

The distribution of the test statistic is obtained in two ways:

toy Monte Carlo generation

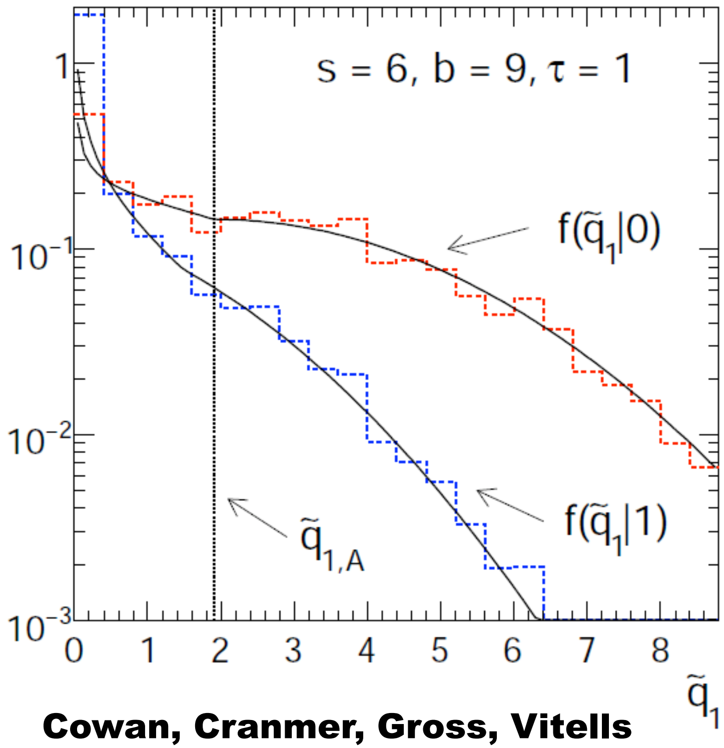
→ a fully frequentist procedure

Introduce randomized auxiliary measurements instead of randomizing nuisance parameters in toys.

Using asymptotic distribution of Profile Likelihood Ratio

used for primary result

Asymptotic vs. toy MC



Asymptotic formula →

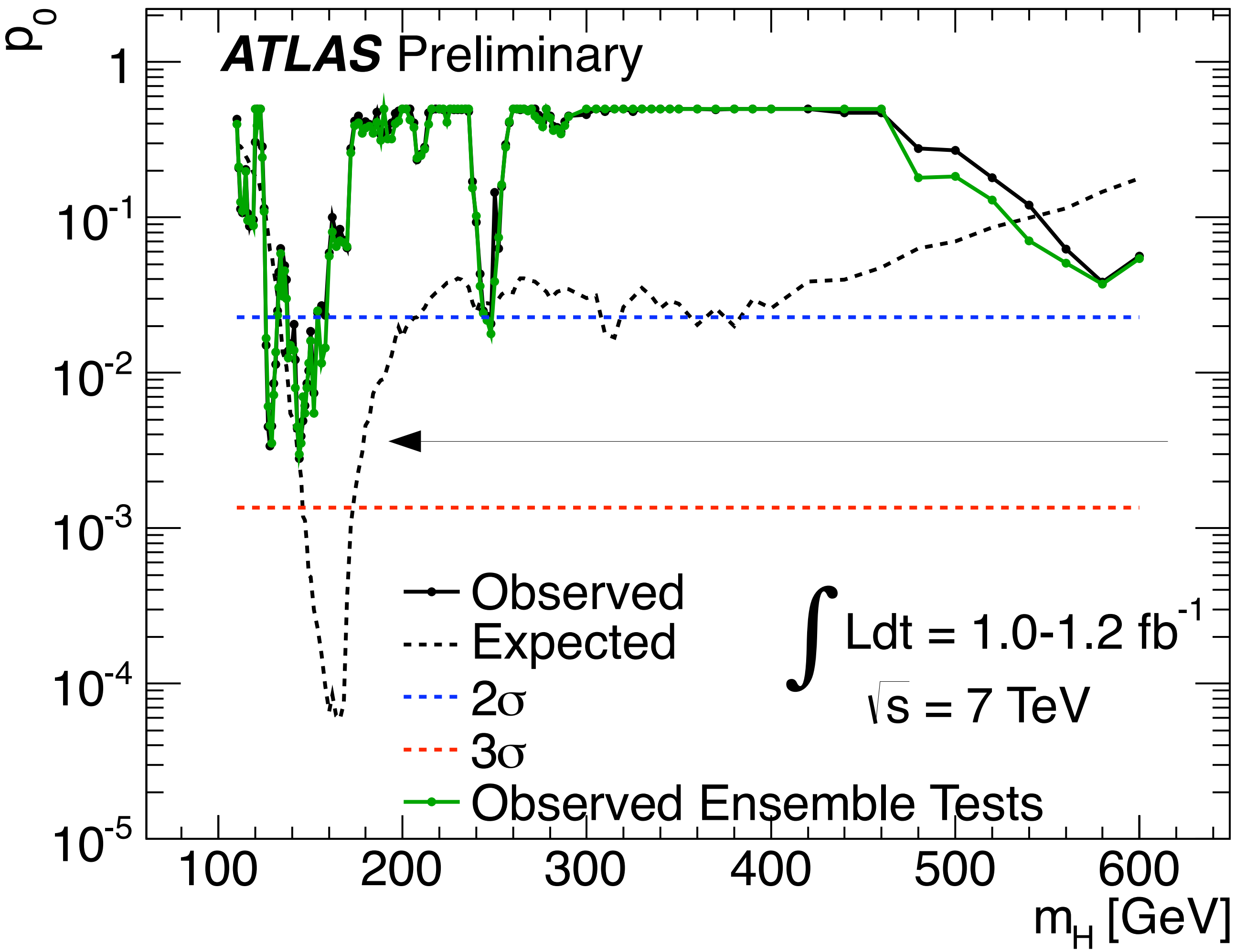
Cowan, Cranmer, Gross, Vitells Eur.Phys.J.C71:1554,2011

Limit result is based on "CLs" : it protects against false exclusion but introduces conservatism.

Bayesian limit provides a cross check: A different approach, but expected to be numerically close to CLs result.

Any excess?

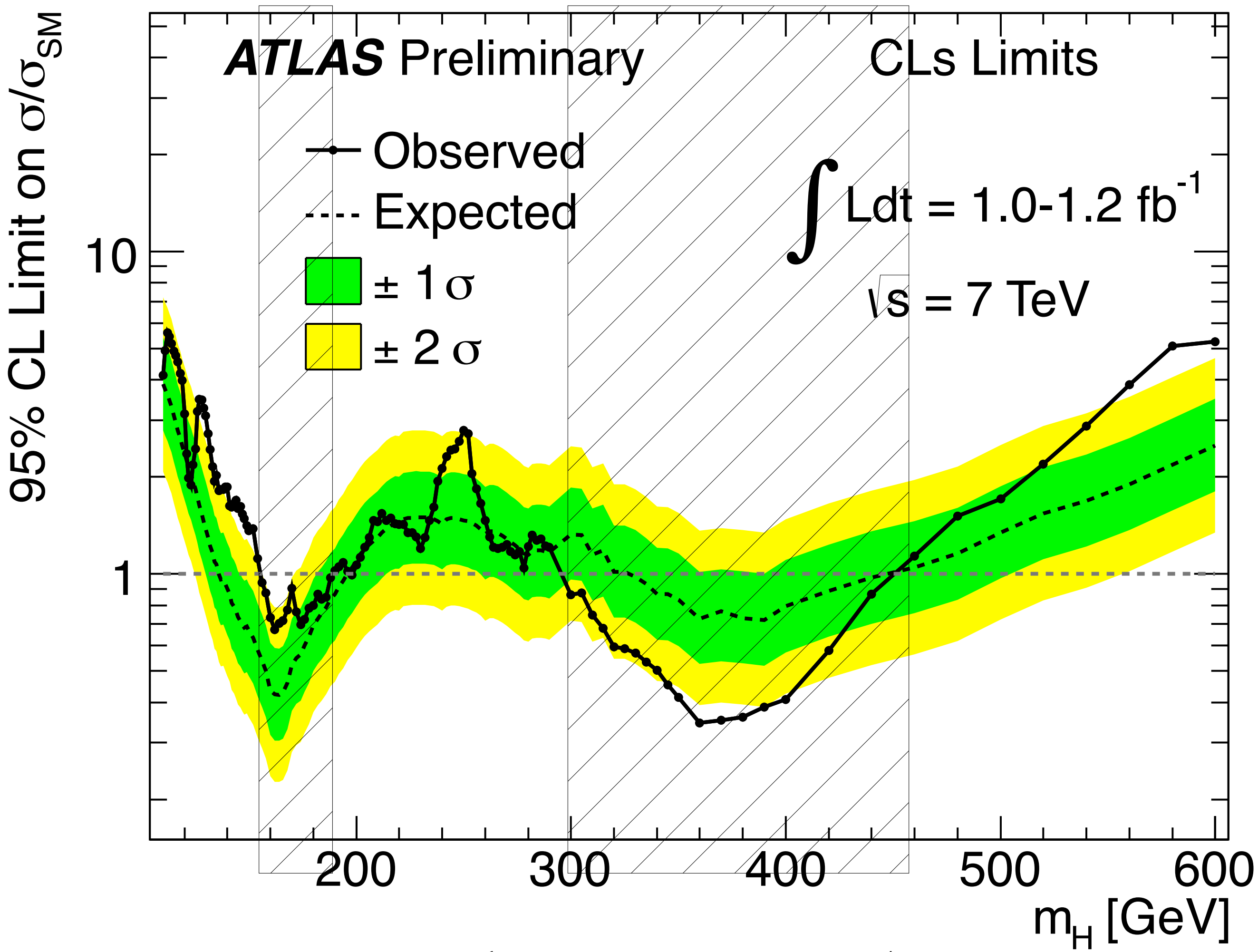
P-value quantifies the incompatibility between data and background-only hypothesis



Inject SM signal

No excess beyond 3σ is observed in the combined search.
An excess around 250GeV and a broad excess around 140GeV are beyond 2 sigma.
Asymptotic approximation behaves well.

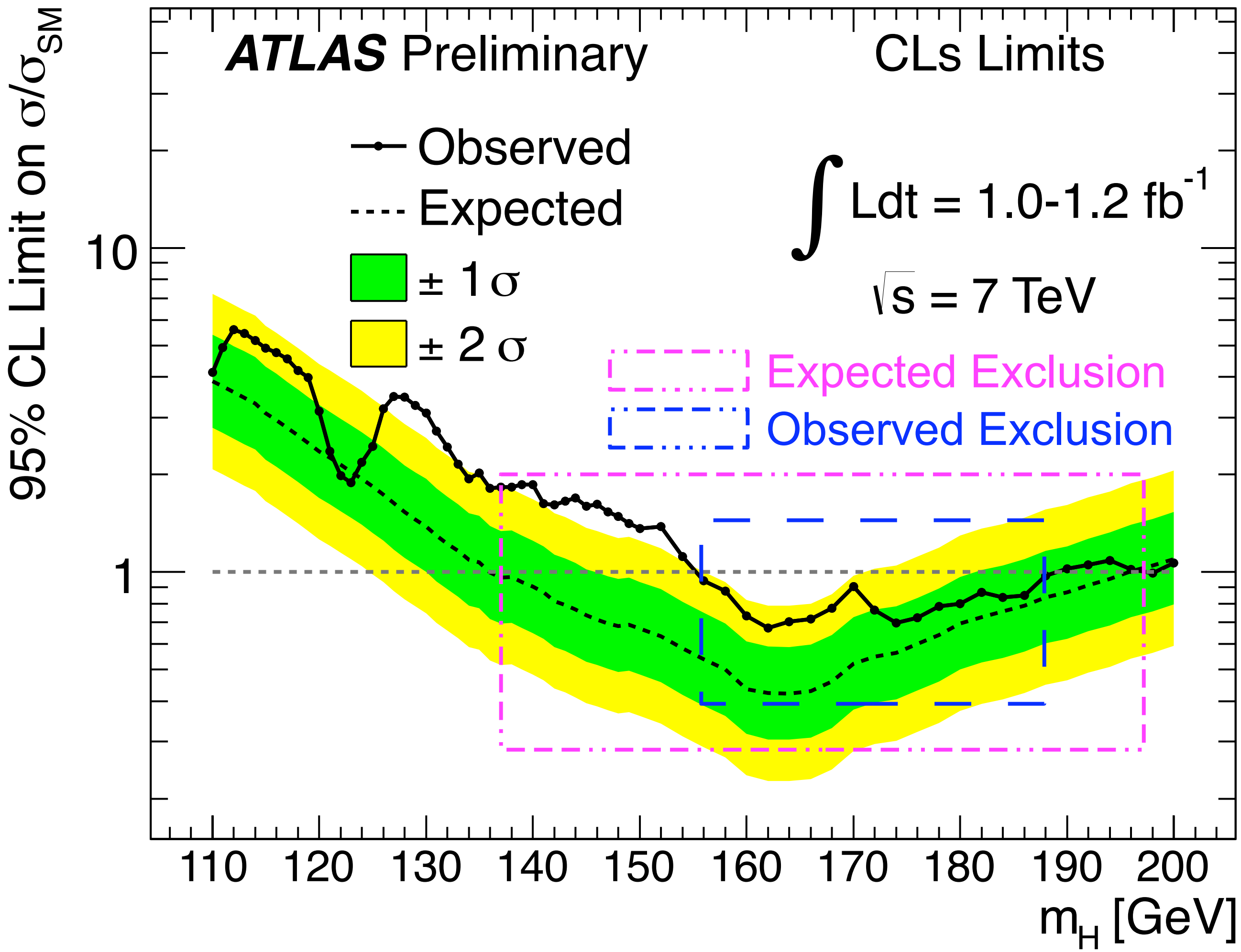
Limits in the full mass range



155<MH<190 and 295 <MH< 450 GeV/c2
excluded at @ 95% CL

H → ZZ → llvv dominates the high mass range exclusion.
H → WW → lvlv dominates the low/intermediate mass range exclusion.
A single channel alone is able to exclude SM Higgs.

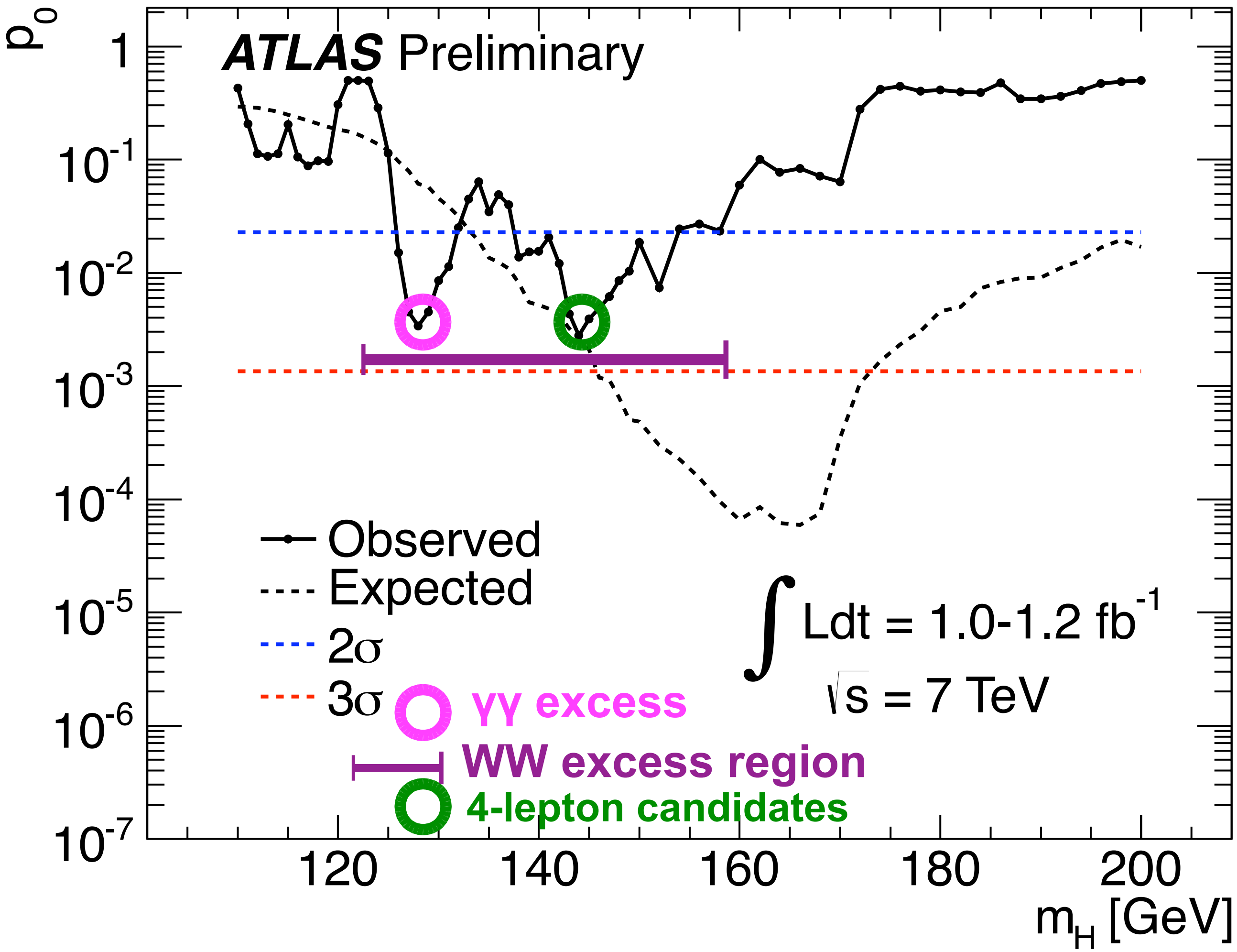
A Closer Look at Low&Intermediate Mass Range



Expected to exclude SM Higgs from 136 GeV to 196 GeV.

The observed limit is affected by the excess in WW → lνlν channel and candidates in 4-lepton channel. A SM Higgs from 155GeV to 190GeV is excluded.

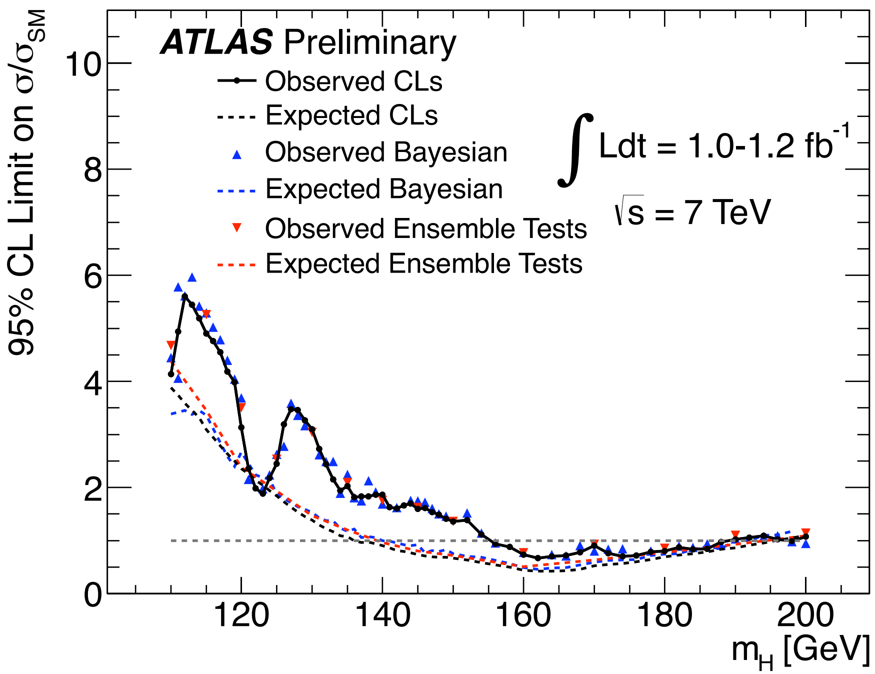
P-value in Low&Intermediate Mass Range

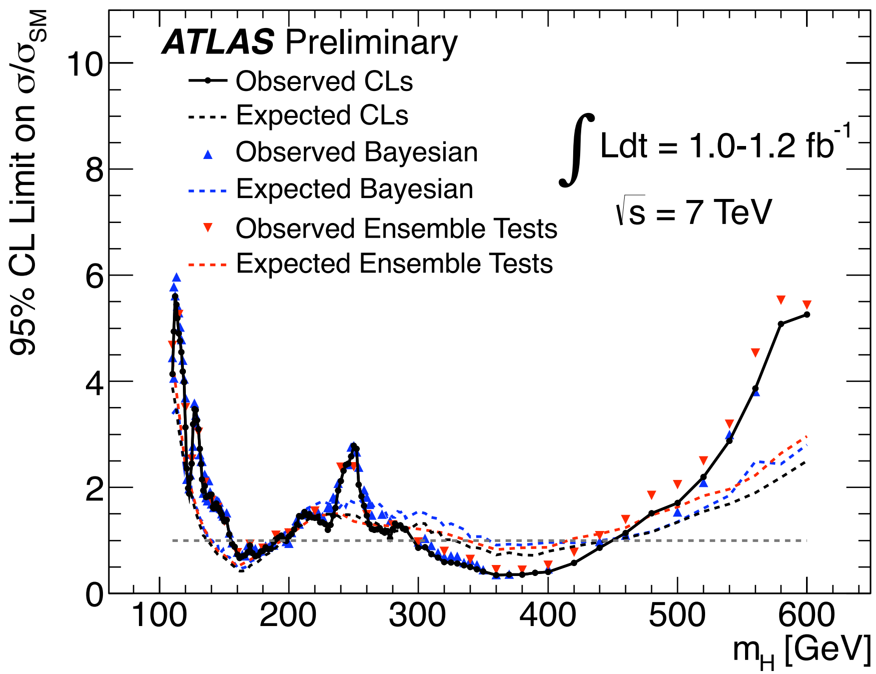


The largest excess at 144GeV has approximately 2.8 sigma significance, corresponding to 0.3% chance of background fluctuation.

This is *local significance*. The chance of such fluctuation appearing anywhere in the mass range considered is much larger than 0.3%.

Cross-Checks





Three implementations of two different approaches:

- Frequentist approach
  - Asymptotic approximation (used as primary result)
  - Toy MC generation
- Bayesian approach

Three implementations show consistent results.

Conclusion and Outlook

- Thanks to the excellent operation of the Large Hadron Collider (LHC) in 2011, 1.23 fb-1 data has been delivered which empowered ATLAS to become sensitive to a Standard Model Higgs boson.
- ATLAS excluded a SM Higgs in mass range [155,190] GeV, and [295,450]GeV.
- In the low-mass range (130 − 150 GeV), an excess of events is observed. The largest *local* significance is approximately 2.8sigma at 144GeV.
    - Considered *LEE*, it's reduced to less than 2sigma → be cool!
- A new version of ATLAS Higgs combination using more data is being prepared.
- The ATLAS+CMS Higgs combination is under way.

→ Stay tuned!