New ATLAS Higgs Results

Tom LeCompte

High Energy Physics Division
Argonne National Laboratory

(On behalf of the ATLAS Collaboration)

An Opening Thought

- This talk is being taped.
- What trouble could that possibly cause?
- Seriously, these results are new (first shown today), I haven’t had time to triple-check that these are the absolutely final plots and numbers.
  - I believe it’s right, but…
- If you’re going to get a plot or number, please take it from the ATLAS note (on the web) rather than from here.

The Washington Post

FINAL

Nixon Says He Won’t Resign

Rhodes Will Vote To Impeach; House To Curtail Debate

Feels Such a Step Would Be ‘Outside The Constitution’

Resignation Urged By GOP Senators

Dismay Pervades White House Staff

Scope of this Talk

I am going to discuss the new ATLAS results in the $\gamma\gamma$ and Z* channel, especially significances, masses and spin-parity.

I refer you to Jianming's talk on WW, bb and $\tau\tau$.

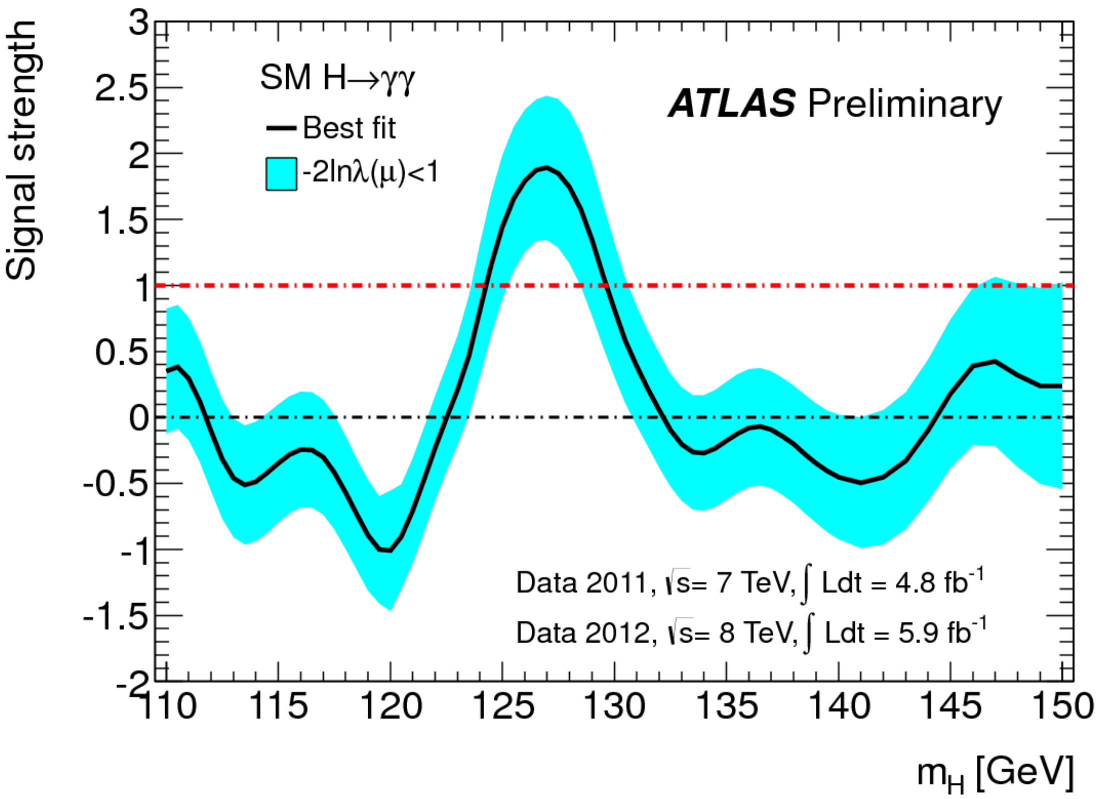
Outline

- Introduction
- Results
  - Gamma-gamma channel
  - ZZ* Channel
  - Combination
- Interpretation
  - Consistency of Mass Results
  - Spin and Coupling
- Conclusions

I did my best to keep this talk short so there would be plenty of time for discussion.

I ask your indulgence not to place this talk on the web for a day or two.

Introduction: Understanding ATLAS Plots



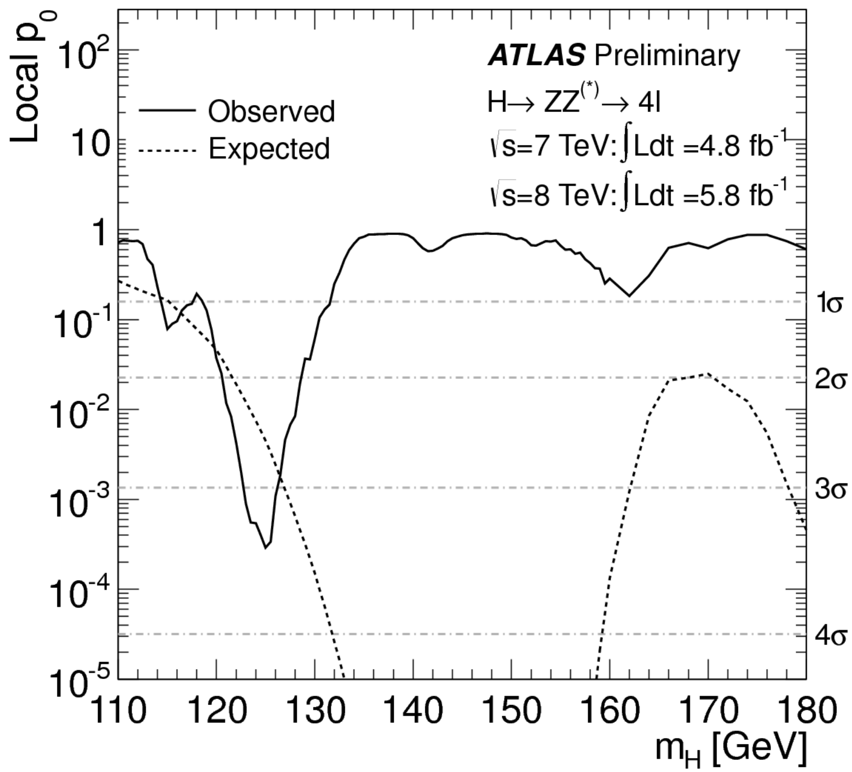
The blue-and-white plots show the signal strength $\mu = \sigma/\sigma_{SM}$ as a function of mass.

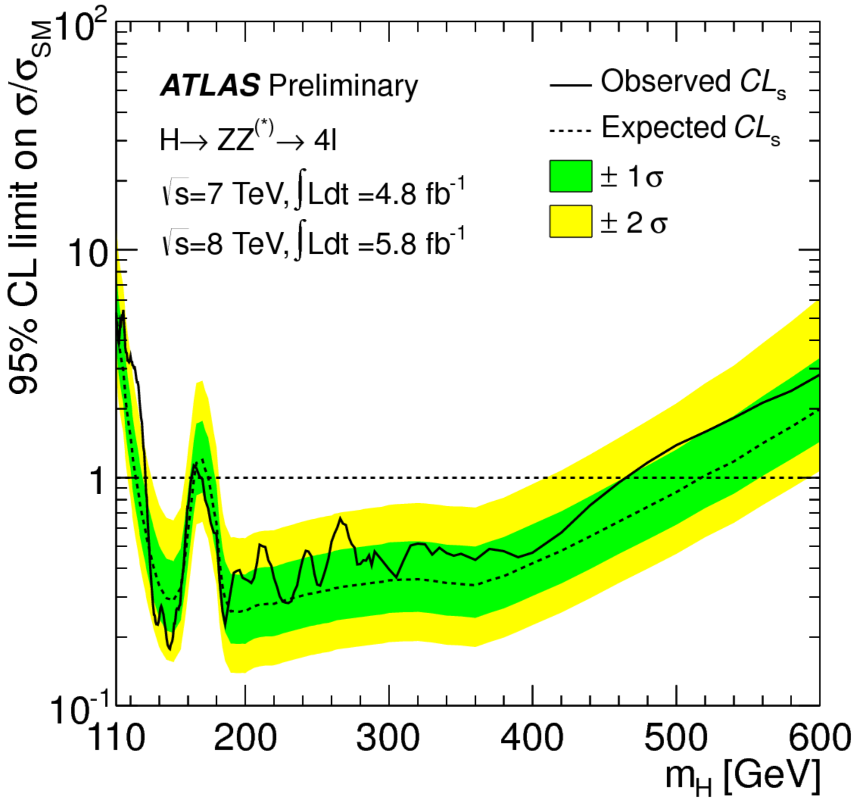
This is the base plot from which the others are derived.

Introduction II:

In the black and white plots, we test how compatible μ is with 0.

Appropriate for ***Discovery.***

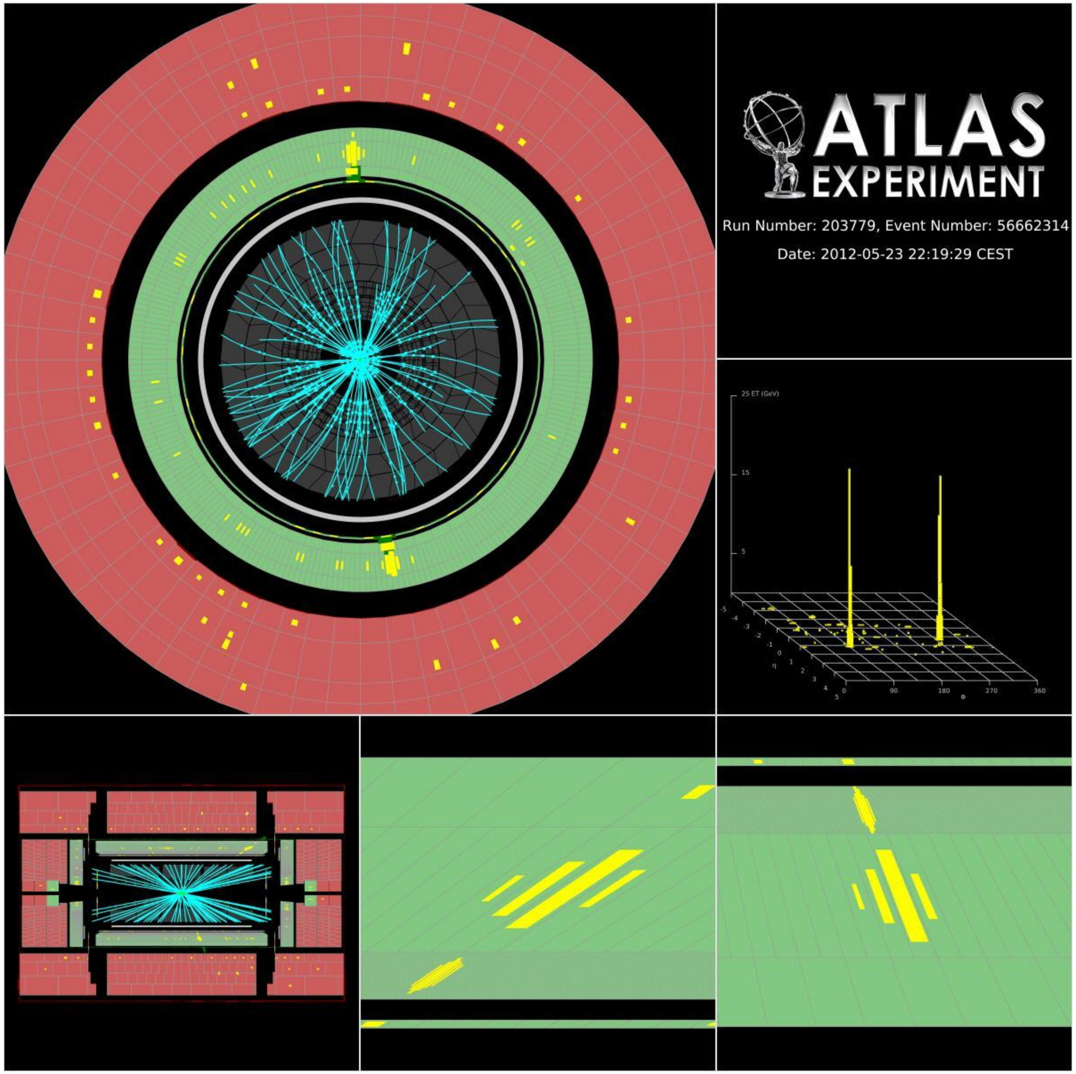




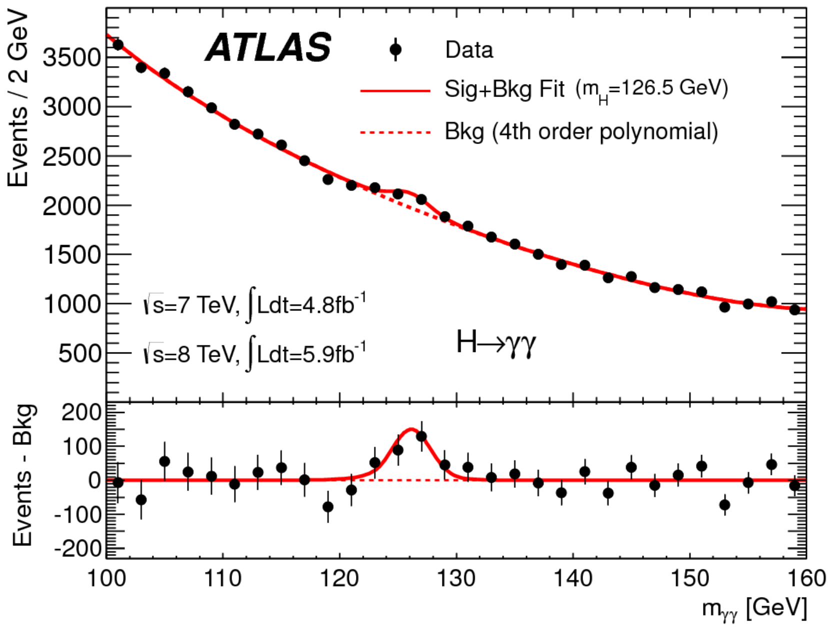
In the green and yellow plots, we test how compatible μ is with 1.

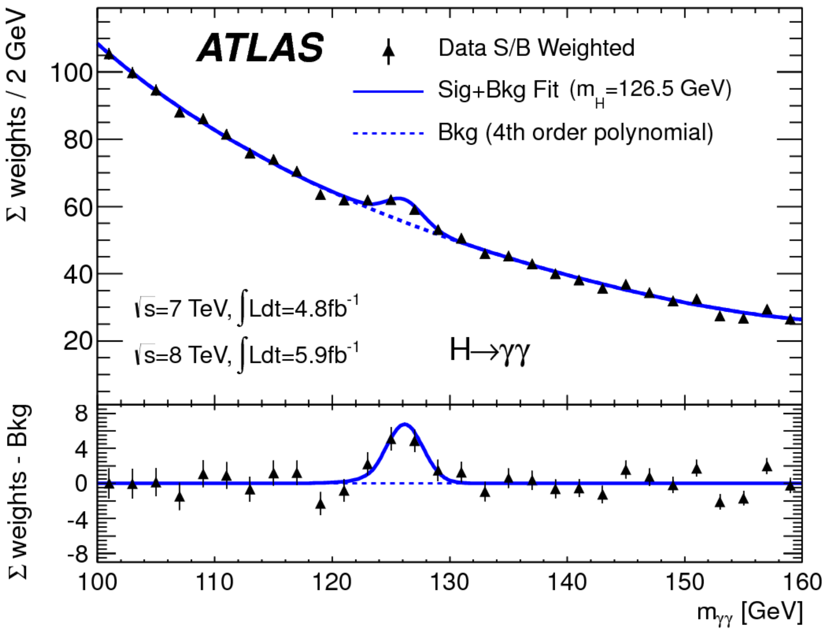
Appropriate for ***Exclusion.***

Two-Photon Channel



From The Discovery Paper





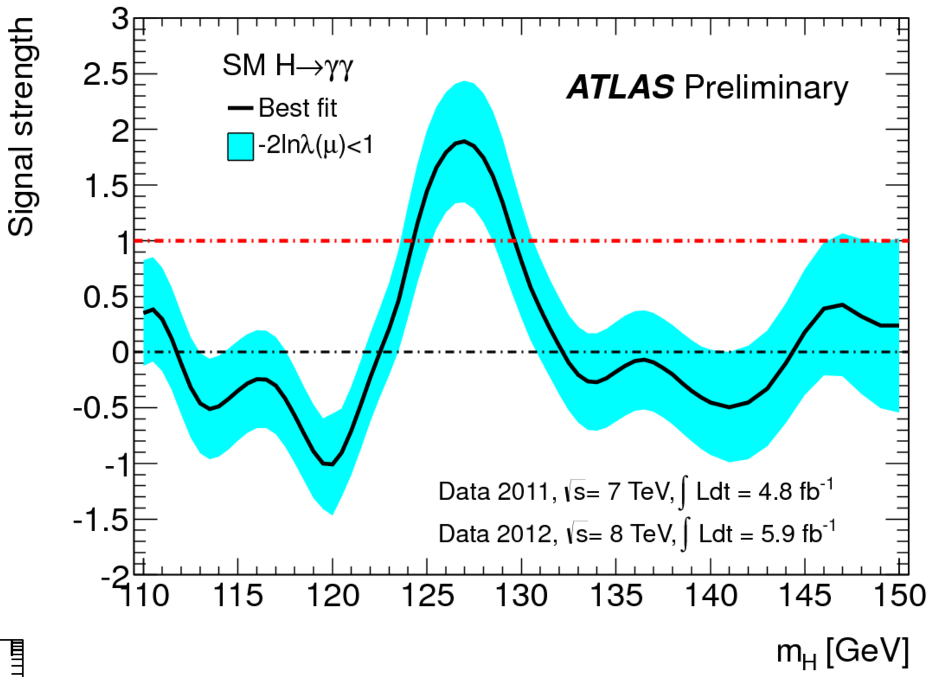
Here we are plotting events. However, the fact that different events are "worth" more than others is hidden. The effect of **dividing into 10 categories** is not evident.

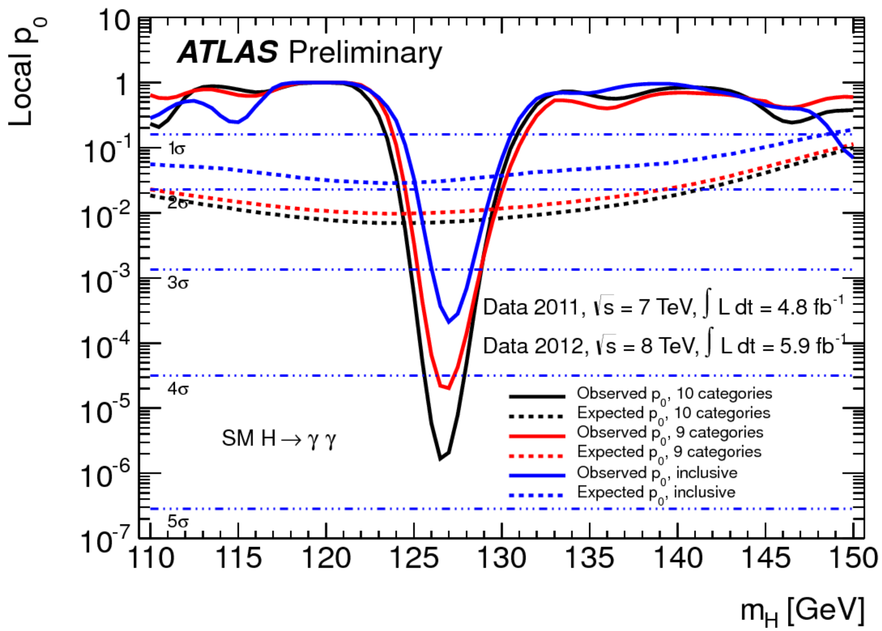
Here we are plotting weights – not events.

Outcome

$$\mu = 1.8 \pm 0.5$$

(at 126 GeV)



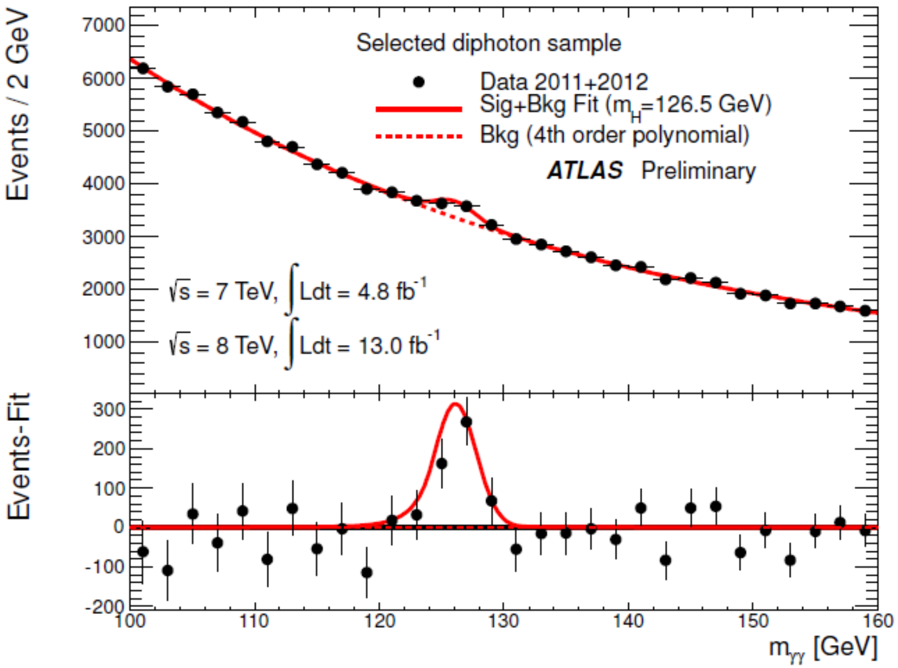


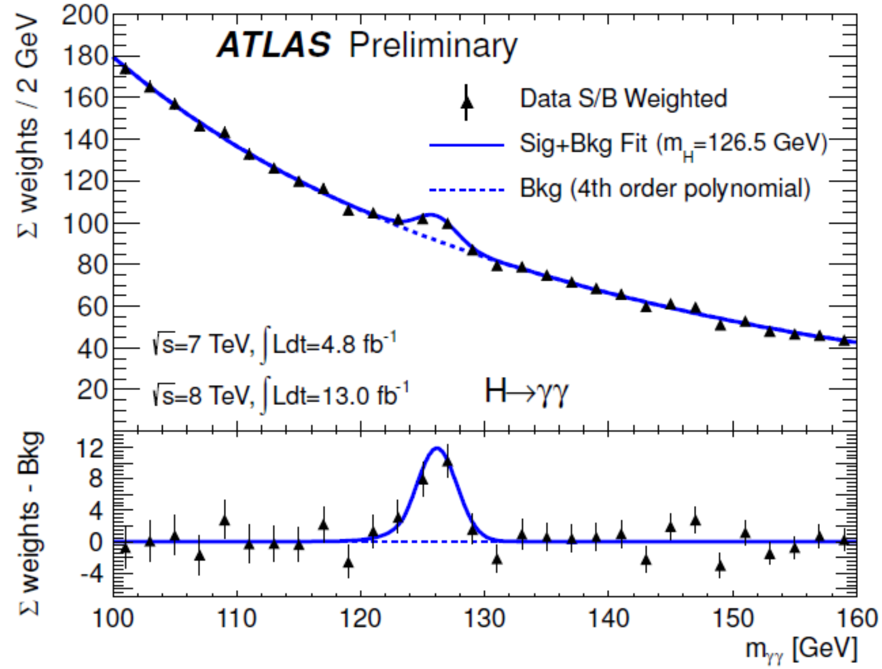
A significance in this channel of ~4½σ (5.9σ in all channels)

What's New?

- 4.8+13.0 fb^{-1} of data vs. 4.8+5.9 fb^{-1}.
  - This is an **update**, not an independent dataset.
- We have gone from 10 to 12 categories
  - One added with a lepton (enhances ttH and VH)
  - One added with a low-mass dijet (also enhances VH)
  - Reminder: A SM Higgs hypothesis is built into the weights, combinations and thus the significance of these searches
- We have improved the isolation and vertex requirements

Updated Results





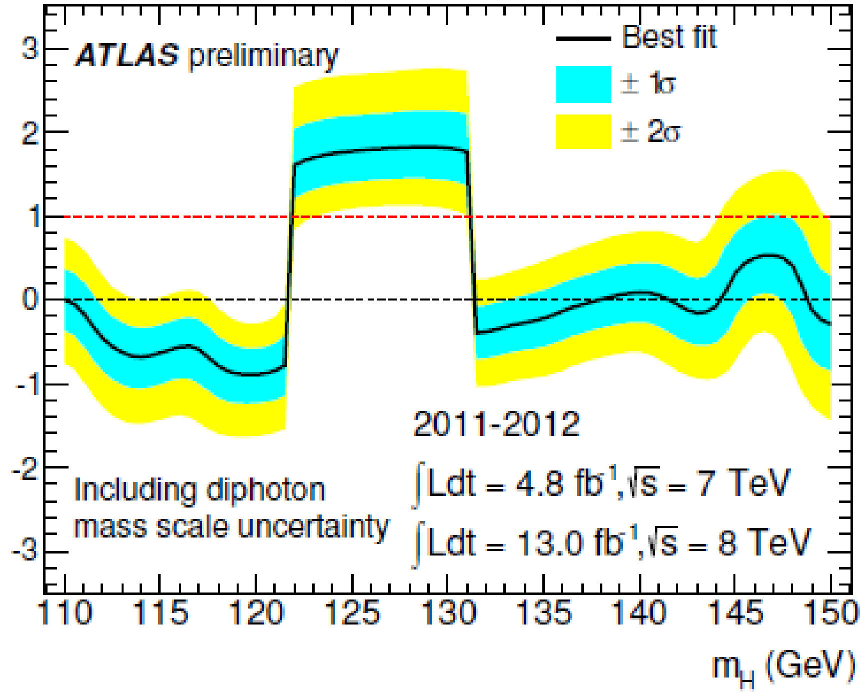
Reminder: Here we are plotting events. However, the fact that different events are "worth" more than others is hidden. The effect of **dividing into 12 categories** is not evident.

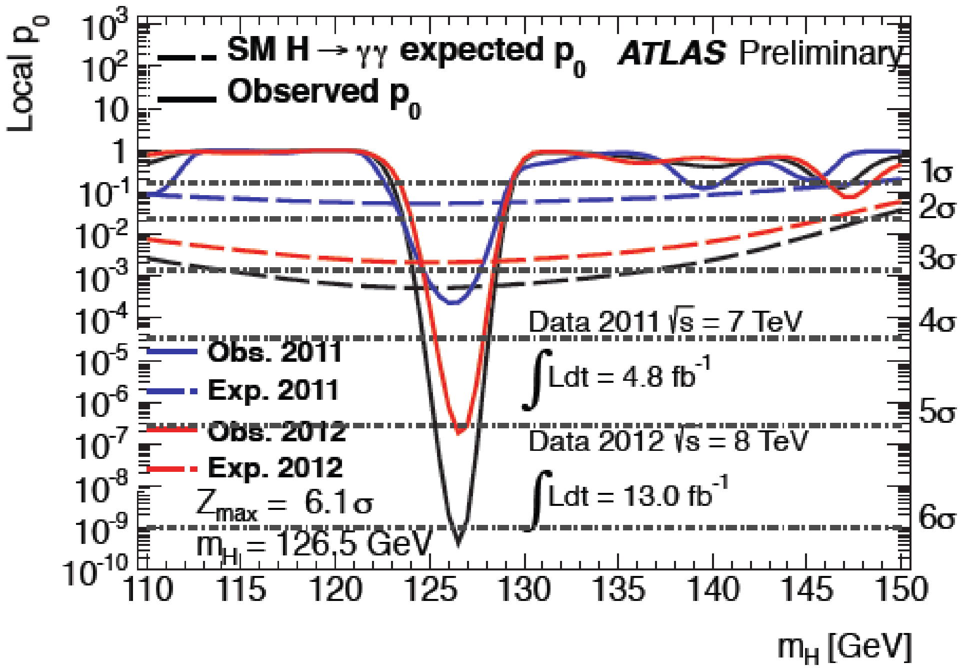
Reminder: Here we are plotting weights. However, it looks like we are plotting events.

Updated Results II

$$\mu = 1.8 \pm 0.3^{+0.29}_{-0.21}$$

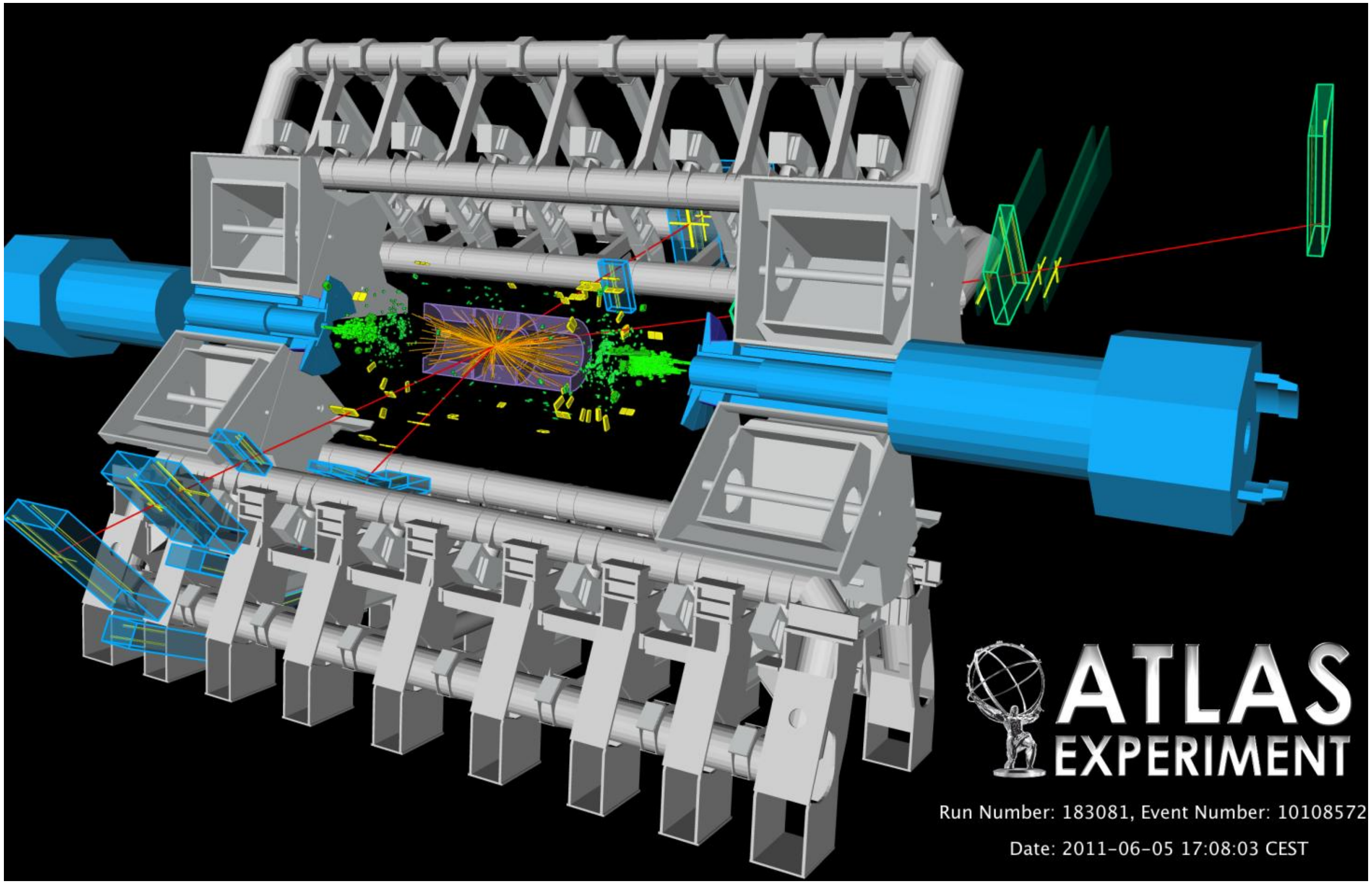
(Was 1.8 ± 0.5)



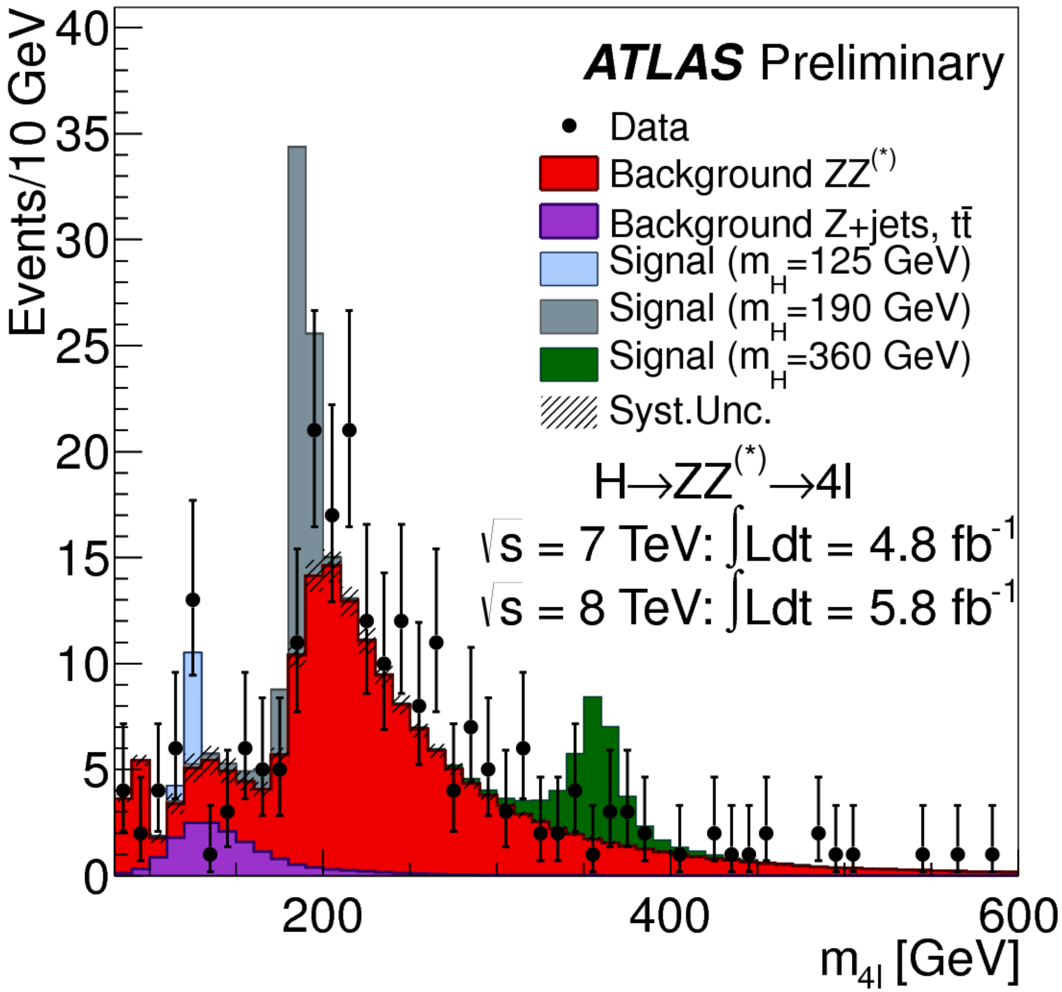


A significance in this channel of 6.1σ (was ~4½σ)

Higgs to ZZ$^{(*)}$ (4 leptons – e's and μ's)

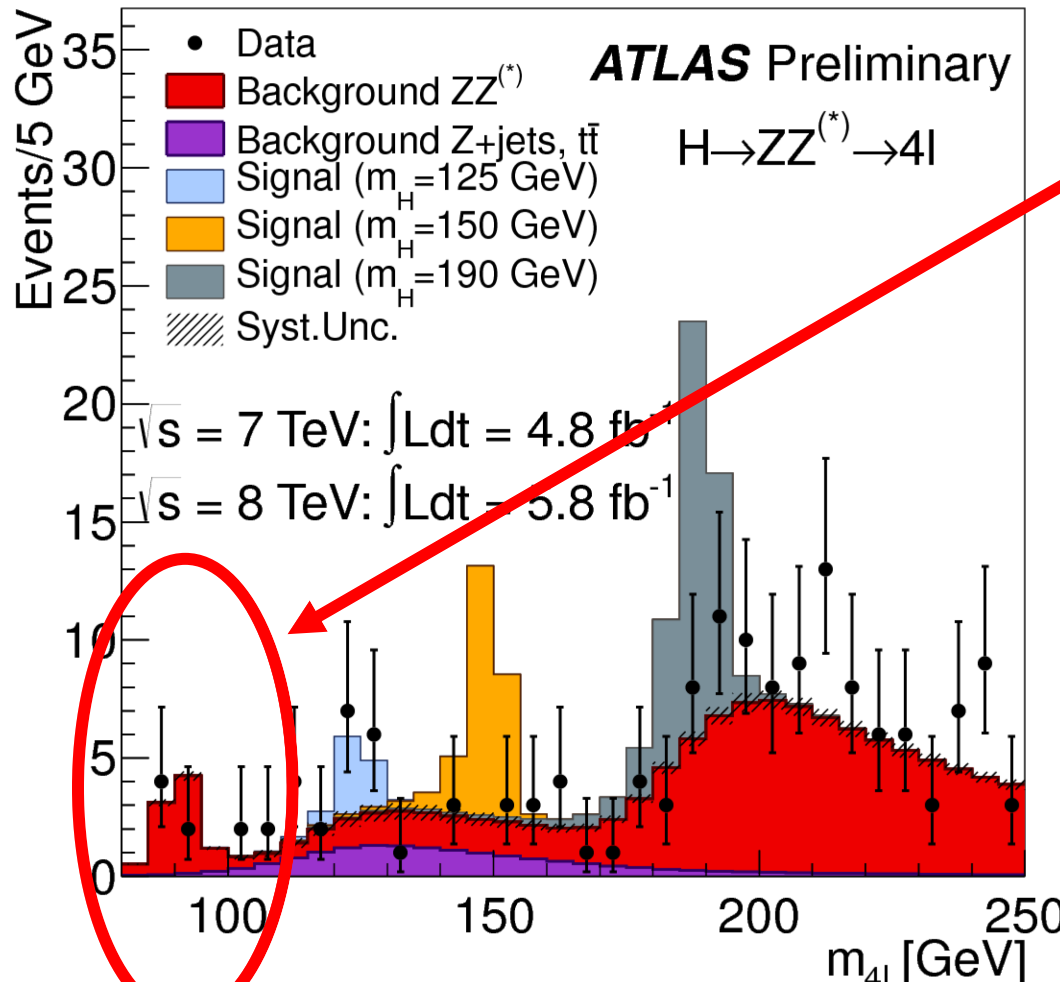


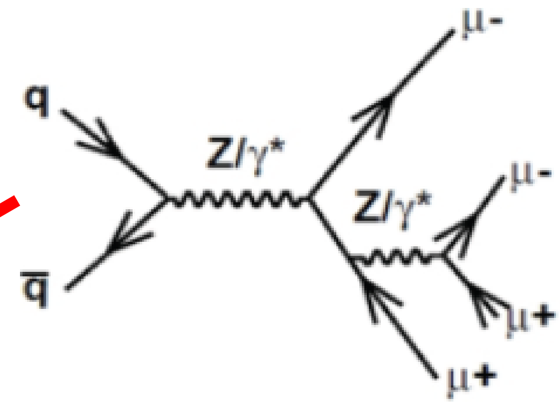
From The Discovery Paper



- We're obviously dealing with small statistics.
  - At 125 GeV, it's 13 events over a predicted background of 5
- The background is almost entirely ZZ and ZZ*
  - Except under the peak at 125 GeV: more on that later.
- There are some interesting features in this plot.

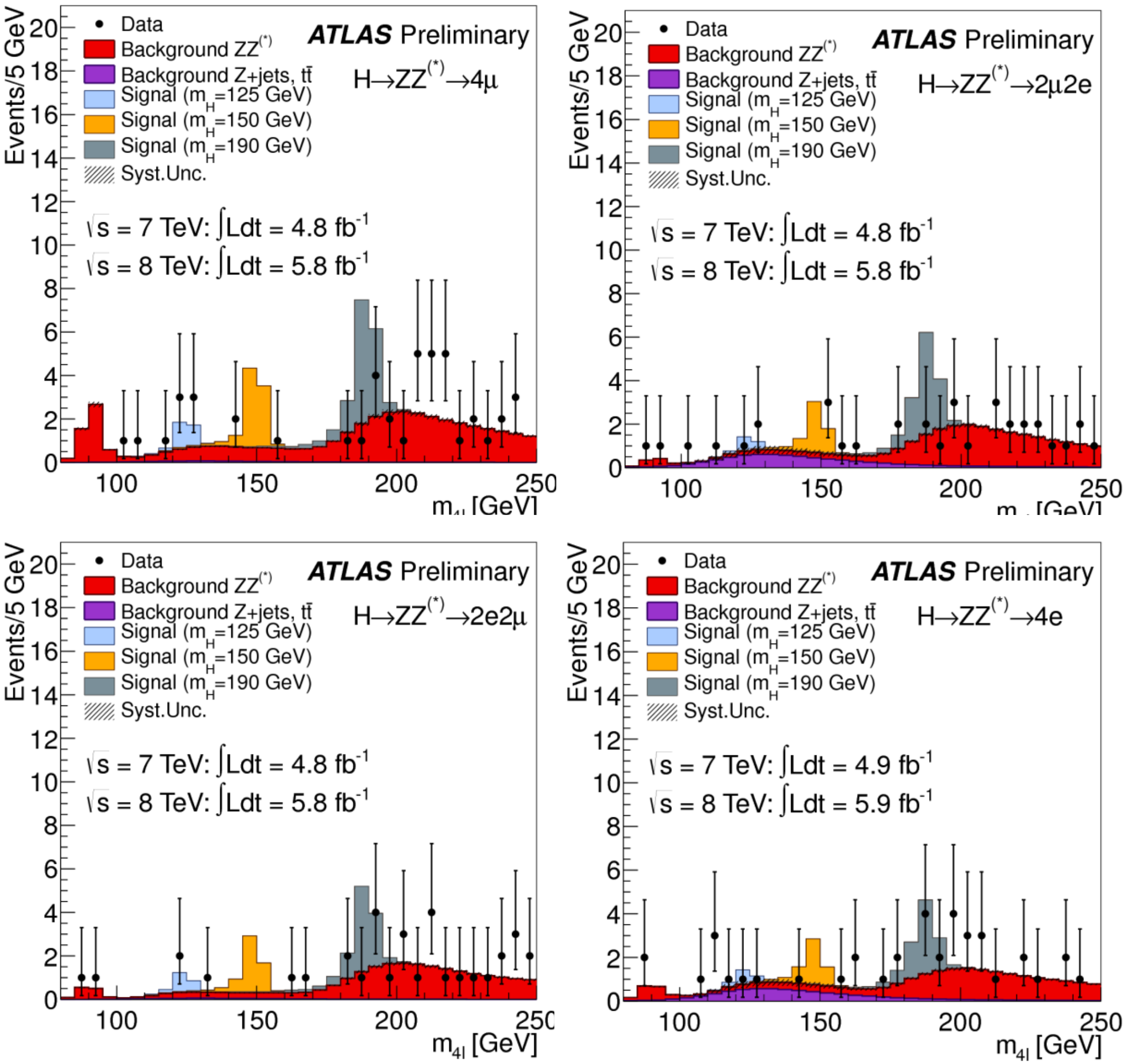
Interesting Feature #1: Z →4 leptons





- There are 6 events that are radiative + internal conversion (i.e. 4 lepton) Z decays.
  - Two each in the 4e, 2e2μ and 2μ2e categories.
  - ATLAS considers a "Z" to be between 50-106 GeV
- These events occur with about the same frequency as a SM Higgs.

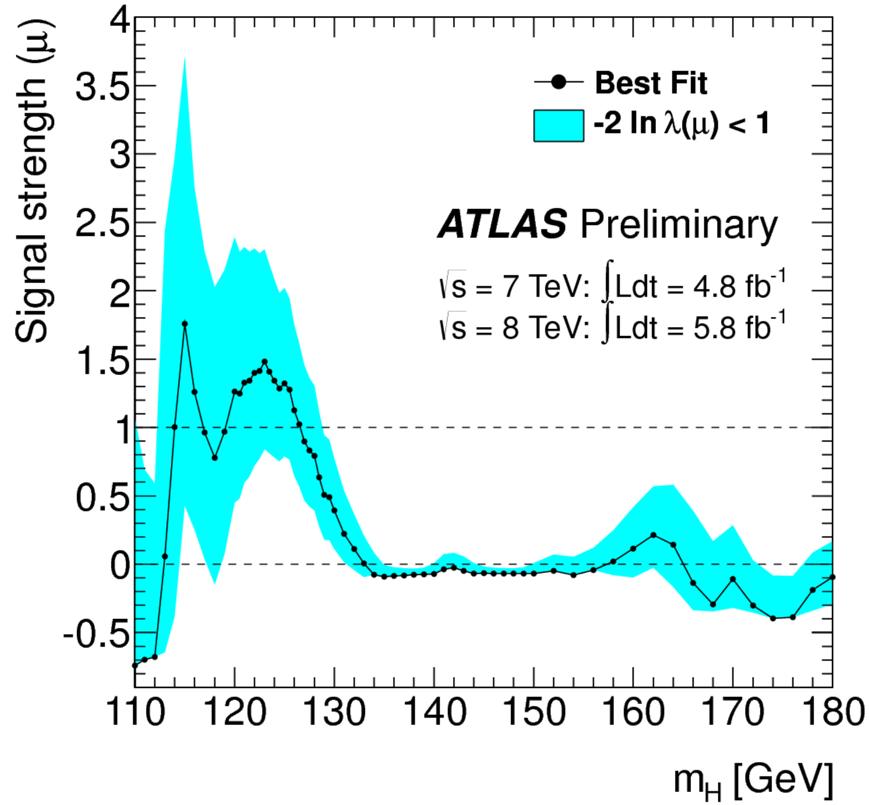
Interesting Feature #2: Decay Modes

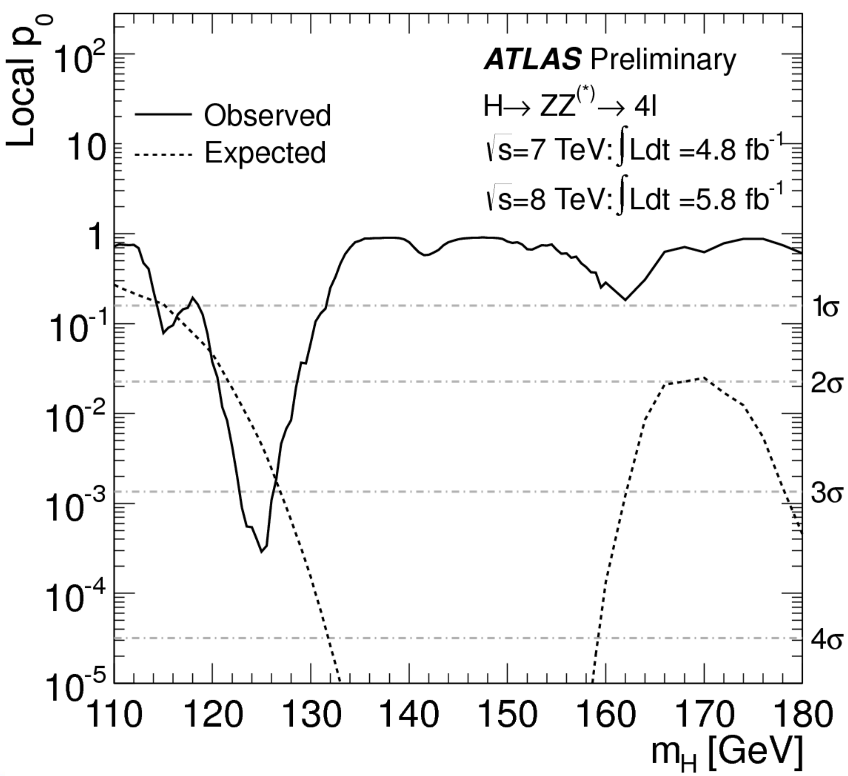


- The excess is not coming from a single channel.
  - Not much more to say with this level of statistics.
- The only channels with significant non ZZ* background are the ones where the off-shell Z* decays to electrons.
  - The higher probability for a jet to fake an isolated electron over an isolated muon comes into play.
  - The mass constraint for the on-shell pair removes most of this.
  - Much of the note concerns itself with the proper assessment of this background.

Outcome

A value for μ is not quoted, but from the graph one can see the 1σ range: ~0.75-2.25, peaking near 1.4-ish.





A significance in this channel of 3.4σ (5.9σ in all channels)

What's New?

- 4.8+13.0 fb^{-1} of data vs. 4.8+5.9 fb^{-1}.
  - This is an **update**, not an independent dataset.

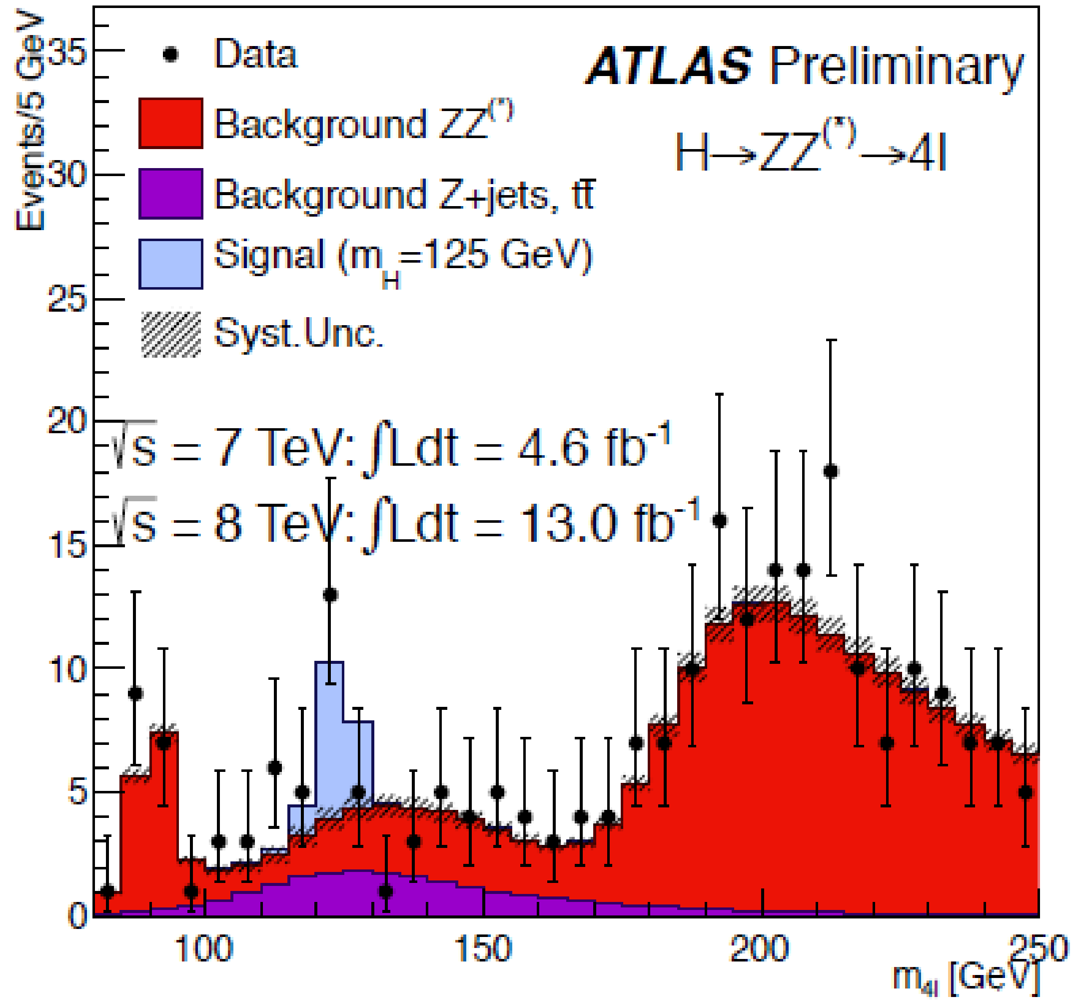
- Slightly better electron ID for 2012 data, especially at low p_T
  - More stringent pixel requirements (rejects against conversions)
  - Tighter ID in the transition region
  - Better bremsstrahlung recovery

Updated Results

In the signal region 125 ± 5 GeV

Observed	18 events
Expected from background only	8.3 ± 0.8
Expected from SM Higgs	9.9 ± 1.3

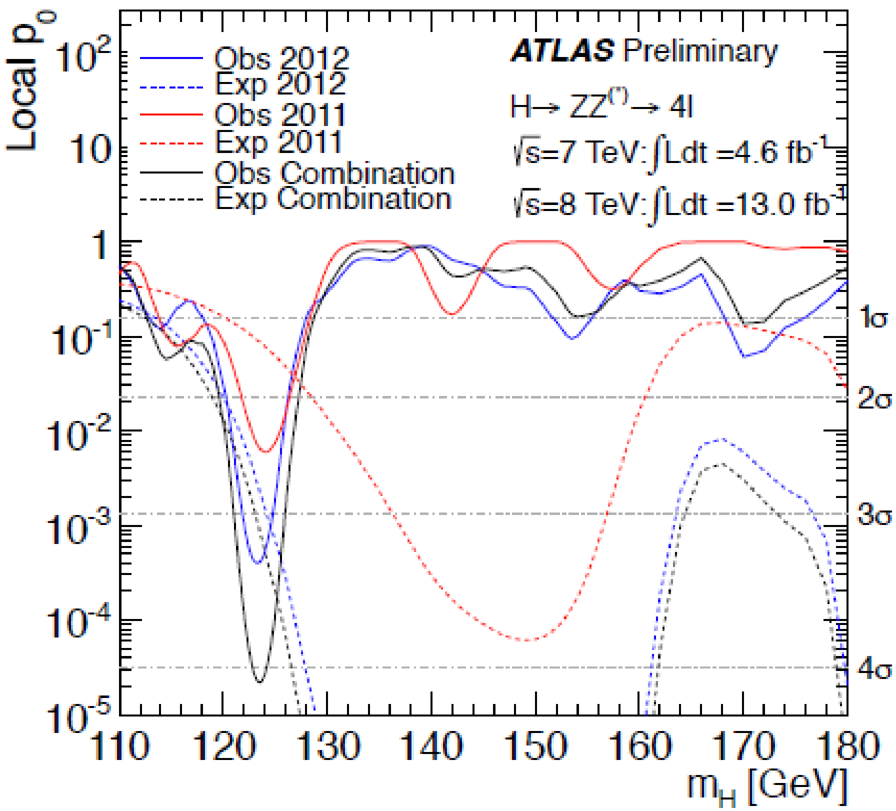
	4μ	2e2μ	2μ2e	4e
Data	8	4	2	4
Expected S/B	1.7	1.7	0.9	0.7
Irreducible/total B	85%	68%	37%	35%



Updated Results

$$\mu = 1.3^{+0.6}_{-0.4}$$

(At 125 GeV)



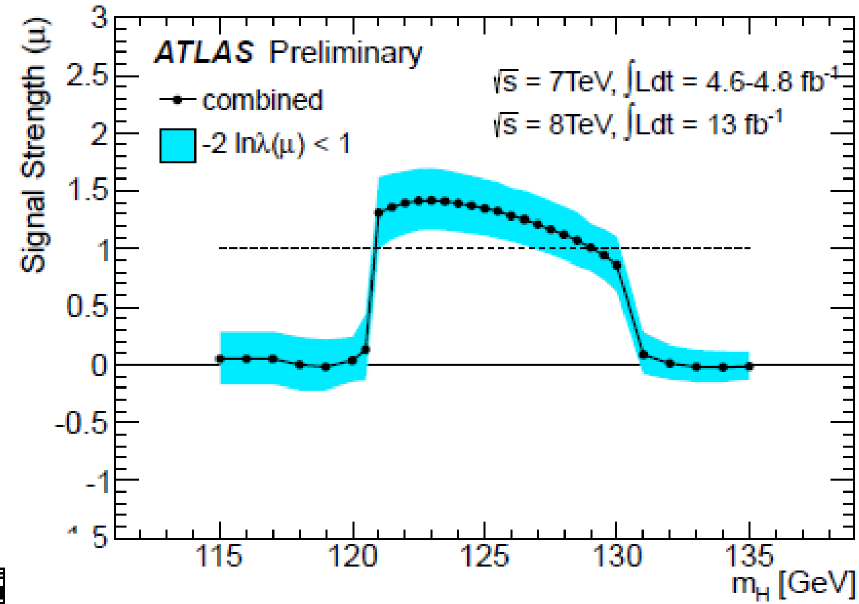
Sorry,
not quite ready

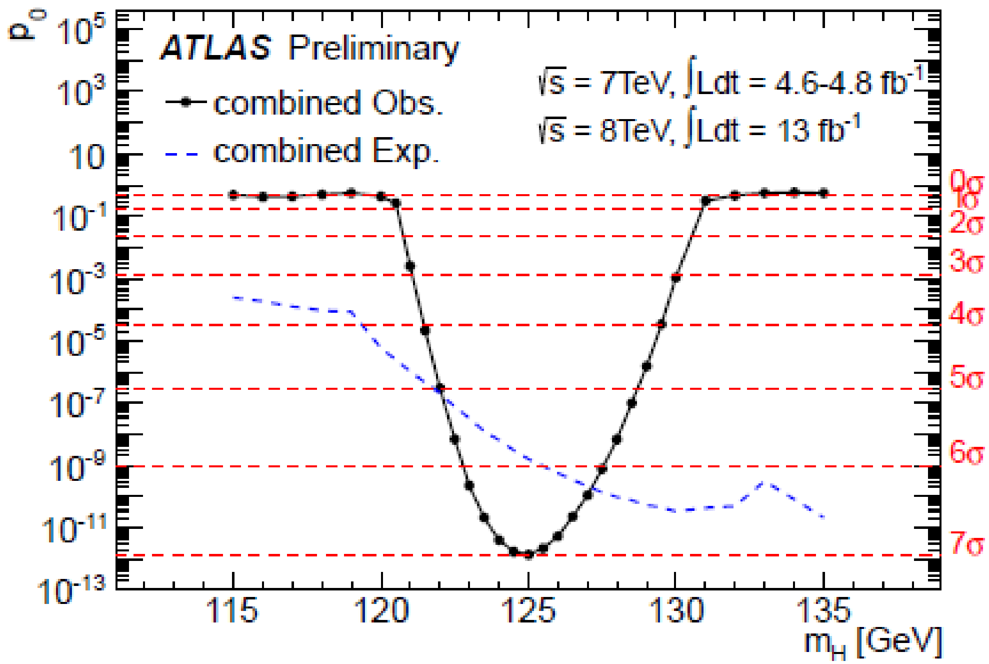
A significance in this channel of 4.1 σ

Updated Combined Results

$$\mu = 1.35 \pm 0.19 \pm 0.15$$

(Was 1.4 ± 0.3)

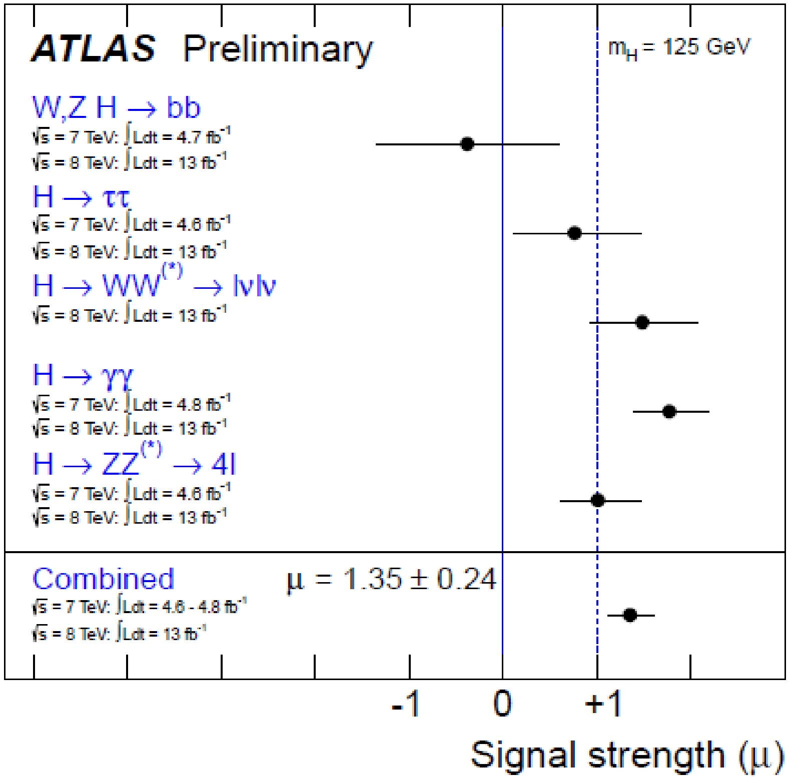




A combined significance of 7σ (was 5.9) – one in a trillion.

Channel by Channel

Higgs Boson Decay	μ (m_H=125.0 GeV)
$VH \to Vbb$	-0.4 ± 1.0
$H \to \tau\tau$	0.8 ± 0.7
$H \to WW^{(*)}$	1.5 ± 0.6
$H \to \gamma\gamma$	1.8 ± 0.4
$H \to ZZ^{(*)}$	1.0 ± 0.4
Combined	1.35 ± 0.24



One expects 3 of 5 points to be within 1σ and all within 2σ. That's what we see.

Meet The New Mass(es)

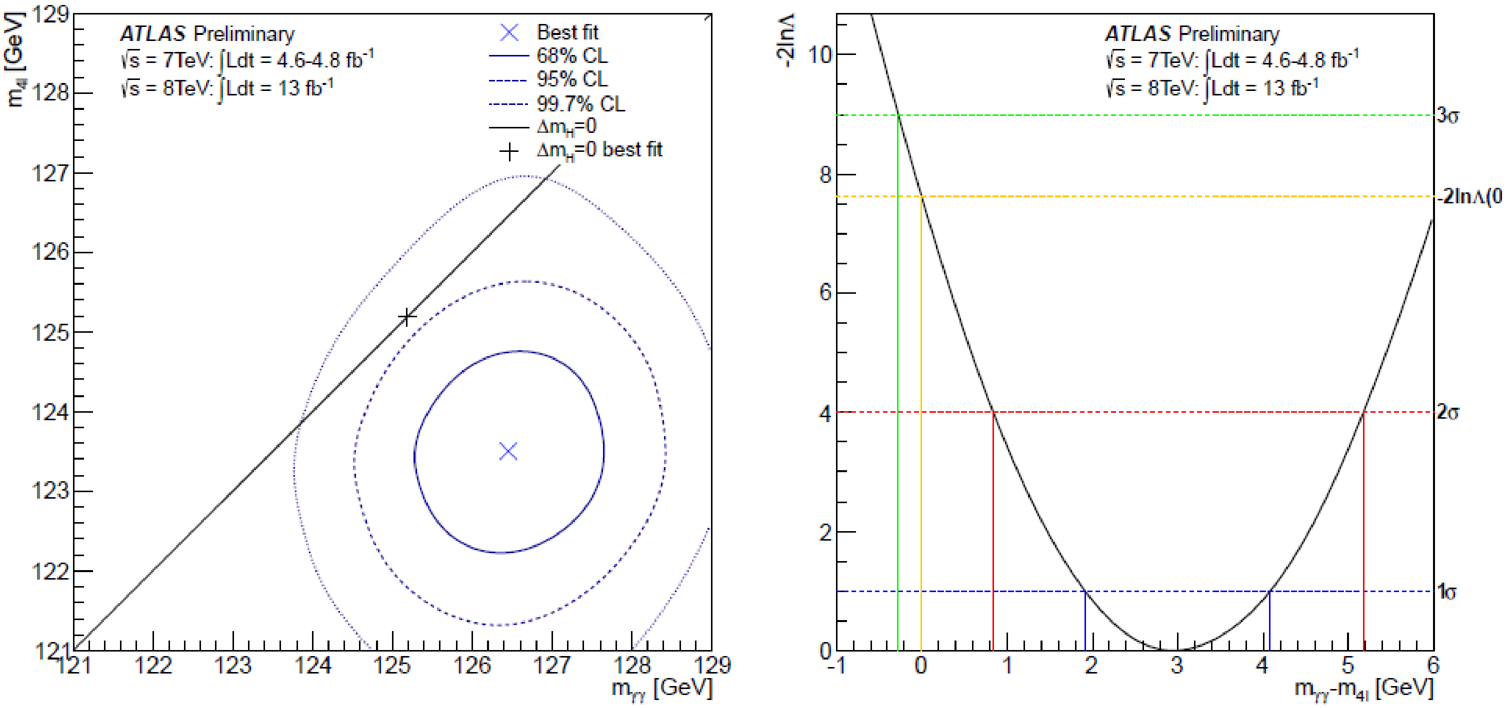
- M(ZZ*)
  - Discovery: "Around 125 GeV"
  - Update: 123.5 ± 0.9 ± +0.4/-0.2
  - Difference: Downward shift
- M($\gamma\gamma$)
  - Discovery: "Around 126.5 GeV"
  - Update: 126.6 ± 0.4 ± 0.4
  - Difference: Small
- Combination:
  - Discovery: 126.0 ± 0.4 ± 0.4
  - Update: 125.2 ± 0.3 ± 0.6
  - Difference: -0.8 GeV (with comparable uncertainty)

The "change", if there is one, comes from the ZZ* channel, which is dominated by the 4μ mode.

That channel has 8 observed events, with an expected 4 from signal and 4 from background.

My conclusion? Mass results are consistent within our sensitivity.

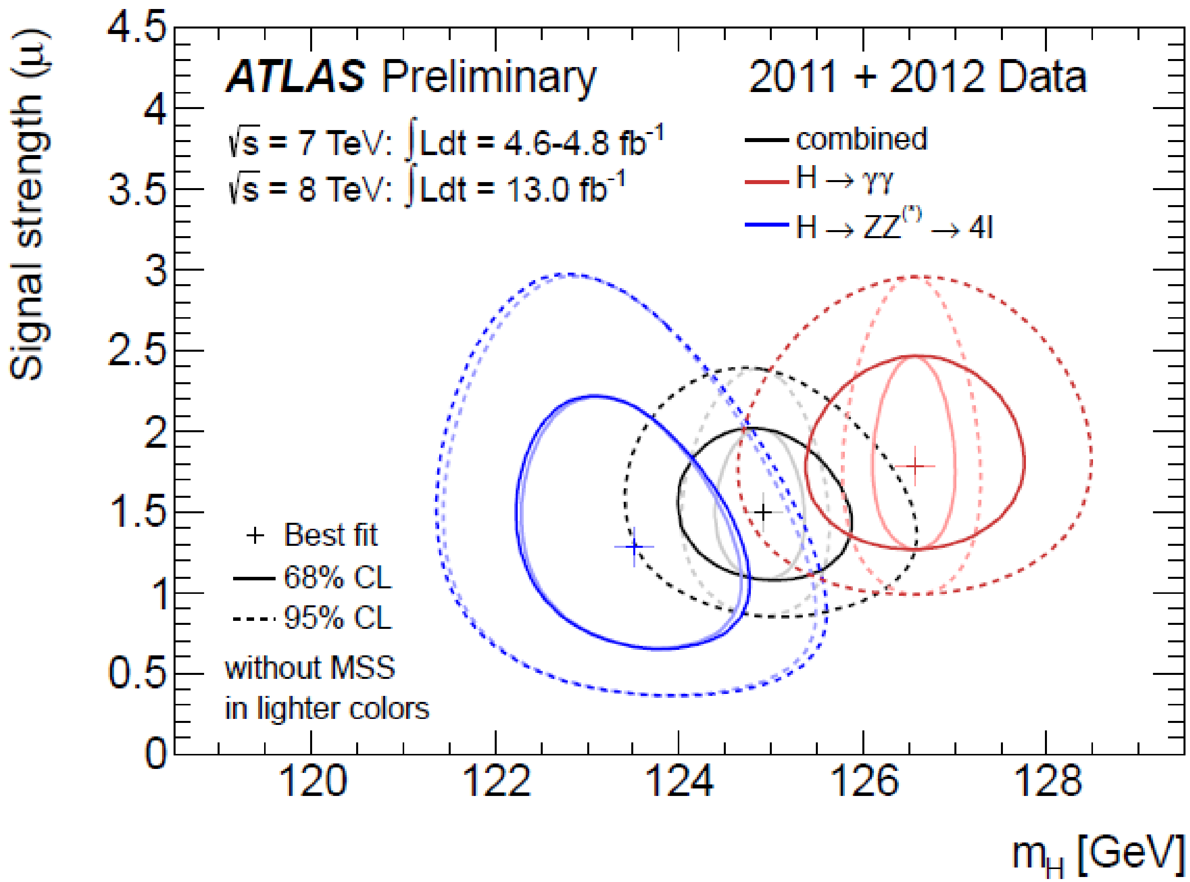
How Consistent are the Masses?



(a) (b)

- These plots make no assumption about consistency of cross-sections
- These plots (slightly) overestimate the significance of the discrepancy
  - It is difficult to precisely quantify this – if we could, we would already have done this.
  - Assume systematics are distributed according toi a Gaussian
  - Use asymptotic formulas instead of Toy Monte Carlos to gauge the ZZ* uncertainty
    - This is a 10-15% effect on that uncertainty (not the difference)

Mass and Cross-Section Consistency



One can stare at this plot for hours and think of all sorts of interesting questions.

Asking the Right Questions

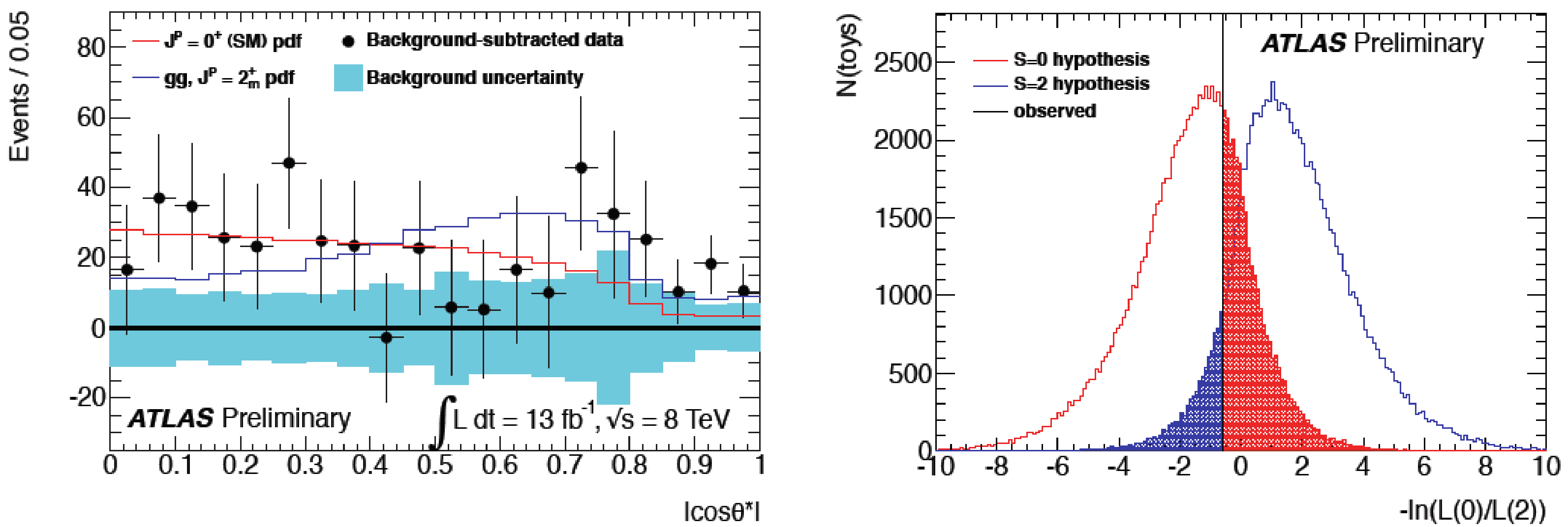
- That plot lets one ask all sorts of questions: i.e. the statistical significances against various hypotheses, such as:
  - ZZ* and $\gamma\gamma$ have a common mass and μ = 1.0000000 times the SM cross-section
  - ZZ* and $\gamma\gamma$ have a common mass and μ is within 7% of the SM cross-section
  - ZZ* and $\gamma\gamma$ have a common mass and common μ (which can be anything)
  - ZZ* and $\gamma\gamma$ have a common mass without any constraints on μ.
  - Etc.

- The significances vary from <1% to >10%.

Spin-Parity ($\gamma\gamma$)

- It is difficult to distinguish an unpolarized* spin-2 particle from a spin-0 particle.
- The clever observation (by many folks) is that it is actually difficult to prepare such a state by collisions of spin-1 gluons and spin-½ quarks. This gives a polar angle dependence to the photon direction in the Higgs-like frame.
  - Flat in $\cos(\theta^*)$ for spin-0
  - $1+6\cos^2(\theta^*)+\cos^4(\theta^*)$ for gg fusion to a graviton-like tensor

θ^* is defined in Collins-Soper frame

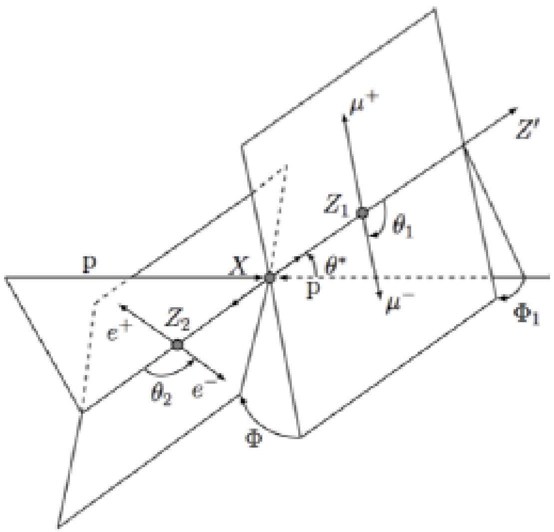


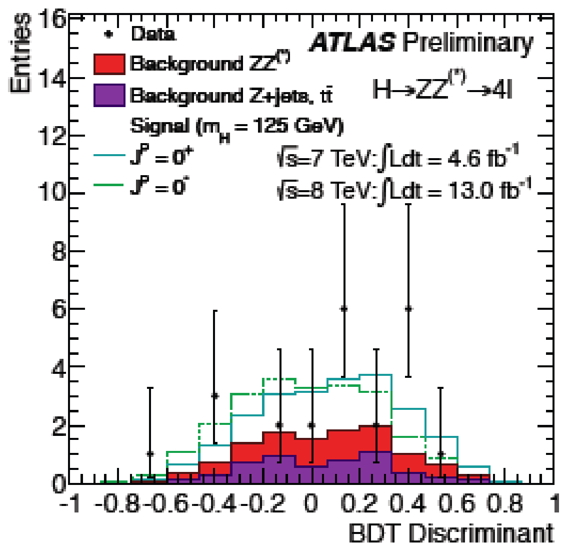
Exclude 2^+ at 91%CL
Compatible with $0^\pm$.

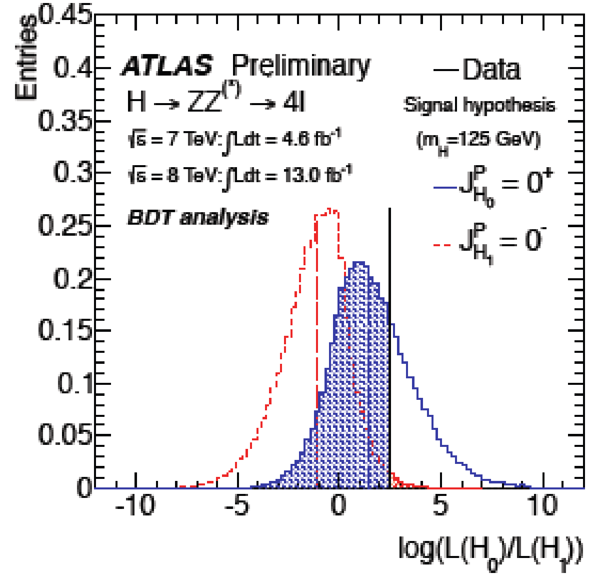
* I am misusing the word here. I don't mean $<p_z> = 0$; I mean an equally populated density matrix.

Spin-Parity (ZZ*)

Using the distributions of 5 production and decay angles combined in BDT or Matrix Element (MELA) discriminants





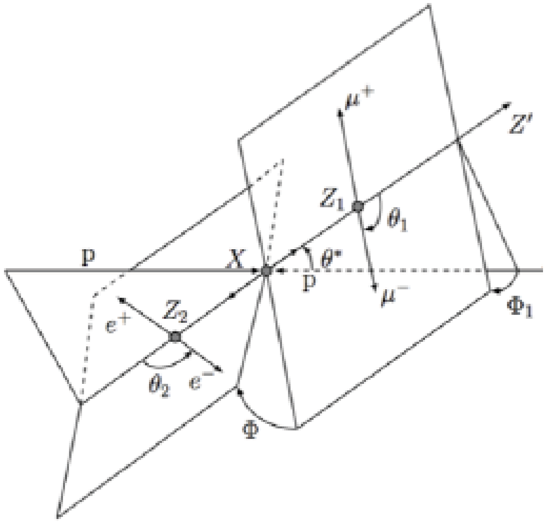


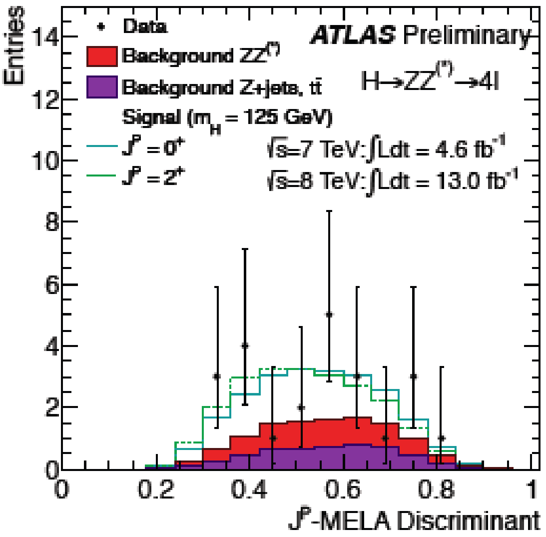
- 0^+ vs 0^- : Expected Exclusion of 0^- at the 96% CL
- Observed exclusion of 0^- at the 99% CL

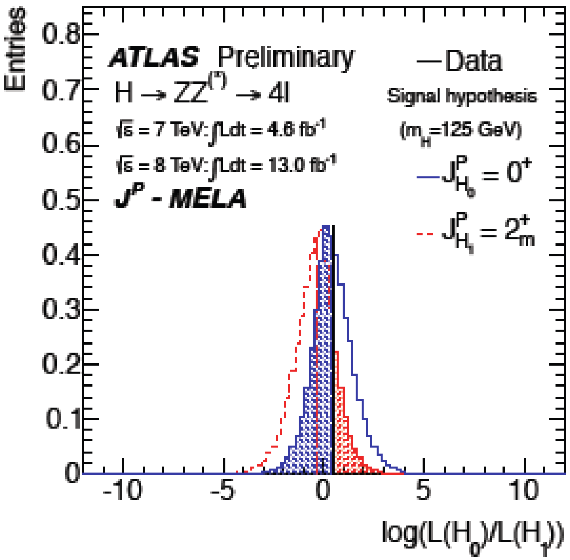
Observation fully compatible with spin 0 (within 0.5 σ)

Spin-Parity (ZZ*)

Using the distributions of 5 production and decay angles combined in BDT or Matrix Element (MELA) discriminants







- 0^+ vs 2^+ : (Low) Expected Exclusion of 2^+ at the 80% CL
- Observed exclusion of spin 2^+ at the 85% CL

  Observation fully compatible with spin 0 (within 0.18 σ)

Conclusions

- The updated ATLAS results are qualitatively similar to the discovery results – we didn't get a surprise.

- There is some tension in the mass measurements in the two precision channels
  - It's driven by a few low mass $ZZ^* \rightarrow 4\mu$ events
  - There are 8 events here, over a background of 4
  - It was a good opportunity to give our systematics a closer look, but I wouldn't call it a hint of new physics. Or even a hint, at this stage. Not with 8-4=4 events.

- Spin/parity analyses are underway
  - We don't have enough data for a definitive statement, but there is no evidence for anything but 0+. Not even hints.

Thanks to the organizers, KITP and Marumi Kado (who helped with this talk)!