Observation of a new resonance in ATLAS at LHC

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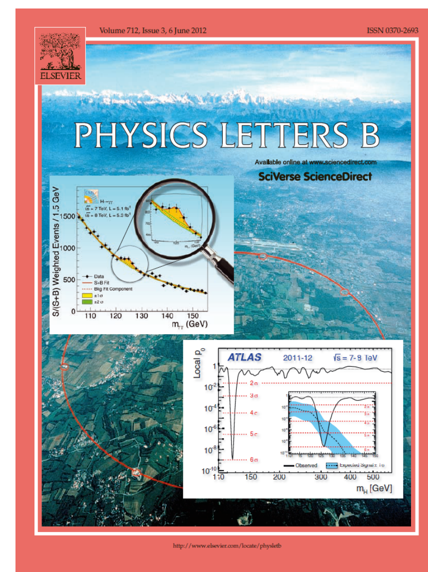
Outline

Physicsworld.com

December 13, 2011,
"tantalizing hints"

July 4th, 2012,
Discovery

July 31st,2012,
submitted to PLB



Outline

- **Introduction**
  - Higgs Production and decays
  - LHC, ATLAS coordinates
  - Limits and significance plots
- **From "tantalizing hints" to July 4th**
  - December 13, 2011 (~ 5 fb^{-1} @ 7 TeV)
  - July 4th, 2012: L += ~5fb^{-1} @ 8 TeV ($\gamma\gamma$, 4l)
  - Combination
- **Post July 4th**
  - $H \rightarrow WW \rightarrow l\nu l\nu$
  - Combination
- **What is next?**
  - Spin, branching, possibilities
- **Conclusion**

Introduction

Introduction

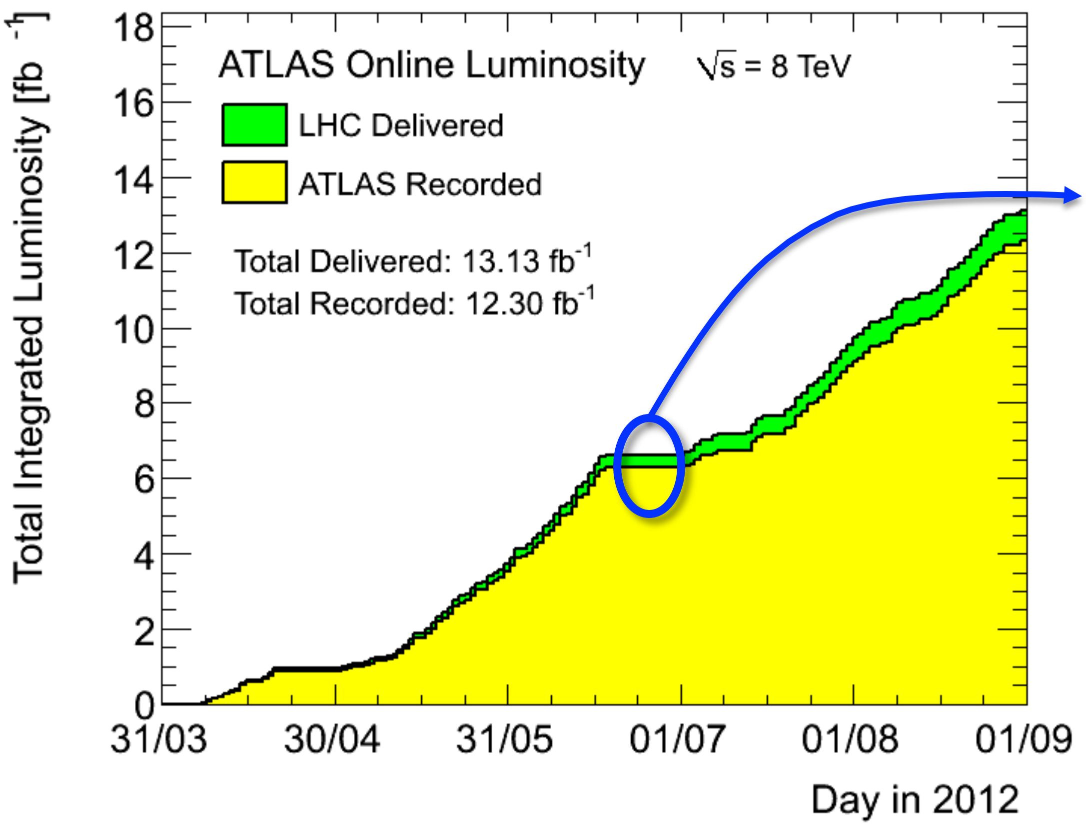
LHC

- 27km circumference, 50-150m below ground, across French-Swiss border
- pp collisions @ $\sqrt{s}$ = 7 TeV in 2011 and 8 TeV now
- Each beam ~ 1400 proton bunches, each bunch ~ 1.5×10^{11} protons
- On average, ~ 20 pp collisions per bunch crossing

  … times 20 MHz bunch crossing rate = 400 M pp collisions per second
- Reduced by trigger systems to ~400 events stored per second

High luminosity

- Cross sections: "barns" (area: 10^{-28} m^2 ~ U nucleus): fb, pb
- Amount of data: fb^{-1}, pb^{-1}. **Data × Cross-section = # events (dimensionless)**



1 fb^{-1} ~ 7×10^{13} collisions

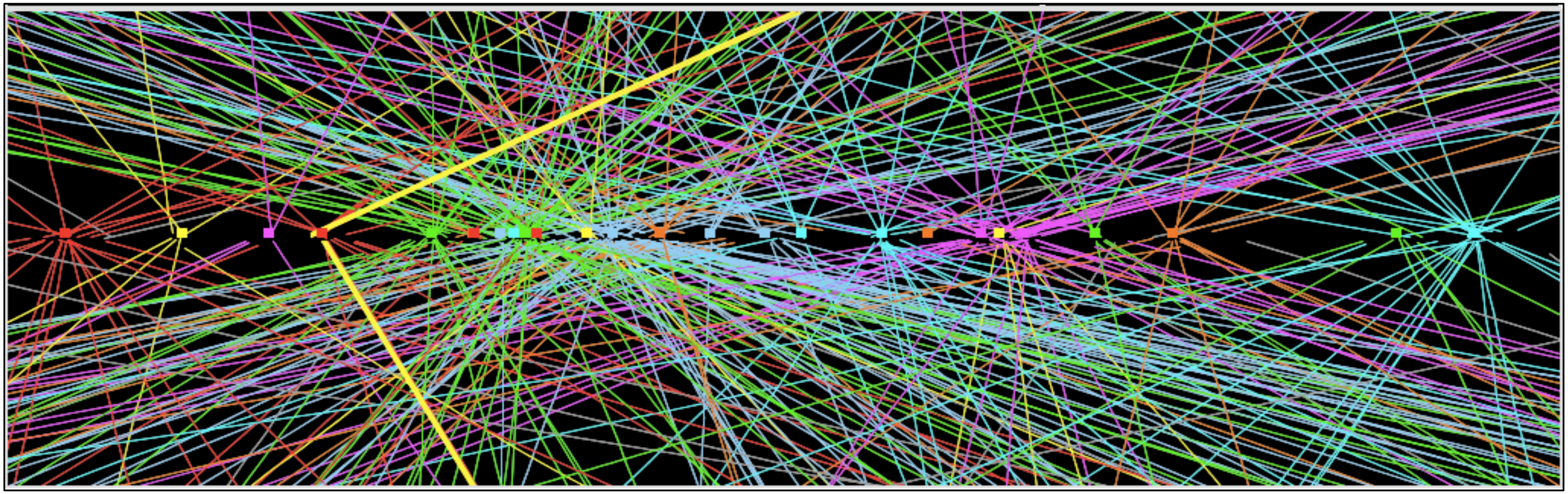
(Rolf Heuer email about 2011 conditions)

- 6.63 fb^{-1} delivered
- 6.28 fb^{-1} recorded (efficiency 94.7%)
- 5.86 fb^{-1} after data quality requirements (available for physics analysis; efficiency 93.3%)

- LHC plans to run pp collisions until Dec. 17, 2012 before 2 year shut down
- Expected in total ~25 fb^{-1} at 8 TeV in 2012

Bunch spacing : 50 ns

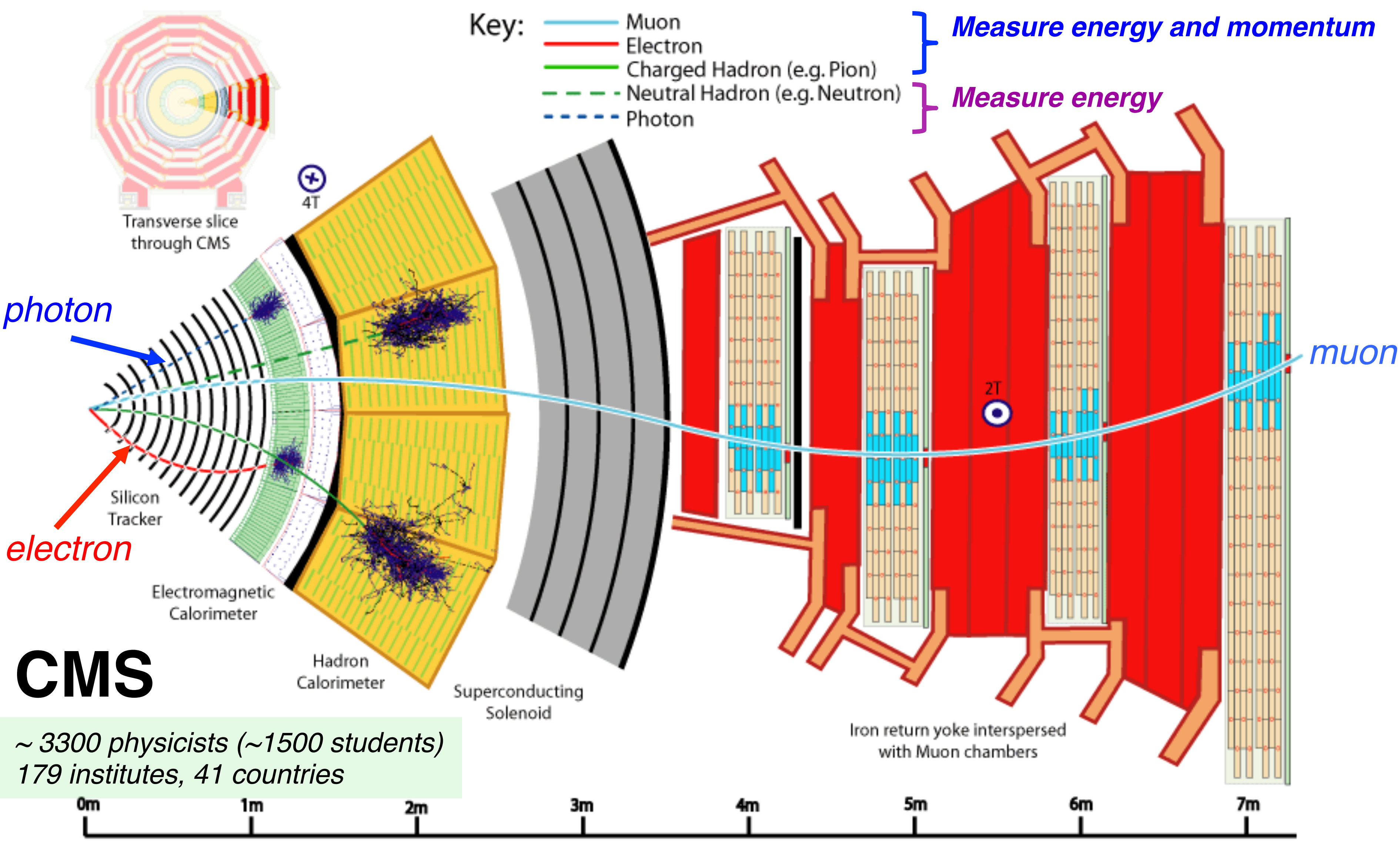
… at a price



Z→μμ event from 2012 data with 25 reconstructed vertices

- Many *pp* interactions per bunch crossing (*in-time pile-up*) and remnants of the detector response to the previous interaction (*out-of-time pile-up*)
- Pile-up robust algorithms developed (for both trigger and offline analyses)
- Reconstruction and identification of physics objects (e, γ, μ, τ, jet, E_T^{miss}) optimized to be robust against pile-up

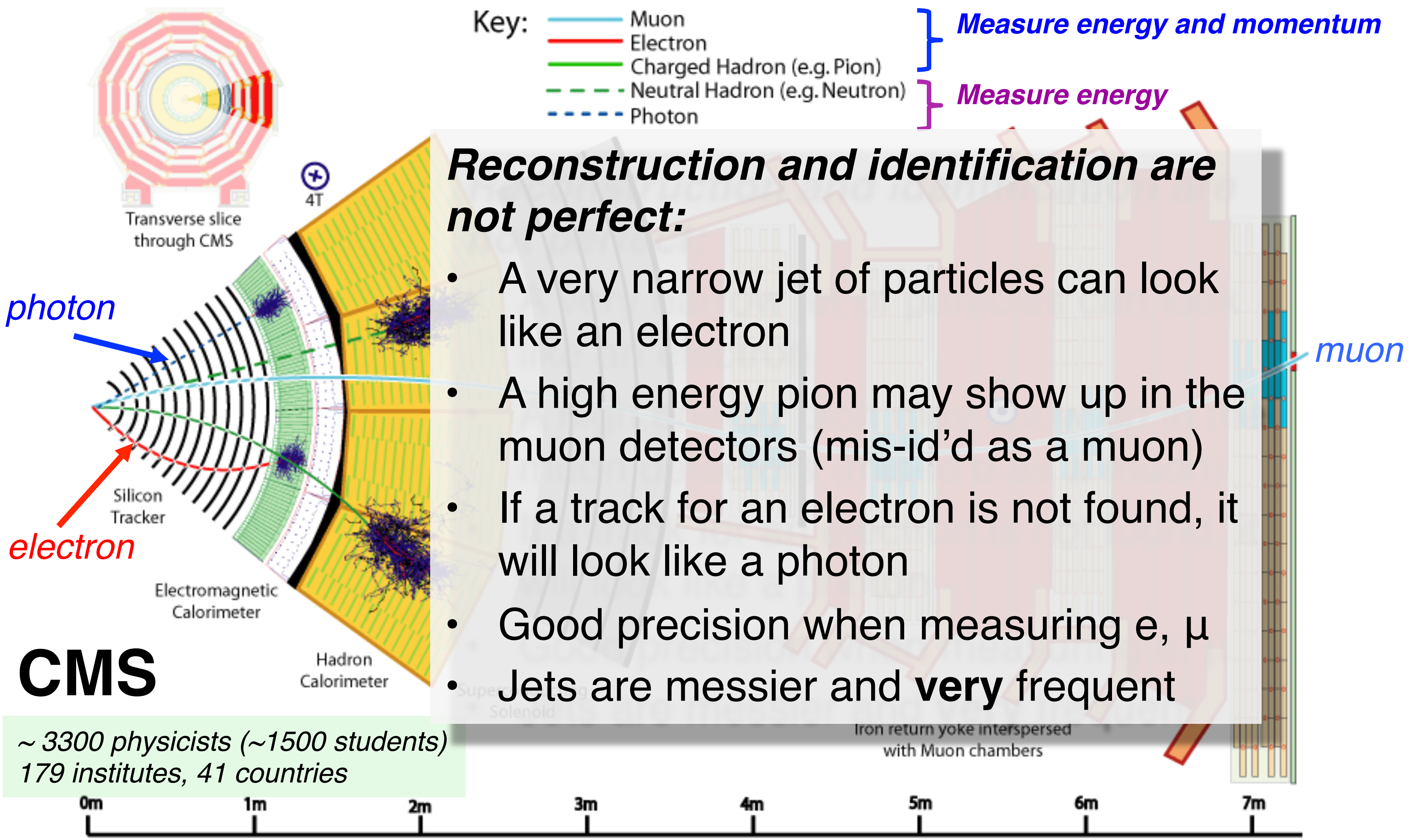
Introduction



CMS

~ 3300 physicists (~1500 students)
179 institutes, 41 countries

Introduction



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Reconstruction and identification are not perfect:

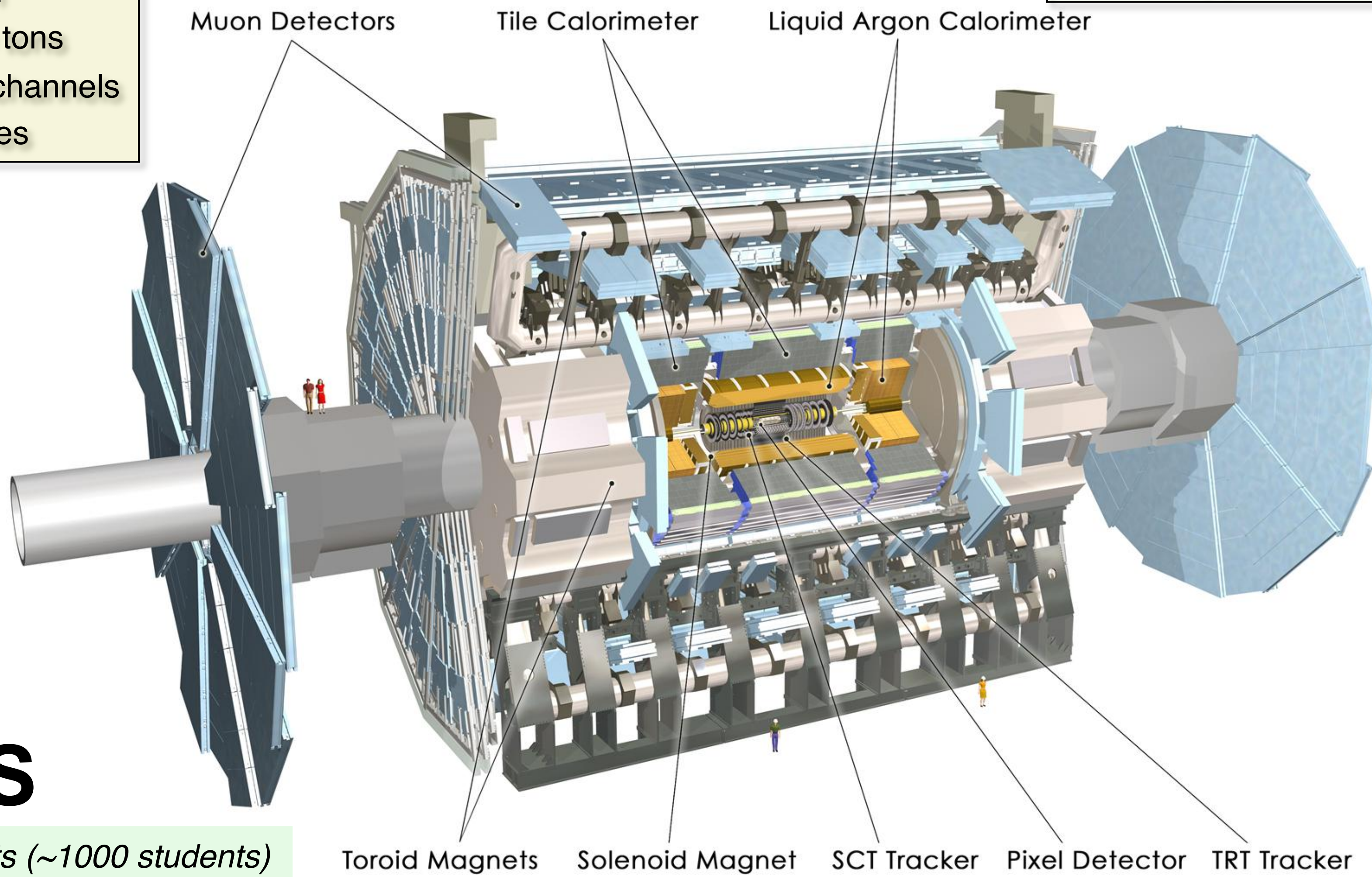
- A very narrow jet of particles can look like an electron
- A high energy pion may show up in the muon detectors (mis-id'd as a muon)
- If a track for an electron is not found, it will look like a photon
- Good precision when measuring e, μ
- Jets are messier and **very** frequent

Introduction

PARTICLE DETECTORS

Length : ~ 46 m
Radius : ~ 12 m
Weight : ~ 7000 tons
~10^8 electronic channels
3000 km of cables

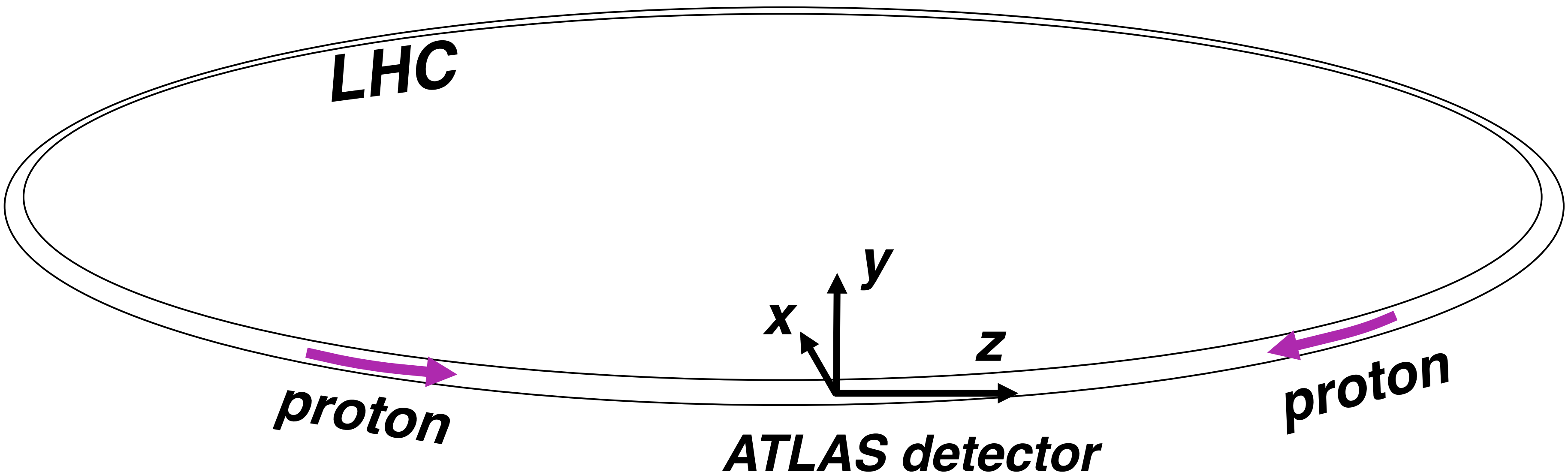
20MHz → ~400Hz by 3-level trigger system



ATLAS

~ 3000 physicists (~1000 students)
176 institutes, 38 countries

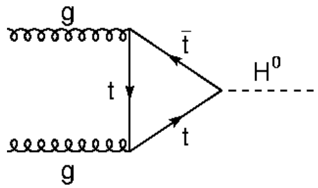
Coordinate system



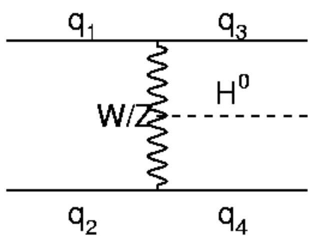
- Right handed coordinate system
  – z along beam pipe, x to center of LHC, y points upwards
- Transverse plane: polar coordinates (r,φ)
  – Φ azimutal angle, around the beampipe
- Pseudorapidity: $\eta = -\ln[\tan(\theta/2)]$, θ is the polar angle

SM Higgs production

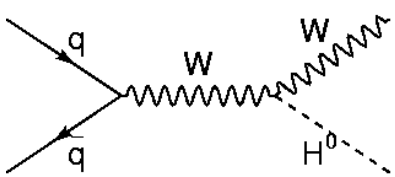
Gluon fusion (dominant at LHC)



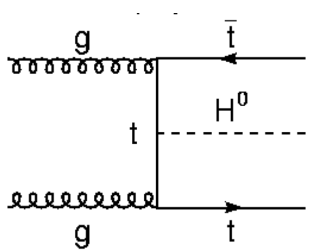
Vector boson fusion

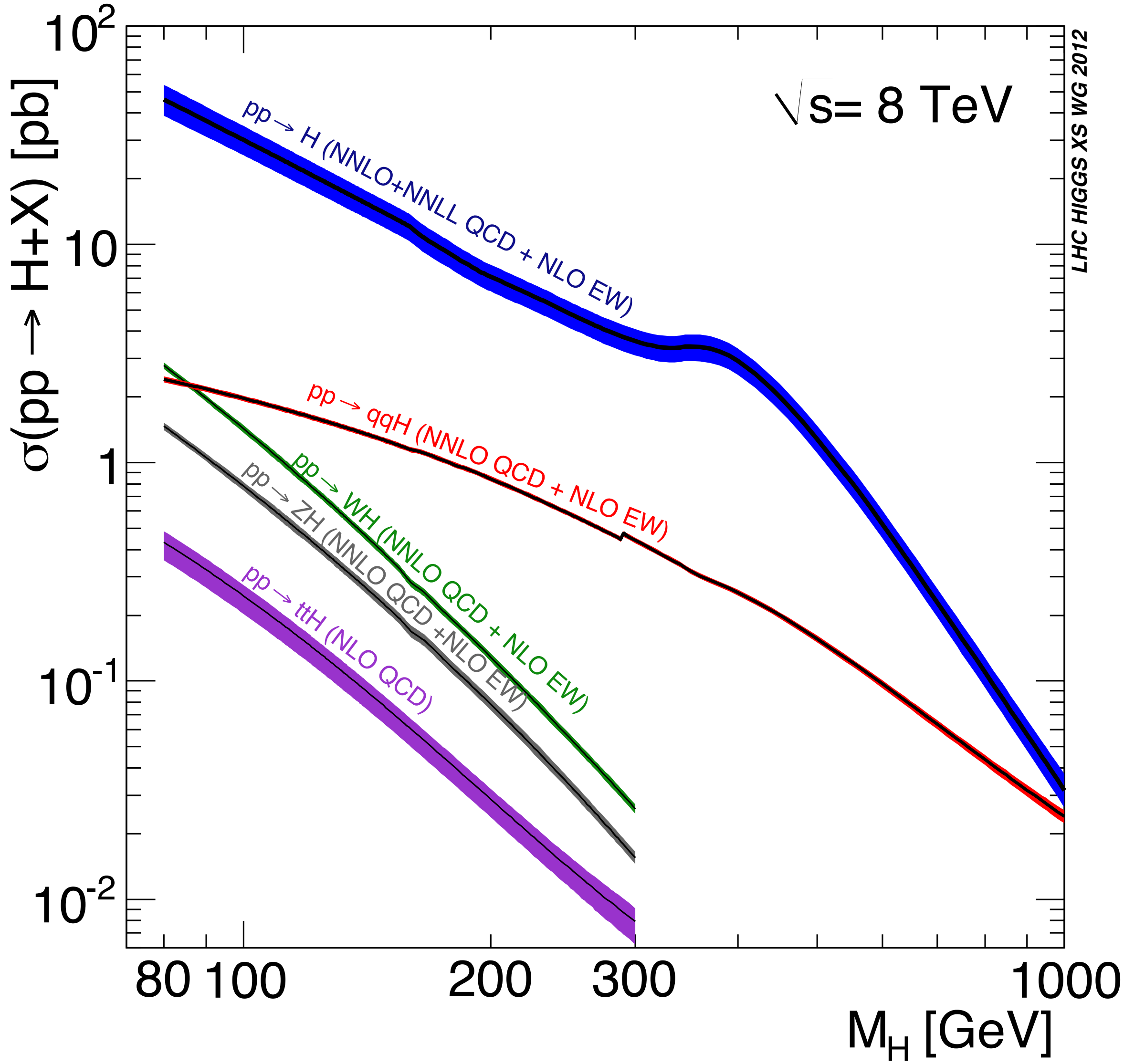


Associated production with Z/W
(Higgs-strahlung)



Associated production with top





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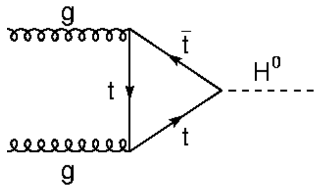

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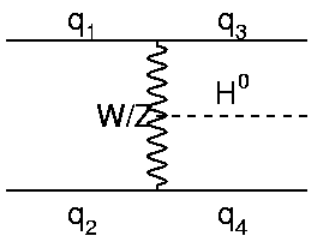

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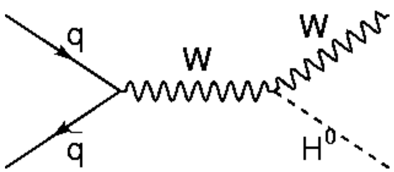

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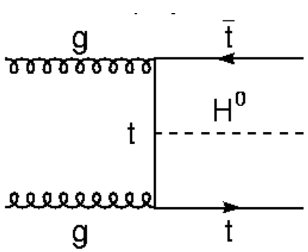
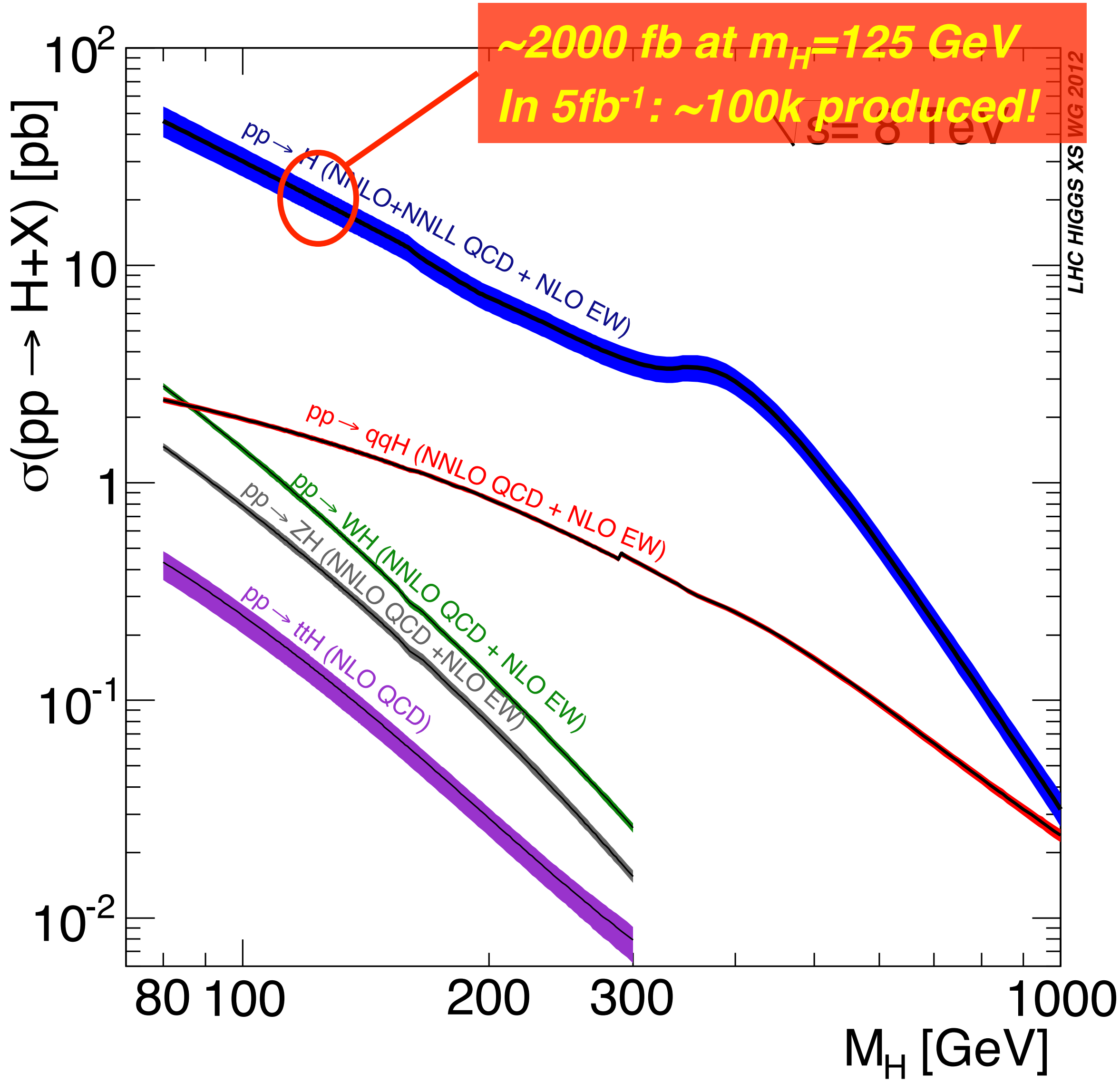
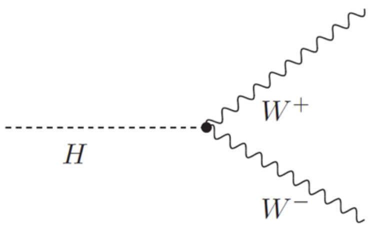




Introduction

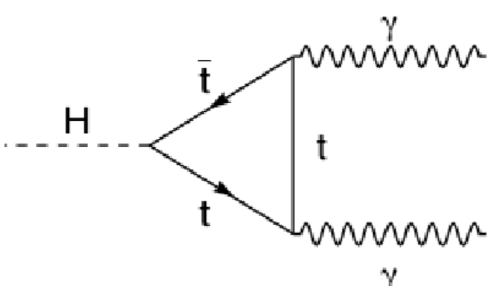
SM Higgs decays

Direct coupling to massive particles

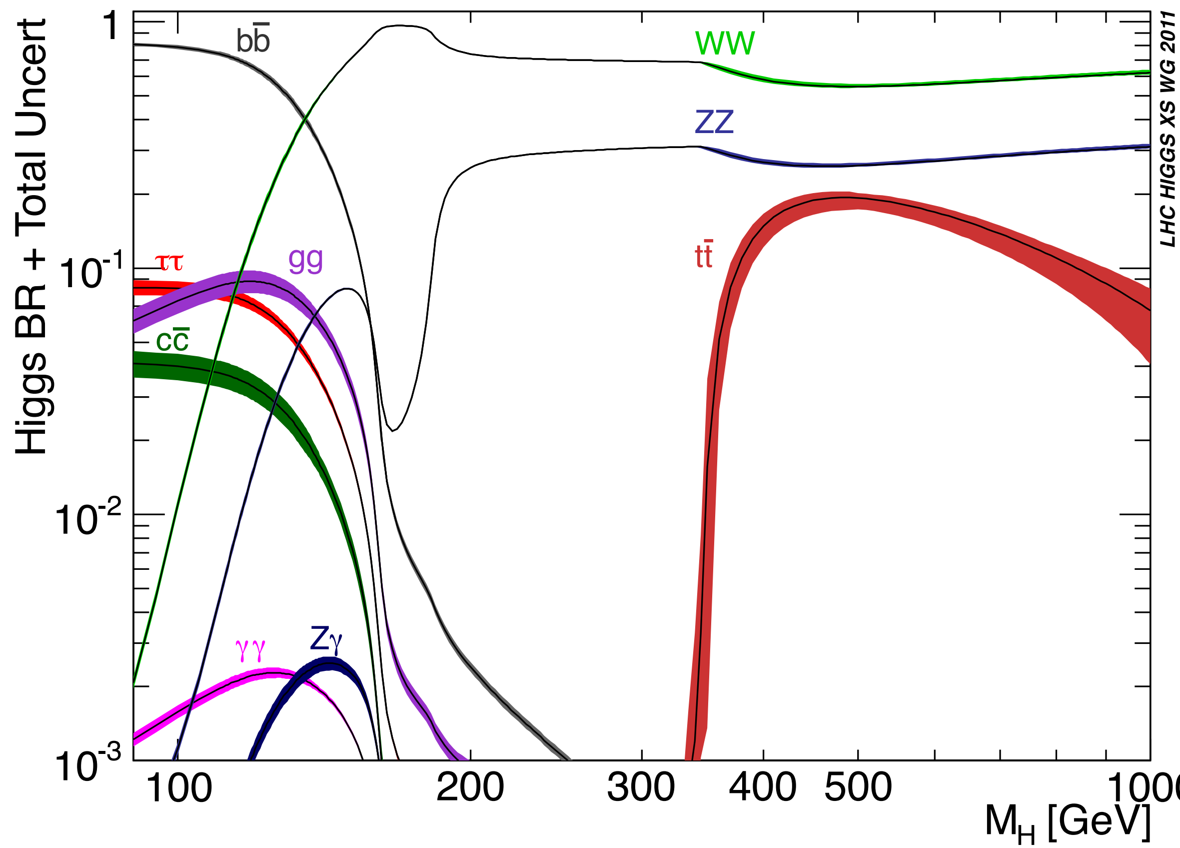


(WW, ZZ, tt, bb, ττ)

Through a triangle loop to massless ones



(gg, γγ)



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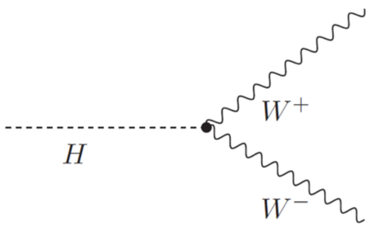

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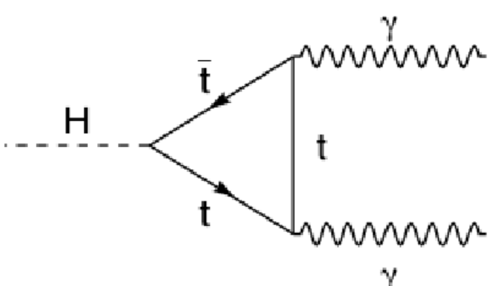

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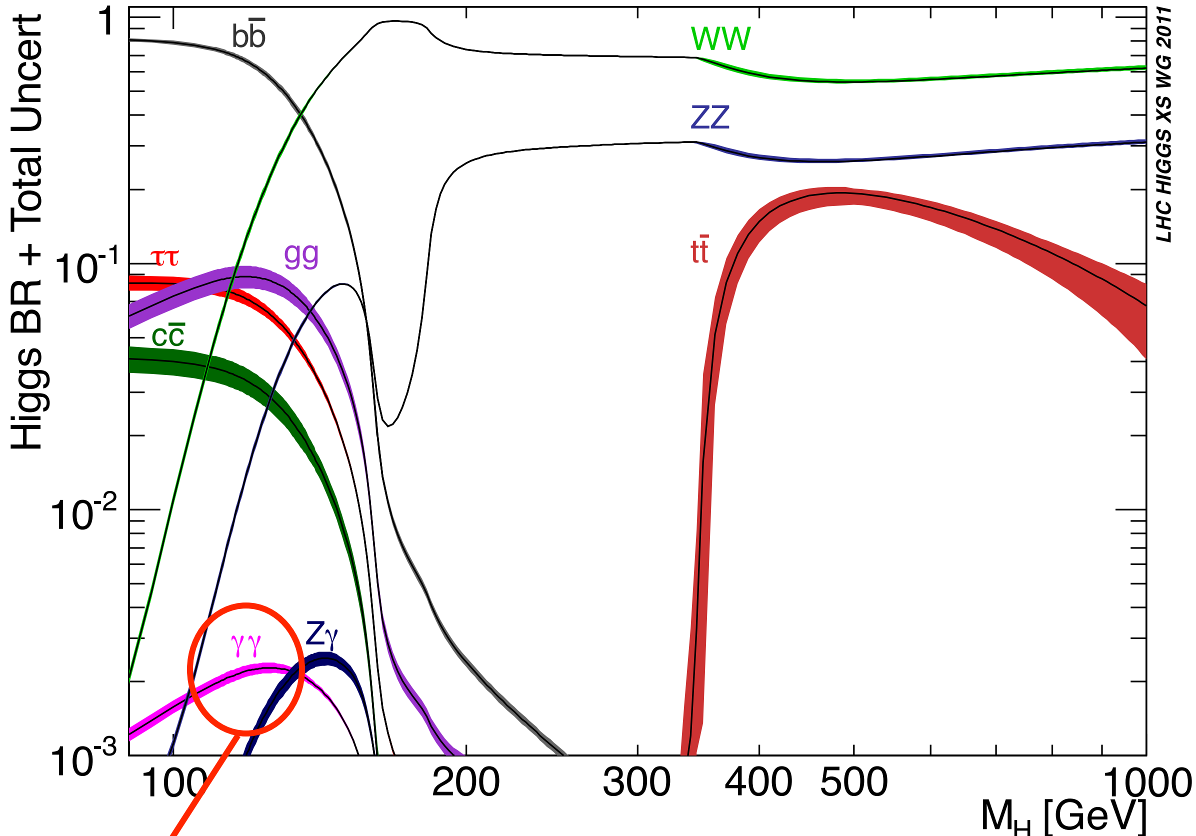
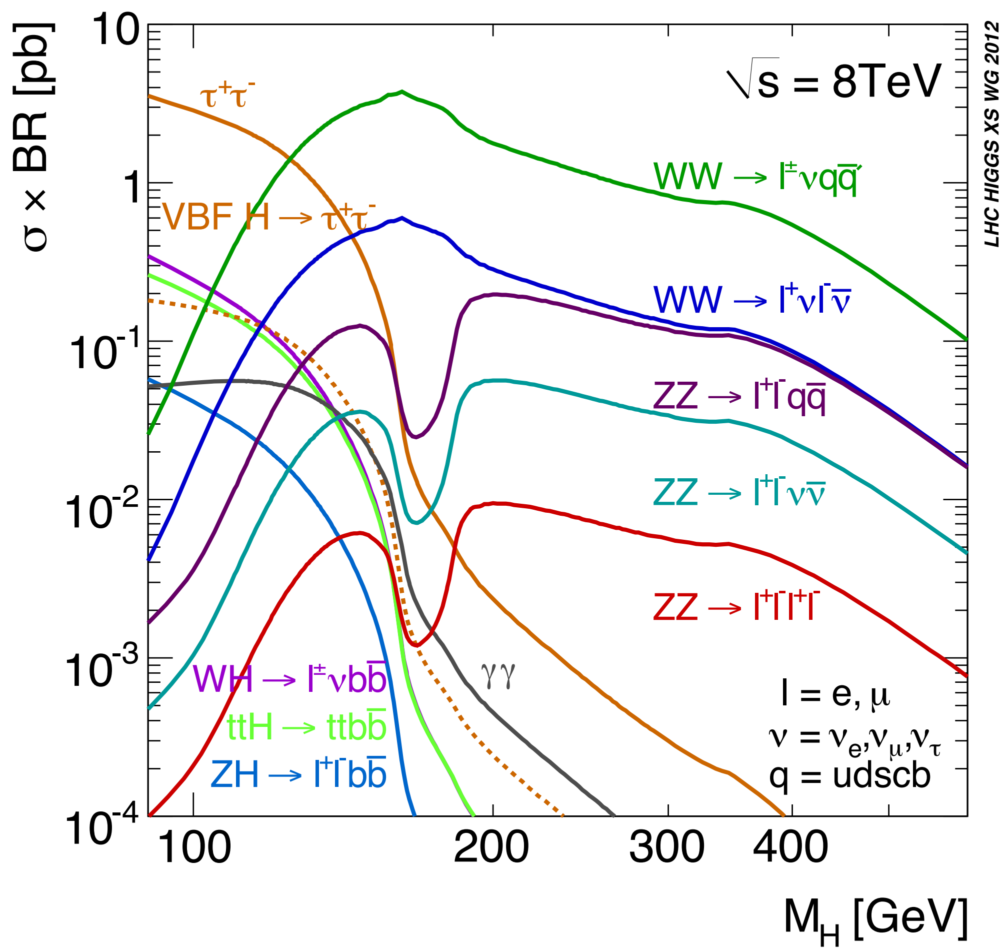


100,000 Higgs bosons produced… times ~0.002 BR to γγ, ~ 200 Higgs to be found via γγ search

Introduction

Cross section times BR

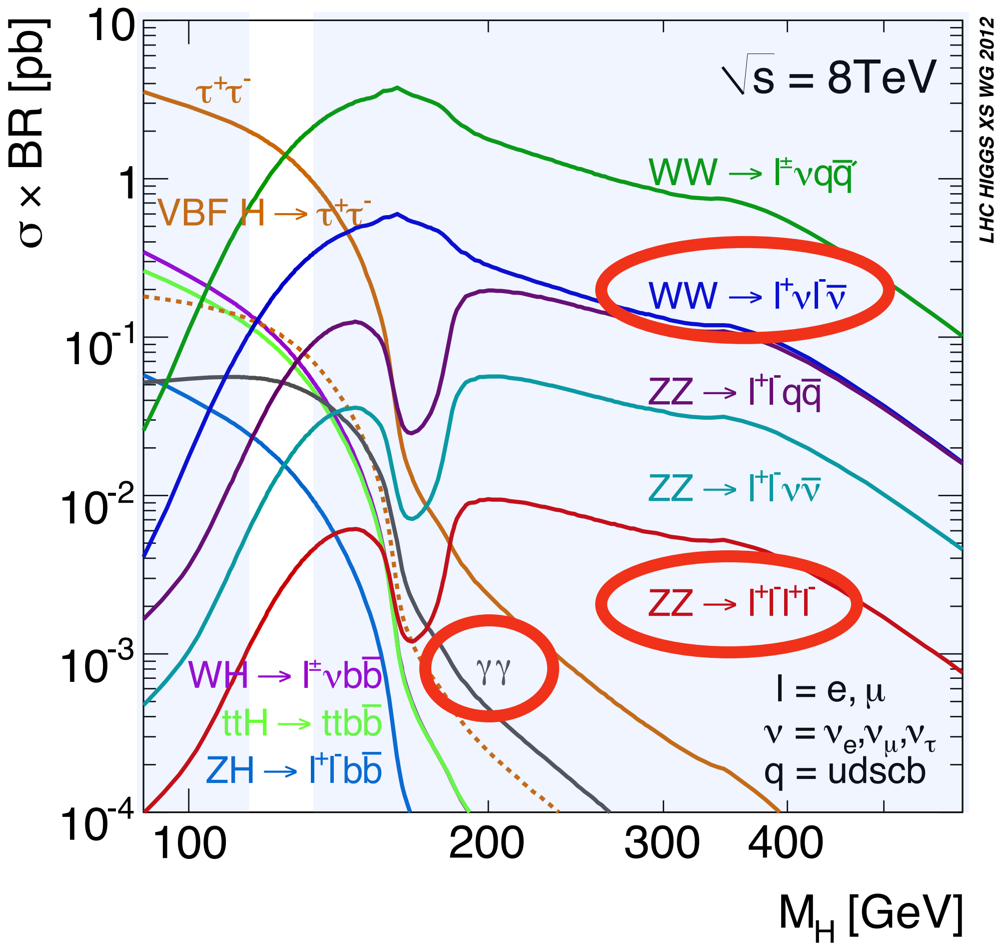


https://twiki.cern.ch/twiki/bin/view/LHCPhysics/CrossSectionsFigures

- WW, ZZ split into decay modes
- Targeting production modes can improve sensitivity
- Not yet the full story!
  - Missing: triggers, efficiencies, resolutions, background cross sections, rejection for each, etc.
  - Low m_H: $\tau\tau$ is largest (cons: detection and backgrounds)
  - High m_H: llvv most sensitive
- Experimentally, $100<m_H<200$ is accessible in the most ways
- All modes labeled in the plot (and more) have been studied; here, we'll focus on three

Introduction

Cross section times BR



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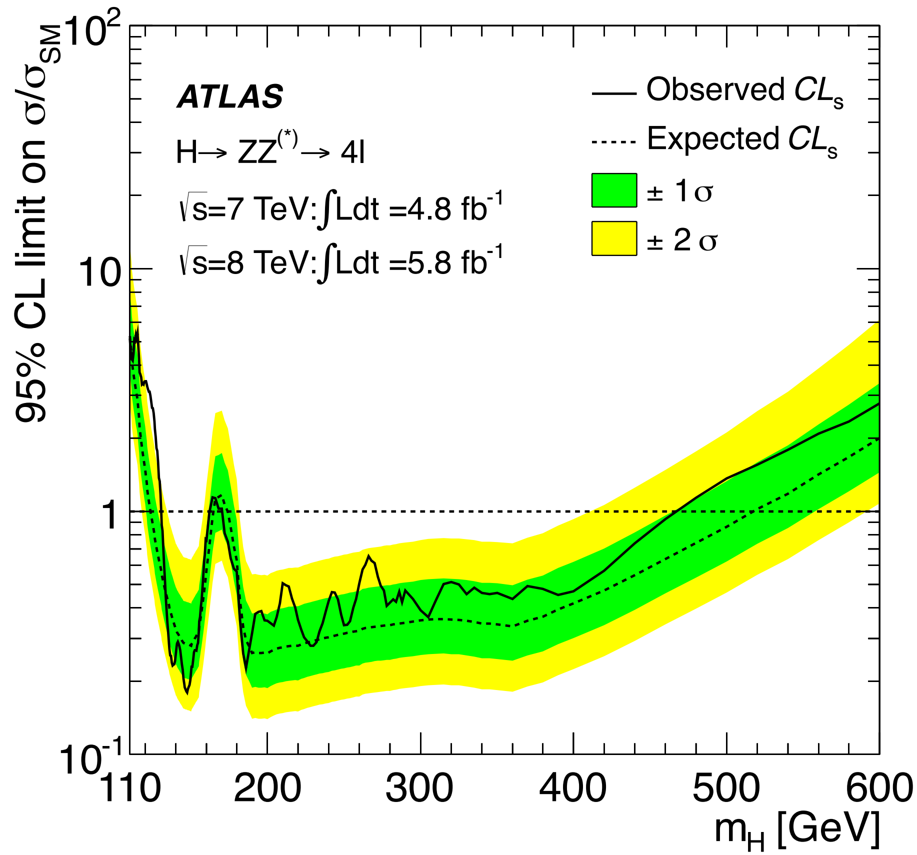
Introduction

- Null search results do provide valuable information:

  What signal sizes can be ruled out?
- Need reliable background estimations
- Always a probabilistic statement
  - Need to state the “CL” (95%)
- Being a random process, uncertainty bands are needed
- “Expected”: median of limits if the signal does not exits
- Observed: from the actual dataset



- Too few events → “strong” limit
- Too many events → “weak” limit

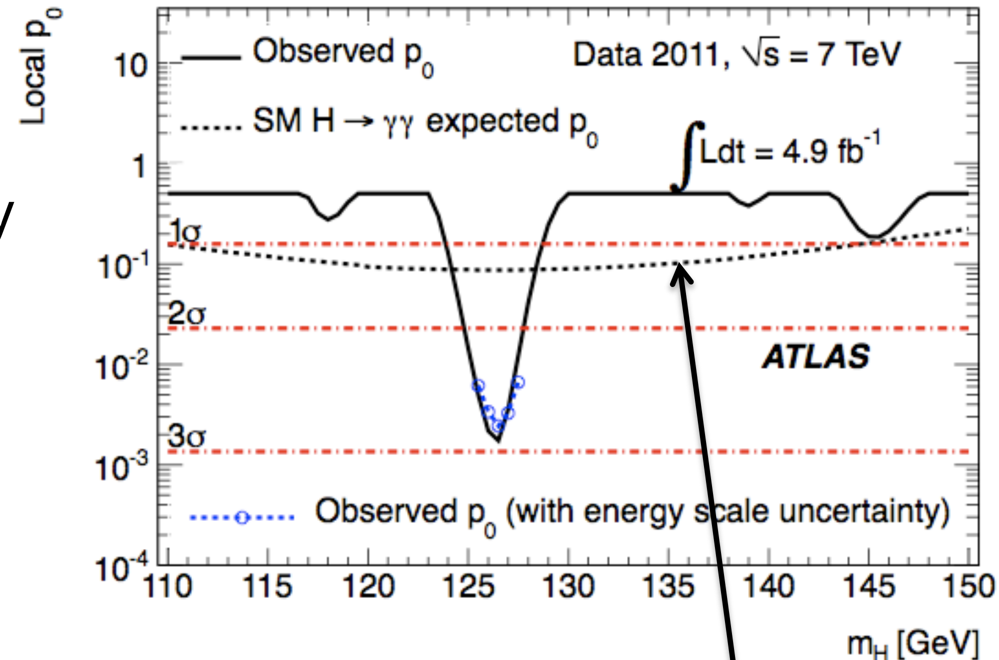
Introduction

- *Too many events* may also, instead, represent a signal
- … do they?

  We quantify it by the probability that background alone would produce an excess as large as observed (or larger)

  → *"Local" p_0*
- Instead of quoting p_0, we refer to it using the "number of sigmas" that it would represent in a Gaussian tail.
  - 1 sigma → $p_0 = 16\%$
  - 3 sigma → $p_0 = 0.13\%$
  - 5 sigma → $p_0 = 2.9\times10^{-7}$

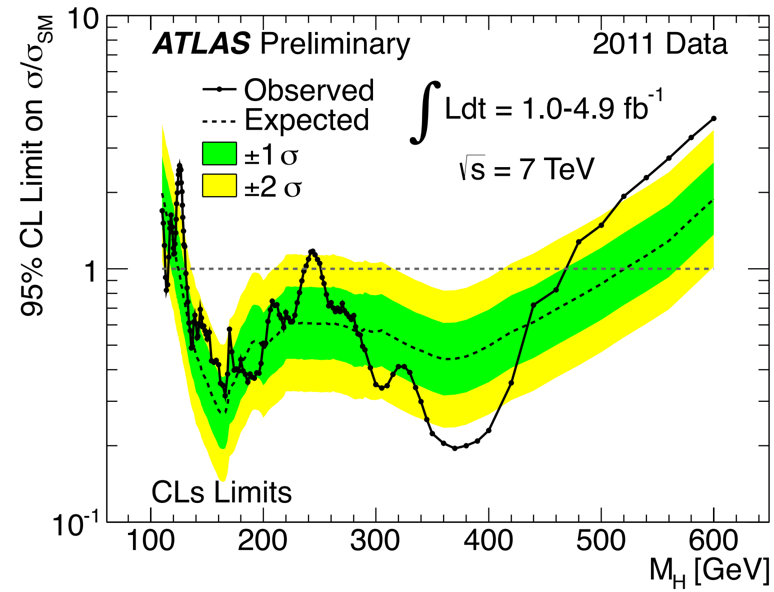
January 2012 PRL Publication

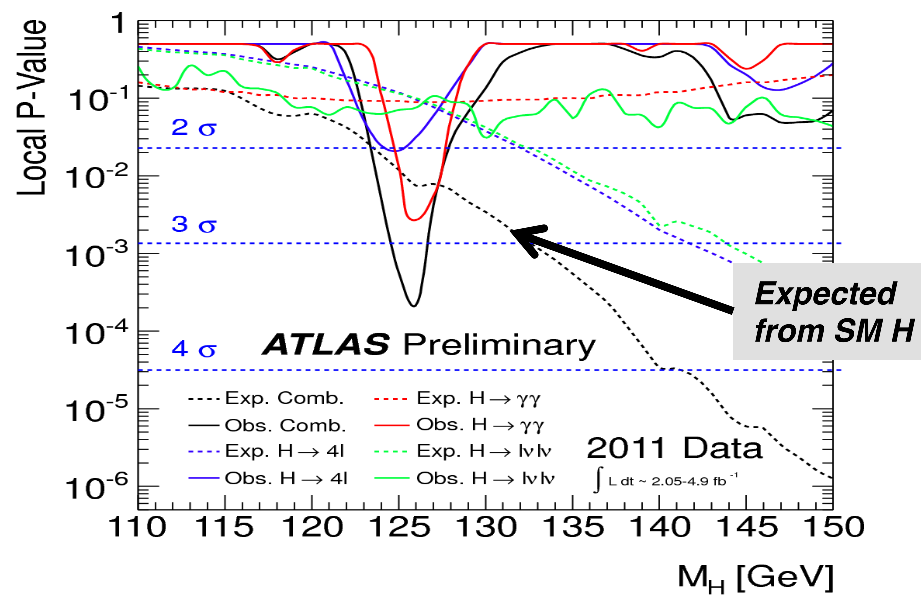


Expected from SM Higgs at given m_H

From “tantalizing hints” to July 4th

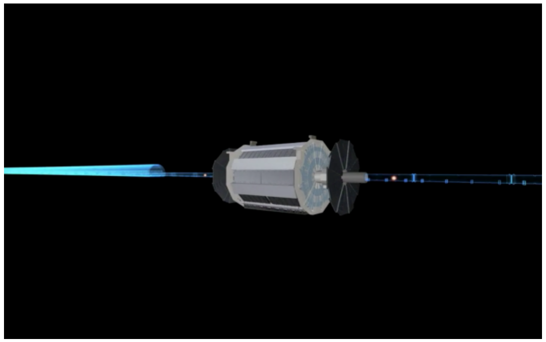
December 13, 2011

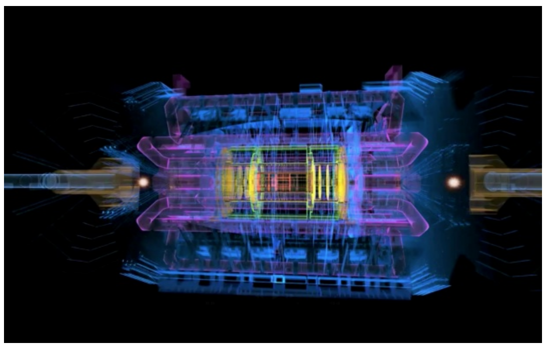


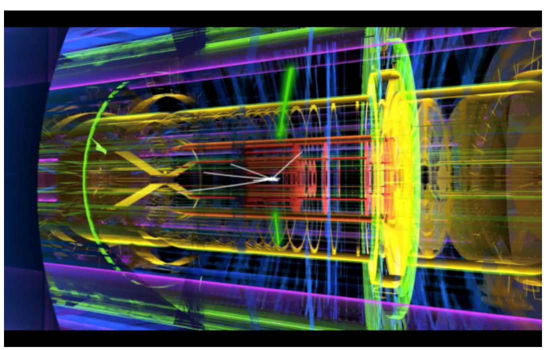


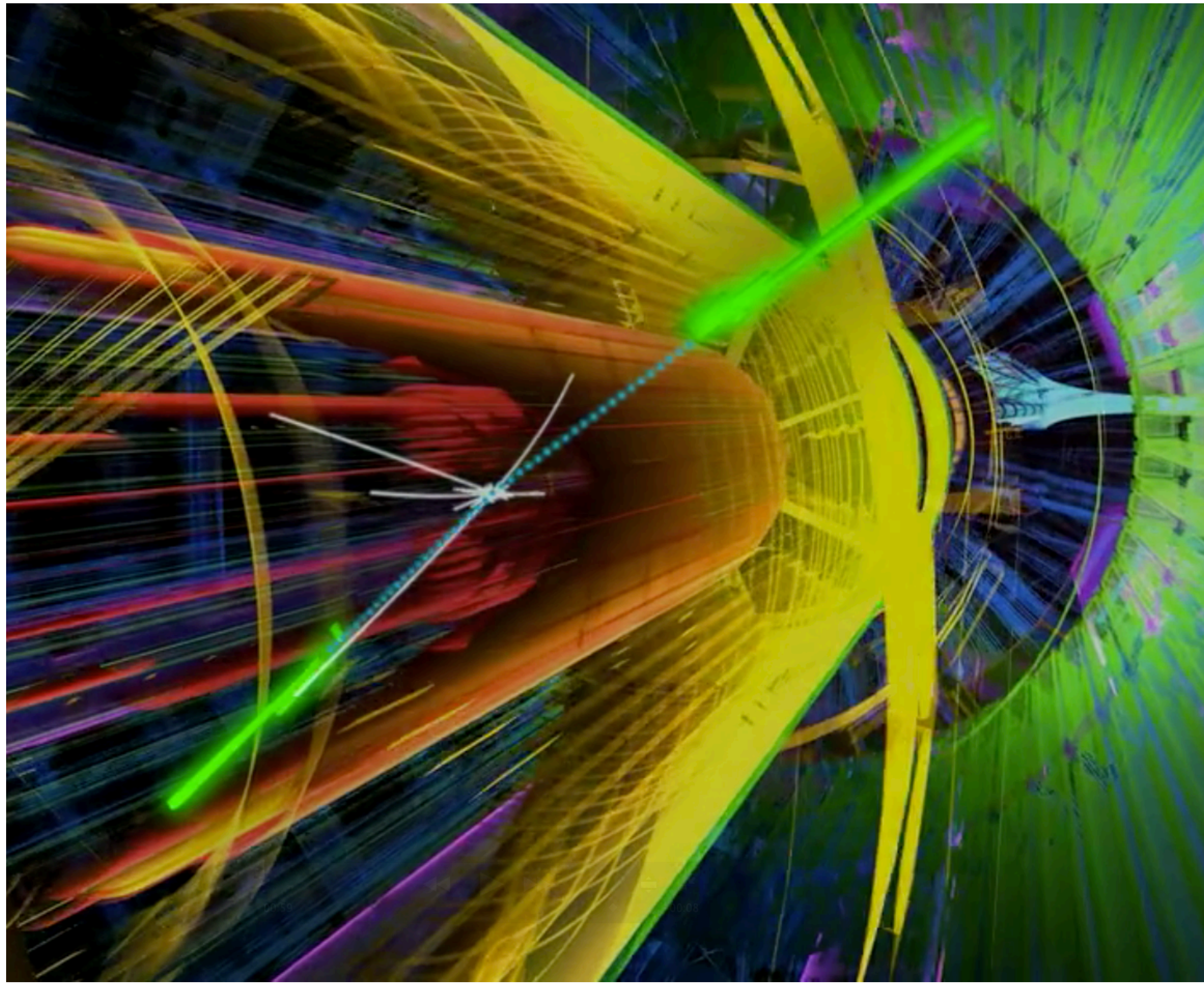
- 7 TeV data, ~ 5 fb^{-1}
- Expected SM Significance: **2.4 σ**
- Observed Local / Global: **3.6** / 2.5 σ
- Dominated by $H \to \gamma\gamma$ and $H \to ZZ \to 4l$

$H \rightarrow \gamma\gamma$



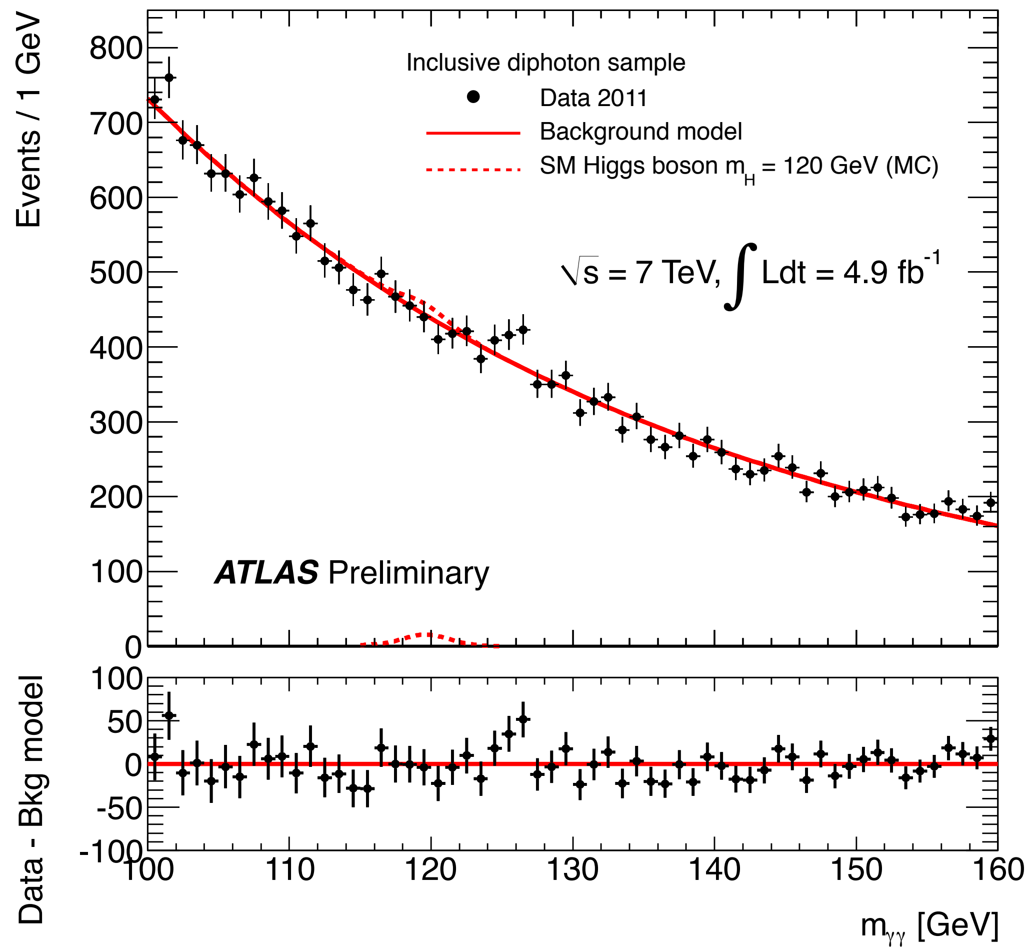






$H\to\gamma\gamma$ Overview

- Search for a narrow $m_{\gamma\gamma}$ peak
  110 < $m_{\gamma\gamma}$ < 150 GeV
- Tens of signal events over a relatively large background
  σ x BR ~50 fb @ m_H ~126 GeV



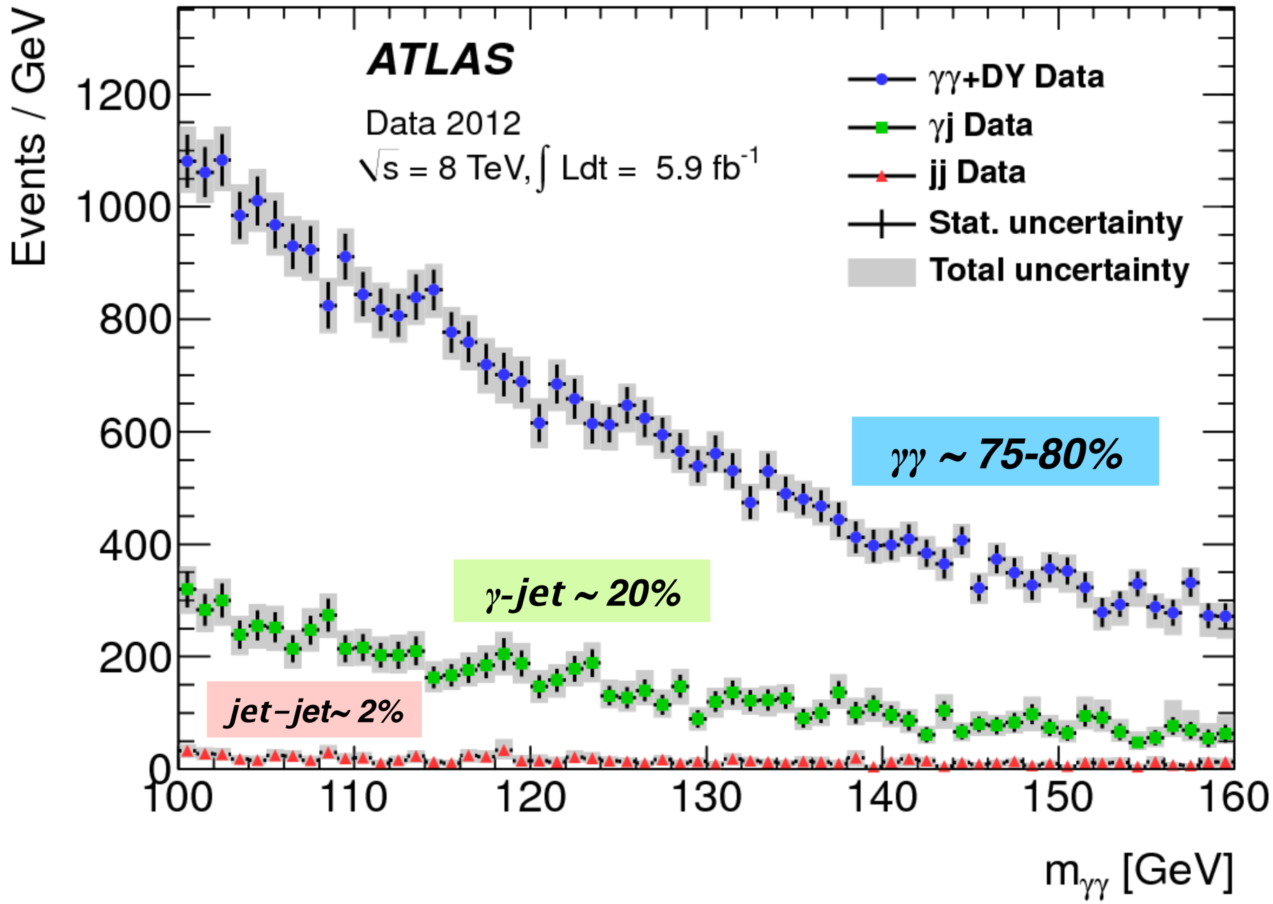
- **Simple topology:**
  2 high-p_T isolated photons
  $E_T(\gamma_1, \gamma_2)$ > 40, 30 GeV

- **Main backgrounds:**
  - $\gamma\gamma$ continuum (irreducible)
  - γ-jet, jet-jet (reducible)

[Above: from CERN Council meeting, on Dec 13, 2011]

H→γγ Background composition

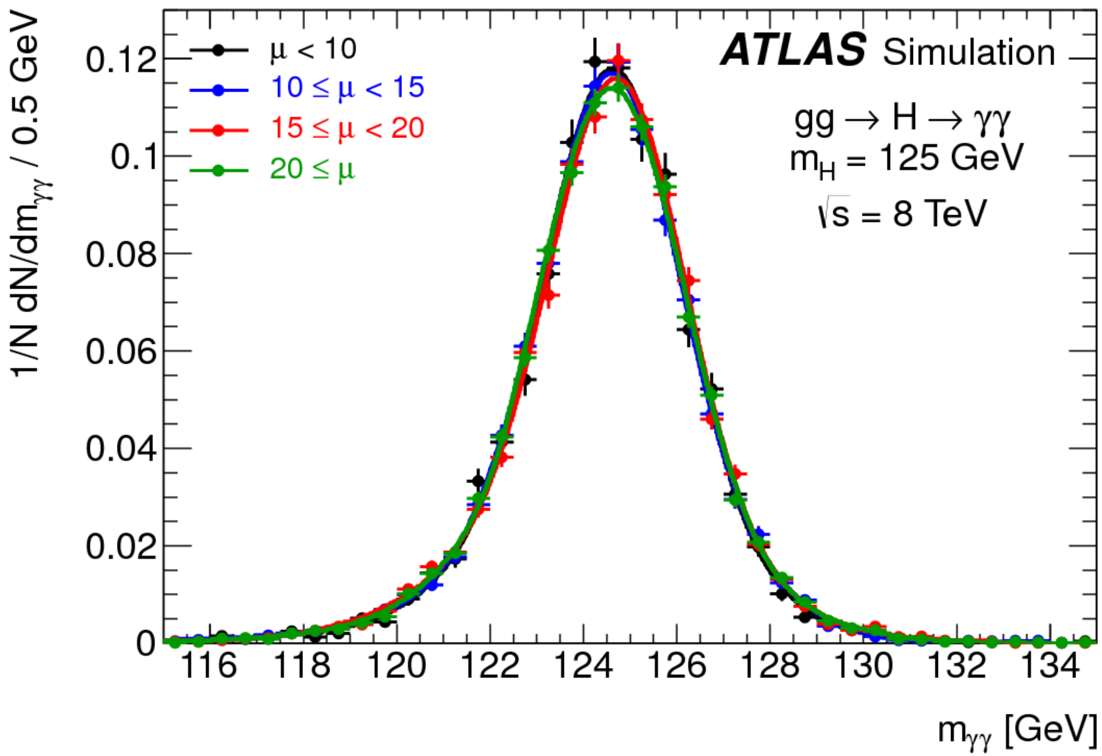
The γγ, γ-jet and jet-jet contributions can be decomposed using control samples defined by photon identification and isolation.

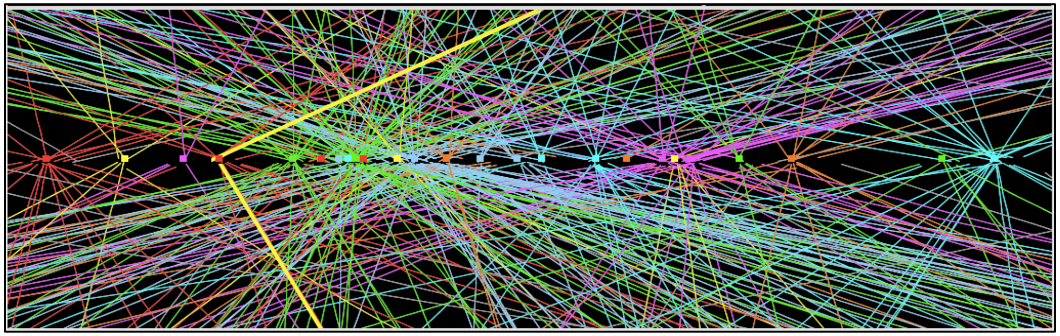


Considerable effort made in background modeling to avoid biases.

Various background models considered, different for different categories.

H→γγ Mass resolution for signal





Mass resolution not affected by pile-up

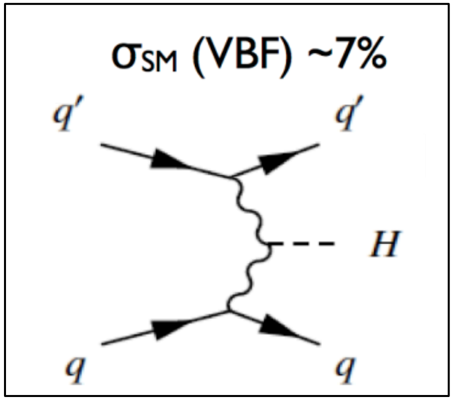
- Mass resolution of inclusive sample: 1.6 GeV

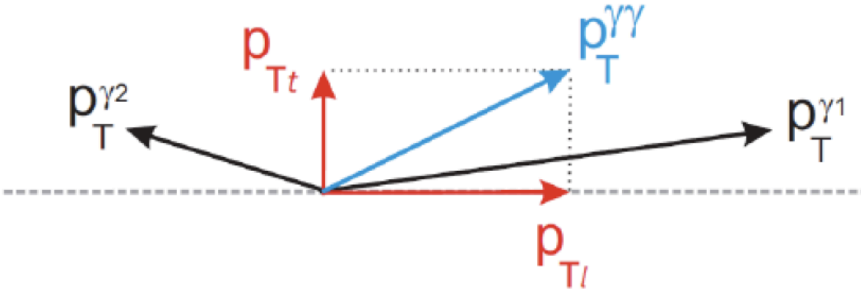
H→γγ Event selection

- Neural-net based photon ID for 2011 data
- Re-optimized cut-based photon ID for 2012, stable with high pileup
- New '2-jets' category for enhanced VBF sensitivity

Events divided in 10 categories based on:

- γ pseudorapidity
- whether γ is converted/unconverted
- p_{Tt} ($p_T^{\gamma\gamma}$ perpendicular to γγ thrust axis);
- 2 jets (VBF-like)



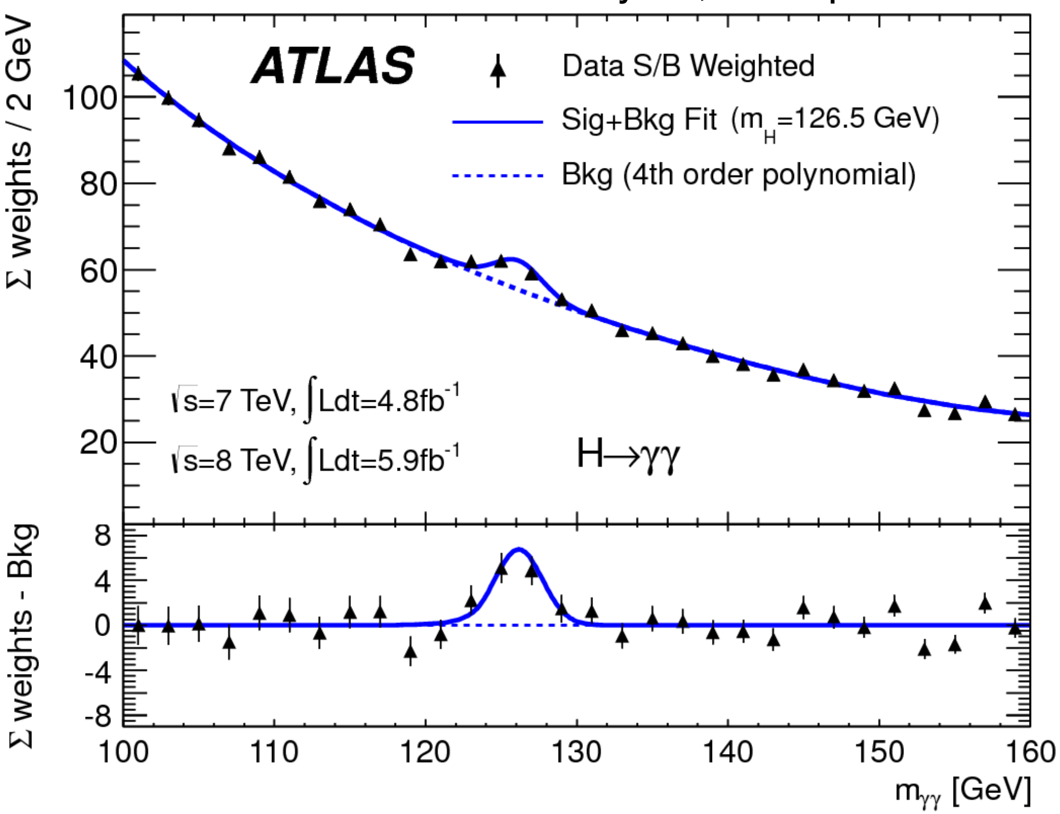


thrust axis

H→γγ Weighted mass distribution

Weighted invariant mass distribution of selected events combining 2012 (35k events) and 2011(24k) data

From July 31, 2012 publication



For m_H=126.5 GeV

- σ×BR = 39 fb at 7 TeV
- σ×BR = 50 fb at 8 TeV

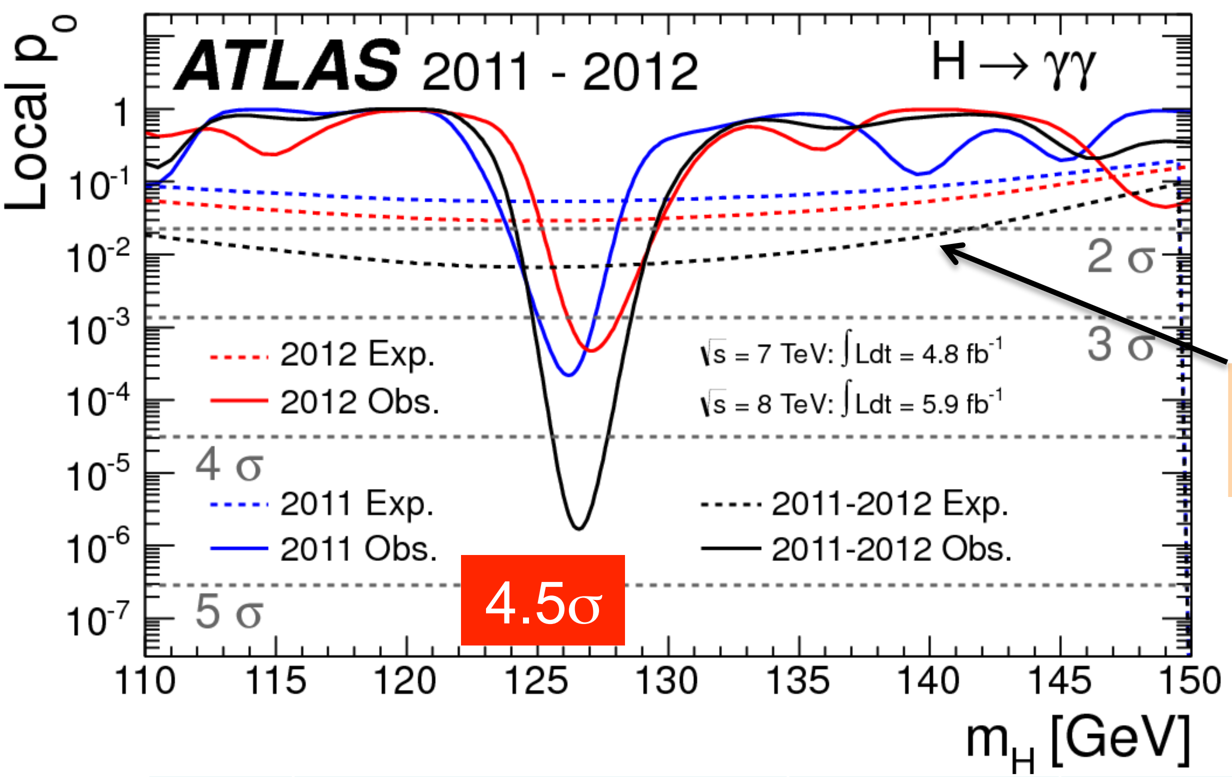
Full results obtained by splitting data into 10 categories, fitting mass distributions separately.

Signal Yield	Observed	Expected
2011	**146.9**	**79.6**
2012	**205.5**	**110.5**

Weight for category i: $\ln(1+S_i/B_i)$

H→γγ Results

From July 31, 2012 publication



p_0: probability for background to fluctuate up to observed data (or higher)

Expected from SM Higgs at given m_H

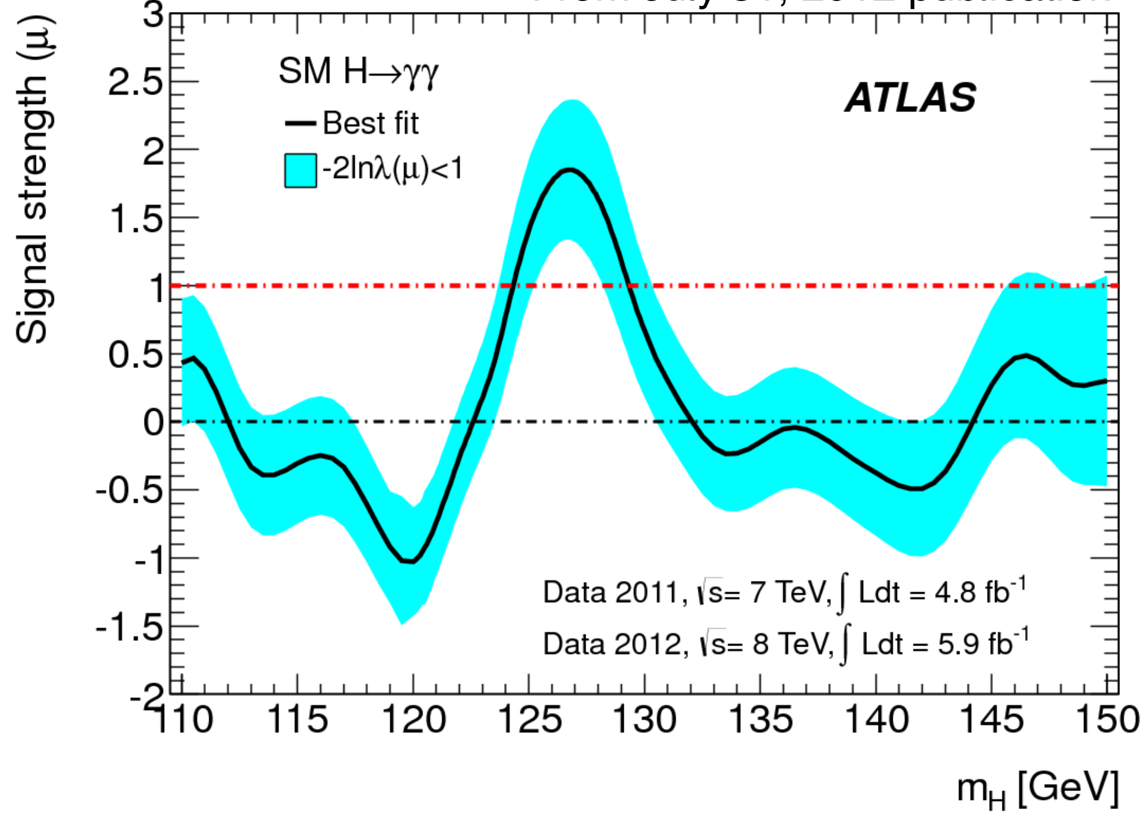
Data	m_H at max deviation	Local p0	Local significance	Expected
2011	126 GeV	3×10^{-4}	3.4σ	1.6σ
2012	127 GeV	7×10^{-4}	3.2σ	1.9σ
Both	126.5 GeV	3×10^{-6}	4.5σ	2.5σ

Global 2011+2012 (including LEE over 110-150 GeV range): 3.6 σ

H→γγ Signal strength

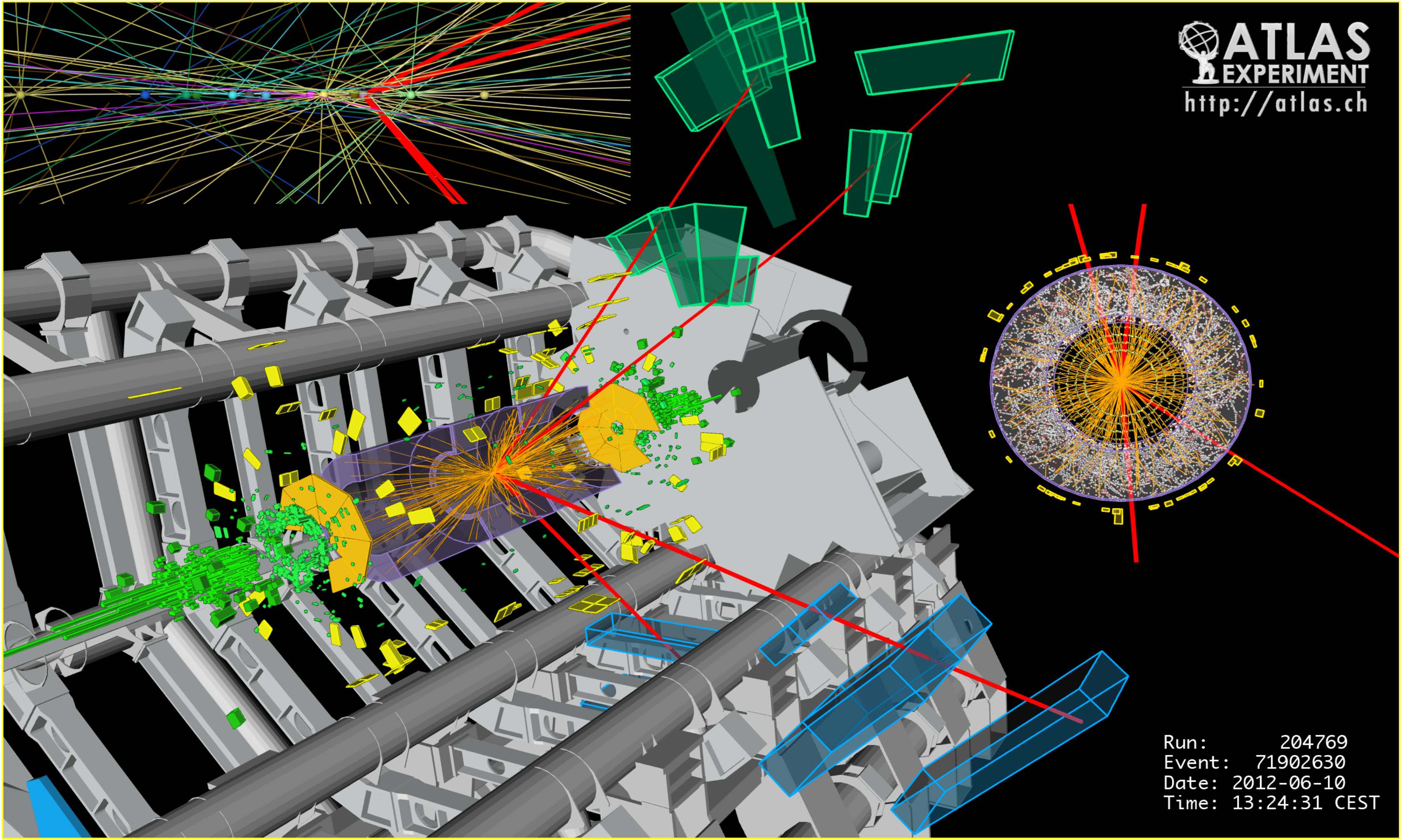
$$\mu = \frac{\sigma \cdot Br}{(\sigma \cdot Br)_{SM}}$$

From July 31, 2012 publication



- Signal strength (μ) = (signal rate from fit to data) / (expected SM signal rate at given m_H)
- Fitted signal strength: μ=1.9±0.5 at m_H=126.5 GeV
- About twice the value expected from the SM Higgs cross section!

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

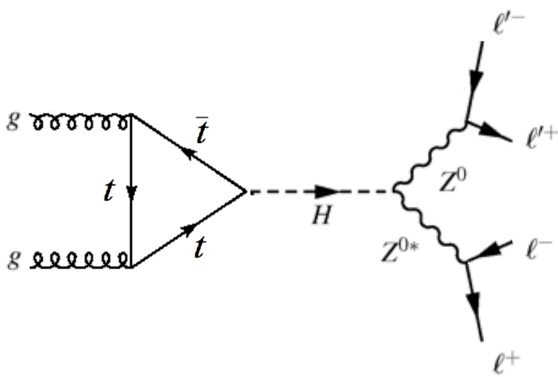


4μ candidate with $m_{4\mu}$=125.1 GeV

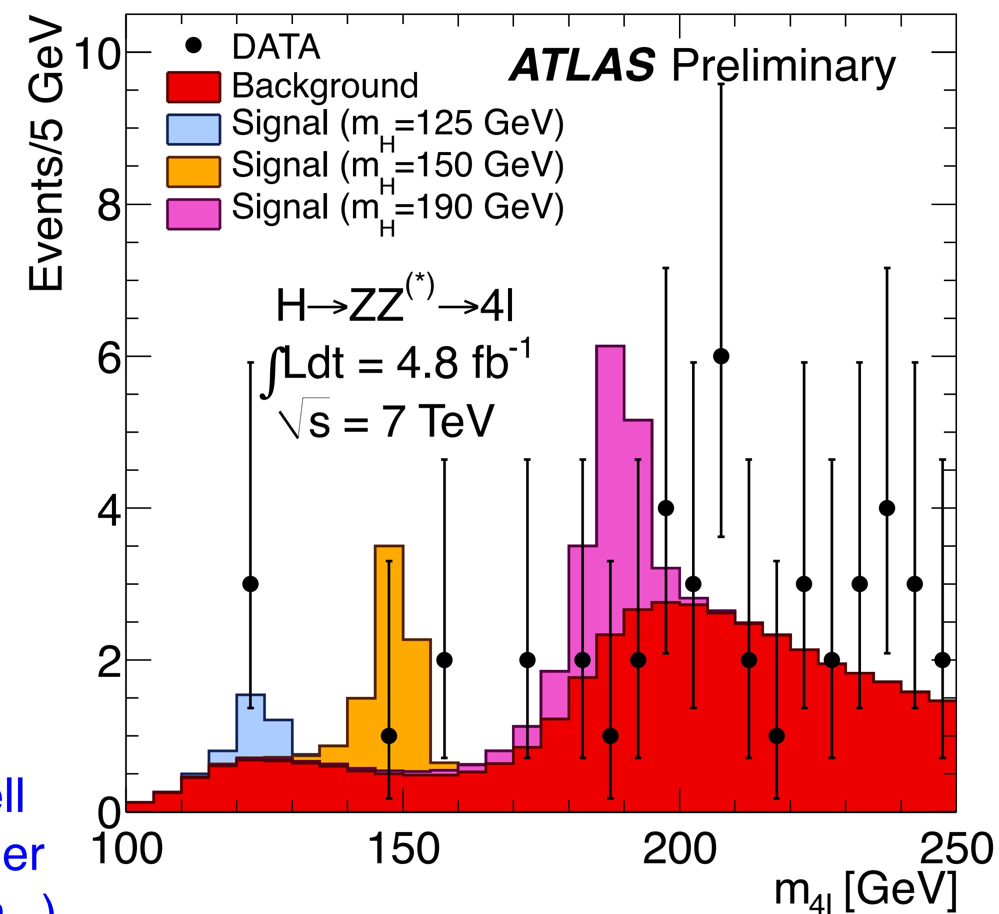
p_T (muons)= 36.1, 47.5, 26.4, 71 .7 GeV m_{12}= 86.3 GeV, m_{34}= 31.6 GeV. 15 reconstructed vertices

$H \to ZZ^{(*)} \to 4l$ Overview

- Search for a narrow m_{4l} peak
  $110 < m_{\gamma\gamma} < 600$ GeV
- A few signal events over a small background; S/B varies with m_{4l}
  σ x BR ~5 fb @ m_H ~125 GeV
- **The "golden channel":**
  4 isolated leptons from IP
  mass resolution ~2% @130 GeV



At low m_H:
one Z on-shell (m_{12}), the other is off-shell (m_{34})

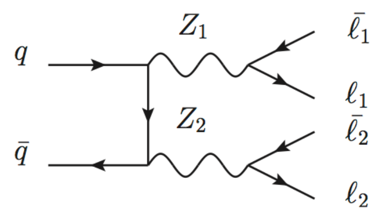


[Above: from CERN Council meeting, Dec 13, 2011]

- Four final states: **4e, 4μ, 2e2μ, 2μ2e**

$H \to ZZ^{(*)} \to 4l$ Background rejection

- **Other processes can end up with four leptons**
  - t tbar : each to Wb, $W \to l\nu$, $b \to$ jet with a lepton
  - Zbb : $Z \to ll$, each b to a jet with a lepton
  - Z+light jets: $Z \to ll$, jets misreconstructed as electrons
  - ZZ production (no Higgs)



- **In tt, Z+jets and Zbb** ("reducible"):
  - There are other particles around the leptons
  - Leptons from b decays come from secondary vertices
  - Reduced by requiring that leptons are isolated and non-displaced
    (sketch isolation and impact parameter)

- **ZZ production is similar to the signal** ("Irreducible")

$H \rightarrow ZZ^{(*)} \rightarrow 4l$ Event selection

Updated analysis for 2011 and 2012 data

- Improved expected sensitivity for low m_H
- Estimate backgrounds using data (sidebands, control regions)
- Development based only on 2011 data and 2012 control regions

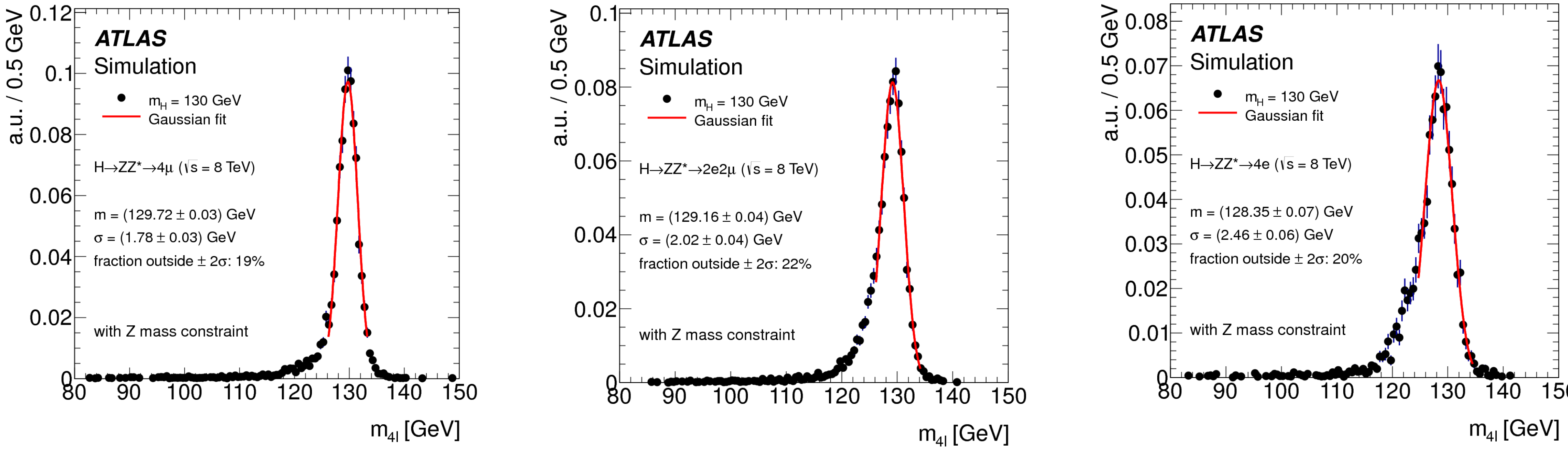
Selection

- At least two pairs of opposite-charge, same-flavor leptons (e,μ)
- p_T thresholds: 20, 15, 10, 7 GeV (6 GeV for muons)
- $50 < m_{12} < 106$ GeV, m_{4l}-dependent cut on m_{34}, $m_{34} < 115$ GeV
- All same-flavor, opposite-sign pairs m_{ll}>5 GeV (J/ψ veto)
- Tracking and calorimeter -based isolation
- Impact parameter significance

$H \rightarrow ZZ^{(*)} \rightarrow 4l$ Mass reconstruction, efficiency

Mass resolution in simulated events at m_H=130 GeV

(with Z mass constraint for m_{12})



4μ: σ=1.8 GeV *2e2μ: σ=2.0 GeV* *4e: σ=2.5 GeV*

Combined reconstruction / selection efficiency for m_H=130 GeV

Significant gains from increased kinematic acceptance and e-ID

Efficiency (%)	4μ	2e2μ	4e
2011 data (old)	27	18	14
2011 data	43	23	17
2012 data	41	27	23

$H \rightarrow ZZ^{(*)} \rightarrow 4l$ Background estimation

Irreducible ($ZZ^{(*)}$): MC simulation normalized to theory cross section

Reducible (ll+jets and tt):

- Comparable to ZZ in the low mass region
- Estimated using data-driven methods
- Background composition depends on flavor of sub-leading lepton pair (i.e., the flavor of the pair of leptons that make the off-shell Z)
  → different approaches for ll+μμ and ll+ee:

  ll+μμ (4μ, 2e2μ):
  - ttbar and Zbb from a fit to m_{12}

  ll+ee (2μ2e, 4e):
  - **Z+XX** control samples

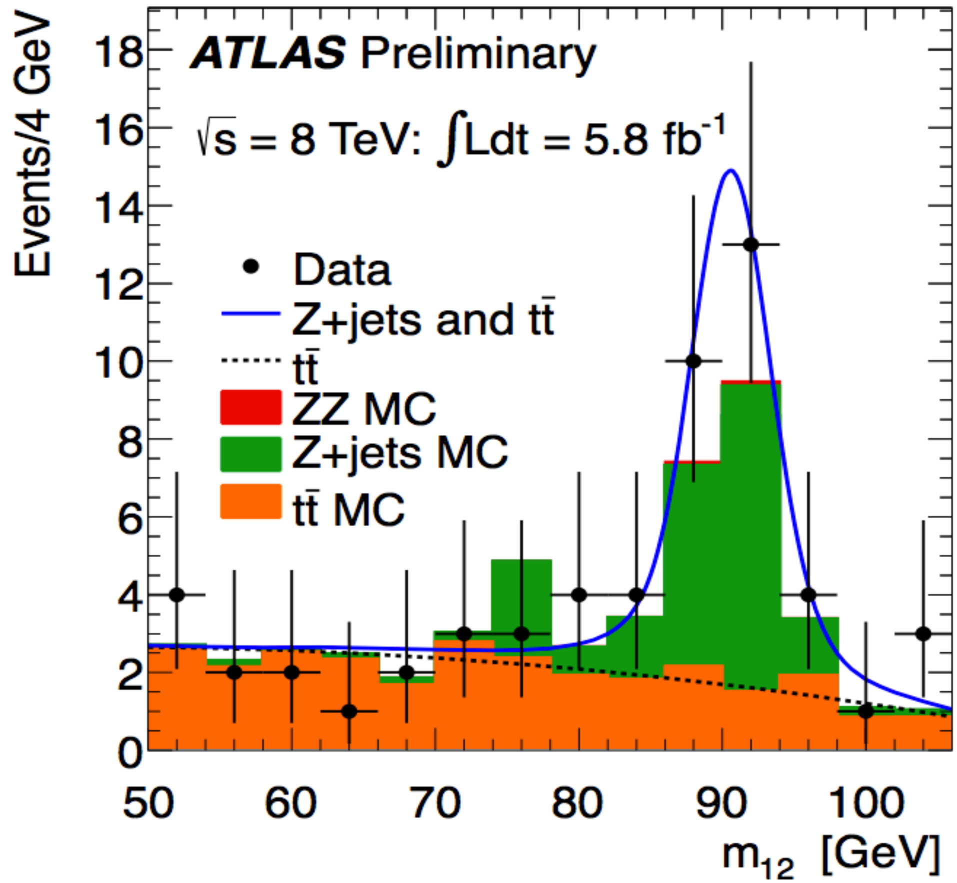
- **General strategy**: Loosen or revert selection, obtain composition, extrapolate to signal region
- **Two methods for each reducible background (nominal, cross-check)**

H→ZZ(*)→4l Background estimation

Fit to m_{12}

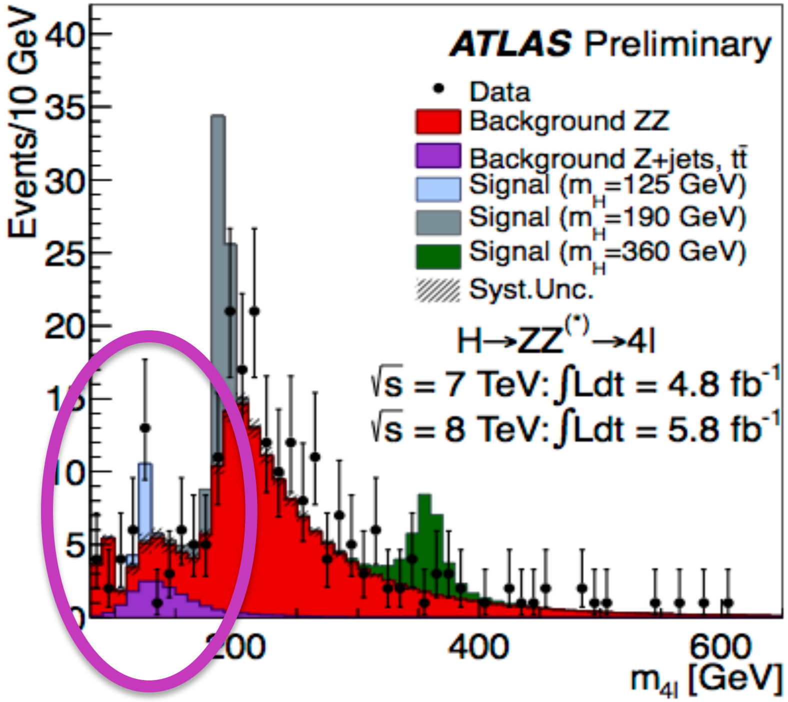
- Change selection on sub-leading leptons to enhance ttbar and reduce ZZ:
  - No isolation cuts
  - At least one lepton should fail the impact parameter cut
- tt and Z+jets estimated via a fit

  Chebychev + BreitWigner⊗CrystalBall
- Extrapolate to signal region via MC-based transfer factor (validated in Z+μ control region)



At least two estimates for each background for each subchannel; good agreement in all cases.

$H \rightarrow ZZ^{(*)} \rightarrow 4l$ Mass spectrum



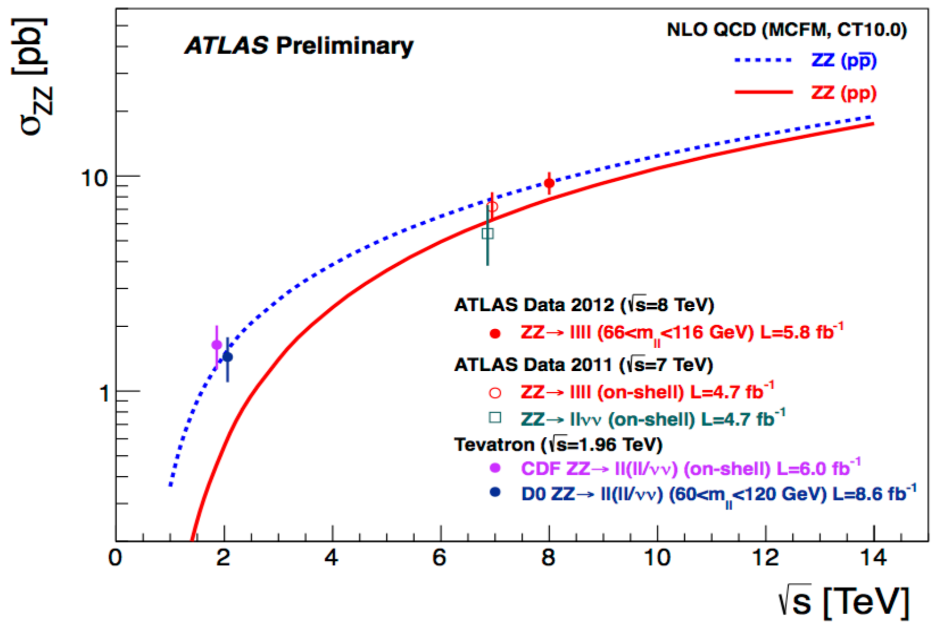
m_{4l} > 160 GeV (dominated by ZZ background):

147 ± 11 events expected

191 observed

~30% more ZZ events than SM prediction
→ in agreement with measured ZZ cross-section in 4l final states at $\sqrt{s}$ = 8 TeV

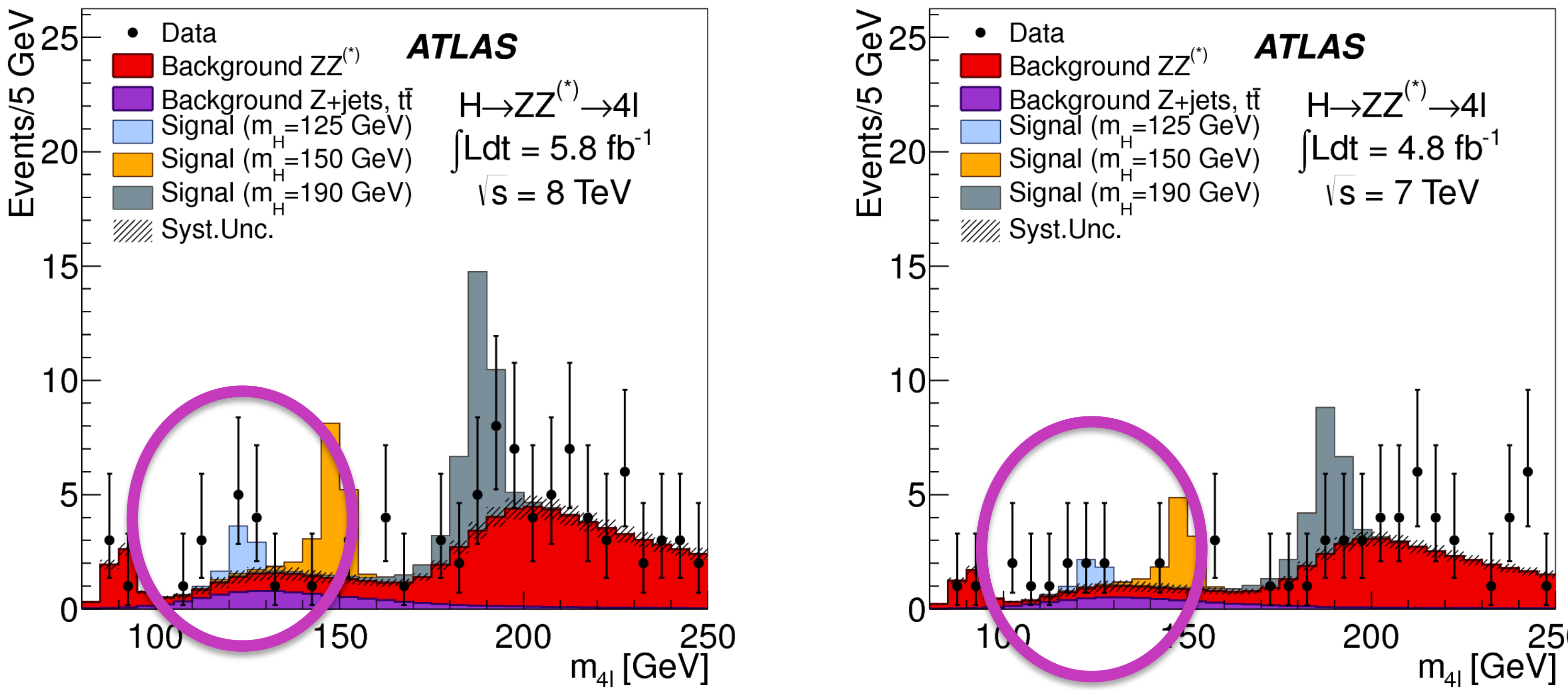
Measured σ (ZZ) = 9.3 ± 1.2 pb
SM (NLO) σ (ZZ) = 7.4 ± 0.4 pb



Discrepancy has negligible impact on the low-mass region < 160 GeV

(no change in results, if in the fit ZZ background is constrained within its uncertainty or left free)

$H \to ZZ^{(*)} \to 4l$ Low mass region

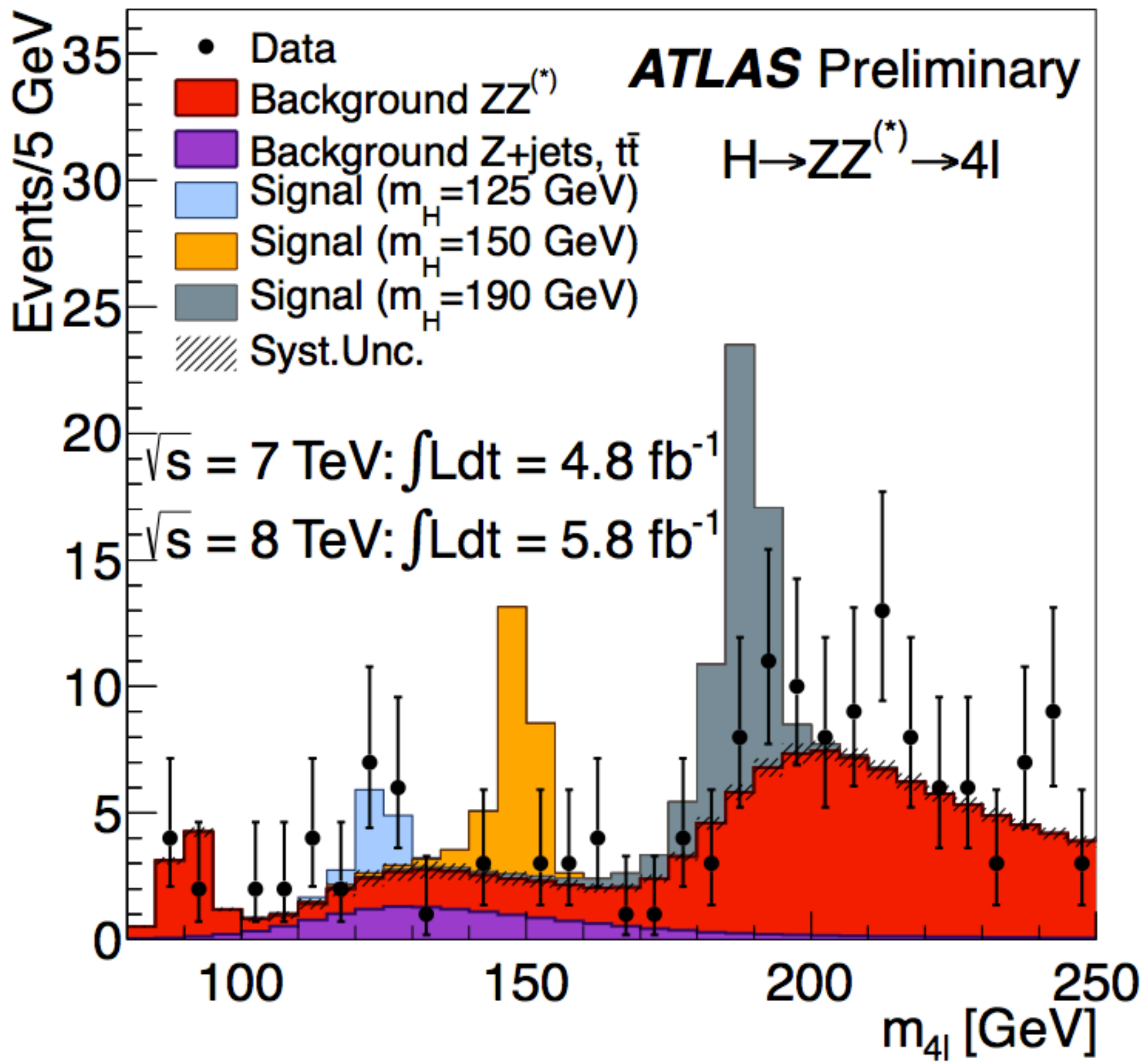


Event counts in $120<m_{4l}<130$ GeV

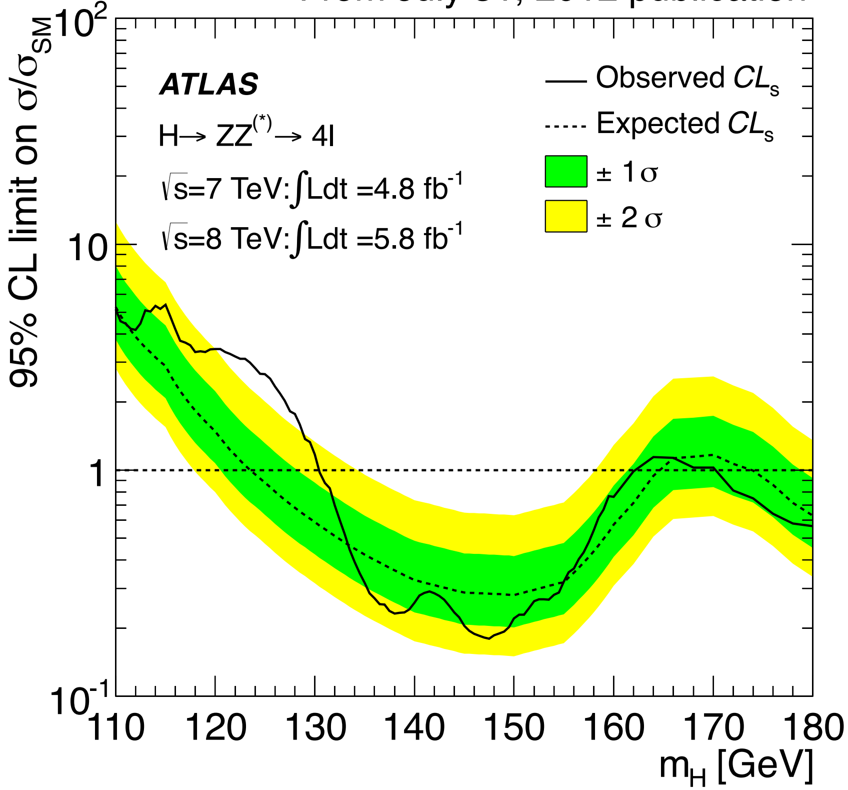
7+8 TeV	4μ	2e2μ + 2μ2e	4e	Sum
Background	1.3 ± 0.1	2.1 ± 0.2	1.5 ± 0.2	**4.9 ± 0.3**
m_H=125 GeV	2.1 ± 0.3	2.3 ± 0.3	0.9 ± 0.1	**5.3 ± 0.4**
Observed	6	5	2	**13**
S/B	1.6	1.1	0.6	**1.1**

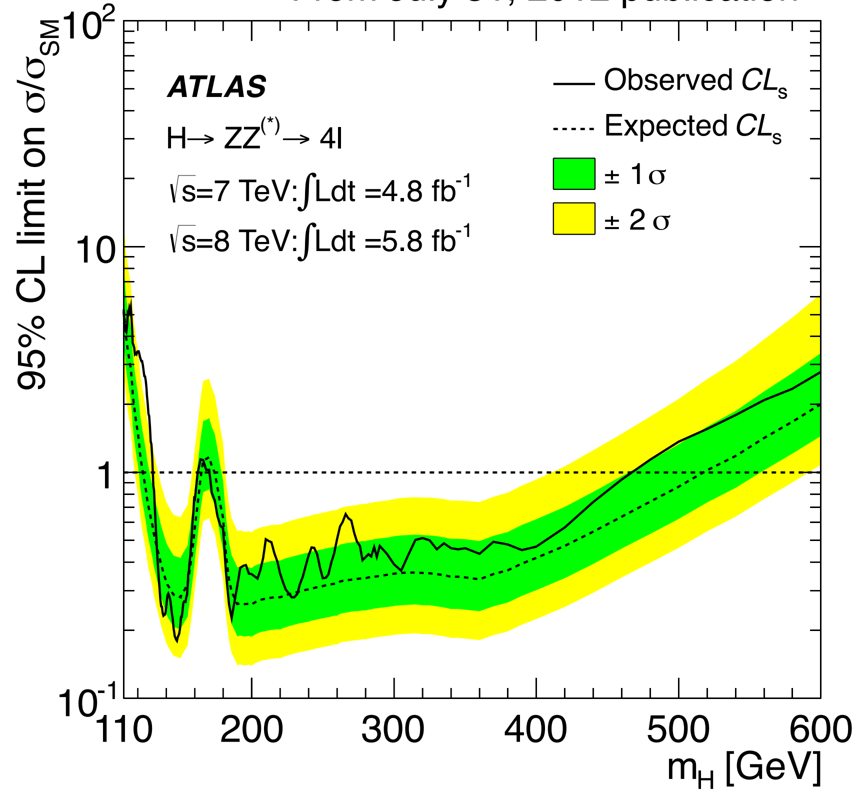
H→ZZ(*)→4l Low mass region

Adding both years' data:



$H \to ZZ^{(*)} \to 4l$ Exclusion limits





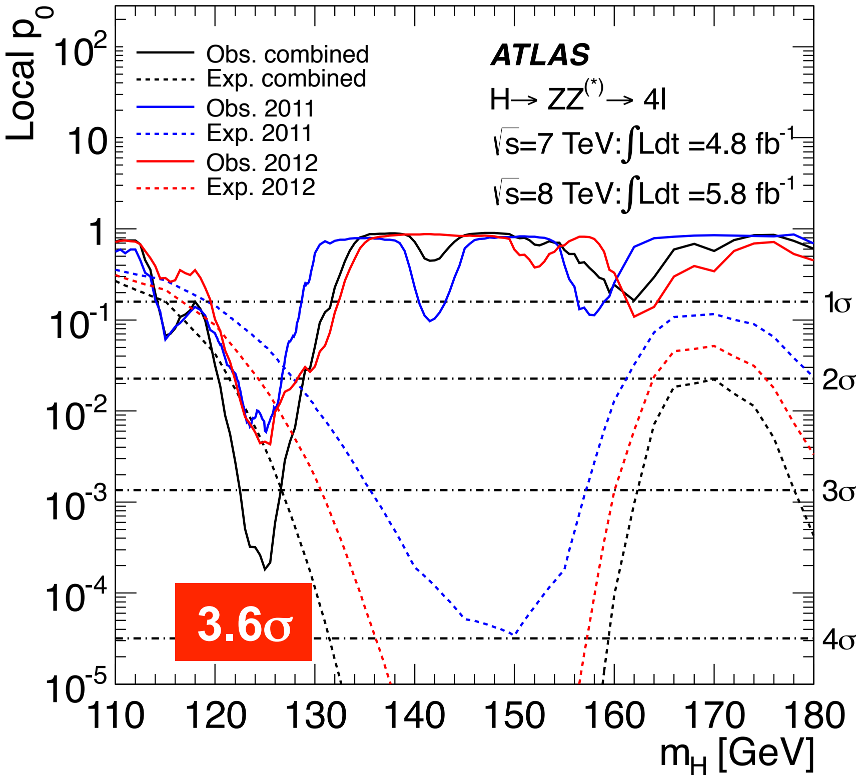
Exclusion at 95% C.L. :

Expected: $124 < m_H < 164$ GeV and $176 < m_H < 500$ GeV

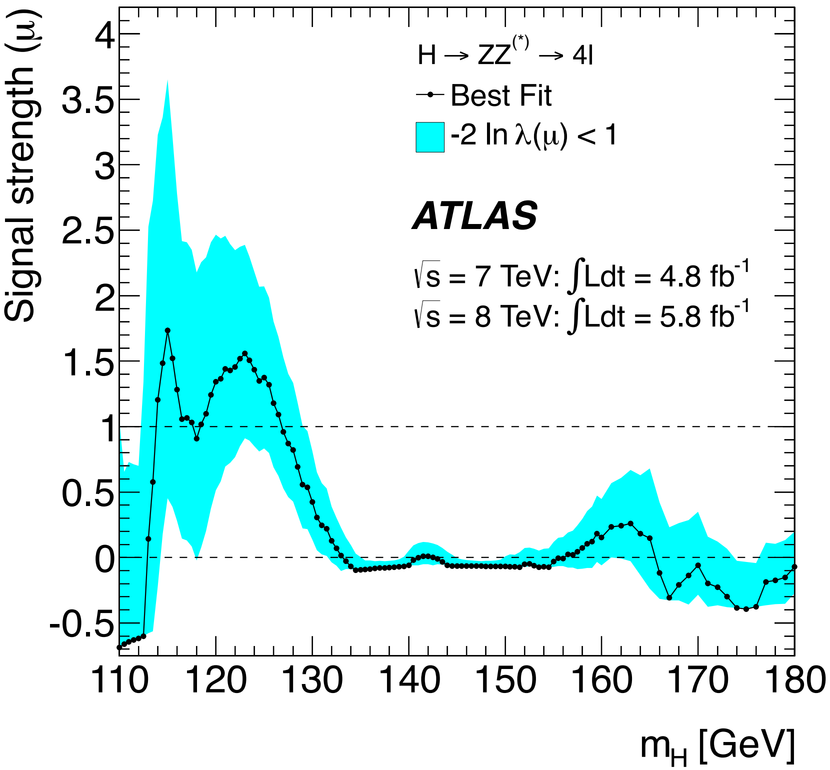
Observed: $131 < m_H < 162$ GeV and $170 < m_H < 460$ GeV

For m_H ~120-130 GeV weaker limit than expected in background-only hypothesis

$H \rightarrow ZZ^{(*)} \rightarrow 4l$ Significance



Best-fit value at 125 GeV: μ=1.4 ± 0.6



Data sample	***m_H at max deviation***	***local p-value***	***local significance***	***expected***
2011	***125 GeV***	***1.1 %***	***2.3 σ***	***1.5 σ***
2012	***125.5 GeV***	***0.4 %***	***2.7 σ***	***2.1 σ***
2011+2012	***125 GeV***	***0.03 %***	***3.4 σ***	***2.6 σ***

Global 2011+2012 (including LEE over full 110-141 GeV range): 2.5σ

Combination up to July 4^{th} 2012

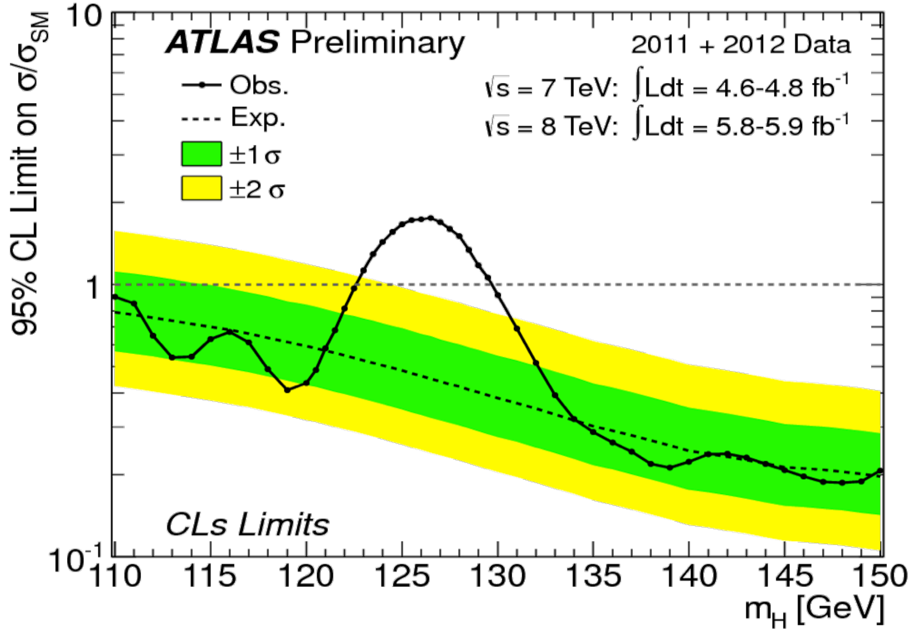
Higgs combination Datasets

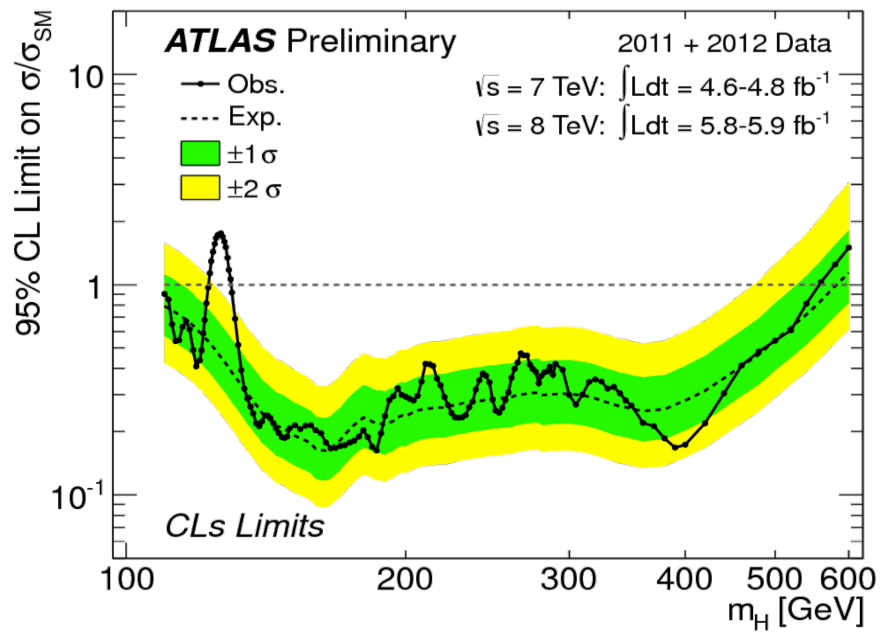
Channels/datasets used:

- $H \rightarrow \gamma\gamma$ — 7 TeV (4.8 fb^{-1}) + 8 TeV (5.9 fb^{-1})
- $H \rightarrow ZZ^{(*)} \rightarrow 4$ leptons — 7 TeV (4.8 fb^{-1}) + 8 TeV (5.8 fb^{-1})
- $H \rightarrow WW$ — 7 TeV (4.7 fb^{-1})
- $H \rightarrow \tau\tau$ — 7 TeV (4.7 fb^{-1})
- W,Z $H \rightarrow bb$ — 7 TeV (4.6-4.7 fb^{-1})

Higgs combination Exclusion limits

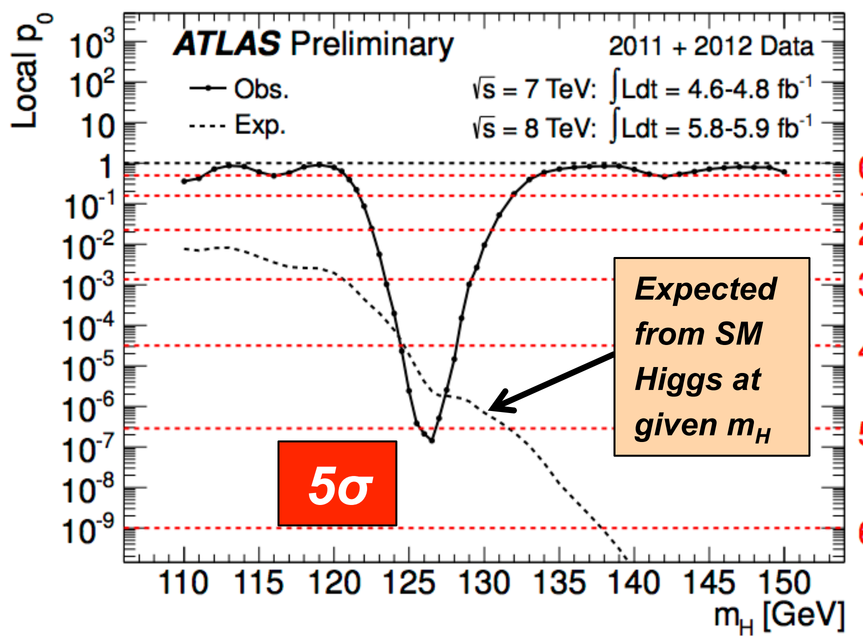
Combining 2011+2012 γγ and 4-lepton analyses with other channels as before (2011)

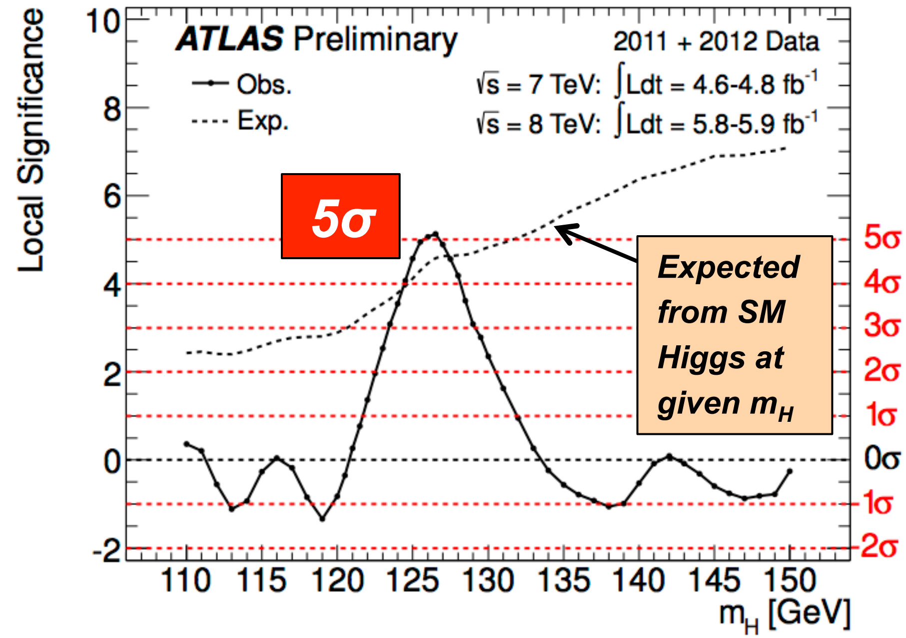




- Exclusion at 95% C.L. :
  - Expected $110 < m_H < 582$ GeV
  - Observed $110 < m_H < 122.6$ GeV, $129.7 < m_H < 558$ GeV
- Region around 126 GeV is not excluded

Higgs combination The excess





Maximum excess observed at m_H = 126.5 GeV

Local significance** (including energy-scale systematics)* ***5.0 σ

p_0** Probability that background fluctuates to the observed data (or higher)* ***3 x 10^{-7}

Expected from SM Higgs m_H=126.5 GeV ***4.6 σ***

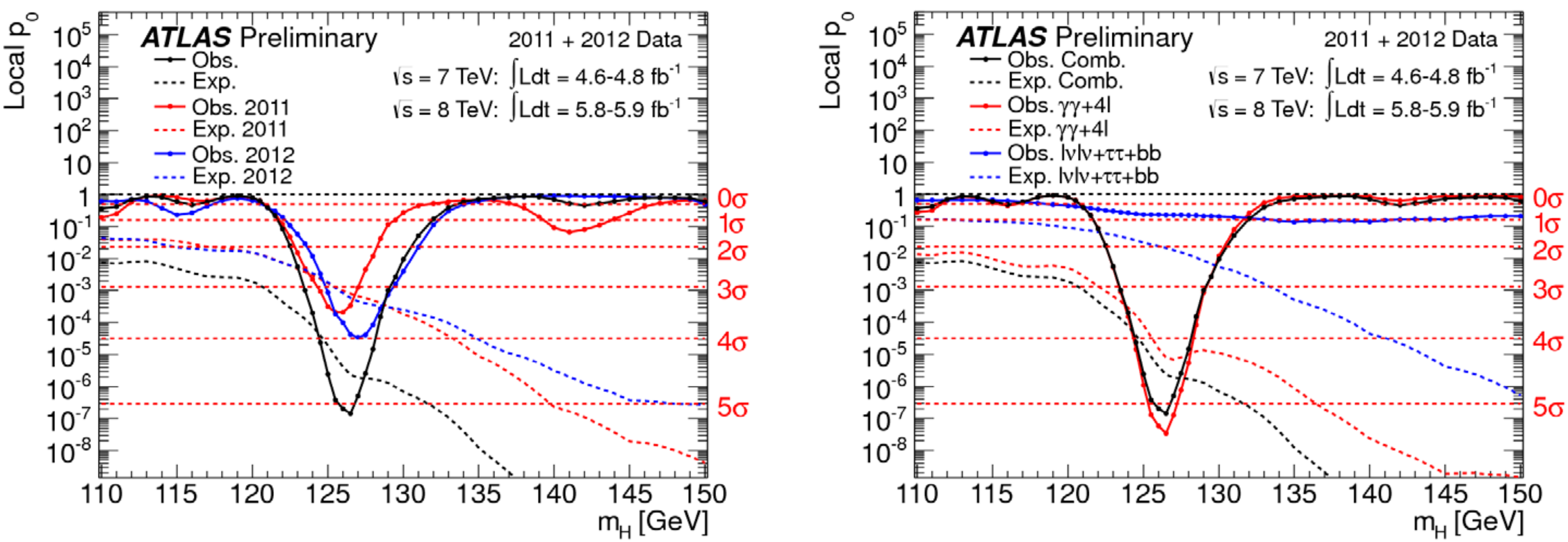
Global significance: 4.1-4.3 σ (for LEE over 110-600 or 110-150 GeV)

Higgs combination Composition

Excess seen in both 2011 and 2012 data:

2011: 3.5σ (obs.) and 3.1σ (exp.)

2012: 4.0σ (obs.) and 3.3σ (exp.)



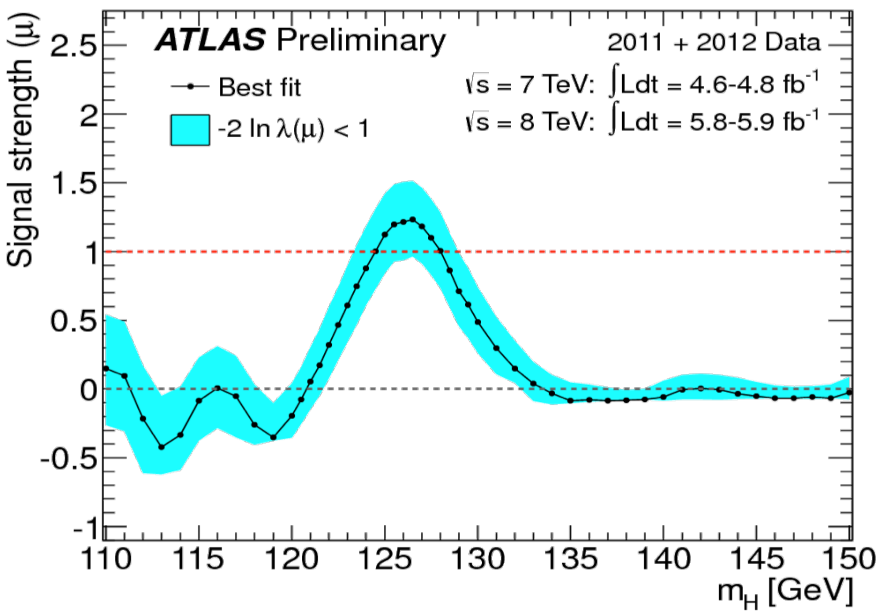
Both years is dominated by H→γγ and H→ZZ→4 leptons

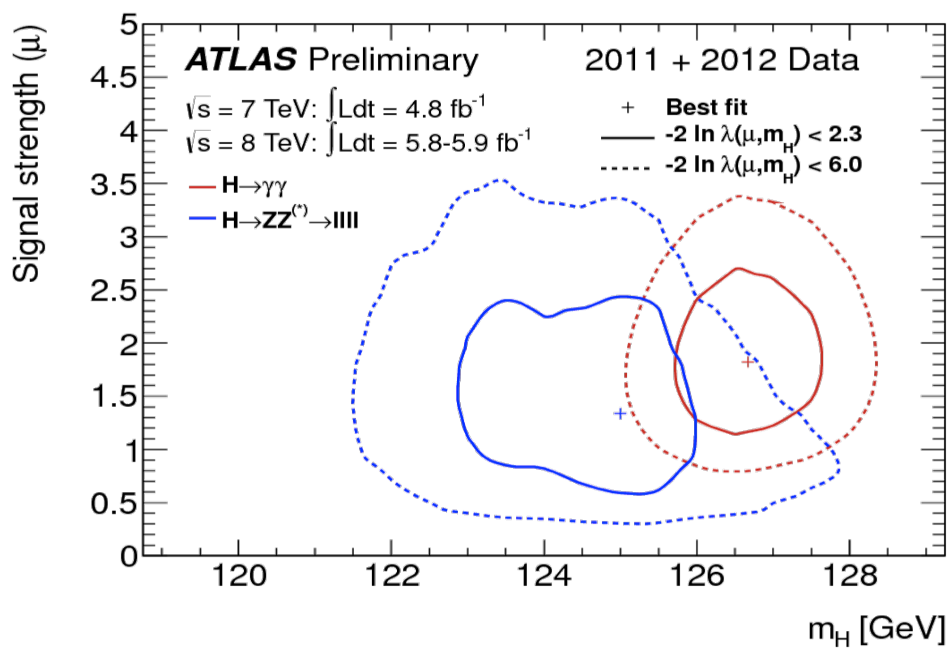
Higgs combination Strength, compatibility

Best fit signal strength (μ) vs m_H

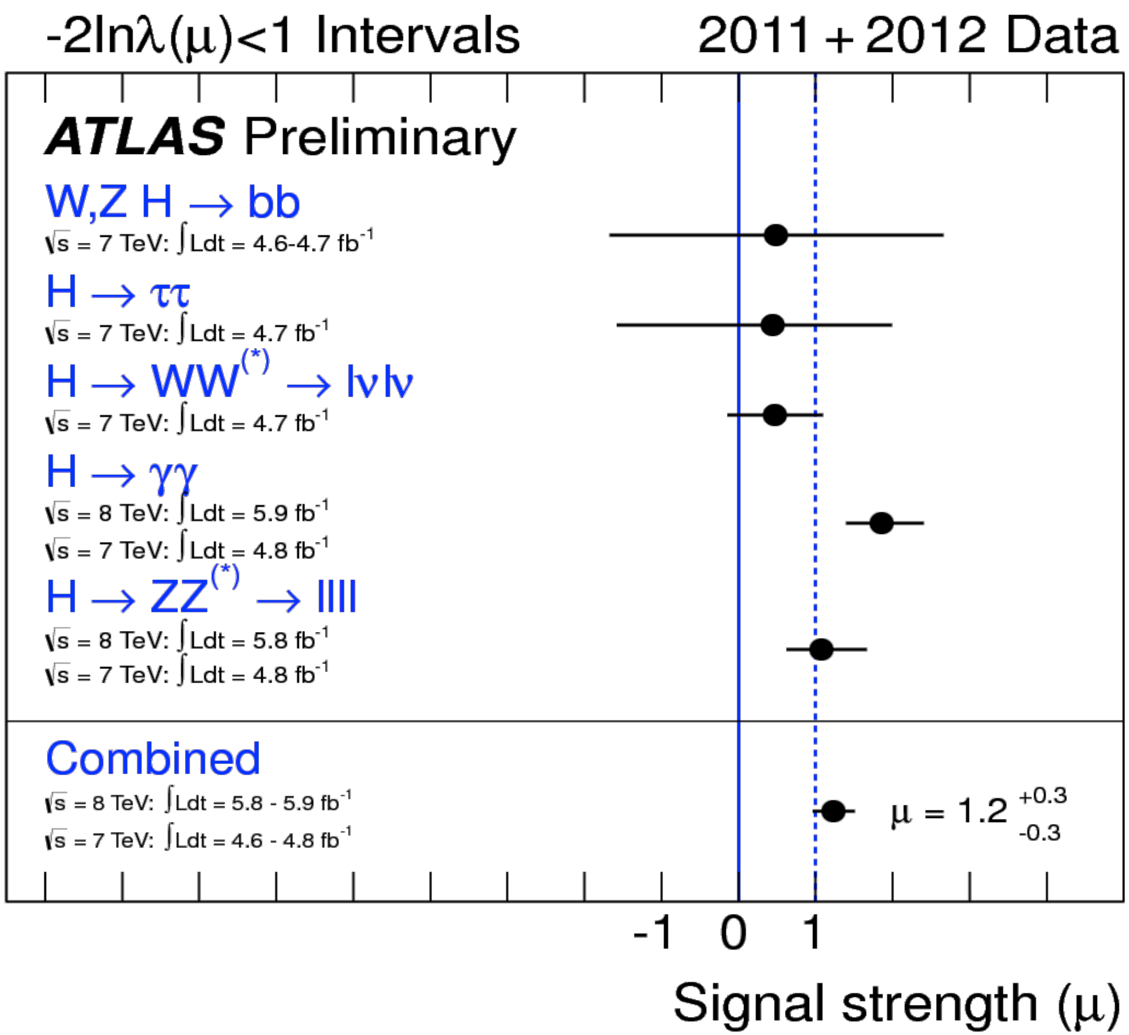
- Scanning m_H to find best-fit value of μ at each m_H
- At 126.5 GeV, μ=1.2 ± 0.3
  - Compatible with SM expectation (μ=1)
  - Max μ Is not at min p_0

- Let m_H and μ float, 2D contour plot around best fit values (~68% solid, 95% dashed)
- Best fit masses for H→γγ and H→4-leptons are compatible.





Higgs combination   Channel contribution



Combined signal strength:

$\mu=1.2 \pm 0.3$

Most important contributions from H→γγ, H→ZZ*→4l, H→WW*→lνlν

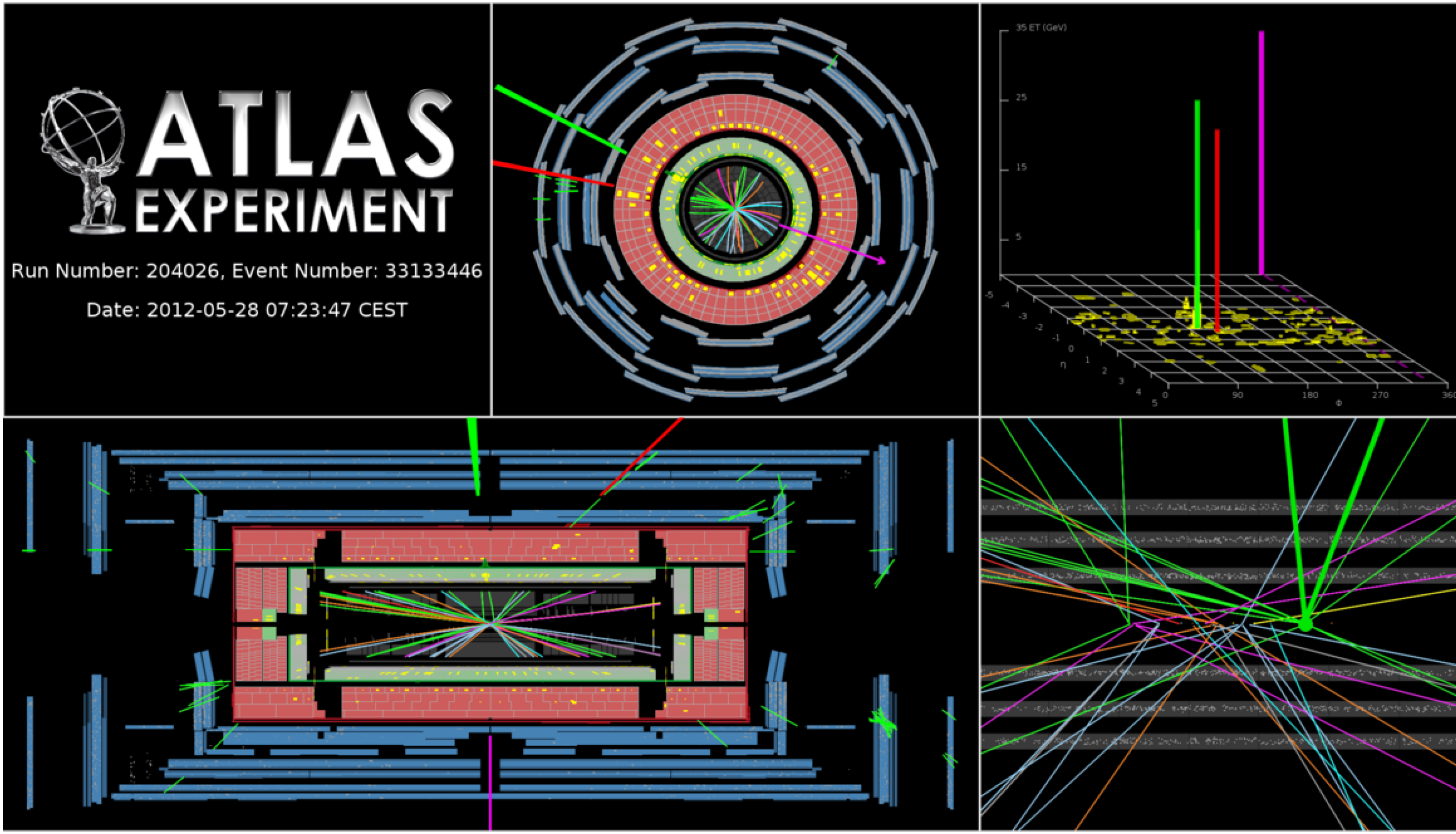
Post July 4^{th} 2012

July 31^{st}, 2012:

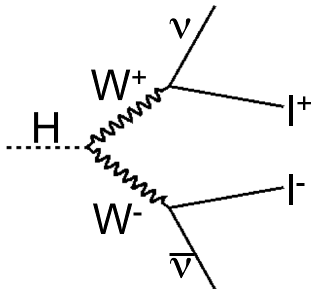
Observation of a New Particle in the Search for the Standard Model Higgs Boson with the ATLAS Detector at the LHC

submitted to Physics Letters B

H→WW$^{(*)}$→lνlν


ATLAS
EXPERIMENT
Run Number: 204026, Event Number: 33133446
Date: 2012-05-28 07:23:47 CEST
35 ET (GeV)
25
15
5
η
Φ
0
90
180
270
360

$H \to WW^{(*)} \to 4l$ Overview



$\sigma(H \to WW^* \to \ell\nu\ell\nu) \approx$ 0.18 pb at 7 TeV ~ 900 in 5 fb^{-1}

$\sigma(H \to WW^* \to \ell\nu\ell\nu) \approx$ 0.23 pb at 8 TeV ~ 1150 in 5 fb^{-1}

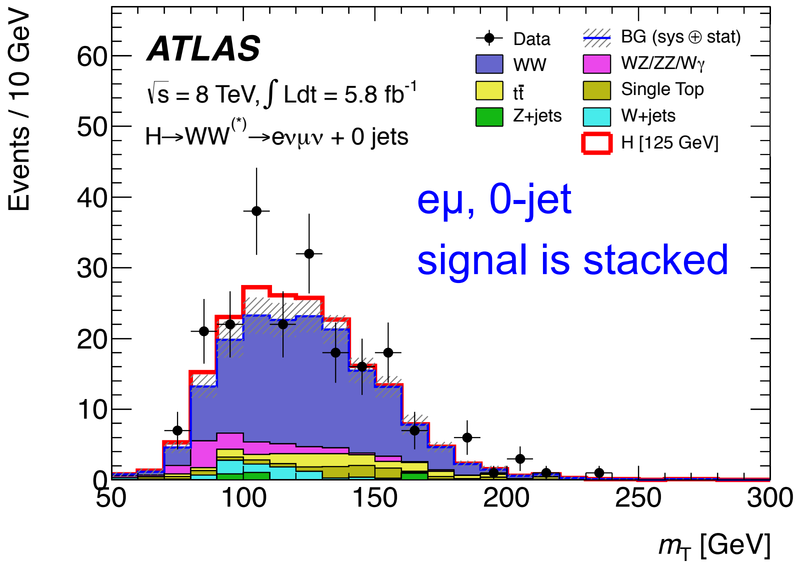
(m_H=125 GeV)

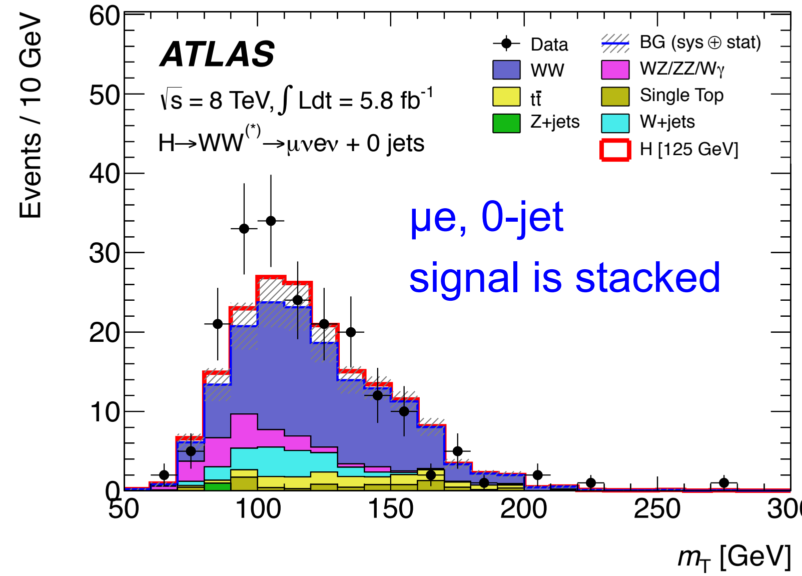
- Large cross section, but the neutrinos cannot be detected
- Detectors cover almost all 4π of solid angle, so we can calculate the missing momentum
- … but only the transverse component is constrained
- Limited mass information can be recovered:

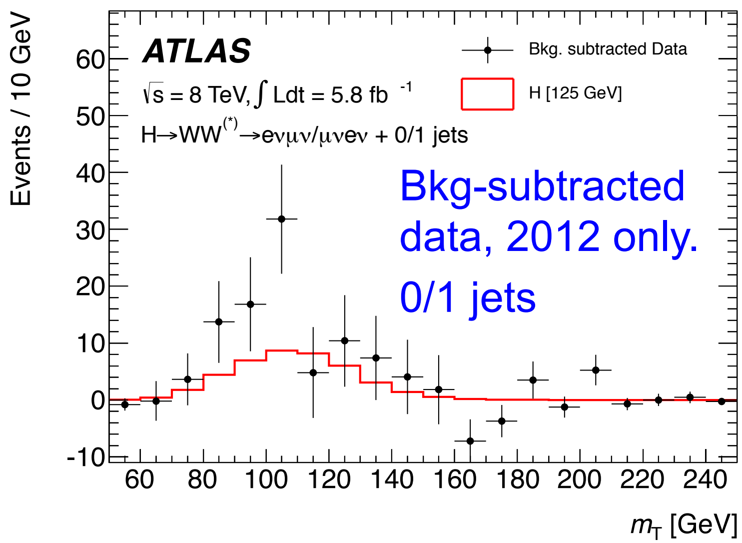
Transverse mass: $m_T = \sqrt{\left(E_T^{ll} + E_T^{miss}\right)^2 - \left|p_T^{ll} + E_T^{miss}\right|^2}$ *with* $E_T^{ll} = \sqrt{\left|p_T^{ll}\right|^2 + m_{ll}^2}$

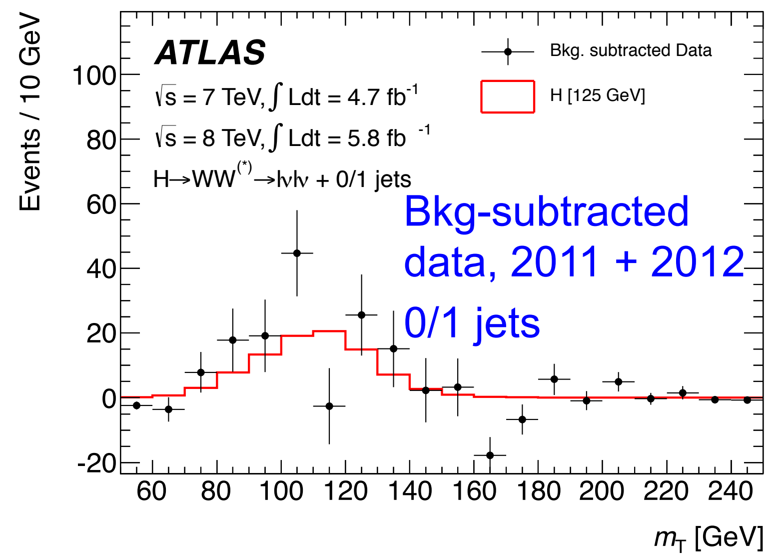
- Rather than a peak, a signal produces a broad distribution

H→WW$^{(*)}$→4l m_T distributions

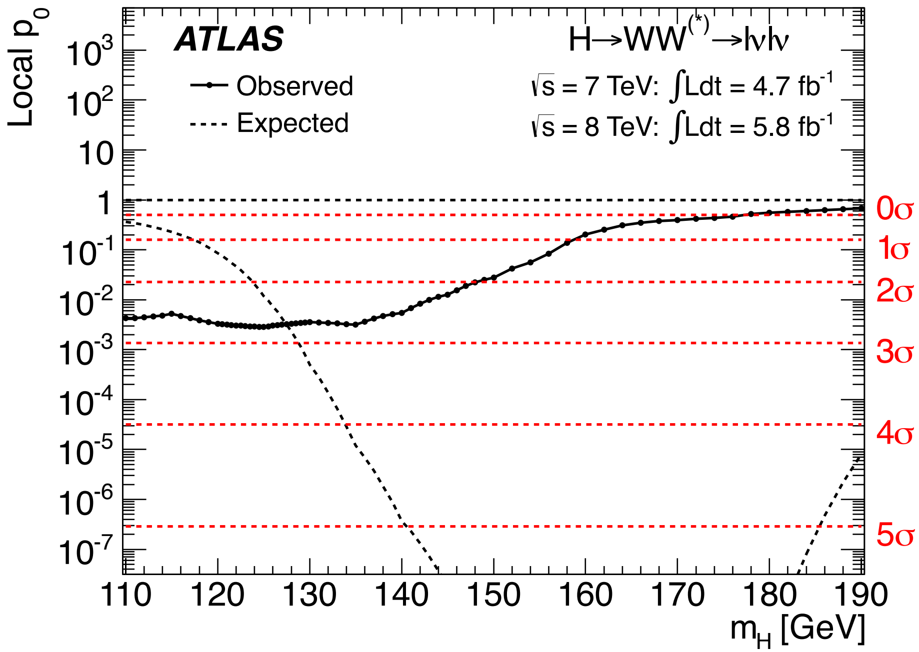


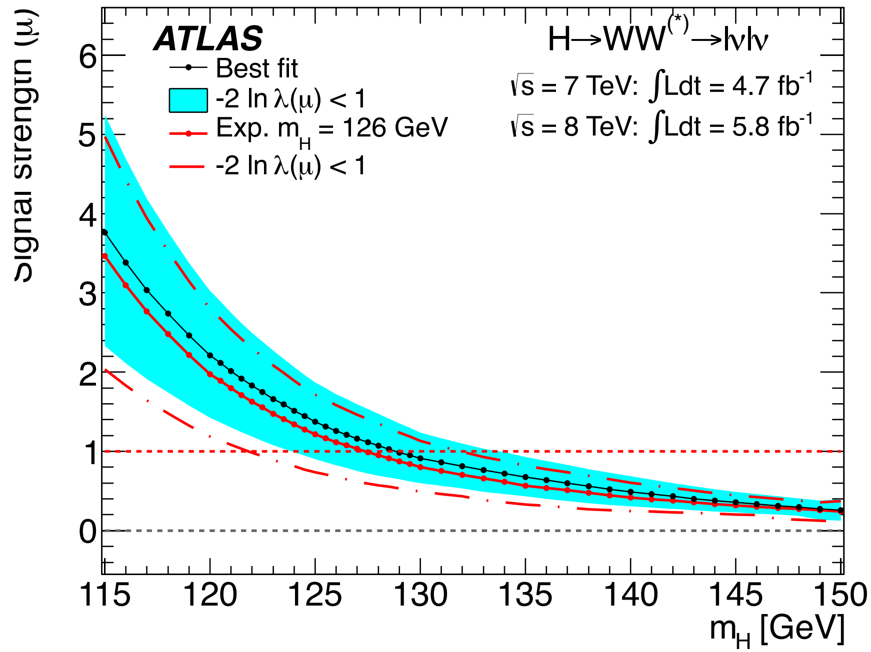






H→WW(*)→4l 2011+2012 data





m_H = 125 GeV:

p_0	Observed significance	Expected significance
3×10^{-3}	2.8 σ	2.3 σ

Signal strength (μ): $\mu = 1.4 \pm 0.5$

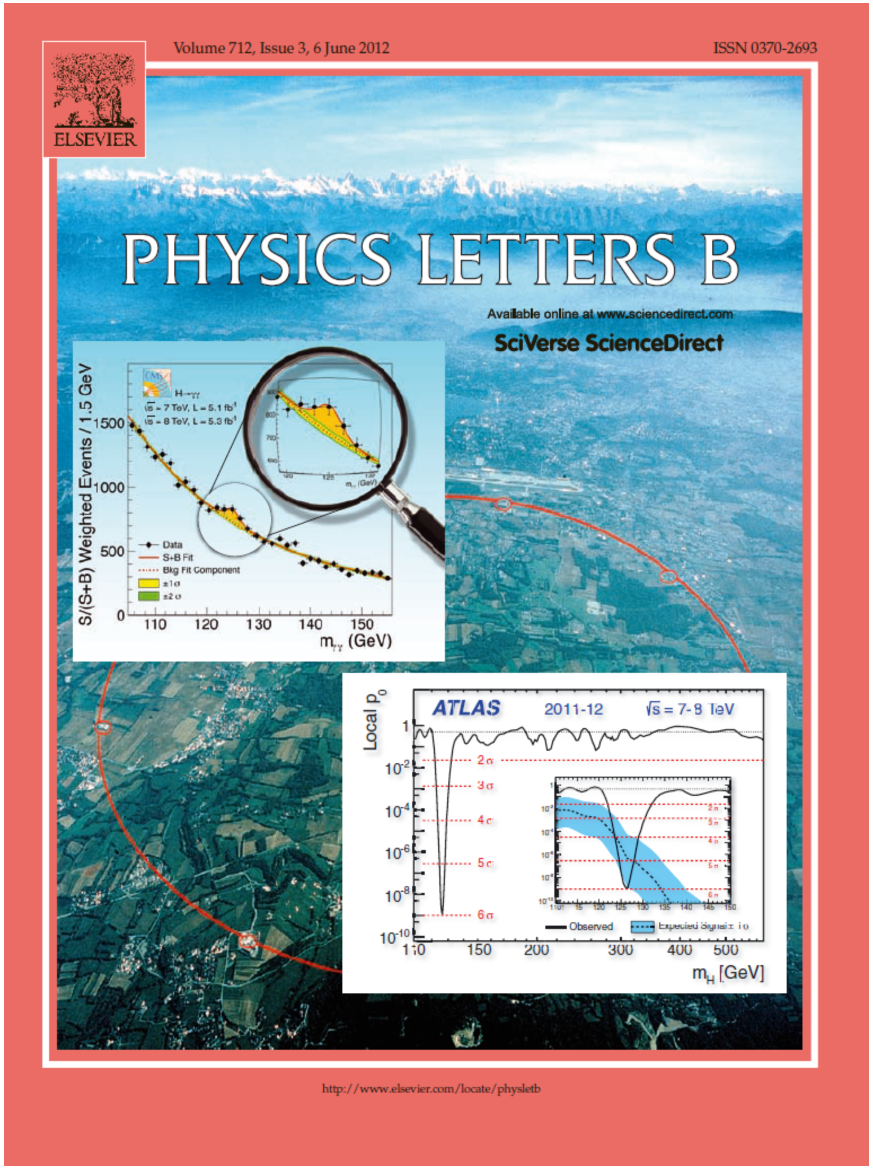
(At 126.0 GeV, μ=1.3±0.5 GeV)

Event yields in 2012:

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

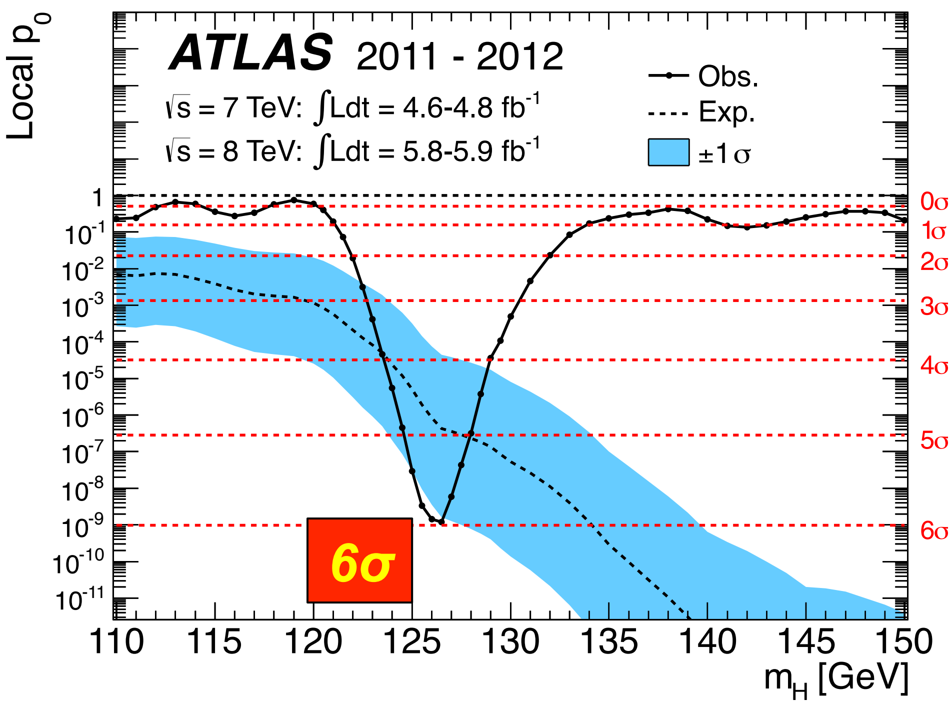
Observation paper

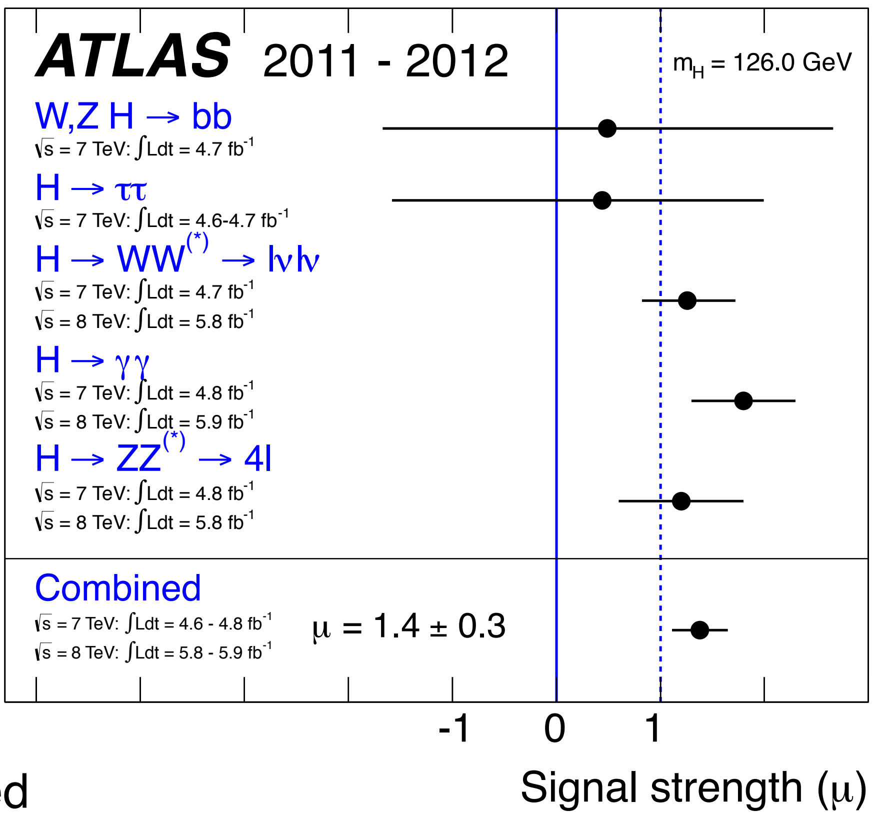
- On July 31st, 2012 both ATLAS and CMS submitted paper drafts to PLB
- ATLAS incorporated the WW analysis into the combination



Observation paper Combined significance

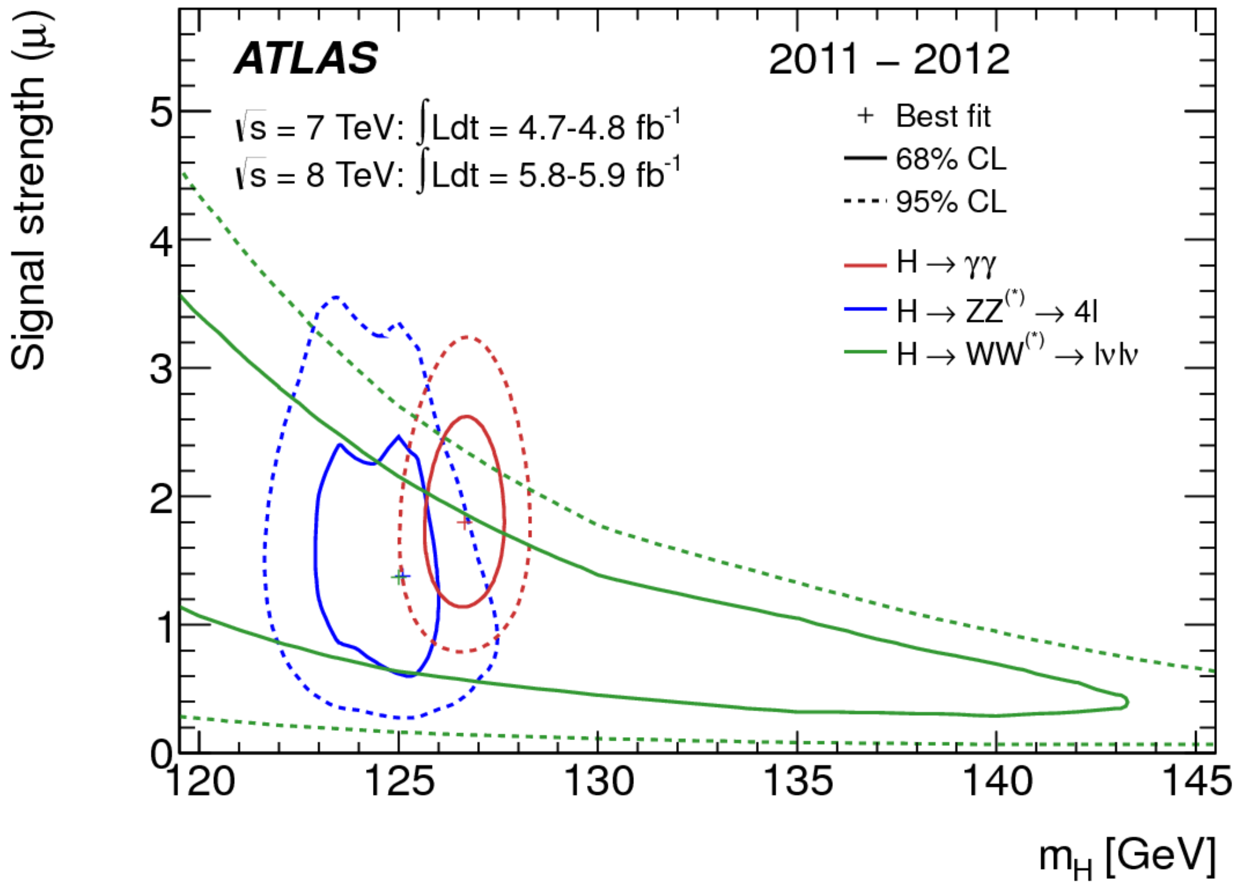
Adding 2012 H→WW data to the ATLAS Higgs combination:





For 6σ, the chances that the events observed were due to random fluctuations are less than one in 1000 million.

Observation paper Mass determination



- Likelihood ratio contours from scan of μ and m_H
- Good agreement despite poor mass resolution in H→WW

$m_H = 126.0 \pm 0.4 \pm 0.4$ GeV

Conclusion

Conclusion What we know

A new resonance has been observed in the search for the SM Higgs boson

- Mass ~ 126 GeV
- No other Higgs-like particle between 111 and 559 GeV
- It decays to 2 photons and to 4-leptons: it is a boson
- Its couplings to gg, ZZ and WW are ~ compatible with SM Higgs

	Observed significance	Expected significance	Signal strength (μ) [at m_H=126.0 GeV]
H→γγ	**4.5 σ**	**2.5 σ**	**1.8 ± 0.5**
H→4-leptons	**3.6 σ**	**2.7 σ**	**1.2 ± 0.6**
H→WW	**2.8 σ**	**2.3 σ**	**1.3 ± 0.5**
Combined with other channels	**5.9 σ**	**4.9 σ**	**1.4 ± 0.3**

Conclusion What is next?

Work in progress on properties of the new particle

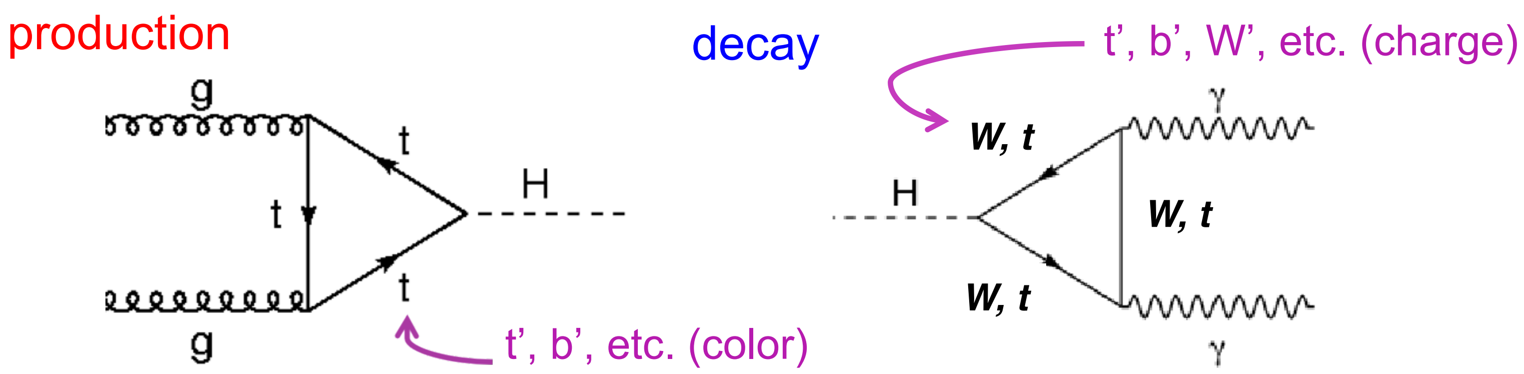
- Spin measurement
  - The SM Higgs boson should have spin 0
  - All elementary particles we know so far are either ½ or 1
  - If confirmed, this would be the first elementary scalar
- Couplings to fermions and cross section
  - So far, only boson couplings observed: ZZ, WW, gg (in ATLAS)
  - H to tau tau and bb to be updated soon (~ Fall)

Extension for data taking until December 17, 2012.
~25 fb^{-1} expected at 8 TeV, to add to 5 fb^{-1} from 2011.

Conclusion Possibilities

If the large signal strength (μ) for $H \rightarrow \gamma\gamma$ (1.9±0.5 for ATLAS, 1.6±0.4 for CMS) is confirmed with more data, new physics may surface:

- In the SM, the most important Higgs production process in pp interactions is gluon fusion through a top triangle.

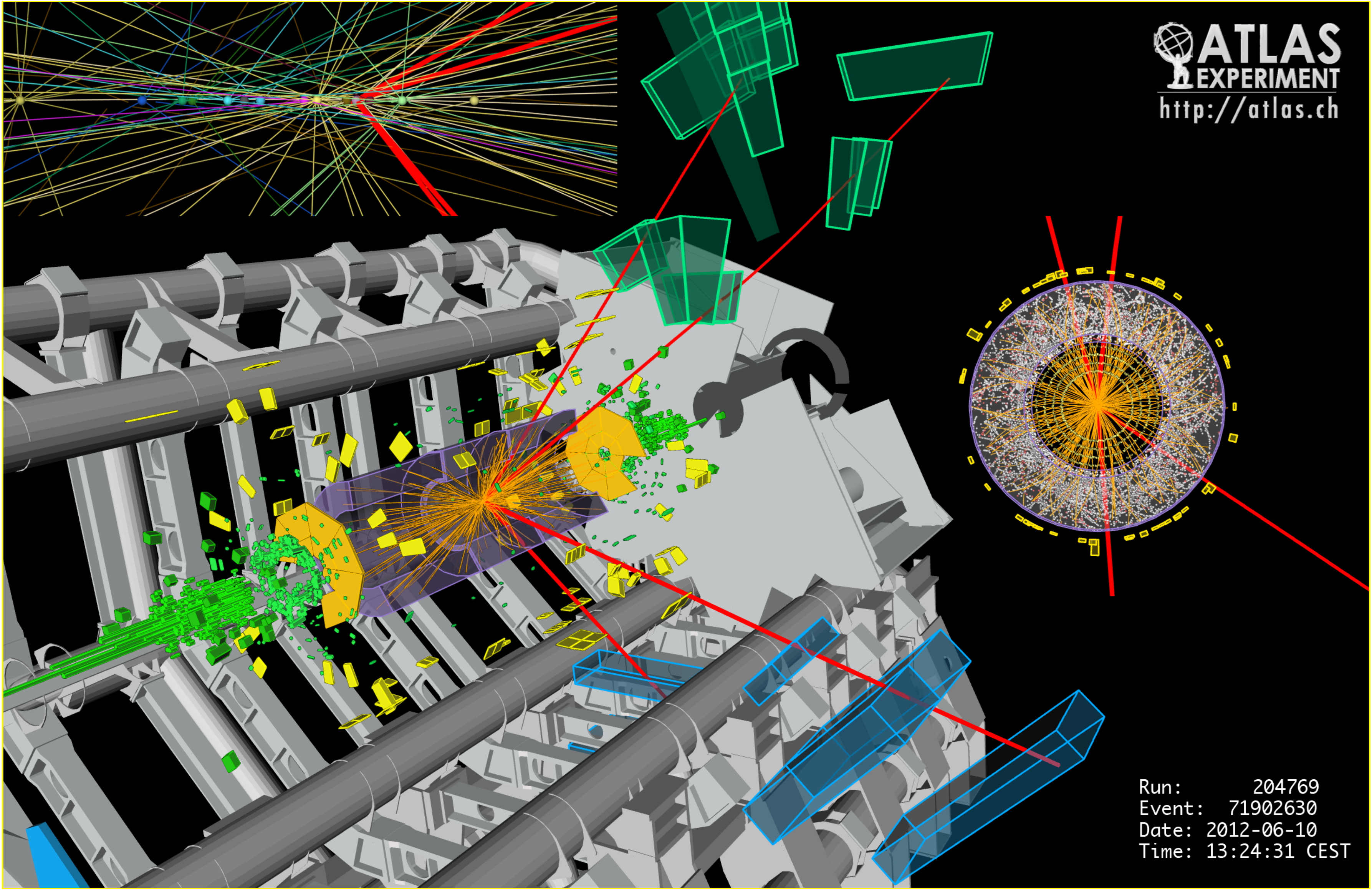


- If the SM is not the whole story, additional heavy particles could contribute to these triangles:
  - New particles with color would contribute to the production triangle
  - New particles with charge would contribute to the decay loop
- The presence of such new particles may enhance Higgs production and its decay into two photons

Backup slides

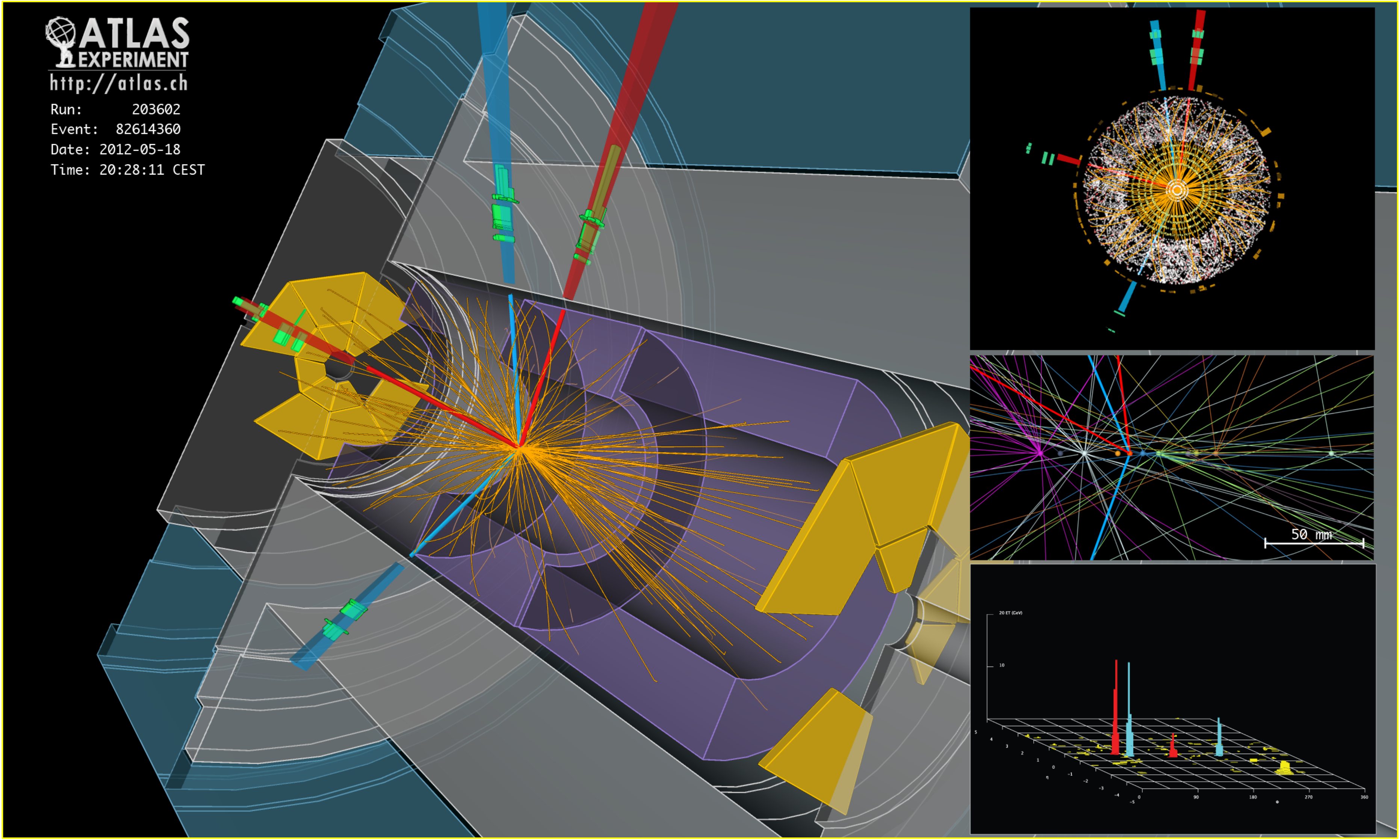
$m_{4\mu}$ = 125.1 GeV

p_T (muons)= 36.1, 47.5, 26.4, 71 .7 [GeV]
m_{12}= 86.3 GeV, m_{34}= 31.6 GeV
15 reconstructed vertices



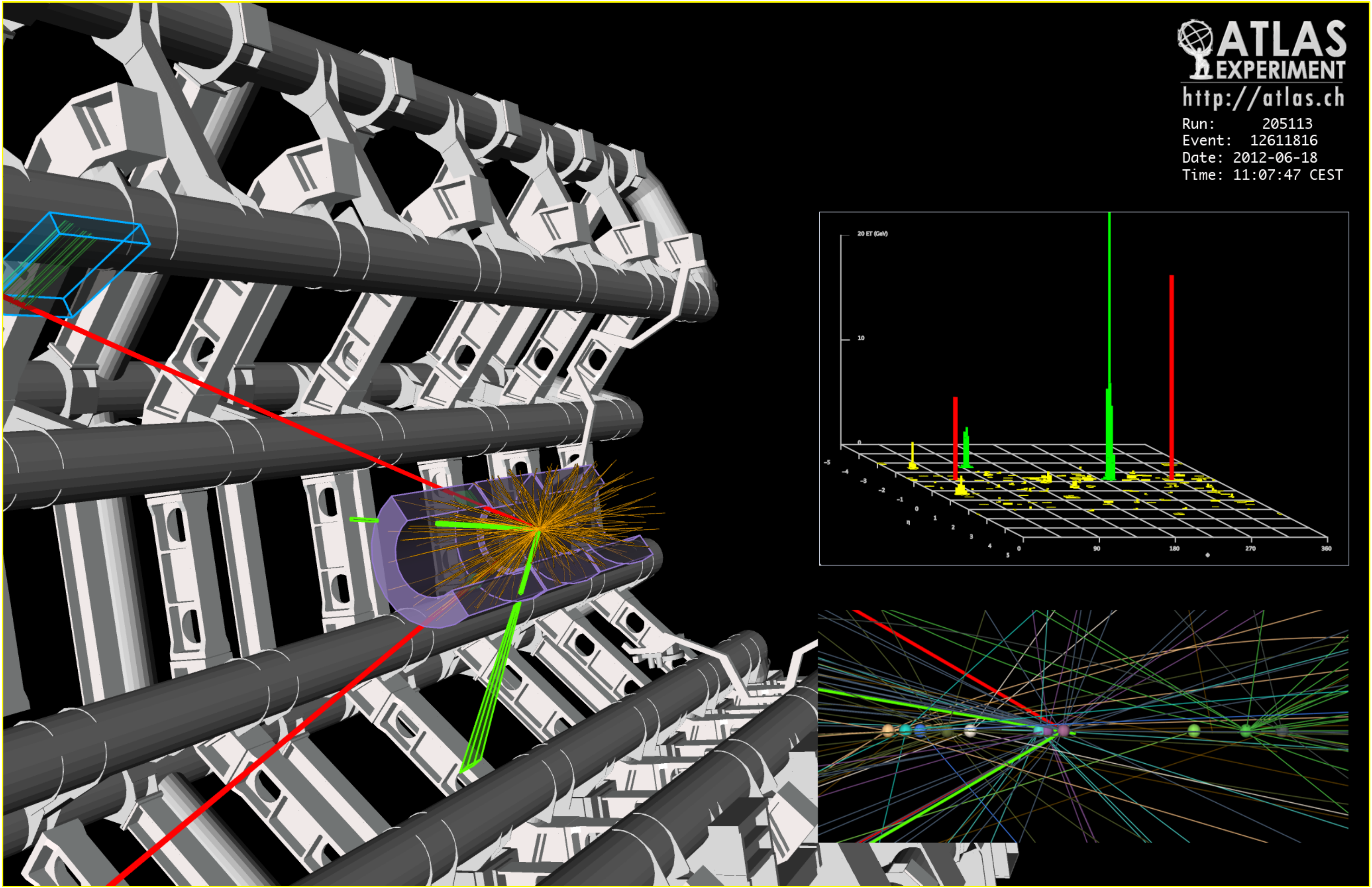
m_{4e} = 124.6 GeV

p_T (electrons)= 24.9, 53.9, 61.9, 17.8 [GeV]
m_{12}= 70.6 GeV, m_{34}= 44.7 GeV
12 reconstructed vertices

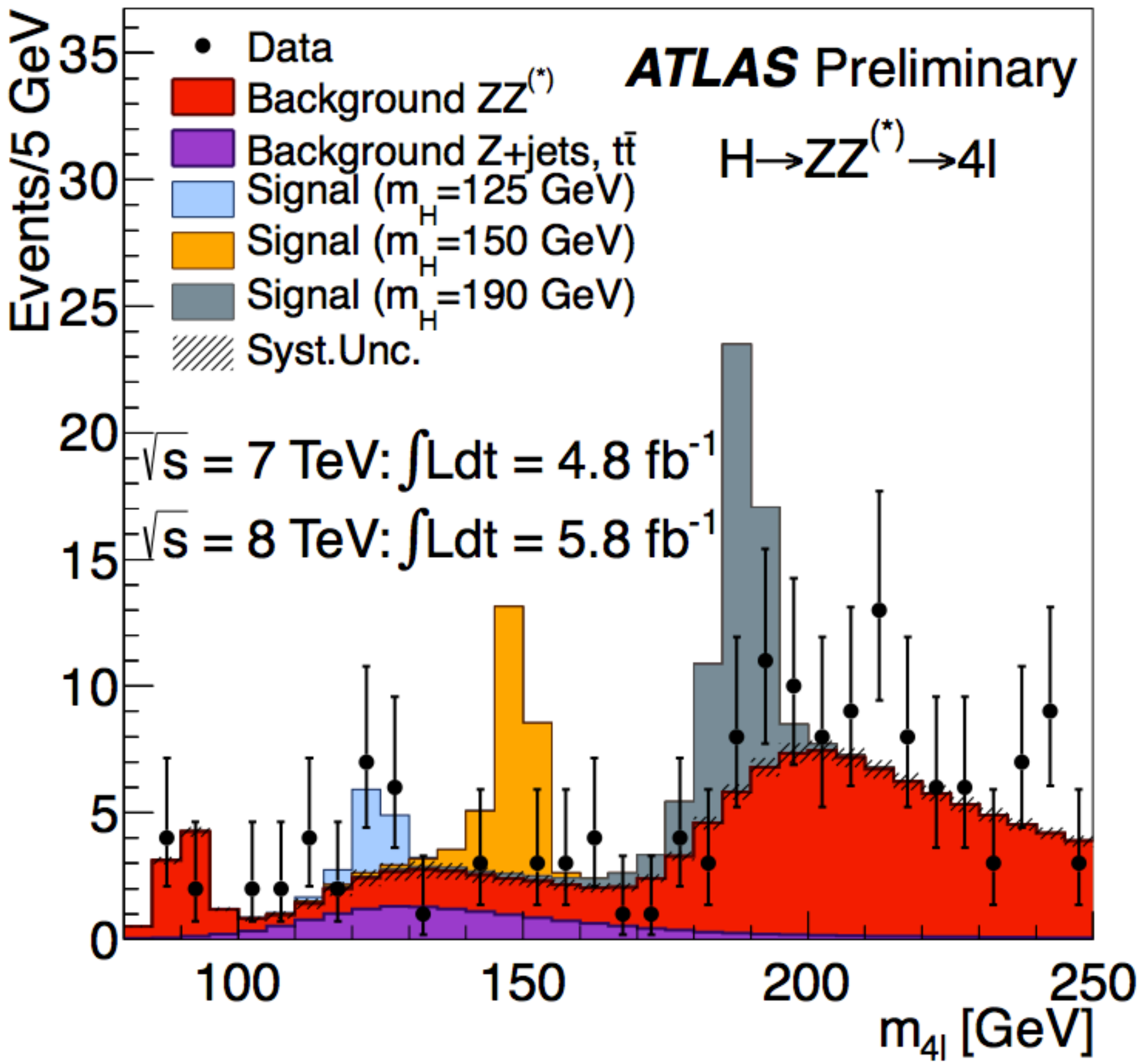


$m_{2e2\mu}$ = 123.9 GeV

p_T (eeμμ)= 18.7, 76, 19.6, 7.9 [GeV]
m_{ee}= 87.9 GeV, $m_{\mu\mu}$= 19.6 GeV
12 reconstructed vertices



2011 data



Events/5 GeV
Data
Background ZZ(*)
Background Z+jets, tt̄
Signal (m_H=125 GeV)
Signal (m_H=150 GeV)
Signal (m_H=190 GeV)
Syst.Unc.
ATLAS Preliminary
H→ZZ(*)→4l
√s = 7 TeV: ∫Ldt = 4.8 fb-1
√s = 8 TeV: ∫Ldt = 5.8 fb-1
0
5
10
15
20
25
30
35
100
150
200
250
m4l [GeV]

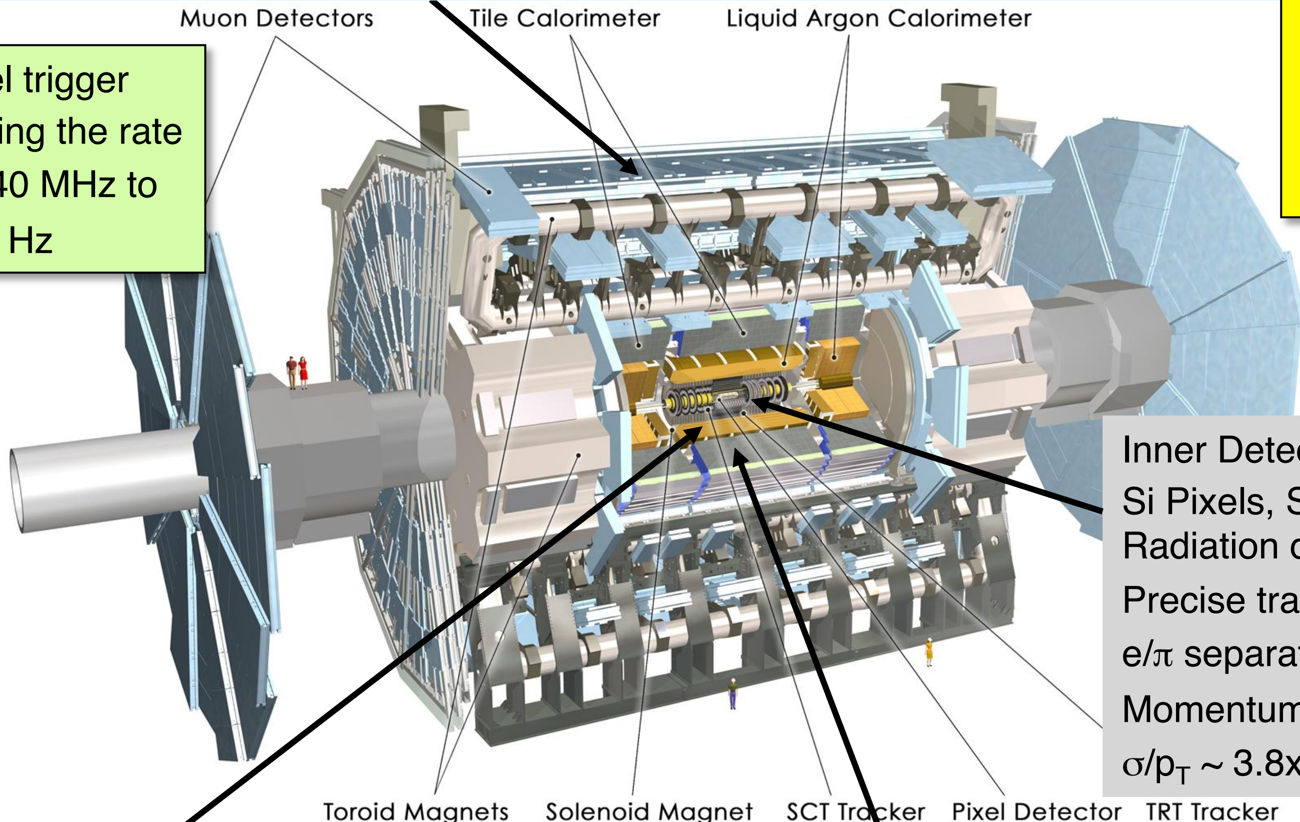
Introduction

ATLAS

Muon Spectrometer ($|\eta|<2.7$) : air-core toroids with gas-based muon chambers
Muon trigger and measurement with momentum resolution < 10% up to $E_{\mu} \sim 1$ TeV

Length : ~ 46 m
Radius : ~ 12 m
Weight : ~ 7000 tons
~10^8 electronic channels
3000 km of cables

3-level trigger reducing the rate from 40 MHz to ~ 400 Hz



Inner Detector ($|\eta|<2.5$, B=2T):
Si Pixels, Si strips, Transition Radiation detector (straws)
Precise tracking and vertexing, e/π separation
Momentum resolution:
$\sigma/p_T \sim 3.8\times10^{-4}\, p_T(\text{GeV}) \oplus 0.015$

EM calorimeter: Pb-LAr Accordion
e/γ trigger, identification and measurement
E-resolution: $\sigma/E \sim 10\%/\sqrt{E}$

HAD calorimetry ($|\eta|<5$): segmentation, hermeticity
Steel/scintillator Tiles (central), Cu/W-LAr (fwd)
Trigger and measurement of jets and missing E_T
E-resolution: $\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$

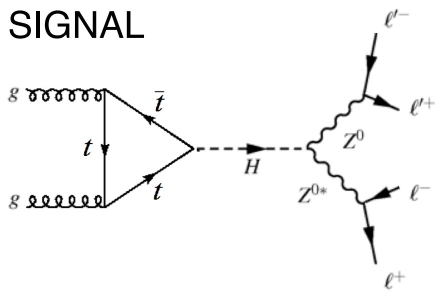
Channel 2 $H \to ZZ^{(*)} \to 4$ leptons

The ***golden channel:*** small rates, but very clean

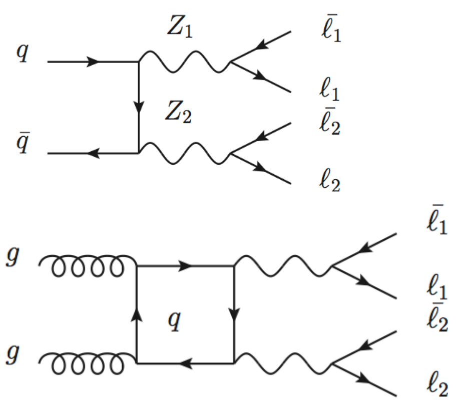
- Cross section X BR ~ 4 fb (@ m_H=125, √s=7 TeV)
- Can be fully reconstructed; excellent mass resolution

20 H→4l produced
Expect 1.4 found in 5 fb^{-1}

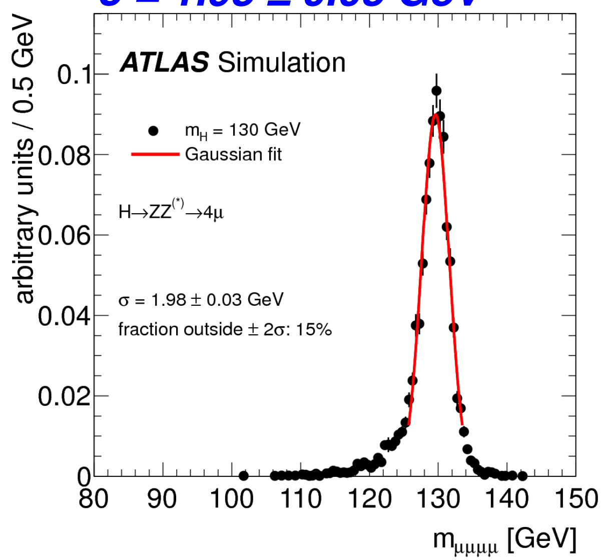
SIGNAL



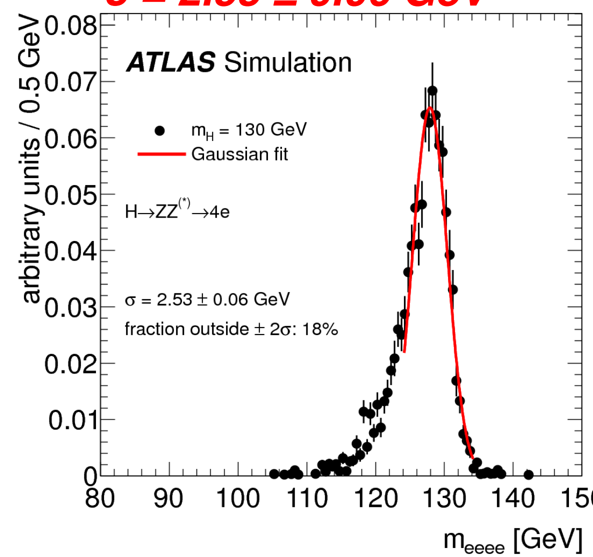
DOMINANT BACKGROUND



H→ZZ$^{(*)}$→4μ
σ = 1.98 ± 0.03 GeV



H→ZZ$^{(*)}$→4e
σ = 2.53 ± 0.06 GeV

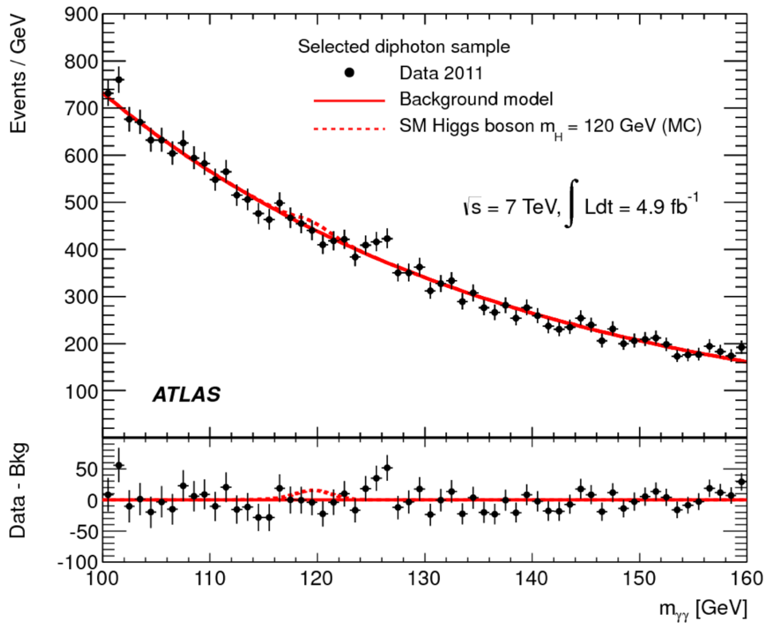


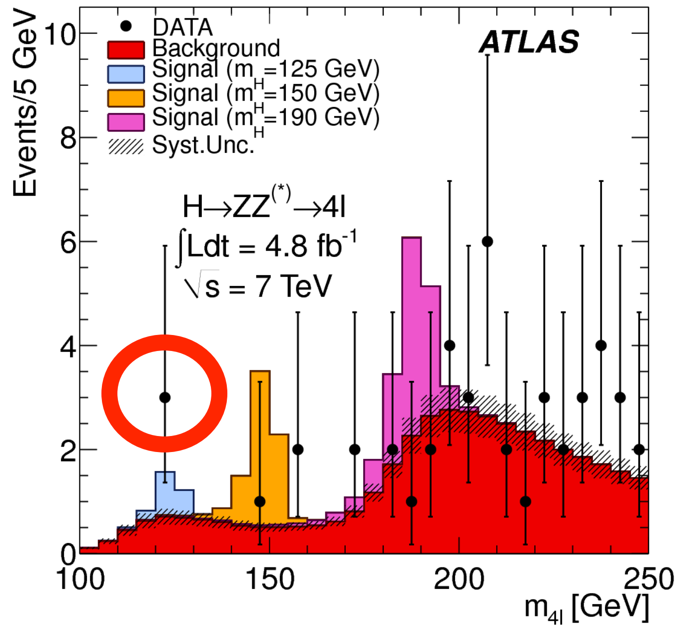
Backgrounds:

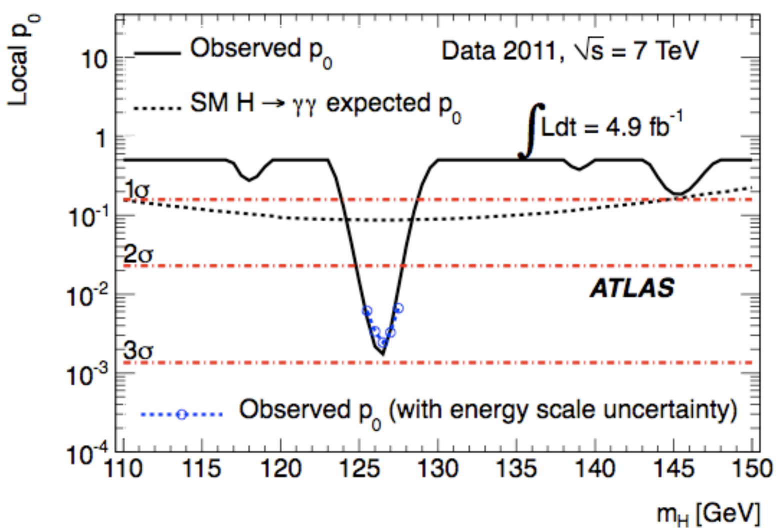
- "Irreducible" SM ZZ (dominant)
- "Reducible" backgrounds: Z+jets, tt

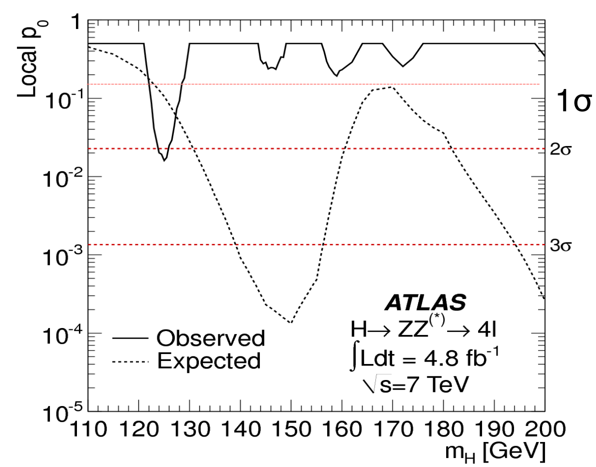
December 13, 2011

February 2012
PRL Publication









December 13, 2011

January 2012
PRL Publication

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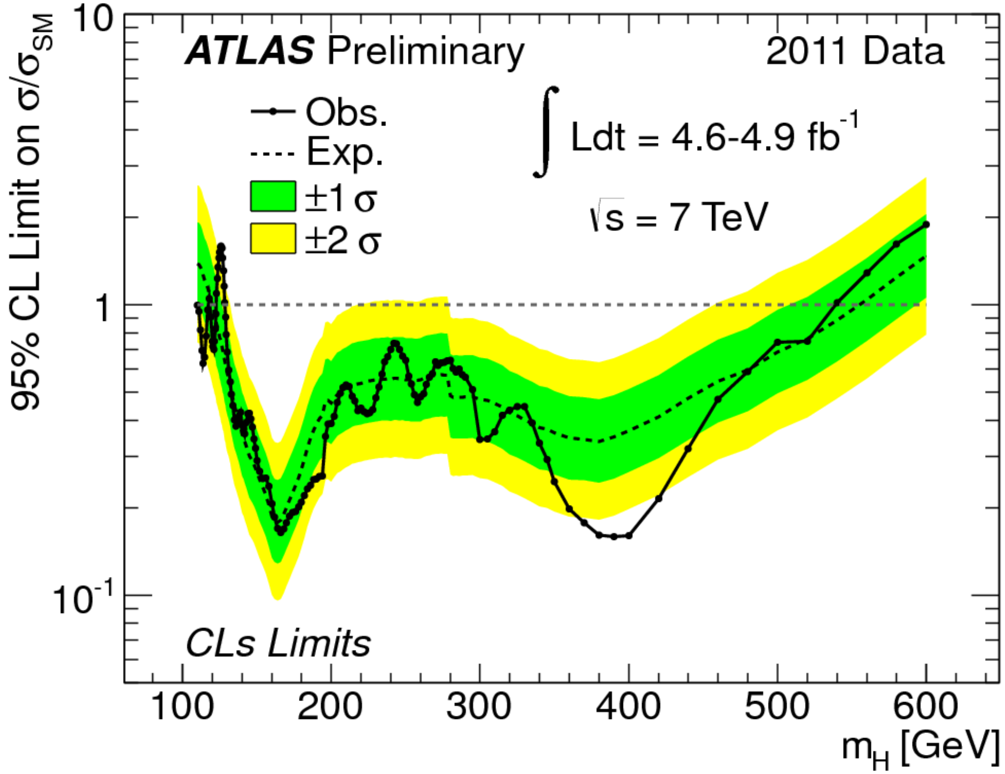


Excluded @ 95% CL:

110 $< m_H <$ 117.5 [GeV]
118.5 $< m_H <$ 122.5 [GeV]
129 $< m_H <$ 539 [GeV]

The window of possible low mass Higgs is now:
$122.5 < m_H < 129$ GeV

•REPLACE BY COUNCIL RESULT

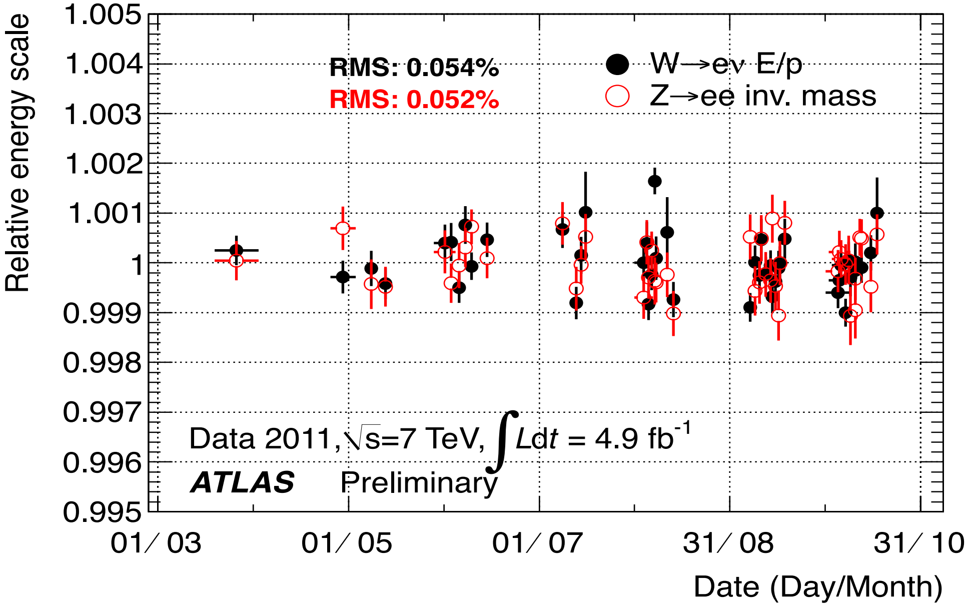
- Significance: at m_H=126 GeV, local significance of **2.5σ**
- Dominated by contributions from *H→γγ* (**2.8σ**) and *H→4 leptons* (**2.1σ**)

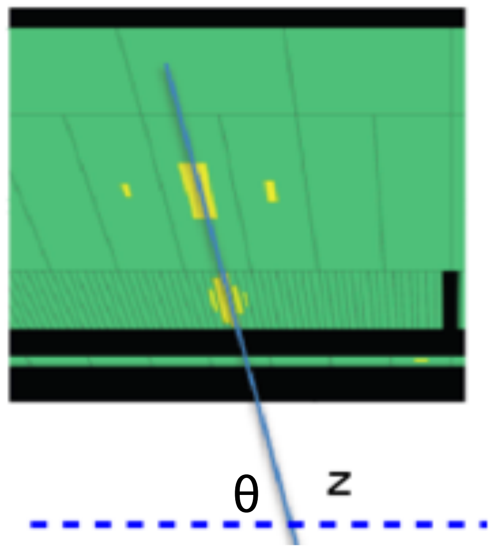
H→γγ Key experimental aspects

$m^2_{\gamma\gamma} = 2 E_1 E_2 (1-\cos\alpha)$

α=opening angle of the two photons

Stability of EM calorimeter response vs time (and pile-up) during full 2011 run better than 0.1%





Measure γ direction with sampling calorimeter → get Z of primary vertex

Calorimeter energy response calibration (from Z→ee, W→eν, J/Ψ →ee):

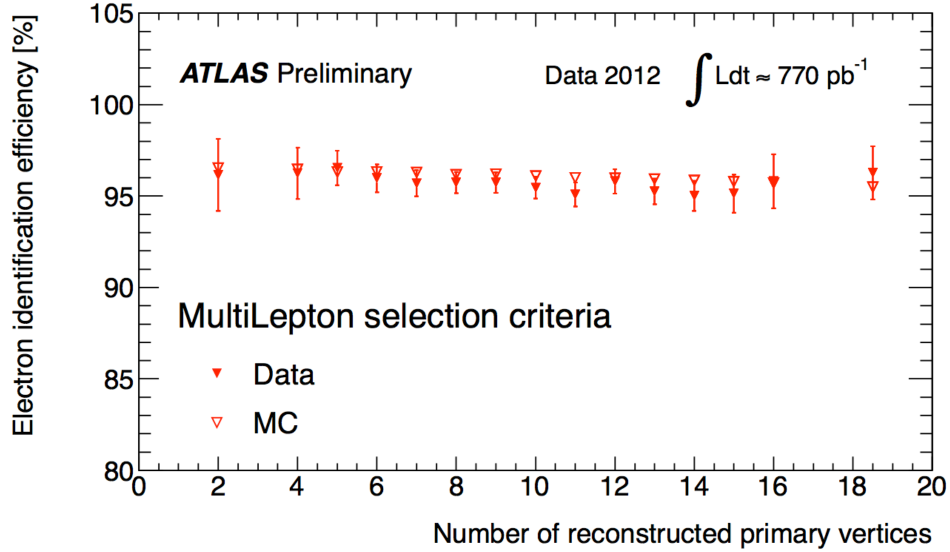
- Energy scale at m_Z known to ~ 0.3%
- Linearity better than 1%
- Constant term of resolution: ~ 1% in barrel, 1.2-2.1% for end-cap

- Calorimeter pointing reduces vertex uncertainty from beam-spot spread from ~ 5-6 cm to ~ 1.5 cm
- Robust against pile-up
- Angular contribution to mass resolution becomes negligible

H→ZZ$^{(*)}$→4l   Lepton reconstruction and id

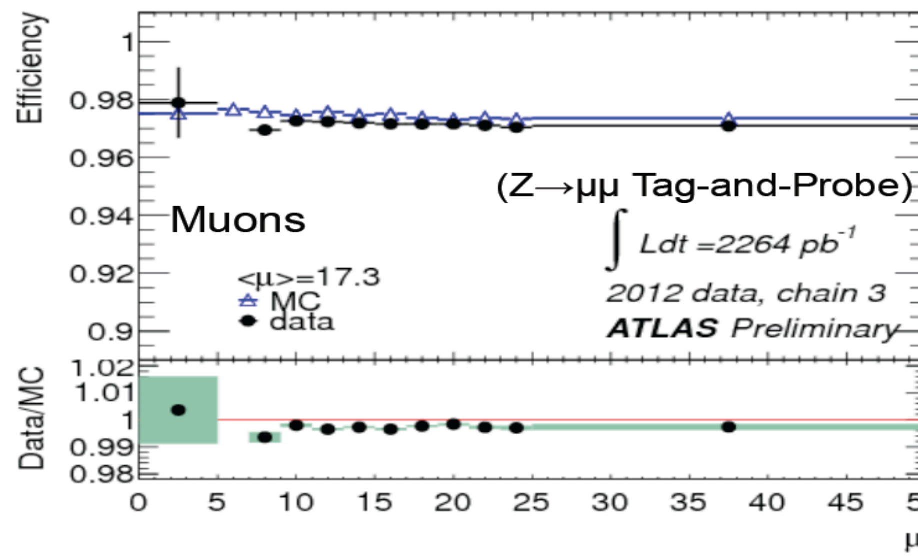
Electrons in 2012 data

- Improved reconstruction
  - New pattern finding/track-fit
- Improved identification
  - Pile-up robust
  - Higher rejection and efficiency than in 2011

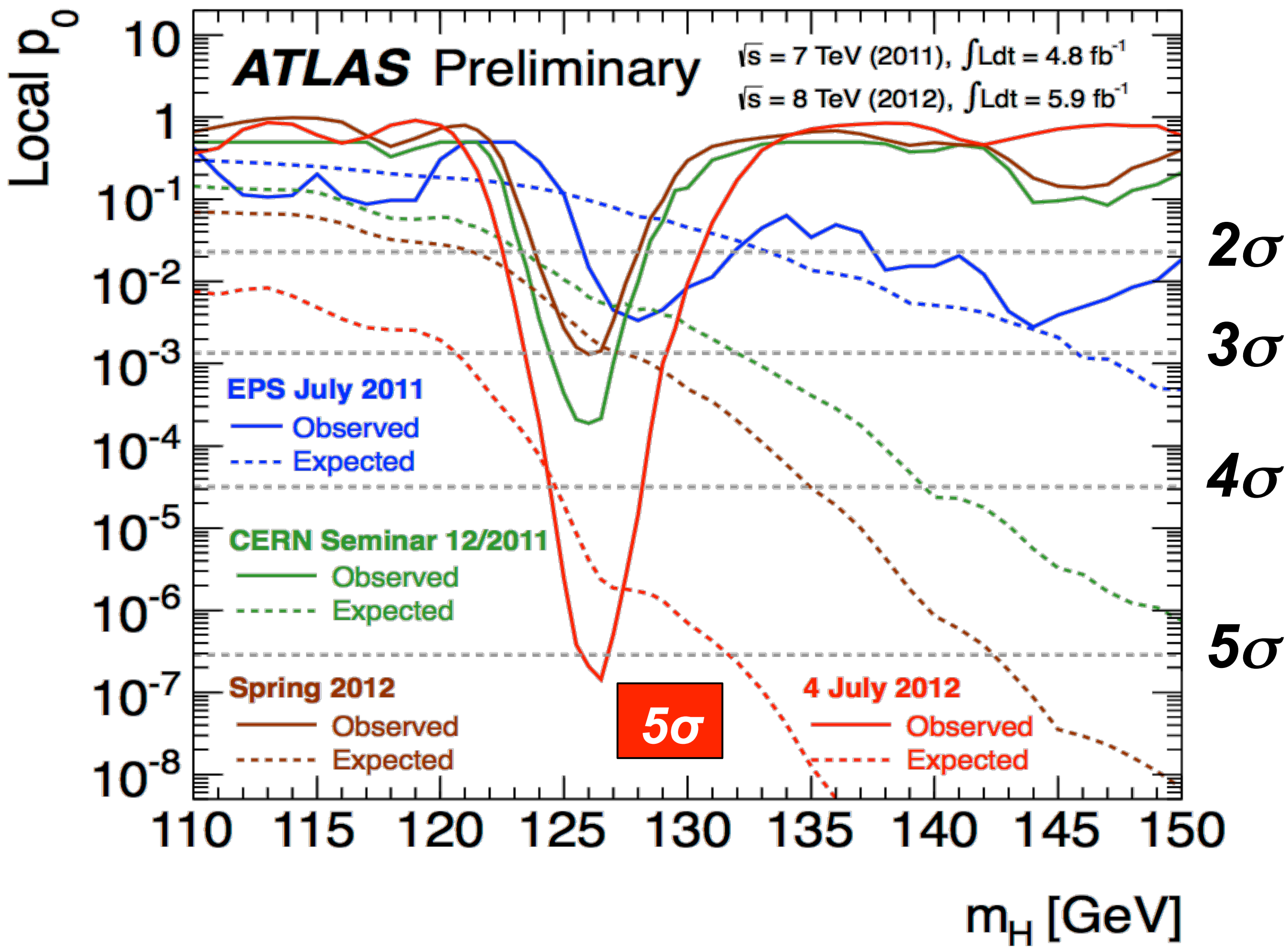


Muons in 2102 data

- Combine Inner Detector (ID) tracks with tracks in Muon Spectrometer (MS)
- Extended coverage:
  - ID-track + energy deposit in calorimeter (|η|<0.1, pT>15 GeV)
  - MS stand-alone (2.5<|η|<2.7)



Higgs combination Evolution over time



EPS July 2011

Council Dec 2011

Spring 2012

ICHEP 2012
(July 4, 2012)