Search for Higgs Boson with ATLAS

Pierre Savard

University of Toronto and TRIUMF

ATLAS/Theory Workshop

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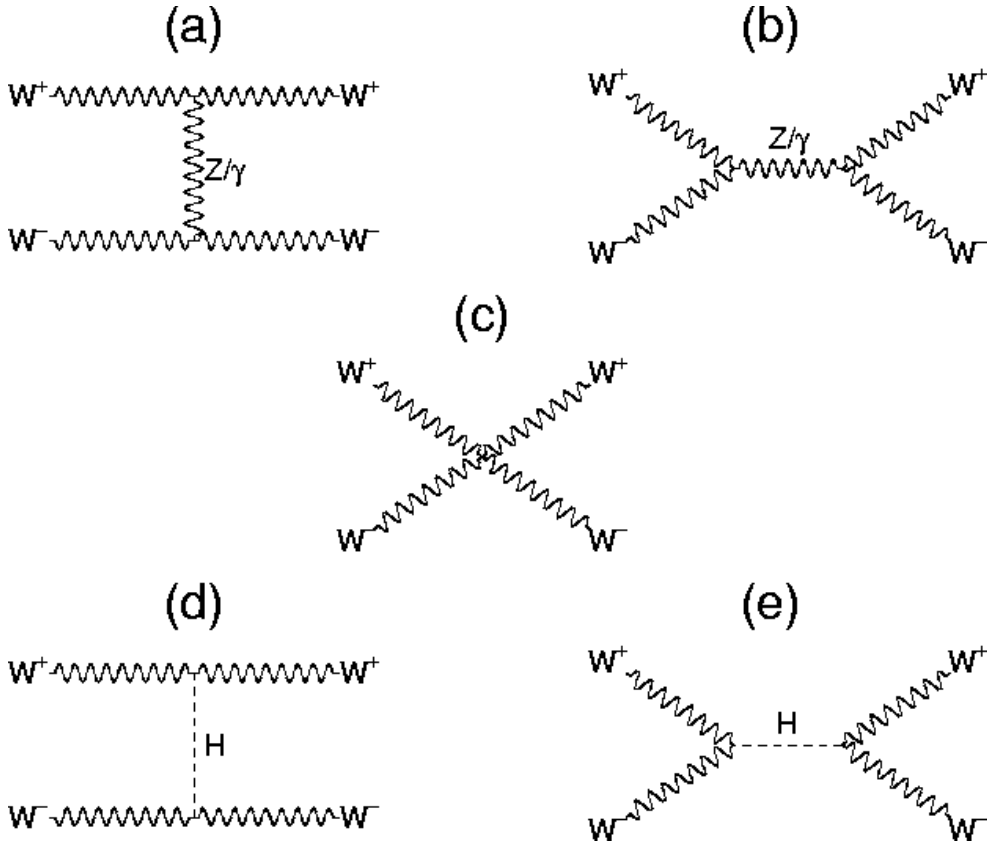
Introduction

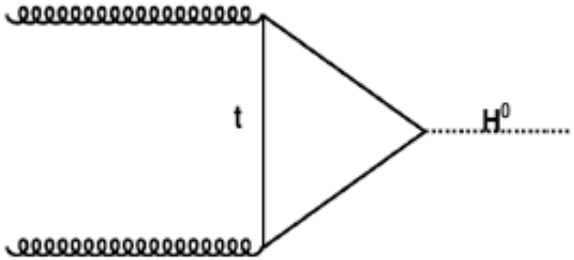
- Cross section for WW scattering becomes unphysical above ~TeV scale without contributions from a Higgs Boson with mass < 1 TeV
- LHC experiments designed to find the SM Higgs or find the non-SM physics that regularizes WW scattering
- Higgs limits from this Summer implied that we would probably need to exploit all design features of the detector



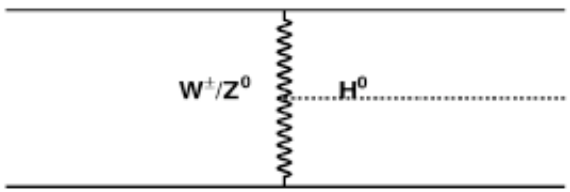
Higgs Production

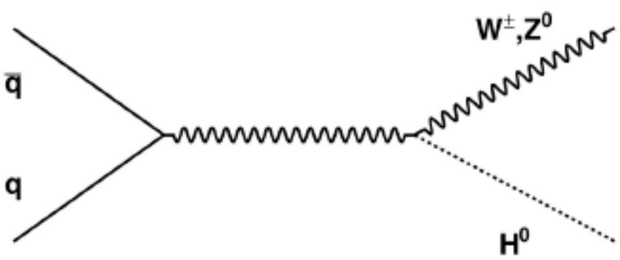
- Higgs production at LHC dominated by “gluon fusion” process
- “Weak boson fusion” is subdominant but has less background

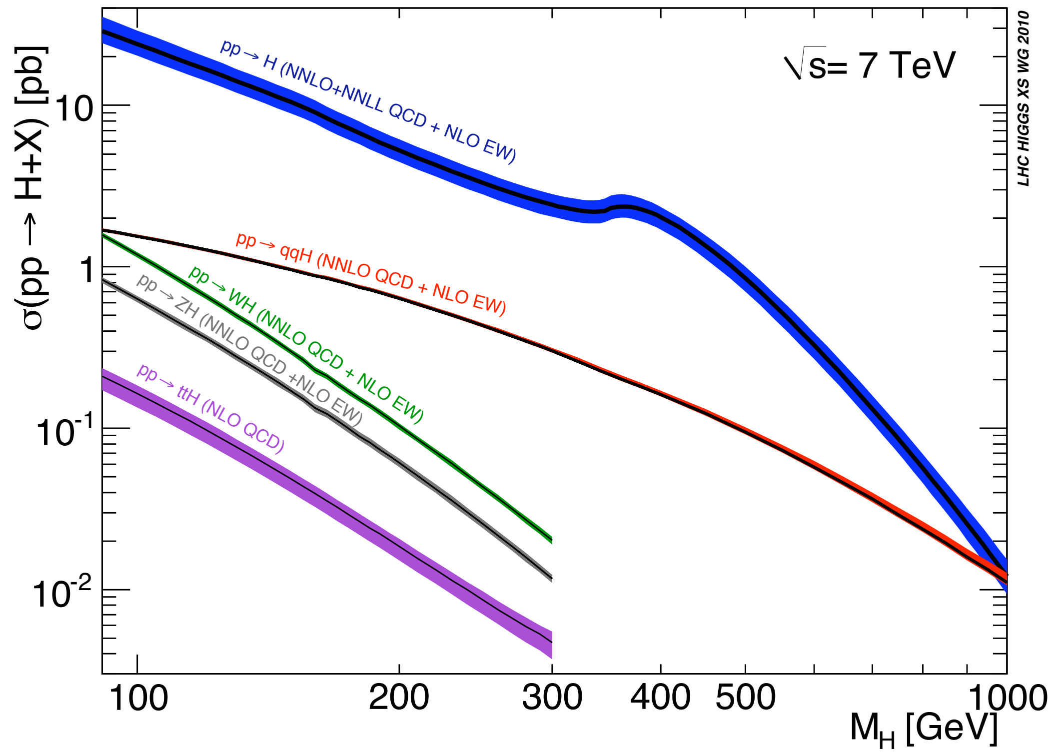
gluon Fusion



Weak Boson Fusion

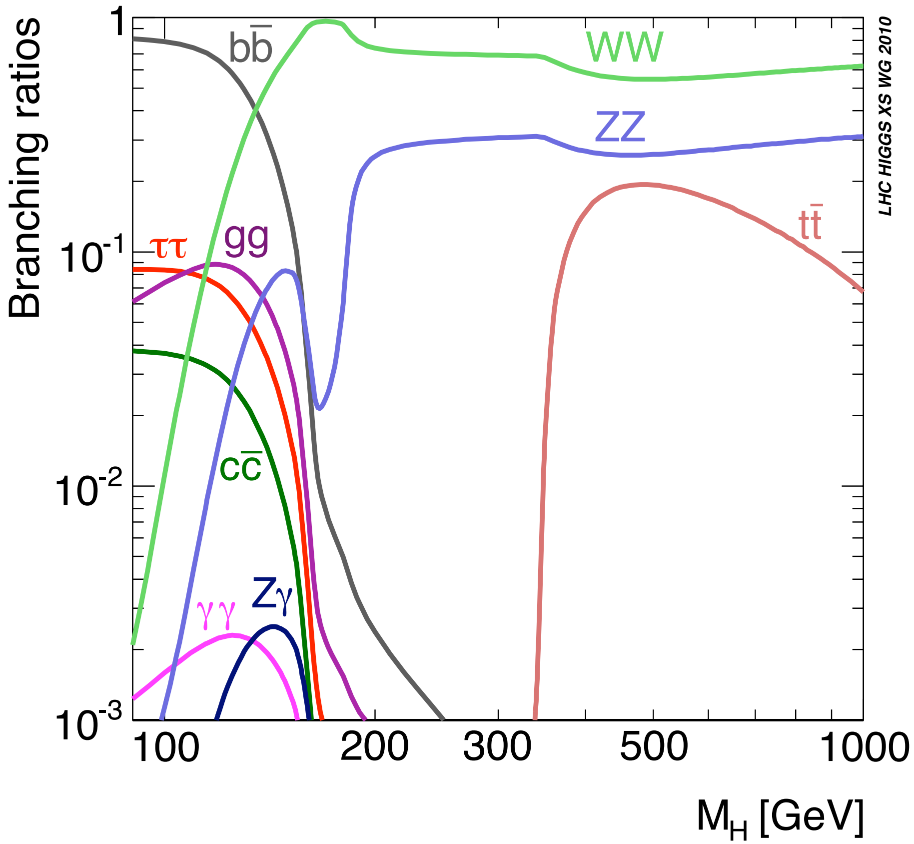


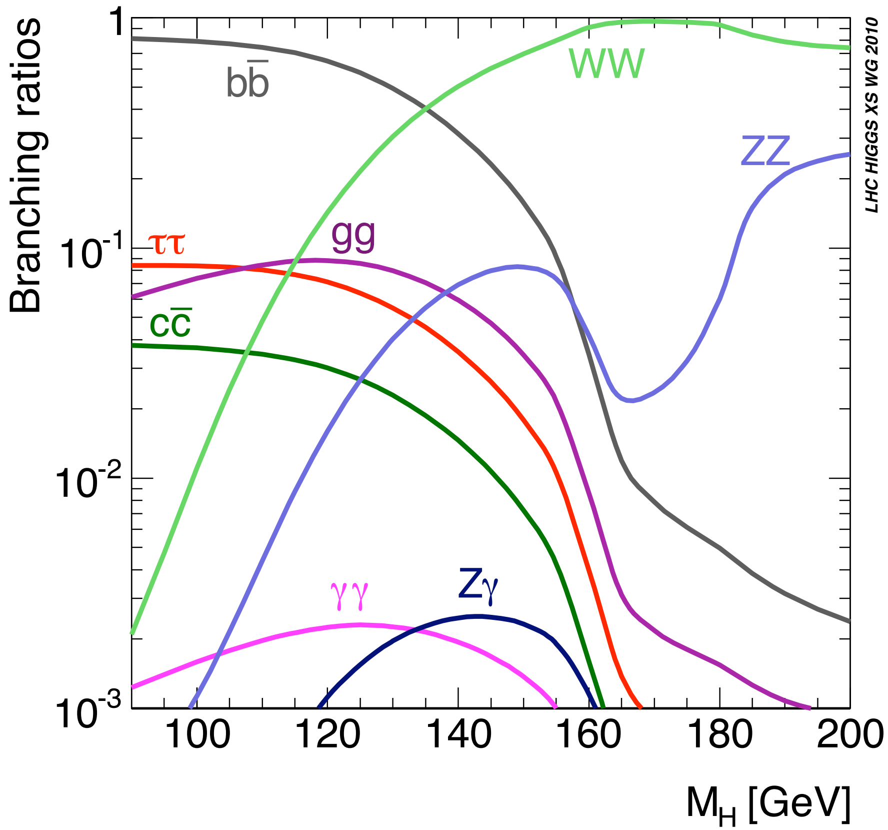




Higgs Decays (1)

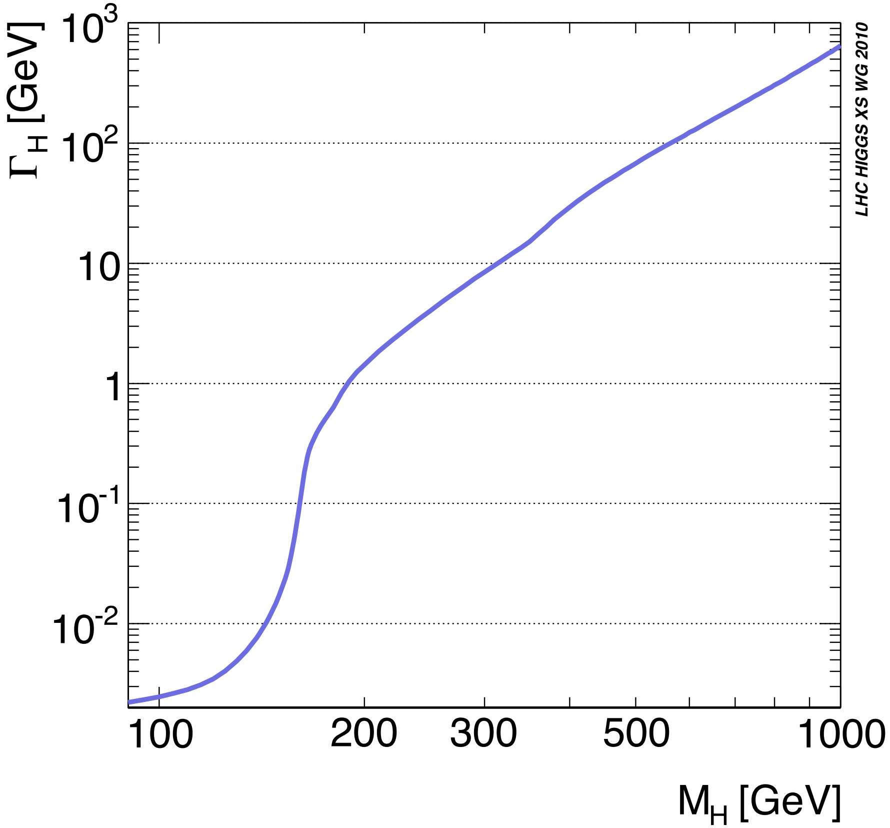
- Standard Model very predictive theory regarding the Higgs: the only unknown parameter is the Higgs mass

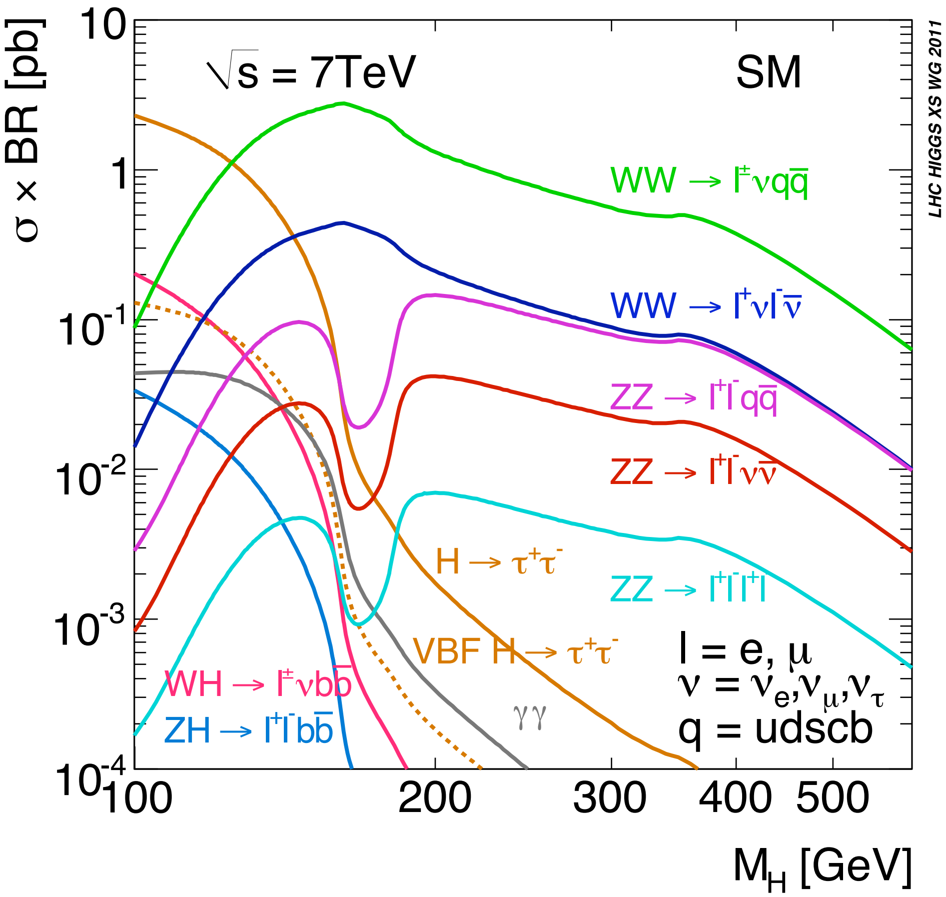




Higgs Decays (2)

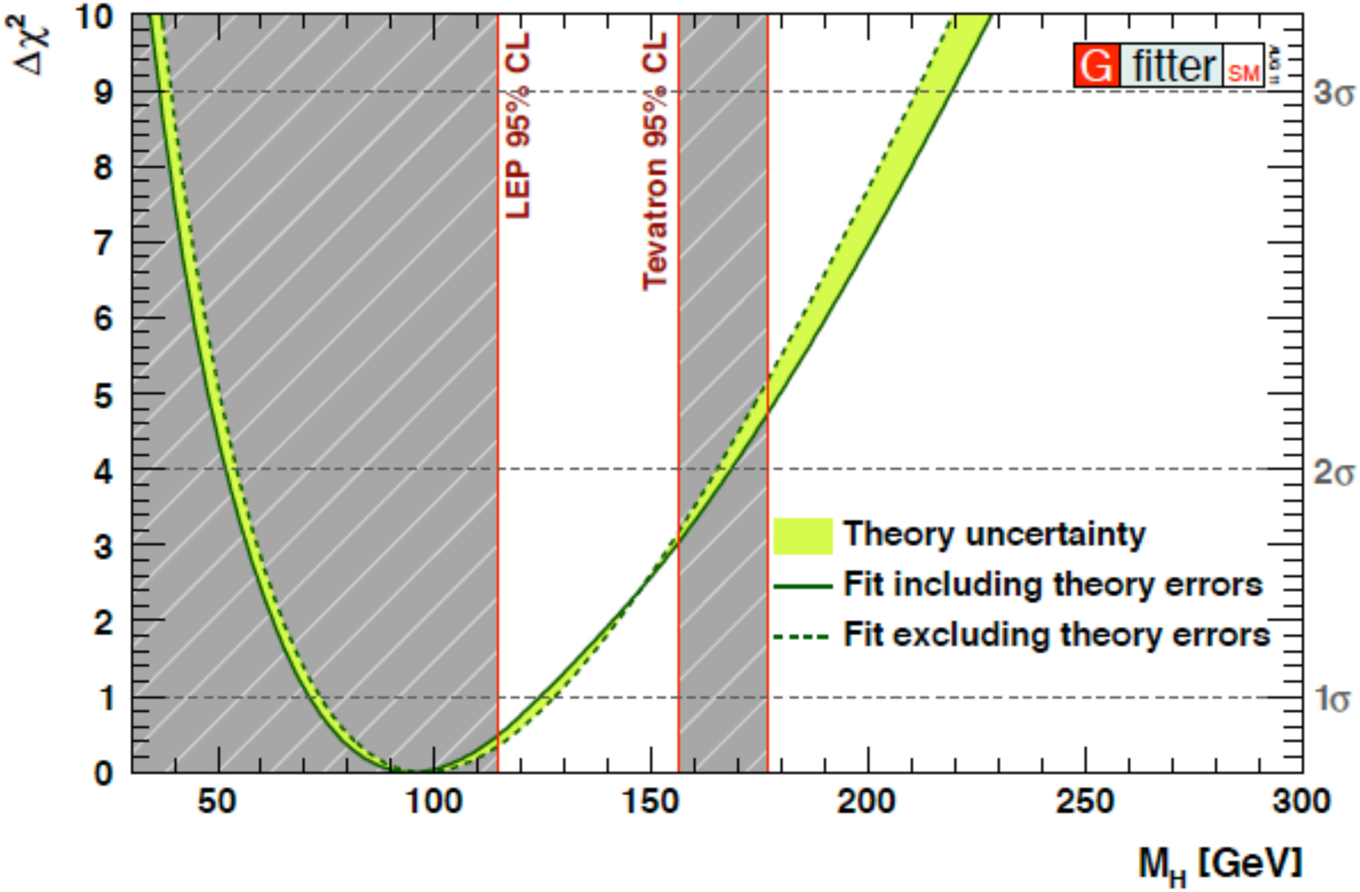
- Left: Higgs width vs mass (experimental resolution will dominate at low mass)
- Right: Higgs cross section times branching ratio to final states





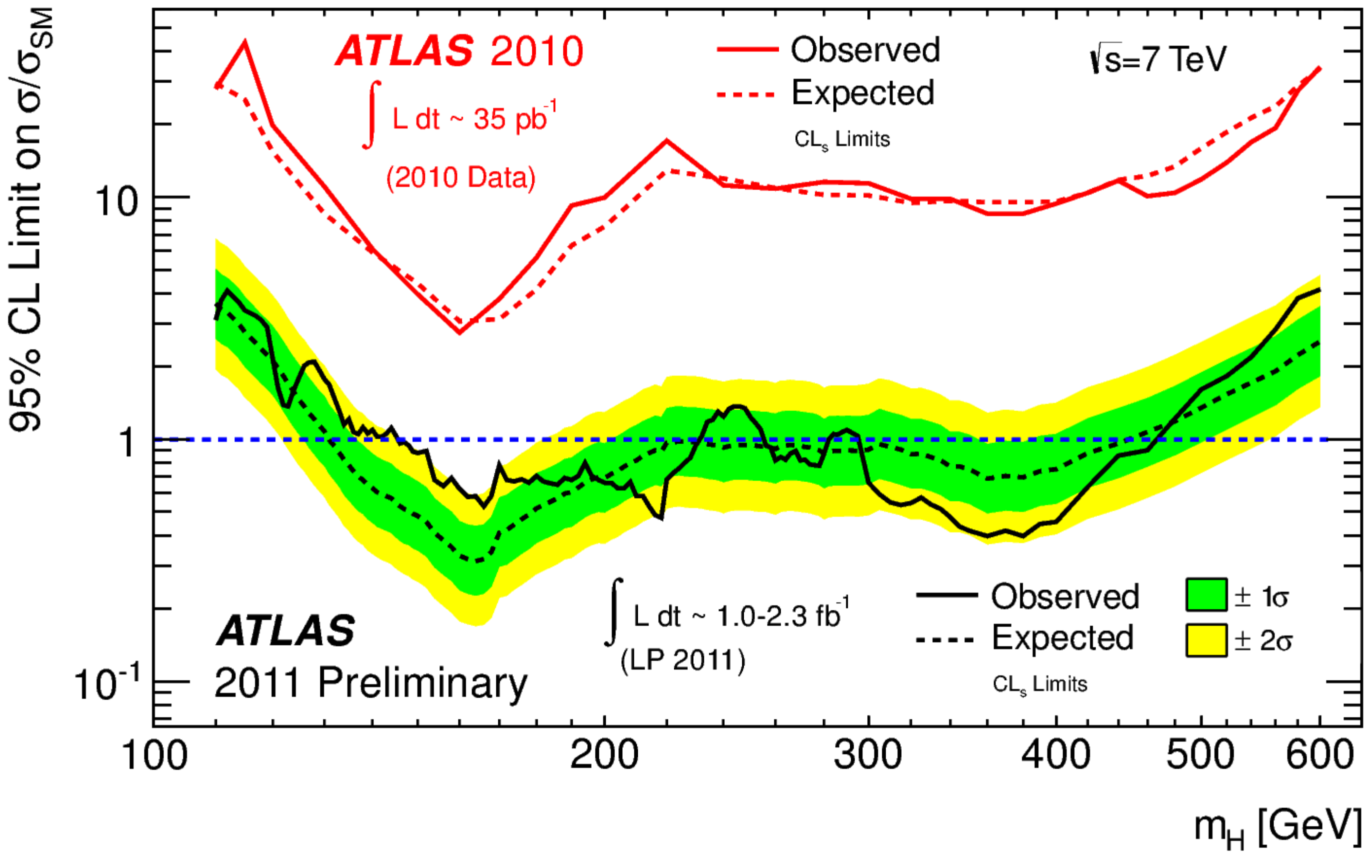
Where is the Higgs?

- Fits to Standard Model data favors a "light" Higgs Boson
- After 2010, at 95% CL, a 40 GeV window was left for the SM Higgs



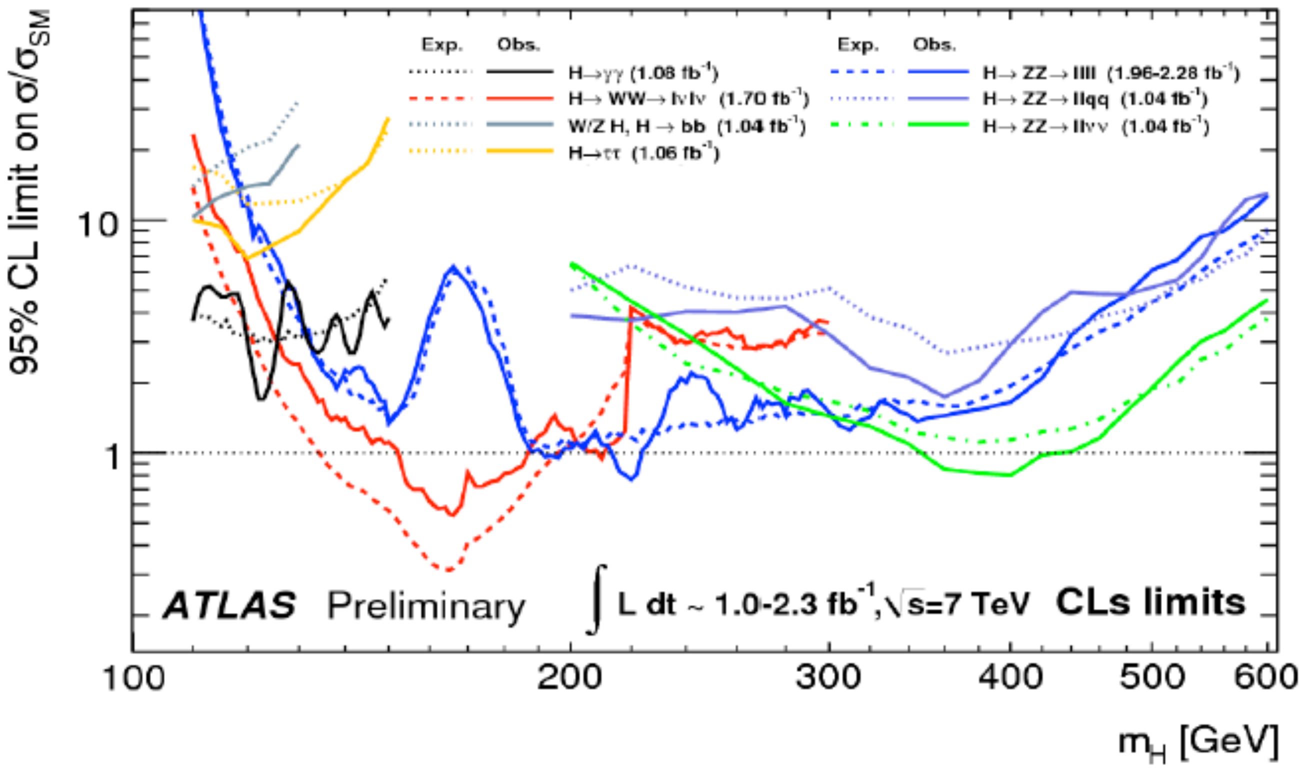
Limits on Higgs Mass

- Results from 2010 and Lepton-Photon 2011: a lot of progress!
- In low mass range: exclude 146-242 GeV (131 GeV expected)



Limits Set for each Decay Channel (before Tuesday)

- H->WW->llνν is the main channel above ~125 (up to 190 GeV)
- H->γγ takes over below ~125 GeV
- H->ZZ->llll was the main search channel for the range ~190-300
- Combining channels, important to improve limits, especially at low mass



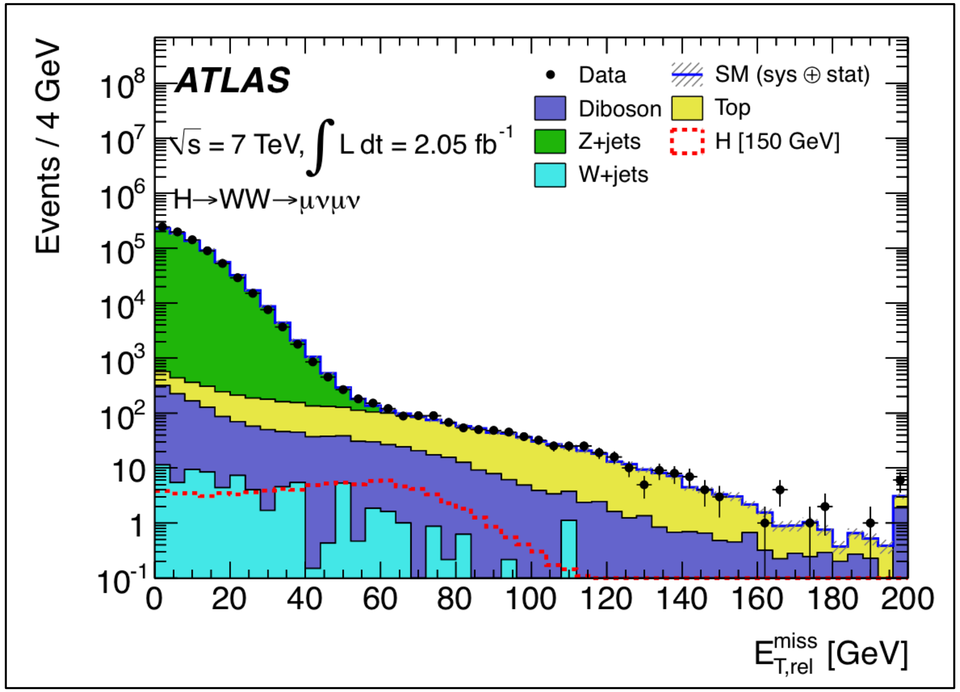
ATLAS Results

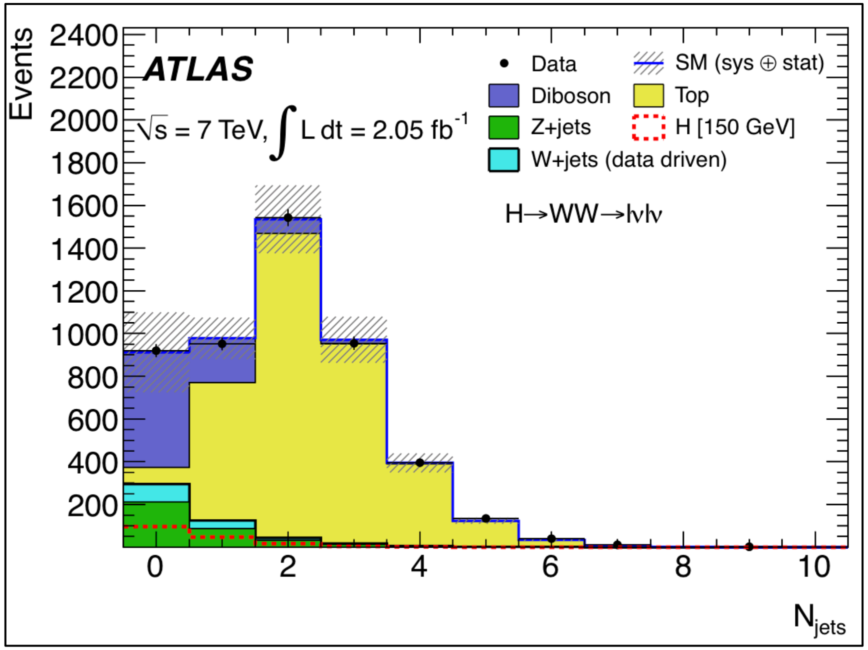
Fabiola Gianotti

Channel	m_H range (GeV)	Int. lumi fb^{-1}	Main backgrounds	Number of signal events after cuts	S/B after cuts	Expected σ/σ_{SM} sensitivity
$H \to \gamma\gamma$	110-150	4.9	$\gamma\gamma$, γj, jj	~70	~0.02	1.6-2
$H \to \tau\tau \to ll+\nu$	110-140	1.1	$Z \to \tau\tau$, top	~0.8	~0.02	30-60
$H \to \tau\tau \to l\tau_{had}$	100-150	1.1	$Z \to \tau\tau$	~10	~5 10^{-3}	10-25
$W/ZH \to bbl(l)$	110-130	1.1	W/Z+jets, top	~6	~5 10^{-3}	15-25
$H \to WW^{(*)} \to l\nu l\nu$	110-300	2.1	WW, top, Z+jet	~20 (130 GeV)	~0.3	0.3-8
$H \to ZZ^{(*)} \to 4l$	110-600	4.8	ZZ*, top, Zbb	~2.5 (130 GeV)	~1.5	0.7-10
$H \to ZZ \to ll\ \nu\nu$	200-600	2.1	ZZ, top, Z+jets	~20 (400 GeV)	~0.3	0.8-4
$H \to ZZ \to ll\ qq$	200-600	2.1	Z+jets, top	2-20 (400 GeV)	0.05-0.5	2-6
$H \to WW \to l\nu qq$	240-600	1.1	W+jets,top,jets	~45 (400 GeV)	10^{-3}	5-10

H →WW*→llνν (1)

- QCD background suppressed by requiring 2 leptons
- Z/DY background reduced with cuts on M_{ll} and missing E_T
- Top background rejection achieved with jet multiplicity cut and b-tagging veto
- Challenges: soft leptons at low Higgs mass (larger backgrounds), understanding MET resolution, poor Higgs mass resolution

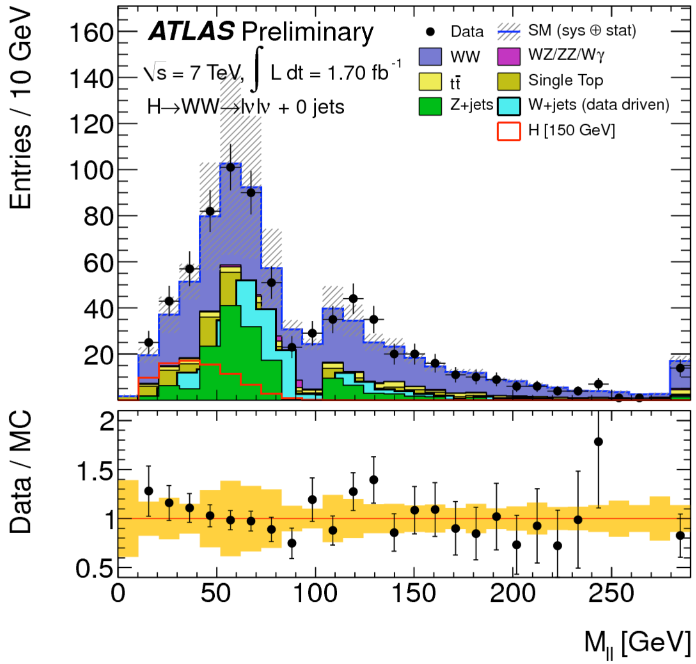


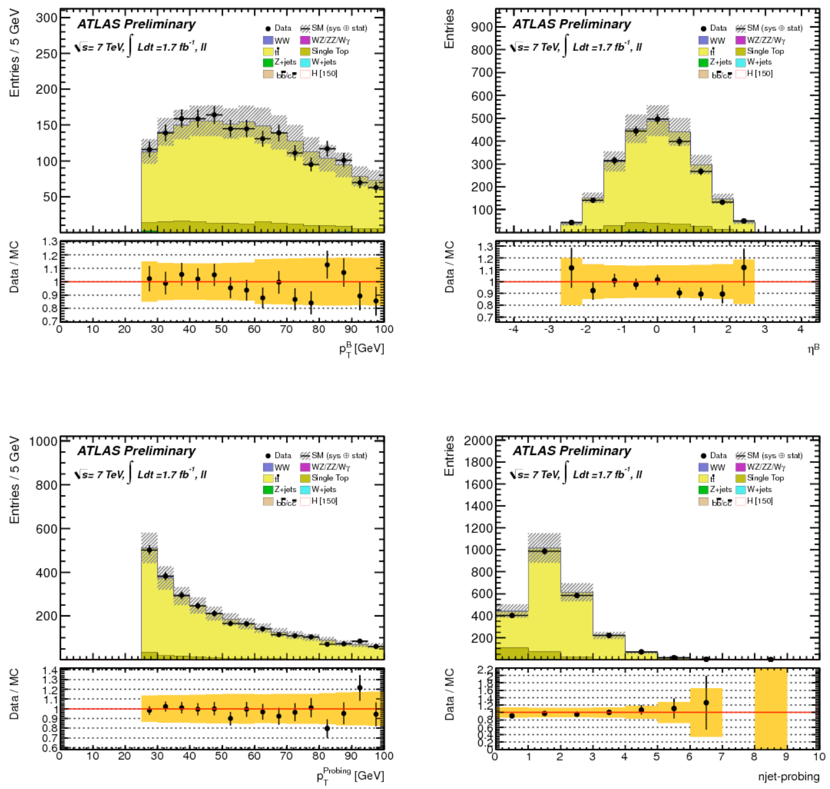


$H \rightarrow WW^* \rightarrow ll\nu\nu$ (2)

- Event selections exploit specific kinematic features and angular distributions of Higgs (e.g. angle between leptons is small)
- Main background normalization estimated from control regions:
  - WW: use regions at large M_{ll} and $\Delta\phi(ll)$
  - Top background estimated by requiring a b-tagged jet and dropping other cuts

Control region	MC expectation	Observed in data
WW 0-jet	296±36	296
WW 1-jet	171±21	184
Top 1-jet	270±69	249

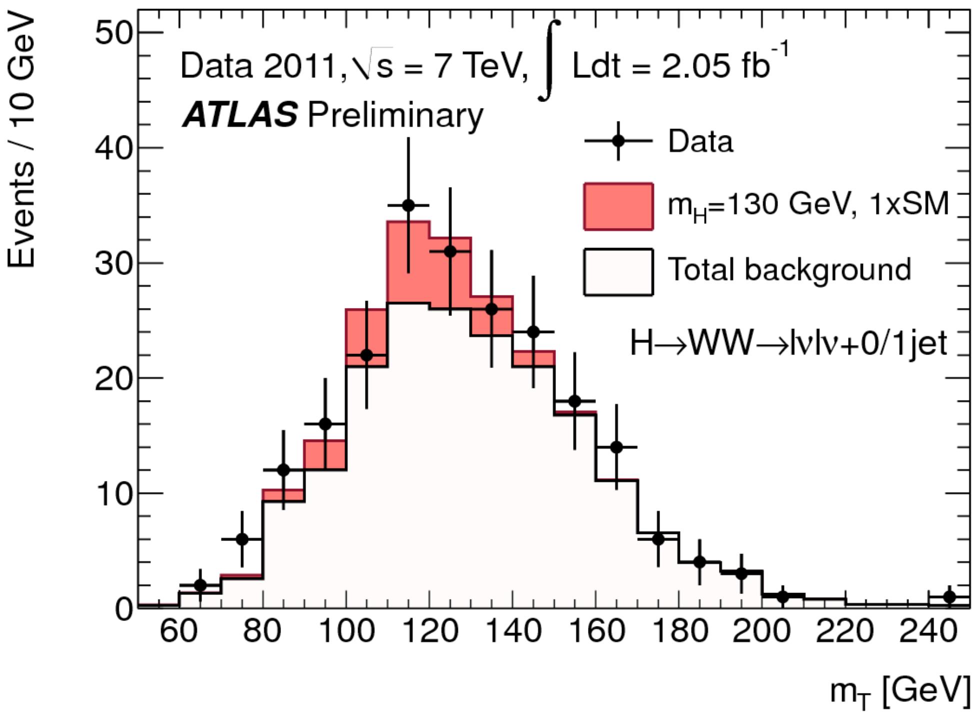




$H \rightarrow WW^* \rightarrow l l \nu \nu$ (3)

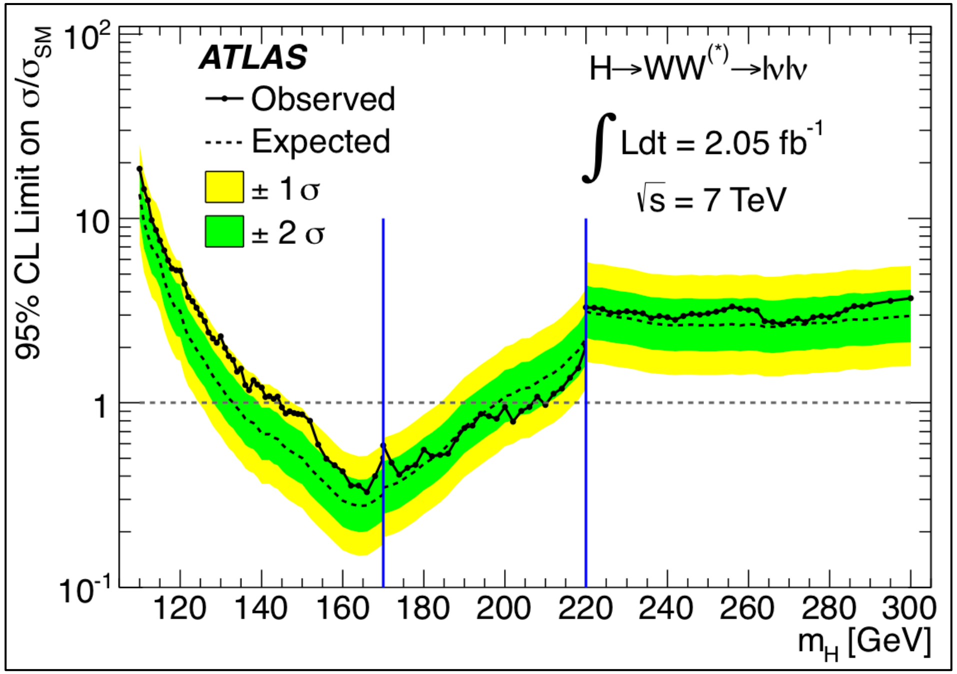
- Reconstruct Higgs candidate transverse mass

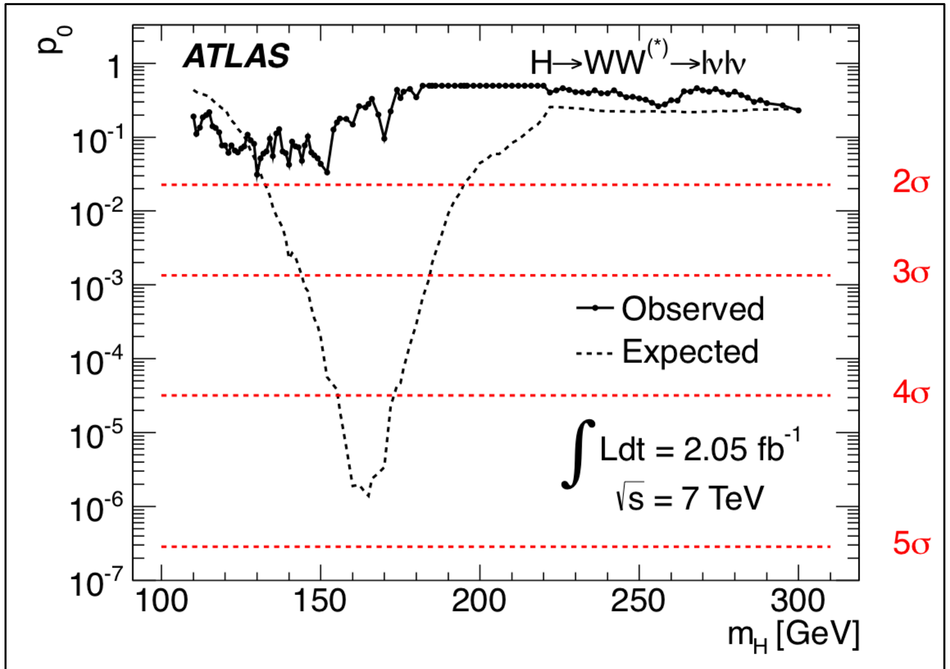
$$m_{\mathrm{T}} = \sqrt{(E_{\mathrm{T}}^{\ell\ell} + E_{\mathrm{T}}^{\mathrm{miss}})^2 - (\mathbf{P}_{\mathrm{T}}^{\ell\ell} + \mathbf{P}_{\mathrm{T}}^{\mathrm{miss}})^2}$$



$H \rightarrow WW^* \rightarrow ll\nu\nu$ (4)

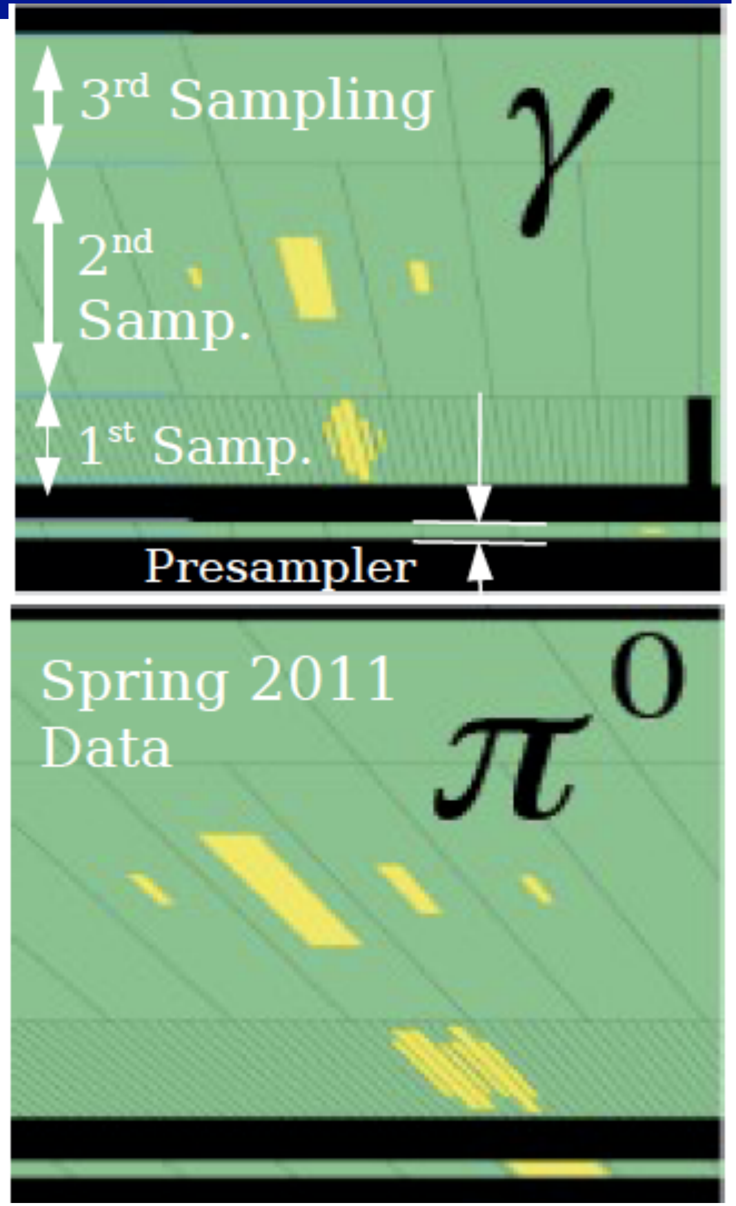
- Results with 2.05 fb^{-1}, to be updated with full dataset very soon…
- Expected exclusion: 135-200. Observed exclusion 145-206
- Maximum excursion at 130 GeV





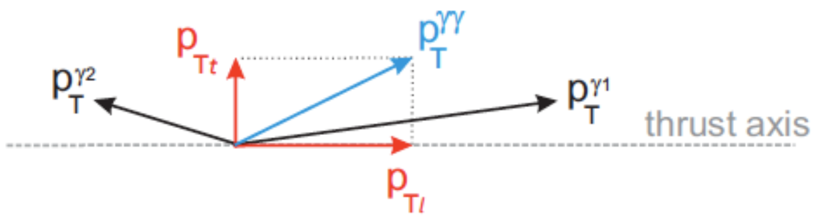
H ⇨ γγ (1)

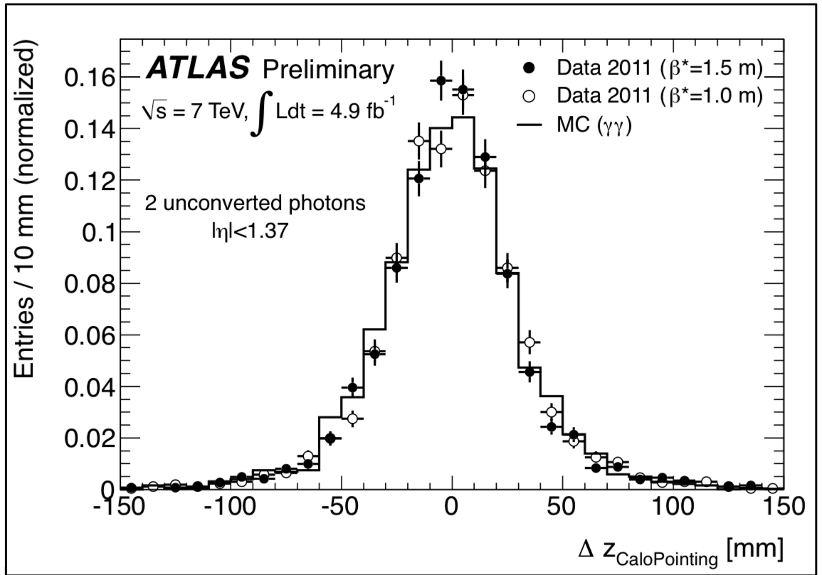
- Small signal and very large backgrounds: need excellent rejection
  - Signal is 0.04 pb
  - γγ continuum ~30 pb
  - γ+jet background ~2x10^5 pb
  - Jet-jet background ~5x10^8 pb
- Photon ID takes advantage of presampler and the lateral and longitudinal segmentation of the EM calorimeter

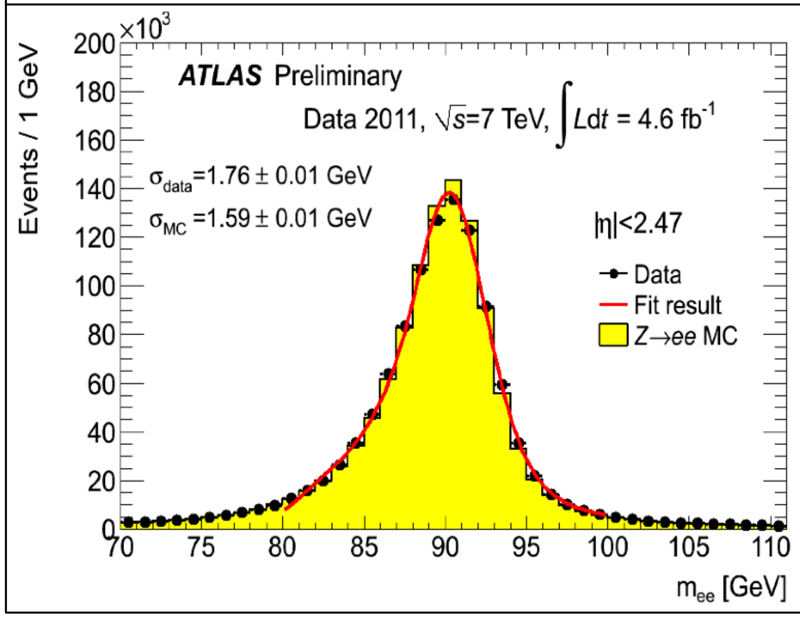


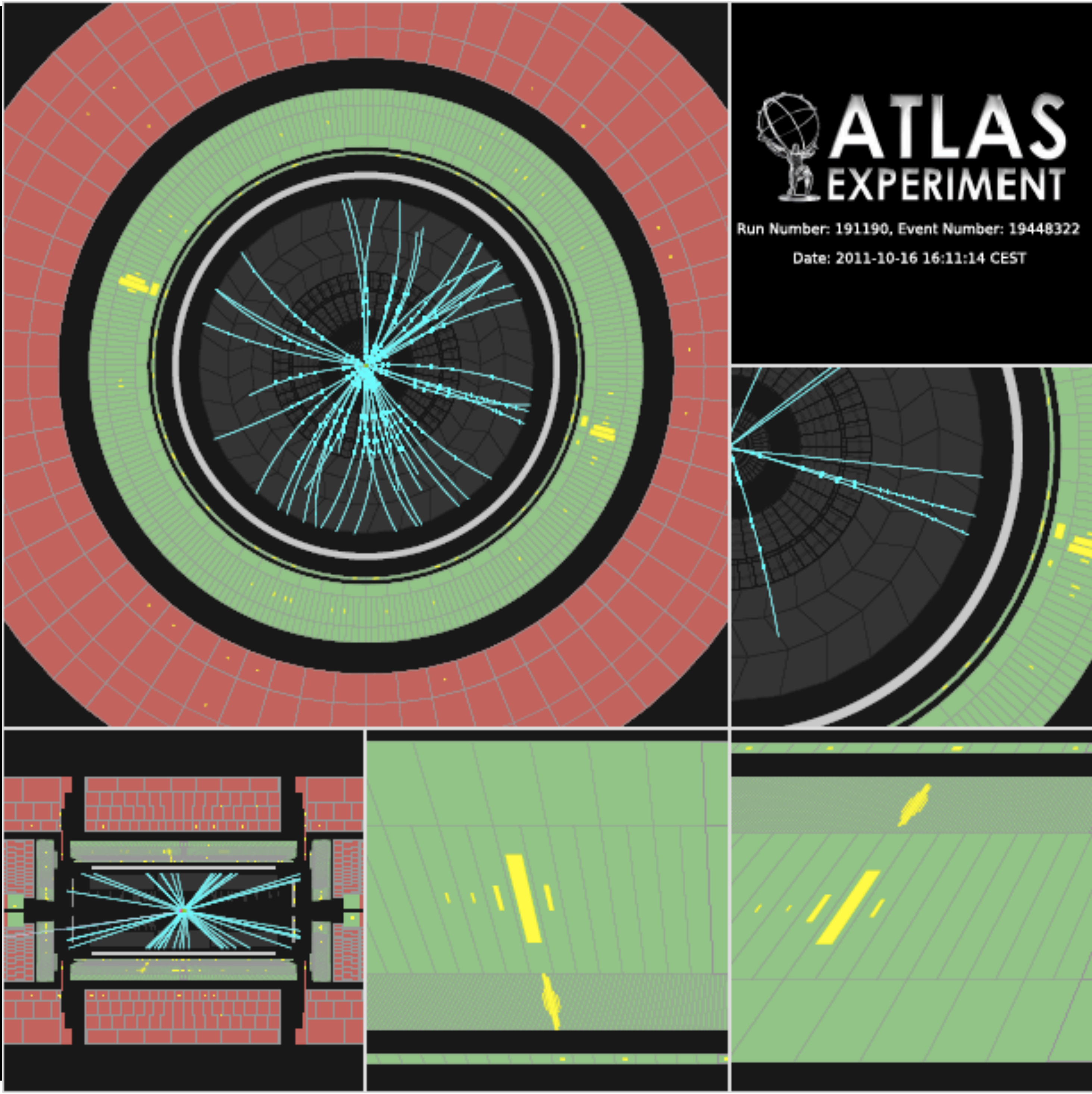
H → γγ (2)

- Improve mass resolution by using pointing information: allows identification of primary vertex (within ~1.5 cm)
- Mass resolution varies from 1.4 to 2.0 GeV for M_H = 120 GeV
  - Depends on calorimeter region
  - Depends on whether photon was converted or not
- To maximize sensitivity, sample divided in 9 categories:
  - Central region vs non-central
  - Converted vs non-converted
  - P_{Tt} cut








ATLAS
EXPERIMENT
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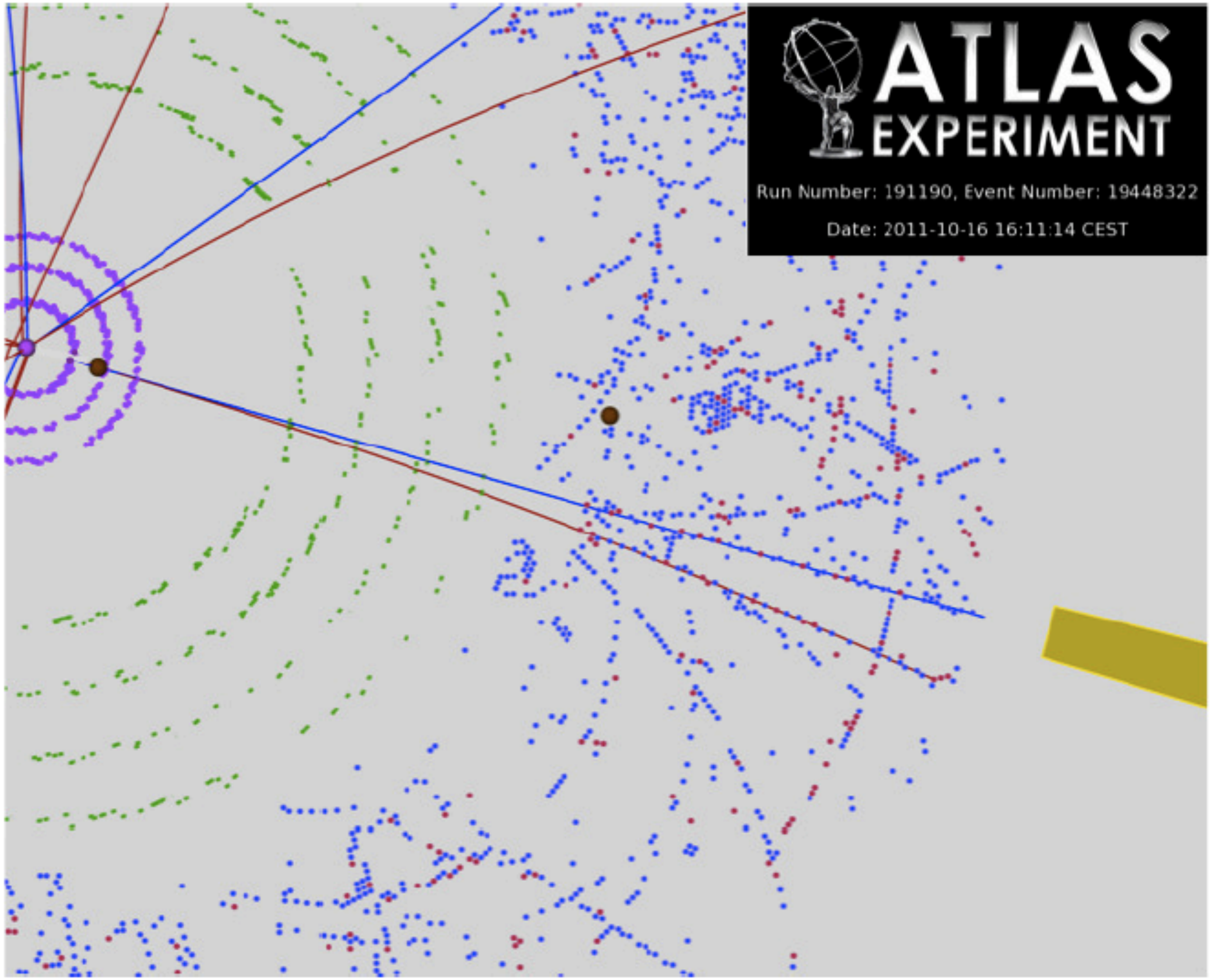
Date: 2011-10-16 16:11:14 CEST

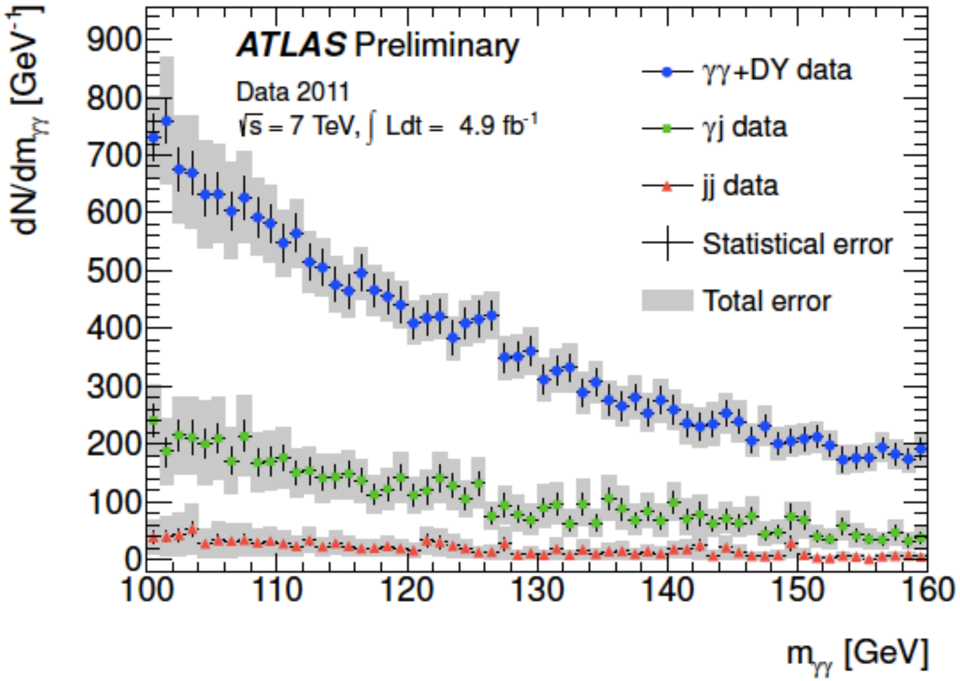
$H \rightarrow \gamma\gamma$ (4)

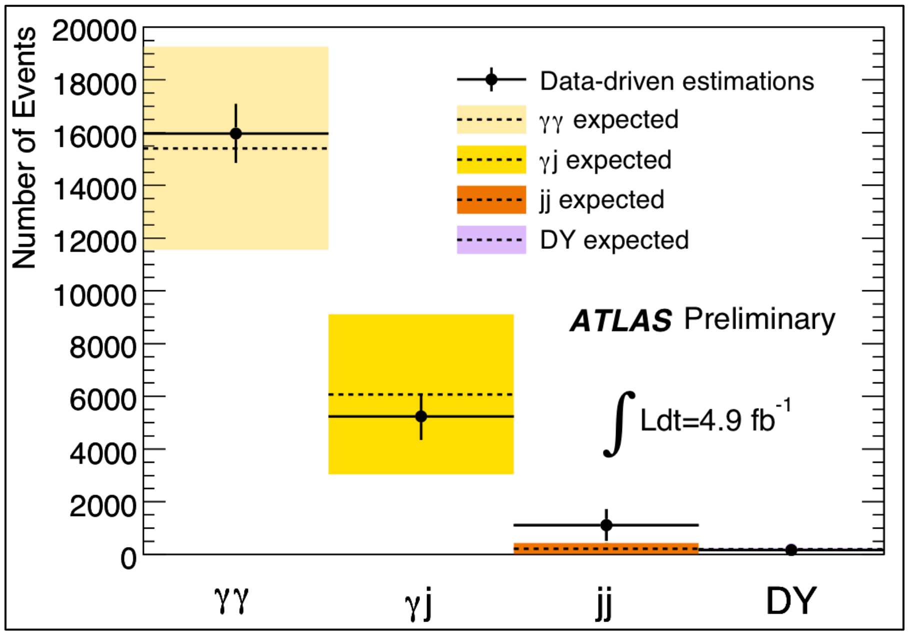
Photon conversion candidate



H➔γγ (5)

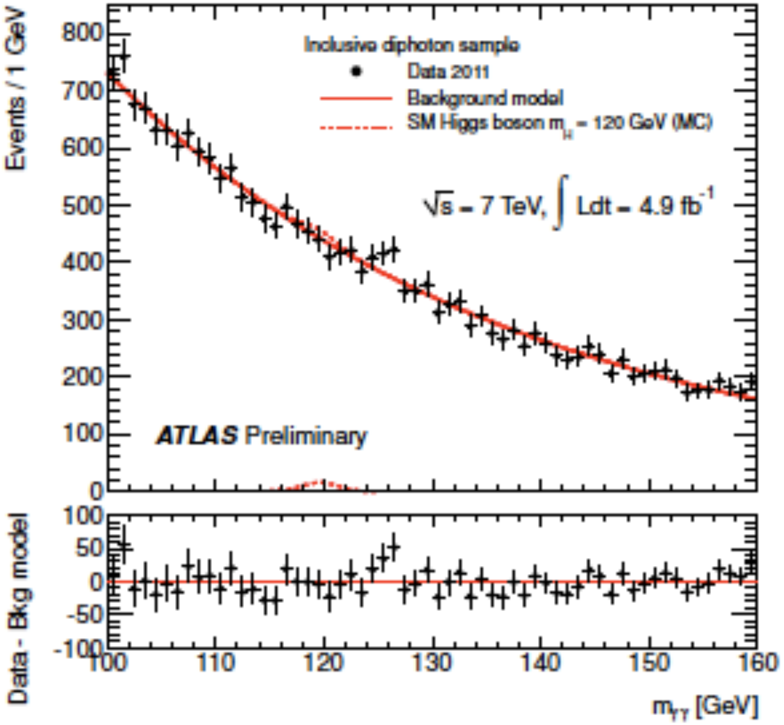
- Systematic uncertainties: signal yield (12%), mass resolution (14%), background modeling (5 events at 120 GeV, 3 events at 150 GeV)
- Background composition:

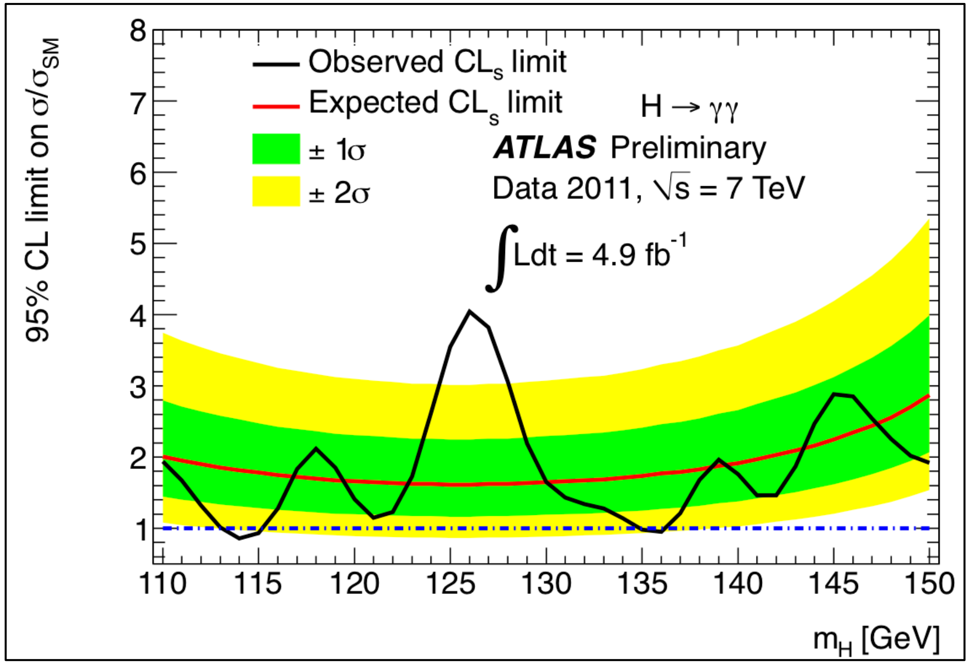




$H \rightarrow \gamma\gamma$ (6)

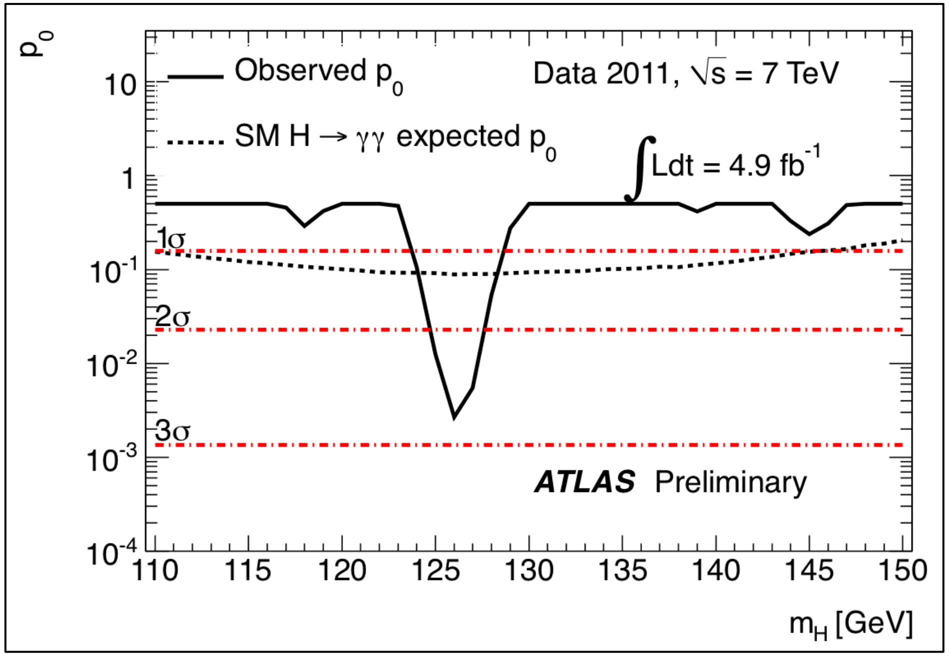
- Diphoton spectrum and limits:

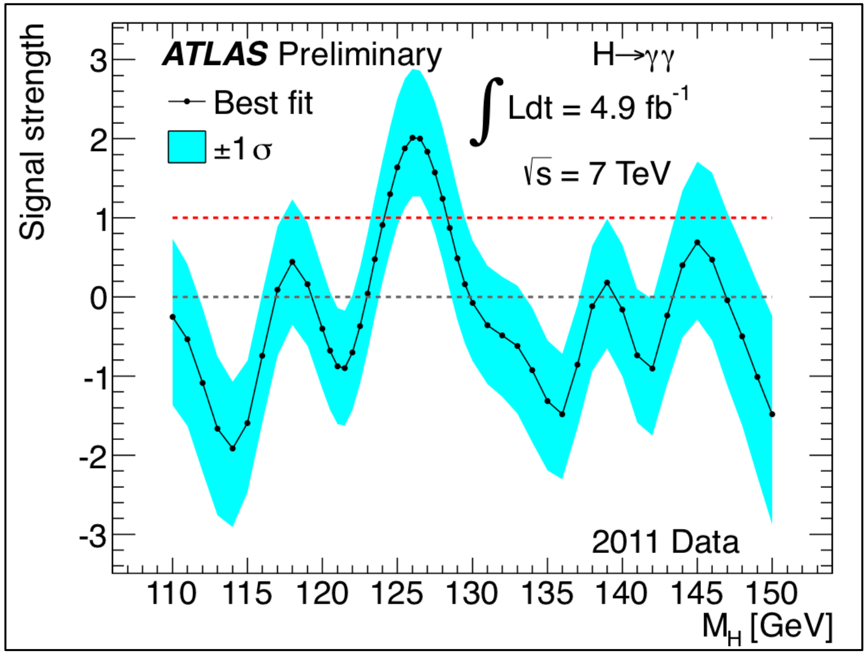




$H \rightarrow \gamma\gamma$ (7)

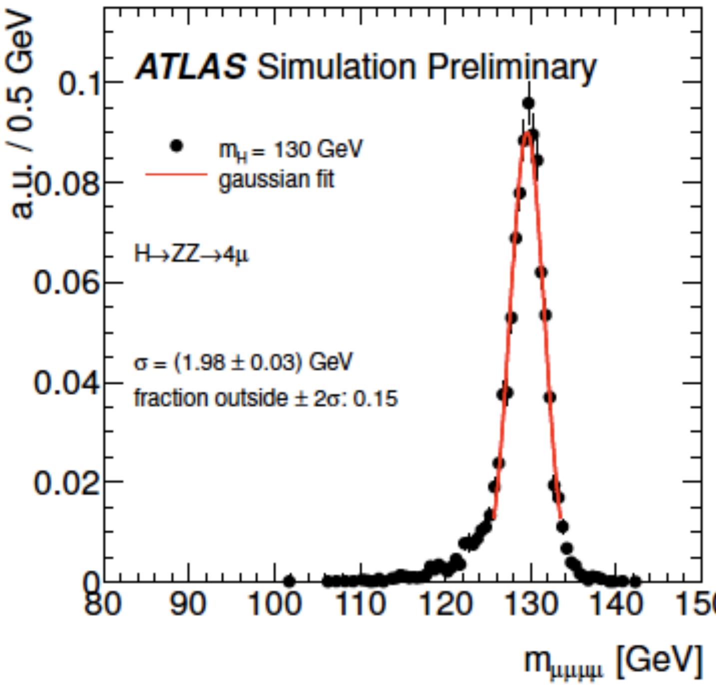
- Consistency of data with background-only expectation (left)
- Expected signal strength (right)

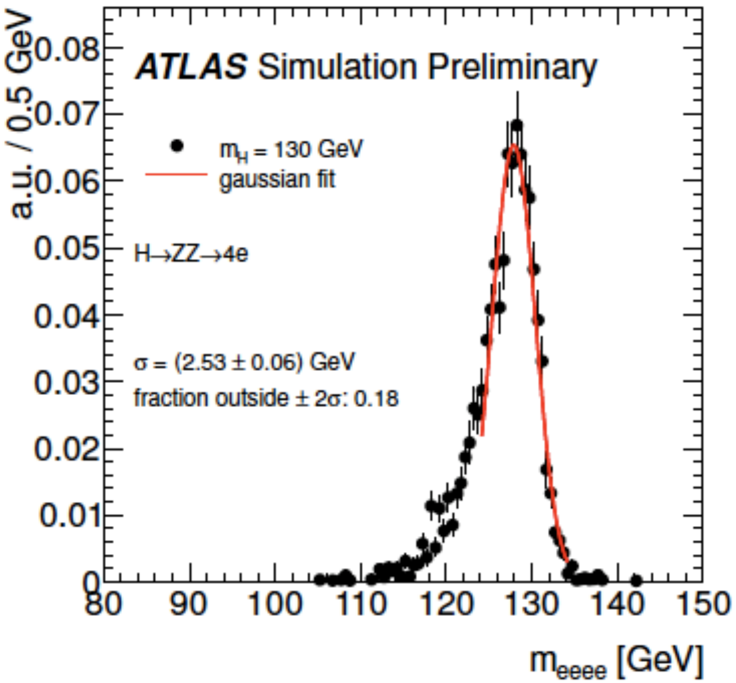




H→ZZ$^{(*)}$→llll (1)

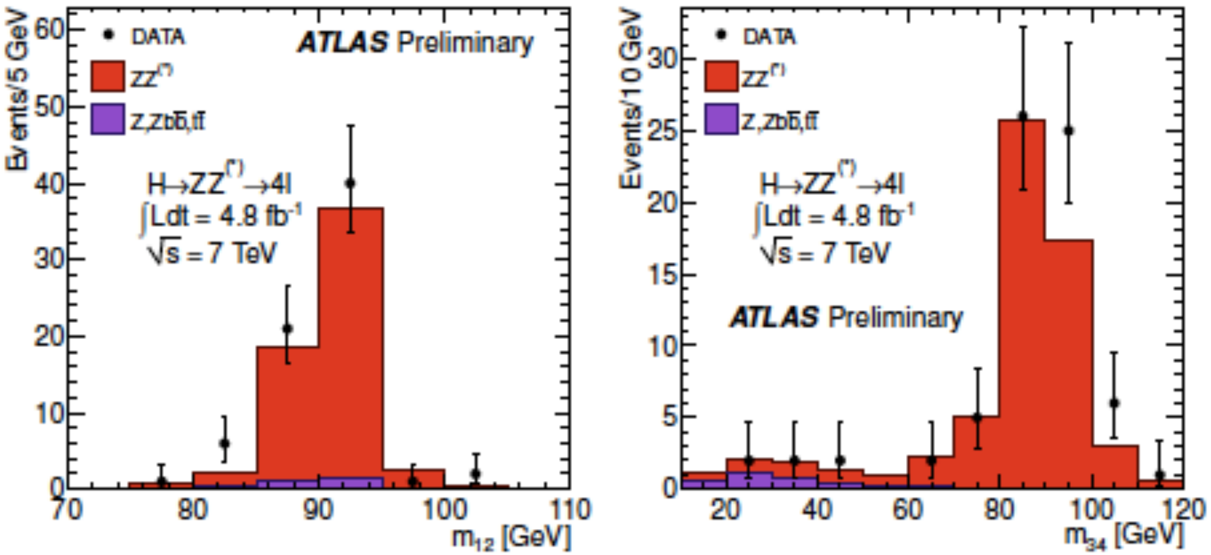
- Clean signal
  - Use isolation, dilepton masses to reduce Z+jets and top backgrounds
- Low rate: need to keep efficiencies high
- Main backgrounds from SM ZZ production
- Good 4-lepton mass resolution helps to enhance signal





H → ZZ$^{(*)}$ → llll (2)

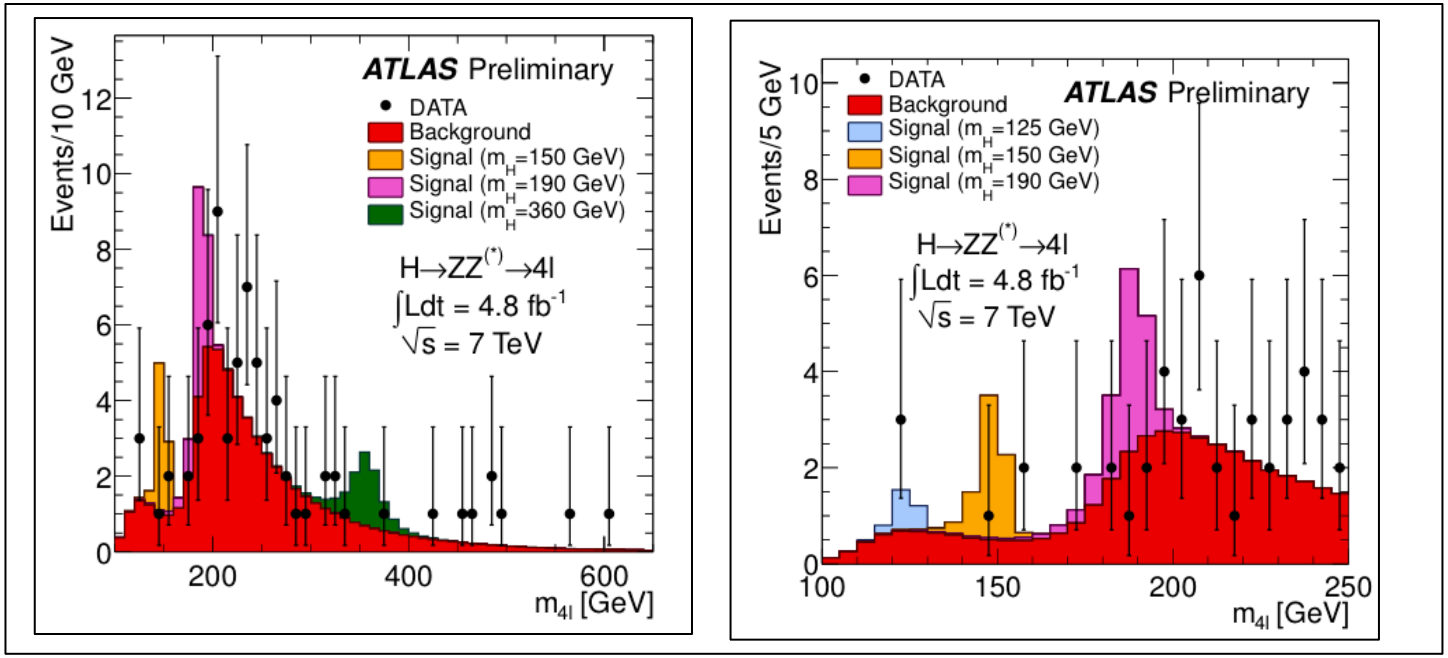
- Selections:
  - 4 leptons with p_T > 20,20,7,7 GeV
  - Pair same-flavour, opposite charge leptons. M_{12}:pair with mass closest to Z
  - M_{12} within 15 GeV of Z mass, minimum M_{34} depends on mass
- Signal efficiency ~15% for M_H of 125 GeV
- M_{12} and M_{34} of candidates:



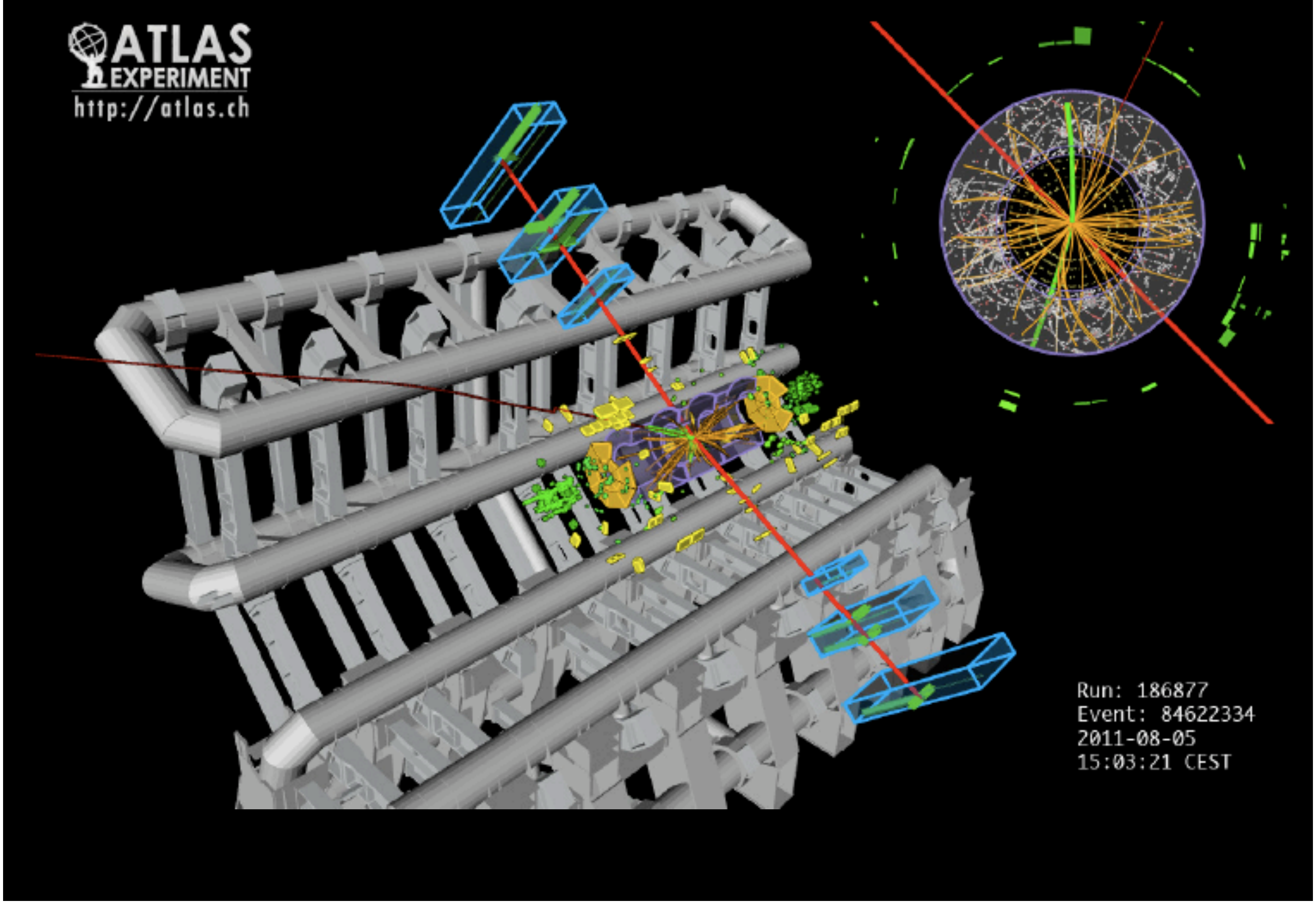
$H \rightarrow ZZ^{(*)} \rightarrow llll$ (3)

Candidate events: 71 observed, 62 +/- 9 predicted

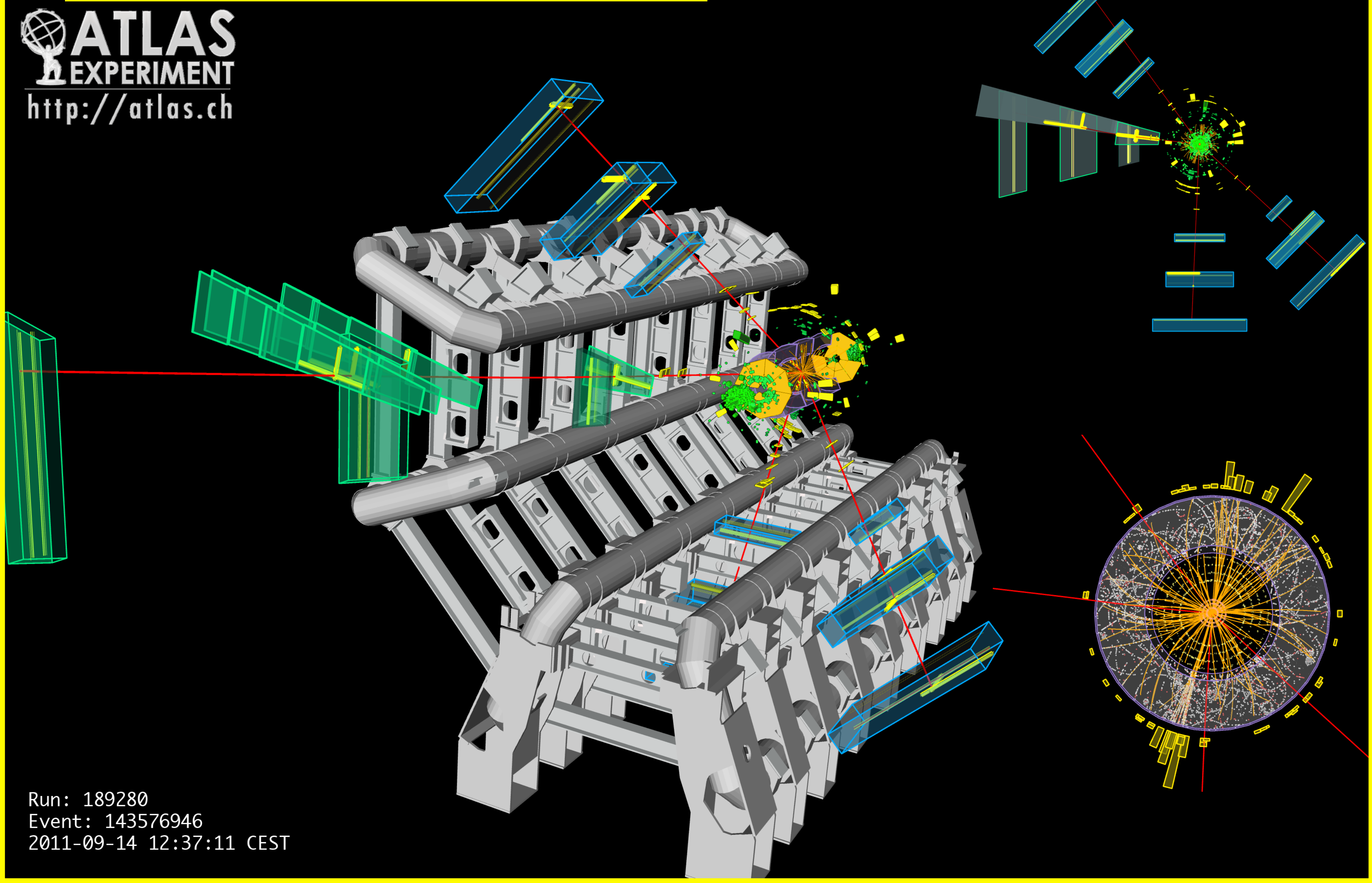
- Systematic uncertainties:
  - Higgs cross-section : ~ 15%, Electron efficiency : ~ 2-8%
  - Zbb, +jets backgrounds : ~ 40%, ZZ* background : ~ 15%

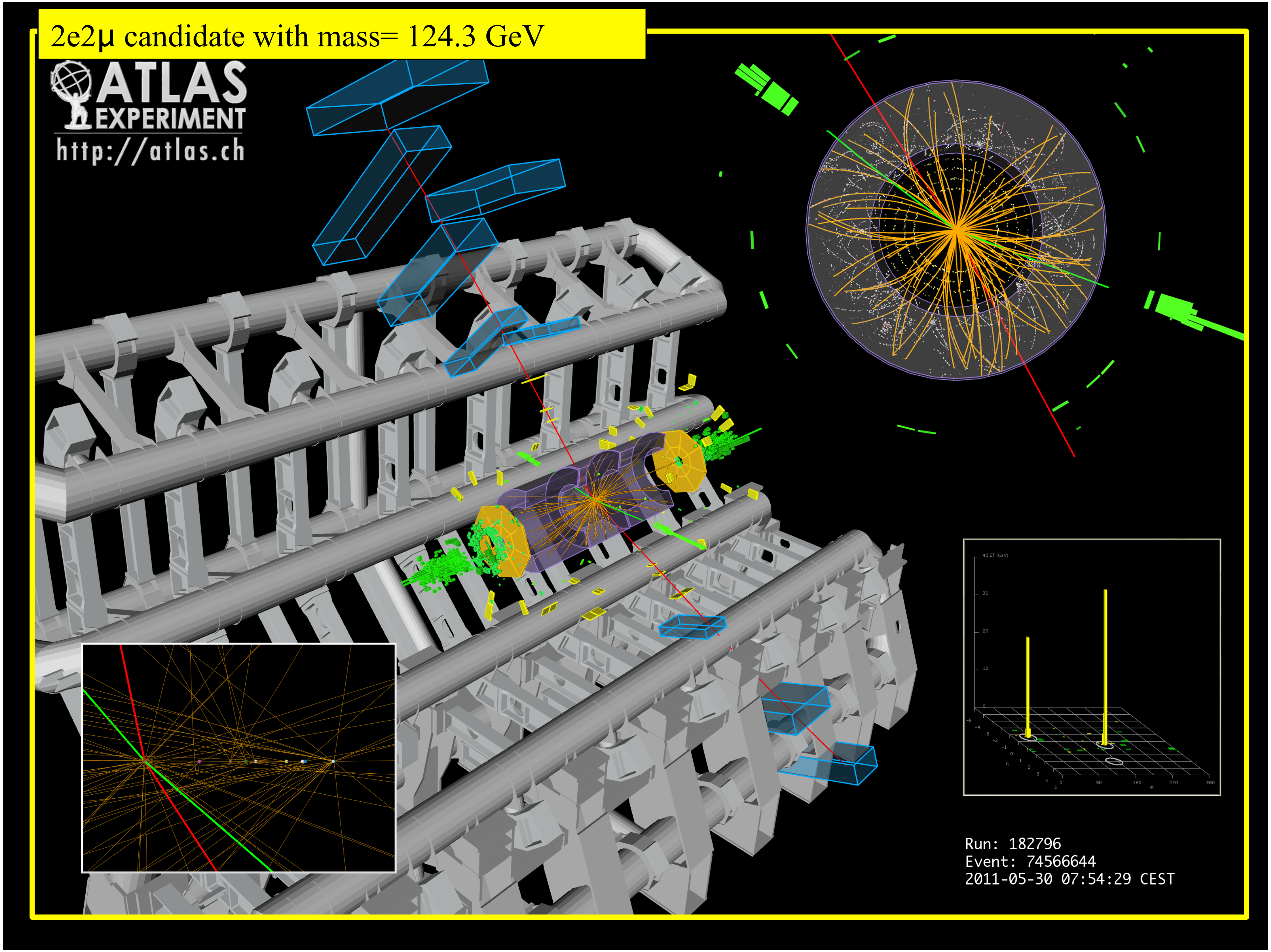


2μ2e candidate with mass = 123.6 GeV



4μ candidate with mass = 124.6 GeV

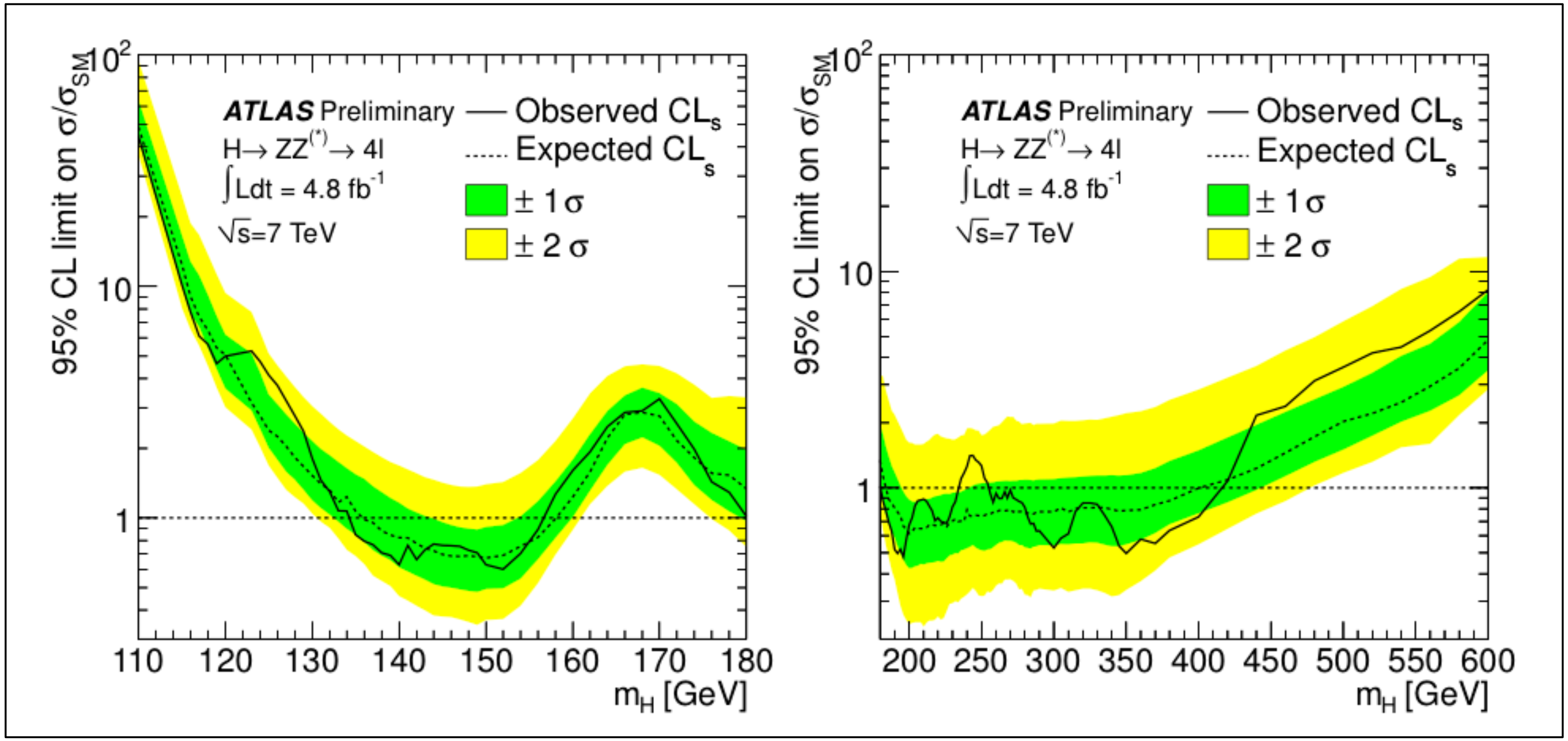



2e2μ candidate with mass= 124.3 GeV
ATLAS
EXPERIMENT
http://atlas.ch
Run: 182796
Event: 74566644
2011-05-30 07:54:29 CEST

$H \rightarrow ZZ^{(*)} \rightarrow llll$ (7)

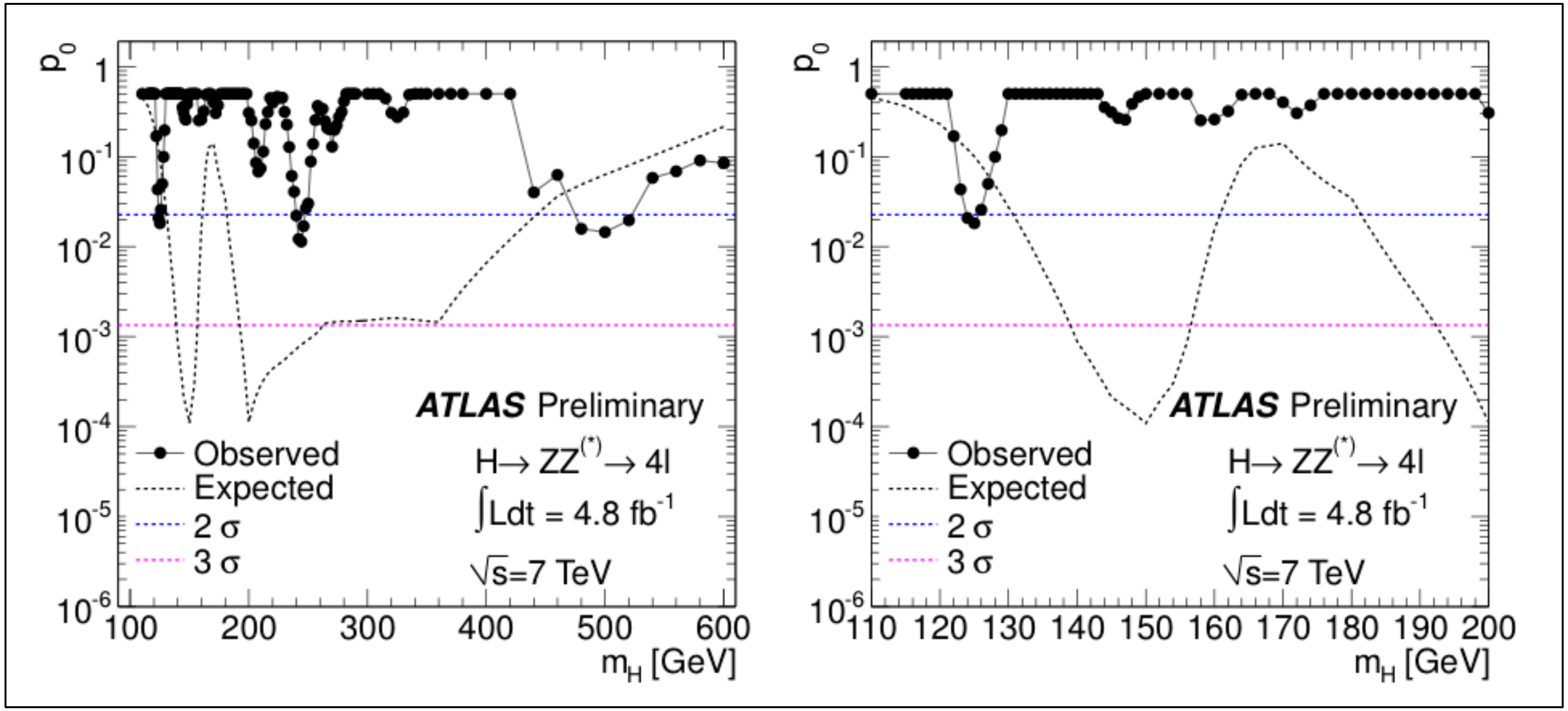
- Limits:

Excluded (95% CL): 135 < mH < 156 GeV and 181 < mH < 415 GeV (except 234-255 GeV)
Expected (95% CL): 137 < mH < 158 GeV and 185 < mH < 400 GeV



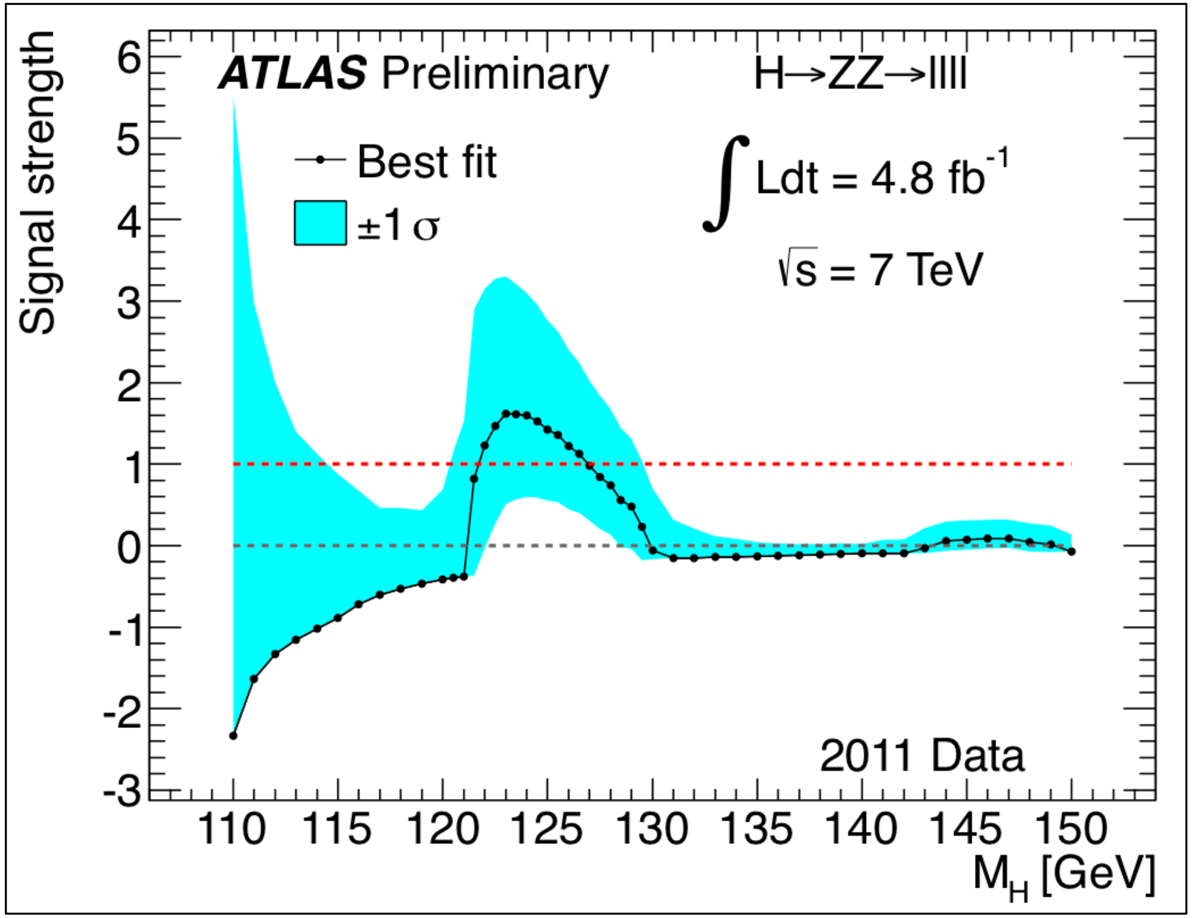
$H \rightarrow ZZ^{(*)} \rightarrow llll$ (8)

- Consistency of data with background only expectation
- Local significances
  - 2.1 σ at 125 GeV
  - 2.3 σ at 244 GeV (excluded by ATLAS-CMS combination)
  - 2.2 σ at 480 GeV



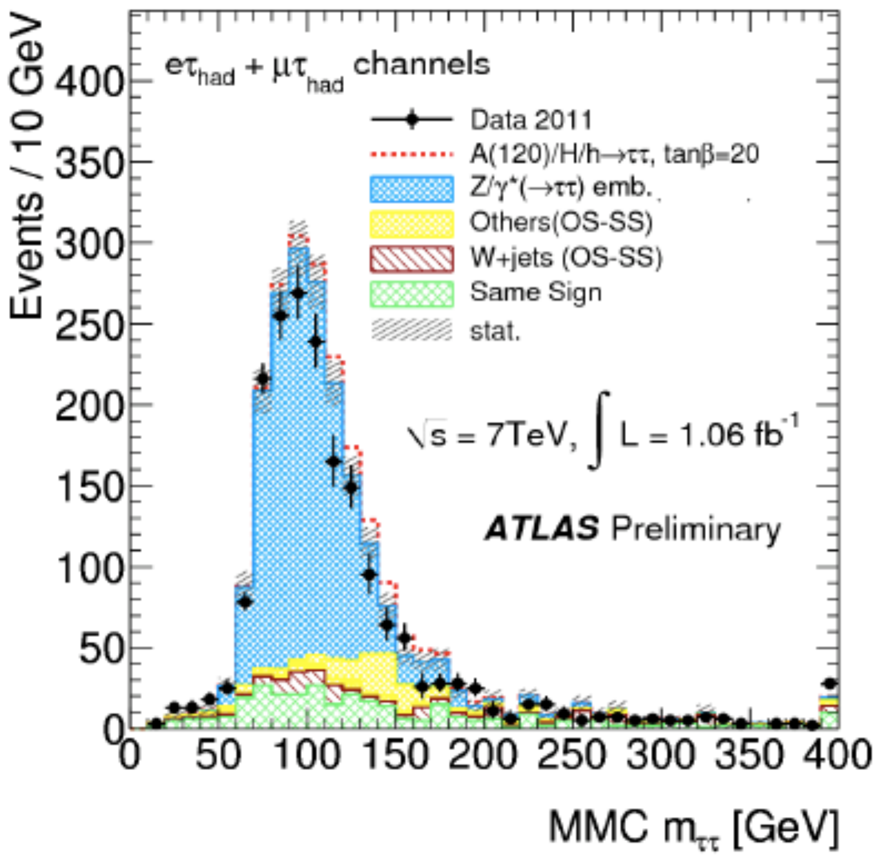
H→ZZ$^{(*)}$→llll (9)

- Compatibility with expected SM Higgs signal strength



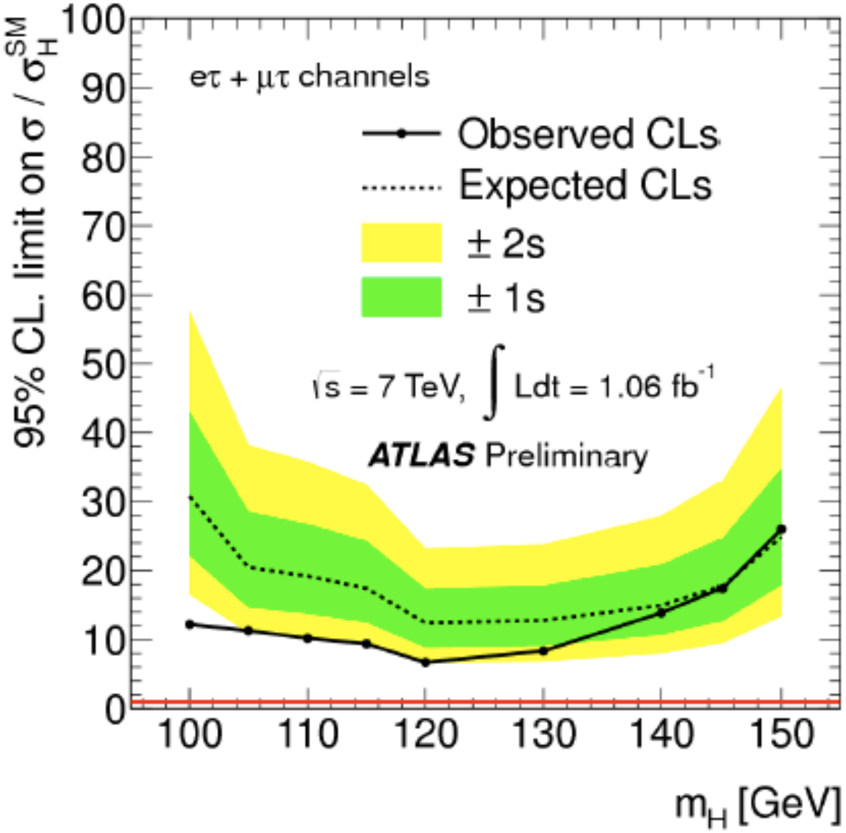
H ➡ ττ (1)

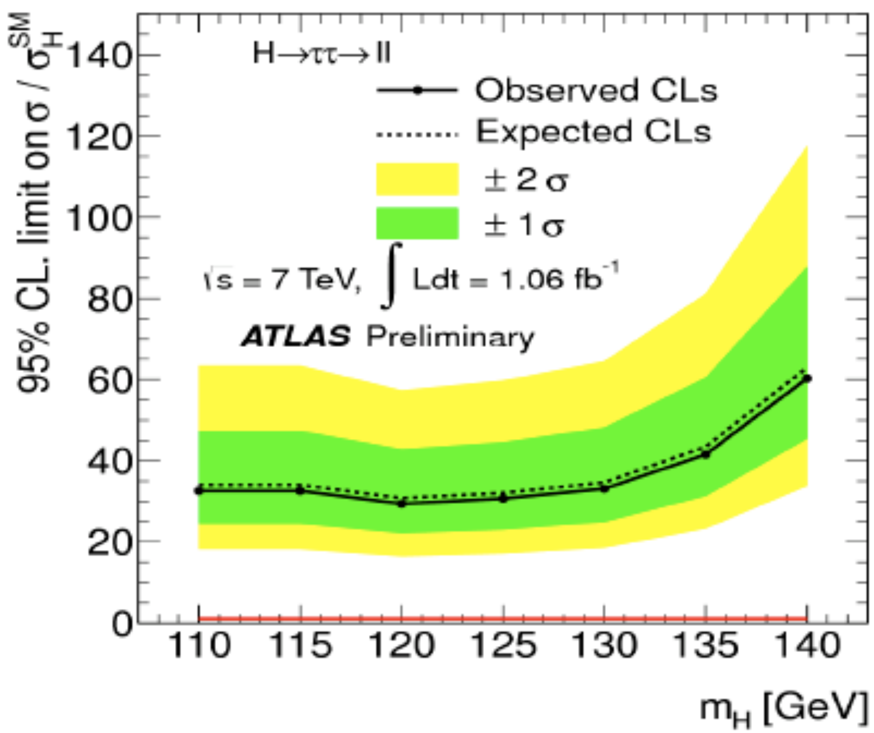
- Important channel in the low mass range
- If Higgs exists: would like to measure coupling to a lepton
- Looking at ττ to ll, lh, hh
- Challenges include:
  - Trigger with LHC running at high luminosity
  - Large backgrounds need to be suppressed
  - Mass resolution/reconstruction
- Many analysis improvements should be available for the Winter conferences with the full 2011 dataset



H→ττ (2)

- Left: limits on SM Higgs with lh: expected limits ~ 15 times SM
- Right: limits on SM Higgs with ll: expected limits ~ 30 times SM



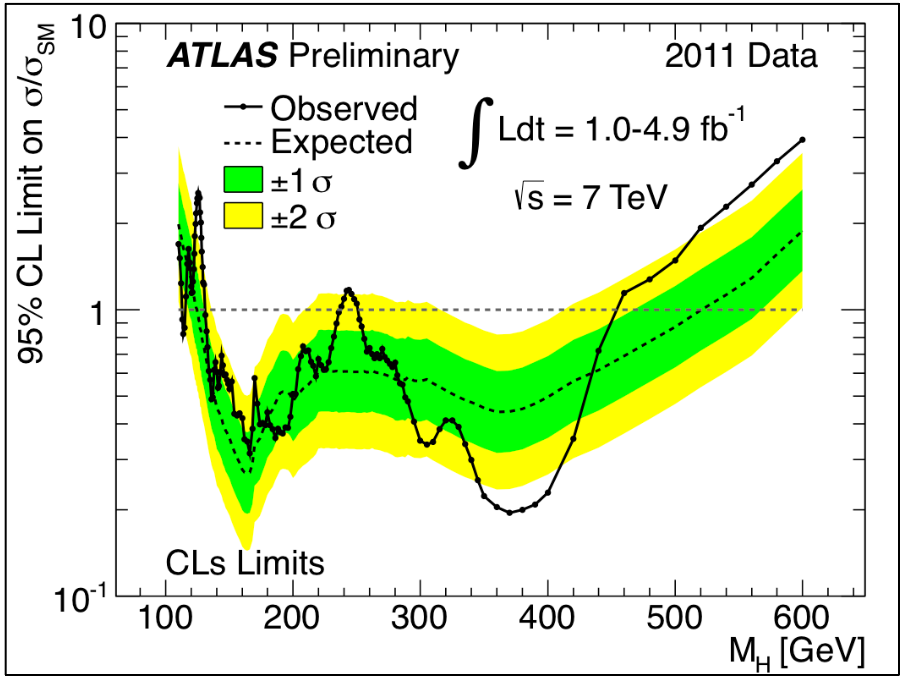


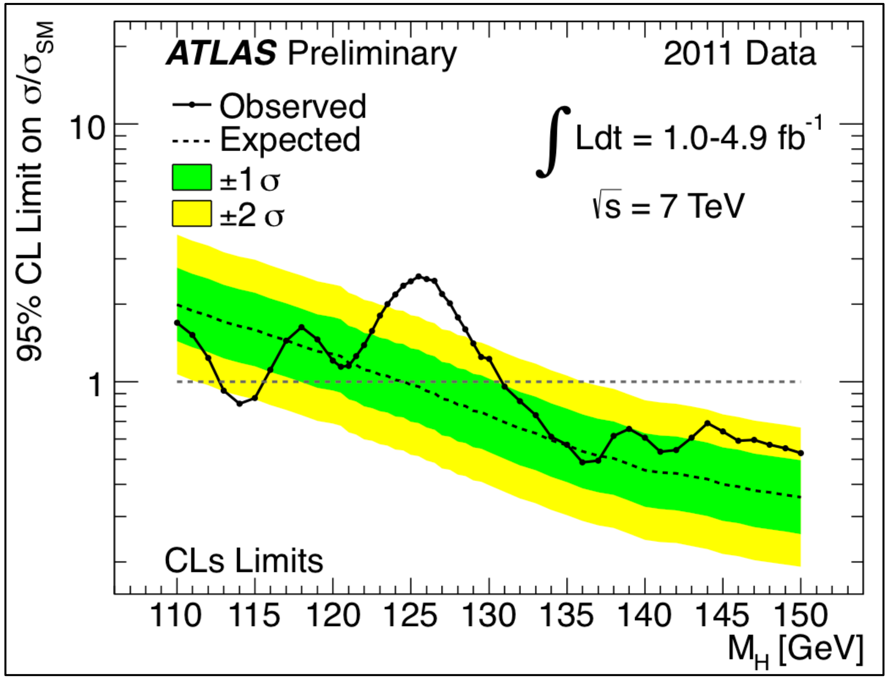
Combination

Observed Exclusions: 112.7 < m_H < 115.5 GeV

131 < m_H < 453 GeV, except 237-251 GeV

Expected Exclusion: 124.6-520 GeV

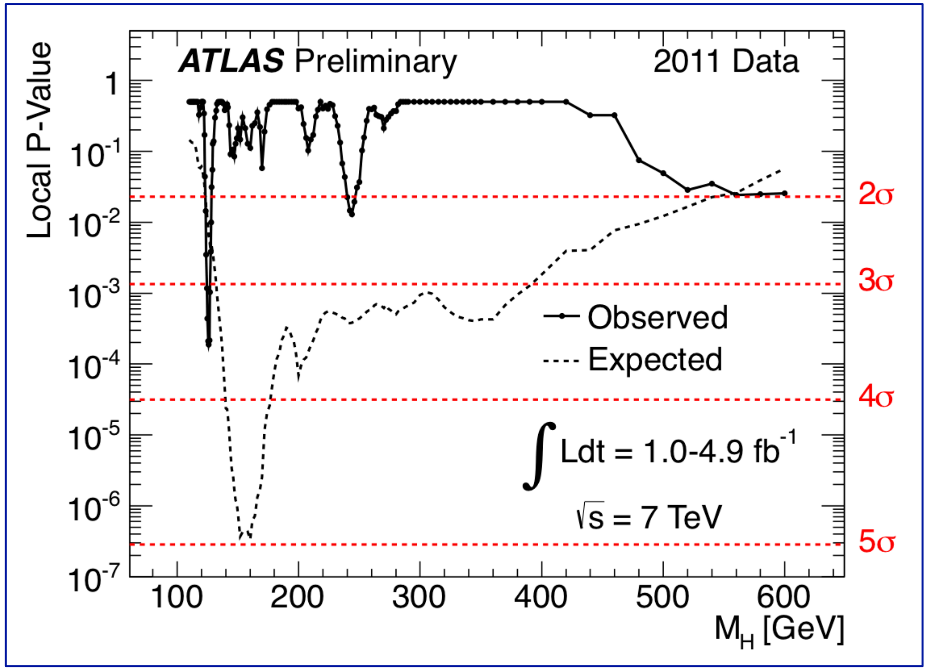


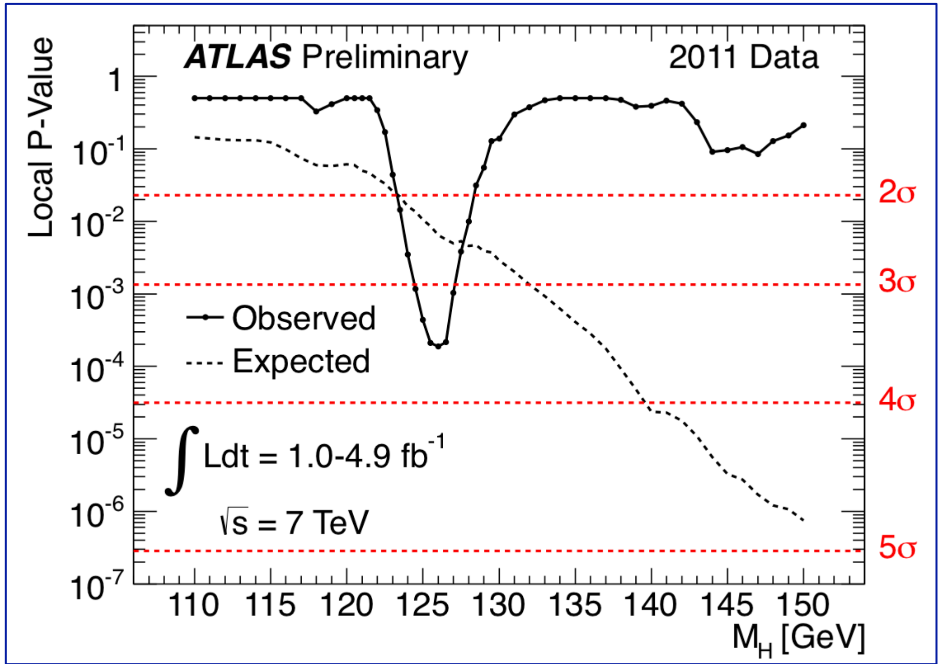


Combination

Consistency with background-only expectation

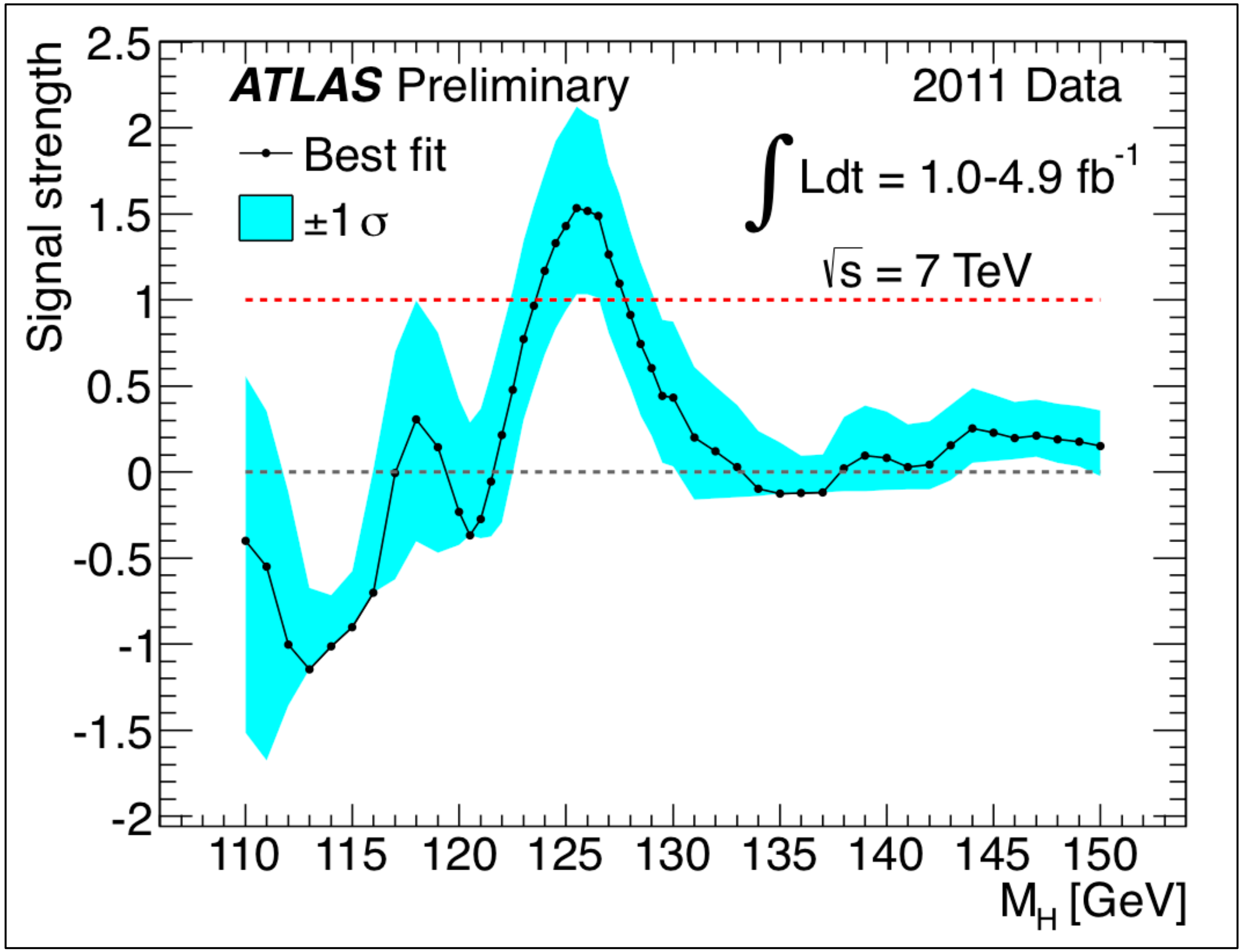
Local p_0-value: 2.2 10^{-4} significance of the excess: 3.6σ
~ 2.8σ H→ γγ, 2.1σ H→ 4l, 1.4σ H→ WW →lνlν (2.1 fb^{-1})





Combination

Compatibility with expected SM Higgs signal strength



ATLAS Next Steps

- Update the WW-> $l\nu l\nu$ analysis with the full 2011 dataset. This will have an impact (one way or another)

- Add tau, ZH,WH analyses: set the stage for 2012

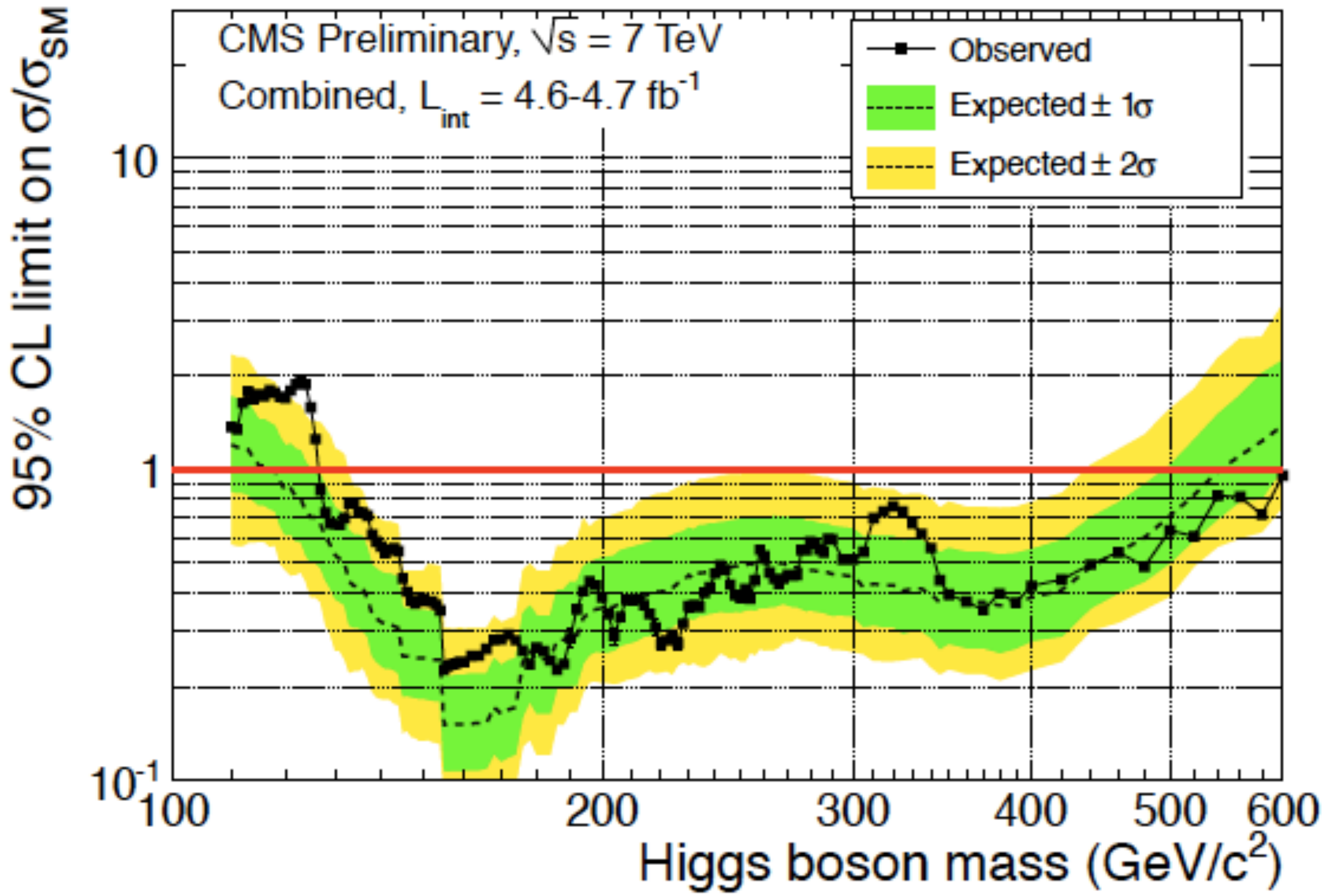
- Plan on publishing in same journal with CMS by the end of January

- Improvements to analyses are in the pipeline
  - Multivariate analyses
  - Improve detector/reconstruction performance

- Analyze the 2012 dataset:
  - ATLAS will reach 5 σ at 125 GeV
  - Can achieve 5 σ with CMS down to 116 GeV
  - Can rule out mass range (if we are dealing with fluctuations)

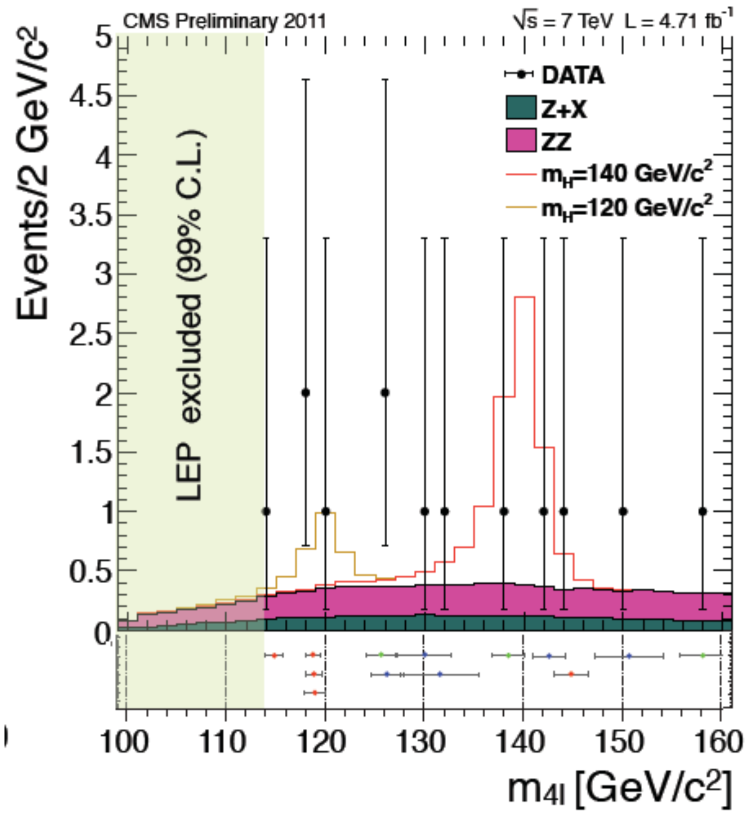
CMS Results

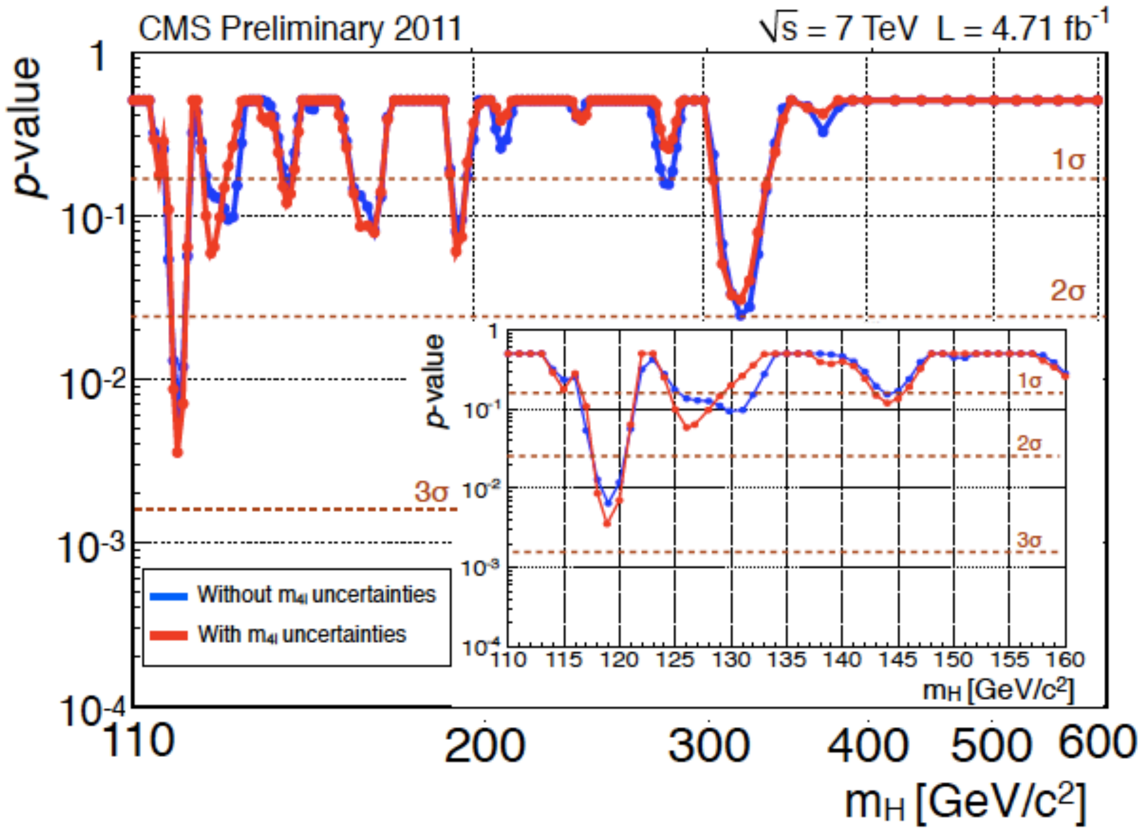
CMS exclusion: 127-600 GeV, expected exclusion: 117-543 GeV



CMS Results

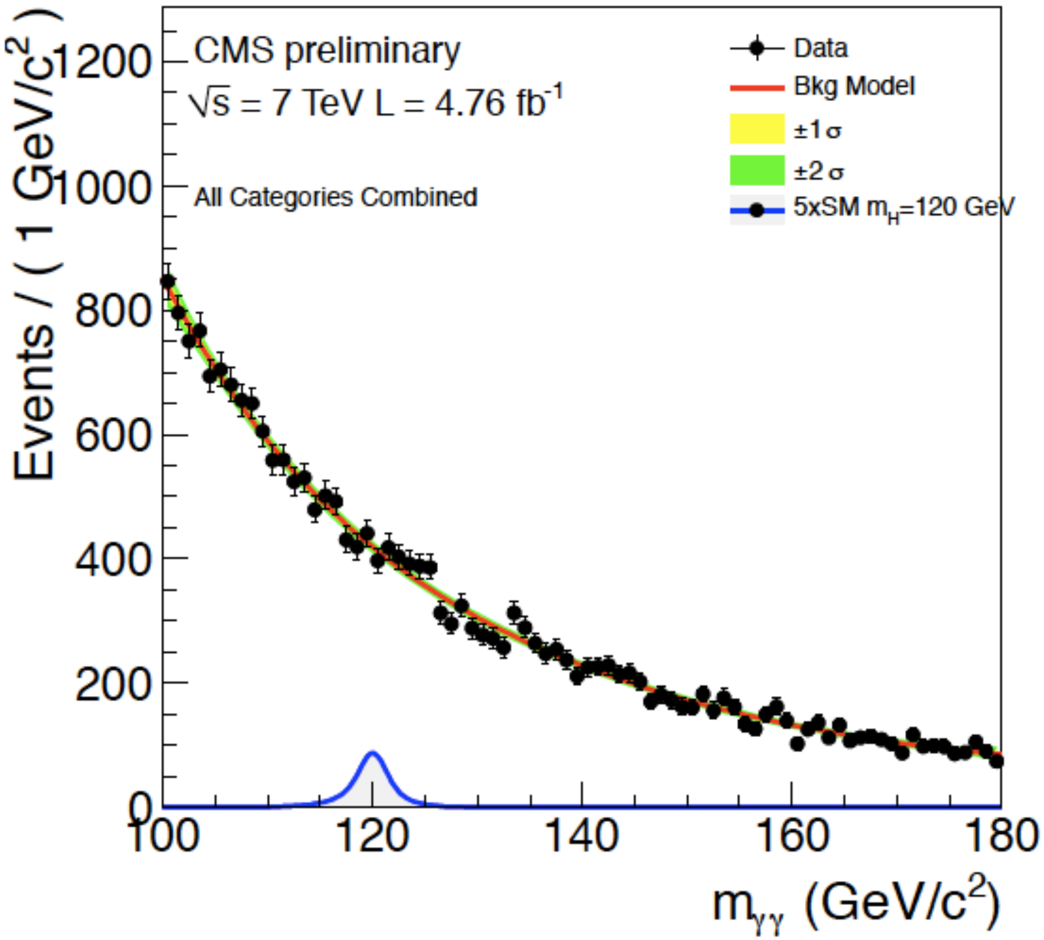
– ZZ Results





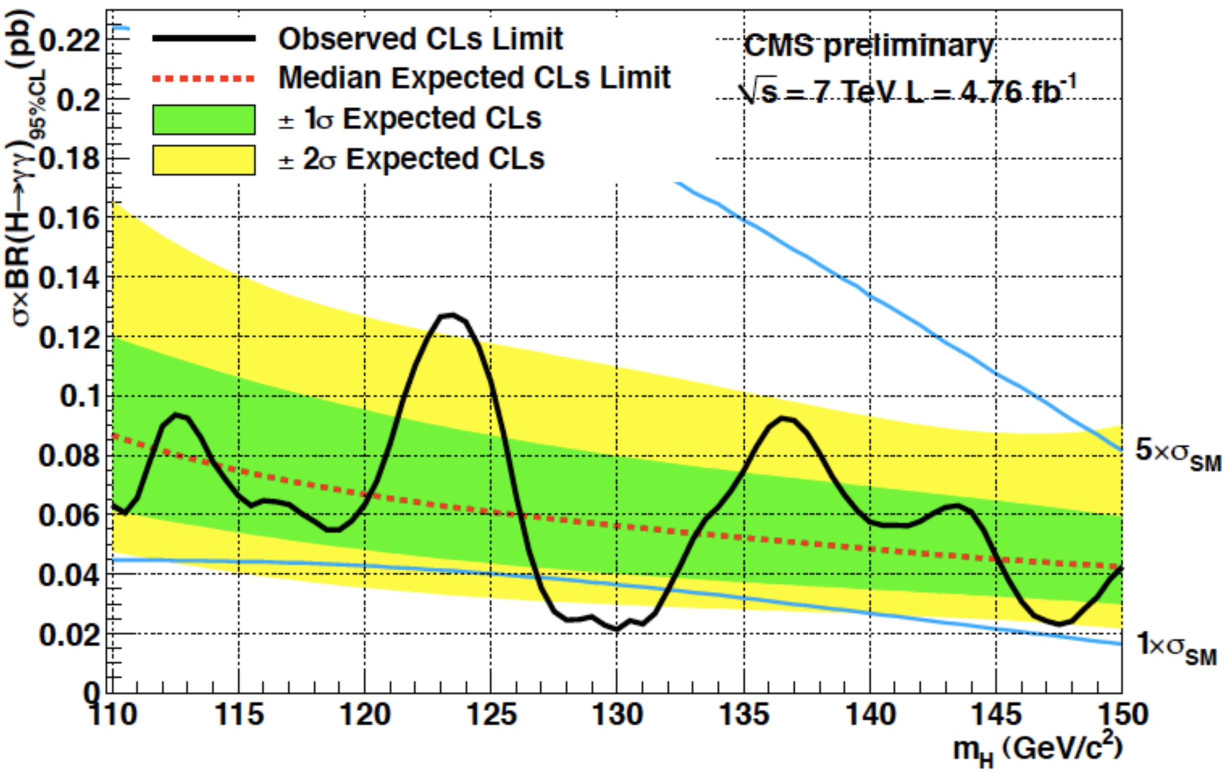
CMS Results

– Diphoton spectrum



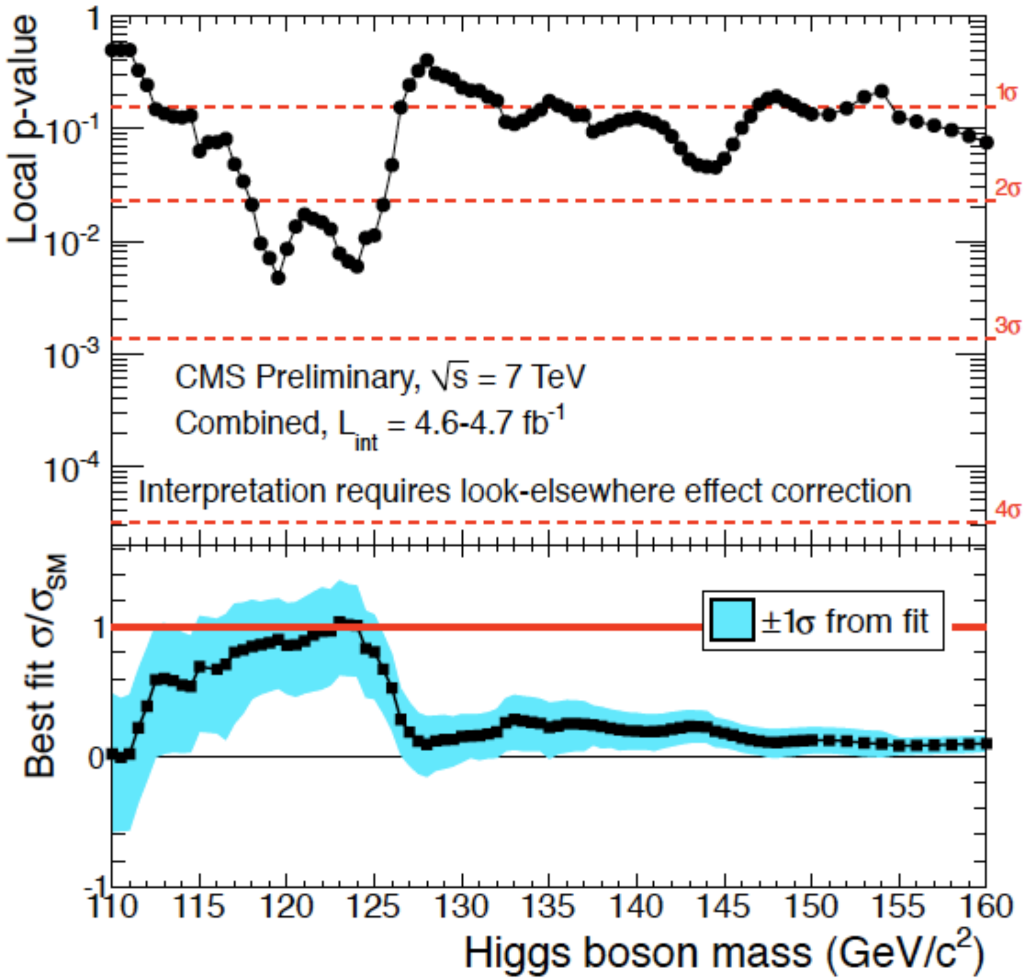
CMS Results

Diphoton limits:



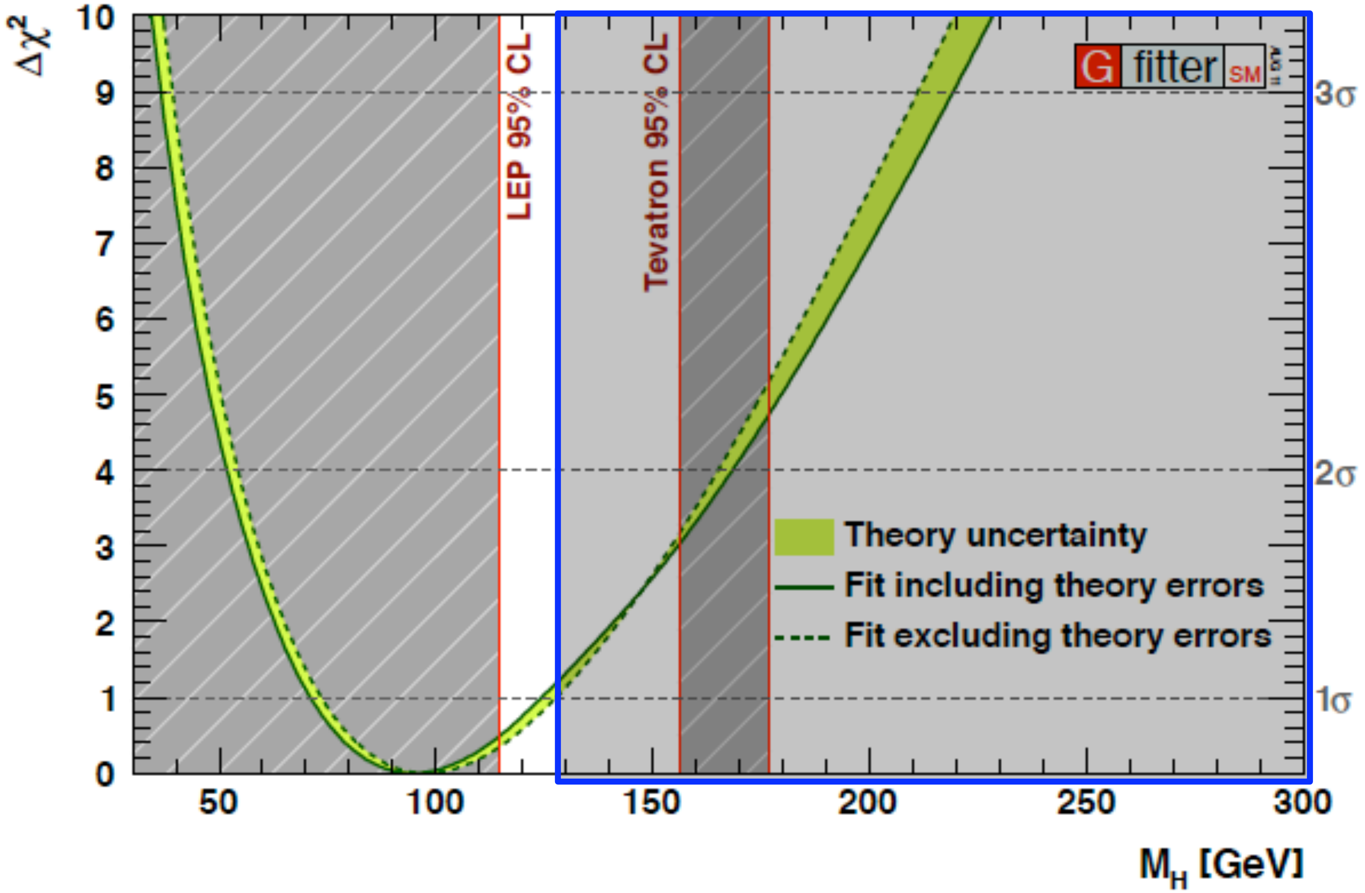
CMS Results

– Combined results, compatibility with background-only hypothesis, compatibility with SM signal strength



Where is the Higgs?

- There is 11 GeV left in the allowed mass range



Conclusions

- Tremendous amount of progress this year in the search for the SM Higgs boson: we have excluded almost all of the mass range
  - Expected exclusions cover essentially all of the mass range
- First hints from ATLAS of a potential signal with a mass around 125 GeV. CMS observations are consistent with a Higgs boson at that mass
- We are not done with the 2011 dataset yet: other channels and improvements will be ready soon
- 2012 is the year of the SM Higgs: we will have a conclusive observation or it will be excluded

Discussion

Should the observed excess be confirmed next year

- Implications for Higgs properties measurements
- Implications for BSM phenomenology
  - Susy
  - Technicolor
  - …
  - Naturalness (http://arxiv.org/pdf/1112.2150)
- Implications for BSM searches