Search for the Standard Model Higgs Boson with the ATLAS experiment

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A. Minaenko
IHEP, Protvino
On behalf of the ATLAS Collaboration

Layout

- **ATLAS detector**
- **Data taking conditions**
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- **Higgs Boson Searches with ATLAS**
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- **H -> $\gamma\gamma$**
- **H -> $WW^{(*)}$ -> $l\nu l\nu$**
- **SM Higgs Combination**
- **Summary**

ATLAS Collaboration: 38 Countries, 137 Institutes, 3000 Scientists, 1000 Students

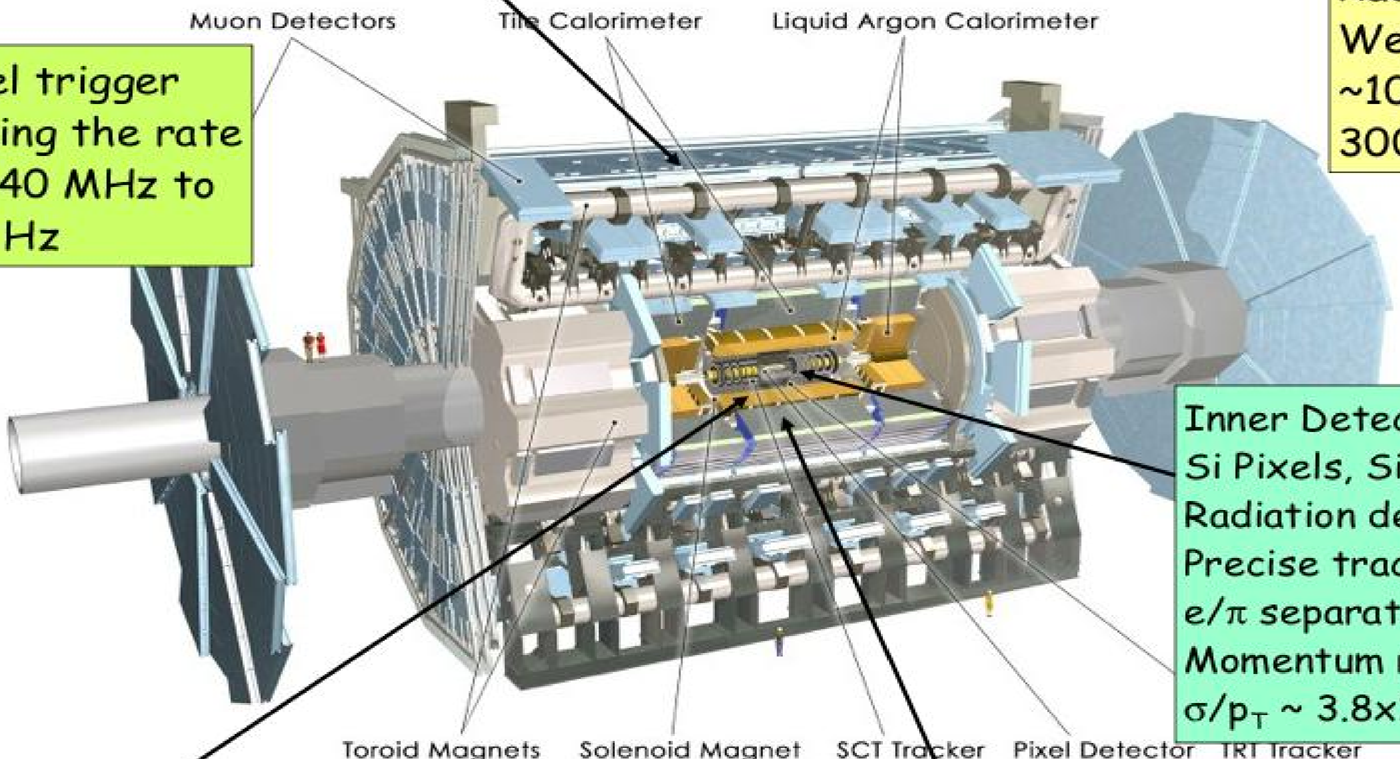
Albany, Alberta, NIKHEF Amsterdam, Ankara, LAPP Annecy, Argonne NL, Arizona, UT Arlington, Athens, NTU Athens, Baku, IFAE Barcelona, Belgrade, Bergen, Berkeley LBL and UC, HU Berlin, Bern, Birmingham, UAN Bogota, Bologna, Bonn, Boston, Brandeis, Brasil Cluster, Bratislava/SAS Kosice, Brookhaven NL, Buenos Aires, Bucharest, Cambridge, Carleton, CERN, Chinese Cluster, Chicago, Chile, Clermont-Ferrand, Columbia, NBI Copenhagen, Cosenza, AGH UST Cracow, IFJ PAN Cracow, SMU Dallas, UT Dallas, DESY, Dortmund, TU Dresden, JINR Dubna, Duke, Edinburgh, Frascati, Freiburg, Geneva, Genoa, Giessen, Glasgow, Göttingen, LPSC Grenoble, Technion Haifa, Hampton, Harvard, Heidelberg, Hiroshima IT, Indiana, Innsbruck, Iowa SU, Iowa, UC Irvine, Istanbul Bogazici, KEK, Kobe, Kyoto, Kyoto UE, Lancaster, UN La Plata, Lecce, Lisbon LIP, Liverpool, Ljubljana, QMW London, RHBNC London, UC London, Lund, UA Madrid, Mainz, Manchester, CPPM Marseille, Massachusetts, MIT, Melbourne, Michigan, Michigan SU, Milano, Minsk NAS, Minsk NCPHEP, Montreal, McGill Montreal, RUPHE Morocco, FIAN Moscow, ITEP Moscow, MEPhI Moscow, MSU Moscow, LMU Munich, MPI Munich, Nagasaki IAS, Nagoya, Naples, New Mexico, New York, Nijmegen, Northern Illinois, BINP Novosibirsk, Ohio SU, Okayama, Oklahoma, Oklahoma SU, Olomouc, Oregon, LAL Orsay, Osaka, Oslo, Oxford, Paris VI and VII, Pavia, Pennsylvania, NPI Petersburg, Pisa, Pittsburgh, CAS Prague, CU Prague, TU Prague, IHEP Protvino, Regina, Rome I, Rome II, Rome III, Rutherford Appleton Laboratory, DAPNIA Saclay, Santa Cruz UC, Sheffield, Shinshu, Siegen, Simon Fraser Burnaby, SLAC, South Africa, Stockholm, KTH Stockholm, Stony Brook, Sydney, Sussex, AS Taipei, Tbilisi, Tel Aviv, Thessaloniki, Tokyo ICEPP, Tokyo MU, Tokyo Tech, Toronto, TRIUMF, Tsukuba, Tufts, Udine/ICTP, Uppsala, UI Urbana, Valencia, UBC Vancouver, Victoria, Waseda, Washington, Weizmann Rehovot, FH Wiener Neustadt, Wisconsin, Wuppertal, Würzburg, Yale, Yerevan

ATLAS Detector

Muon Spectrometer ($|\eta|<2.7$) : air-core toroids with gas-based muon chambers
Muon trigger and measurement with momentum resolution < 10% up to E_μ ~ 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 ~200 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:
$\sigma/p_T \sim 3.8\times10^{-4}\, p_T(\mathrm{GeV}) \oplus 0.015$

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

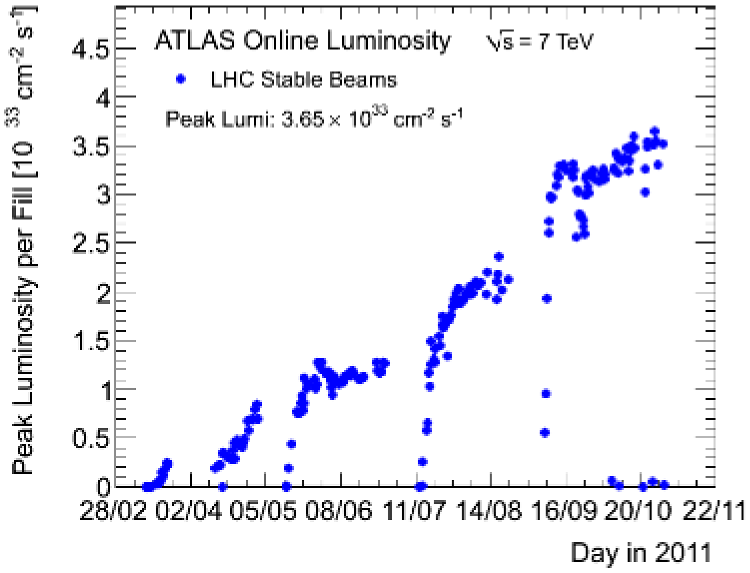
HAD calorimetry ($|\eta|<5$): segmentation, hermeticity
Fe/scintillator Tiles (central), Cu/W-LAr (fwd)
Trigger and measurement of jets and missing E_T
E-resolution: $\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$

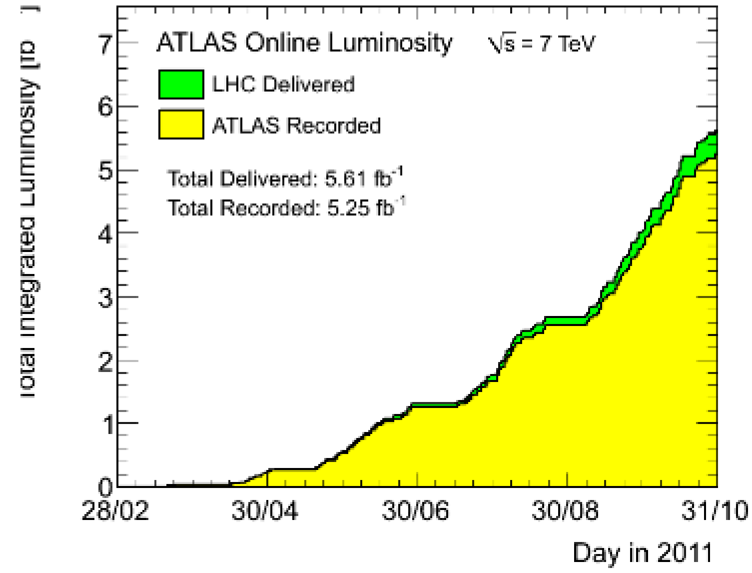
ATLAS Hardware Status

Subdetector	Number of Channels	Approximate Operational Fraction
Pixels	80 M	96.4%
SCT Silicon Strips	6.3 M	99.2%
TRT Transition Radiation Tracker	350 k	97.5%
LAr EM Calorimeter	170 k	99.8%
Tile calorimeter	9800	96.2%
Hadronic endcap LAr calorimeter	5600	99.6%
Forward LAr calorimeter	3500	99.8%
LVL1 Calo trigger	7160	99.9%
LVL1 Muon RPC trigger	370 k	99.0%
LVL1 Muon TGC trigger	320 k	100%
MDT Muon Drift Tubes	350 k	99.7%
CSC Cathode Strip Chambers	31 k	97.7%
RPC Barrel Muon Chambers	370 k	97.0%
TGC Endcap Muon Chambers	320 k	97.9%
Total	88 M	> 96 %

- Operational fraction of detector channels exceeds 96% for the entire year
- Expect to repair most of the failed channels during the downtime
  - In 2010 was able to restore detector to >99%

ATLAS Peak and Integrated Luminosity

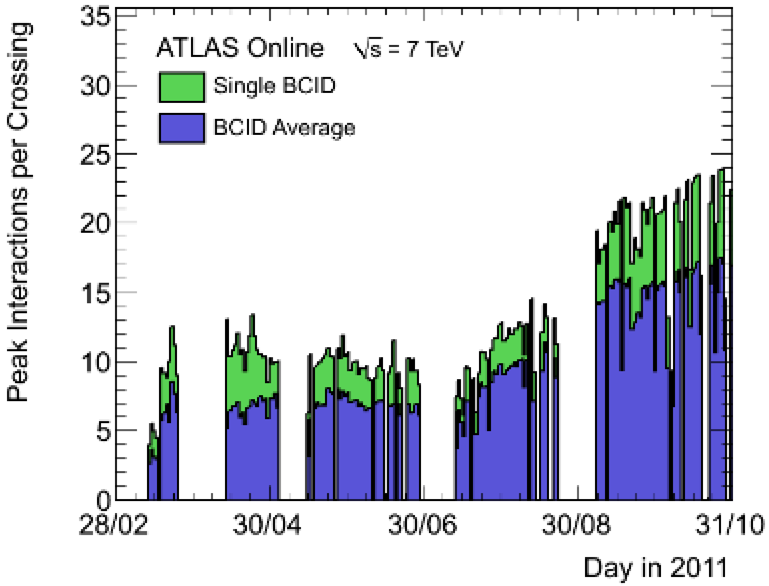


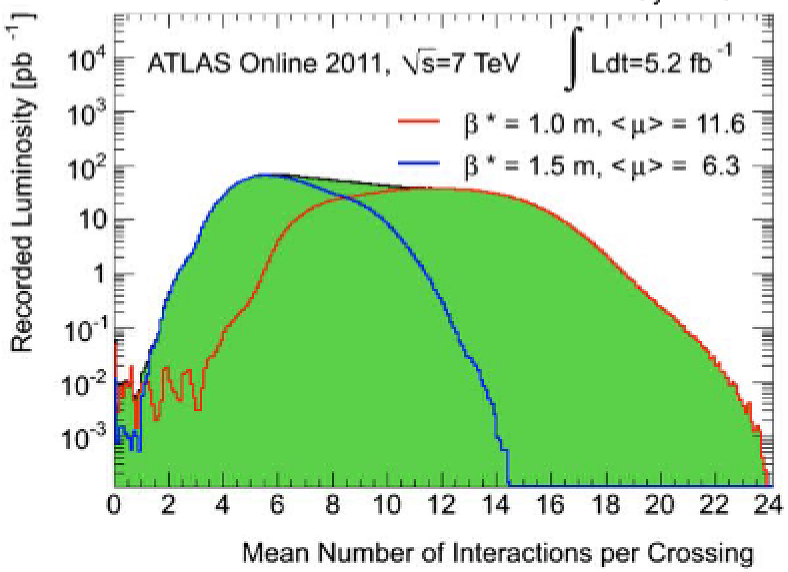


- Spectacular performance of the LHC
  - Surpassed design values for several critical machine parameters
- Selected records
  - Peak luminosity: $3.65 \cdot 10^{33}$ cm^{-2} s^{-1}
  - Maximum recorded in one day 135 pb^{-1} (about three times of all of 2010)
  - Of a total delivered 5.61 fb^{-1} recorded 5.25 fb^{-1}
  - 93.5 % total data-taking efficiency

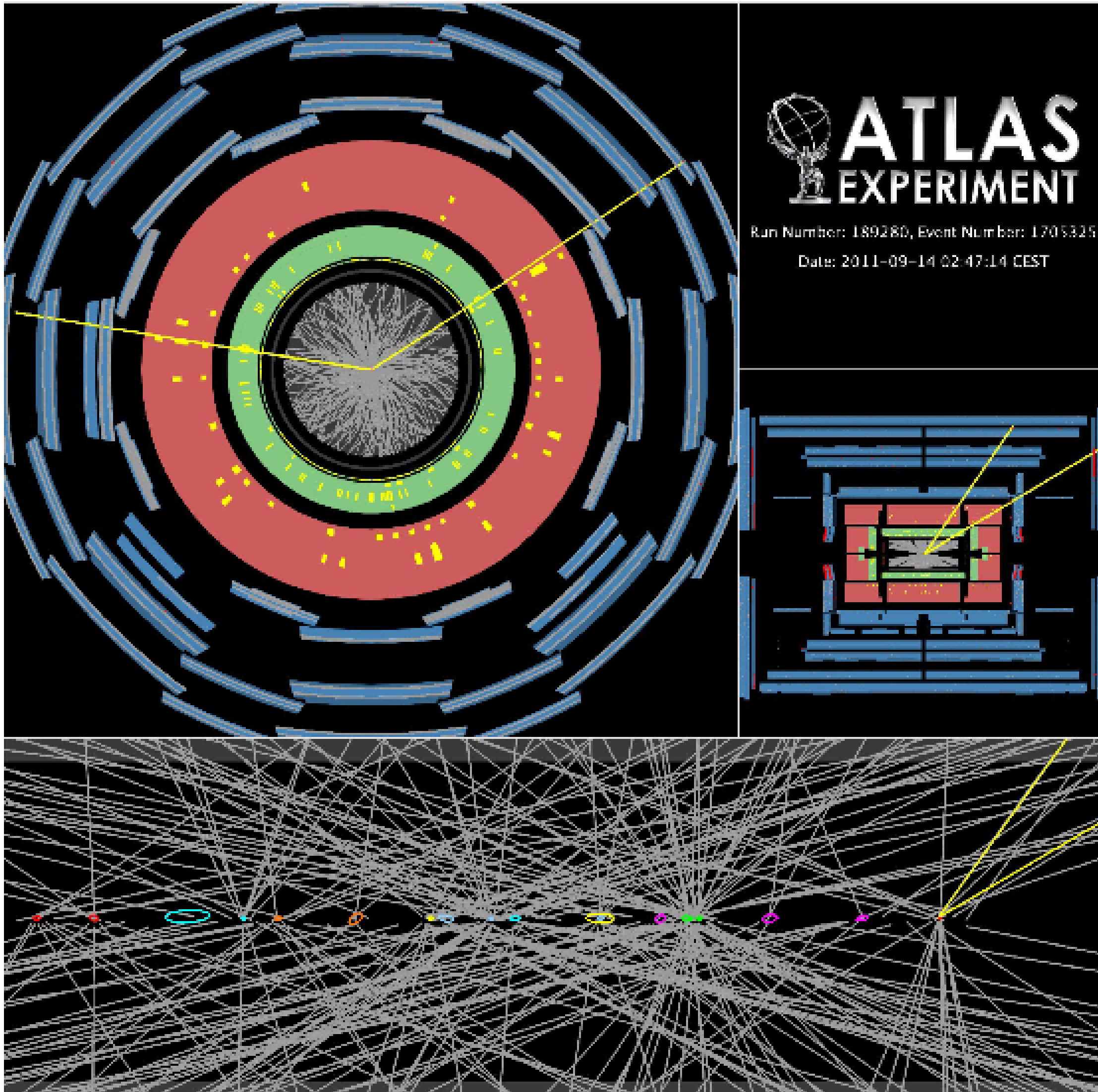
Pile-Up

- In September, beam spot size was reduced through smaller β-function at the IP: $\beta^* = 1.5$ m $\rightarrow$ 1 m
- Mean number of interactions increased from $<\mu> = 6$ to 12 (beam average) over the year
- Peak interactions per crossing exceeding 16 for beam average
- Peaking at 24 for individual bunches
  - This equals the number of interactions per bunch crossing expected by the design LHC parameters





Pile-Up



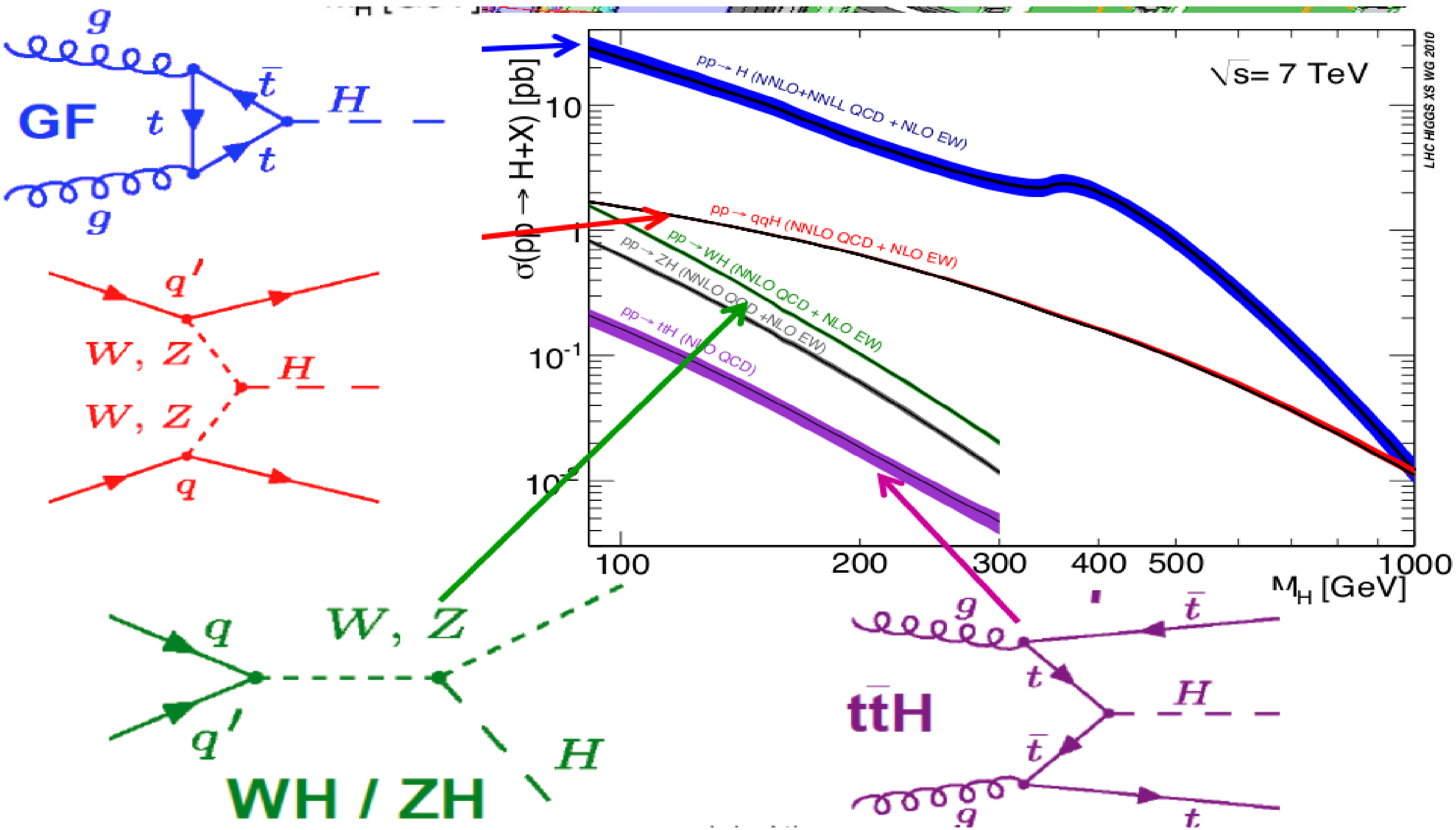
- 50 ns bunch spacing (rather than 25 ns design) with higher than nominal bunch charges pushed in-time pile-up past (original) expectations
- A challenge for:
  - Tracking and vertexing
  - Lepton isolation
  - Jet energy scale/resolution
  - Missing transverse energy reconstruction
  - Reconstruction CPU time

$Z \to \mu\mu$ event with 20 reconstructed vertices

Standard Model Higgs Boson

- **In the Standard Model (SM) of particle physics the Higgs mechanism is responsible for breaking electroweak symmetry and it is giving mass to the W and Z bosons**
- **Higgs mechanism predicts the existence of a scalar boson with non-zero mass, the Higgs boson. But it can not predict its mass, so it can be found only experimentally**
- **LEP experiments yielded a direct mass limit of $m_H > 114.4$ GeV at 95% CL**
- **Indirect limits have been placed on the Higgs boson mass by the LEP, SLD and Tevatron experiments from electroweak precision measurements**
- **The corresponding upper limit on the Higgs mass at 95% CL is $m_H < 152$ GeV**

SM Higgs Production



- Total σ_H~15 pb at m_H=120 GeV
- Vector-boson fusion (VBF) cross section is relatively high
- WH, ZH smaller fraction

SM Higgs Decays

H Decays

Standard Model specifies decay branching ratios vs. m_H

At high mass (m_H > 160 GeV):

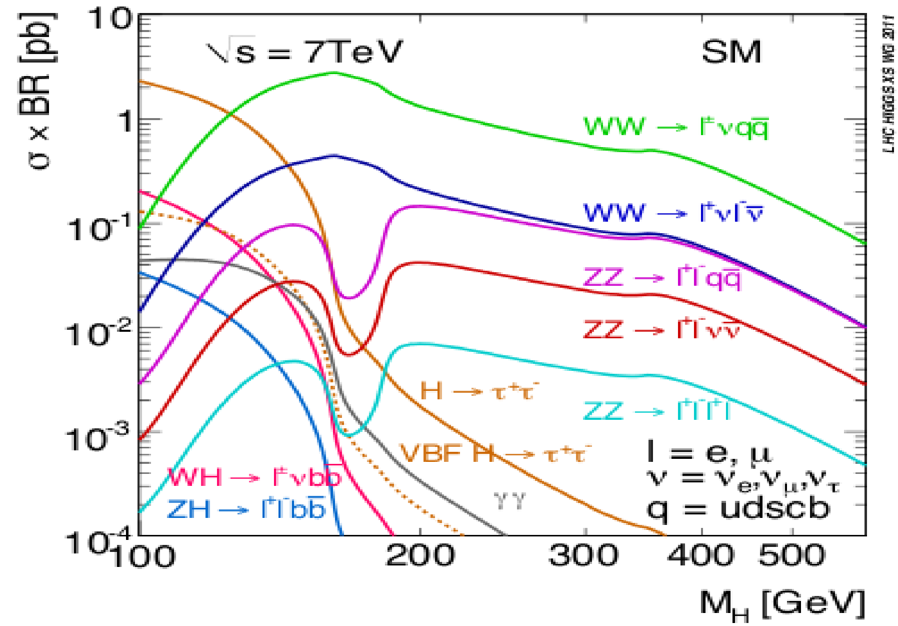
- $H \rightarrow WW$
- $H \rightarrow ZZ$

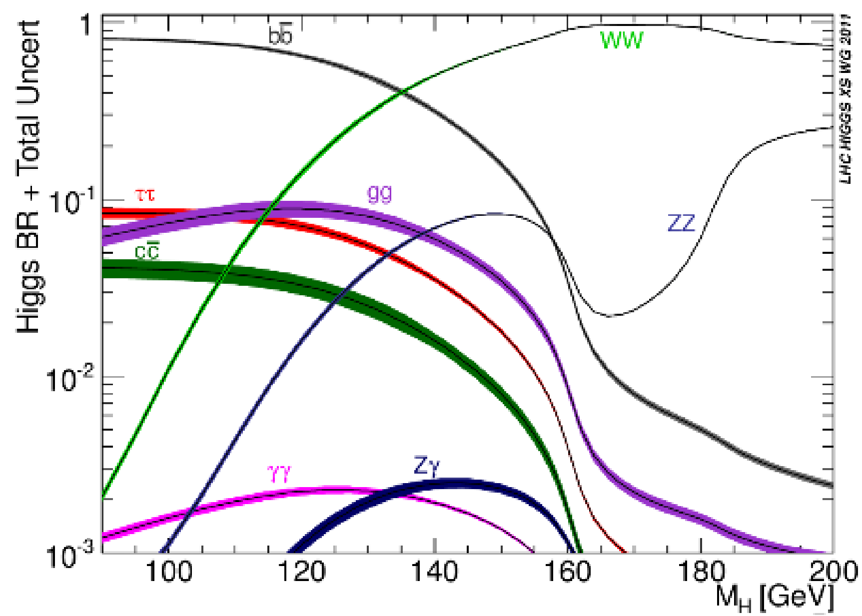
provide ~all the sensitivity, we subdivide by the W/Z decay mode

At low mass (m_H < 160 GeV):

- $H \rightarrow b\bar{b}$
- $H \rightarrow \tau\tau$
- $H \rightarrow \gamma\gamma$
- $H \rightarrow WW(*)$
- $H \rightarrow ZZ(*)$

all play a role…





Higgs Boson Searches with ATLAS

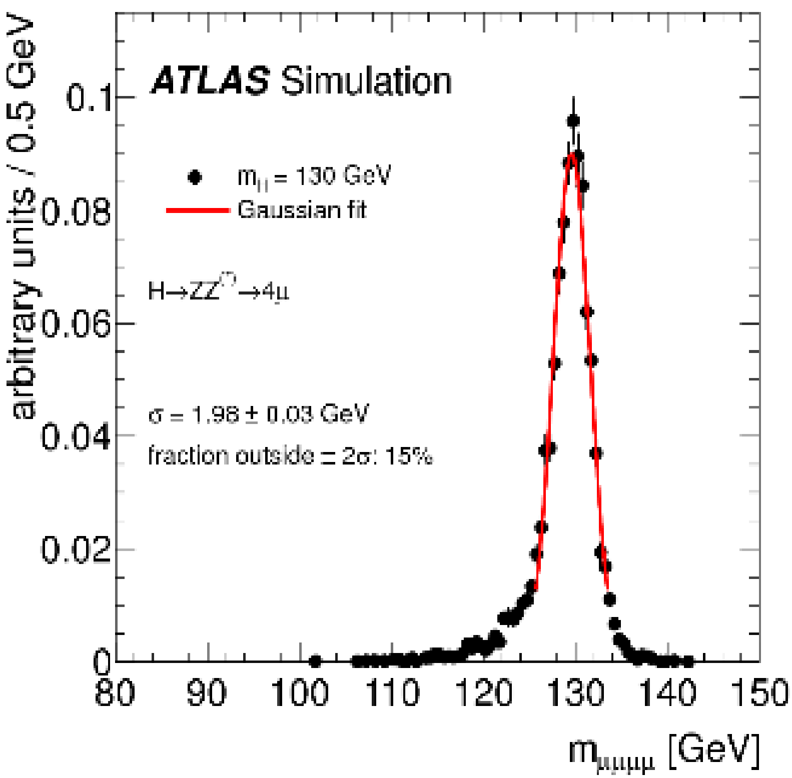
Searches in the following channels have been pursued with 2011 data

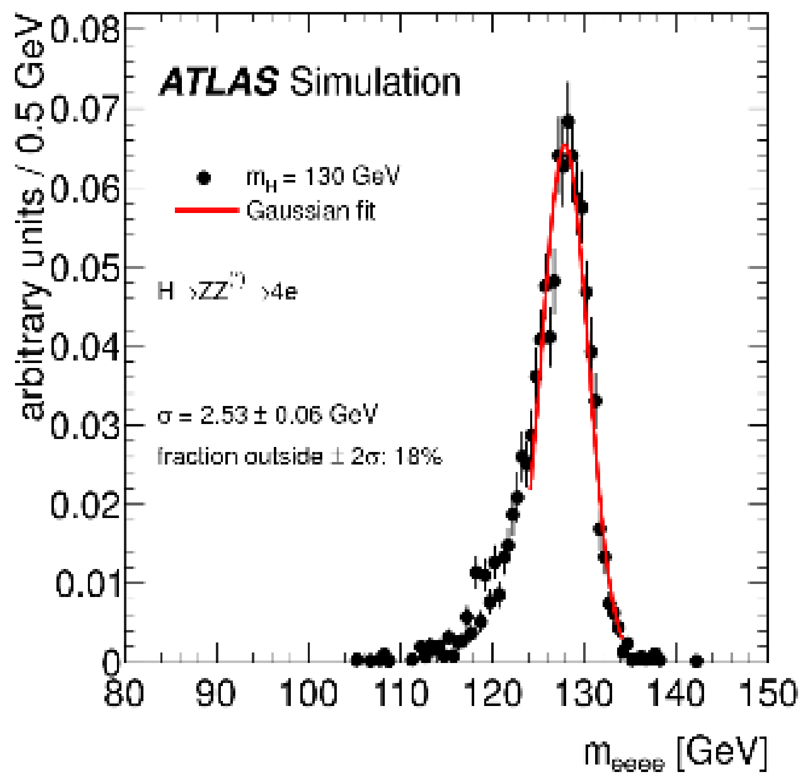
Channel	Higgs mass range (GeV)	$\int \mathcal{L}dt$ (fb^{-1})	Reference
Low m_H, good mass resolution			
$H \to \gamma\gamma$	110-150	4.9	arXiv:1202:1414
$H \to ZZ^{(*)} \to 4l$	110-600	4.8	arXiv:1202:1415
Low m_H, limited mass resolution			
$H \to WW^{(*)} \to l\nu l\nu$	110-600	4.7	CONF-2012-012
$H \to \tau\tau(\mathrm{ll, lh, hh})$	100-150	4.7	CONF-2012-014
$VH, H \to b\bar{b}$	110-130	4.7	CONF-2012-015
High m_H			
$H \to ZZ \to ll\nu\nu$	200-600	4.7	CONF-2012-016
$H \to ZZ \to llqq$	200-600	4.7	CONF-2012-017
$H \to WW \to l\nu qq$	300-600	4.7	CONF-2012-018

- **Profile likelihood ratio is used to test the hypothesized signal strength $\mu = \sigma/\sigma_{SM}$ (Eur.Phys.J.C71:1554,2011)**
- **Exclusion limits on μ are set at 95% confidence level using the CL_s method (G.Phys G 28, (2002), 2693-2704)**
- **ATLAS public results can be found at: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HiggsPublicResults**

H -> ZZ$^{(*)}$ -> 4l (golden channel)

- Low cross section (2-5 fb) but very clean signature and low background
- Two pairs of same flavor high pT opposite charged isolated leptons, at least one is compatible with narrow Z peak
- Require four isolated electrons or muons with pT > 20, 20, 7, 7 GeV
- One pair of leptons must come from Z decay
- Search for a 4 lepton narrow mass resonance
- 4 event categories: 4e , 2e 2μ, 4μ
- Irreducible SM ZZ* background
- Reducible Z+jets and tt backgrounds





H -> ZZ$^{(*)}$ -> 4l: electrons, muons

Electrons

- Electron reconstruction and identification efficiency 85 – 90%
- Understand electron performance with benchmark data processes: $J/\psi \to ee$, $Z \to ee$ and $W \to e\,\nu$
- Track and calorimeter based isolation to suppress Zbb and tt backgrounds

- Systematic uncertainties:
  - Efficiency: < 3%
  - Energy scale: < 1%
  - Energy resolution: < 0.5%

Muons

- Muon reconstruction and identification efficiency > 95%
- Accurate alignment of inner detector and muon system (MS)
- Combined momentum measurement using ID and MS
- Track and calorimeter based isolation to suppress Zbb and tt backgrounds

- Systematic uncertainties:
  - Efficiency: < 1%
  - Momentum resolution: < 0.5%

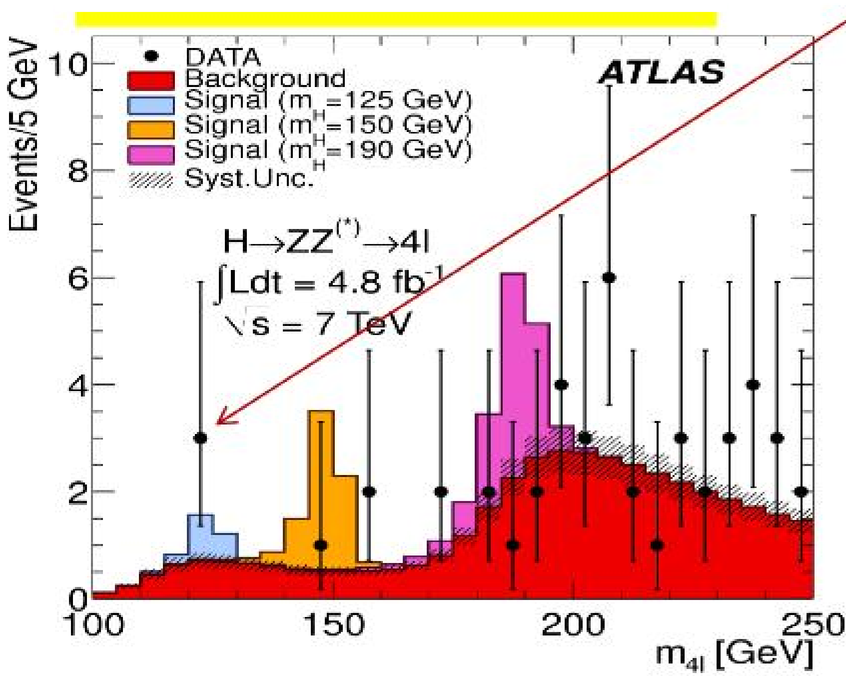
H -> ZZ$^{(*)}$ -> 4l: four-lepton invariant mass

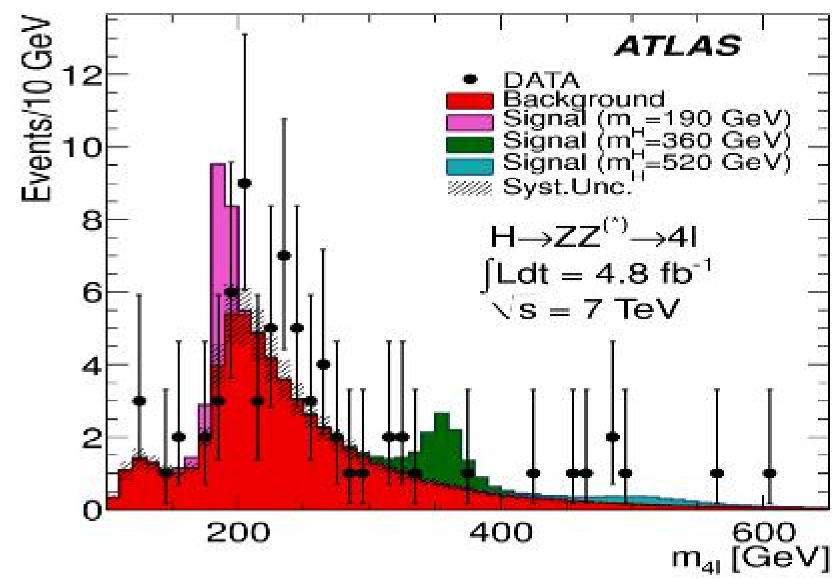
- Selected 71 candidate events
- Expect 62 ± 9 background events
- Fit four-lepton mass spectrum for Higgs signal

$m_{4l} < 180$ GeV:

	4μ	$2e2\mu$	$4e$
Total Bkg.	2.2 ± 0.3	4.3 ± 0.8	2.8 ± 0.8
$m_H = 130$ GeV	1.00 ± 0.17	1.22 ± 0.21	0.43 ± 0.08
Data	3	3	2

Two $2e2\mu$ candidates with m_{4l}=123.6, 124.3 GeV
One 4μ candidate with m_{4l}=124.6 GeV





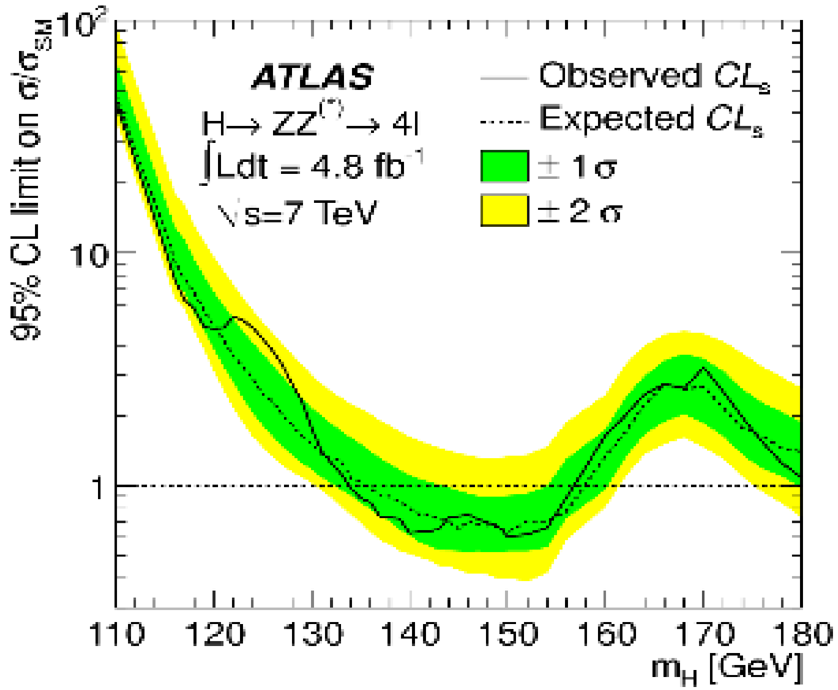
H -> ZZ$^{(*)}$ -> 4l: results

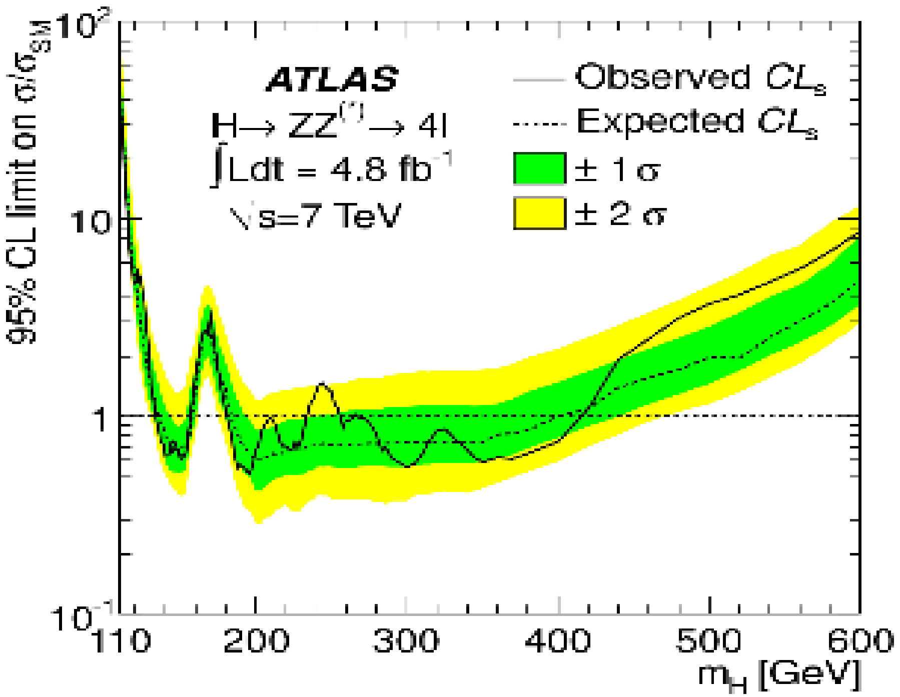
Consistency of observed data with background only hypothesis:

- **Excesses at 125 GeV, 244 GeV and 500 GeV with local significances of 2.1, 2.2 and 2.1 σ**
- **None of these excesses is significant with the look-elsewhere effect included**

Exclusion limits:

- **SM Higgs is excluded in the mass ranges 134-156 GeV, 182-233 GeV, 256-265 GeV and 268-415 GeV at the 95% confidence level**



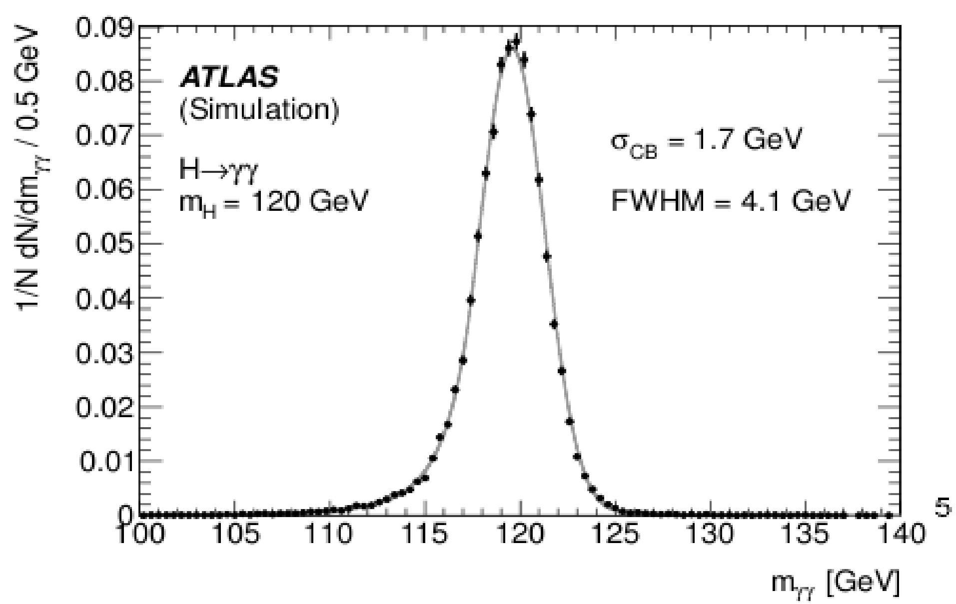


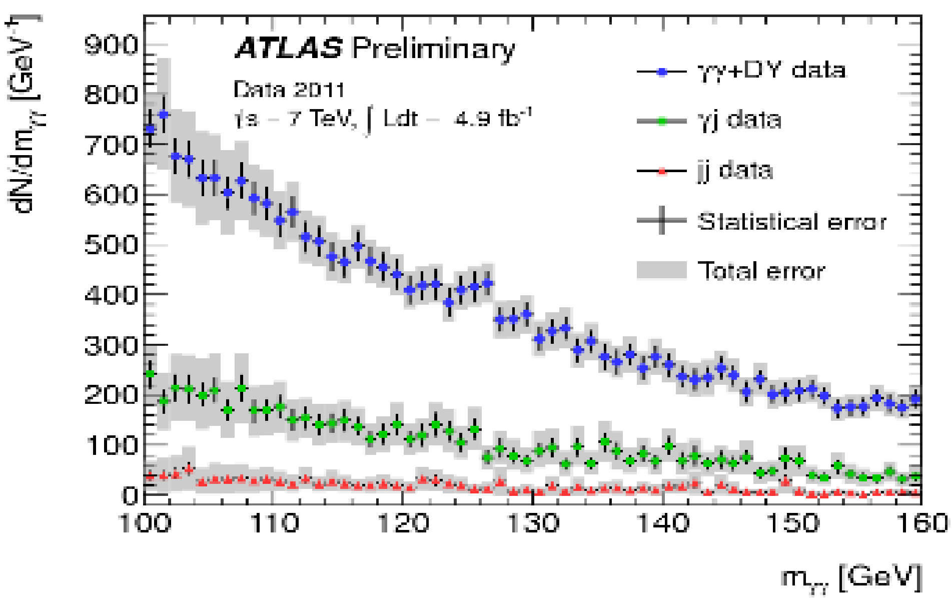
arXiv:1202.1415

H -> γγ

- Branching ratio is very small (0.2%) but clean signature
- Two energetic isolated photons (p_T > 40, 25 GeV) giving narrow mass peak
- Search for a narrow mass peak in di-photon mass spectrum
- Requires excellent EM energy resolution
- Split events in 9 categories to optimize signal/background
- SM backgrounds are determined from sidebands
- Background composition measured from data

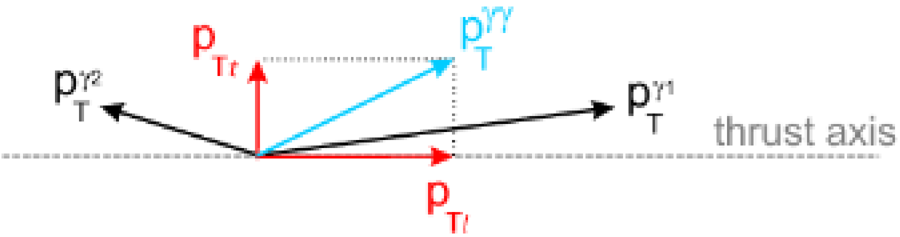
$\gamma\gamma$	$j\gamma$	jj	Z/γ^*
$71 \pm 5\%$	$23 \pm 4\%$	$5 \pm 3\%$	$0.7 \pm 0.1\%$



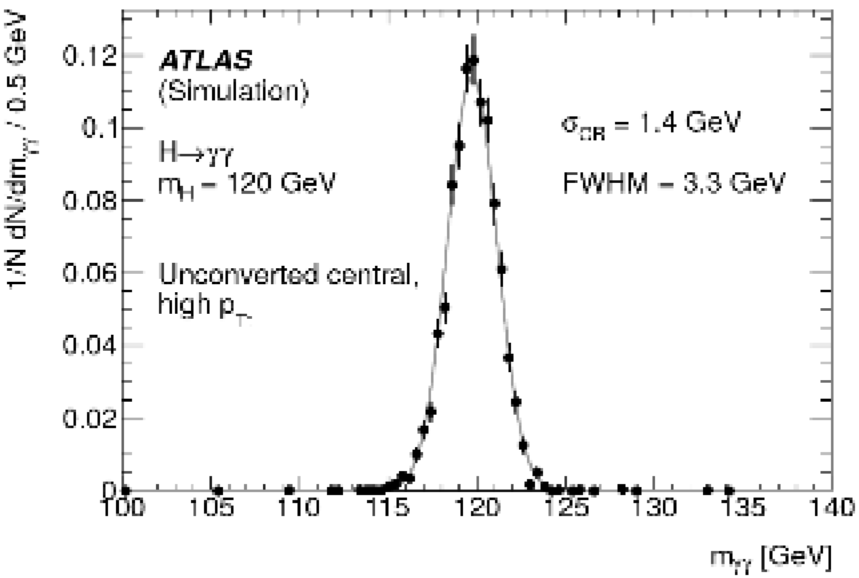


H -> γγ: analysis categories

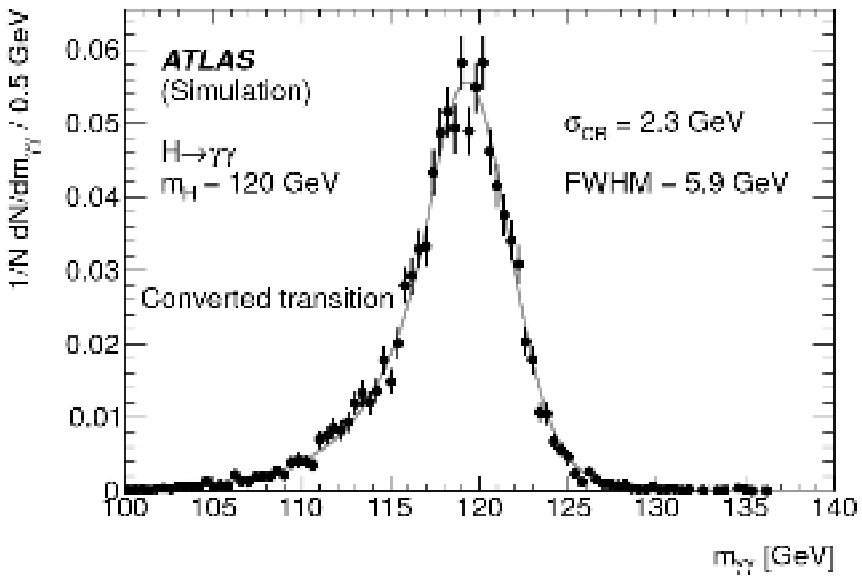
- 9 categories
- Converted and unconverted
- Central, endcap, transition region
- High (>40 GeV) and low (<40GeV) γγ p_T orthogonal to the thrust axis



Best: σ = 1.4 GeV, S/B=0.11

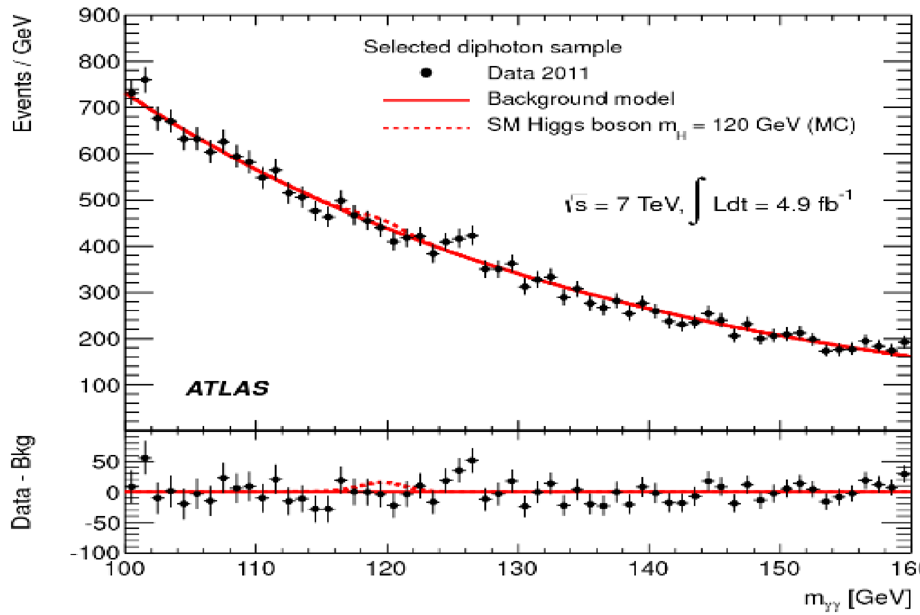


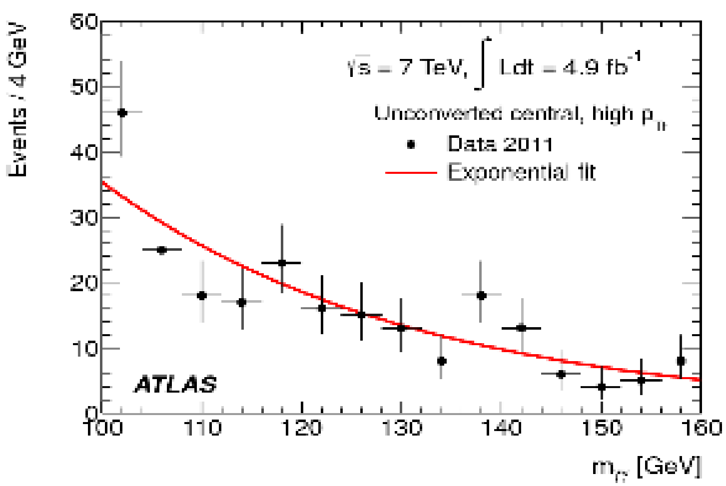
Worst: σ = 2.3 GeV, S/B=0.01

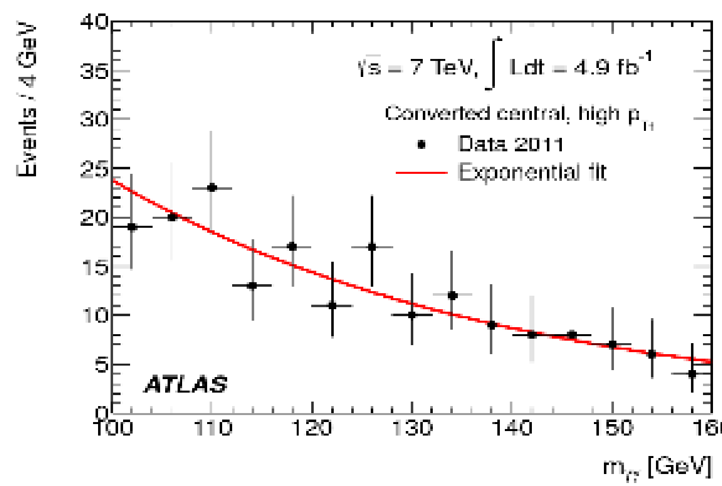


H -> γγ:

- Selected 22489 events in a mass region 100-160 GeV
- Expect 69 signal events at m_H = 125 GeV
- Fit signal with Crystal Ball (core) + Gaussian (tails)
- Fit background with exponential



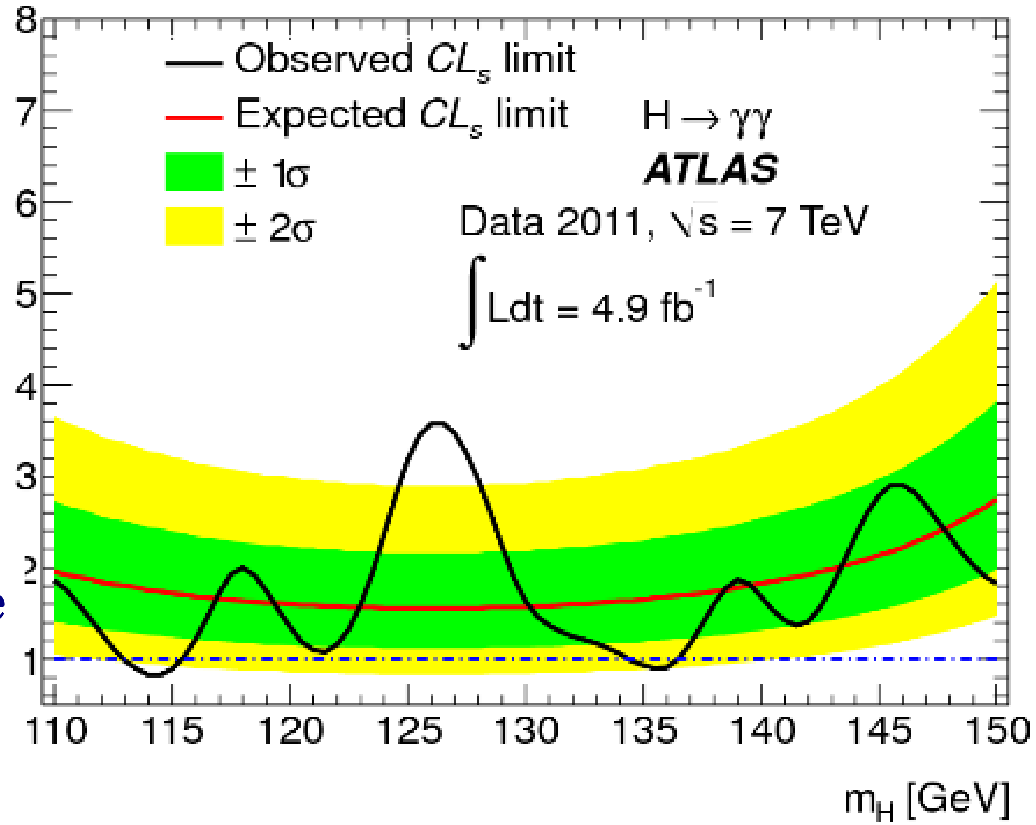




H -> γγ: Results

Consistency of observed data with background only hypothesis:

- **The largest excess is at 126.5 GeV with local significance of 2.8 σ**
- **1.5 σ with look-elsewhere effect in the range 110-150 GeV**



Exclusion limits:

- **SM Higgs excluded at 95% confidence level in the ranges 113-115 GeV and 134.5-136 GeV**

arXiv:1202.1414

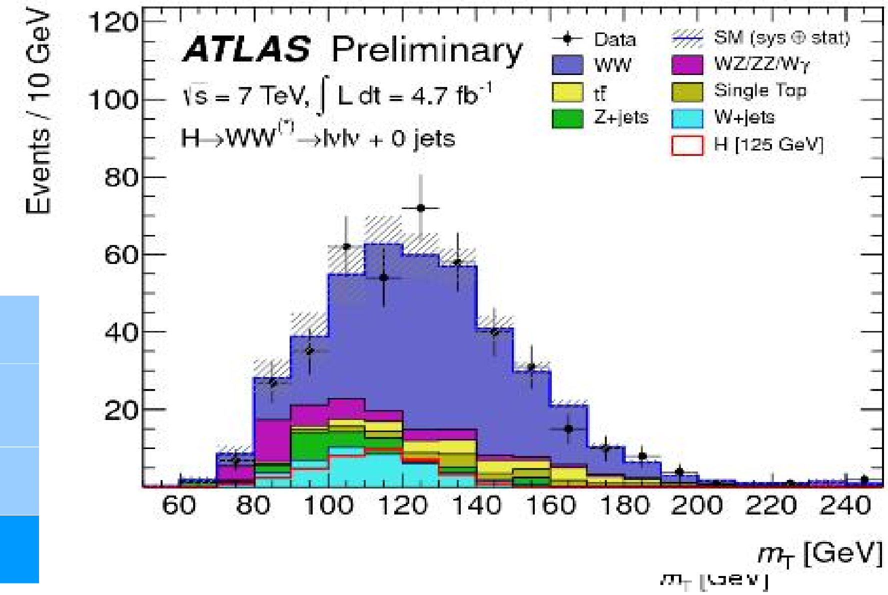
H -> WW$^{(*)}$ -> lνlν

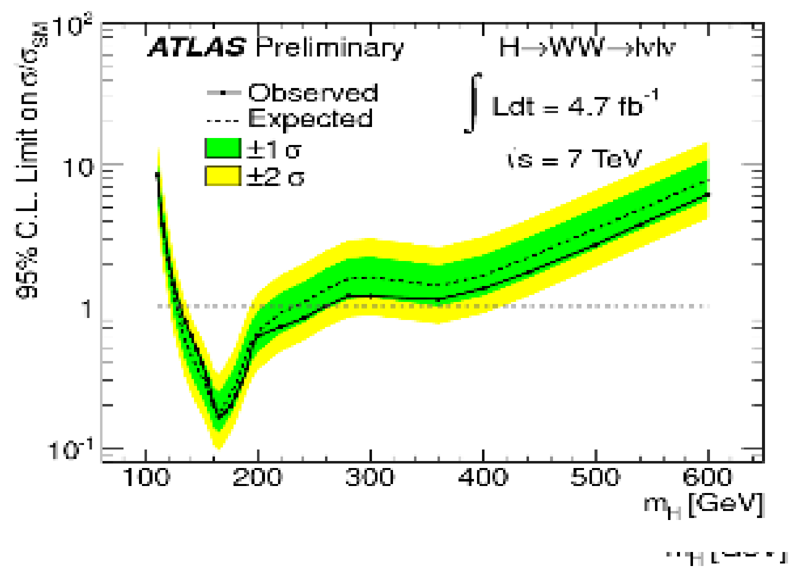
- **2 neutrinos - no mass reconstruction possible, use m_T instead**
- **Channel covers rather vast mass range**
- **Signature: 2 high p_T opposite sign isolated leptons (p_T > 25, 15 GeV) with large missing E_T**
- **Three lepton flavor channels (ee, μμ, eμ) ⊗ 3 jet multiplicity bins (0, 1, 2) (9 subchannels in total)**
- **Veto Z with mass window $|m_{ll} – m_Z| < 15$ GeV for ee , μμ**
- **$E_{T, miss}$ > 45 GeV (25 GeV) for ee and μμ (e μ)**
- **Irreducible background from SM WW**
- **Topological cuts against irreducible WW using Higgs zero spin (require small $\Delta\varphi_{ll}$)**
- **Reducible backgrounds from SM processes with mis-identified objects: W+jets, Z+jets, tt, single top, W + γ , W + γ* , WZ , ZZ**
- **Different kinematic cuts are used to suppress reduced background**
- **b tag veto to suppress top background**

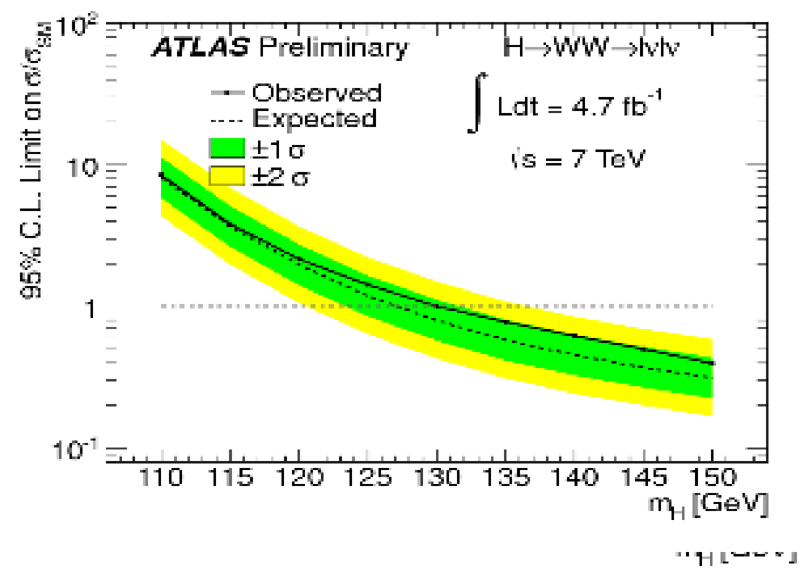
H -> WW$^{(*)}$ -> lνlν: results

- **Fit transverse mass distribution**
- **SM Higgs boson is excluded in the range 130-260 GeV at the 95% confidence level**

	0-jet	1-jet	2-jet
M_H = 125 Gev	25±7	6±2	0.4±0.2
Total bkg.	173±22	45±7	0.5±0.2
Observed	174	56	0







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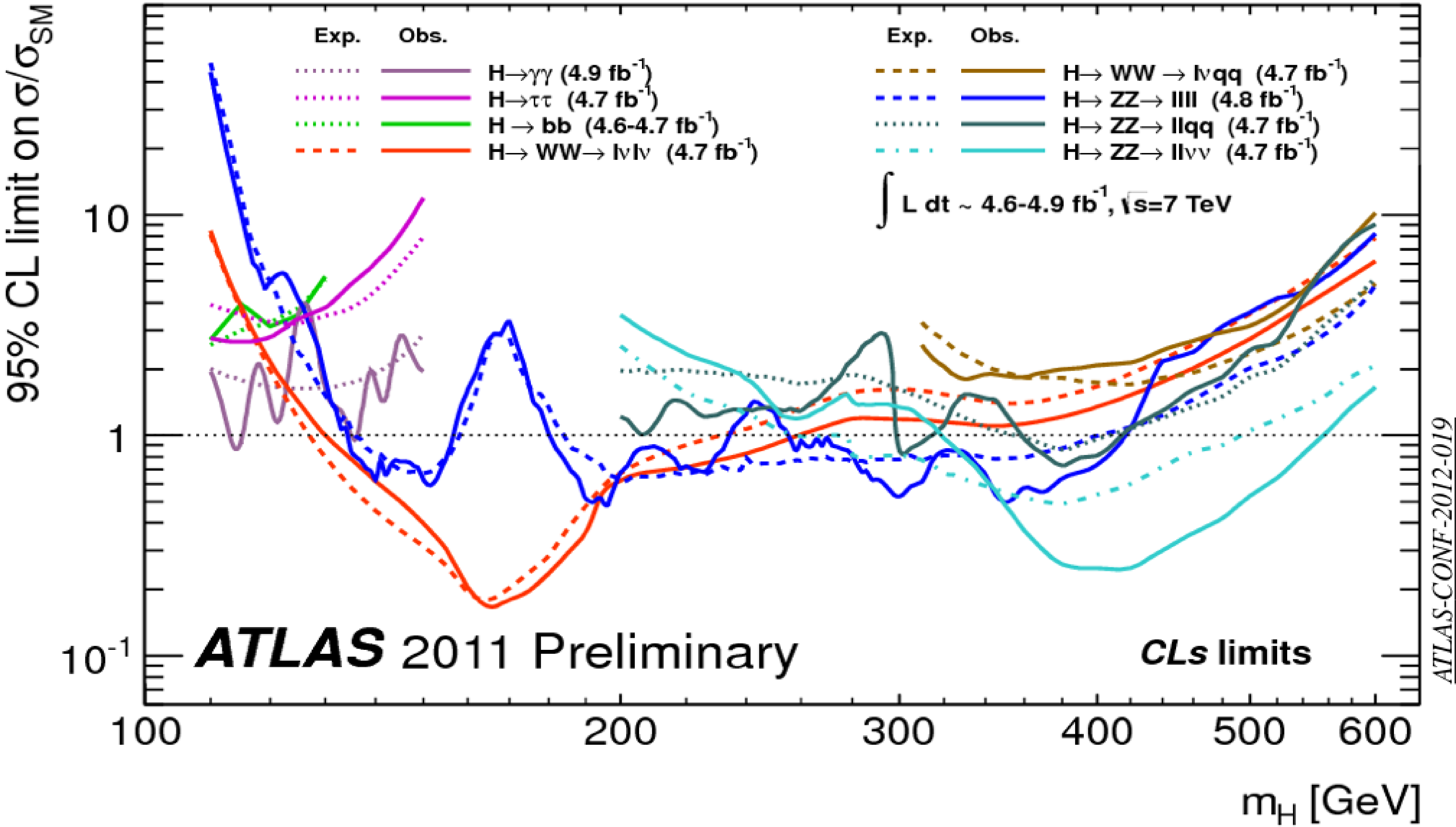
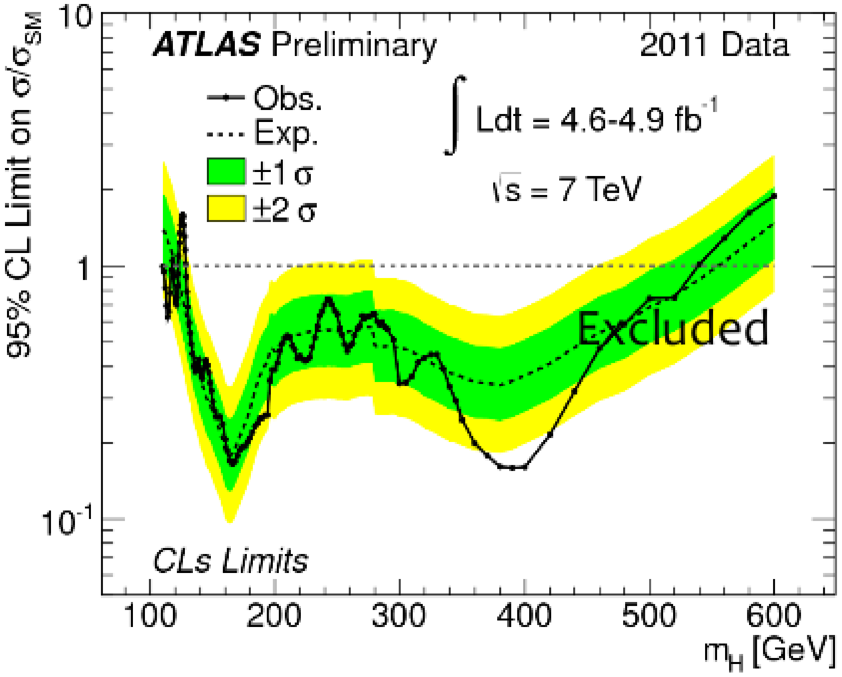
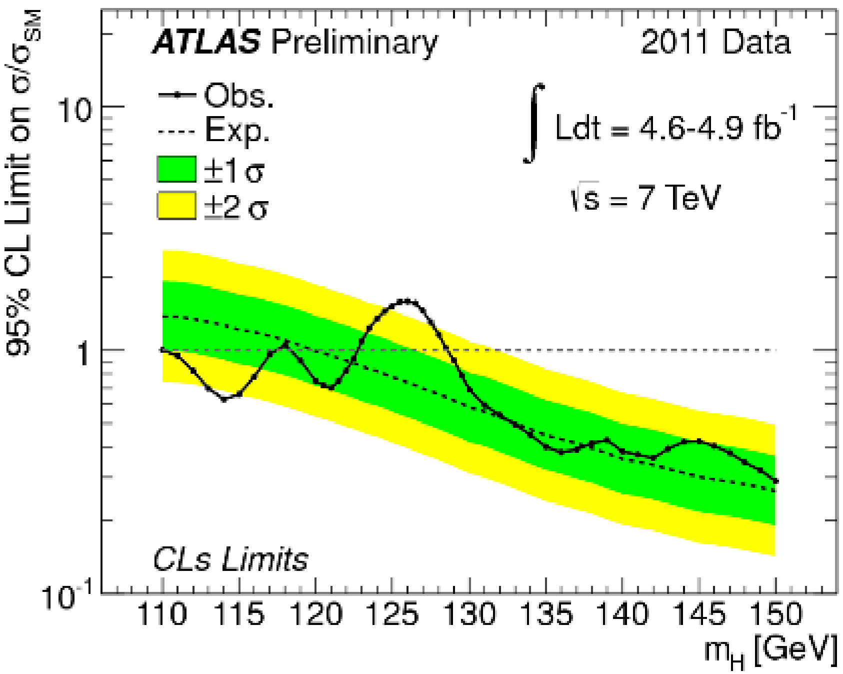
SM Higgs Combination



SM Higgs Combination





Expected Exclusion @ 95% CL: 120-555 GeV

Observed exclusion @95% CL: 110-117.5, 118.5-122.5, 129-539 GeV

Observed exclusion @ 99% CL: 130-486 GeV

ATLAS-CONF-2012-019

Summary

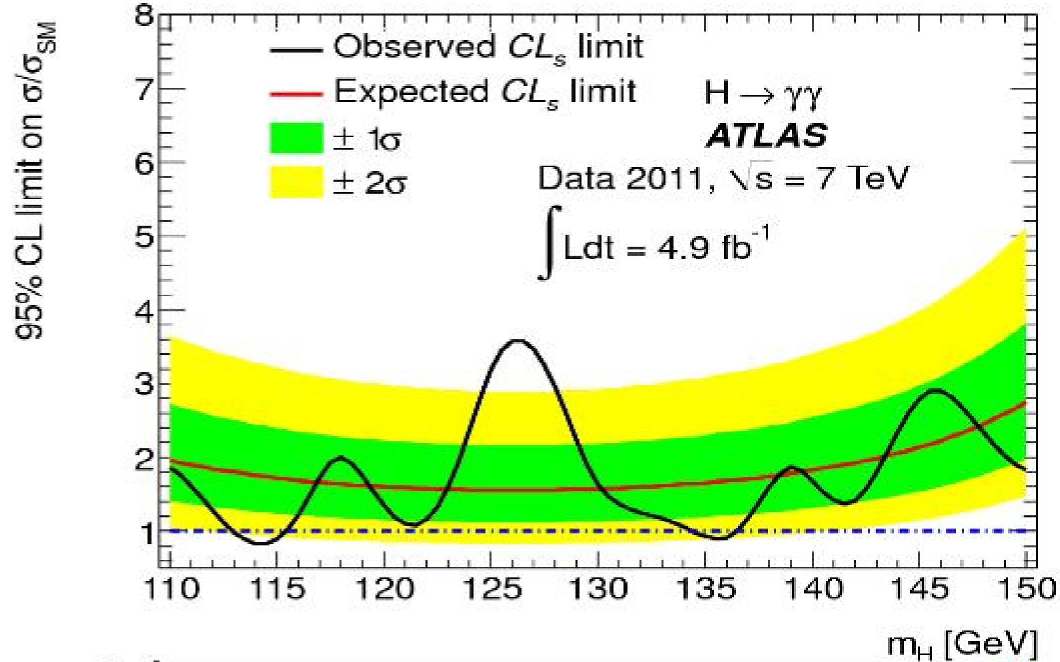
- **Latest results on the search for the SM Higgs boson from ATLAS have been obtained using 12 distinct channels with the full 2011 data of 4.7 fb^{-1}**
- **No evidence yet for the Higgs boson**
- **Only small region for the SM Higgs boson mass range is still allowed from 117.5-118.5 GeV or 122.5-129 GeV. The rest (up to 539 GeV) is excluded at the 95% confidence level**
- **The range 130-486 GeV is excluded at the 99% confidence level**
- **The excess of events near 126 GeV has a maximum local significance of 2.5 σ. Not yet possible to distinguish between background fluctuations or a Higgs boson signal**
- **The LHC & ATLAS are running well at 8 TeV now**
- **The expected integral luminosity by the end of 2012 is about 15-20 fb^{-1}**

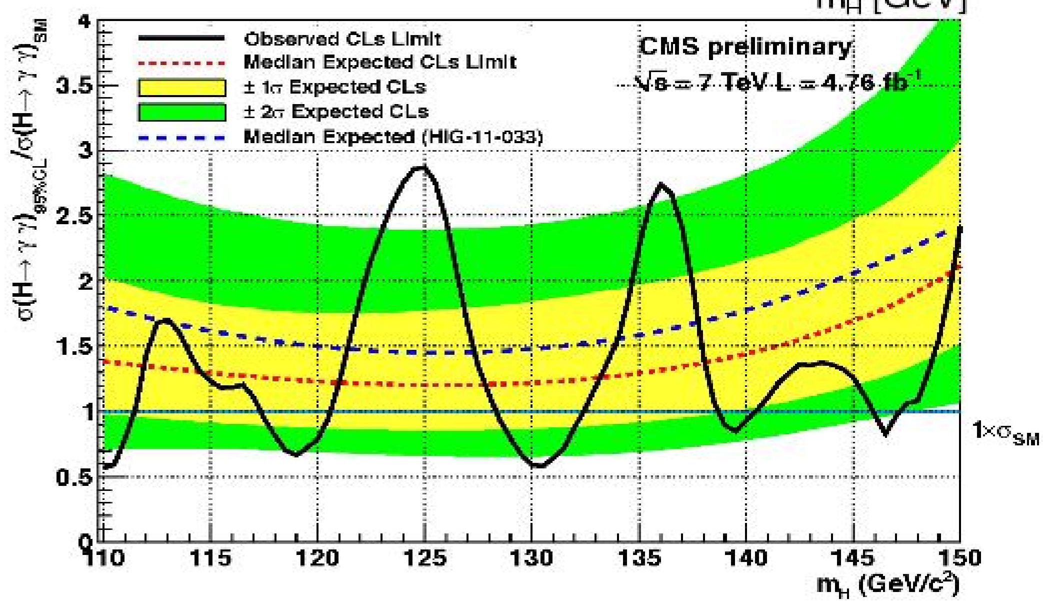
Backup slide 1

H → γγ

Expected limit is around 1.2-1.6 times SM cross-section

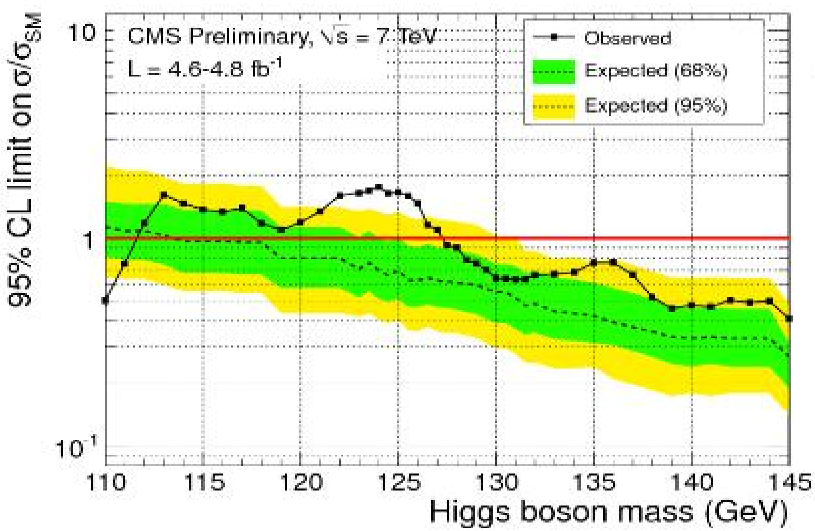
We do expect fluctuations due to statistics and the good mass resolution

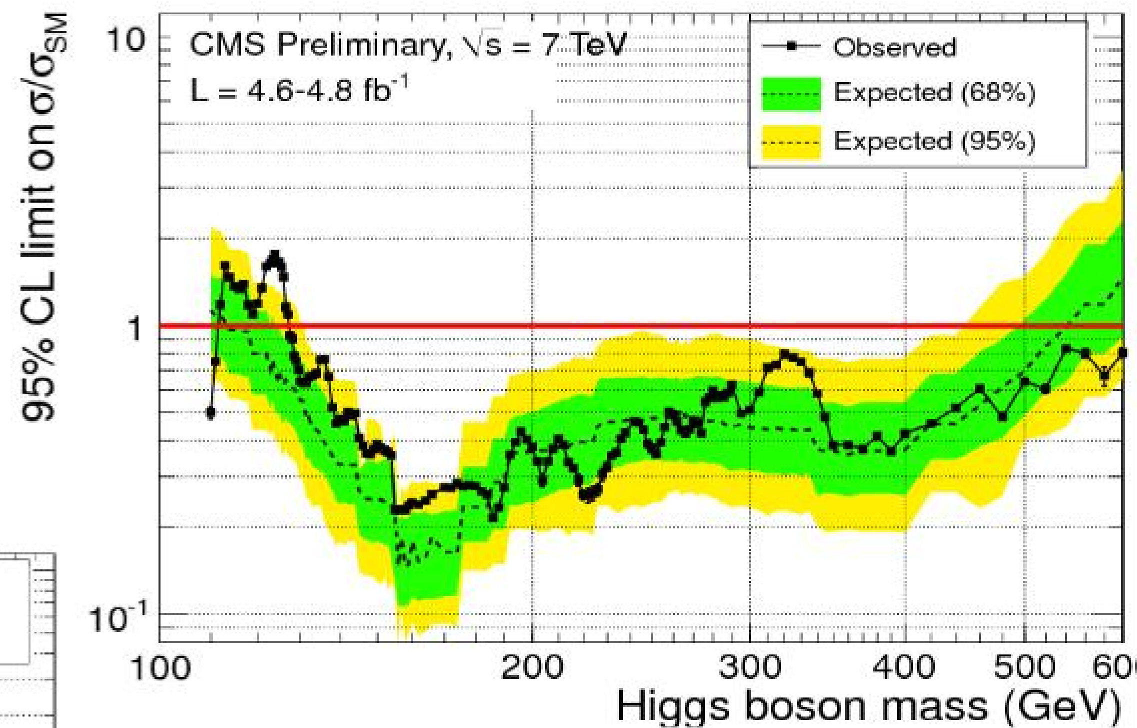




Backup slide 2

CMS Combination





Exclude at 95% CL: 127.5-600 GeV
Expected 95% CL exclusion: 114.5-543 GeV
Exclude 129-525 GeV at 99% CL