ATLAS Higgs Searches and Experiment Overview

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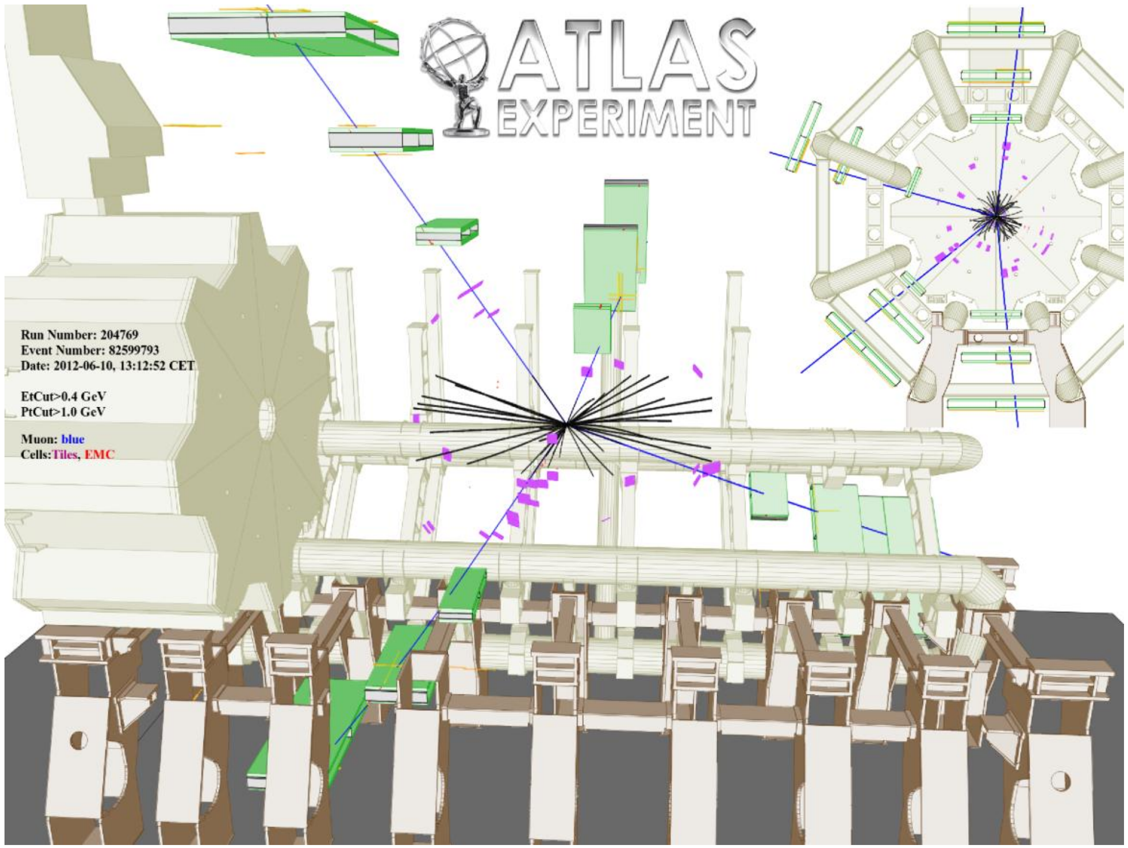
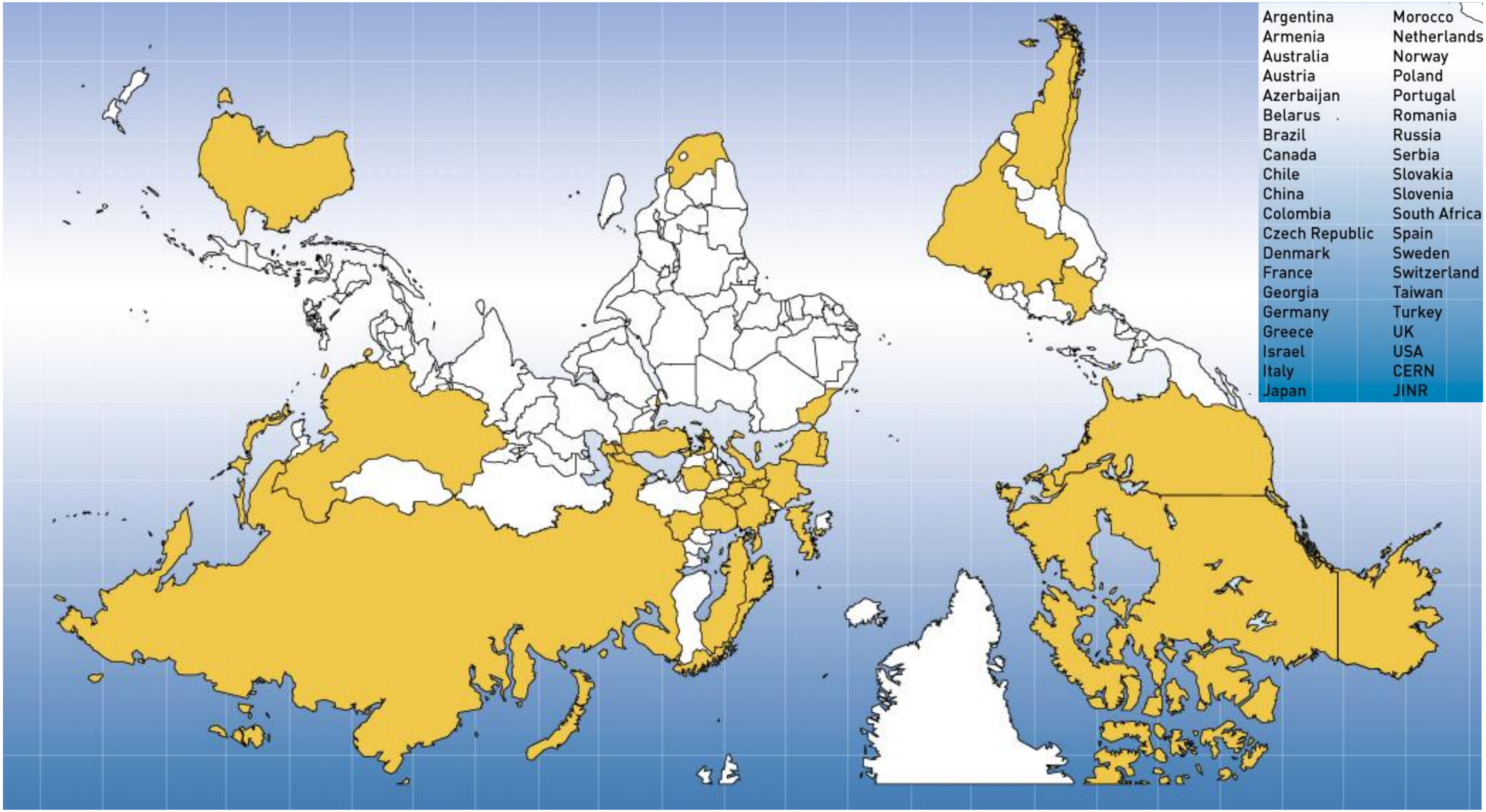
on behalf of the ATLAS collaboration

36th International Conference on High Energy Physics – Melbourne, Australia

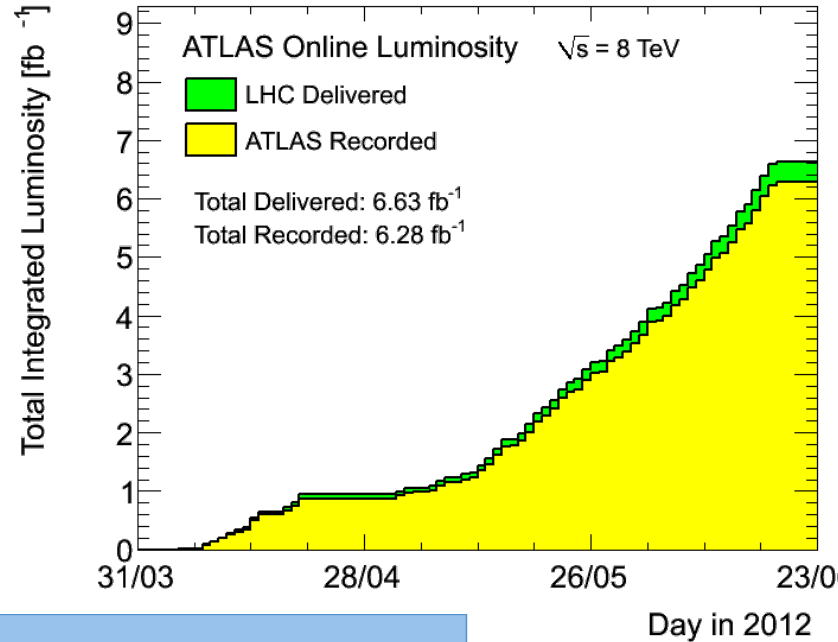


The ATLAS Collaboration



ATLAS in 2012: Data-taking and data quality

- Very good start to 2012 data-taking at 8 TeV
  - 6.3 fb^{-1} recorded with ~95% data-taking efficiency
  - 5.8 fb^{-1} available for typical analysis selections
    - 93.6% data-quality efficiency, will improve after reprocessing this year's data



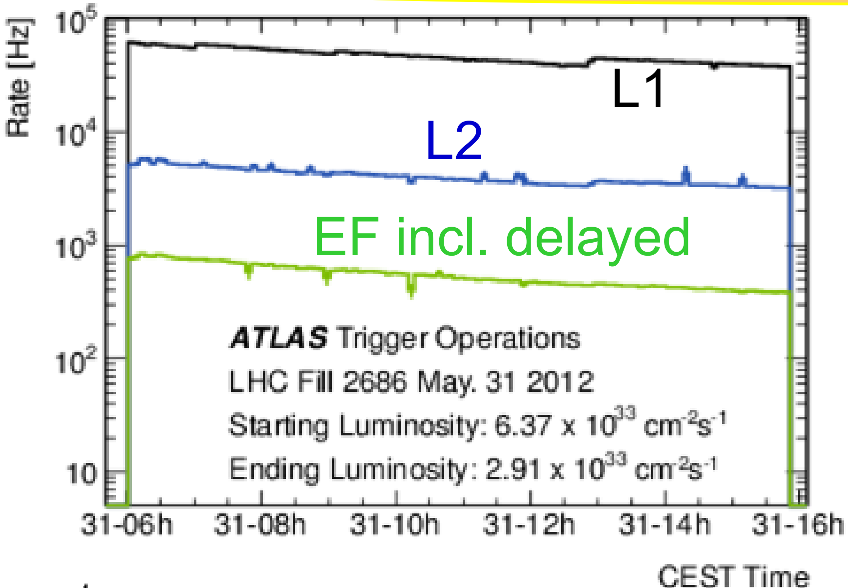
ATLAS p-p run: April-June 2012

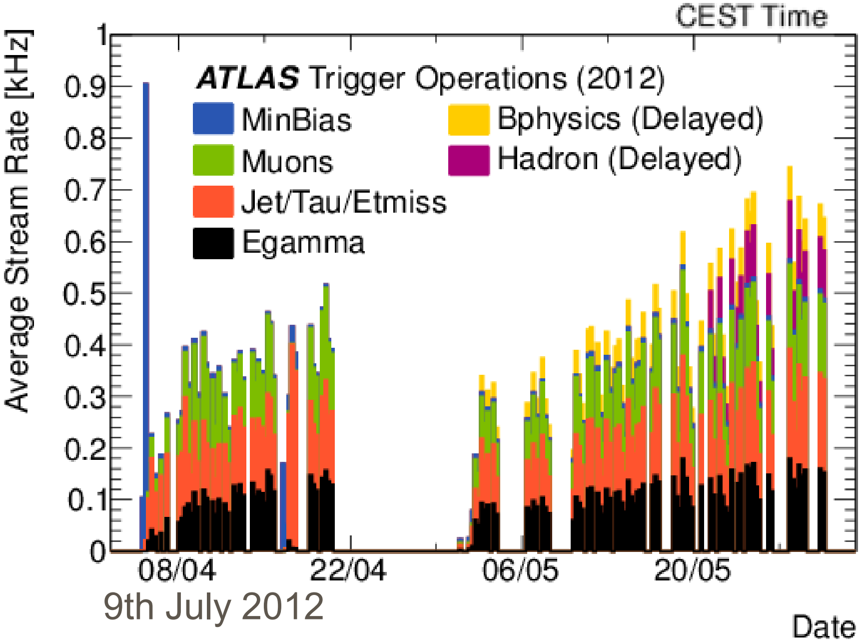
Inner Tracker			Calorimeters		Muon Spectrometer				Magnets	
Pixel	SCT	TRT	LAr	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
100	99.6	100	96.2	99.1	100	99.6	100	100	99.4	100

All good for physics: 93.6%

Luminosity weighted relative detector uptime and good quality data delivery during 2012 stable beams in pp collisions at √s=8 TeV between April 4th and June 18th (in %) – corresponding to 6.3 fb^{-1} of recorded data. The inefficiencies in the LAr calorimeter will partially be recovered in the future.

The ATLAS trigger in 2012 data





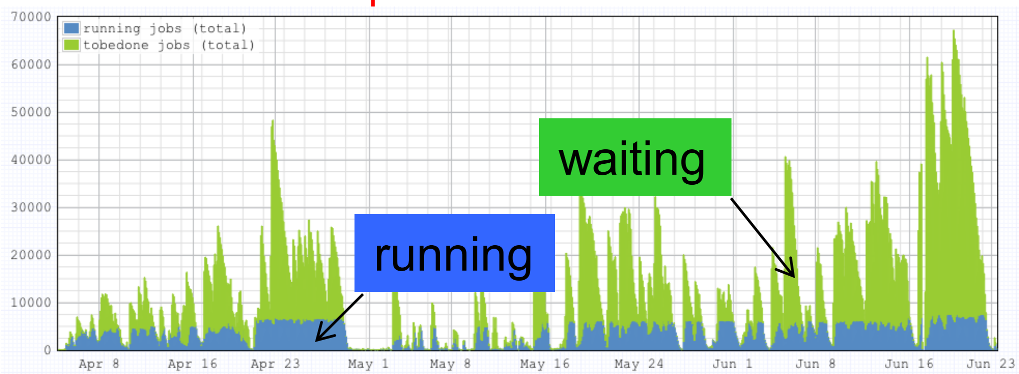
- Menu optimised for 7×10^{33} cm^{-2}s^{-1} at 8 TeV
  - ~65 kHZ L1, average 400 Hz EF output rate
  - Enable lower-priority triggers in long fills
- Some 'staple' menu items at 7×10^{33} cm^{-2}s^{-1}

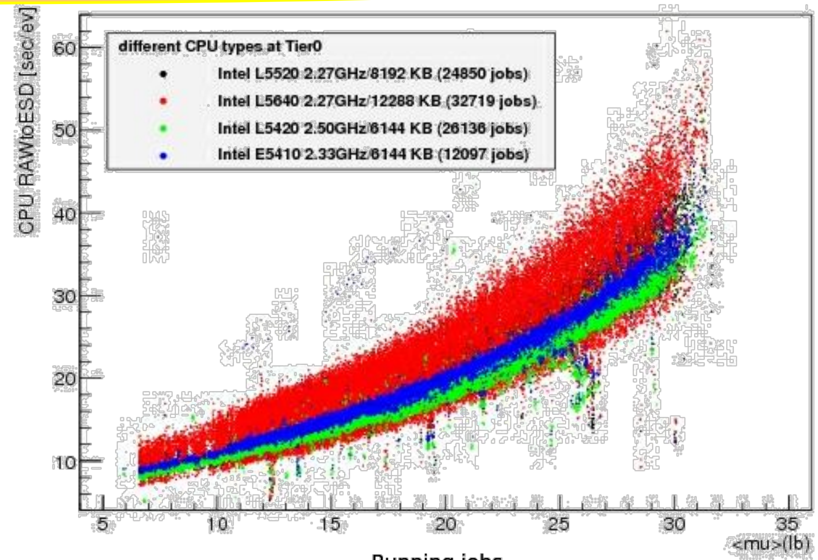
Offline (GeV)	**L1 thr (GeV)**	**L1 rate (kHz)**	**EF thr (GeV)**	**EF rate (Hz) @ 5 10^{33}**
e > 25	18	17	24	70
μ > 25	15	8	24	45
dilepton	10-15	15	8-18	21
2γ 25-40	10-16	12	20-35	17
2τ 30-45	11-15	12	20-29	12
Jet > 360	75	2	2	5
MET 120	40	2	80	17

  - Additional b-physics and hadronic triggers to 'delayed' streams for later processing

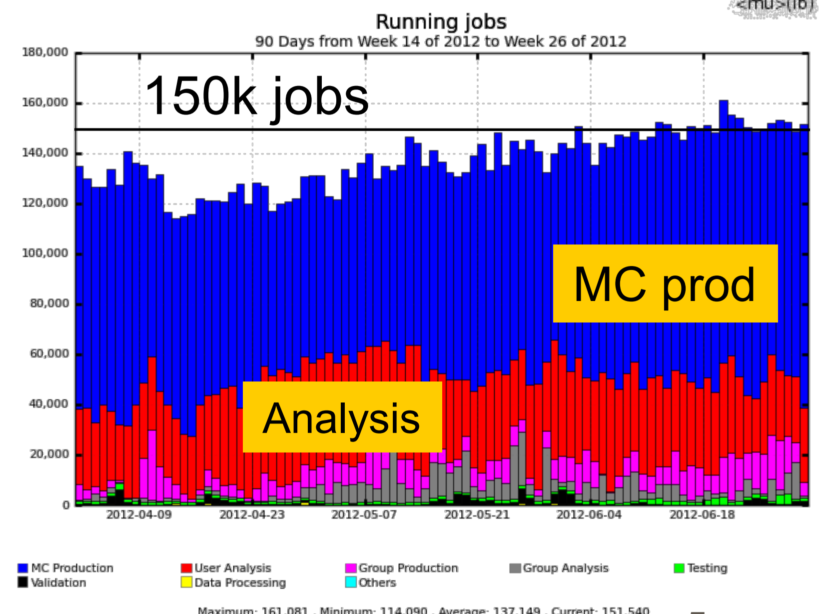
ATLAS offline computing

- Prompt data reconstruction at Tier-0 has kept up with LHC performance in last weeks
  - Extra resources used – up to 7.5k CPU cores
  - 15-40 seconds/event for RAW→ESD step
    - In line with expectations from simulation

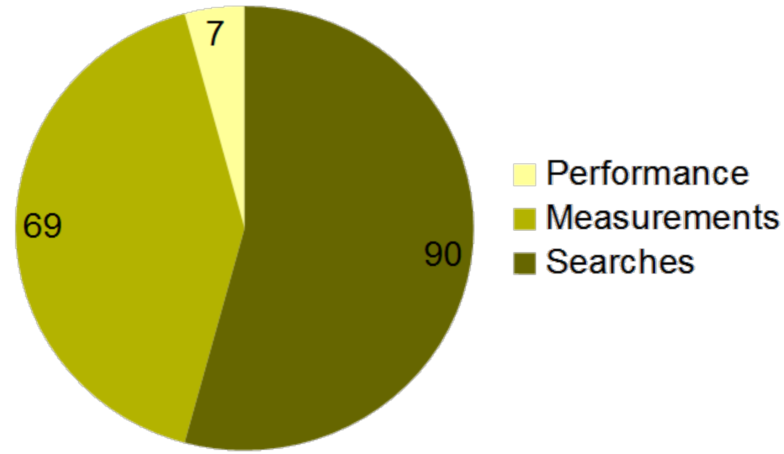




- World-wide Grid computing is essential
  - Up to 150k simultaneous jobs running in parallel
    - Mainly MC simulation and user analysis jobs
  - Computing centres give resources beyond pledged commitments
    - Very beneficial for the broad physics program



Physics analysis and publications

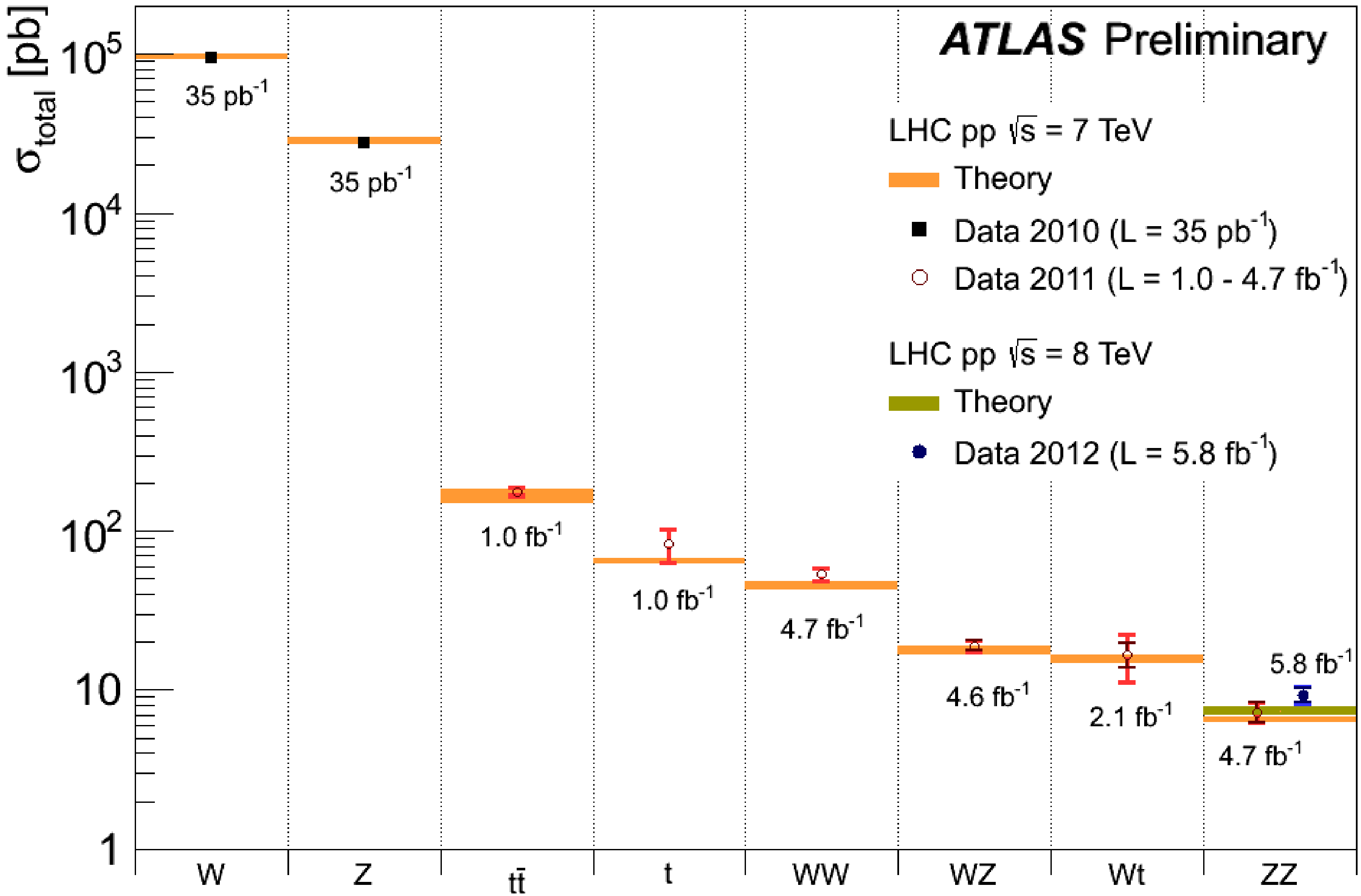


- 166 papers on collision data
  - Average of ~2 papers/week this year
- 363 CONF notes with preliminary results
  - 35 new CONF notes for this conference
- ATLAS results available at https://twiki.cern.ch/twiki/bin/view/AtlasPublic
- No time to review all the new ATLAS physics results for this conference
  - See ATLAS parallel session talks, and other plenary talks:

Subject	Speaker	Subject	Speaker
Top physics	Thomas Müller	Jets/QCD	Dmitry Bandurin
Electroweak	Joao Guimaraes	Soft QCD	Paul Newman
SUSY	Andy Parker	Heavy flavour	Sheldon Stone
BSM searches	Steve Worm	Heavy ions	Johanna Stachel

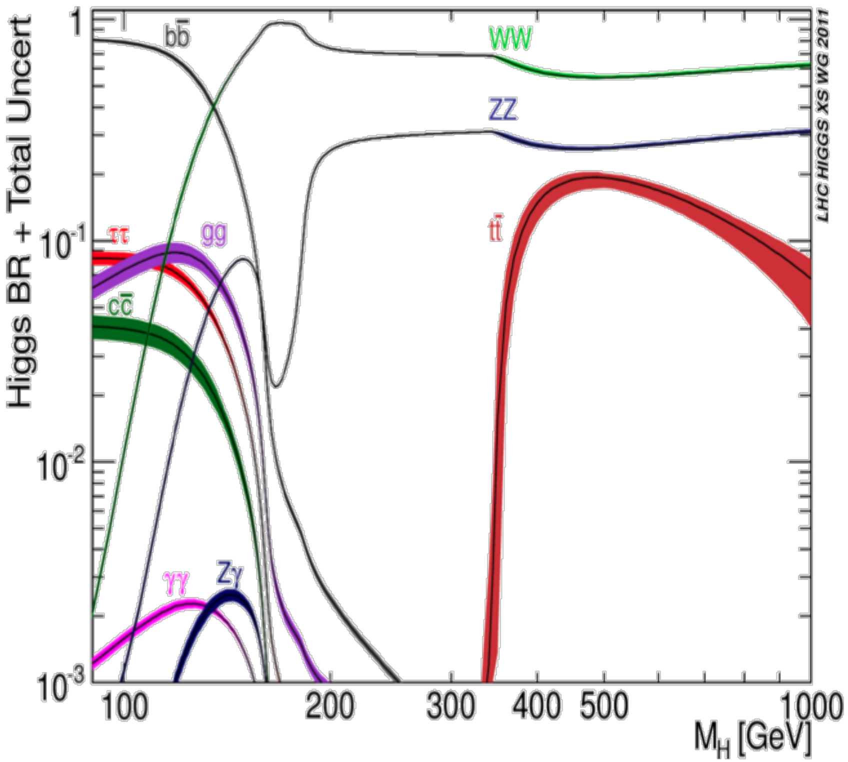
Summary of Standard Model measurements

- Foundations for searches - measurements of W, Z, diboson and top prod^{n}:



Search for the SM Higgs – story from 2011 data

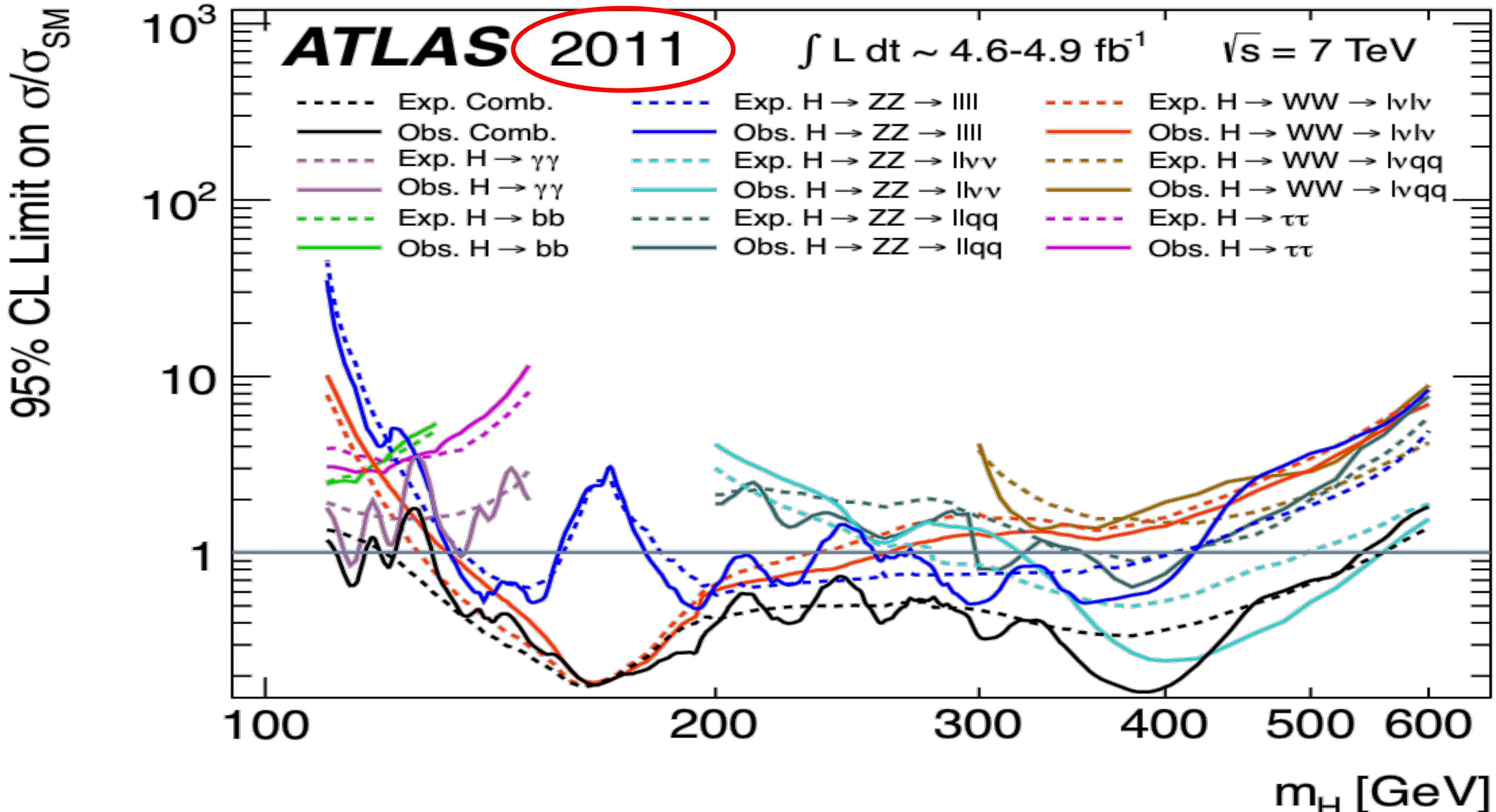
- SM Higgs phenomenology precisely predicted, apart from mass m_H
  - Production dominated by gg fusion; then VBF $qq \rightarrow qqH$, associated WH and ZH
  - Decay modes vary with m_H as $H \rightarrow WW(*)$ and then $H \rightarrow ZZ(*)$ open up



Decay	m_H range (GeV)	arXiv
$H \rightarrow \gamma\gamma$	110-150 (*)	1202.1414
$H \rightarrow ZZ(*) \rightarrow 4l$	110-600 (*)	1202.1415
$H \rightarrow ZZ \rightarrow llqq$	200-280-600	1206.2443
$H \rightarrow ZZ \rightarrow ll\nu\nu$	200-300-600	1205.6744
$H \rightarrow WW(*) \rightarrow l\nu l\nu$	110-200-300-600	1206.0756
$H \rightarrow WW \rightarrow l\nu qq$	300-600	1206.6074
$H \rightarrow \tau\tau \rightarrow ll, l\tau_h, \tau_h\tau_h$	110-150	1206.5971
$VH \rightarrow l\nu bb, llbb, \nu\nu bb$	110-130	1207.0210

- 2011 combination (arXiv 1207.0319) takes all info (signal/control regions) from all modes, fits to the SM Higgs signal model (prod^n/decay modes) as function of m_H
  - Scale the overall production rate coherently by a 'signal-strength' parameter μ

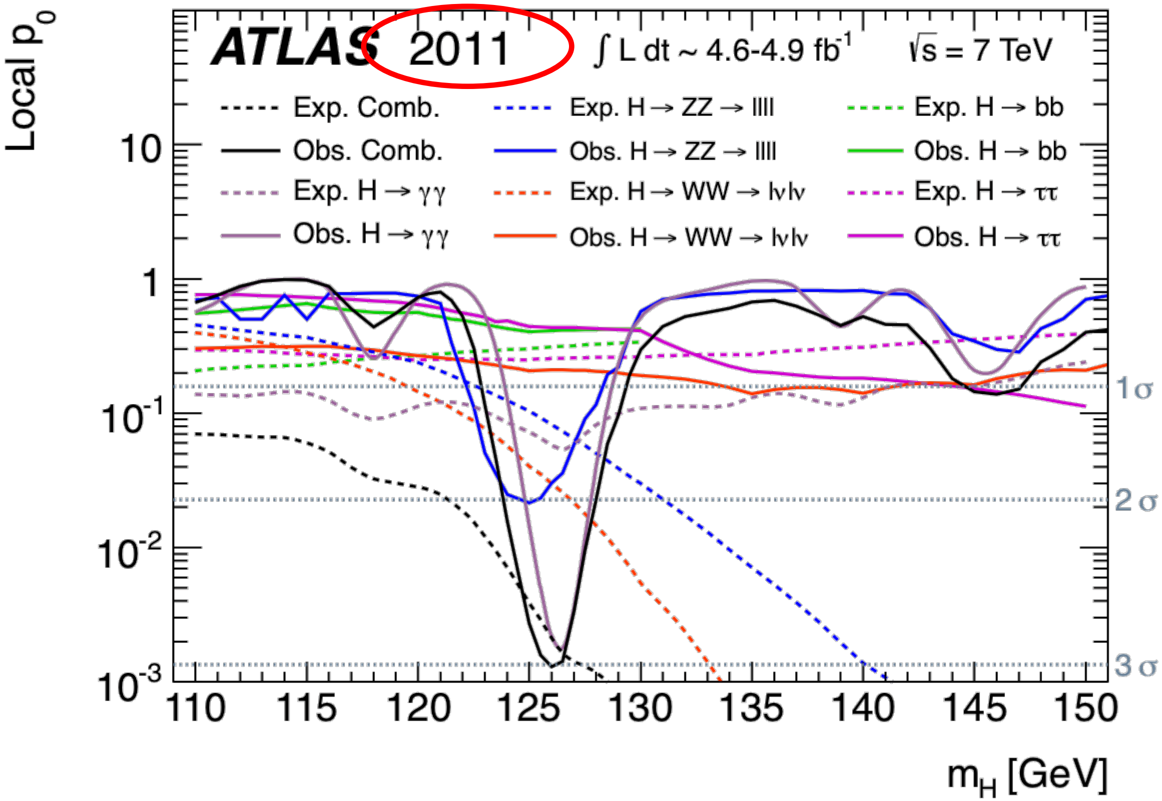
Exclusion with the 2011 data



- Expected exclusion of μ=1 in absence of signal is **120-560** GeV
- **114.4-116.6**, **119.4-122.1** and **129.2-541** GeV are excluded at 95% CL
  - And 130.7-506 GeV excluded at 99% CL

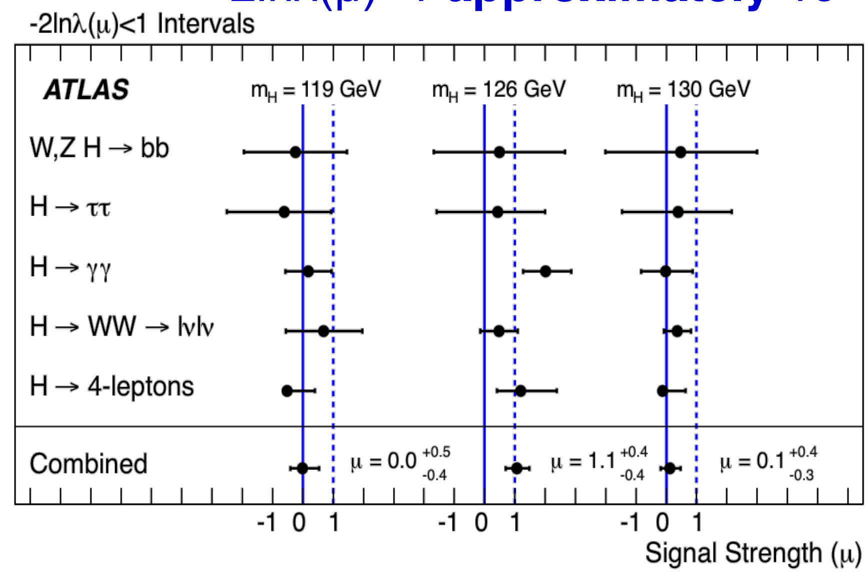
Hints in the 2011 data

- Compatibility with background-only hypothesis quantified with local p_0



Channel	γγ	ZZ	WW	Comb
Observed **local** p_0	2.8	2.1	0.8	2.9
Exp. m_H=126 GeV	1.4	1.4	1.9	2.9

- Best-fit signal strength μ for different assumed m_H
  - $-2\ln\lambda(\mu)<1$ **approximately** 1σ

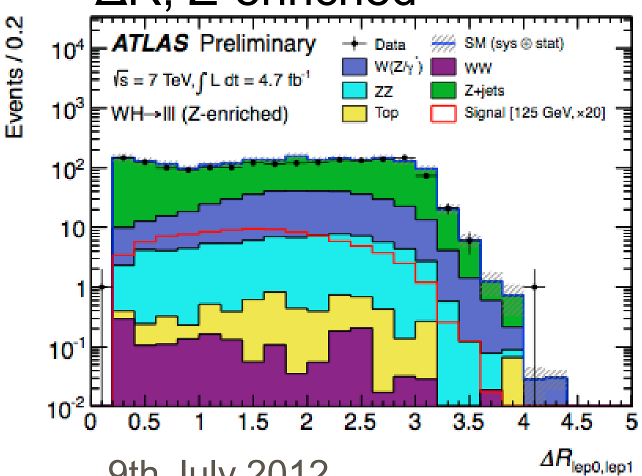


- Minimum p_0 at m_H=126 GeV
- 'Look elsewhere effect': Probability for a combined excess as least as significant in 110-600 GeV is **15%** (~1σ)

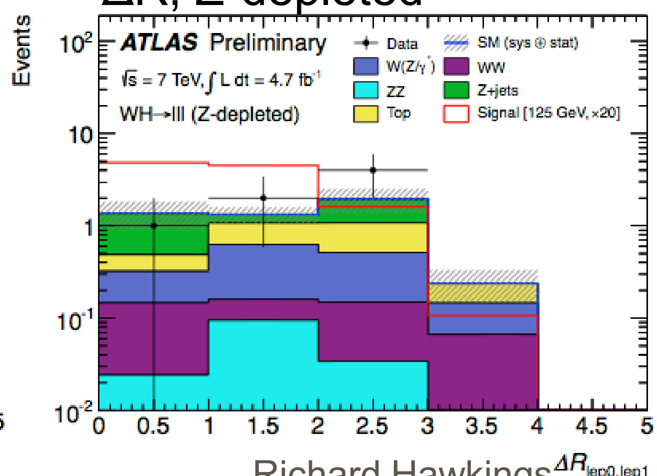
WH→WWW search with 2011 data

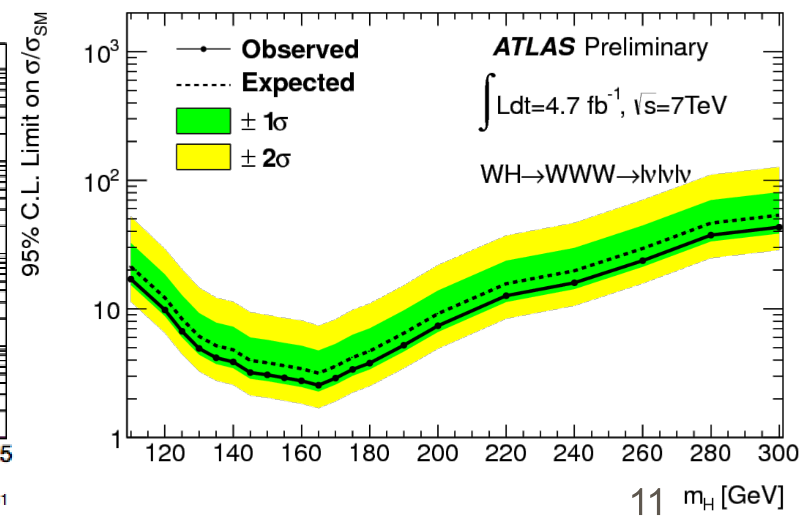
- Associated prod^{n} of WH probes different production mechanism (few % of gg)
  - High sensitivity to HWW coupling, especially in H→WW decay sub-channel
- Search for WH→WWW→lνlνlν – 3 leptons and missing-E_T in final state
  - Select signal based on 3 isolated leptons, at most one jet (without b-tag)
  - Split into 'Z-enriched' (one lepton pair charges/flavours consistent with Z, veto on Z-mass), and 'Z-depleted' samples
  - Final selection using missing-ET and ΔR between oppositely charged leptons (ΔR<0.2)
    - Veto events selected by standard H→WW→lνlν analysis
- No excess seen, limit set between 2.7 (at m_H=165 GeV) and 43x SM expectation

ΔR, Z-enriched



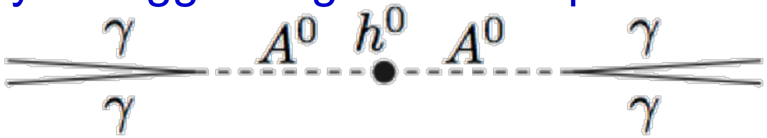
ΔR, Z-depleted



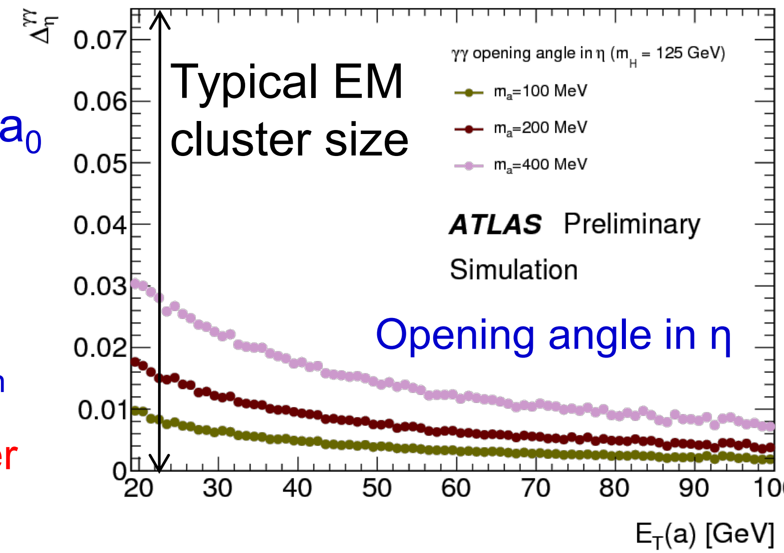


Non-SM H→4γ

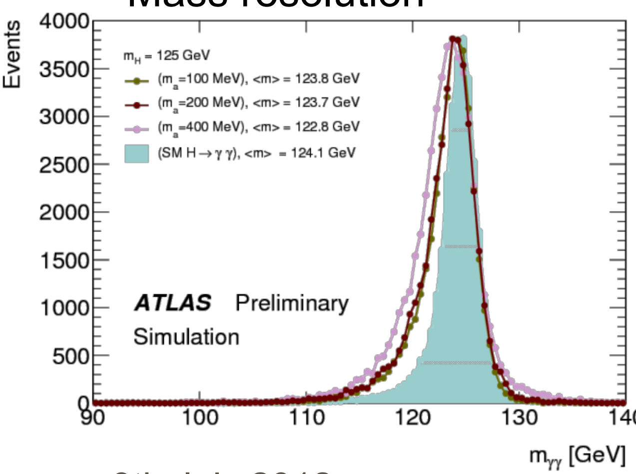
- Interest in other models with similar signature
  - Decay of Higgs to light CP-odd pseudoscalars $H \rightarrow a_0 a_0$



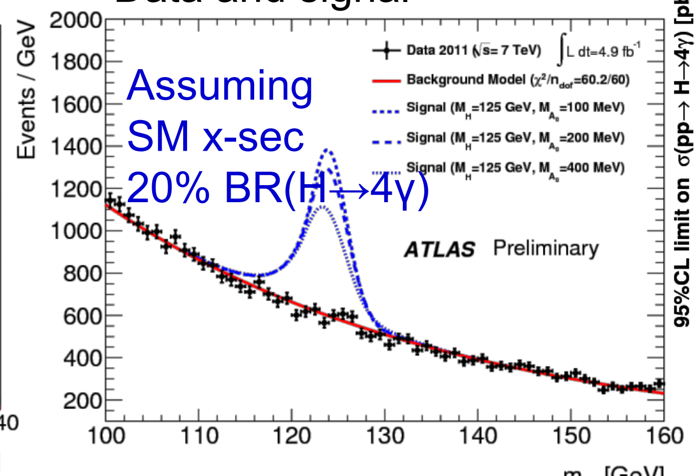
  - a_0 decays to two very collimated photons with small separation, mimics $H \rightarrow \gamma\gamma$ with slightly degraded resl^n
    - Relax photon identification for broader (merged) shower
    - Applicable for a_0 decays <~0.5m, $100 < m(a_0) < 400$ MeV
  - No signal observed, set limits on $\sigma \times BR(H \rightarrow 4\gamma)$



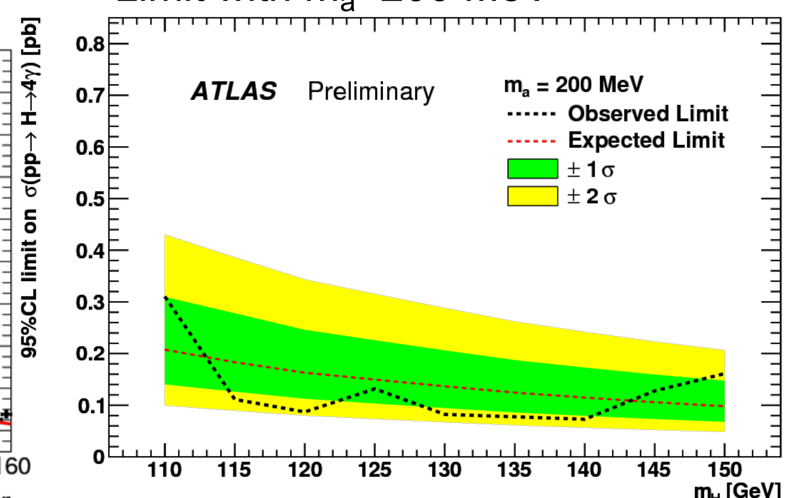
Mass resolution



Data and signal

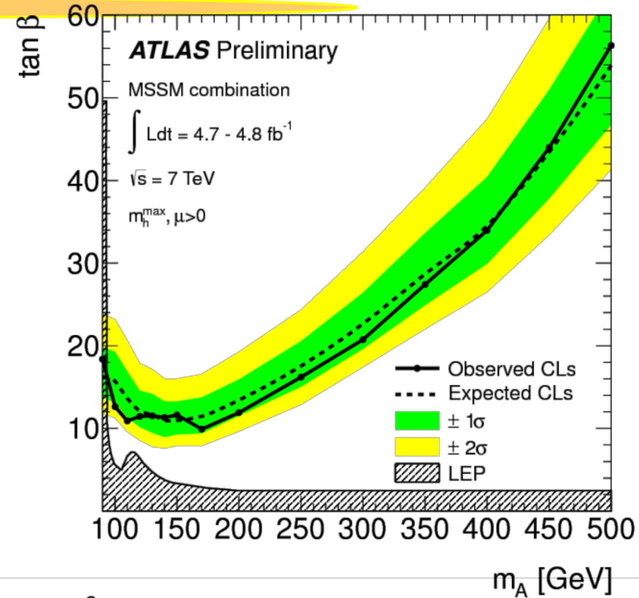


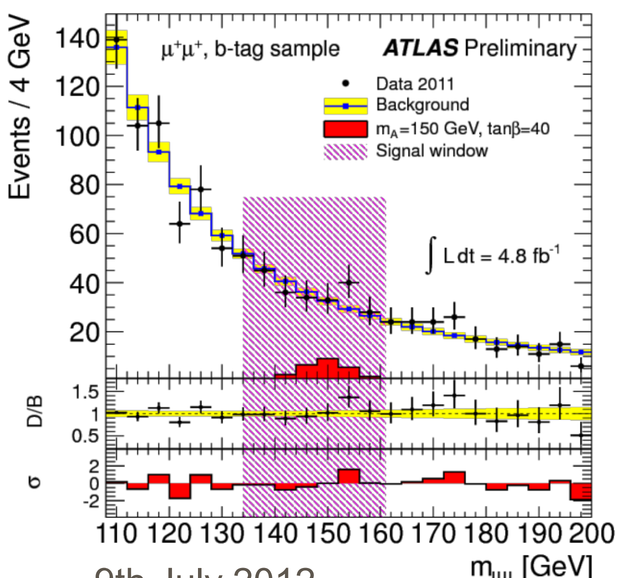
Limit with m_a=200 MeV

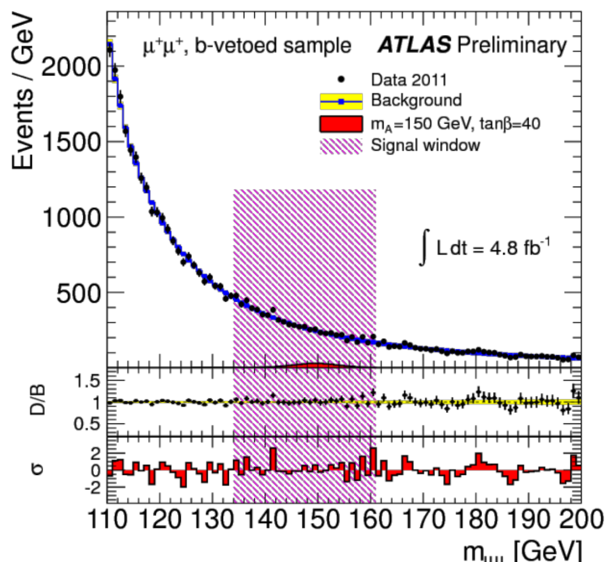


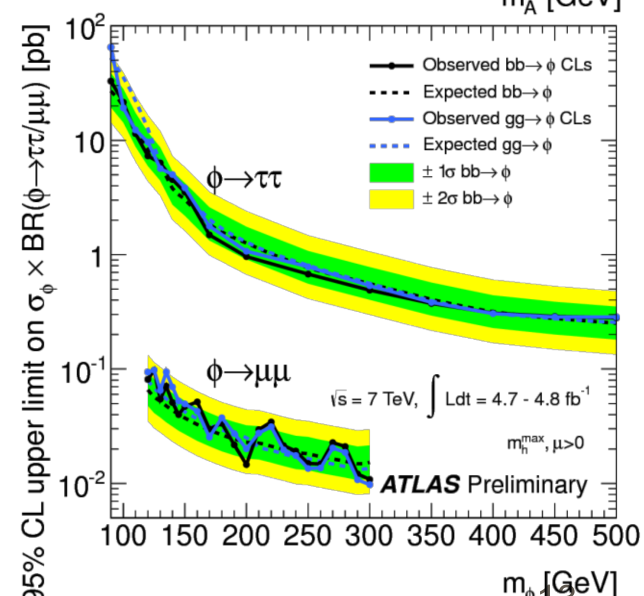
MSSM neutral Higgs searches

- 3 neutral Higgs bosons Φ in MSSM: h, H and A
  - Production via gluon fusion and b-quark annihilation
    - Cross-sections rise with tanβ, b-assoc. becomes dominant
  - Decay into b-bbar (90%), ττ (10%), μμ (0.04%)
- Search in both b-tagged and b-vetoed samples
  - μμ: clean signature, good mass resolution, but low rates
  - ττ: Similar to SM H→ττ but with b-tagged/vetoed sel
  - Set limits in $(m_A, \tan\beta)$ plane and generically on σ.BR



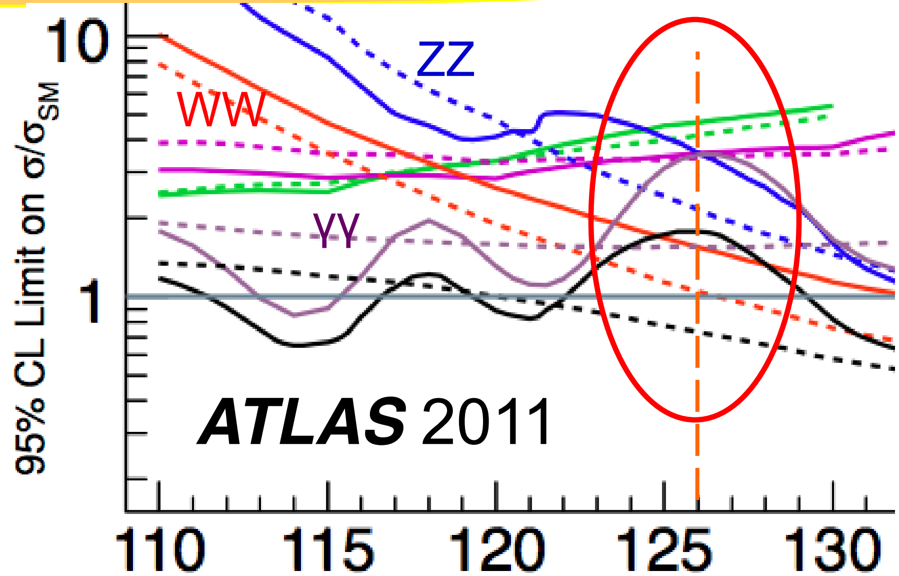


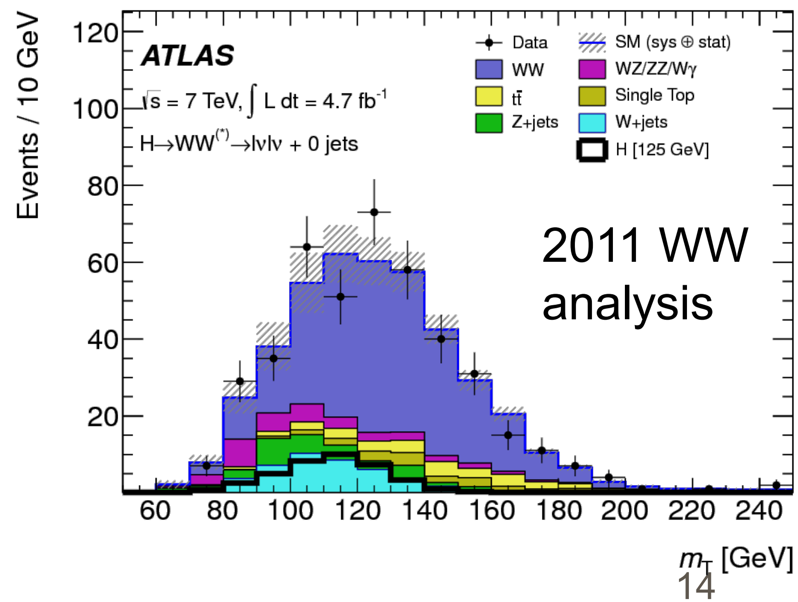




Strategy for 2012 SM Higgs analysis

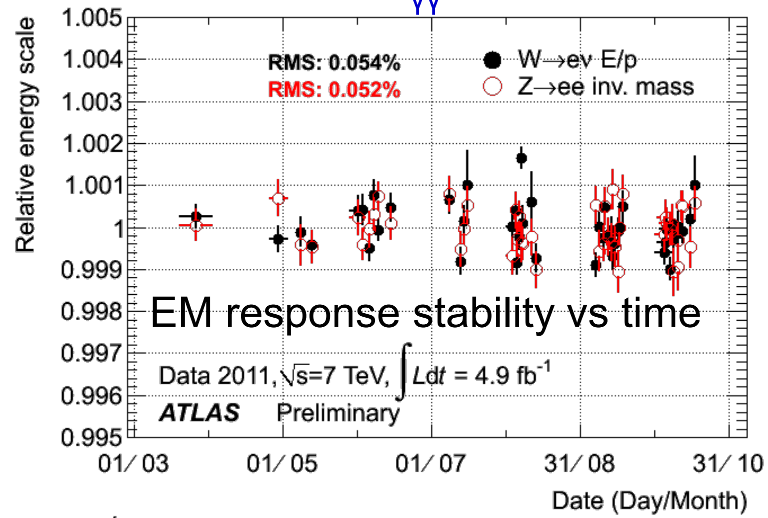
- Most sensitive channels at m_H=126 GeV are H→WW→lνlν, H→γγ and H→ZZ(*)→4l
  - Latter two have good mass resolution, and rely on photons, electrons and muons
    - Easier objects in a high pileup environment
- First priority on these two channels
  - Reoptimise analyses for high pileup and low m_H based on MC and 2011 control regions
  - All selections and analysis techniques fixed **before** looking at 2012 data
- WW is more difficult – expect broad excess in transverse mass distribution
  - Requires excellent understanding of (b)-jets, missing-E_T in high pileup environment
  - Understand everything thoroughly in control regions before 'unblinding'
  - Plan to have results for end-July paper



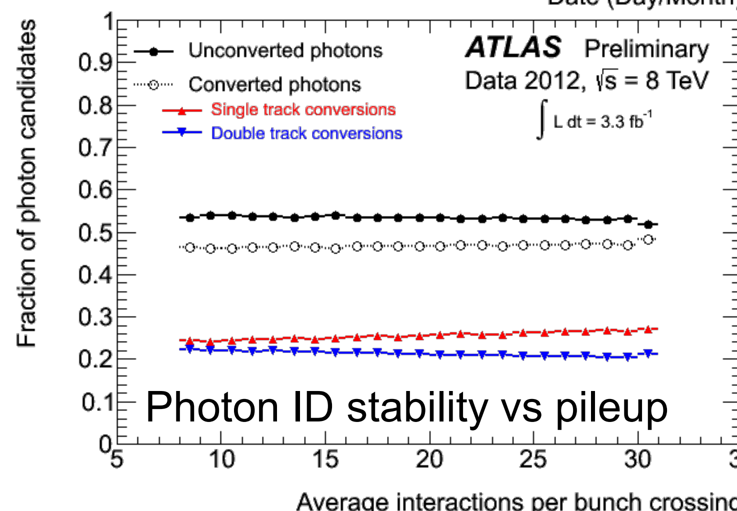


Update of the H→γγ analysis: 2011+2012 data

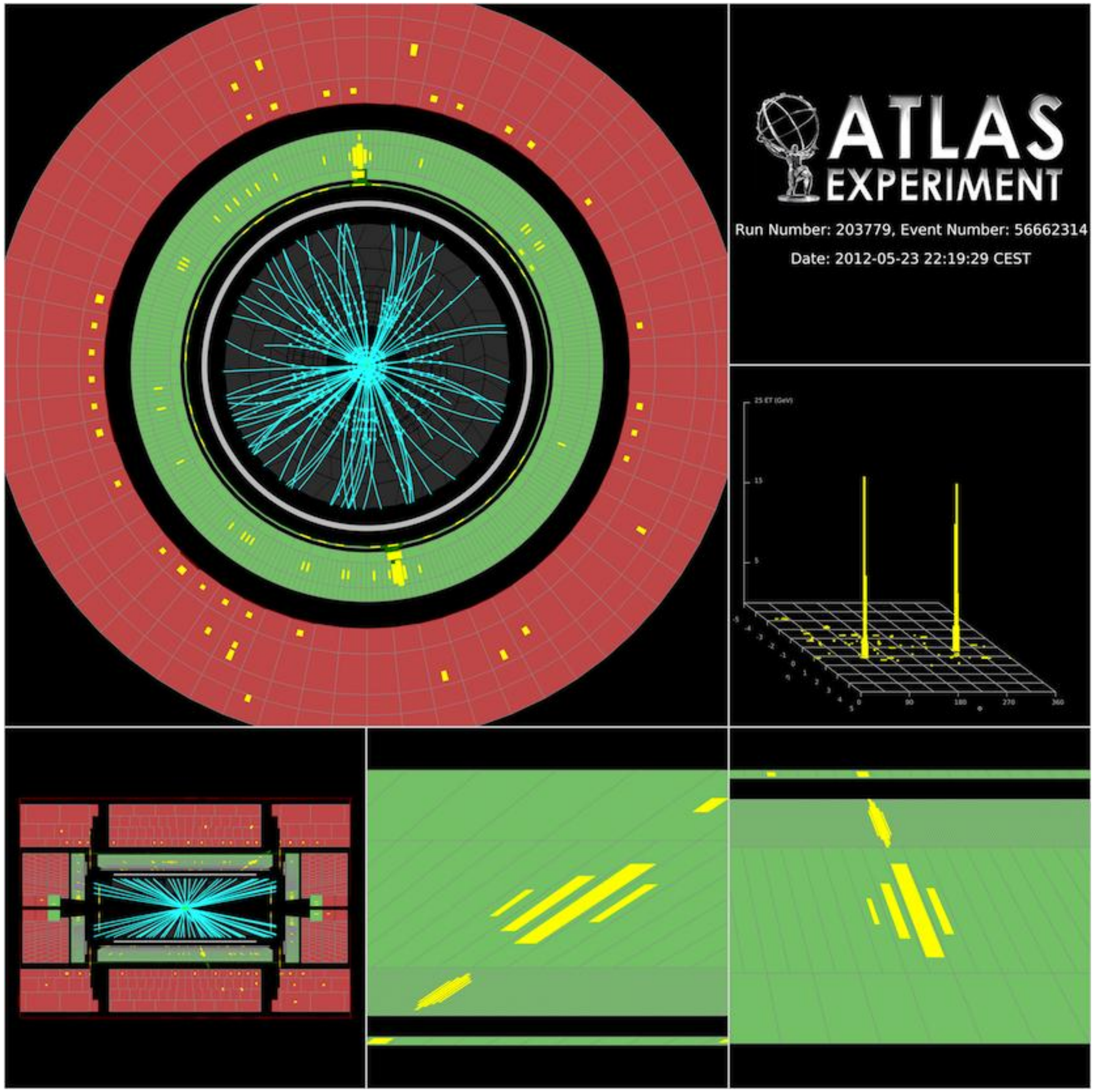
- Select diphoton events, look for a narrow peak in the $m_{\gamma\gamma}$ distribution
  - Fit background using data, in categories with different S/B ratio and $m_{\gamma\gamma}$-resolution
- Comprehensive analysis reoptimisation
  - Optimised kinematic requirements
  - Neural-net based photon ID for 2011 data
  - Reopt. photon ID for 2012, stable with high pileup
  - Improved 'topological' calorimeter isolation
  - New '2-jets' category for enhanced VBF sensitivity



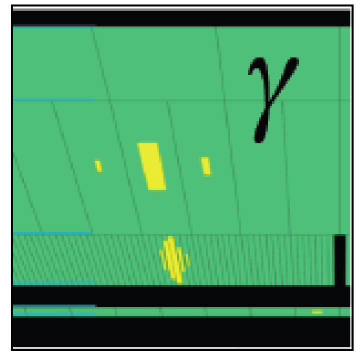
Selection	2011 old	2011 new	2012
Trigger $p_T(\gamma)$	2γ20	2γ20	γ35γ25
Offline $p_T(\gamma)$	40, 25 GeV	40, 30 GeV	40, 30 GeV
Photon ID	Cuts	Neural net	Reopt. cuts
Isolation (ΔR=0.4)	Cell-based < 5 GeV	Topo. <4 GeV	Topo, <4 GeV
Categories	9	10	10

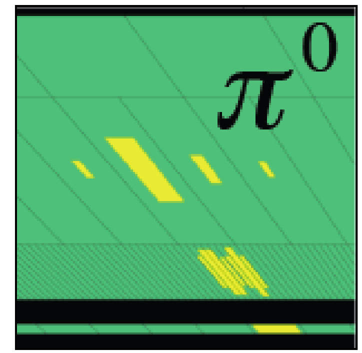


Event display: γγ candidate, 2012 data



- Separation of γ and π^0 in LAr calorimeter
  - Photon 'pointing' to locate primary vertex

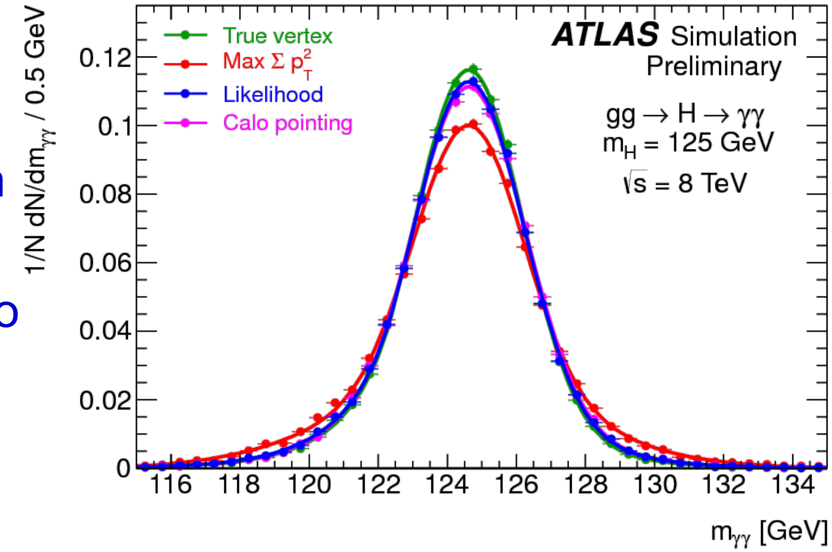


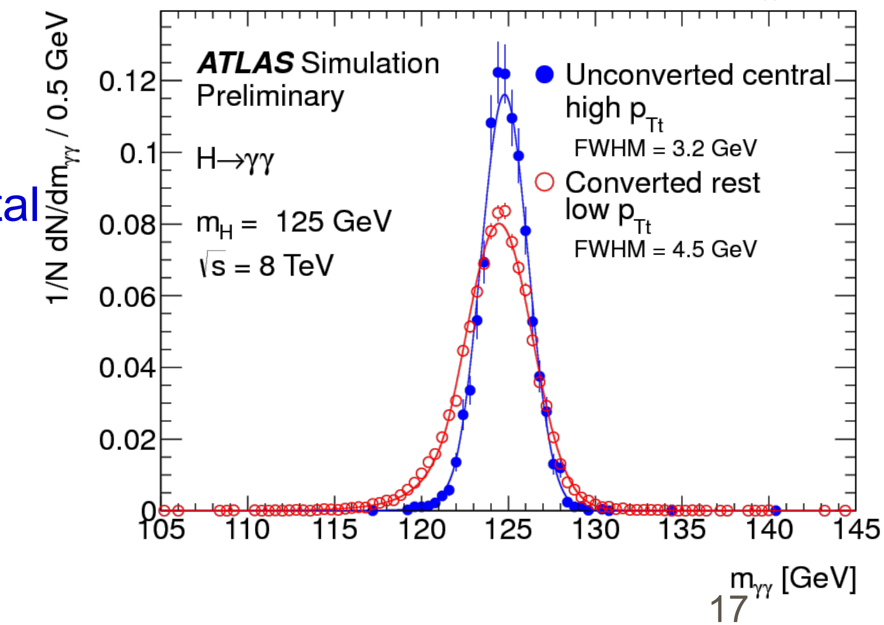


- Composition of γγ sample:
  - 75-80% QCD γγ production
  - 20-25% γ-jet or jet-jet, jet mis-ID e.g. due to hard π^0

H→γγ analysis: Mass resolution

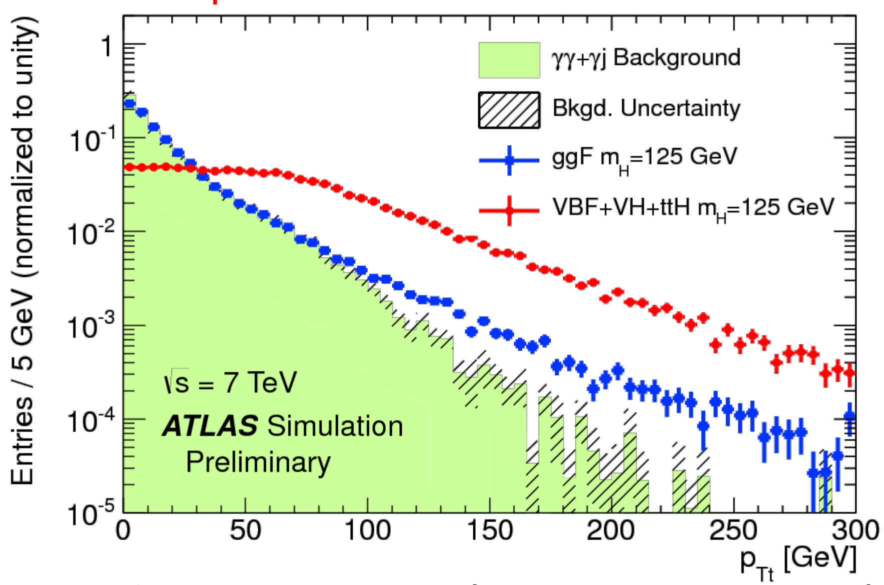
- Reconstruct angles and energies of photons
  - Calorimeter 'pointing' (longitudinal segmentation) & conversion vertex (if available) give σ_{zvtx}~15mm
    - Sufficient for good $m_{\gamma\gamma}$ resolution
  - 2-jet category requires correct primary vertex ID to associate jets from hard scattering
    - Likelihood combines standard Σp_T^2 method with photon pointing and conversion information
- Photon energies calibrated using Z→ee
  - Small MC-based corrections for both converted and unconverted photons
  - Expected H→γγ signal shape modelled by Crystal Ball+Gaussian function
    - FWHM varies from 3-6 GeV depending on event category (converted/unconverted, η, p_T)





H→γγ: Analysis categories

- Categorize events by S/B based on
  - Both photons unconverted or ≥1 converted
  - Both photons central (|η|<0.75), one in transition region, or rest
  - Diphoton p_{Tt}< or > 60 GeV
    - Diphoton transverse momentum wrt thrust

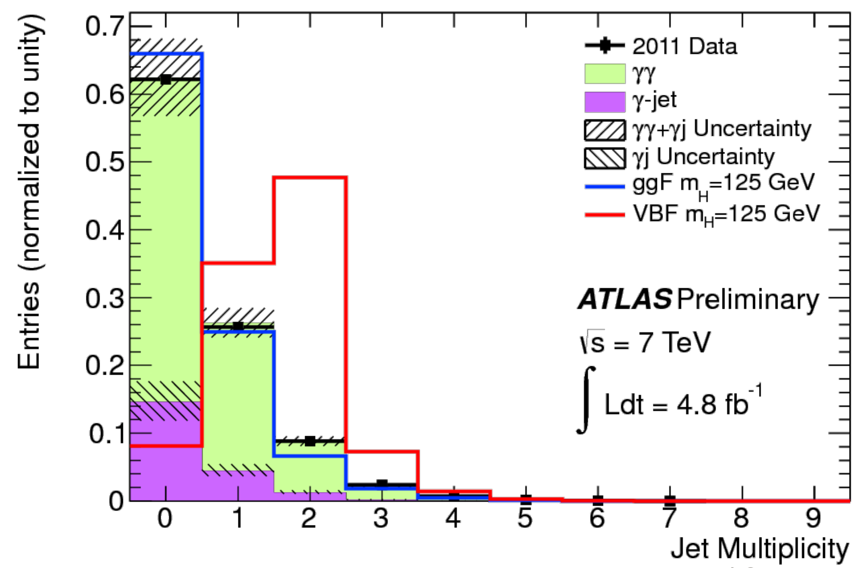


- New 2-jet category (sensitive to VBF)
  - Two p_T>25-30 GeV jets, $\Delta\eta_{jj}$>2.8, m_{jj}>400 GeV
  - Dijet and diphoton back-to-back: $\Delta\Phi$>2.6

8 TeV sample

90% signal window

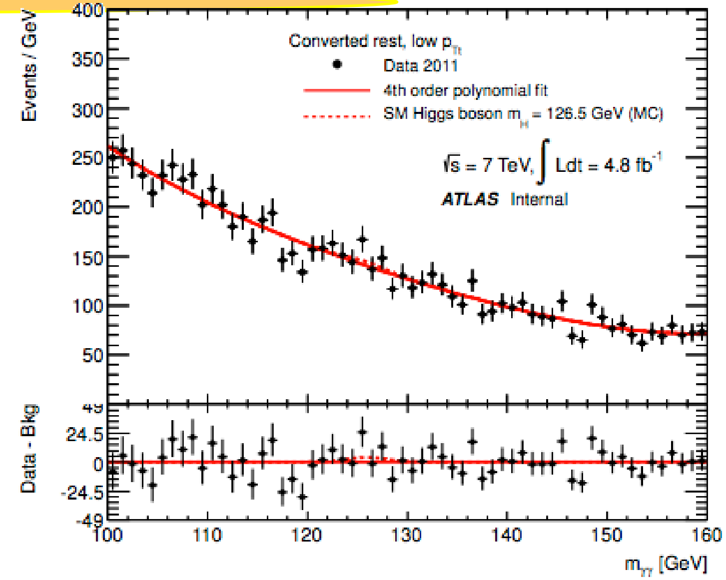
Category	σ_{CB} [GeV]	FWHM [GeV]	Observed [N_{evt}]	S [N_{evt}]	B [N_{evt}]
Inclusive	1.63	3.87	3693	100.4	3635
Unconverted central, low p_{Tt}	1.45	3.42	235	13.0	215
Unconverted central, high p_{Tt}	1.37	3.23	15	2.3	14
Unconverted rest, low p_{Tt}	1.57	3.72	1131	28.3	1133
Unconverted rest, high p_{Tt}	1.51	3.55	75	4.8	68
Converted central, low p_{Tt}	1.67	3.94	208	8.2	193
Converted central, high p_{Tt}	1.50	3.54	13	1.5	10
Converted rest, low p_{Tt}	1.93	4.54	1350	24.6	1346
Converted rest, high p_{Tt}	1.68	3.96	69	4.1	72
Converted transition	2.65	6.24	880	11.7	845
2-jets	1.57	3.70	18	2.6	12

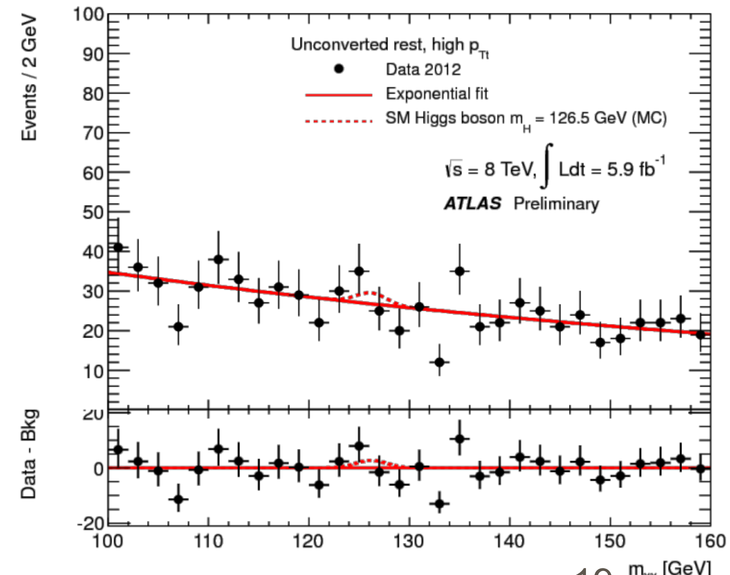


H→γγ analysis: fitting the background

- Fit function: potential shape bias vs statistics
  - Explored with high-stat MC before looking at data, modeling γγ, γ-jet and jet-jet backgrounds
  - Considered n-order Bernstein polynomial, exp(P2) or exponential
  - Chose based on small potential bias for 125 GeV
    - Largest residual bias seen in b/g MC experiments over 110-150 GeV taken as signal yield systematic

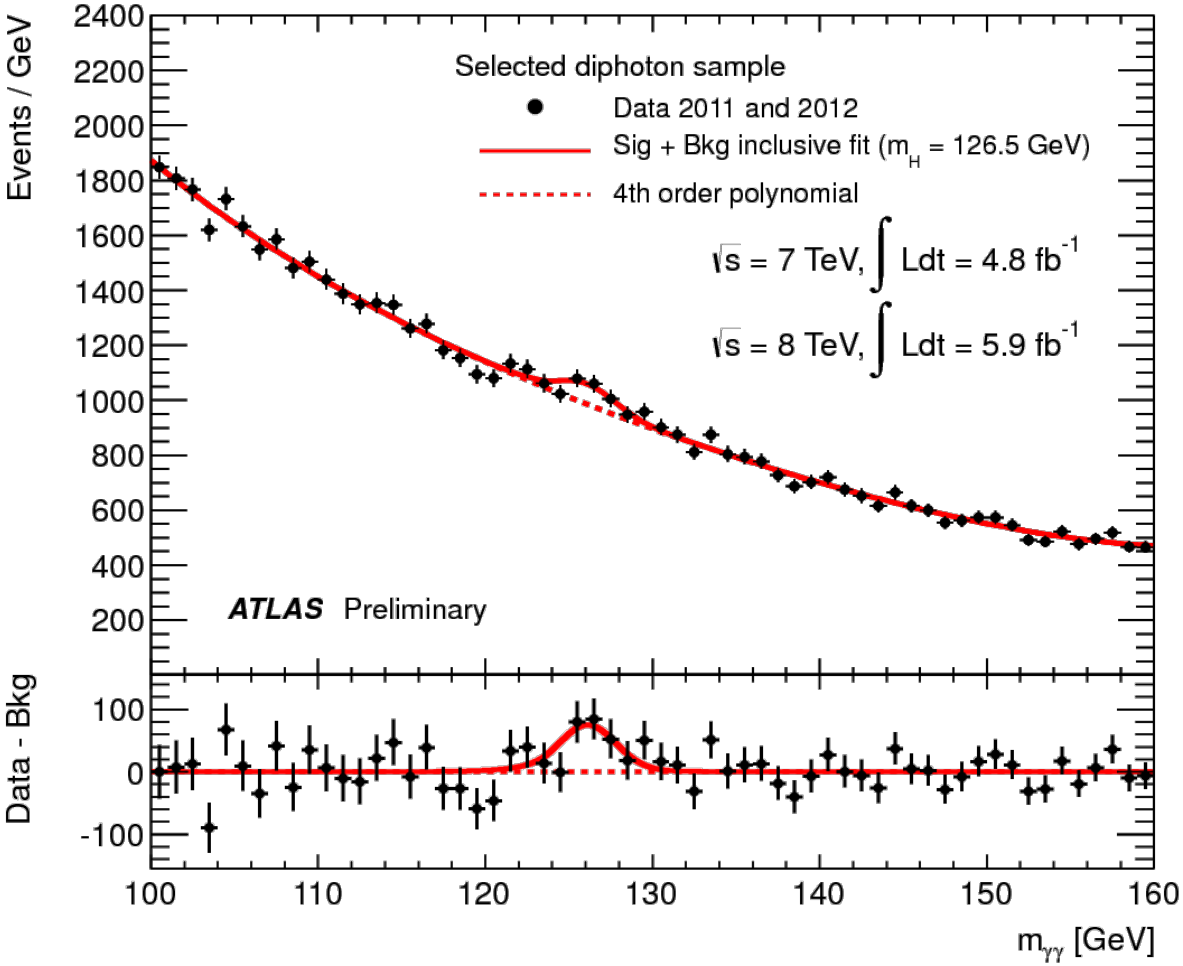
Category	Parametrization	Uncertainty [N_{evt}] $\sqrt{s}$ = 7 TeV	Uncertainty [N_{evt}] $\sqrt{s}$ = 8 TeV
Inclusive	4th order pol.	7.3	10.6
Unconverted central, low p_{Tt}	Exp. of 2nd order pol.	2.1	3.0
Unconverted central, high p_{Tt}	Exponential	0.2	0.3
Unconverted rest, low p_{Tt}	4th order pol.	2.2	3.3
Unconverted rest, high p_{Tt}	Exponential	0.5	0.8
Converted central, low p_{Tt}	Exp. of 2nd order pol.	1.6	2.3
Converted central, high p_{Tt}	Exponential	0.3	0.4
Converted rest, low p_{Tt}	4th order pol.	4.6	6.8
Converted rest, high p_{Tt}	Exponential	0.5	0.7
Converted transition	Exp. of 2nd order pol.	3.2	4.6
2-jets	Exponential	0.4	0.6





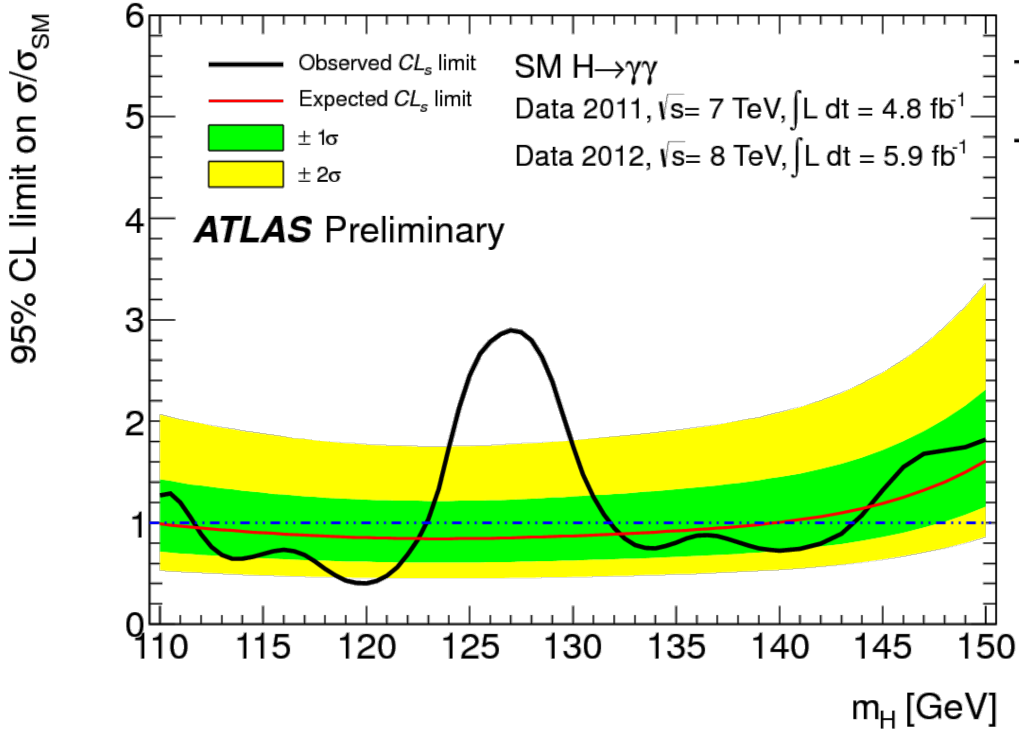
H→γγ analysis: invariant mass distributions

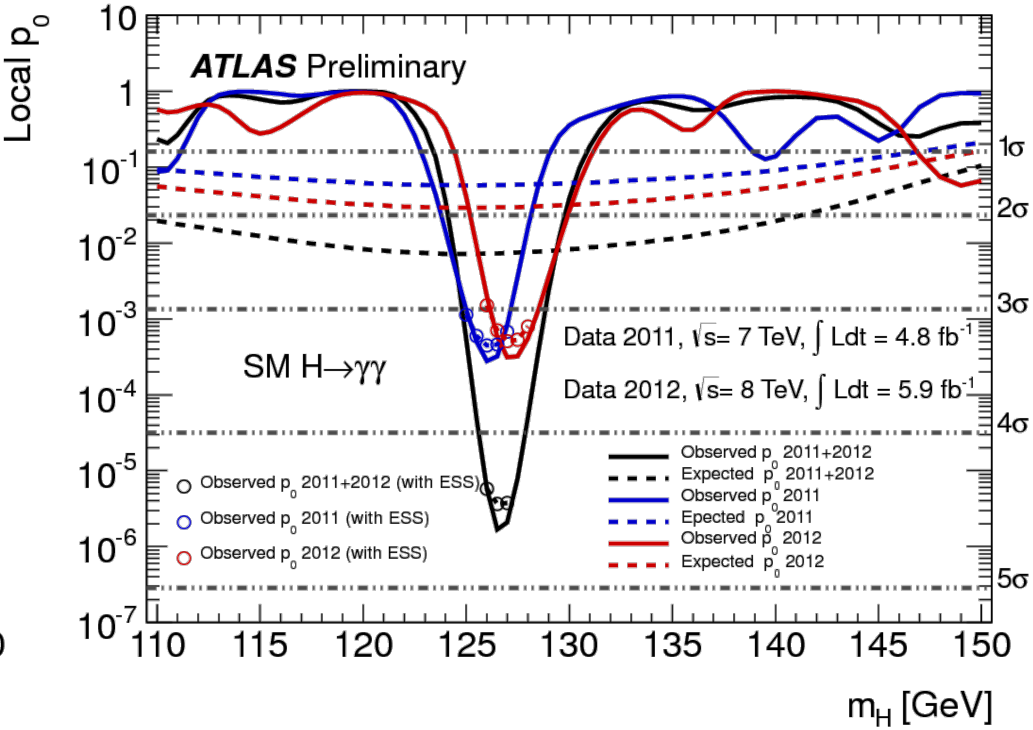
- Invariant mass distribution combining 2012 (35271 events) and 2011 (23788)



- Simple unweighted sum of events passing γγ selection and kinematic cuts, before categorization
  - Fit to signal model at 126.5 GeV+4th order Bernstein b/g mode
- Full results obtained by splitting data into 10 categories and fitting mass distributions separately …

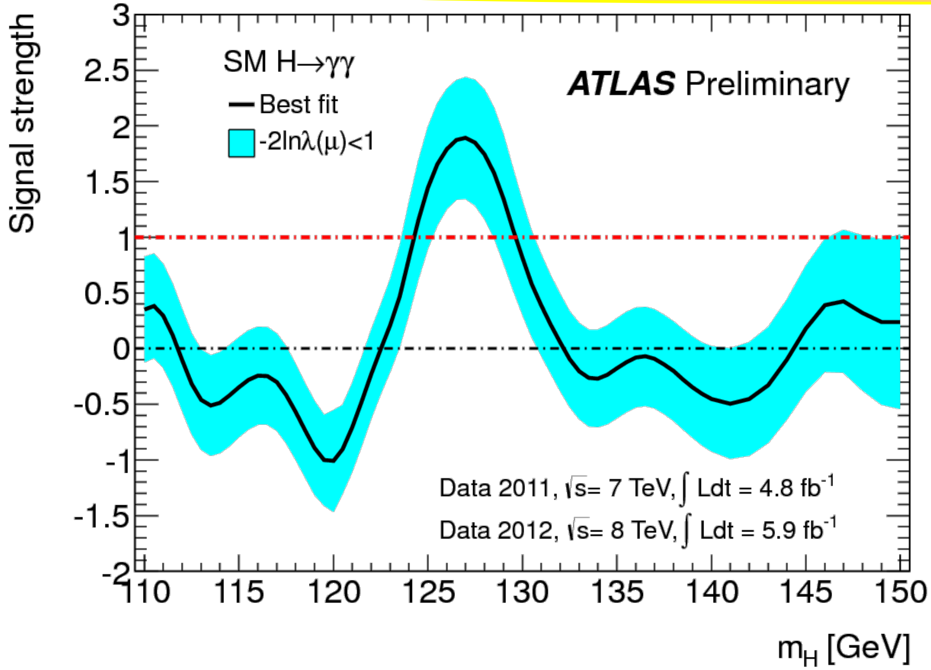
H→γγ analysis: 10-category results





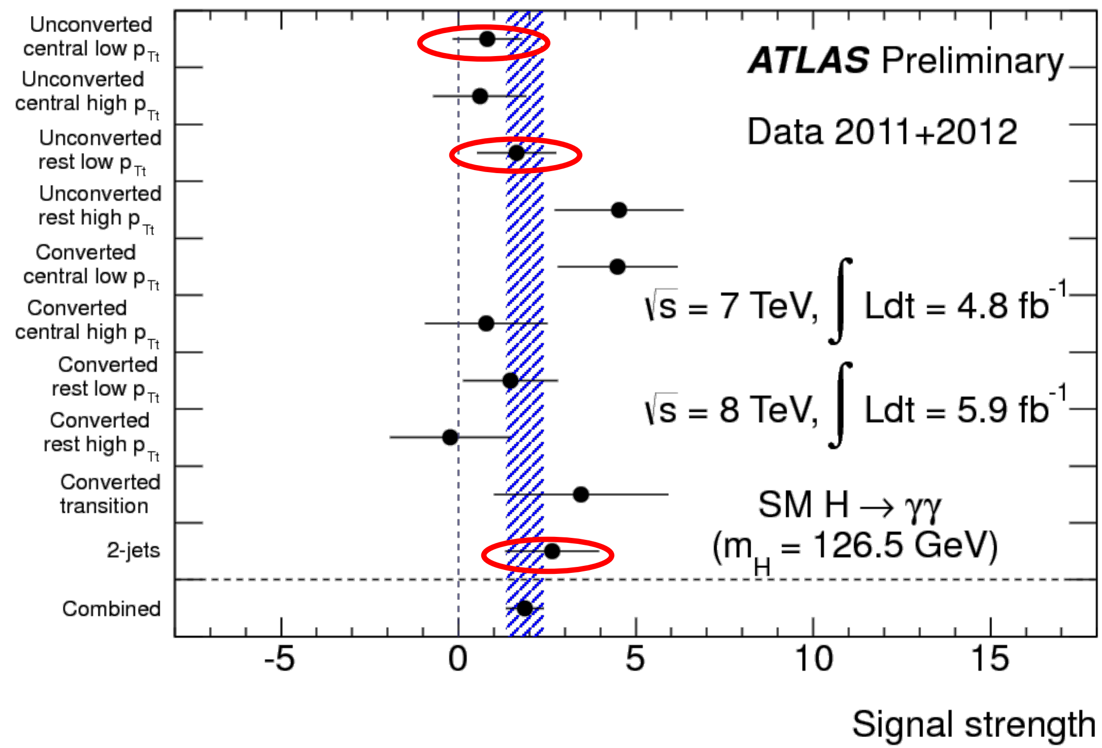
- Expected exclusion from 110-139.5 GeV
  - Observed exclusion from 112-122.5 GeV and 132-143 GeV
- Most significant deviation from background hypothesis at m_H=126.5 GeV
  - Local signif. 4.7σ, reduced to 4.5σ accounting for 0.6% systematic on γ energy scale
    - For a SM Higgs at mH=126.5 GeV, expected significance would be 2.4σ
  - Similar-sized excesses in both 2011 (3.5σ) and 2012 (3.4σ), compatible masses

H→γγ: Signal strength and categories

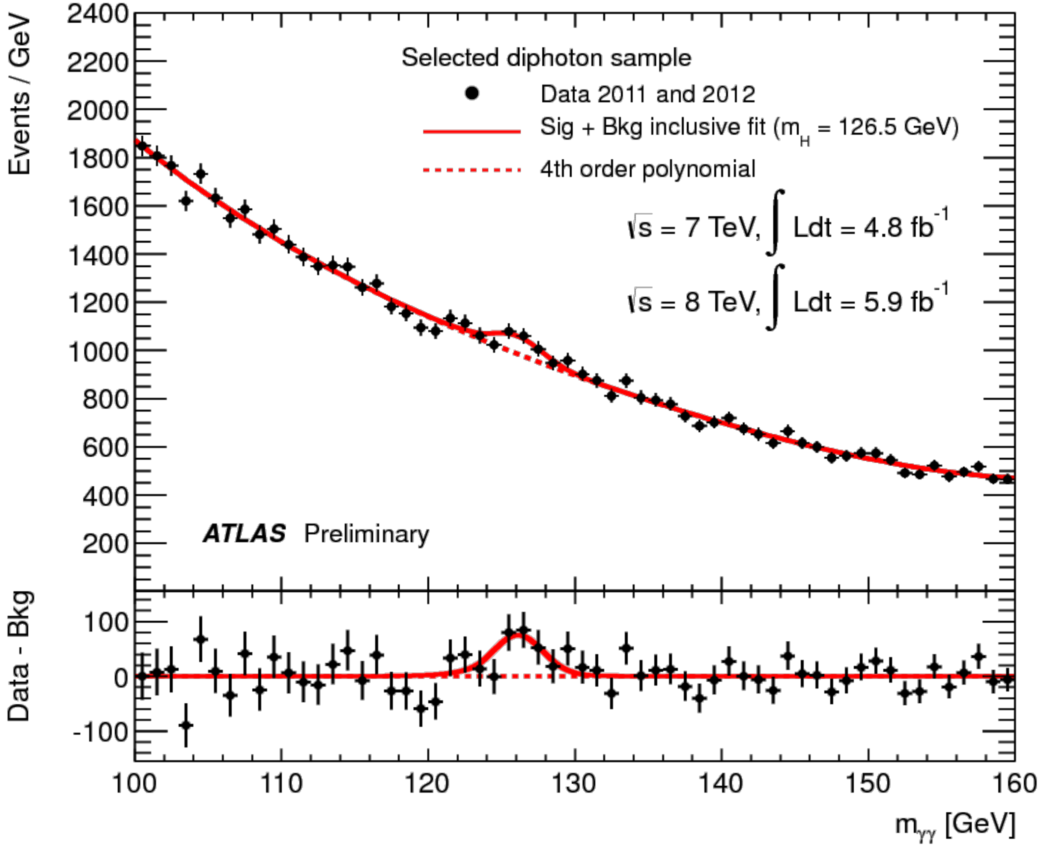


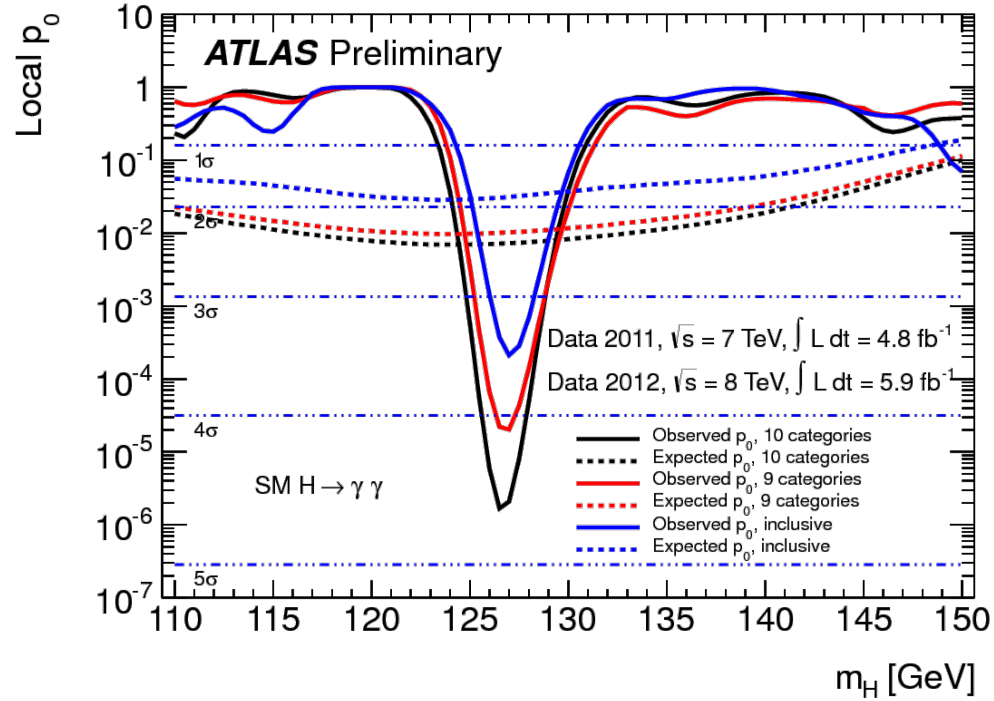
- Fitted signal strength μ=1.9±0.5 at m_H=126.5 GeV

- Breakdown of results by fit categories
  - Most sensitive categories indicated
  - No particular surprises



- Effect of simple fit to inclusive sample instead of 10 analysis categories





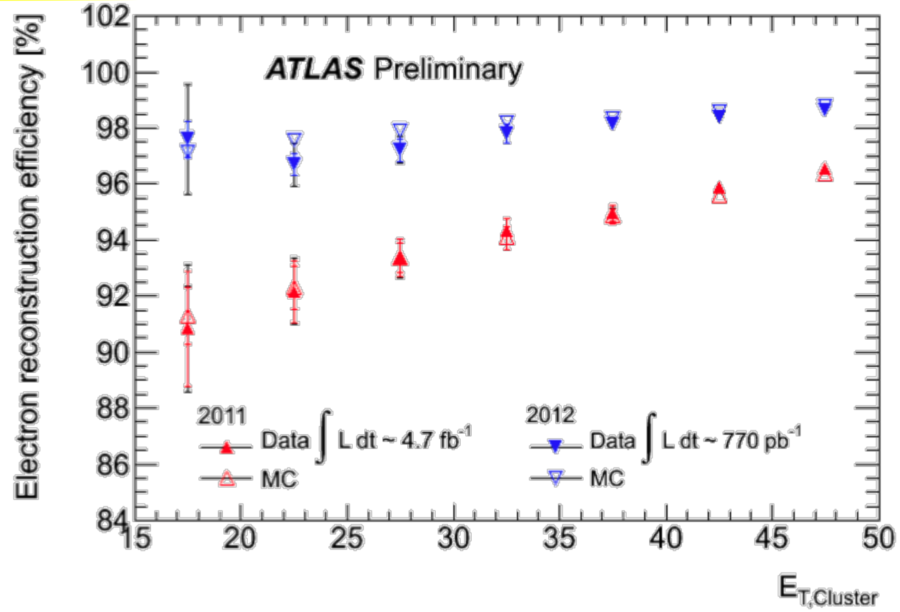
- Local significance of excess is 3.5σ (inclusive) rather than 4.7σ (10-category)
  - Intermediate effect of dropping separate two-jet category also shown – 9 category analysis as initially used for 2011 data

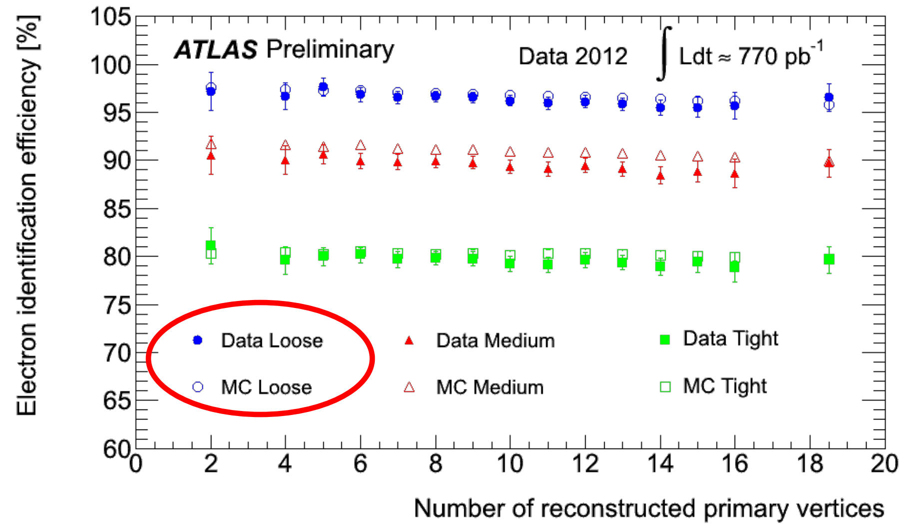
Update of the H→4l analysis: 2011+2012 data

- Reoptimise for low m_H using MC / 2011 data control regions, before looking at 2012 data
  - Improved electron reconstruction in 2012
    - Allowing for bremsstrahlung in pat-rec
    - Electron tracks fitted with GSF (both years)
  - Improved e-ID selection stable against pileup
  - Standalone muons in 2.5<|η|<2.7
  - Additional calo-tagged muons for |η|<0.1
- Revised kinematic selection:

Selection	Original	Optimised
Lepton p_T (e/μ)	20,20,7,7	20,15,10,7/6
m_{12} selection	$\|m_{12}-m_Z\|<15$	$50<m_{12}<106$
m_{34} selection	$m_{min}<m_{34}<115$	$m_{min}<m_{34}<115$

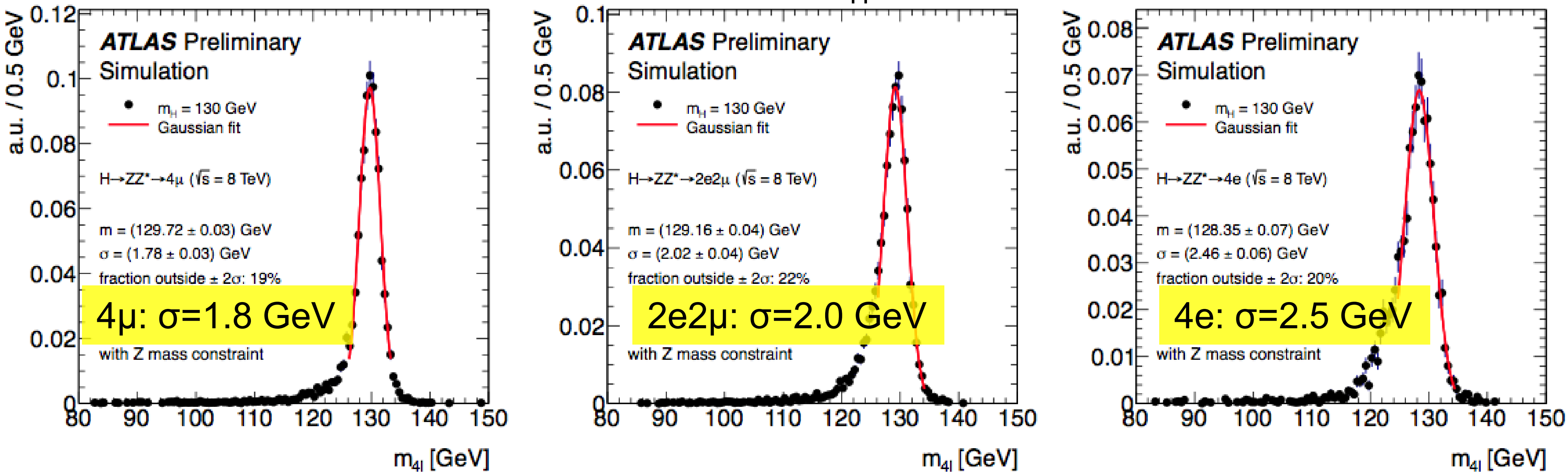
$m_{4\ell}$ (GeV)	≤120	130	150	160	165	180	≥190
m_{34} threshold (GeV)	17.5	22.5	30	30	35	40	50





H→4l: Mass reconstruction and efficiency

- Reconstruct 4-lepton invariant mass and look for a peak
  - Constrain leading lepton pair to m_Z for m_{4l}<190 GeV, both pairs otherwise
- Mass resolution in simulated events at m_H=130 GeV

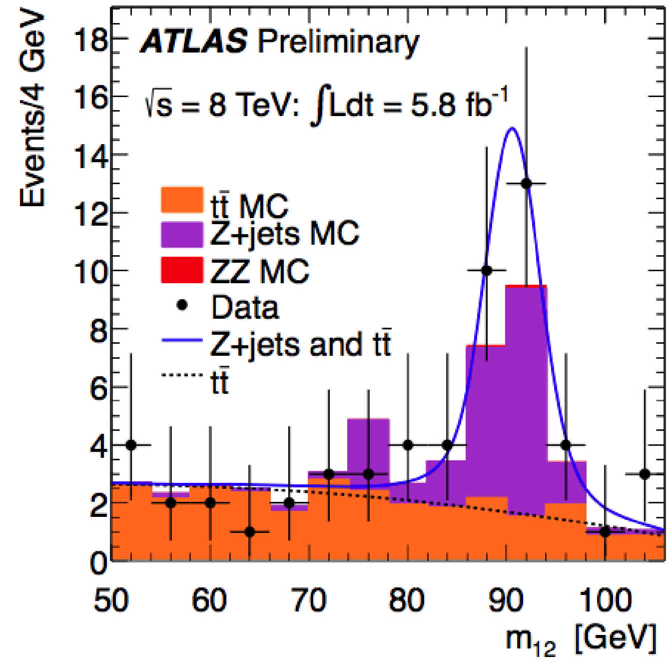


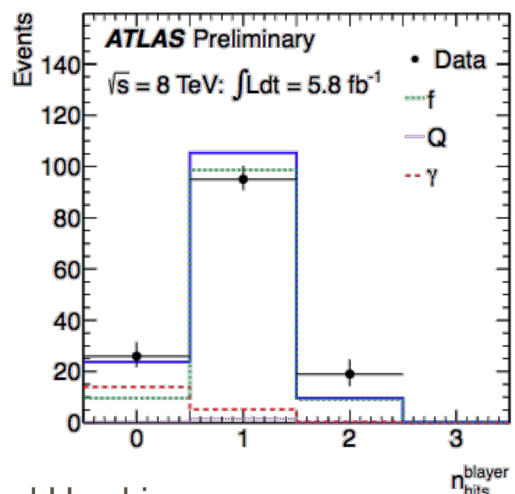
- Combined reconstruction / selection efficiency for m_H=130 GeV
  - Significant gains from increased kinematic acceptance and e-ID

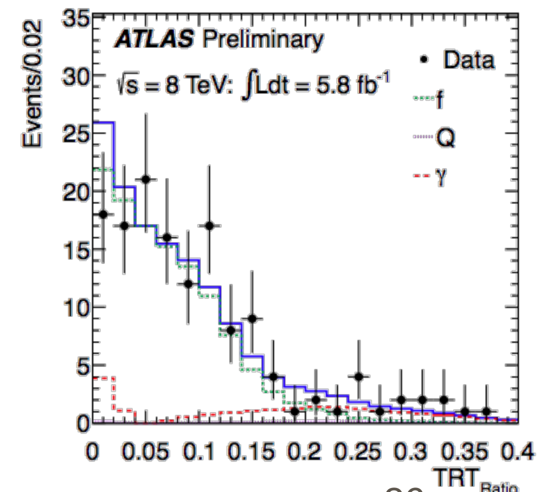
Efficiency (%)	4μ	2μ2e	4e
2011 data (old)	27	18	14
2011 data (new)	43	23	17
2012 data (new)	41	27	23

H→4l: Background estimates I

- Background dominated by continuum ZZ(*)→4l
  - Zbb, Zqq and t-tbar also important at low m_H
  - Isolation / impact parameter (IP) cuts reduce but do not eliminate background from non-prompt leptons
    - More significant when low-mass pair is ee (4e, 2μ2e)
- Continuum background taken from simulation
- In 4μ and 2e2μ, use bb-enriched control region
  - Remove low-m pair isolation, require significant IP
  - Fit norm^n of Zbb and tt, extrapolate to signal region
- In 4e and 2μ2e larger contribution from γ-conversions / hadronic fakes
  - Relax selection, fit components using b-layer, TRT high-threshold and calorimeter-shape variables
  - Fit normalisation and extrapolate
  - Cross-check with fit to relaxed 'same-sign' selection on 4th lepton

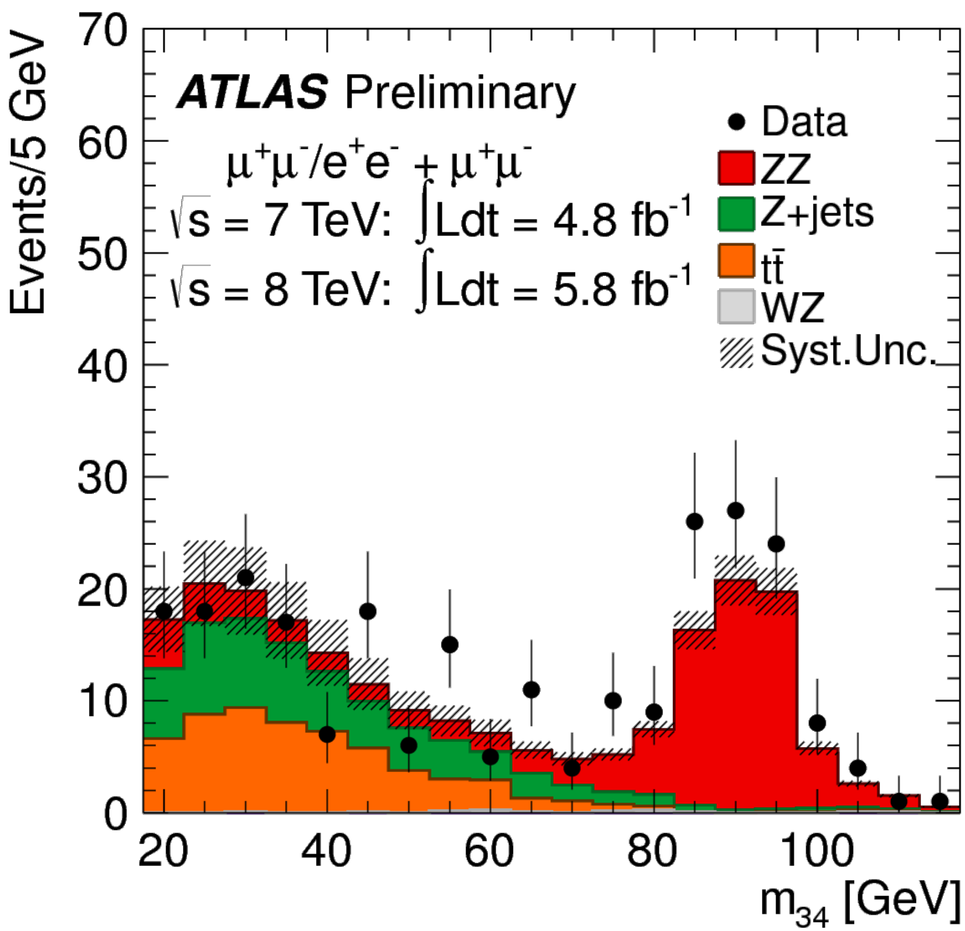


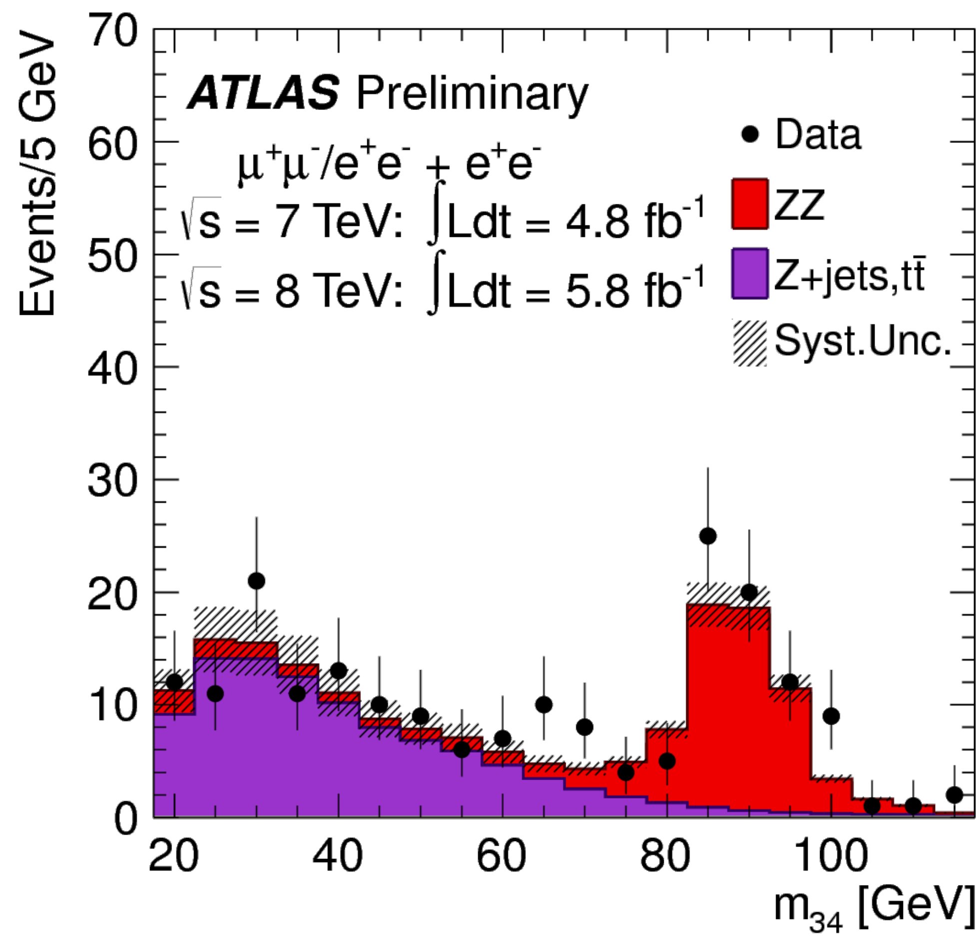




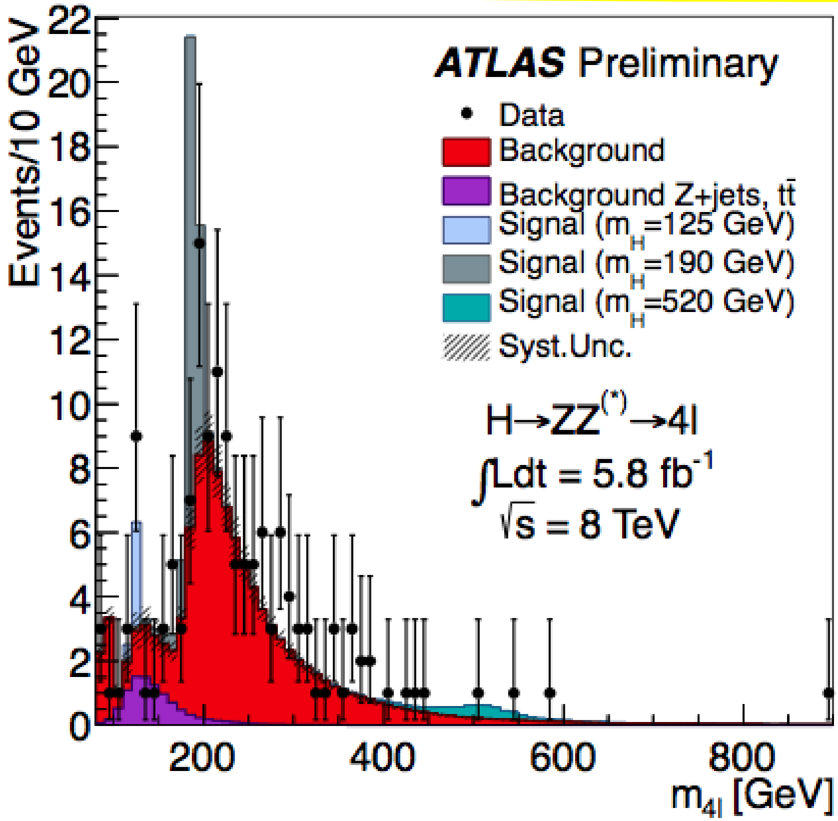
H→4l: Background estimates II

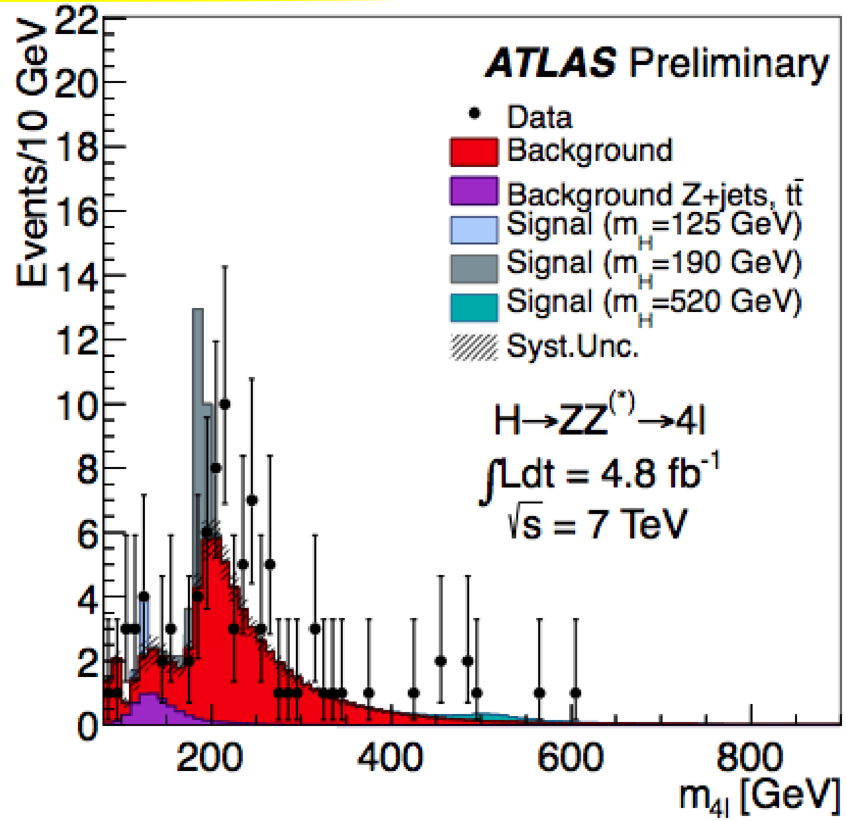
- Cross-check background estimates by applying isolation to first lepton pair only
  - Agreement at high mass (ZZ(*)) and low mass (Zbb, Zqq, ttbar)





H→4 leptons: Selection results

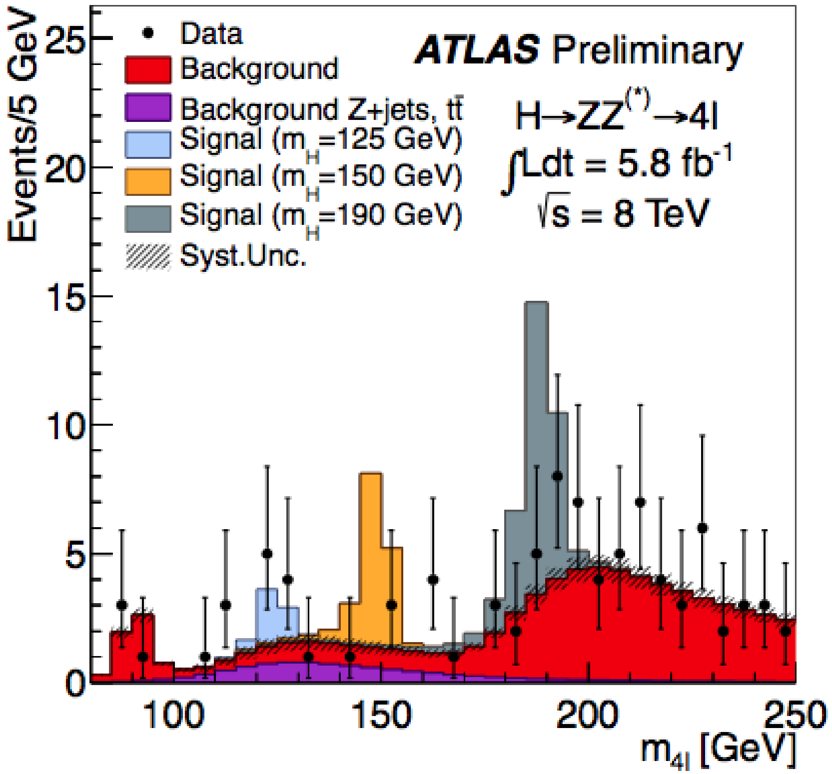


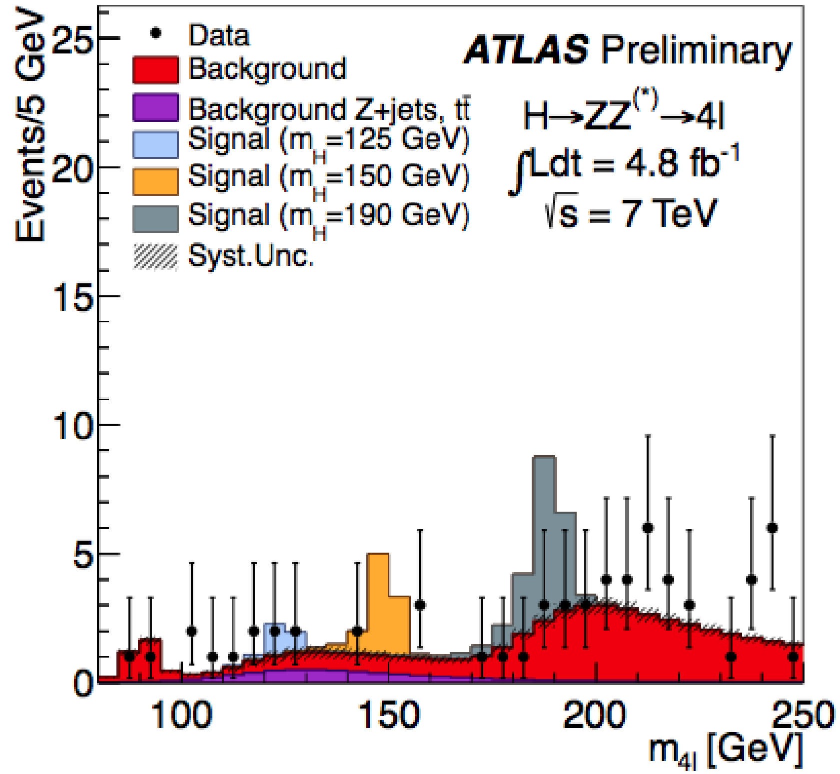


7+8 TeV	4μ-low	4μ-hi	2e2μ-low	2e2μ-hi	4e-low	4e-hi
Background	11.8	45.8	12.7	71.1	9.6	29.8
Data	12	59	16	89	11	43
m_H=125 GeV	2.4		2.7		1.2	

low=m_{4l}<160 GeV

H→4 leptons: Low mass candidates

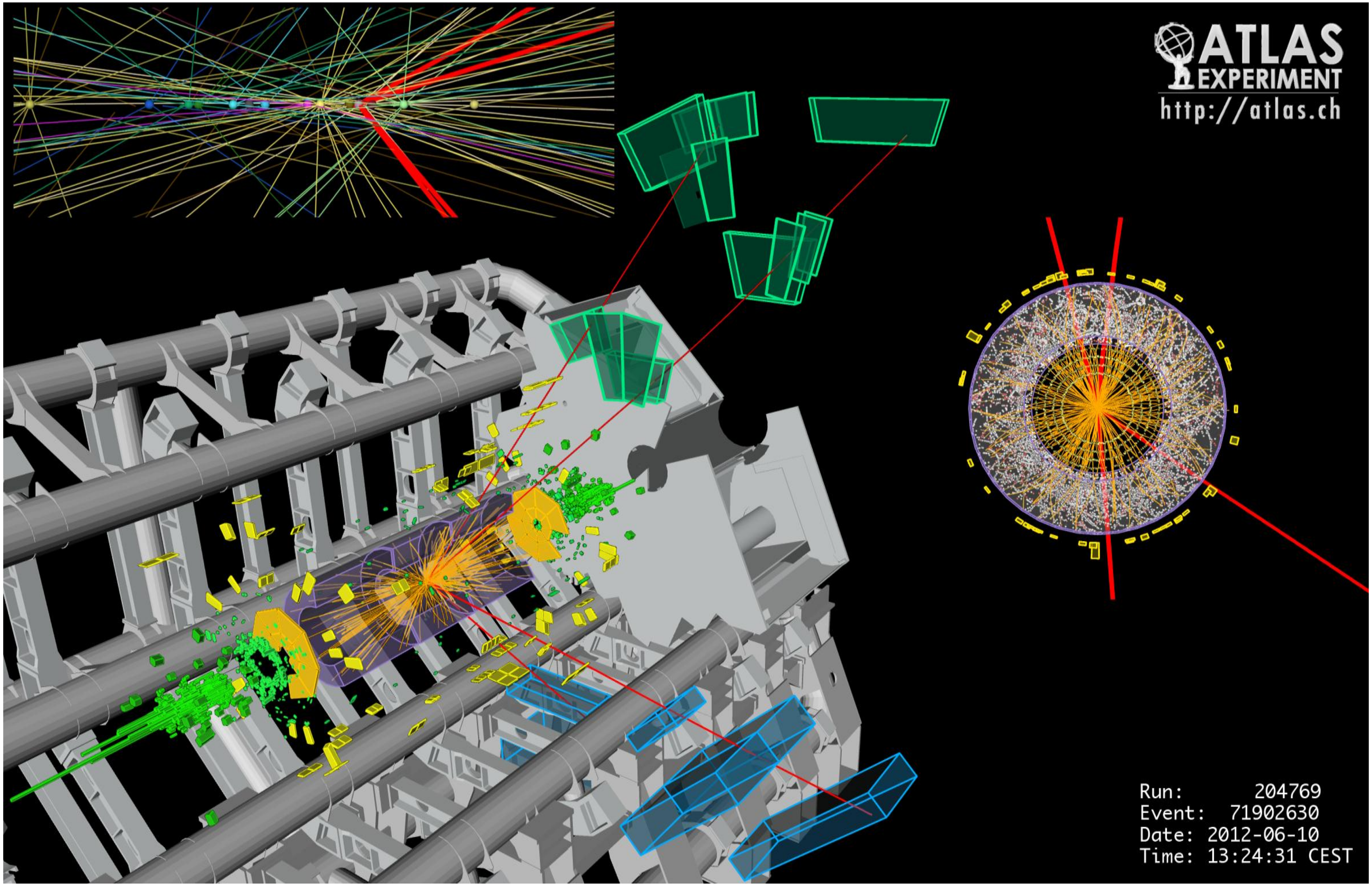




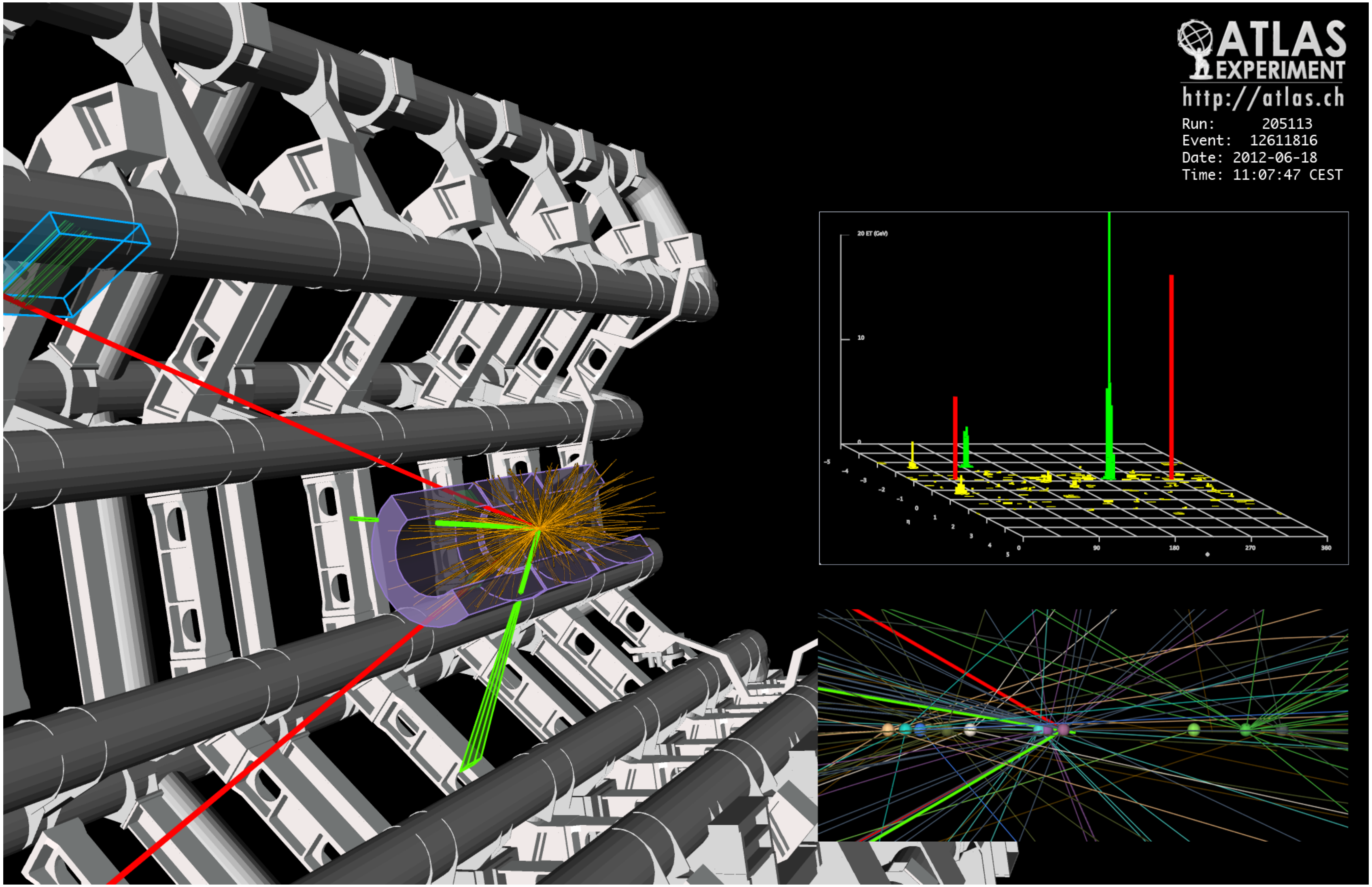
$120 < m_{4l} < 130$ GeV
Event counts

7+8 TeV	4μ	2e2μ	4e
Background	1.3±0.1	2.2±0.2	1.6±0.2
Data	6	5	2
m_H=125 GeV	2.1±0.3	2.3±0.3	0.9±0.1
S/B	1.6	1.0	0.6

Event Display: 4μ

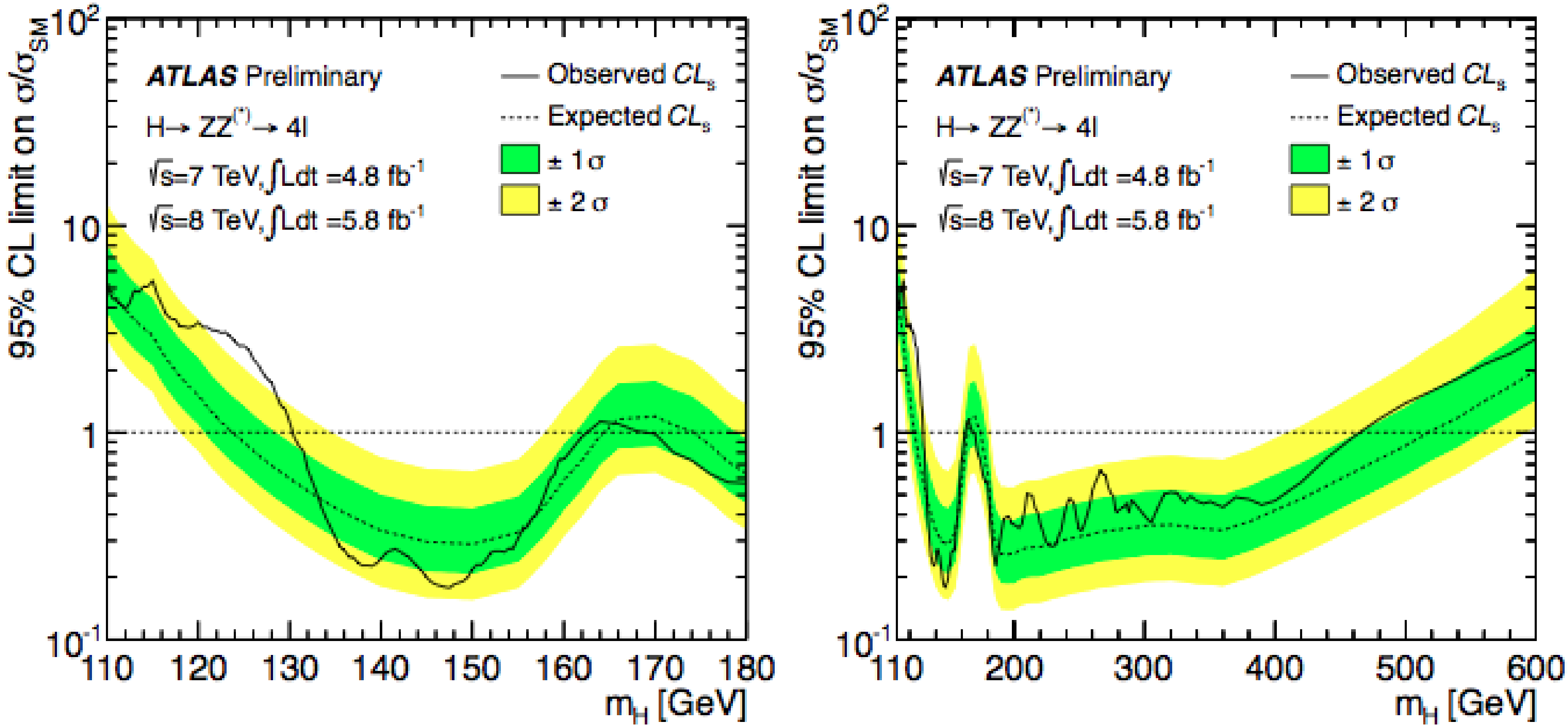


Event display: 2e2μ



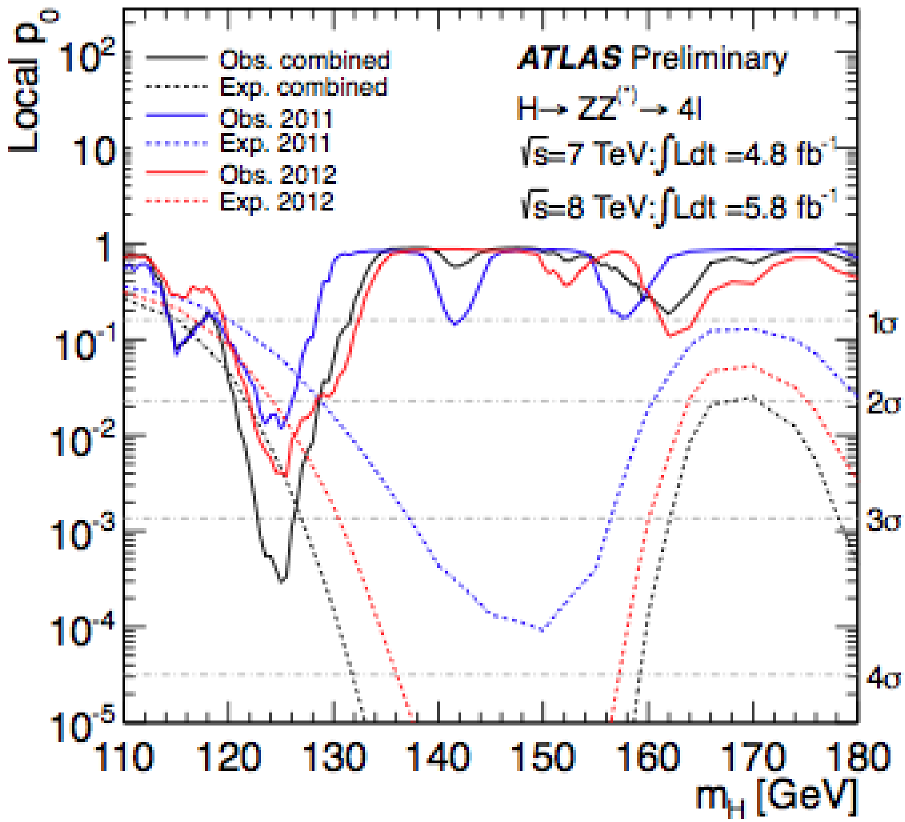
H→4 leptons: Exclusions

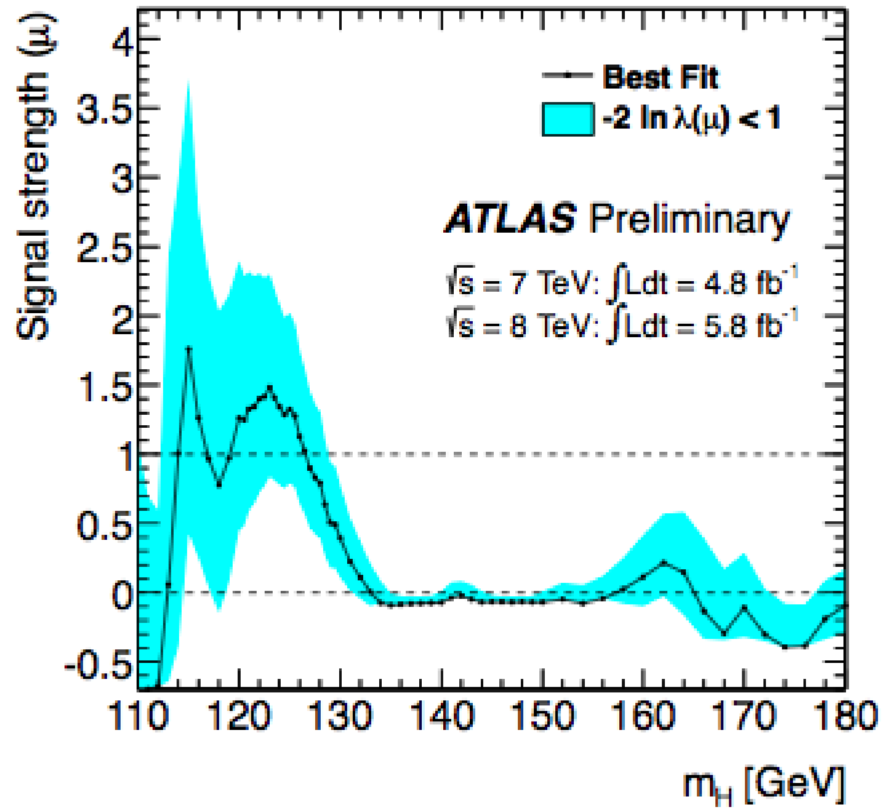
- Exclusion from the combined 2011+12 dataset



- Expected exclusion from 124-164 GeV and 176-500 GeV
  - SM Higgs is excluded at 95% from 131-162 GeV and 170-460 GeV
  - Region around 126 GeV cannot be excluded

H→4-leptons: Compatibility with background

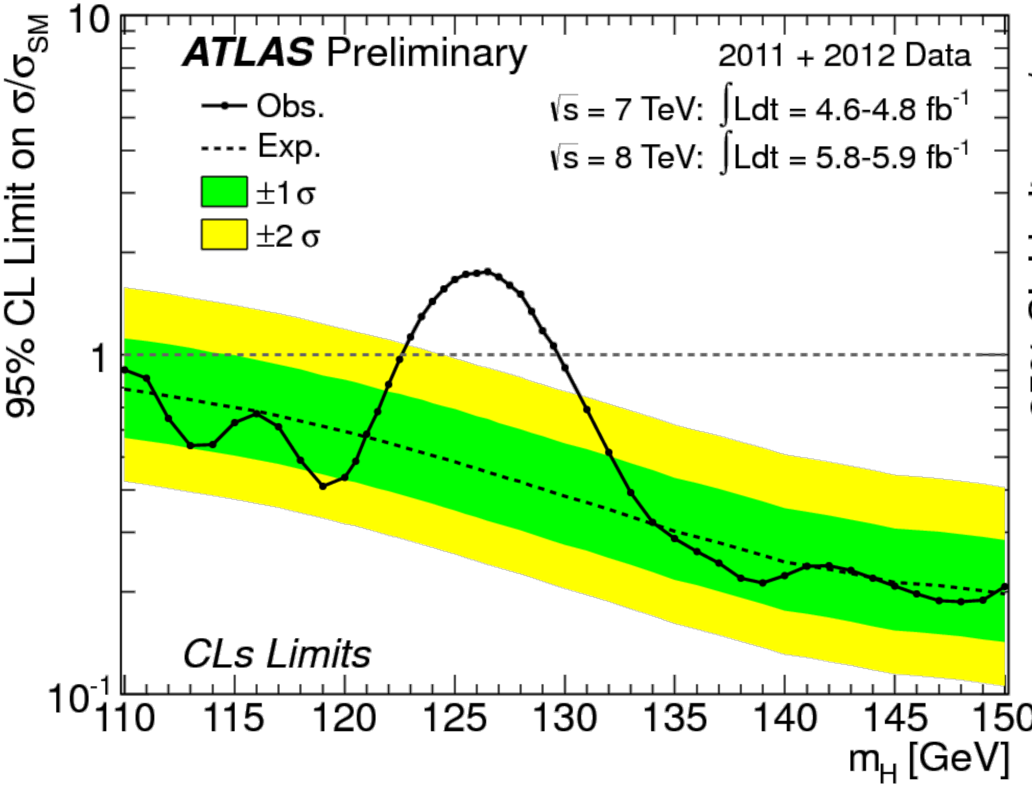


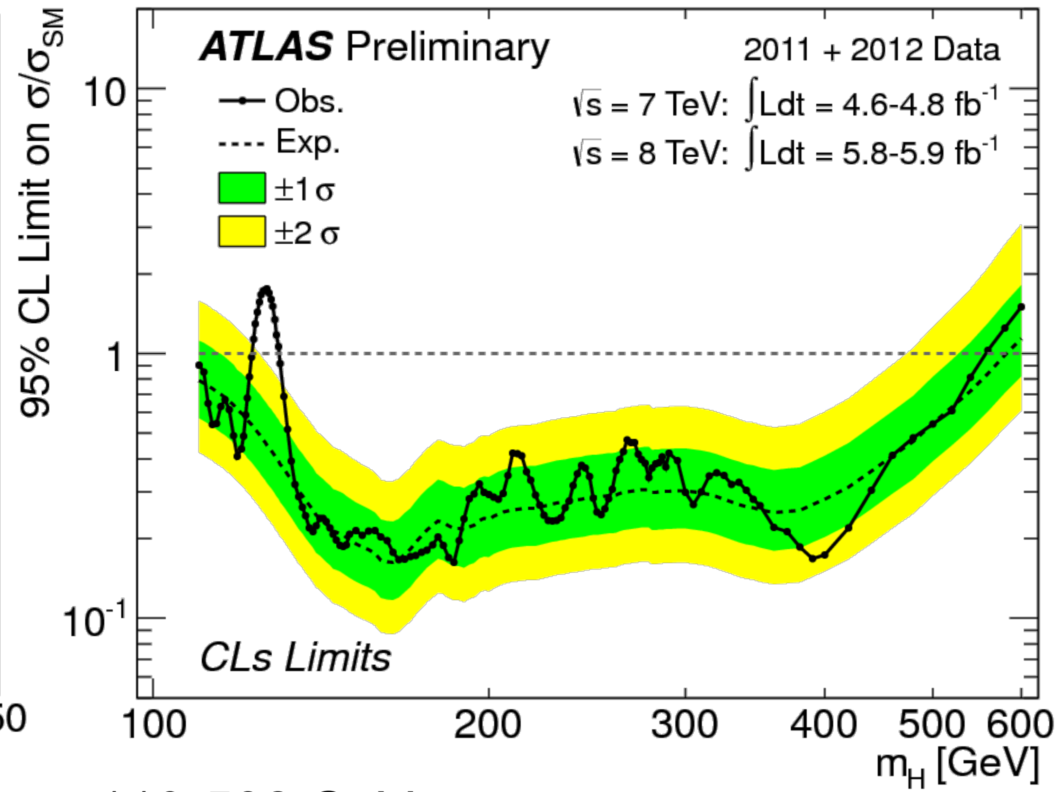


- Most significant deviation from background-only hypothesis at m_H=125 GeV
  - Local p_0 value 0.029% or 3.4σ, globally 2.1σ with LEE in range 110-600 GeV
  - Both 2011 and 2012 data contribute to excess in same mass range
  - Signal strength μ compatible with 1 around this mass

Updated combined SM Higgs exclusion

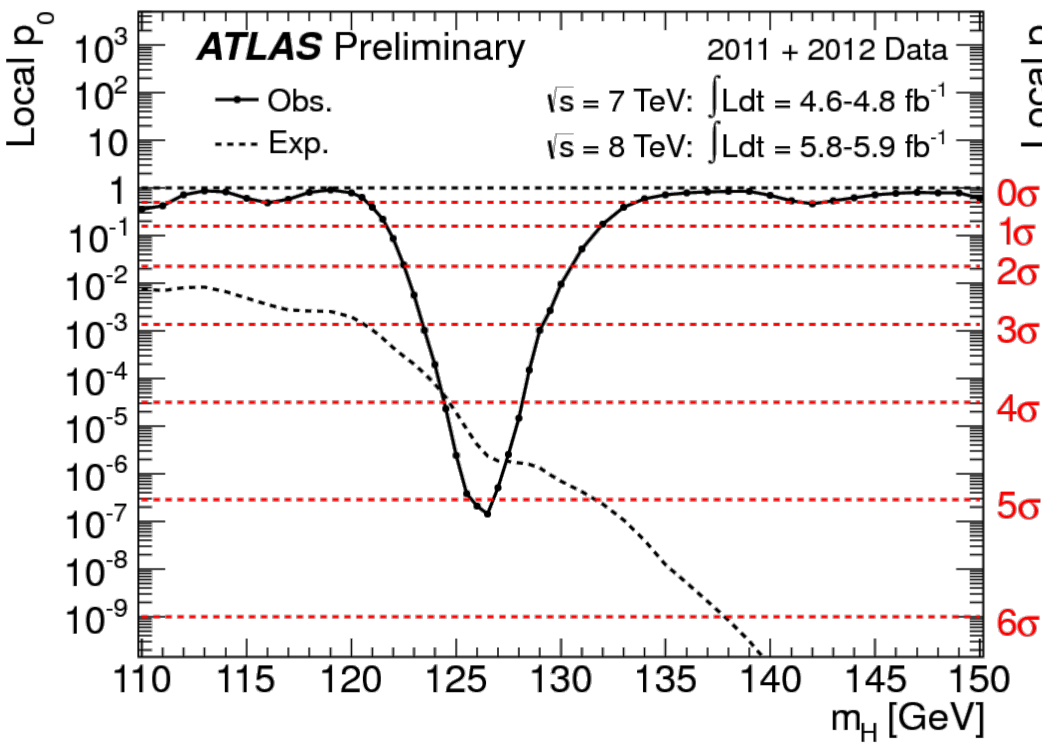
- Combining updated 2011+2012 γγ and 4-lepton analysis with others as before

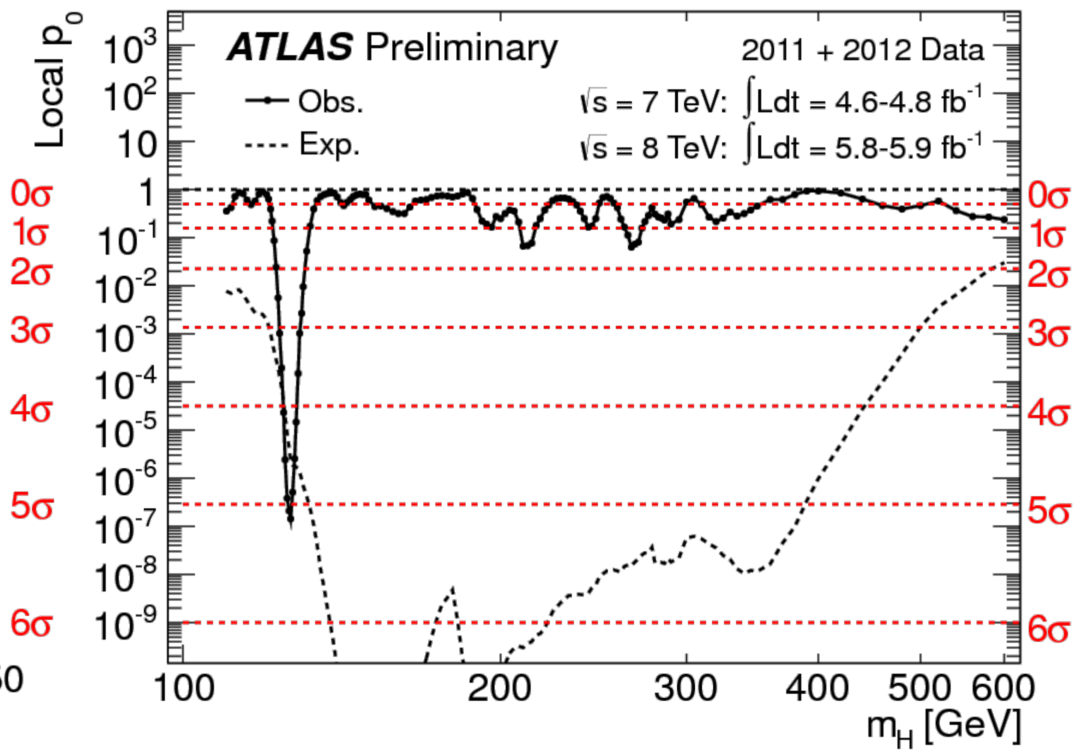




- Expected exclusion with this dataset from 110-582 GeV
  - Observed exclusion from 110-122.6 GeV and 129.7-558 GeV
    - 111.7-121.8 GeV and 130.7-523 GeV excluded at 99% CL
  - Region around 126 GeV cannot be excluded

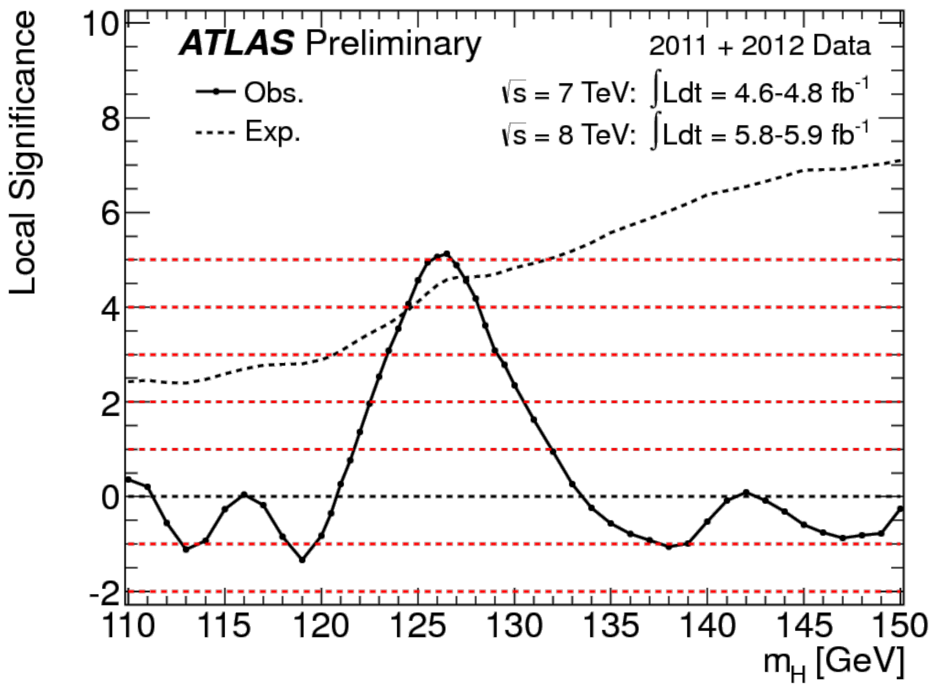
Combined search: Compatibility with background

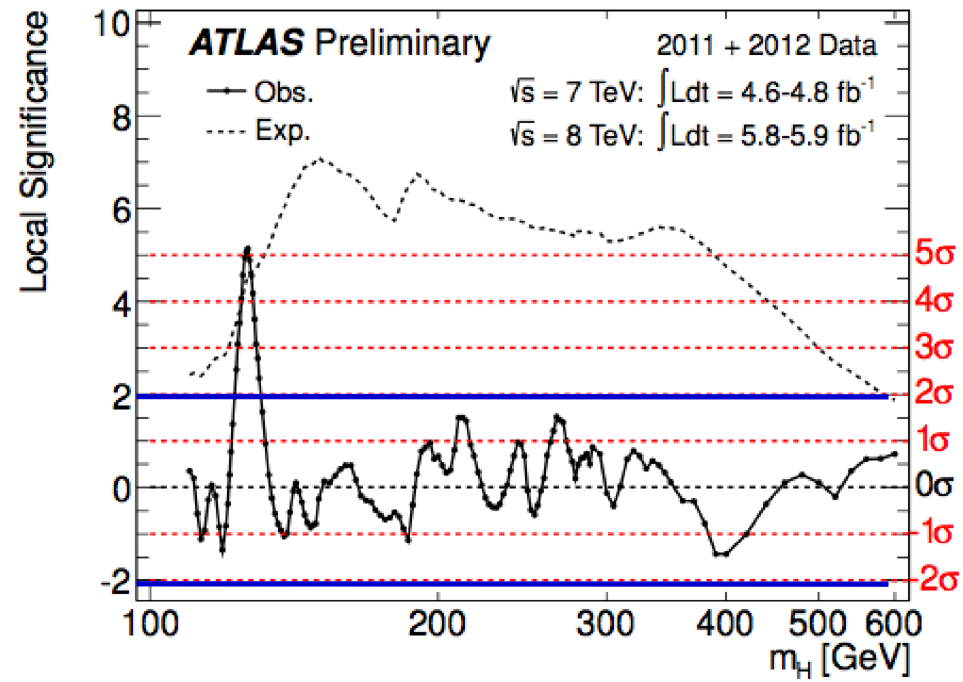




- Smallest p_0 value corresponds to local significance of 5.1σ at m_H=126.5 GeV
  - Expected value if SM Higgs of mass 126.5 GeV exists is 4.6σ
- Significance mildly sensitive to energy scale and resolution systematics (ESS)
  - Important for photons and electrons, negligible for muons
  - ESS estimated to reduce local significance to 5.0σ

Combined search: Significance of signal

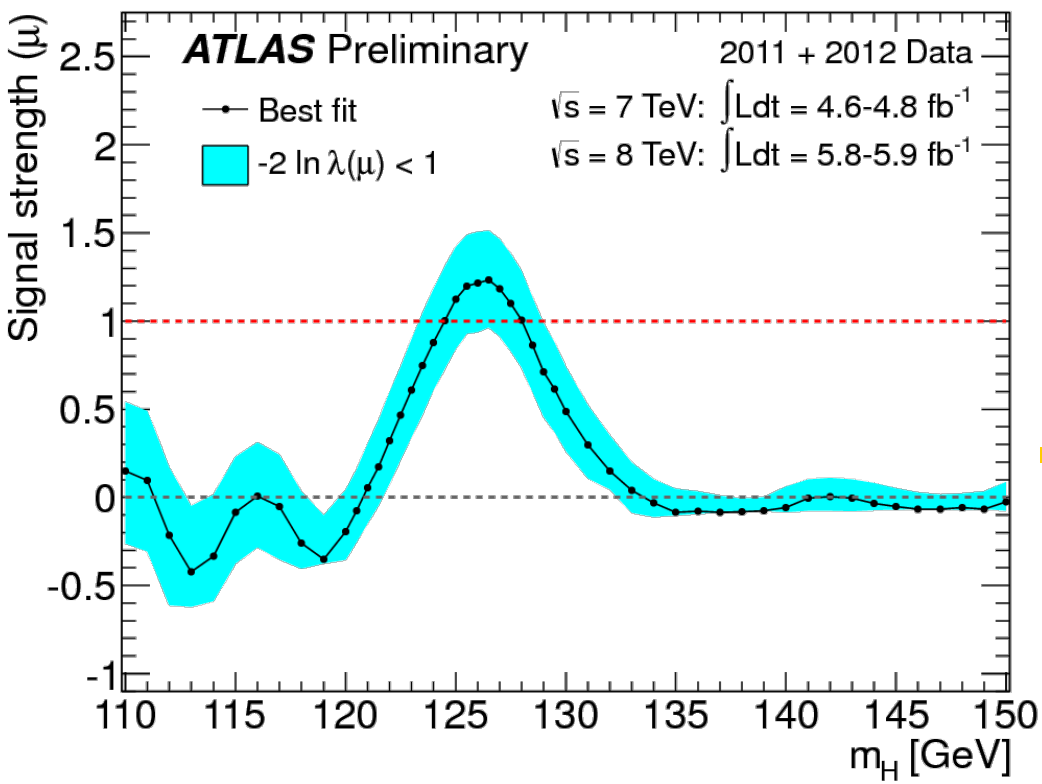


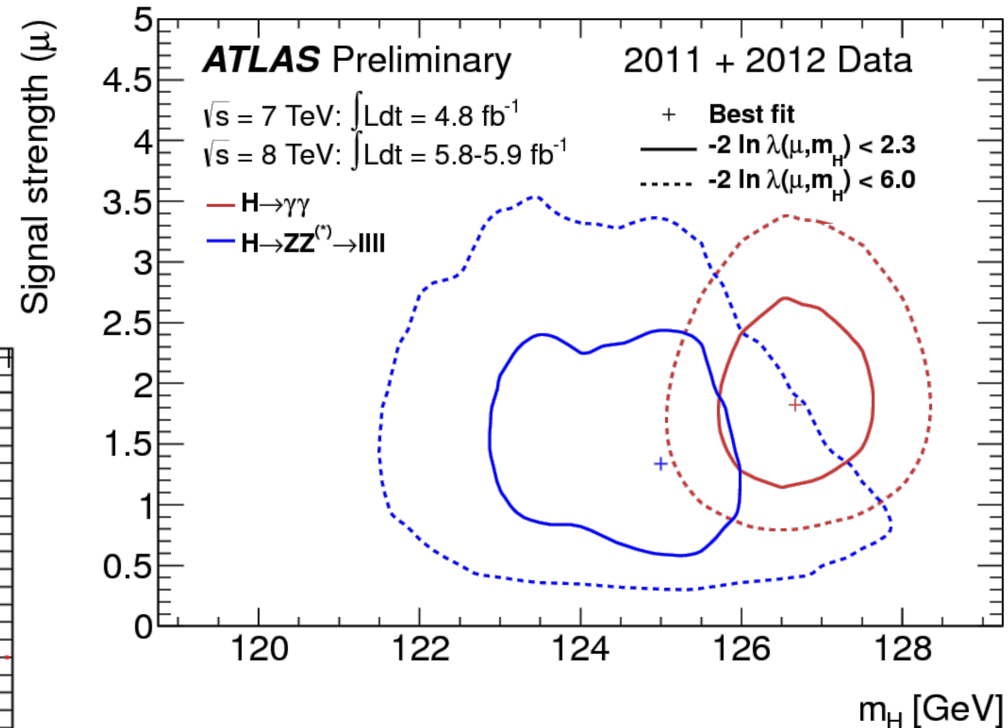


- Alternative view in terms of signal significance
  - Local p_0 is within ±2σ of background-only everywhere except close to ~126 GeV
- Look-elsewhere effect correction depends on mass range considered
  - Global p_0 of 4.1σ in 110-600 GeV, 4.3σ in 110-150 GeV (H→γγ search range)
- 2012 data alone (γγ+4-lepton) – local p_0 of 4.0σ at 127 GeV
  - Global significance 3.1σ in 110-130.7 GeV, range not excluded at 99% CL in 2011

Investigating the excess

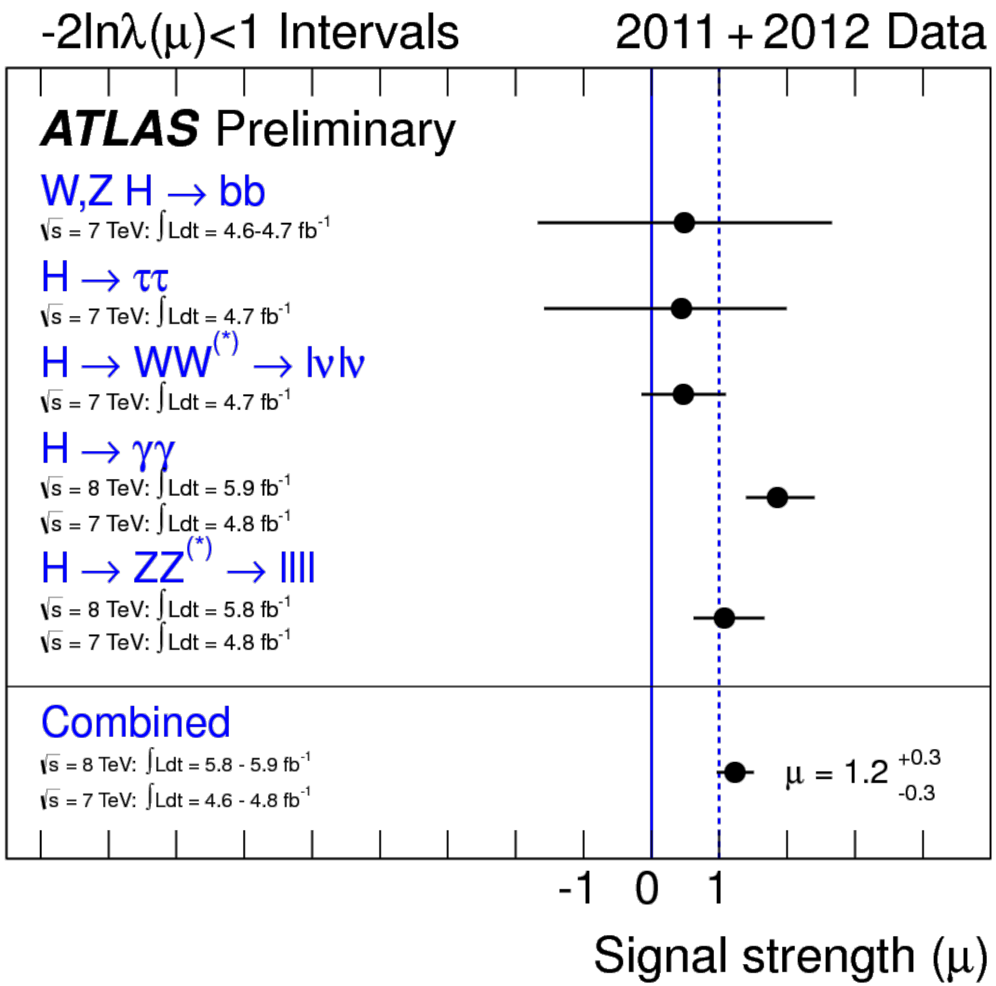
- Comb^n best fit signal strength μ vs m_H
  - Made by scanning m_H and finding the best-fit value of μ at each m_H
  - At 126.5 GeV, μ=1.2±0.3
    - Compatible with SM expectation (μ=1)





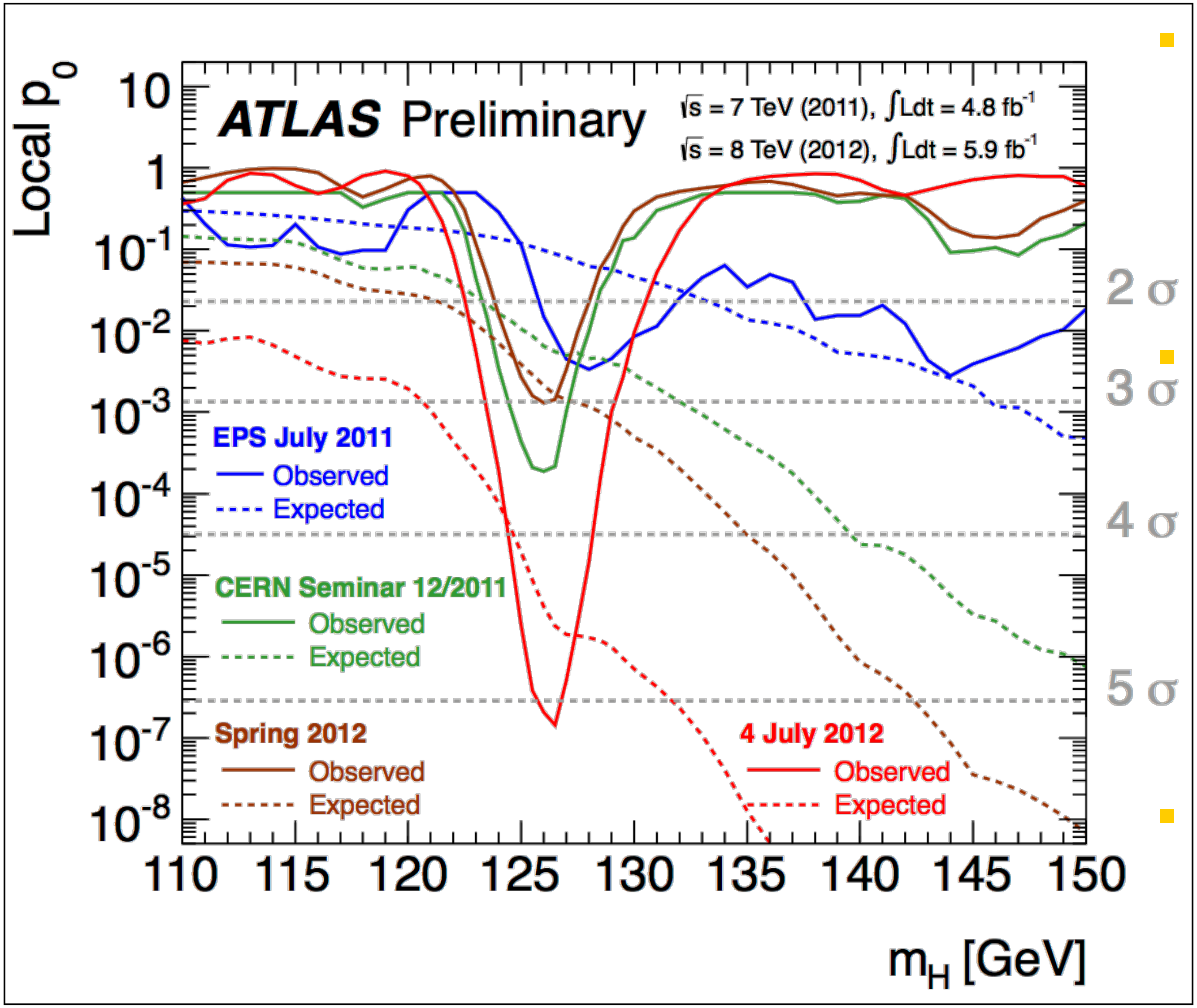
- Let m_H and μ float, 2D contour plot around best fit values
  - Done **separately** for H→γγ and H→4-leptons
  - Best fit masses are compatible
    - ESS has only a small effect

Contributions of the different channels



- Contributions of different channels at 126.5 GeV
  - Most important contributions from H→γγ, H→ZZ(*)→4l, H→WW(*)→lνlν

Developments over time



- History of p_0 values
  - EPS July 2011
  - Council Dec 2011
  - Spring 2012
  - ICHEP 2012
- With hindsight, gradual development of the excess over time
- N.B. No energy scale systematics

Conclusions

- A very interesting and busy time for the ATLAS collaboration
  - 2012 data-taking going very well – high efficiency, good data quality
  - Many thanks to the LHC and other CERN teams for the fantastic machine performance
    - Hope for 15-20 fb^{-1} at 8 TeV for the full 2012 data-sample, to add to 5 fb^{-1} from 2011
  - Many new precision measurements and new physics searches on 2010-2011 data
  - Unfortunately no hints of new BSM physics yet, but …
- Observation of a significant excess of events in the search for the SM Higgs
  - Excess around m_H=126.5 GeV in $\gamma\gamma$ (4.5σ local sig.) and 4-leptons (3.4σ)
    - Excesses are compatible with each other and with SM Higgs boson production
  - Combined search sees excess with local significance of **5.0σ** at m_H=126.5 GeV
  - Evidence for a new, narrow resonance at a mass near 126.5 GeV
- A very exciting time lies ahead …
  - Look forward to adding more channels and more data in the next months to learn more about what we are seeing

Spare slides …

H→γγ: Production modes

- Expected signal contributions from different H production modes

$\sqrt{s}$	Category	Events	$gg \to H$ [%]	VBF [%]	WH [%]	ZH [%]	ttH [%]
7 TeV	Inclusive	79.3	87.8	7.3	2.9	1.6	0.4
	Unconverted central, low p_{Tt}	10.4	92.9	4.0	1.8	1.0	0.2
	Unconverted central, high p_{Tt}	1.5	66.5	15.7	9.9	5.7	2.4
	Unconverted rest, low p_{Tt}	21.6	92.8	3.9	2	1.1	0.2
	Unconverted rest, high p_{Tt}	2.7	65.4	16.1	10.8	6.1	1.8
	Converted central, low p_{Tt}	6.7	92.8	4.0	1.9	1.0	0.2
	Converted central, high p_{Tt}	1.0	66.6	15.3	10	5.7	2.5
	Converted rest, low p_{Tt}	21.0	92.8	3.8	2.0	1.1	0.2
	Converted rest, high p_{Tt}	2.7	65.3	16.0	11.0	5.9	1.8
	Converted transition	9.5	89.4	5.2	3.3	1.7	0.3
	2-jets	2.2	22.5	76.7	0.4	0.2	0.1
8 TeV	Inclusive	111.6	88.5	7.4	2.7	1.6	0.5
	Unconverted central, low p_{Tt}	14.4	92.9	4.2	1.7	1.0	0.2
	Unconverted central, high p_{Tt}	2.5	72.5	14.1	6.9	4.2	2.3
	Unconverted rest, low p_{Tt}	31.4	92.5	4.1	2.0	1.1	0.2
	Unconverted rest, high p_{Tt}	5.3	72.1	13.8	7.8	4.6	1.7
	Converted central, low p_{Tt}	9.1	92.8	4.3	1.7	1.0	0.3
	Converted central, high p_{Tt}	1.6	72.7	13.7	7.1	4.1	2.3
	Converted rest, low p_{Tt}	27.3	92.5	4.2	2.0	1.1	0.2
	Converted rest, high p_{Tt}	4.6	70.8	14.4	8.3	4.7	1.7
	Converted transition	13.0	88.8	6.0	3.1	1.8	0.4
	2-jets	2.9	30.4	68.4	0.4	0.2	0.2

H→γγ: Systematics I

- Signal yield systematics

Systematic uncertainties	$\sqrt{s}$ = 7 TeV [%]	$\sqrt{s}$ = 8 TeV [%]
Signal event yield		
Photon identification	±8.4	±10.8
Effect of pileup on photon rec/ID	±4	±4
Photon energy scale	±0.3	±0.3
Photon Isolation	±0.4	±0.5
Trigger	±1	±1
Higgs boson cross section (perturbative)	$gg \to H$: $^{+12}_{-8}$, VBF: ±0.3, WH: $^{+0.2}_{-0.8}$, ZH: $^{+1.4}_{-1.6}$, ttH: $^{+3}_{-9}$; $gg \to H + 2$ jets: ±25	$gg \to H$: $^{+7}_{-8}$, VBF: ±0.2, WH: $^{+0.2}_{-0.6}$, ZH: $^{+1.6}_{-1.5}$, ttH: $^{+4}_{-9}$; $gg \to H + 2$ jets: ±25
Higgs boson cross section (PDF+α_S)	$gg \to H$: $^{+8}_{-7}$, VBF: $^{+2.5}_{-2.1}$, VH: ±3.5, ttH: ±9	$gg \to H$: $^{+8}_{-7}$, VBF: $^{+2.6}_{-2.8}$, VH: ±3.5, ttH: ±8
Higgs boson branching ratio	±5	±5
Higgs boson p_T modeling	low p_{Tt}: ±1.1, high p_{Tt}: ∓12.5, 2-jets: ∓9	low p_{Tt}: ±1.1, high p_{Tt}: ∓12.5, 2-jets: ∓9
Underlying Event (2-jets)	VBF: ±6, Others: ±30	VBF: ±6, Others: ±30
Luminosity	±1.8	±3.6

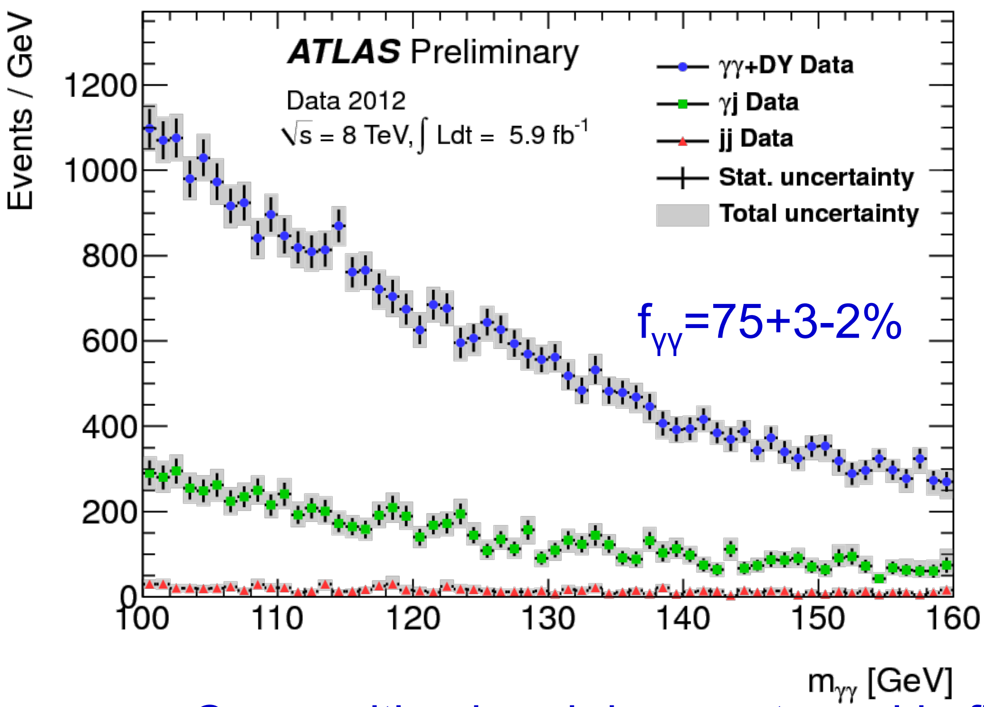
H→γγ: Systematics II

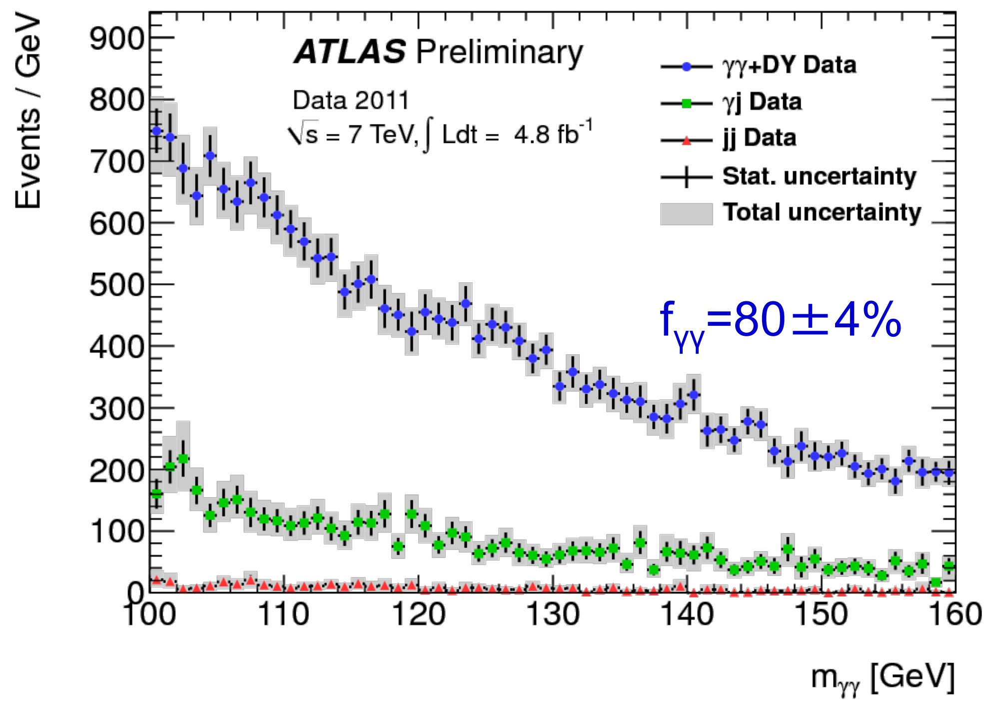
- Migration and resolution systematics

Signal category migration		
Material	Unconv: ±4, Conv: ∓3.5	
Effect of pileup on photon rec/ID	Unconv: ±3, Conv: ∓2, 2-jets: ±2	Unconv: ±2, Conv: ∓2, 2-jets: ±12
Jet energy scale	low p_{Tt}	
	$gg \to H$: ±0.1, VBF: ±2.6, Others: ±0.1	$gg \to H$: ±0.1, VBF: ±2.3, Others: ±0.1
	high p_{Tt}	
	$gg \to H$: ±0.1, VBF: ±4, Others: ±0.1	$gg \to H$: ±0.1, VBF: ±4, Others: ±0.1
	2-jets	
	$gg \to H$: ∓19, VBF: ∓8, Others: ∓15	$gg \to H$: ∓18, VBF: ∓9, Others: ∓13
Jet-vertex-fraction		2-jets: ±13, Others: ∓0.3
Primary vertex selection	negligible	
Signal mass resolution		
Calorimeter energy resolution	±12	
Electron to photon extrapolation	±6	
Effect of pileup on energy resolution	±4	
Primary vertex selection	negligible	
Signal mass position		
Photon energy scale	±0.6	

H→γγ: Background composition

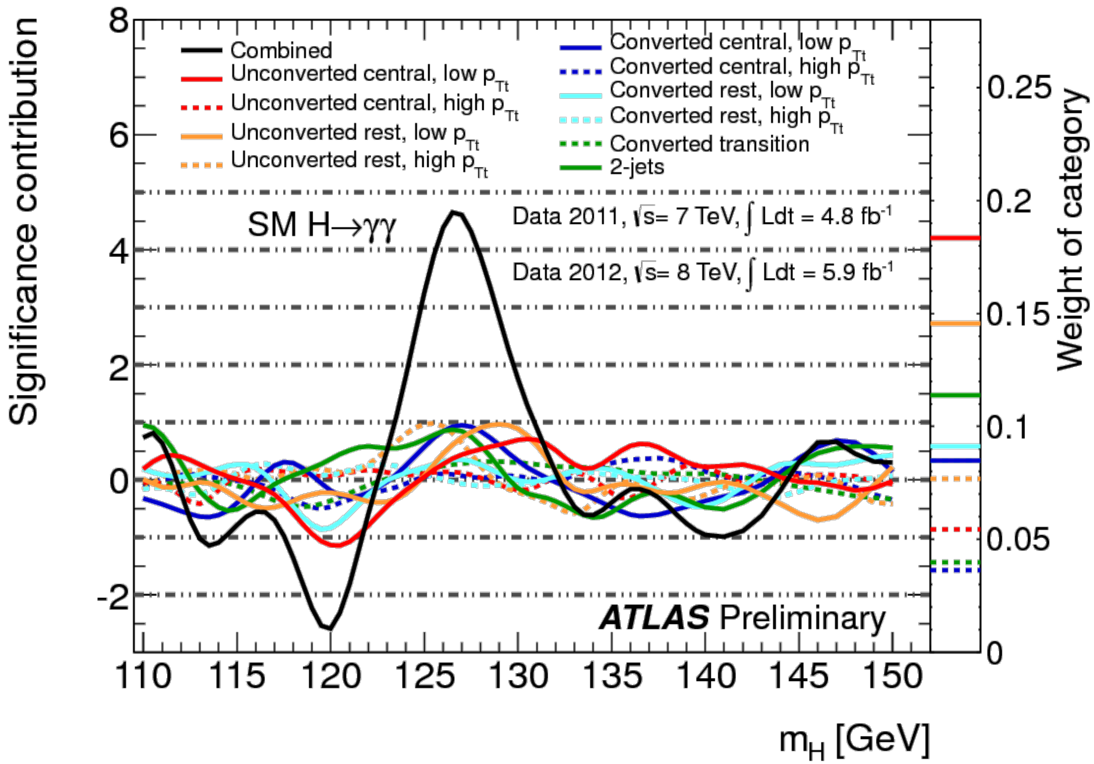
- Background dominated by irreducible QCD diphoton production
  - Subleading contribution from events with 1 or 2 jets (with e.g. hard π^0) mis-ID as γ
  - Composition measured by relaxing photon-ID and/or isolation criteria, as fn of $m_{\gamma\gamma}$
    - Small contribution from DY Z/γ*→ee, with mis-ID e, concentrated at low mass

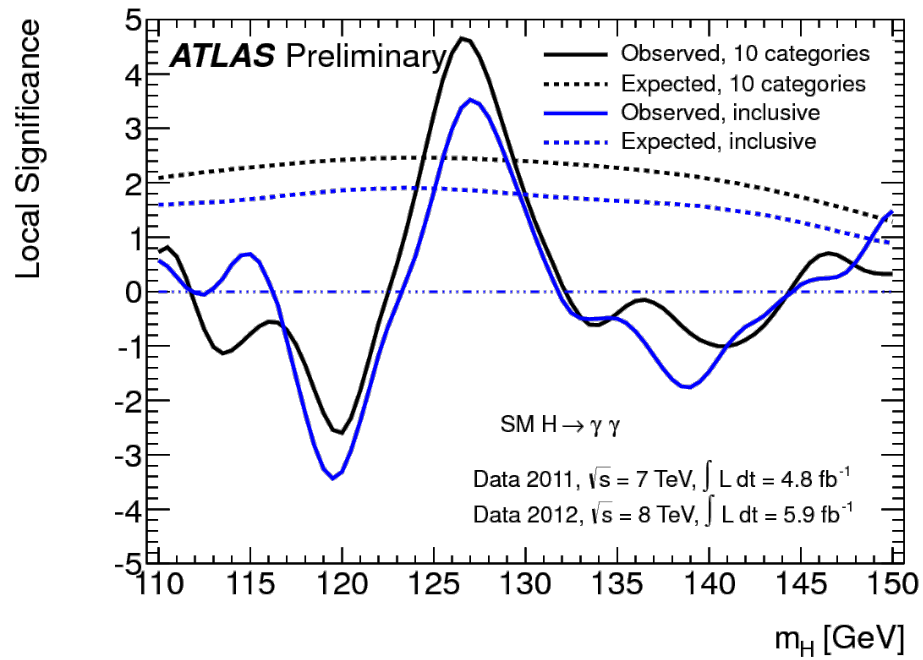




  - Composition breakdown not used in final analysis - actual background level and shape fitted directly from data

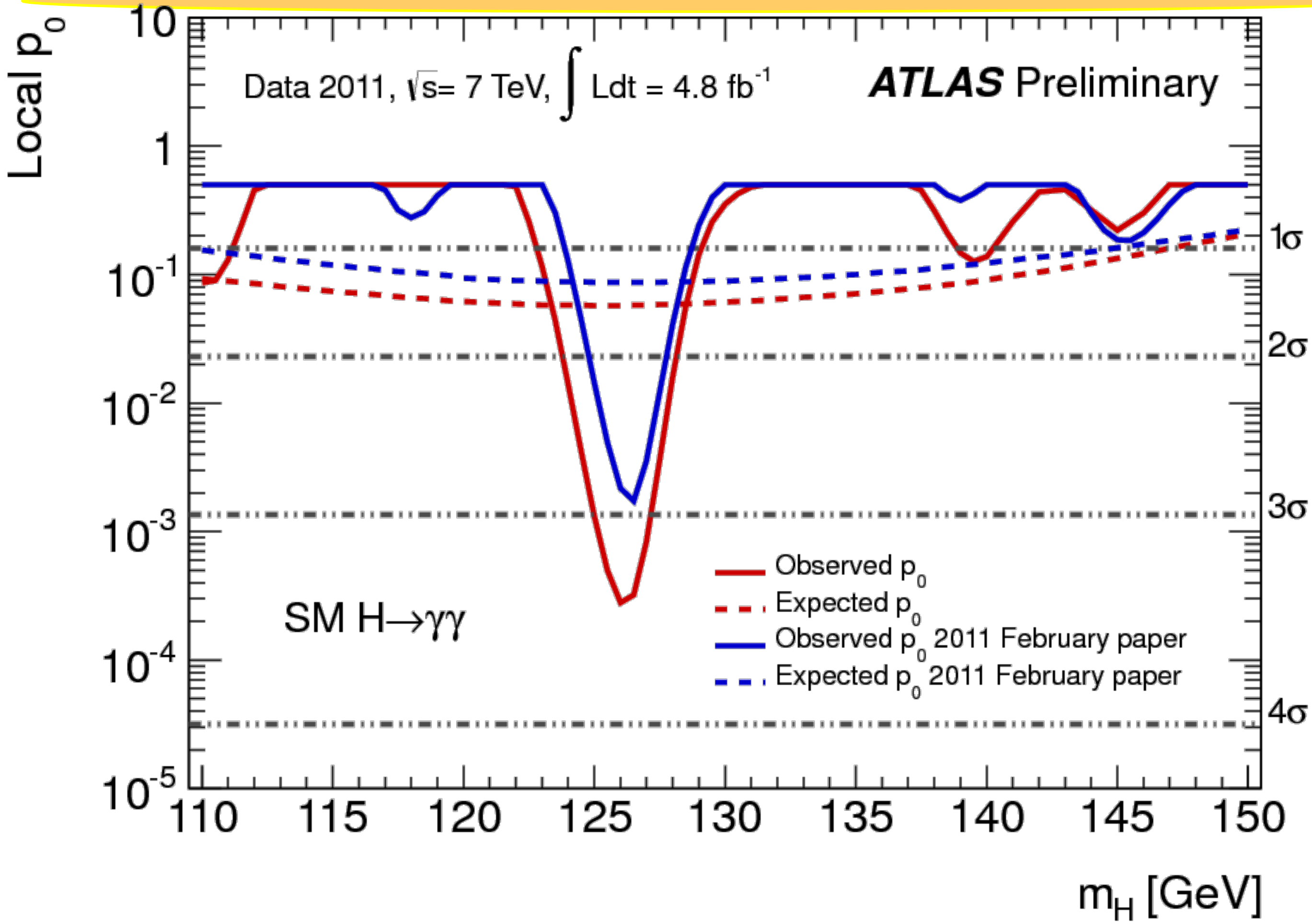
H→γγ: Event weighting





- Weights defined as $w_i=\sigma^2/\sigma_i^2$, σ_i is expected stat. uncertainty on category i
  - Weighted significance $Z'_i=\sqrt{w_i}Z_i$, where Zi is significance of category i
- Comparison of local significances vs m_H for 10-categories and inclusive
  - In 10-category fit, deficit at ~120 GeV has a local significance of 2.6σ
    - Or global 1.2σ with LEE

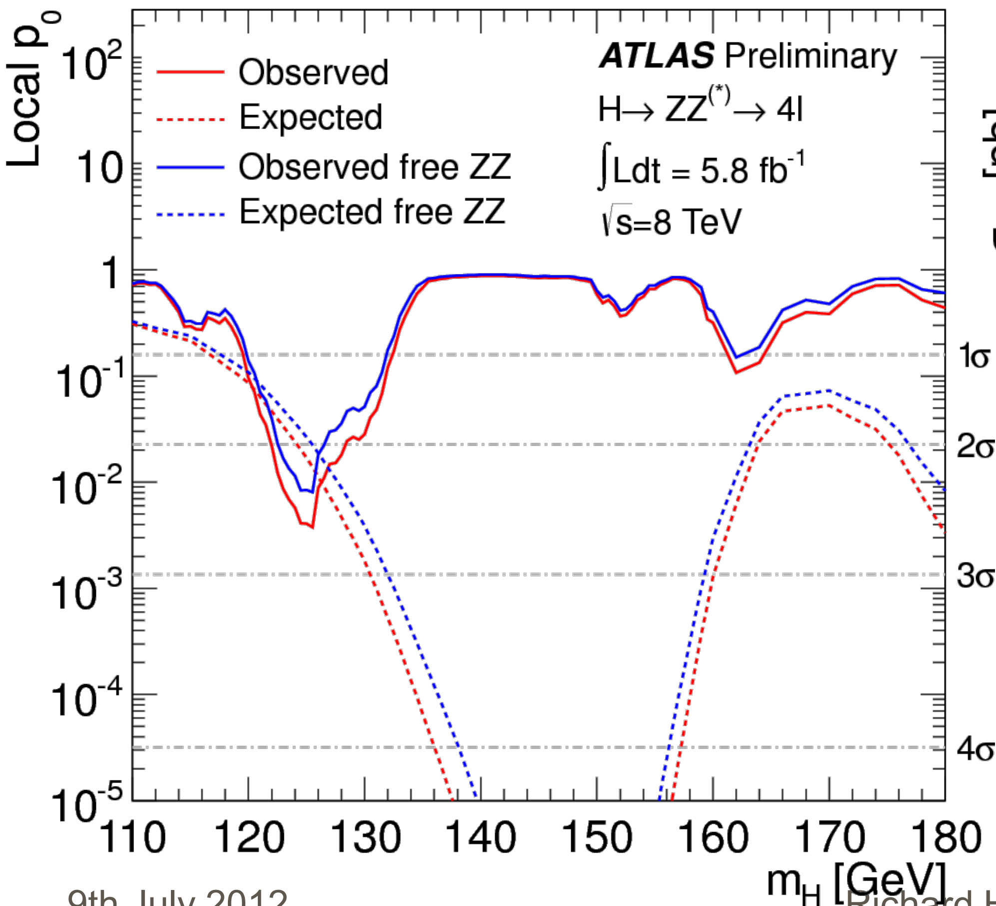
H→γγ: Comparison of old/new 2011 analyses

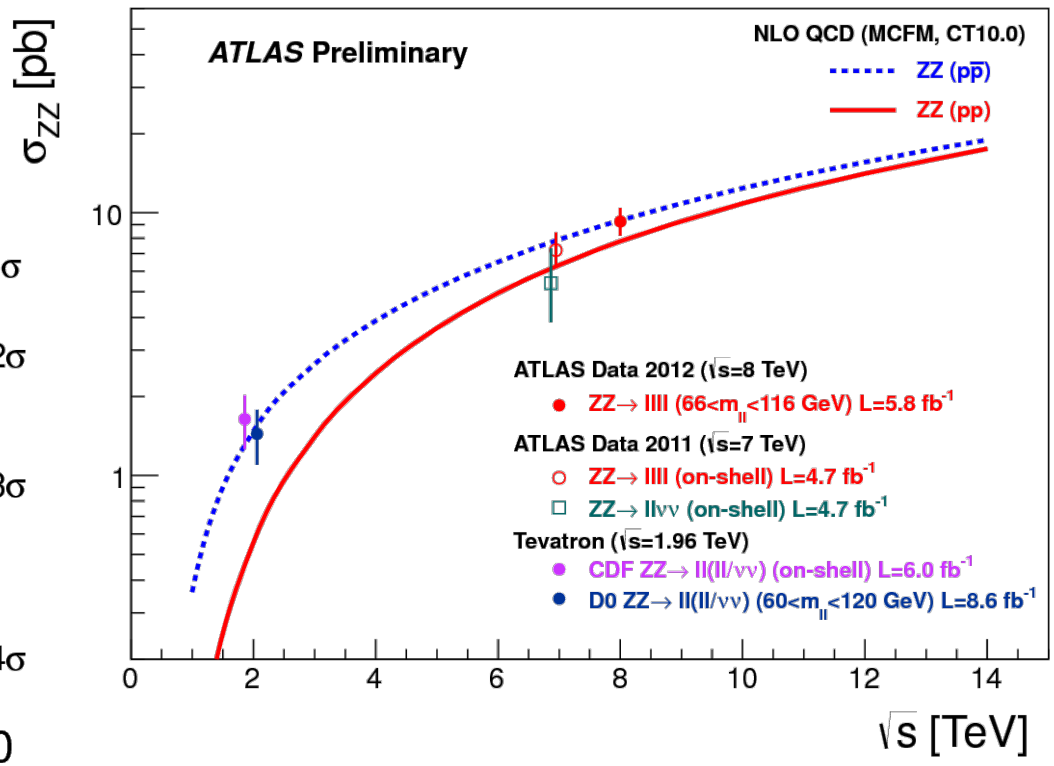


- Current 2011 analysis: 3.5σ at 126 GeV
- Original 2011 analysis: 2.8σ at 126.5 GeV (with ESS)

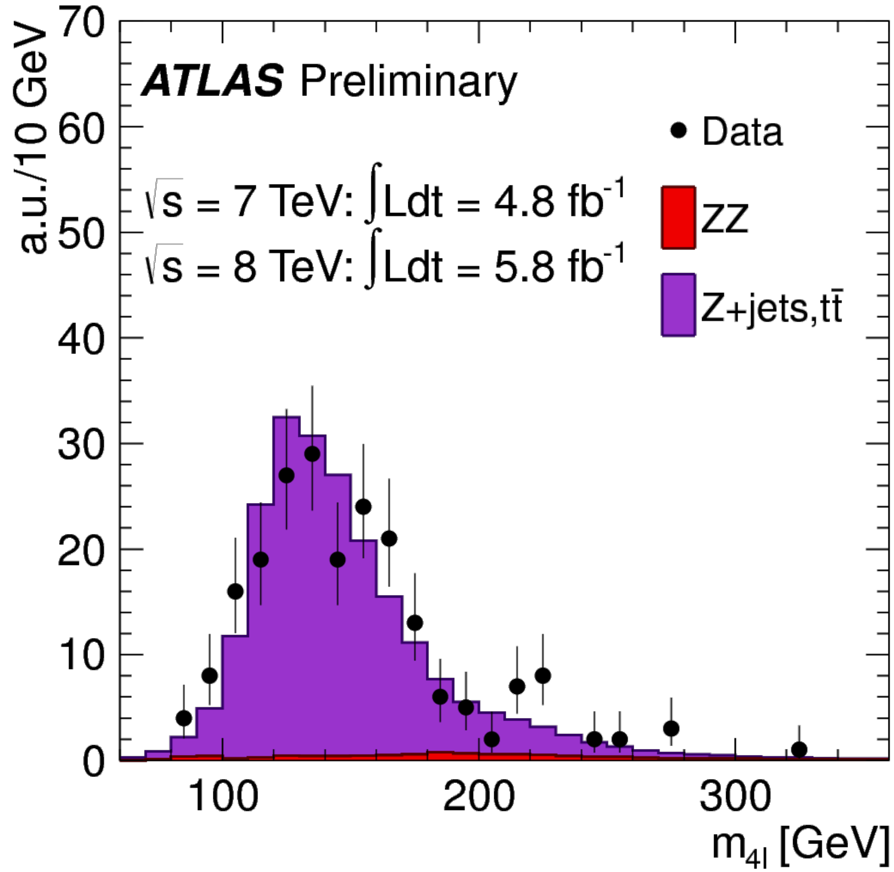
H→4 leptons: ZZ normalisation

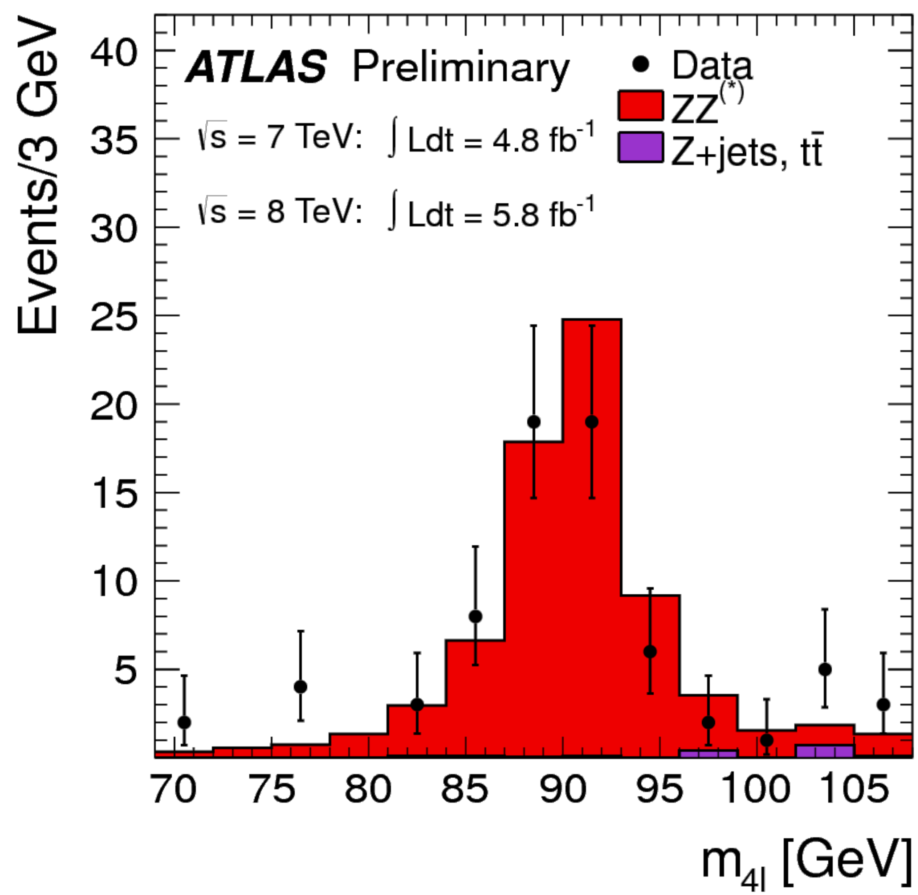
- See 20-30% more events at high mass than predicted by MC
  - Also seen ZZ cross-section analysis: ~25% high, but consistent with prediction
- Allow ZZ(*) normalisation to float – no significant change in p_0 for 125 GeV





H→4 leptons: Background modelling





- Validation of of Z+jets/ttbar background shape in control sample
  - Sub-leading dileptons fail isolation or impact parameter cuts
- Modelling of single resonant Z→4l peak, relaxing m_{12}, m_{34} and p_T cuts

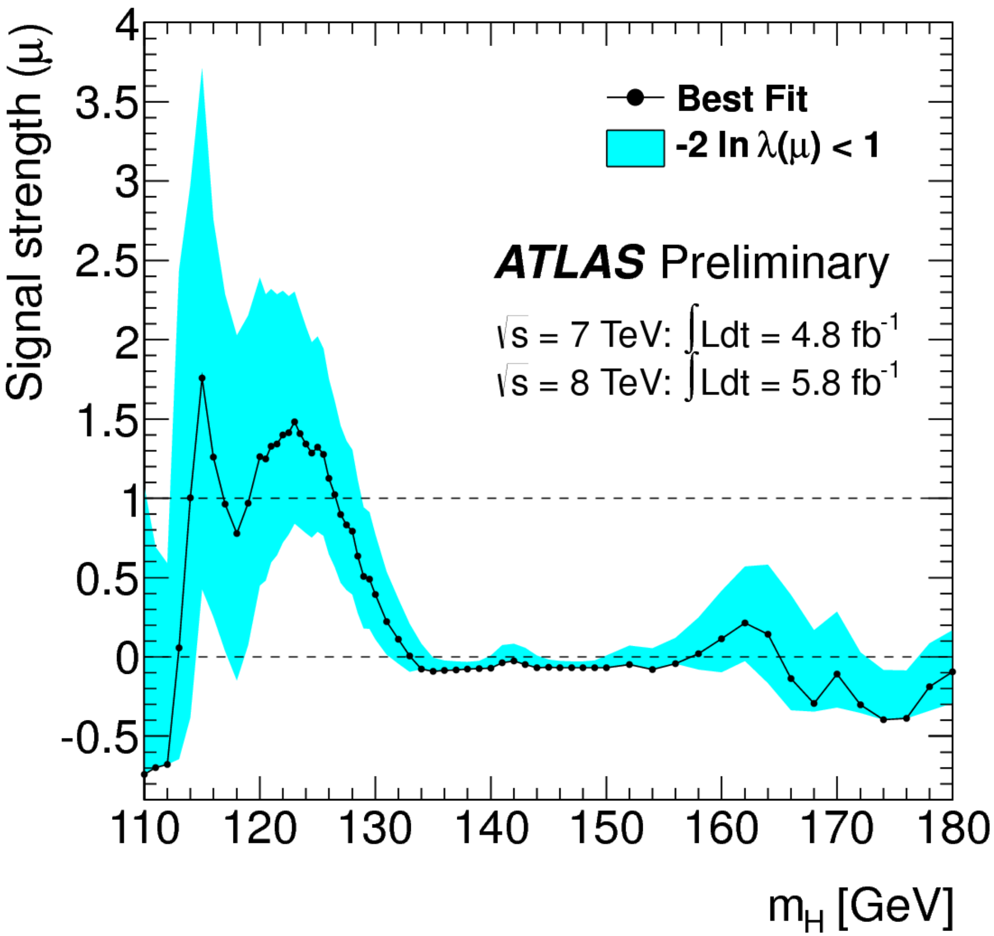
H→4 leptons: Reducible backgrounds

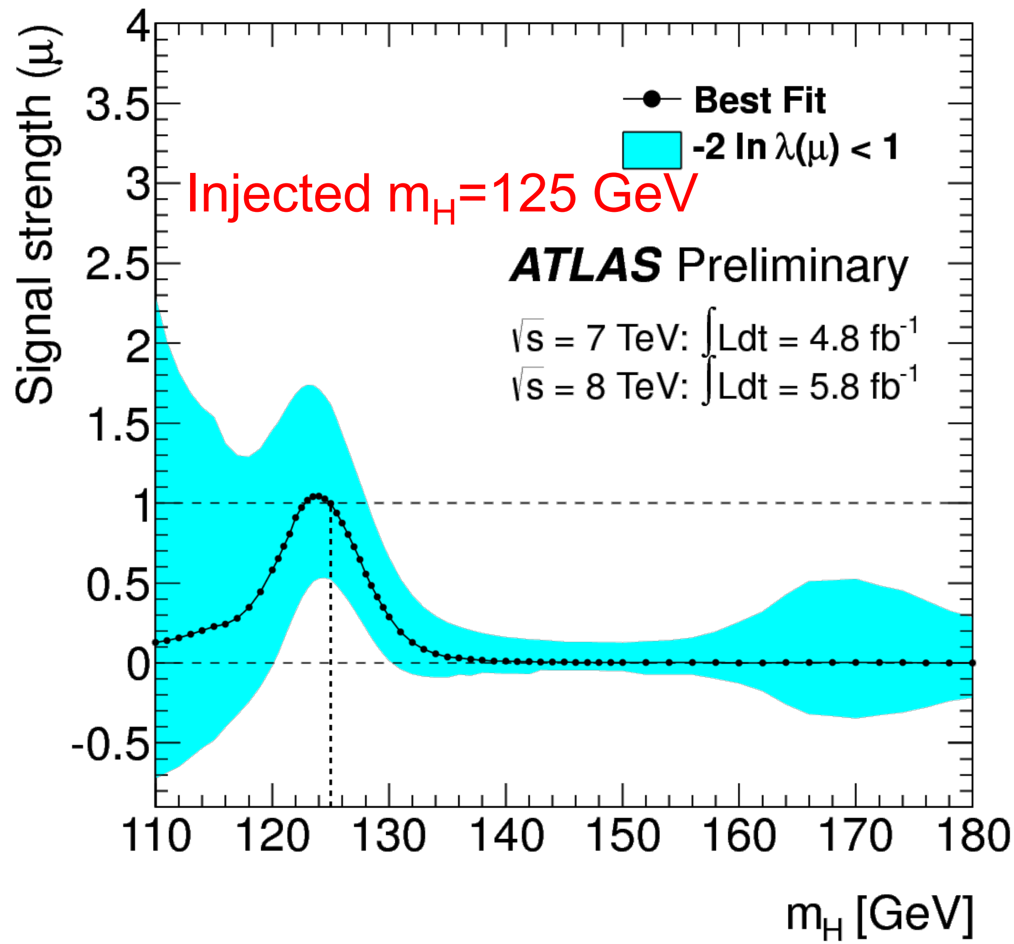
- Summary of estimates for non-resonant b/g, † = primary estimate

Method	8 TeV Estimate	7 TeV Estimate
4μ		
m_{12} fit: $Z+$jets contribution	$0.51\pm 0.13 \pm 0.16^{\dagger}$	$0.25\pm 0.10 \pm 0.08^{\dagger}$
m_{12} fit: $t\bar{t}$ contribution	$0.044\pm 0.015\pm 0.015^{\dagger}$	$0.022\pm 0.010\pm 0.011^{\dagger}$
$t\bar{t}$ from $e^{\pm}\mu^{\mp}+\mu^{\pm}\mu^{\mp}$	$0.058\pm 0.015\pm 0.019$	$0.025\pm 0.009\pm 0.014$
$2e2\mu$		
m_{12} fit: $Z+$jets contribution	$0.41\pm 0.10 \pm 0.13^{\dagger}$	$0.20\pm 0.08 \pm 0.06^{\dagger}$
m_{12} fit: $t\bar{t}$ contribution	$0.040\pm 0.013\pm 0.013^{\dagger}$	$0.020\pm 0.009\pm 0.011^{\dagger}$
$t\bar{t}$ from $e^{\pm}\mu^{\mp}+\mu^{\pm}\mu^{\mp}$	$0.051\pm 0.013\pm 0.017$	$0.024\pm 0.009\pm 0.014$
$2\mu 2e$		
$\ell\ell+e^{\pm}e^{\mp}$	$4.9\pm 0.8 \pm 0.7^{\dagger}$	$2.6\pm 0.4 \pm 0.4^{\dagger}$
$\ell\ell+e^{\pm}e^{\pm}$	$4.1\pm 0.6 \pm 0.8$	$3.7\pm 0.9 \pm 0.6$
$3\ell+\ell$ (same-sign)	$3.5\pm 0.5 \pm 0.5$	$2.0\pm 0.5 \pm 0.3$
$4e$		
$\ell\ell+e^{\pm}e^{\mp}$	$3.9\pm 0.7 \pm 0.8^{\dagger}$	$3.1\pm 0.6 \pm 0.5^{\dagger}$
$\ell\ell+e^{\pm}e^{\pm}$	$3.1\pm 0.5 \pm 0.6$	$3.2\pm 0.6 \pm 0.5$
$3\ell+\ell$ (same-sign)	$3.0\pm 0.4 \pm 0.4$	$2.2\pm 0.5 \pm 0.3$

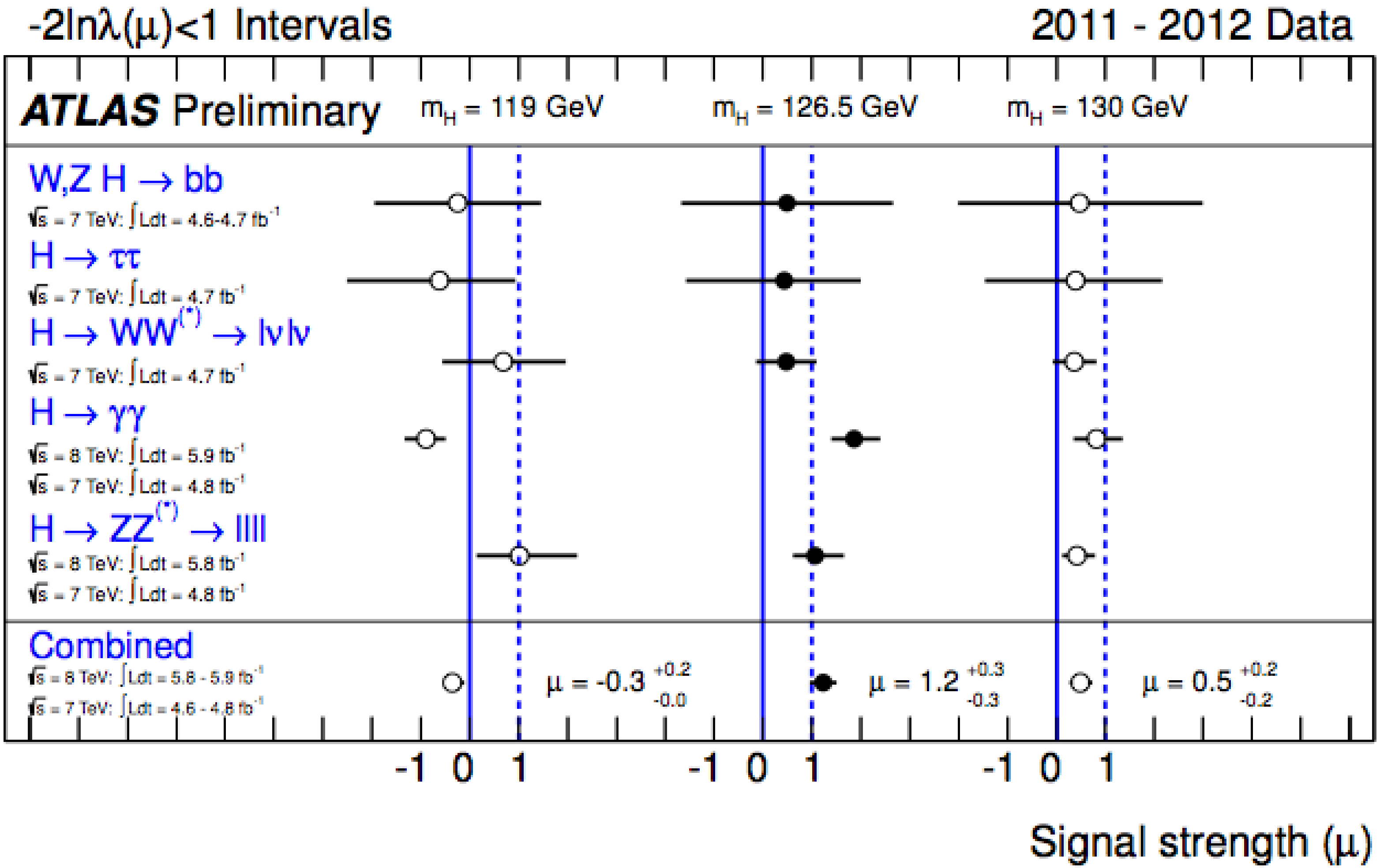
H→4 leptons: signal injection

- Comparison of data with MC with injected SM m_H=125 GeV signal





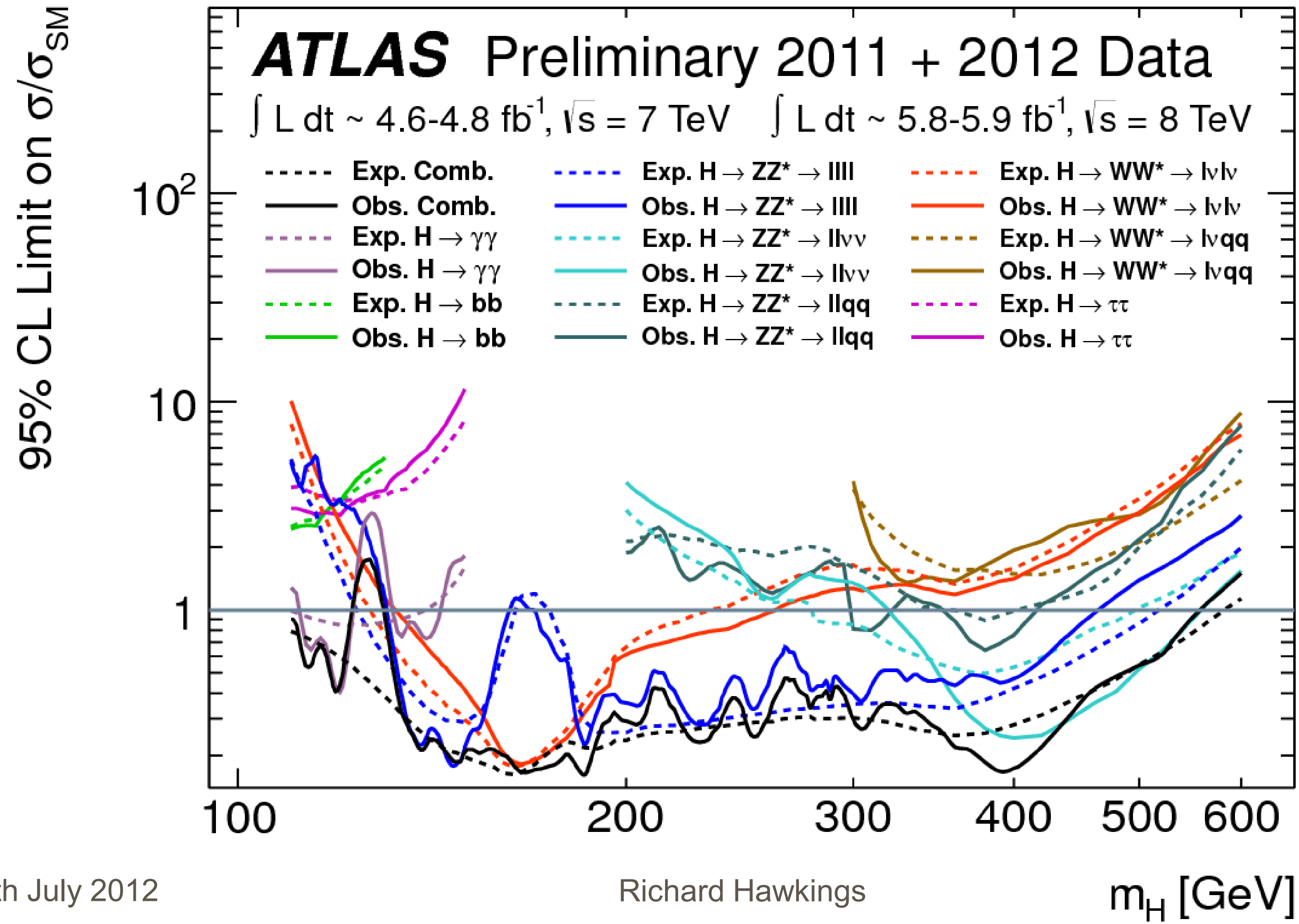
Combination: Different channels, different m_H



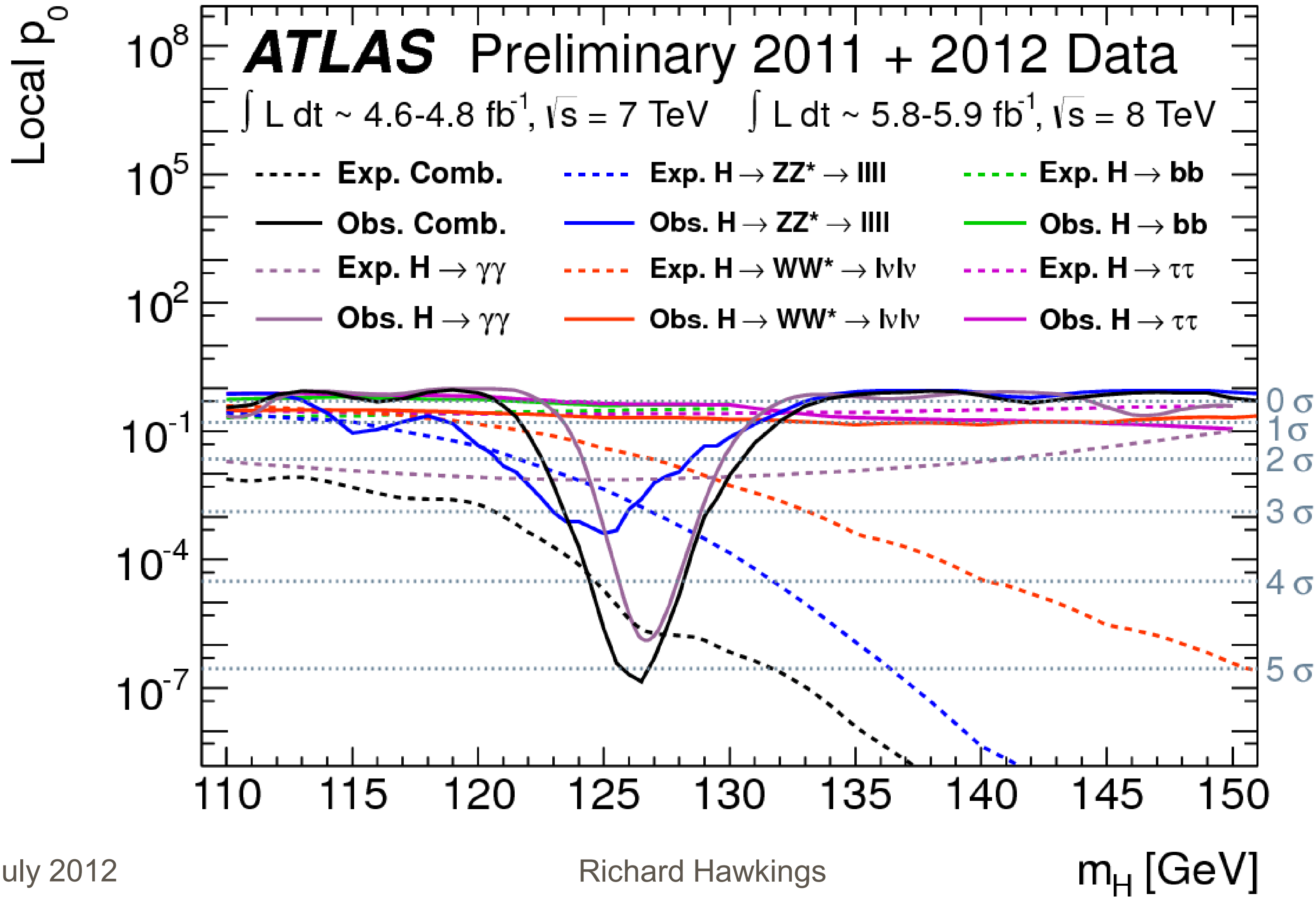
- Contributions of different channels at 119, 126.5 and 130 GeV
  - Most important contributions from H→γγ, H→ZZ(*)→4l, H→WW(*)→lνlν

Combination: Exclusion per channel

- Combination of all channels, 2011+2012 data

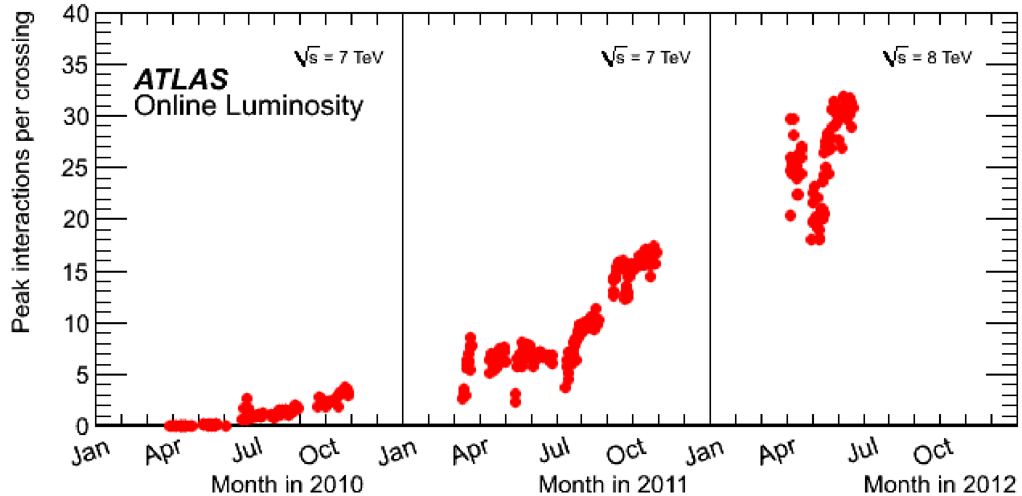


- Combination of all channels, 2011+2012 data

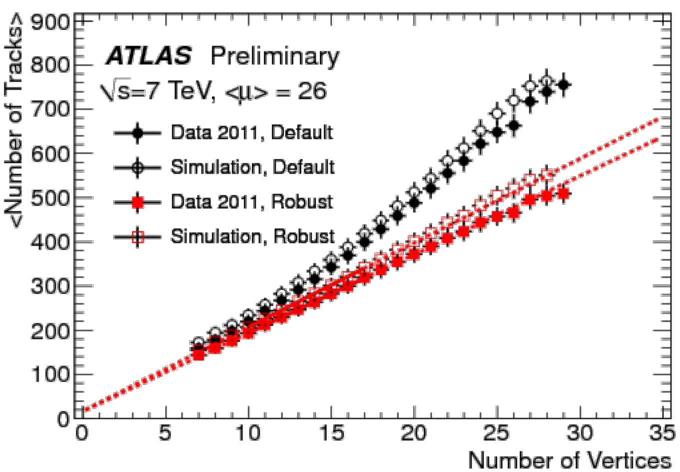


Dealing with high pileup

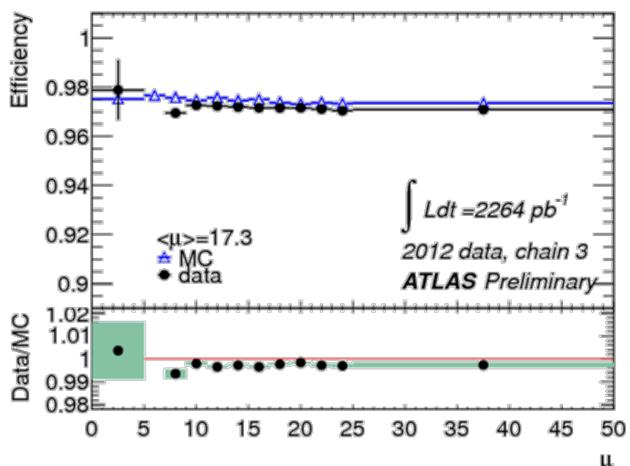
- Peak level of pileup – 30 int/crossing
  - Double that in 2011
- Major effort to optimise trigger and reconstruction algorithms
  - Robust, pileup insensitive
- e.g. robust tracking cuts, improved tau identification



Linearity – tracks vs. vertices



Muon reco. efficiency



Tau background rejection