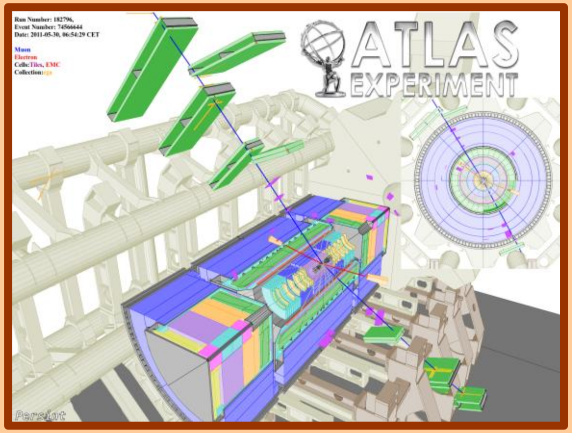
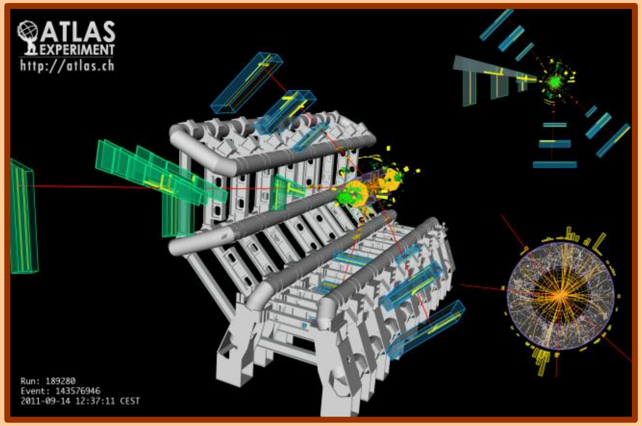
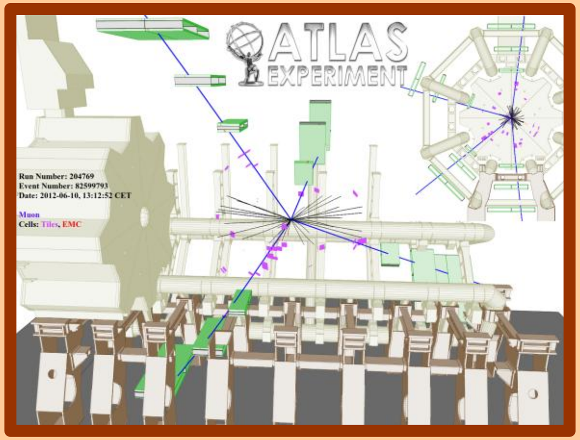
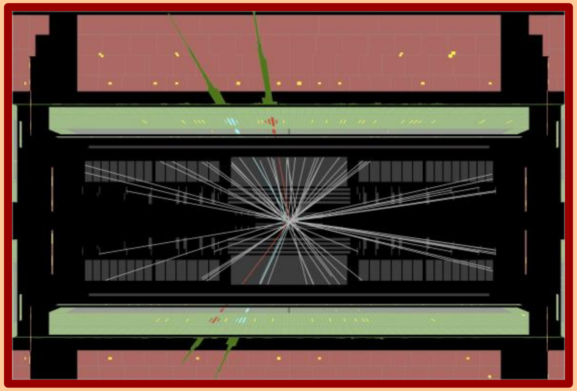




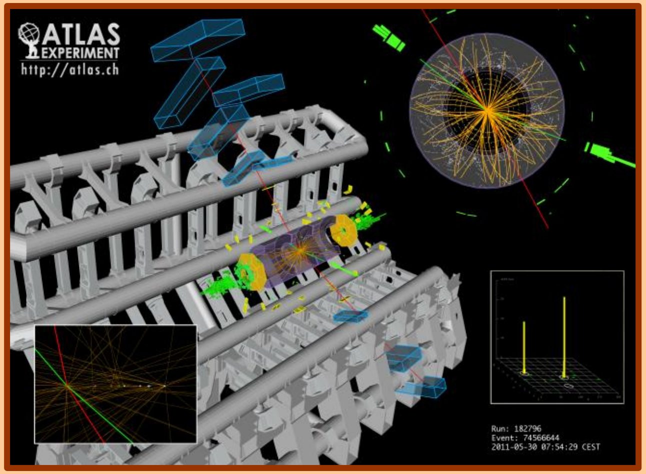


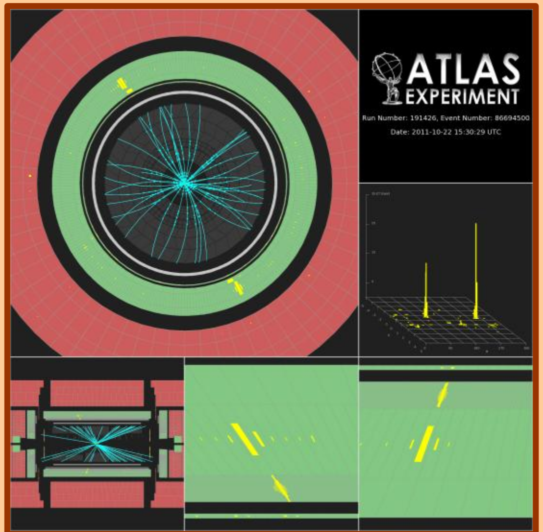
How did ATLAS discover a Higgs-like boson?

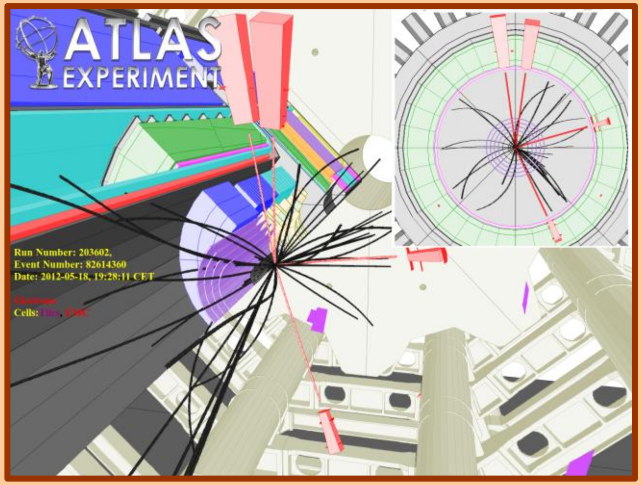


Scientific Symposium on the occasion of the 20th Anniversary
of Czech Republic at CERN, 26 October 2012

Fabiola Gianotti (CERN)







Stepping stones toward a discovery (and many other nice results ..)

More than 20 years of hard, talented work from conception to start of operation discussed by P. Jenni

More recent ingredients

Outstanding performance of the LHC

Excellent ATLAS data-taking efficiency and data quality

Detector and trigger performance approaching ultimate expectation:

☐ experience gained with 2011 data propagated to trigger, reconstruction and simulation → improved detector understanding, alignment and calibration,

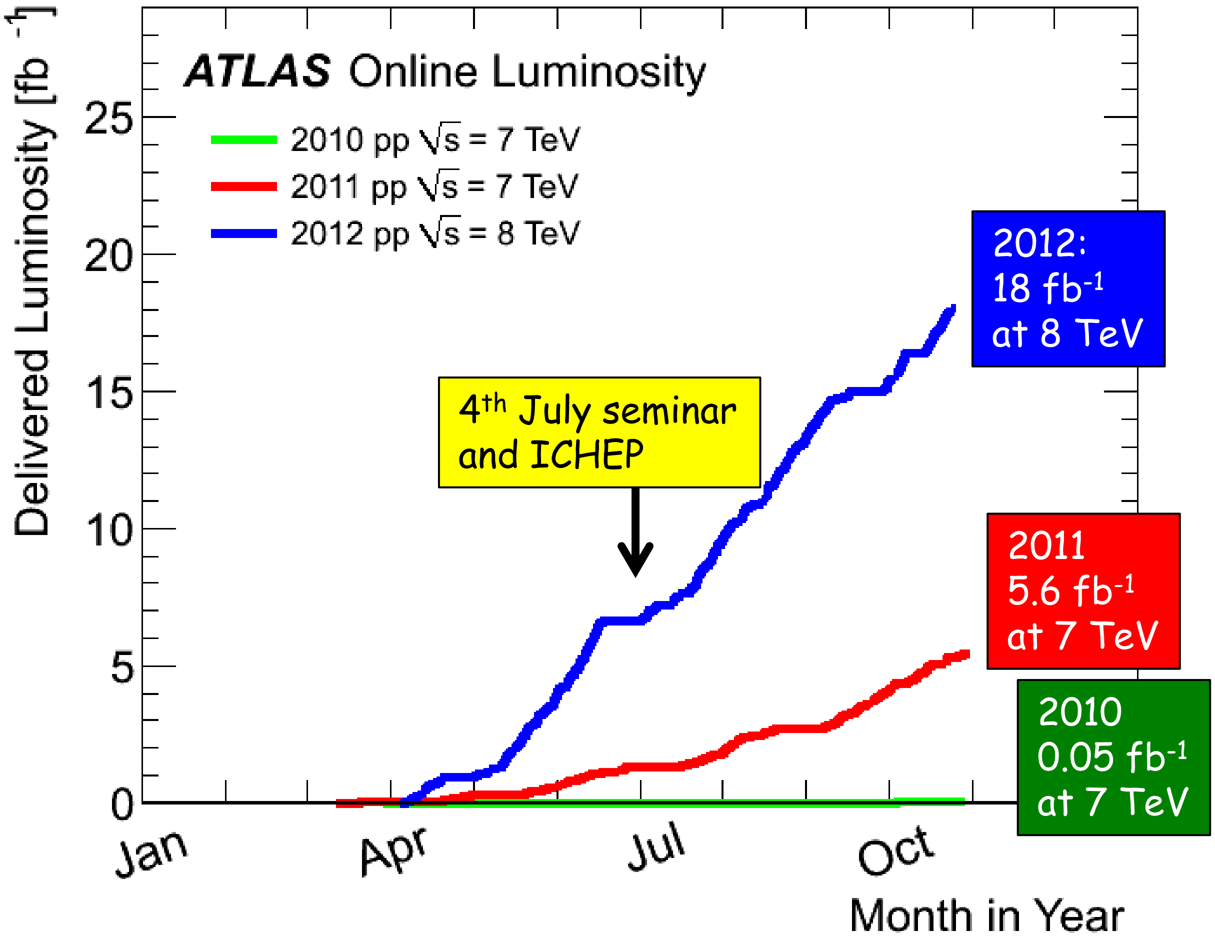
☐ huge effort since Fall 2011 to prepare for higher pile-up in 2012 and mitigate impact on trigger and reconstruction and identification of physics objects → sizeable gain in efficiency for e/γ/μ, jets, E_T^{miss} , pile-up dependence minimized …

Superb performance of the Computing Grid (resources over-stressed) allowing people (students !) from all over the world to do data analysis very effectively → see P. Jenni's talk

Detailed studies of Standard Model processes important on their own and as background to searches → see P. Jenni's talk

→ Huge amount of painstaking foundation work !

Luminosity delivered to ATLAS since the beginning



4th July seminar and ICHEP

2012:
18 fb^{-1}
at 8 TeV

2011
5.6 fb^{-1}
at 7 TeV

2010
0.05 fb^{-1}
at 7 TeV

Max luminosity:
~ 7.7 x10^{33} cm^{-2} s^{-1}

BIG THANKS to the LHC team

2012 detector operation, data-taking efficiency, data quality

Fraction of non-operational detector channels:
(depends on the sub-detector)
few permil (most cases) to 5%

Data-taking efficiency = (recorded lumi)/(delivered lumi): ~ 93.7%

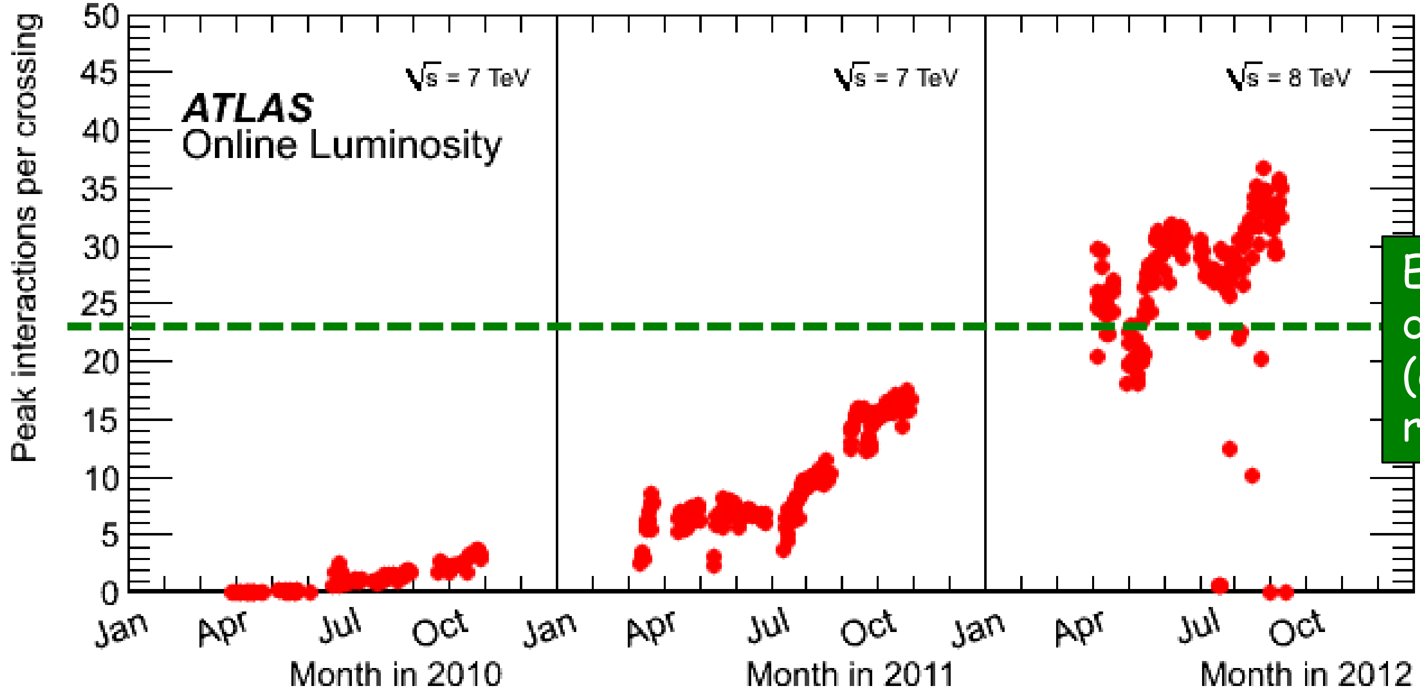
Good-quality data fraction, used for analysis :
(will increase further with data reprocessing)
> 93 %

~ 90%

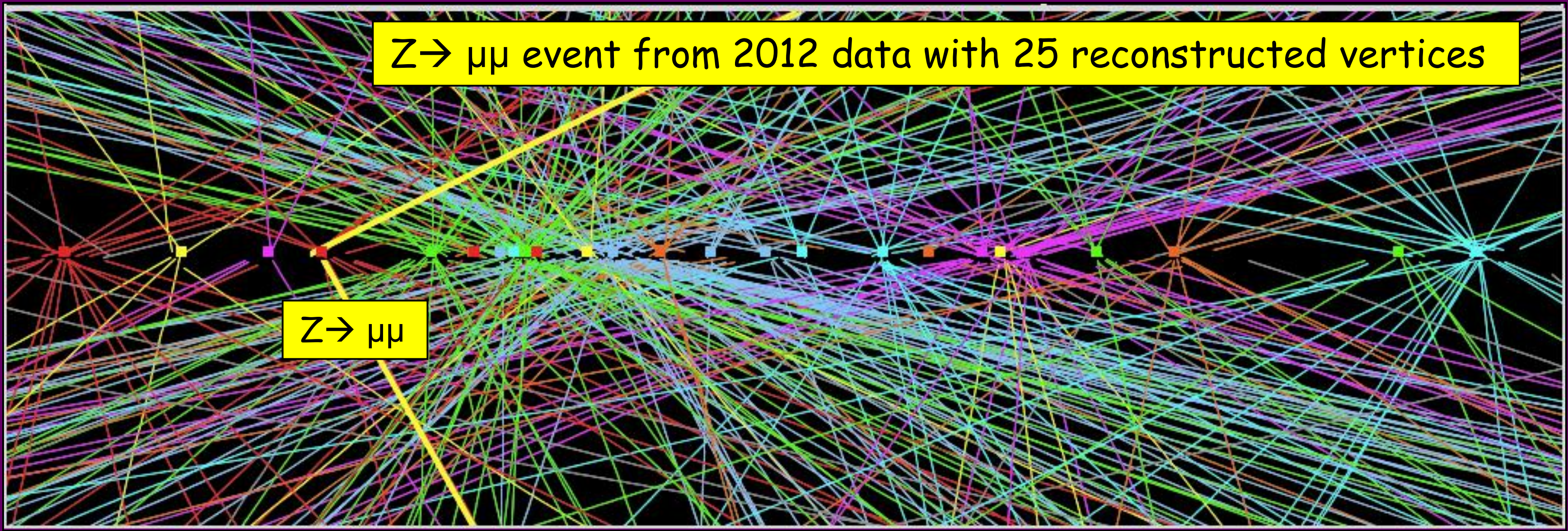
of the delivered luminosity used for physics
(slightly larger fraction than in 2011):

❑ in spite of the very fresh data
❑ in spite of the harsher conditions in 2012

The BIG challenge in 2012: PILE-UP



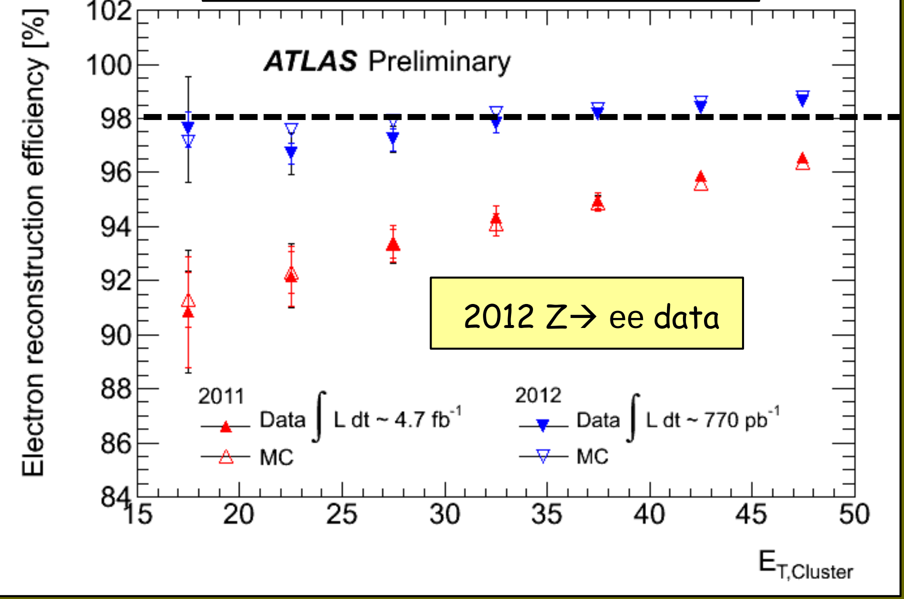
Experiment's design value (expected to be reached at $L=10^{34}$!)



Z→ μμ event from 2012 data with 25 reconstructed vertices

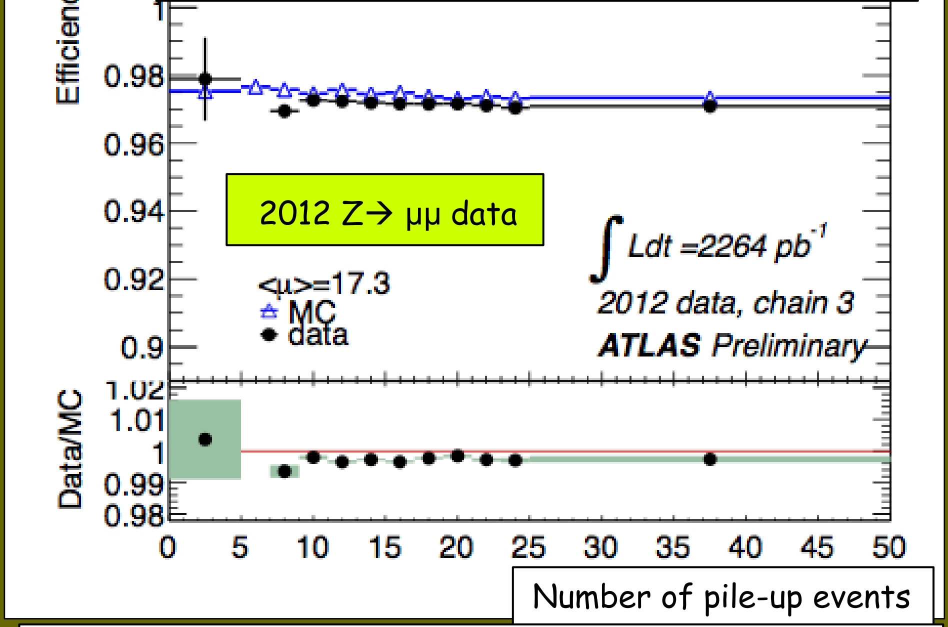
Z→ μμ

Improved e± reconstruction to recover Brem losses



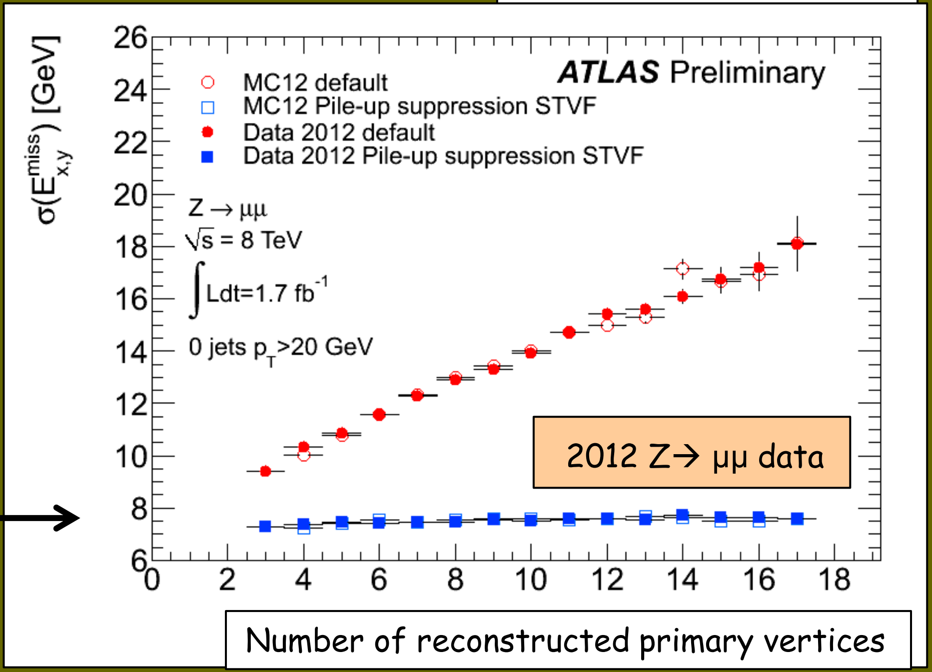
2012 Z→ ee data

Muon reconstruction efficiency ~ 97% down to p_T ~ 6 GeV over $|\eta|<2.7$



2012 Z→ μμ data

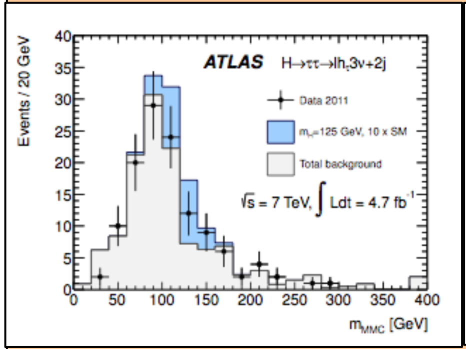
Number of pile-up events

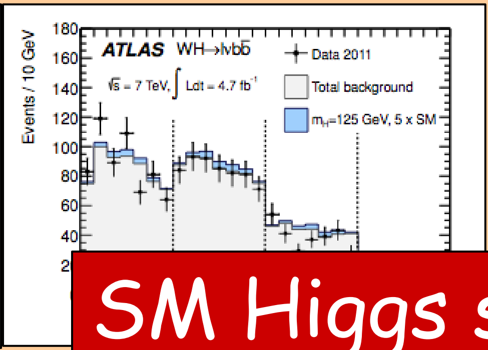


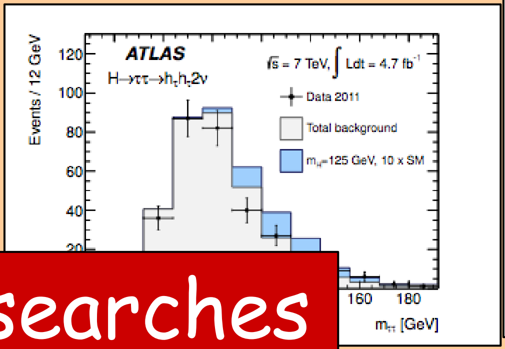
2012 Z→ μμ data

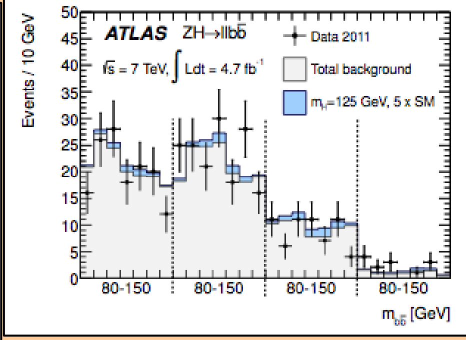
Number of reconstructed primary vertices

E_T^{miss} resolution vs pile-up **before** and **after** pile-up suppression using tracks →







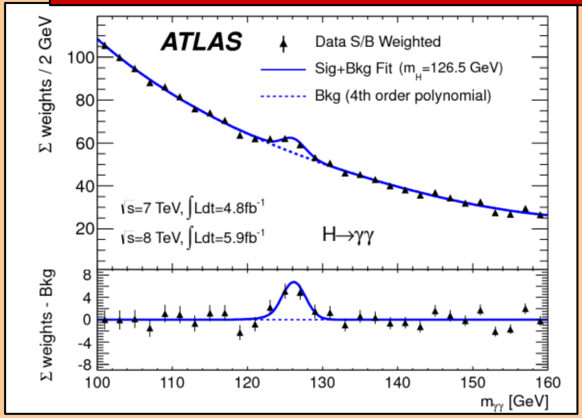


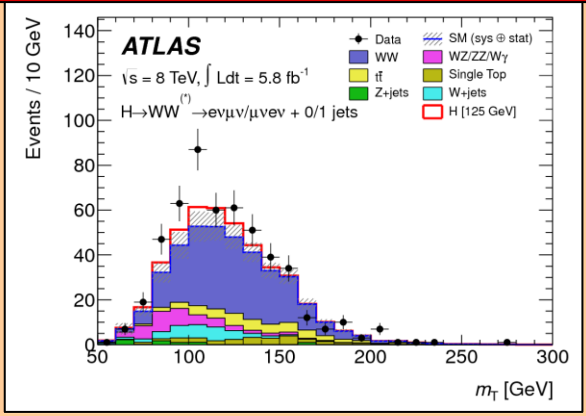
SM Higgs searches

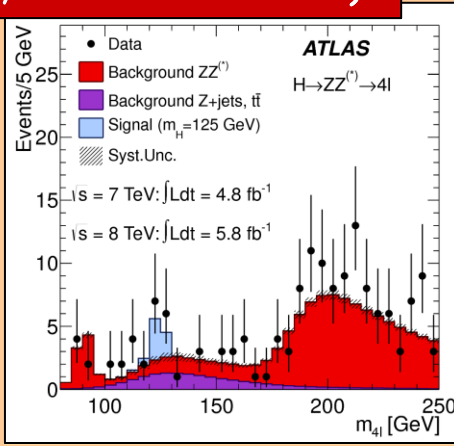
Results based on:

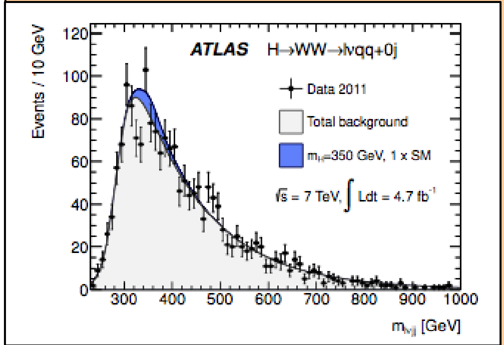
- ❑ ~ 4.9 fb^{-1} √s =7 TeV data (2011) + ~5.9 fb^{-1} √s = 8 TeV data (2012) → total: ~10.7 fb^{-1} for H→ γγ, H→ ZZ* → 4l, H→ WW* → lνlν
- ❑ ~ 4.9 fb^{-1} of √s =7 TeV data (2011) for H→ ττ, W/ZH→ bb and high-mass channels

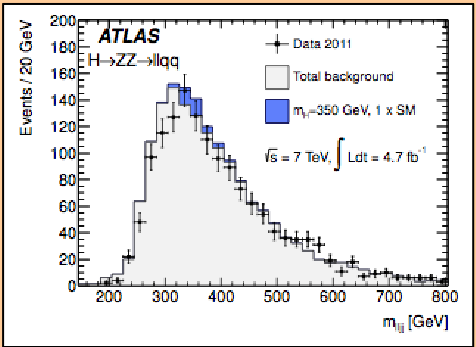
Update with ~ 13 fb^{-1} of 2012 data planned for HCP Workshop (Kyoto, 12-16 November)

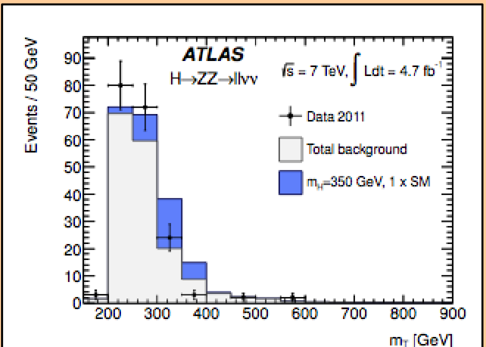


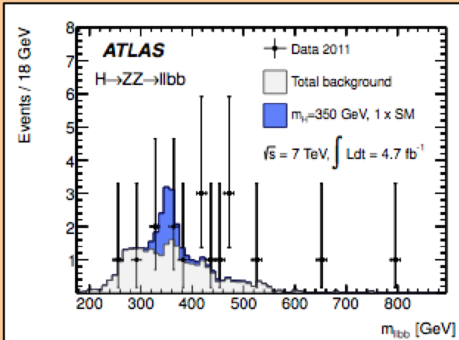




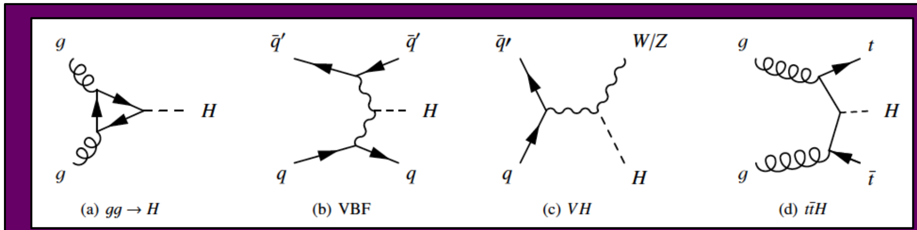


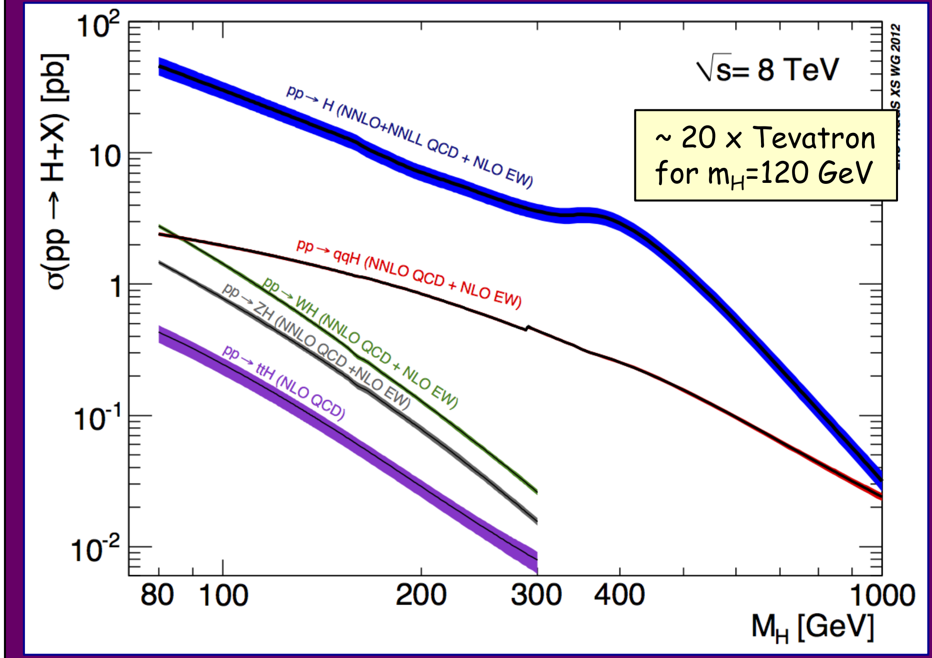




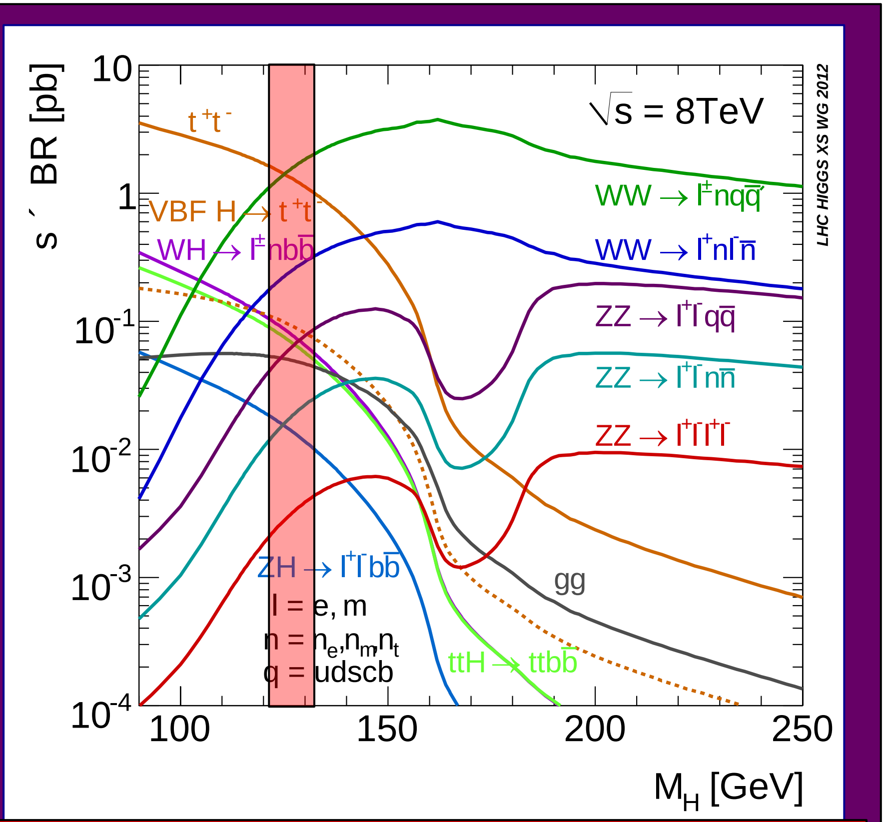


SM Higgs production cross-section and decay modes





~ 20 x Tevatron for m_H=120 GeV



Most sensitive channels (decreasing order) for 120 <m_H< 130 GeV:

H→ ZZ*→ 4l, H→ γγ, H→ WW*→ lνlν

H→ ττ

W/ZH→ W/Z bb

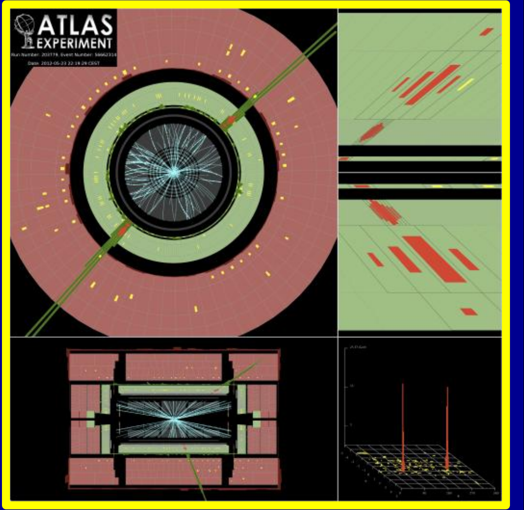
√s=7 → 8 TeV:

- ❑ Higgs cross-section increases by ~ 1.3 for m_H ~ 125 GeV
- ❑ Similar increase for several irreducible backgrounds: e.g. 1.2-1.25 for γγ, di-bosons
- ❑ Reducible backgrounds increase more: e.g. 1.3-1.4 for tt, Zbb

→ Expected increase in Higgs sensitivity: 10-15%

$H \rightarrow \gamma\gamma$

$110 \leq m_H \leq 150$ GeV



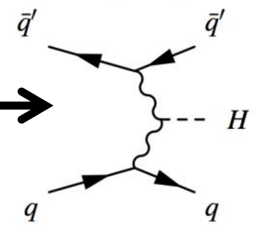
$\sigma \times BR \sim 50$ fb $m_H \sim 126$ GeV

- Simple topology: two high-p_T isolated photons
  $E_T(\gamma_1, \gamma_2) > 40, 30$ GeV
- Main background: γγ continuum (irreducible, smooth, ..)

To increase sensitivity, events divided in 10 categories based on
- γ rapidity
- converted/unconverted γ
- p_{Tt} ($p_T^{\gamma\gamma}$ perpendicular to γγ thrust axis)
- presence of 2 forward jets (targeting VBF process) →

Gain in analysis sensitivity in 2012: + 15%

σ_{SM} (VBF) ~7%

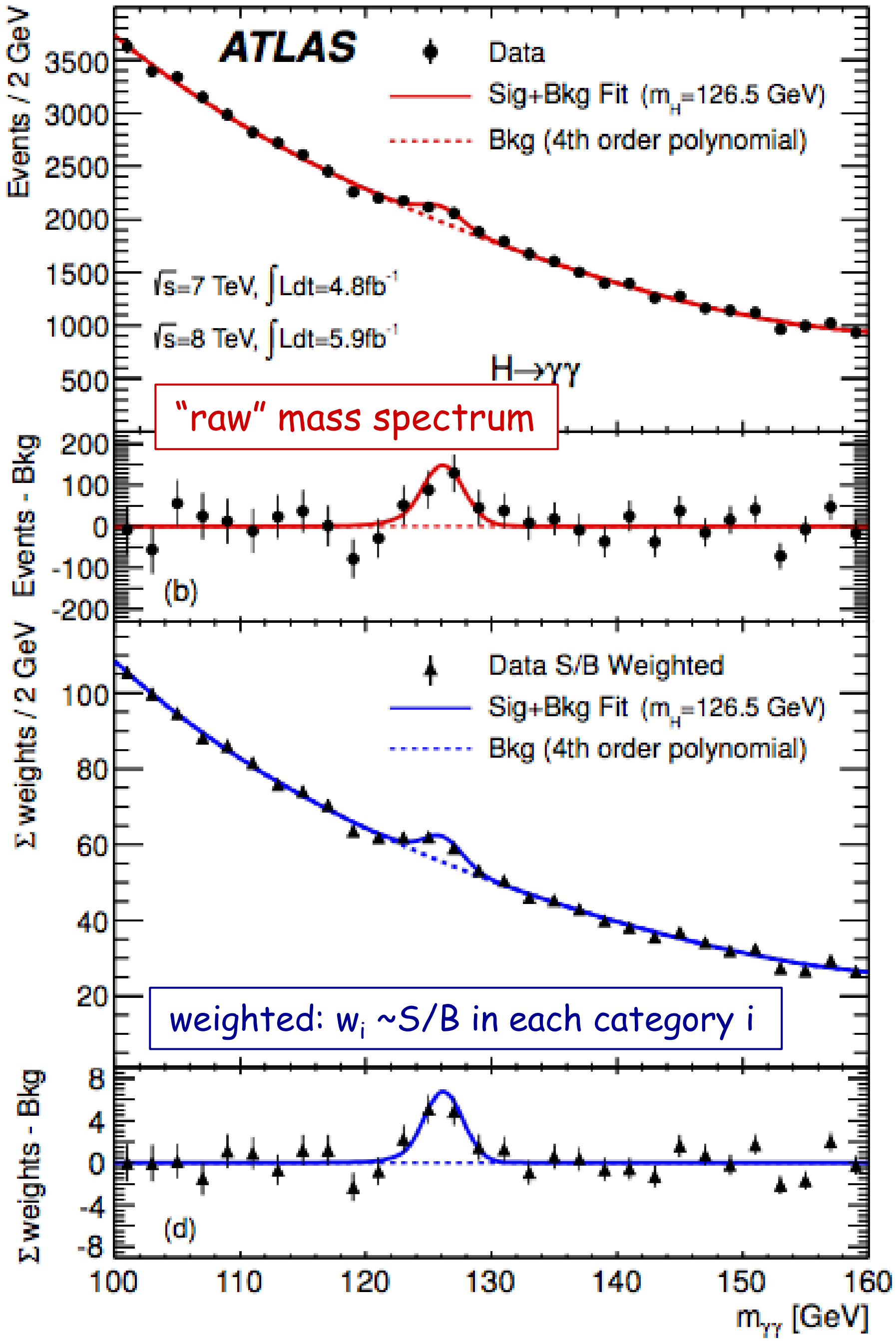


2 jets with
$p_T > 25$-30 GeV
$|\eta| < 4.5$
$|\Delta\eta|_{jj} > 2.8$
$M_{jj} > 400$ GeV
$|\Delta\varphi|$ $(\gamma\gamma$-$jj) > 2.6$

After all selections, expect (10.7 fb^{-1}, $m_H \sim 126$ GeV)
~ 170 signal events
~ 6340 background events in mass window
→ S/B ~ 3% inclusive (~ 20% 2jet category)

Crucial experimental aspects:
- excellent γγ mass resolution to observe narrow signal peak above irreducible background
- powerful γ identification to suppress γj and jj background with jet → π^0 → fake γ

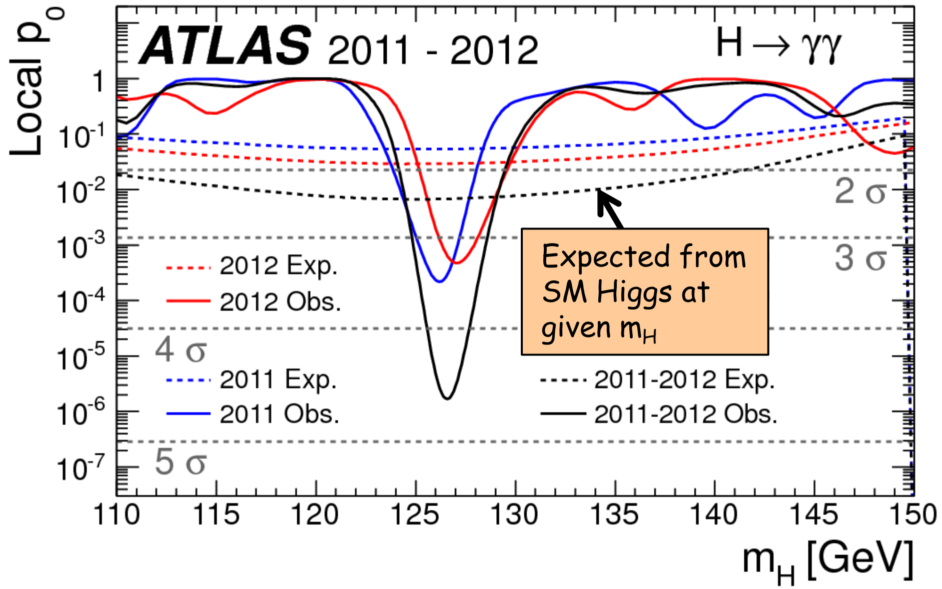
After all selections: 59059 events



"raw" mass spectrum

weighted: w_i ~S/B in each category i

p-value: consistency of data with background-only expectation



Expected from SM Higgs at given m_H

Data sample	m_H of max significance	local significance obs. (exp. SM H)
2011	126 GeV	3.4 σ (1.6)
2012	127 GeV	3.2 σ (1.9)
2011+2012	126.5 GeV	4.5 σ (2.5)

$H \rightarrow ZZ^{(*)} \rightarrow 4l$ (4e, 4μ, 2e2μ)

$110 < m_H < 600$ GeV

$\sigma \times BR \sim 2.5$ fb $m_H \sim 126$ GeV

- ☐ Very small cross-section, but:
  - -- mass can be fully reconstructed → events should cluster in a (narrow) peak
  - -- pure: $S/B \sim 1$
- ☐ 4 leptons: $p_T^{1,2,3,4} > 20,15,10,7\text{-}6$ (e-μ) GeV; $50 < m_{12} < 106$ GeV; $m_{34} > 17.5\text{-}50$ GeV (vs m_H)
- ☐ Main backgrounds:
  - -- $ZZ^{(*)}$: irreducible
  - -- low-mass region $m_H < 2m_Z$: Zbb, Z+jets, tt with two leptons from b-jets or q-jets

→ Suppressed with isolation and impact parameter cuts on two softest leptons

Crucial experimental aspects:

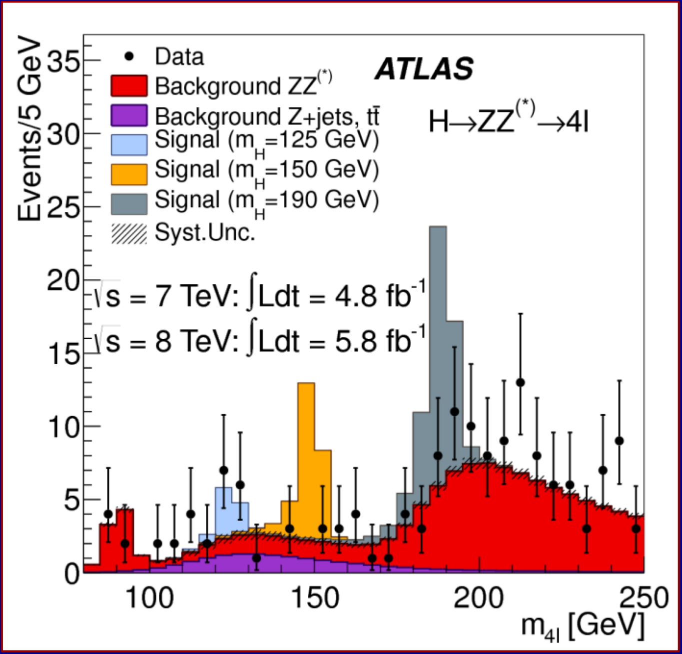
- ☐ High lepton acceptance, reconstruction and identification efficiency down to lowest p_T
- ☐ Good lepton energy/momentum resolution
- ☐ Good control of reducible backgrounds (Zbb, Z+jets, tt) in low-mass region:
  - → cannot rely on MC alone (theoretical uncertainties, b/q-jet → lepton modeling, ..)
  - → need to validate MC with data in background-enriched control regions

Main improvements in analysis in 2012:

- ☐ kinematic cuts optimized/relaxed to increase signal sensitivity at low mass
- ☐ increased $e^{\pm}$ reconstruction and identification efficiency at low p_T and pile-up robustness

→ Gain 20%-30% in sensitivity compared to last year's analysis

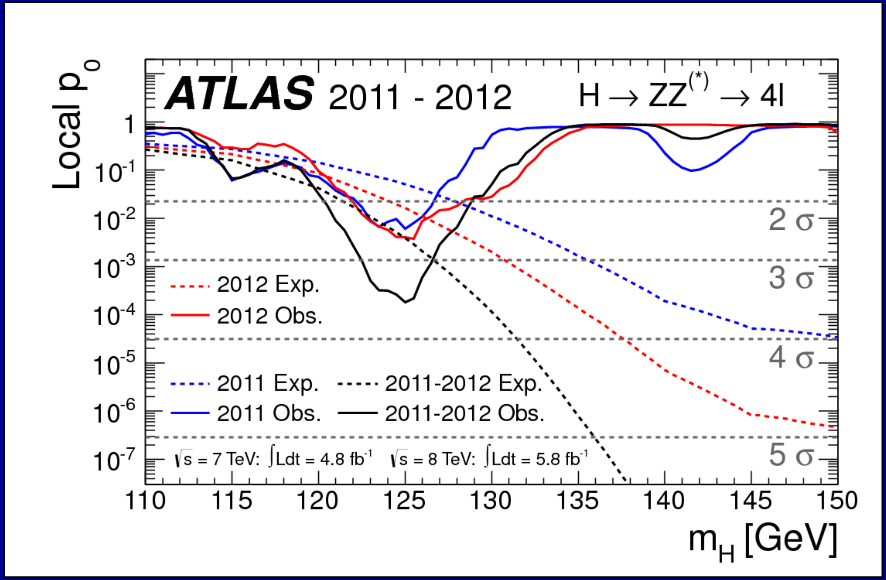
Reconstructed 4l mass spectrum after all selections



In the region 125 ± 5 GeV

Observed	13 events
Expected from background only	4.9 ± 1
Expected from Higgs signal	5.3 ± .8

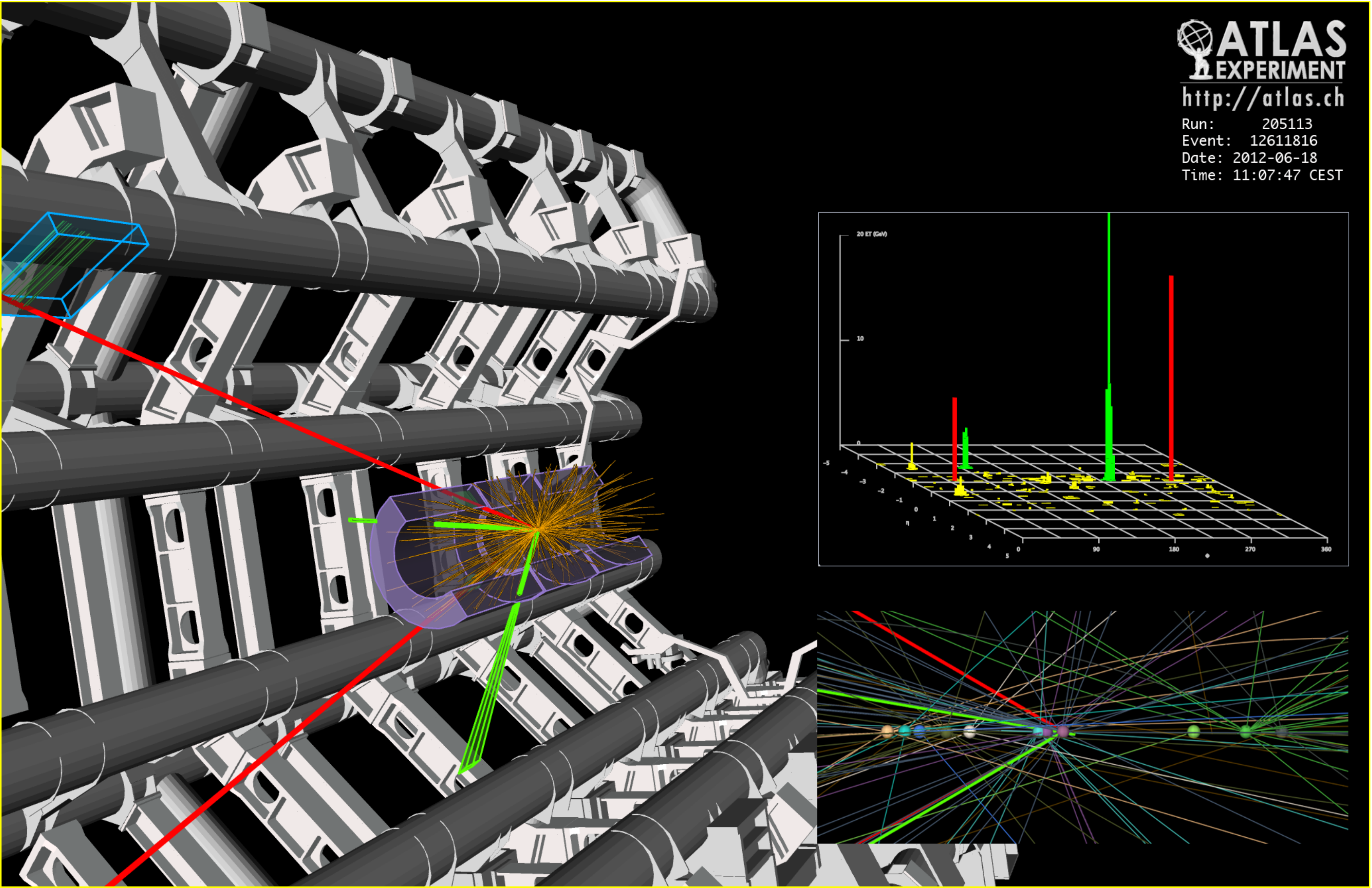
	4μ	2e2μ	4e
Data	6	5	2
Expected S/B	1.6	1.1	0.6
Reducible/total B	10%	60%	70%



Data sample	m_H of max significance	local significance obs. (exp. SM H)
2011	125 GeV	2.5 σ (1.6)
2012	125.5 GeV	2.6 σ (2.1)
2011+2012	125 GeV	3.6 σ (2.7)

2e2μ candidate with $m_{2e2\mu}$= 123.9 GeV

p_T (e,e,μ,μ)= 18.7, 76, 19.6, 7.9 GeV, m (e^+e^-)= 87.9 GeV, m($\mu^+\mu^-$) =19.6 GeV
12 reconstructed vertices



$H \to WW^{(*)} \to l\nu l\nu$ ($e\nu e\nu$, $\mu\nu\mu\nu$, $e\nu\mu\nu$)

$110 < m_H < 600$ GeV

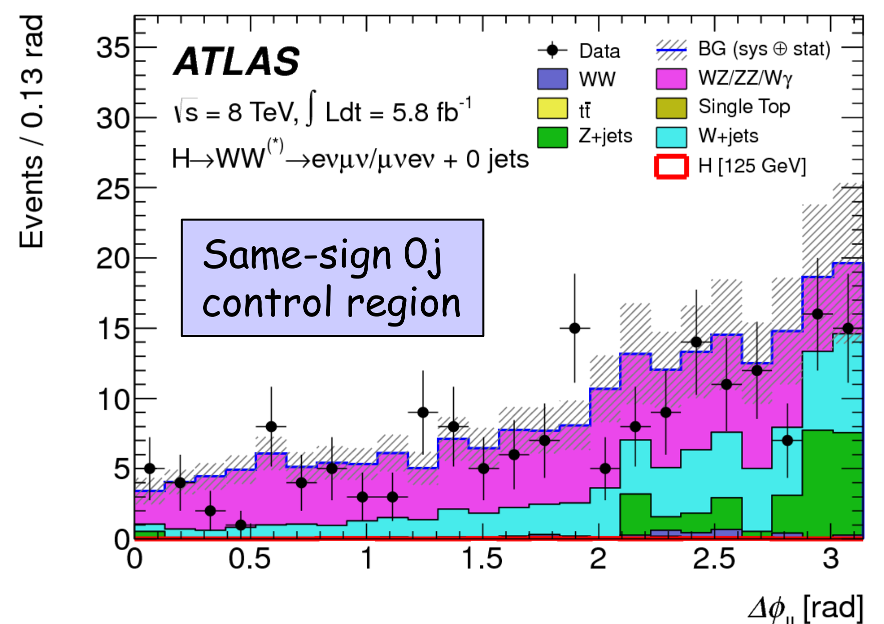
$\sigma \times BR \sim 200$ fb   for $m_H \sim 125$ GeV

- Large cross section
- However: 2ν in final state → mass peak cannot be reconstructed → “counting channel”
- $H \to e\nu\mu\nu$ studied with 2012 data: ~ 85% of sensitivity, less Drell-Yan background

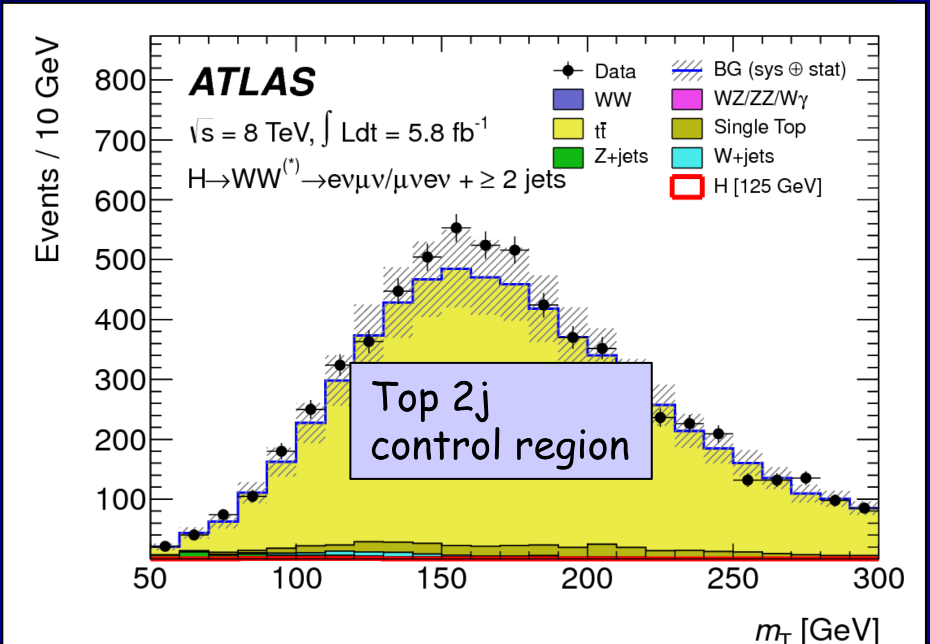
- 2 isolated opposite-sign leptons, $p_T > 25, 15$ GeV
- Main backgrounds: WW, top, Z+jets, W+jets
  → large E_T^{miss}, $m_{ll} \neq m_Z$, b-jet veto ..+ topological cuts: p_{Tll}, m_{ll}, $\Delta\phi_{ll}$ (smaller for scalar Higgs)

Crucial experimental aspects:

- understanding of E_t^{miss}
- very good modeling of background in signal region → use signal-free control regions in data to constrain MC → use MC to extrapolate to signal region

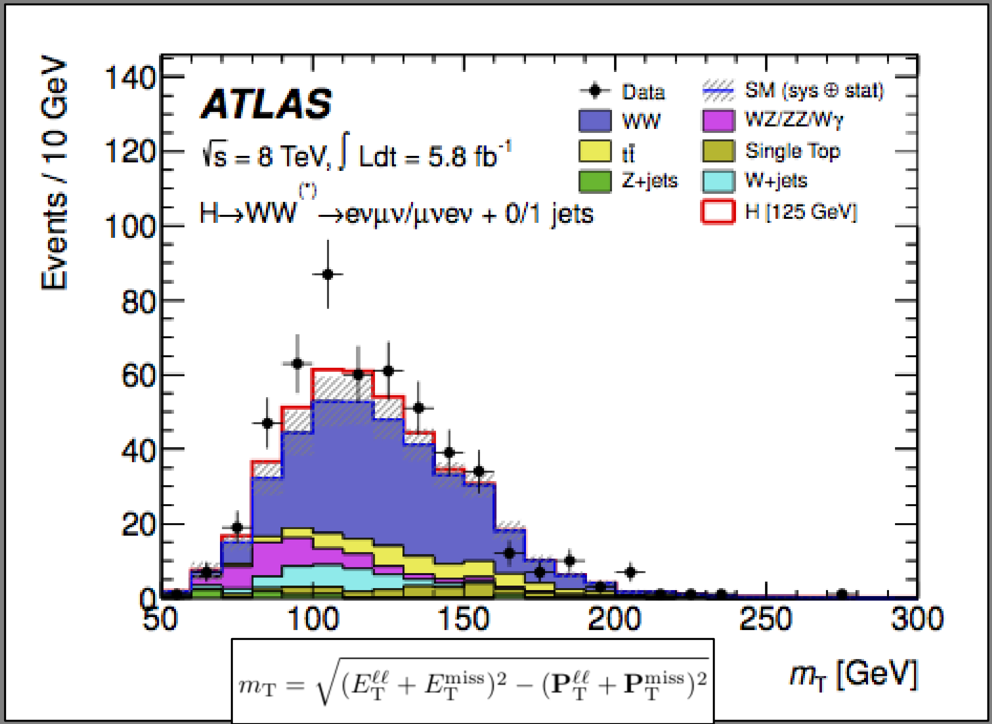


Same-sign 0j control region



Top 2j control region

After all selections

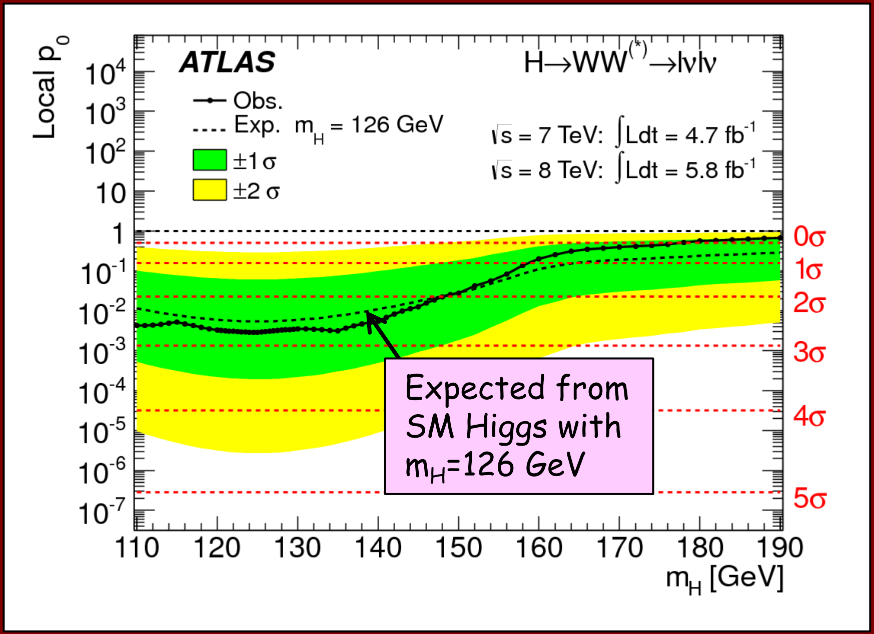


$$m_T = \sqrt{(E_T^{\ell\ell} + E_T^{\text{miss}})^2 - (\mathbf{P}_T^{\ell\ell} + \mathbf{P}_T^{\text{miss}})^2}$$

Observed:	223 events
expected from background only	168 ± 20
expected from Higgs m_H=126 GeV	25 ± 5

Data sample	m_H of max significance	local significance obs. (exp. SM H)
2011	135 GeV	1.1 σ (3.4)
2012	120 GeV	3.3 σ (1.0)
2011+2012	125 GeV	2.8 σ (2.3)

Broad excess, extending over > 50 GeV in mass, due to poor mass resolution

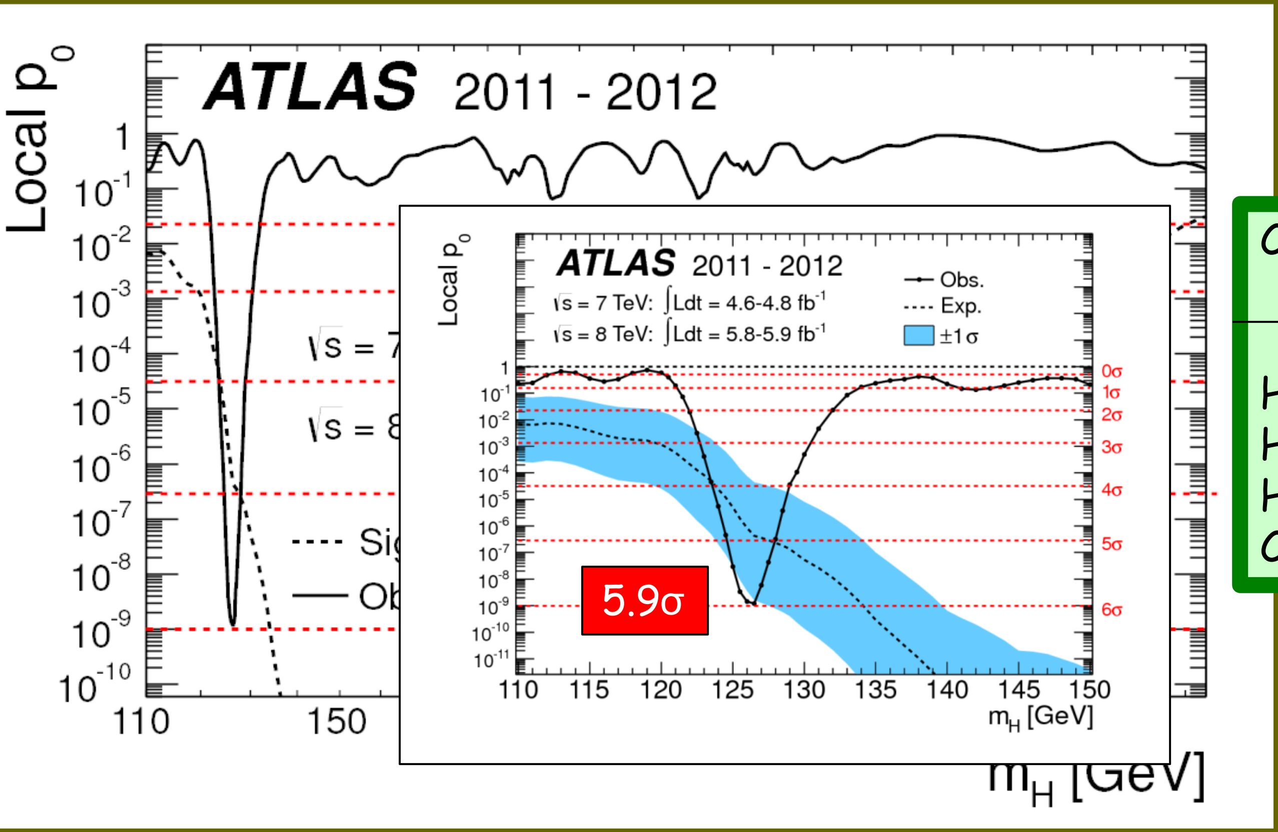


Expected from SM Higgs with m_H=126 GeV

Intermezzo …


caglecartoons.com
ELEMENTARY PARTICLE RESPONSIBLE FOR MASS
CERN
AMERICAN OBESITY
See! IT'S NOT MY FAULT- I WAS BORN WITH TOO MANY HIGGS BOSONS.
MikeKeefe INTOON.COM 7·6·12

Combining all (12) channels together



Channel	Obs. significance (exp. from SM H)
H→ γγ H→ 4l H→ lνlν Combined	4.5 σ (2.5) 3.6 σ (2.7) 2.8 σ (2.3) 5.9 σ (4.9)

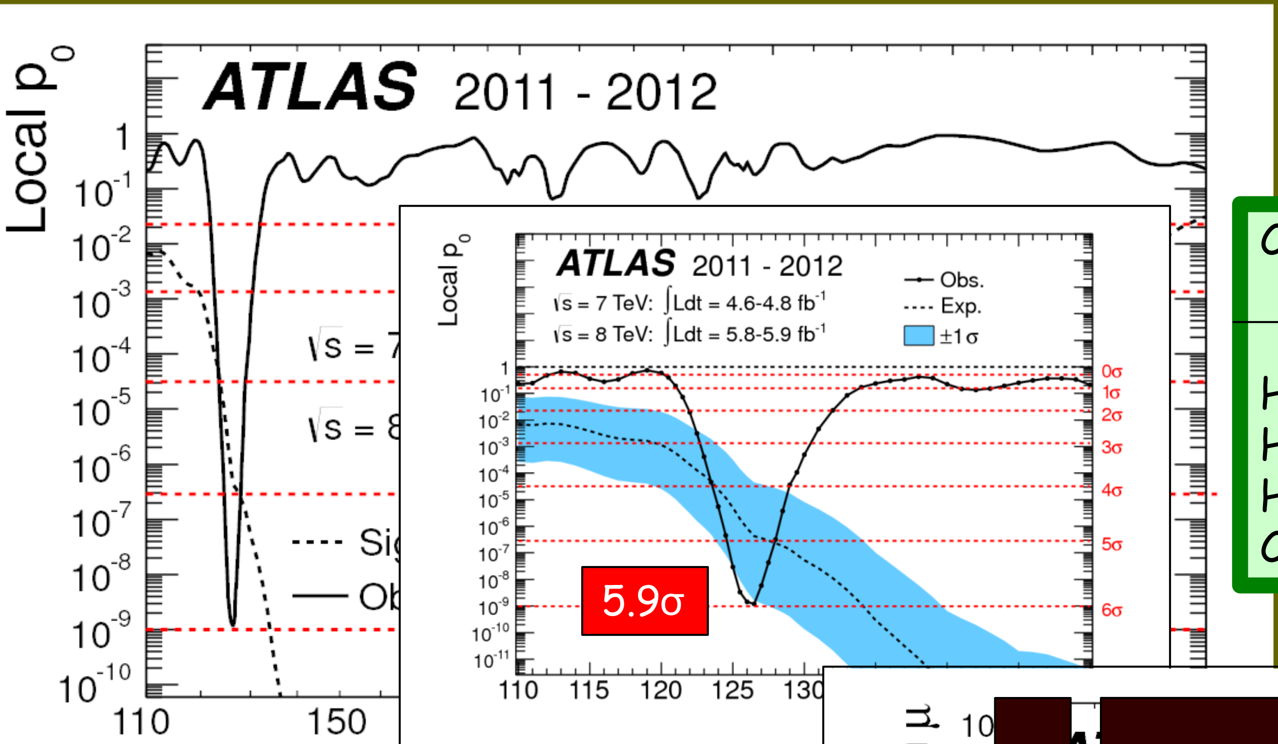
For $m_H \sim 126.5$ GeV

Probability of background fluctuation: 1.7×10^{-9}

Local significance 5.9 σ

Global significance: ~ 5.2 σ

Combining all (12) channels together



5.9σ

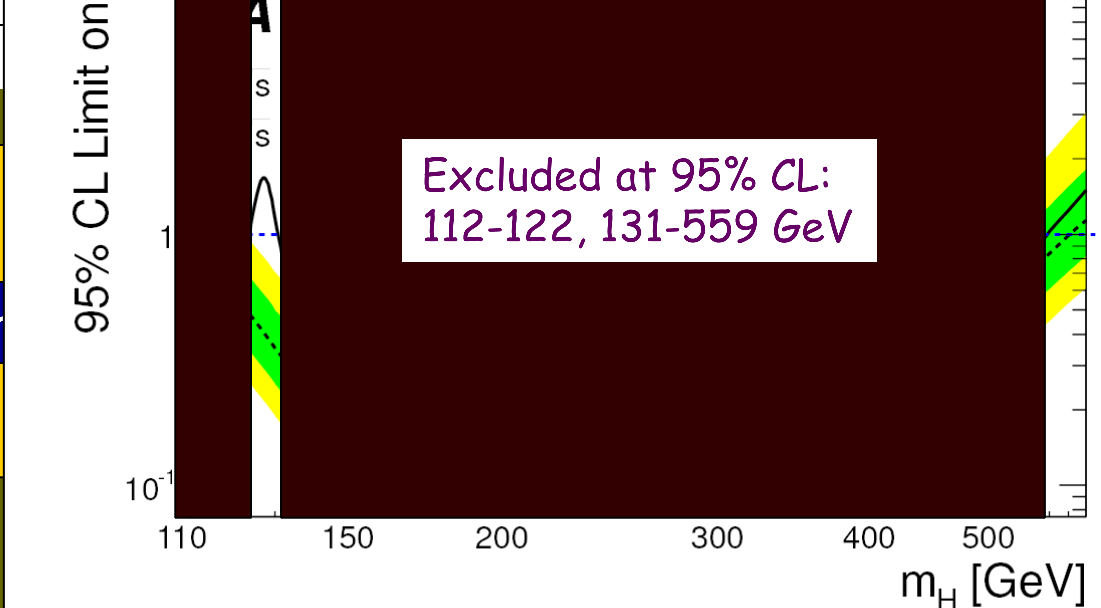
Channel	Obs. significance (exp. from SM H)
H→ γγ H→ 4l H→ lνlν Combined	4.5 σ (2.5) 3.6 σ (2.7) 2.8 σ (2.3) 5.9 σ (4.9)

For m_H ~ 126.5 GeV

Probability of background fluctuatior

Local significance 5.9 σ

Global significance: ~ 5.2 σ



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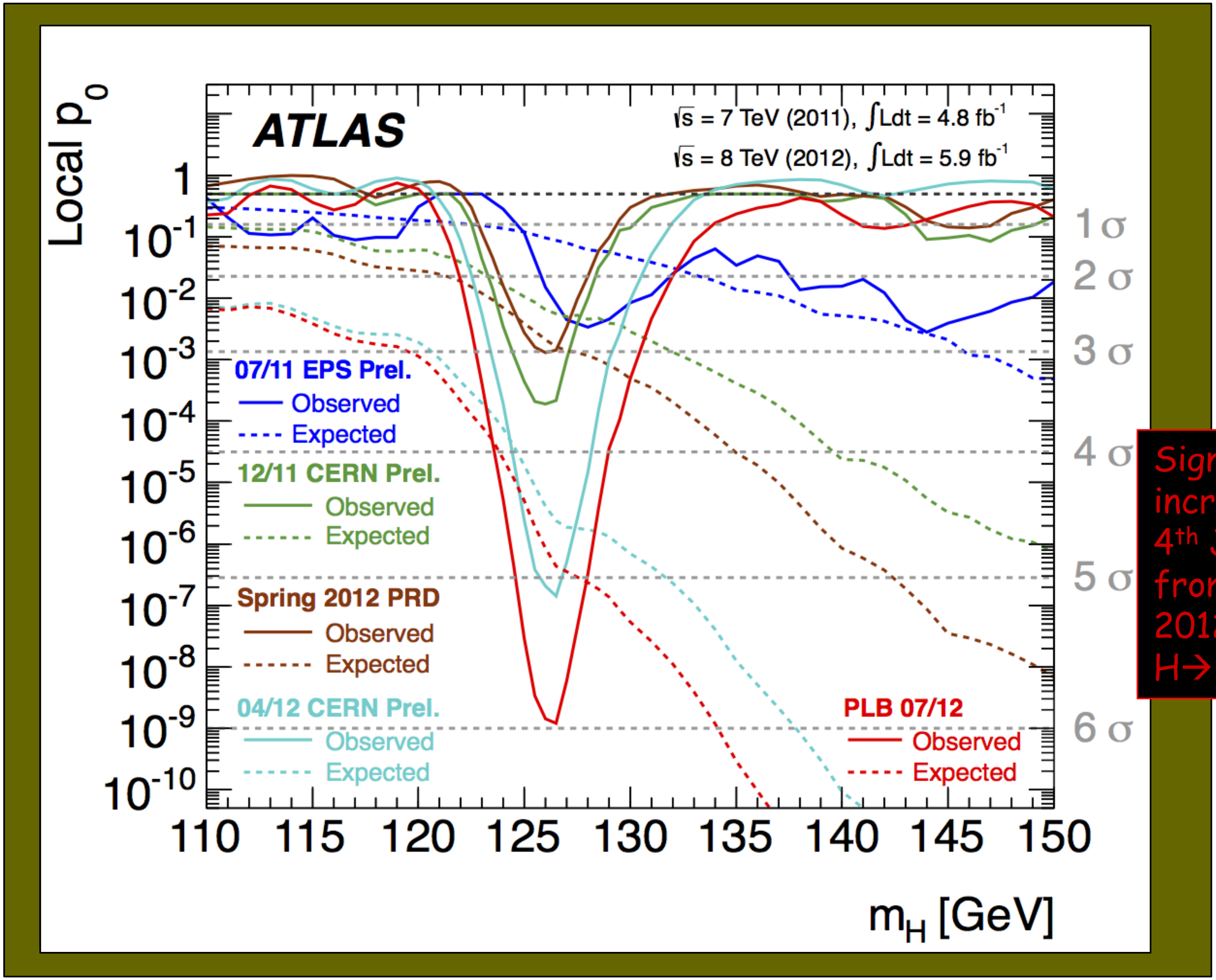
Excluded at 95% CL:
112-122, 131-559 GeV

Evolution of the excess with time



Significance increase from 4th July to now from including 2012 data for H→ WW* search

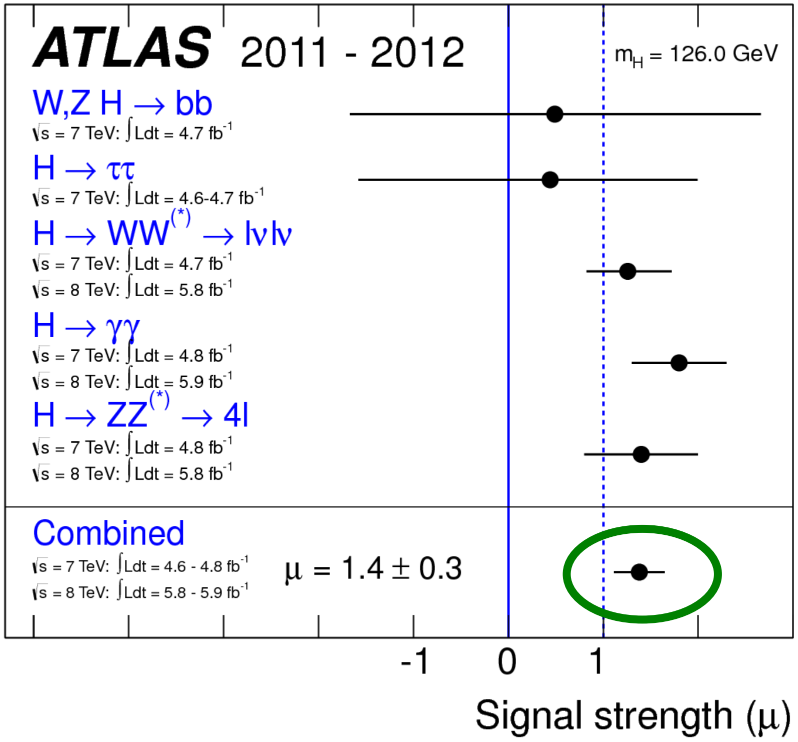
Are we sure we carefully looked at all backgrounds ?

http://www.wordle.net/

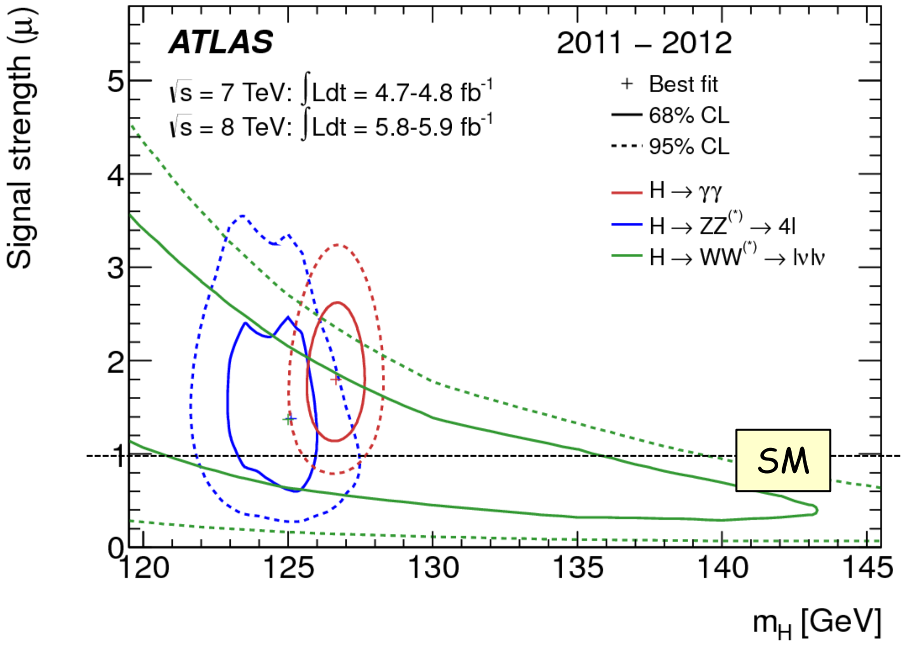
Characterizing the new particle: mass and signal strength

Estimated mass:
$m_H = 126 \pm 0.4\ (\text{stat}) \pm 0.4\ (\text{syst})$ GeV

μ = signal strength normalized to the SM Higgs expectation at $m_H = 126$ GeV



2-dim likelihood fit to signal mass and strength

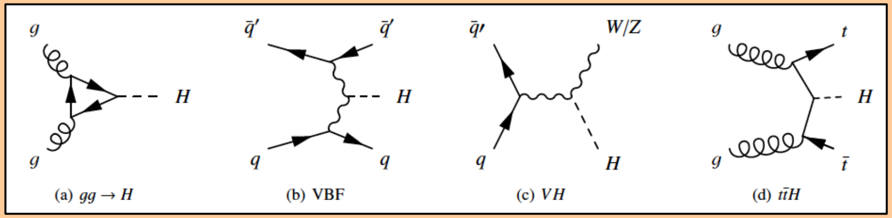


Best-fit value at 126 GeV:

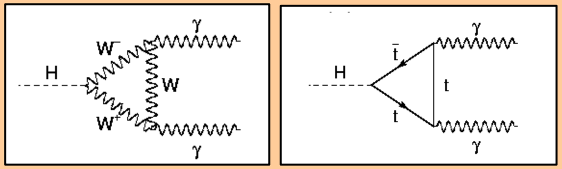
μ = 1.4 ± 0.3

→ in agreement with the expectation for a SM Higgs within the present statistical uncertainty

Characterizing the new particle: first measurements of couplings (examples ..)

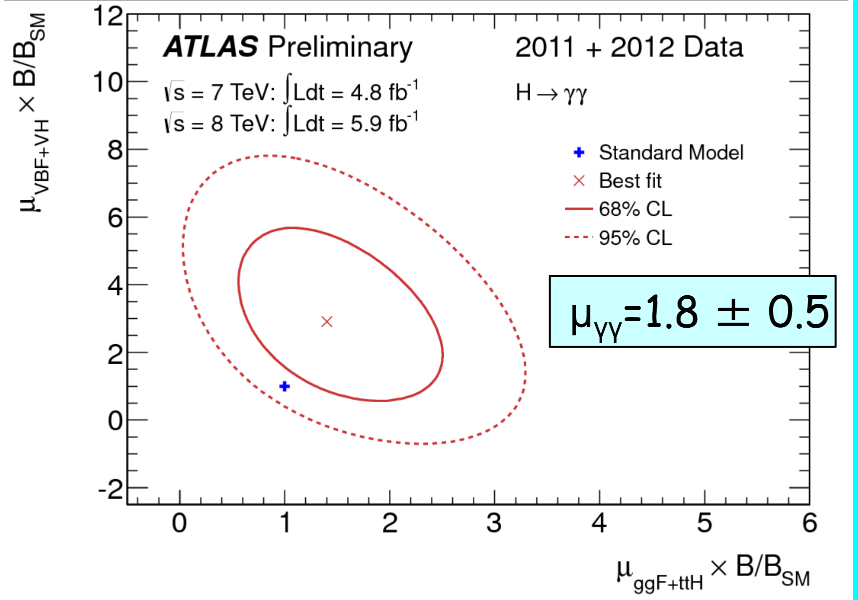


(a) $gg \to H$ (b) VBF (c) VH (d) $t\bar{t}H$



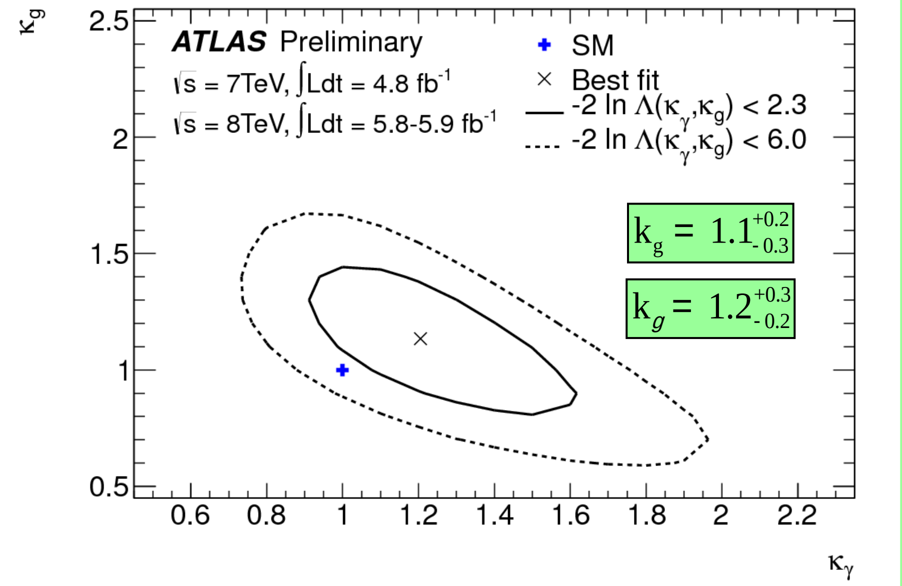
$$k_i^2 = \frac{G_i^{data}}{G_i^{SM}}$$

Explore tension SM-data from H→ γγ different production modes (VBF, ggF)



$\mu_{\gamma\gamma}$=1.8 ± 0.5

New particles in the gg → H and H→ γγ loops ?



$k_g = 1.1^{+0.2}_{-0.3}$

$k_g = 1.2^{+0.3}_{-0.2}$

$$\frac{k_W}{k_Z} = 1.07^{+0.35}_{-0.27}$$

BR (H→ invisible or undetected) < 0.84 at 95% CL

Couplings to fermions k_F weakly constrained by direct H → ττ , bb;
indirect constraints from ggF (tt loop) indicate it's non-vanishing (see spare slides)

Higgs: the next steps …

MORE DATA essential to:

- ☐ Establish the observation in more channels (ττ, bb, more exclusive topologies ..)
- ☐ Measure nature and properties of the new particle (J^{CP}, couplings, ..) with increasing precision → test compatibility with SM Higgs; how is Higgs mechanism implemented ?
- ☐ How much does this "Higgs" contribute to restoring $V_L V_L$ unitarity at high mass ?
- ☐ Natural Higgs or fine-tuned Higgs ? If natural: what stabilizes its mass (SUSY? Other New Physics ?)?

End 2012

Assuming ~30 fb^{-1} (~25 fb^{-1} 8 TeV + 5 fb^{-1} 7 TeV) expect from a SM Higgs:

- ☐ 4-5 σ from each of $H \to \gamma\gamma$, $H \to l\nu l\nu$, $H \to 4l$ per experiment
- ☐ ~ 3 σ from $H \to \tau\tau$ and ~ 3 σ from $W/ZH \to W/Z\ bb$ (already achieved by Tevatron !) per experiment
- ☐ Separation $0^+/2^+$ and O^+/O^- at 4σ level combining ATLAS and CMS

Further ahead (present LHC plans):

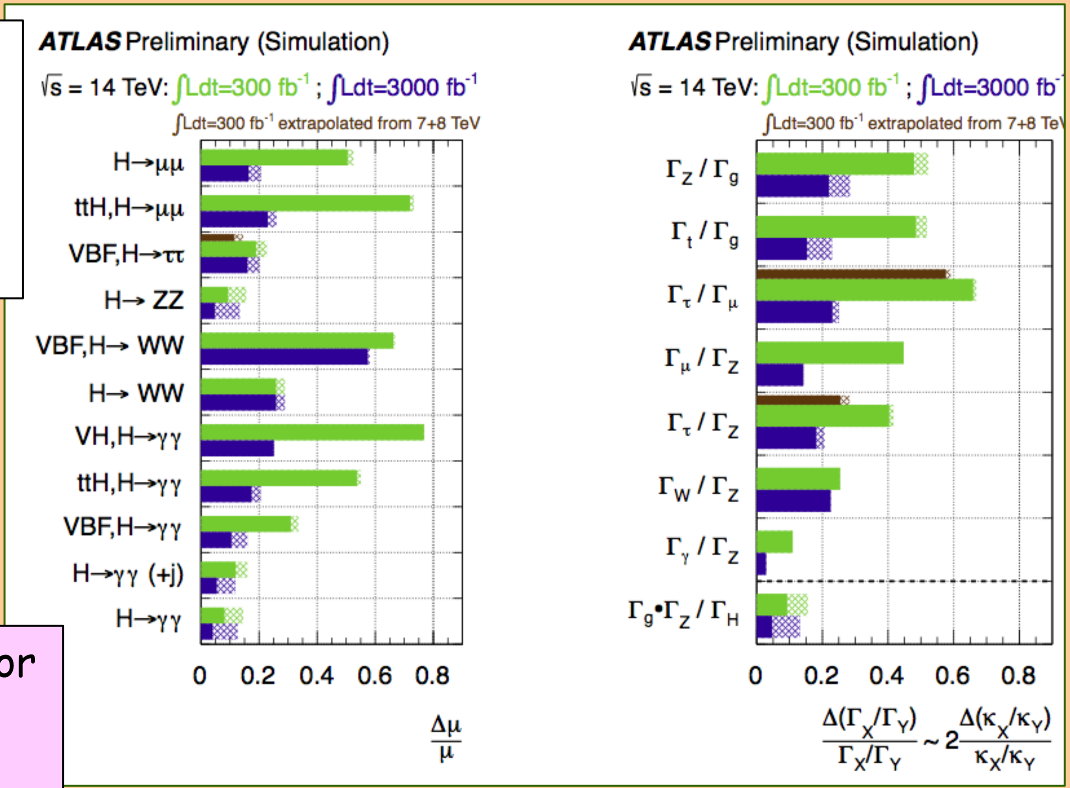
2013-2014: shut-down (LS1)
2015-2017: $\sqrt{s}$ ~ 13 TeV, L ~ 10^{34} , ~ 100 fb^{-1}
2018: shut-down (LS2)
2019-2021: $\sqrt{s}$ ~ 13 TeV, L ~ 2×10^{34} , ~ 300 fb^{-1}
2022-2023: shut-down (LS3)
2023- 2030 ?: $\sqrt{s}$ ~ 13 TeV, L ~ 5×10^{34} , ~ 3000 fb^{-1} (HL-LHC)

Spin/CP can be determined at > 5σ with 300 fb^{-1} for a non-mixed state

Without constraints, ratios of couplings can be measured with typical precisions:

- ☐ 20-50% with ~ 300 fb^{-1}
- ☐ 5-25% with 3000 fb^{-1}

per experiment



Measurements of rare decays with 3000 fb^{-1} :

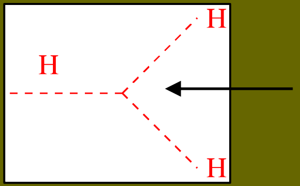
ttH → ttγγ: 200 events

H → μμ : 6σ

per experiment

Assuming Γ_H (SM) and one scale factor for the fermion/vector sector → measure k_F, k_V to 6% (3%) with 300 (3000) fb^{-1} per experiment

Higgs self-couplings: ~ 3σ per experiment expected from HH → bbγγ channel with 3000 fb^{-1}; HH→ bbττ also promising ~ 30% measurement of Λ/Λ_{SM} may be achieved



~ λv

$m_H^2 = 2 \lambda v^2$

Note: -- these results are very preliminary (work of a few months) and conservative

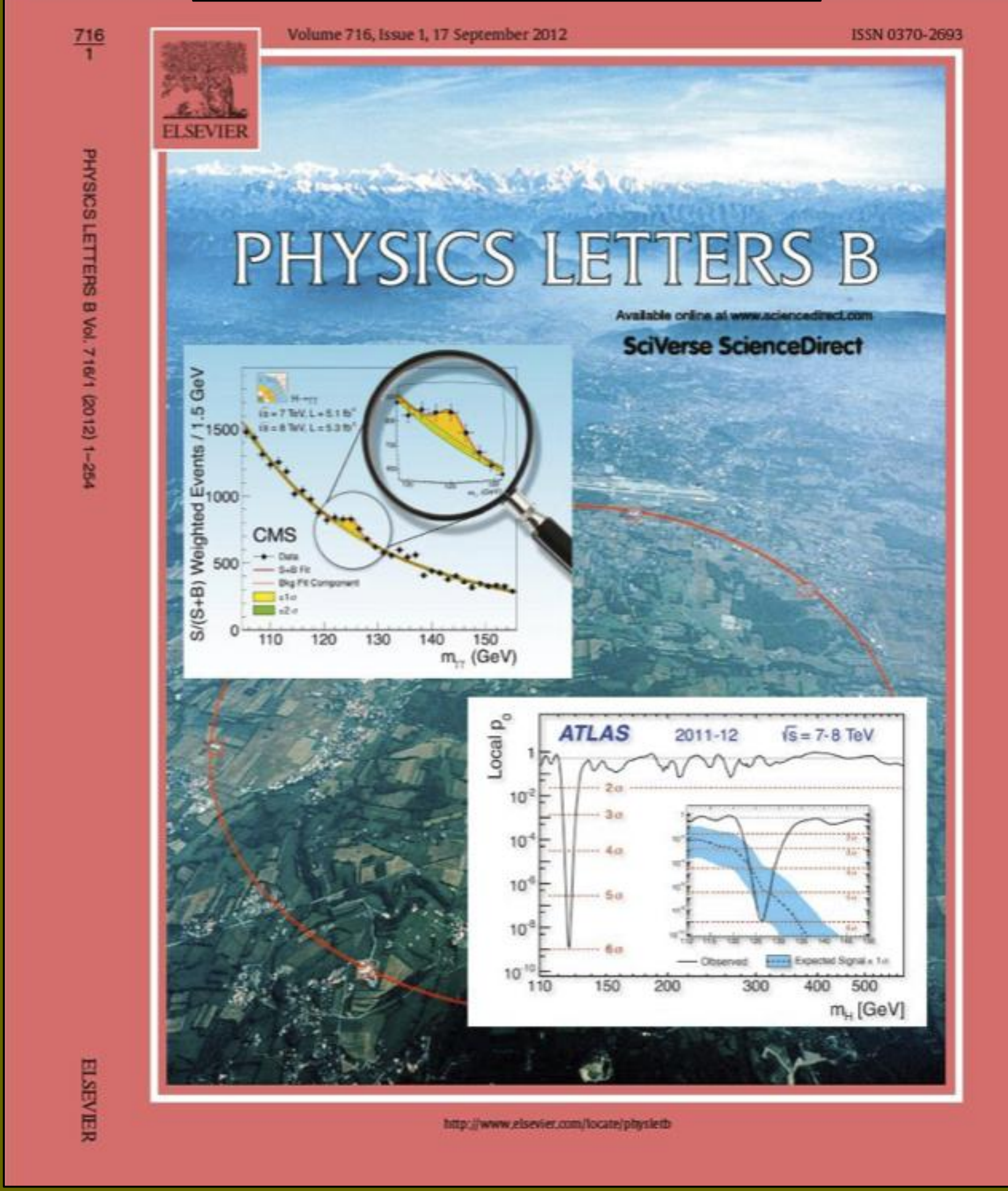
-- physics potential of LHC upgrade is much more than just Higgs

Conclusions

Similar, very nice results from CMS

ATLAS and CMS “Higgs discovery” papers published side by side in Phys. Lett. B716 (2012)

Physics Letters B cover



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Superb performance and accomplishments of the LHC accelerator, experiments and Computing Grid in less than 3 years of operation.

ATLAS has recorded ~5.2 fb^{-1} at $\sqrt{s}$ =7 TeV in 2011 and ~17 fb^{-1} in 2012 at $\sqrt{s}$ =8 TeV

The whole experiment works very well in all its components, from smooth and efficient operation of the detector, trigger and computing to the fast delivery of physics results.

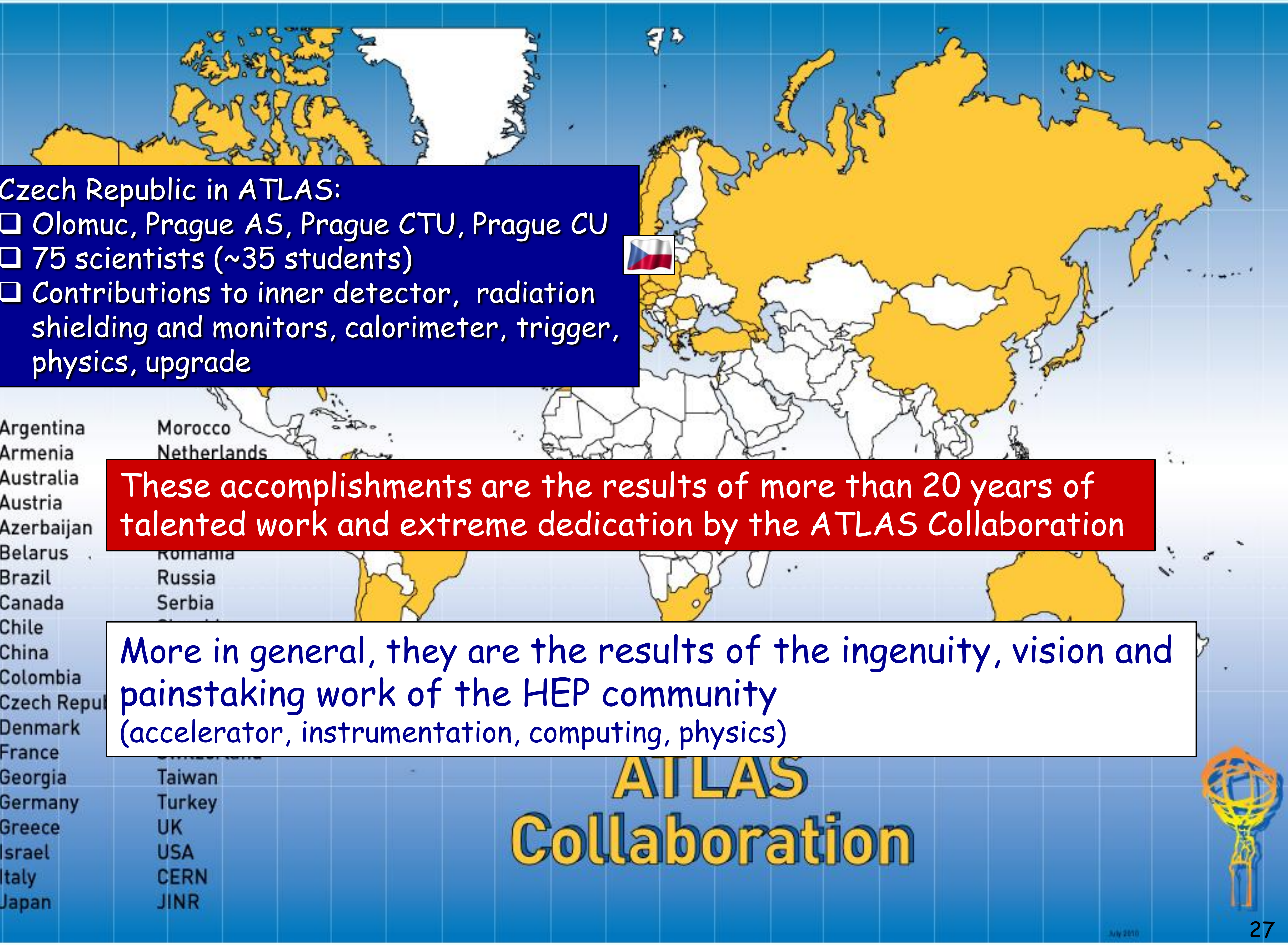
Huge physics output covered in >200 papers and > 400 Conference notes (not only Higgs!): a wealth of measurements and searches; no New Physics (yet !)

In July 2012 ATLAS has reported the discovery of a new Higgs-like boson:

- ☐ with significance ~6σ, driven by $H\to\gamma\gamma$, 4l, with contributions also from $H\to l\nu l\nu$
- ☐ signal strength: 1.4± 0.3 of the Standard Model Higgs expectation
- ☐ mass: 126 ± 0.4 (stat) ± 0.4 (syst) GeV
- ☐ first couplings measurements consistent with SM within present (large) uncertainties

If it is a SM Higgs boson, it's very kind of Nature to have chosen this mass → accessible at LHC in $\gamma\gamma$, $ZZ^*\to 4l$, $WW^*\to l\nu l\nu$, bb, ττ, and (HL-LHC) μμ

The era of precise "Higgs measurements" has started. In parallel, quest for New Physics at TeV scale more and more motivated: natural EW scale or desert scenario ? → LHC and its upgrade will have a lot to say



Czech Republic in ATLAS:
- ❑ Olomuc, Prague AS, Prague CTU, Prague CU
- ❑ 75 scientists (~35 students)
- ❑ Contributions to inner detector, radiation shielding and monitors, calorimeter, trigger, physics, upgrade

Argentina
Armenia
Australia
Austria
Azerbaijan
Belarus
Brazil
Canada
Chile
China
Colombia
Czech Repu
Denmark
France
Georgia
Germany
Greece
Israel
Italy
Japan

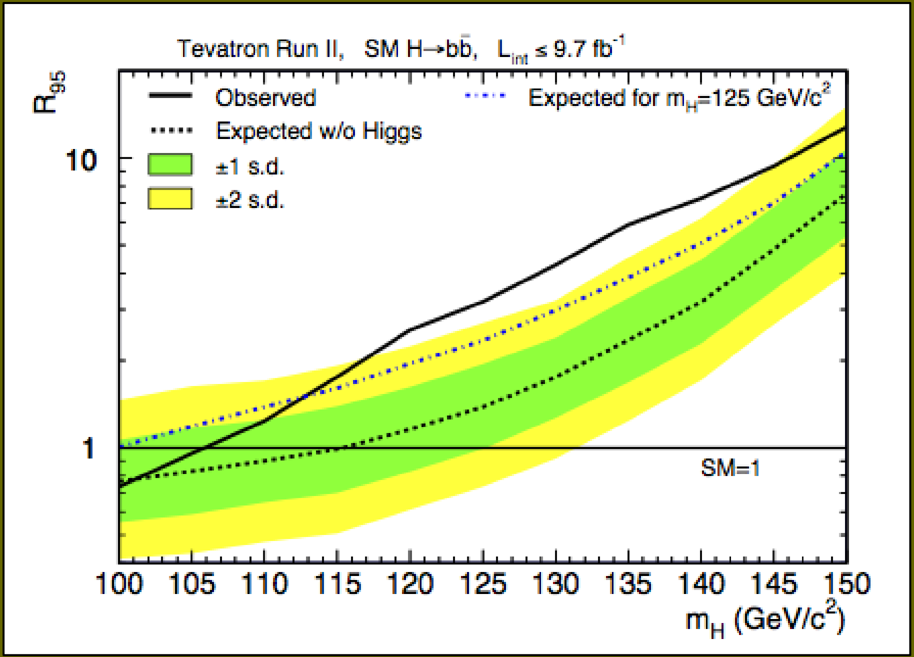
Morocco
Netherlands
Romania
Russia
Serbia
Taiwan
Turkey
UK
USA
CERN
JINR

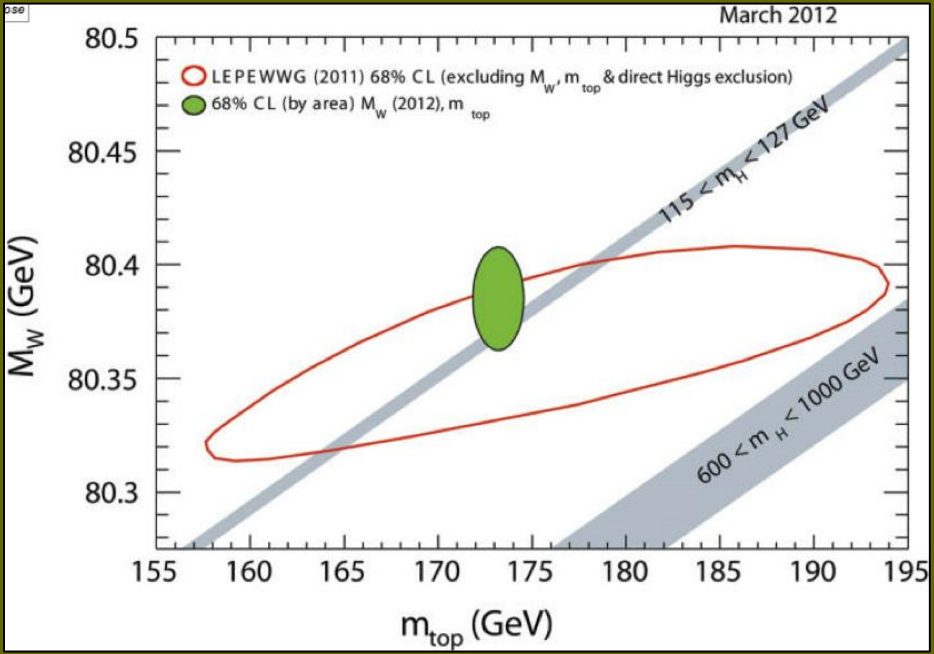
These accomplishments are the results of more than 20 years of talented work and extreme dedication by the ATLAS Collaboration

More in general, they are the results of the ingenuity, vision and painstaking work of the HEP community
(accelerator, instrumentation, computing, physics)

SPARES

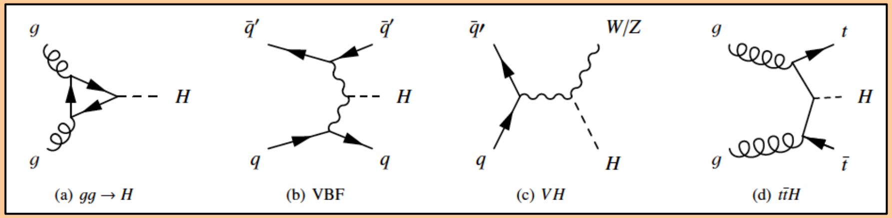
The Tevatron legacy

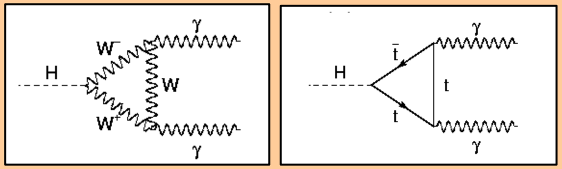




M_W dominates internal consistency tests of SM. Hard for LHC to improve on Tevatron superb precision (16 MeV !) → Tevatron will contribute to full picture still for a long time

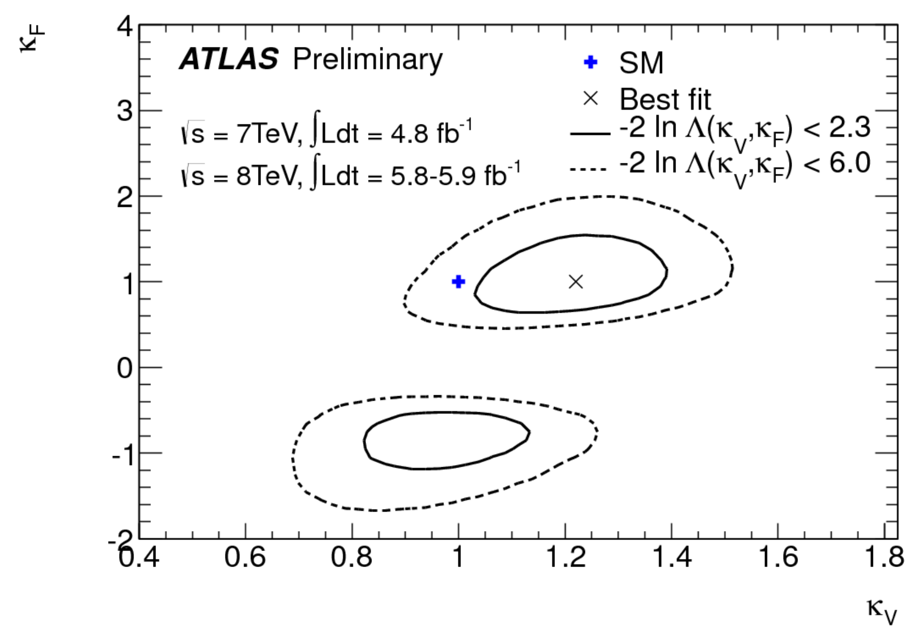
Characterizing the new particle: first measurements of couplings (examples ..)



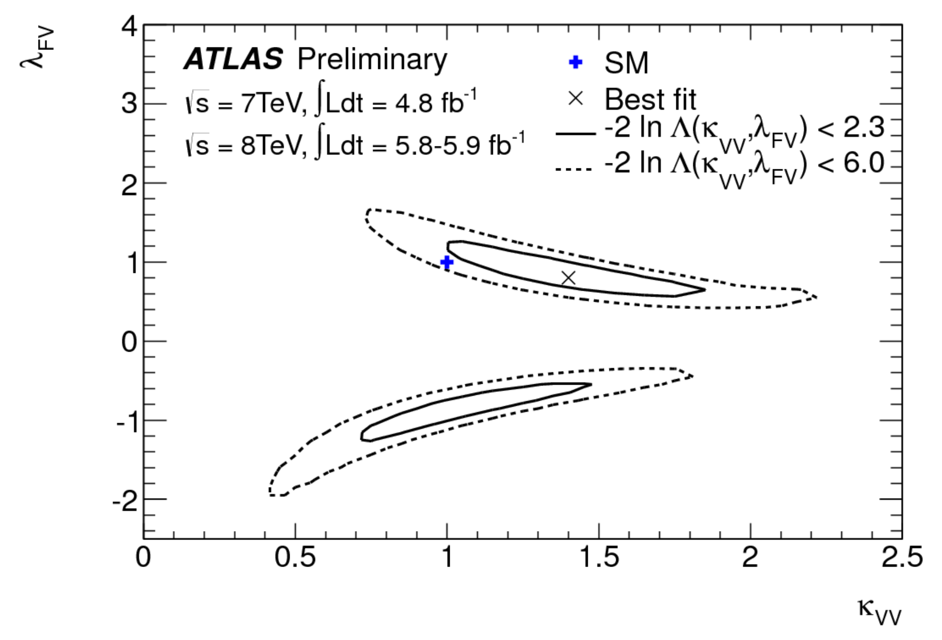


$$k_i^2 = \frac{G_i^{data}}{G_i^{SM}}$$

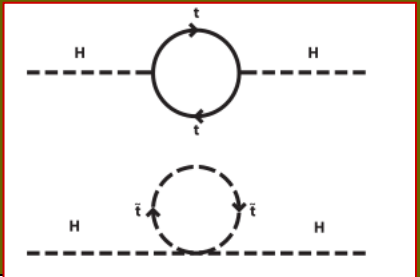
Couplings to fermions vs couplings to bosons assuming SM width (driven by large bb BR)

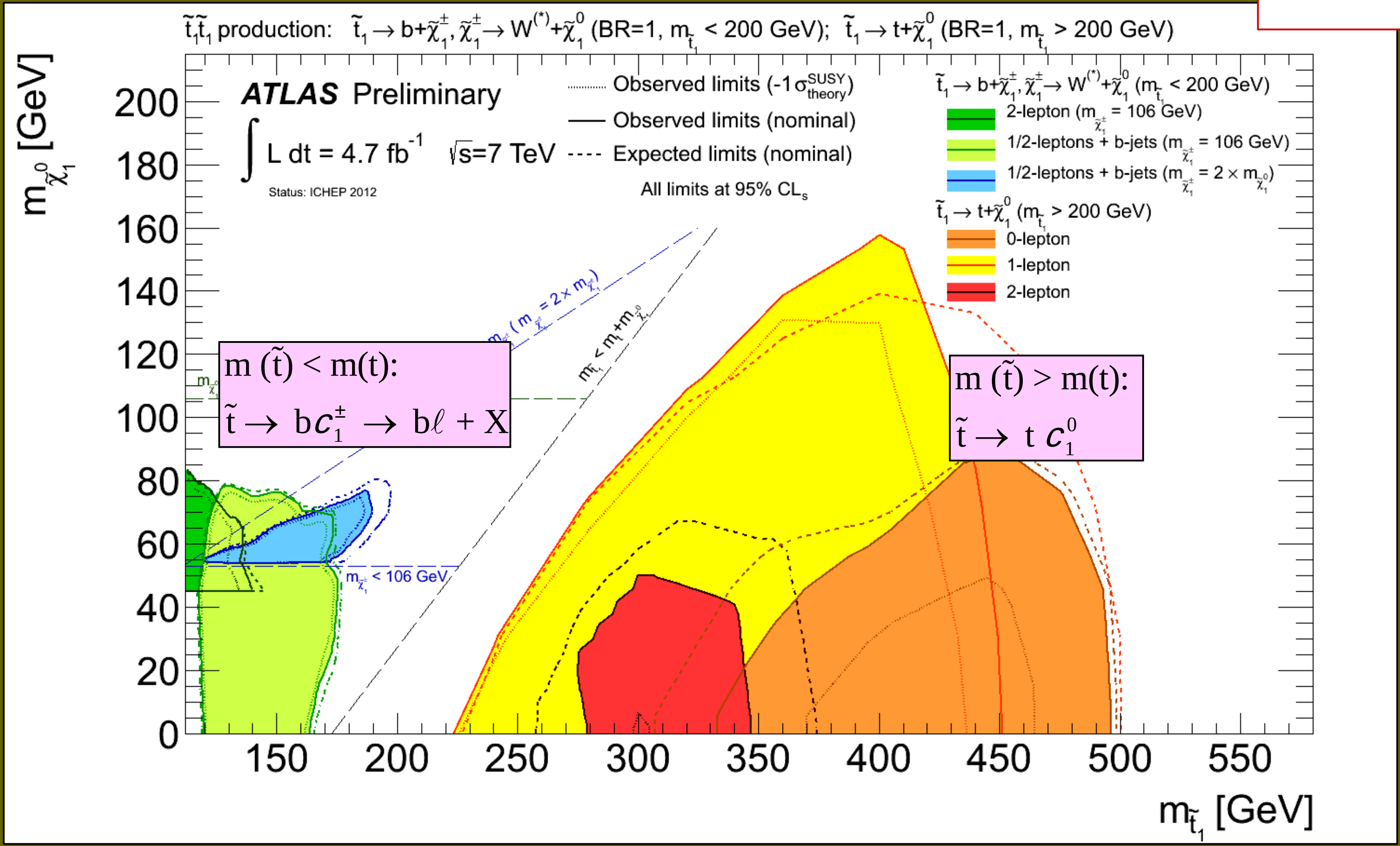


Ratio of couplings to fermions and bosons (λ_{VF}) without assumptions on the SM width



Is the Higgs mass stabilized by New Physics ?





m ($\tilde{t}$) < m(t):

$\tilde{t} \to b c_1^{\pm} \to b\ell + X$

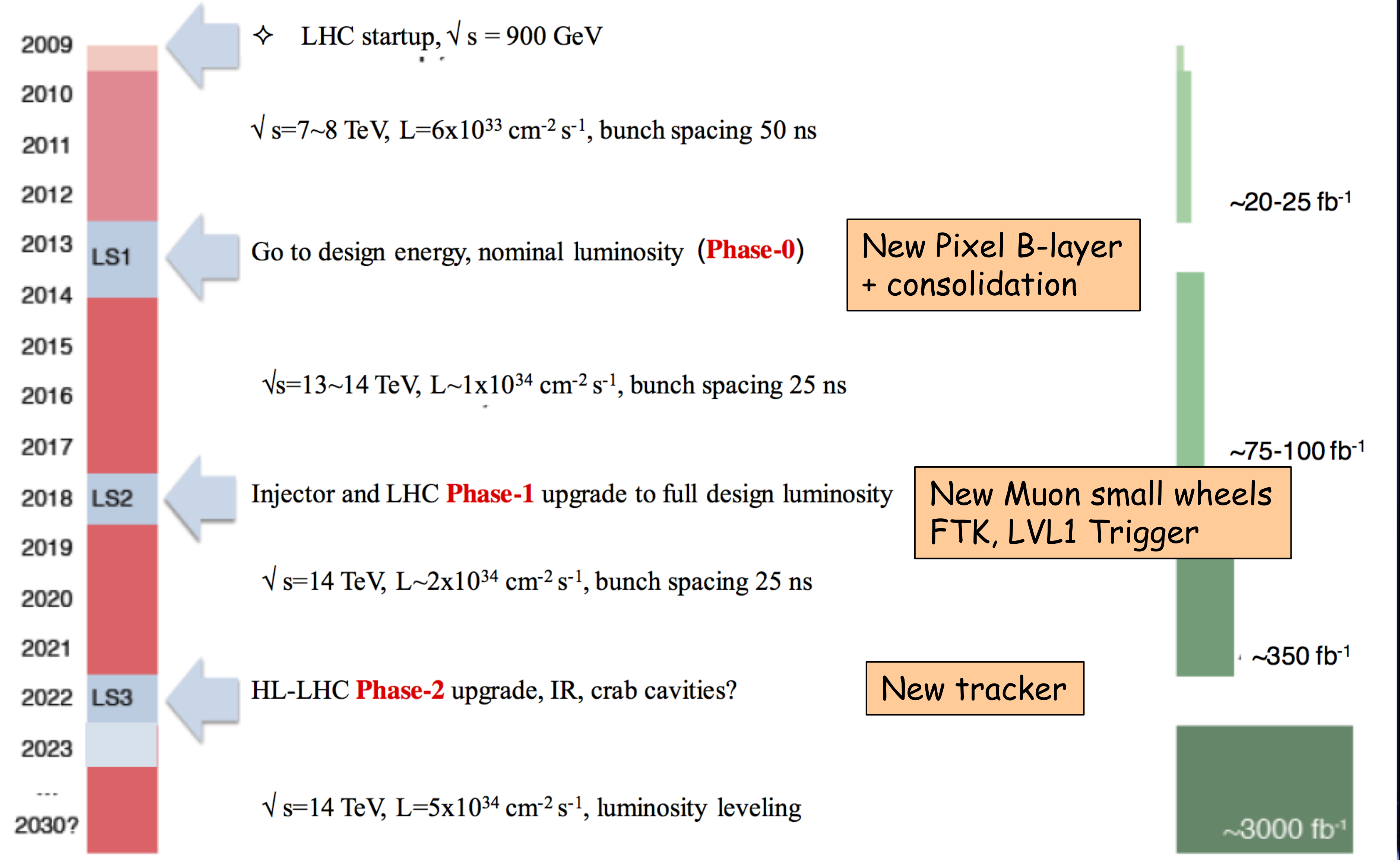
m ($\tilde{t}$) > m(t):

$\tilde{t} \to t\ c_1^0$

With ~ 30 fb^{-1} by end 2012: expect to cover stop masses up to ~ 700-800 GeV and most of hole at m_{stop} ~ 200 GeV (by allowing branching ratios stop→ t χ^0_1 and stop → b $\chi^{\pm}_1$ to vary)

Further ahead: present LHC upgrade plans

ATLAS



✧ LHC startup, $\sqrt{s}$ = 900 GeV

$\sqrt{s}$=7~8 TeV, L=6x10^{33} cm^{-2} s^{-1}, bunch spacing 50 ns

Go to design energy, nominal luminosity (**Phase-0**)

New Pixel B-layer
+ consolidation

$\sqrt{s}$=13~14 TeV, L~1x10^{34} cm^{-2} s^{-1}, bunch spacing 25 ns

Injector and LHC **Phase-1** upgrade to full design luminosity

New Muon small wheels
FTK, LVL1 Trigger

$\sqrt{s}$=14 TeV, L~2x10^{34} cm^{-2} s^{-1}, bunch spacing 25 ns

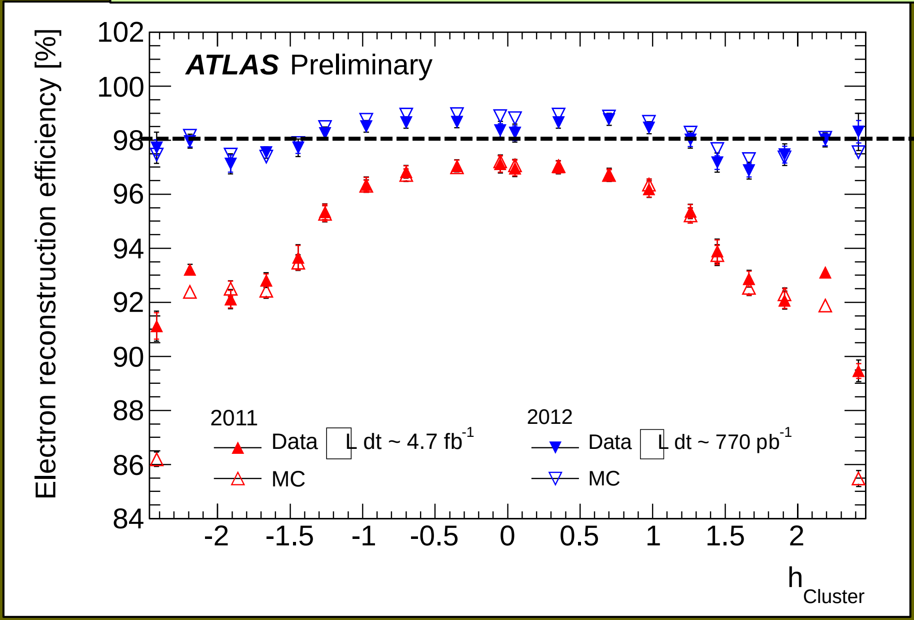
HL-LHC **Phase-2** upgrade, IR, crab cavities?

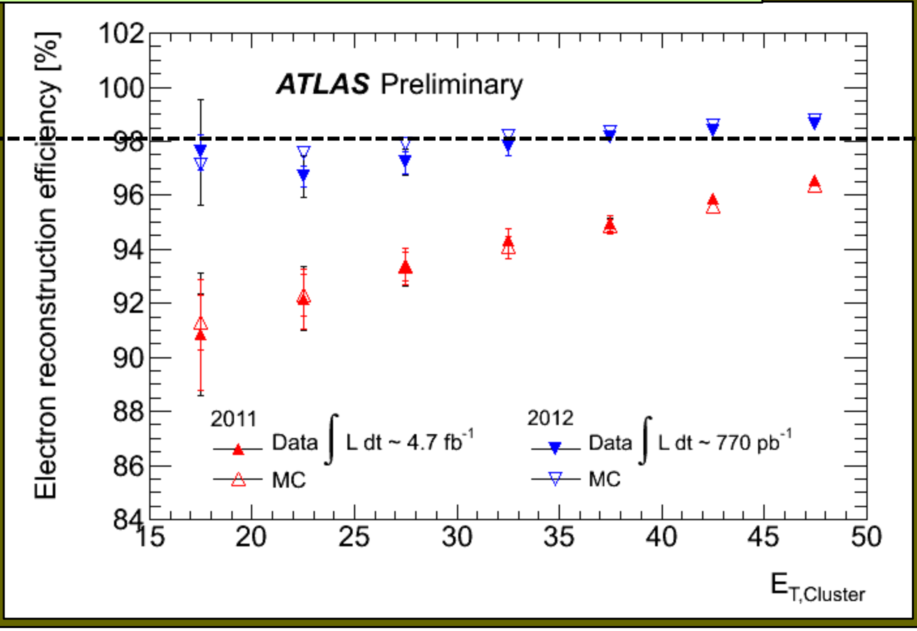
New tracker

$\sqrt{s}$=14 TeV, L=5x10^{34} cm^{-2} s^{-1}, luminosity leveling

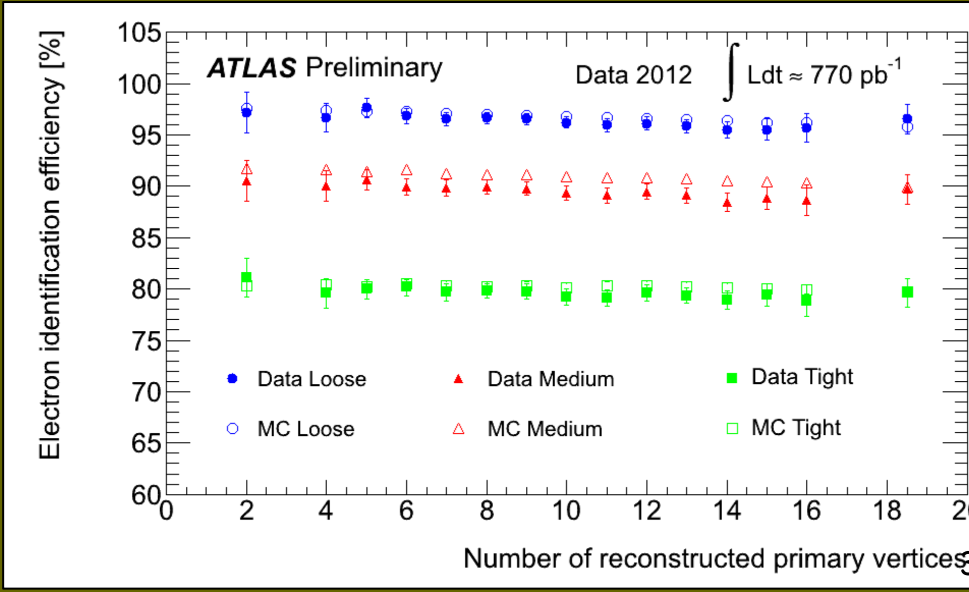
High efficiency for low-p_T electrons (affected by material) crucial for H→ 4e, 2μ2e

Improved track reconstruction and fitting to recover $e^{\pm}$ undergoing hard Brem
→ achieved ~ 98% reconstruction efficiency, flatter vs η and E_T





Re-optimized $e^{\pm}$ identification using pile-up robust variables (e.g. Transition Radiation, calorimeter strips) → achieved ~ 95% identification efficiency, ~ flat vs pile-up; higher rejections of fakes

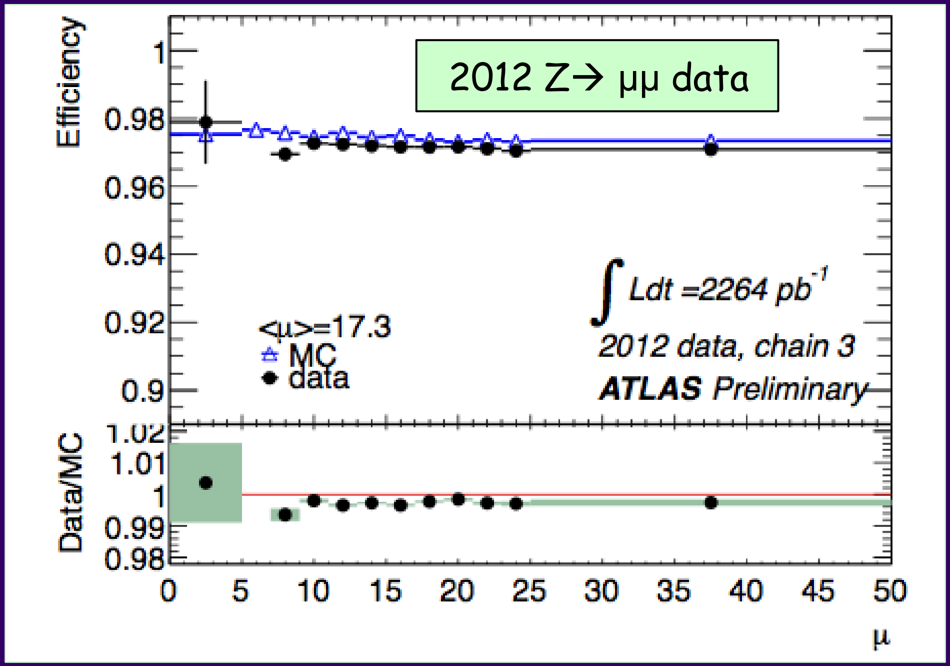


Results are from Z→ ee data and MC tag-and-probe

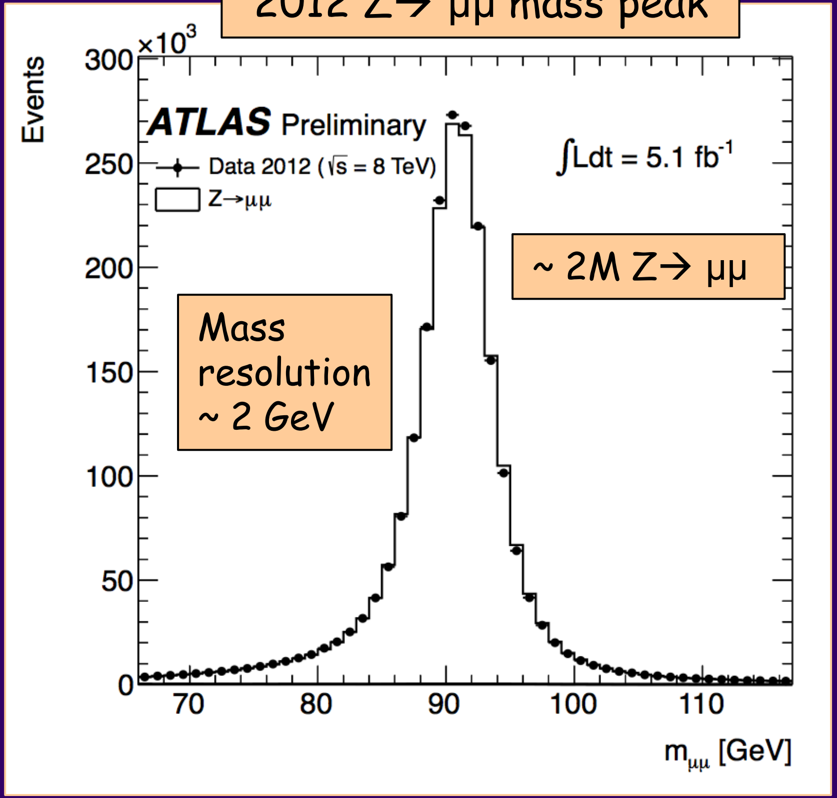
Muons reconstructed down to $p_T = 6$ GeV over $|\eta|<2.7$

Reconstruction efficiency ~ 97%
~ flat over full range

Total acceptance x efficiency
for H→ 4μ: ~ 40% (+45% gain)

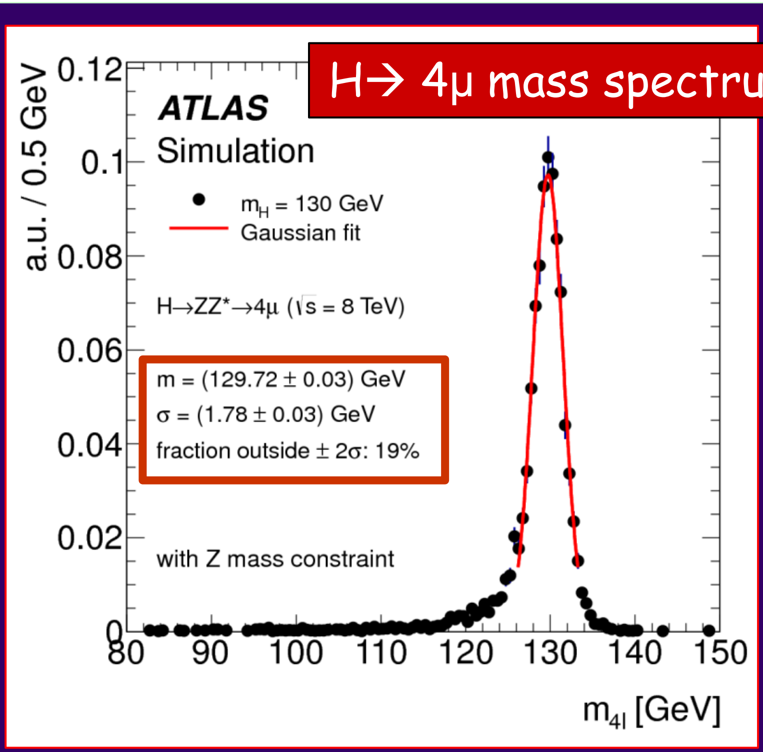

2012 Z→ μμ data

2012 Z→ μμ mass peak


~ 2M Z→ μμ

Mass
resolution
~ 2 GeV

H→ 4μ mass spectrum

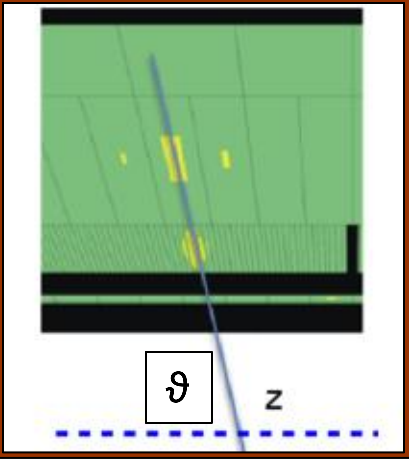


$m^2_{\gamma\gamma} = 2\, E_1\, E_2\, (1-\cos\alpha)$

α=opening angle of the two photons

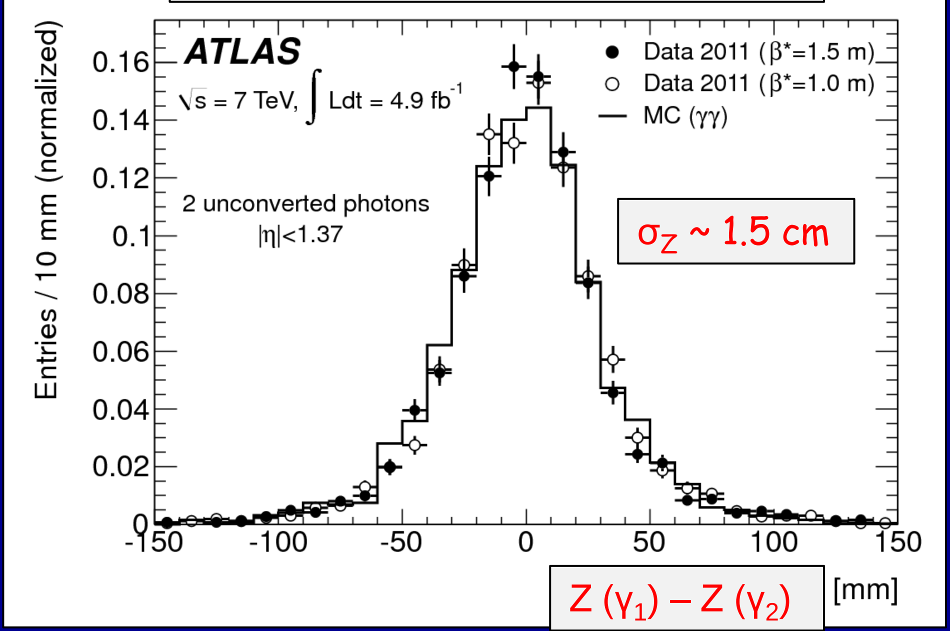
High pile-up: many vertices distributed over
σ_Z (LHC beam spot) ~ 5-6 cm
→ difficult to know which one has produced the γγ pair

Primary vertex from:
- ☐ EM calorimeter longitudinal (and lateral) segmentation
- ☐ tracks from converted photons



Measure γ direction with calo
→ get Z of primary vertex

Z-vertex measured in γγ events from calorimeter "pointing"



σ_Z ~ 1.5 cm

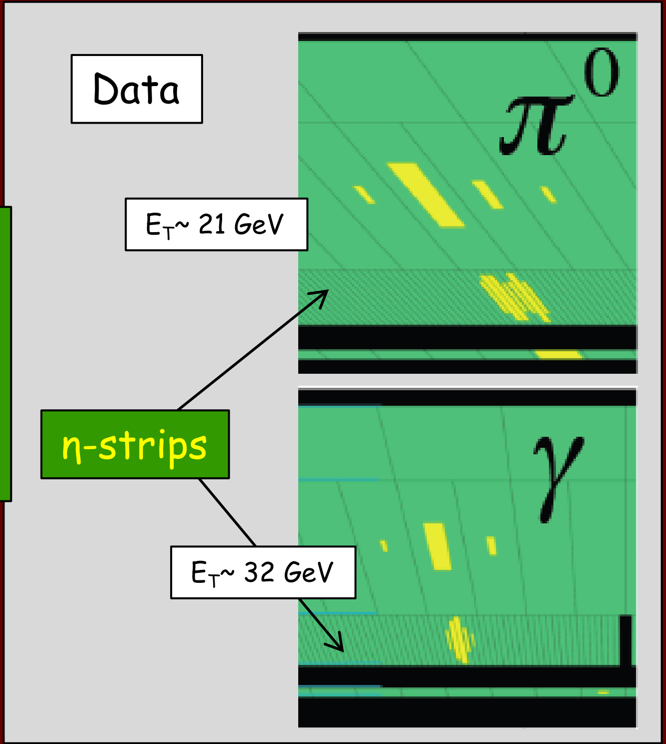
Z (γ_1) – Z (γ_2)

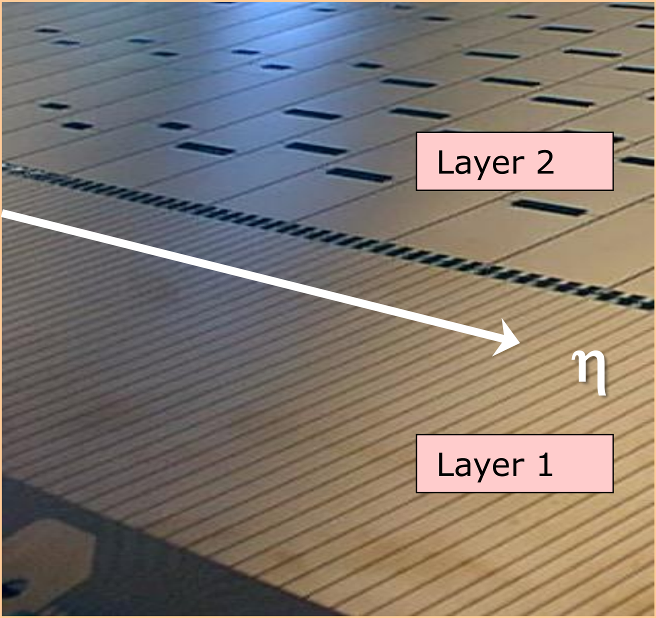
Note:
- ☐ Calorimeter pointing alone reduces vertex uncertainty from beam spot spread of ~ 5-6 cm to ~ 1.5 cm and is robust against pile-up

→ good enough to make contribution to mass resolution from angular term negligible
- ☐ Addition of track information (less pile-up robust) needed to reject fake jets from pile-up in 2j/VBF category

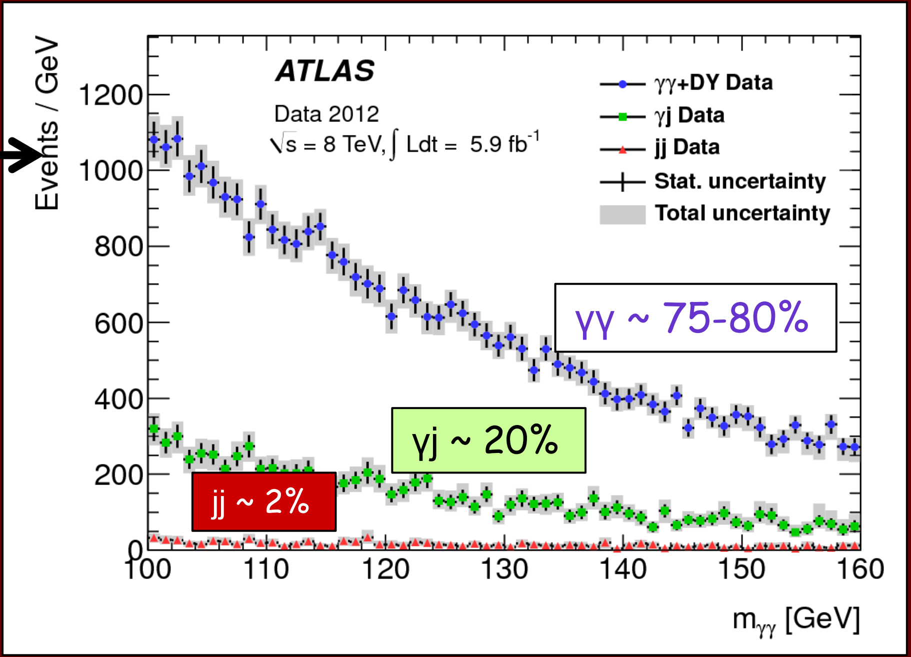
γ/jet separation

Determined choice of fine lateral segmentation (4mm η-strips) of the first compartment of ATLAS EM calorimeter





Data-driven decomposition of selected γγ sample



γγ ~ 75-80%

γj ~ 20%

jj ~ 2%

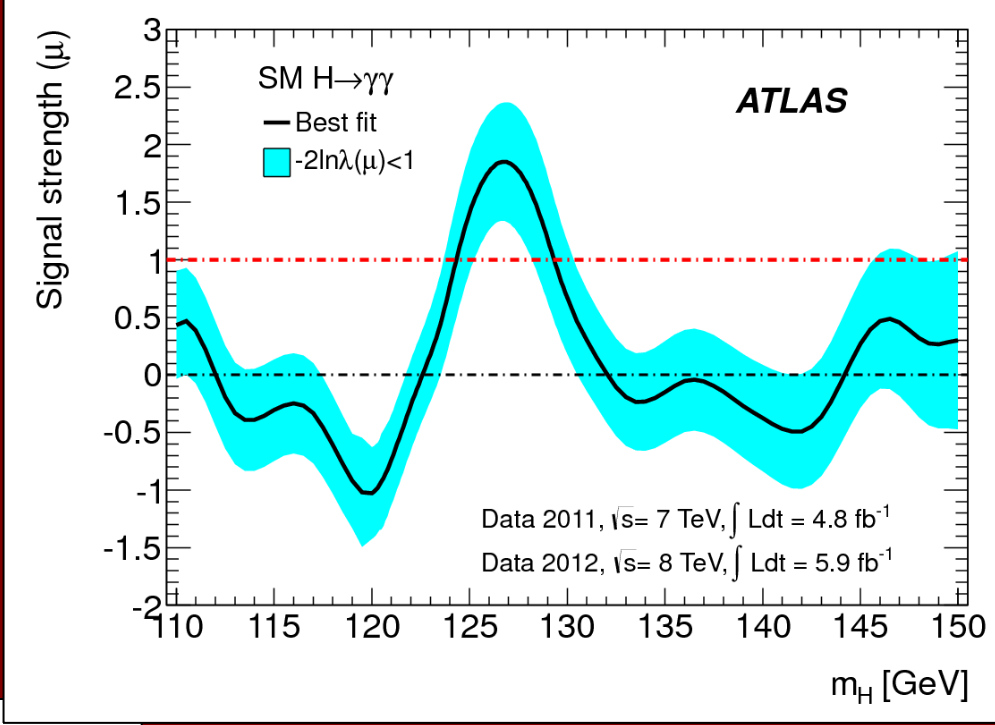
High γγ purity thanks to:

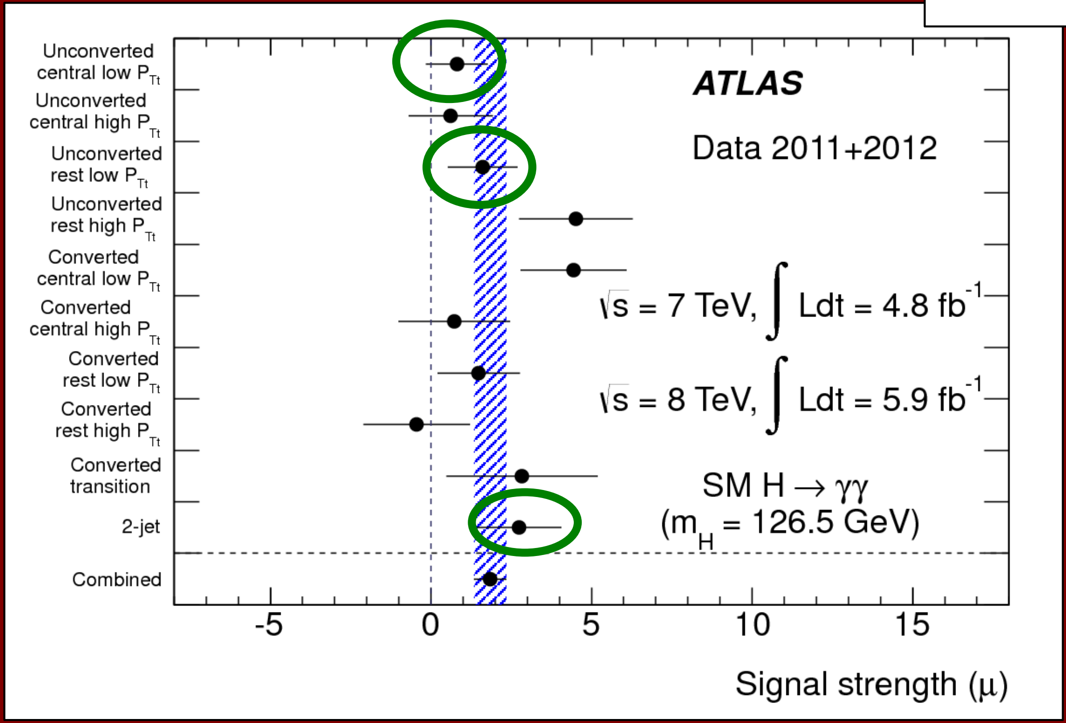
R_j ~10^4
ε (γ) ~ 90%

Fitted signal strength

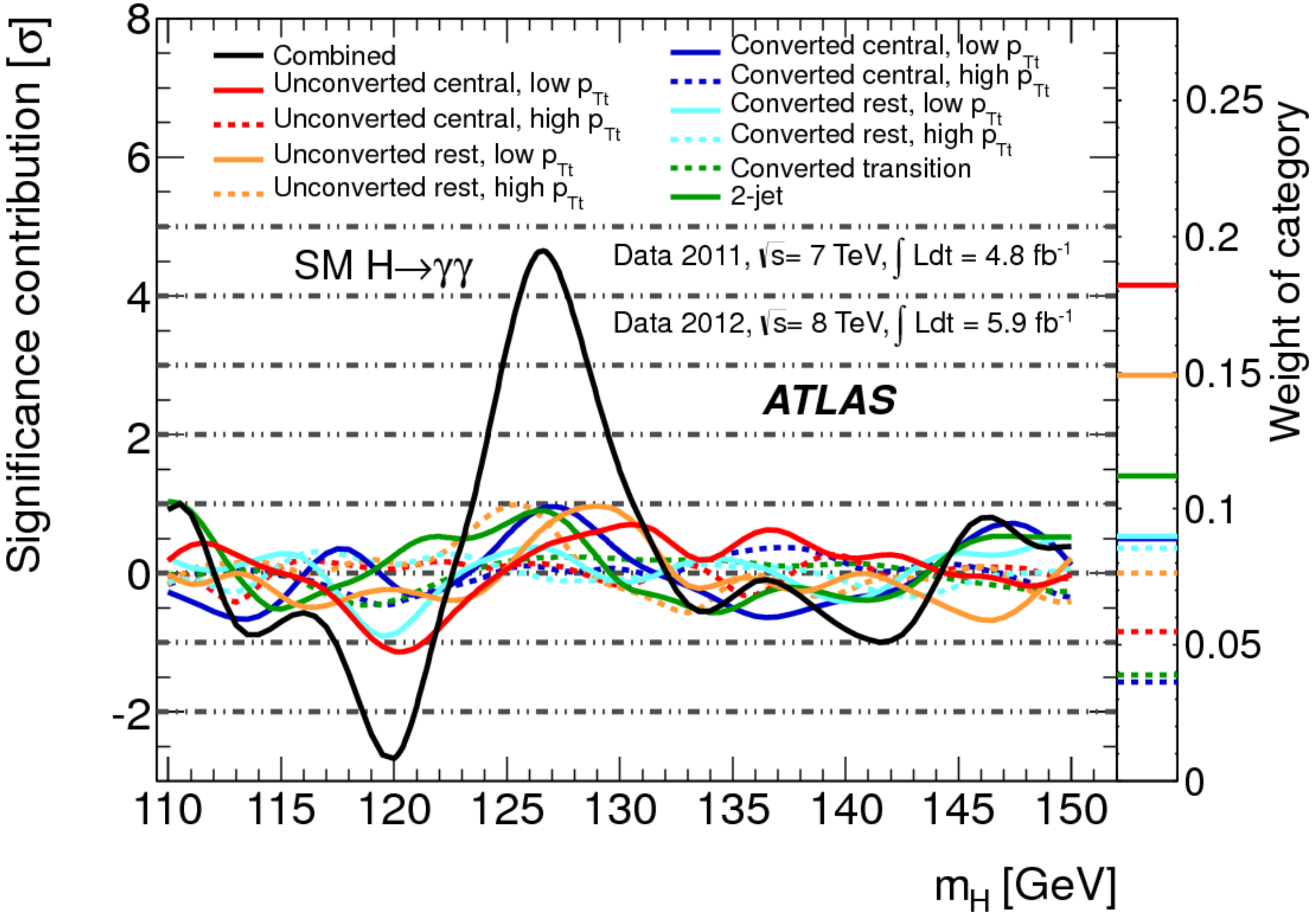
Normalized to SM Higgs expectation at given m_H (μ)

Best-fit value at 126.5 GeV: μ=1.9 ± 0.5



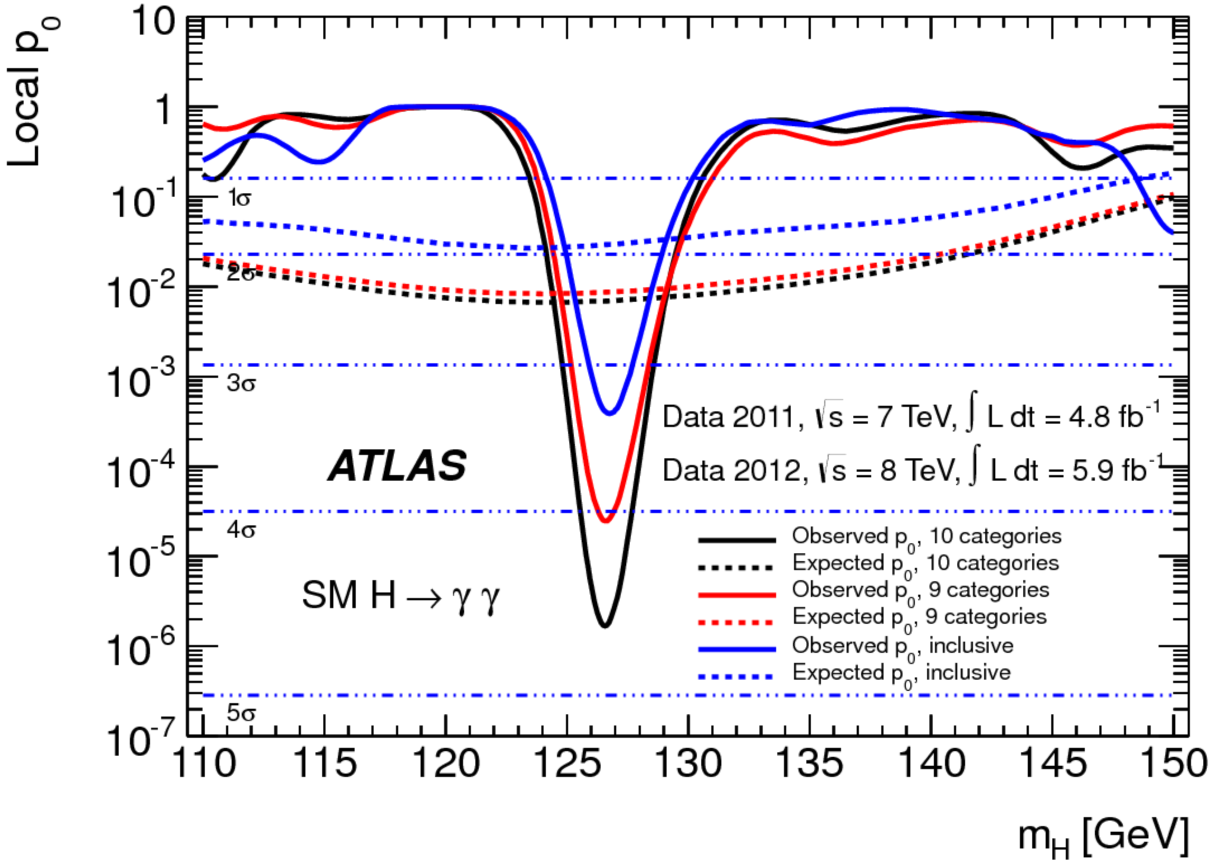


Consistent results from various categories within uncertainties (most sensitive ones indicated)



-2.5 σ downward fluctuation at $m_{\gamma\gamma}$~ 119 GeV

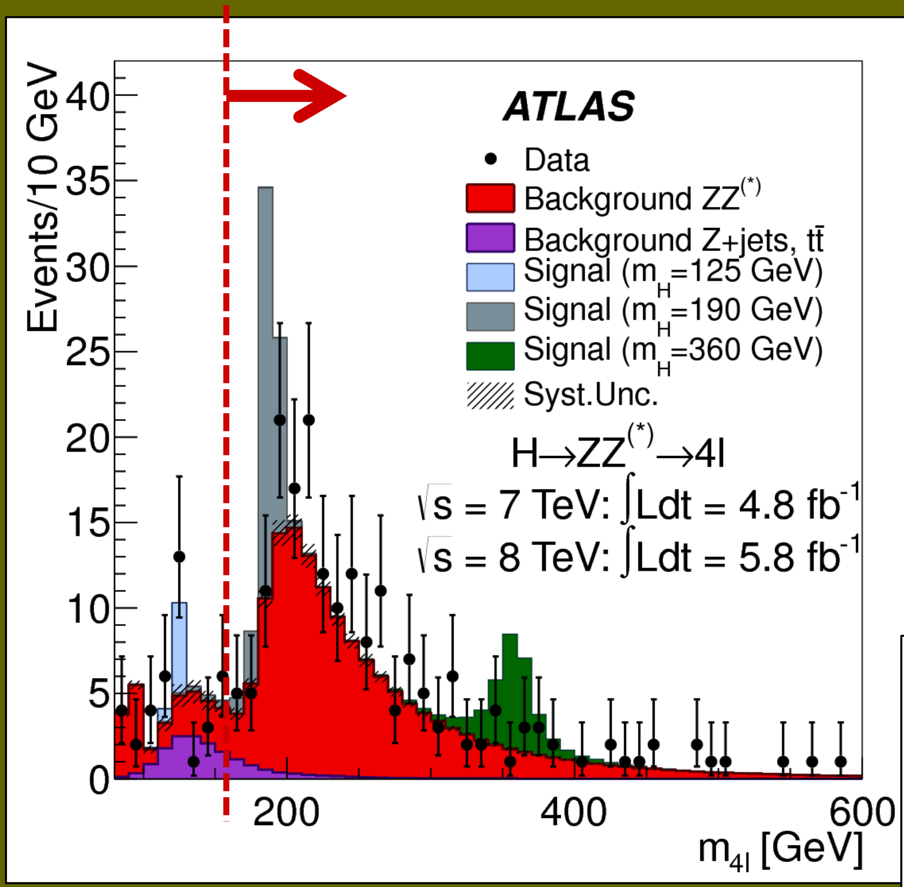
- ☐ probability 15% (~1 σ)
- ☐ does not affect significance of fitted signal
- ☐ unlike "signal" excess does not appear in most significant categories



Categories provide ~ 30% gain in sensitivity compared to inclusive analysis.
However, excess remains also with simpler inclusive analysis: ~ 3.5 σ

2jet/VBF category brings ~ 3% gain in expected sensitivity; observed gains in data are 10-15% (both years)
Caveat: 2jet category affected by largest systematics (~ 20% on signal yield)

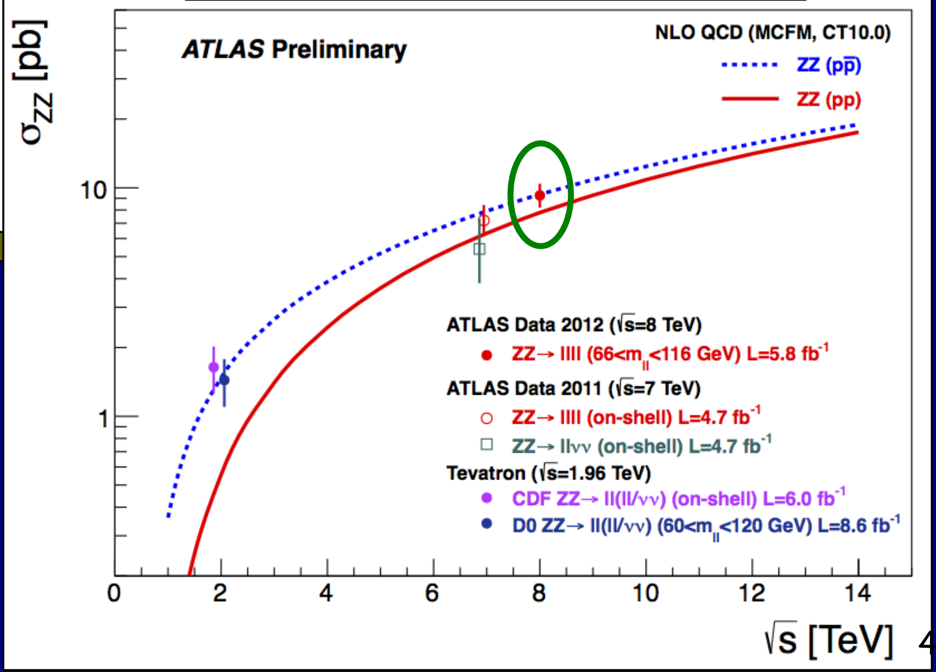
H→ 4l mass spectrum after all selections: 2011+2012 data



m(4l) > 160 GeV
(dominated by ZZ background):
147 ± 11 events expected
191 observed

~ 1.3 times more ZZ events in data than SM prediction →in agreement with measured ZZ cross-section in 4l final states at √s = 8 TeV

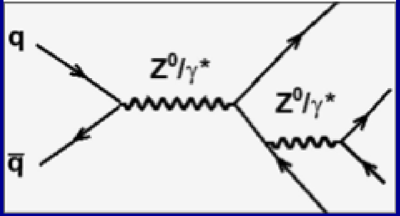
Measured σ (ZZ) = 9.3 ± 1.2 pb
SM (NLO) σ (ZZ) = 7.4± 0.4 pb



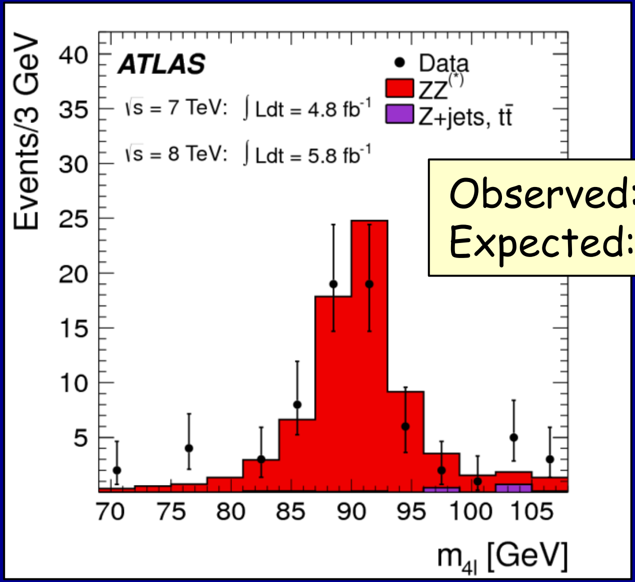
Discrepancy has negligible impact on the low-mass region < 160 GeV
(no change in results if in the fit ZZ is constrained to its uncertainty or left free)

H→ 4l mass spectrum after all selections: 2011+2012 data

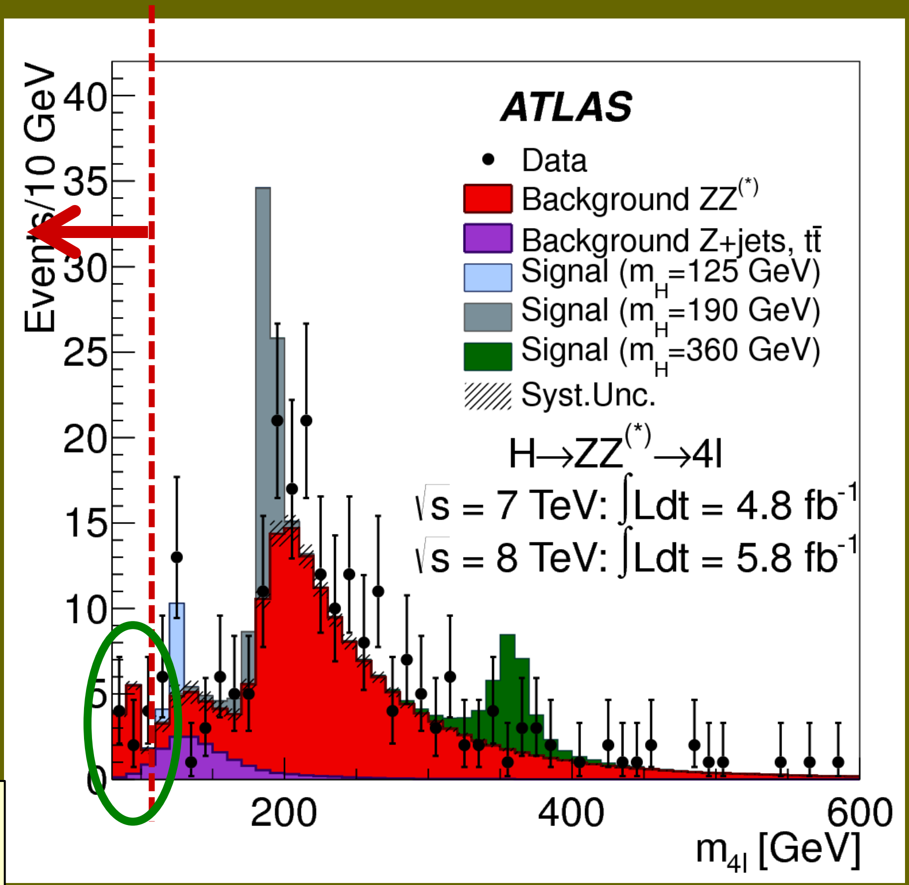
Peak at m(4l) ~ 90 GeV from single-resonant Z→ 4l production

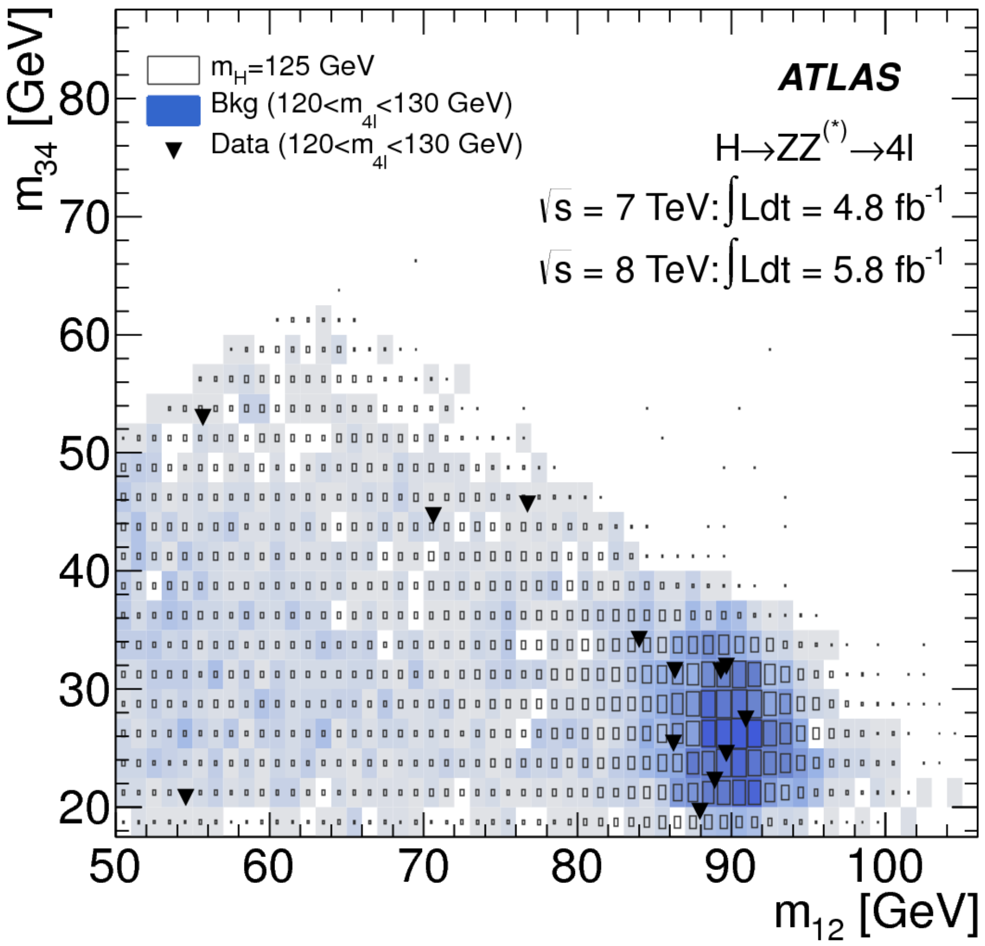


Enhanced by relaxing cuts on m_{12}, m_{34} and $p_T(\mu_4)$



Observed: 57 events
Expected: 65 ± 5



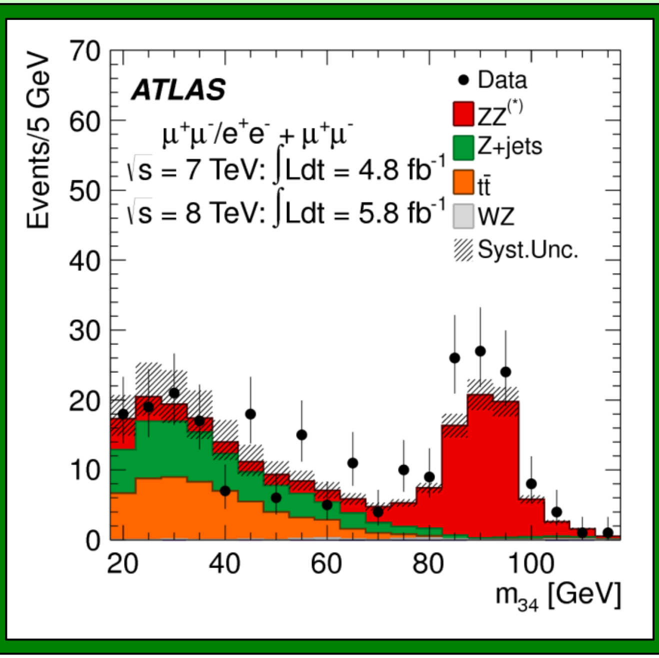

m_H=125 GeV
Bkg (120<m_{4l}<130 GeV)
Data (120<m_{4l}<130 GeV)
ATLAS
$H \rightarrow ZZ^{(*)} \rightarrow 4l$
$\sqrt{s}$ = 7 TeV: $\int Ldt$ = 4.8 fb^{-1}
$\sqrt{s}$ = 8 TeV: $\int Ldt$ = 5.8 fb^{-1}
m_{34} [GeV]
m_{12} [GeV]
20
30
40
50
60
70
80
50
60
70
80
90
100

Reducible backgrounds from Z+jets, Zbb, tt giving 2 genuine + 2 fake leptons measured using background-enriched, signal-depleted control regions in data

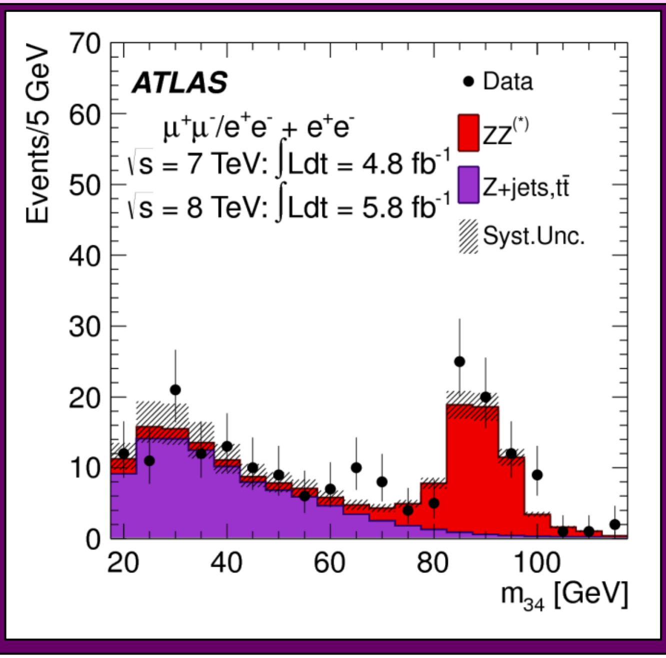
Typical control regions:

- ☐ leading lepton pair (l_1l_2) satisfies all selections
- ☐ sub-leading pair (l_3l_4): no isolation nor impact parameter requirements applied

$l_3l_4 = \mu\mu$ → background dominated by tt and Zbb in low mass region



l_3l_4 = ee → background dominated by Z+jets in low mass region



- ☐ Data well described by MC within uncertainties (ZZ excess at high mass …)
- ☐ Samples of Z+"μ" and Z+"e" used to compare efficiencies of isolation and impact parameter cuts between data and MC → good agreement → MC used to estimate background contamination in signal region
- ☐ Several cross-checks made with different control regions → consistent results

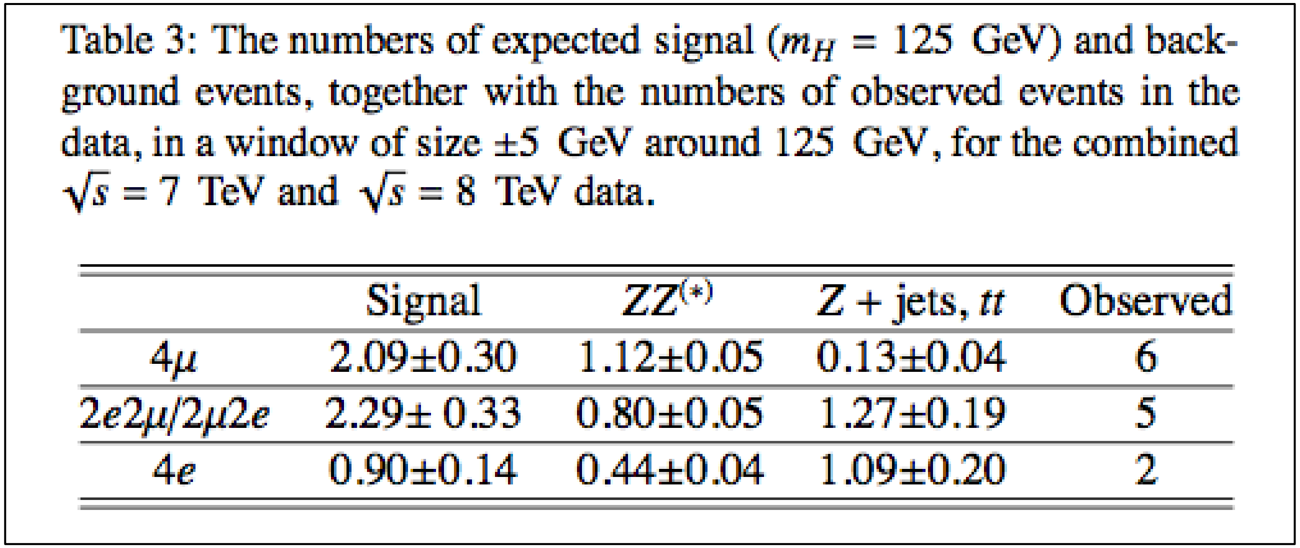
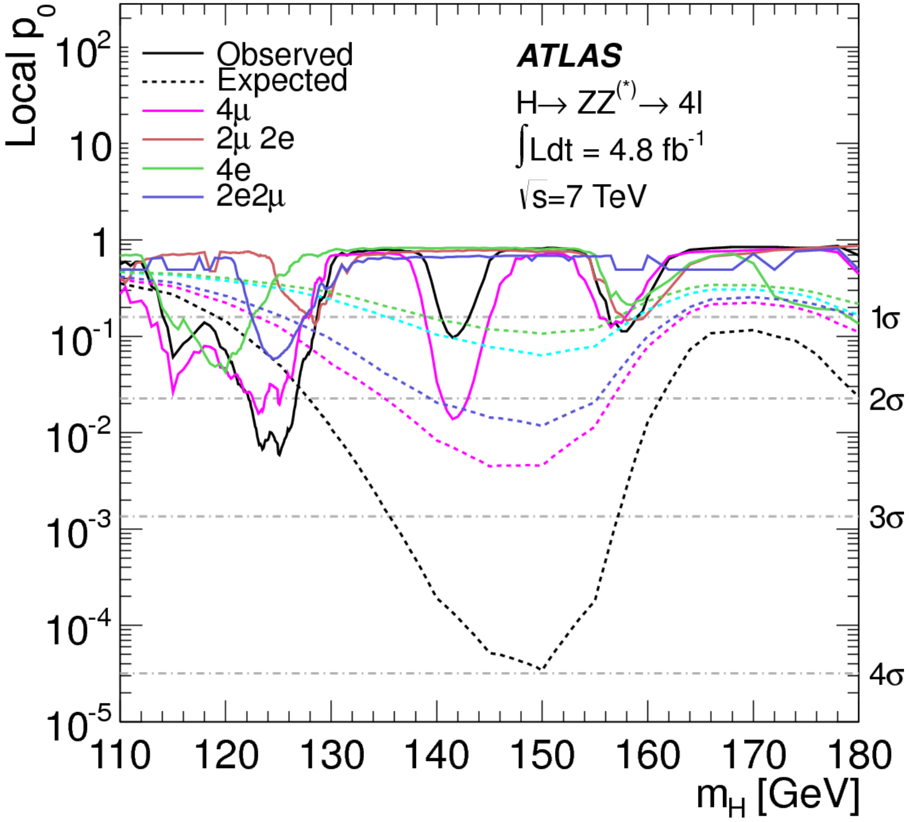


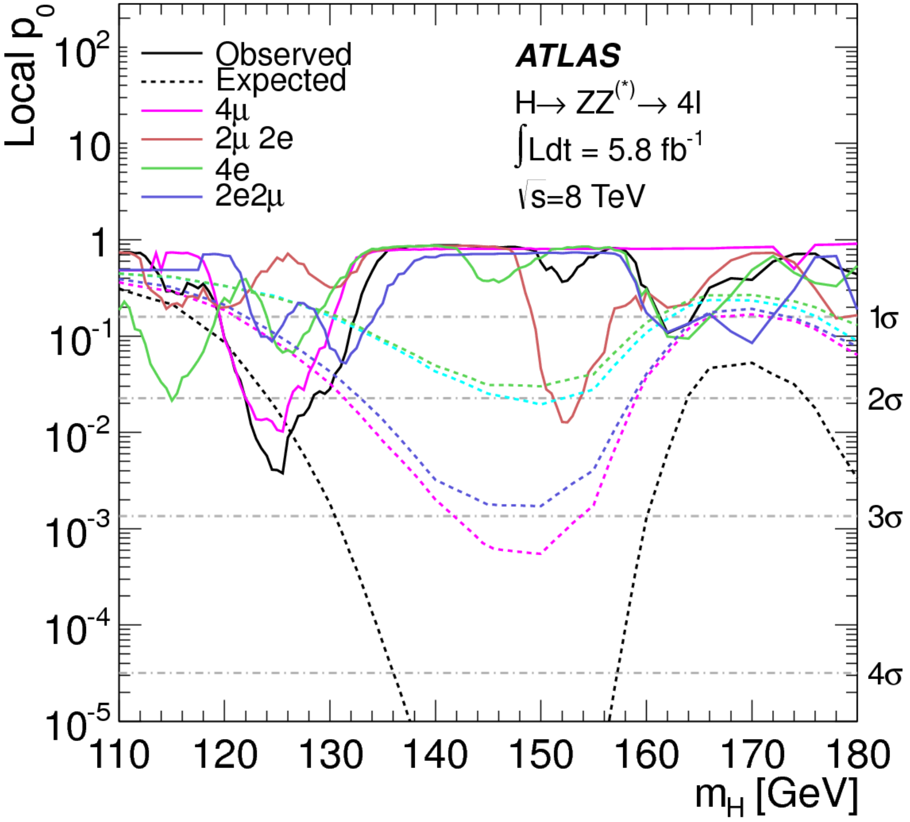
Table 3: The numbers of expected signal (m_H = 125 GeV) and background events, together with the numbers of observed events in the data, in a window of size ±5 GeV around 125 GeV, for the combined $\sqrt{s}$ = 7 TeV and $\sqrt{s}$ = 8 TeV data.

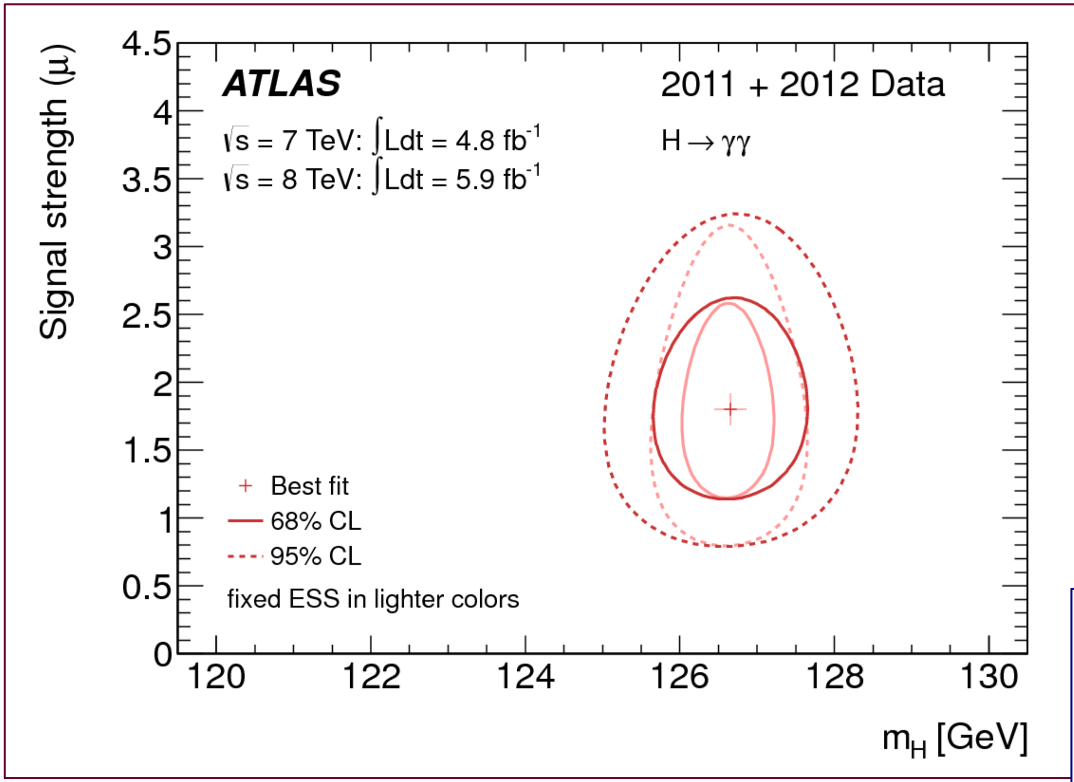
	Signal	$ZZ^{(*)}$	Z + jets, $t\bar{t}$	Observed
4μ	2.09±0.30	1.12±0.05	0.13±0.04	6
$2e2\mu/2\mu2e$	2.29± 0.33	0.80±0.05	1.27±0.19	5
$4e$	0.90±0.14	0.44±0.04	1.09±0.20	2

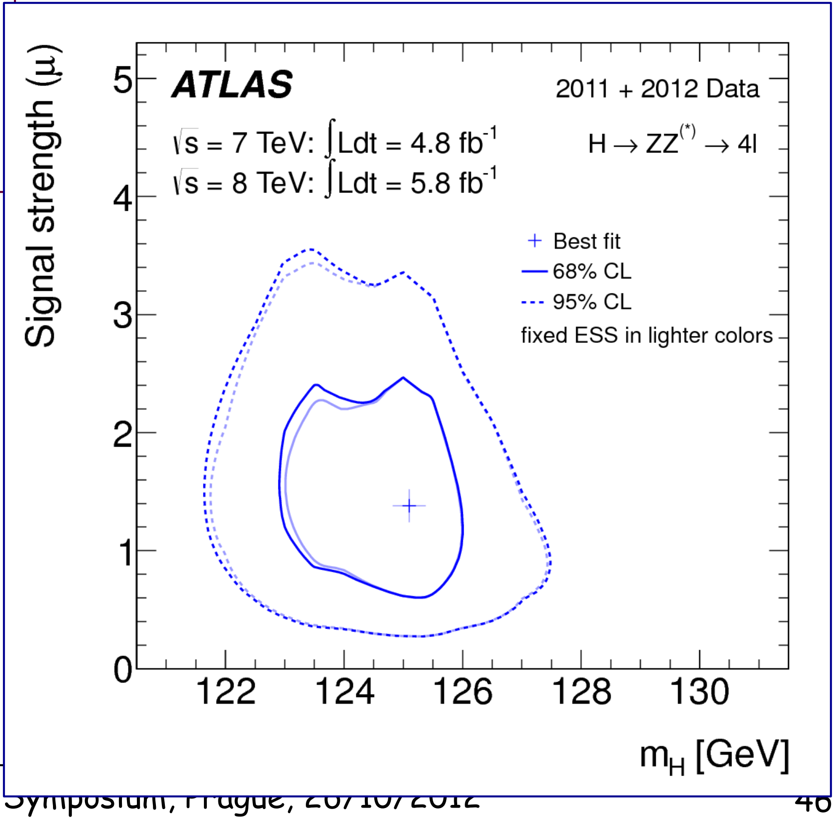
Main systematic uncertainties

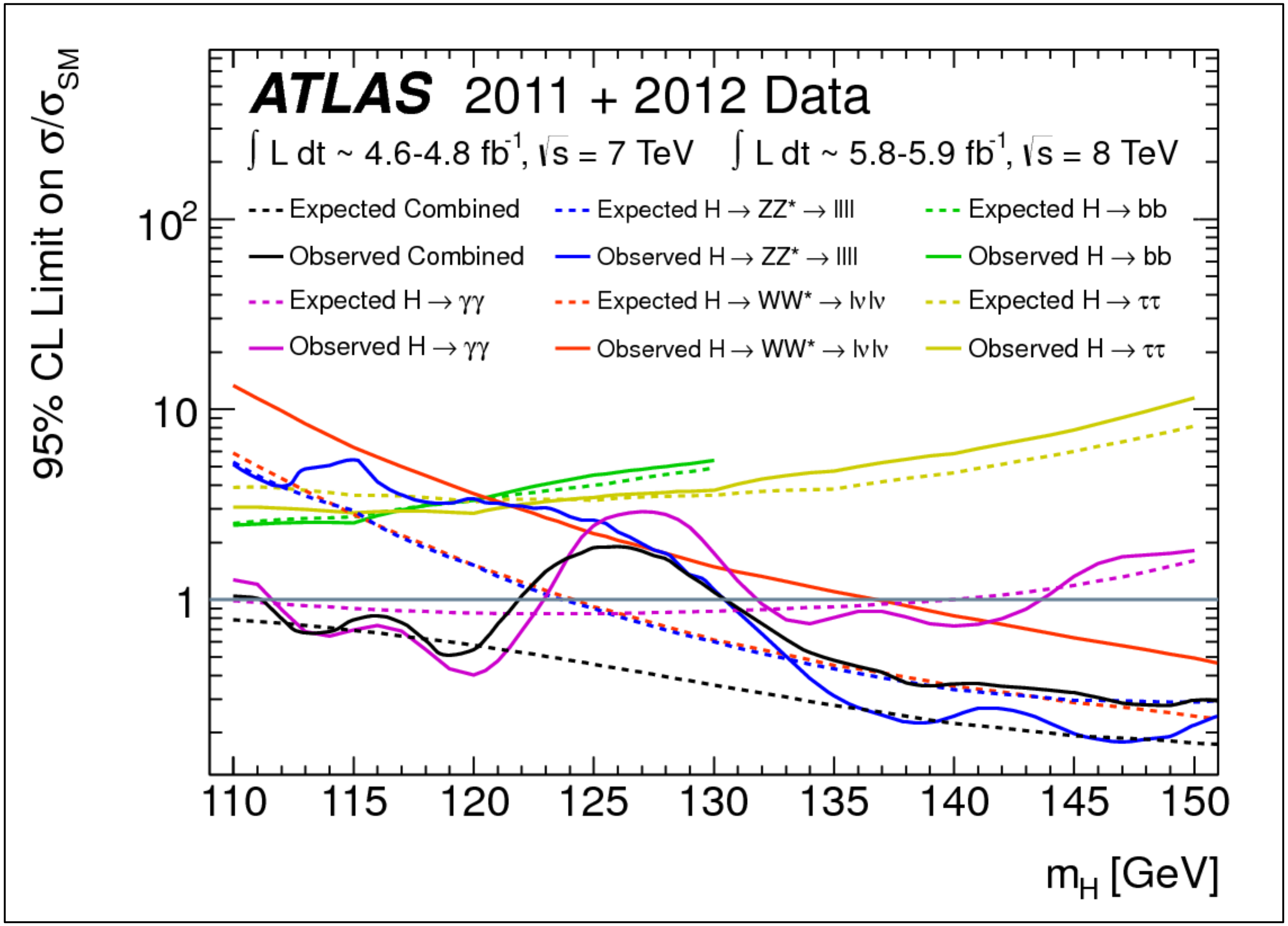
Higgs cross-section	: ~ 20%
Electron efficiency	: ~8% (4e)
ZZ* background	: ~ 15%
Reducible backgrounds	: ~ 40%


Local p_0
Observed
Expected
4μ
2μ 2e
4e
2e2μ
ATLAS
$H\rightarrow ZZ^{(*)}\rightarrow 4l$
$\int Ldt$ = 4.8 fb^{-1}
$\sqrt{s}$=7 TeV
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
1σ
2σ
3σ
4σ
110
120
130
140
150
160
170
180
m_H [GeV]


Local p_0
Observed
Expected
4μ
2μ 2e
4e
2e2μ
ATLAS
$H\rightarrow ZZ^{(*)}\rightarrow 4l$
$\int Ldt$ = 5.8 fb^{-1}
$\sqrt{s}$=8 TeV
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
1σ
2σ
3σ
4σ
110
120
130
140
150
160
170
180
m_H [GeV]


ATLAS
2011 + 2012 Data
$\sqrt{s}$ = 7 TeV: $\int Ldt$ = 4.8 fb^{-1}
$\sqrt{s}$ = 8 TeV: $\int Ldt$ = 5.9 fb^{-1}
$H \rightarrow \gamma\gamma$
Best fit
68% CL
95% CL
fixed ESS in lighter colors
Signal strength (μ)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
120
122
124
126
128
130
m_H [GeV]

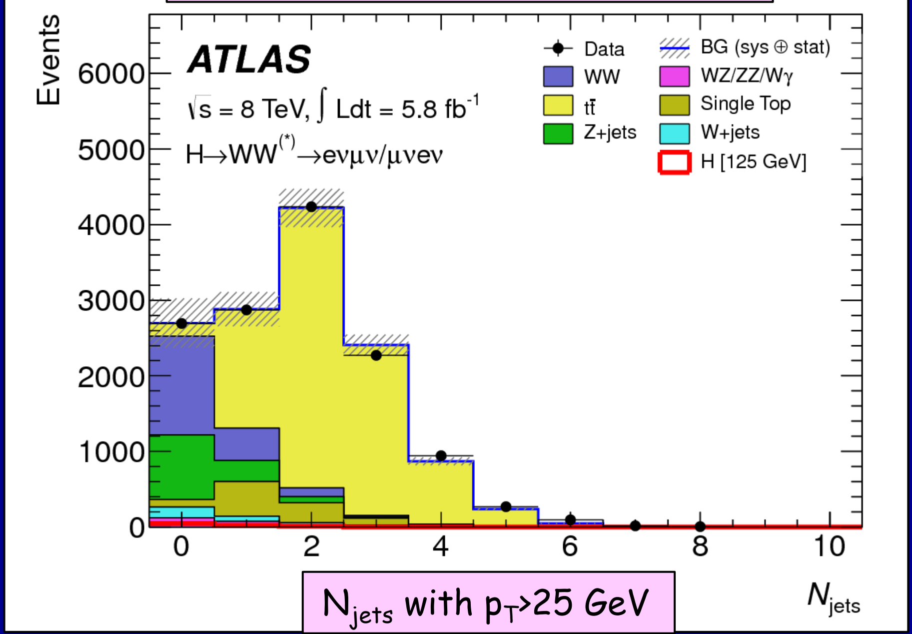

ATLAS
2011 + 2012 Data
$\sqrt{s}$ = 7 TeV: $\int Ldt$ = 4.8 fb^{-1}
$\sqrt{s}$ = 8 TeV: $\int Ldt$ = 5.8 fb^{-1}
$H \rightarrow ZZ^{(*)} \rightarrow 4l$
Best fit
68% CL
95% CL
fixed ESS in lighter colors
Signal strength (μ)
5
4
3
2
1
0
122
124
126
128
130
m_H [GeV]


ATLAS 2011 + 2012 Data
∫ L dt ~ 4.6-4.8 fb^{-1}, √s = 7 TeV ∫ L dt ~ 5.8-5.9 fb^{-1}, √s = 8 TeV
Expected Combined
Observed Combined
Expected H → γγ
Observed H → γγ
Expected H → ZZ* → llll
Observed H → ZZ* → llll
Expected H → WW* → lνlν
Observed H → WW* → lνlν
Expected H → bb
Observed H → bb
Expected H → ττ
Observed H → ττ
95% CL Limit on σ/σ$_{SM}$
10^2
10
1
110
115
120
125
130
135
140
145
150
m$_H$ [GeV]

☐ To increase sensitivity, events divided in 3 categories: 0-jet, 1-jet, 2-jet

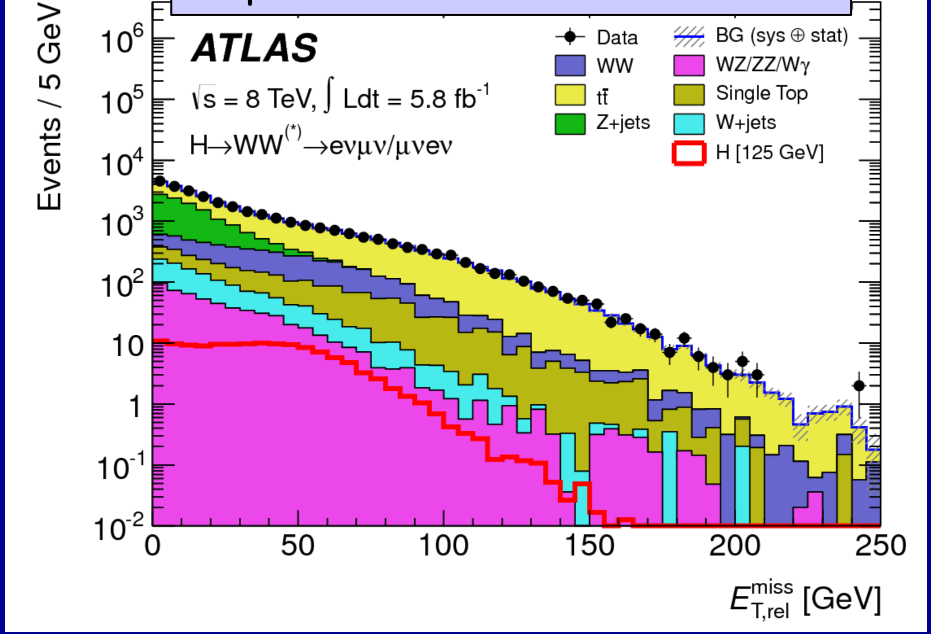
☐ 2-jet: VBF-like cuts:
$|\Delta\eta|_{jj} > 3.8$. $M_{jj} > 500$ GeV, central-jet veto

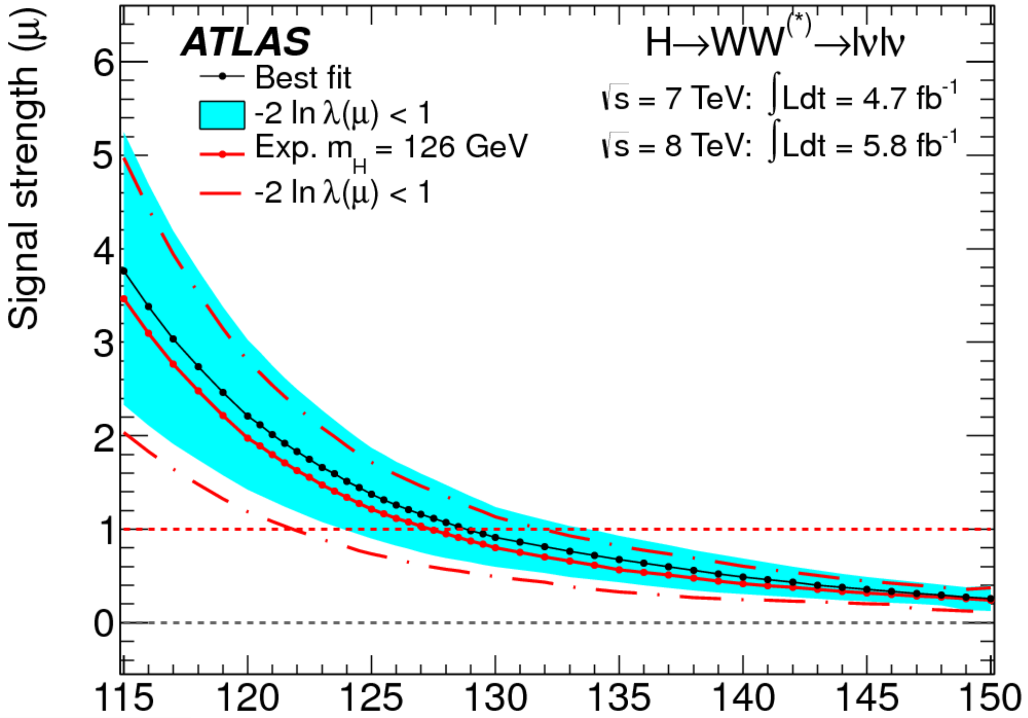
After leptons, m_Z and E_T^{miss} cuts

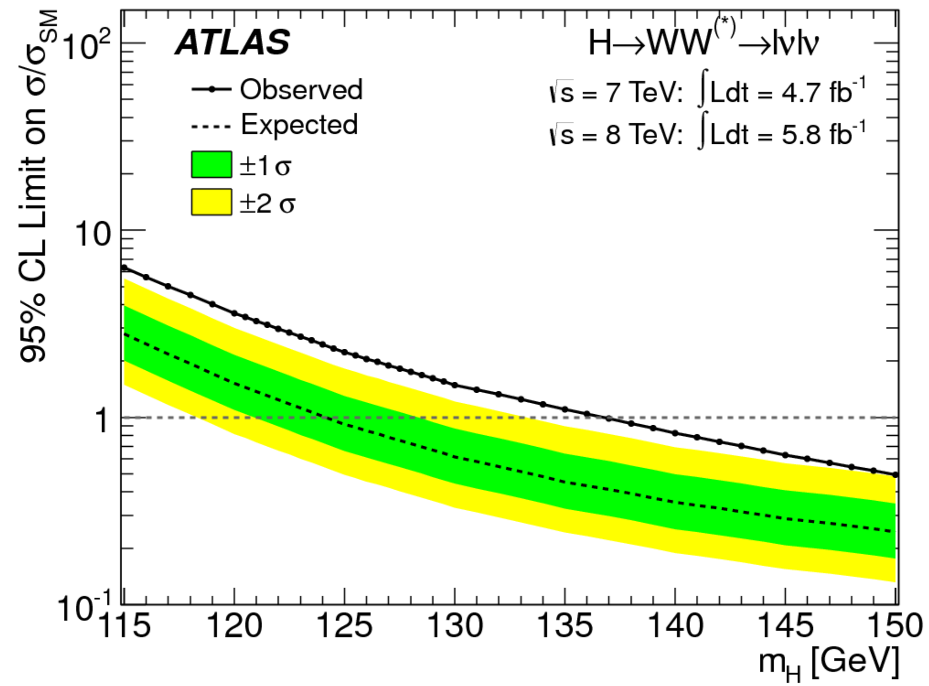


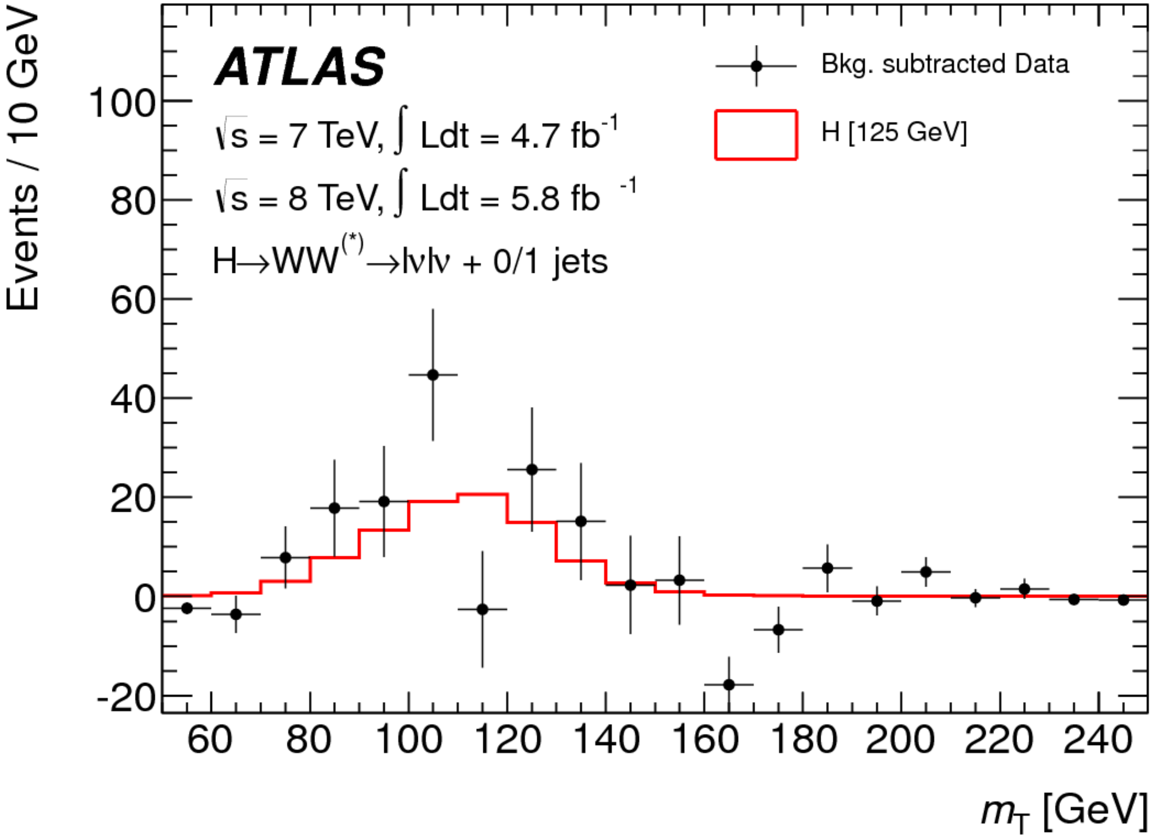
N_{jets} with p_T>25 GeV

E_T^{miss} distribution for eμ events at pre-selection level




ATLAS
H→WW(*)→lνlν
Best fit
-2 ln λ(μ) < 1
Exp. m_H = 126 GeV
-2 ln λ(μ) < 1
√s = 7 TeV: ∫Ldt = 4.7 fb-1
√s = 8 TeV: ∫Ldt = 5.8 fb-1
Signal strength (μ)
0
1
2
3
4
5
6
115
120
125
130
135
140
145
150
m_H [GeV]


ATLAS
H→WW(*)→lνlν
Observed
Expected
±1 σ
±2 σ
√s = 7 TeV: ∫Ldt = 4.7 fb-1
√s = 8 TeV: ∫Ldt = 5.8 fb-1
95% CL Limit on σ/σ_SM
10-1
1
10
10^2
115
120
125
130
135
140
145
150
m_H [GeV]


ATLAS
$\sqrt{s}$ = 7 TeV, $\int$ Ldt = 4.7 fb^{-1}
$\sqrt{s}$ = 8 TeV, $\int$ Ldt = 5.8 fb^{-1}
H→WW$^{(*)}$→lνlν + 0/1 jets
Bkg. subtracted Data
H [125 GeV]
Events / 10 GeV
100
80
60
40
20
0
-20
60
80
100
120
140
160
180
200
220
240
m_T [GeV]

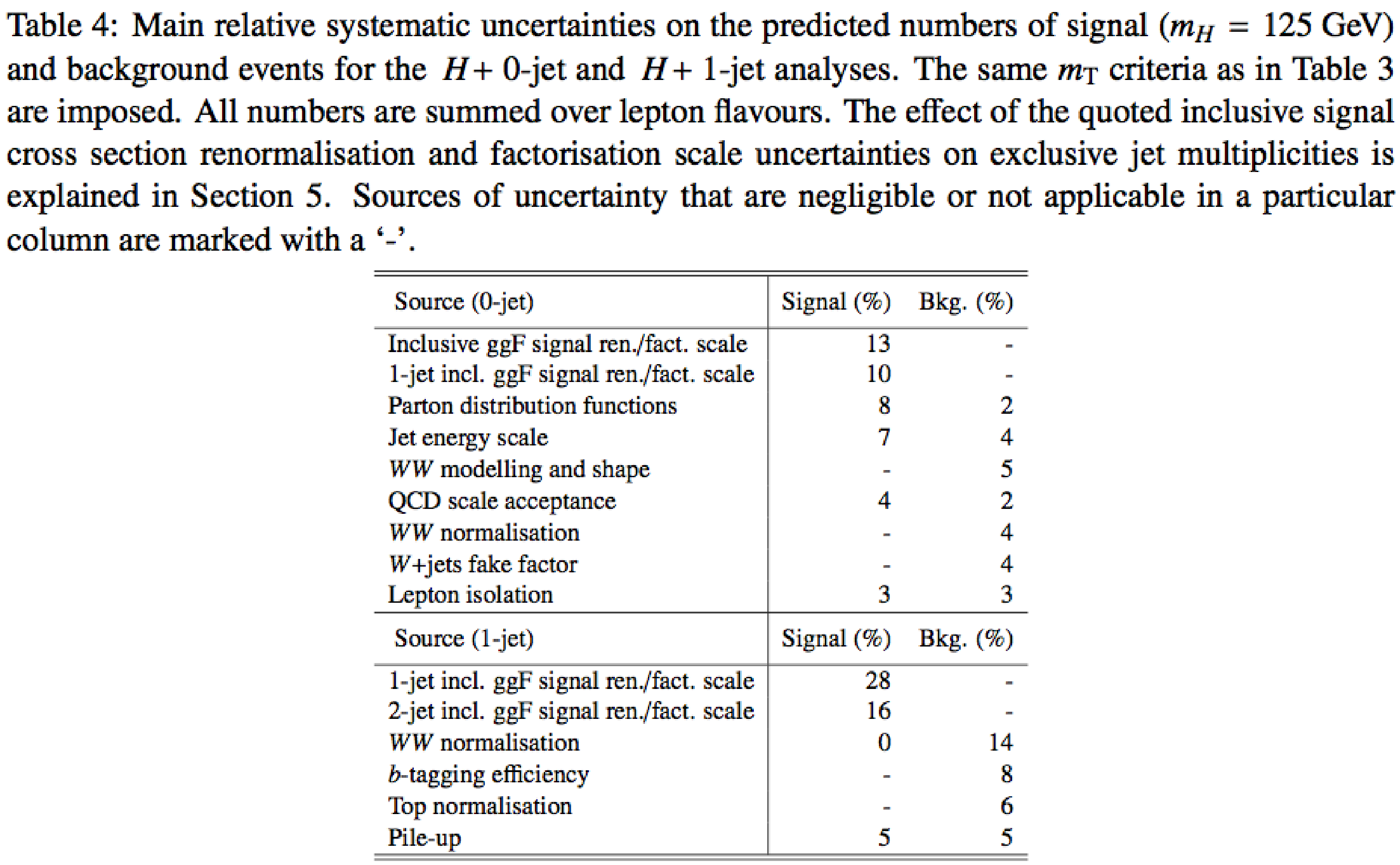
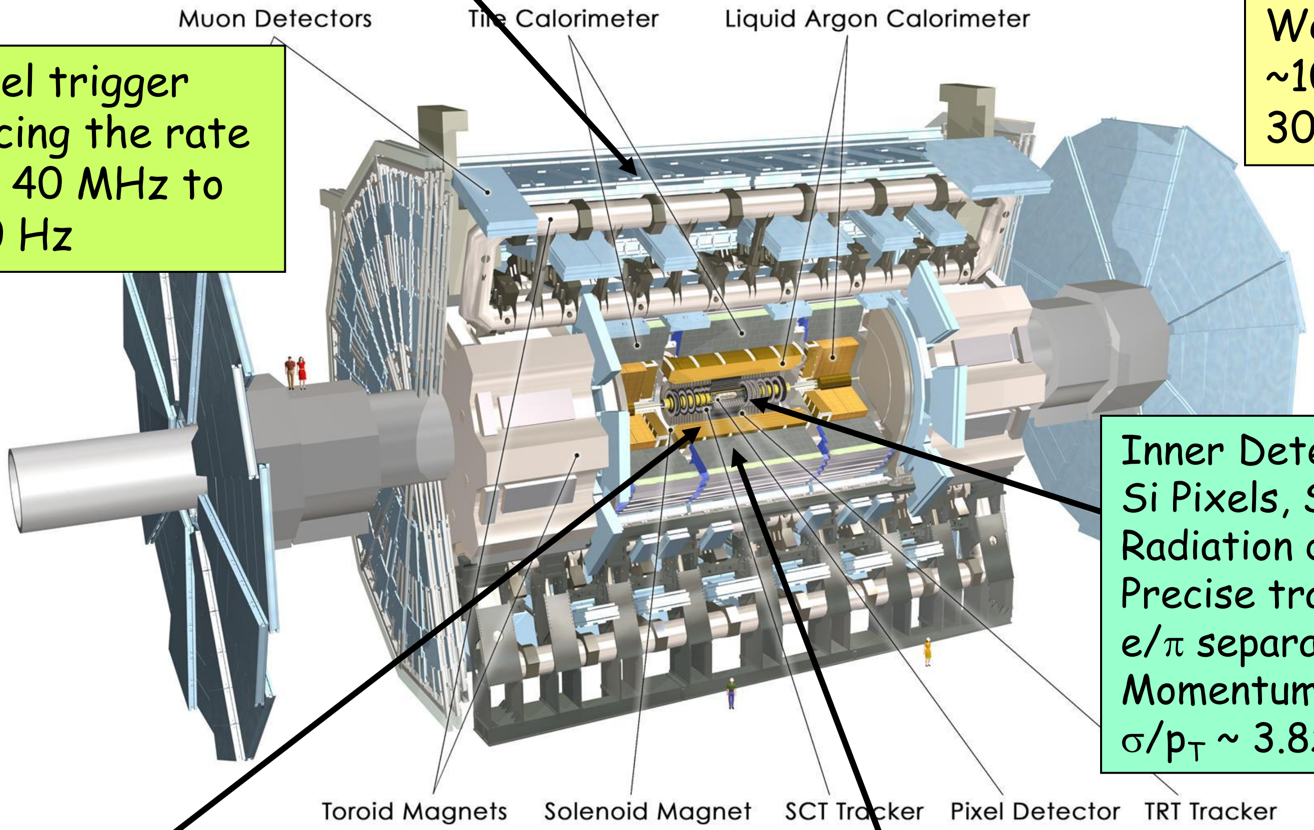


Table 4: Main relative systematic uncertainties on the predicted numbers of signal ($m_H = 125$ GeV) and background events for the $H+$ 0-jet and $H+$ 1-jet analyses. The same m_T criteria as in Table 3 are imposed. All numbers are summed over lepton flavours. The effect of the quoted inclusive signal cross section renormalisation and factorisation scale uncertainties on exclusive jet multiplicities is explained in Section 5. Sources of uncertainty that are negligible or not applicable in a particular column are marked with a '-'.

Source (0-jet)	Signal (%)	Bkg. (%)
Inclusive ggF signal ren./fact. scale	13	-
1-jet incl. ggF signal ren./fact. scale	10	-
Parton distribution functions	8	2
Jet energy scale	7	4
WW modelling and shape	-	5
QCD scale acceptance	4	2
WW normalisation	-	4
W+jets fake factor	-	4
Lepton isolation	3	3
Source (1-jet)	**Signal (%)**	**Bkg. (%)**
1-jet incl. ggF signal ren./fact. scale	28	-
2-jet incl. ggF signal ren./fact. scale	16	-
WW normalisation	0	14
b-tagging efficiency	-	8
Top normalisation	-	6
Pile-up	5	5

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



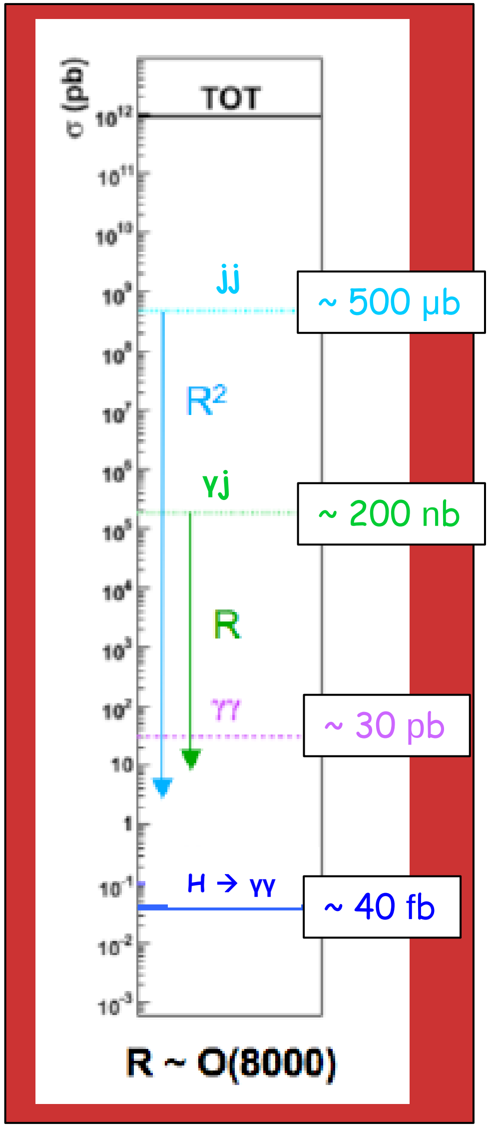
Length : ~ 46 m
Radius : ~ 12 m
Weight : ~ 7000 tons
~10^8 electronic channels
3000 km of cables

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:
$\sigma/p_T \sim 3.8\times10^{-4}\, p_T(\text{GeV}) \oplus 0.015$

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


σ (pb)
10^12
10^11
10^10
10^9
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10
1
10^-1
10^-2
10^-3
TOT
jj
~ 500 μb
R²
γj
~ 200 nb
R
γγ
~ 30 pb
H → γγ
~ 40 fb
R ~ O(8000)