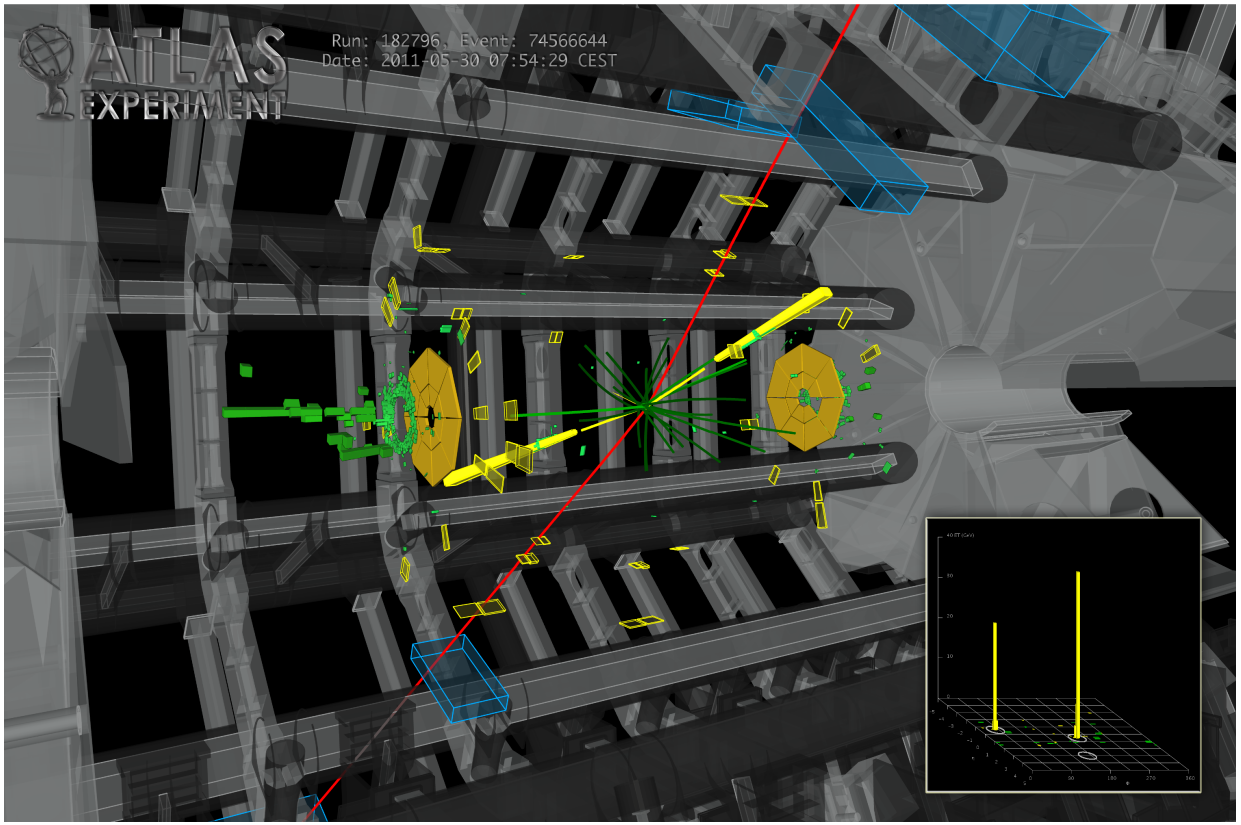
Higgs Boson Searches with ATLAS



Kirill Prokofiev

NYU

on behalf of the

ATLAS Collaboration

Outline

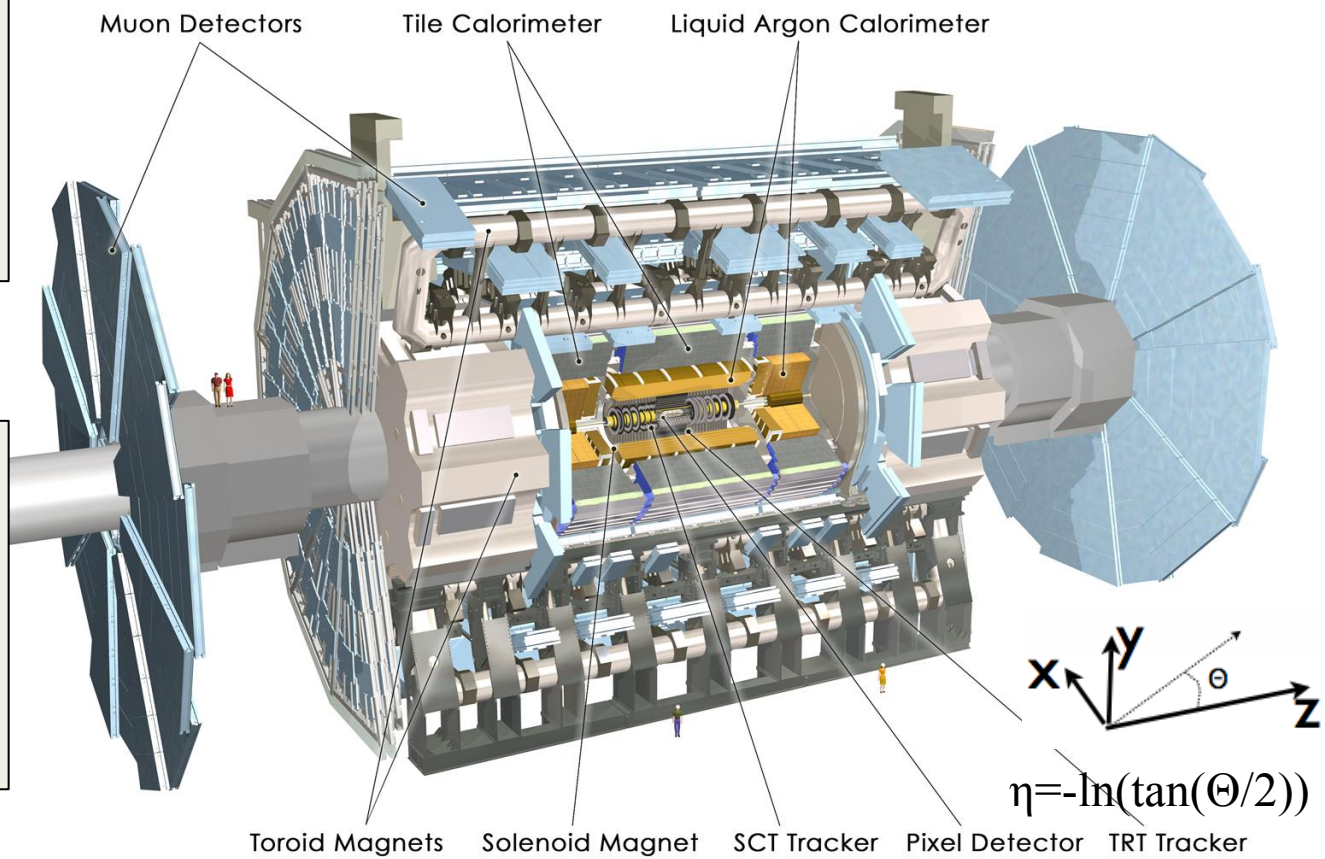
- ATLAS Detector
- Operation in 2010 and 2011
- Standard Model Higgs searches
- Standard Model Higgs combined result
- Searches beyond the Standard Model
- Summary

ATLAS detector overview

EM Calorimeter: (|η|<4.9) Pb-LAr accordion structure provides e/γ trigger, identification, measurement:
σ/E ~10%√E
Hadronic (Tile): provides trigger, jet measurement, E_T^{miss}
σ/E ~50%√E ⊕ 0.03. (|η|<1.7)

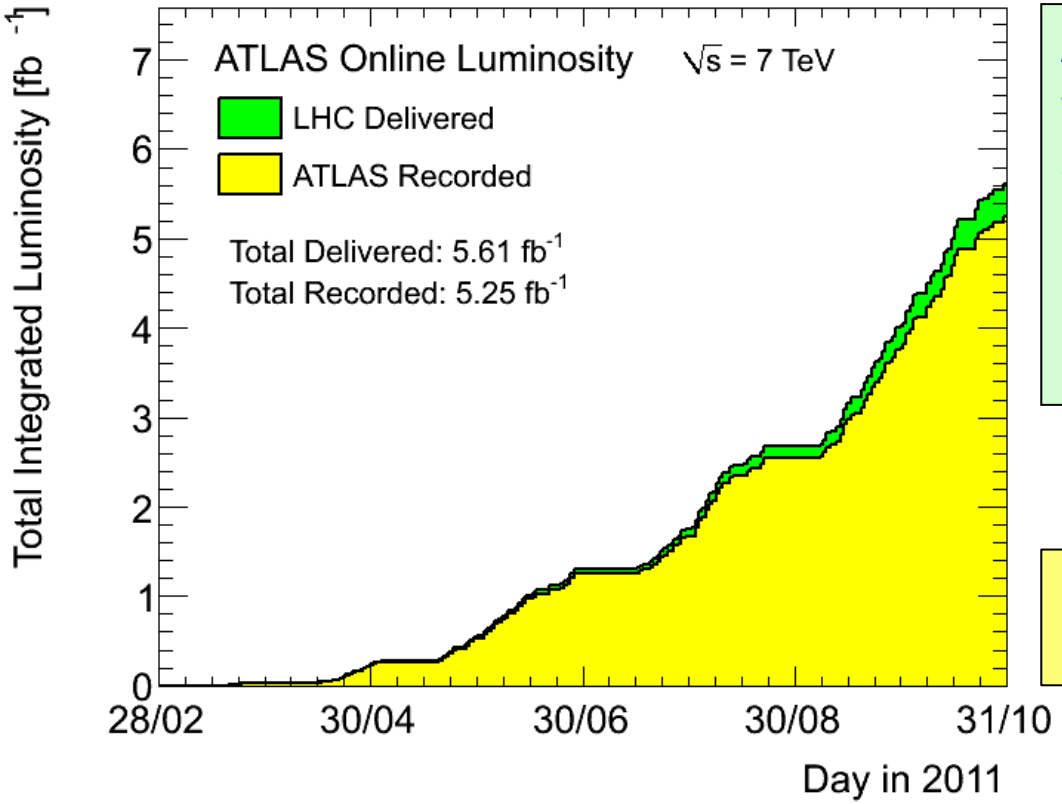
The Inner Detector provides around 3 pixel, 8 SCT and 30 TRT measurements per charged track at η = 0. Coverage: |η| < 2.5 (2.0 for TRT)
Resolution goal:
$\sigma_{pT}/p_T = 0.05\% \, p_T \oplus 1\%$

Muon spectrometer: high precision tracking and trigger chambers.
|η| coverage up to 2.7.
Magnetic field produced by 3x8 air-core toroids.



Data taking in 2010 and 2011

		Delivered	Recorded
pp	2010	**48.1 pb^{-1}**	**45.0 pb^{-1}**
pp	2011	**5.61 fb^{-1}**	**5.25 pb^{-1}**



ATLAS luminosity detectors calibrated with van der Meer beam separation scans.

- 5 different luminosity detectors.
- In 2010: $d\mathcal{L}/\mathcal{L}$ ~3.4%. In 2011: $d\mathcal{L}/\mathcal{L}$ ~3.9%.

Only data of 2011 are shown in this presentation

arXiv::11012185v1

ATLAS-CONF-2011-116

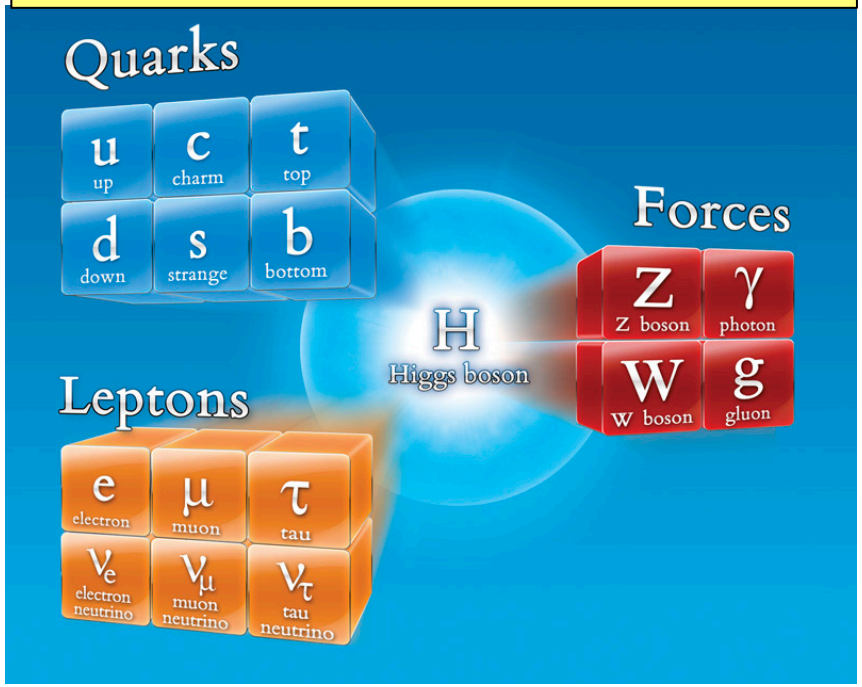
Standard Model Higgs boson

- Higgs mechanism: most probable mechanism for the electroweak symmetry breaking. Used both in the Standard Model and theories beyond.
- In the Standard Model, the vector bosons and the fermions acquire mass via coupling to the Higgs field.
- Physical manifestation of the Higgs field in the Standard Model: scalar Higgs boson.
- Theories beyond the Standard Model often require presence of several Higgs bosons.
- Presently, the Higgs boson is the missing part of the Standard Model. No evidence for Higgses predicted by other theories is found either.

LEP: m_H>114.4 GeV.

Tevatron: exclusion of 147< m_H<179 GeV region.

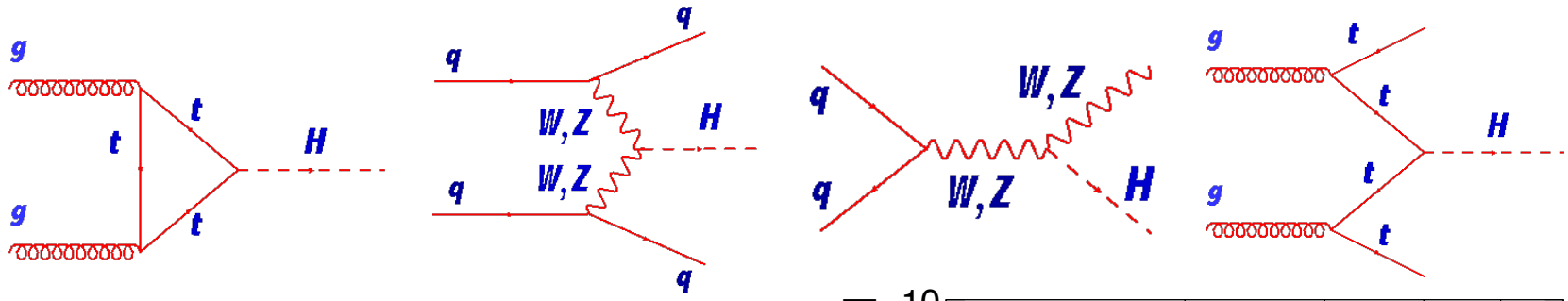
Indirect limits come from the precision measurements of electroweak observables.

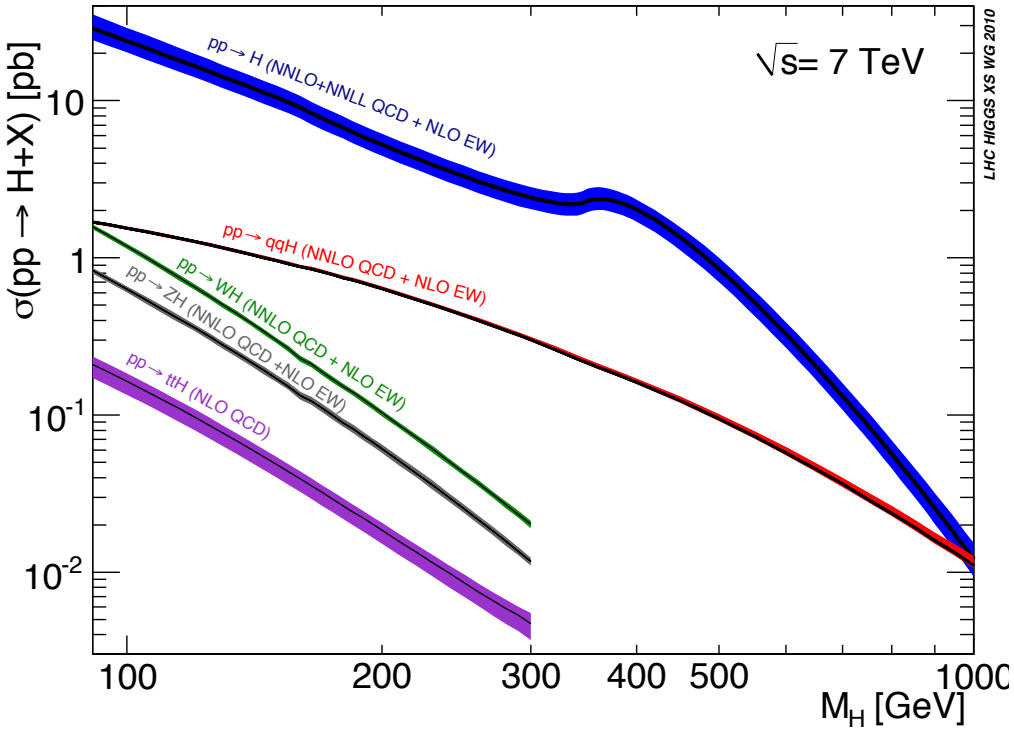


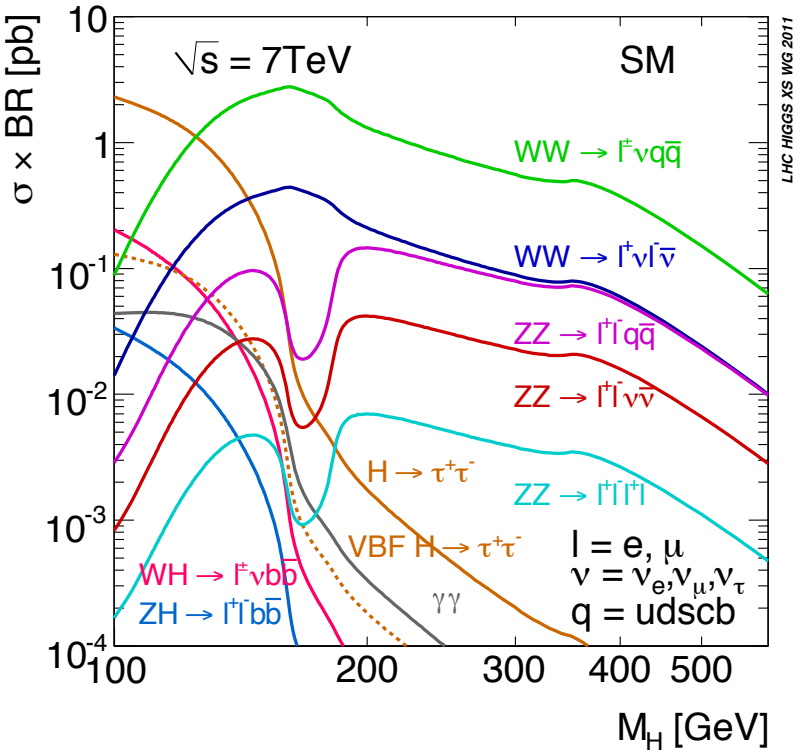
arXiv::1203.3774

Standard Model Higgs searches

Gluon-gluon fusion | Vector boson fusion | Associated production







Considered search channels

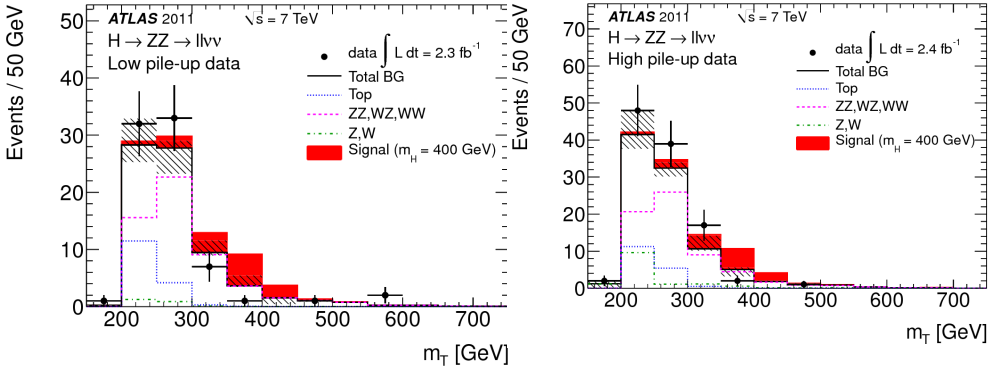
Higgs Decay	Subsequent Decay	Additional Sub-Channels	m_H Range	L [fb^{-1}]
$H \to \gamma\gamma$	–	9 sub-channels ($p_{T_t} \otimes \eta_\gamma \otimes$ conversion)	110-150	4.9
$H \to ZZ$	$\ell\ell\ell'\ell'$	$\{4e, 2e2\mu, 2\mu2e, 4\mu\}$	110-600	4.8
	$\ell\ell\nu\bar{\nu}$	$\{ee, \mu\mu\} \otimes$ {low pile-up, high pile-up}	200-280-600	4.7
	$\ell\ell q\bar{q}$	{b-tagged, untagged}	200-300-600	4.7
$H \to WW$	$\ell\nu\ell\nu$	$\{ee, e\mu, \mu\mu\} \otimes$ {0-jet, 1-jet, VBF}	110-300-600	4.7
	$\ell\nu q\bar{q}'$	$\{e, \mu\} \otimes$ {0-jet, 1-jet}	300-600	4.7
$H \to \tau^+\tau^-$	$\ell\ell 4\nu$	$\{e\mu\} \otimes$ {0-jet} $\oplus$ {1-jet, VBF, VH}	110-150	4.7
	$\ell\tau_{\text{had}}3\nu$	$\{e, \mu\} \otimes$ {0-jet} $\otimes \{E_T^{\text{miss}} \gtrless 20$ GeV$\}$ $\oplus \{e, \mu\} \otimes$ {1-jet, VBF}	110-150	4.7
	$\tau_{\text{had}}\tau_{\text{had}}2\nu$	{1-jet}	110-150	4.7
$VH \to b\bar{b}$	$Z \to \nu\bar{\nu}$	$E_T^{\text{miss}} \in \{120-160, 160-200, \geq 200$ GeV$\}$	110-130	4.6
	$W \to \ell\nu$	$p_T^W \in \{<50, 50-100, 100-200, \geq 200$ GeV$\}$	110-130	4.7
	$Z \to \ell\ell$	$p_T^Z \in \{<50, 50-100, 100-200, \geq 200$ GeV$\}$	110-130	4.7

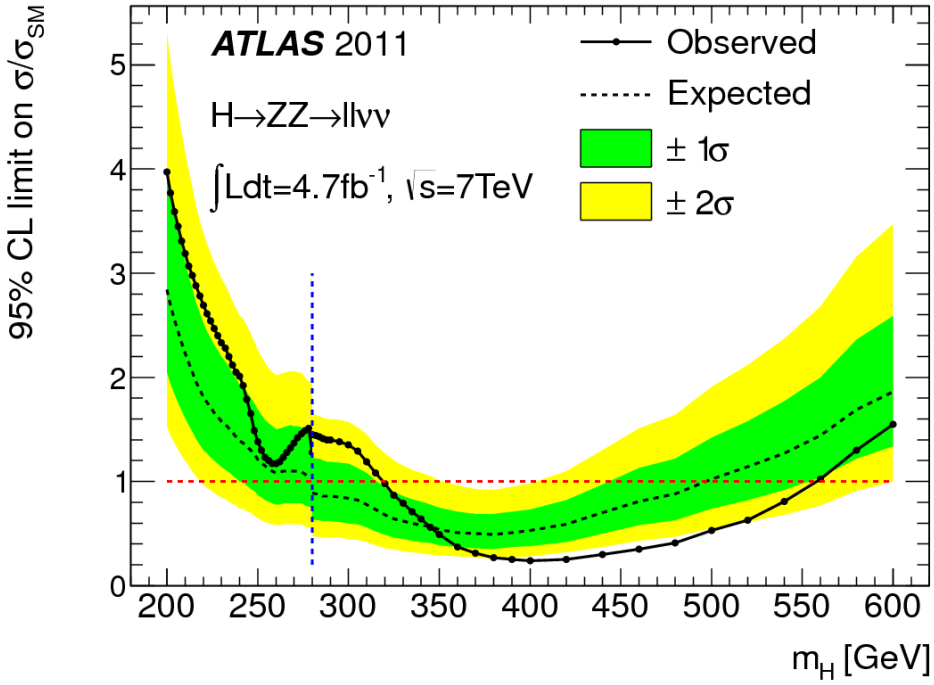
- For the Standard Model Higgs searches, ATLAS uses a variety of final states . The final result is the combination of all considered modes.
- Search performed in the range m_H = 110 – 600 GeV.
- High mass Higgs search: ZZ→llqq, ZZ→llvv, WW→lvqq.

Standard Model Higgs searches in the high mass region (200-600 GeV)

$H \rightarrow ZZ \rightarrow llvv$

Average pp collision multiplicity per BC:
<μ>=6.3 <μ>=11.6



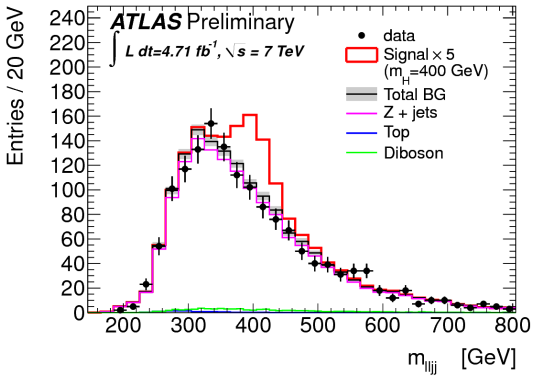


- Most sensitive channel in the high mass range: high BR and clean signature.
- Pile-up dependent due to the E_T^{miss}.
- Separate analyses for m_H<280 and m_H≥280 GeV: different cuts for E_T^{miss} and Δϕ(ll).
- Background normalization:
  - ZZ, WW: Monte Carlo.
  - WZ: Monte Carlo verified in 3-lepton control region in data.
  - Top: Monte Carlo verified in eμ and m_{ll} sidebands + *b*-tag.
  - Inclusive W: same sign ee and eμ pairs.
  - Inclusive Z: Inverted Δϕ(p_T^{miss}, p_T^{jet})
- No significant excess observed.
- Observed (expected) exclusion in the region 319 - 558 GeV (280 - 497 GeV).

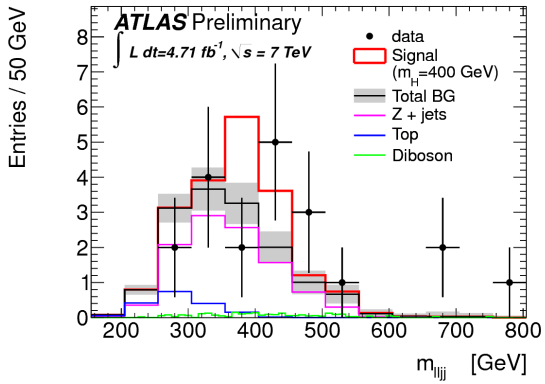
arXiv:1205.6744v1

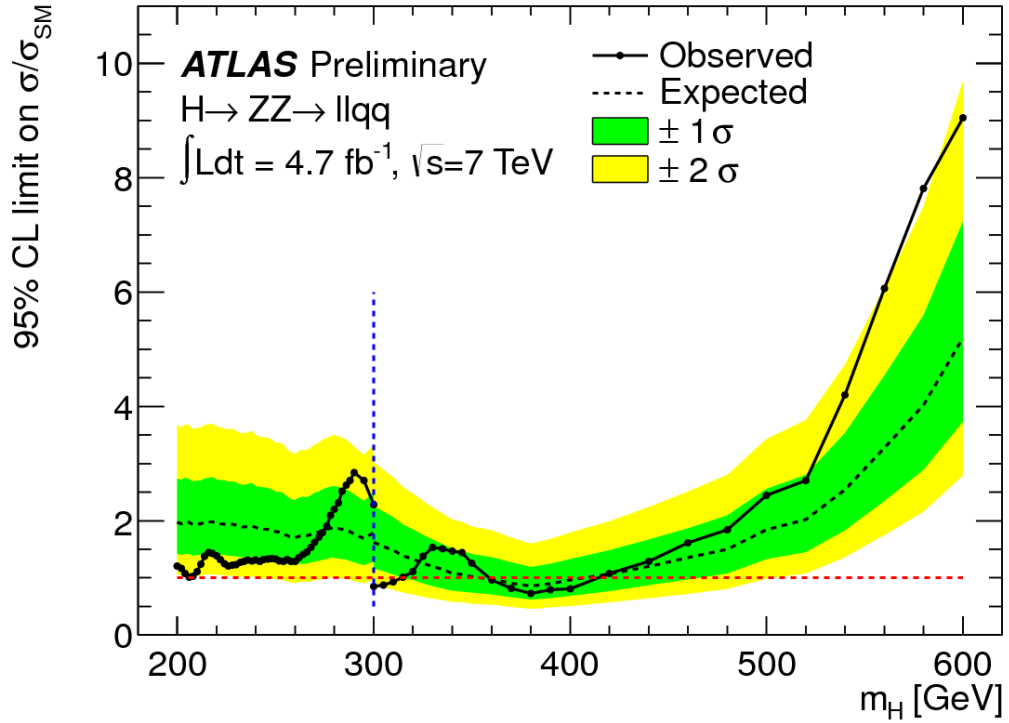
$H \rightarrow ZZ \rightarrow llq\bar{q}$

untagged



b-tag

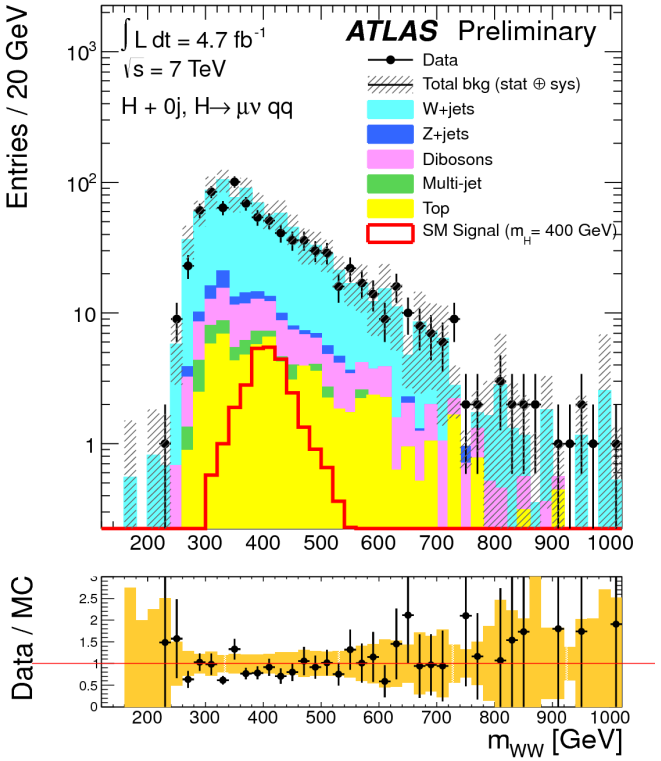




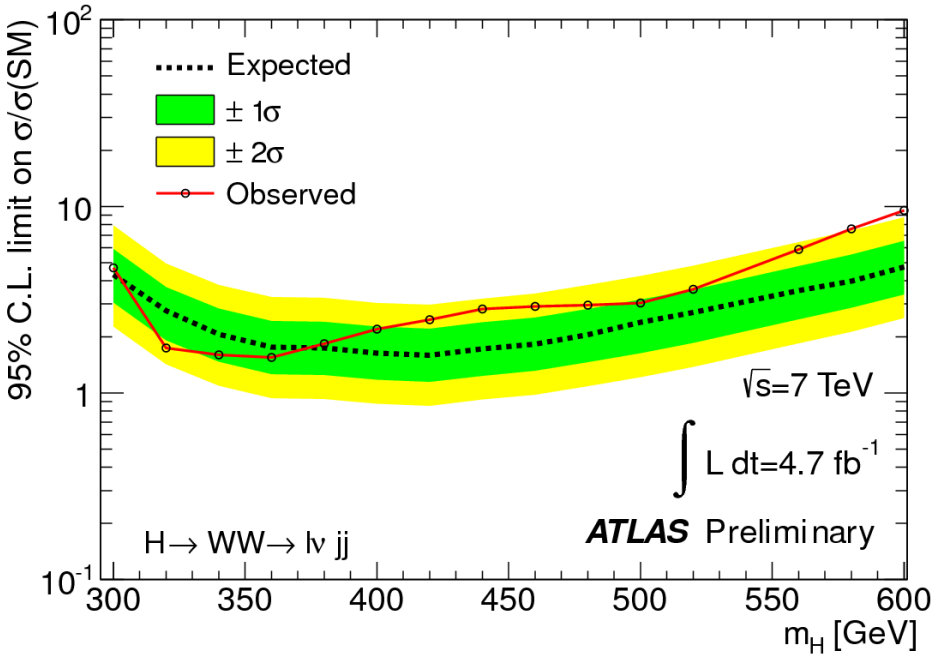
- Using m_{lljj} as discriminating variable.
- Separate analyses for $m_H<300$ and $m_H \geq 300$ GeV. Higher mass Higgses produce Z's with significant momenta: special angular treatment allows better background rejection (Z+jets).
- Further split into <2 b-tags and 2 b-tags selections.
- Z+jet: shape from MC, normalization from data (m_{jj} sidebands).
- No significant excess in the whole mass region.
- Observed (expected) exclusion in the mass region: $300<m_H<310$ GeV and $360<m_H<400$ GeV ($360<m_H<400$ GeV).

ATLAS-CONF-2012-017

$H \rightarrow WW \rightarrow l\nu q\bar{q}$



- One neutrino – full mass reconstruction possible.
- Separate analyses for H + 0, 1(ggF), 2 (VBF) jets.
- M(lν)=M(W) constraint for mass reconstruction.
- Backgrounds: W+jets, Z+jets, diboson,ttbar, etc.
- Backgrounds: from fit to the m(lνjj) spectrum. Shape taken from Monte Carlo studies, tested on m_{jj} sidebands.



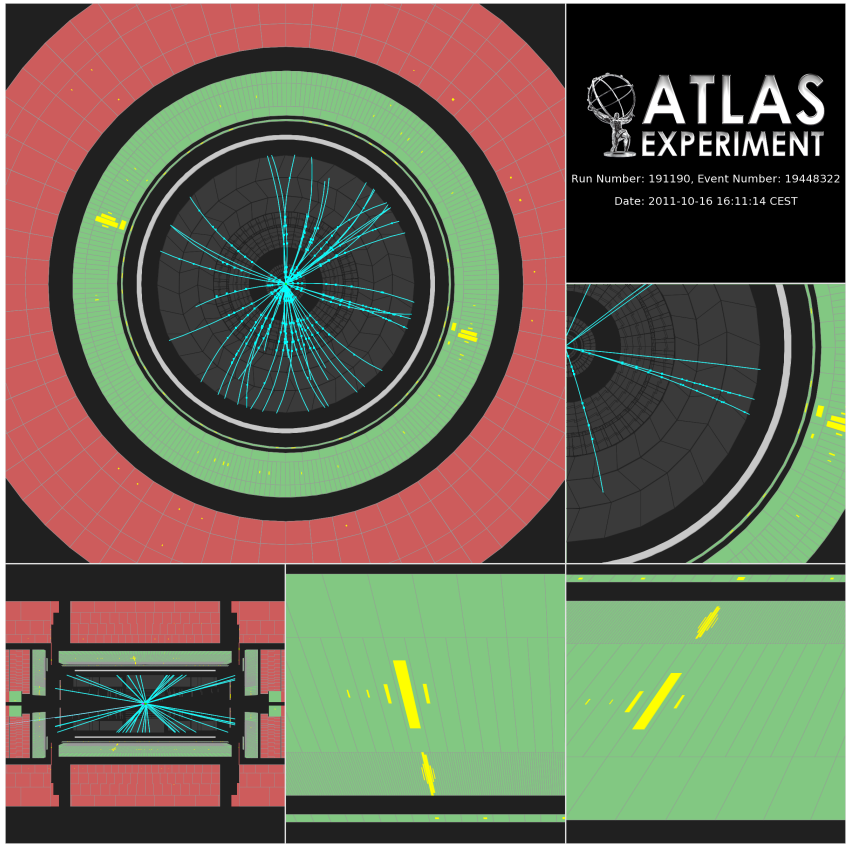
- No significant excesses in the full mass range.
- Best sensitivity obtained at 400 GeV for combination of H+0 and H+1 jet channels.
- Here an upper limit on the H->WW cross section of 2.6 pb (2.2×SM) is set. Expected: 2.2 pb (1.7×SM).

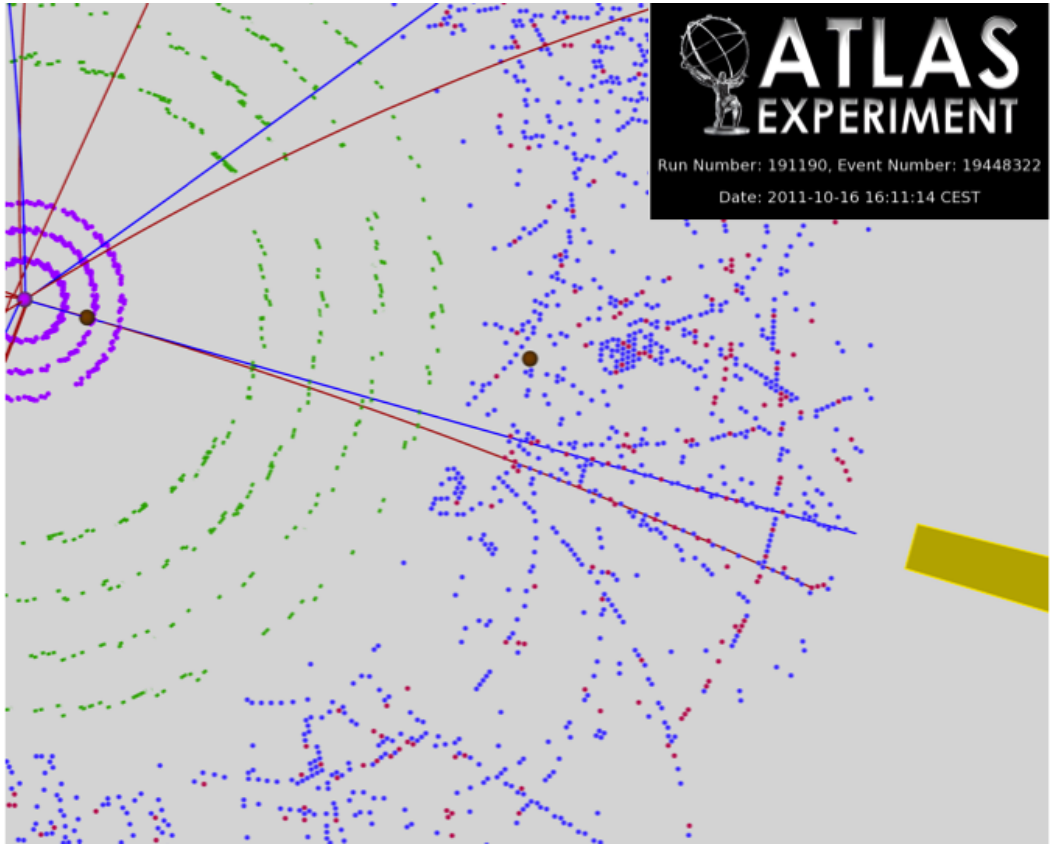
ATLAS-CONF-2012-018

Standard Model Higgs searches in the low mass region

$H \rightarrow \gamma\gamma$

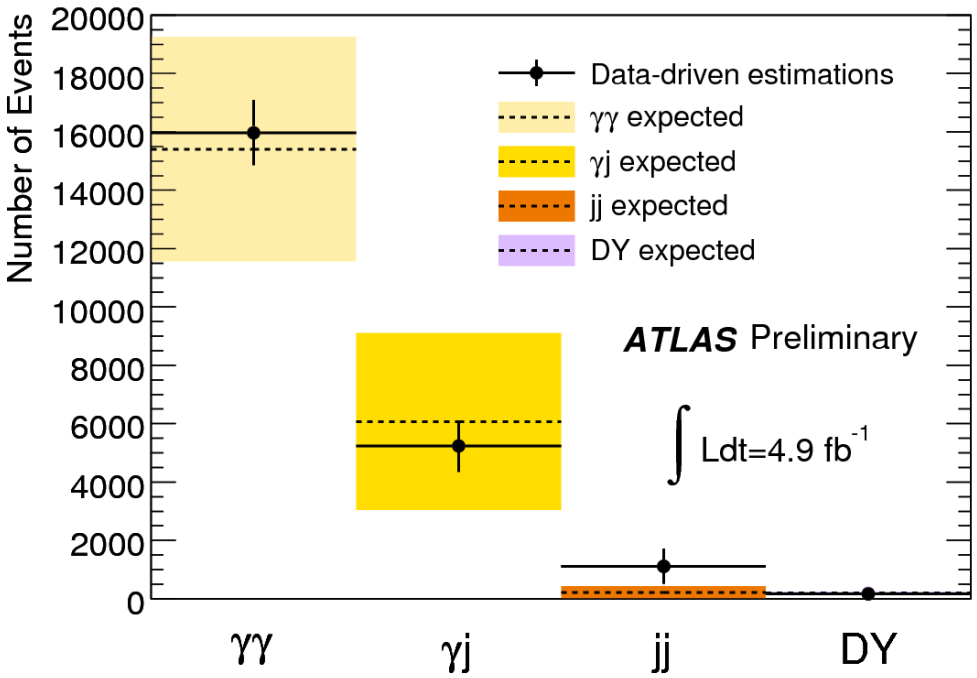
- Using 4.9 fb^{-1}.
- Separate analyses for 9 photon categories of resolution, defined according to η, (un)conversion status and di-photon momentum component transverse to thrust axis.
- $E_T(\gamma_1)$>40 GeV; $E_T(\gamma_2)$>25GeV.
- Calorimeter isolation of 5 GeV in ΔR<0.4 around reconstructed photons.





ATLAS-CONF-2011-161, arXiv:1202.1414

$H \rightarrow \gamma\gamma$

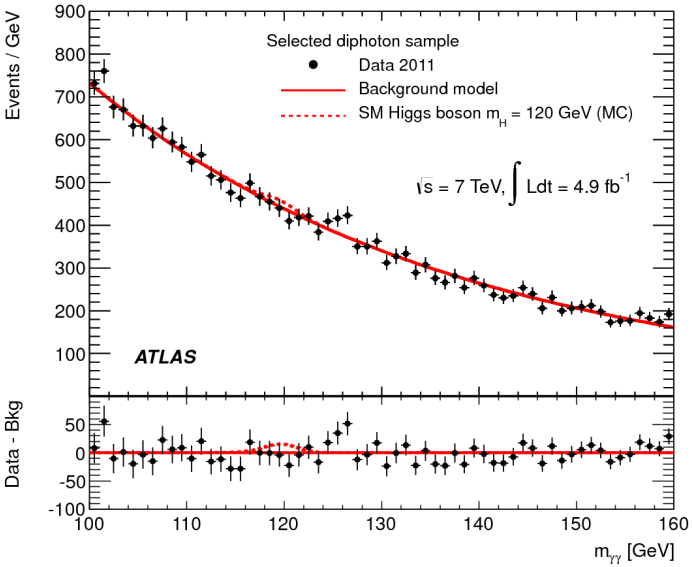


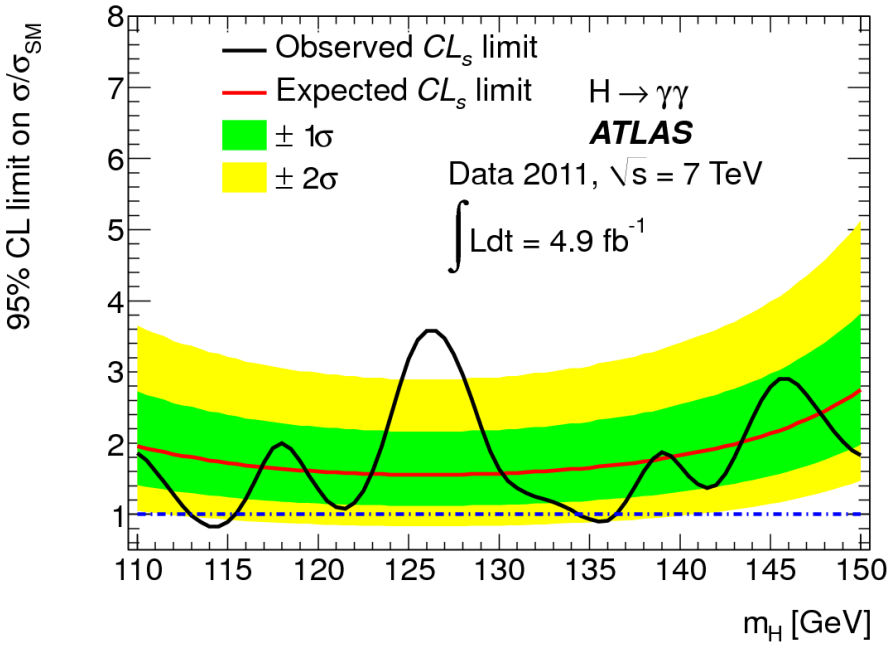
- Main backgrounds:
  - Irreducible γγ
  - Reducible jγ
  - Reducible jj
- Composition checked with control data: inverted photon isolation and ID criteria to estimate jet component.
- Di-photon purity: (71±5)%
- Event fractions are consistent between data-driven estimates and Monte Carlo.

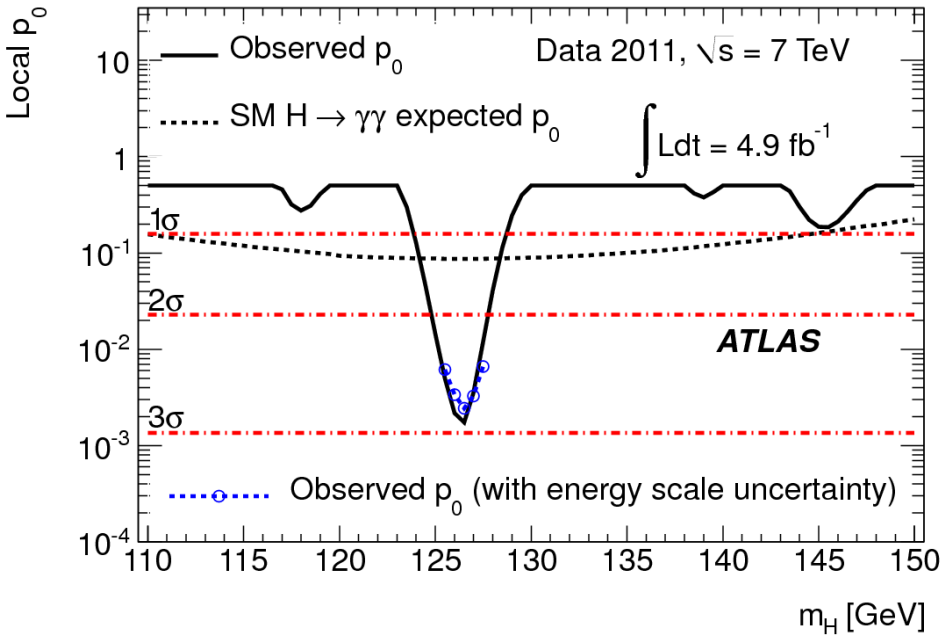
- Background estimated from the fit to the $m_{\gamma\gamma}$ distribution:
  - Simultaneous fit for all 9 categories.
  - Exponential model.

$H \rightarrow \gamma\gamma$

- Maximum deviation from background-only hypothesis at 126.5 GeV.
- Local significance 2.8 standard deviations.
- Global significance (look elsewhere effect accounted for): 1.5 standard deviations for m_H=110-150 GeV.
- Observed exclusion: 113-115 GeV and 134.5-136 GeV.
- Expected (observed) exclusion in the full mass range: between 1.6 and 2.7×σ_{SM} (0.83 and 3.6×σ_{SM}).

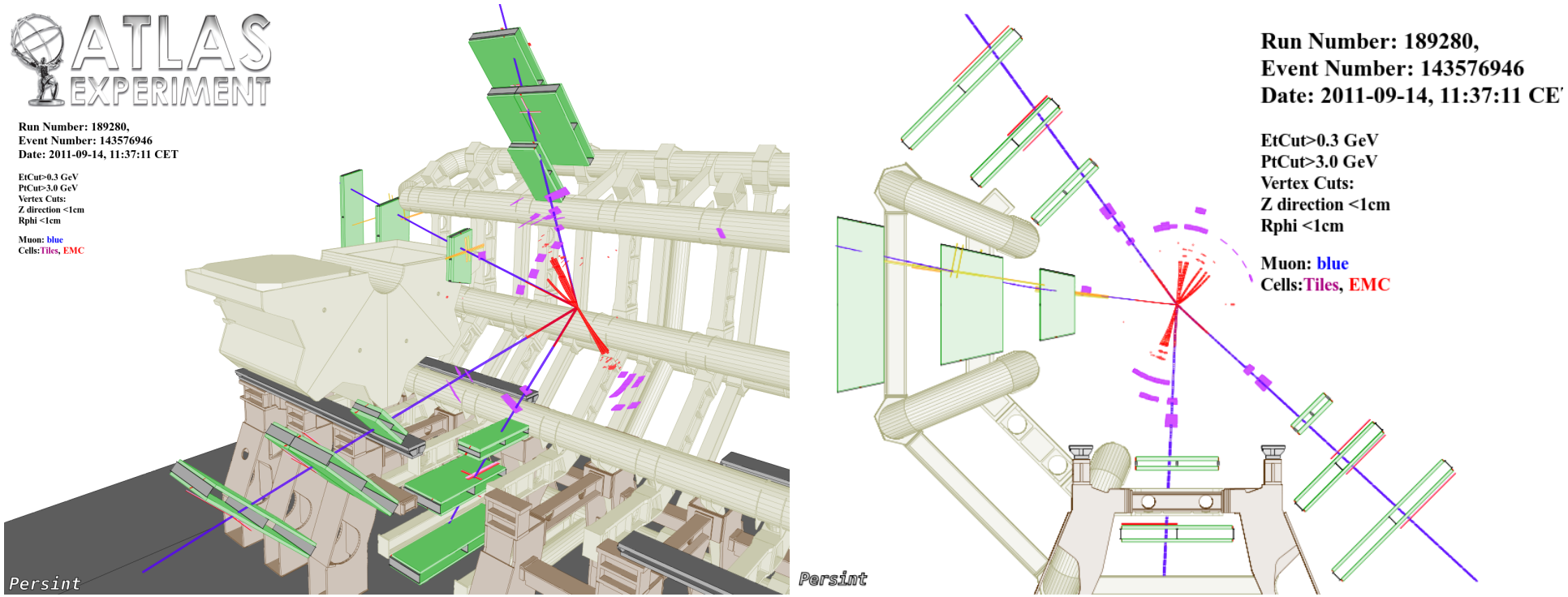






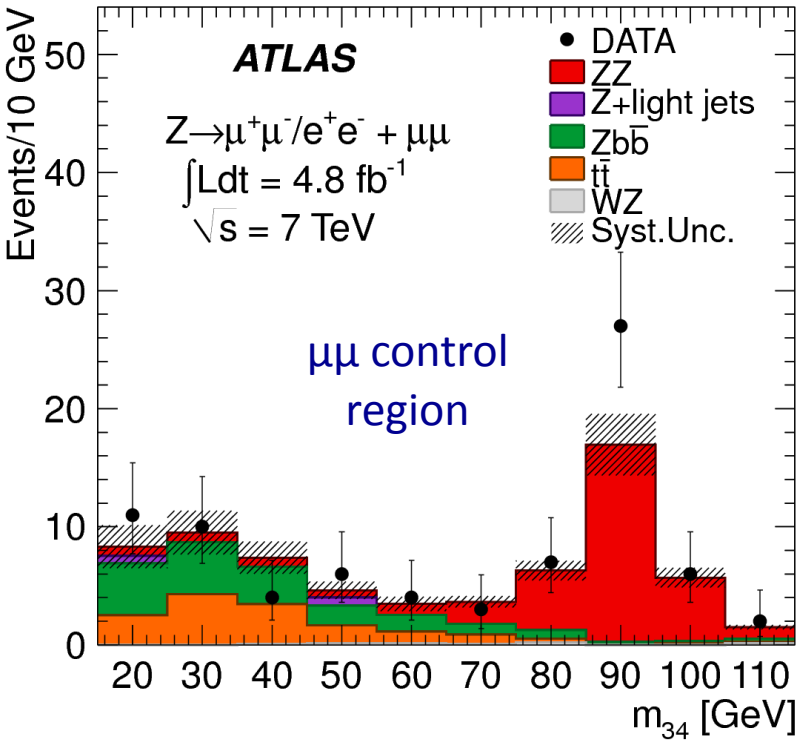
$H \rightarrow ZZ^{(*)} \rightarrow llll$

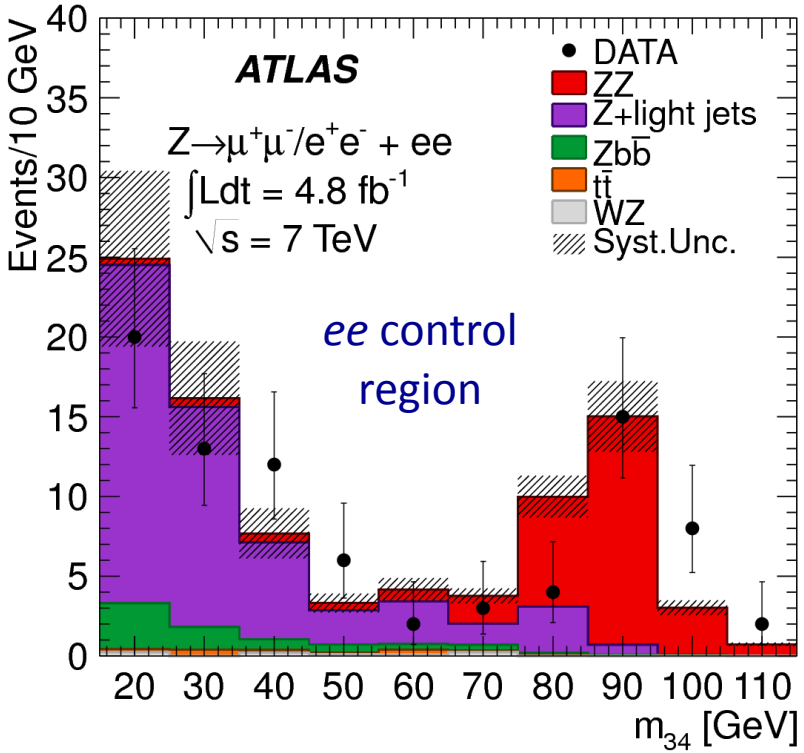
- Golden discovery channel: clean signature with low background.
- Four event categories: eeee, eeμμ, μμee, μμμμ.
- Search in the range 110 GeV to 600 GeV.
- Main backgrounds: ZZ (irreducible), tt, Zbb, Z+jets.



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

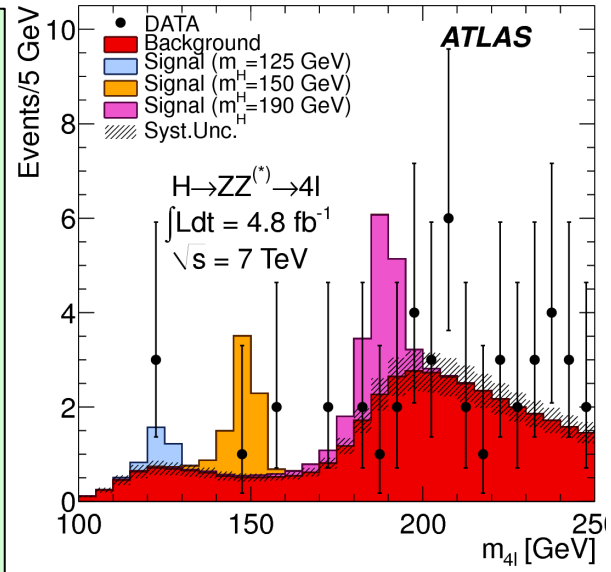
- Background estimation.
  - $ZZ^{(*)}$: from simulation.
  - Z+jets, Zbb: using control regions without applying the charge, isolation and impact parameter requirements on the second lepton pair.
  - ttbar: control region with opposite-sign electron-muon pairs consistent with the *Z* boson mass and two additional same-flavor leptons.

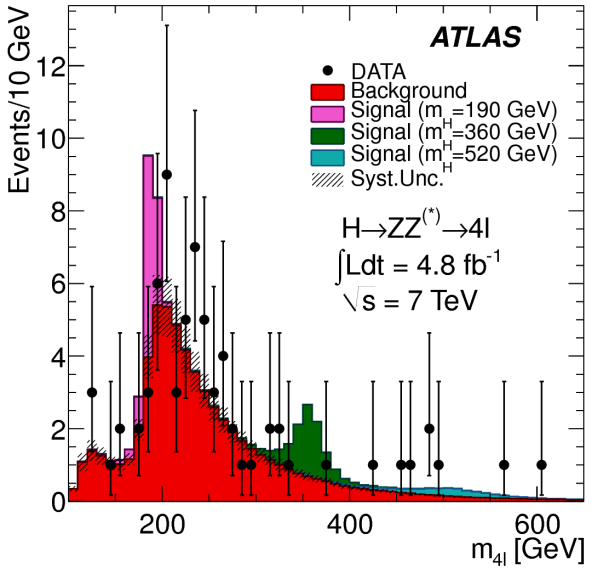


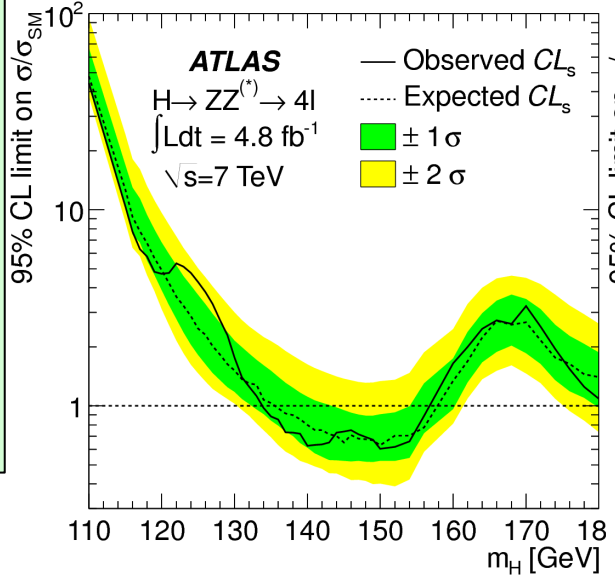


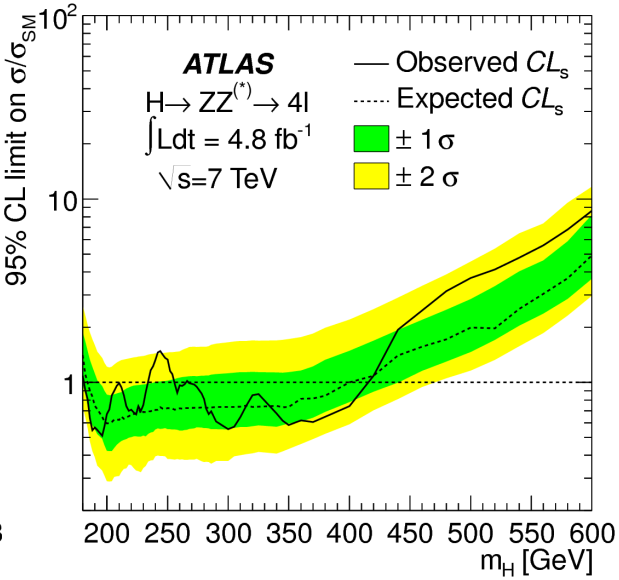
$H \rightarrow ZZ^{(*)} \rightarrow llll$

- Deviations from background expectation at: 125 , 244 and 500 GeV.
- Local significances: 2.1σ, 2.2σ, 2.1σ respectively.
- Observed exclusion:
  134 – 156 GeV,
  182 – 233 GeV,
  256 – 265 GeV and
  268 – 415 GeV.
- Expected exclusion:
  137 – 158 GeV
  and 185 – 400 GeV.



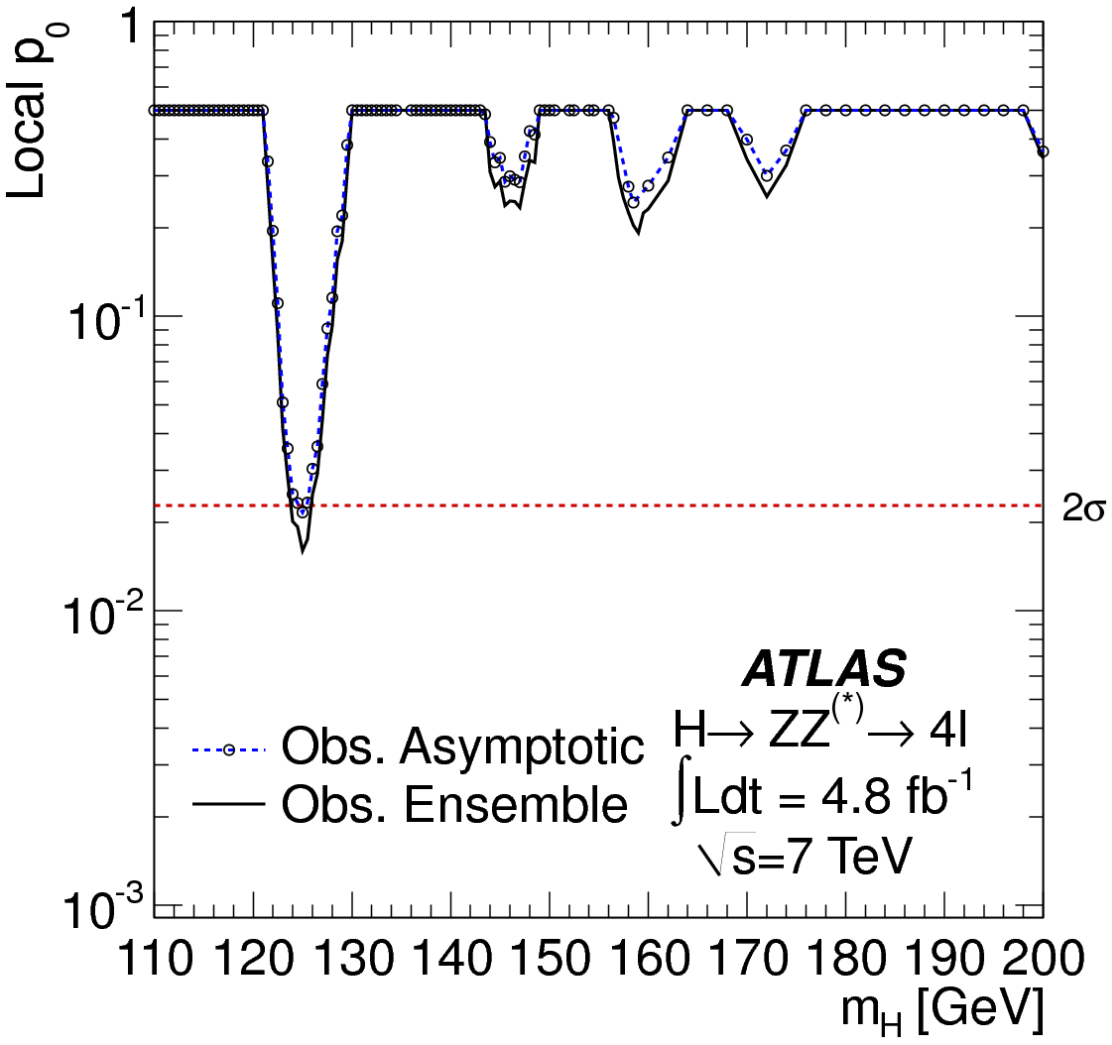






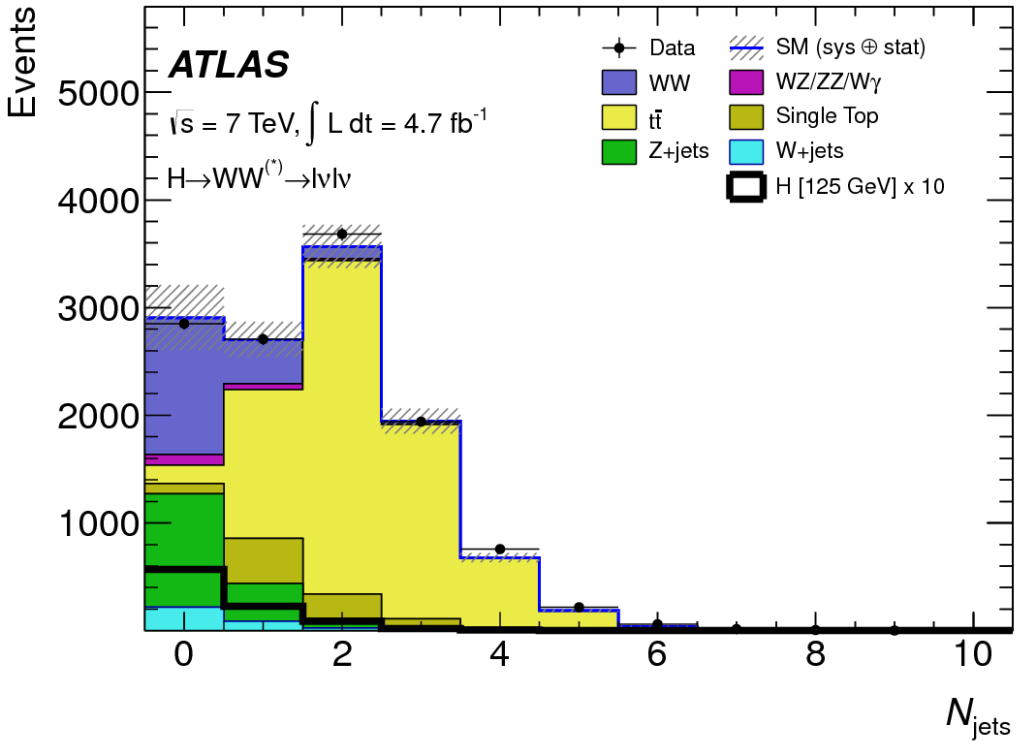
$H \rightarrow ZZ^{(*)} \rightarrow llll$

- p_0 values for observed excesses:
- m_H = 125 GeV: p_0 = 1.8%
- m_H = 244 GeV: p_0 = 1.1%
- m_H = 500 GeV: p_0=1.4%.
- Once the look-elsewhere effect is considered, none of these excesses is significant by itself.



$H \rightarrow WW \rightarrow l\nu l\nu$

- Sensitive in the range 110 GeV to 600 GeV
- Most sensitive in the range 120 GeV to 180 GeV.
- Three channels are combined: $\mu\nu_\mu\mu\nu_\mu$, $e\nu_e\mu\nu_\mu$, $e\nu_e e\nu_e$.
- Uses m_T as discriminating variable: full mass reconstruction is not possible.
- Analysis: 2 oppositely charged leptons, MET, Z-veto, m_{ll} and $\Delta\phi_{ll}$ cuts.
- Jet multiplicity: 0,1,2 (VBF): different background compositions and cuts.

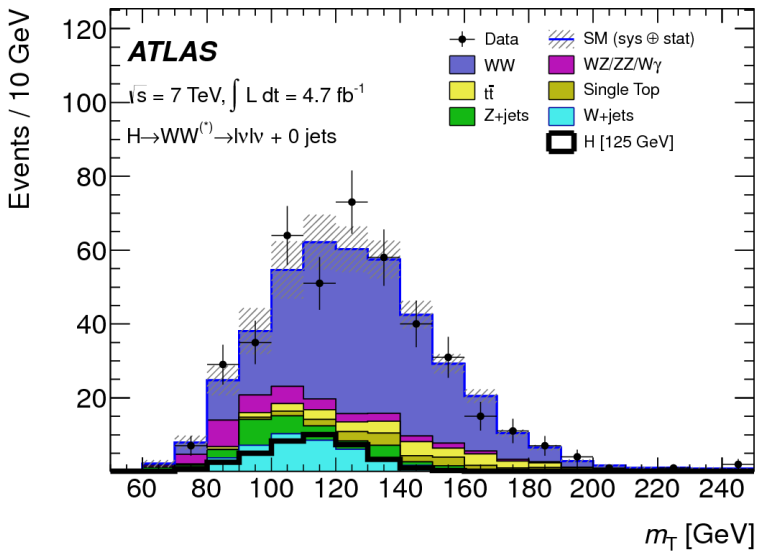


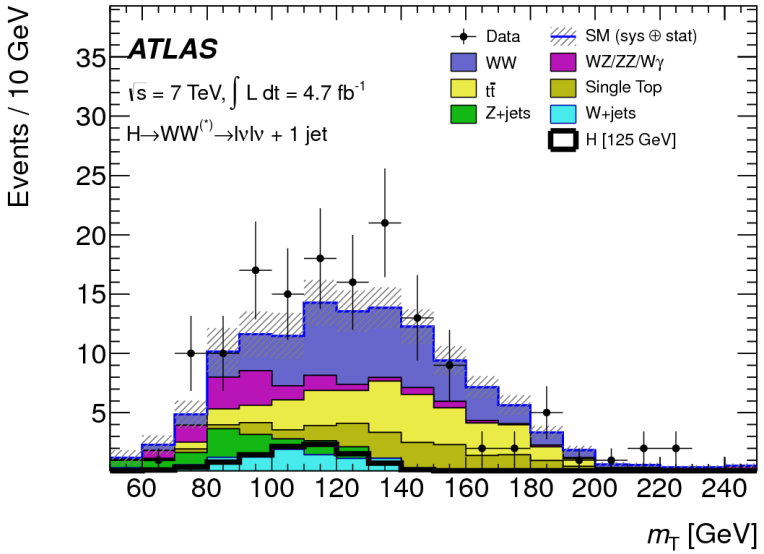
- Backgrounds (0 an1 jet):
  - WW, top: MC prediction normalized to control region. WW: Removed $\Delta\phi_{ll}$ cut, modified m_{ll} cut. Top: 0-jet case-pre-selection, 1 and 2 jet cases – removing b-tag veto and m_{ll} and $\Delta\phi_{ll}$ requirements.
  - Z + jets: control region ($\Delta\phi_{ll}$).
  - W + jets: control region – inverted lepton isolation.
- Backgrounds (2 jets):
  - WW: MC prediction.

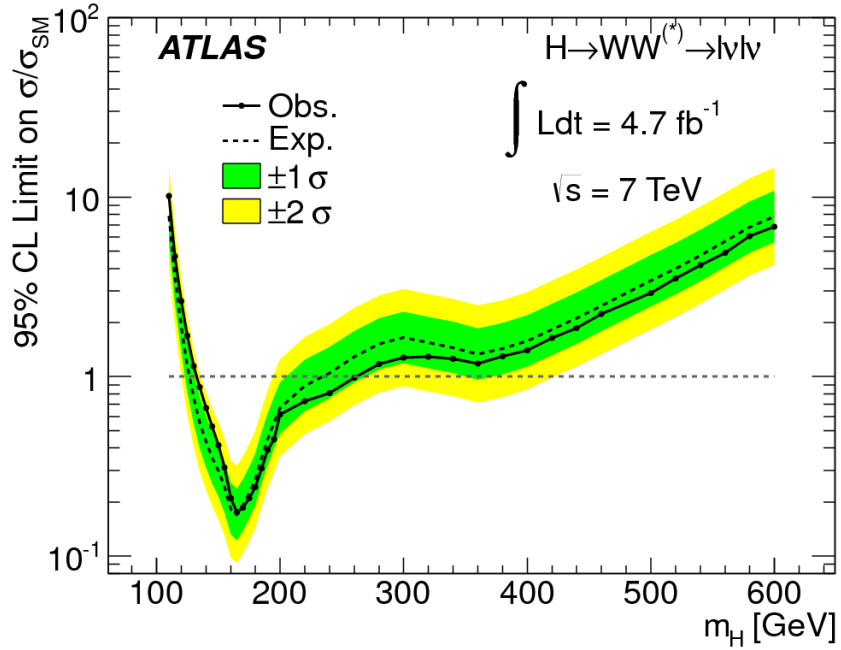
arXiv:1206.0756

$H \rightarrow WW \rightarrow l\nu l\nu$

Low mass selection:
m_H<200 GeV



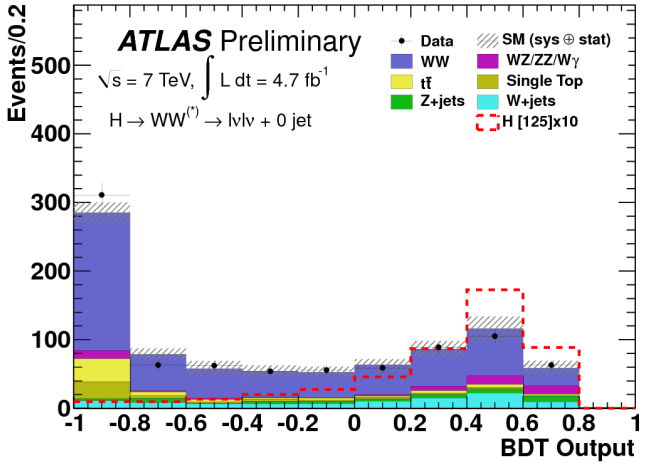


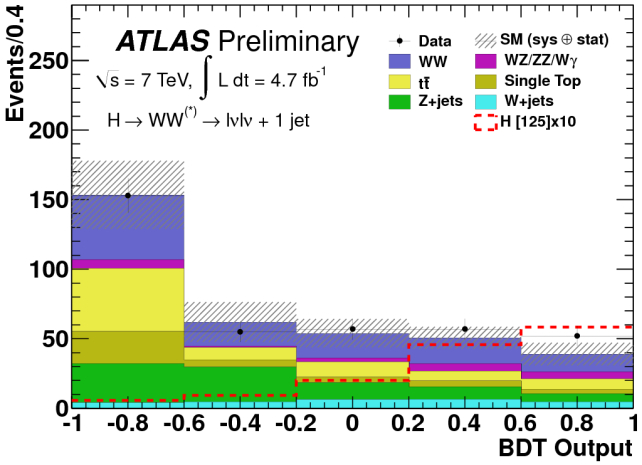


- No significant excess observed in the whole mass region.
- Observed exclusion: $133 < m_H < 261$ GeV.
- Expected exclusion: $127 < m_H < 233$ GeV.

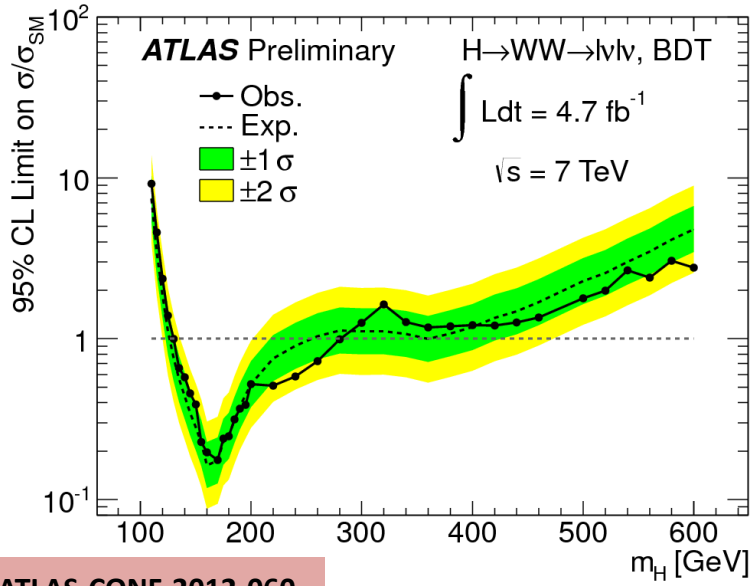
$H \rightarrow WW \rightarrow l\nu l\nu$

- First ATLAS Higgs analysis using multivariate techniques. Matrix Element and Boosted Decision Tree (BDT) used. BDT trained on four kinematic variables: m_{ll}, p_T^{ll}, m_T, $\Delta\phi_{ll}$.





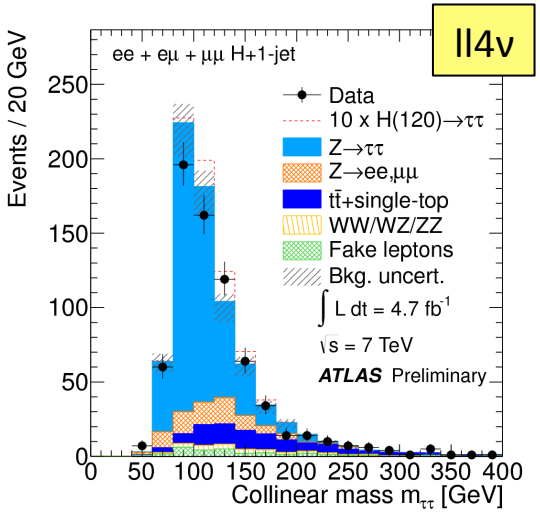
BDT output weight distributions for Higgs signal and background events satisfying all selection criteria in the 0-jet and 1-jet channel. m_H=125GeV.

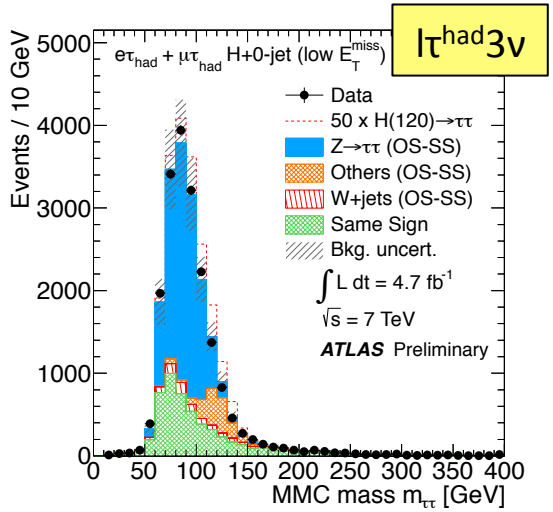


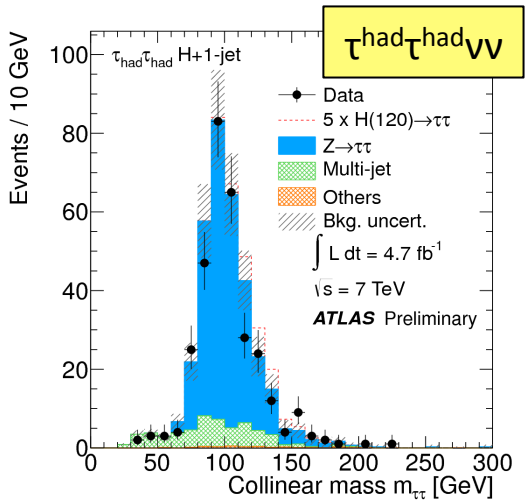
- No significant excess observed in the whole mass region.
- Observed exclusion: $130 < m_H < 281$ GeV.
- Expected exclusion: $127 < m_H < 255$ GeV.

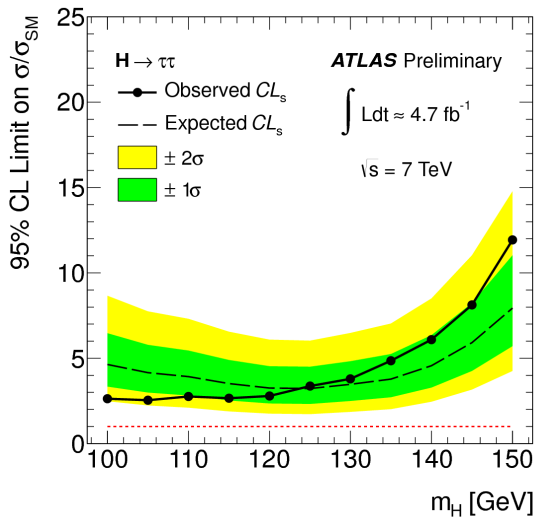
ATLAS-CONF-2012-060

$H \rightarrow \tau\tau$





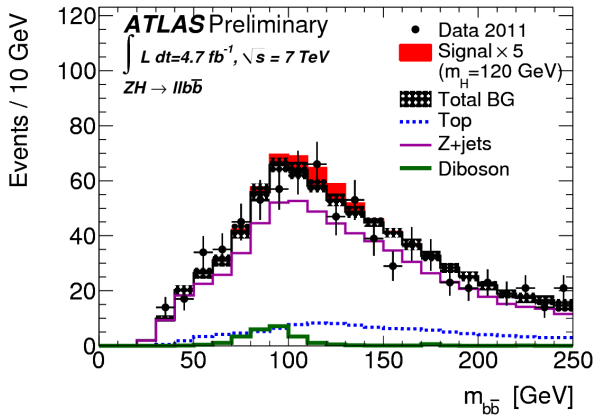


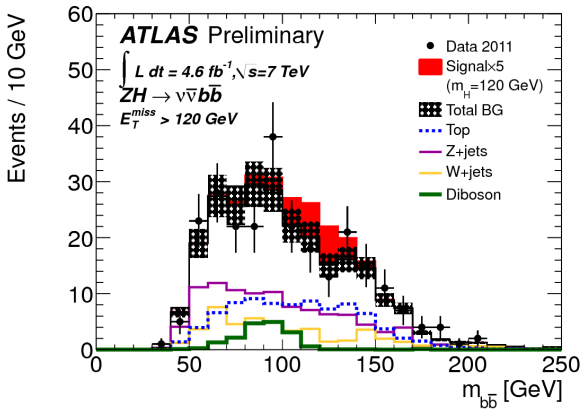


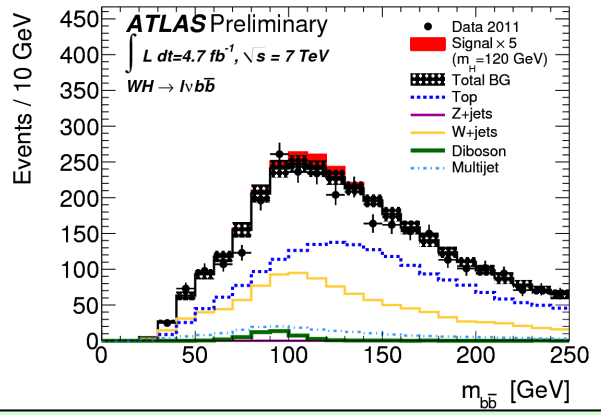
- Searches in $H \rightarrow \tau^+\tau^- \rightarrow ll4\nu$, $l\tau^{had}3\nu$ and $\tau^{had}\tau^{had}\nu\nu$ channels.
- Using jets to enhance the S/B separation: categorized to 0,1-jet (VH) and 2jet (VBF) channels.
- $H \rightarrow \tau\tau \rightarrow ll4\nu$: collinear mass approximation in the 1 and 2 jet channels, effective mass for 0 jets.
- $H \rightarrow \tau\tau \rightarrow l\tau^{had}3\nu$: missing mass calculator.
- $H \rightarrow \tau\tau \rightarrow \tau^{had}\tau^{had}\,2\nu$: collinear mass approximation.
- No significant excesses are seen in the combined full mass range.
- Expected (observed) upper limits: 2.5 (3.2) and 11.9 (7.9)×σ_{SM}.

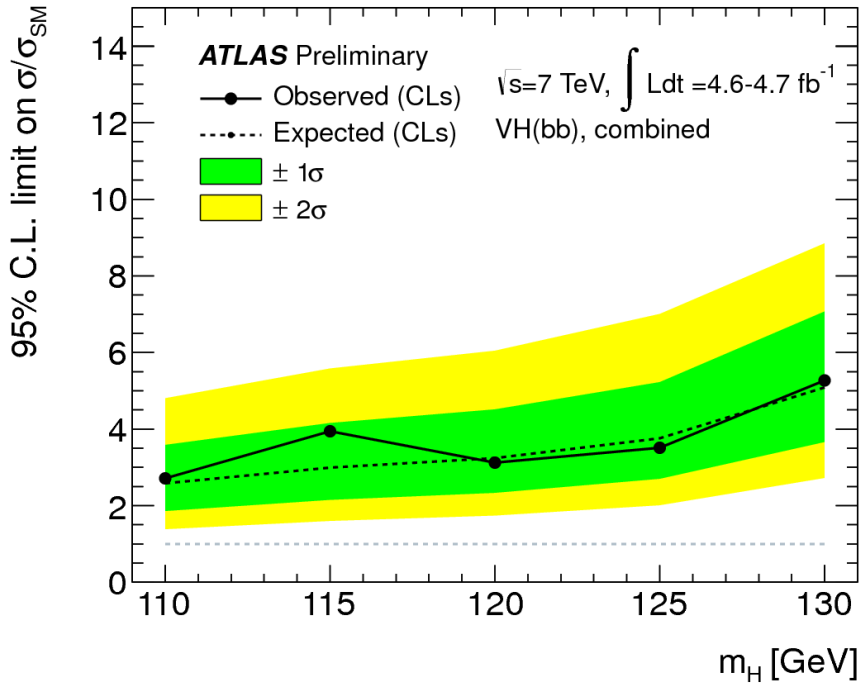
ATLAS-CONF-2012-014

$(W/Z)H \rightarrow b\bar{b}$







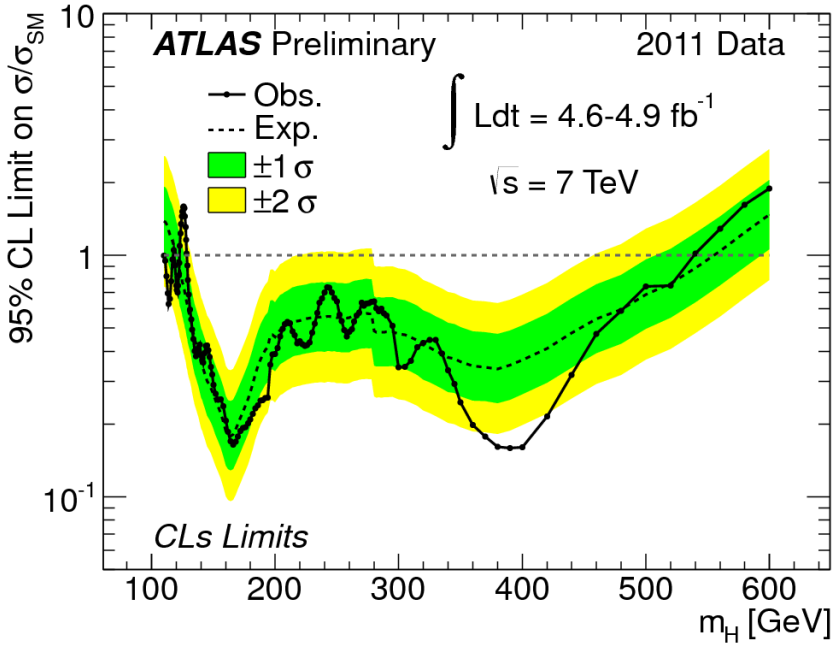


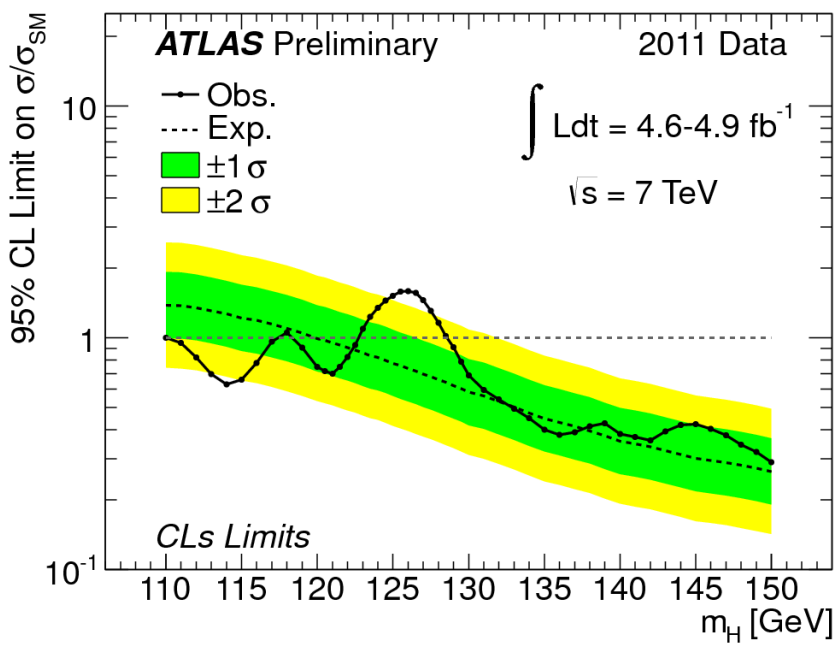
- Exactly 2 b-tagged jets.
- Discriminating on m_{bb} variable.
- *ZH → llbb, ZH → vvbb, WH → lvbb*
- Higgs production channel in association with a leptonicaly decaying vector boson.
- No significant excess in the whole range.
- The observed (expected) upper limits on Higgs boson production: 2.7 (2.6) to 5.3 (5.1) times the Standard Model cross section (110 and 130 GeV).

ATLAS-CONF-2012-015

Standard Model Combination

- The individual Standard Model Higgs search channels are combined.
- Expected exclusion range in the absence of signal: 120 to 555 GeV.
- Observed exclusion for the Standard Model Higgs at 95% CL: 110.0 GeV to 117.5 GeV, 118.5 GeV to 122.5 GeV, and 129 GeV to 539 GeV.
- Observed exclusion at 99% CL: 130 GeV to 486 GeV.
- An excess is observed around m_H~126 GeV with a local significance of 2.5σ.

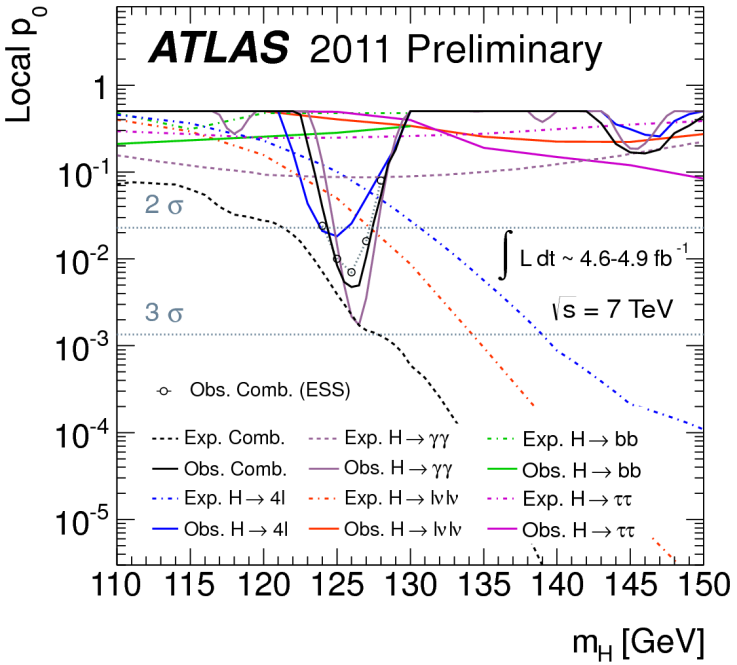


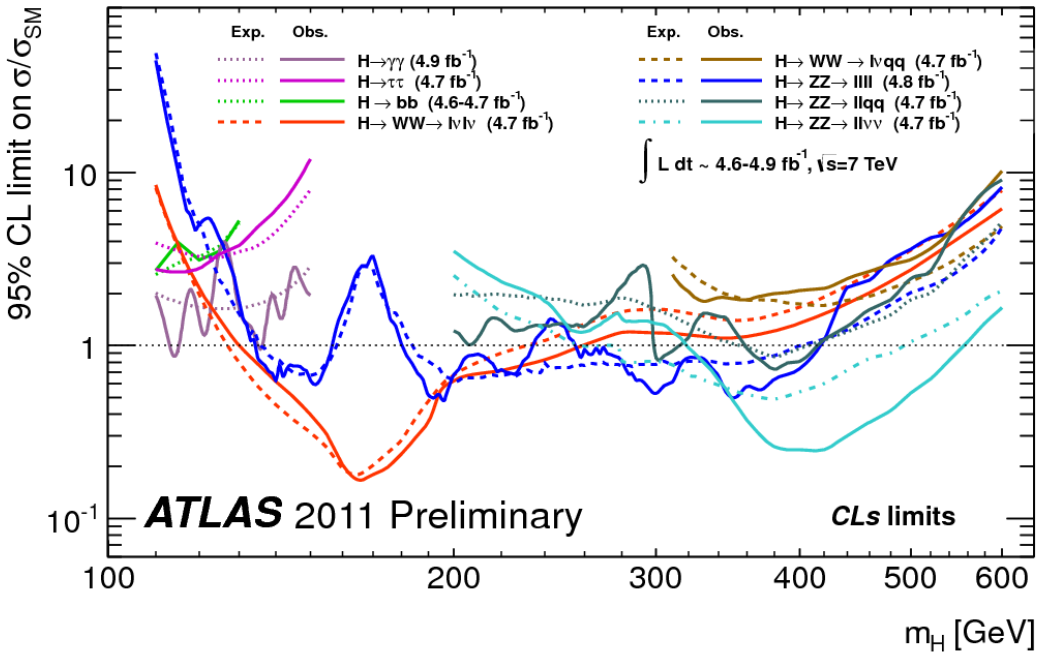


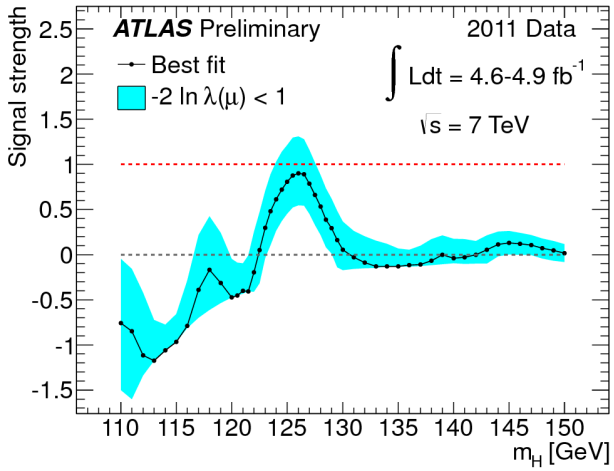
ATLAS-CONF-2012-019

SM Combination

- An excess at m_H~126 GeV: local significance of 2.5σ.
- Expected significance for SM Higgs boson for that mass hypothesis: 2.9σ.
- The global probability for such an excess in mass range 110-600 GeV: 30%.
- For 110-146 GeV range: 10%.



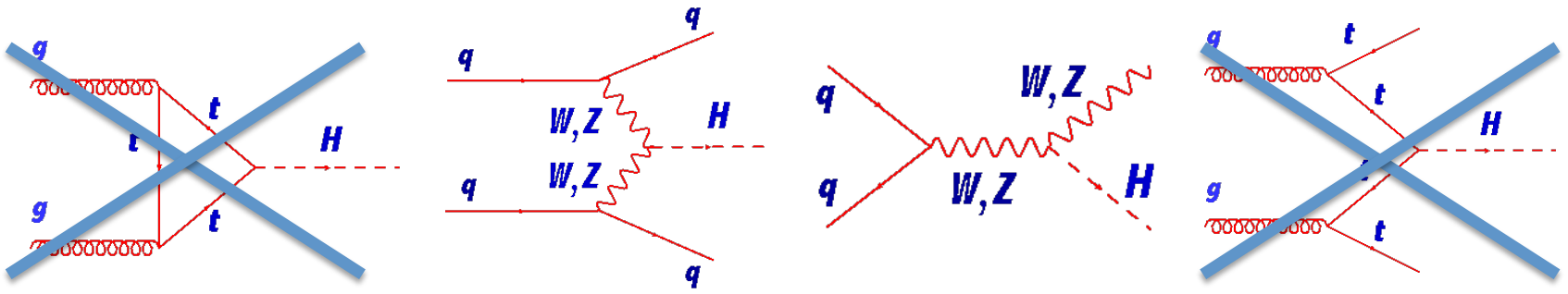




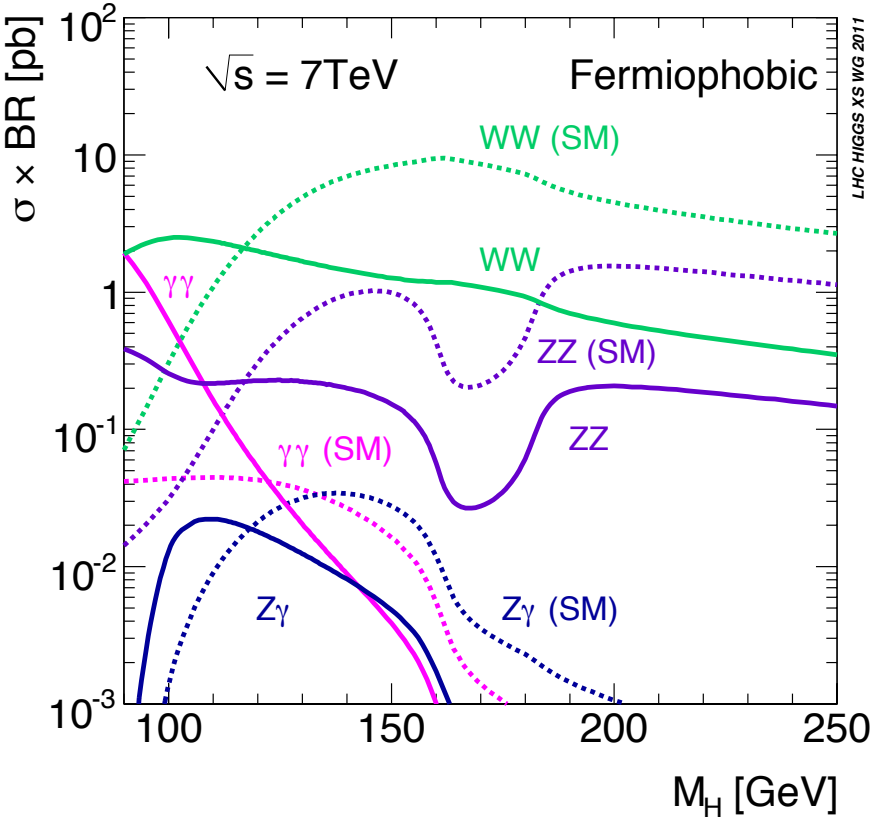
Beyond the Standard Model Higgs searches

- Fermiophobic Higgs to two photons.
- MSSM Neutral Higgses.
- MSSM Charged Higgses.

Fermiophobic Higgs

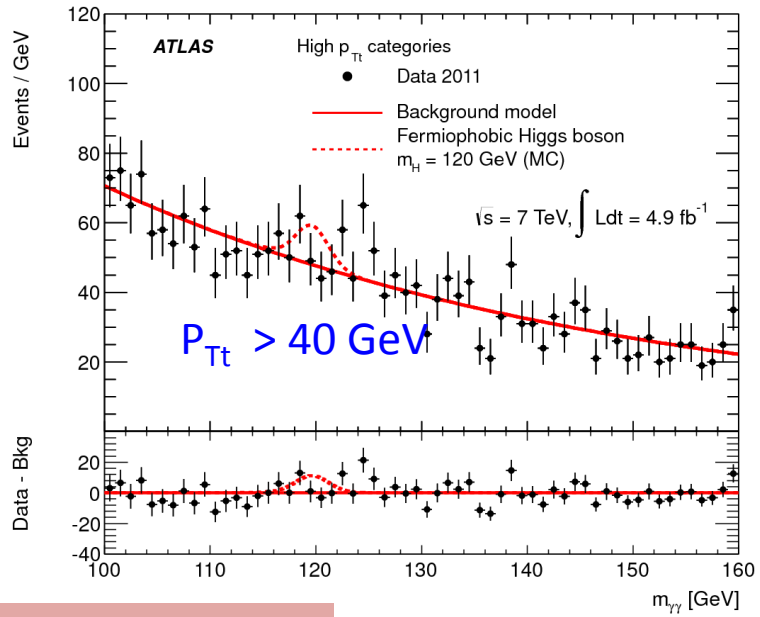


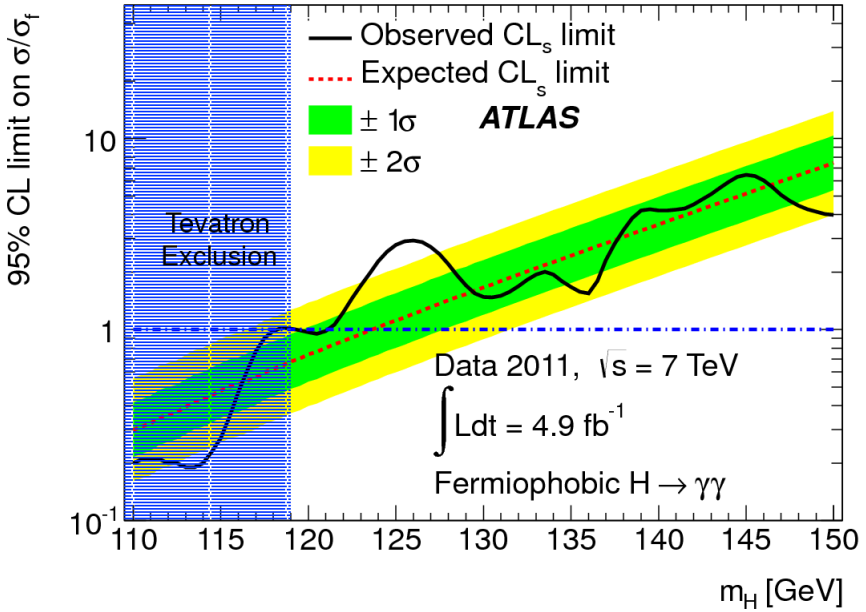
- Decreased couplings to some or all fermions in two Higgs doublet and triplet models.
- Production: Vector Boson Fusion or associated production (VH).
- Decays: WW, ZZ, Zγ, γγ.
- Excluded below 119 GeV by LEP and Tevatron.



Fermiophobic $H \rightarrow \gamma\gamma$

- 4.9 fb^{-1}. Benchmark model: all Higgs-fermion couplings are set to 0; SM values kept for boson couplings.
- Same analysis as for the Standard Model Higgs di-photon searches: 9 event categories + separate treatment for high and low P_{Tt}.
- Signal model: Crystal Ball + Gaussian.
- Expected exclusion: 110 – 123.5 GeV; Observed exclusion: 110 – 118.0 GeV and 119.5 – 121 GeV.
- Largest excess: at 125.5 GeV, with a local significance of 2.9 σ (1.6 σ accounting for look elsewhere effect).



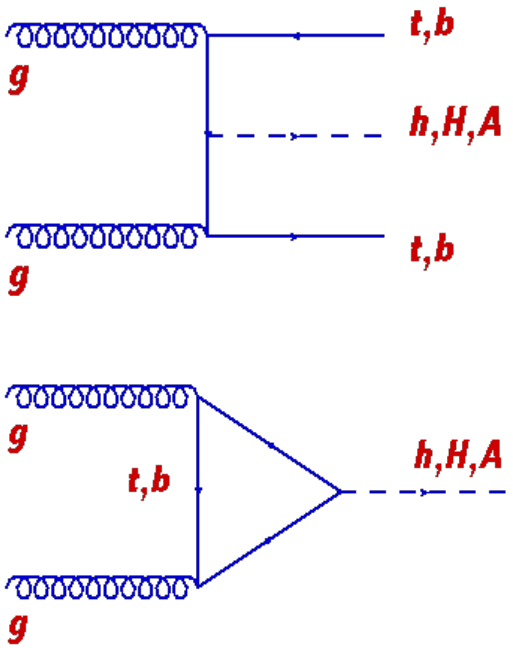


ATLAS-CONF-2012-013

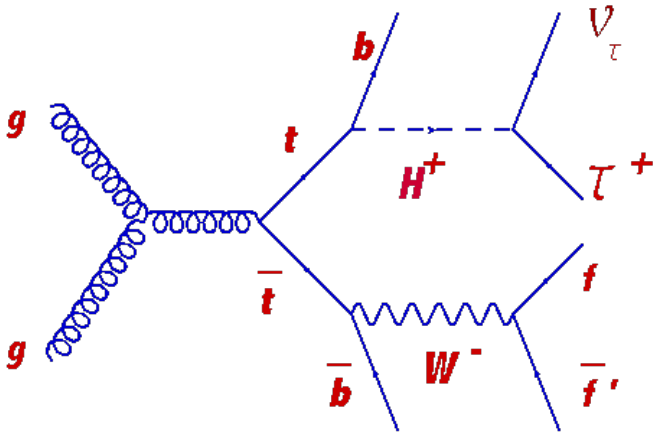
MSSM Higgses

- Minimal Supersymmetric extension of the Standard Model.
- Two Higgs doublets; 5 physical Higgs bosons: H,h,A,$H^{\pm}$
- Free parameters at tree level: m_A, $\tan\beta = v_u/v_d$
- SM Higgs (m_H>140 GeV): WW and ZZ are dominant decays.
- MSSM Higgs: enhanced couplings to 3d generation down-type fermions.

Neutral

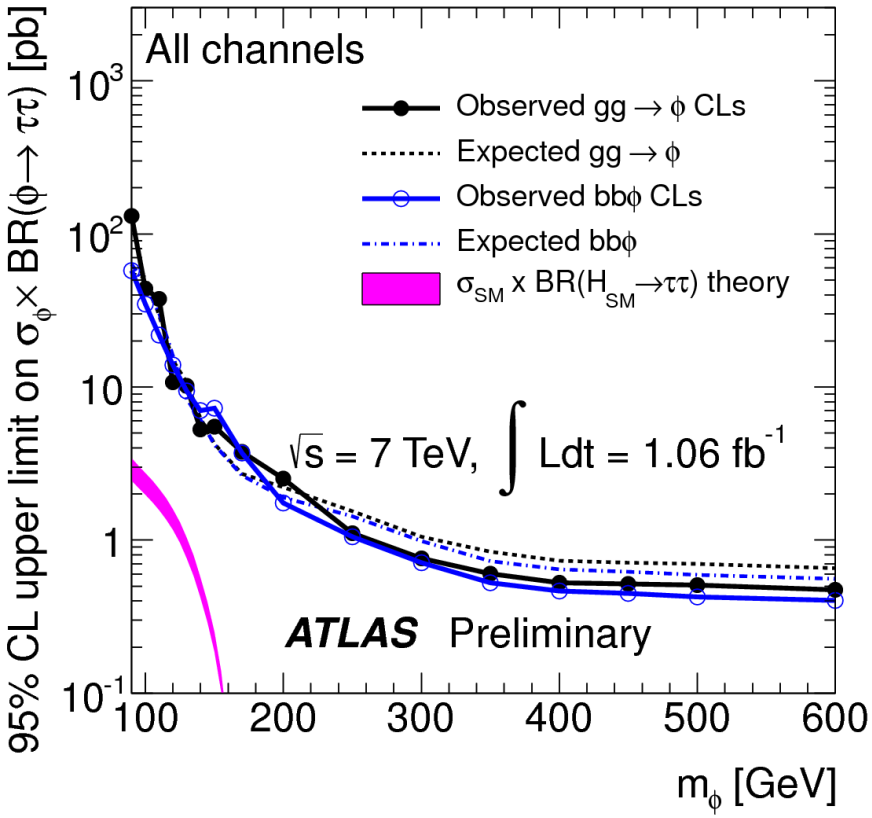


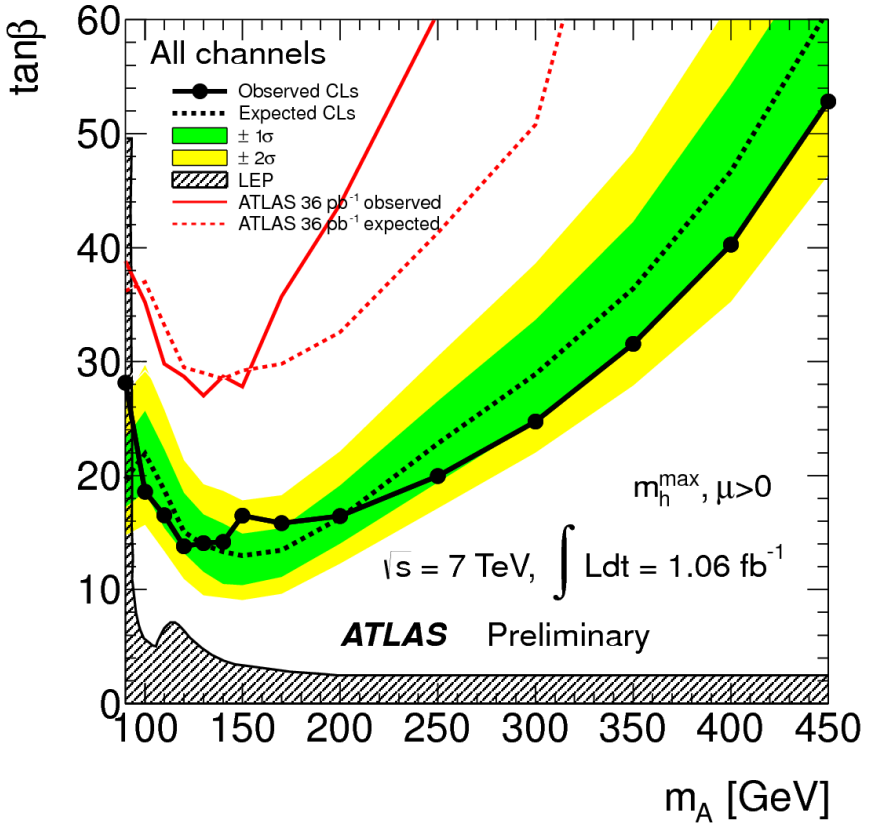
Charged



Neutral MSSM Higgs searches

- Searches in the ττ decay mode. (1.06 fb^{-1})
- *eμ4ν, eτ$_{had}$3ν,* μτ$_{had}$3ν, and τ$_{had}$τ$_{had}$2ν final states are considered.
- Similar to the SM search, effective mass for ll searches, MMC for lτ$_{had}$ searches, visible mass for τ$_{had}$τ$_{had}$ used.
- Backgrounds – mostly data-driven methods.



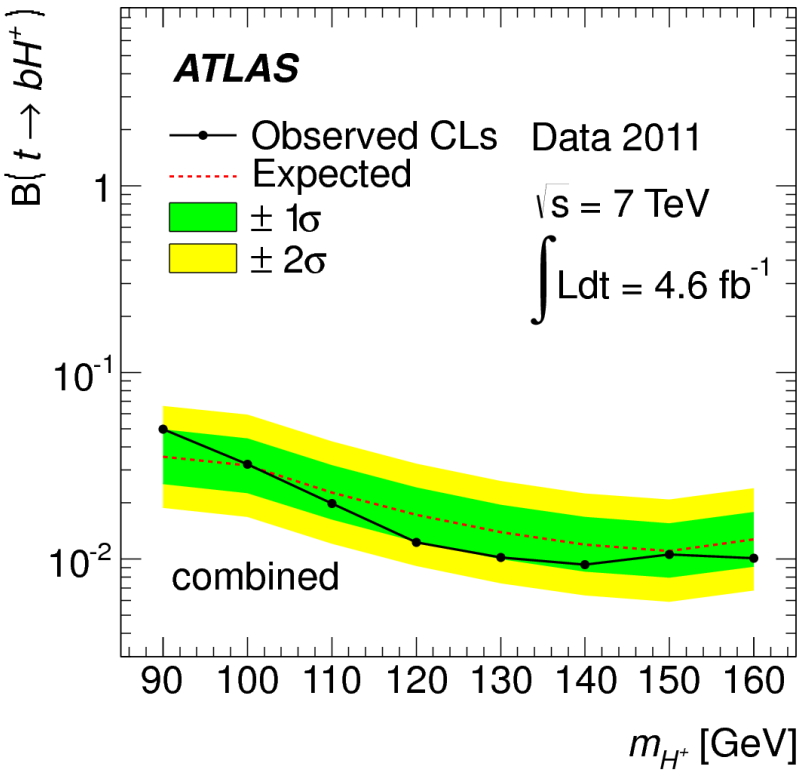


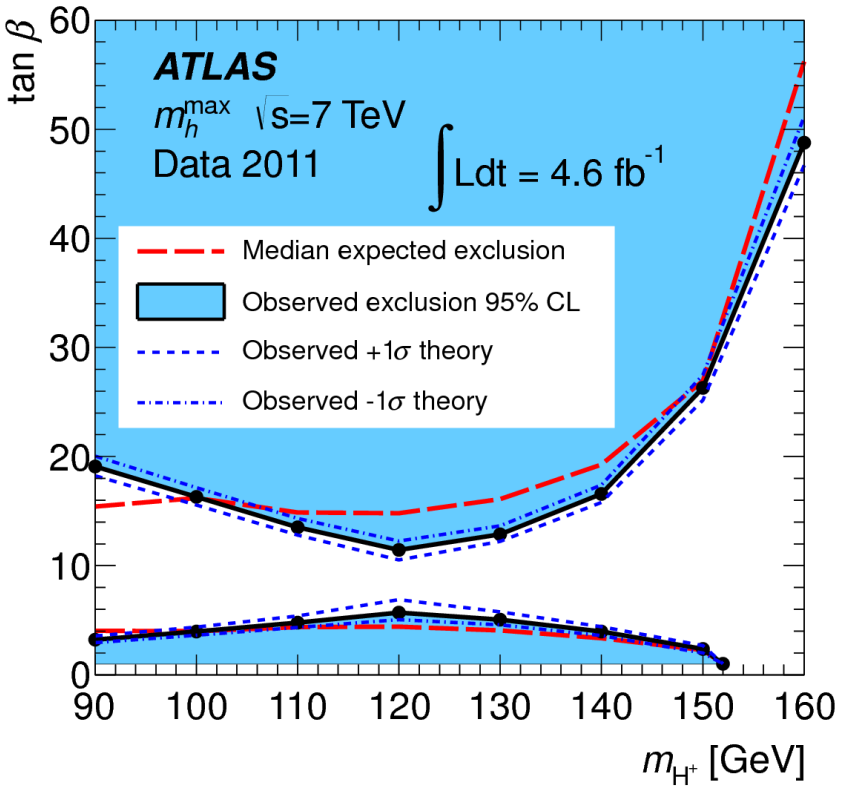
ATLAS-CONF-2011-132

Charged MSSM Higgs searches

ATLAS-CONF-2012-011 arXiv:1204.2760

- Searches in the $\tau^+\nu$ decay mode. (4.6 fb^{-1}). Selecting $t\bar{t}$ events with τ lepton in the final state. Considering both hadronic and leptonic τ decays.
  - lepton+jets: $t\bar{t} \rightarrow bb\,W\,H^+ \rightarrow bb\,(qq)\,(\tau_{lep}\nu)$,
  - τ+lepton: $t\bar{t} \rightarrow bb\,W\,H^+ \rightarrow b\,b\,(l\nu)\,(\tau_{had}\nu)$,
  - τ+jets: $t\bar{t} \rightarrow bb\,W\,H^+ \rightarrow bb\,(qq)\,(\tau_{had}\nu)$.
- Special set of discriminating variables for each final state.
- Main backgrounds: $t\bar{t}$(Monte Carlo), Z/γ+jets, W+jets, multijet (data-driven).





Summary

- In the year 2011 ATLAS was searching for the Higgs boson in variety of final states. Both Standard Model and beyond hypotheses are tested.

- Standard Model
  - Searches in several channels with 4.7 fb^{-1} to 4.9 fb^{-1}.
  - Few individual excesses observed in 2 photon, 4 leptons final states.
  - The overall combination of search channels is performed.
  - Expected exclusion range in the absence of signal: 120 GeV to 555 GeV.
  - Observed exclusion for the Standard Model Higgs at 95% CL: 110.0 GeV to 117.5 GeV, 118.5 GeV to 122.5 GeV, and 129 GeV to 539 GeV.
  - An excess is observed around m_H~126 GeV with a local significance of 2.5σ.

- Beyond the Standard Model
  - Searches in several models including fermiophobic and MSSM Higgses.
  - In fermiophobic model, a small excess is observed at the same place as in the Standard Model search.
  - Neutral and charged MSSM Higgses were searched for in channels containing τ leptons in the final state. Upper limits on their production cross-section are set.

Backup

Backup