Higgs at ATLAS

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III CPAN days
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Outline

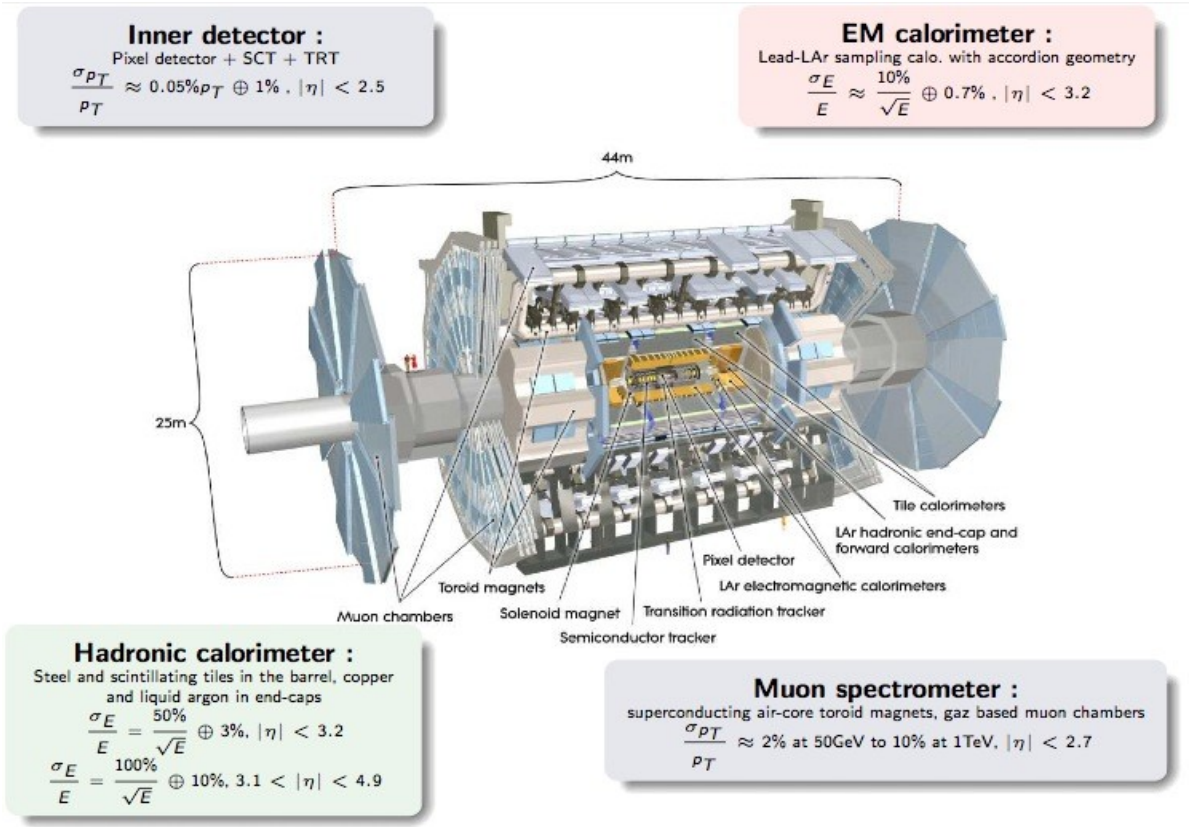
LHC and ATLAS

Individual SM Higgs searches:

- H→ γγ
- H→ bb
- H→ ττ
- H→ WW(lνlν, lνqq)
- H→ ZZ(4l, 2l2ν, 2l2q)

Combined limits

Conclusions



LHC and ATLAS

- Very successful operation in 2011!

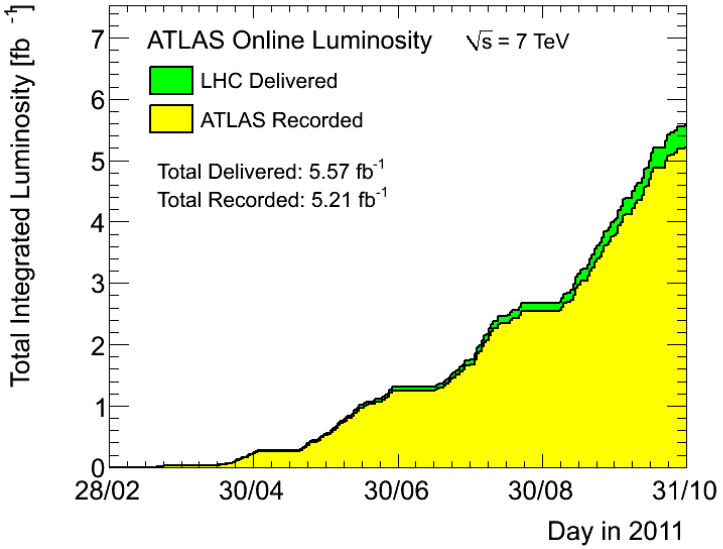
- LHC delivered **5.2 fb^{-1}** at $\sqrt{s} = 7$ TeV during 2011:
  - Peak luminosity **3.65 x 10^{33} cm^{2} s^{-1}**
  - Pile-Up effect is a "challenge" for extracting physics!

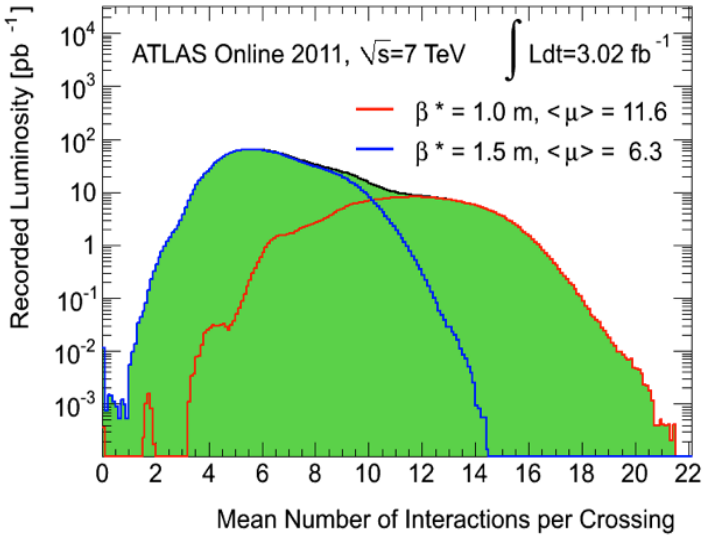
<#evts/bunch collision> from 6 to 12 (after EPS), depending on LHC conditions. Progress understanding impact on performance, with data & simulation.

  - Continue run until end of 2012 before long shutdown to prepare for higher energies.

- ATLAS recorded more than 93% of LHC delivered luminosity during stable beams (yellow).
  - Efficiency accounts for turn off of the sensitive detector to allow a beam dump or beam studies

Already analyzed 2.3 fb^{-1}





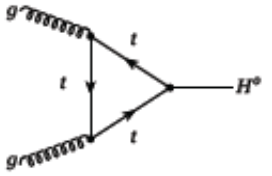
Higgs boson production

Searches for a Standard Model Higgs Boson

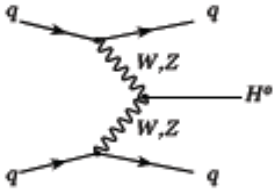
First item of the ATLAS physics program in 2011-2012 run:

Discovery or exclusion of the Standard Model Higgs Boson in the full allowed mass range.

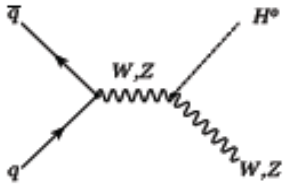
Gluon Fusion
gg→H (dominant)

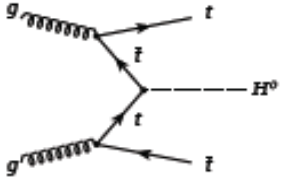


Vector Boson Fusion
qq'→ qq'H (less suppressed at higher M_H)

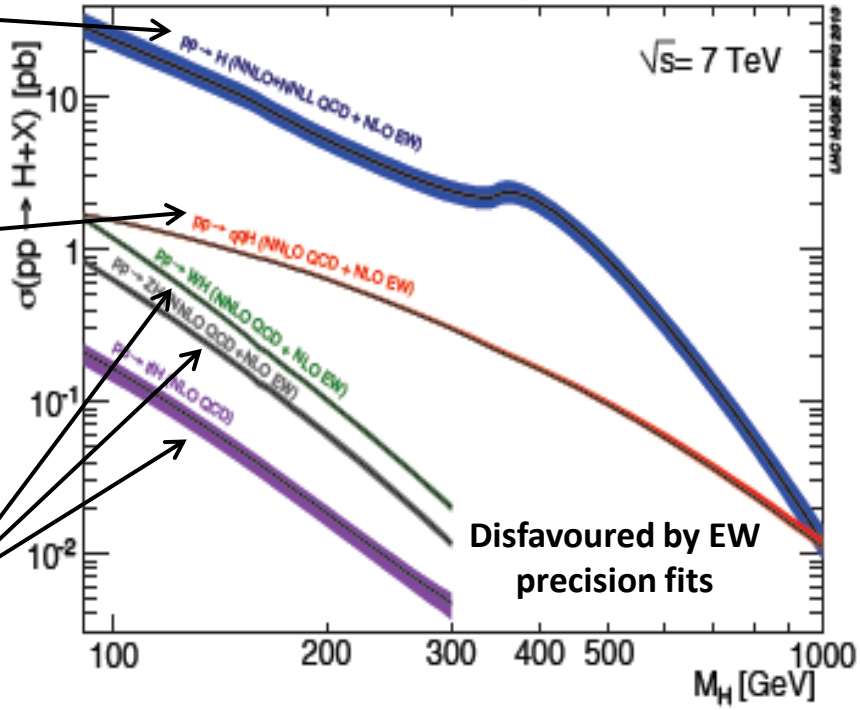


Associated production qq/gg→WH/ZH/ttH
(ttH contribute to H→bb,γγ)





CERN-2011-02; arXiv:1101.0593



Gluon-gluon fusion is the most abundant production channel, but **VBF** and **associated production** can be experimentally more favourable in specific cases.

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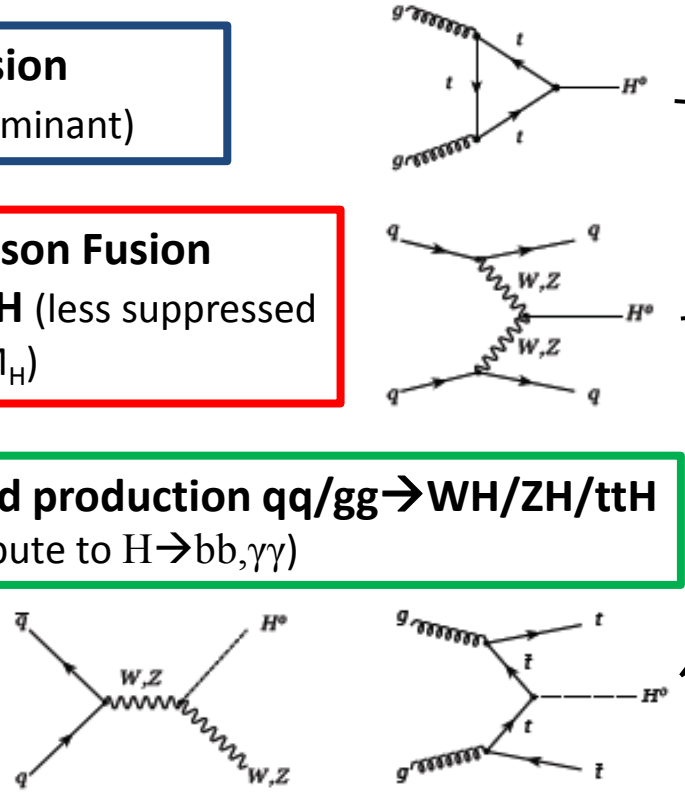

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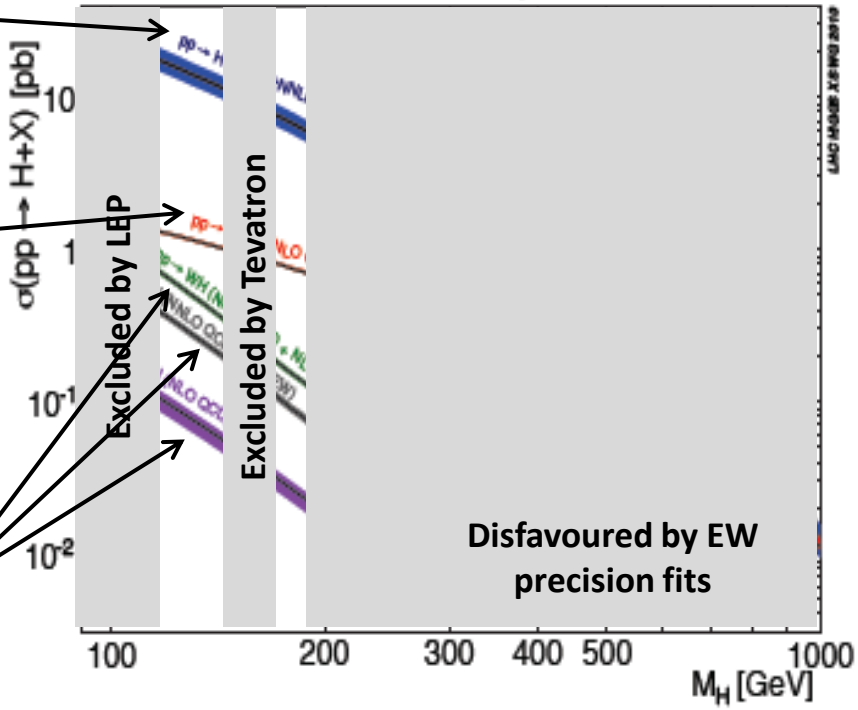
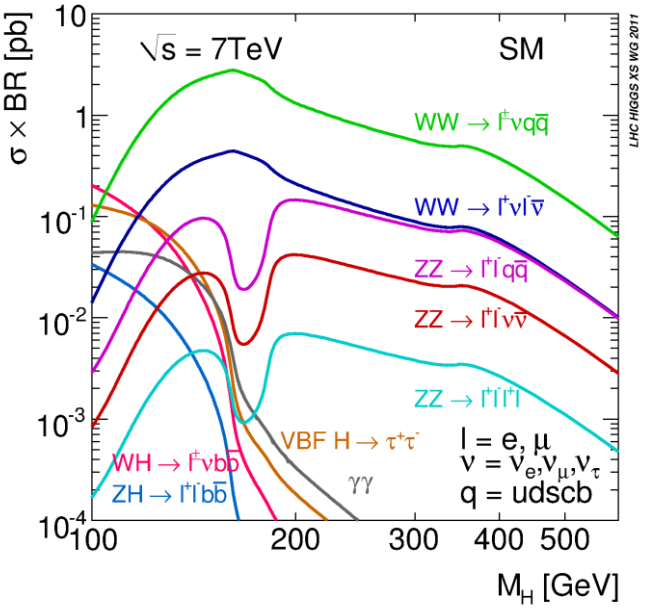


Gluon-gluon fusion is the most abundant production channel, but **VBF** and **associated production** can be experimentally more favourable in specific cases.

SM Higgs search channels

Depending on Higgs mass different channels become relevant.



Channel	Mass range (GeV)	Lumi (fb^{-1})	Comments
H→ γγ	110 – 150	1.08	Low BR. Mass-peak with best resolution
Z(W)H→Z(W)bb	110 – 150	1.04	Performed as a counting analysis
H→ ττ	110 – 150	1.06	Good Signal/background
H→WW(*)→lvlv	110 – 300	1.70	Most sensitive
H→ZZ(*)→llll	110 – 600	2.20	Golden channel
H→WW(*)→lvqq	240 – 600	1.04	Higest rate
H→ZZ(*)→llqq	200 – 600	1.04	Higest rate
H→ZZ(*)→llvv	200 - 600	2.05	Good at high mass

Integrated luminosity and **background rejections** are the two important issues

SM Higgs boson searches: analysis strategy

"**Cut & Count**" based analysis:

- **Trigger** (changing along data taking)

- **Event selection**
  - Object definition (lepton, jets, missing E_T, …);
  - Collision event selection (common to all channels);
  - Specific event selection and acceptance definition

- **Background evaluation**
  - Mostly, data-driven methods:
    1) Count events in background enhanced control regions
    2) Extrapolation to signal region based on MC or data

- For each value of m_H **likelihood fit** of data in one or more variables

- **Confidence interval** based on CL_s method on $\mu = \frac{\sigma}{\sigma_{SM}}$

Then: channel combination → Confidence intervals for μ vs. m_H

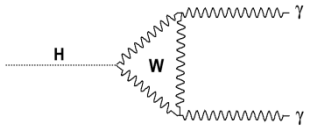
$H \rightarrow \gamma\gamma$

H→γγ: the low mass "golden channel"

Features:

- Region of interest: **$110 < M_H < 140$** GeV
- Low branching ratio BUT **very clean signature with limited background**.

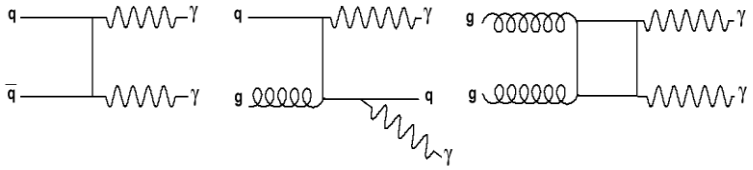
Signal



The main backgrounds:

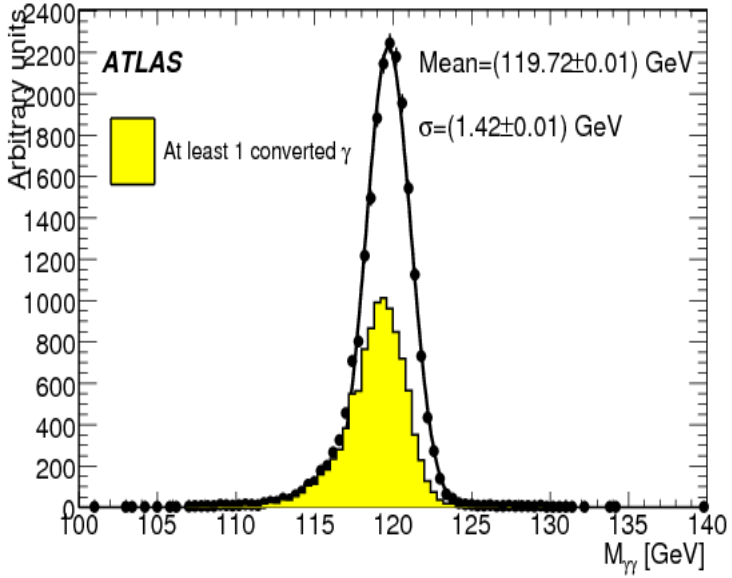
- **Irreducible**: Di-photon (72%) γγ and Drell-Yan
- **Reducible**: Photon + jets and di-jets due to fakes (jet is misidentified as γ).

Irreducible background: pp→ γ + X



Discriminant variable:

$m_{\gamma\gamma}$, resolution 1.4 GeV



H→γγ: the low mass "golden channel"

Trigger:

2 photons with E_T>20GeV (99% efficient)

Selection:

Events are selected requiring two photons

2 isolated photons: p^1_T>40 GeV; p^2_T>25 GeV with invariant mass 100 < $m_{\gamma\gamma}$ < 160 GeV

Powerful γ ID to reduce background from jets faking γs: shower shapes, track isolation cut

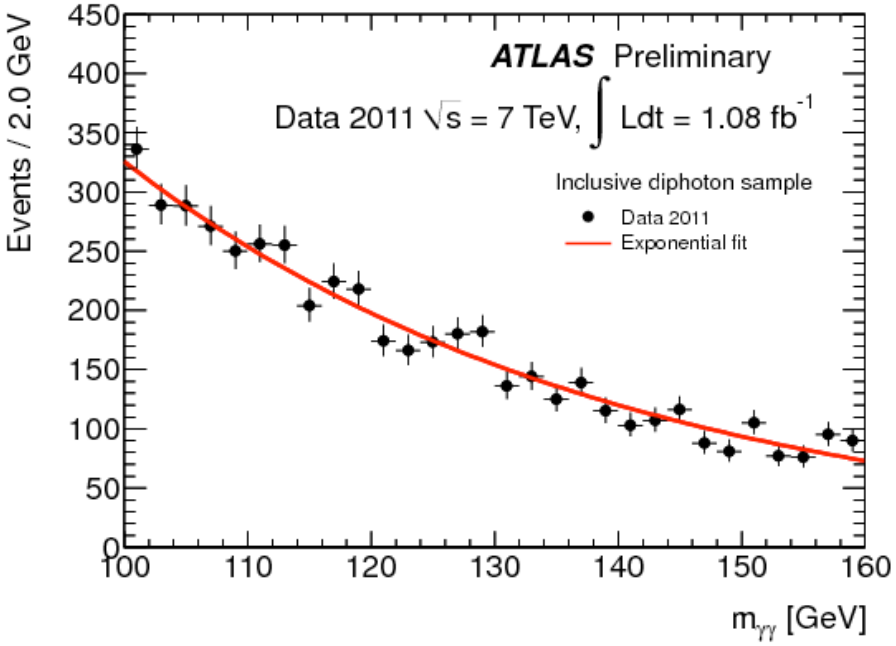
Combination of **EM-calorimeter & tracking** information:

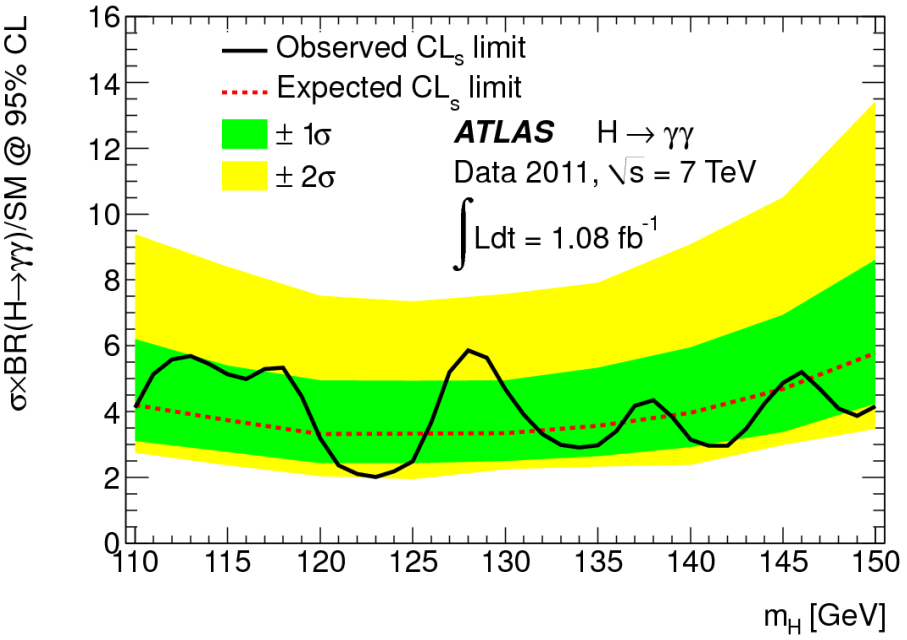
- Reconstruccion of γ-conversions
- Better reconstruccion of primary vertex and the direction of the γs.

H→γγ: the low mass "golden channel"

Background estimation

- Double sideband method
- Electron/Photon fake rates from Z decays





No signal found:

Set upper limits on μ for $110<m_H<150$ GeV

UV-Wisconsin group is involved in this analysis channel.

H→bb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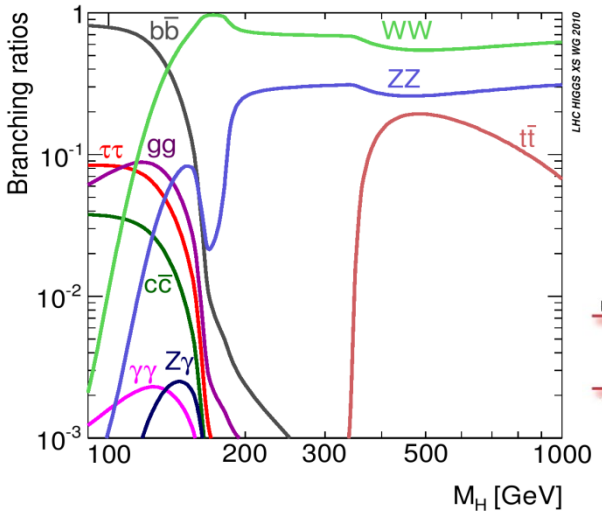
H→bb searches in ZH/WH production

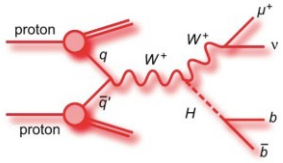
Conditions:

The H→bb channel is the dominant decay mode at low masses BUT gluon fusion production searches are limited by the huge SM bb background.

Searches for **associated production** with Z or W bosons are feasibles in the bb channel in the range **$110 < m_H < 130$ GeV**:

- WH cross section factor is 2x higer than ZH, but important top background
- ZH less affected by top background





Analysis:

Simple and robust:

- Select Z or W and search for 2 additional b jets
- Search Higgs in m_{bb} spectrum.

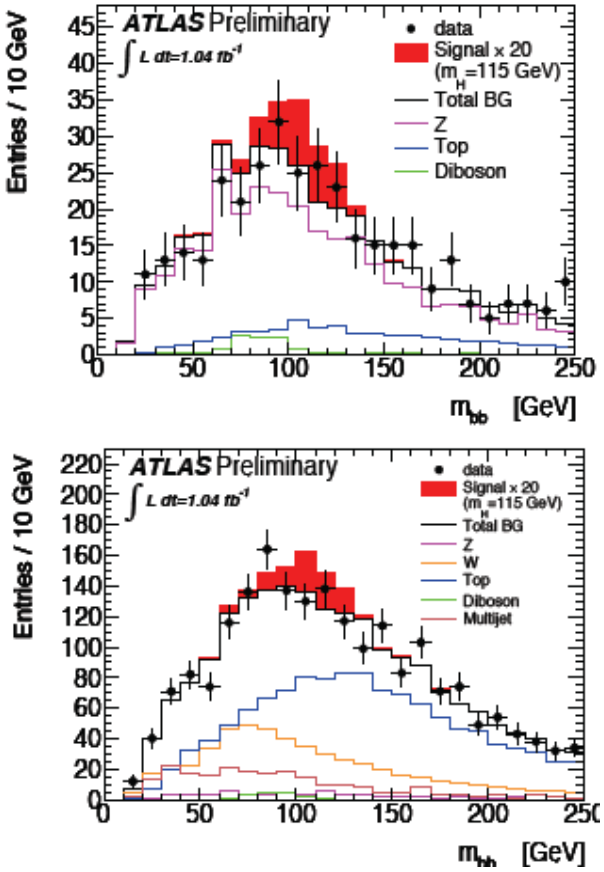
Selection:

Variable	ZH	WH
Ne or Nμ	2	1
P_T	> 20 GeV	> 25 GeV
E_T^{miss}	< 50 GeV	> 25 GeV
N_j	>2	= 2

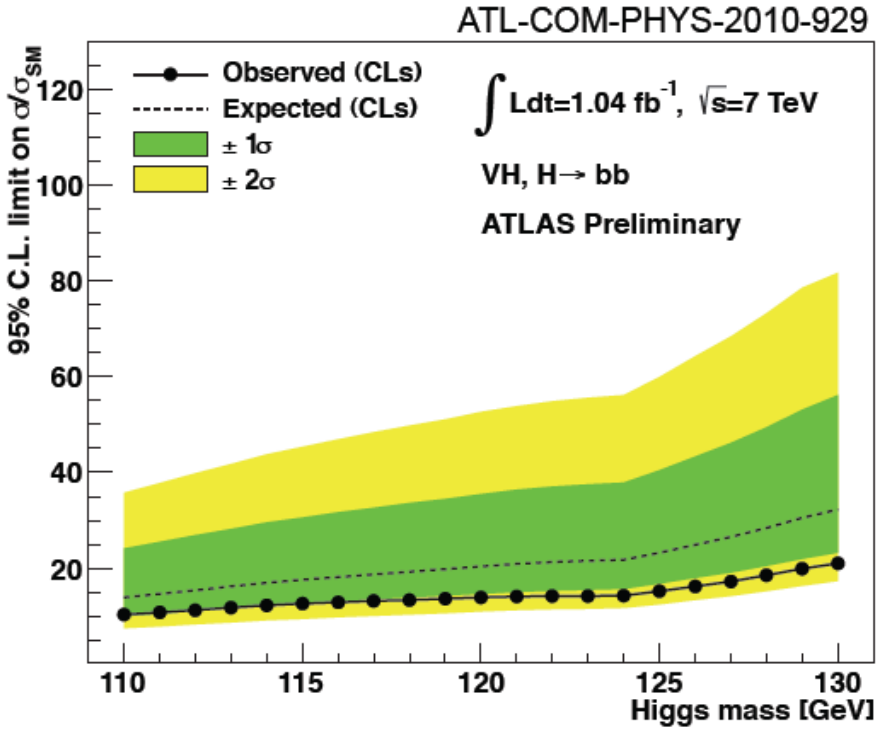
H→bb searches in ZH/WH production

Invariant mass used as observable:

- Observation compatible with background fluctuation.



Exclusion limits with 1fb^{-1} are 15x SM



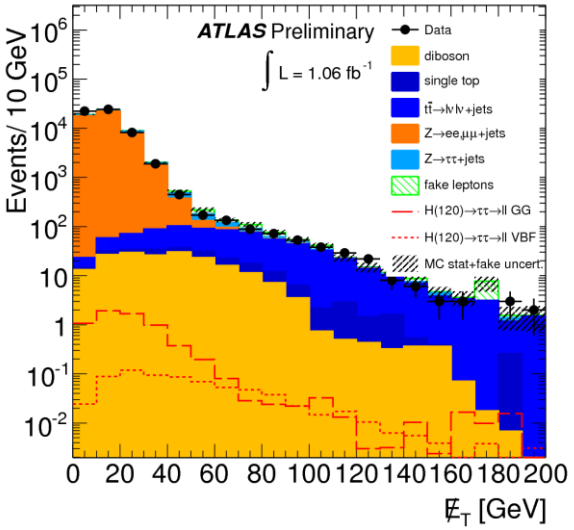
Alternative approach to search for boosted Higgs increases the signal to background ratio:

- Decreases the angle between Higgs decay products
- Jet substructure analysis showing promising results.

$H \rightarrow \tau\tau$

H→ττ

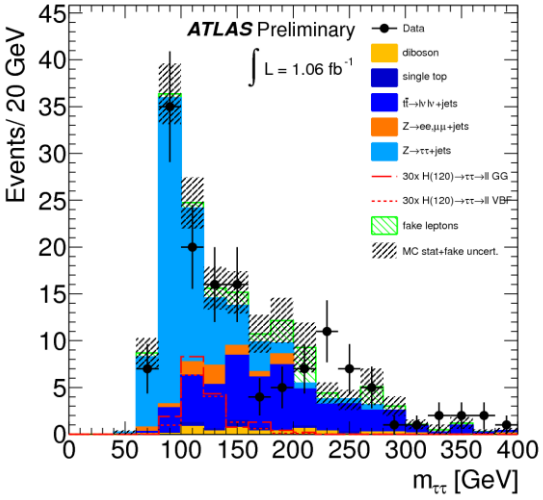
- The H→ττ channel has clear signature but moderate branching ratio in the range **$100 < m_H < 140$ GeV**
  - Searches for associated productions with jets enhance the signal-to-background ratio: H→ ττ→ll+4ν (l=e,μ).
  - Search for H→ ττ→lh covered by MSSM (backup)



- Preselection cuts

pT > 20 GeV for electrons and 18 GeV for muons

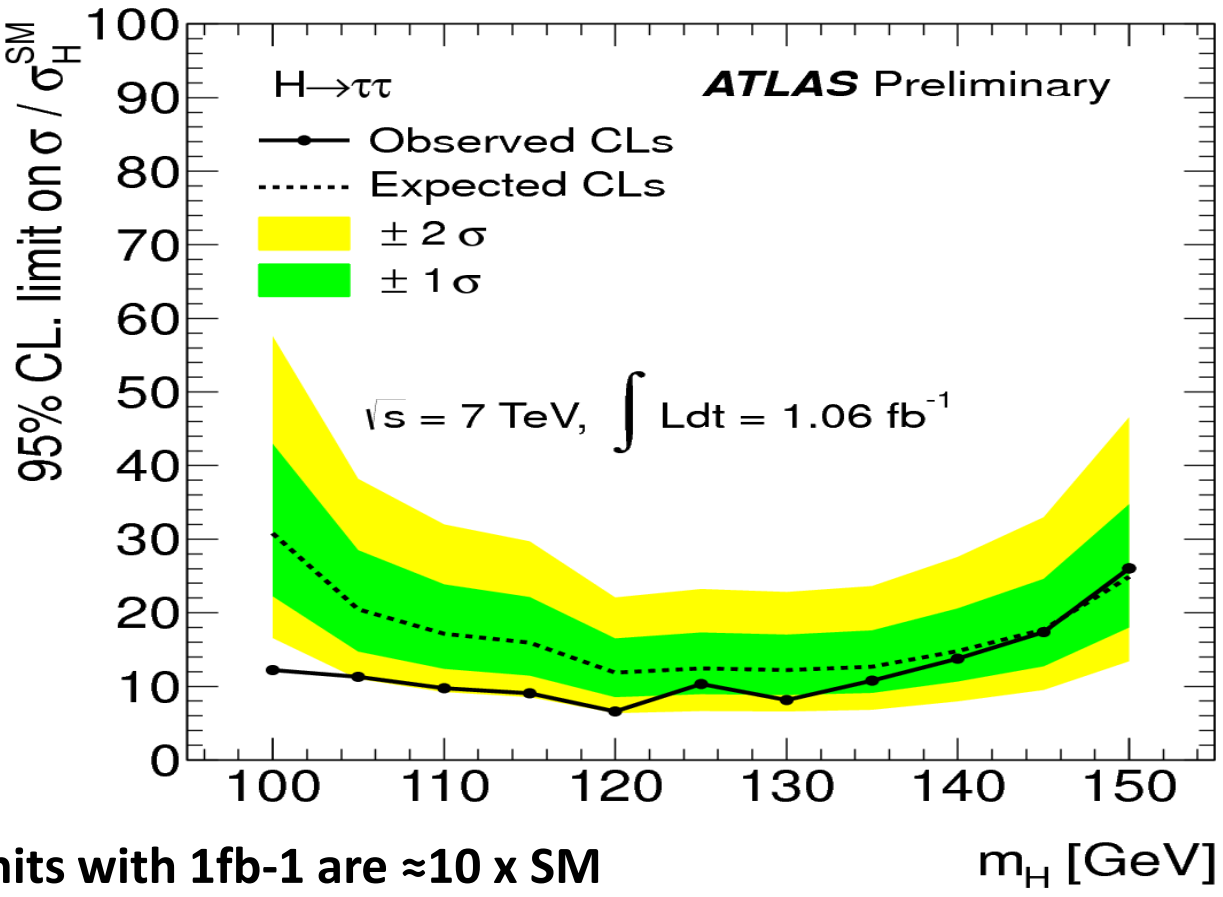
Variable	Same flavour	Different flavour
Ne or/and Nμ	Ne = 2 or Nμ = 2	Ne = 1 and Nμ = 1
mll	30 < mll < 75 GeV	30 < mll < 100 GeV
pTjet	> 40 GeV	> 40 GeV
ETmiss	> 30 GeV	> 20 GeV



UV-Wisconsin group is working in this analysis channel.

H→ττ

Limits for the combination of the to ll and lh channnels (ATLAS-CONF-2011-135)



Exclusion limits with 1fb-1 are ≈10 x SM in Higgs mass range from 100-120 GeV

CONF notes contributing to the combined results:
ATLAS-CONF-2011-132 for lh and ATLAS-CONF-2011-133 for ll

H→WW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H→WW*→lνlν

The H→WW*→lνlν channel benefits from the large branching ratio and very clean dilepton signal.

Event selection

Preselection cuts require two opposite sign leptons and large E_T^{miss} :

Leading p_T > 25 GeV and subleading p_T > 15 GeV (20 for electron).

E_T^{miss} > 40 GeV (ee, mumu) and 25 GeV (eμ)

m_{ll} > 15 GeV to reduce Drell-Yan

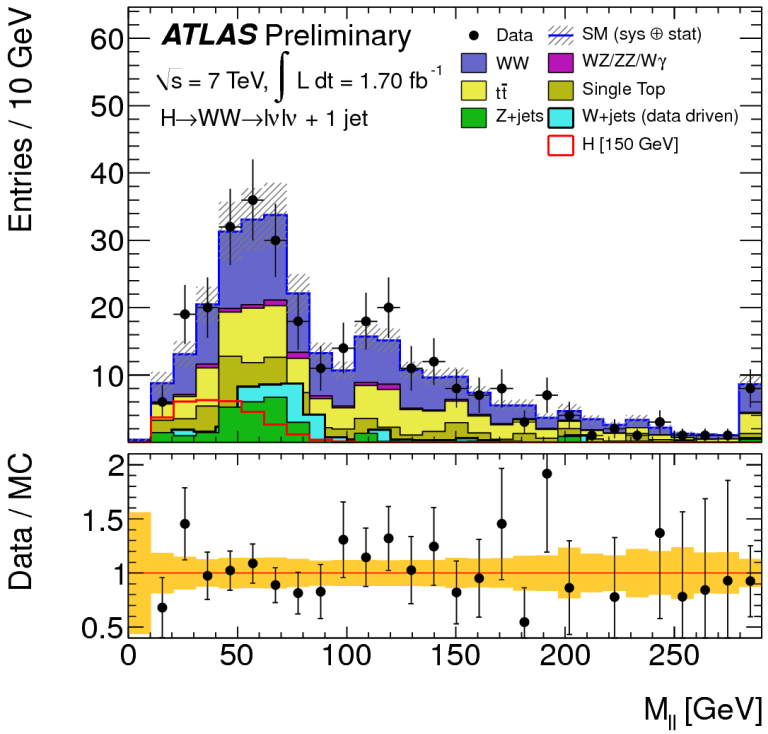
$|m_Z - m_{ll}|$ > 15 GeV to reduce Z

Topological cuts

$\Delta\varphi_{ll}$ < 1.3 (1.8 for m_H > 170 GeV) due to spin correlation of WW*

Sliding window on the transverse mass (0.75 x m_H < mT < m_H)

Use **invariant mass as discriminating** observable.

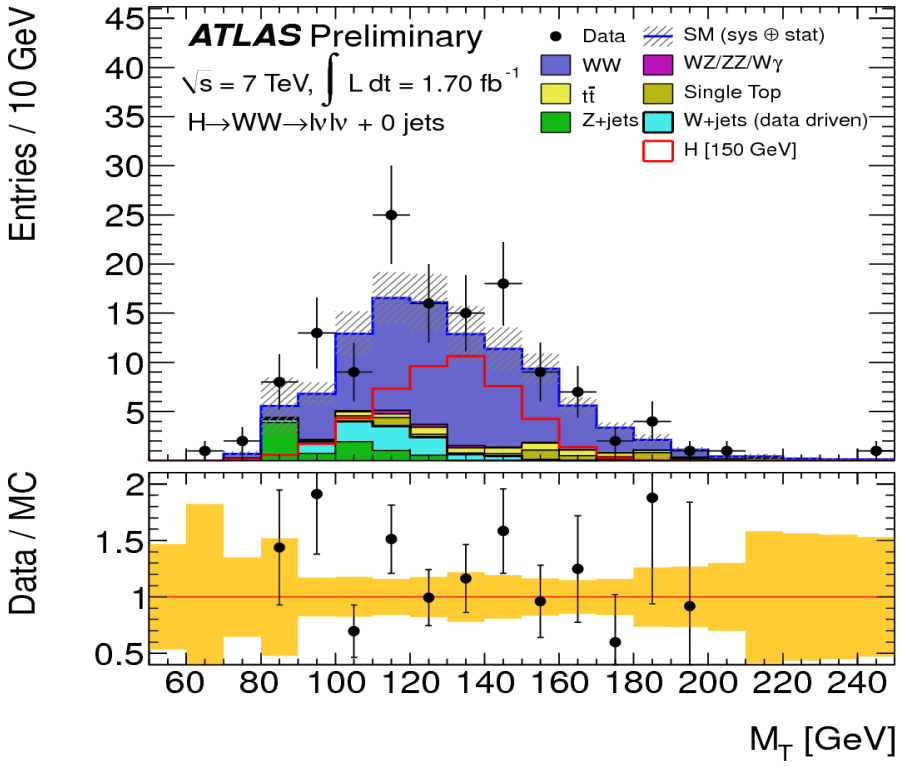


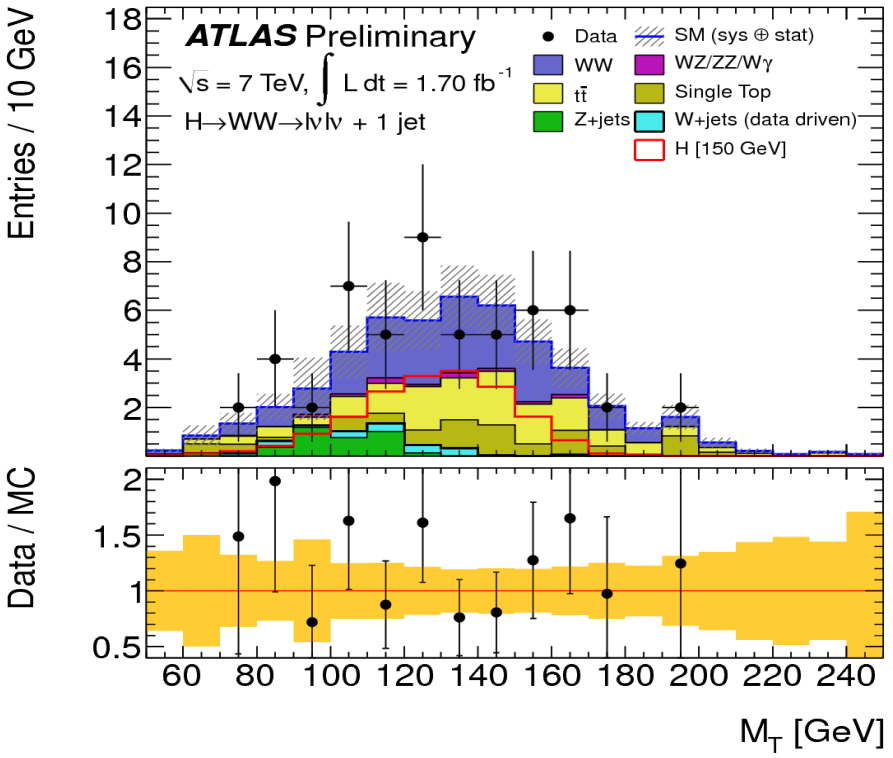
UV-Wisconsin group is strongly involved in this analysis channel.

H→WW*→lνlν

Analysis is split in events with 0 and 1 hadronic jet

Counting experiment with the **transverse mass** as the final discriminator

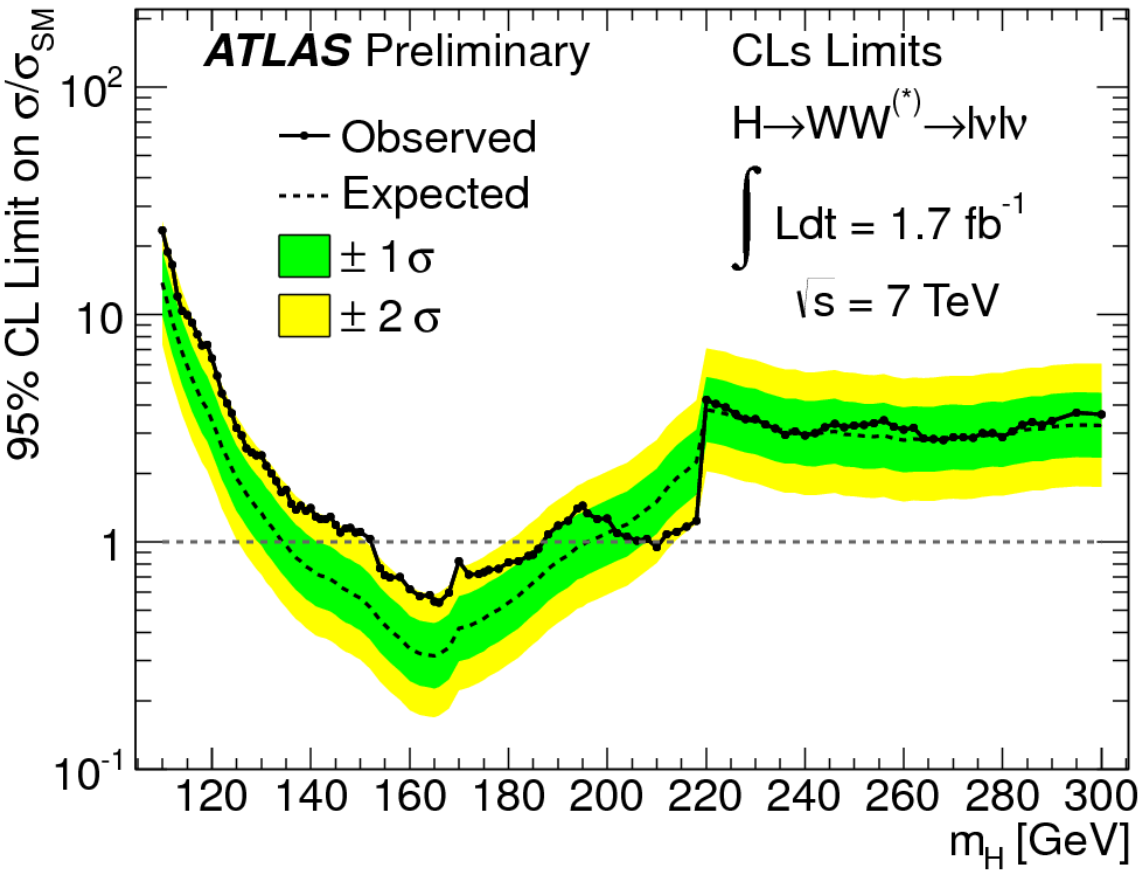




After cut on transverse mass:

$$m_T = \sqrt{\left(E_T^{ll} + E_T^{miss}\right)^2 - \left(P_T^{ll} + P_T^{miss}\right)^2}$$

H→WW*→lνlν



SM Higgs exclusion from 150-186 GeV

H→WW*→lvqq

The H→WW*→lvqq channel is explored at high masses due to its large branching ratio.

- Analysis performed in the range **240 < m_H < 600 GeV**
- Large sensitivity for all range through Higgs mass peak, especially for $m_H \approx 350$ GeV.

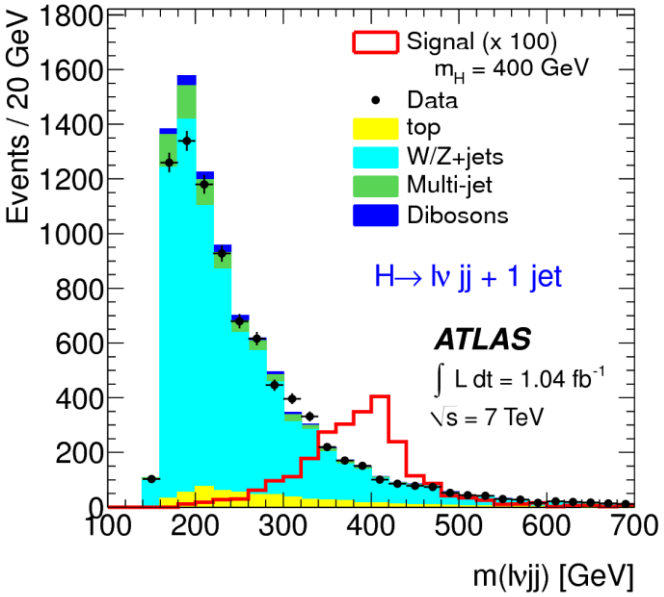
Event selection

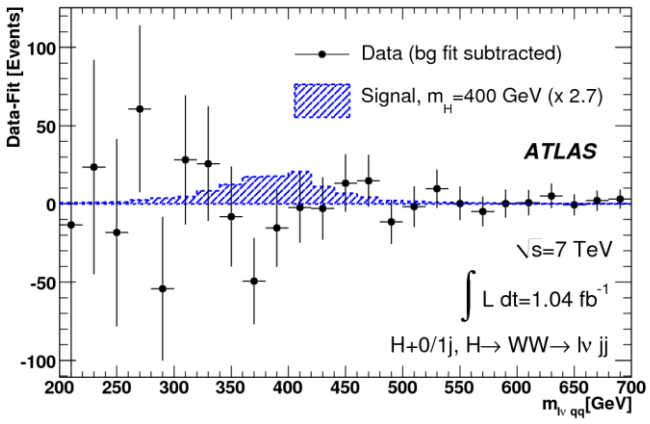
Event selection requires one lepton, large Etmiss and jets:

- Exactly one lepton in the event with pT > 30 GeV
- Etmiss > 30 GeV
- Two or three jets where one pair is required to come from the W → 71 < M_{jj} < 91 GeV

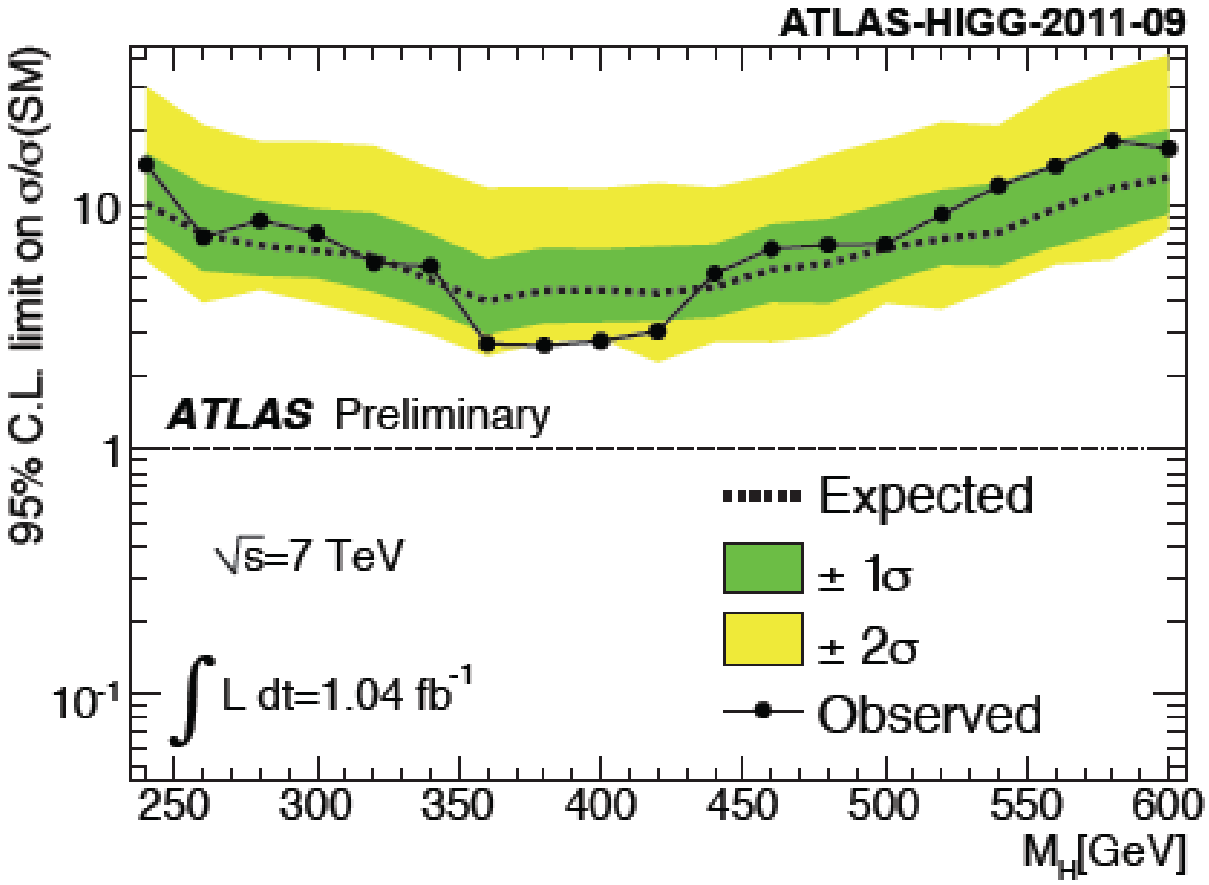
Search for a peak in M(lvqq) over the continuous background

- Reconstruct invariant mass of one W from lv system and another W form qq system.





H→WW*→lvqq



Sensitivity is 5-10 x SM. Downward fluctuation around 400 GeV

H→ZZ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H → ZZ* → llqq

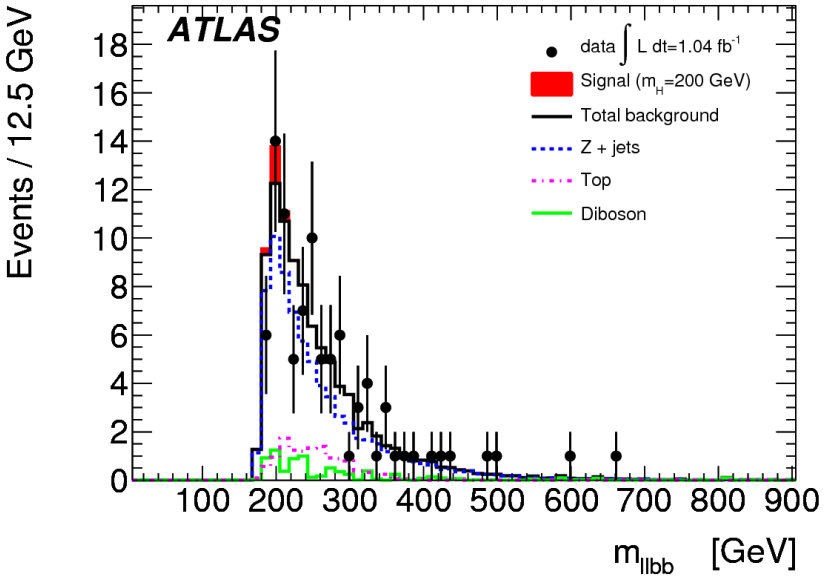
The H→ZZ→llqq search requires two leptons and two jets from Z decay

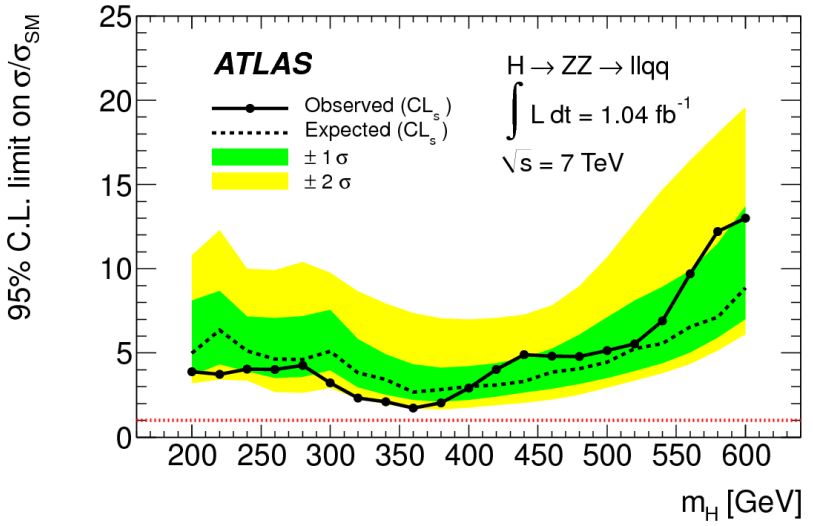
- Channel has highest H→ZZ rate
- Analysis performed for masses in the range 200 < mH < 600 GeV

Preselection cuts:

- Two same flavour leptons
- 76 < mll < 106 GeV
- Etmiss < 50 GeV
- Two or more jets
- 70 < mjj < 105 GeV

All decay products from the Higgs boson are reconstructed in the **invariant mass**



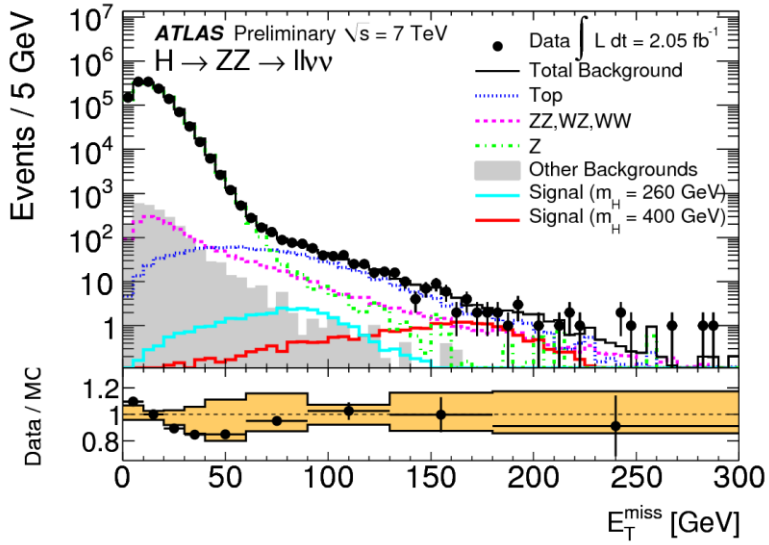


H→ZZ* → llvv

The H→ZZ→llvv search requires two leptons and large Etmiss:

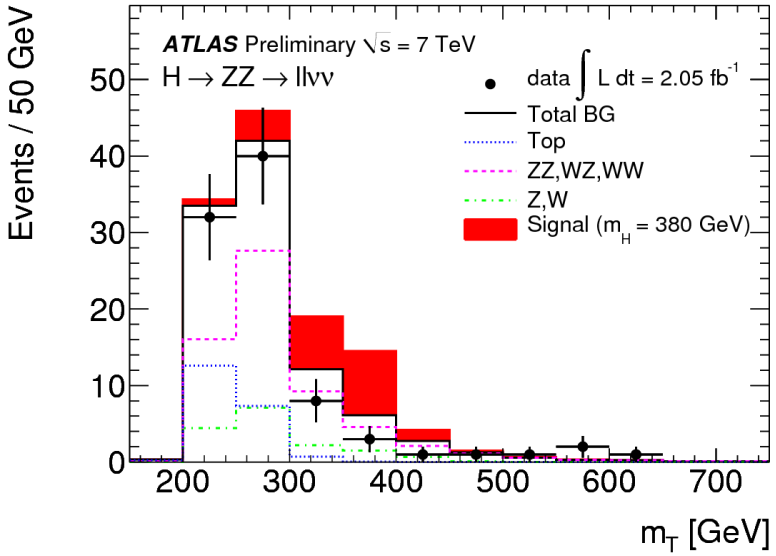
- Z→vv is seen through missing energy
- Higher rate than H→ZZ→llll
- Analysis performed for masses in the range

200 < m_H< 600 GeV



Preselection cuts:

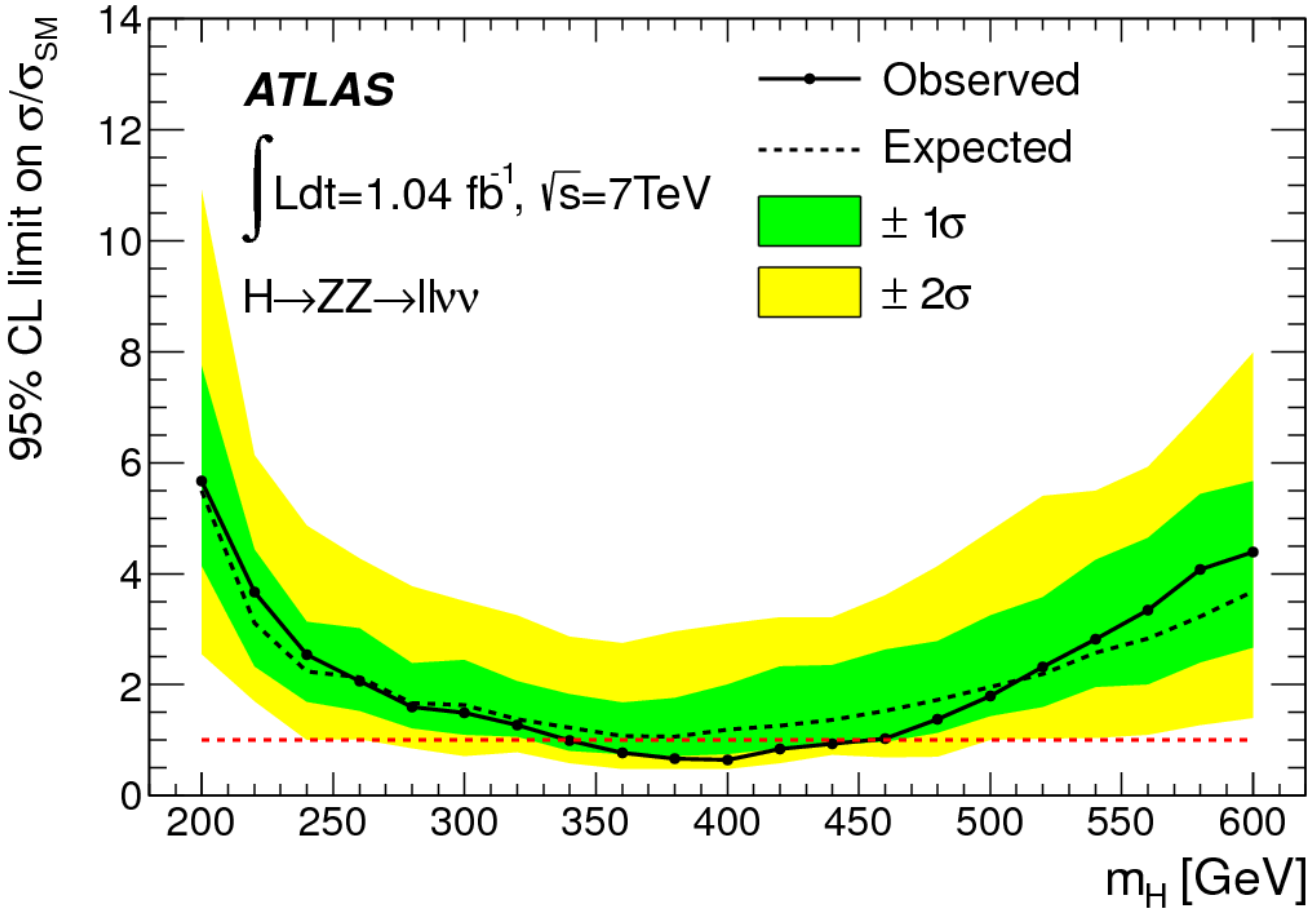
- b-jet veto
- E_T^{miss} > 66 GeV (82 GeV for m_H > 240 GeV)
- DeltaPhi(ll) < 2.64 (2.25 for m_H > 240 GeV)



Discriminating variable:

Transverse mass is used as the discriminating distribution instead of the invariant mass.

H→ZZ* → llνν



SM Higgs exclusion from 350 – 440 GeV

H→ZZ*→llll

"Golden channel"

The H→ZZ→llll is a very clean channel due to small backgrounds:

- Mass range **$100 < m_H < 600$ GeV**
- Three different channels: 4e, 4μ, 2e2μ

Event Selection:

Require 4 isolated leptons:

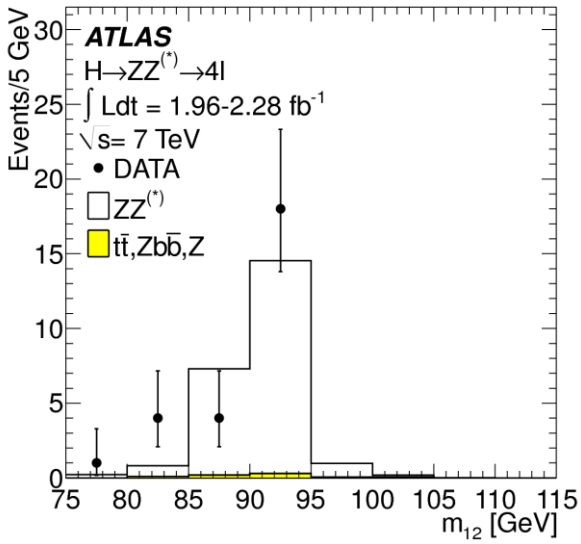
- $E_T > 20$ GeV for electrons and 18 GeV for muons
- At least one pair compatible with Z peak:

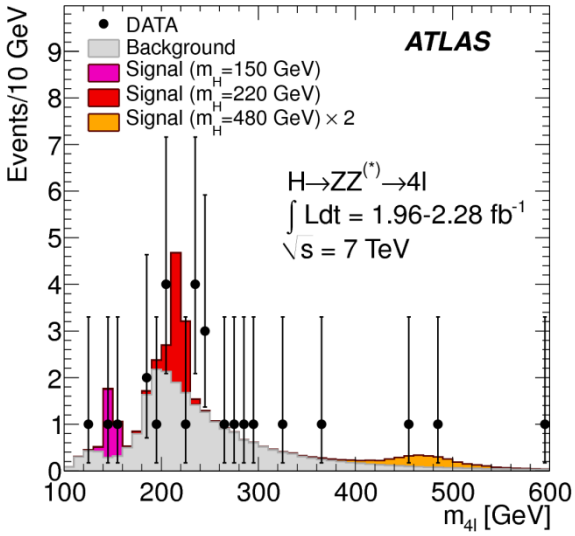
$|m_{12} - m_Z| < 15$ GeV, m_{12}: mass of pair closest to Z

- for $m_H < 180$ GeV, one Z can be off-shell
- at higher masses both should be compatible

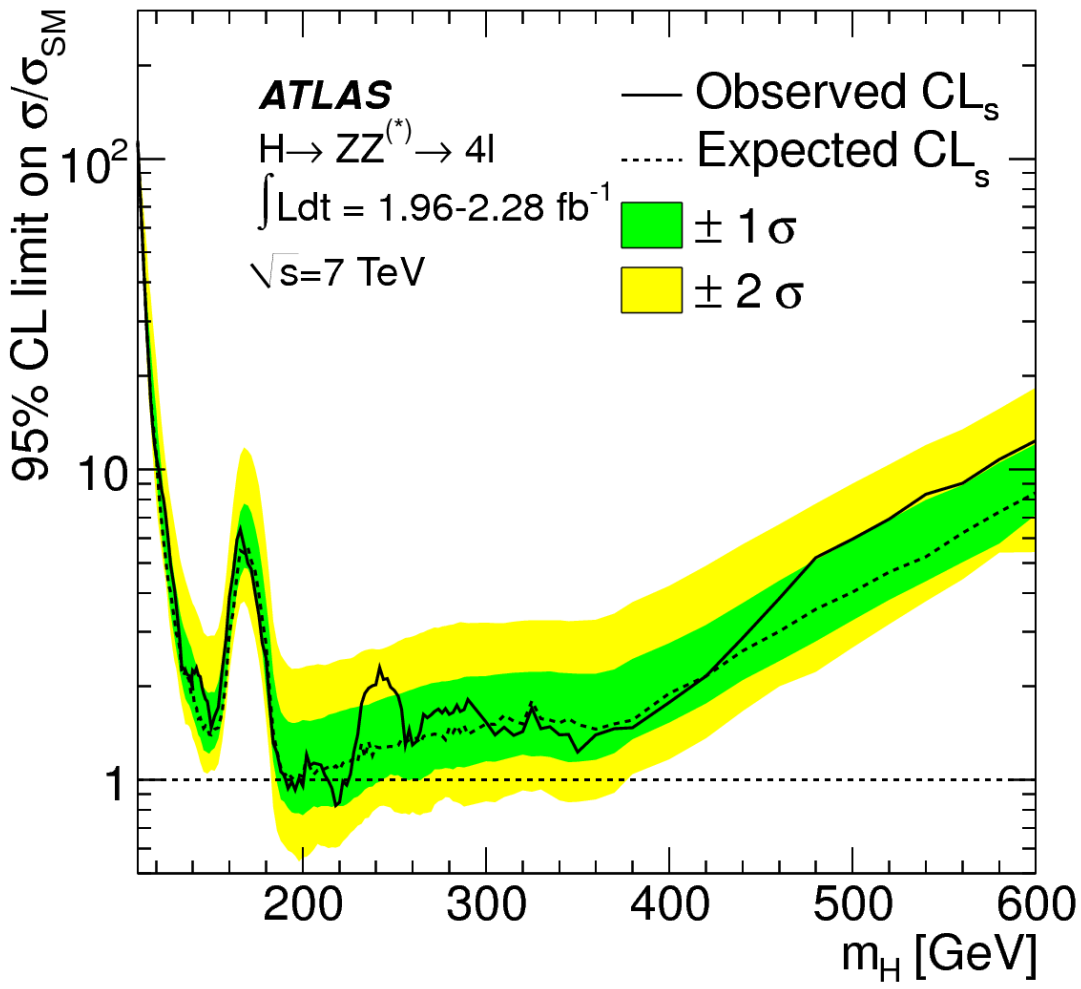
Discriminant variable is the **invariant mass** of the four leptons: m4l

- Already collected 27 candidate events.





H→ZZ*→llll



SM Higgs exclusion around 200 GeV

Higgs boson searches: combined limits

Higgs boson searches: summary of single limits

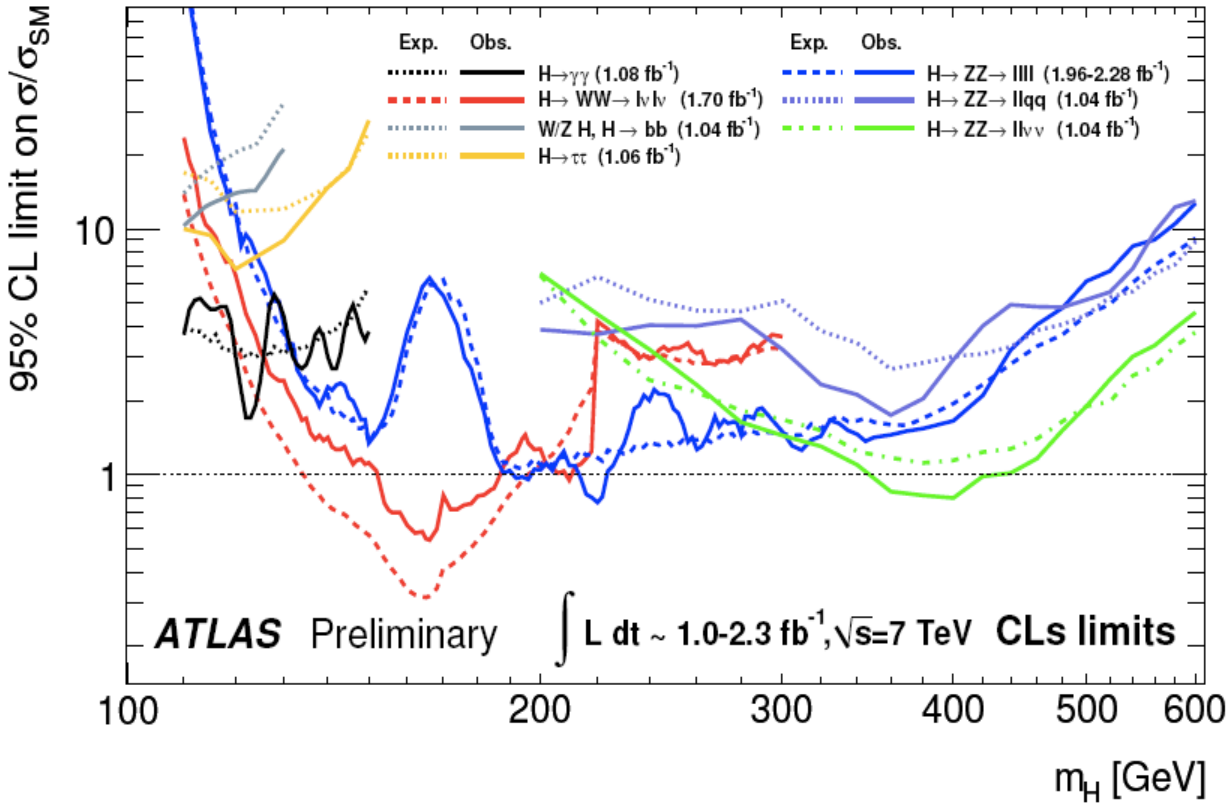
95% C.L. limit on μ for all channels:

→ solid colored lines: observed limit

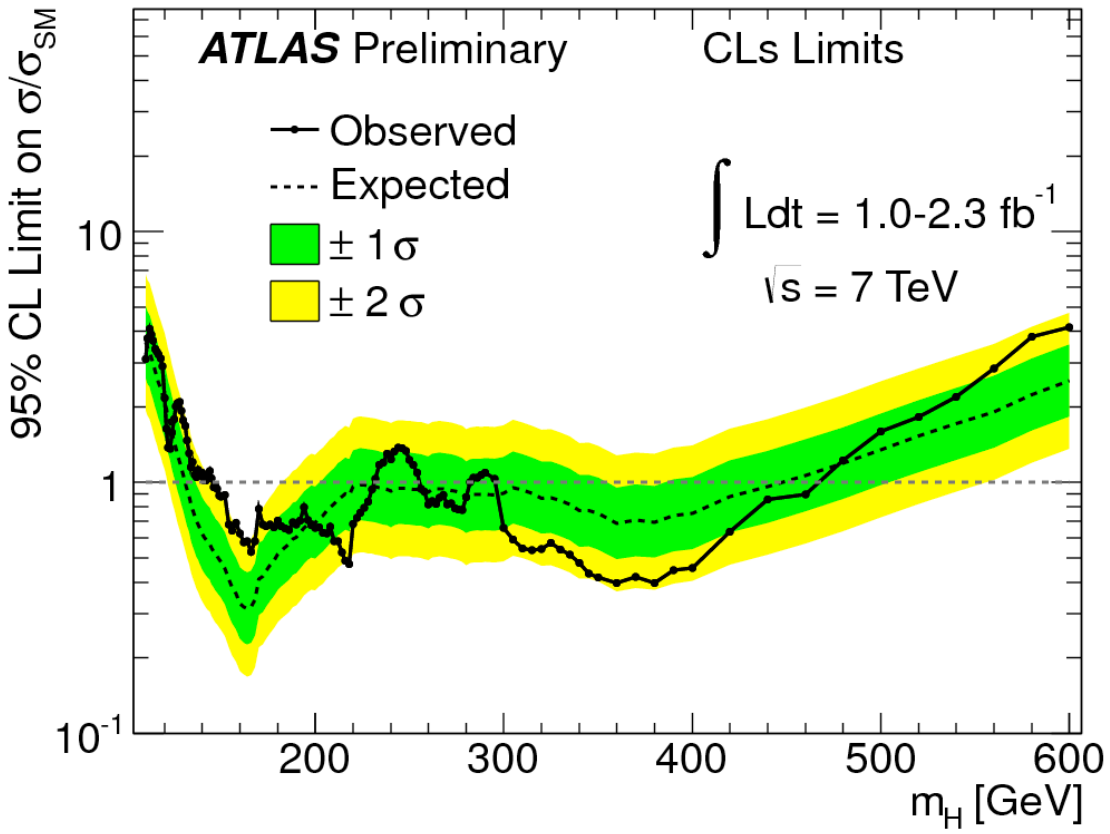
→ dashed/dotted colored lines: expected limit based on MC pseudo-experiments

Observed > Expected → data "over-fluctuate"

Observed < Expected → data "under-fluctuate"



Higgs boson searches: combined limits



Strong contribution for UV-Wisconsin group

ATLAS excludes @ 95% CL a SM Higgs Boson with mass in the three ranges: $146<m_H<232$ GeV, $256<m_H<282$ GeV and $296<m_H<466$ GeV(expected exclusion $131<m_H<447$ GeV). Poor consistency with "background only hypothesys" in the region $130<m_H<170$ GeV.

Conclusions

• Proton-proton collisions produced by the LHC and corresponding to an integrated luminosity up to 2 fb^{-1} have been analyzed by ATLAS.

• No significant excess (<2.1σ) is found in the mass range 110-600 GeV studies by ATLAS. Exclusion limits at 95% C.L. are placed in mass regions:
146-232 GeV
256-282 GeV
296-466 GeV

• No significant/conclusive evidence of Higgs production. Intriguing excess at low mass region.

• More integrated luminosity will help understand our data, improve the analysis and increase our sensitivity. By end of 2012 with O(10 fb^{-1}) a conclusive answer on the Standard Model Higgs should be obtained.

IFIC-Wisconsin group

IFIC(*)-Wisconsin(**) group

- Xin Chen (PostDoc**)
- Amanda Kruse (PhD student**)
- Yesenia Hernández (PhD student*)
- Bruce Mellado García (IP**)
- Yibin Pan (senior scientist**)
- Alberto Valero (engineer*)
- Victoria Castillo (UV professor*)
- Antonio Ferrer Soria (UV professor*)
- Emilio Higón (UV professor*)
- Carlos Solans (PostDoc*)
- Juan Antonio Valls Ferrer (IP*)
- Yingchun Zhu (PostDoc**)
- Luca Fiorini (researcher*)

Collaboration

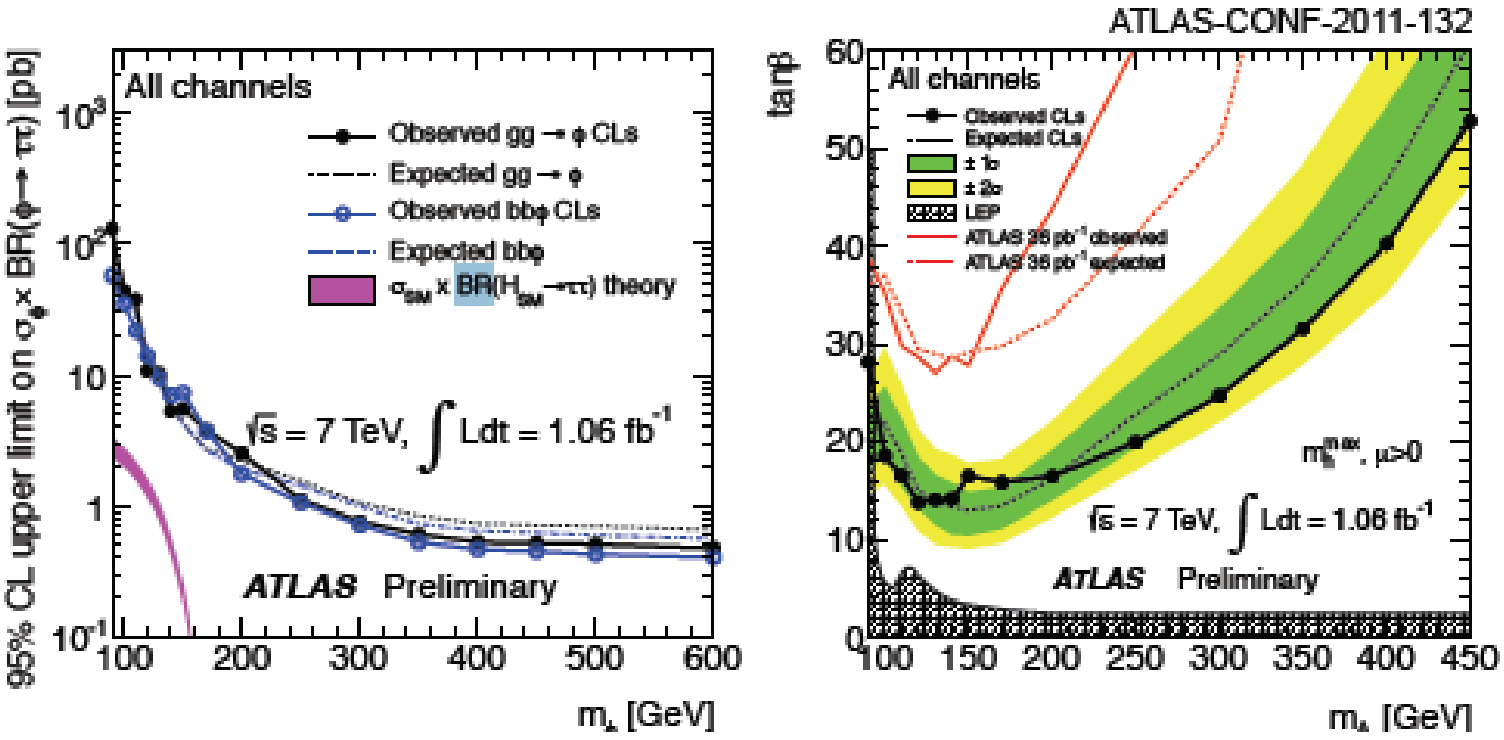
- Laboratoire de l'accelérateur linéaire (LAL):
  - Zhiqing Zhang (IP)
  - Xifeng Ruan (PhD student)

Backup

MSSM H→ττ

Exclusion limits including three final states: ll, lh, hh

- Model independent limit: Generic MSSM Higgs production cross-section times branching ratio to tau pairs.
- Results in the m_h^{max} scenario excludes tanβ ≈14 for low mass



UV-Wisconsin group is working in this analysis channel.