Higgs Searches at ATLAS

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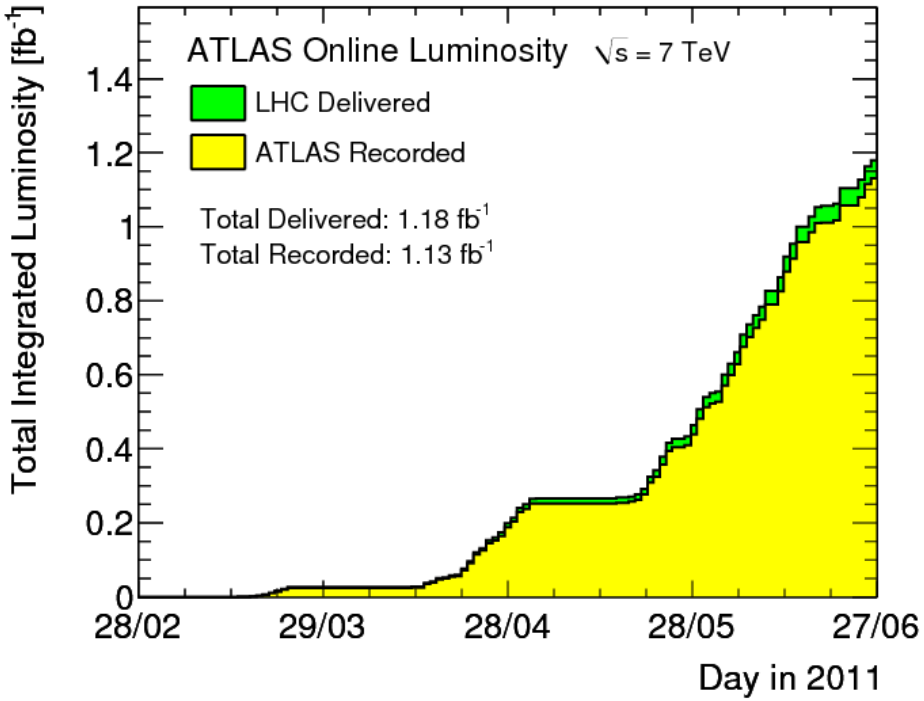
on behalf of the ATLAS collaboration

Outline

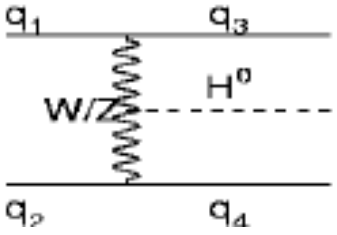
- LHC and ATLAS
- SM Higgs Boson
  - Production
  - Decay modes
  - Combination
- MSSM Higgs bosons
- Summary

LHC and ATLAS

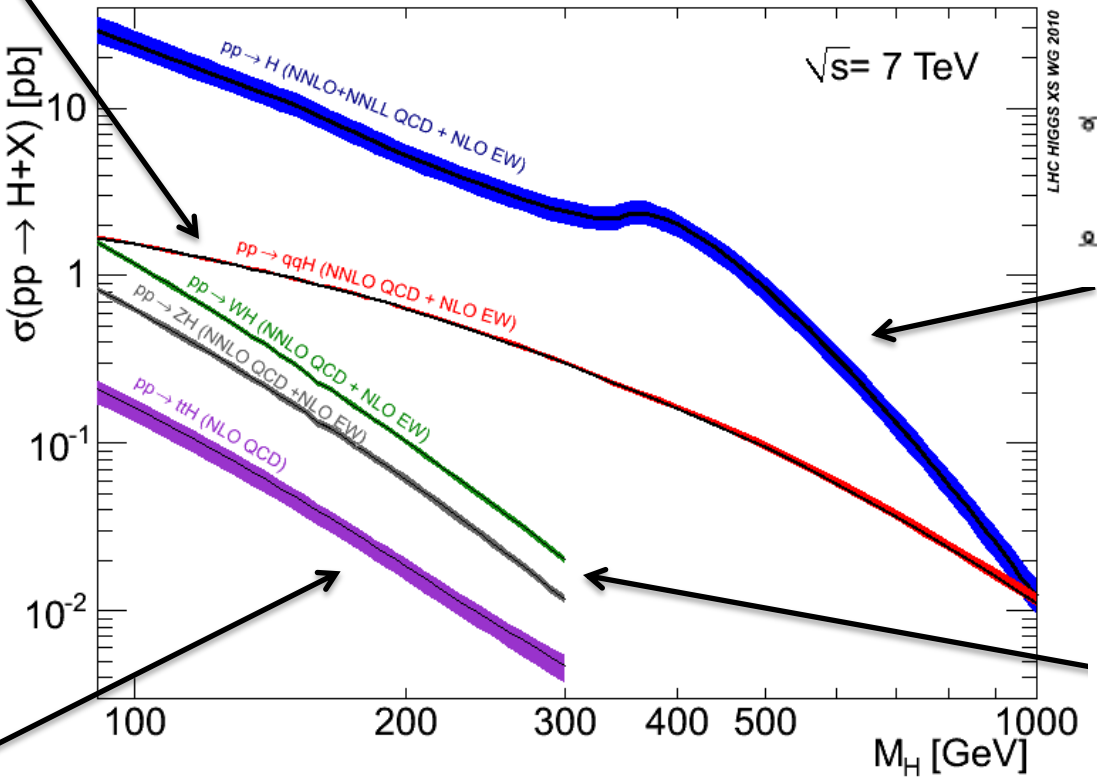
- In 2010:
  - Proton proton collisions
  - ATLAS recorded 45 pb^{-1} of integrated luminosity at √s=7 TeV
  - Depending on data quality selections, 35 pb^{-1} or more used in analysis
- In 2011:
  - Running since early March with √s=7 TeV
  - **>1 fb^{-1} data has been recorded**
  - Hope for 4-5 fb^{-1} of integrated luminosity before the end of the year
- Beyond:
  - LHC will run in 2012
  - Then, long shutdown and run at higher energy.

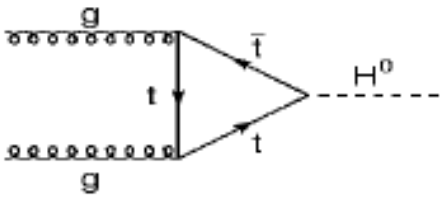


SM Higgs Boson - Production

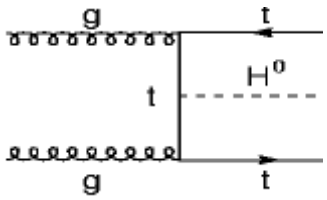


VBF (less suppressed at higher M_H)

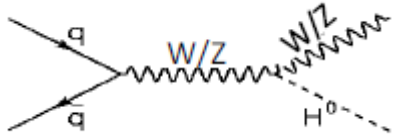




gluon-fusion (dominant)



ttH (contribute to H->γγ, bb)



WH/ZH (contribute to H->γγ, bb)

Signal cross section and its uncertainties are given by
"Handbook of LHC Higgs Cross sections:
1. Inclusive Observables" arXiv: 1101.0593(hep-ph)

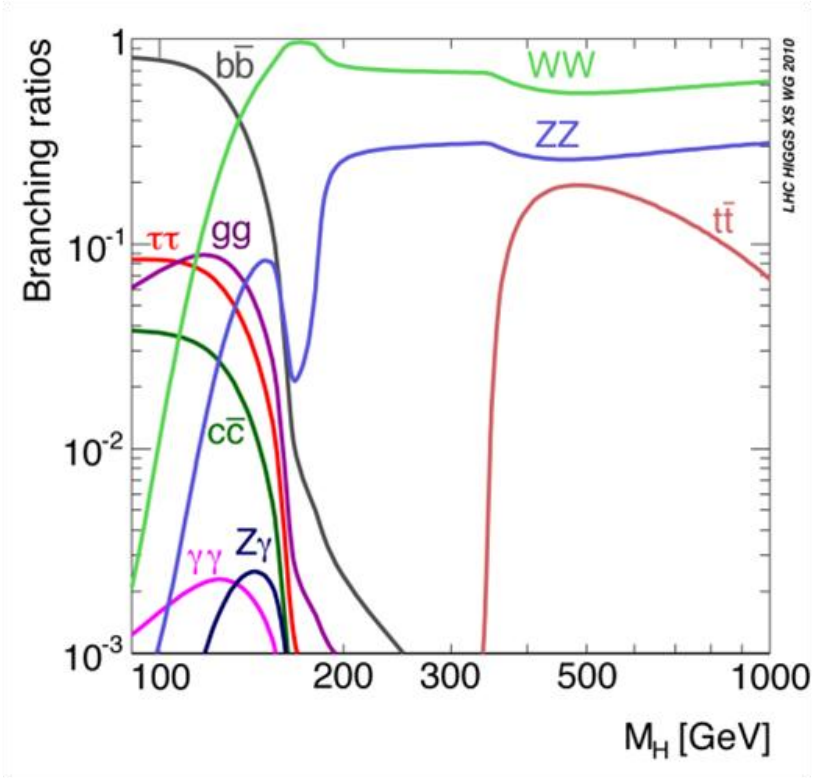
SM Higgs Boson - Decay

Decay modes:

- H -> WW
  - Dominant in intermediate and high mass regions
- H -> ZZ
- H -> $\gamma\gamma$
  - Low BR
  - Relevant in low mass region
  - Clean signature
- H -> bb (not in this talk)
  - Dominant in low mass region
  - Very challenging (high QCD background)
- H -> $\tau\tau$ (not in this talk)
  - Low production rate
  - High Z -> $\tau\tau$ background

The Challenge:

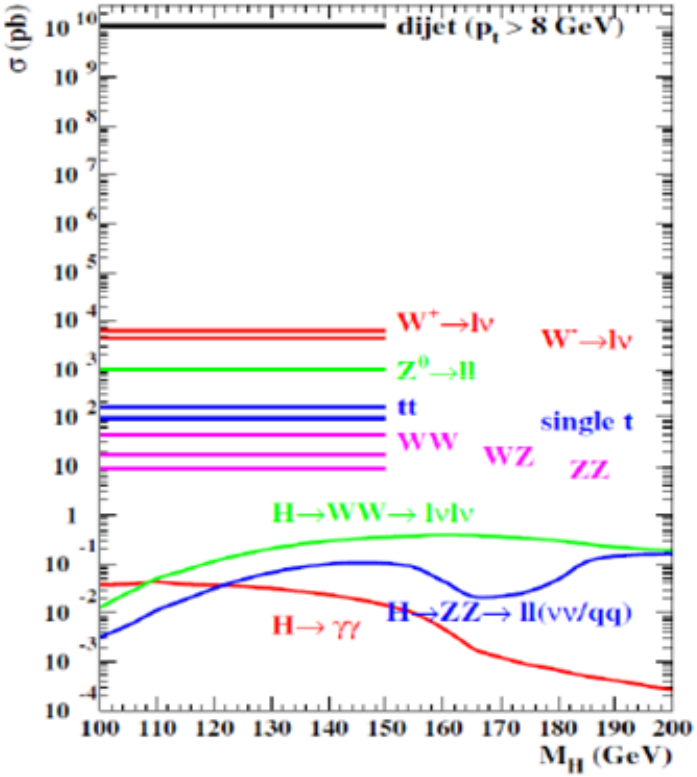
<1 detectable Higgs boson per 10^{12} collisions



SM Higgs Boson

Decay modes:

- H -> WW
  - Dominant in intermediate and high mass region
- H -> ZZ
- H -> $\gamma\gamma$
  - low BR
  - Important in low mass region
  - Clean signature
- H -> bb (not in this talk)
  - Dominant in low mass region
  - Very challenging (high QCD bg)
- H -> $\tau\tau$ (not in this talk)
  - Low production rate
  - High Z -> $\tau\tau$ background



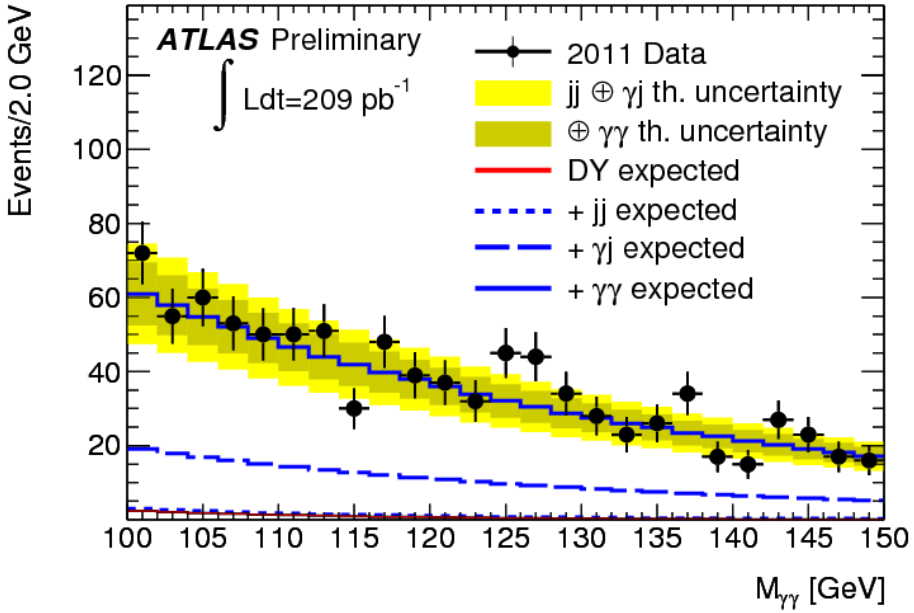
The Challenge:

<1 detectable Higgs boson per 10^{12} collisions

SM Higgs Boson

H -> γγ (data 2011):

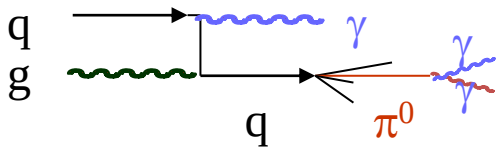
- Mass range 110-140 GeV
- Preselection cuts:
  - **2 isolated photons with pT > 25 GeV and |η| < 2.37, fulfilling tight shower shape requirements**
  - **1 γ with pT > 40 GeV**
  - 100 < Mγγ < 150 GeV



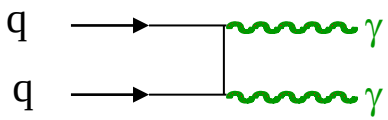
SM Higgs Boson

H -> γγ (data 2011):

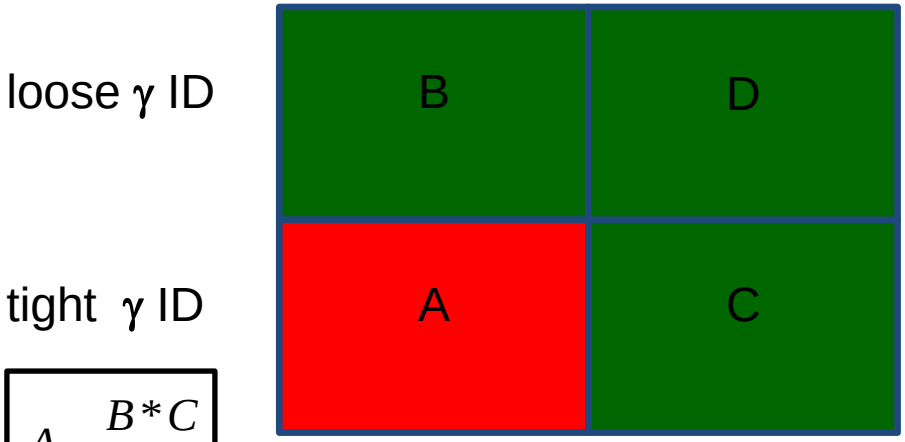
- Main backgrounds:
  - Reducible (γ-jet and Jet-jet)



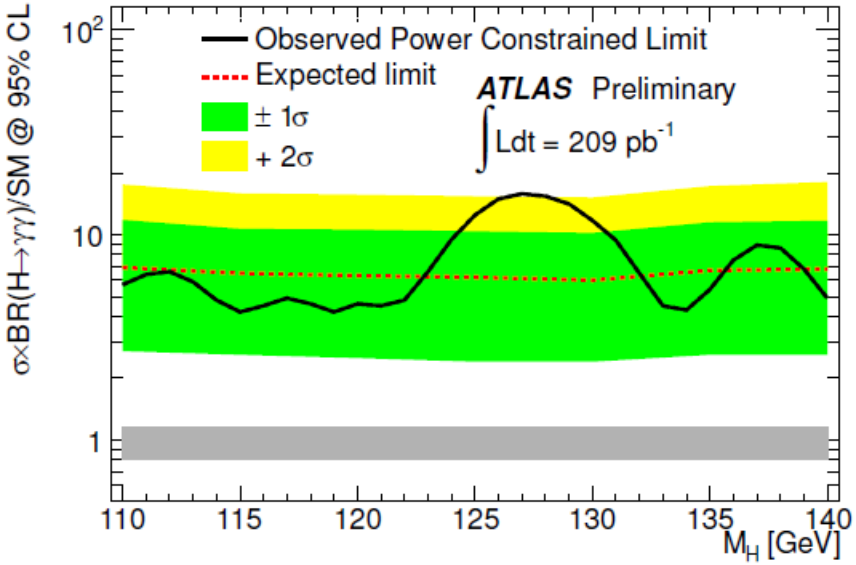
  - Irreducible (γγ and Drell-Yan)



- Strategy to estimate:
  - Double sideband method
  - Electron photon fake rate from Z → ee
- Limit: The observed excluded σ ranges from 4.2 to 15.8 times the σ_{SM} at 95% CL (6-7 was expected)

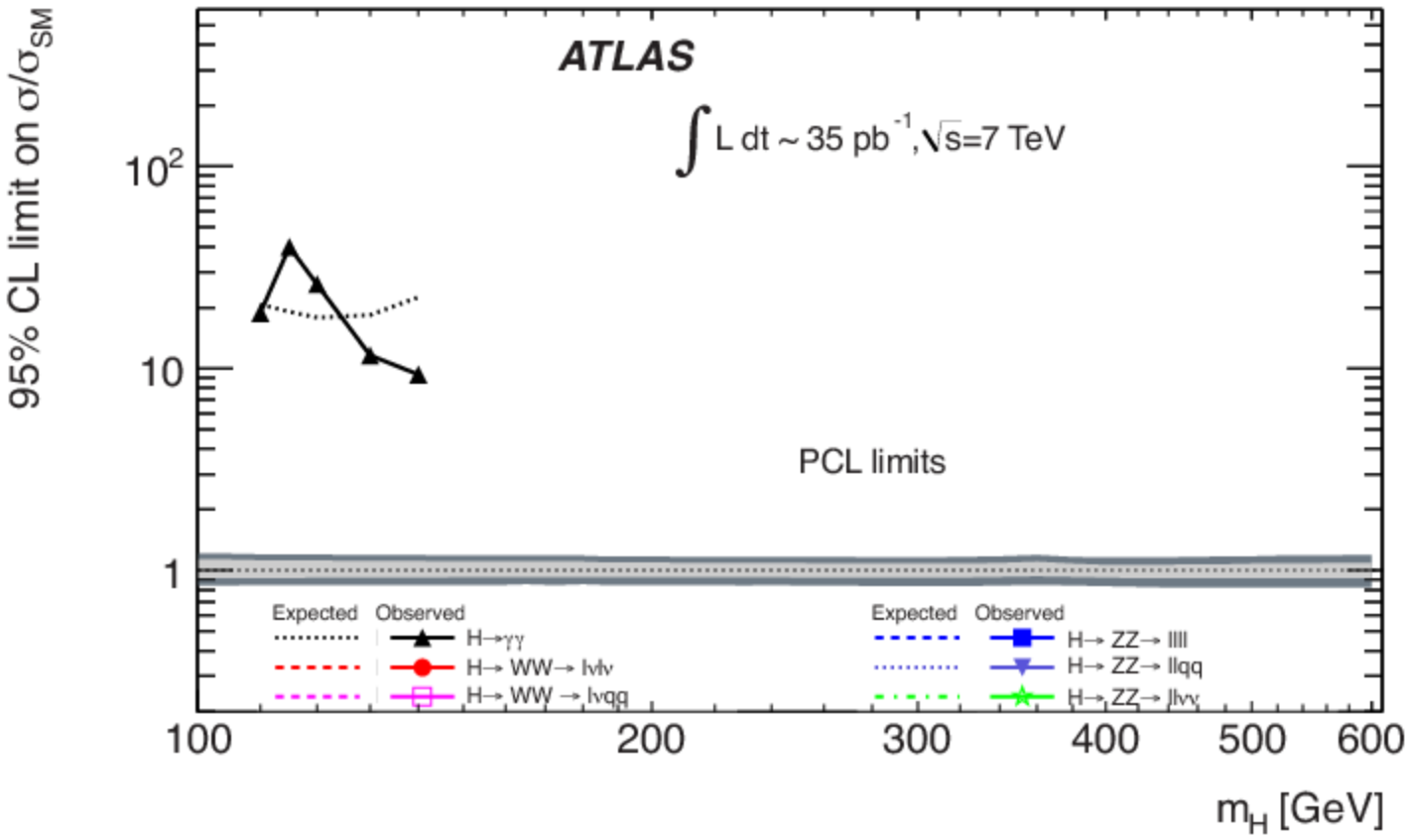


$$A = \frac{B * C}{D}$$



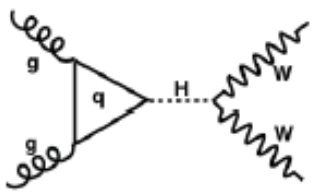
SM Higgs Boson

H -> γγ (data 2010):

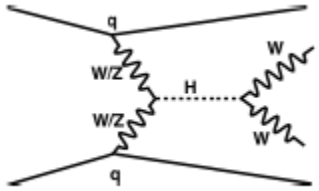


SM Higgs Boson

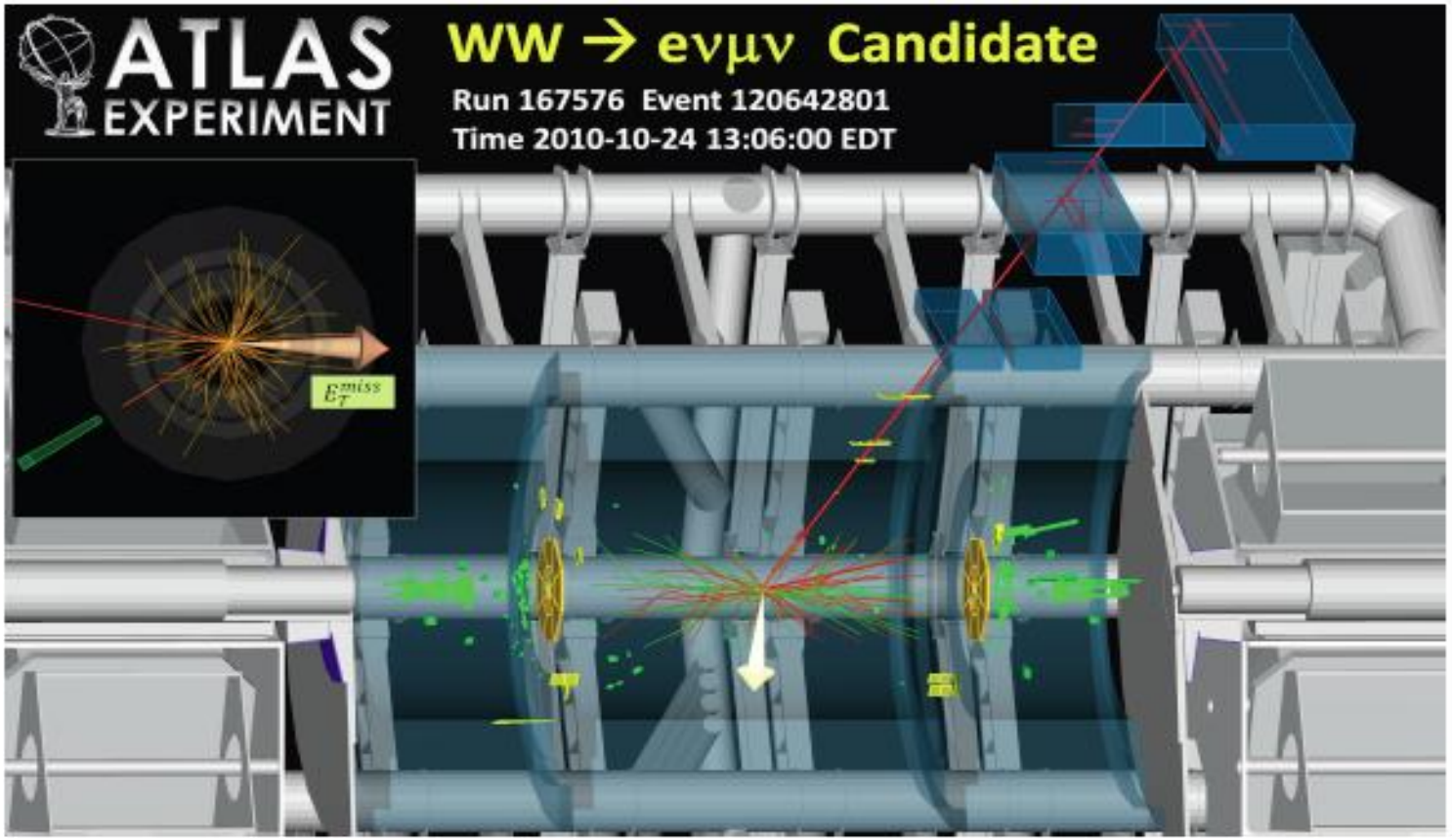
H -> WW (data 2010):



ggF



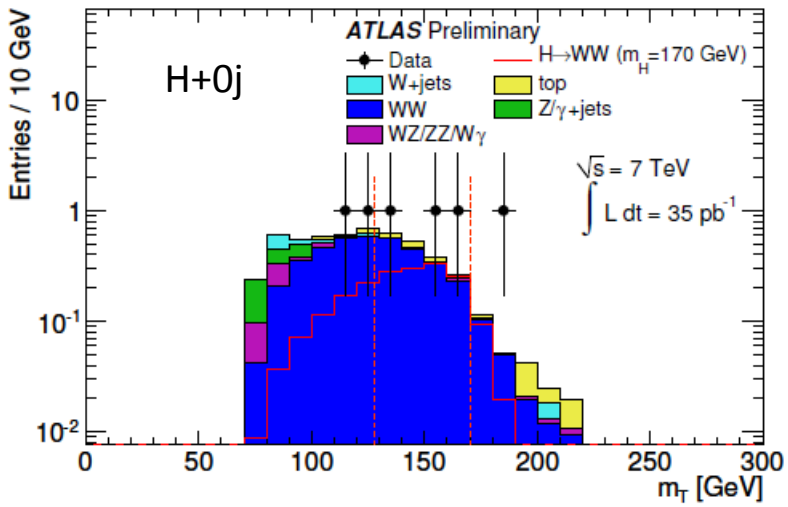
VBF



SM Higgs Boson

$H \to WW^* \to l\nu l\nu$ ($l=e,\mu$):

- Mass range 120-200 GeV
  Most sensitive to $M_H=2M_W$
- 9 channels – (H+0j, 1j, 2j) * (ee, μμ, eμ)
  - Jet pT > 25 GeV and Jet $|\eta| < 4.5$
- Preselection cuts:
  - **2 opposite-sign hard and isolated leptons**
  - **MET > 30 GeV**
  - **M_{ll} > 15 GeV**, $|M_{ll}-M_Z| > 10$ GeV
    (for ll=ee, μμ)
- Topological selection (optimized according to mass regions and channels):
  - b jet veto
  - **$\Delta\phi_{ll}$ < 1.3, 1.8**
  - **M_{ll} < 50, 65, 80 GeV** and $|P_T^{ll}| > 30$ GeV
  - Transverse mass **$0.75*M_H<M_T<M_H$**



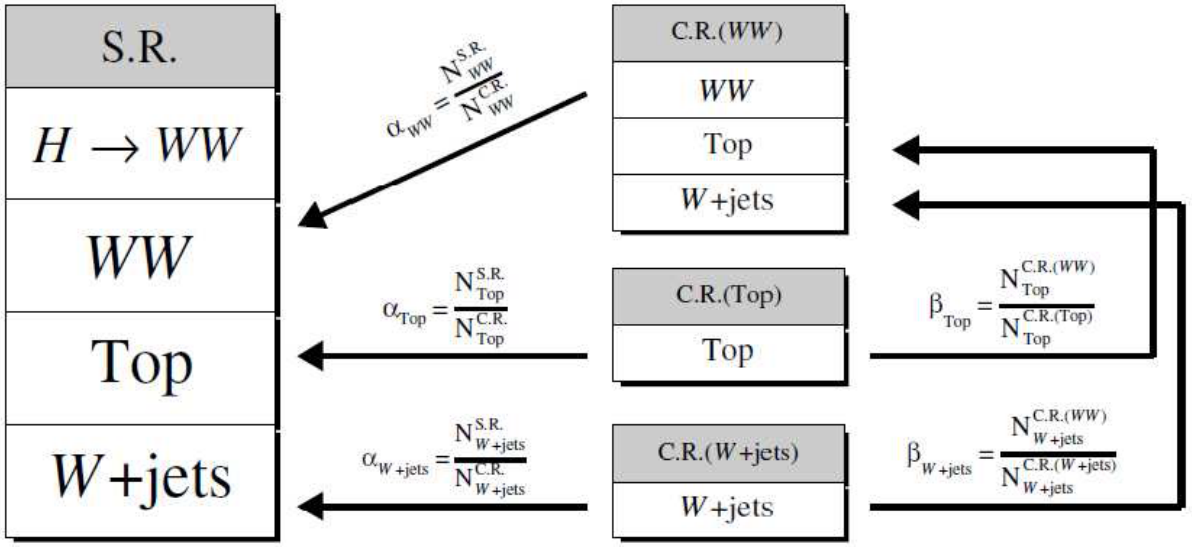
SM Higgs Boson

H -> WW* -> lνlν (l=e,μ):

- Main backgrounds:
  - **WW** (M_{ll} and $\Delta\phi_{ll}$)
  - Z+jets (ABCD - M_{ll} and MET)
  - Top (jet veto, reverse the b jet veto)
  - W+jets (anti isolation)

- Data driven method
  - Define control regions (sample enriched in particular backgrounds)
  - Subtract the contamination of other backgrounds in control regions
  - Define "comparable" variables
  - Propagate estimation from control regions to signal regions (using scales from data/MC)

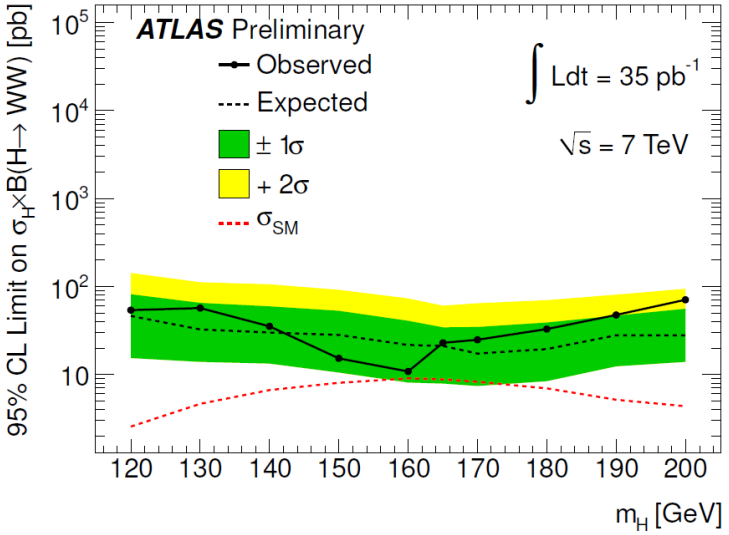
$$N_{WW}^{SR} = \alpha_{WW} \times (N_{WW}^{CR} - \beta_{top} \cdot N_{top}^{CR} - \ldots)$$

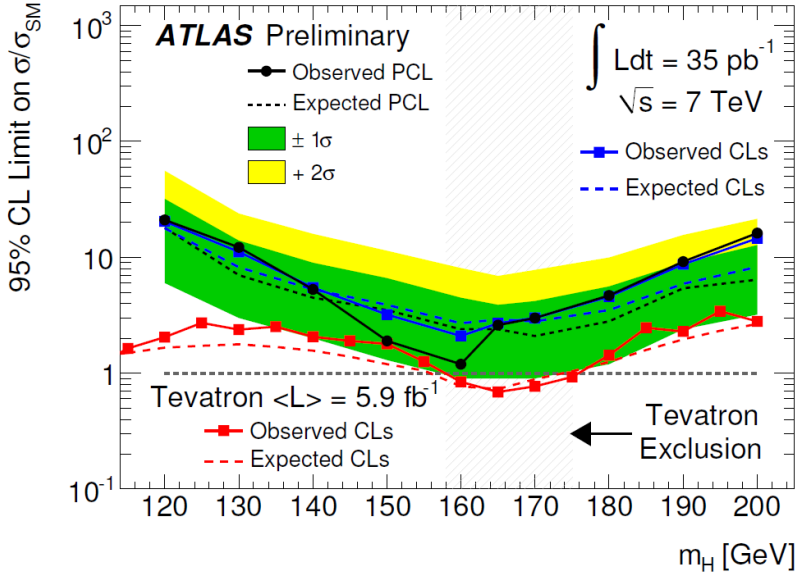


SM Higgs Boson

H -> WW* -> lνlν (l=e,μ):

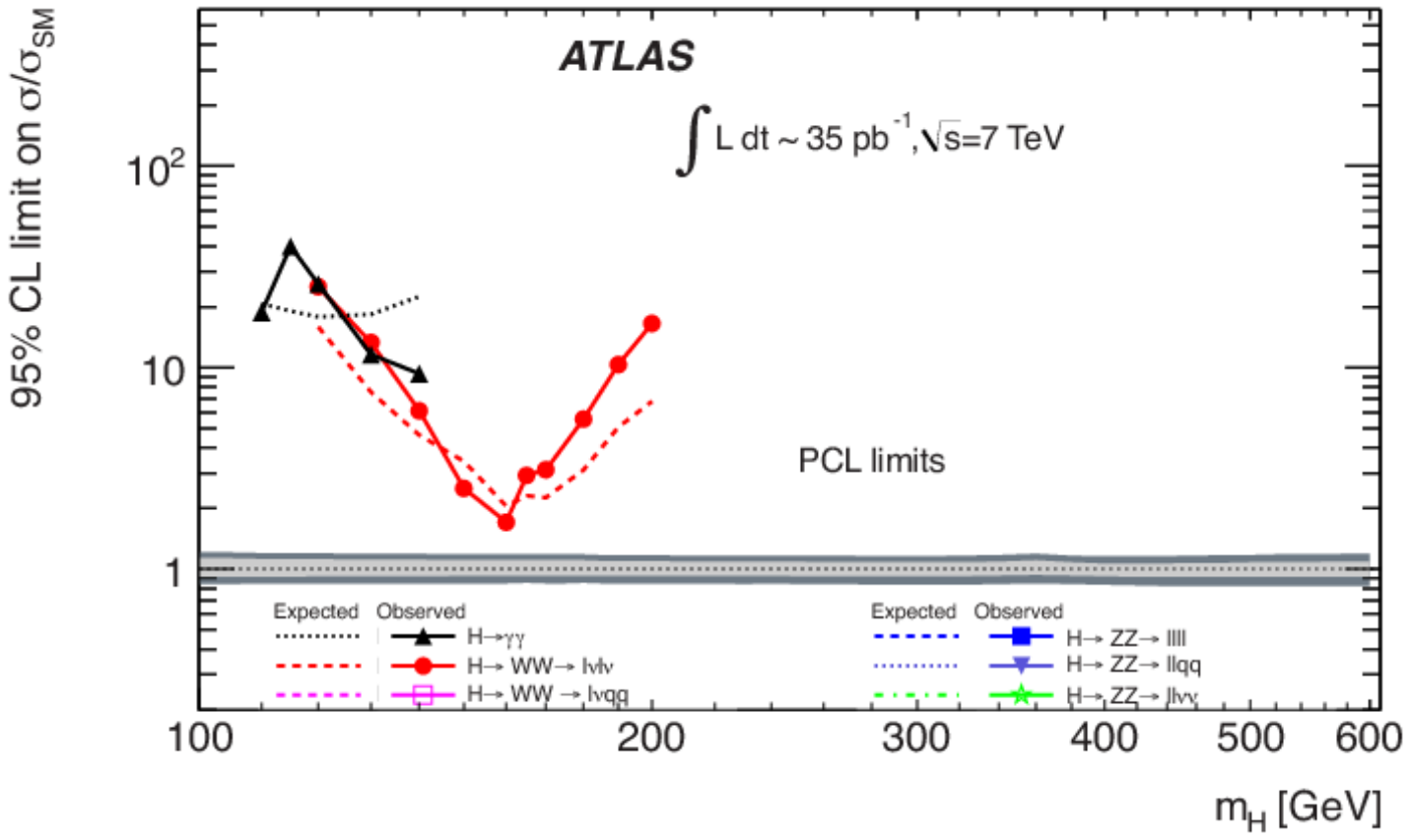
- Exclusion limit
- A 95% CL upper limit on σ x BR(H->WW*) :
  54 pb @ M_H=120 GeV
  11 pb @ M_H=160 GeV
  71 pb @ M_H=200 GeV
- 1.2 x σ_{SM} excluded @ M_H = 160 GeV (2.4 was expected)





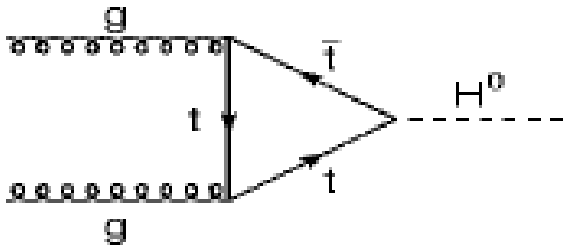
SM Higgs Boson

H -> WW* -> lνlν (l=e,μ):



SM Higgs Boson

H -> WW* -> lνqq (l=e,μ):

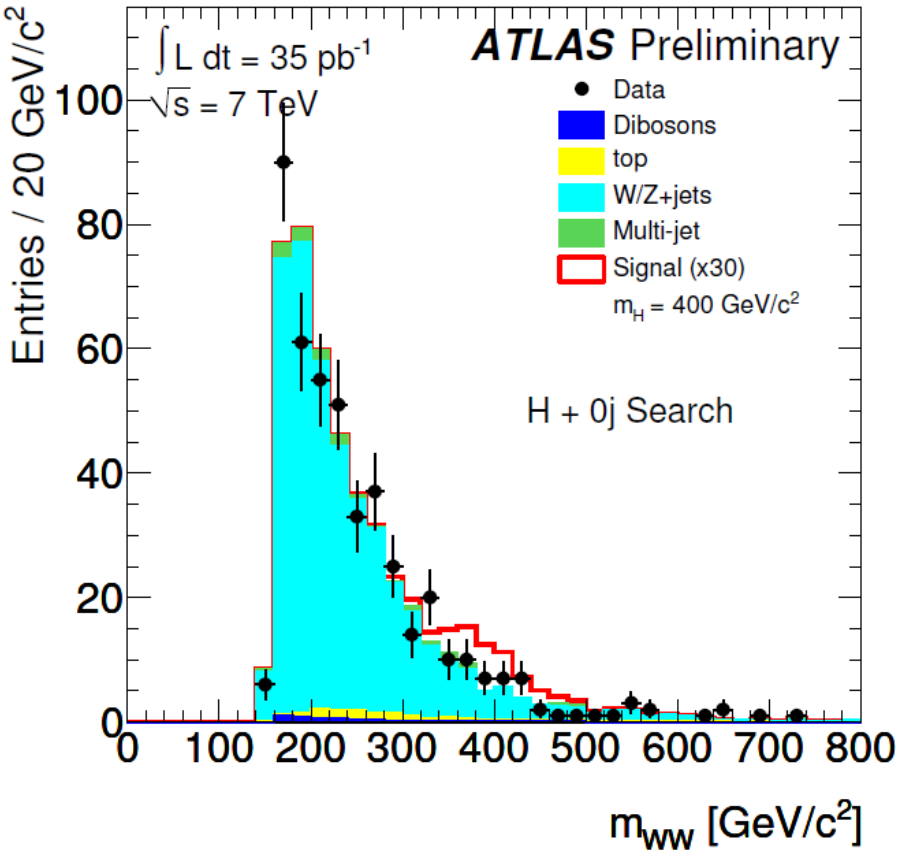


- Mass range 220-600 GeV
  Models: SM and 4th generation of fermions
- 2 channels – H+0j, 1j
  - Jet pT > 30 GeV and Jet $|\eta| < 4.5$
- Preselection cuts:
  - **1 muon or electron (fullfill tight selection criteria) with pT > 30 GeV**
  - 0 additional muon or electron (fullfill medium selection criteria) with pT > 20 GeV
  - **MET > 30 GeV** (against QCD)
  - **2 or 3 jets with pT > 30 GeV and $|\eta| < 4.5$**
  - 2 jets with $71 < M_{jj} < 91$ GeV and $|\eta| < 2.8$
  - b jet veto (against top)

SM Higgs Boson

H -> WW* -> lνqq (l=e,μ):

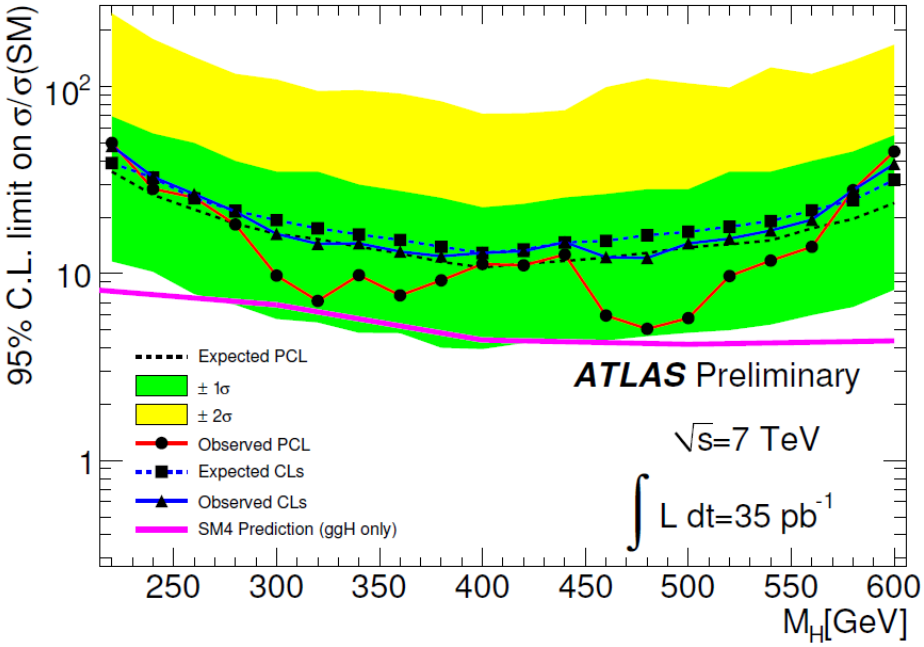
- Main backgrounds:
  - W/Z+jets (Data)
  - Multi-jet (Data)
  - Top (MC)
  - Diboson (MC)
- Strategy to estimate:
  - Data driven method:
    - Estimation using a fit to E_T^{miss} distribution
    - Shape from MC (W/Z+jets) or from an anti isolated region (multi-jet)
- Mass reconstruction
  - Using $M_{l\nu} = M_W$ constraint
  - Smallest $|P_z^{\nu}|$



SM Higgs Boson

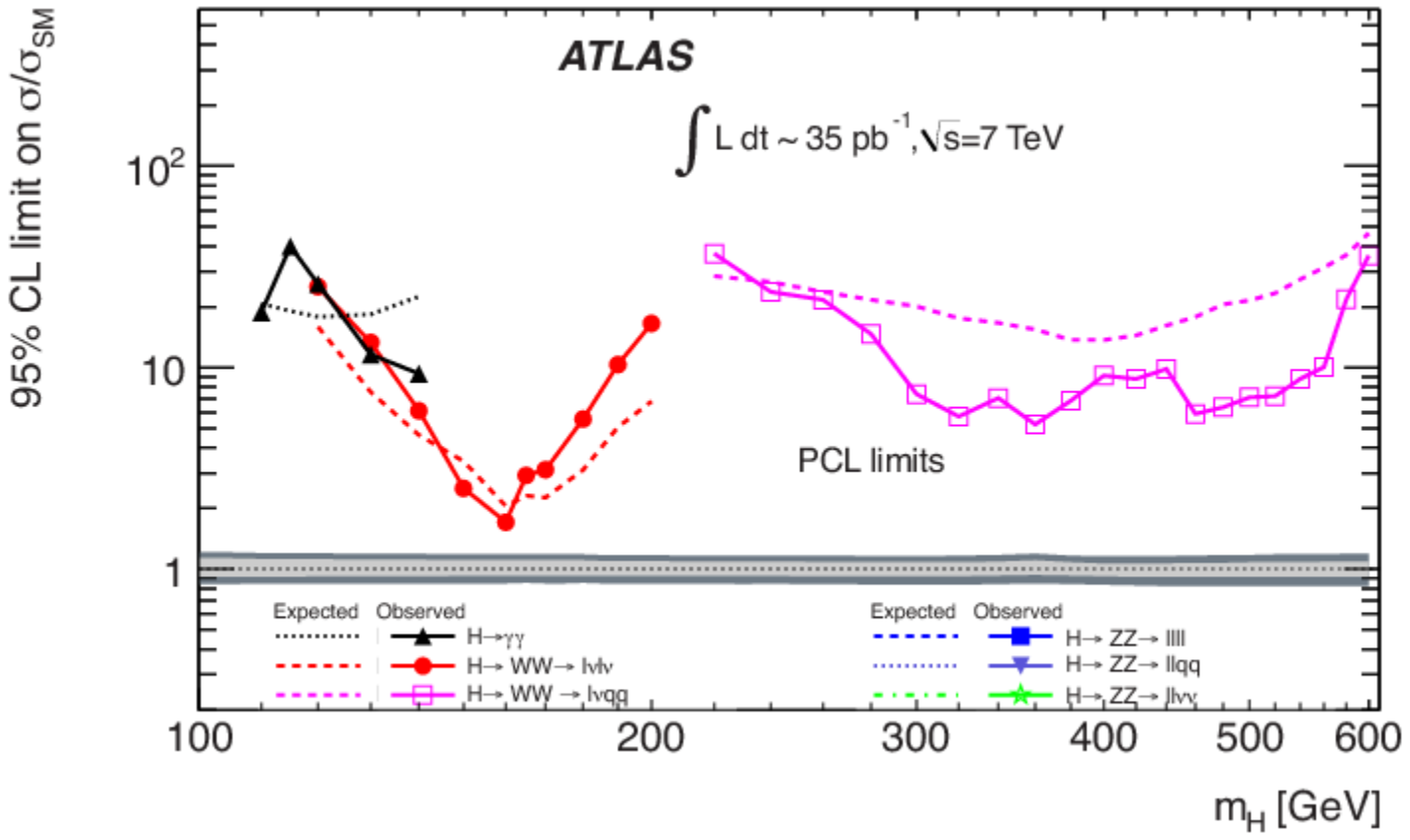
H -> WW* -> lνqq (l=e,μ):

- Exclusion limit
- Exponential fit to the background to set limits with a profile likelihood (systematic sources as nuisance parameters)
- At M_H = 320 GeV, the 95% CL upper limit is approximately 7.13 x σ_{SM} (15.3 was expected)
- For the SM4 prediction, no value of M_H is excluded.



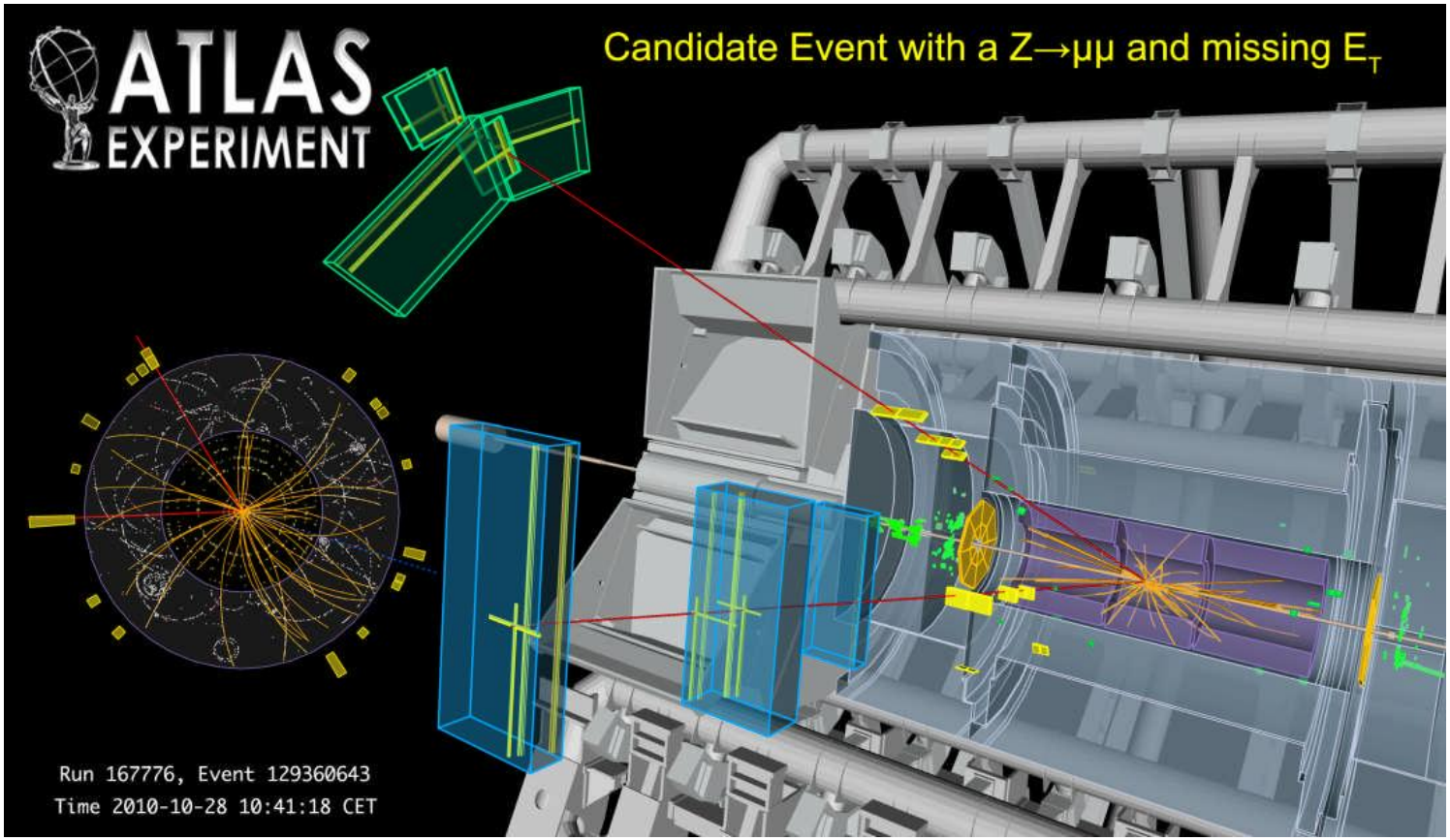
SM Higgs Boson

H -> WW* -> lνqq (l=e,μ):



SM Higgs Boson

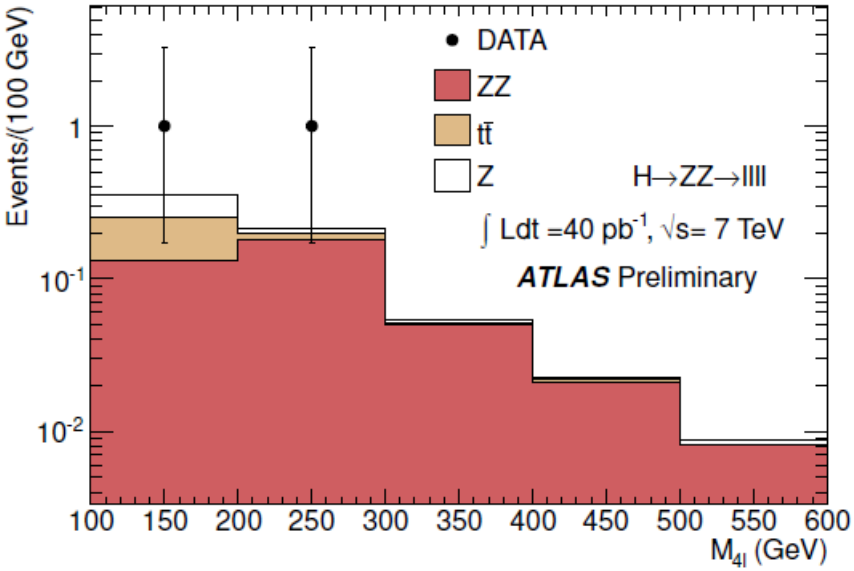
H -> ZZ (data 2010):



SM Higgs Boson

$H \rightarrow ZZ^* \rightarrow llll$ (l=e,μ):

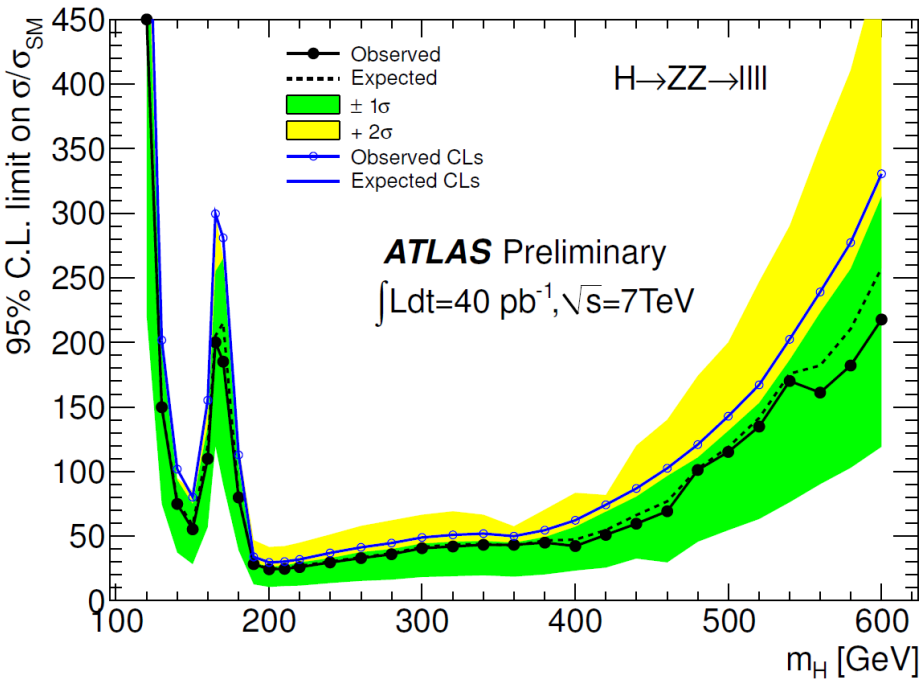
- Mass range 130-600 GeV
  Fully reconstructed final state
- Preselection cuts:
  - **>1 quadruplet of 2 pairs of same-flavour opposite charge leptons**:
    - >2 leptons in the quadruplet with pT > 20 GeV
    - Z_{l1l2} – the dilepton pair closest to the Z boson mass
      $|M_{l1l2}-M_Z| < \Delta M_{12}$ (12-15 GeV)
    - Z_{l3l4} – the sub leading
      (M_{l3l4} > 15-60 GeV)
    - ΔR (l,l') > 0.1 for all leptons
  - Suppress leptons from b-hadrons with impact parameter significance requirements on the 2 least energetic leptons



SM Higgs Boson

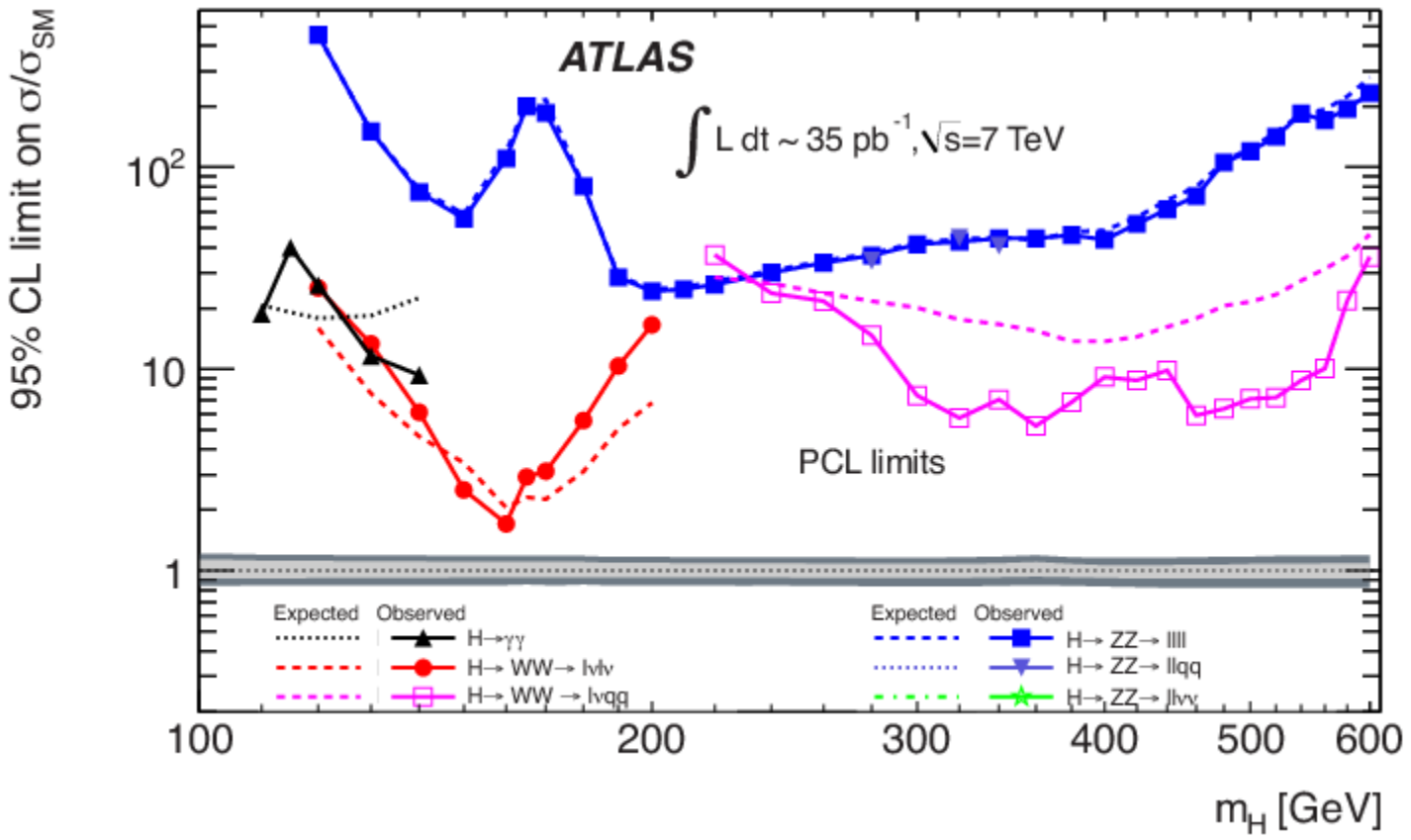
H -> ZZ* -> llll (l=e,μ):

- Backgrounds
  - ZZ (irreducible)
  - Z+QQ (reducible)
- Limit:
  - At M_H < 130 GeV – too low BR
  - At M_H ~ 160 GeV – 2 on shell W
  - At M_H > 180 GeV – 2 on shell Z
  - At M_H = 200 GeV, the 95% CL upper limit on σ is approximately 24 x σ_{SM} (25 was expected)



SM Higgs Boson

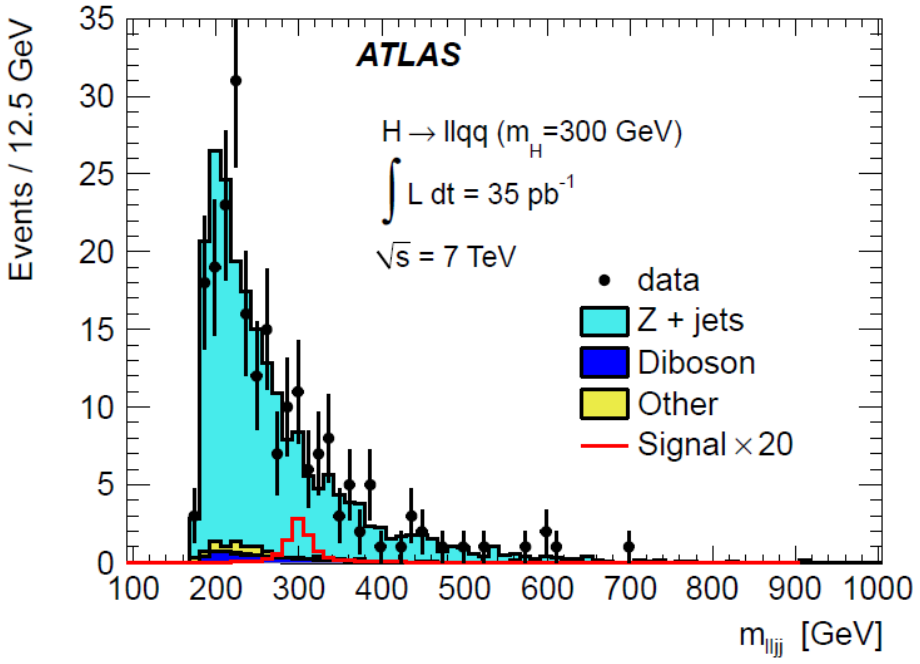
H -> ZZ* -> llll (l=e,μ):



SM Higgs Boson

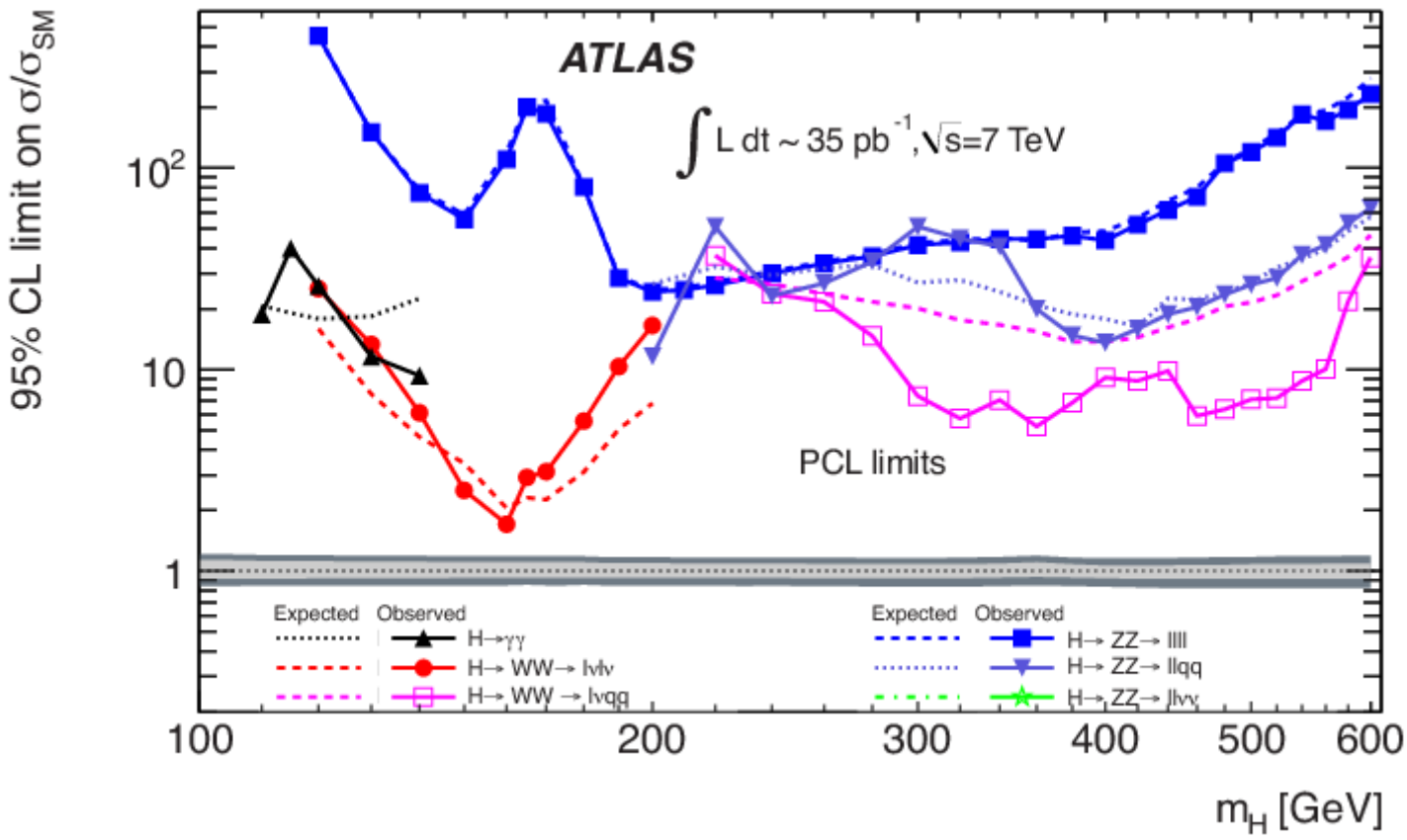
H -> ZZ* -> llqq (l=e,μ):

- Mass range 200-600 GeV
  2 on shell Z – suppress background
- Preselection cuts:
  - **2 same flavour leptons (muon opposite sign)**
  - $76 < M_{ll} < 106$ GeV
  - MET < 50 GeV
  - **≥ 2 jets with 70 < Mjj < 105 GeV**
  - For $M_H \geq 360$ GeV:
    - Jet pT > 50 GeV
    - $\Delta\phi_{jj} < \pi/2$ and $\Delta\phi_{ll} < \pi/2$
  - Constraining the dijet to the Z mass
- Backgrounds:
  - Diboson (irreducible – MC)
  - Z+jets (MC – after verifying in control region)
  - Top pair (reverse MET and M_{ll})
  - Multijet (data)



SM Higgs Boson

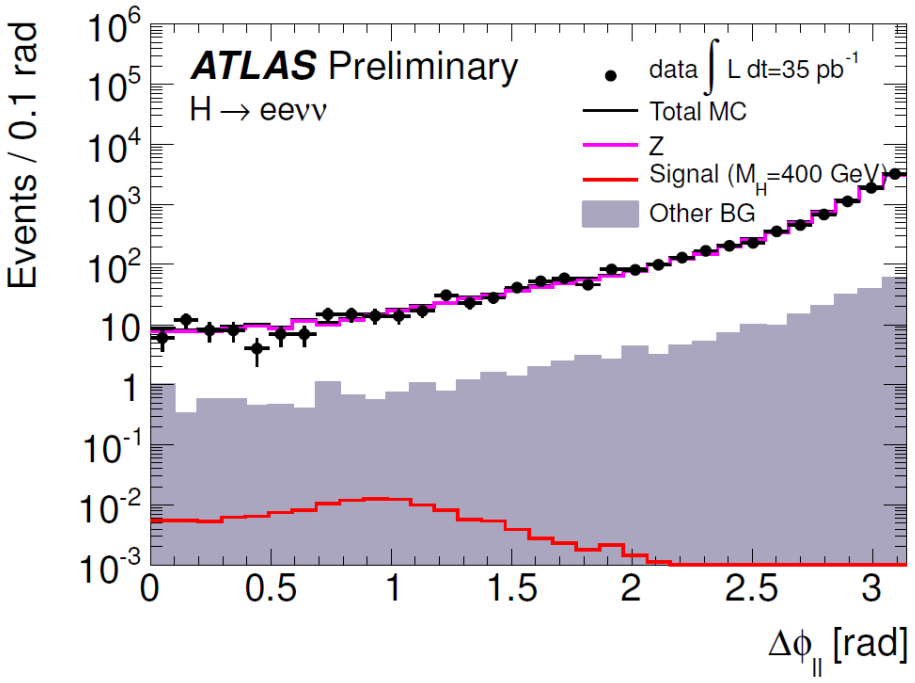
H -> ZZ* -> llqq (l=e,μ):



SM Higgs Boson

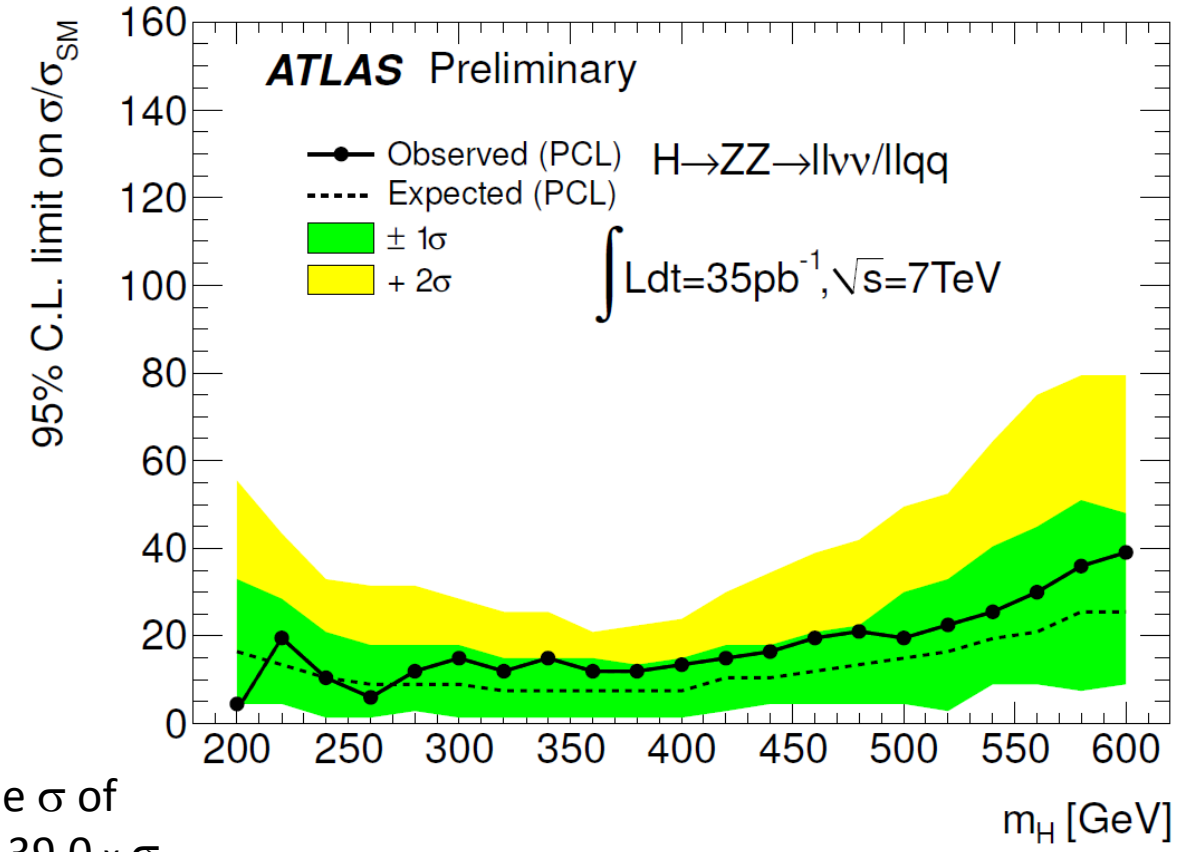
$H \to ZZ^* \to ll\nu\nu$ ($l=e,\mu$):

- Preselection cuts:
  - b jet veto
  - For M_H < 280 GeV:
    - **MET > 66 GeV**
    - $\Delta\phi_{ll}$ < 2.64
    - $\Delta\phi_{ll}$ > 1 ($M_H \leq 260$ GeV)
  - For $M_H \geq 280$GeV:
    - **MET > 82 GeV**
    - $\Delta\phi_{ll}$ < 2.25
  - Looking for the transverse mass
- Backgrounds:
  - Top pair and W+jets (control region)
- Significant contribution from H->WW->lvlv , but orthogonal selection, no overlapping events



SM Higgs Boson

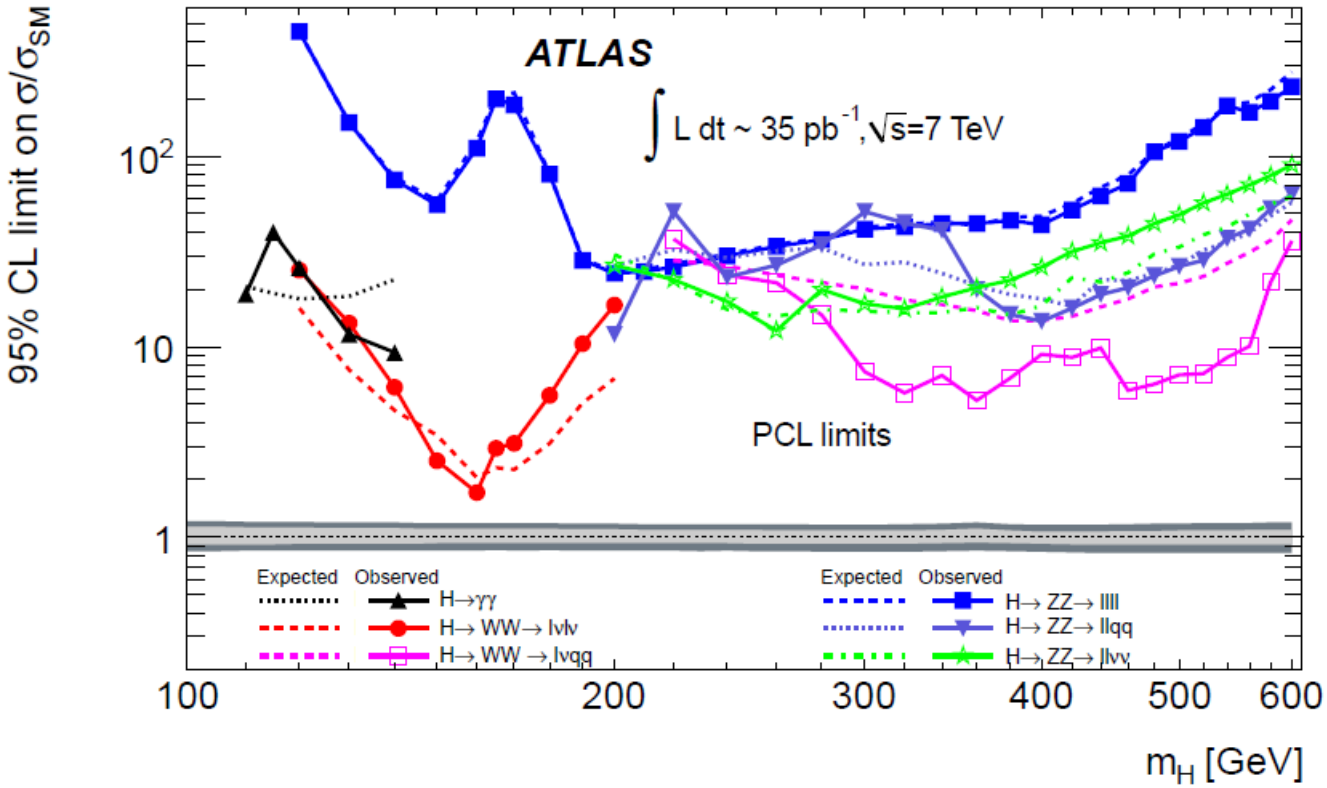
H -> ZZ* -> llqq/llνν (l=e,μ):



Upper limit on the σ of between 3.5 and 39.0 x σ_{SM} (6.5 – 25 was expected)

SM Higgs Boson

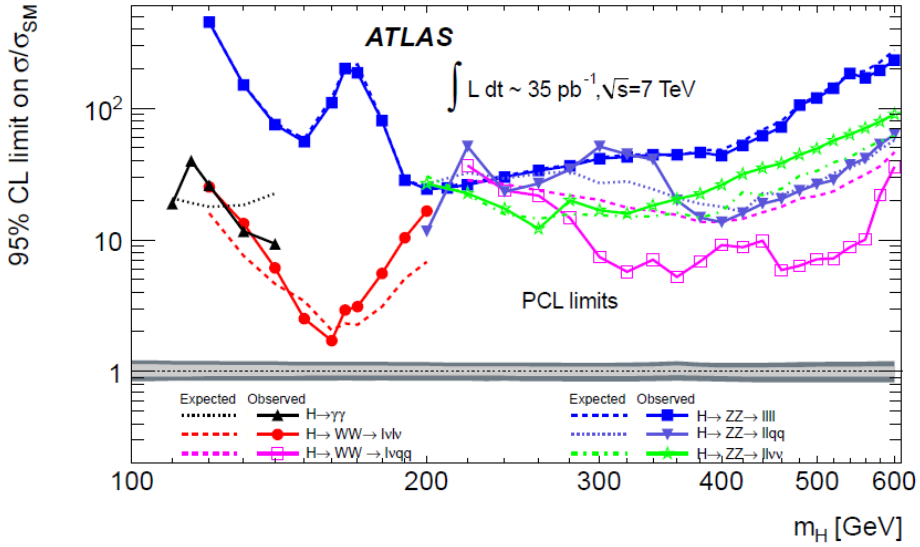
H -> ZZ* -> llqq/llνν (l=e,μ):



SM Higgs Boson

Combination (data 2010):

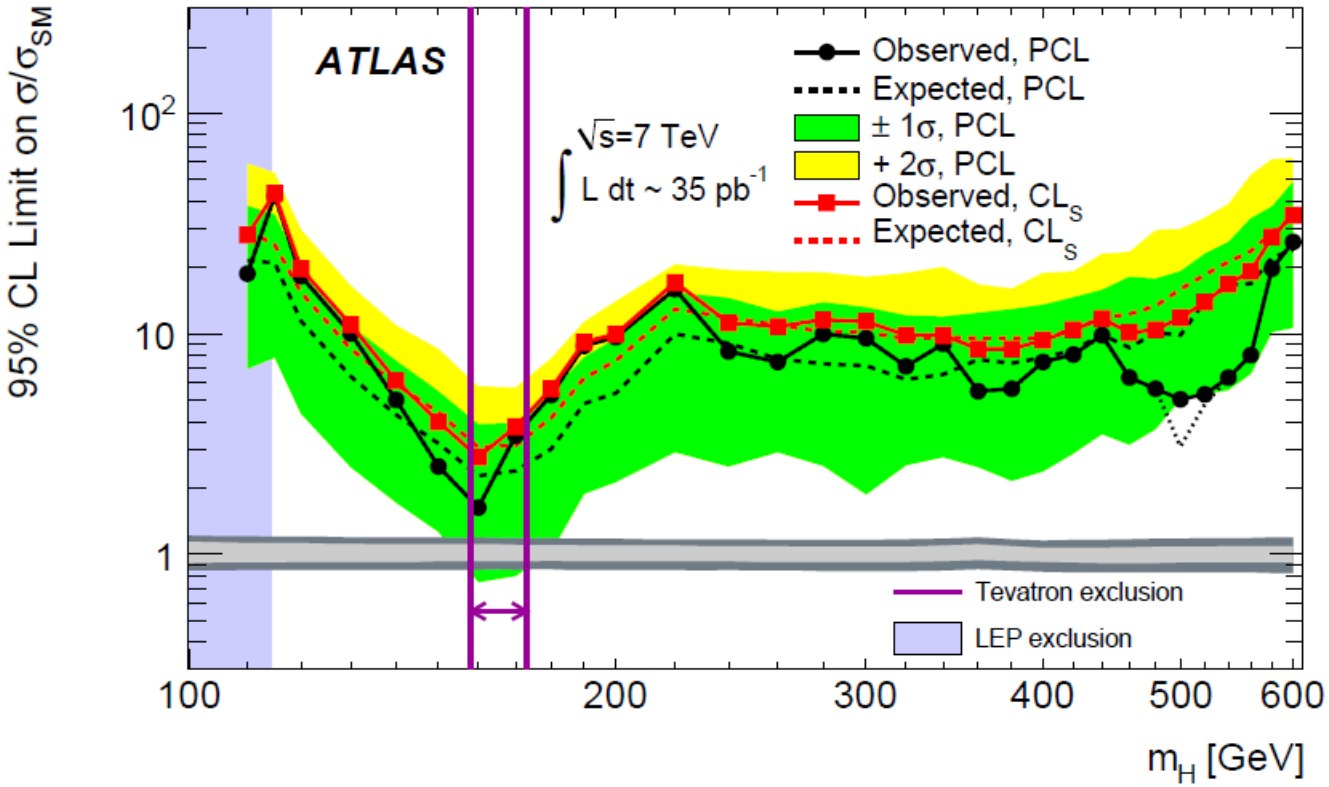
- The expected and observed cross section limits, normalized to the σ_{SM}, as a function of the Higgs boson mass for the individual search channels.
- The visually most apparent difference between expected and observed limit is in the H -> WW -> lvqq channel, which has a deficit approaching one sigma both at 320 and 480 GeV.
- These results use the profile likelihood method with a power constraint (PCL).
- The theory uncertainties:
  - Gluon-Fusion: 15-20%
  - VBF: 3-9%



SM Higgs Boson

Combination (data 2010):

- The expected and observed upper limits on the total σ divided by the expected SM Higgs boson σ.
- **Highest sensitivity is in the mass range 160-170 GeV**

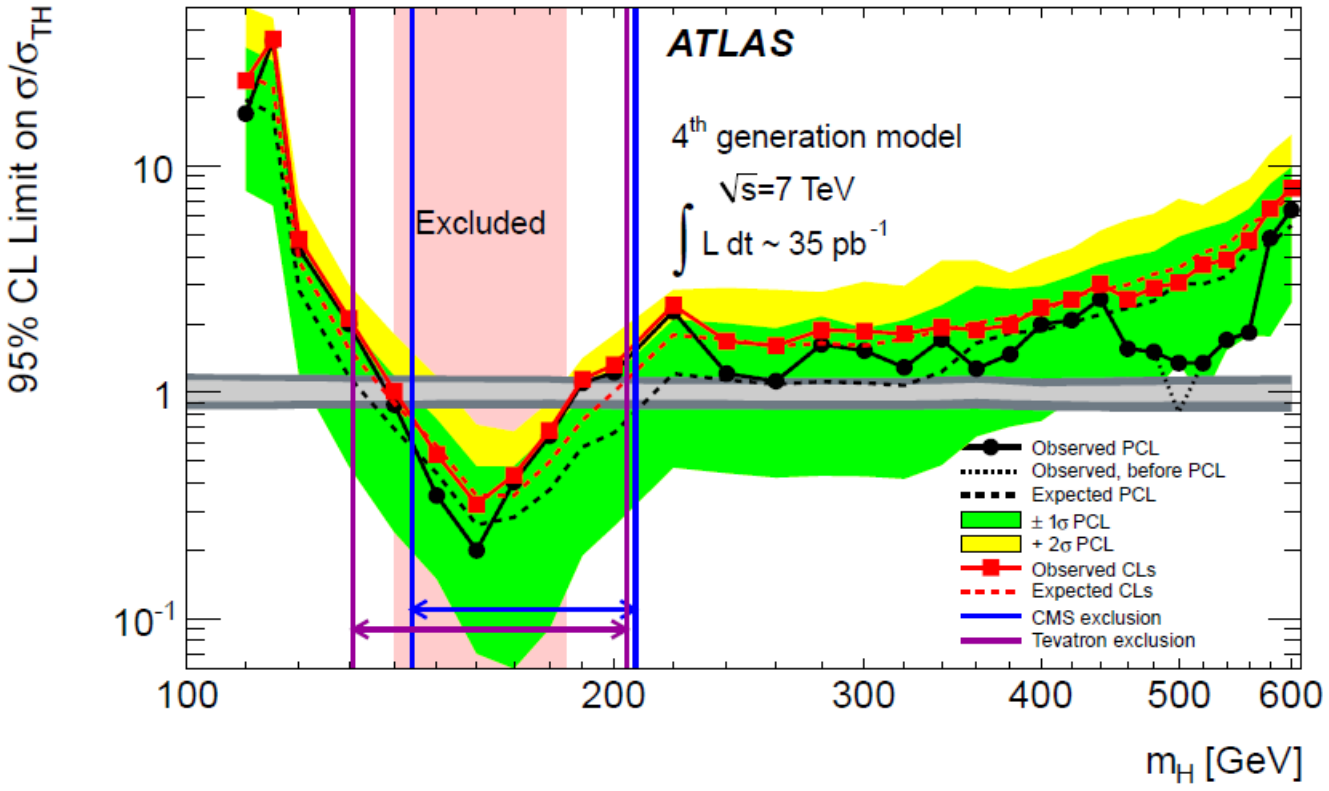


arXiv 1106.2748v2

SM Higgs Boson

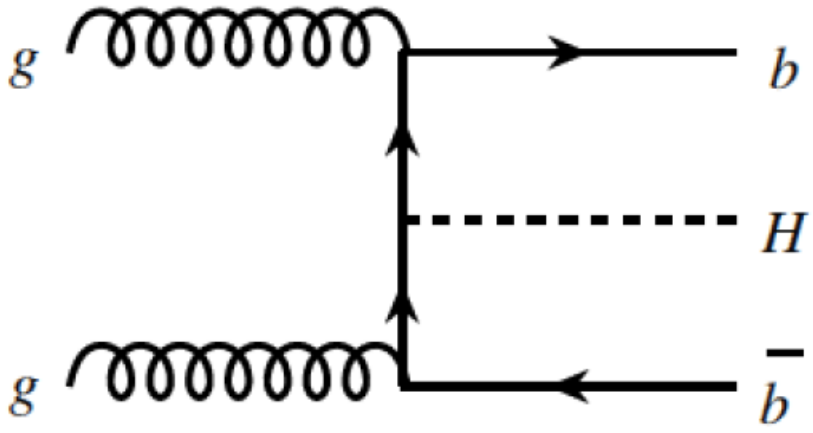
Combination (data 2010):

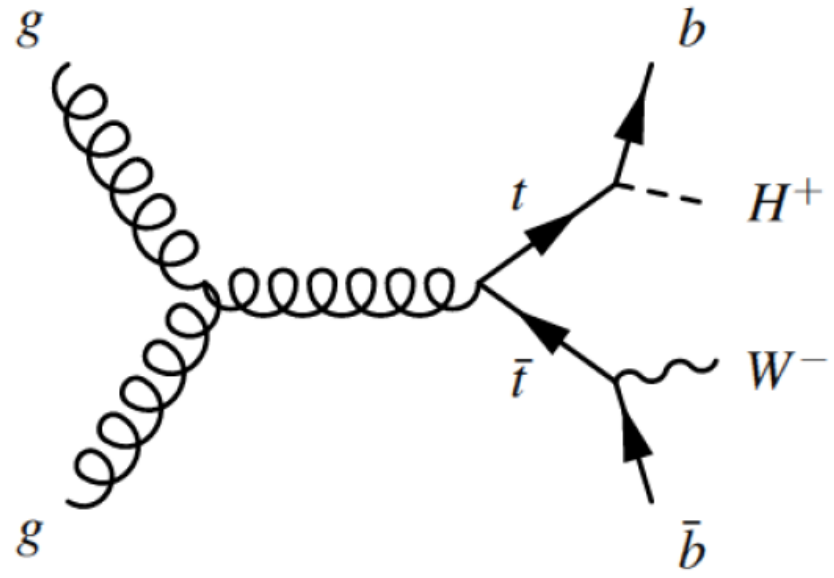
- The expected and observed upper limits on the total σ divided by the expected 4SM Higgs boson σ.
- **Excluded for a Higgs mass in range 140 – 185 GeV**
  (135-210 GeV was expected)



MSSM Higgs Bosons

- **MSSM – Minimal Supersymmetric Standard Model**
- At tree level, MSSM Higgs sector described by two parameters:
  - M_A = mass of CP odd Higgs
  - tanβ = ratio of the 'vev' of 2 Higgs doublets
- **MSSM Higgs: h, H, A, H±**
  - Neutral Higgs bosons – h (CP even), H (CP even), A (CP odd)
  - Charged Higgs bosons - $H^{\pm}$
- On top of the SM channels, one could also observe:
  - $H \rightarrow \mu\mu, \tau\tau$
  - $H^+ \rightarrow \tau\nu$, *cs* ($M_{H^+} < M_t$)
  - $H^+ \rightarrow \chi^+ \chi^0$
- $\sigma_{MSSM} \sim (\tan\beta)^2 \times \sigma_{SM}$

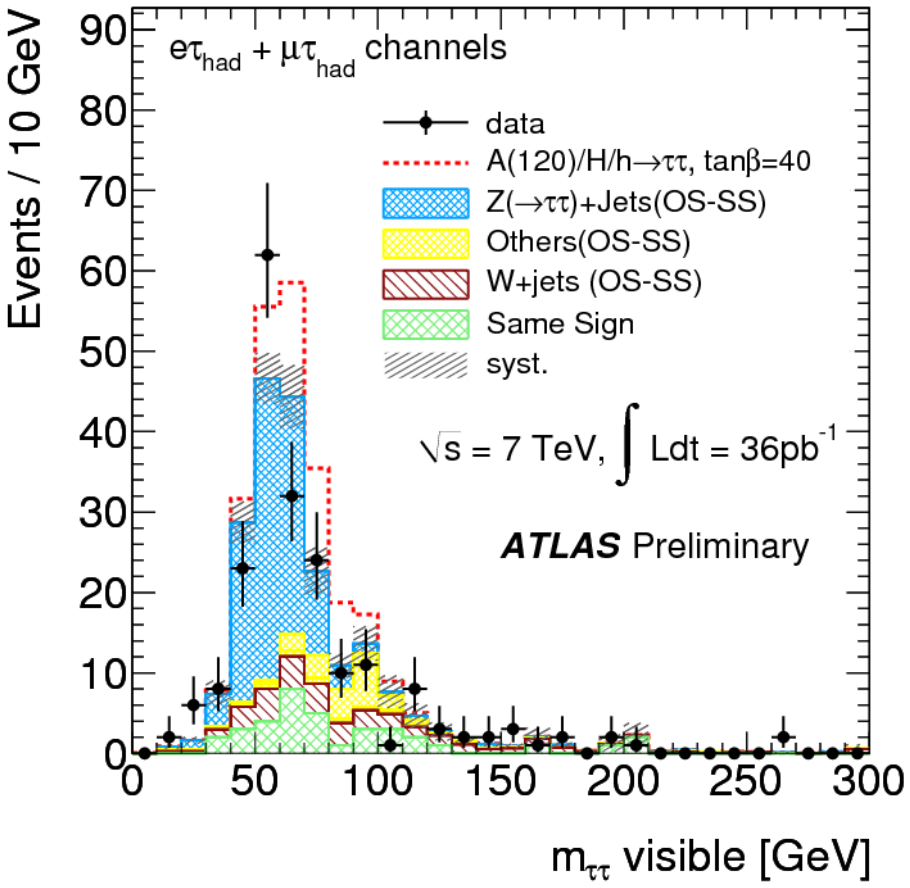




MSSM Higgs Bosons

$H \to \tau\tau \to l\nu\tau_{had}$ ($l=e,\mu$):

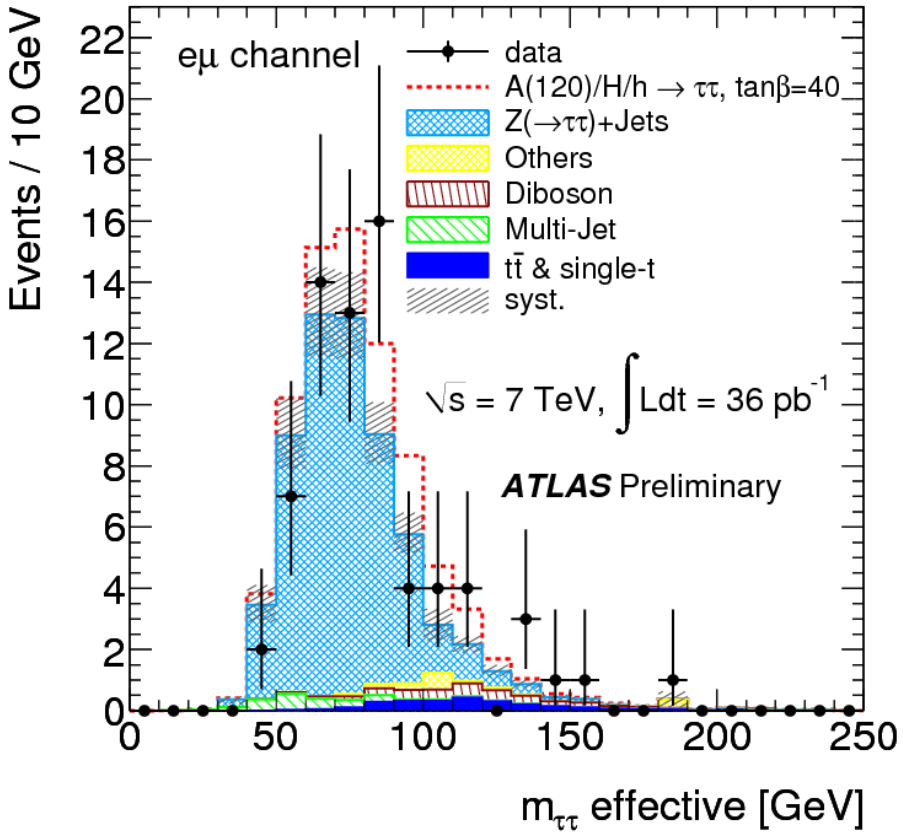
- Mass range 90-300 GeV
- Preselection cuts:
  - **$N_e+N_\mu = 1$**
  - $pT_e > 20$ GeV, $pT_\mu > 15$ GeV
  - **$N_\tau = 1$**, $pT_{\tau,vis} > 20$ GeV
  - $Q_\tau \cdot Q_{e/\mu} = -1$
  - **MET > 20 GeV**
  - $M_T < 30$ GeV
- Backgrounds
  - $Z \to \tau\tau$ (Validate with $Z \to \mu\mu$ data by embedding τ's in the place of μ)
  - QCD and W+jets (same sign control sample)
  - $Z \to ee, \mu\mu$ (MC)
  - Diboson (MC)
  - Top (MC)



MSSM Higgs Bosons

H -> ττ -> eμ+4ν:

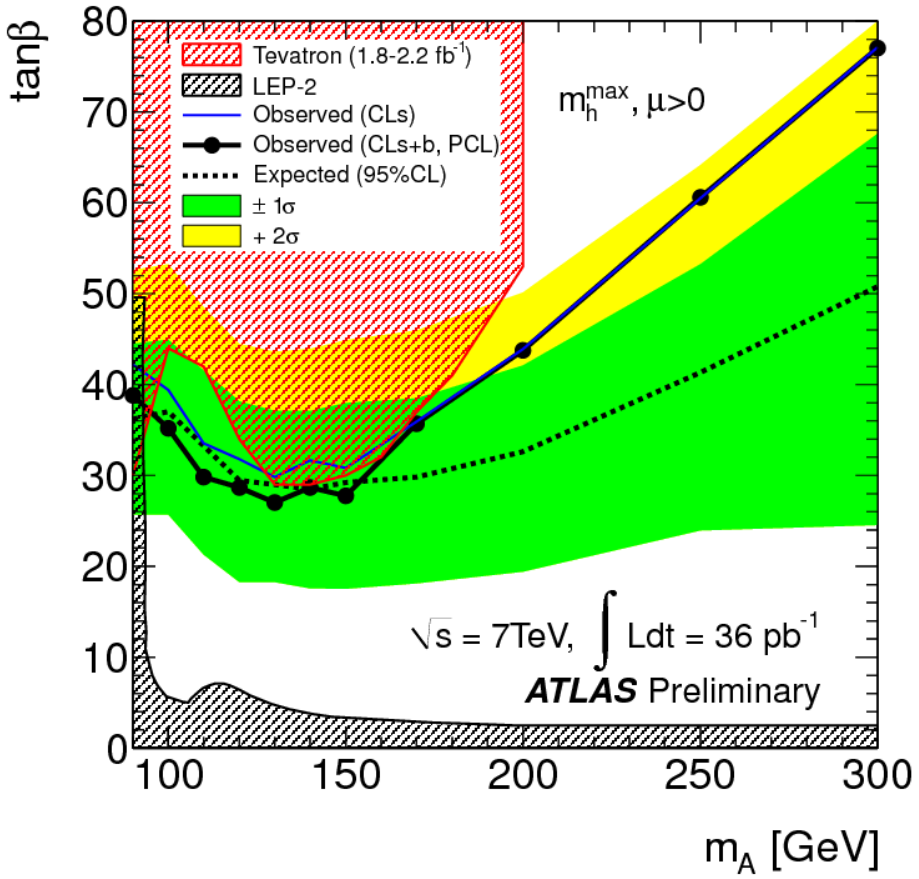
- Mass range 90-300 GeV
- Preselection cuts:
  - $N_e = 1$
  - $N_\mu = 1$
  - $pT^e > 20$ GeV, $pT^\mu > 15$ GeV
  - $Q_\mu \cdot Q_e = -1$
  - $H_T < 120$ GeV (against TOP)
- Backgrounds
  - Z -> ττ (embedding method for validation)
  - QCD (ABCD method)
  - W+jets (MC)
  - Z -> ee, μμ (MC)
  - Diboson (MC)
  - Top (MC)



MSSM Higgs Bosons

H -> ττ -> lντ_{had} (l=e,μ):

- Exclusion limit
- Low Higgs mass:
  ≥ tan β ~ 30
- High tan β:
  200 ≤ M_A ≤ 300 GeV



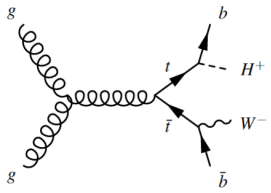
MSSM Higgs Bosons

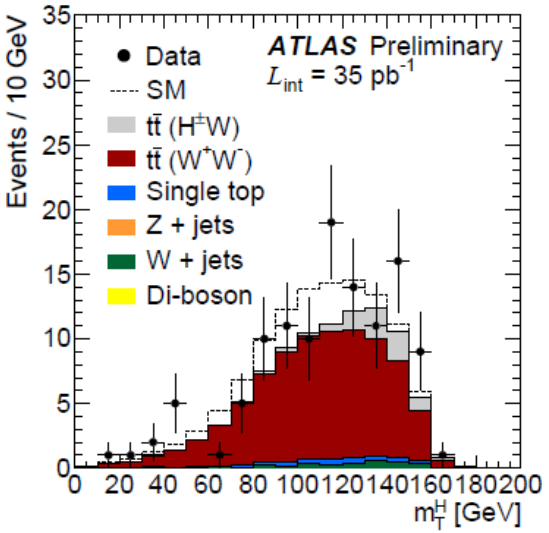
Charged Higgs:

$H^+ \rightarrow \tau\nu$ ($\tan\beta > 1$):

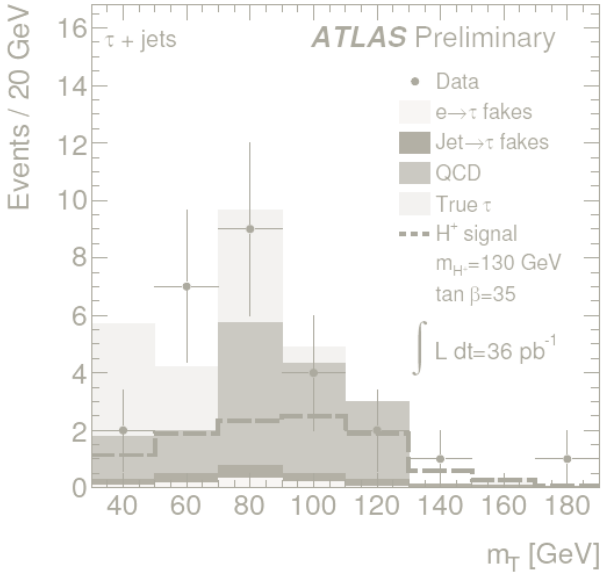
- $\tau \rightarrow \nu l \nu$ (leptonic tau)
  - W -> lν (di-lepton) or W -> qq (single lepton)
  - Discriminating variables:
    - COS θ* and M_T^H / M_{T2}^H

$$(m_T^H)^2 = \left(\sqrt{m_{\text{top}}^2 + (\vec{p}_T^{\,l} + \vec{p}_T^{\,b} + \vec{p}_T^{\,\text{miss}})^2} - p_T^b \right)^2 - \left(\vec{p}_T^{\,l} + \vec{p}_T^{\,\text{miss}} \right)^2$$





- $\tau \rightarrow \nu qq$ (hadronic tau)
  - W -> lν / qq
  - Estimating backgrounds from data
    - Fakes from electrons
    - Fakes from muons
    - Fakes from jets
    - QCD



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$$\cos\theta_l^* = \frac{2m_{bl}^2}{m_{\text{top}}^2 - m_W^2} - 1$$

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  - W -> lν / qq
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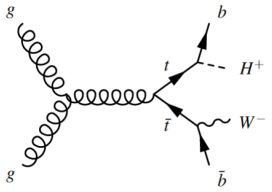

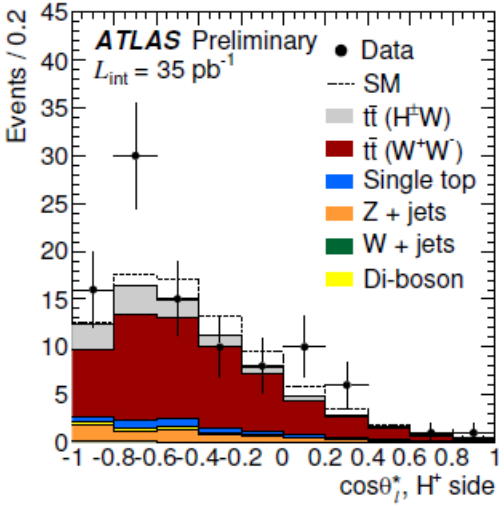

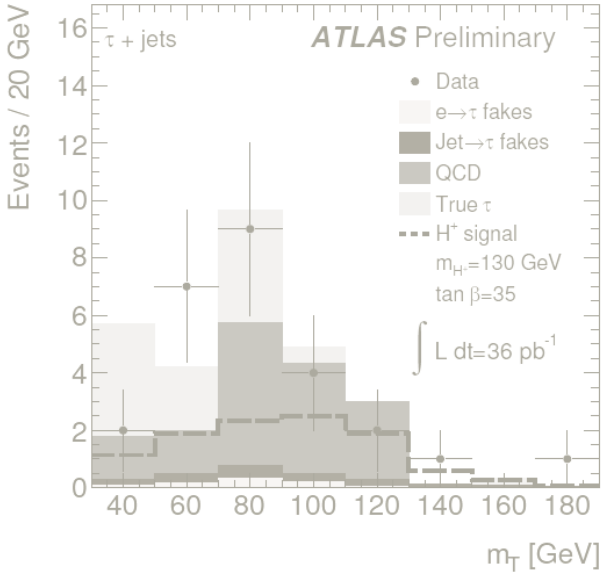

MSSM Higgs Bosons

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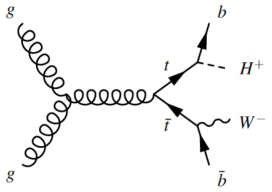
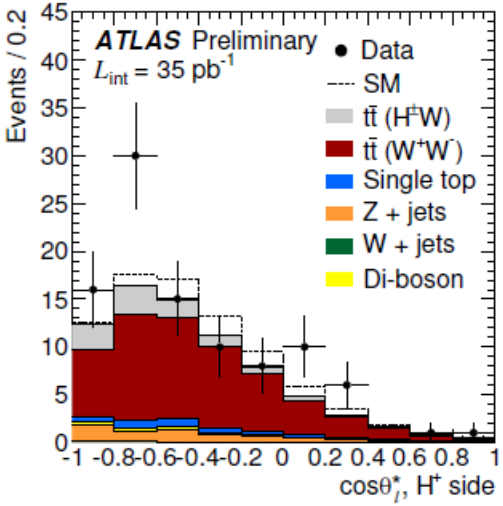
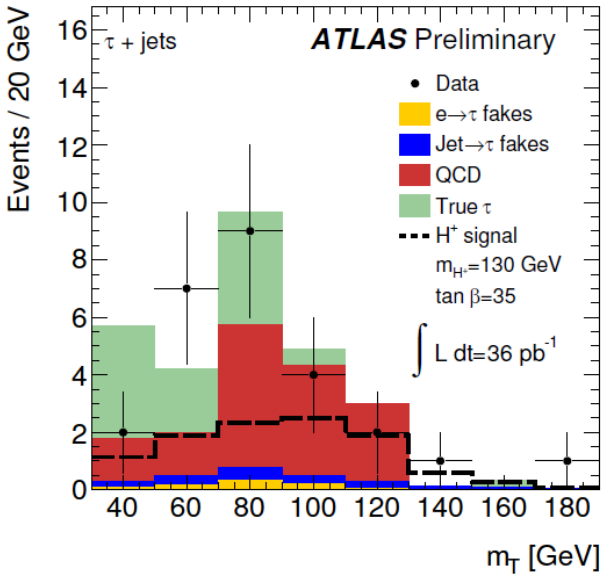


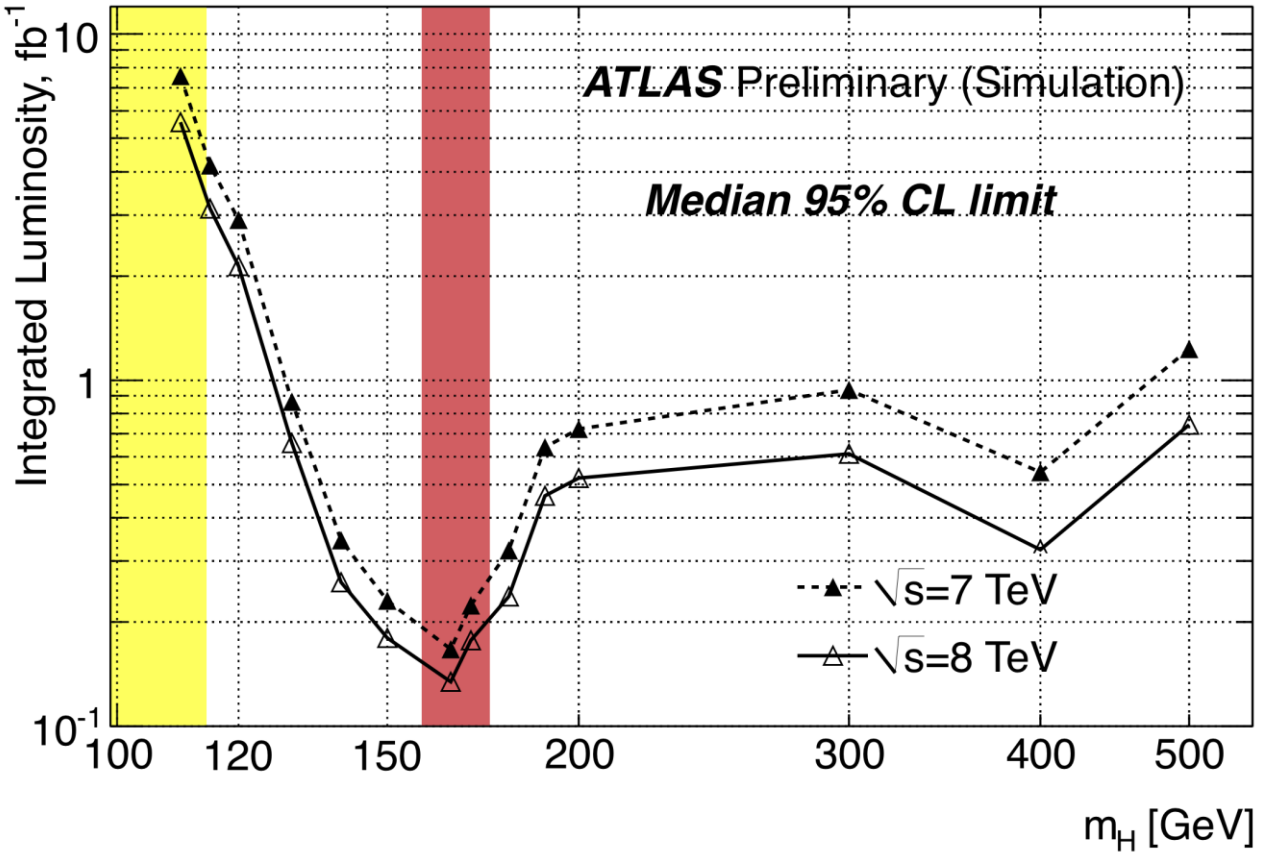




Summary

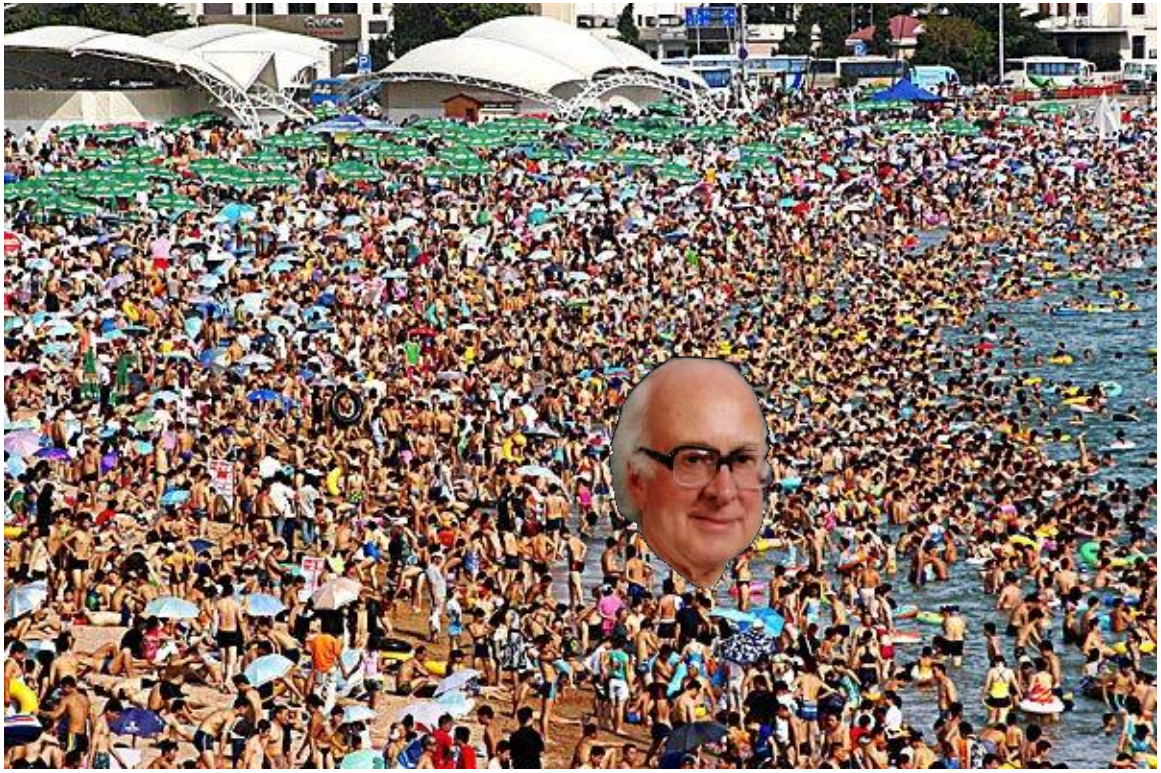
- With ~36 pb^{-1}, ATLAS excluded the $Higgs_{4SM}$ at $140 < M_H < 185$ GeV
- ATLAS also put an upper limit of $2.3 \times \sigma_{SM}$ in 160-170 GeV
- With 1 fb^{-1} of data, ATLAS expects to achieve a combined SM-like Higgs boson exclusion sensitivity in the range $130 < M_H < 460$ GeV

Summary


Integrated Luminosity, fb^{-1}
10
1
10^{-1}
100
120
150
200
300
400
500
m_H [GeV]
ATLAS Preliminary (Simulation)
Median 95% CL limit
$\sqrt{s}$=7 TeV
$\sqrt{s}$=8 TeV

Next year presentation

Next year presentation



Next year presentation