# Higgs Searches in ATLAS

*Henso ABREU*, LAL-Orsay

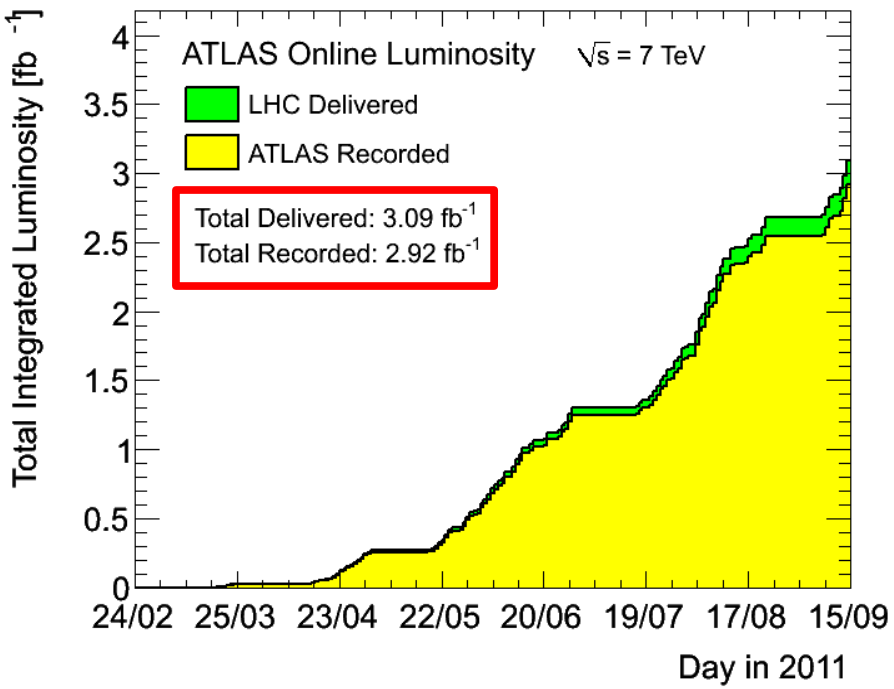
*QFTHEP'2011* Workshop

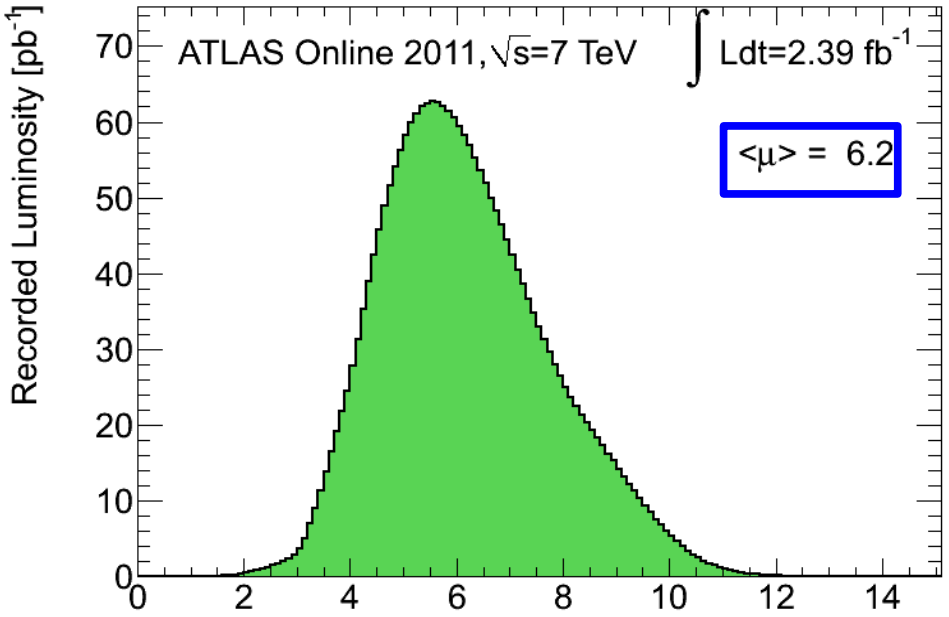
Sochi, 24th Sept. – 1th Oct. 2011

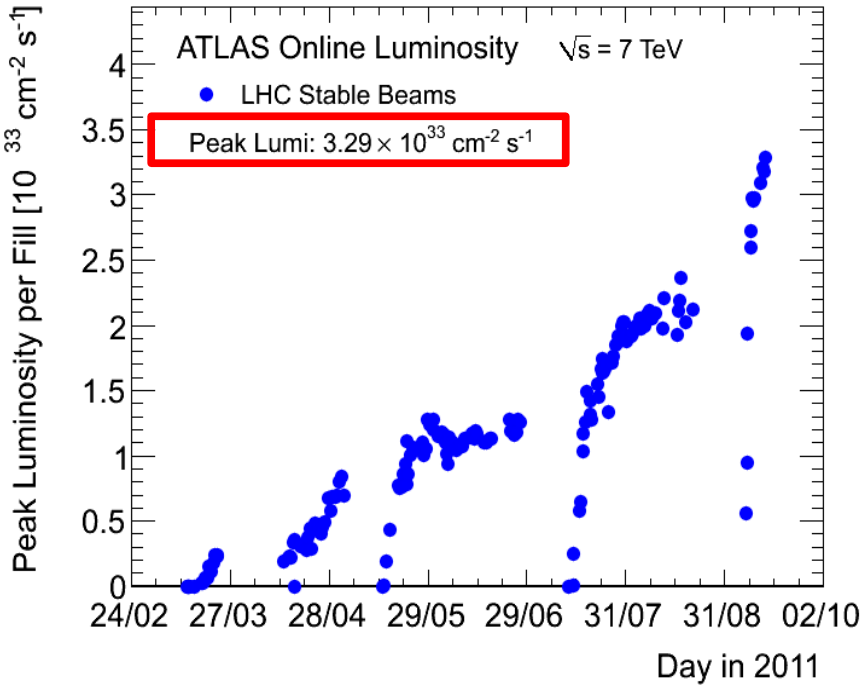
# OUTLINE

- The ATLAS detector data-taking in 2011
- SM Higgs boson production and decay
- SM Higgs searches
- SM Higgs Combination
- MSSM Higgs searches
- Summary

# ATLAS Data Taking in 2011



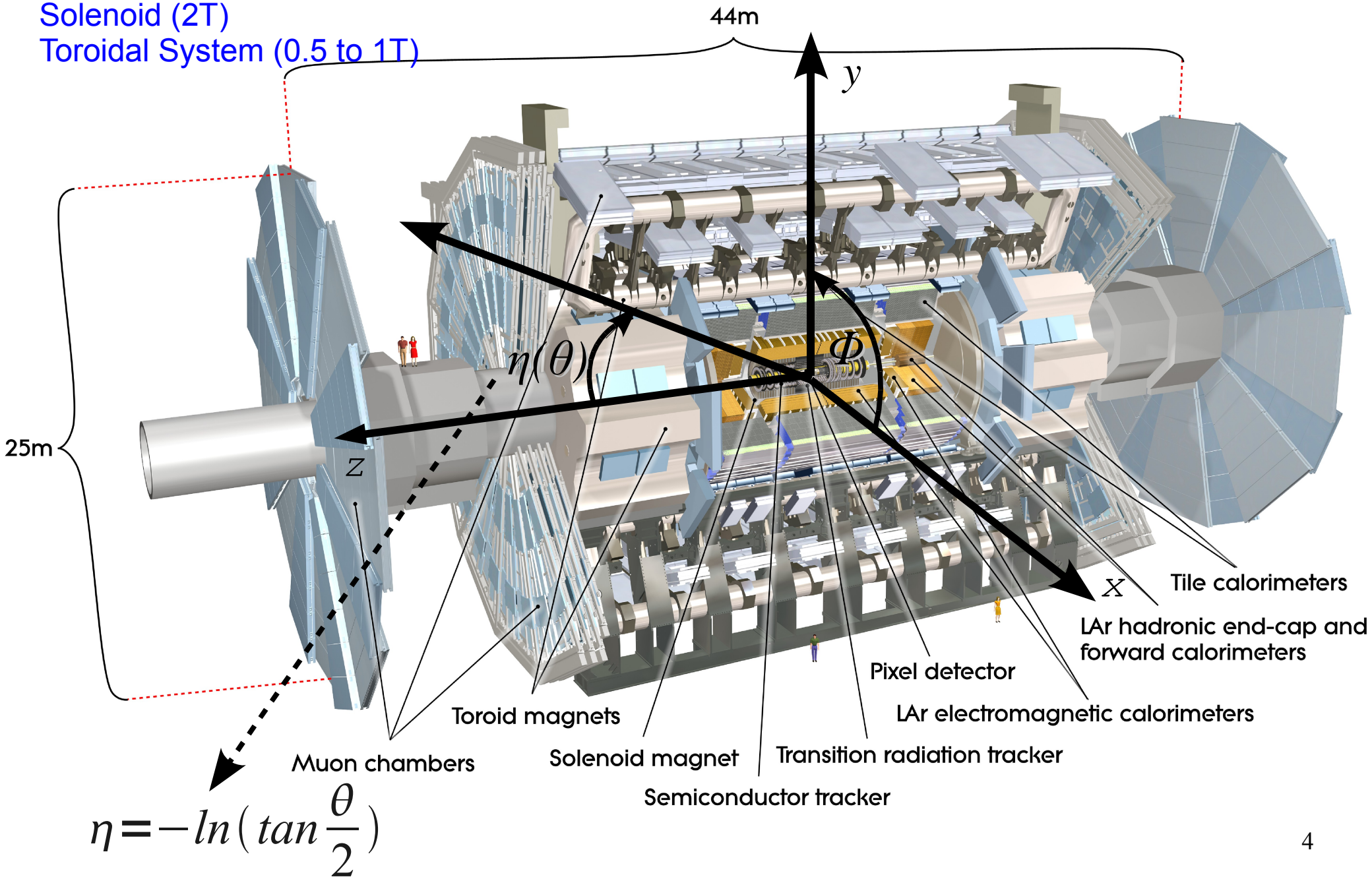



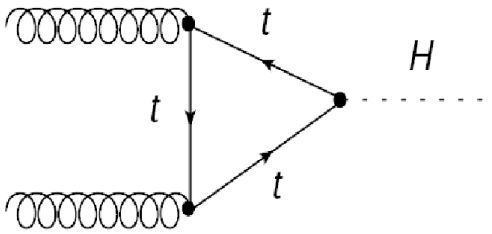

- Data taking efficiency ~ 95 %
- Expected data by December 2011 ~ *4 fb$^{-1}$??*

- **<u>Pile-up challenge</u>**
  - Impact on JET, MET, Isolation ...
  - Much progress in understanding performances with high level of pile-up.

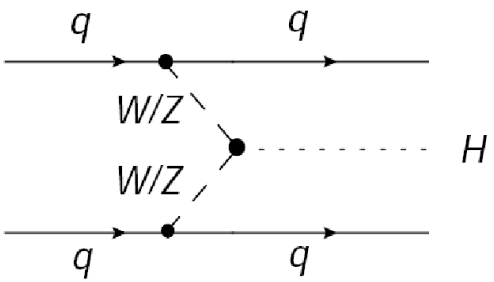
# A Toroidal LHC ApparatuS (ATLAS)



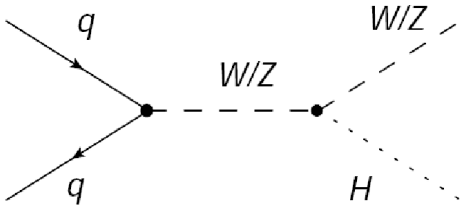
# SM Higgs boson production at the LHC



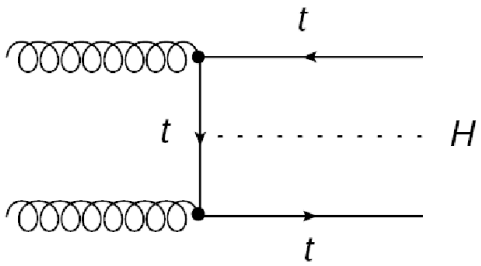

*gluon fusion*



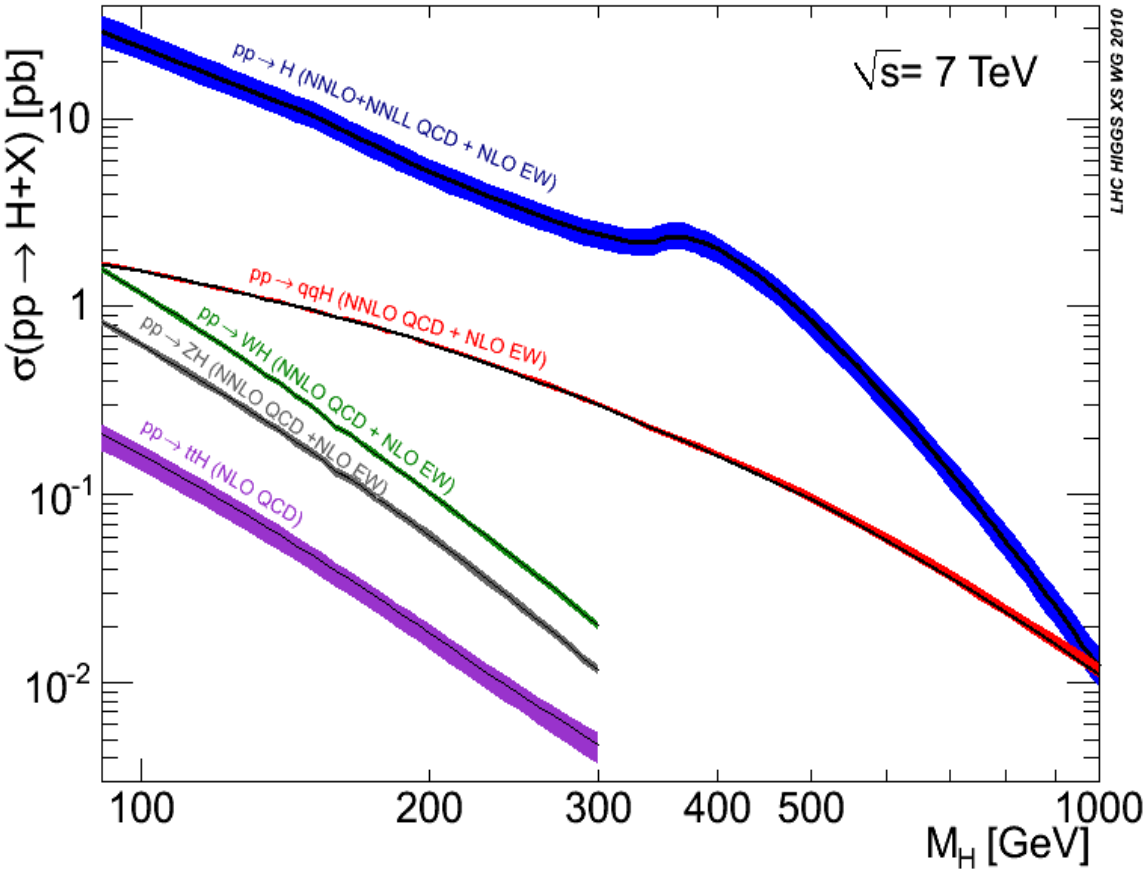

*Vector-Boson-Fusion (VBF)*




*associated production (W/Z)*



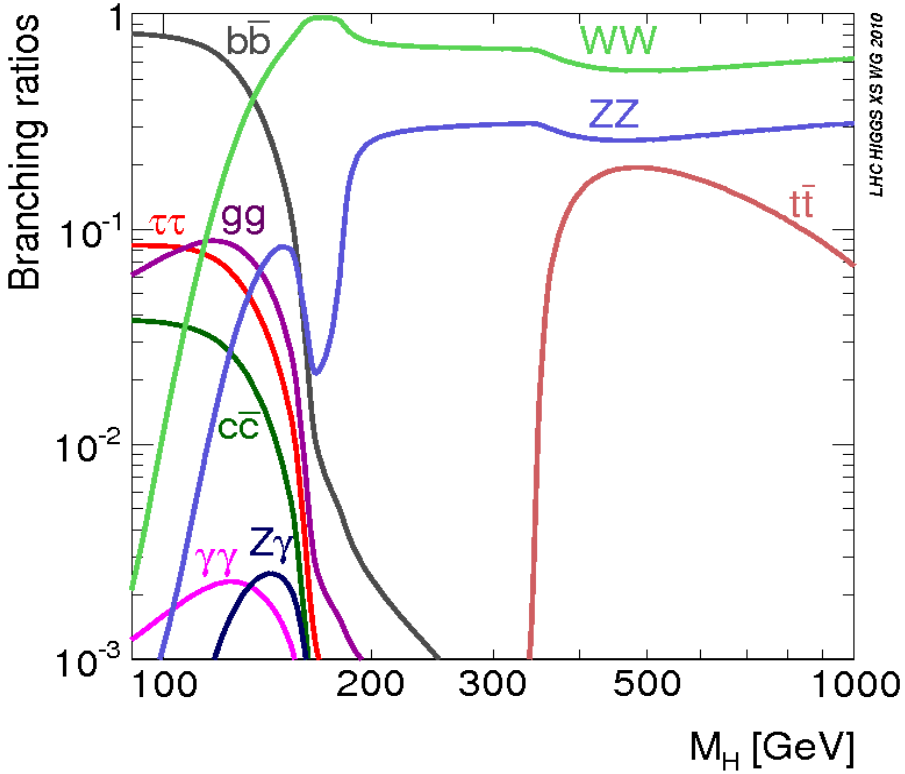

*associated production (ttbar)*

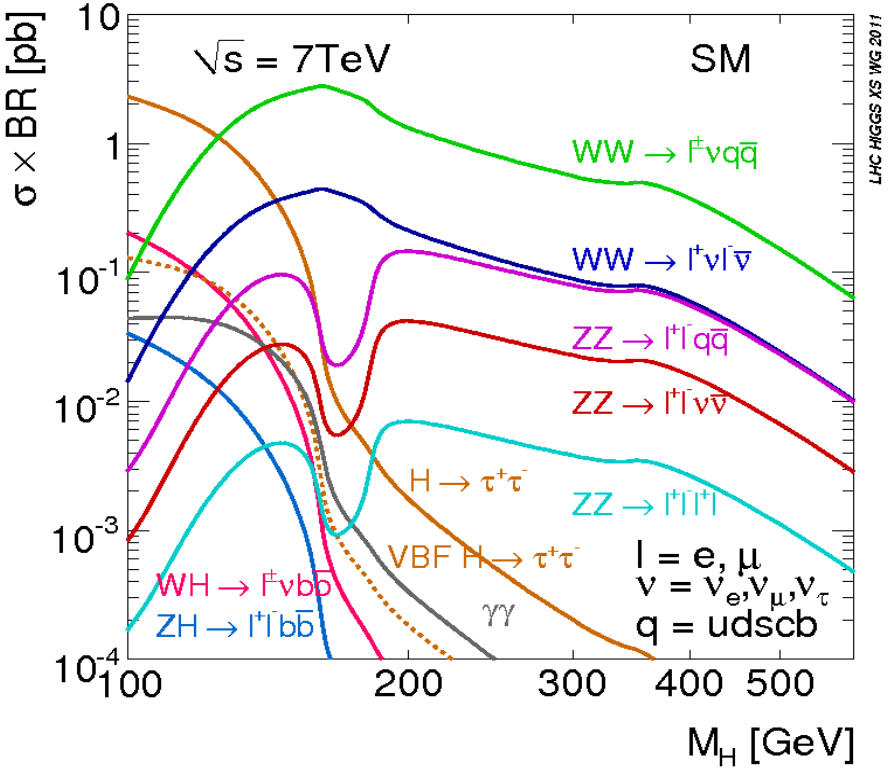



Typical uncertainties on total cross-sections

| | | |
|---|---|---|
| gg | 15-20 % | NNLO + NNLL + NLO EW |
| VBF | 5 % | NNLO + NLO EW |
| WH, ZH | 5 % | NNLO + NLO EW |
| $t\bar{t}$H | 15 % | NNLO |

# SM Higgs Decay Modes vs Mass at the LHC



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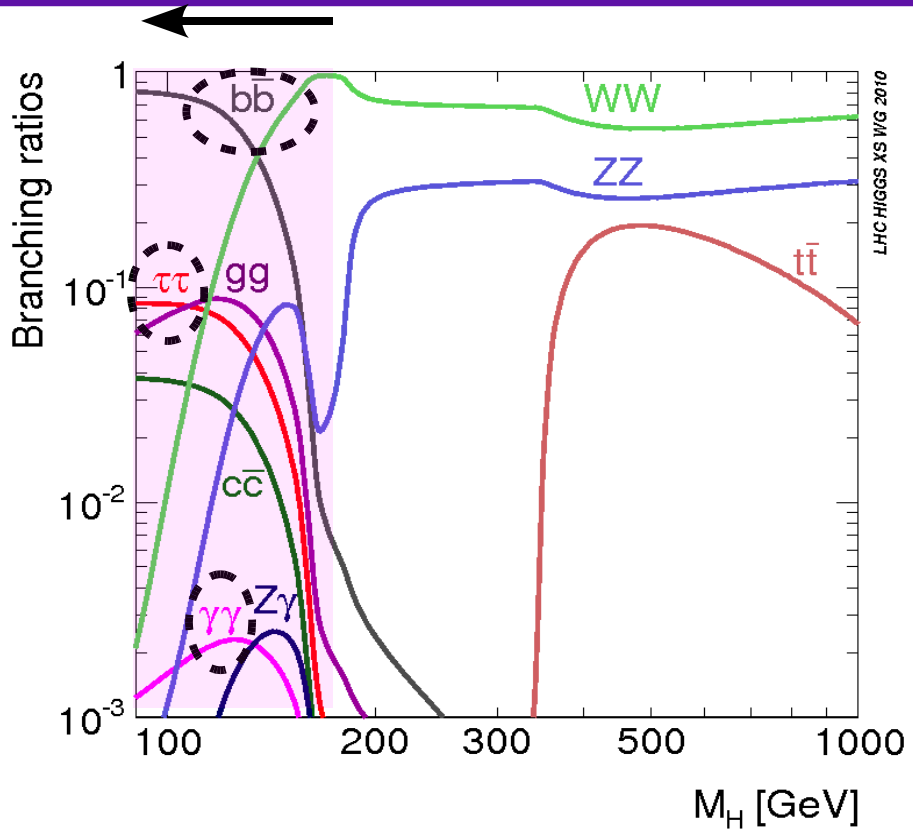


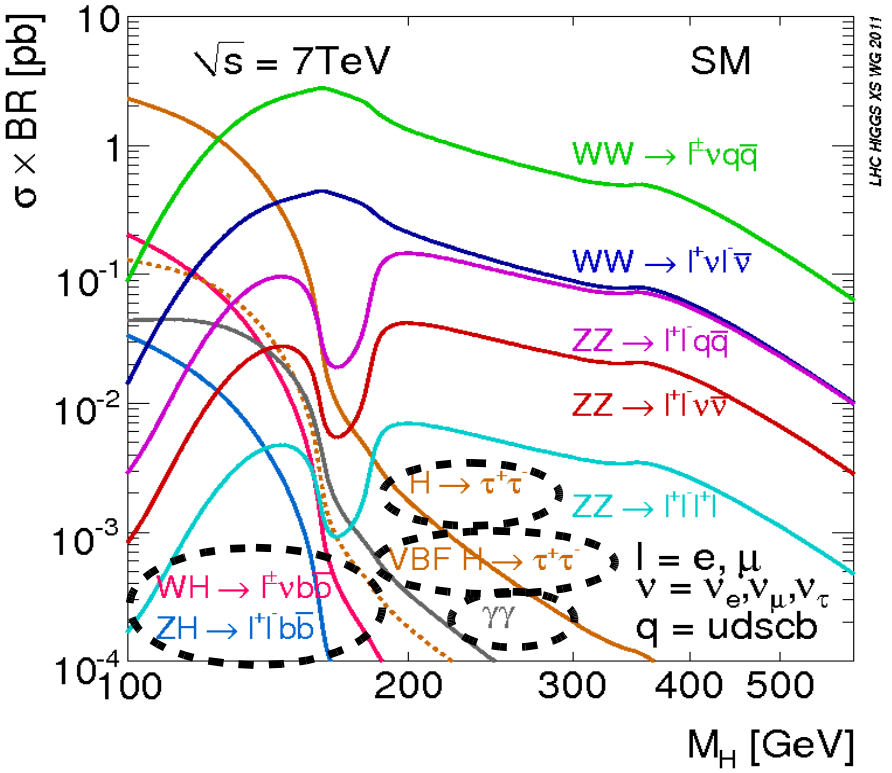


**Low mass regime:** ***$m_H$ < 140 GeV***

- $H \to \gamma\gamma$ : rare, but the best for this mass range.
- $W/Z + H \to b\bar{b}$ : dominant model at low mass. Higgs to quark couplings
- $H \to \tau\tau$ : good signal/background ratio, rare, use VBF signature.

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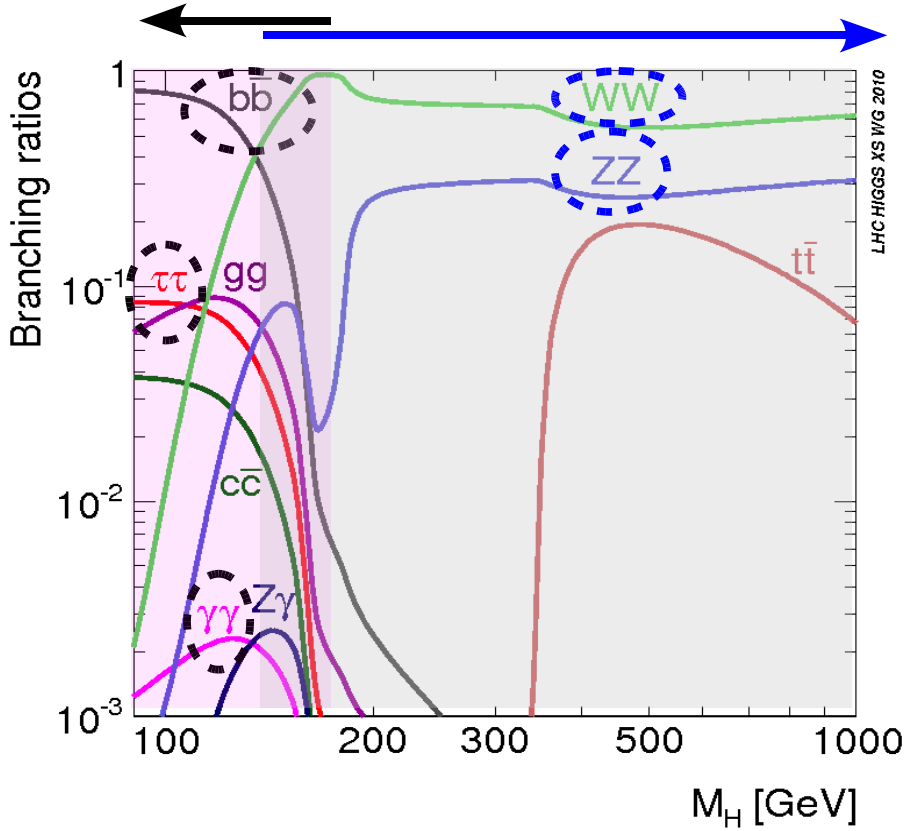


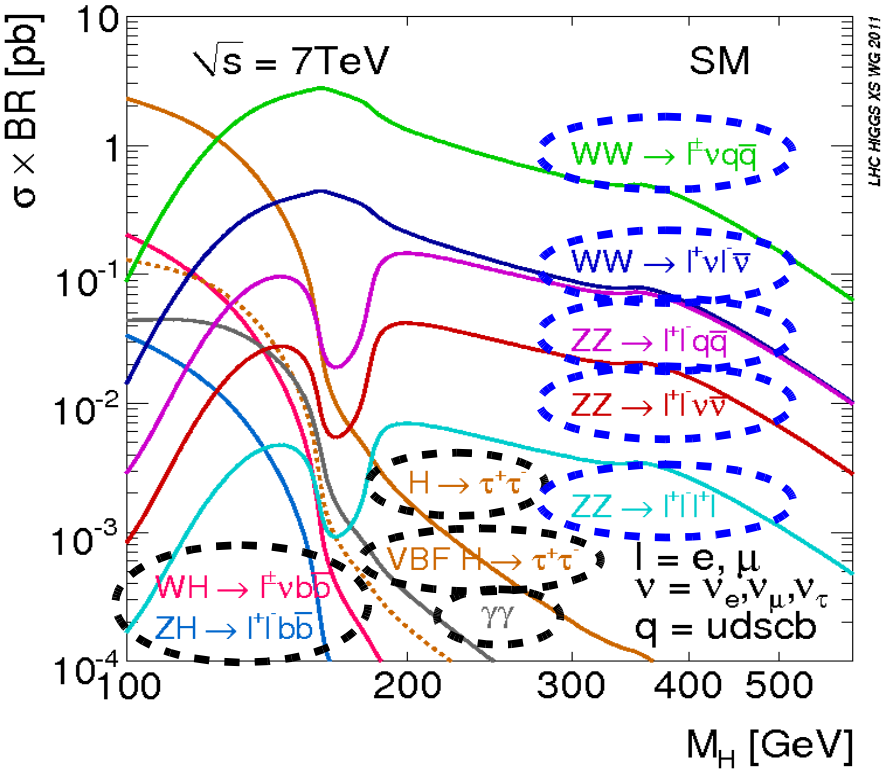


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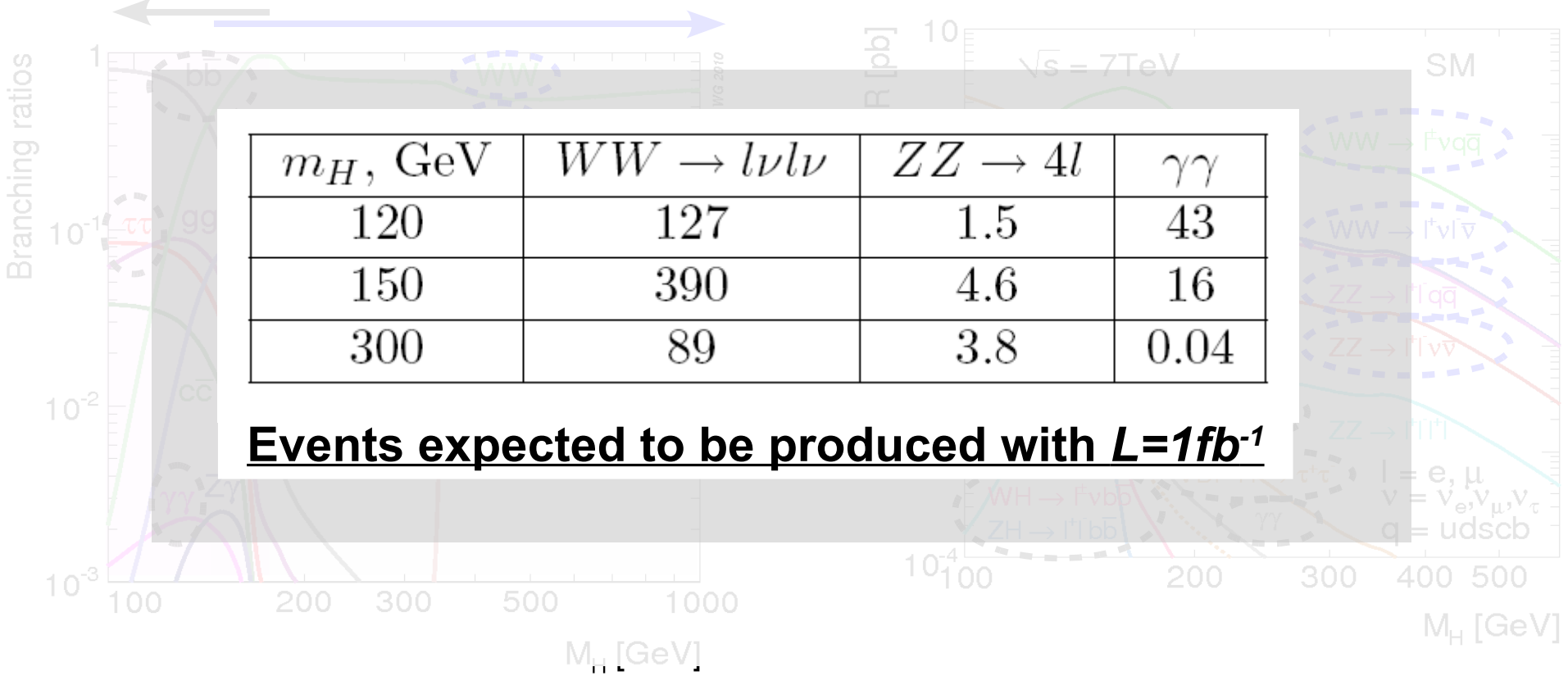
**intermediate&high mass regime:** $m_H$>140 GeV

- $H \to WW^{(*)}$:
  - → *lvlv* : intermediate range.
  - → *lvqq*: high BR, relevant at high masses.
- $H \to ZZ^{(*)}$:
  - → *4l* : golden channel
  - → *llvv* : good for high mass
  - → *llqq*: high mass, but higher background

# SM Higgs Decay Modes vs Mass at the LHC

| $m_H$, GeV | $WW \to l\nu l\nu$ | $ZZ \to 4l$ | $\gamma\gamma$ |
|---|---|---|---|
| 120 | 127 | 1.5 | 43 |
| 150 | 390 | 4.6 | 16 |
| 300 | 89 | 3.8 | 0.04 |

**Events expected to be produced with *L=1fb$^{-1}$***




**Low mass regime:** ***$m_H$<140 GeV***

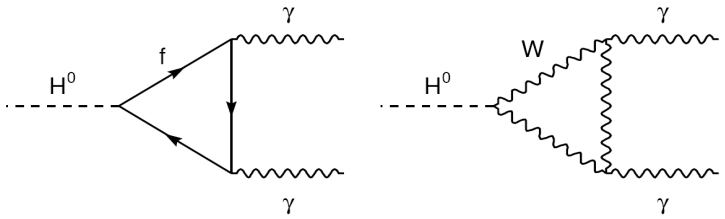
- $H \to \gamma\gamma$: rare, but th → **L=1.08 fb$^{-1}$**
  mass range.
- $W/Z+H \to b\bar{b}$: d → **L=1.04 fb$^{-1}$**
  low mass. Higgs to quark couplings
- $H \to \tau\tau$: good signal → **L=1.06 fb$^{-1}$**
  ratio, rare, use VBF signature.

**intermediate&high mass regime:** ***$m_H$>140 GeV***

- $H \to WW^{(*)}$:
  - $\to lvlv$ : inter → **L=1.70 fb$^{-1}$**
  - $\to lvqq$: high BR re → **L=1.04 fb$^{-1}$** masses.
- $H \to ZZ^{(*)}$:
  - $\to 4l$ : golden → **L~2.20 fb$^{-1}$**
  - $\to llvv$ : good for → **L=1.04 fb$^{-1}$**
  - $\to llqq$: high mass, → **L=1.04 fb$^{-1}$** ckground

# SM Higgs Searches in ATLAS : $H \rightarrow \gamma\gamma$

- **Higgs to 2γ :**




- Small BR (~$2.2 \times 10^{-3}$ → $m_H = 120$ GeV)

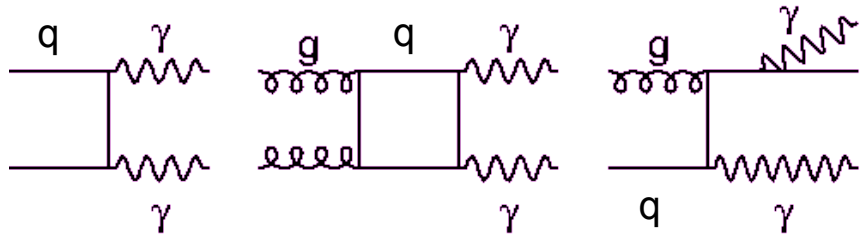
BUT

- *Clean signature with narrow mass peak.*
- Very good mass resolution (~1.7 GeV)

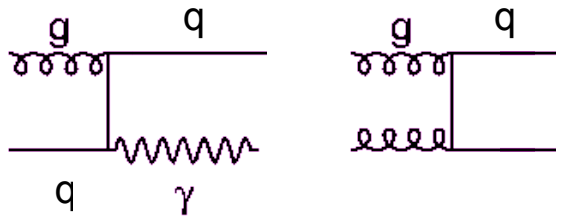
→ Need good γ reco/identification
→ Need proper conversion handling
→ Need good γ direction measurement

- **Background :**

**- Irreducible**




**- Reducible :** *one or more jets misidentified as photons*




*- Drell-Yan process: electrons misidentified as photons.*

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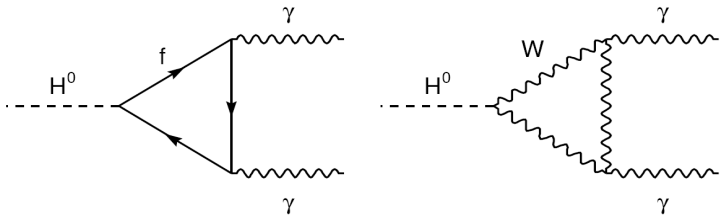


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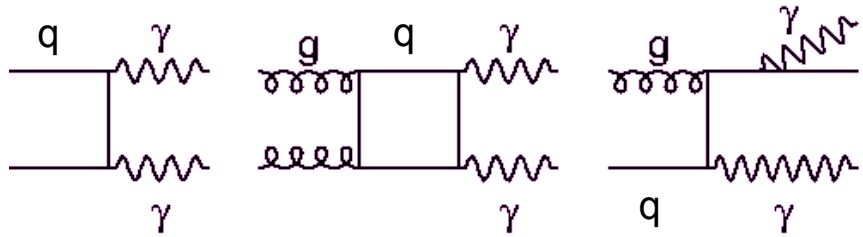


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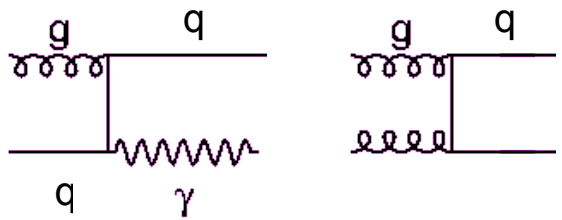
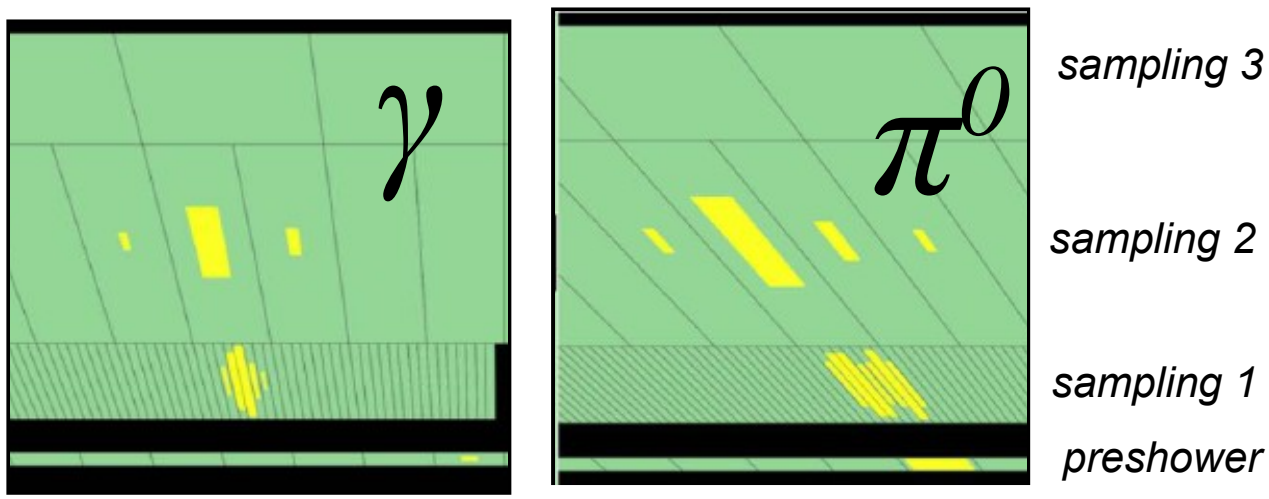



*- Drell-Yan process: electrons misidentified as photons.*

- **Events selection:**

- Photon identification (id) based both on lateral and longitudinal segmentation of the EM calo.

- Two high-quality (tight ID) *isolated* γ:
  - $p_{T\gamma 1} > 40$ GeV; $p_{T\gamma 2} > 25$ GeV
  - $|\eta_\gamma| < 1.37$ and $1.52 < |\eta_\gamma| < 2.37$



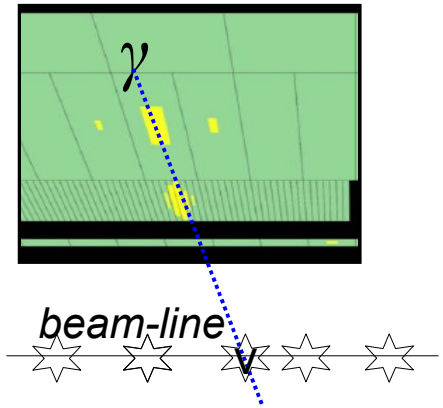

*Spring 2010 data*

# SM Higgs Searches in ATLAS : $H \rightarrow \gamma\gamma$

*Mass reconstruction*

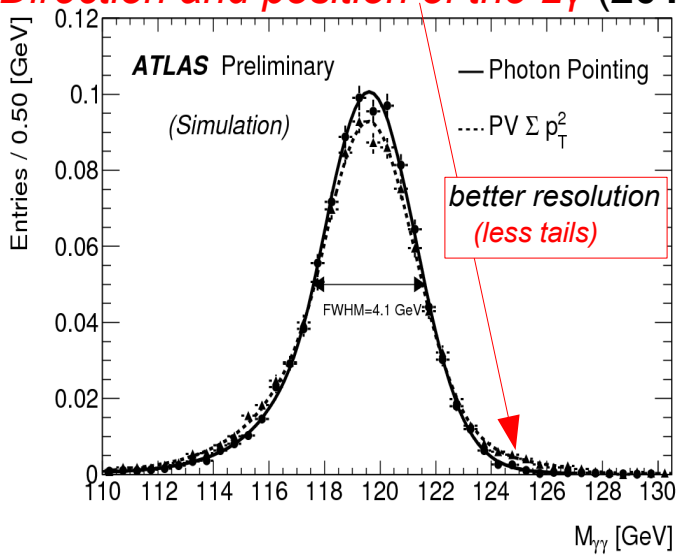
$$m_{\gamma\gamma}^2 = 2\,E_1^{\gamma}\,E_2^{\gamma}\,(1-\cos\alpha_{12})$$

- use γ direction measured in calo (ATLAS) to complement primary vertex ID.
- use conversions as well




*Tracks with highest $\Sigma p_T^2$* ***(2010)***

*Direction and position of the 2γ* **(2011)**



# SM Higgs Searches in ATLAS : $H \rightarrow \gamma\gamma$

*Tracks with highest $\Sigma p_T^2$ (**2010**)*
*Direction and position of the 2γ* (**2011**)

## *Mass reconstruction*

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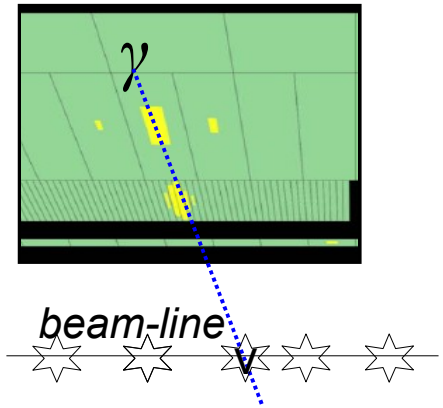
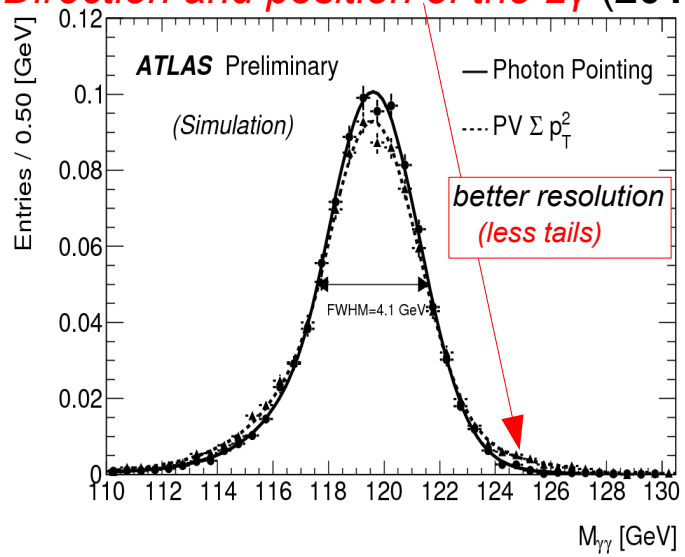
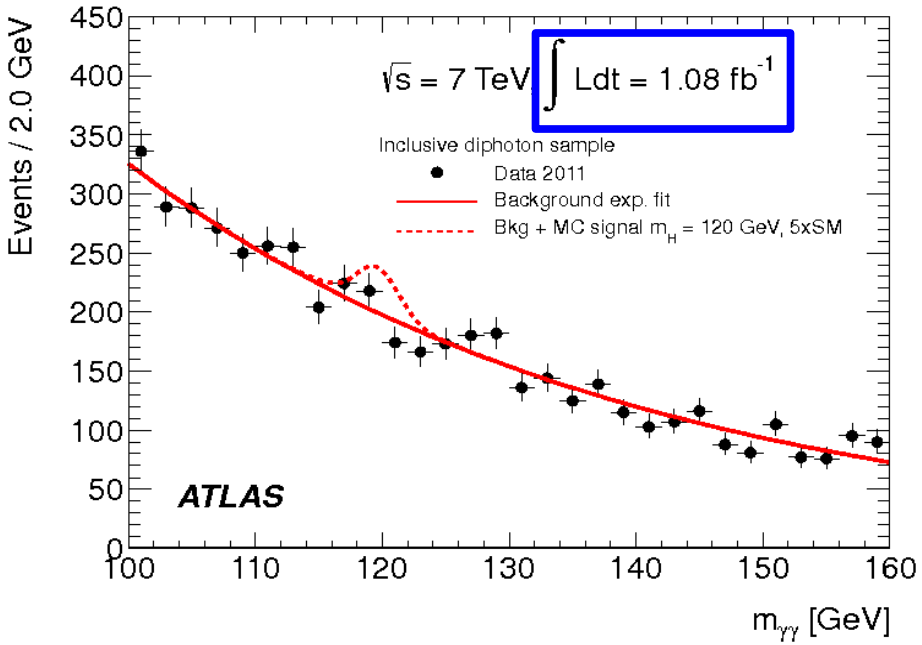



## Invariant mass spectrum




Performed analysis classifying data into 5 categories ( |η| regions in EM Calo and unconv/conv photons)

Fit to this spectrum by each category:
- *real γγ events dominant* (data-driven estimations*)
- Falling exponential → Background
- Crystal Ball + Gaussian with wide σ → Signal

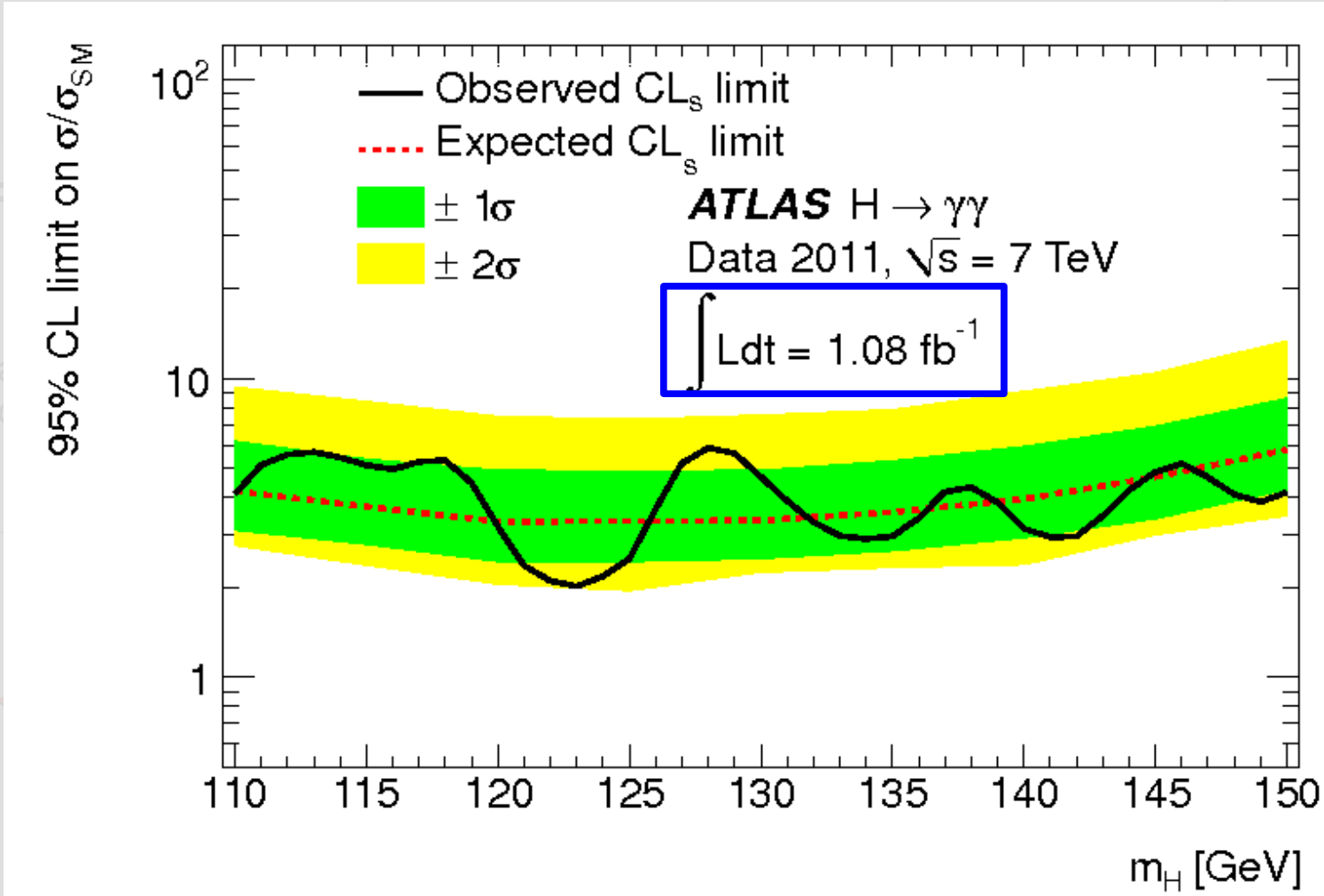
No indication of a significant excess is found

Limits on SM Higgs production cross-section are set.



** more information slide 44*

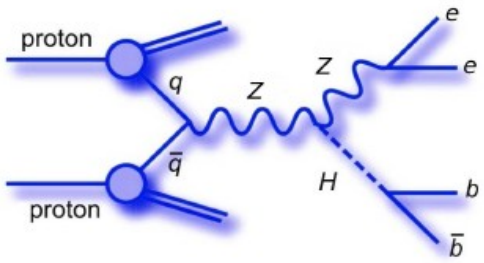
# SM Higgs Searches in ATLAS : $H \rightarrow \gamma\gamma$

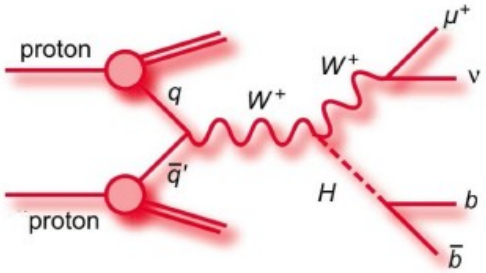



**We exclude ~4 times the SM production cross-section**

# SM Higgs Searches in ATLAS : W/Z + $H \rightarrow b\bar{b}$

$$ZH \rightarrow l\,l\,b\,\bar{b}, \quad WH \rightarrow l\,\nu\,b\,\bar{b}$$
$$\sigma_{WH} \approx 2 \times \sigma_{ZH}$$




- **Signature**
  - High $p_T$ isolated leptons (+$E_T^{miss}$ *for WH analysis*)
  - 2 b-jets ($E_T$ > *20 GeV*)
- **Backgrounds**
  - W/Z + jets
  - QCD multijets production
  - Top quark production (ZH less affected)
  - Dibosons *WW*, *ZZ*, *ZW*

# SM Higgs Searches in ATLAS : W/Z + $H \to b\bar{b}$

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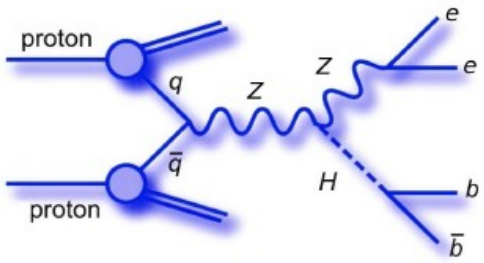


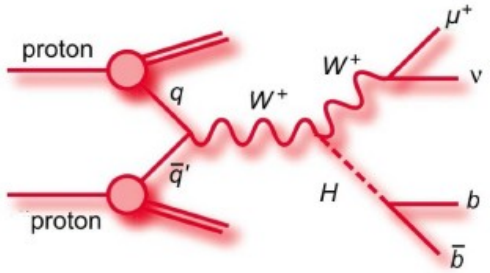


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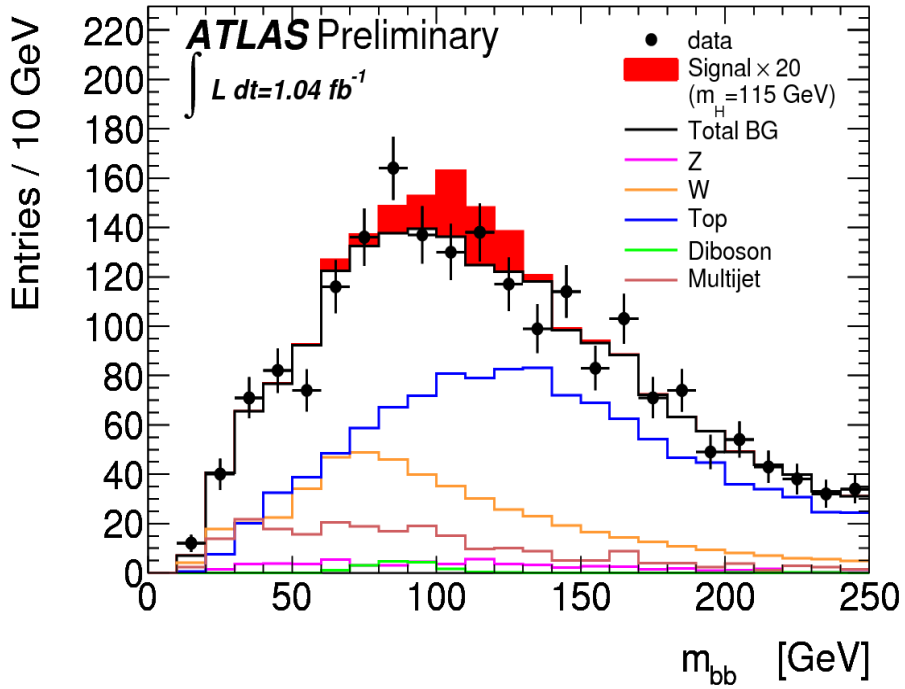


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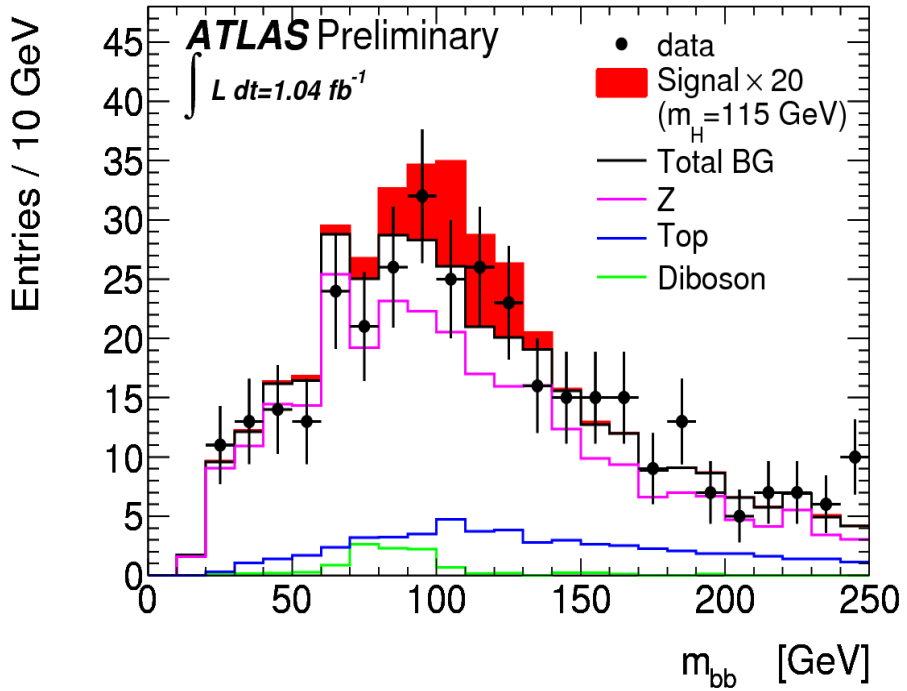

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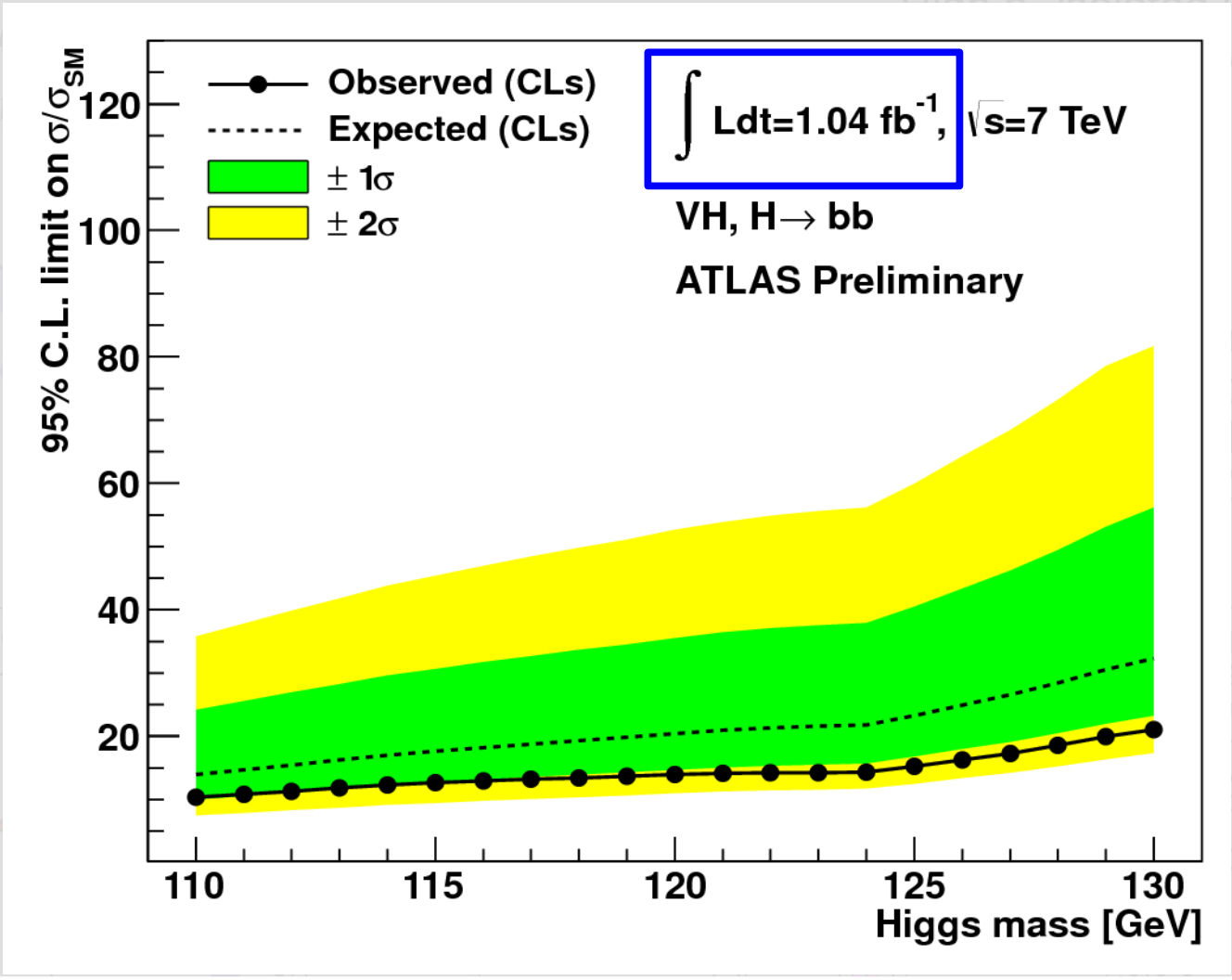
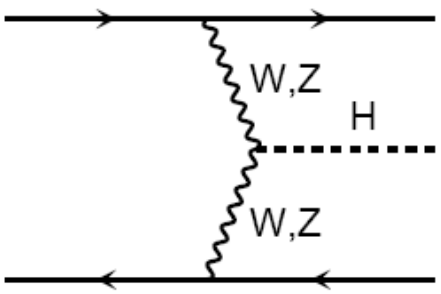
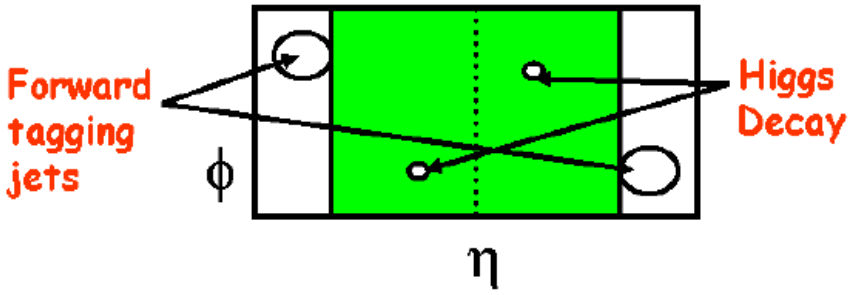



**We exclude ~10-20 times the SM production cross-section**

# SM Higgs Searches in ATLAS : $H \rightarrow \tau\,\tau$



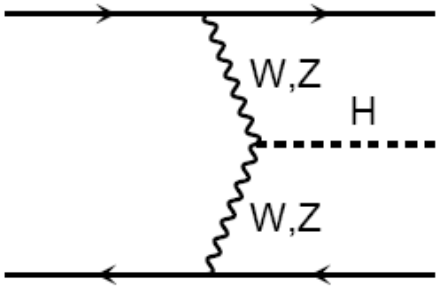

$$H \rightarrow \tau\,\tau \rightarrow l\,l + 4\,\nu$$

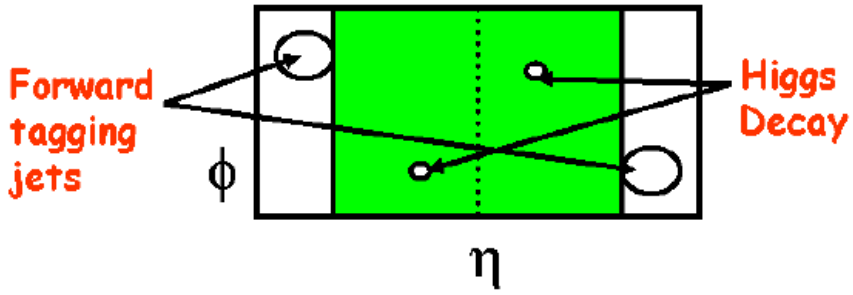



The VBF production offer the advantage of a small background, at the price of a low signal production rate ***(Not yet used in ATLAS)***

- **Main Backgrounds**
  - $Z/\gamma^{*} \rightarrow \tau\tau$ (irreducible)
  - W/Z + jets
  - Dibosons
  - $t\,\bar{t}$ and single-*t*
  - QCD multijets

# SM Higgs Searches in ATLAS : $H \rightarrow \tau\tau$

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  - $t\bar{t}$ and single-*t*
  - QCD multijets

$$H \rightarrow \tau\tau \rightarrow l\,l + 4\,\nu$$

- **Event Selection:**
  - $N_e + N_\mu = 2$, $\sum Q_e + Q_\mu = 0$, $m_{ll} > 20$ GeV
    $p_T^e > 15$ GeV $|\eta_e| < 2.47$
    $p_T^\mu > 10$ GeV $|\eta_\mu| < 2.57$
  - $N_{jet} \geq 1$ with $p^{jet} > 40$ GeV
  - $E_t^{miss} > 30(20)$ GeV for SF (DF)

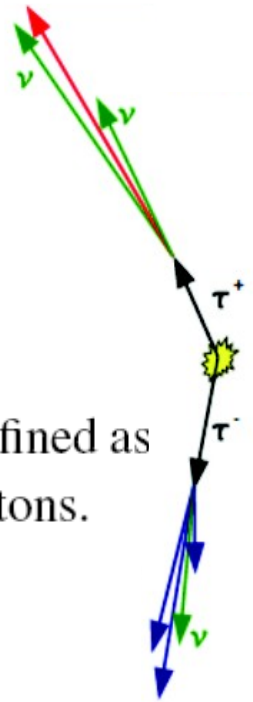
*Mass reconstruction*

***collinear approximation***

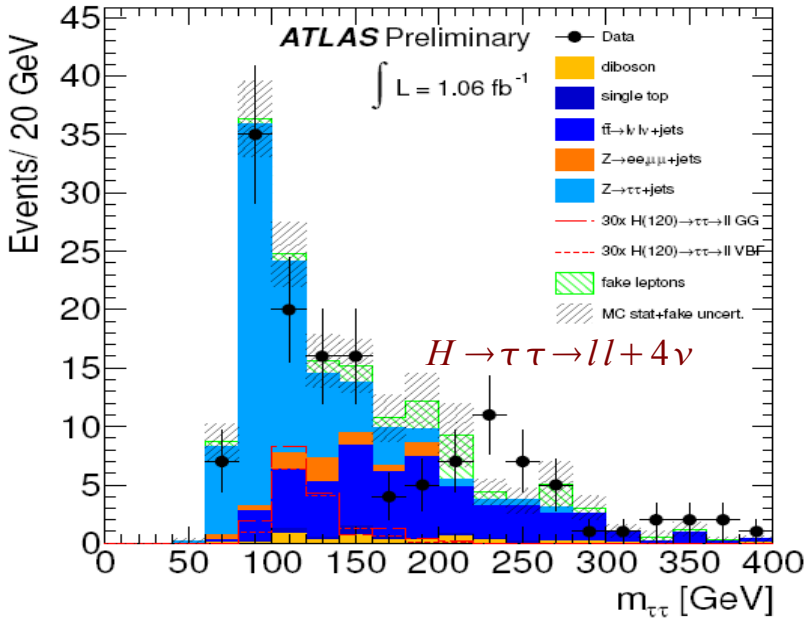
$$m_{\tau\tau} = \frac{m_{vis}}{\sqrt{x_1 x_2}}$$

where $m_{vis}$ is the visible mass defined as the invariant mass of the two leptons.

$$x_{1,2} = \frac{p_{vis1,2}}{(p_{vis1,2} + p_{mis1,2})}$$

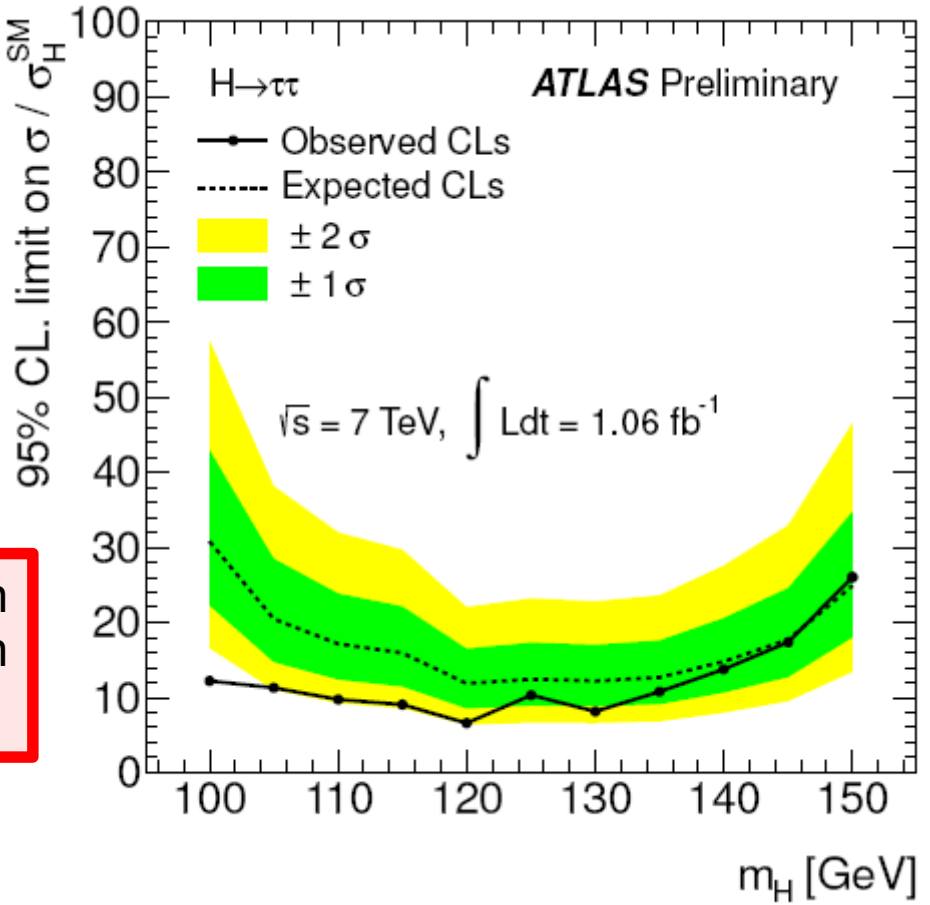


# SM Higgs Searches in ATLAS : $H \rightarrow \tau\tau$




$m_{\tau\tau}$ invariant mass after cuts. The QCD jets, W + jets, $Z/\gamma^{*} \rightarrow \tau\tau$ estimated form data. All other contributions are estimated using simulated event samples.

| | yield |
|---|---|
| Total background expectation | $47.4 \pm 3.9$ |
| Observed data | 46 |
| $gg \rightarrow H$ (120 GeV) | $0.44 \pm 0.05$ |
| VBF (120 GeV) | $0.38 \pm 0.02$ |




Expected and observed 95% C.L. Exclusion limits (~10–20 x) for a neutral Higgs boson production in the SM as a function of $m_{H.}$

# SM Higgs Searches in ATLAS : $H \rightarrow WW^{(*)} \rightarrow l\nu l\nu$

The most sensitive channel for $130 < m_H < 200$ GeV

*Poor mass information due to neutrinos*

*Main background are: WW and other di-boson (WZ,ZZ,Wγ), W+jets,Drell-Yan,top and QCD jets*

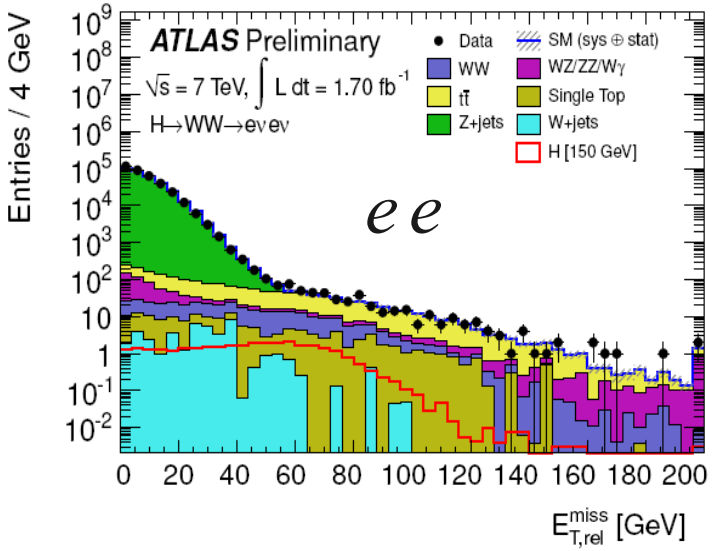
- **Signal characteristics**
  - two (opposite sign) high $p_T$ isolated leptons
  - *Large $E_T^{miss}$*

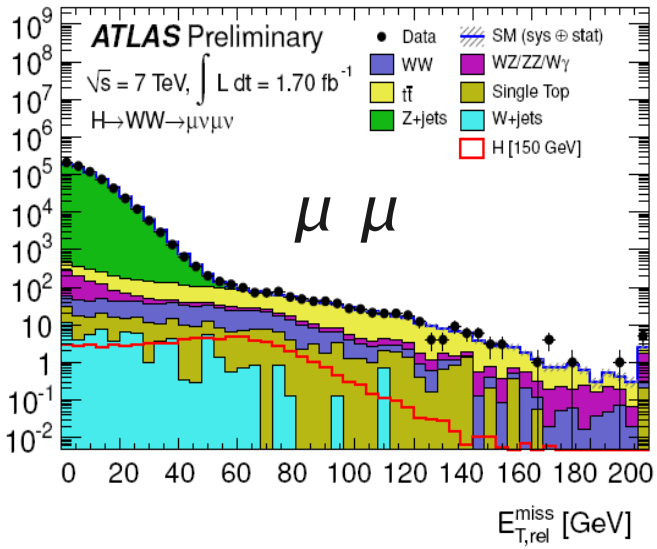
*Event pre-selection (against QCD, W+jets, DY):*

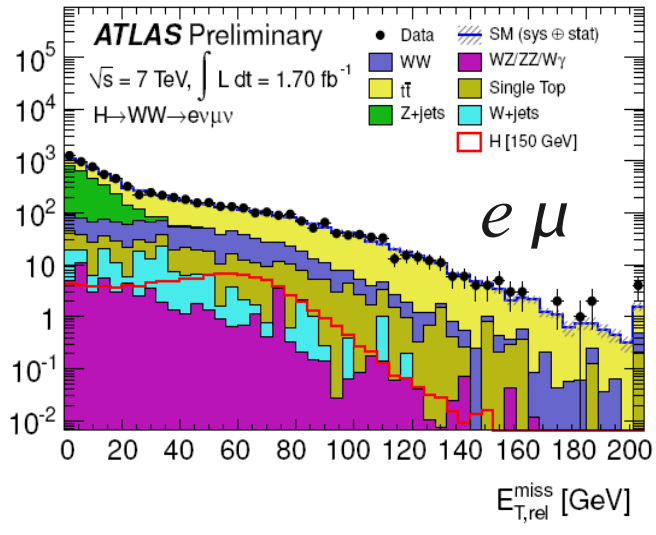
| $ll$ | $e-e$ | $\mu-\mu$ | $e-\mu$ |
|---|---|---|---|
| $p_T$ leading [GeV] | 25 | 25 | 25 |
| $p_T$ subleading [GeV] | 20 | 15 | $e: 15,\ \mu: 20$ |
| $E_T^{miss}$rel | 40 | 40 | 25 |

$$E_{\mathrm{T,rel}}^{\mathrm{miss}} = \begin{cases} E_{\mathrm{T}}^{\mathrm{miss}} & \text{if } \Delta\phi \geq \pi/2 \\ E_{\mathrm{T}}^{\mathrm{miss}} \cdot \sin\Delta\phi & \text{if } \Delta\phi < \pi/2 \end{cases}$$

$$\Delta\phi = \min(\Delta\phi(E_{\mathrm{T}}^{\mathrm{miss}}, \ell),\ \Delta\phi(E_{\mathrm{T}}^{\mathrm{miss}}, j))$$



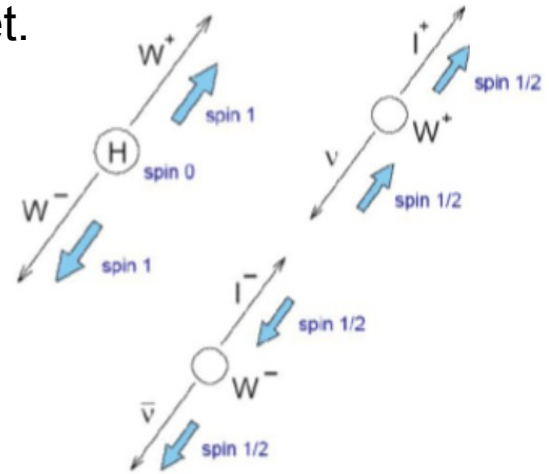



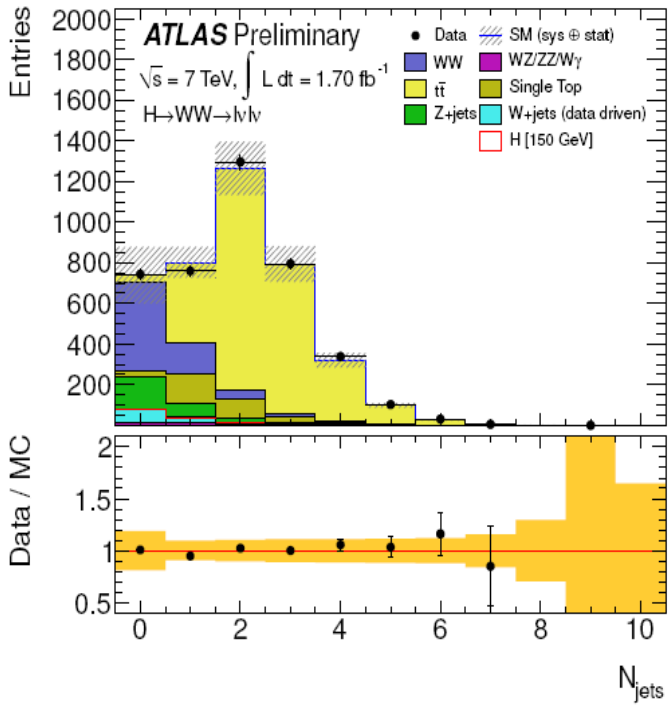



# SM Higgs Searches in ATLAS : $H \rightarrow WW^{(*)} \rightarrow l\nu l\nu$

*After preselection, classify events according the # of jets*

- Events with no jets with
  $p_T$>25 GeV and $|\eta|$<2.45
- Events with exactly one jet.
  *Apply b-tag veto*.

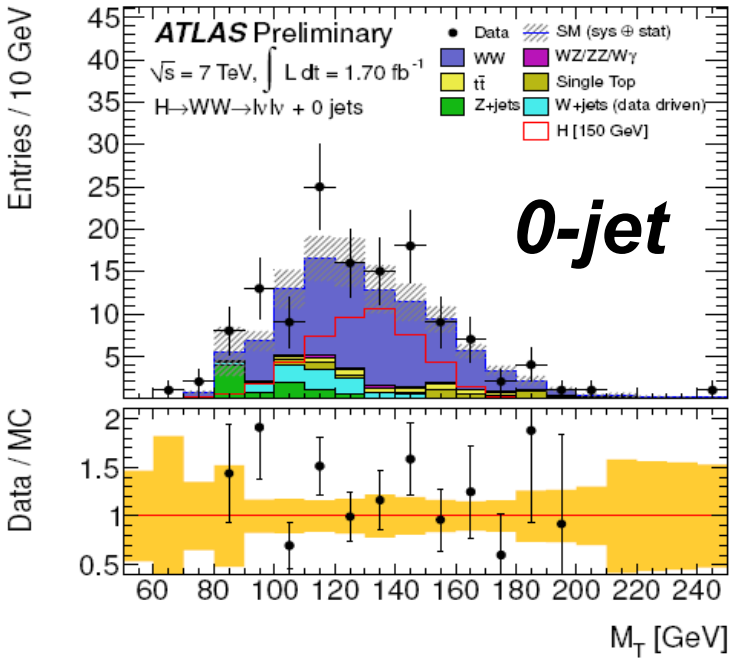



*Apply topological cuts*
*($m^{ll}$, $p_T^{ll}$, $\Delta\phi^{ll}$ ← spin correlations)*

*Reconstruct transverse mass $m_T$*
*(apply $m_H$ dependent cut : 0.75 x $m_H$<$m_T$<$m_H$ )*

$$m_{\mathrm{T}} = \sqrt{(E_{\mathrm{T}}^{\ell\ell} + E_{\mathrm{T}}^{\mathrm{miss}})^2 - (\mathbf{p}_{\mathrm{T}}^{\ell\ell} + \mathbf{p}_{\mathrm{T}}^{\mathrm{miss}})^2},$$

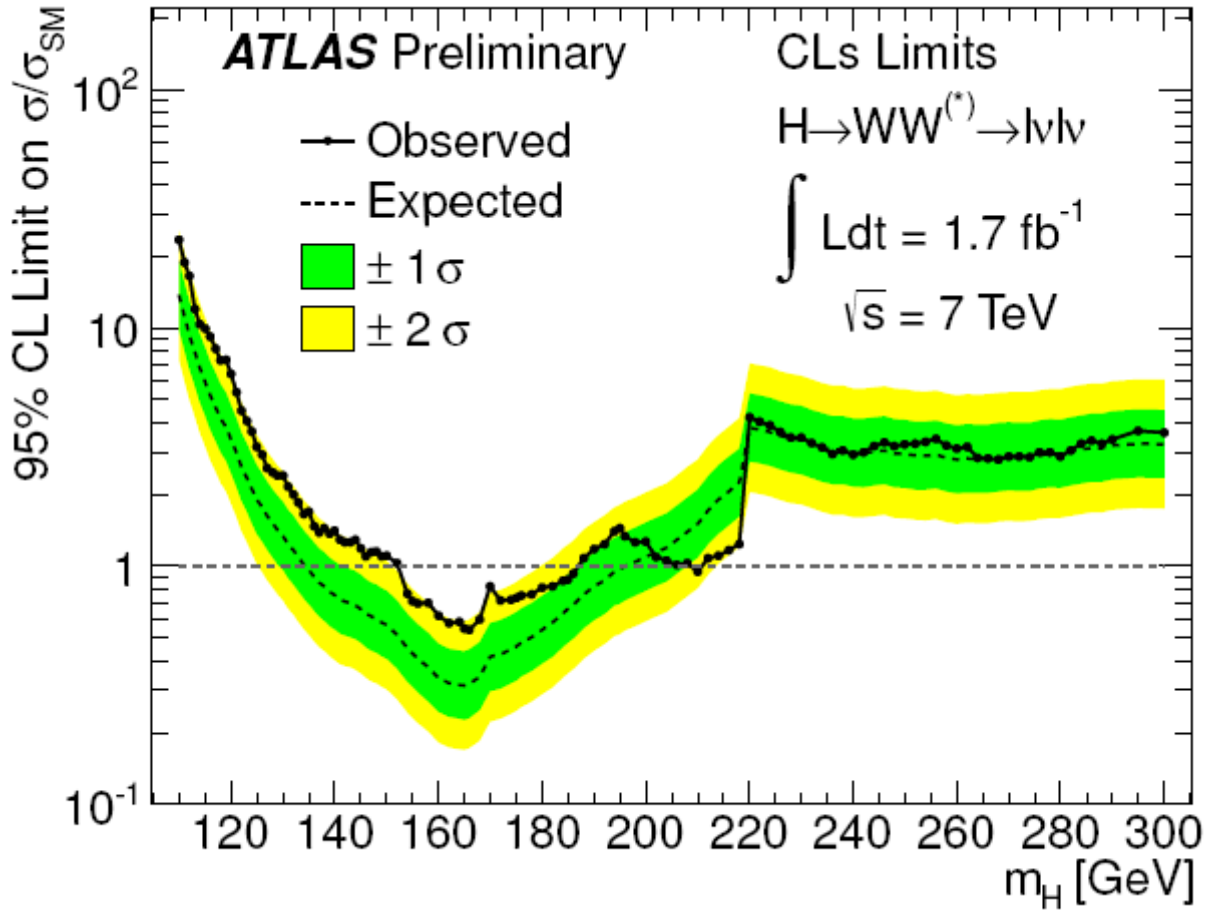



- *top* , *WW, W+jets*, Z+jets* background obtained using "data driven" methods.

*full data-driven

# SM Higgs Searches in ATLAS : $H \rightarrow WW^{(*)} \rightarrow l\nu l\nu$

## $H \rightarrow WW^{(*)} \rightarrow l\nu l\nu$ exclusion limits




**A SM Higgs boson with *154<$m_H$<186* GeV is excluded at 95% C.L.**

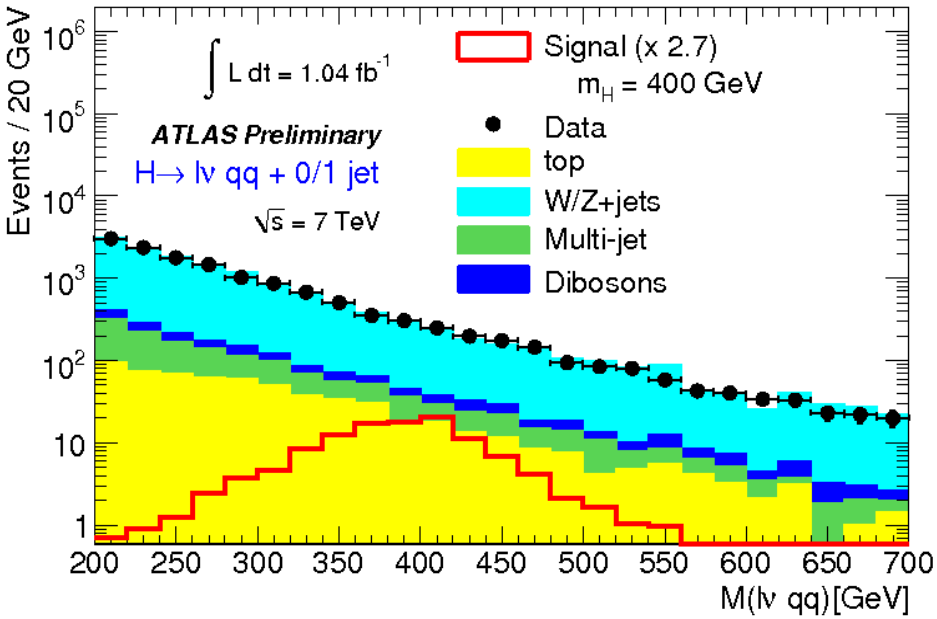
- **Expected exclusion: *135<$m_H$<196* GeV at 95% C.L**
- **In the mass range *130-150* GeV, the observed limit is within *2σ*.**

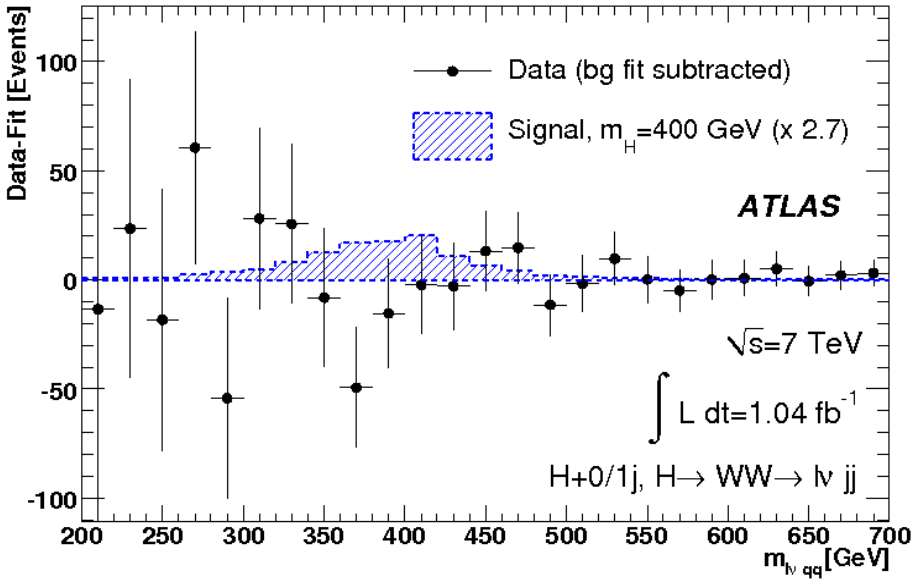
# SM Higgs Searches in ATLAS : $H \rightarrow WW \rightarrow l\nu qq$

- The channel $H \rightarrow WW \rightarrow l\nu qq$ has large branching ratio at large Higgs boson masses
- Analysis performed for ***240<m$_H$<600* GeV**

- **Selection**
  - Exactly one lepton ($e$ or $\mu$) with $p_T$>*30* GeV
  - Require $E_T^{miss}$ >*30* GeV
  - Events are require to have exactly two or three jets
    (categories: *H + 0-jets* and *H + 1-jets*)

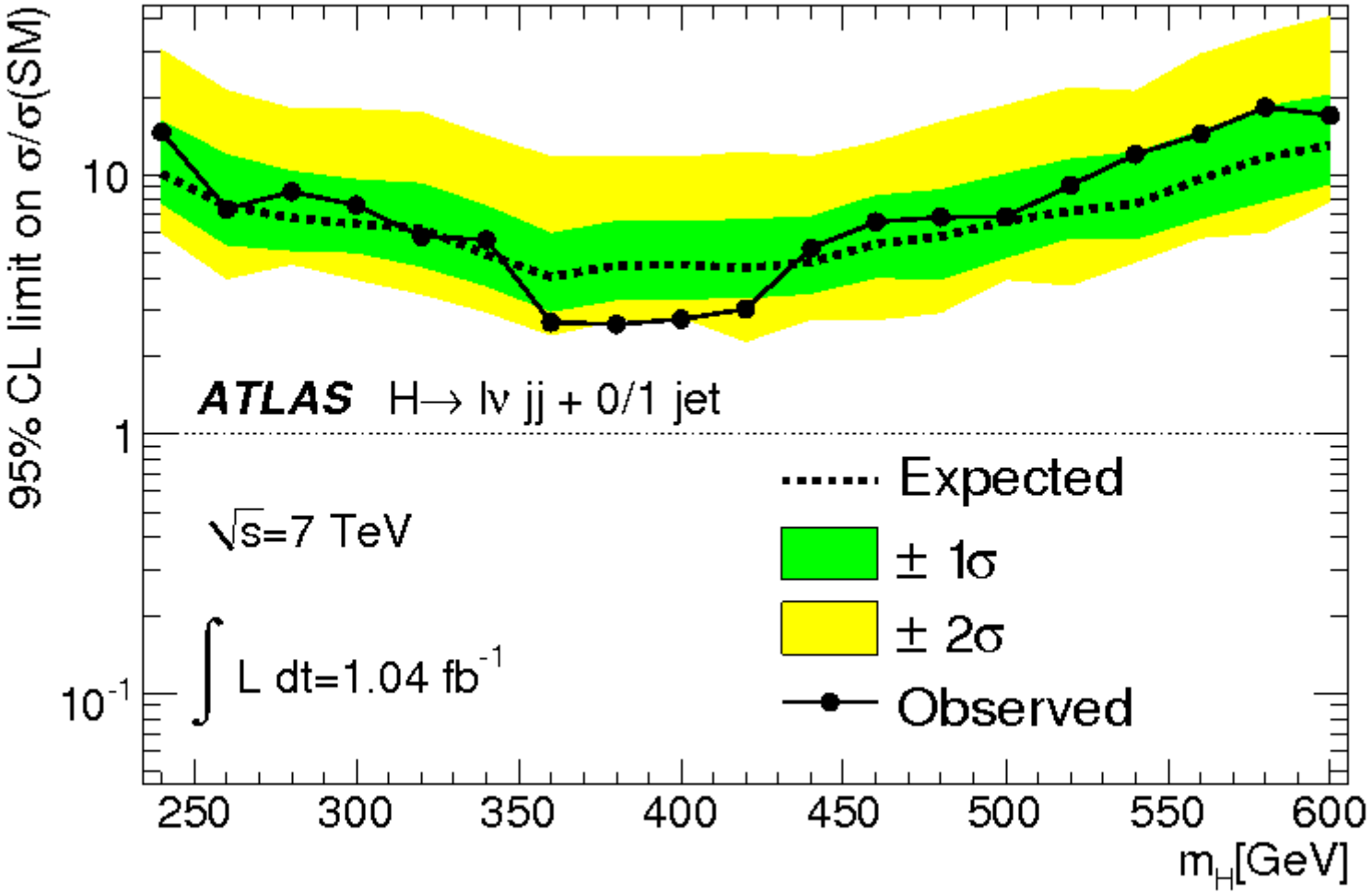
- **Strategy**
  - ***Search a peak in the m$_{l\nu qq}$***
    - Using the constraint *m(lν)=m(W)* *and m(qq)=m(W)*
      *(this works for m$_H$>2m$_W$)*



# SM Higgs Searches in ATLAS : $H \rightarrow WW \rightarrow lvqq$

## $H \rightarrow WW \rightarrow lvqq$ exclusion limits




**The upper limit at $m_H$=400 GeV is 2.7 times the SM cross-section**

**- Expected limit for $m_H$=400 GeV is ~5 times the SM cross-section**

# SM Higgs Searches in ATLAS : $H \rightarrow ZZ^{(*)} \rightarrow 4l$

- The "golden channel" for SM Higgs searches
- To search for a narrow resonance peak over the continuum *4l* mass distribution
- Exploring the $m_H$ range between 130-600 GeV

- **Background**
  - Irreducible $ZZ^{(*)}$
  - Reducible:

    *Z+jets , ttbar* → *2l2v2b*, Z+bb
    (removed by cuts in the lepton isolation and impact parameter)

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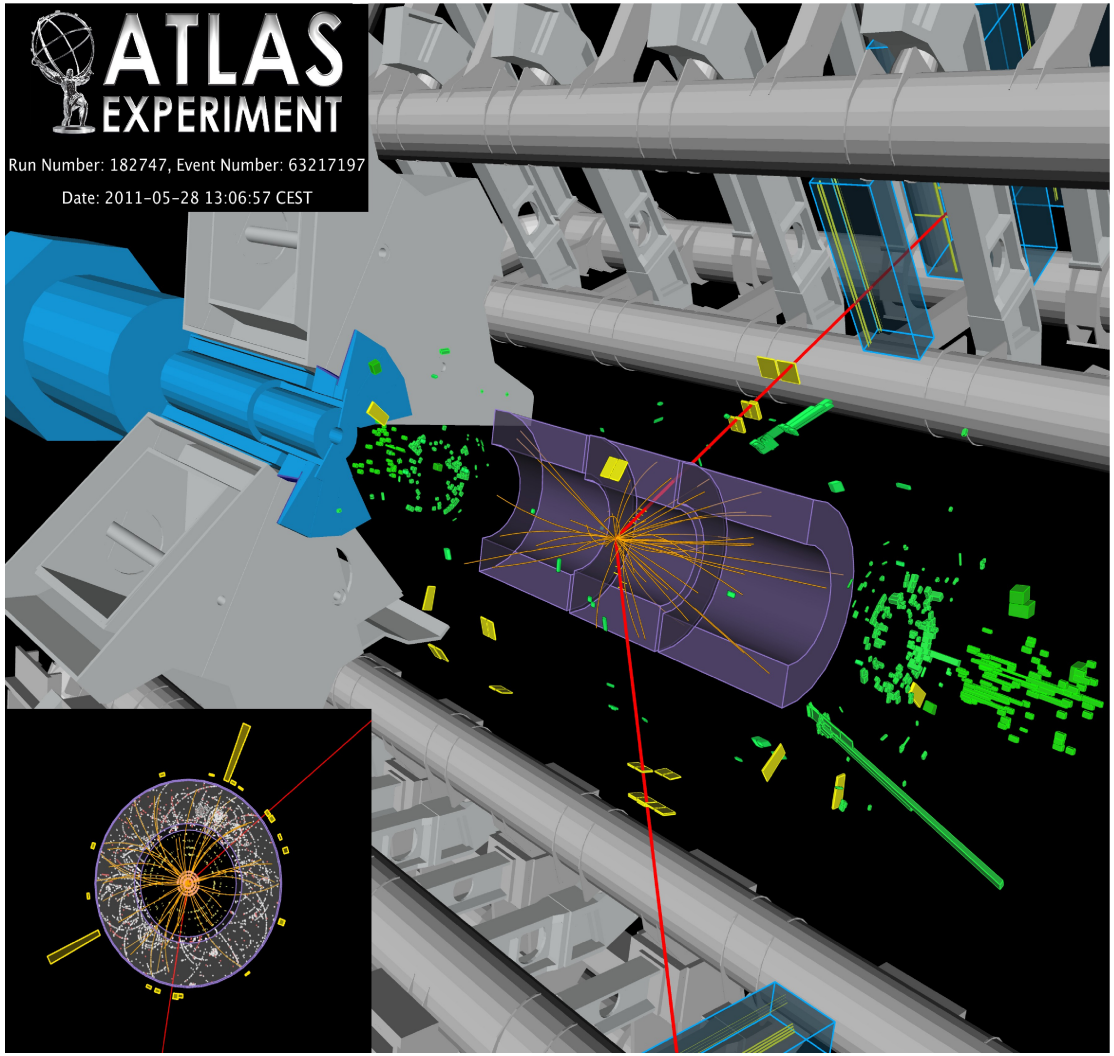
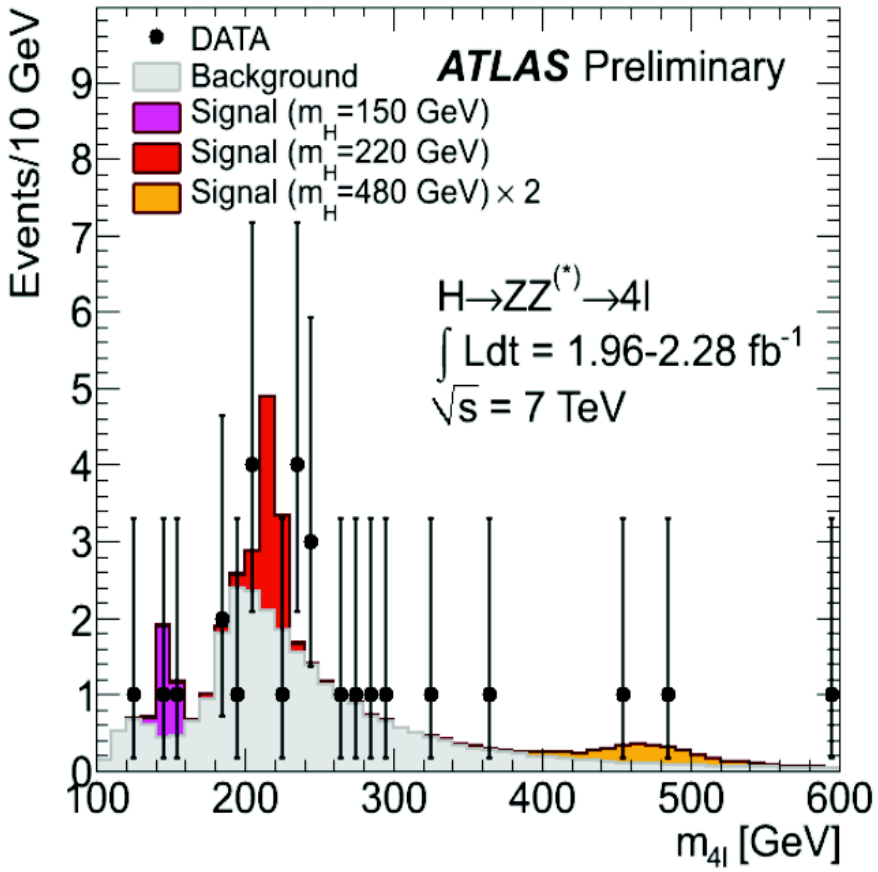
  - Irreducible $ZZ^{(*)}$
  - Reducible:

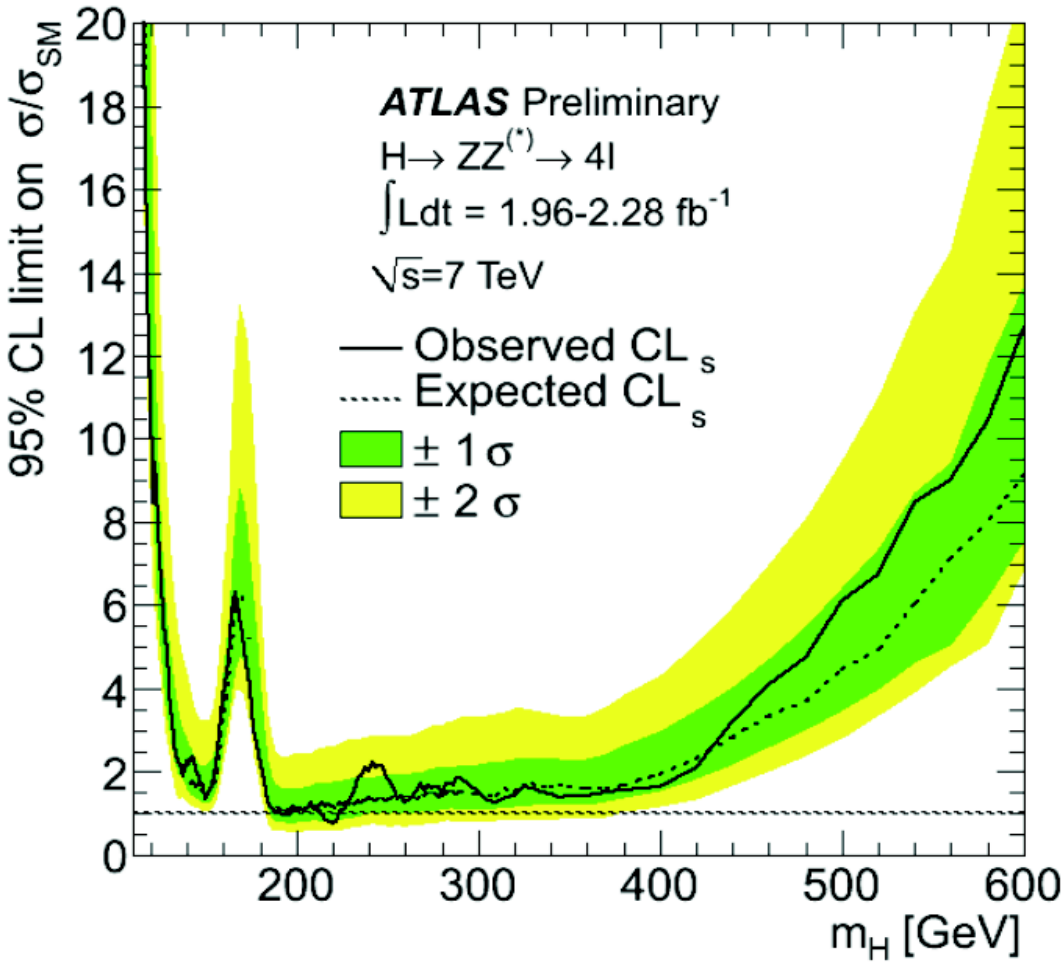
    *Z+jets , ttbar* $\rightarrow$ *2l2v2b*, *Z*+bb
    (removed by cuts in the lepton isolation and impact parameter)

- **Event selection**
  - Trigger: inclusive high-pt *e* or *μ*
  - Two isolated same-flavor lepton pairs with opposite charge
  - One lepton pair close to $M_Z$ mass window
  - $m_H$ dependent cuts on the second pair
  - $\Delta\phi^{ll} > 0.1$ for all leptons



# SM Higgs Searches in ATLAS : $H \rightarrow ZZ^{(*)} \rightarrow 4l$




· **A total of 27 events are selected by analysis algorithm :**

six *4e*, nine *2e2μ* and twelve *4μ*

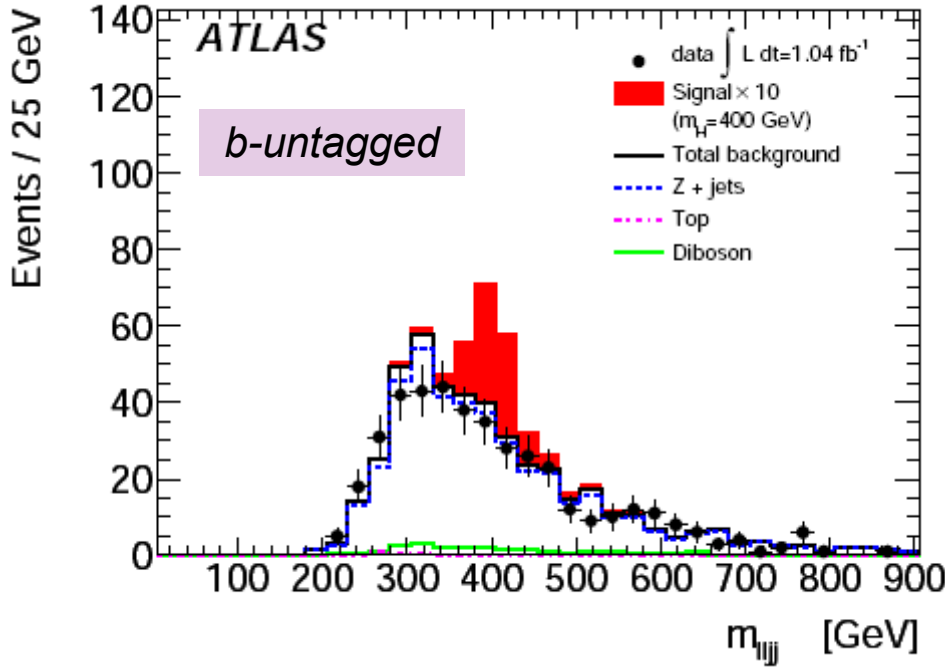
· **Very close the SM cross-section**

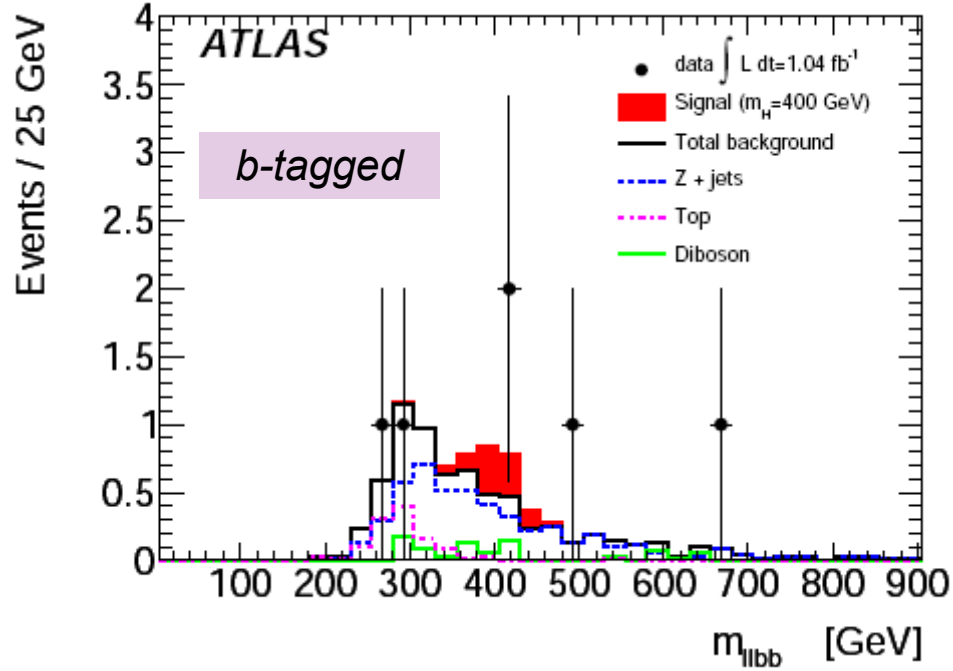
· **Some Higgs mass values already excluded around $m_H$ = 200 GeV**

# SM Higgs Searches in ATLAS : $H \rightarrow ZZ \rightarrow llqq$

- **Mass range 200-600 GeV**
- Signature: Z → ll + 2 jets fin
- Main Background QCD *Z + jets*

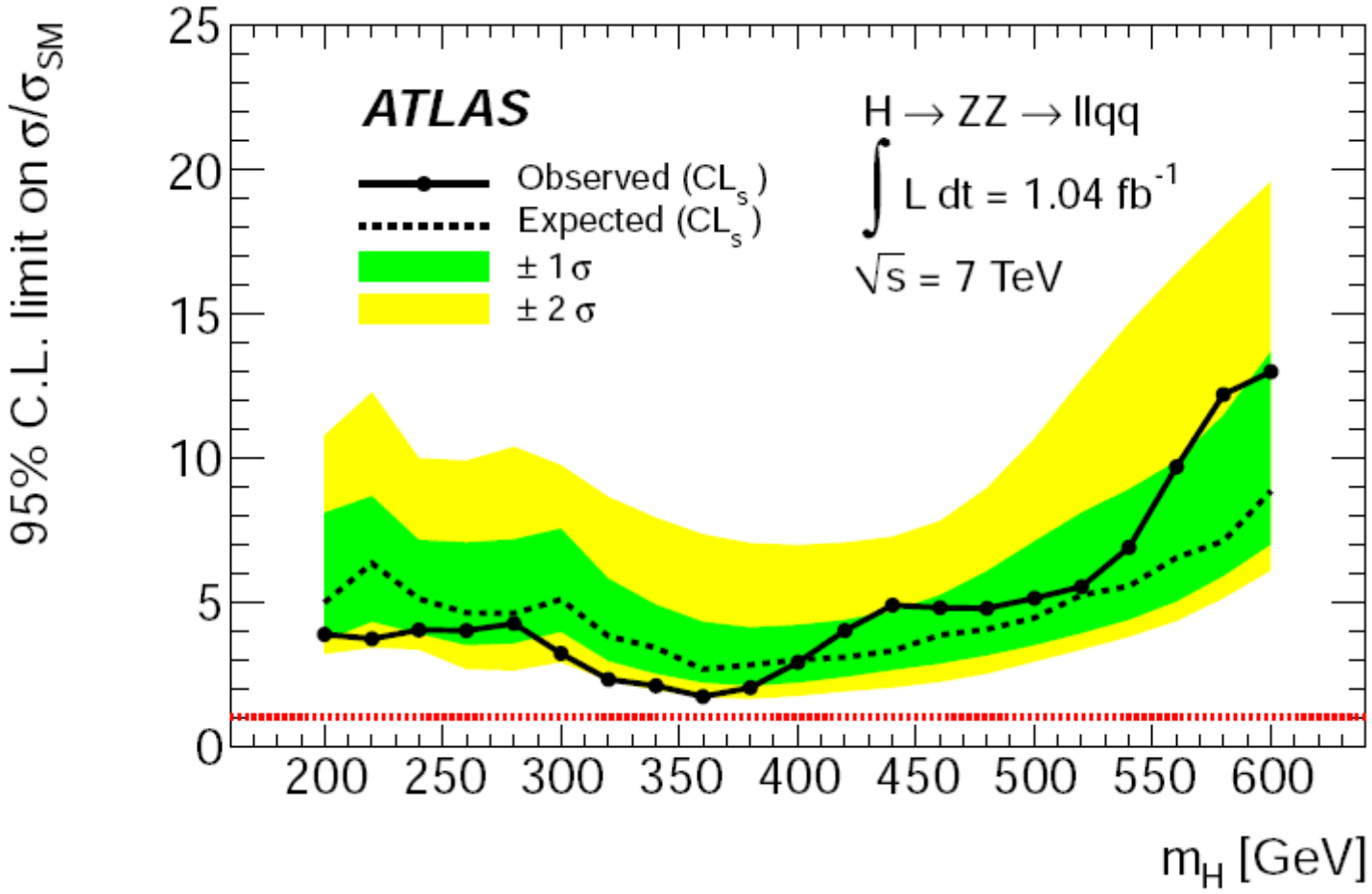
- **Event selection:**
  - *Same flavor pair of isolated leptons (muon opposite sign)*
  - $p_T$>*20* GeV and *76*<$m_{ll}$<*106* GeV
  - $E_T^{miss}$ < 50 GeV
  - ≥ *2 jets with 70*<$m_{jj}$<*105 GeV*
  - *For* $m_H \geq 360$ *GeV:*
    - *Jet* $p_T$ > *50 GeV*
    - $\Delta\phi^{ll} < \pi/2$ *and* $\Delta\phi^{jj} < \pi/2$



# SM Higgs Searches in ATLAS : $H \rightarrow ZZ \rightarrow llqq$

## $H \rightarrow ZZ \rightarrow llqq$ exclusion limits




**Good sensitivity in a wide mass range**

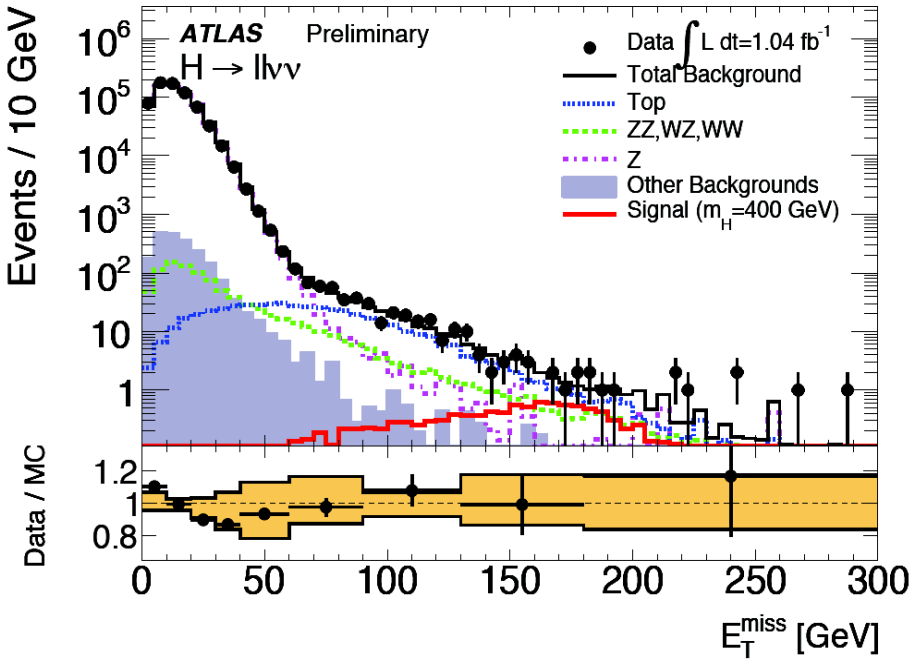
- **Expected limit between 2.7 – 9 x SM cross-section**
- **Observed 1.7 x SM cross-section for $m_H$ = *360* GeV**

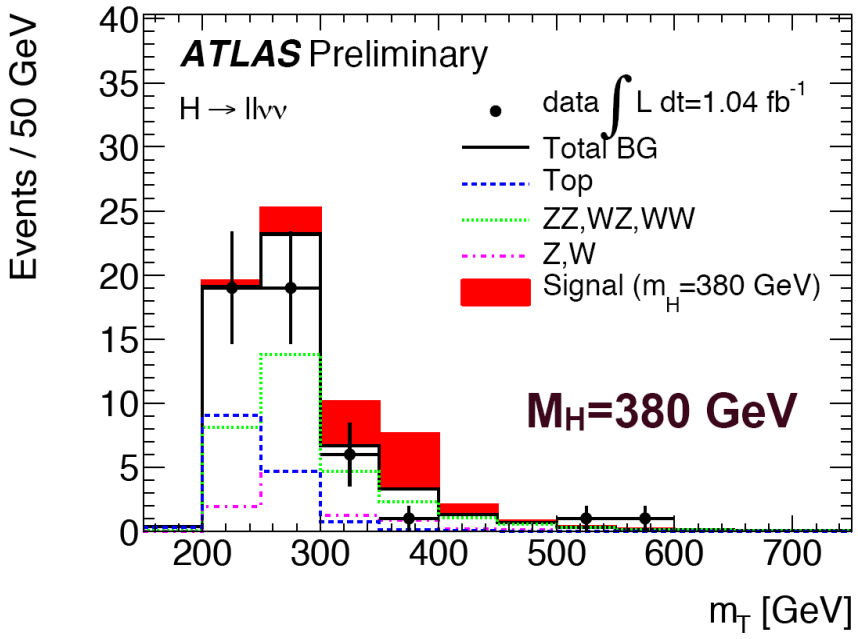
# SM Higgs Searches in ATLAS : $H \rightarrow ZZ \rightarrow llvv$

- **Mass range 200-600 GeV**. Much BR higher than the 4-lepton channel
- Signature: Z → ll + large $E_T^{miss}$
  significant contribution H → WW → *lvlv* (no overlapping due to orthogonal selection)
- Background. (*irreducible)* Diboson, (r*educible):* QCD, W/Z+jets, top

- One pair of high $p_T$ isolated lepton
- b-jet veto, 3th lepton and additional topological cuts against reducible background ($\Delta\phi^{ll}$)
- Looking for $m_T$ distribution:

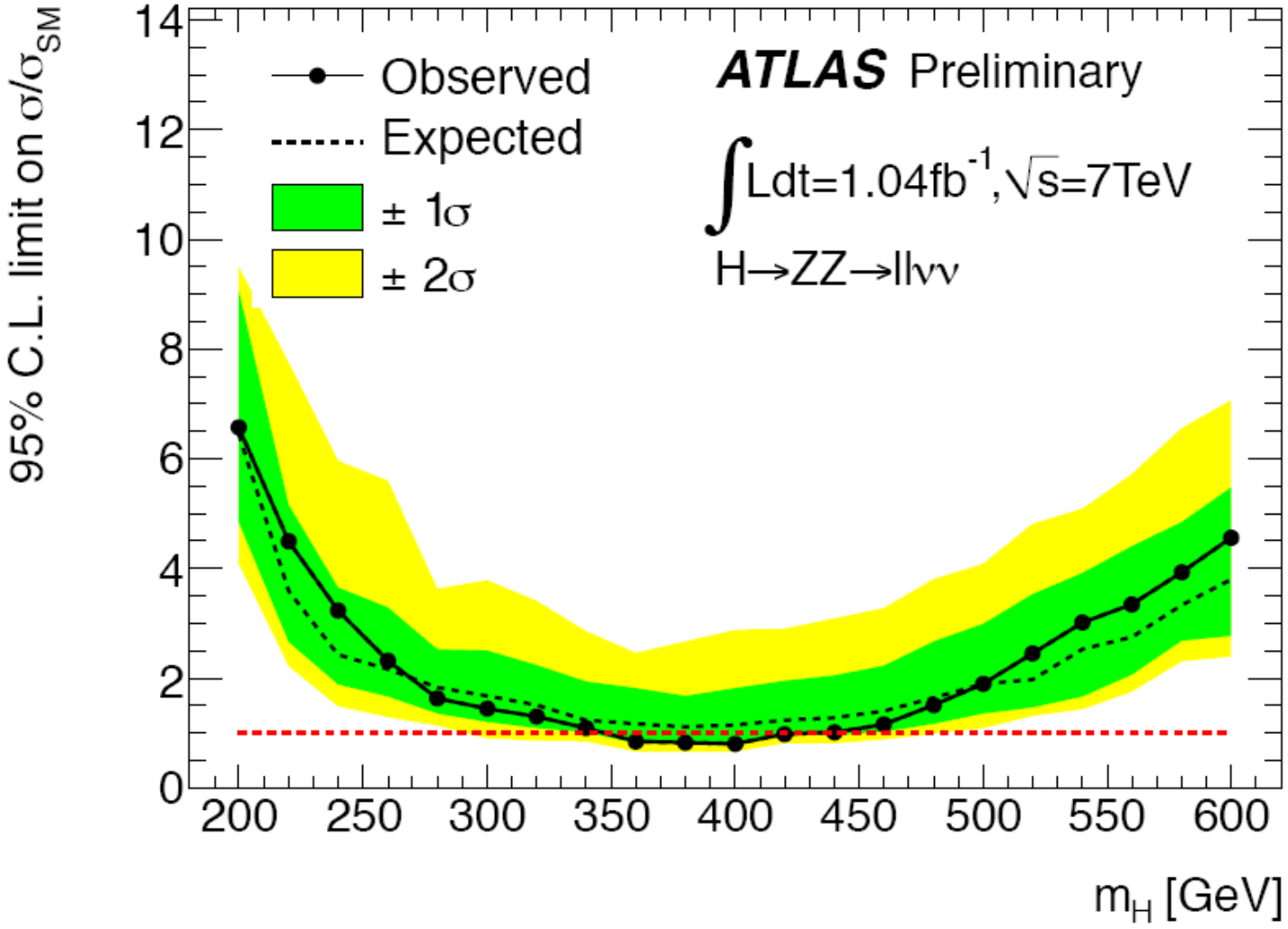
$$m_T^2 \equiv \left[\sqrt{m_Z^2 + |\vec{P}_T^{ll}|^2} + \sqrt{m_Z^2 + |\vec{P}_T^{miss}|^2}\right]^2 - \left[\vec{P}_T^{ll} + \vec{P}_T^{miss}\right]^2$$



# SM Higgs Searches in ATLAS : $H \rightarrow ZZ \rightarrow llvv$

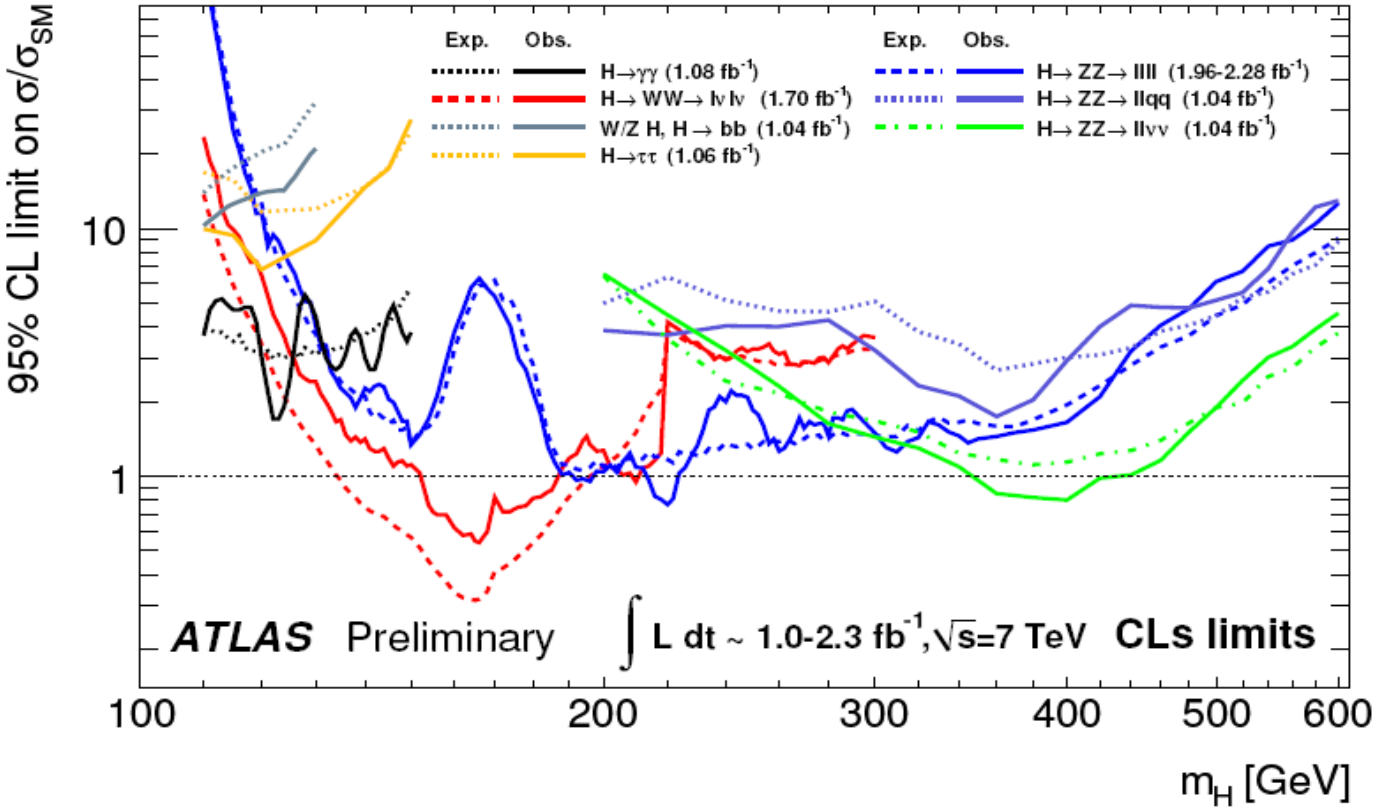
## $H \rightarrow ZZ \rightarrow llvv$ exclusion limits




- Expected limit between 1.7 – 7 x SM cross-section
- Exclusion SM Higgs boson mass between 360 – 420 GeV

# ATLAS SM Higgs Combinations

**The expected (dashed) and observed (solid) cross-sections limits for individual channels, as functions of the Higgs boson mass**




***Combined channels:***

$H \rightarrow \gamma\gamma$

$W/Z + H \rightarrow b\bar{b}$

$H \rightarrow \tau\tau$

$H \rightarrow WW^{(*)} \rightarrow l\nu l\nu$

$H \rightarrow ZZ \rightarrow llqq$

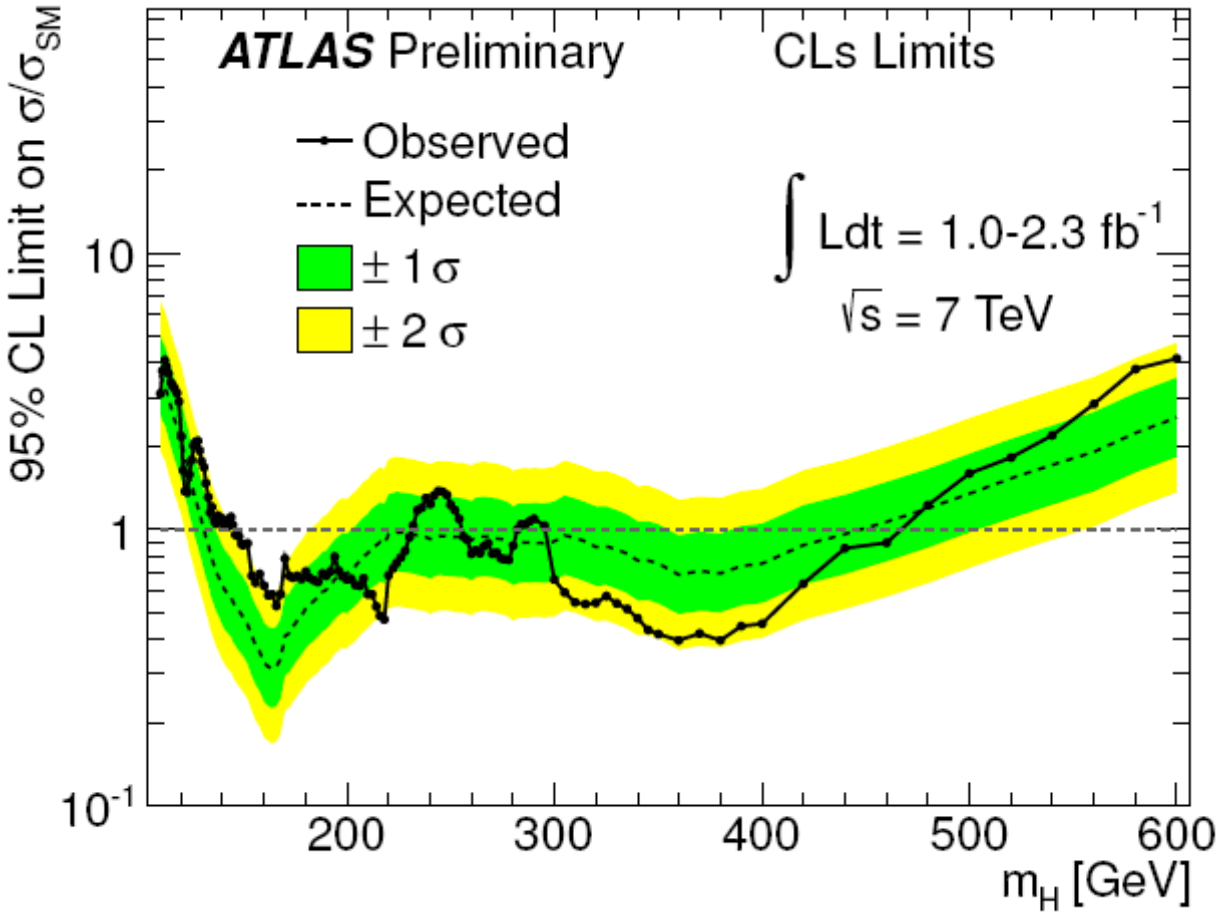
$H \rightarrow ZZ \rightarrow ll\nu\nu$

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

- Correlated uncertainties detector-related (energy scales, reco efficiency, luminosity, etc...) are taking into account.
- In other cases (background from data) uncertainties are *uncorrelated*.
- Theory uncertainties: Higgs boson cross-section, PDF uncertainties 100% correlated among different channels.

# ATLAS SM Higgs Combinations

The combined upper limit on the Standard Model Higgs boson production cross-section as functions of the Higgs boson mass. This is a 95% CL limit using the CLs method in the entire mass range.




SM Higgs boson mass excluded at 95% C.L:

- $146 < m_H < 232$ GeV
- $256 < m_H < 282$ GeV
- $296 < m_H < 466$ GeV

CL is above 99% in the region between 160-220 GeV and exceeds 99% between 300-420 GeV

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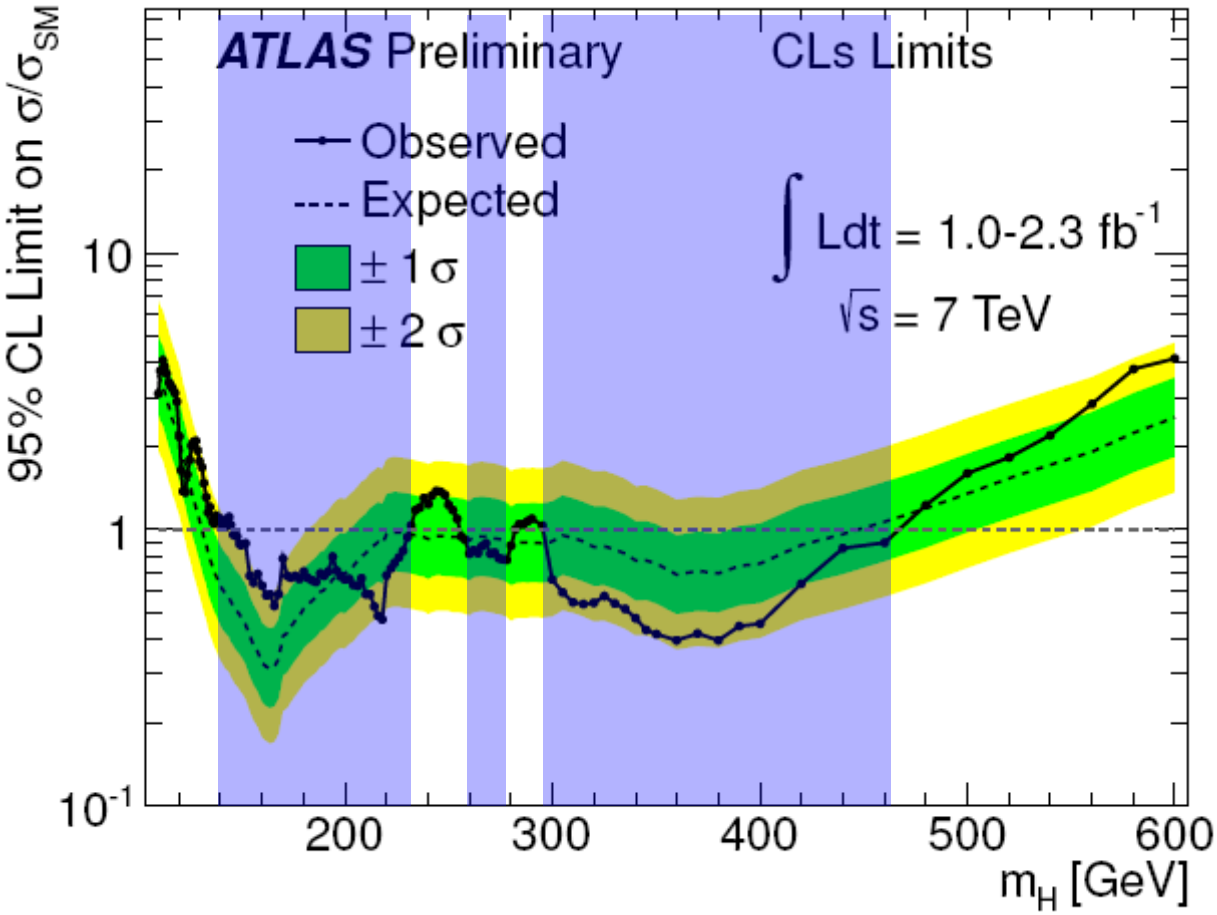


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# OUTLINE

- The ATLAS detector data-taking in 2011
- SM Higgs boson production and decay
- SM Higgs searches
- SM Higgs Combination
- MSSM Higgs searches
- Summary

# MSSM Higgs searches: $H/A/h \rightarrow \tau\tau$

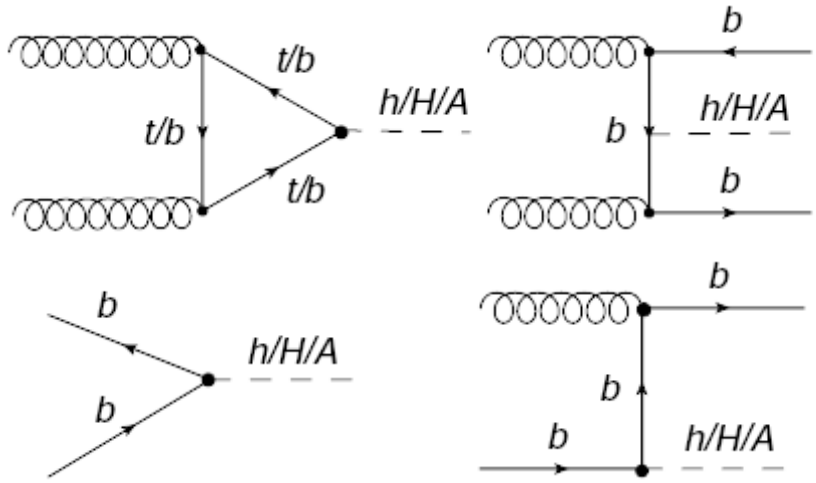
- **Minimal SuperSymmetric Standard Model (2 Higgs doublets Model are required)**

  → *h/H/A,H± (with CP-even h, H and the CP-odd A electrically neutral)*

- Neutral Higgs(es) to *tau-lepton* pairs strongly enhanced for large regions of the parameter space

  - $m_A$ = mass CP-odd Higgs

  - *tanβ* = ratio of the 'vev' of 2 Higgs doubles




- Studies the final states:
  - $e\mu 4\nu$
  - $e\tau_{had}3\nu$, $\mu\tau_{had}3\nu$ , $\tau_{had}\tau_{had}2\nu$
- Background : Z, W+jets, Diboson, top, QCD jets

# MSSM Higgs searches: $H/A/h \rightarrow \tau\tau$

- **Minimal SuperSymmetric Standard Model (2 Higgs doublets Model are required)**

  → *h/H/A,H$^{\pm}$ (with CP-even h, H and the CP-odd A electrically neutral)*

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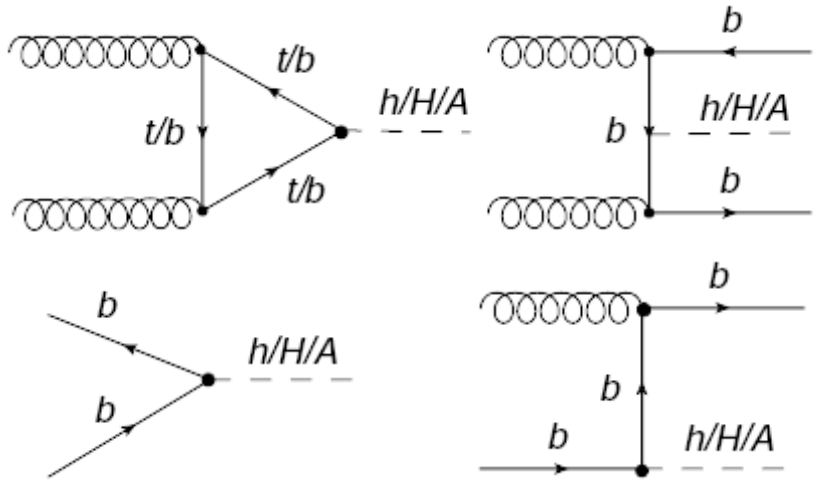


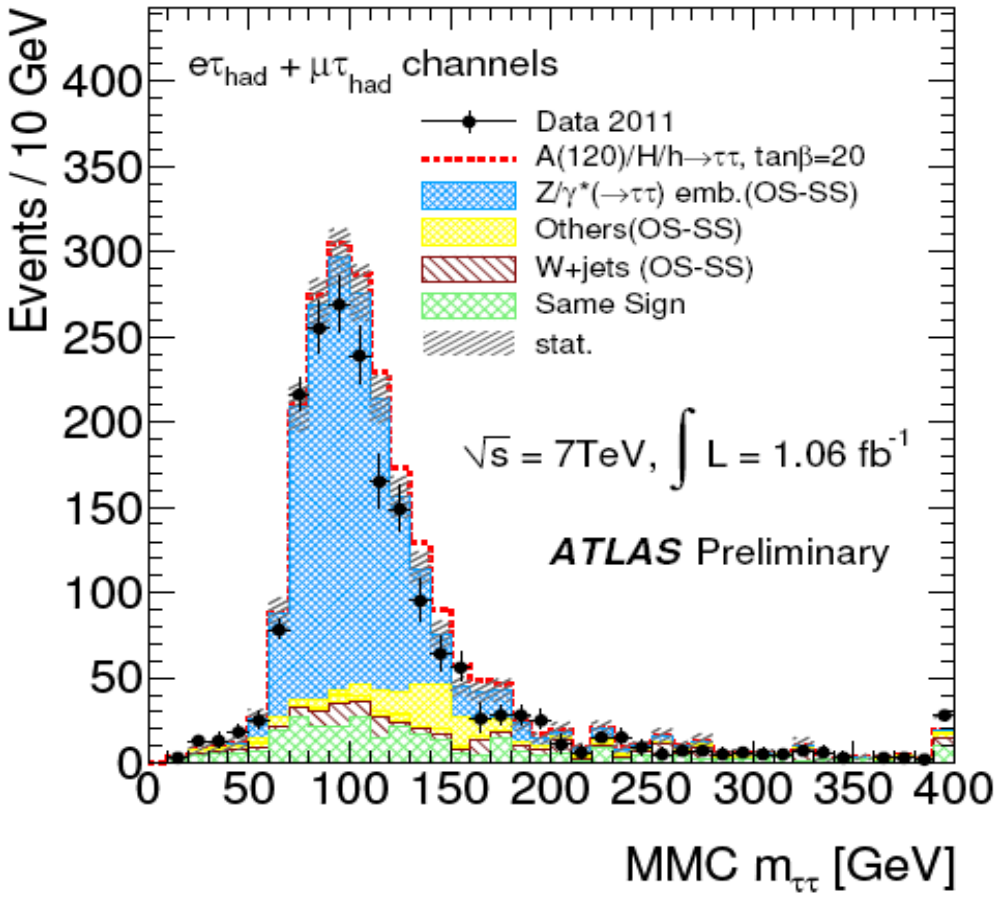

- Studies the final states:
  - *eμ4ν*
  - $e\tau_{had}3\nu$, $\mu\tau_{had}3\nu$ , $\tau_{had}\tau_{had}2\nu$
- Background : Z, W+jets, Diboson, top, QCD jets

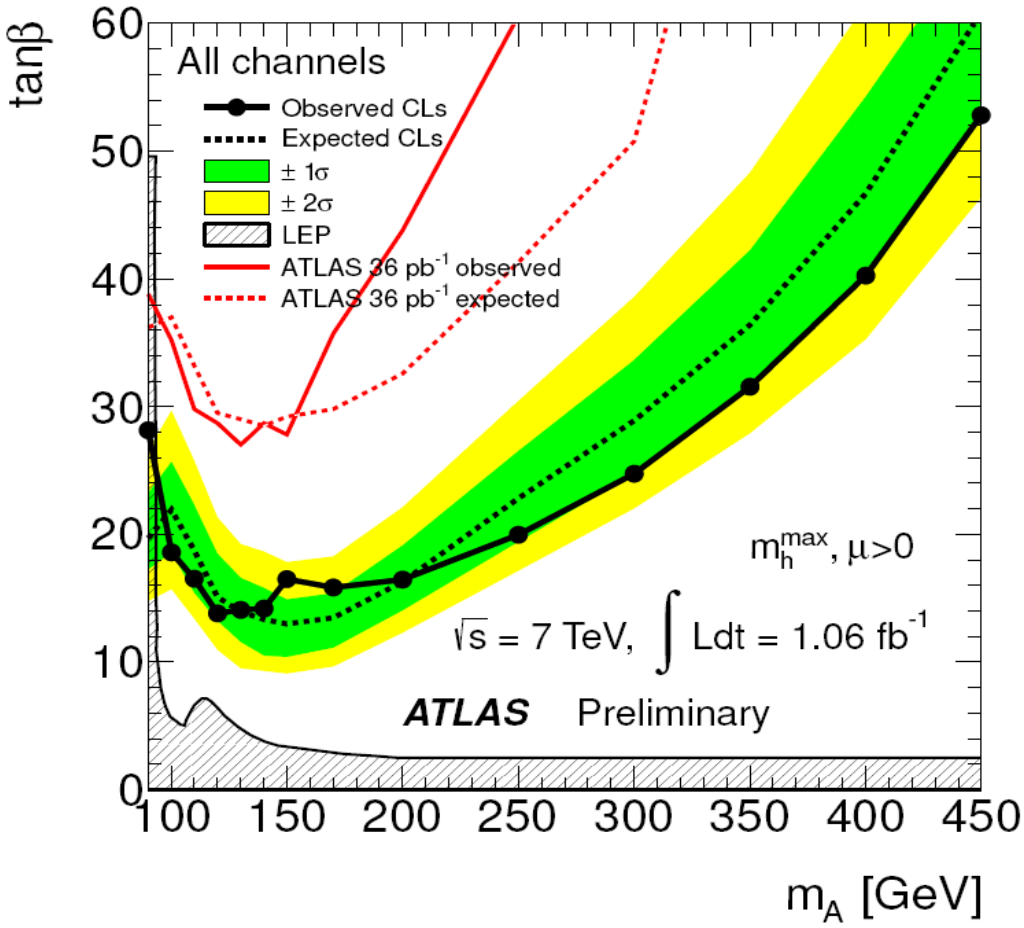
- Events selection:
  - High-$p_T$ isolated lepton, good quality high-$p_T$ hadronic taus.
  - *e/μ* veto in the $\tau_{had}\tau_{had}2\nu$ final channel

$$m_{\tau\tau}^{\text{effective}} = \sqrt{(p_{\tau^+} + p_{\tau^-} + p_{\text{miss}})^2}$$

- $m_{\tau\tau}$ mass reconstruction considering the angle between visible decay product and neutrinos as PDF

# MSSM Higgs searches: *H/A/h* → ττ




**- Expected and observed limits in the $m_A$- *tanβ* plane**

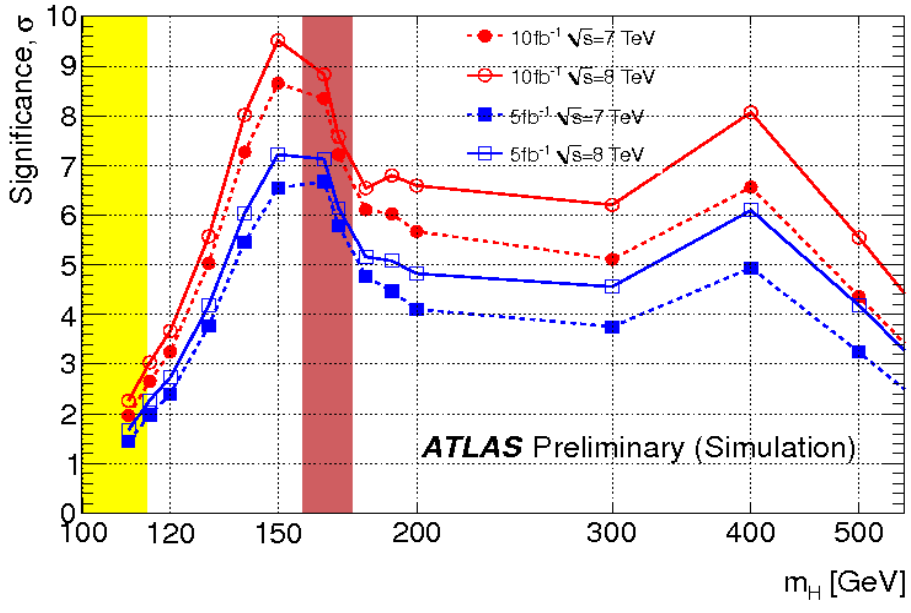
# Summary

- proton – proton collision data provided by the LHC during the 2011 allows the first constraint on the Standard Model Higgs boson production at the LHC

- With a data sample corresponding to an integrated luminosity between 1 and more than 2 $fb^{-1}$ first LHC exclusion limits on SM Higgs searches in the mass range between **110-600 GeV** have been set.

  - Exclusions at 95% C.L. :
    - *146<$m_H$<232* GeV, *256<$m_H$<282* GeV , *296<$m_H$<466* GeV

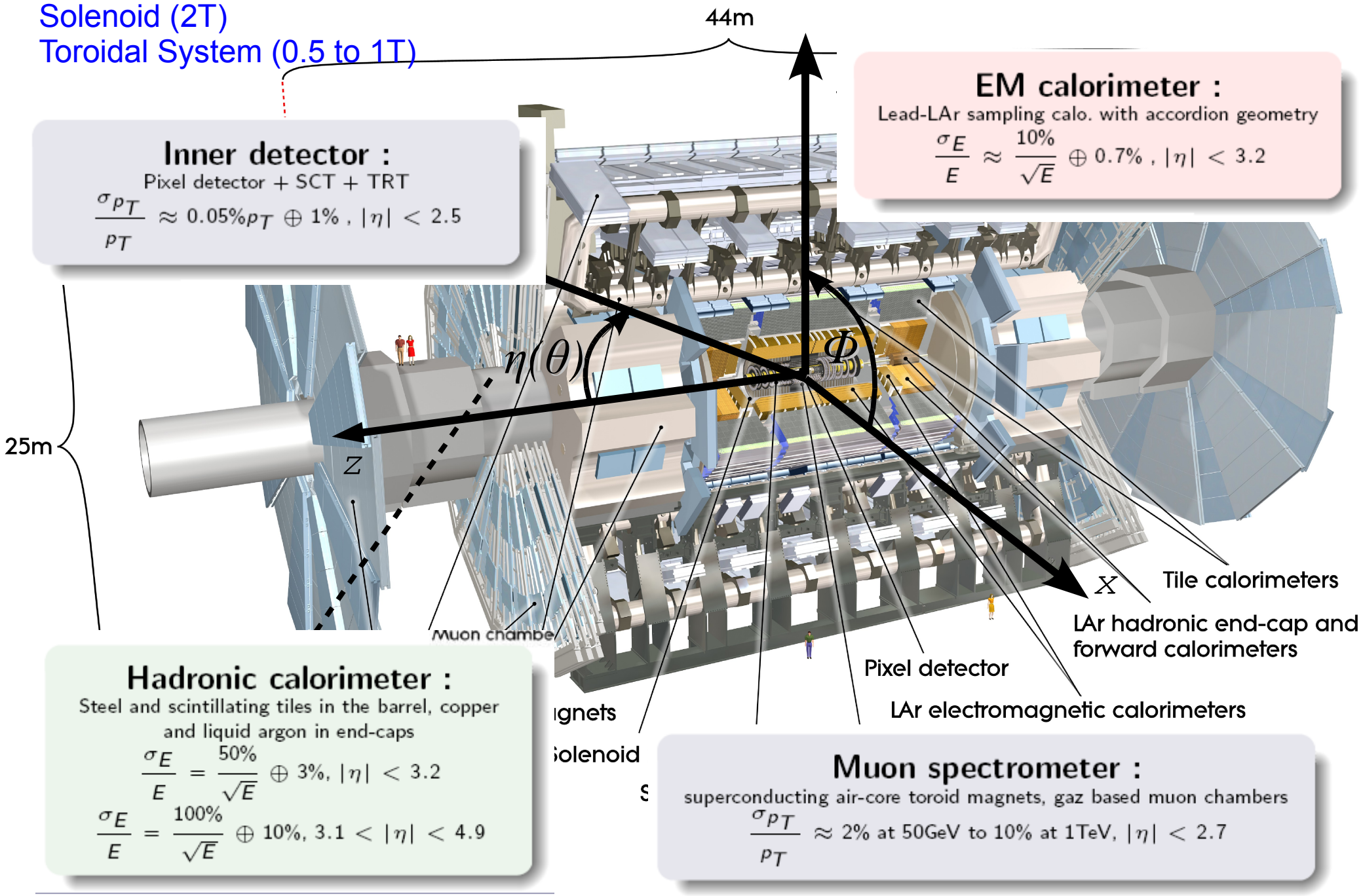
  - More integrated luminosity is essential to understand our data, improve the analysis and to increase our sensitivity to a wider mass interval



# BACKUP

# A Toroidal LHC ApparatuS (ATLAS)

Solenoid (2T)
Toroidal System (0.5 to 1T)




## Inner detector :

Pixel detector + SCT + TRT

$$\frac{\sigma_{p_T}}{p_T} \approx 0.05\% p_T \oplus 1\% \,, \; |\eta| < 2.5$$

## EM calorimeter :

Lead-LAr sampling calo. with accordion geometry

$$\frac{\sigma_E}{E} \approx \frac{10\%}{\sqrt{E}} \oplus 0.7\% \,, \; |\eta| < 3.2$$

## Hadronic calorimeter :

Steel and scintillating tiles in the barrel, copper and liquid argon in end-caps

$$\frac{\sigma_E}{E} = \frac{50\%}{\sqrt{E}} \oplus 3\%, \; |\eta| < 3.2$$

$$\frac{\sigma_E}{E} = \frac{100\%}{\sqrt{E}} \oplus 10\%, \; 3.1 < |\eta| < 4.9$$

## Muon spectrometer :

superconducting air-core toroid magnets, gaz based muon chambers

$$\frac{\sigma_{p_T}}{p_T} \approx 2\% \text{ at } 50\text{GeV to } 10\% \text{ at } 1\text{TeV}, \; |\eta| < 2.7$$

# OUTLINE

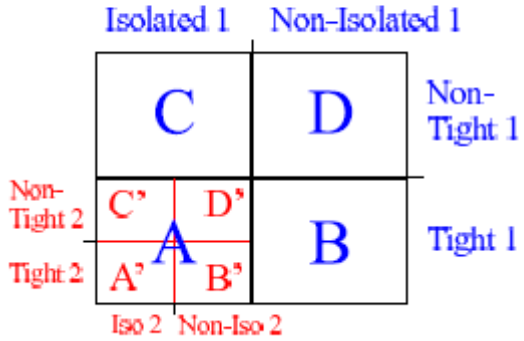
Summary of final states with their background estimation techniques

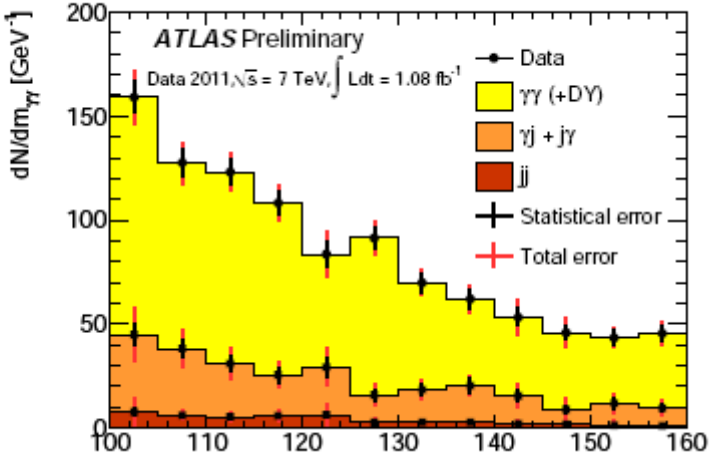
| Channel | | btag (veto) | Jets | MET (GeV) | Shape | Mass Range (GeV/$c^2$) | Main backgrounds |
|---|---|---|---|---|---|---|---|
| γγ | | | | | $M_{gg}$ | 110-150 | γγ (from sidebands) |
| WH | | ✓ | 2 | | $M_{bb}$ | 110-130 | Top (3j - high $M_{bb}$) and W+jets (low $M_{bb}$) |
| ZH | | ✓ | 2 | | $M_{bb}$ | 110-130 | Z+jets (low $M_{bb}$) |
| WW (lνlν) | 0-jet | | 0 | >30 | | 110-240 | WW (control region $M_{ll}$) |
| | 1-jet | veto | 1 | >30 | | 110-240 | Top (from reverse btag) and WW ($M_{ll}$ CR) |
| WW (lνqq) | 0-jet | | 0 | >30 | $M_{WW}$ | 200-600 | W+jets (sidebands) |
| | 1-jet | veto | 1 | >30 | $M_{WW}$ | 200-600 | W+jets (sidebands) |
| ZZ (llνν) | | ✓ | | >30 | $M_T$ | 200-600 | VV(from MC) and top (MC and checks) |
| ZZ (llqq) | | ✓ | 2 | <50 | $M_{llqq}$ | 200-600 | Z+jets (from MC) and top (from MC) |
| ZZ (4l) | | IP | | | $M_{4l}$ | 110-600 | ZZ (from MC), Z+jets (MC) and top (CR) |

**Kyle Crammer at EPS 2011**

# Higgs decaying into two photons at the LHC (systematics)

- **Background estimation:**
  - 2x2D sidebands method.
  - Electron photon fake rate from Z → ee




| Uncertainties on the signal yield | Total ±12% |
|---|---|
| Reconstruction and identification efficiency | ±11% |
| Isolation cut efficiency | ±3% |
| Trigger efficiency | ±1% |
| Luminosity | 3.7% |
| Effect of $p_T^H$ modelling on the kinematical cut acceptance | 1% |
| **Uncertainties on the invariant mass resolution** | **Total ±14%** |
| Constant term of the cluster energy resolution | ±12% |
| Photon calibration from extrapolation of energy scale calibration of electrons | ±6% |
| Contribution of pileup fluctuations to the cluster energy measurement | < 3% |
| Photon angle measurements | 1% |

# W/Z + H → bb production

| $m_H$ (GeV) | $\sigma(WH)$ (pb) | $\sigma(ZH)$ (pb) | Branching Ratios $H \longrightarrow b\bar{b}$ |
|---|---|---|---|
| 110 | 0.875 | 0.472 | 0.745 |
| 115 | 0.755 | 0.360 | 0.705 |
| 120 | 0.656 | 0.316 | 0.649 |
| 125 | 0.573 | 0.278 | 0.578 |
| 130 | 0.501 | 0.245 | 0.494 |

# $H \rightarrow WW^{(*)} \rightarrow l\nu l\nu$ . Background estimate

- Background estimate from data in counting experiment is essential
- In the current version of this analysis we estimate from data the two largest backgrounds, namely those from WW and top
  - Approach:
    - Define control regions rich in WW or top backgrounds and measure this backgrounds in data
    - Extrapolate this measurement to the signal region(s) using MC shapes
- W+ jets entirely determined from data
- Remaining backgrounds (smaller) are taken from MC
  - Apply scale factor to Drell-Yan for potential $E_T^{miss}$ mis-modelling

$$N_{data}^{S.R.} = \alpha \times N_{data}^{C.R.}, \qquad \alpha = \frac{N_{MC}^{S.R.}}{N_{MC}^{C.R.}}$$

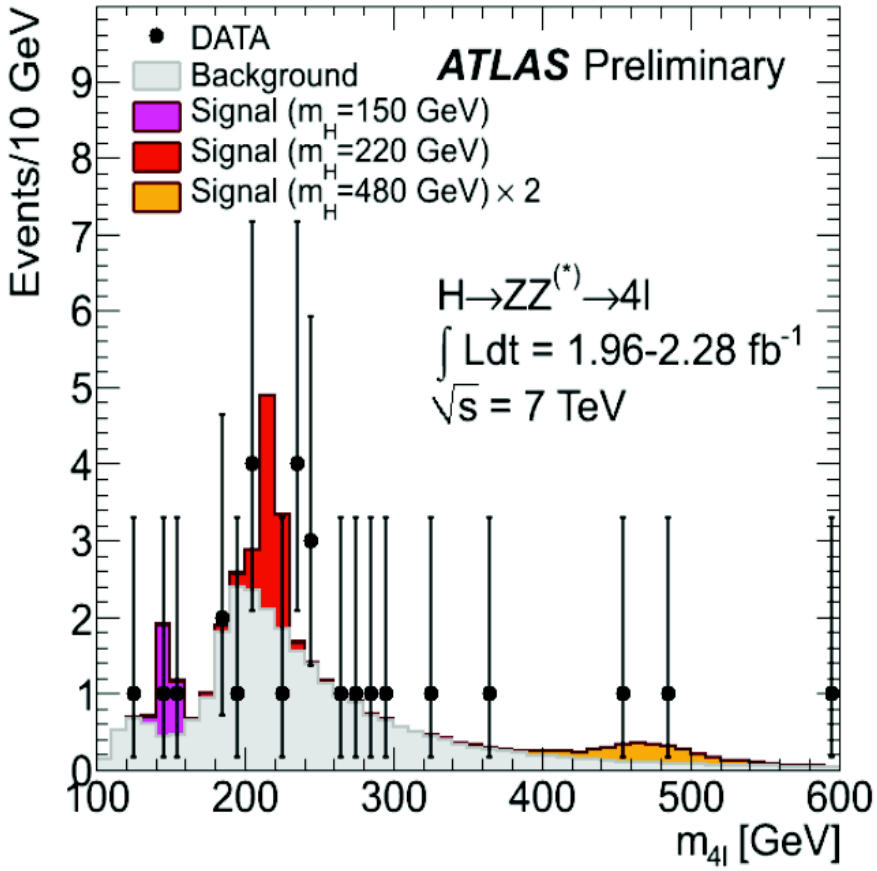
| Control Region | MC expectation | Observed |
|---|---|---|
| WW 0-jet | 250±50 | 237 |
| WW 1-jet | 139±18 | 144 |
| Top 1-jet | 350±100 | 316 |

# SM Higgs Searches in ATLAS : $H \rightarrow ZZ^{(*)} \rightarrow 4l$

- *$ZZ^{(*)}$ from MC predictions*
  - Theory uncertainty 15%

- *Top from MC predictions*
  - Yield validated in control region
  - Theory uncertainty 10%

- *Z+jets normalized to data using ctrl-regions*
  - inversion of isolation and IP parameter cuts.
  - Uncertainty: 20-40% (dominated b statics in ctrl-region and extrapolation t signal region)



# 4th generation

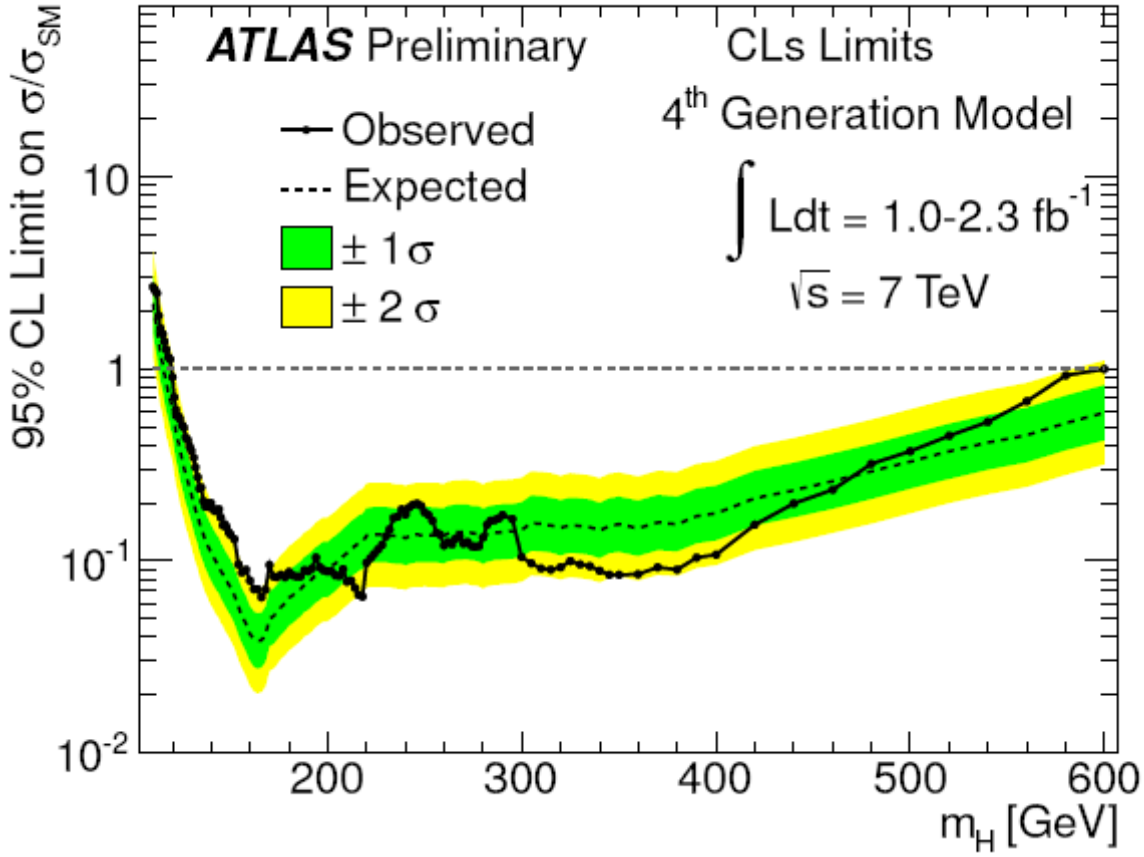
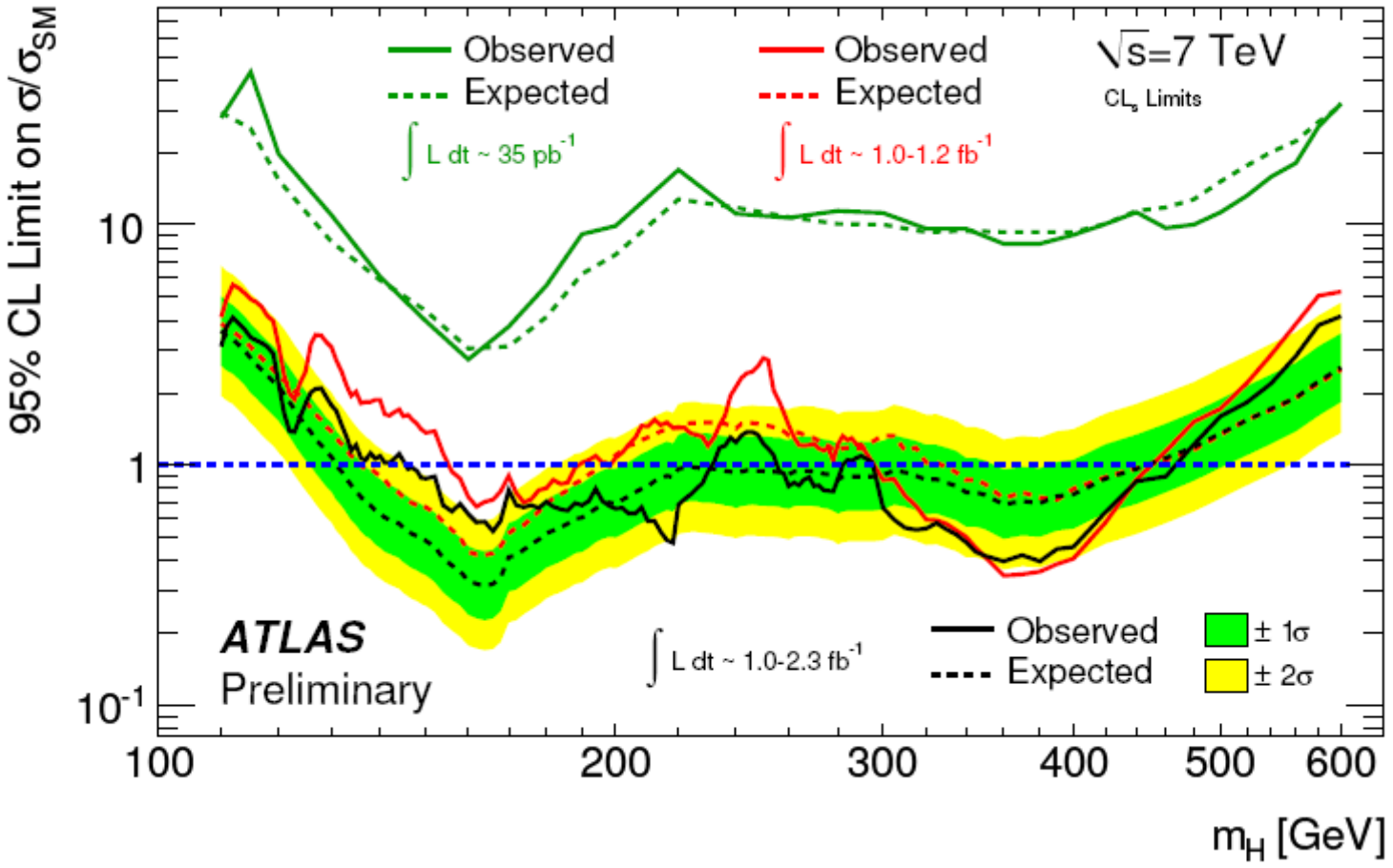



Figure 7: The combined upper limit on the Higgs boson production cross section in the framework of a Standard Model with the addition of a heavy fourth generation of fermions divided by its expectation as a function of $m_H$ is indicated by the solid line. This is a 95% CL limit using the $CL_s$ method. The dotted line shows the median expected limit in the absence of a signal and the green and yellow bands reflect the corresponding 68% and 95% expected regions.

# ATLAS SM Higgs Combinations 2010-2011 Evolution




**The expected (dashed) and observed (solid) cross-sections limits for individual channels, as functions of the Higgs boson mass**