Search for the Standard Model Higgs to WW in the fully leptonic decay channel at the ATLAS experiment

Sara Diglio
University of Melbourne

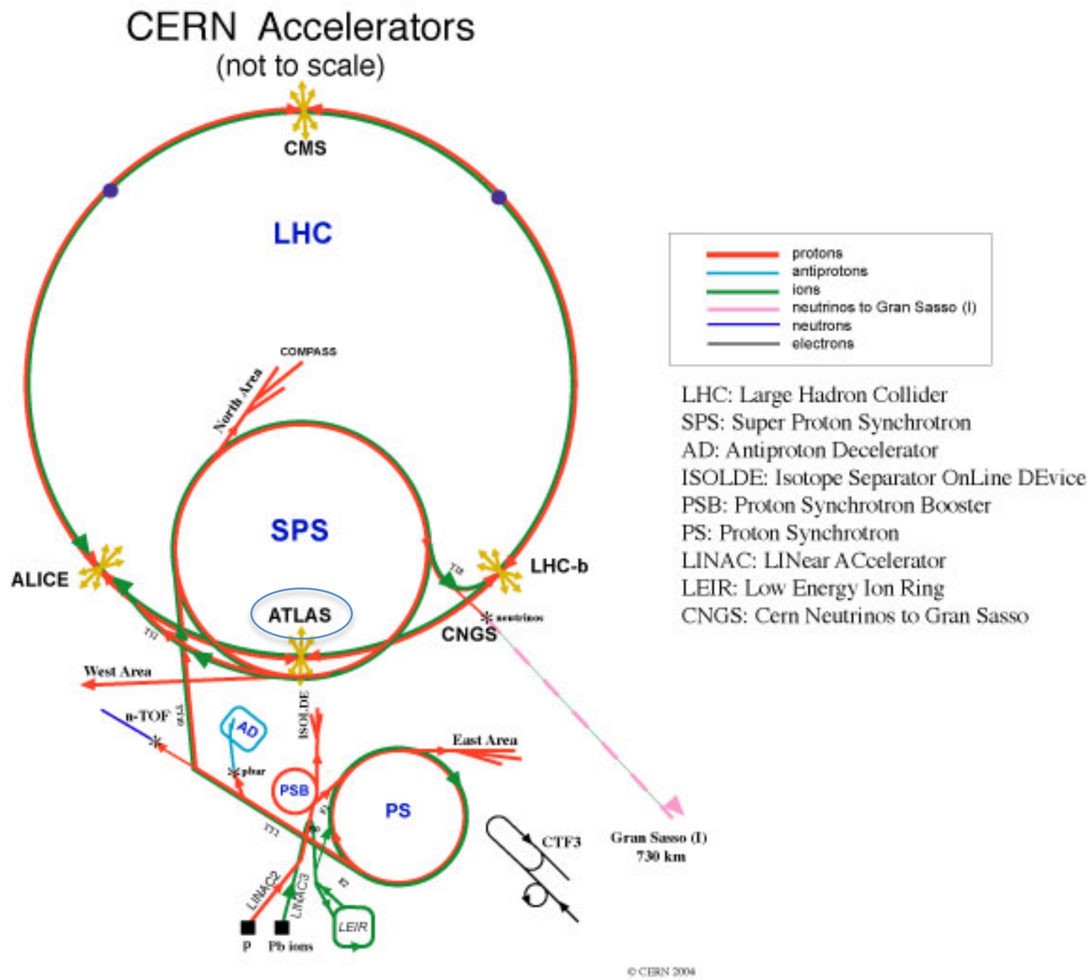
Outline

- The experimental environment: LHC and ATLAS
  - Basic concept on particles interaction and detection
- Higgs production and decay at LHC
- The H→ WW → lνlν channel:
  - Event selection
  - Background estimation
  - Limits
- Conclusions

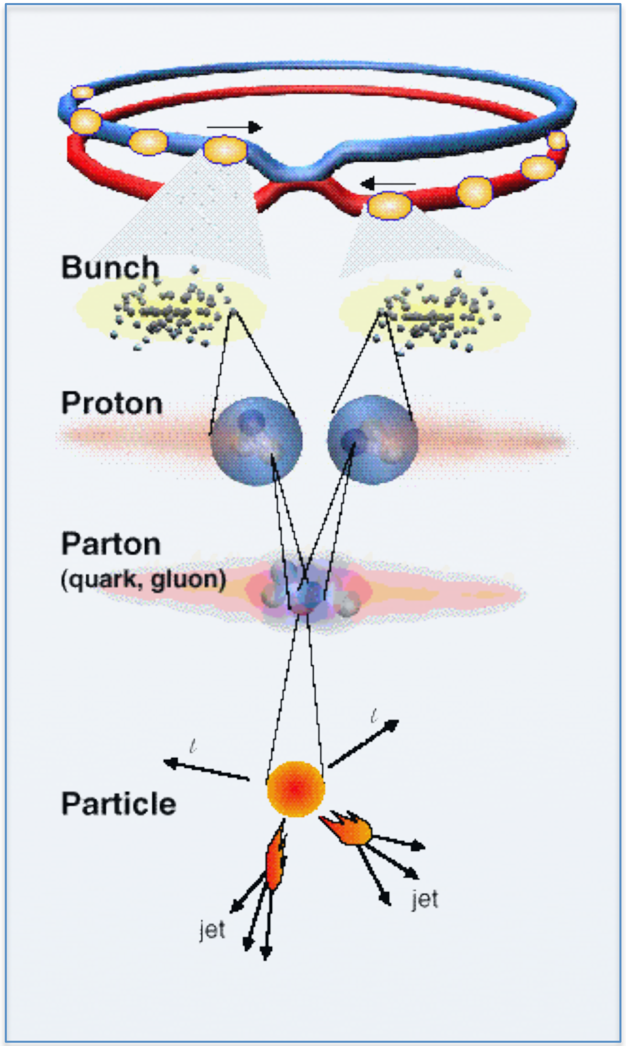
Most of the material from **Rencontres de Moriond 2012:**
- Sandra Kortner
- Ralf Bernhard
- Josh Kunkle

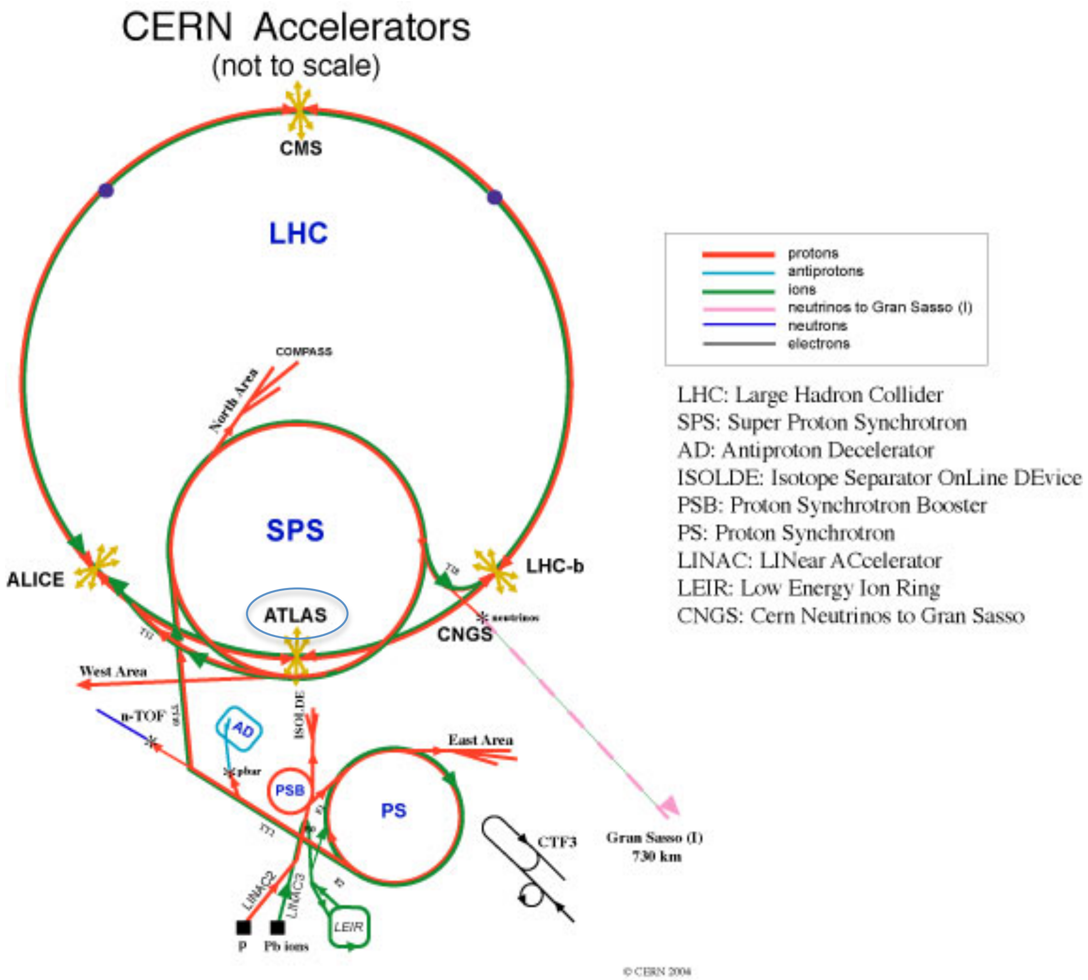
Large Hadron Collider

Proton – proton collider
Center of mass energy:
7 TeV (in 2011)

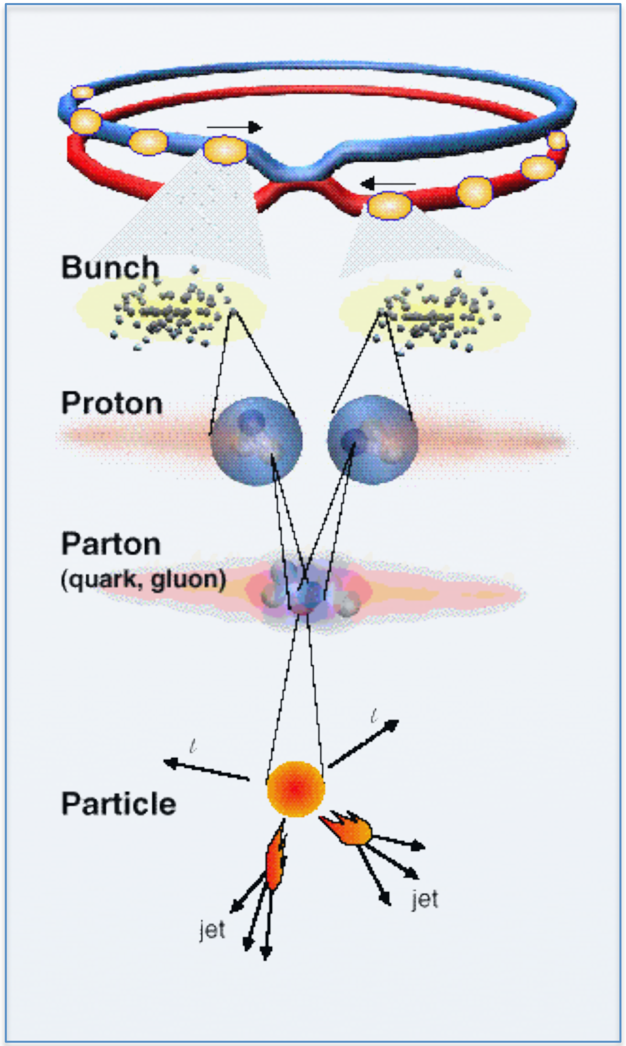


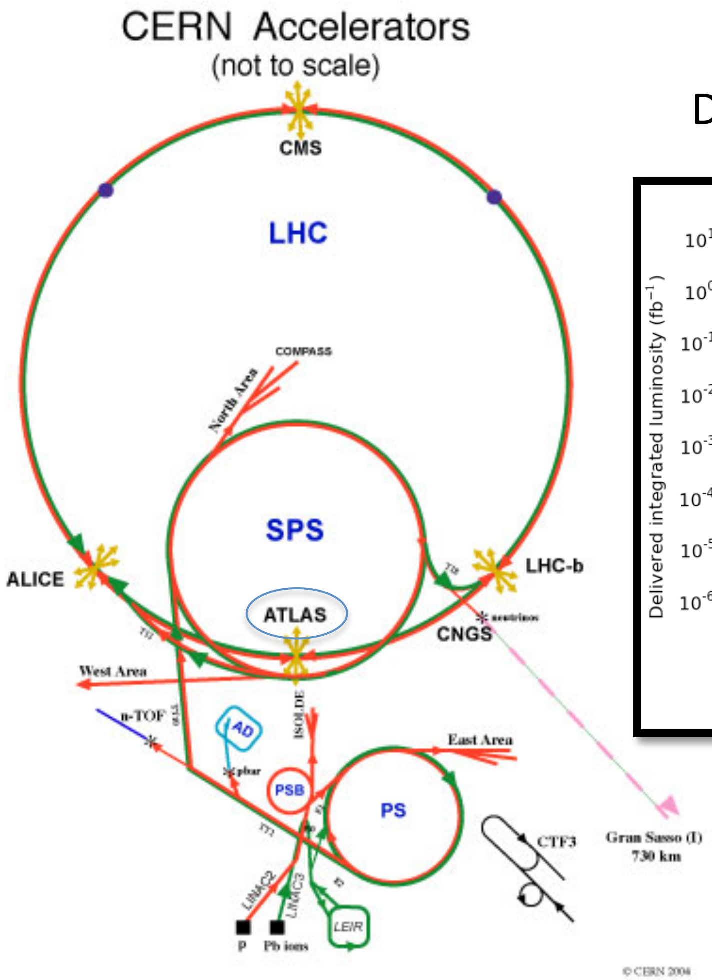
Large Hadron Collider



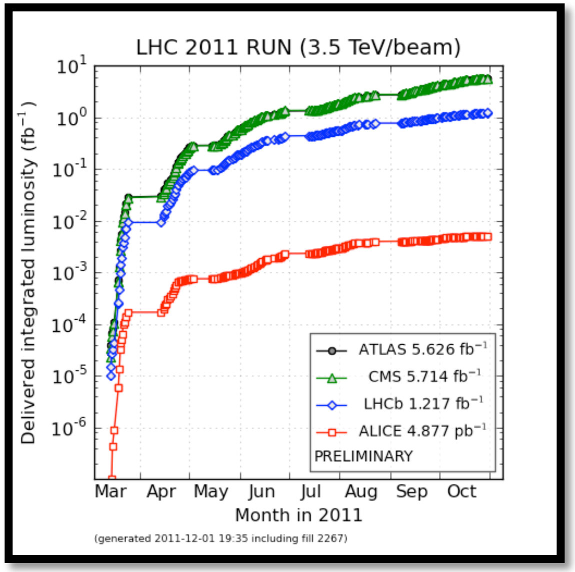


Large Hadron Collider



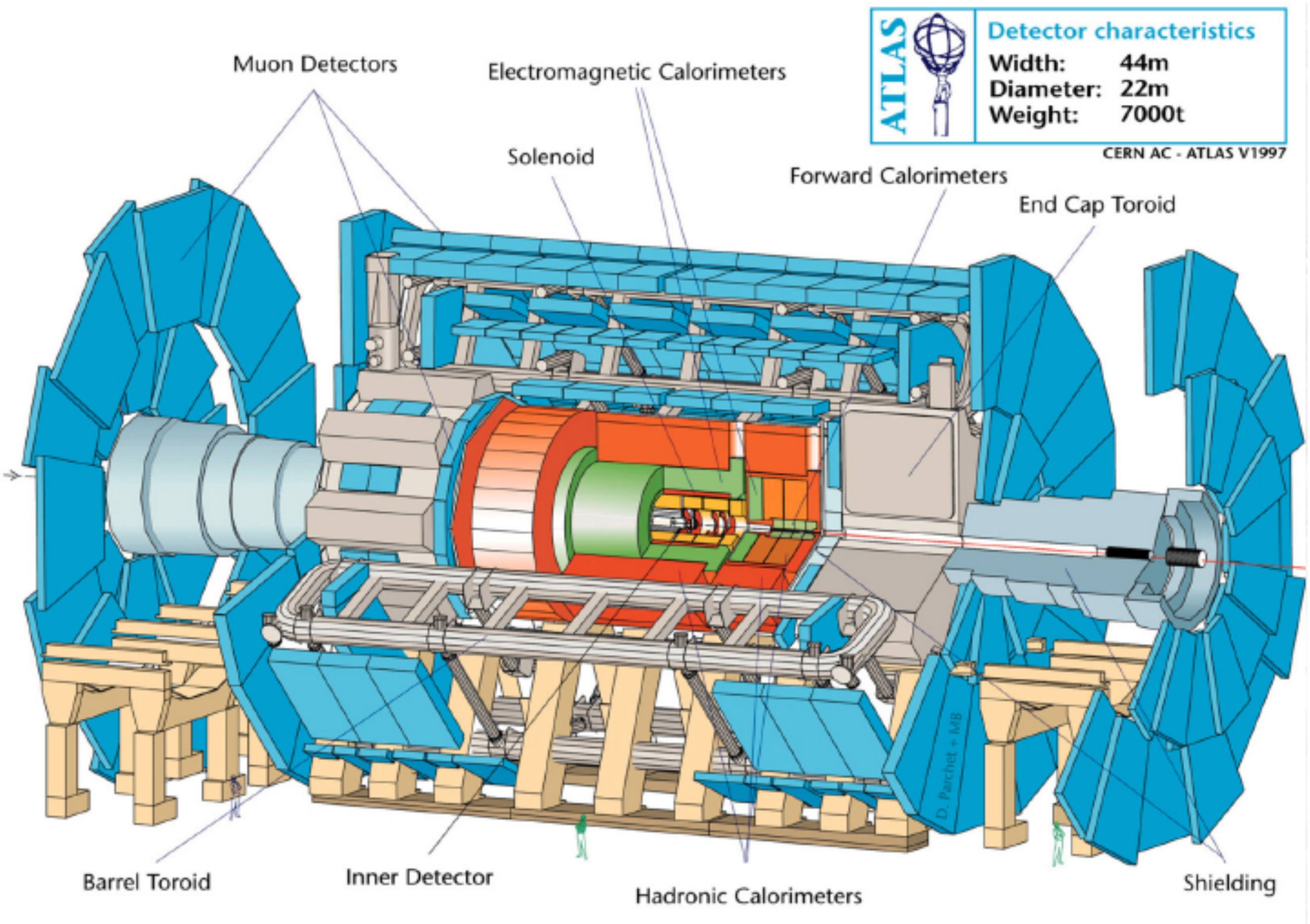


Data collected in 2011

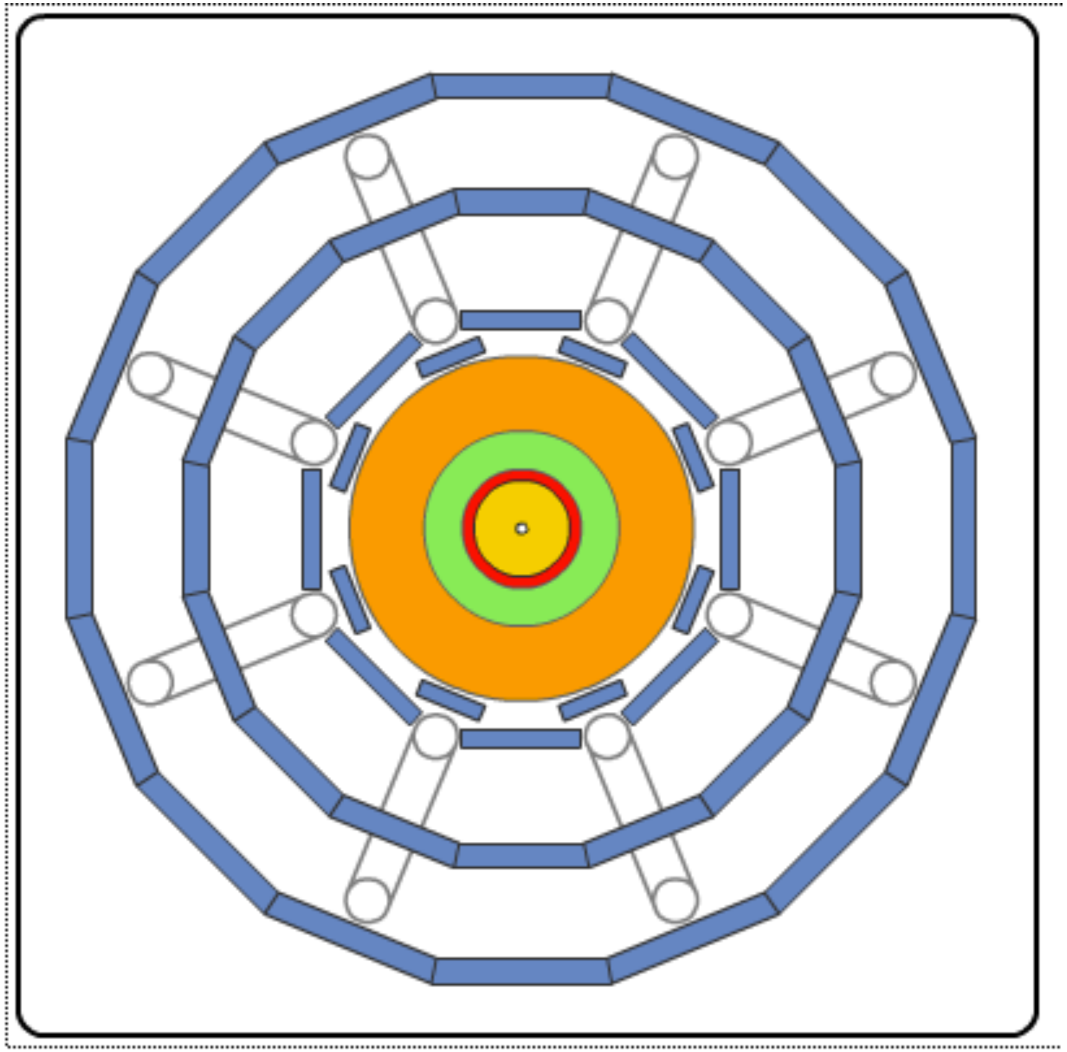


ATLAS results shown in this presentation correspond to an integrated luminosity of **~ 4.7 fb^{-1}**

A Toroidal LHC ApparatuS



The ATLAS Detector



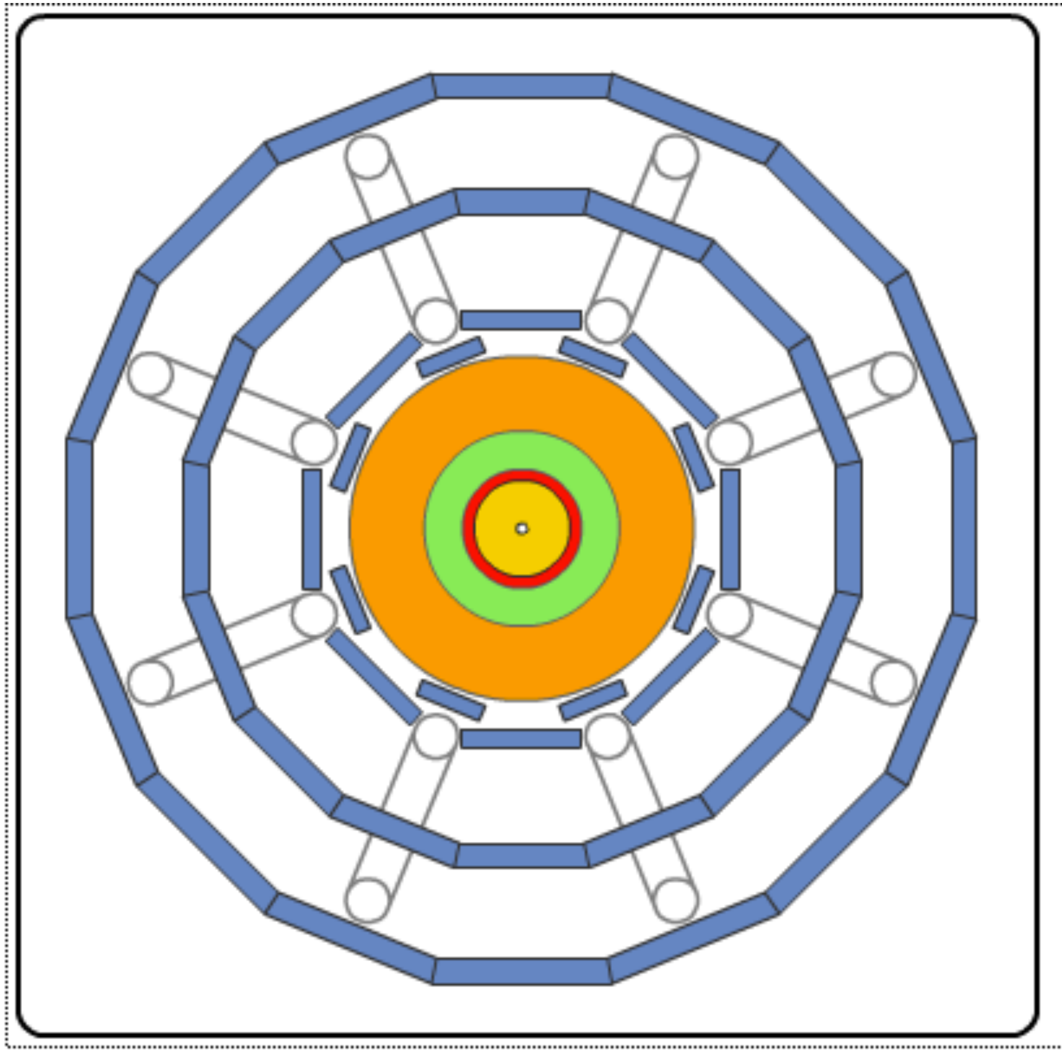
Tracking Detector

The inner region of the detector is filled with highly segmented sensing device, so that **charged particle** trajectories can be determined

Solenoid magnet

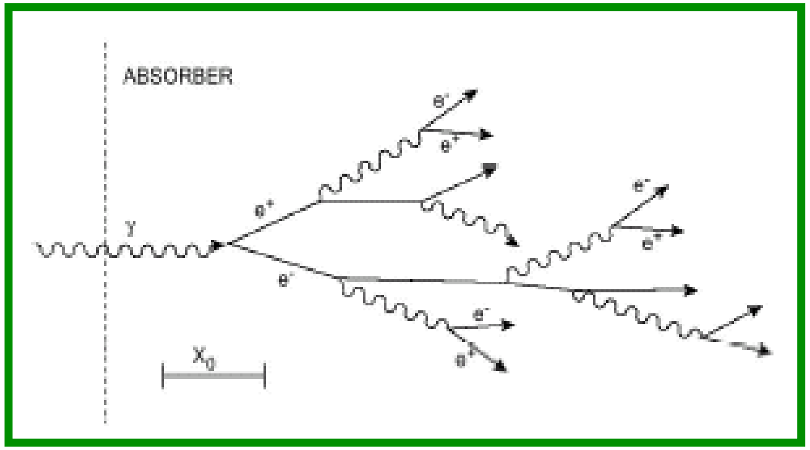
The path of a charged particle curves in a magnetic field. The radius of curvature and direction tell the momentum and the sign of the charge

The ATLAS Detector

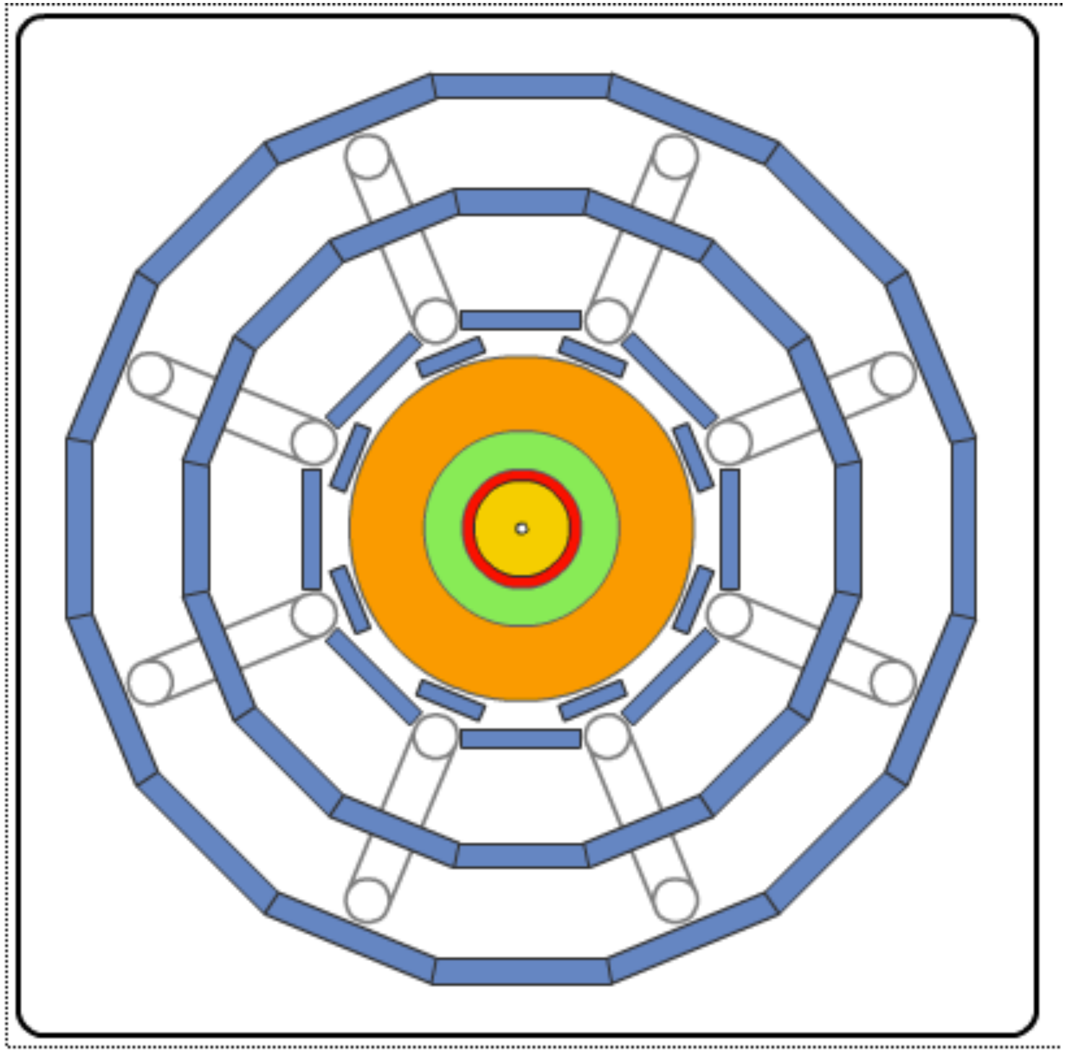


Electromagnetic Calorimeter

The device measures the total **e+,e-** and **photons** (γ). These particles produce showers of e+e- pairs in the material and irradiate photons. The photons then make e+e- pairs etc. The number of final e+e- pairs is propotional to the energy of the initiating particle

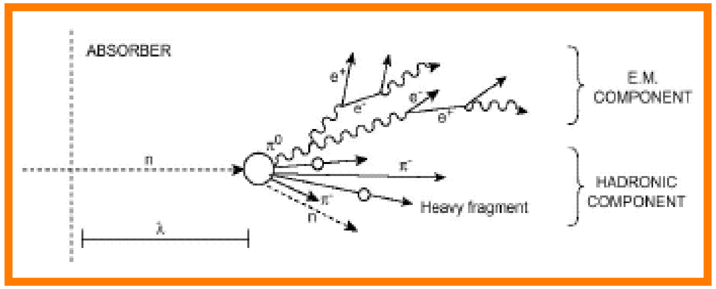


The ATLAS Detector



Hadron Calorimeter

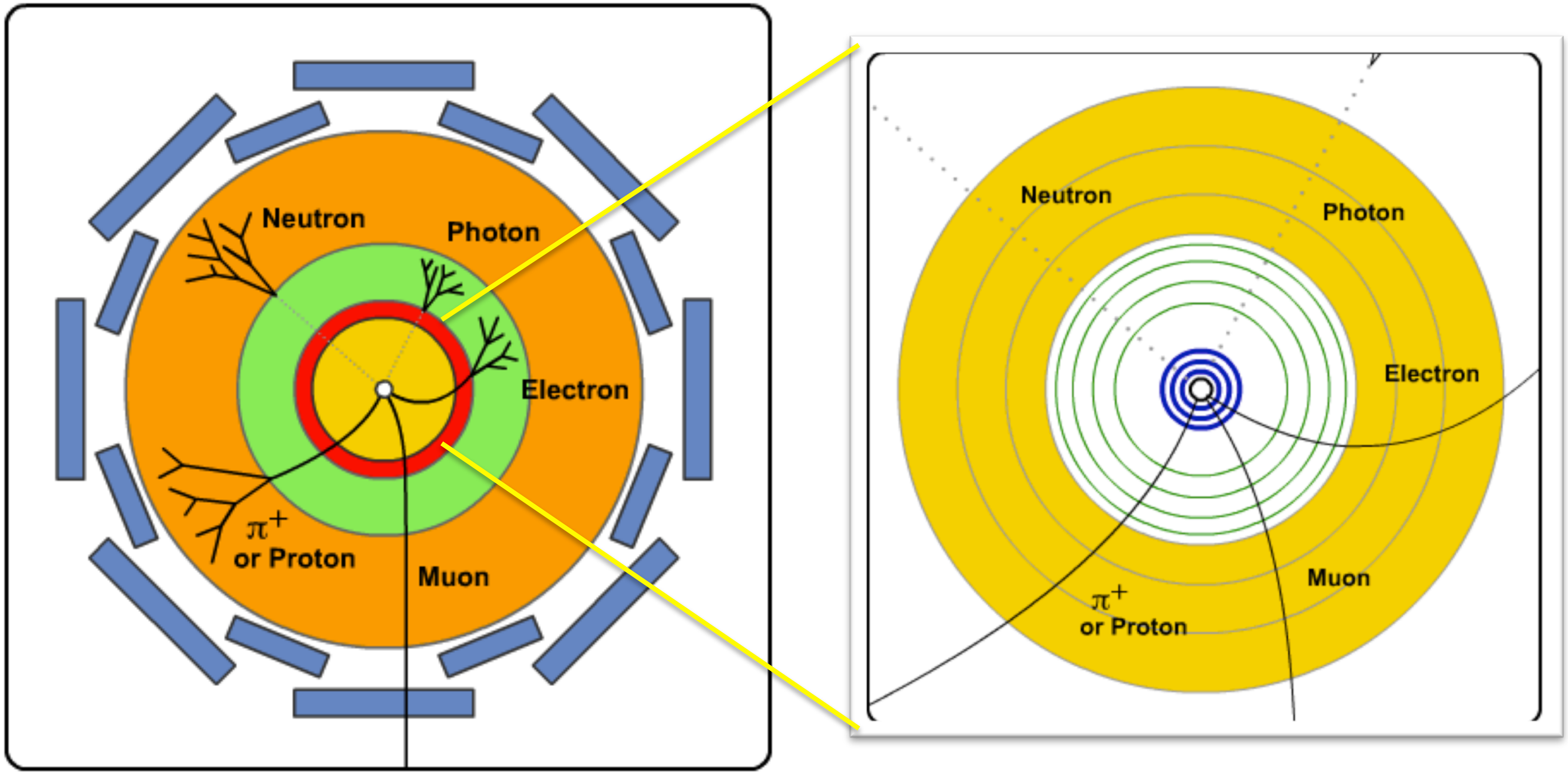
This device measures the total energy of hadrons. The **hadrons** interact with the dense material in the region, producing shower of charged particles called jets. The energy that these charged particles deposit is the measured



Muon Detector

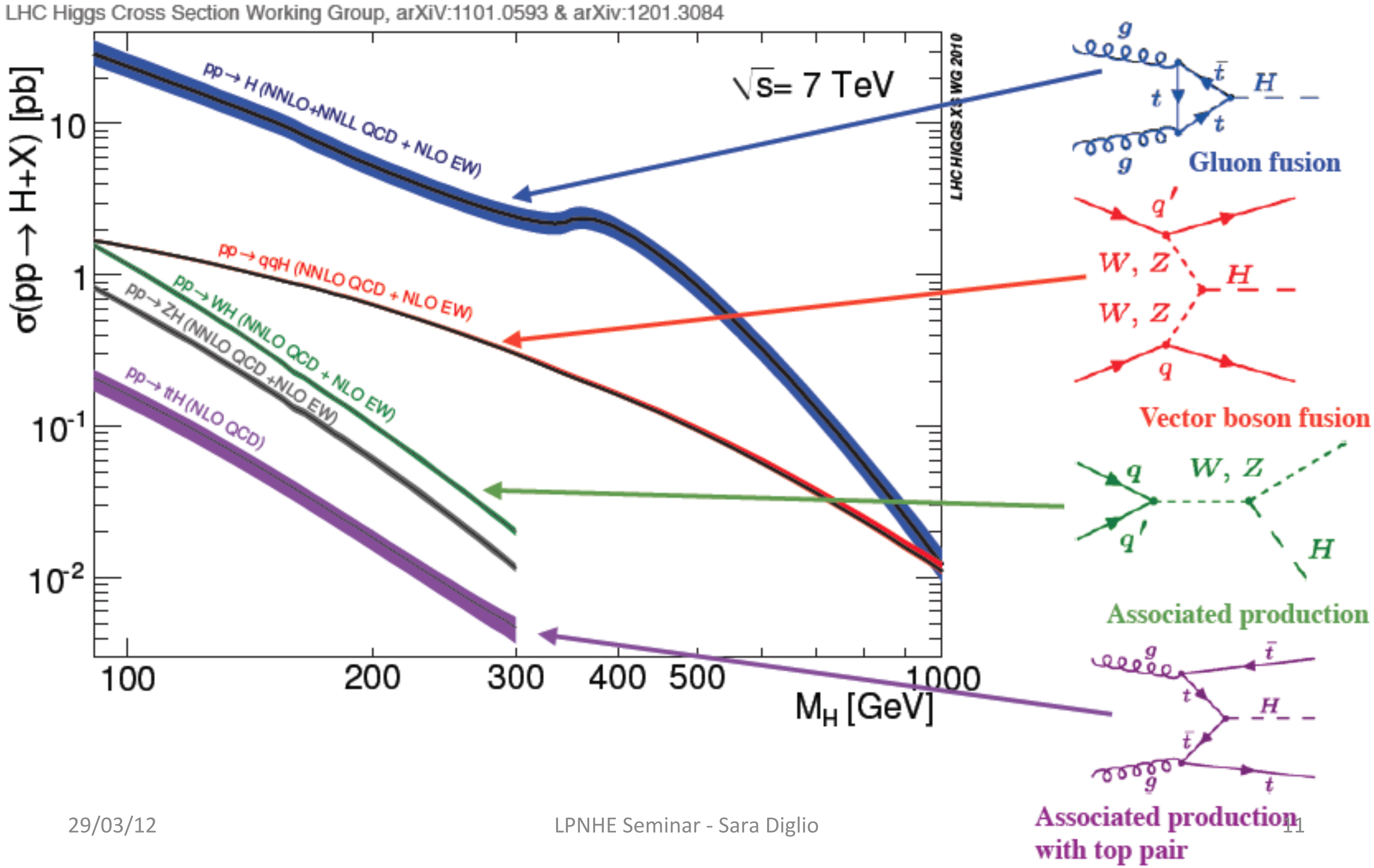
Only **muons** and neutrinos get this far. The muons are detected, but weakly interacting neutrinos can be inferred by the missing energy

The ATLAS Detector

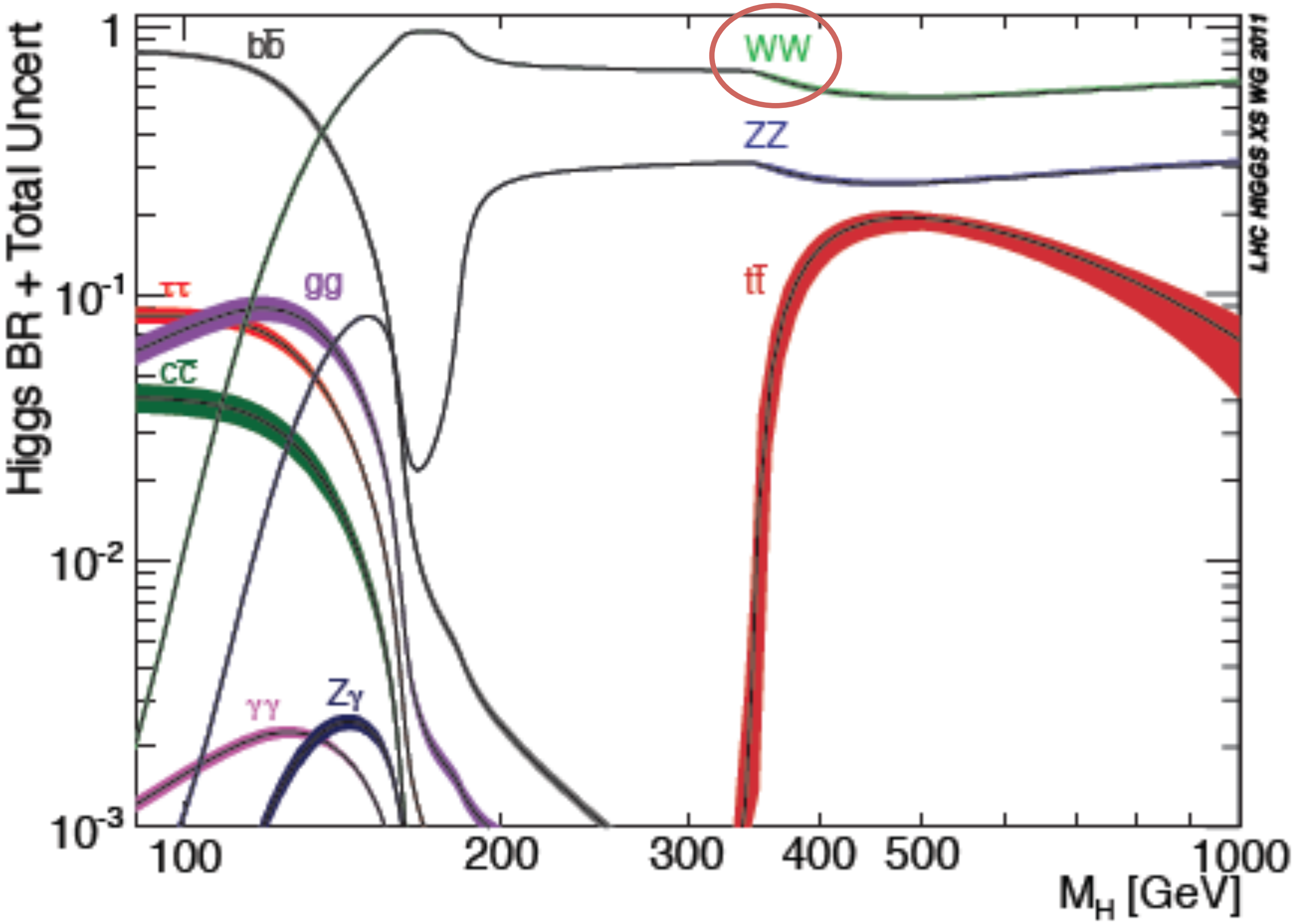


Neutrinos are not detected, but measured trough the missing energy of the process

Higgs Boson Production at the LHC



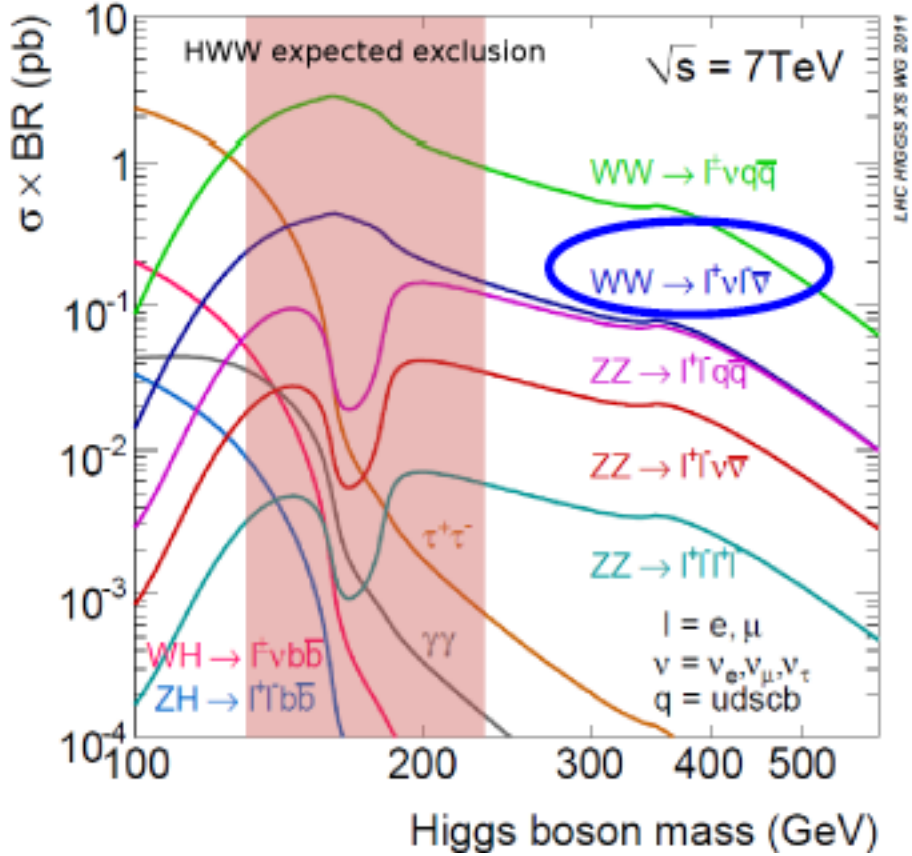
Higgs Boson decay



H→WW→lνlν

Why we search in H→WW→lνlν

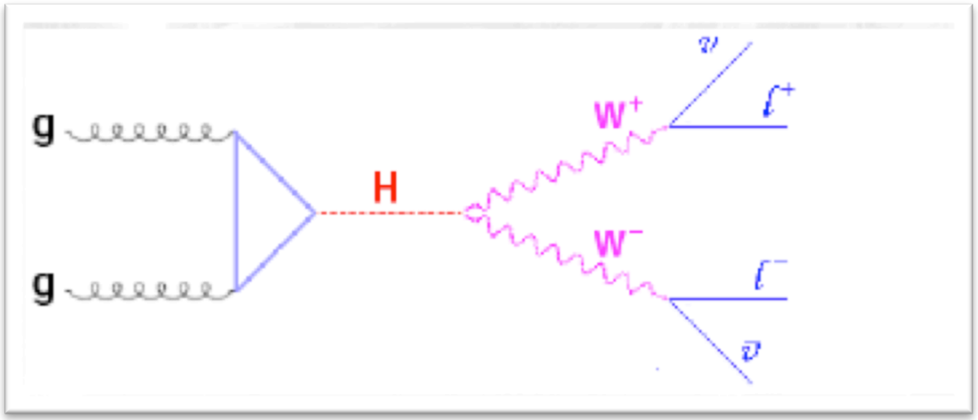
- Most sensitive channel in a broad mass range :
  mH ~ 120-180 GeV
- Expected sensitivity extends to low m_H



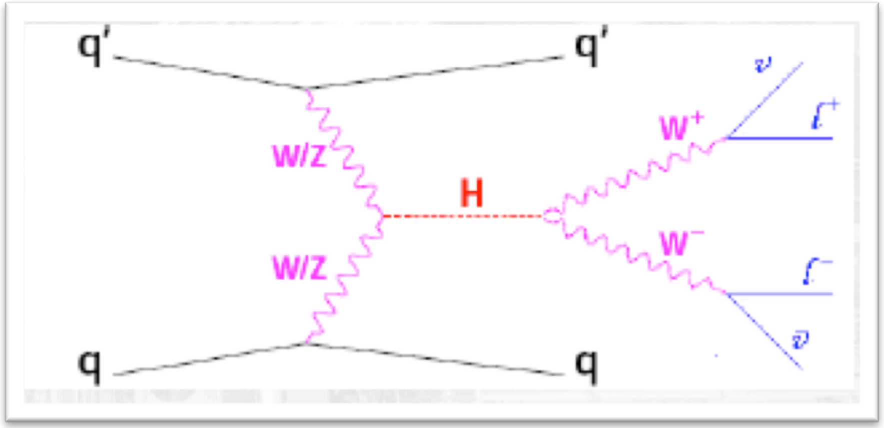
H→WW→lνlν (l=e,μ)

- Higgs produced via:

gluon-gluon fusion (ggF)



vector-boson fusion (VBF)



- 3 lepton pair final states : ee, μμ, eμ
- Separate search into 0, 1 and 2 jet bins with tailored cuts for each channel
  - Then systematic uncertainties can be treated differently

Some of the features (difficulties?)

Final state
2 leptons + Missing Energy + jets (in 1 and 2 jets channel)

- Signal is a broad excess of events
- No mass reconstruction possible due to 2ν
  → Missing energy as part of the signature
- Backgrounds with cross sections many orders of magnitude bigger than signal
  → Must have confidence in background model to identify an emerging signal
- The measurement is affected by large theoretical and detector uncertainties

Main Backgrounds

For different jet multiplicities the impact of the different backgrounds is different

- QCD WW

(dominant in 0 and 1 jet)

- tt

(dominant in 2 jets)

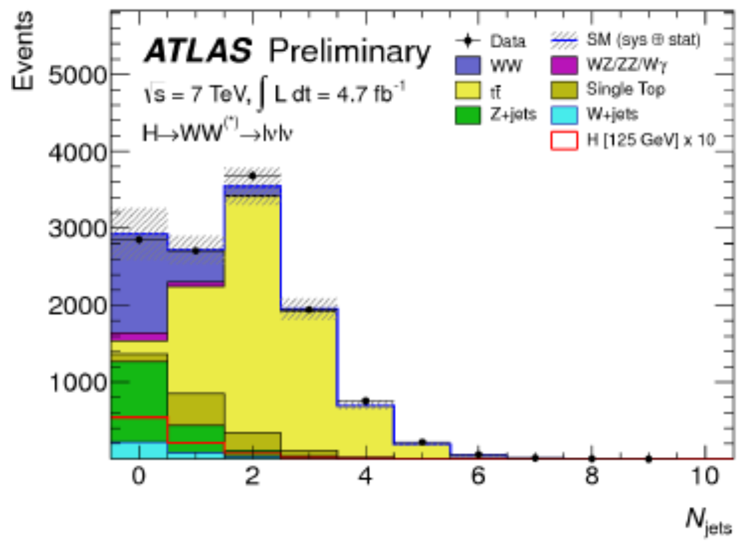
- Z/γ*+jets

(same flavor channels)

- W+jets

(cross sections many orders of magnitude bigger than Higgs production)

Categorisation in 0,1,2 jets bin to handle different background contamination



Other Backgrounds

- WZ + ZZ – Small backgrounds. Estimate from Simulation
- Single Top – Included in the Top background. Differences in b-jet kinematics shown to be negligible
- Wγ* - Important at low mass. Background estimate currently from Monte Carlo. Data driven methods are being developed.

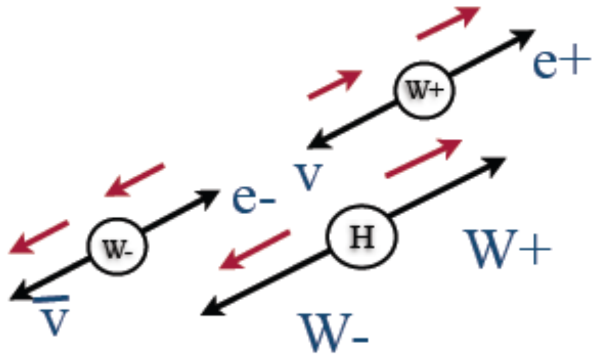
Strategy

- Finding discriminating variables between signal and different backgrounds
- Apply Cut-based analysis
- Background estimation: use data-driven estimates for main backgrounds:
  - Define control regions (sample enriched in particular backgrounds) reversing or changing some cuts from the signal-like region
  - Subtract the contamination of other backgrounds in control regions
  - Propagate estimation from control regions to signal regions (using scales from data/MC)
- Extract the limits

Discriminating variables: WW

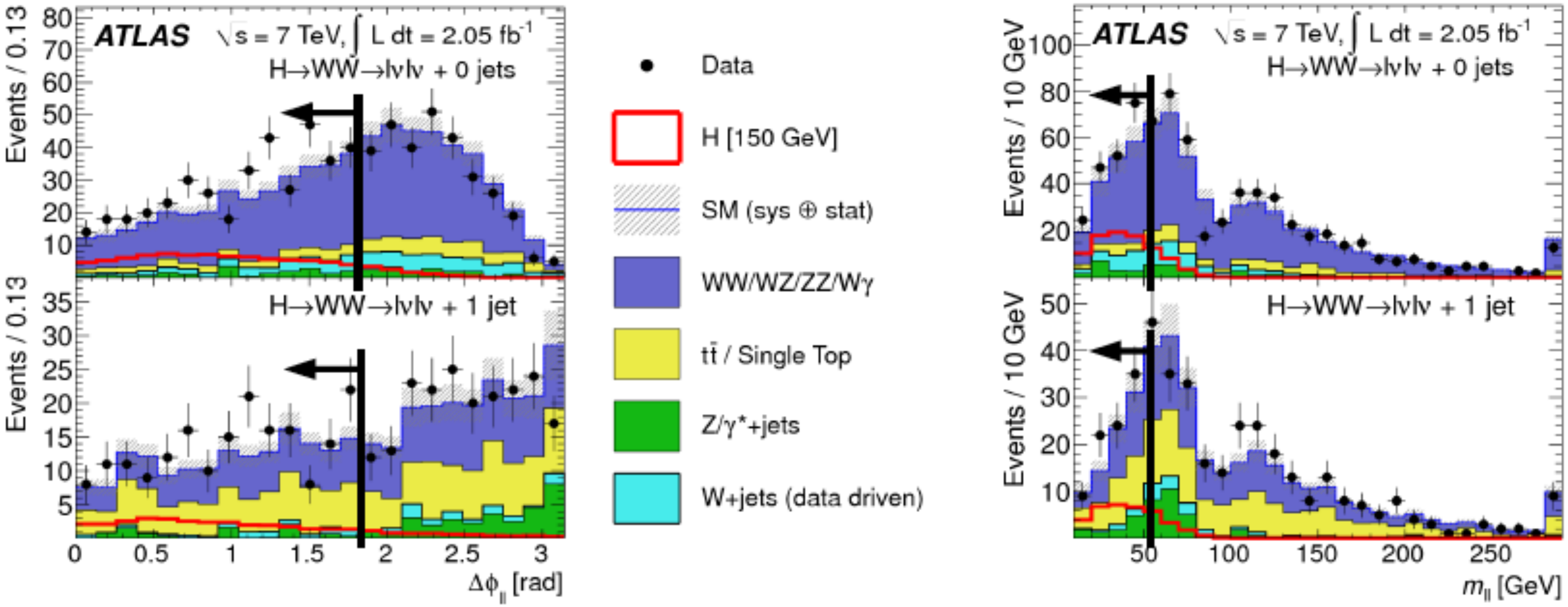
Exploit spin-0 nature of Higgs

→ WW spin correlation



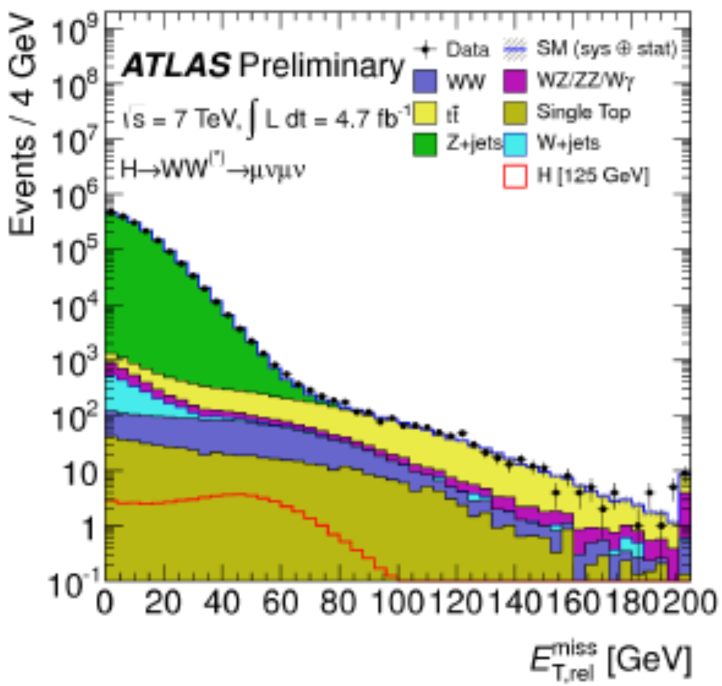
Require small $\Delta\varphi(l^+, l^-)$

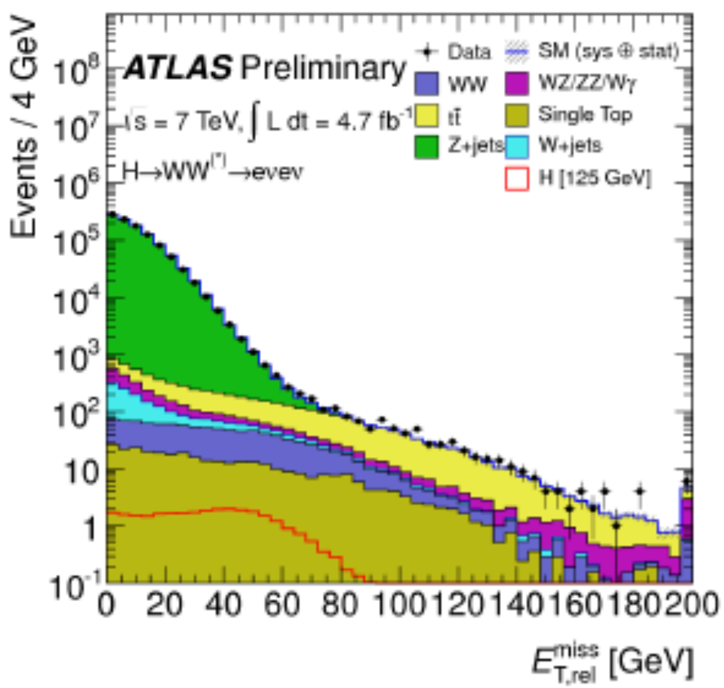
Require low $m(l^+, l^-)$



Discriminating variables: Z+jets

Missing Energy Distributions

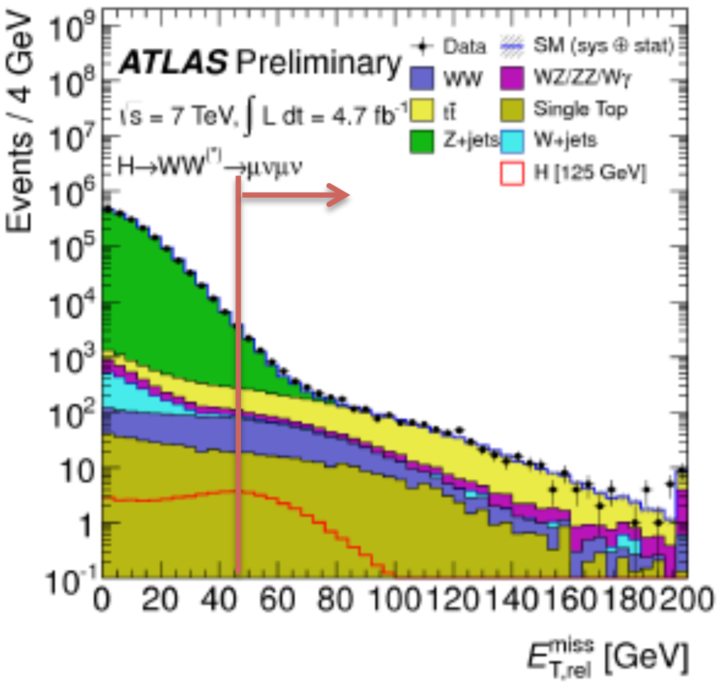


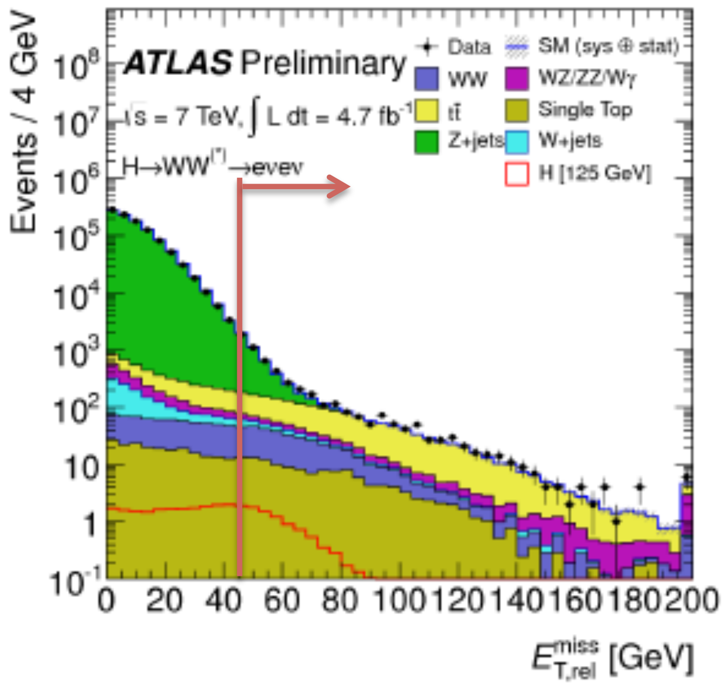


Discriminating variables: Z+jets

Missing Energy Distributions

The cut removes the majority of Z+jets events





Event selection

common to 0, 1 and 2 jets bin

- Two isolated opposite-sign leptons
- Invariant mass of the two leptons
- Z mass veto
- Large missing transverse energy

Event selection

common to 0, 1 and 2 jets bin

- Two isolated opposite-sign leptons

  Leading lepton p_T > 25 GeV

- Invariant mass of the two leptons

  m_{ll}>12 GeV for ee and $\mu\mu$ channel, m_{ll}>10 GeV for eμ channel

- Z mass veto

  $|m_{ll}-m_Z|$>15 GeV for ee and $\mu\mu$ channel

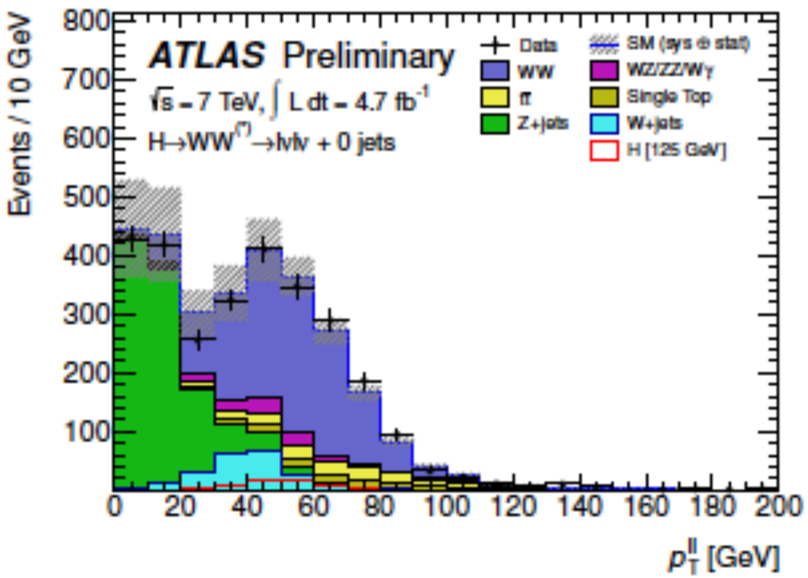
- Large missing transverse energy

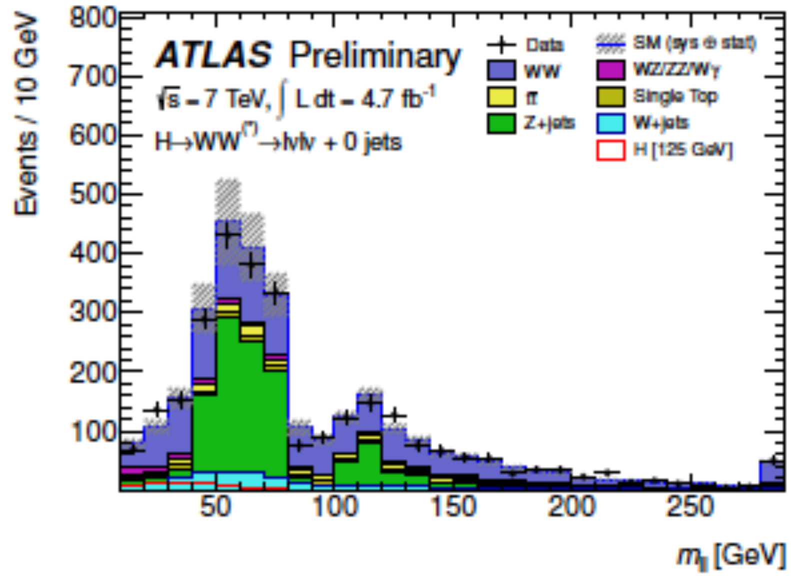
  E_T^{miss} > 45 GeV for ee and $\mu\mu$ channel, E_T^{miss} > 25 GeV for eμ channel

Event selection

depending 0, 1 and 2 jet bin

- 0 jet :



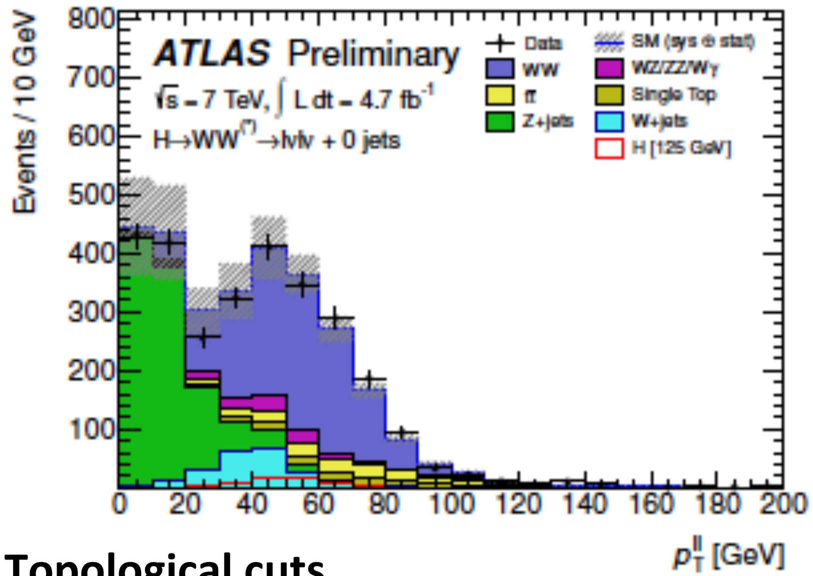


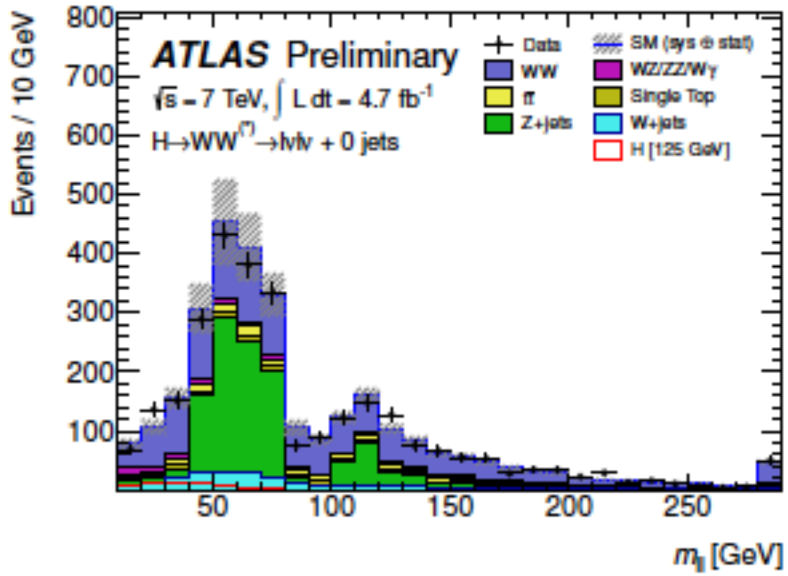
Event selection

depending 0, 1 and 2 jet bin

- 0 jet : transverse momentum of leptons pair

p_T^{ll} > 45 GeV for ee and $\mu\mu$ channel, p_T^{ll} > 30 GeV for eμ channel





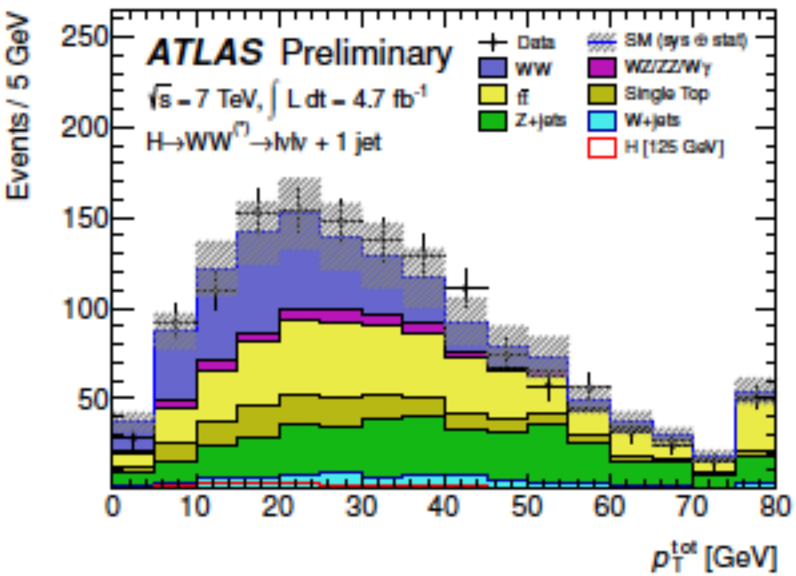
Topological cuts

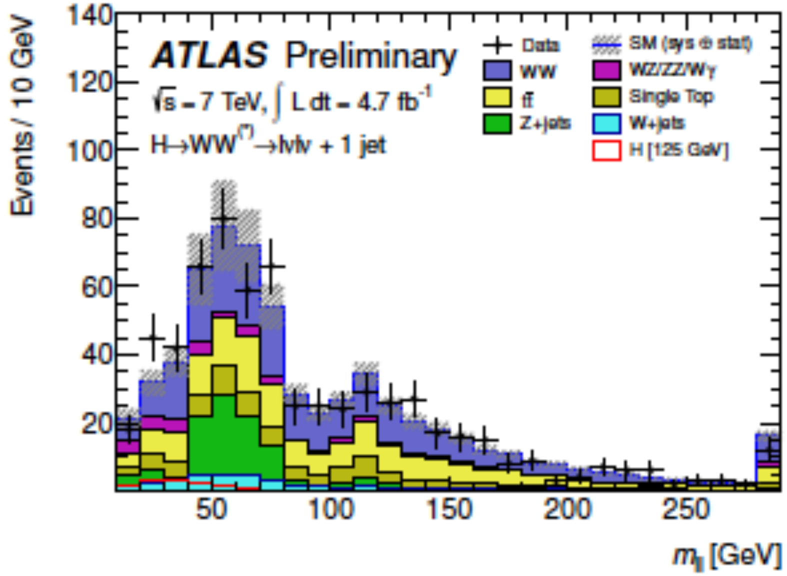
Low mass selection m_H<200 GeV	High mass selection m_H>200 GeV
m_{ll}<50 GeV $\Delta\phi_{ll}$ < 1.8	m_{ll} <150 GeV

Event selection

depending 0, 1 and 2 jet bin

- 1 jet



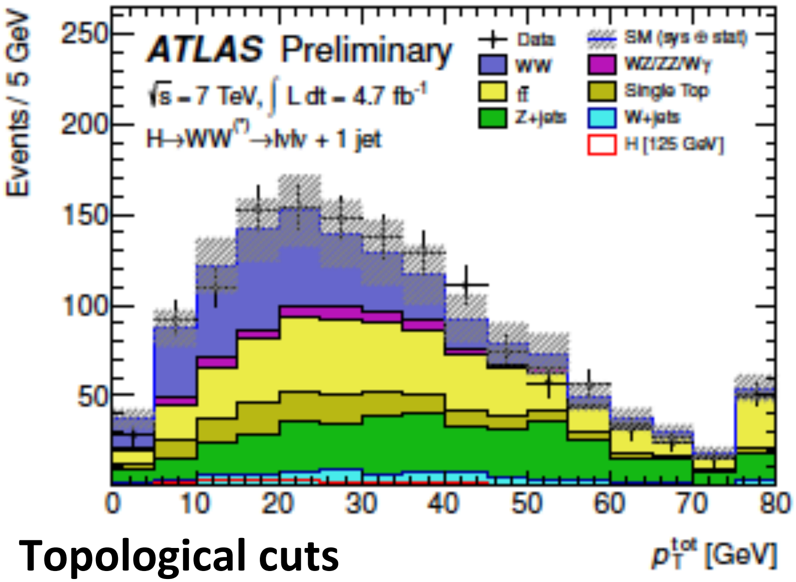


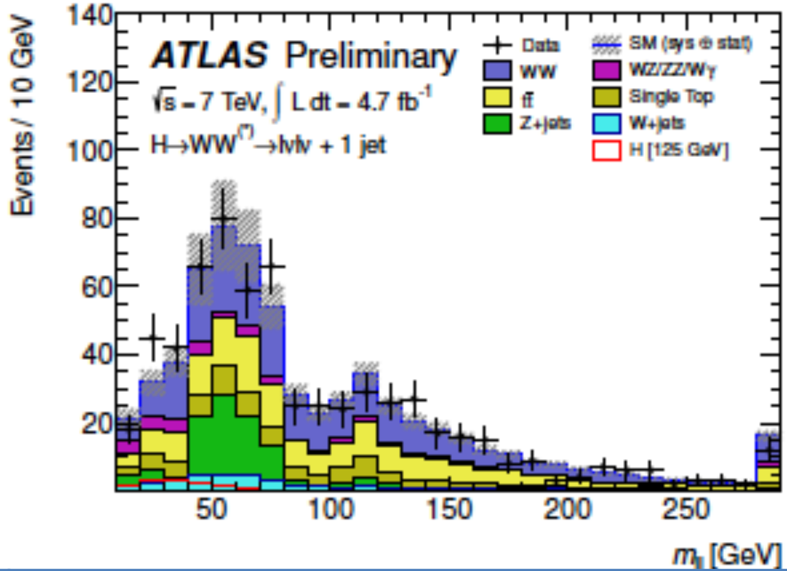
Event selection

depending 0, 1 and 2 jet bin

- 1 jet : b tagging, transverse total momentum, Z→ ττ veto

p_T^{jet} > 25 GeV and $|\eta^{jet}|$ < 3.2, No b jet, p_T^{total} < 30 GeV, No Z → ττ





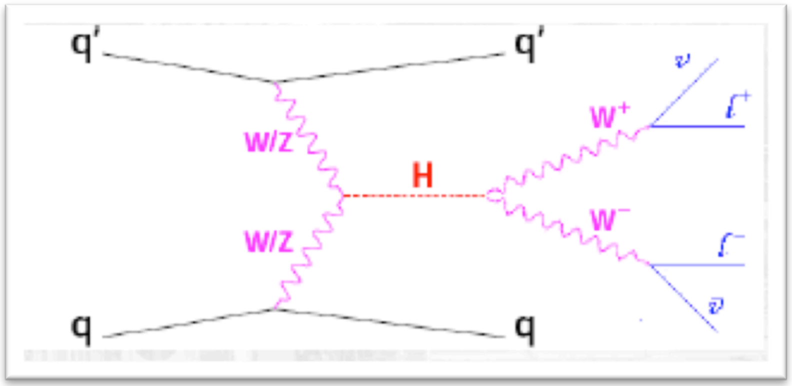
Topological cuts

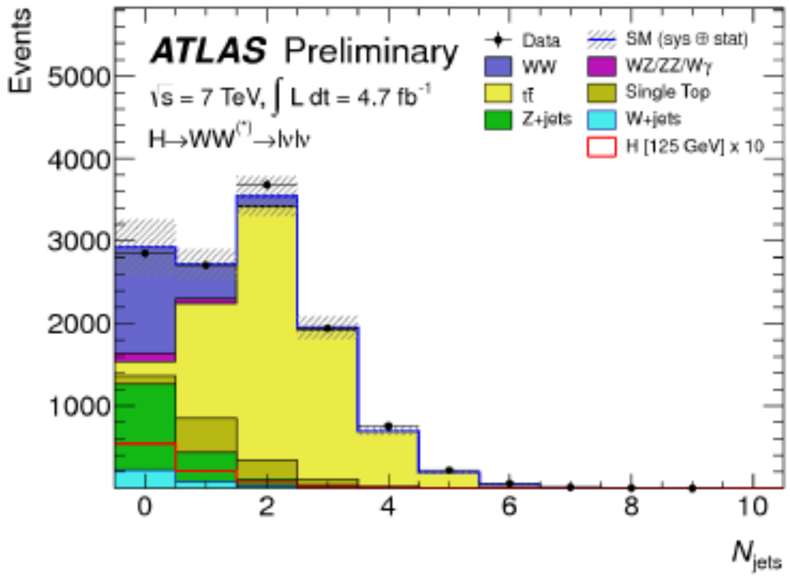
Low mass selection m_H<200 GeV	High mass selection m_H>200 GeV
m_{ll}<50 GeV $\Delta\phi_{ll}$ < 1.8	m_{ll} <150 GeV

Event selection

depending 0, 1 and 2 jet bin

- 2 jet :
- ≥ 2 jet suffers from large contamination from top
- VBF is peculiar: very forward high p_T jets, very high di-jet invariant mass
- selection tuned on VBF-like signal





Event selection

depending 0, 1 and 2 jet bin

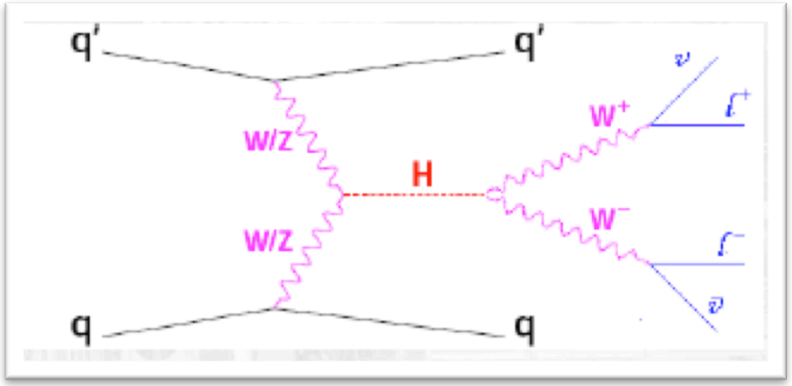
- 2 jet : 2 forward jets back to back , central jet veto, b tagging, transverse total momentum, Z→ $\tau\tau$ veto

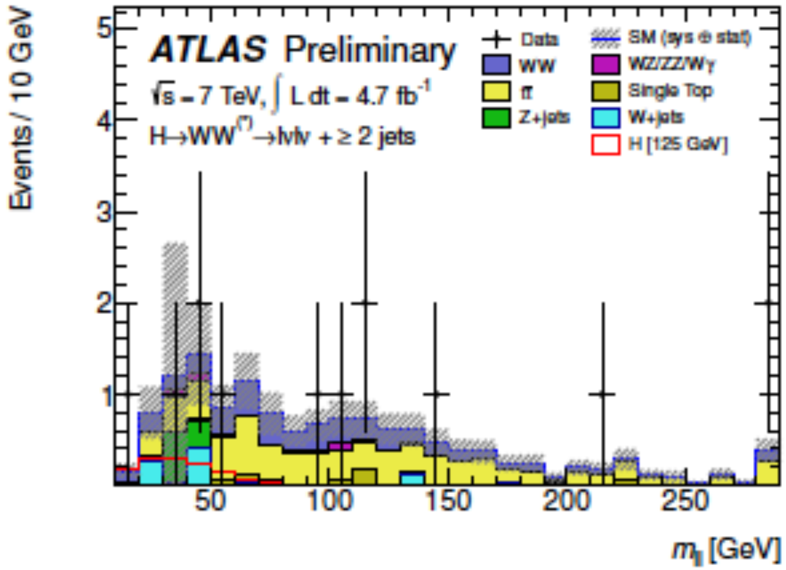
  2 jets with $p_T^{jet} > 25$ GeV and $|\eta^{jet}| < 3.2$

  $\eta_{j1} * \eta_{j2} < 0$, $|\eta_{j1} - \eta_{j1}| > 3.8$, $m_{jj} > 500$ GeV

  No additional jets in $|\eta| < 3.2$

  No b jet, $p_T^{total} < 30$ GeV, No Z → $\tau\tau$





Topological cuts

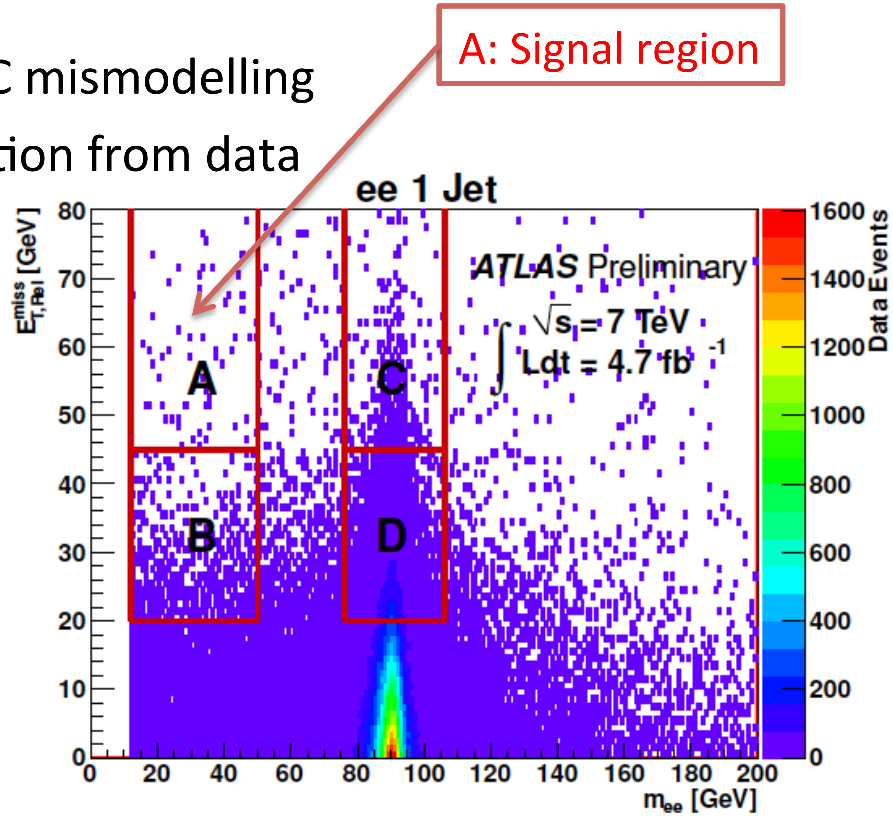
Low mass selection m_H<200 GeV	High mass selection m_H>200 GeV
m_{ll}<80 GeV $\Delta\phi_{ll}$ < 1.8	m_{ll} <150 GeV

Background Normalisation and Control Samples

The dominant backgrounds are normalised using control samples obtained from the data with similar selections as those used in the signal region but with some criteria reversed or modified to create signal-depleted, background-enriched regions

Z+jets background estimation

- Drell Yan has shown to be the most systematics affected background
- Method use to correct the mismodelling of E_t^{miss} tails
- Method fully data driven
- Use no Z/DY MC → unaffected by MC mismodelling
- Only use MC for background subtraction from data
- $A^{est}_{Z+jets} = B^{obs} \times \frac{C^{obs}}{D^{obs}}$ Number of observed events in data
- ABCD is applied independently in each jet bin
- The uncertainty on this background amounts to:
  - 56% in 0 jet bin
  - 25% in 1 jet bin

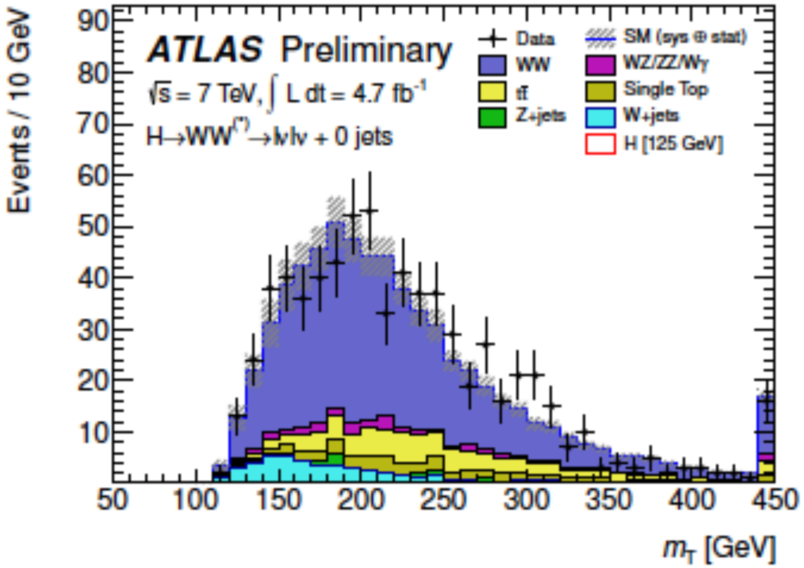


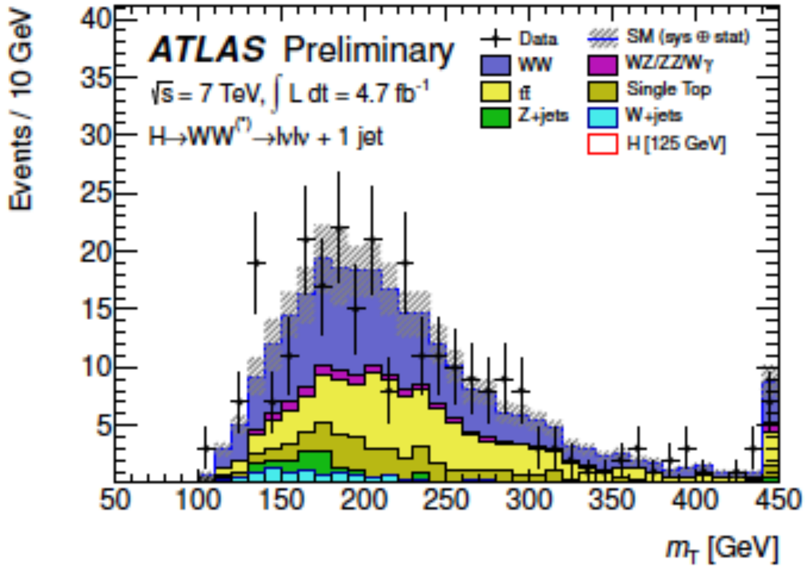
WW background estimation

- The WW background MC prediction is normalised using a control region defined with:
  - same selection as for signal region except the topological cuts (ΔΦ and mT)

    - m_{ll} > 80 GeV for eμ

    - m_{ll} > (m_Z + 15 GeV) for ee/μμ
- Control region only used for m_H< 200 GeV,
- Monte carlo prediction is used for m_H > 200 GeV and for 2 jet bin





- The total uncertainty in the signal region is:

  10% for 0 jet bin and 24% for 1-jet bin

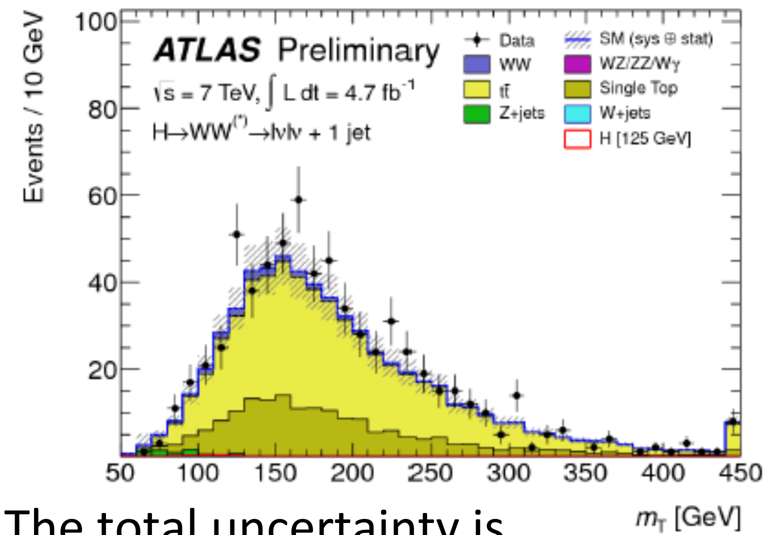
Top background estimation

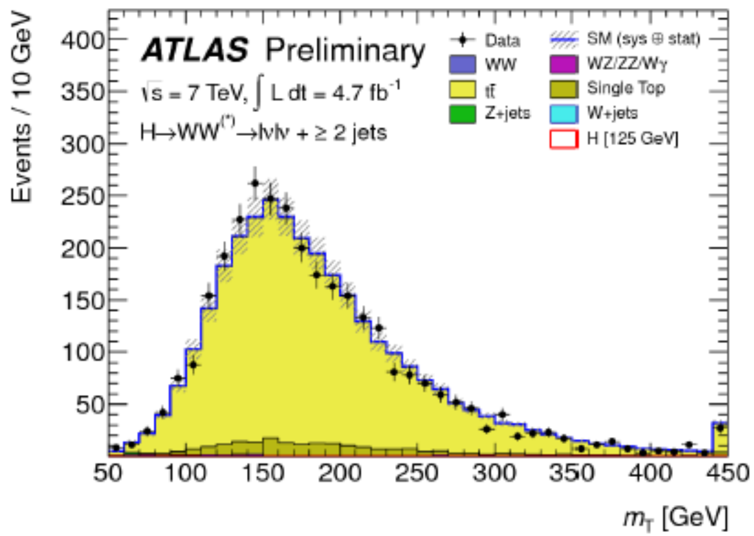
- 0 jet bin

the estimated number of top background events is extrapolated from the number of events satisfying the pre-selection criteria

- 1 jet and 2 jet bin

the top background MC prediction is normalised to the data using a control sample defined by reversing the b-jet veto and removing the topological cuts





- The total uncertainty is
  - 23% in 0 jet bin
  - 30% in 1 and 2 jet bin

W + jets background estimation

Contribution estimated using a data control sample of events where

- One lepton that satisfies the identification and isolation criteria
- One lepton that fails these criteria while satisfying a loosened selection (**"anti-identified"**)

'Fakeable lepton' method: fully data-driven

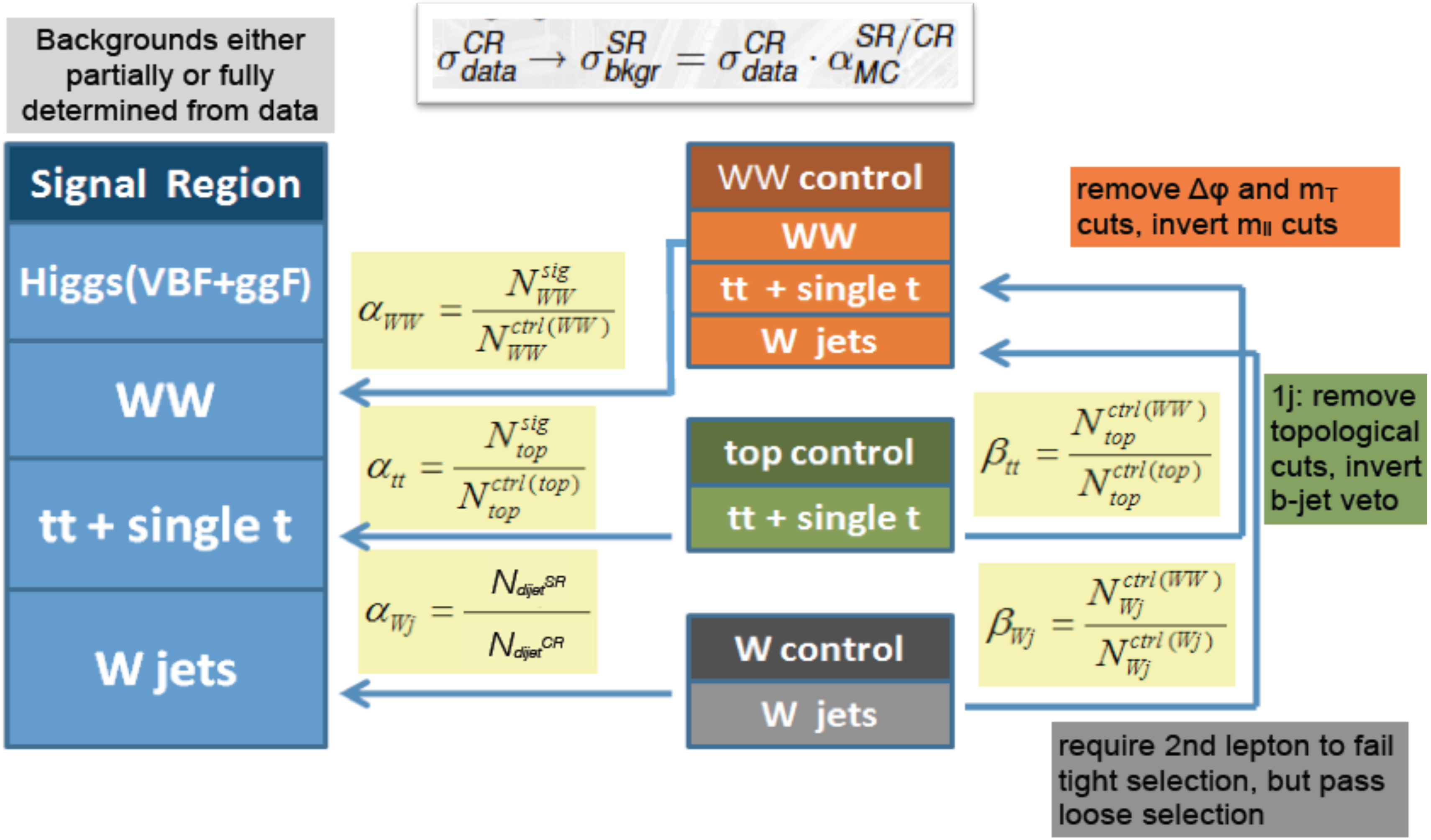
W+jets control region to determine normalization

$$N_{\text{one id(from W)+one fake}} = \frac{N_{\text{id obj}}}{N_{\text{anti-id obj}}} \times N_{\text{one id(fromW)+one fakeable}}$$

- The total uncertainty on the fake factor is estimated to be 30–50% for lepton $p_T < 30$ GeV and of the order of 100% for $p_T > 30$ GeV
- The background predicted for this process in the 2 jet bin is negligible

Data Driven Background estimation

In order to estimate the impact of the main backgrounds, different control regions can be defined reversing or changing some cuts from the signal-like region.



Background estimation

WW	Top
CR: no $\Delta\phi_{ll}$ cut, modified m_{ll} cut → Reject with $\Delta\phi_{ll}$ and m_{ll} cuts **65 % of Background**	CR: no $\Delta\phi_{ll}$ and m_{ll} cuts b-jet tag requirement → Reject with jet cuts **5% of Background**
W + jets	**Z/γ* + jets**
CR: inverted lepton ID passing loose criteria → Reject with isolation and lepton ID **10 % of Background**	CR: $\lvert m_{ll} - m_Z \rvert < 15$ GeV, correcting for ETmiss tail mismodeling →Reject with missing transverse energy cut **5% of Background**

Remaining backgrounds from Di-Bosons are estimated using simulation

Results for mH = 125 GeV

0 jet	**ee**	**μμ**	**eμ**
Total bkg	58 ± 5	114 ± 10	257 ± 13
Signal	3.8 ± 0.1	9.0 ± 0.1	25 ± 0.2
Observed	52	138	237

1 jet	**ee**	**μμ**	**eμ**
Total bkg	21 ± 3	37 ± 5	76 ± 6
Signal	1.1 ± 0.1	2.3 ± 0.1	6.0 ± 0.1
Observed	19	36	90

Statistical uncertainties only

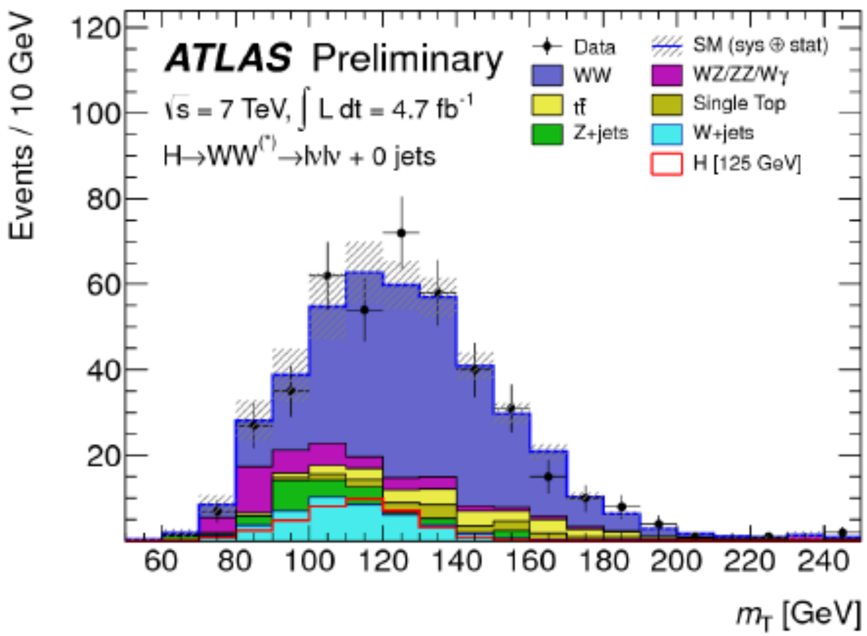
No significant excess found

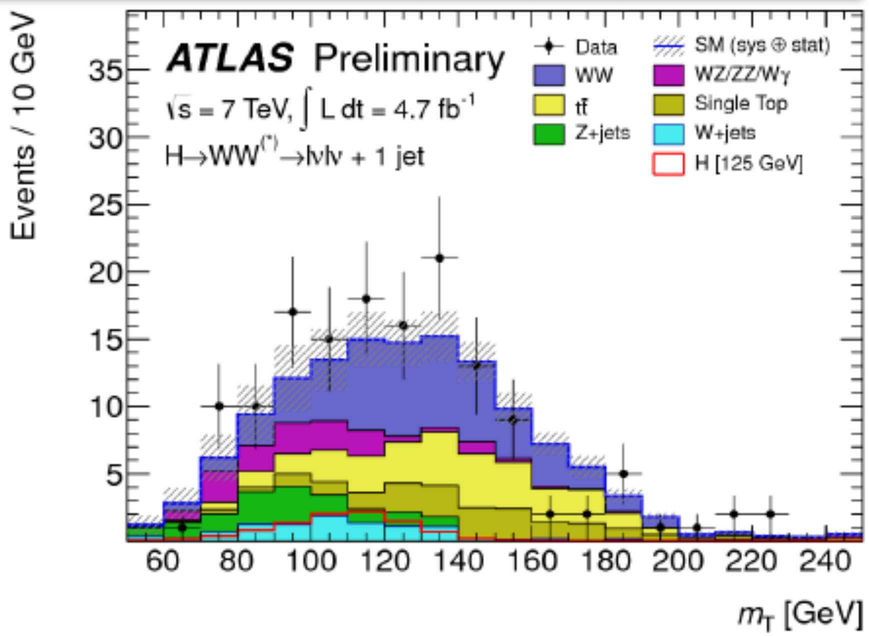
Final distributions

After all analysis cuts

- Transverse Mass (m_T) is a proxy for Higgs mass for WW channel
- 125 GeV Higgs signal shown
- No significant excess observed
- Fit m_T shape to extract limits

$$\Rightarrow m_T = \sqrt{\left(E_T^{\ell\ell} + E_T^{miss}\right)^2 - \left|\vec{p}_T^{\,\ell\ell} + \vec{p}_T^{\,miss}\right|^2}$$

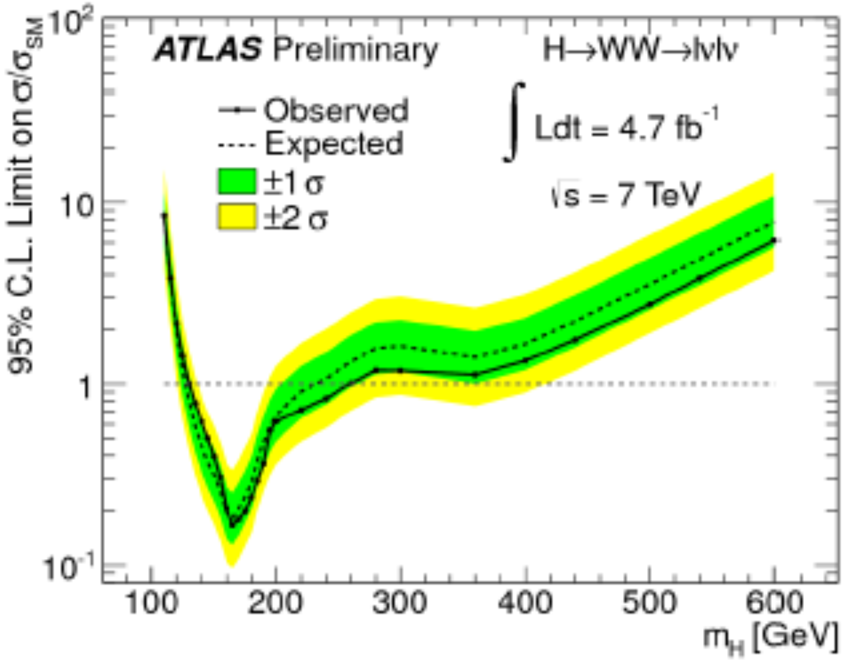


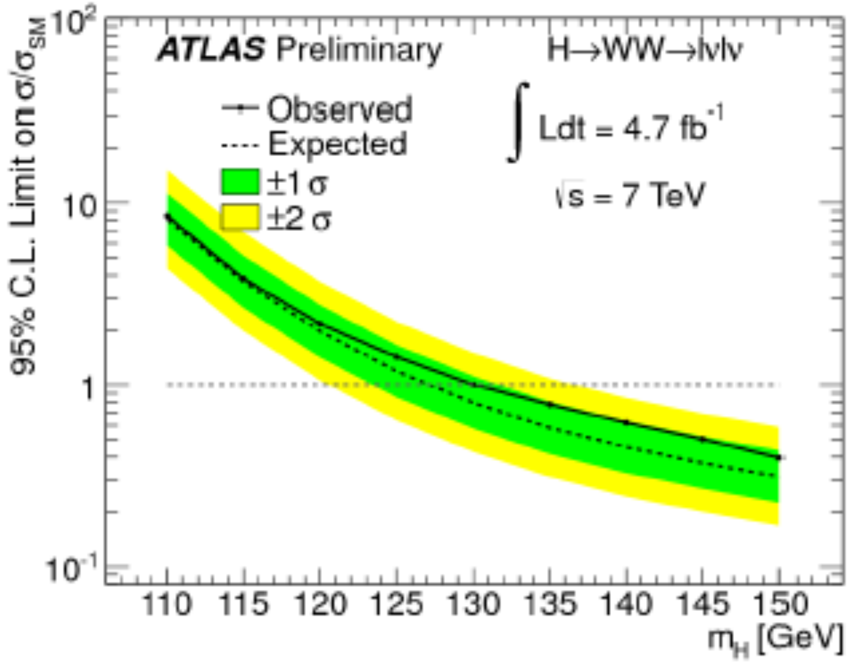


Limits results

Likelihood for each m_H in 9 channels (ee, $\mu\mu$, eμ) x (0 jet, 1 jet, 2 jet)

- Expected 95% C.L. Exclusion : 127 GeV < m_H < 234 GeV
- Observed 95% C.L. Exclusion : 130 GeV < m_H < 260 GeV



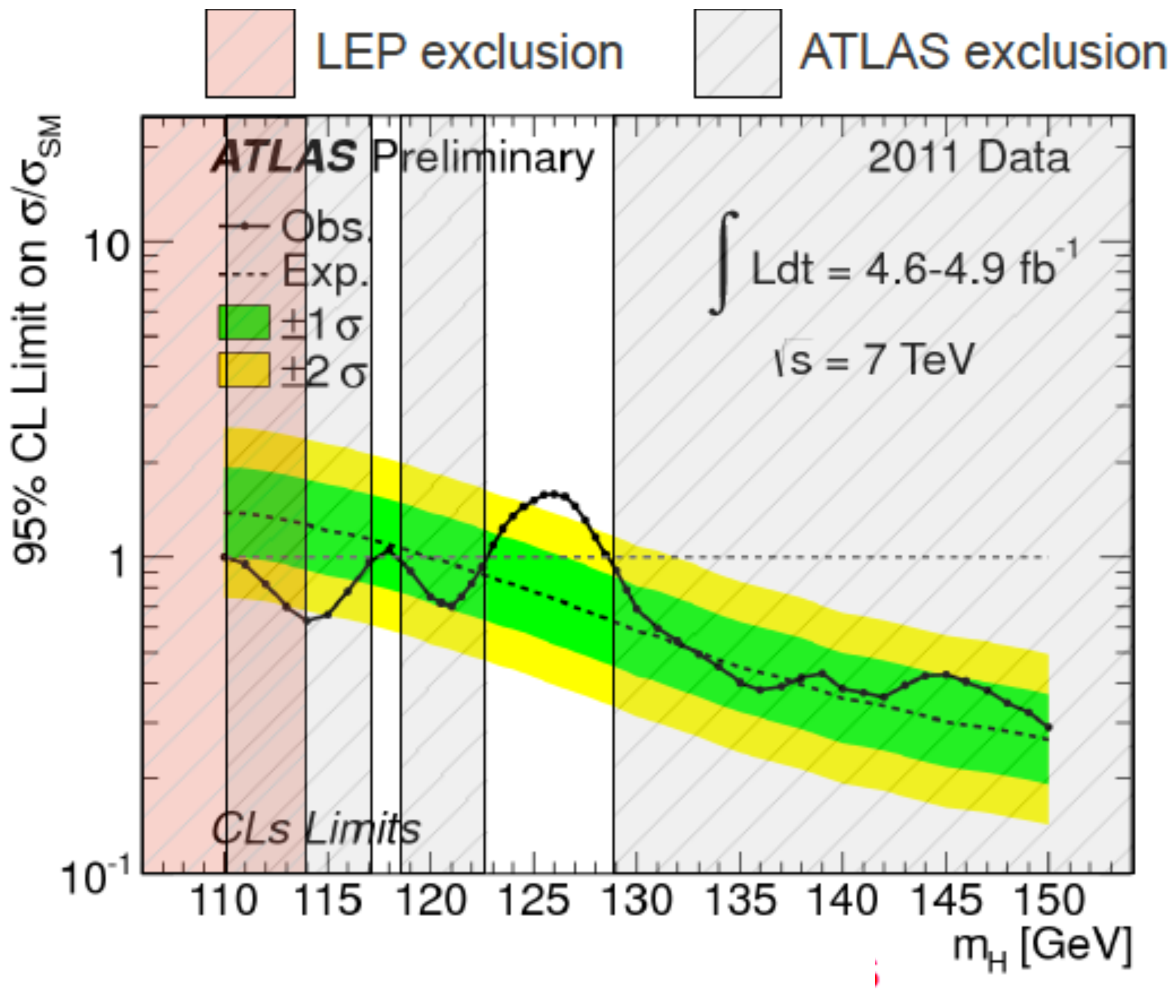


Combination and Conclusions

- 9 channels for the $H \rightarrow WW \rightarrow l\nu l\nu$ process have been analyzed: (ee, $\mu\mu$, eμ) x (0 , 1 , 2 jet)
- No significant excess observed
- **<u>Combination with other channels</u>**
- Allowed Scalar Boson mass has been squeezed into a tiny region:

  117.5-118.5 GeV or
  122.5-129 GeV

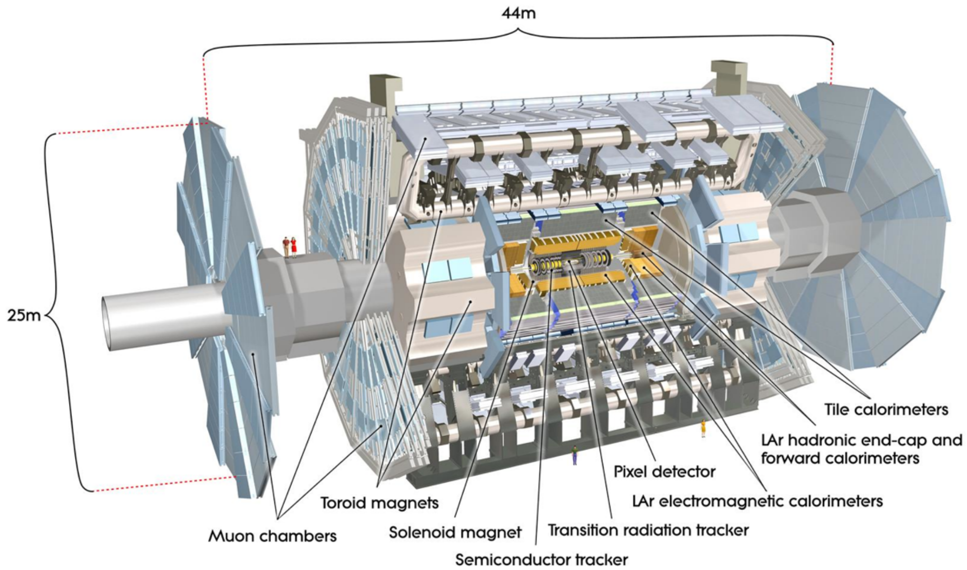
- Not yet possible to distinguish between background fluctuation or a Higgs boson signal
- Expect discovery or exclusion with 2012 data



Backup

The Atlas Detector

- **Inner Detector**
  - $|\eta|<2.5$, solenoid B=2T
  - Si Pixels,
    Si strips, TRT
  - Tracking and vertexing
  - e/π separation
  - Resolution: $\sigma/p_T \sim 3.8\times10^{-4} p_T[\mathrm{GeV}] \oplus 0.015$



- **EM calorimeter**
  - $|\eta|<3.2$
  - LAr/Pb accordion structure e/γ trigger, id + measurement
  - E-resolution: $\sigma/E \sim 10\%/\sqrt{E}$

- **HAD calorimeter**
  - $|\eta|<3.2$ (Forward Calo. $|\eta|<4.8$)
  - Scint./Fe tiles in the central, W (Cu)/LAr in fwd region
  - Trigger, jets + missing Et
  - E-resolution: $\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$

- **Muon Spectrometer**
  - $|\eta|<2.7$
  - Toroid B-Field
  - Muon Momentum resolution < 10% up to ~ 1 TeV

Systematic table

Table 7: Experimental sources of systematic uncertainty per object or event.

Source of Uncertainty	Treatment in the analysis
Jet Energy Resolution (JER)	MC jet resolution smeared using jet p_T, η-dependent parametrization
Jet Energy Scale (JES)	global JES: $< 14\%$ for jet $p_T > 25$ GeV and $\|\eta\| < 4.5$ pileup: $< 5\%$ for jet $p_T > 20$ GeV
Electron Selection Efficiency	Separate systematics for electron identification, reconstruction and isolation, added in quadrature Identification: 8% for $p_T < 15$ GeV, decreasing to 1% for $p_T > 30$ GeV in the central region Reconstruction: 0.6 - 1.2% for $p_T > 15$ GeV trigger: 1% uncertainty Total uncertainty of 2-5% depending on η and E_T
Electron Energy Scale	Uncertainty smaller than 1%, depending on η and E_T
Electron Energy Resolution	Energy varied within its uncertainty, 0.6% of the energy at most
Muon Selection Efficiency	0.3-1% as a function of η and p_T reconstruction smaller than 1%
Muon Momentum Scale and Resolution	Uncertainty smaller than 1%
b-tagging Efficiency	p_T dependent scale factor uncertainties, 4.8 - 13.7%
Missing Transverse Energy	Using METUtility package
Missing Transverse Energy PileUP	10% from JetTauEtMiss 2010 reccommendations
Luminosity	3.9% [50]

MVA BDT

- Training with the 4 variables cut-based analysis is cutting on: m_T , m_{ll} , p_{Tll}, $\Delta\phi_{ll}$
- Using ttbar control region in 1 jet (bjet veto reversed)
- Using WW control region for M_H<200 GeV, floating the WW normalization (with theory constraints) above, for both 0 and 1 jet bins
- Wjets fully data-driven

Higgs searches at ATLAS and CMS

Searches performend in 12 distinct channels using the full 2011 dataset.

Channel	m_H range (GeV)	Backgrounds	$\mathcal{L}$ (fb^{-1})	Reference
low-m_H, good mass resolution				
$H \to \gamma\gamma$	110-150	$\gamma\gamma$, γj, jj	4.9	arXiv:1202.1414
$H \to ZZ^{(*)} \to 4\ell$	110-600	$ZZ^{(*)}$, $Z+jets$, $t\bar{t}$	4.8	arXiv:1202.1415
low-m_H, limited mass resolution				
$H \to WW^{(*)} \to \ell\nu\ell\nu$	110-600	WW, $t\bar{t}$, $W/Z+jet$	4.7	CONF-2012-012
$H \to \tau\tau(ll, lh, hh)$	100-150	$Z \to \tau\tau$, $t\bar{t}$	4.7	CONF-2012-014
$VH, H \to bb$	110-130	$W/Z+jets$, $t\bar{t}$	4.7	CONF-2012-015
high-m_H				
$H \to ZZ \to \ell\ell\nu\nu$	200-600	diboson, $t\bar{t}$, $Z+jets$	4.7	CONF-2012-016
$H \to ZZ \to \ell\ell jj$	200-600	$Z+jets$, $t\bar{t}$, diboson	4.7	CONF-2012-017
$H \to WW \to \ell\nu jj$	300-600	$W+jets$, $t\bar{t}$, multijets	4.7	CONF-2012-018

ATLAS
From Sandra Kortner
Moriond EW 2012

	Channel	m_H range (GeV)	Luminosity (fb^{-1})	Sub-channels	m_H resolution
new	$H \to \gamma\gamma$	110–150	4.8	2	1–2%
	$H \to \tau\tau \to e\tau_h/\mu\tau_h/e\mu + X$	110–145	4.6	9	20%
new	$H \to \tau\tau \to \mu\mu + X$	110–140	4.5	3	20%
new	$WH \to e\mu\tau_h/\mu\mu\tau_h + \nu's$	100–140	4.7	2	20%
	$(W/Z)H \to (e\nu/\mu\nu/ee/\mu\mu/\nu\nu)(bb)$	110–135	4.7	5	10%
	$H \to WW^* \to 2\ell 2\nu$	110–600	4.6	5	20%
new	$WH \to W(WW^*) \to 3\ell 3\nu$	110–200	4.6	1	20%
	$H \to ZZ^{(*)} \to 4\ell$	110–600	4.7	3	1–2%
	$H \to ZZ^{(*)} \to 2\ell 2q$	130–164 200–600	4.6	6	3% 3%
	$H \to ZZ \to 2\ell 2\tau$	190–600	4.7	8	10–15%
	$H \to ZZ \to 2\ell 2\nu$	250–600	4.6	2	7%

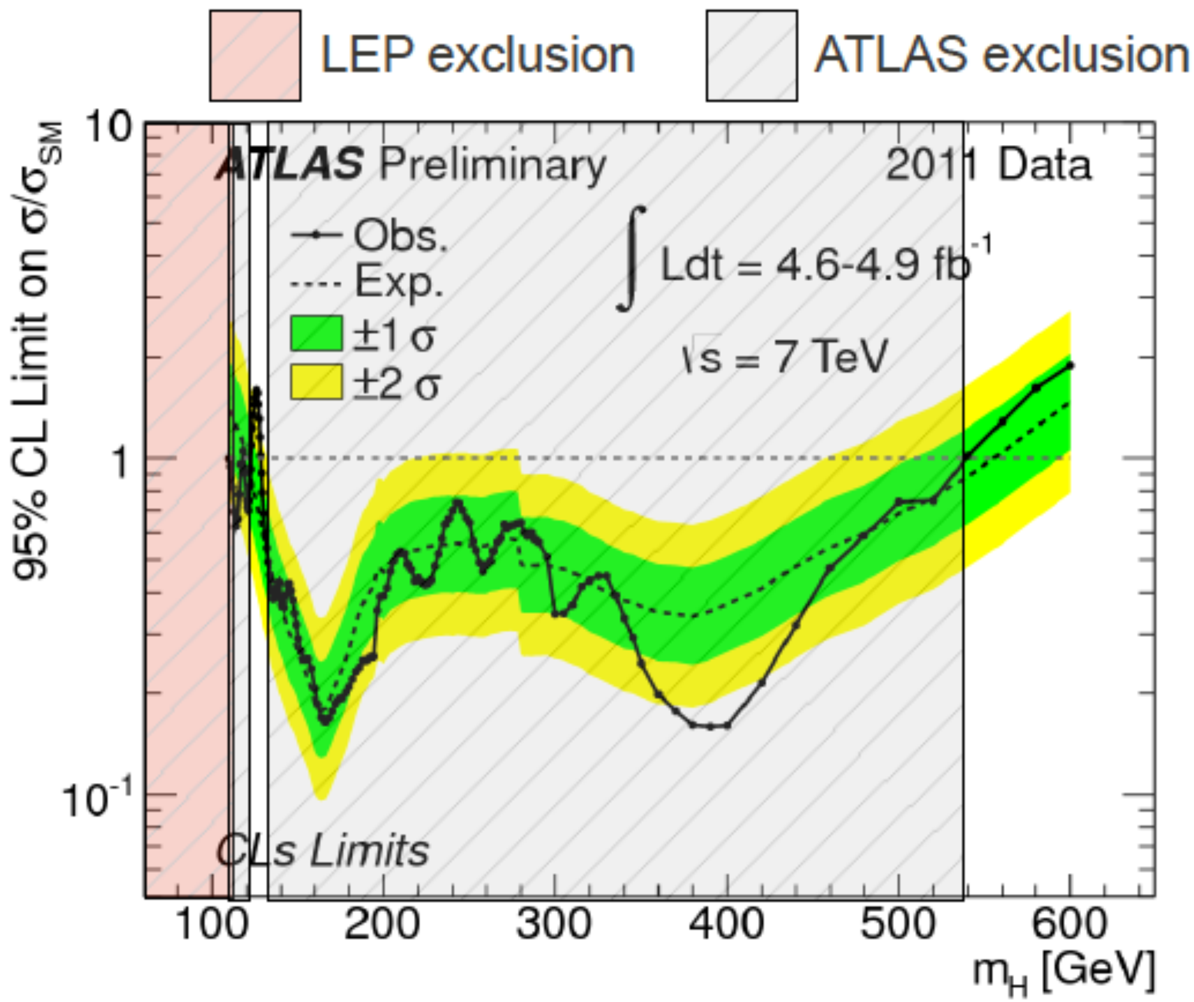
CMS
From Adi Bornheim
Moriond QCD 2012

Detector related systematic uncertainties

Physics object	Source	Uncertainty on signal yield	Most affected channels
	luminosity	3.9%	
Photon	efficiency	11%	$\gamma\gamma$
Electron	efficiency	<3%	4ℓ
	energy scale	<1%	
	energy resolution	<0.5%	
Muon	efficiency	<1%	4ℓ
	momentum resolution	<1%	
Jet	energy scale	up to 12%	$\tau\tau$, bb, $\ell\ell jj$, $\ell\nu jj$
	resolution	up to 20%	$\ell\nu jj$
b-tagging	efficiency	up to 15%	bb
τ-jet	efficiency	up to 8%	$\tau\tau$

From Sandra Kortner presentation
@ Rencontres de Moriond EW

Combination with other channels



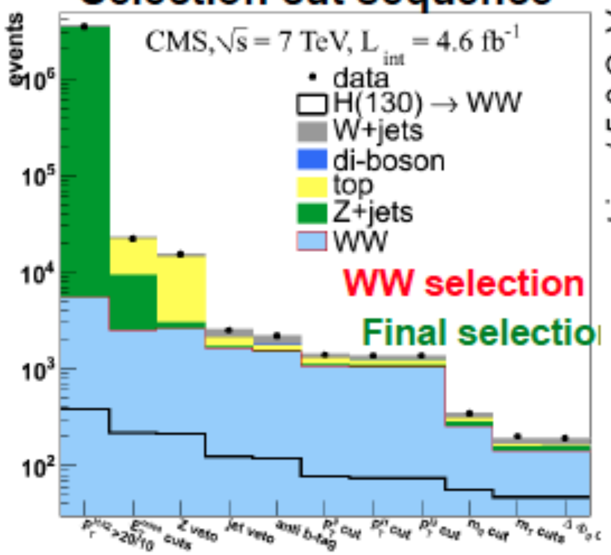
HIG-11-024
arXiv:1202.1489
Accepted by PLB

H→WW→2l2nu

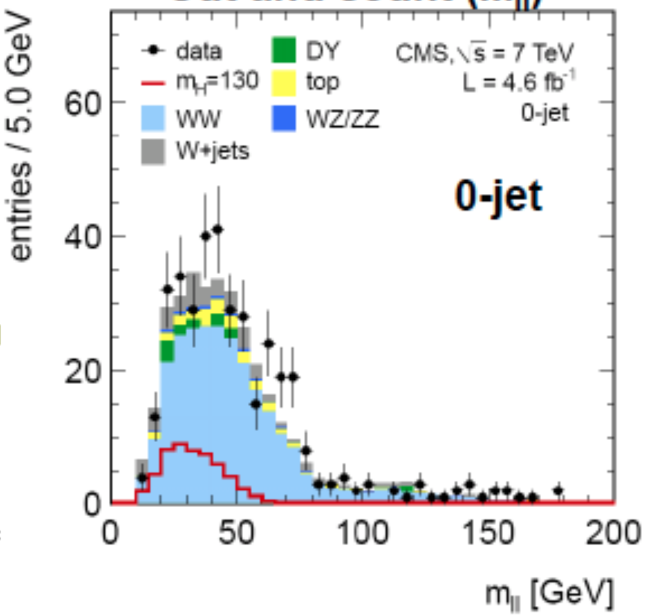
- Analysis performed in exclusive jet multiplicities (0,1,2-jet bins) and flavour (ee, μμ, eμ), as a cut and count and MVA (0 and 1 jet only).
  - Cuts and MVA training optimised in bins of M_H ,advantage of boosted Higgs.
  - Lepton trigger and ID down to 10 GeV (MVA Id for electrons).
  - N_{Vtx}-dependent cut on projected MET wrt nearest lepton, minimum of global MET and vtx-associated charged particle MET.
  - Veto on soft muon, b-tag, third lepton and Z.
  - Uncertainties on signal ~20%, background ~15%.

From Adi Bornheim
Moriond QCD 2012

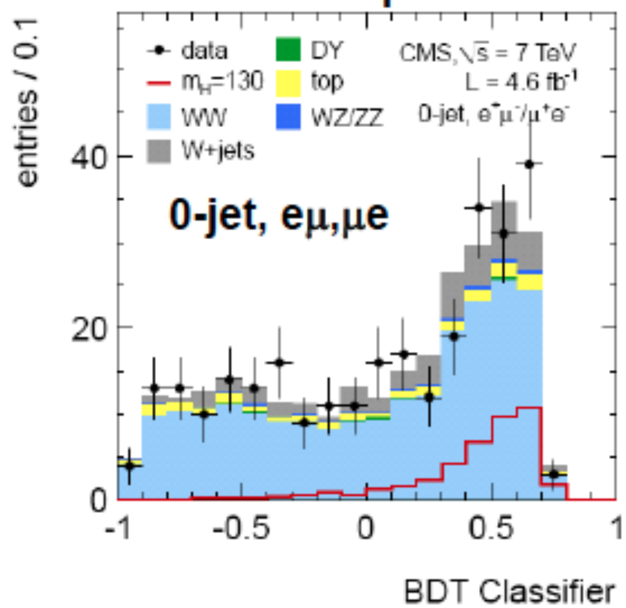
Selection cut sequence



Cut and count (M_{ll})



MVA output

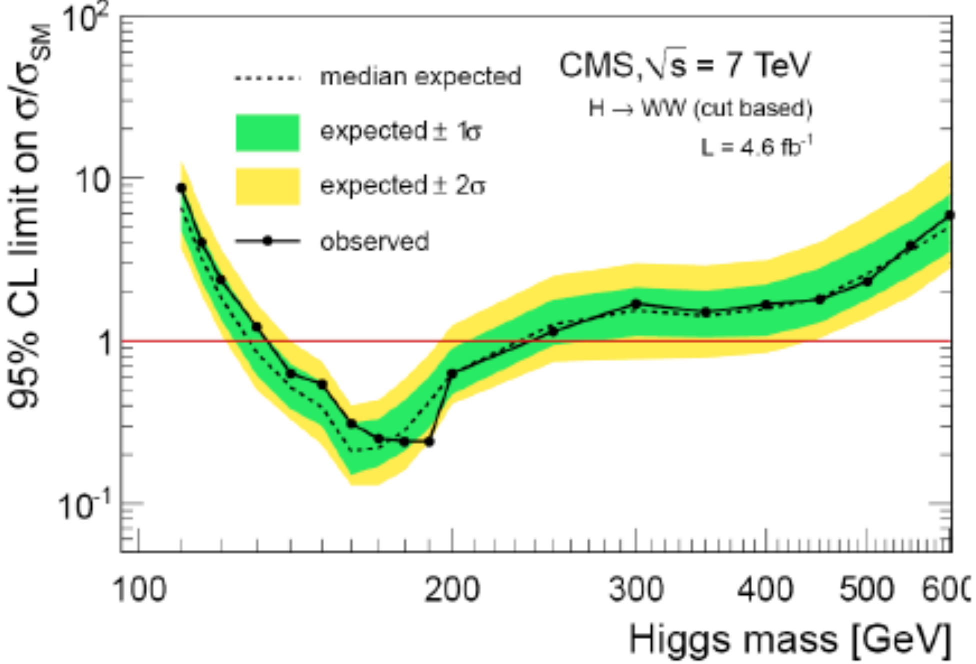


HIG-11-024
arXiv:1202.1489
Accepted by PLB

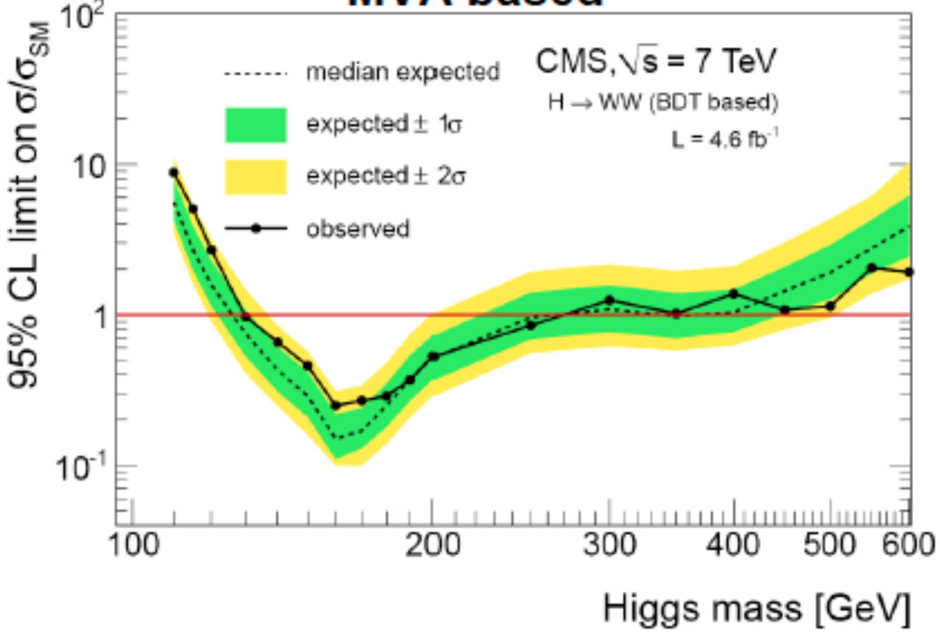
H→WW→2l2nu

From Adi Bornheim
Moriond QCD 2012

Cut based



MVA based

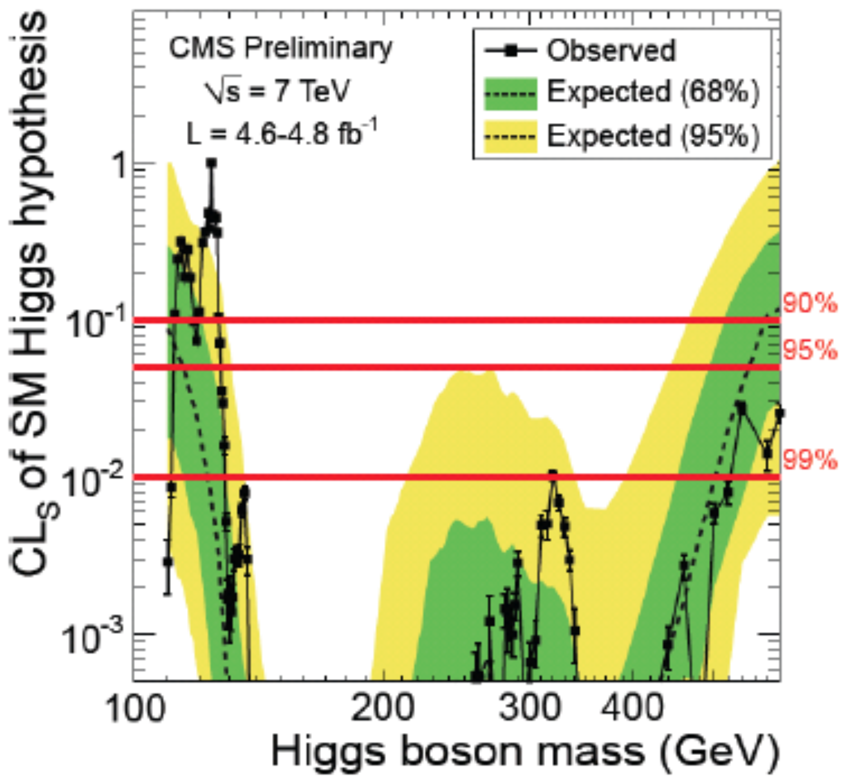


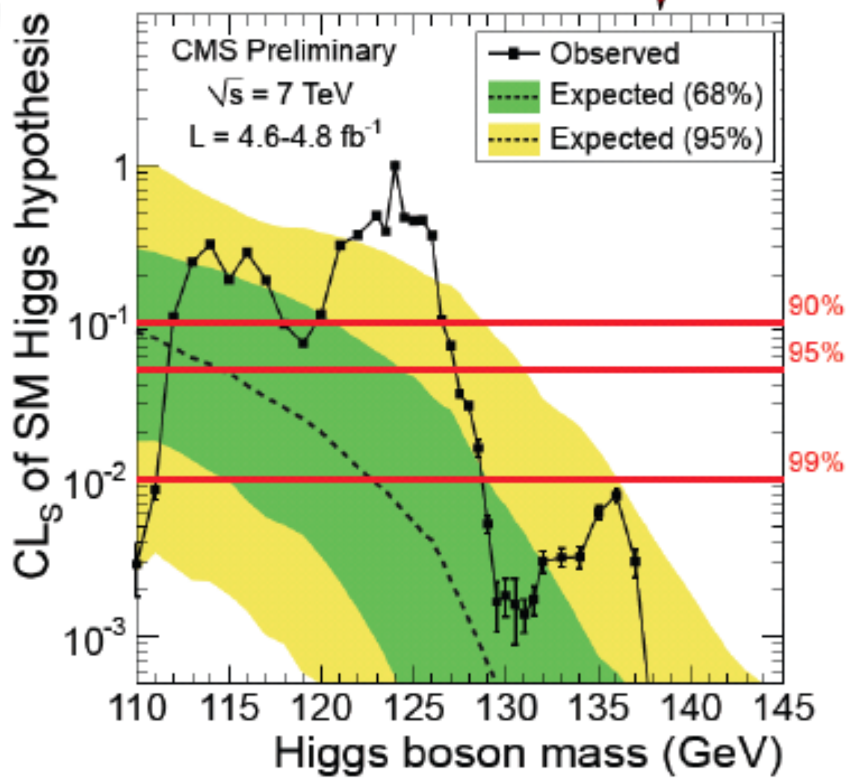
- **MVA analysis limits (entering the combination) :**
  - **95% CL expected exclusion for M_H in [127-270] GeV.**
  - **95% CL observed exclusion for M_H in [129-270] GeV.**
- **Slight excess at low mass in MVA analysis.**

CMS Document
HIG-12-008

Combination : Limit

NEW





- Expected 95% exclusion M_H in [114.5-543] GeV
- Observed 95% exclusion M_H in [127.5-600] GeV
  99% exclusion M_H in [129-525] GeV
- 95% allowed mass range : [114.5-127.5] GeV
- Exclusion range at low masses limited by excess in data.

From Adi Bornheim
Moriond QCD 2012