Search for the SM Higgs boson in the $H \rightarrow WW^{(*)} \rightarrow l\nu l\nu$ decay channel at LHC

MINI-WORKSHOP ON HIGGS SEARCH AT LHC
March 28, 2012 - LNF

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Istituto Nazionale di Fisica Nucleare

Outline

- LHC operations in 2011
- Higgs production and decay
- The $H \rightarrow WW^{(*)} \rightarrow l\nu l\nu$ searches in ATLAS and CMS
  - Experimental signature
  - Backgrounds
  - Systematic uncertainties
  - Results

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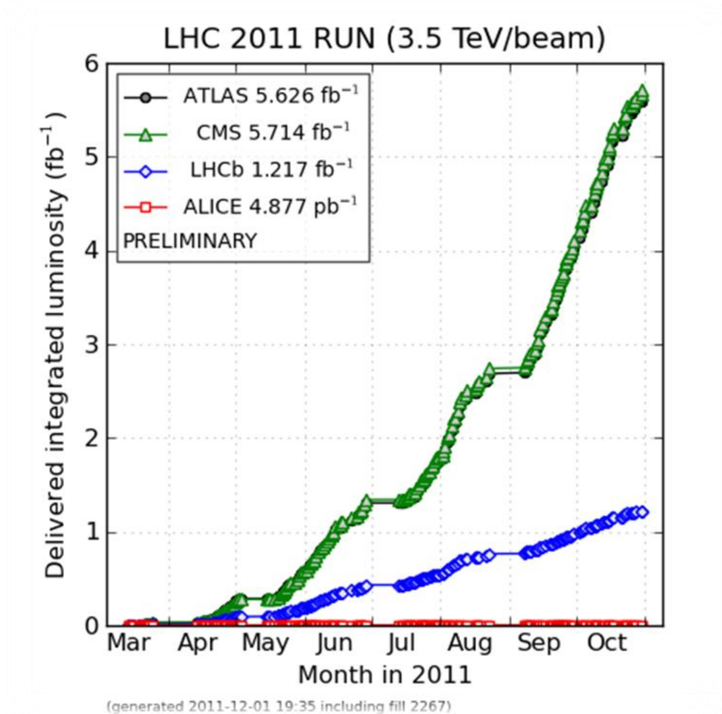
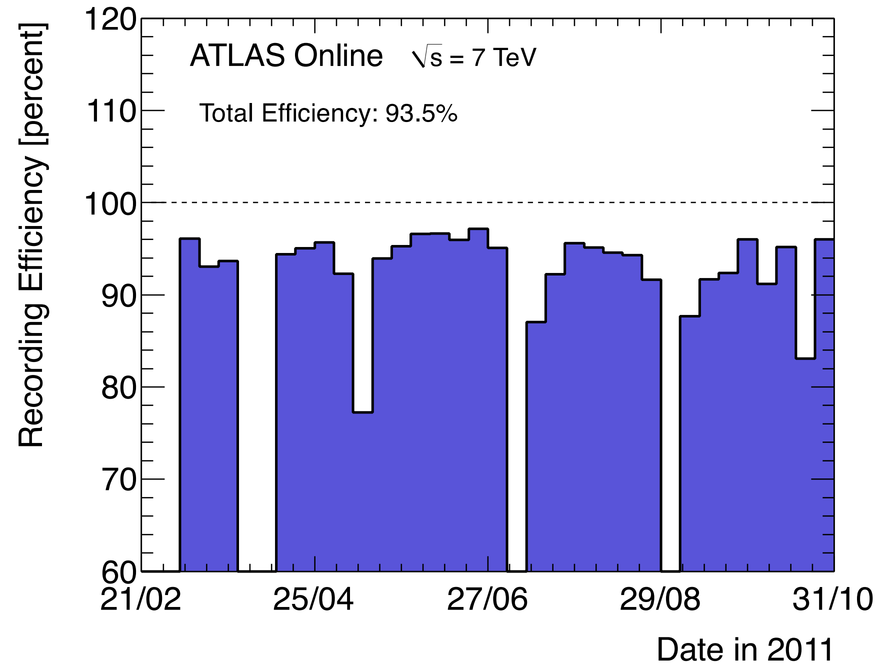
LHC operation: the 2011 data taking





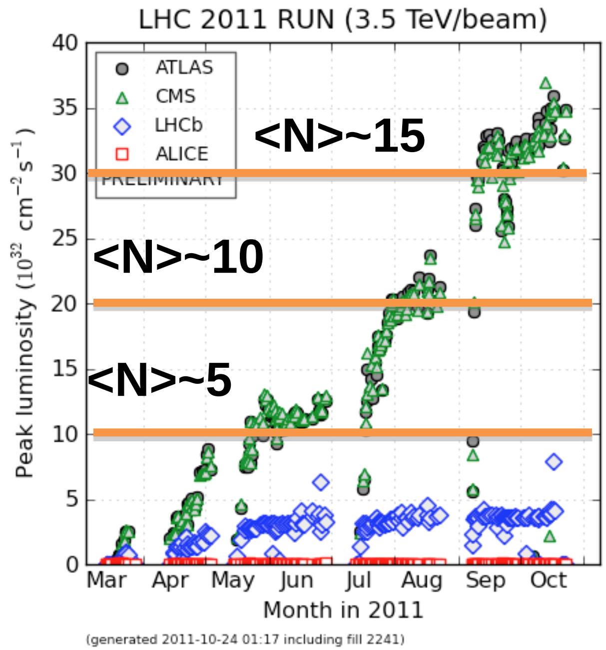
Excellent LHC performances in 2011:

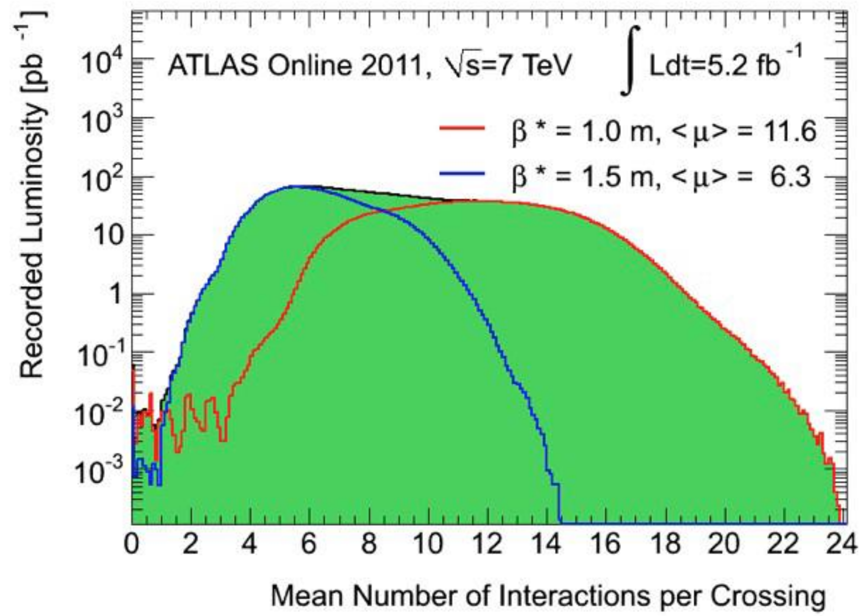
- Delivered 5.7 fb^{-1} @ATLAS and CMS
- Peak luminosity s $3.6\ 10^{33}\ cm^{-2}\ s^{-1}$
- several machine parameters pushed beyond design

Experiments perform very well:

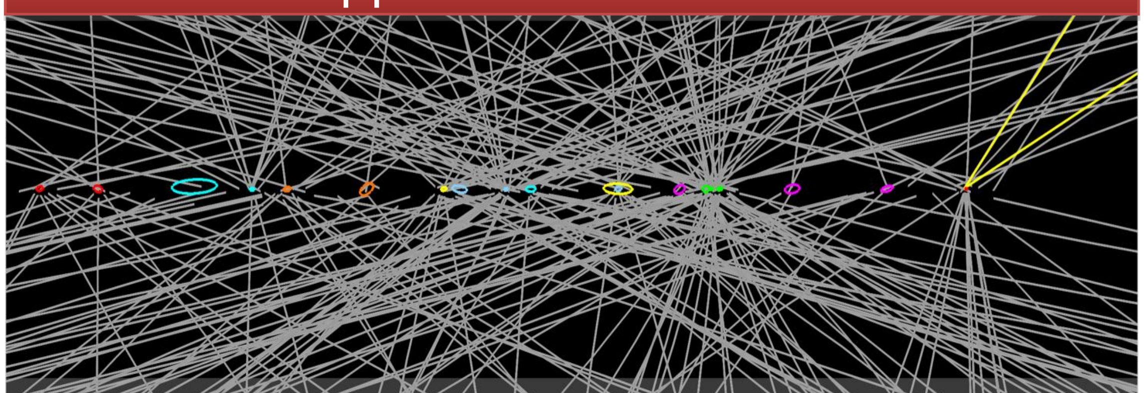
- High data taking efficiency
  - ATLAS(93.5%) CMS(91%)
- High fraction (90-96%) used for the analyses

…and a new challenge: the pileup





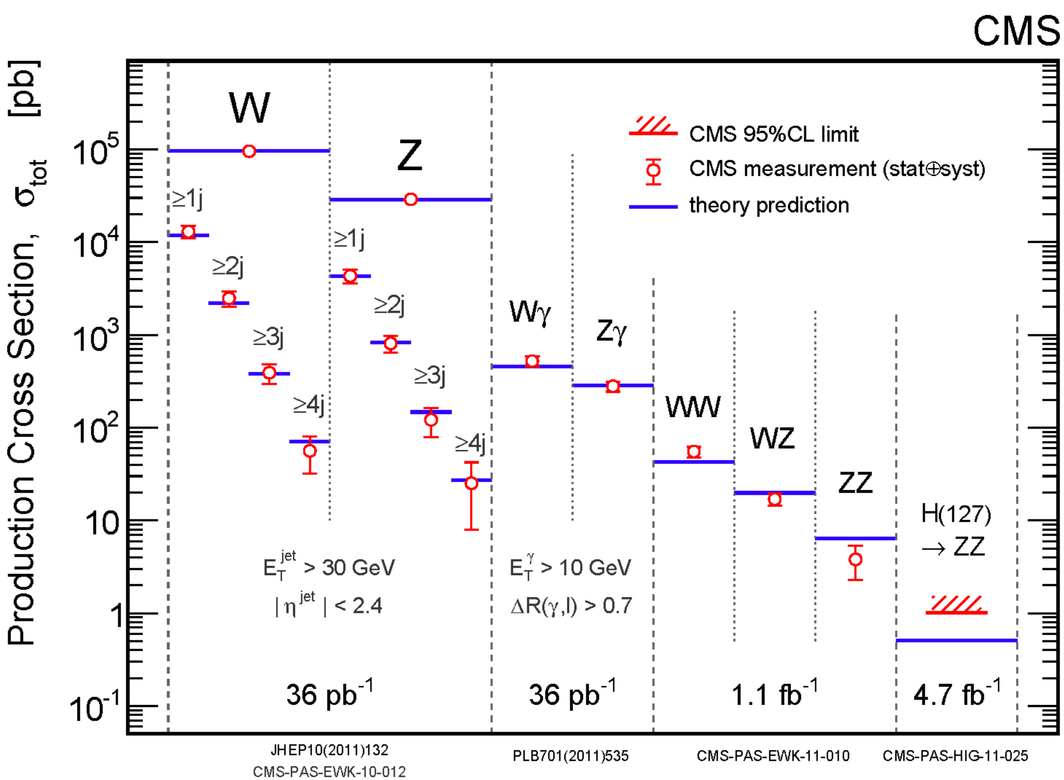
Z⟶ μμ candidate with 20 vertices



A possible problem for:

- Trigger
- Lepton isolation
- E_T miss
- JES-JER

The SM @ √s=7 TeV



- An impressive number of processes have already been measure
- Cross-sections measured up to few pb
  - Excellent agreement with the Standard Model predictions
- Important for background estimates in Higgs boson searches

- Useful as benchmark processes for object performance studies

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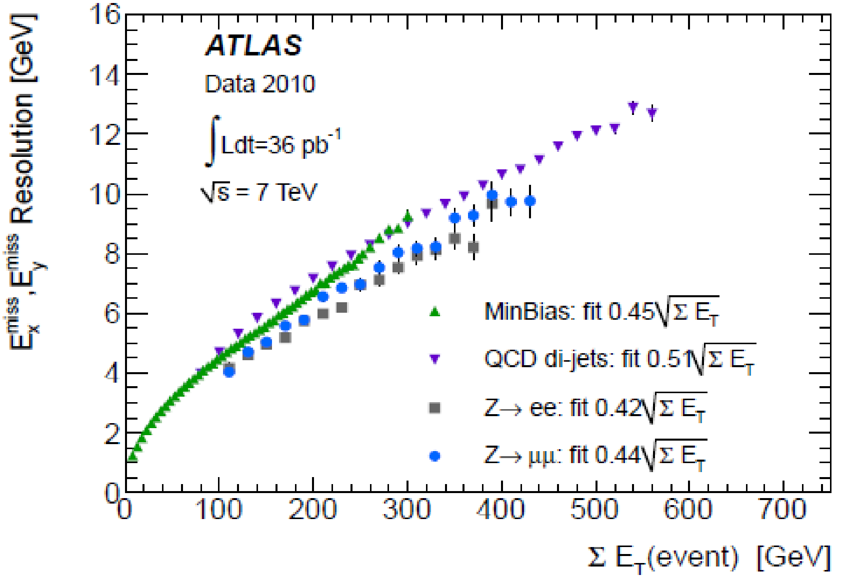
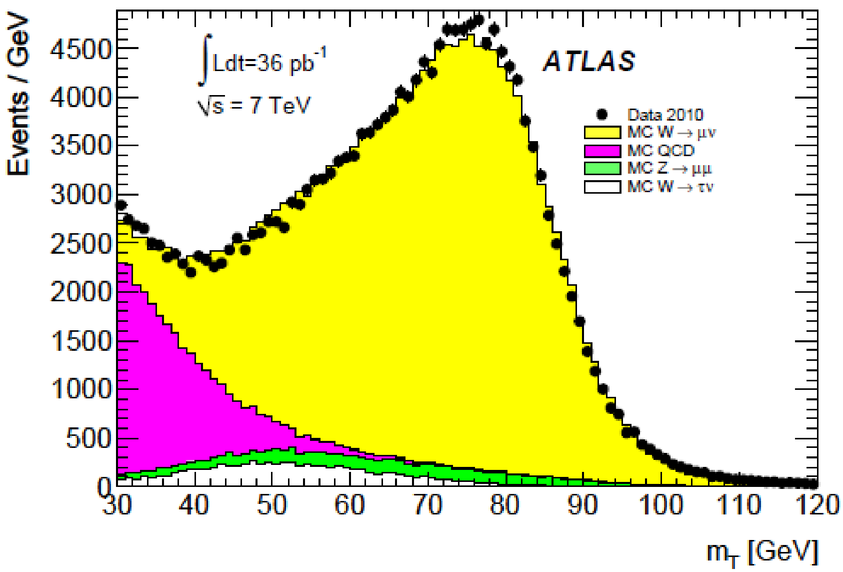
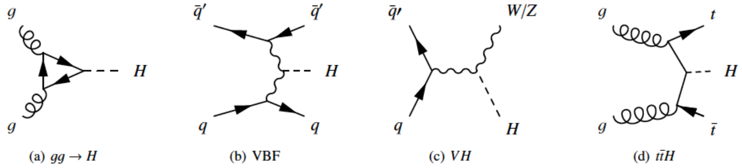
Understanding of detector performances: E_T^{miss}

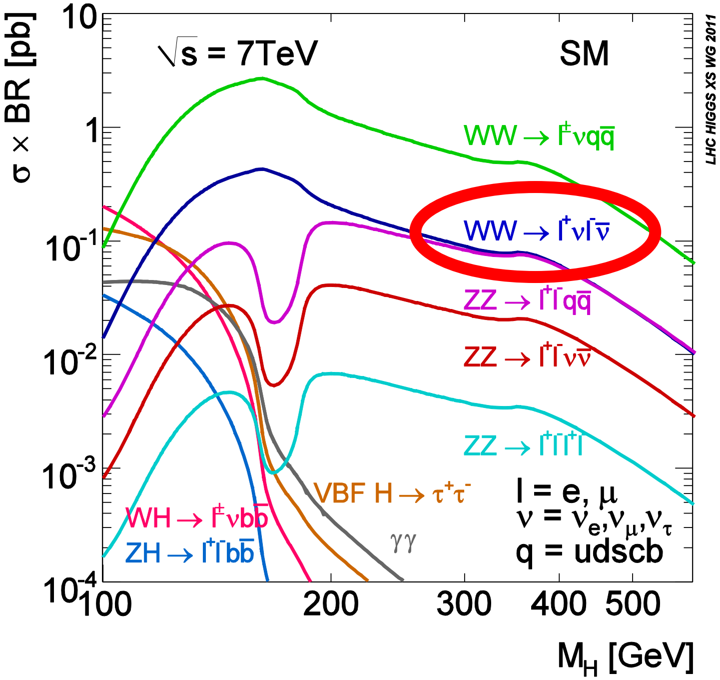


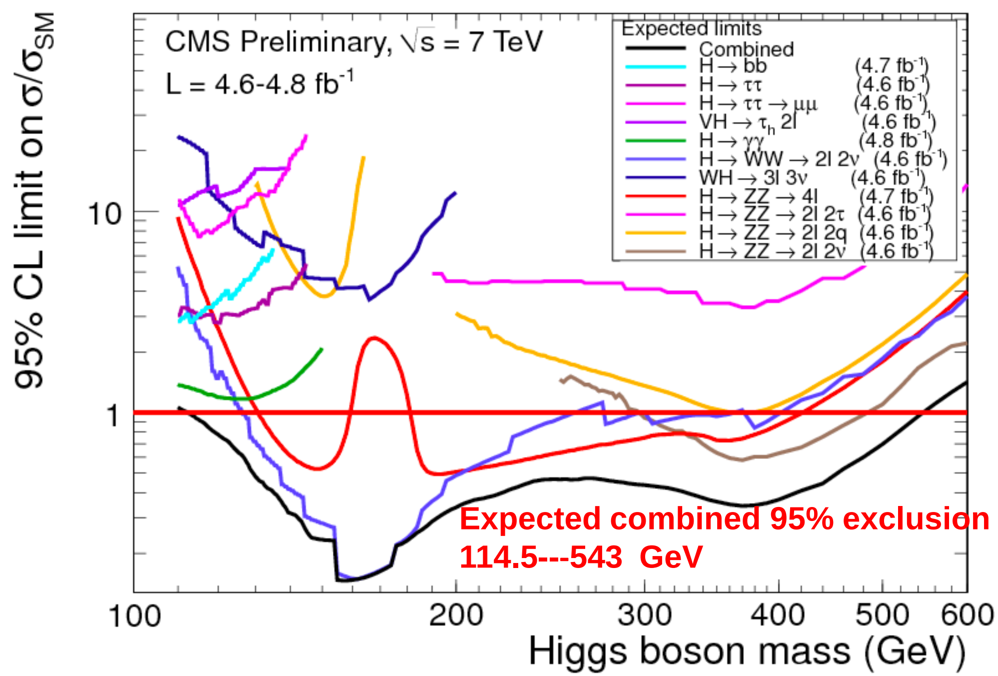


- ➢Z →ll : no true MET
  - ➢ Resolution can be estimated as the width distribution of E_x^{miss} and E_y^{miss}
  - ➢ Fundamental to understand (and reduce) especially with the increasing pileup
- ➢W →lv : real MET
  - ➢ m_T fit of the letpon- E_T^{miss} system
  - ➢Determination of the E_T^{miss} scale



Higgs boson @ LHC





- ➢NNLO prediction for SM Higgs production cross section in most cases
  - ➢ theory uncertainties reduced to < 20% (e.g. ggf: pdf ~8%, scale ~ 10%)
- ➢Huge progress also in the theoretical predictions of numerous and complex backgrounds
- ➢H → WW →lνlν most sensitive channel

H → WW final state

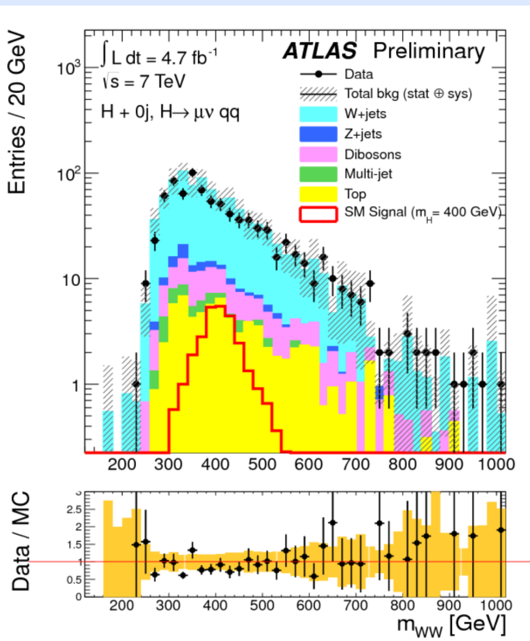
- Three possible final state for H → WW

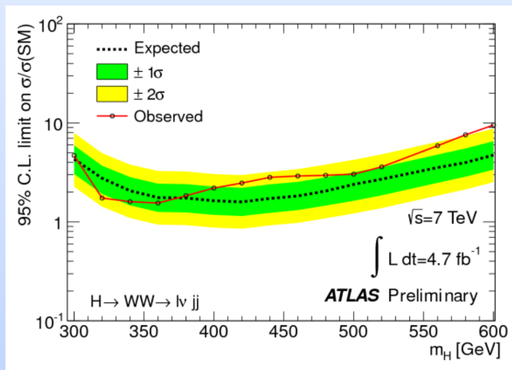
H→WW→lvlv

- Relatively clean, background dominated by irreducible WW background.

This talk

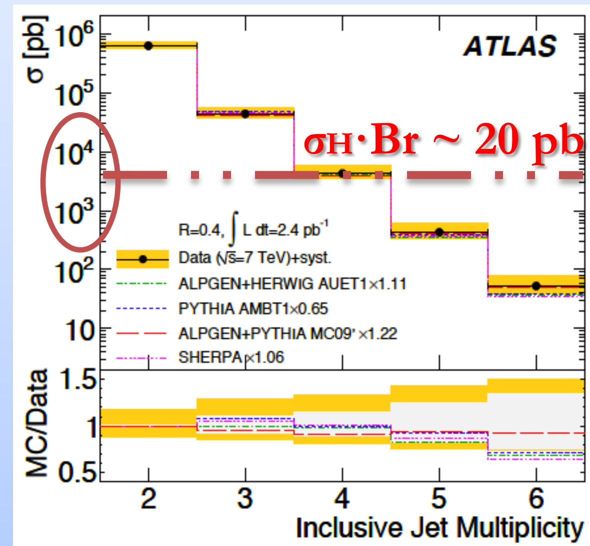
H→WW→lvqq





- High W+jets background
- used at high m_H
- excluded x2 SM x-sec

H→WW→4q



- Hopeless due to QCD bkg

Not covered in this talk

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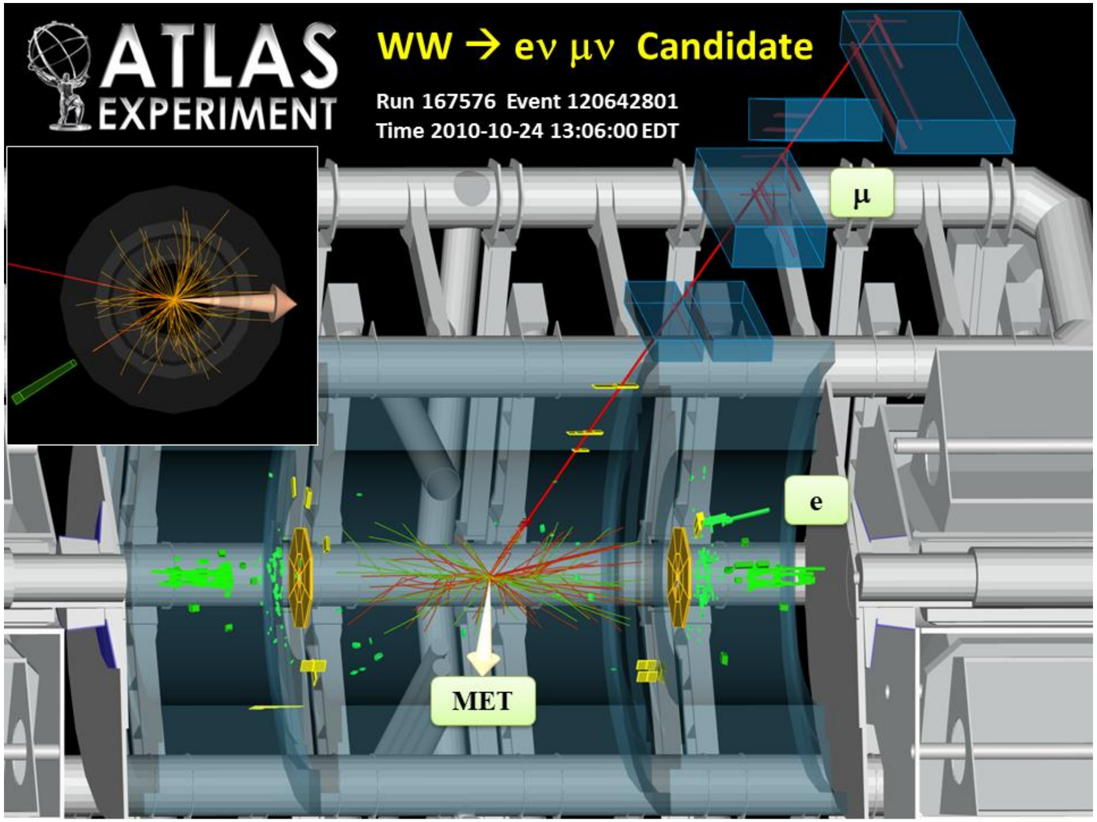
The H→WW$^{(*)}$→lνlν channel

Experimental signature:

- Two leptons (e or μ):
  - Opposite sign
  - Isolated
  - High p_T
- Two neutrinos:
  - Large E_T^{miss}
  - No mass peak (mass resolution~20%)→ counting experiment

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



Main Backgrounds:

- WW irreducible (topological cut helps)
- W+jet, Z+jet, tt, WZ, ZZ

The Challenge: understand backgrounds and normalize to control regions

Event selection I

Similar approach for ATLAS and CMS

Single lepton trigger (ATLAS)

Single or di-lepton trigger(CMS)

object selection

Leading lepton: p_T>25 GeV (20 GeV)

sub-leading leptons: p_T>15 GeV (10GeV)

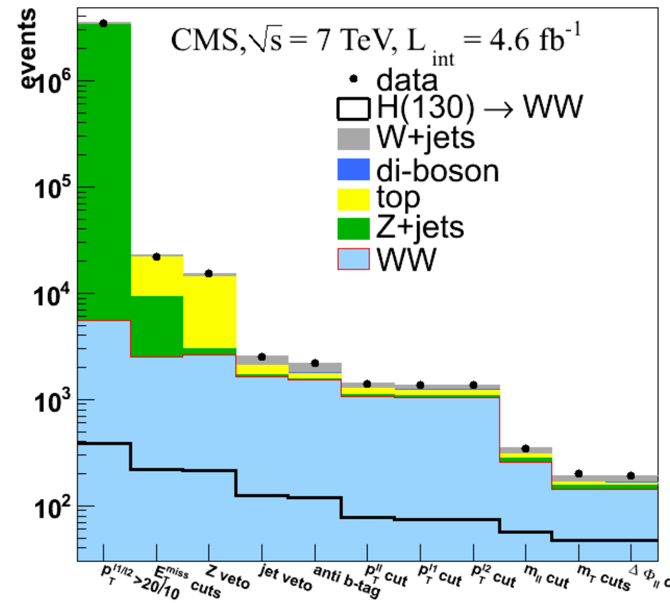
Jets anti-btagged : p_T>25 GeV (30 GeV)

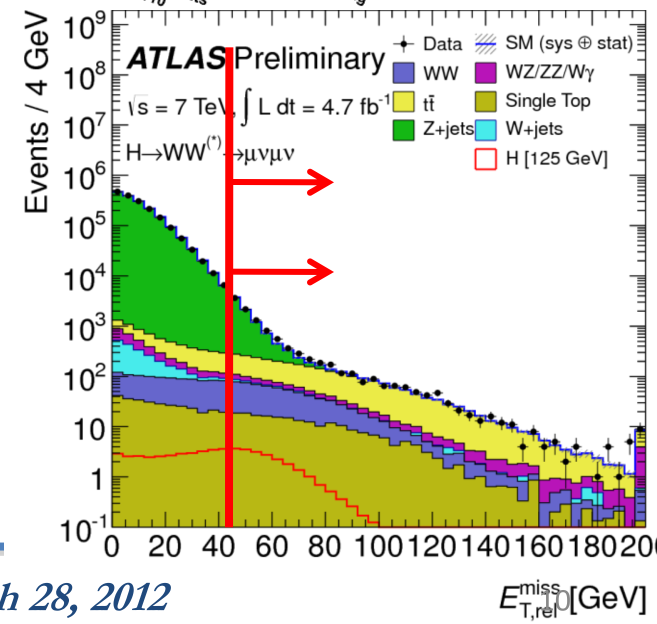
MET

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

ee, μμ: $E_{T,rel}^{miss}$> 45 GeV (40 GeV,nvtx dependent)

eμ: $E_{T,rel}^{miss}$> 25 GeV (20 GeV)





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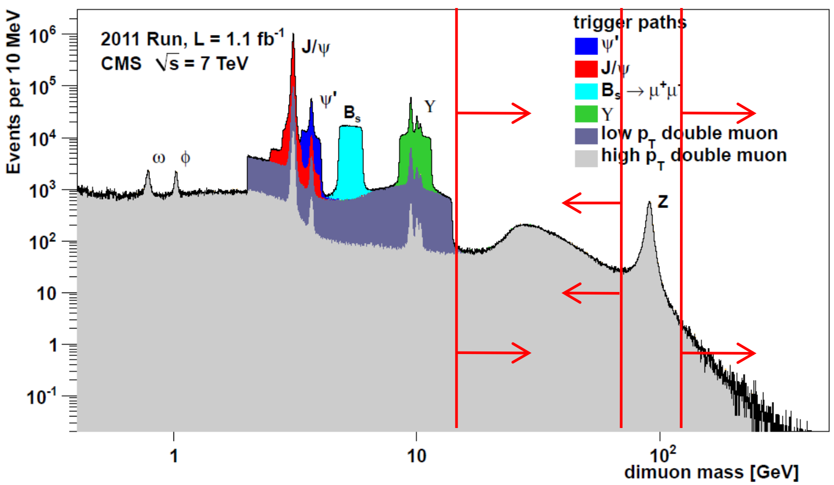
Event selection II

m_{ll}

Z veto for ee, μμ : $|m_{ll} - m_Z| > 15$ GeV (common)

$m_{ll} > 12$ GeV (ee, μμ) $m_{ll} > 10$ GeV (eμ)

$m_{ll} > 20$ GeV (ee, μμ) $m_{ll} > 12$ GeV (eμ)

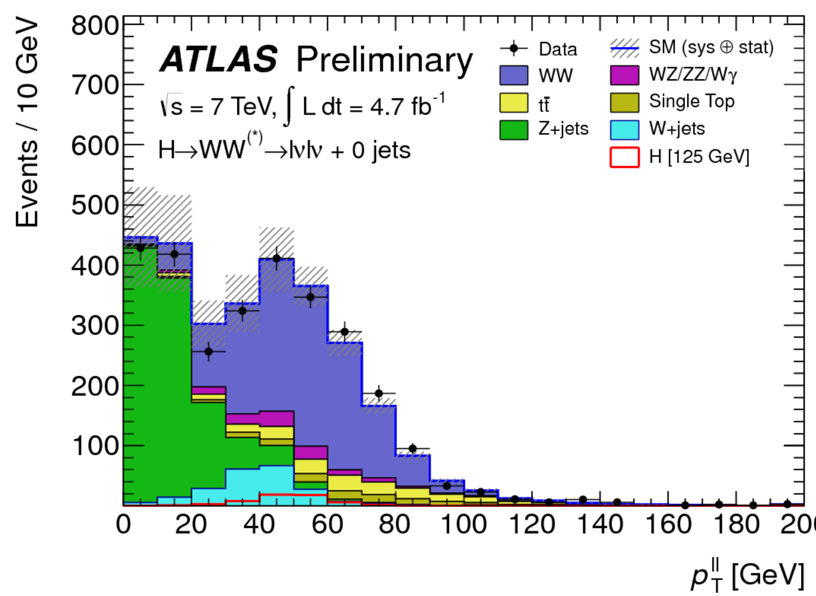


p_T^{ll}

Additional DY rejection

$p_T^{ll} > 45$ GeV (ee, μμ) $p_T^{ll} > 30$ GeV (eμ)

$p_T^{ll} > 45$ GeV



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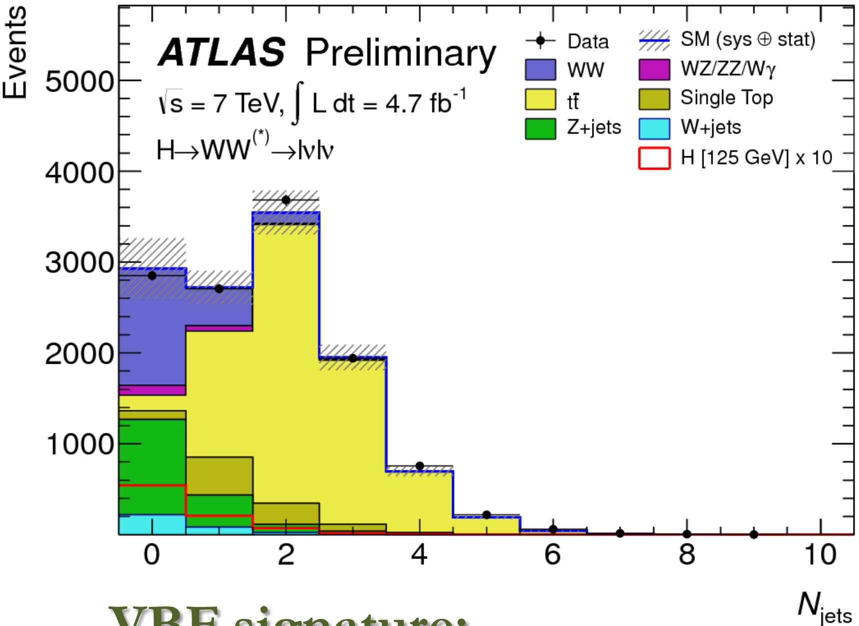
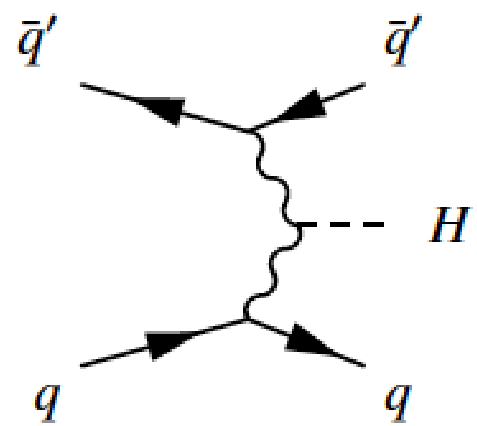
Jet multiplicity & VBF



- Different **tt contamination** depending on the number of jets per event
  - tt final state: llvv+bjets+Njets
  - Anti b-jet veto used for tt bkg reduction
- Analysis performed in **jet categories**:
  - 0 jet : very clean
  - 1 jet : tt contamination
  - 2 jet : tt contamination, **VBF topology handle**

VBF signature:

- very forward high p_T jets, very high M_{jj}
  - 2 jet selection tuned on VBF-like signal
- central jet veto (ATLAS) :
  - no selected jets in $|\eta| < 3.2$
- 2 highest p_T jets back to back in η
  - $\Delta\eta_{jj} > 3.8$, $m_{jj} > 500$ GeV (ATLAS)
  - $\Delta\eta_{jj} > 3.5$, $m_{jj} > 450$ GeV (CMS)



Topological cuts

➤Extra requirements to optimize the sensitivity for a SM Higgs boson search

ATLAS

- ➤3 m_H regions
- ➤$\Delta\varphi_{ll}$
- ➤m_{ll}
- ➤m_T shape for fit

Low mass selection	Intermediate mass selection	High mass selection
m_H < 200 GeV	m_H =200 GeV – 300 GeV	m_H > 300 GeV
Mll < 50 GeV 2jet low mass: Mll < 80 GeV	Mll < 150 GeV	No Mll cut to increase signal acceptance
ΔΦ < 1.8	---	---
m_T shape used in fit (0jet,1jet)	m_T shape used in fit (0jet,1jet)	m_T shape used in fit (0jet,1jet)

CMS

- ➤ optimized for various m_H values
  - ➤Leading and subleading p_T
  - ➤$\Delta\varphi_{ll}$
  - ➤m_{ll}
  - ➤m_T range

m_H [GeV]	$p_T^{\ell,max}$ [GeV]	$p_T^{\ell,min}$ [GeV]	$m_{\ell\ell}$ [GeV]	$\Delta\phi_{\ell\ell}$ [°]	m_T [GeV]
	>	>	<	<	[,]
120	20	10 (15)	40	115	[80,120]
130	25	10 (15)	45	90	[80,125]
160	30	25	50	60	[90,160]
200	40	25	90	100	[120,200]
250	55	25	150	140	[120,250]
300	70	25	200	175	[120,300]
400	90	25	300	175	[120,400]

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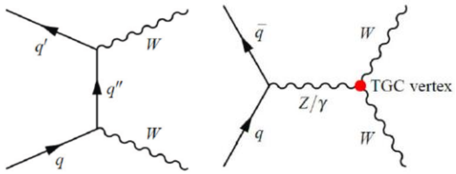
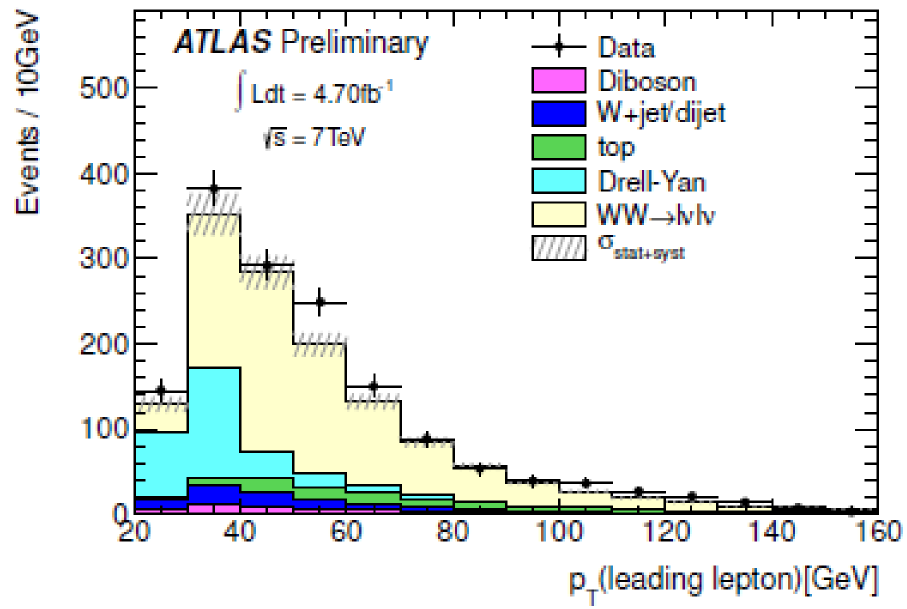
The Backgrounds



SM WW Backgournds

- ➢Crucial background for H→WW search
  - ➢Same signature
- ➢Interesting because sensitive to anomalous TGCs
- ➢Main backgrounds:
  - ➢Z+jets and top



- ➢Production cross section measured from both ATLAS and CMS

ATLAS	53.4±2.1(stat.)±4.5(syst.)±2.1(lumi.) pb	*ATLAS-CONF-2012-025*
CMS	55.3±3.3(stat.)±6.9(syst.)±3.3(lumi.) pb	*CMS-PAS-EWK-11-010*

- ➢NLO prediction: 45.1±2.8 pb

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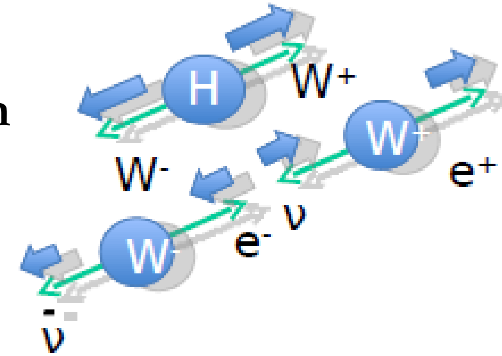
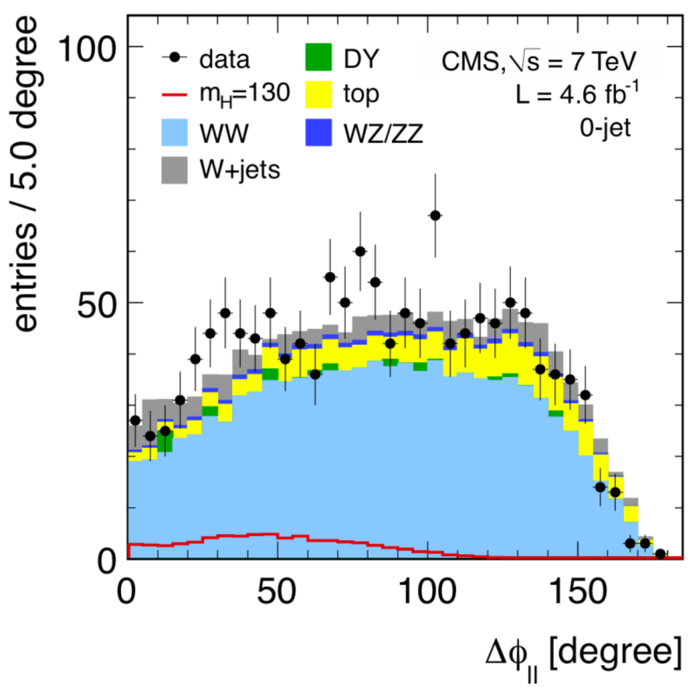
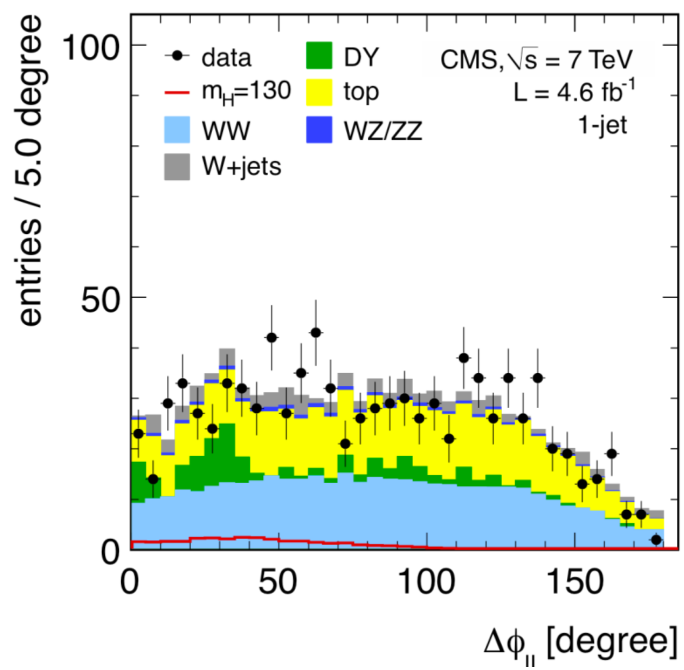
WW background

- Irreducible background: same final state of H→WW
  - Only way to distinguish it → exploit spin correlation
- Leptons tends to go in the same direction
- Low m_{ll}

$$m_{ll} = \sqrt{2E_1E_2(1-\cos\Delta\varphi_{12})}$$







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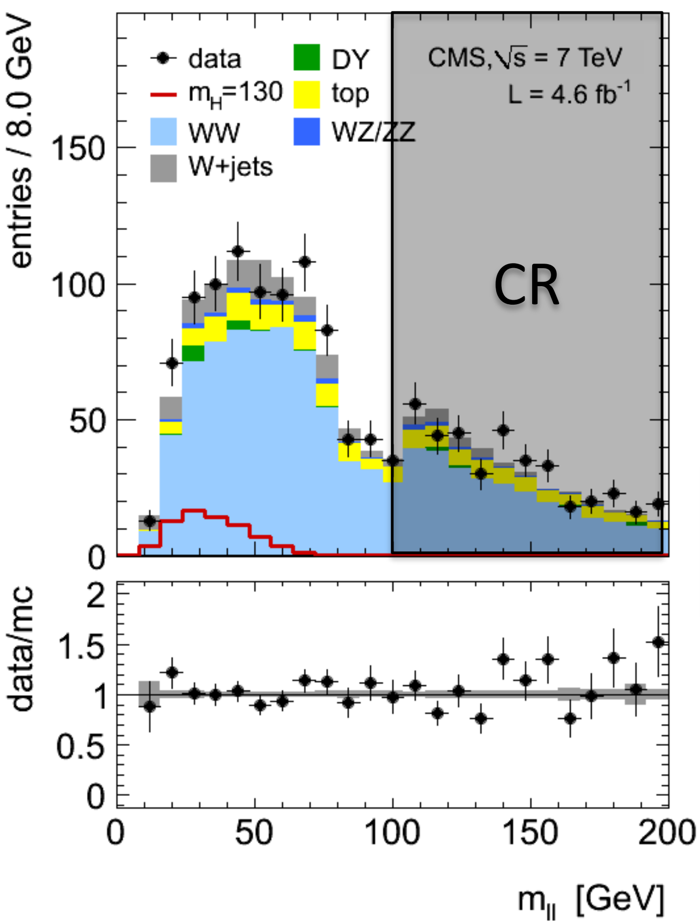
WW backgroung control region



- WW non-resonant contribution estimated from data in the low-mass $m_H < 200$ GeV.
- done using events with a high dilepton mass+ MC extrapolation into signal region

$$N^{WW}_{S.R.} = N^{WW}_{C.R.} \cdot \alpha$$

ATLAS

$M_{ll} > 80$ GeV for eμ

$M_{ll} > (m_Z + 15$ GeV) for ee/μμ

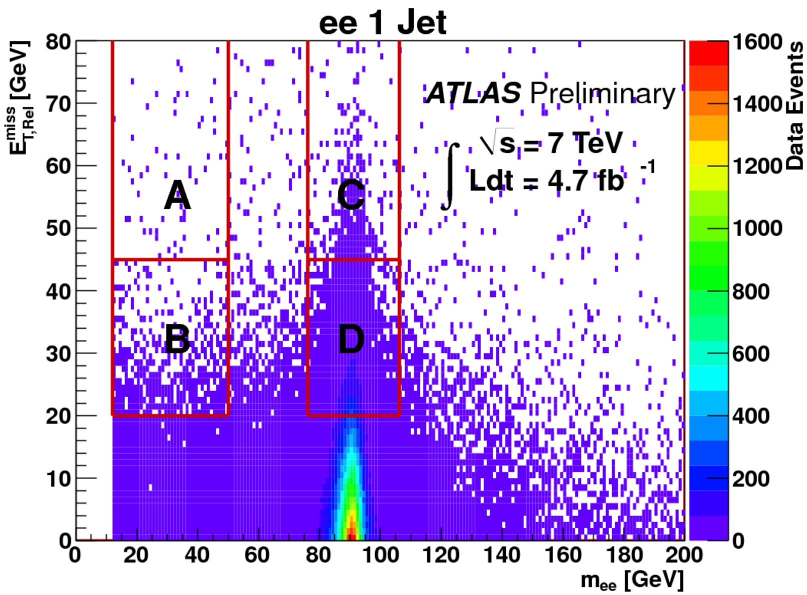
CMS

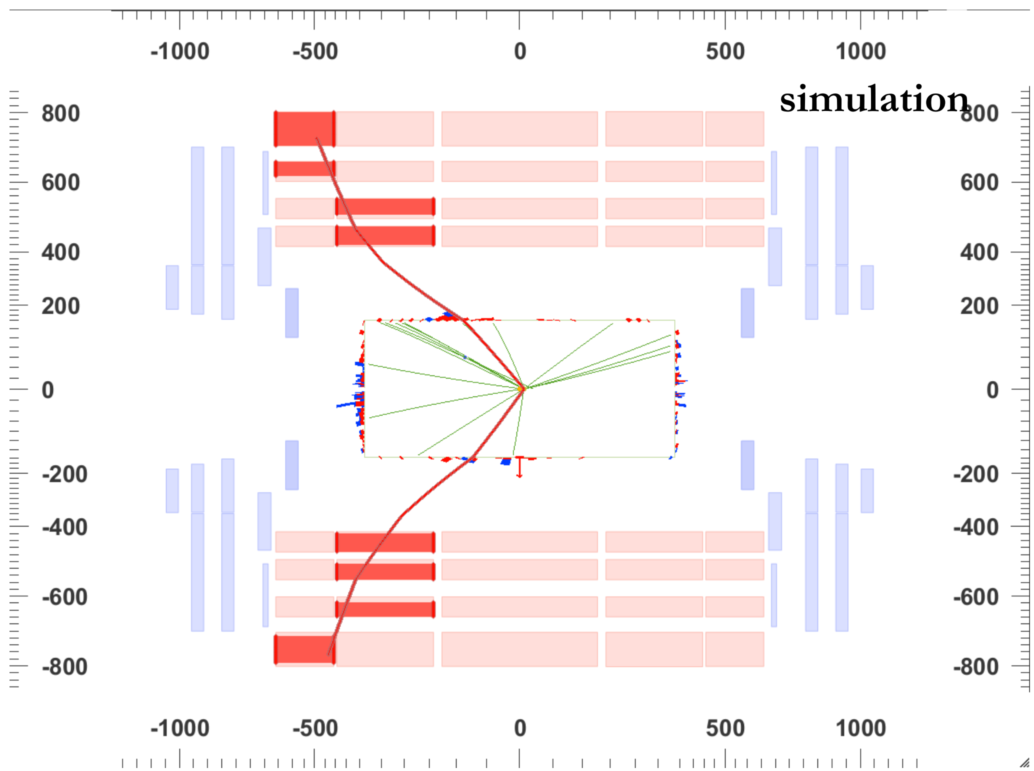
$M_{ll} > 100$ GeV

- For $m_H > 200$ GeV large overlap between H→WW and non resonant WW
  - simulation is used for the estimation

The total uncertainty: 10% for 0-jet and 24% for 1-jet selections

Drell Yan background





Z/γ^* + jets

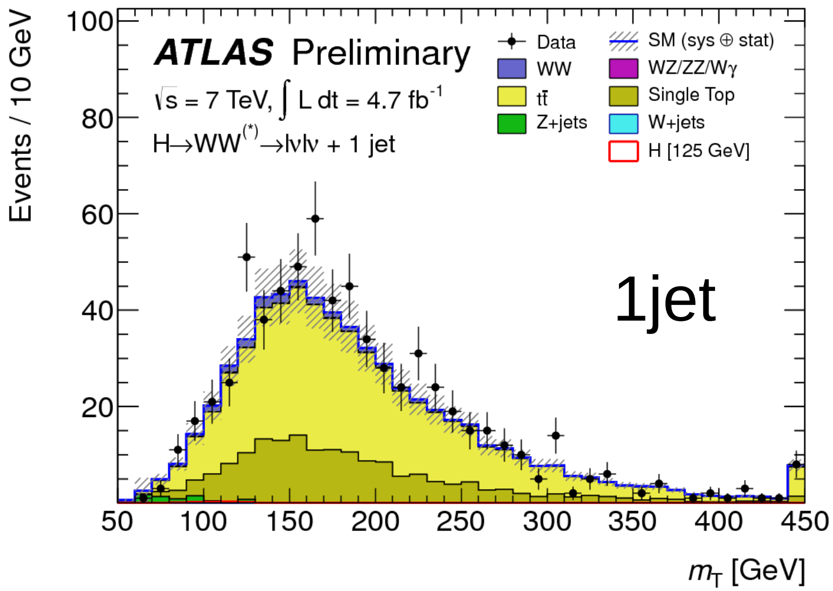
mainly rejected with $E_{T,rel}^{miss}$ cut

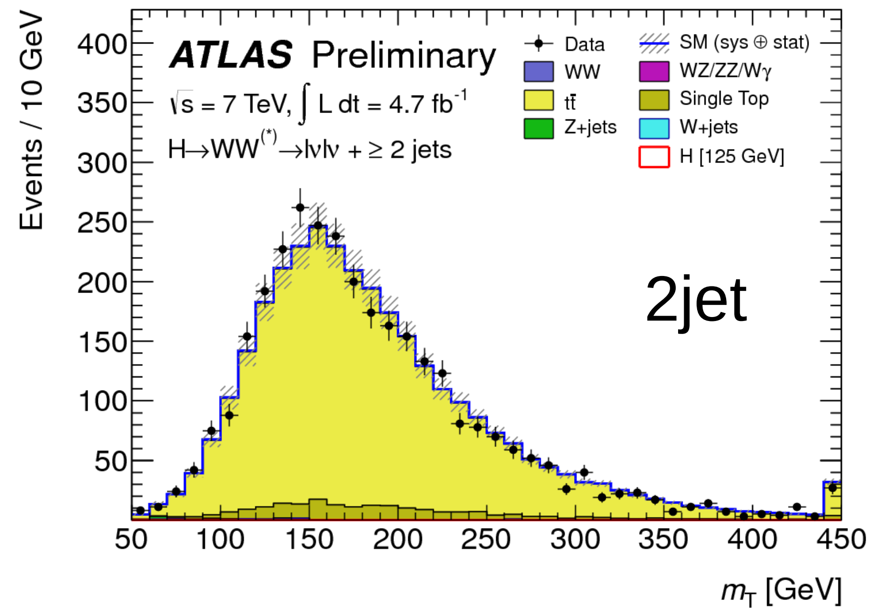
Normalize MC using Z control region – ABCD method using METRel-Mll

$$A_{data} = B_{data} \times \frac{C_{data}}{D_{data}}$$

Uncertainty : 56% for H+0jet and 25% for H+1jet analysis respectively

Top background





- **Definition of data control sample to normalize MC predicion**
- **E.g. H+ 1-jet and H+ 2-jet analyses,**
  - **reversing the b-jet veto**
  - **Remove the requirements on $\Delta\varphi_{ll}$ m_{ll}.**

ATLAS : 23% uncertainty for the 0-jet channel, 30% otherwise

CMS: 25% uncertainty for the 0-jet channel, 10% otherwise

Other backgrounds

- **W+jets background**
  - control sample with inverted lepton ID passing loose criteria
- **WZ/ZZ**
  - Leptons coming from two different bosons
  - estimated from MC simulation
- **Wγ***
  - Normalization from high purity three-lepton control sample
- **Wγ** estimated from simulation
  - Cross-checked with same sign sample

CMS and ATLAS Results

arXiv:1202.1489,CMS-HIG-11-024

ATLAS-CONF-2012-012

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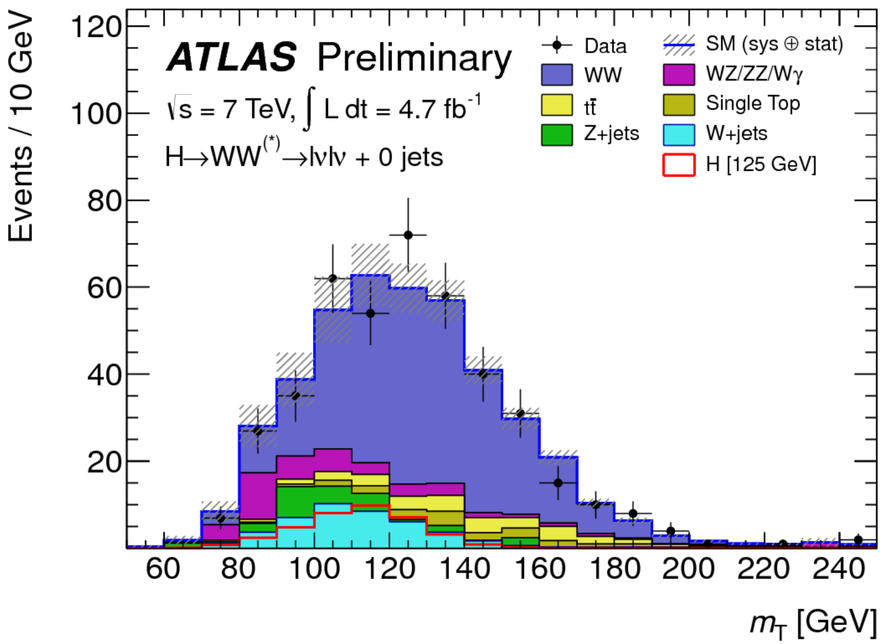
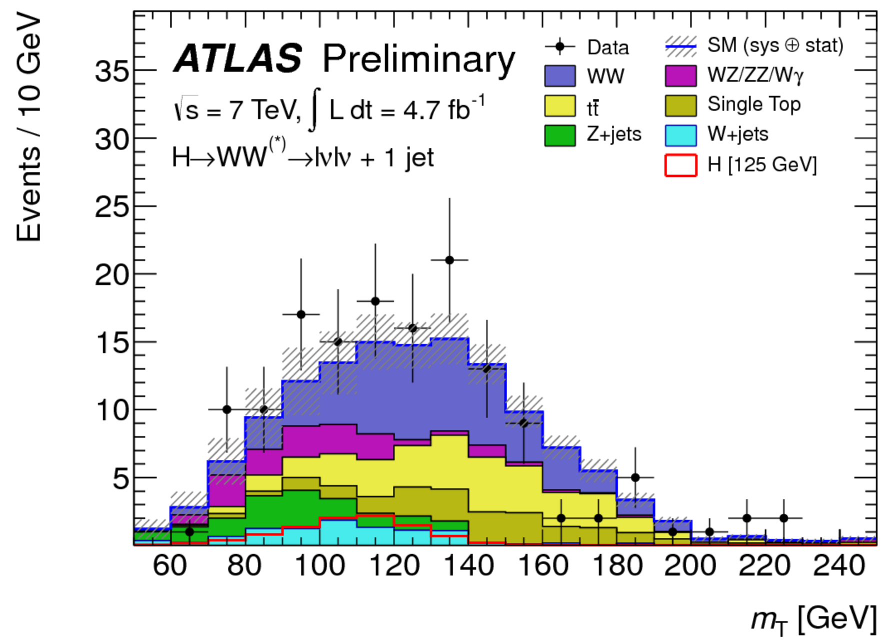
ATLAS Results





		Signal	Total Bkg.	Obs.
0-jet	$m_H = 125$ GeV	25 ± 7	173 ± 22	174
	$m_H = 240$ GeV	60 ± 17	607 ± 63	629
1-jet	$m_H = 125$ GeV	6 ± 2	45 ± 7	56
	$m_H = 240$ GeV	23 ± 9	229 ± 55	232
2-jet	$m_H = 125$ GeV	0.4 ± 0.2	0.5 ± 0.2	0
	$m_H = 240$ GeV	2.5 ± 0.6	4.2 ± 1.7	2

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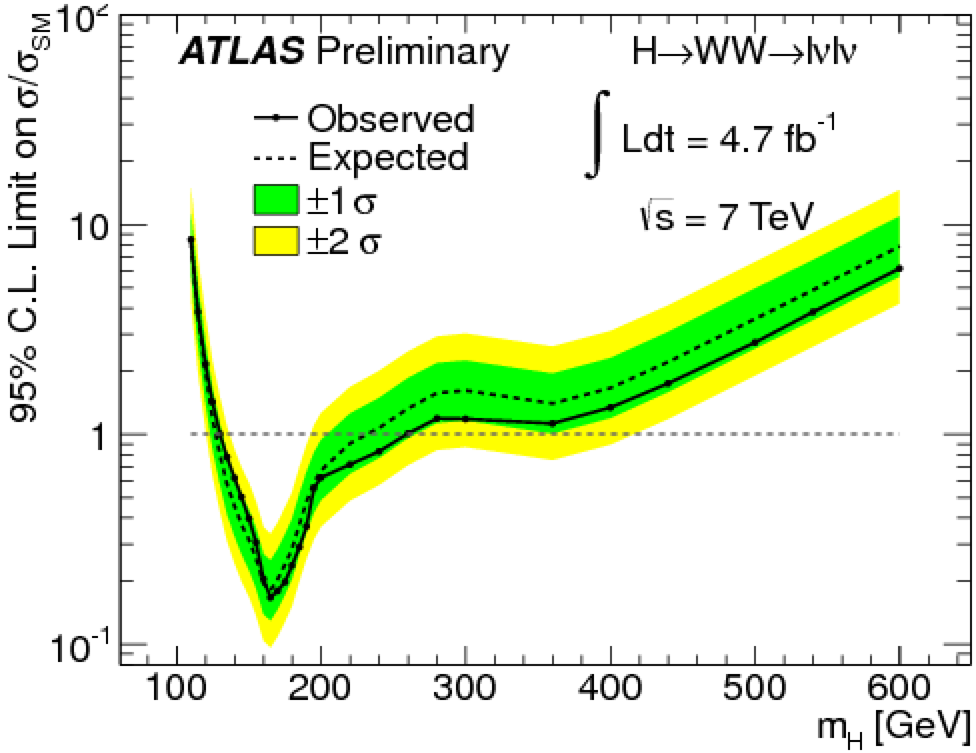
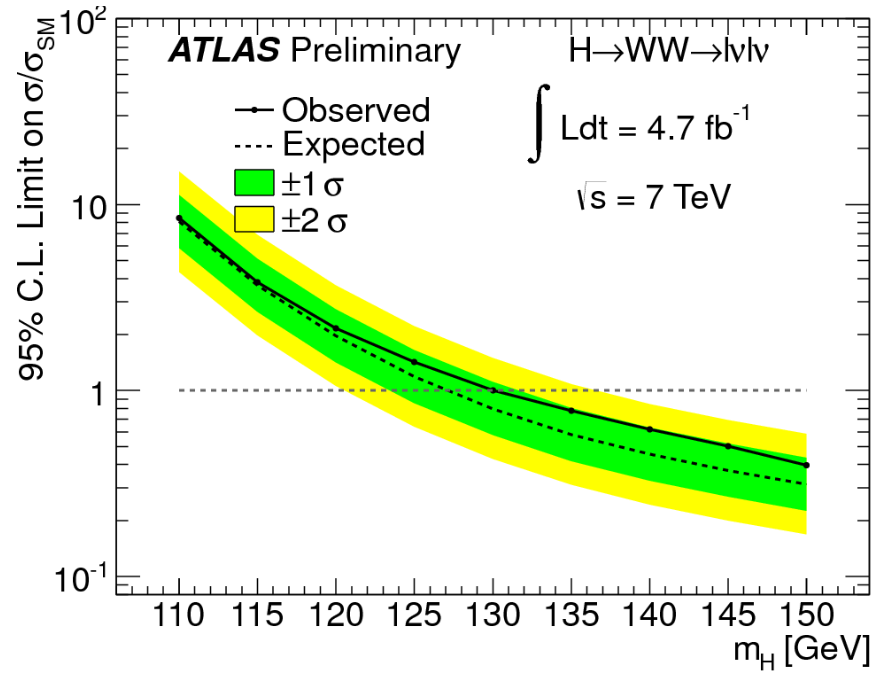
ATLAS Results





- **in 9 channels (ee, μμ, eμ) x (0 jet, 1 jet, 2 jet) for each M_H**
- **No significant excess in the mass range $110<m_H<600$ GeV**
  - **95% C.L. expected exclusion for $127 < m_H < 234$ GeV**
  - **95% C.L. observed exclusion for $130 < m_H < 260$ GeV**

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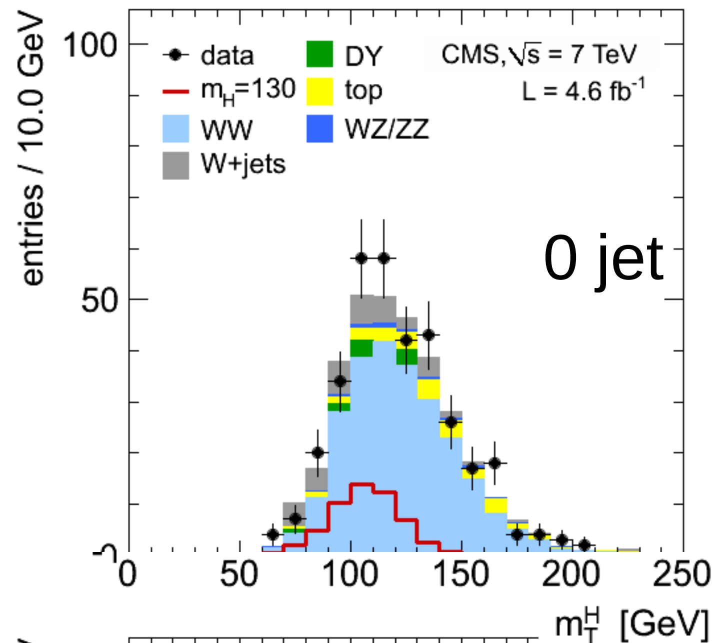
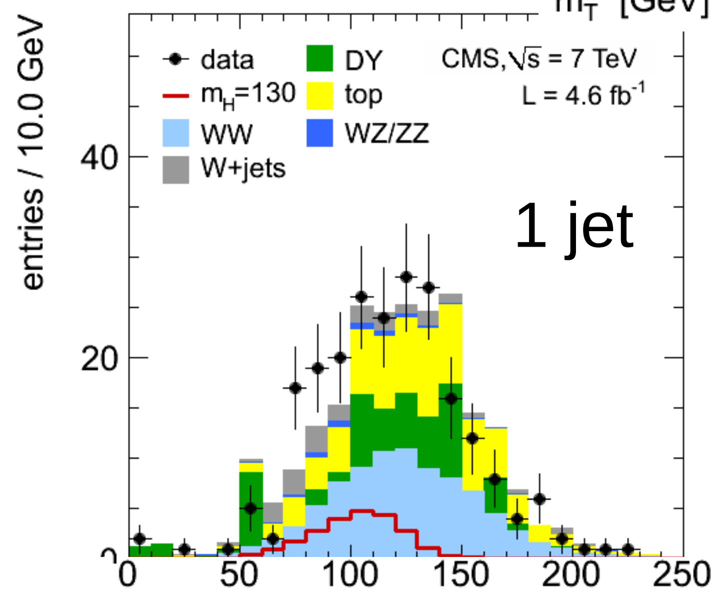
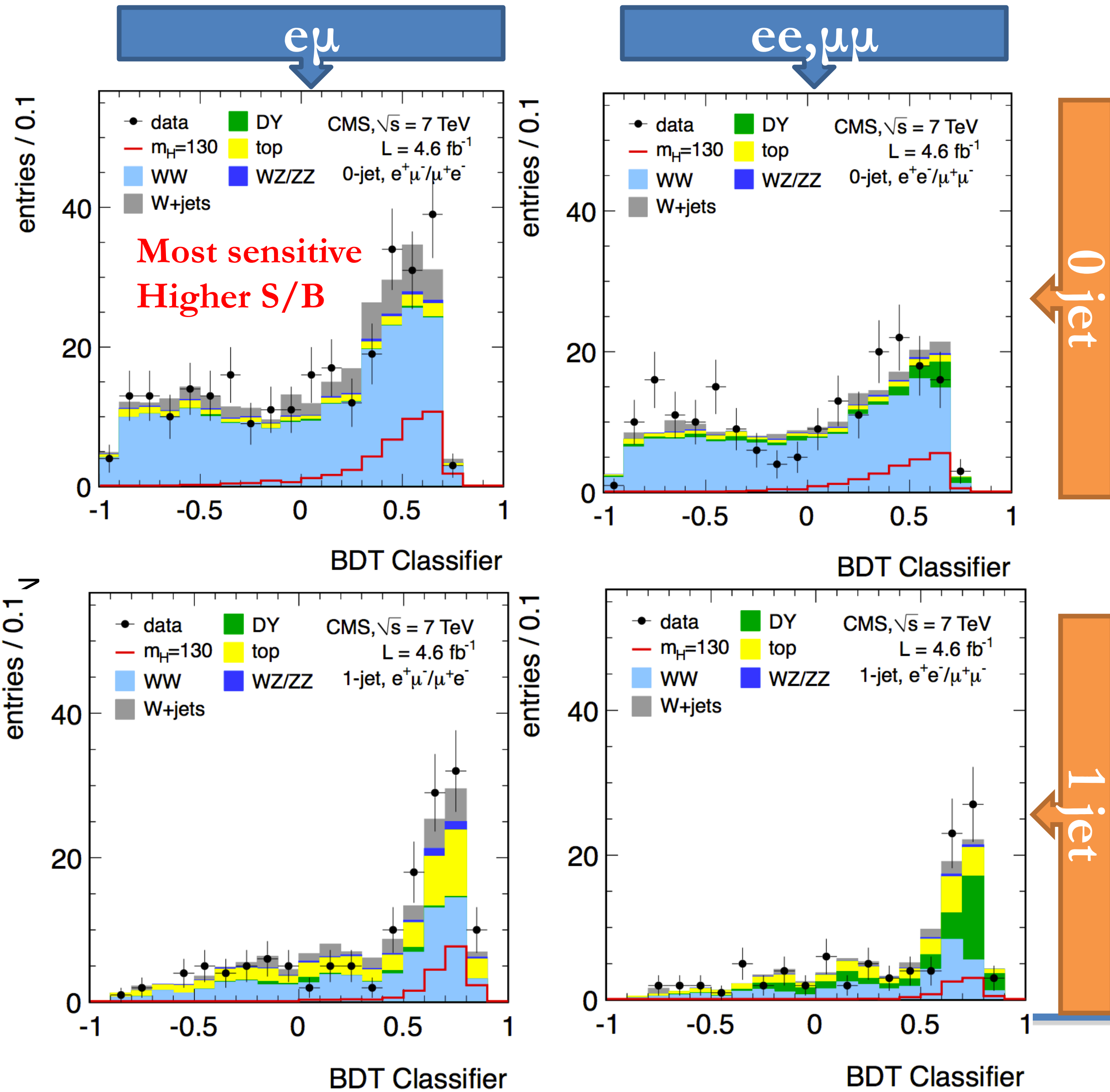
CMS Results

m_H	data	all bkg.	$H \to W^+W^-$
0 jet			
120	136	136.7 ± 12.7	15.7 ± 0.8
130	193	191.5 ± 14.0	45.2 ± 2.1
160	111	101.7 ± 6.8	122.9 ± 5.6
200	159	140.8 ± 6.8	48.8 ± 2.2
400	109	110.8 ± 5.8	17.5 ± 0.8
1 jet			
120	72	59.5 ± 5.9	6.5 ± 0.3
130	105	79.9 ± 7.7	17.6 ± 0.8
160	86	70.8 ± 6.0	60.2 ± 2.6
200	111	130.8 ± 6.7	25.8 ± 1.1
400	128	123.6 ± 5.3	12.2 ± 0.5
2 jet			
120	8	11.3 ± 3.6	1.1 ± 0.1
130	10	13.3 ± 4.0	2.7 ± 0.2
160	12	15.9 ± 4.6	12.2 ± 0.7
200	13	17.8 ± 5.0	8.4 ± 0.5
400	20	23.8 ± 6.4	2.5 ± 0.1



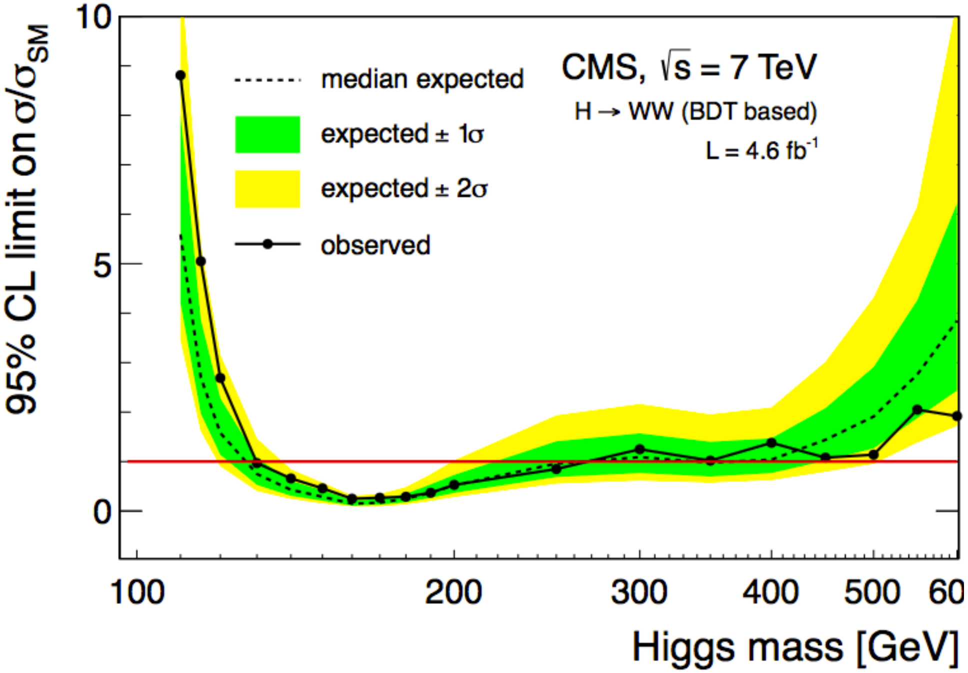


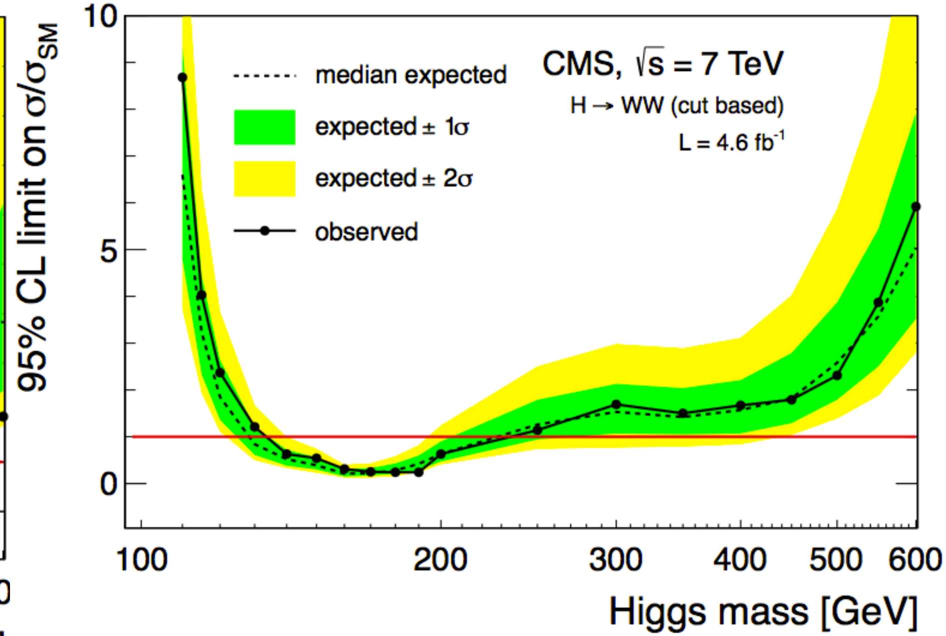
Multivariate approach



- BDT trained at different masses
  - $H \to WW$ signal and non-resonant WW background
- Inputs: p_T^{lept}, M_{ll}, $\Delta\varphi_{ll}$, ΔR_{ll}, M_T
- Uncertainties:
  - signal efficiency ~20%
  - background ~15%
- BDT classifier output used for CL estimation

CMS Results





- No significant excess in the mass range $110<m_H<600$ GeV
  - 95% C.L. expected exclusion for $127 < m_H < 270$ GeV
  - 95% C.L. observed exclusion for $129 < m_H < 270$ GeV
- Small excess at low mass (BDT analysis)

Conclusions

- $H \to WW \to l\nu l\nu$ is one of the most sensitive Higgs search channels
  - Fundamental ingredient in the final combination with the other channels
- $H \to WW \to l\nu l\nu$ exclusion limits:
  - ATLAS : range 130-260 GeV
  - CMS : range 129-270 GeV
- No hint for a Standard Model Higgs in this channel.
- With the 2012 data we will be able to "close the gap"
  - Expect discovery or exclusion this year!
- …in the meantime LHC…

Last Update: Mar 27 at 13:24 Mar 28 2012

LHC Machine Coordination Planning

MachineCoordinators: Ralph Assmann, Jorg Wenninger
Goals week 13: Beam commissioning

Allowed injected intensity: 1 nominal
Allowed intensity 450 GeV: Safe beam
Allowed intensity 4.0 TeV: 1 probe

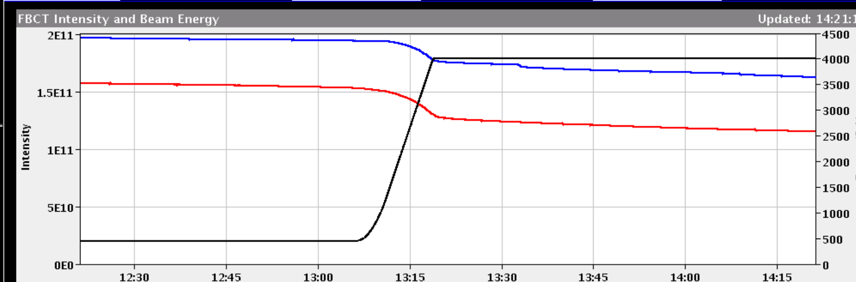
Tue A	TCDQ/dump protection
Tue N	Probe bunches through full cycle
Wed MA	Collimation setup at 4 TeV
Wed AN	Injection and dump work
Thu M	Nominal bunches in collisions

Latest LHC news and results:
http://www.cern.ch/lhc-commissioning/news-2012/LHC-latest-news.html

LHC Page1 Fill: 2417 E: 4000 GeV 28-03-12 14:21:11

BEAM SETUP: FLAT TOP

Energy:	4000 GeV	I(B1):	1.59e+11	I(B2):	1.19e+11



Comments 28-03-2012 13:43:01 :

Collimation setup at 4TeV ongoing

BIS status and SMP flags	B1	B2
Link Status of Beam Permits	false	false
Global Beam Permit	true	true
Setup Beam	true	true
Beam Presence	true	true
Moveable Devices Allowed In	false	false
Stable Beams	false	false

AFS: Single_7b_4_4_4 PM Status B1 ENABLED PM Status B2 ENABLED

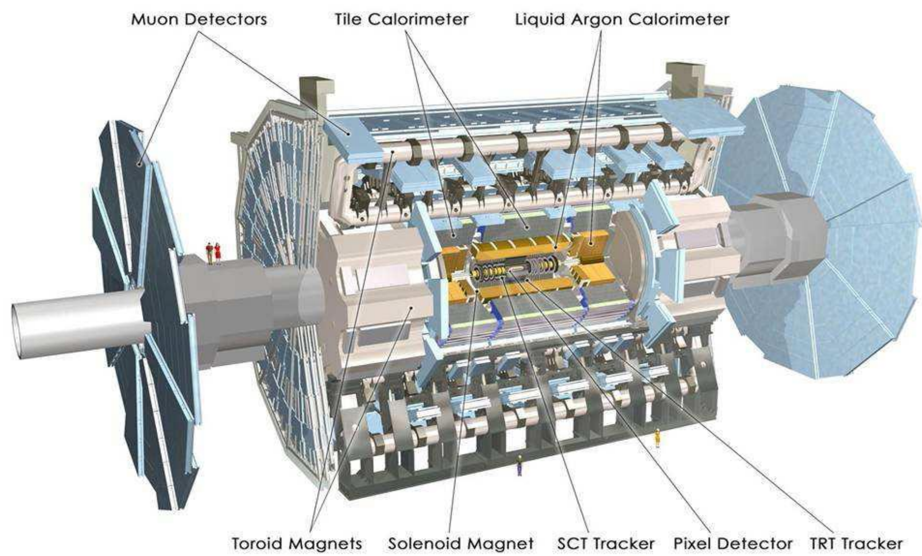
Collisions at √s=8 TeV will arrive very soon !!

backup

ATLAS and CMS Detectors

ATLAS

- ➢ 2T superconducting solenoid. Inner Detector: silicon pixel/strip tracker with a straw tube tracker. $|\eta| < 2.5$
- ➢ LAr electromagnetic and iron-scintillator tile hadronic calorimeters cover $|\eta| < 4.9$.
- ➢ Muon spectrometer in toroidal magnetic field covers $|\eta| < 2.7$.

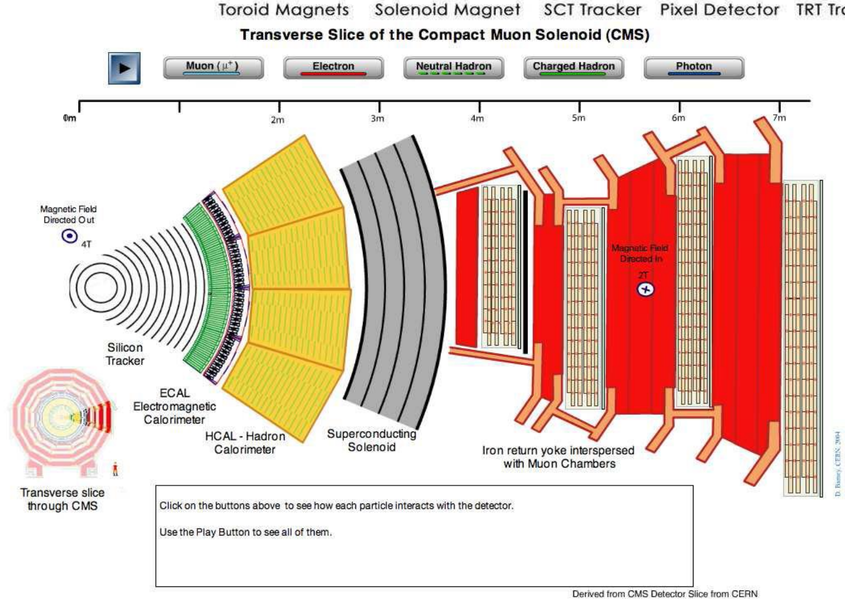


CMS:

3.8T superconducting solenoid. Silicon pixel and strip tracker cover $|\eta| < 2.5$

Crystal electromagnetic and brass-scintillator hadronic calorimeters cover $|\eta| < 3.0$ and a Quartz-fiber Cherenkov calorimeter covers to $|\eta| < 5.0$.

Muons gas-ionization detectors in the solenoid yoke.

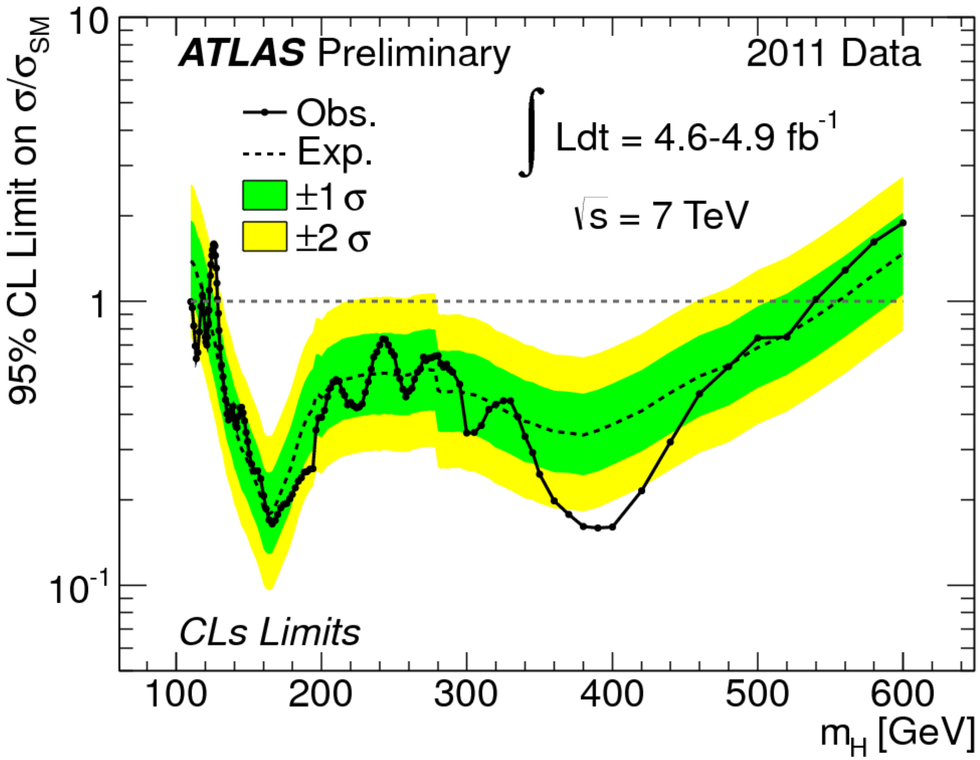


CMS

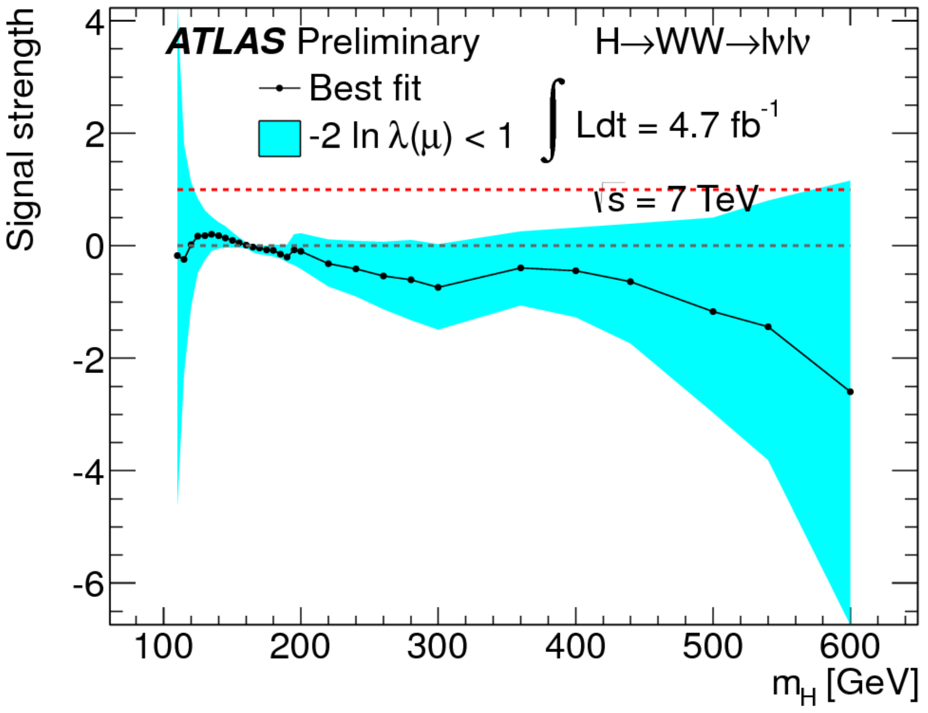
m_H	data	all bkg.	$H \to W^+W^-$
120	136	136.7 ± 12.7	15.7 ± 0.8
130	193	191.5 ± 14.0	45.2 ± 2.1
160	111	101.7 ± 6.8	122.9 ± 5.6
200	159	140.8 ± 6.8	48.8 ± 2.2
400	109	110.8 ± 5.8	17.5 ± 0.8
120	72	59.5 ± 5.9	6.5 ± 0.3
130	105	79.9 ± 7.7	17.6 ± 0.8
160	86	70.8 ± 6.0	60.2 ± 2.6
200	111	130.8 ± 6.7	25.8 ± 1.1
400	128	123.6 ± 5.3	12.2 ± 0.5
120	8	11.3 ± 3.6	1.1 ± 0.1
130	10	13.3 ± 4.0	2.7 ± 0.2
160	12	15.9 ± 4.6	12.2 ± 0.7
200	13	17.8 ± 5.0	8.4 ± 0.5
400	20	23.8 ± 6.4	2.5 ± 0.1

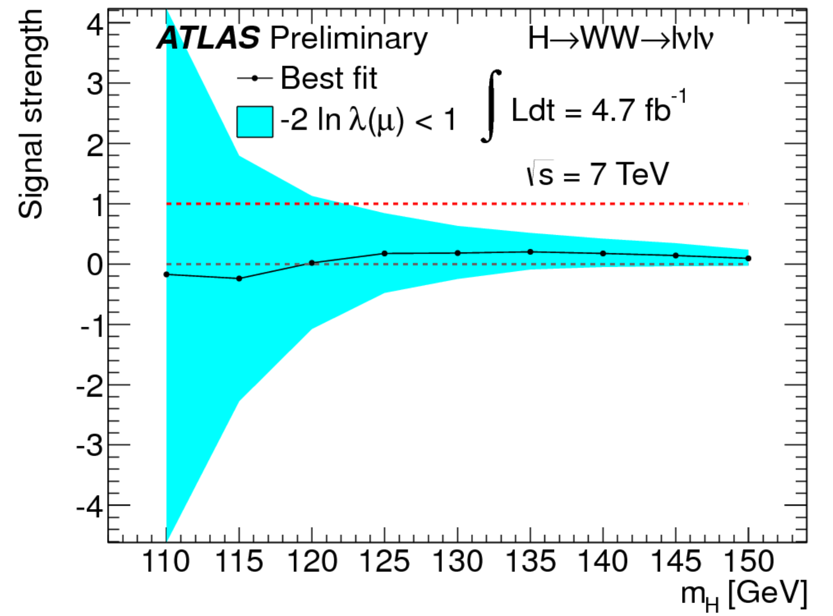
ATLAS

		Signal	Total Bkg.	Obs.
0-jet	$m_H = 125$ GeV	25 ± 7	173 ± 22	174
	$m_H = 240$ GeV	60 ± 17	607 ± 63	629
1-jet	$m_H = 125$ GeV	6 ± 2	45 ± 7	56
	$m_H = 240$ GeV	23 ± 9	229 ± 55	232
2-jet	$m_H = 125$ GeV	0.4 ± 0.2	0.5 ± 0.2	0
	$m_H = 240$ GeV	2.5 ± 0.6	4.2 ± 1.7	2


ATLAS Preliminary
2011 Data
Obs.
Exp.
±1 σ
±2 σ
∫ Ldt = 4.6-4.9 fb^-1
√s = 7 TeV
CLs Limits
95% CL Limit on σ/σSM
mH [GeV]
10
1
10^-1
100
200
300
400
500
600

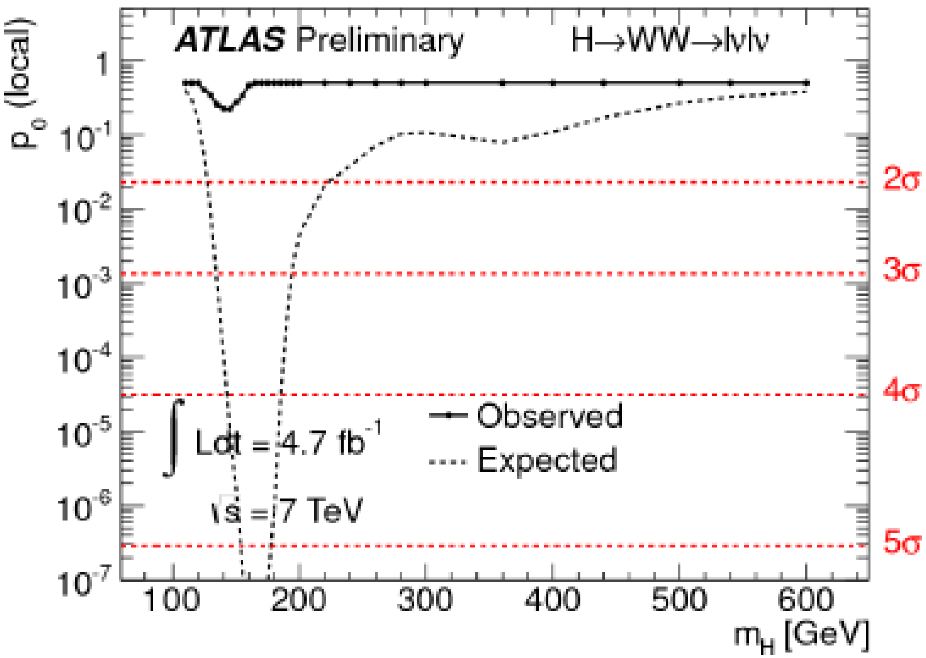
Signal strenght ATLAS



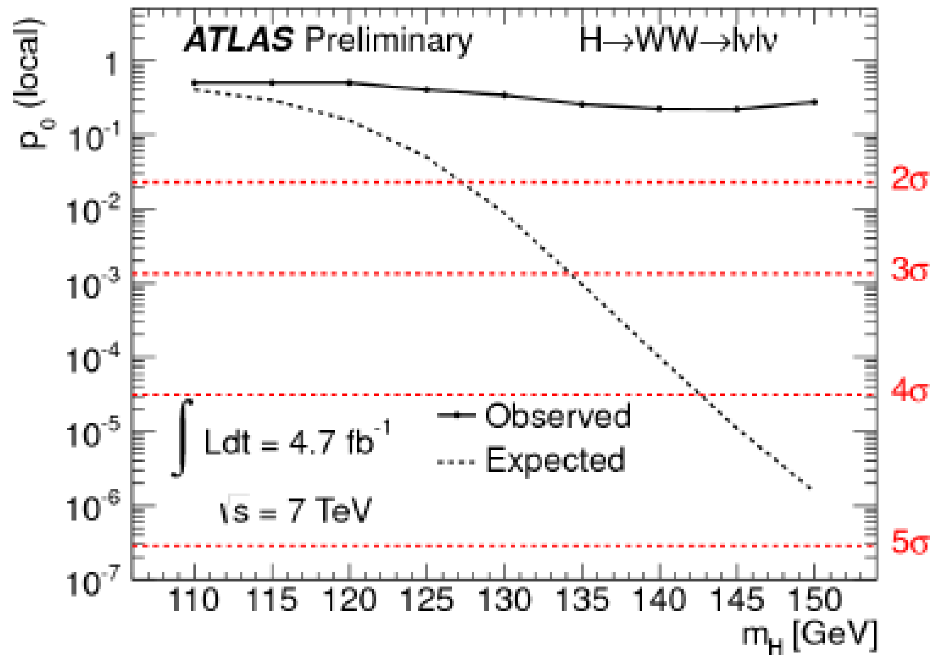


Roberto

p0

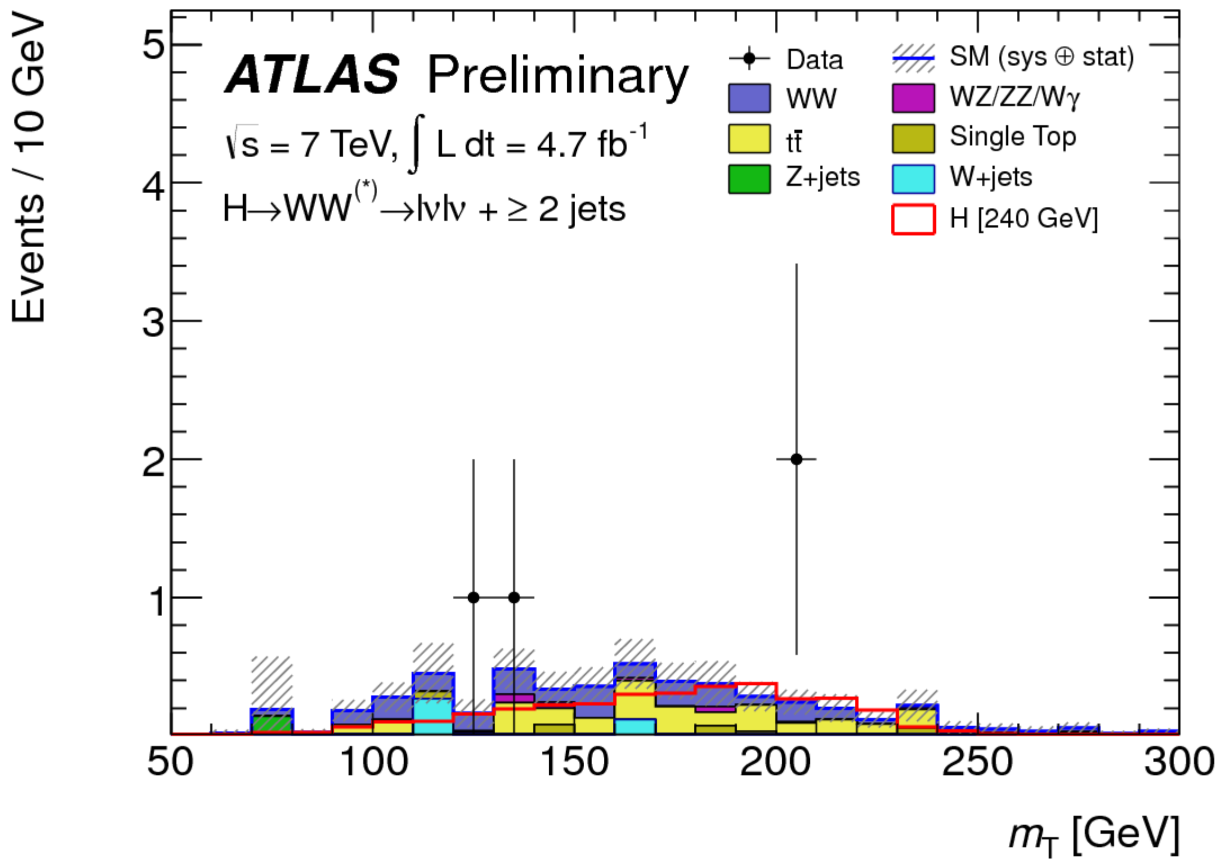


ATLAS Preliminary
H→WW→lνlν
$\int Ldt = 4.7\ fb^{-1}$
$\sqrt{s} = 7\ TeV$
Observed
Expected
2σ
3σ
4σ
5σ
p_0 (local)
m_H [GeV]

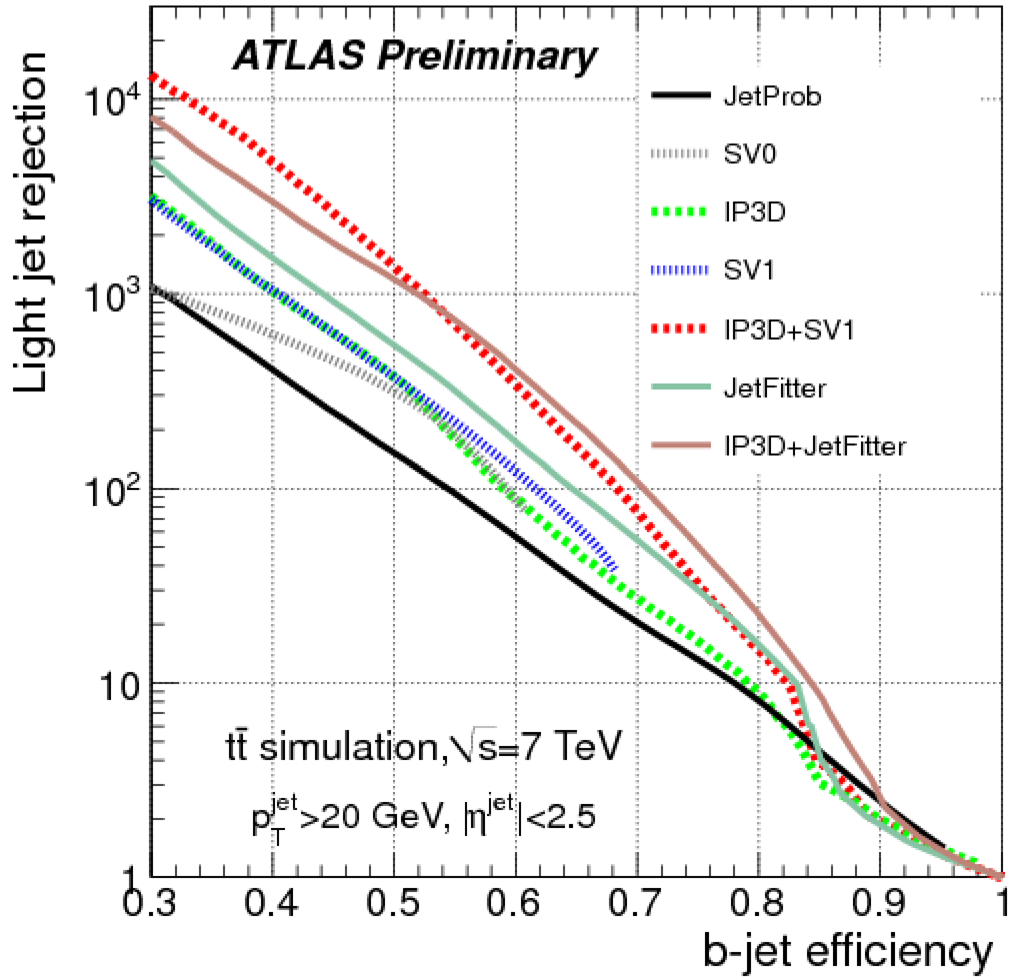


ATLAS Preliminary
H→WW→lνlν
$\int Ldt = 4.7\ fb^{-1}$
$\sqrt{s} = 7\ TeV$
Observed
Expected
2σ
3σ
4σ
5σ
p_0 (local)
m_H [GeV]

mT 2 jet



Events / 10 GeV
ATLAS Preliminary
√s = 7 TeV, ∫ L dt = 4.7 fb⁻¹
H→WW(*)→lνlν + ≥ 2 jets
Data
WW
tt̄
Z+jets
SM (sys ⊕ stat)
WZ/ZZ/Wγ
Single Top
W+jets
H [240 GeV]
5
4
3
2
1
50
100
150
200
250
300
mT [GeV]


ATLAS Preliminary
Light jet rejection
10^4
10^3
10^2
10
1
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
b-jet efficiency
JetProb
SV0
IP3D
SV1
IP3D+SV1
JetFitter
IP3D+JetFitter
$t\bar{t}$ simulation, $\sqrt{s}$=7 TeV
p_T^{jet}>20 GeV, $|\eta^{jet}|$<2.5