European Physical Society

HEP 2011

Electroweak Brief Overview and Higgs Searches at LHC

Closing in on the Search for the Higgs Boson

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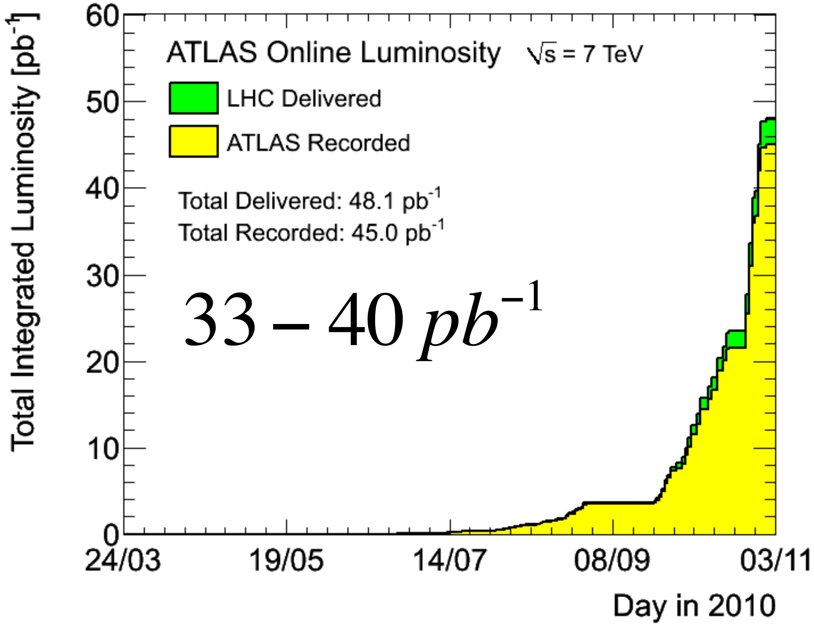
Two Years of Remarkable LHC operations

Glimpse at the Luminosity

2010

Re-discovery of the SM at LHC

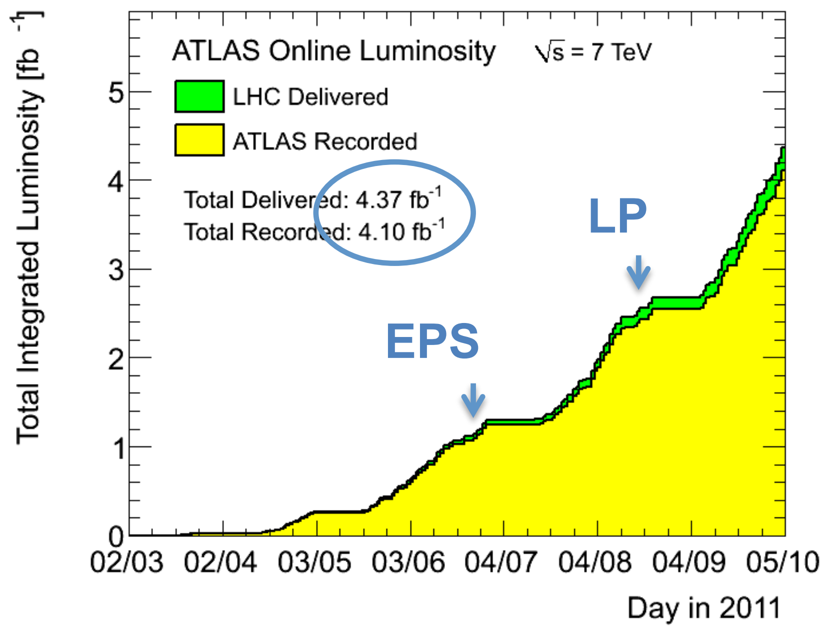


$$33 - 40\ pb^{-1}$$

Measurement of rather detailed properties of the W and Z boson production

2011 $\sim 4\ fb^{-1}$

Closing in on the Higgs search



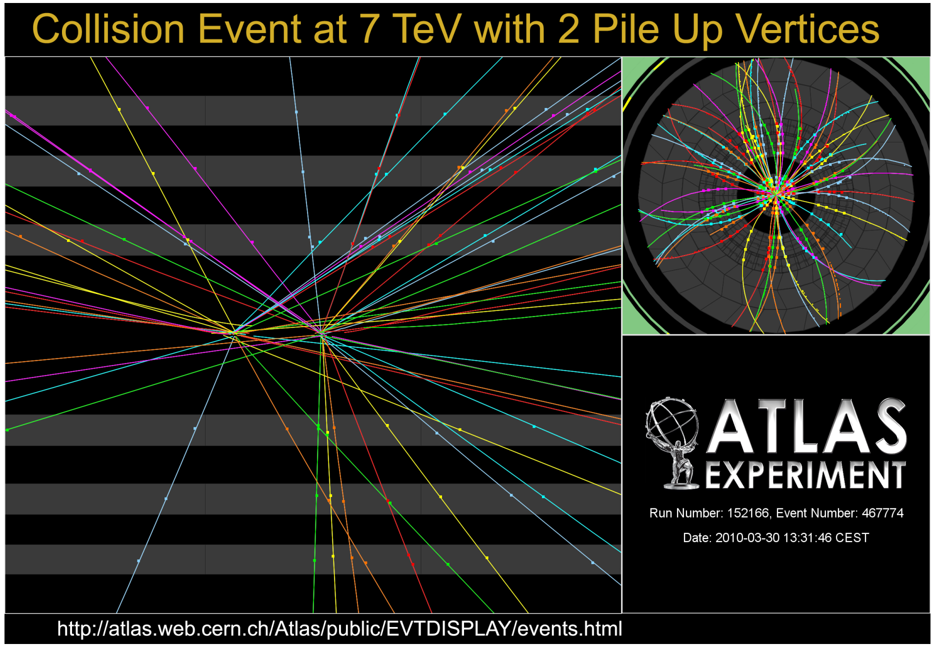
$1.0 - 1.2\ fb^{-1}$ $2.2\ fb^{-1}$

Measurement of di-boson production and Higgs searches

Two Years of Remarkable LHC operations

The Pile-up (PU) evolution

2010	*2011*
O(2) Pile-up events (per bunch crossing)	O(6) Pile-up events (per bunch crossing)
150 ns inter-bunch spacing	50 ns inter-bunch spacing



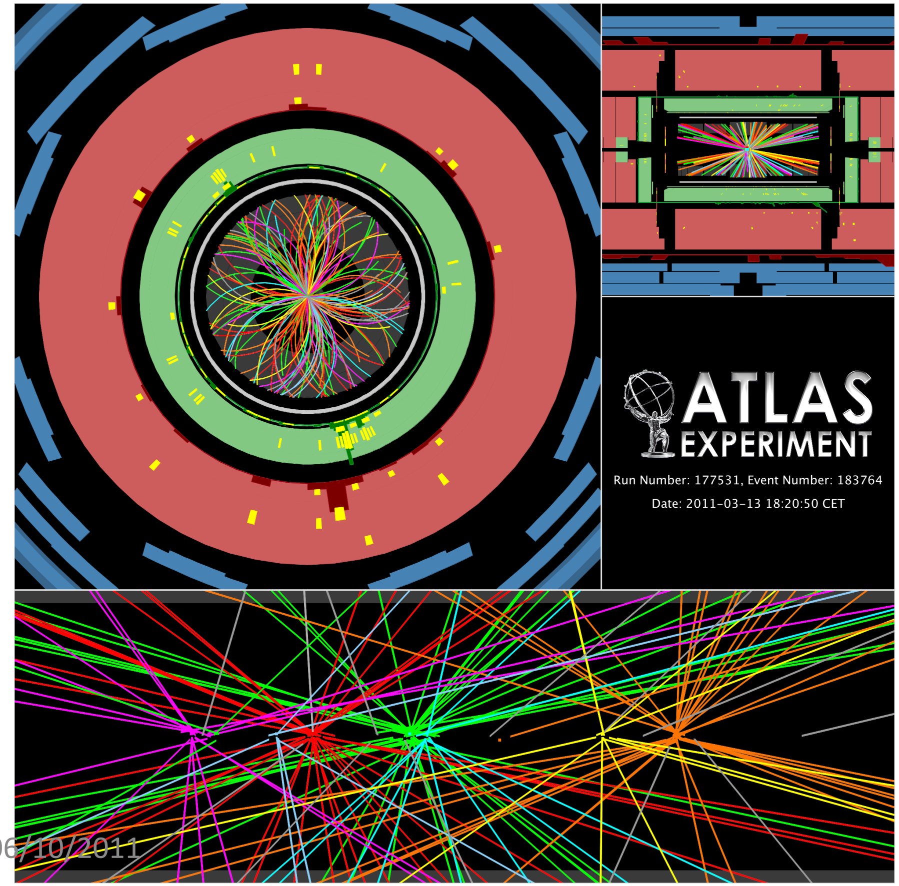


Illustration of events taken at random (filled) bunch crossings

Two Years of Remarkable LHC operations

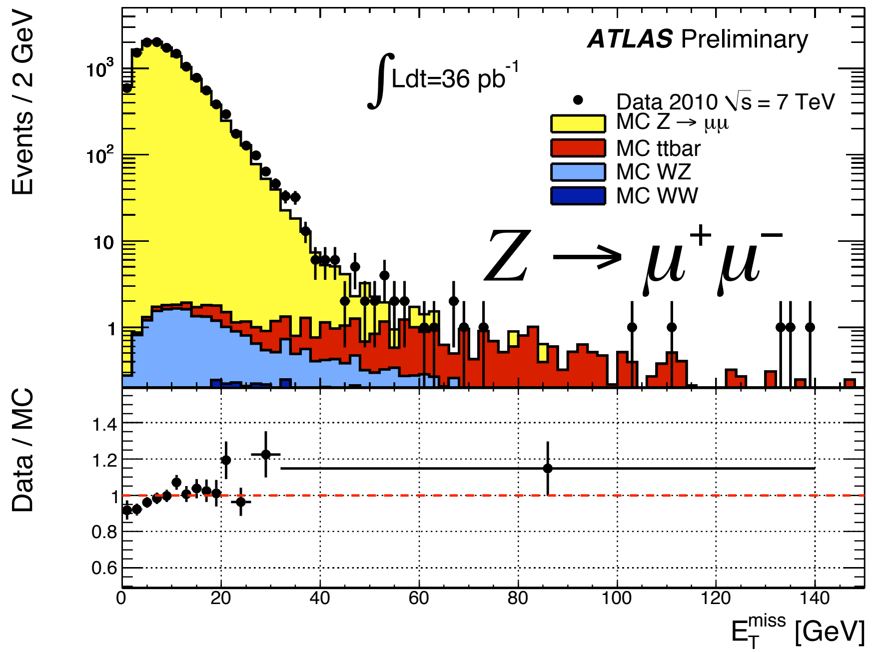
The Pile-up (PU) evolution

2010

O(2) Pile-up events (per bunch crossing)

150 ns inter-bunch spacing

Very small effect of Out-of-Time PU



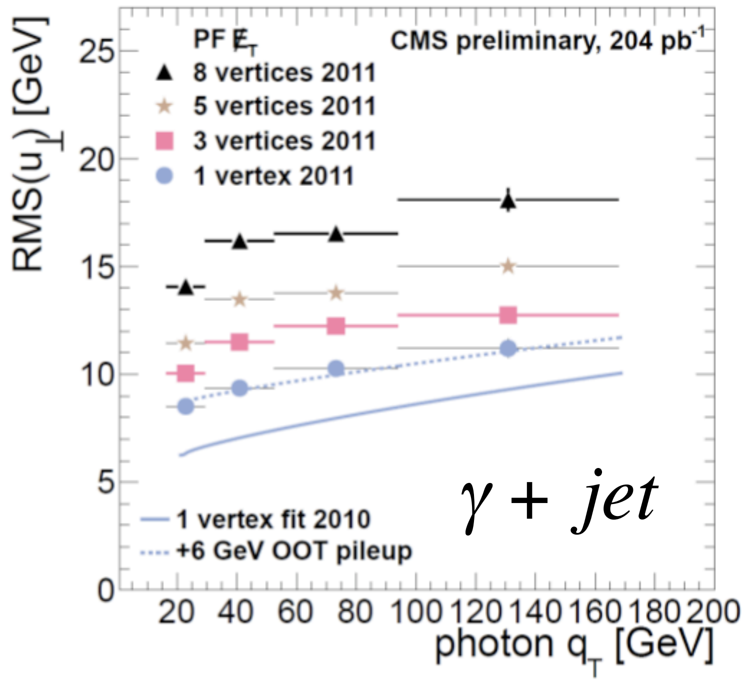
Very nice description from MC (ATLAS and CMS)

2011

O(6) Pile-up events (per bunch crossing)

50 ns inter-bunch spacing

Important Out-of-Time PU



Far more difficult, relies also on the bunch position in the train…

The Higgs Hunt in the LHC Era…

2010

2011

Preamble : Breakthroughs in Phenomenolgy

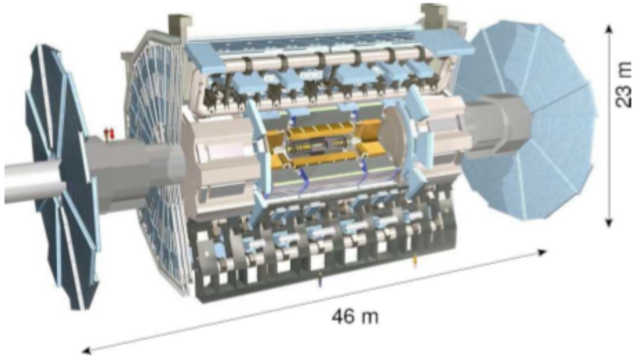
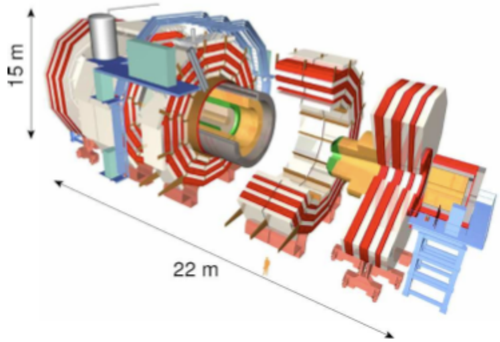
Several breakthroughs in the past decade have drastically changed the theory prospective to the hadron collider processes.

- The "Next-to…" revolution :
  - Breakthrough ideas in computation of loops (sewing together tree level amplitudes).
  - NLO generators, blackhat, NLOjet++, Phox, MCFM, etc…
  - NLO generators w/ PS, MC@NLO and POWHEG.
  - NLO+NLL or NNLL, CAESAR, ResBos, HqT
  - NNLO, FEHIP, FEWZ, HNNLO, DYNNLO
  - …
- NNLO PDFs sets
- Parton Shower (and Matrix Element matching) improvements :

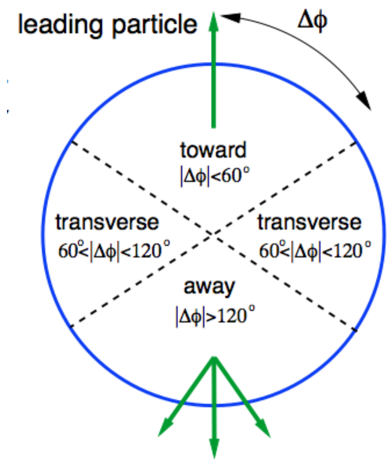
  Pythia (8.1), Herwig++, Sherpa and CKKW (1.3) and MadGraph (5.0) performing very well (Including description of the Pile Up and the underlying event).

- The Jet revolution (Fast Jet) : Allowing to compute in reasonable time infra-red safe k_T jets.

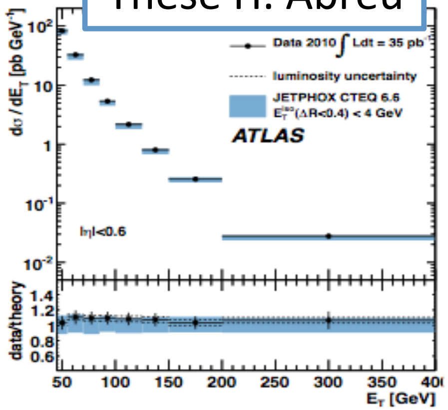
The ATLAS and CMS Detectors In a Nutshell

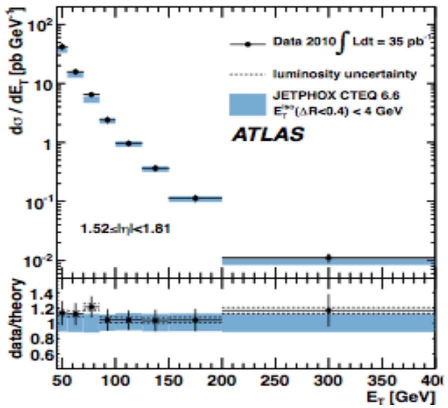
Sub System	ATLAS	CMS
Design		
Magnet(s)	Solenoid (within EM Calo) 2T 3 Air-core Toroids	Solenoid 3.8T Calorimeters Inside
Inner Tracking	Pixels, Si-strips, TRT PID w/ TRT and dE/dx $\sigma_{p_T}/p_T \sim 5\times 10^{-4} p_T \oplus 0.01$	Pixels and Si-strips PID w/ dE/dx $\sigma_{p_T}/p_T \sim 1.5\times 10^{-4} p_T \oplus 0.005$
EM Calorimeter	Lead-Larg Sampling w/ longitudinal segmentation $\sigma_E/E \sim 10\%/\sqrt{E} \oplus 0.007$	Lead-Tungstate Crys. Homogeneous w/o longitudinal segmentation $\sigma_E/E \sim 3\%/\sqrt{E} \oplus 0.5\%$
Hadronic Calorimeter	Fe-Scint. & Cu-Larg (fwd) $\gtrsim 11\lambda_0$ $\sigma_E/E \sim 50\%/\sqrt{E} \oplus 0.03$	Brass-scint. $\gtrsim 7\lambda_0$ Tail Catcher $\sigma_E/E \sim 100\%/\sqrt{E} \oplus 0.05$
Muon Spectrometer System Acc. ATLAS 2.7 & CMS 2.4	Instrumented Air Core (std. alone) $\sigma_{p_T}/p_T \sim 4\,\%$ (at 50 GeV) $\sim 11\,\%$ (at 1 TeV)	Instrumented Iron return yoke $\sigma_{p_T}/p_T \sim 1\%$ (at 50 GeV) $\sim 10\%$ (at 1 TeV)

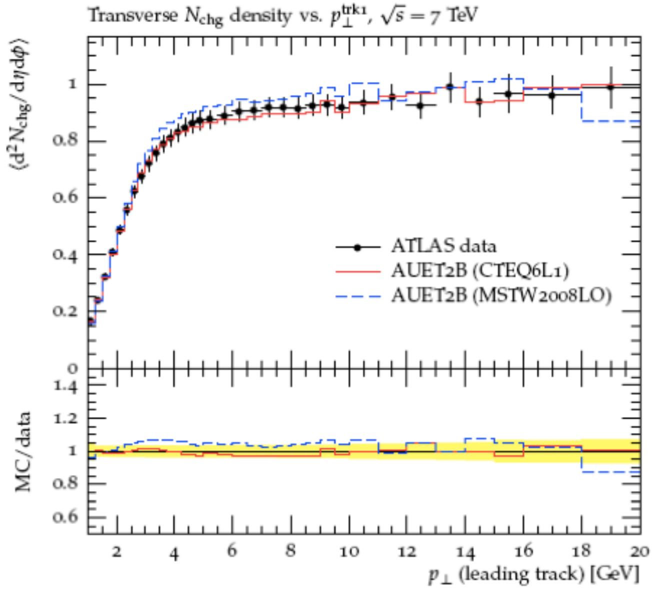
QCD



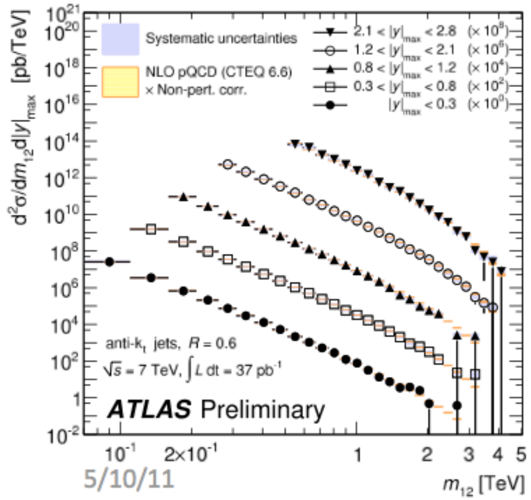
These H. Abreu

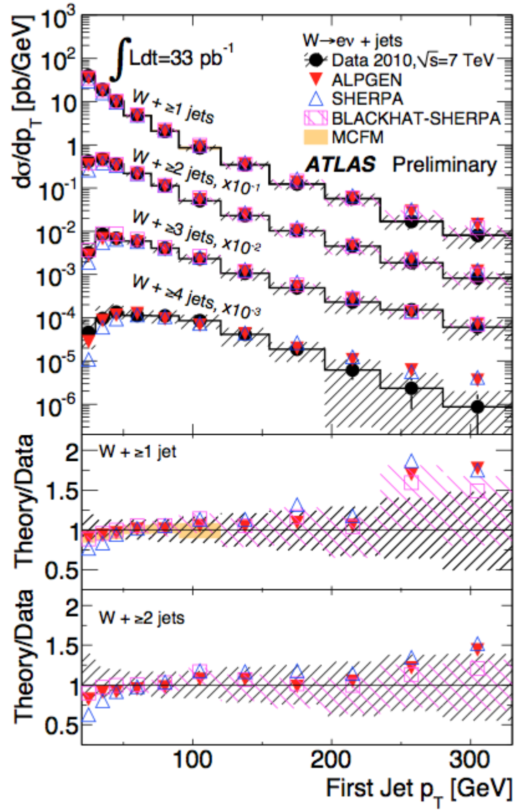


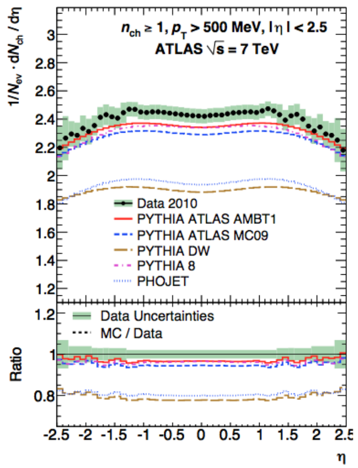


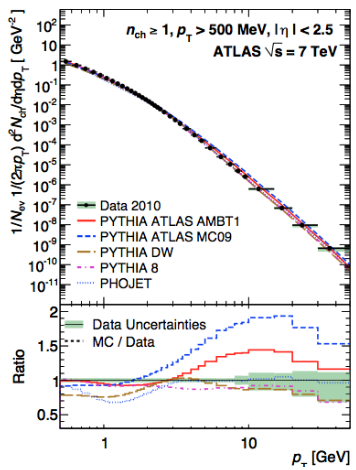


10^2 10^3 p_T [GeV]

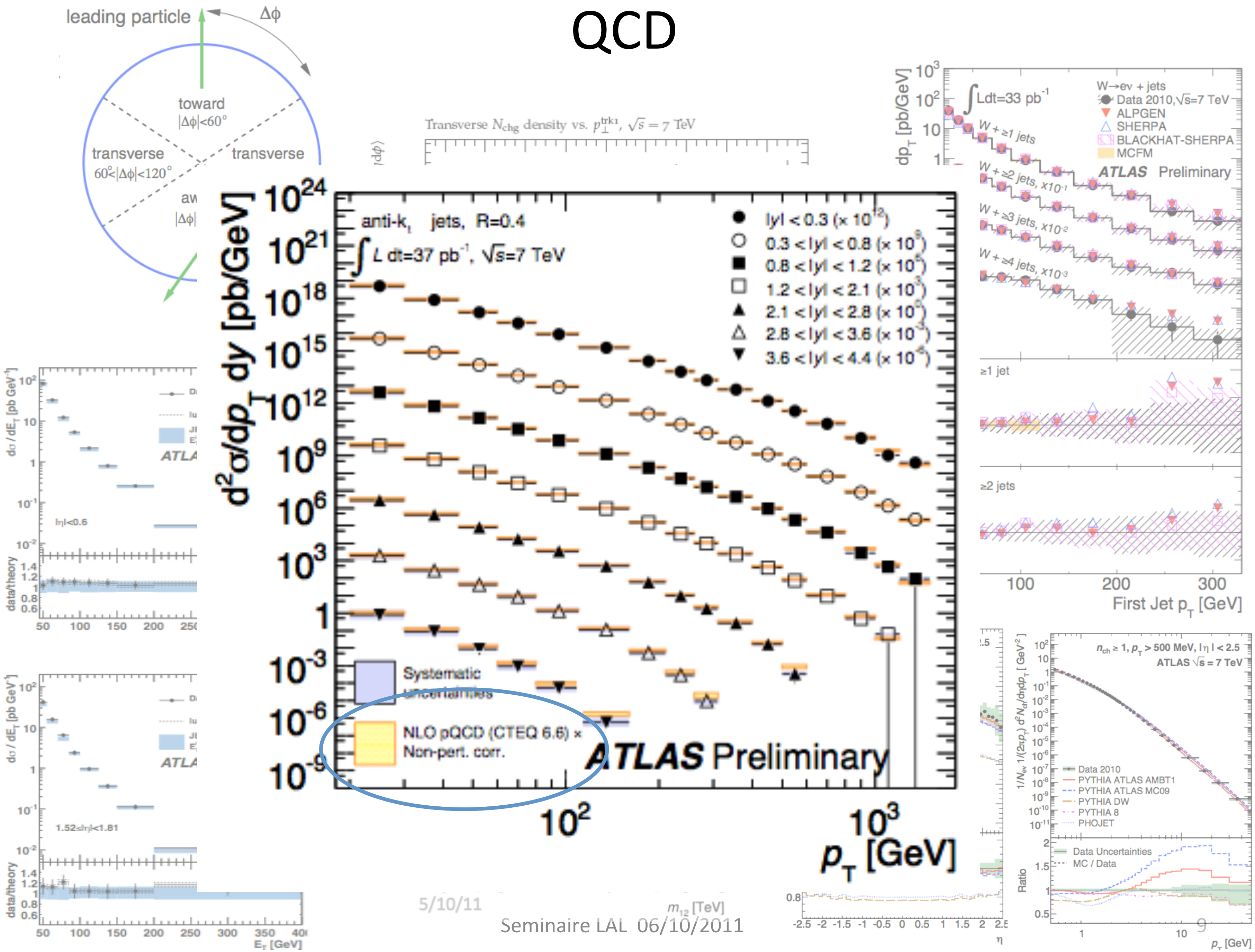








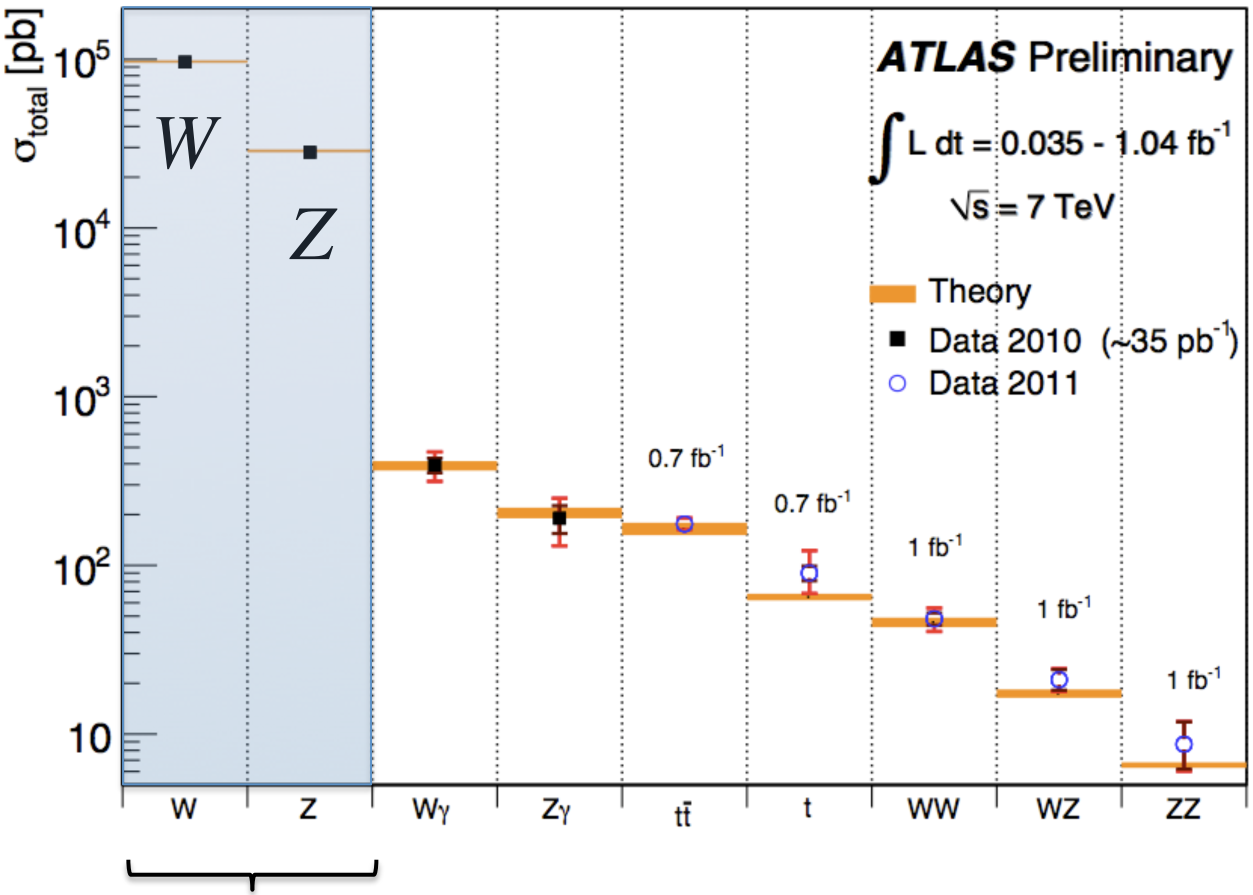
QCD



leading particle
Δϕ
toward
|Δϕ|<60°
transverse
60°<|Δϕ|<120°
transverse
anti-k_t jets, R=0.4
∫L dt=37 pb^-1, √s=7 TeV
|y| < 0.3 (× 10^12)
0.3 < |y| < 0.8 (× 10^9)
0.8 < |y| < 1.2 (× 10^6)
1.2 < |y| < 2.1 (× 10^3)
2.1 < |y| < 2.8 (× 10^0)
2.8 < |y| < 3.6 (× 10^-3)
3.6 < |y| < 4.4 (× 10^-6)
Systematic uncertainties
NLO pQCD (CTEQ 6.6) × Non-pert. corr.
ATLAS Preliminary
d²σ/dp_T dy [pb/GeV]
p_T [GeV]
W→eν + jets
Data 2010, √s=7 TeV
ALPGEN
SHERPA
BLACKHAT-SHERPA
MCFM
∫Ldt=33 pb^-1
ATLAS Preliminary
First Jet p_T [GeV]
n_ch ≥ 1, p_T > 500 MeV, |η| < 2.5
ATLAS √s = 7 TeV
Data 2010
PYTHIA ATLAS AMBT1
PYTHIA ATLAS MC09
PYTHIA DW
PYTHIA 8
PHOJET
Data Uncertainties
MC / Data

W and Z production Properties

Mostly with 2010 data (sufficient)

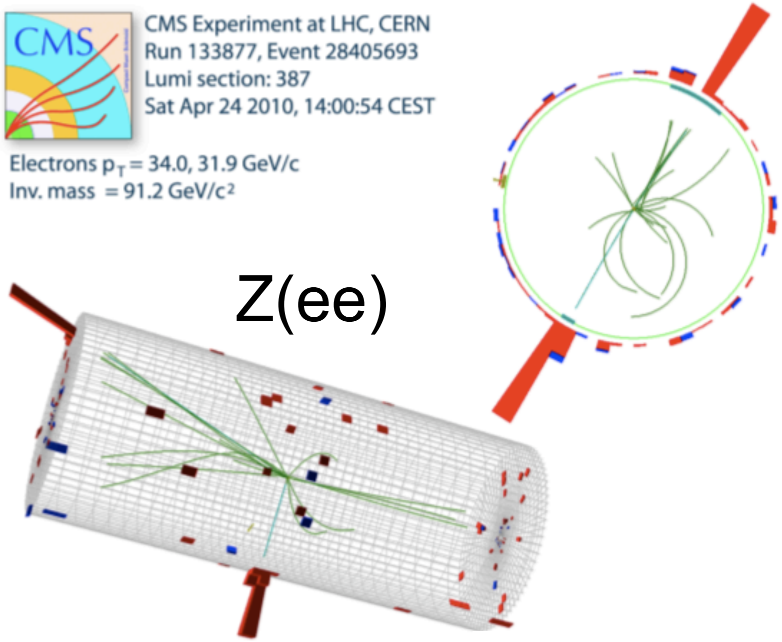


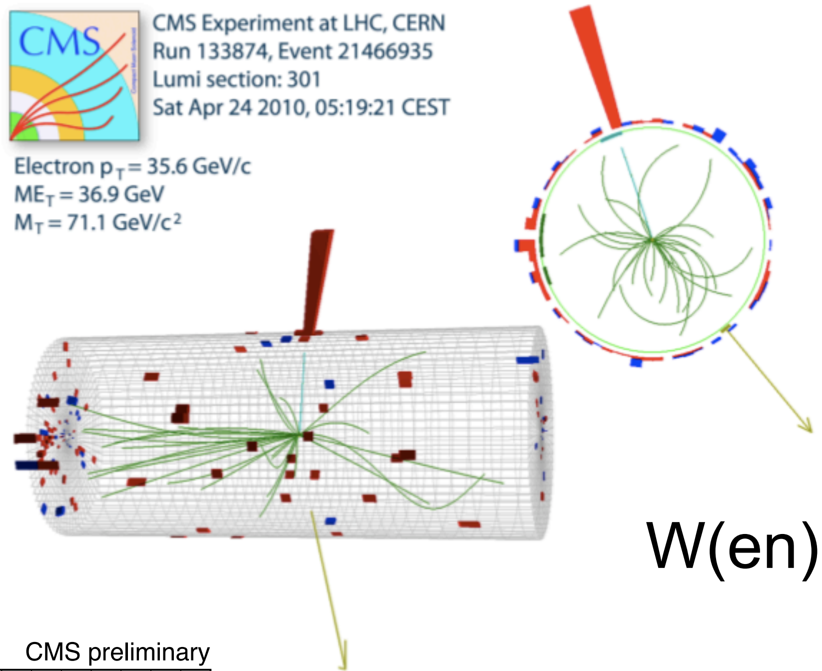
Theory at (N)NLO

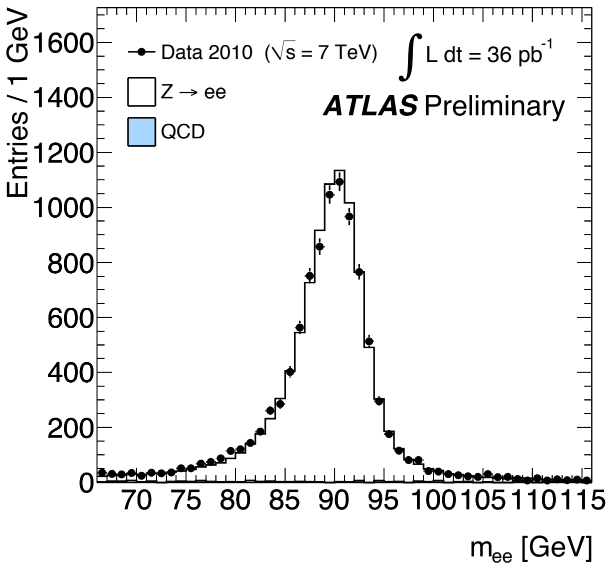
Measurement of detailed properties of the W and Z boson production

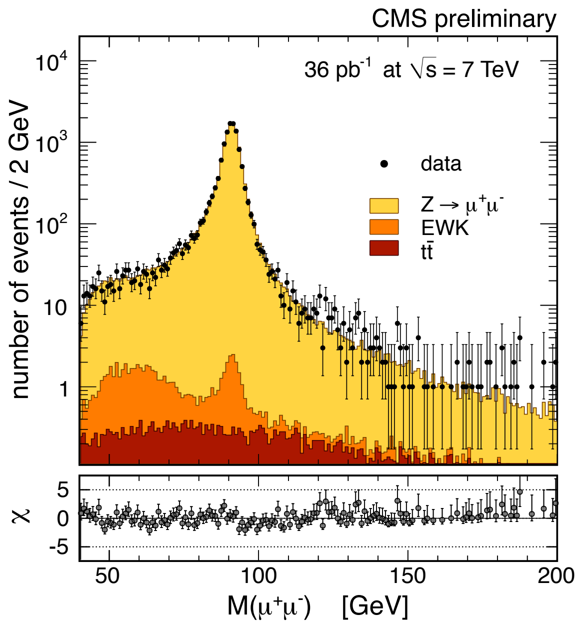
Properties of the W and Z Production

Simple and Clean Event Selection









Z selection:

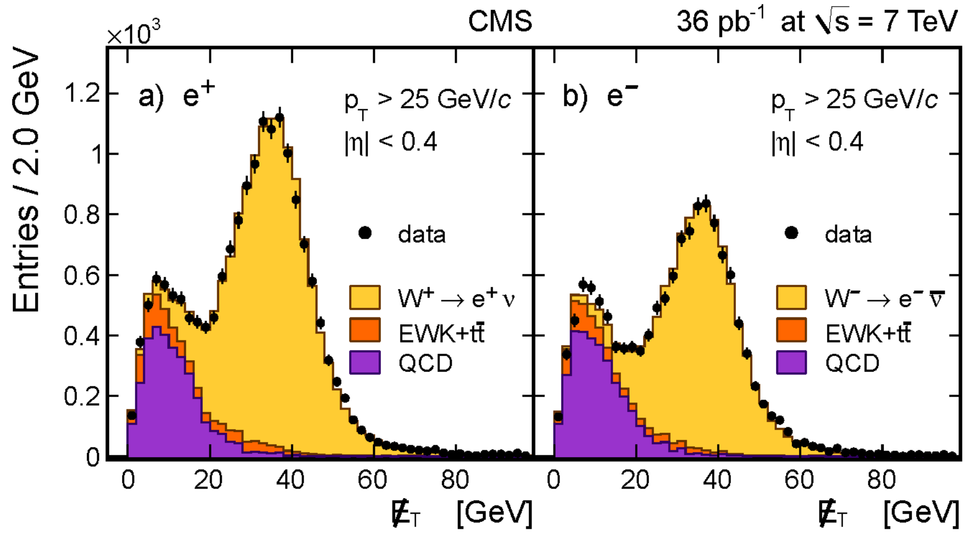
- 2 OS Isolated leptons
- (pT>20-25 GeV)

ATLAS ~200 kZ (ee) / fb^{-1}

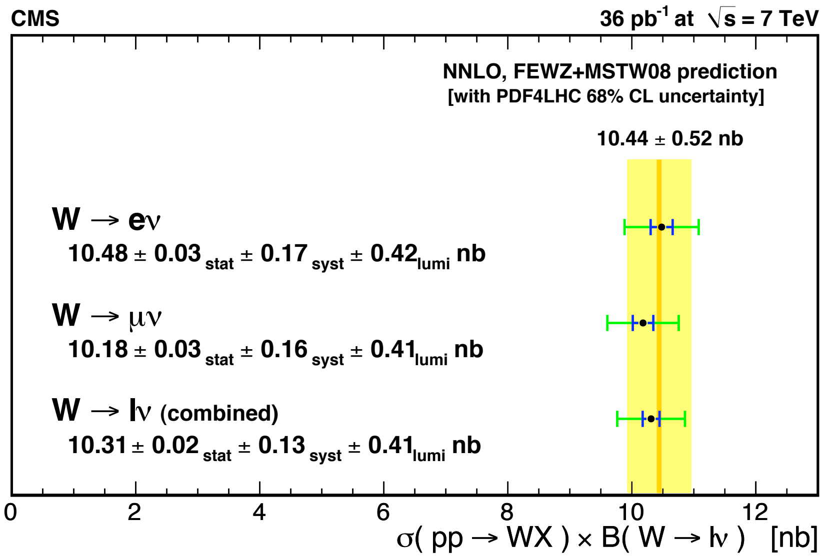
- W selection:
  - p_T lepton (pT>20-25 GeV)
  - Loose cut on met

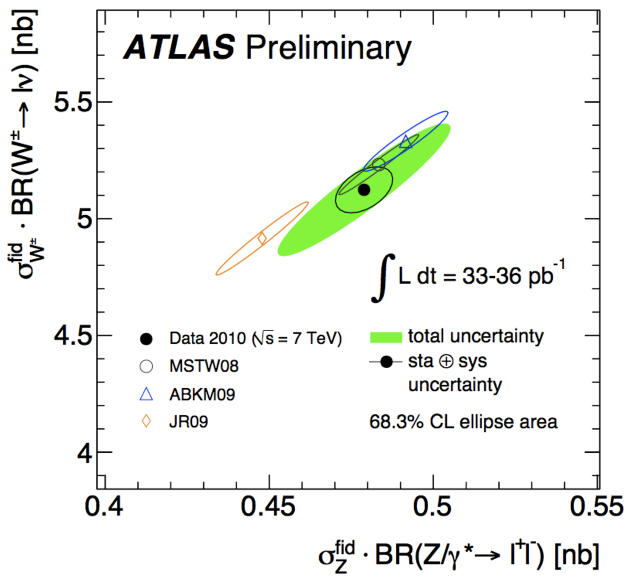
  (or not cut at all CMS)

ATLAS ~ 4MW (ee) / fb^{-1}



- Cross section measurements and W/Z Ratios



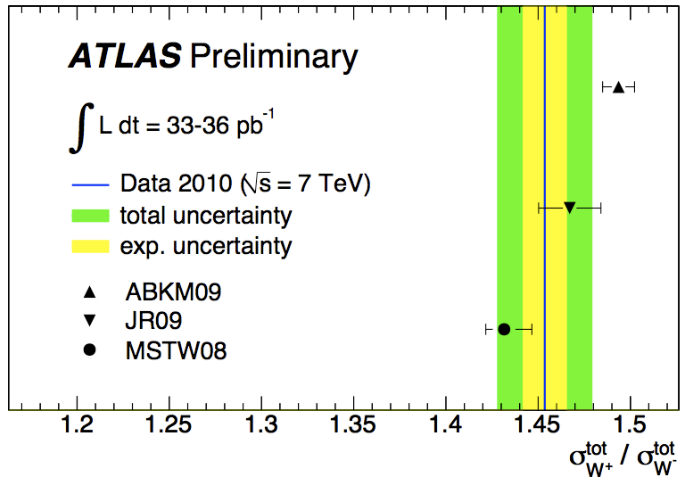


- Measurements in excellent agreement with the NNLO prediction (FEWZ)

W Charge Asymetry

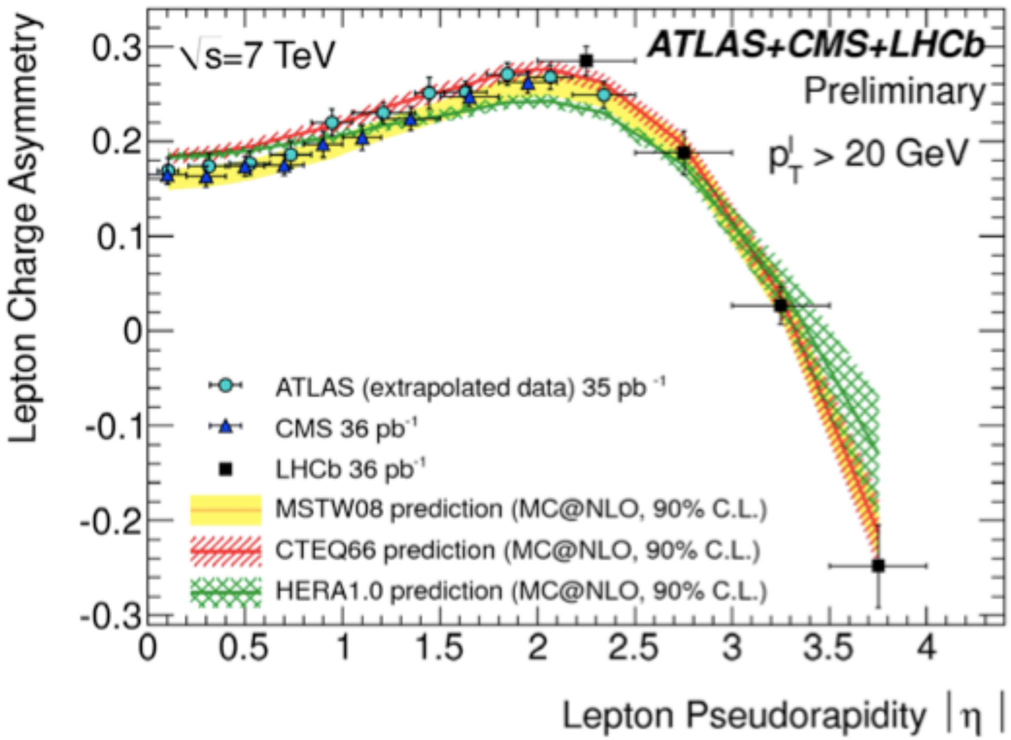
- W charge asymmetry (x1.4 more +) :

$$A_\ell = \frac{\frac{\partial\sigma}{\partial\eta}(\ell^+) - \frac{\partial\sigma}{\partial\eta}(\ell^-)}{\frac{\partial\sigma}{\partial\eta}(\ell^+) + \frac{\partial\sigma}{\partial\eta}(\ell^-)}$$



- Combining ATLAS, CMS and LHCb
… constraining PDFs…

These J.-B. Blanchard



W Charge Asymetry

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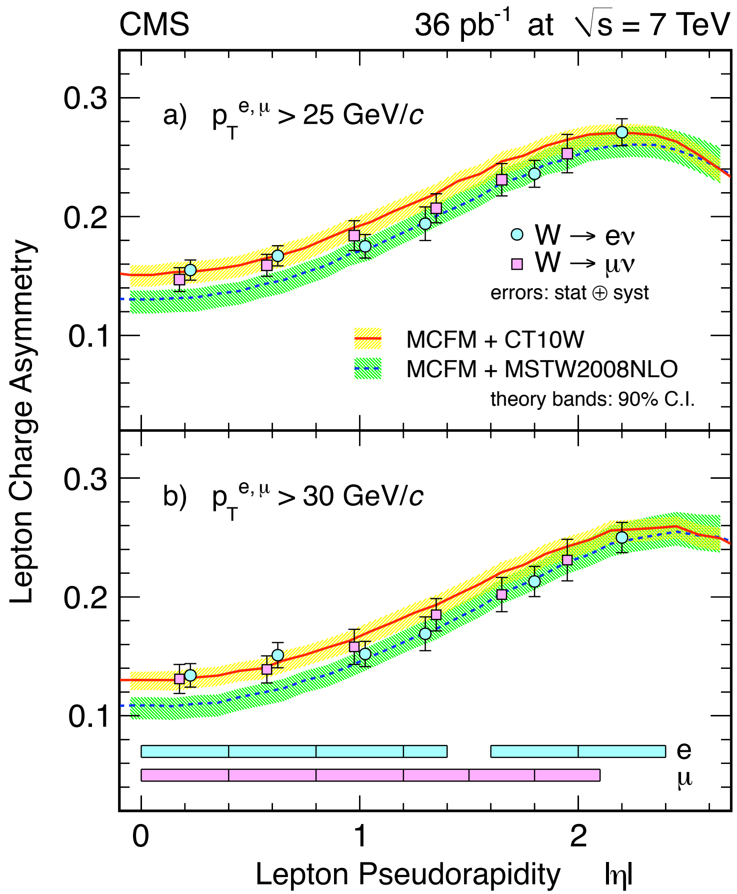
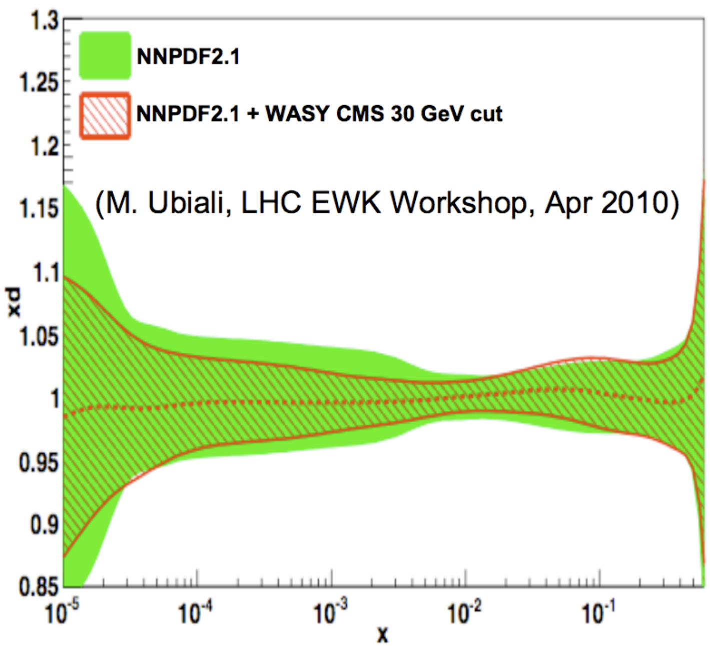
$$A_\ell = \frac{\frac{\partial\sigma}{\partial\eta}(\ell^+) - \frac{\partial\sigma}{\partial\eta}(\ell^-)}{\frac{\partial\sigma}{\partial\eta}(\ell^+) + \frac{\partial\sigma}{\partial\eta}(\ell^-)}$$

- Constraining PDFs… Already constraining u, d, qbar by almost 40%

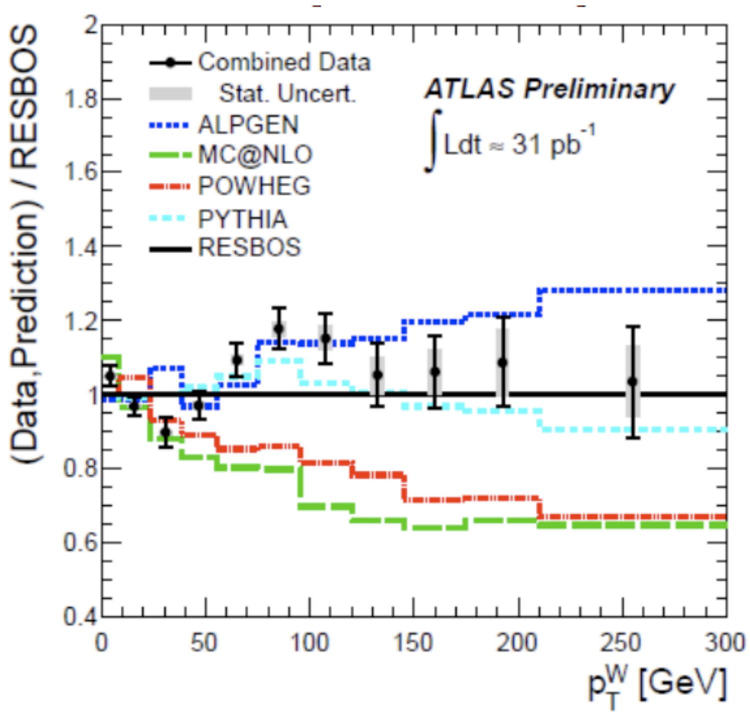


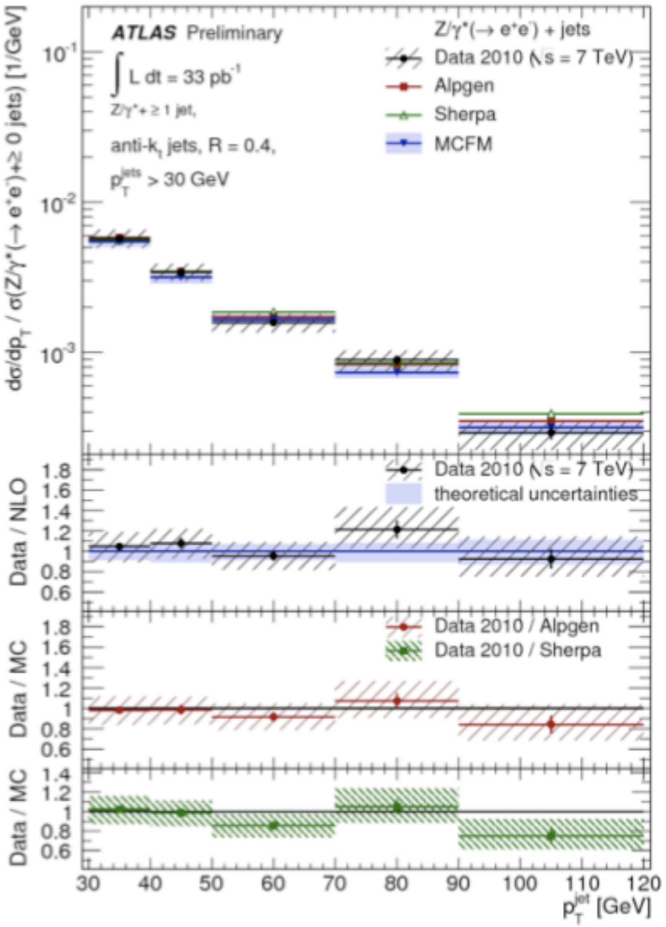


(From the NNPDF group)

-W p_T measurements probe the ME-PS matching, the NLO calculations and the rsummation :

Pythia seems to be in better agreement than ResBos in the W p_T

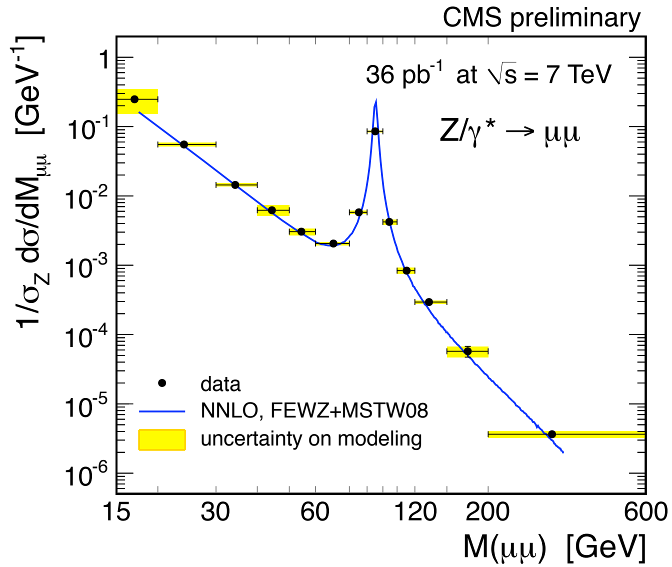




- W and Z+jets in remarkable agreement with ME-PS

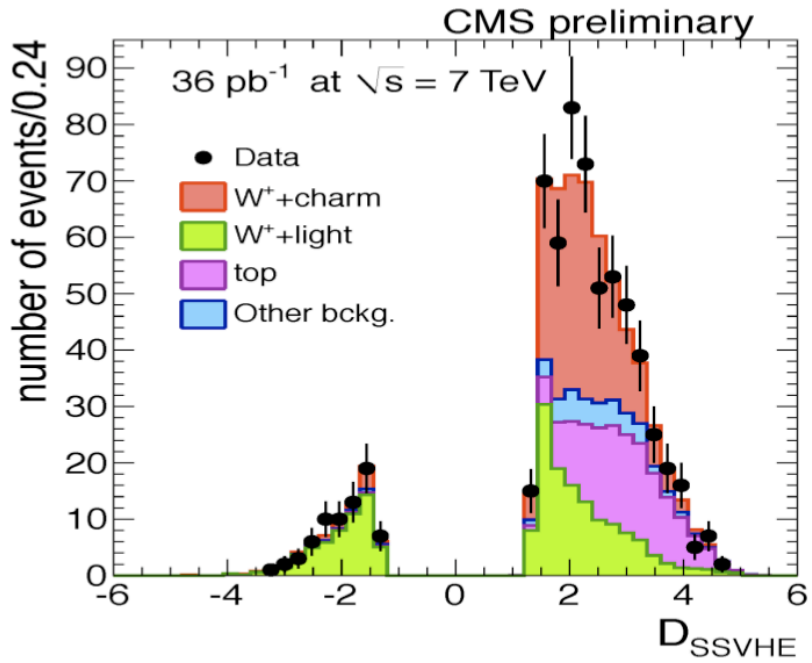
- … and Drell Yan!

Very impressive results in such a small amount of time

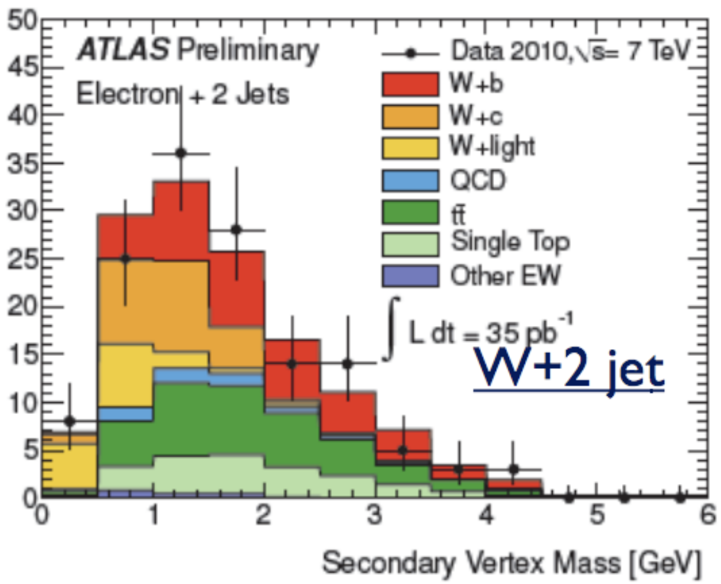


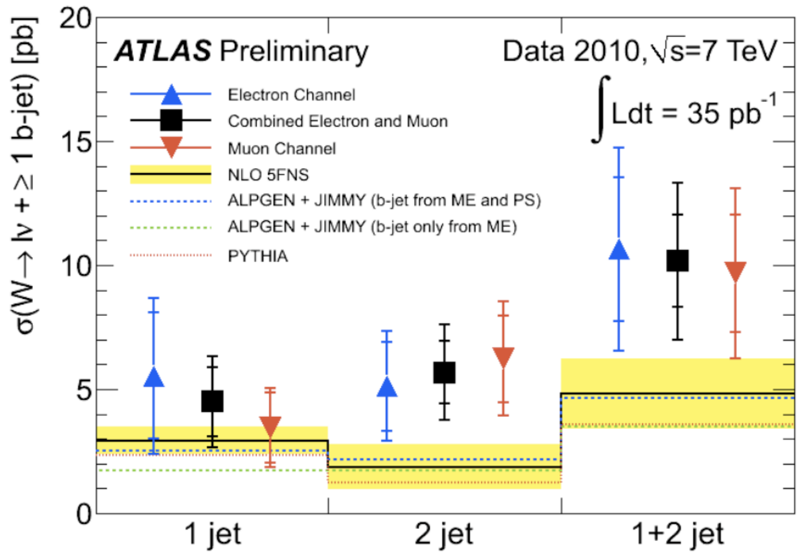
W and Heavy Flavors

- W+Heavy flavor is dominated by Charm
- Makes it a probe of strange content!
- Need vertex mass to disentangle the W+b



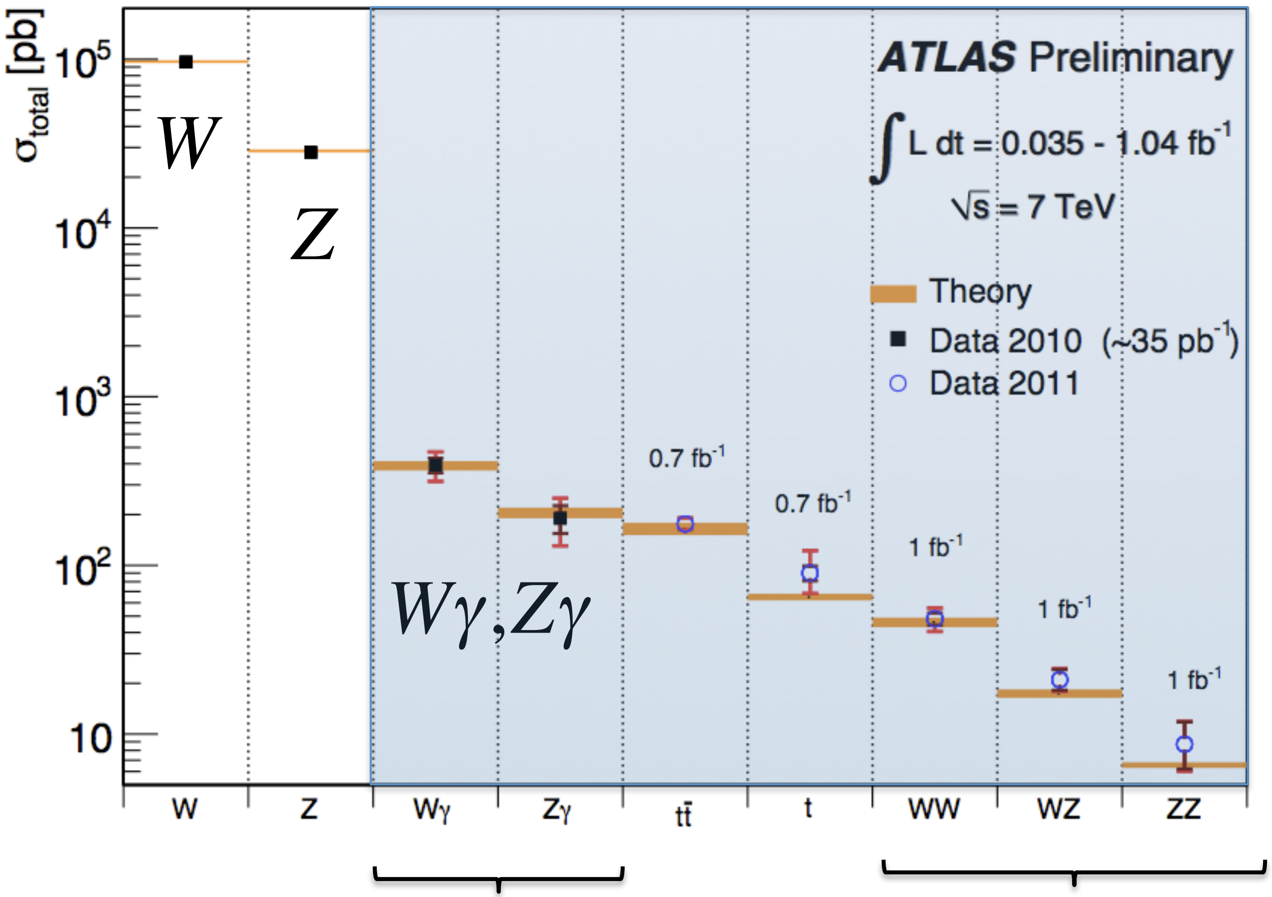
These are very important control samples for the W,Z H to bb analyses!





Diboson Studies

The ATLAS Summary



Theory at NLO

Measurement of di-boson production

Measurement of DiBoson Production

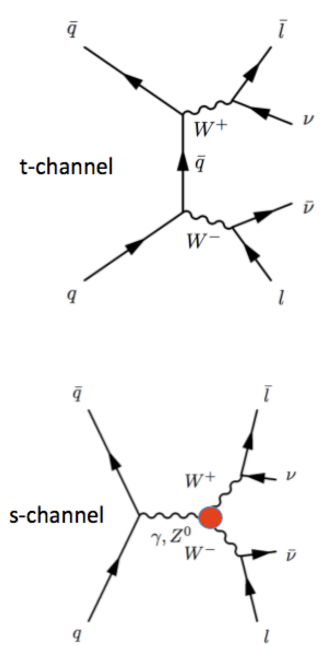
-Challenging analyses, extremely important in understanding the backgrounds to the search for the Higgs in diboson channels.

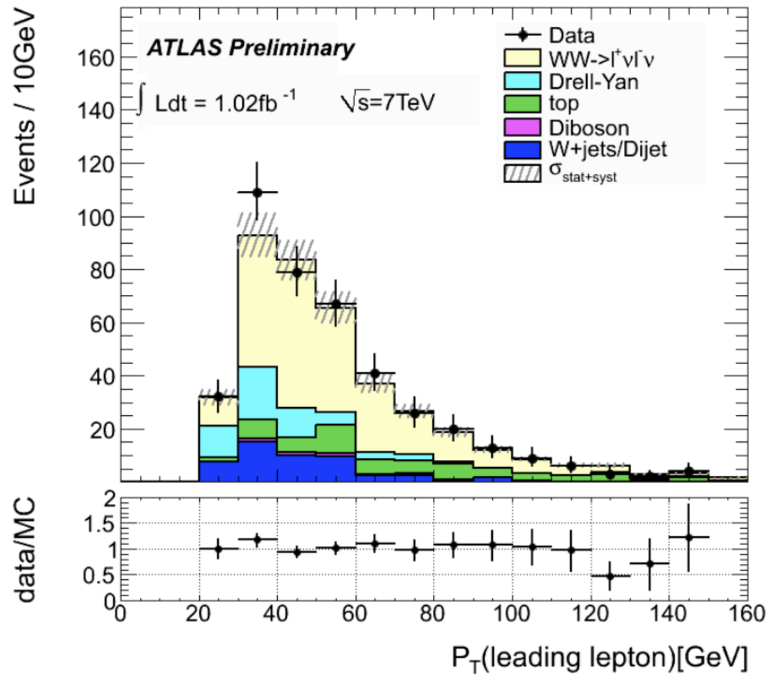
- Starting to gather a conspicuous amount of diboson events…

-Important to study anomalous Triple Gauge boson Couplings (TGCs)

-WW (lnln) Channels :

Cut	ATLAS	CMS
Lead. l p_T (GeV)	25	20
Trail. l p_T (GeV)	20	10
MET	25-45	30
Z – J/ψ Veto	✓	✓
Jet-veto	✓	✓
B-veto		✓

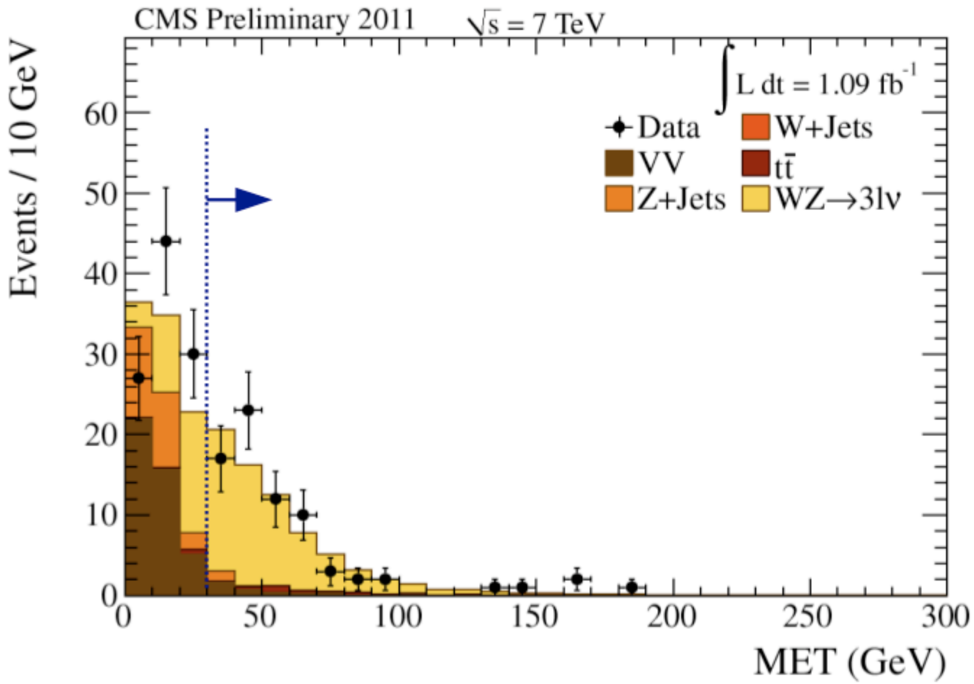




Typically ~400 events
Purity ~60%

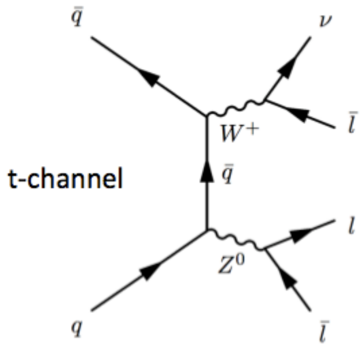
- WZ (3lν) Channels :

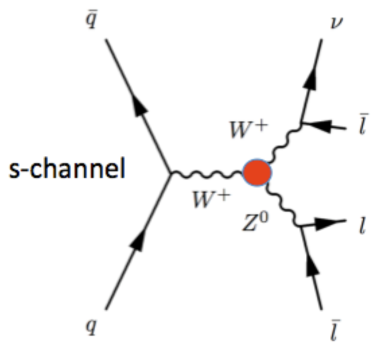
Cut	ATLAS	CMS
Lead. l p_T (GeV)	15	20
Trail. l p_T (GeV)	20	10
MET	25	30
Second Z Veto		✓
W - M_T	✓	



- Good compromise statistics and purity :

Typically ~80 events
Purity ~90%

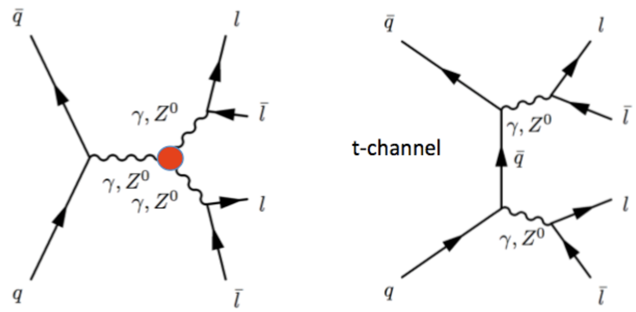




- ZZ(4l) Channels :

- Essentialy background free channel (allows for lower p_T cut on leptons)

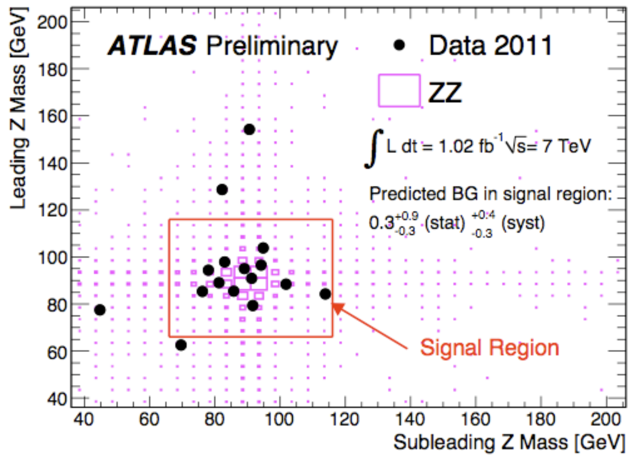
Cut	ATLAS	CMS
Lead. l p_T (GeV)	15 (μ) - 25 (e)	20
Trail. l p_T (GeV)	15 (μ) - 20 (e)	5 (μ) - 7 (e)
Z Window (GeV)	25	30

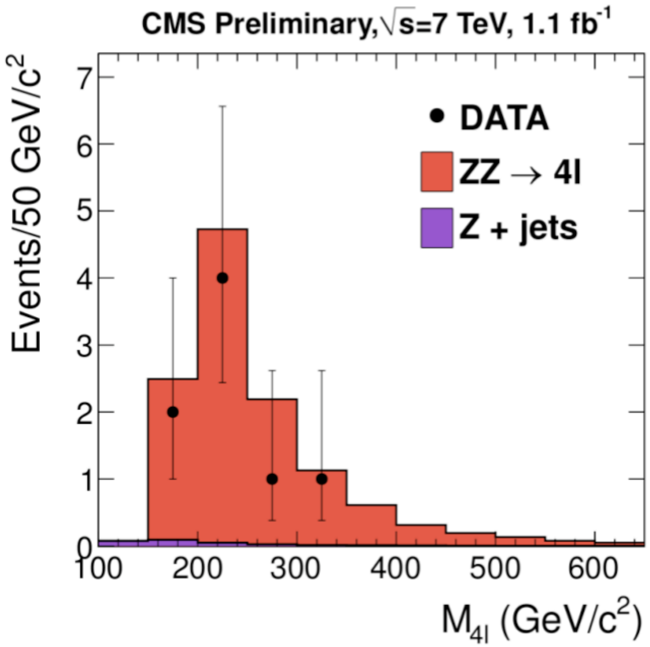


Not existent in SM

Typically ~10 events (bkg negligible)

- In this case both Z are on-mass shell





- CMS : Performed a 2l2τ analysis (1 event observed and 2.2 expected with purity of ~60%)

Results :

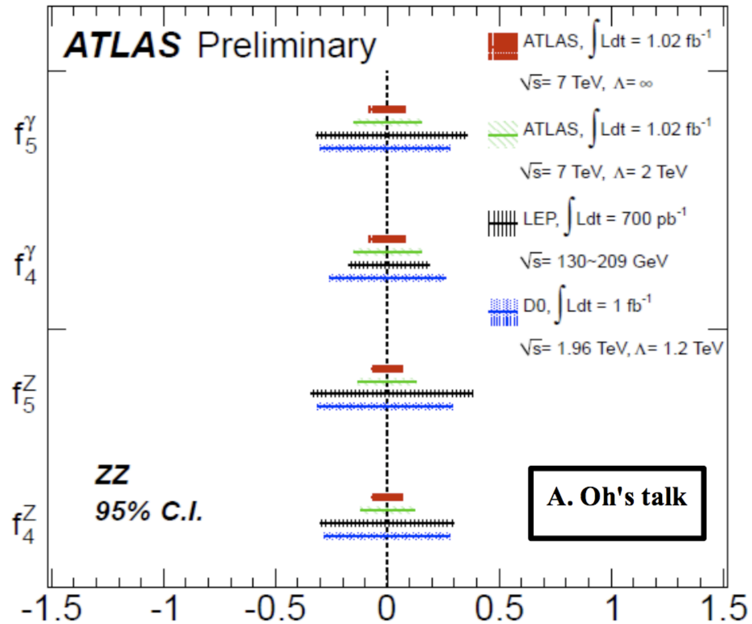
Cross Section (pb)	WW		WZ		ZZ	
	ATLAS	CMS	ATLAS	CMS	ATLAS	CMS
Exp. Total	46	43	17.2	20	6.5	6.4
Measured	48.2	55.3	21.1	17.0	8.4	3.8
Stat. Uncert.	±4	±3.3	±1.2	±2.4	±0.6	±1.5
Syst. Uncert.	±6.4	±6.9	±0.9	±1.0	±0.3	±0.2
Luminosity	±1.8	±3.3	±0.9	±1.0	±0.3	±0.2

- Good agreement between measurements and NLO prediction.

- Interpretation in terms of anomalous TGC's :

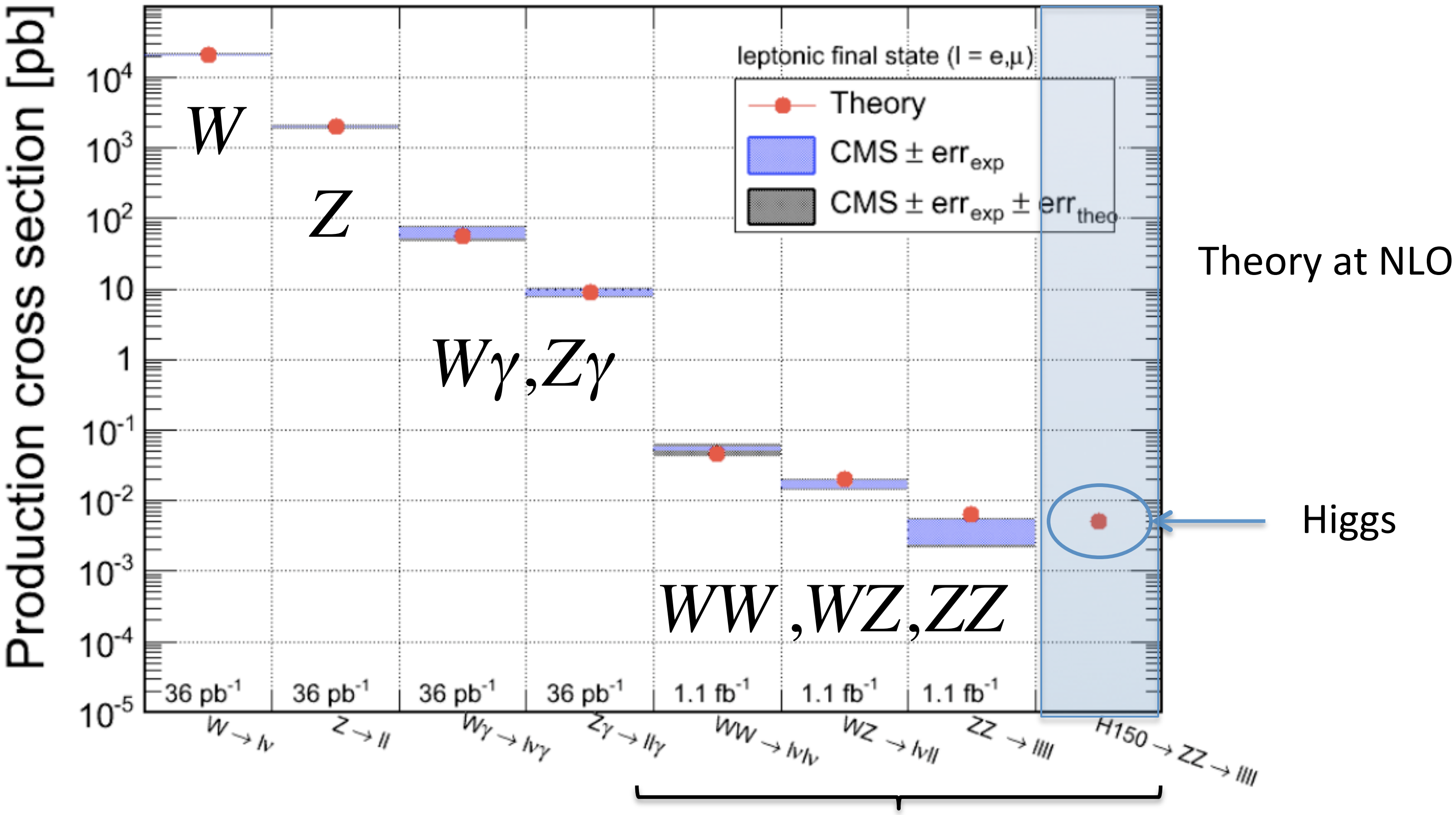
  - Already stringent limits on anomalous TGC

  - Many other diboson results not show here (in particular in final states with photons)



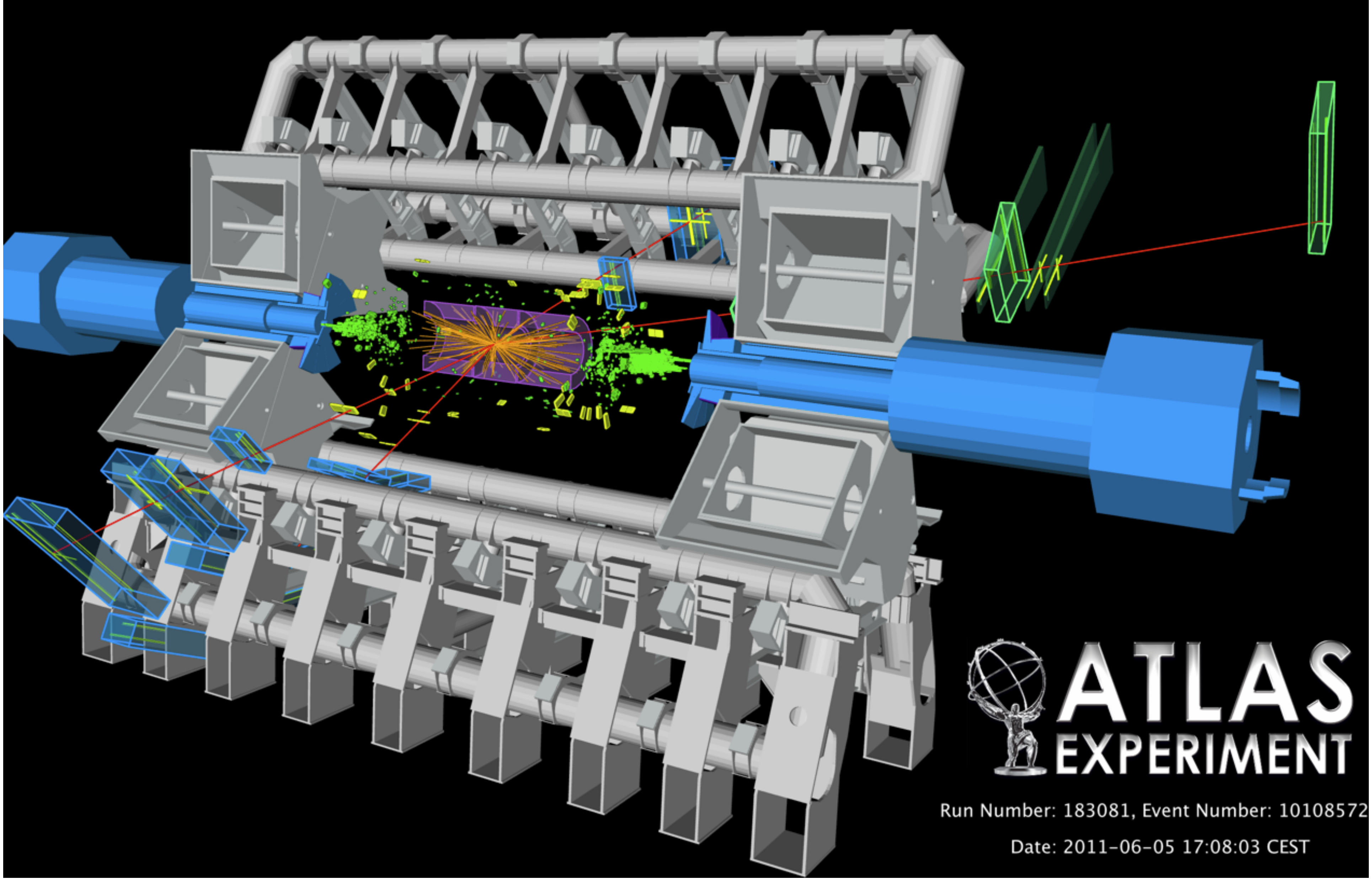
From Standard EW Process to the Higgs Production

The CMS Summary



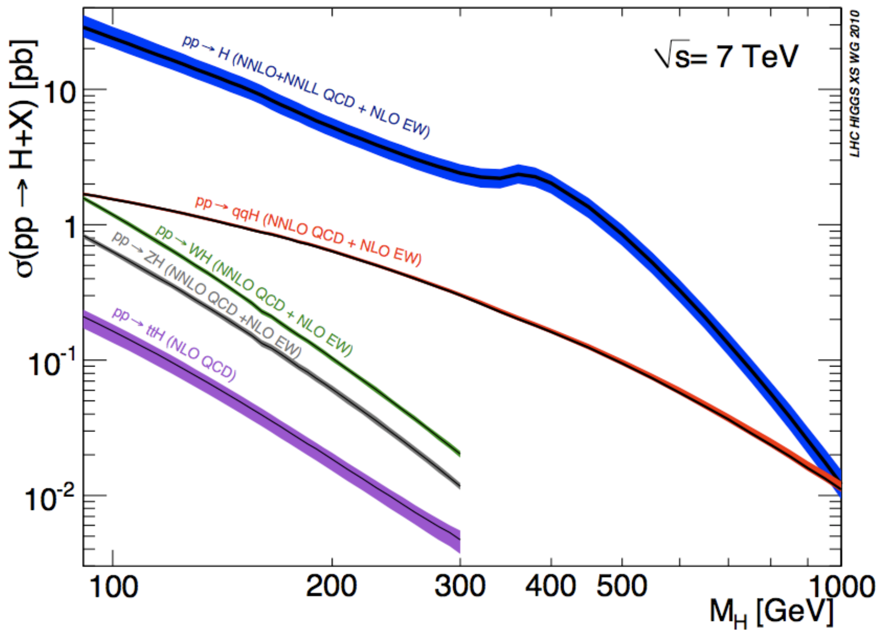
Measurement of di-boson production and Higgs searches

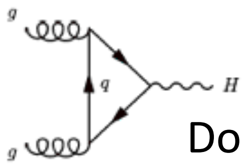
4 μ event … *Standard EW only or Higgs?*



The Main Production Modes

Data driven background estimates legitimate use of NNLO cross sections!





- Gluon fusion process :

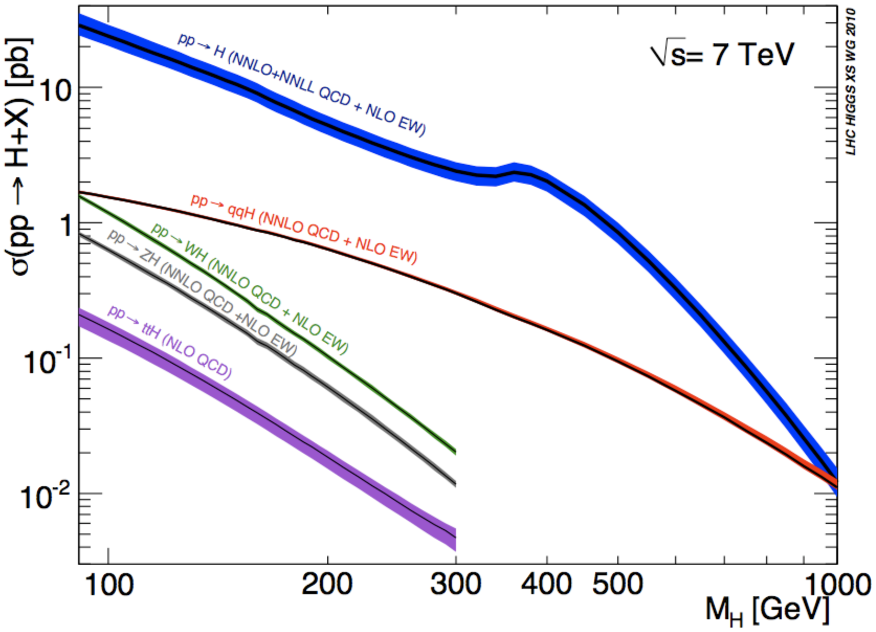
Dominant process known at NNnLO

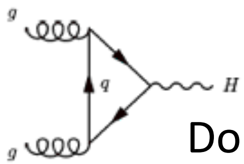
However rather large TH uncertainty* ~O(15%) due to the large corrections for gluon initiated process

* TH uncertainty mostly from scale variation and PDFs, $\delta\sigma_{\text{PDF-}\alpha s}$~8-10% and $\delta\sigma_{\text{Scale}}$~ 7-8%

The Main Production Modes

Data driven background estimates legitimate use of NNLO cross sections!





- Gluon fusion process :

Dominant process known at NNnLO

~100 kEvts produced at 120 GeV

* TH uncertainty mostly from scale variation and PDFs, $\delta\sigma_{\text{PDF-}\alpha s}$~8-10% and $\delta\sigma_{\text{Scale}}$~ 7-8%

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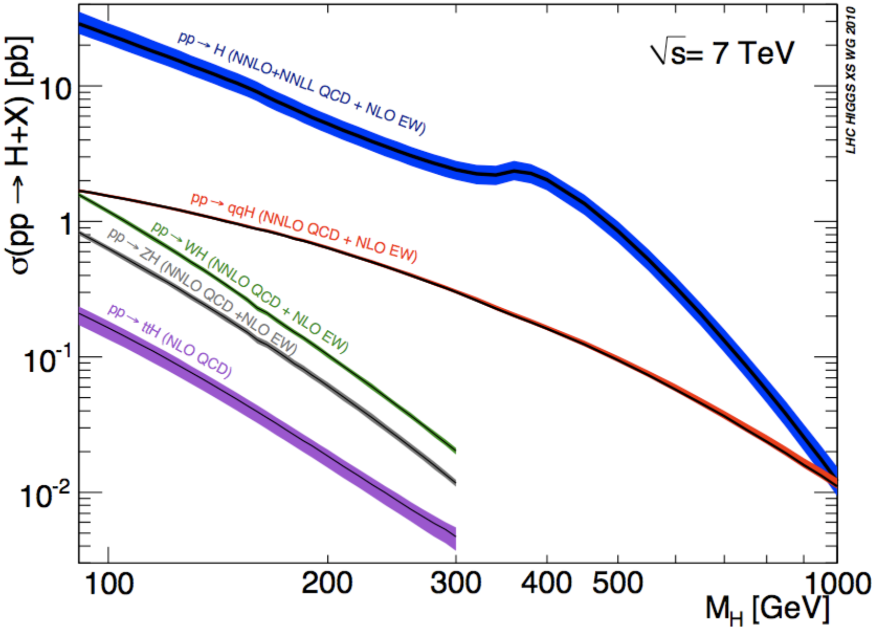

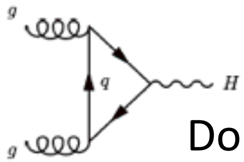

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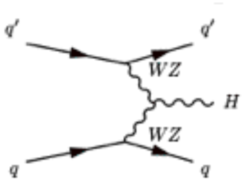

- Vector Boson Fusion :

known at NLO TH uncertainty ~O(5%)

Rather distinctive features w/ two conspicuous forward jets and a rapidity gap

* TH uncertainty mostly from scale variation and PDFs, $\delta\sigma_{PDF\text{-}\alpha s}$~8-10% and $\delta\sigma_{Scale\sim}$ 7-8%

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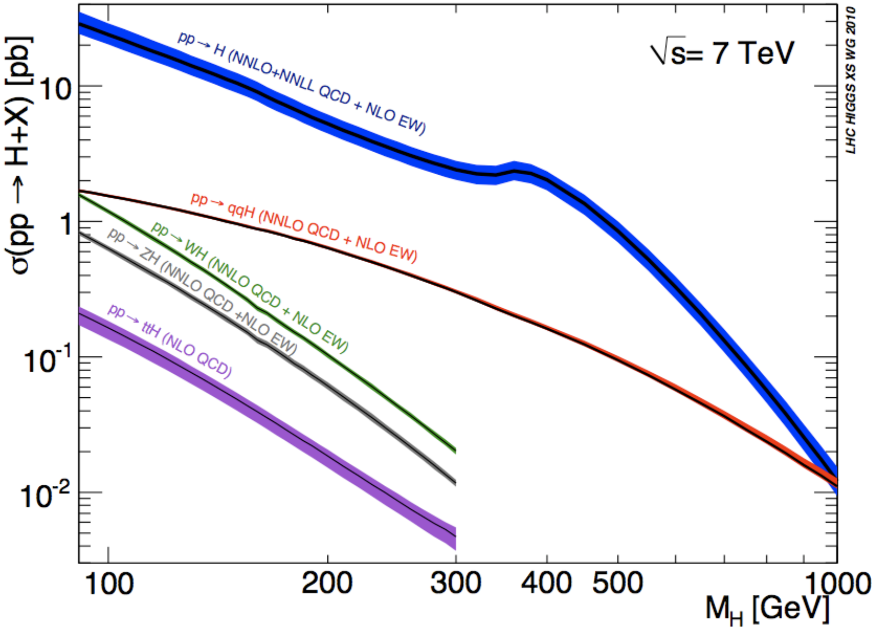

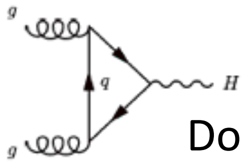

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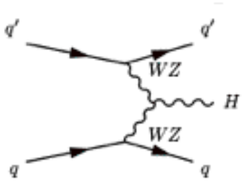

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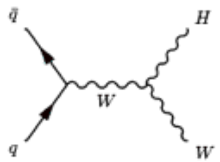
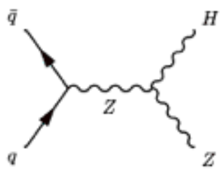
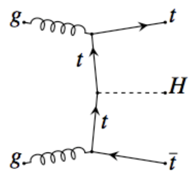




- Associated Production with W and Z :

known at NNLO TH uncertainty ~O(5%)

Very distinctive feature with a Z or W decaying leptonically



- Associated Production with top pair :

known at NLO TH uncertainty ~O(15%)

Quite distinctive but also quite crowded

* TH uncertainty mostly from scale variation and PDFs, $\delta\sigma_{PDF-\alpha s}$~8-10% and $\delta\sigma_{Scale}$~ 7-8%

Decay Modes

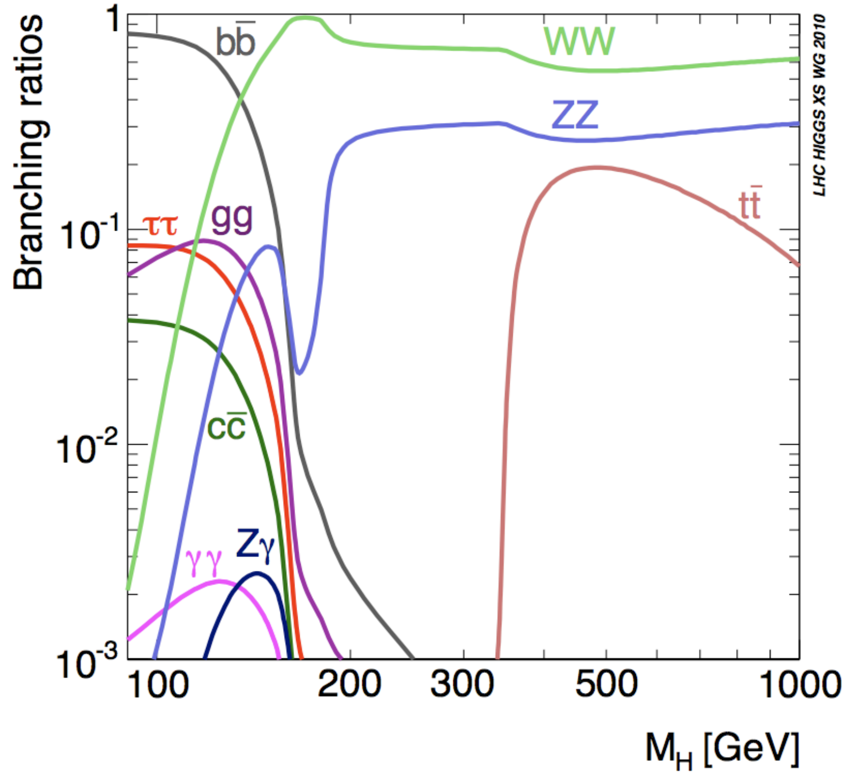
Pure Branching Fractions

- The dominant b-decay channel

Huge backgrounds, needs distinctive features at production level and beyond… Associate production W,Z H and Boost!

- The ττ channel

Also needs distinctive production features, typically VBF. Can also be done inclusively, especially since the NEW MASS RECOSTRUCTION techniques



Decay Modes

Exclusive Modes Cross Sections

- The dominant b-decay channel

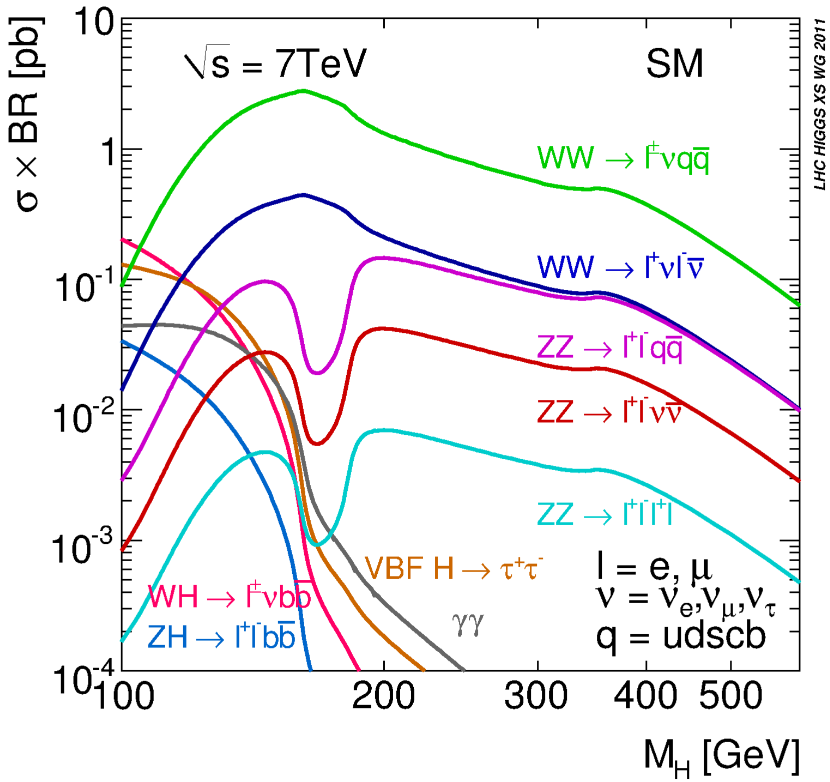
Huge backgrounds, needs distinctive features at production level and beyond… Associate production W,Z H and Boost!

- The ττ channel

Also needs distinctive production features, typically VBF. Can also be done inclusively, especially since the NEW MASS RECOSTRUCTION techniques

- The γγ channel

Dominant Channel in the very low mass range. Small branching but sizable yield. Very distinctive signature on its own.



- The WW Channels

- Dilepton (lnln) channel is dominant in the low mass (very poor mass resolution, essentially counting experiment)
- Semi leptonic (lnqq) largest event yield effective at large mass where the background is smaller.

- The ZZ Channels

- 4-leptons : “Golden mode” smallest event yield but large s/b ratio
- semi-leptonic (llqq) larger event yield but also much larger background (make use of the large branching Z in bb)
- 2-leptons 2-neutrinos (llnn) : Best compromise yield/purity. Dominant channel at high mass

Production Modes and Decay Channels

Channel		ggF	VBF	W,Z H	ttH
$\gamma\gamma$		✓	✓	✓	✓
$\tau\tau$		✓	✓		
W,Z H (bb)				✓	
ZZ (llll)		✓	✓		
WW ($l\nu l\nu$)	0-jet	✓			
	1-jet	✓	✓		
	VBF	✓	✓		
WW ($l\nu qq$)	0-jet	✓	✓		
	1-jet	✓	✓		
ZZ ($ll\nu\nu$)		✓	✓		
ZZ ($ll\tau\tau$)		✓	✓		
ZZ (llqq)		✓	✓		

Low Mass : Challenging Range

110 -150 GeV/c^2

Intermediate : Wide Range

110 - 600 GeV/c^2

High Mass : Larger contribution from VBF

200 - 600 GeV/c^2

Not theory difficulties above 500 GeV/c^2

Take home message : - Mostly ggF analyses

- VBF important at High Mass (caution with the Higgs width)

Analyses Preparation

Common LHC efforts to agree on non consensual issues :

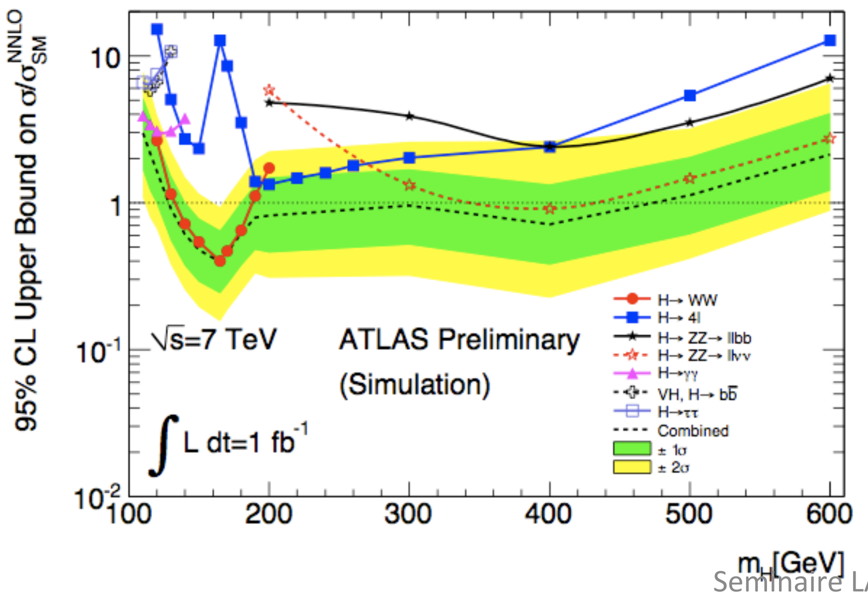
- Common effort LHC-wide to compute cross sections and branching ratios and…
  - Use common standard model input parameters (NNLO signal cross section)
  - Common strategy on correlated systematic uncertainties (scale variation, PDFs, α_S, etc…)

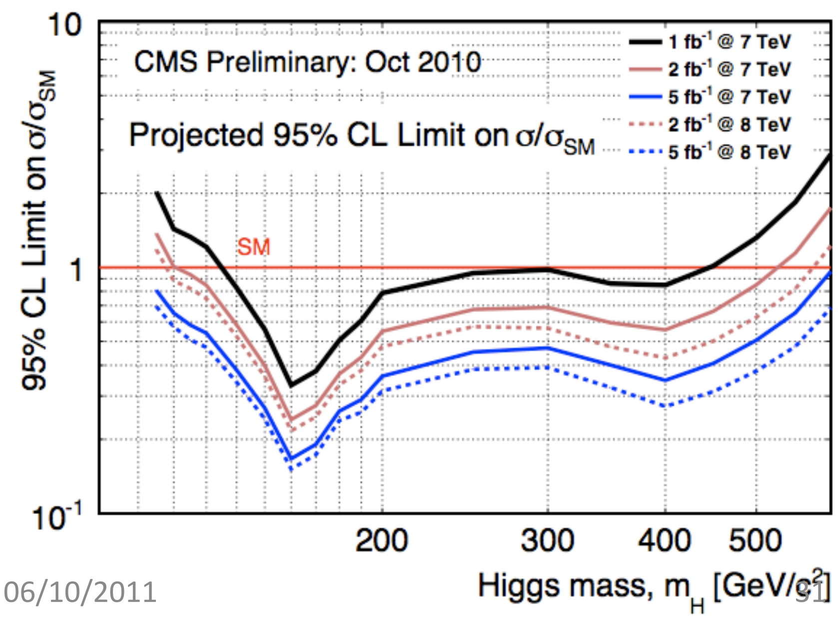
https://twiki.cern.ch/twiki/bin/view/LHCPhysics/CrossSections

- Common effort to define statistical methods to derive limits and quantify an excess

  Important to allow an efficient subsequent ATLAS-CMS combination

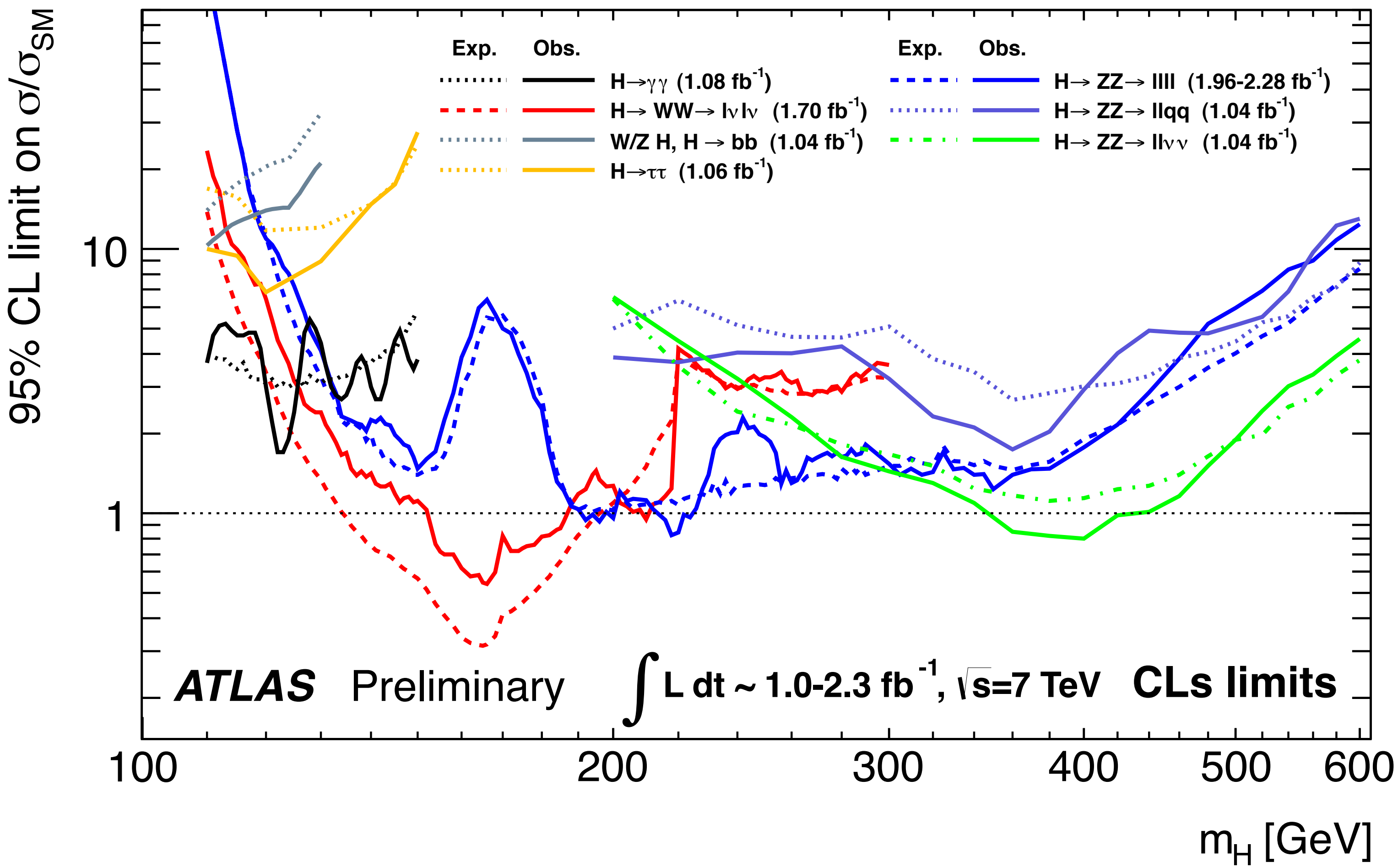
The Projections of the Higgs Searches as Guidelines for Chamonix Workshop





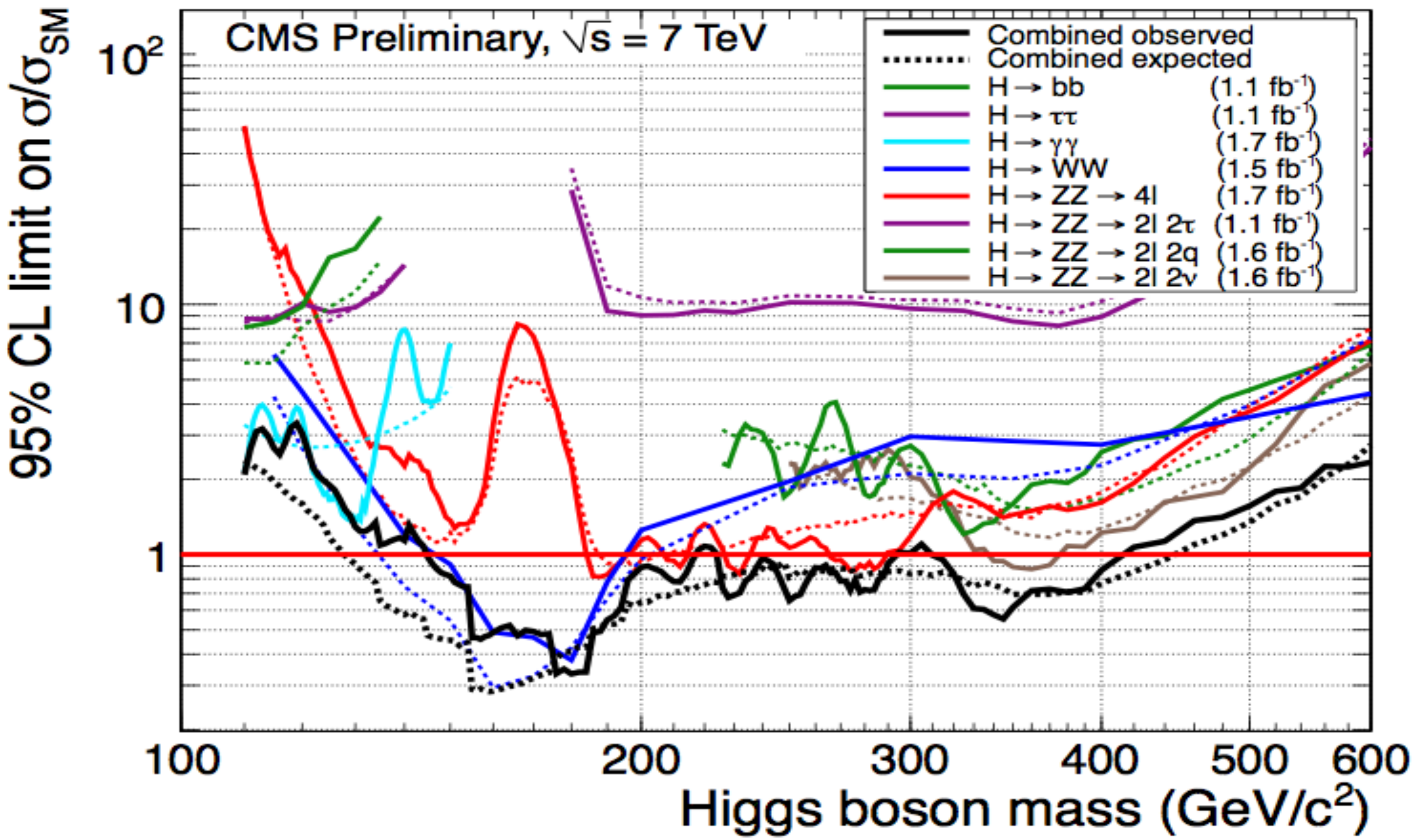
Channels Overview

The Complete ATLAS Picture



Channels Overview

The Complete CMSPicture

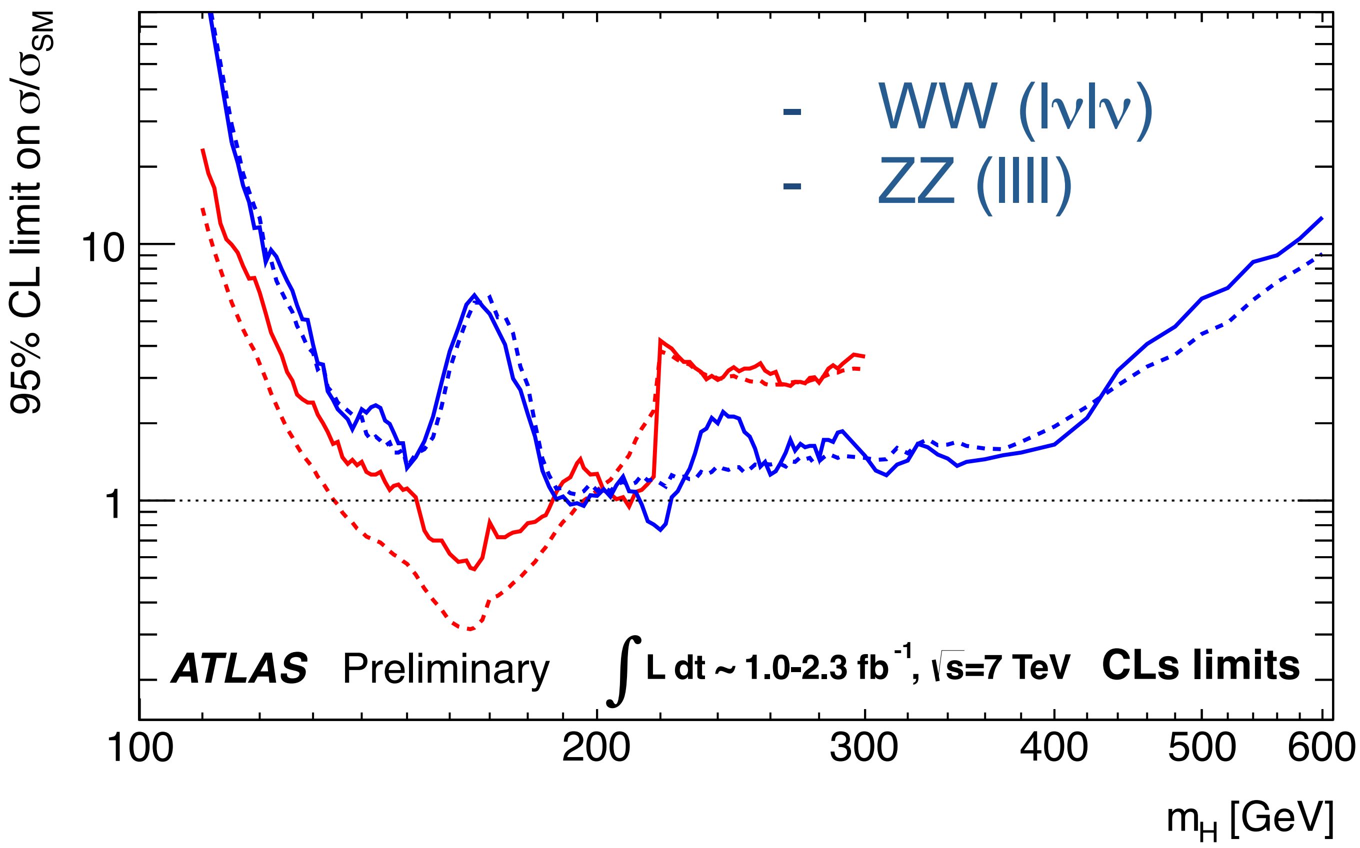


Channels nano Review

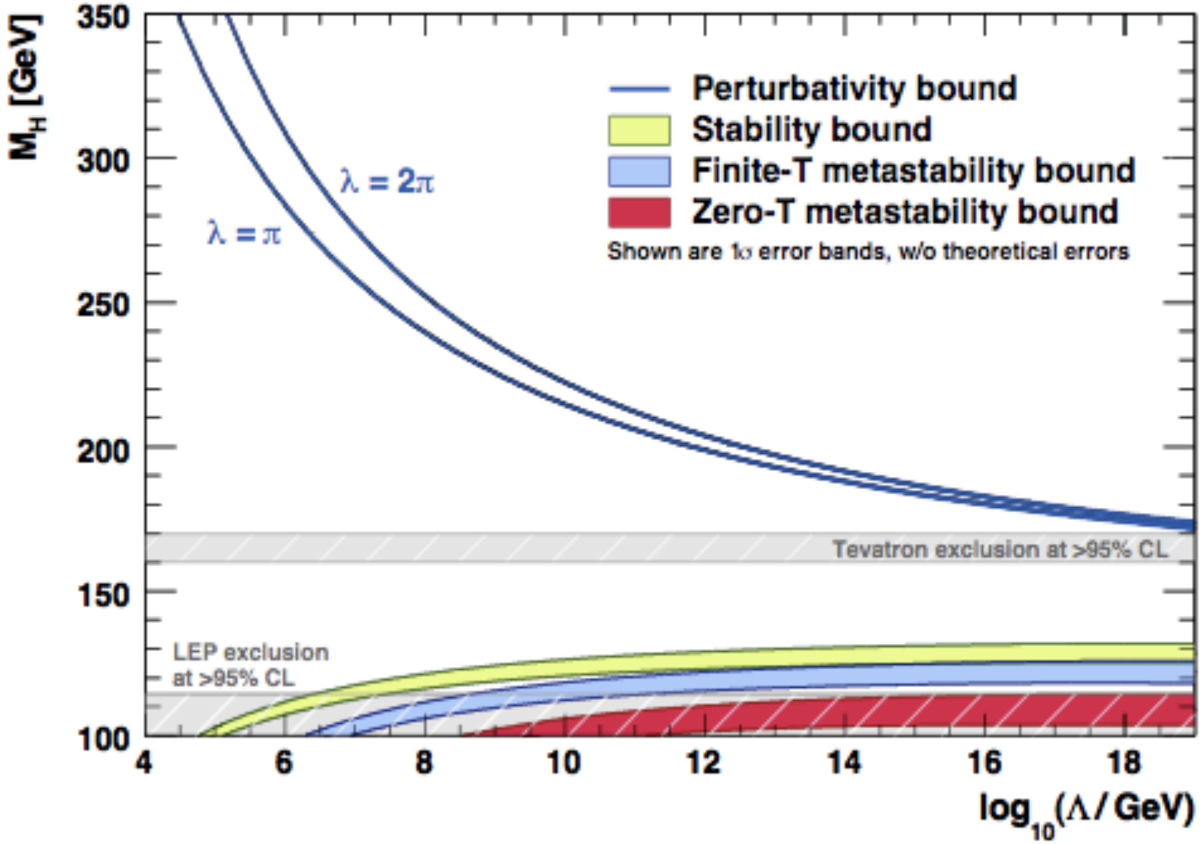
Channel		btag (veto)	Jets	MET (GeV)	Shape	Mass Range (GeV/c^2)	Main backgrounds
$\gamma\gamma$					$M_{\gamma\gamma}$	110-150	$\gamma\gamma$ (from sidebands)
$\tau\tau$		✓	✓		$M_{\tau\tau}$	110-140	Z from data driven methods
WH		✓	2		M_{bb}	110-130	Top (3j - high M_{bb}) and W+jets (low M_{bb})
ZH		✓	2		M_{bb}	110-130	Z+jets (low M_{bb})
WW ($l\nu l\nu$)	0-jet		0	>30		110-600	WW (control region M_{ll})
	1-jet	veto	1	>30		110-600	Top (from reverse btag) and WW (M_{ll} CR)
	VBF*	veto	2	>30		110-600	Top from CS
WW** ($l\nu qq$)	0-jet		0	>30	M_{WW}	200-600	W+jets (sidebands)
	1-jet	veto	1	>30	M_{WW}	200-600	W+jets (sidebands)
ZZ (llll)		IP			M_{4l}	110-600	ZZ (from MC), Z+jets and top (CR)
ZZ ($ll\tau\tau$)*					$M_{2l2\tau}$	200-600	ZZ (From Z - data)
ZZ ($ll\nu\nu$)		✓		>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)

* CMS only / ** ATLAS only

Intermediate & Wide Range Channels

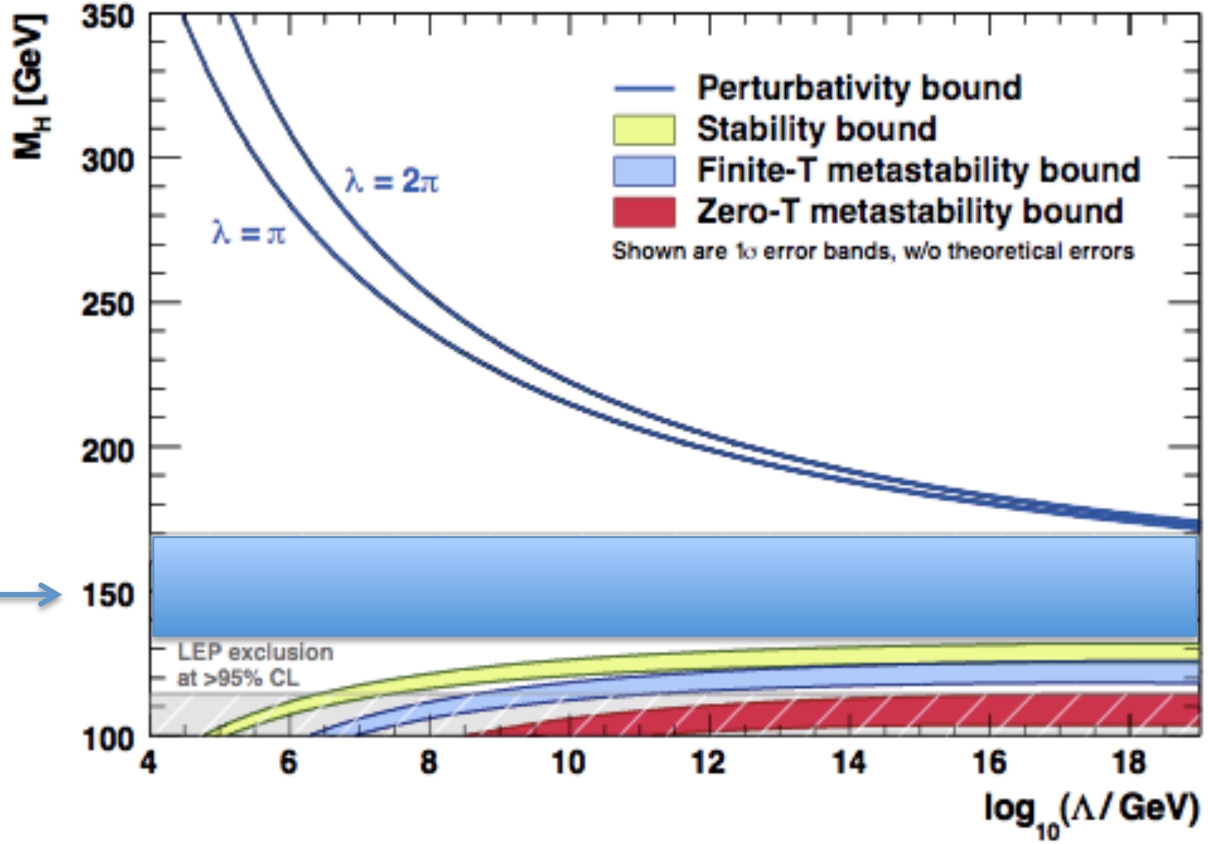


Intermediate & Wide Range Channels



Intermediate & Wide Range Channels

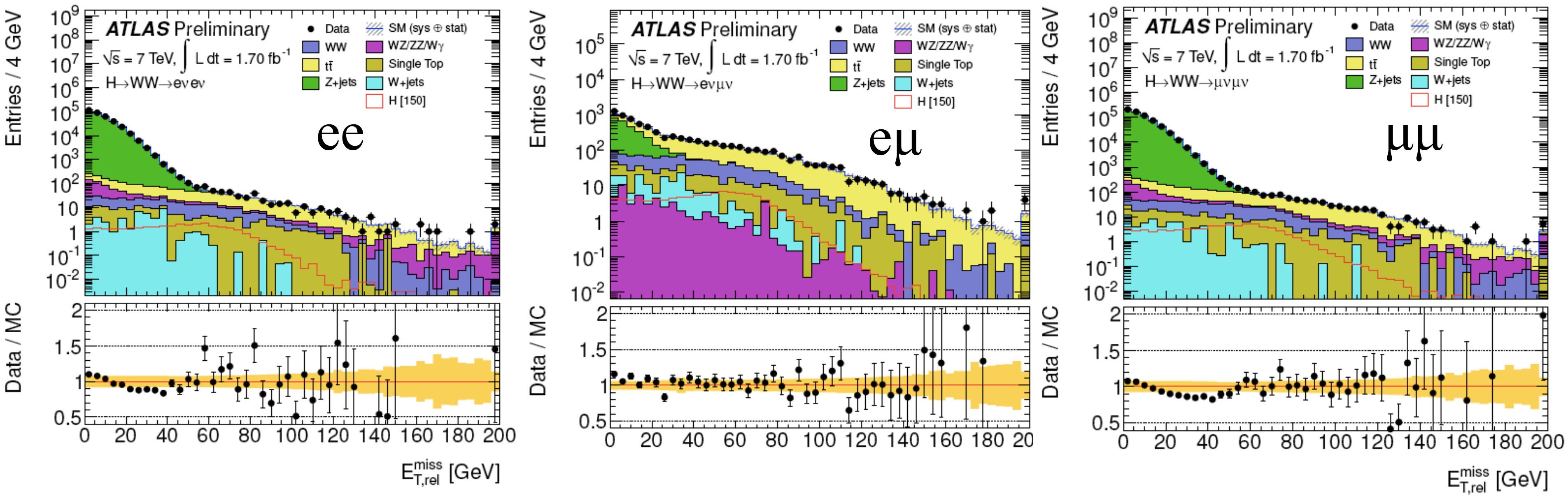
The desert still valid hypothesis?



Higgs Boson Search in the WW→lνlν

Key features :

- Not a search for a mass peak : Counting experiment only!
- Search carried out in 0, 1 and 2 (VBF – CMS only) bins in numbers of jets
- ATLAS cut based only / CMS cut based and MVA (EPS only)
- Good control of the WW and top backgrounds is essential!



ATLAS MET distribution (not as easy as in the 2010 data!)

Higgs Boson Search in the WW→lνlν

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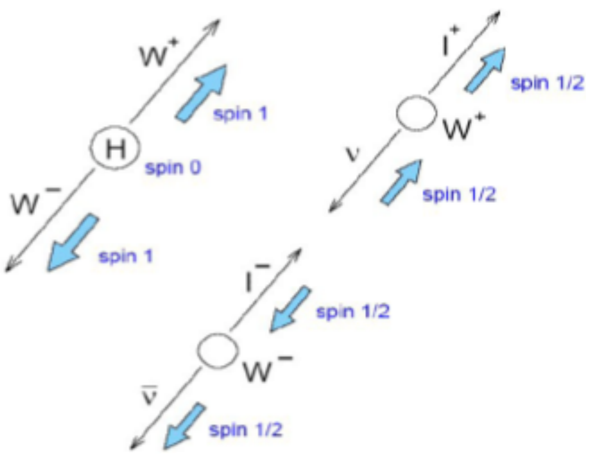
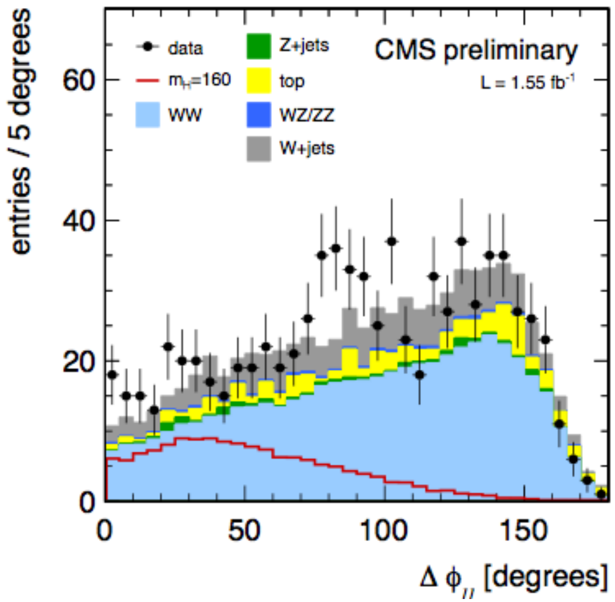
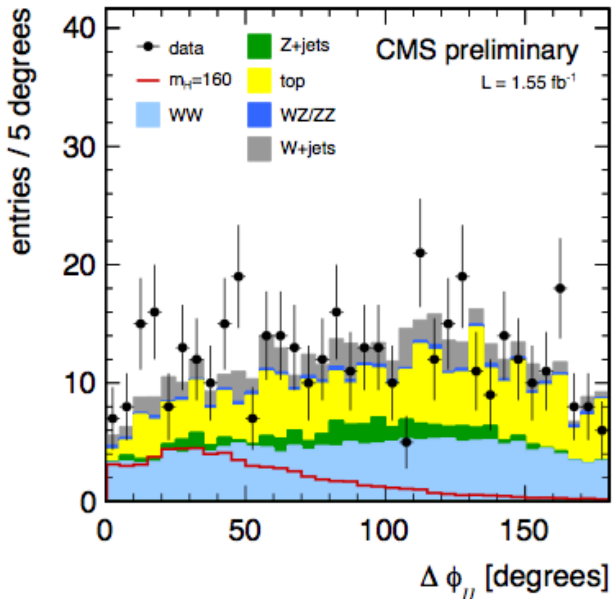
- Not a search for a mass peak : Counting experiment only!
- Search carried out in various bins in numbers of jets
- ATLAS cut based only / CMS cut based and MVA (EPS only)
- Good control of the WW and top backgrounds is essential!
- Use of spin correlations is essential for the analysis and to define control regions…







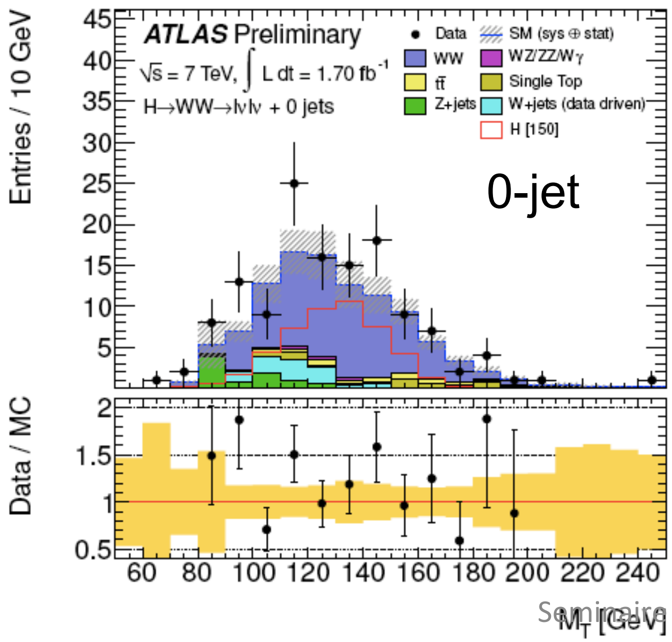
Higgs Boson Search in the WW→lνlν

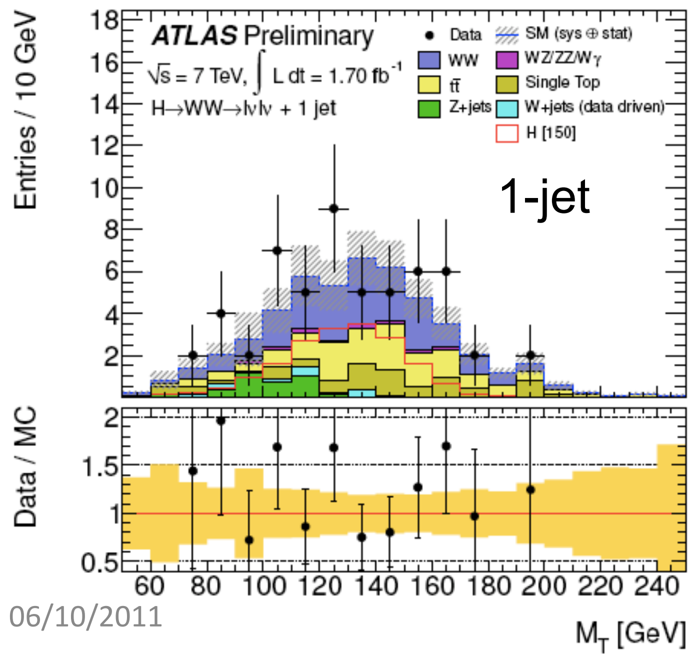
- ATLAS 0 and 1 jets (after topological cuts (m^{ll}, p_T^{ll}, $\Delta\varphi^{ll}$)

Reconstruct the transverse mass m_T and apply the cut $0.75\times m_H < m_T < m_H$

- CMS 0, 1 and VBF (2-jets) and specific cuts for each mass hypothesis (m^{ll}, p_T^{ll}, $\Delta\varphi^{ll}$, M_T)

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

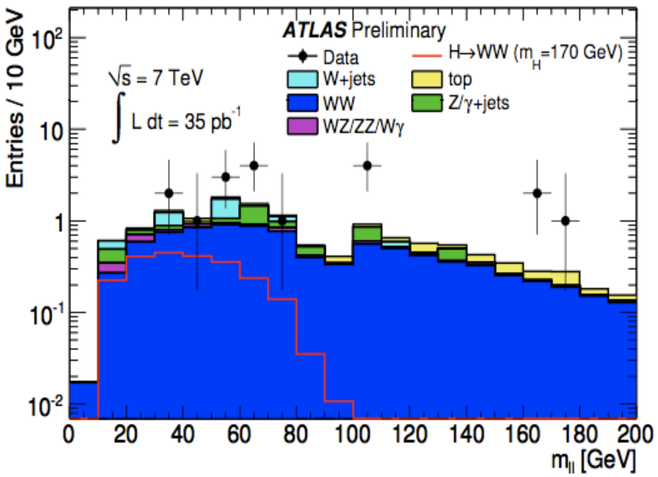




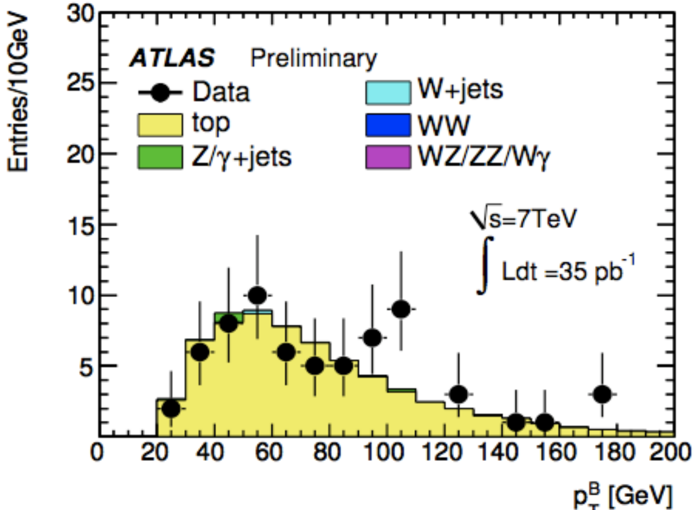
A Word on Control Regions

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

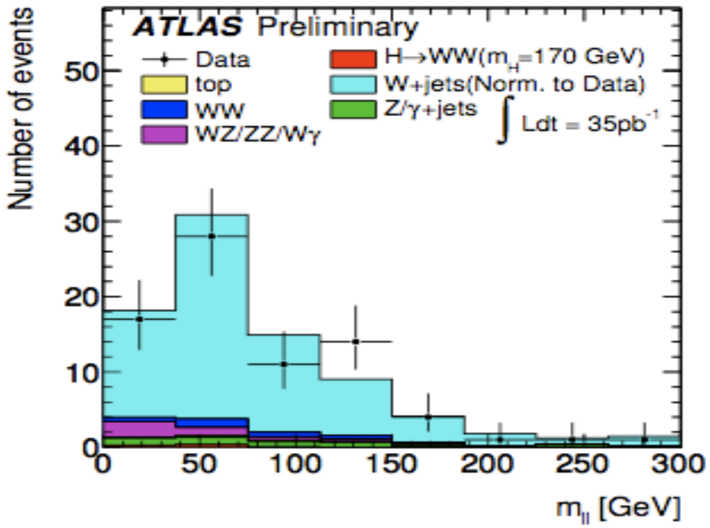
- WW : From side bands in M_{ll}



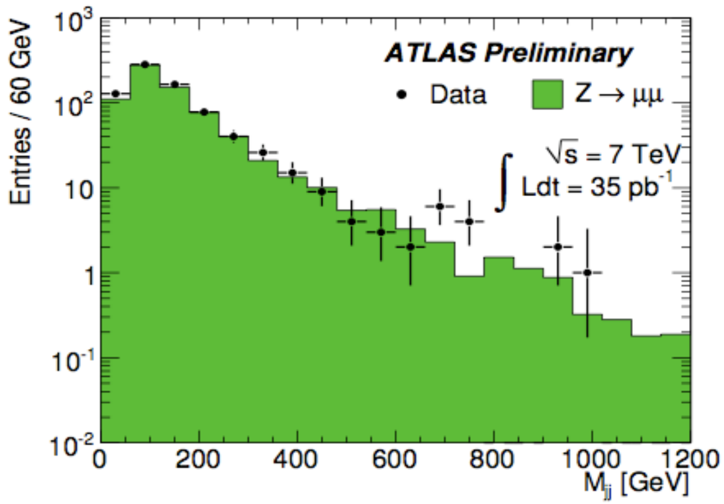
- Top : b-tagging CS (MC for CMS)



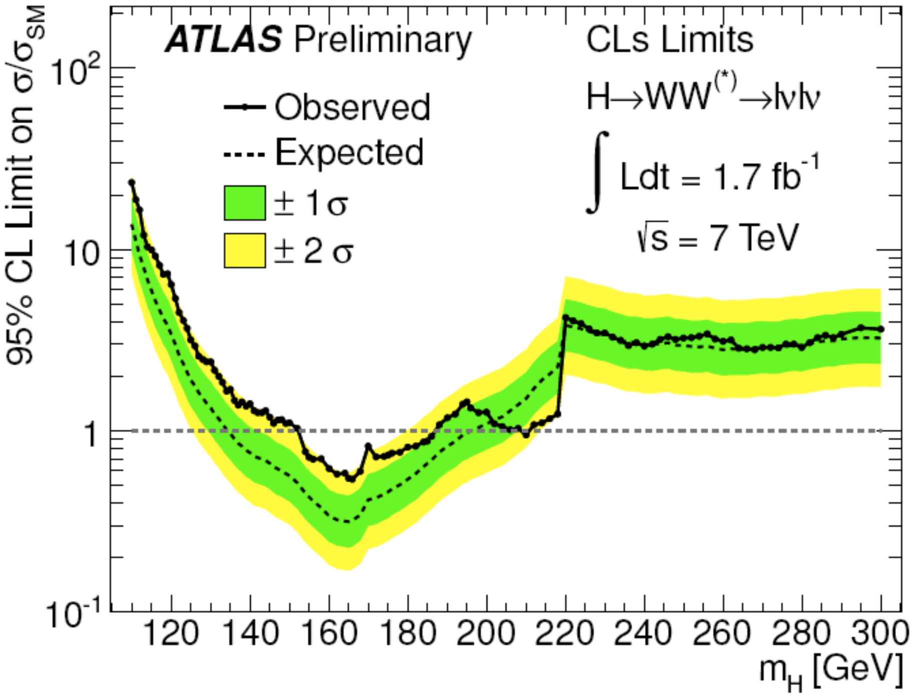
- W+jets : Loose ID on second lepton

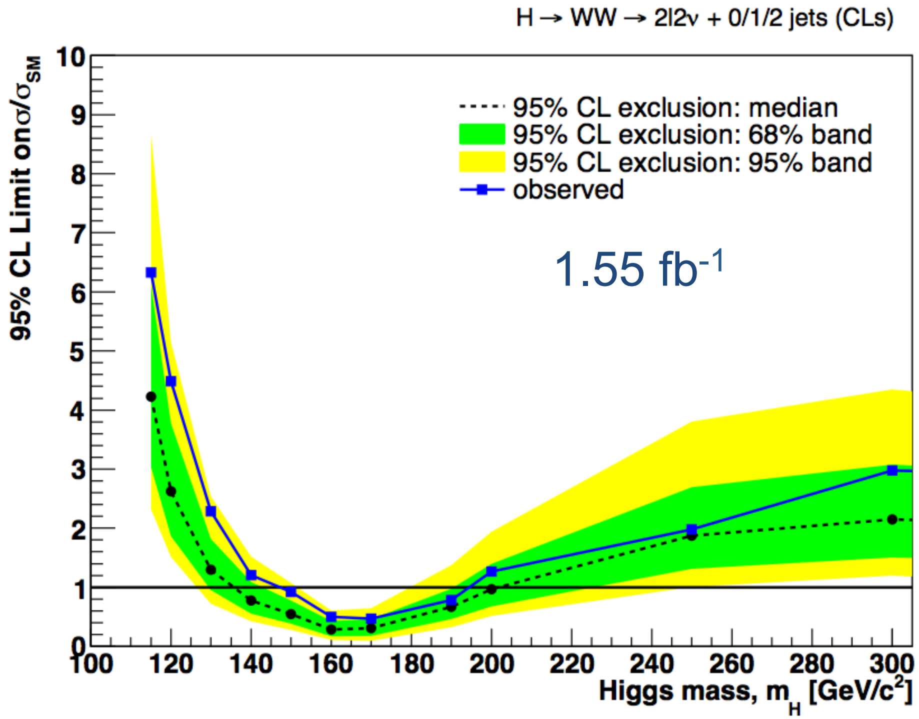


- Z+jets : ABCD method in M_{ll} MET plane



Higgs Boson Search in the WW→lνlν

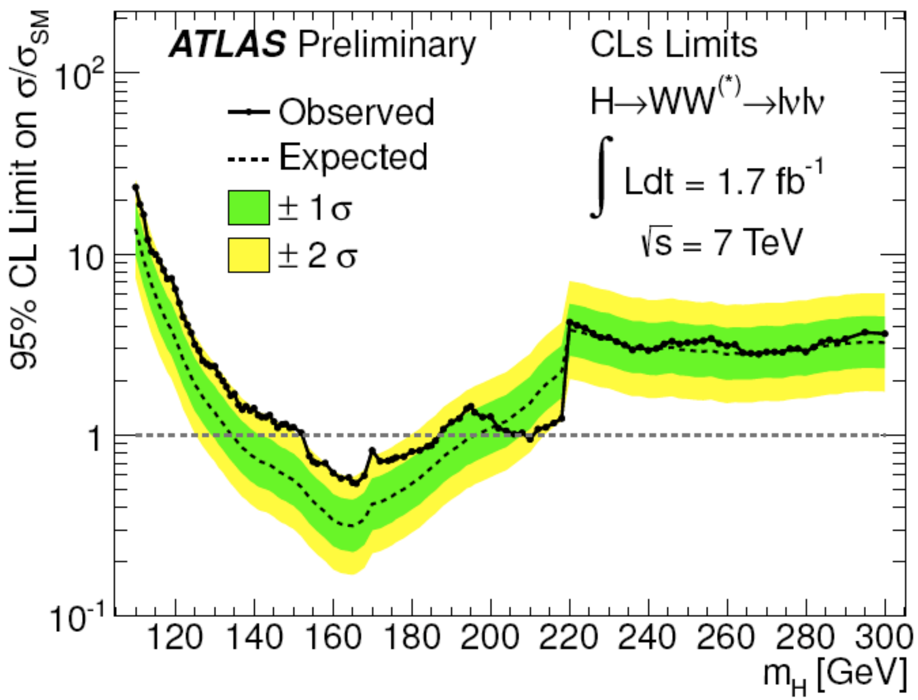


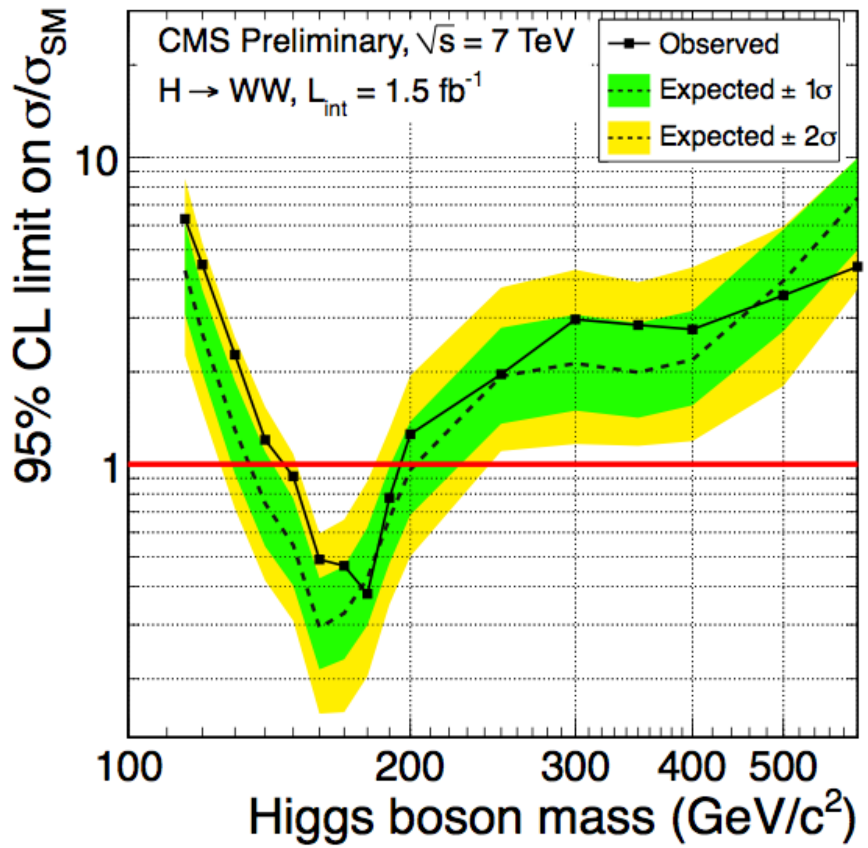


Main differences between ATLAS and CMS :

- Electron/Muon minimum pT requirement (ATLAS 25/15 GeV/c and CMS 10/10 GeV/c)
- Use of the VBF (2-jet) category in CMS

Higgs Boson Search in the WW→lνlν



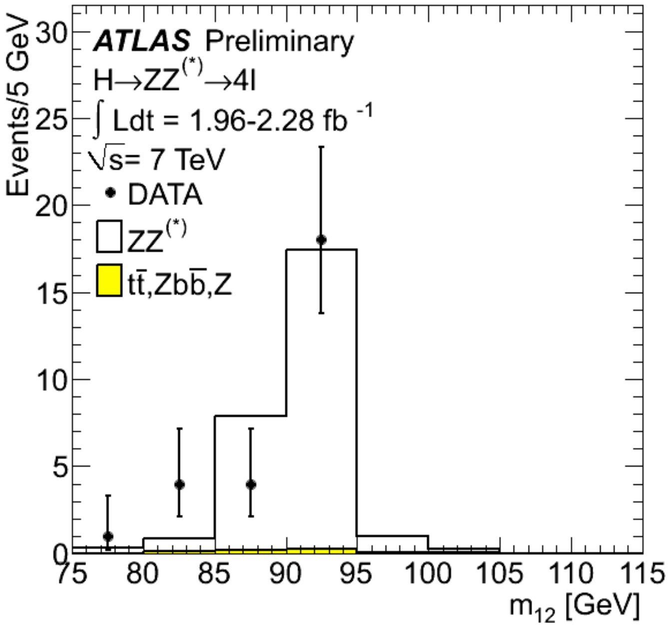


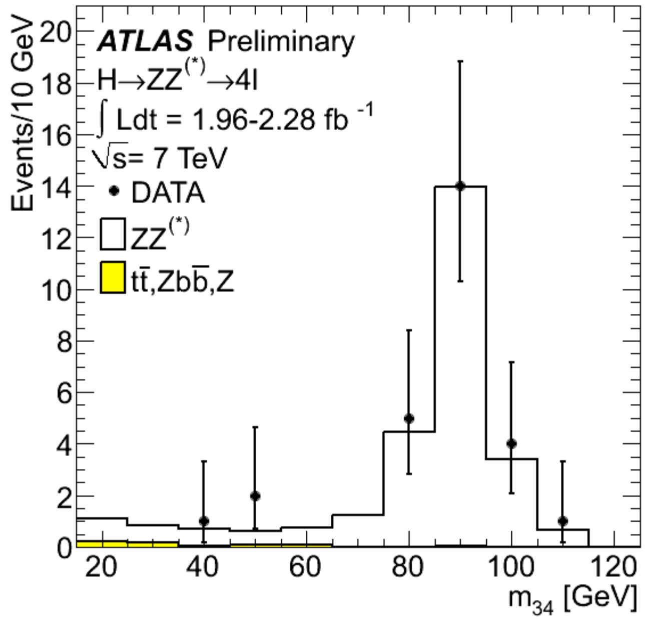
Main differences between ATLAS and CMS :

- Electron/Muon minimum pT requirement (ATLAS 25/15 GeV/c and CMS 10/10 GeV/c)
- Use of the VBF (2-jet) category in CMS
- Mass Range investigated (in CMS up to 600 GeV/c^2)

Higgs Boson Search in the $ZZ^{(*)} \rightarrow 4l$
"Golden Channel"

- Difference with the cross section : one Z allowed to be off-mass shell (m_H < 180 GeV)
- p_T thresholds similar for ATLAS and CMS
- Main Background ZZ from Monte Carlo (ATLAS) and derived from Z (CMS)
- Other backgrounds (Zbb and top) data driven (but small)





Higgs Boson Search in the $ZZ^{(*)} \rightarrow 4l$

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- p_T thresholds similar for ATLAS and CMS
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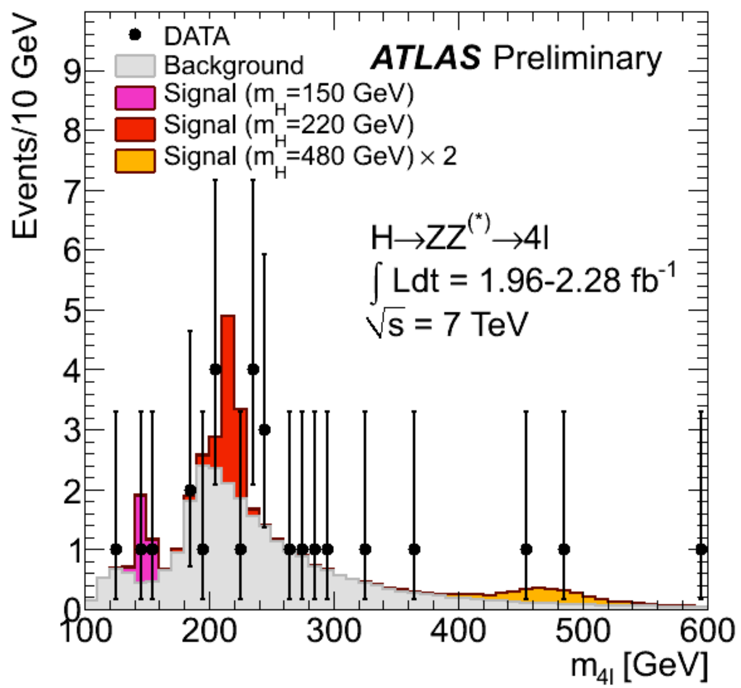
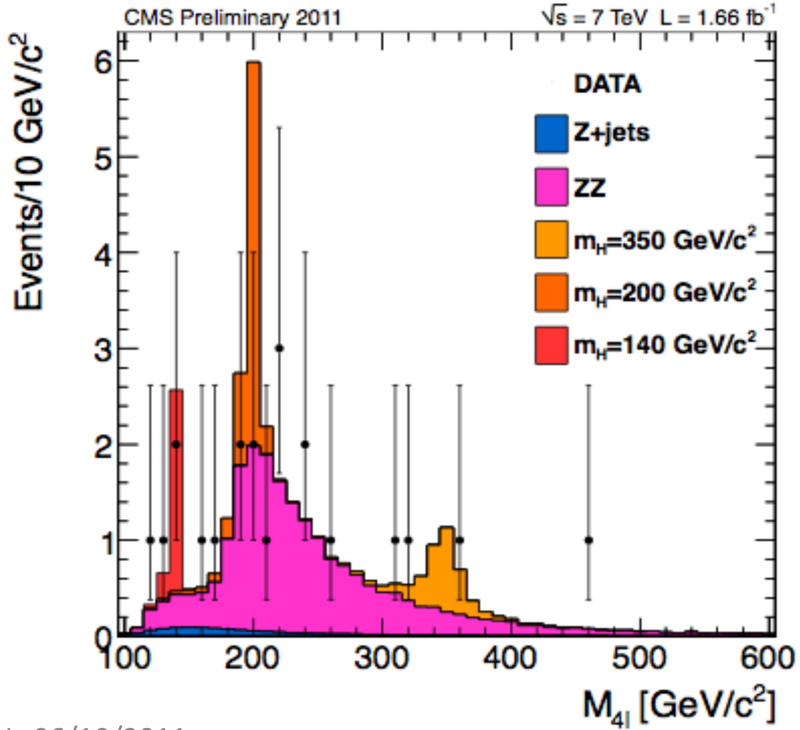
- Other backgrounds (Zbb and top) data driven (but small)

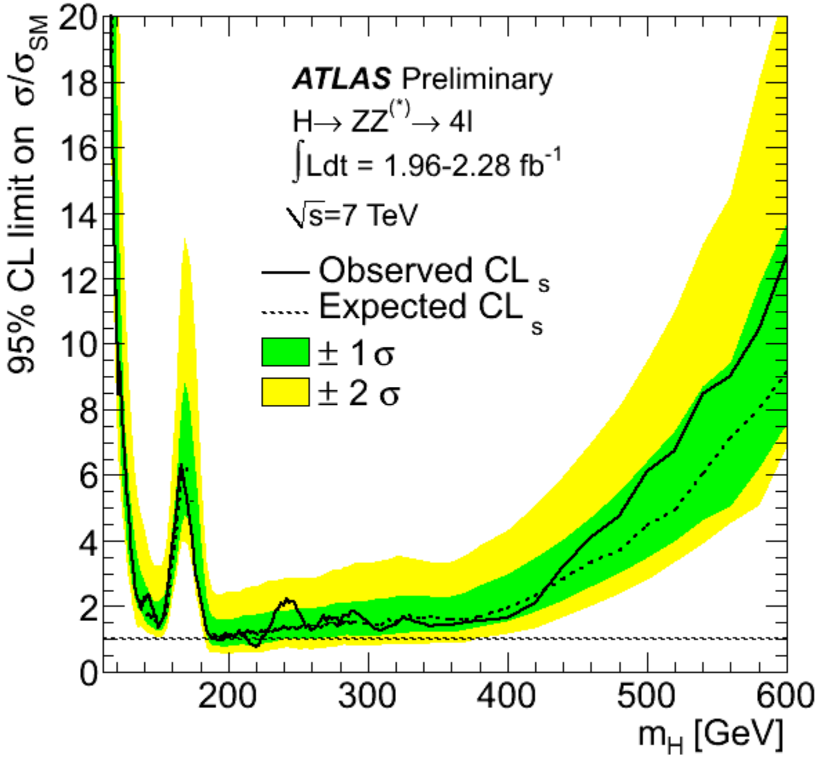
FWHM@130 GeV 4.5 (4μ) and 6.5 (4e)

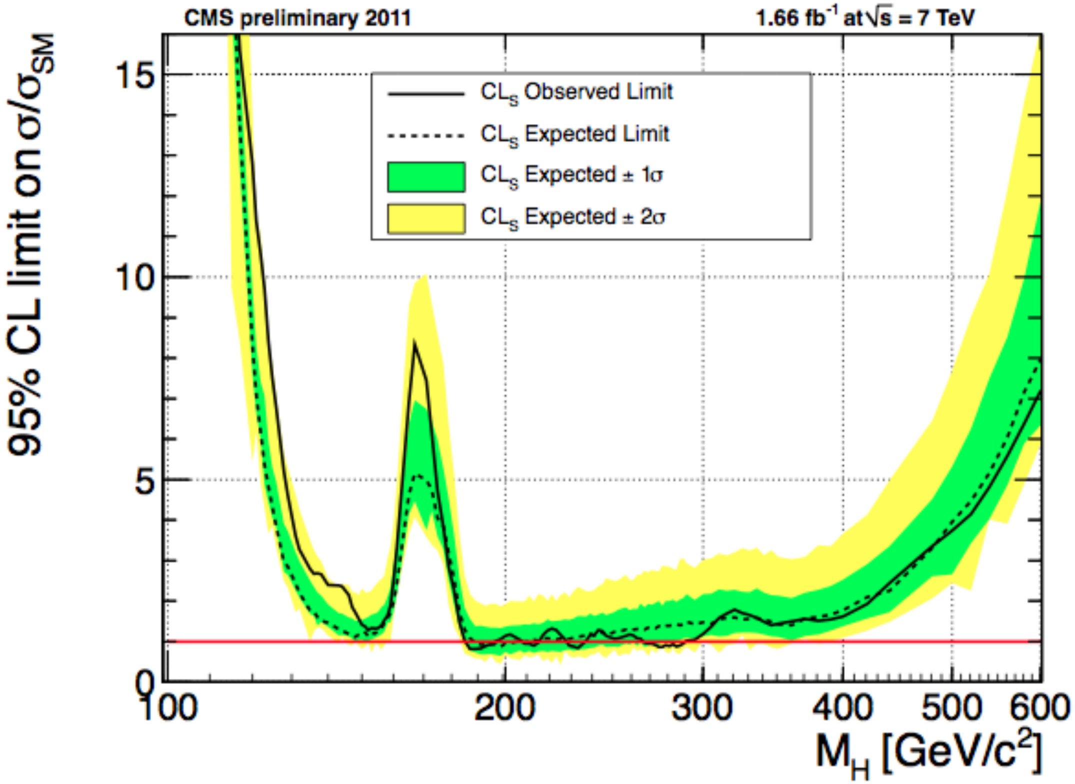


FWHM@150 GeV 3.8 (4μ) and 6.3 (4e)



Higgs Boson Search in the $ZZ^{(*)} \rightarrow 4l$

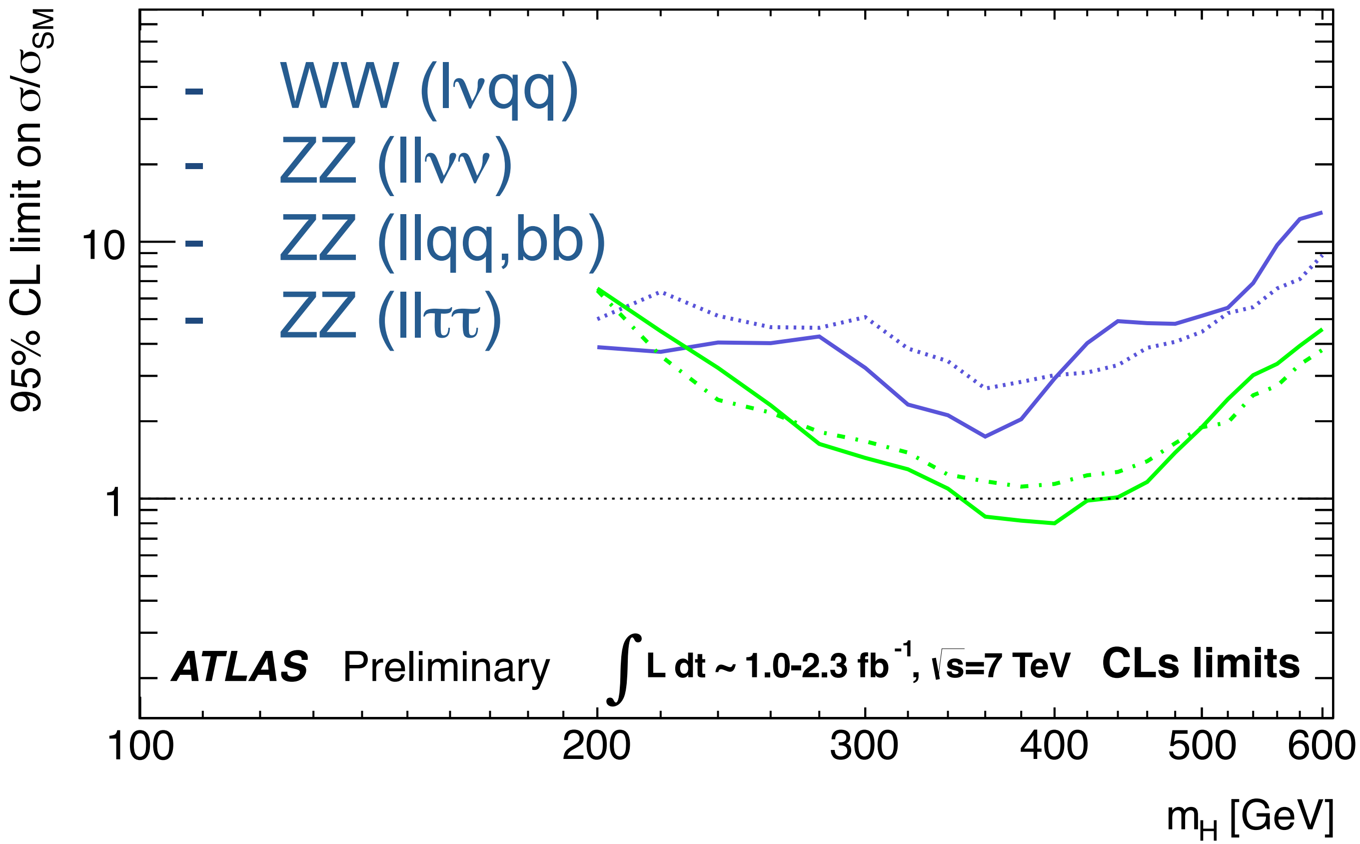




Main differences between ATLAS and CMS :

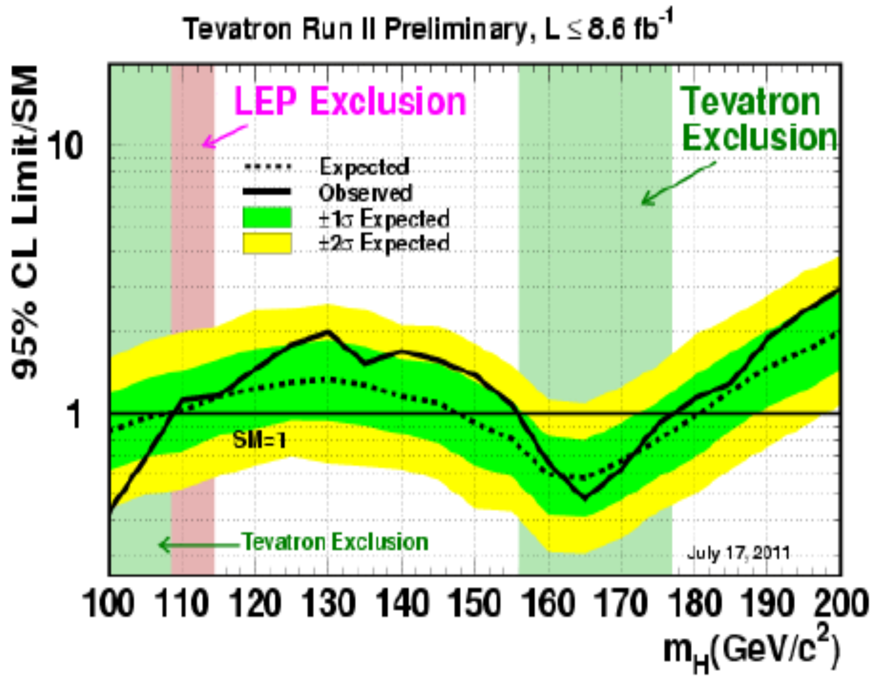
- ATLAS larger integrated luminosity
- Electron/Muon minimum pT requirement (ATLAS 7/7 GeV/c and CMS 7/5 GeV/c)
- Efficiencies/resolution differences … (?)

High Mass Channels



High Mass Channels

The Higgs Search Exclusion before LHC



SM Higgs excluded @ 95% C.L.

$156 < m_H < 177$ GeV obs ($148 < m_H < 180$ GeV exp)

$100 < m_H < 108$ GeV obs ($100 < m_H < 109$ GeV exp)

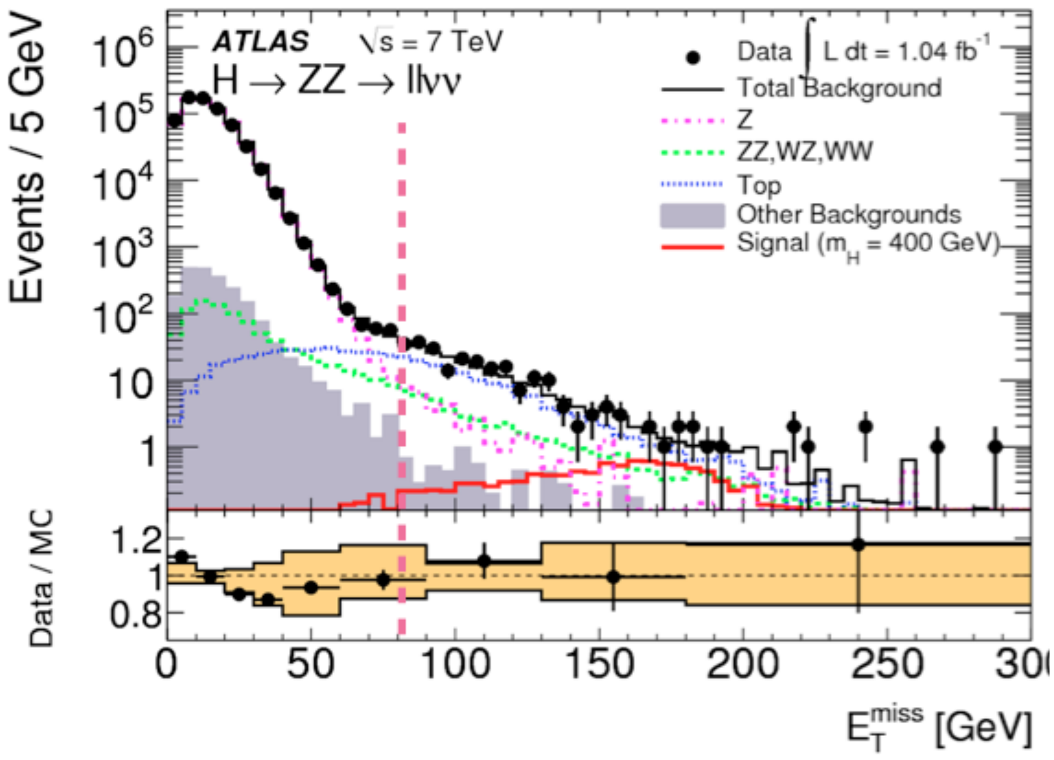
...

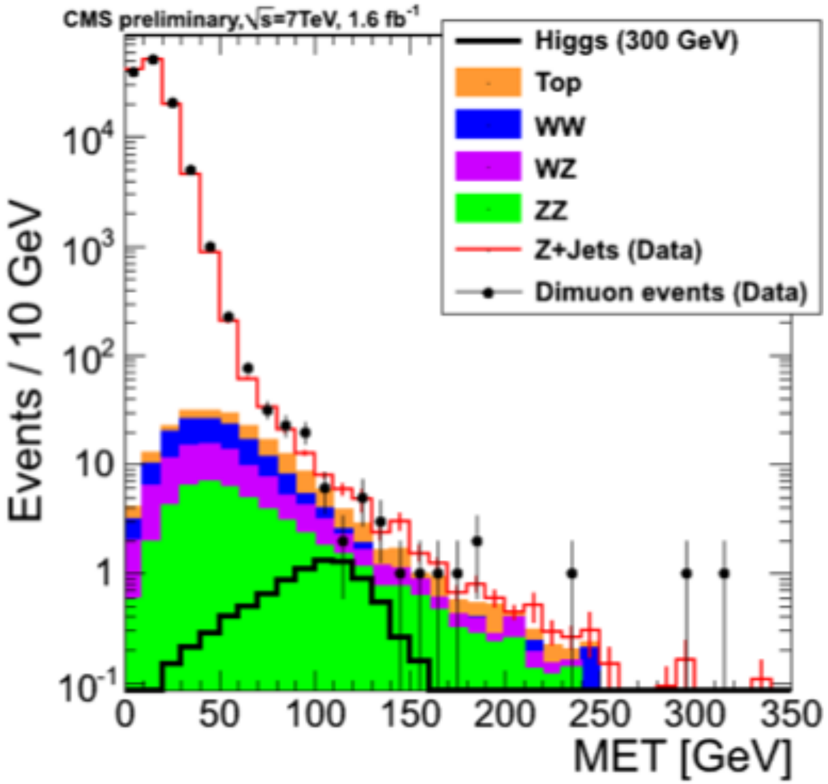
Higgs Boson Search in the ZZ→llνν

Key features of these analyses :

- llνν almost no mass resolution

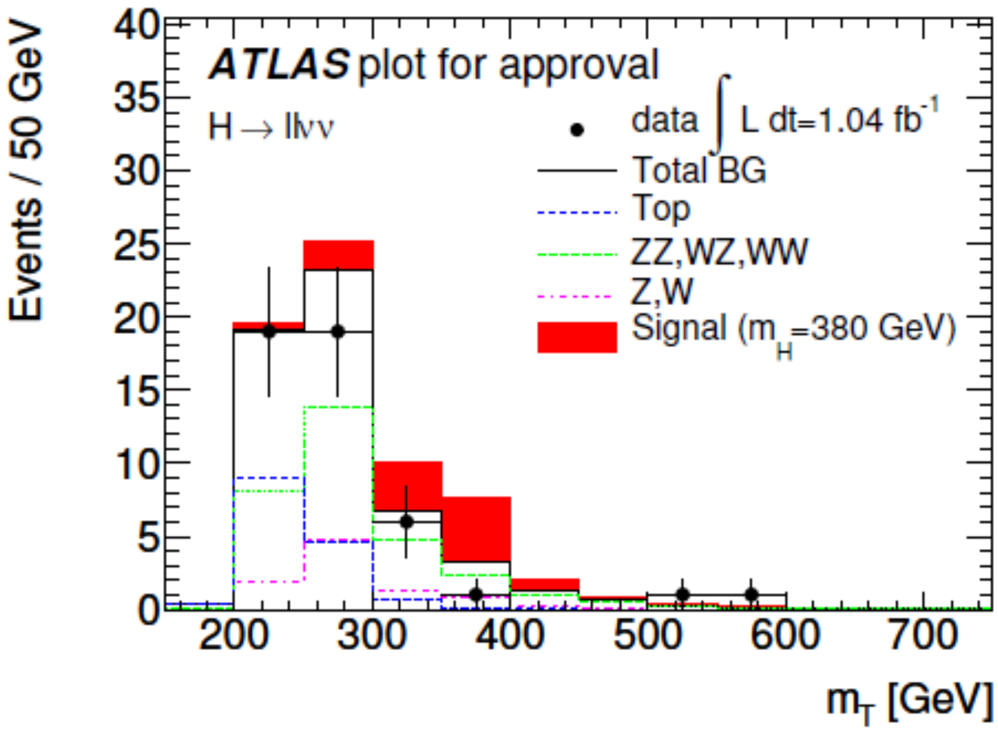
- Low backgrounds but good resolution and modeling of the MET necessary

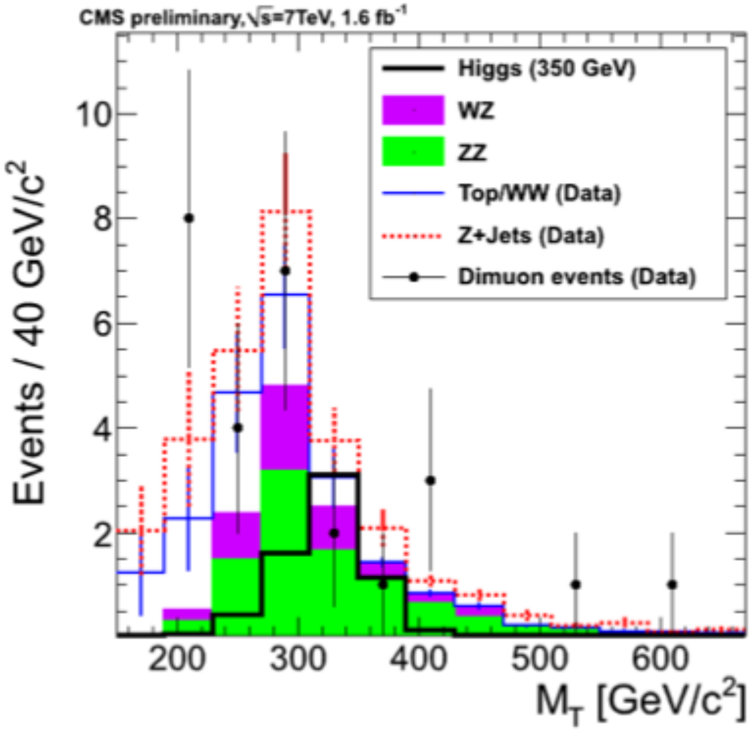




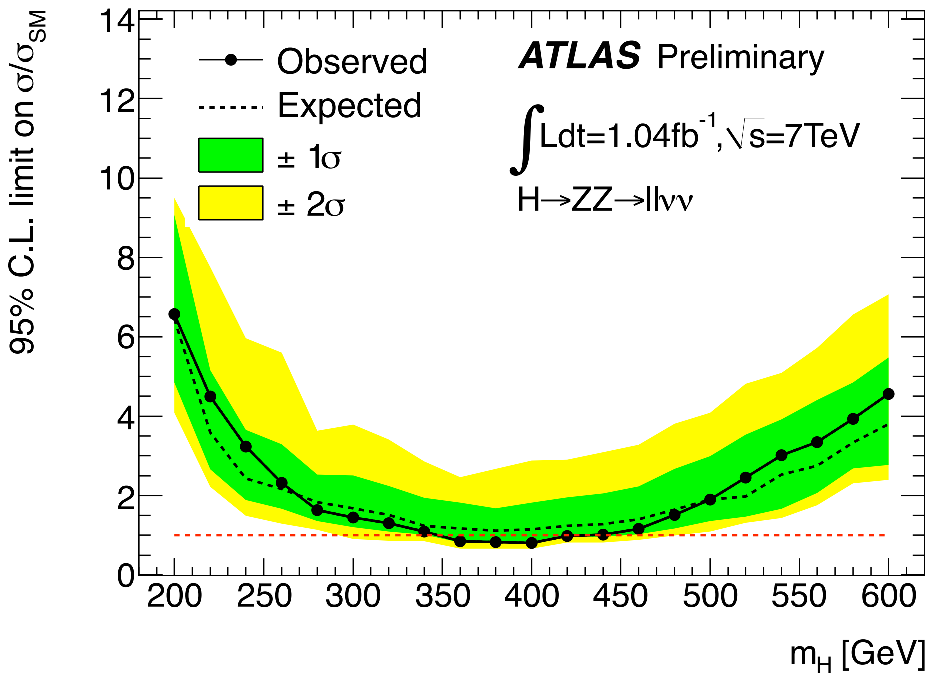
Higgs Boson Search in the ZZ→llνν

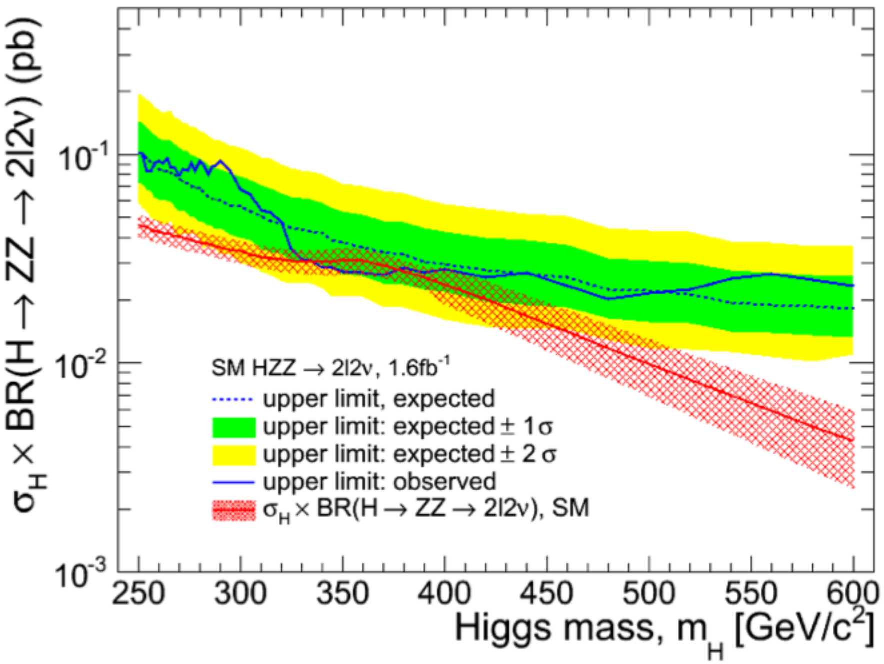
After analysis cuts (M_{ll}, b-jet veto, MET, $\Delta\phi_{ll}$) in both ATLAS and CMS





Higgs Boson Search in the ZZ→llνν





Main differences between ATLAS and CMS :

- CMS larger integrated luminosity.
- ATLAS shape analysis and CMS counting experiment.

Higgs Boson Search in the ZZ→llqq, llbb

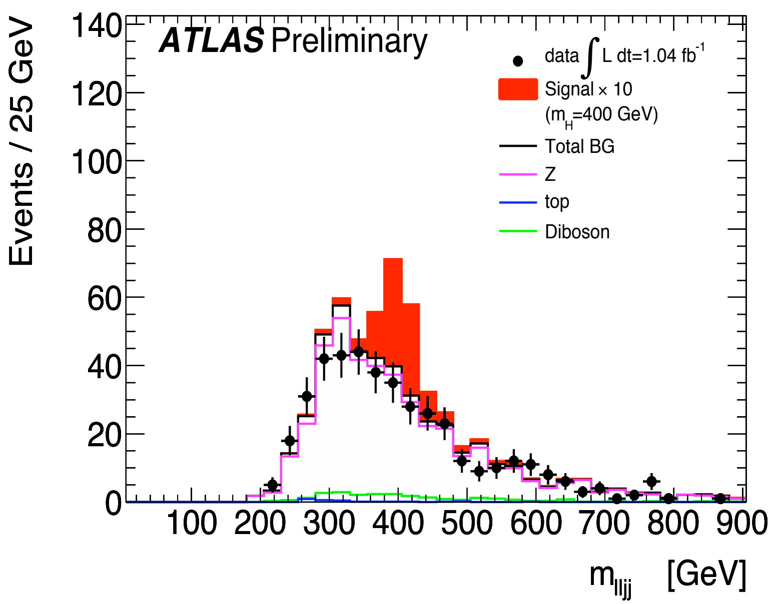
Key features of these analyses :

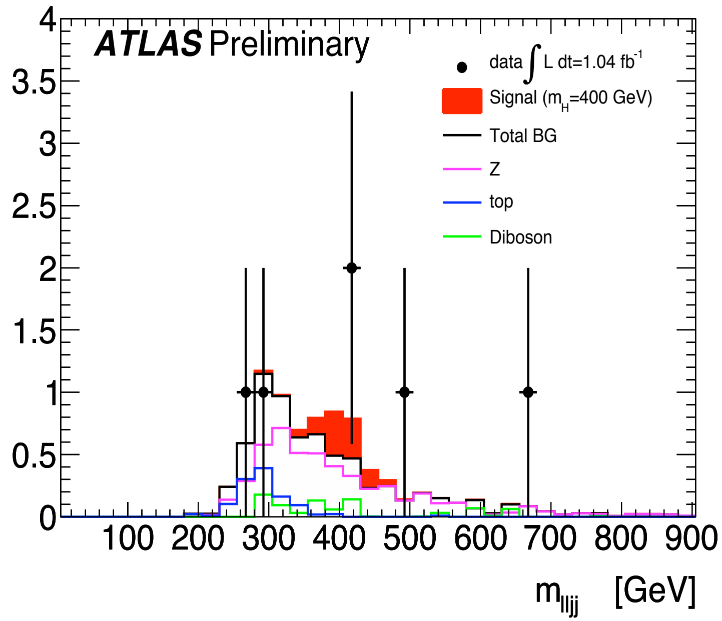
- llνν almost no mass resolution important normalization of backgrounds

- llqq Control :

  - Analyses in 0, 1 and 2 b-tag categories (control of b-tag efficiencies)

  - Control of background shape





Higgs Boson Search in the ZZ→llqq, llbb

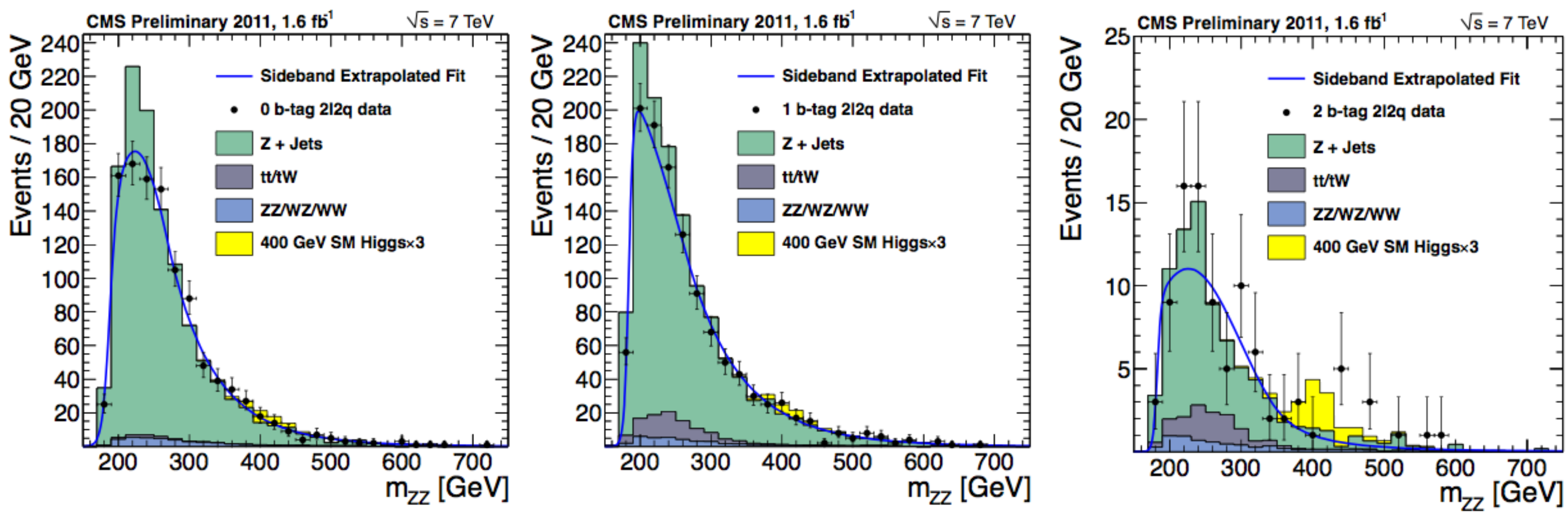
Key features of these analyses :

- llνν almost no mass resolution important normalization of backgrounds

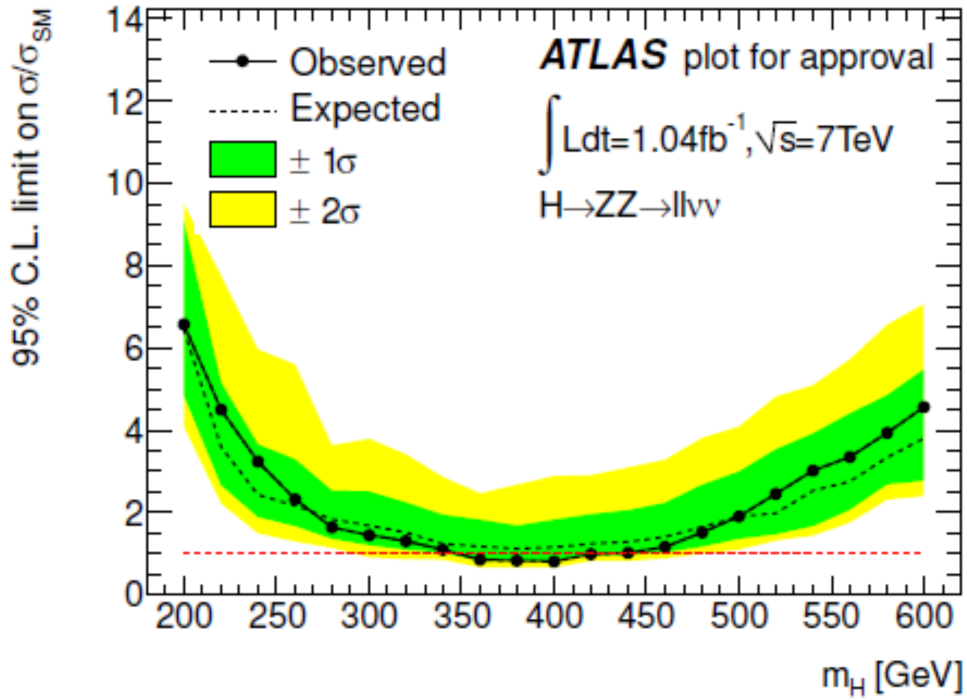
- llqq Control :

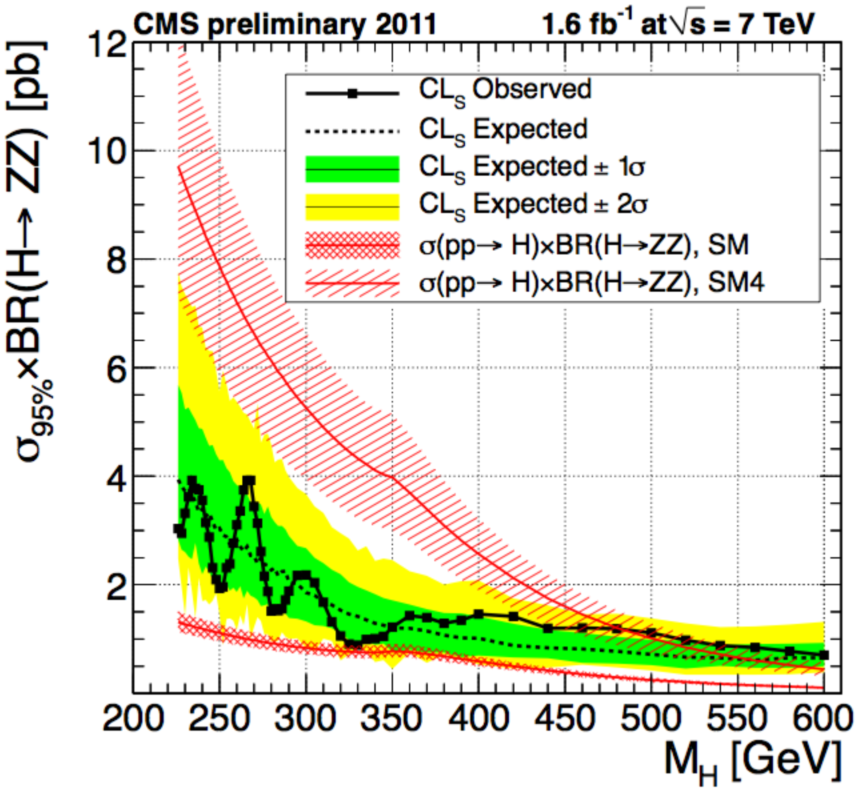
  - Analyses in 0, 1 and 2 b-tag categories (control of b-tag efficiencies)

  - Control of background shape



Higgs Boson Search in the ZZ→llqq, llbb



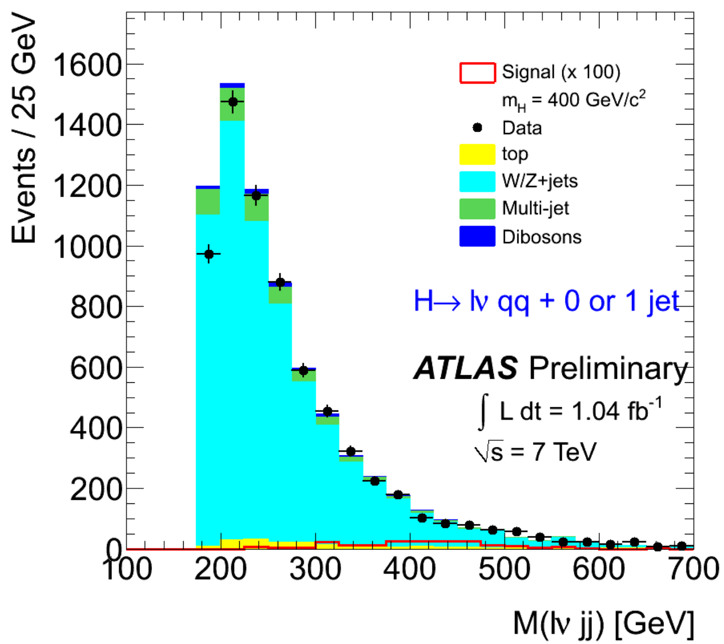


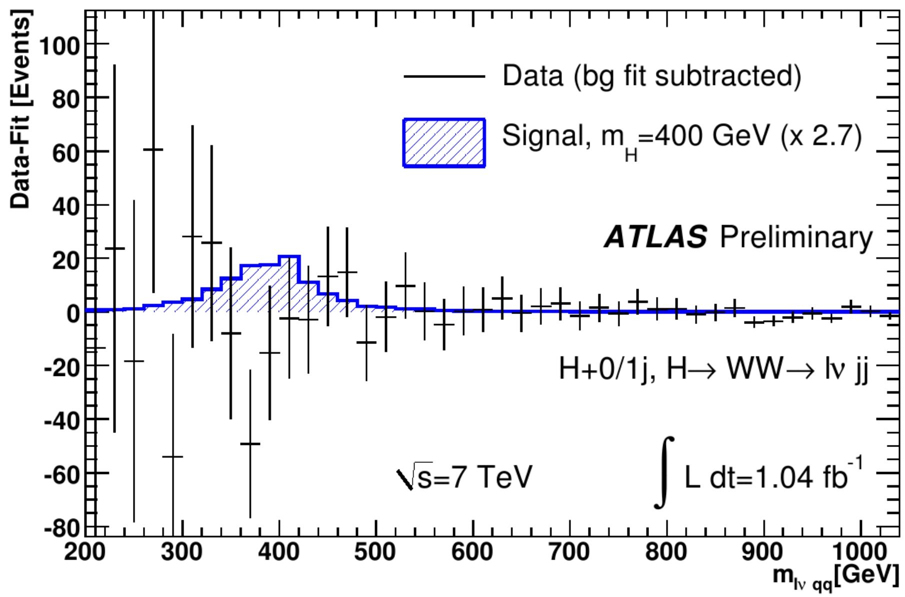
Main differences between ATLAS and CMS :

- CMS larger integrated luminosity.
- ATLAS shape analysis and CMS counting experiment.

Higgs Boson Search in the WW→lνqq
(ATLAS only)

- Largest event yield channel
- Also large backgrounds
- Reconstructed invariant mass constraint $M_{l\nu} = m_W$ Good relative mass resolution
- Background estimated from a fit model (side bands)





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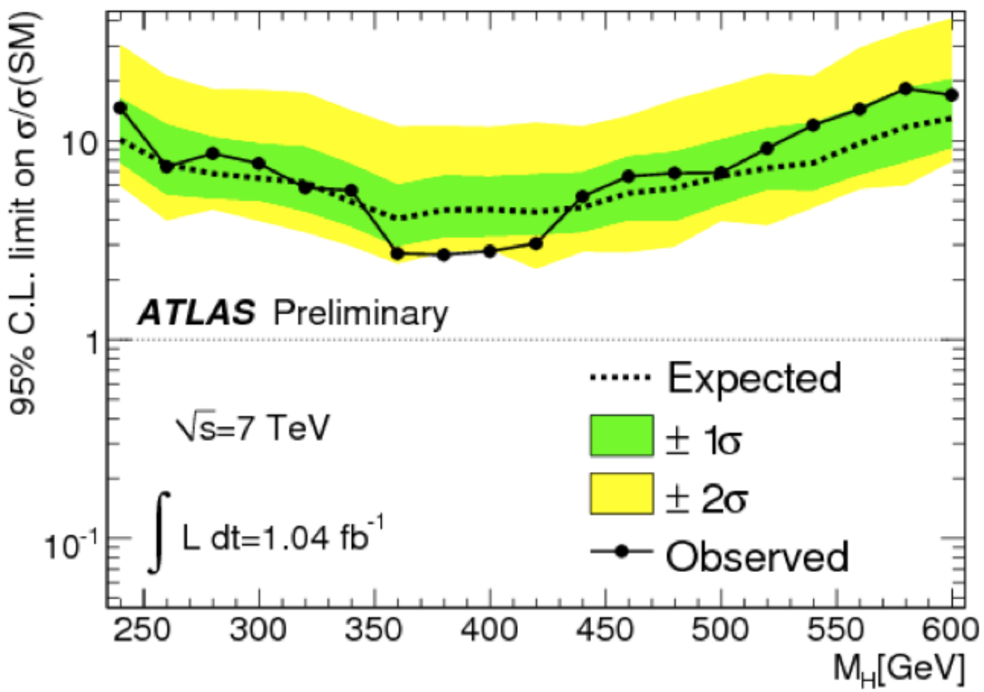
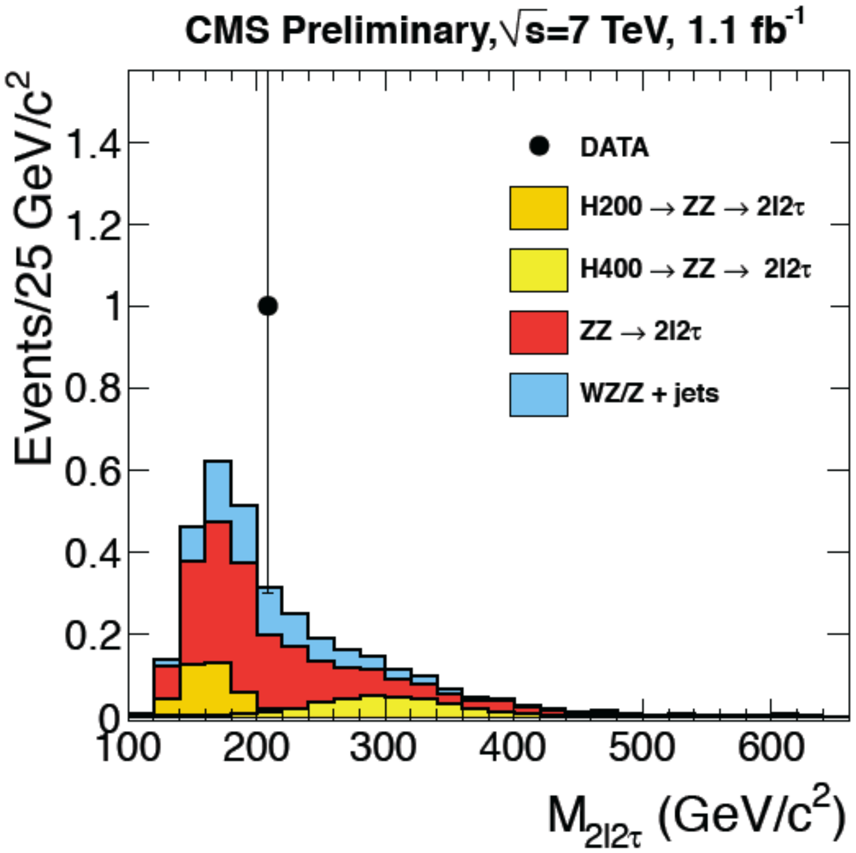
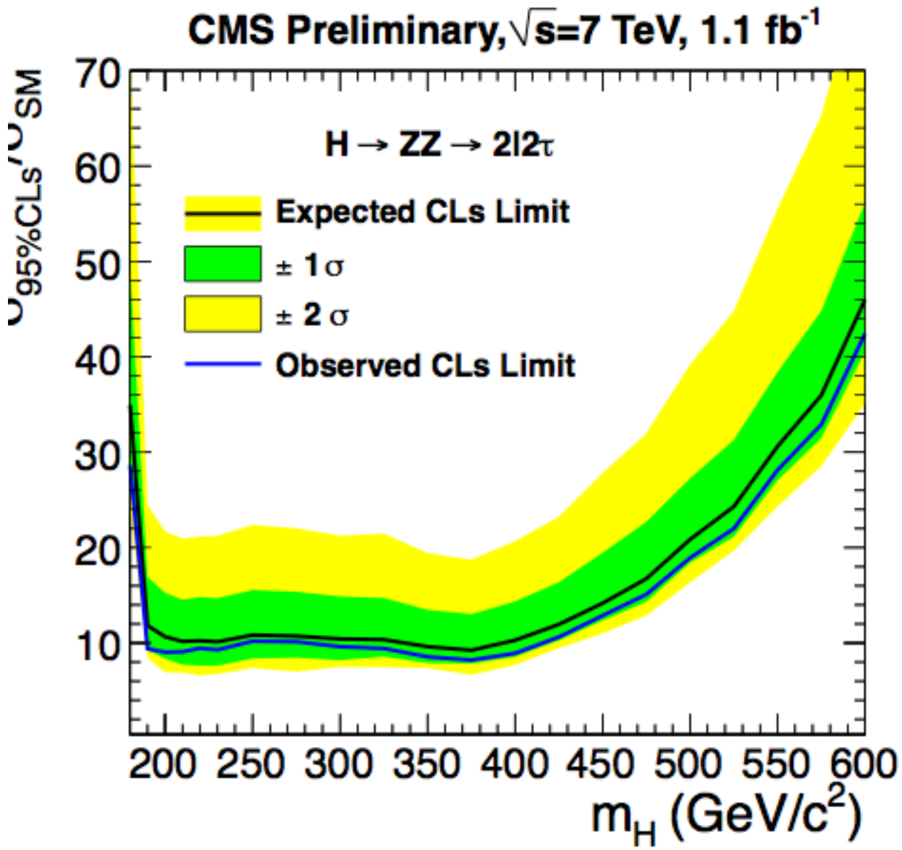


Not in the Combination

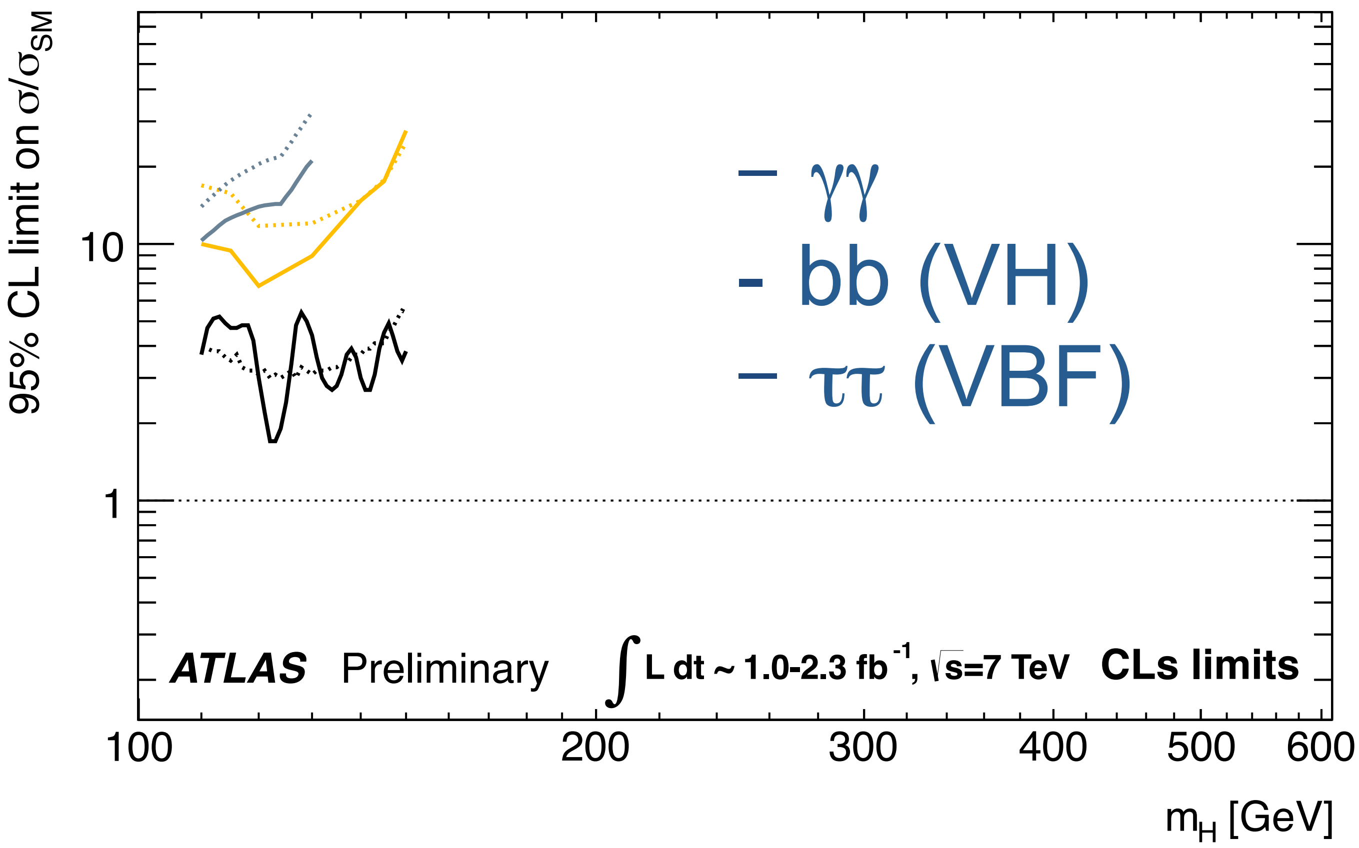
Higgs Boson Search in the $ZZ^{(*)} \rightarrow 2l2\tau$
"CMS Only"

- Main background ZZ (measured from Z)
- Important to control Z+jets background



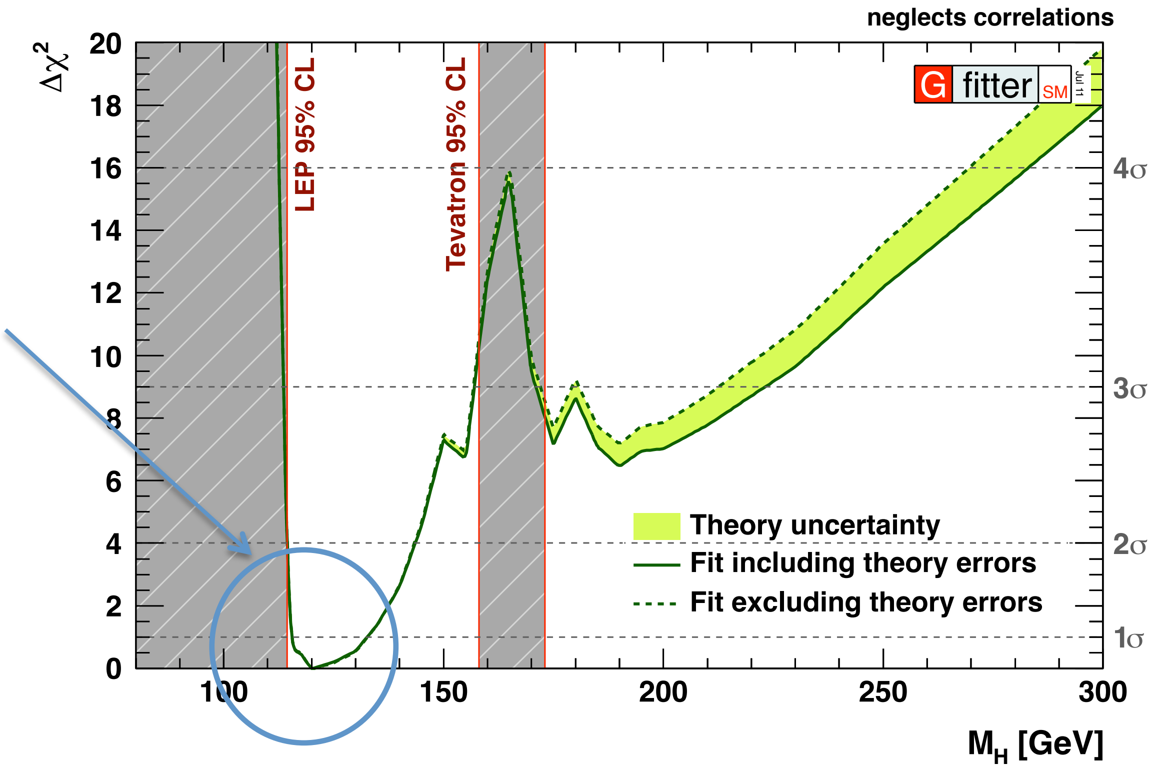


Low Mass Channels



Low Mass Channels

Favored since more than a decade by the precision EW data

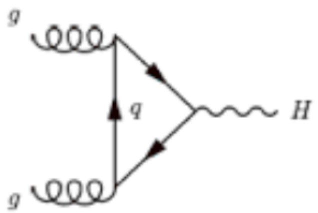


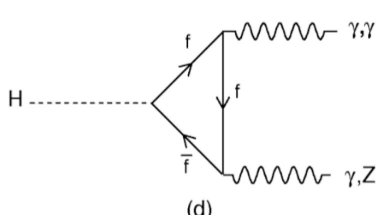
DiPhoton Channel

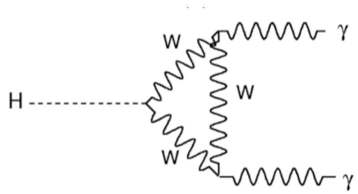
Common Misconceptions and Basic Facts

- Small branching… but amongst largest yields (Dominant Channel in the very low mass range 110-125 GeV)

- Main production and decay processes occur through loops :







A priori potentially large enhancement… *… Not so obviously enhanced (e.g. SUSY, SM4)*

Still e.g. NMMSSM (U. Ellwanger Phys.Lett. ***B 698****, 293-296,2011) up to x6 at low masses, Fermiophobia…*

- If observed implies that it does not originate from spin 1 : Landau-Yang theorem

L. Landau, Dokl. Akad. Nauk. , USSR **60**, 207 (1948) and C. N. Yang, Phys. Rev. **77**, 242 (1950).

- Extremely simple event selection : two photons 25/40 GeV (ATLAS) and 30/40 GeV (CMS)

-Key features :

-Invariant mass resolution

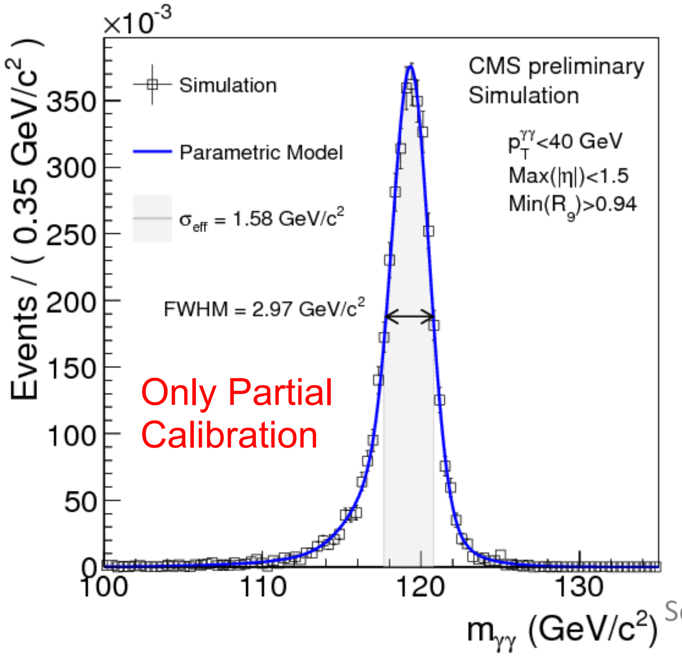
- Energy response carateristics of EM-Calorimeters

- Energy calibration

- Interaction vertex position (IP spread of 5.6 cm, assuming (0,0,0) adds ~1.4 GeV in mass resolution equiv. to the calo. $M_{\gamma\gamma}$ resolution itself).

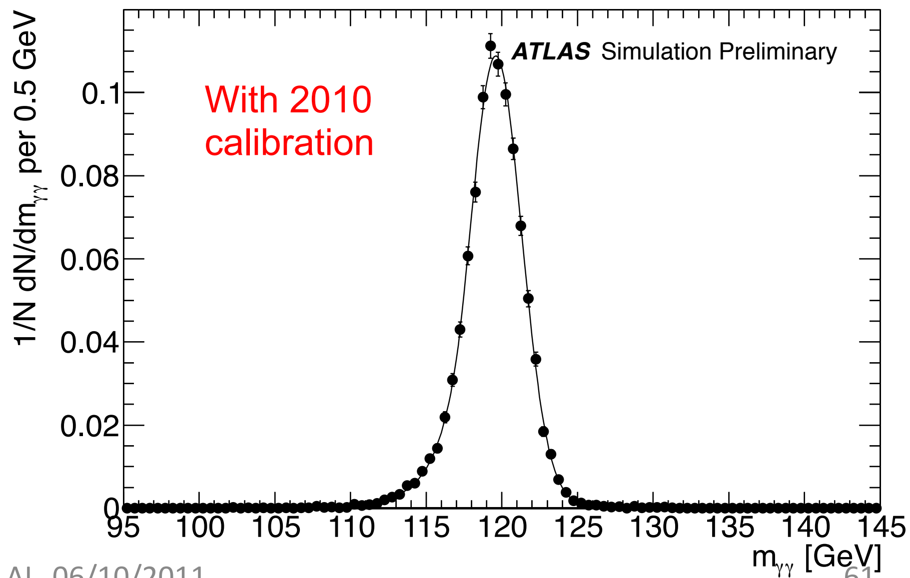
Transparence Calibration Crucial

$$\sigma \sim 1.6 \text{ GeV}$$



Calibration for Material Upstream important

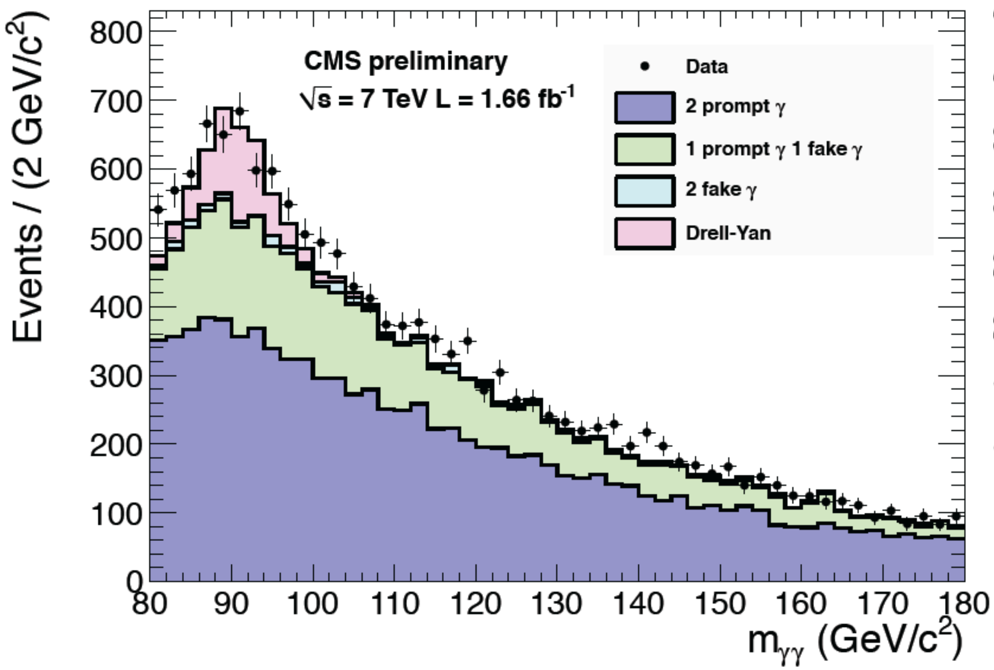
$$\sigma \sim 1.7 \text{ GeV}$$

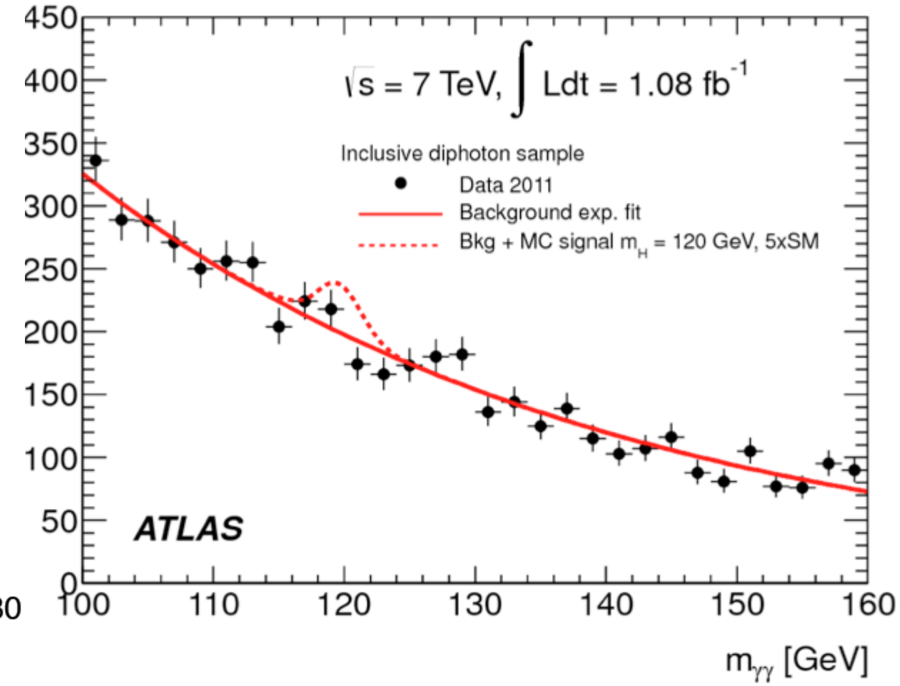


-Key features :

- -Invariant mass resolution
  - - Energy response characteristics of EM-Calorimeters
  - - Energy calibration
  - - Interaction vertex position (IP spread of 5.6 cm, assuming (0,0,0) adds ~1.4 GeV in mass resolution equiv. to the calo. M_{gg} resolution itself).

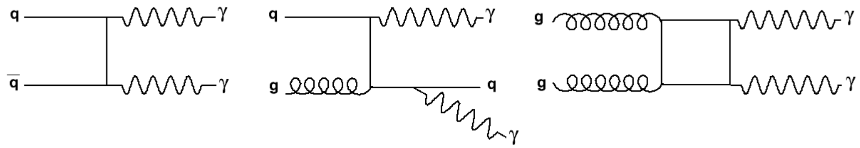
- Background rejection γ/π^0 also critical





- Backgrounds :

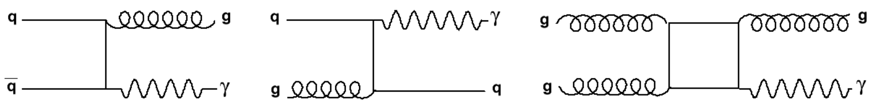
Irreducible background:



Born $O(\alpha^2)$ | Bremsstrahlung $O(\alpha_s\alpha^2)$ | Box diagram $O(\alpha^2_s\alpha^2)$

Theoretical uncertainty: ~ **25 %** (NLO: 20%)

Reducible background:



$O(\alpha_s\alpha)$ | $O(\alpha_s\alpha)$ | $O(\alpha^3_s\alpha)$

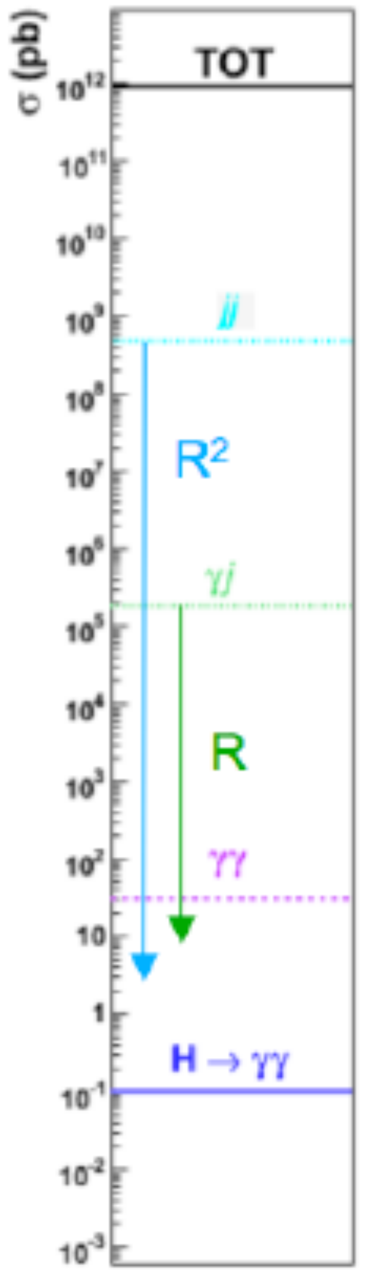
γ-jet $\sigma \approx 1.8 \times 10^5$ pb
jet-jet $\sigma \approx 4.8 \times 10^8$ pb

γ-jet **need rejection R~O(10 [4])**
jet-jet need rejection R~O(10 [7])

Main background from leading π^0 Fragmentation

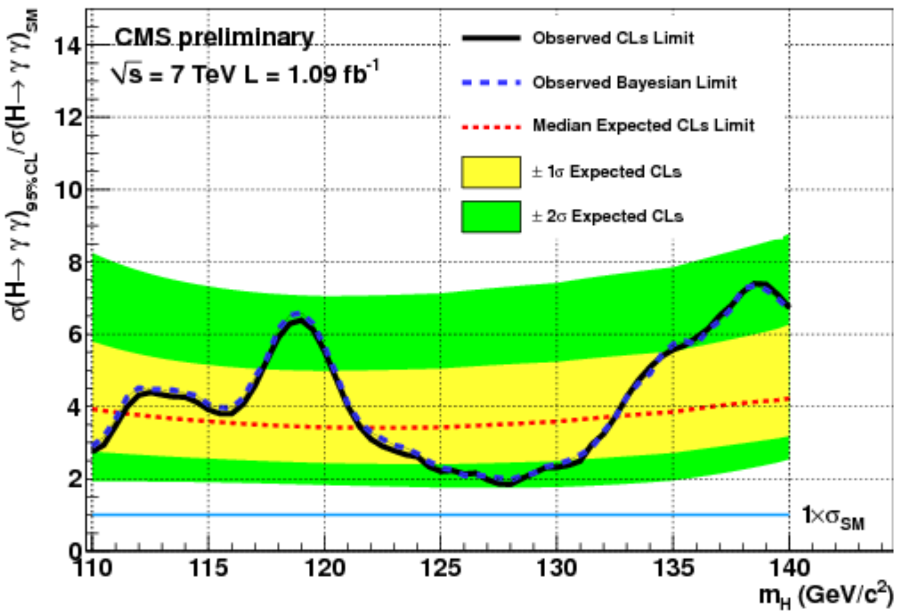
Theoretical uncertainty: ~ **30%** (dominated by NLO cross-section)

Purity measured on data, typically ~70% !

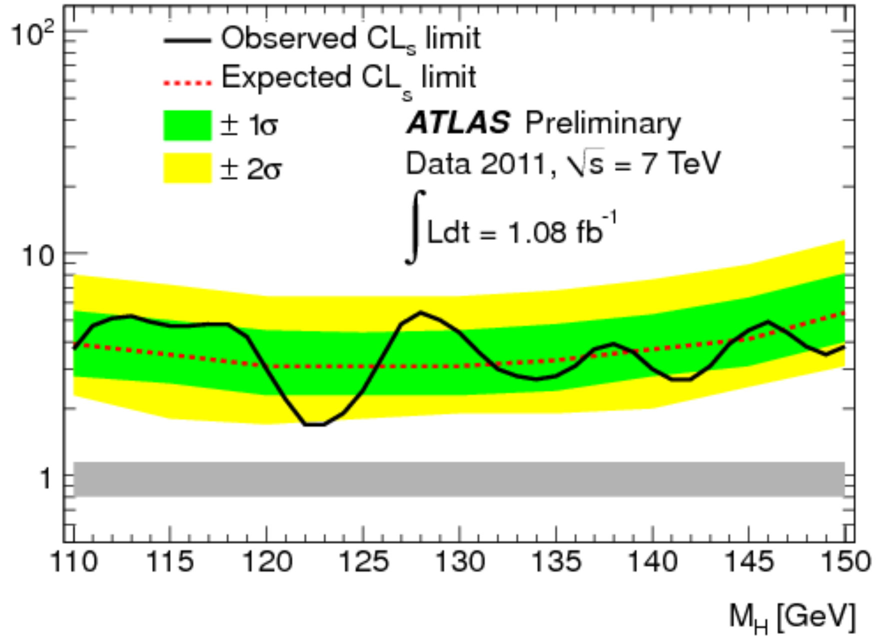


R ~ O(8000)

EPS

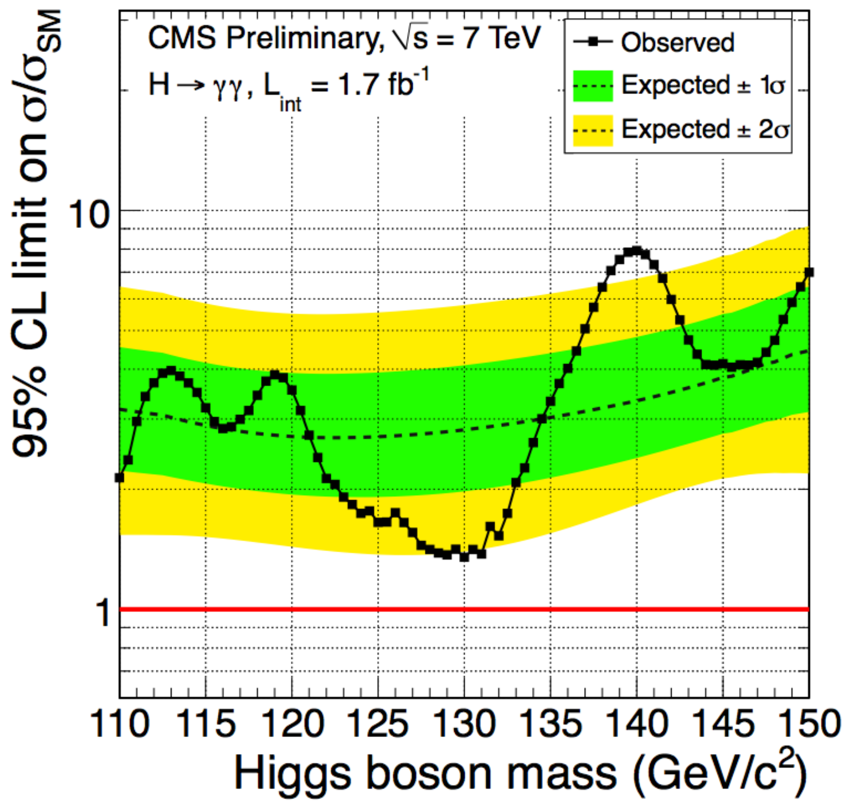


EPS

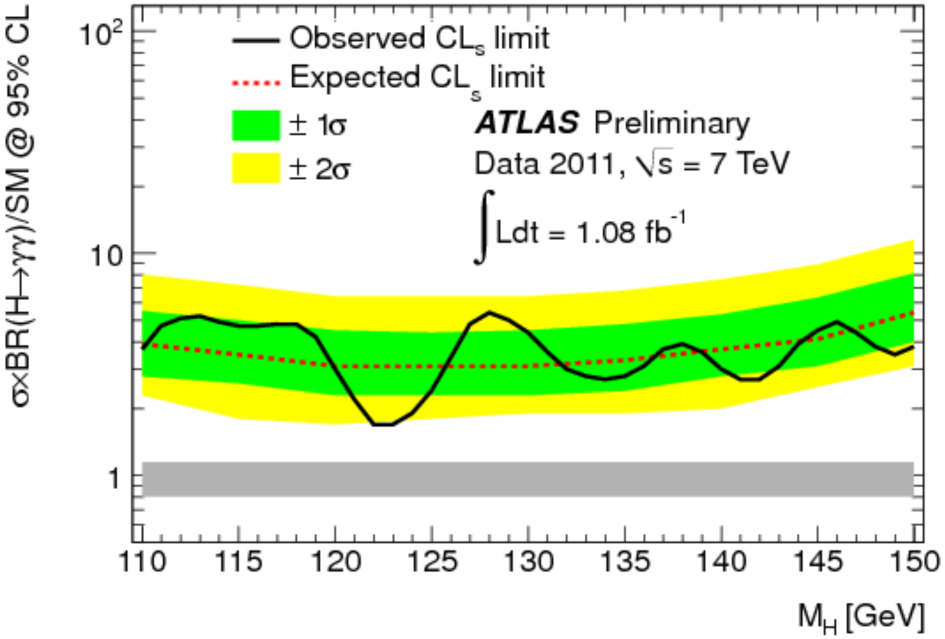


- ATLAS and CMS very similar performance
- Main differences between ATLAS and CMS (very similar analyses) :
    - Use of $P_T^{\gamma\gamma}$ categories
    - Electron/Muon minimum pT requirement (ATLAS 15/7 GeV/c and CMS 7/5 GeV/c)
    - Different lepton ID efficiencies?

LP



EPS



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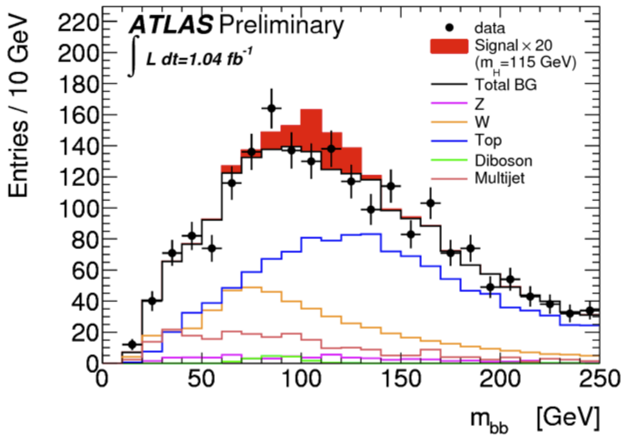
    - Different lepton ID efficiencies?

Higgs Boson Search in the VH, H→bb
(ATLAS)

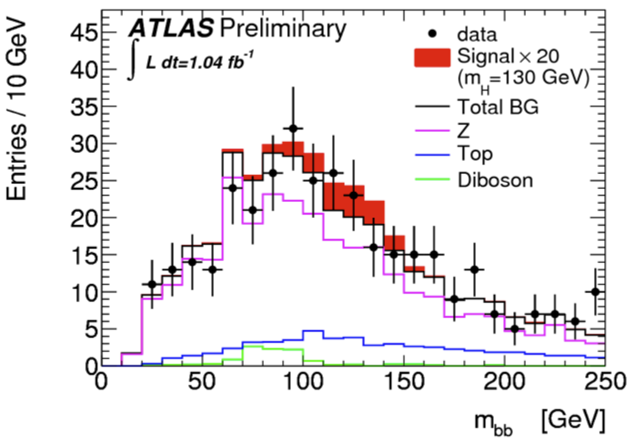
- At the heart of a completely new analysis trend : Jet substructure (Not yet applied)

- Not as strong as the diphoton but important to gather information about the couplings.

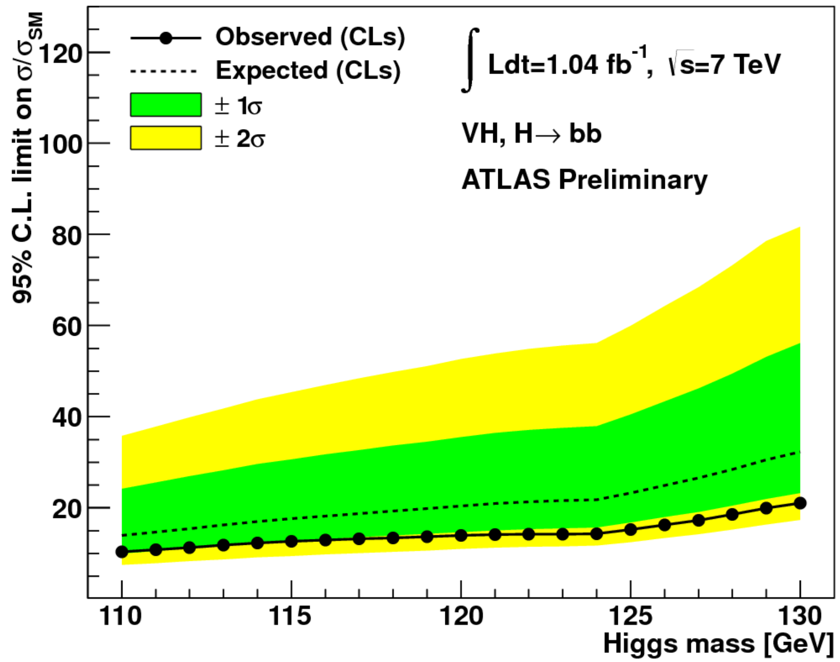
- Backgrounds are estimated from control samples :



WH main bkg :
-Top prod.
-- W+jets



ZH main bkg :
Z+jets

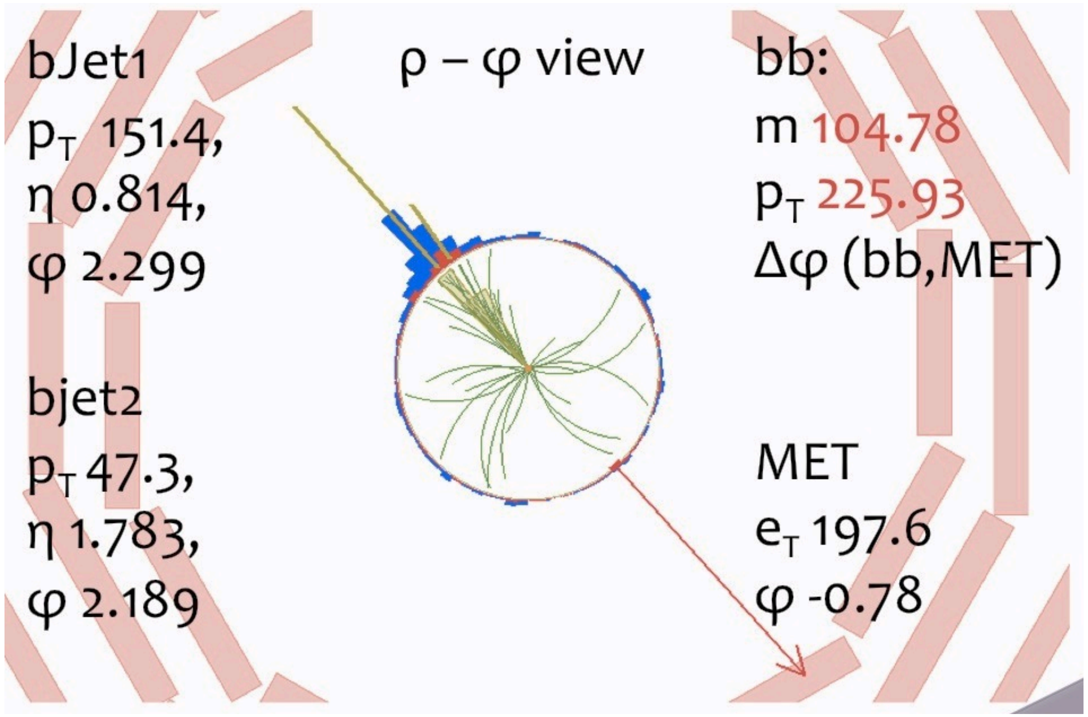


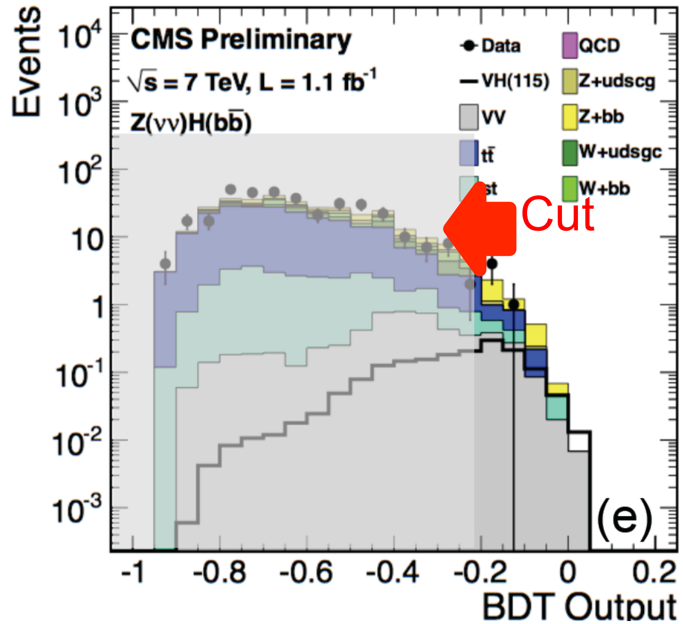
Sensitivity ~15 x σ_{SM}
Limit ~10-15 x σ_{SM}

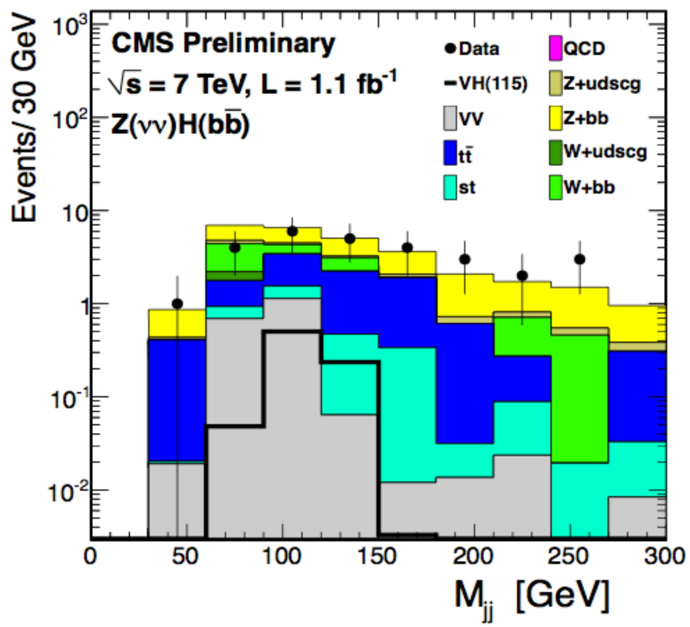
Higgs Boson Search in the Boosted VH, H→bb
(CMS)

3 Channels (llbb,lνbb and ννbb)

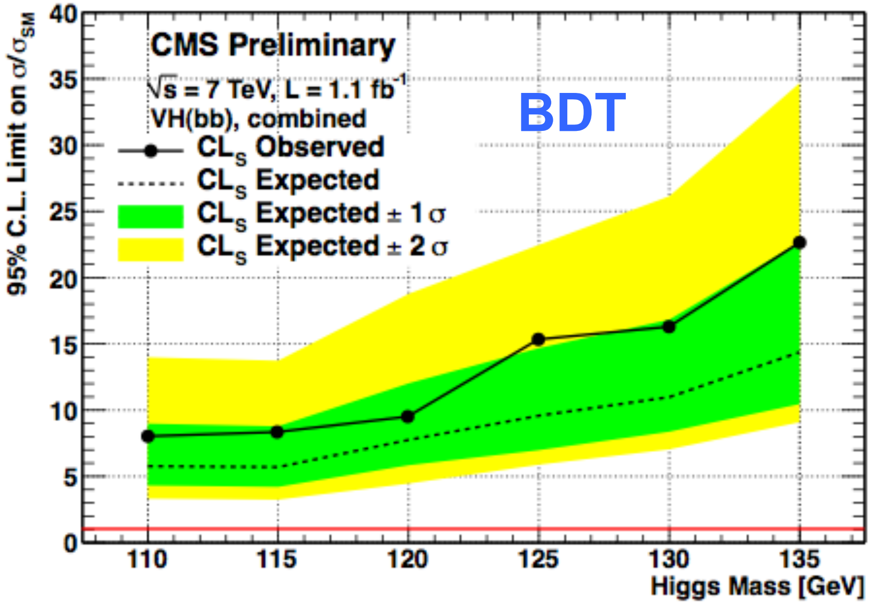
- $P_T(V)$> 100-160 GeV (boosted W/Z)
- VH topology : ΔΦ(V,H) > 2.9-2.95
- Tight b-tagging & MET quality
- Backgrounds estimated from control data
- Two approaches BDT and M_{jj}

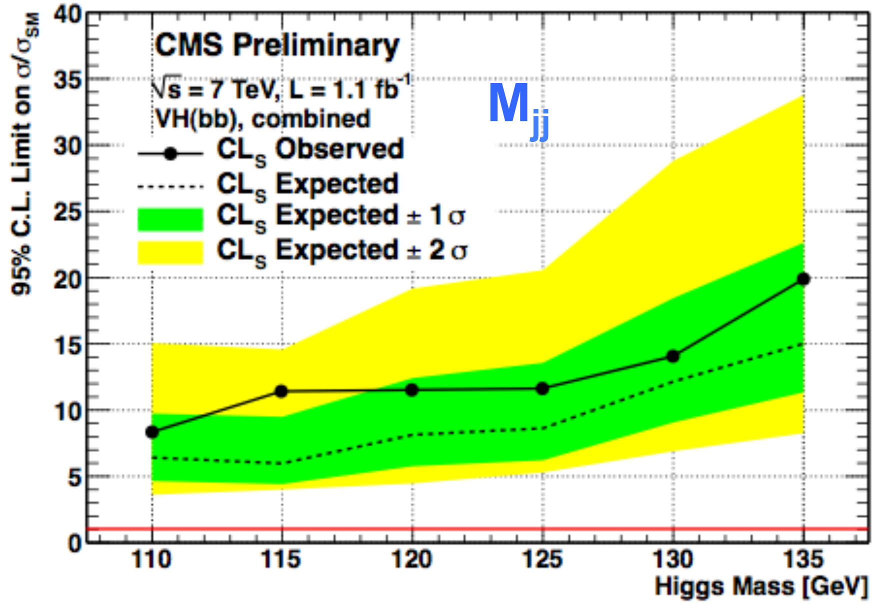






Higgs Boson Search in the Boosted VH, H→bb
(CMS)



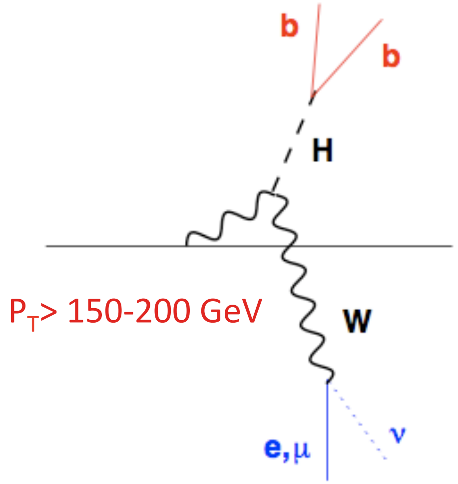


Main differences between ATLAS and CMS :

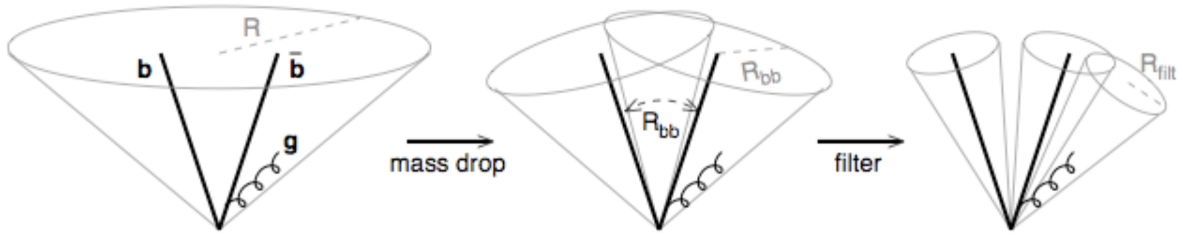
- Boosted analysis (not yet substructure analysis) in CMS
- Use of BDT in CMS
- bbνν channel in CMS

Jet Substructure

- Use Higgs only at high p_T to improve acceptance and reduce bkg.
- The Higgs would be a single jet, then investigate the jet structure, RECIPE :



Butterworth, Davison, Salam, Rubin



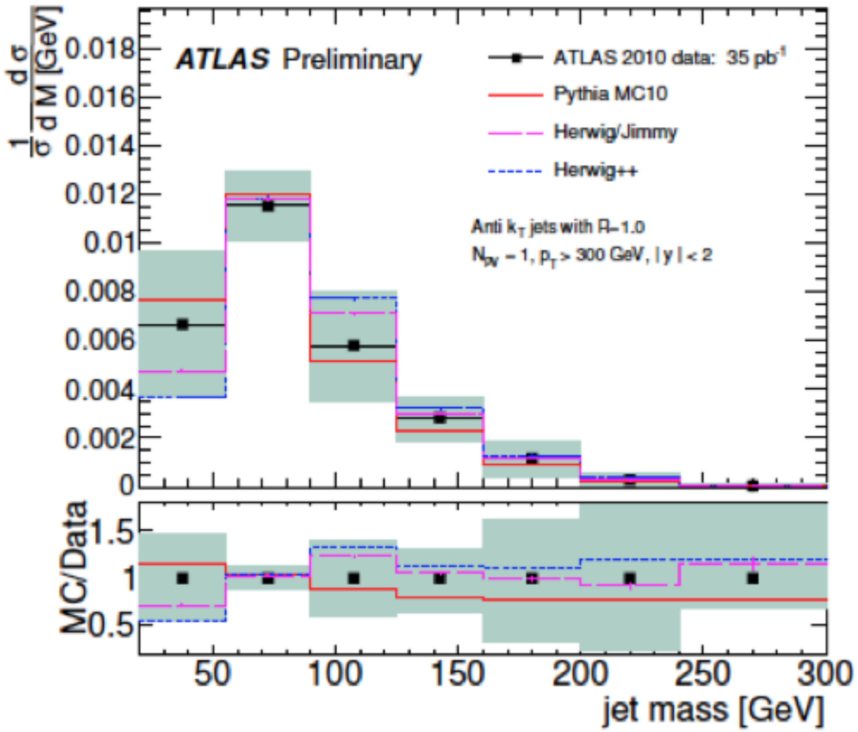
Fat jet
With mass m

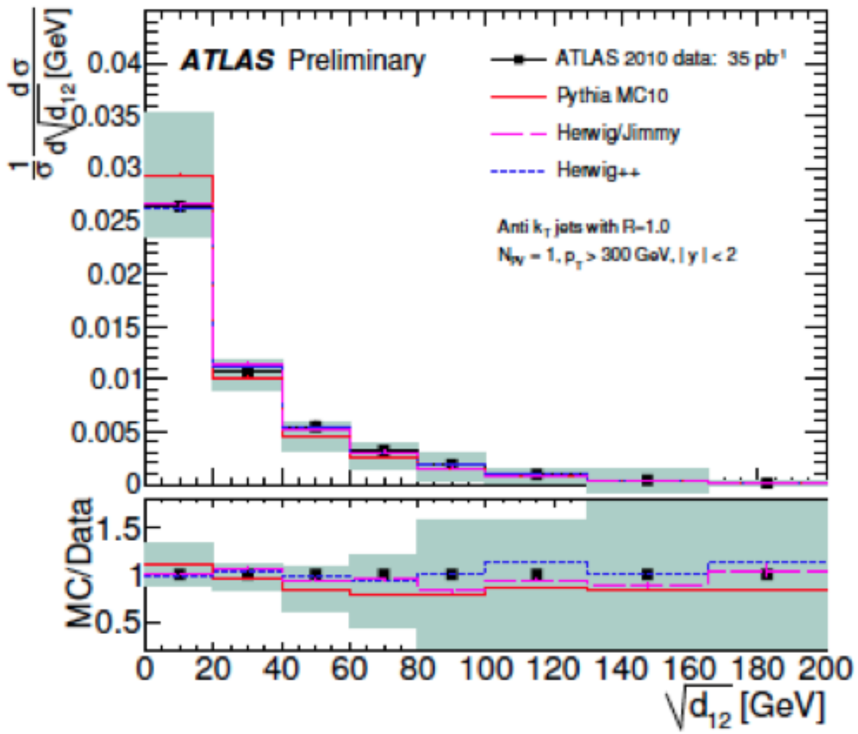
- Use the Cambridge-Aachen jet algorithm Dokshitzer et al. 97'
  (Clustering based on the R-distances between objects, iterate until $\Delta R>1.2$)
- Undo the last stage of clustering defining J_1 and J_2
  If $\max(m_1,m_2) < 2m/3$ then there is a "mass drop"
- If there is a mass drop apply b-tagging
- Then recluster using a $R_{filt} = \min(0.3, R_{J1,J2})$

First Steps Towards Jet Substructure

- Further checks in Jet Mass and splitting scale (checking Shower models) :

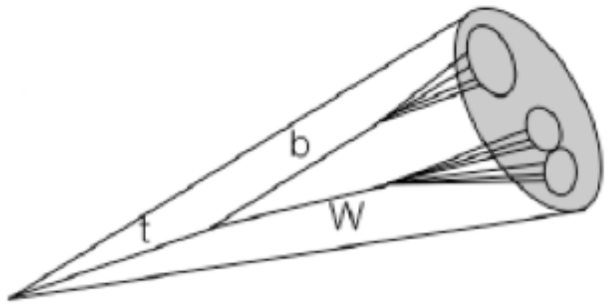
$$\sqrt{d_{12}} = \min(p_{T,1}, p_{T,2})\delta R_{12}$$

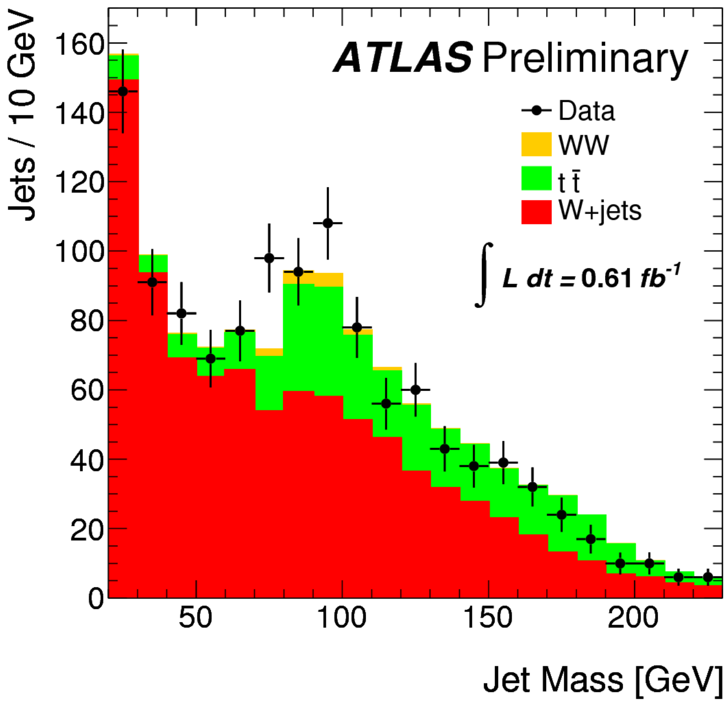


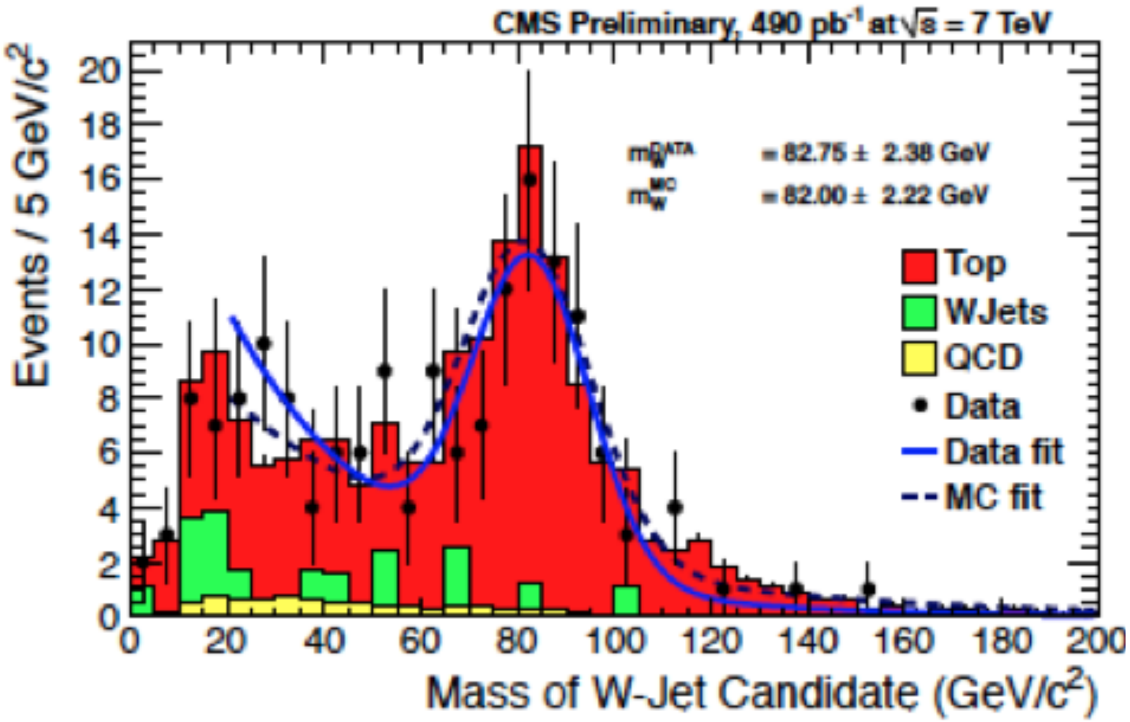


Fat-Top-Jet Samples

- Very encouraging first results (top-jet) :

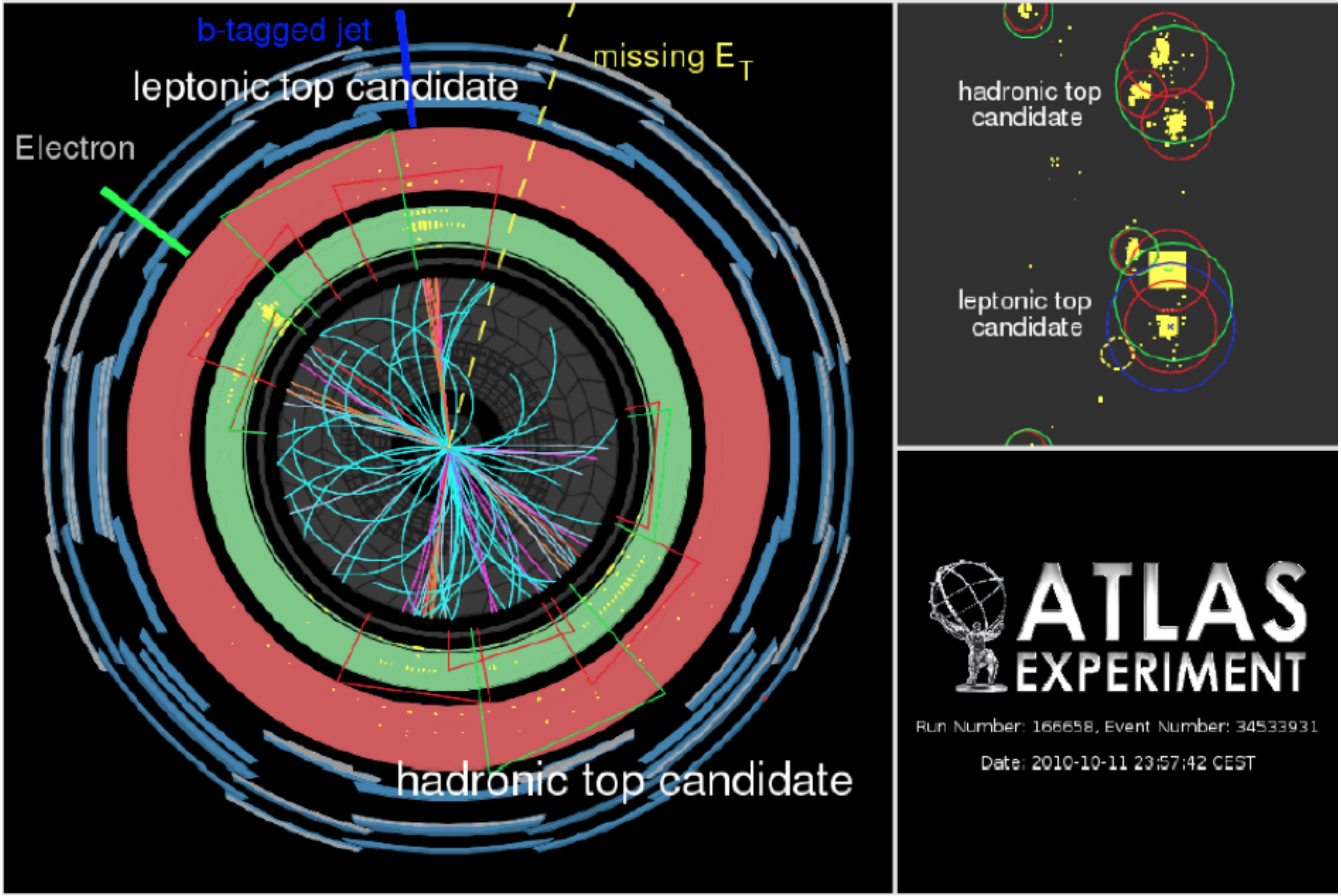






CMS with b-tagging !

Hadronic Top Candidate (E_T = 356 GeV, 3 subjets, M=197 GeV)



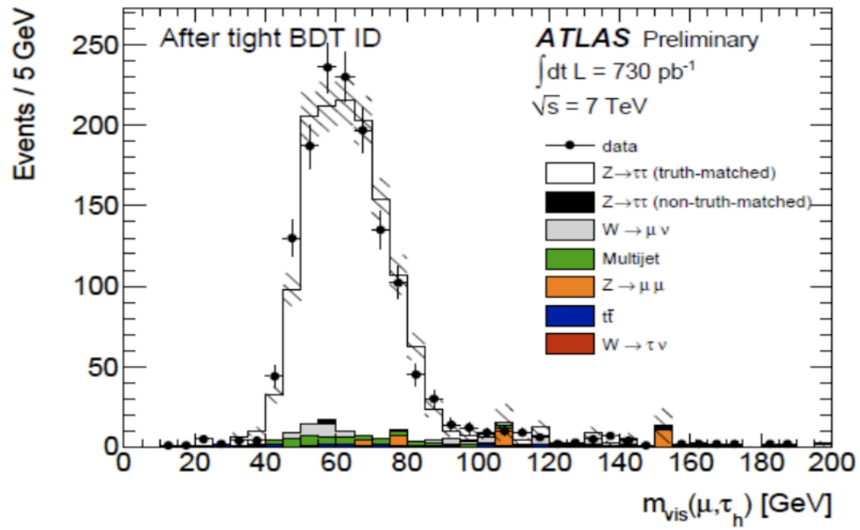
Inclusive H→ττ Search

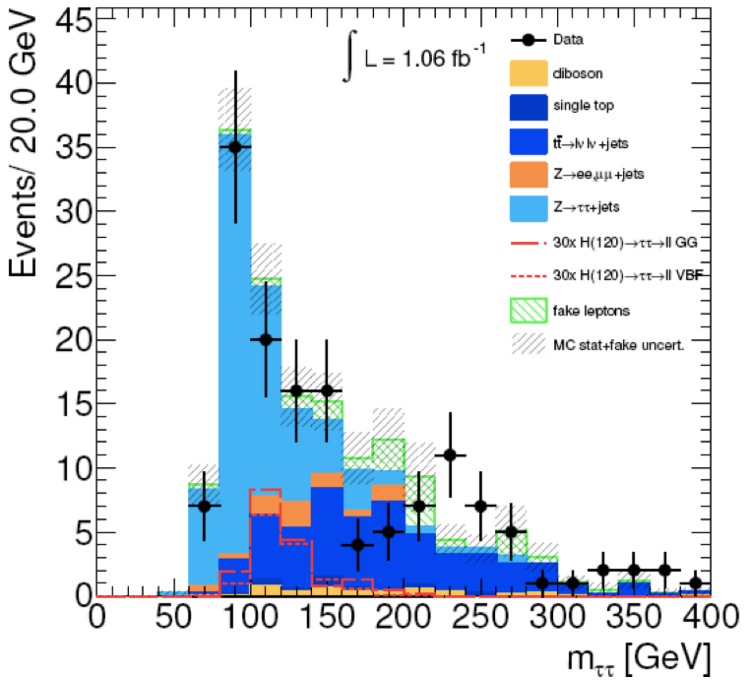
- W and Z Cross sections in taus measured in CMS and ATLAS.

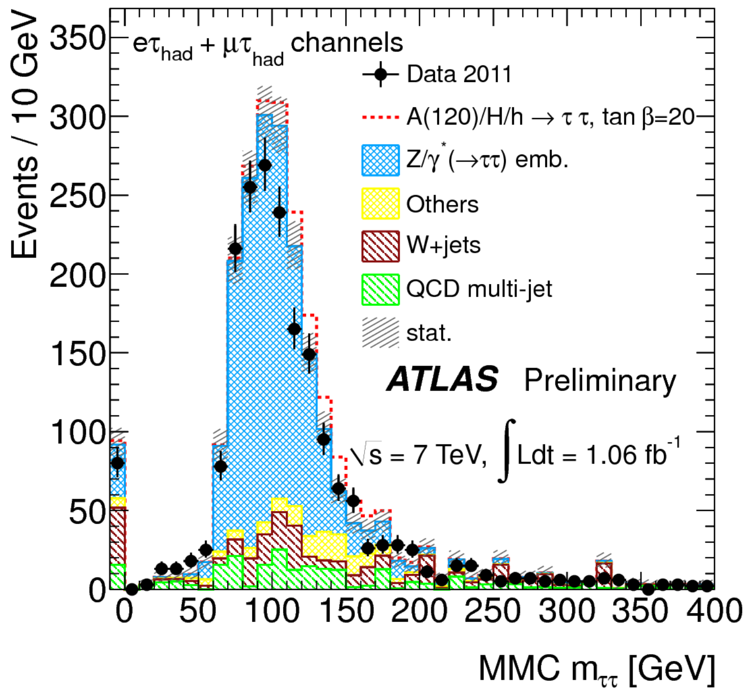
- New Mass reconstruction techniques lead to improved mass resolution even when collinear approximation not fully efficient (MMC).

- New perspectives in SM inclusive searches.

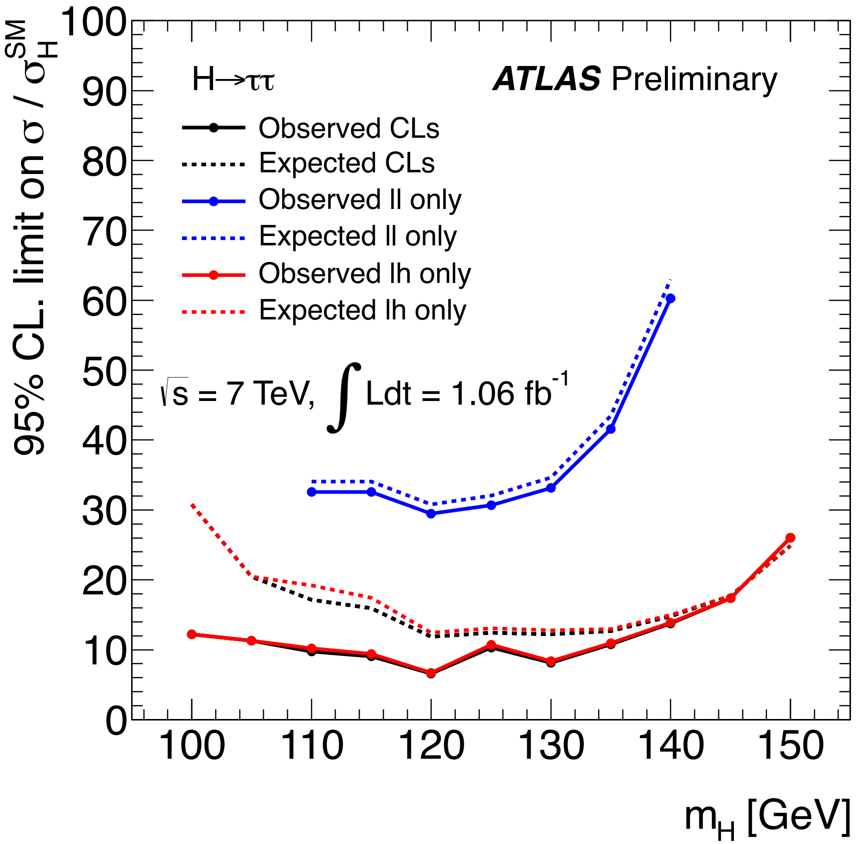
- Background estimated using embedding techniques (partially data-driven)

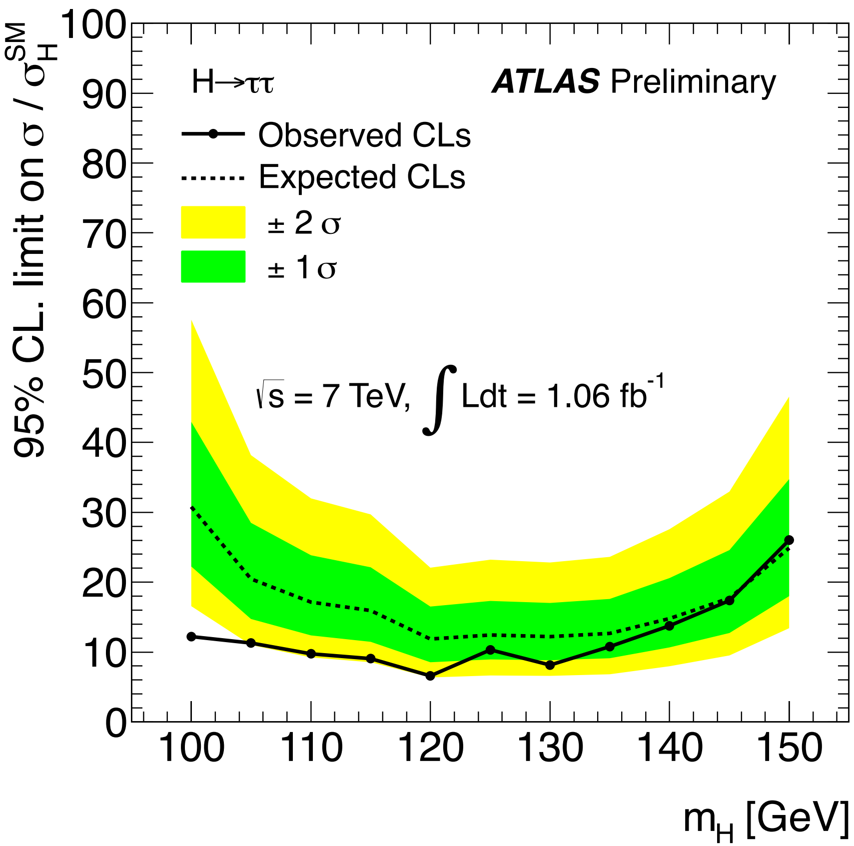






Inclusive H→ττ Search

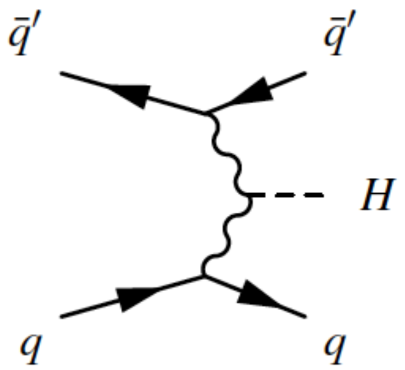


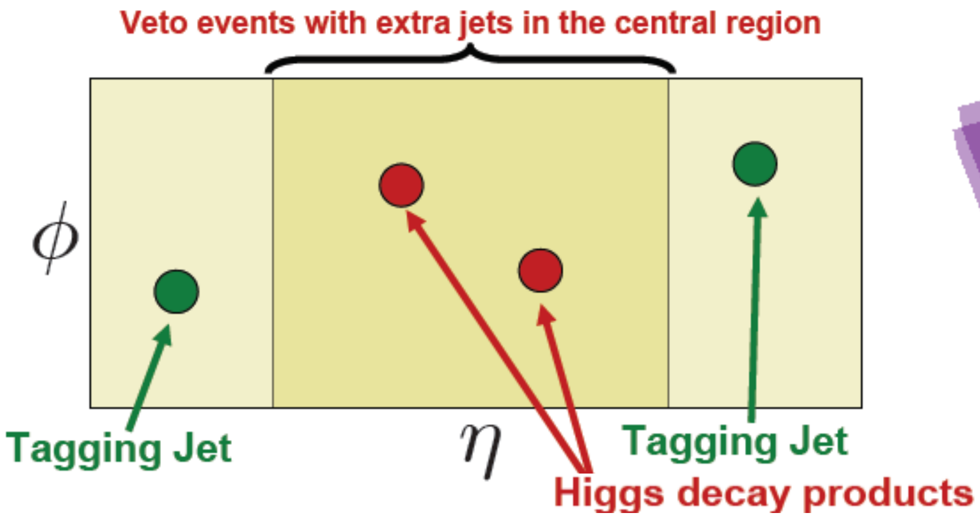


- Still not very sensitive
- Background dominated by Z events (with a small contribution from top)

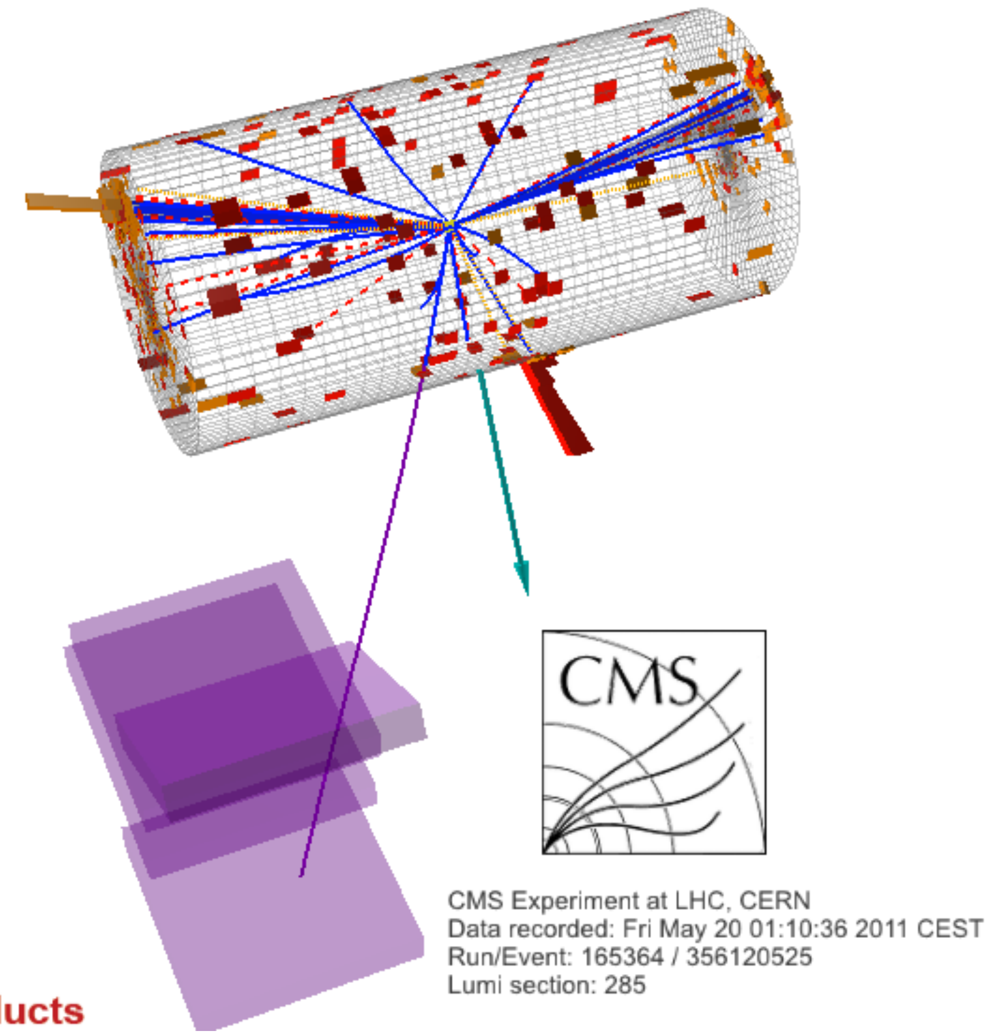
Higgs Boson Search in the VBF H→ττ (CMS only)

- VBF features in CMS to improve purity and sensitivity (to reject Z background)

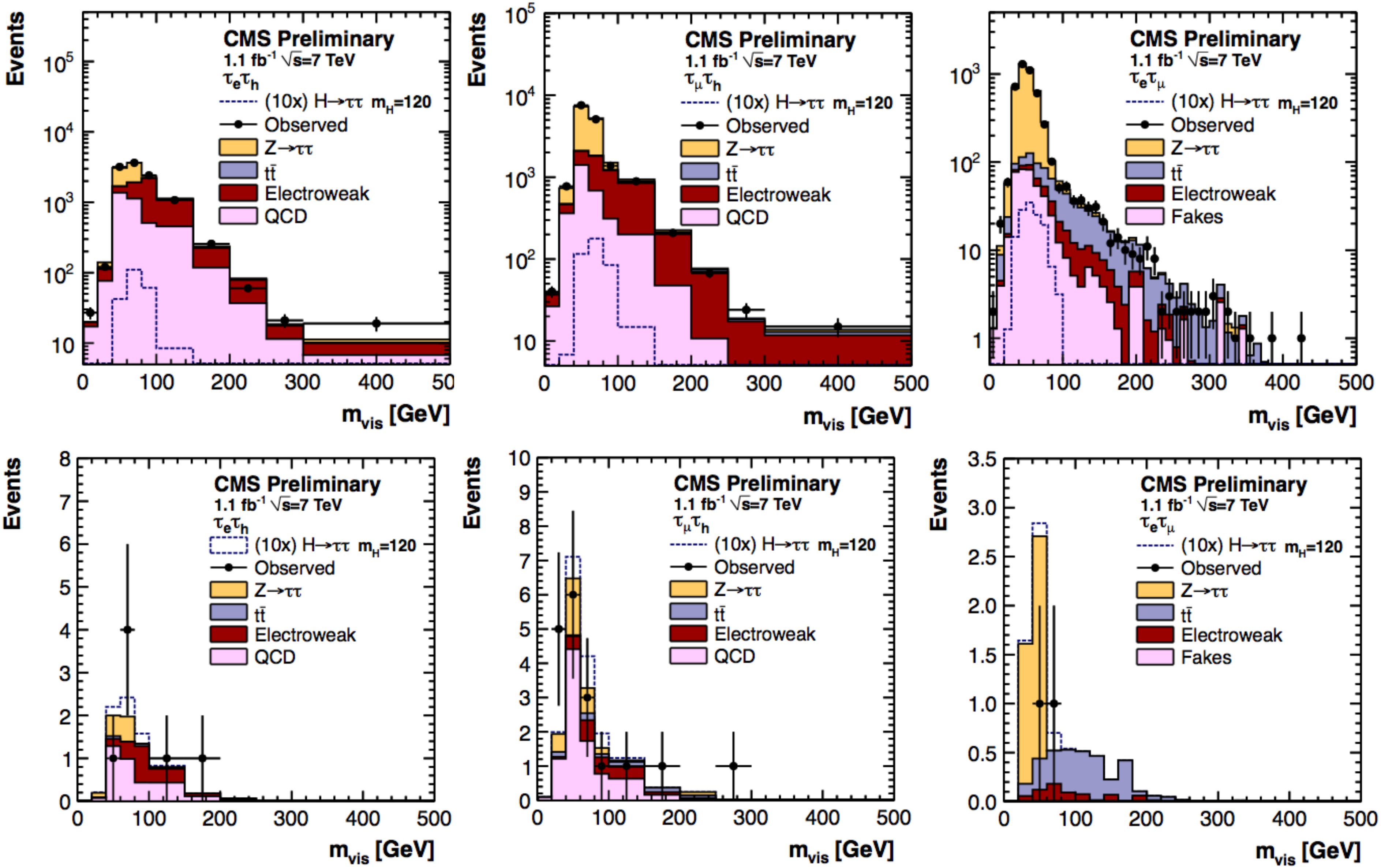




Textbook Event

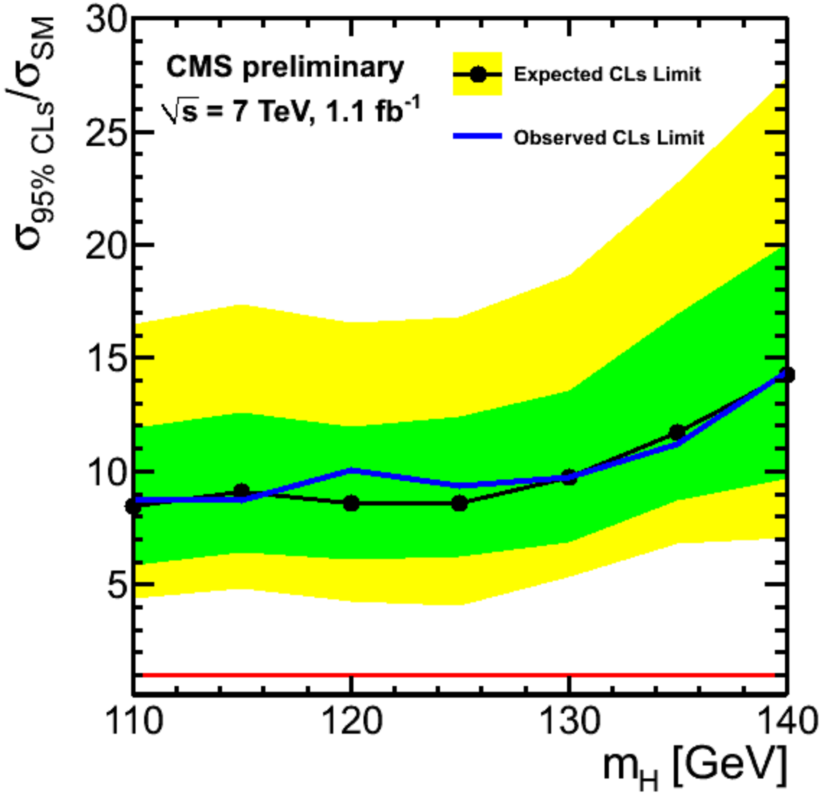


Higgs Boson Search in the VBF H→ττ
(CMS only)



Higgs Boson Search in the VBF $H \rightarrow \tau\tau$
(CMS only)

- Nice rejection properties verified.
- Only visible mass used in this analysis
- Results should improve with new mass reconstruction methods but not drastically as it is already VBF!
- Caution : Sensitive to pile-up!



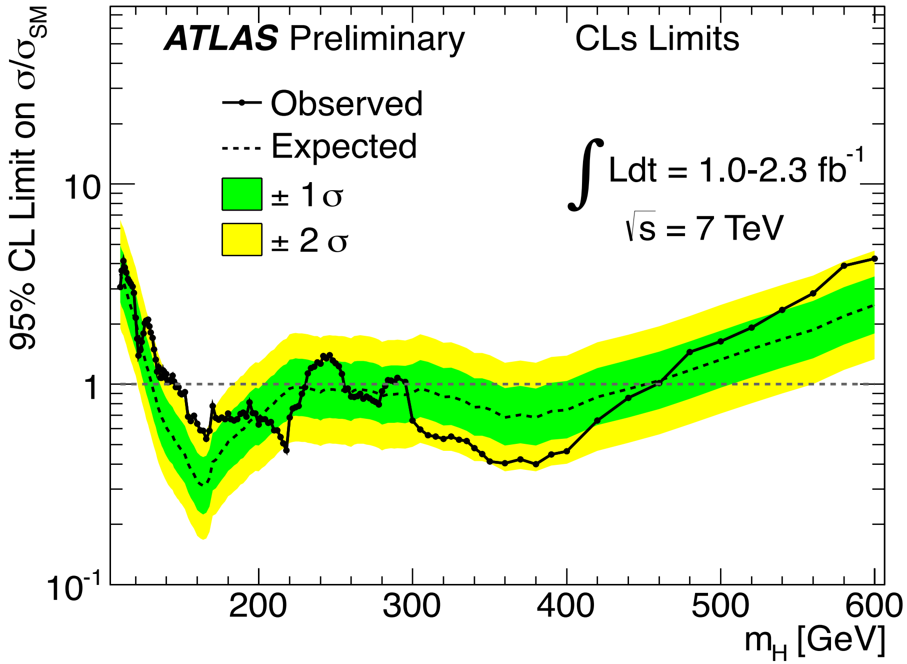
- Main differences between ATLAS and CMS (very similar analyses) :
    - Use of VBF production features (CMS)
    - Use of new mass reconstruction technique (inclusive analysis – ATLAS)

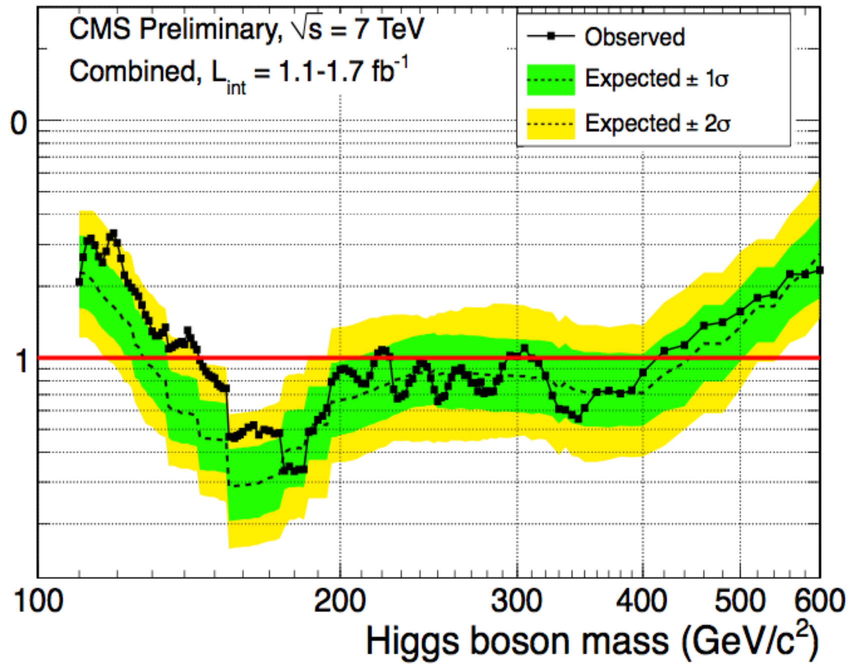
Combination

Combination of All Channels

The ATLAS and CMS Combinations

A new landscape of Higgs Exclusion has Emerged!





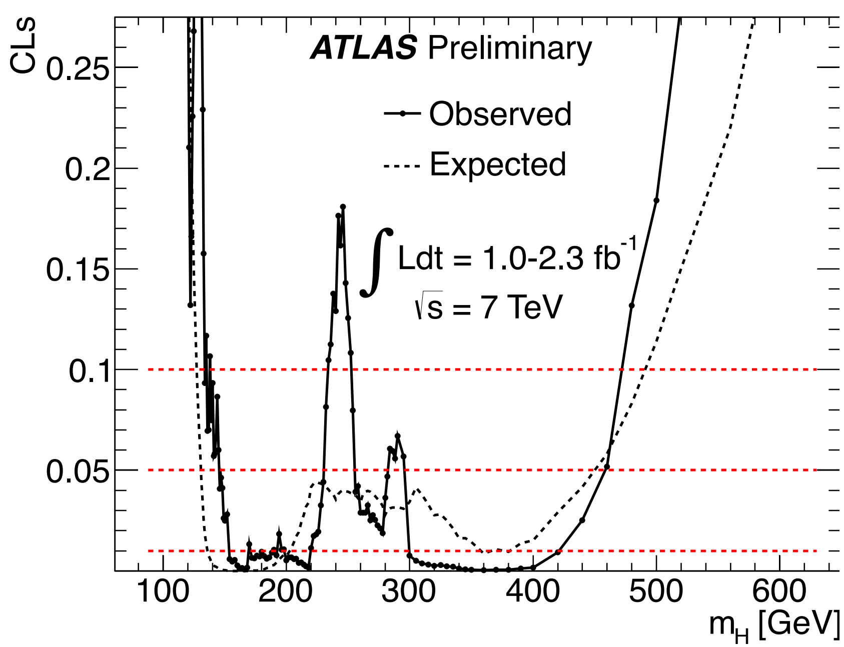
Expected : 131 – 450 GeV
Observed : 146-230, 256-282, 296-459 GeV

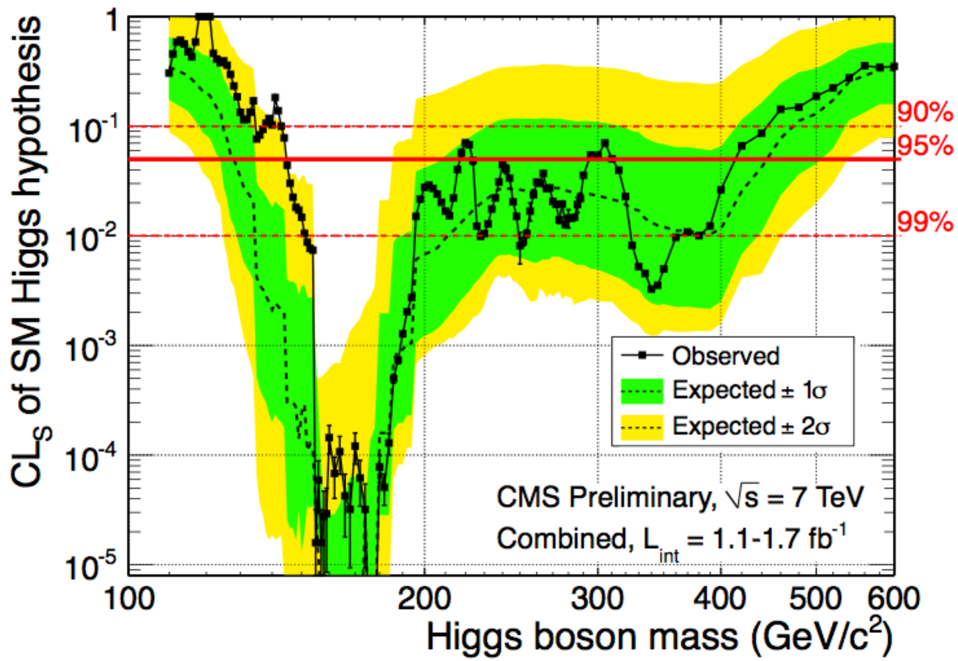
Expected : 130 – 440 GeV
Observed : 145-216, 226-288, 310-400 GeV

Combination of All Channels

The ATLAS and CMS Combinations

A new landscape of Higgs Exclusion has Emerged!

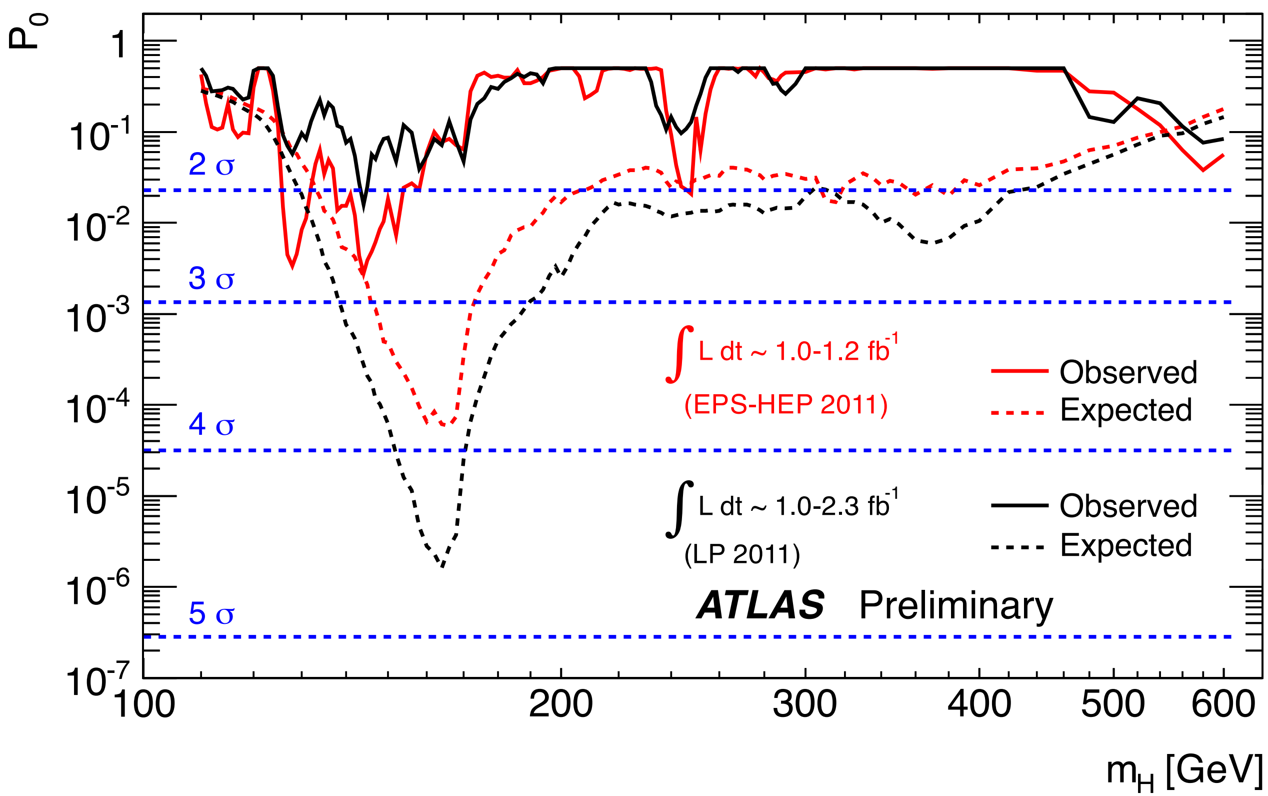




Significant Excesses?

In ATLAS…

Estimator for a discovery : Probability for a background only experiment to be more signal-like than observed!

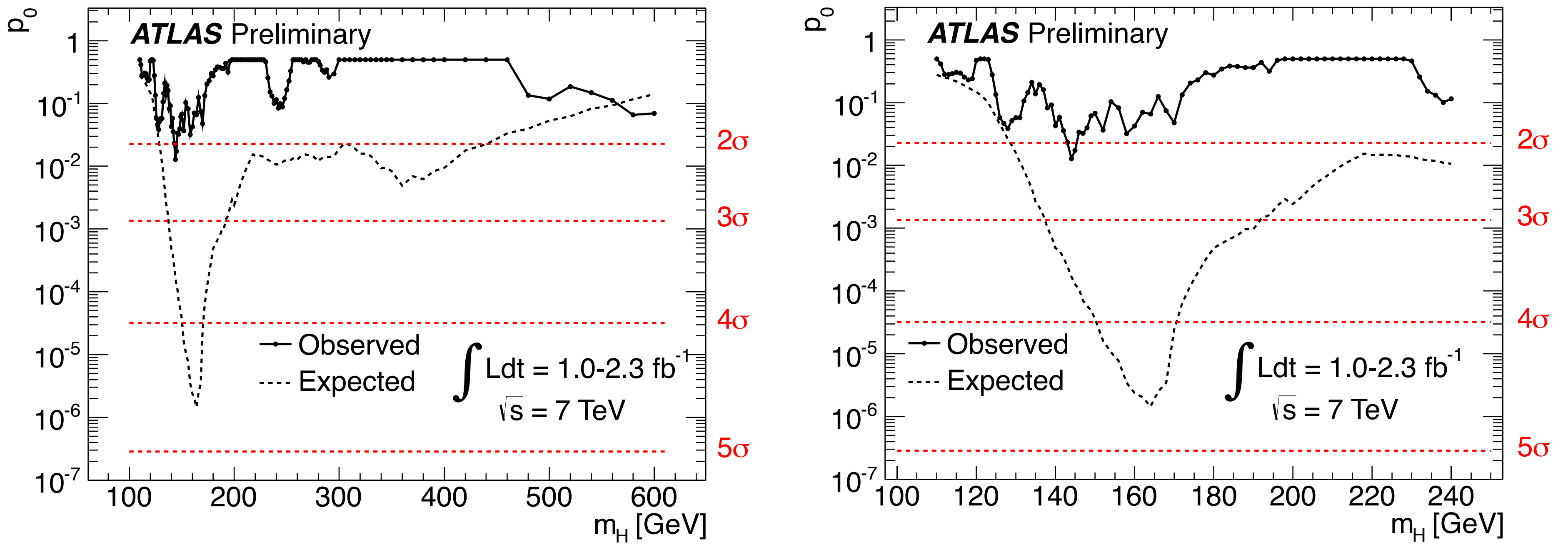


Beware of the trial factor (factor of ~O(40)) !

Closer Look at the LP Result

In ATLAS…

Estimator for a discovery : Probability for a background only experiment to be more signal-like than observed!



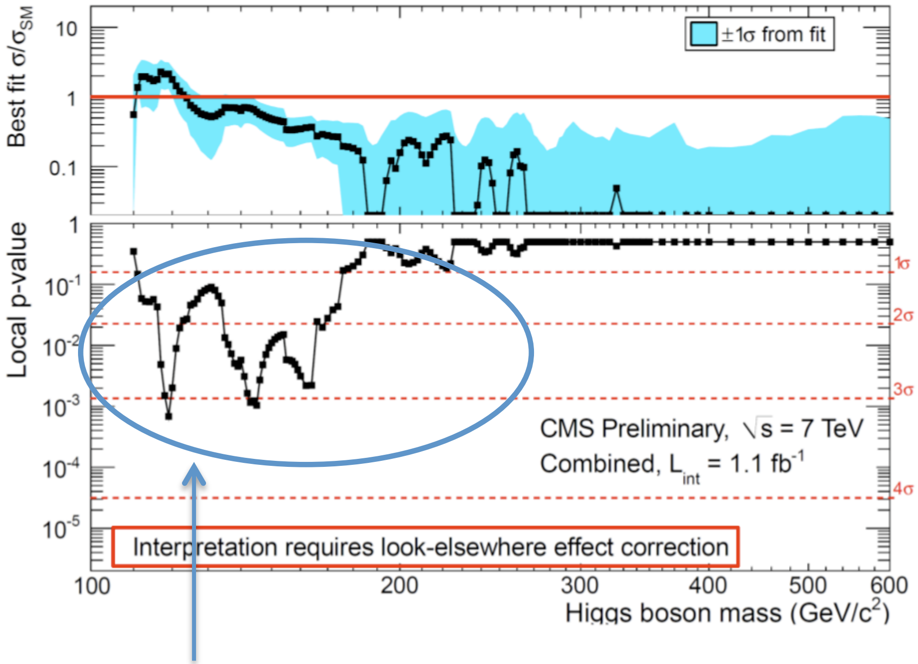
No significant excess seen anymore (at most ~2σ)

Significant Excesses?

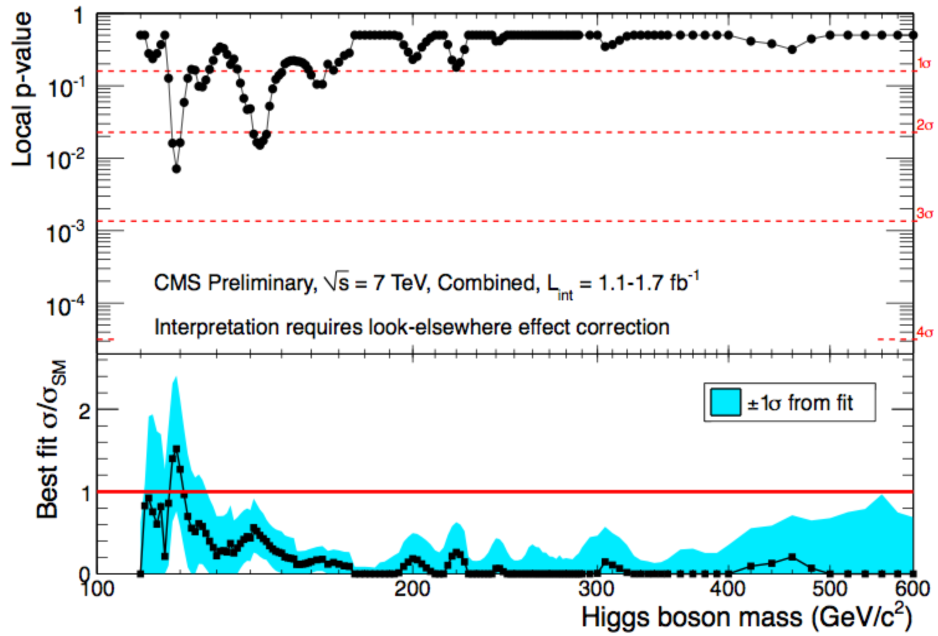
In CMS…

Estimator for a discovery : Probability for a background only experiment to be more signal-like than observed!

EPS

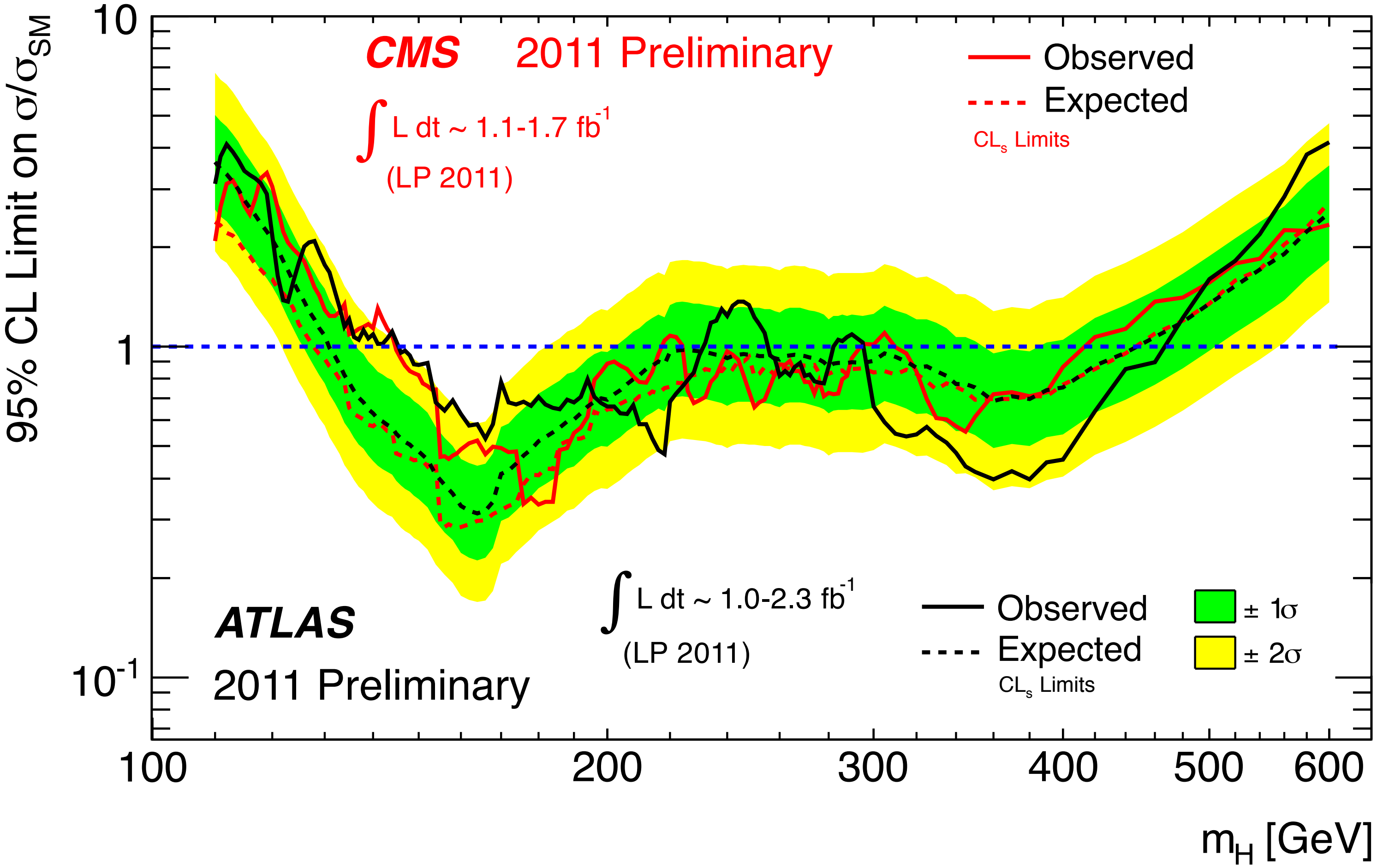


LP

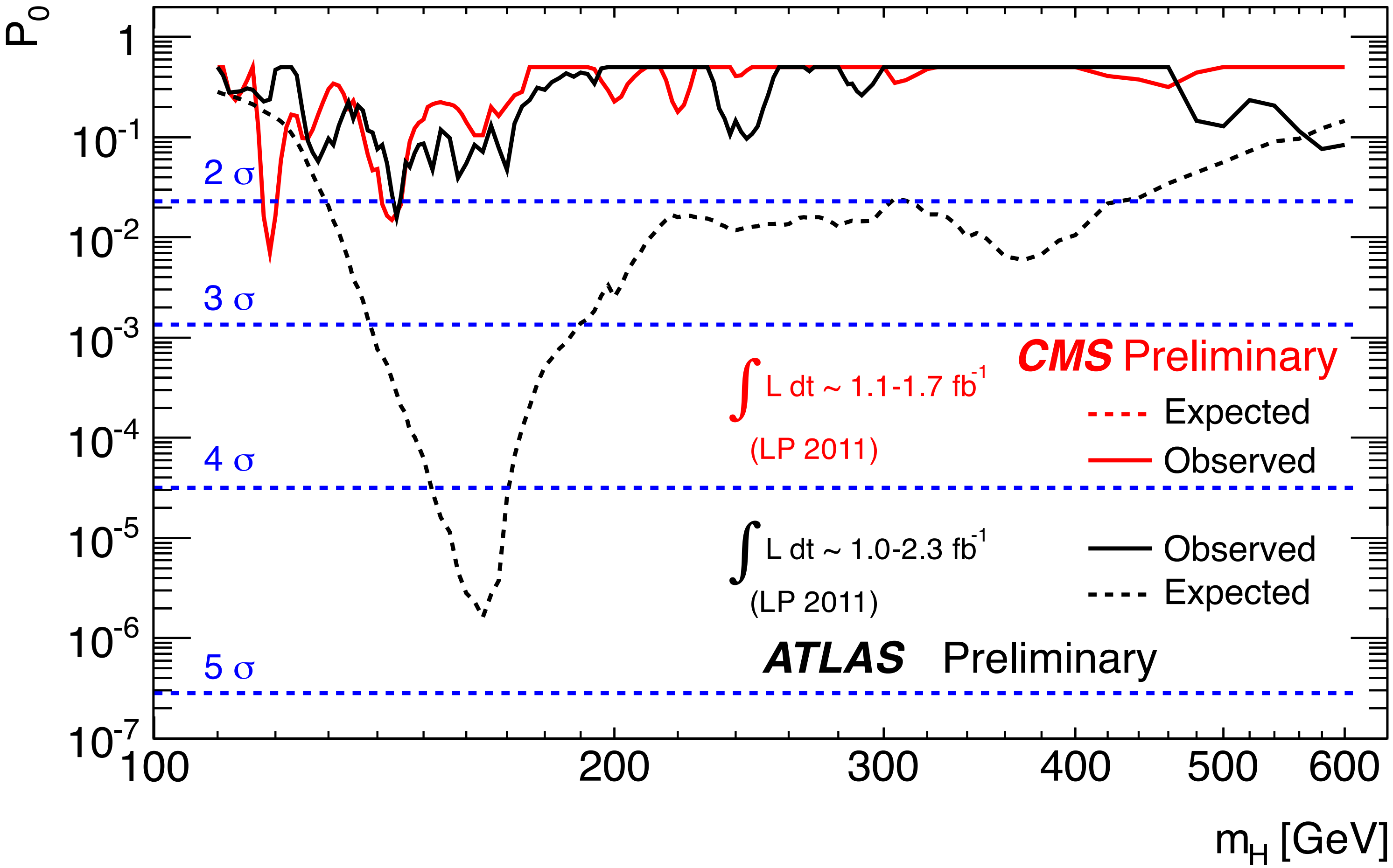


Trial Factor Needed!

ATLAS and CMS



ATLAS and CMS



Lessons from Latest LHC results

Outlook from Theory (D. Gross) - EPS -

1.- The Standard Theory (EW and QCD) is unbelievably successfull*

2.- Rapidly closing in on the Higgs**

3.- Colored sparticles are not around the corner

4.- No sign of (easily discoverable) new physics

* At LHC NNLO calculations and the entire NLO ME/PS toolkit are now mature and have proven to work beautifully.

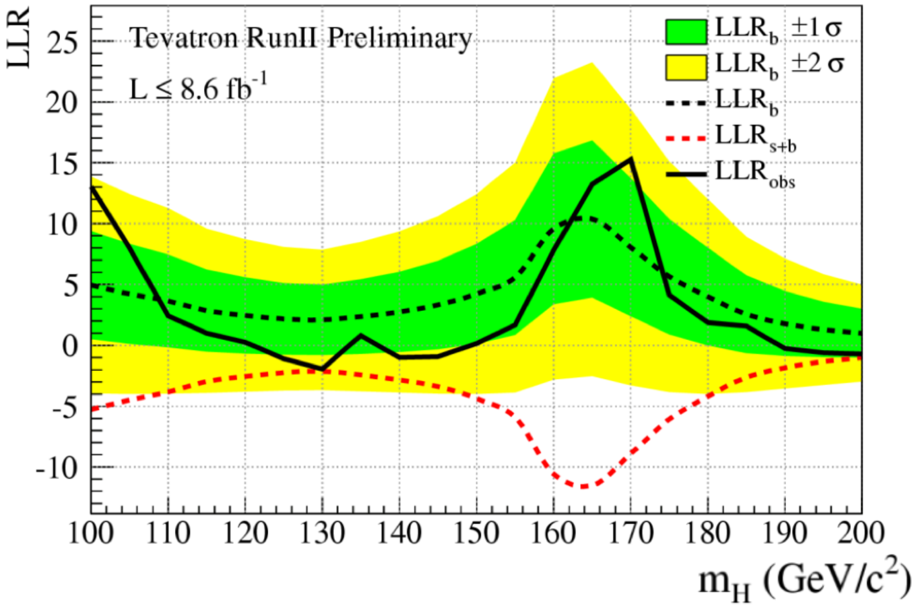
** The Landscape of Higgs search exclusions has drastically changed

Apologies for the very large number of subjects that have not been shown in this talk, there are a lot!

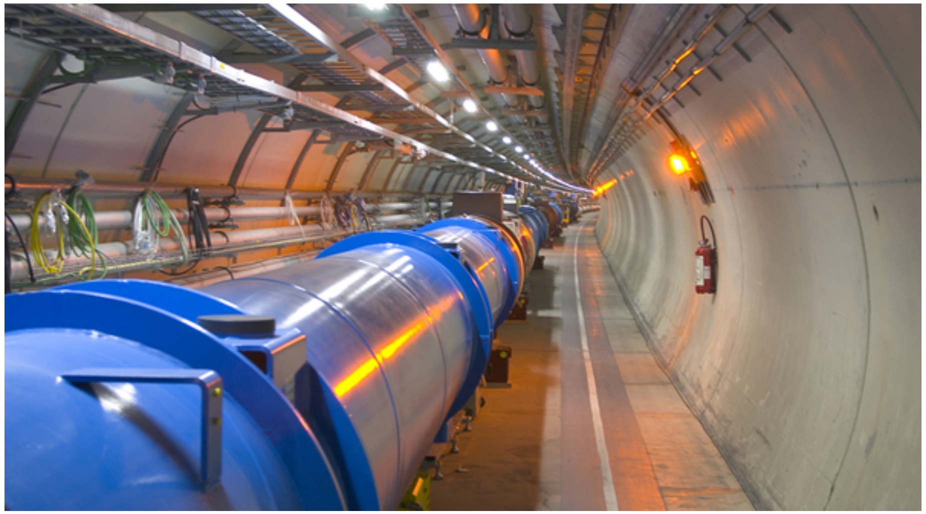
Outlook

What Next?

The Tevatron, the world's highest-energy proton-antiproton collider, has shut down on Sept. 30, 2011.



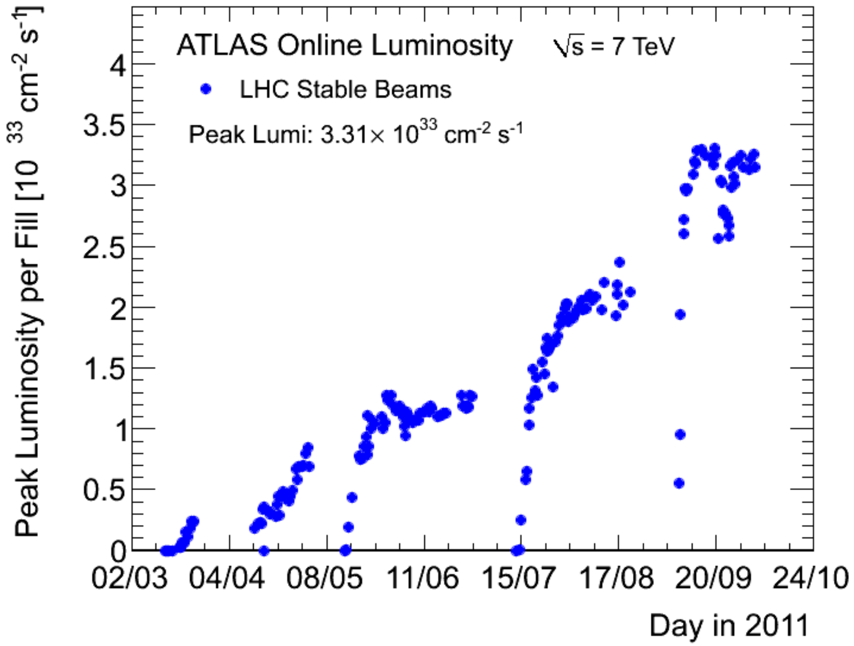
Year	Lumi	Total	c.o.m. Energy
2011	5	5	7 TeV
2012	10-15	15-20	7-8 TeV
2013	LS1	15-20	LS1
2014	LS1	15-20	LS1
2015	>10	>25	>12 TeV



What Next by the End of the Year?

By end of october, per exp. 5 fb^{-1}

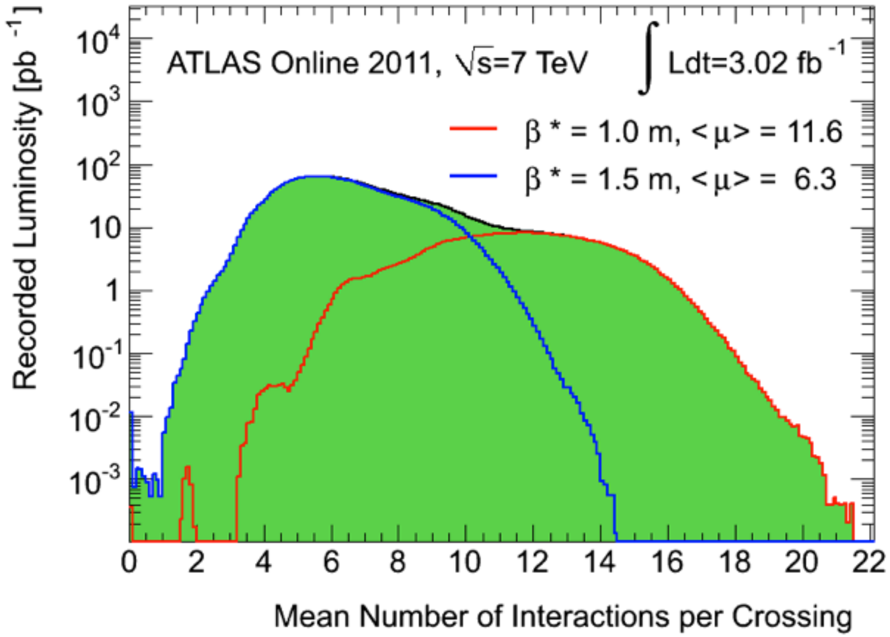
- New runs at higher luminosity…



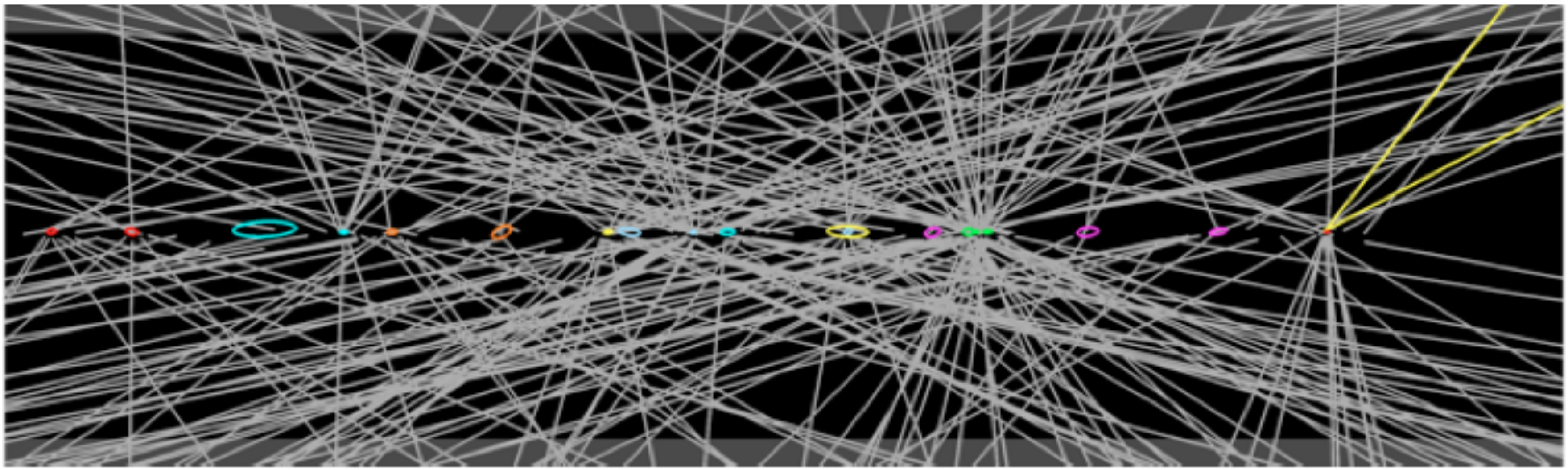
What Next by the End of the Year?

By end of october, per exp. 5 fb^{-1}

- New runs at higher luminosity…
- Much higher PU!



Recent event with 15 Vertices



What Next by the End of the Year?

By end of october, per exp. 5 fb^{-1}

Undisclosed Information

ATLAS & CMS combination should be sensitive most of the available mass range for exclusion this year… almost possible for each experiment (modulo improvements)

What About Now?

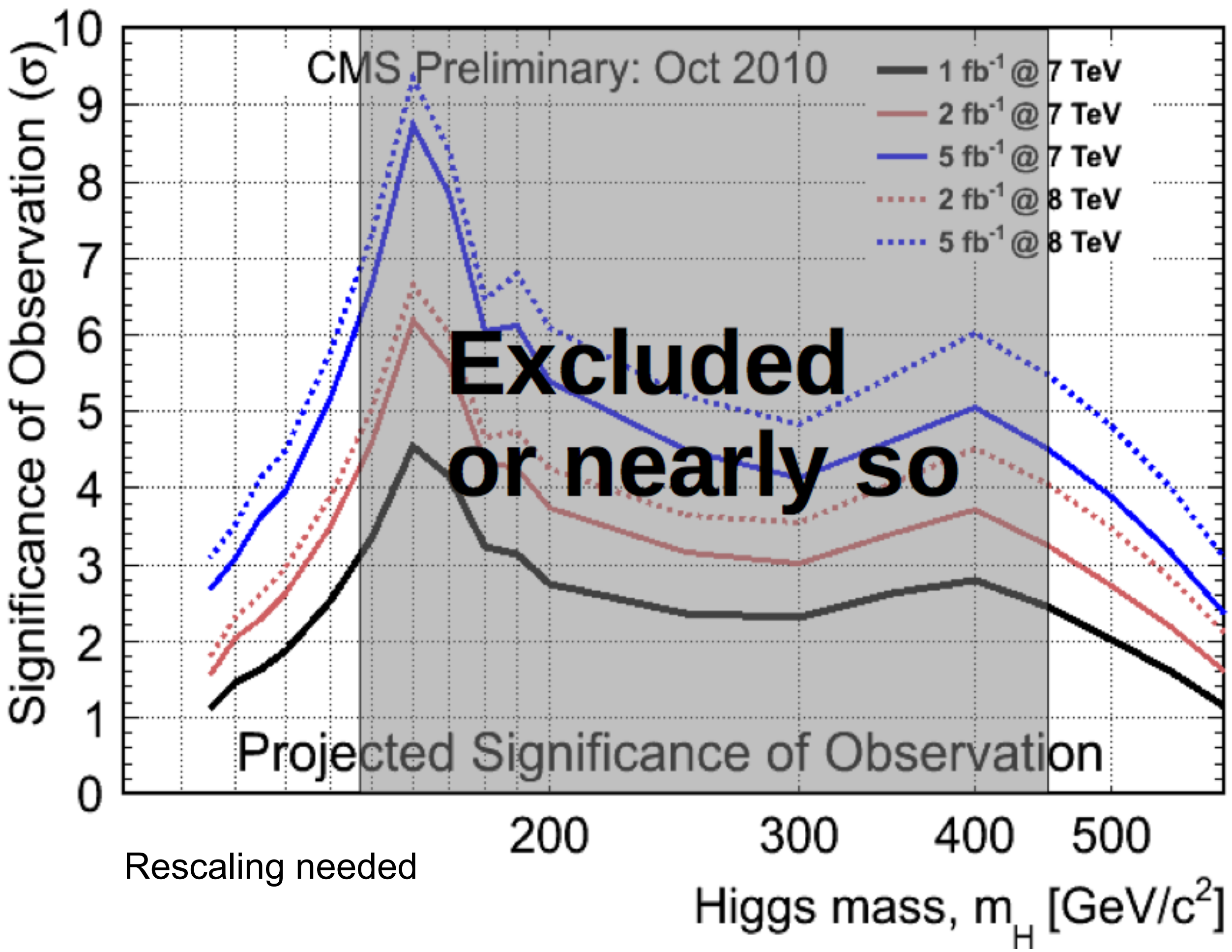
… with Tevatron …

Undisclosed Information

ATLAS, CMS & TeVatron combined is sensitive in the entire low mass range…

…and by LS1?

By end of 2012, per exp. 15-20 fb^{-1}



Nearly sensitive at the 5σ level over most of the available Higgs boson masses

The Higgs Hunt in 2012…

- To reach optimal analyses will require
    - More work on performances (at all levels of the analyses)
    - Analysis improvements/optimization
- The Higgs boson will not be unveiled easily…

The Higgs Hunt in 2012…

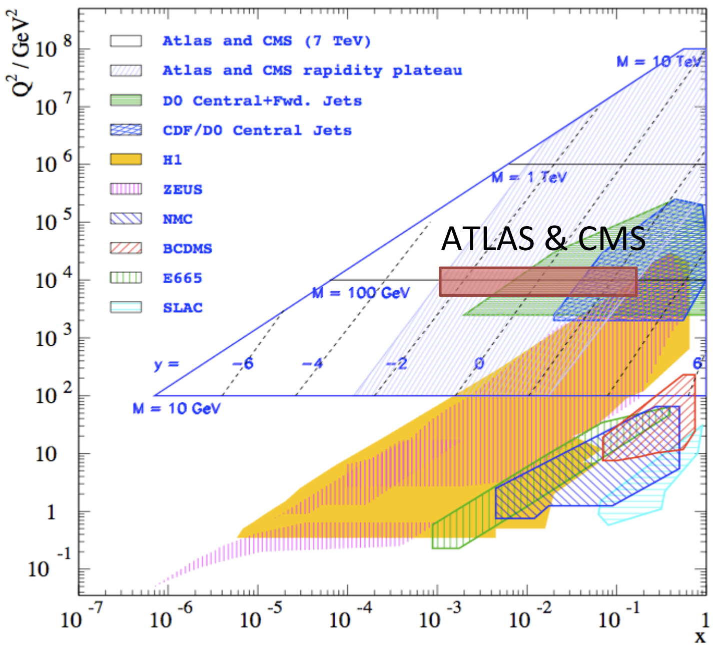
- To reach optimal analyses will require
  - More work on performances (at all levels of the analyses)
  - Analysis improvements/optimization
- The Higgs boson will not be unveiled easily…
- 2012 should bring more definitive answers

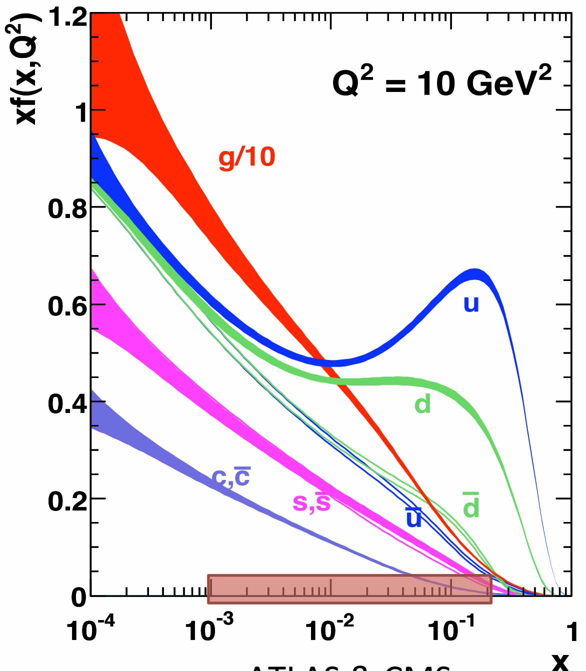
Backup

Properties of the W and Z Production

- Used to understand and calibrate our detector response (trigger, identification, resolution, efficiencies)

- Dominant signal and/or background in many other analyses and searches for new physics (top, Higgs, SUSY, ...)





ATLAS & CMS

$$u + \bar{d}(\bar{s}) \rightarrow W^+$$
$$d + \bar{u}(\bar{c}) \rightarrow W^-$$

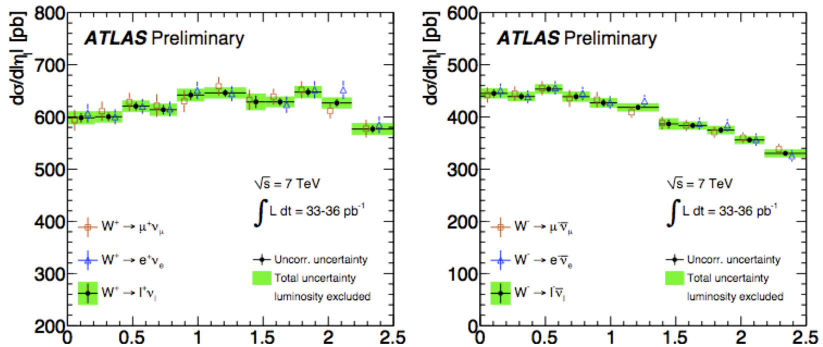
W production (largely with one valence quark) is highly charge asymmetric

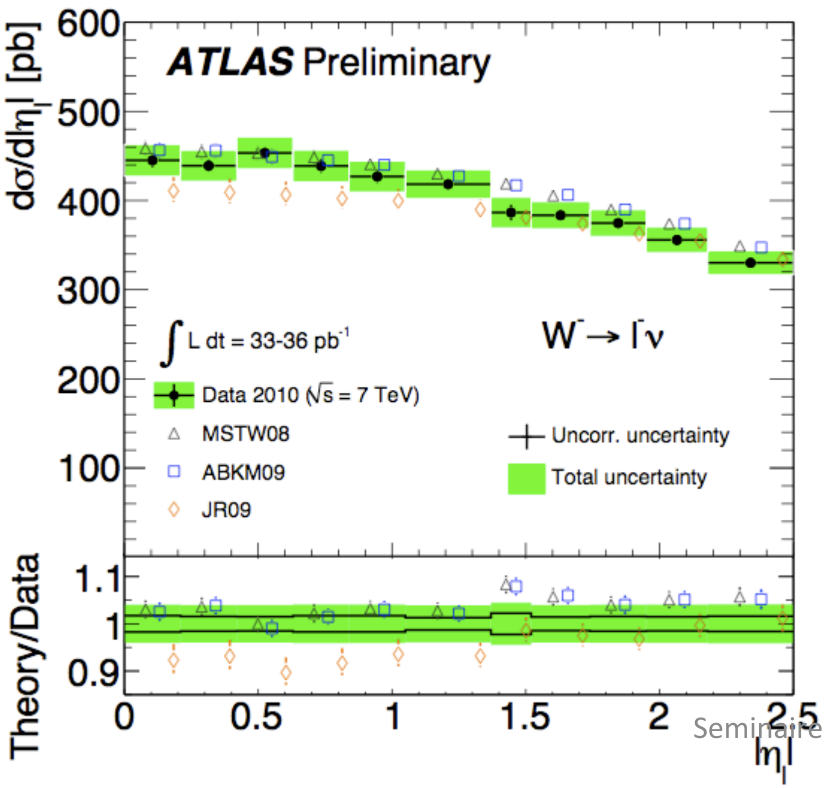
Differential Cross Sections

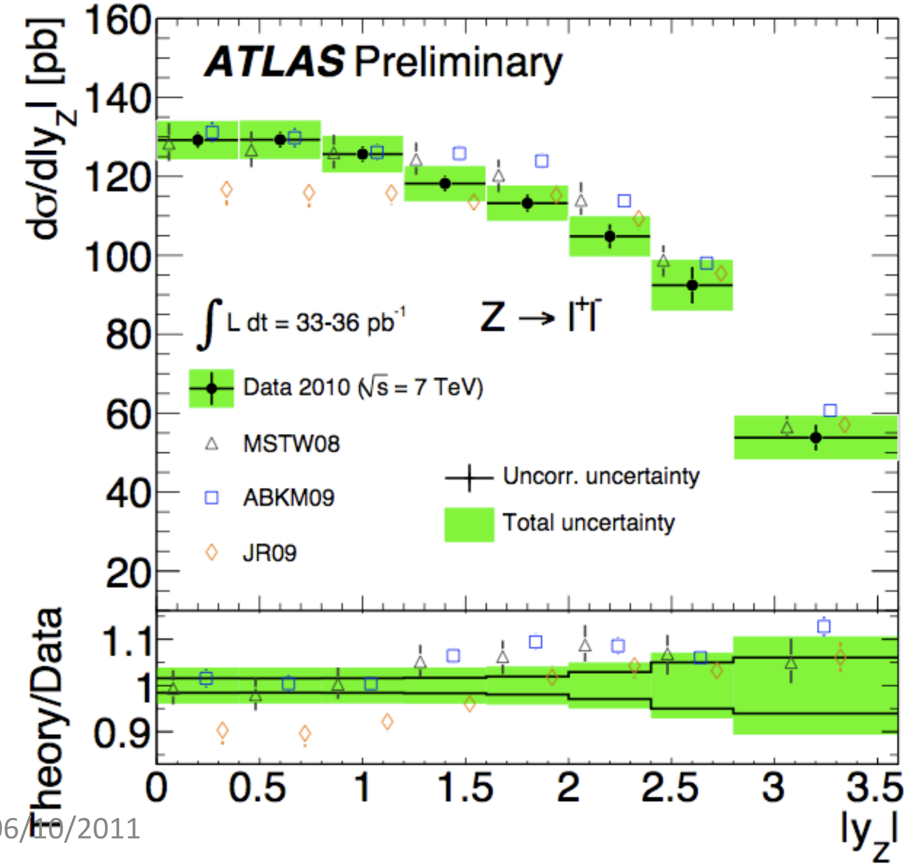
-Differential cross sections for both the W and Z production measured.

- Rather well described by predictions of NNLO PDF sets considered

- Measurements can impact on PDF central values and uncertainties







Statistical Combination Methods

Combination methods and (RooStats) code are the same as those used for the 2010 paper and are the official LHC-HCG tools

Based on the profile likelihood (PL) estimator :

	Test statistic	Profiled?	Test statistic sampling
LEP	$q_\mu = -2\ln\frac{\mathcal{L}(data\|\mu,\tilde{\theta})}{\mathcal{L}(data\|0,\tilde{\theta})}$	no	Bayesian-frequentist hybrid
Tevatron	$q_\mu = -2\ln\frac{\mathcal{L}(data\|\mu,\hat{\theta}_\mu)}{\mathcal{L}(data\|0,\hat{\theta}_0)}$	yes	Bayesian-frequentist hybrid
LHC	$q_\mu = -2\ln\frac{\mathcal{L}(data\|\mu,\hat{\theta}_\mu)}{\mathcal{L}(data\|\hat{\mu},\hat{\theta})}$	yes $(0 \leq \hat{\mu} \leq \mu)$	frequentist

Profiling allows to fully take advantage of the constraints on nuisance paramters

The Unconditional Ensemble

$$\mathcal{L}(\mathrm{data}\,|\,\mu,\theta) = \mathrm{Poisson}\,(\,\mathrm{data}\,|\,\mu\cdot s(\theta)+b(\theta)\,)\cdot p(\tilde{\theta}|\theta)$$

Signal region main measurement

Control region auxiliary measurement

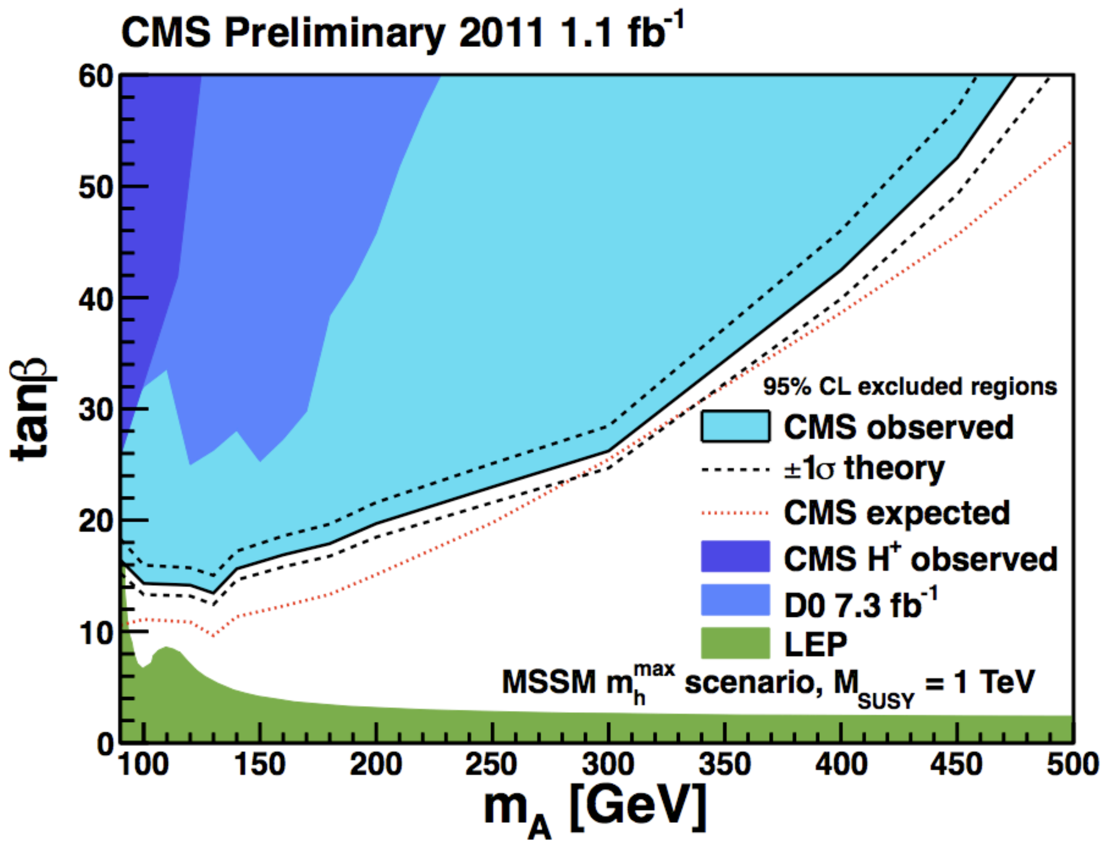
To account in a fully frequentist fashion the systematic uncertainties :

- The nuisance parameter is fixed for generation to default measured value

- Fitted in toys

- The auxiliary measurement is randomized

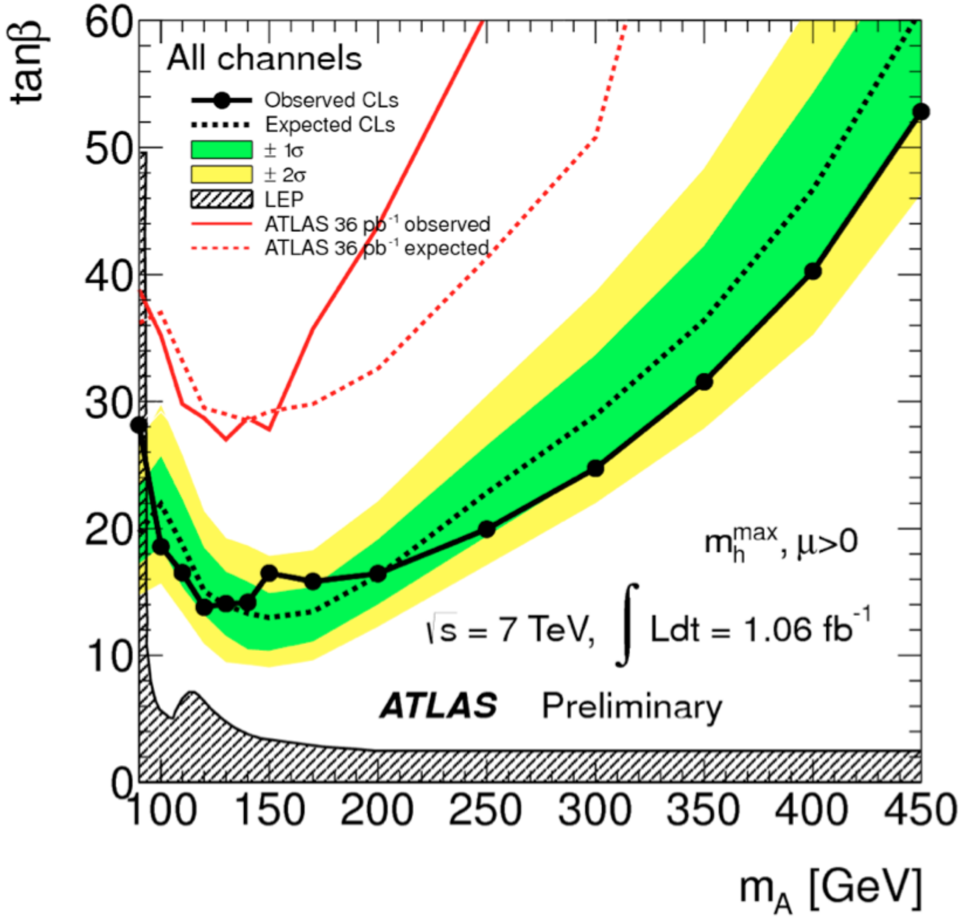
Higgs Boson Search with tau Leptons in the MSSM



Different analysis strategy : Combination of $H^{\pm}$ and $(b)\Phi^0 \to (b)\tau^+\tau^-$

Already probing below the interesting $\tan\beta$~30 region over wide mass range!

Higgs Boson Search with tau Leptons in the MSSM

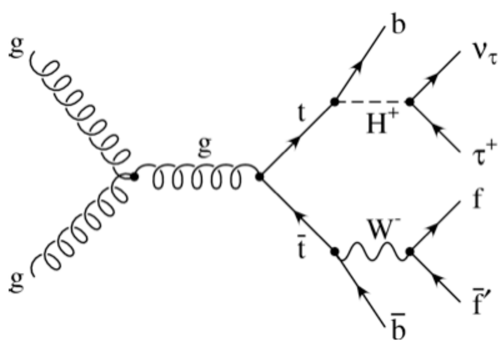


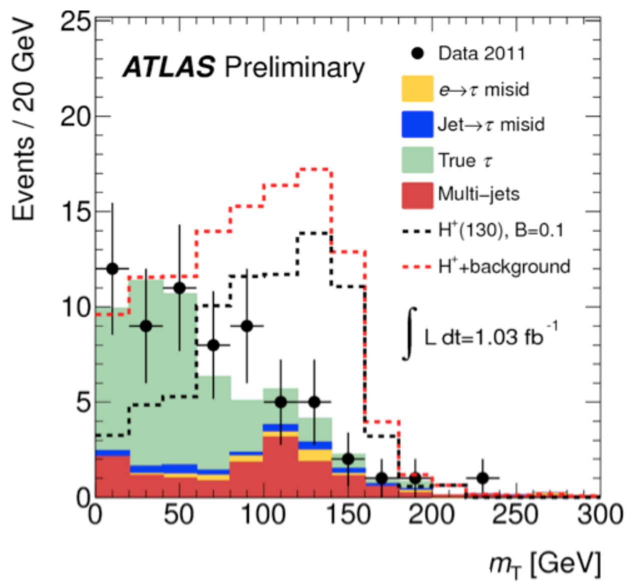
Different analysis strategy : Combination of $H^{\pm}$ and $(b)\Phi^0 \rightarrow (b)\tau^+\tau^-$

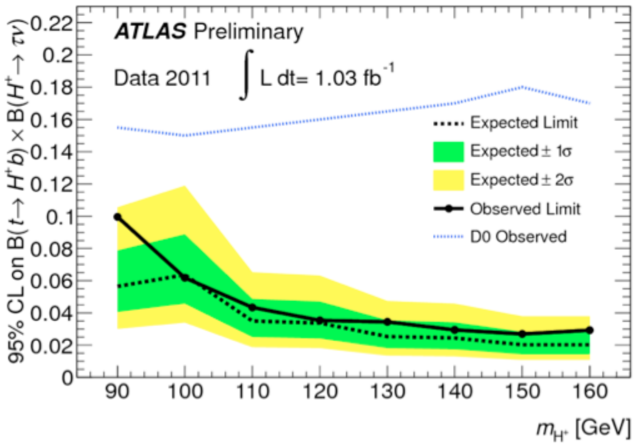
Already probing below the interesting $\tan\beta$~30 region over wide mass range!

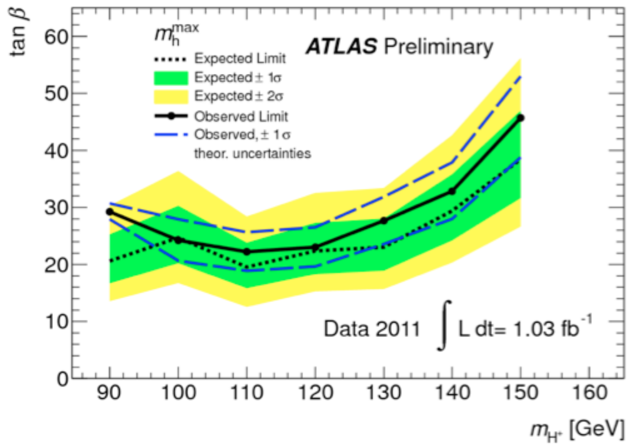
Higgs Boson Search Charged Higgs

Charged Higgs in top decays









CMS-PAS-HIG-11-001

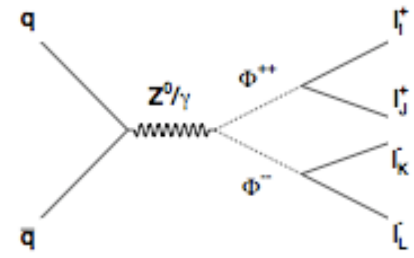
Doubly Charged Higgs

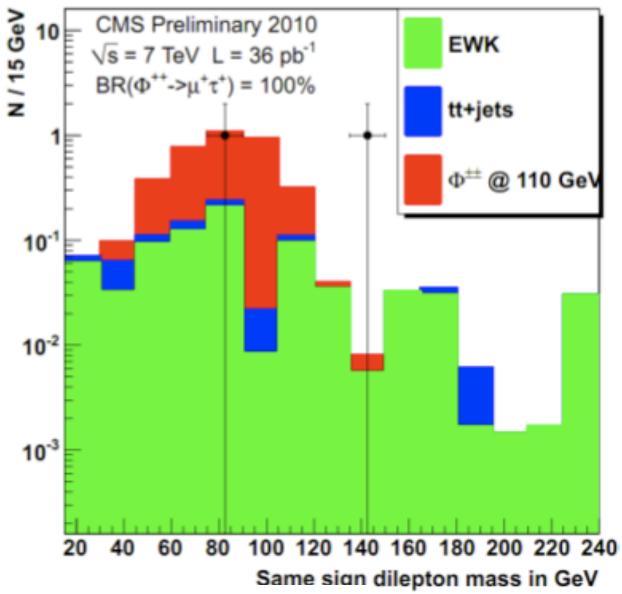
- extending Standard Model adding scalar triplet (motivated by Seesaw mechanism for neutrino masses). Leads to a doubly charged Higgs $H^{\pm\pm}$.

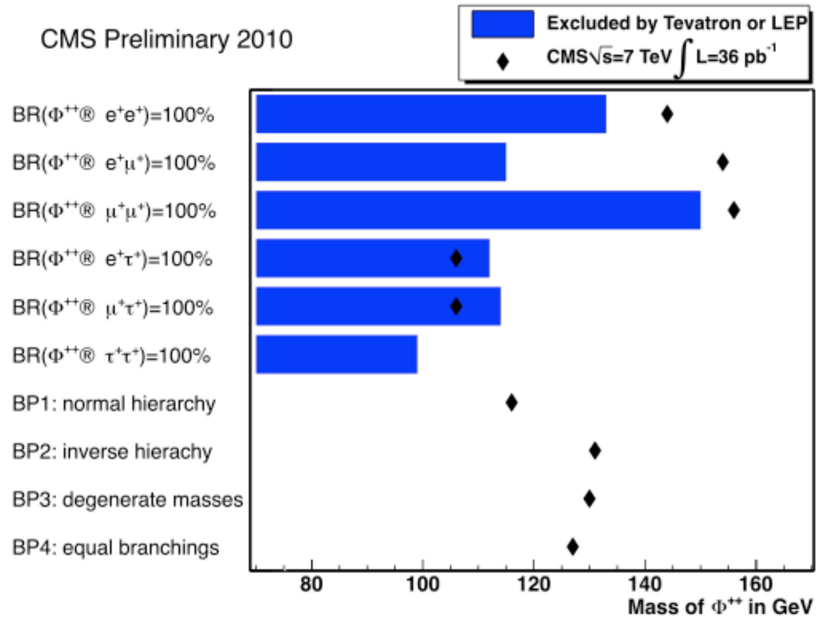
- Use di-lepton $H^{\pm\pm}$ decay topologies in four or three leptons.

- Look for SS di-lepton resonances.

- Limits







Normal Hierarchy / Inverse Hierarchy / Degenerate State

Limits comparable or better than previous experiments

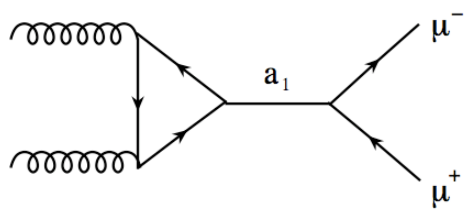
ATLAS-CONF-2011-020

Search for a light CP-odd Higgs boson in the $\mu^+\mu^-$ Final State

- NMSSM : additional singlet complex field leads to 1 additional CP-even and one CP-odd Higgs

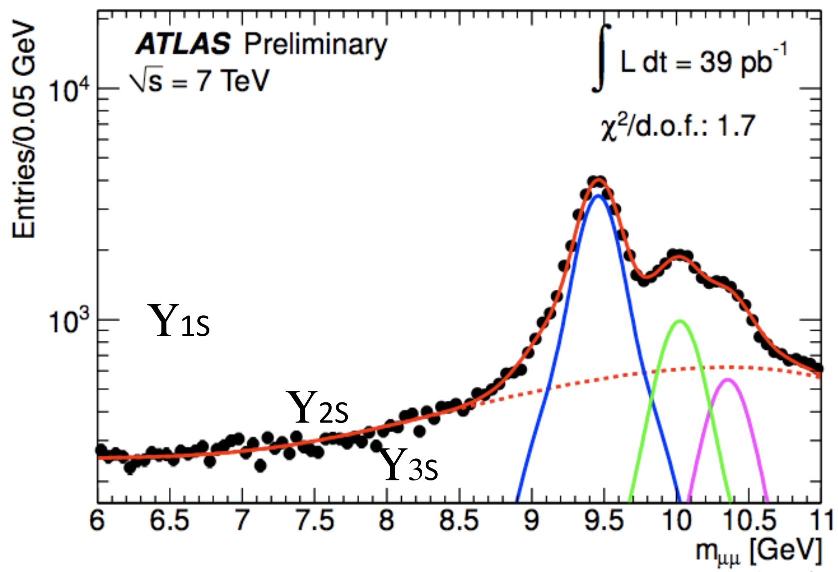
In the low mass region (below $2m_b$) lightest CP-even Higgs evades LEP limits this mass region is referred to as ideal Higgs scenario.

Search performed in the [6-9] and [11-12] mass range (avoiding Υ resonances 1S, 2S and 3S due to uncertainties on their production rates).



Simple selection of two isolated muons p_T> 4 GeV

$$a_1 = \cos\theta_A a_{MSSM} + \sin\theta_A a_S$$



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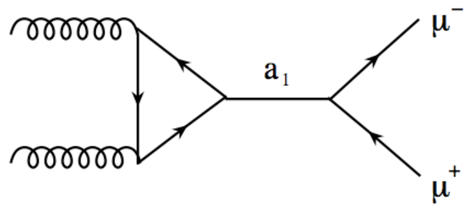

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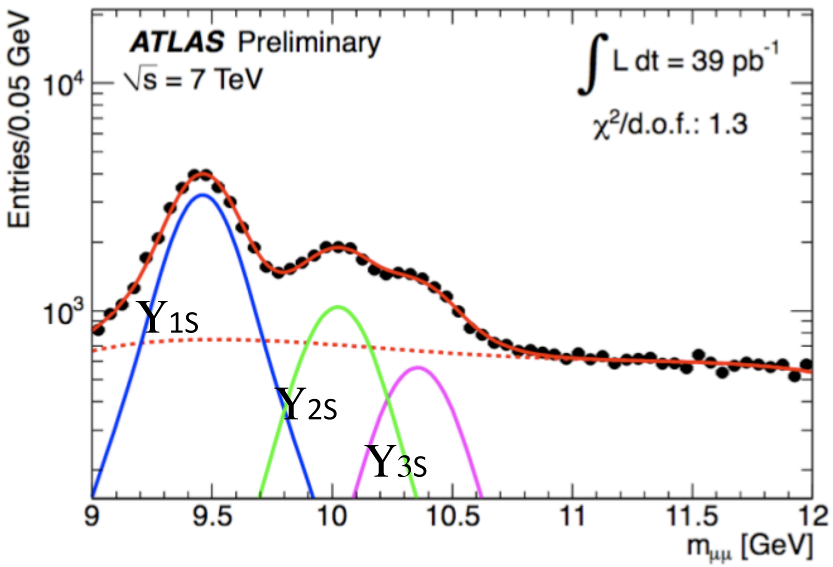

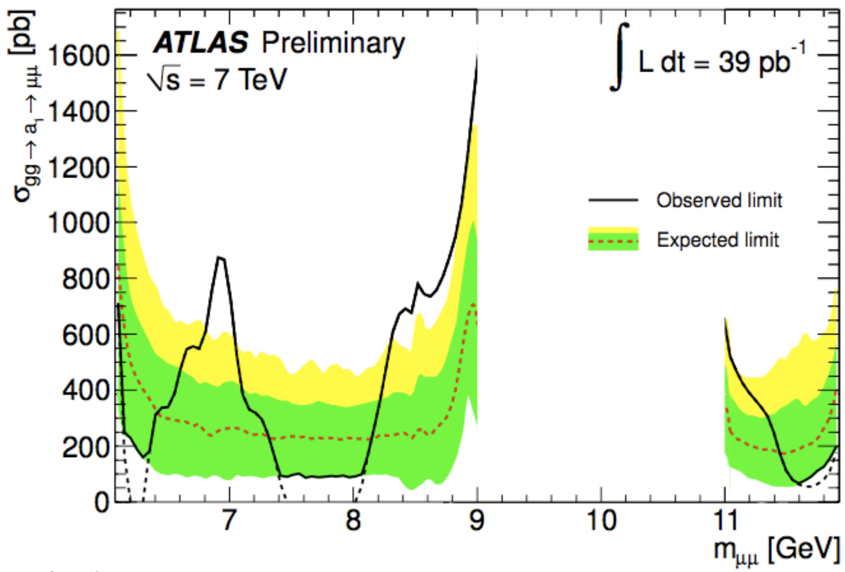

Constraints on regions with high tan β and small CP-Odd mixing angle cos θ_A ~