Electroweak Physics and Higgs Searches at LHC

Closing in on the Search for the Higgs Boson at LHC

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On behalf of the ATLAS and CMS Collaborations

Colloquia on the Latest LHC Results Presented at the
International Conference on High energy Physics

European Physical Society

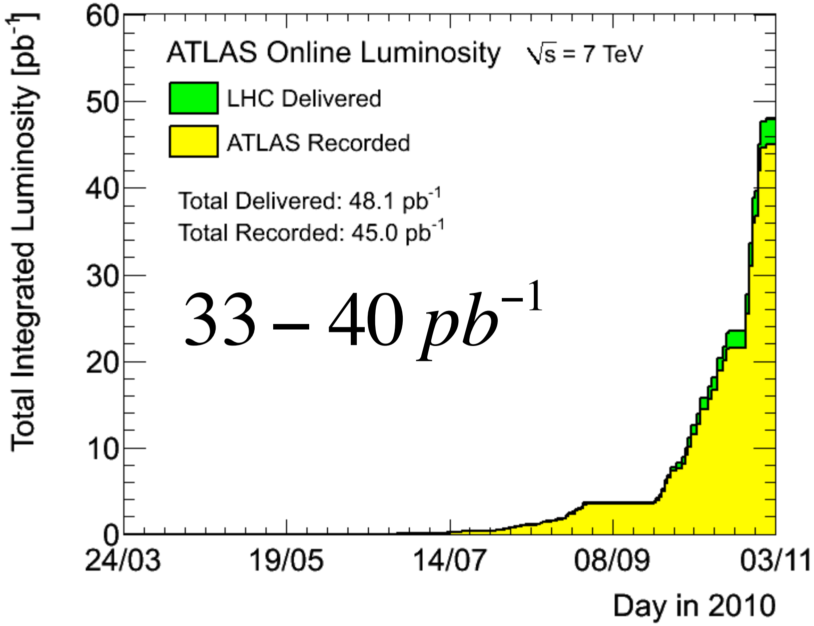
HEP 2011

Two Years of Remarkable LHC operations

Congratulations and thank you!

2010

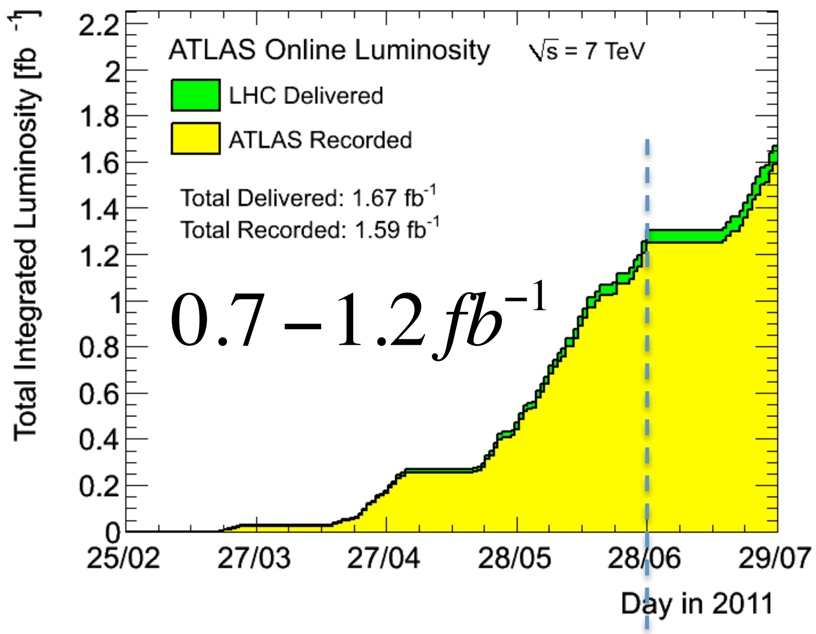
Re-discovery of the SM at LHC



Measurement of detailed properties of the W and Z boson production

2011

Closing in on the Higgs search



Technical Stop

~2 Weeks to finalize analyses !

Measurement of di-boson production and Higgs searches

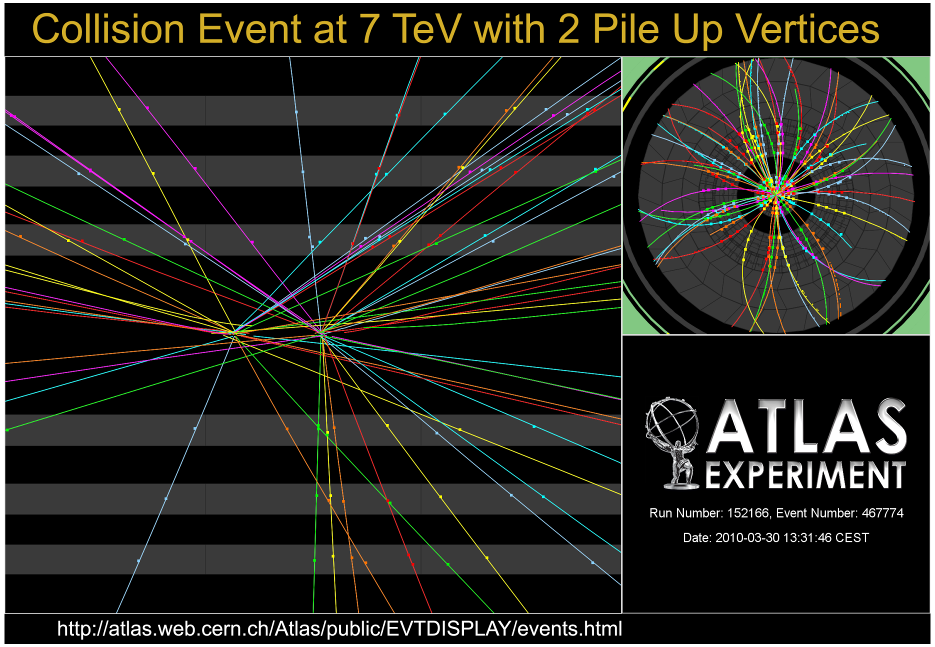
Two Years of Remarkable LHC operations

Congratulations and thank you!

2010

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

150 ns inter-bunch spacing



2011

O(8) Pile-up events (per bunch crossing)

50 ns inter-bunch spacing

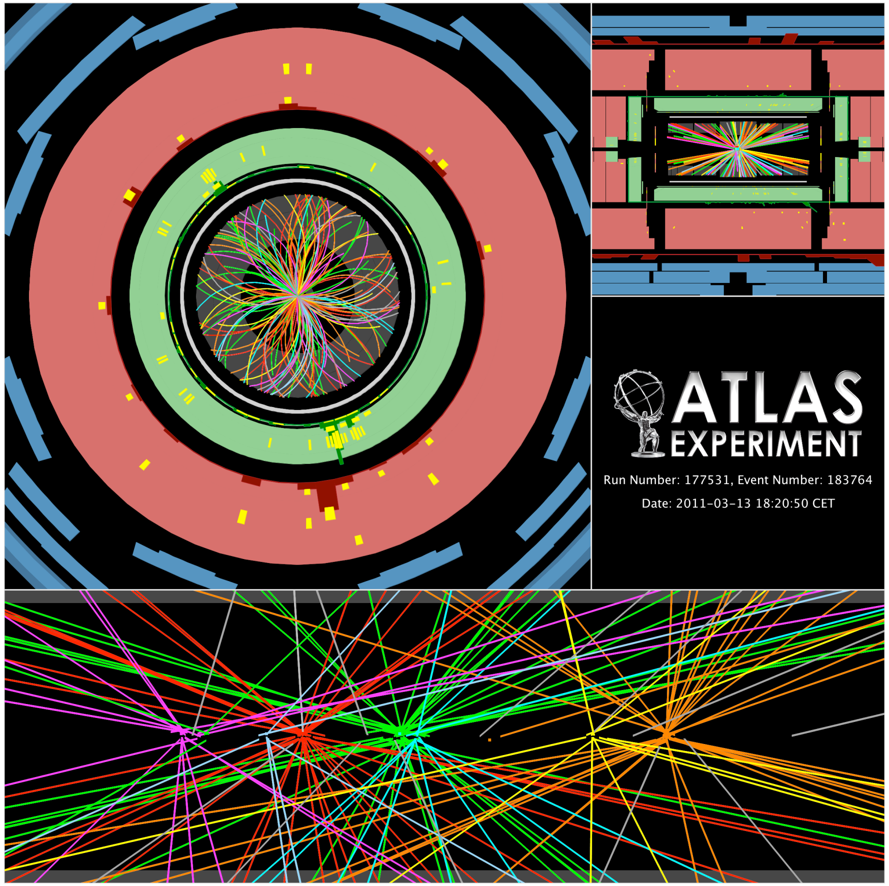
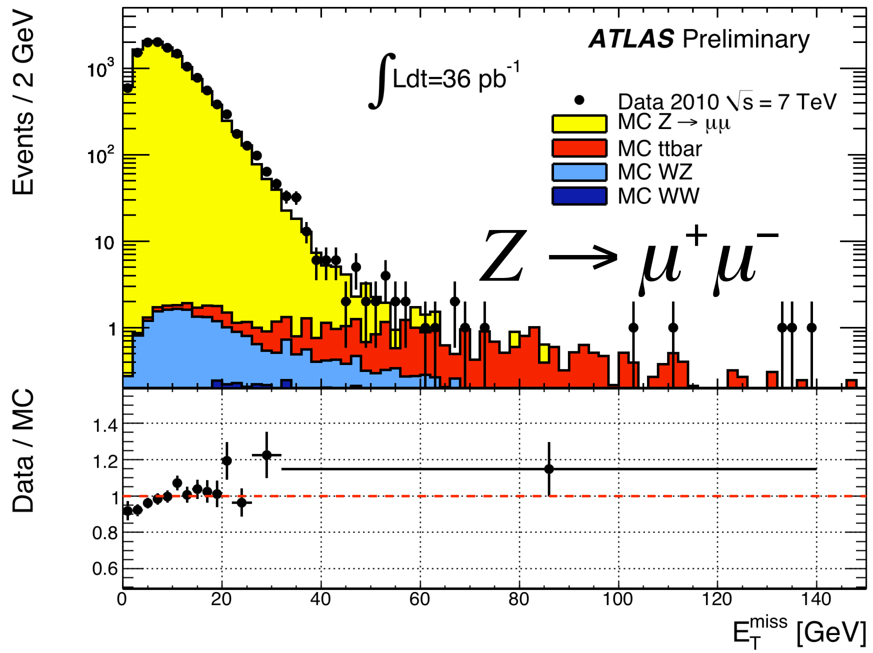


Illustration of events taken at random (filled) bunch crossings

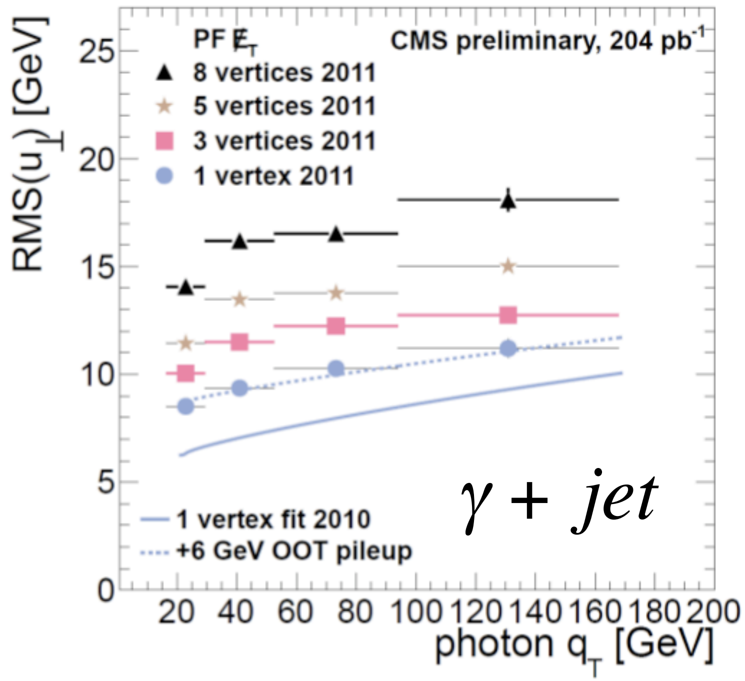
Two Years of Remarkable LHC operations

Congratulations and thank you!

2010	*2011*
O(2) Pile-up events (per bunch crossing)	O(8) Pile-up events (per bunch crossing)
150 ns inter-bunch spacing	50 ns inter-bunch spacing
Very small effect of Out-of-Time PU	Important Out-of-Time PU

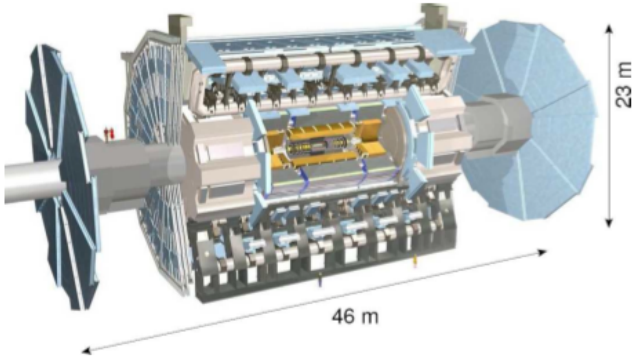
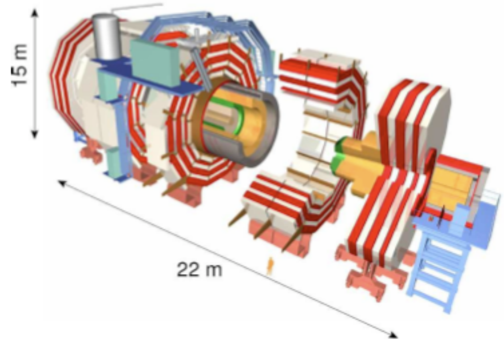


Very nice description from MC (ATLAS and CMS)



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

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)

Preamble : Theoretical Breakthroughs

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

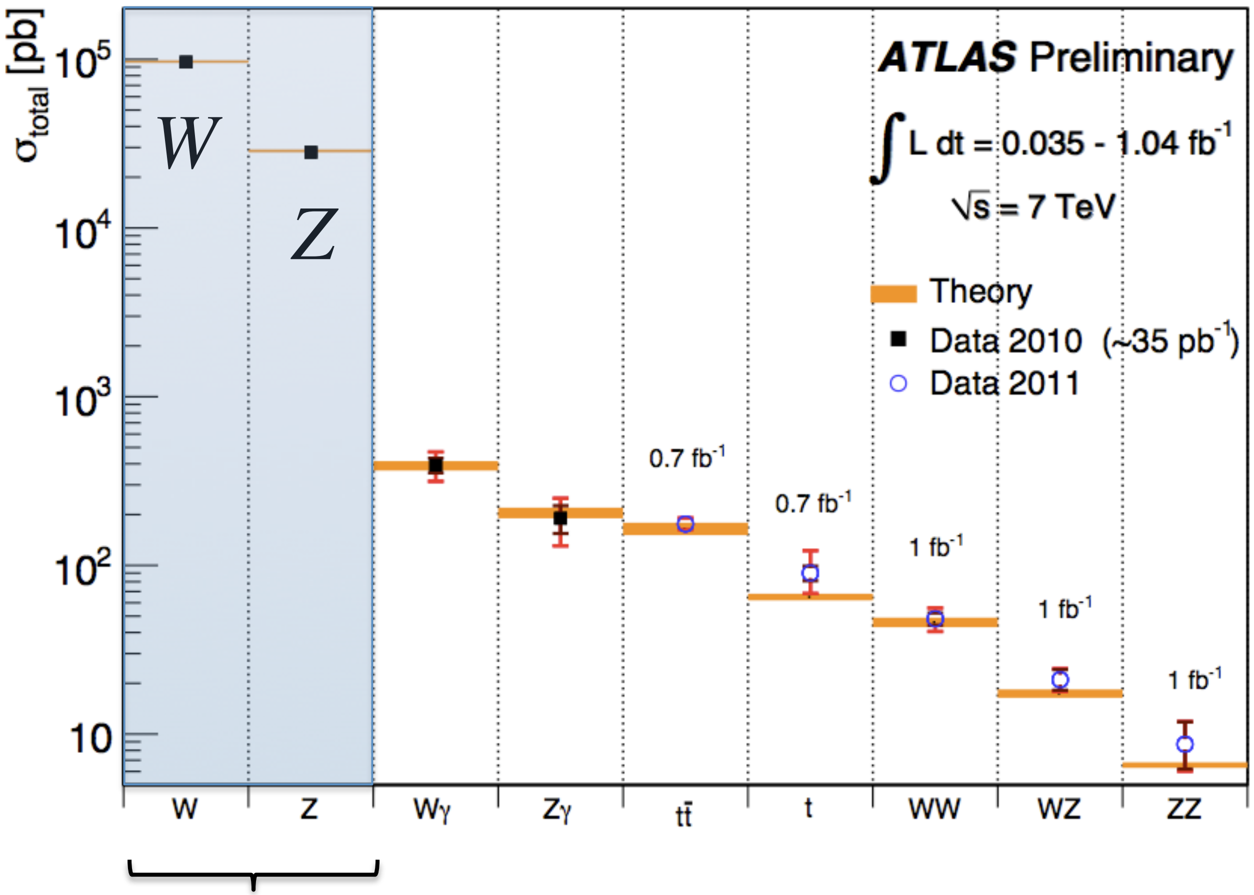
- The "Next-to..." revolution :
  - Breakthrough ideas in computation of loops (sewing together tree level amplitudes).
  - NLO generators, blackhat, NLOjet++, Phox, MCFM, etc...
  - NLO generators w/ PS, MC@NLO and POWHEG.
  - NLO+NLL or NNLL, CAESAR, ResBos, HqT
  - NNLO, FEHIP, FEWZ, HNNLO, DYNNLO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

W and Z production Properties

Mostly with 2010 data (sufficient)



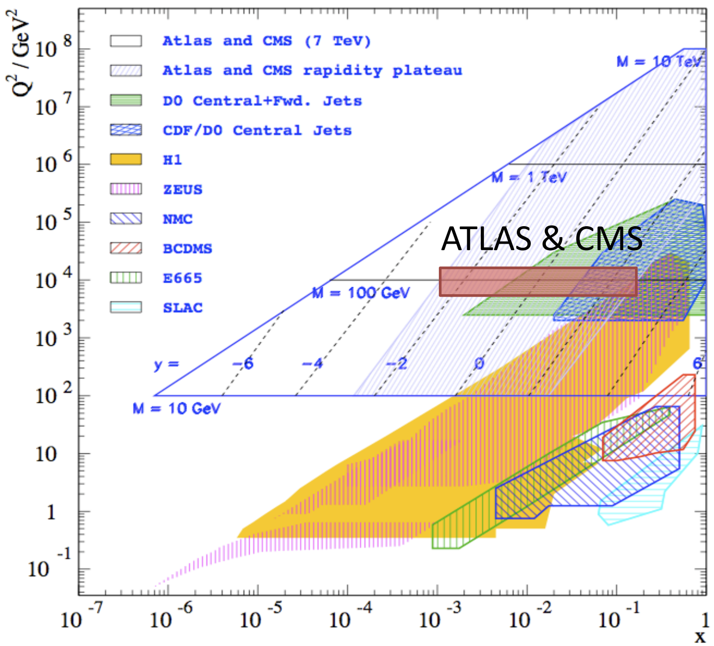
Theory at NLO

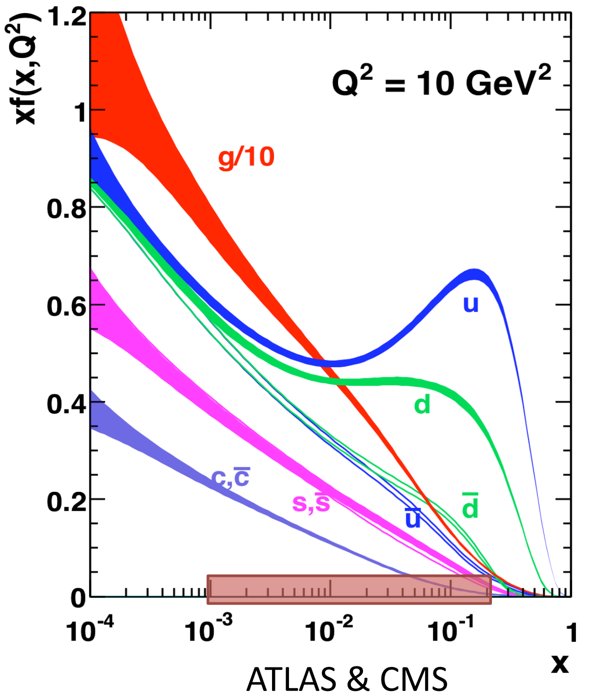
Measurement of detailed properties of the W and Z boson production

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, ...)

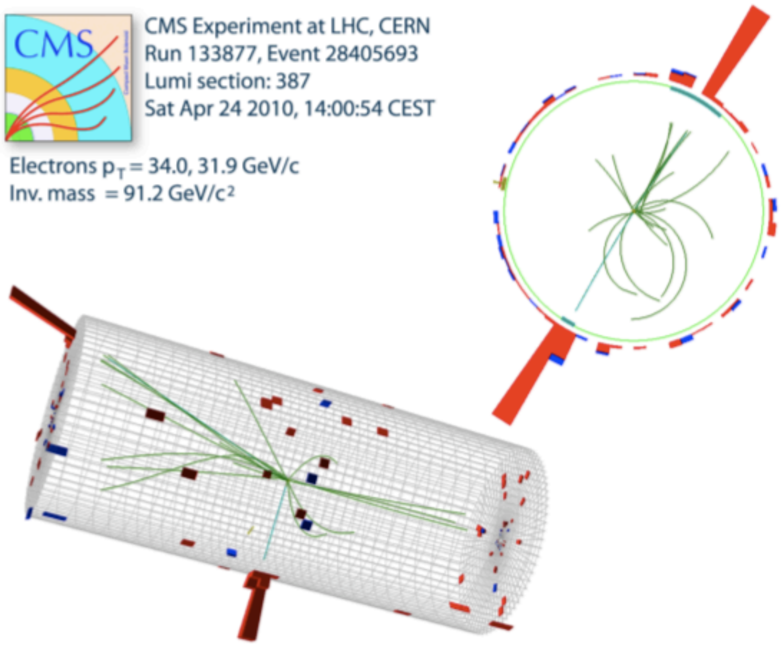


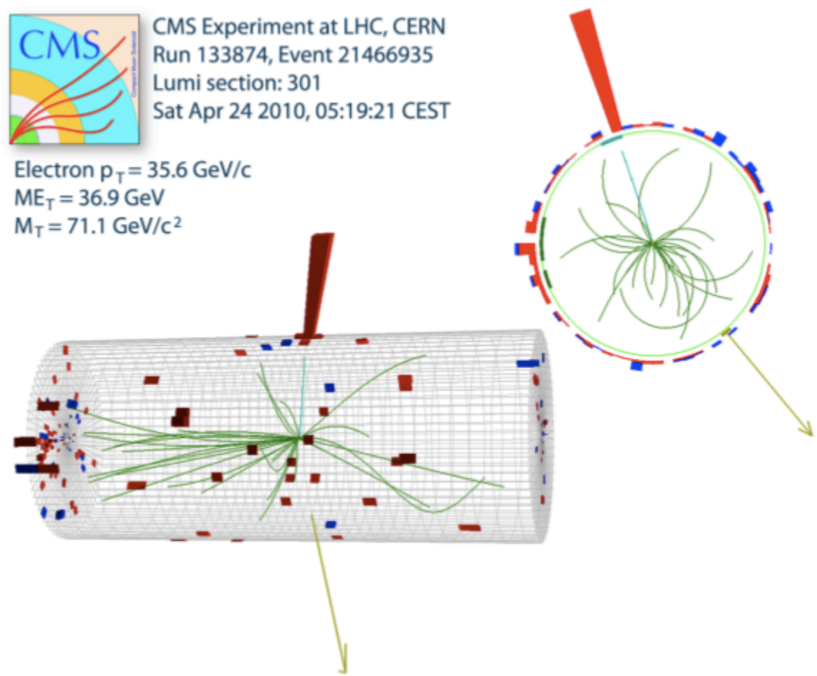


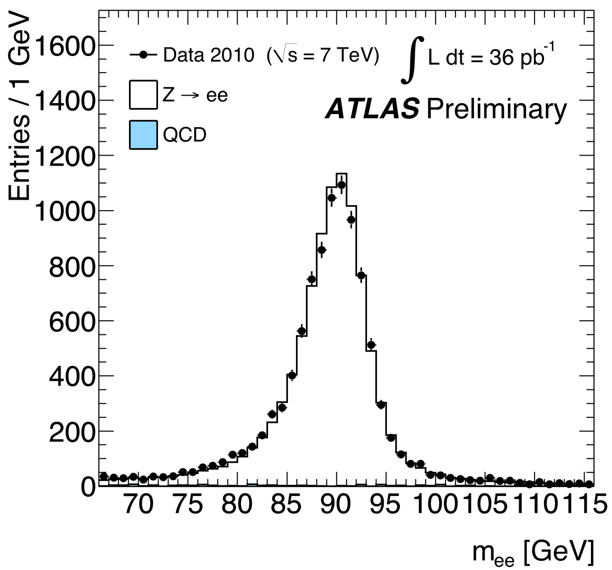
$$u + \bar{d}(\bar{s}) \rightarrow W^{+}$$
$$d + \bar{u}(\bar{c}) \rightarrow W^{-}$$

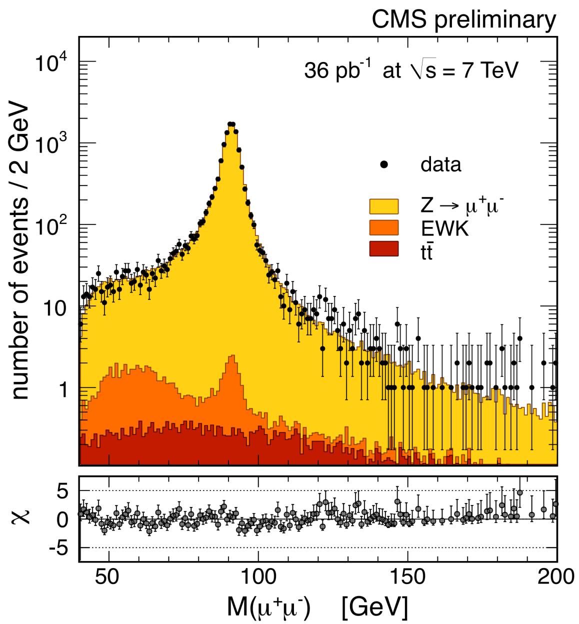
W production (largelywith one valence quark) is highly charge asymmetric

Simple and Clean Event Selection









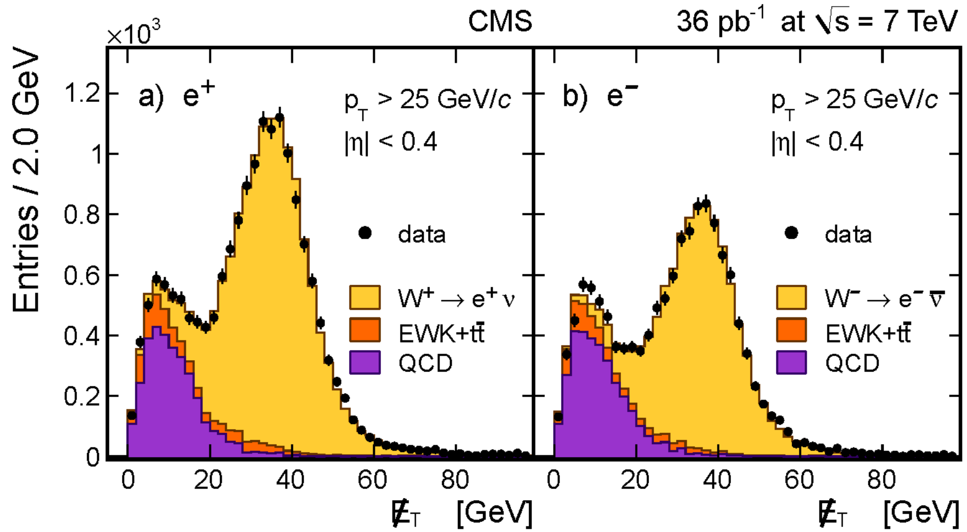
Z selection:

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

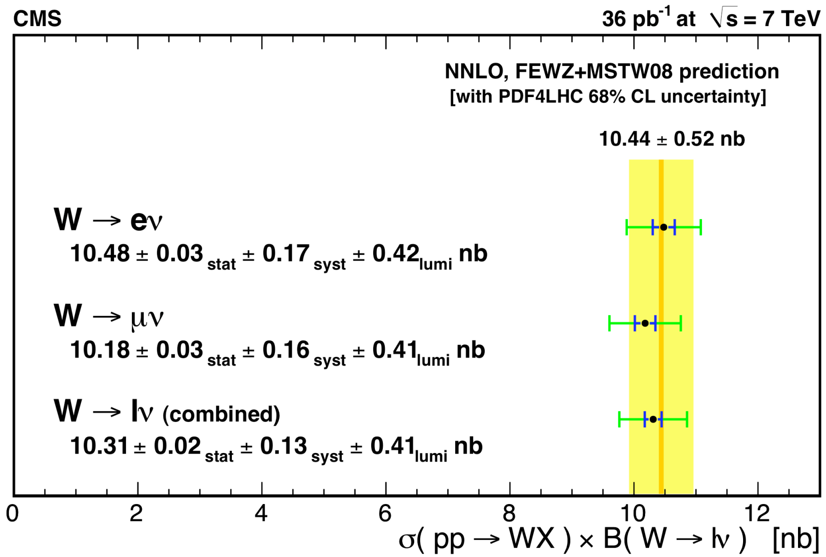
ATLAS ~ 200 kZ (ee)

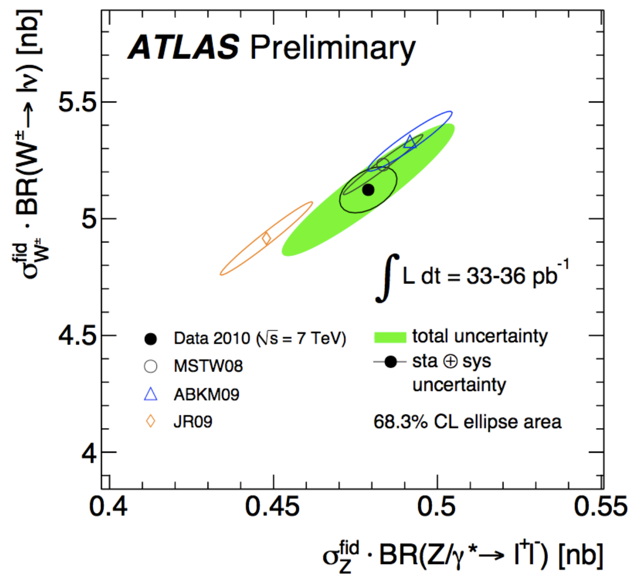
- W selection:
  - p_T lepton (pT>20-25 GeV)
  - Loose cut on met
  (or not cut at all CMS)

ATLAS ~ 4MW (ee)



- Cross section measurements and W/Z Ratios





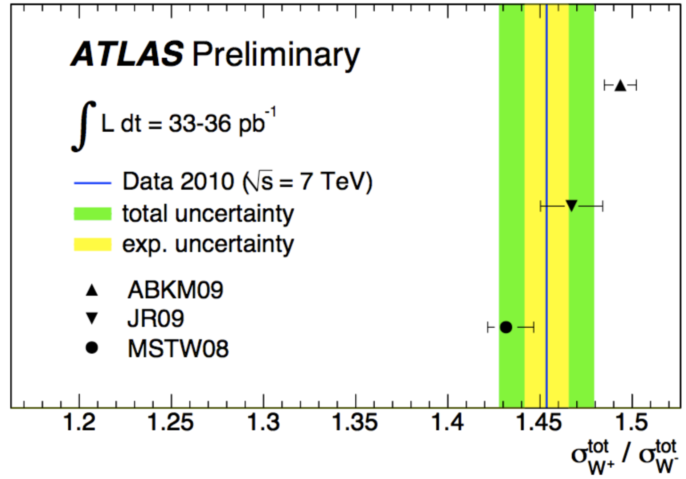
- Measurements in excellent agreement with the NNLO prediction (FEWZ)

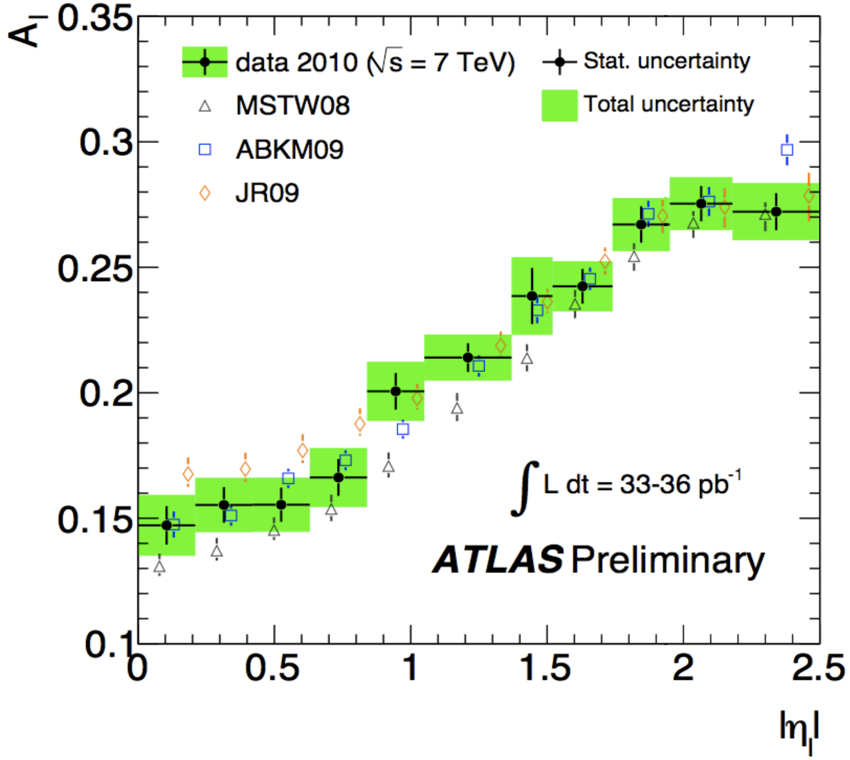
W Charge Asymetry

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

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

- Constraining PDFs…





W Charge Asymmetry

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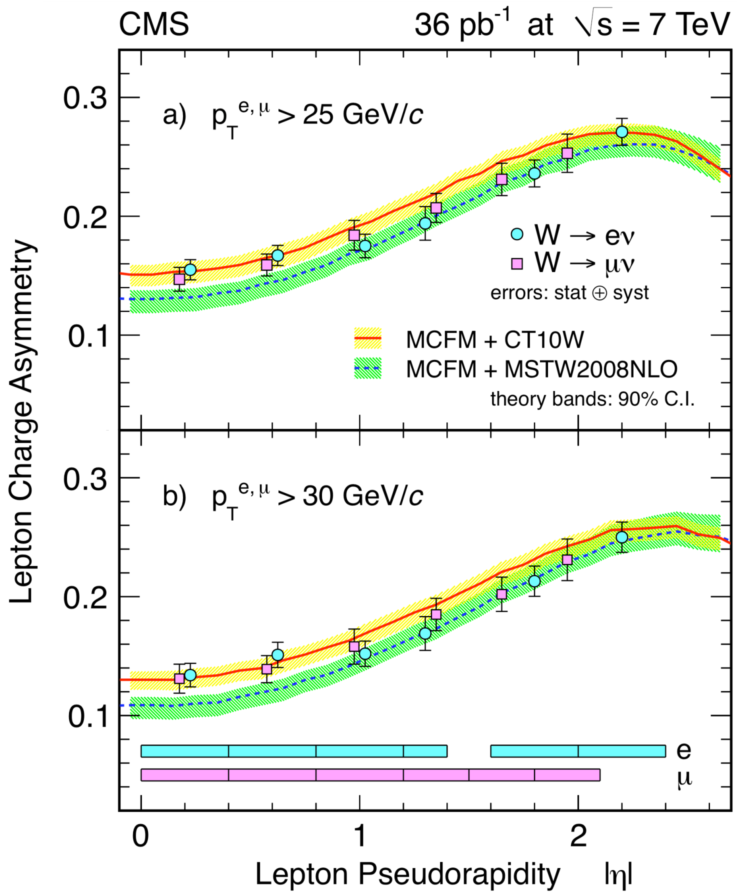
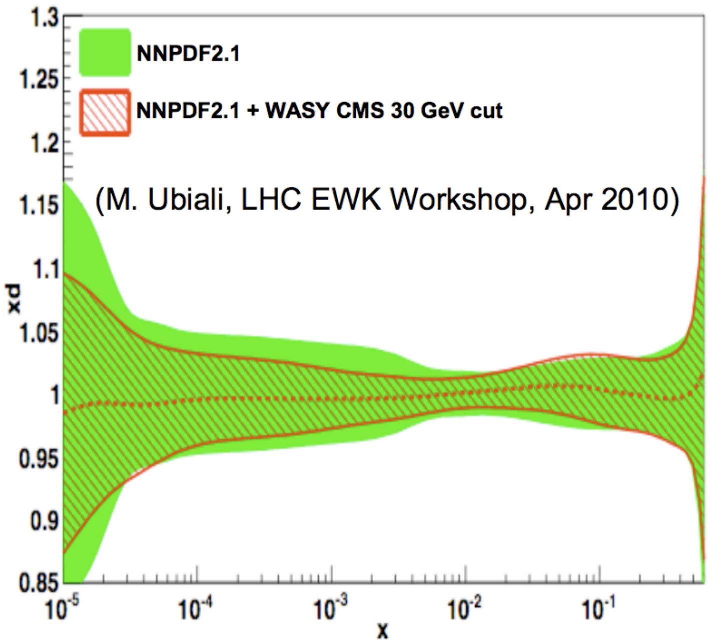
- Constraining PDFs… Already constraining u, d, qbar by almost 40%





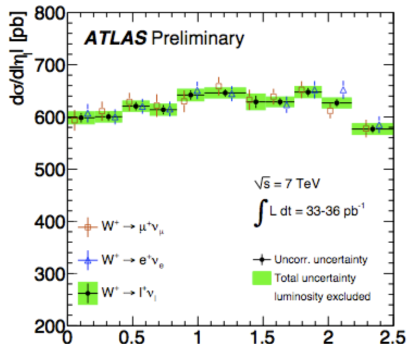
(From the NNPDF group)

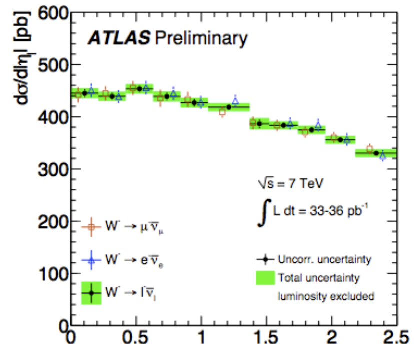
Differential Cross Sections

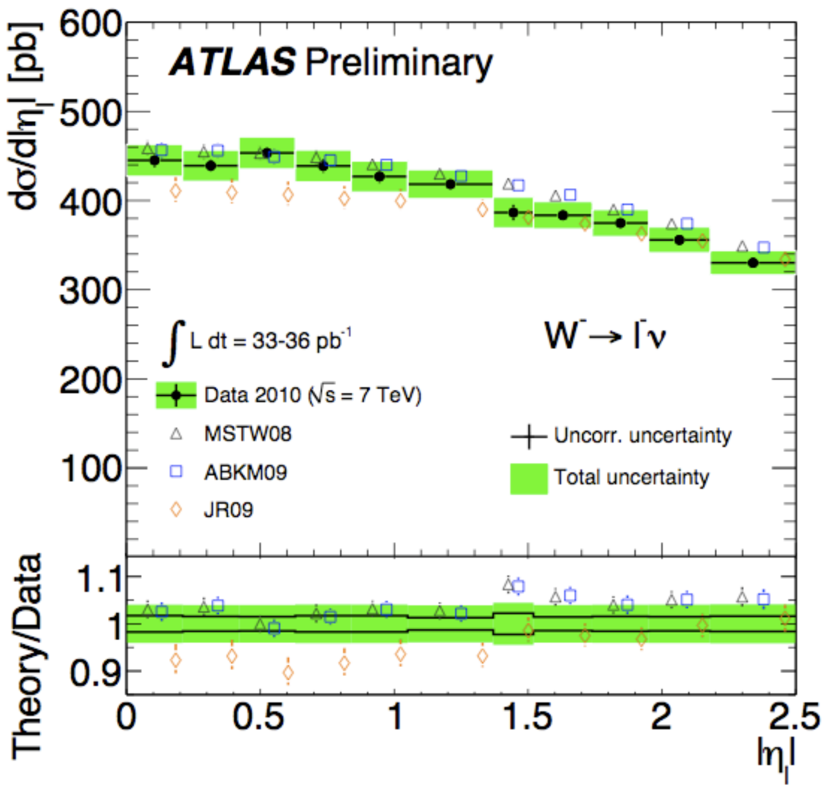
-Differential cross sections for both the W and Z production measured.

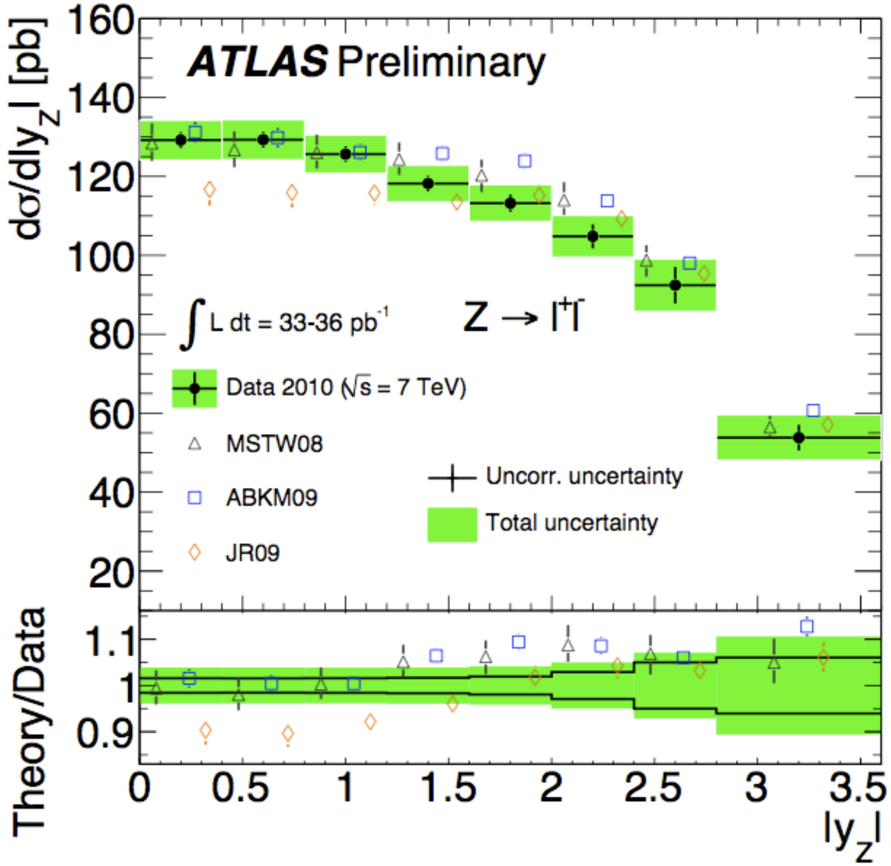
- Rather well described by predictions of NNLO PDF sets considered

- Measurements can impact on PDF central values and uncertainties



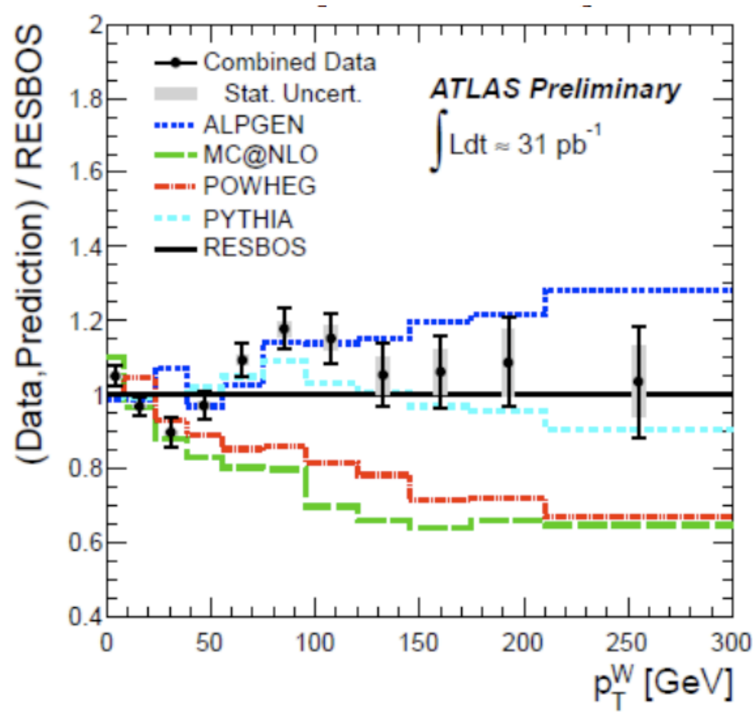


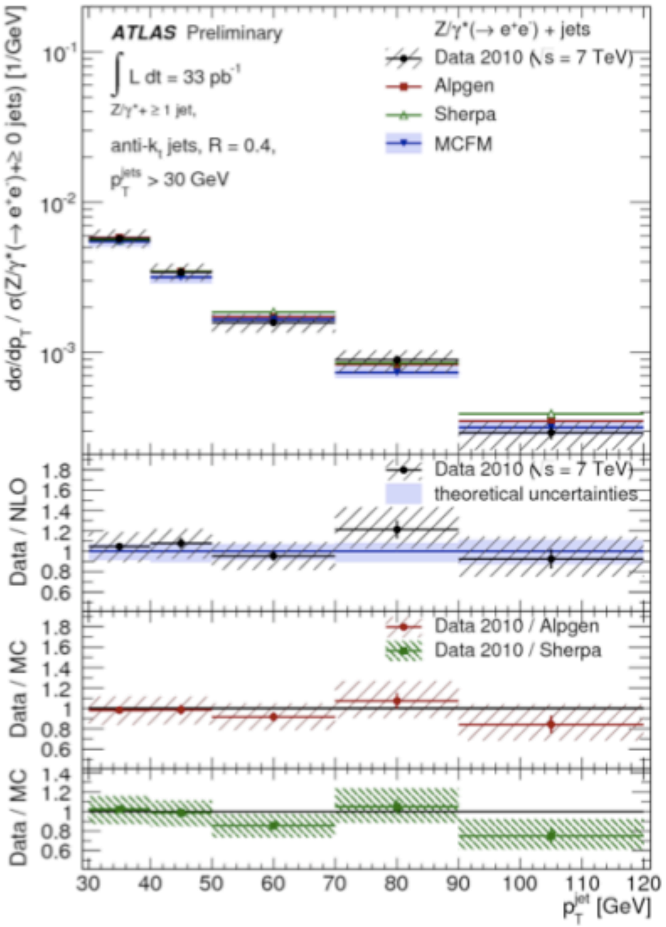




-W p_T measurements probe the ME-PS matching, the NLO calculations and the rsummation :

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

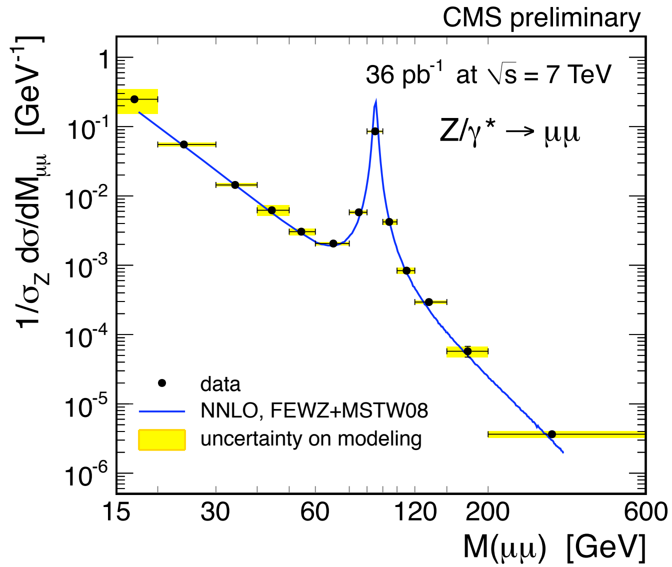




- W and Z+jets in remarkable agreement with ME-PS

- … and Drell Yan!

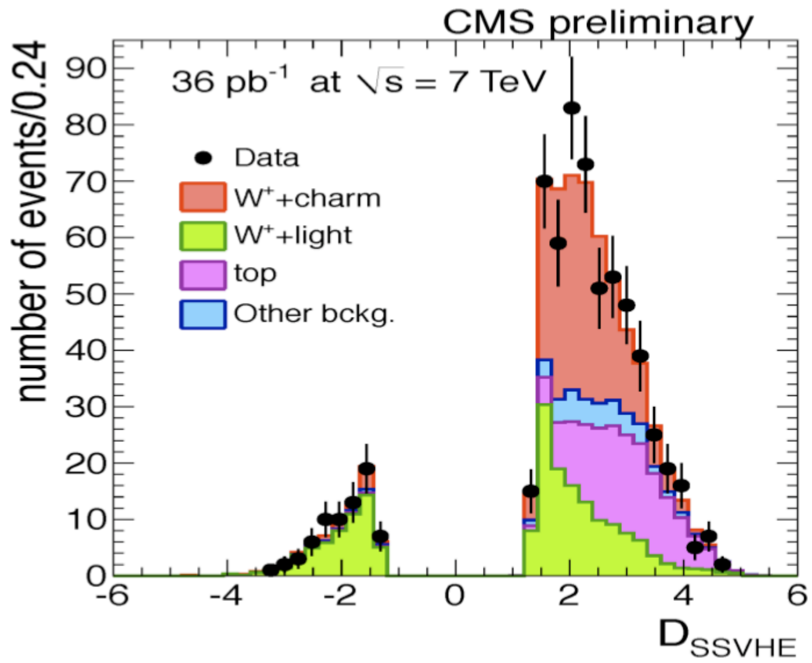
Very impressive results in such a small amount of time

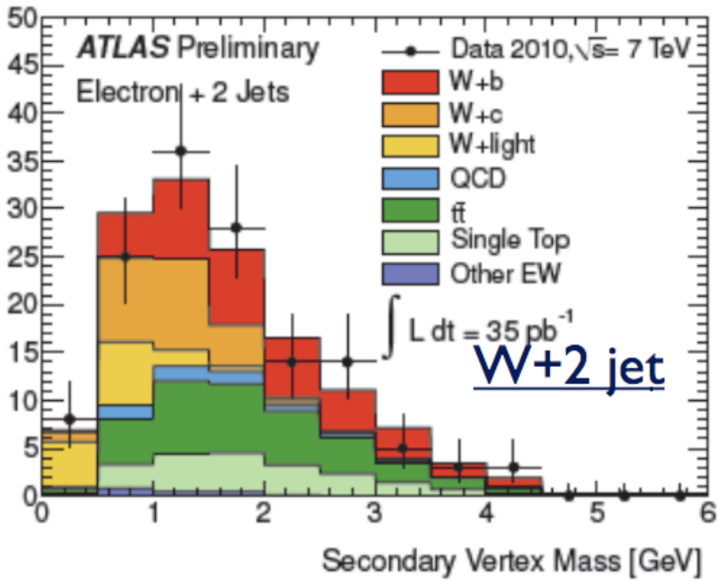


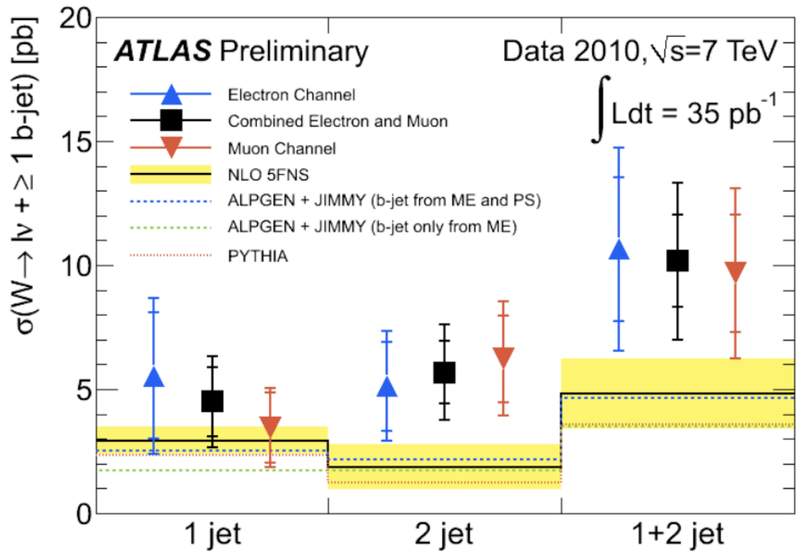
W and Heavy Flavors

- 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!

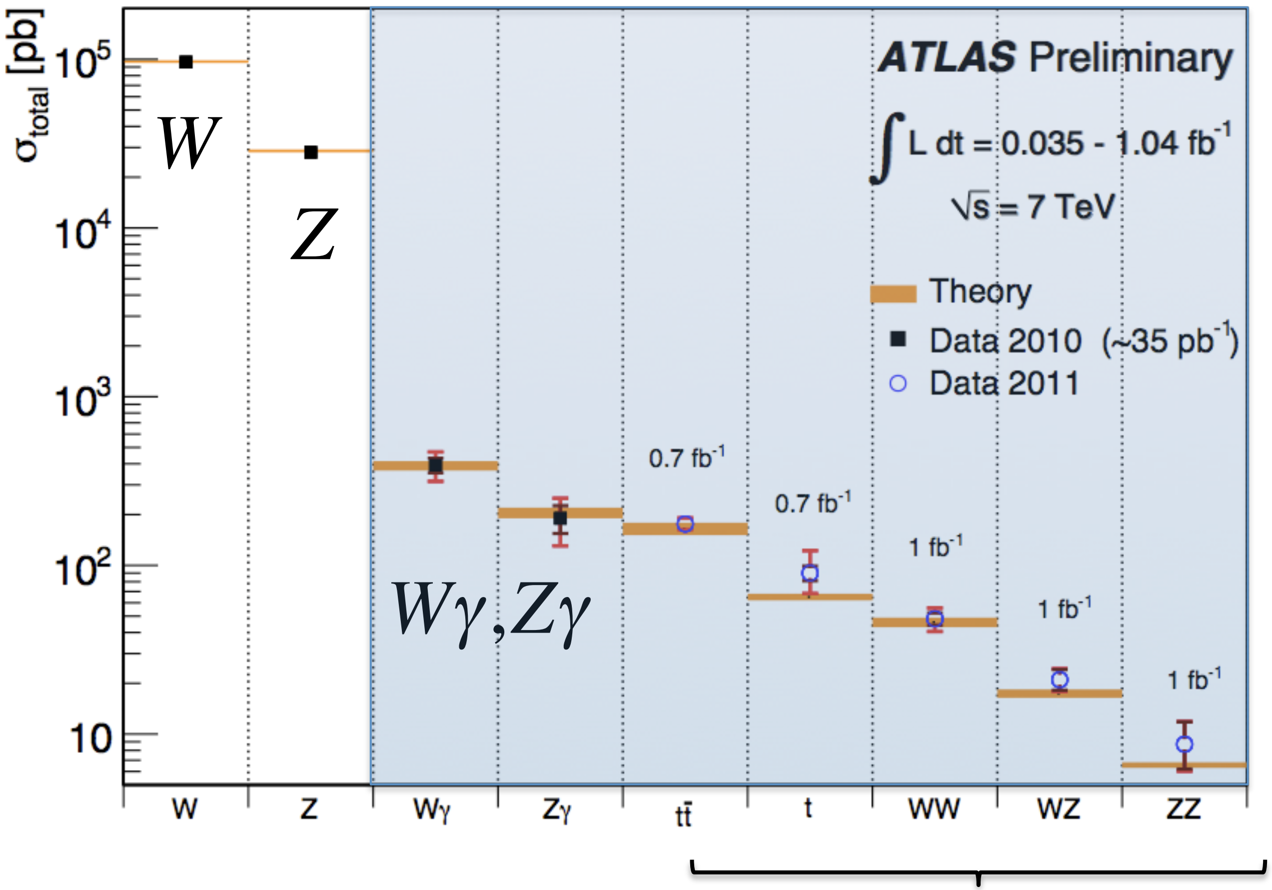






Diboson Studies

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 Higgsin diboson channels.

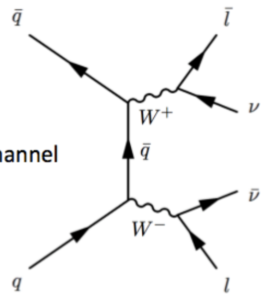
- Starting to gather a conspicuous mount of diboson events…

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

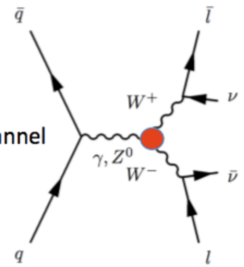
-WW (lnln) Channels :

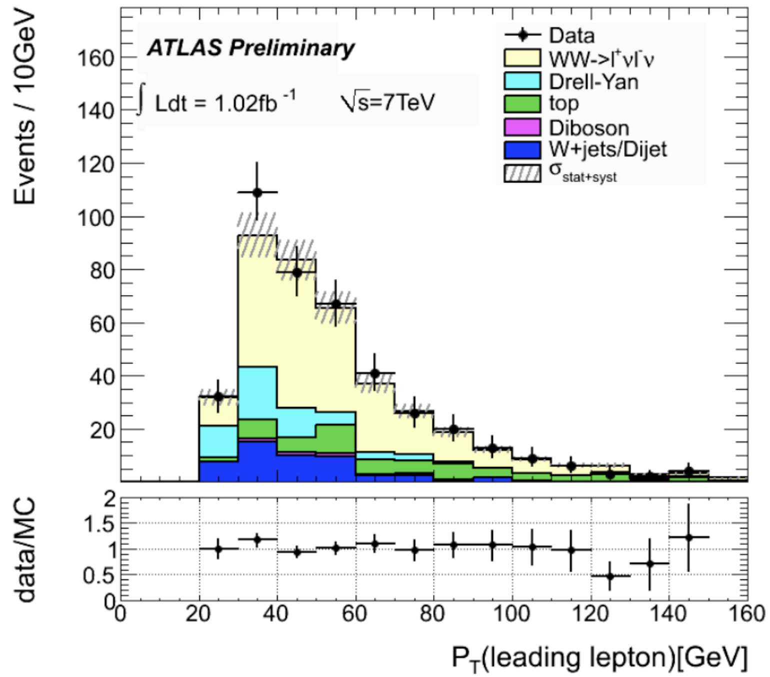
Cut	ATLAS	CMS
Lead. l p_T (GeV)	25	20
Trail. l p_T (GeV)	20	10
MET	25-45	30
Z – J/ψ Veto	✓	✓
Jet-veto	✓	✓
B-veto		✓

t-channel



s-channel

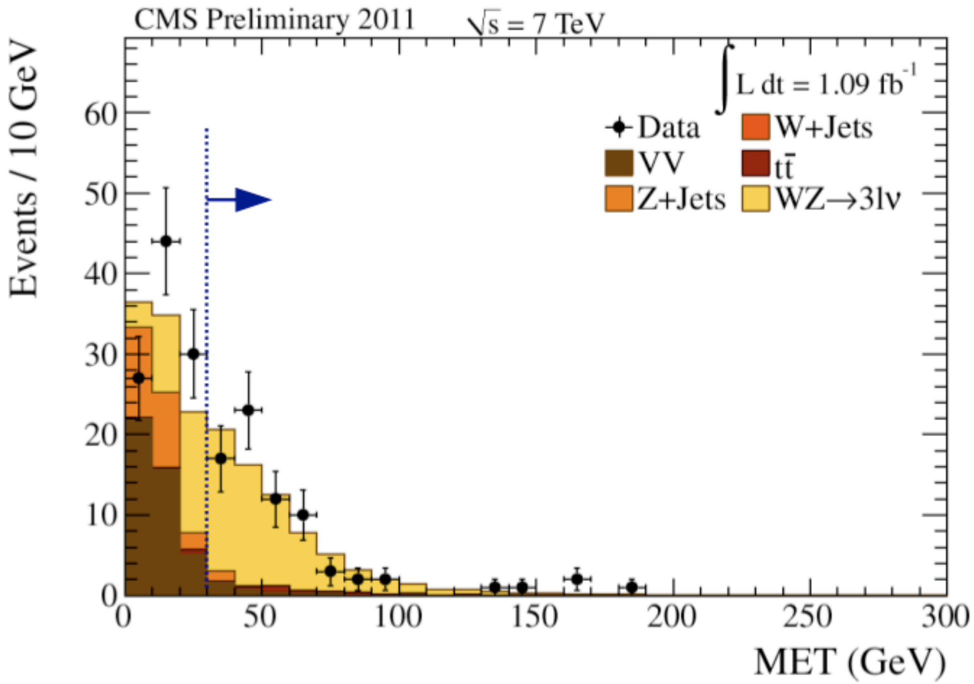




Typically ~400 events
Purity ~60%

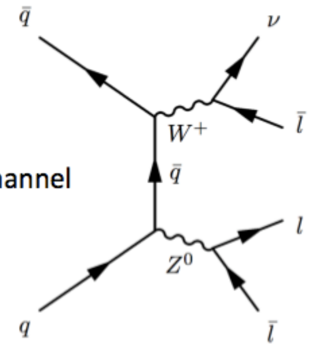
- WZ (3lν) Channels :

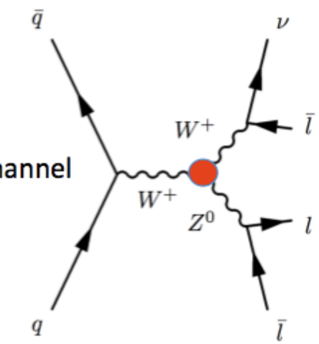
Cut	ATLAS	CMS
Lead. l p_T (GeV)	15	20
Trail. l p_T (GeV)	20	10
MET	25	30
Second Z Veto		✓
W - M_T	✓	



- Good compromise statistics and purity :

Typically ~80 events
Purity ~90%

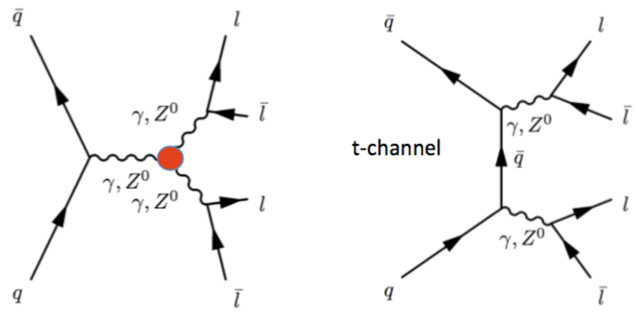




- ZZ(4l) Channels :

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

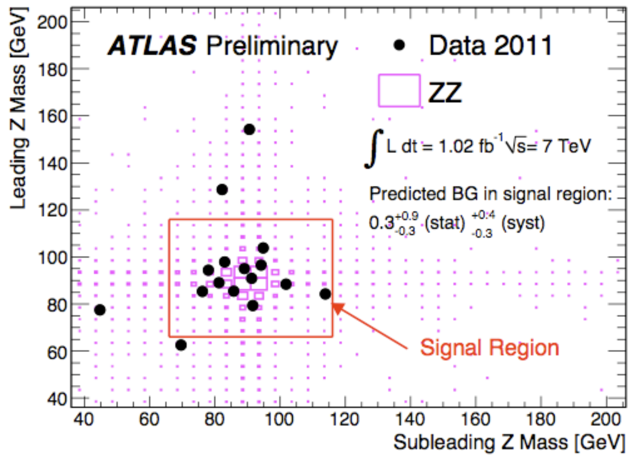
Cut	ATLAS	CMS
Lead. l p_T (GeV)	15 (μ) - 25 (e)	20
Trail. l p_T (GeV)	15 (μ) - 20 (e)	5 (μ) - 7 (e)
Z Window (GeV)	25	30

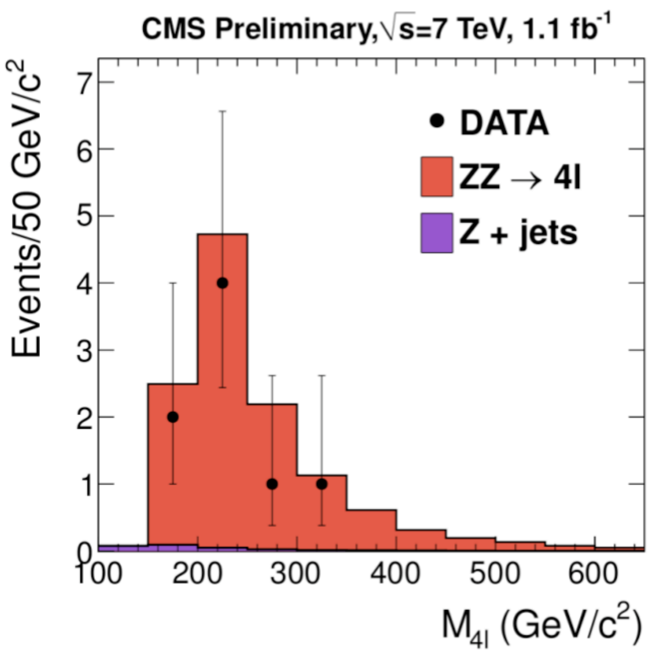


Not existent in SM

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 :

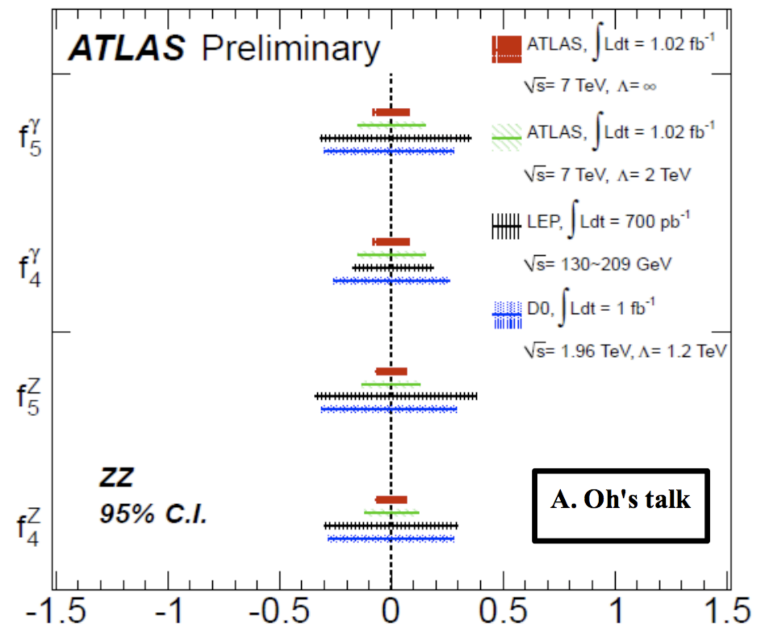
Cross Section (pb)	WW		WZ		ZZ	
	ATLAS	CMS	ATLAS	CMS	ATLAS	CMS
Exp. Total	46	43	17.2	20	6.5	6.4
Measured	48.2	55.3	21.1	17.0	8.4	3.8
Stat. Uncert.	±4	±3.3	±1.2	±2.4	±0.6	±1.5
Syst. Uncert.	±6.4	±6.9	±0.9	±1.0	±0.3	±0.2
Luminosity	±1.8	±3.3	±0.9	±1.0	±0.3	±0.2

- Good agreement between measurements and NLO prediction.

- Interpretation in terms of anomalous TGC's :

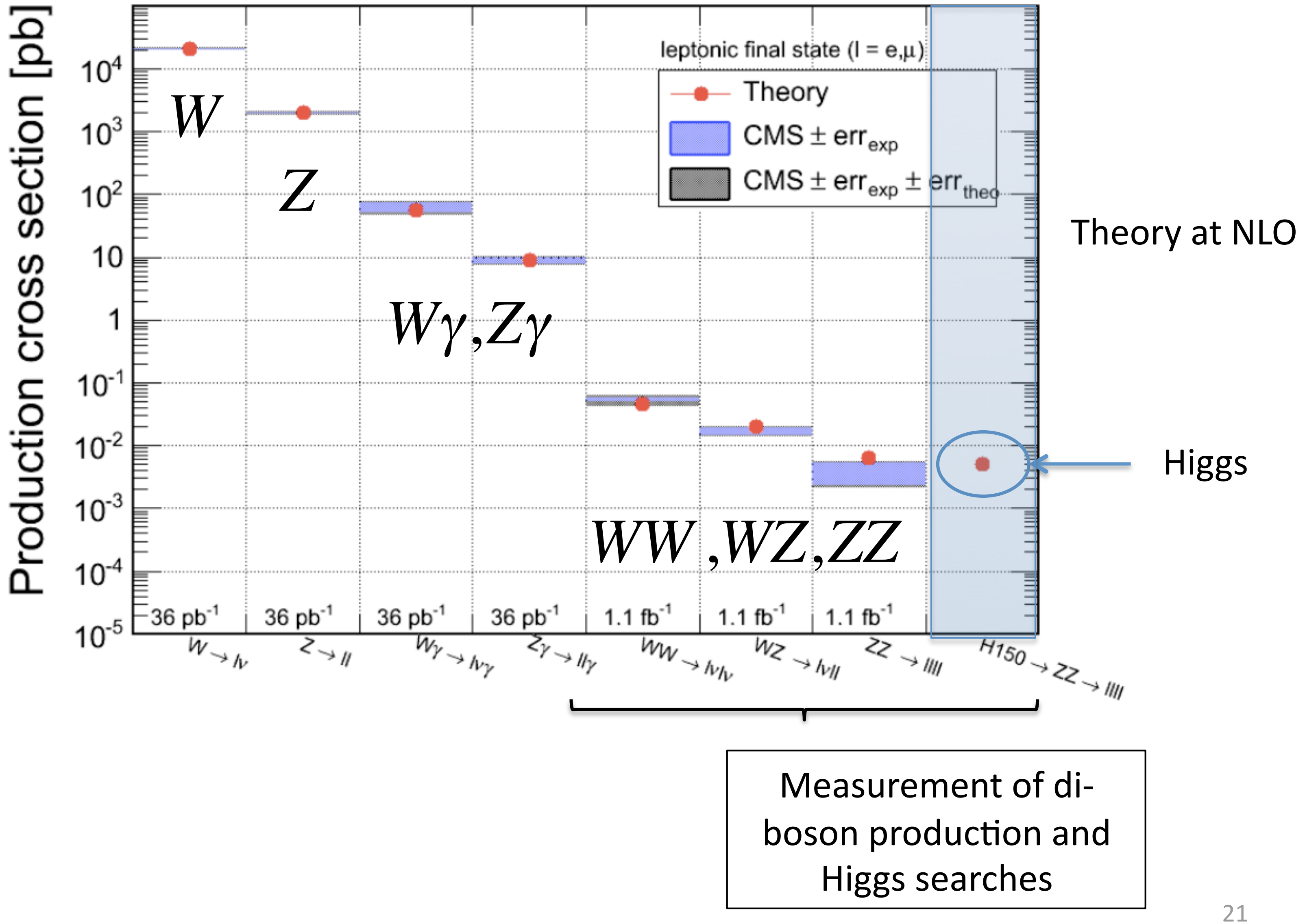
    - Already stringent limits on anomalous TGC

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

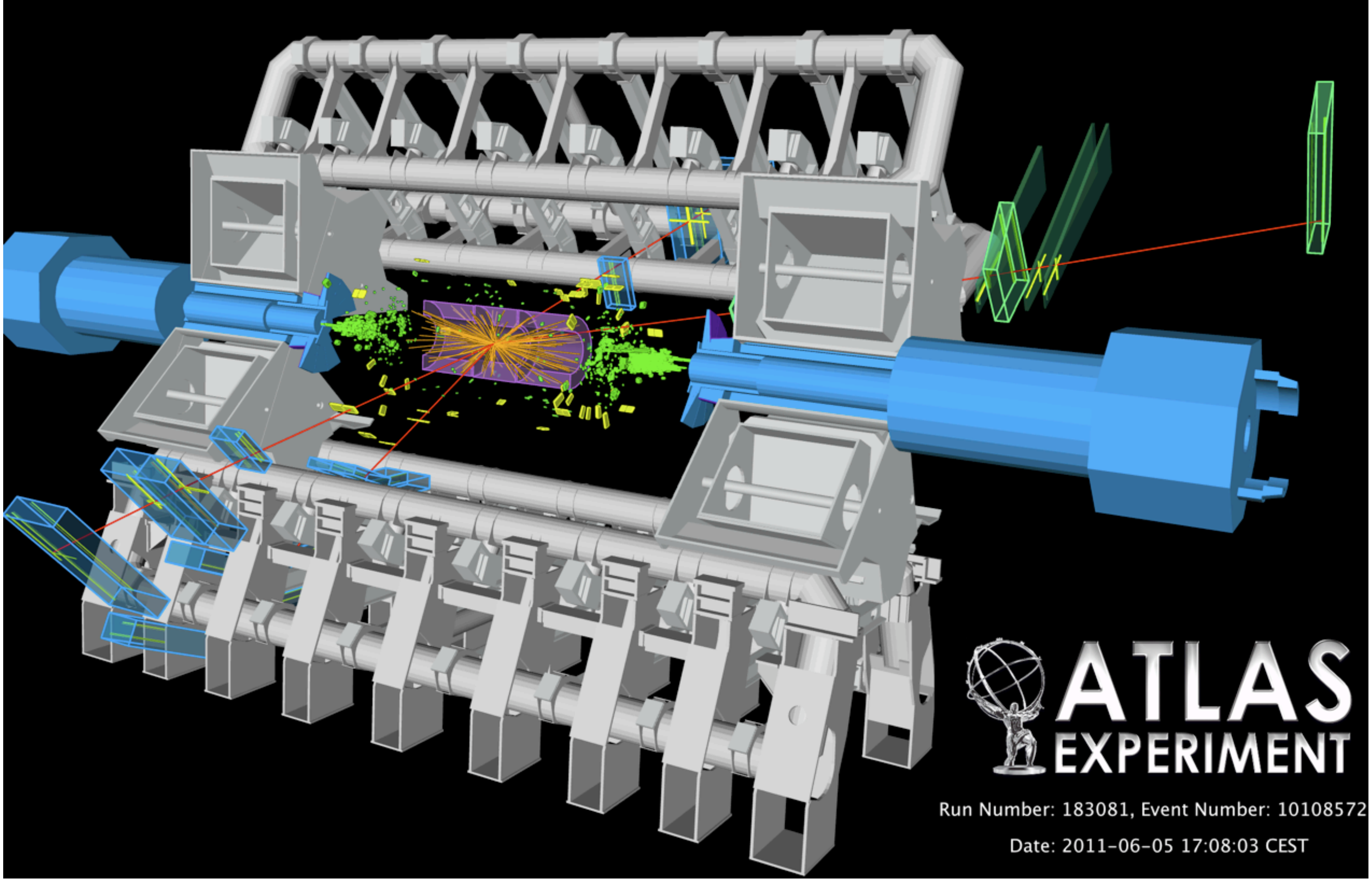


From Standard EW Process to the Higgs Production

The CMS Summary

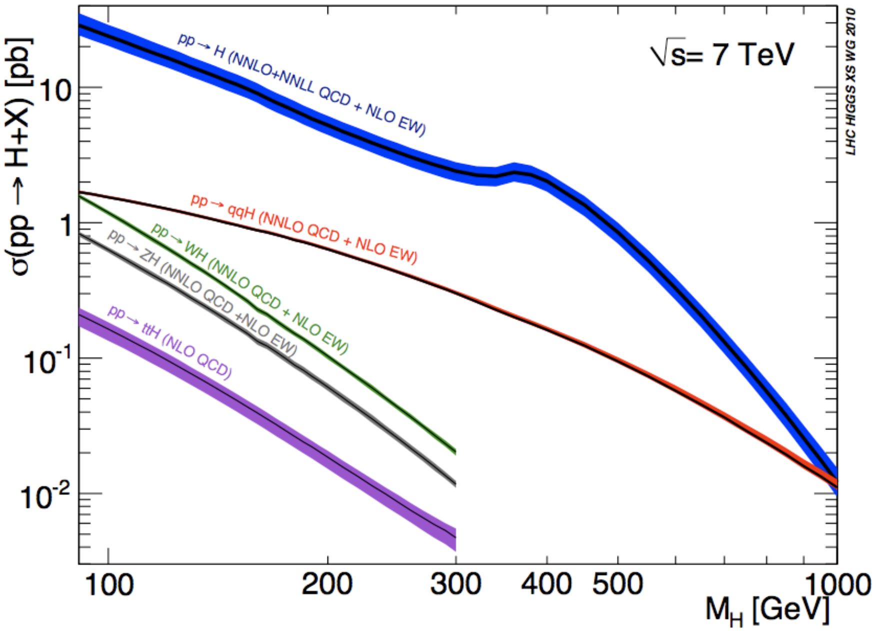


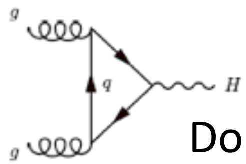
4 μ event … *Standard EW only or Higgs?*



The Main Production Modes

Data driven background estimates legitimate use of NNLO cross sections!

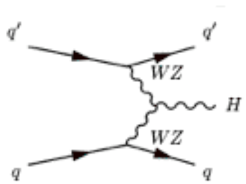




- Gluon fusion process :

Dominant process known at NNnLO

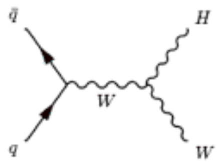
However rather large TH uncertainty* ~O(15%) due to the large corrections for gluon initiated process

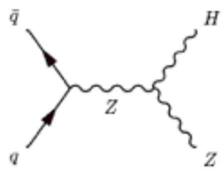


- Vector Boson Fusion :

known at NLO TH uncertainty ~O(5%)

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

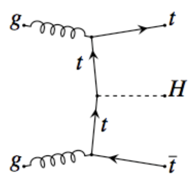




- Associated Production with W and Z :

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

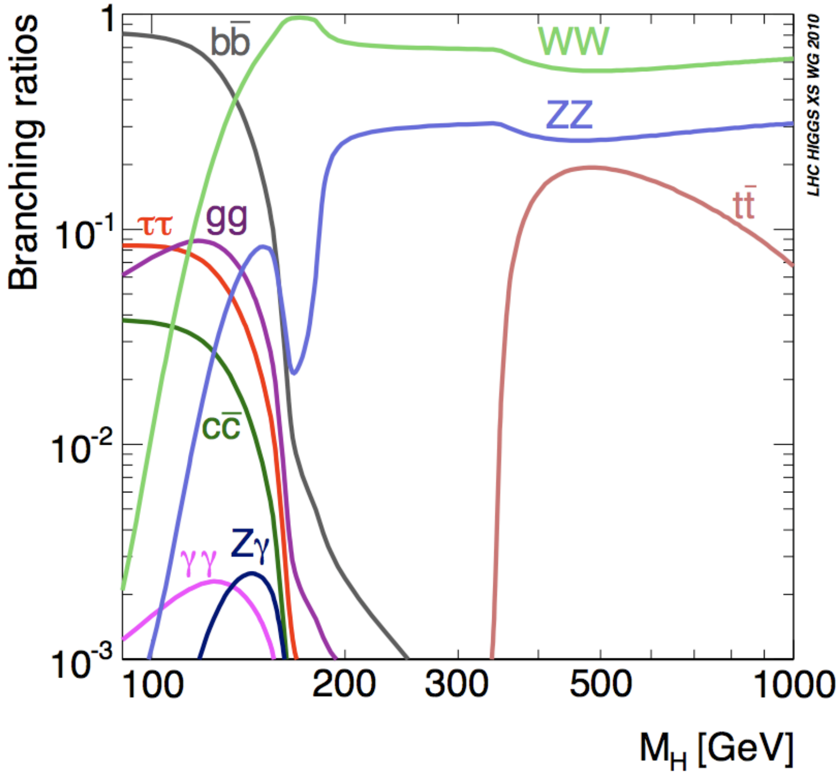
Pure Branching Fractions

- The dominant b-decay channel

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

- The $\tau\tau$ 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

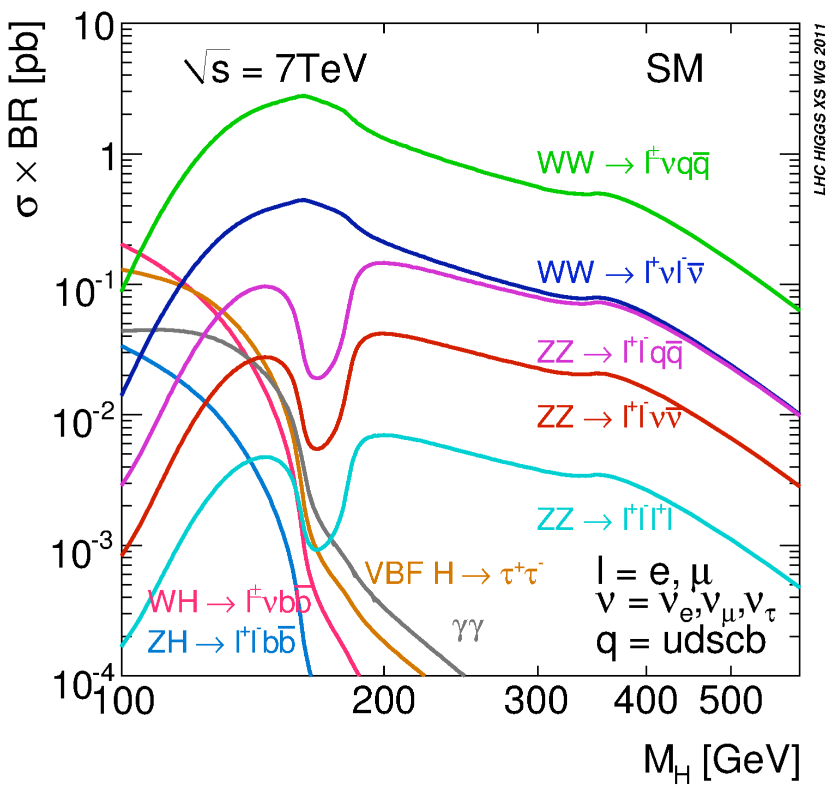
Huge backgrounds, needs distinctive features at production level and beyond… Associate production W,Z H and Boost!

- The $\tau\tau$ channel

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

- The $\gamma\gamma$ 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 banching Z in bb)
- 2-leptons 2-neutrinos (llnn) : Best compromise yield/purity. Dominant channel at high mass

Analyses Preparation

Common LHC efforts to agree on non consensual issues :

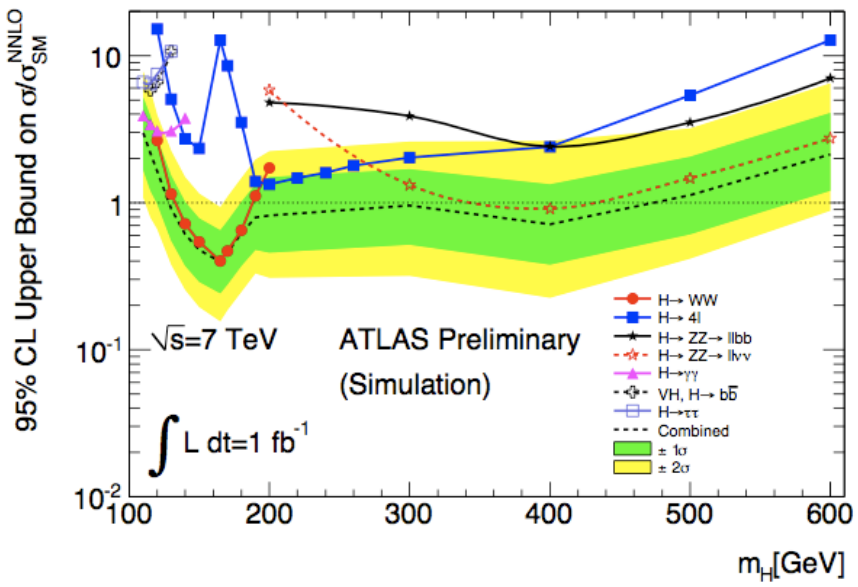
- Common effort LHC-wide to compute cross sections and branching ratios and…
  - Use common standard model input parameters (NNLO signal cross section)
  - Common strategy on correlated systematic uncertainties (scale variation, PDFs, α_S, etc…)

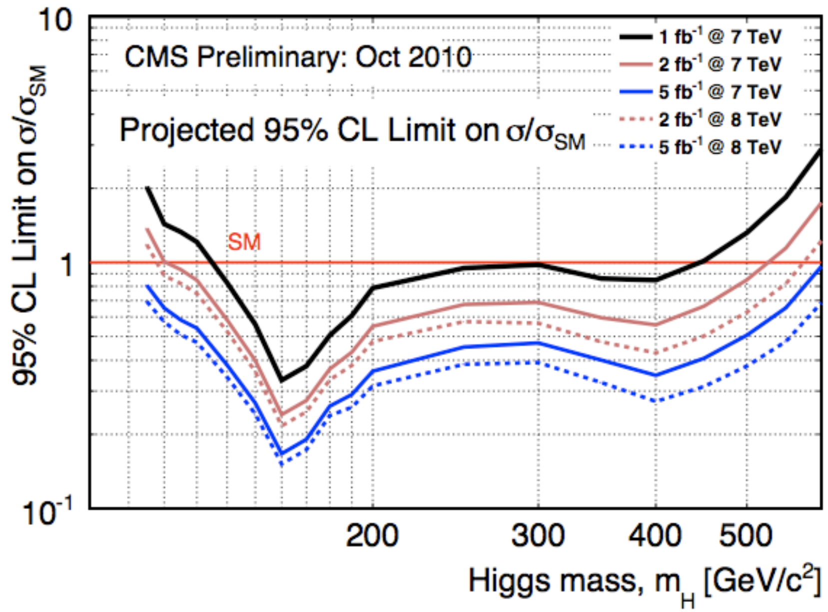
https://twiki.cern.ch/twiki/bin/view/LHCPhysics/CrossSections

- 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 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 ($ll\nu\nu$)		✓		>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

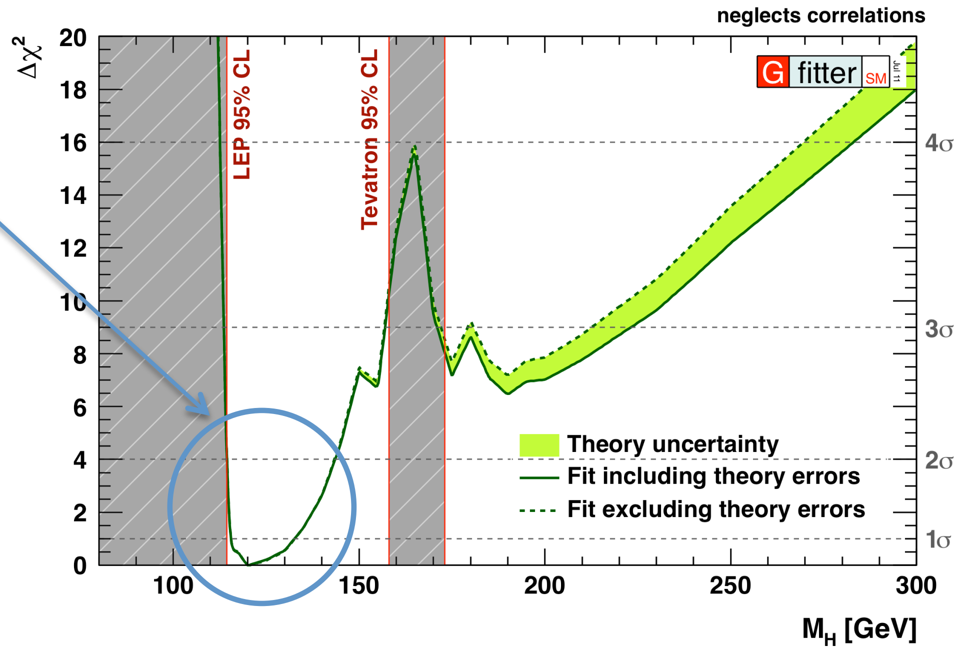
Take home message :
- Detectors are fully used in these analyses
- Backgrounds are derived from data (some inputs from MC)

Low Mass Channels

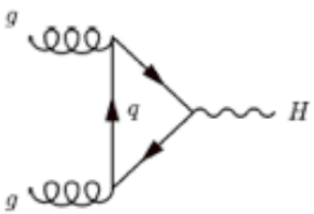
Low Mass Channels

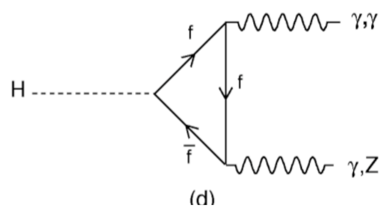
DiPhoton Channel

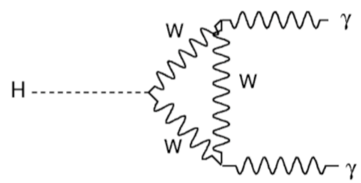
- Dominant Channel in the very low mass range (110-125 GeV)



- Main production and decay processes occur through loops :







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

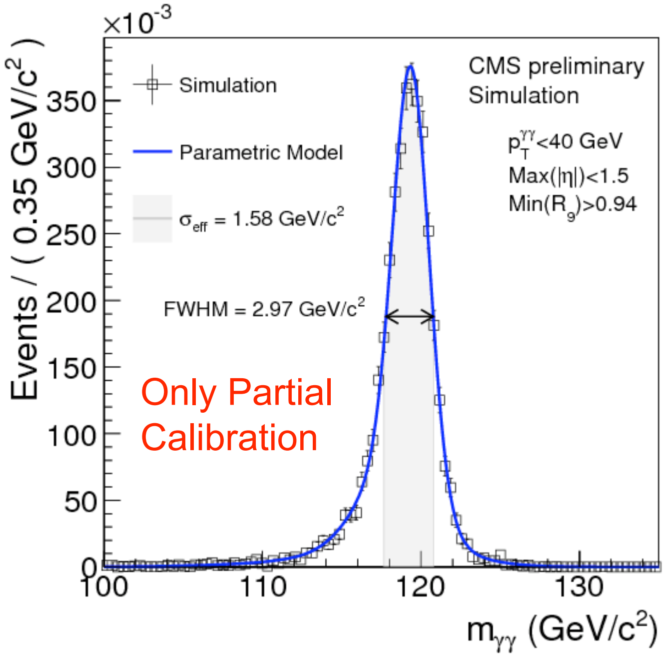
-Key features :

-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).

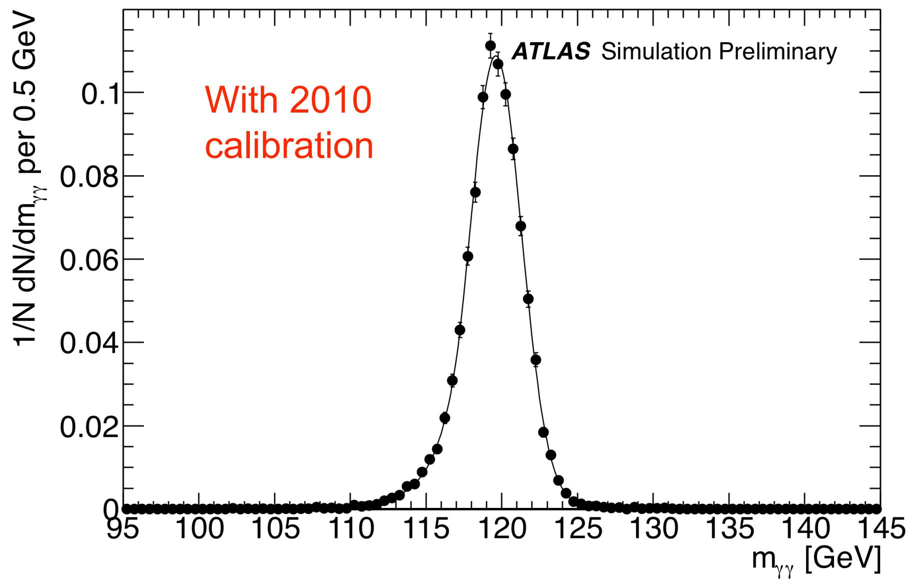
Transparence Calibration Crucial

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



Calibration for Material Upstream important

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



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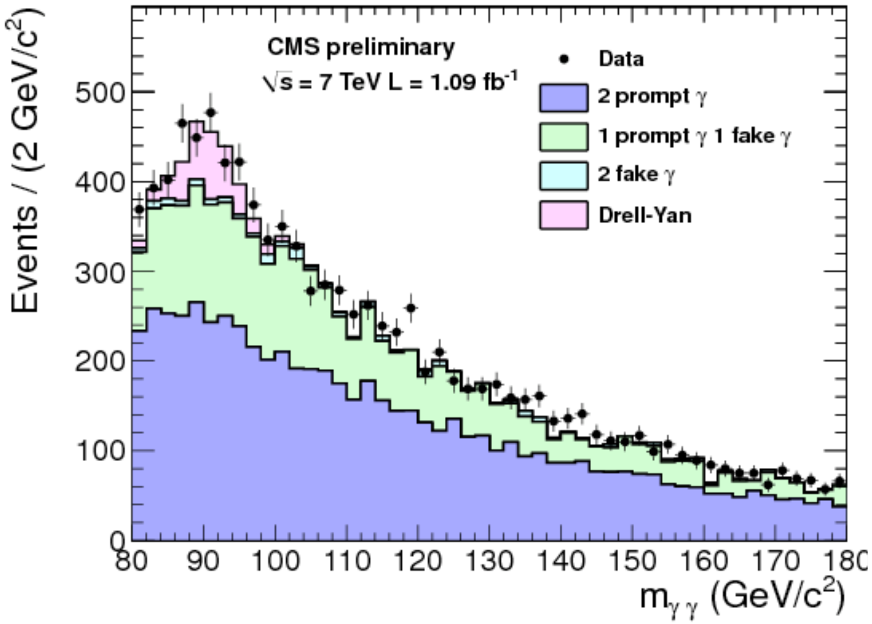
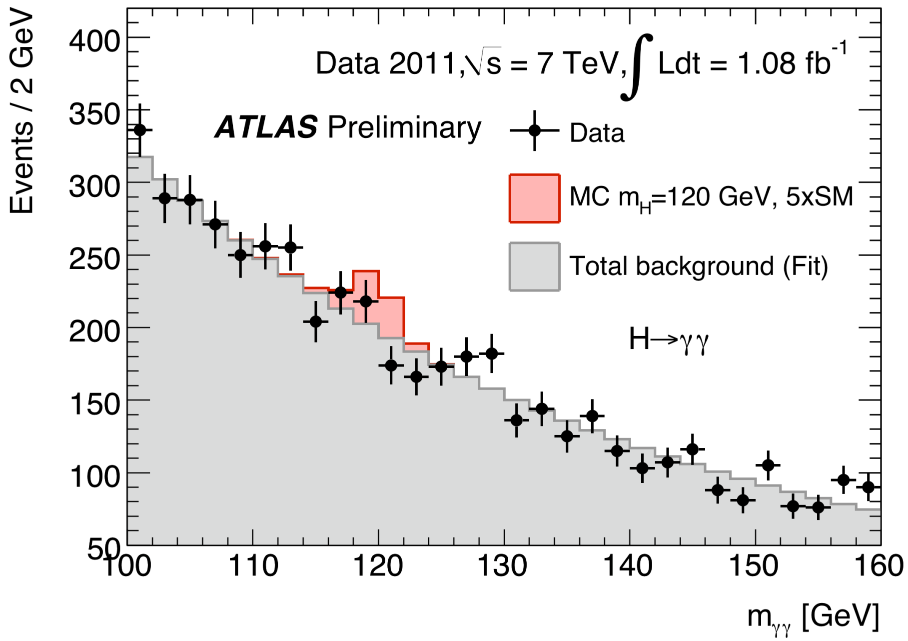
- Background rejection γ/π^0 also critical





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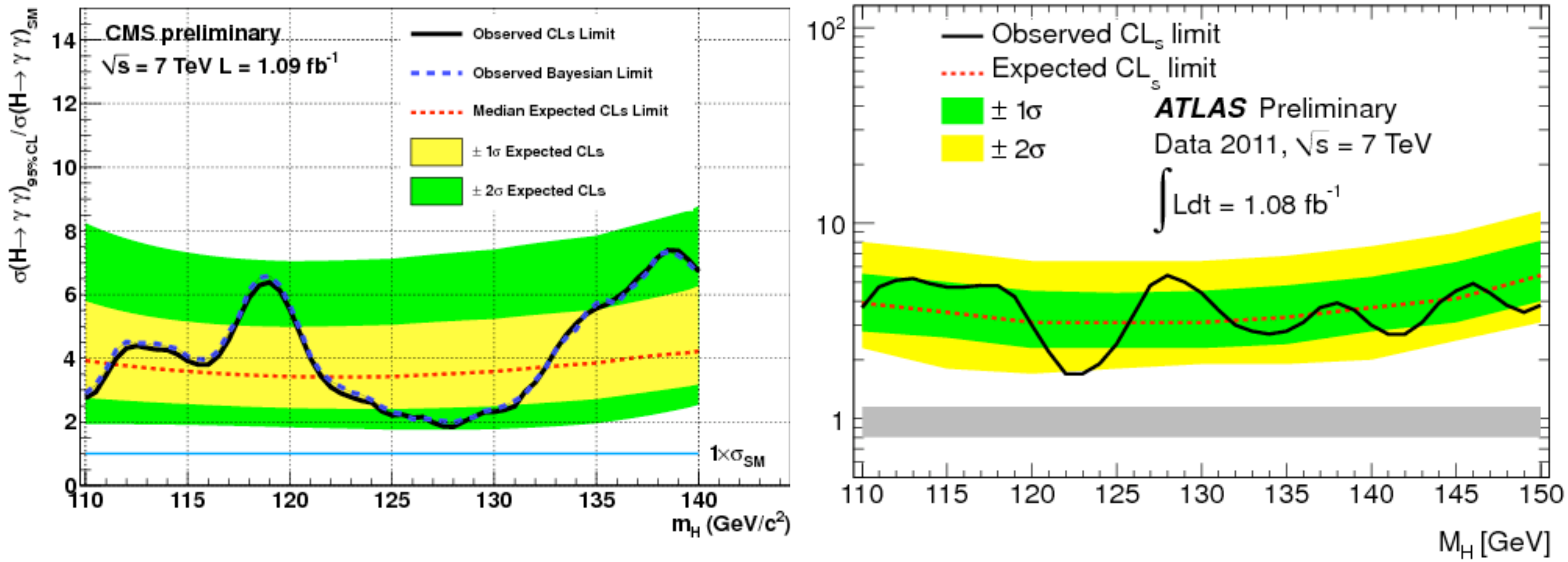
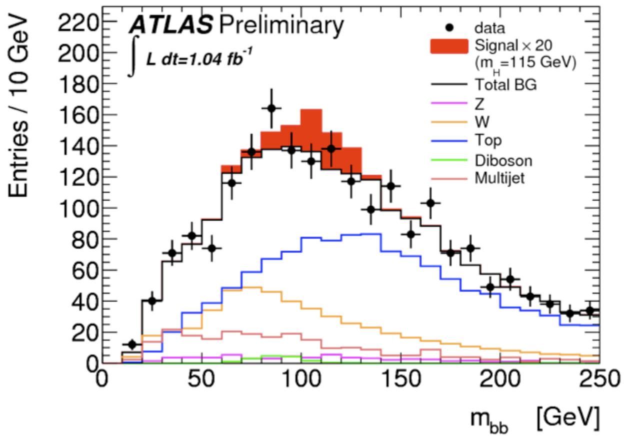


Higgs Boson Search in the VH, H→bb
(ATLAS only)

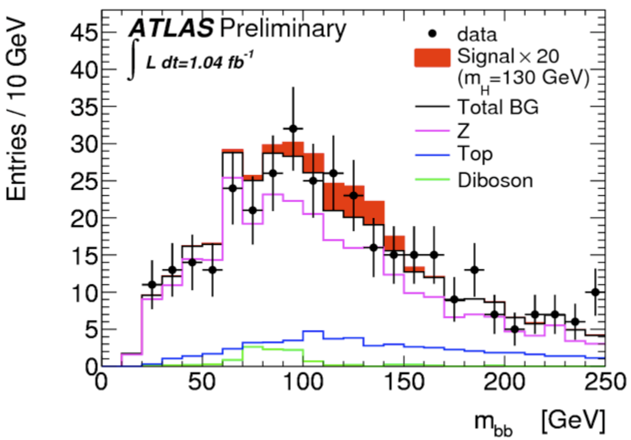
- At the heart of a completely new analysis trend : Jet substructure (Not yet applied)

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

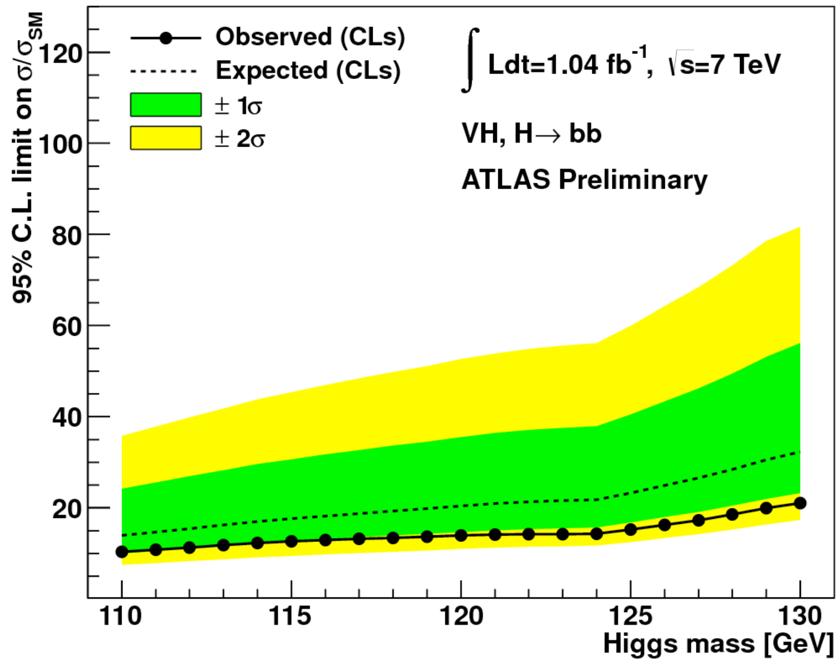
- Backgrounds are estimated from control samples :



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



ZH main bkg :
Z+jets

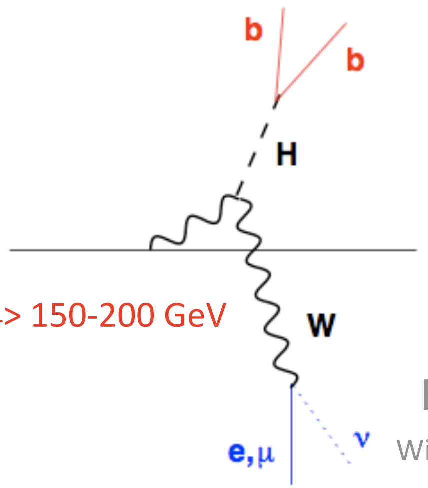


Sensitivity	~15 x σ_{SM}
Limit	~10-15 x σ_{SM}

First Steps Towards Jet Substructure

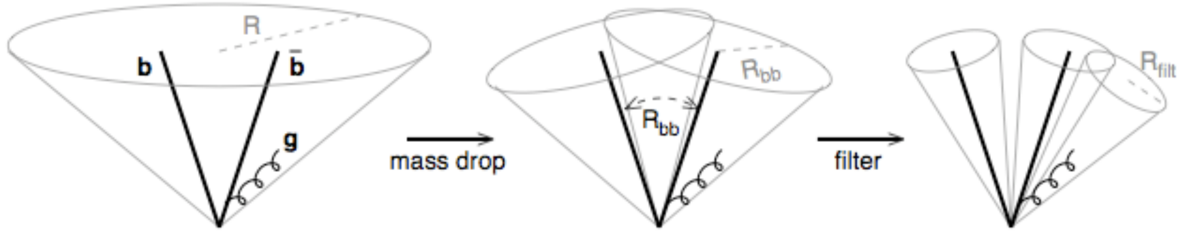
- Use Higgs only at high p_T to improve acceptance and reduce bkg.

- The Higgs would be a single jet, then investigate the jet structure, RECIPE :



P_T> 150-200 GeV

Butterworth, Davison, Salam, Rubin



Fat jet

With mass m

- Use the Cambridge-Aachen jet algorithm Dokshitzer et al. 97'

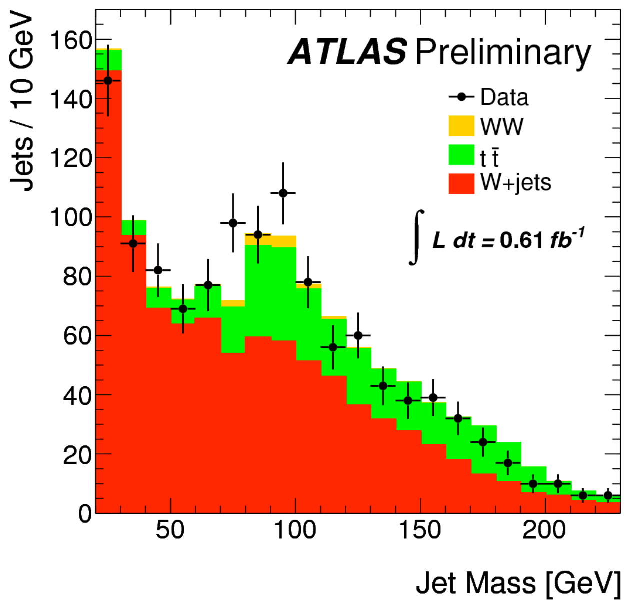
(Clustering based on the R-distances between objects, iterate until $\Delta R>1.2$)

- 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"

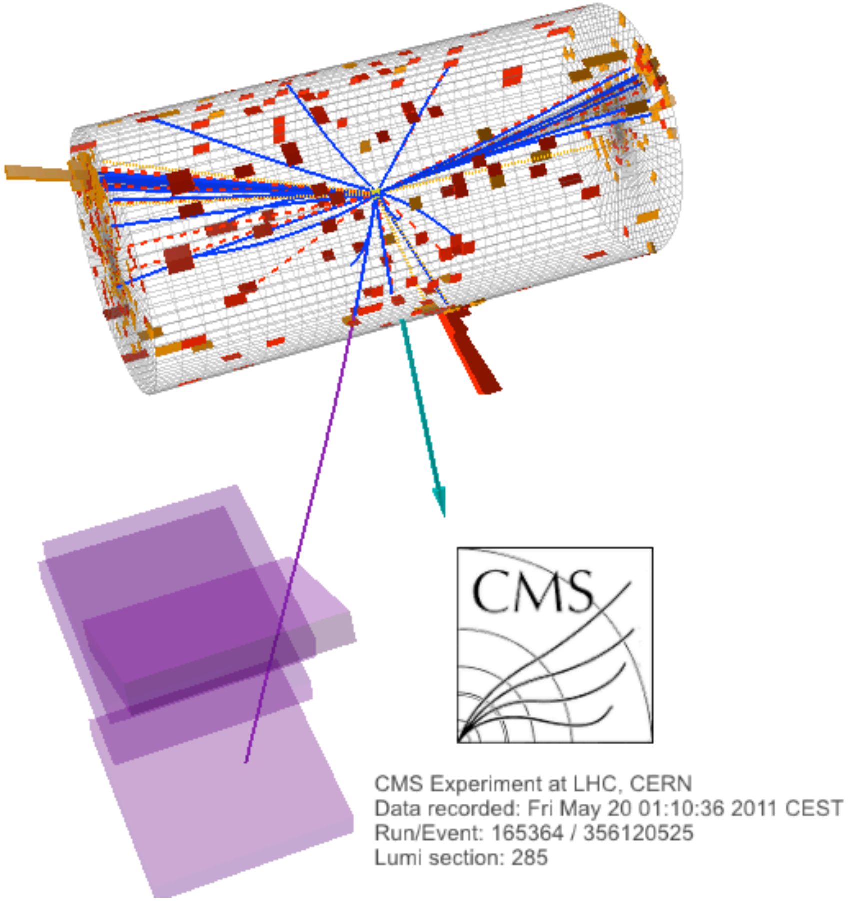
- If there is a mass drop apply b-tagging

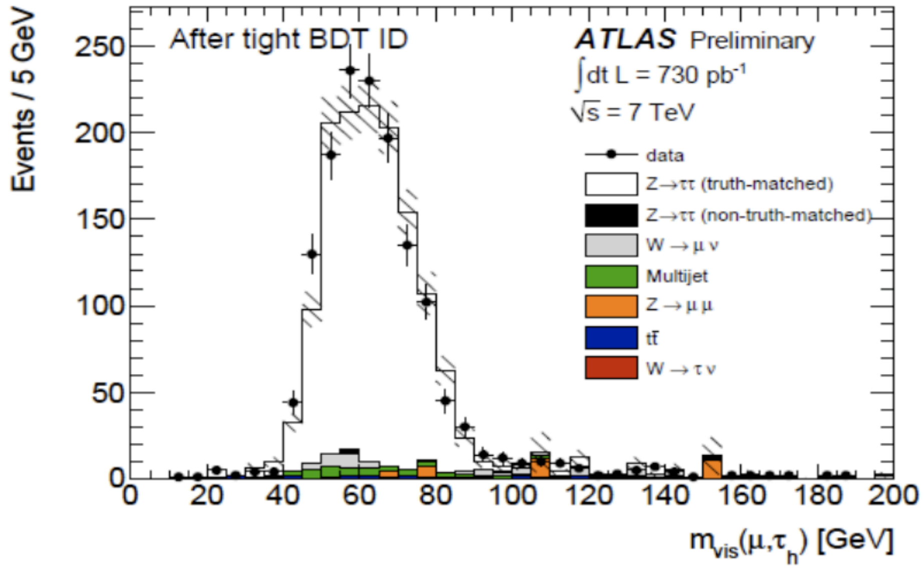
- Then recluster using a $R_{filt} = \min(0.3, R_{J1,J2})$



Splendid first observation of the hadronic W-fat-jet in top events

Higgs Boson Search in the VBF H→ττ





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

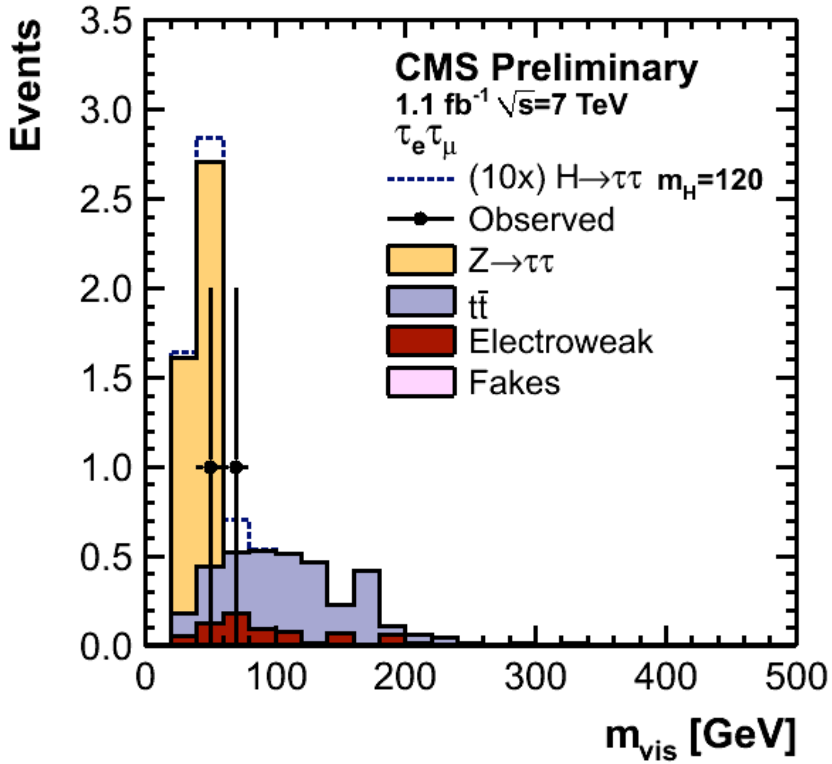
- Search in the SM carried out in the VBF mode :

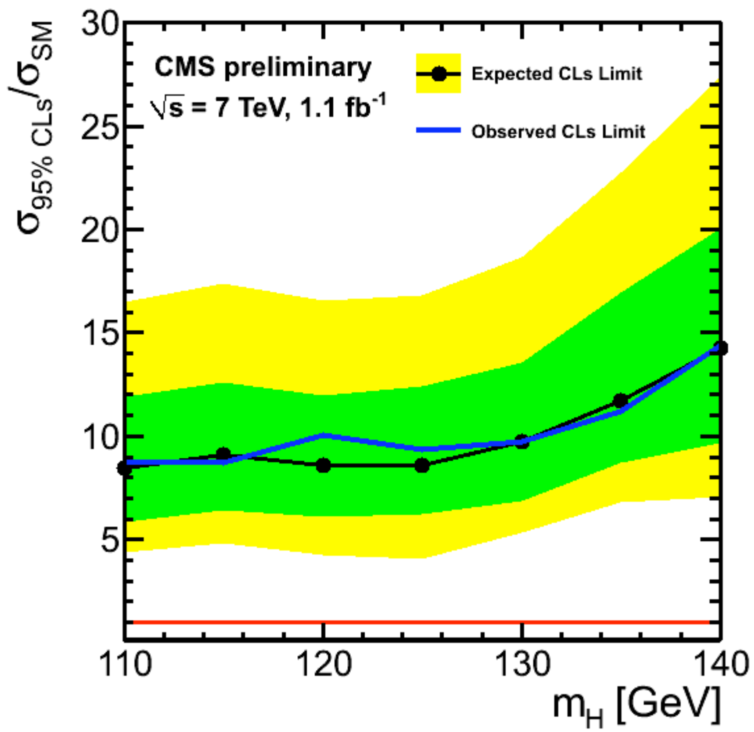
    - Beautiful VBF μ−τ candidate in CMS!

    - Dilepton and semi-leptonic topologies considered

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

- Backgrounds are dominated by Z production estimated with data-driven metohds
- Limits are about $9x\sigma_{SM}$
- Results will improve with new mass rconstruction methods!



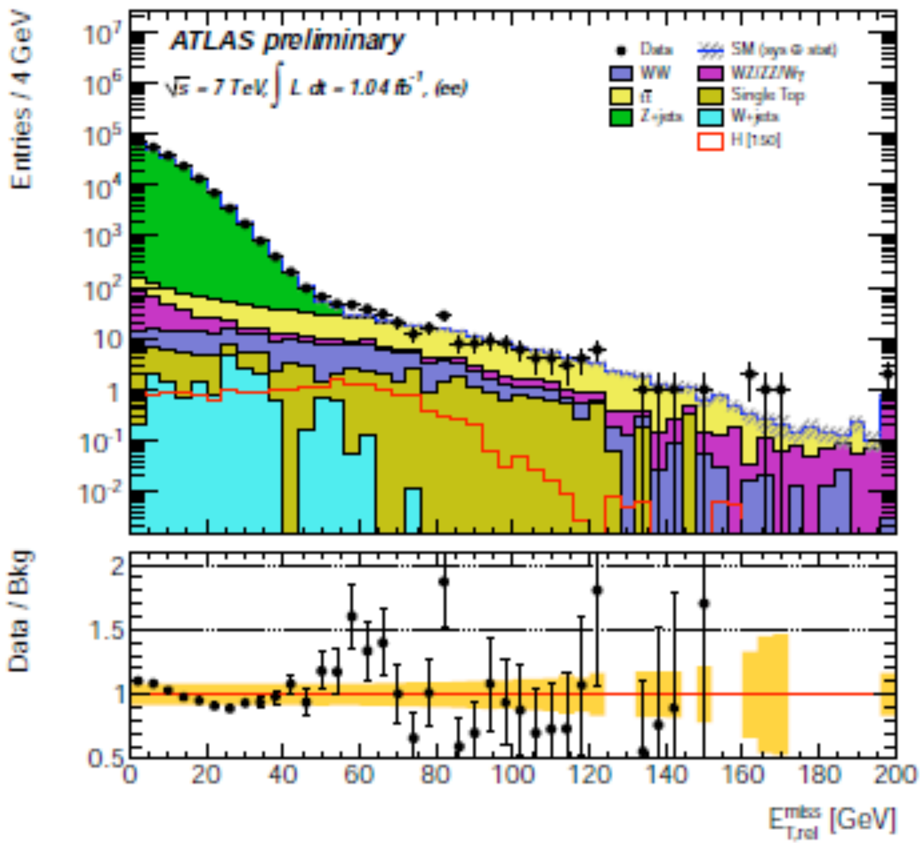


Intermediate Mass Channels

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) bins in numbers of jets
- ATLAS cut based only / CMS cut based and MVA
- Good control of the WW and top backgrounds is essential!

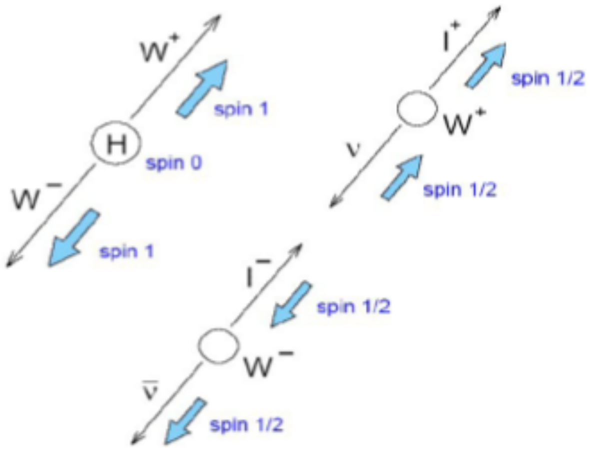


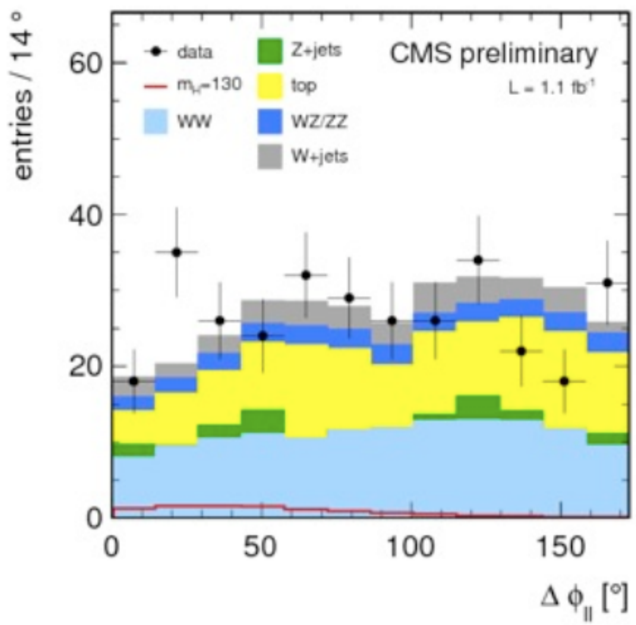
ATLAS MET distribution (not as easy as in the 2010 data!)

Higgs Boson Search in the WW→lνlν

Key features :

- 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
- 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

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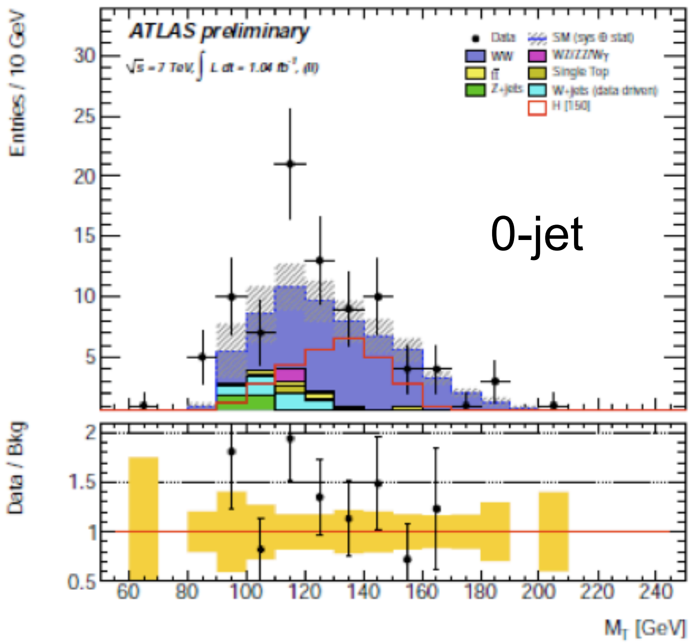
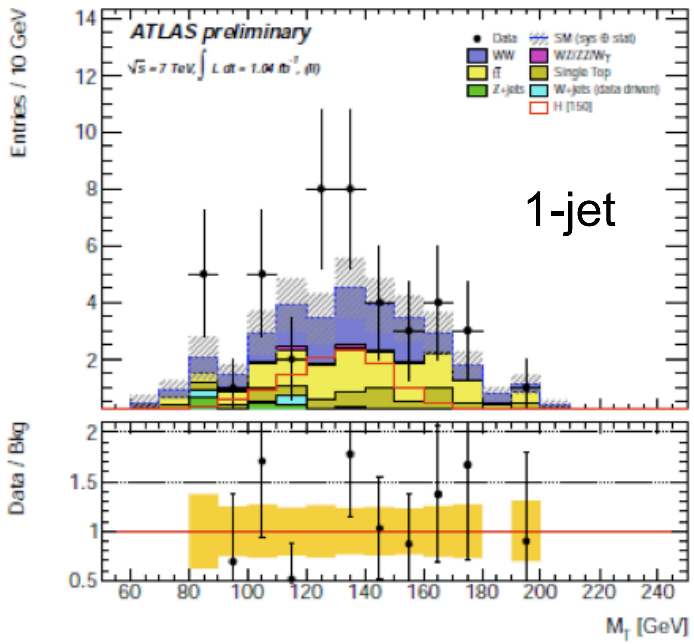
Slight Excess Observed



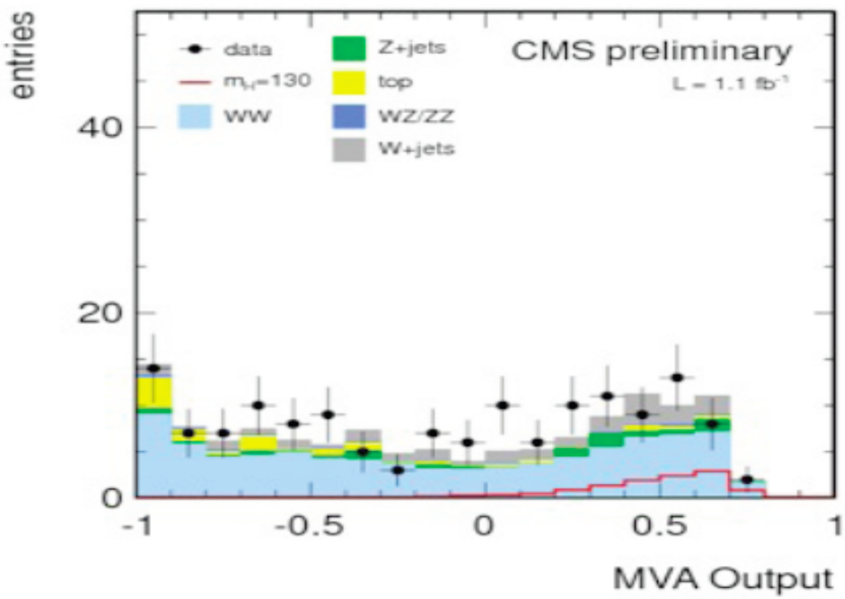


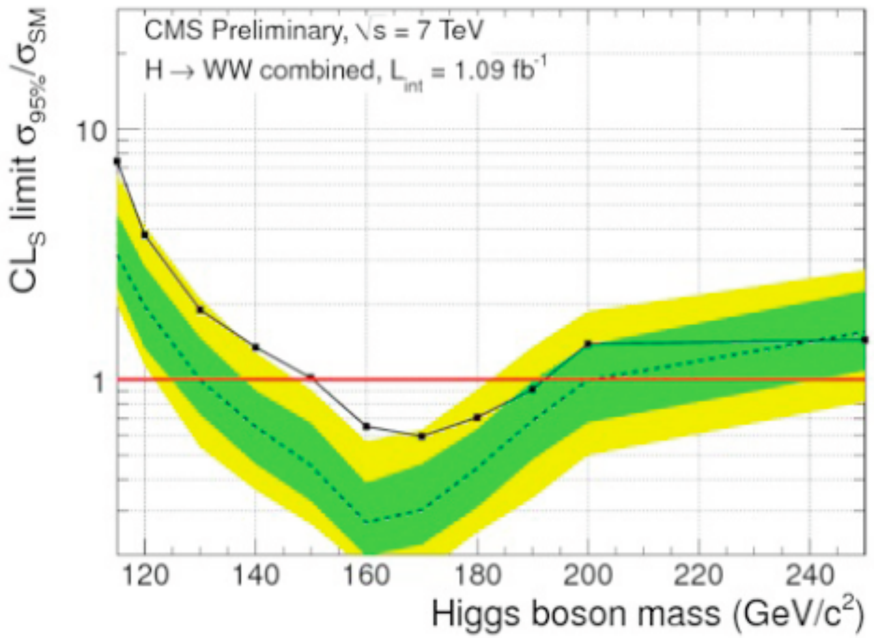
Higgs Boson Search in the $WW \rightarrow l\nu l\nu$

Key features :

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

Slight Excess Observed





Higgs Boson Search in the WW→lνlν

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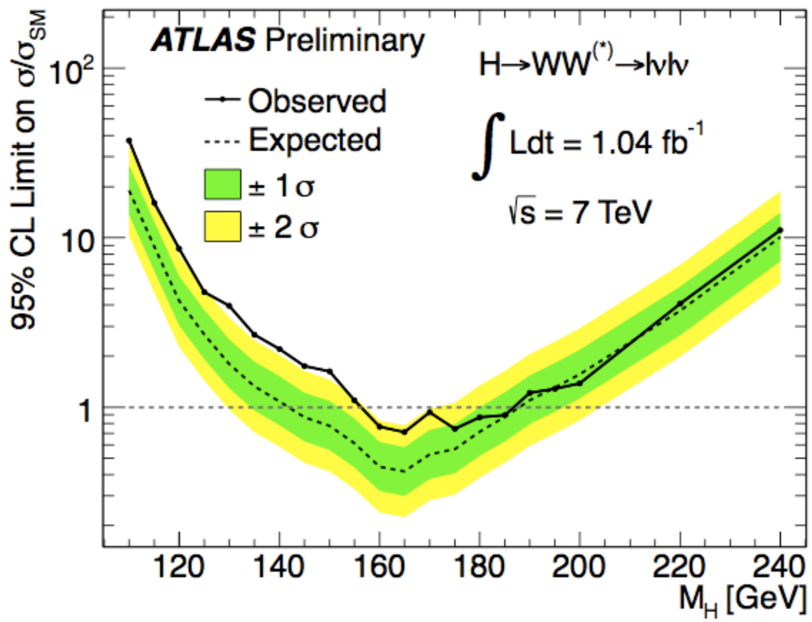
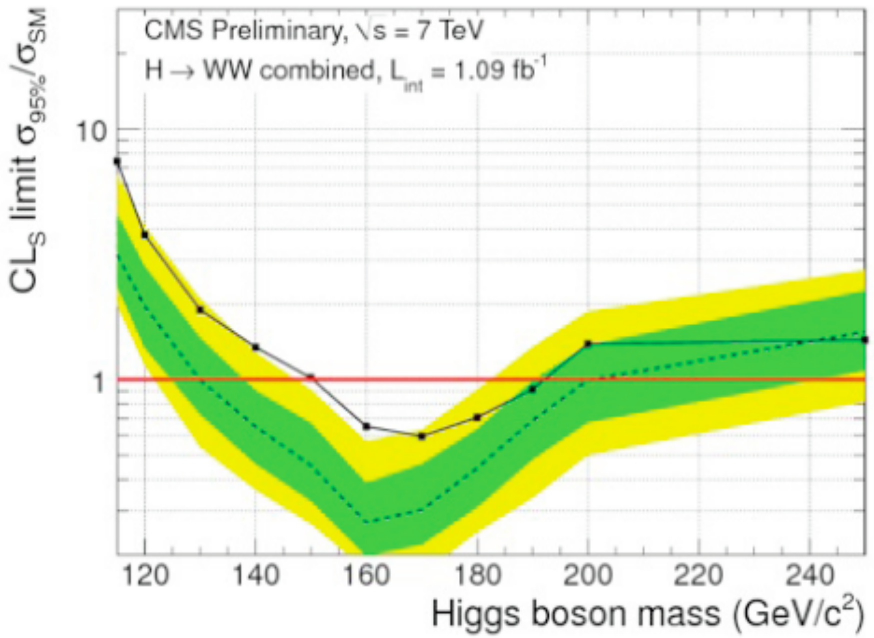
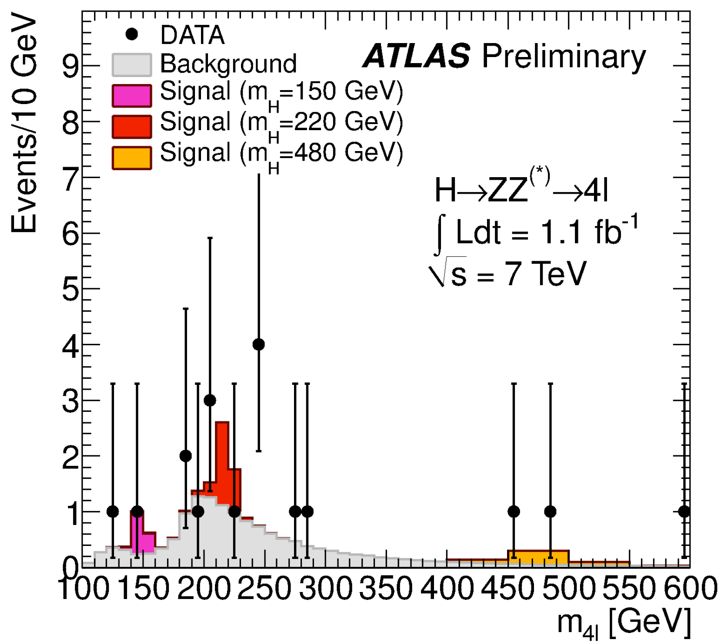
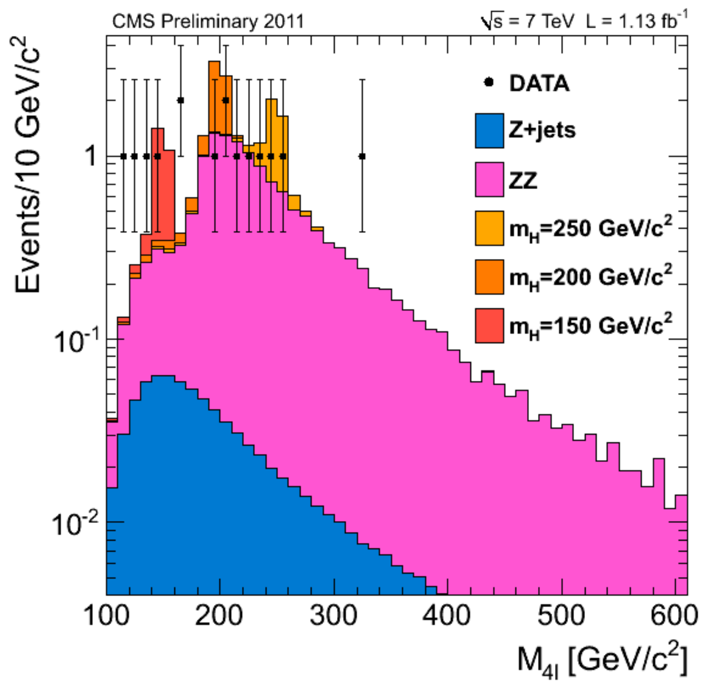




Higgs Boson Search in the $ZZ^{(*)} \to 4l$
"Golden Channel"

- Difference with the cross section : one Z allowed to be off-mass shell (m_H < 180 GeV)
- p_T thresholds lowered (7 GeV) for ATLAS
- Main Background ZZ normalized in the Monte Carlo (checked in the ZZ Cross Section)
- Other backgrounds (Zbb and top) data driven (but small)





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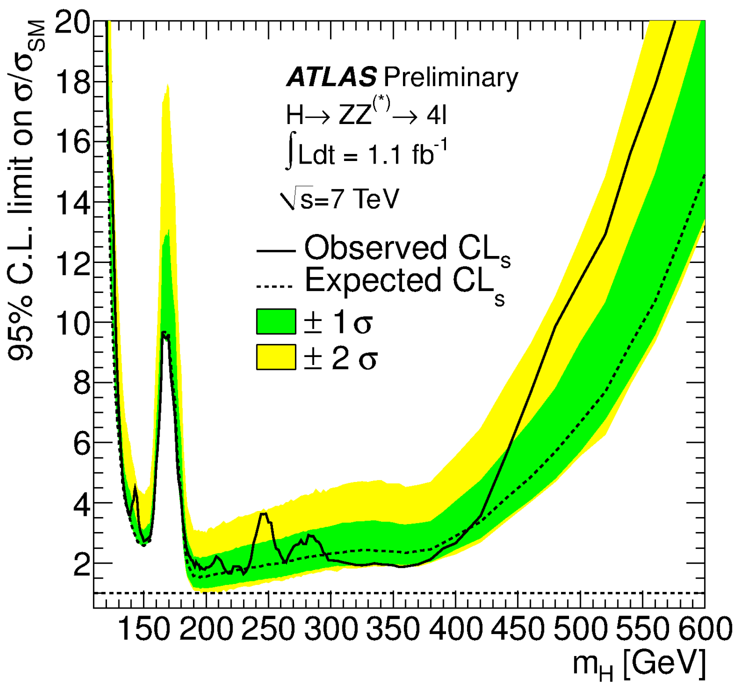
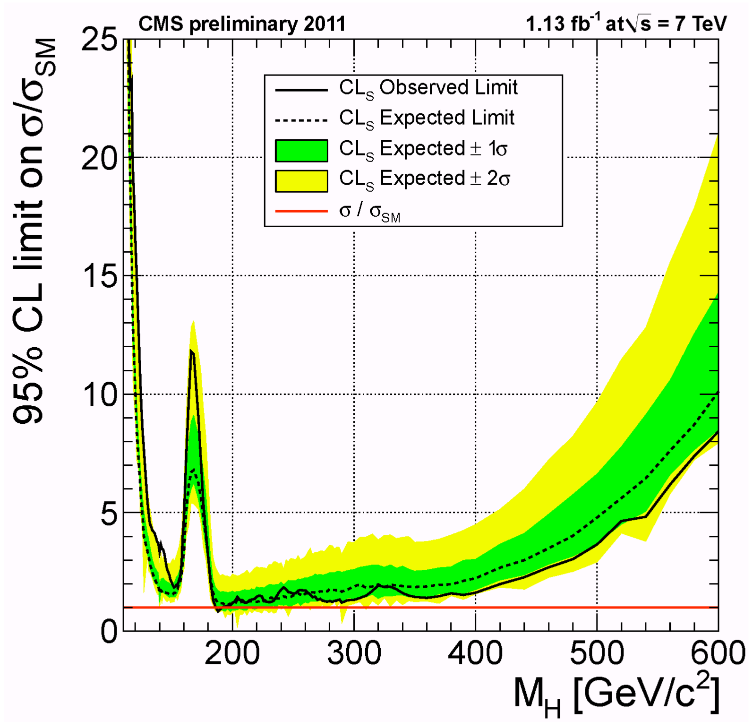
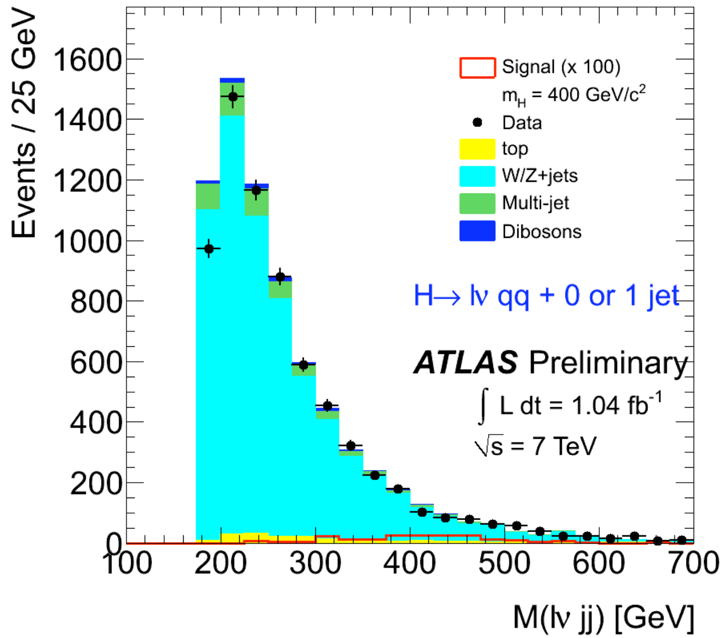


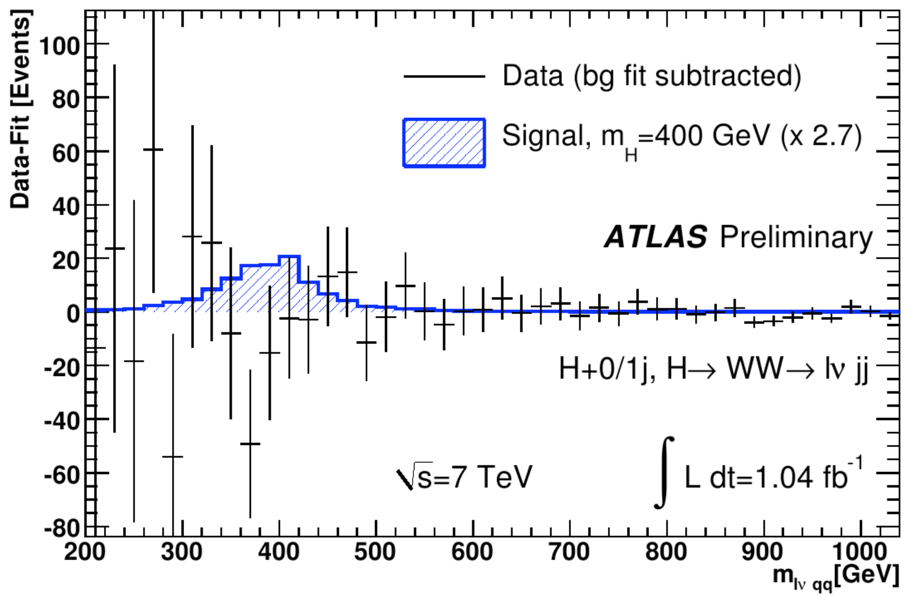


High Mass Channels

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

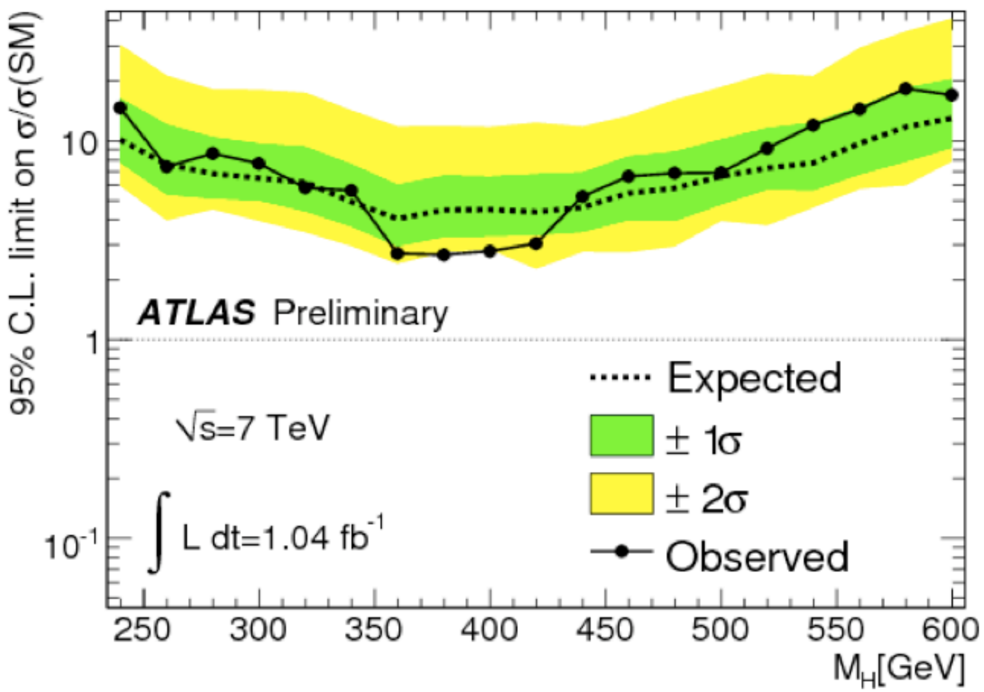
- Largest event yield channel
- Also large backgrounds
- Reconstructed invariant mass constraint $M_{l\nu} = m_W$ Good relative mass resolution
- Background estimated from a fit model (side bands)





Higgs Boson Search in the $WW \rightarrow l\nu qq$
(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)



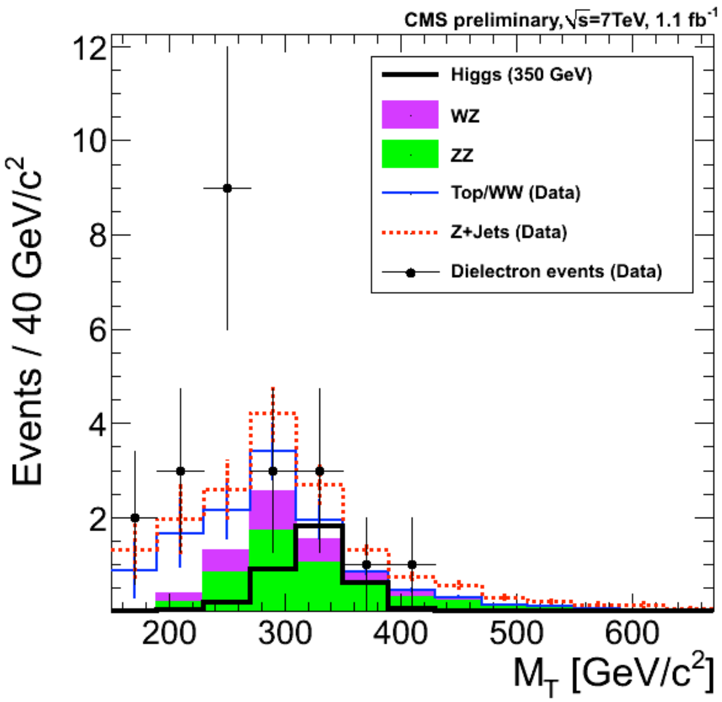
Sensitivity $\sim 4 \times \sigma_{SM}$

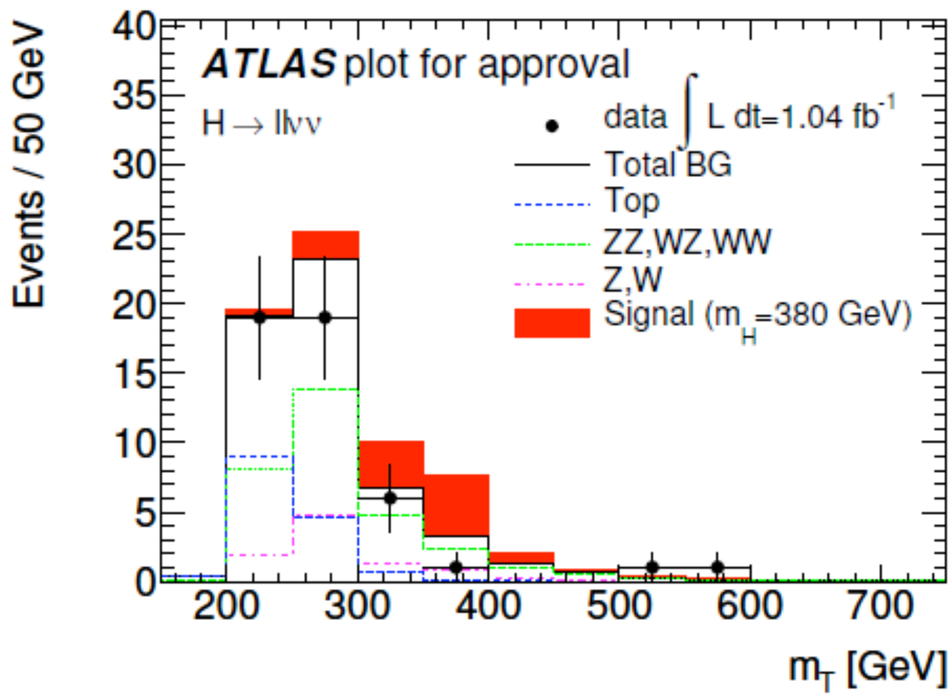
Limit $\sim 2\text{-}10 \times \sigma_{SM}$

Higgs Boson Search in the ZZ→llνν, llqq, llbb

Key features of these analyses :

- llνν almost no mass resolution important normalization of backgrounds

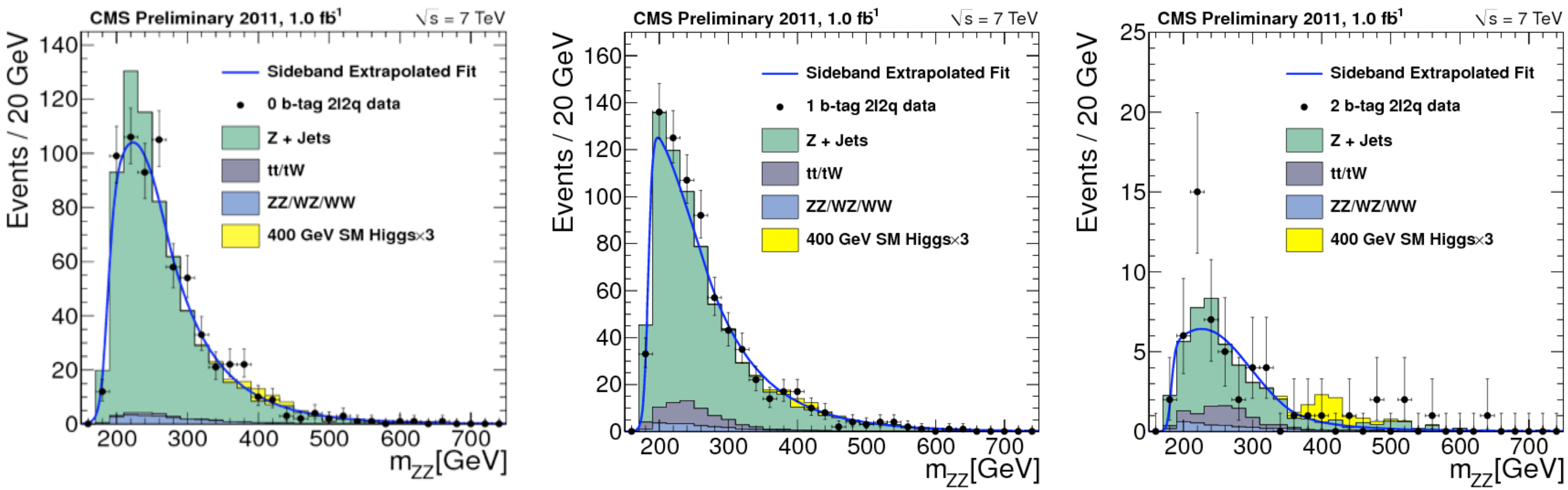




Higgs Boson Search in the ZZ→llνν, llqq, llbb

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



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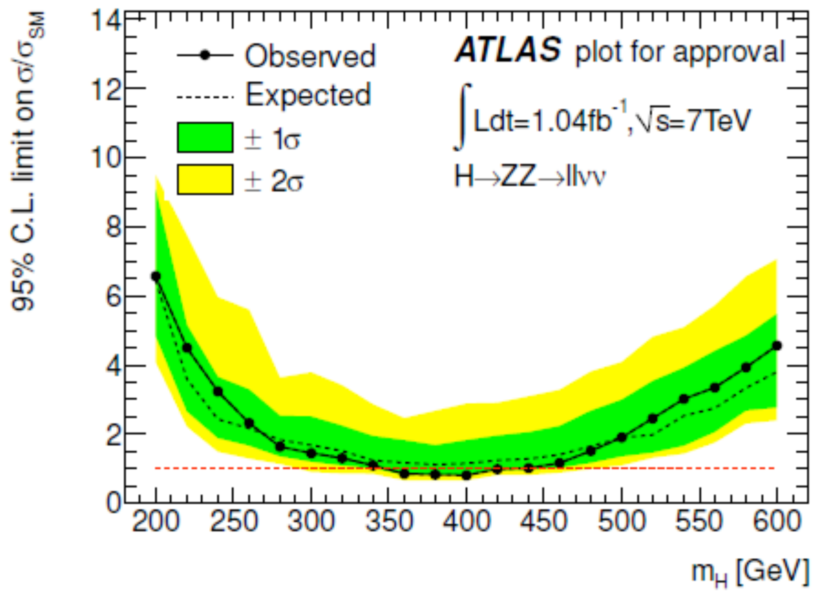
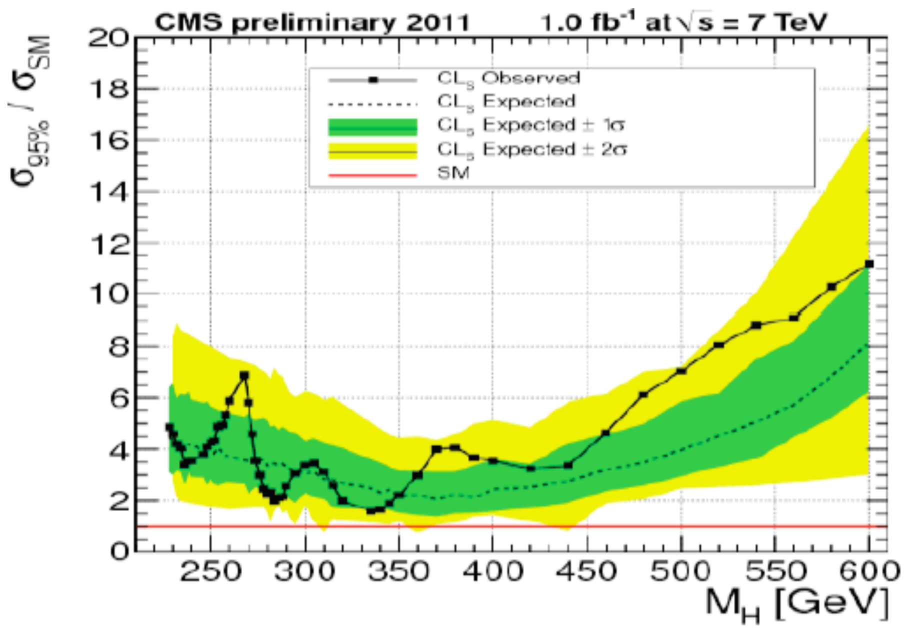
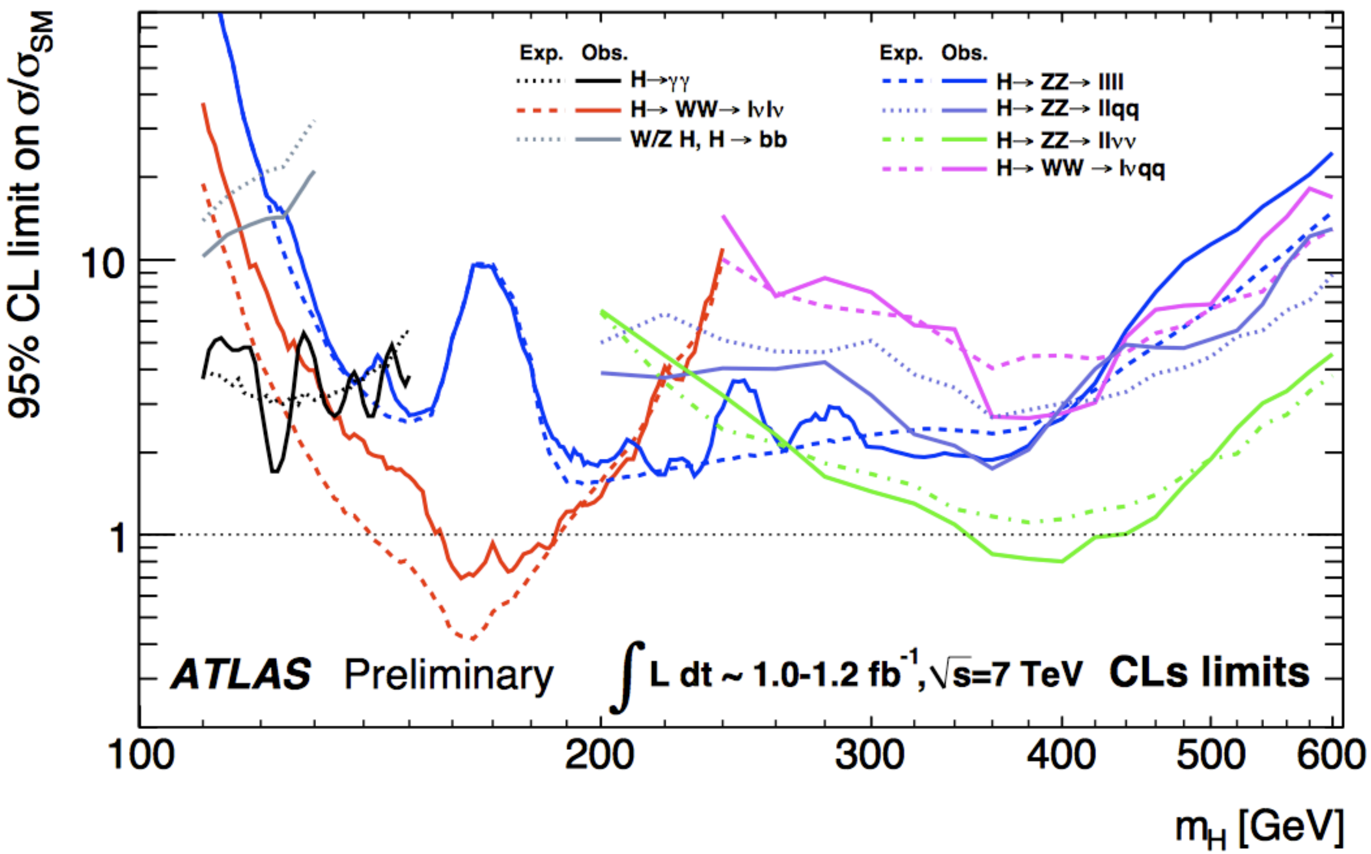




Combination

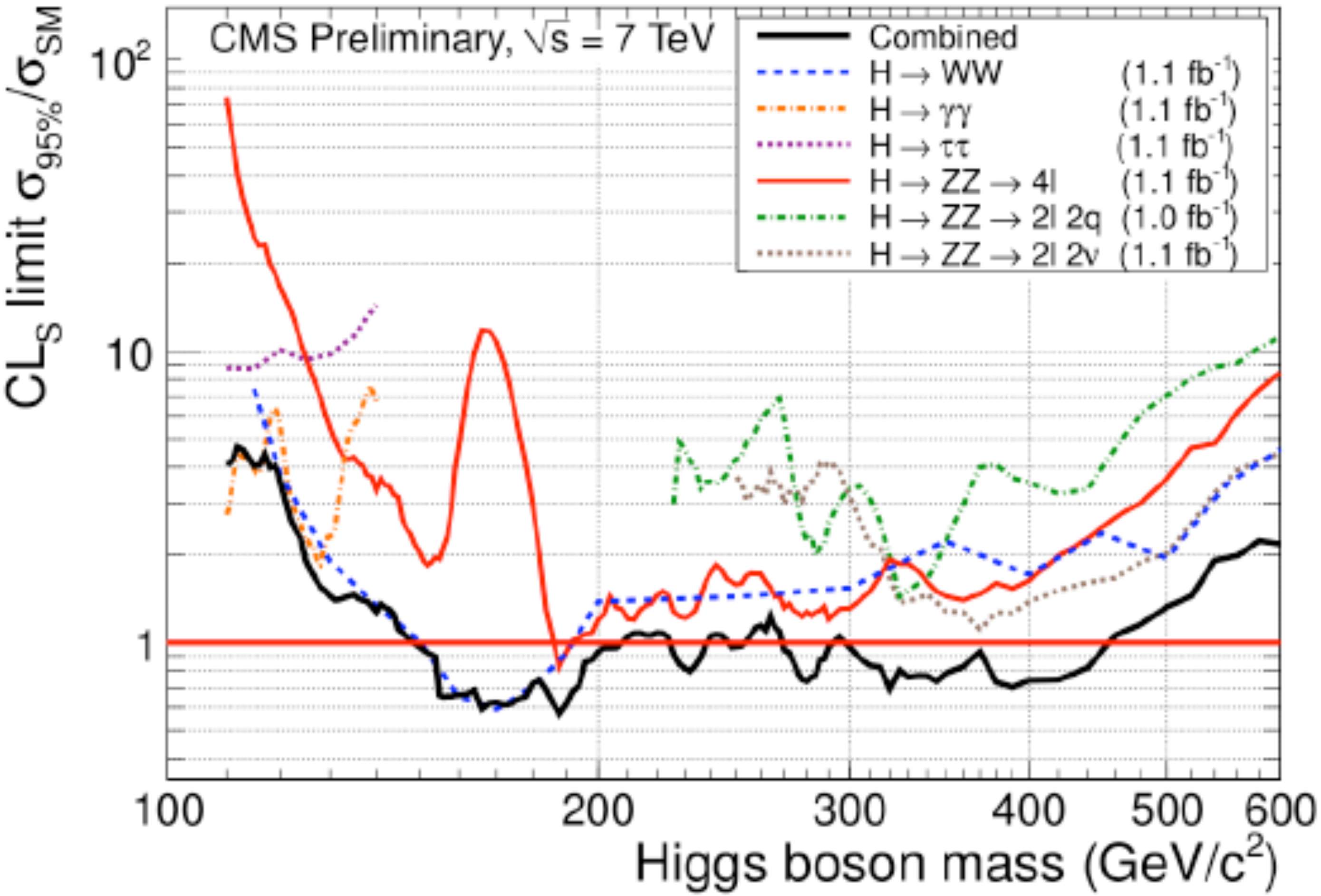
Combination of All Channels

The Complete ATLAS Picture



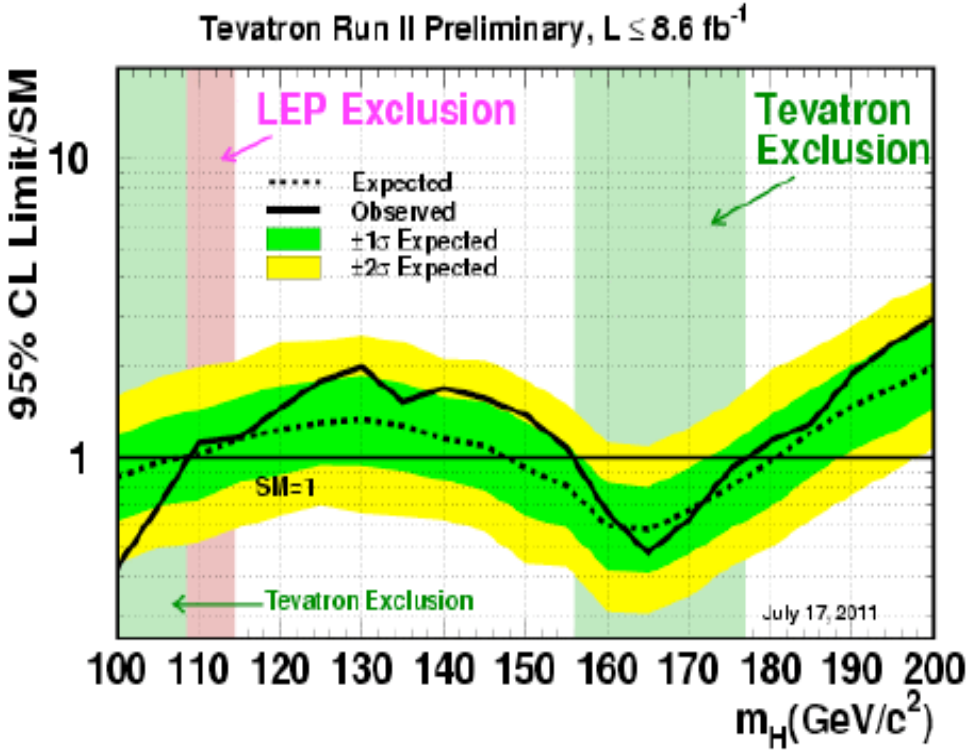
Combination of All Channels

The Complete CMS Picture



Combination of All Channels

The Higgs Search Exclusion before without LHC



SM Higgs excluded @ 95% C.L.

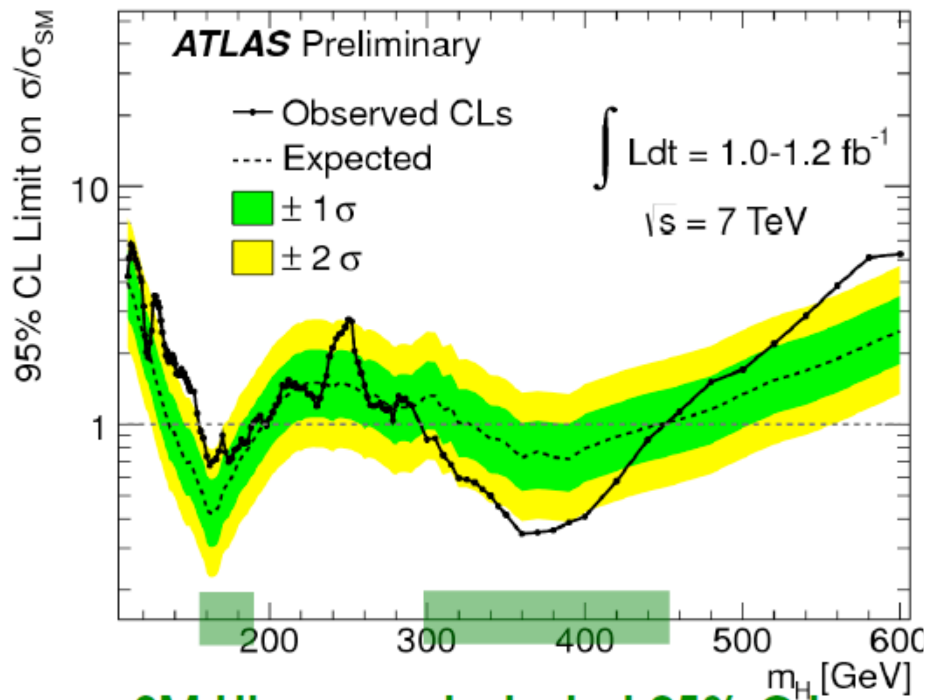
$156 < m_H < 177$ GeV obs ($148 < m_H < 180$ GeV exp)

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

Combination of All Channels

The ATLAS and CMS Combinations

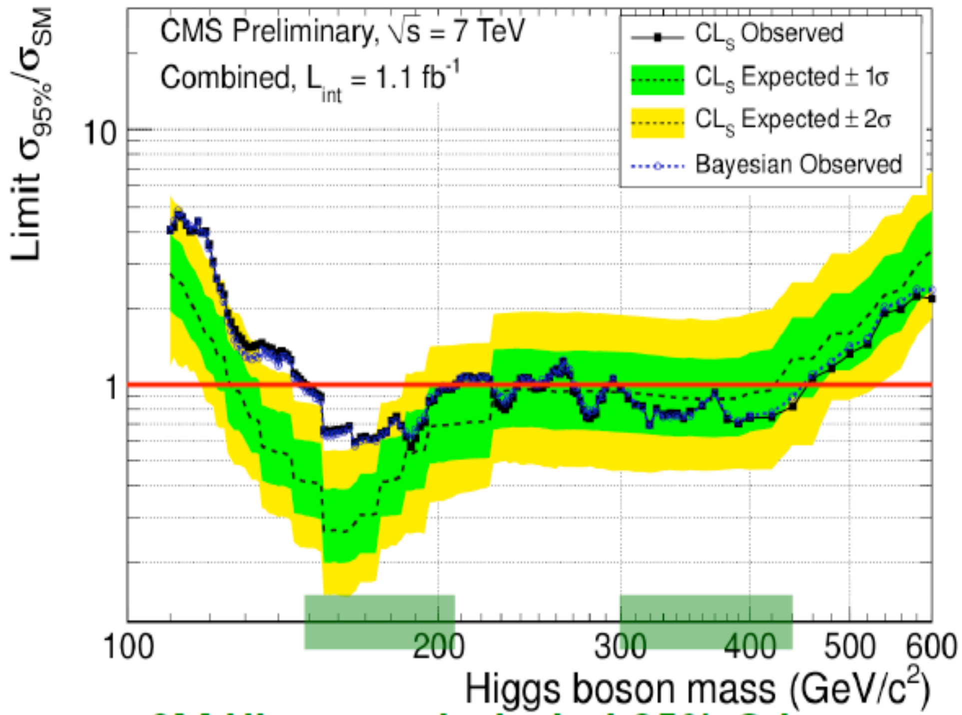
A new landscape of Higgs Exclusion has Emerged!



SM Higgs excluded at 95% C.L.

$155 < M_H < 190$ GeV

$295 < M_H < 450$ GeV



SM Higgs excluded at 95% C.L.

$149 < M_H < 206$ GeV

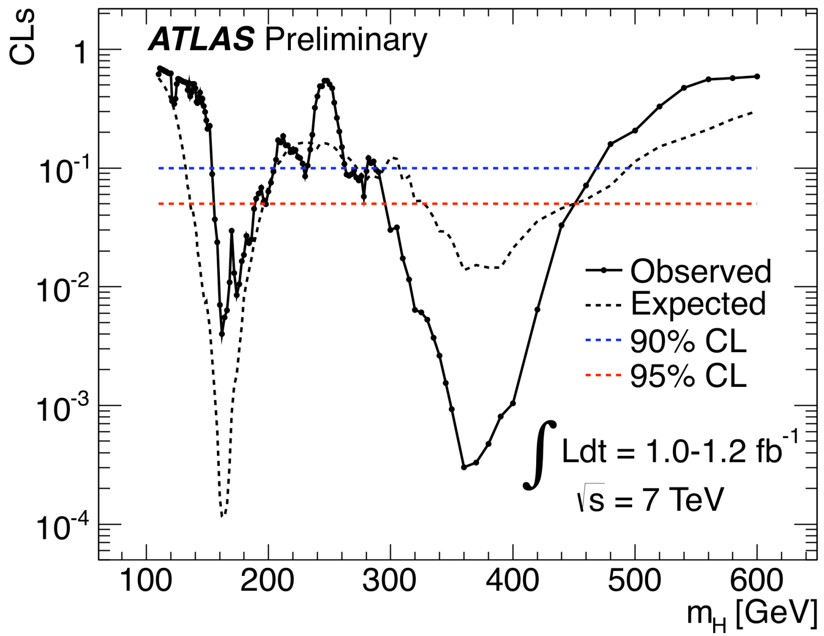
$300 < M_H < 440$ GeV

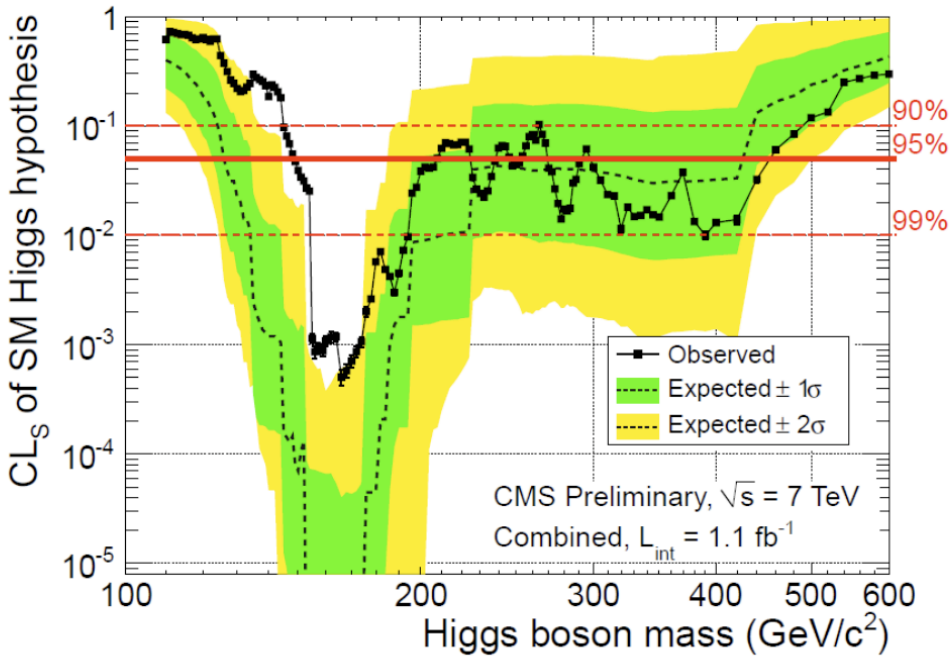
Combination of All Channels

The ATLAS and CMS Combinations

A new landscape of Higgs Exclusion has Emerged!

Another view (LEP style)



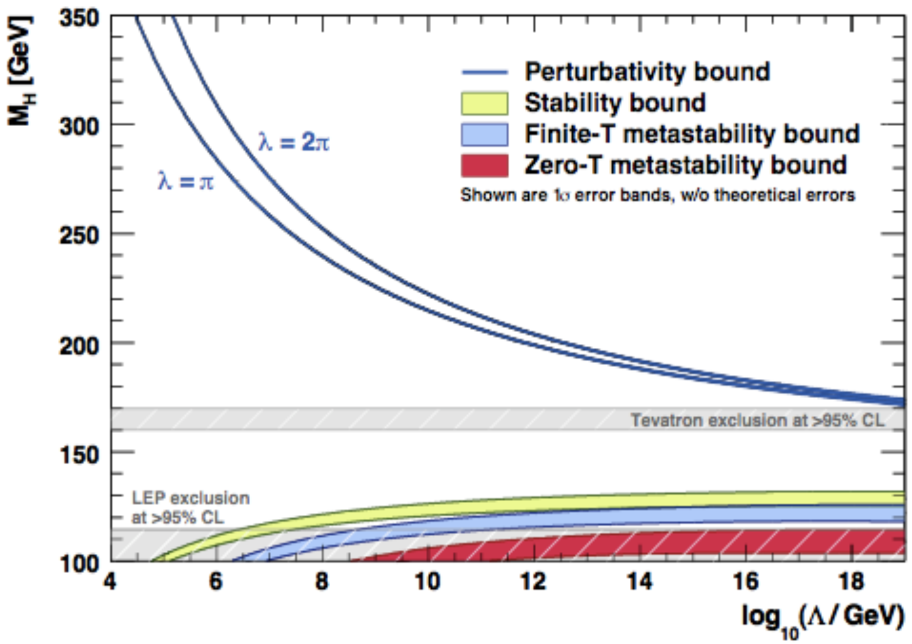


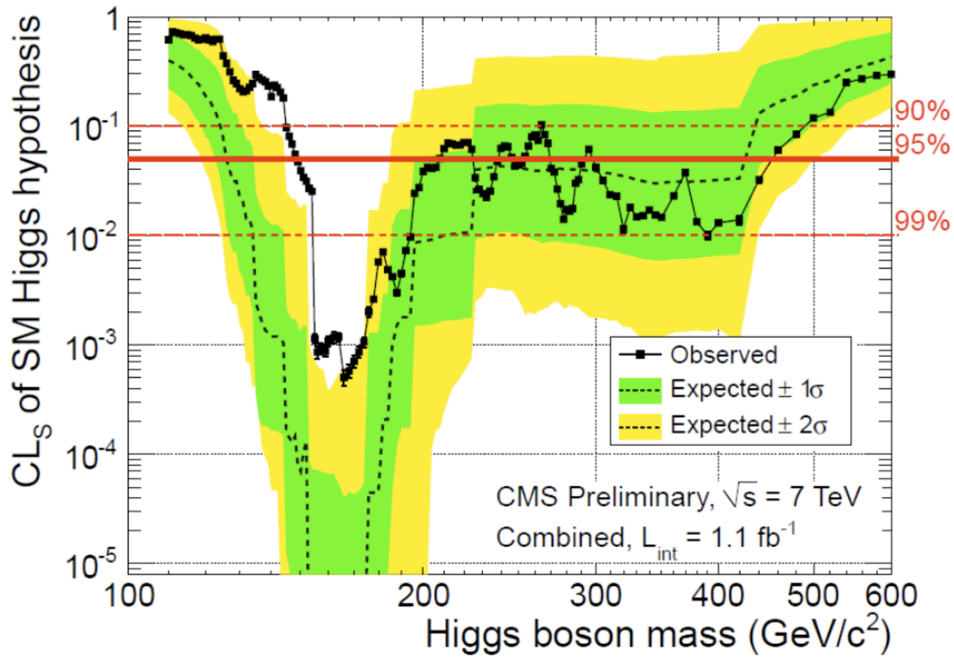
Combination of All Channels

The ATLAS and CMS Combinations

A new landscape of Higgs Exclusion has Emerged!

Yet another perspective…



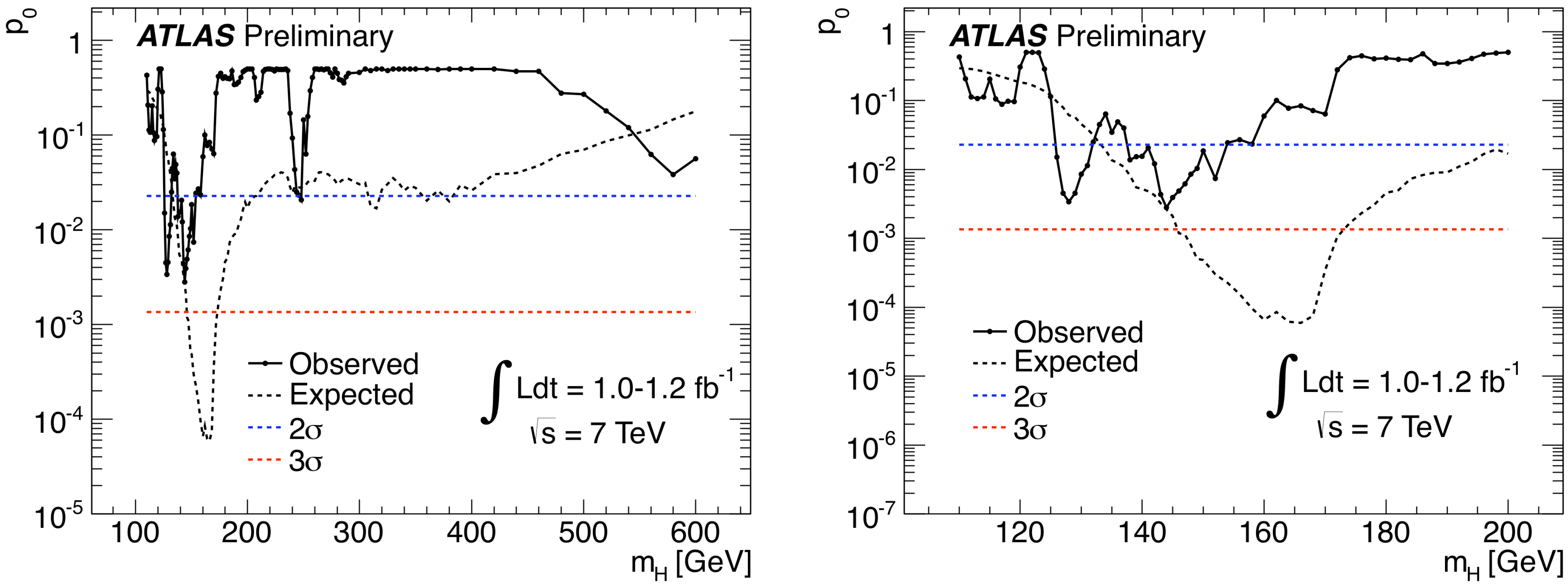


Closing in very rapidly in the allowed Higgs mass domain…

Are there any Hints Anywhere to be Seen ?

In ATLAS…

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



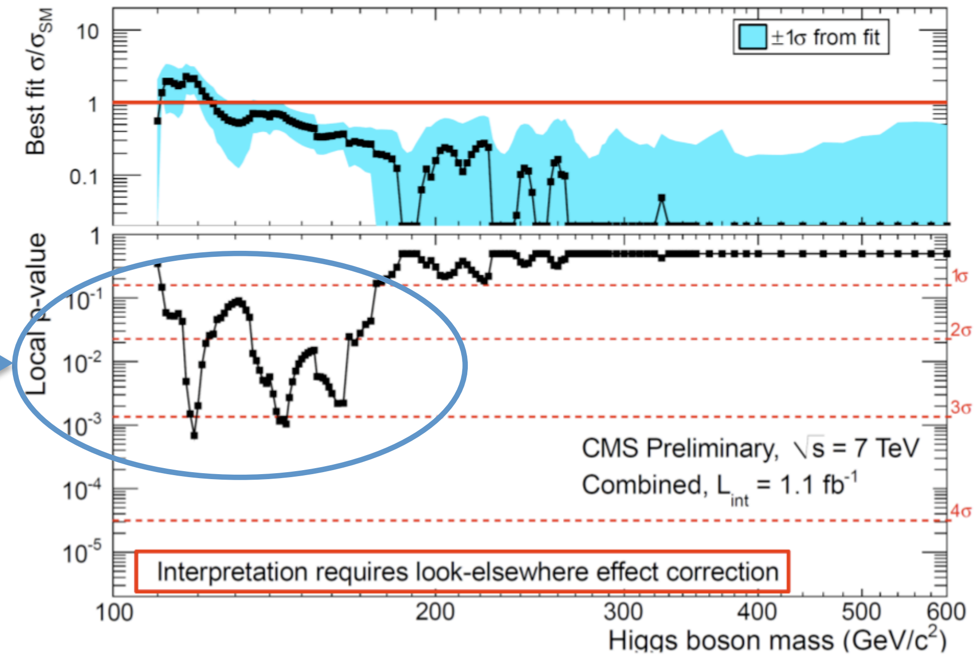
Beware of the trial factor (here 2.8s boils down to ~10% - factor of ~O(40)) !

Are there any Hints Anywhere to be Seen ?

In ATLAS…

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

Trial Factor Needed!

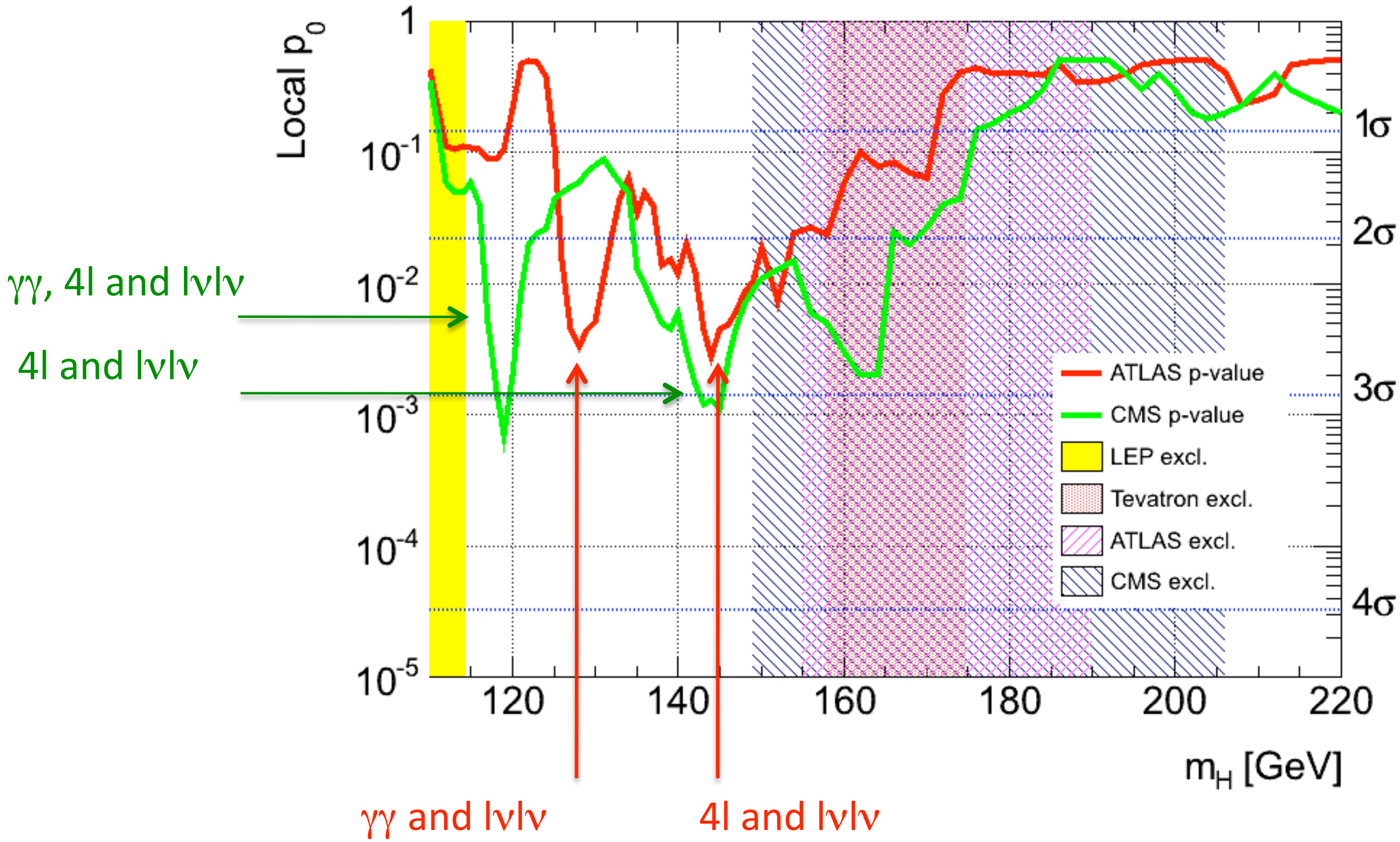


Beware of the trial factor (here 3.1s at ~120 GeV but 3 peaks) !

Are there any Hints Anywhere to be Seen ?

In ATLAS and CMS together (but not combined)

Bill Murray (EPS)



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** (Tantalizing hints in 120-150 GeV range)

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!

It has been a wonderful year, many thanks and congratulations to the LHC!
Bonnes fetes de Geneve…

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	$q_\mu = -2\ln\frac{\mathcal{L}(data\vert\mu,\tilde{\theta})}{\mathcal{L}(data\vert 0,\tilde{\theta})}$	no	Bayesian-frequentist hybrid
Tevatron	$q_\mu = -2\ln\frac{\mathcal{L}(data\vert\mu,\hat{\theta}_\mu)}{\mathcal{L}(data\vert 0,\hat{\theta}_0)}$	yes	Bayesian-frequentist hybrid
LHC	$q_\mu = -2\ln\frac{\mathcal{L}(data\vert\mu,\hat{\theta}_\mu)}{\mathcal{L}(data\vert\hat{\mu},\hat{\theta})}$	yes $(0 \leq \hat{\mu} \leq \mu)$	frequentist

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

The Unconditional Ensemble

$$\mathcal{L}(\text{data} \,|\, \mu, \theta) = \underbrace{\text{Poisson}\,(\,\text{data} \,|\, \mu \cdot s(\theta) + b(\theta)\,)}_{\text{Signal region main measurement}} \cdot \underbrace{p(\tilde{\theta}|\theta)}_{\text{Control region auxiliary measurement}}$$

Signal region main measurement

Control region auxiliary measurement

To account in a fully frequentist fashion the systematic uncertainties :

- The nuisance parameter θ is fixed for generation to default measured value $\tilde{\theta}_0$

- Fitted $\hat{\theta}, \hat{\hat{\theta}}$ in toys

- The auxiliary measurement $\tilde{\theta}$ is randomized

Related Lectures

Essentially all are, but in particular…

- Concepts in particle physics (J.-P. Derendinger)

- Notions of the Standard Model (R. Godbole)

- Notions of Particle detectors (R. Werner)

- Notions of Experimental High Energy Physics - trigger (B. Dahmes)

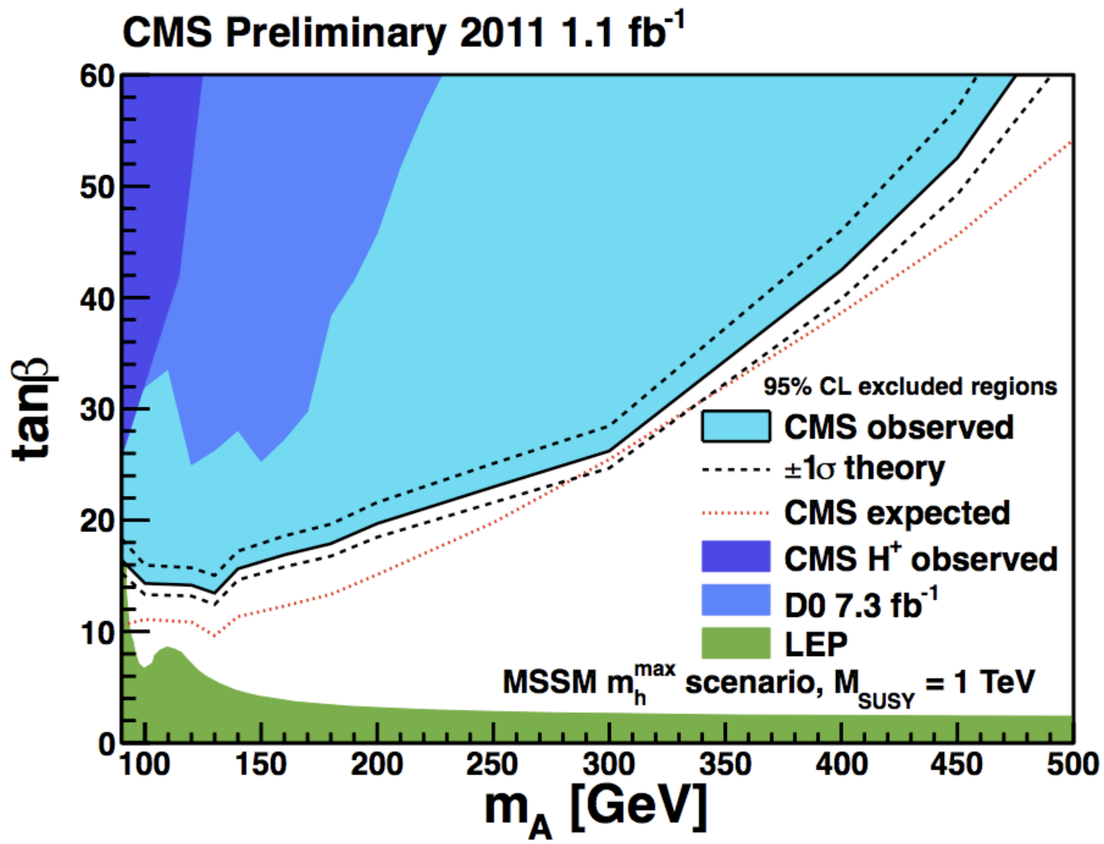
- Notions of Experimental High Energy Physics - object reconstruction (J. Boyd)

- Concepts in Statistical analysis (G. Cowan)

- Standard Model and Higgs Physics at Hadron Colliders (P. Mattig)

Most results already presented in this Lecture – Different prospective

Higgs Boson Search with tau Leptons in the MSSM



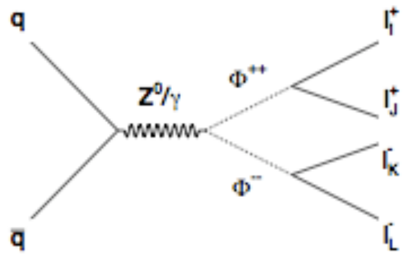
Different analysis strategy : Combination of $H^{\pm}$ and $(b)\Phi^0 \rightarrow (b)\tau^+\tau^-$

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

CMS-PAS-HIG-11-001

Doubly Charged Higgs

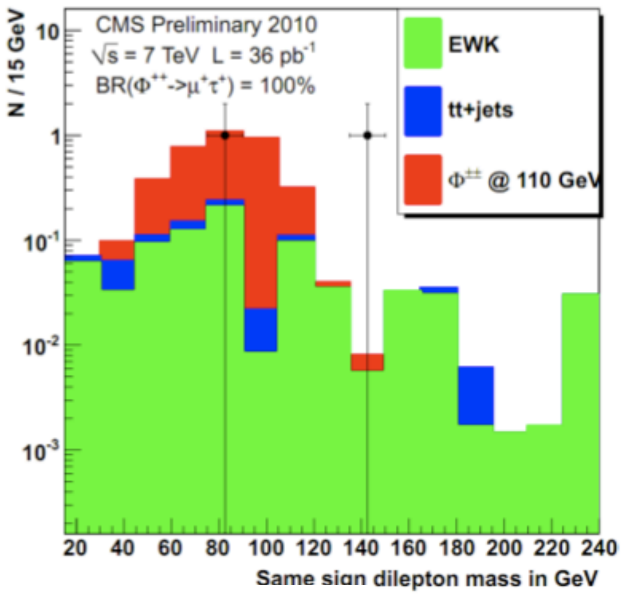
- extending Standard Model adding scalar triplet (motivated by Seesaw mechanism for neutrino masses). Leads to a doubly charged Higgs $H^{\pm\pm}$.

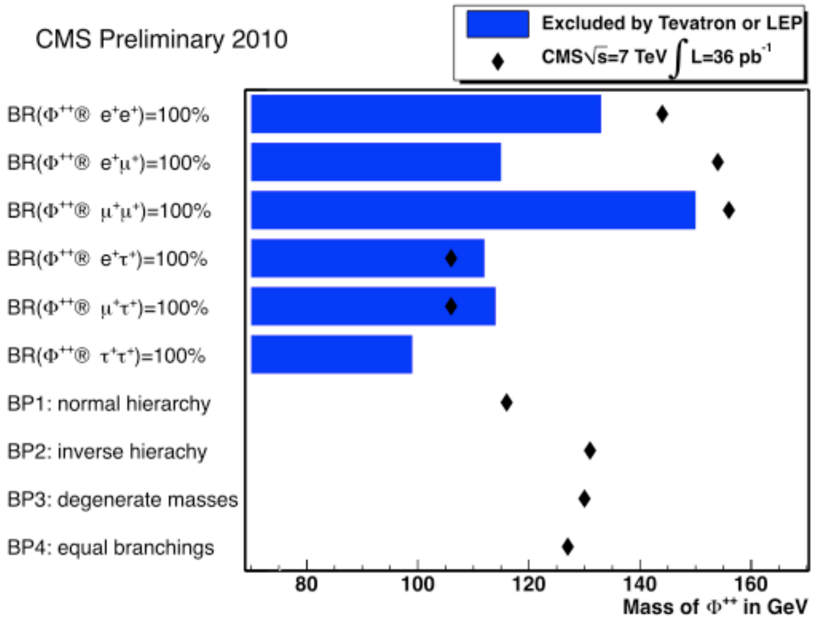


- Use di-lepton $H^{\pm\pm}$ decay topologies in four or three leptons.

- Look for SS di-lepton resonances.

- Limits





Normal Hierarchy / Inverse Hierarchy / Degenerate State

Limits comparable or better than previous experiments

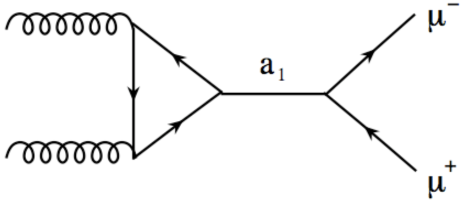
ATLAS-CONF-2011-020

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

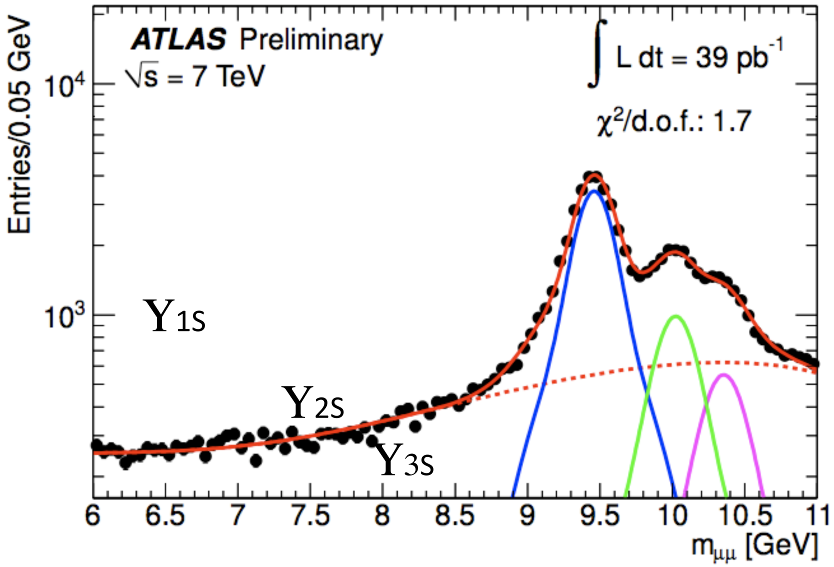
In the low mass region (below $2m_b$) lightest CP-even Higgs evades LEP limits this mass region is referred to as ideal Higgs scenario.

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).



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

Simple selection of two isolated muons p_T> 4 GeV



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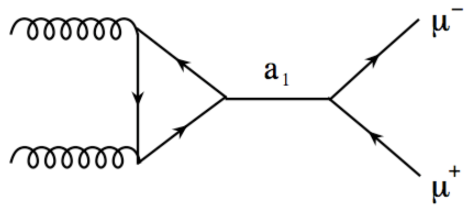

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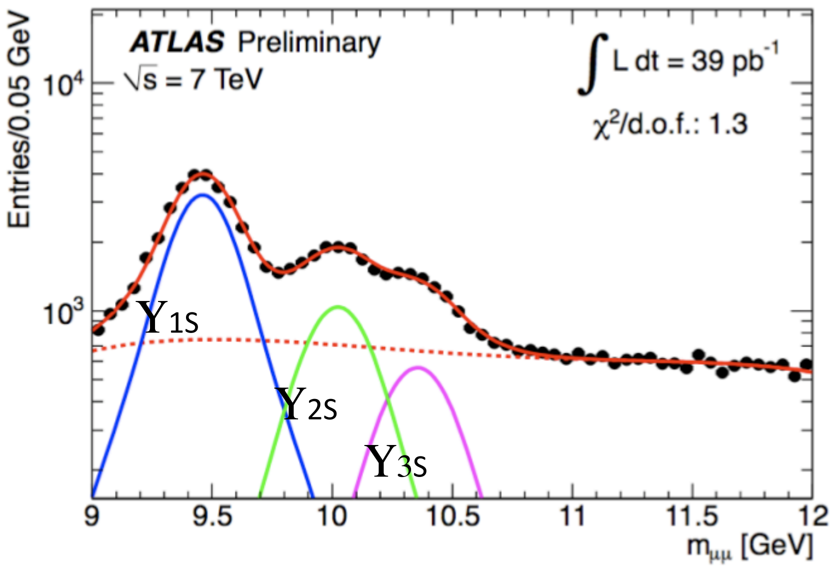

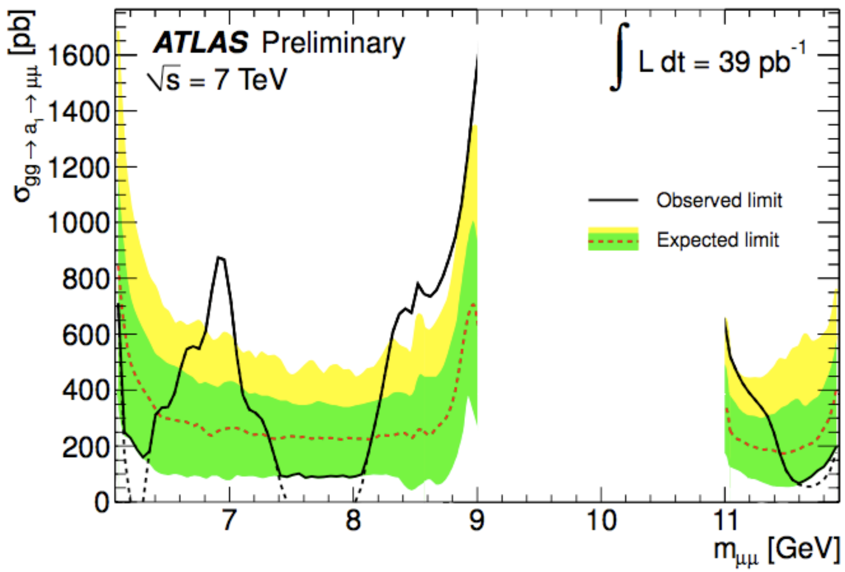

Constraints on regions with high tan β and small CP-Odd mixing angle cos θ_A ~ 1