

SCALARS 2011

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August 26-29, 2011

Warsaw, Poland

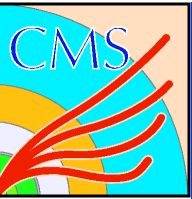
Maria Skłodowska-Curie Year: special event on Aug 25



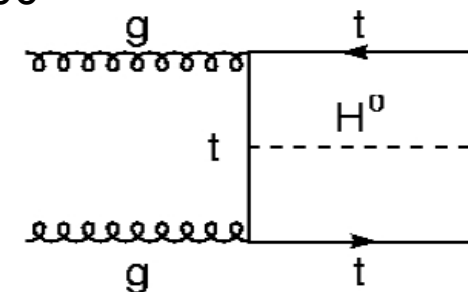
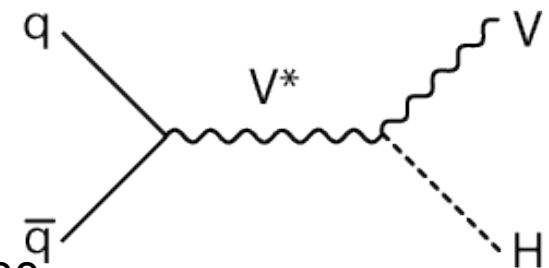
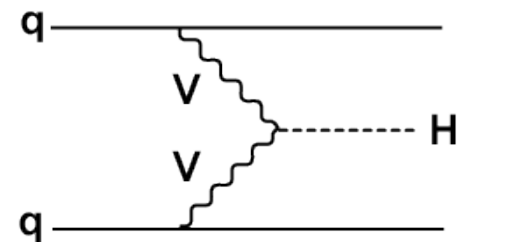
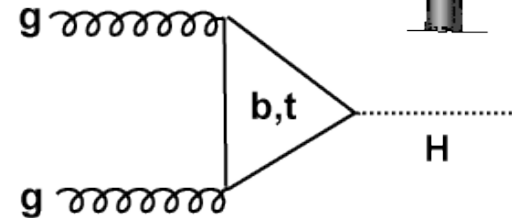
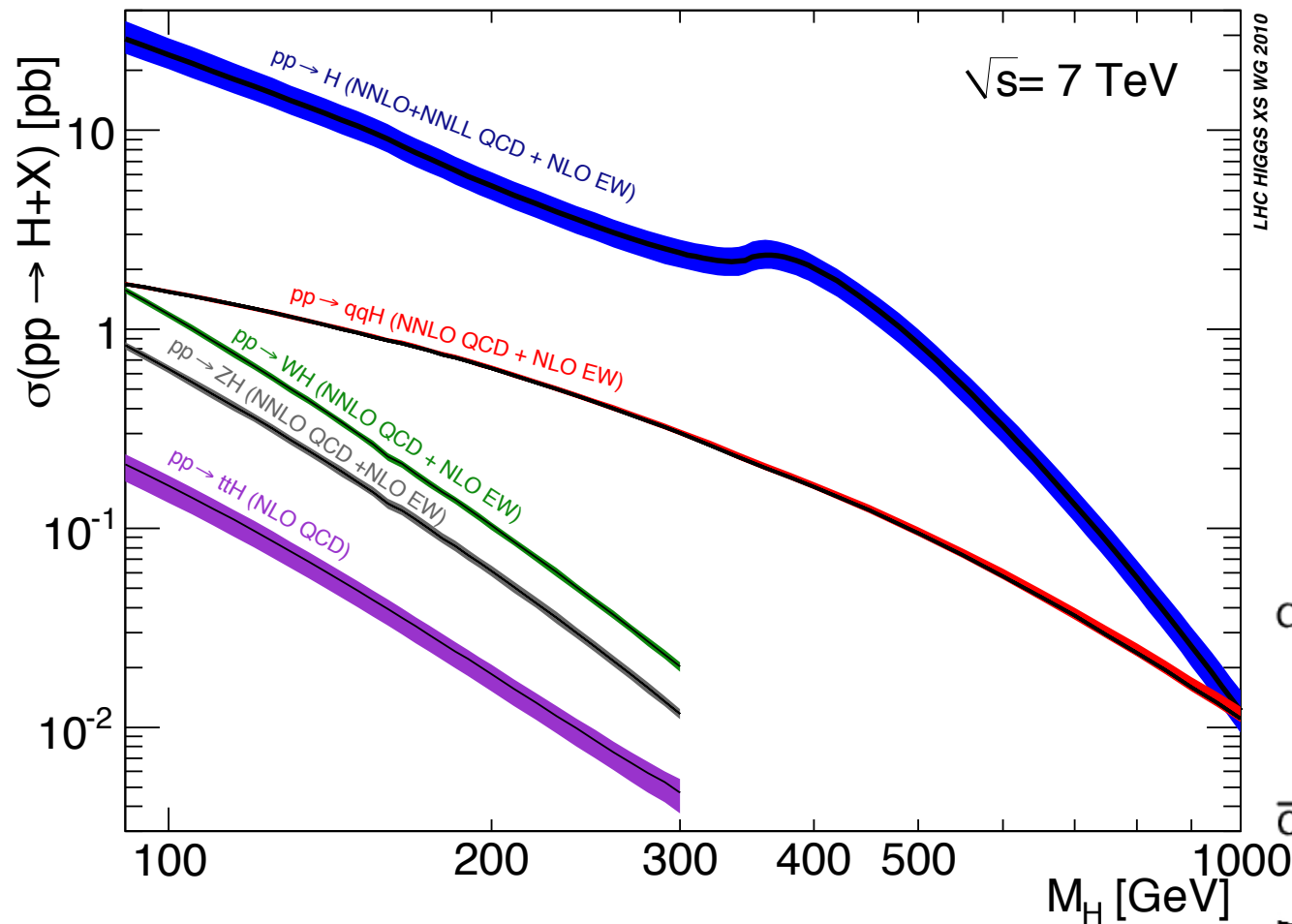
Search for the SM Higgs boson in the first femtobarns of the LHC data with CMS and ATLAS detectors

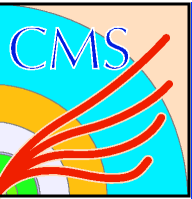
Slawek Tkaczyk

FERMILAB

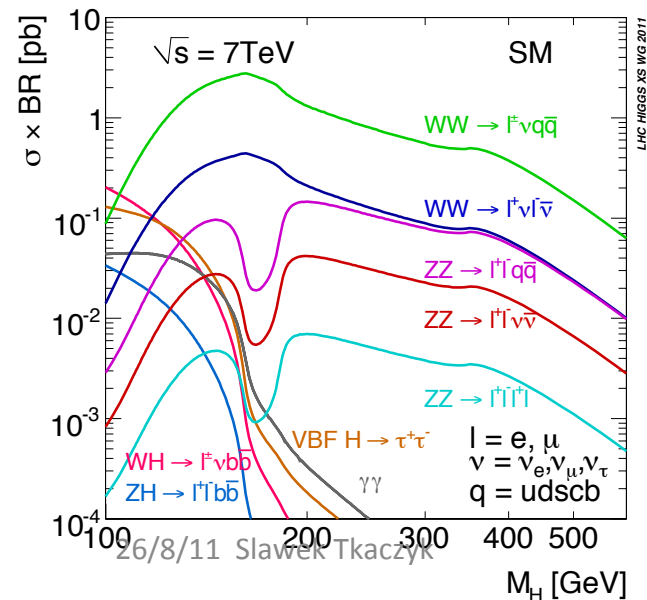
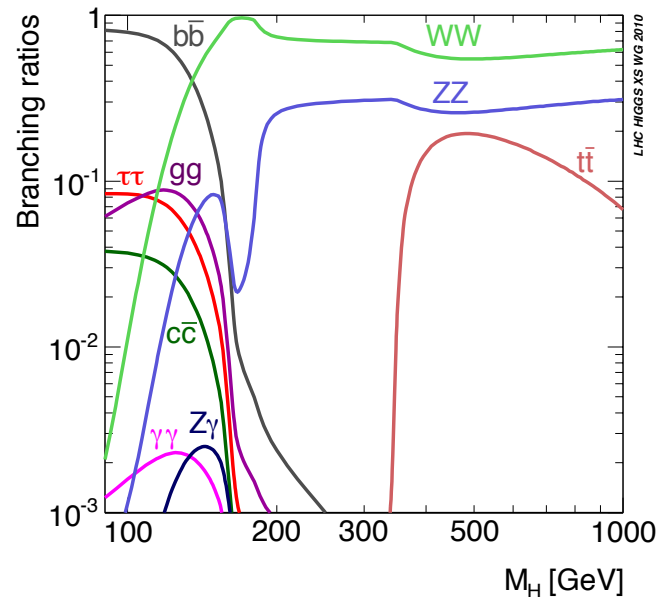


Higgs production at LHC





SM Higgs Decay Modes



- **Wide mass range**
- **WW:**
 - $l\nu l\nu$: clean signature
 - $l\nu q\bar{q}$: highest rate
- **ZZ:**
 - decay channels: $4l, 2l2q, 2l2\nu, 2l2\tau$
 - sharp resolution: $4l$
- **Low mass range**
- **$\tau\tau$:**
 - four decay channels
 - can benefit from VBF production
- **$\gamma\gamma$:**
 - Small BR
 - Sharp resolution
- **bb :**
 - challenging
 - boosted H



Summary of Analyzed Channels



TODAY: Second round of preliminary Higgs search results in 2011

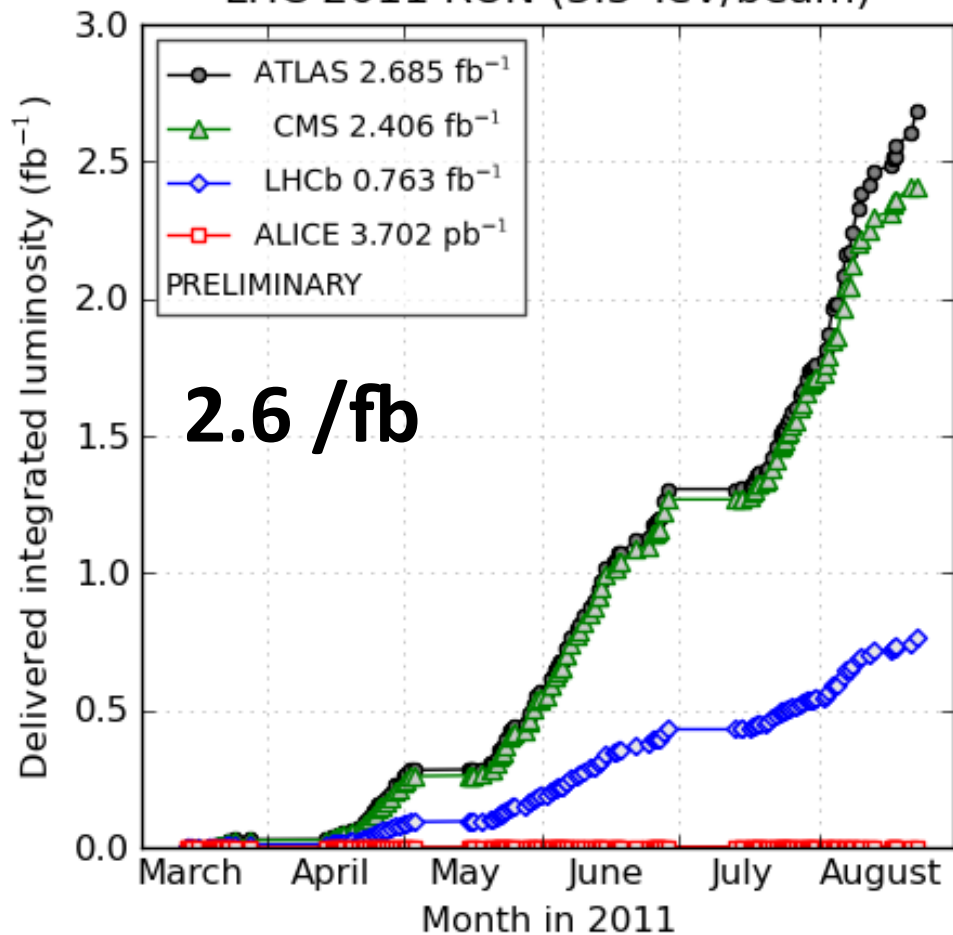
	CMS			ATLAS		
Mode	Mass Range	Data Used (/fb)	Document	Mass Range	Data Used (/fb)	Document
$H \rightarrow WW \rightarrow 2l 2\nu$	110-600	1.5	HIG-11-014	110-300	1.7	ATLAS-CONF-NOTE-2011-134
$H \rightarrow WW \rightarrow 2l 2q$				250-600	1.04	
$H \rightarrow ZZ \rightarrow 4l$	110-600	1.7	HIG-11-015	120-600	2.2	
$H \rightarrow ZZ \rightarrow 2l 2\tau$	180-600	1.1	HIG-11-013			
$H \rightarrow ZZ \rightarrow 2l 2q$	226-600	1.6	HIG-11-017	200-600	1.04	
$H \rightarrow ZZ \rightarrow 2l 2\nu$	250-600	1.5	HIG-11-016	200-600	1.04	
$H \rightarrow \gamma\gamma$	110-150	1.7	HIG-11-021	110-150	1.08	
$H \rightarrow b\bar{b}$	110-135	1.1	HIG-11-012	110-130	1.04	
$H \rightarrow \tau\tau$	110-140	1.1	HIG-11-009	100-150	1.06	ATLAS-CONF-NOTE-2011-132



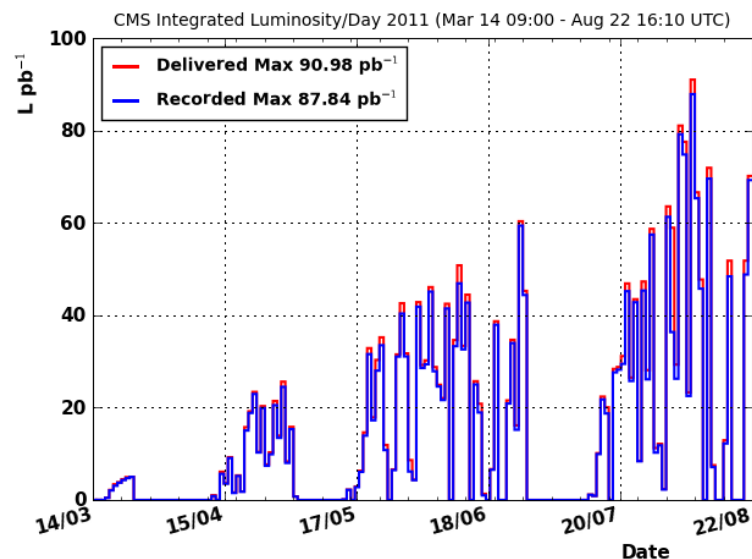
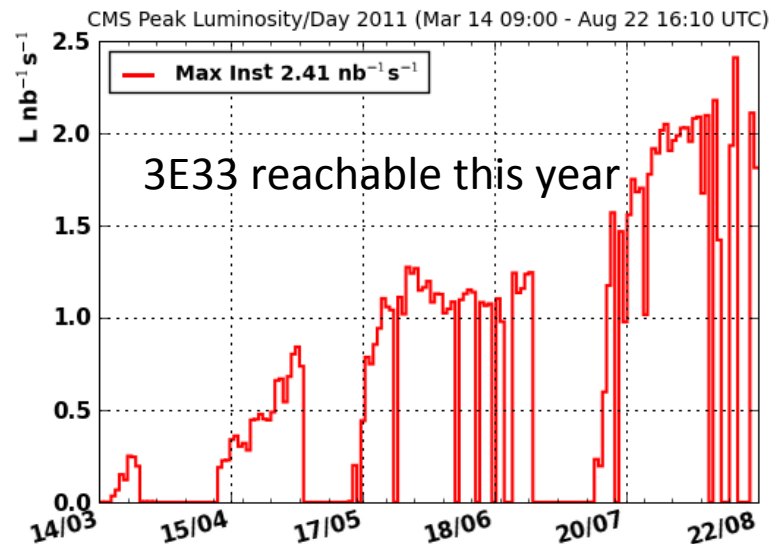
LHC Performance



LHC 2011 RUN (3.5 TeV/beam)

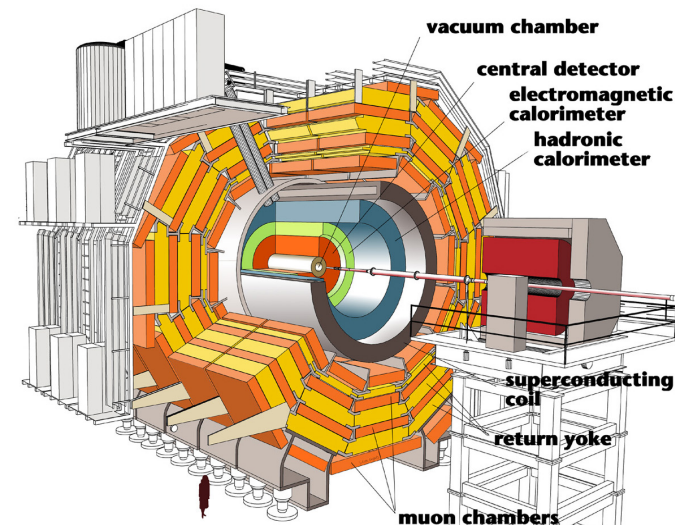
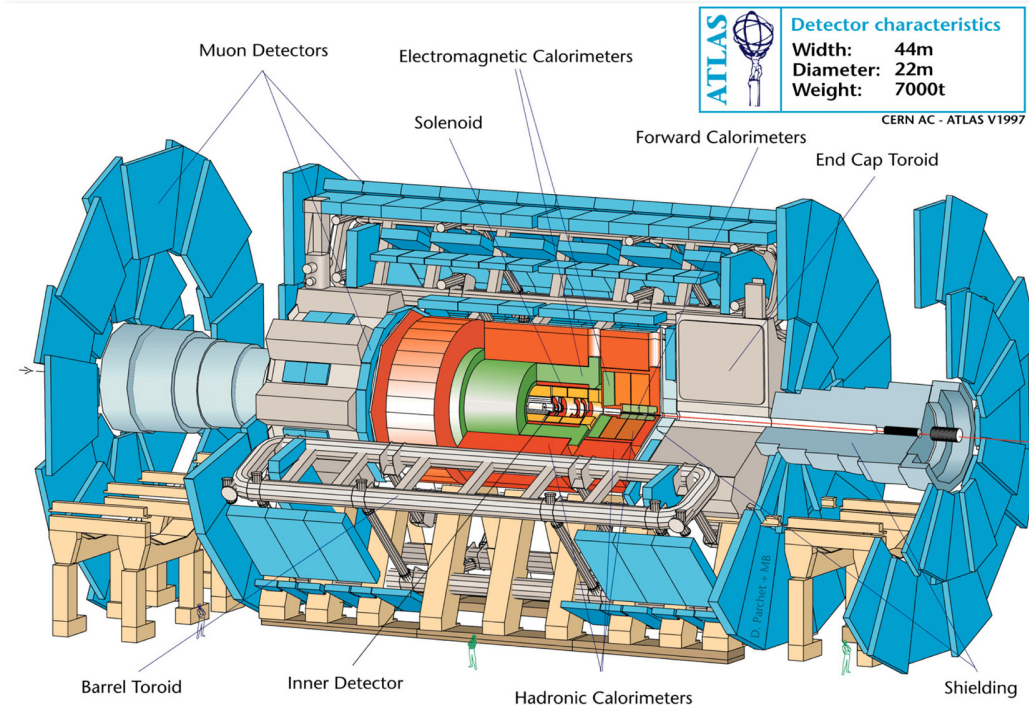


(generated 2011-08-24 01:28 including fill 2040)





LHC Detectors



Detector characteristics

Width: 22m
Diameter: 15m
Weight: 14'500t

Tracking: $|\eta| < 2.5$, $B = 2T$

- Si pixels and strips
- Transition radiation detector

Calorimetry: $|\eta| < 5$

- EM: sampling; Pb/LAr accordion
- HAD: Sampling Fe/scint. + Cu-W/LAr

Muon Spectrometer: $|\eta| < 2.7$

- Air-core toroids with muon chambers

Tracking: $|\eta| < 2.5$, $B = 3.8T$

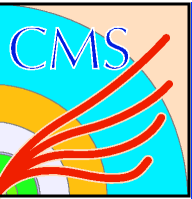
- Si pixels and strips

Calorimetry: $|\eta|^{\text{em}} < 2.5$ $|\eta|^{\text{had}} < 5$

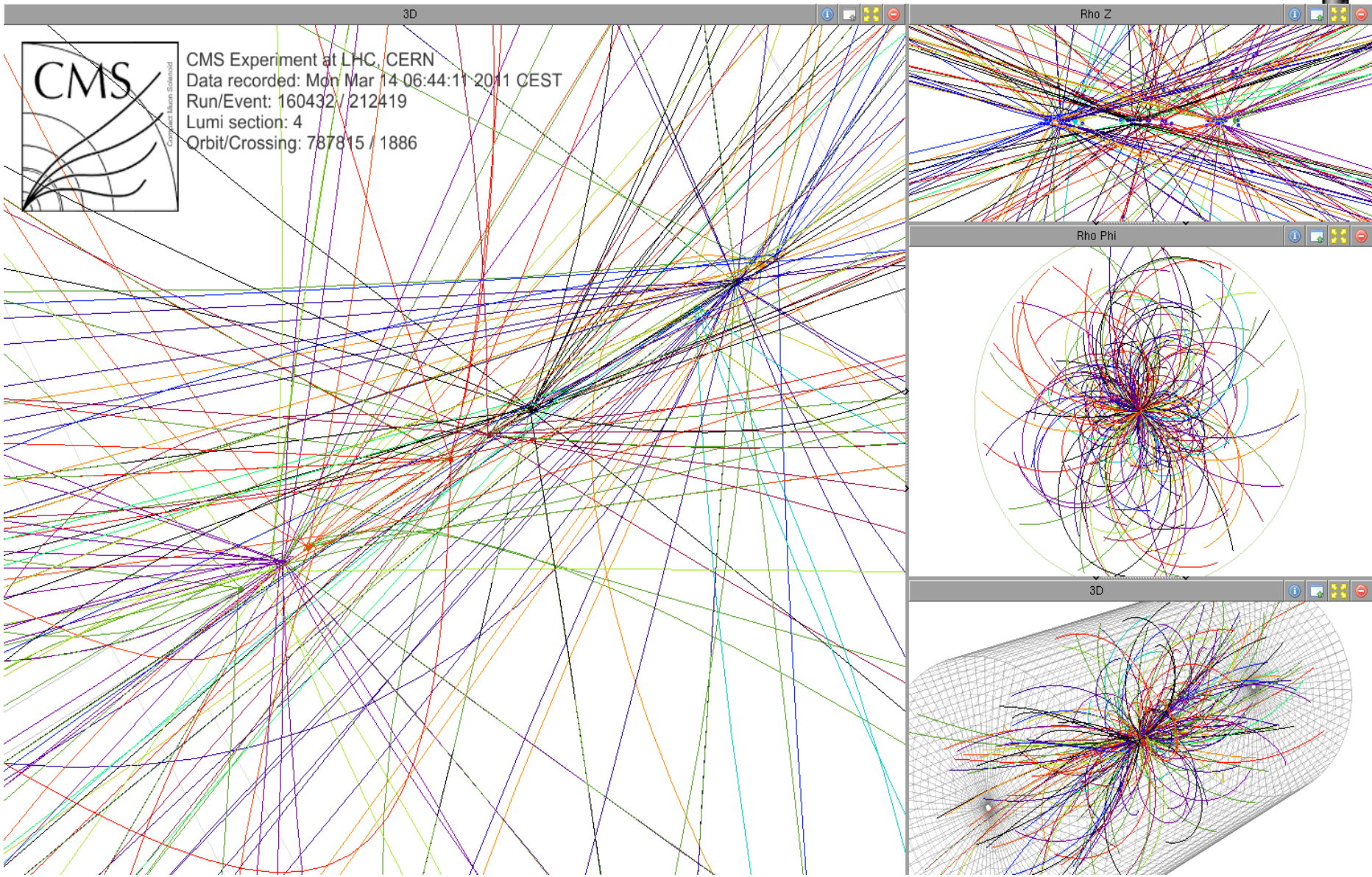
- EM: homogeneous PbWO_4 crystals
- HAD: Cu-Zn/scint. + Fe/Quartz

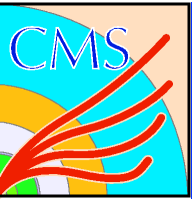
Muon Spectrometer: $|\eta| < 2.7$

- Solenoid return yoke instrumented



Multiple Interactions Event

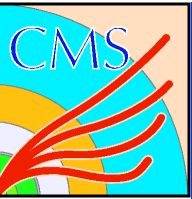




Statistical Analysis of the Channels



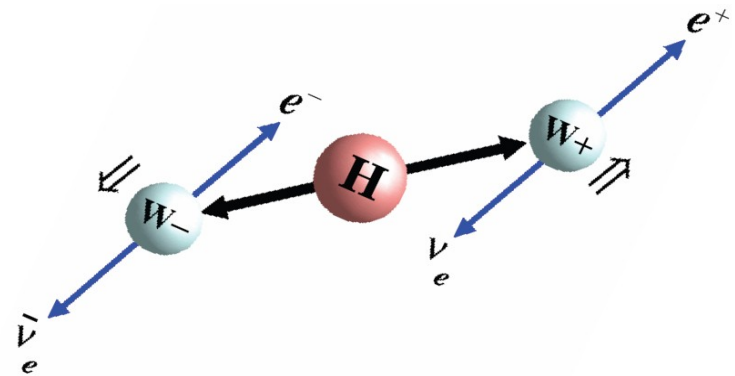
- Profile likelihood test statistics used to derive 95% CL
 - Modified frequentist approach – CLs prescription
 - 95% CL Higgs cross section limits in units of SM expectation
 - Form joint likelihood when combining channels
 - Include correlated and uncorrelated systematic uncertainties
- Use CLs and Bayesian methods
 - Good agreement found
 - Quote CLs as final results
- Signal strength $\mu = \sigma / \sigma_{\text{SM}}$ indicates by which factor SM Higgs cross section would have to be rescaled to best match the observed data
 - The green and yellow bands represent 1- and 2-sigma expectations in the absence of a signal
- p-value estimates probability of upward background fluctuation at least as high as the excess observed in data



H $\rightarrow$ WW(*) Channel



- High sensitivity to presence of Higgs over broad range [110,600]
- WW selection in terms of jet multiplicity: 0-, 1-, 2-jet bins
 - Count jets with $p_T > 30 \text{ GeV}$
- Background estimation:
 - Data driven: Top, WW, W+jets, DY(ee, $\mu\mu$)
 - MC based: DY($\tau\tau$), $W\gamma$, WZ, ZZ
- Small azimuthal angle between the leptons – W spin correlations – opposite spins expected
- Challenge to understand the effects of the event pile-up
- Signal extraction in CUT BASED analysis
 - M_H dependent cut optimization with additional cuts on p_T , M_T , M_{ll} , and $\Delta\phi_{ll}$
- In 2-jet bin:
 - Additional selection for the VBF topology
 - $\Delta\eta_{jj} > 3.5$ and $M_{jj} > 450 \text{ GeV}$





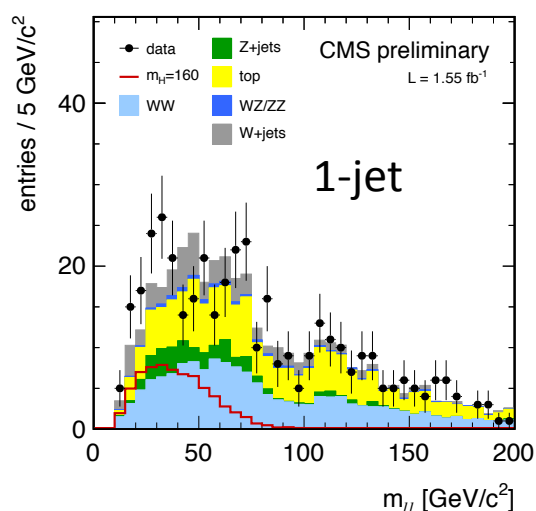
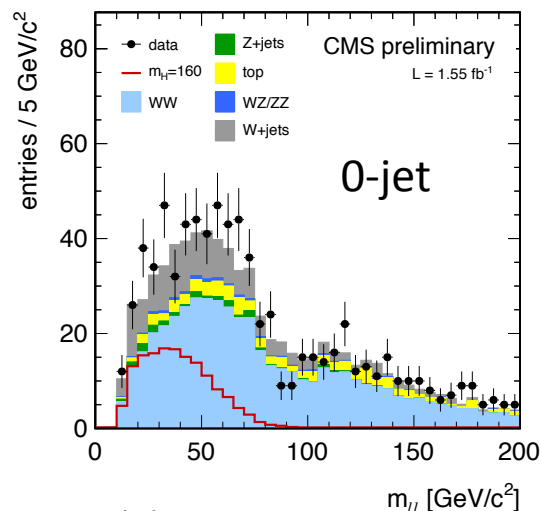
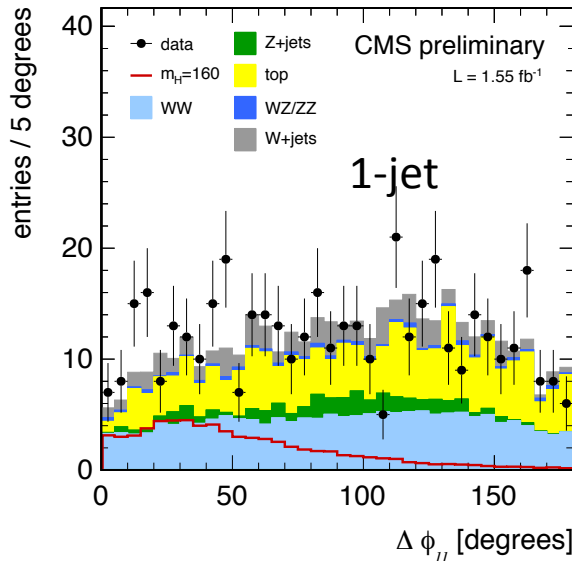
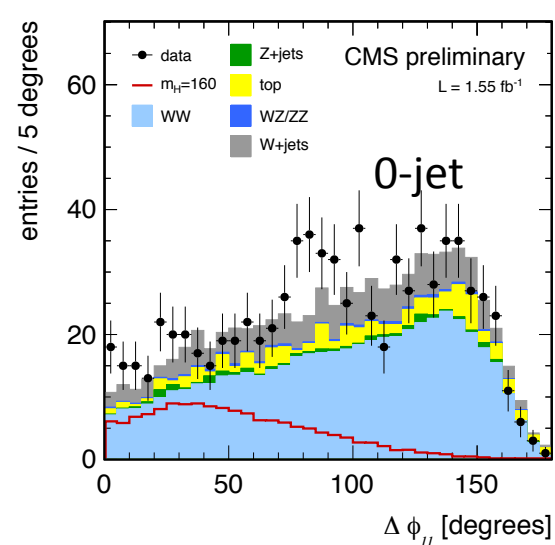
H- $\rightarrow$ WW* $\rightarrow$ 2l2 ν Channel



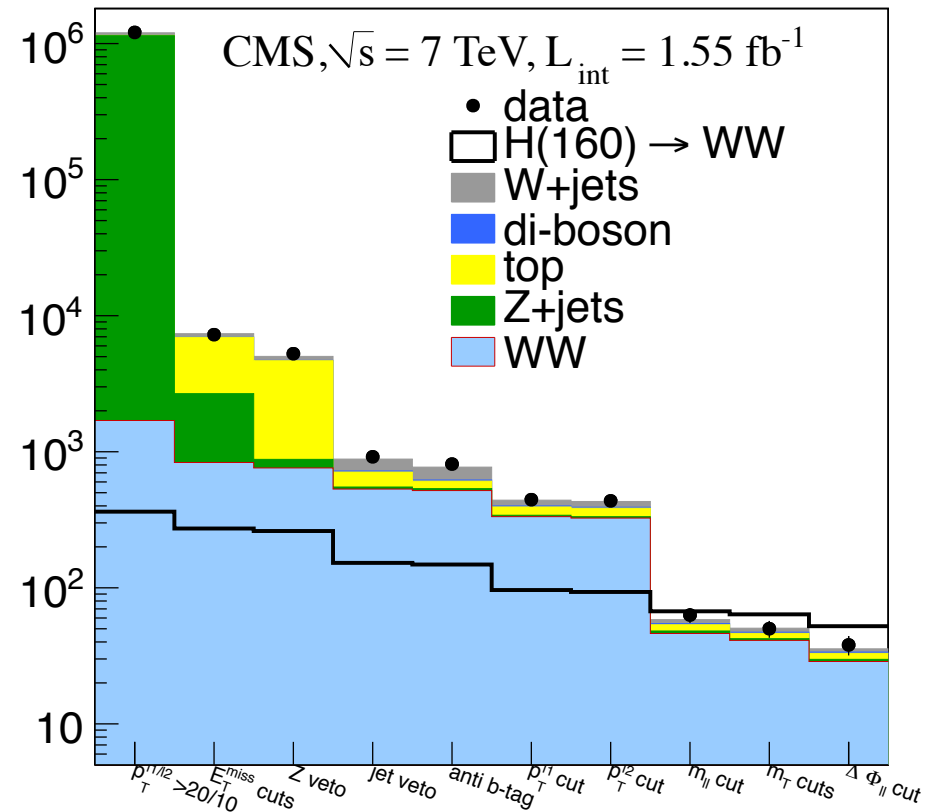
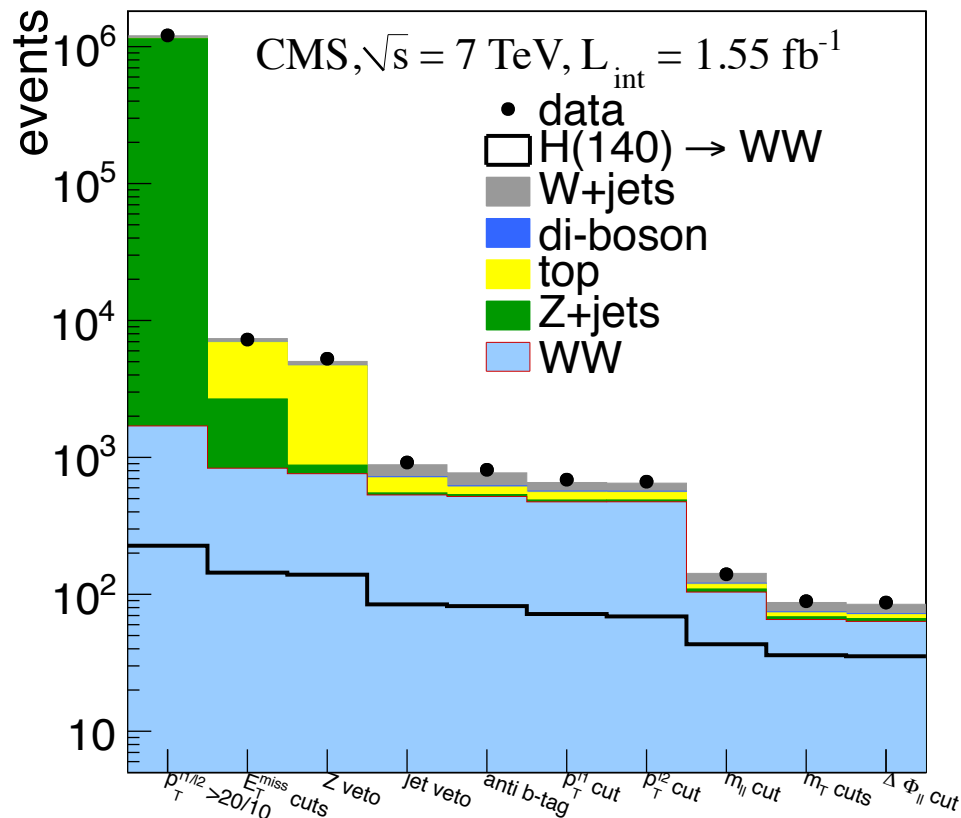
Kinematic Distributions after WW selection

WW Event selection:

- Events collected on single and double lepton triggers
- Exactly 2 well identified isolated leptons (ee, e μ , $\mu\mu$) of opposite sign
 - Pt>20Gev for leading; Pt>10Gev for trailing lepton
- Large Missing Energy (MET) thus no mass peak
- Reject events with identified b-decays to reduce top contamination
- Same flavor leptons inconsistent with the Z decay
- Reject events with dileptons recoiling against a leading jet to reduce Z+jets



H $\rightarrow$ WW* $\rightarrow$ 2l2 ν



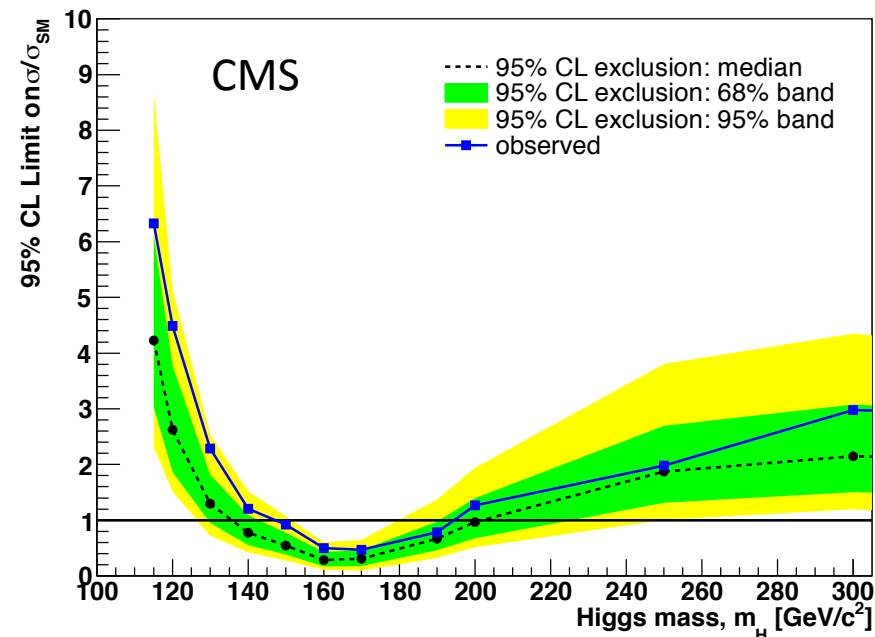
Cut evolution in 0-jet bin



H → WW* → 2l2ν



H → WW → 2l2ν + 0/1/2 jets (CLs)



• Observed exclusion region for SM Higgs with cut based analysis:

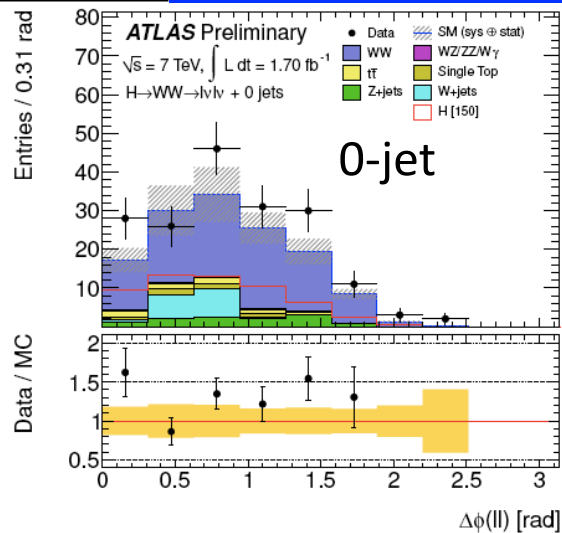
- [147,194] GeV at 95% CL
- Smaller than expectations
- MVA based analysis update soon

MH=140 GeV

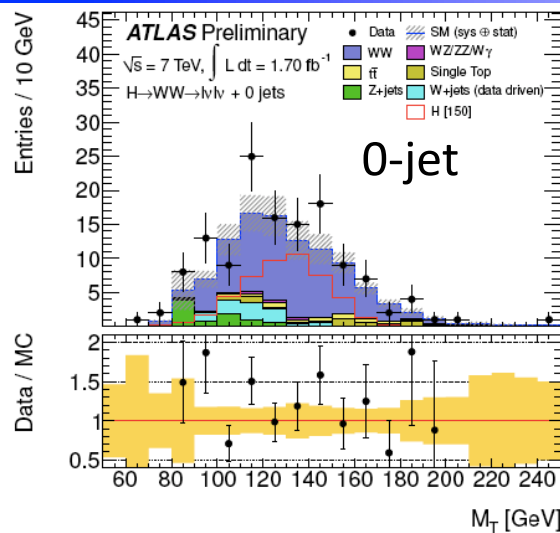
process	Higgs	$qq \rightarrow WW$	$gg \rightarrow WW$	VV	top	$Z/\gamma^* \rightarrow \ell^+\ell^-$	W + jets	ΣBkg	data
0-jet bin, SF	18.8 ± 4.2	31.5 ± 5.5	1.5 ± 0.8	0.8 ± 0.1	3.1 ± 1.1	0.1 ± 0.0	5.6 ± 2.3	44.0 ± 6.2	46
0-jet bin, OF	15.9 ± 3.6	29.1 ± 5.1	1.3 ± 0.7	0.5 ± 0.1	1.4 ± 0.5	3.1 ± 4.2	5.3 ± 2.2	40.6 ± 7.0	41
1-jet bin, SF	6.6 ± 2.2	8.3 ± 3.1	0.5 ± 0.3	0.5 ± 0.1	5.6 ± 1.2	0.2 ± 0.1	2.4 ± 1.1	17.8 ± 3.5	23
1-jet bin, OF	4.6 ± 1.5	5.8 ± 2.2	0.3 ± 0.2	0.3 ± 0.1	3.2 ± 0.8	1.2 ± 2.7	1.5 ± 0.9	12.6 ± 3.7	23
2-jet bin	0.5 ± 0.1	0.6 ± 0.2	0.1 ± 0.1	0.0 ± 0.0	2.6 ± 1.5	0.8 ± 0.6	1.0 ± 0.6	5.3 ± 1.7	7



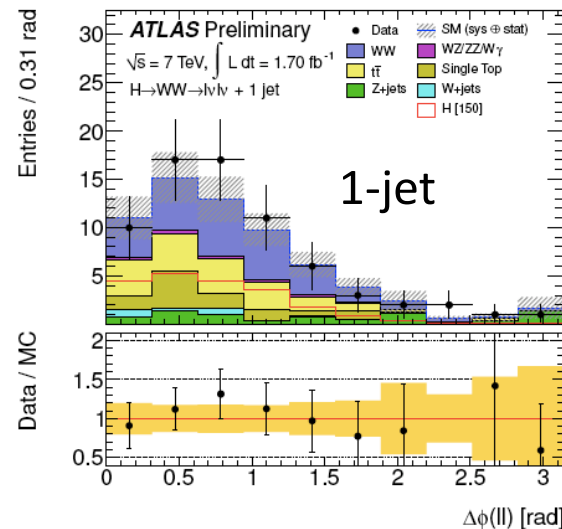
H → WW* → 2l2ν



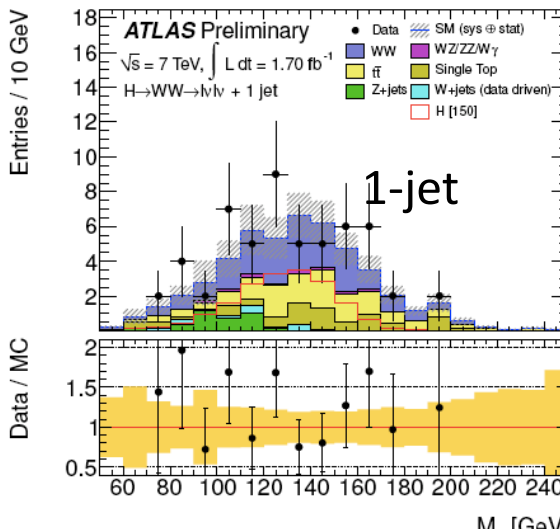
0-jet



0-jet



1-jet



1-jet

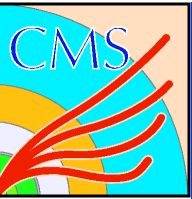
Event yields after full selection

Final selection, optimized for $m_H = 150 \text{ GeV}$

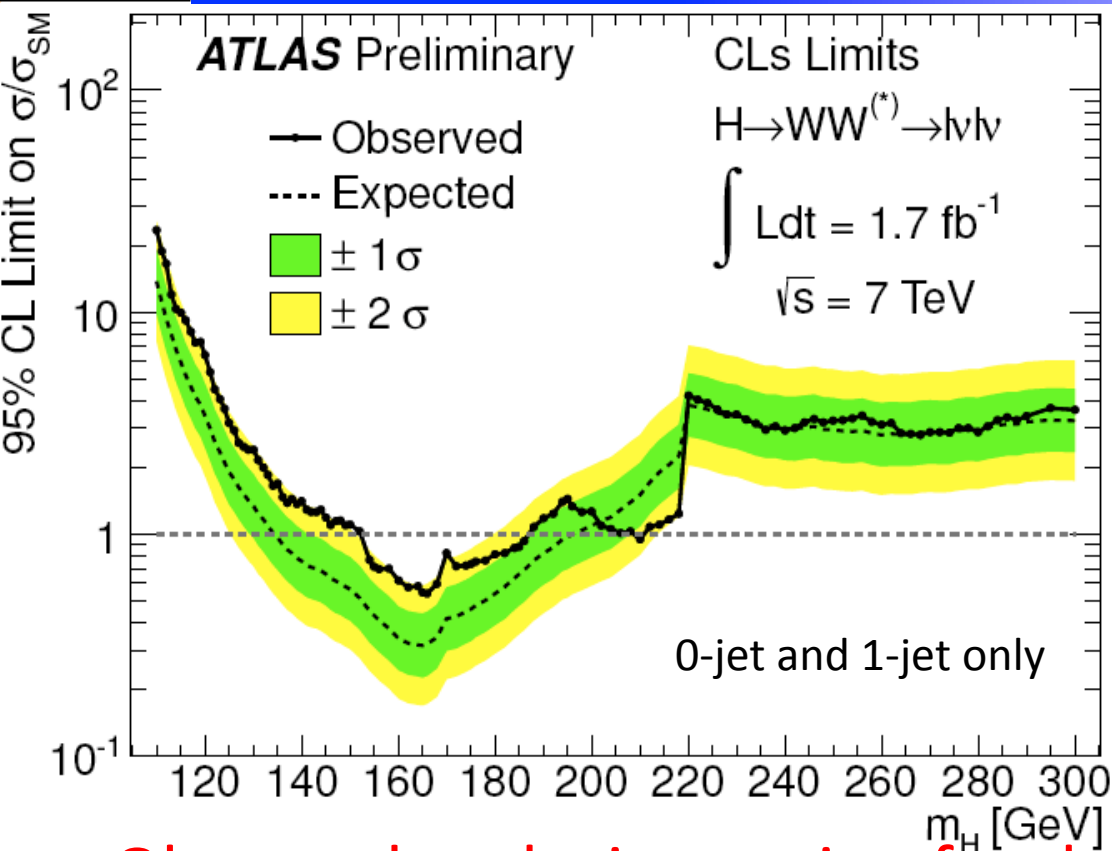
	WW	ttbar	Total SM back.	Data	Higgs $m_H = 150$
0-jet	43±6	2.2±1.4	53±9	70	34±7
1-jet	10±2	6.9±1.9	23±4	23	12±3

dilepton azimuthal angle
after p_T^{ll} and m^{ll} cuts

Transverse mass after all
cuts (except m_T itself)



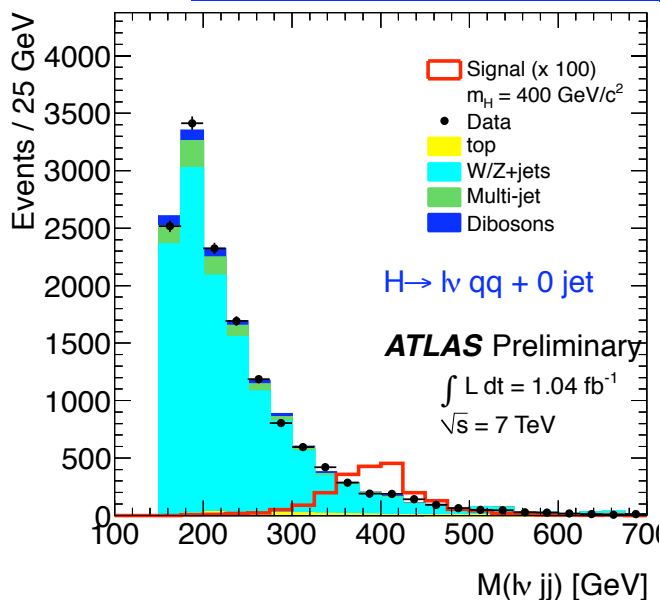
$H \rightarrow WW^* \rightarrow 2l2\nu$



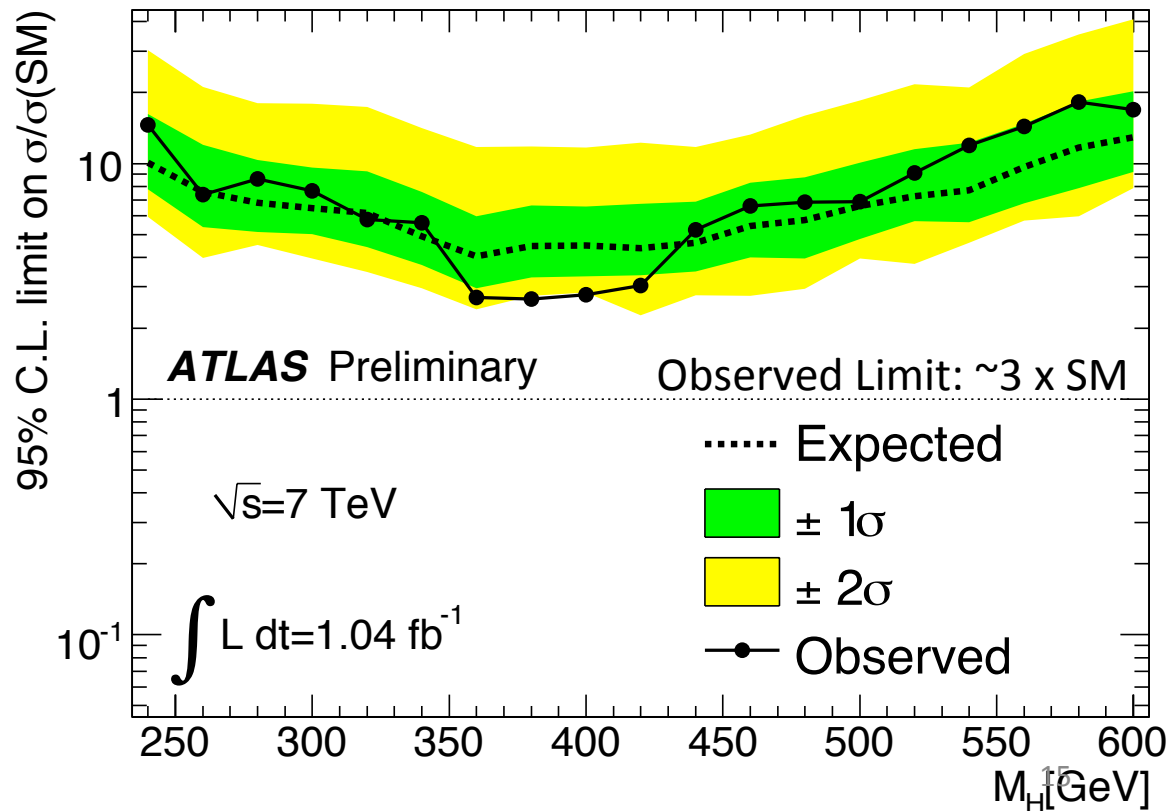
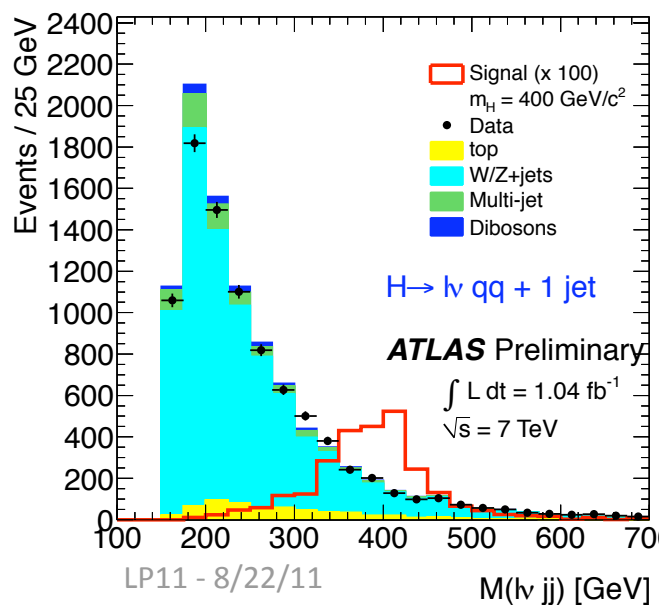
- Observed exclusion region for the SM Higgs:
 - [154,186] GeV at 95% CL
 - Expected: [135,196]
 - Jump at 220GeV due to change in selection

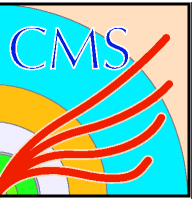


H $\rightarrow$ WW $\rightarrow$ $l\nu$ qq

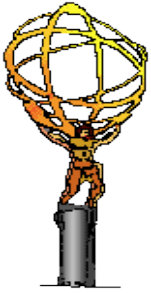


- Large BR for high mass Higgs
- Suffers from large W+jets backgrounds
- Selection: a high pT lepton, large MET and 2 jets consistent with W decay
- Search for peak in the M($l\nu$ qq)

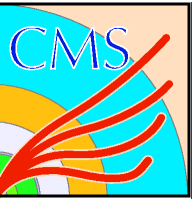




$H \rightarrow ZZ^*$



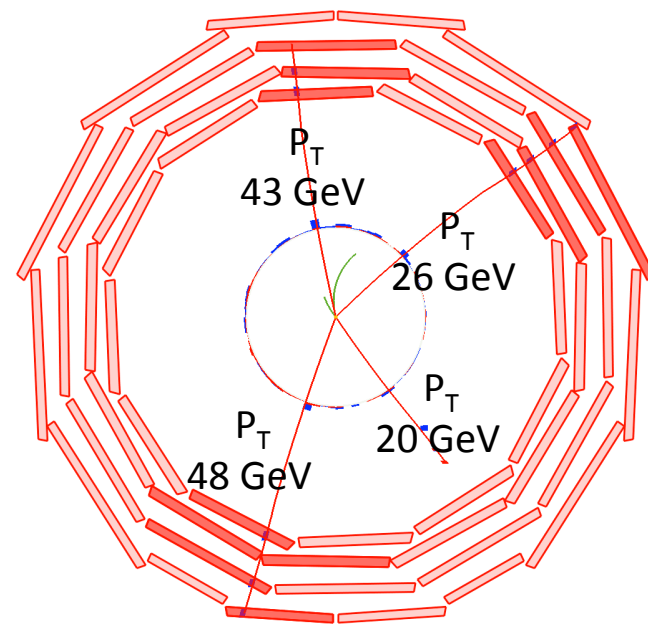
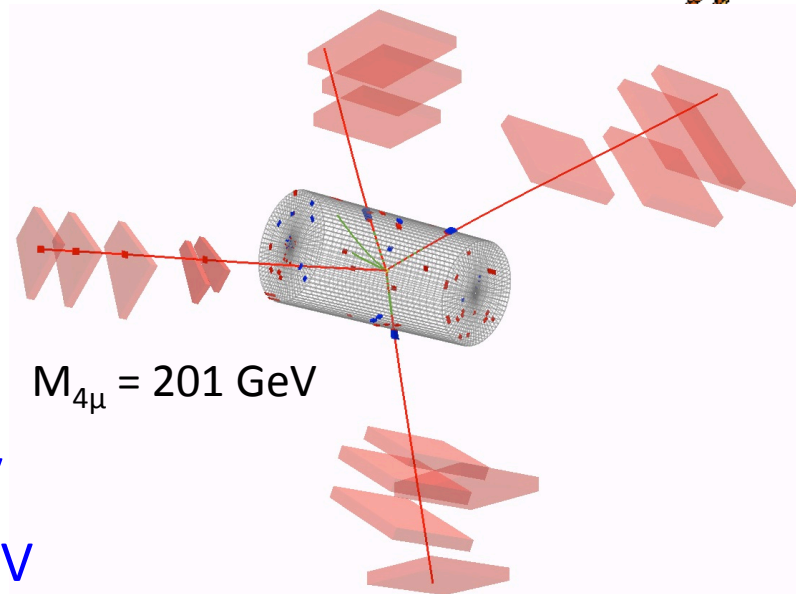
- $HIGGS \rightarrow ZZ^*$
 - Key decay mode in the SM Higgs search
- $ZZ^* \rightarrow 4 \text{ leptons}$
- $ZZ \rightarrow 2 \text{ leptons} + 2 \text{ neutrinos}$
- $ZZ \rightarrow 2 \text{ lepton} + 2 \text{ quarks}$
- $ZZ \rightarrow 2 \text{ leptons} + 2 \text{ tau leptons}$



H $\rightarrow$ ZZ $\rightarrow$ 4 leptons



- Four energetic and isolated leptons
- Two pairs make Z boson candidates
 - First pair: Z $\rightarrow$ ee, $\mu\mu$ closest to Z mass with $120 > m_{ll} > 60$ GeV
 - Second lepton pair: ($M_{ll} > 100$ GeV)
 - Baseline selection: $120 > M_Z > 20$ GeV
 - High mass selection: $120 > M_Z > 60$ GeV
- Clean signal expected
 - Narrow peak in the mass spectrum – mass resolution 2-4 GeV
 - Small backgrounds
 - Main background: ZZ, estimated from data and shape from simulation

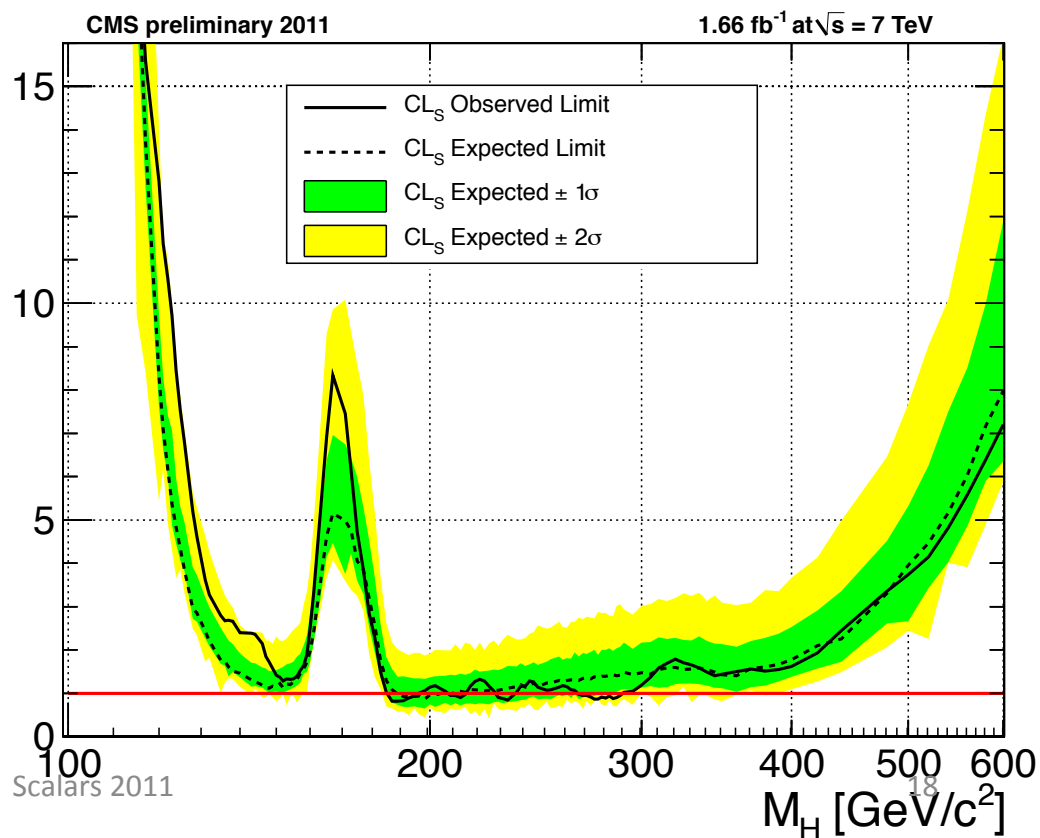
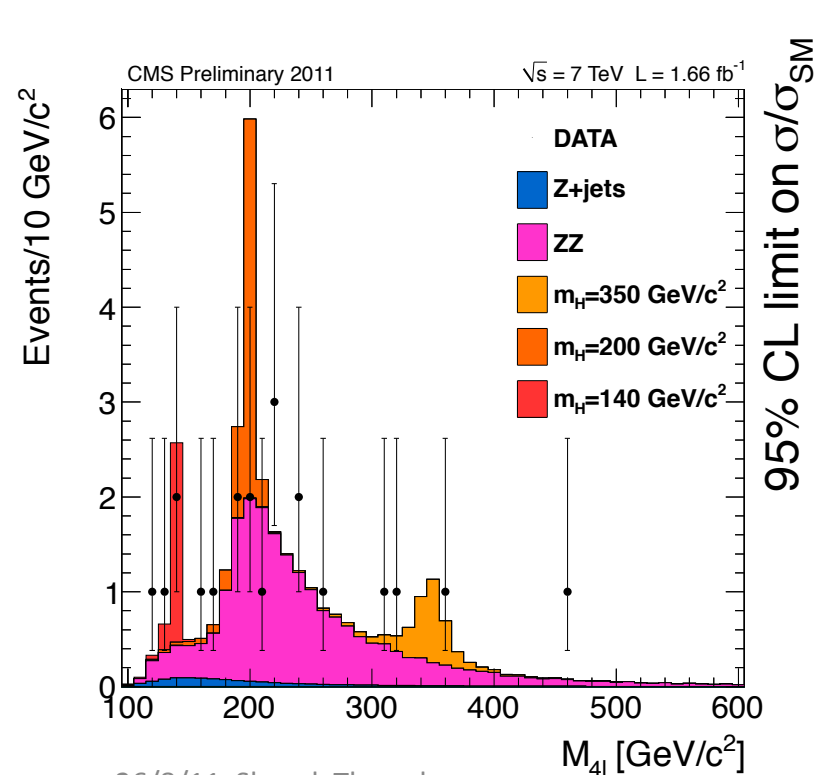




H $\rightarrow$ ZZ* $\rightarrow$ 4l



- MC and data agree
- Expected signal as a sharp peak
- 21 evts observed (21.2 $\pm$ 0.8 expected)
- No clusters of events present
- 6 evts observed below kinematical threshold (2.8 $\pm$ 0.2 expected)

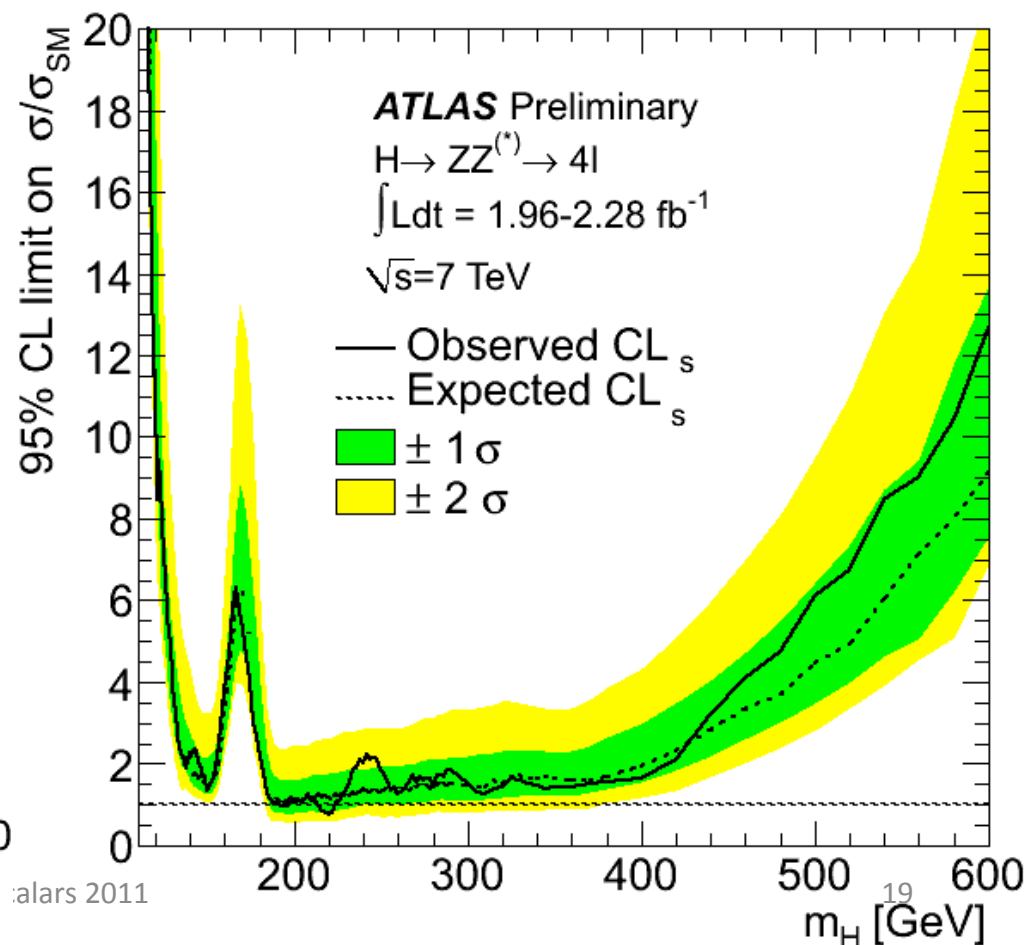
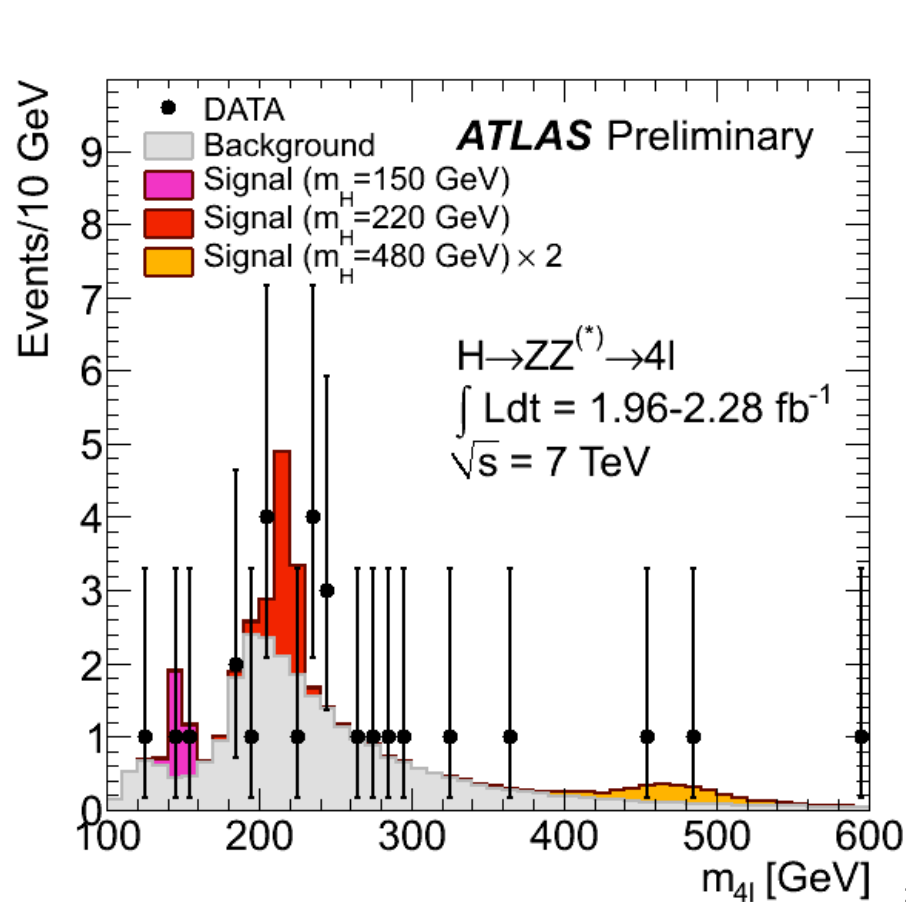




H $\rightarrow$ ZZ $^{*}\rightarrow$ 4l



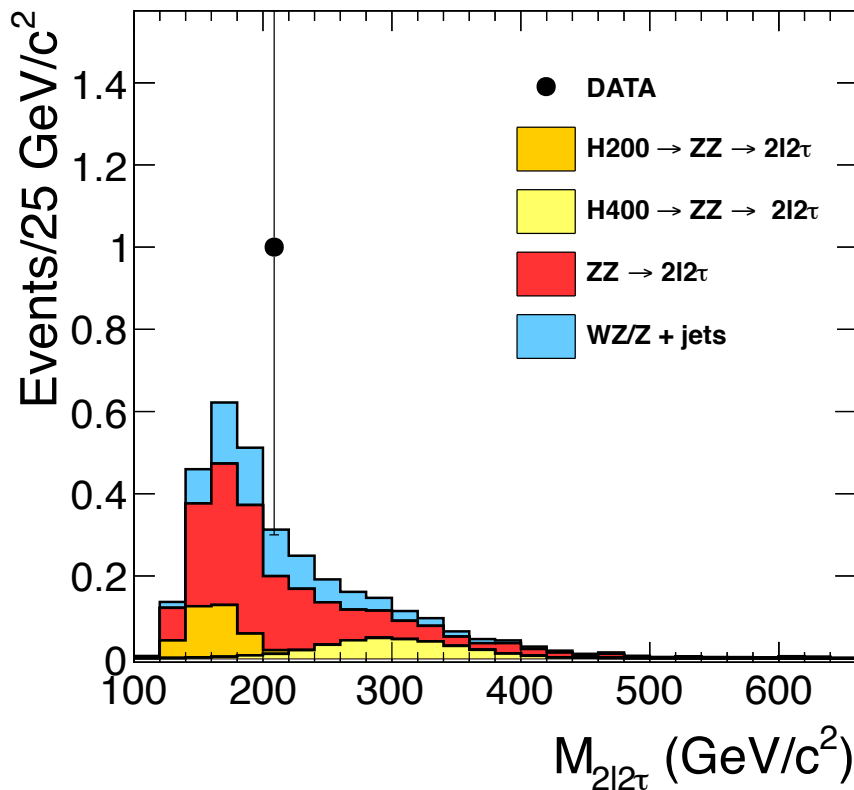
- 27 evts observed (28 $\pm$ 4 expected)
- Exclusion at 1 x SM cross section



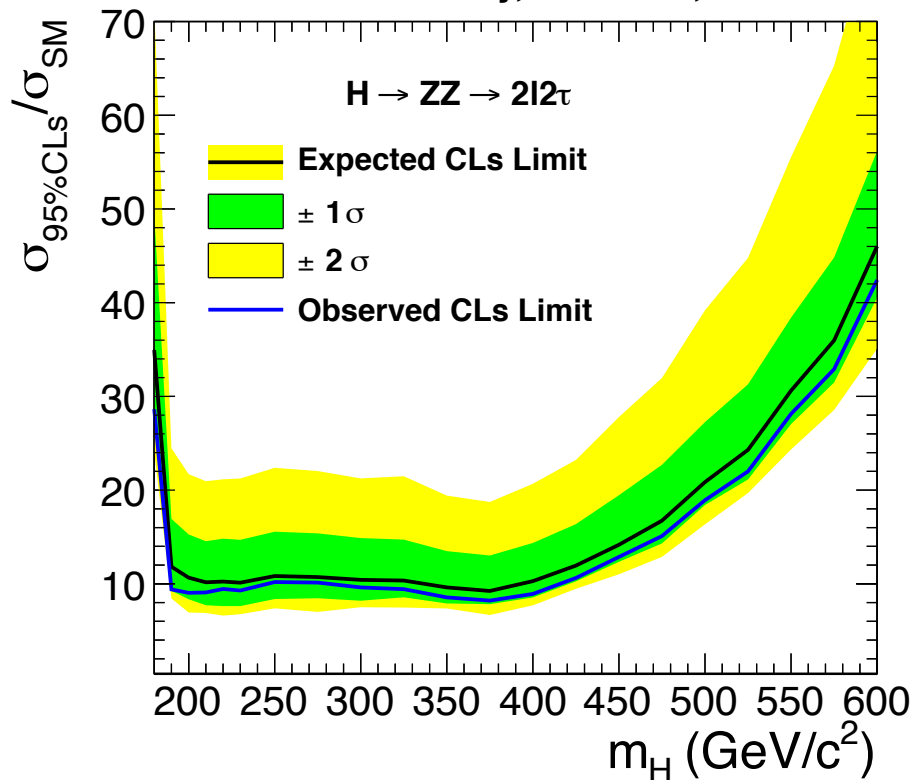
H $\rightarrow$ ZZ $\rightarrow$ 2l 2 τ (new for LP)



CMS Preliminary, $\sqrt{s}=7$ TeV, 1.1 fb^{-1}



CMS Preliminary, $\sqrt{s}=7$ TeV, 1.1 fb^{-1}



Exclusion at $\sim 10 \times$ SM cross section

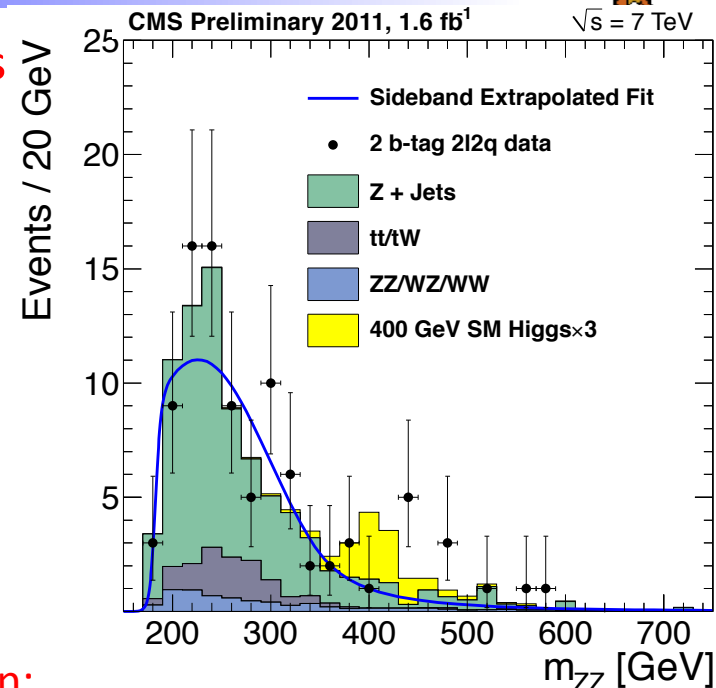
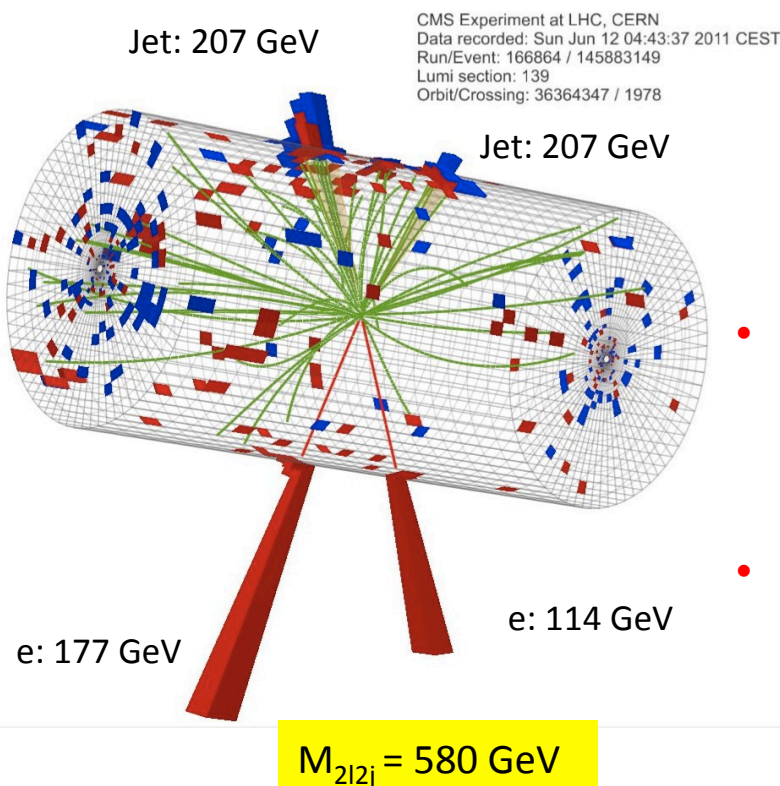
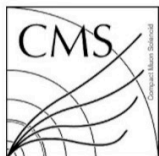


H $\rightarrow$ ZZ $\rightarrow$ 2l 2q

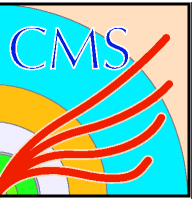


$\sqrt{s} = 7$ TeV

- Higher BR compared to 4l mode – x20 more events
- Worse mass resolution with 2jets – less precision
- Events analyzed in bins with 0,1,2 b-jets



- **Z selection:**
 - 70 < M_{Z1_l} < 110 GeV (against ttbar)
 - 75 < M_{Z2_jj} < 105 GeV (against ttbar and Z+jets)
 - Use 5 angles of scalar H in a likelihood discriminant
- **Backgrounds:**
 - Large contribution from Z+jets suppressed by MET cut
 - Small additions from VV, ttbar and QCD multijet

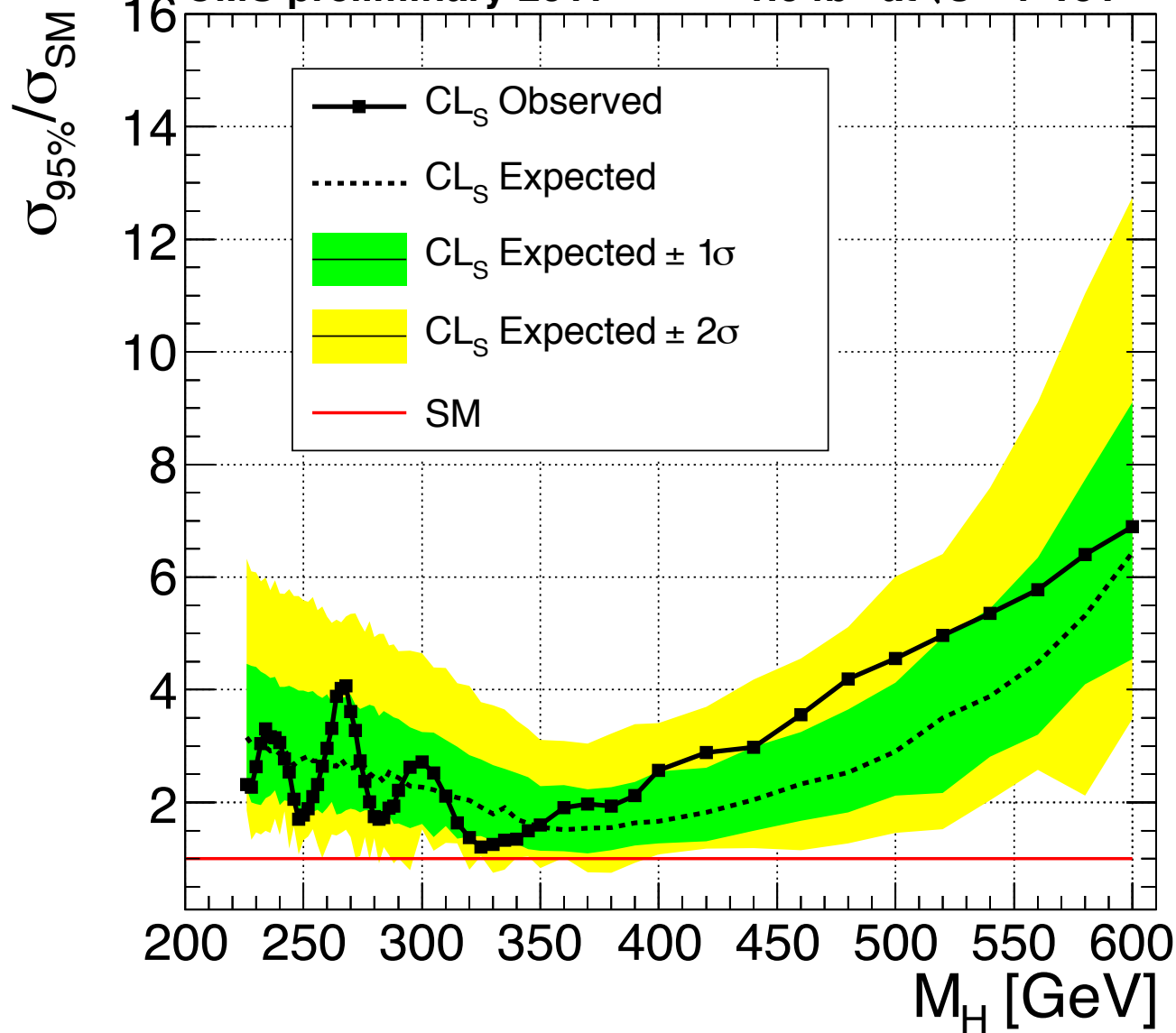


$H \rightarrow ZZ \rightarrow 2l 2q$



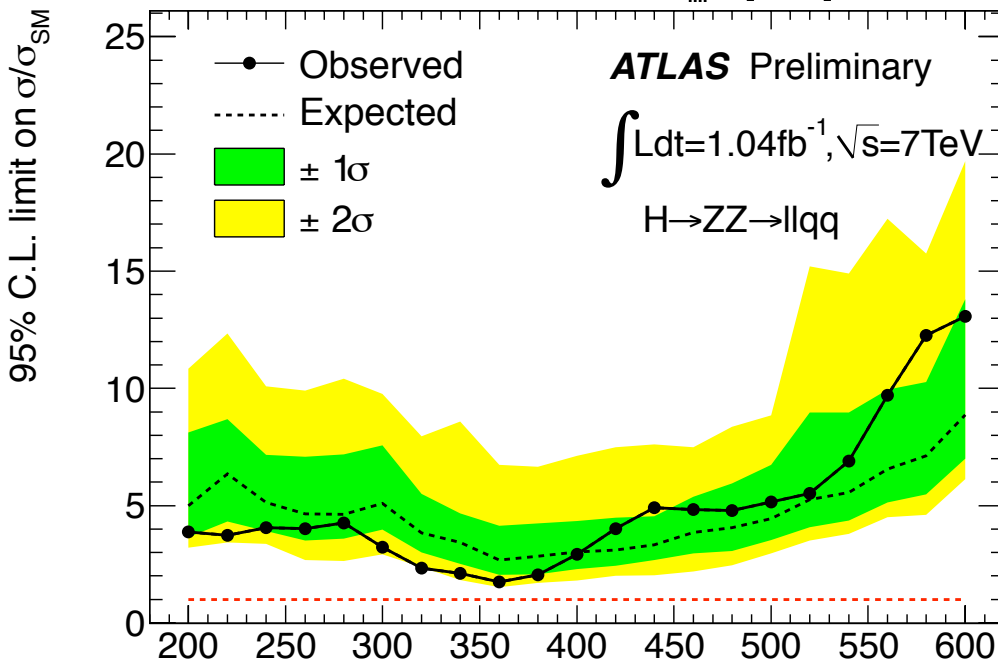
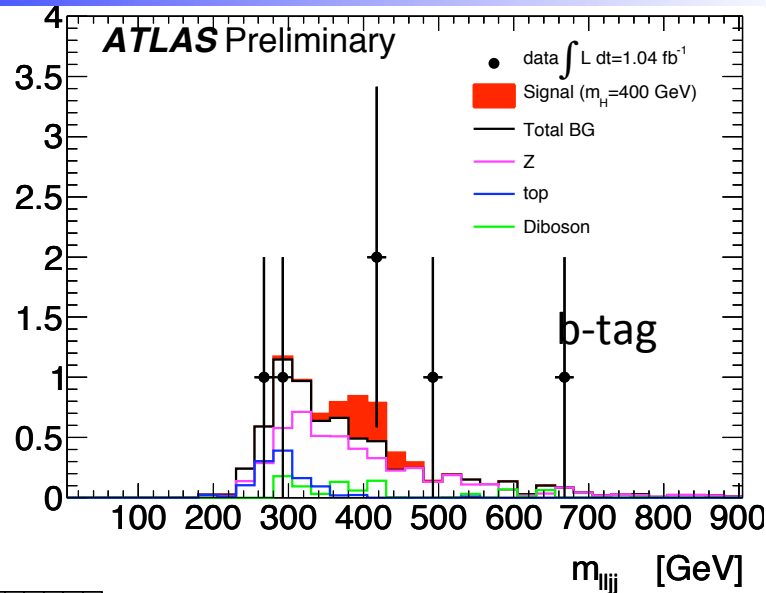
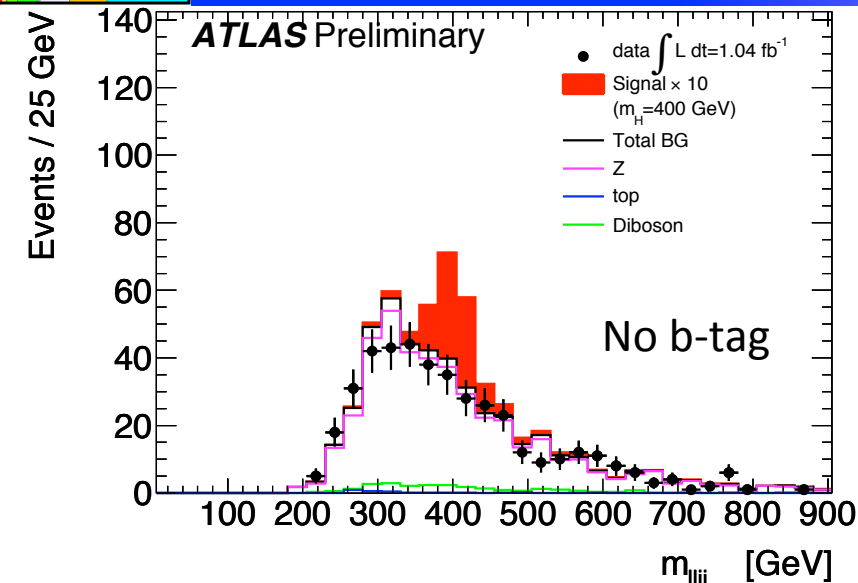
CMS preliminary 2011

1.6 fb^{-1} at $\sqrt{s} = 7 \text{ TeV}$





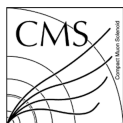
H $\rightarrow$ ZZ $\rightarrow$ 2l 2q



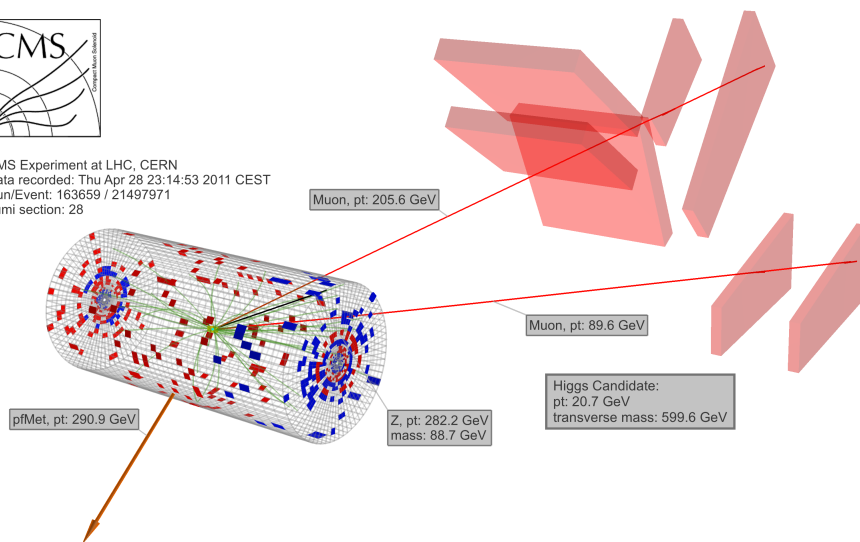
- **Z selection:**
 - $76 < M_{Z1_{ll}} < 106 \text{ GeV}$ (against ttbar)
 - $70 < M_{Z2_{jj}} < 105 \text{ GeV}$ (against ttbar and Z+jets)
 - $P_{t \text{ jet}} > 25 \text{ GeV}$ MET $< 50 \text{ GeV}$
 - Veto third lepton
- **Backgrounds:**
 - Large contribution from Z+jets suppressed by MET cut
 - Small additions from VV, ttbar and QCD multijet
- Observed limit: 1.7 x SM for $m_H = 360 \text{ GeV}$
- Expected limit: 2.7-9 times the SM predictions



H → ZZ → 2l2ν

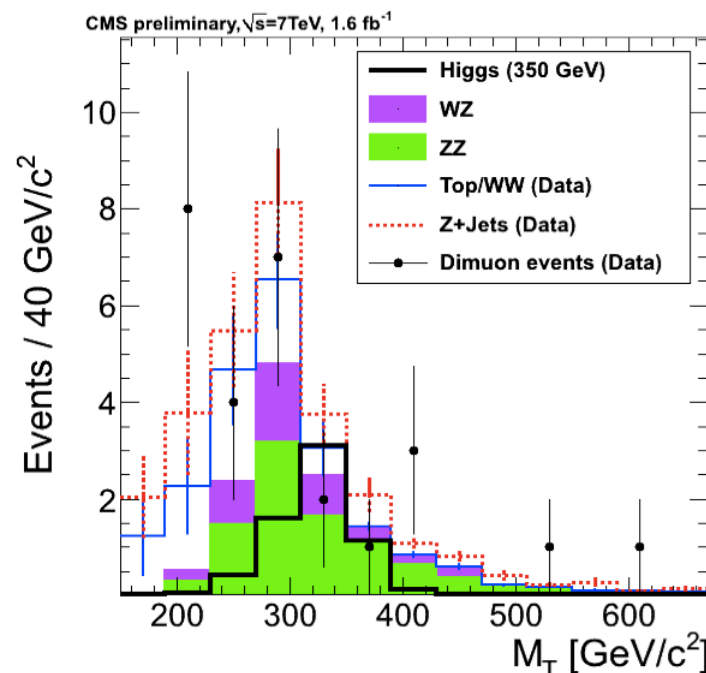
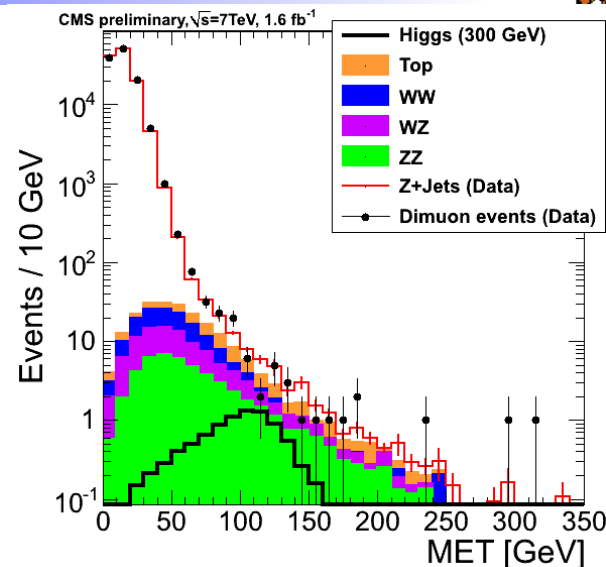


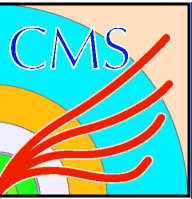
CMS Experiment at LHC, CERN
Data recorded: Thu Apr 28 23:14:53 2011 CEST
Run/Event: 163659 / 21497971
Lumi section: 28



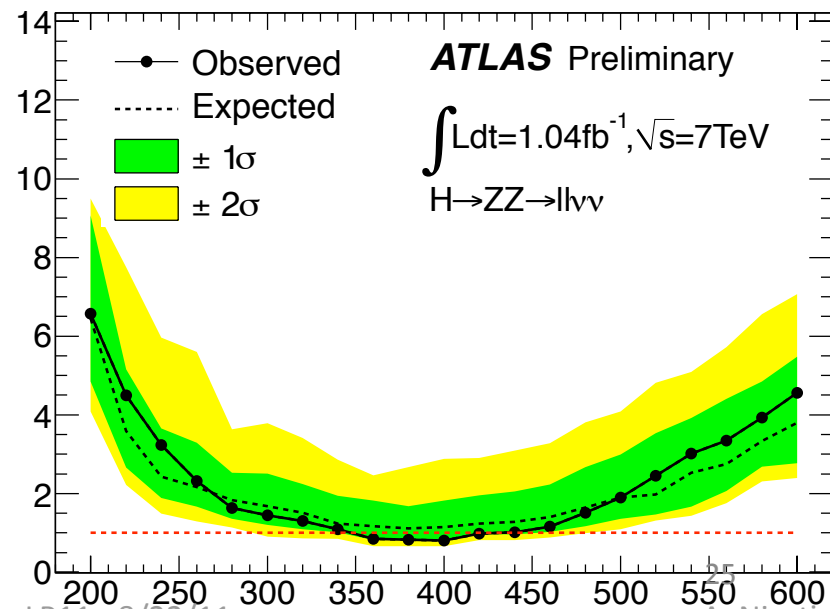
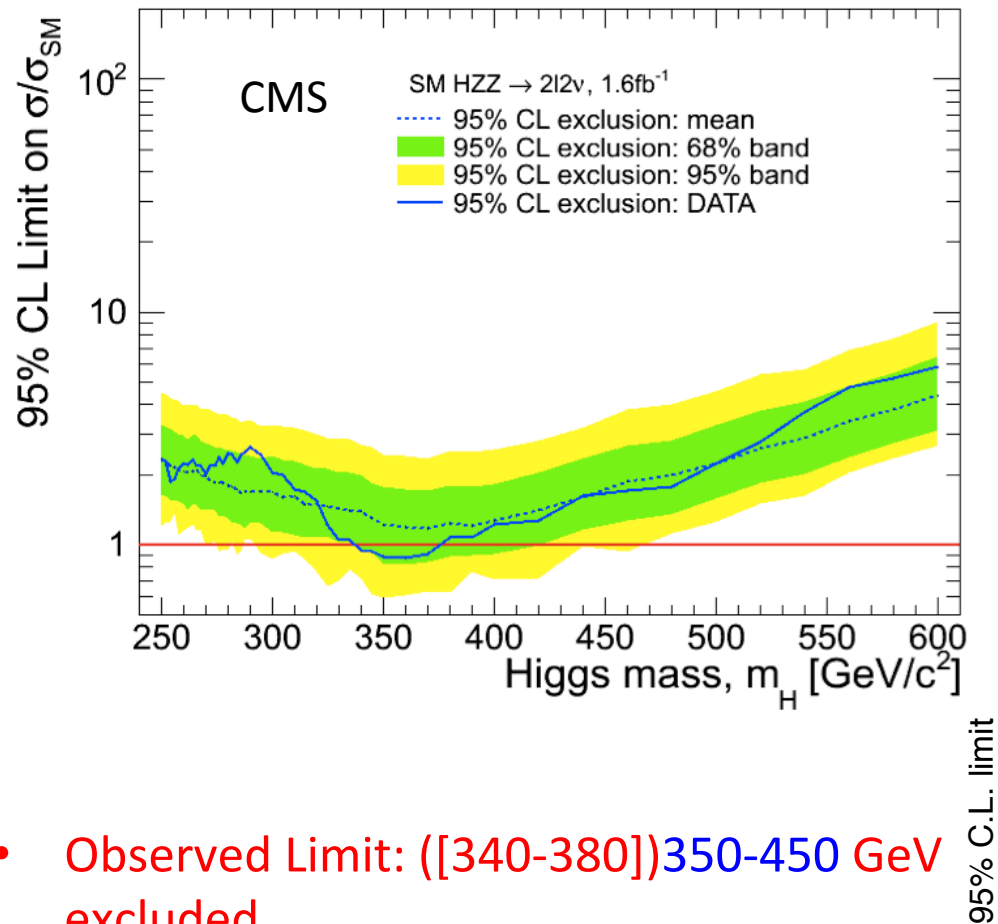
$$M_T^2 = (\sqrt{P_{TZ}^2 + M_Z^2} + \sqrt{MET^2 + M_Z^2})^2 - (\vec{P}_{TZ} + \vec{MET})^2$$

- Clean signature
- Two opposite sign leptons with $|M_{ll} - M_Z| < 15$ GeV, $p_{Tl} > 25$ GeV
- Main bkgds: Z+jets, ttbar, VV from data and MC
- $MET > 69 - 170$ GeV (slides with M_H)
 - Suppresses Z+jets





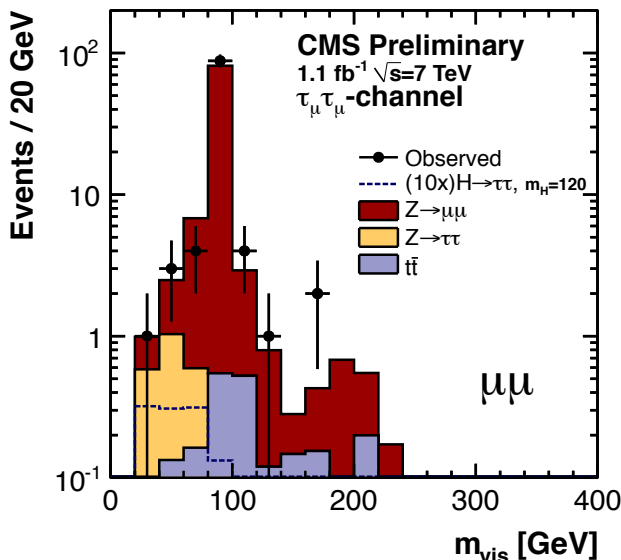
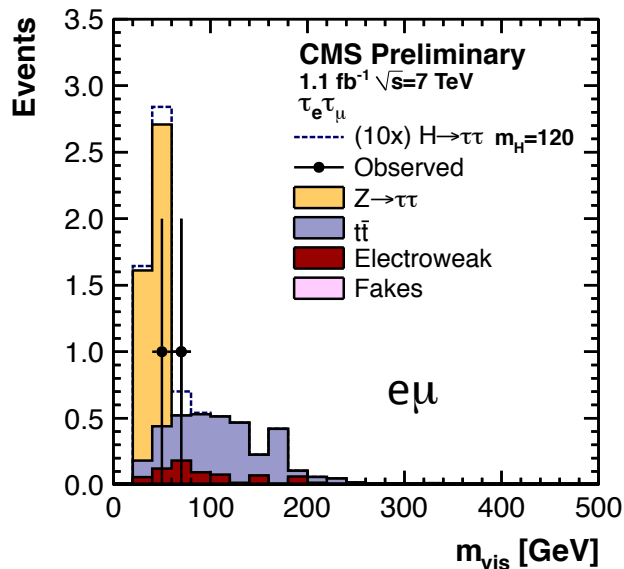
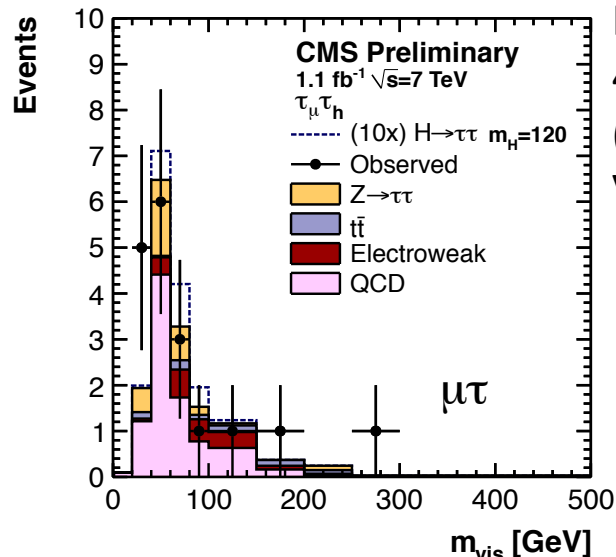
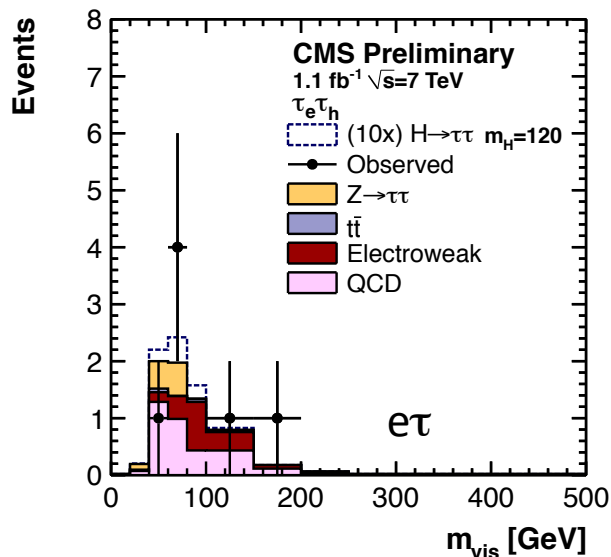
H $\rightarrow$ ZZ $\rightarrow$ 2l2 ν



- Observed Limit: ([340-380])350-450 GeV excluded
- Expected: 1.3 x SM Higgs cross section

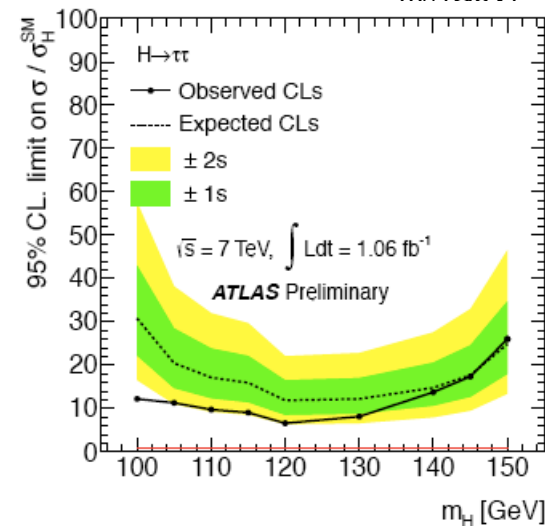
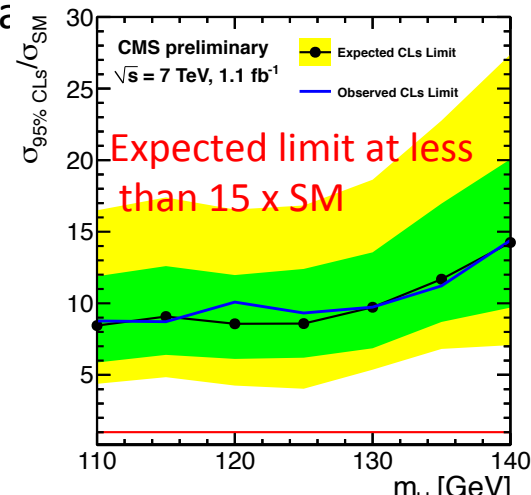


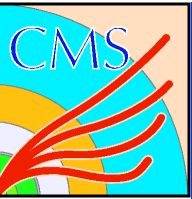
H → ττ



Promising channel for low mass
4 τ decay modes considered
(eτ, μτ, eμ, μμ)

VBF search

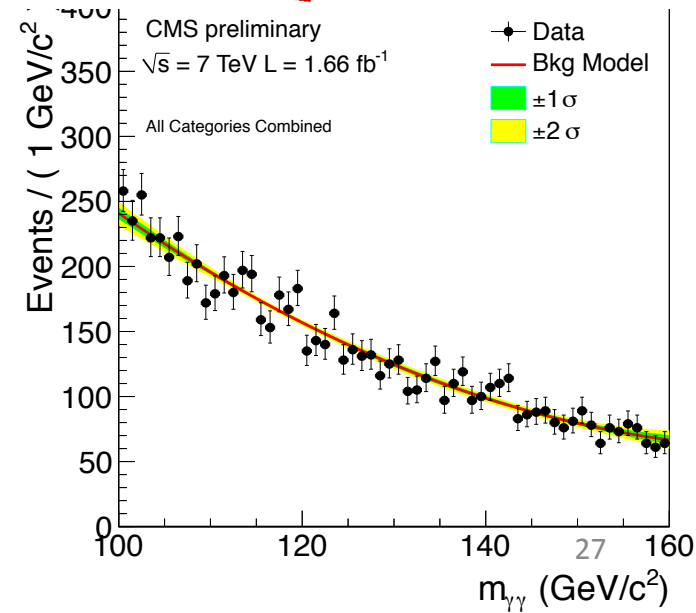
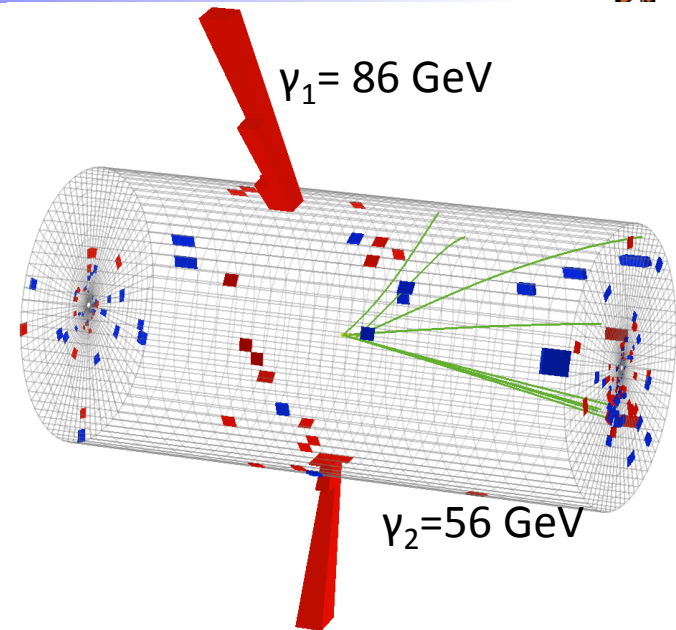




H- $\rightarrow\gamma\gamma$ Decay

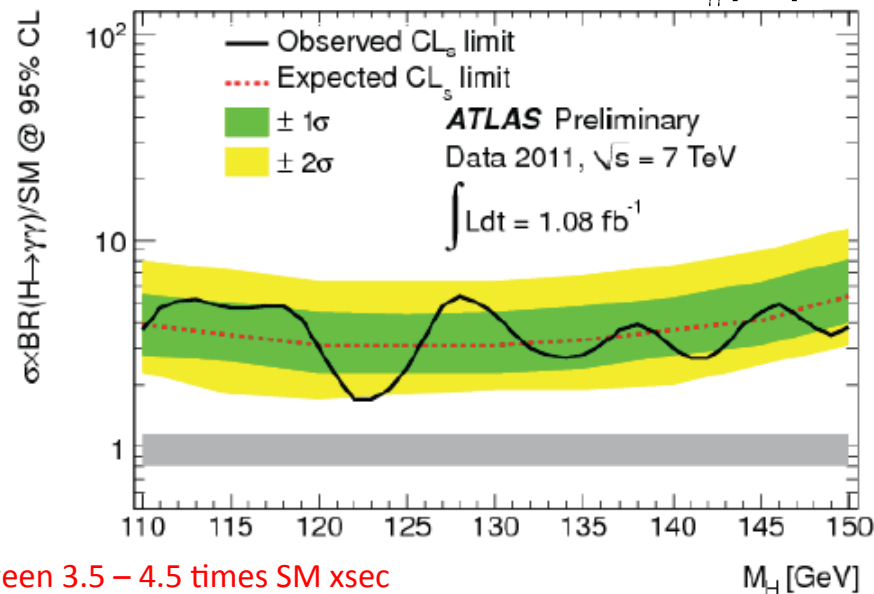
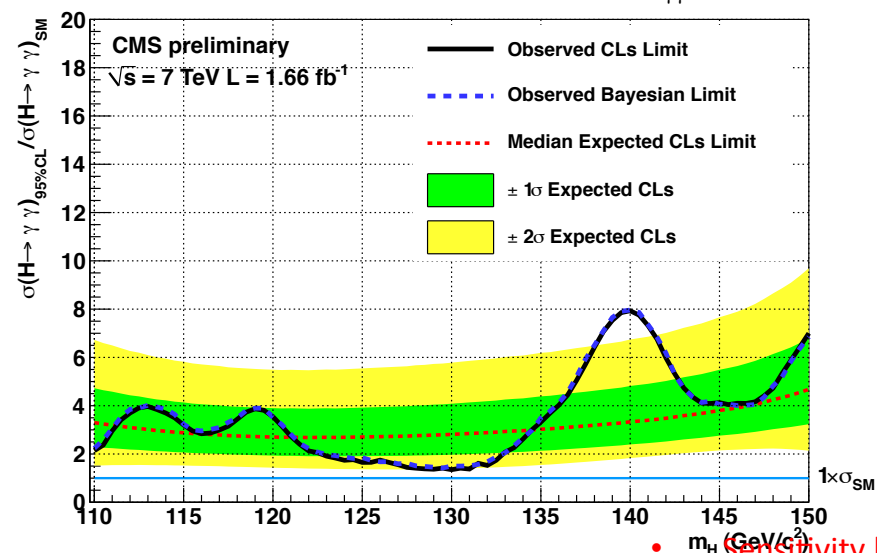
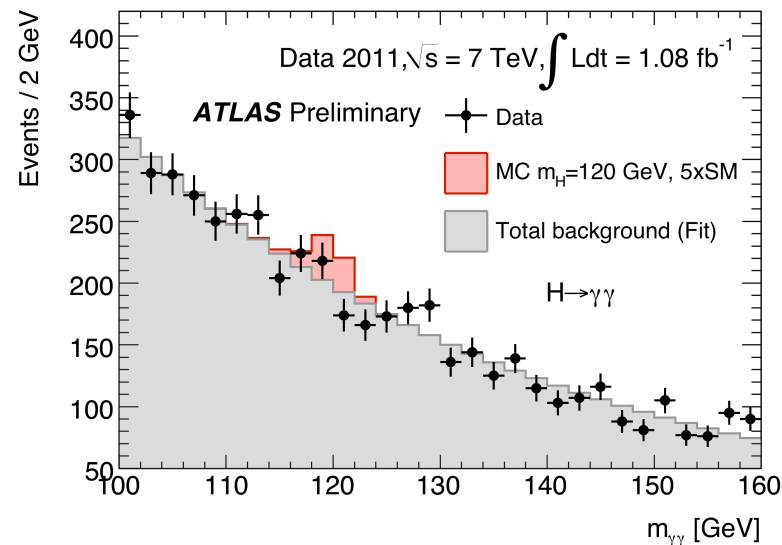
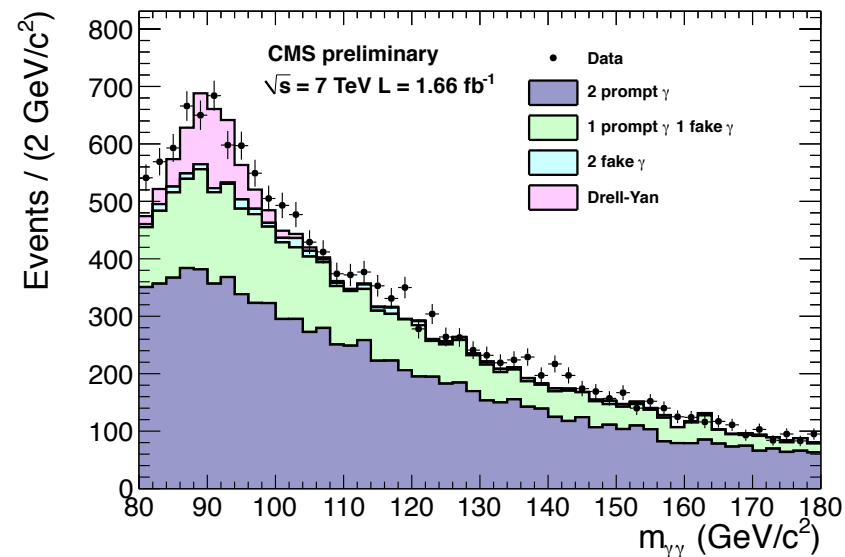
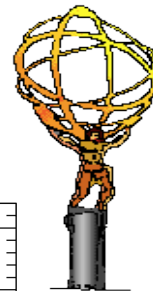


- One of the most sensitive channels at low mass despite small branching ratio
- Event Signature: two photons and sharp peak in invariant mass distribution
- Mass Resolution ~ 3 GeV
 - design resolution 0.5% for $E(g) > 100$ GeV
 - Importance of material distribution upstream
 - Transparency corrections
 - Background rejection critical g/π^0
- Event selection:
 - Two isolated photons with large transverse momentum
 - Di-photon mass reconstruction – proper vertex assignment $\rightarrow$ dedicated algorithms
 - $Z \rightarrow ll$ decays to validate vertex assignment and energy scale and resolution
 - 8 CMS(5ATLAS) data categories depending on P_t and mass resolution and conversion status
 - Simple background model - exponential
 - Signal sum of Gauss Functions with parameters taken from $Z \rightarrow ee$ data



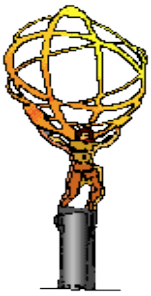


H- $\rightarrow\gamma\gamma$ Results



- Sensitivity between 3.5 – 4.5 times SM xsec
- Observed exclusion between 2-7 times SM xsec
- Limits set in agreement with sensitivity

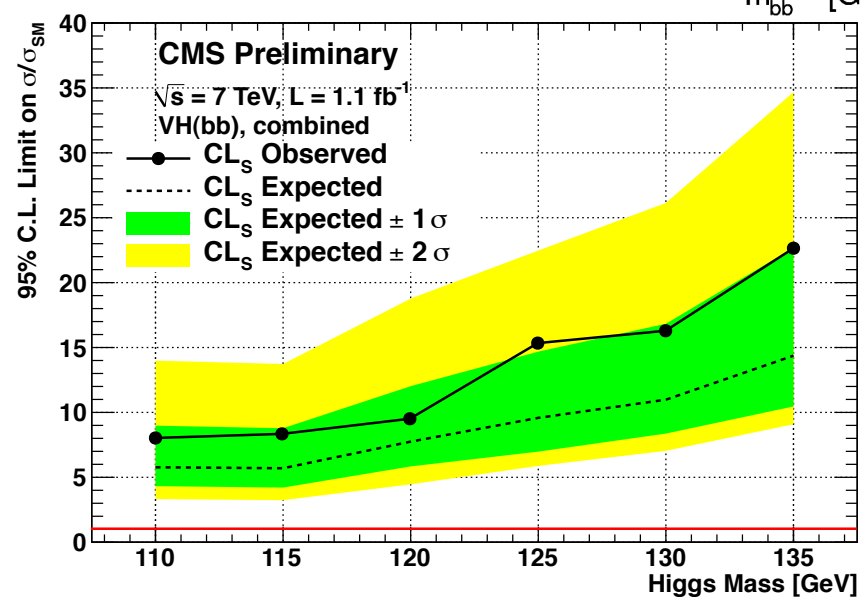
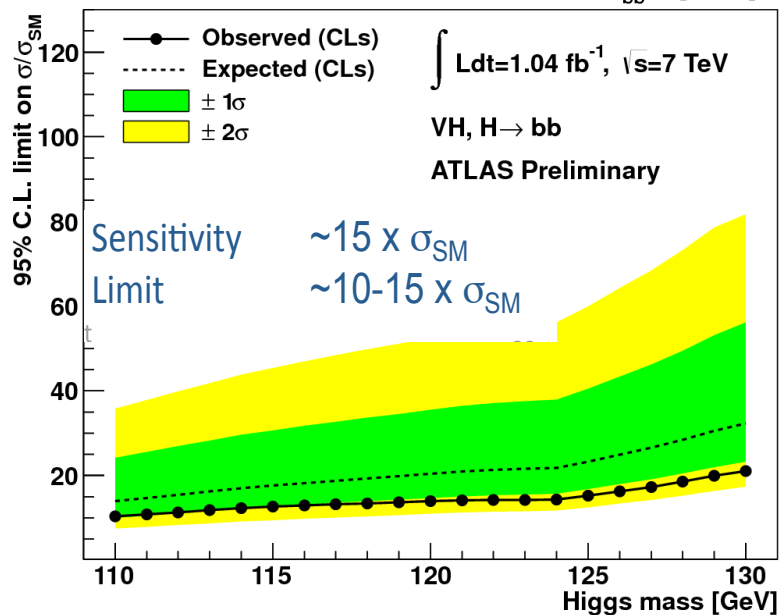
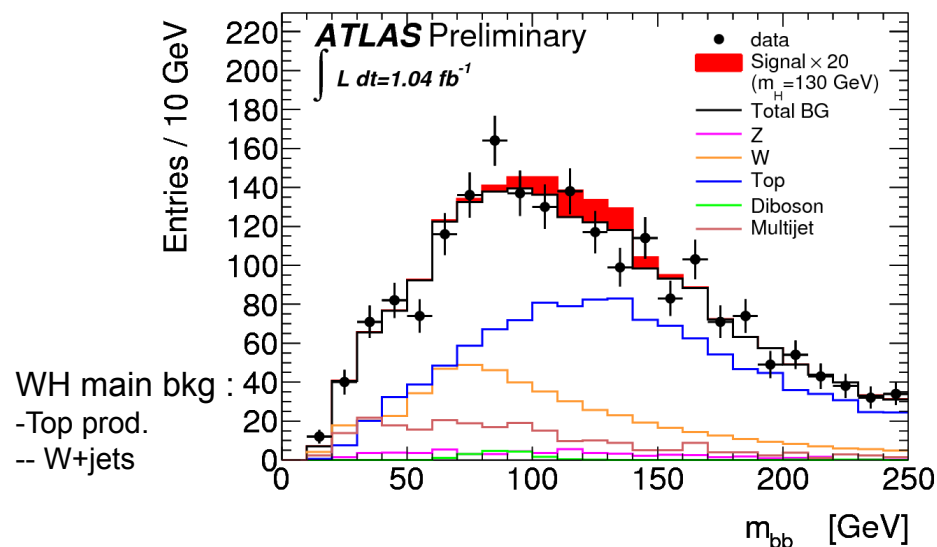
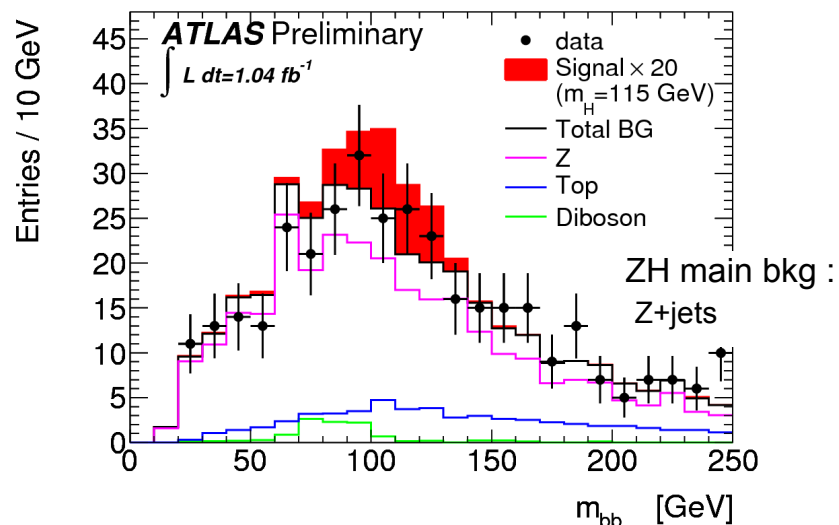
VH, $H \rightarrow b\bar{b}$



- Important channel to get information about the H couplings to quarks
- Dominant decay channel for light Higgs
 - Huge $b\bar{b}$ backgrounds
- Associated production VH to get the boosted H
 - Better control of the abundant QCD backgrounds
- Selection: $V(W,Z)$ $P_t > 100-160$ GeV giving a boost to H
- Good b-tagging and MET quality
- Top, VV, Wjj background shapes from MC fit to the data

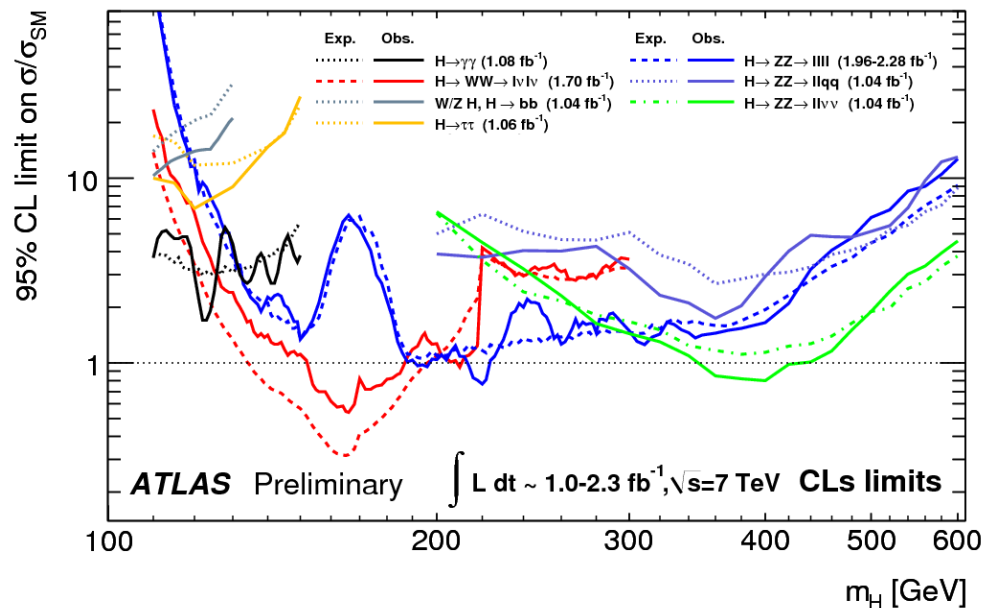


VH, H- $\rightarrow$ bb

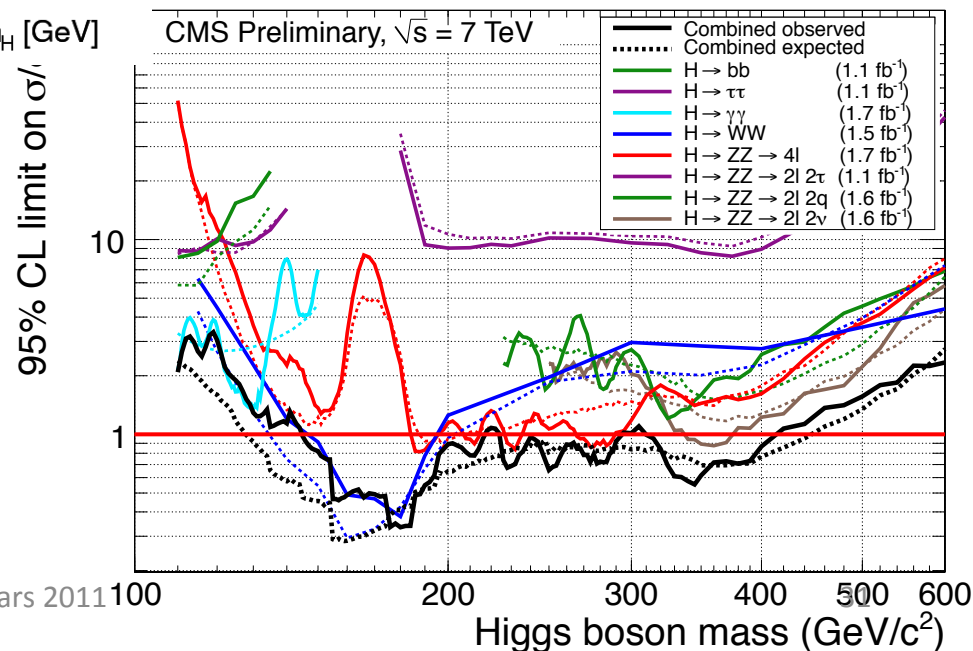




Higgs Combination

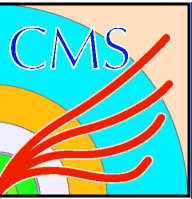


m_H [GeV]

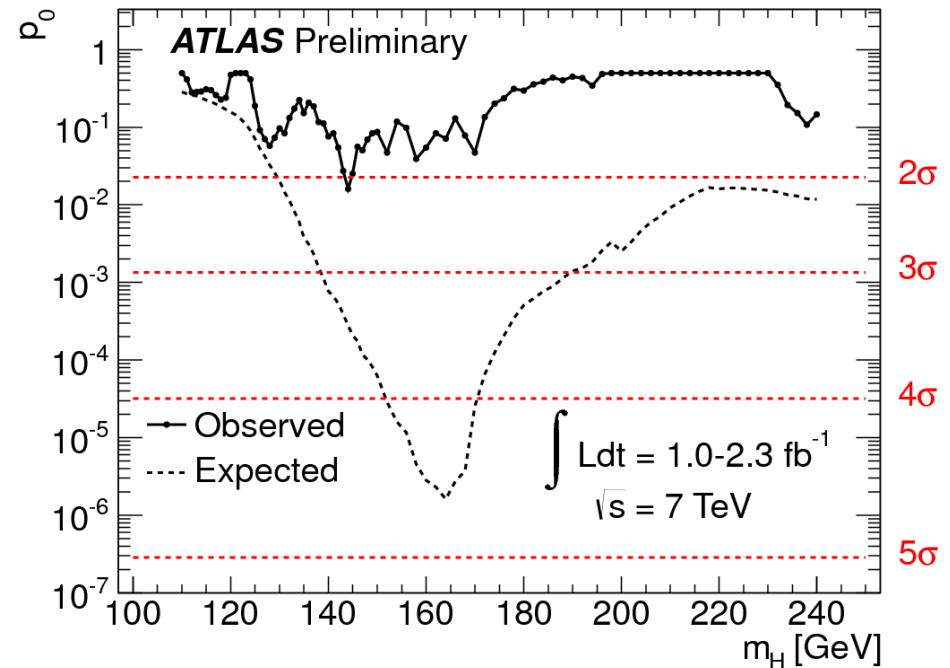
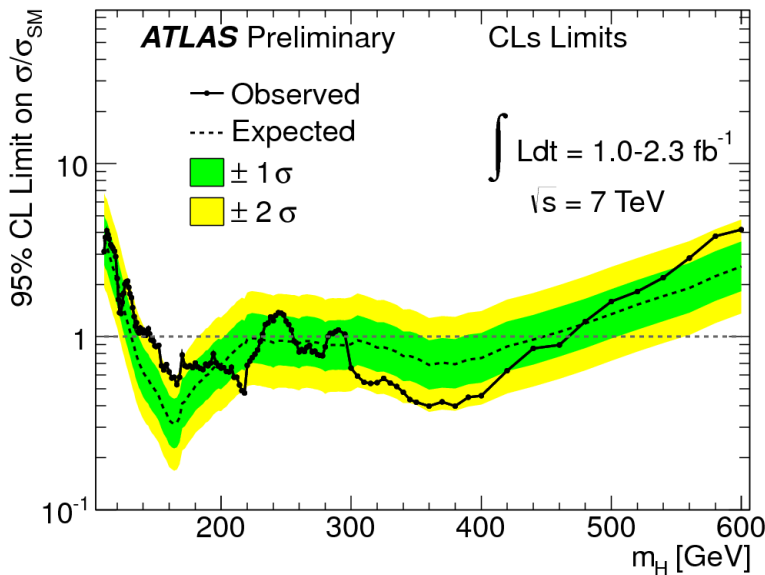
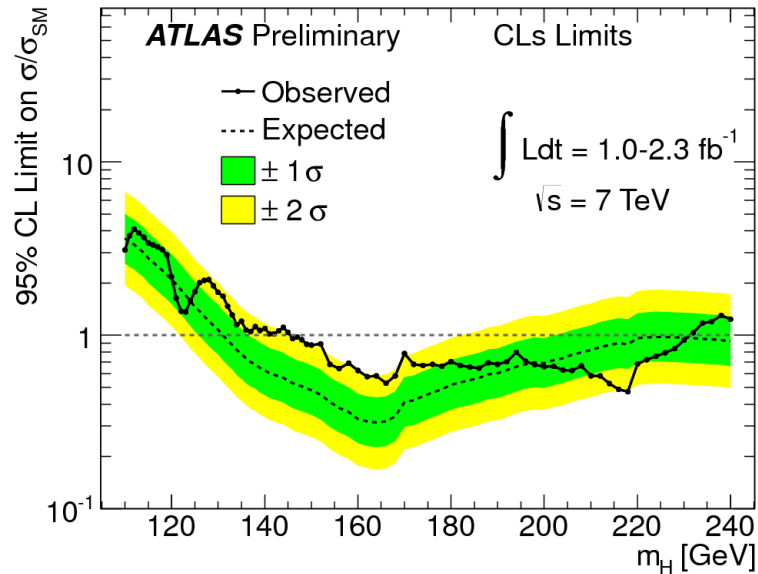


Scalars 2011

- Sensitivities different in detail but on average similar



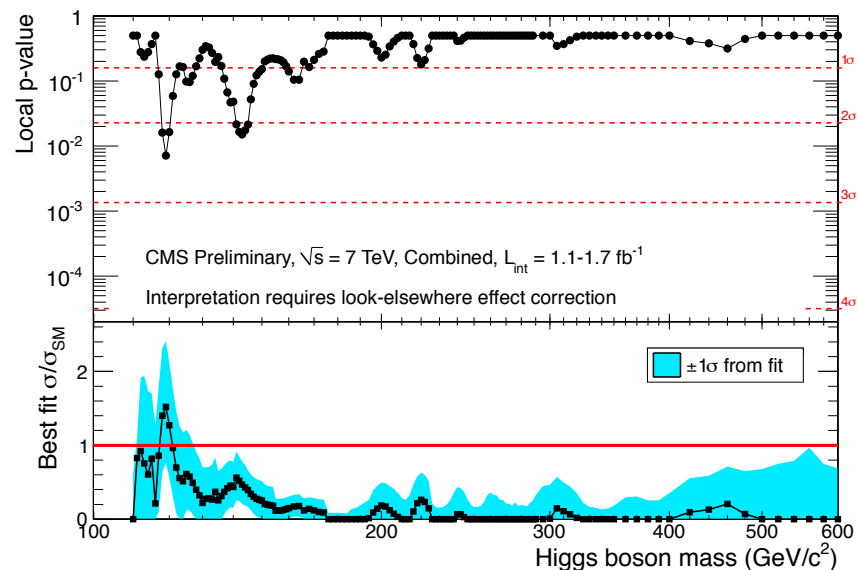
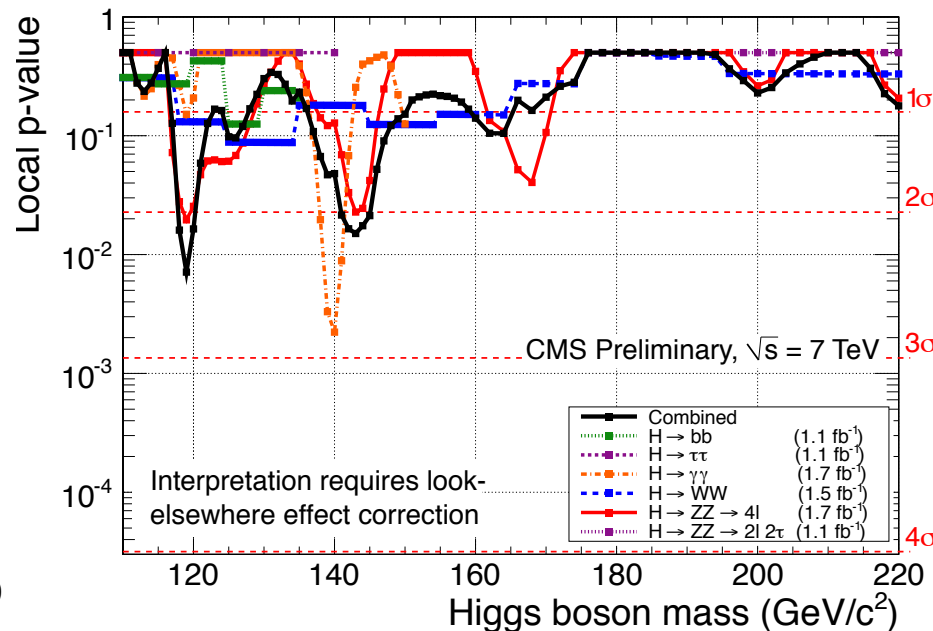
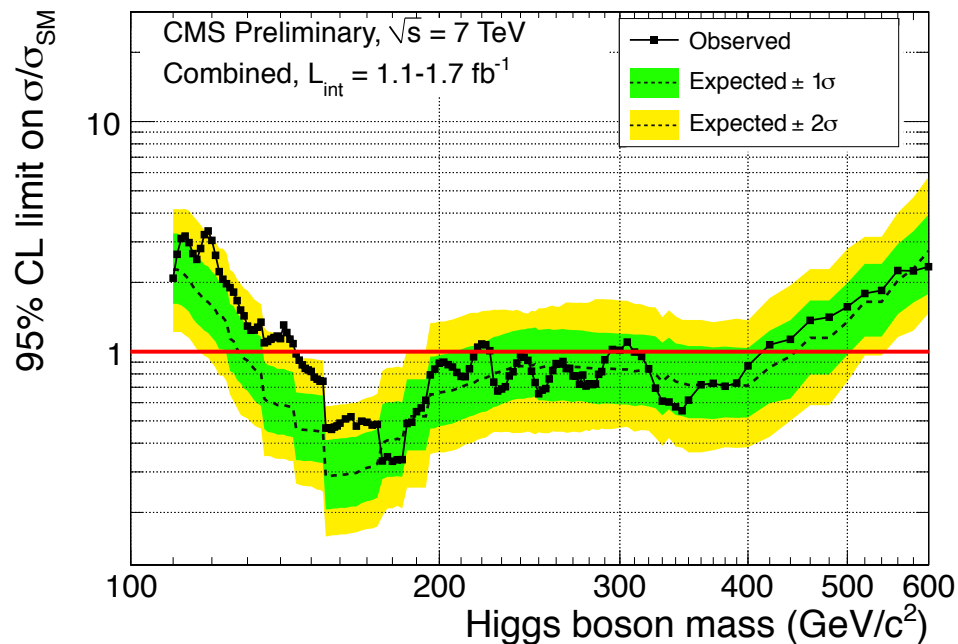
ATLAS Higgs Combination



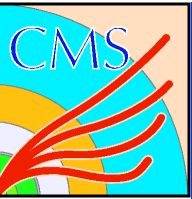
- SM Higgs excluded at 95%CL:
 - $146 < M_H < 232 \text{ GeV}$
 - $256 < M_H < 282 \text{ GeV}$
 - $296 < M_H < 466 \text{ GeV}$
- Probability of background-only experiment to fluctuate thus far
- Observed below expected



CMS Higgs Combination



- SM Higgs excluded at 95%CL:
 - $145 < M_H < 216 \text{ GeV}$
 - $226 < M_H < 288 \text{ GeV}$
 - $310 < M_H < 400 \text{ GeV}$
- Probability to see an excess at least as large as observed is 0.4 (LEE corrected)



SUMMARY



- CMS and ATLAS have searched for the SM Higgs in 8 (7) decay channels with integrated luminosity up to 1.7 (2.3) /fb
- No significant excess of signal like events observed
- Expected 95% exclusion range in the absence of signal 130-440 GeV
- Observed 95% exclusions are in ranges: [145-216], [226,288], [310,400] or [146-232], [256,282], [296,466]
 - The gaps are consistent with statistical fluctuations
- Indication of light SM Higgs boson in the LHC data ($M_H < 145$ GeV)
- **LHC data sample is growing rapidly and determination of the source of the excess at low masses is imminent.**