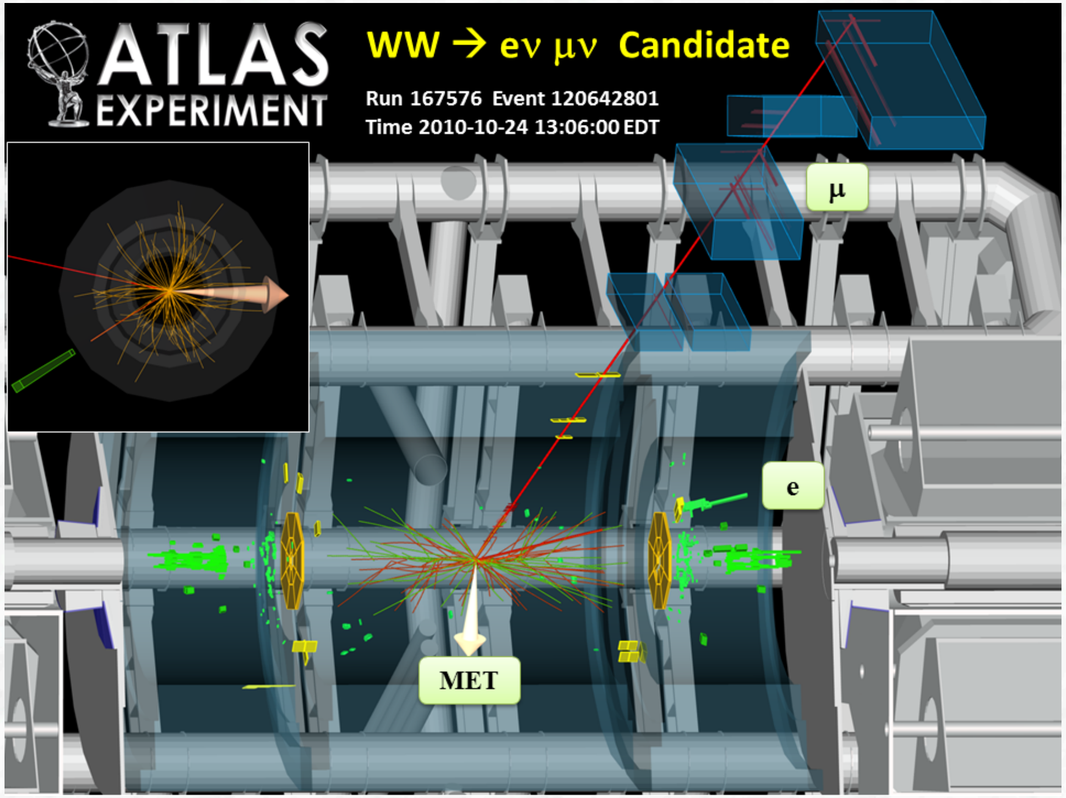
Search for the Higgs Boson at the LHC



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Outline of the talk:

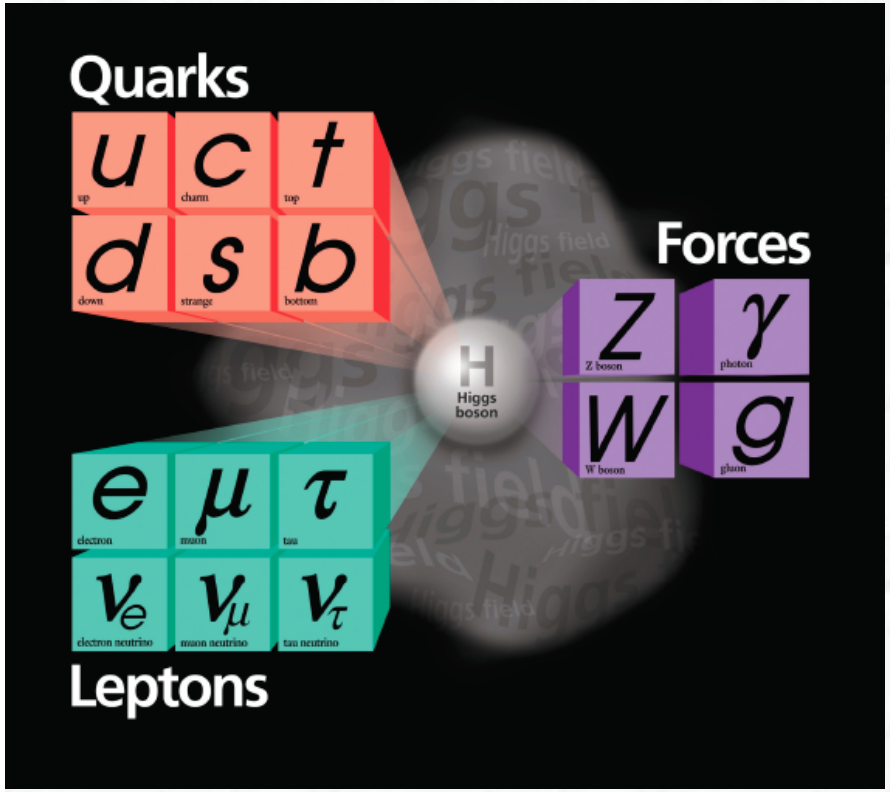
1. Introduction, the Higgs boson in the Standard Model

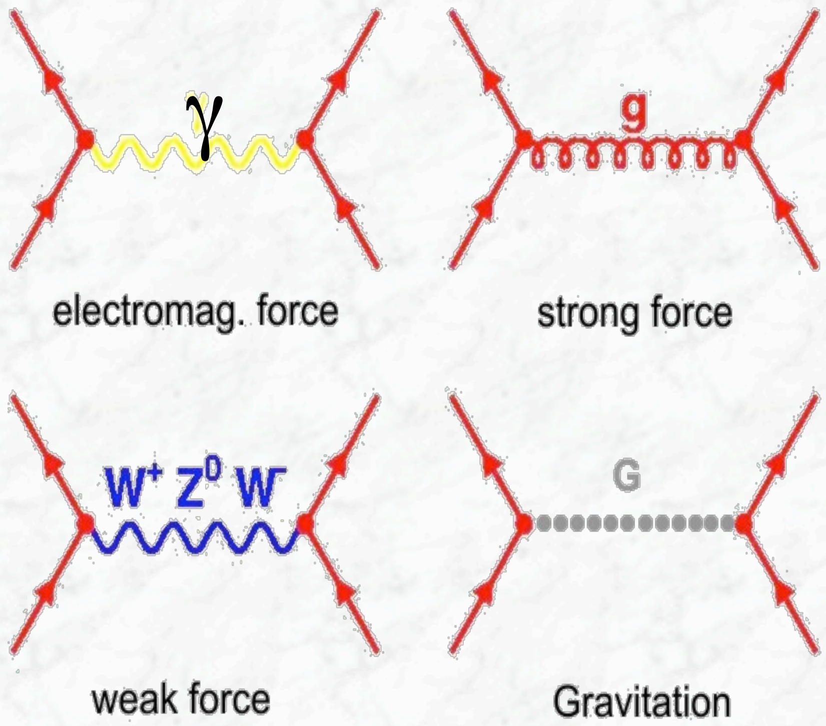
2. The Standard Model Higgs boson search
   - ATLAS and CMS results in various channels (with some focus on $H \rightarrow WW \rightarrow l\nu\, l\nu$)
   - The combination of searches

3. Prospects and outlook

Disclaimer: I will try to highlight the most important results on searches for the Higgs boson.
The coverage is not complete, i.e. not all results available will be presented.

The Standard Model of Particle Physics





(i) Constituents of matter: quarks and leptons

(ii) Four fundamental forces

(described by quantum field theories, except gravitation)

(iii) The Higgs field (problem of mass)

Why do we need the Higgs Boson?

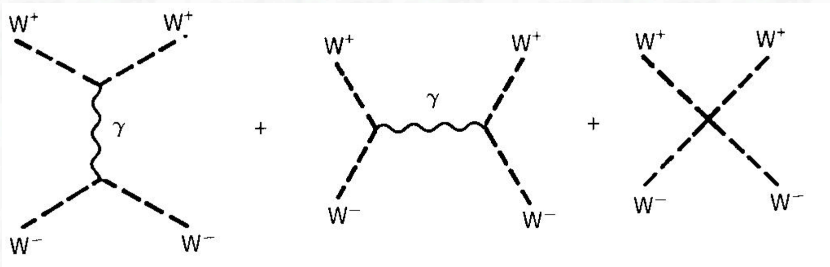
The Higgs boson enters the Standard Model to solve two fundamental problems:

- Masses of the vector bosons W and Z:

  Experimental results: $M_W = 80.399 \pm 0.023$ GeV / c^2
  $M_Z = 91.1875 \pm 0.0021$ GeV / c^2

  A local gauge invariant theory requires massless gauge fields

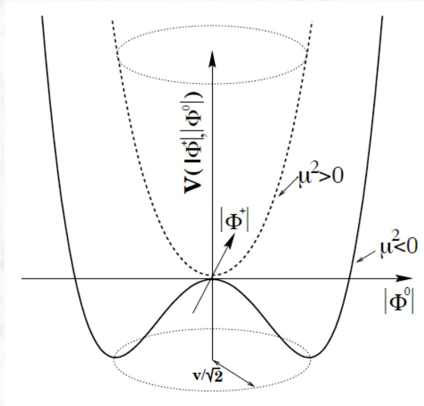
- Divergences in the theory (scattering of W bosons)



$$-iM(W^+W^- \rightarrow W^+W^-) \sim \frac{s}{M_W^2} \quad \text{for} \quad s \rightarrow \infty$$

The Higgs mechanism

Spontaneous breaking of the SU(2) x U(1) gauge symmetry



- Scalar fields are introduced $\phi = \frac{1}{\sqrt{2}}\begin{pmatrix}\phi_1 + i\phi_2 \\ \phi_3 + i\phi_4\end{pmatrix} = \begin{pmatrix}\phi^+ \\ \phi^0\end{pmatrix}$

Potential : $V(\phi) = \mu^2(\phi^*\phi) + \lambda(\phi^*\phi)^2$

- For $\mu^2 < 0$, $\lambda > 0$, minimum of potential: $\phi_1^2 + \phi_2^2 + \phi_3^2 + \phi_4^2 = v^2$ $v^2 = -\mu^2/\lambda$

- Perturbation theory around ground state:

$$\phi_0(x) = \frac{1}{\sqrt{2}}\begin{pmatrix}0 \\ v + h(x)\end{pmatrix} \Rightarrow$$

3 massive vector fields: $m_{W^\pm} = \frac{1}{2} vg$ $m_Z = \frac{m_W}{\cos\theta_W}$

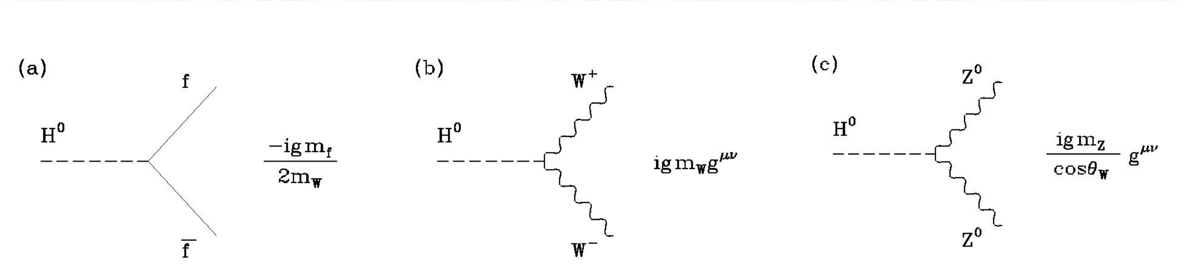
1 massless vector field: $m_\gamma = 0$

1 massive scalar field: **The Higgs boson H** $m_H = \sqrt{\lambda v^2}$

v = vacuum expectation value $v = \frac{1}{\sqrt{\sqrt{2} G_F}} = 246\ \mathrm{GeV}$

The Higgs mechanism (cont.)

- Coupling terms of W- and Z-bosons and fermions to the Higgs field:



- The introduced scalar fields can also be used to generate **fermion masses**

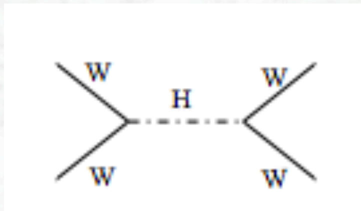
$$m_f = g_f v/\sqrt{2} \Rightarrow g_f = m_f\sqrt{2}/v$$

(where g_f is the coupling of the Higgs field to the fermion)

- Higgs boson self-coupling $L = \ldots - \lambda v \mathrm{h}^3 - \frac{1}{4}\lambda \mathrm{h}^4$

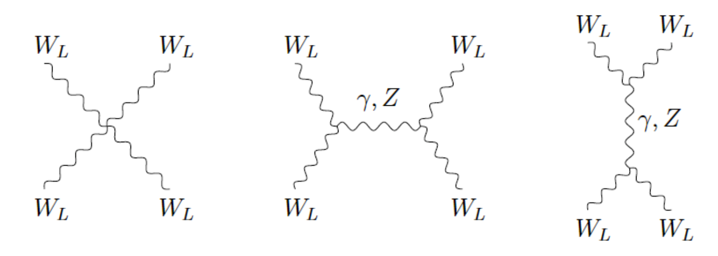
and finally

- Higgs boson regulates divergences in the WW scattering cross section



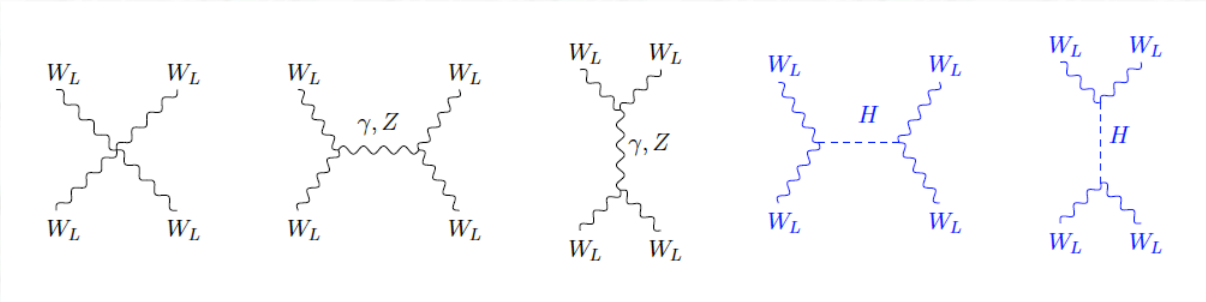
The Higgs boson as a UV regulator

Scattering of longitudinally polarized W bosons



$$-iM(W^+W^- \rightarrow W^+W^-) \sim \frac{s}{m_W^2} \quad \text{for} \quad s \rightarrow \infty$$

Higgs boson guarantees unitarity (if its mass is < ~1 TeV)



$$-iM(W^+W^- \rightarrow W^+W^-) \sim m_H^2 \quad \text{for} \quad s \rightarrow \infty$$

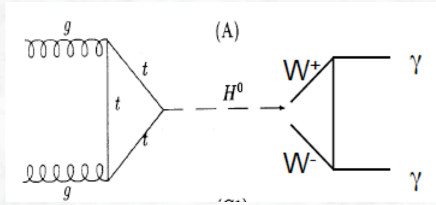
Higgs Boson Decays

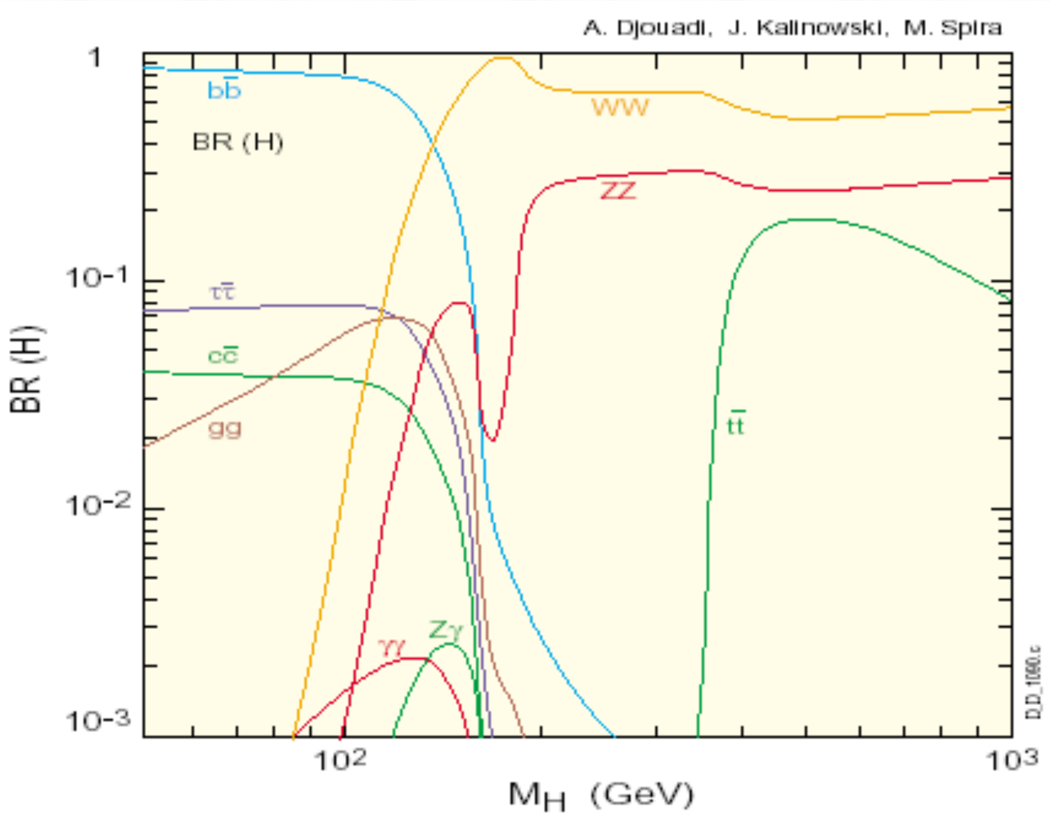
The decay properties of the Higgs boson are fixed, if the **mass** is known:

H

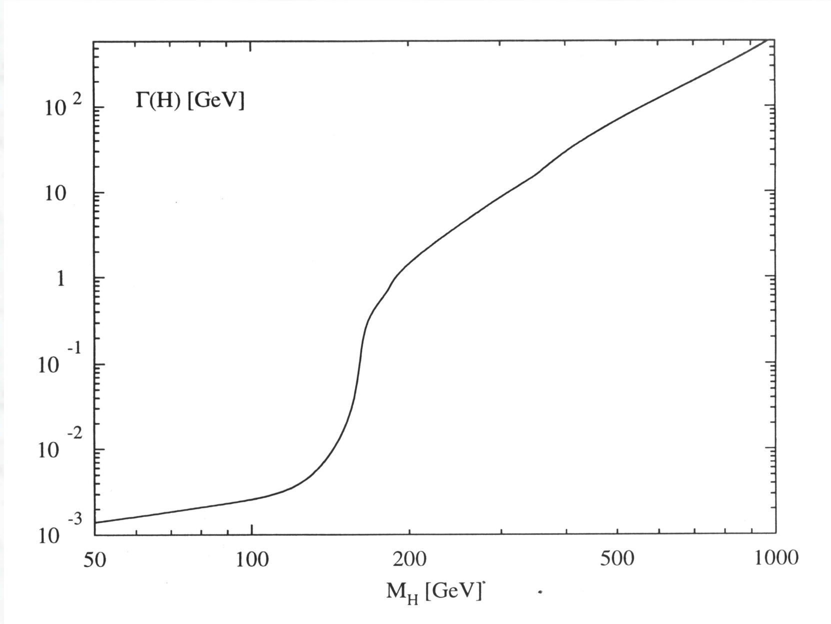
W^+, Z, t, b, c, τ^+,.........., g, γ

W^-, Z, t, b, c, τ ,.........., g, γ





Total width



Constraints on the Higgs boson mass

1. Constraints from theory

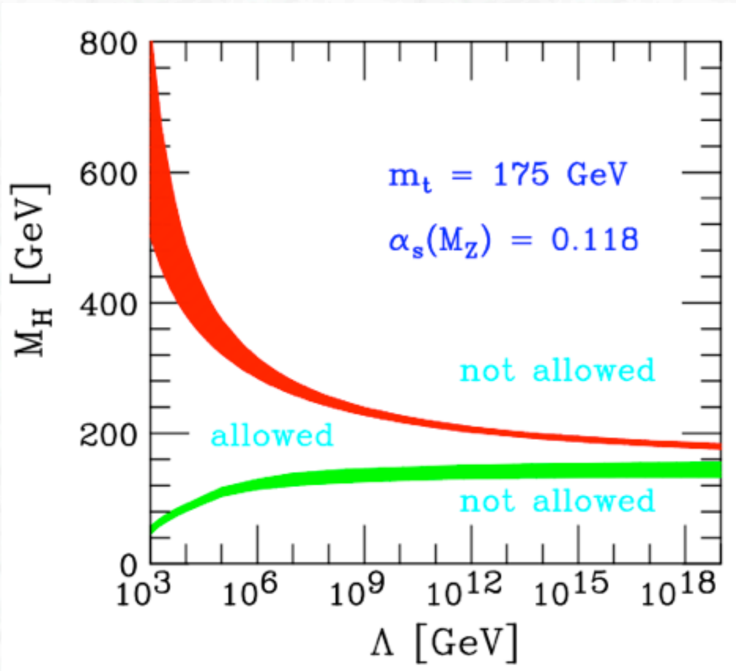
2. Indirect limits from electroweak precision data (theory and experiment)

3. Limits from Direct Searches (LEP, Tevatron)

(i) Tighter Higgs mass constraints from theory:

Stronger bounds on the Higgs-boson mass result from the energy dependence of the Higgs coupling λ (Q^2)
(if the Standard Model is assumed to be valid up to some scale Λ)

$$\lambda(Q^2) = \lambda_0 \left\{ 1 + \frac{3\lambda_0}{2\pi^2} \log\left(2\frac{Q^2}{v^2}\right) + \ldots - \frac{3g_t^4}{32\pi^2} \log\left(2\frac{Q^2}{v^2}\right) + \ldots \right\} \qquad \text{where} \quad \lambda_0 = \frac{m_h^2}{v^2}$$



Hambye, Risselmann et al.

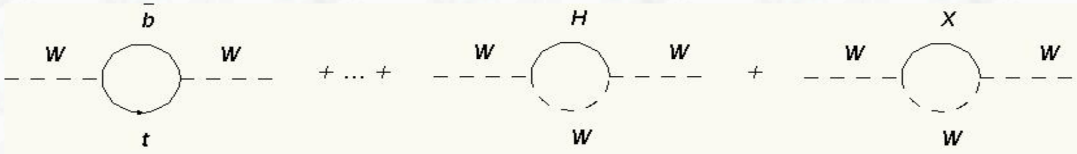
Upper bound: diverging coupling (Landau Pole)

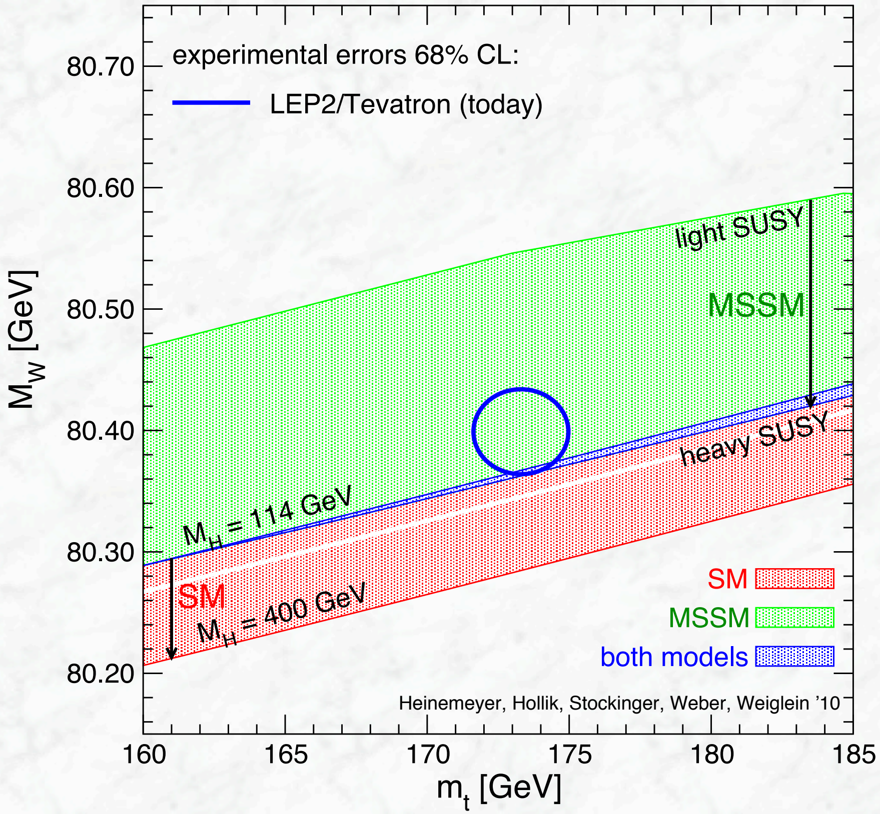
Lower bound: stability of the vacuum (negative contribution from top quark dominates)

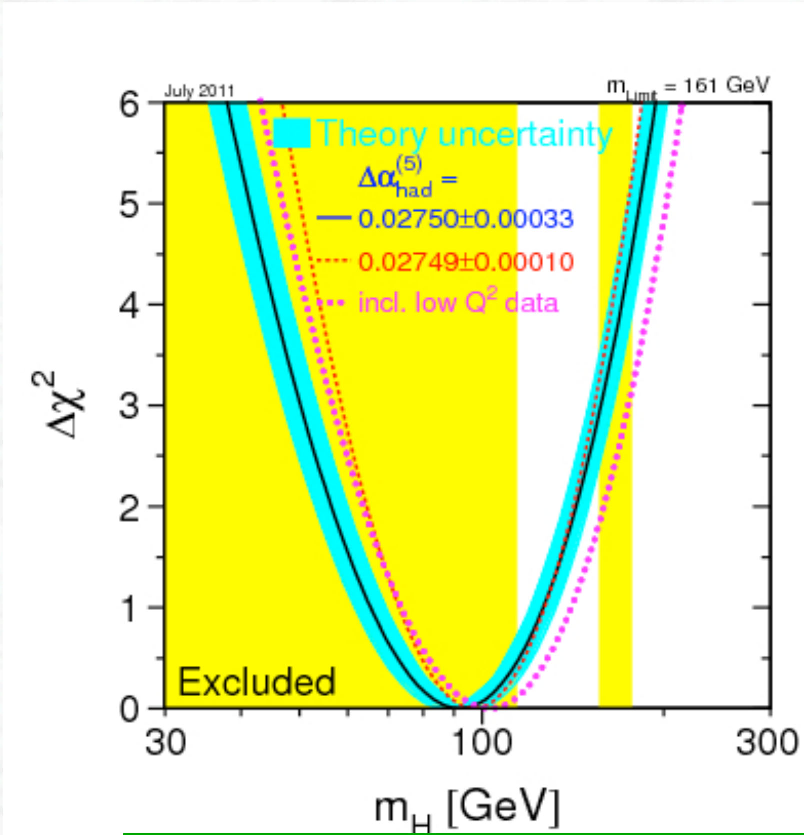
Mass bounds depend on scale Λ up to which the Standard Model should be valid

(ii) Indirect limits from electroweak precision data (m_W and m_t)

Sensitivity to the Higgs boson and other new particles via quantum corrections:



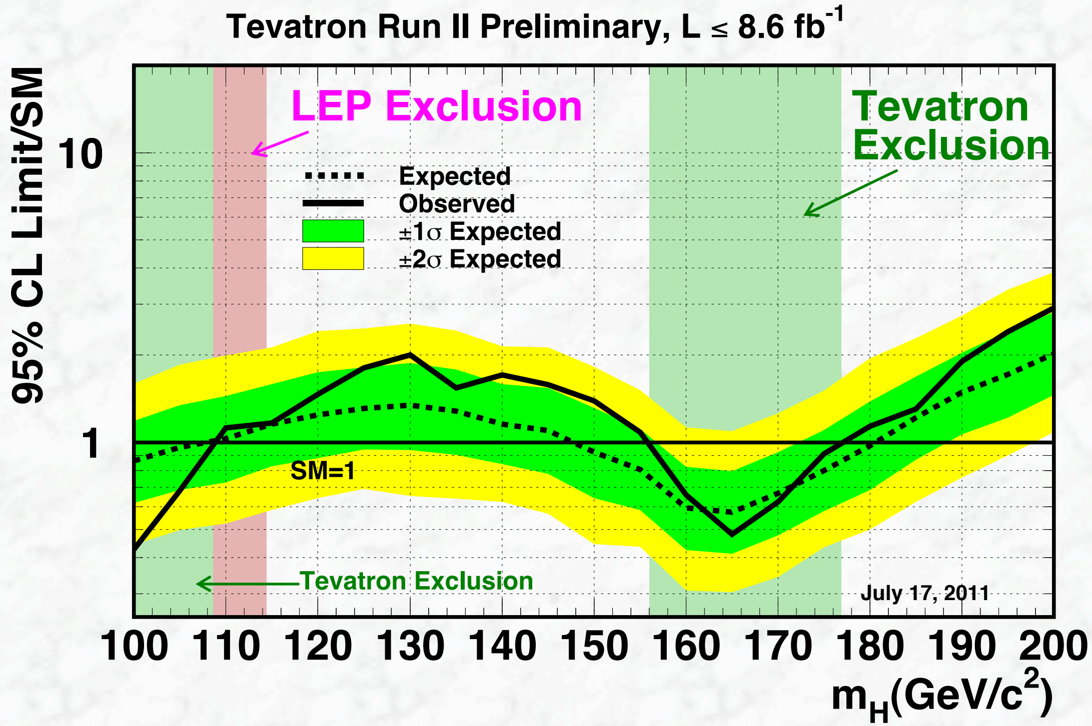


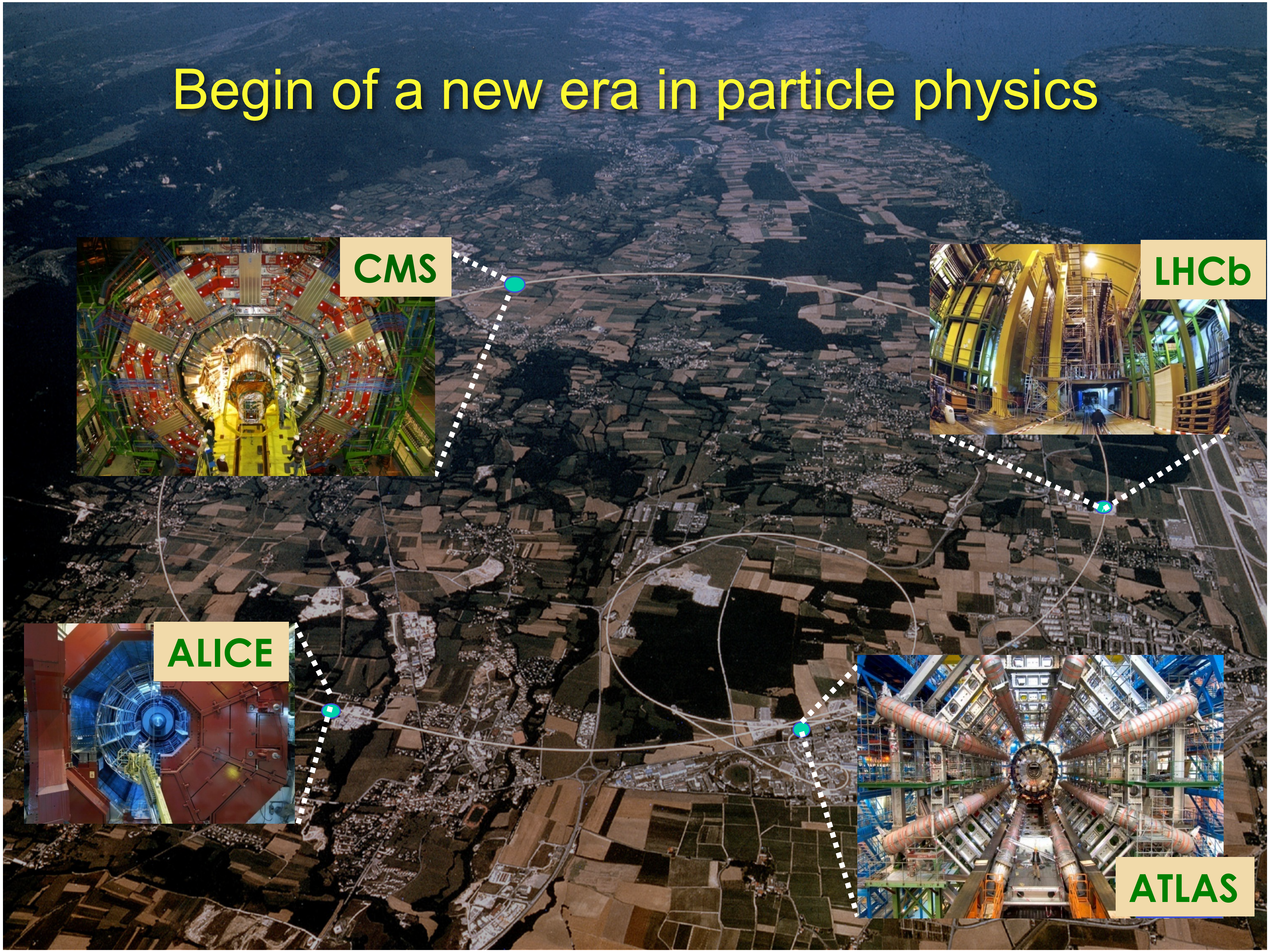


m_H = 92 $^{+34}_{-26}$ GeV/c^2
m_H < 161 GeV/c^2 (95 % CL)

(iii) Constraints from direct searches

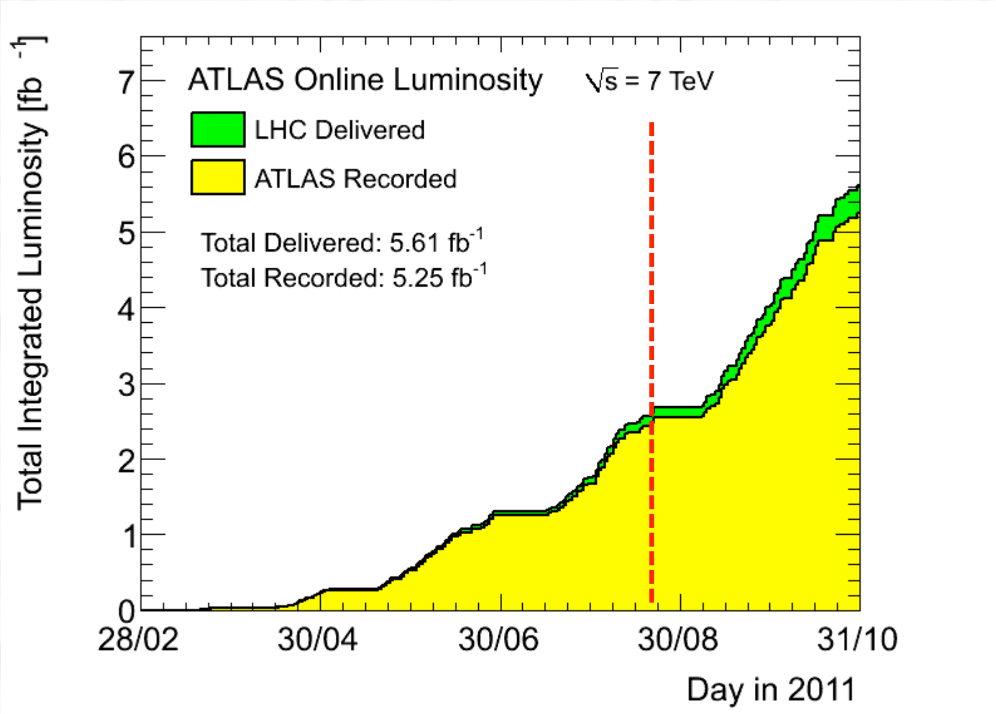
- $m_H > 114.4$ GeV from direct searches at LEP
- $m_H < 156$ GeV .or. $m_H > 177$ GeV from direct searches at the Tevatron



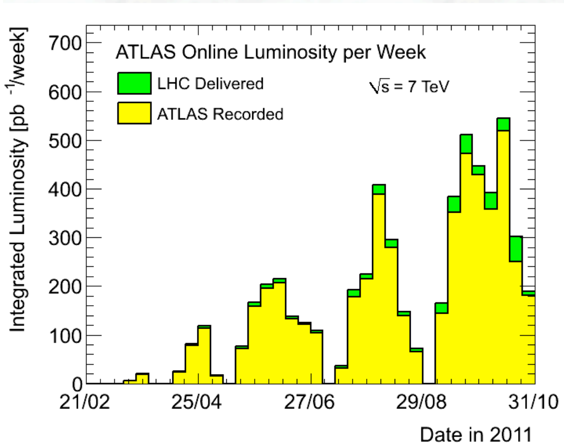

Begin of a new era in particle physics
CMS
LHCb
ALICE
ATLAS

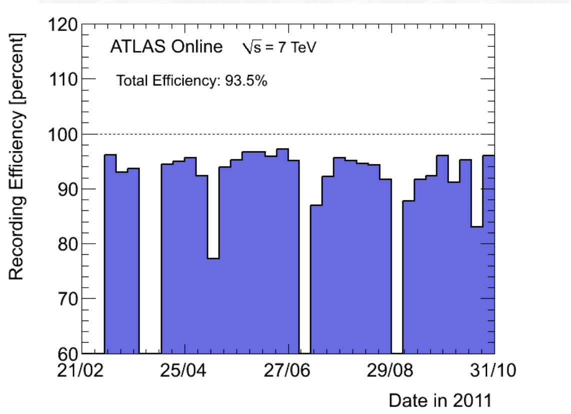
Data taking in 2011

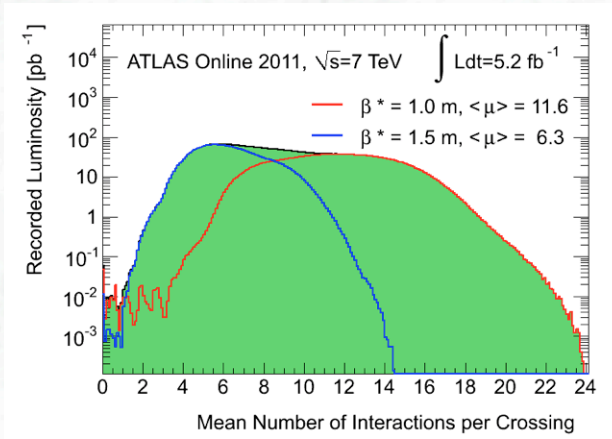
Original goal to collect 1 fb^{-1} already surpassed in June 2011



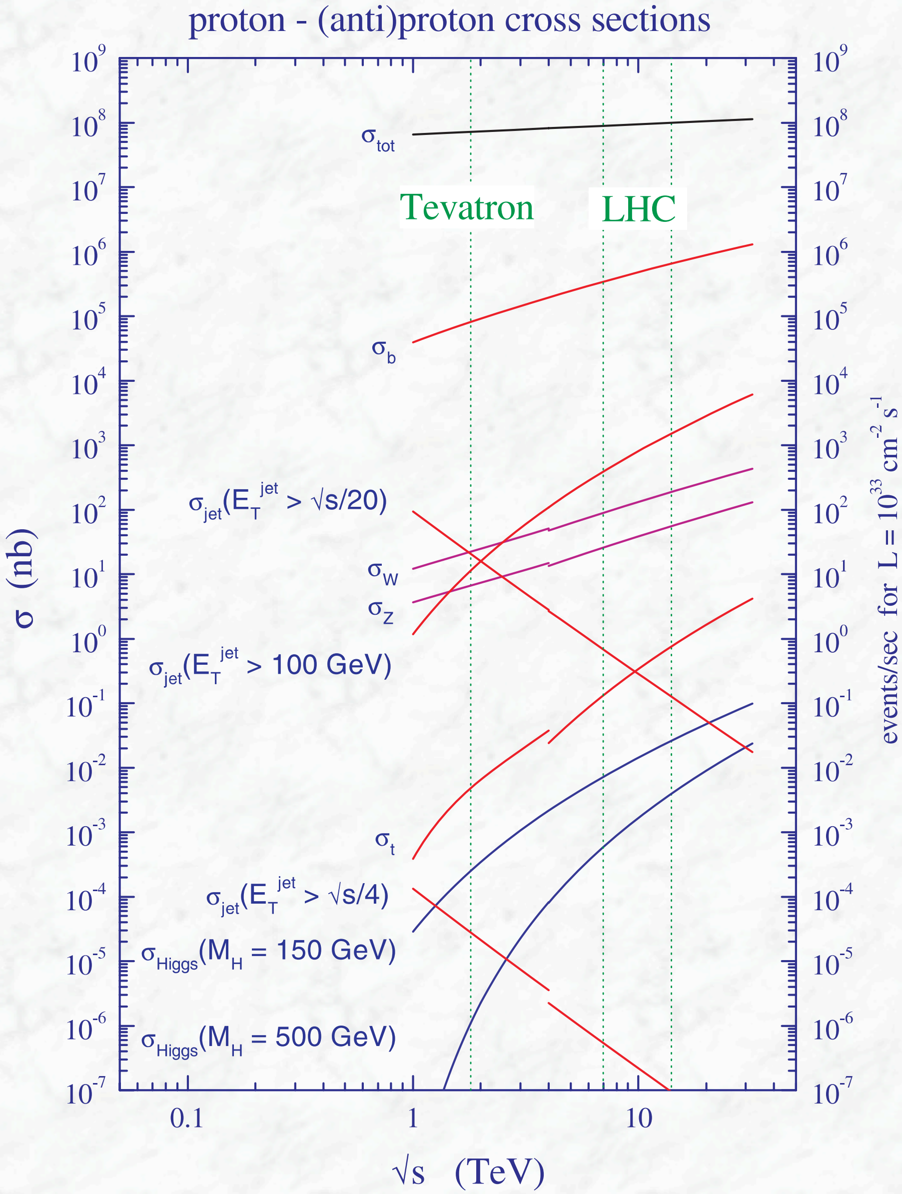
- World record on instantaneous luminosity on 22. April 2011:
  $4.67\ 10^{32}\ cm^{-2}\ s^{-1}$
  (Tevatron record: $4.02\ 10^{32}\ cm^{-2}\ s^{-1}$)
  meanwhile: $> 10^{33}\ cm^{-2}\ s^{-1}$
- Collect per day as much luminosity as in 2010
- Data taking efficiency is high
- Pile-up is high
  (high intensity bunches)







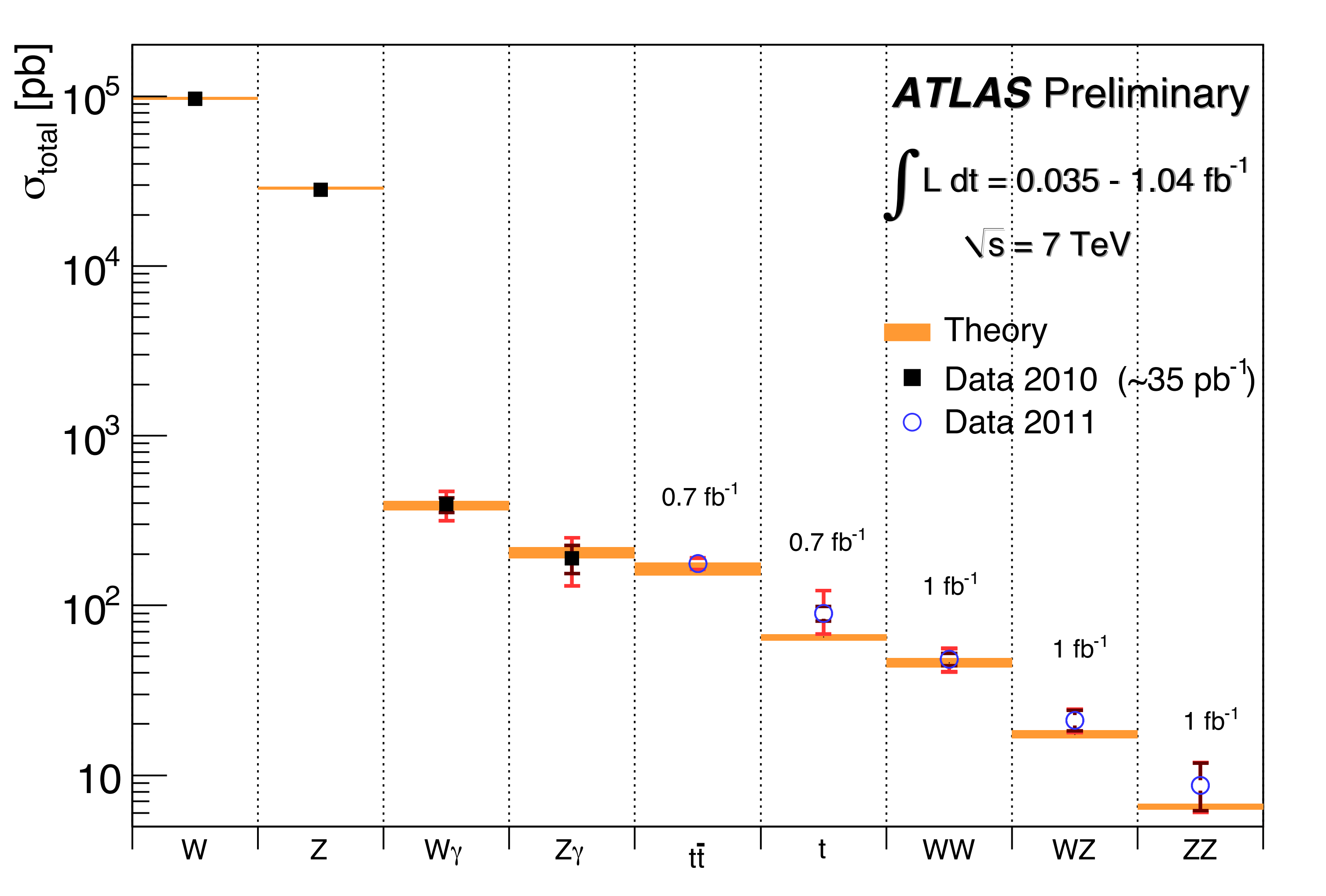
Production Cross Sections at the LHC



Rates for $L = 10^{34}\ cm^{-2}\ s^{-1}$: (LHC)

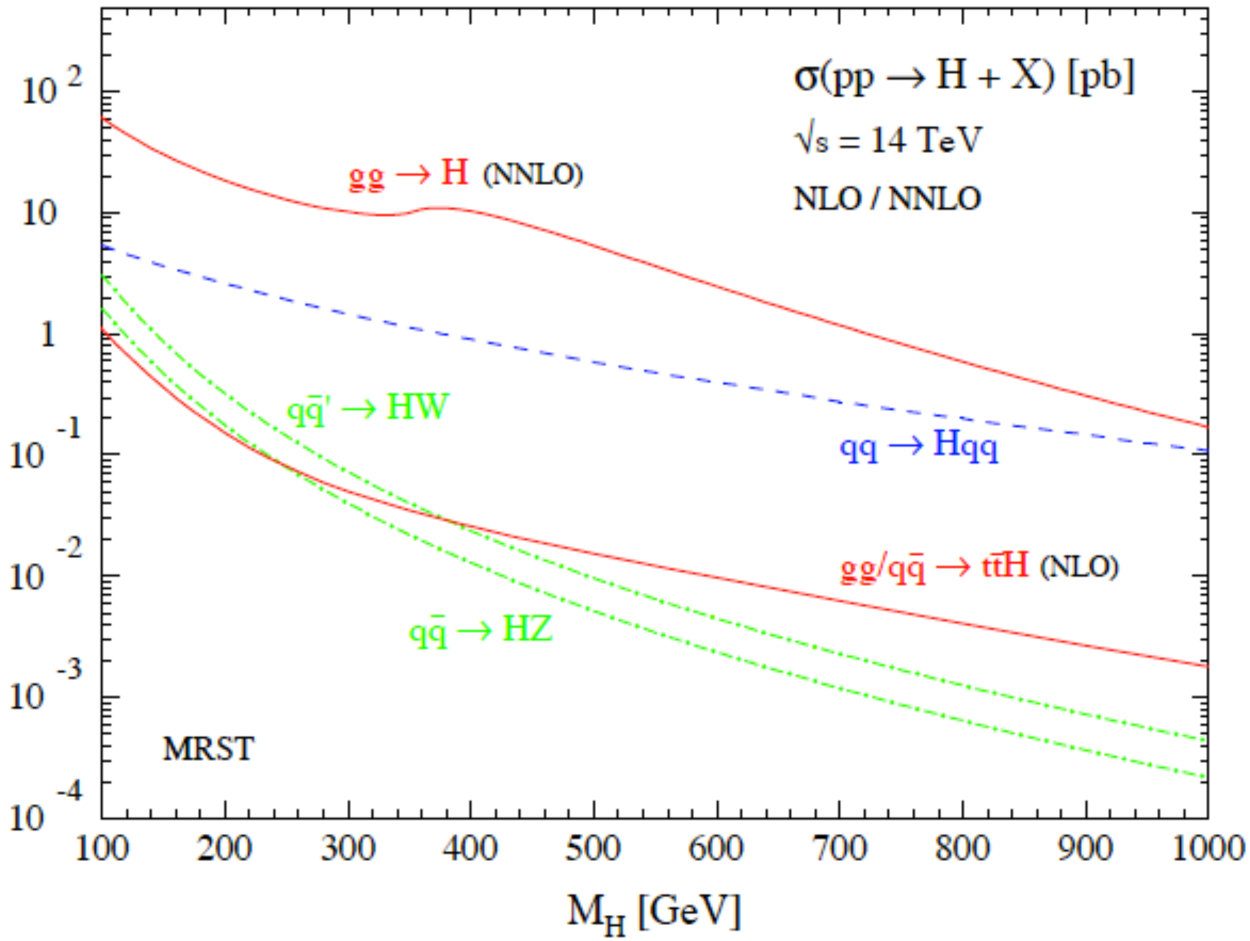
• Inelastic proton-proton reactions:	10^9 / s
• bb pairs	$5\ 10^6$ / s
• tt pairs	8 / s
• $W \rightarrow e\ \nu$	150 / s
• $Z \rightarrow e\ e$	15 / s
• **Higgs (150 GeV)**	**0.2 / s**
• **Gluino, Squarks (1 TeV)**	**0.03 / s**

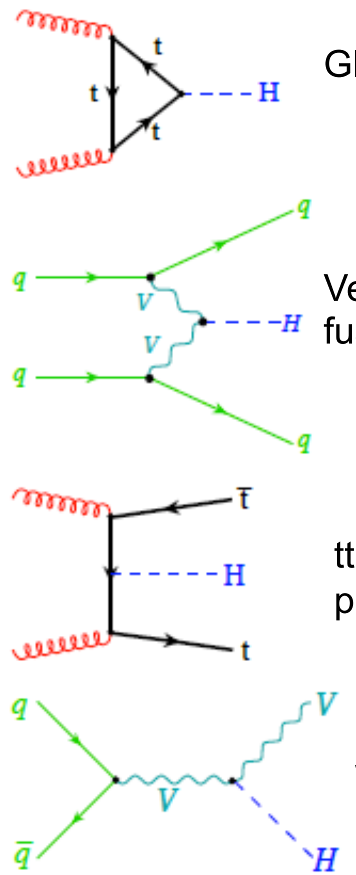
An impressive number of processes has already been measured



- Excellent agreement with the Standard Model predications

Higgs boson production at the LHC





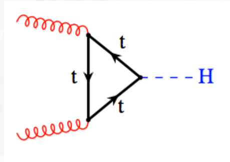
Gluon Fusion

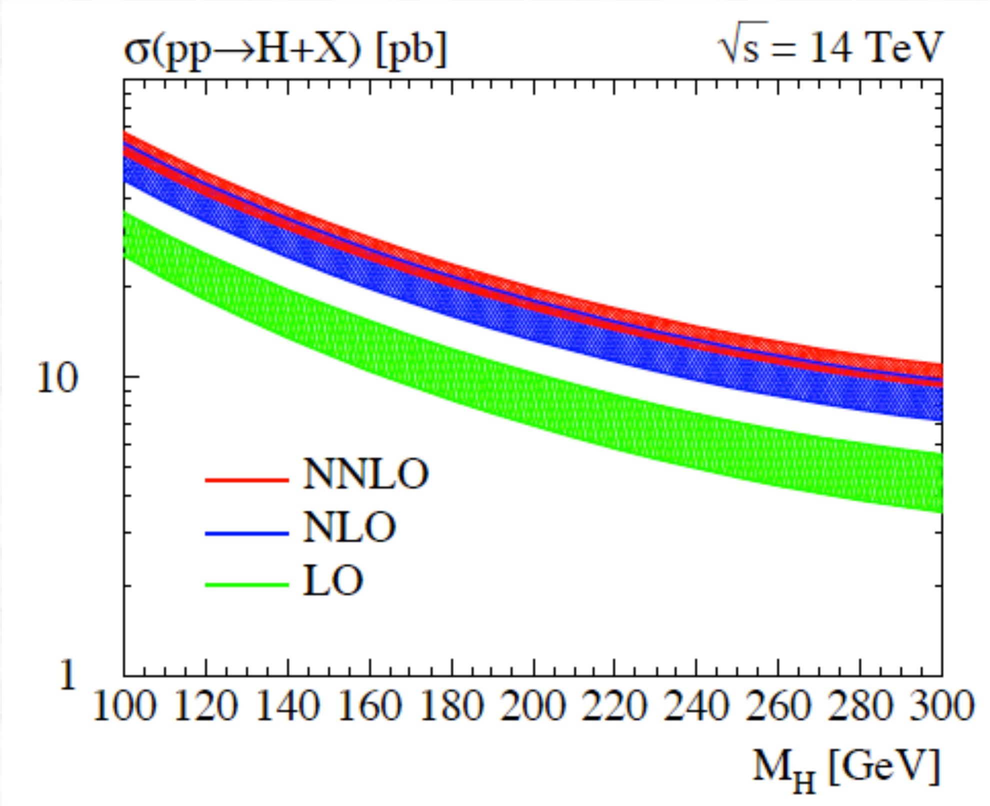
Vector boson fusion

tt associated production

WH/ZH associated production

Higher order corrections:



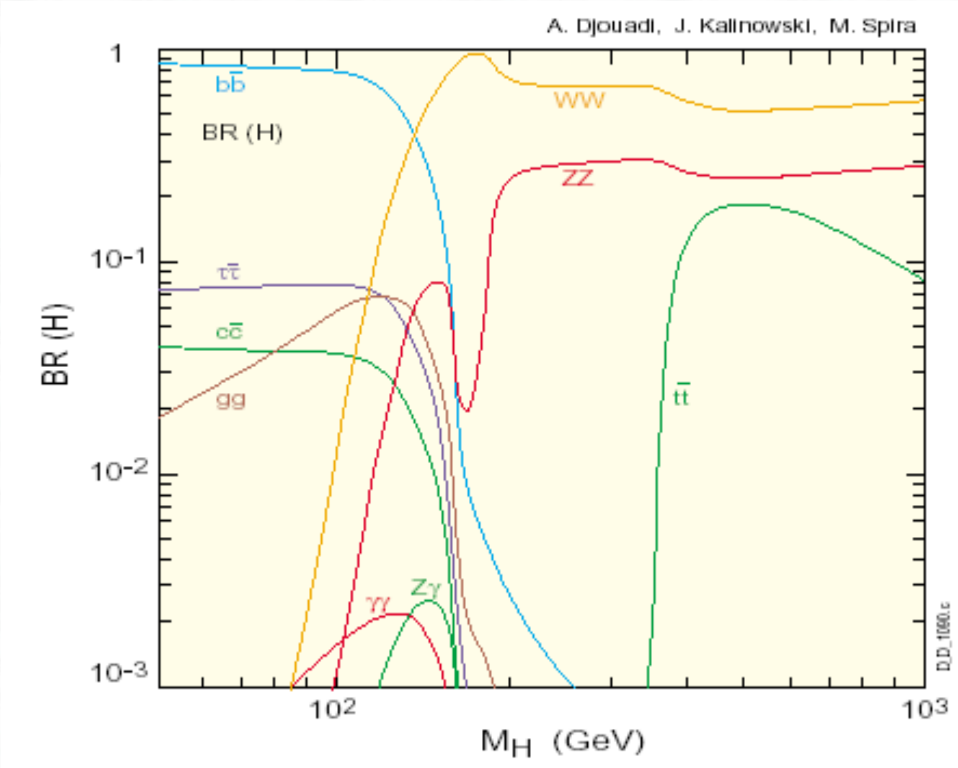


- Spira, Djouadi, Graudenz, Zerwas (1991)
- Dawson (1991)

- Harlander, Kilgore (2002)
- Anastasiou, Melnikov (2002)
- Ravindran, Smith, van Neerven (2003)

Independent variation of renormalization and factorization scales (with $0.5\ m_H < \mu_F, \mu_R < 2\ m_H$)

Useful Higgs Boson Decays at Hadron Colliders



at high mass:
Lepton final states
(via H → WW , ZZ)

at low mass:
Lepton and Photon final states
(via H → WW*, ZZ*)

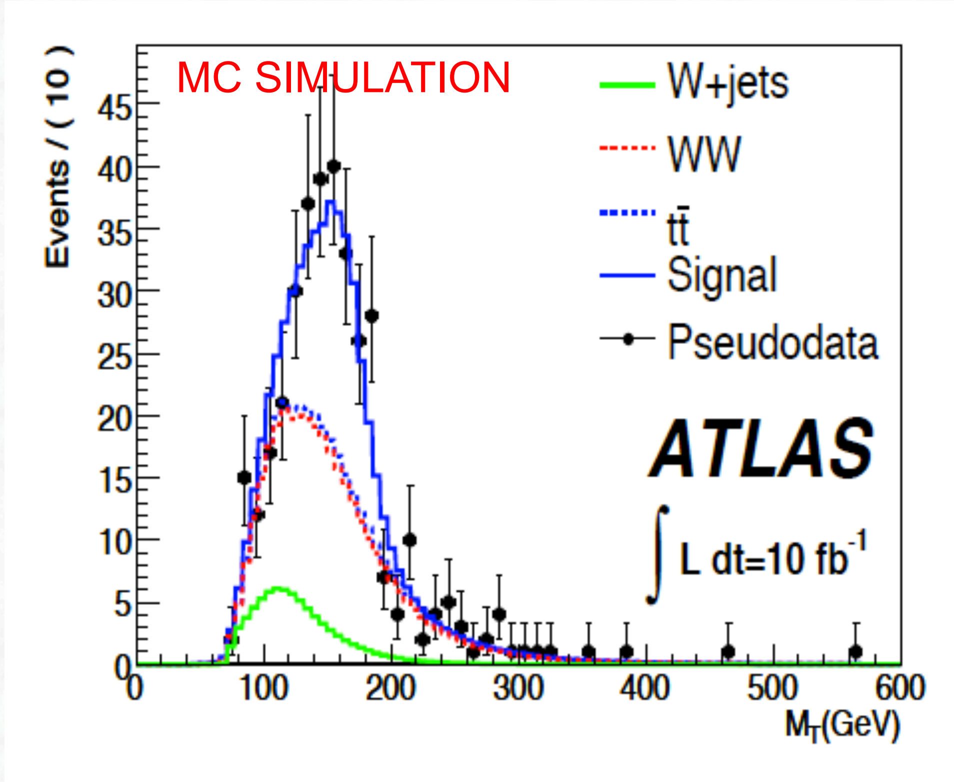
Tau final states

The dominant **bb decay mode** is only useable in the associated production mode (ttH, W/Z H)

(due to the huge QCD jet background, leptons from W/Z or tt decays)

H → WW → ℓν ℓν

- Large H → WW BR for m_H ~ 160 GeV/c^2
- Neutrinos → no mass peak,
  → use transverse mass

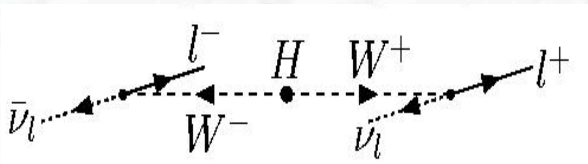


$$m_T = \sqrt{(E_T^{\ell\ell} + E_T^{miss})^2 - (\mathbf{p}_T^{\ell\ell} + \mathbf{p}_T^{miss})^2}$$

- Large backgrounds: WW, Wt, tt

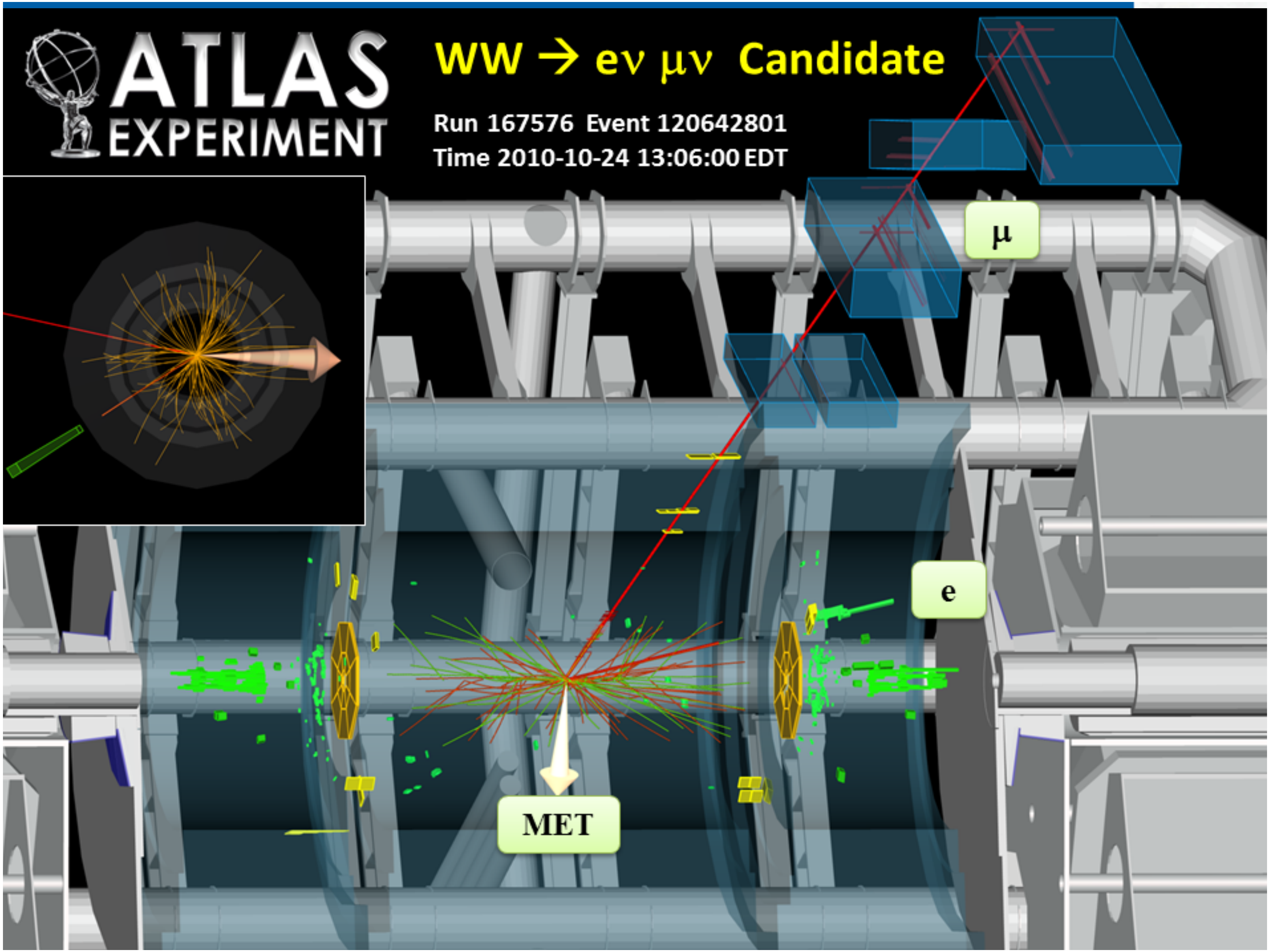
- Two main discriminants:

  (i) Lepton angular correlation



  (ii) Jet veto: no jet activity
  in central detector region

Channel with highest sensitivity !
Sensitive to a Standard Model Higgs boson already now, with 1 fb^{-1} !

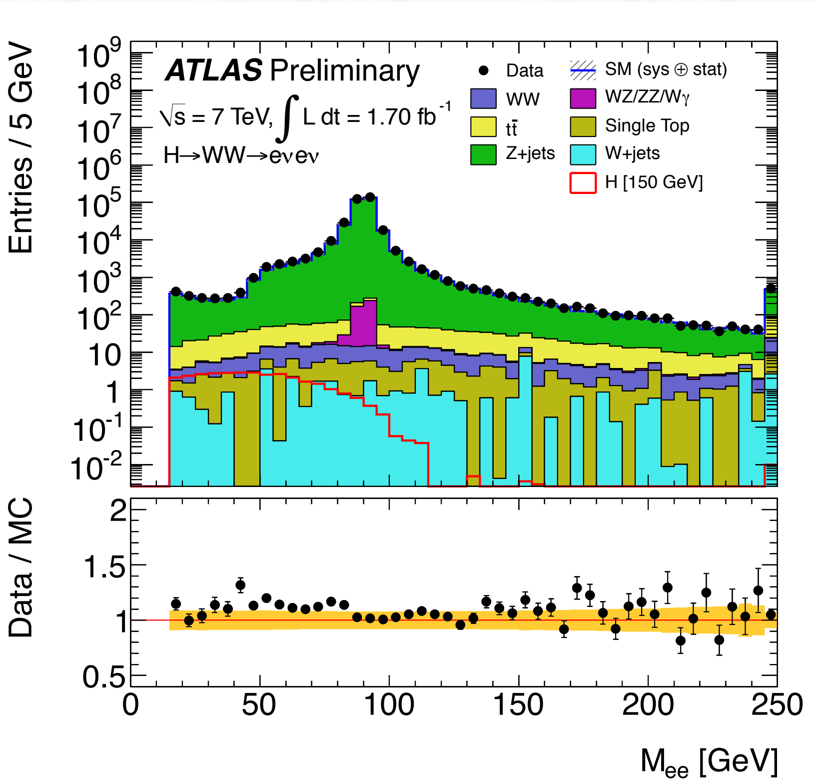

ATLAS EXPERIMENT
WW → eν μν Candidate
Run 167576 Event 120642801
Time 2010-10-24 13:06:00 EDT
μ
e
MET

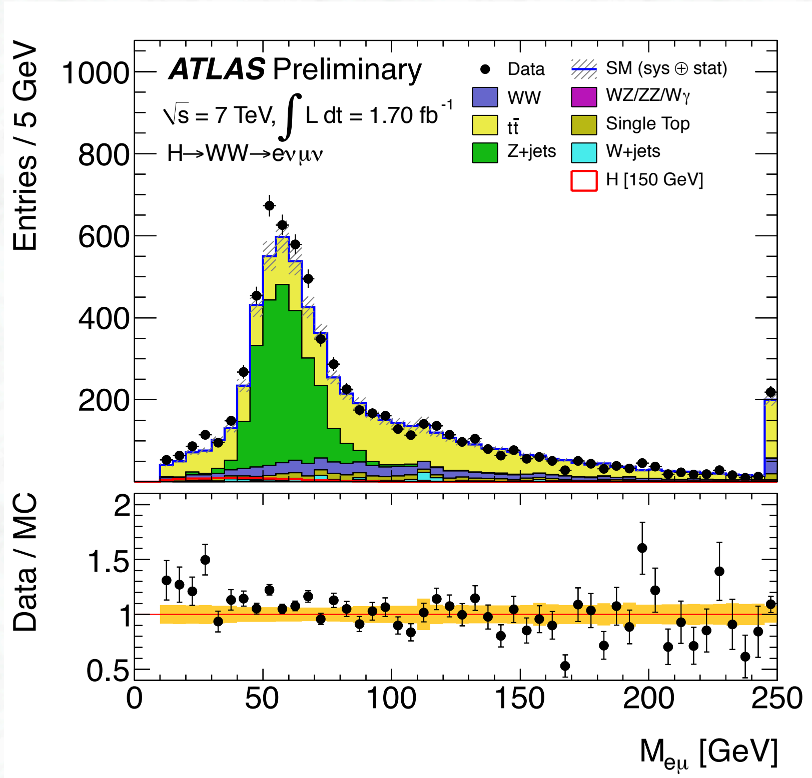
Search for H → WW → lν lν

L_{int} = 1.70 fb^{-1}

- Select events with two opposite sign leptons (e, μ) $p_T(l_1)$ > 25 GeV
  $p_T(l_2)$ > 20 GeV (e), 15 GeV (μ)

- First look at invariant mass distributions → good agreement for all channels



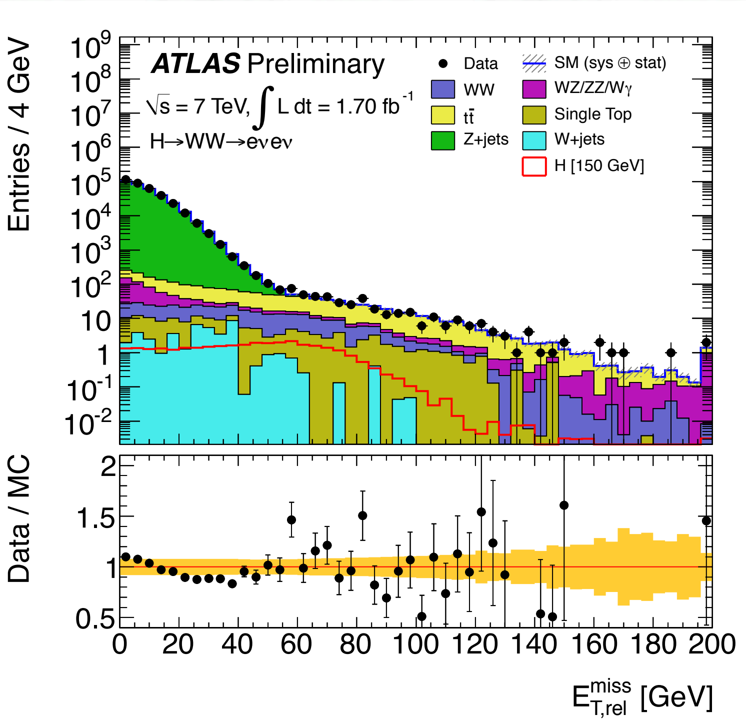


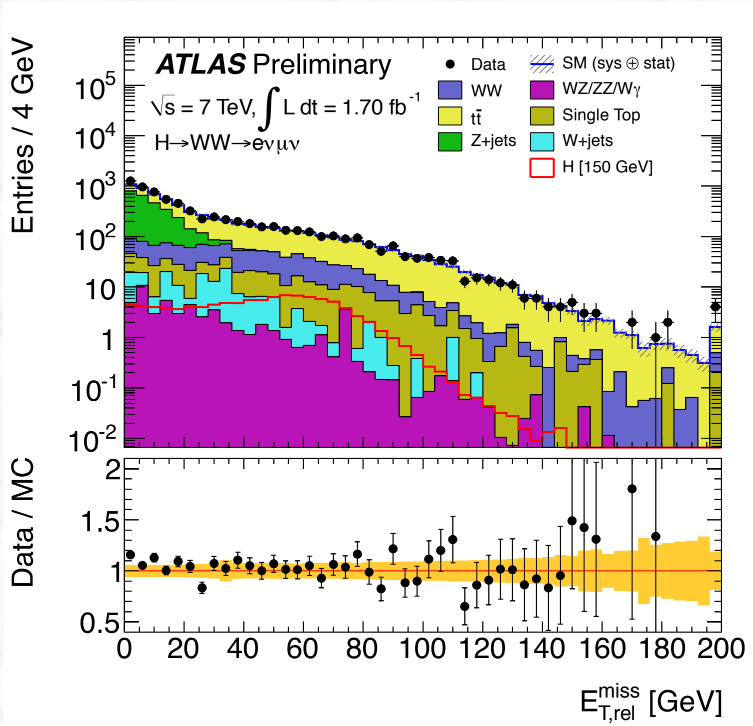
ee, μμ: large Z/γ* production background (Drell-Yan), can be rejected by Z mass veto
eμ : residual contribution from Z→ ττ – eνν μνν and top production

Search for H → WW → lν lν (cont.)

- Additional discrimination: missing transverse energy

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





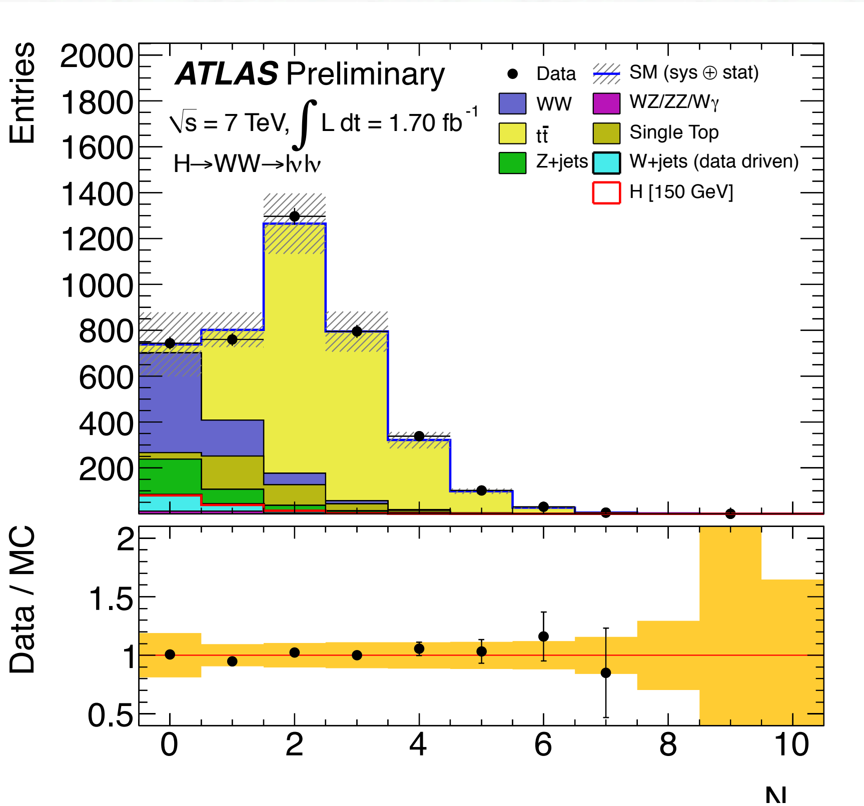
Apply additional cuts on: Z-mass veto (previous slide) $|m_{ll} - m_Z| < 15$ GeV (ee, μμ)

$E_{\mathrm{T,rel}}^{\mathrm{miss}} > 40$ GeV (ee,μμ),

> 25 GeV (eμ)

Search for H → WW → lν lν (cont.)

- Split sample according to jet multiplicity (E_T > 25 GeV)
  (different production modes, different background compositions)



- Jet distribution well described

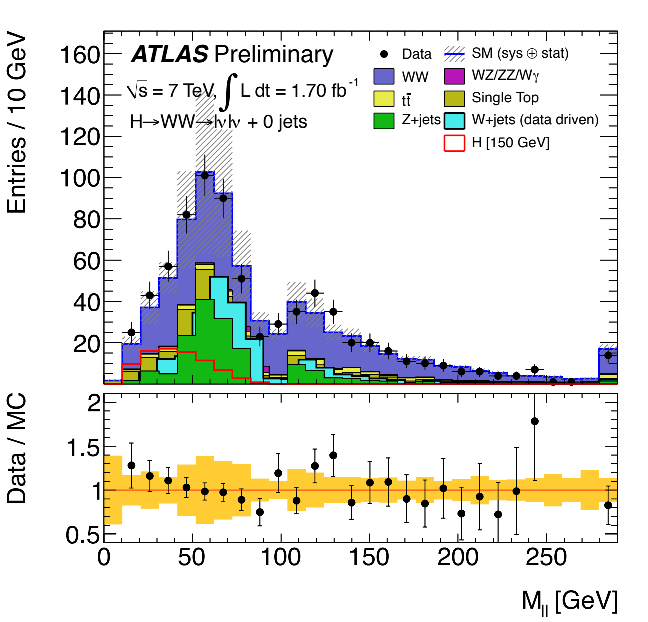
  # observed events: 4051
  # expected background: 4000 ± 500

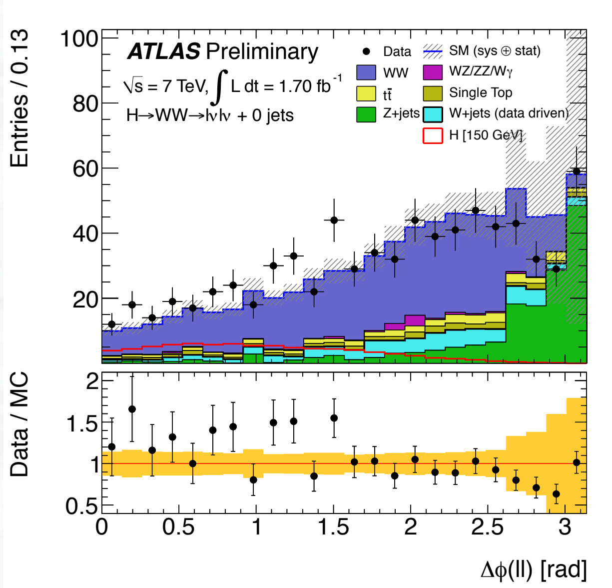
→ Select 0- and 1-jet events

	WW	$Z/\gamma^* +$ jets	$t\bar{t}$	$tW/tb/tqb$	$WZ/ZZ/W\gamma$	Total Bkg.	Observed
$m_{\ell\ell} > 15$ GeV, $m_{e\mu} > 10$ GeV	1380 ± 100	970000 ± 70000	6200 ± 600	630 ± 70	1200 ± 100	970000 ± 70000	997813
$\lvert m_Z - m_{\ell\ell}\rvert > 15$ GeV	1220 ± 80	91000 ± 7000	5500 ± 600	560 ± 60	92 ± 9	98000 ± 7000	104253
$E_{\mathrm{T,rel}}^{\mathrm{miss}}$	660 ± 50	300 ± 200	2700 ± 300	310 ± 40	28 ± 4	4000 ± 500	4051

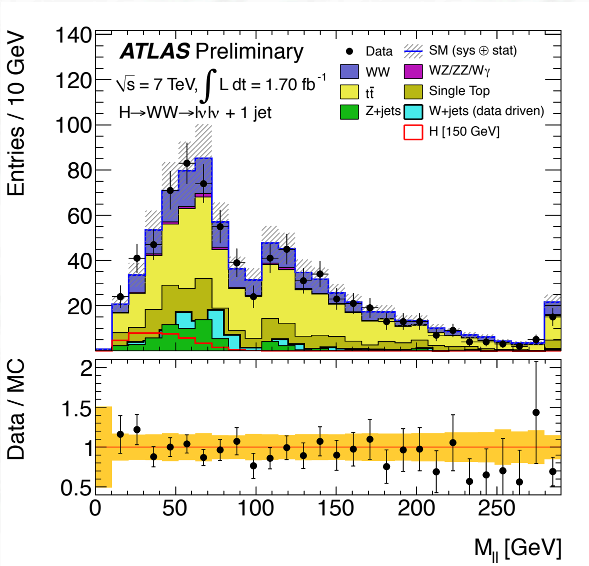
Search for H → WW → lν lν (cont.)

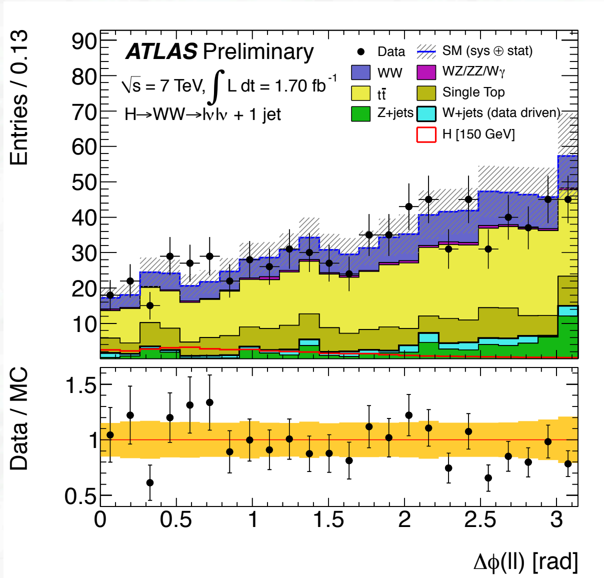
- Further discrimination using m_{ll} and $\Delta\phi$ between the two leptons:





0 jet



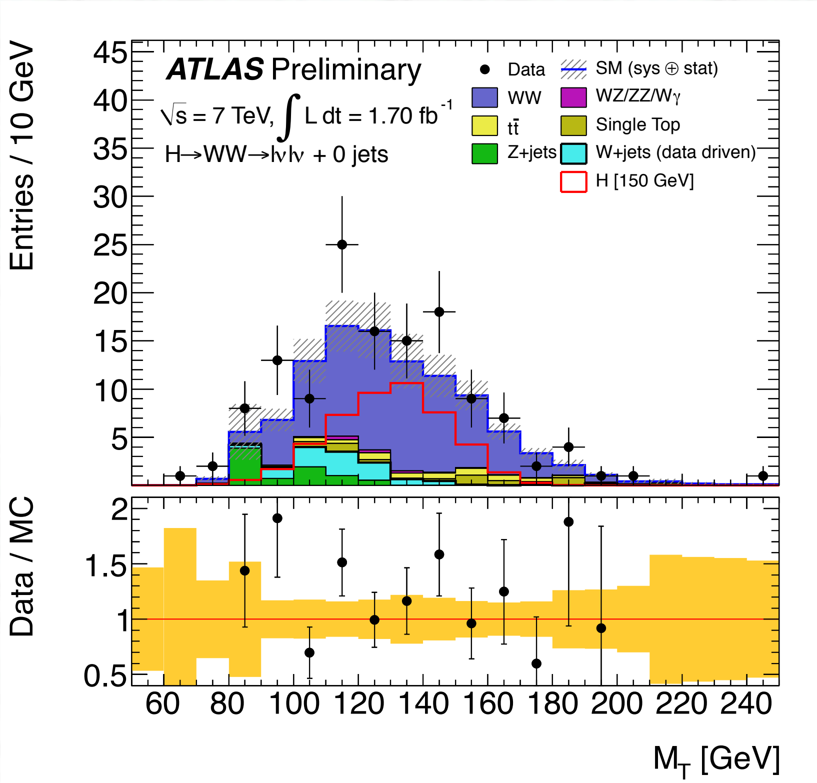


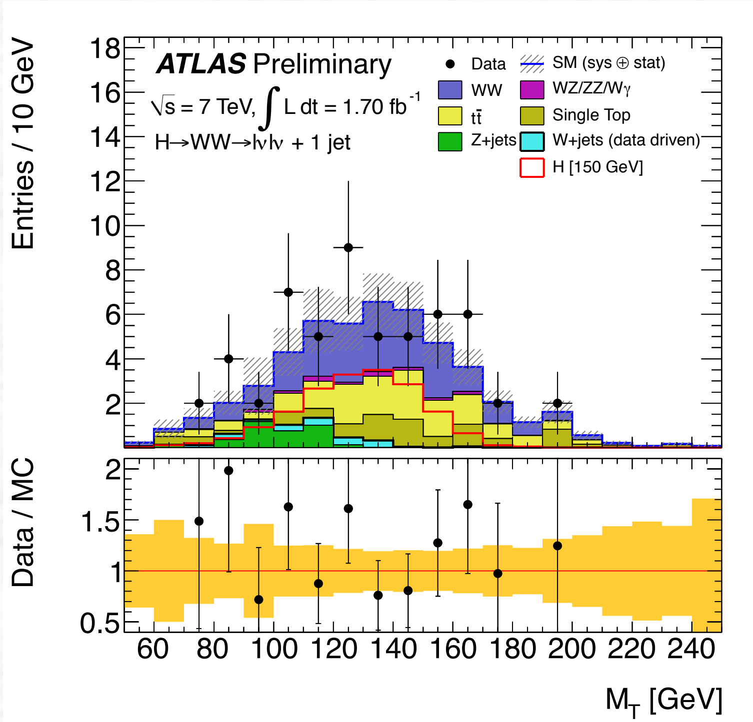
1 jet

Search for H → WW → lν lν (cont.)

Transverse mass distributions:

$$m_T = \sqrt{(E_T^{\ell\ell} + E_T^{miss})^2 - (\mathbf{p}_T^{\ell\ell} + \mathbf{p}_T^{miss})^2}$$

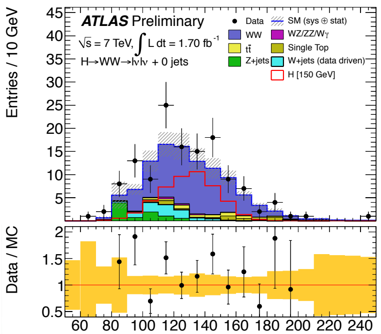




- No evidence for an excess above Standard Model backgrounds
- Use statistical methods to quantify this and extract a limit on the production cross section

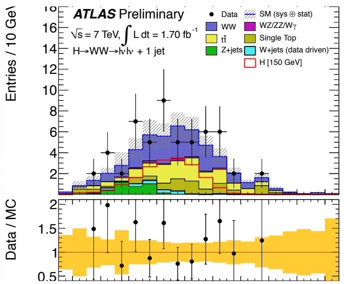
Search for H → WW → lν lν (cont.)

- number of events at various cut stages-



0 jet

	Signal	WW	W + jets	Z/γ^* + jets	$t\bar{t}$	$tW/tb/tqb$	$WZ/ZZ/W\gamma$	Total Bkg.	Observed
Jet Veto	82 ± 17	430 ± 40	70 ± 40	160 ± 150	37 ± 13	28 ± 7	11 ± 3	740 ± 160	738
$\lvert P_T^{\ell\ell}\rvert$ > 30 GeV	79 ± 17	390 ± 40	60 ± 30	28 ± 11	35 ± 12	25 ± 7	10 ± 3	540 ± 80	574
$m_{\ell\ell}$ < 50 GeV	56 ± 12	98 ± 13	17 ± 7	12 ± 7	6 ± 3	4.8 ± 1.5	1.2 ± 0.4	139 ± 20	175
$\Delta\phi_{\ell\ell}$ < 1.3	48 ± 11	76 ± 10	9 ± 4	8 ± 6	5 ± 2	4.8 ± 1.5	1.1 ± 0.3	105 ± 16	131
$0.75\, m_H < m_T < m_H$	34 ± 7	43 ± 6	5 ± 2	2 ± 4	2.2 ± 1.4	1.2 ± 0.8	0.7 ± 0.3	53 ± 9	70
ee	5.2 ± 1.2	6.2 ± 0.9	0.9 ± 0.4	0.8 ± 1.4	0.3 ± 0.3	0 ± 0.3	0.07 ± 0.05	8.2 ± 1.7	9
$e\mu$	17 ± 4	22 ± 3	2.8 ± 1.3	0 ± 1.3	1.1 ± 0.5	0.8 ± 0.6	0.31 ± 0.19	27 ± 4	32
$\mu\mu$	11 ± 2	14 ± 2	1.0 ± 0.6	1 ± 3	0.8 ± 1.1	0.4 ± 0.4	0.31 ± 0.09	18 ± 5	29



1 jet

	Signal	WW	W + jets	Z/γ^* + jets	$t\bar{t}$	$tW/tb/tqb$	$WZ/ZZ/W\gamma$	Total Bkg.	Observed
1 jet	41 ± 7	158 ± 16	31 ± 19	60 ± 60	390 ± 100	140 ± 20	10.7 ± 1.4	800 ± 120	756
b-jet veto	40 ± 7	154 ± 16	29 ± 18	60 ± 50	140 ± 40	54 ± 9	10.6 ± 1.4	450 ± 70	440
P_T^{tot} < 30 GeV	32 ± 6	127 ± 13	16 ± 9	30 ± 30	90 ± 20	41 ± 7	7.0 ± 0.9	310 ± 50	312
$Z \to \tau\tau$ veto	32 ± 6	124 ± 14	14 ± 7	30 ± 20	84 ± 19	39 ± 7	6.8 ± 1.4	300 ± 30	301
$m_{\ell\ell}$ < 50 GeV	22 ± 5	27 ± 5	2.1 ± 1.0	8 ± 6	17 ± 6	9 ± 2	1.5 ± 0.4	64 ± 10	69
$\Delta\phi_{\ell\ell}$ < 1.3	19 ± 4	21 ± 4	1.8 ± 0.9	4 ± 5	14 ± 5	8 ± 2	1.2 ± 0.3	50 ± 9	54
$0.75\, m_H < m_T < m_H$	12 ± 3	10 ± 2	0.8 ± 0.4	1.1 ± 1.8	6.9 ± 1.9	3.4 ± 1.4	0.6 ± 0.3	23 ± 4	23
ee	1.7 ± 0.4	1.4 ± 0.4	0.12 ± 0.06	0.07 ± 0.12	0.6 ± 0.3	0.5 ± 0.3	0.10 ± 0.09	2.8 ± 0.7	5
$e\mu$	6.3 ± 1.5	5.7 ± 1.3	0.5 ± 0.3	0.6 ± 1.0	3.7 ± 1.3	2.0 ± 1.0	0.39 ± 0.20	13 ± 3	11
$\mu\mu$	3.9 ± 0.9	3.3 ± 0.7	0.1 ± 0.2	0.5 ± 0.5	2.6 ± 1.5	1.0 ± 0.9	0.08 ± 0.06	8 ± 2	7

How are the backgrounds normalized?

- Most important backgrounds are WW continuum production and tt production

  Both are well described by the Standard Model calculations / Monte Carlos

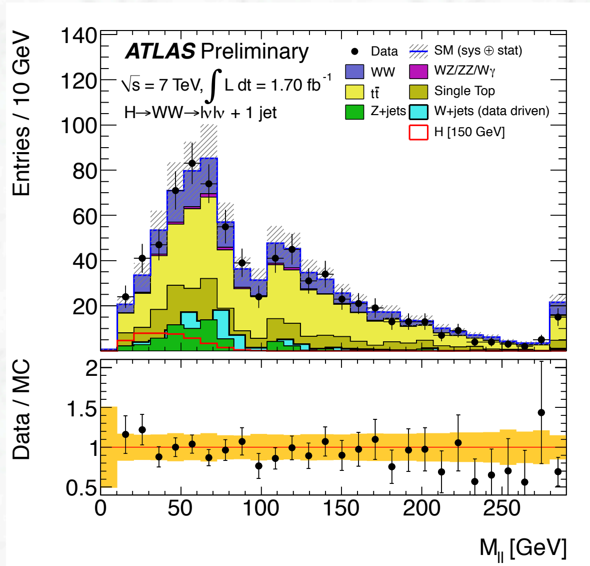
- Cross-check / normalization is performed in defined control regions

  * WW control region:
  remove cuts on $\Delta\phi$ cut and require:

  m_{ll} > 80 GeV/c^2 ($e\mu$)
  m_{ll} > m_Z + 15 GeV/c^2 ($ee,\mu\mu$)

  * tt control region via b-tag selections

  * Z+jets / Drell-Yan (suffers from E_T^{miss} / lepton mismodelling)



Number of events in WW control region

	Signal	WW	W + jets	Z/γ^* + jets	$t\bar{t}$	$tW/tb/tqb$	$WZ/ZZ/W\gamma$	Total Bkg.	Observed
$ee + e\mu + \mu\mu$	1.4 ± 0.3	190 ± 20	18 ± 15	5 ± 7	22 ± 9	13 ± 4	7 ± 3	250 ± 50	238
ee	0.020 ± 0.011	22 ± 3	3 ± 3	1 ± 5	3.8 ± 1.9	1.1 ± 1.0	0.29 ± 0.09	30 ± 6	45
$e\mu$	1.4 ± 0.3	126 ± 17	14 ± 10	0.9 ± 0.7	13 ± 6	8 ± 2	5 ± 3	170 ± 40	150
$\mu\mu$	0.030 ± 0.012	38 ± 5	1.6 ± 1.5	4 ± 3	5 ± 2	4.0 ± 1.4	1.1 ± 0.3	53 ± 8	43

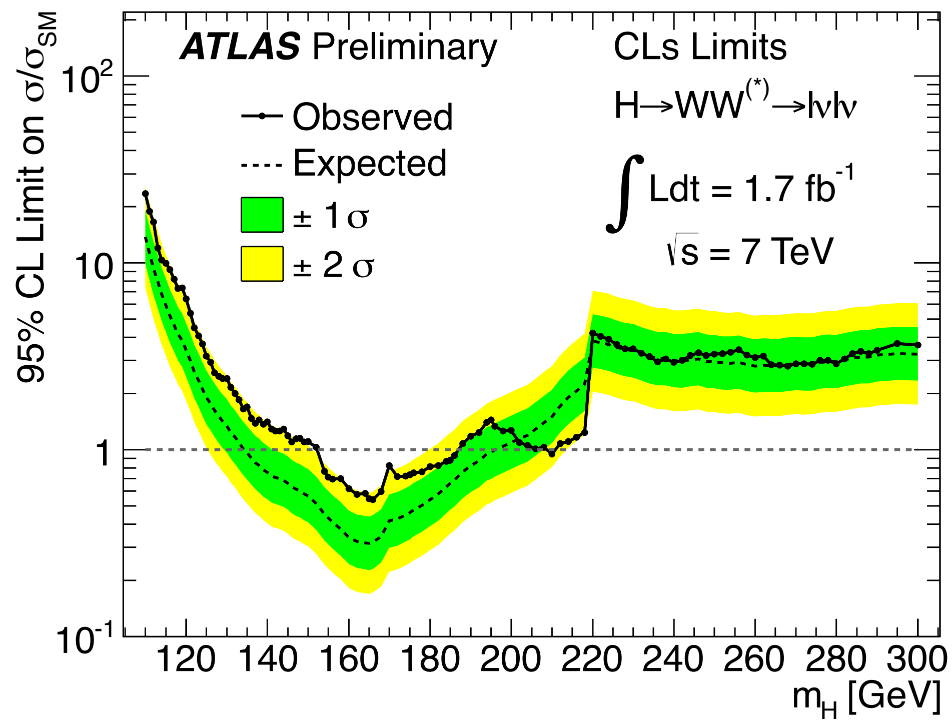
Systematic uncertainties

Table 2: Experimental sources of systematic uncertainty per object or event.

Source of Uncertainty	Treatment in the analysis
Jet Energy Resolution (JER)	$\sim$ 14%, see Ref. [69]
Jet Energy Scale (JES)	Takes into account close-by jets effect, jet flavor composition uncertainty
	and event pile-up uncertainty in addition to global JES uncertainty
	Global JES < 10% for $p_{\mathrm{T}} > 15$ GeV and $\lvert\eta\rvert < 4.5$, see Ref. [70]
	Pile-up uncertainty 2-5% for $\lvert\eta\rvert < 2.1$ and 3-7% for $2.1 < \lvert\eta\rvert < 4.5$
	These are summed in quadrature before application.
Electron Selection Efficiency	Separate systematics for electron identification,
	reconstruction and isolation, added in quadrature
	Total uncertainty of 2-5% depending on η and E_T
Electron Energy Scale	Uncertainty smaller than 1%, depending on η and E_T
Electron Energy Resolution	Energy varied within its uncertainty, 0.6% of the energy at most
Muon Selection Efficiency	0.3-1% as a function of η and p_{T}
Muon Momentum Scale	η dependent scale offset in p_{T}, up to $\sim$ 0.13%
Muon Momentum Resolution	p_{T} and η dependent resolution smearing functions, $\leq 5\%$
b-tagging Efficiency	p_{T} dependent scale factor uncertainties, 5.6-15%, see Ref. [68]
b-tagging Mis-tag Rate	up to 21% as a function of p_{T}, see Ref. [68]
Missing Transverse Energy	13.2% uncertainty on topological cluster energy
	Electron and muon p_{T} changes from smearing propagated to MET
	Effect of out-of-time pileup: MET smeared by 5 GeV in 1/3 of MC events
Luminosity	3.7% [25]

Sensitivity and exclusion

- Calculate cross sections that can be excluded with a 95% C.L. = σ_{95}
- Normalize them to the Standard Model cross sections for a given Higgs mass



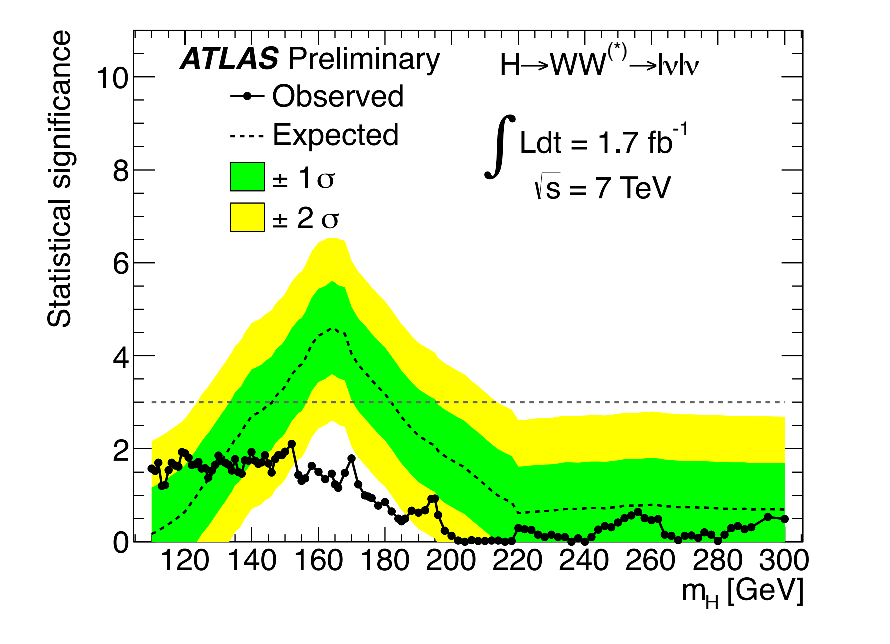
Excluded mass regions (95% C.L.):

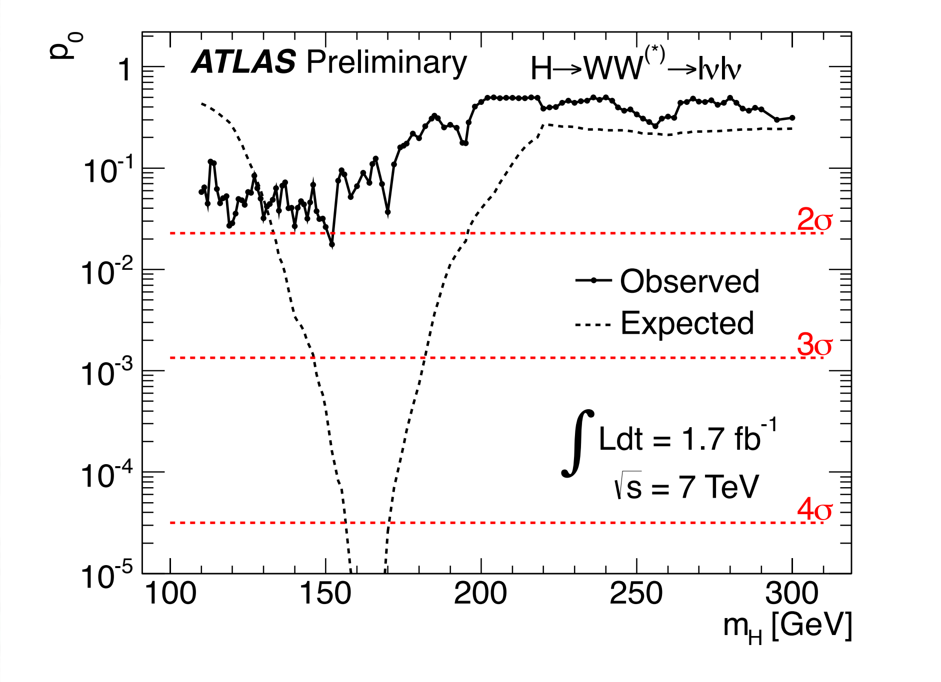
$154 < m_H < 186$ GeV

Expected exclusion:
$135 < m_H < 196$ GeV

- The observed limits at neighboring mass points are highly correlated due to the limited mass resolution in this final state;
- Jump in the expected and observed limits at 220 GeV is caused by a change in the selection at that point

Significance for H → WW

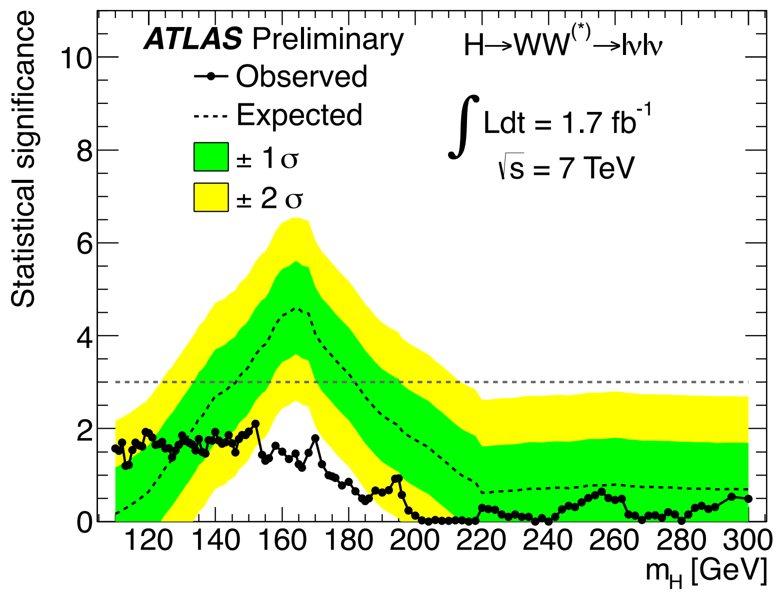


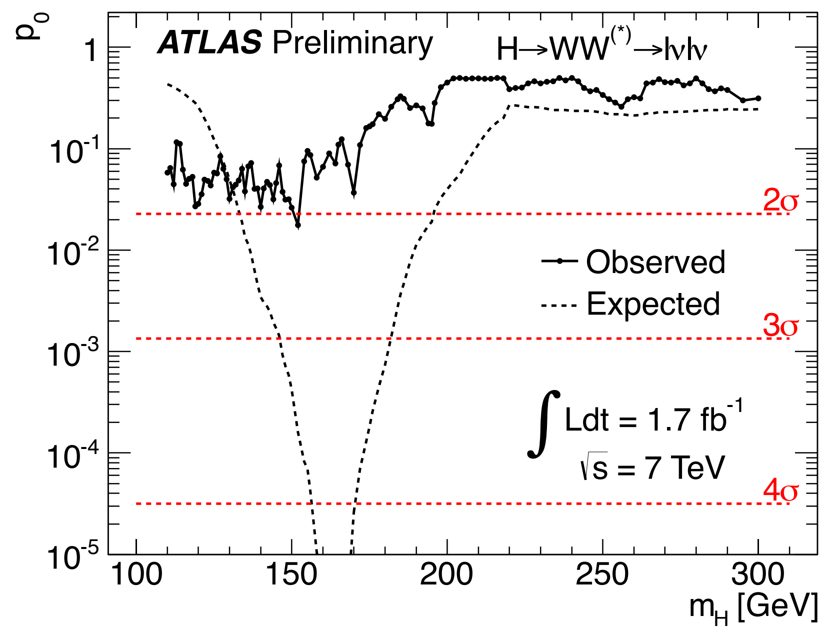


The expected (dashed) and observed (solid) signal significances

The expected (dashed) and observed (solid) probabilities for the background-only scenario, P_0

Significance for H → WW





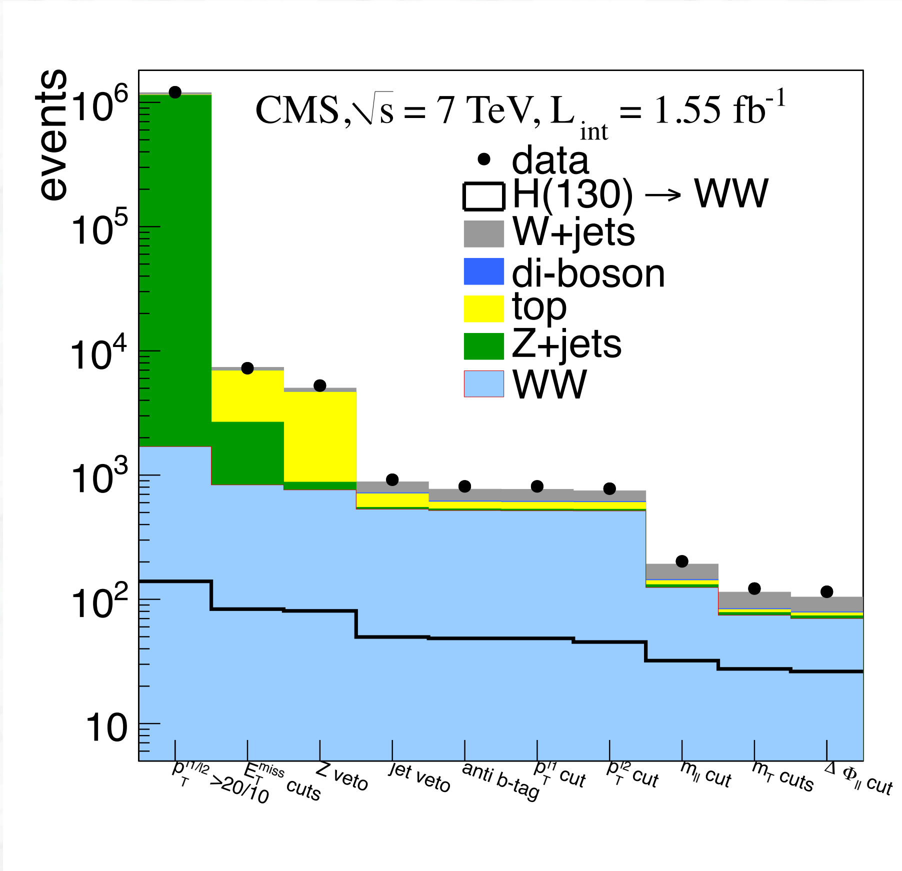
The expected (dashed) and observed (solid) signal significances

The expected (dashed) and observed (solid) probabilities for the background-only scenario, P_0

What does the CMS experiment see ?

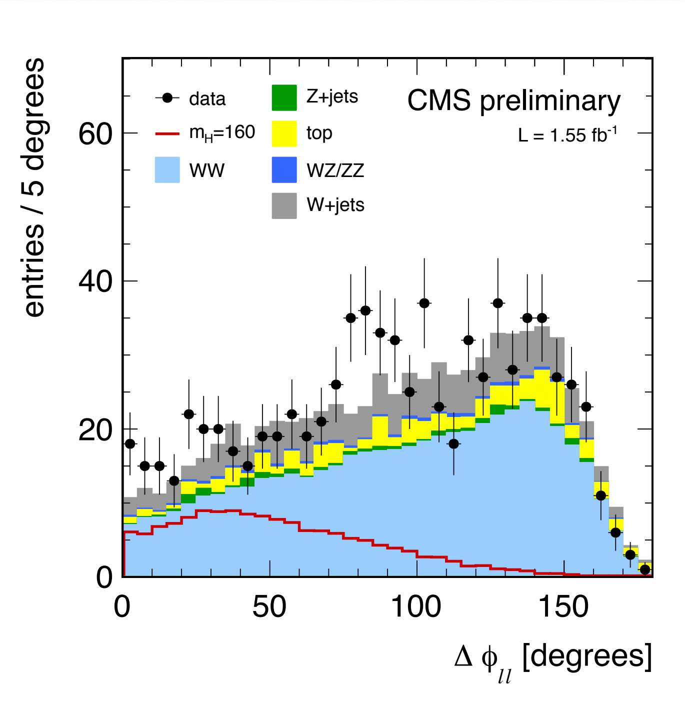
$L_{int} = 1.55\ fb^{-1}$

- A very similar analysis
- Good agreement between data and expectations from Standard Model processes without a Higgs boson

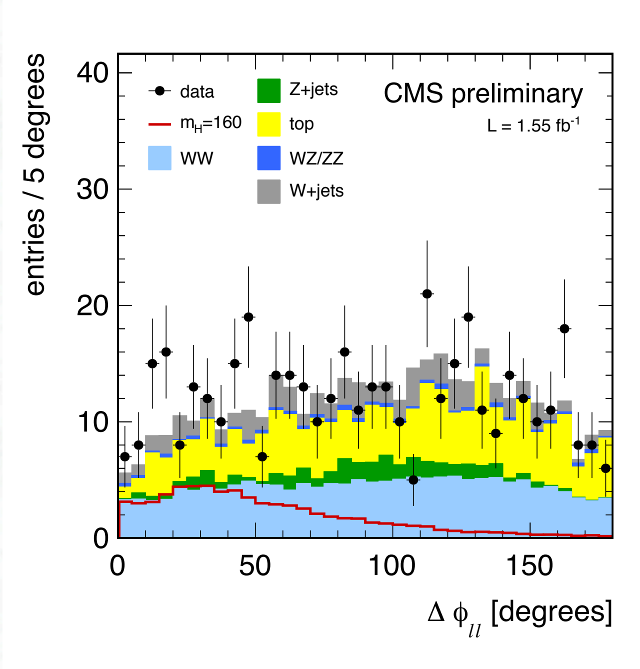


Results from CMS on the H → WW → ℓν ℓν search:

L = 1.55 fb^{-1} (large fraction of 2011 data)



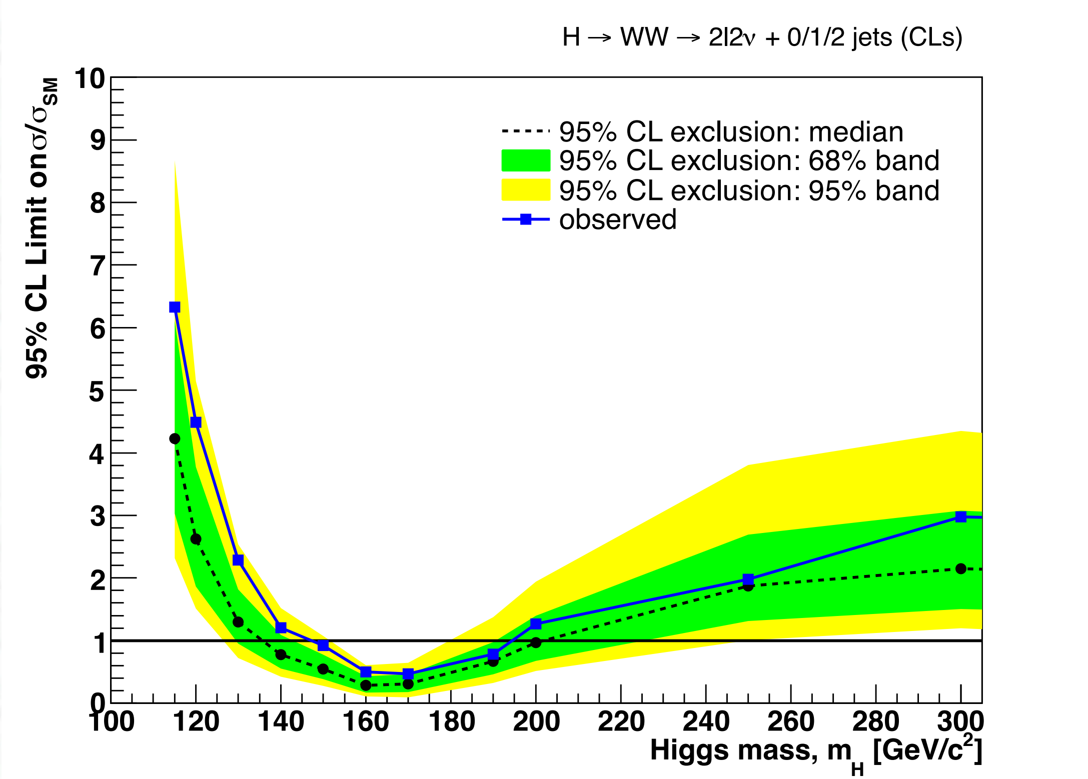
ll + E_T^{miss} + 0 jets



ll + E_T^{miss} + 1 jet

- Data are in “reasonable” agreement with expectations from Standard Model processes;
- Important background normalized using control regions in data (like ATLAS)

CMS sensitivity and exclusion



Excluded mass regions (95% C.L.):

$147 < m_H < 194$ GeV

Expected exclusion:
$135 < m_H < 200$ GeV

- Very similar results as the ATLAS collaboration:

  Similar sensitivity, similar excluded mass range, 2σ like excess at low mass

What can be the cause of this excess?

- $H \rightarrow WW$ is a "difficult" channel !

  - no resonant structure / mass reconstruction not possible

- Excess can be due to:

  - First indications of a signal ?

  - A statistical fluctuation ?

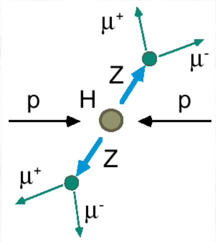
  - systematic uncertainties in modelling of the Standard Model backgrounds (low mass)
    correlated systematic uncertainties between the two experiments, since they use the same Monte Carlo generators

- More data needed to perform many more systematic checks

- Support from other channels needed, e.g. $H \rightarrow ZZ^*$ or $H \rightarrow \gamma\gamma$

$H \to ZZ^{(*)} \to \ell\ell\ell\ell$

Signal: σ BR = 5.7 fb (m_H = 100 GeV)



$P_T(1,2) > 20$ GeV
$P_T(3,4) > 7$ GeV
$|\eta| < 2.5$
Isolated leptons

$M(\ell\ell) \sim M_Z$
$M(\ell'\ell') \sim < M_Z$

Background: Top production

$tt \to Wb\ Wb \to \ell\nu\ c\ell\nu\ \ell\nu\ c\ell\nu$

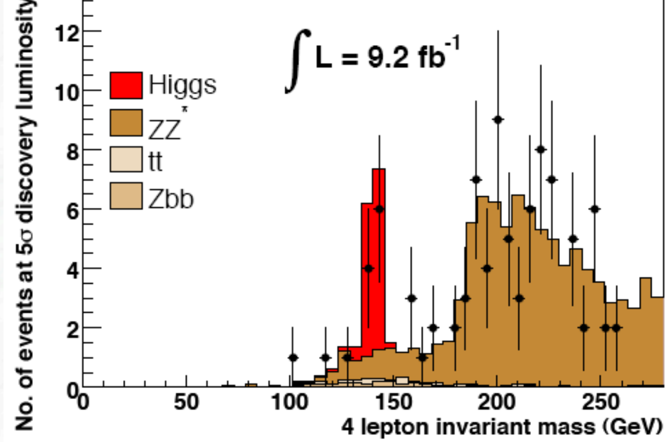
σ BR ≈ 1300 fb

Associated production Z bb

$Z\ bb \to \ell\ell\ c\ell\nu\ c\ell\nu$

Background rejection:
Leptons from b-quark decays
→ non isolated
→ do not originate from primary vertex
(B-meson lifetime: ~ 1.5 ps)

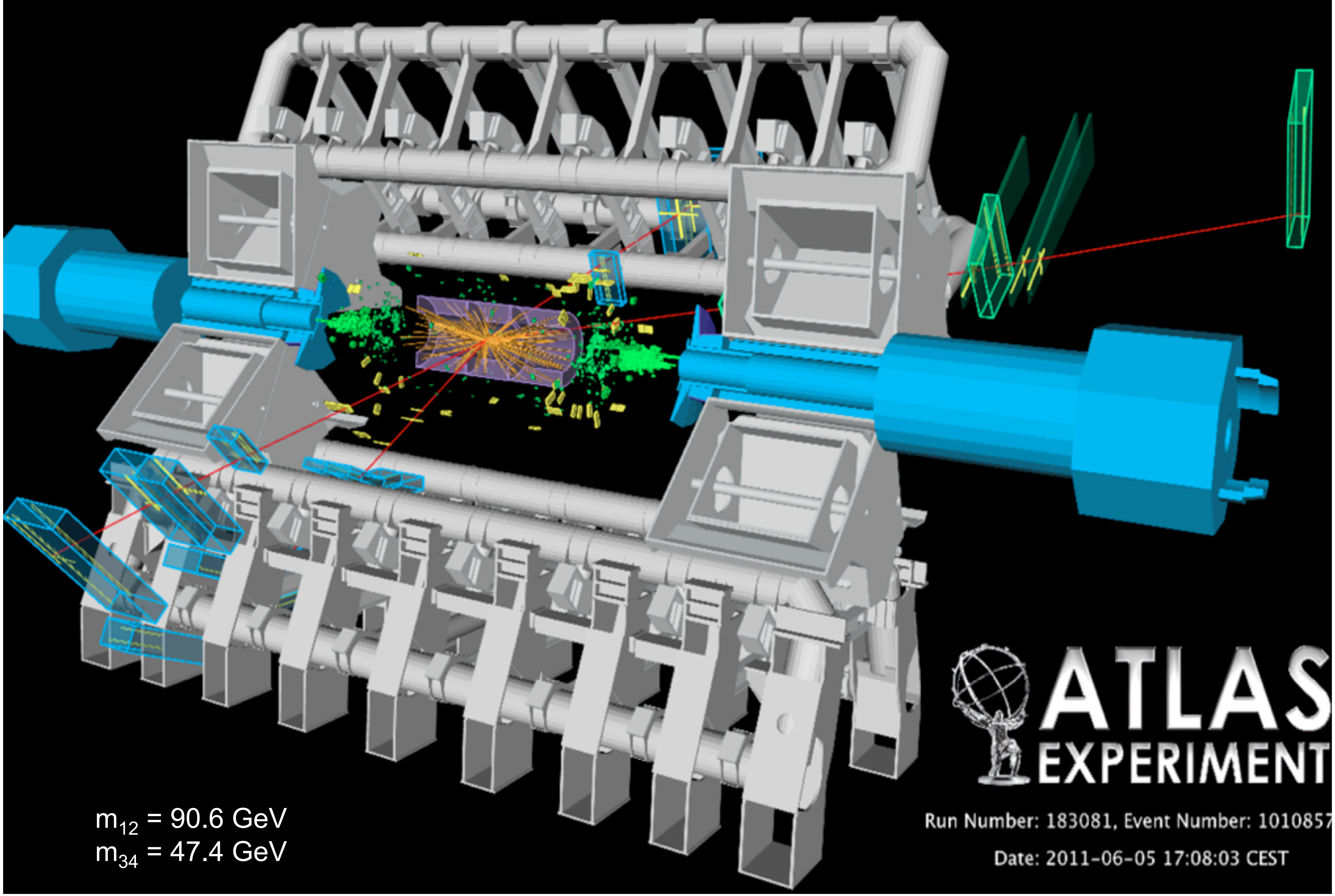
MC SIMULATION



Dominant background after isolation cuts: ZZ continuum

Discovery potential in mass range from ~130 to ~600 GeV/c^2

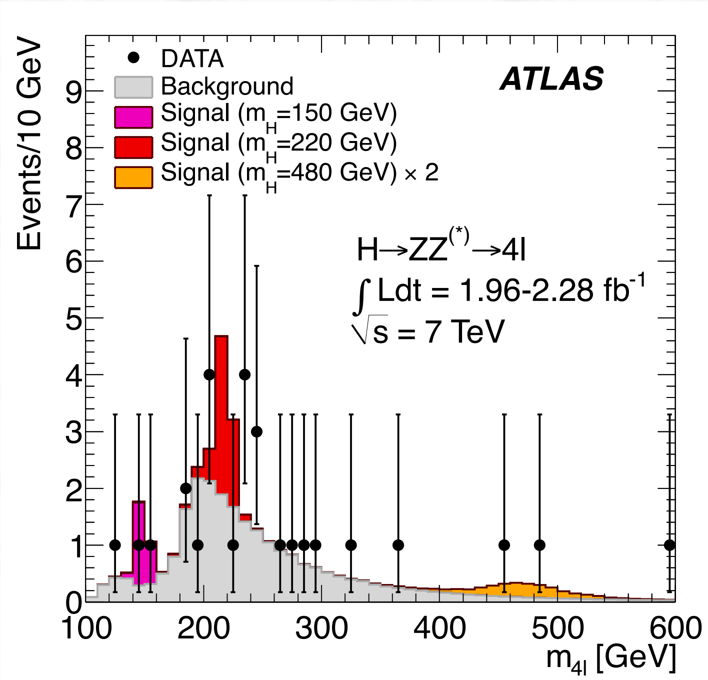
$H \rightarrow ZZ^{(*)} \rightarrow \mu\mu\ \mu\mu$ candidate event

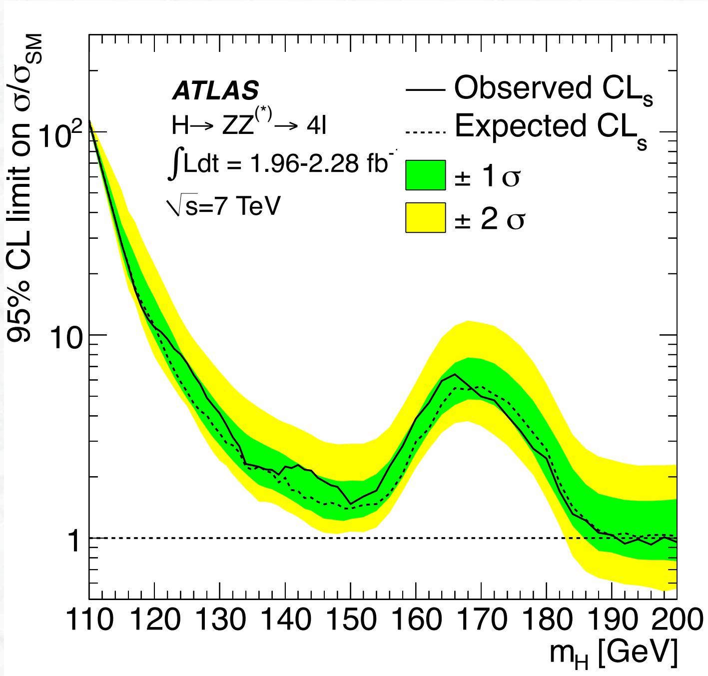


ATLAS results on H → ZZ* → 4 l searches

- Data corresponding to 2.28 fb^{-1} (taken up to August 2011) included
- No excess above Standard Model expectations visible

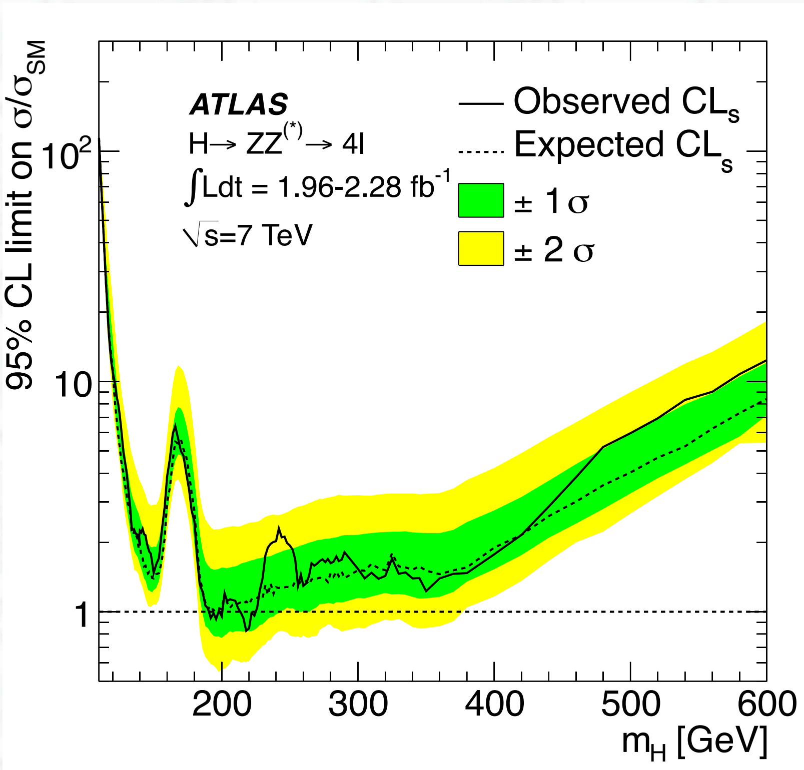
L_{int} = 1.96 - 2.28 fb^{-1}

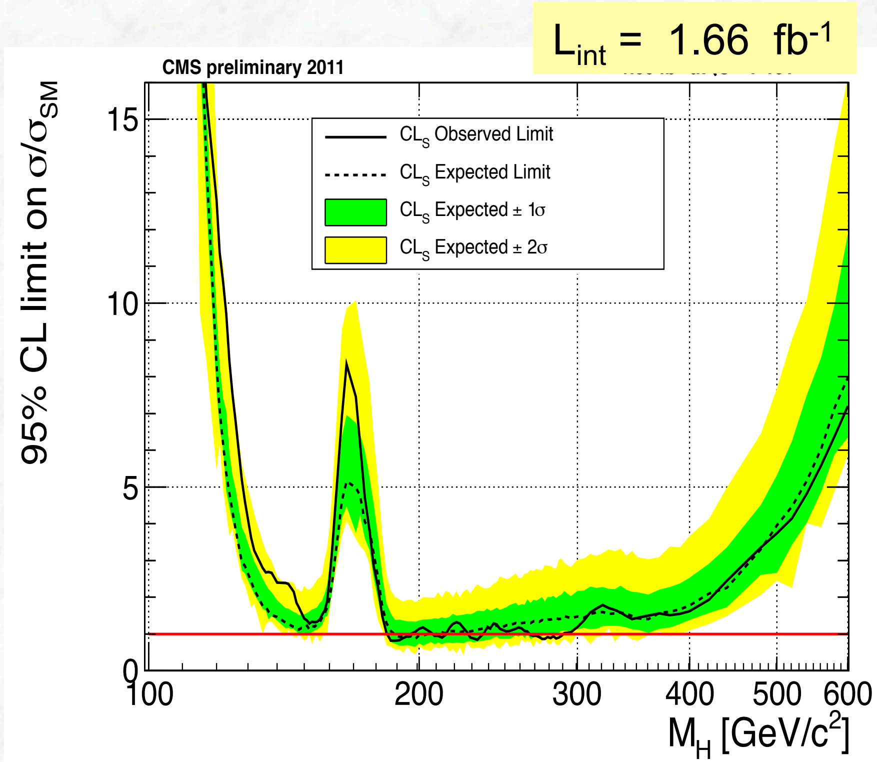




- Rare decay → still limited by the available integrated luminosity
- Challenging for m_H < 130 GeV, requires low p_T leptons
- However, Standard Model sensitivity already reached at high mass

ATLAS and CMS results for H → ZZ* → 4 l over the full mass range

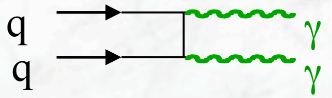




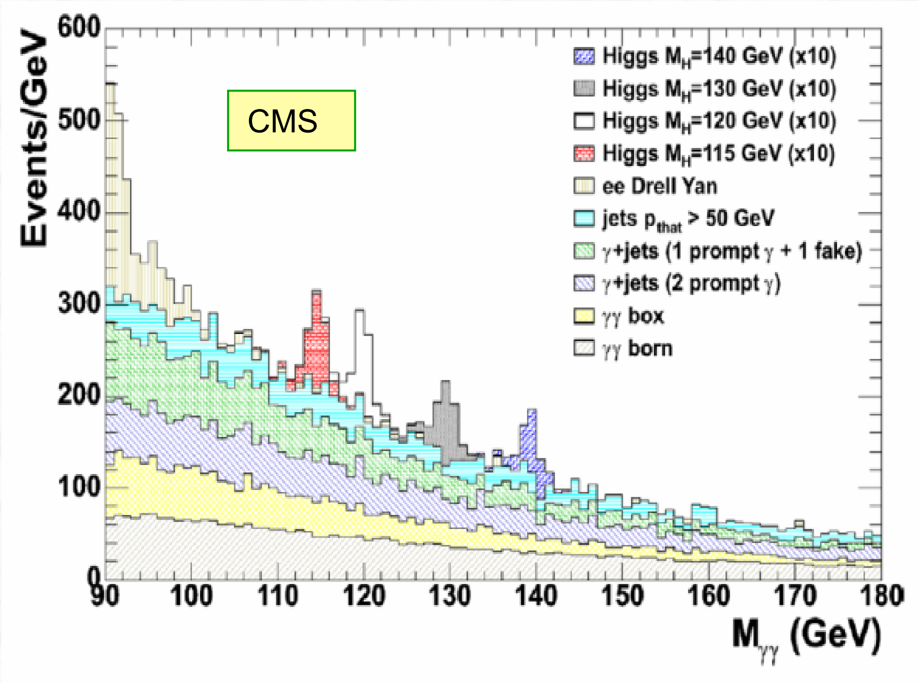
Decay modes at low mass: $H \rightarrow \gamma\gamma$

Main backgrounds:

$\gamma\gamma$ irreducible background

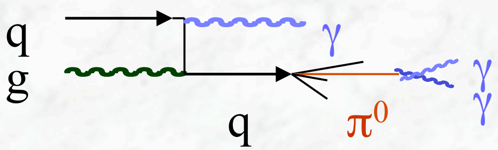


MC SIMULATION



Signal expectation x 10, for 1 fb^{-1}

γ-jet and jet-jet (reducible)



$\sigma_{\gamma j+jj} \sim 10^6\ \sigma_{\gamma\gamma}$ with large uncertainties

$\rightarrow$ need $R_j > 10^3$ for $\varepsilon_\gamma \approx 80\%$ to get

$\sigma_{\gamma j+jj} \ll \sigma_{\gamma\gamma}$

- Main exp. tools for background suppression:
  - photon identification
  - γ / jet separation (calorimeter + tracker)

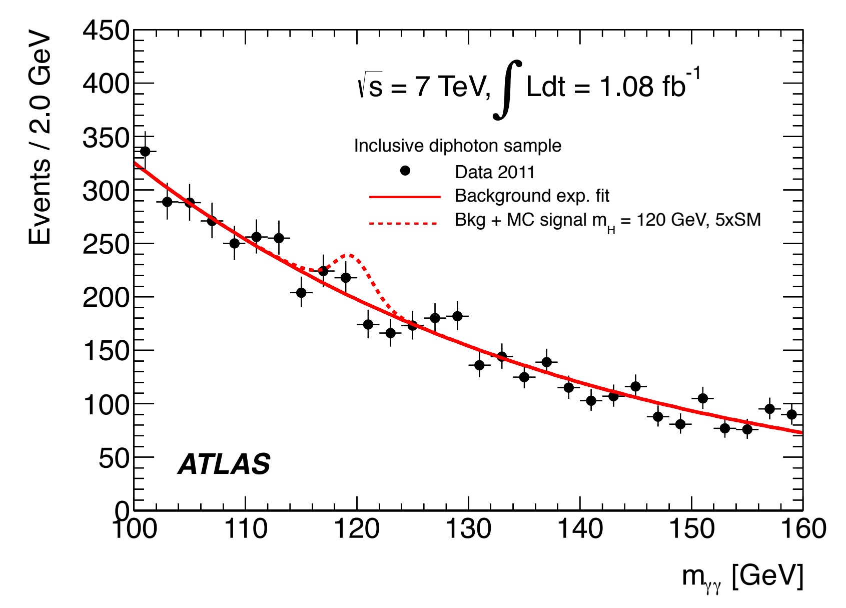
Sensitivity in the low mass region, however,
higher integrated luminosities required

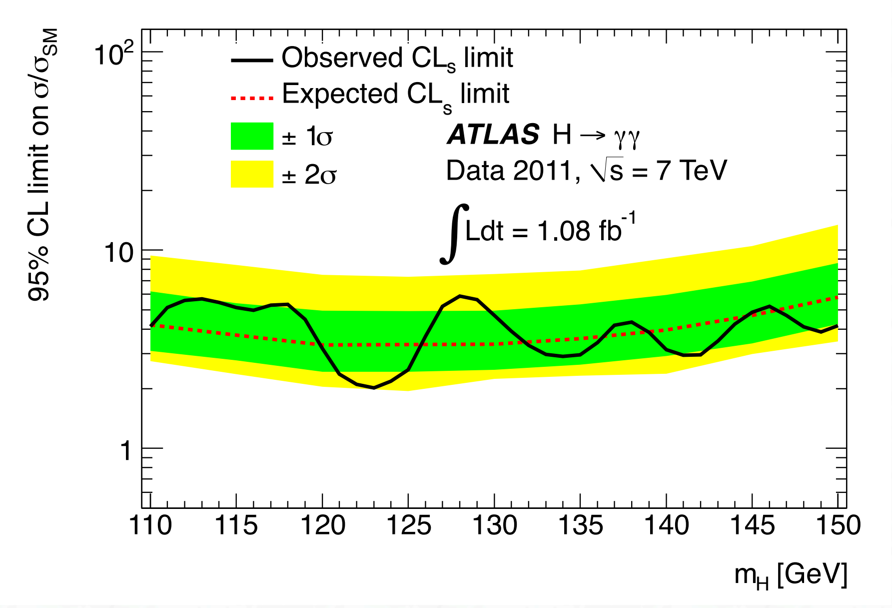
ATLAS results on H → γγ searches

- Data corresponding to 1.08 fb^{-1} analyzed, more to come soon…

L_{int} = 1.08 fb^{-1}

- Sensitivity to Standard Model Higgs boson cross section not yet reached, as expected



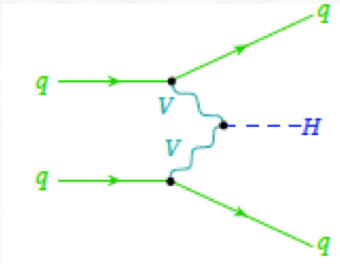


- Sensitivity is stable / flat in the low mass region, access to the 115 GeV region;
- Channel is less sensitive to pile-up

More channels at low mass ?

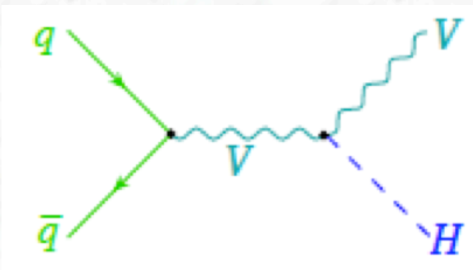
With higher integrated luminosities more channels are expected to contribute:

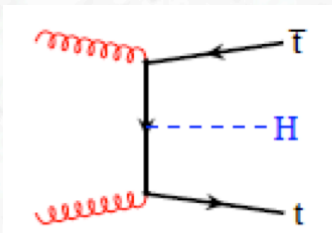
(i) Tau decay mode via Vector Boson Fusion: qq H → qq τ τ (challenging)



(ii) bb decay mode via the associated production with vector bosons or top quarks:

WH, ZH or ttH with H → bb (very challenging)





Higgs boson search at high mass ?

- Search at high mass is easier at the LHC;

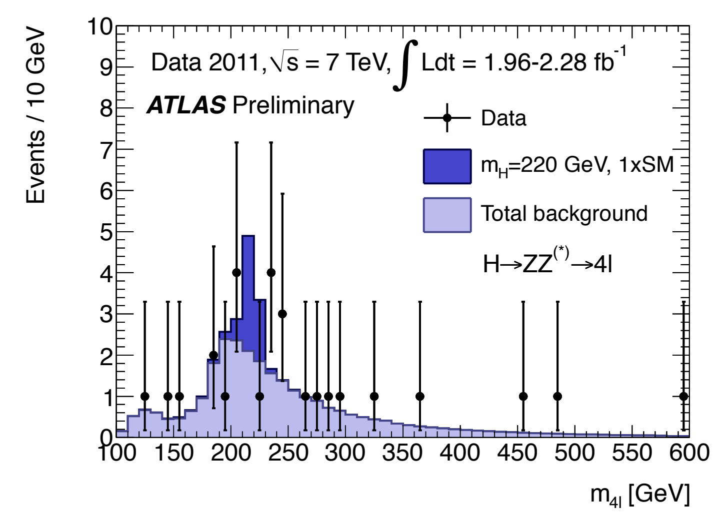
- Higgs boson decays nearly 100% into WW or ZZ pairs, which give charged leptons, neutrinos, b-jets,…

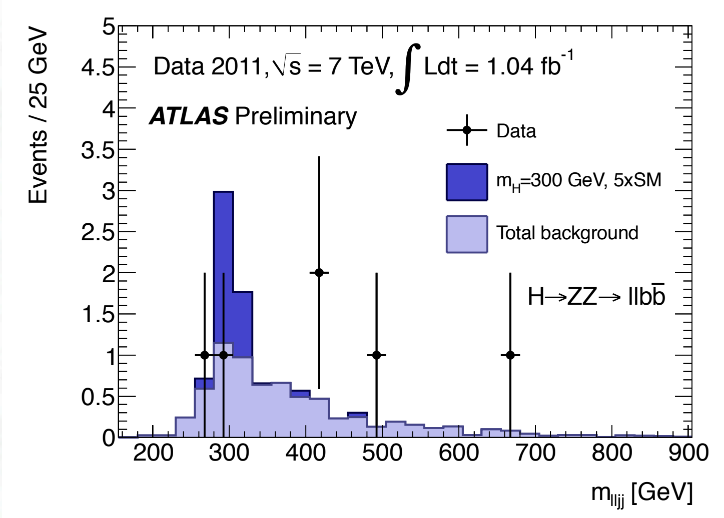
- Important search channels:

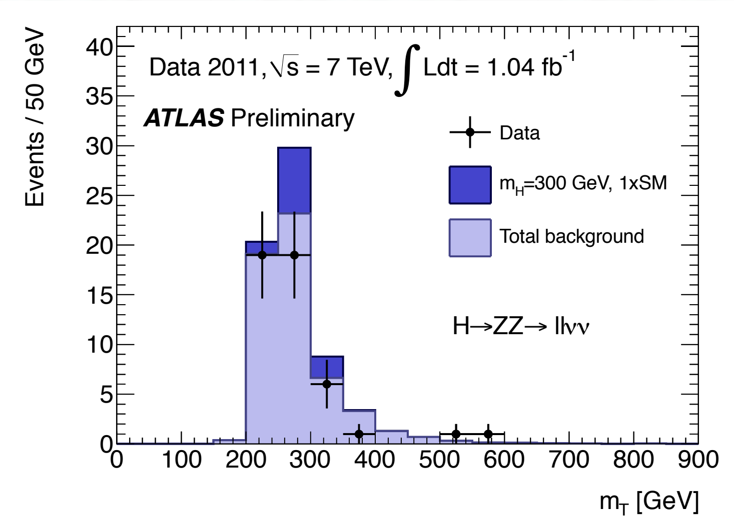
  - $H \rightarrow WW \rightarrow \ell\nu\ \ell\nu$
  - $H \rightarrow WW \rightarrow \ell\nu\ qq$
  - $H \rightarrow ZZ \rightarrow \ell\ell\ \ell\ell$
  - $H \rightarrow ZZ \rightarrow \ell\ell\ qq$
  - $H \rightarrow ZZ \rightarrow \ell\ell\ \nu\nu$

Results from ATLAS on various high mass search channels:

L = 1.04 – 2.28 fb^{-1} (up to data taken shortly before Lepton-photon conference)



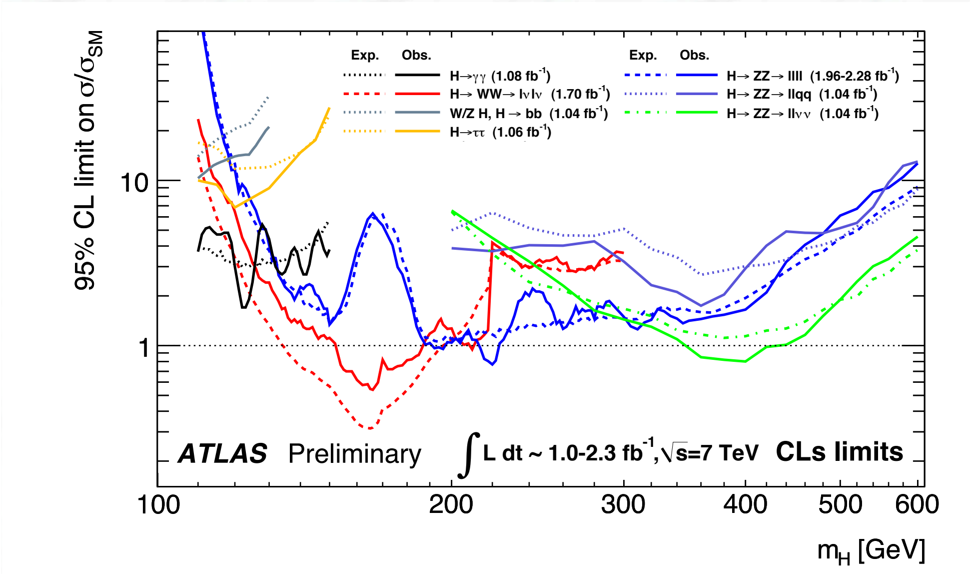


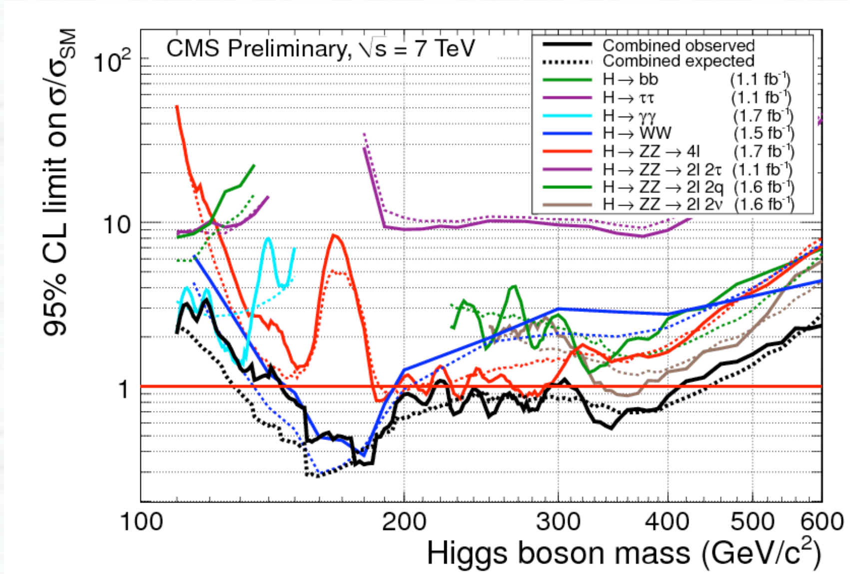


Also in these channels: data are consistent with expectations from Standard Model background processes

→ work out significances / statistics

Current status of the Higgs boson search at the LHC
-ATLAS and CMS-





- The two collaborations show similar performance

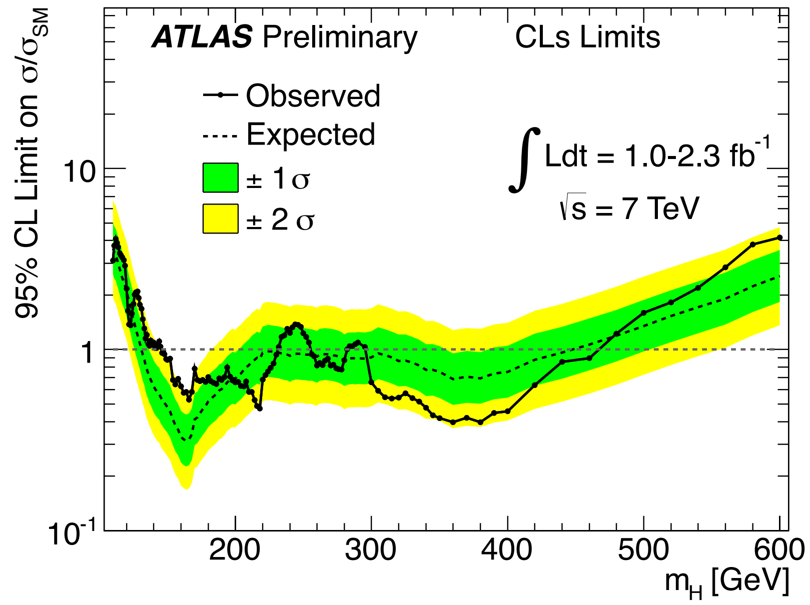
  - in terms of analysis power in the collaboration (many channels)
  - in terms of sensitivity
  - in terms of conclusions on the existence of the Higgs boson

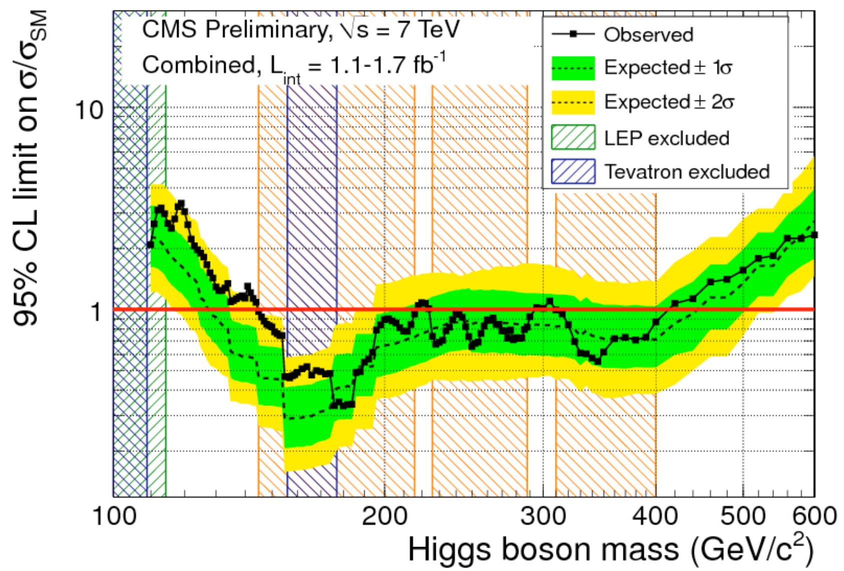
Putting everything together
The grand combination of channels

V. Sharma

- So far: ATLAS and CMS combinations available (summer conferences)
- Combination ATLAS + CMS is also ready; will be released this Friday, at HCP conference

Current status of the Higgs boson search at the LHC
-ATLAS and CMS combinations-





Excluded mass regions (95% C.L.):

$146 < m_H < 232$ GeV
$256 < m_H < 282$ GeV
$296 < m_H < 466$ GeV

Excluded mass regions (95% C.L.):

$145 < m_H < 216$ GeV
$226 < m_H < 288$ GeV
$310 < m_H < 400$ GeV

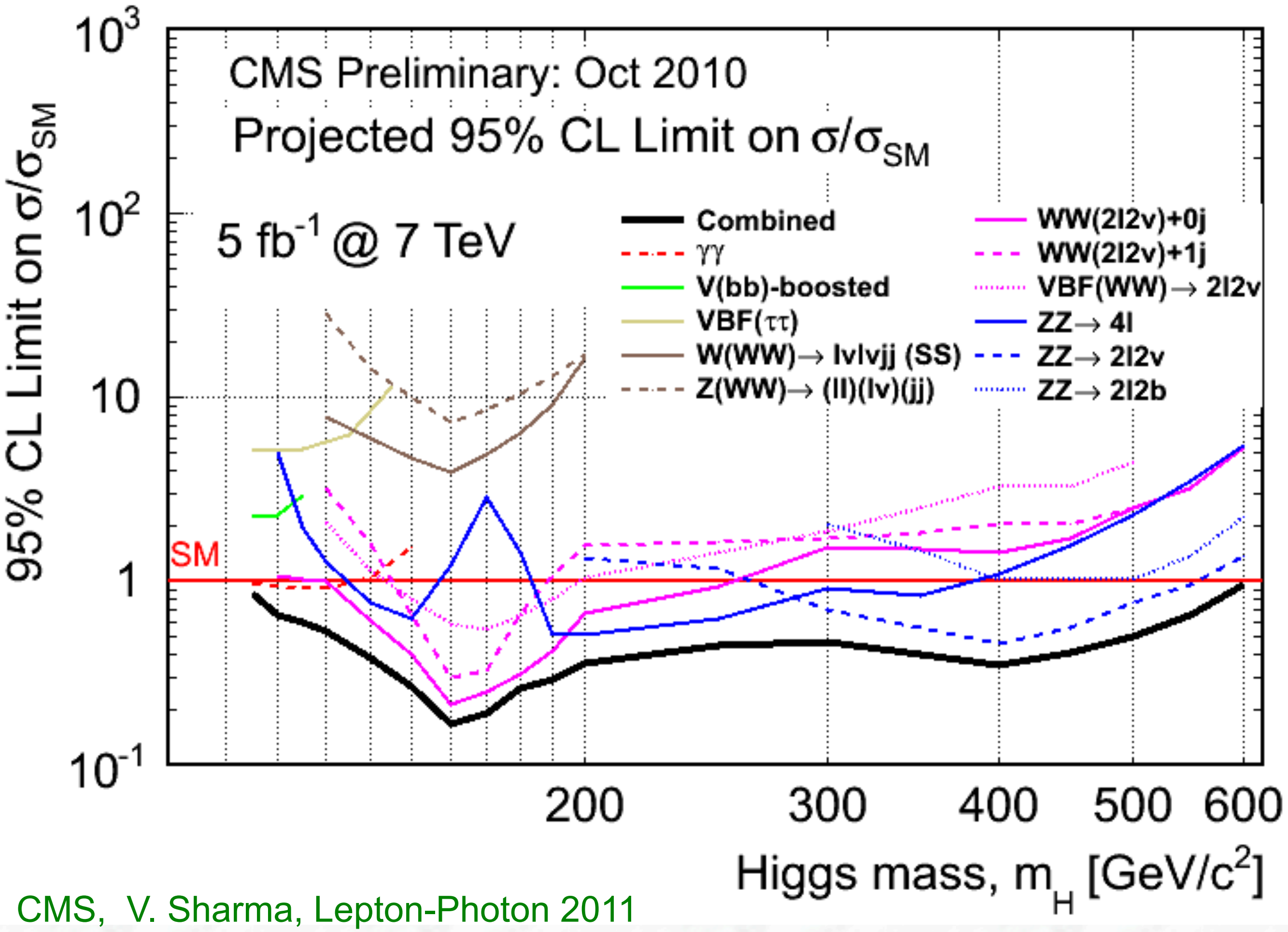
Prospects (new future)

- What can be done with 5 fb^{-1} of data ?
  Will most likely be shown in December this year, council meeting at CERN

- How much luminosity is needed for a 3σ evidence or a 5σ discovery?
  (in particular at low mass)

- Can the Higgs be ruled out?
  or can it be discovered with the 2011/2012 data?

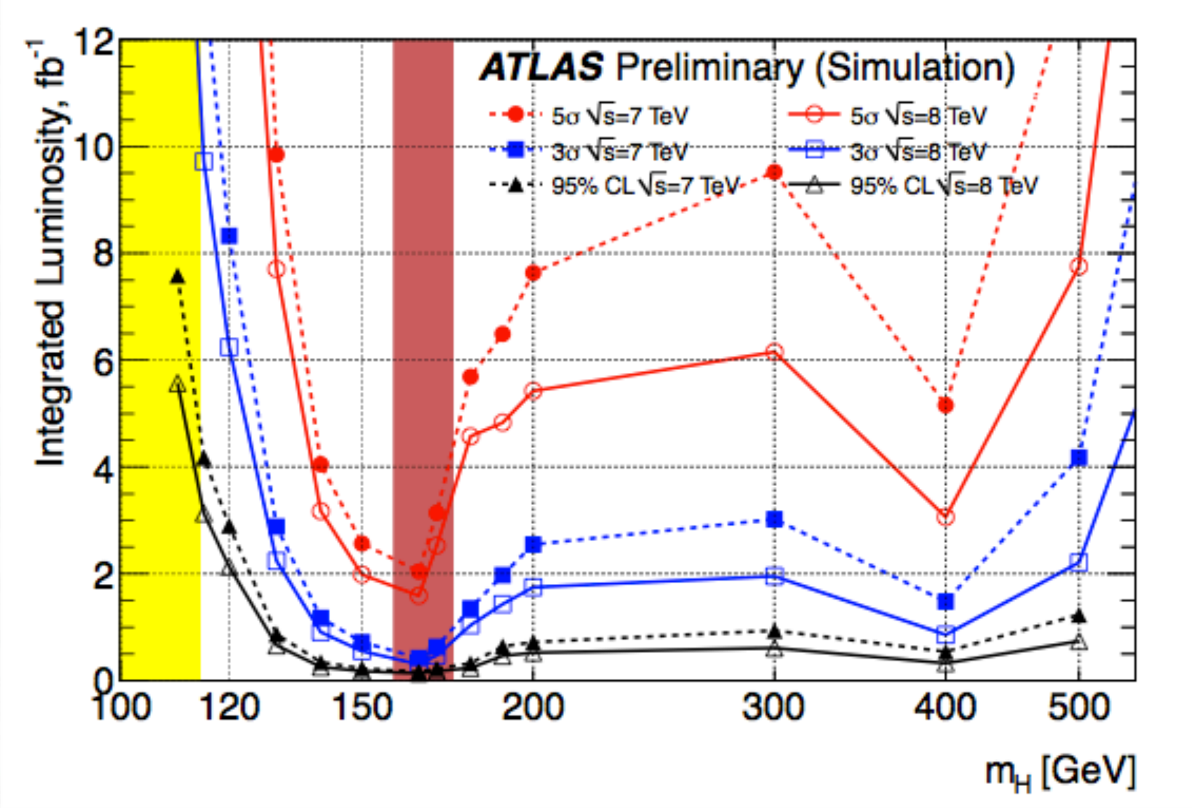
Expectations for higher integrated luminosities
-95% C.L. exclusion limits-



CMS, V. Sharma, Lepton-Photon 2011

- 95% C.L. exclusion can be reached with 5 fb^{-1} in one experiment
- However, needs the combination of all low-mass channels

Expectations for higher integrated luminosities
-discovery significances-



- For a 3σ effect in one experiment for a Higgs boson with a mass of 115 GeV more than 10 fb^{-1} will be needed
- Significant gain by increasing the energy from 7 to 8 TeV; 3σ with ~10 fb^{-1}
- Combined result of the two experiments will be interesting !

What, if no Higgs boson is found

- Well, this would be a big discovery !

  The Standard Model would be proven to be wrong

- Maybe Nature is not as simple as thought ?

  In this case: the LHC is a unique facility to investigate further

  - It might "only" take more running time
    (e.g modified couplings in more complicated Higgs scenarios, like composite Higgs bosons)

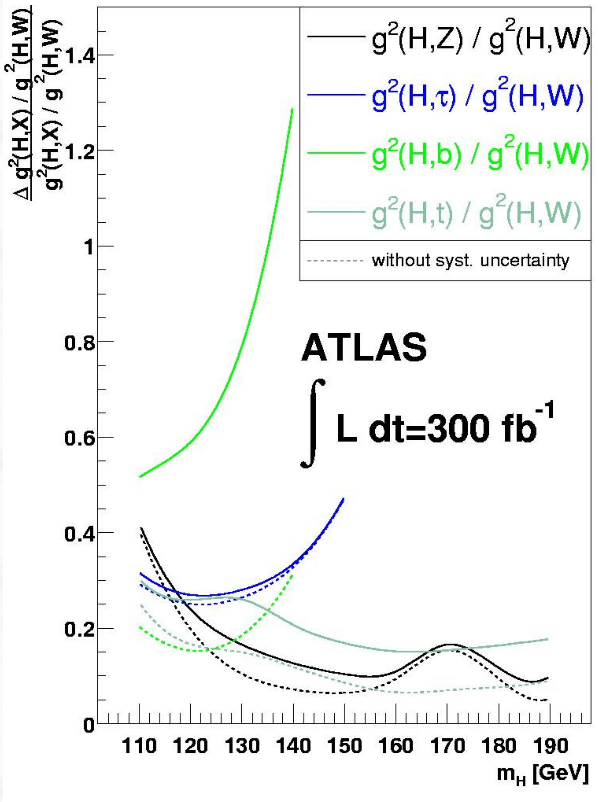
  - We all might get many years older before WW scattering is precisely measured

  - Invisibly decaying Higgs sceanrios are very very difficult to be measured at the LHC

What, if the Higgs boson will be found soon

- Well, this would be a big discovery !

→ Measure its parameters and prove that it is a Higgs boson

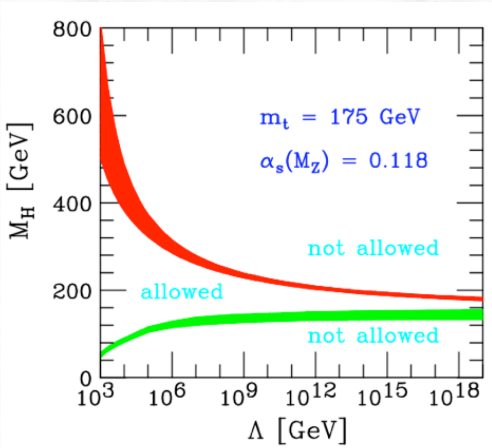


Example:

Precision on ratio of couplings to W coupling at the 20% level, needs high luminosity

Higgs boson self coupling very difficult to measure;
maybe not even possible at the sLHC
(needs further studies)

- A discovery of a light Higgs boson would also indicate "new physics"



Summary and Conclusions

- LHC machine and detectors are running extremely well !

- An impressive list of high quality physics measurements has already been performed

- The search for the Higgs boson has started very well

  - So far: data consistent with the Standard Model background hypothesis without a Higgs boson signal

  - Important new mass ranges have been excluded;
    however, the most interesting one not yet covered, but sensitivity will be reached soon

- Exiting times ahead of us !