Experimental Search for Higgs

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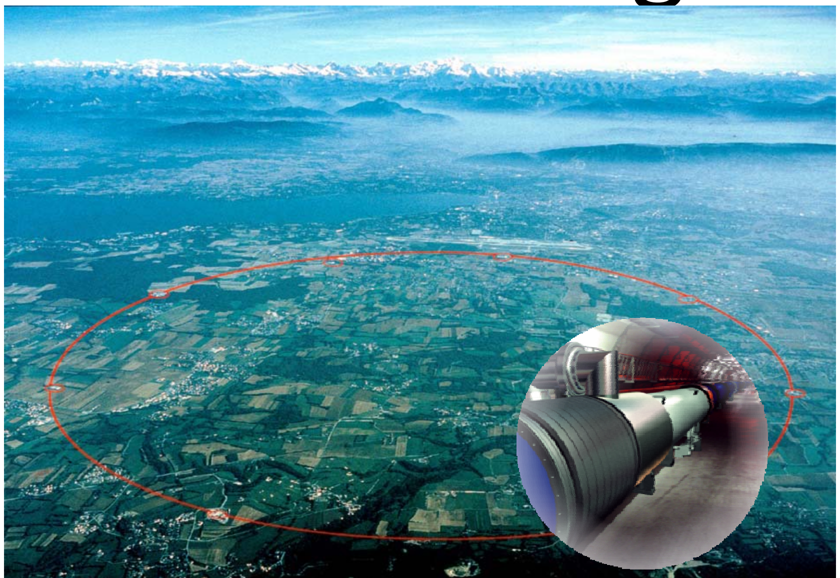
One Day Workshop on the LHC Physics: Electroweak and Higgs

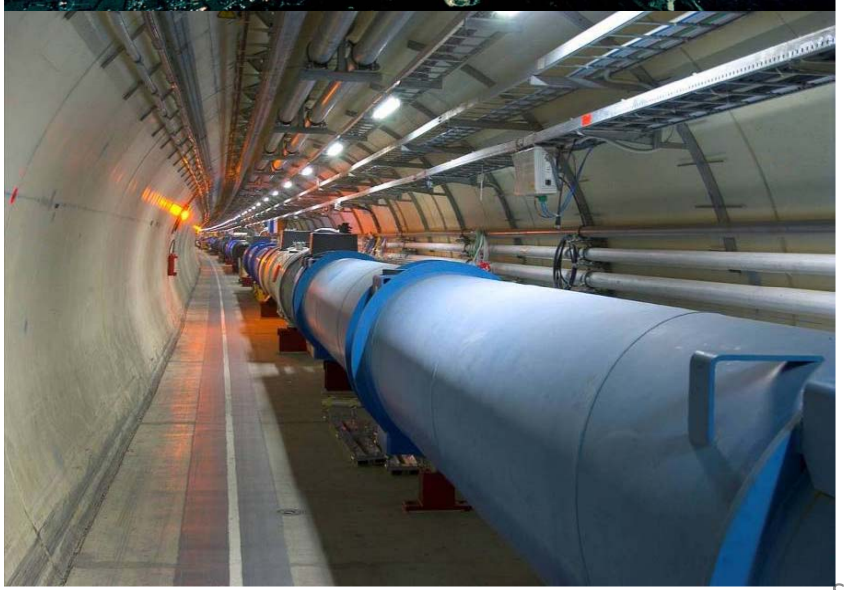
Aban 22, 1387

Outline

- LHC/CMS
- What we know now
- Higgs Production in LHC
- Higgs decay
- CMS/ATLAS potential for Higgs discovery

The Large Hadron Collider





- 2835 + 2835 proton bunches
  separated by 7.5 m
  → collisions every 25 ns
  = 40 MHz crossing rate

- 10^{11} protons per bunch

- at 10^{34}/cm^2/s
  ≈ 25 pp interactions per crossing
  pile-up

→ ≈ 10^9 pp interactions per second !!!

- in each collision
  ≈ 1600 charged particles produced

  enormous challenge for the detectors

The LHC Machine and Experiments

ATLAS/CMS Coverage

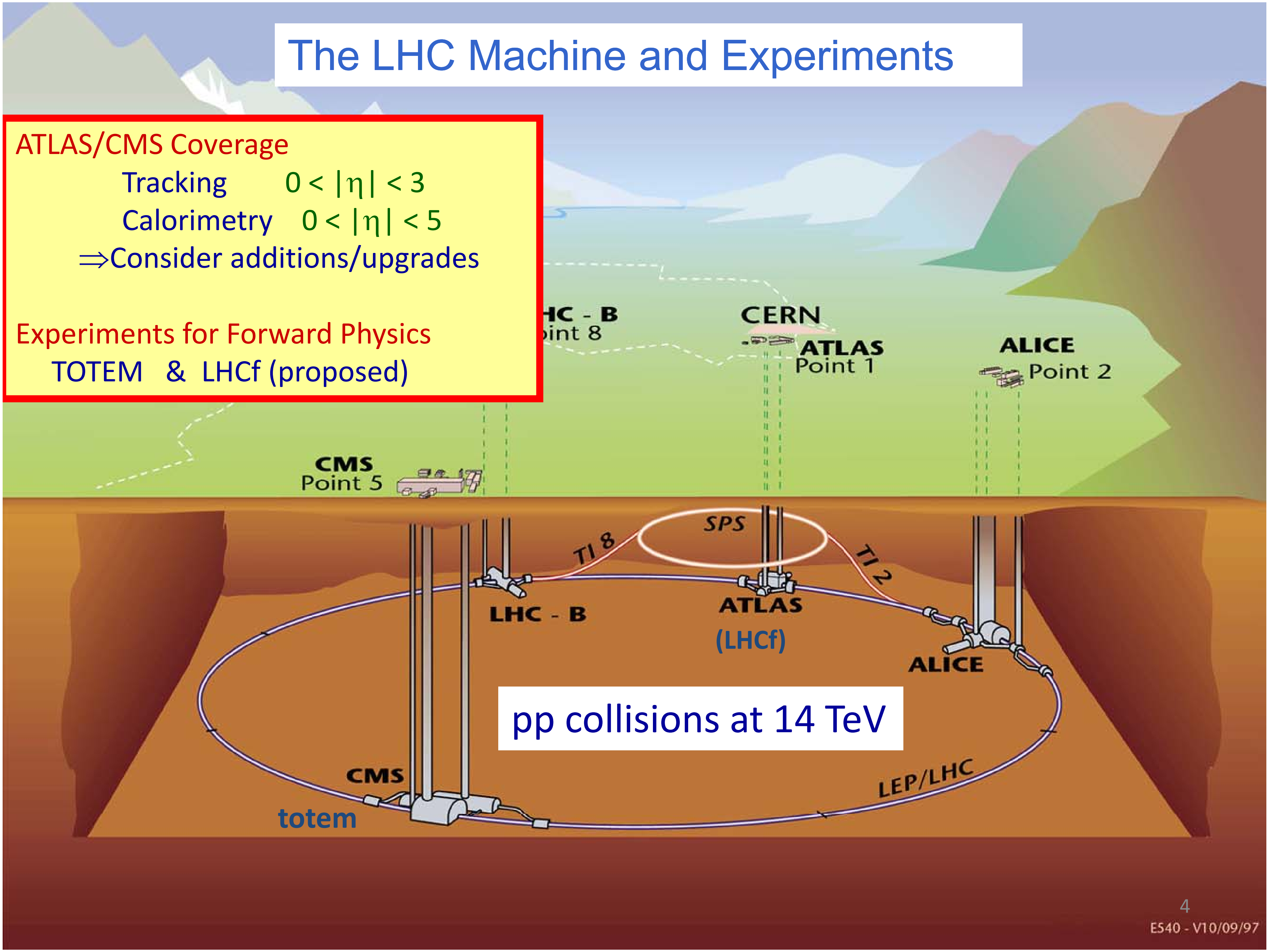
Tracking $0 < |\eta| < 3$

Calorimetry $0 < |\eta| < 5$

⇒Consider additions/upgrades

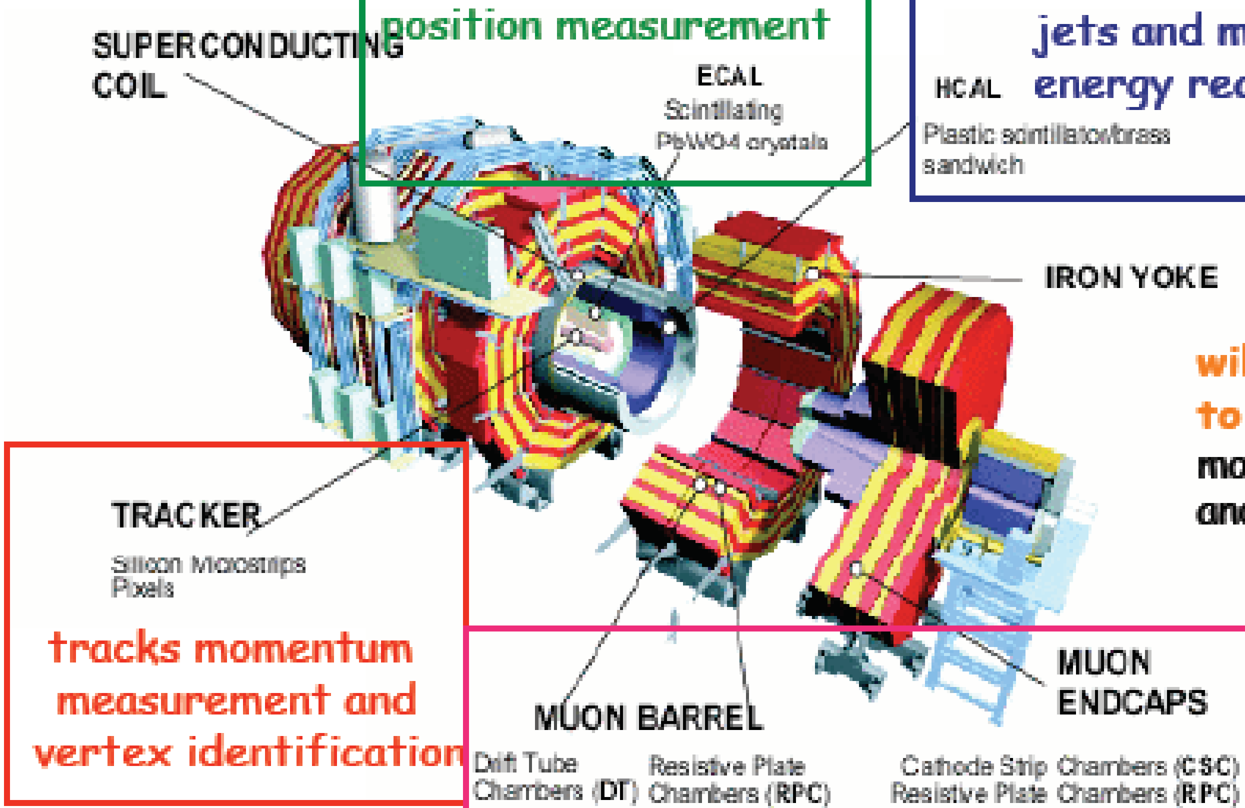
Experiments for Forward Physics

TOTEM & LHCf (proposed)



pp collisions at 14 TeV

CMS Experiment



e/γ energy and position measurement

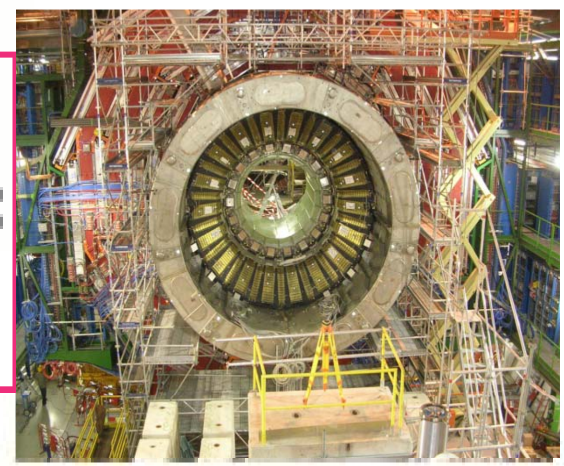
jets and missing energy reconstruction

tracks momentum measurement and vertex identification

muon tracks reconstruction and momentum measurement

will be ready according to new LHC schedule

more details in 'Detectors and Data Handling' session



CMS vs ATLAS

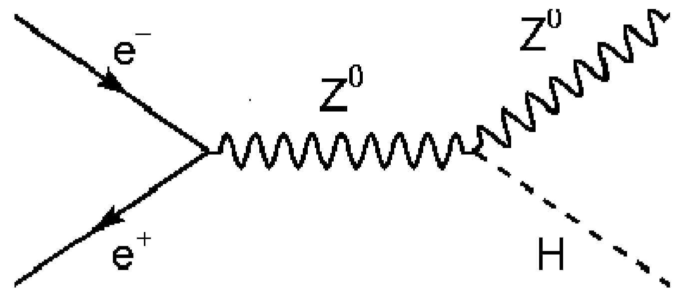
	ATLAS	CMS
MAGNET (S)	Air-core toroids + solenoid in inner cavity 4 magnets Calorimeters in field-free region	Solenoid Only 1 magnet Calorimeters inside field
TRACKER	Si pixels+ strips TRT → particle identification B=2T $\sigma/p_T \sim 5\times10^{-4}\, p_T \oplus 0.01$	Si pixels + strips No particle identification B=4T $\sigma/p_T \sim 1.5\times10^{-4}\, p_T \oplus 0.005$
EM CALO	Pb-liquid argon $\sigma/E \sim 10\%/\sqrt{E}$ uniform longitudinal segmentation	$PbWO_4$ crystals $\sigma/E \sim 2\text{-}5\%/\sqrt{E}$ no longitudinal segm.
HAD CALO	Fe-scint. + Cu-liquid argon (10 λ) $\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$	Cu-scint. (> 5.8 λ +catcher) $\sigma/E \sim 100\%/\sqrt{E} \oplus 0.05$
MUON	Air → $\sigma/p_T \sim 7\%$ at 1 TeV standalone	Fe → $\sigma/p_T \sim 5\%$ at 1 TeV combining with tracker

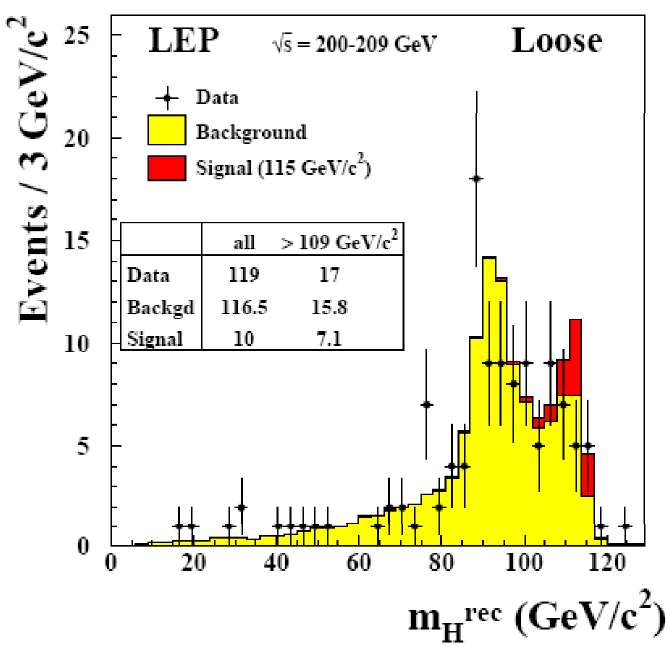
F. Gianotti, ICHEP06, Moscow, 02/08/2006 51

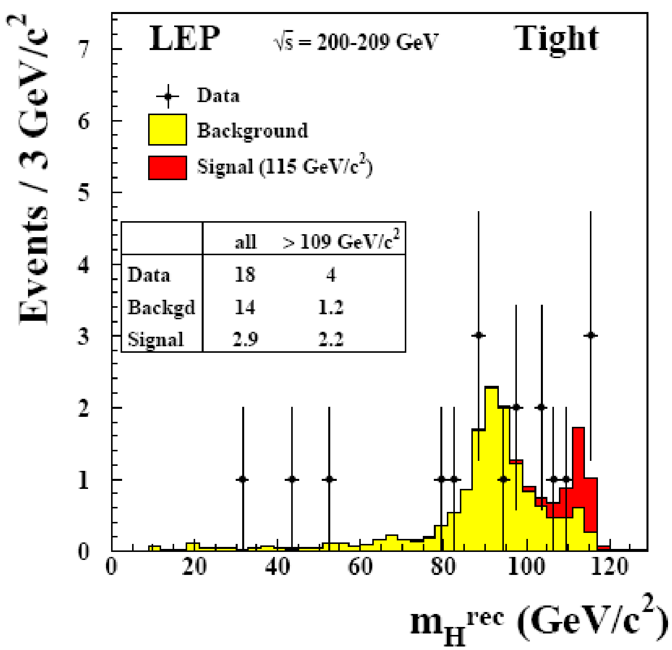
Direct Search

Higgs-strahlung, the dominant production process for a standard model Higgs at LEP2.

direct (from LEP2): mH > 114.4 GeV/c2







Constraints from precision data

$$\alpha = \frac{1}{4\pi}\frac{g^2 g'^2}{g^2+g'^2} = \frac{1}{137.03599976(50)}$$

$$G_F = \frac{1}{\sqrt{2}v^2} = 1.16637(1)\times 10^{-5}\ \mathrm{GeV}^{-2}$$

$$m_Z = \frac{1}{2}\sqrt{g^2+g'^2}\,v = 91.1875(21)\ \mathrm{GeV}\ ,$$

where the uncertainty is given in parentheses. The value of α is extracted from low-energy experiments, G_F is extracted from the muon lifetime, and m_Z is measured from e^+e^- annihilation near the Z mass.

At tree level, we can express m_W as

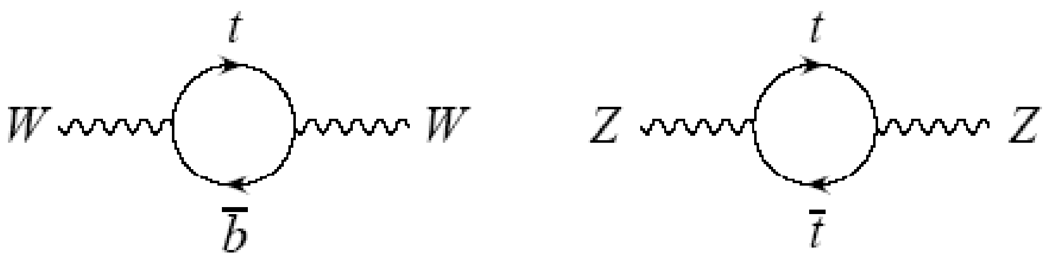
$$m_W^2 = \frac{1}{\sin^2\theta_W}\frac{\pi\alpha}{\sqrt{2}G_F}$$

where

$$\sin^2\theta_W = 1 - \frac{m_W^2}{m_Z^2}$$

Clues to the Higgs boson mass

From the sensitivity of electroweak observables to the mass of the top, we are able to measure its mass, even without directly producing it

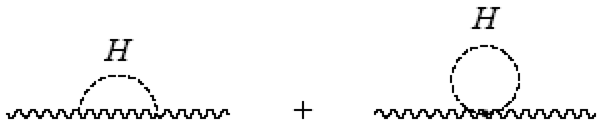


These quantum corrections alter the link between W and Z boson masses

$$m_W^2 = \frac{1}{\sin^2\theta_W\,(1-\Delta\rho)}\frac{\pi\alpha}{\sqrt{2}G_F} \qquad \Delta\rho_{(\mathrm{top})} \approx -\frac{3G_F}{8\pi^2\sqrt{2}}\frac{1}{\tan^2\theta_W}m_t^2$$

The strong dependence on m_t^2 accounts for the precision of the top-quark mass estimates derived from electroweak observables.

The Higgs boson quantum corrections are typically smaller than the top-quark corrections, and exhibit a more subtle dependence on m_H than the m_t^2 dependence of the top-quark corrections.



$$\Delta\rho_{(\text{Higgs})} = \frac{11 G_F m_Z^2 \cos^2\theta_W}{24\sqrt{2}\pi^2} \log\left(\frac{m_H^2}{m_W^2}\right)$$

Since m_Z has been determined at LEP to 23 ppm, it is interesting to examine the dependence of m_W upon m_t and m_H.

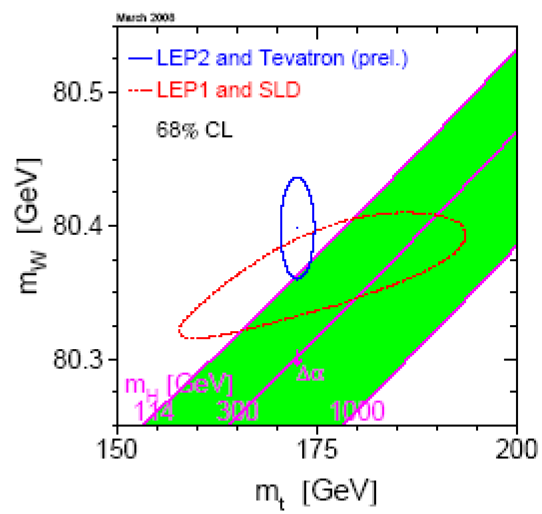
Indirect measurements of m_W and m_t (solid line)

Direct measurements of m_W and m_t (dotted line)

$m_t = 172.6 \pm 1.4$ GeV

$m_W = 80.398 \pm 0.025$ GeV

both shown as one-standard-deviation regions.



The indirect and direct determinations are in reasonable agreement and both favor a light Higgs boson, within the framework of the SM.

SM Higgs mass fit to EW precision data

$$m_H = 87^{+36}_{-27}\ \text{GeV}$$

Including theory uncertainty

$$m_H < 160\ \text{GeV} \quad (95\%\ \text{CL})$$

Does not include

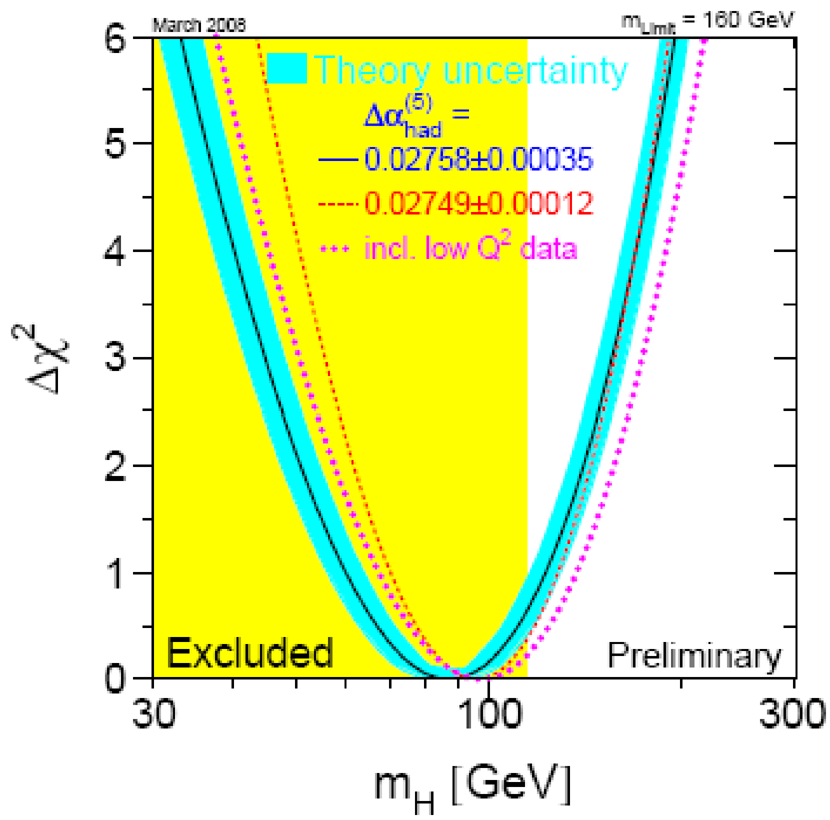
Direct search limit from LEP

$$m_H > 114\ \text{GeV} \quad (95\%\ \text{CL})$$

Renormalize probability for

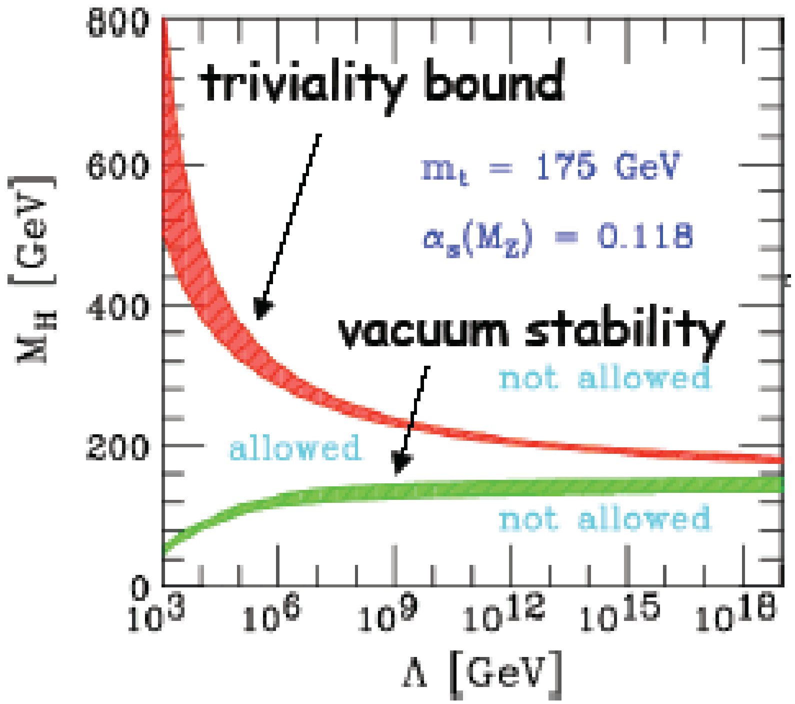
$m_H > 114$ GeV to 100%:

$$m_H < 190\ \text{GeV} \quad (95\%\ \text{CL})$$



Theoretical Bounds

Riesselmann, hep-ph/9711456

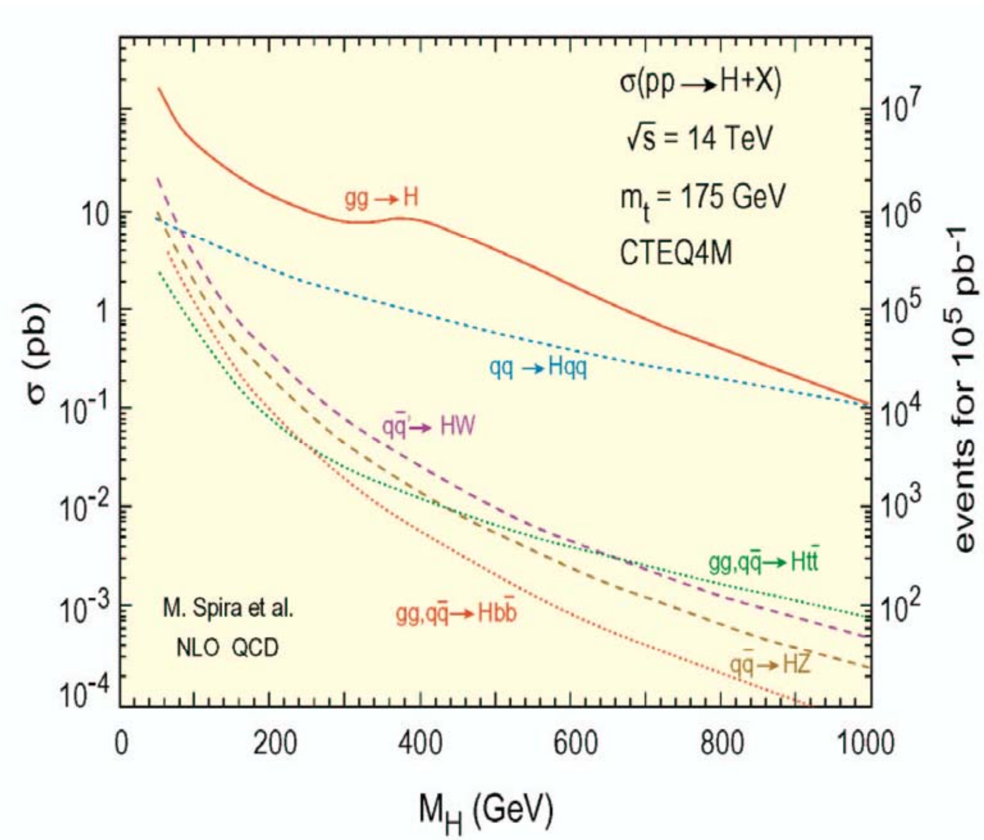


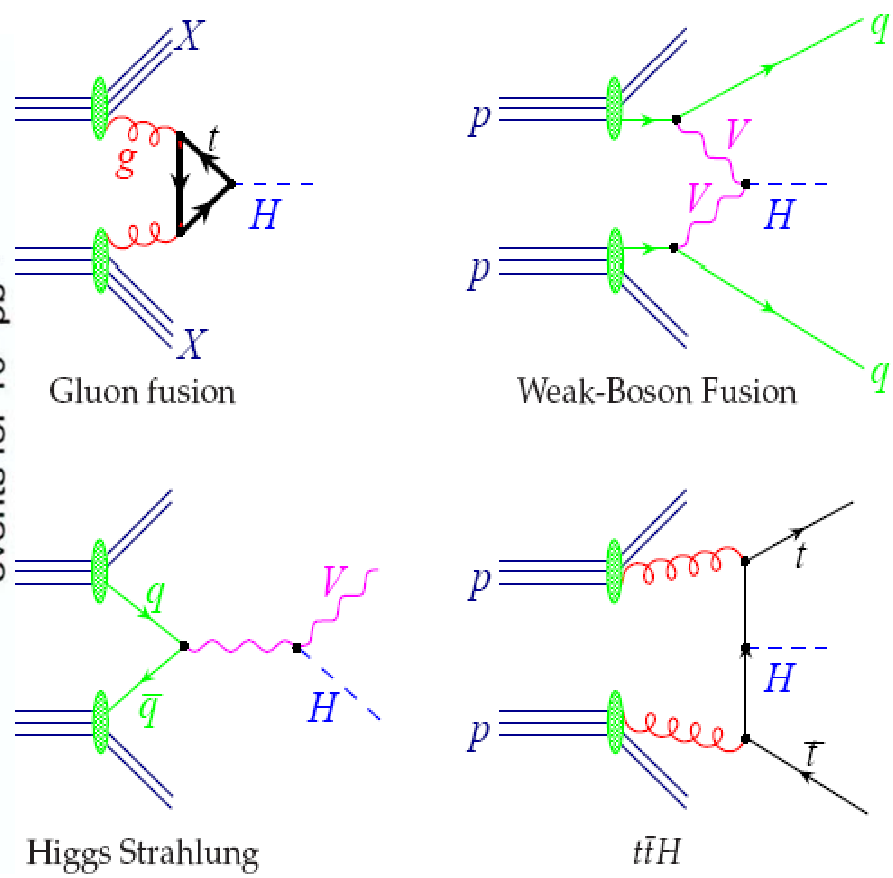
Notice the small window ~130 GeV < M_H <~180 GeV, where the theory is valid up to the Planck scale

$M_{Planck} = (\bar{h}c/GNewton)^{1/2} \approx 1.22 \times 10^{19}$ GeV.

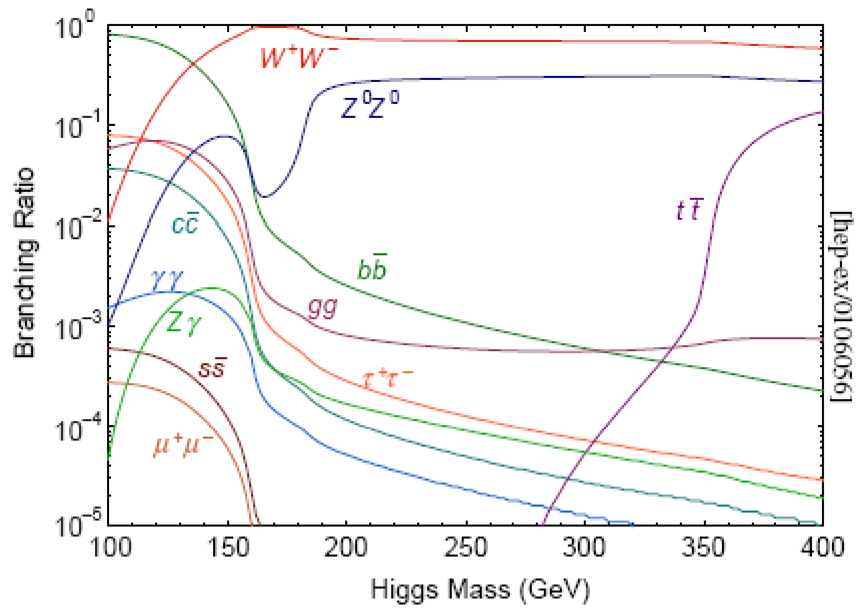
For a cutoff scale of Λ > 1000 TeV the Higgs boson should lie in the mass window 110 GeV < M_H < *300 GeV*

Higgs Production at LHC





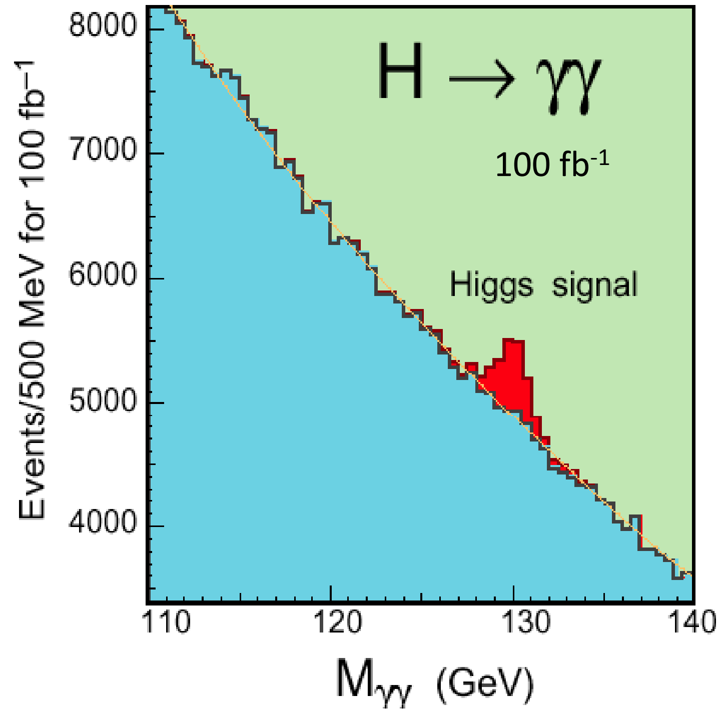
Higgs decay



Above 350 GeV H→ ttbar is opened, it is below ZZ

An intermediate mass Higgs ($m_Z < m_H < 2m_Z$)

- Higgs below ~150 GeV decays to b-bbar, difficult to detect , QCD Bkg, low trigger efficiency (soft jets, no leptons).

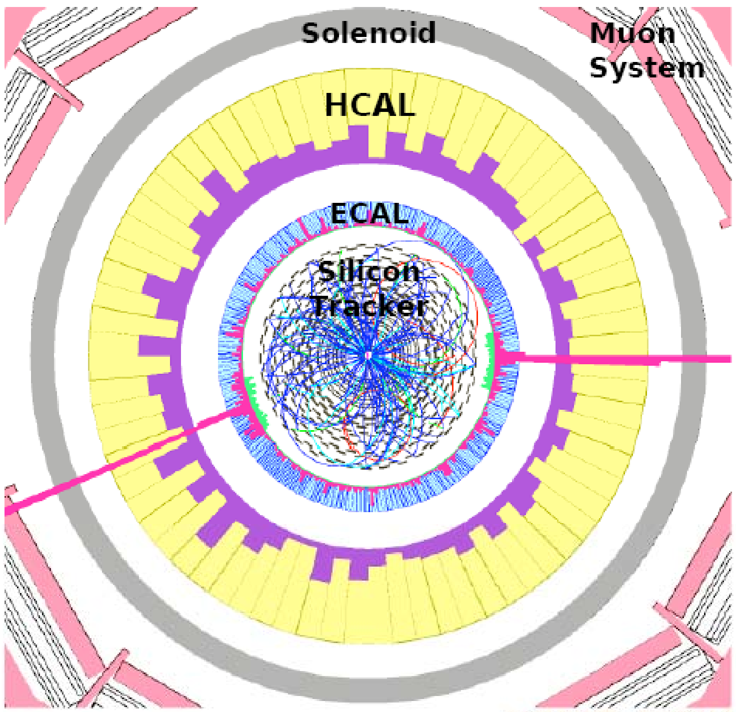


- H→γγ is much cleaner.

CMS is tuned for this range.

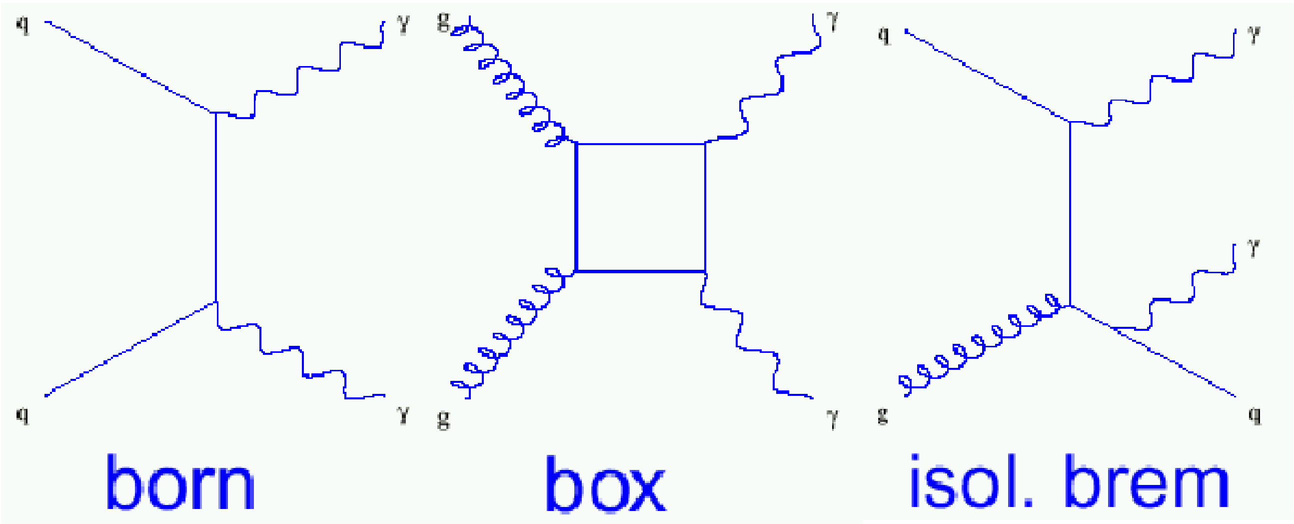
BR ~ 0.002 (M_H= 120 GeV)

CMS event view



CMS NOTE - 2006/112

Backgrounds for H→$\gamma\gamma$



- important tool to suppress bkg.:

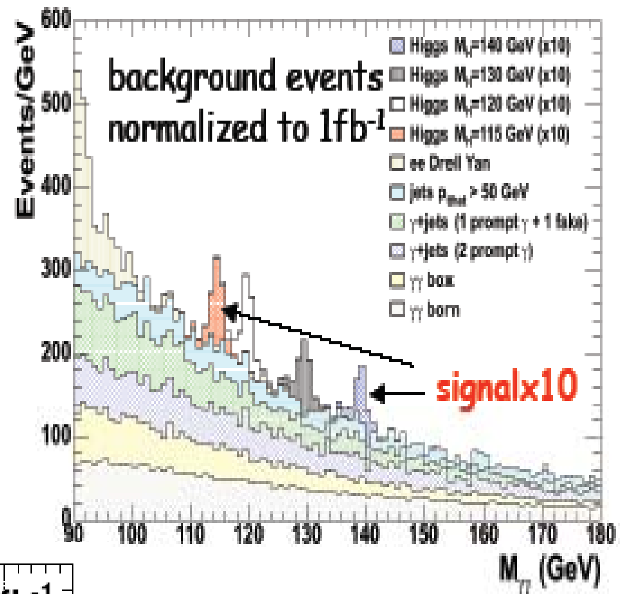
photon ID and isolation: misidentified jets are accompanied by particles measured in tracker, e.m. and had. Calorimeters

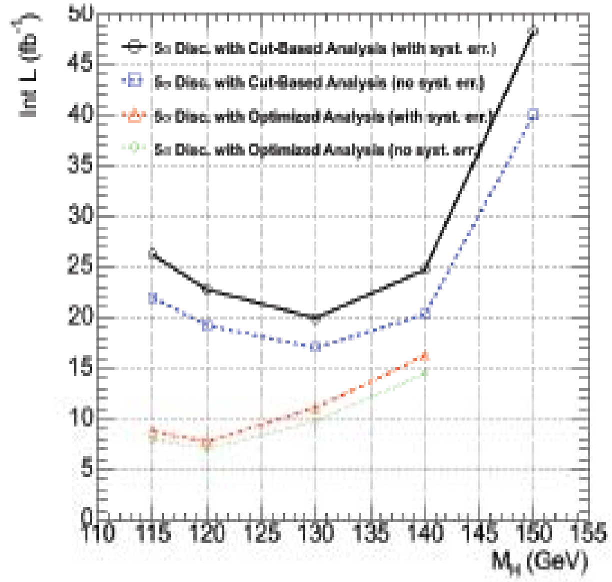
- primary vertex:

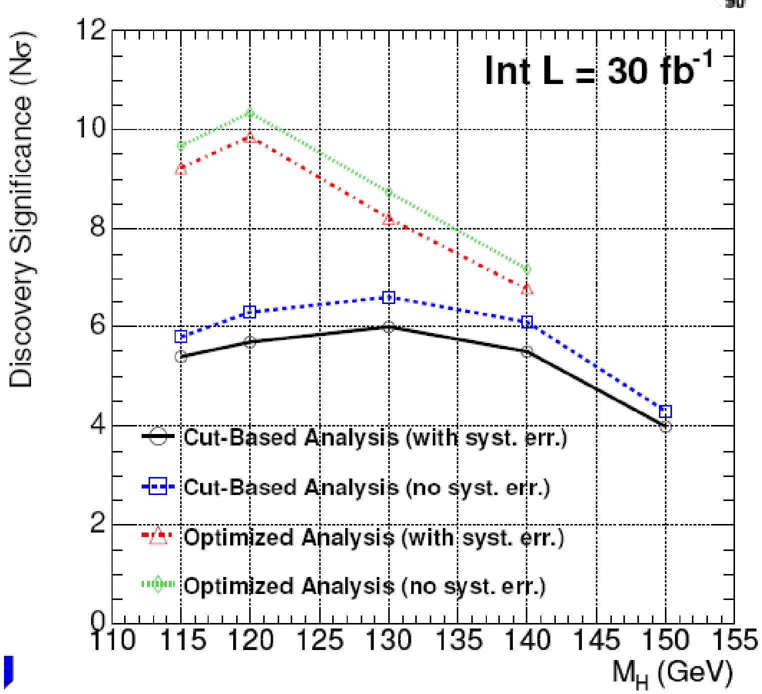
- e.m. energy measurement precise, but not the direction
- longitudinal spread of interaction vertices ~53 mm

=> $\boldsymbol{m}_{\mathbf{H}}$ smeared by 1.5 GeV if average vertex position is used

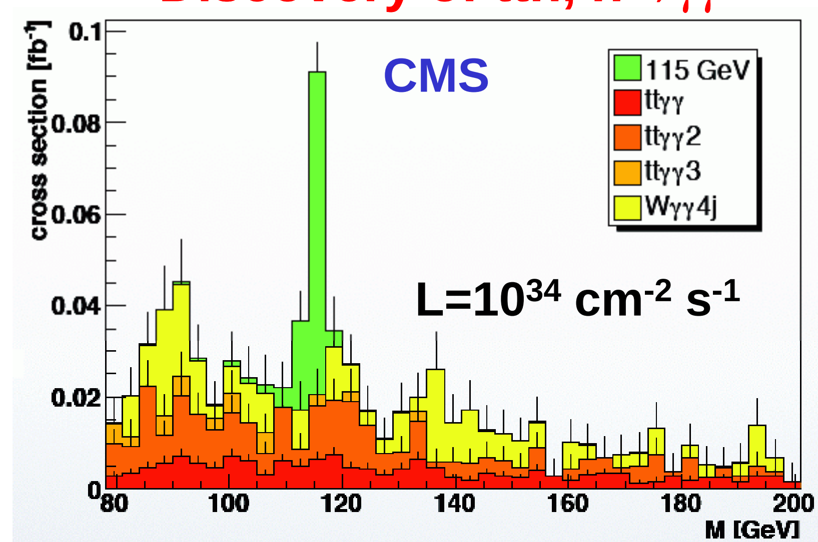
Sensitivity for H→γγ





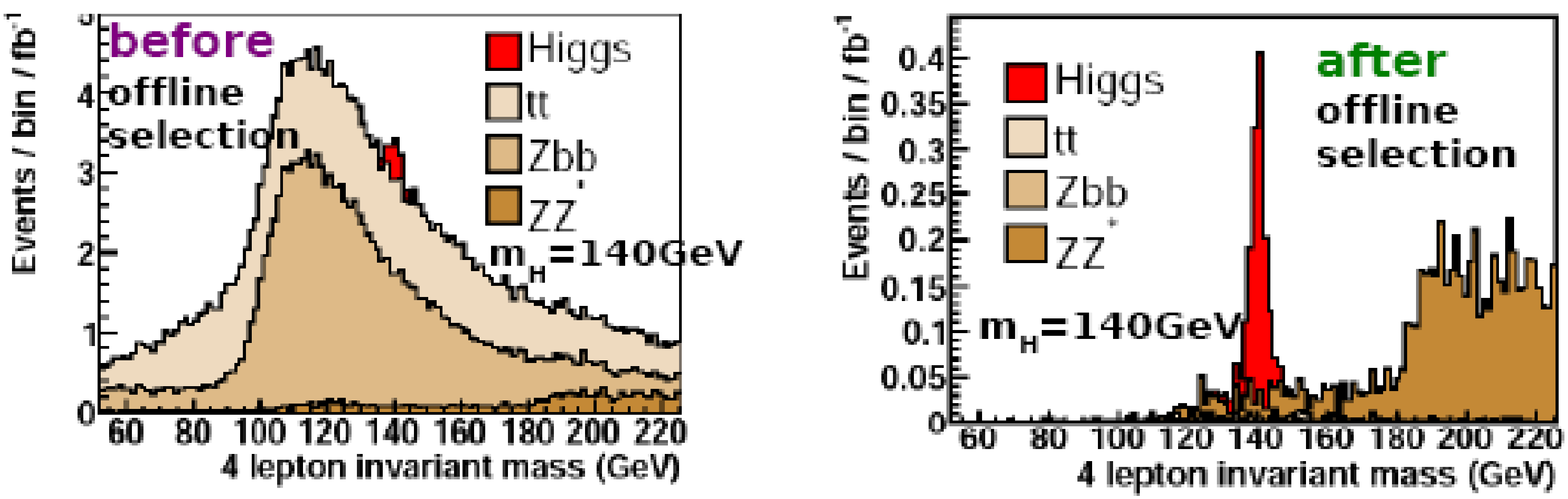


Discovery of tth, h→γγ



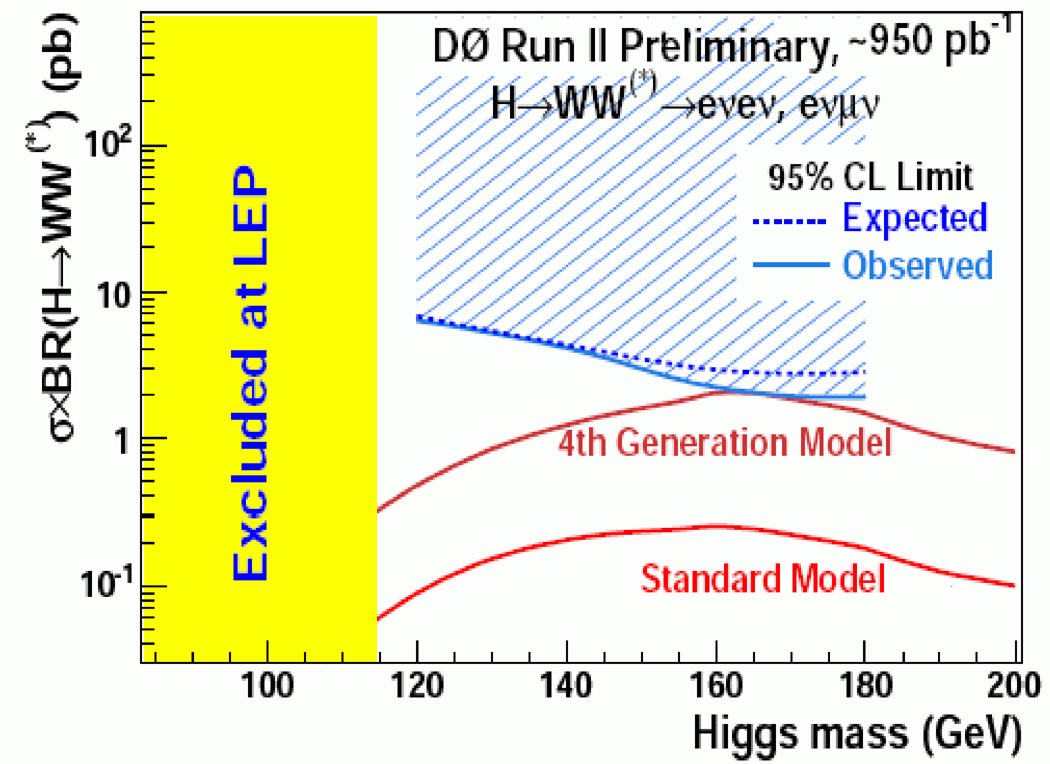
An intermediate mass higgs (cntd)

- 150 < M_H < 190 GeV Thanks to clean leptons, H→ZZ^* is the best channel to discover and characterize the Higgs. For Z^* the Z mass constraint does not work.

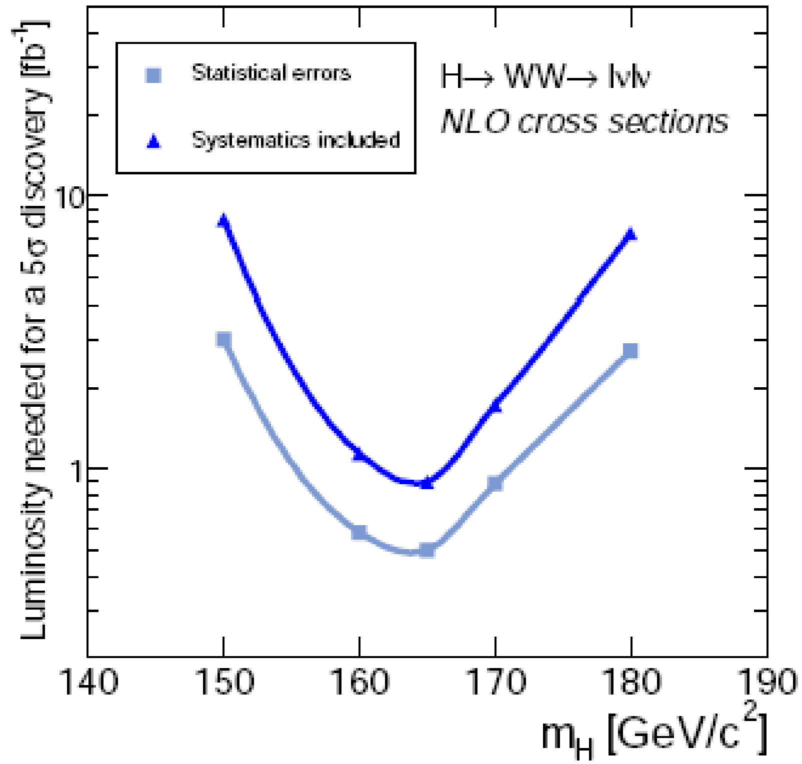


Sensitivity for $H \rightarrow W^+W^- \rightarrow l\nu l\nu$
$150 < M_H < 190$ GeV

Direct exclusion from D0



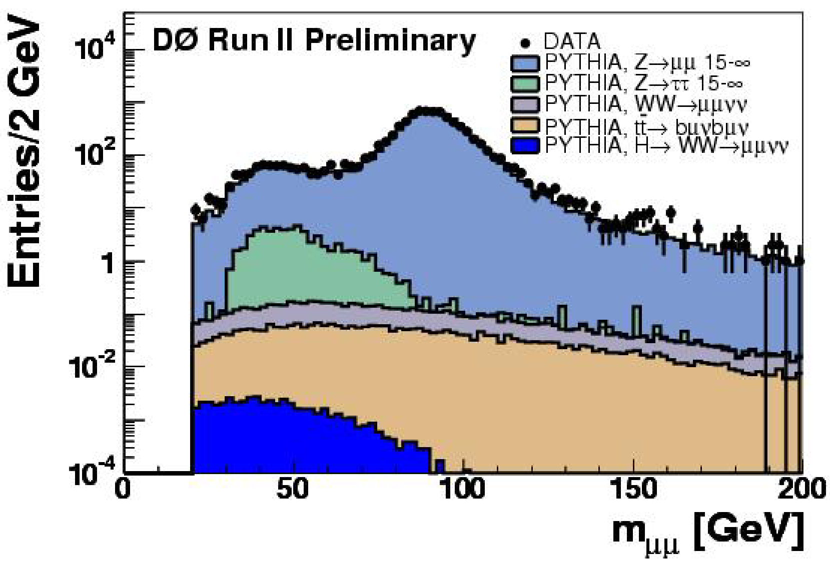
CMS

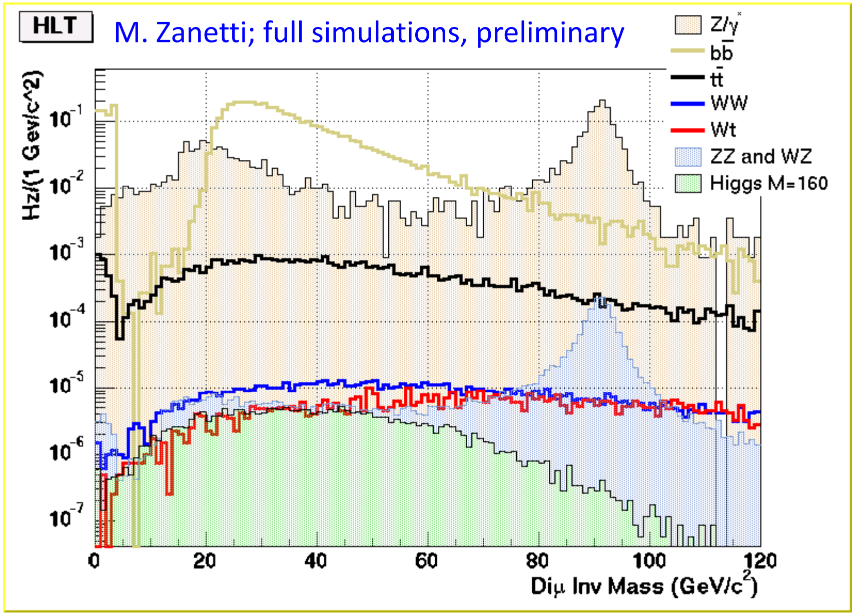


H->WW->2l analysis at TeV and LHC (I)

Tevatron data and MC (PYTHIA) **LHC (CMS) Monte Carlo (PYTHIA)**

M_H=160 GeV

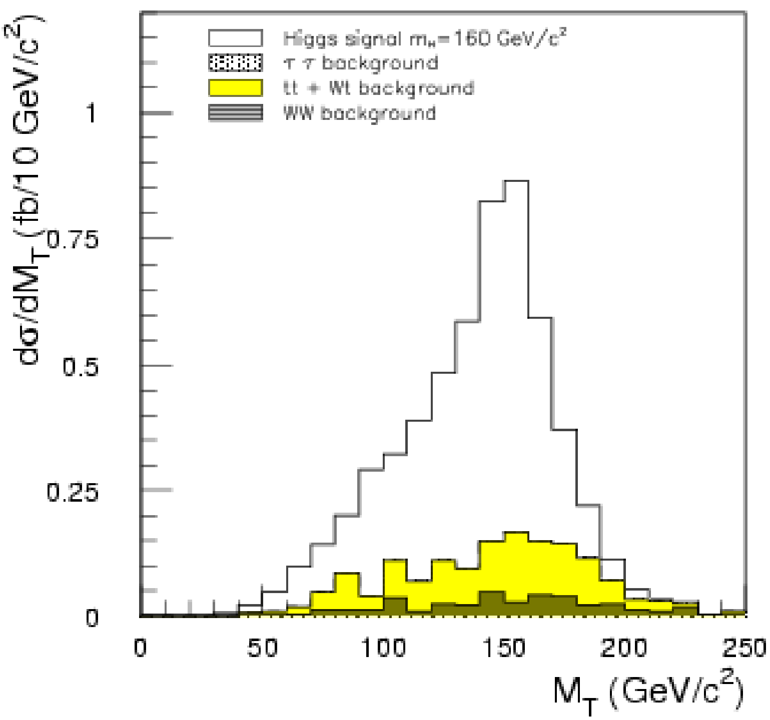


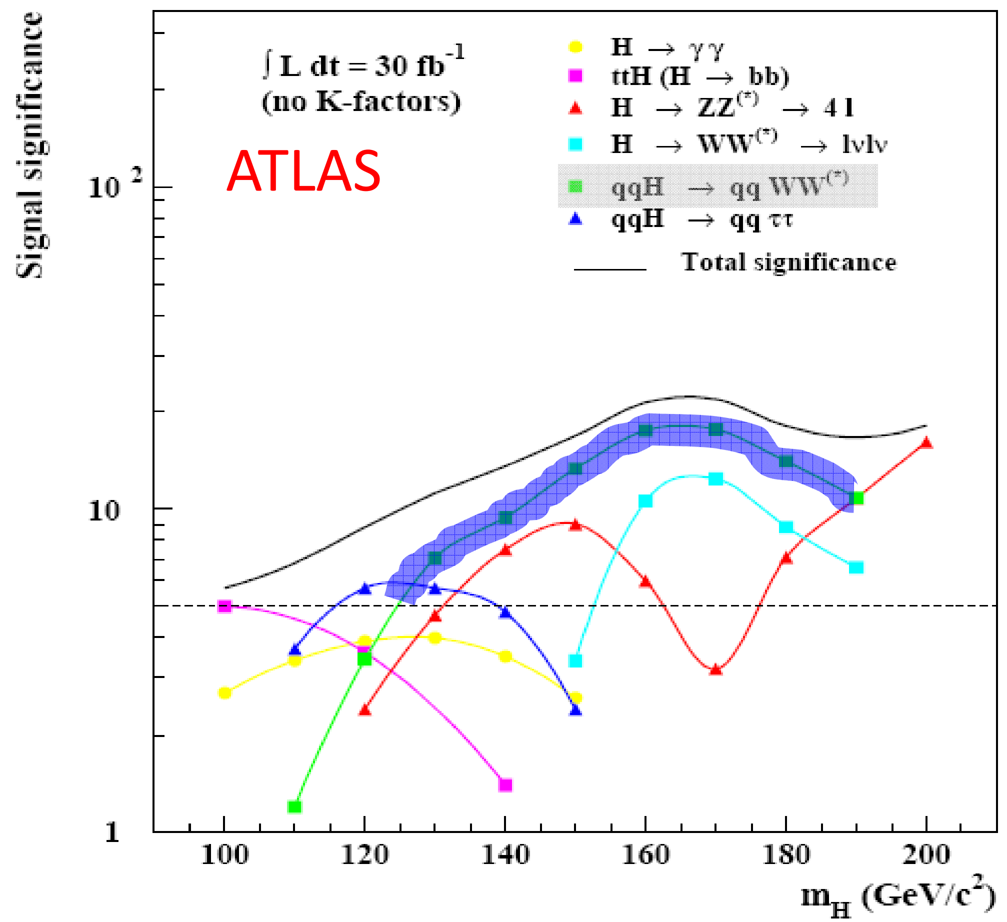


Very similar event selections:

- cuts on lepton p_T
- cut on miss E_T, Z resonance veto
- jet veto against tt~
- $\Delta\phi$(ll) cut is particularly important; exploit spin correlations

ATLAS


Higgs signal m_H=160 GeV/c²
τ τ background
tt + Wt background
WW background
dσ/dM$_T$ (fb/10 GeV/c²)
M$_T$ (GeV/c²)

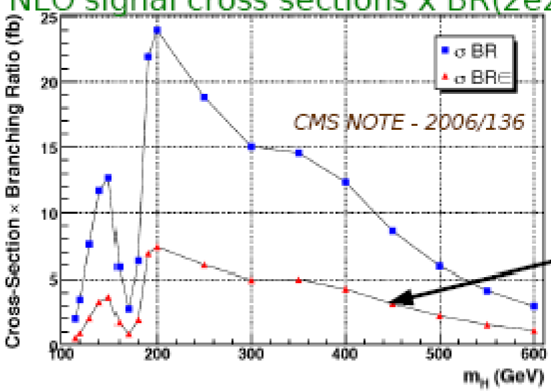

∫L dt = 30 fb^{-1}
(no K-factors)
ATLAS
H → γγ
ttH (H → bb)
H → ZZ$^{(*)}$ → 4 l
H → WW$^{(*)}$ → lνlν
qqH → qq WW$^{(*)}$
qqH → qq ττ
Total significance
Signal significance
m$_H$ (GeV/c²)

A heavy Higgs ($2m_Z < m_H <$ 650 GeV)

- $H \rightarrow ZZ \rightarrow l^+l^-l^+l^-$ is the golden channel for Higgs decays.
- Irreducible Bkg is direct ZZ production. It can be controlled.
- With increasing the mass production/decay rate reduces e.g, less than 200 Higgs particles with m_H = 700 GeV decay in $H \rightarrow ZZ \rightarrow l^+l^-l^+l^-$ channel in a year at high luminosity.

Sensitivity for H→ZZ→4 l

NLO signal cross sections x BR(2e2mu):

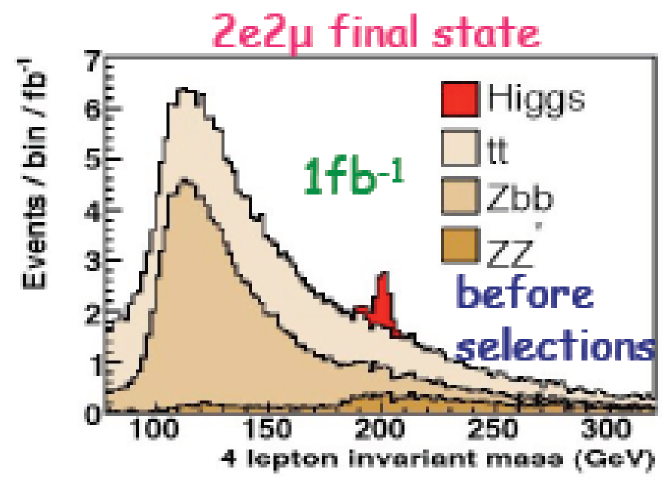


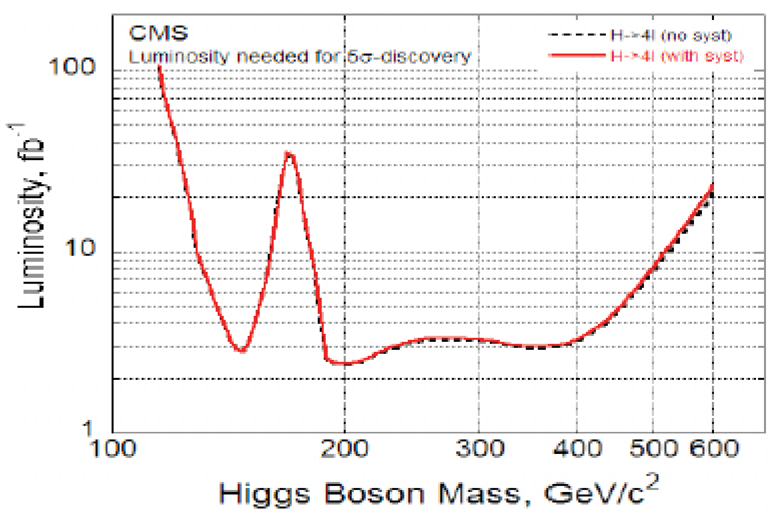
- gluon fusion and vector boson fusion considered

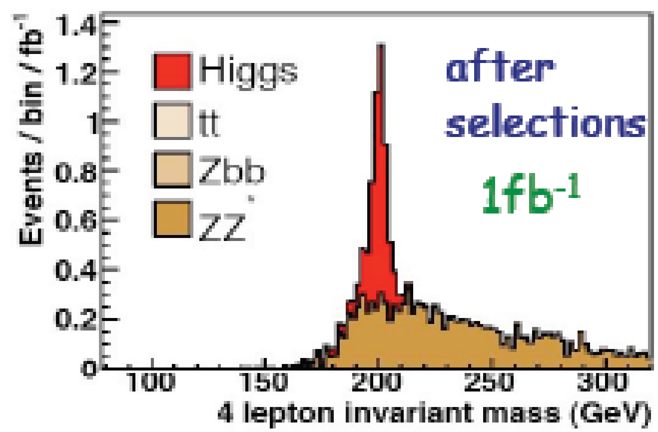
generator preselection: (CMS)

p_t(e) > 5GeV , eta<2.7

p_t(mu) > 3GeV, eta<2.4







A very heavy Higgs ($m_H > 650$ GeV)

- To increase the statistics, the decay channel is changed.
- The decay channel $H \rightarrow W^+W^- \rightarrow l\nu jj$, has a branching ratio of just below 30% giving it a rate some 50 times higher than the four lepton channel from $H \rightarrow ZZ$ decays.
- Mass measurement is very difficult and rough. No mass peak. Only event counting works.

CMS capability

	H→bb	H→ττ	H→γγ	H→WW	H→ZZ
inclusive			YES	YES	YES
qqH		YES		YES	YES
W/Z+H					
ttH					

- filled boxes: detailed analysis available
- YES: sure discovery at $\int L < 30 fb^{-1}$ in the appropriate masses range

Prospects for SM Higgs

Tevatron

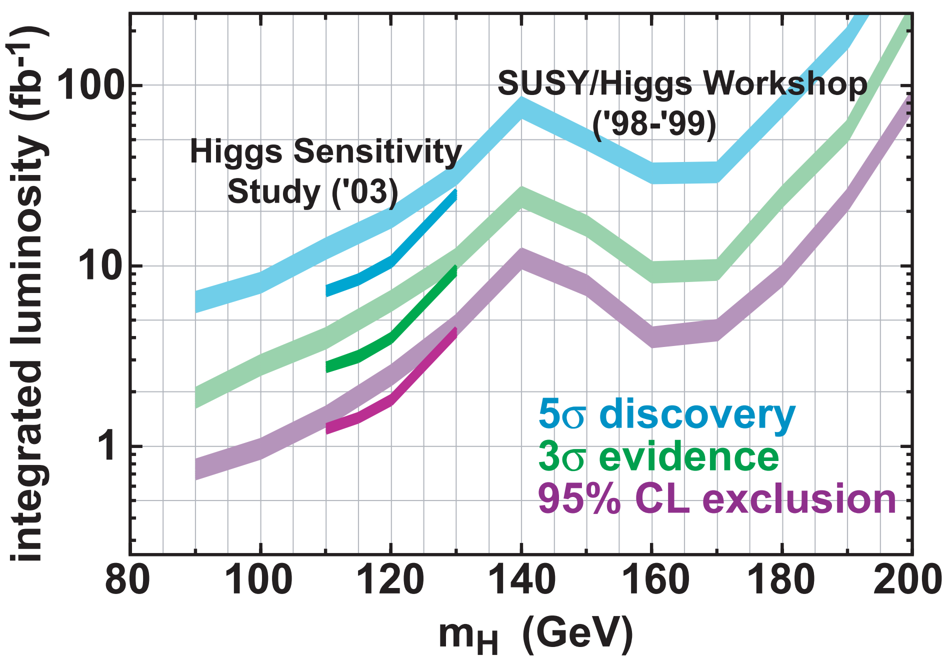
SM Higgs at 170 GeV/c²

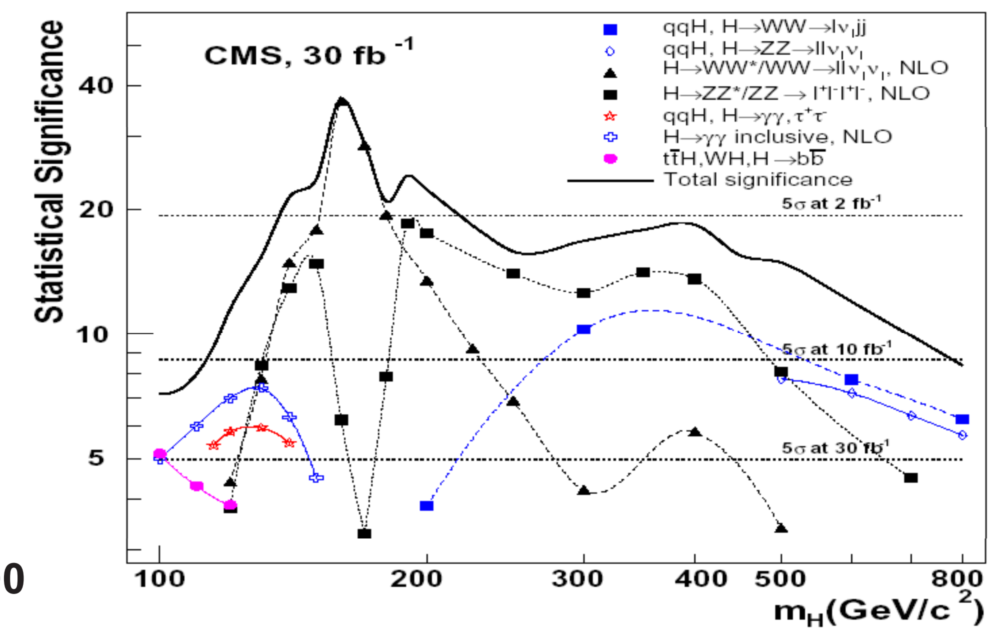
- excluded at 95 % C.L. in 2008
- 3 σ evidence for 120 GeV/c² in 2009 (?)

LHC; one experiment

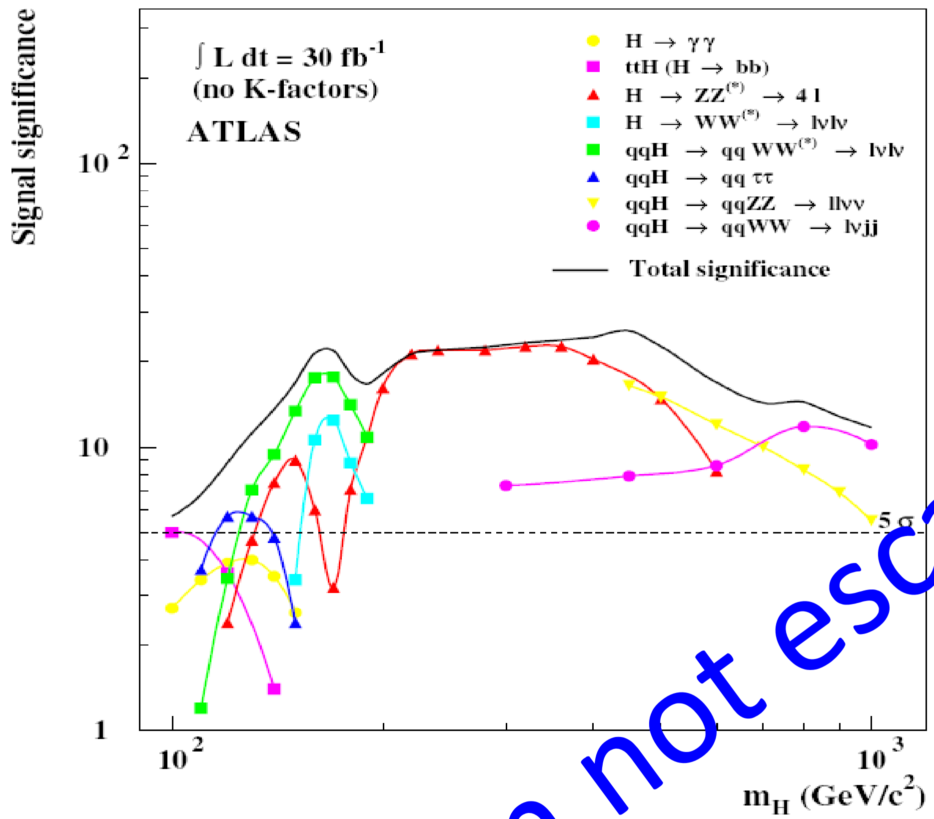
(CMS example)

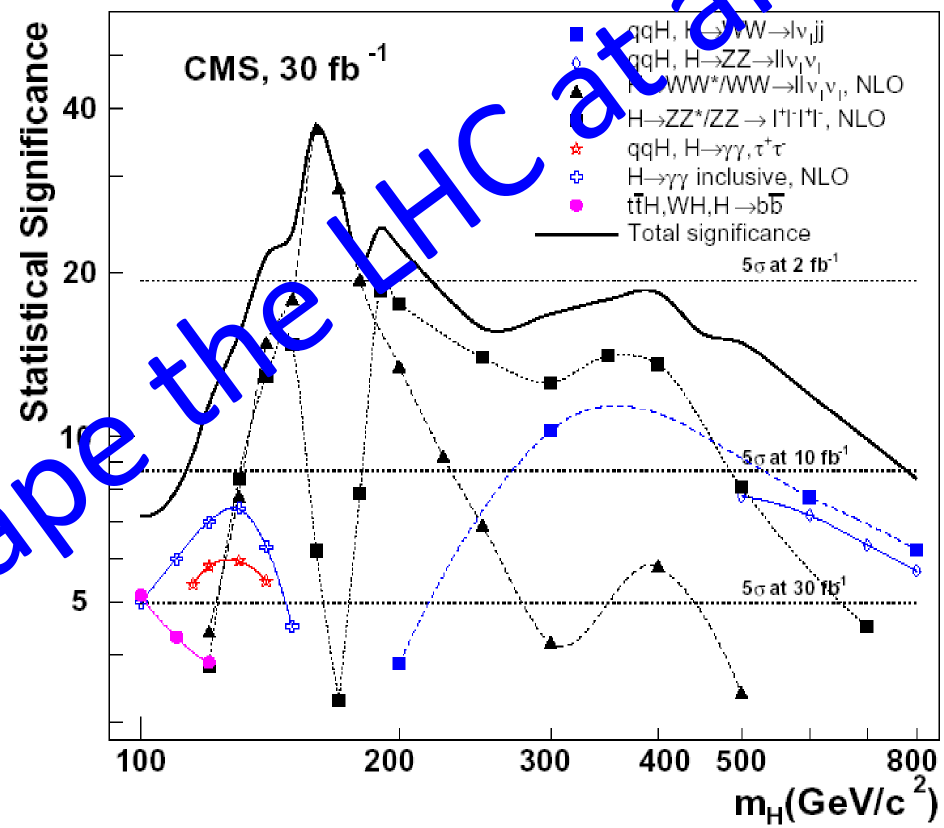
30 fb⁻¹ : 5 σ discovery combining all channels for M_H > 114 GeV;





CMS vs ATLAS





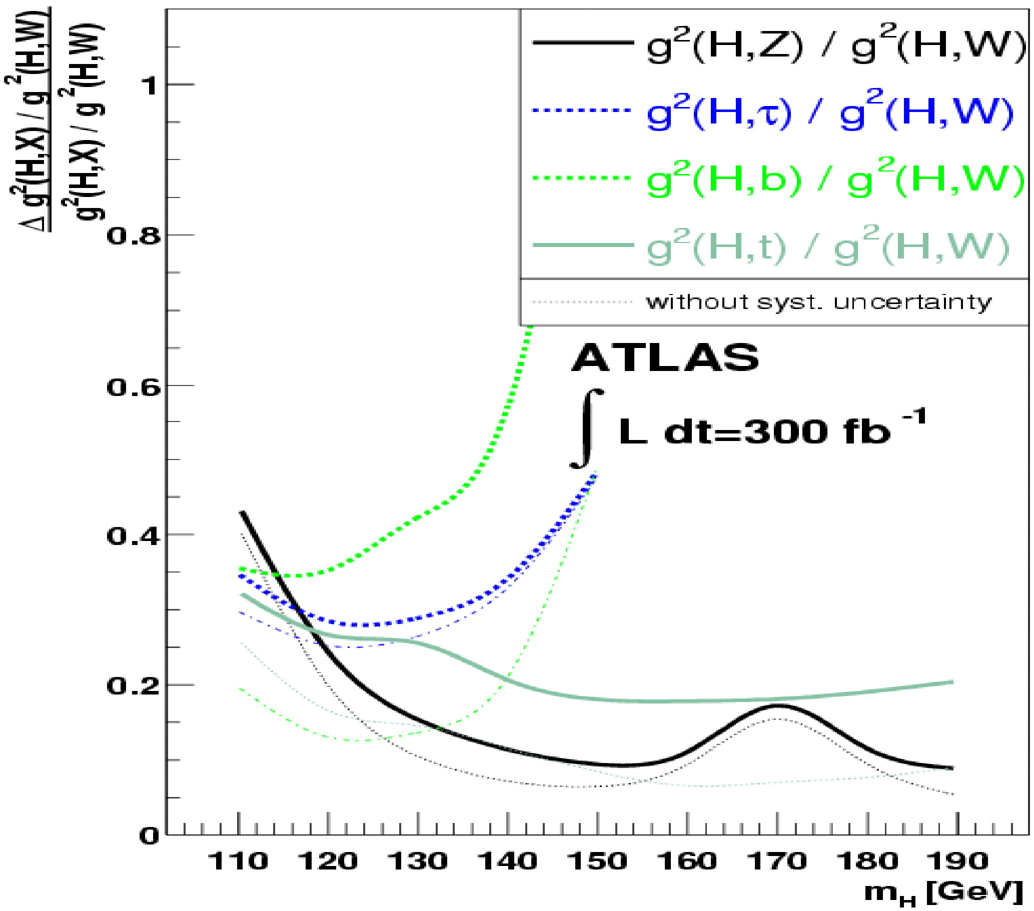
Higgs can not escape the LHC at all.

Benchmark luminosities:

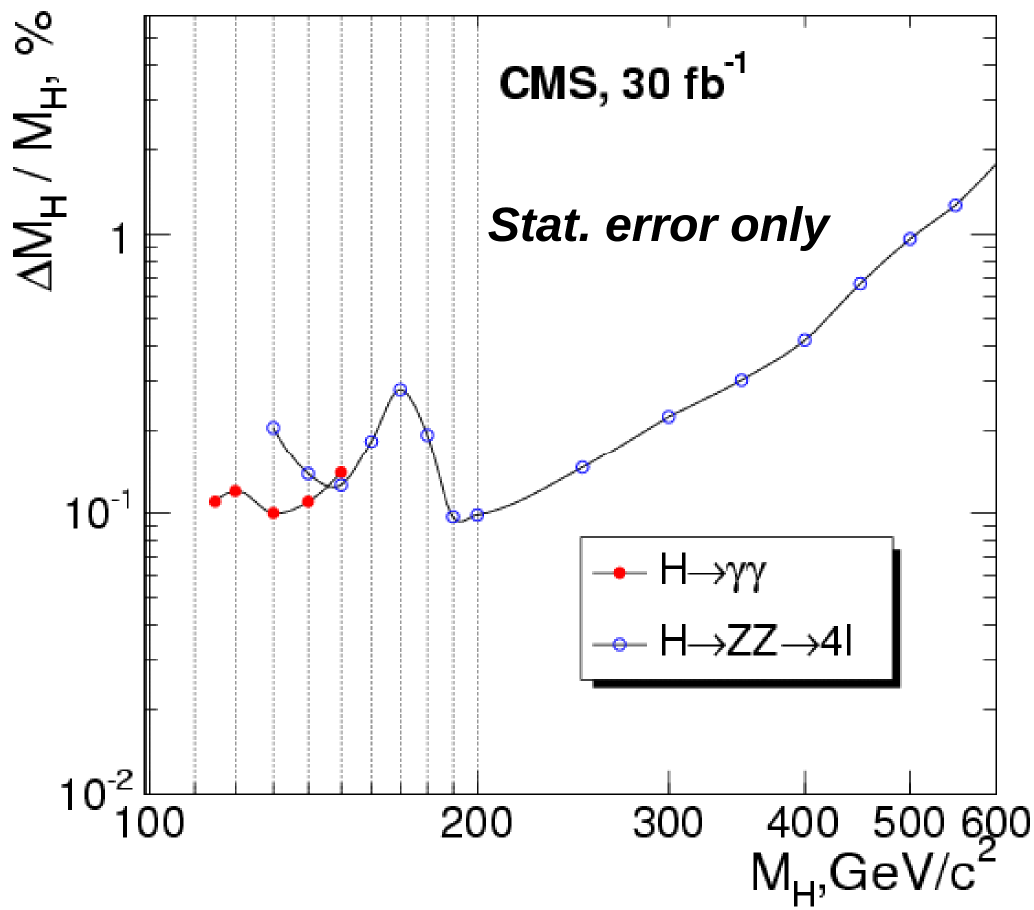
- $0.2\ fb^{-1}$: exclusion limits will start carving into SM Higgs x-section
- $1\ fb^{-1}$: discoveries become possible if M_H~170 GeV
- $10\ fb^{-1}$: SM Higgs is discovered (or excluded) in full range

Higgs Coupling measurement

ATL-PHYS-PUB-2003/030

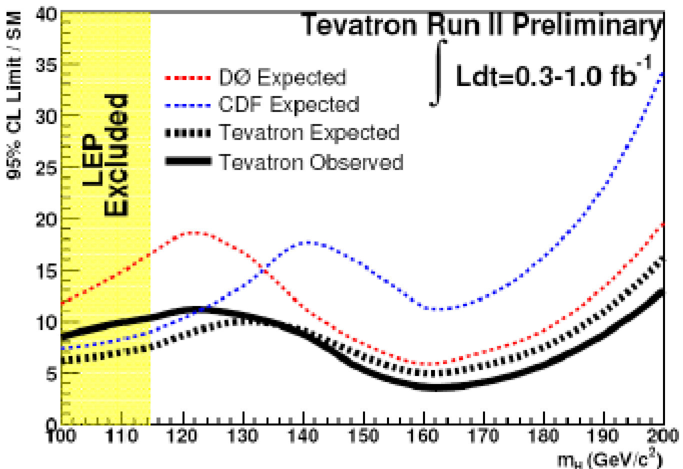


Higgs Mass Accuracy



Tevatron

search at Tevatron:
most sensitive around
160 GeV (H->WW)



(95% exclusion limit on Higgs production cross section normalized to SM cross section)

Summer 08 combined results of CDF and D0
H with 170 GeV/c^2 is excluded at 95 % C.L.