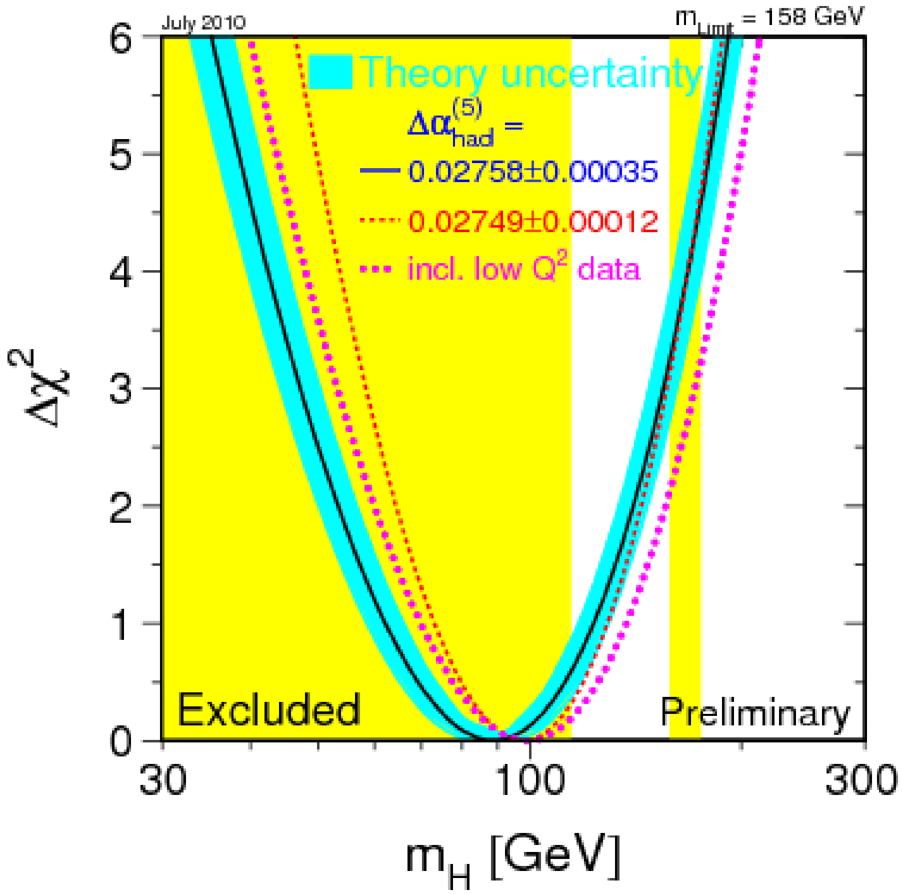
Higgs Boson Search



Indirect limits on Higgs mass from fits to electro-weak data:

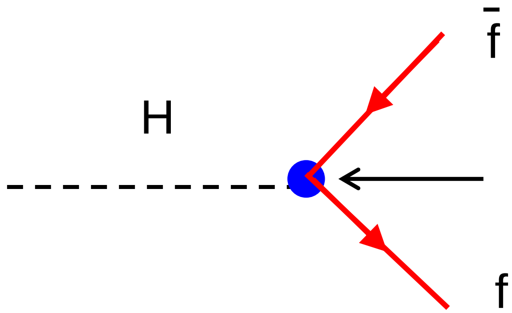
$m_H = 89\ ^{+35}_{-26}$ GeV

$m_H < 158$ GeV (95% CL)

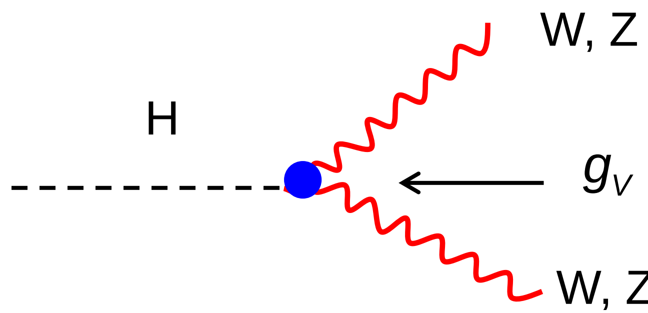
Status July 2010

In the following we will discuss the direct searches for the Higgs boson:
LEP (e^+e^- collisions) and Tevatron/LHC ($p\bar{p}$ / pp collisions)

Higgs decay



$$g_f = \frac{\sqrt{2}\, m_f}{\upsilon}$$



$$g_V = \frac{2 m_V^2}{\upsilon}$$

Higgs decay widths / branching ratios:

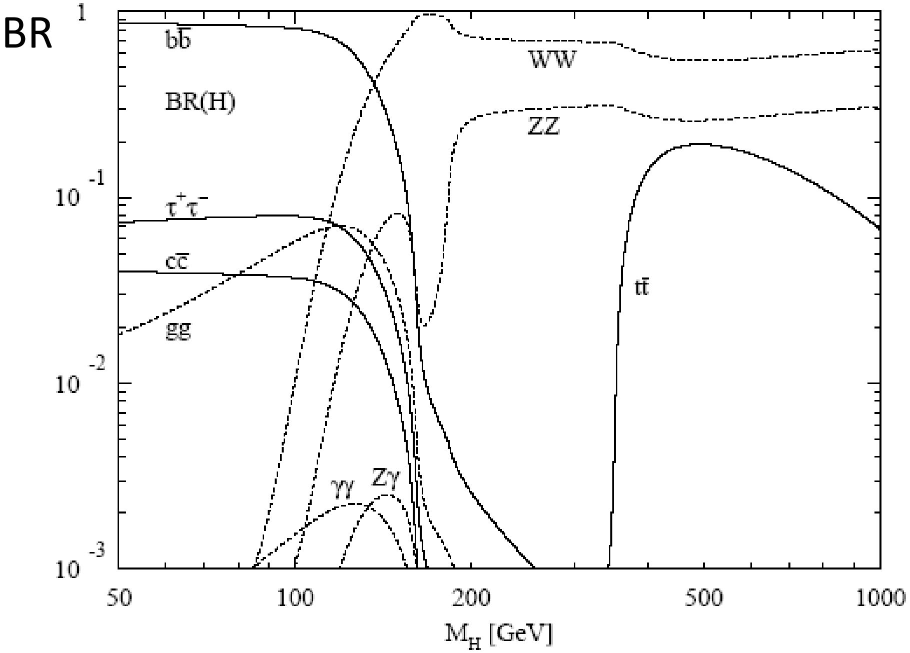
$$\Gamma(H \to f\bar{f}) = N_c \frac{G_F m_f^2 M_H}{4\pi\sqrt{2}} \times (\text{kinematical factor})$$

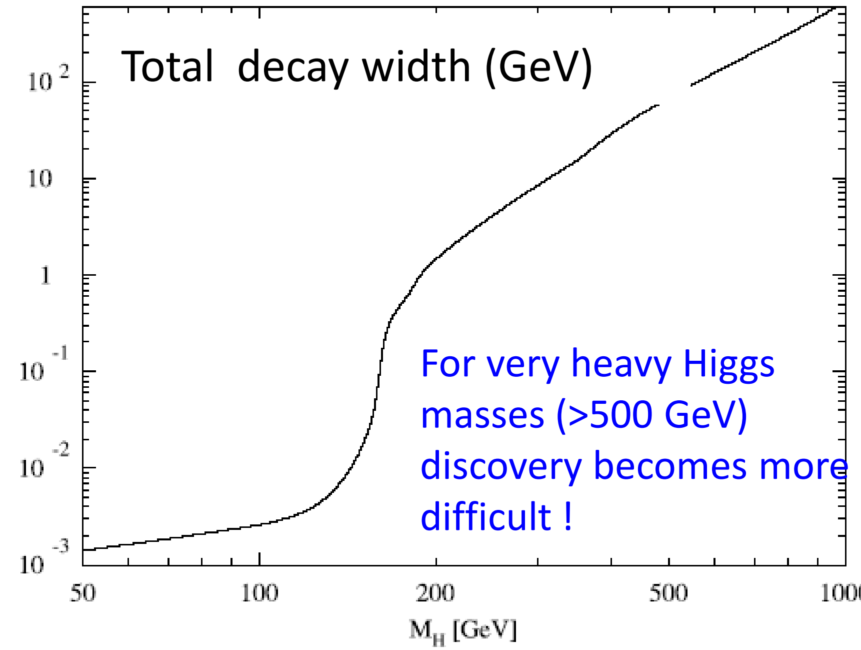
Higgs couples preferentially to heaviest fermions

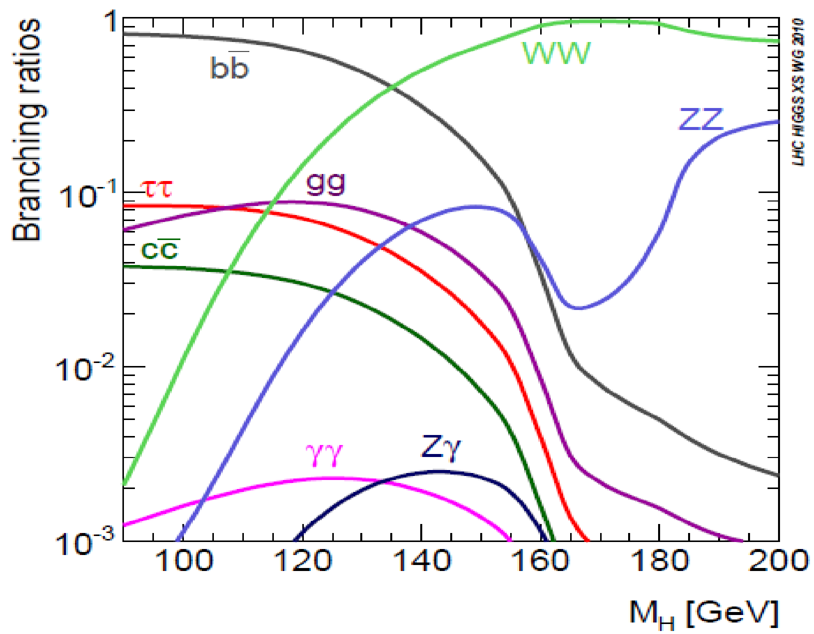
$$\Gamma(H \to WW, ZZ) \sim \delta_V \frac{G_F M_H^3}{16\pi\sqrt{2}} \times (\text{kinematical factor})$$

… or to heavy bosons. (At LEP not accessible)

$$\delta_V = 2, 1 (W, Z)$$

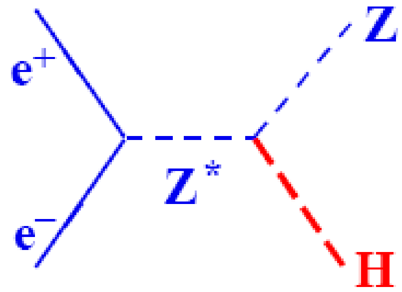

BR
BR(H)
bb̄
WW
ZZ
τ+τ−
cc̄
gg
tt̄
γγ
Zγ
1
10 -1
10 -2
10 -3
50
100
200
500
1000
M_H [GeV]

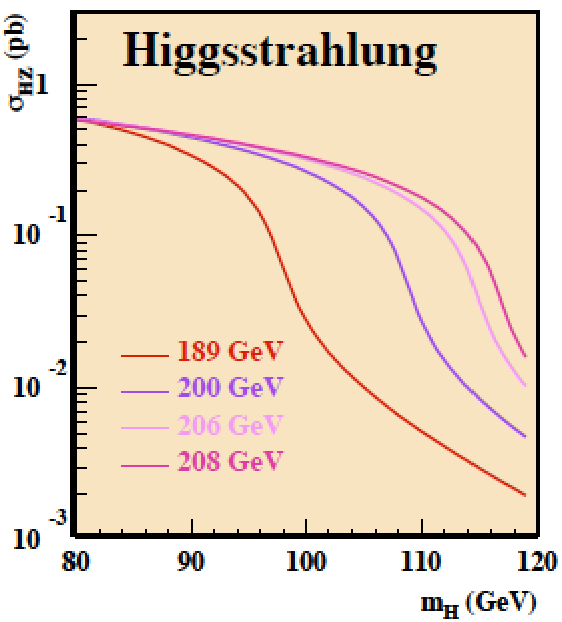

Total decay width (GeV)
For very heavy Higgs masses (>500 GeV) discovery becomes more difficult !
10 2
10
1
10 -1
10 -2
10 -3
50
100
200
500
1000
M_H [GeV]


Branching ratios
bb̄
WW
ZZ
ττ
gg
cc̄
γγ
Zγ
LHC HIGGS XS WG 2010
1
10-1
10-2
10-3
100
120
140
160
180
200
M_H [GeV]

1. Higgs Search at LEP (e^+e^- at $\sqrt{s}$=91, 160…206 GeV)

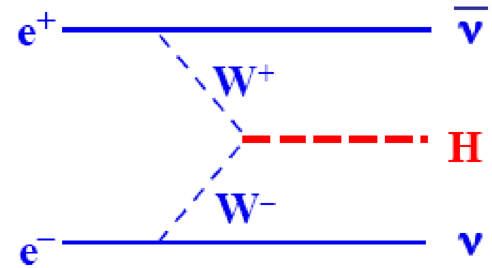
Higgs - Bremsstrahlung

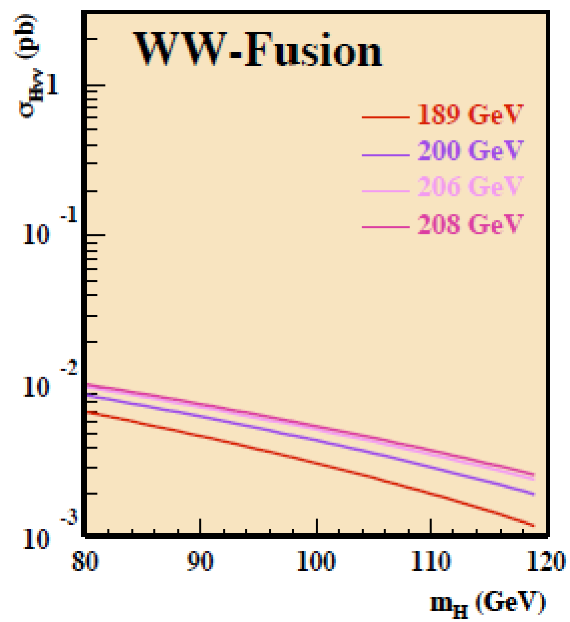




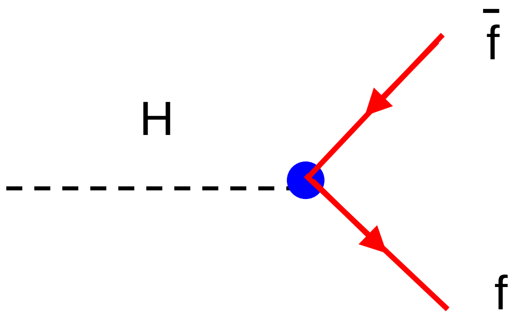
Mass reach: $m_H < \sqrt{s} - 91$ GeV

WW - Fusion



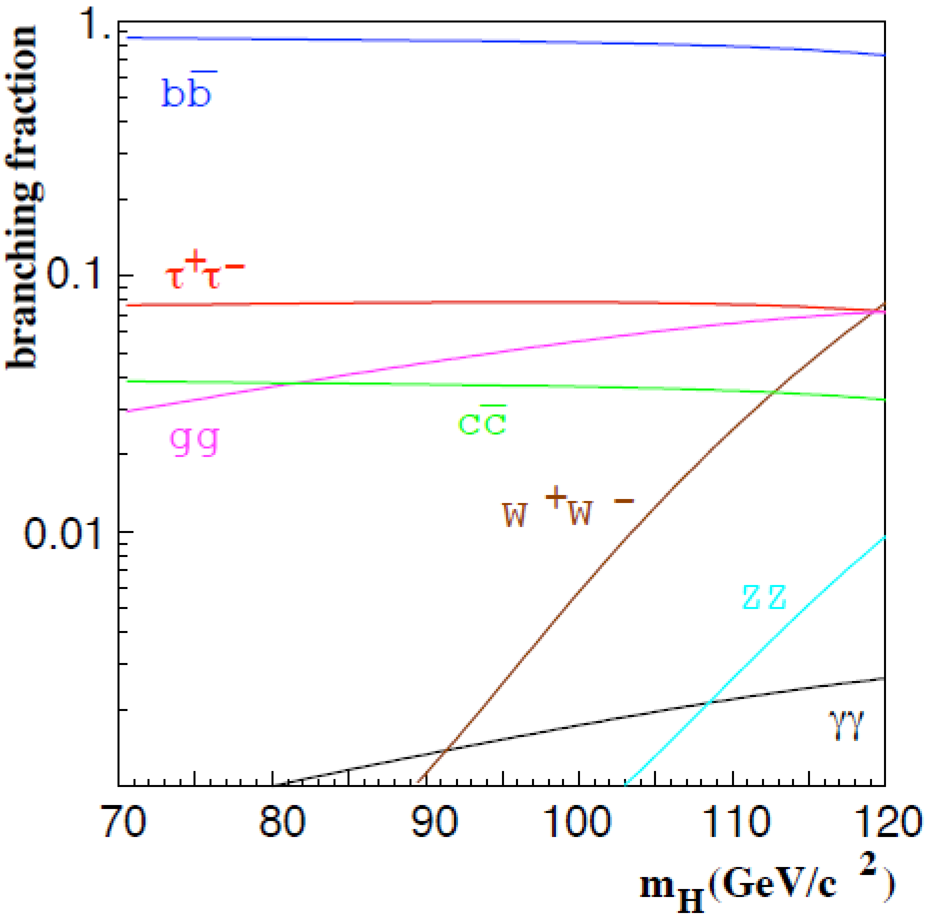


Relevant Higgs decays at LEP:



$$\Gamma(H \to f\bar{f}) \sim \frac{G_F m_f^2 M_H}{4\pi\sqrt{2}}$$

H $\to$ b$\bar{\text{b}}$ is dominant.



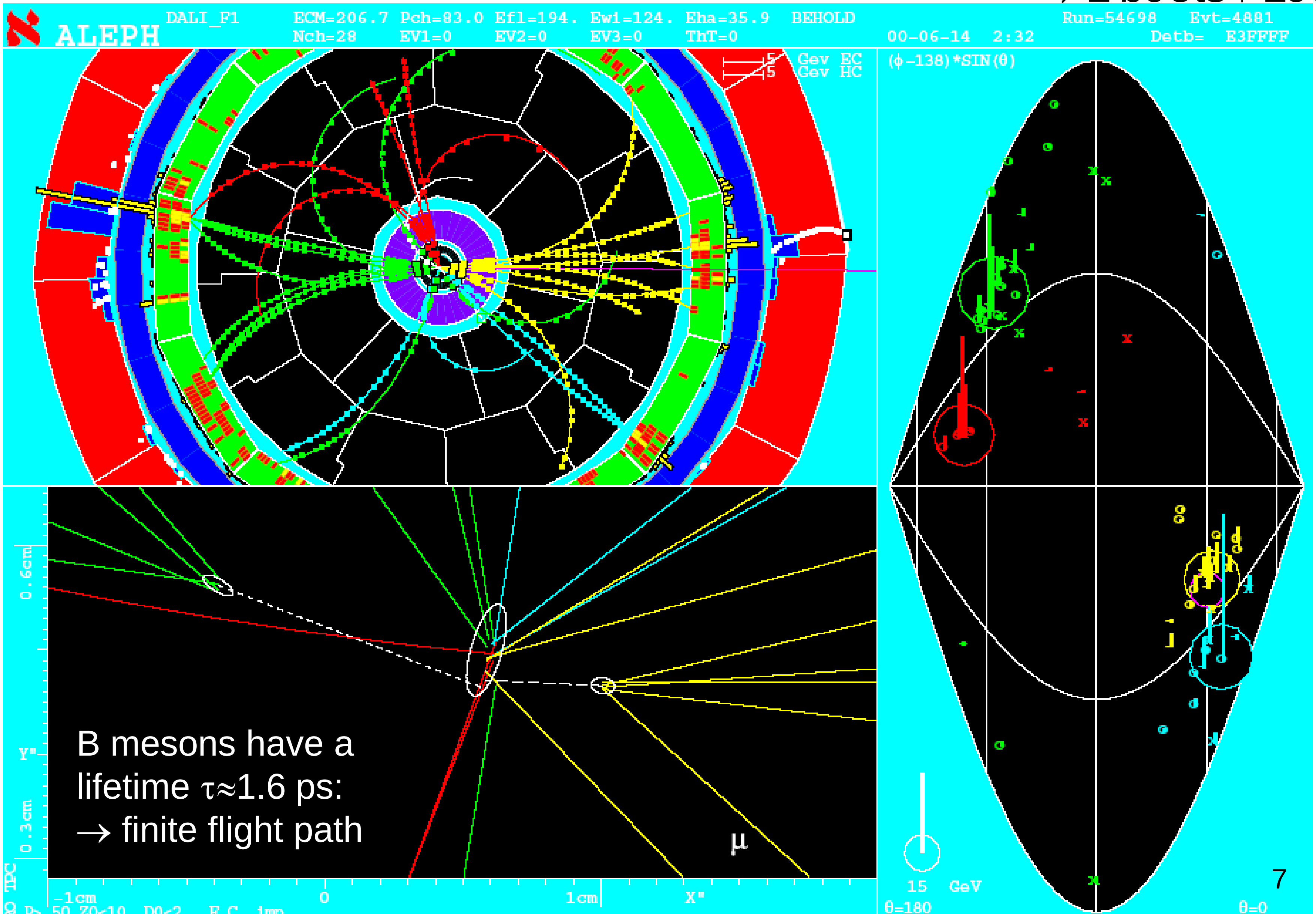
Higgs signatures at LEP: Z* → ZH (dominant)

Process	signature		background
$H \to b\bar{b}$, $Z \to q\bar{q}$	4-jets	51%	WW → qqqq ZZ → qqqq QCD 4-jets
$H \to b\bar{b}$, $Z \to \nu\bar{\nu}$	missing energy	15%	WW → qqlν ZZ → bbνν
$H \to b\bar{b}$, $Z \to \tau^+\tau^-$	τ-channel	2.4%	WW → qqτν ZZ → bbττ ZZ → qqττ QCD low mult. jets
$H \to \tau^+\tau^-$, $Z \to q\bar{q}$	τ-channel	5.1%	
$H \to b\bar{b}$, $Z \to e^+e^-$, $\mu^+\mu^-$	lepton channel	4.9%	ZZ → bbee ZZ → bbμμ

Higgs search at LEP includes 80% of the final states, selection efficiency ~40 - 50%

Higgs candidate with M_H=114 GeV

$$e^+e^- \to H(b\bar{b})Z(q\bar{q})$$
$$\to 2\,\mathrm{bJets} + 2\mathrm{Jets}$$



Is there a Higgs at 114 GeV ?

LEP
final result

Observation:

17 candidate events

Expectation:

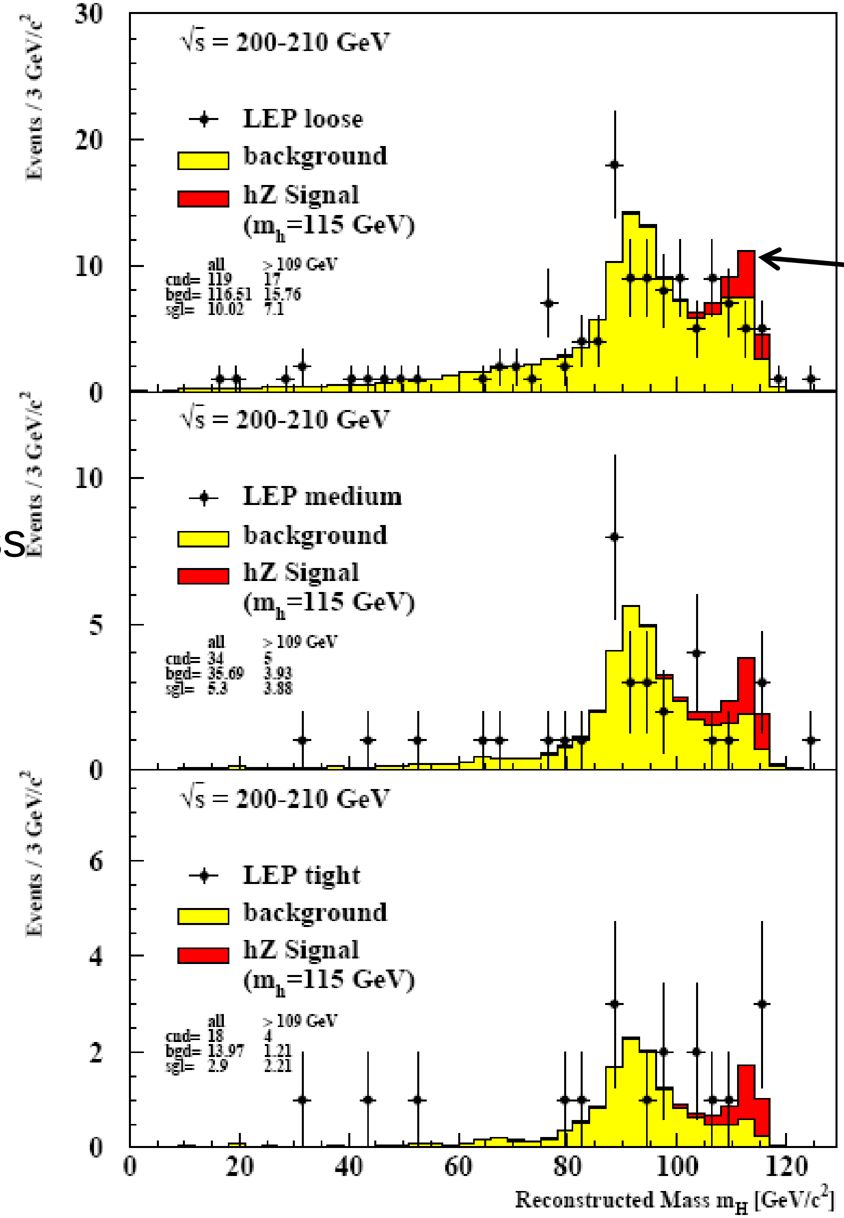
15.8 background events

8.4 signal events for $M_H = 115$ GeV

	Expt	E_{cm}	channel	M^{rec} (GeV)	$\ln(1+s/b)$ @ 115 GeV
1	A	206.6	4 jet	114.1	1.76
2	A	206.6	4 jet	114.4	1.44
3	A	206.4	4 jet	109.9	0.59
4	L	206.4	Emiss	115.0	0.53
5	A	205.1	Lept.	117.3	0.49
6	A	206.5	Tau	115.2	0.45
7	O	206.4	4 jet	108.2	0.43
8	A	206.4	4 jet	114.4	0.41
9	L	206.4	4 jet	108.3	0.30
10	D	206.6	4 jet	110.7	0.28
11	A	207.4	4 jet	102.8	0.27
12	D	206.6	4 jet	97.4	0.23
13	O	201.5	Emiss	111.2	0.22
14	L	206.0	Emiss	110.1	0.21
15	A	206.5	4 jet	114.2	0.19
16	D	206.6	4 jet	108.2	0.19
17	L	206.6	4 jet	109.6	0.18

Invariant mass of LEP Higgs candidates

Tightness of cuts



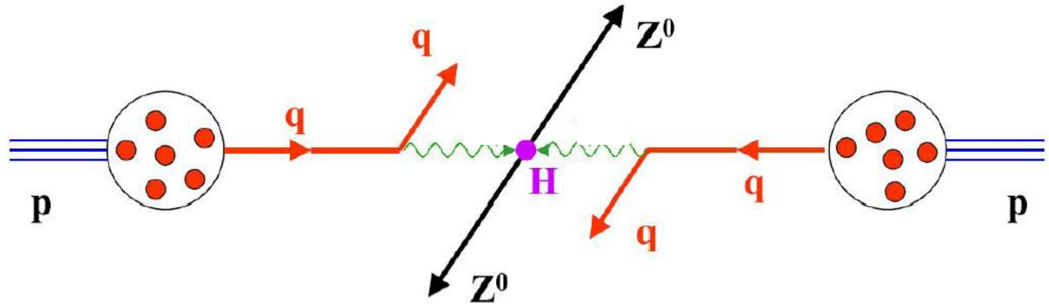
Expected Higgs signal for m_h = 115 GeV

No signal above background seen

LEP excluded a 114.4 GeV Higgs @ 95% CL

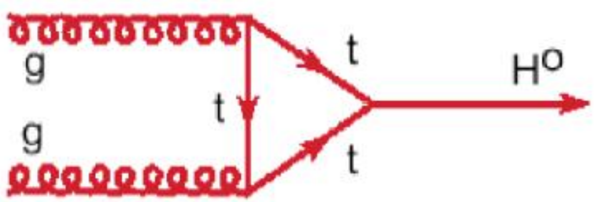
Higgs-Limit:
(200…210) GeV – m_Z = 114.4 GeV

2. Higgs Search at $p\overset{(-)}{p}$ colliders (LHC/Tevatron)

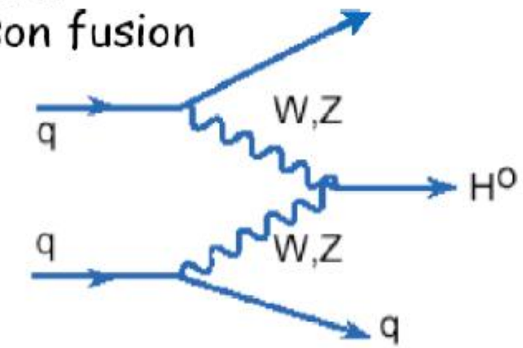


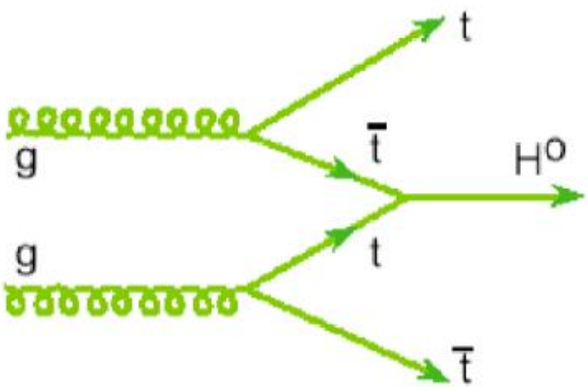
dominant at LHC

1. Gluon fusion

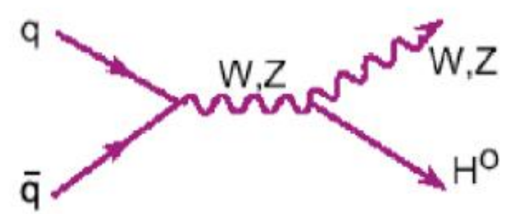


2. Vector boson fusion

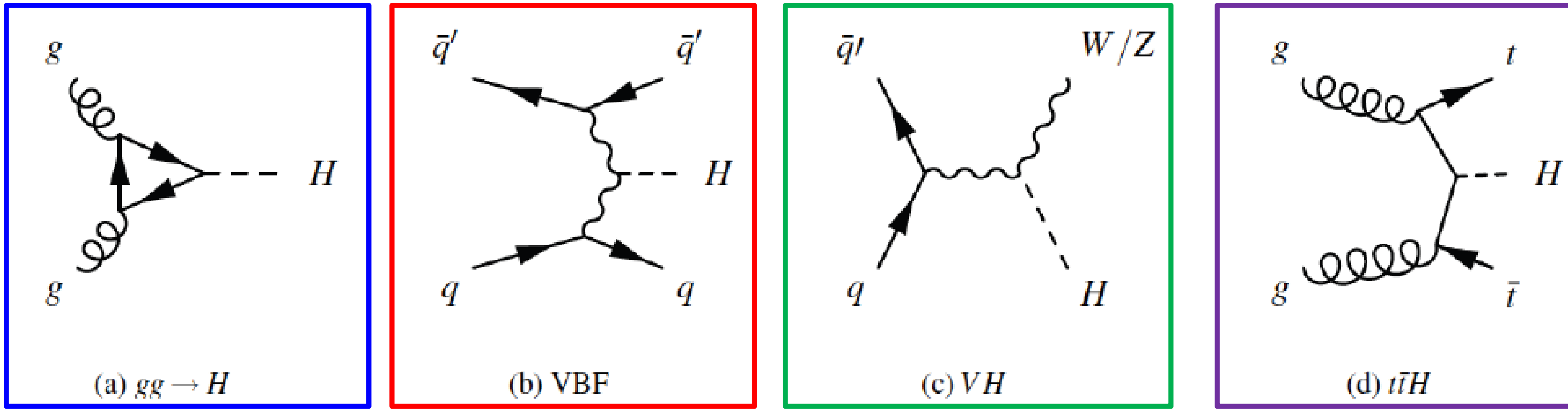




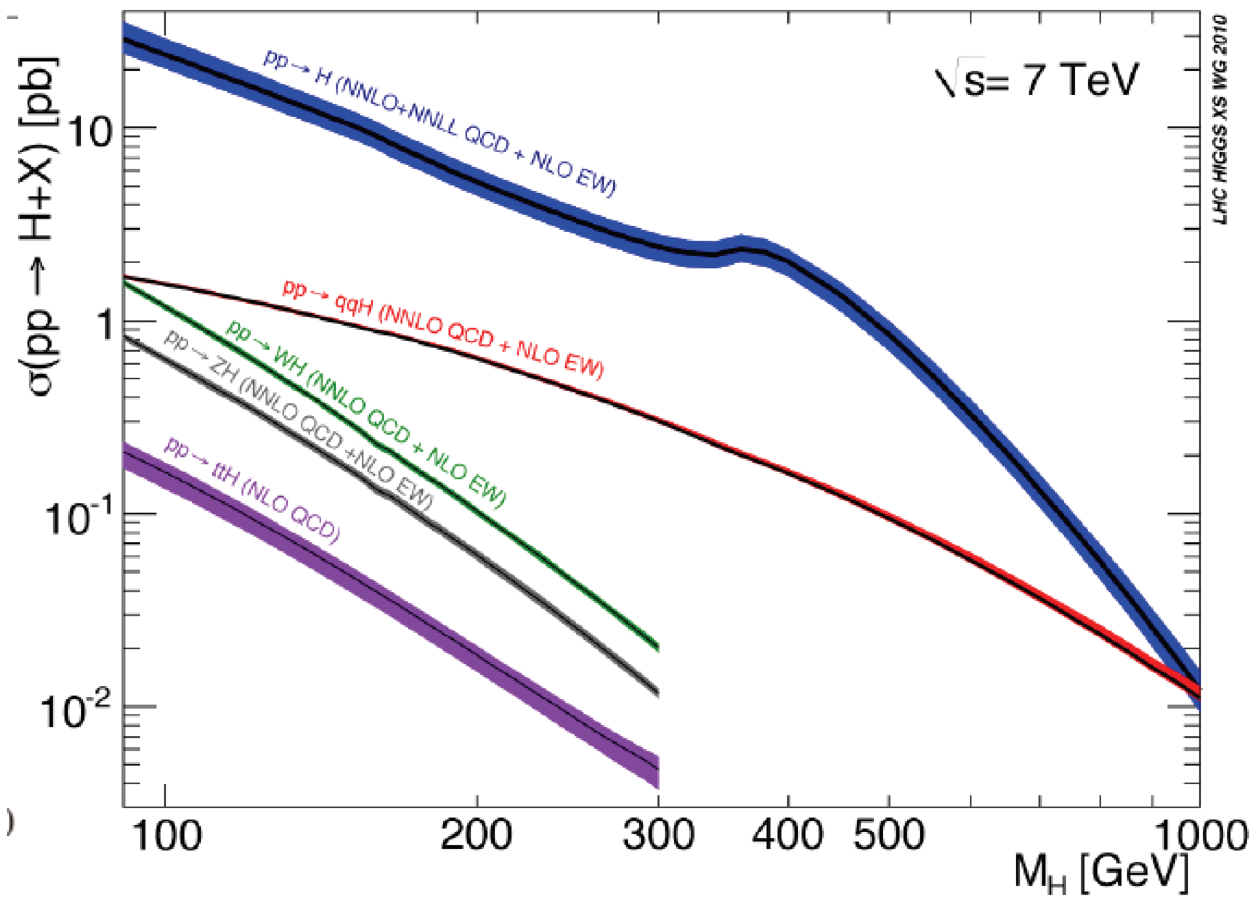
3. $t\bar{t}$-fusion



4. Associated production

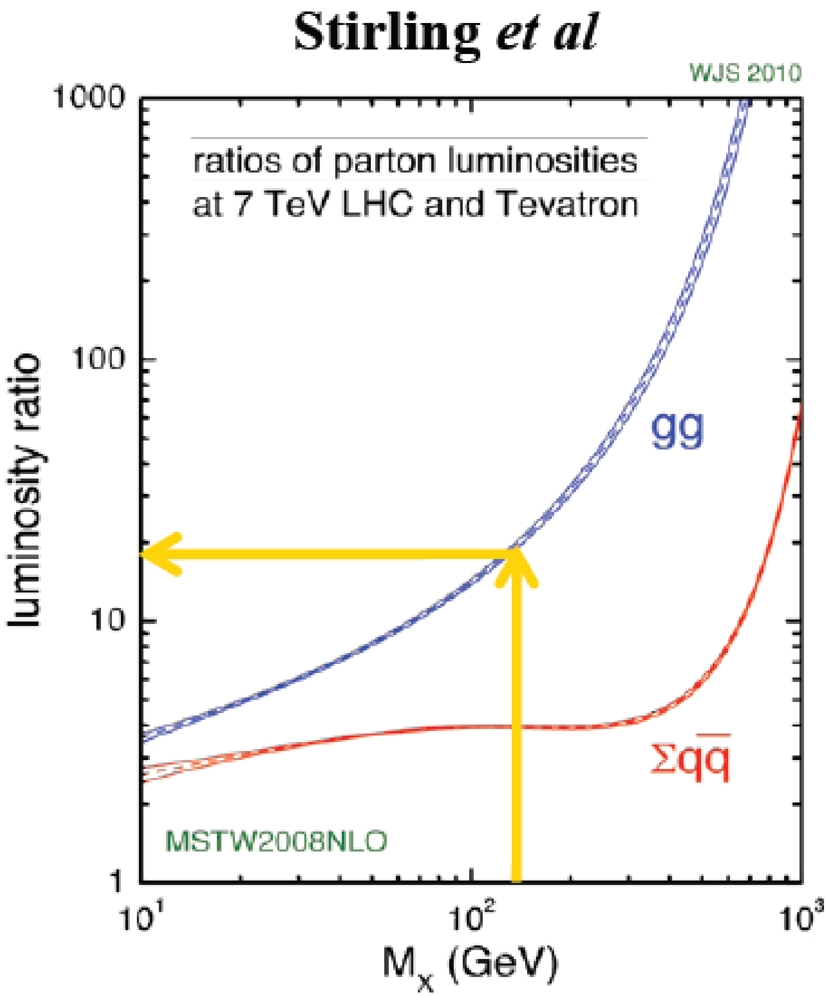


Contributions to Higgs production cross section for pp @ 7 TeV



Comparison between LHC at 7 TeV and Tevatron at 2 TeV

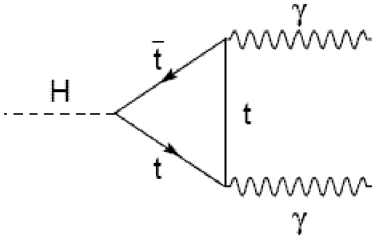
- At the same pp luminosity the effective parton-parton luminosity at LHC is by a huge factor larger.
- The larger the Higgs mass the larger the effect is.
- Example: for M_H >140 GeV, effective gg-luminosity at LHC is at least 15× larger than at Tevatron



Higgs decays relevant for searches at LHC

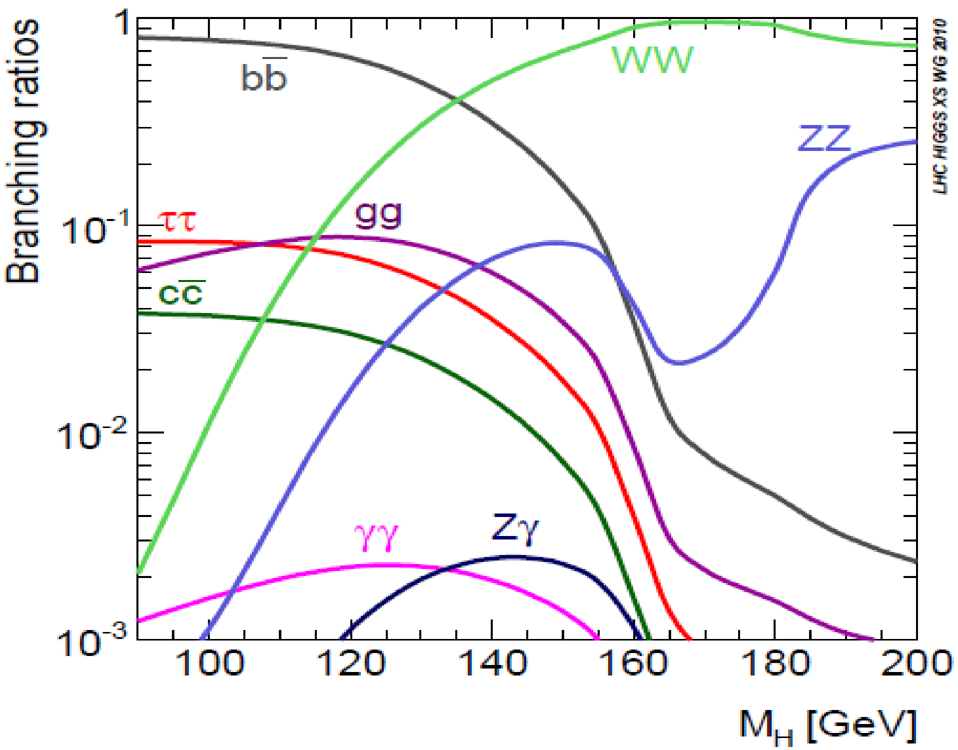
For M_H < 135 GeV:

- ~~$H \rightarrow bb$ (too much backgrd.)~~
- $H \rightarrow \tau\tau$
- $H \rightarrow \gamma\gamma$



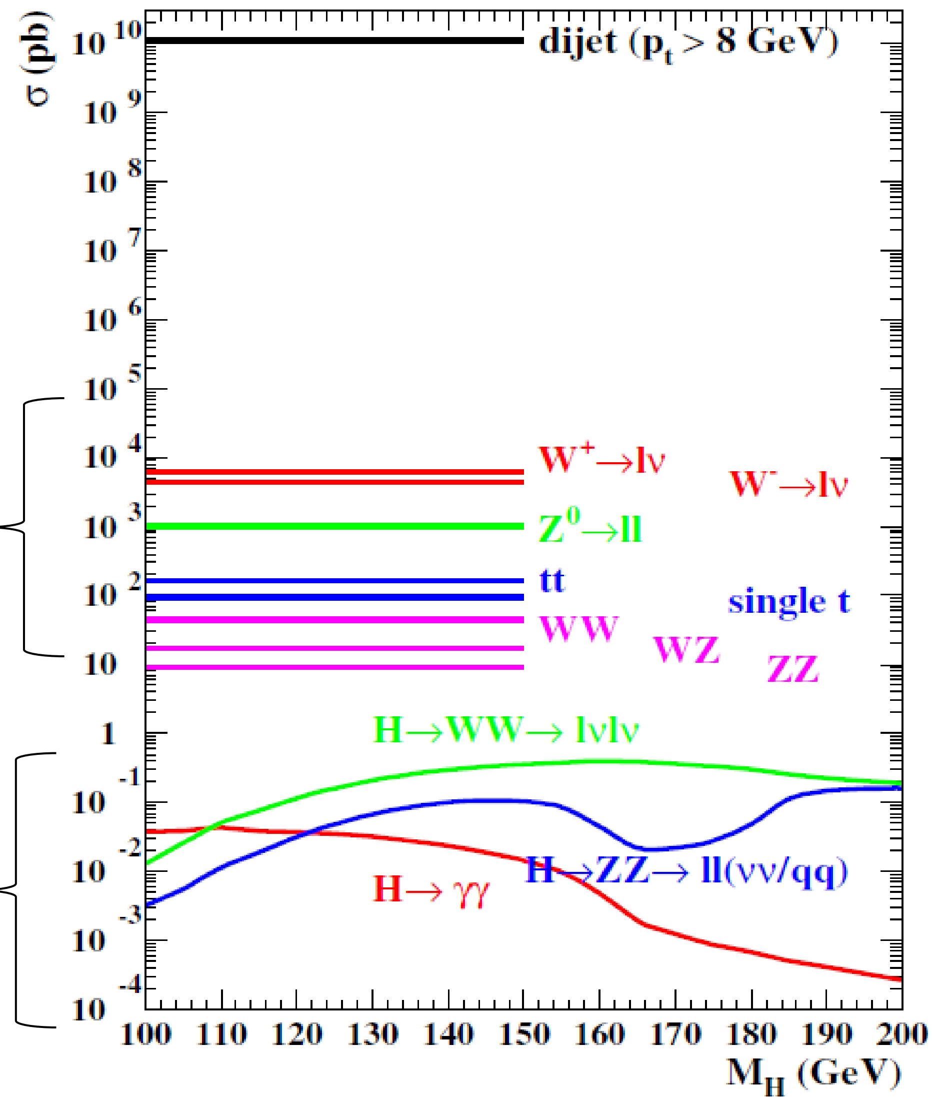
For M_H > 135 GeV:

- $H \rightarrow W W$
- $H \rightarrow Z Z$ ("golden decay")



Challenge: Tiny Signal-to-Background Ratio

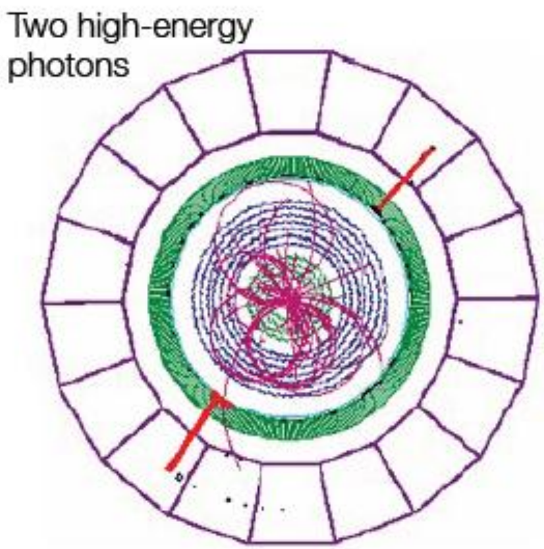
Backgrounds

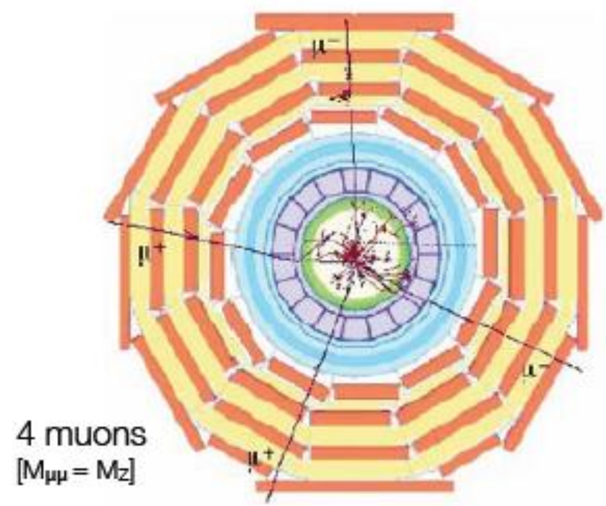


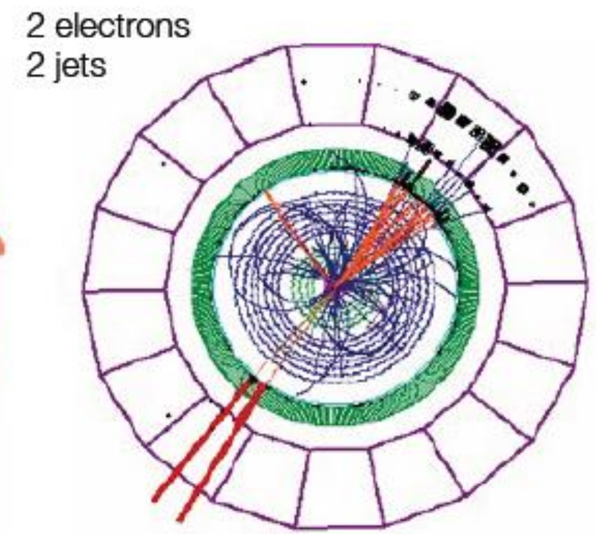
< 1 detectable Higgs boson per 10^{12} collisions

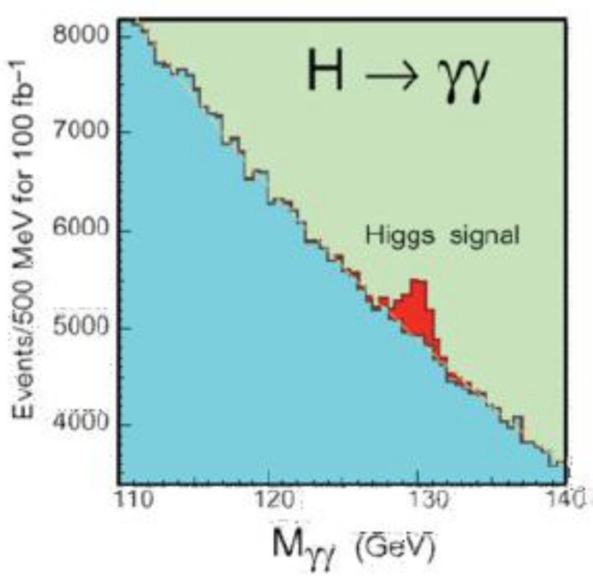
needs clean signatures

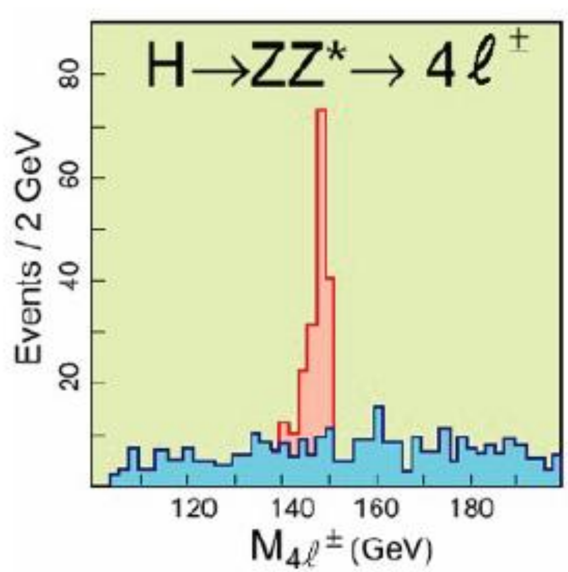
Examples for “clean” Higgs Signatures

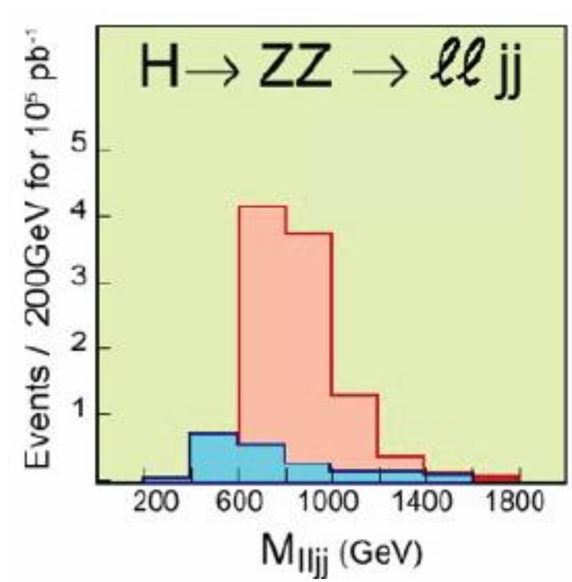




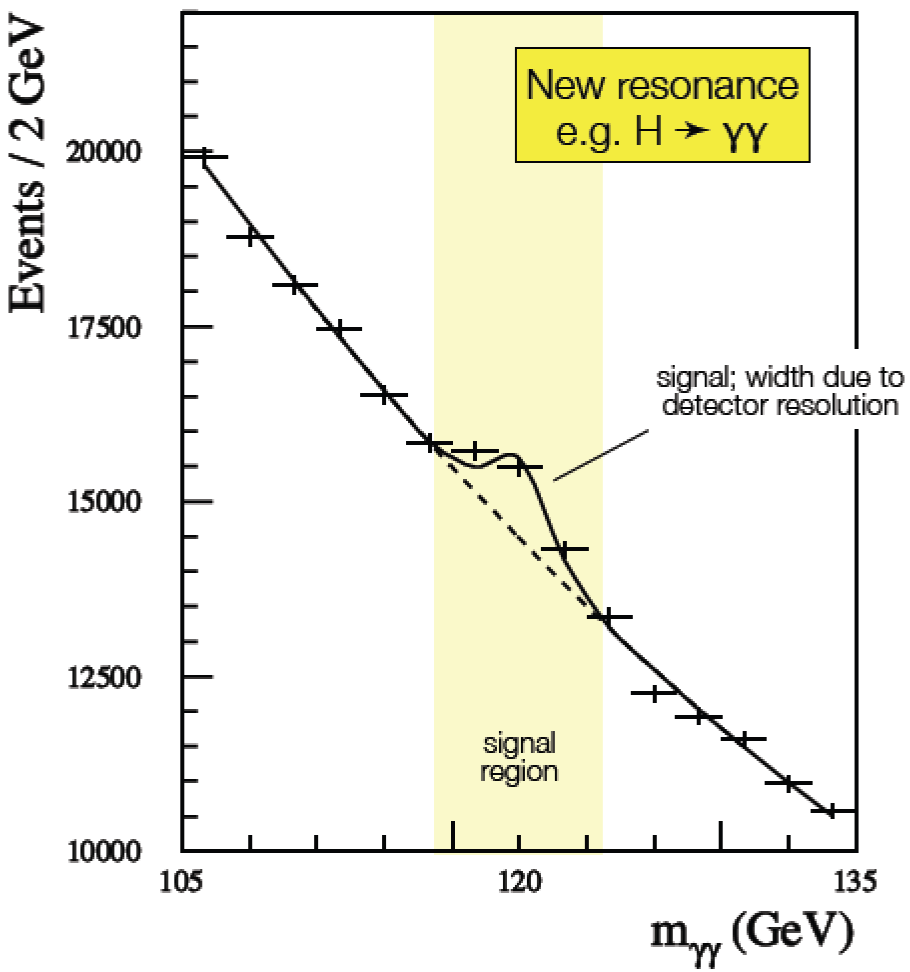








When to claim a discovery?



Signal significance:

$$S = \frac{N_s}{\sqrt{N_B + N_s}}$$

N_S = Signal evts.
N_B = Bckgr. evts.

Discovery = 5σ: (agreement between physicists)

N_s is 5 times larger than the statistical uncertainty on $N_{tot}=N_s+N_B$.

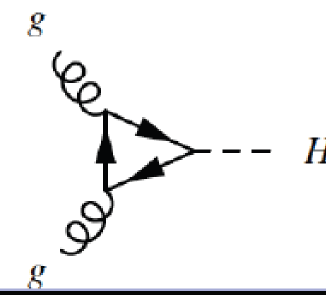
Probability for statistical fluctuation:
P-value for nσ: $1 - \text{erf}(n/\sqrt{2}.)$

Here (5σ): P-value = 6×10^{-7}

Successful Higgs Search:

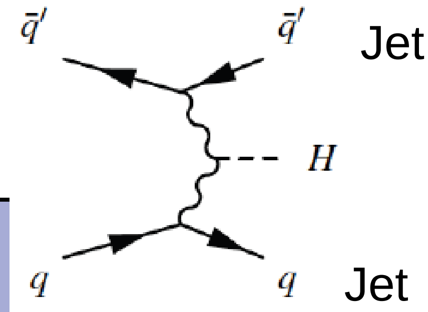
- Use decay channels w/ small backgrounds
- Maximize signal resolution
- Maximize luminosity

gg → Higgs Signatures

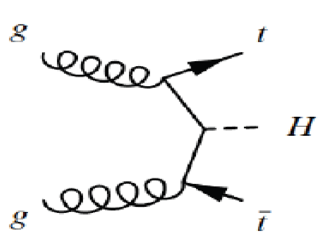


Channel	LHC Potential
$gg \to H \to bb$	Huge QCD background ($gg \to bb$); extremely difficult
$gg \to H \to \tau\tau$	Higgs with low p_T, hard to discriminate from background; problematic
$gg \to H \to \gamma\gamma$	Small rate, large combinatorial background, but excellent determination of m_H (CMS: crystal calorimeter)
$gg \to H \to WW$	Large rate, but 2 neutrinos in leptonic decay, Higgs spin accessible via lepton angular correlations
$gg \to H \to ZZ$	$ZZ \to 4\mu$: "gold-plated" channel for high-mass Higgs (ATLAS: muon spectrometer)

WBF → Higgs Signatures

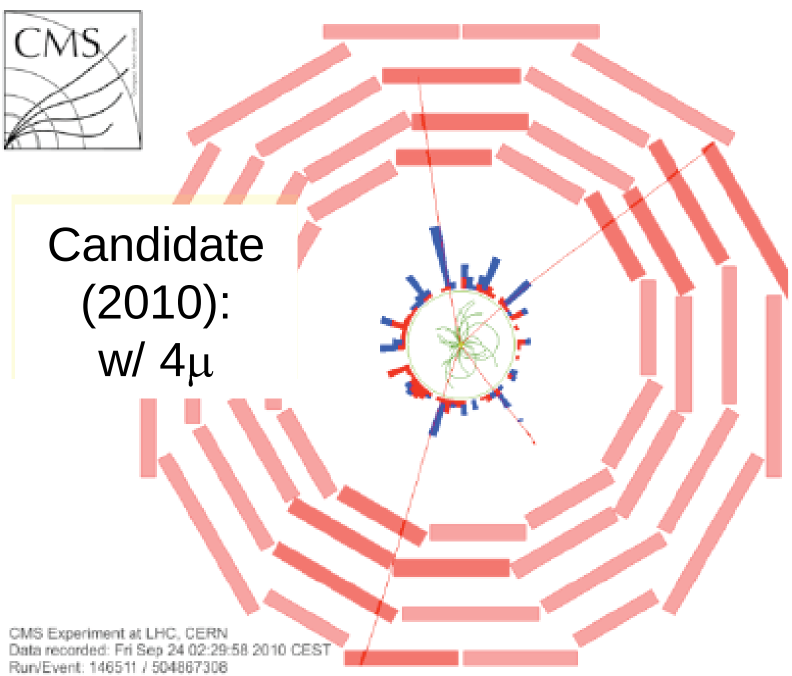


Channel	LHC Potential
qq ➛ qq H [with H ➛ bb]	Very large QCD background (gg/qq ➛ bbqq); still very difficult
qq ➛ qq H [with H ➛ ττ]	Higher p_T than direct channel; interesting discovery channel for m_H < 135 GeV
qq ➛ qq H [with H ➛ γγ]	Most likely combined with gg ➛ H ➛ γγ to inclusive diphoton signal
qq ➛ qq H [with H ➛ WW]	Additional background suppression w.r.t. direct channel; interesting discovery channel for m_H > 135 GeV
gg ➛ ttH [with H ➛ bb]	Top-associated production; Seemed very promising, but overwhelmed by SM ttbb production



Search for H→ZZ→4 Leptons (“golden decay”)

Candidate (2010): w/ 4μ



$P_t^{\mu 1} = 48.1$ GeV

$P_t^{\mu 2} = 43.4$ GeV

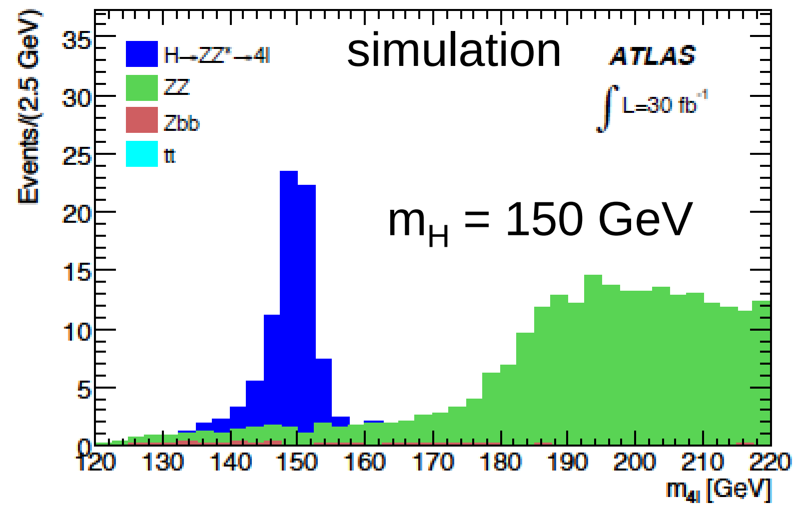
$P_t^{\mu 3} = 25.9$ GeV

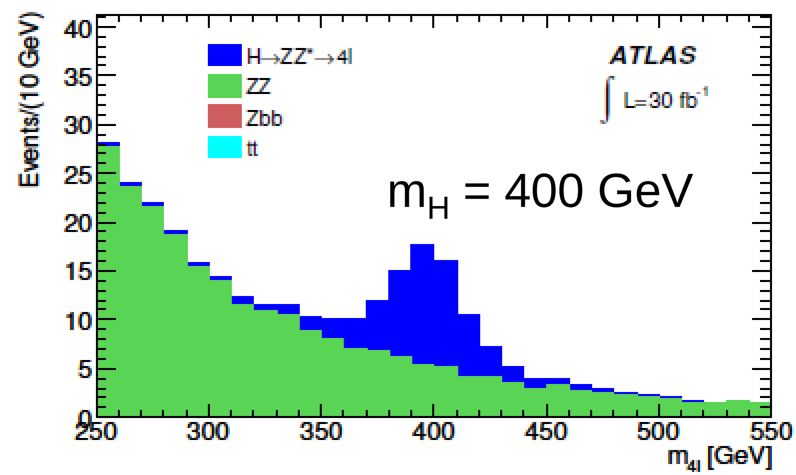
$P_t^{\mu 4} = 19.6$ GeV

$M_{\mu 1 \mu 2} = 92.15$ GeV

$M_{\mu 3 \mu 4} = 92.24$ GeV

$M_{4\mu} = 201$ GeV





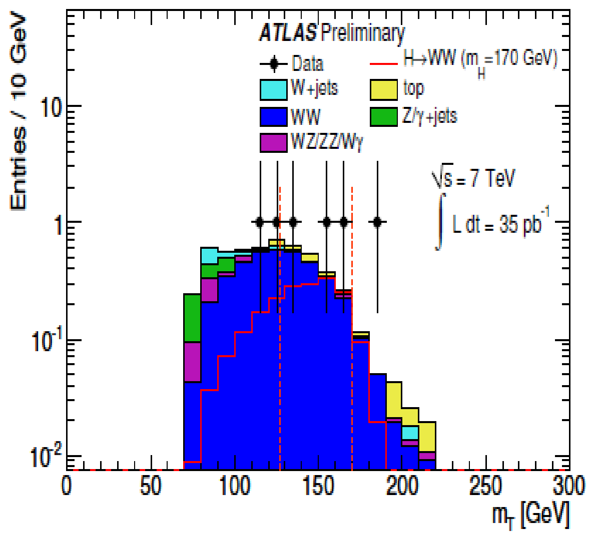
Statistics of 2010 data to low to set limits from the 4-lepton channel.
H→ZZ → llνν, llqq have higher sensitivity.

Excellent prospect in the range between 130 … 600 GeV

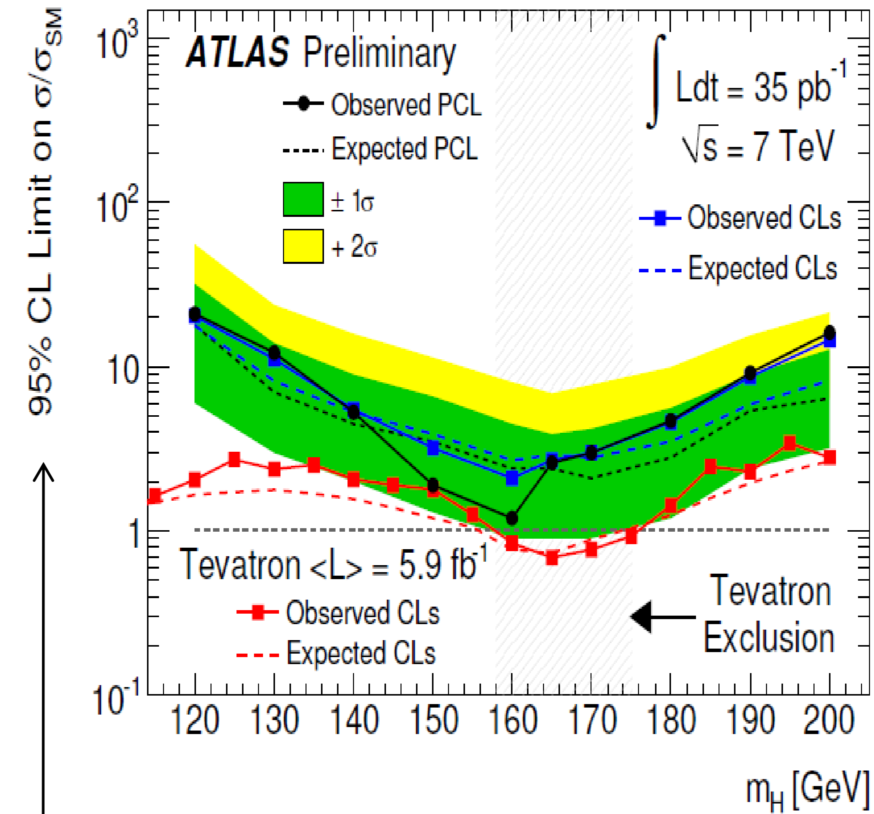
Search for H→WW→ l ν l ν (ATLAS w/ 35 pb^{-1})

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

0 Jet



	0 jet	1 jet	2jet
Data	3	1	0
BG	1.7 0.3	1.3 0.5	0.02 0.03

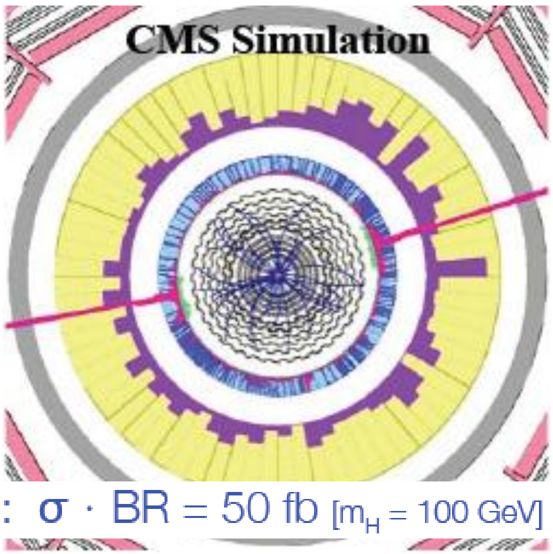


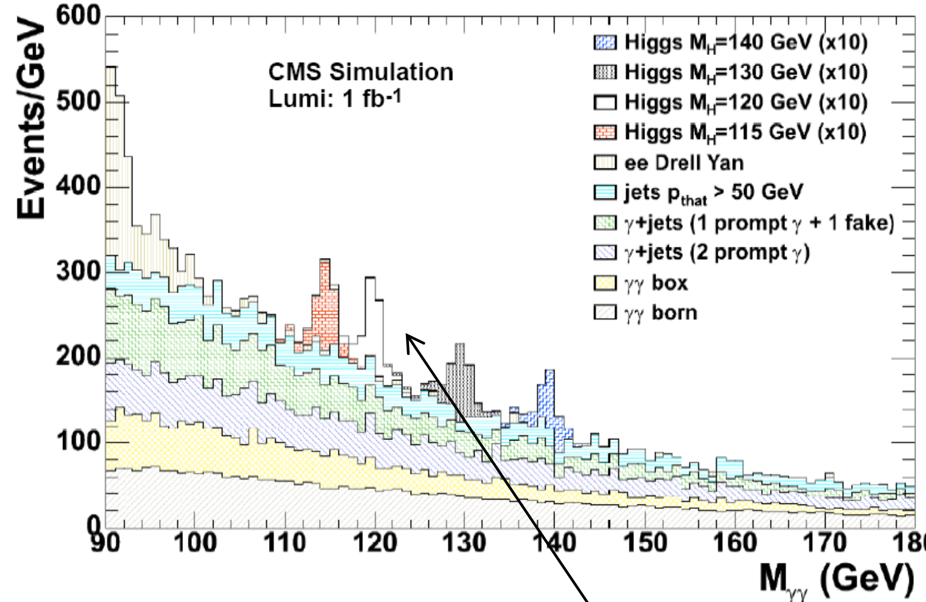
Limit on cross section normalized to SM Higgs cross section (includes BR)

ATLAS:
1.2 x SM cross section σ_{SM}
excluded at M_H = 160 GeV

ATLAS, M. Schumacher, Moriond 2011.

Search for H → γγ (for 114 GeV < m_H < 140 GeV)





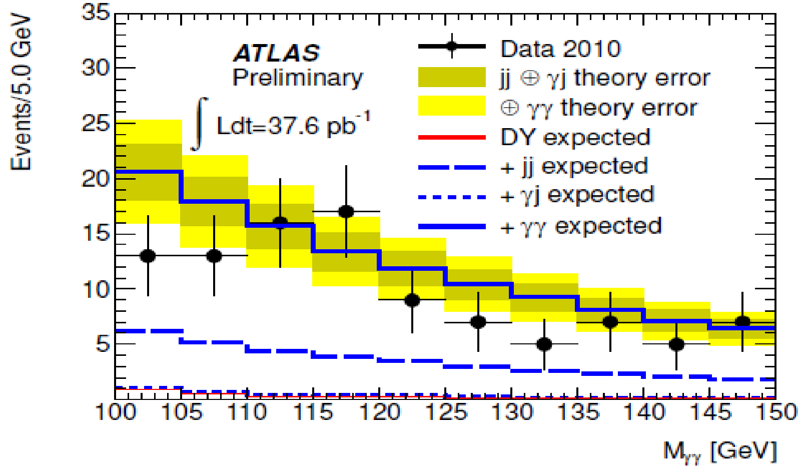
Signal shown scaled with factor x10!

Main backgrounds:
- 2γ production: irreducible background
- γj and jj production: reducible background
  jet rejection of > 10^3 is required

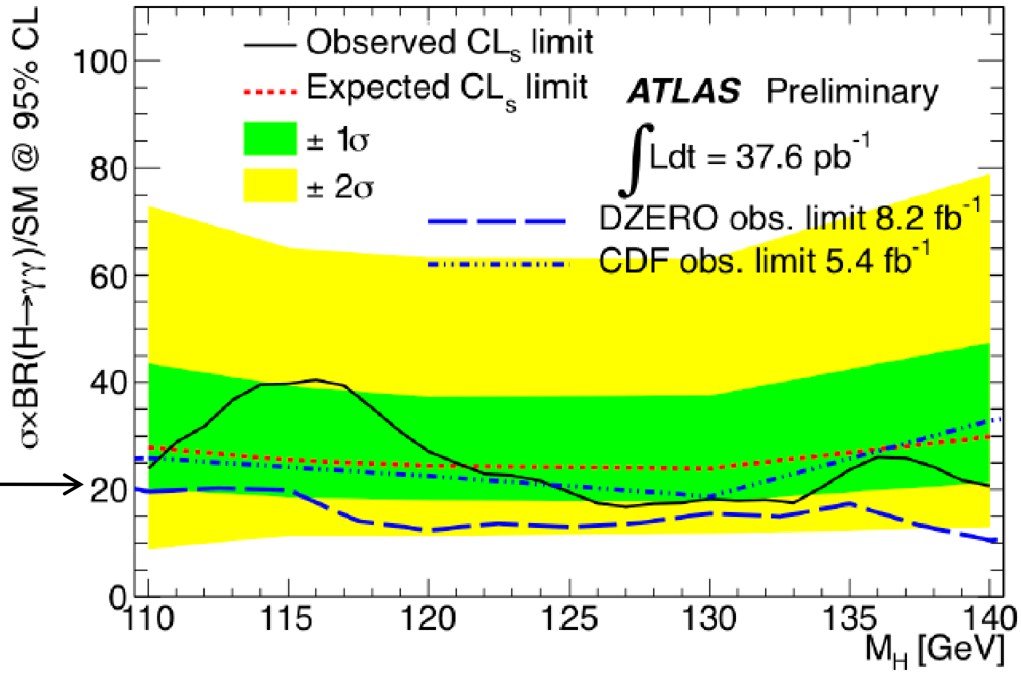
demands excellent calorimetry

Needs excellent detector calibration and a lot of statistics!

H→γγ search:



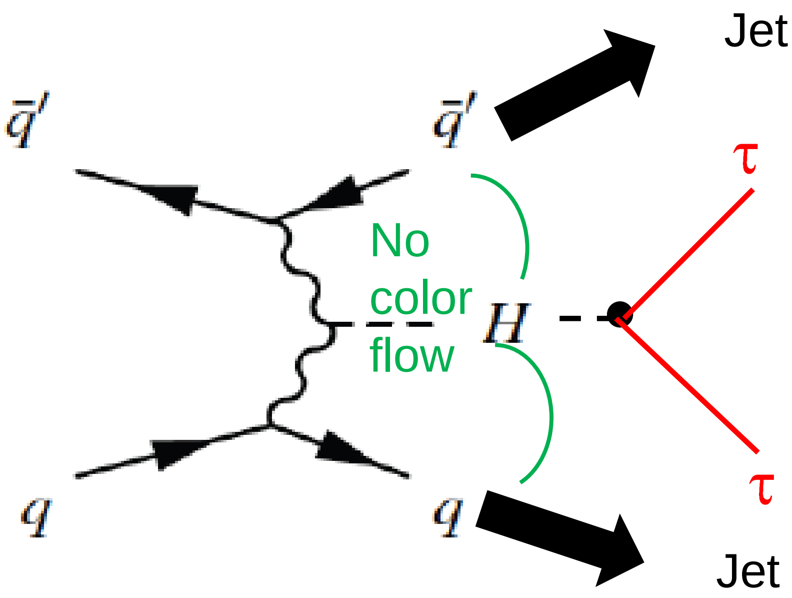
20× Standard Model

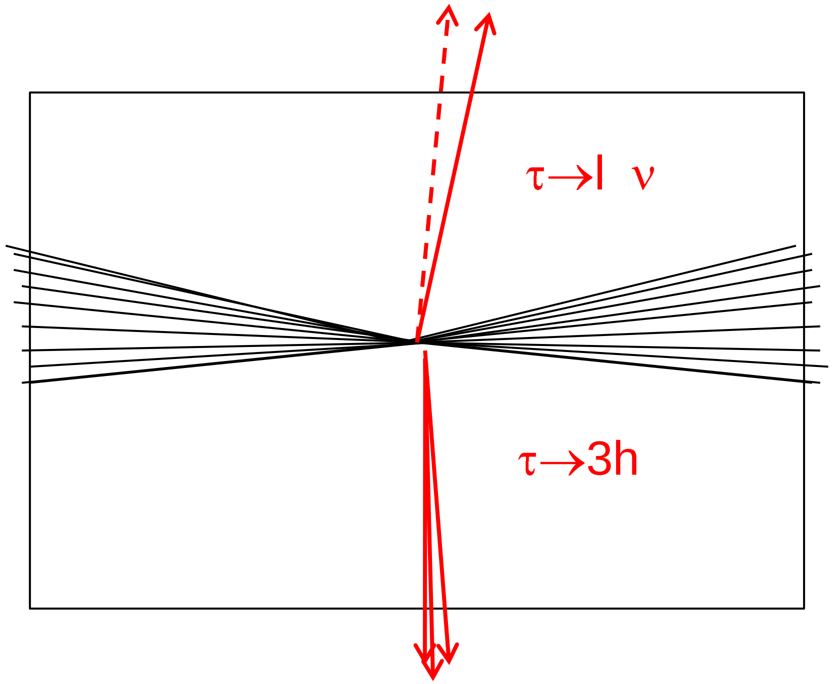


Although already compatible with Tevatron the current ATLAS limits provide no constraints for the Higgs search.

WBF → H → ττ → (lν) τ_{Had}

115 GeV < m_H < 145 GeV





Forward jets help to suppress backgrounds.

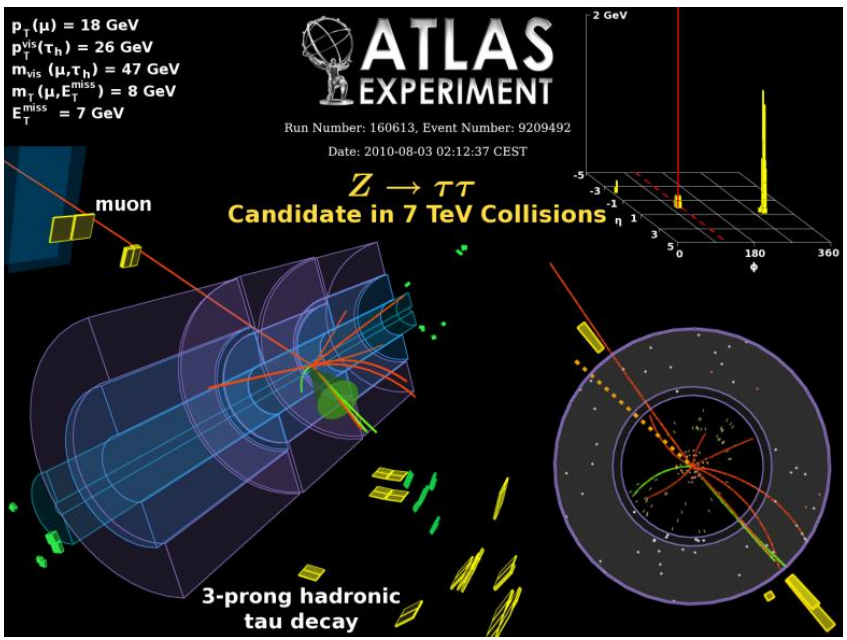
Status of $H \to \tau\tau \to (l\nu)\ \tau_{Had}$ search (gg-fusion)

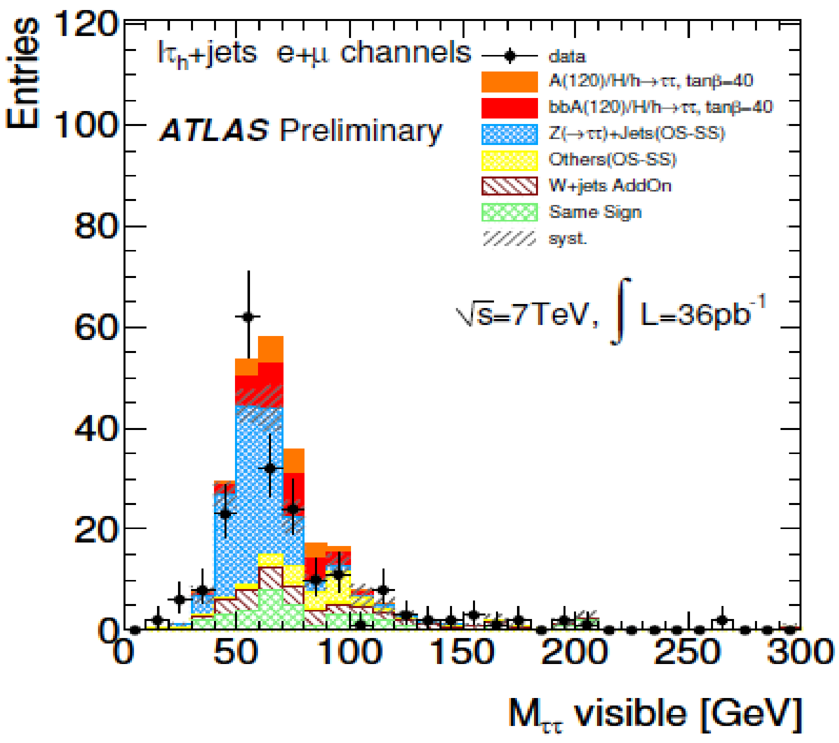
Channel covers also SUSY Higgs:
H here stands for “neutral Higgs boson”.

Backgrounds:

- irreducible: $Z \to \tau\tau$, $tt \to l\tau_{had} X$
- reducible: W+jets,tt,$Z \to ll$, ..

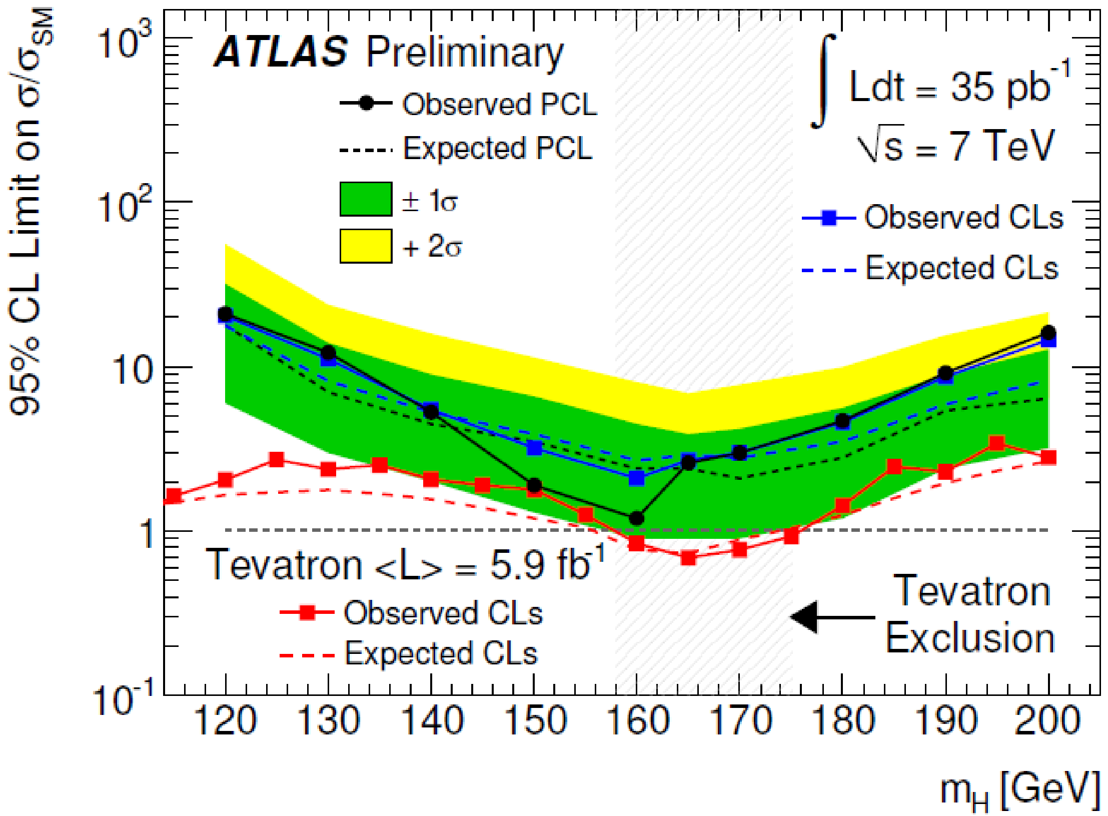
So far no jets required: statistics to low $\to$ no serious limits for SM-Higgs.





Status of Higgs Search

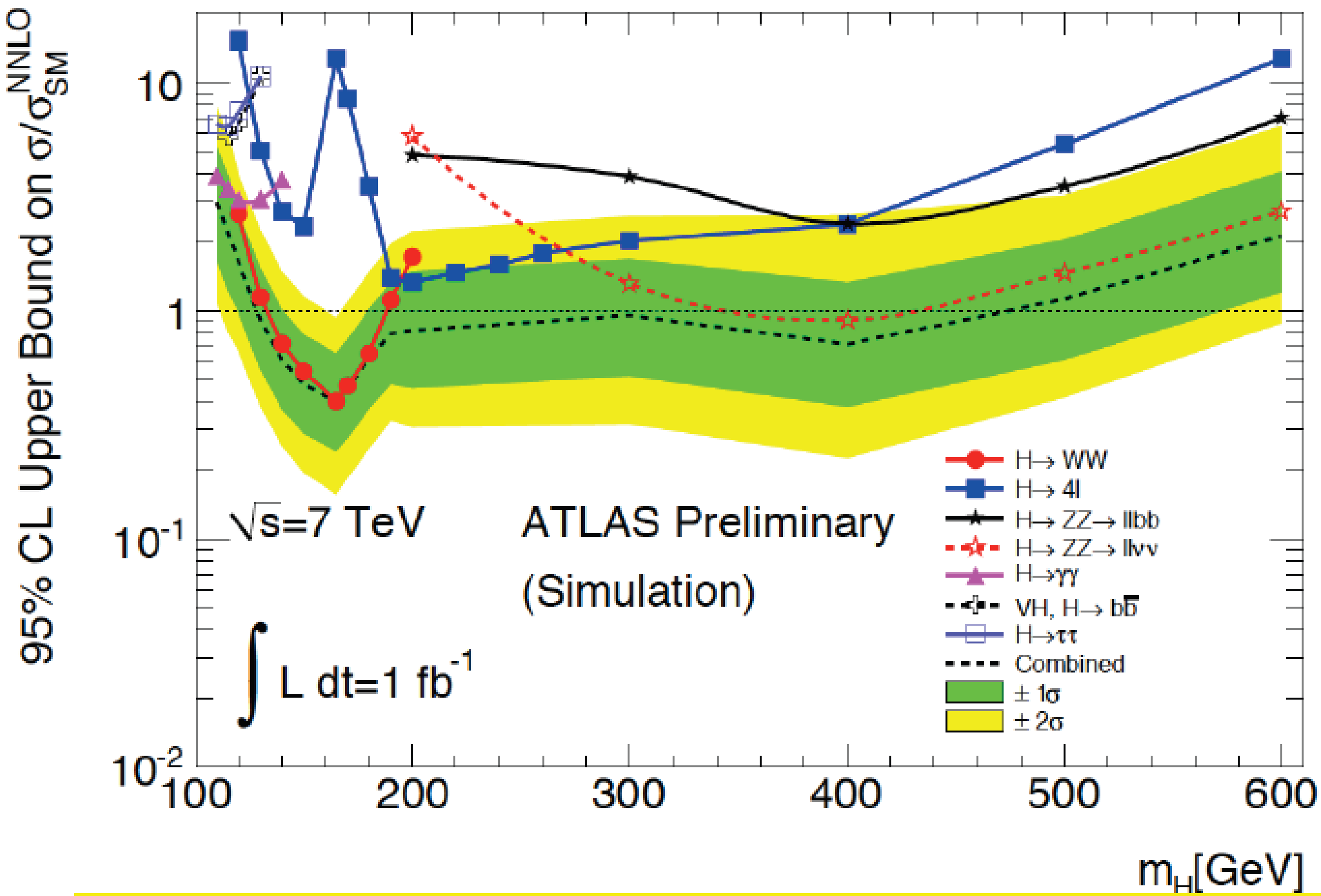
Most stringent limit from $H \rightarrow WW$ search.



Most constraining are still Tevatron results:

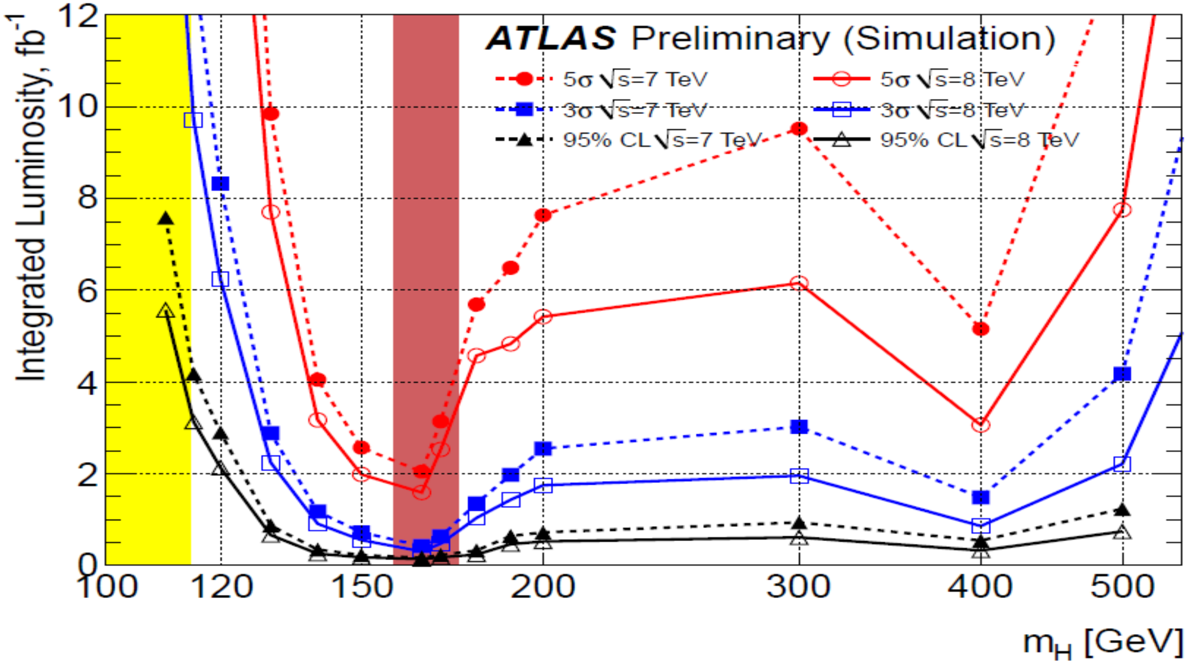
Excluded @ 95% CL: 158 GeV $< m_H <$ 173 GeV

ATLAS Prospects for 1 fb^{-1} (summer 2011)



ATLAS & CMS projections are in excellent agreement

Prospect for Higgs Search



ATLAS + CMS ≈ 2 x CMS	95% CL exclusion	3σ sensitivity	5σ sensitivity
1 fb^{-1}	120 - 530	135 - 475	152 - 175
2 fb^{-1}	114 - 585	120 - 545	140 - 200
5 fb^{-1}	114 - 600	114 - 600	128 - 482
10 fb^{-1}	114 - 600	114 - 600	117 - 535