Search for the Standard Model Higgs at LHC (Part I)

Guillelmo Gómez-Ceballos

(MIT)

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Taller de Altas Energías

SM Higgs Search at LHC

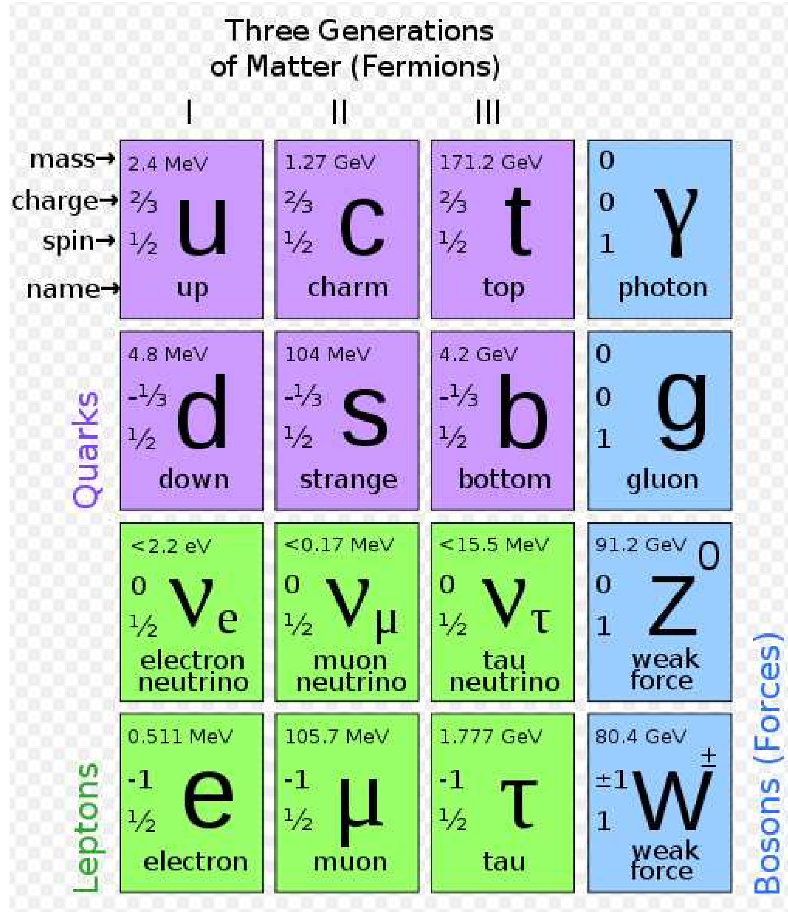
- Direct search from LEP: $m_H > 114.4$ GeV at 95% C.L.
- Major goal at LHC
- Very clear precisions for production mechanics, cross-sections and branching ratios within the Standard Model
- Mass is an unknown parameter!

Introduction

Standard Model of Particle Physics

Fundamental particles:

- ☞ 6 quarks, 6 leptons is enough
- ☞ bulk of visible matter: *u*, *d* and *e*
- ☞ anti-particle for each particle



Fundamental interactions:

- ☞ strong: gluons
- ☞ weak: $W^{\pm}$, Z^{0}
- ☞ electromagnetic: photons
- ☞ gravitational: graviton?

Higgs field → Higgs particle

W/Z Bosons Branching Ratios

Z	
Decay	Fraction (%)
$\mu\mu$	3.336
ee	3.336
$\tau\tau$	3.336
$\nu\nu$	20.0
$q\bar{q}$	70.0

W	
Decay	Fraction (%)
$\mu\nu$	10.83
$e\nu$	10.83
$\tau\nu$	10.83
qq'	67.51

Particle Physics in One Page

$$\mathcal{L} = -\frac{1}{4}F^a_{\mu\nu}F^{a\,\mu\nu} + i\bar{\Psi}D\psi$$ *The gauge sector* (1)

$$+\psi_i\lambda_{ij}\psi_j h + h.c.$$ *The flavor sector* (2)

$$+|D_\mu h|^2 - V(h)$$ *The EWSB sector* (3)

$$+N_i M_{ij} N_j$$ *The* ν–mass sector (4)
(if Majorana)

(1) : best tested, at least to per-mille accuracy

(2) + (4) : main developments of last 5 years, different in nature, both highly significant

(3): the most elusive, so far

Mass Problem

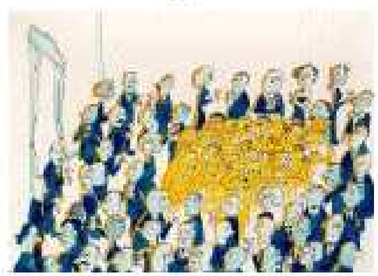
- The Standard Model taken into account Spin 1 (bosons) and Spin 1/2 (fermions) only predict massless particles
- Nervertheless W/Z bosons and leptons are massive
- Higgs field is introduced to add mass to those particles
- A new particle, the Higgs boson, is predicted coming from its own interaction

Higgs Mechanics: Poor Man Explanation

The Higgs field is like a room full of physicists chattering quietly:

A particle is a well-known scientist walking in, attracting a cluster of admirers, thereby receiving resistance to movement ("mass").


The Higgs boson is like a rumor crossing the room, creating the same kind of clustering, but this time among the scientists themselves.

Higgs Mechanics: Physicists Explanation

SM: all particles receive their mass via interaction with the vacuum expectation value of the Higgs field

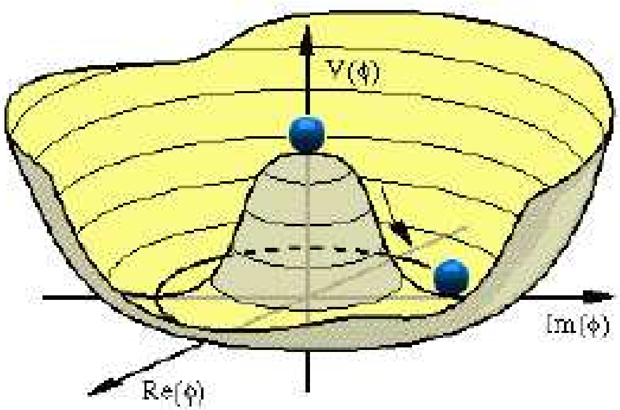
↪ "a quantum-field theoretical ether theory"

but: "medium Higgs field" has its own particle excitation = Higgs boson

Important ingredient: "spontaneous symmetry breaking"

↪ non-vanishing vacuum expectation value of a scalar field

SM: "ad hoc" introduced Higgs potential drives symmetry breaking



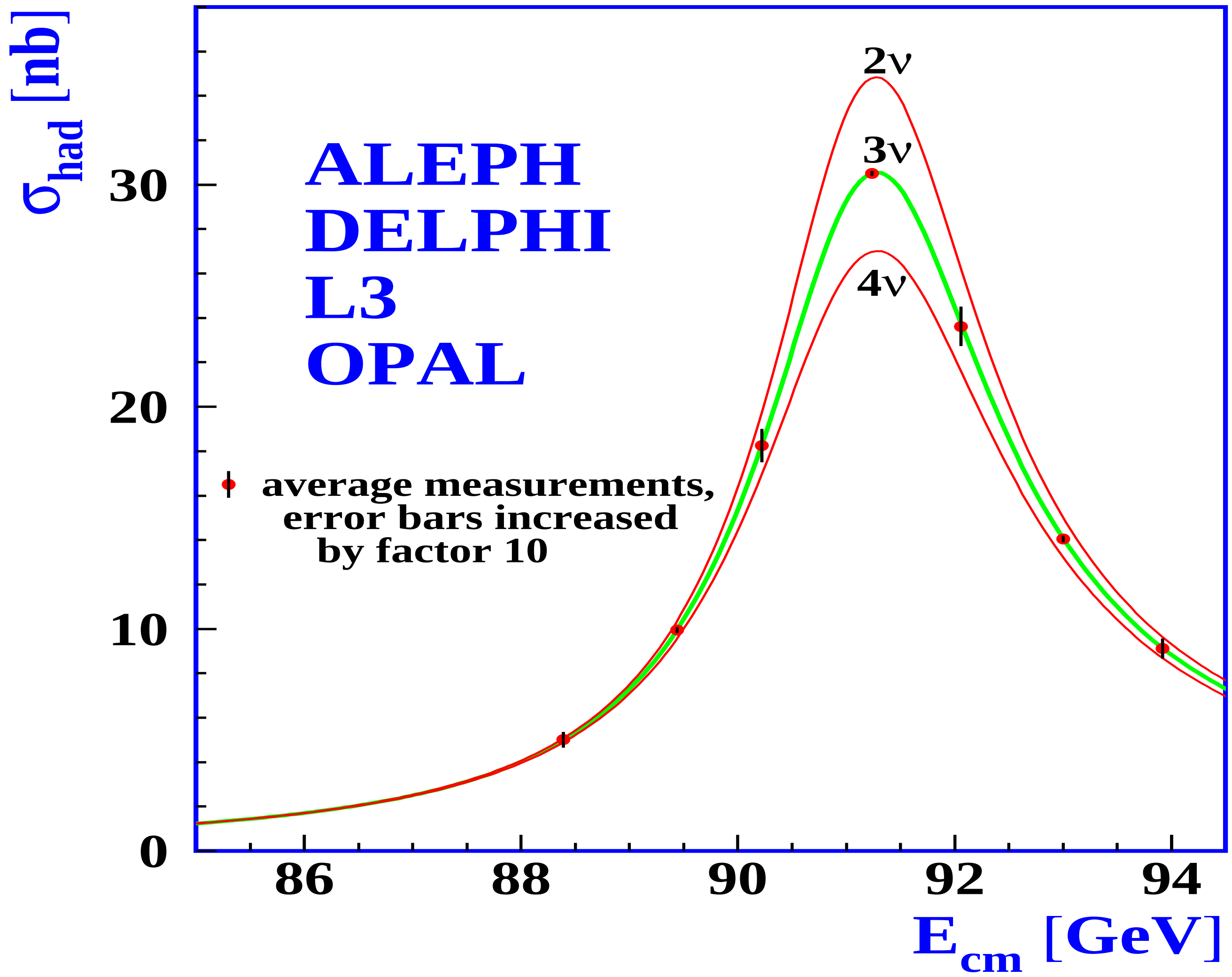
Investigation of Higgs self-interaction

↪ window to mechanism of symmetry breaking

Predictions & Inputs

- ☞ Highly predictive: large variety of phenomena has confirmed the Standard Model
- ☞ Particles predicted before observed: W and Z bosons, gluons, top and charm quarks, ν_τ
- ☞ Basic inputs:
  - ☞ SU(2) and U(1) gauge couplings g and g0
  - ☞ $v = \sqrt{2} < 0|\phi^0|0 >$ (vacuum of theory)
  - ☞ Higgs mass M_H, value unknown (enters radiative corrections)
  - ☞ heavy fermion masses, m_t, m_b... (phase space, radiative corrections)
  - ☞ strong coupling α_s (enters radiative corrections)
- ☞ Trade v, g, g' for precisely known quantities:
  - ☞ $G_F = \frac{1}{\sqrt{s} v^2}$ from τ_μ ($G_F = 1.16637(1) \times 10^{-5}\ GeV^{-2}$)
  - ☞ $\alpha = 1/137.03599911(46)$ (but must extrapolate to M_Z)
  - ☞ M_Z (or $sin^2\theta_W$)

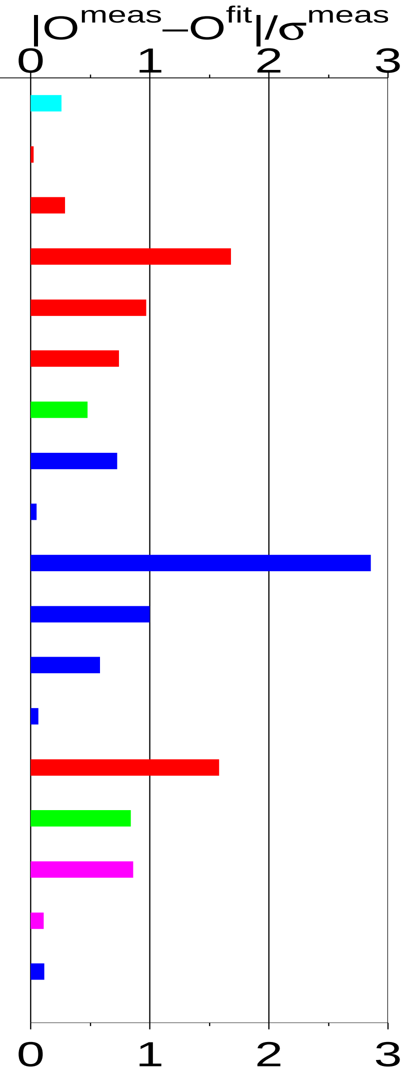
Just 3 Light Neutrinos



Please, pay attention to the errors!

Pulls from Several Measurements

	Measurement	Fit
$\Delta\alpha_{had}^{(5)}(m_Z)$	0.02758 ± 0.00035	0.02767
m_Z [GeV]	91.1875 ± 0.0021	91.1874
Γ_Z [GeV]	2.4952 ± 0.0023	2.4959
σ_{had}^{0} [nb]	41.540 ± 0.037	41.478
R_l	20.767 ± 0.025	20.743
$A_{fb}^{0,l}$	0.01714 ± 0.00095	0.01643
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1480
R_b	0.21629 ± 0.00066	0.21581
R_c	0.1721 ± 0.0030	0.1722
$A_{fb}^{0,b}$	0.0992 ± 0.0016	0.1038
$A_{fb}^{0,c}$	0.0707 ± 0.0035	0.0742
A_b	0.923 ± 0.020	0.935
A_c	0.670 ± 0.027	0.668
A_l(SLD)	0.1513 ± 0.0021	0.1480
$\sin^2\theta_{eff}^{lept}(Q_{fb})$	0.2324 ± 0.0012	0.2314
m_W [GeV]	80.398 ± 0.025	80.377
Γ_W [GeV]	2.097 ± 0.048	2.092
m_t [GeV]	172.6 ± 1.4	172.8



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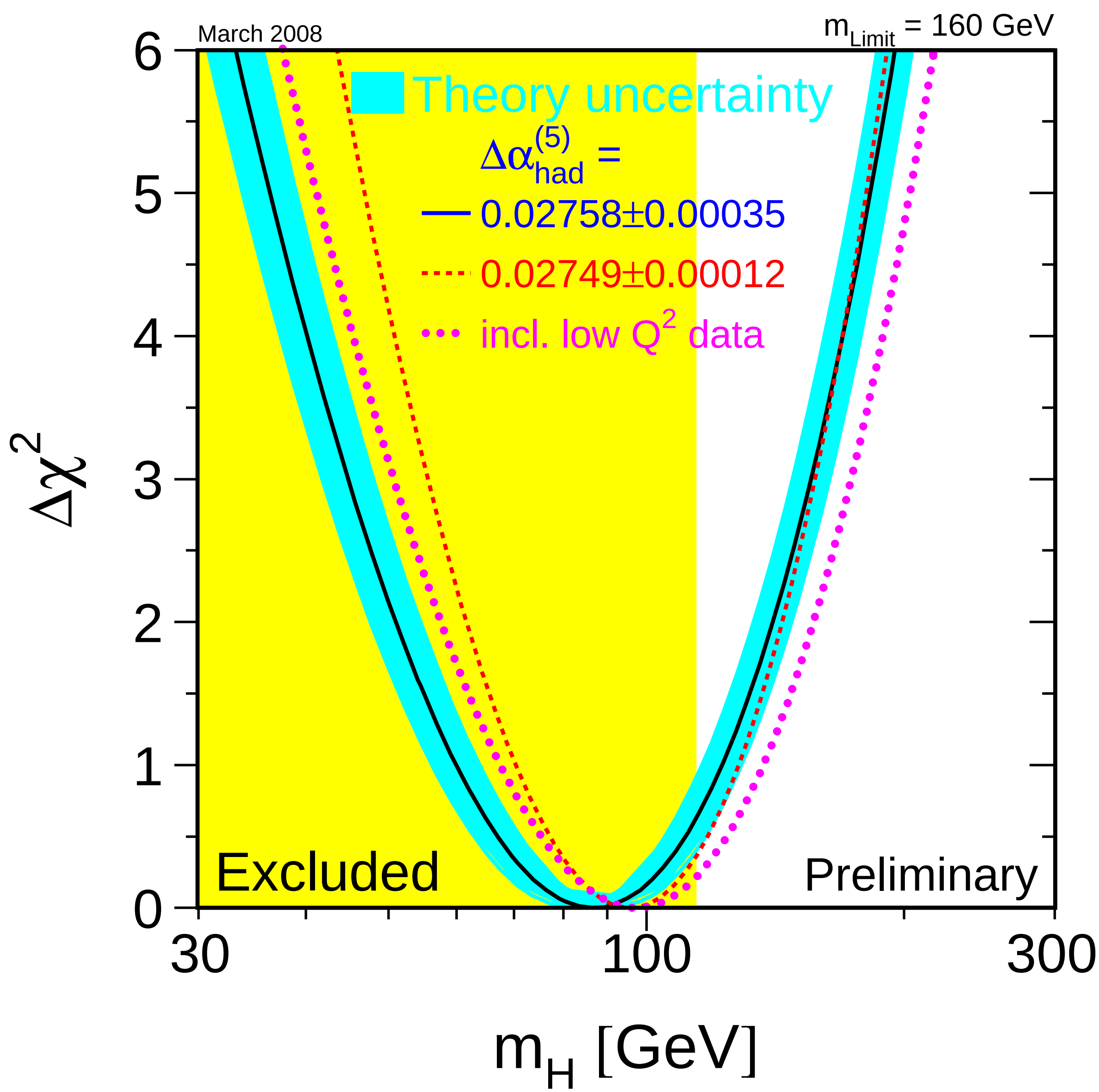
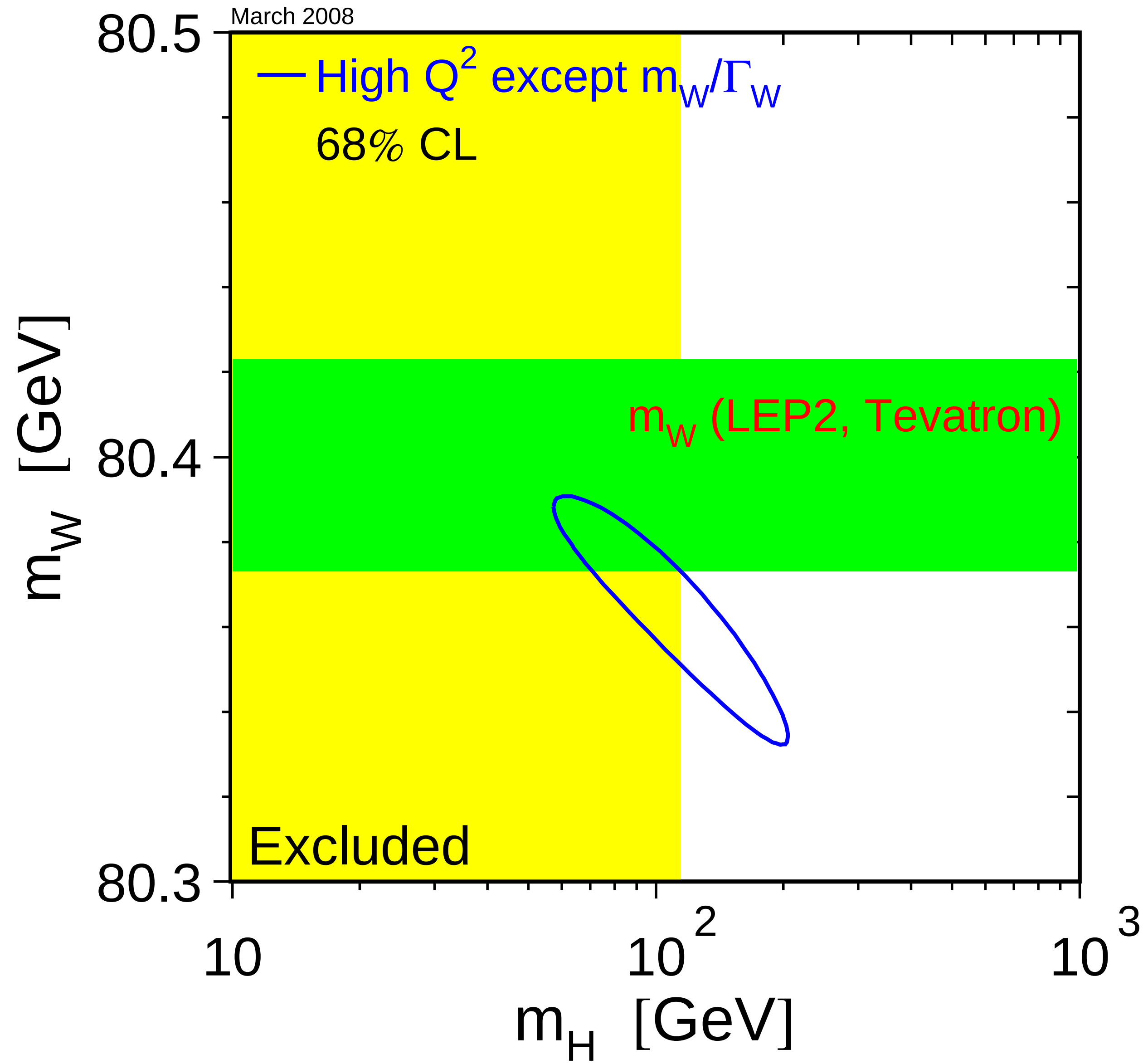
Higgs Mass from Precision Measurements



m_H vs. m_W



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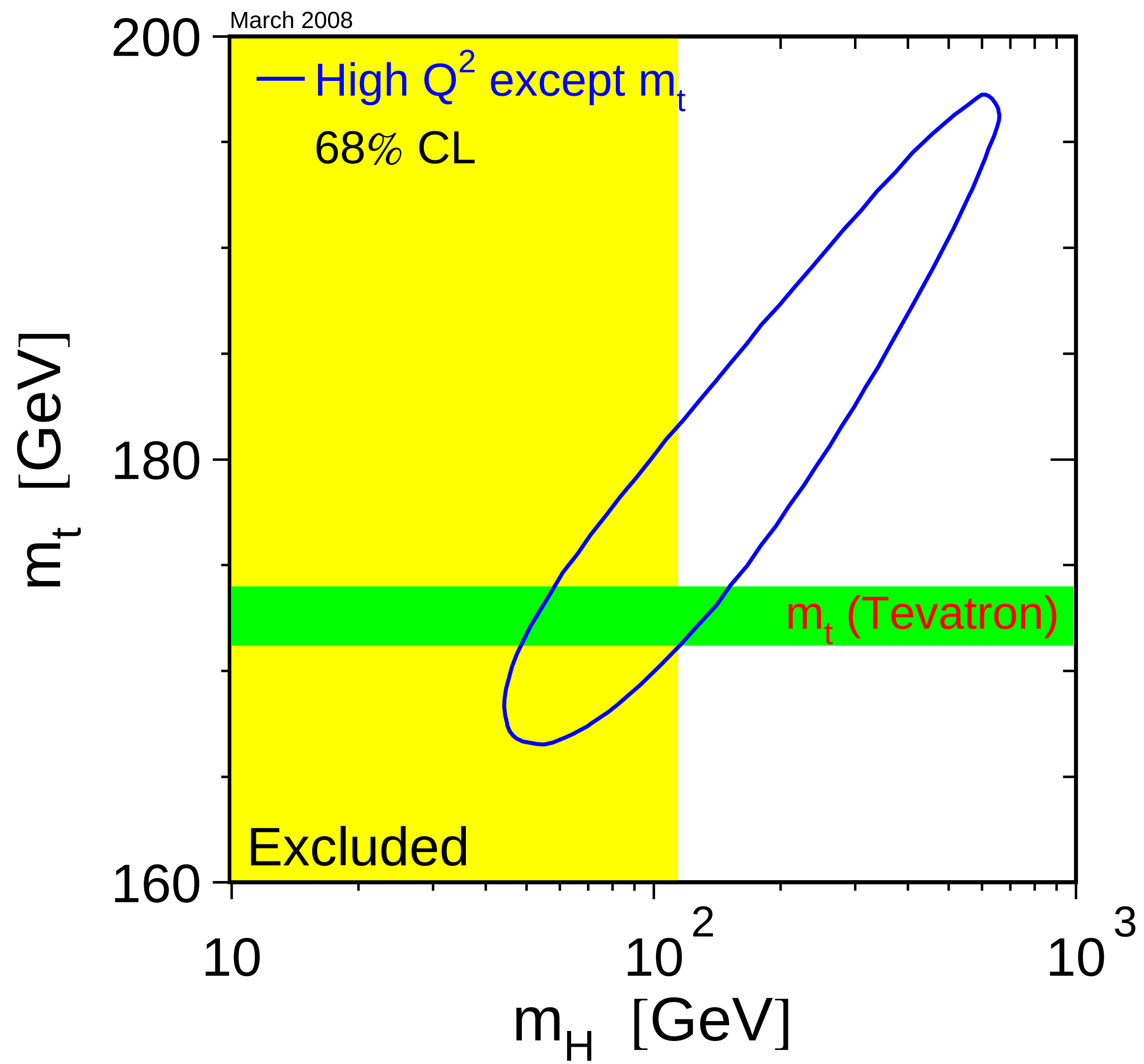
80.5
80.4
80.3
High Q² except m_W/Γ_W
68% CL
m_W (LEP2, Tevatron)
Excluded
10
10²
10³
m_H [GeV]
m_W [GeV]

m_H vs. m_t



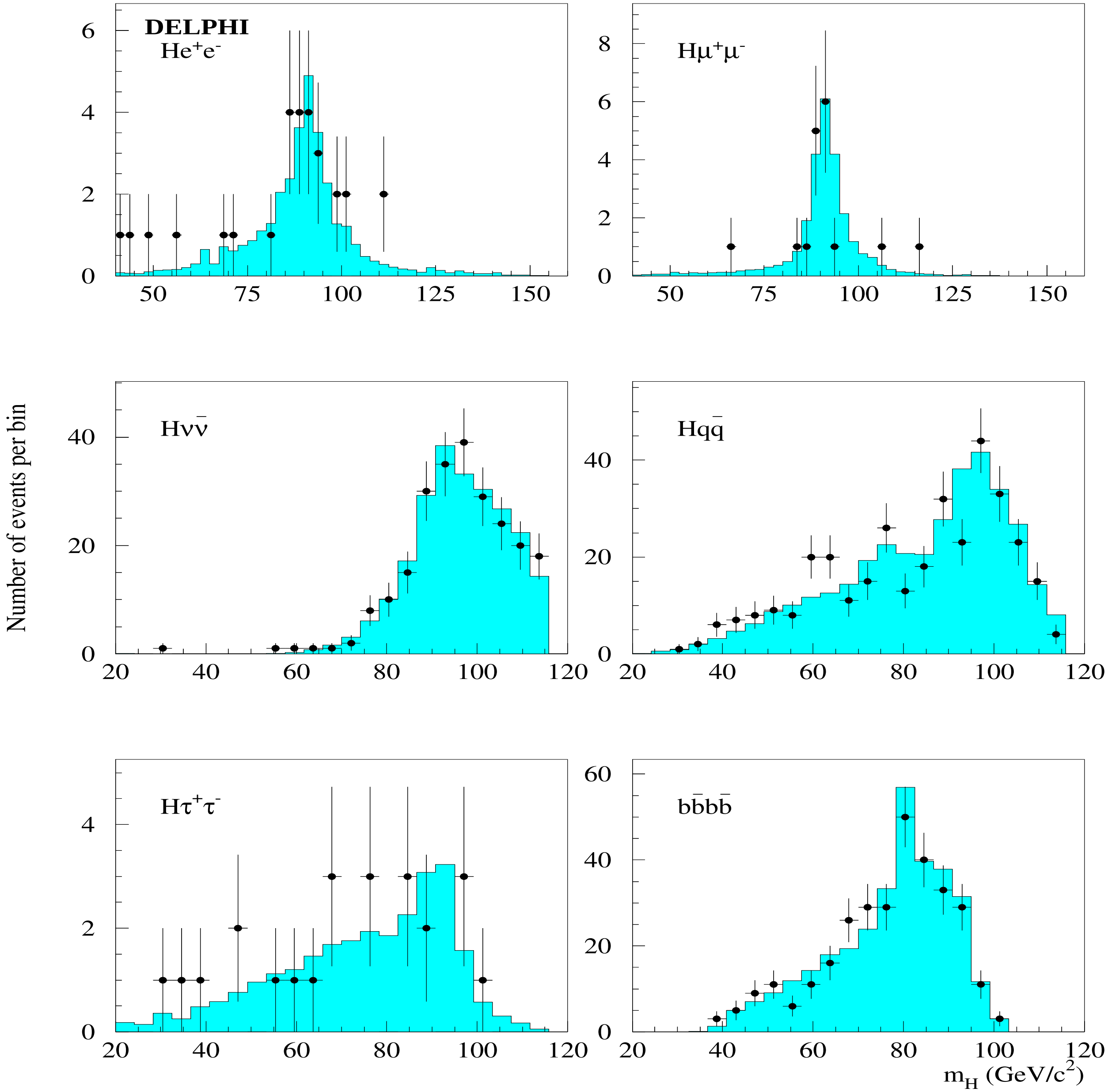
March 2008
High Q2 except mt
68% CL
mt (Tevatron)
Excluded
200
180
160
10
10 2
10 3
mt [GeV]
mH [GeV]

Direct SM Higgs Searches at LEP & TeVatron

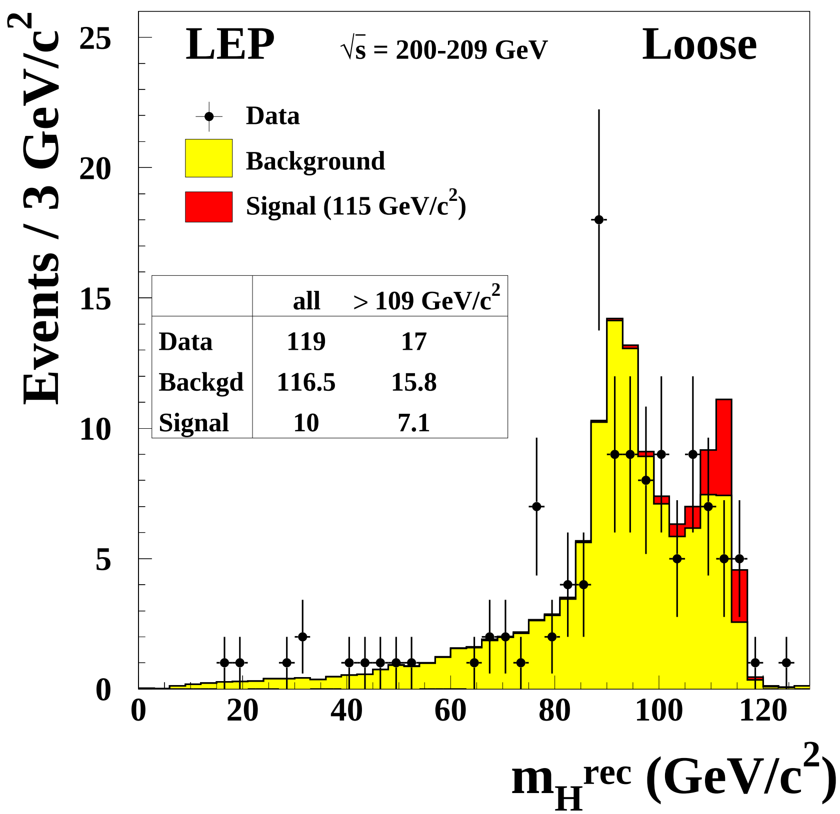
Direct SM Higgs Searches at LEP (I)

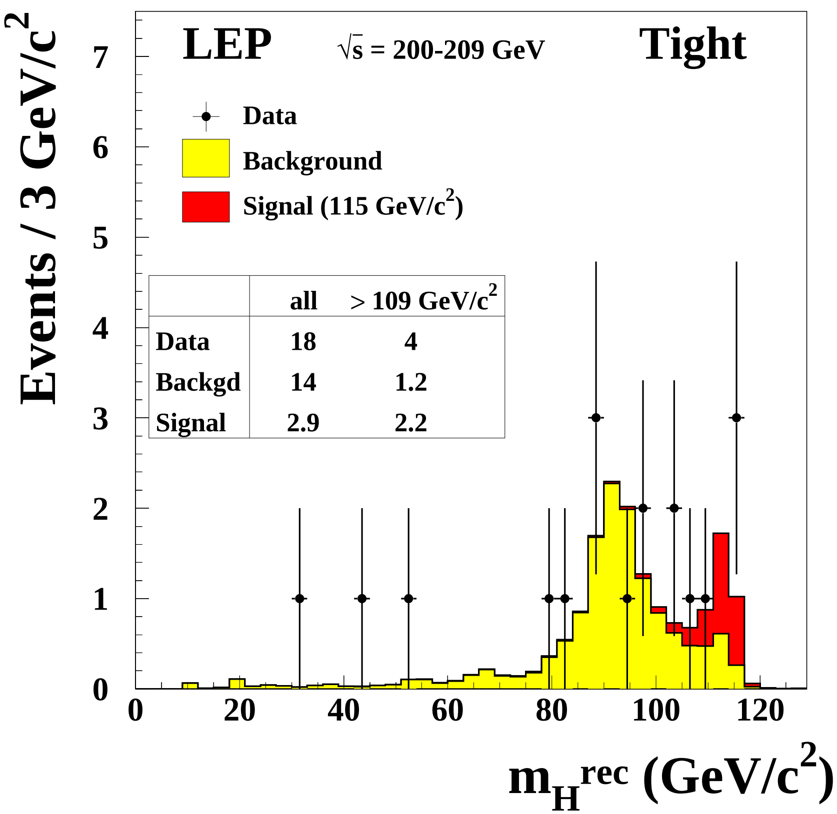
- A lot of Higgs searches at LEP time
- Main decay channels for $m_H \sim 100$ GeV/c^2 (more details later):
  - ☞ $BR(H \to b\bar{b}) \sim 90\%$
  - ☞ $BR(H \to \tau\tau) \sim 10\%$
- Main SM production: $e^+e^- \to HZ^0$
  - ☞ $BR(HZ \to b\bar{b}q\bar{q}) \sim 90\% \times 70\% = 63\%$
  - ☞ $BR(HZ \to b\bar{b}\nu\nu) \sim 90\% \times 20\% = 18\%$
  - ☞ $BR(HZ \to b\bar{b}\ell\ell) \sim 90\% \times 6.6\% = 6\%$
  - ☞ $BR(HZ \to b\bar{b}\tau\tau) \sim 90\% \times 3.3\% = 3\%$
  - ☞ $BR(HZ \to \tau\tau q\bar{q}) \sim 10\% \times 70\% = 7\%$

Direct SM Higgs Searches at LEP (II)



Direct SM Higgs Searches at LEP (III)





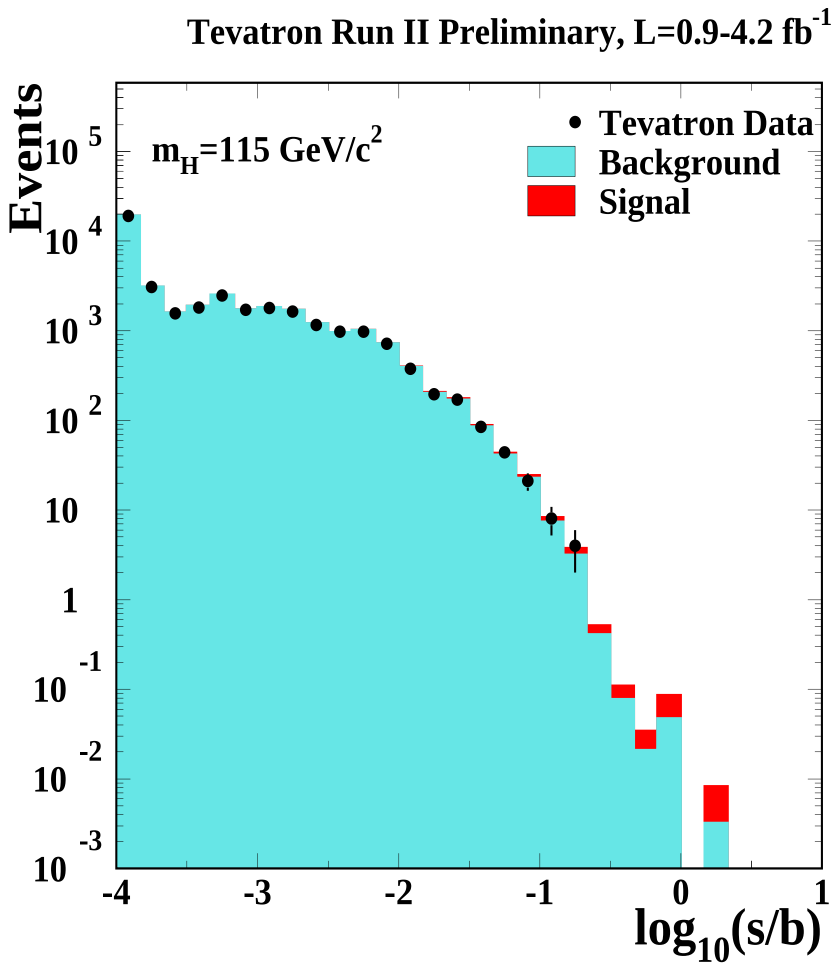
☞ No significant excess found in the SM LEP Higgs searches

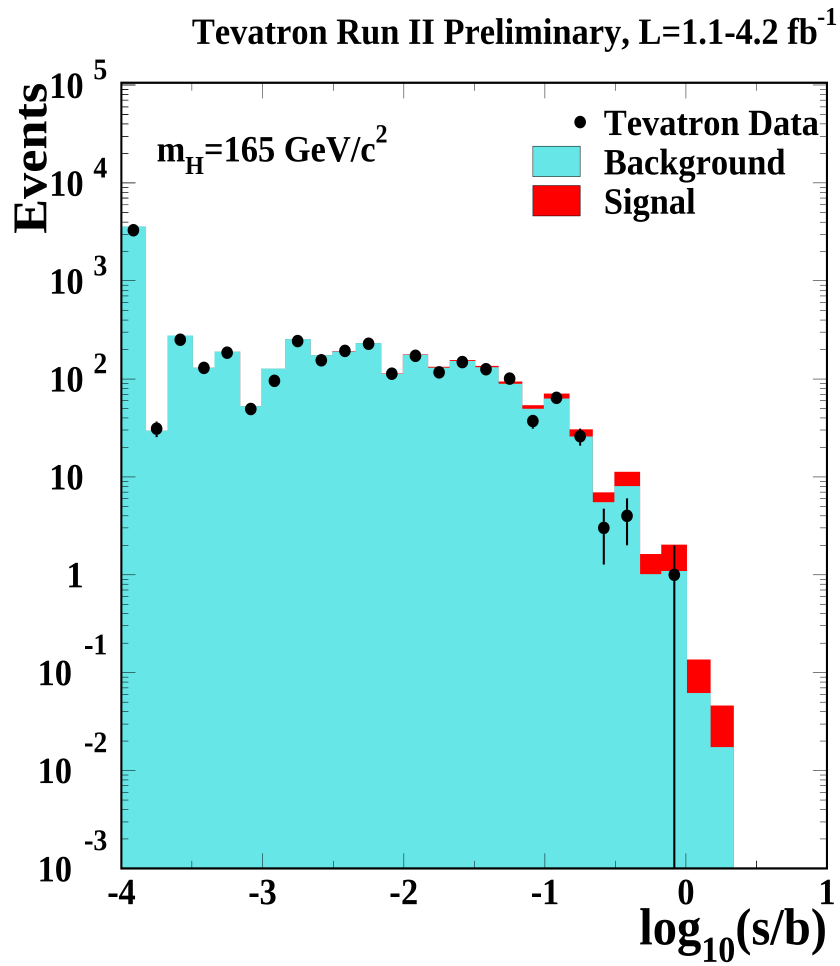
☞ $m_H > 114.4$ GeV at 95% C.L.

Direct SM Higgs Searches at the TeVatron (I)

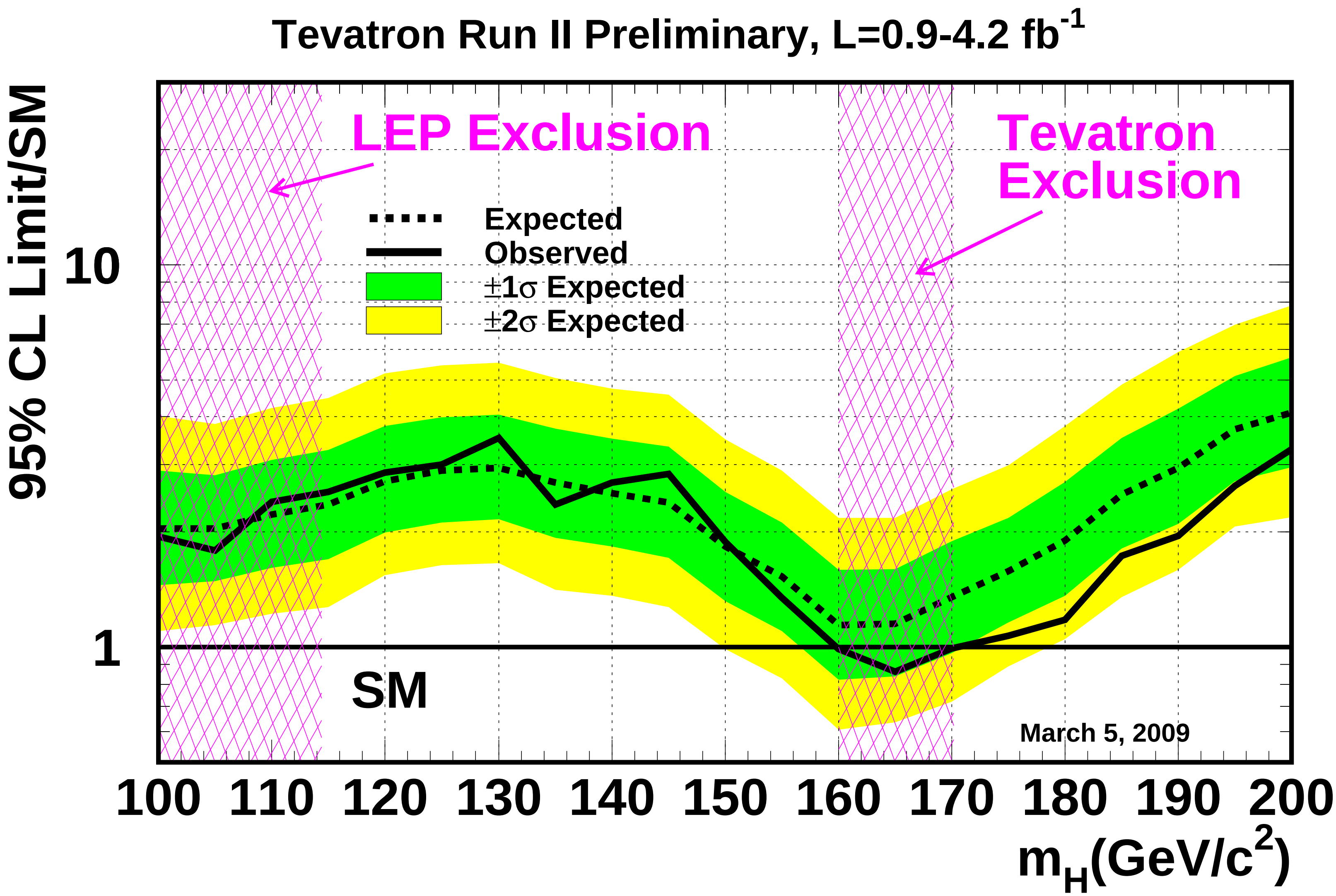
- A lot of Higgs searches at this moment
- Tough analyses, very sophisticated techniques
- Main SM production: $gg \to H$, VH $(V = W/Z)$
  - ☞ high mass (150-200 GeV/c^2):
    - ☞ $H \to WW \to 2\ell 2\nu$
  - ☞ low mass (100-150 GeV/c^2):
    - ☞ $WH \to \ell\nu b\bar{b}$
    - ☞ $ZH \to \ell\ell b\bar{b}$
    - ☞ $ZH \to \nu\nu b\bar{b}$
- 75 mutually exclusive final states considered in the last round of combination!

Direct SM Higgs Searches at the TeVatron (II)





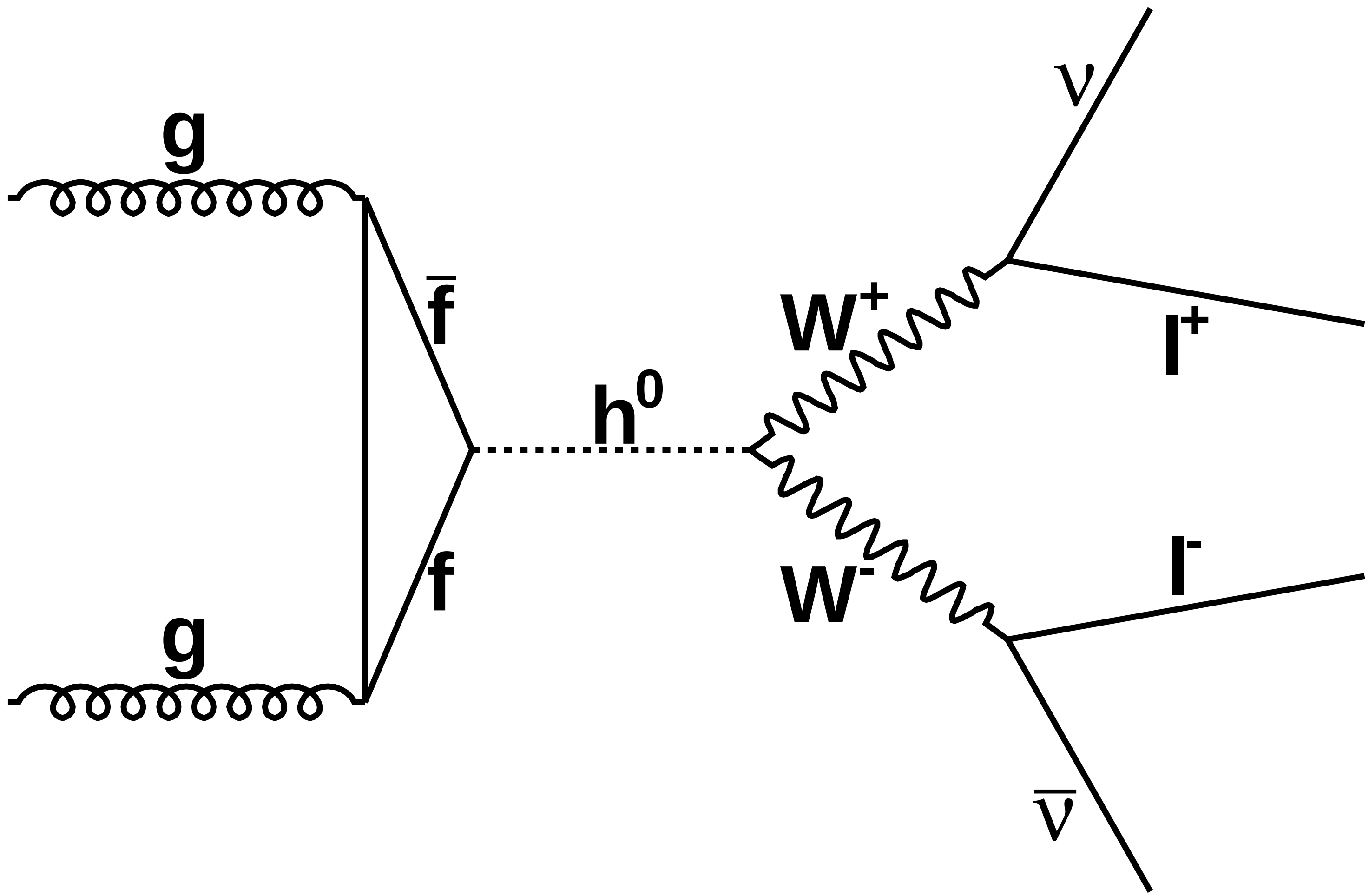
Direct SM Higgs Searches at the TeVatron (III)



Production Mechanics

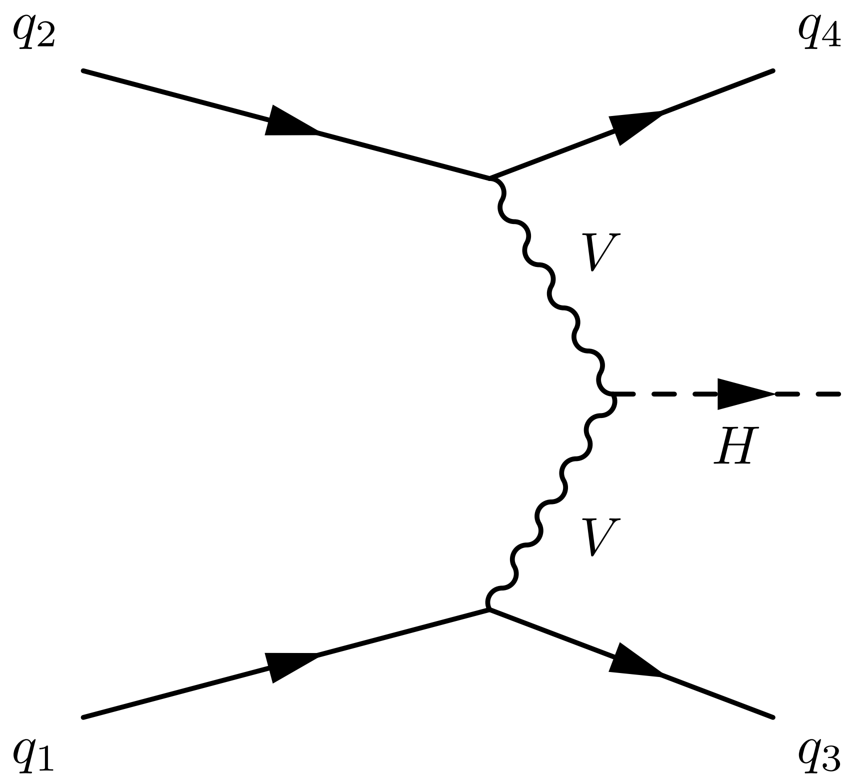
- Gluon Fusion: $gg \to H$
- Weak Boson Fusion (WBF): qqH
- Associated Production with Z/W: VH, $V = W/Z$
- Associated Production with $\mathrm{t\bar{t}}$: $\mathrm{t\bar{t}}H$

Gluon Fusion: $gg \rightarrow H$



- Main production mechanic
- Little jet activity (except from gluon radiation)

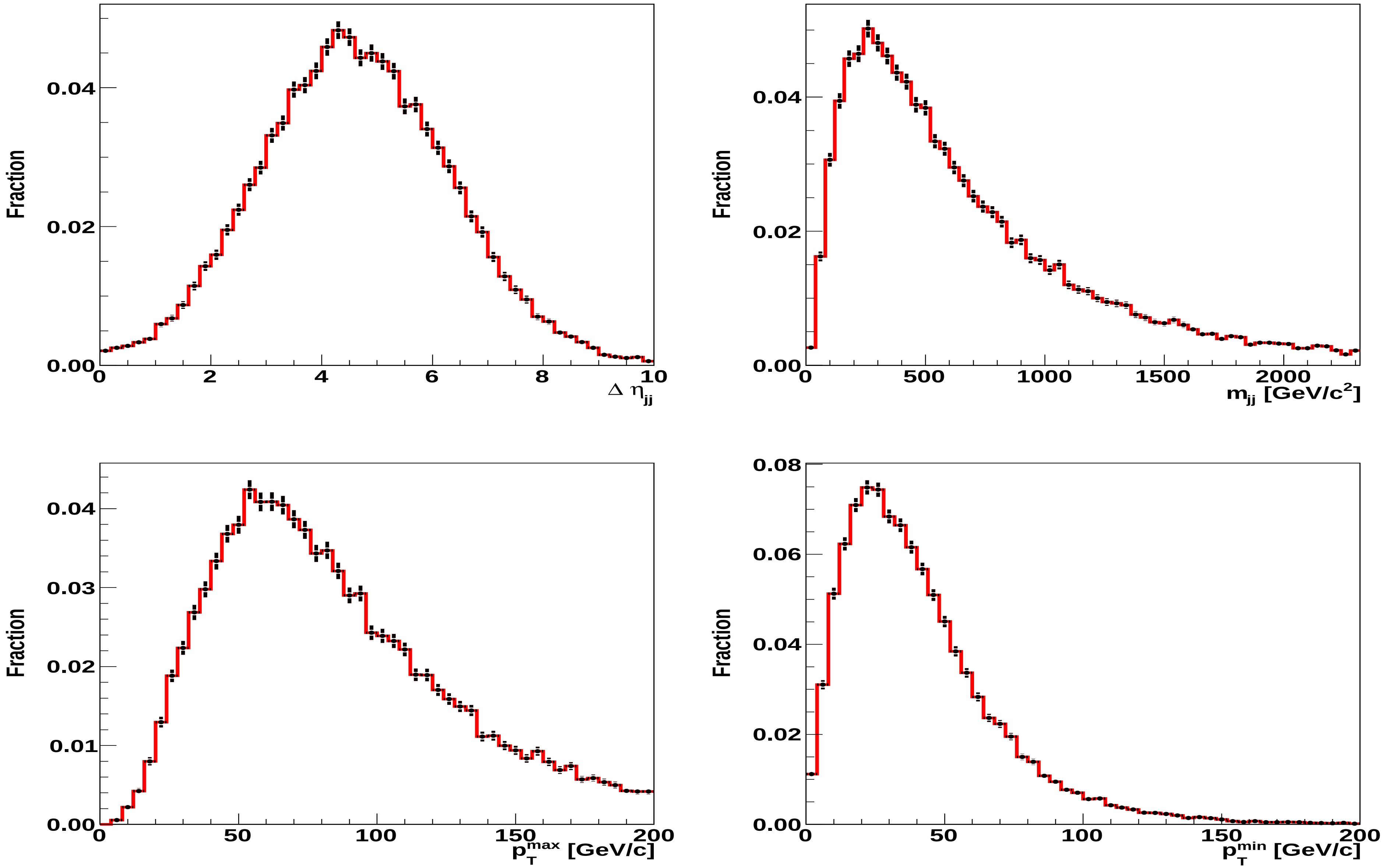
Weak Boson Fusion (WBF): *qqH*



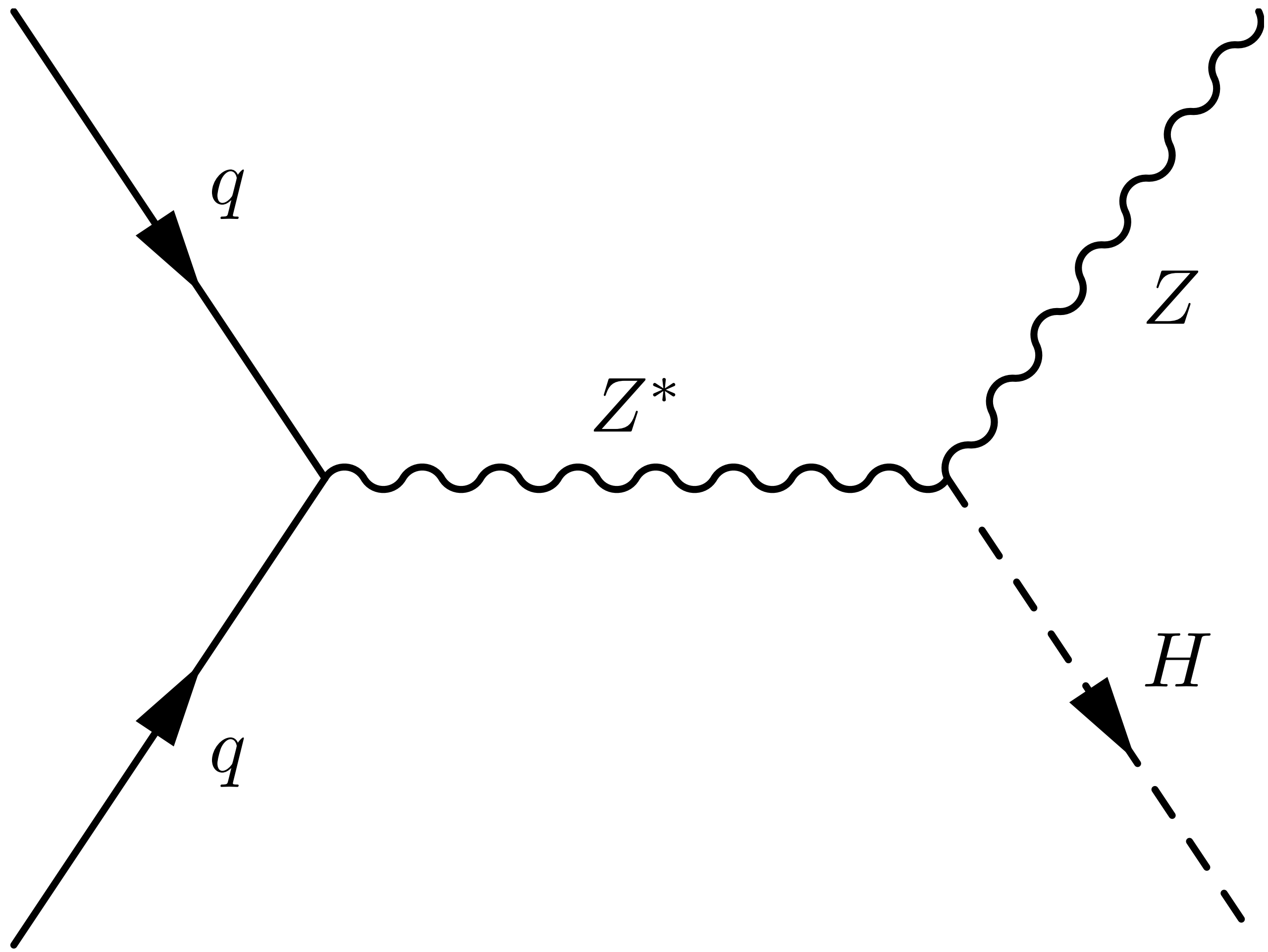
- Cross-section ~10 times smaller than $gg \rightarrow H$, but very particular topology

- Higgs produced together with two forward-backward hard energetic jets

Tagging Jets in *qqH* Events

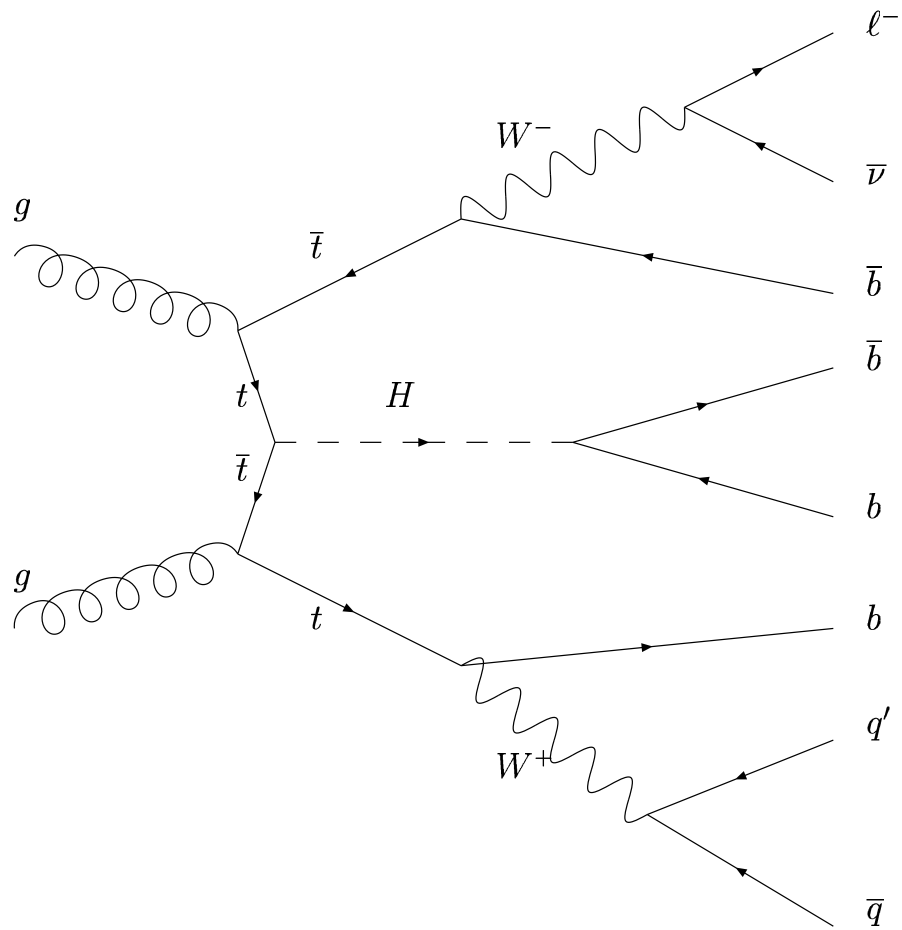


Associated Production with Z/W: VH, $V = W/Z$



- Less important processes than in the TeVatron
- Interesting for low Higgs masses, high luminosity

Associated Production with $t\bar{t}$: $t\bar{t}H$



- Very important process to measure Higgs couplings
- Very challenging analysis

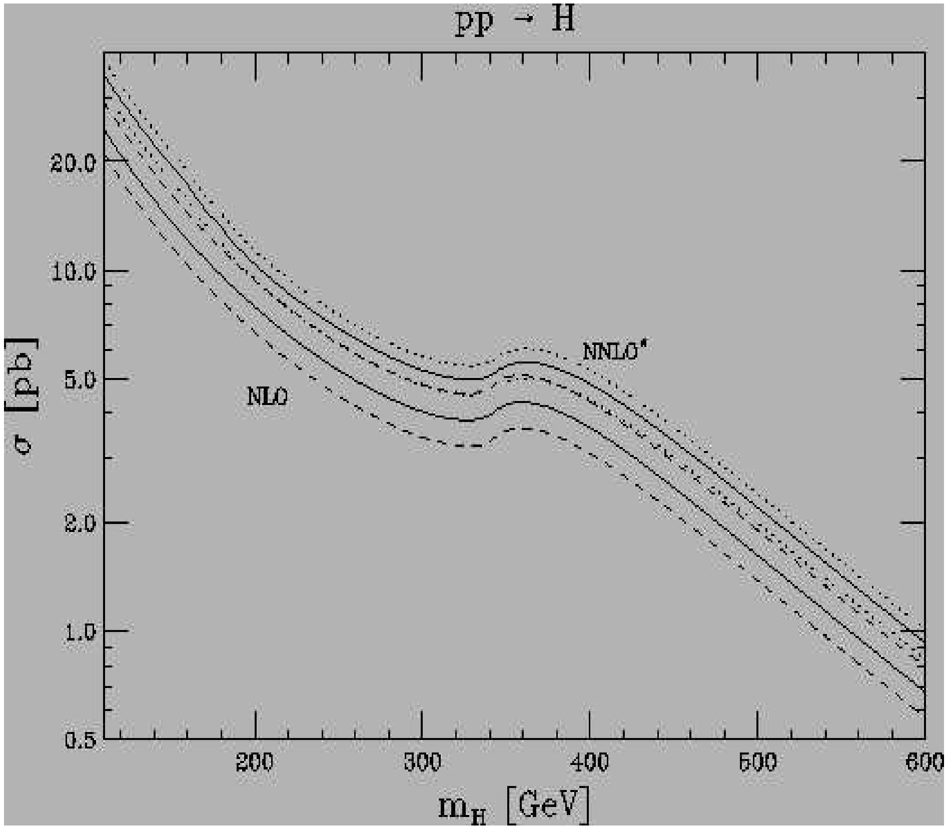
Cross-Sections

Comments

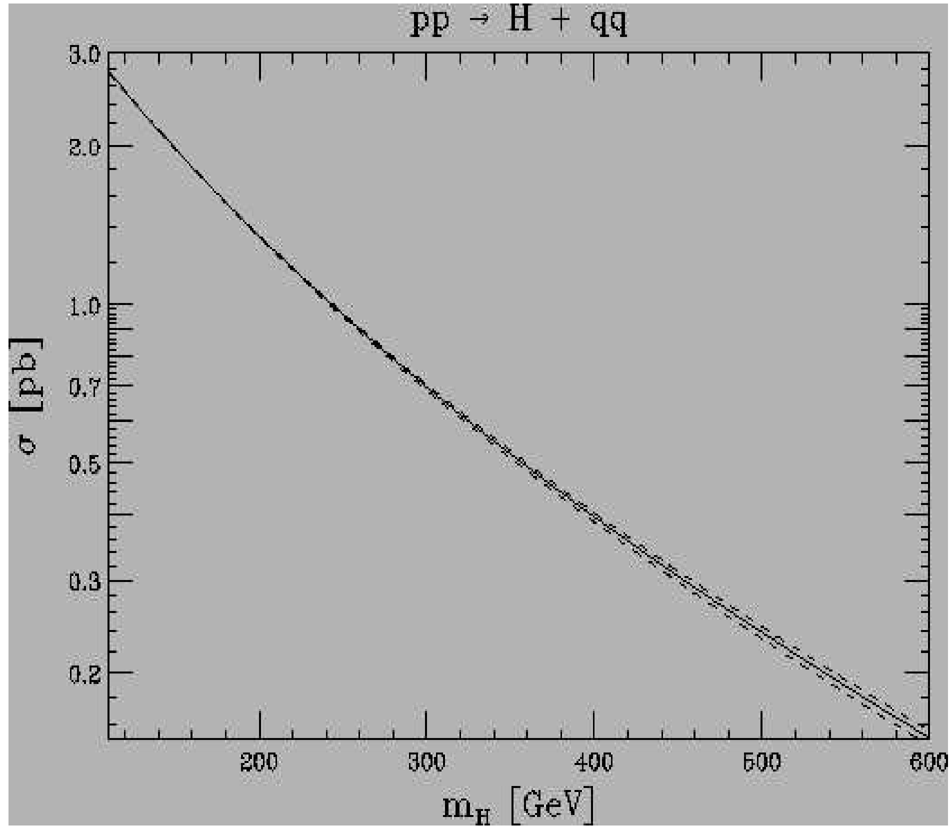
- Reported cross-section at $\sqrt{s} = 10\ TeV$
- Similar behavior at $\sqrt{s} = 14\ TeV$, “just” a factor ~2 smaller values
- CTEQ6 PDF sets are used for NLO computations, the newest MSTW2008 PDF sets for NNLO computations

$gg \to H$ & qqH

$gg \to H$



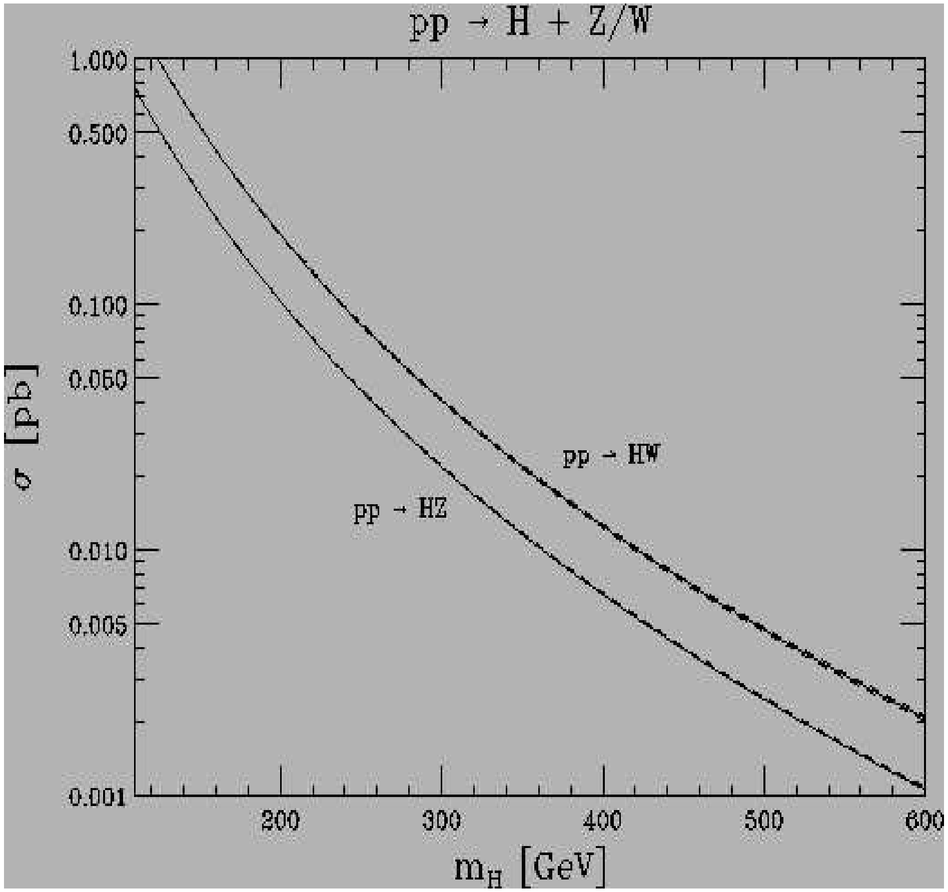
qqH



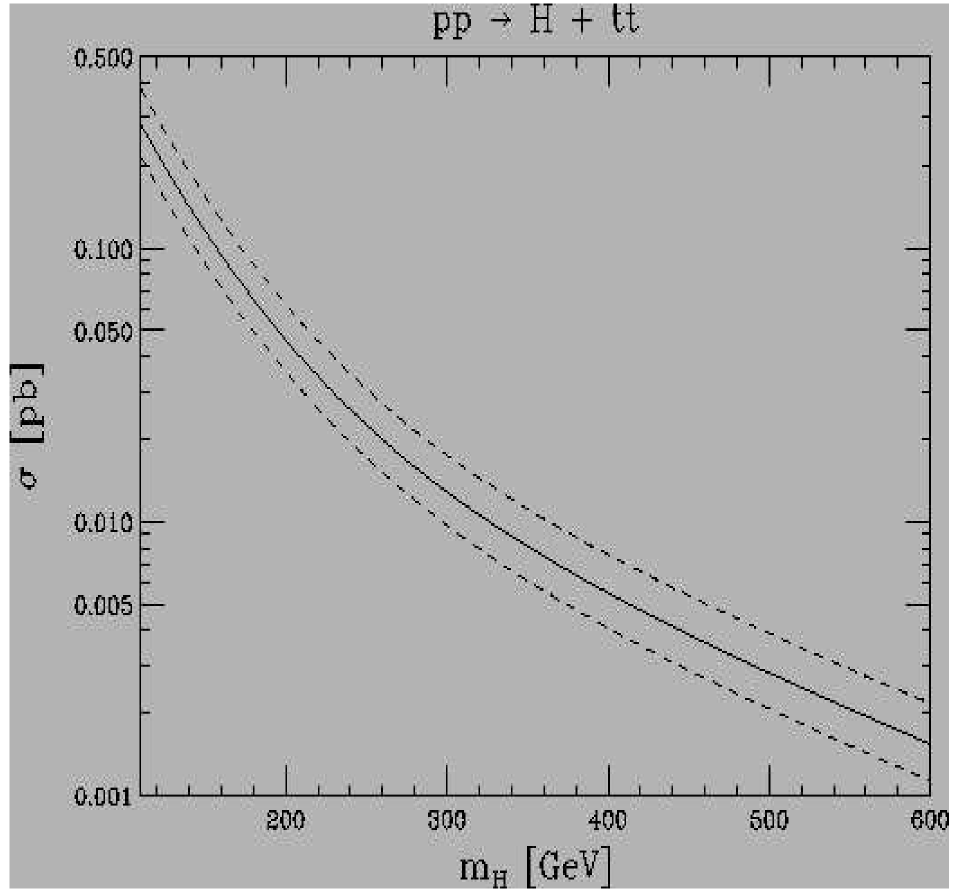
- $\sigma^{gg \to H} / \sigma^{qqH} \sim 10$
- Increased in $\sigma^{gg \to H}$ for $m_H \sim 350$ GeV/c^2 due to the appearance of $H \to t\bar{t}$ decays in that region

Associated Production with $Z/W/t\bar{t}$

VH



$t\bar{t}H$



Branching Ratios,
Higgs Decays

Branching Ratios vs. Higgs Mass

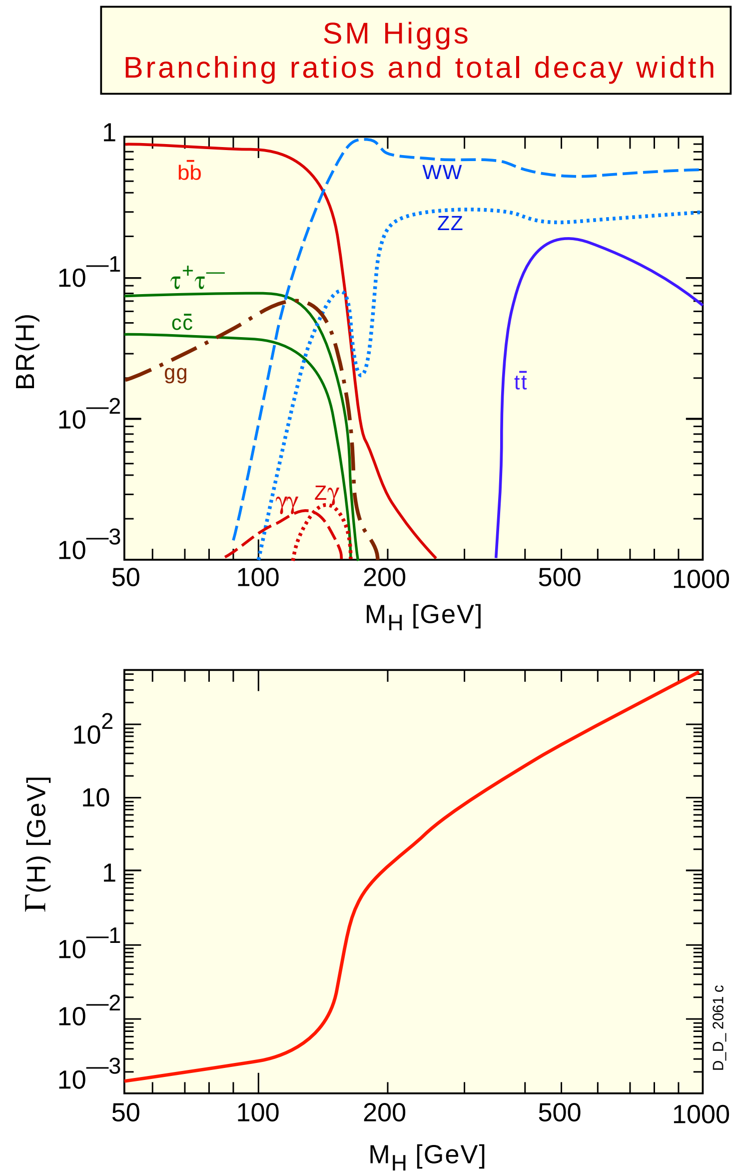
Partial widths at tree level:

- ☞ $\Gamma(H \to f\bar{f}) \propto N_c m_f^2 \beta^3 m_H$
- ☞ $\Gamma(H \to VV) \propto \delta_V \beta m_H^3 (1 - \tau_V + \frac{3}{4}\tau_V^2)$

$\beta^2 = 1 - 4m_f^2/m_H^2$, $\tau_V = 4m_V^2/m_H^2$

$N_c = 3$ for quarks and $N_c = 1$ for leptons

$\delta_W = 2$, $\delta_Z = 1$



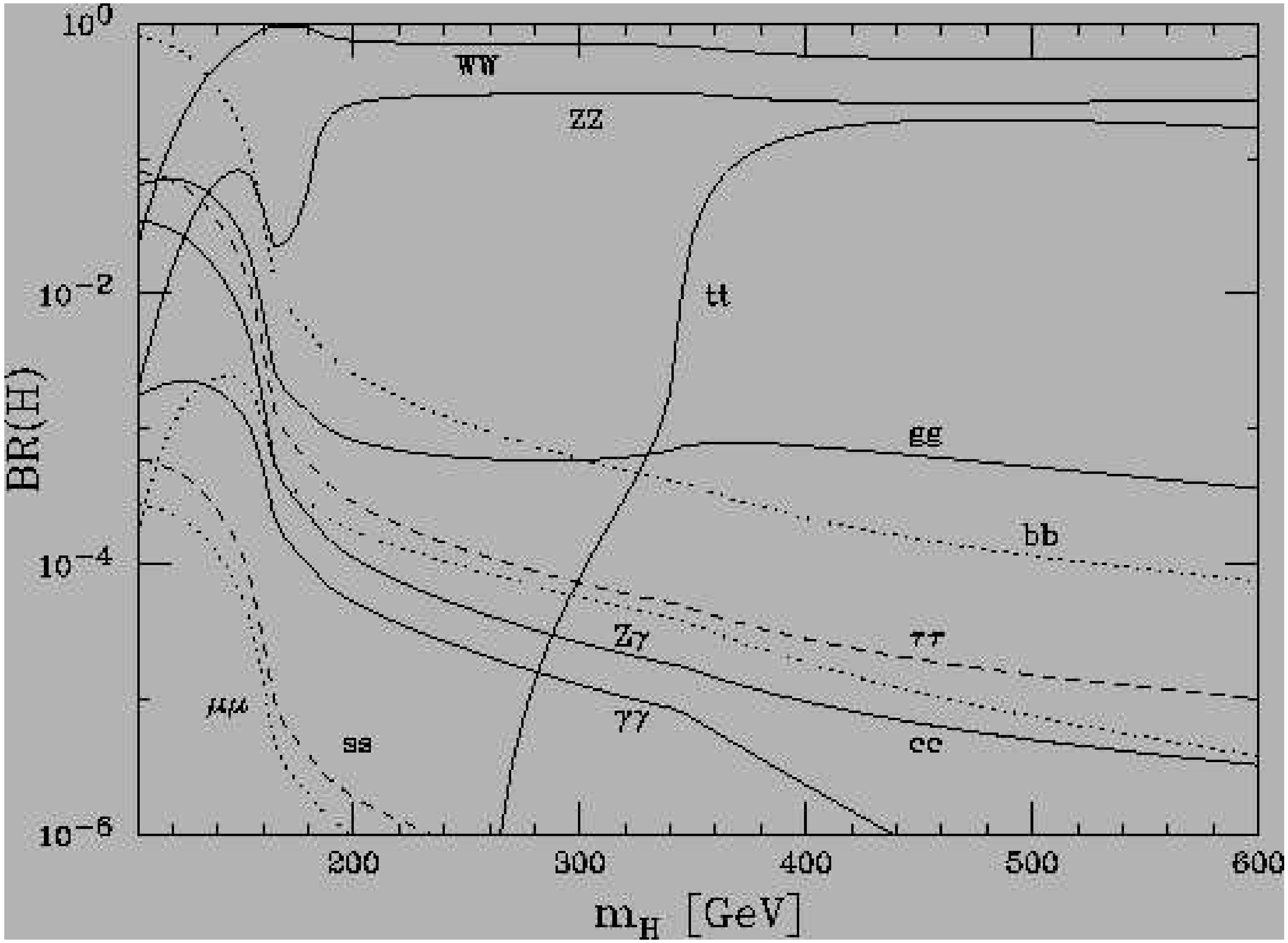
Low mass region:

- ☞ $H \to b\bar{b}$ dominant

Higgs mass region:

- ☞ $\Gamma_{tot} \approx \Gamma(H \to WW) + \Gamma(H \to ZZ)$
- ☞ $m_H \approx 1.4\,\text{TeV/c}^2 \to \Gamma_{tot} \approx m_H$

Main Higgs Decay Modes



☞ $m_H <$ 150 GeV/c^2: $H \to b\bar{b}, \tau\tau, \gamma\gamma$ ($H \to WW$ already relevant)

☞ $m_H >$ 150 GeV/c^2: $H \to WW, ZZ$

Decay Modes at LHC

Decay	$gg \to H$	qqH	$ttH,\ ZH,\ WH$
$H \to \gamma\gamma$	yes	yes	high L
$H \to bb$	no trigger	no trigger	high L
$H \to WW \to 4q$	no trigger	no trigger	high L
$H \to WW \to 2\ell 2\nu$	yes	yes	yes
$H \to WW \to 2q\ell\nu$	high L	yes	yes
$H \to \tau\tau \to \ell h\nu's$	yes	yes	high L
$H \to \tau\tau \to \ell\ell\nu's$	yes	yes	high L
$H \to \tau\tau \to hh\nu's$	no trigger	no trigger	high L
$H \to ZZ \to 4\ell$	yes	yes	high L
$H \to ZZ \to 2q2\ell$	yes	yes	high L
$H \to ZZ \to 2\ell 2\nu$	yes	yes	high L
$H \to ZZ \to 4\nu$	no trigger	no trigger	no trigger
$H \to ZZ \to 4q$	no trigger	no trigger	high L
$H \to ZZ \to 2q2\nu$	no trigger	no trigger	high L

(*) "no trigger" == no ℓ/γ HLT, "yes" ==can be done with $\mathcal{L} < 50\text{fb}^{-1}$, "high $\mathcal{L}$" == ~100 fb^{-1} region