PHYS 5326 – Lecture #21

Monday, Apr. 9, 2003
Dr. Jae Yu

- Higgs Mass Theoretical Upper Bounds
- SM Higgs Production Processes in Hadron Colliders
- Winter 03 Experimental Results

Higgs Particles

- What are the Higgs particles we are looking for?
  - Standard Model Higgs: Single neutral scalar
  - MSSM Higgs: Five scalar and pseudoscalar particles
    - h^0, H^0, $H^{+/-}$ and A^0
  - Higgs in Other Models
- What are the most distinct characteristics of Higgs particles?
  - In both SM and MSSM, the Higgs particles interact with fermions through Yukawa coupling whose strength mostly is set by the fermion masses.

Theoretical M_H Upper Bound in SM

From the SU_2xU_1 *L*

$$L = \left|Df\right|^2 - \frac{l}{2}\left[\left|f\right|^2 - \frac{v^2}{2}\right]^2 - g_d \overline{d}_L f d_R - g_u \overline{u}_L f^c u_R + h.c.$$

Where, the scale *v* is the EWSB scale, $v = 1/\sqrt{\sqrt{2}G_F} \approx 246\ GeV$,
and the mass of the Higgs particle and fermions are

$$M_H = l v^2$$

$$m_f = \frac{g_f v}{\sqrt{2}}$$

Where λ is the quartic coupling
and g_f is the Yukawa coupling

Theoretical M_H Upper Bound in SM

While M_H cannot be predicted in SM, internal consistency and extrapolation to high energies can provide upper and lower bounds.

Based on the general principle of t-E uncertainty, particles become unphysical if their masses grow indefinitely. Therefore M_H must be bound to preserve the unitarity in the perturbative regime. and the mass of the Higgs particle and fermions are

From an asymptotic expansion of a $W_L W_L$ S-wave scattering, an upper limit on M_H can be obtained:

$$M_H^2 \leq 2\sqrt{2}p \Big/ G_F \approx (850\ GeV)^2$$

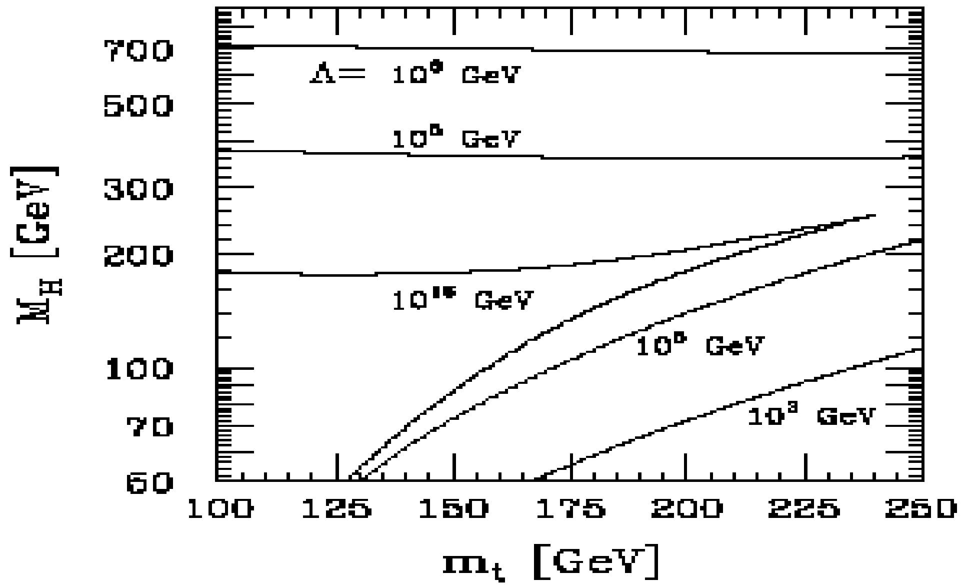
Theoretical M_H Upper Bound in SM

The SM tells that there is no new physics between EWSB scale (~1TeV) and the GUT scale (10^{19}GeV). This can provide a restrictive upper limit because the SM can extend to a scale Λ before a new type of strong short range interaction can occur between the fundamental particles.

From the variation of quartic Higgs coupling, λ, and the top-Higgs Yukawa coupling, g_t, with energy parameterized by $t=\log(\mu^2/v^2)$, and requiring $\lambda(\Lambda)$ to be finite, one can obtain the Higgs mass upper bound

$$M_H^2 \le 8\pi^2 v^2 \Big/ 3\log\left(v^2/\lambda^2\right)$$

Theoretical M_H Upper Bound in SM



For the central m_t=175GeV

Λ_{SM}	M_H
1 TeV	$55 \le M_H \le 700 GeV$
10^{19}GeV	$130 \le M_H \le 190 GeV$

SM Higgs Properties

- Profiles of Higgs Particles determined by its mass
- The Yukawa coupling of Higgs to fermions set by the fermion mass, m_j, and to the electroweak gauge bosons by their masses, M_V.

$$g_{ffH} = \left[\sqrt{2}G_F\right]^{1/2} m_f$$

$$g_{VVH} = 2\left[\sqrt{2}G_F\right]^{1/2} M_V^2$$

Physical observables, the total decay width, lifetime and branching ratio to specific final states are determined by these parameters.

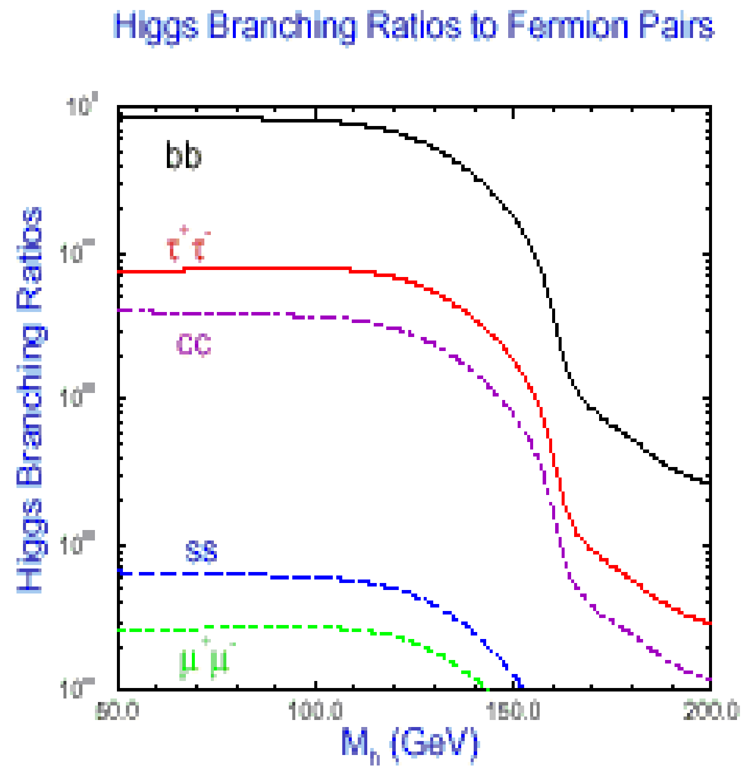
Higgs Decay to Fermions

Higgs partial decay width to fermions are

$$\Gamma\left(H \to f\bar{f}\right) = N_c \frac{G_F}{4\sqrt{2p}} g_{ffH}\, m_f^2\left(M_H^2\right) M_H$$

Number of color quantum numbers, 1 or 3

For M_H=100GeV,
$m_b(M_H^2)$~3GeV,
$m_c(M_H^2)$~0.6GeV



Higgs Decay to Gauge Boson Pairs

$$\Gamma(H \to VV)$$
$$= d_V \frac{G_F}{16\sqrt{2}p} M_H^3 \left(1 - 4x + 12x^2\right) b_V$$

Where $x = M_V^2 / M_H^2$ and

$d_V = 2$ or 1 for W or Z

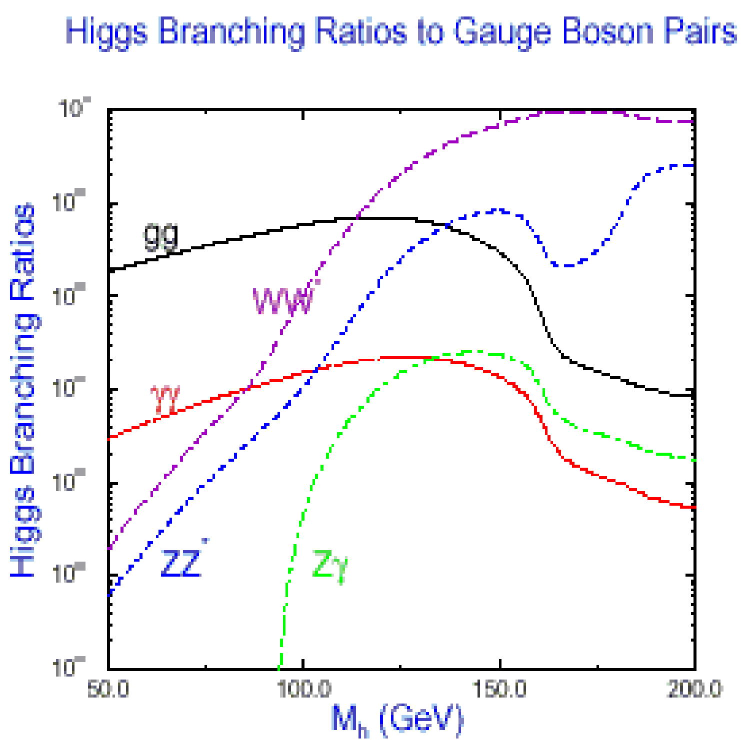
$$\Gamma\left(H \to VV^*\right)$$
$$= \frac{3G_F^2 M_V^4}{16p^3} M_H R(x) d_V^{'}$$

Where $d_W^{'} = 1$ and

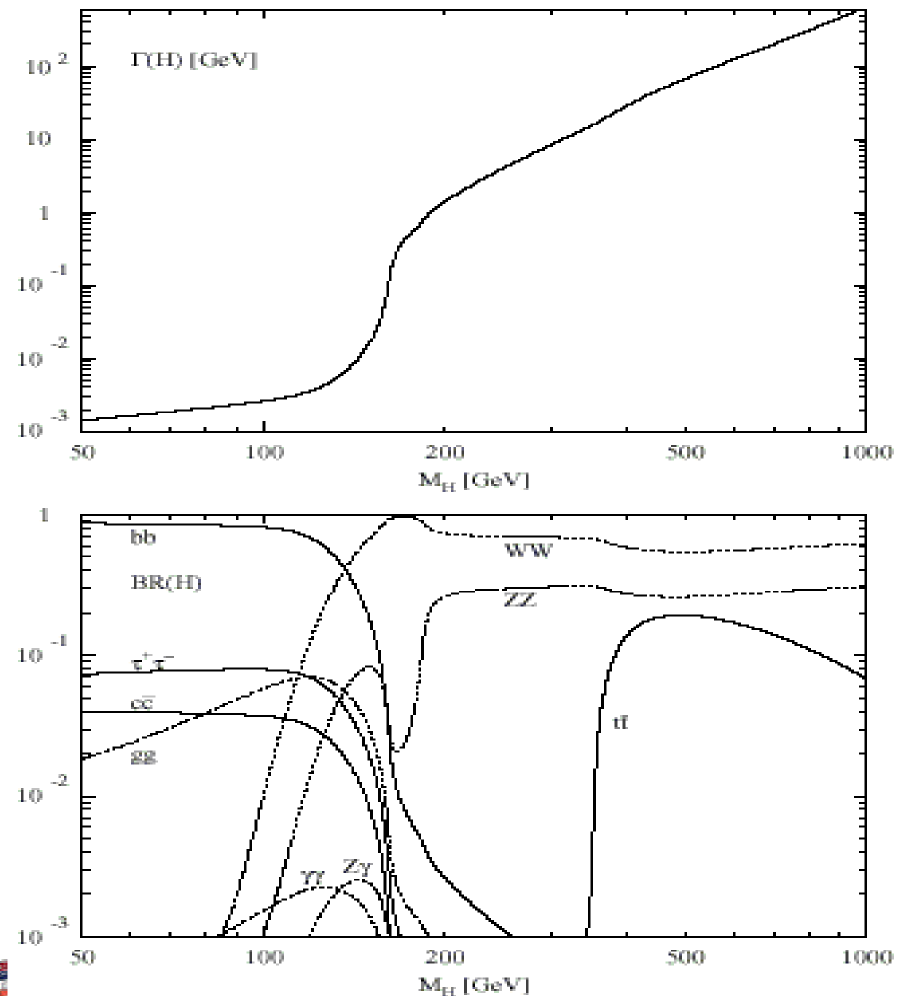
$d_Z^{'} = 7/12 - 10\sin^2 q_W / 9 + 40 \sin^4 q_W / 27$

$$\Gamma\left(H \to gg\right)$$
$$= \frac{3G_F^2 a^2}{128\sqrt{2}p^3} M_H^3 \left|\frac{4}{3} N_c e_t^2 - 7\right|^2$$

Valid in the limit $M_H^2 << 4M_W^2, 4M_t^2$

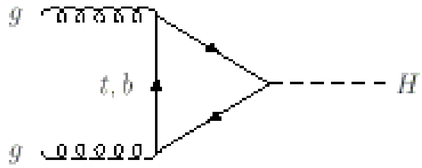


Summary of SM Higgs Branching Ratio



Higgs Production Processes at Hadron Colliders

Gluon fusion: $gg \rightarrow H$

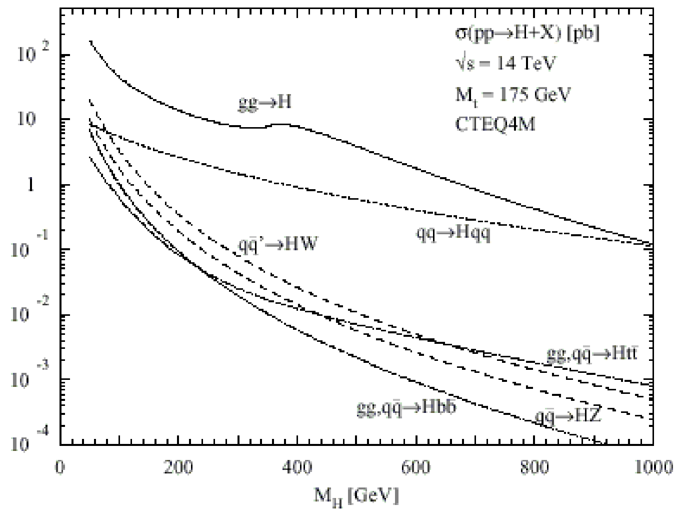


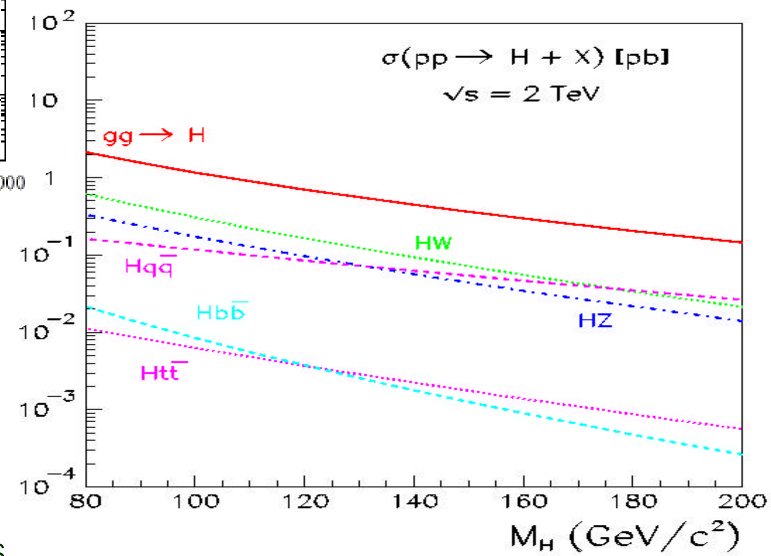
WW, ZZ Fusion: $W^{+}W^{-}, ZZ \rightarrow H$

Higgs-strahlung off W,Z: $q\bar{q} \rightarrow W^{*}, Z^{*} \rightarrow W, Z + H$

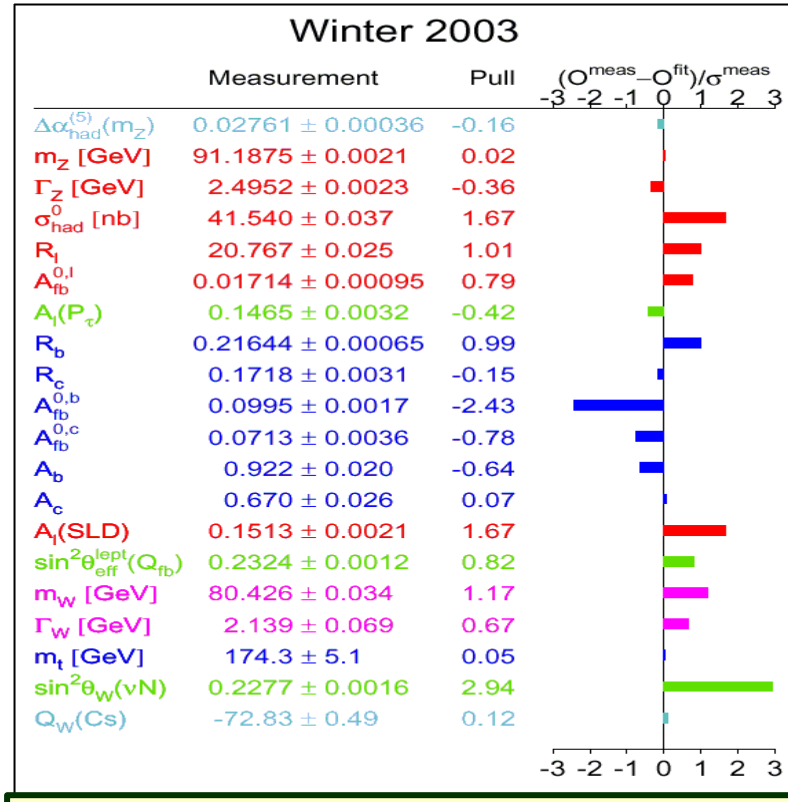
Higgs Bremsstrahlung off top: $q\bar{q}, gg \rightarrow t\bar{t} + H$

Hadron Collider SM Higgs Production σ





What do we know as of Winter 03?



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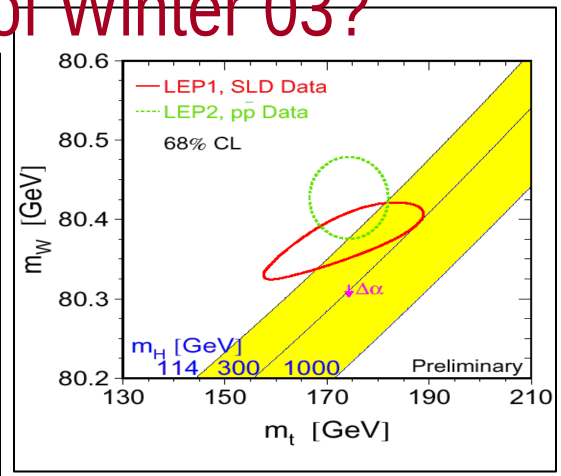
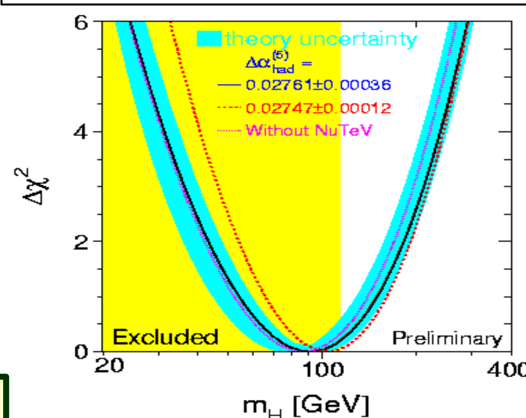
	Measurement	Pull
$\Delta\alpha_{had}^{(5)}(m_Z)$	0.02761 ± 0.00036	-0.16
m_Z [GeV]	91.1875 ± 0.0021	0.02
Γ_Z [GeV]	2.4952 ± 0.0023	-0.36
σ_{had}^0 [nb]	41.540 ± 0.037	1.67
R_l	20.767 ± 0.025	1.01
$A_{fb}^{0,l}$	0.01714 ± 0.00095	0.79
$A_l(P_\tau)$	0.1465 ± 0.0032	-0.42
R_b	0.21644 ± 0.00065	0.99
R_c	0.1718 ± 0.0031	-0.15
$A_{fb}^{0,b}$	0.0995 ± 0.0017	-2.43
$A_{fb}^{0,c}$	0.0713 ± 0.0036	-0.78
A_b	0.922 ± 0.020	-0.64
A_c	0.670 ± 0.026	0.07
A_l(SLD)	0.1513 ± 0.0021	1.67
$\sin^2\theta_{eff}^{lept}(Q_{fb})$	0.2324 ± 0.0012	0.82
m_W [GeV]	80.426 ± 0.034	1.17
Γ_W [GeV]	2.139 ± 0.069	0.67
m_t [GeV]	174.3 ± 5.1	0.05
$\sin^2\theta_W(\nu N)$	0.2277 ± 0.0016	2.94
$Q_W(Cs)$	-72.83 ± 0.49	0.12





LEP EWWG: http://www.cern.ch/LEPEWWG

$114<M_H<300+700$ GeV

Homework Assignment

- Study the summary SM Higgs branching ratio plot in slide 10 and plan experimental strategies to search for Higgs particles in the following two scenarios
  – M_H=115GeV
  – M_H >150GeV
- Due: Wednesday, Apr. 16