Higgs Physics
at Hadron Colliders:
The Tevatron

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Higgs Physics at Hadron Colliders: The Tevatron

- **Introduction: What do we know today?**

— Precision data from LEP, SLC, Tevatron
$\Longrightarrow$ Standard Model (SM) provides an excellent fit to all observables
  — There is one missing ingredient in the SM

The Higgs boson

$\Longrightarrow$ responsable for giving mass to all other particles
The mass of the SM Higgs is an unknown parameter

- **How these issues may be connected?**

— Precision data: $M_t, M_W, \sin^2\theta_W \to m_H$ (indirect)
  — Direct m_H searches (LEP)

Standard Model Vs New Physics (NP)

What can we learn from RUN 2?

- Precision measurements:

  Top Physics   (explore hints for NP)

  W Mass

$\rightarrow M_t$–M_W–M_H Correlation

$A_{\mathrm{FB}} \leftrightarrow \sin^2 \theta_W$

- B Physics

- Direct Standard Model Higgs Searches

Explore masses beyond LEP bound and probe the tantalizing hint from LEP?

- New Physics Searches   (see T. Kamon's talk)

Explore some channels with excess over SM predictions at RUN 1 and search for:

  Supersymmetry $\longrightarrow$ MSSM Higgs Bosons

  New Exotic Quarks

  Strong Dynamics

- Explore new ideas : Extra Dimensions

Precision Measurements:
Top Quark Mass, W Mass and $\sin^2 \theta_W$

Run 1 measurements: CDF and DØ

$$M_t = 174.3 \pm 5.1 \text{ GeV}$$

$$M_W = 80.452 \pm 0.062 \text{ GeV}$$

A_{FB} measured at Z pole $\Longrightarrow$ meas. of $\sin^2 \theta_W$.

$$u\bar{u} + d\bar{d} \to Z \to \ell^+ \ell^-.$$

CDF Run 1: $A_{\text{FB}} = 0.070 \pm 0.015_{\text{stat}} \pm 0.004_{\text{syst}}$

Run 2 Expectations [per experiment]:

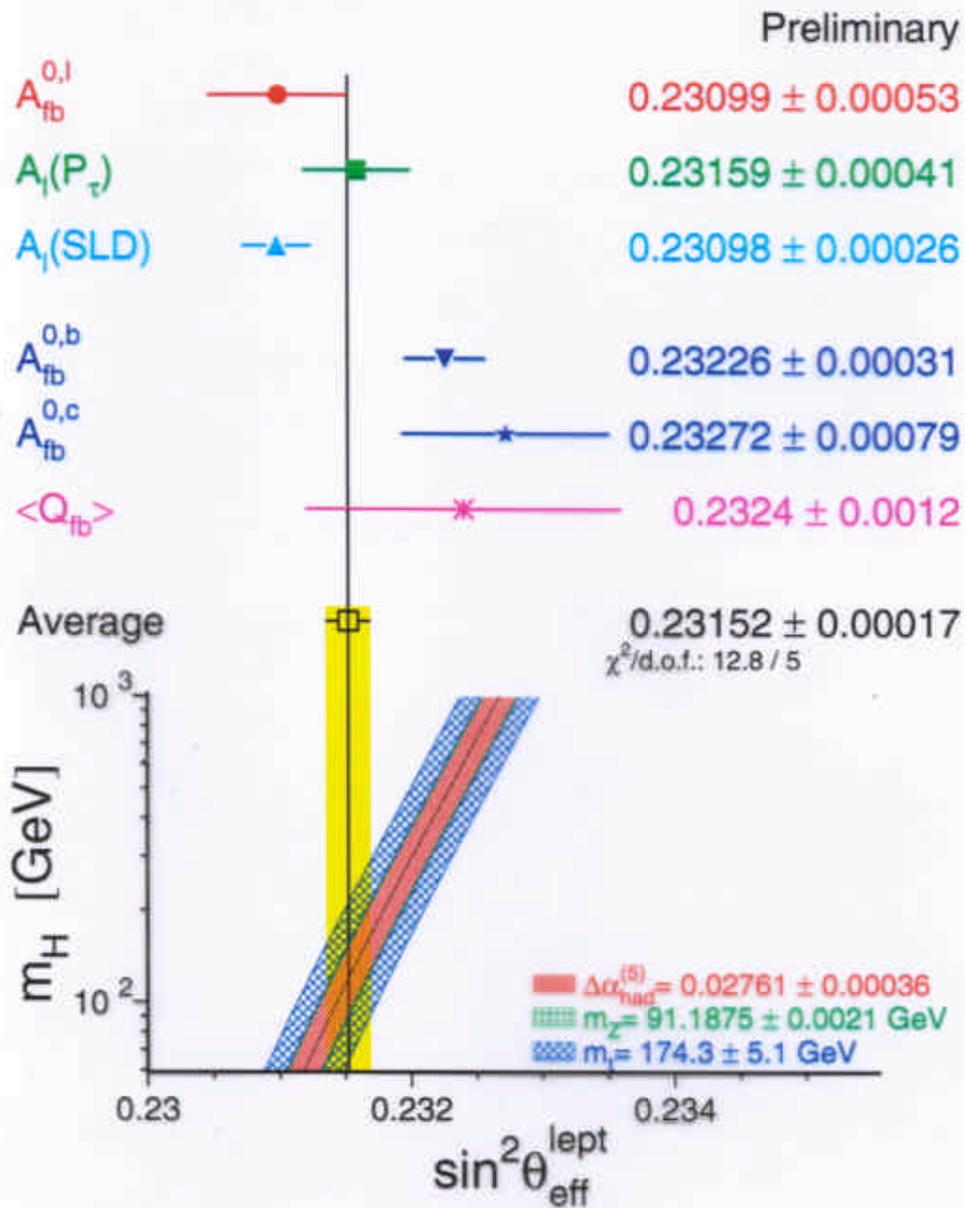| $\int \mathcal{L}$ [fb^{-1}]	2	10	15	30
δM_t [GeV]	≈ 3	≈ 2		≈ 1
δM_W [MeV]	30		20	15
δA_{FB} (stat.)		0.0016		0.0009
$\delta \sin^2 \theta_W^*$		0.00028		0.00016

The current *world average* has $\delta \sin^2 \theta_W^* = 0.00017$.
This would help to understand the discrepancy in $\sin^2 \theta_W^*$
from $A_\ell(\text{SLD})$ and A_{FB}^b.

Compare the two most precise values:

they disagree at the 3σ level!

Preliminary

$A_{fb}^{0,l}$		0.23099 ± 0.00053
$A_l(P_\tau)$		0.23159 ± 0.00041
$A_l(SLD)$		0.23098 ± 0.00026
$A_{fb}^{0,b}$		0.23226 ± 0.00031
$A_{fb}^{0,c}$		0.23272 ± 0.00079
$\langle Q_{fb} \rangle$		0.2324 ± 0.0012
Average		0.23152 ± 0.00017

$\chi^2/\text{d.o.f.}: 12.8 / 5$

$\Delta\alpha_{had}^{(5)} = 0.02761 \pm 0.00036$
$m_Z = 91.1875 \pm 0.0021$ GeV
$m_t = 174.3 \pm 5.1$ GeV

m_H [GeV]

$\sin^2\theta_{eff}^{lept}$

The $\chi^2/\text{d.o.f}$ is mediocre.

M_t–M_W–M_H Correlation

- Direct M_t and M_W meas. from LEP and Tevatron
- Indirect M_t and M_W determination from SM fit to precision data (LEP, SLD, νN)
- SM relationship for M_t–M_W–M_H

  $\implies$ crucial information on M_H
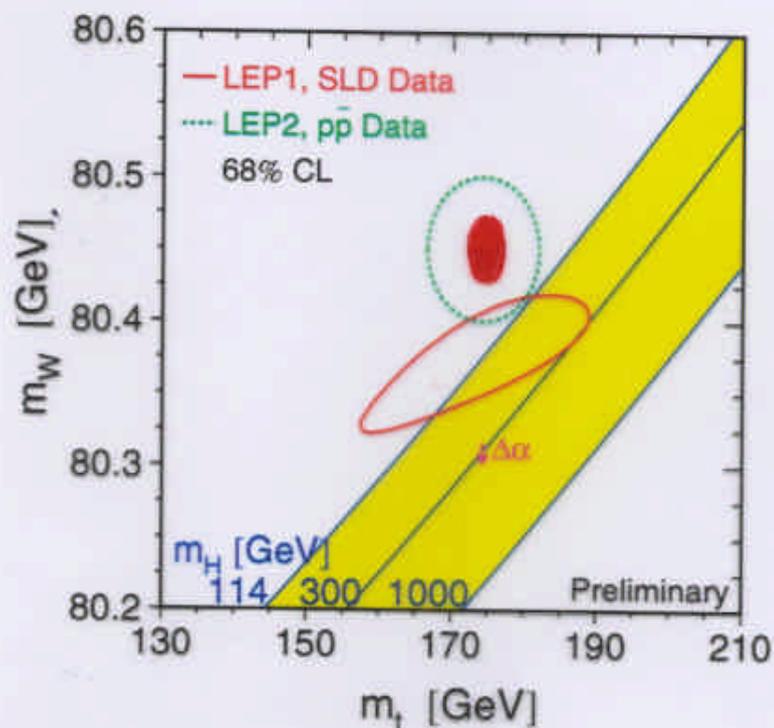
Light SM Higgs Boson $\longrightarrow$ strongly favoured by data

$\delta M_t \sim 3\,(2)$ GeV $\Longleftrightarrow$ $\delta M_W \sim 20\,(12)$ MeV

Maximal use of the obtained δM_t, δM_W accuracy

Higgs Physics

Within the Standard Model:

— LEP final results $\Longrightarrow m_{h_{\mathrm{SM}}} \geq 114.1$ GeV

Hint of a Higgs at about 115 GeV ??

— Limit from precision electroweak data:

$\Longrightarrow m_{h_{\mathrm{SM}}} \leq 196$ GeV at 95 % C.L.

$\Downarrow$

Upgraded Tevatron $\longrightarrow$ good sensitivity precisely in this mass region

$\downarrow$

Next chance to reveal mechanism of Electroweak Symmetry Breaking

— from perturbativity and stability bounds:

• for 130 GeV $\lesssim m_{h_{\mathrm{SM}}} \lesssim 200$ GeV
$\Longrightarrow$ SM description valid up to $\Lambda \sim 10^{13}$–10^{19} GeV

• for $m_{h_{\mathrm{SM}}} \lesssim 130$ GeV
$\Longrightarrow$ New Physics expected to appear at $\Lambda \ll M_{\mathrm{Pl}}$

$(\Lambda \sim 10^5$–10^9 GeV$)$

SM Higgs Production Cross Sections
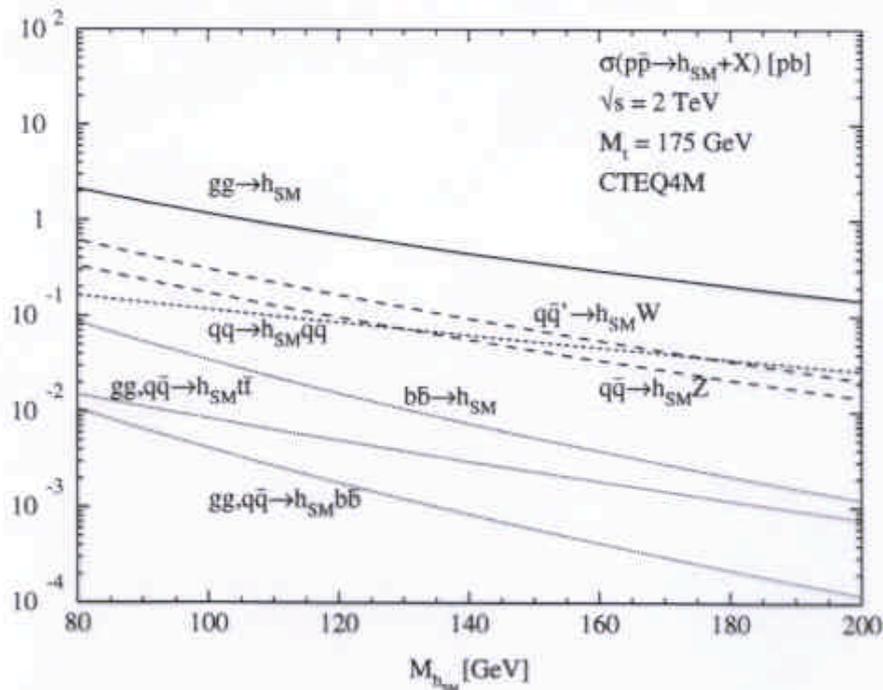
- $gg \to h_{SM}$ —→ largest cross section

NLO QCD corr. $\Longrightarrow$ a factor 2 larger!

$\qquad$ NNLO $\Longrightarrow \sim 10\text{–}30\%$ increase

$\quad$ theoretical uncertainties:

scale dependence & h.o. effects $\sim 15\%$ $\qquad$ PDF's $\approx 10\%$

- $q\bar{q} \to W^{\pm} h_{SM}$ —→ 2nd largest if $m_h < 175$ GeV
  $\quad \to Z\, h_{SM}$ —→ about factor 2 lower

QCD corrections about 30%

$\quad$ theoretical uncertainties:

scale dependence & h.o. effects $\sim 15\%$ $\qquad$ PDF's $\approx 15\%$

- $gg, q\bar{q} \rightarrow t\bar{t}\, h_{\mathrm{SM}}$

NLO QCD corrections recently completed

Size of corrections depends sensitively on the choice of
normalization/factorization scale μ in α_S & PDF's at LO:
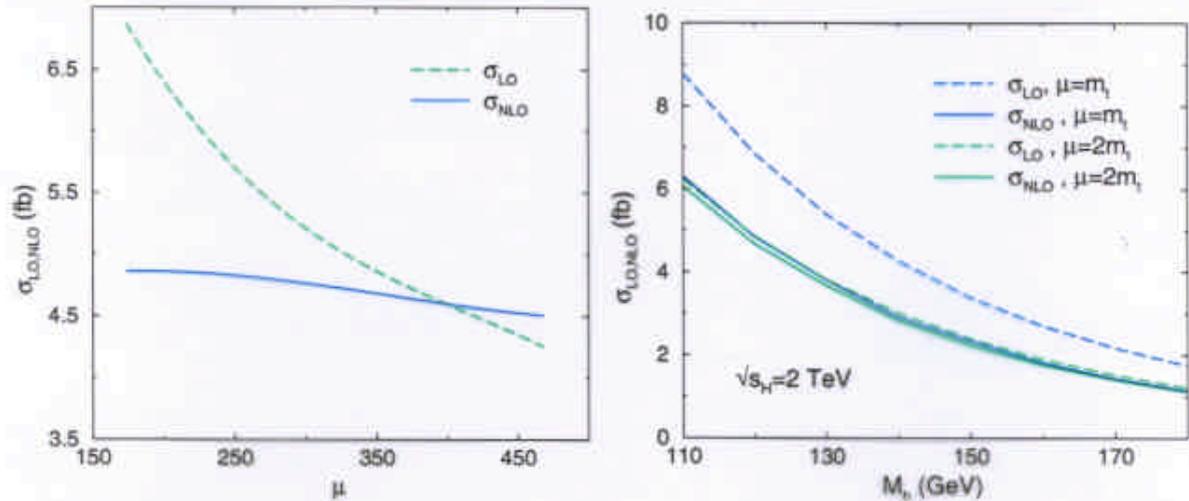
L.Reina, S.Dawson, D.Wackeroth

W.Beenakker, S.Dittmaier, M.Krämer, B.Plümper, M.Spira, P.M.Zerwas

NLO $\Longrightarrow$ cross section of order 1–5 fb

for $m_{h_{\mathrm{SM}}}$ within the reach of the Tevatron

- Vector Boson Fusion: $q\bar{q} \rightarrow q\bar{q}\, h_{\mathrm{SM}}$

(also, $ud \rightarrow du\, h_{\mathrm{SM}}$ + c.c.)

QCD corrections $\sim 10\%$

- $gg, q\bar{q} \to bb\, h_{\rm SM}$

tree level, fixing α_S, PDF's and h_b at scale $m_{h_{\rm SM}}$

$\implies$ implicitly includes part of QCD correc. to full inclusive cross section, but

$\longrightarrow$ significant QCD correc. from kinematic region where b's emitted in the forward direction $\implies$ large collinear logs $\propto \alpha_S \ln(m^2_{h_{\rm SM}}/m^2_b) \sim \mathcal{O}(1)$ which must be resummed in generation of b-quark distrib. function

$\implies$ fully inclusive QCD cross section well approx. by $b\bar{b} \to h_{\rm SM}$ + QCD correc. (one order of magnitude larger)

Realistic simulation: ultimately needs QCD corrected differential cross section for $b\bar{b}\, h_{\rm SM}$

Studies for   (i) $h_{\rm SM} + 2\,b$'s   (ii) $h_{\rm SM} + 1\,b+$ jet

If only $1\,b$ tagged $\implies$ sufficient to consider $bg \to b\, h_{\rm SM}$

$\implies$ computed at NLO QCD

Campbell, Ellis, Maltoni, Willenbrock

$p\bar{p}\to hb$ @ Tevatron
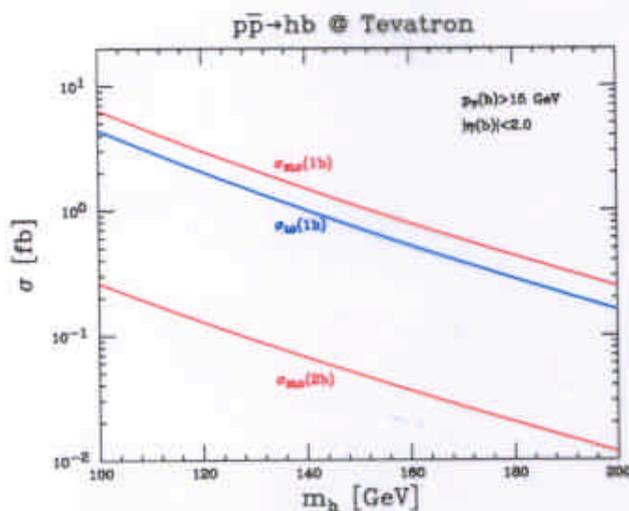
$y_b = y_b(m_{h_{\rm SM}}) \quad \alpha_S = \alpha_S(m_{h_{\rm SM}})$
at 1-loop (2-loop) for LO (NLO) curves
$\sigma(1b)$: $1\,b$ in tagging region
$\sigma^{\rm LO}(2b)$: $2\,b$'s in tagging region
$\sigma^{\rm NLO}(1b) \sim 2\,\sigma^{\rm LO}(1b)$

SM Higgs Decay Modes
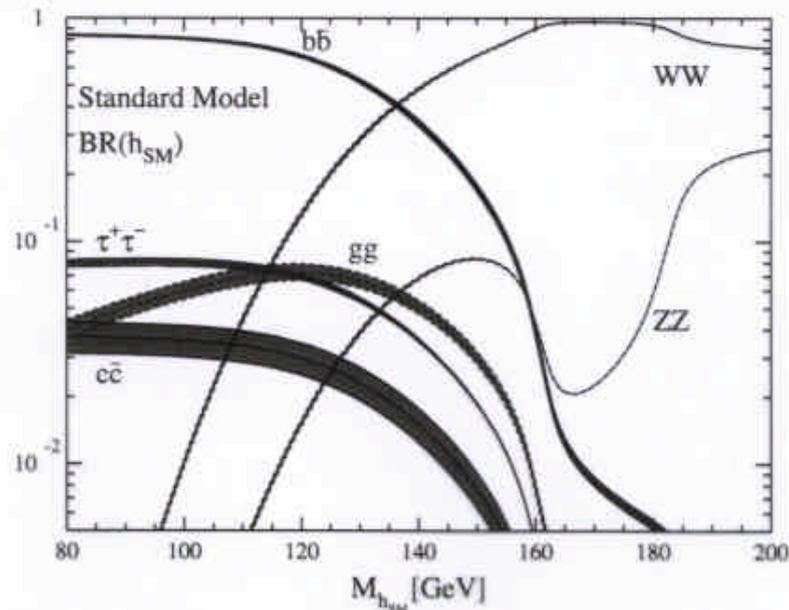
uncertainties: $\alpha_s(M_Z) = 0.12 \pm 0.003$ $M_t = 174 \pm 5$ GeV

$\bar{m}_b(M_b) = 4.22 \pm 0.05$ GeV $\bar{m}_c(M_c) = 1.22 \pm 0.06$ GeV

- $m_{h_{SM}} \lesssim 135$ GeV $\implies h_{SM} \to b\bar{b}$ dominant

- $m_{h_{SM}} \gtrsim 135$ GeV $\implies h_{SM} \to WW^*$ dominant

leading QCD corrections to decays into quark pairs
$$\implies m_f(m_{h_{SM}}) \text{ in tree level formula}$$

IMPORTANT: expected hierarchy of Higgs decays:

$BR(\tau^+\tau^-) < 10^{-1}\, BR(b\bar{b}) \longrightarrow \mathcal{O}\left(m_b^2/m_\tau^2\right) \times 3_{(\text{color})}$

$BR(c\bar{c}) < BR(\tau^+\tau^-) \longrightarrow$ due to smallness of $\bar{m}_c(m_{h_{SM}})$

SM Higgs Prospects at the Tevatron

- $M_H \leq 130\text{GeV} \implies p\bar{p} \to VH \to Vb\bar{b}$ (V = W,Z)

   signal: leptonic decays of W,Z

   $\ell\nu b\bar{b}$ and $\nu\bar{\nu}b\bar{b}$, $\ell^+\ell^- b\bar{b}$

   main backgrounds:

   for Wh_{SM}: $Wb\bar{b}$, $t\bar{t}$, WZ, single-t

   for Zh_{SM}: $Zb\bar{b}$, ZZ, $t\bar{t}$, $W^* \to t\bar{b}$

- $M_H \geq 130\text{GeV} \implies p\bar{p} \to VH \to VWW^*$
$$\implies p\bar{p} \to H \to WW^*$$

   signal:

   $\ell^+\ell^-$+jets, $\ell^\pm\ell^\pm$, 3ℓ

   main backgrounds:

   WW, WZ, ZZ, W+jets, Z+jets

Crucial Issues in the Analysis:

- b-tagging efficiency   • M_{bb} resolution
- background estimation
- mass window *vs.* spectrum fit

Higgs/SUSY Workshop & Higgs WG Report results
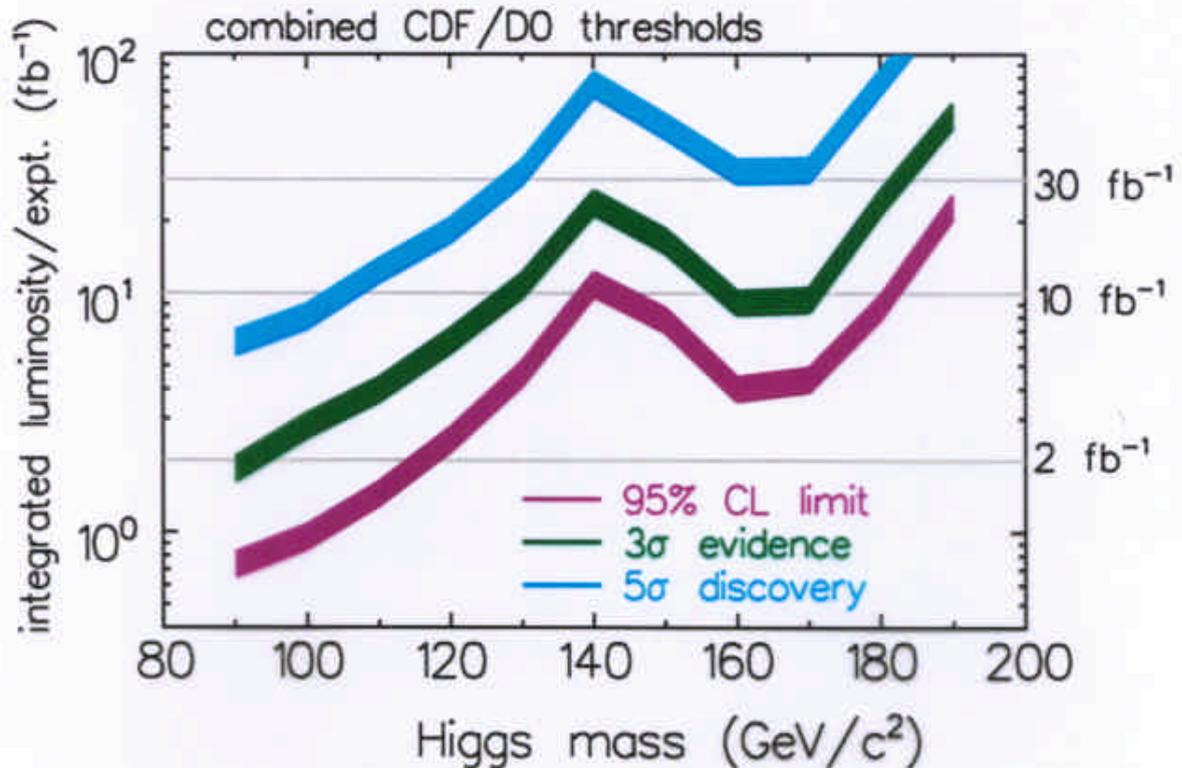
- $m_{h_{\text{SM}}} \leq 180$ GeV $\Longrightarrow$ 95 % C.L. excl. $\to 10$ fb^{-1}/exp.
  3σ evidence $\to 20$ fb^{-1}/exp. 5σ discovery $\to \approx 60$ fb^{-1}/exp.

- $m_{h_{\text{SM}}} \leq 130$ GeV $\Longrightarrow$ 95 % C.L. excl. $\to 5$ fb^{-1}/exp.
  3σ evidence $\to 10$ fb^{-1}/exp. 5σ discovery $\to \approx 30$ fb^{-1}/exp.

- $m_{h_{\text{SM}}} \approx 115$ GeV (LEP Hint?) $\Longrightarrow 3\sigma$ with ≈ 5 fb^{-1}/exp.
  $\Longrightarrow 5\sigma$ with ≈ 15 fb^{-1}/exp.

Crucial Issues with the Analysis

$\boxed{b\text{-tagging}}$ *note:* $\mathcal{L}$ scales with ϵ_b^2

HWG considered Run 1 efficiencies (ϵ_b)

$\longrightarrow$ probably conservative by 10–20%

$\boxed{b\bar{b} \text{ Mass Resolution}}$

assumed 10% (compare to 13.5% for $Z \to b\bar{b}$ in Run 1)

Run 2: hope to attain 10–12% for $h \to b\bar{b}$

$\boxed{\text{Background Estimation}}$

• assume QCD background in $\nu\bar{\nu}b\bar{b}$ channel equal to sum of all other backgrounds (based on Run 1 results)

• $W b\bar{b} \to$ Ellis *et al.* studies yet to be implemented

$\boxed{\text{Multivariate Methods}}$

assume 30% improvement from neural network

$\to$ investigate training with real data

$\boxed{\text{Mass Window }vs.\text{ Spectrum Fit}}$

• performed simple event counting within mass window

• studies by T.Kruse & J.Conway indicate $\sim 20\%$ reduction in required $\mathcal{L}$ from fitting

$\boxed{\text{Systematic Uncertainties}}$

assumed 10% max uncertainty on background rate

$\longrightarrow$ tough to achieve

$\longrightarrow$ need to measure bg shape and normalization

New Studies

Goldstein et al. '00

- striking final states:

$$h \to b\bar{b} \Longrightarrow W^+ W^- b\bar{b}\, b\bar{b}$$

$$h \to WW^* \Longrightarrow W^+ W^- b\bar{b}\, WW^*$$

- backgrounds:
  - $t\bar{t}$+jets, $t\bar{t} + b\bar{b}$, $t\bar{t} + Z(\to b\bar{b})$, $WZ + jj$
  - $t\bar{t}$+jets, $t\bar{t} + W$, $t\bar{t} + Z(\to \ell^+\ell^-)$

$m_h < 140$ GeV: $\ell^{\pm} jj\, b\bar{b}b\bar{b}\,\not{E}_T$ (considered w/ 3b-tags)

(other options either too small or not studied)

Results before NLO cross sections available:

For $m_{h_{SM}} = 120$ GeV $\Longrightarrow$

     15 fb^{-1} gives 2.8σ (1 exp), 4.1σ (2 exp)   .

After NLO σ's considered:

$\longrightarrow$ signal is factor ~ 0.7 smaller

     $\Longrightarrow$ factor 2 more luminosity needed

$(h \to WW^*$ channel is more difficult$)$

NLO impact on σ's in Run II Analysis

$$\boxed{gg \rightarrow h \rightarrow \tau^+ \tau^-}$$
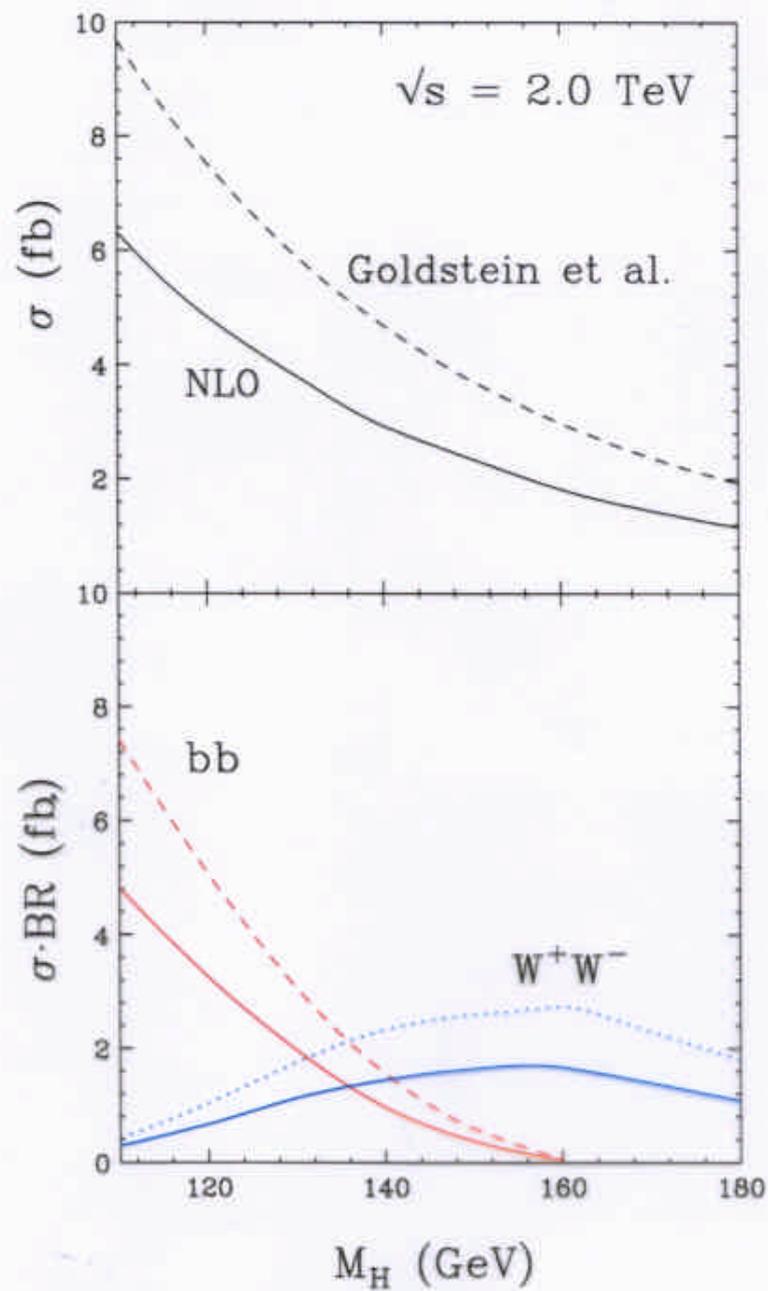
signal: consider leptonic and hadronic decays for efficiency

- good simulation tool for τ decays available
- better understanding of τ-ID efficiencies

backgrounds: $Z j \rightarrow \tau^+ \tau^- j$ (irred.), $3j \rightarrow \tau^+ \tau^- j$ (mis-ID)
$W^\pm jj$, $W^+ W^- j$ ($W \rightarrow \tau$, j faking τ) smaller

m_h	120 GeV	130 GeV	140 GeV
95% CL exclusion $L(\text{fb}^{-1})$	15	18	33
5σ discovery $L(\text{fb}^{-1})$	94	110	210
κ for 95% CL (2 fb^{-1})	2.6	3.0	4.1
κ for 95% CL (15 fb^{-1})	0.97	1.1	1.4
κ for 5σ (2 fb^{-1})	6.7	7.5	10
κ for 5σ (15 fb^{-1})	2.5	2.7	3.7

K-factors over SM rate in new theories to achieve a
95% CL exclusion or 5σ discovery with given $\mathcal{L}$

Combining these with results from the Higgs report:

$\Longrightarrow$ 10–20% (up to 35%) improvement in required $\mathcal{L}$

$\Longrightarrow$ sensitivity in $m_{h_{\text{SM}}} \sim 120$–140 GeV range improved

H_1, H_2 doublets $\Longrightarrow$ 2 CP-even Higgs h, H

1 CP-odd state A   2 charged Higgs $H^\pm$

Higgs masses and couplings given in terms of two

parameters: m_A and $\tan\beta \equiv v_2/v_1$

mixing angle $\alpha \Longrightarrow \cos^2(\beta - \alpha) = \frac{m_h^2(m_Z^2 - m_h^2)}{m_A^2(m_H^2 - m_h^2)}$

Couplings to gauge bosons and fermions (norm. to SM)

hZZ, hWW, ZhA, $WH^\pm h$ $\longrightarrow \sin(\beta - \alpha)$

HZZ, HWW, ZHA, $WH^\pm H$ $\longrightarrow \cos(\beta - \alpha)$

(h,H,A) $u\bar{u} \longrightarrow \cos\alpha/\sin\beta, \ \sin\alpha/\sin\beta, \ 1/\tan\beta$

(h,H,A) $b\bar{b} \longrightarrow -\sin\alpha/\cos\beta, \ \cos\alpha/\cos\beta, \ \tan\beta$

If $m_A \gg M_Z \rightarrow$ decoupling limit

• $\cos(\beta - \alpha) = 0$ up to correc. $\mathcal{O}(m_Z^2/m_A^2)$

• lightest Higgs has SM-like couplings and mass
$m_h^2 \simeq m_Z^2 \cos^2 2\beta$

• other Higgs bosons: heavy and roughly degenerate
$m_A \simeq m_H \simeq m_H^\pm$ up to correc. $\mathcal{O}(m_Z^2/m_A^2)$

important quantum correc. due to loops of particles and their superpartners: incomplete cancellation due to SUSY breaking $\Longrightarrow$ main effects: top and stop loops; bottom and sbottom loops in large $\tan \beta$ regime

$$m_h^2 = M_Z^2 \cos^2 2\beta + \frac{2\, g_2^2\, m_t^4}{8\pi^2\, M_W^2} \left[\ln(M_S^2/m_t^2) + \frac{X_t^2}{M_S^2}\left(1 - \frac{X_t^2}{12\, M_S^2}\right) \right] + \text{h.o}$$

$M_S^2 = \frac{1}{2}(m_{\tilde{t}_1}^2 + m_{\tilde{t}_2}^2)$ and $X_t = A_t - \mu/\tan\beta \longrightarrow$ stop mixing

- two-loop log. and non-log. effects are numerically important $\rightarrow$ computed by different methods:
    - diagrammatic   - effective potential
    - RG-improved effective potential (see Haber's talk)

- upper limit on Higgs mass: $m_h \lesssim 135$ GeV

$$M_S = 1 \rightarrow 2 \text{ TeV} \Longrightarrow \Delta\, m_h \simeq 2 - 5 \text{ GeV}$$
$$\Delta\, m_t = 1 \text{ GeV} \Longrightarrow \Delta\, m_h \sim 1 \text{ GeV}$$

- main effects already present in one-loop formulae
    - m_t^4 enhancement
    - depend. on $\tilde{t}$-mixing X_t
        $\Longrightarrow$ max. value $X_t \sim \sqrt{6} M_S$ (scheme depend.)
        small asym. at h.o.
    - logarithmic sensitivity to $m_{\tilde{t}_i}$

Radiative Corrections to Higgs Boson Couplings

$\boxed{1}$ Through rad. correc. to the CP-even Higgs mass matrix, $\delta\mathcal{M}_{ij}^2$, which defines the mixing angle α

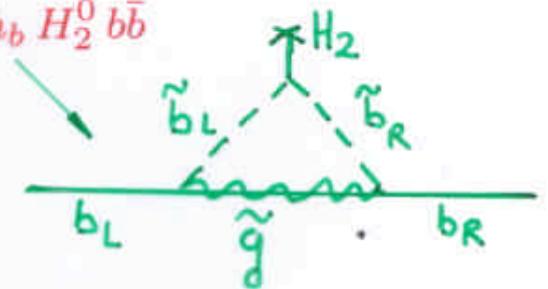$$\sin\alpha\cos\alpha = \mathcal{M}_{12}^2 / \sqrt{(\mathrm{Tr}\mathcal{M}^2)^2 - 4\det\mathcal{M}^2}$$

important effects of rad. correc. on $\sin\alpha$ or $\cos\alpha$ depending on sign of μA_t and magnitude of A_t/M_S.

$\implies$ govern couplings of Higgs to fermions

$\implies$ via rad. correc. to $\underline{\cos(\beta-\alpha)}$ and $\underline{\sin(\beta-\alpha)}$ governs Higgs couplings to vector bosons

$\boxed{2}$ SUSY vertex correc. to Yukawa couplings, which modify the effective Lagrangian, coupling Higgs to fermions

$$\mathcal{L}_{\mathrm{eff}} \longrightarrow h_b\, H_1^0\, b\bar{b} + \Delta h_b\, H_2^0\, b\bar{b}$$

Δh_b modifies the m_b–h_b relation

$$m_b \simeq h_b v_1 + \Delta h_b v_2 = h_b\, v\cos\beta\left(1 + \frac{\Delta h_b}{h_b}\tan\beta\right)$$

$$\Delta_b = \frac{\Delta h_b}{h_b}\tan\beta \sim \frac{2\alpha_S}{3\pi}\frac{\mu\, M_{\tilde{g}}}{\max(m_{\tilde{b}_1}^2, m_{\tilde{b}_2}^2, M_{\tilde{g}}^2)}\tan\beta$$

$$\Delta_b \sim \mathcal{O}(1) \text{ if } \tan\beta \text{ large}$$

Modified Higgs Boson Couplings to b-quarks

$$g_{h\,b\bar{b}} \simeq \frac{-\sin\alpha\, m_b}{v\cos\beta(1+\Delta_b)}\left(1 - \Delta_b/\tan\alpha\tan\beta\right)$$

$$g_{H\,b\bar{b}} \simeq \frac{\cos\alpha\, m_b}{v\cos\beta(1+\Delta_b)}\left(1 - \Delta_b\tan\alpha/\tan\beta\right)$$

$$g_{A\,b\bar{b}} \simeq \frac{m_b}{v(1+\Delta_b)}\tan\beta$$

- similar effects on τ coupling but $|\Delta_\tau| \ll |\Delta_b|$

Important modifications of couplings occur for regions of MSSM parameter space
$\longrightarrow$ dep. on sign and values of μA_t, μA_b, $\mu M_{\tilde{g}}$
and magnitudes of $M_{\tilde{g}}/M_S$, μ/M_S

- destroy the basic relation: $g_{h\,b\bar{b}}/g_{h\,\tau\tau} \sim m_b/m_\tau$

- <u>strong suppression</u> of coupling of h (H) to bottoms
  if $\tan\alpha \simeq \Delta_b/\tan\beta$ $((\tan\alpha)^{-1} \simeq -\Delta_b/\tan\beta)$

$\Longrightarrow$ main decay modes of SM-like MSSM Higgs
$b\bar{b} \sim 80\%$ $\tau^+\tau^- \sim 7-8\%$
drastically changed $\Longrightarrow$ other decay modes enhanced

$\Longrightarrow$ Higgs phenomenology at colliders revisited!!

Decay Patterns of MSSM Higgs Bosons

- large $\tan\beta$: h, H, A to $b\bar{b}$, $\tau^+\tau^-$ dominate

- low $\tan\beta$: richer pattern

   (still decays to $b\bar{b}$, $\tau^+\tau^-$ significant if $m_\phi \lesssim 2m_t$)
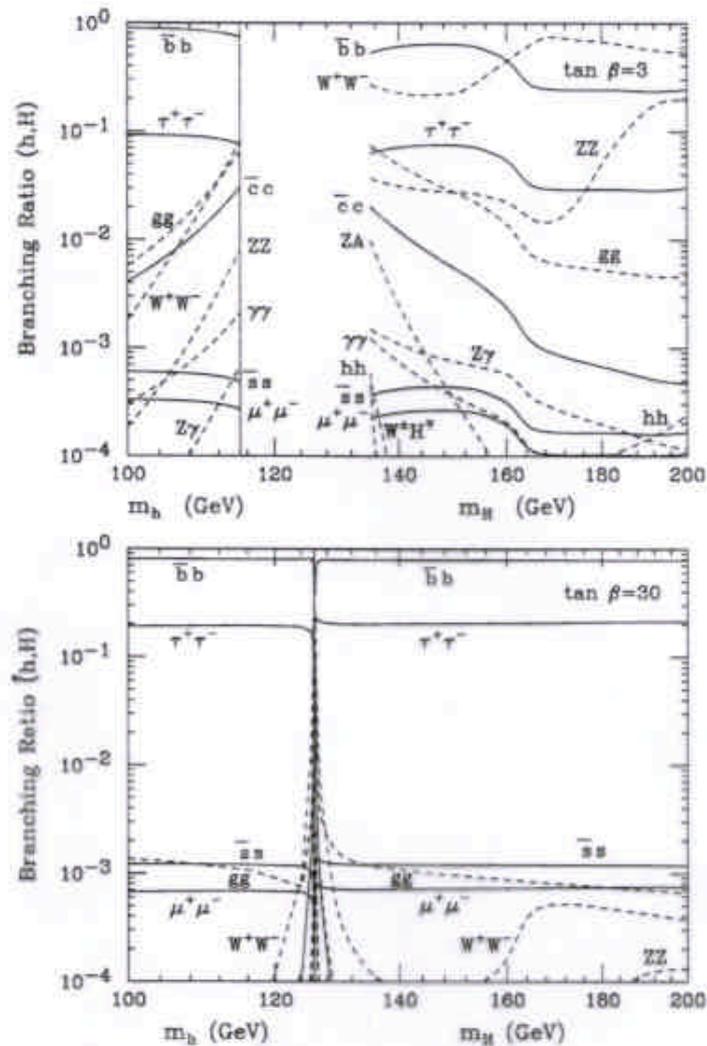
$$M_S = 1 \text{ TeV} \qquad X_t = \sqrt{6}\, M_S$$

Decay to SUSY particles $\longrightarrow$ when open, very important

MSSM Charged Higgs Searches

Run 1 analyses search for charged Higgs in top decays:

$H^+ \longrightarrow \tau^+ \nu_\tau$ large $\tan\beta$

$H^+ \longrightarrow c\bar{s}$ low $\tan\beta$

Similar to neutral Higgs case, one has important radiative corrections for large $\tan\beta$

$$g_{H^- t\bar{b}} \simeq \left\{ \frac{m_t}{v} \cot\beta \left[1 - \frac{1}{1+\Delta_t} \frac{\Delta h_t}{h_t} \tan\beta \right] P_R \right.$$
$$\left. + \frac{m_b}{v} \tan\beta \left[\frac{1}{(1+\Delta_b)} \right] P_L \right\}, \quad (1)$$

also Δm_τ corrections in $g_{H^- \tau \nu_\tau}$ may be included

Drastic variations on $\tan\beta - m_{H^\pm}$ plane bounds, depending on MSSM parameter space

- Curves of constant BR for $t \to bH^+$ after resummation of LO and NLO logarithms of QCD corrections included

M.C., Garcia, Nierste, Wagner

BR($t > H^+ b$)
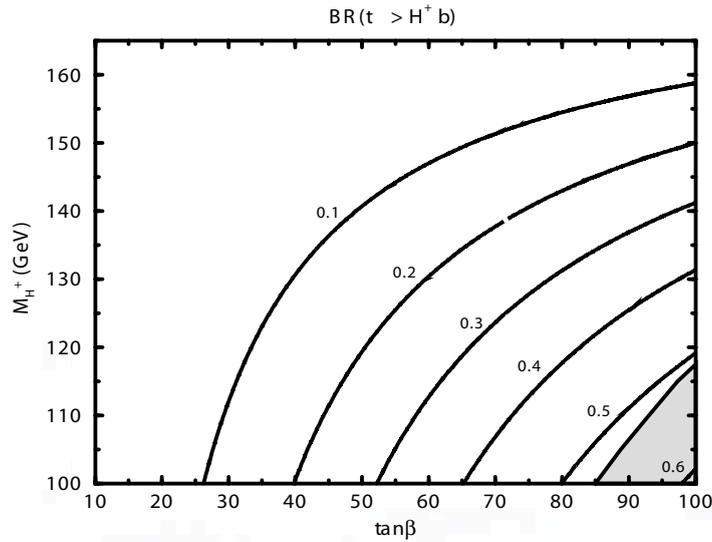
- Same as above, after including dominant SUSY correc. for large $\tan \beta$ for different sets of SUSY parameters. Shaded area excluded by Run1 DO frequentist analysis

BR($t > H^+ b$)
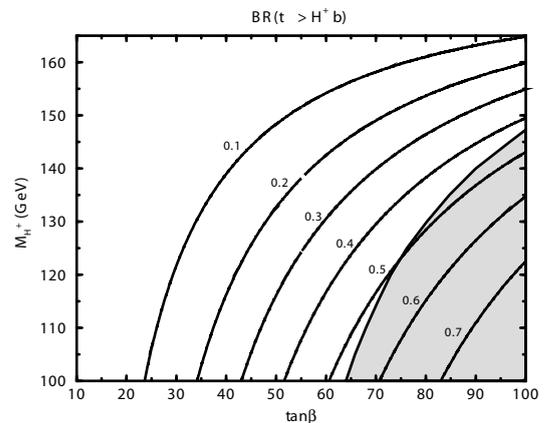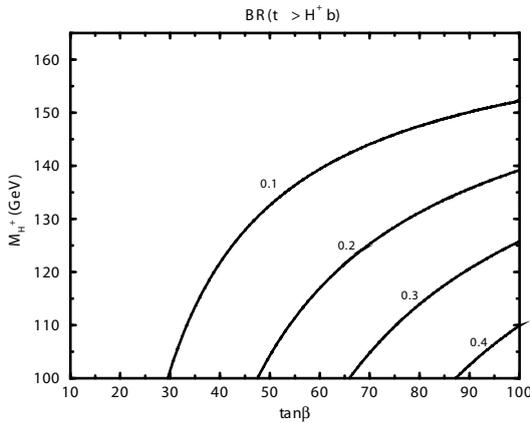
RUN 2 studies for $p\bar{p} \to tbH^{\pm}$:

Belyaev, Garcia, Gavsch, Sola

- charged Higgs signal may be viable in the 220–250 GeV mass range or excluded at 95 % C.L. up to 300 GeV

$M_{\mathrm{SUSY}} = 1$ TeV, $\mu = 300$ GeV,

$A = \mu/\tan\beta + \sqrt{6} \times M_{SUSY}$ (max. mixing)

Belyaev, Han, Rosenfeld
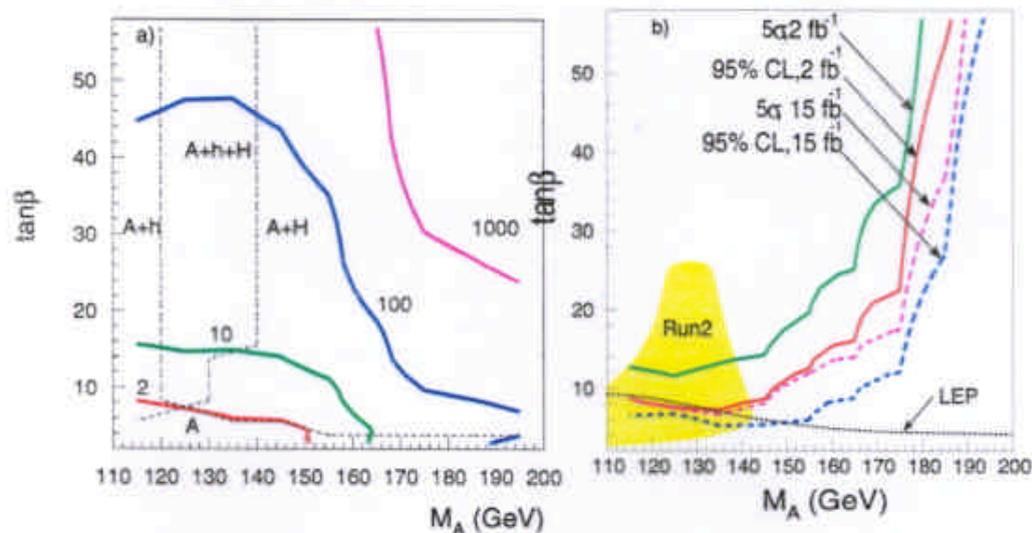
- with the $\tau\tau$ mode could reach $5\sigma(2\sigma)$ full coverage for SUSY Higgs parameters with 15 fb^{-1} (2 fb^{-1})!
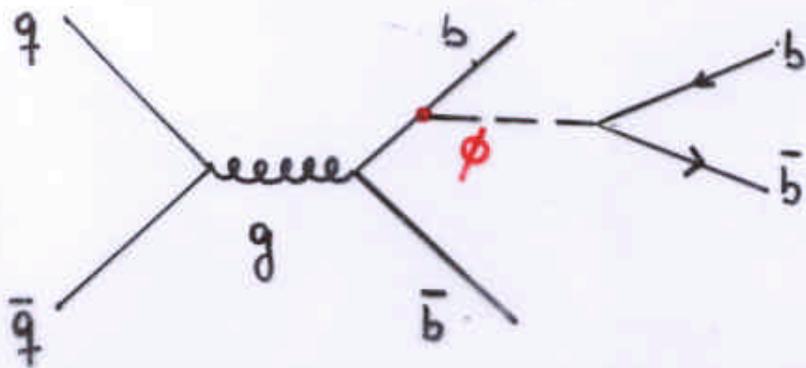
Note: No enhancement if in some region of the parameter space $h b\bar{b}$ Yukawa coupling is accidently suppressed: the increasing of the $h \to \tau\bar{\tau}$ branching fraction balanced by the reduction in the Higgs production via the $h b\bar{b}$ coupling.

Neutral MSSM Higgs Channel Studies
at the Upgraded Tevatron
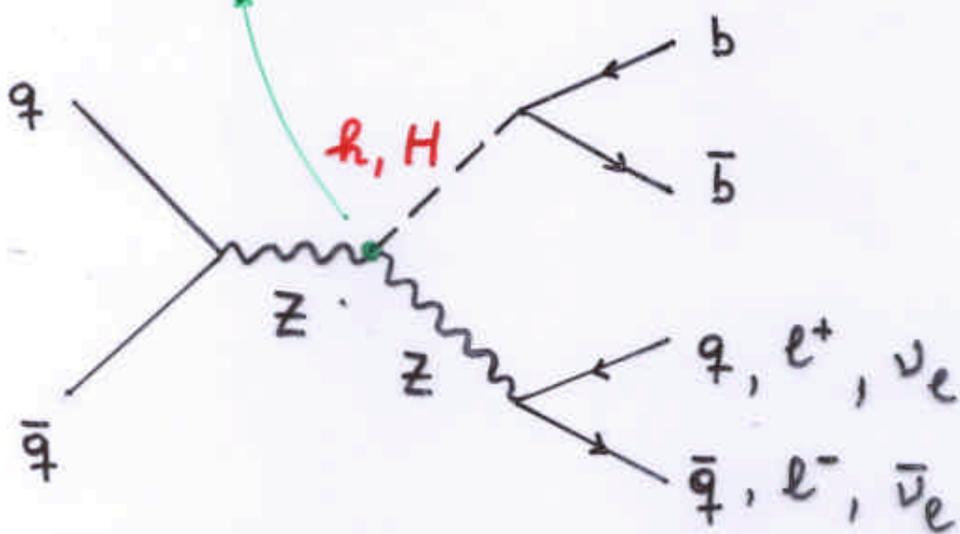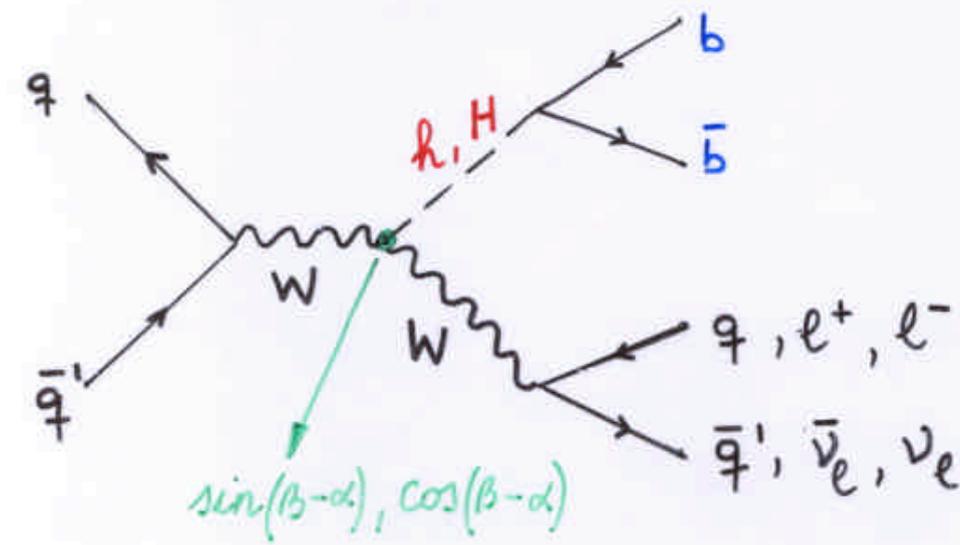
based on SM simulation
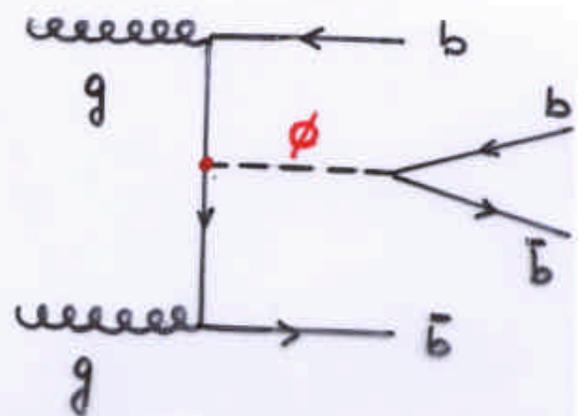
with $\phi = h, A$ or $H, A \rightarrow$ large $\tan^2\beta$ enhancem

'small α_{eff} Higgs scenario'
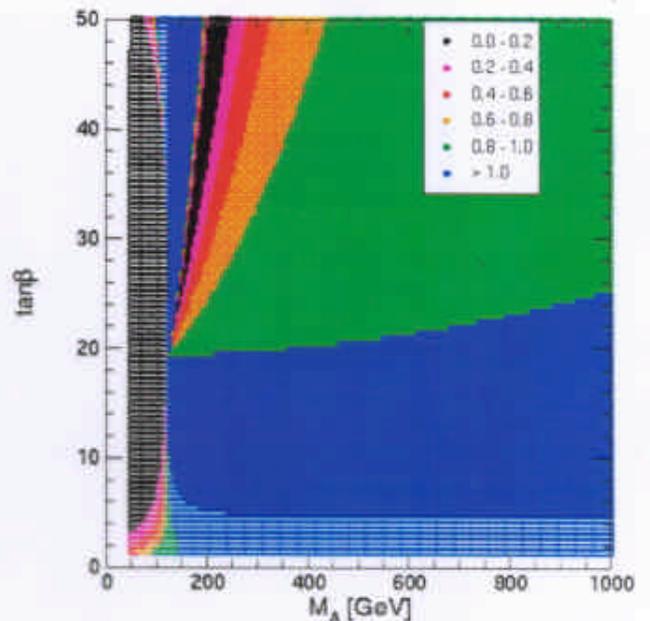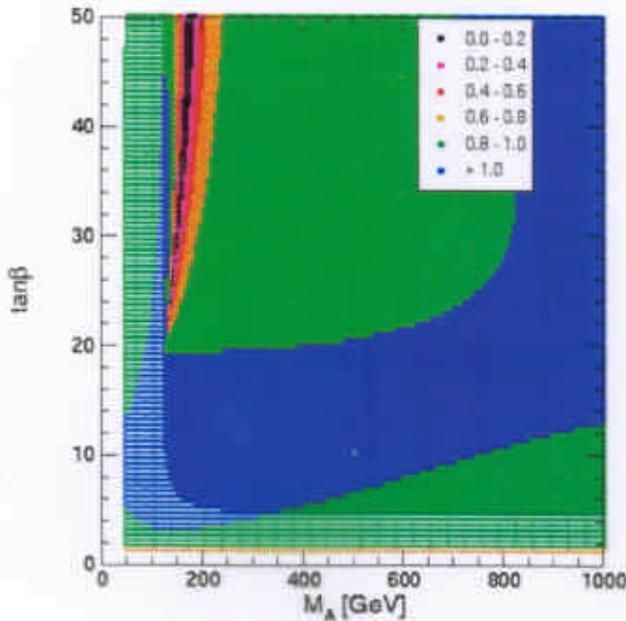
M.C., Heinemeyer, Weig..
Weiglein, '02.

$$\frac{\sigma \times BR^{\text{MSSM}}}{\sigma \times BR^{\text{SM}}}$$ for $W^* \to Wh \to Wb\bar{b}$

$W^* \to Wh \to W\tau^+\tau^-$

$\sigma(WWh) \times BR(h \to bb)$

$\sigma(WWh) \times BR(h \to \tau\tau)$

Benchmark Scenario

$M_S = 800 \text{ GeV}$ $\mu = 2.5 M_S$ $M_2 = 500 \text{ GeV}$

$X_t^{\overline{MS}} = 1200 \text{ GeV}$ $A_b = A_t$ $M_{\tilde{g}} = 500 \text{ GeV}$

Significant suppression for $\tan\beta \gtrsim 20$

$m_A \lesssim 250 \text{ GeV} \to$ for

$400 \text{ GeV} \to$ for

difficult region for Wh (Tevatron), WW fusion + tth (LHC)

MSSM Higgs sector Feasibility Studies

Tevatron Higgs WG '00

maximal
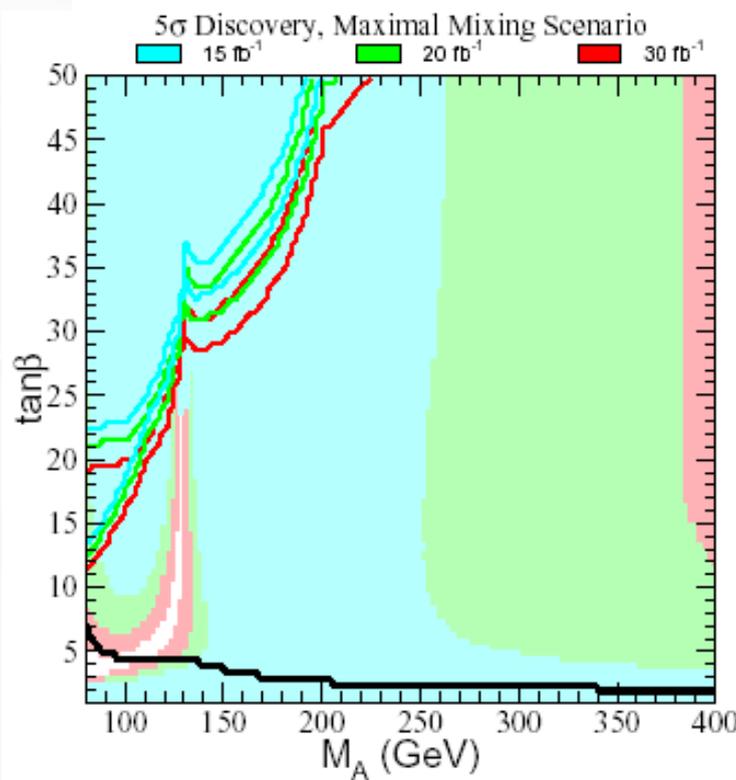mixing
scenario

$\Downarrow$

$m_h^{max} \simeq 130\, GeV$

5σ Discovery, Maximal Mixing Scenario

15 fb⁻¹   20 fb⁻¹   30 fb⁻¹

tanβ M_A (GeV)

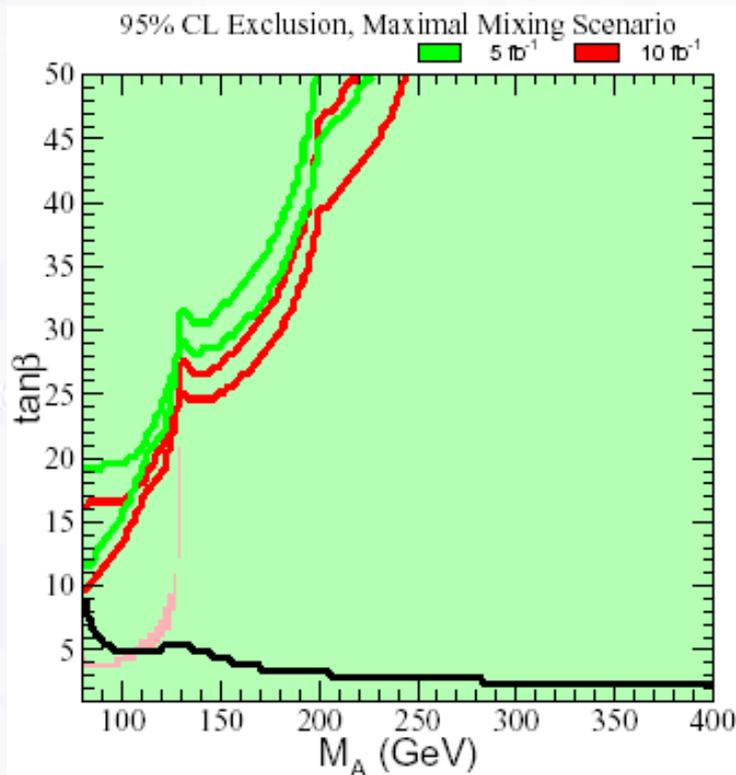5σ discovery

$p\bar{p} \rightarrow Vh/H \rightarrow V$
(shaded are

most part of
param. space
explored with
$\simeq 5\, fb^{-1}$
(95% C.L. excl.)

but
good coverage
for discovery

$\Rightarrow \sim 20\, fb^{-1}$
required

95% CL Exclusion, Maximal Mixing Scenario

5 fb⁻¹   10 fb⁻¹

tanβ M_A (GeV)

$p\bar{p} \rightarrow \phi b\bar{b} \rightarrow b\bar{b}$
(solid lines)

$\langle \phi = A/h$ or A/H
tanβ - enhance
$b\bar{b}$ coupling$\rangle$

95% C.L.
Exclusion

CP Violation & the MSSM Higgs Sector

SUSY Breaking parameters in the
stop/sbottom/gluino sector *may be complex*
$\rightarrow$ CP Violation induced through loop effects

- mixing between the 3 neutral states

h, H, A $\rightarrow$ H_1, H_2 H_3 mixed CP parity states

- upper bound on lightest Higgs mass remains the
same

$$m_{H_1} \leq 135 \text{GeV}$$

- couplings of Higgs bosons to gauge bosons and
fermions can crucially differ from CP conserving case

$\Longrightarrow$ CP violation $\rightarrow$ important phenomenological .
consequences on LEP results and on Tevatron/LHC
expectations $\qquad\qquad$ $\Longrightarrow$ *example*

Note: CPV necessary for Electroweak Baryogenesis
$\Longrightarrow$ when testing ELW Baryogenesis through Higgs
physics, CPV studies of Higgs sector neccesary

Large $\tan\beta$ scenario and sizeable phase of A_t (stop mixing param.), $arg(A_t) \geq 90^o$
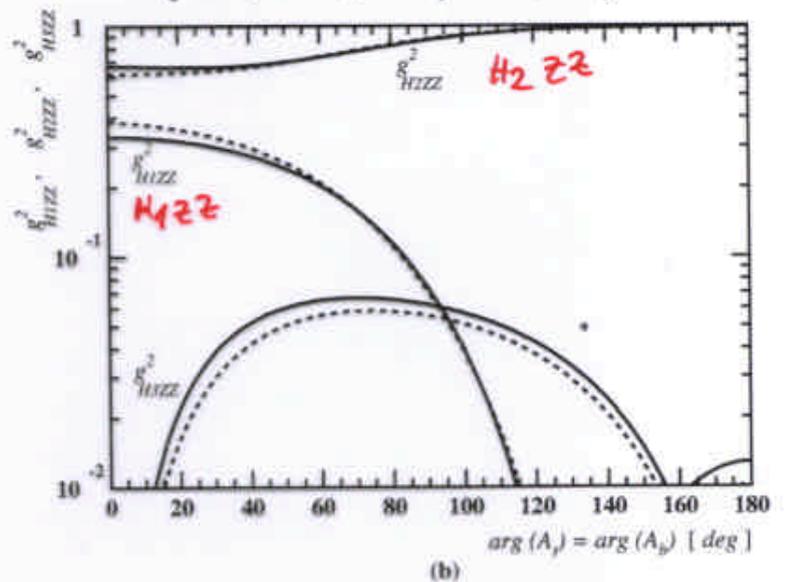
- interesting case: $M_{H_1} \approx 90$ GeV but out of LEP reach, all other channels: ZH_2, ZH_3, H_1H_2, H_1H_3 kin. inaccessible.

- $M_{H_1} \rightarrow$ also very difficult at the Tevatron due to small $g^2_{H_1VV}$ coupl.

M_{H_1}, M_{H_2}, small variation with CP violating phase of A_t, but strong variation of the couplings
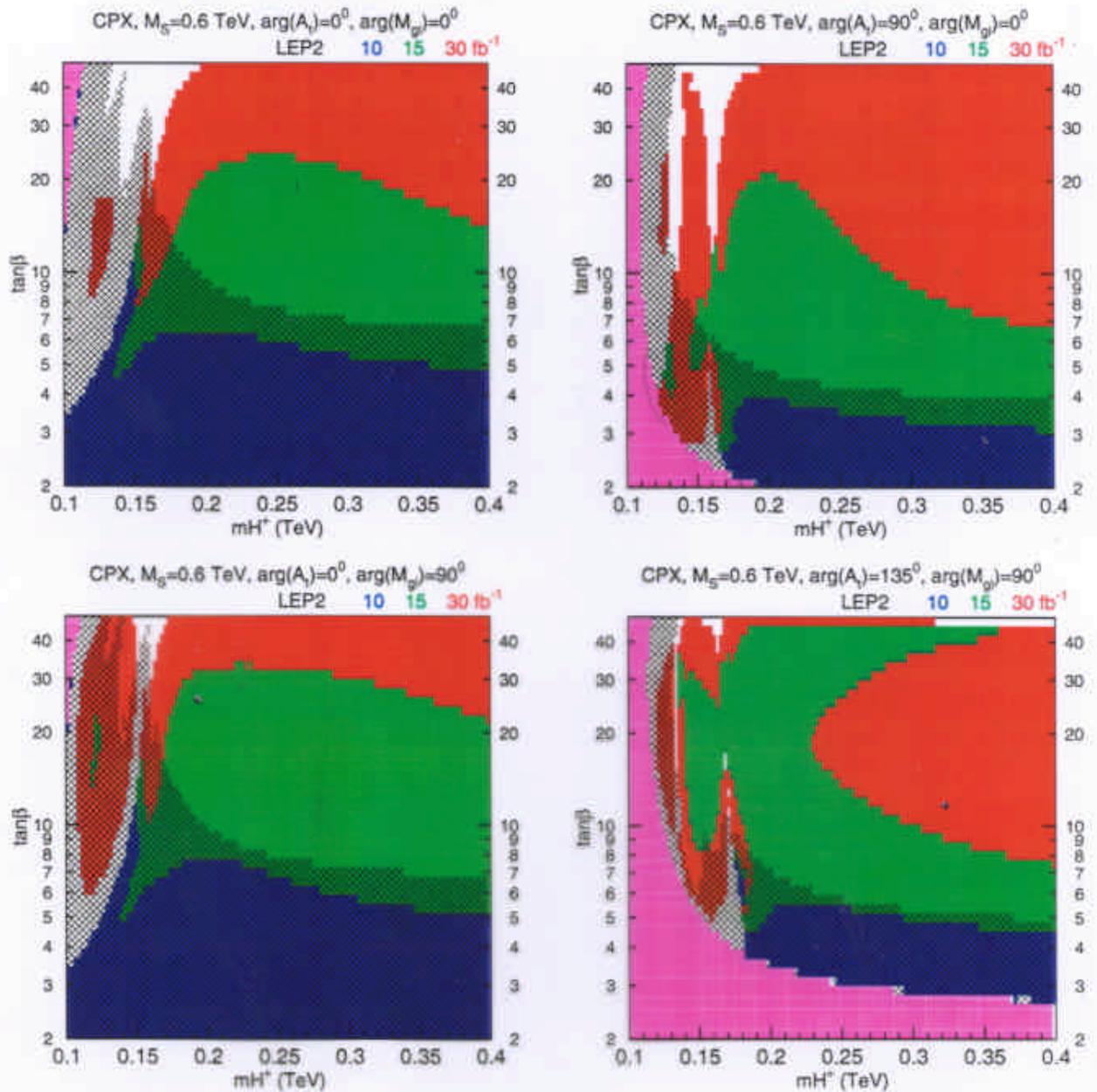

(a)
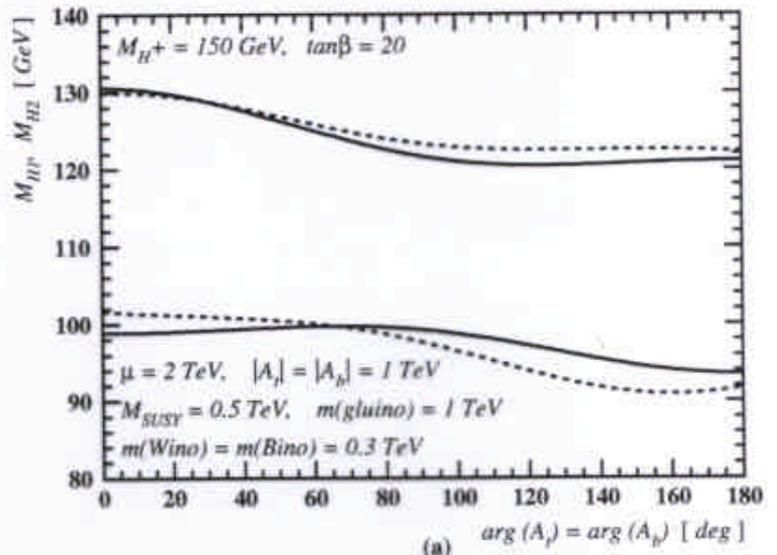
(M.C., Ellis, Pilaftsis, Wegner)

(b)

▬ The Tevatron will detect $M_{H_2} \sim 120$ GeV if sufficient integrated Luminosity (≥ 15 fb^{-1}) collected

Effect of CP-violating Phases
on the Tevatron Higgs Discovery Reach

(M.C., Ellis, Mrenna, Pilaftsis, Wagner)

Higgs Physics at the Tevatron

Marcela Carena, Fermilab

Conclusions

Tevatron Run 2 $\Longrightarrow$ very rich and broad physics potential

■ For a SM Higgs, test the region of mass preferred by precision data with 10 fb^{-1} of total integrated luminosity

■ With 2 fb^{-1} can test LEP hint of a Higgs with mass of about 115 GeV

and with 5 (15) fb^{-1} can confirm such a SM Higgs at the 3 (5) sigma level

■ With 5 fb^{-1} can explore most of the MSSM parameters space via SM-like Higgs searches
• Wh/H and Zh/H with $H, h \to b\bar{b}$

and with 15 to 20 fb^{-1} has discovery reach of a SM-like Higgs over a vast region of SUSY parameter space.

■ Search for non-SM Higgs bosons in a variety of channels

• $b\bar{b}H, h, A$ with $H, h, A \to b\bar{b}, \tau^+\tau^-$;

• $gg \to h, H, A$, with $h, H, A \to \tau\tau$;

• $\bar{t}H^+b$, with $H^+ \to \tau^+\nu, t\bar{b}$.

with sensitivity up to masses of about 300 GeV.

■ If nature is kind, the Tevatron has a real chance of discovering one or more Higgs bosons in the coming years !