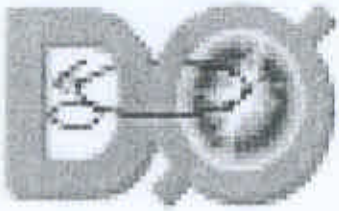
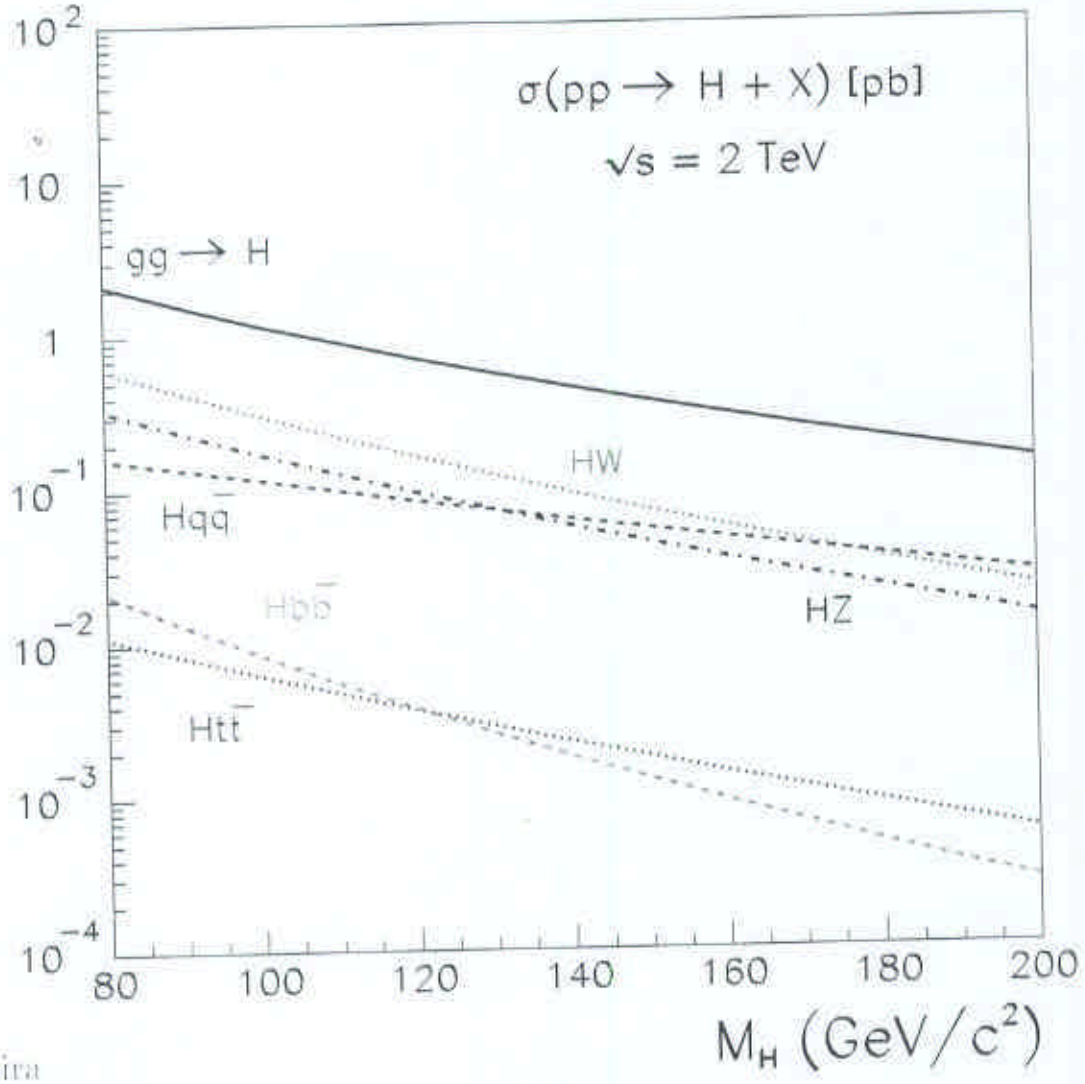
Higgs Searches at the Tevatron



Maria Teresa P. Roco
FERMILAB

- Run I Standard Model and SUSY Higgs Searches
- Run II Prospects

International Conference on High Energy Physics
Osaka, July 27 - Aug 3, 2000

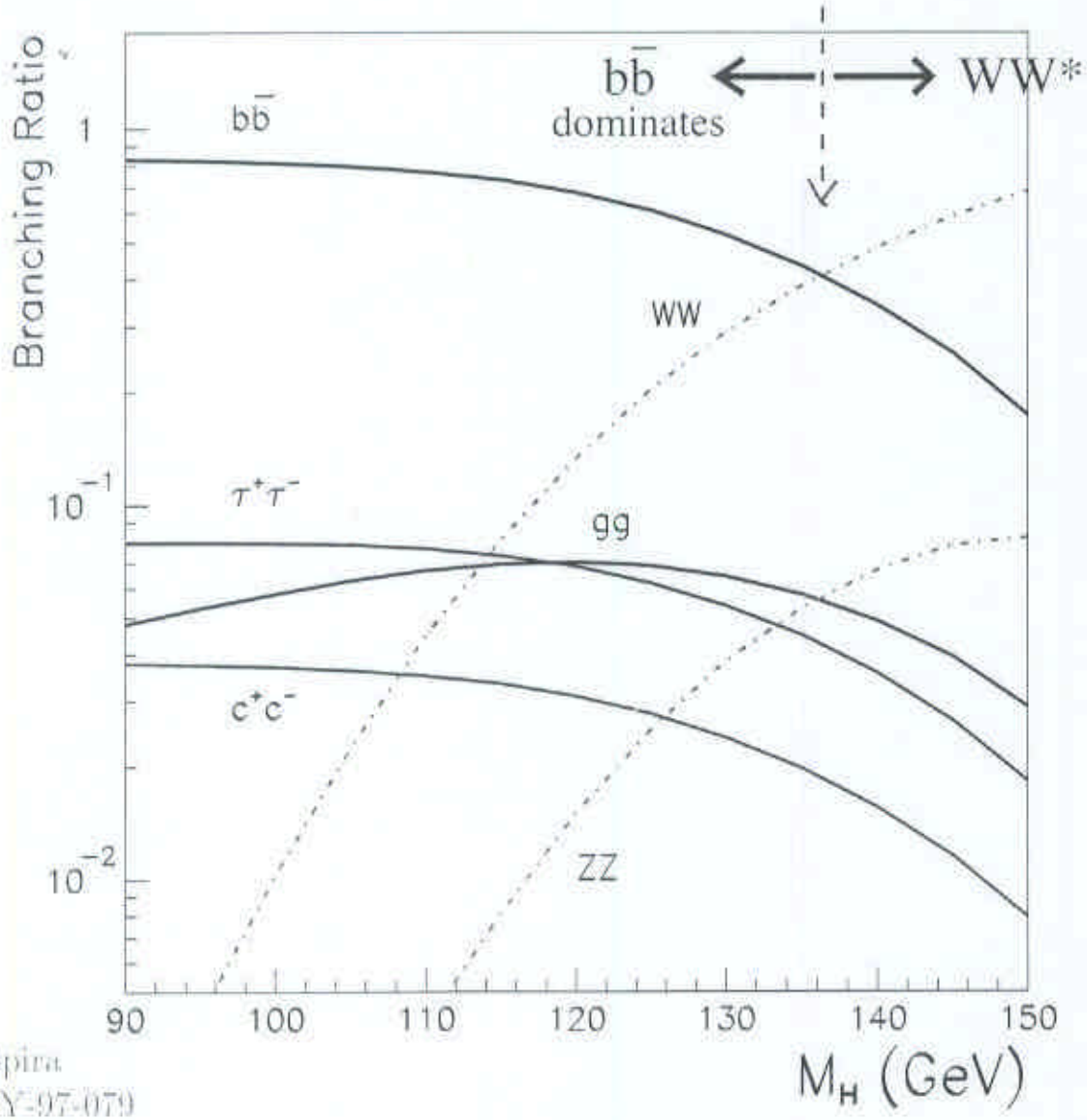


M. Spira
DESY-98-159

Typical signal and BG cross sections at $\sqrt{s} = 2$ TeV

	$\sigma[pb]$ $(m_H = 120\ \mathrm{GeV/c^2})$
$gg \to H$	0.70
WH	0.16
ZH	0.10
WZ	3.2
$Wb\bar{b}$	11.0
$t\bar{t}$	6.0
$tb + tq + tbq$	3.4
QCD	$O(10^6)$

SM Higgs Decays



M. Spira
DESY-97-079

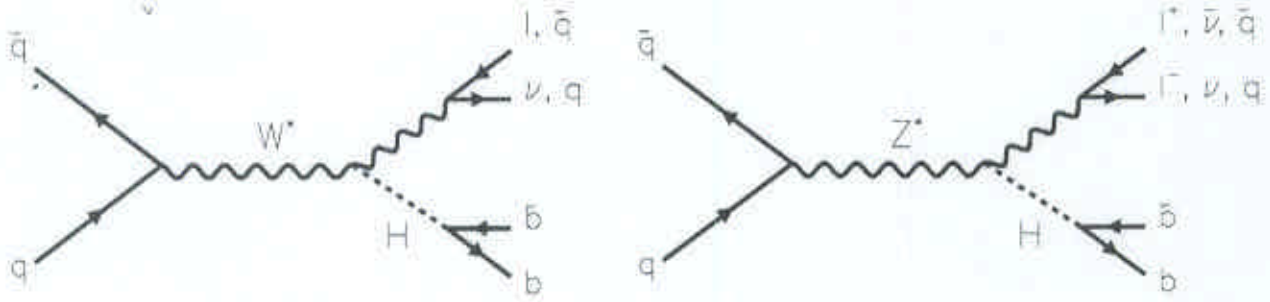
- $M_H < 130$ GeV/c^2 dominant decay mode is $H \to b\bar{b}$

  WH/ZH final states: $q\bar{q}b\bar{b}$, $l\nu b\bar{b}$ and $\nu\bar{\nu}b\bar{b}$, $l^+l^-b\bar{b}$

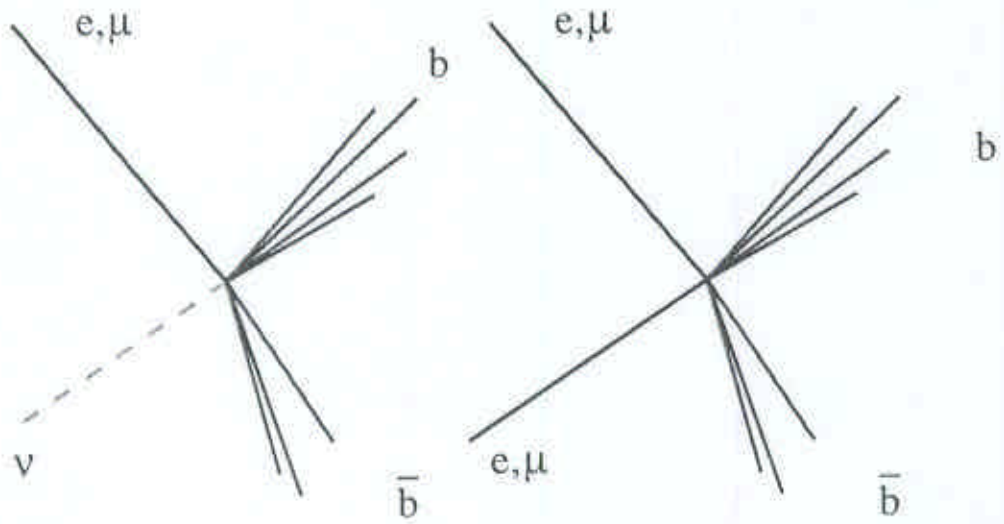
- for $M_H > 130$ GeV/c^2, $H \to WW$ dominates

  WW final states with > 2 leptons: $l^\pm l^\pm jj$, $l^+l^-\nu\bar{\nu}$

Higgs Strahlung off W/Z Bosons

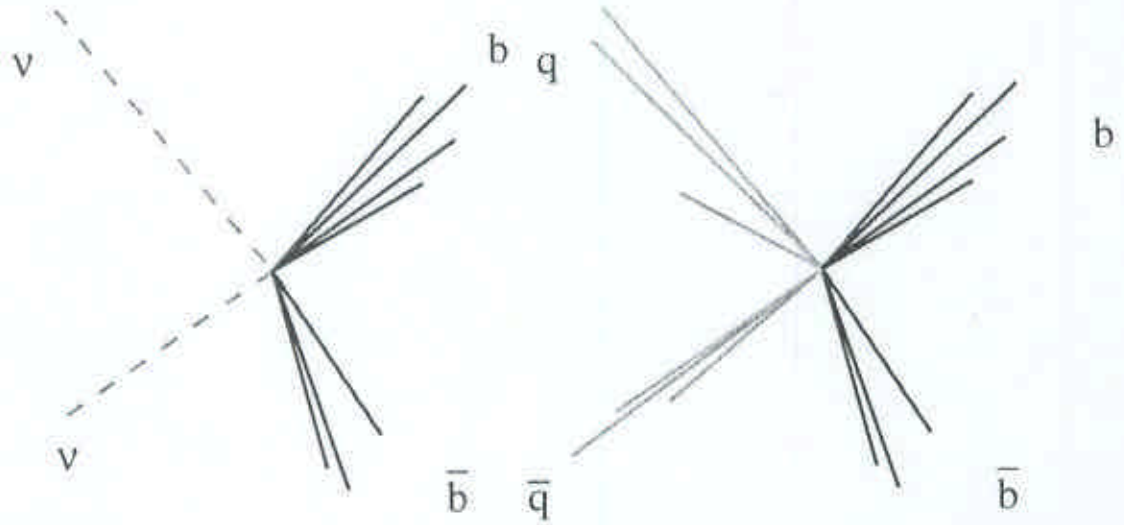


Topologies:



BG: $Wb\bar{b}, t\bar{t}, WZ, t\bar{b}, tbq$

BG: $Zb\bar{b}, t\bar{t}, ZZ, t\bar{b}$



BG: $Zb\bar{b}, t\bar{t}, ZZ, t\bar{b}$

BG: QCD multijets

- PRL 79:3819, 1997
- Event selection:

  primary lepton (e or μ) with $E_T > 20$ GeV

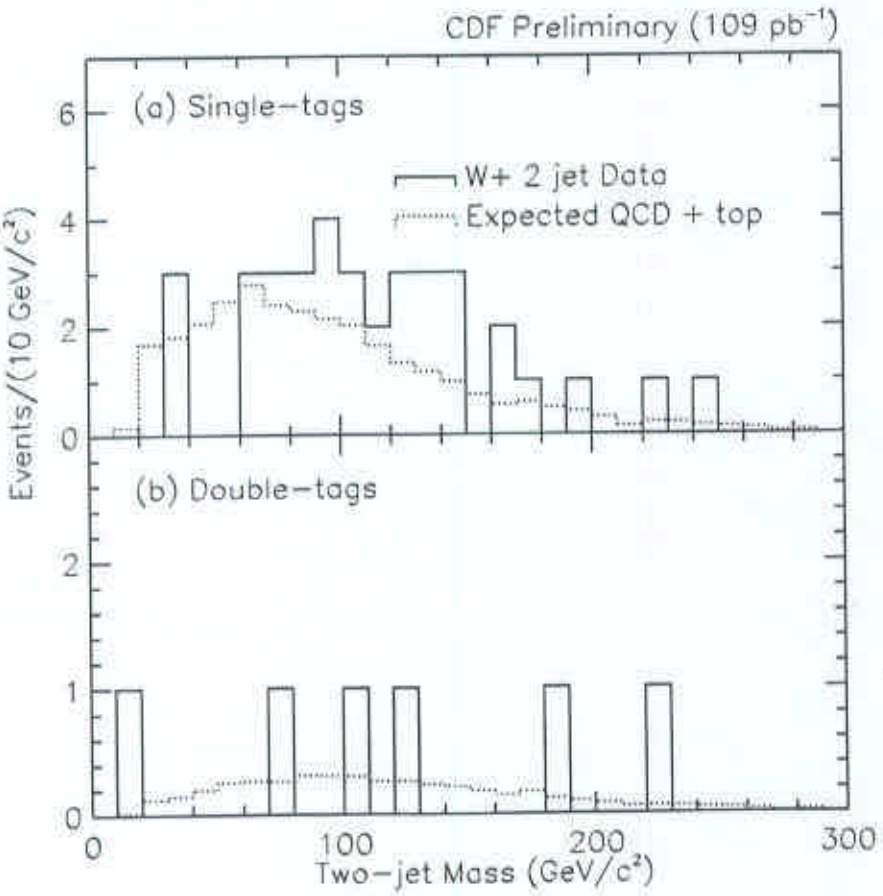
  $\not\!\!\vec{E}_T > 20$ GeV

  two jets with $E_T > 15$ GeV and $|\eta| < 2$

  Single tag analysis $\to$ 1 jet SVX tagged

  Double tag analysis $\to$ SVX OR lepton tagged

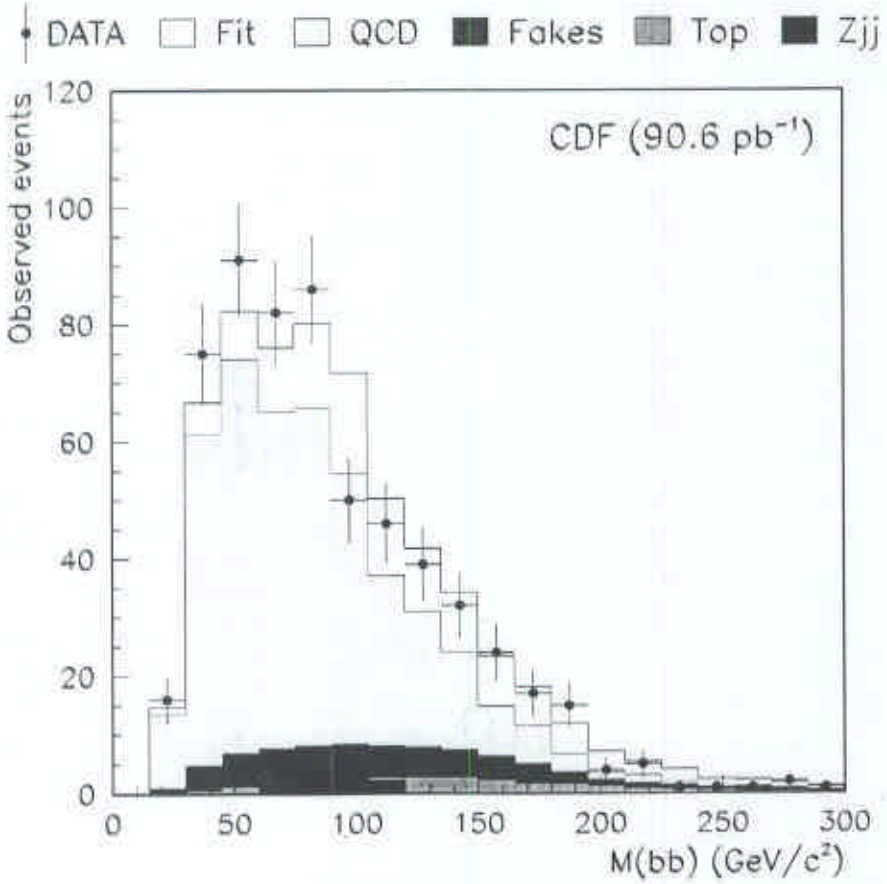
- 36 (6) single (double) tag events
- BGs: 30 ± 5 (3 ± 0.6) single (double) tag events
- Binned likelihood fit of M_{jj} spectrum



- PRL 81:5748, 1998
- Event selection:

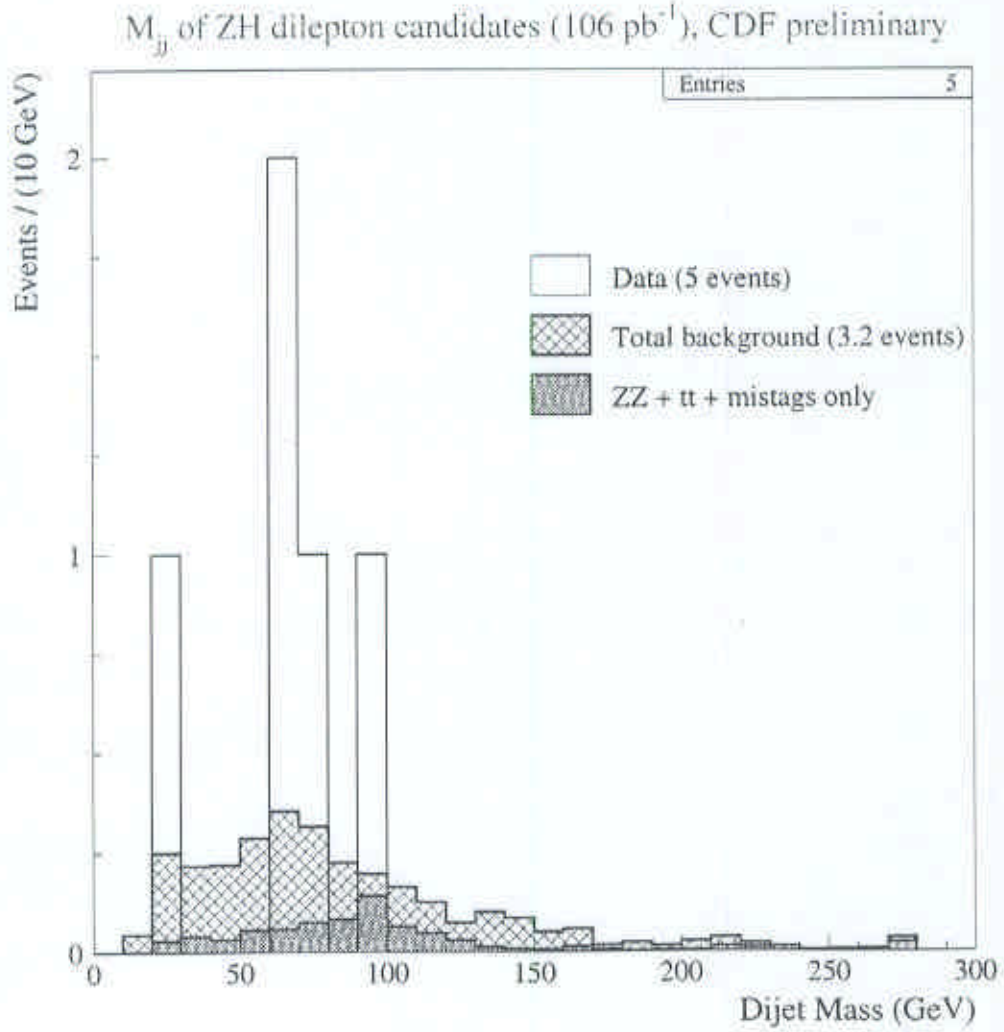
  ≥ 4 jets with $E_T > 15$ GeV and $|\eta| < 2$
  two jets tagged by the SVX
  $P_T(b\bar{b}) > 50$ GeV/c

- 589 events pass selection
- Binned likelihood fit of M_{bb} spectrum to signal and background shapes, with signal and QCD free $\Rightarrow$ 600 background events, signal consistent with zero.



Cut	N_{ee}	$N_{\mu\mu}$
2 leptons	7029	3758
$76 \leq M_{ll} \leq 106$ GeV/c^2	5892	2880
2 or 3 jets with $E_T > 15$ GeV	105	54
$\not\!\!\vec{E}_T < 50$ GeV	105	53
≥ 1 SVX tag	2	3

expect 3.2 ± 0.7 BG events from
$Z + h.f.$, mistags, ZZ, WZ, $t\bar{t}$ + single top



Search for $ZH \to \nu\bar{\nu}b\bar{b}$

- Event Selection

  $\not\!\!\vec{E}_T > 40$ GeV

  2 or 3 jets with $E_T > 15$ GeV and $|\eta| < 2$

  $\Delta\phi(j_1, j_2) \leq 150^o$, minimum $\Delta\phi(\not\!\!\vec{E}_T, j) \geq 60^o$

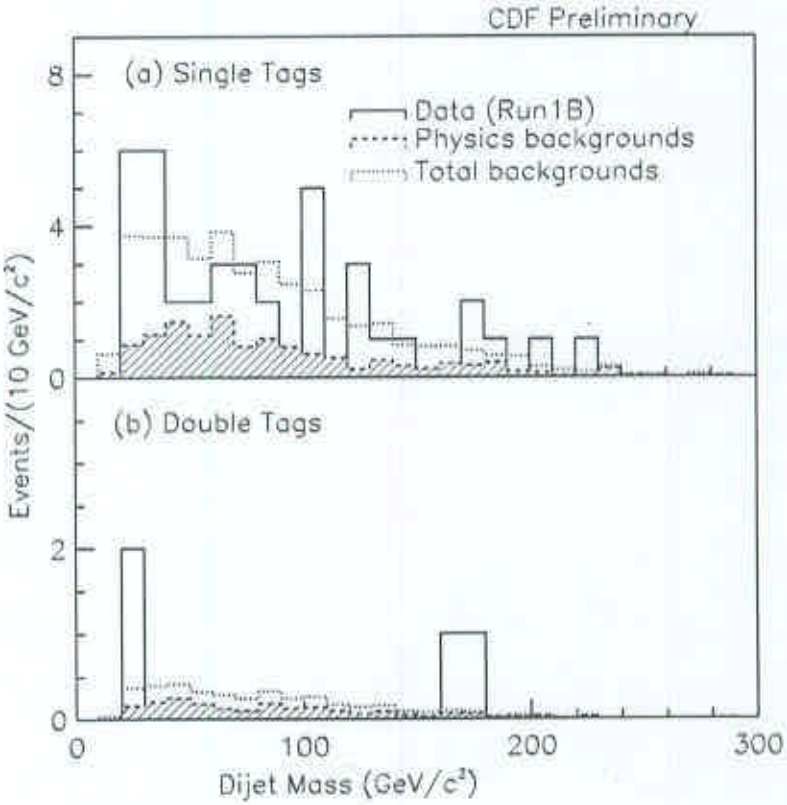
  Single tag $\Rightarrow$ 1 SVX tag

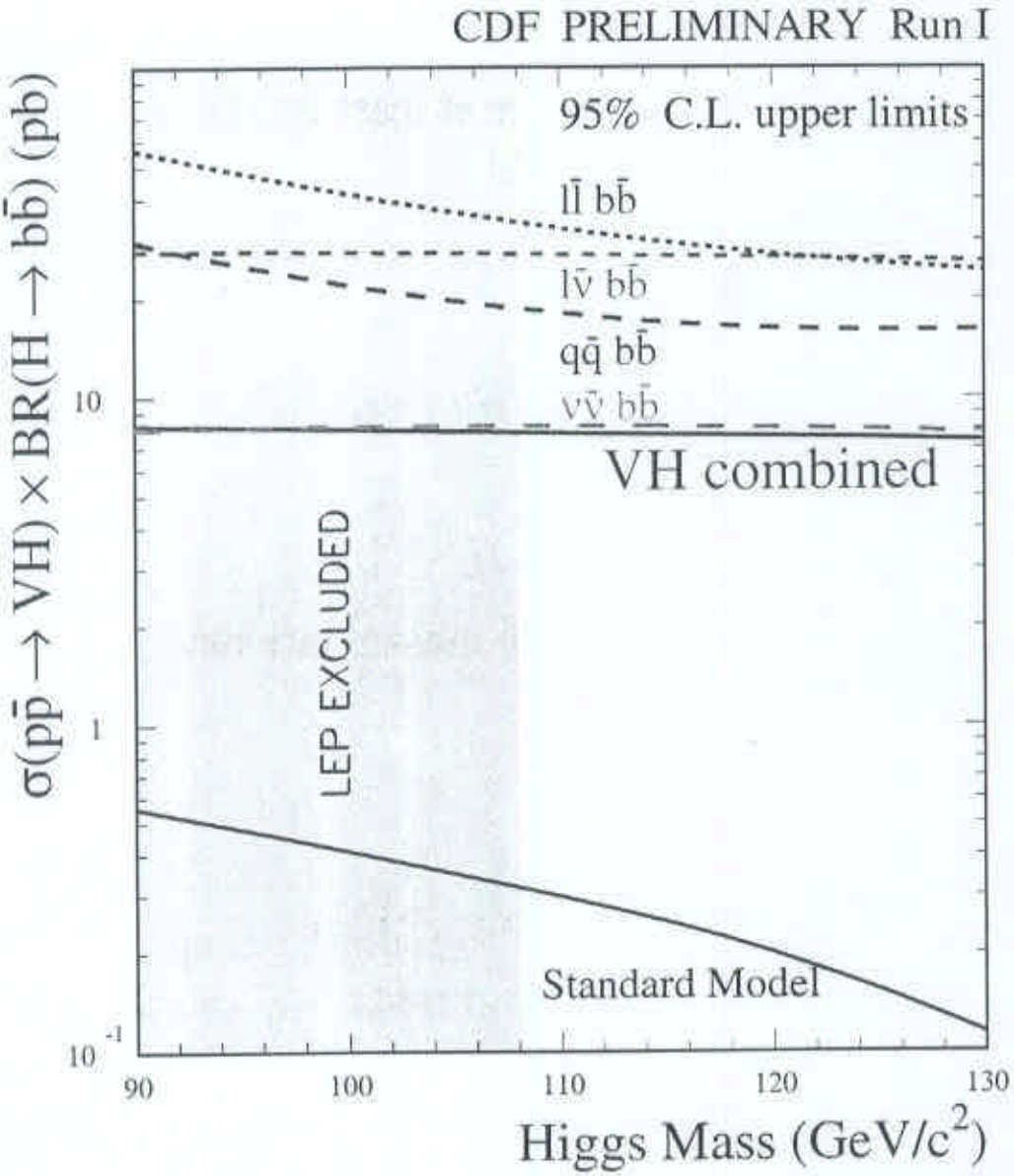
  Double tag $\Rightarrow$ SVX OR JetProb tagged

Background Source	Single Tagging	Double Tagging
QCD	26.2 ± 3.0	1.9 ± 0.4
$W/Z + h.f.$	10.2 ± 2.5	1.0 ± 0.2
$t\bar{t}$ + Single top	2.4 ± 0.6	0.8 ± 0.2
$WZ + ZZ$	0.4 ± 0.1	0.2 ± 0.0
TOTAL	39.2 ± 4.4	3.9 ± 0.6

CDF (90 pb^{-1})

observed: 44
40 single tags
4 double tags





CDF 95% CL limits
for cross sections times branching ratios for

- $p\bar{p} \rightarrow WH \rightarrow \ell\nu b\bar{b}$
- $p\bar{p} \rightarrow ZH \rightarrow \nu\bar{\nu}b\bar{b}$
- $p\bar{p} \rightarrow ZH \rightarrow \ell^+\ell^- b\bar{b}$
- $p\bar{p} \rightarrow (W/Z)H \rightarrow q\bar{q}b\bar{b}$

SUSY Higgs

- SUSY implementation requires at least two Higgs field doublets
  $\rightarrow$ there are two in the MSSM

  - 5 physical Higgs bosons

    2 CP even scalars h^o, H^o $\quad (m_{h^o} < m_{H^o})$

    1 CP-odd scalar A^o

    2 charged scalars H^+, H^-

  - MSSM predicted tree level mass relations

    $m_{h^o} < m_{Z^o} \leq m_{H^o}$

    $m_{A^o} \leq m_{H^o}$

    $m_{H^\pm} \geq m_{W^\pm}$

  - significant mass shifts due to radiative loop corrections predominantly from top and scalar top quarks ($\tilde{t}$)

    $$\Delta\, m^2_{h^o} \sim \frac{m^4_{top}}{m^2_W}\left(\ln \frac{m^2_{\tilde{t}_1} m^2_{\tilde{t}_2}}{m^4_{top}} + \ldots\right)$$

  - for any SUSY parameter choice

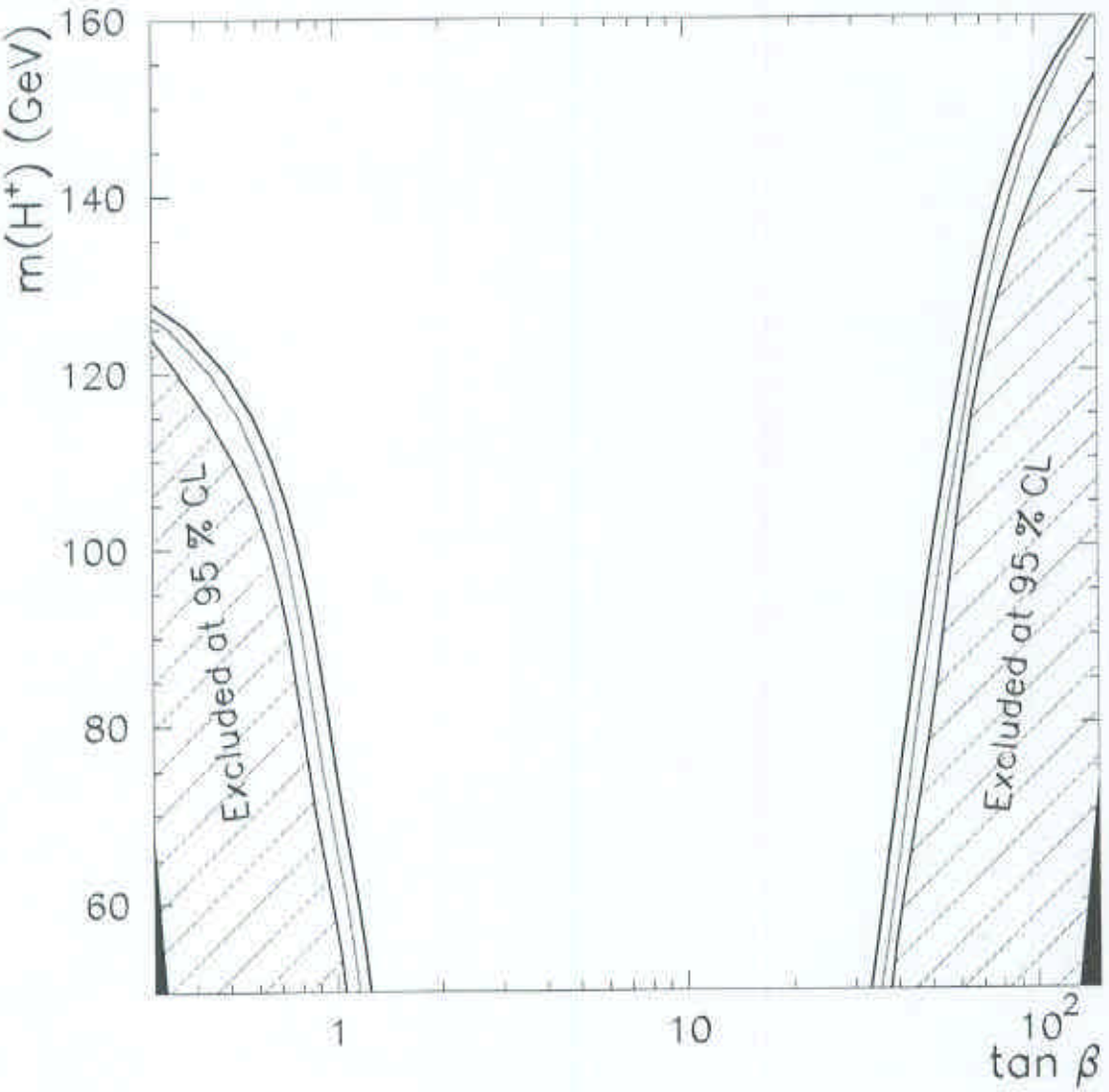
    $$m_{h^o} < 130 \text{ GeV}$$

- Free parameters: pseudoscalar mass m_A and $\tan\beta = v_u/v_d$
- $M_{SUSY} (= 1TeV/c^2)$
- stop mixing parameter X_t (min=0/max=$2M_{SUSY}$)

Charged Higgs from Top Quark Decays

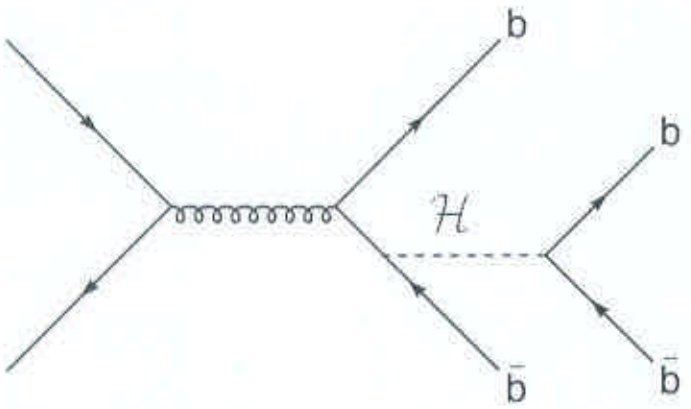
if $M_{H^+} < m_t - m_b$
then $t \to H^+ b$ can compete with SM mode $t \to W^+ b$
with $H^+ \to \tau^+ \nu$, $c\bar{s}$, $W b \bar{b}$

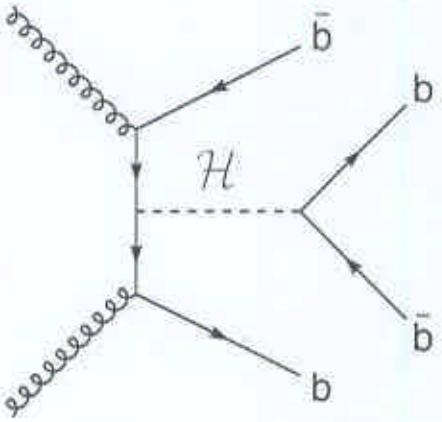
DØ: indirect search ($t\bar{t}$ disappearance)



- Exclusion contours for $\sigma(t\bar{t}) = 4.5,\ 5.0,\ 5.5$ pb
  search restricted to $0.3 < \tan\beta < 150$

Motivation for Studying $p\bar{p} \rightarrow b\bar{b}\mathcal{H}$





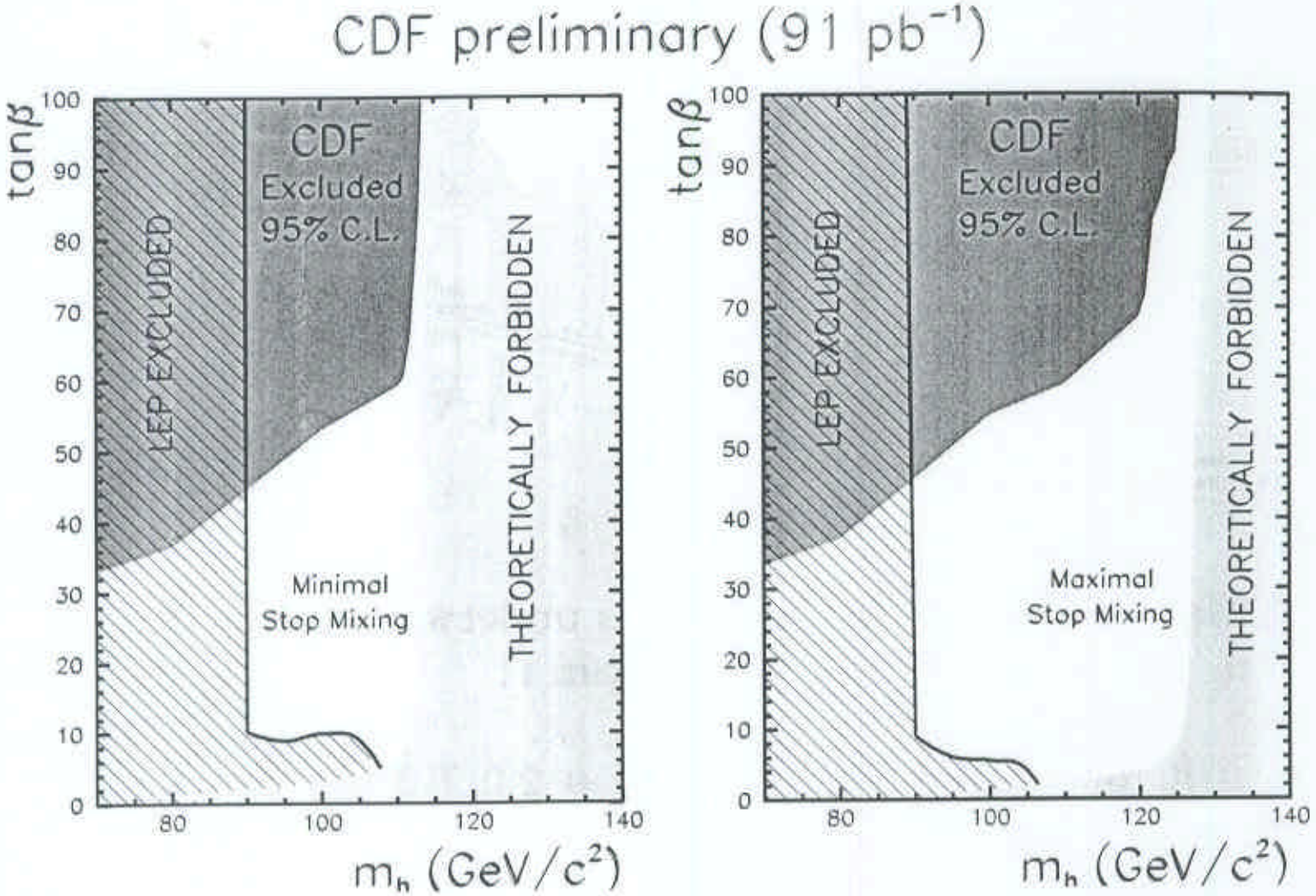
$\mathcal{H} = h^o, A^o, H^o$

* **MSSM:** Yukawa coupling of the $\mathcal{H}$ and b quark is expected to be large leading to an enhanced $b\bar{b}\mathcal{H}$ production at large $\tan\beta$

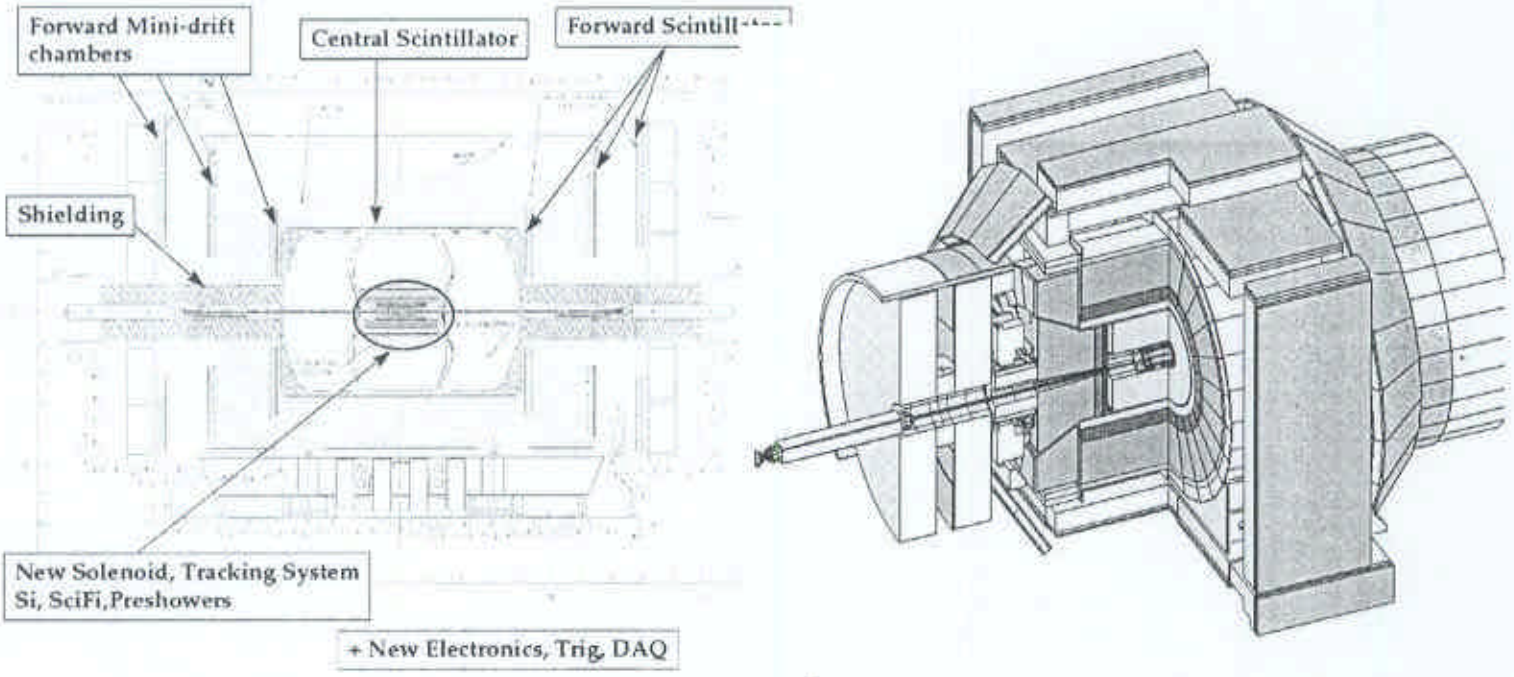
$$\sigma(p\bar{p} \rightarrow b\bar{b}\mathcal{H}) = (g_b^{h,A,H})^2 \, \sigma(p\bar{p} \rightarrow b\bar{b}H_{SM})$$

where

$$g_b^h \sim \sin\alpha / \cos\beta$$
$$g_b^H \sim \cos\alpha / \cos\beta$$
$$g_b^A \sim \tan\beta$$



- 95% CL exclusion region in the $\tan\beta$ and m_h parameter space for two scenarios:
  $\Rightarrow$ no mixing and maximal mixing



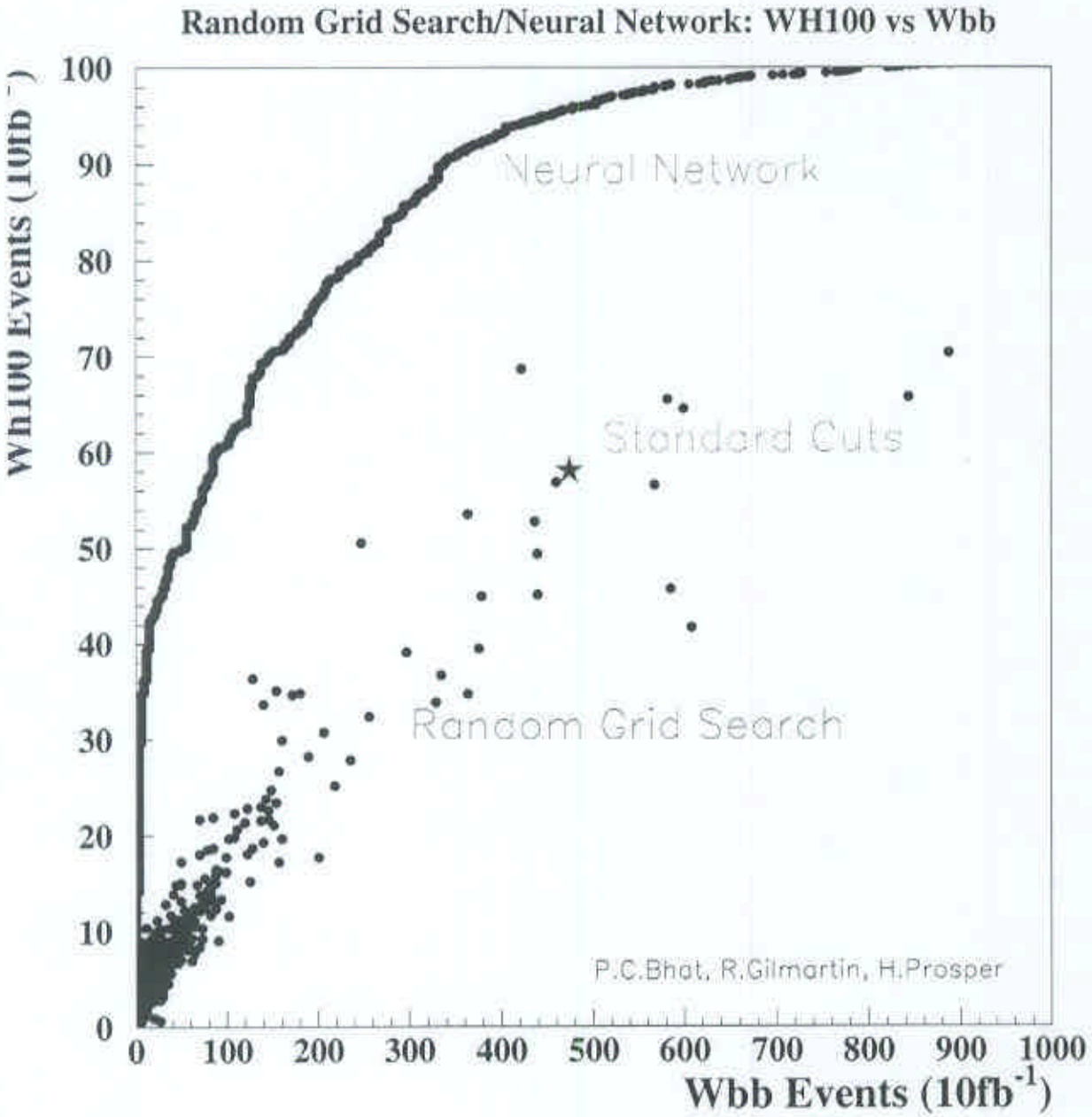
Major DØ and CDF upgrades underway in preparation for Tevatron Run II

△ higher CM energy 1.8 TeV → 2.0 TeV
△ higher inst. luminosity → 2 $\times 10^{32}$ cm^{-2} s^{-1}
△ Run IIa-b total luminosity ≥ 15 fb^{-1}/expt

DØ
new solenoid, silicon and fiber trackers, muon chambers, triggers and DAQ

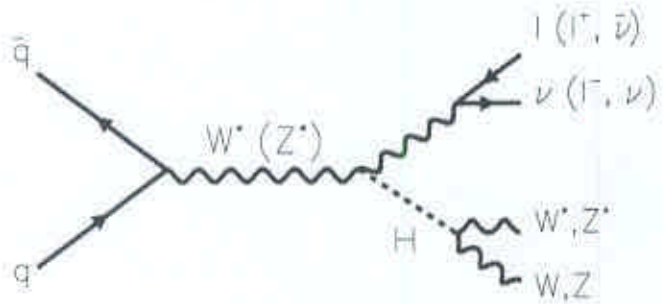
CDF
new silicon and central outer trackers, plug calorimeter, muon chambers, triggers and DAQ

Neural Network Analysis of $WH \to l\nu b\bar{b}$

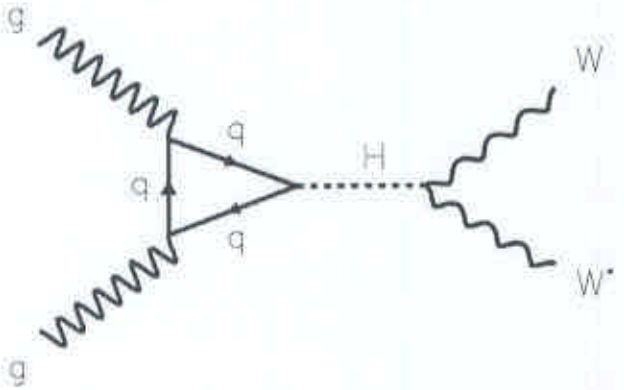


- results from this initial study are very encouraging !!
- significant improvement over conventional (1-D) selection cuts

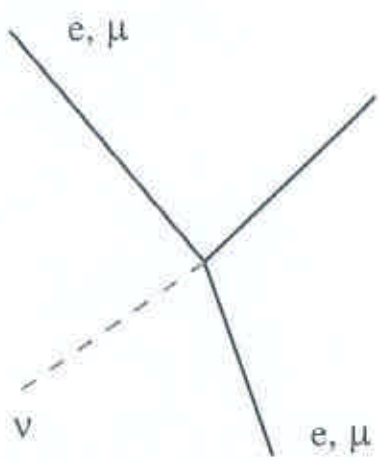
Higgs Strahlung off W/Z Bosons

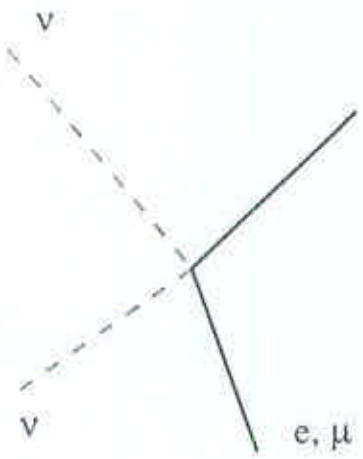


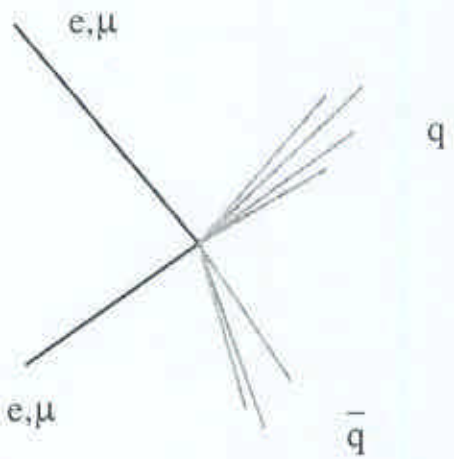
Gluon-Gluon Fusion $gg \to H$



Topologies:





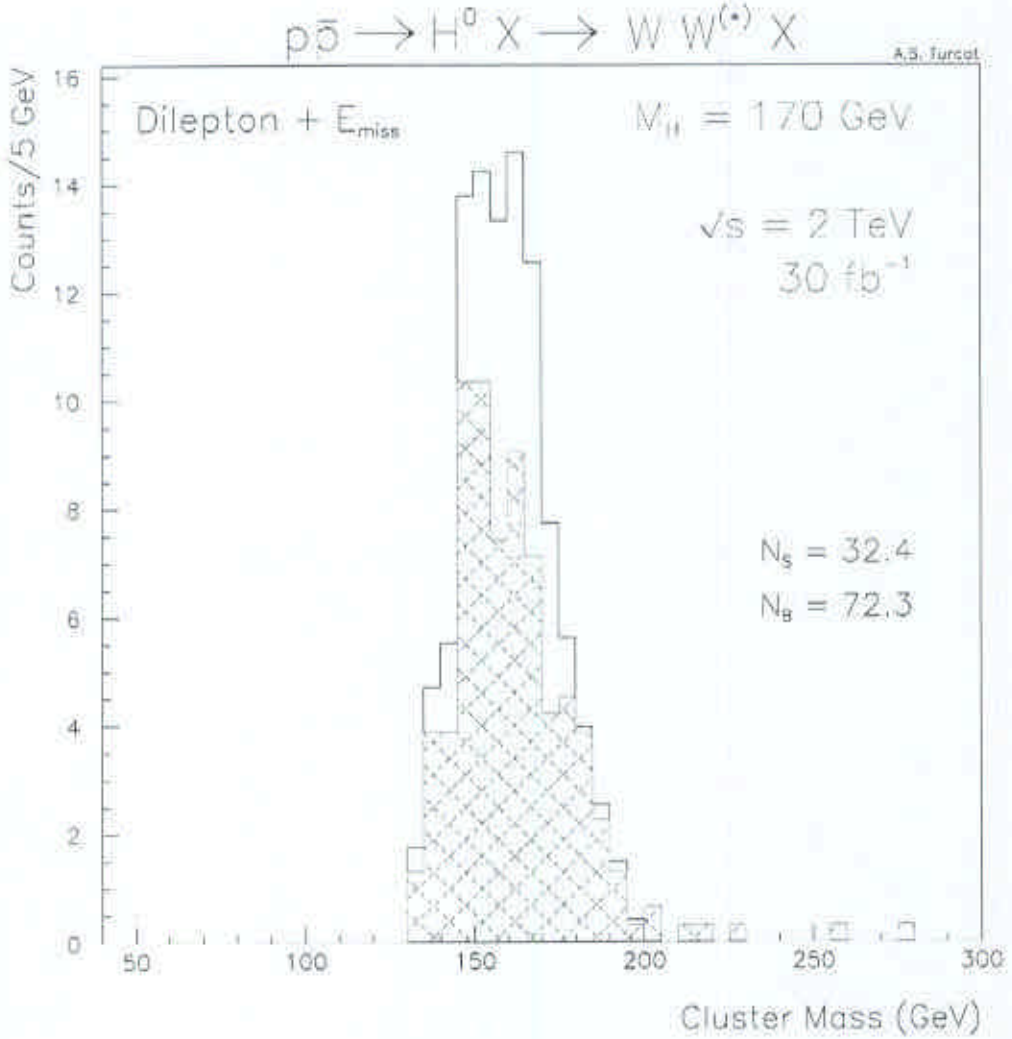


BG: WZ, WW, ZZ $WW, t\bar{t}, WZ, ZZ$ $WW, WZ, ZZ, t\bar{t}, W/Zjj$

$\ell^+\ell^-\nu\bar{\nu}$ channel

→ lots of finely tuned cuts

→ use "cluster transverse mass" to sharpen mass

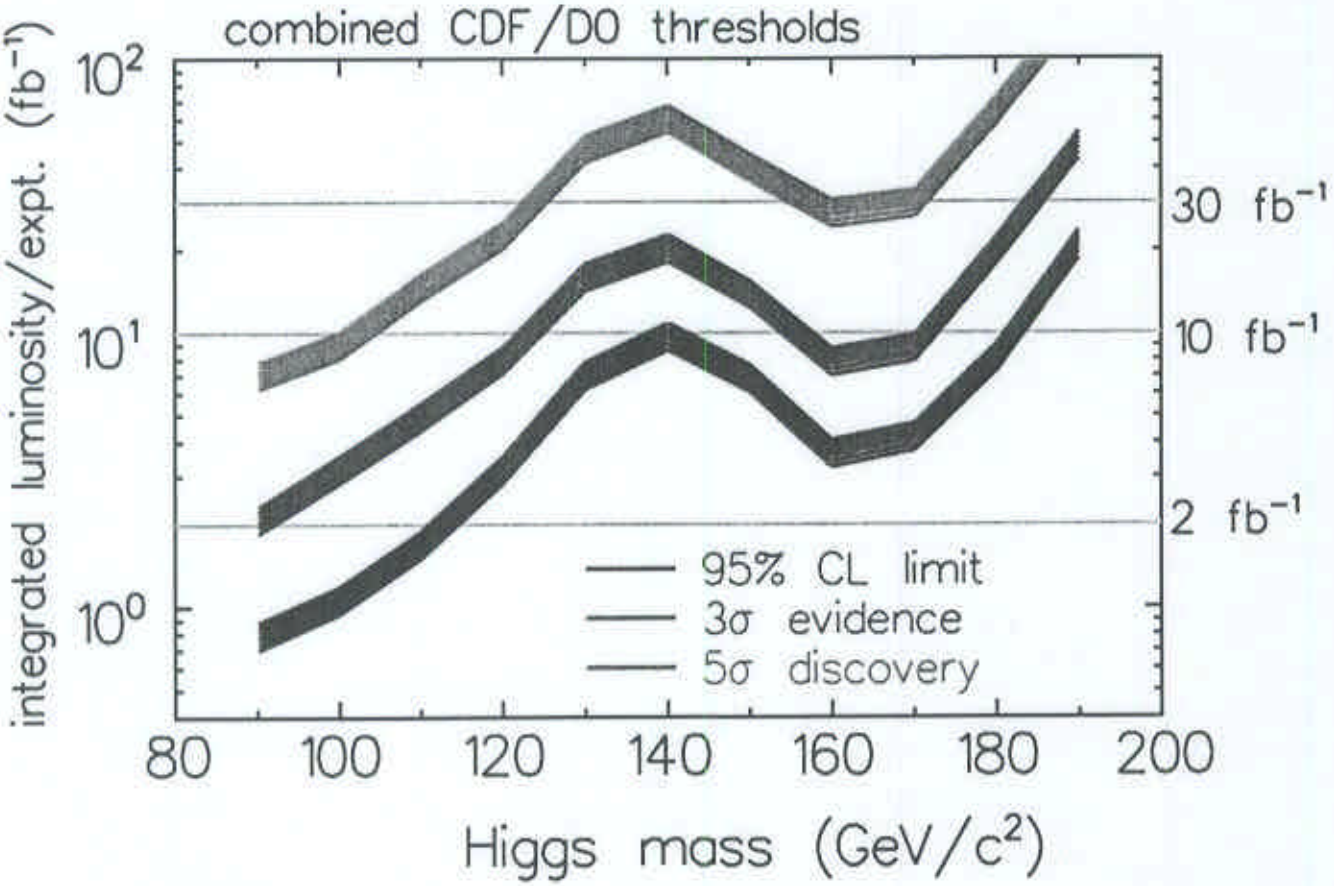


$$M_C \equiv \sqrt{p_T^2(\ell\ell) + m^2(\ell\ell)} + \not{E}_T$$

SM Higgs Sensitivity: Combined Channel Thresholds

- 30% improved $M_{b\bar{b}}$ resolution
- Run II acceptance $\times$ 1.3 NN improvement

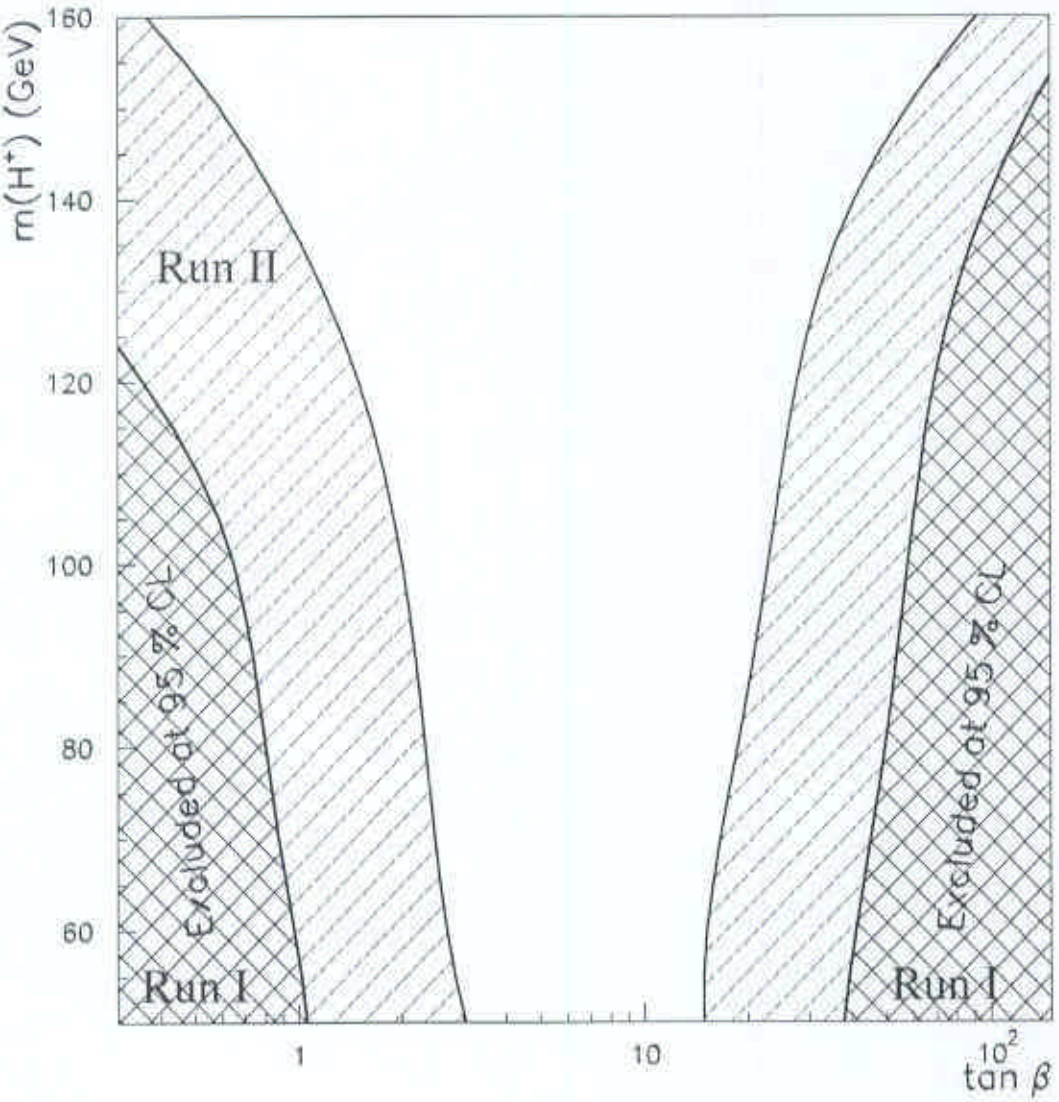
$\Rightarrow$ Main systematic uncertainties from the estimation of the various backgrounds, $b\bar{b}$ mass resolution and b-tagging efficiency



- lower edge of band gives best etimate
- band extends upward 30% for systematics

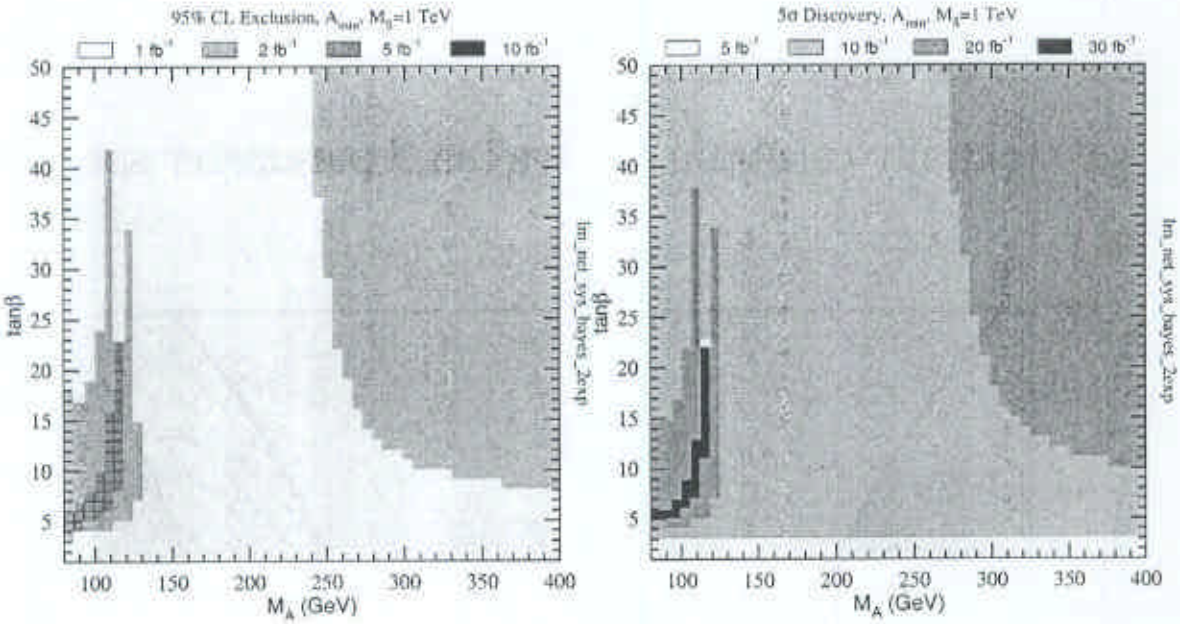
Charged Higgs Limits Projected for Run II

- SM requires t to decay almost exclusively via $t \to W^+b$
- if a charged Higgs exists with $M_H^+ < M_t - M_b$, the competing decay mode BR($t \to H^+b$) can be excluded at 95% CL for $M_{H^\pm} < 160$ GeV/c^2
- can substantially constrain M_H^+ vs tan β parameter space

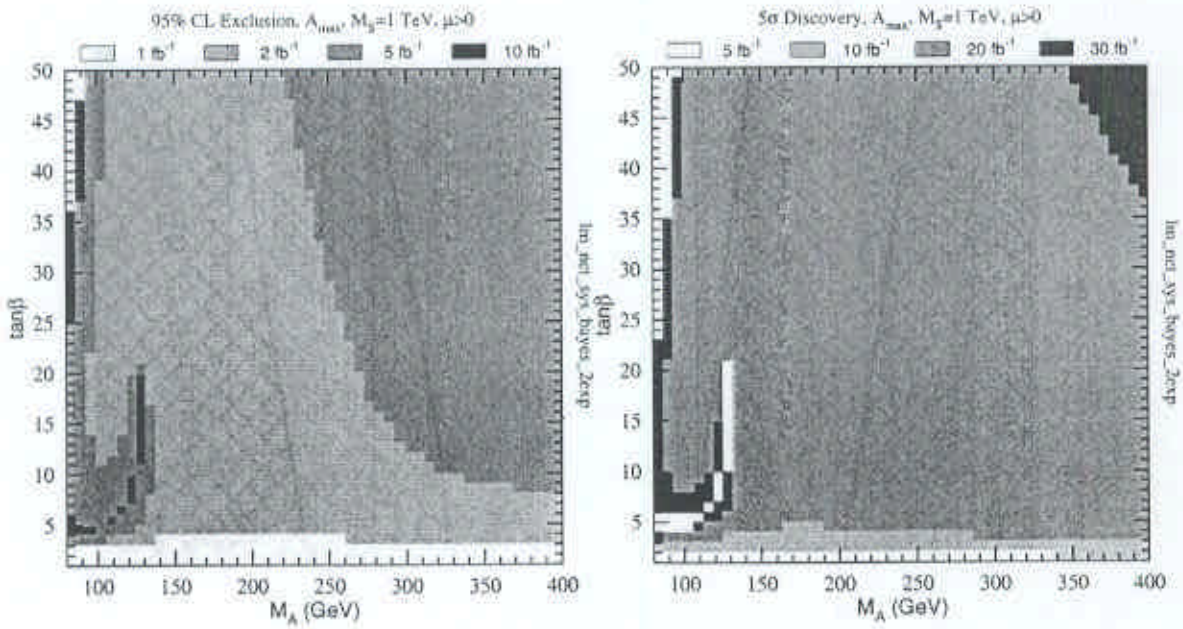


MSSM discovery/exclusion from SM Higgs channels

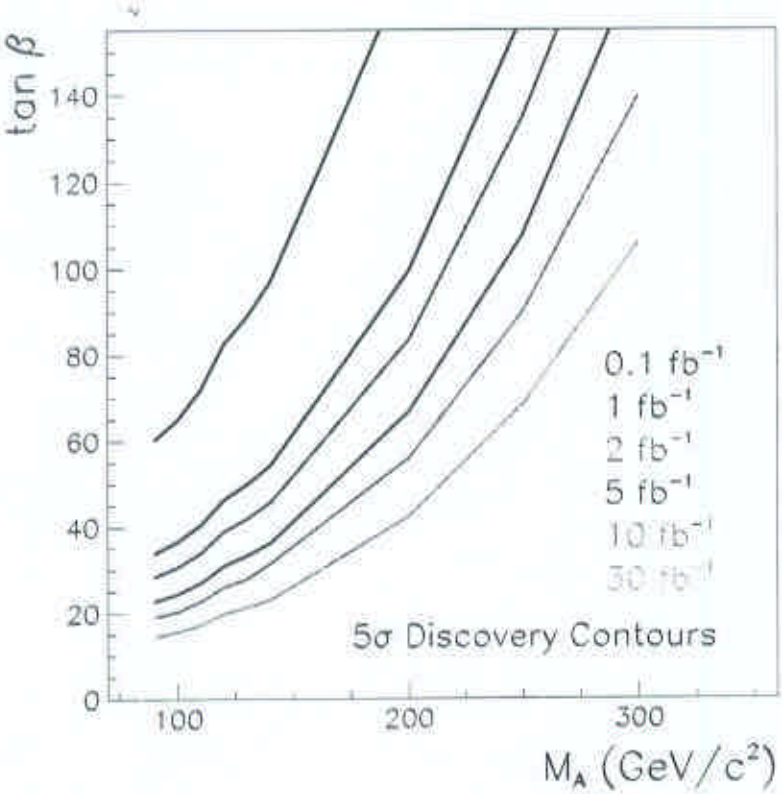
A_{min}, $M_s = 1$ TeV



A_{max}, $M_s = 1$ TeV



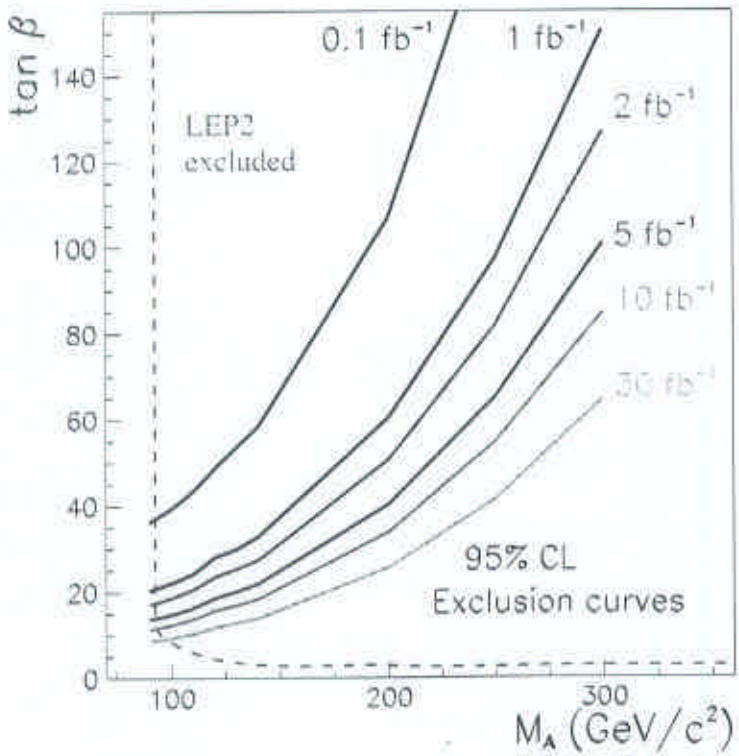
$$p\bar{p} \to b\bar{b} + (h, A, H) \to b\bar{b}b\bar{b}$$



Discovery at
$\mathcal{L} = 30$ fb^{-1}

$\tan\beta = 40$
$\Rightarrow M_A \leq 200$ GeV/c^2

$\tan\beta = 20$
$\Rightarrow M_A \leq 125$ GeV/c^2



Exclusion at
$\mathcal{L} = 30$ fb^{-1}

$(\tan\beta = 40)$
$\Rightarrow M_A < 240$ GeV/c^2

$(\tan\beta = 20)$
$\Rightarrow M_A < 175$ GeV/c^2

Conclusion:

Key issues affecting the Tevatron ultimate reach:
- laboratory schedule
- accelerator performance
- detector performance

The Tevatron has a window of opportunity before the LHC starts...

Exciting prospects for Higgs discovery in Run II !