Higgs Boson Working Group Summary

plenary talks: J. Gunion, V. Barger

Contributed talks on Higgs physics:

John Womersley: SM Higgs @ the Tevatron

Dave Rainwater: $H \to \gamma\gamma$ @ the LHC

Tao Han: Higgs Physics @ the NLC

Maria Krawczyk: Higgs Searches in 2D Models

Howie Haber: MSSM Higgs Properties

Tom Greening: SUSY Higgs @ LEP

Chung Kao: Higgs Physics @ the LHC

S. Mrenna: SUSY Higgs @ the Tevatron

Jack Gunion: Comparative studies: LHC, NLC, FMC

Bill Marciano: Higgs Resonance @ FMC

W.Y. Keung: $\not{CP}$ in Higgs Sector @ FMC

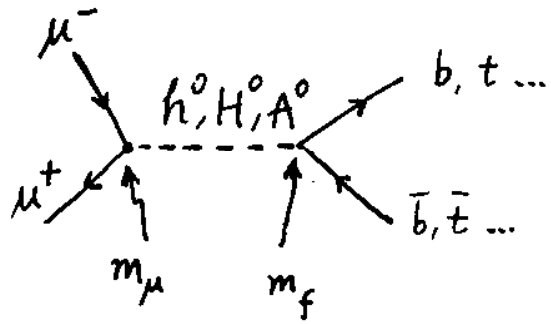
T. Tokhonin: $\mu^+\mu^- \to Zh^0, \gamma h^0$

D. Bowser-Chao: $\mu^+\mu^- \to \gamma h^0$

The Unique Physics Opportunity

at the FMC:

the S-channel Higgs boson Production



$$\bar{\sigma} = \begin{cases} \dfrac{\sqrt{2\pi}\,\pi}{m_h^2} \cdot \dfrac{\Gamma(h \to \mu^+\mu^-)}{\sigma_{\sqrt{s}}} \cdot BR(h \to X) & \text{for } \Gamma_{tot} \ll \sigma_{\sqrt{s}} \\[2ex] \dfrac{4\pi}{m_h^2} \cdot BR(h \to \mu^+\mu^-) \cdot BR(h \to X) & \text{for } \Gamma_{tot} \gg \sigma_{\sqrt{s}} \end{cases}$$

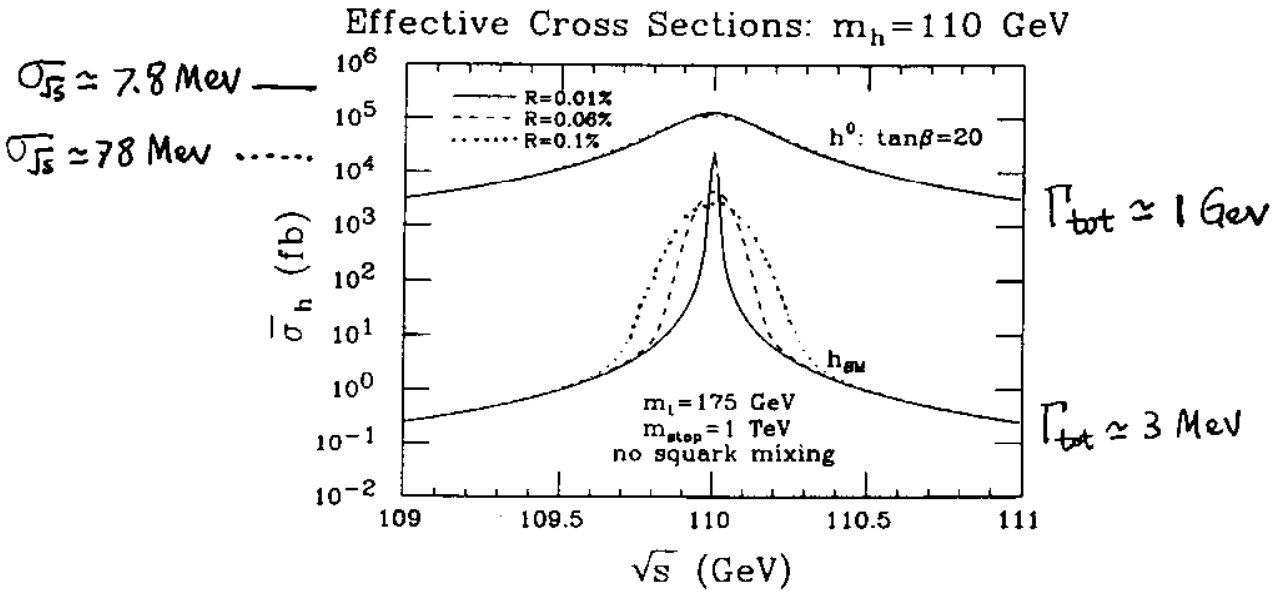


Figure 2: The effective cross section, $\overline{\sigma}_h$, obtained after convoluting σ_h with the Gaussian distributions $R = 0.01\%$, $R = 0.06\%$, and $R = 0.1\%$, is plotted as a function of $\sqrt{s}$ taking $m_h = 110$ GeV.

Barger
Berger
Gunion
Han

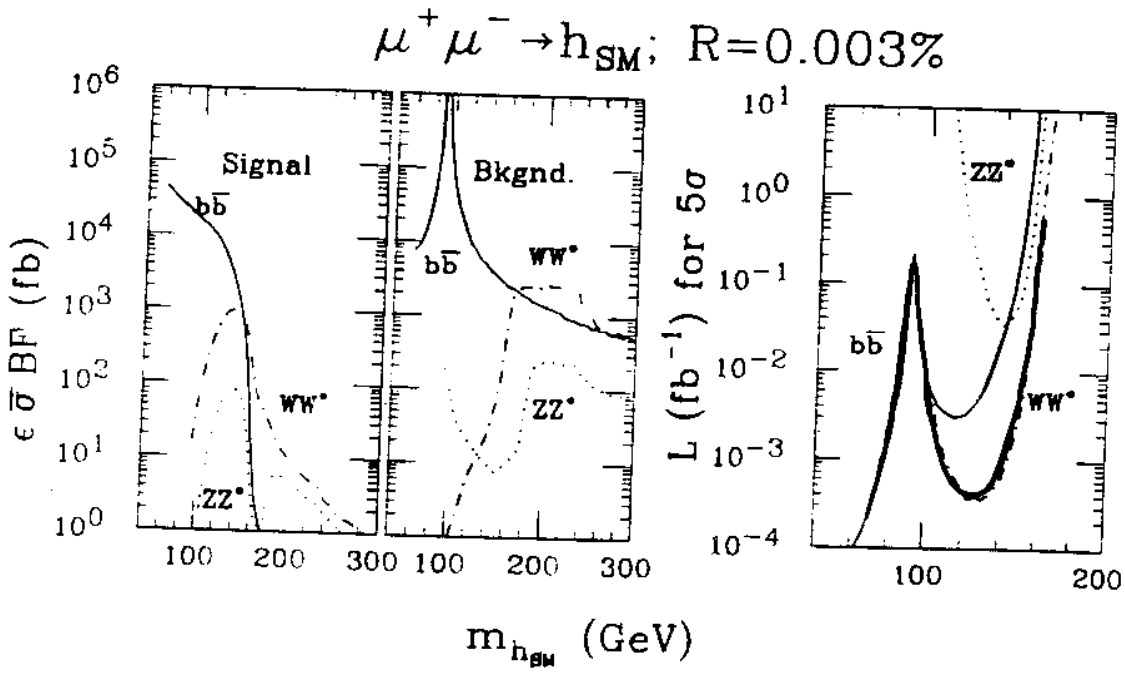
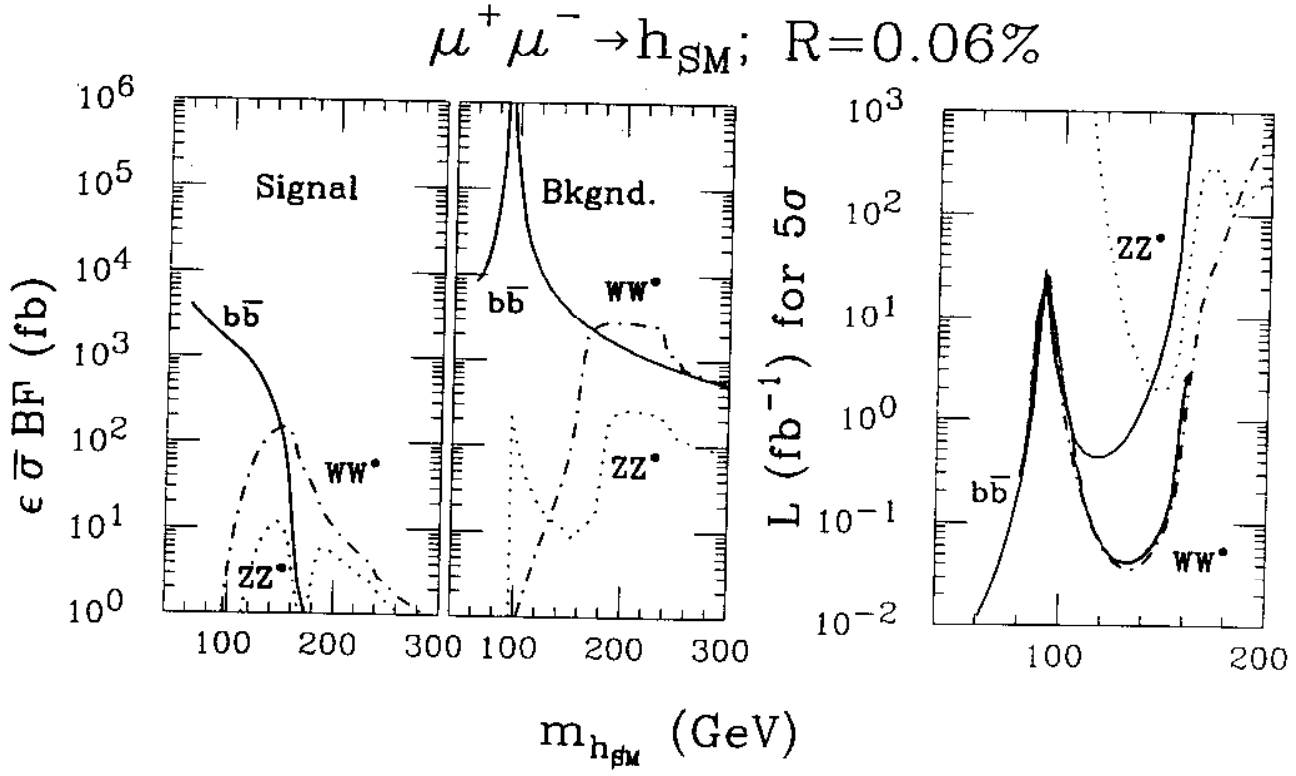


Figure 4: SM rates and L required for 5σ observation as a function of $m_{h_{SM}}$.

For $80\ \text{GeV} < m_h < 150\ \text{GeV}$ $(m_h \neq M_Z)$

$\mathcal{L} < 10^{-3} \sim 10^{-2}\ \text{fb}^{-1} \Rightarrow 5\sigma$ discovery

[at a given m_h]

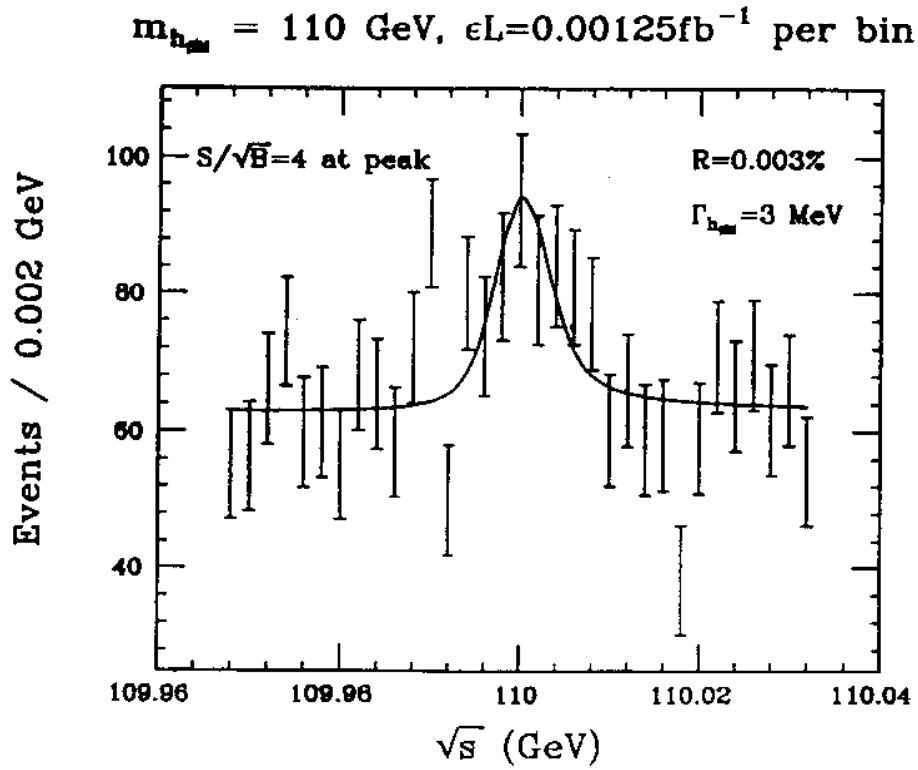

$\mu^+\mu^- \to h_{SM}$; R=0.06%
Signal
Bkgnd.
$b\bar{b}$
WW*
ZZ*
$\epsilon\,\bar{\sigma}\,BF$ (fb)
L (fb^{-1}) for 5σ
$m_{h_{SM}}$ (GeV)

Rough Scan.

A priori, Knowing $m_h \sim 110$ GeV $\pm$ 100 MeV (LHC)

$\Rightarrow$ need $\mathcal{L} \sim 0.0015\ fb^{-1} \cdot (100\ MeV/\sigma_{\sqrt{s}}) = 0.075\ fb^{-1}$.

Scan determines $\Delta m \sim 1$ MeV



1.5 Yr @ 0.05 fb^{-1}/Yr

Once h-mass determined to ~1 MeV, make 3-point scan over peak with high luminosity

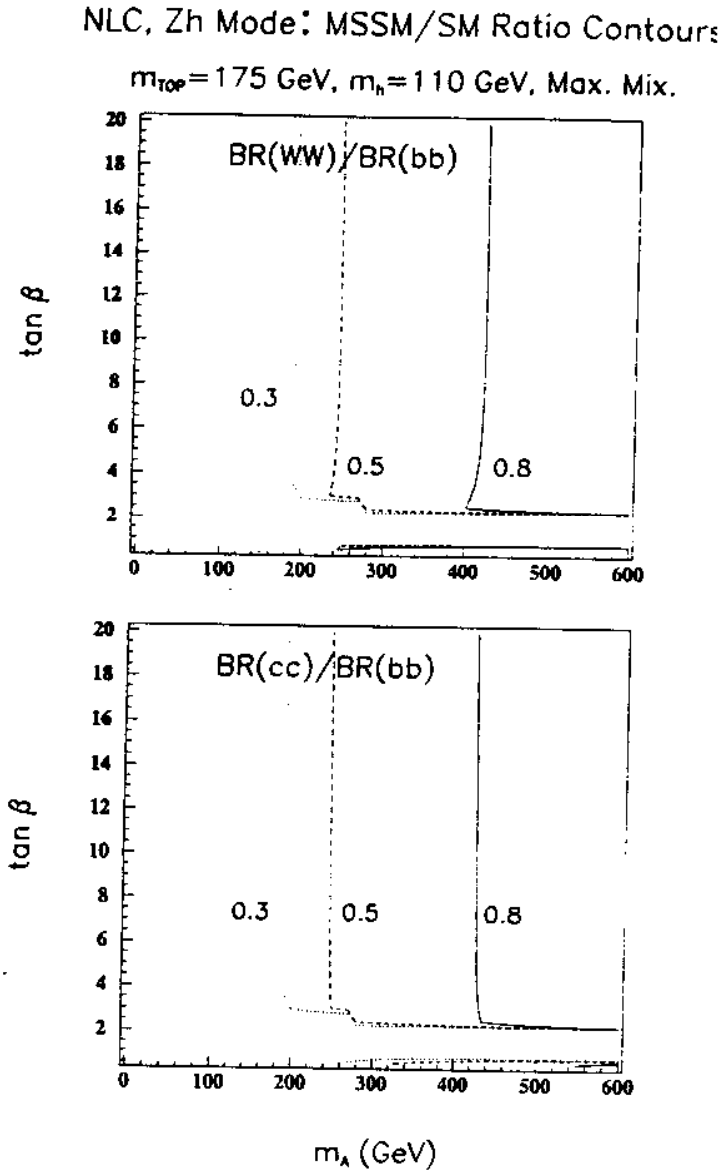
- L_1 at $\sqrt{s}$ = resonance peak
- $2.5L_1$ at wings: $\sqrt{s}$ = peak $\pm\, 2\sigma_{\sqrt{s}}$

With $L = 0.4\ \mathrm{fb}^{-1}$ obtain accuracies $\Delta m_h \sim 0.1$ MeV

Γ_h^{tot}	16%	$\Delta\Gamma_h \sim 0.5$ MeV
$\sigma\mathrm{BF}(b\bar{b})$	3%	
$\sigma\mathrm{BF}(WW^*)$	15%	

$\Rightarrow$ 8 Yr running @ $0.5\times10^{31}\ \mathrm{cm}^{-2}\,\mathrm{s}^{-1}$!

$L = 0.4\ \mathrm{fb}^{-1}$ scan $\Rightarrow \frac{WW^*}{\tau^+\tau^-} \to \pm 18\%,\ \frac{c\bar{c}}{\tau^+\tau^-} \to \pm 22\%,\ \frac{WW^*}{b\bar{b}} \to \pm 15\%,\ \frac{c\bar{c}}{b\bar{b}} \to \pm 20\%$

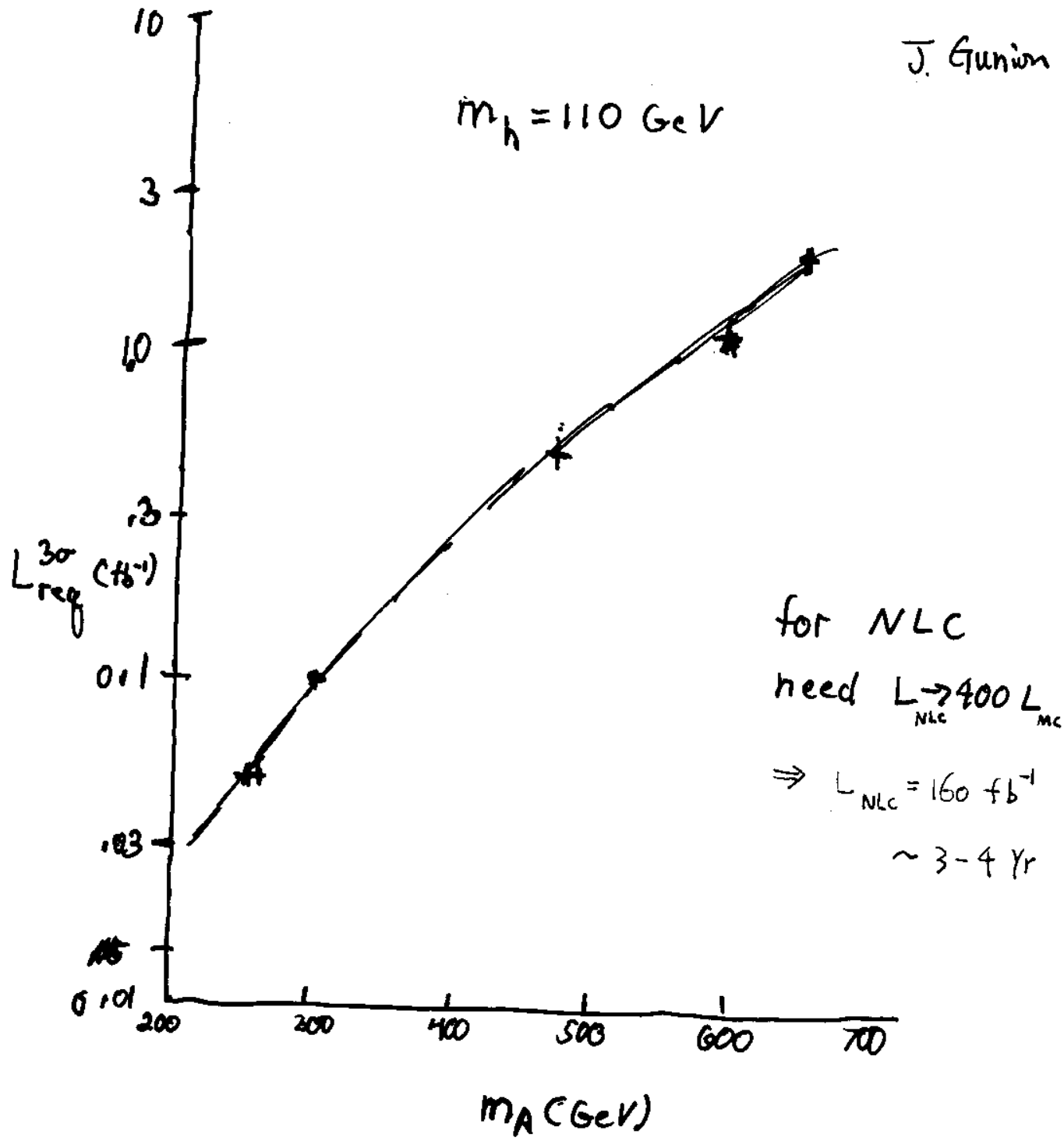


in SM: = 1

Figure 3: Constant value contours in $(m_{A^0}, \tan\beta)$ parameter space for the rate ratios $[WW^*/b\bar{b}]_{h^0}/[WW^*/b\bar{b}]_{h_{SM}}$ and $[c\bar{c}/b\bar{b}]_{h^0}/[c\bar{c}/b\bar{b}]_{h_{SM}}$, for "maximal-mixing" with fixed m_{h^0} = 110 GeV. Same contours apply for $b \to \tau$.

Combining $\Rightarrow$ ~~[illegible] sensitivity up to $m_{A^0} \sim 400$ GeV~~.

for which it's hard to observe at LHC, NLC (800 GeV)?



Distinguishing h^0 (MSSM) from h_{SM} (SM)
via $\frac{WW}{b\bar{b}}$, $\frac{WW}{\tau\tau}$, $\frac{c\bar{c}}{b\bar{b}}$, $\frac{c\bar{c}}{\tau\tau}$.

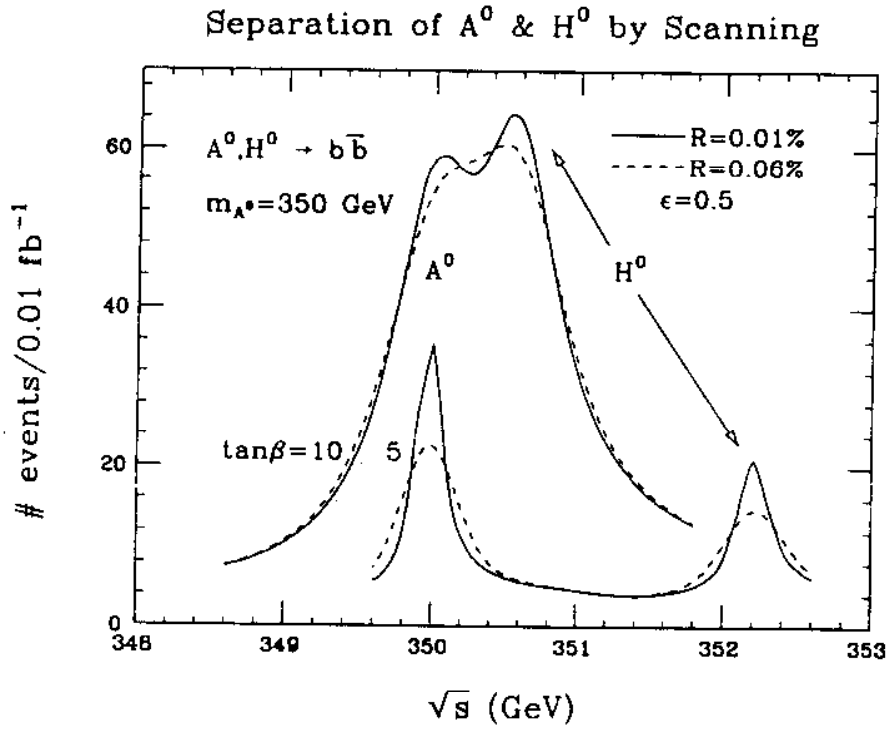


Figure 6: Plot of $b\bar{b}$ final state event rate as a function of $\sqrt{s}$ for $m_{A^0} = 350$ GeV, in the cases $\tan\beta = 5$ and 10, resulting from the H^0, A^0 resonances and the $b\bar{b}$ continuum background. We have taken $L = 0.01$ fb^{-1} (at any given $\sqrt{s}$), $\epsilon = 0.5$, $m_t = 175$ GeV, and included two-loop/RGE-improved radiative corrections to Higgs masses, mixing angles and self-couplings using $m_{\tilde{t}} = 1$ TeV and neglecting squark mixing. SUSY decays are assumed to be absent. Curves are given for two resolution choices: $R = 0.01\%$ and $R = 0.06\%$

Further Improvement Possible:

- final state angular distributions

  e.g. $d\sigma / d\cos\theta_f$ $\quad H \to f\bar{f}$ flat

  $Z \to f\bar{f}$ more F-B ward

- beam Polarization:

  to reach the Same $S/\sqrt{B}$,

  $\mathcal{L}_p$ needed is reduced by:

  $$\frac{1-P^2}{(1+P^2)^2}.$$

But: for $P \simeq 60\%$ $\Rightarrow$ $35\% \mathcal{L}_0$

marginally enough to Compansate

$\mathcal{L}(P=20\%) \Rightarrow \frac{1}{4}\mathcal{L}(P=60\%)$

Conclusions:

- $\mu^+\mu^- \to h^0, H^0, A^0$ unique feature

  determine Γ_H, $m_H < \mathcal{O}(1\,\text{MeV})$; $BR(b\bar{b}, WW, c\bar{c}\cdots)$

  Need: best energy resolution $R \sim 0.003\%$

  highest luminosity $\mathcal{L} \gtrsim \mathcal{O}(5\times10^{31}\,\text{cm}^{-2}\,\text{s}^{-1})$

- Beyond FMC, $\sqrt{s} \sim 500$ GeV $\sim$ TeV

  $\mu^+\mu^- \to H^0, A^0$ & H^0A^0, H^+H^-

  may go beyond any other machines

Muon Colliders are H, A, higgs factories!

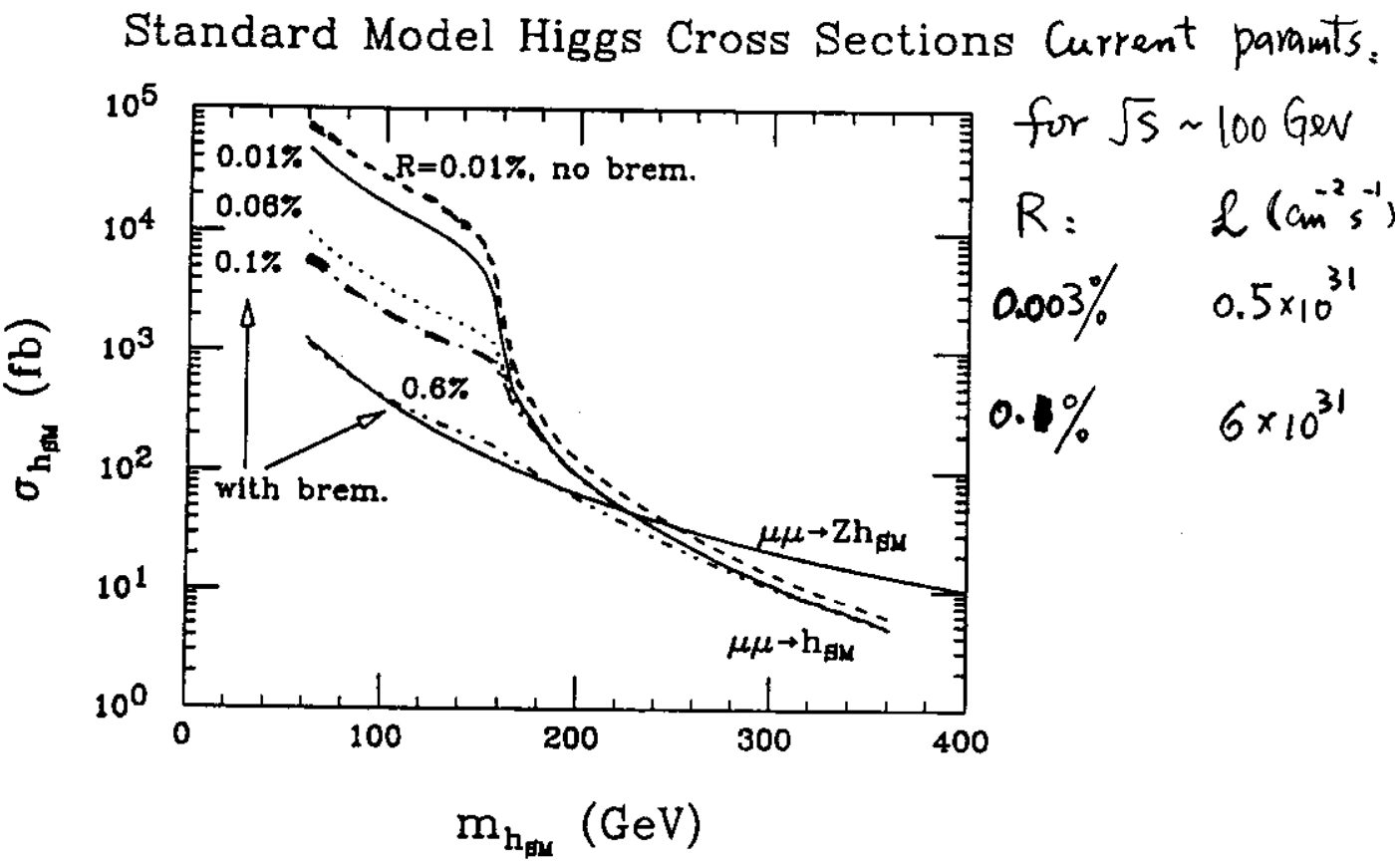


Figure 9: Cross sections versus $m_{h_{SM}}$ for inclusive SM Higgs production: (i) the s-channel $\overline{\sigma}_h$ for $\mu^+\mu^- \to h_{SM}$ with $R = 0.01\%$, 0.06%, 0.1% and 0.6%, and (ii) $\sigma(\mu^+\mu^- \to Zh_{SM})$ at $\sqrt{s} = m_Z + \sqrt{2}m_{h_{SM}}$. Also shown is the result for $R = 0.01\%$ if bremsstrahlung effects are not included.

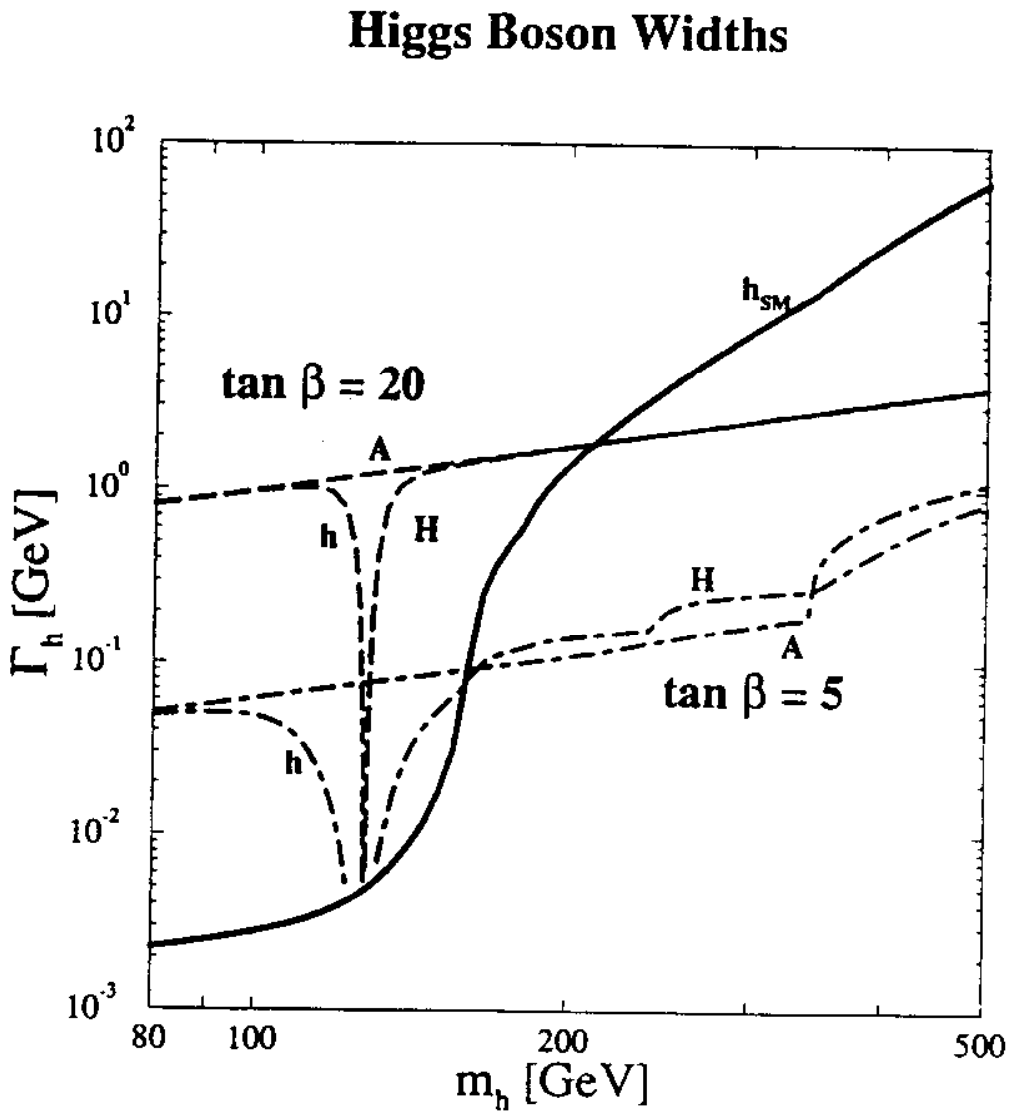


FIG. 1. Total width vs mass of the SM and MSSM Higgs bosons, for $\tan\beta = 5$ and 20 in the MSSM.

Table 5: Percentage errors (1σ) for $\sigma BF(h_{SM} \to b\bar{b}, WW^*, ZZ^*)$ (extracted from channel rates) and $\Gamma^{tot}_{h_{SM}}$ for s-channel Higgs production at the MC assuming beam energy resolution of $R = 0.003\%$. Results are presented for two integrated four-year luminosities: $L = 0.4$ fb^{-1} ($L = 4$ fb^{-1}). An optimized three-point scan is employed [which, for the cross section measurements, is equivalent to $L \sim 0.2$ fb^{-1} ($L = 2$ fb^{-1}) at the $\sqrt{s} = m_{h_{SM}}$ peak].

Quantity	Errors			
Mass (GeV)	**80**	m_Z	**100**	**110**
$\sigma BF(b\bar{b})$	2.4%(0.8%)	21%(7%)	4%(1.3%)	3%(1%)
$\sigma BF(c\bar{c})$	?	?	?	8%(3%)
$\sigma BF(\tau^+\tau^-)$	?	?	?	19%(7%)
$\sigma BF(WW^*)$	–	–	32%(10%)	15%(5%)
$\sigma BF(ZZ^*)$	–	–	–	190%(62%)
$\Gamma^{tot}_{h_{SM}}$	10%(3%)	78%(25%)	30%(10%)	16%(5%)
Mass (GeV)	**120**	**130**	**140**	**150**
$\sigma BF(b\bar{b})$	3%(1%)	5%(1.5%)	9%(3%)	28%(9%)
$\sigma BF(WW^*)$	10%(3%)	8%(2.5%)	7%(2.3%)	9%(3%)
$\sigma BF(ZZ^*)$	50%(16%)	30%(10%)	16%(8%)	34%(1%)
$\Gamma^{tot}_{h_{SM}}$	16%(5%)	18%(6%)	29%(9%)	105%(34%)

At $L = 0.4\,\text{fb}^{-1}$ (≥ 4 years at $R = 0.003\%$) the errors for $\sigma BF(h_{SM} \to b\bar{b})$ are small, but those for $\Gamma^{tot}_{h_{SM}}$ are not wonderful.

*Note from Eq. (0.2) that $\sigma(\mu^+\mu^- \to h \to X)$ provides a determination of $\Gamma(h \to \mu^+\mu^-)BF(h \to X)$ unless $\sigma_{\sqrt{s}} \ll \Gamma^{tot}_h$.