

Linear Collider Higgs Studies: Snowmass & Beyond

Outline:

- Our Snowmass "shopping list" and what was done with each item (remaining projects, i.e., for Chicago)
- Updated status of Snowmass analyses

Not including CLIC and $\gamma\gamma$ Higgs studies...

*Linear Collider
Detector (LCD) Working
Group Meeting*

*SLAC, Stanford, CA
16 October 2001*

*Rick Van Kooten
Indiana University*

Where we stand, code:



Possible
future project



Started at
Snowmass,
needs continuation



Snowmass study,
finished or
close to

The Questions and Projects

SM Higgs

- Q: How well can one measure mass and width as a function of Higgs mass?



Haijun Yang, lighter Higgs, writeup in



- Concentrate on optimal \sqrt{s} , and thresh. scan option at lower energy IP



*(Torrence,
beam energy)*

- Impact of beamstrahlung spectrum and how well can it *really* be measured (compare NLC/TESLA)



(Niels Meyer)

- Simulation and strategy for measuring width directly for masses > 200 GeV

- Q: How well can one measure Br's and couplings as a function of Higgs mass and \sqrt{s} ?



- Find how high in mass can measure "rare" $\text{Br}(bb)$ (and $\text{Br}(ff)$) and what precision? (fuller simulations)



Detector group

- Dijet resolution and detector needed for separation of WW , ZZ decays (into hadrons)?



- Extraction of (indirect) width using all available info; full correlations of errors, use of HFITTER.

⇒ What about $M_h > 170$ GeV, mostly WW , ZZ decays

- Q: Is $\gamma\gamma$ needed for total Higgs width for light Higgs?

Projects:

- Q: What is the optimal experimental program to determine spin / parity / CP nature of Higgs?

- **(P)** More complete simulations and analyses of angular distributions **(SM)** *D. Miller, threshold, SUSY Higgs*
- Mixed CP? / CP violation?

Simulations of:

(SM) $\Rightarrow t t H$, energy and angular analysis
(Yukawa)

(SM) $\Rightarrow H \rightarrow t t, H \rightarrow \tau \tau$
polarization "self-analysis"

- Q: What is the optimal program to determine Higgs self couplings?

- ? **(SM)** • In multiple Higgs production, what dijet resolution, detector performance, luminosity needed?
 \Rightarrow How high can go in Higgs mass?


- (P)** • Any way at all to get quartic couplings?

- Q: What is the utility of positron polarization in Higgs measurements?

-  Take most beneficial case, simulations and backgrounds

SUSY

- Q: How far in reach to detect presence of H/A states? With what precision?

-  See previous project on correlated Br and σ errors, which errors important? use of HFITTER

- Q: How far in mass can one still disentangle the close to degenerate H/A states ?

-  Simulations and realistic backgs.



- Q: Can one measure $\tan\beta$ from SUSY Higgs states alone (in a fully model independent way)?



- Simulations of measurements of H/A masses and branching ratios (remember, no handy Z recoil for the Br's!!)



- Q: How well can one measure an invisible branching ratio (particularly if small)?



- Full simulations with realistic **backgrounds** of Z recoiling against "nothing"



- ...with large width too...

- Q: What additional measurements possible if other SUSY particles accessible?



- Simulations of measurement of Br for e.g., $h \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_2^0$

(P1: interplay between

$$h \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_2^0 \text{ and e.g. } \tilde{\chi}_1^\pm \rightarrow h X)$$



- Br's for other unusual decay modes (e.g., P1: radions, gg , ...)



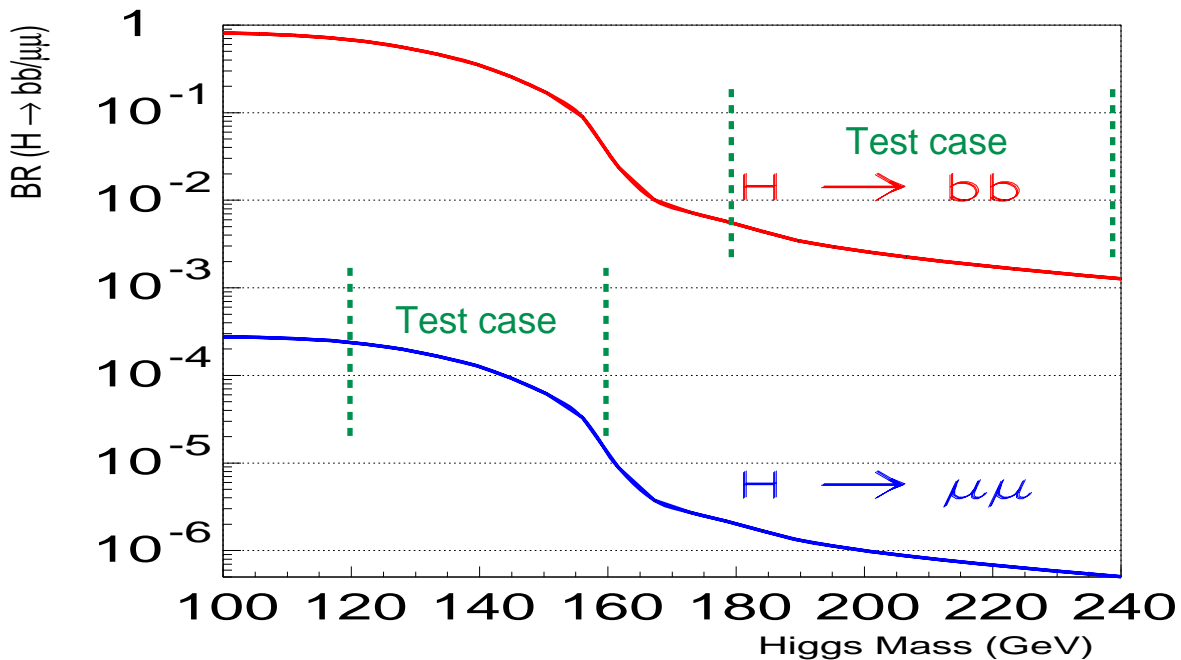
- Other "elusive" models, e.g., nasty 2HDM, need direct



observation of $H/A/H^\pm$ states

"Rare" Br's

Battaglia, Desch



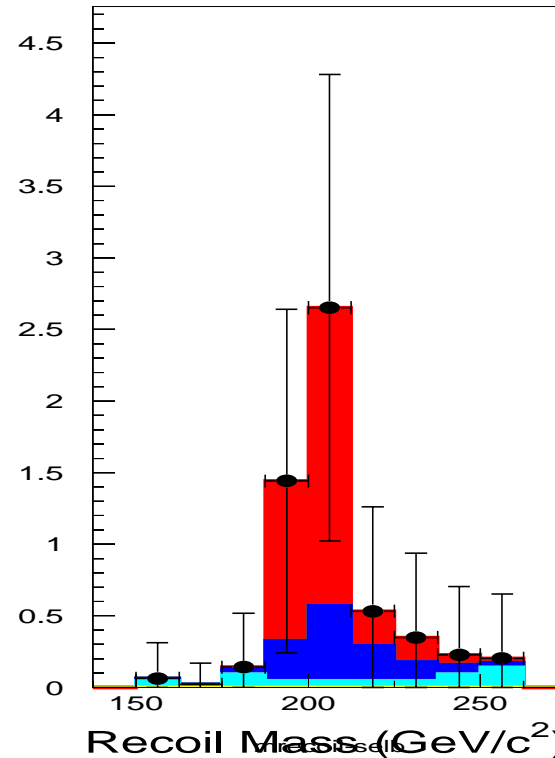
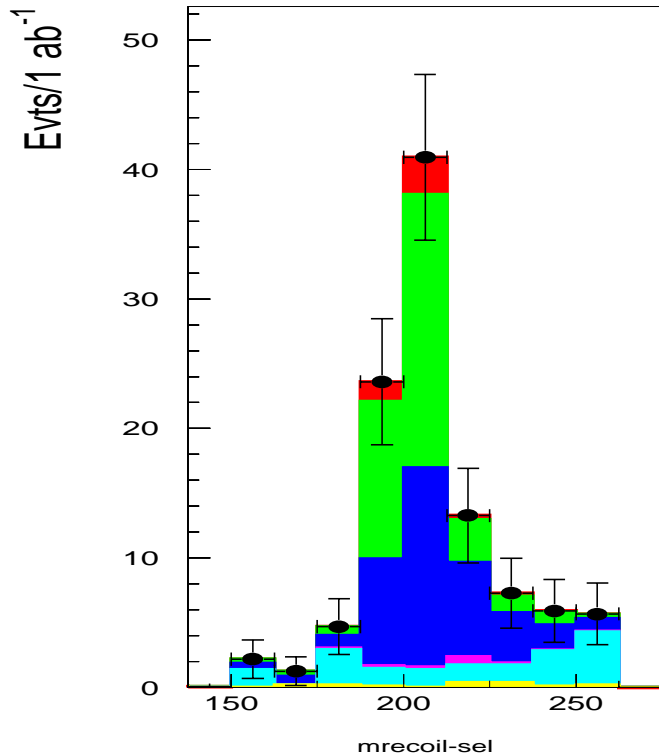
- ❖ Higgs analyses mostly concerned with $e^+ e^- \rightarrow H^0 Z^0$ at $\sqrt{s} = 350 - 500$ GeV to profit from favourable kinematics and constraints.
- ❖ However HZ production cross-section never exceeds 120 fb and ZZ, $Z \rightarrow ll q\bar{q}$ represents irreducible background.
- ❖ At higher energies $H^0 \nu\bar{\nu}$ becomes the dominant mode with $\log \frac{s}{M_H^2}$.

TESLA at $\sqrt{s} = 0.8$ TeV with $L = 1 \text{ ab}^{-1}$

$$H^0 \rightarrow b\bar{b}$$

Battaglia, Desch

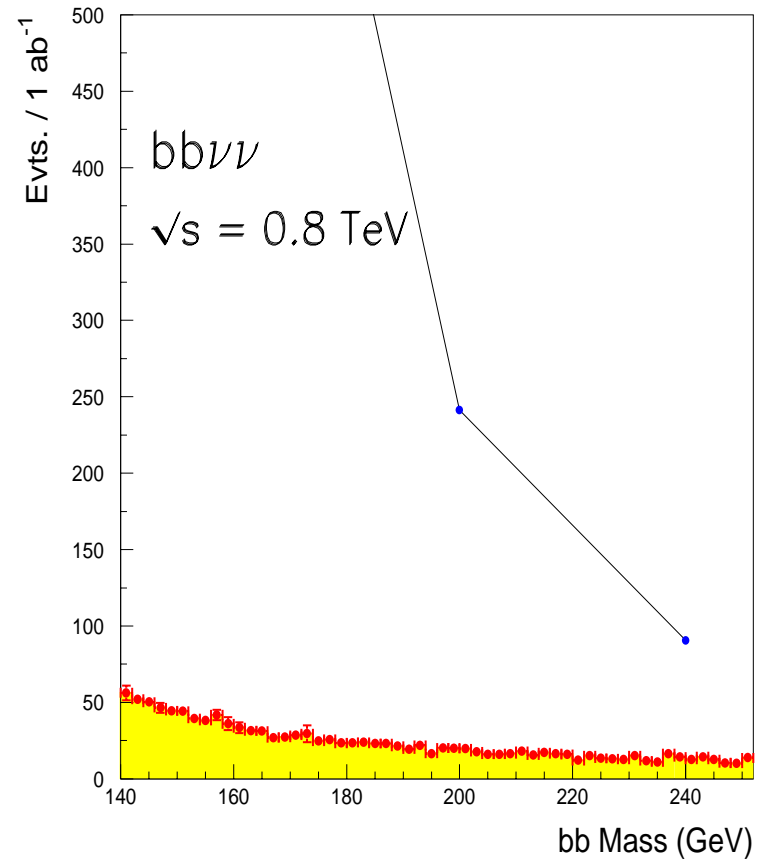
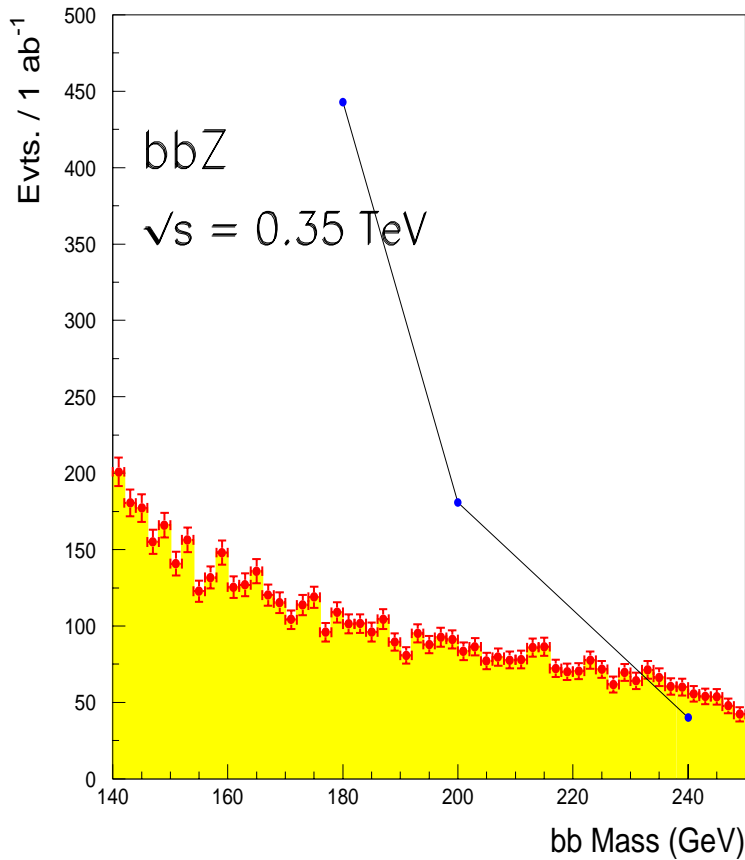
$e^+ e^- \rightarrow ZH(200) \rightarrow llb\bar{b}$ at $\sqrt{s} = 350$ GeV
 Before b-tagging After b-tagging



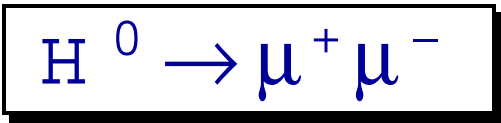
bb coupling to
 ~15-20%
 for 200 GeV mass,
 $\sqrt{s} = 350$ GeV
 using *HZ*

- ◆ Feasible to reduce $H \rightarrow WW$ and ZZ by topology and b-tagging
- ◆ At $\sqrt{s} = 350$ GeV dominant $e^+ e^- \rightarrow ZZ$ background limits use of $Z \rightarrow \text{hadrons}$

A comparison of HZ and H^{-} Processes
 Estimated Bkg and $Nb(H \rightarrow b\bar{b})$ for $L = 1 \text{ ab}^{-1}$

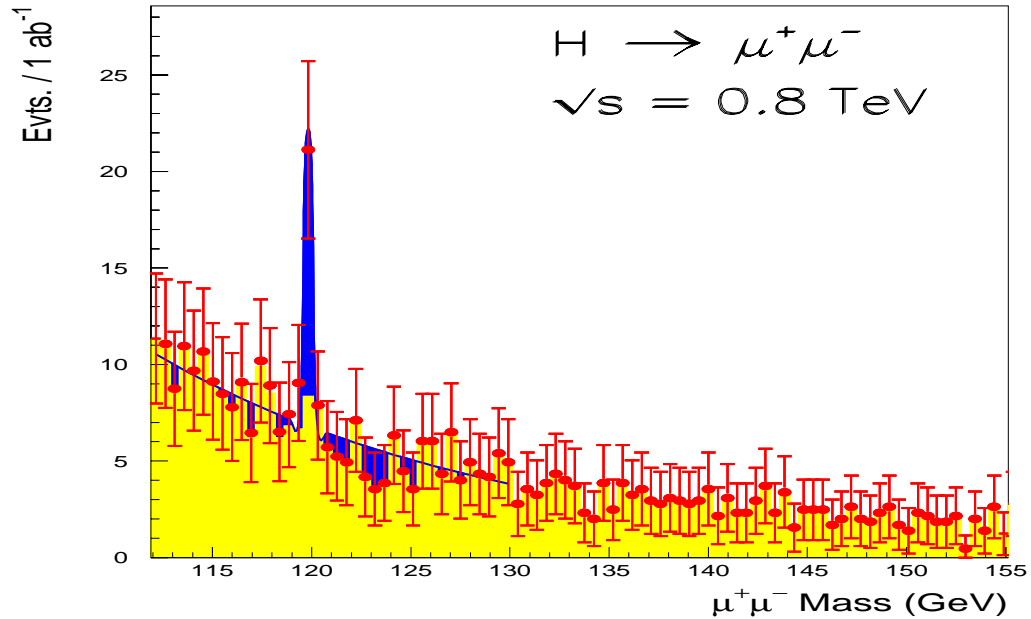


$e^+e^- \rightarrow H\nu\bar{\nu}$, $H \rightarrow b\bar{b}$ at $\sqrt{s} = 0.8 \text{ TeV}$ appears a promising channel for probing g_{bb} for a heavy Higgs boson.



Battaglia, Desch

- ❖ Reconstruct $2 \mu s + E_{\text{missing}}$ final states, cut on M_{recoil} and $E_{\mu\mu}$
- ❖ Background estimated from $ZZ\nu\nu$, $WW\nu\nu$ and inclusive $\mu\mu$ processes evaluated with Comphep w/o Higgs contribution



$\sqrt{s} = 0.8 \text{ TeV}$
with $L = 1 \text{ ab}^{-1}$

M_H	120 GeV
BR/BR	0.320

- ❖ Signal of $H \rightarrow \mu\mu$ can be extracted for $M_H \sim 120 \text{ GeV}$ and $g_{H\mu\mu}$ estimated with $\sim 15\%$ accuracy at TESLA-800 with 1 ab^{-1}

SM HIGGS δ_{BR}/BR RESULTS

J. Brau, C. Potter and M. Iwasaki

University of Oregon


Snowmass 2001

Mode	115	120	140	160	180	200
$h_{SM} \rightarrow WW^*$	0.16	0.10	0.03	0.02	0.03	0.04
$h_{SM} \rightarrow b\bar{b}$	0.027	0.029	0.038	0.13	0.59	-
$h_{SM} \rightarrow \tau^+\tau^-$	0.07	0.08	0.10	0.36	-	-
$h_{SM} \rightarrow c\bar{c}$	0.31	0.39	0.44	-	-	-
$h_{SM} \rightarrow gg$	0.16	0.18	0.23	-	-	-
$h_{SM} \rightarrow c\bar{c} + gg$	0.15	0.16	0.20	-	-	-


We assume $\sqrt{s}=500$ GeV, $250 fb^{-1}$ running with $P(e^-) = -0.8$, $250 fb^{-1}$ running with $P(e^-) = +0.8$, $e^+e^- \rightarrow Zh_{SM}$ production only, imperfect hadronic Z decay reconstruction and the NLD Large (L) Detector with standard vertex detector configuration.

If we assume, for example, $\sqrt{s}=350$ GeV, $1 ab^{-1}$, both $e^+e^- \rightarrow Zh_{SM}$ and $e^+e^- \rightarrow \nu\nu H$ production modes and perfect hadronic Z decay reconstruction, we obtain $\delta_{BR}/BR \approx 0.19$ for $h_{SM} \rightarrow b\bar{b}$ when $m_{h_{SM}} = 180$ GeV.

More complete simulations:

 $\Rightarrow ttH$, energy and angular analysis
(Yukawa)

- Ramon Miquel, Manel Martinez ttH for Yukawa top threshold, nearly complete at Snowmass
(Yukawa coupling difficult, 30% error best case, only for lighter Higgs)
- Ari Kiiskinen, branching ratio to tt in ZH

 $\Rightarrow H \rightarrow tt, H \rightarrow \tau\tau$
polarization "self-analysis" for CP

- Sherry Towers:
PYTHIA successfully modified to include CP violation in the Higgs sector (by mixing the MSSM Higgs states), mods. available from Sherry, interested into continuing for Chicago meeting
- Gary Bowers:
Pandora can now do the CP odd case; analysis package setup awaiting for code from Peskin. CP results in the next weeks.

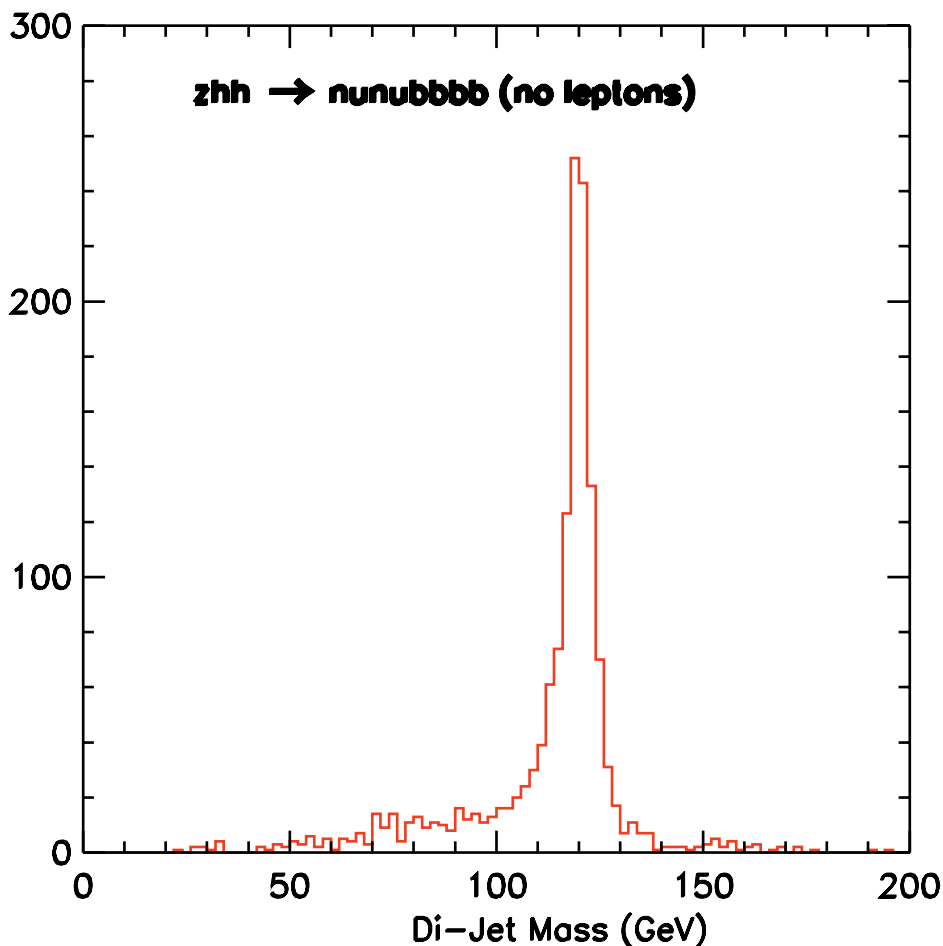
- Q: What is the optimal program to determine Higgs self couplings?

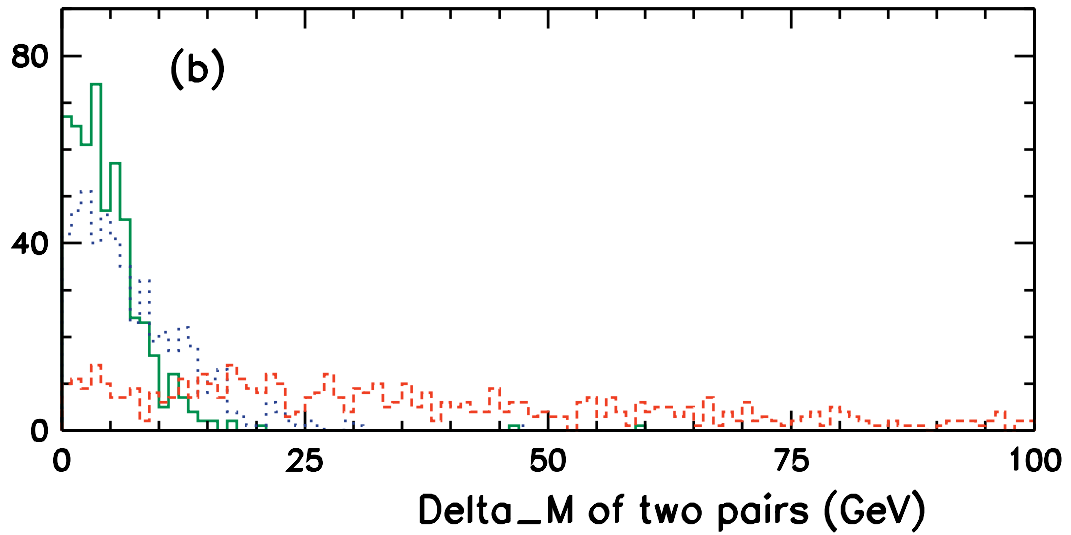
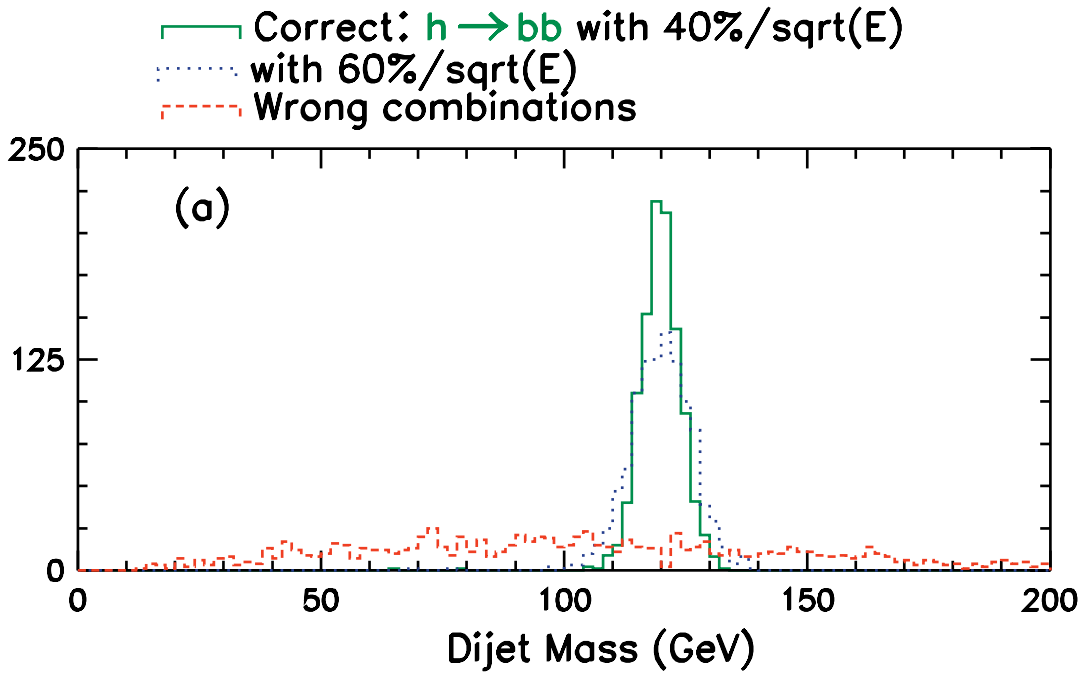


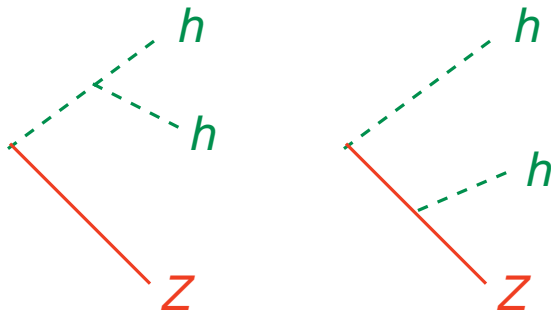
- In multiple Higgs production, what dijet resolution, detector performance, luminosity needed?

Wei-Ming Yao: Jet energy resolution and study of $ZHH \rightarrow \nu\nu bbbb$ ("finish in next weeks")

Mass without semileptonic decay:



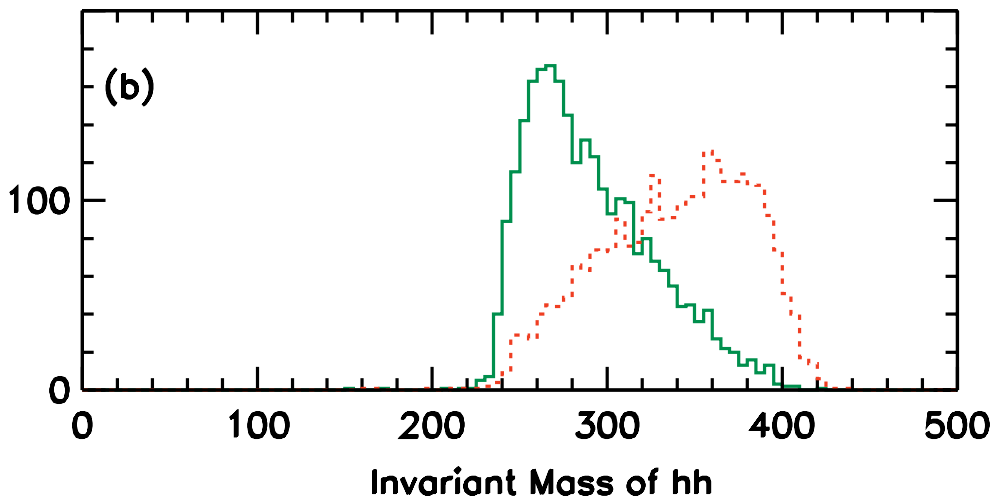
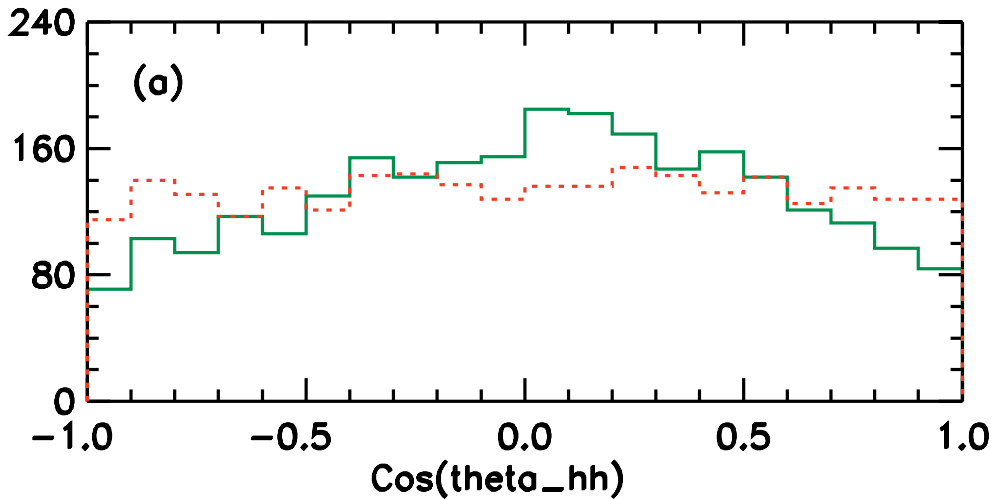




- Separation of hhh vs. ZZh components via kinematics:

Yao

— h \rightarrow hh
- - - z \rightarrow zh



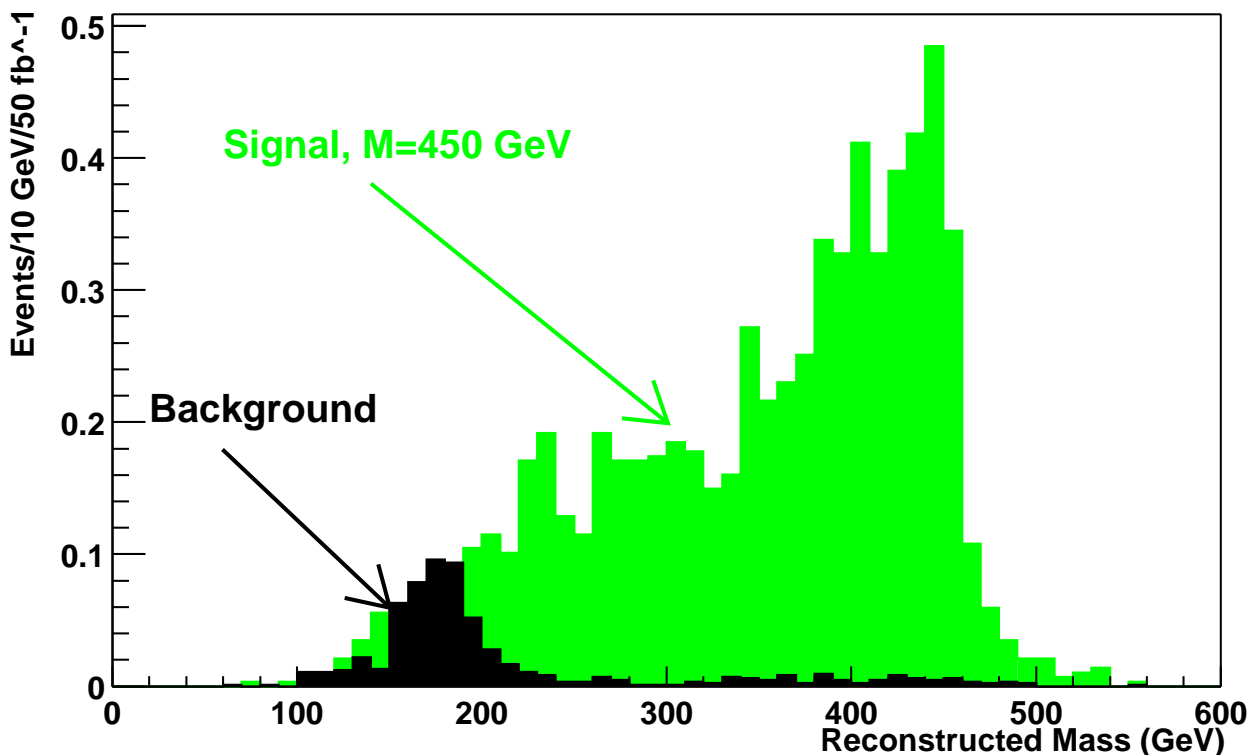


- Simulations of measurements of H/A masses and branching ratios (remember, no handy Z recoil for the Br's!!)

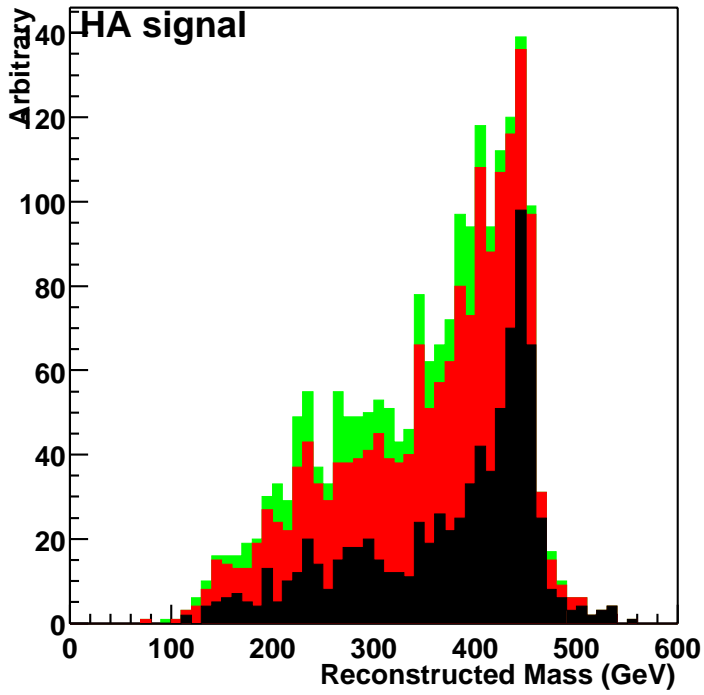


John Butler, John Hobbs: HA pair production, 1 TeV each of mass of 400–475 GeV (i.e., \sim degenerate), large $\tan\beta$ so mostly decays into $b\bar{b}$ for each

Four b -jets, choose pairing with minimum invariant mass difference, dominant background is $t\bar{t}$, charm mistagged as b :



Butler, Hobbs



Both b's hadronic decay

One b semileptonic

Both b's semileptonic

- 5σ observability
with 50 fb^{-1}

- Q: How well can one measure an invisible branching ratio (particularly if small)?

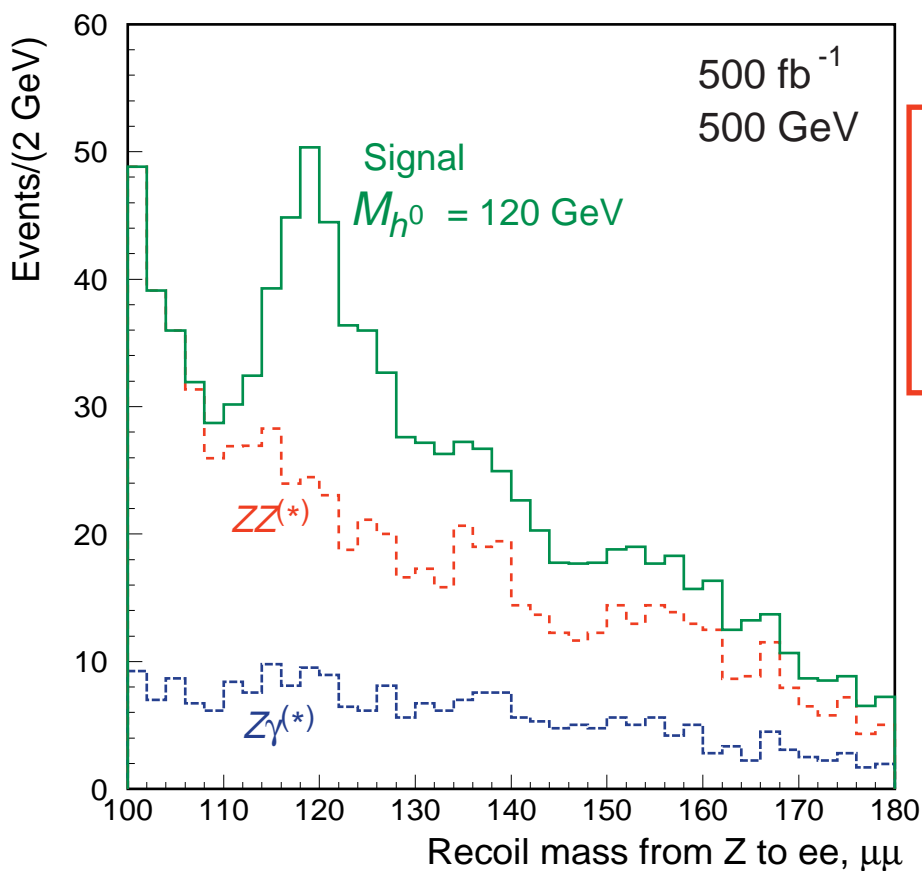


- Simulations with realistic backgrounds of Z recoiling against "nothing"

RvK

- $hZ \rightarrow$ all
 ↳ invisible
 Explicitly search for Z recoiling against "nothing" (previously, e.g., $[1 - \sum \text{Br}'s]$)

- Test case, e.g., Wells et al., hep-ph/002178,
 $\delta = 4$ extra dimensions,
 $\text{Br}(h \rightarrow \text{invis}) = 38\%$, $\Gamma_{\text{inv}} \sim 2 \text{ MeV}$



- Measure
 $\frac{\delta \text{Br}(h \rightarrow \text{invis})}{\text{Br}(h \rightarrow \text{invis})} \sim 11\%$

- Add hadronic Z decays: with $\delta E/E = 40\%/\sqrt{E}$,

$$\frac{\delta \text{Br}(h \rightarrow \text{invis})}{\text{Br}(h \rightarrow \text{invis})} \sim 7.5\%$$

- Using info from Wells et al., hep-ph/002178 (see next page), limits on no. extra dimensions δ vs Higgs mass

RvK



- Repeat for "stealthy" large invisible width models
- Combine with (following correlations) separate measure of

- $\Gamma_{\text{tot}}^{\text{indirect}} - \Gamma_{\text{visible}}^{\text{meas}}$

and/or

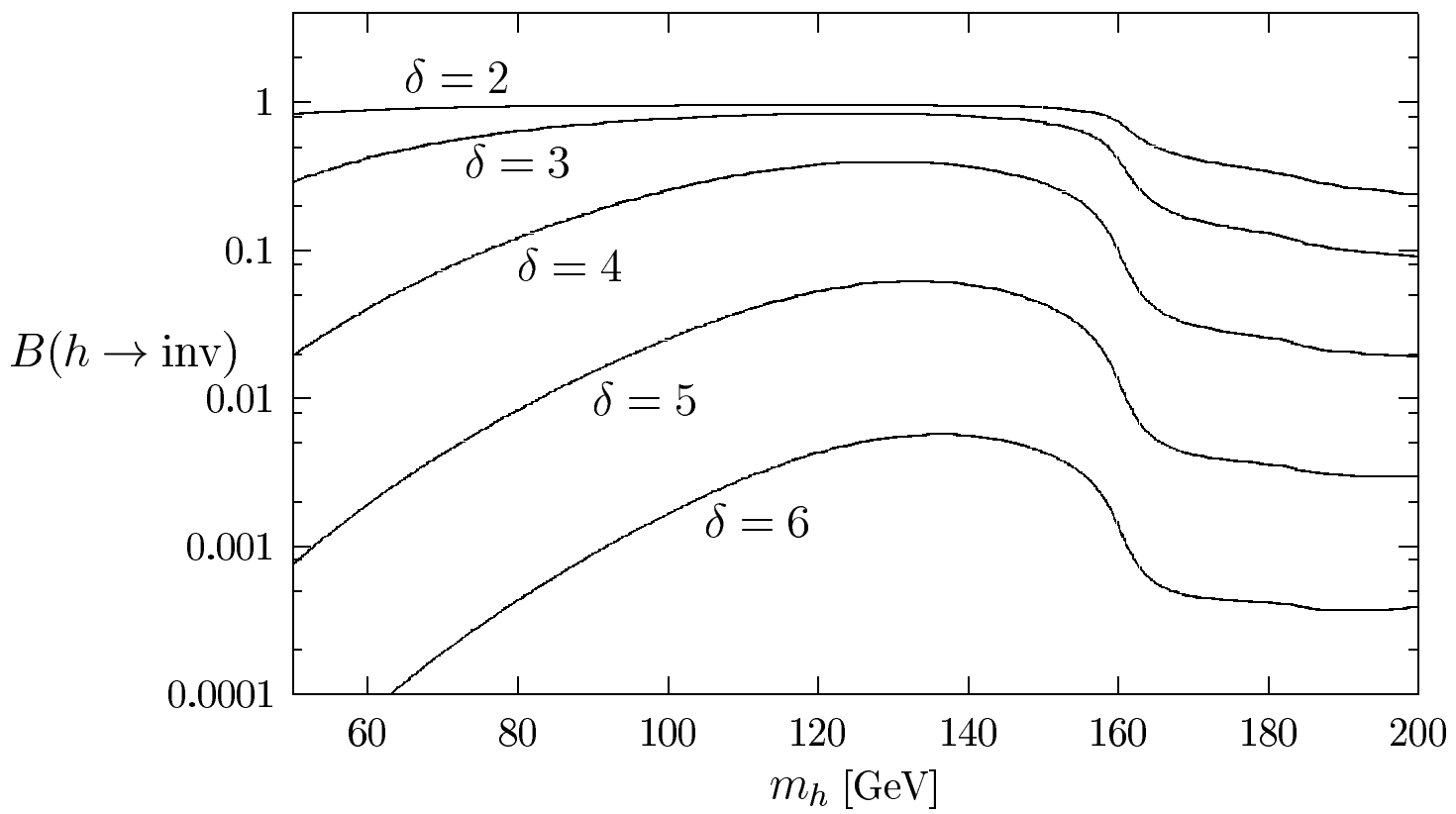
- $\Gamma_{\text{tot}}^{\text{indirect}} - \Gamma_{\text{tot}}^{\text{SM}}$

- Q: What additional measurements possible if other SUSY particles accessible?



- Simulations of measurement of Br for e.g., $h \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_2^0$

⇒ Graf interested, Mrenna, RvK were getting four-vectors generated



Summary

- Definitely no lack of projects! New people did become involved at Snowmass, but arm-twisting still needed....

- Grab a  or  !

- Broad overview of needs:

Light Higgs: filling in few Br's,
serious CP studies

Heavy/intermediate mass Higgs:

Lots of studies still to do/to continue
(heavy properties, *HA* and implications)

Overall: intelligent global fits, HFITTER,
expertise in North American group