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:

P — **Possible future project**

SM — **Started at Snowmass, needs continuation**

SM — **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?

SM *Haijun Yang, lighter Higgs, writeup in*

P
- Concentrate on optimal √s, and thresh. scan option at lower energy IP

? P *(Torrence, beam energy)*
- Impact of beamstrahlung spectrum and how well can it *really* be measured (compare NLC/TESLA)

SM *(Niels Meyer)*
- Full 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 $\sqrt{s}$?

SM

- Find how high in mass can measure "rare" Br(*bb*) (and Br(*ff*)) and what precision? (fuller simulations)

? P

Detector group

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

P

- Extraction of (indirect) width using all available into; 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
  - Full simulations and analyses of angular distributions

    SM *D. Miller, threshold, SUSY Higgs*
  - Mixed CP? / CP violation?

  Full simulations:

  SM ⇒ $t\,t\,H$, energy and angular analysis

  (Yukawa)

  SM ⇒ $H \to t\,t$, $H \to \tau\,\tau$ 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? (full simulations)

    ⇒ 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?

  P
  - Take most beneficial case, full simulation and backgrounds

SUSY

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

  P
  - 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 ?

  SM
  - Full simulations and realistic backgs.

  SM

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

  SM
  - Simulations of measurements of *H/A* masses and branching ratios

  SM
  (remember, no handy *Z* recoil for the Br's!!)

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

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

  SM
  - ...with large width too...

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

SM

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

  (P1: interplay between $h \to \tilde{\chi}_1^0 \tilde{\chi}_2^0$ and e.g. $\tilde{\chi}_1^\pm \to h\, X$)

SM

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

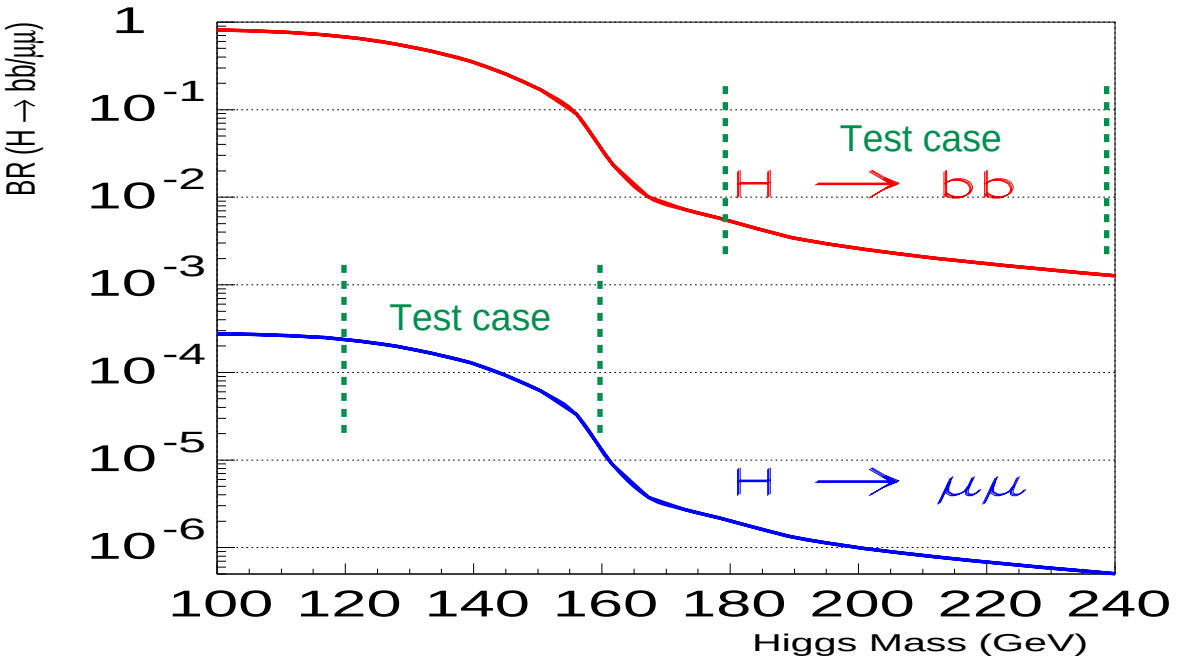
P

SM

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

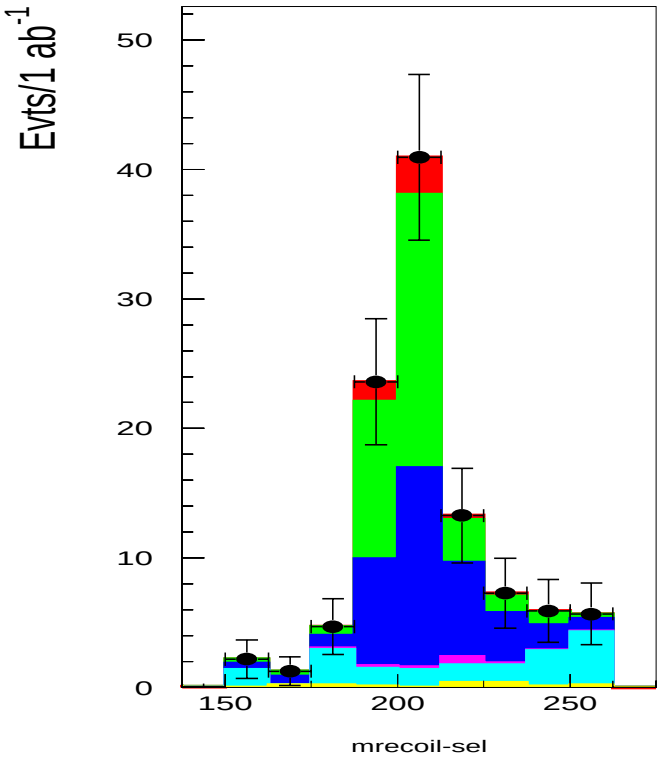
TESLA at $\sqrt{s}$ = 0.8 TeV with $L = 1\ ab^{-1}$

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

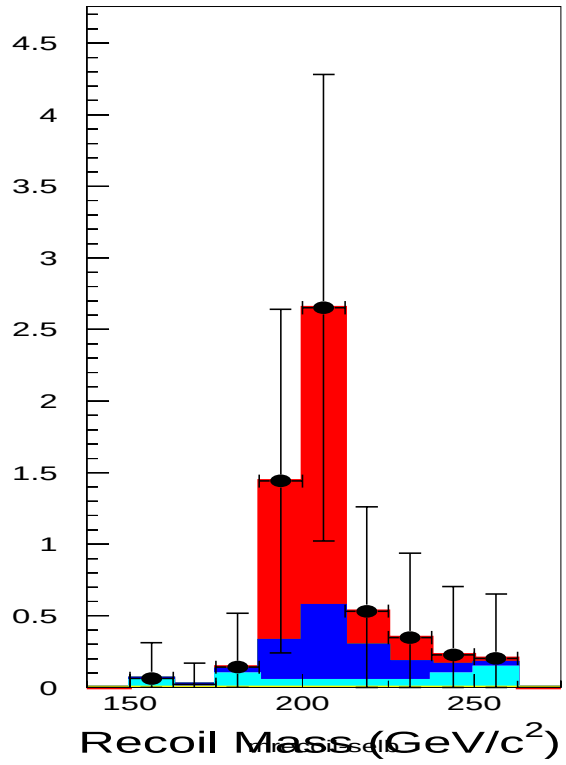
Battaglia, Desch

$e^+e \to ZH(200) \to llb\bar{b}$ at $\sqrt{s}$ = 350 GeV

Before b-tagging



After b-tagging

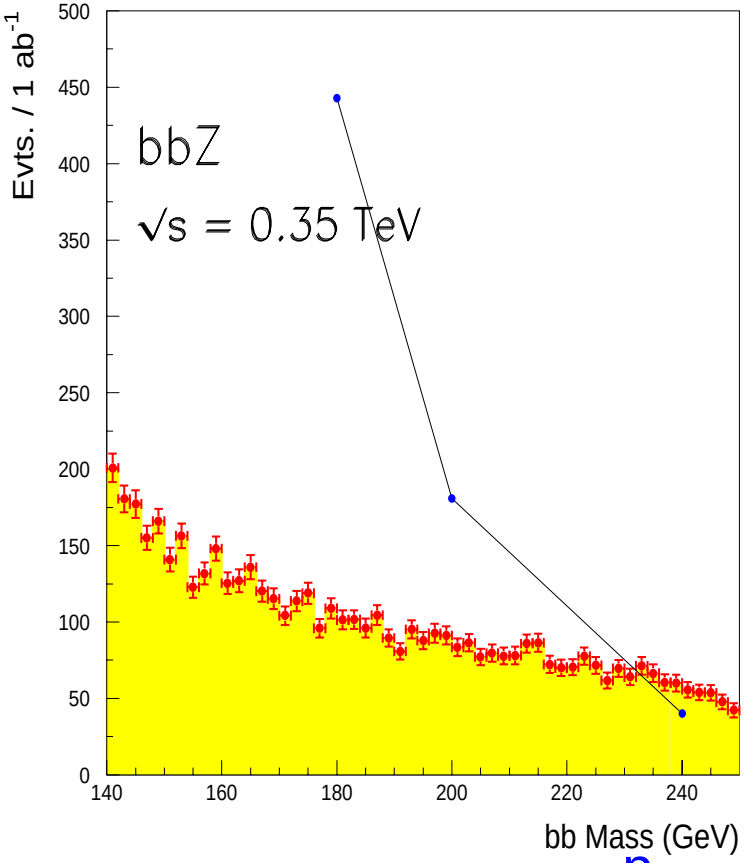


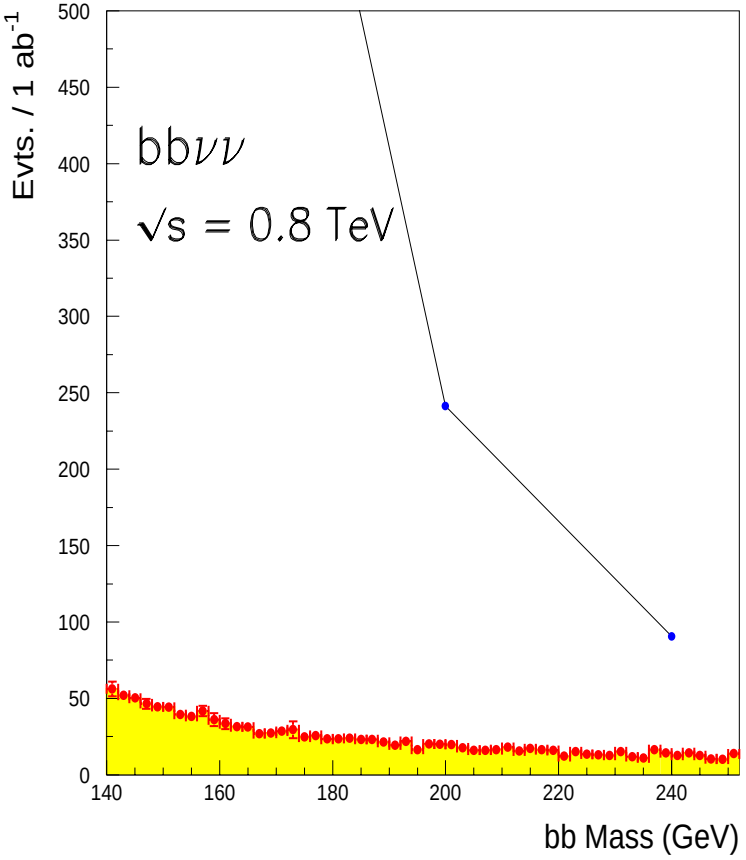
bb coupling to ~15-20% for 200 GeV mass, sqrt(s) = 350 GeV using *HZ*

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

A comparison of HZ and $H\bar{\nu}$ Processes

Estimated Bkg and Nb($H \to b\bar{b}$) for $^{R}L = 1\ ab^{-1}$



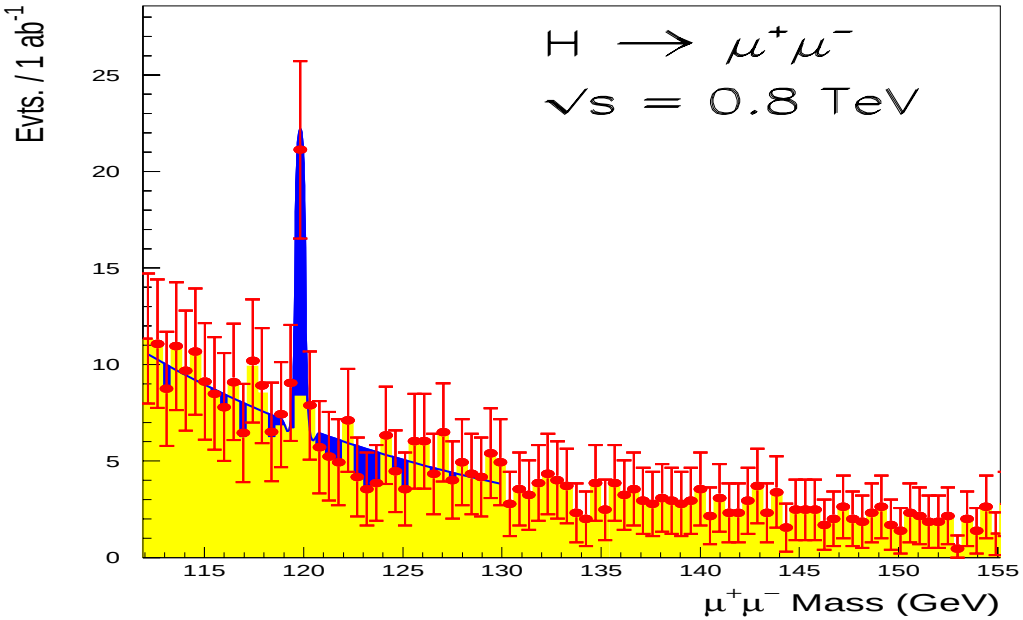


$e^{+}e \to H\nu\bar{\nu}$, $H \to b\bar{b}$ at $^{p}s\bar{} = 0.8$ TeV appears a promising channel for probing g_{Hbb} for a heavy Higgs boson.

$H^0 \to \mu^+\mu^-$

Battaglia, Desch

- Reconstruct 2 μs + $E_{missing}$ final states, cut on M_{recoil} and $E_{\mu\mu}$
- Background estimated from ZZνν, WWνν and inclusive μμ processes evaluated with Comphep w/o Higgs contribution



p_{s}^{-} = 0.8 TeV
with ^{R}L = 1 ab ^{1}

M_H	120 GeV
BR/BR	0.320

- Signal of H→μμ can be extracted for M_H ~120 GeV and $g_{H\mu\mu}$ estimated with ~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
$h_{SM} \to WW^\star$	0.16	0.10	0.03	0.02	0.03	0.04
$h_{SM} \to b\bar{b}$	0.027	0.029	0.038	0.13	0.59	-
$h_{SM} \to \tau^+\tau^-$	0.07	0.08	0.10	0.36	-	-
$h_{SM} \to c\bar{c}$	0.31	0.39	0.44	-	-	-
$h_{SM} \to gg$	0.16	0.18	0.23	-	-	-
$h_{SM} \to c\bar{c} + gg$	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 $P(e^-) = +0.8$, $e^+e^- \to Zh_{SM}$ 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 $e^+e^- \to Zh_{SM}$ and $e^+e^- \to \nu\nu H$ production modes and perfect hadronic Z decay reconstruction, we obtain δ_{BR}/BR ≈0.19 for $h_{SM} \to b\bar{b}$ when $m_{h_{SM}}$ =180 GeV.

Full simulations:

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

- 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 Kiiskninen, branching ratio to *tt* in *ZH*

SM ⇒ $H \to t\,t$, $H \to \tau\,\tau$ 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.

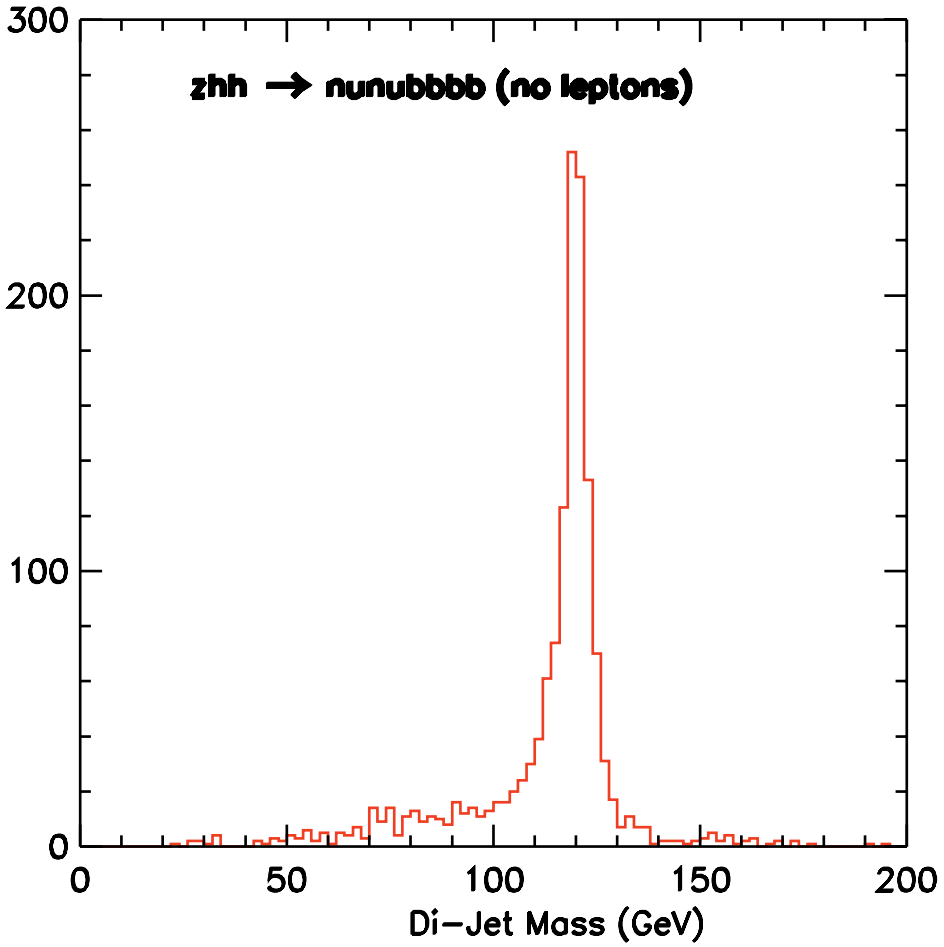
- Q: What is the optimal program to determine Higgs self couplings?

  ? SM

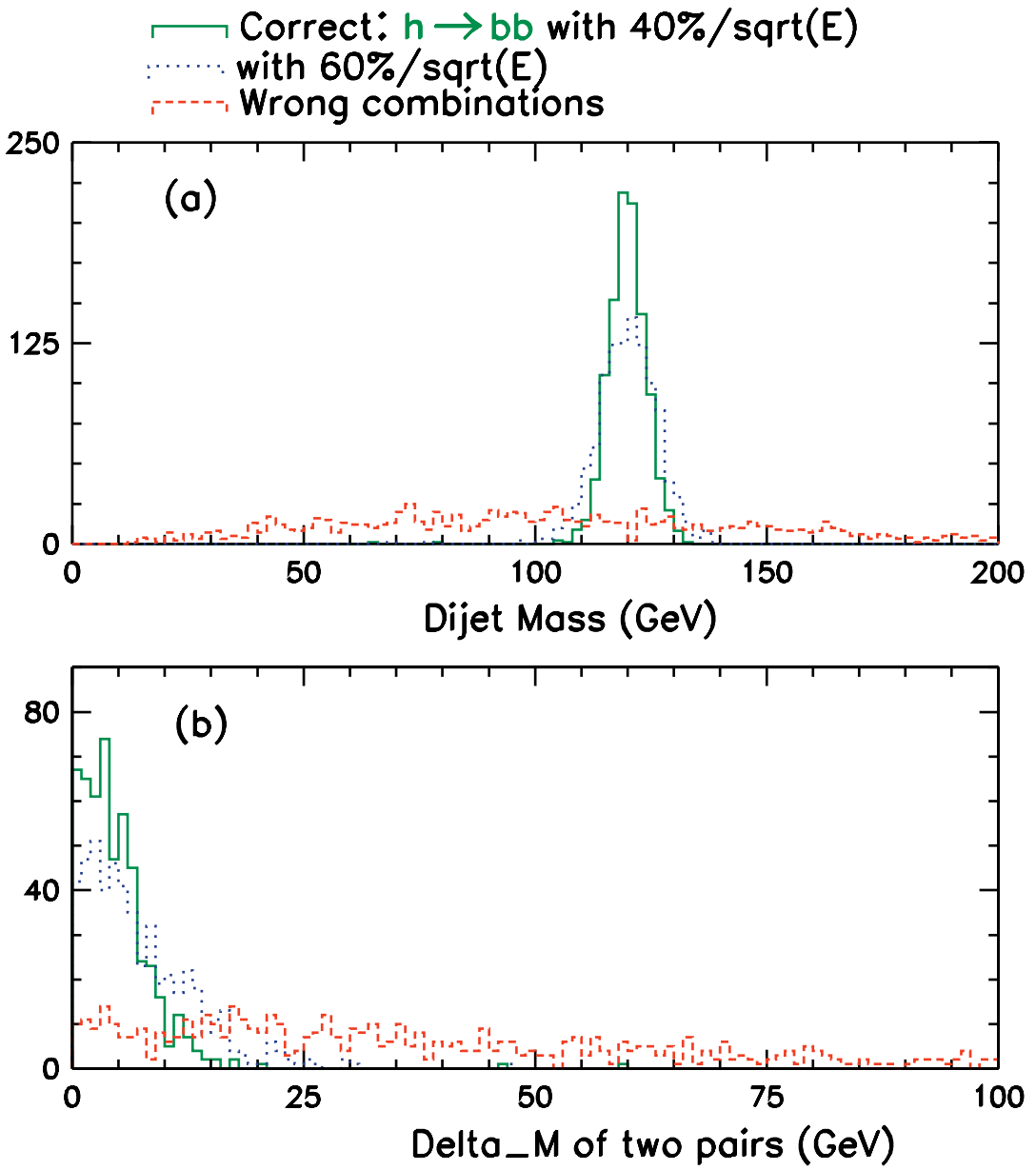
  - In multiple Higgs production, what dijet resolution, detector performance, luminosity needed? (full simulations)

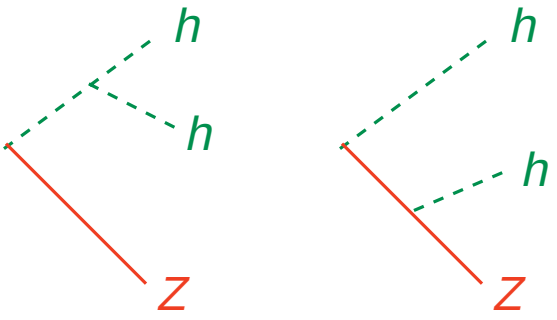
Wei-Ming Yao: Jet energy resolution and study of $ZHH \rightarrow \nu\nu bbbb$ ("finish in next weeks")

Mass without semileptonic decay:



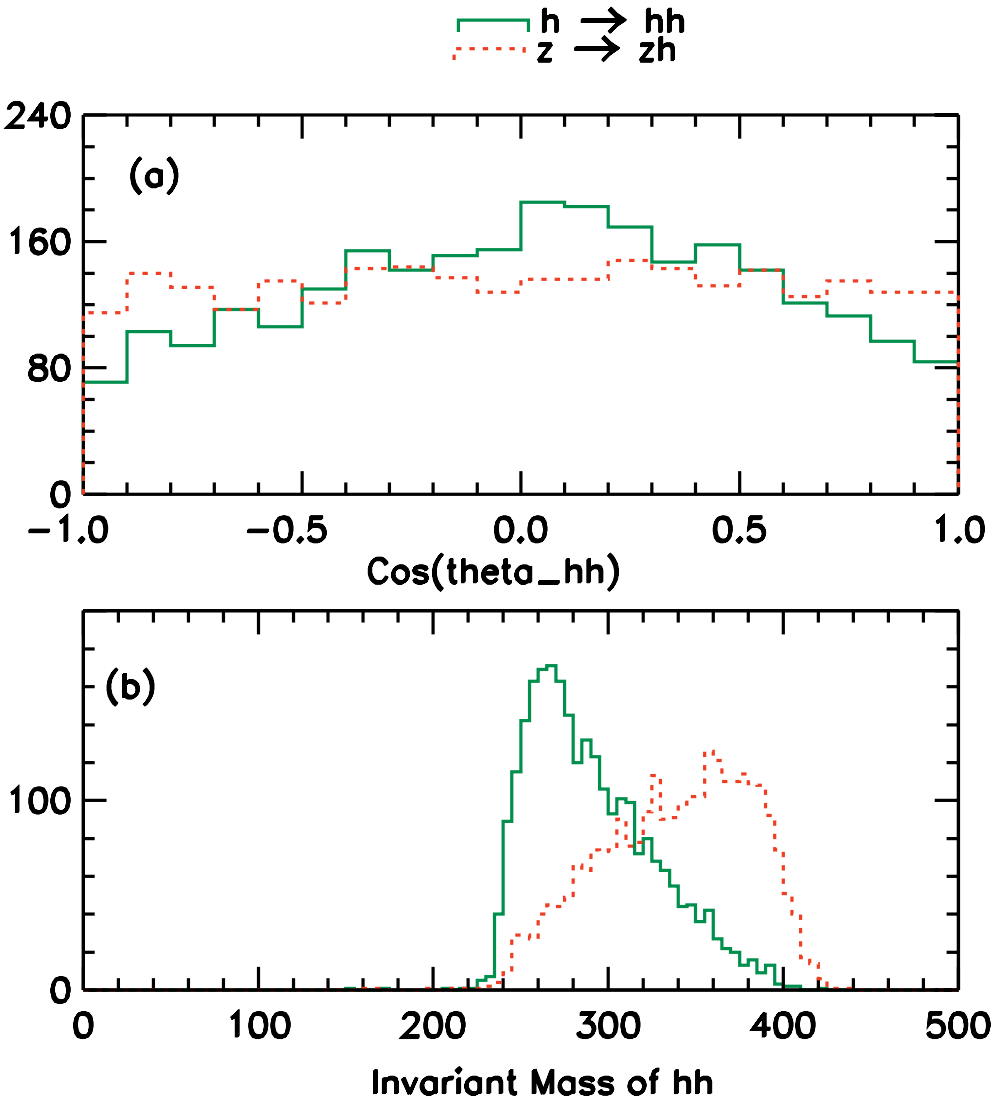
Yao


Correct: h → bb with 40%/sqrt(E)
with 60%/sqrt(E)
Wrong combinations
(a)
250
125
0
0
50
100
150
200
Dijet Mass (GeV)
(b)
80
40
0
0
25
50
75
100
Delta_M of two pairs (GeV)



- Separation of *hhh* vs. *ZZh* components via kinematics:

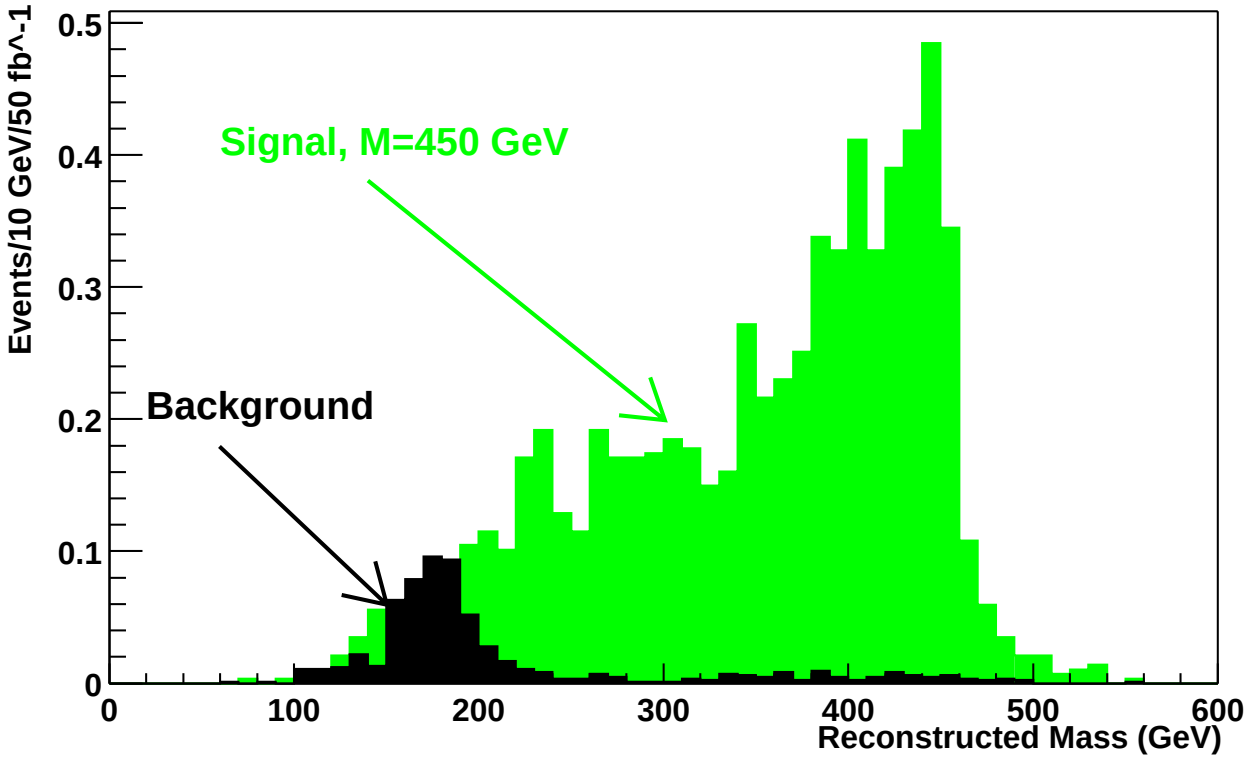
Yao



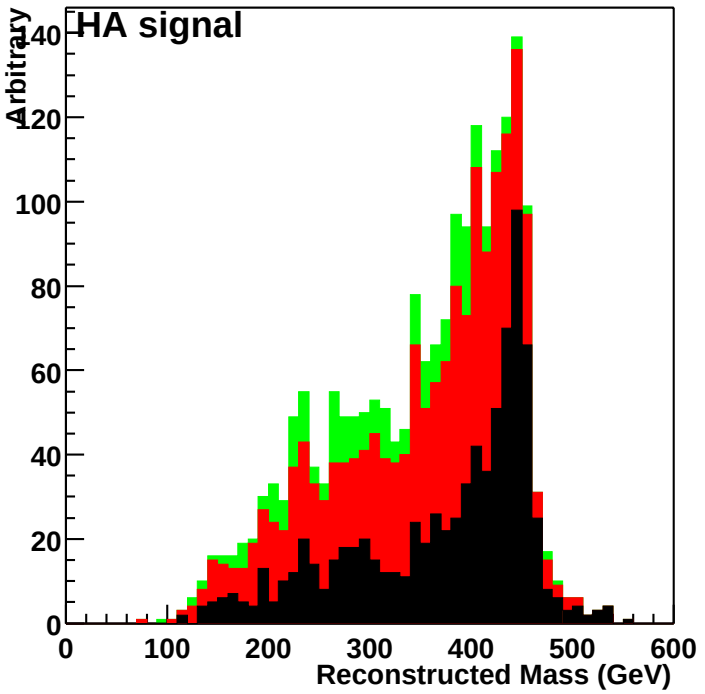
- Simulations of measurements of *H/A* masses and branching ratios (remember, no handy *Z* recoil for the Br's!!)

John Butler, John Hobbs: *HA* pair production, 1 TeV each of mass of 400–475 GeV (i.e., ~degenerate), large tanβ 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)?

SM

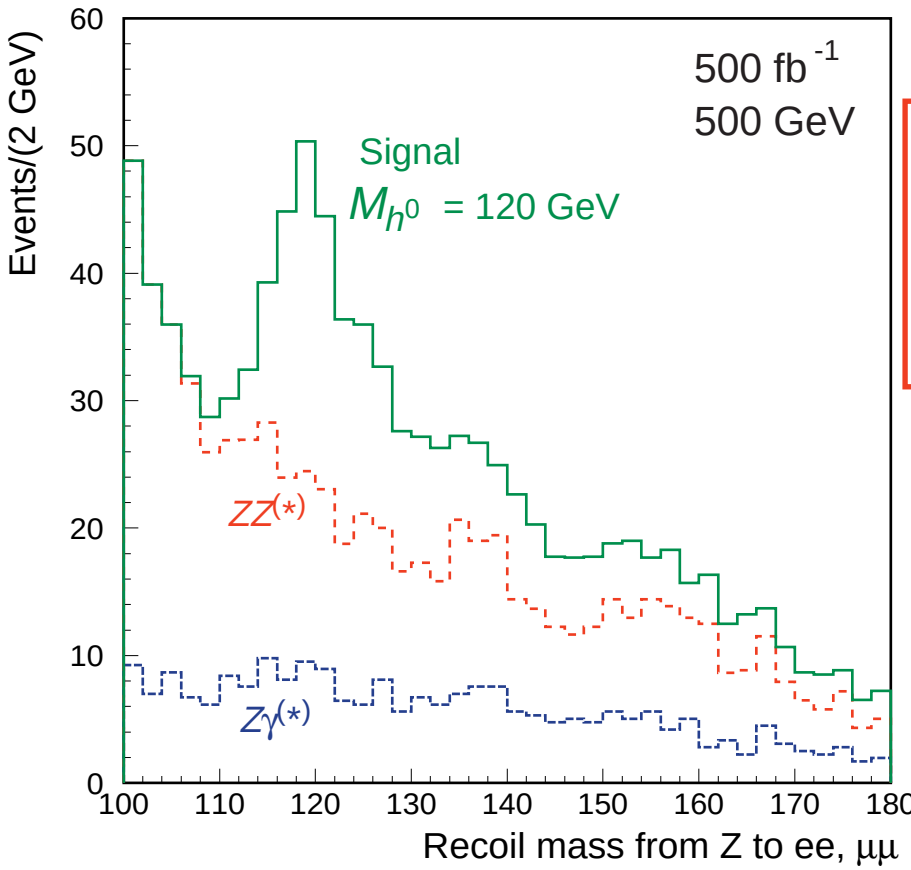
- Full simulations with realistic backgrounds of *Z* recoiling against "nothing"

RvK

- *hZ* → *all*
  - → *invisible*

Explicitly search for Z recoiling against "nothing" (previously, e.g., [1 -ΣBr's])

- Test case, e.g., Wells et al., hep-ph/002178,
  δ = 4 extra dimensions,
  Br(*h* → invis) = 38%, Γ_{inv} ~ 2 MeV



- Measure

$$\frac{\delta Br(h \to \text{invis})}{Br(h \to \text{invis})} \sim 11\%$$

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

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

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

RvK

SM

- Repeat for "stealthy" large invisible width models
- Combine with (following correlations) separate measure of
  - $\Gamma^{\text{indirect}}_{\text{tot}} - \Gamma^{\text{meas}}_{\text{visible}}$

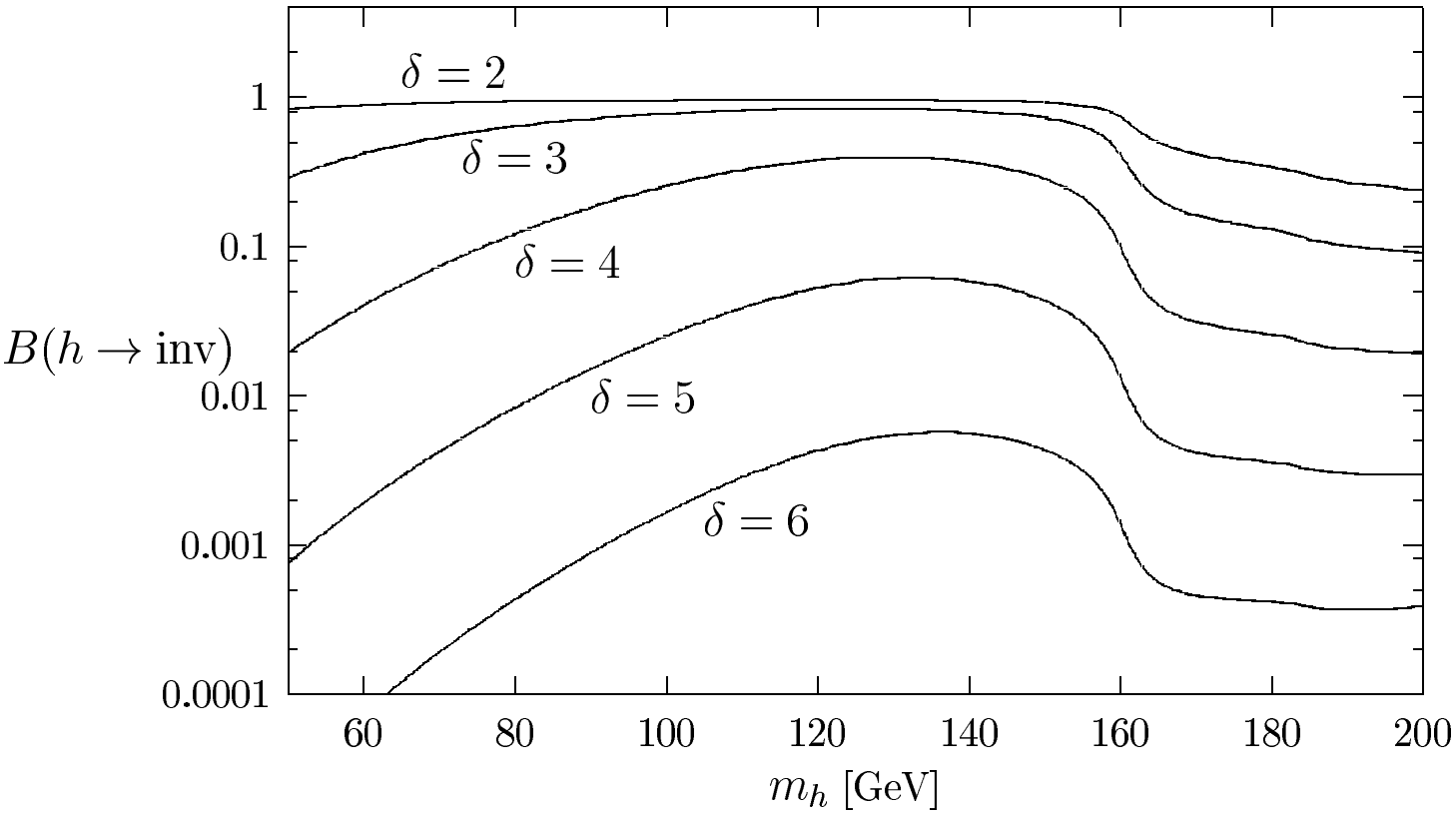
  and/or
  - $\Gamma^{\text{indirect}}_{\text{tot}} - \Gamma^{\text{SM}}_{\text{tot}}$

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

SM

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

$\Rightarrow$ Graf interested, Mrenna, RvK were getting four-vectors generated


$\delta = 2$
$\delta = 3$
$\delta = 4$
$\delta = 5$
$\delta = 6$
1
0.1
0.01
0.001
0.0001
$B(h \to \text{inv})$
60
80
100
120
140
160
180
200
m_h [GeV]

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