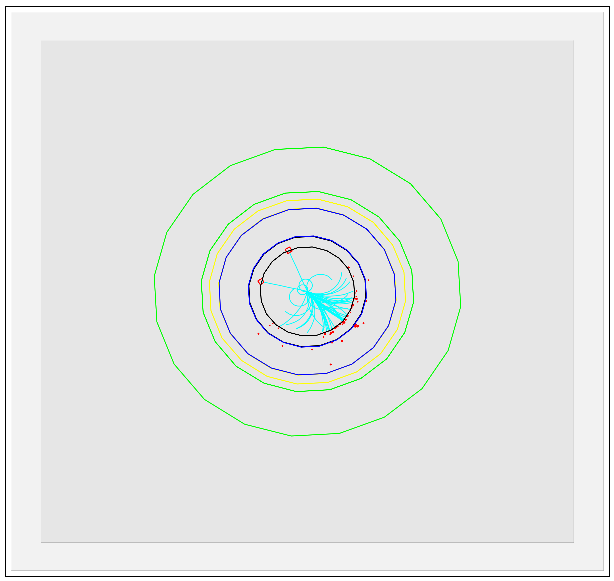
SM HIGGS BRANCHING RATIO MEASUREMENTS AT A LINEAR COLLIDER



$(e^+e^- \rightarrow ZH \rightarrow b\bar{b}, \sqrt{s} = 500GeV)$

Snowmass 2001

Session P1 Working Group 2

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PARAMETERS

We assume for this study:

- $\sqrt{s}$ =500 GeV Linear Collider
- Luminosity $\int dtL = 500$ fb^{-1}
- 250 fb^{-1} running with 80% right polarized electrons
- 250 fb^{-1} running with 80% left polarized electrons
- 115, 120, 140 and 160 GeV Standard Model Higgs boson masses

DATA SIMULATION

Pandora v2.1 Monte Carlo (M. Peskin) includes:

- Polarized beams
- Beamstrahlung
- Initial state radiation

Interface to Tauola and Pythia (M. Iwasaki):

- τ decay
- Parton shower
- Hadronization

DETECTOR SIMULATION

NLD Large Detector Configuration:

- Vertex Detector: 5 μm res., $r_{in} = 1.2$cm
- Central Tracker: 25-200 cm
- Electromagnetic Calorimeter: 200-250 cm
- Hadronic Calorimeter: 250-374 cm
- 3 T Magnetic Coil
- Muon Detector: 450-650 cm

NLD detector simulation implemented on Root C++ libraries (M. Iwasaki)

EVENT SELECTION

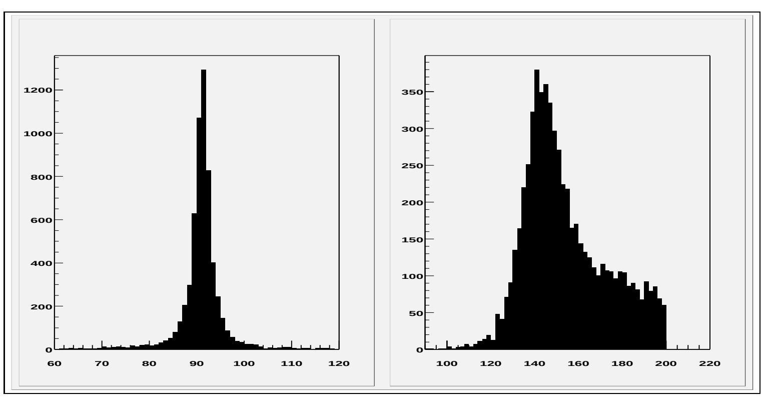
We select for $e^+e^- \to HZ \to l^+l^-$ $(l = e, \mu)$

- Reconstruct all lepton pair masses in an event
- Select pair with mass closest to m_Z
- Calculate recoil mass
- Apply cuts on masses:

$$|m_Z - m_{l^+l^-}| < 10 \text{ GeV}$$

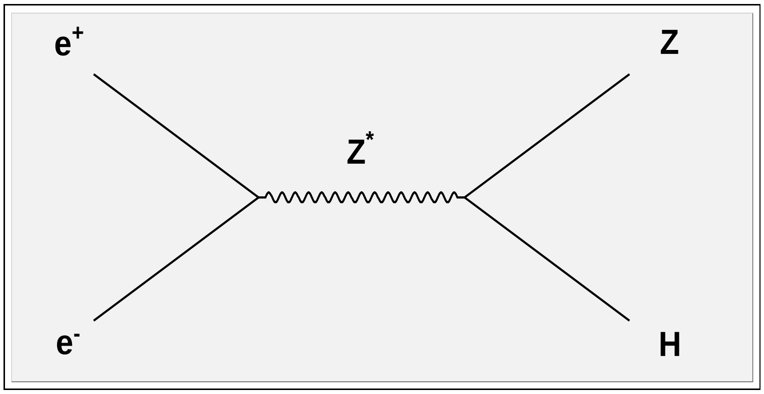
$$m_H - 10 \text{ GeV} < m_{recoil} < m_H + 20 \text{ GeV}$$

- Include hadronic Z decays by scaling signal up by a factor of 4 (D. Strom, LEP II experience)



Signal event reconstructed Z and recoil mass distributions.

SIGNAL



Cross sections for $e^+e^- \to ZH$ with $Z \to l^+l^-$ ($l = e, \mu$) are in fb with 80% left polarized electrons.

Mode	115	120	140	160
$H \to b\bar{b}$	5.9	3.5	1.5	0.24
$H \to WW^\star$	0.68	0.74	2.4	5.8
$H \to c\bar{c}$	0.24	0.14	0.064	0.0099
$H \to \tau^+\tau^-$	0.62	0.38	0.17	0.027
$H \to gg$	0.41	0.27	0.16	0.033
$H \to ZZ^\star$	0.050	0.08	0.34	0.19

BACKGROUND

Approximately 29%/31%/36%/39% (115/120/140/160) of signal events pass the mass selection cuts and are then subjected to decay mode cuts.

A small fraction of backgrounds also pass the cuts. Primary backgrounds, with cross sections for left,right polarizations are:

- $e^+e^- \rightarrow W^+W^-$ ($\sigma \approx 14300, 1700$ fb)
- $e^+e^- \rightarrow q\bar{q}$ ($\sigma \approx 16000, 11000$ fb)
- $e^+e^- \rightarrow ZZ$ ($\sigma \approx 560, 340$ fb)
- $e^+e^- \rightarrow t\bar{t}$ ($\sigma \approx 740, 400$ fb)

The most pernicious of these is $e^+e^- \rightarrow ZZ$, especially for the lighter Higgs cases.

Therefore the Higgs mass is reconstructed using tracks and unassociated clusters and cuts are made at the Higgs decay mode level.

CUT-BASED DECAY MODE TAGS

For $H \to \tau^+\tau^-$:

- reconstructed Higgs mass inconsistent with Z mass
- low track multiplicity ($\leq$6)

For $H \to WW^\star \to$ 2 jets :

- high momentum lepton in event ($>$10 GeV)
- high momentum lepton is isolated ($E_{cone} <$ 10 GeV)

For $H \to WW^\star \to$ 4 jets :

- force event to 4 jets
- best jet pair must satisfy $|m_W - m_{jj}| <$ 10 GeV
- jet algorithm y_{cut} value y_{32} $>$0.04
- thrust in Higgs frame $<$ 0.88

CUT-BASED TAGS (CONT.)

For $H \to b\bar{b}$:

- force event to 2 jets
- calculate m_{p_t} with ZVTop (D. Jackson, impl. T. Abe)
- require $m_{p_t} > 2$ GeV for at least one jet

For $H \to c\bar{c}$:

- force event to 2 jets
- tag jet charm if m_{p_t} <2 GeV, N_{sig} >10, p_{jet}/p_{kin} >0.45
- require no jet tagged as beauty, at least one jet tagged as charm, and neither jet contains tertiary vertices

For $H \to gg$:

- require no tags from preceding modes
- neither jet has secondary vertices
- no high momentum leptons (<1 GeV)

NEURAL NETWORK STRUCTURE AND TRAINING

In order to optimize these results, the parameters and their cut values were used as inputs to a neural network.

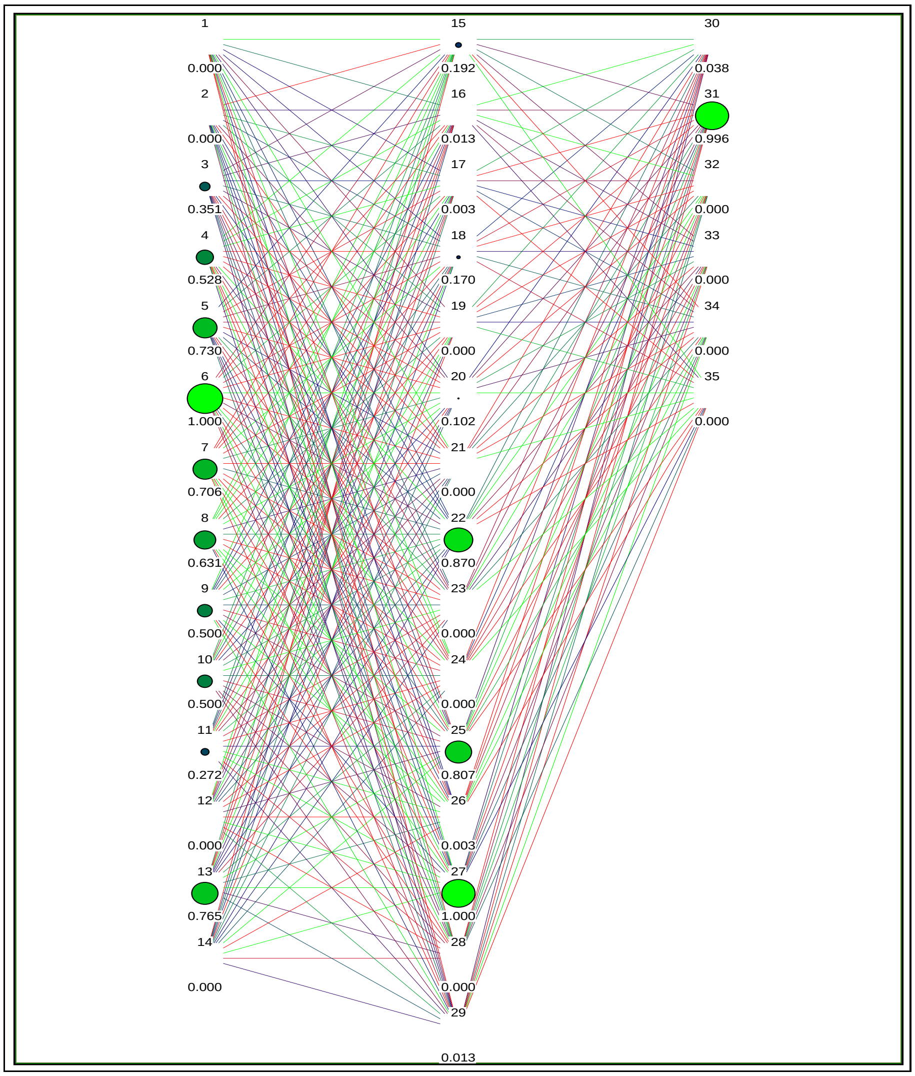
• The neural network has 14 input units (one for each parameter), 15 hidden units, and 6 outputs (one for each decay mode).

• It is fully connected and uses standard back propagation as its learning algorithm.

• To speed and perhaps improve the training, the parameters were mapped to the interval [0,1] by the map $p \mapsto 1 - \exp[-(p/p_{cut})^2 \ln 2]$.

• For each set parameters in an event $H \to X$, training asked the network to ouput a 1 for the $H \to X$ output unit and a 0 for the other output units.

NEURAL NETWORK TOPOLOGY



State of the neural network for an event $H \to c\bar{c}$.

NEURAL NETWORK OPTIMIZATION

• The space C of all possible neural network output cut values is the unit cube in R^6.

• Each point in C maps to signal S and background B for a given mode $H \to X$ and thence to fractional branching ratio $\delta_{BR}/BR = \sqrt{S+B}/S$, purity $p = S/(S+B)$, and efficiency $\epsilon = S/(\sigma \int dtL)$.

• Minimizing $\sqrt{S+B}/S$ for a particular mode mode $H \to X$ is equivalent to finding the optimal set of neural network output cut values for $H \to X$.

• For a given mode $H \to X$, the boundary of the image of C under the (p, ϵ) map is the optimal purity/efficiency curve.

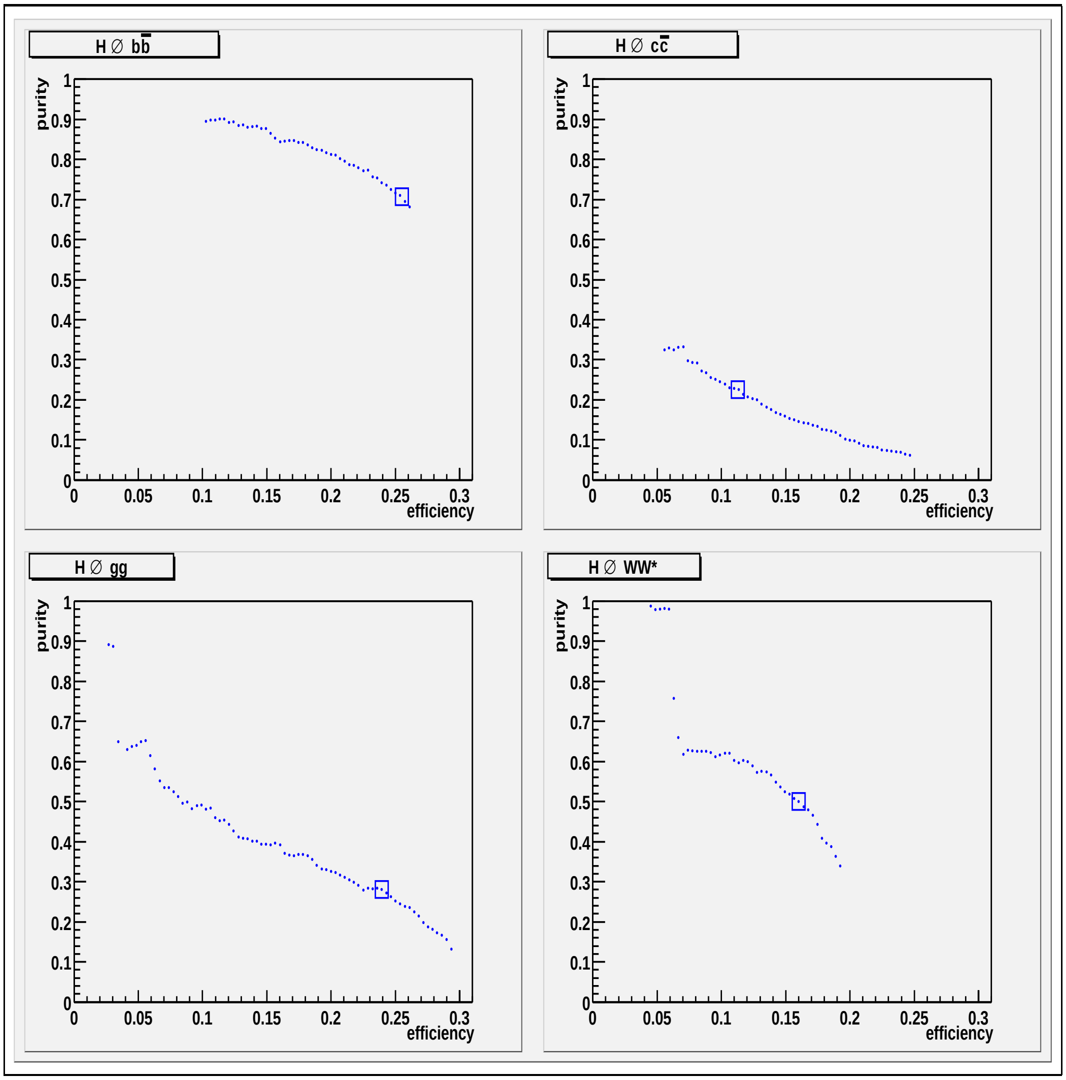
• We sampled S and B for each mode in the cube on a lattice with 10^6 points.

MISTAGS AND SIGNAL FOR 120 GEV CASE

The analyzed 500 fb^{-1} data sample is listed vertically. The number of signal event tags is listed horizontally.

Sample	$WW^\star$	$b\bar{b}$	$c\bar{c}$	$\tau^+\tau^-$	gg
$H \rightarrow WW^\star$	214	12.7	3.3	0.5	98
$H \rightarrow b\bar{b}$	27.9	1599	59.7	0	13.9
$H \rightarrow c\bar{c}$	7.0	13.6	29.3	0.02	12.2
$H \rightarrow \tau^+\tau^-$	0.3	0	0.3	189.6	0
$H \rightarrow gg$	52.7	9.8	3.0	0	112.8
$H \rightarrow ZZ^\star$	1.0	0.6	0.1	0	0
$e^+e^- \rightarrow ZZ$	123.2	524.7	38.6	24.8	161.1
$e^+e^- \rightarrow WW$	0	0	0	0	0
$e^+e^- \rightarrow q\bar{q}$	0	0	0	0	0
$e^+e^- \rightarrow t\bar{t}$	0	0	0	0	0

PURITY/EFFICIENCY PLOTS



Purity vs. efficiency for the case $m_H = 120$ GeV. The maximum possible efficiency is 0.31 due to mass cuts.

FRACTIONAL BRANCHING RATIO RESULTS

Listed below are the fractional branching ratio errors δ_{BR}/BR.

Mode	115	120	140	160	180	200
$\bullet H \to WW^\star$	0.16	0.10	0.03	0.02	0.03	0.04
$\bullet H \to b\overline{b}$	0.027	0.029	0.038	0.13	0.59	-
$\bullet H \to \tau^+\tau^-$	0.07	0.08	0.10	0.36	-	-
$\bullet H \to c\overline{c}$	0.31	0.39	0.44	-	-	-
$\bullet H \to gg$	0.16	0.18	0.23	-	-	-
$\bullet H \to c\overline{c} + gg$	0.15	0.16	0.20	-	-	-

OTHER HIGGS BRANCHING RATIO STUDIES

Study	$\sqrt{s}$/GeV	$\int dtL/fb^{-1}$	Mode	$P(e^-)$
• H/B/B	500	50	ZH	0
• N/K	300	50	ZH	-0.95
• B	350	500	$ZH + H\nu\bar{\nu}$	0
• B/R	350	500	ZH	0
• B/P/I	500	500	ZH	±0.8

H/B/B=M.D. Hildreth, T.L. Barklow and D.L. Burke, Phys. Rev. Lett., 49, 3441 1994

N/K=I. Nakamura and K. Kawagoe, in Proceedings of the Workshop on Physics and Experiments with Linear Colliders, vol. II, World Scientific, Singapore 1996.

B=M. Battaglia, in Proceedings of the International Workshop on Linear Colliders LCWS99 1999.

B/R=G. Borisov and F. Richard, in Proceedings of the International Workshop on Linear Colliders LCWS99 1999.

B/P/I=J. Brau, C. Potter and M. Iwasaki, in Proceedings of the Linear Collider Workshop LCWS2000 2000.

COMPARISON TO OTHER HIGGS BR STUDIES

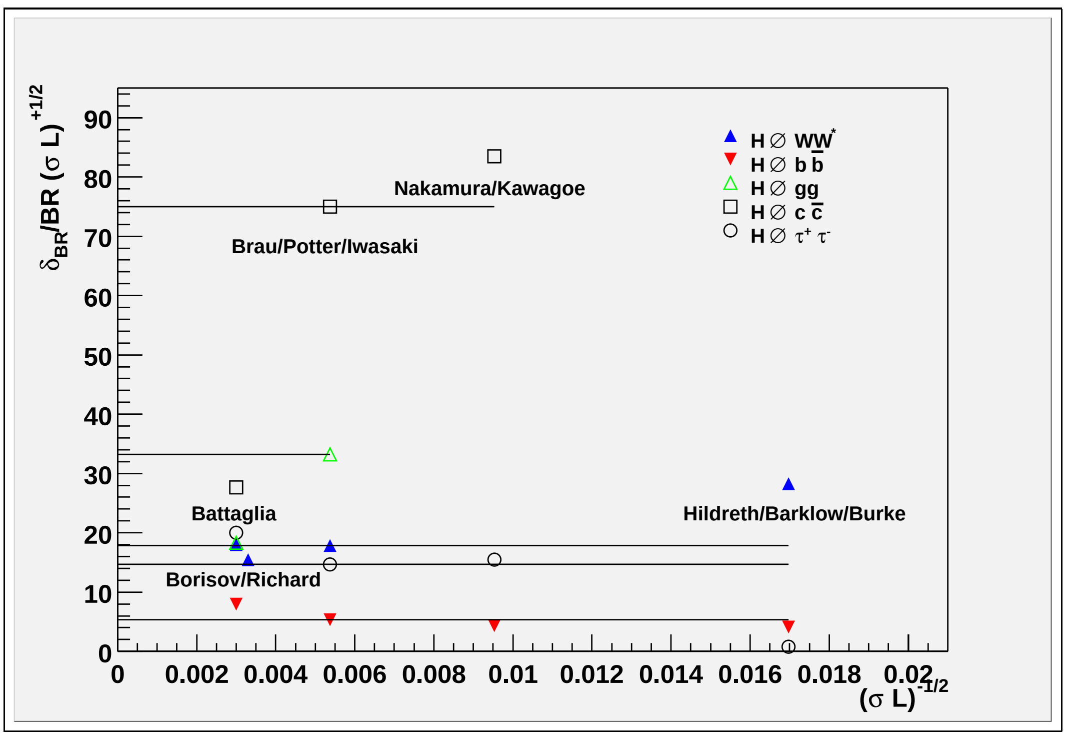
The fractional branching ratio errors δ_{BR}/BR from each study are shown in the table below. Here $m_H = 120$ GeV.

Mode	H/B/B	N/K	B	B/R	B/P/I
• $H \to WW^\star$	0.48	-	0.054	0.051	0.10
• $H \to b\bar{b}$	0.07	0.041	0.024	-	0.029
• $H \to c\bar{c}$	-	0.80	0.083	-	0.39
• $H \to gg$	-	-	0.055	-	0.18
• $H \to \tau^+\tau^-$	0.14	0.15	0.06	-	0.08
• $H \to c\bar{c} + gg$	0.39	0.17	-	-	0.16

Given the different parameters assumed in each study, such a direct comparison may be misleading.

CONSISTENCY CHECK

The fractional branching ratio error δ_{BR}/BR goes like $(\sigma \int dtL)^{-1/2}$. The former divided by the latter is plotted against the latter for the case $m_H = 120$ GeV.



Broadly, the results are consistent though there is some discrepancy in the $H \to c\bar{c}$ and $H \to gg$ results.

IMPROVING THE STUDY

By the end of Snowmass 2001, this study should be extended and improved in the following ways:

- Analyze higher Higgs mass cases.

- Confer with other authors to resolve differences in results ($H \to c\bar{c}$ and $H \to gg$).

- Consider how to apply this analysis to the light MSSM h^0 in the decoupling limit.