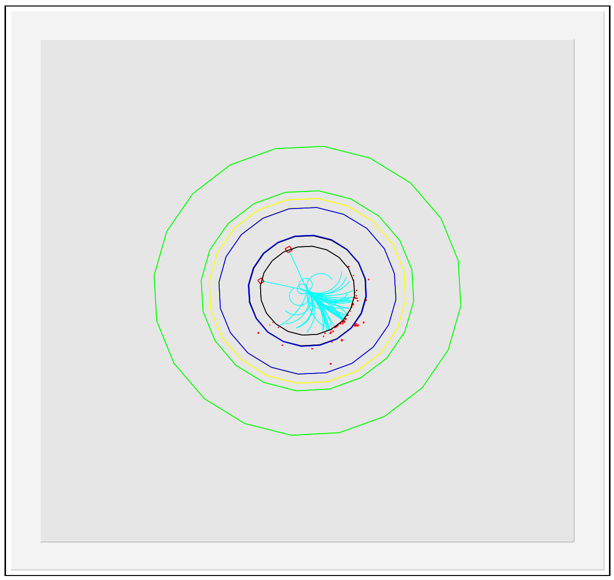
HIGGS BRANCHING RATIO MEASUREMENTS AT A FUTURE LINEAR COLLIDER *



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

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*This work was presented at the LCWS 2000 Workshop and will be published in the workshop proceedings.

MOTIVATION

- The Higgs boson will probably be discovered at the LHC or Tevatron, which are unsuitably hostile environments for precision measurements.

- This provides a compelling argument for 500 GeV-1 TeV Linear Collider.

- The Linear Collider would allow a test of competing models of electroweak symmetry breaking.

- In this study we simulate the Linear Collider and place expected confidence limits on the Standard Model Higgs branching ratios.

- In order to optimize the vertex detector design, five different configurations based on inner radius and resolution are simulated.

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
- 120 GeV and 140 GeV 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

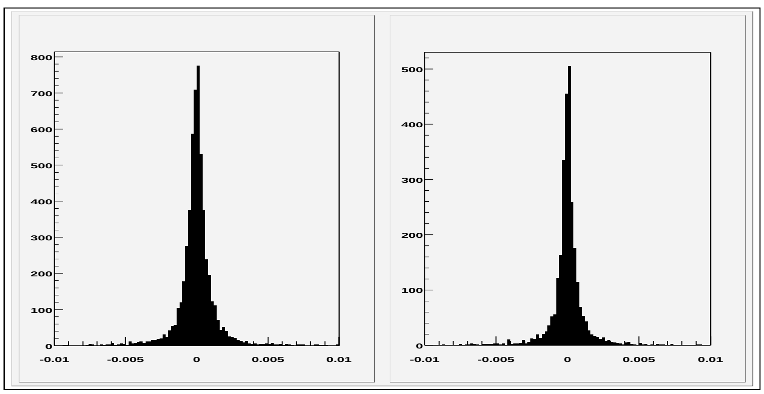
NLD Large Detector Configuration:

- Vertex Detector: we vary the hit resolution (3,4,5 μm) and inner radius (1.2,2.4 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)

VERTEX DETECTOR CONFIGURATIONS

- C1: r_{in} =1.2cm, 5μm res. yields
$$\sigma_{IP} = (1.8, 1.8, 6.4)\mu\text{m}$$
- C2: r_{in} =2.4cm, 5μm res. yields
$$\sigma_{IP} = (2.9, 2.9, 11.1)\mu\text{m}$$
- C3: r_{in} =1.2cm, 3μm res. yields
$$\sigma_{IP} = (1.5, 1.5, 5.6)\mu\text{m}$$
- C4: r_{in} =2.4cm, 3μm res. yields
$$\sigma_{IP} = (2.6, 2.6, 10.3)\mu\text{m}$$
- C5: r_{in} =1.2cm, 4μm res. yields
$$\sigma_{IP} = (1.7, 1.7, 6.3)\mu\text{m}$$



IP Δxy and Δz in cm for C1.

EVENT SELECTION

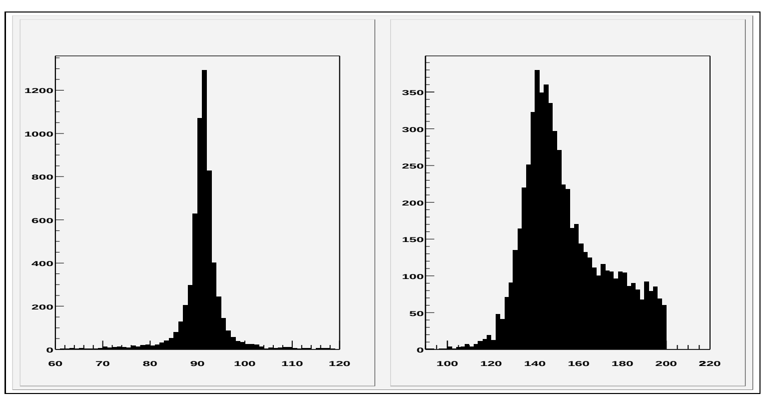
We select for $e^+e^- \to HZ \to l^+l^-$ $(l = e, \mu)$

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

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

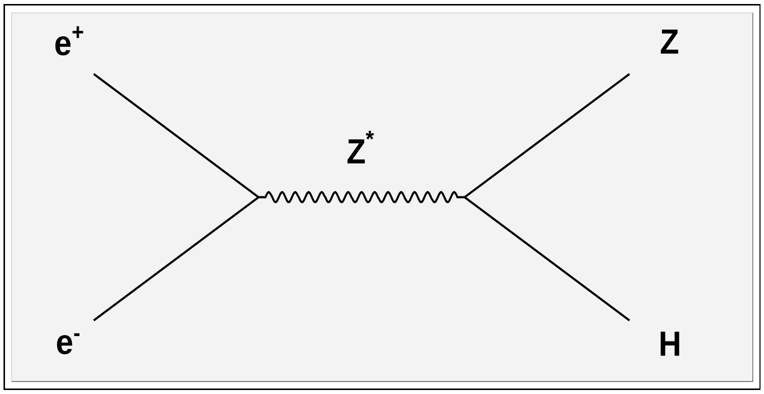
$$m_H - 10 \text{ GeV} < m_{recoil} < m_H + 20 \text{ GeV}$$

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



Reconstructed Z and recoil mass distributions.

SIGNAL



We look for $e^+e^- \rightarrow HZ \rightarrow l^+l^-$ with the Higgs decays specified below. Cross sections are for 120/140 GeV Higgs masses with 80% left polarized electrons.

- $H \rightarrow b\bar{b}$ ($\sigma \approx$ 3.5/1.5 fb)
- $H \rightarrow WW^\star$ ($\sigma \approx$ 0.74/2.4 fb)
- $H \rightarrow c\bar{c}$ ($\sigma \approx$ 0.14/0.064 fb)
- $H \rightarrow \tau^+\tau^-$ ($\sigma \approx$ 0.38/0.17 fb)
- $H \rightarrow gg$ ($\sigma \approx$ 0.27/0.16 fb)

For $\int dtL$=250 fb^{-1}, these cross sections translate to several hundreds of events for W and b events, and several tens for the c, τ, and g events.

BACKGROUND

Approximately 31% (120 GeV) and 36% (140 GeV) 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:

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

The most pernicious of these is $e^+e^- \to ZZ$, especially for the 120 GeV Higgs case.

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 $H \rightarrow b\bar{b}$:

- 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 $H \rightarrow c\bar{c}$:

- 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 $H \rightarrow gg$:

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

NEURAL NETWORK TAGGING

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

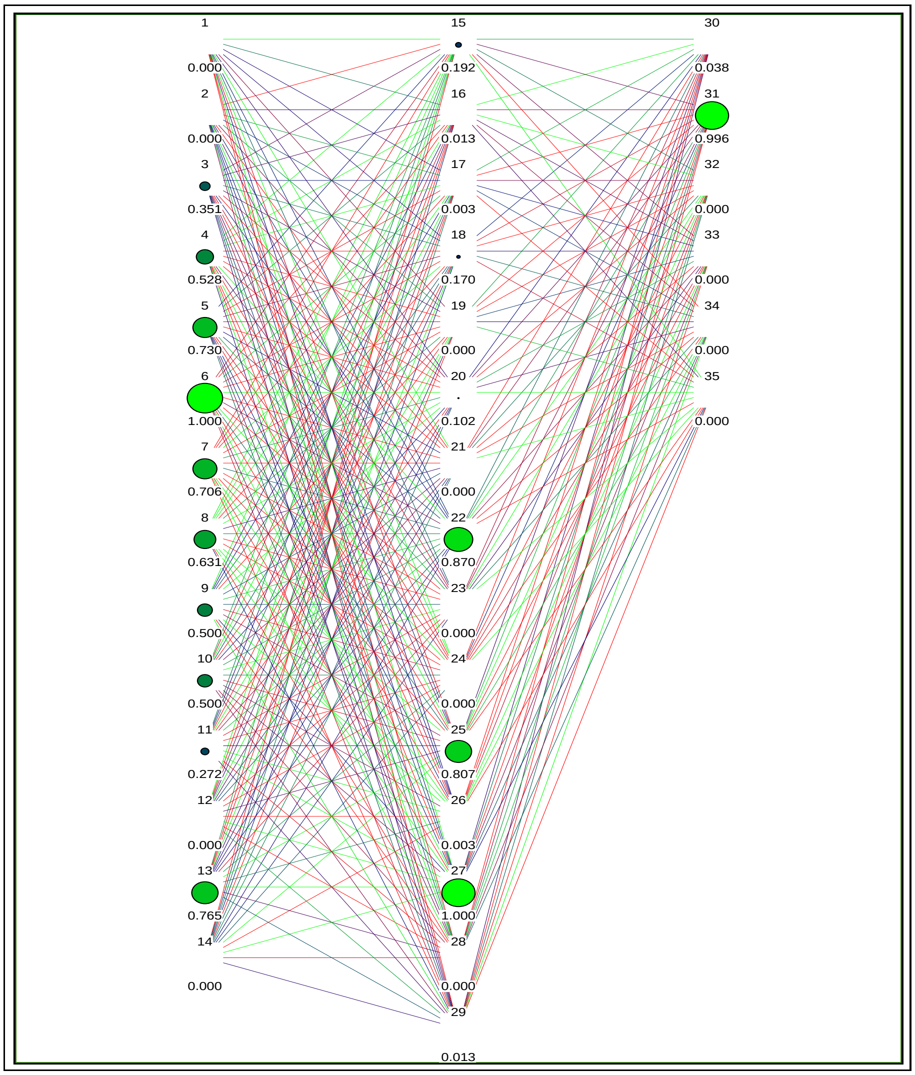
The neural network has 14 input units (one for each parameter), 15 hidden units, and 6 outputs (one for each decay mode). It is fully connected and uses standard back propagation as its learning algorithm.

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.

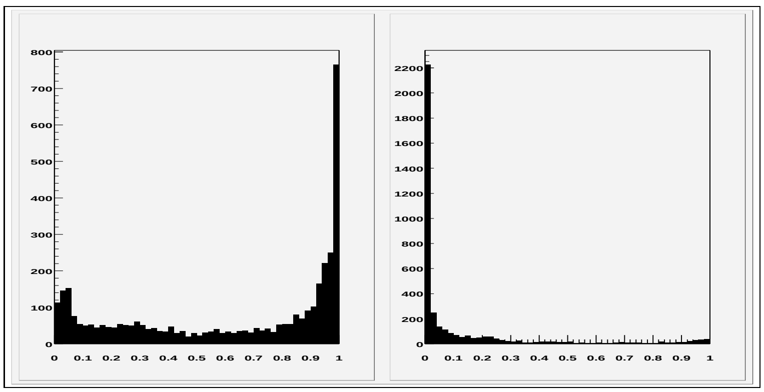
An event is tagged $H \to X$ if the neural network $H \to X$ output is larger than 0.5 and no other output is larger than 0.5.

NEURAL NETWORK TOPOLOGY

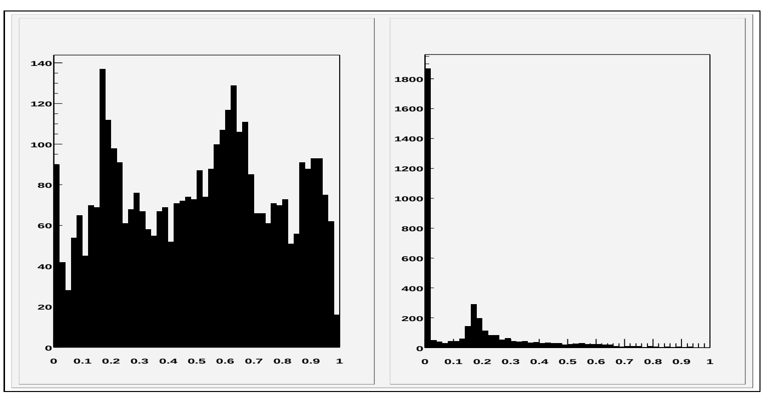


State of the neural network for an event $H \to c\bar{c}$.

NEURAL NETWORK OUTPUT DISTRIBUTIONS



NN $H \to c\bar{c}$ outputs for 3800 $H \to c\bar{c}$ events (left) and 3800 $H \to b\bar{b}$ events (right).



NN $H \to gg$ outputs for 3800 $H \to gg$ events (left) and 3800 $H \to WW^{\star}$ events (right).

C1-C5 BRANCHING RATIO RESULTS

For the $m_H = 140$ GeV case, the branching ratios (in %) and expected errors errors (in $\pm$%) are:

Mode	BR	C1	C2	C3	C4	C5
• $H \to WW^\star$	51	1.9	1.9	1.9	1.9	1.9
• $H \to b\bar{b}$	34	1.3	1.3	1.3	1.3	1.3
• $H \to c\bar{c}$	1.4	0.67	0.70	0.66	0.69	0.67
• $H \to gg$	3.5	2.4	2.4	2.4	2.4	2.4
• $H \to \tau^+\tau^-$	3.6	0.6	0.6	0.6	0.6	0.6

We conclude that modest improvement in measuring the $H \to c\bar{c}$ branching ratio is seen by moving the vertex detector closer to the IP and improving the resolution.

In general, however, the branching ratio error measurements were only weakly dependent on vertex detector configuration.

C1 BRANCHING RATIO RESULTS

Mode	m_H =120 GeV	m_H = 140 GeV
• $H \to b\bar{b}$	$69 \pm 2.0\%$	$34 \pm 1.4\%$
• $H \to WW^\star$	$14 \pm 1.5\%$	$51 \pm 2.0\%$
• $H \to c\bar{c}$	$2.8 \pm 1.3\%$	$1.4 \pm 0.72\%$
• $H \to gg$	$5.2 \pm 1.9\%$	$3.5 \pm 2.6\%$
• $H \to \tau^+\tau^-$	$7.1 \pm 1.1\%$	$3.6 \pm 0.6\%$

We conclude that for all configurations and Higgs decay modes, a 500 GeV Linear Collider will measure branching ratios with excellent sensitivity.

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

COMPARISON TO OTHER HIGGS BR STUDIES

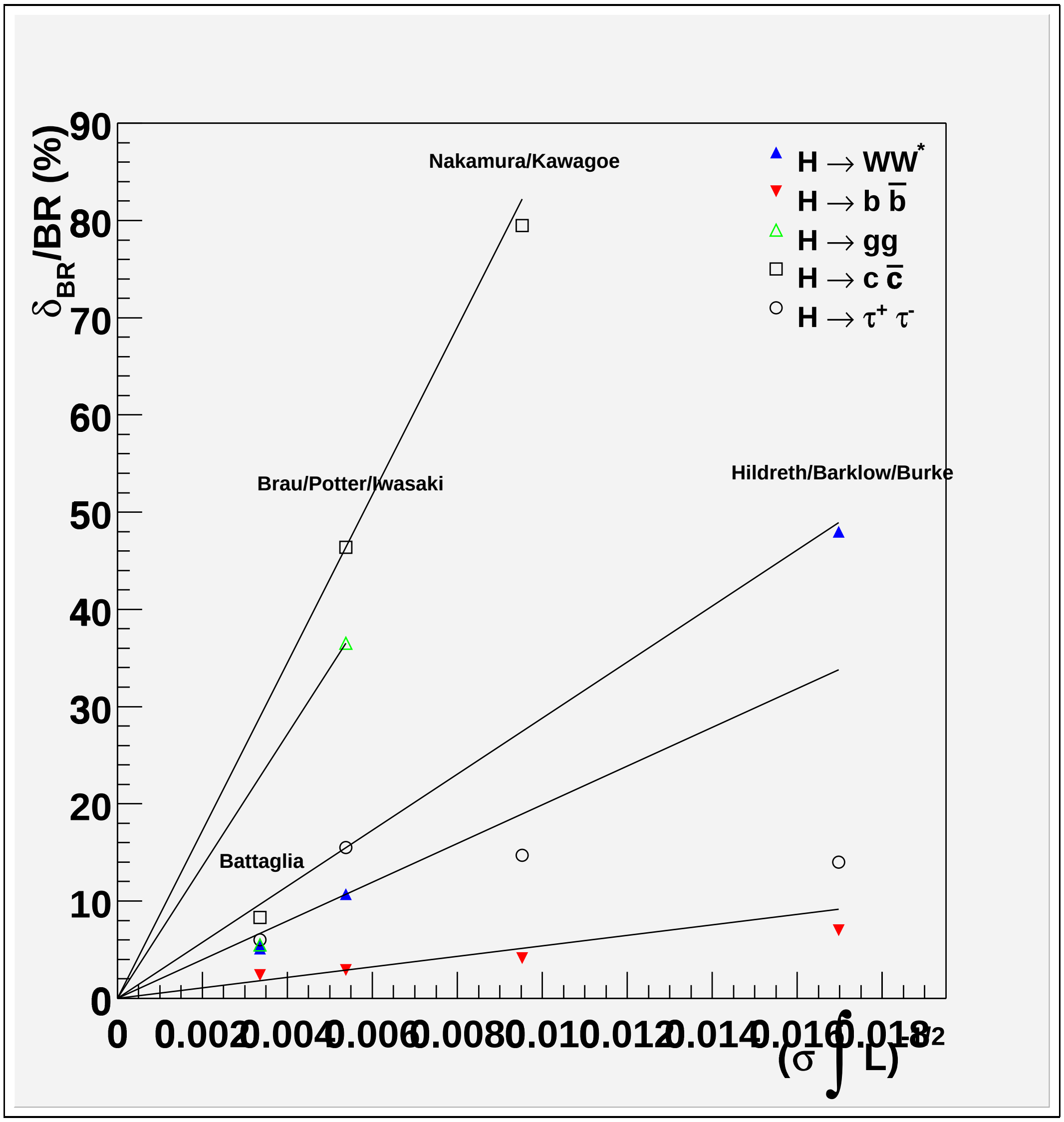
The fractional branching ratio errors δ_{BR}/BR from each study are shown in the table below.

Mode	H/B/B	N/K	B	B/P/I
• $H \to WW^{\star}$	48	-	5.4	10.7
• $H \to b\bar{b}$	7	4.1	2.4	2.9
• $H \to c\bar{c}$	-	79.5	8.3	46.4
• $H \to gg$	-	-	5.5	36.5
• $H \to \tau^+\tau^-$	14	14.7	6.0	15.5
• $H \to c\bar{c}, gg$	39	17.4	-	-

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

CONSISTENCY CHECK

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



Broadly, the results are consistent though the Battaglia study results seem conspicuously good. Our $H \to \tau^+\tau^-$ result seems conspicuously bad.

IMPROVING THE STUDY

This study can be improved in numerous ways.

For example, we can:

- include hadronic Z decays
- reduce backgrounds
- add new decay separation parameters
- utilize neural networks better

The study can be extended (with effort) to include:

- other Higgs decay modes ($H \to ZZ^{\star}, \gamma\gamma$)
- Higgs production by WW fusion ($e^{+}e^{-} \to H\nu\bar{\nu}$)
- MSSM Higgs sector