Higgs Coupling Measurements at a 1 TeV LC

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Higgs Branching Fractions from TESLA TDR

Channel	$M_H = 120\,\mathrm{GeV}$	$M_H = 140\,\mathrm{GeV}$	$M_H = 160\,\mathrm{GeV}$
$H^0/h^0 \to b\bar{b}$	$\pm\ 0.024$	$\pm\ 0.026$	$\pm\ 0.065$
$H^0/h^0 \to c\bar{c}$	$\pm\ 0.083$	$\pm\ 0.190$	
$H^0/h^0 \to gg$	$\pm\ 0.055$	$\pm\ 0.140$	
$H^0/h^0 \to \tau^+\tau^-$	$\pm\ 0.050$	$\pm\ 0.080$	

Table 2.2.5: *Relative accuracy in the determination of Higgs boson branching ratios for $500\,fb^{-1}$ at $\sqrt{s} = 350\,GeV$.*

Channel	$M_H = 120\,\mathrm{GeV}$	$140\,\mathrm{GeV}$	$160\,\mathrm{GeV}$
$\sigma(e^+e^- \to H^0 Z)$	$\pm\ 0.025$	$\pm\ 0.027$	$\pm\ 0.030$
$H^0 \to WW^*$	$\pm\ 0.051$	$\pm\ 0.025$	$\pm\ 0.021$
$H^0 \to ZZ^*$			$\pm\ 0.169$

Table 2.2.3: *Relative accuracy in the determination of the SM Higgs boson production cross–sections and decay rates into gauge bosons for $500\,fb^{-1}$ at $\sqrt{s} = 350\,GeV$ and $500\,GeV$.*

Take cue from Battaglia & DeRoeck results for $B_{h\to\mu\mu}$ at CLIC and investigate branching fraction measurements in WW fusion at a 1 TeV LC.

$e^-_{pol} = -80\% \quad L = 500\ (1000)\ fb^{-1} \quad for \quad \sqrt{s} = 350\ (1000)\ GeV:$

$\sqrt{s}$ (GeV)	e^+_{pol} (%)	Higgs Mass (GeV) 120	140	160	200
350	0	110280	89150	69975	37385
350	+50	159115	128520	100800	53775
1000	0	386550	350690	317530	259190
1000	+50	569750	516830	467900	382070

Results presented for $h \to b\bar{b}, W^+W^-, gg, \gamma\gamma, ZZ$

No results for $h \to c\bar{c}, \tau^+\tau^-$ since detailed charm-tagging beyond scope and Higgs mass resolution for $h \to \tau^+\tau^-$ severely degraded by neutrinos.

Monte Carlo Simulation

- WHIZARD Monte Carlo is used to generate all 0,2,4,6-fermion and top quark dominated 8-fermion processes. The CIRCE parameterization of the NLC design at Ecm=1TeV is used to simulated beamstrahlung.
- Higgs production and decay to b-quarks and taus automatically included in WHIZARD 4-fermion simulation. For other Higgs decay modes WHIZARD simulates $e^+e^- \to f\,\bar{f}\,h$ and PYTHIA then peforms the decays.
- PYTHIA is used for final state QED & QCD parton showering, fragmentation, particle decay.
- 100% electron and positron polarization is assumed in all event generation. Data sets are combined to simulate -80% electron and 50% positron polarization.
- SIMDET V4.0 simulation of the TESLA detector is used for detector simulation.

$h \to b\bar{b}$

Require:

$$|\cos\theta_{thrust}| < 0.95$$

$$20 < PT_{vis} < 500 \text{ GeV}$$

$$100 < E_{vis} < 400 \text{ GeV}$$

$$N_{isolated\ leptons} = 0$$

$$2 \le N_{jets} \le 3$$

$$7 \le \mathrm{N}_{chg} \le 19$$

$7 \le N_{imp} \le 19$ where N_{imp} is number of large impact parameter charged tracks

$$M_h - 10 \text{ GeV} < M_{vis} < M_h + 6 \text{ GeV}$$

$$e^+e^- \rightarrow \nu_e \overline{\nu}_e h$$
$$\quad |\!\rightarrow b\bar{b}$$

$M_h = 120\ GeV$

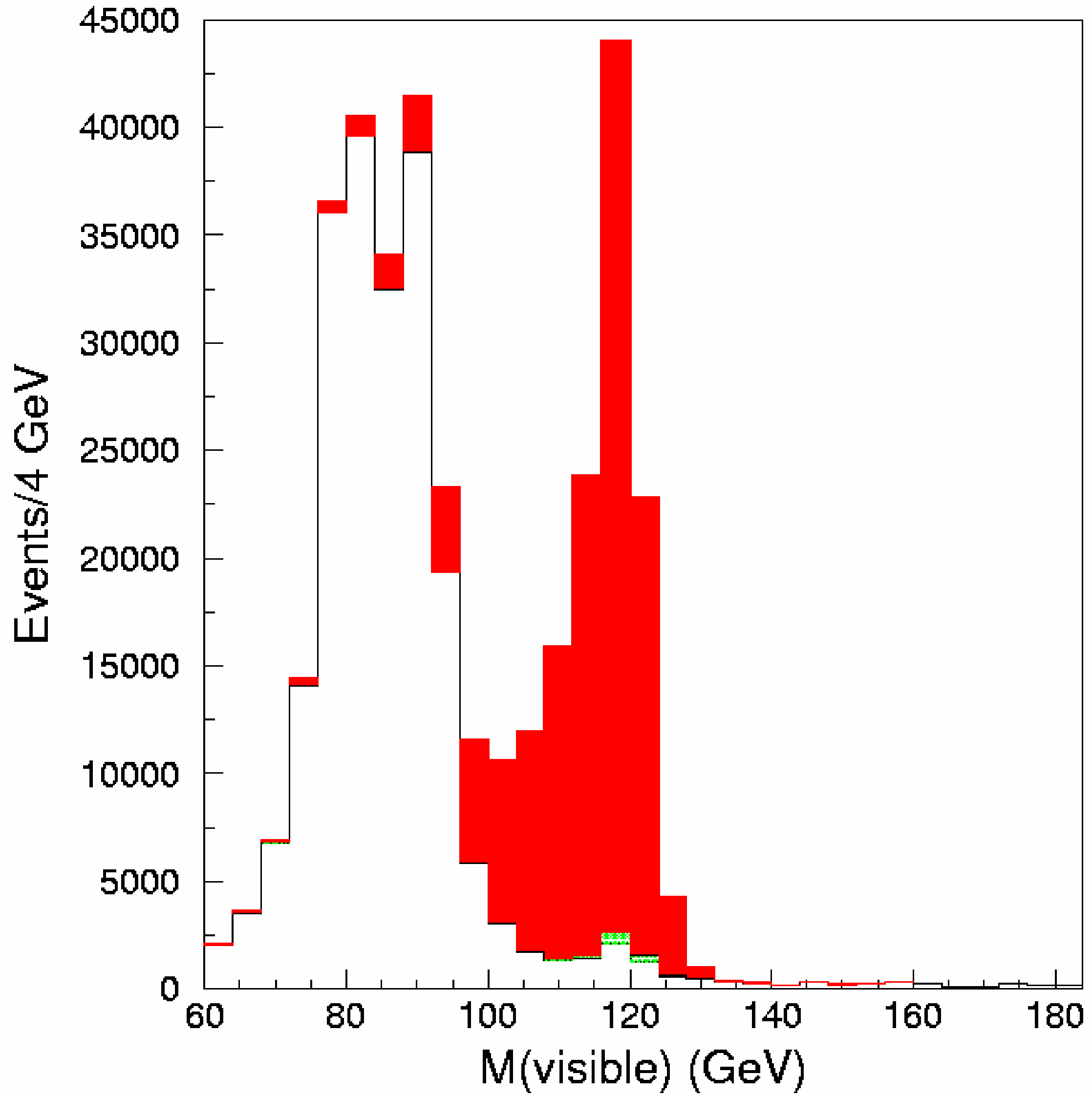
$\sqrt{s} = 1\ TeV$

$L = 1\ ab^{-1}$

All 2,4,6-fermion and top-resonance 8-fermion backgrounds included

Background passing cuts (white histogram) is mostly

$$e^+e^- \rightarrow e\nu W$$
$$eeZ$$
$$\nu\nu Z$$



Red histogram: $h \rightarrow b\bar{b}$

Green histogram: $h \rightarrow c\bar{c}$ (70%) gg (20%) WW^* (5%) ZZ^* (5%)

$$e^+e^- \rightarrow \nu_e \bar{\nu}_e h$$
$$\qquad\qquad |\!\rightarrow b\bar{b}$$

$M_h = 200\ GeV$

$\sqrt{s} = 1\ TeV$

$L = 1\ ab^{-1}$

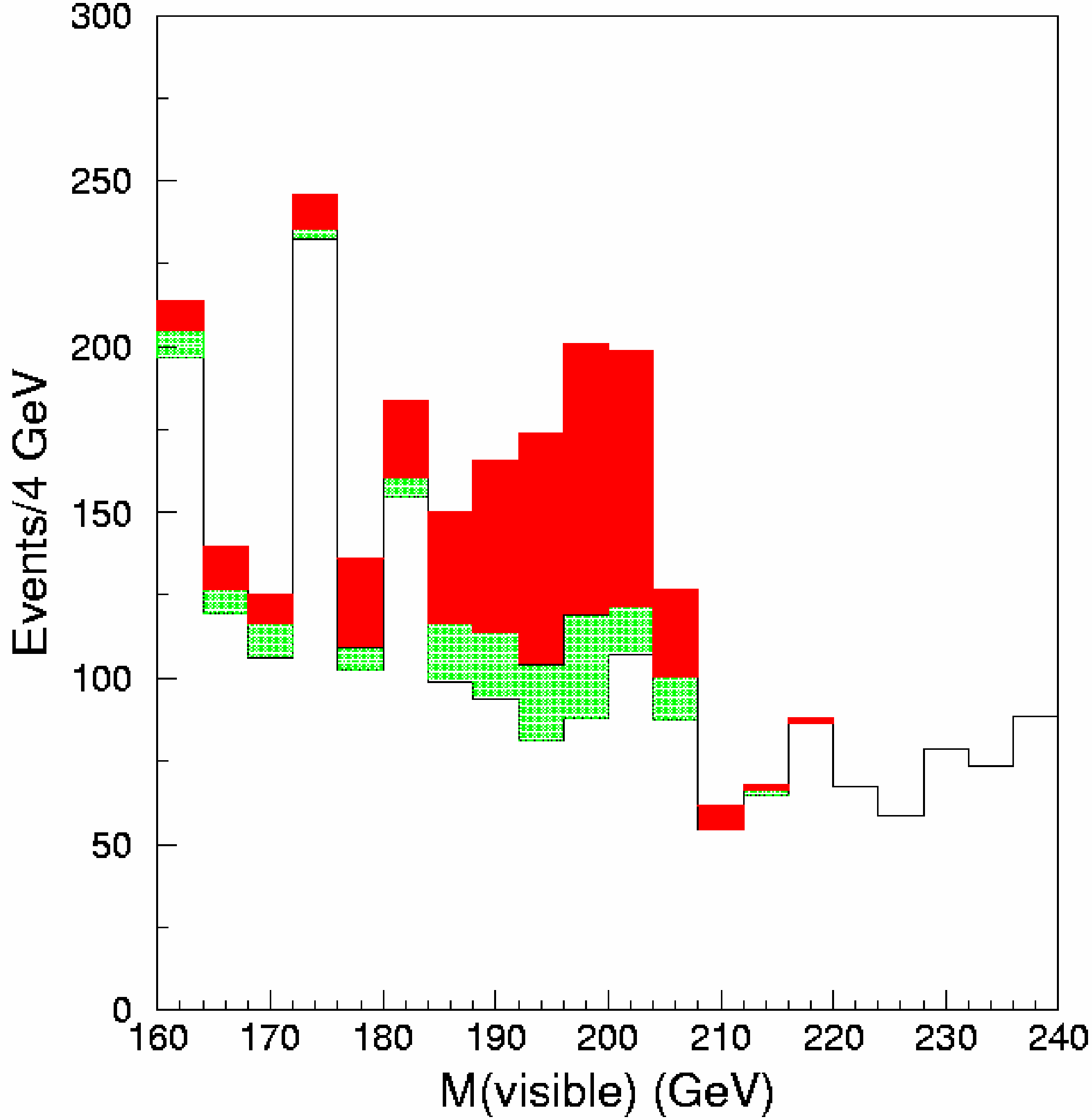
All 2,4,6-fermion and top-resonance 8-fermion backgrounds included

Background passing cuts (white histogram) is mostly

$$e^+e^- \rightarrow e^+e^-W^+W^-$$

Red histogram: $h \rightarrow b\bar{b}$

Green histogram: $h \rightarrow WW,\ ZZ$



$h \rightarrow \gamma\gamma$

Require:

$$|\cos\theta_{thrust}| < 0.95$$

$$20 < PT_{vis} < 500 \text{ GeV}$$

$$100 < E_{vis} < 400 \text{ GeV}$$

$$N_{isolated\ leptons} = 0$$

$$N_{jets} = 2$$

$$\mathrm{N}_{chg} = 0$$

$$N_{imp} = 0$$

$$M_h - 2 \text{ GeV} < M_{vis} < M_h + 1 \text{ GeV}$$

$$e^+e^- \rightarrow \nu_e \overline{\nu}_e h$$
$$\quad\quad\quad\quad |\!\rightarrow \gamma\gamma$$

$M_h = 120\ GeV$

$\sqrt{s} = 1\ TeV$

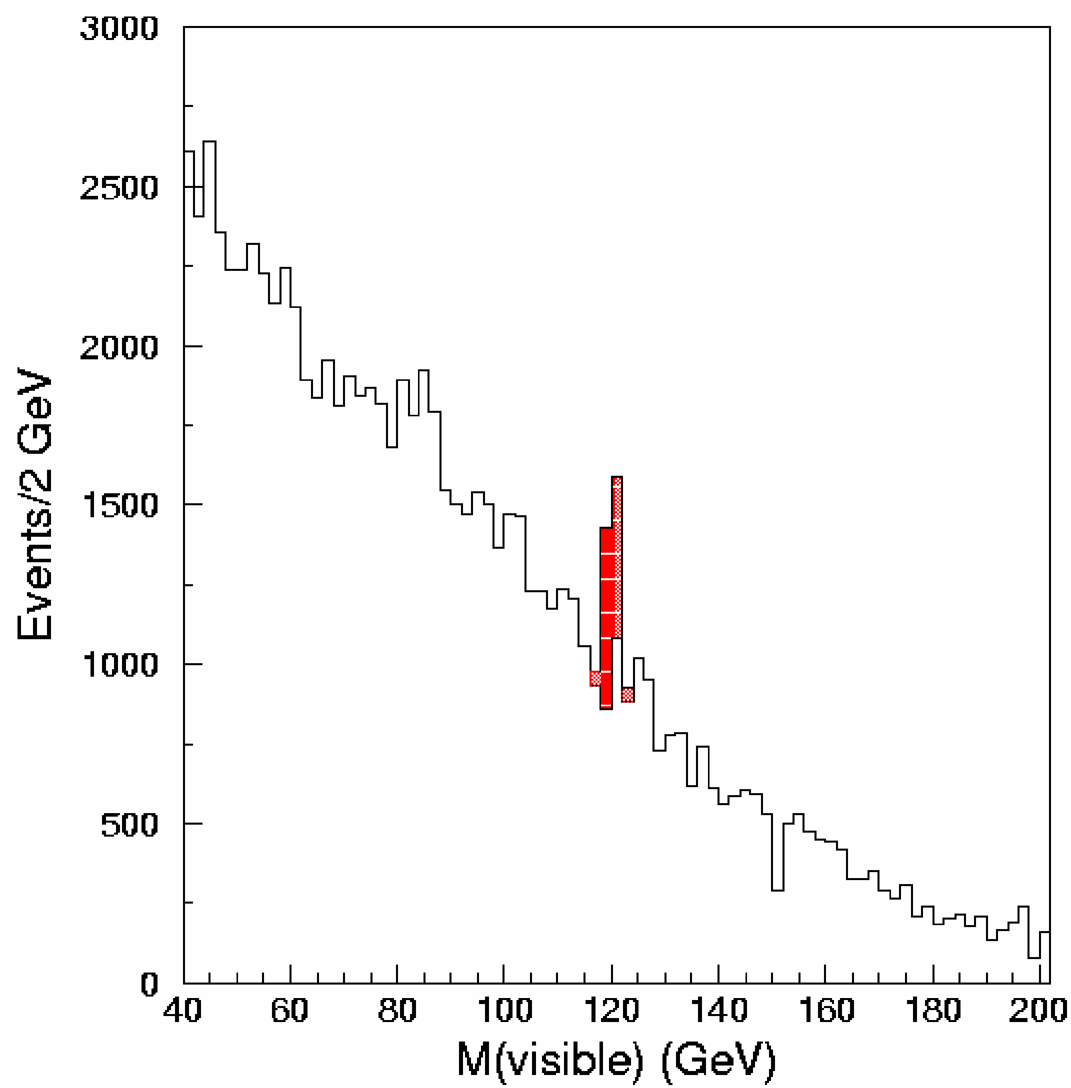
$L = 1\ ab^{-1}$

All 2,4,6-fermion and top-resonance 8-fermion backgrounds included

Non-Higgs background (white histogram) is mostly

$e^+e^- \rightarrow \nu\nu\gamma\gamma$

Red histogram: $h \rightarrow \gamma\gamma$



$$e^+e^- \to \nu_e \overline{\nu}_e h$$
$$\quad \mapsto \gamma\gamma$$

$M_h = 160\ GeV$

$\sqrt{s} = 1\ TeV$

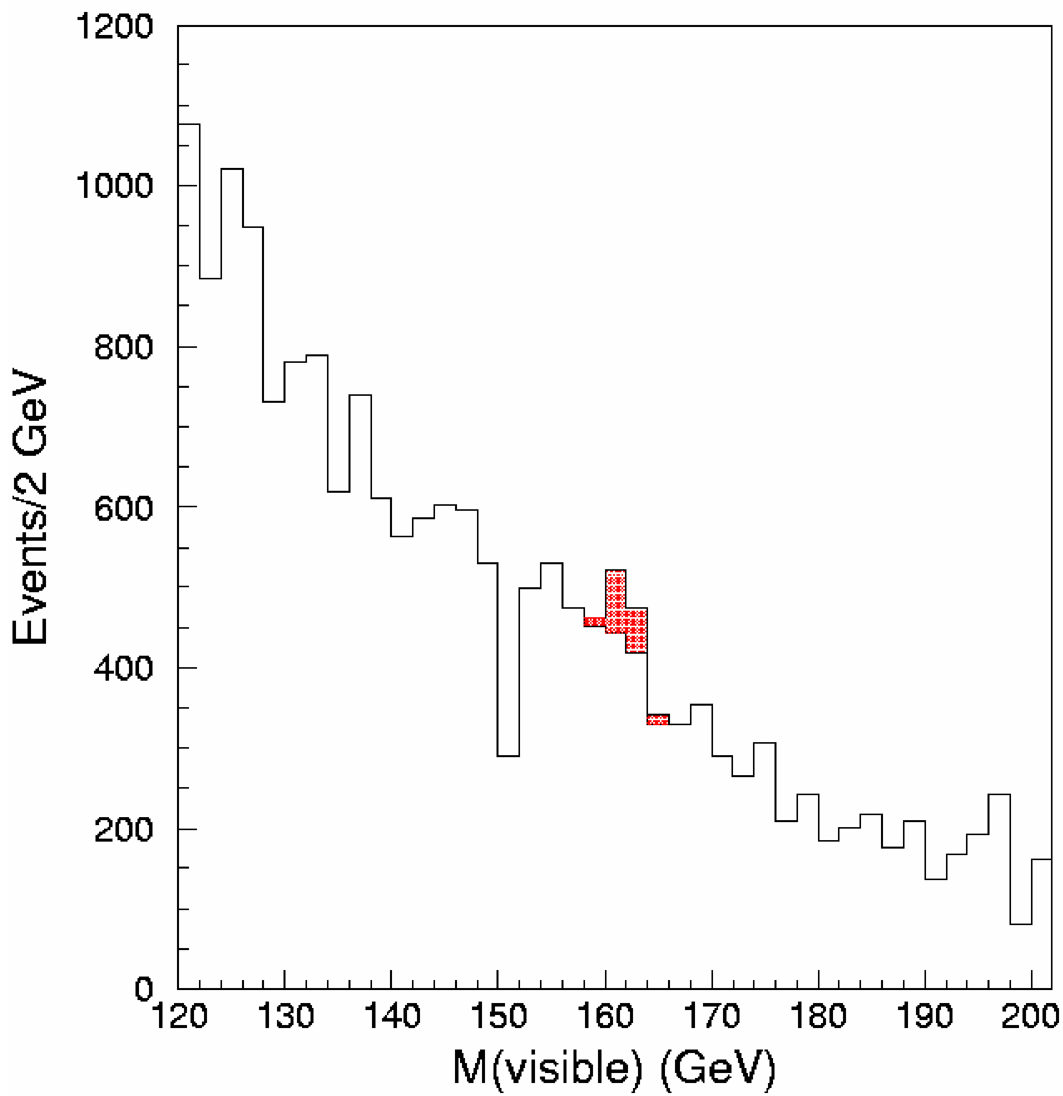
$L = 1\ ab^{-1}$

All 2,4,6-fermion and top-resonance 8-fermion backgrounds included

Non-Higgs background (white histogram) is mostly

$$e^+e^- \to \nu\nu\gamma\gamma$$

Red histogram: $h \to \gamma\gamma$



$h \rightarrow WW$

Require:

$$|\cos\theta_{thrust}| < 0.95$$

$$20 < PT_{vis} < 500 \text{ GeV}$$

$$100 < E_{vis} < 400 \text{ GeV}$$

$$N_{isolated\ leptons} = 0$$

$$4 \leq N_{jets} \leq 5$$

$$16 \leq \mathrm{N}_{chg} \leq 44$$

$$N_{imp} \leq 6$$

$$M_h - 10 \text{ GeV} < M_{vis} < M_h + 6 \text{ GeV}$$

$$e^+e^- \to \nu_e \overline{\nu}_e h$$
$$|\to WW^*$$

$M_h = 120\ GeV$

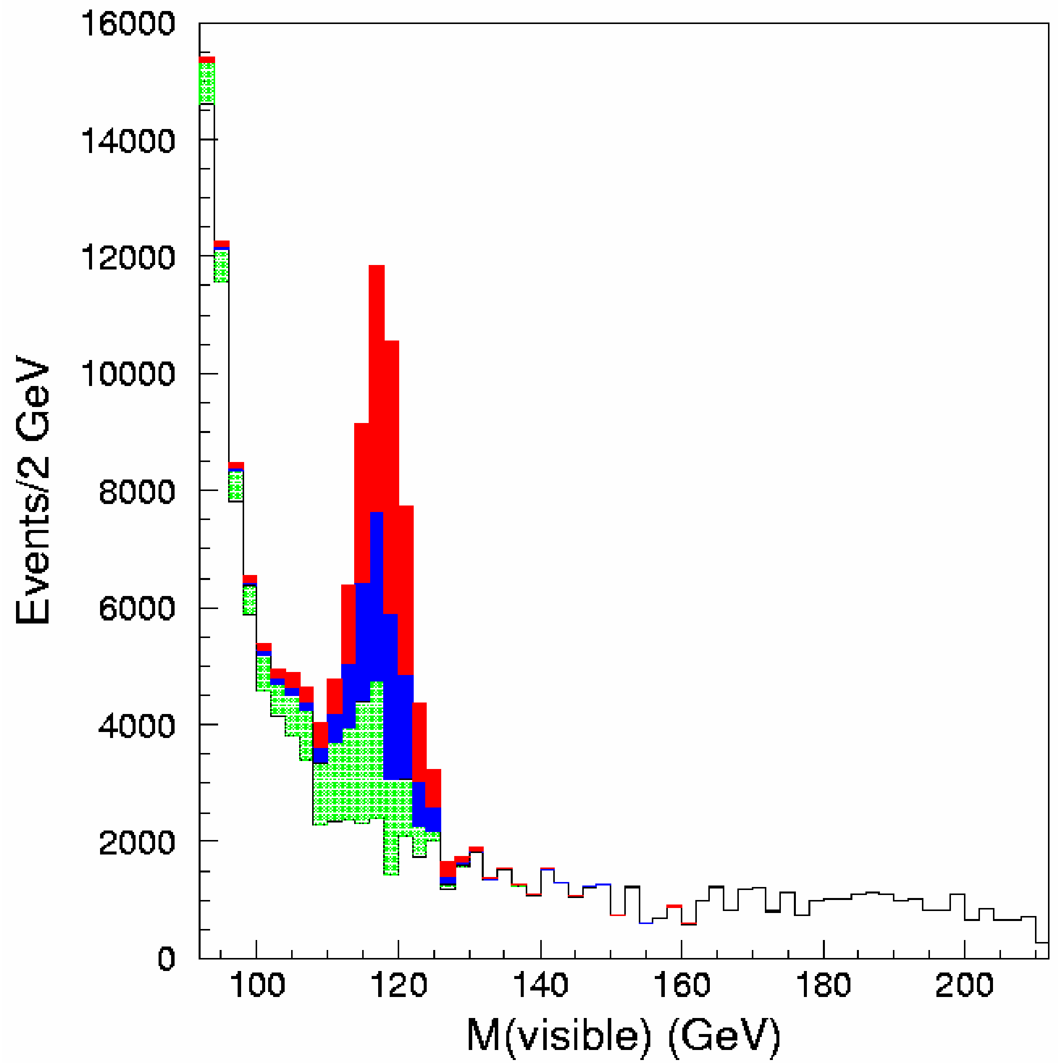
$\sqrt{s} = 1\ TeV$

$L = 1\ ab^{-1}$

All 2,4,6-fermion and top-resonance 8-fermion backgrounds included

Non-Higgs background (white histogram) is mostly

$$e^+e^- \to e\nu W$$
$$(W\gamma \to ud)$$



Red histogram: $h \to WW^*$

Blue histogram: $h \to gg$ (63%)

Green histogram: $h \to b\overline{b}$ (14%) $c\overline{c}$ (12%) ZZ^*(12%)

$$e^+e^- \to \nu_e \overline{\nu}_e h$$
$$\quad\quad\quad\quad |\!\to WW^*$$

$M_h = 120\ GeV$

$\sqrt{s} = 1\ TeV$

$L = 1\ ab^{-1}$

All 2,4,6-fermion and top-resonance 8-fermion backgrounds included

Non-Higgs background (white histogram) is mostly

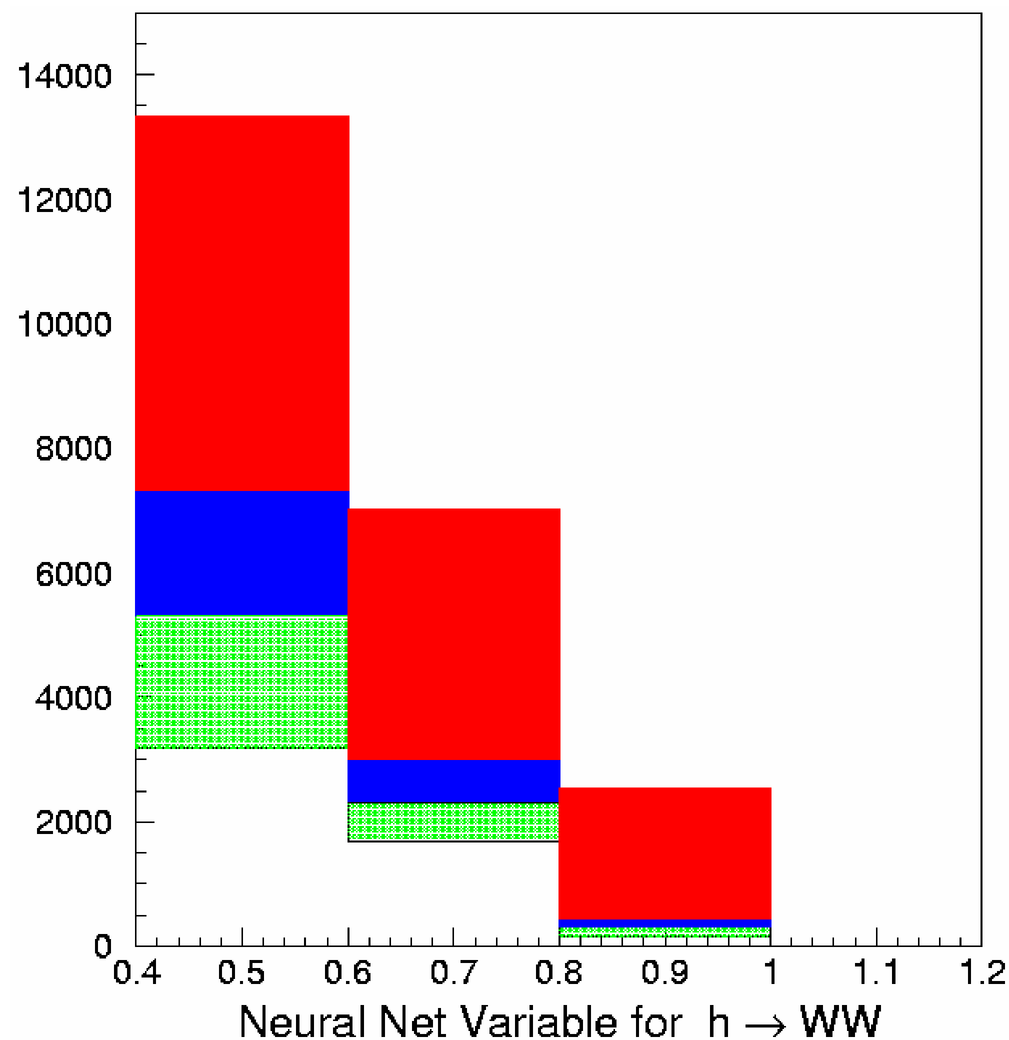
$e^+e^- \to e\nu W$

$(W\gamma \to ud)$

Red histogram: $h \to WW^*$

Blue histogram: $h \to gg$

Green histogram: $h \to b\overline{b},\ c\overline{c},\ ZZ^*$



Statistical Accuracy for $\sigma \bullet B_{xx}$ Assuming

$$e^{-}_{pol} = -80\% \quad e^{+}_{pol} = +50\% \quad L = 1000\ fb^{-1} \quad \sqrt{s} = 1000\ GeV$$

	Higgs Mass (GeV)				
	115	120	140	160	200
$\Delta(\sigma \cdot B_{bb})/(\sigma \cdot B_{bb})$	± 0.003	± 0.004	± 0.005	± 0.018	± 0.090
$\Delta(\sigma \cdot B_{WW})/(\sigma \cdot B_{WW})$	± 0.021	± 0.013	± 0.005	± 0.004	± 0.005
$\Delta(\sigma \cdot B_{gg})/(\sigma \cdot B_{gg})$	± 0.014	± 0.015	± 0.025	± 0.145	
$\Delta(\sigma \cdot B_{\gamma\gamma})/(\sigma \cdot B_{\gamma\gamma})$	± 0.053	± 0.051	± 0.059	± 0.237	
$\Delta(\sigma \cdot B_{ZZ})/(\sigma \cdot B_{ZZ})$					± 0.013

Convert $\sigma \bullet B_{xx}$ to B_{xx}, Γ_{tot} Using $b\bar{b}, WW$ Branching Fractions Measured at Ecm=350 GeV

$$B_{xx} = (\sigma \cdot B_{xx})(\sigma \cdot B_{WW})^{-1} B^*_{WW} = (\sigma \cdot B_{xx})(\sigma \cdot B_{bb})^{-1} B^*_{bb}$$

$$\Gamma_{tot} \propto (\sigma \cdot B_{bb})(B^*_{bb})^{-1}(B^*_{WW})^{-1} = (\sigma \cdot B_{bb})^2(\sigma \cdot B_{WW})^{-1}(B^*_{bb})^{-2}$$

Assumed errors on B^*_{bb}, B^*_{WW} measured at Ecm=350 GeV:

	Higgs Mass (GeV)				
	115	120	140	160	200
$\Delta B^*_{bb}/B^*_{bb}$	± 0.015	± 0.017	± 0.026	± 0.065	± 0.340
$\Delta B^*_{WW}/B^*_{WW}$	± 0.061	± 0.051	± 0.025	± 0.010	± 0.025

Use Direct Method (J.-C. Brient, LC-PHSM-2002-003) when branching fraction is large because binomial statistics reduces error by $\sqrt{1 - B_{xx}}$

Statistical Accuracy for B_{xx}, Γ_{tot} Assuming

$e^-_{pol} = -80\%$ $e^+_{pol} = +50\%$ $L = 1000\ fb^{-1}$ $\sqrt{s} = 1000\ GeV$

and errors on B^*_{bb}, B^*_{WW} from previous slide

	Higgs Mass (GeV)				
	115	120	140	160	200
$\Delta B_{bb}/B_{bb}$	± 0.015	± 0.016	± 0.018	± 0.020	± 0.090
$\Delta B_{WW}/B_{WW}$	± 0.024	± 0.020	± 0.018	± 0.010	± 0.025
$\Delta B_{gg}/B_{gg}$	± 0.021	± 0.023	± 0.035	± 0.146	
$\Delta B_{\gamma\gamma}/B_{\gamma\gamma}$	± 0.055	± 0.054	± 0.062	± 0.237	
$\Delta \Gamma_{tot}/\Gamma_{tot}$	± 0.035	± 0.034	± 0.036	± 0.020	± 0.050

TESLA TDR:

Channel	$M_H = 120\,\mathrm{GeV}$	$M_H = 140\,\mathrm{GeV}$	$M_H = 160\,\mathrm{GeV}$
$H^0/h^0 \to b\bar{b}$	$\pm$ 0.024	$\pm$ 0.026	$\pm$ 0.065
$H^0/h^0 \to c\bar{c}$	$\pm$ 0.083	$\pm$ 0.190	
$H^0/h^0 \to gg$	$\pm$ 0.055	$\pm$ 0.140	
$H^0/h^0 \to \tau^+\tau^-$	$\pm$ 0.050	$\pm$ 0.080	

$\Gamma_{H\to X}$	$\mathrm{BR}(H \to X)$	$M_H = 120\,\mathrm{GeV}$	140 GeV	160 GeV
$WW = WW\nu\nu$	$H^0 \to WW$	± 0.061	± 0.045	± 0.134

THIS ANALYSIS:

	Higgs Mass (GeV)				
	115	120	140	160	200
$\Delta B_{bb}/B_{bb}$	± 0.015	± 0.016	± 0.018	± 0.020	± 0.090
$\Delta B_{WW}/B_{WW}$	± 0.024	± 0.020	± 0.018	± 0.010	± 0.025
$\Delta B_{gg}/B_{gg}$	± 0.021	± 0.023	± 0.035	± 0.146	
$\Delta B_{\gamma\gamma}/B_{\gamma\gamma}$	± 0.055	± 0.054	± 0.062	± 0.237	
$\Delta \Gamma_{tot}/\Gamma_{tot}$	± 0.035	± 0.034	± 0.036	± 0.020	± 0.050

Assumed errors from Ecm=350 GeV:

	Higgs Mass (GeV)				
	115	120	140	160	200
$\Delta B^*_{bb}/B^*_{bb}$	±0.015	±0.017	±0.026	±0.065	±0.340
$\Delta B^*_{WW}/B^*_{WW}$	±0.061	±0.051	±0.025	±0.010	±0.025

THIS ANALYSIS:

	Higgs Mass (GeV)				
	115	120	140	160	200
$\Delta B_{bb}/B_{bb}$	±0.015	±0.016	±0.018	±0.020	±0.090
$\Delta B_{WW}/B_{WW}$	±0.024	±0.020	±0.018	±0.010	±0.025

Try to use ZZ fusion to measure Γ_{ZZ}

Optimize signal for $e^+e^- \to e^+e^-h$ at 1 TeV

using only the final state e^+e^-

Take the largest mass e^+e^- pair in the event and require:

$$0.8 < \cos\theta_{e^-} < 0.9975$$

$$-0.9975 < \cos\theta_{e^+} < -0.8$$

$$|\cos\theta_{ee}| < 0.98$$

$$650 \text{ GeV} < M_{ee} < 870 \text{ GeV}$$

$$0.8 < acopl_{ee}$$

$e^+e^- \to e^+e^- h$

$M_h = 115\ GeV$

$\sqrt{s} = 1\ TeV$

$L = 1\ ab^{-1}$

All 2,4,6-fermion and top-resonance 8-fermion backgrounds included

Non-Higgs background (white histogram) is mostly

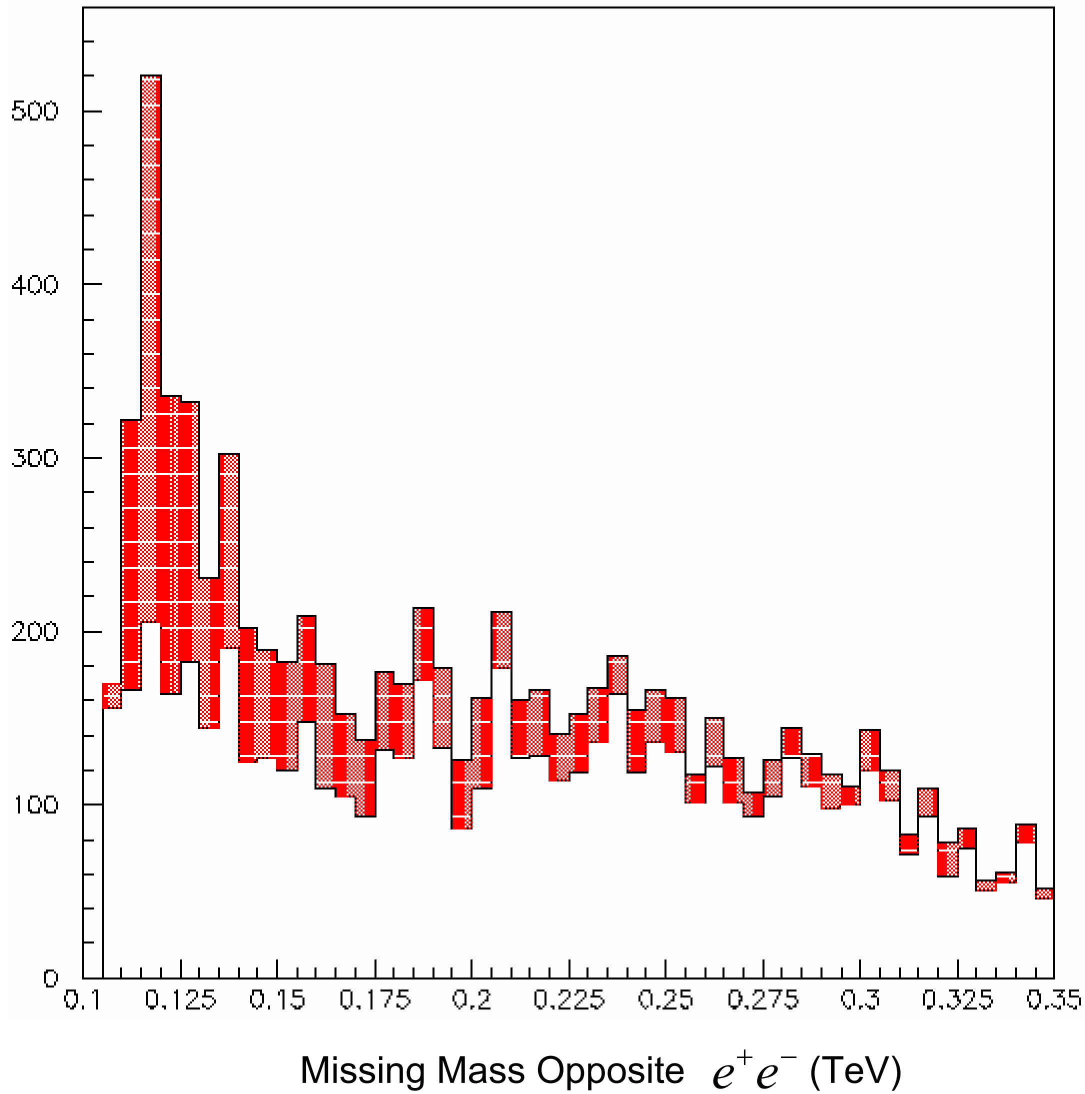
$e^+e^- \to e^+e^-$

$e^+e^- \to e^+e^- q\bar{q}$

$e^+e^- \to e^+e^- l^+l^-$

$e^+e^- \to e^+e^- W^+W^-$

Red histogram: $e^+e^- \to e^+e^- h$

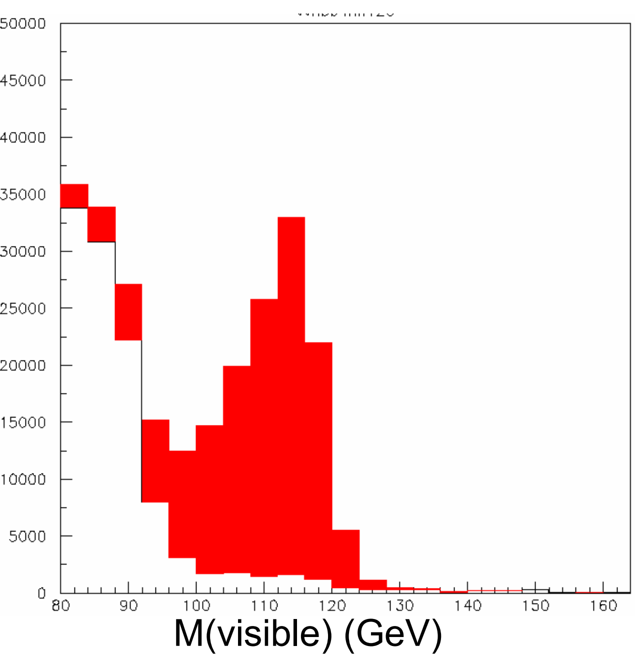


Include background from $\gamma\gamma \to$ hadrons

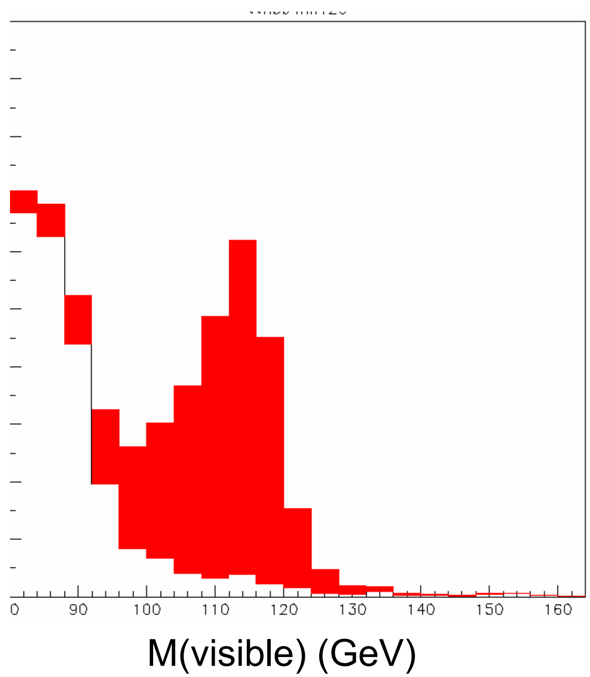
$$e^+e^- \to \nu_e \bar{\nu}_e h \qquad M_h = 115\ \text{GeV} \qquad \sqrt{s} = 1\ \text{TeV}$$

Remove eflow objects with $p_T < 0.5$ GeV or $|\cos\theta| > 0.98$

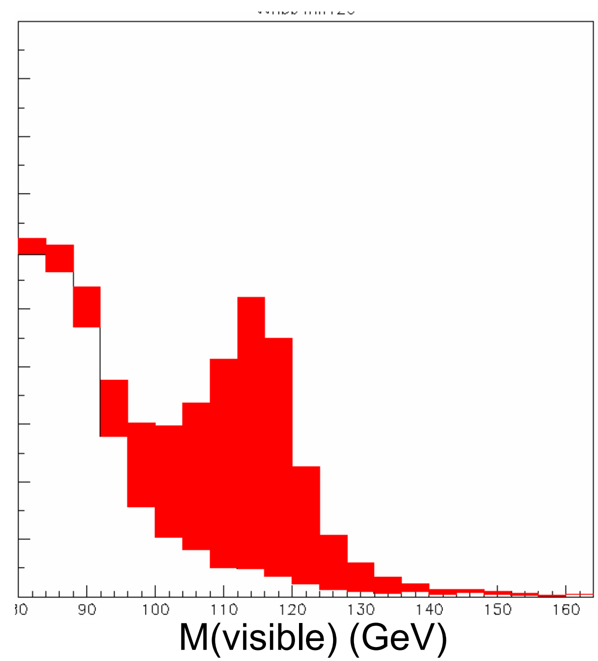
0 BX



1 BX



4 BX



$$\frac{\Delta(\sigma \cdot B_{bb})}{(\sigma \cdot B_{bb})} = .0031$$

$$\frac{\Delta(\sigma \cdot B_{bb})}{(\sigma \cdot B_{bb})} = .0033$$

$$\frac{\Delta(\sigma \cdot B_{bb})}{(\sigma \cdot B_{bb})} = .0035$$

Summary

- Couplings of Higgs bosons can continue to be measured as the energy of a LC is upgraded to 1 TeV.
- Higgs event rate is very large at 1 TeV and rare decay modes inaccessible at 350 GeV can be probed such as b quark decays for Mh=200 GeV and gluon-gluon, gamma-gamma decays for Mh=140 GeV. Branching ratio errors are also improved for decay modes with moderate branching fractions.
- Higgs branching ratio to b quarks or to W W measured with the direct method at Ecm=350 GeV should replace the Zh cross section as the parameter used to convert (sigma X BR) to branching ratios.
- The measurement of the Higgs BR to charm quarks at Ecm=1 TeV would be an interesting topic for charm tagging experts