ILC Higgs Coupling Precision and Systematic Errors

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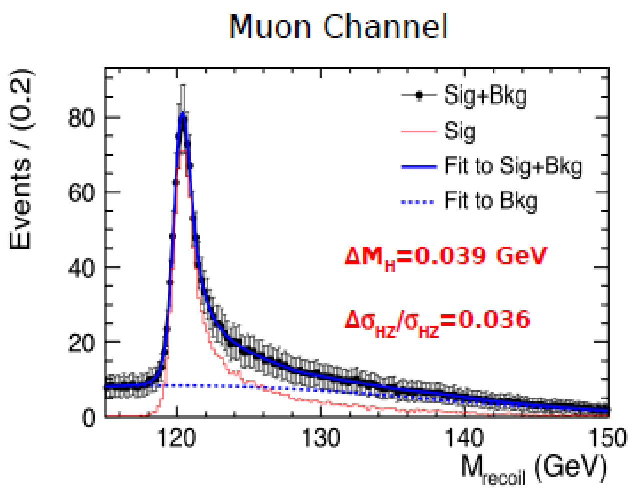
Outline

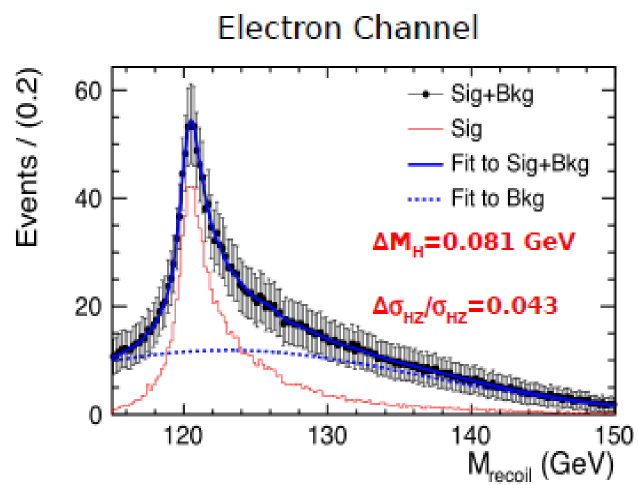
- Review of ILC Higgs Coupling Precisions
- Experimental and Theoretical Systematic Errors
- Limits on BSM decays and the Ultimate Higgs Coupling Precision

ILC Measurement of $\sigma(e^+e^- \to ZH)$ $\sqrt{s} = 250$ GeV

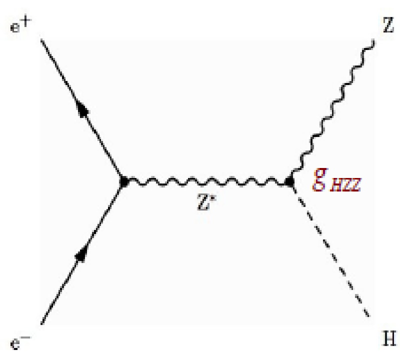
Higgs Recoil Measurement of Higgs Mass and Higgstrahlung Cross Section



Very Precise Measurement
S/B = 8 in Peak Region



Less Precise
Bremsstrahlung in detector material



ILC: $\Delta M_H = .025$ GeV, $\Delta\sigma_{HZ} / \sigma_{HZ}$=1.4% for L= 500 fb^{-1}

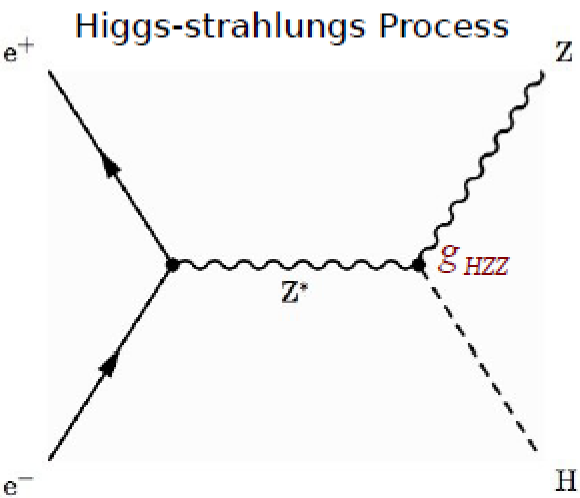
$\Delta M_H = .013$ GeV, $\Delta\sigma_{HZ} / \sigma_{HZ}$=0.7% for L=2000 fb^{-1}

$\sigma_{HZ} \sim g_{HZZ}^2$

$\Rightarrow \Delta g_{HZZ} / g_{HZZ} = 0.7\%$ (0.35%) for L=500 (2000) fb^{-1}

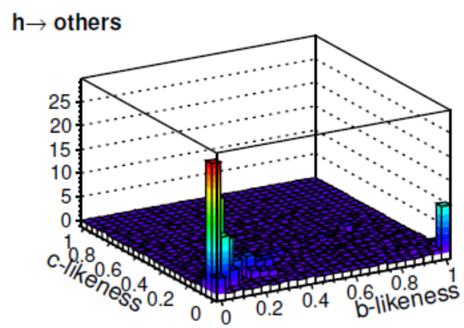
[from leptonic recoil alone]

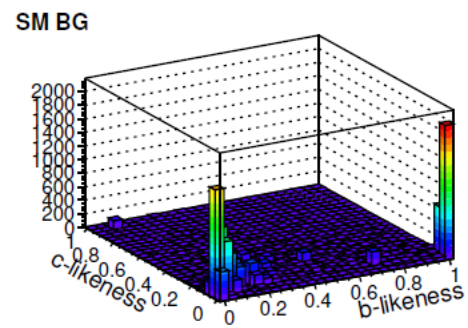
ILC $\sigma \times$BR measurements using $e^{+}e^{-} \rightarrow ZH$ $\quad \sqrt{s} = 250$ GeV

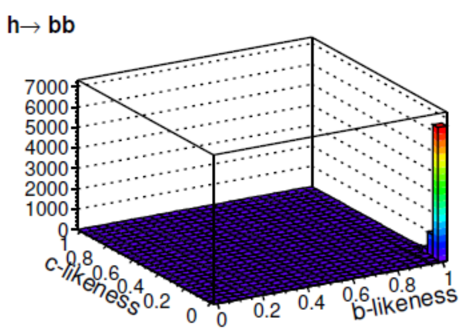


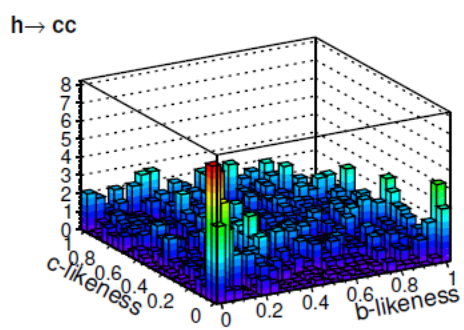
All Z decays are used for measurement of $\sigma \times$BR. These include Z $\rightarrow qq$ and Z $\rightarrow \nu\nu$.

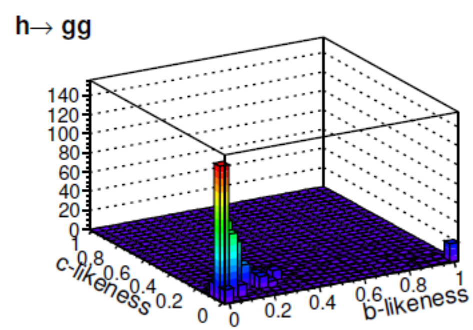
Flavor tagging very important for distinguishing different decay modes



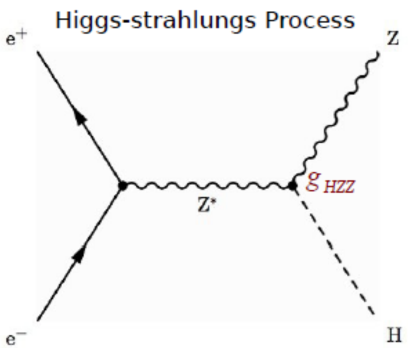


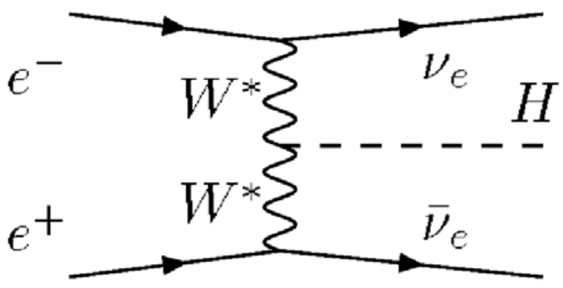






$e^+e^- \to ZH, \nu\nu\mathrm{H}\ \sqrt{s} = 350$ GeV



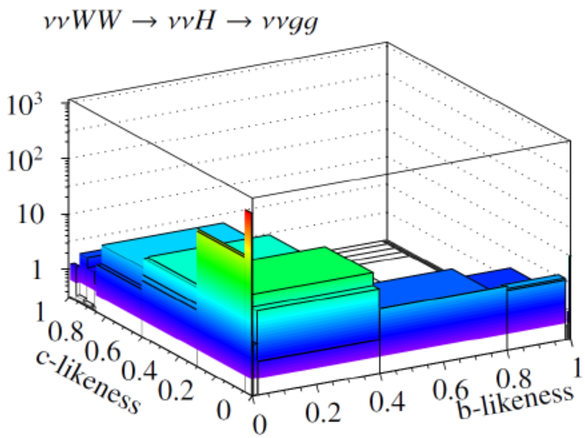


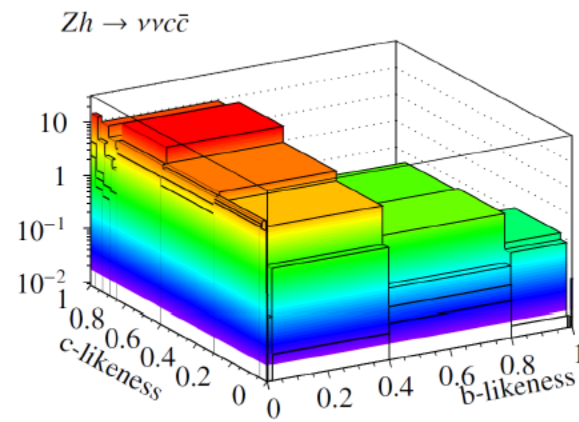
All of the $\sigma \bullet BR$ Higgstrahlung studies that were done at $\sqrt{s} = 250$ GeV can also be done at $\sqrt{s} = 350$ GeV . Precisions for $\sigma \bullet BR$ are comparable, as is the precision for σ(ZH) once Z $\to q\bar{q}$ decays are included.

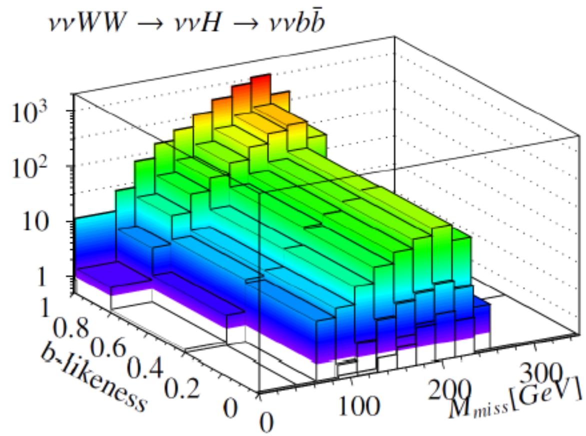
WW fusion production of the Higgs at $\sqrt{s} = 350$ GeV provides a much better measurement of g_{HWW} compared to $\sqrt{s} = 250$ GeV. This gives a much improved estimate of the total Higgs width Γ_H which in turn significantly improves the coupling errors obtained from $\sigma \bullet BR$ measurements made at $\sqrt{s} = 250$ GeV. WW fusion also provides additional $\sigma \bullet BR$ measurements.

The recoil Higgs mass measurement is significantly worse at $\sqrt{s} = 350$ GeV with respect to $\sqrt{s} = 250$ GeV. However, there is hope that direct calorimeter Higgs mass measurements using $e^+e^- \to \nu\nu H$ will recover the precision (two ongoing studies were presented at this conference)

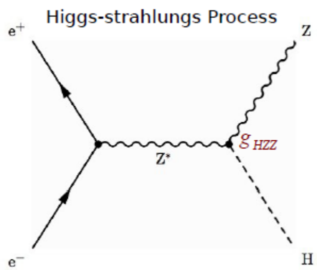
$e^{+}e^{-} \rightarrow ZH,\ \nu\nu\,\mathrm{H}\ \sqrt{s} = 350$ GeV

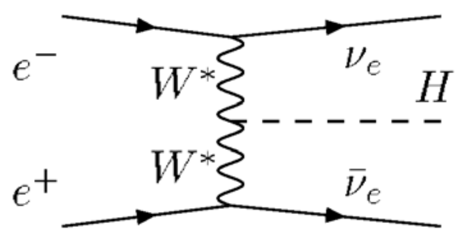


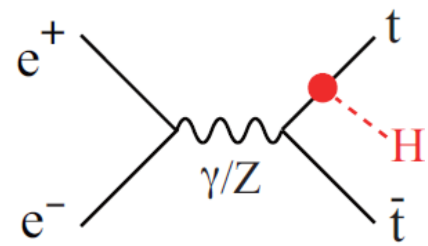


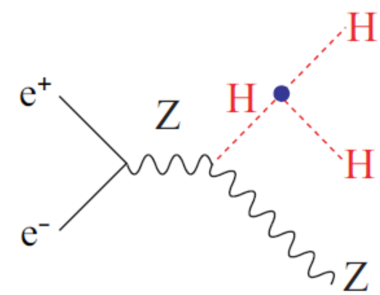


$e^+e^- \to ZH, \nu\nu \mathrm{H}, \mathrm{t\bar{t}H}, \mathrm{ZHH}\ \sqrt{s} = 500$ GeV









The g_{HWW} coupling can also be measured well at $\sqrt{s} = 500$ GeV through WW fusion production of the Higgs. Also the measurement of $\sigma(e^+e^- \to \nu\nu H) \times BR(H \to X)$ can be made for many Higgs decay modes $H \to X$.

Through $e^+e^- \to ttH$ the top Yukawa coupling can be measured to $\Delta y_t / y_t = 18\%$ with 500 fb^{-1} at $\sqrt{s} = 500$ GeV. With same luminosity at $\sqrt{s} = 550$ GeV the precision is $\Delta y_t / y_t = 7.2\%$.

The ZHH channel is open at $\sqrt{s} = 500$ GeV. The Higgs self coupling can be measured to 27% with 4 ab^{-1} assuming the true value is the SM value.

Summary of ILC Higgs Measurement Precisions

From "500 GeV ILC Operating Scenarios" arXiv : 1506.07830

$\int \mathscr{L} dt$ at $\sqrt{s}$	$250\,\mathrm{fb}^{-1}$ at $250\,\mathrm{GeV}$		$330\,\mathrm{fb}^{-1}$ at $350\,\mathrm{GeV}$		$500\,\mathrm{fb}^{-1}$ at $500\,\mathrm{GeV}$		
$P(e^-, e^+)$	(-80%,+30%)						
production	Zh	$\nu\bar{\nu}h$	Zh	$\nu\bar{\nu}h$	Zh	$\nu\bar{\nu}h$	$t\bar{t}h$
$\Delta\sigma/\sigma$	[39] 2.0%	-	[10, 40] 1.6%	-	3.0	-	-
BR(invis.) [41]	$< 0.9\%$	-	$< 1.2\%$	-	$< 2.4\%$	-	-
decay	$\Delta(\sigma \cdot BR)/(\sigma \cdot BR)$						
$h \to bb$	1.2%	10.5%	1.3%	1.3%	1.8%	0.7%	28%
$h \to c\bar{c}$	8.3%	-	9.9%	13%	13%	6.2%	-
$h \to gg$	7.0%	-	7.3%	8.6%	11%	4.1%	-
$h \to WW^*$	6.4%	-	6.8%	5.0%	9.2%	2.4%	-
$h \to \tau^+\tau^-$	[42] 3.2%	-	[43] 3.5%	19%	5.4%	9.0%	-
$h \to ZZ^*$	19%	-	22%	17%	25%	8.2%	-
$h \to \gamma\gamma$	34%	-	34%	[44] 39%	34%	[44] 19%	-
$h \to \mu^+\mu^-$ [45]	72%	-	76%	140%	88%	72%	-

H-20: Preferred 20 year Running Scenario

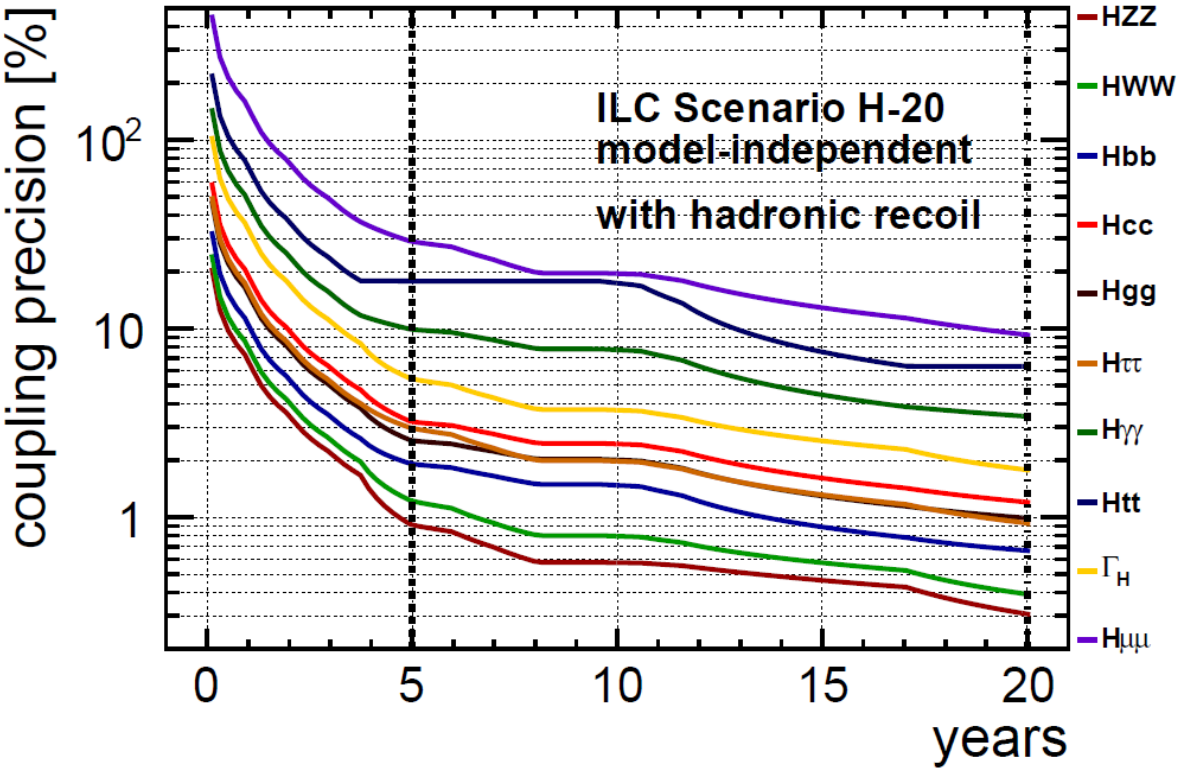
	$\sqrt{s}$	$\int \mathscr{L} dt$	L_{peak}	Ramp				T	T_{tot}	Comment
	[GeV]	[fb^{-1}]	[fb^{-1}/a]	1	2	3	4	[a]	[a]	
Physics run	500	500	288	0.1	0.3	0.6	1.0	3.7	3.7	TDR nominal at 5 Hz
Physics run	350	200	160	1.0	1.0	1.0	1.0	1.3	5.0	TDR nominal at 5 Hz
Physics run	250	500	240	0.25	0.75	1.0	1.0	3.1	8.1	operation at 10 Hz
Shutdown								1.5	9.6	Luminosity upgrade
Physics run	500	3500	576	0.1	0.5	1.0	1.0	7.4	17.0	TDR lumi-up at 5 Hz
Physics run	250	1500	480	1.0	1.0	1.0	1.0	3.2	20.2	lumi-up operation at 10 Hz

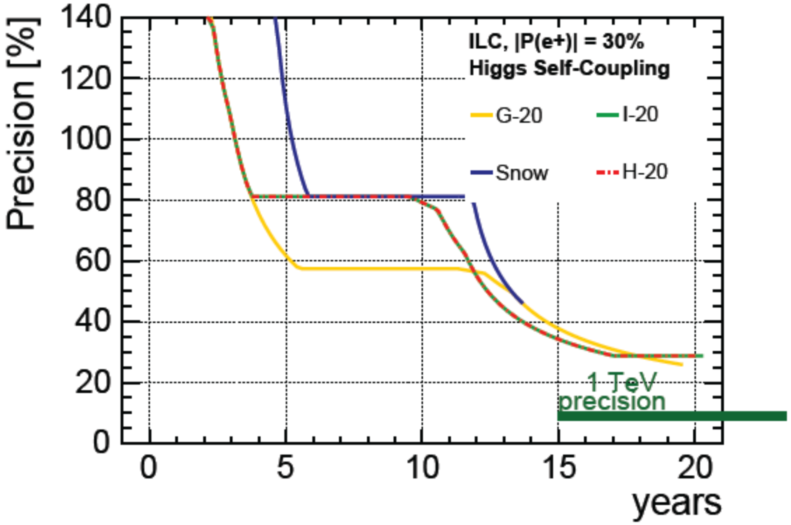
Table 7: Scenario H-20: Sequence of energy stages and their real-time conditions.

H-20

	first phase	lumi upgrade	total
250 GeV	500 fb^{-1}	1500 fb^{-1}	2 ab^{-1}
350 GeV	200 fb^{-1}		0.2 ab^{-1}
500 GeV	500 fb^{-1}	3500 fb^{-1}	4 ab^{-1}
time	8.1 yrs	10.6 yrs	20.2 yrs*

ILC Higgs Coupling Precision vs Time





ILC Higgs Coupling Precisions

Topic	Parameter	Initial Phase (H20 @ 8yrs)	Full Data Set (H20 @ 20yrs)	units	ref.
Higgs	m_h	25	15	MeV	[51]
	$g(hZZ)$	0.58	0.31	%	[8]
	$g(hWW)$	0.81	0.42	%	[8]
	$g(hb\bar{b})$	1.5	0.7	%	[8]
	$g(hgg)$	2.3	1.0	%	[8]
	$g(h\gamma\gamma)$	7.8	3.4	%	[8]
		1.2	1.0	%, w. LHC results	[52]
	$g(h\tau\tau)$	1.9	0.9	%	[8]
	$g(hc\bar{c})$	2.7	1.2	%	[8]
	$g(ht\bar{t})$	18	6.3	%, direct	[8]
		20	20	%, $t\bar{t}$ threshold	[53]
	$g(h\mu\mu)$	20	9.2	%	[8]
	$g(hhh)$	77	27	%	[8]
	Γ_{tot}	3.8	1.8	%	[8]
	Γ_{invis}	0.54	0.29	%, 95% conf. limit	[8]

[8] D. M. Asner *et al.*, "ILC Higgs White Paper," arXiv:1310.0763 [hep-ph].

[51] H. Li, arXiv:1007.2999 [hep-ex].

[52] M. E. Peskin, in the Proceedings of the APS DPF Community Summer Study (Snowmass 2013), arXiv:1312.4974 [hep-ph].

[53] T. Horiguchi, A. Ishikawa, T. Suehara, K. Fujii, Y. Sumino, Y. Kiyo and H. Yamamoto, arXiv:1310.0563 [hep-ex].

Higgs Physics Systematic Errors

Given that the statistical errors of many of the Higgs cross section and σ•BR reach the several per-mil level for the full H20 program, systematic errors must typically be 0.1% or less.

The following systematic errors have been considered:

- Flavor Tagging
- Luminosity
- Polarization
- Model Independence of ZH Recoil Measurements
- Theory Error

Higgs Physics Systematic Errors

Luminosity, Polarization, & Flavor Tagging Systematic Errors Assumed in 2013 Snowmass Higgs White Paper:

	Baseline	LumUp
luminosity	0.1%	0.05%
polarization	0.1%	0.05%
b-tag efficiency	0.3%	0.15%

$$\frac{\Delta L}{L} = \frac{2\Delta\theta}{\theta_{min}}, \quad \theta_{min} = 46 \text{ mrad} \quad \Delta\theta < 0.02 \text{ mrad}$$

ΔR(sensors) < 30 μm

polarization obtained from polarimeters upstream and downstream of IP

+ physics processes such as $e^+e^- \to W^+W^-$

b-tag efficiency errors obtained from a quick studying using $e^+e^- \to ZZ \to l^+l^-b\bar{b}$ as a control sample; could be improved with additional control sample processes

Higgs Physics Systematic Errors

Model Independence of ZH Recoil Measurements

In order to use the hadronic ZH recoil measurement in our Higgs analyses we have to quantify the penalty associated with the fact that $\sigma(ZH \to q\,\bar{q} + X)$ is "almost model independent". By how much must we blow up $\Delta\sigma(ZH \to q\,\bar{q} + X)$ to account for the fact that the efficiencies differ by as much as 7%?

Model Independent?

★ **Combining visible + invisible analysis: wanted M.I.**

- **i.e. efficiency independent of Higgs decay mode**

Decay mode	$\varepsilon^{\mathrm{vis}}_{\mathscr{L}>0.65}$	$\varepsilon^{\mathrm{vis}}_{\mathscr{L}>0.60}$	$\varepsilon^{\mathrm{vis}} + \varepsilon^{\mathrm{invis}}$
$\mathrm{H} \to \mathrm{invis.}$	<0.1 %	22.0 %	22.0 %
$\mathrm{H} \to \mathrm{q\bar{q}/gg}$	22.2 %	<0.1 %	22.2 %
$\mathrm{H} \to \mathrm{WW}^*$	21.6 %	0.1 %	21.7 %
$\mathrm{H} \to \mathrm{ZZ}^*$	20.2 %	1.0 %	21.2 %
$\mathrm{H} \to \tau^+\tau^-$	24.7 %	0.3 %	24.9 %
$\mathrm{H} \to \gamma\gamma$	25.8 %	<0.1 %	25.8 %
$\mathrm{H} \to \mathrm{Z}\gamma$	18.5 %	0.3 %	18.8 %
$\mathrm{H} \to \mathrm{WW}^* \to \mathrm{q\bar{q}q\bar{q}}$	21.3 %	<0.1 %	21.3 %
$\mathrm{H} \to \mathrm{WW}^* \to \mathrm{q\bar{q}l\nu}$	21.9 %	<0.1 %	21.9 %
$\mathrm{H} \to \mathrm{WW}^* \to \mathrm{q\bar{q}\tau\nu}$	22.1 %	<0.1 %	22.1 %
$\mathrm{H} \to \mathrm{WW}^* \to \mathrm{l\nu l\nu}$	24.8 %	0.1 %	25.0 %
$\mathrm{H} \to \mathrm{WW}^* \to \mathrm{l\nu\tau\nu}$	20.5 %	0.8 %	22.1 %
$\mathrm{H} \to \mathrm{WW}^* \to \tau\nu\tau\nu$	16.4 %	2.5 %	18.9 %

Very similar efficiencies

Look at wide range of WW topologies

Mark Thomson Oshu City, September 2014 21

Model Independence of ZH Recoil Measurements

It is not sufficient to vary the SM Higgs branching ratios to estimate this systematic error. The problem is the BSM decays; they cannot be accounted for in this way.

To handle the BSM decays we have used an approach where we use all of our $\sigma \bullet BR$ measurements for SM Higgs decays to obtain an estimate of the average signal efficiency for $\sigma(ZH \to q\bar{q} + X)$. It is then straightforward to propagate the $\sigma \bullet BR_i$ errors, as well as the systematic errors on the individual decay mode efficiencies for the $\sigma(ZH \to q\bar{q} + X)$ selection, to the error on $\sigma(ZH \to q\bar{q} + X)$.

Model Independence of ZH Recoil Measurements

Let

$\Psi \equiv \sigma(ZH \to q\bar{q} + X)$

$\Omega =$ Number of signal + background events in $\sigma(ZH \to q\bar{q} + X)$ analysis

$\mathrm{B} =$ Predicted number of background events in $\sigma(ZH \to q\bar{q} + X)$ analysis

Ξ = Average efficiency for signal events to pass $\sigma(ZH \to q\bar{q} + X)$ analysis

$L =$ luminosity

$$\Psi = \frac{\Omega - \mathrm{B}}{L\,\Xi} = \frac{1}{\Xi}\sum_i \psi_i \xi_i = \sum_i \psi_i \quad \text{where}$$

$\psi_i = \sigma(ZH) \bullet BR_i$

$\xi_i =$ efficiency for events from Higgs decay i to pass $\sigma(ZH \to q\bar{q} + X)$ analysis

$$\Xi = \frac{\sum_i \psi_i \xi_i}{\sum_i \psi_i}$$

Model Independence of ZH Recoil Measurements

$$\psi_i = \frac{\omega_i - \beta_i}{L\,\eta_i}$$

$\omega_i =$ Number of signal + background events in $\sigma(ZH)\bullet BR_i$ analysis

$\beta_i =$ Predicted number of background events in $\sigma(ZH)\bullet BR_i$ analysis

η_i = efficiency for Higgs decay i to pass $\sigma\bullet BR_i$ analysis

K_i = number of signal + background events common to had Z recoil and $\sigma\bullet BR_i$ analyses

E = number of signal + background events unique to had Z recoil analysis

ε_i = number of signal + background events events unique to $\sigma\bullet BR_i$ analysis

$$\Omega = \mathrm{E} + \sum_i \mathrm{K}_i \qquad S \equiv \Omega\text{-B} \qquad \mathrm{T} \equiv \frac{\sqrt{S+\mathrm{B}}}{S}$$

$$\omega_i = \mathrm{K}_i + \varepsilon_i \qquad s_i \equiv \omega_i - \beta_i \qquad \tau_i \equiv \frac{\sqrt{s_i + \beta_i}}{s_i}$$

$$\lambda_i \equiv \frac{\mathrm{K}_i}{\omega_i} \qquad N \equiv L\,\sigma_{ZH} \qquad r_i \equiv BR_i \qquad \delta_i \equiv \xi_i - \Xi$$

$$\left(\frac{\Delta\Psi}{\Psi}\right)^2 = \mathrm{T}^2\left\{1 + \frac{N^2}{\Omega}\sum_i r_i^2\left[\tau_i^2\left(\delta_i^2 - 2\lambda_i\eta_i\delta_i\right) + \Delta\xi_i^2\right]\right\}$$

This is our result for the error on $\sigma(ZH \rightarrow q\,\bar{q} + X)$

Model Independence of ZH Recoil Measurements

$$\left(\frac{\Delta\sigma(ZH \to q\,\bar{q} + X)}{\sigma(ZH \to q\,\bar{q} + X)}\right)^2 = \mathrm{T}^2 \left\{1 + \frac{N^2}{\Omega}\sum_i r_i^2 \left[\tau_i^2\delta_i^2 + \Delta\xi_i^2\right]\right\} \quad \text{i.e. sys err} = \frac{1}{2}\frac{N^2}{\Omega}\sum_i r_i^2 \left[\tau_i^2\delta_i^2 + \Delta\xi_i^2\right]$$

Assume $\sqrt{s} = 350$ GeV and L=500 fb^{-1}

$$\mathrm{N} = L\,\sigma_{ZH} = 45383 \quad r_i = BR_i = (1 - BR_{BSM})BR_i(SM) \qquad \tau_i(SM) = \frac{\Delta\sigma \bullet \mathrm{BR}_i(SM)}{\sigma \bullet \mathrm{BR}_i(SM)} = \frac{\sqrt{s_i + \beta_i}}{s_i}$$

Assume $\mathrm{T} = \frac{\sqrt{S + \mathrm{B}}}{S} = 0.014$ $\quad \Omega$=S+B $= 17738$ and $\xi_i(SM)$ given in the table four pages back.

We assume that the vis+invis efficiency values in the table four pages back cover all possible BSM decays since they cover all SM decays from completely invisible to fully hadronic multi-jet decays. Assuming no knowledge of the properties of the BSM decays we can then set

$$\xi_{BSM} = 0.5 * [\xi_{vis+invis}(\max) + \xi_{vis+invis}(\min)] = 0.5 * [0.258 + 0.188] = 0.22$$
$$\Delta\xi_{BSM} = 0.5 * [\xi_{vis+invis}(\max) - \xi_{vis+invis}(\min)] = .035$$

Model Independence of ZH Recoil Measurements

$$\left(\frac{\Delta\sigma(ZH \to q\bar{q}+X)}{\sigma(ZH \to q\bar{q}+X)}\right)^2 = \mathrm{T}^2\left\{1+\frac{N^2}{\Omega}\sum_i r_i^2\left[\tau_i^2\delta_i^2+\Delta\xi_i^2\right]\right\} \quad \text{i.e. sys err} = \frac{1}{2}\frac{N^2}{\Omega}\sum_i r_i^2\left[\tau_i^2\delta_i^2+\Delta\xi_i^2\right]$$

We next obtain the error $\frac{\Delta\sigma \bullet \mathrm{BR}_{BSM}}{\sigma \bullet \mathrm{BR}_{BSM}}$ from Michael Peskin's Higgs coupling fit program. We do not use the $\sum_i BR_i = 1$ constraint, and to begin with we only use the leptonic recoil σ_{ZH} measurement. This provides a model independent measurement of g_{BSM}. For $\sqrt{s} = 350$ GeV, L=500 fb^{-1} Michael's program gives $\frac{\Delta \mathrm{g}_{BSM}}{\mathrm{g}_{BSM}} = 0.032$ which we multiply by two to get $\frac{\Delta\sigma \bullet \mathrm{BR}_{BSM}}{\sigma \bullet \mathrm{BR}_{BSM}} = 0.064$. We take this error to mean that $0 < BR(H \to BSM) < 2 \times 0.064$, and set the measured $BR(H \to BSM) = 0.064$. This gives a model independent hadronic recoil cross section error of $\frac{\Delta\sigma(ZH \to q\bar{q}+X)}{\sigma(ZH \to q\bar{q}+X)} = 0.014 * 1.27 = 0.018$.

We then add this new model indepdendent hadronic recoil σ_{ZH} measurement as input to Michael's program to obtain a new error $\frac{\Delta\sigma \bullet \mathrm{BR}_{BSM}}{\sigma \bullet \mathrm{BR}_{BSM}} = 0.041$. Setting $BR(H \to BSM) = 0.041$ we then obtain a new model independent hadronic recoil σ_{ZH} error of $\frac{\Delta\sigma(ZH \to q\bar{q}+X)}{\sigma(ZH \to q\bar{q}+X)} = 0.014 * 1.12 = 0.016$.

Iterating again we arrive at $BR(H \to BSM) = 0.039$ and $\frac{\Delta\sigma(ZH \to q\bar{q}+X)}{\sigma(ZH \to q\bar{q}+X)} = 0.014 * 1.11 = 0.016$. Further interations don't give any improvement.

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Model Independence of ZH Recoil Measurements

$$\left(\frac{\Delta\sigma(ZH \to q\,\bar{q} + X)}{\sigma(ZH \to q\,\bar{q} + X)}\right)^2 = \mathrm{T}^2 \left\{1 + \frac{N^2}{\Omega}\sum_i r_i^{\,2}\left[\tau_i^2\delta_i^2 + \Delta\xi_i^2\right]\right\} \quad \text{i.e. sys err} = \frac{1}{2}\frac{N^2}{\Omega}\sum_i r_i^{\,2}\left[\tau_i^2\delta_i^2 + \Delta\xi_i^2\right]$$

We have shown that $\frac{1}{2}\frac{N^2}{\Omega}\sum_i r_i^{\,2}\left[\tau_i^2\delta_i^2 + \Delta\xi_i^2\right] = 0.11$ for $\sqrt{s} = 350$ GeV, L=500 fb^{-1}.

How does this scale with luminosity?

$\frac{N^2}{\Omega} \propto L$ $\quad \tau_i^2 \propto L^{-1}$ $\quad r_i^{\,2}$ is independent of lumi except $r_{BSM}^2 = \tau_{BSM}^2 \propto L^{-1}$.

If we assume $\Delta\xi_i = 0$ except $\Delta\xi_{BSM} = 0.035$ then

$\frac{1}{2}\frac{N^2}{\Omega}\sum_i r_i^{\,2}\left[\tau_i^2\delta_i^2 + \Delta\xi_i^2\right] = 0.11$ independent of the luminosity at $\sqrt{s} = 350$ GeV.

Model Independence of ZH Recoil Measurements

Caveats for hadronic recoil systematic error calculation :

(1) This systematic error analysis was only done at $\sqrt{s} = 350$ GeV; it has not yet been done for $\sqrt{s} = 250$ & 500 GeV

(2) These results assume that the true $r_{BSM} = BR(H \to$ BSM) is small. As the true r_{BSM} grows we need to keep the product $r_{BSM}\Delta\xi_{BSM}$ constant to maintain the same systematic error, where ξ_{BSM} is the effieciency for BSM Higgs decays to pass the hadronic recoil analysis. For example

true r_{BSM}	required $\Delta\xi_{BSM}$
.05	0.027
.10	0.014
.15	0.0091
.20	0.0068

These $\Delta\xi_{BSM}$ requirements may seem stringent for the larger values of true r_{BSM} . However as r_{BSM} grows we will have more *BSM* decays to analyze and the required improvement in Monte Carlo modelling of the *BSM* decays should follow.

ILC model independent global coupling fit using 32 $\sigma \bullet BR$ measurements Y_i and σ_{ZH} measurement Y_{33}

$$\chi^2 = \sum_{i=1}^{i=33} \left(\frac{Y_i - Y_i^{'}}{\Delta Y_i}\right)^2 ,$$

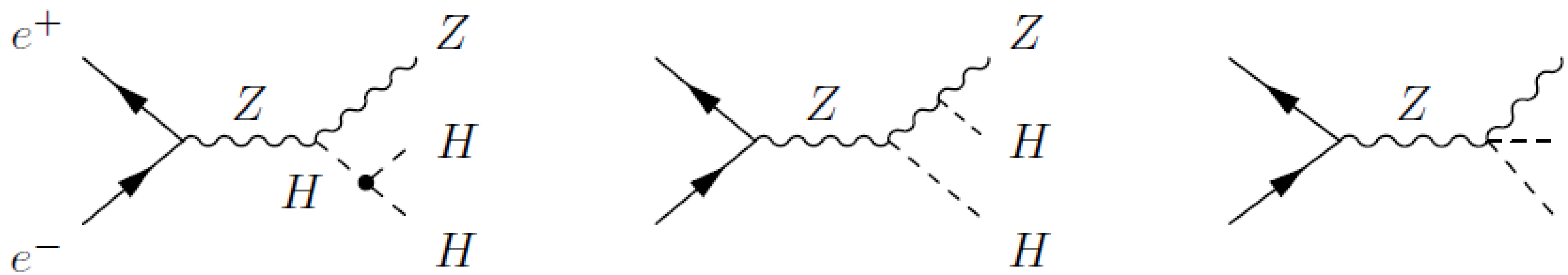
$$Y_i^{'} = F_i \cdot \frac{g^2_{HZZ} g^2_{Hb\bar{b}}}{\Gamma_0}, \text{ or } Y_i^{'} = F_i \cdot \frac{g^2_{HWW} g^2_{Hb\bar{b}}}{\Gamma_0}, \text{ or } Y_i^{'} = F_i \cdot \frac{g^2_{Htt} g^2_{Hb\bar{b}}}{\Gamma_0}$$

$$F_i = S_i G_i \quad \text{where } S_i = \left(\frac{\sigma_{ZH}}{g_Z^2}\right), \ \left(\frac{\sigma_{\nu\bar{\nu}H}}{g_W^2}\right), \ \text{or } \left(\frac{\sigma_{t\bar{t}H}}{g_t^2}\right), \ \text{and } G_i = \left(\frac{\Gamma_i}{g_i^2}\right).$$

The cross section calculations S_i do not involve QCD ISR.
The partial width calculations G_i do not require quark masses as input.

It is felt that the total theory errors for S_i and G_i - as well as the errors on the SM calculations for σ_i and Γ_i - will be at the 0.1% level at the time of ILC running.

ILC Higgs Self Coupling Measurement at $\sqrt{s} = 500$ GeV From $\sigma(e^+e^- \to ZHH)$



g_{hZZ} fixed to value from $\sigma(ZH)$ measurement

To handle g_{hhZZ} one can

(1) Assume g_{hhZZ} is fixed to SM value

(2) Assume g_{hhZZ} is fixed to some value related to measured g_{hZZ}

(3) Simultaneously measure g_{hhh} & g_{hhZZ}

Options (1) and (2) would have an additional theory systematic error associated with these assumptions

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Towards the Ultimate ILC Higgs Coupling Precision

or why it is important to pursue a good $BR(H \to BSM)$ measurement even if, as a result of this effort, no BSM decays are found.

Perform coupling fit with $\sum_i BR_i = 1$ including $\Delta BR(H \to BSM)$ for

(the constraint $\sum_i BR_i = 1$ is model independent if $\Delta BR(H \to BSM)$ is included in the fit)

ILC Higgs Coupling Precision assuming 20 year H20 scenario

$BR(H \to BSM)$ (95% CL)	no meas.	$< 7.2\%$	$< 3.6\%$	$< 1.8\%$	$< 0.9\%$	$< 0.09\%$
ZZ	0.31%	0.29%	0.26%	0.22%	0.20%	0.19%
WW	0.38%	0.36%	0.31%	0.25%	0.21%	0.19%
bb	0.60%	0.57%	0.52%	0.46%	0.42%	0.40%
$\tau^+\tau^-$	0.88%	0.86%	0.83%	0.79%	0.77%	0.76%
gg	0.92%	0.91%	0.88%	0.86%	0.85%	0.84%
cc	1.1%	1.1%	1.1%	1.1%	1.1%	1.0%
$\gamma\gamma$	3.1%	3.1%	3.1%	3.1%	3.1%	3.1%
Γ_{tot}	1.7%	1.6%	1.3%	1.0%	0.84%	0.74%

Summary

- For most of the Higgs decay modes the ILC obtains model independent errors ranging from a few per-mil to a few percent for the full H-20 program

- An error of 27% can be obtained for the Higgs self coupling assuming the full H-20 program.

- With statistical precision reaching a few per-mil, systematic errors become important. Arguments were made that both experimental and theoretical systematic errors can be held to the 0.1% level, but much work is needed to realize this.

- BSM decays, or the limits on BSM decays, play an interesting role in both the model independence of the hadronic recoil ZH cross section analysis, and in the achievement of the ultimate Higgs coupling precision at the ILC.