Report on ILC Parameters Committee Higgs Question

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Presented at SiD Workshop by
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Oct 26, 2006

1) **Assuming a Higgs mass of 120 GeV, what is the achievable precision for the mass measurement**

   a) **at threshold ?**

   b) **at Ecm=350 GeV?**

hep-ph/0302113

Determination of the Higgs boson spin with a linear e^+e^- collider

M.T. Dova[†], P. Garcia-Abia[*] and W. Lohmann[‡1]

Cross section for $e^+e^- \to ZH$ at threshold has been considered in the past for measurement of Higgs spin. How much does it help the mass measurement?

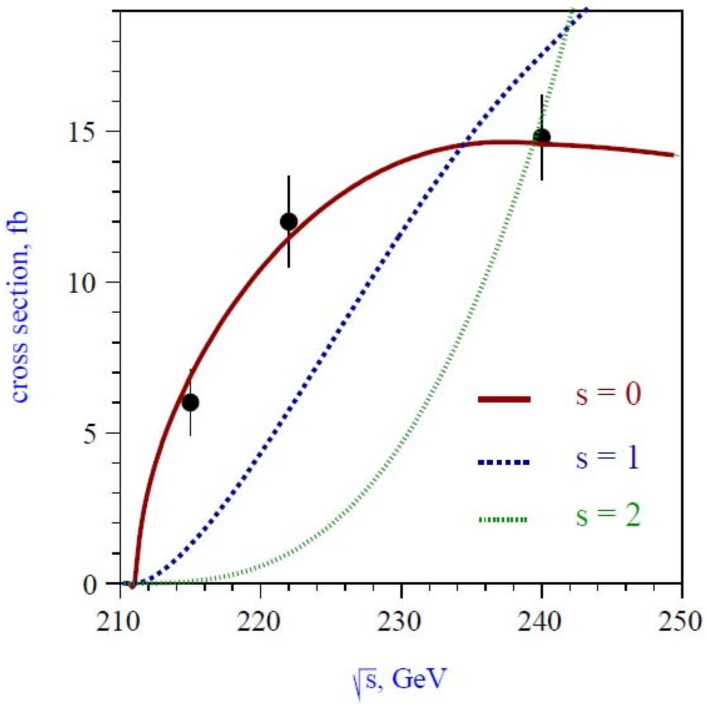


FIGURE 2. The cross sections determined at $\sqrt{s}$ = 215, 222 and 240 GeV (dots) and the predictions for s=0 (full line), s=1 (dashed line) and s=2 (dotted line).

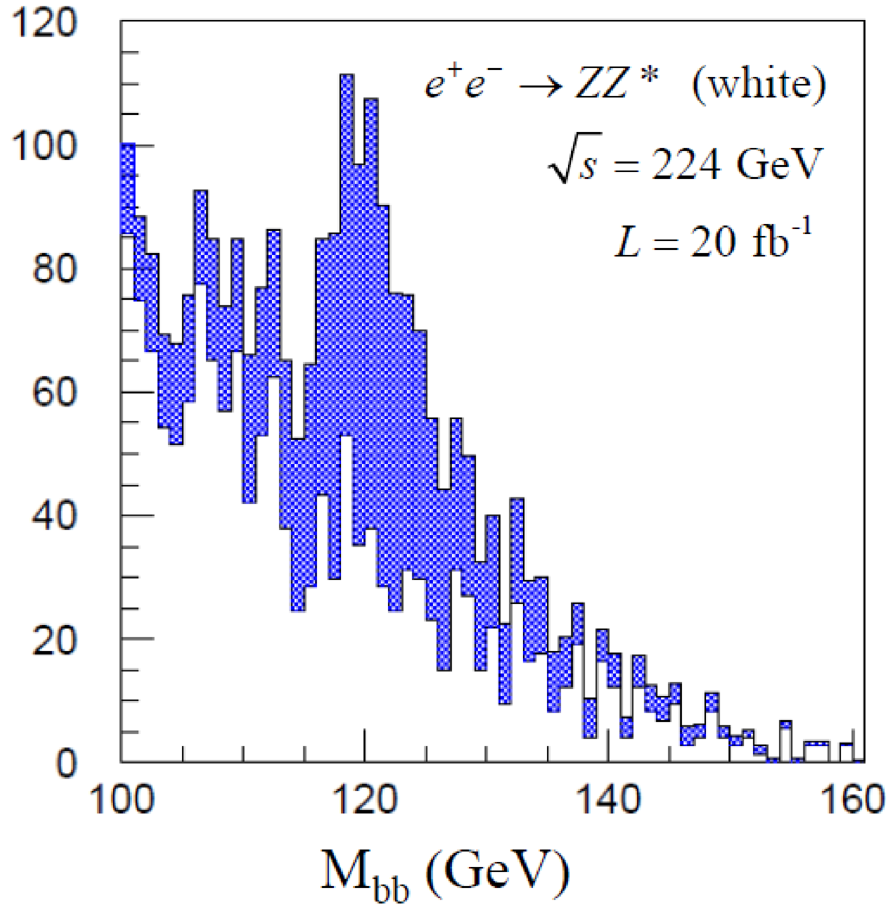
Threshold Scan

- The channel $e^+e^- \to llH \to llX$, $l = e, \mu$ provides the only model independent method of measuring the Higgs cross section at threshold if no branching fraction information is available.
- A relative accuracy of at least 2% for $BR(H \to b\bar{b})$ is required to utilize the channel $e^+e^- \to qqH \to qqbb$ in a model independent threshold measurement of the Higgs mass.

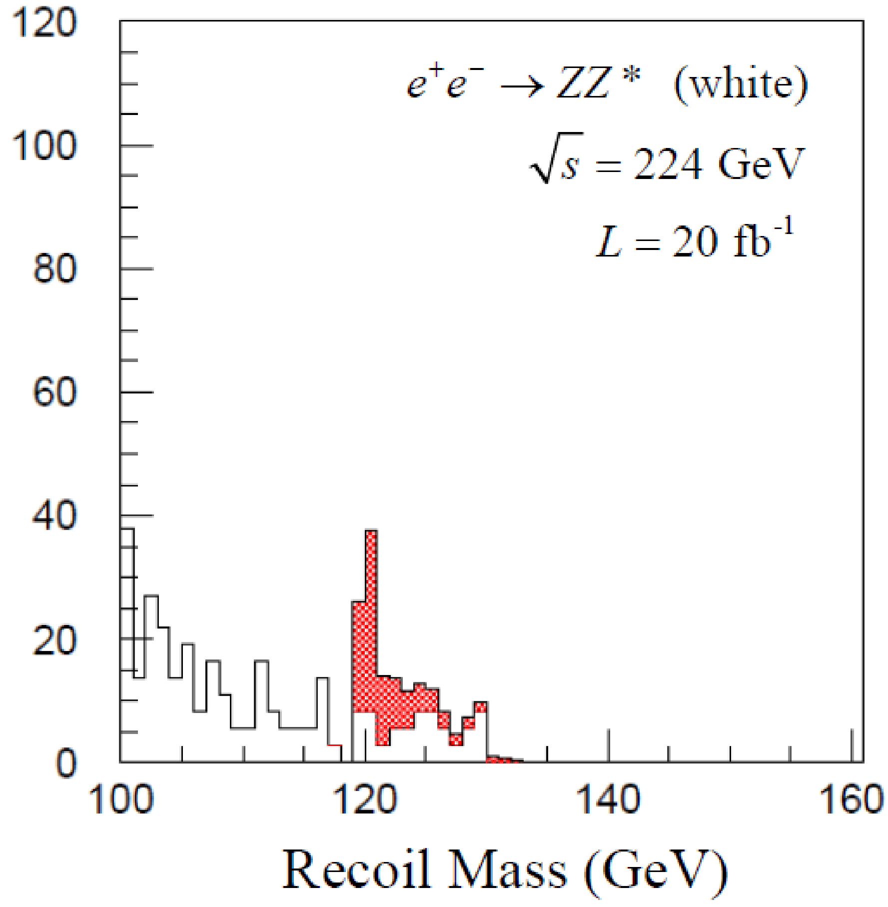
Threshold Scan

Higgs mass distributions for signals in two channels at Ecm=224 GeV following preselection cuts.

$e^+e^- \to ZH \to qqbb$ (blue)



$e^+e^- \to ZH \to llX$ (red)



Threshold Scan

Channel	ΔM_H (GeV)		$L_{eff} = \left[\frac{(\Delta M_H)_{\text{beamstr ON}}}{(\Delta M_H)_{\text{beamstr OFF}}} \right]^2$
	Beamstrahlung Off	Beamstrahlung On	
llX	0.5039	0.6107	1.469
$qqbb$	0.2124	0.2490	1.374
$\mu\mu X + qqbb$	0.1966	0.2318	1.390

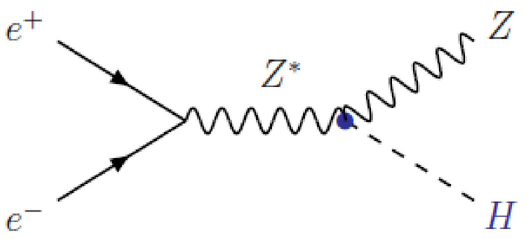
Table 1 Higgs mass error based on a fit of Higgstrahlung cross sections measured at Ecm= 213, 215, 217, 220, and 224 GeV with a luminosity of 20 fb^{-1} per point. The results for the qqbb channel are only valid if the Higgs bbar branching ratio has been measured with at least a 2% relative accuracy.

e^- pol	e^+ pol	$\sigma(\mu\mu H)$ (fb)	$\sigma(ZZ^*)$ (fb)	$S(500\,fb^{-1})$	$B(500\,fb^{-1})$	$\sqrt{(S+B)}/S$	L_{eff}
0	0	4.90	107.1	614.7	358.6	0.051	1.00
-0.8	0	5.76	134.2	722.6	449.4	0.047	1.18
-0.8	+0,6	8.76	205.8	1098.8	689.3	0.038	1.80

Table 2 Signal (S) and background (B) numbers following selection cuts for the Higgstrahlung process in the $\mu\mu X$ channel for different intial state polarizations.

$$L_{eff} = \frac{S_{00} + B_{00}}{S_{00}^2} \left(\frac{S+B}{S^2} \right)^{-1}$$

Ecm=350 GeV

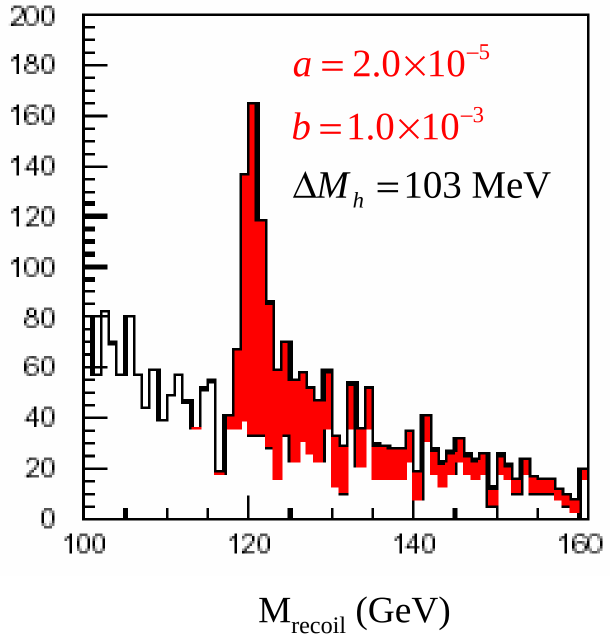


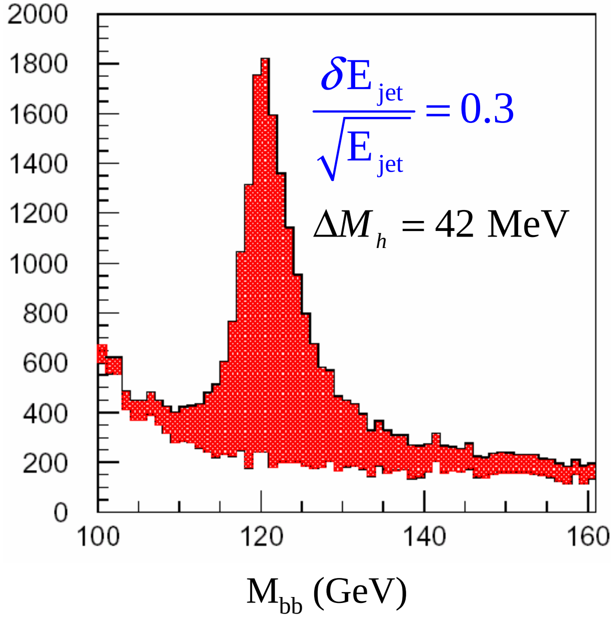
$$e^+e^- \to ZH$$
$$\to \mu^+\mu^- X$$

$$e^+e^- \to ZH$$
$$\to qqb\bar{b}$$

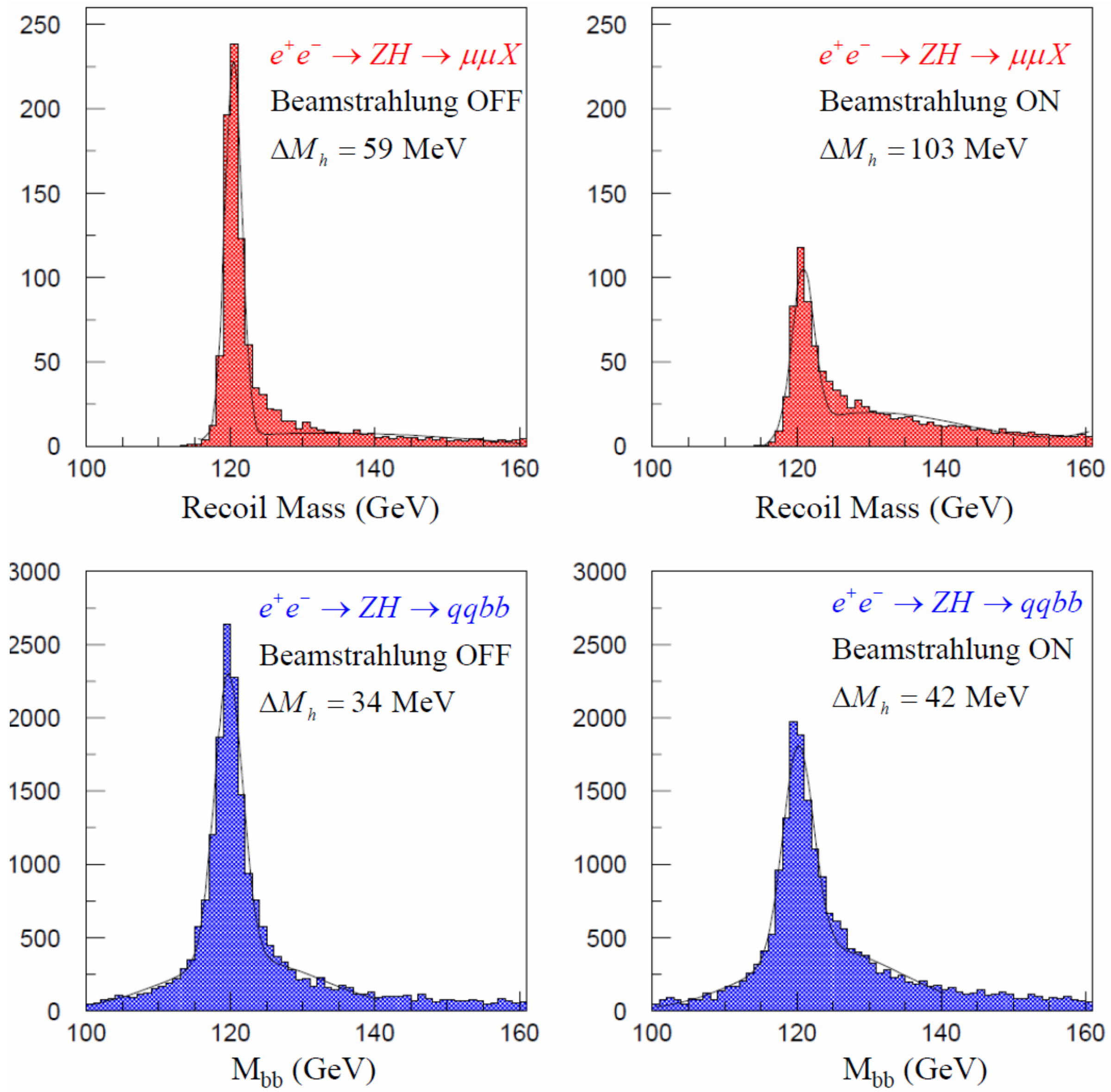
$$L = 500\ fb^{-1}$$

$$\frac{\delta p_t}{p_t^2} = a \oplus \frac{b}{p_t \sin\theta}$$





Ecm=350 GeV



$e^+e^- \to ZH \to \mu\mu X$
Beamstrahlung OFF
$\Delta M_h = 59$ MeV
Recoil Mass (GeV)
$e^+e^- \to ZH \to \mu\mu X$
Beamstrahlung ON
$\Delta M_h = 103$ MeV
Recoil Mass (GeV)
$e^+e^- \to ZH \to qqbb$
Beamstrahlung OFF
$\Delta M_h = 34$ MeV
M_{bb} (GeV)
$e^+e^- \to ZH \to qqbb$
Beamstrahlung ON
$\Delta M_h = 42$ MeV
M_{bb} (GeV)

Ecm=350 GeV

	Beamstrahlung Off			Beamstrahlung On			
Channel	σ_j (GeV)	A_j	$\Delta M_H = \frac{(\Delta M_H)_0}{\sqrt{L_{eff}}}$ (GeV)	σ_j (GeV)	A_j	$(\Delta M_H)_0$ (GeV)	$L_{eff} = \frac{(\sigma_j / A_j)_{\text{beamstr ON}}}{(\sigma_j / A_j)_{\text{beamstr OFF}}}$
$\mu\mu X$	1.169	222.3	0.059	1.491	94.10	0.103	3.01
$qqbb$	1.957	1968.4	0.034	2.132	1462.5	0.042	1.50

Table 3 Results of fitting Gaussian+polynomial to $\mu\mu X$ recoil mass distribution and Gaussian+Gaussian to the qqbb reconstructed Higgs mass distribution. Also shown are the estimates of the beamstrahlung off Higgs mass error based on these fit values. The errors on the Higgs mass with beamstrahlung on are taken from a previous study.

technique	Statistical error (GeV)	Beam energy systematic error (GeV)
recoil mass	0.103	0.200
$ZH \to llbb$	0.072	0.035
$ZH \to qqbb$	0.042	0.028
Combined	0.034	0.027

Table 4 Statistical and energy scale systematic errors for the Higgs mass measurements at the ILC with M_H=120 GeV, E_{cm}=350 GeV, 500 fb^{-1} luminosity, and a 200 ppm center of mass energy scale error. The combined energy scale systematic error includes the effects of correlations between the three measurements.

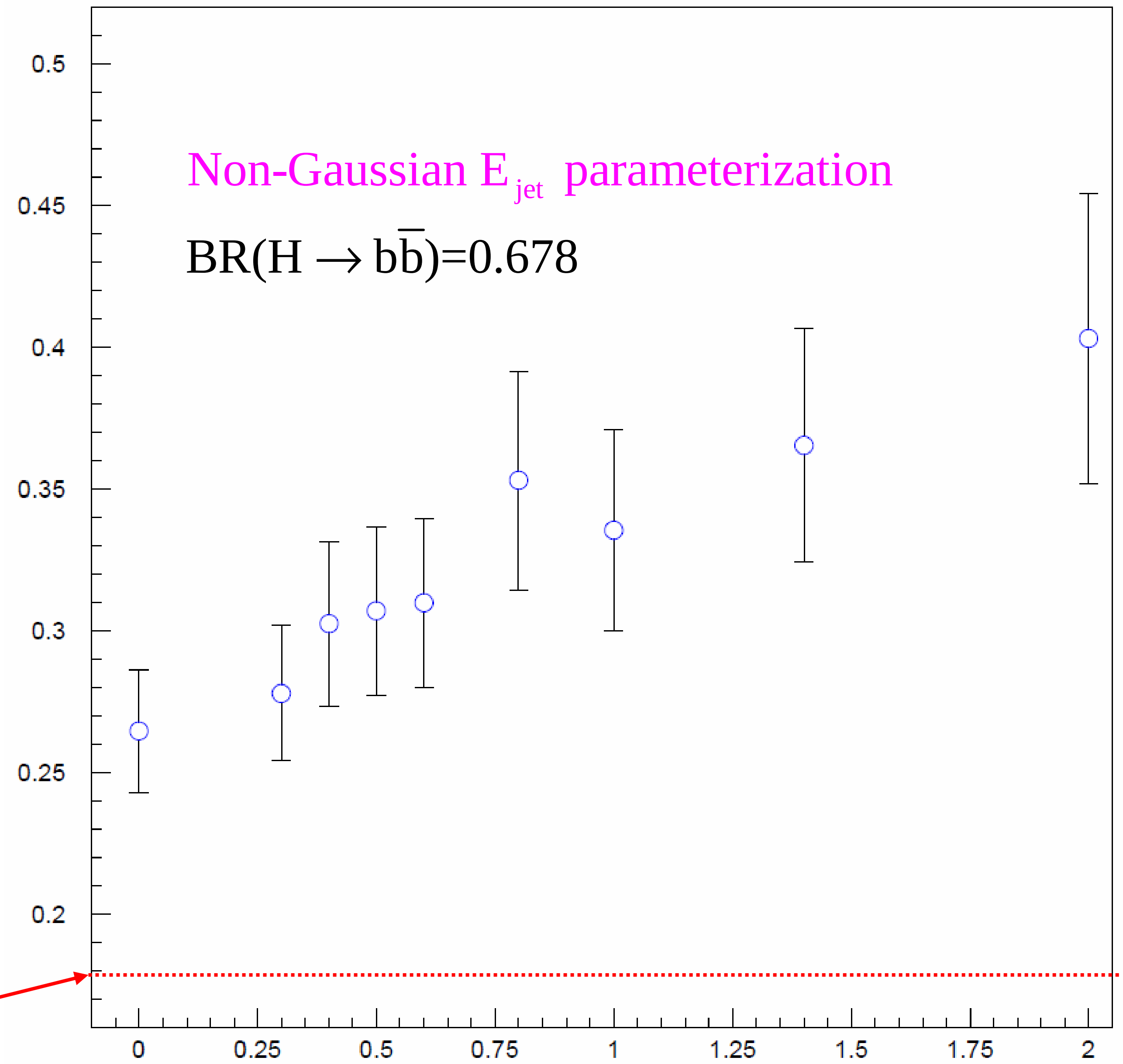
3) What is the expected precision achievable for the measurement of the triple Higgs coupling at center of mass energies of 0.5 and 1.0 TeV?

Triple Higgs Coupling at Ecm=500 GeV

$$e^+e^- \rightarrow ZHH$$
$$\rightarrow qqb\bar{b}b\bar{b}$$

$$\sqrt{s} = 500\ GeV$$
$$L = 2000\ fb^{-1}$$

$$\frac{\Delta g_{hhh}}{g_{hhh}}$$



TESLA TDR result

for $\frac{\delta E_{jet}}{\sqrt{E_{jet}}} = 0.3$

$$\frac{\delta E_{jet}}{\sqrt{E_{jet}}}\ (GeV^{\frac{1}{2}})$$

Can’t Replicate TESLA TDR signal efficiency and background rejection:

$\sigma(e^+e^- \to ZHH) = 0.186$ fb at $\sqrt{s} = 500$ GeV

$\mathrm{BR}(H \to b\bar{b}) = 0.678$ for $M_H = 120$ GeV $\mathrm{BR}(Z \to qq) = 0.699$ $\mathrm{BR}(Z \to l^+l^-) = 0.1$

Before cuts $N_{qqHH} = 65$ $N_{llHH} = 9$ and $N_{qqbbbb} = 30$ $N_{llbbbb} = 4$ for 500 fb^{-1}

$B^{recoil} > 1$ means one or more b-jets in system recoiling against Z

$B^{recoil} > 2$ means two or more b-jets in system recoiling against Z

W^+W^- and $Z\gamma$ are mostly $W^+\bar{t}b$ and $t\bar{t}\gamma$ -- i.e. $t\bar{t}$

One major difference between this analysis and TESLA TDR is that 3 of 4 jets recoiling against the Z must be tagged as b-jets in order to control $t\bar{t}$ background, given these preselection cuts.

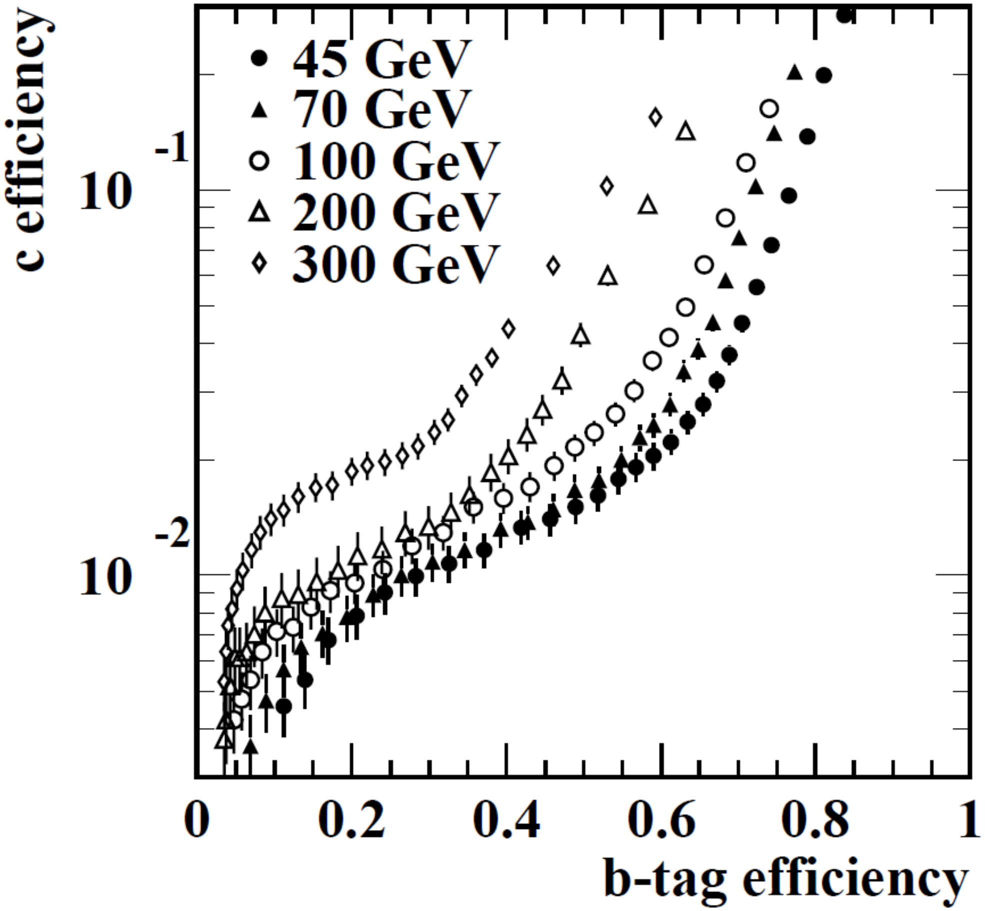
process	preselection	b-content $\mathcal{B}^{recoil}>1$	b-content $\mathcal{B}^{recoil}>2$	NNet >0
$hhq\bar{q}$	41.4	34.	27.1	27.5
$hh\ell^+\ell^-$	6.7	6.2	5.1	6.4
total hhZ	49.1	40.2	32.2	33.9
WW	2114.	233.	74.3	32.
$Z\gamma$	44938.	116.	34.	24.
ZZ	484.	7.4	0.	0.
WWZ	331.	0.6	0.	0.14
ZZZ	56.6	19.	9.	8.4
hZ	174.	0.	0.	0.
$t\bar{t}h$	3.	0.	0.	0.
total bkg.	48089.	376.	117.4	64.3
s/b	0.1%	11%	27%	53%
$s/\sqrt{b}$	0.22	2.	3.	4.2
selection index		B	C	D

Table 2: *Numbers of events with $\mathcal{L}$= 500fb^{-1} expected both for signal and background processes at preselection level, standard selections (two set of cut on $\mathcal{B}^{recoil}$) and multivariable analysis; s/b and $s/\sqrt{b}$ are also indicated.*

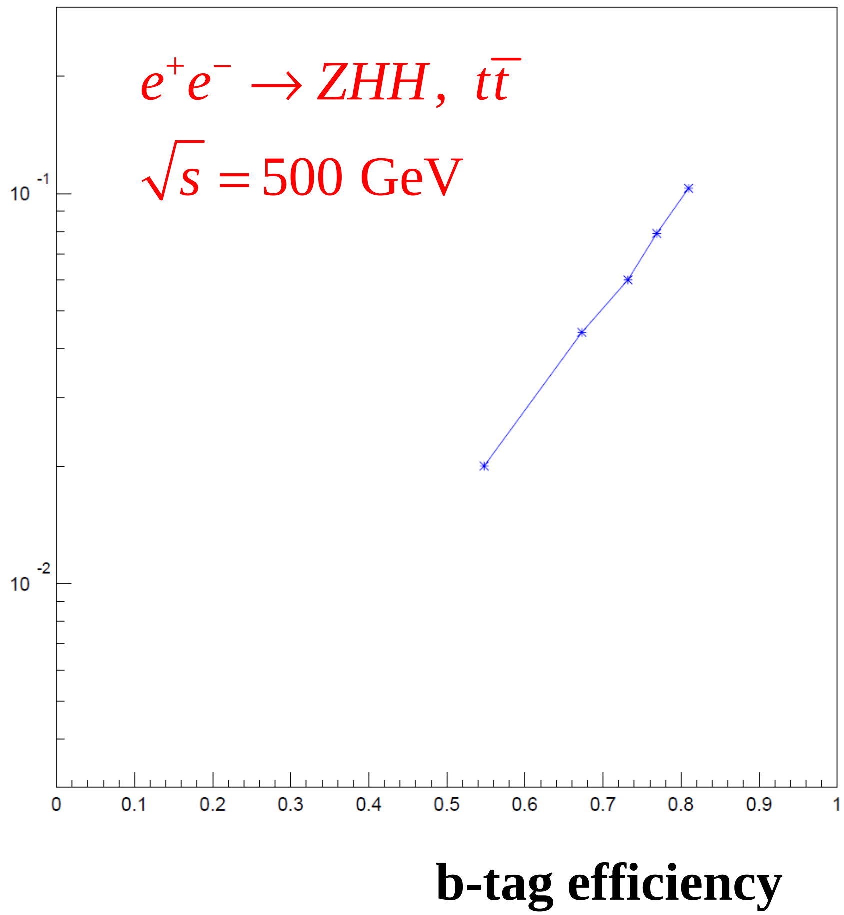
C. Castanier et al. hep-ex/0101028

charm mis-id efficiency versus b-tag efficiency

R. Hawkings, LC-PHSM-2000-021



SiD ZHH Analysis

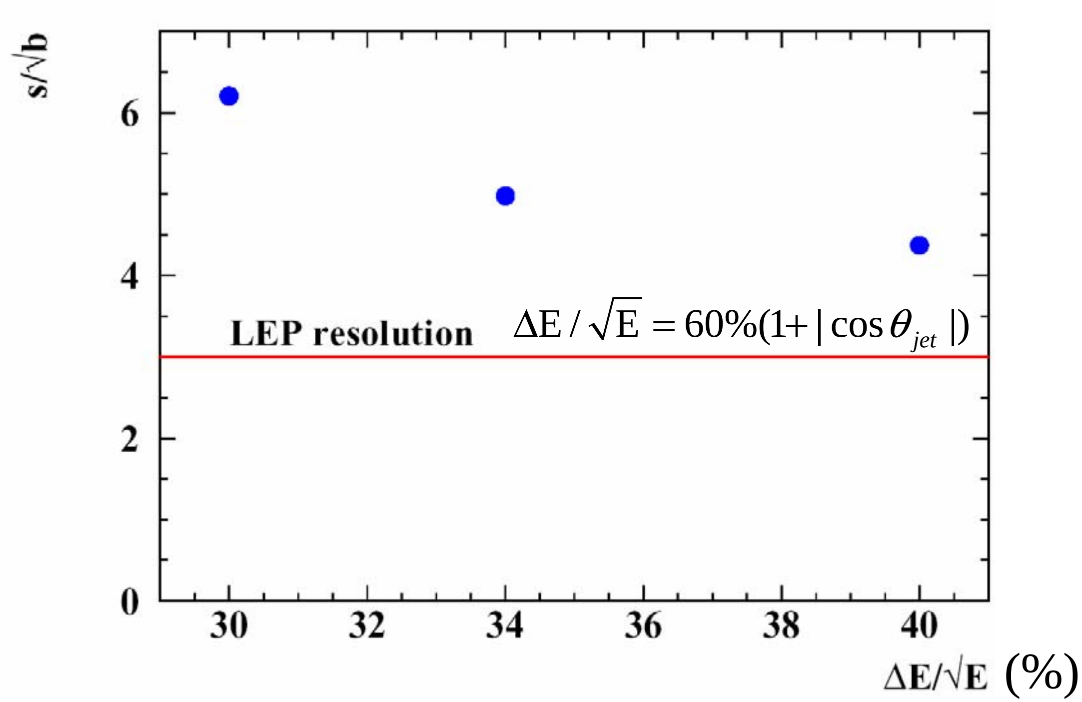


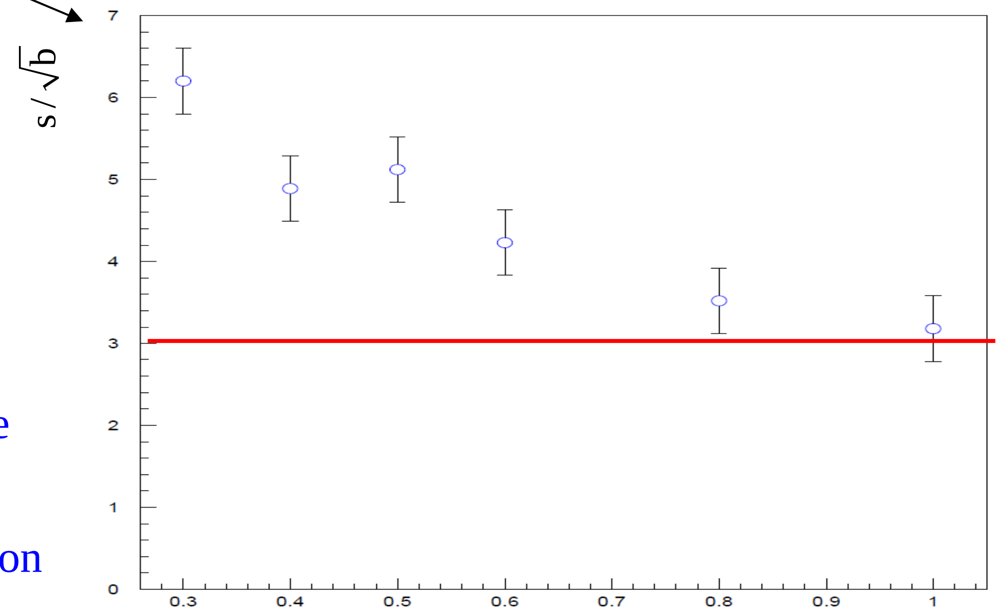
$$e^+e^- \to ZHH$$
$$\to qqb\bar{b}b\bar{b},$$
$$l^+l^-b\bar{b}b\bar{b}$$
$$\sqrt{s} = 500\ GeV$$
$$L = 1000\ fb^{-1}$$

Non-Gaussian E_{jet} parameterization

$BR(H \to b\bar{b}) = 0.853$

include $qqb\bar{b}b\bar{b}$ & $l^+l^-b\bar{b}b\bar{b}$





$s/\sqrt{b}$ is a poor measure of Δg_{HHH} :

(1) $s/\sqrt{s+b}$ should be used when signal & background comparable

(2) We don't cut on the neural net variable and count remaining events; the whole neural net distribtion following preselection is used to fit for g_{HHH}

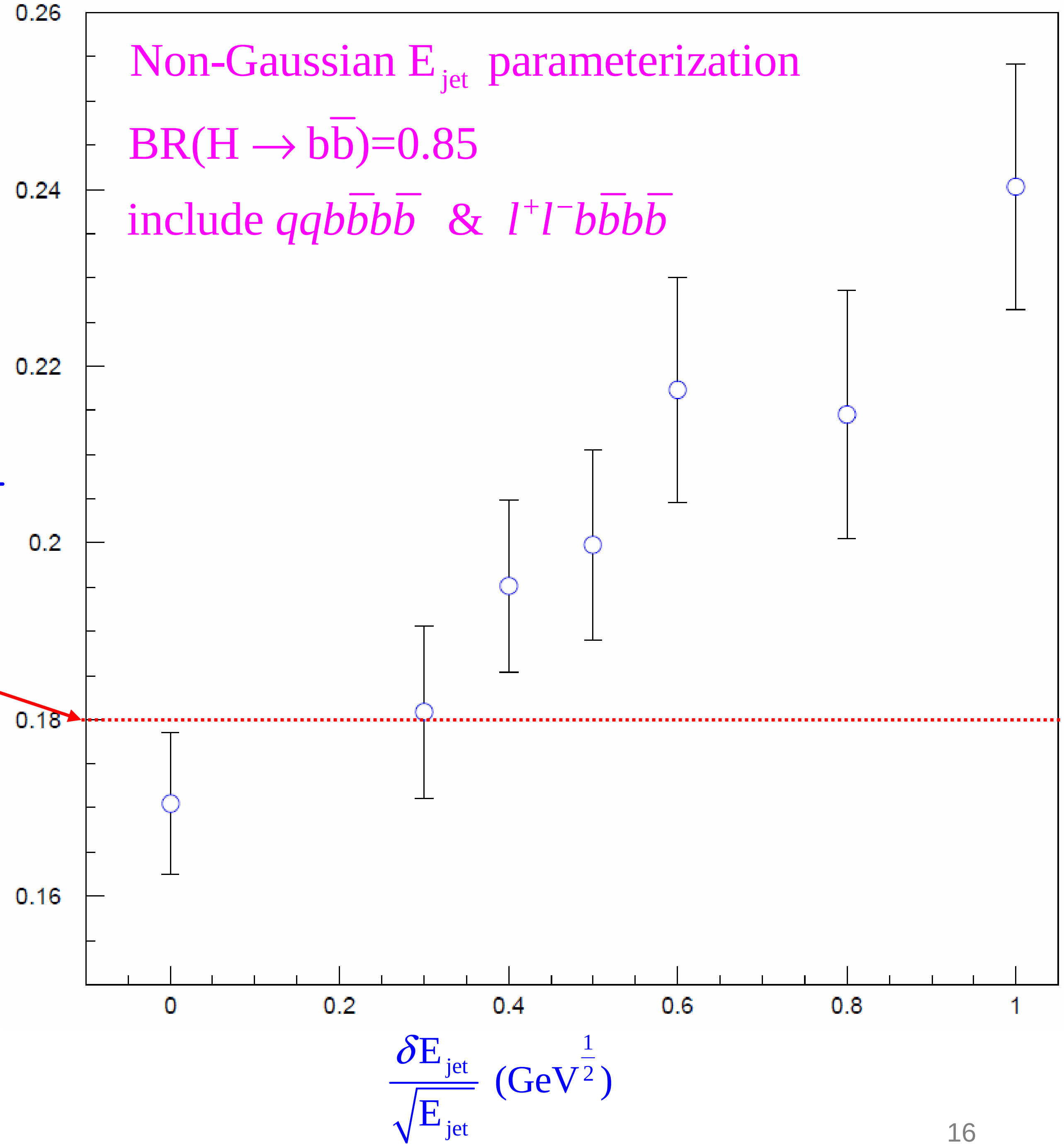
$$e^+e^- \to ZHH$$
$$\to qqb\bar{b}b\bar{b},$$
$$l^+l^-b\bar{b}b\bar{b}$$

$\sqrt{s} = 500\ GeV$

$L = 2000\ fb^{-1}$

$$\frac{\Delta g_{hhh}}{g_{hhh}}$$

TESLA TDR result for $\frac{\delta E_{jet}}{\sqrt{E_{jet}}} = 0.3$



$\Delta E/\sqrt{E} = 60\% \to 30\%$

equiv to $1.4\times$ Lumi

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

$$\sqrt{s} = 500\ GeV$$

$$L = 2000\ fb^{-1}$$

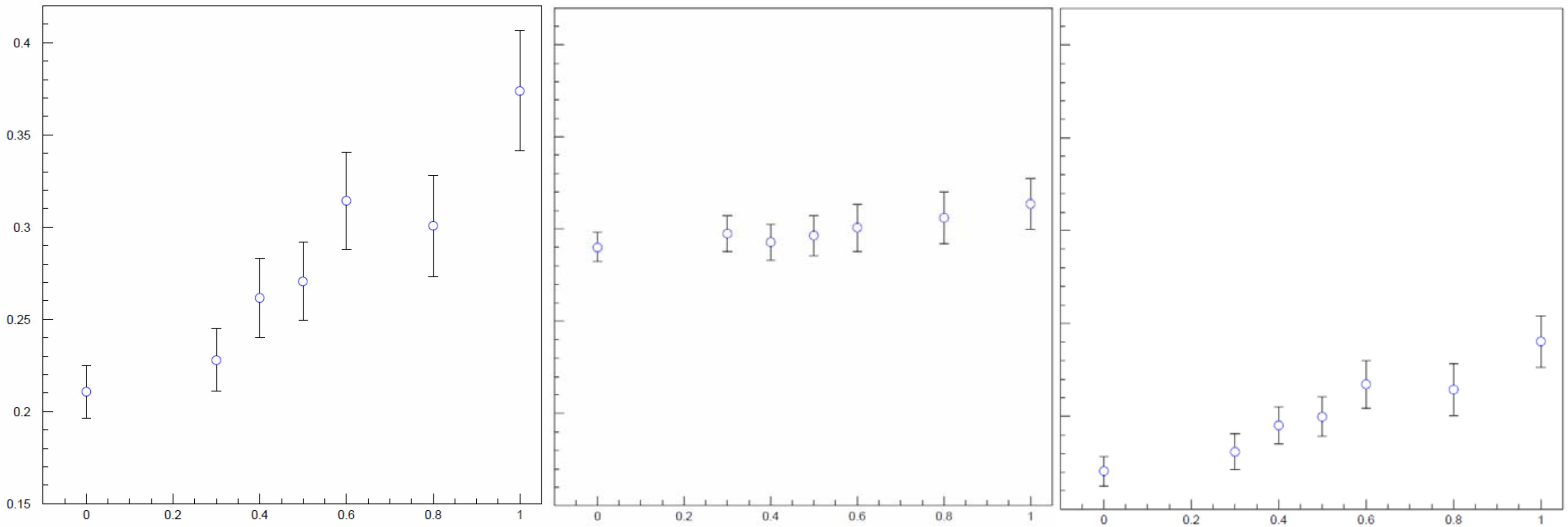
SiD

Non-Gaussian E_{jet} parameterization

$BR(H \to b\bar{b}) = 0.85$

$qqb\bar{b}b\bar{b}$ only | $l^+l^-b\bar{b}b\bar{b}$ | $qqb\bar{b}b\bar{b}$ & $l^+l^-b\bar{b}b\bar{b}$

$$\frac{\Delta g_{hhh}}{g_{hhh}}$$



$$\frac{\delta E_{jet}}{\sqrt{E_{jet}}}\ (GeV^{\frac{1}{2}})$$

$qqb\bar{b}b\bar{b}$ only

$$e^+e^- \rightarrow ZHH$$

$\sqrt{s} = 500\ GeV$

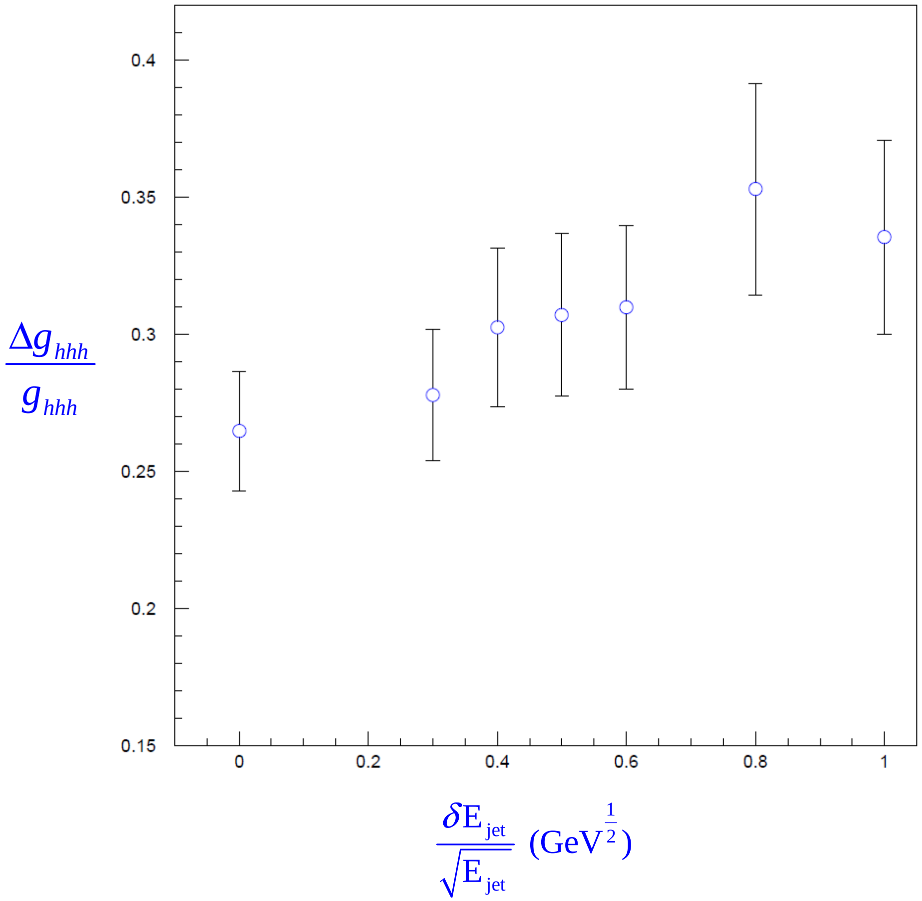
$L = 2000\ fb^{-1}$

SiD

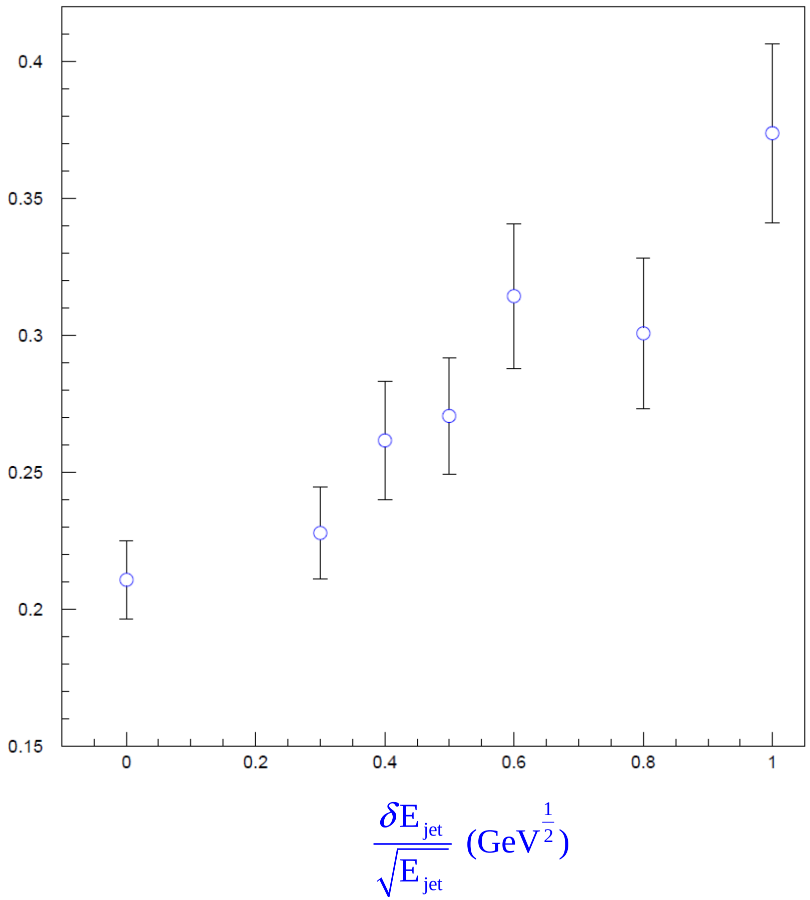
Non-Gaussian E_{jet} parameterization

$qqb\bar{b}b\bar{b}$ only

BR($H \rightarrow b\bar{b}$)=0.68



BR($H \rightarrow b\bar{b}$)=0.85

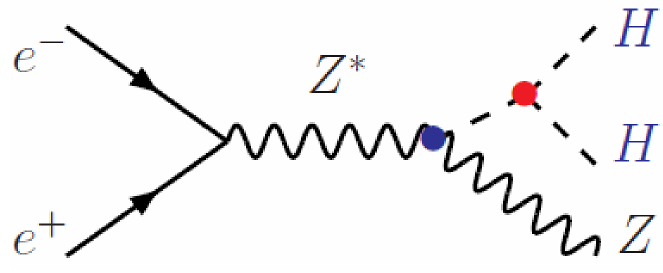


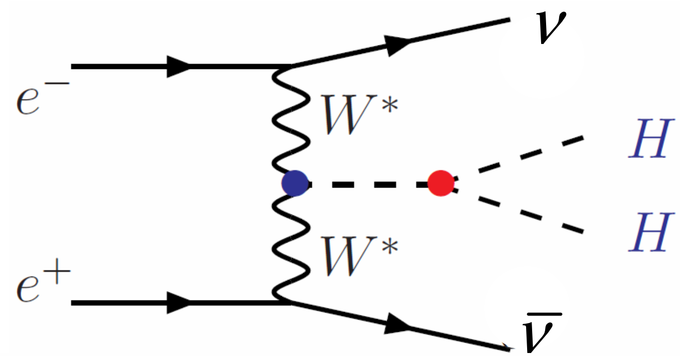
Jet Energy Resolution Conclusions

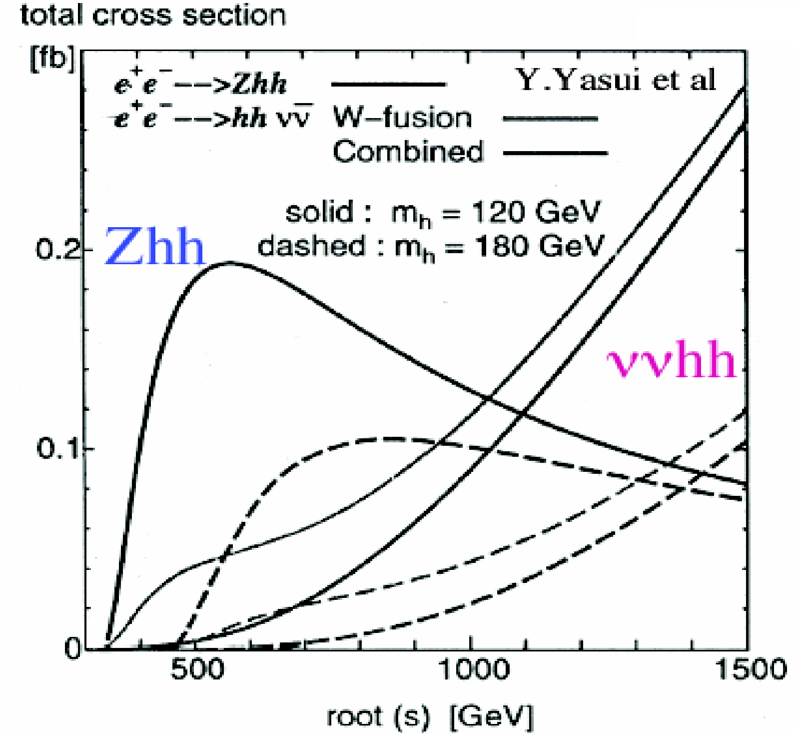
- Most ILC physics studies indicate an effective luminosity gain of 40% as the jet energy resolution is improved from 60% to 30% over sqrt(E).
- The TESLA TDR study of g_{HHH} appeared to show an effective luminosity gain of a factor of 4 as the jet energy resolution is improved from 60% to 30%. However the data point at 60% corresponded in truth to 100%/sqrt(E) resolution, and the quantity S/sqrt(B) was a poor measure of Δg_{HHH}. Assuming BR($H \rightarrow bb$)=0.853 and adding the contribution from $ZHH \rightarrow llbbbb$, the SiD analysis can replicate the TESLA TDR result. The effective luminosity gain is 40% when the jet energy resolution is improved from 60% to 30% over sqrt(E).
- More physics studies involving direct W and Z production are required before conclusions can be drawn regarding required calorimeter performace.

Results from study of triple Higgs coupling error versus jet energy resolution do not reflect ultimate g_{HHH} precision at the ILC.

Methods will be developed to exploit other Higgs decay modes. Analysis at $\sqrt{s} = 1$ TeV will lead to a significant improvement. A precision of 10% can be eventually be achieved when data at $\sqrt{s} = 0.5$ & 1.0 TeV is combined.







Triple Higgs Coupling at Ecm=500 GeV

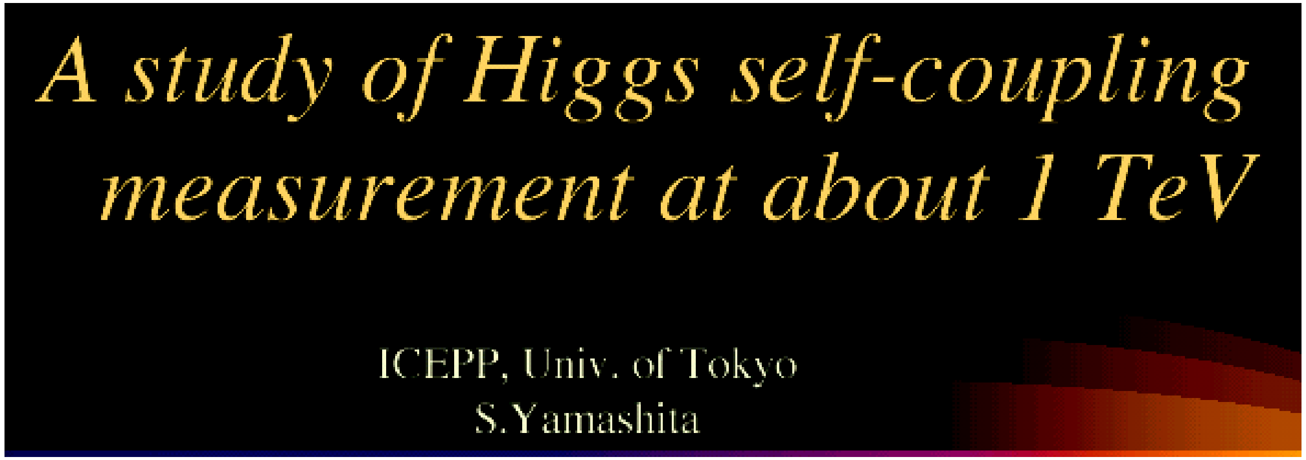
Beamstrahlung	$\sigma(ZHH)$ (fb)	$\sigma(t\bar{t})$ (fb)	$S(2000\,fb^{-1})$	$B(2000\,fb^{-1})$	$\sqrt{(S+B)}/S$	L_{eff}
ON	0.155	389.7	62.0	77.9	0.191	1.00
OFF	0.159	386.9	63.6	77.4	0.187	1.04

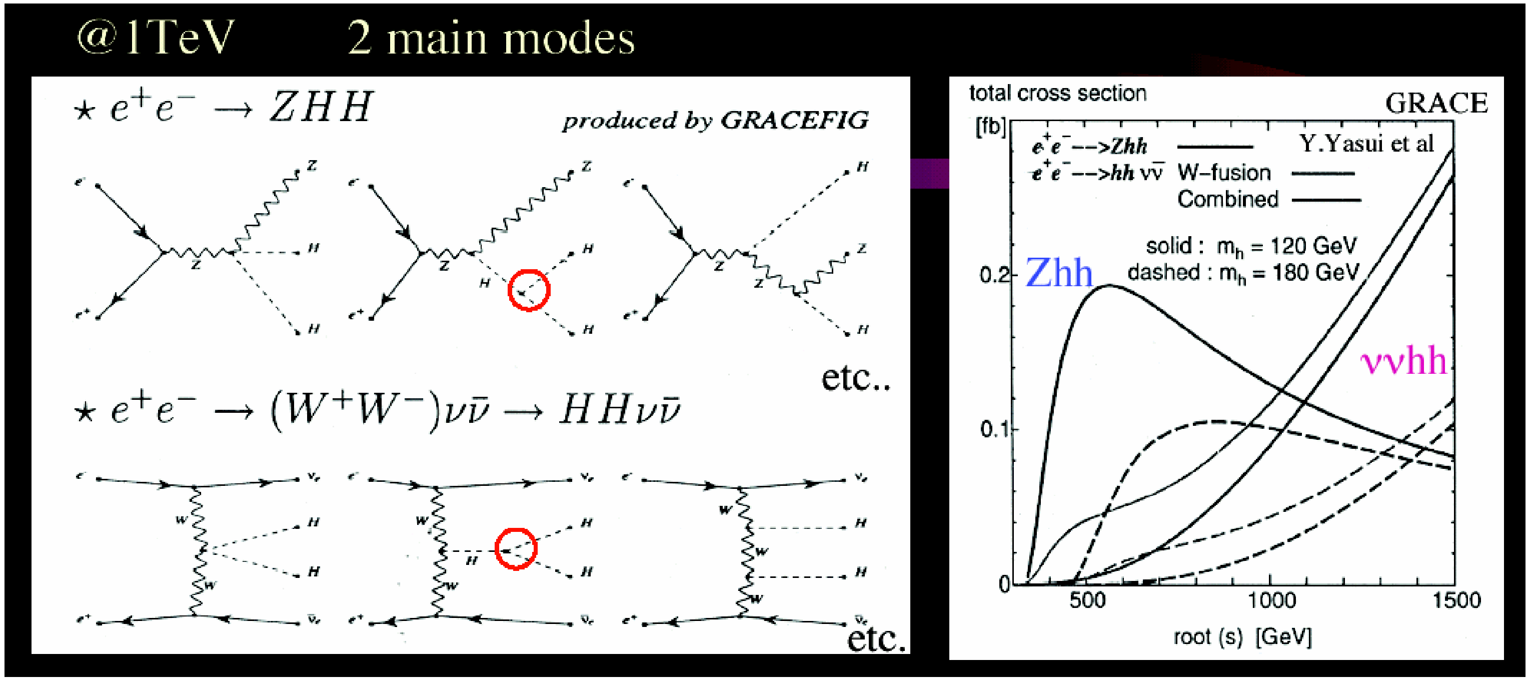
Table 11 Cross sections before cuts as well as signal (S) and background (B) following cuts for beamstrahlung on and off assuming E_{cm}=500 GeV and 2000 fb-1 luminosity. The signal efficiency is 0.2 and the background efficiency is 10^{-4}.

e^- pol	e^+ pol	$\sigma(ZHH)$ (fb)	$\sigma(t\bar{t})$ (fb)	$S(2000\,fb^{-1})$	$B(2000\,fb^{-1})$	$\sqrt{(S+B)}/S$	L_{eff}
0	0	0.155	532.0	62.0	106.4	0.209	1.00
-0.8	0	0.182	704.7	72.8	140.9	0.201	1.08
-0.8	+0,6	0.277	1089.6	110.8	217.9	0.164	1.62
+0.8	0	0.128	359.2	51.0	71.8	0.217	0.93
+0.8	-0.6	0.182	485.0	72.8	97.0	0.179	1.36

Table 12 Cross sections before cuts as well as signal (S) and background (B) following cuts for different initial state polarizations assuming E_{cm}=500 GeV and 2000 fb-1 luminosity. The signal efficiency is 0.2 and the background efficiency is 10^{-4}.

Triple Higgs Coupling at Ecm=1000 GeV





Triple Higgs Coupling at Ecm=1000 GeV

For M_h=120 GeV: Λ measurement sensitivity (c

for $\Lambda = \Lambda_{SM}$	Λ/Λ_{SM}=1.0 +0.13 -0.11 (1σ)
Λ/Λ_{SM}=0.6	0.6 +0.10 -0.07 (1σ)
Λ/Λ_{SM}=1.4	1.4 +0.14 -0.18 (1σ)

Analysis is premature, and can increase the sensitivity. - e.g. when non-b decay of Higgs is included (especially important for M_h>130 GeV)

Relative phase (and sign) of Λ can be measured using interference comparing results from Zhh and fusion processes, or results of different E_{cm}'s.

Triple Higgs Coupling at Ecm=1000 GeV

Beamstrahlung	$\sigma(\nu\nu HH)$ (fb)	$S(1000\,fb^{-1})$	$1/\sqrt{S}$	L_{eff}	$\frac{\Delta g_{hhh}}{g_{hhh}}$
ON	0.2086	66.75	0.122	1.00	0.12
OFF	0.2269	72.61	0.117	1.09	0.11

Table 13 Cross section before cuts as well as signal (S) following cuts for beamstrahlung on and off assuming E_{cm}=1000 GeV 1000 fb-1 luminosity, -80% electron polarization and 0% positron polarization. The signal efficiency is 32%.

e^- pol	e^+ pol	$\sigma(\nu\nu HH)$ (fb)	$S(1000\,fb^{-1})$	$1/\sqrt{S}$	L_{eff}	$\frac{\Delta g_{hhh}}{g_{hhh}}$
0	0	0.0758	24.24	0.203	0.58	0.14
-0.8	0	0.1309	41.89	0.155	1.00	0.12
-0.8	+0,6	0.2086	66.75	0.122	1.61	0.09

Table 14 Cross sections before cuts as well as signal (S) following cuts for different initial state polarizations assuming E_{cm}=1000 GeV and 1000 fb-1 luminosity. The signal efficiency is 0.32 .