Pheno Parallel Talk, May 4th 2015

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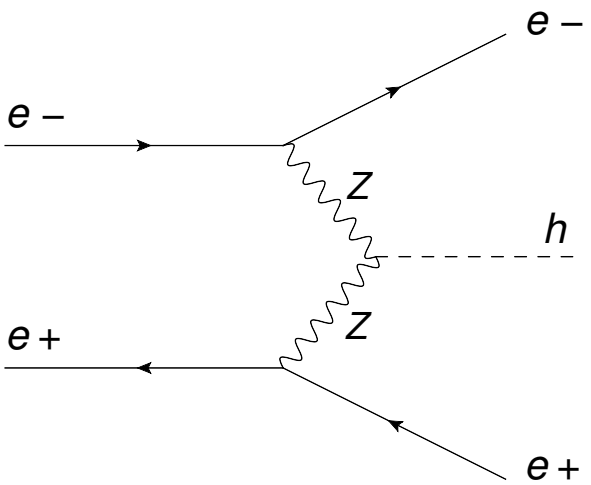


Improving ZZh coupling measurement through ZZ fusion channel at ILC

Based on work with T. Han, Z. Liu and J. Sayre

arXiv: 1504.01399

Contents:

- Introduction
  - Inclusive cross section
  - ILC
- Analysis
  - Signal, Background
  - Kinematic Variables, Cuts and Distribution
  - Multivariate log-likelihood analysis
- Results
- Possible constraints on dim-6 Operators

Main Results: Improved sensitivity on Higgs width and couplings:

Relative Error %	ILC 250+500		ILC 250+500+1000	
$\delta\sigma_{Zh}$	6.0%		2.5%	
Improvement		with HL-LHC		with HL-LHC
Γ	4.8 → 4.7	4.8 → 4.6	4.5 → 3.7	4.5 → 3.7
g_Z	0.99 → 0.94	0.99 → 0.94	0.98 → 0.75	0.98 → 0.75
g_W	1.1 → 1.1	1.1 → 1.1	1.1 → 0.89	1.1 → 0.88
g_b	1.5 → 1.5	1.5 → 1.5	1.3 → 1.2	1.3 → 1.1

Table 6. The improvement on selected coupling precisions by incorporating our ZZ fusion analysis from a typical 10-parameter model-independent fit. We show both the ILC exclusive results and ILC combined with the optimistic CMS HL-LHC input [27]. For details of fitting scheme and combination scheme, see Ref. [16]. The results for ILC 250/500/1000 (GeV) assume 250/500/1000 fb^{-1} integrated luminosities.

- Higgs Precision measurement

- A light Higgs at 125.09±0.21 (stat.)±0.11 (syst.) GeV

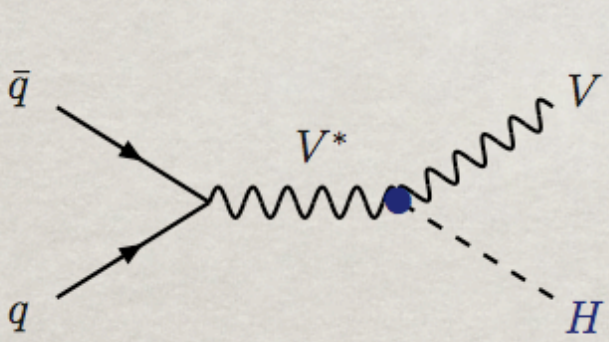
(CMS+ATLAS)

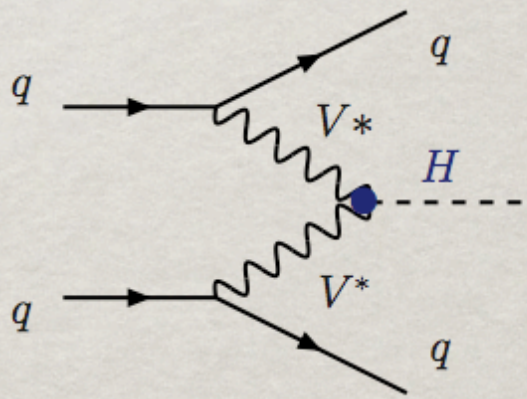
- Poorly constrained width accommodates potentially BSM physics.

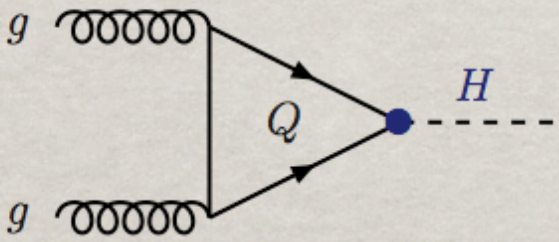
- From previous analysis (ILC included), the model independent Higgs width is constrained to ~5%.

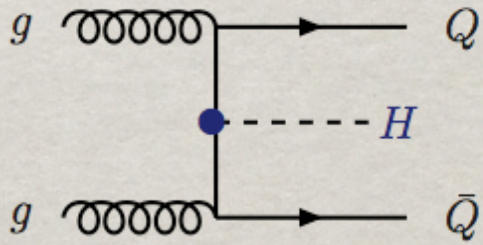
Higgs production at the LHC:

associated production with W/Z :	$q\bar{q} \longrightarrow V + H$
vector boson fusion :	$qq \longrightarrow V^*V^* \longrightarrow qq + H$
gluon − gluon fusion :	$gg \longrightarrow H$
associated production with heavy quarks :	$gg, q\bar{q} \longrightarrow Q\bar{Q} + H$



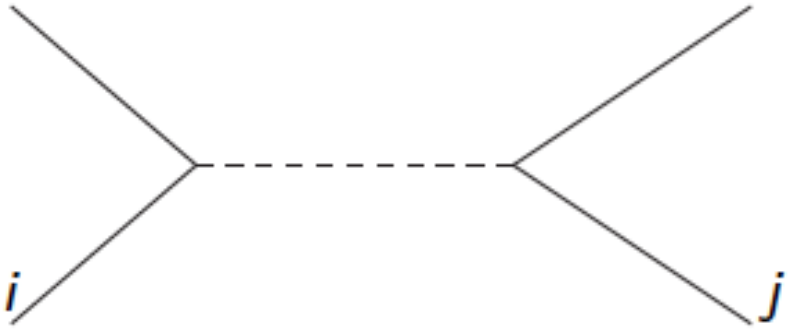






- Credit: Higgs production at the LHC, T. Han

Problems



$$\sigma_{ij} \propto \frac{g_i^2 g_j^2}{\Gamma} \quad \text{(NWA)}$$

"Scaling degeneracy"

Solution

Inclusive Higgs Production Cross section from the Higgs coupling to A :

$$\sigma_A^{inc} \propto g_A^2$$

- Potential precision on Higgs couplings and total width at the ILC, T. Han, Z. Liu, J. Sayre

ILC collider

(International Linear Collider)

A linear lepton (e+ e-) collider

Advantages:

Definite initial state: e-, e+

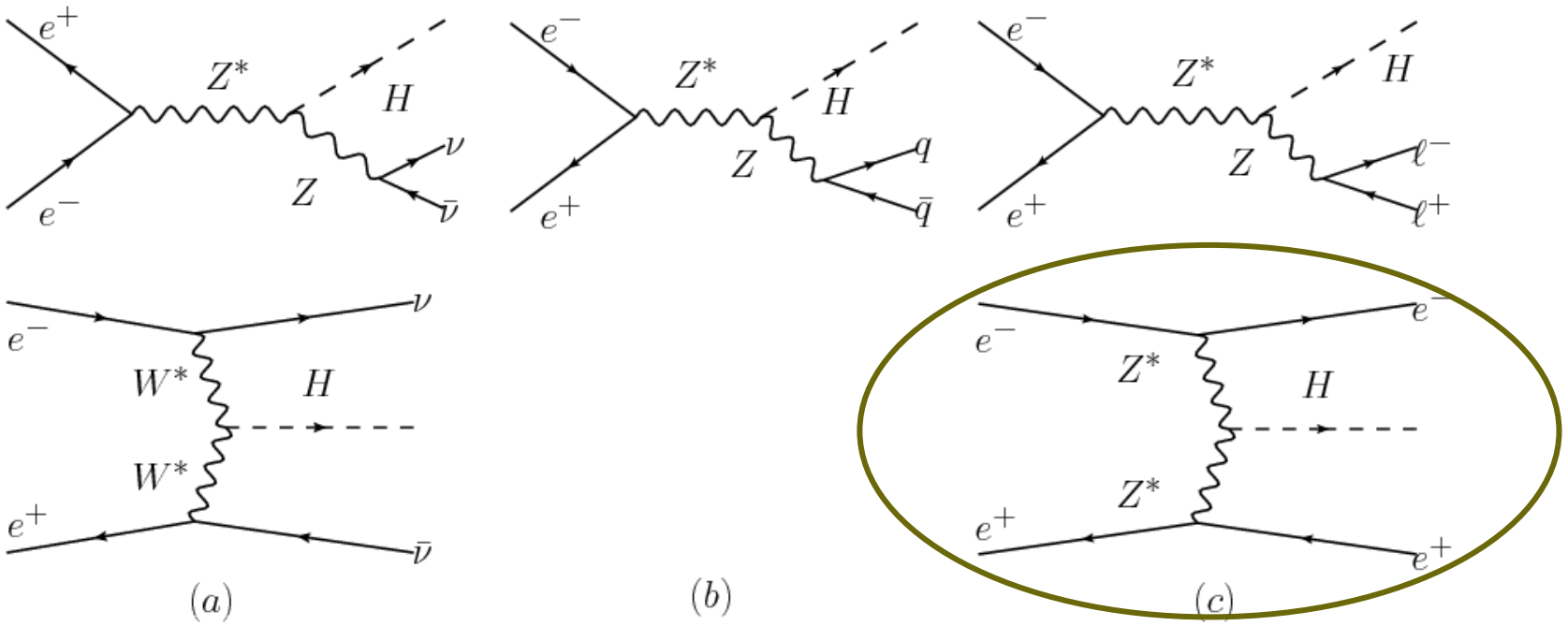
Definite center of mass energy: $\sqrt{s}$

Previous study:

- Inclusive cross-section σ_A^{inc} can be measured to relative errors 2.6% and 3%, from studying "Higgsstrahlung" channel at 250Gev and 500Gev ILC.
- Suggested to look at ZZ fusion channel

- Potential precision on Higgs couplings and total width at the ILC, T. Han, Z. Liu, J. Sayre

Higgs Production at an e+ e- collider



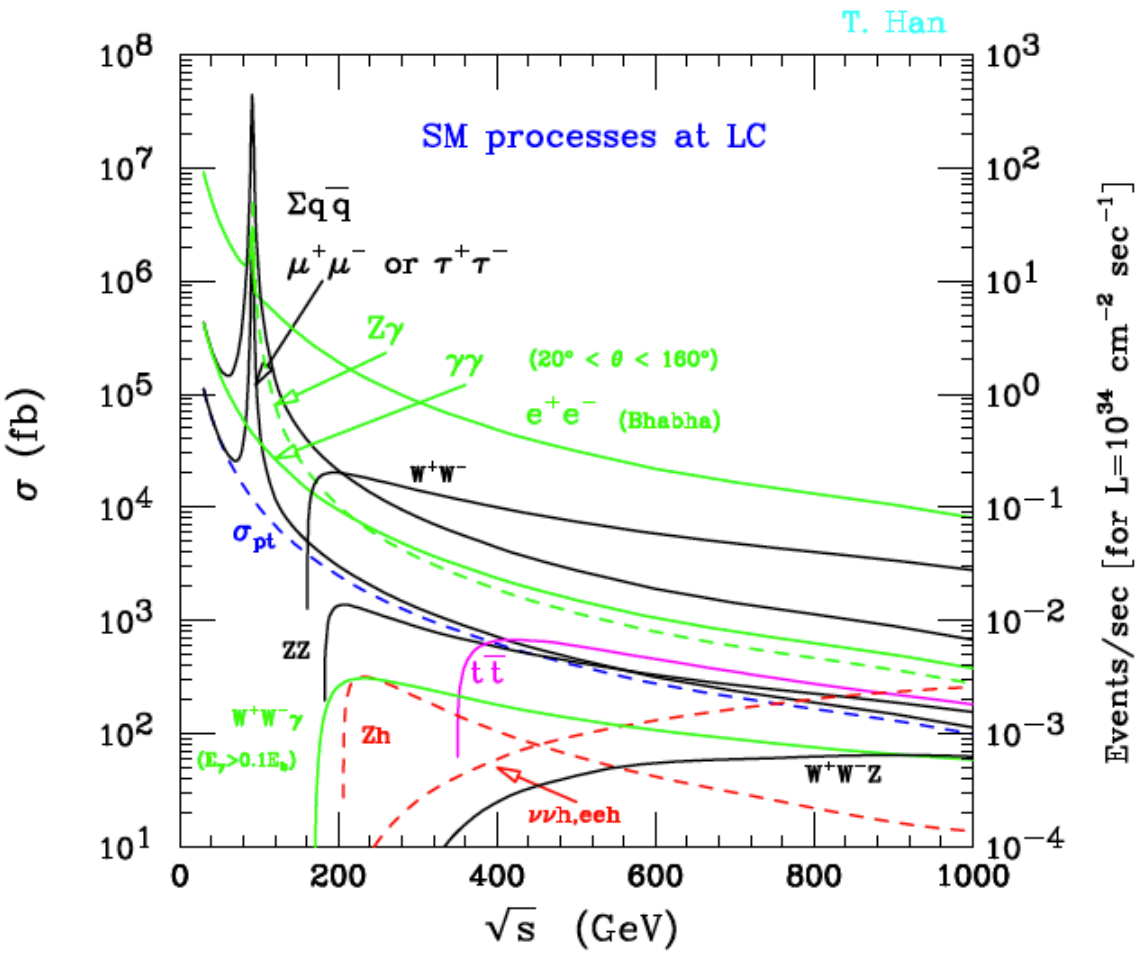
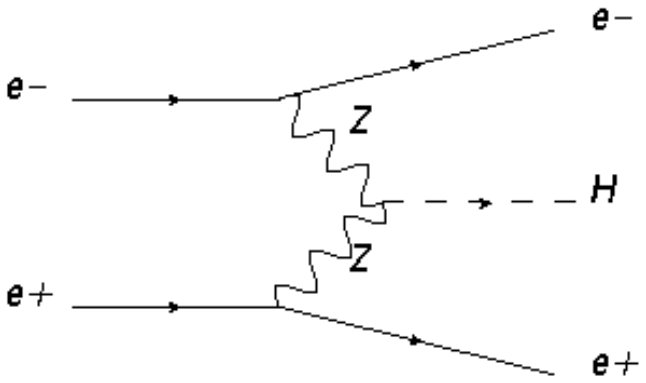


FIG. 2: Scattering cross sections versus c.m. energy for the SM processes in e^+e^- collisioins. The Higgs boson mass has been taken as 120 GeV.

Signal and Background definition



Processes list:

e- e+ > e- e+ h
e- e+ > e- e+ v v~
e- e+ > e- e+ q q~
e- e+ > e- e+ l- l+
e- e+ > e- e+ a a
e- e+ > e- e+ a

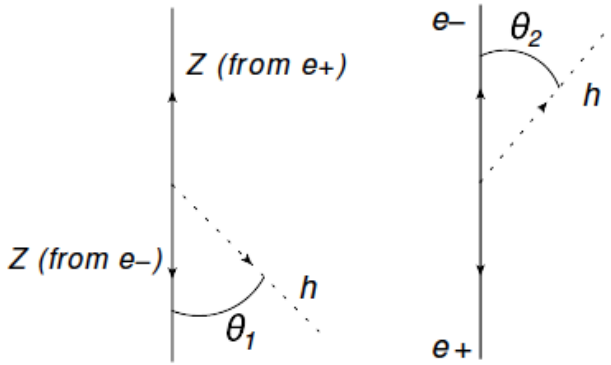
Whizard 1.95 (ISR, Beam-strahlung) and Pythia (FSR, hadronizatiton)
SGV – fast detector simulation

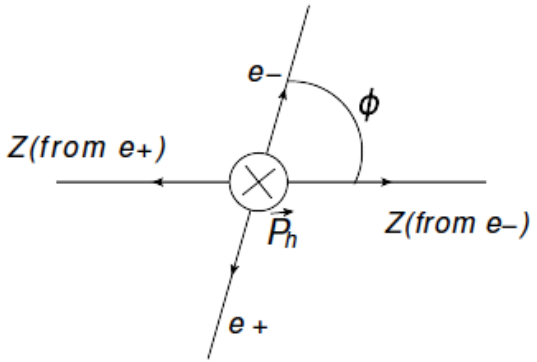
Kinematic Variables:

- mee: invariant mass of the outgoing e- e+ pair
- mrec: recoil mass of the outgoing e- e+ pair

$$m_{rec}^2 \equiv s - 2\sqrt{s}E_{ee} + m_{ee}^2.$$

- θ_1 is the angle between the boosted momentum of the outgoing e+e- pair and the beam-line; θ_2 is the angle between the outgoing e- in e-e+ rest frame and the momentum of e+e- pair in the lab frame; ϕ_3 is the azimuthal angle of the outgoing e- relative to the plane defined by the outgoing e+e- pair and the beam-line in the lab frame.





Cuts and Distribution:

- Signal Identification:
  - recoil mass peak at Higgs mass;
  - Finite Pt of Higgs
- Dominant Backgrounds:
  - e-e+>W-W+>eenn1
  - e-e+ > eea (Bhabha scattering)

Cut 1	$95\ \text{GeV} < m_{\text{rec}} < 300\ \text{GeV}$ $500\ \text{GeV} < m_{ee} < 870\ \text{GeV}$ $p_{T(ee)} > 50\ \text{GeV}$ veto 1 iso. photon $E^*_\gamma < 200\ \text{GeV}$
Cut 2	$0.14 < \theta_2 < 3.0$ $\phi < 1.5$

- Signal and background cross section (fb) at ILC 500 GeV

Process	Generator Level (fb)	Cut1 (fb)	Cut2 (fb)
$ee \to eeh$(Signal)	11.5	3.48	3.11
$ee \to ee\nu_e\nu_e$	659	23.9	16.0
$ee \to ee\nu_{\mu,\tau}\nu_{\mu,\tau}$	78.6	1.02	0.70
$ee \to eeqq$	1850	9.33	6.88
$ee \to eell$	4420	5.18	4.42
$ee \to ee\gamma\gamma$	1640	1.18	0.60
$ee \to ee\gamma$	165000	1.32	0.66
Total Background	174000	41.9	29.2
$\delta\sigma/\sigma$	-	8.7%	8.2%

Sensitivity on the signal: $$\frac{\delta\sigma}{\sigma} = \frac{\sqrt{N_s + N_b}}{N_s},$$

Distribution

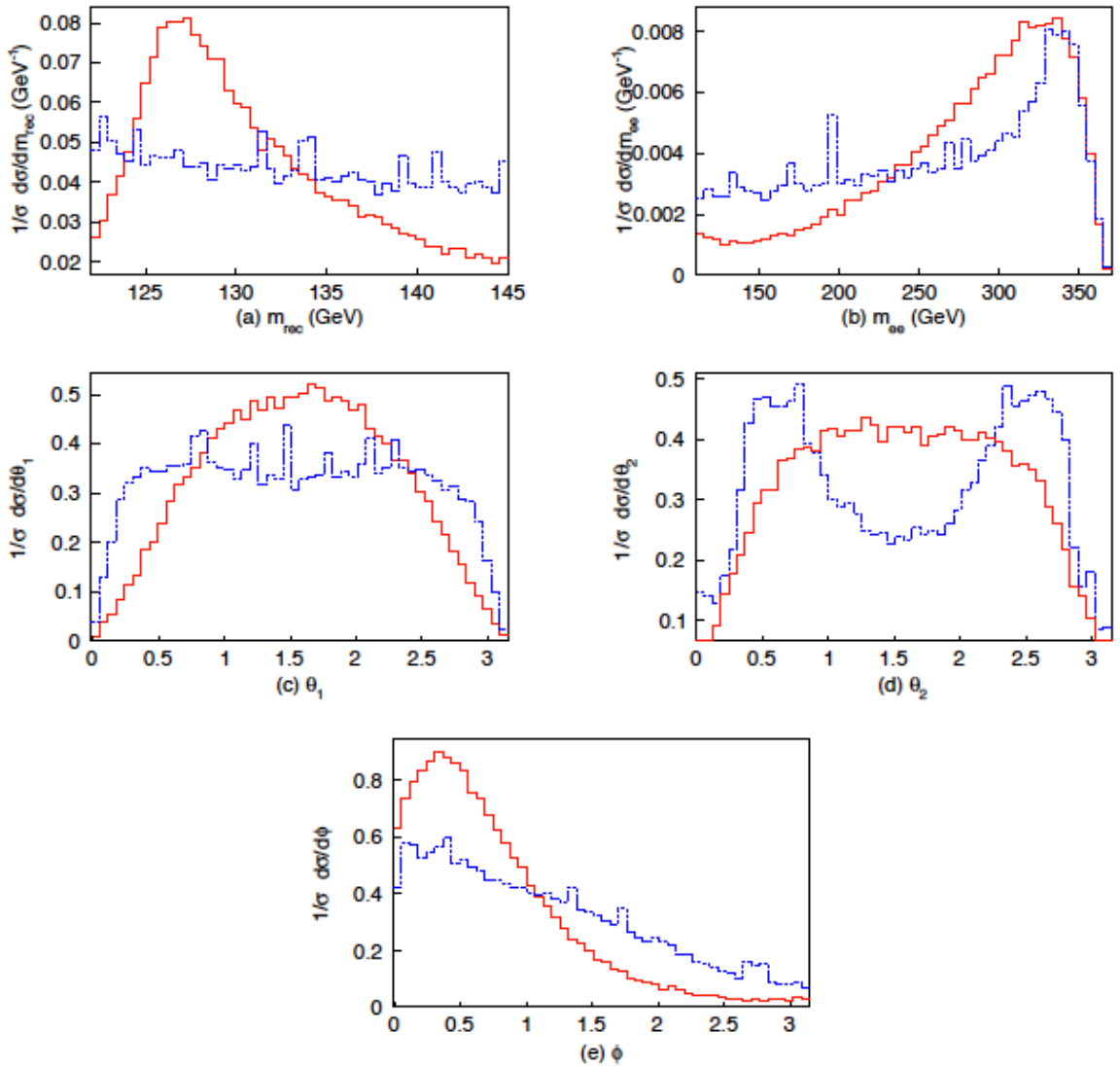


Figure 4. Comparison of signal (solid red) and total background (dashed blue) distributions for variables m_{rec}, m_{ee}, θ_1, θ_2 and ϕ at $\sqrt{s} = 500$ GeV. Cut1 in Table 2 is applied. For clarity, both signal and background distributions are normalized to unity.

Similar analysis gives results for 1TeV case:

Cut 1	$95\ \text{GeV} < m_{\text{rec}} < 300\ \text{GeV}$ $500\ \text{GeV} < m_{ee} < 870\ \text{GeV}$ $p_{T(ee)} > 50\ \text{GeV}$ veto 1 iso. photon $E^*_\gamma < 200\ \text{GeV}$
Cut 2	$0.14 < \theta_2 < 3.0$ $\phi < 1.5$

Process	Generator Level (fb)	Cut1(fb)	Cut2(fb)
$ee \to eeh$(Signal)	24.1	8.18	7.52
$ee \to ee\nu_e\nu_e$	978	31.5	17.2
$ee \to ee\nu_{\mu,\tau}\nu_{\mu,\tau}$	93.9	3.24	1.64
$ee \to eeqq$	2830	24.1	13.6
$ee \to eell$	6690	13.7	10.8
$ee \to ee\gamma\gamma$	3180	2.68	1.10
$ee \to ee\gamma$	175000	4.73	2.28
Total Background	189000	80.0	46.6
$\delta\sigma/\sigma$	-	3.6%	3.1%

Multivariate analysis: using log-likelihood

We can do slightly better by making use of the shape of distribution.

Define log-likelihood on the five-dimensional space:

$$LL_P(n_i;\nu_i) = 2\sum_i \left[n_i \ln\left(\frac{n_i}{\nu_i}\right) + \nu_i - n_i \right]$$

Where in each bin:

- vi = expected value , background + signal
- ni = background + r*signal
- The 1-sigma deviation corresponds to LL = 1.

Results of 1TeV log-likelihood

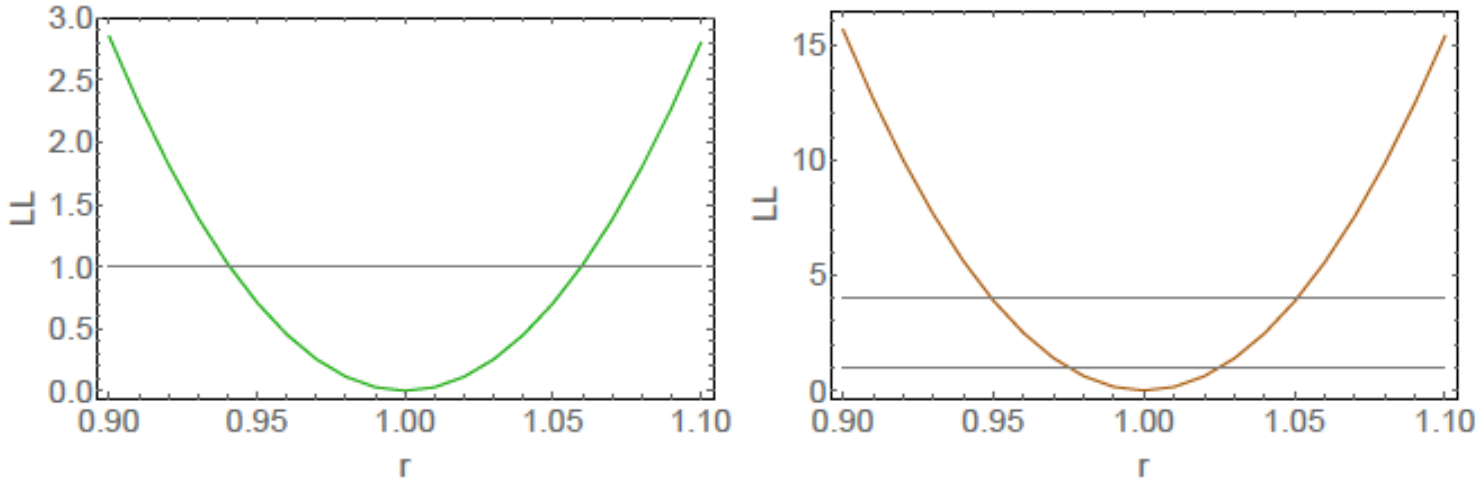


Figure 6. 5-dimensional Log-likelihood as a function of the relative cross section r defined below Eq. (2.5) for (*left panel):* 500 GeV case and (*right panel):* 1 TeV case. For both analyses, Cut1 is applied.

Sensitivity improved to 6%(2.5%) for the 500GeV(1TeV) using log-likelihood calculation.

Main Results: Improved sensitivity on Higgs width and couplings:

Relative Error %	ILC 250+500		ILC 250+500+1000	
$\delta\sigma_{Zh}$	6.0%		2.5%	
Improvement		with HL-LHC		with HL-LHC
Γ	4.8 → 4.7	4.8 → 4.6	4.5 → 3.7	4.5 → 3.7
g_Z	0.99 → 0.94	0.99 → 0.94	0.98 → 0.75	0.98 → 0.75
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Constraints on dim-6 operator:

From studying the ZZ fusion channel, we have now much more improved sensitivity to ZZh coupling at 500GeV and 1TeV c.m. energy:

We did some constraints on two representative dim-6 operators:

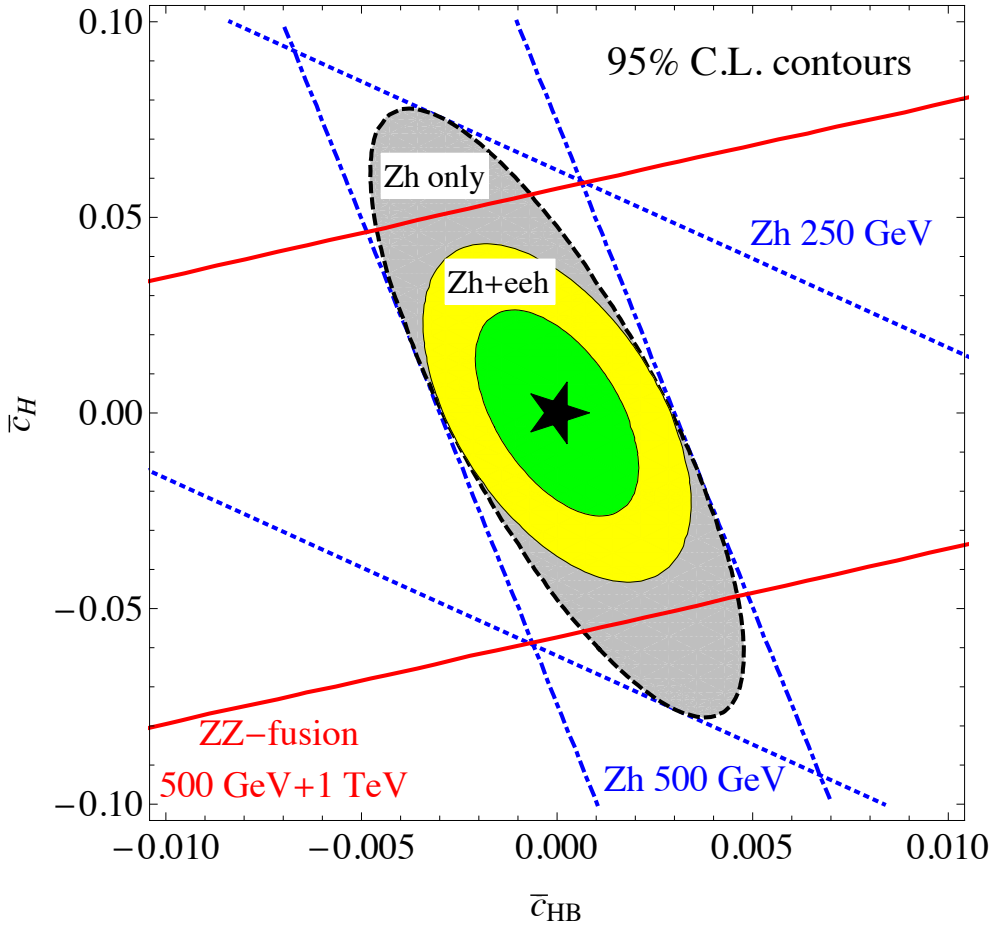
$$\mathcal{O}_H = \partial^\mu(\phi^\dagger\phi)\partial_\mu(\phi^\dagger\phi), \qquad \mathcal{O}_{HB} = g' D^\mu\phi^\dagger D^\nu\phi B_{\mu\nu},$$

$$\mathcal{L}^{dim-6} \supset \frac{c_H}{2\Lambda^2}\mathcal{O}_H + \frac{c_{HB}}{\Lambda^2}\mathcal{O}_{HB},$$

$$\bar{c}_H = \frac{v^2}{\Lambda^2}c_H \text{ and } \bar{c}_{HB} = \frac{m_W^2}{\Lambda^2}c_{HB}.$$

$$\begin{aligned}
\text{ILC 250 GeV}: \quad \tfrac{\Delta\sigma}{\sigma}(Zh) &\approx -\bar{c}_H - 4.5\,\bar{c}_{HB},\\
\text{ILC 500 GeV}: \quad \tfrac{\Delta\sigma}{\sigma}(Zh) &\approx -\bar{c}_H - 25\,\bar{c}_{HB},\\
\tfrac{\Delta\sigma}{\sigma}(e^-e^+h) &\approx -\bar{c}_H + 1.1\,\bar{c}_{HB},\\
\text{ILC 1 TeV}: \quad \tfrac{\Delta\sigma}{\sigma}(e^-e^+h) &\approx -\bar{c}_H + 2.4\,\bar{c}_{HB}.
\end{aligned}$$

Constraints on dim-6 operator:



Final Remarks:

- Combing the ZZ fusion and Higgsstrahlung channels, the model-independent measurement of the inclusive cross section ZH can be improved to 1.5%, which is ~25% improvement over existing studies.
- Sensitivities on the inclusive cross section ZH at multiple energies at ILC offers the possibility to distinguish contributions from different BSM operators.
- As an example, we showed that by including the ZZ fusion channel, constraints on two representative operators improve as large as 50% compare to studies with Higgsstrahlung channel alone.

- Thank you for the attention.

Backup Plots: ZZ-fusion (1Tev)

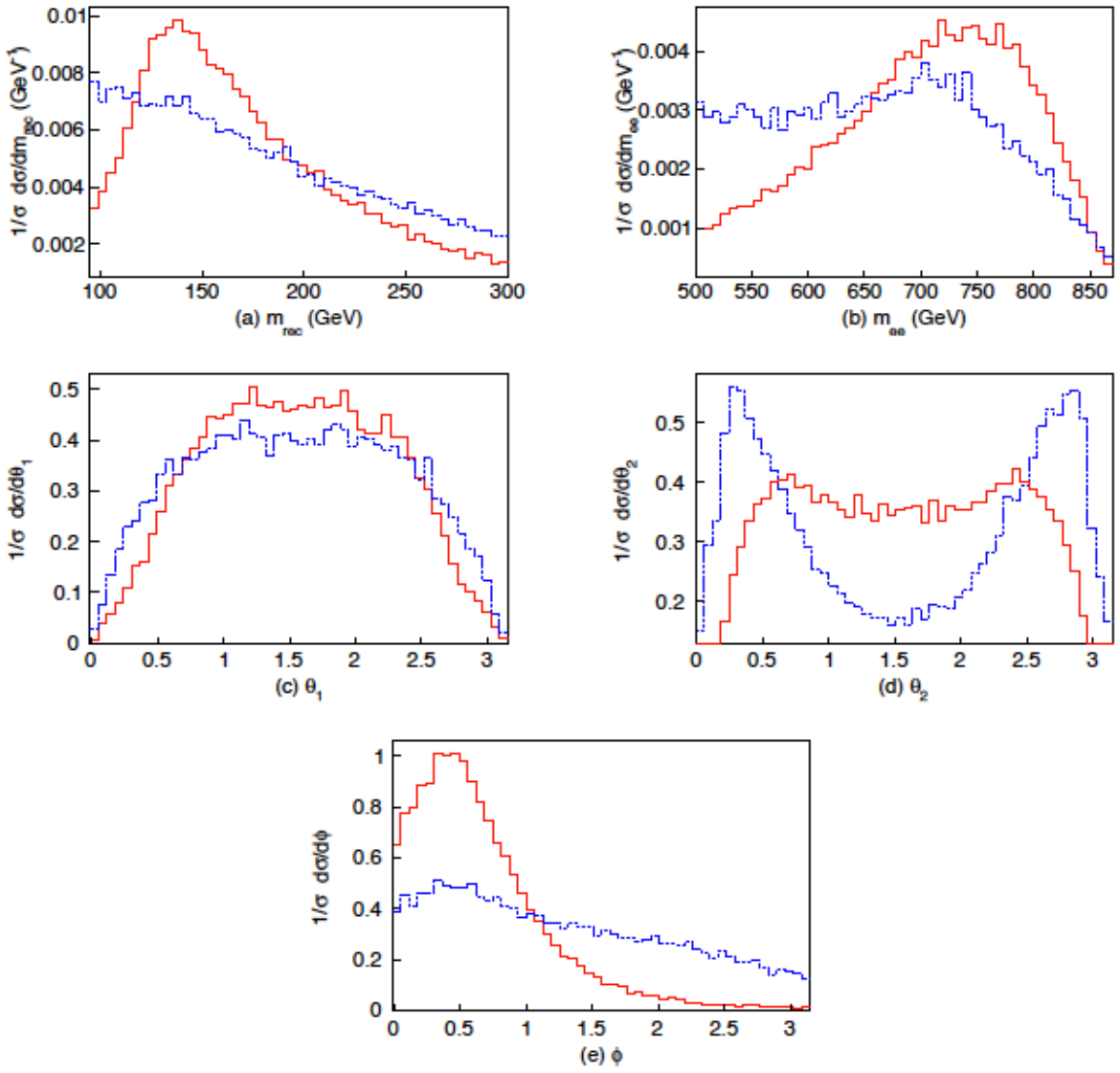


Figure 5. Comparison of signal (solid red) and total background (dashed blue) distributions for variables m_{rec}, m_{ee}, θ_1, θ_2 and ϕ at $\sqrt{s} = 1$ TeV. Cut1 in Table 4 is applied. For clarity, both signal and background distributions are normalized to unity.

Backup: previous Studies on Higgs coupling constraints at ILC

Facility		ILC	
$\sqrt{s}$ (GeV)	250	500	1000
$\int \mathcal{L}dt$ (fb^{-1})	250	+500	+1000
$P(e^-, e^+)$	$(-0.8, +0.3)$	$(-0.8, +0.3)$	$(-0.8, +0.2)$
Γ_H	12%	5.0%	4.6%
κ_γ	18%	8.4%	4.0%
κ_g	6.4%	2.3%	1.6%
κ_W	4.9%	1.2%	1.2%
κ_Z	1.3%	1.0%	1.0%
κ_μ	91%	91%	16%
κ_τ	5.8%	2.4%	1.8%
κ_c	6.8%	2.8%	1.8%
κ_b	5.3%	1.7%	1.3%
κ_t	–	14%	3.2%
BR_{inv}	0.9%	$< 0.9\%$	$< 0.9\%$

$$\kappa_Z = \frac{g_{ZZH}}{g_{ZZH}^{SM}}$$

Snowmass Higgs Report (2013)

Backup: BSM model on Higgs coupling

Table 1-8. *Generic size of Higgs coupling modifications from the Standard Model values when all new particles are $M \sim 1$ TeV and mixing angles satisfy precision electroweak fits. The Decoupling MSSM numbers assume $\tan\beta = 3.2$ and a stop mass of 1 TeV with $X_t = 0$ for the κ_γ prediction.*

Model	κ_V	κ_b	κ_γ
Singlet Mixing	$\sim 6\%$	$\sim 6\%$	$\sim 6\%$
2HDM	$\sim 1\%$	$\sim 10\%$	$\sim 1\%$
Decoupling MSSM	$\sim -0.0013\%$	$\sim 1.6\%$	$\sim -.4\%$
Composite	$\sim -3\%$	$\sim -(3-9)\%$	$\sim -9\%$
Top Partner	$\sim -2\%$	$\sim -2\%$	$\sim +1\%$

arxiv:1310.8361, Jan 2014, Snowmass Higgs working group report