Measurement of the Higgs Boson Coupling to the Top Quark and the Higgs Boson Self-Coupling at ILC

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on behalf of the ILC Physics and Detector Study

The International Linear Collider is a proposed 50 km electron-positron collider in the Kitakami hills in northern Japan. Precision measurements of Higgs properties and direct searches for new physics will complement the LHC experiments and their upgrades in our drive to answer open questions about the universe and the origin of matter. Two detector concepts have been validated as being feasible to deliver the necessary precision.
In its baseline configuration the machine has a collision energy of about 500 GeV, upgradeable to 1 TeV. The electron beam is 80% polarized. The polarization of the positron beam is 30% at 500 GeV and 20% at 1 TeV. The integrated luminosity in a high-luminosity scenario is 1.6 ab^{-1} at 500 GeV and 2.5 ab^{-1} at 1 TeV.
The measurements of the Higgs boson self-coupling and the coupling to the top quark are important pieces of the ILC physics program.

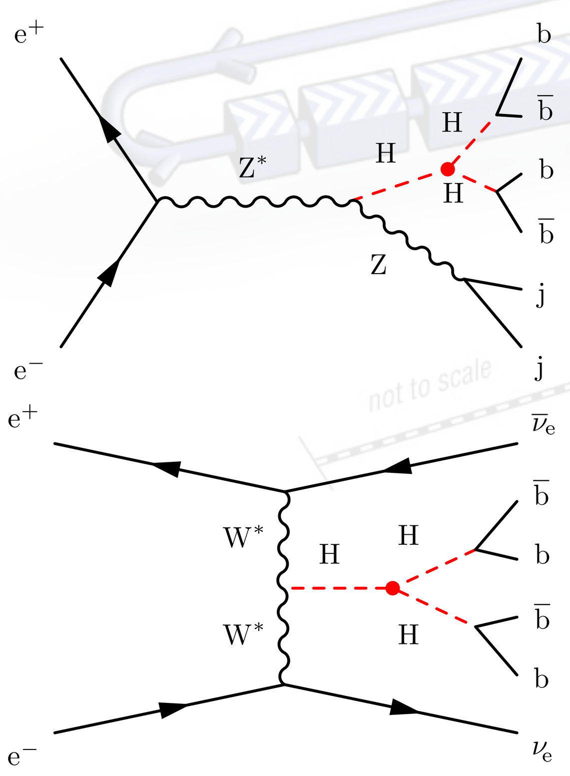
Measurement of the tri-linear Higgs self-coupling

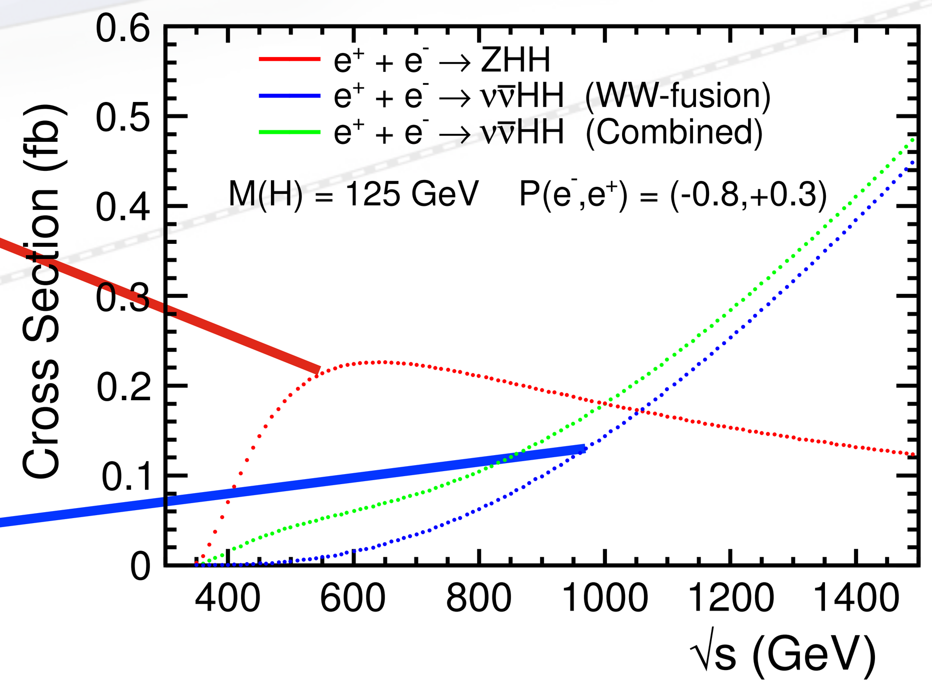
The Higgs potential after electroweak symmetry breaking

$$\mathcal{L} = \frac{1}{2}(\partial_\mu \sigma)^2 - \lambda v^2 \sigma^2 - \lambda_{\mathrm{HHH}} v \sigma^3 - \frac{1}{4}\lambda_{\mathrm{HHHH}} \sigma^4$$

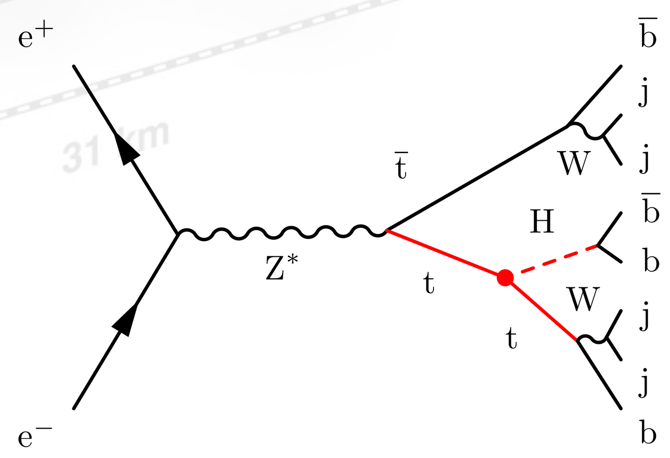
In the Standard Model:

$$\lambda \equiv \lambda_{\mathrm{HHH}} \equiv \lambda_{\mathrm{HHHH}}$$

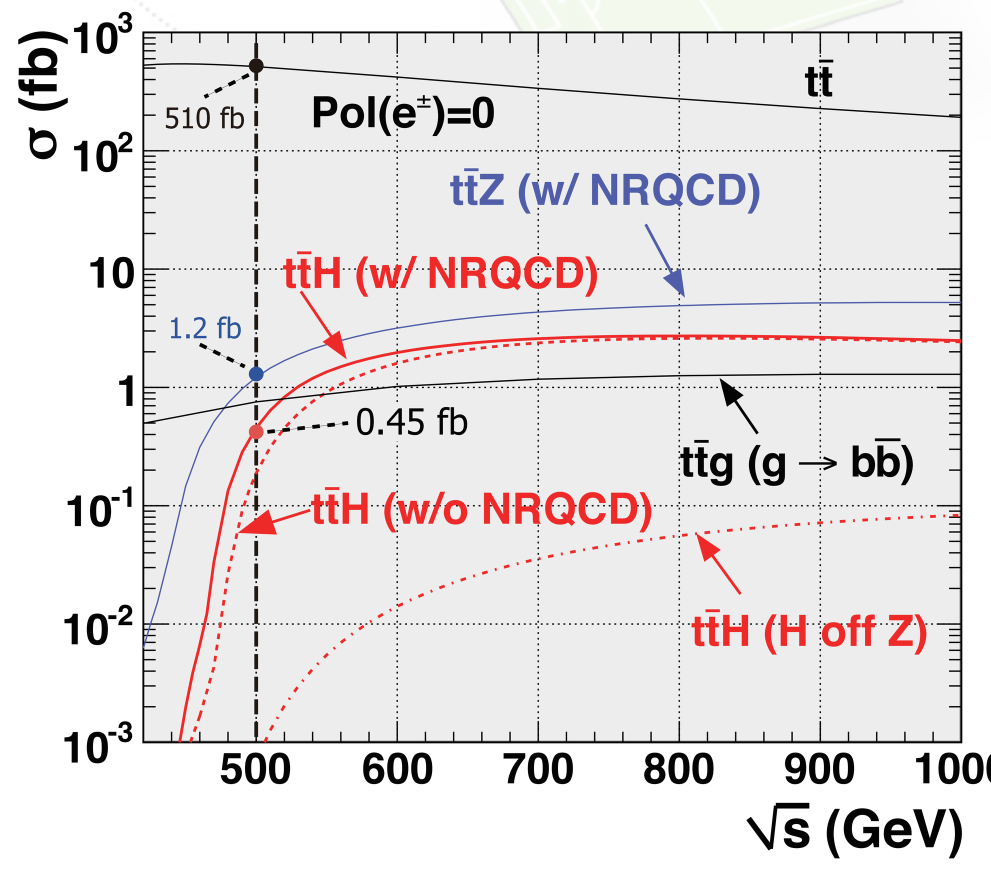




Measurement of the Higgs coupling to the top quark



Direct observation of the ttH final state is feasible at 500 GeV thanks to bound-state effects. The measurement at 1 TeV benefits from much improved signal to background ratio.



Analysis Outline:

1. Vertex Reconstruction
2. Selection of Isolated Leptons
3. Jet Clustering
4. Flavor Tagging
5. Multivariate Classification
6. Weighting of events that are more likely to contribute to the measurement of λ_{HHH}

$\sqrt{s}$ = 500 GeV, 1.6 ab^{-1}

Channel	signal events	back ground	cross section	coupling λ_{HHH}
$\mathrm{ZHH} \to \mathrm{e^+e^-b\bar{b}b\bar{b}}$	1.9	3.2	0.84 σ	0.64 σ
$\mathrm{ZHH} \to \mu^+\mu^-\mathrm{b\bar{b}b\bar{b}}$	2.6	5.6	0.90 σ	0.74 σ
$\mathrm{ZHH} \to \nu\bar{\nu}\mathrm{b\bar{b}b\bar{b}}$	3.0	3.2	1.22 σ	1.09 σ
$\mathrm{ZHH} \to \mathrm{b\bar{b}b\bar{b}b\bar{b}}$	6.6	17.8	1.34 σ	1.29 σ
$\mathrm{ZHH} \to q\bar{q}\mathrm{b\bar{b}b\bar{b}}$	7.0	31.4	1.12 σ	1.06 σ

$q \in \mathrm{d, u, s, c}$

not all diagrams with double Higgs production contribute to trilinear self-coupling measurement

Self-coupling analysis	Polarization (e-, e+) Luminosity	Precision on final state	Precision on coupling λ_{HHH}
ZHH (500 GeV) [3] $\mathrm{HH \to b\bar{b}b\bar{b}}$	(-0.8, +0.3) 1.6 $\mathrm{ab^{-1}}$	4.5 σ	66%
+ ZHH + vvHH (1 TeV) $\mathrm{HH \to b\bar{b}b\bar{b}}$	(-0.8,+0.2) 2.5 $\mathrm{ab^{-1}}$	7.2 σ	16%
+ $\mathrm{HH \to b\bar{b}WW}$ [11]	(in progress)	≈ 9 σ	≈ 13%

$\sqrt{s}$ = 1 TeV, 2.5 ab^{-1}, both polarization states

Detector			ILD		SiD	
		Before cuts	After cuts			
			6 jets	8 jets	6 jets	8 jets
$\mathrm{t\bar{t}H}$	4 jets	379	47	1	52	4
$\mathrm{t\bar{t}H}$	6 jets	1572	520	164	479	144
$\mathrm{t\bar{t}H}$	8 jets	1632	5	914	4	749
$\mathrm{t\bar{t}H}$	other	2615	25	63	30	38
$\mathrm{t\bar{t}Z}$		13331	315	651	264	468
$\mathrm{t\bar{t}b\bar{b}}$		3586	314	557	250	452
$\mathrm{t\bar{t}}$		772002	653	1284	580	954

Analysis Outline:

1. Vertex Reconstruction
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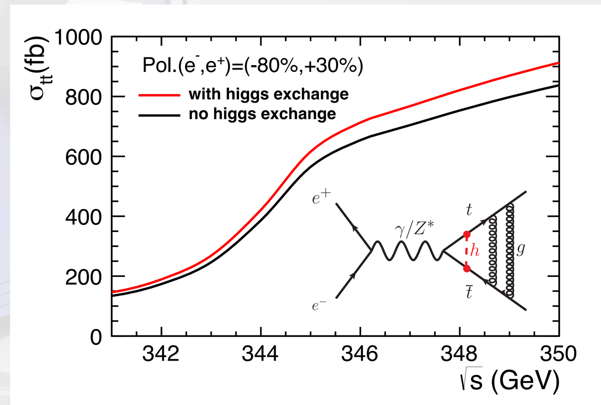
Analysis	Polarization (e-, e+) Luminosity	Precision on coupling yt
ttH (500 GeV)	(-0.8, +0.3) 1.6 $\mathrm{ab^{-1}}$	≈ 9%
ttH (1 TeV) [1]	(∓0.8,±0.2) 1.0 $\mathrm{ab^{-1}}$	4.3-4.5%
HiLumi scenario	500 GeV (-0.8, 0.3) + 1 TeV (-0.8, +0.2)	≈ 2%



First sensitivity to top Yukawa measurement at the top threshold: statistical uncertainty: 5.9% (3 parameter fit (m_t, Γ_t, y_t))

Data Samples:

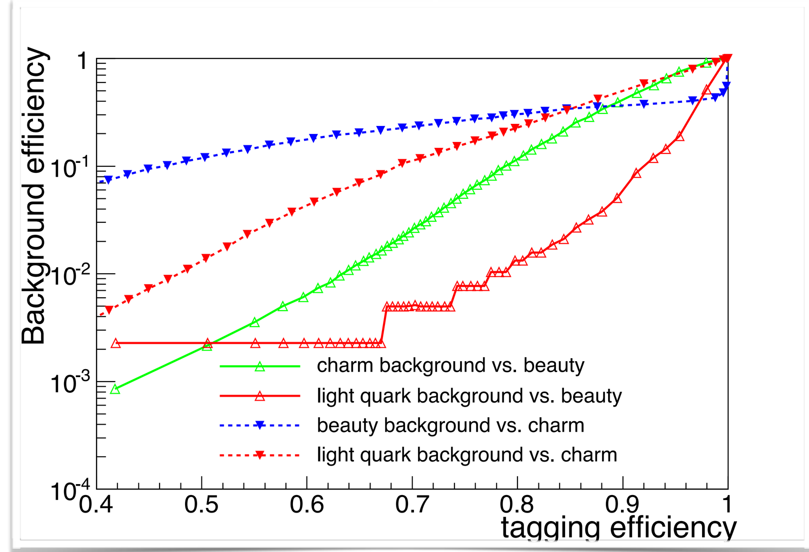
1. Samples prepared with physsim[5], whizard[6,7] and pythia 6.4[8]
2. Detailed simulation of the detector concepts with GEANT4
3. Hadron production from beam background included
4. Event reconstruction with PandoraPFA[9] and LCFIPlus
5. Jet finding with FastJet: hadron-kt algorithm to reduce beam-induced background

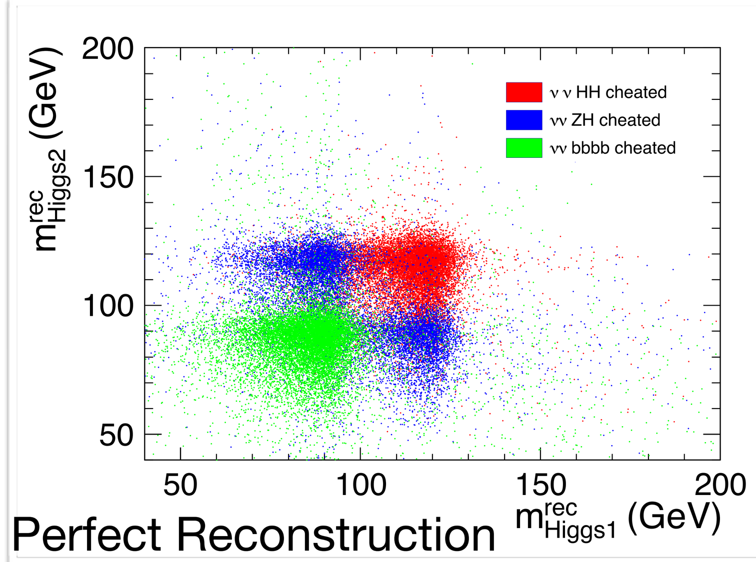
Jet Reconstruction

Building on the Particle Flow paradigm, the ILC detectors allow the reconstruction of jets with unprecedented resolution even in complex environments. The goal is to reconstruct heavy bosons with a resolution of a few GeV.

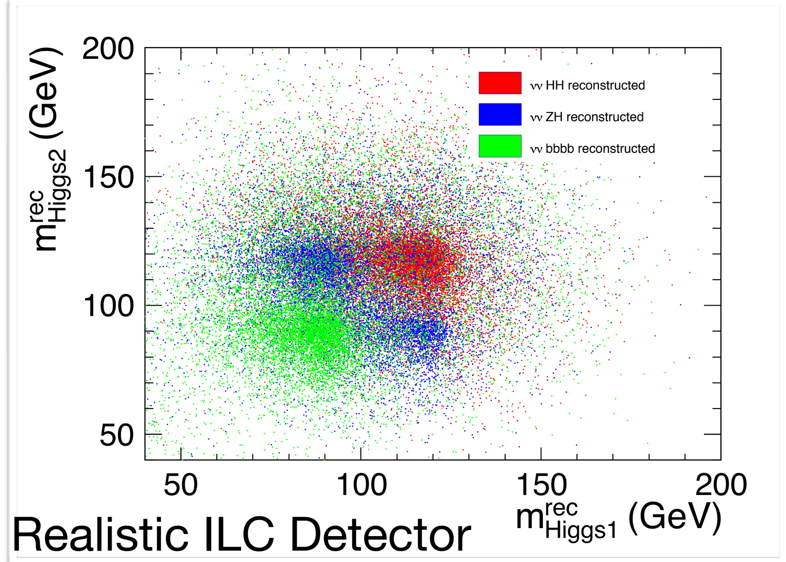
Flavor Tagging — LCFIPlus

Building on vertex reconstruction techniques developed at the previous linear collider, the ILC detectors will have excellent flavor tagging capabilities, for b and c quarks. The innermost layer of the vertex detector is only 14 mm (SiD) to 16 mm (ILD) from the interaction.





Perfect Reconstruction



Realistic ILC Detector

The analyses are challenged by low cross sections and by the ability to reconstruct complex events with precise tagging of heavy quark flavors. The Higgs couplings to the top quark and the Higgs tri-linear self-coupling can be measured with statistical uncertainties of ≈ 2% and ≈ 13%, respectively, in the luminosity-upgrade scenario.

References:

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[3] Claude Duerig, “Higgs self-coupling measurement at the ILC”, AWLC14
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