Higgs Physics at the ILC

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FOR THE ILC DETECTOR AND PHYSICS COMMUNITY

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Other ILC Presentations

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Jim Brau: 500 GeV ILC Operating Scenarios
Tuesday, 14:48

Stefania Gori: Exploration of Physics Beyond the Standard Model at the International Linear Collider
Tuesday 17:15

Graham Wilson: Top Quark Physics at a Future Linear Collider
Tuesday, 17:30

Andy White: The SiD Detector for the International Linear Collider
Wednesday, 17:45 https://indico.cern.ch/event/361123/session/7/contribution/152

Deepanjali GOSWAMI: Type-III seesaw fermionic triplets at the International Linear Collider
Tuesday, 15:15

The LHC experiments have found a new scalar particle → consistent with a SUSY Higgs boson

bottom line

This Higgs Boson changes everything.

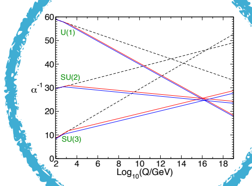
We're obligated to understand it using all tools.

... And to use it as a tool for discovery

BSM motivations

baryogenesis

$\theta\, G\tilde{G}$



$m^2|H|^2$

quantum gravity

inflation

Λ

dark matter

flavorgenesis

m_ν

Josh Ruderman (NYU)

Overview

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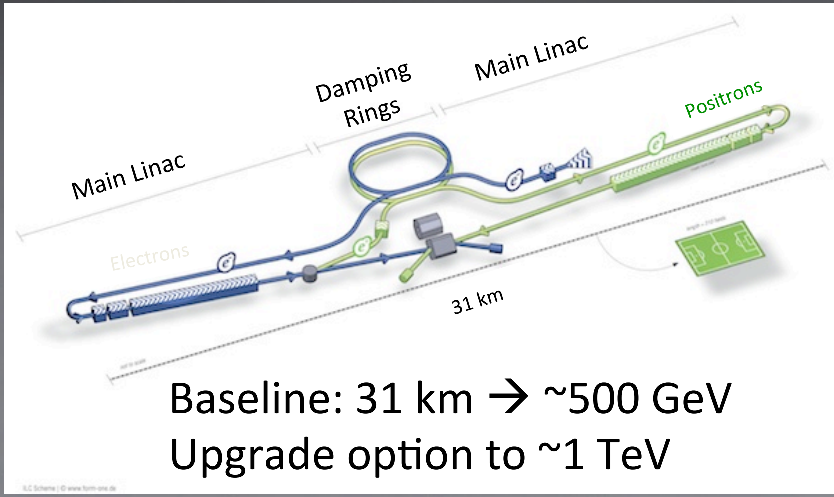
- The ILC accelerator and detectors
- Higgs physics at the ILC
  - Fermions
  - Self-coupling
  - Top Yukawa
  - Combined Fit
- Summary

The ILC accelerator and detectors

The ILC Accelerator



- TDR has been delivered in 2012
- Technology being installed in XFEL at DESY
- Candidate site in Japan has been studied
- Layout being targeted towards site

From the P5 report: *As the physics case is extremely strong, …*
Recommendation 11: *Motivated by the* ***strong scientific importance*** *of the ILC and the recent initiative in Japan to host it, the U.S. should engage in modest and appropriate levels of ILC accelerator and detector design in areas where the U.S. can contribute critical expertise. Consider higher levels of collaboration if ILC proceeds.*

ILC Baseline Operating Scenario
arXiv:1506.07830v1 [hep-ex]

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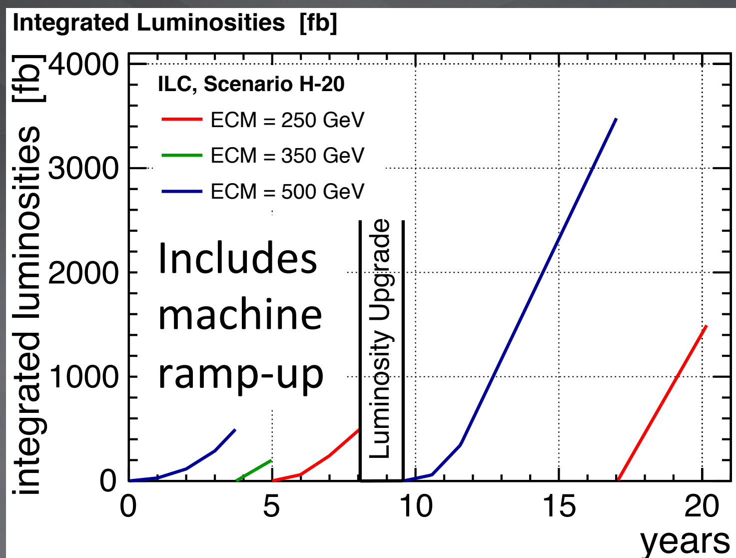

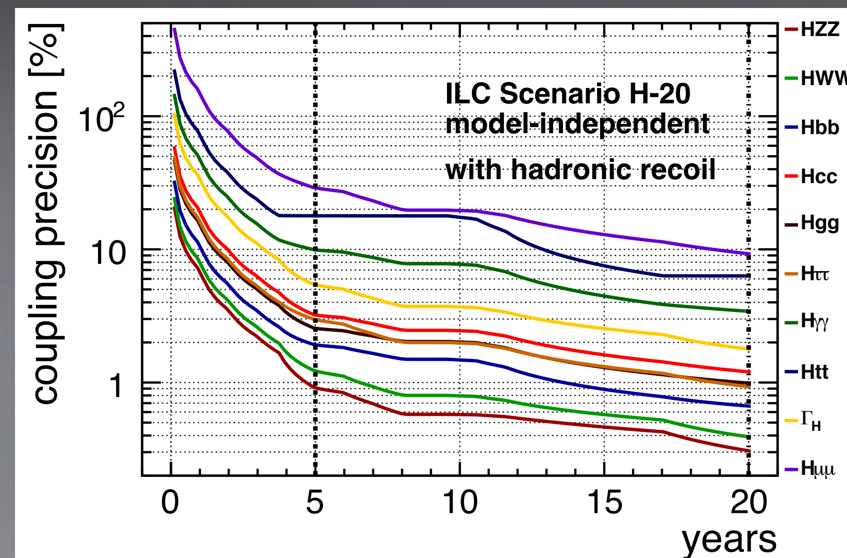

- Start at baseline energy
  - Pursue full program from day 1, including ttH, self-coupling, BSM searches
- Add runs at thresholds for higher precision: 350 GeV (top), 250 GeV (ZH)
- Run at other thresholds possible, informed by LHC or early ILC Data
- Goal: per cent-level precision on (most) Higgs couplings
- Possible upgrade to 1 TeV to improve ttH, self-coupling measurements, access potential heavy states

Comparison with the LHC

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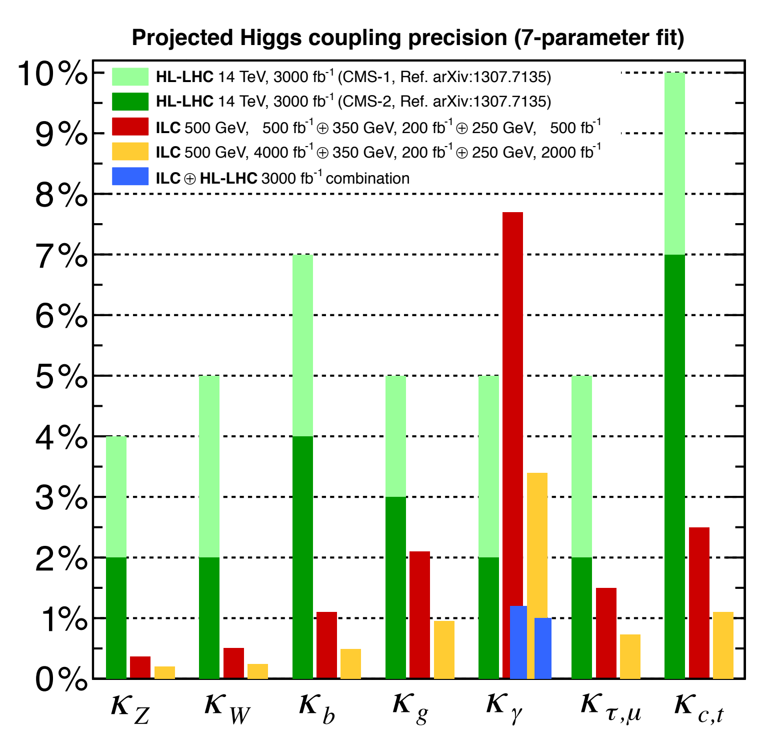
HL-LHC program will measure several Higgs couplings to <10%

The ILC program will improve upon this precision by ~ one order of magnitude.

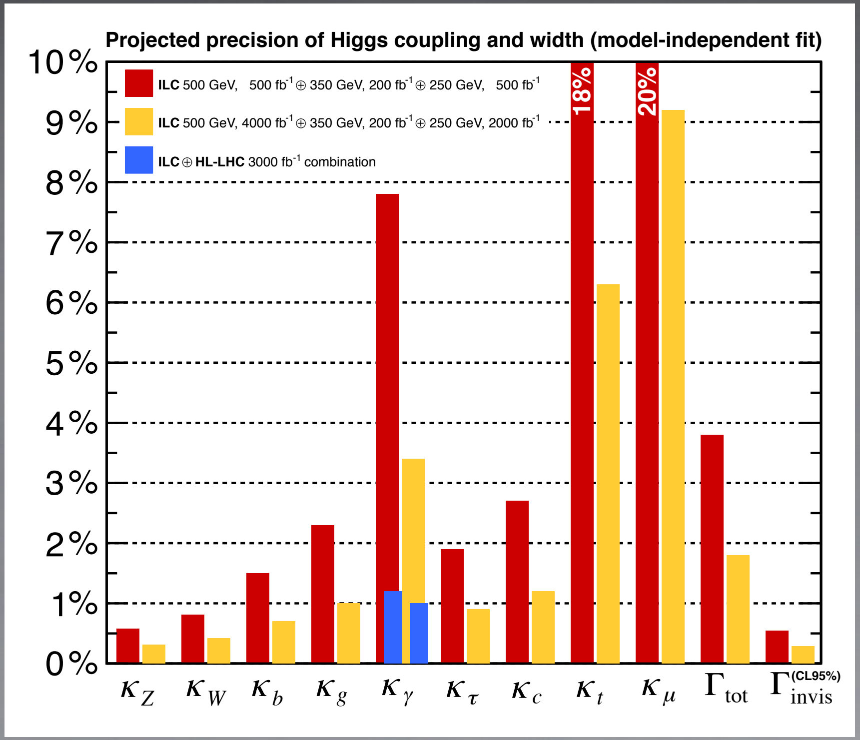


Model-independent measurements at the ILC

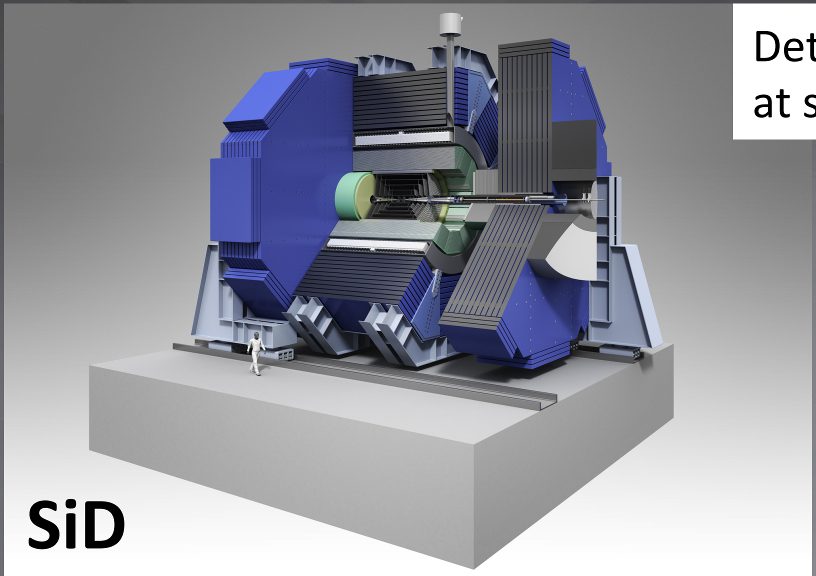
HL-LHC program will measure several Higgs couplings to <10%

The ILC program will improve upon this precision by ~ one order of magnitude.

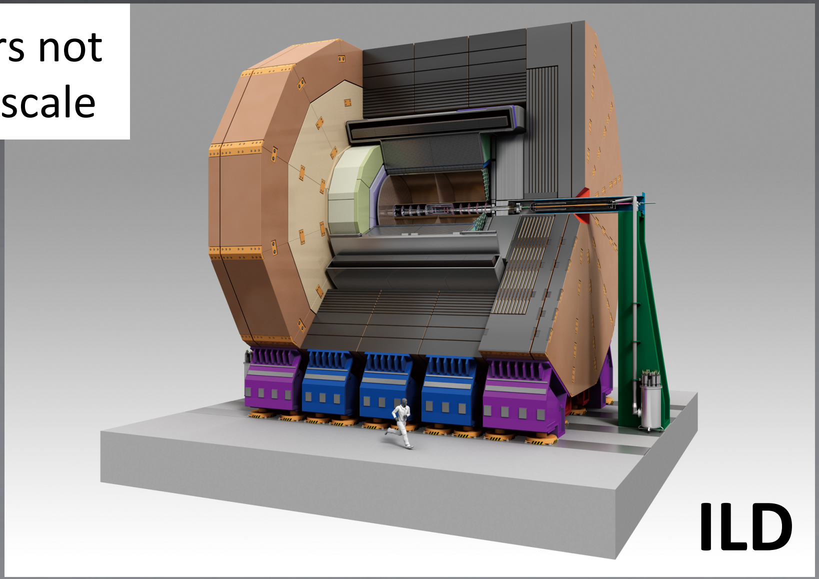
ILC will add measurements. Studies can be carried out in a self-contained and model-independent way



ILC Detectors



Detectors not at same scale



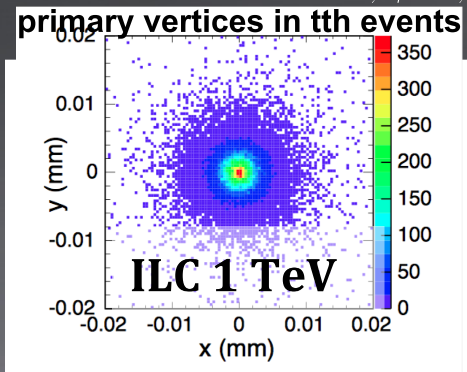
5 T field
Silicon Tracking

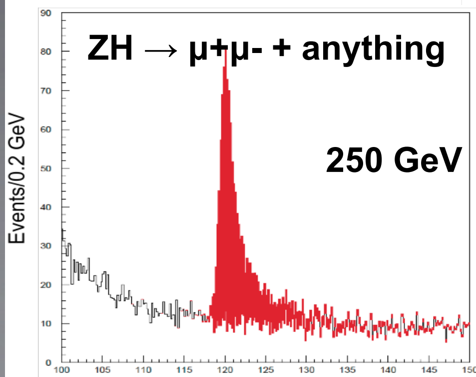
3.5 T field
Gaseous Tracking

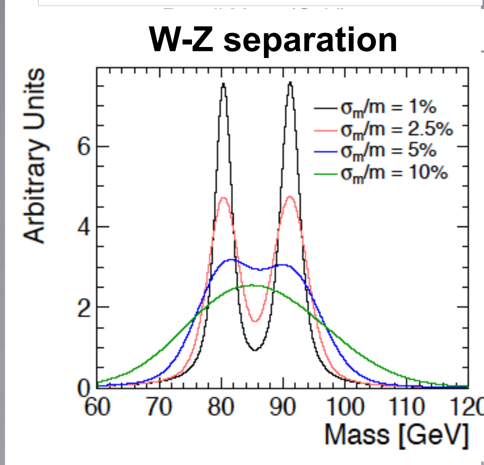
Pixelated Si-W ECAL
Highly Granular HCAL
Optimized for Particle Flow (calorimeter inside coil)
No Trigger
Shared Beam Time in Push-Pull setup
Both can deliver the physics. Now shifting gears towards TDR

Detector Requirements are driven by Higgs physics

- Exceptionally good impact parameter resolution, time stamping, material budget in the vertex detector
  - R&D ongoing to meet all of these requirements
- Extremely low material budget in the main tracker, with high tracking efficiency
  - $\sigma(1/p) \sim 2.5 \times 10^{-5}$
- Not only good calorimeter resolution, but excellent track-shower matching and shower separation







Status of Machine and Detectors

- The ILC accelerator has completed its TDR
- A potential site has been identified
- Japan is investigating the possibility to host the machine at the government level
- Two Detector concepts have been designed to deliver high-precision physics
  - Measurements of Higgs properties drive the design on many fronts
- The concept groups are moving towards the start of a TDR process

The ILC TDR

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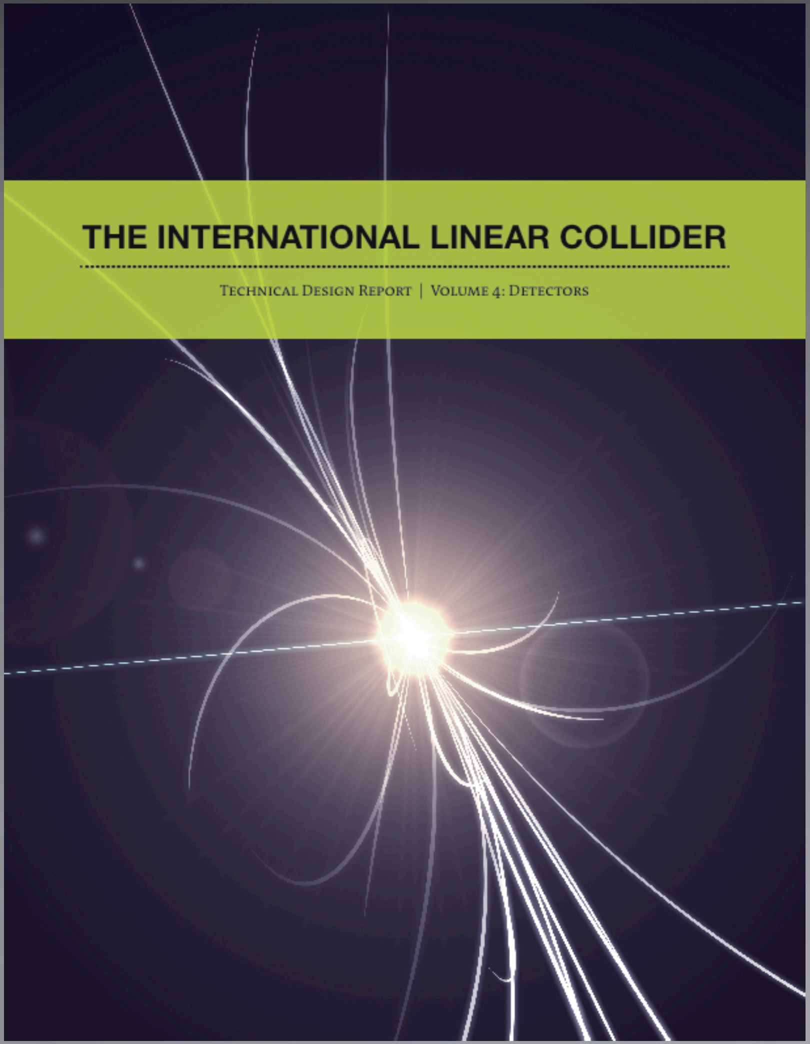
Volume 1 – Executive Summary:
http://arxiv.org/abs/1306.6327

Volume 2 – Physics:
http://arxiv.org/abs/1306.6352

Volume 3.I – Accelerator R&D in the Technical Design Phase:
http://arxiv.org/abs/1306.6353

Volume 3.II – Accelerator Baseline Design
http://arxiv.org/abs/1306.6328

Volume 4 – Detectors:
http://arxiv.org/abs/1306.6329

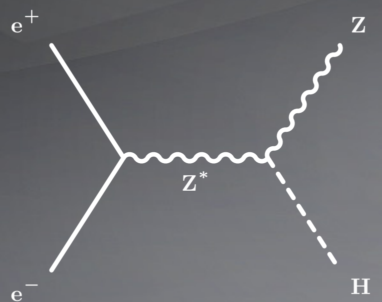


Physics with Higgs bosons at the ILC

Higgs Production at the ILC

Baseline of 500 GeV

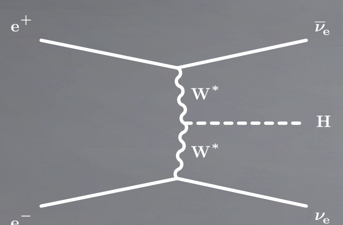
A Higgs program in 3 stages

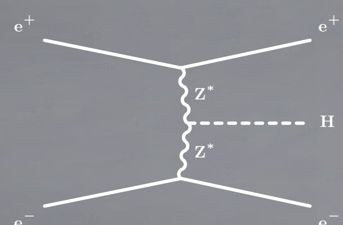


Recoil method: ILC staple at all stages

Z --> ll for precision

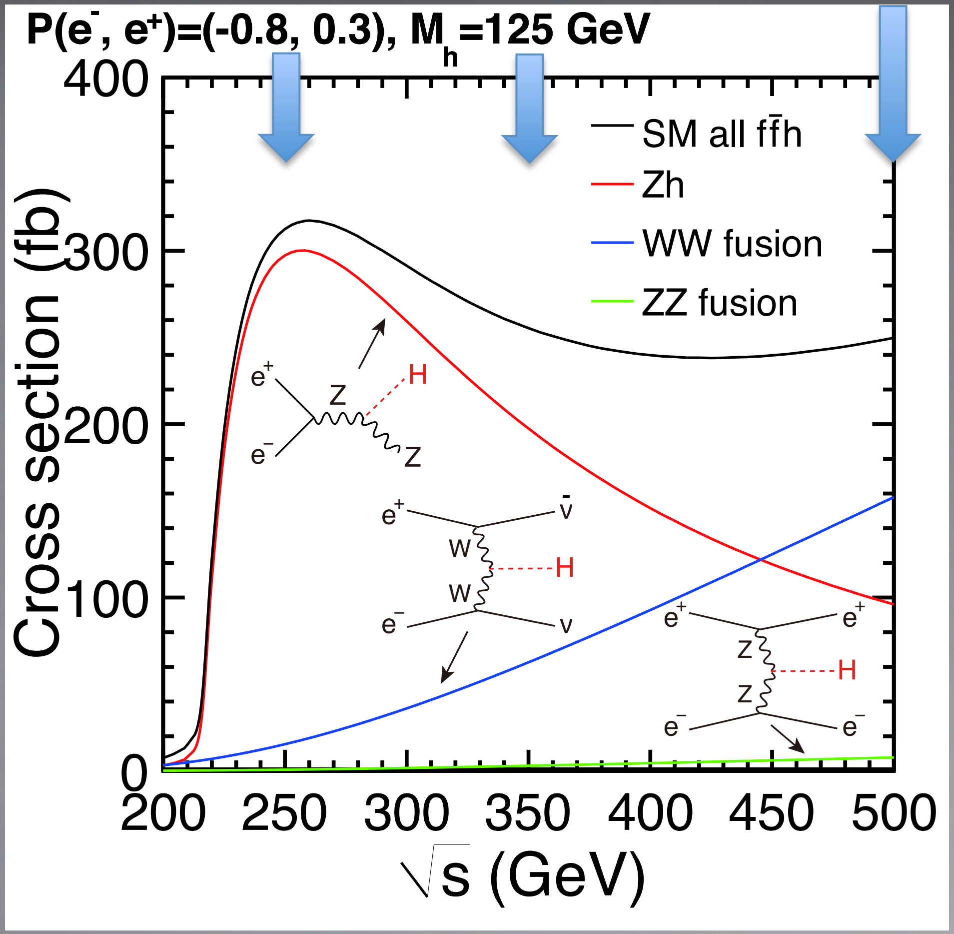
Z --> qq for higher cross section





Vector boson fusion cross section increases at higher energies

Starting Point



Higgsstrahlung at the ILC

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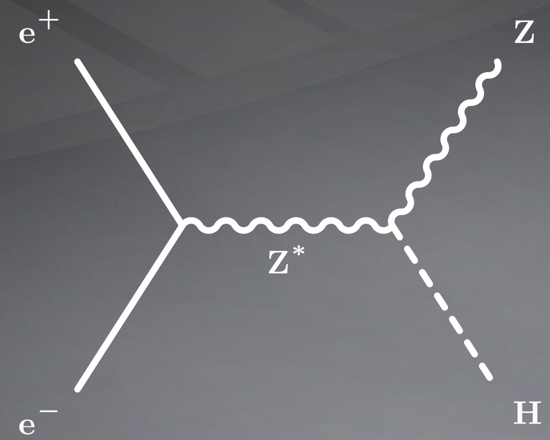
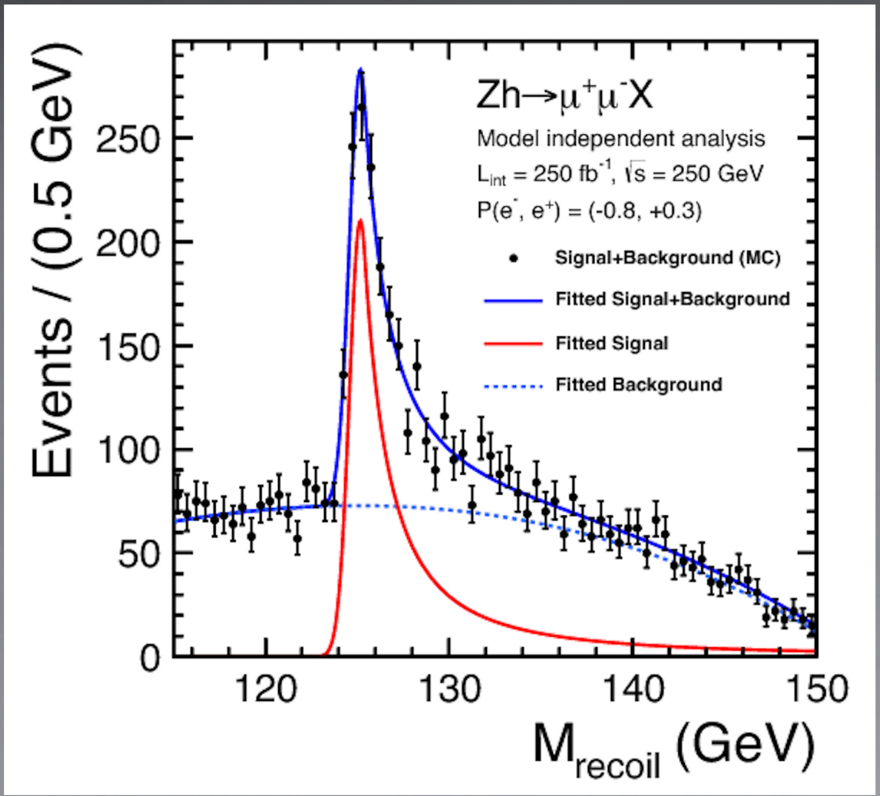


$$M_{recoil} = \left((\sqrt{s} - E_Z)^2 - P_Z^2 \right)^{1/2}$$



Well-known initial state at ILC allows to measure the Higgs in a model-independent way: Reconstruction efficiencies the same for all decays to within < 1%

Sensitivity to invisible decays, certain CP violating scenarios

This method has the smallest uncertainty near threshold.

Higgs to b and c Quarks, gluons

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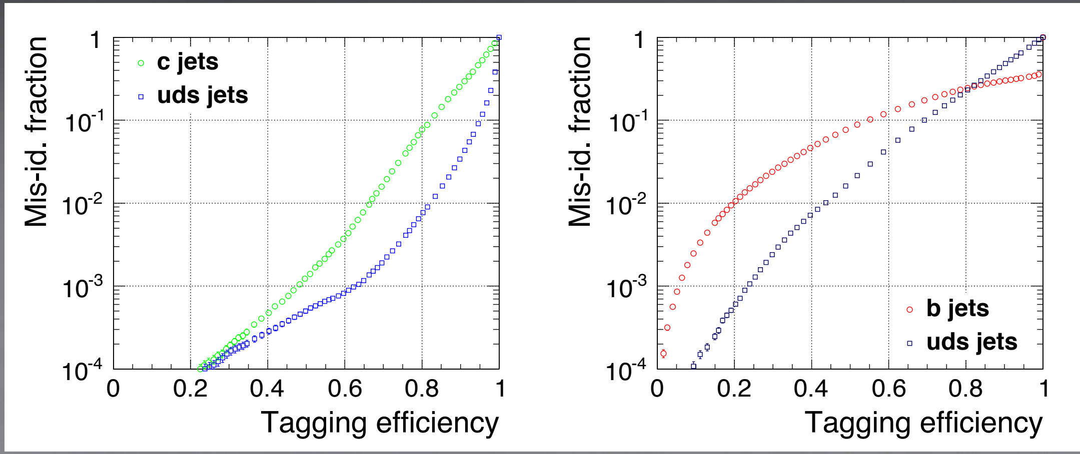
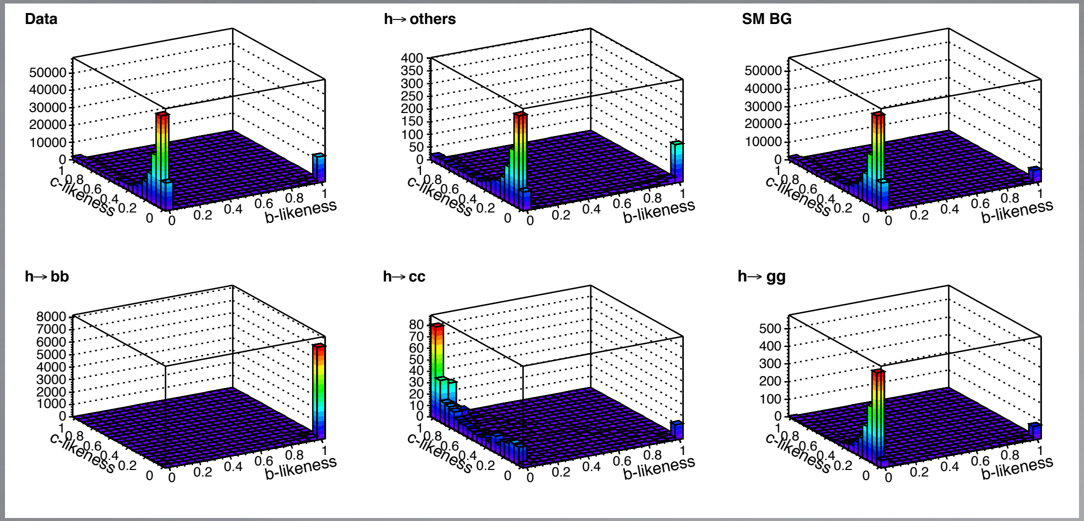
- Higgs decays to jets benefit from excellent vertex detector
  - b- and c-tagging
- Jet-clustering after vertex finding as to not break up the vertices
- Branching ratios extracted simultaneously with template method





Measurement precision goals:

g(Hbb) = 0.7%

g(Hcc) = 1.2%

g(Hgg) = 1.0%

Higgs Decay to τ Leptons

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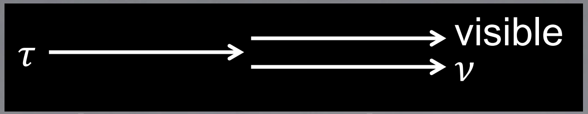
- Ideal probe for new physics: Sizeable BR, well-known τ mass, CP properties in angular analysis
- Reconstruction in hadronic recoil: qqττ
- Analysis steps: τ "jet" finder, jet charge
- Collinear Approximation:



  - Visible τ decay products and ν are collinear
  - No other source of missing momentum
  - Result: 1.9% baseline, 0.9% luminosity upgrade

Higgs Total Width

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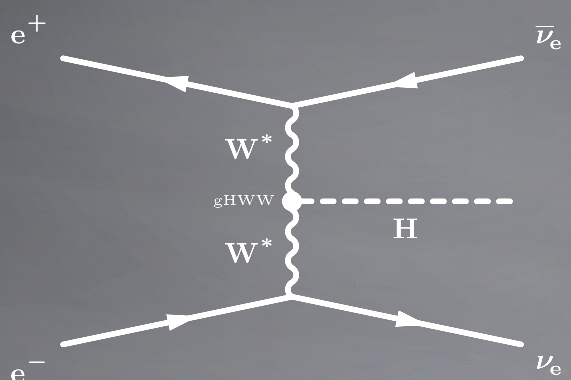
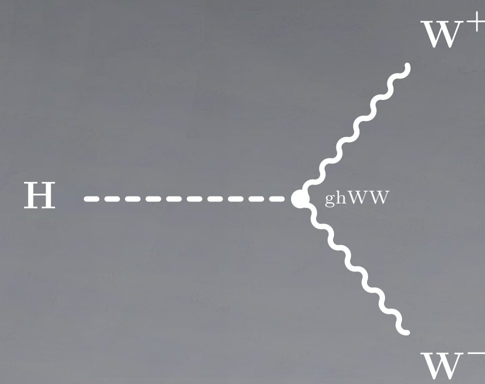
Standard Model: $\Delta\Gamma_H \cong 4$ MeV

At the LHC: Use rate of off-shell H → ZZ: 22 MeV, 100 times better than direct method

At the ILC: Use the fact that the same tree-level coupling enters production and decay and that ZH cross section can be measured inclusively



g_{HWW} in both, production and decay



$$\Gamma_H = \frac{\Gamma(H \to WW)}{\mathcal{BR}(H \to WW)} \propto \frac{g^2_{HWW}}{\mathcal{BR}(H \to WW)}$$

$$\frac{g^2_{HWW}}{g^2_{HZZ}} \propto \frac{\sigma_{\nu\nu H} \times \mathcal{BR}(H \to b\bar{b})}{\sigma_{ZH} \times \mathcal{BR}(H \to b\bar{b})}$$

Expected Precision 500 GeV: $\Delta\Gamma_H / \Gamma_H$ = 3.8%
Luminosity upgrade 500 GeV: $\Delta\Gamma_H / \Gamma_H$ = 1.8%

$\Delta g_{HWW} / g_{HWW}$ = 1.8%
$\Delta g_{HWW} / g_{HWW}$ = 0.42%

Tri-Linear Higgs Self-Coupling

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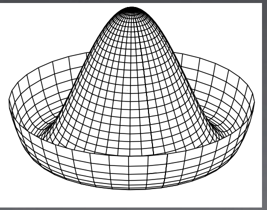
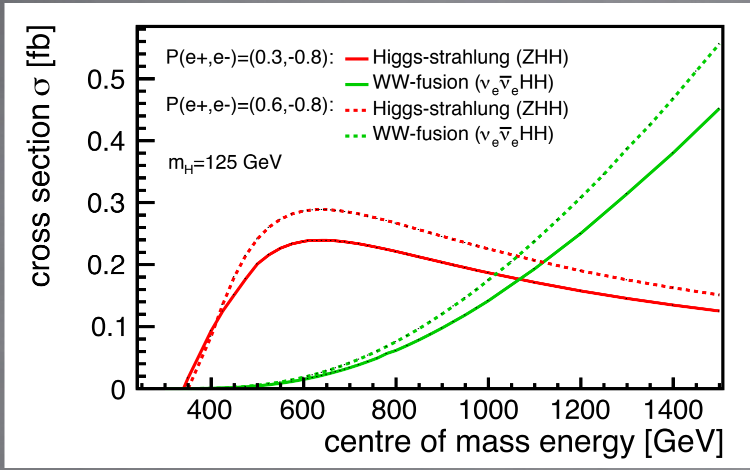
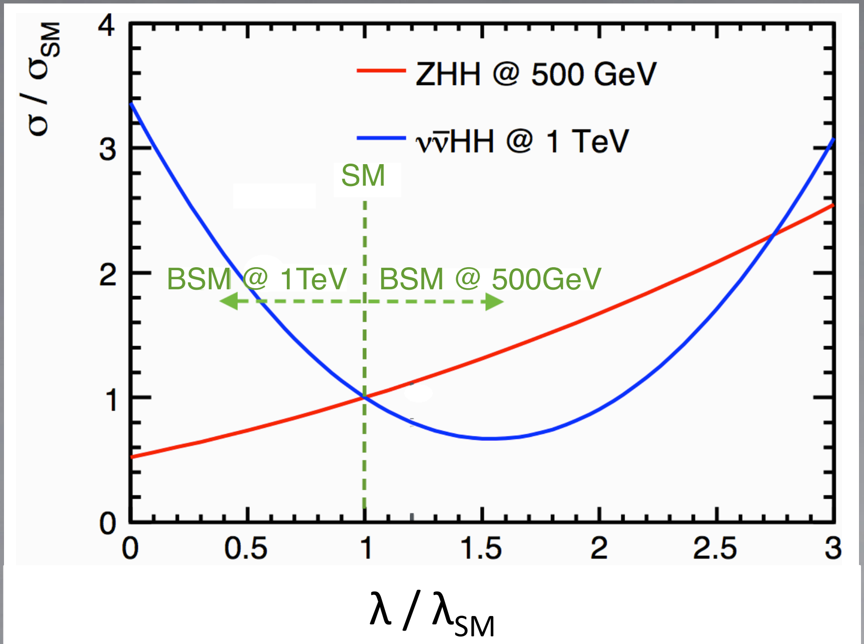
$$\mathbf{V} = \frac{1}{2}\mathbf{m_H^2}\mathbf{\Phi_H^2} + \lambda\mathbf{v}\mathbf{\Phi_H^3} + \frac{1}{4}\kappa\mathbf{\Phi_H^4}$$



In the SM, self-coupling terms fixed by mass. Other models can lead to potentially large deviations. Important to measure independently.

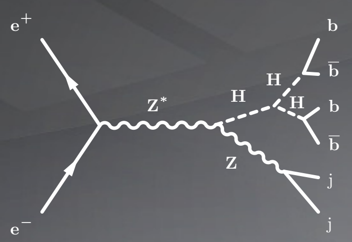
At the ILC: Measure the rate of double Higgs production
ZHH (500 GeV) or HHνν (1 TeV)

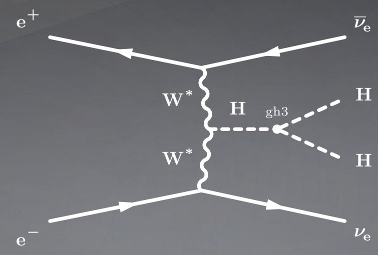




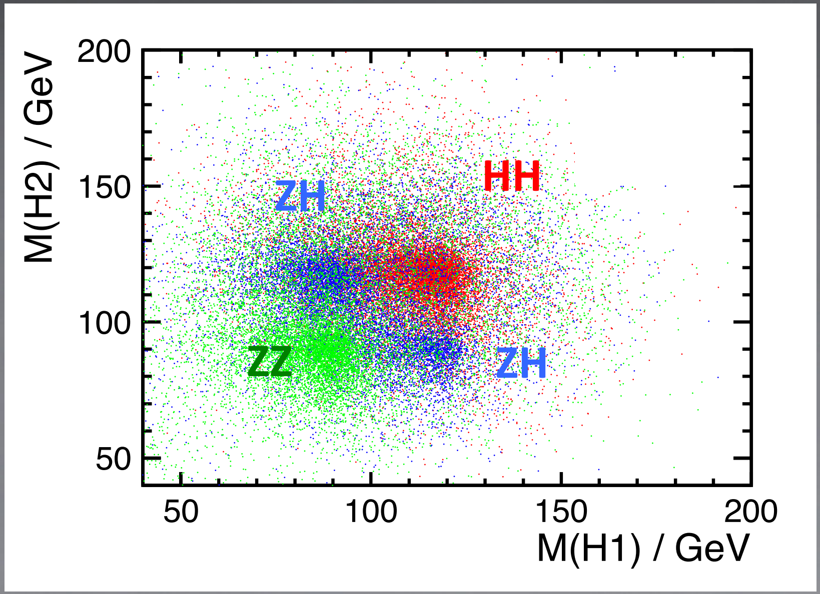
Deviations in λ lead to a change in cross section

Measurement of double Higgs Production at the ILC

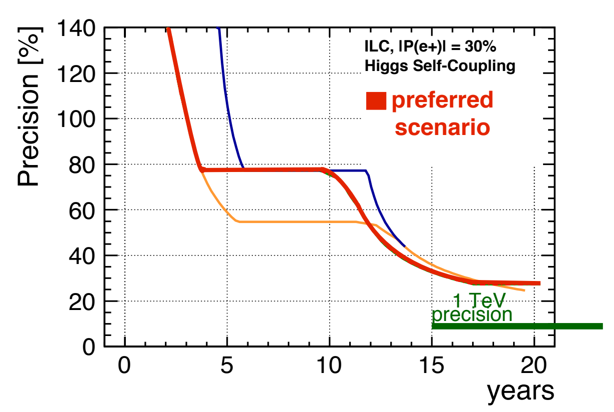




Very challenging experimentally: Low signal rates, high multiplicity.
b – tagging, jet clustering…



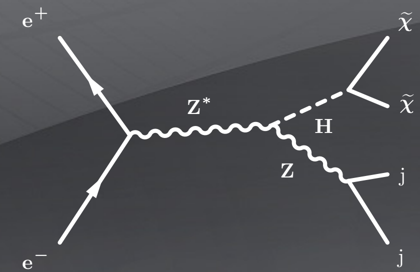
Mass resolution in double Higgs production and dominant background at 500 GeV



Experimental precision limited by jet clustering.

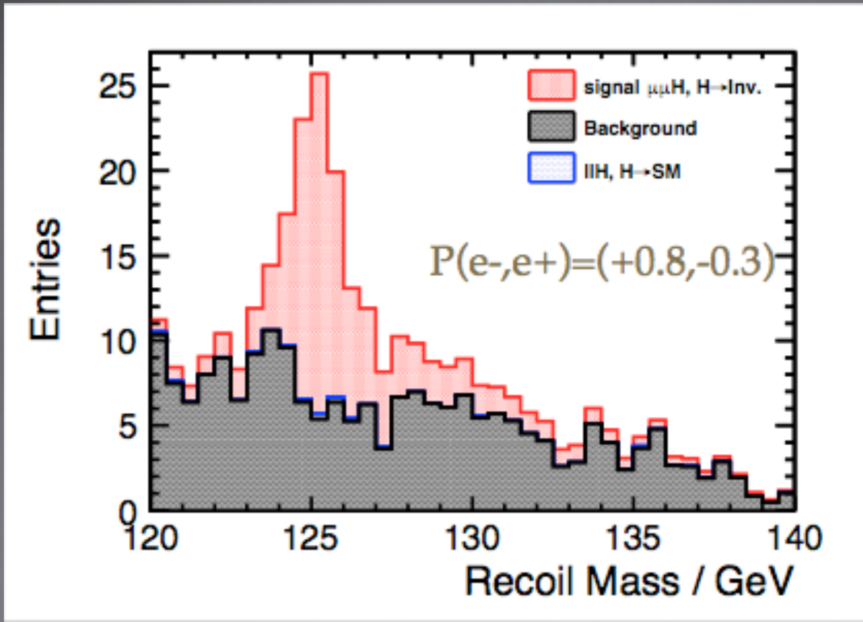
Estimate: 27%
Estimate with 1 TeV upgrade: ~10%

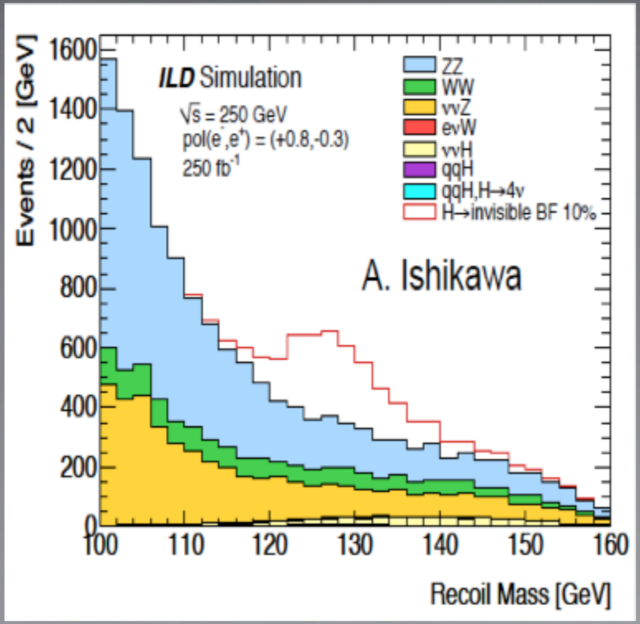
Invisible Higgs Decays



Invisible Higgs decays occur in the SM, e.g. BR (H → ZZ→ νν) ~ 0.4%

Higgs decay to e.g. neutralinos kinematically allowed, if $2m_X < m_H$





Dominant background channels + 25x SM signal

HL-LHC predictions: < 6-17%

ILC Sensitivity down to ~SM prediction in full ILC program: 95% CL: BF < 0.27%

Top Yukawa coupling in the baseline

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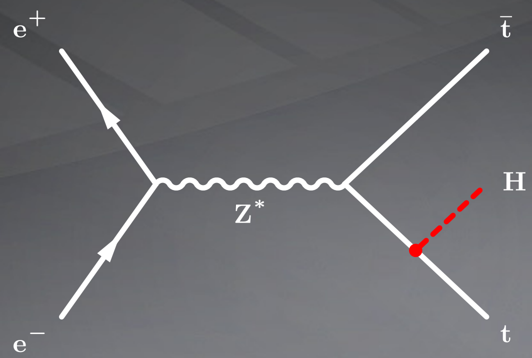
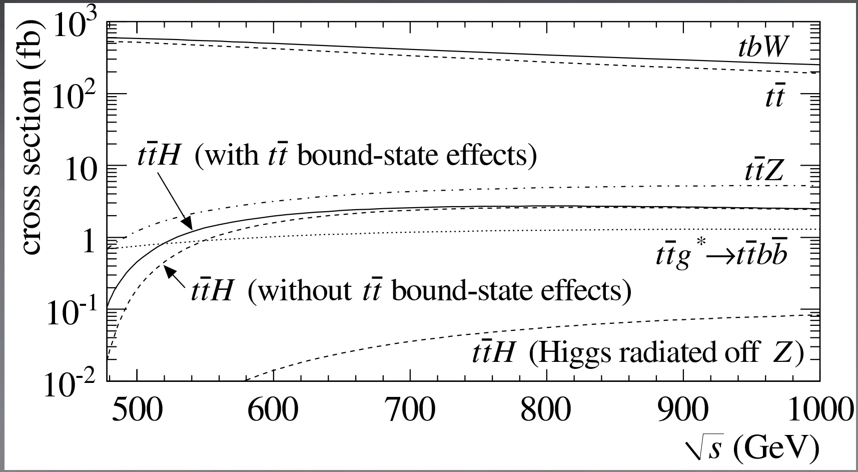
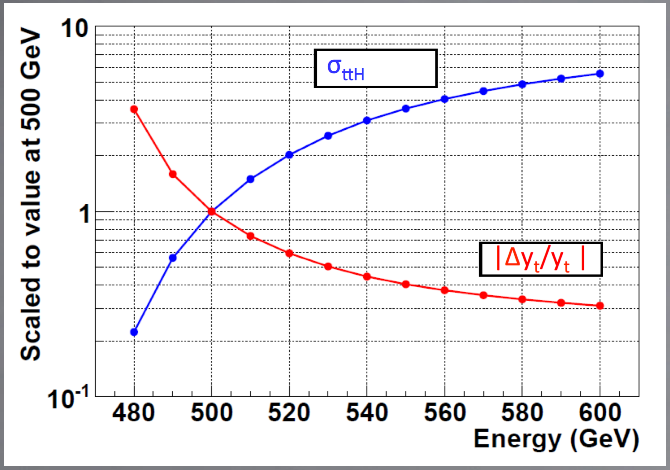


Main production channel of ttH at ILC



Cross section of ttH production at ILC with unpolarized beams

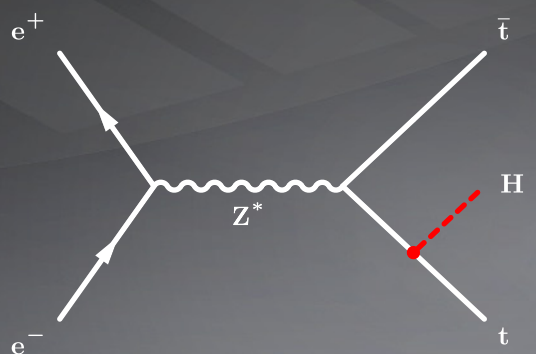


Coupling measurement at baseline energy: 18%,
In full program w/ luminosity upgrade: 6.3%

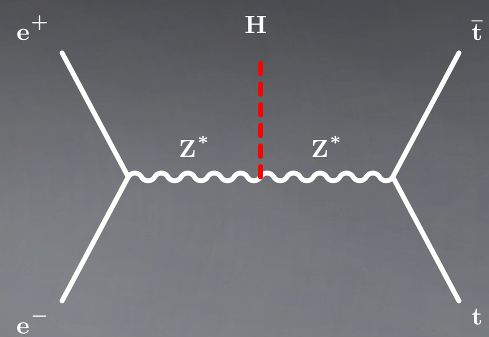
Important to reach at least baseline energy.
Potential at higher energy:
Coupling measurement in full program ~3%

Top Yukawa coupling at 1 TeV

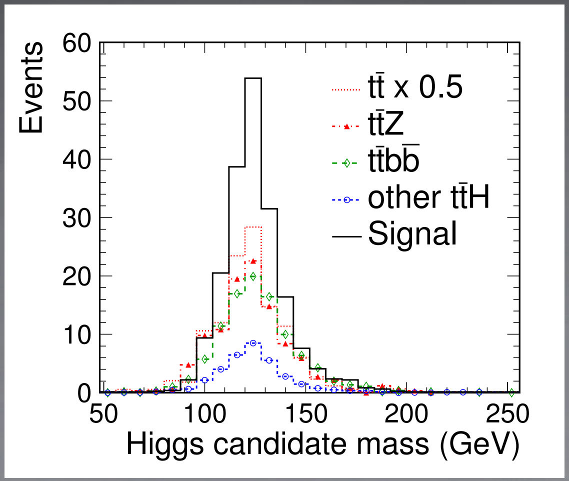
doi:10.1140/epjc/s10052-015-3532-4



Main production channel of ttH at ILC



ttH channel not sensitive to top Yukawa coupling,~4% effect



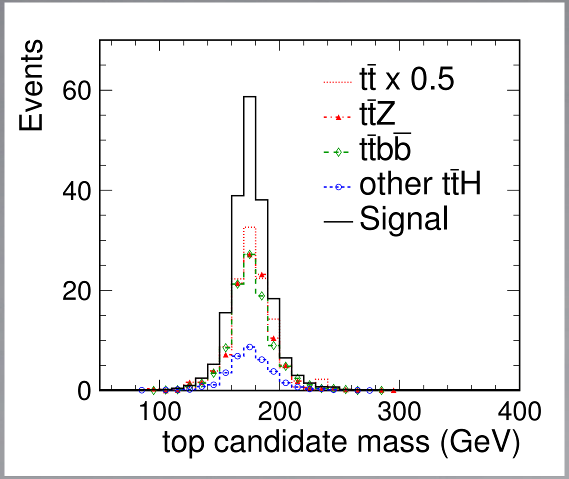
Analysis in 6-jet+lepton and in 8-jet mode

Main background processes:

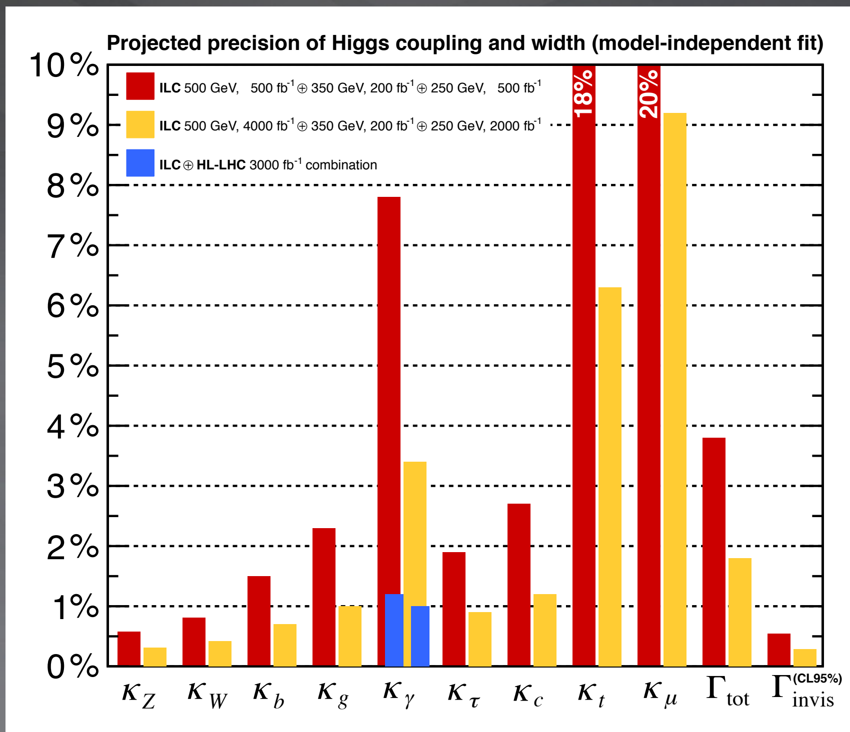
Other Higgs decays, ttZ, ttbb, tt

4% with 1 ab^{-1} at 1 TeV with only left-handed polarization.

Expected precision with full ILC program + Energy upgrade: 2%



Global Fit of Higgs couplings



Best measurement of cross section:
σ_{ZH} from recoil method. Error < 2.5%

parameter	ILC500	ILC500 LumiUp
Γ_H	3.8%	1.8%
g(HZZ)	0.58%	0.31%
g(HWW)	0.81%	0.42%
g(Hbb)	1.5%	0.7%
g(Hcc)	2.7%	1.2%
g(Hgg)	2.3%	1.0%
g(ττ)	1.9%	0.9%
g(Hγγ)	7.8%	3.4%
g(Hγγ)+LHC	1.2%	1.0%
g(Hμμ)	20%	9.2%
g(Htt)	18%	6.3%

Precision Measurements are not optional

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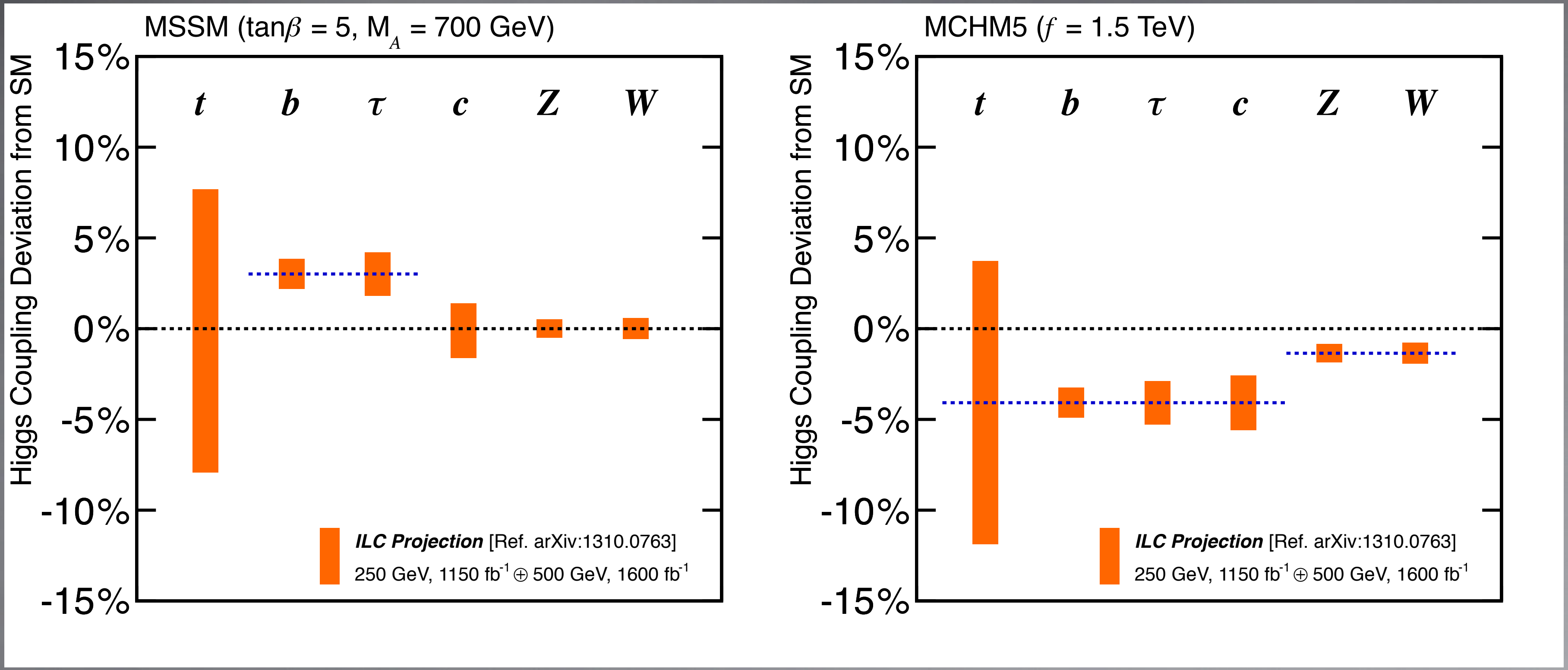
Supersymmetry (MSSM)

Composite Higgs (MCHM5)



ILC 250+500 LumiUp

Disclaimer

- The numbers presented here are based on realistic simulation studies including beam background, with current reconstruction.
- The LHC experiments are demonstrating how much clever approaches in analysis and reconstruction can improve error bars.

Conclusions

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- The LHC experiments have discovered a Higgs boson consistent with various BSM models
- It will take ILC precision to really use the Higgs as a tool for new discovery, as recommended by P5
  - Higgs bosons are an integral part of the ILC physics program. BSM searches, top properties and Higgs physics are tightly coupled thanks to this precision
- From the P5 Executive Summary: "*As the physics case is extremely strong, all Scenarios include ILC support at some level through a decision point within the next 5 years.*"
  - This support will help take the project to the next level

Thank you for your attention

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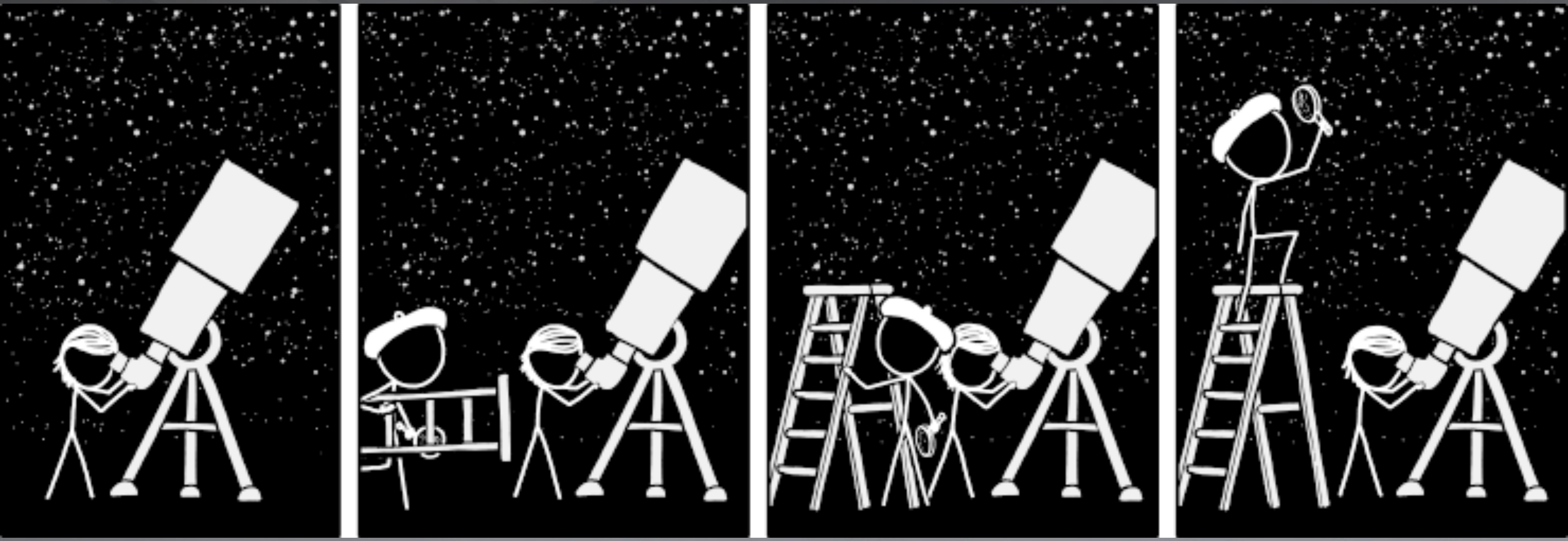
- Acknowledgements (=material stolen from):
- Claude Dürig, Junping Tian, Hiroaki Ono, Shun Watanuki, Josh Ruderman, Chip Brock, Shinichi Kawada, Graham Wilson, Akiya Miyamoto
- ILC Physics WG, ILC Parameters WG



Backup

LC NEWSLINE
THE NEWSLETTER OF THE LINEAR COLLIDER COMMUNITY

DIRECTOR'S CORNER

Japanese diet members go to Washington

Harry Weerts | 11 June 2015

US and Japanese officials and members of the physics community met in Washington, D.C.

There was a visit by Japanese Diet members to Washington DC from 26 to 29 April (see *"Discussions at the political level over the ILC in US and Europe"* in this issue of *LC NewsLine* *link to Rika's story*). I attended two of those meetings, one on 28 April at the Hudson Institute and one on 29 April at the Japanese Society for the Promotion of Science (JSPS) in Washington, D.C.

Since the other article already describes the 28-April meeting, I will concentrate here on other one. The meeting was graciously hosted by the new director of JSPS in Washington , Mitsuaki Nozaki, former Asian Director for ILC's Global Design Effort. It was attended by Diet members Mr. Ryu Shionoya and Mr. Shun-ichi Suzuki and several researches from Japan, including Satoru Yamashita, Hitoshi Murayama, Atsuto Suzuki and several others. The purpose of the meeting was to update our Japanese colleagues on activities related to ILC in the US. The attendance from the US and from Europe consisted of Lyn Evans (LCC Director), Andy Lankford (HEPAP chair), Jim Siegrist and Michael Salamon (DOE), as well as represenatives from US institutions: Mike Harrison, Paul Grannis, Dmitri Denisov, Jim Brau, Andy White, Marc Ross, and myself.

The meeting started with status reports on High Energy Physics Advisory Panel (HEPAP) and P5 (Lankford), US status (Siegrist), ILC status (Evans) followed by activity reports on superconducting radio frequency (SRF) R&D at Fermilab (Denisov), the Linac Coherent Light Source (Ross), ILC detector Ttchnology (White) and international collaborations (Grannis).

The agenda and talks are at https://agenda.linearcollider.org/event/6745/.

LCC Deputy Director Hitoshi Murayama (left) explains ILC physics to Japanese Diet members Mr. Suzuki (middle) and Mr. Shionoya (right) at JSPS Washington

In my mind the situation in the US can be best described like this: following the P5 recommendations there is support in the US for participation in the Linear Collider Collaboration, support for accelerator R&D in areas where the US contributes uniquely and an overall effort in SRF R&D to improve cavity performance, which might lead to a cost reduction in the overall ILC project. Efforts on physics and detector developments and R&D exist, but are at a minimal level.

At the meeting a handout was distributed by our Japanese colleagues, in which the suggestion was made for a US- Japan congressional caucus to be formed to discuss scientific and technical projects like nuclear energy, the International Space Station, advanced computing, or future colliders, with ILC as the obvious intended focus. This was also raised at the meeting on 28 April, but not as concrete as it was described at this meeting. It was also suggested that a US researcher be identified who would be the conduit to the caucus to educate and inform them of developments.

The handout and proposal by our Japanese colleagues, was a new suggestion and a bit of a surprise to the US side, but it was decided that the American Linear Collider Committee (ALCC) would take this under consideration and see how these suggestions can be implemented in the US and in the US system. This has been discussed at the follow-up ALCC meeting at the beginning of May. As another follow-up to the 28-April meeting there was a meeting between US researchers and the president of the Hudson Institute, Ken Weinstein. The purpose of the meeting was to provide some more background to the Hudson Institute on high-energy physics, its global nature and how the ILC fits in, as well as to start exploring how this institute may help with making the ILC part of a broader Japan-US science and technology framework that enables discussions between the two countries, including the ILC.

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	$\sqrt{s}$	$\int \mathscr{L} dt$	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.

Topic	Parameter	Initial Phase	Full Data Set	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]
Top	m_t	50	50	MeV (m_t(1S))	[54]
	Γ_t	60	60	MeV	[53]
	g_L^γ	0.8	0.6	%	[49]
	g_R^γ	0.8	0.6	%	[49]
	g_L^Z	1.0	0.6	%	[49]
	g_R^Z	2.5	1.0	%	[49]
	F_2^γ	0.001	0.001	absolute	[49]
	F_2^Z	0.002	0.002	absolute	[49]
W	m_W	2.8	2.4	MeV	[36]
	g_1^Z	8.5×10^{-4}	6×10^{-4}	absolute	[55]
	κ_γ	9.2×10^{-4}	7×10^{-4}	absolute	[55]
	λ_γ	7×10^{-4}	2.5×10^{-4}	absolute	[55]
Dark Matter	EFT Λ: D5	2.3	3.0	TeV, 90% conf. limit	[32]
	EFT Λ: D8	2.2	2.8	TeV, 90% conf. limit	[32]