Higgs/EWSB Summary

Keisuke Fujii (KEK)

Higgs/EWSB Sessions

7 Sessions altogether

Joint Higgs/BSM Session - DESY Auditorium (09:00-10:30)

time	[id] title	presenter
09:00	[46] Higgs physics with CMS	SAVIN, Alexander
09:30	[47] Higgs physics with ATLAS	ZANZI, Daniele
10:00	[48] Search for BSM Higgs in ATLAS	SIMONIELLO, Rosa
10:15	[49] Beyond Standard Model Higgs searches at CMS	WOLF, Roger

LHC

Higgs, EWSB - DESY Auditorium (11:00-13:00)

time	[id] title	presenter
11:00	[50] How well do we need to measure Higgs boson couplings?	RZEHAK, Heidi
11:25	[51] Higgs to tau tau branching ratio study in the ILC with ILD detector	KAWADA, Shin-ichi
11:50	[52] Measurement of the Higgs boson decay to tau leptons at a CLIC collider operating at 350 and 1400 GeV	Dr. MUENNICH, Astrid
12:10	[53] Measurement accuracy of Higgs branching ratio in ILC	Dr. ONO, Hiroaki
12:35	[54] SFitter: Higgs Couplings at the LHC and LC	PLEHN, Tilman

$H \rightarrow bb$, cc, gg, $\tau\tau$, WW^*, $\mu\mu$

Theoretical expectations

Joint Higgs/BSM Session - DESY Auditorium (14:30-16:00)

time	[id] title	presenter
14:30	[41] The status of constrained SUSY and implications for the Higgs boson	SARRAZIN, Bjorn
14:50	[42] Implications of SUSY and Higgs Searches for the ILC	HEINEMEYER, Sven
15:10	[43] SUSY strongly-coupled Higgs sector and electroweak baryogenesis	Mr. YAMADA, Toshifumi
15:30	[44] Higgs inflation in a radiative seesaw model	Mr. NABESHIMA, Takehiro
15:45	[45] The Higgs boson mixes with an SU(2) septet	Prof. TSUMURA, Koji

Higgs, EWSB - DESY Auditorium (16:30-18:00)

time	[id] title	presenter
16:30	[63] Search for invisible Higgs decays at the ILC	Dr. ISHIKAWA, Akimasa
16:55	[57] The Higgs ILC White paper	Dr. BARKLOW, Timothy
17:25	[58] Determination of the CP parity of Higgs bosons in their tau decay channels at the ILC	BERGE, Stefan

$H \rightarrow$ invisible, CP property

Joint Higgs/Top Session - DESY Auditorium (11:00-13:00) Top Yukawa

time	[id] title	presenter
11:00	[267] Impact of m_t measurements on precision tests of the SM and the MSSM	HEINEMEYER, Sven
11:25	[67] yukawa top ILD -> Associated production of the Higgs boson with a top pair at the ILC	TANABE, Tomohiko
11:50	[68] Measurement of the top Yukawa coupling at sqrt(s) = 1 TeV using the SiD detector	Dr. ROLOFF, Philipp
12:15	[69] Measurement of the top Yukawa coupling at a 1.4 TeV CLIC collider	REDFORD, Sophie
12:35	[70] Top anomalous magnetic moment and Higgs decays	LABUN, Lance

Higgs, EWSB - DESY Auditorium (14:00-15:30) Coupling meas. at CLIC

time	[id] title	presenter
14:00	[60] Measurement of the Higgs couplings to b- and c-quarks and to gluons at 350 GeV, 1.4 TeV and 3 TeV CLIC	Dr. LASTOVICKA, Tomas
14:25	[61] Measurement of the Higgs couplings to gauge bosons at CLIC	SICKING, Eva
14:50	[62] Measurement of the Higgs boson decay to muons at a CLIC collider operating at 1.4 and 3 TeV	BOZOVIC-JELISAVCIC, Ivanka
15:10	[56] Higgs Production from SUSY Decays at the LC	HEINEMEYER, Sven

Higgs, EWSB - DESY Auditorium (16:00-17:15) Self-coupling

time	[id] title	presenter
16:00	[64] Study of Higgs self-coupling at 500 GeV and 1 TeV at ILC	Dr. TIAN, Junping
16:20	[65] Higgs Self Coupling Analysis using the events containing H->WW* decay	Mr. KURATA, Masakazu
16:40	[66] Measurement of the Higgs self-coupling at 1.4 and 3 TeV	STRUBE, Jan Fridolf

3 joint sessions
- 2 with BSM (incl. 1 LHC session)
- 1 with top

29 talks
- 10 theory talks
- 19 exp. talks (incl. 4 LHC talks)

A lot of post DBD (ILC) / CDR (CLIC) analyses on going --> inputs to Snowmass process (Tim)

LHC

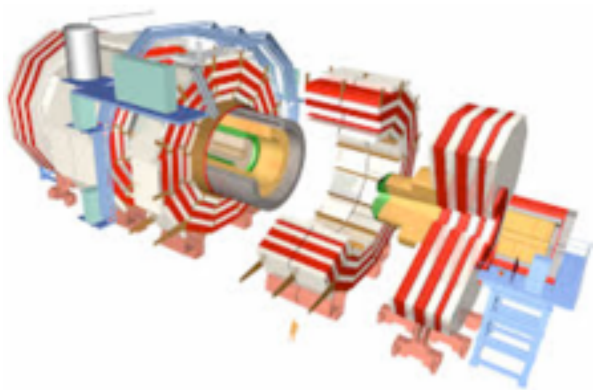
Higgs Results from CMS

- X(125): observed in different decay modes:
  - X→ZZ* (~7σ), γγ (~4σ), ττ (~3σ), WW*

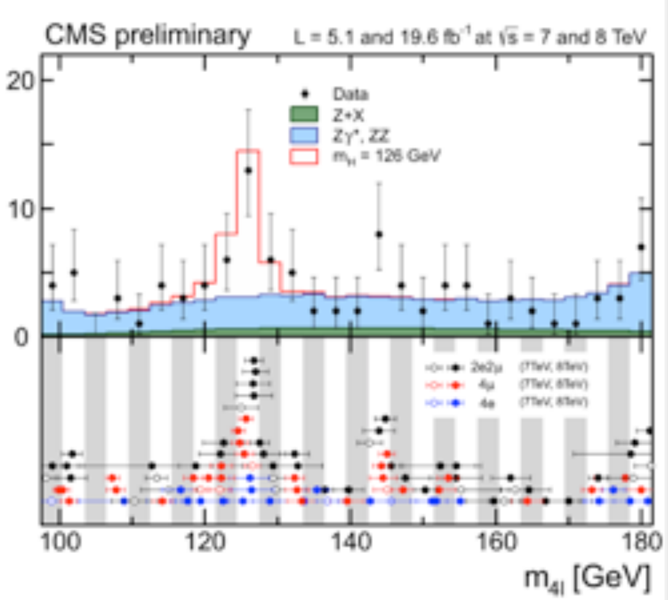
  which already allow nontrivial test of couplings

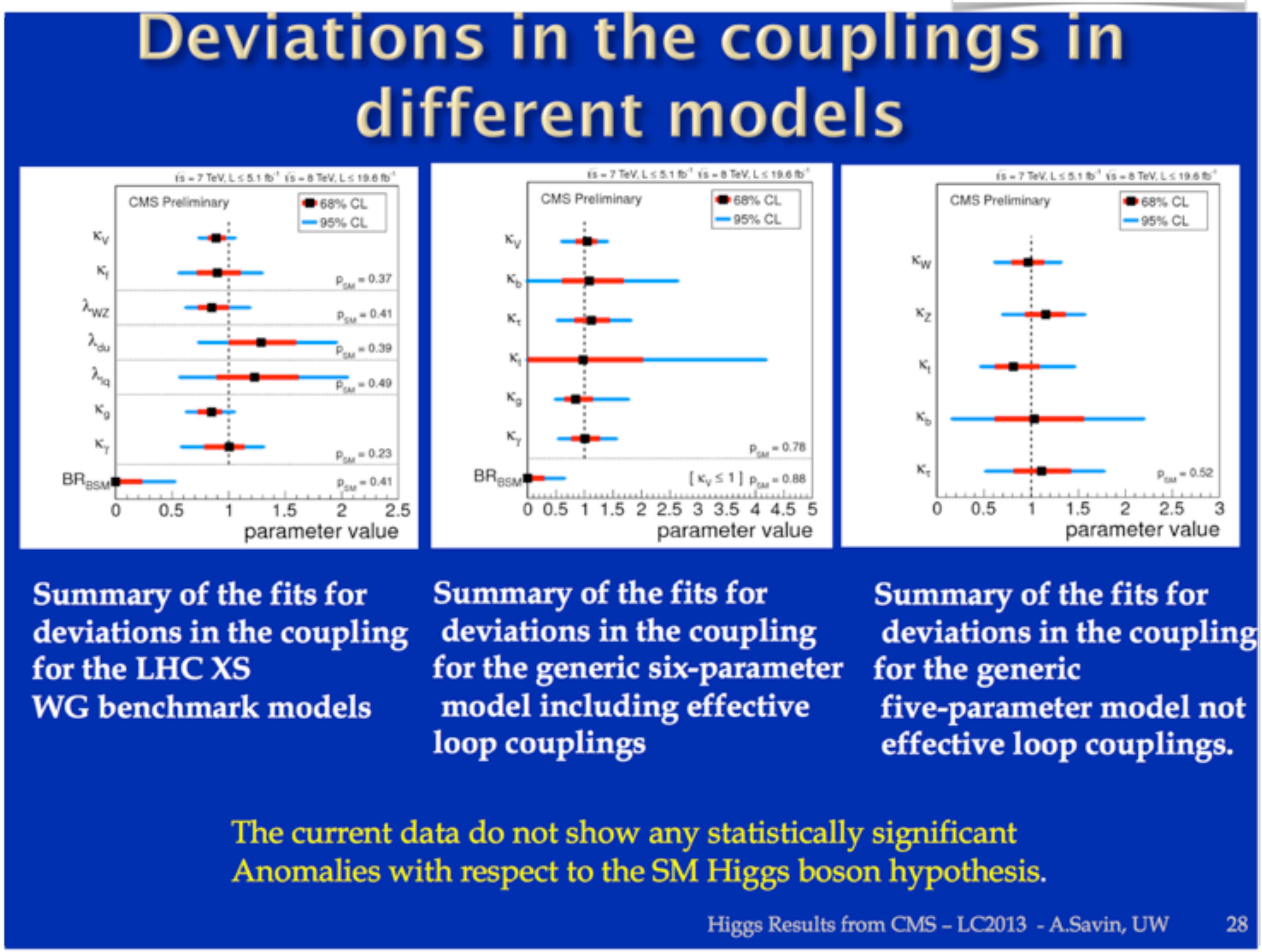
Alexander A. Savin

CMS



X→ZZ*→4l



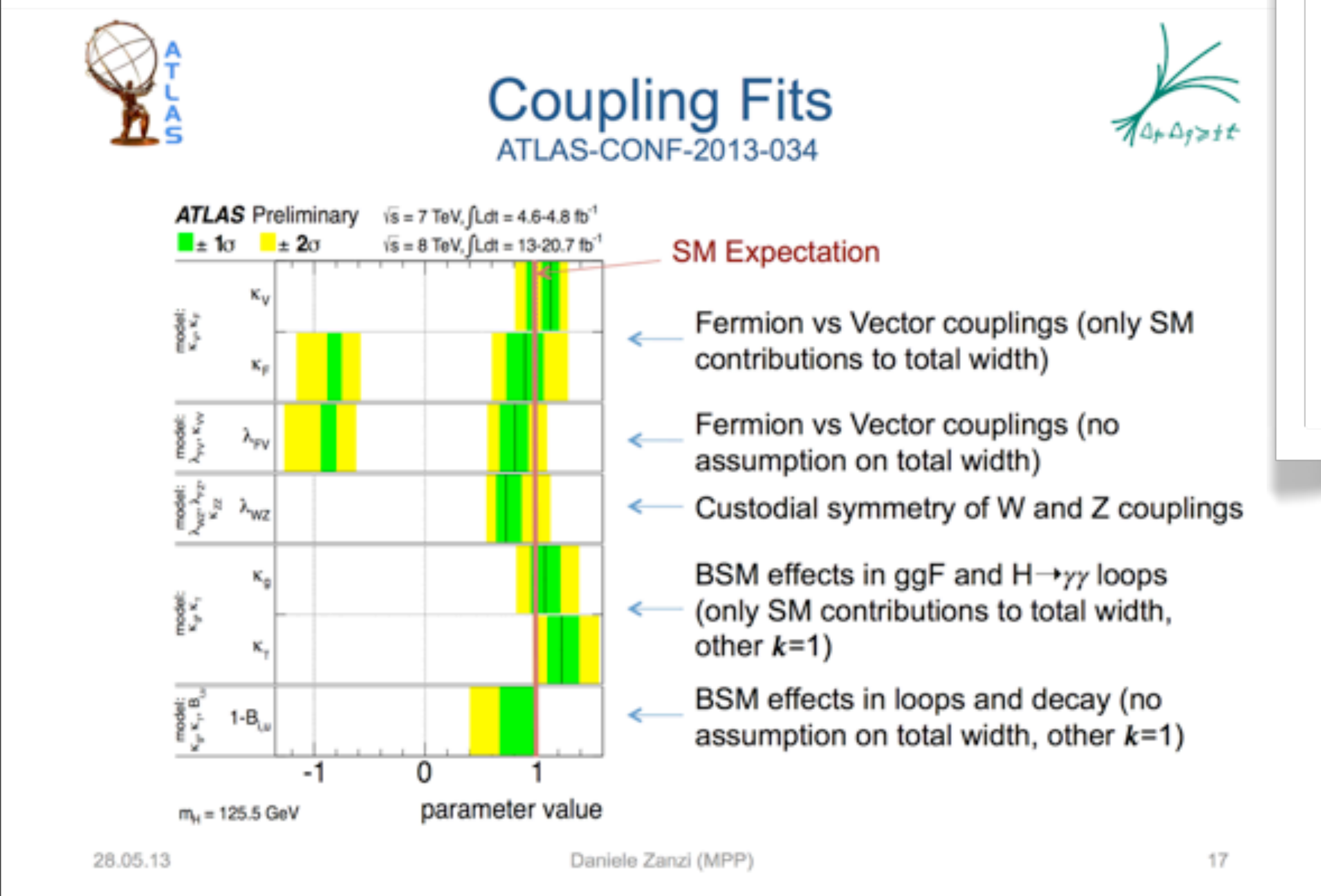


Higgs Results from ATLAS

- X125: observed in different decay modes:
  - X→ZZ* (~7σ), γγ (~7.4σ), WW* (3.8σ)

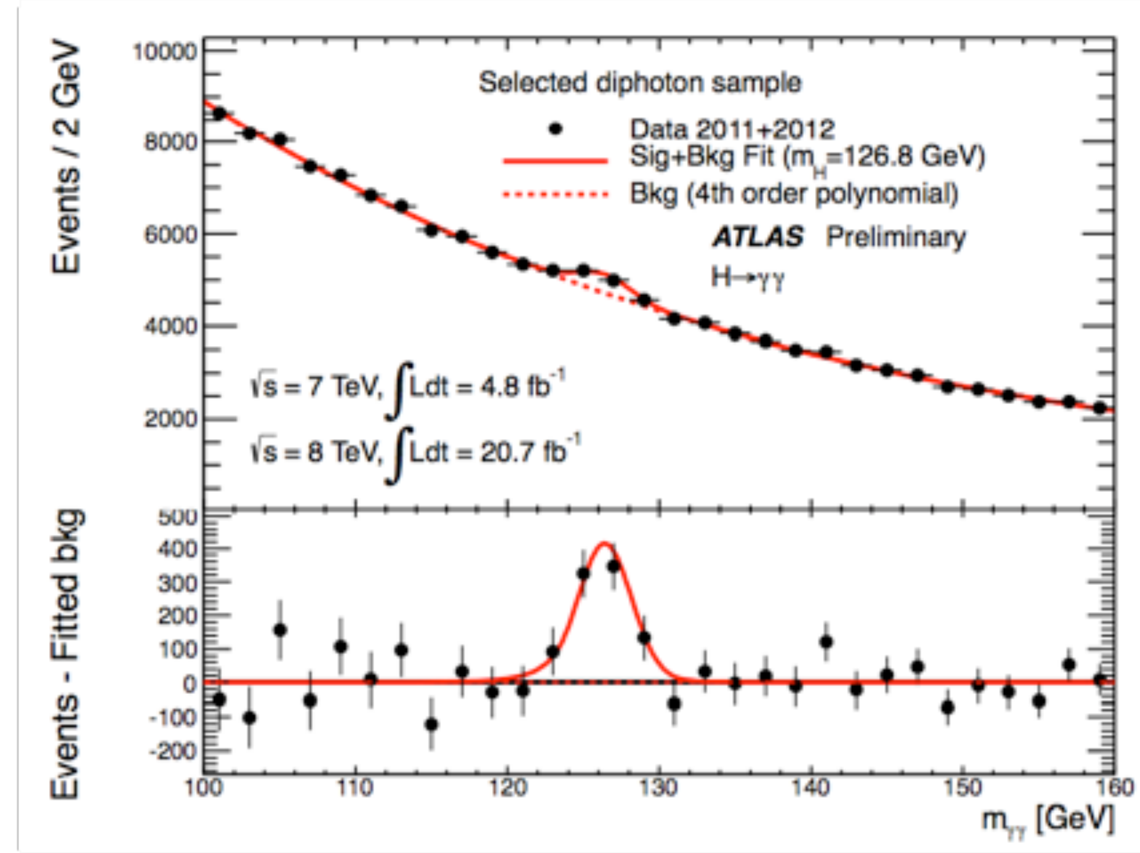
  which already allow nontrivial test of couplings

ATLAS



Daniele Zanzi

H→γγ

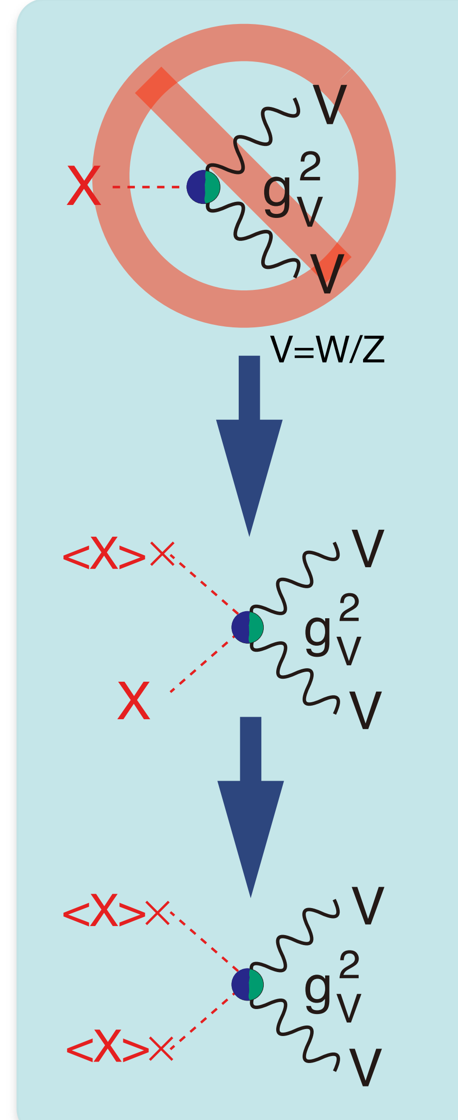


- X(125) → γγ means X is a neutral boson and J ≠ 1 (Landau-Yang theorem).
- Angular analysis prefers $J^P=0^+$ against other spin parity assignments.

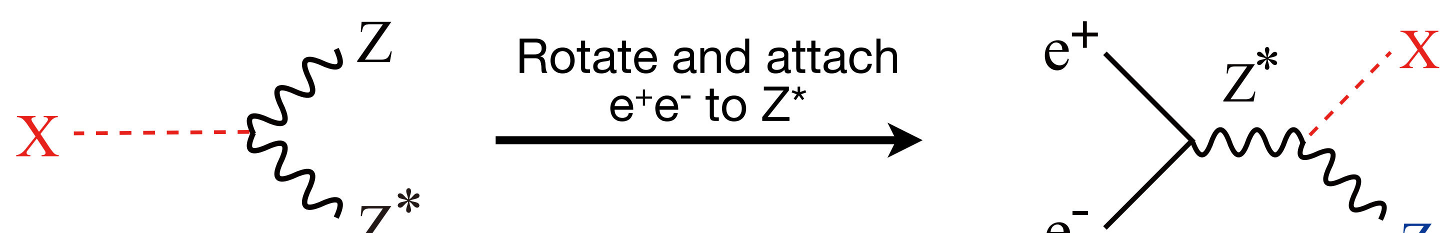
It looks really like a Higgs boson!

Since the July 4th, the world has changed!

The discovery of the ~125 GeV boson at LHC could be called a quantum jump.

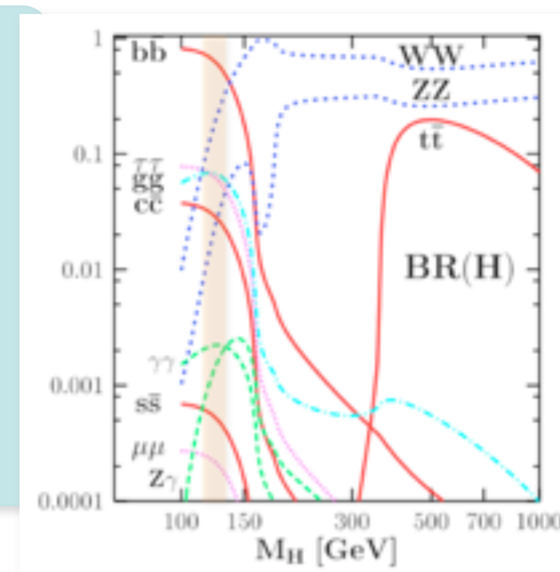


- X(125) → ZZ*, WW* ⇒ ∃ XVV couplings: (V=W/Z: gauge bosons)
- There is no gauge coupling like XVV, only XXVV or XXV
  ⇒ XVV probably from XXVV with one X replaced by <X> ≠ 0, namely <X>XVV
  ⇒ There must be <X><X>VV, a mass term for V.
  ⇒ X is at least part of the origin of the masses of V=W/Z.
  ⇒ This is a great step forward but we need to know whether <X> saturates the SM vev = 246GeV.
- X →ZZ* means, X can be produced via e^+e^- → Z* → ZX.



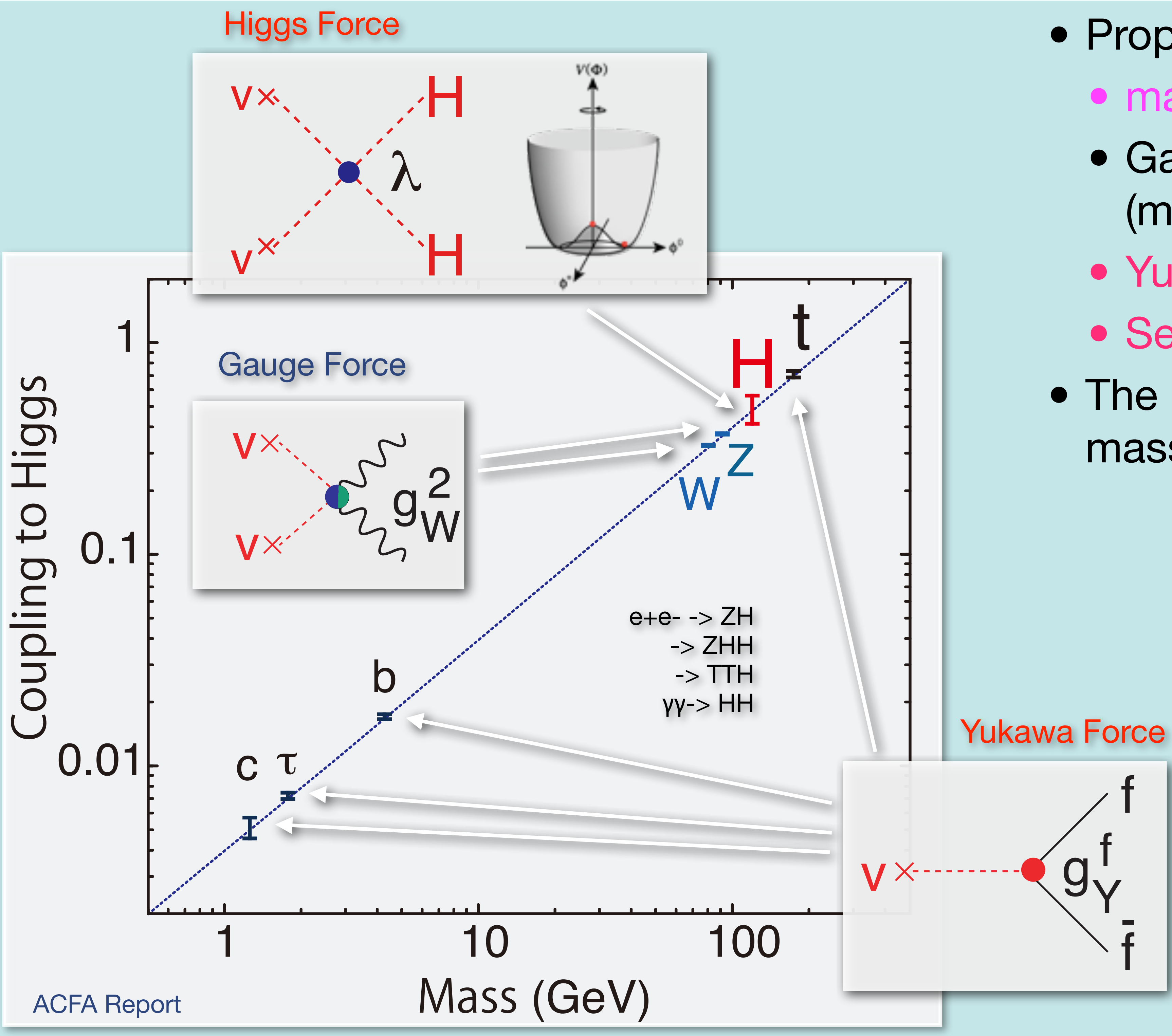
- By the same token,
  X → WW* means, X can be produced via W fusion: e^+e^- → $\nu\nu X$.

- So we now know that the major Higgs production mechanisms are indeed available at a LC ⇒ No lose theorem for the LC.
- ~125GeV is the best place for the LC, where variety of decay modes are accessible.
- We need to check this ~125GeV boson in detail to see if it has indeed all the required properties of the vacuum condensate.



What Properties to Measure?

The Key is the Mass-Coupling Relation



- Properties to measure are
  - mass, width, J^{PC}
  - Gauge quantum numbers (multiplet structure)
  - Yukawa couplings
  - Self-coupling
- The key is to measure the mass-coupling relation

If the 125GeV boson is the one to give masses to all the SM particles, coupling should be proportional to mass.

Any deviation from the straight line signals BSM!

The Higgs is a window to BSM physics!

Our Mission = Bottom-up Model-Independent Reconstruction of the EWSB Sector

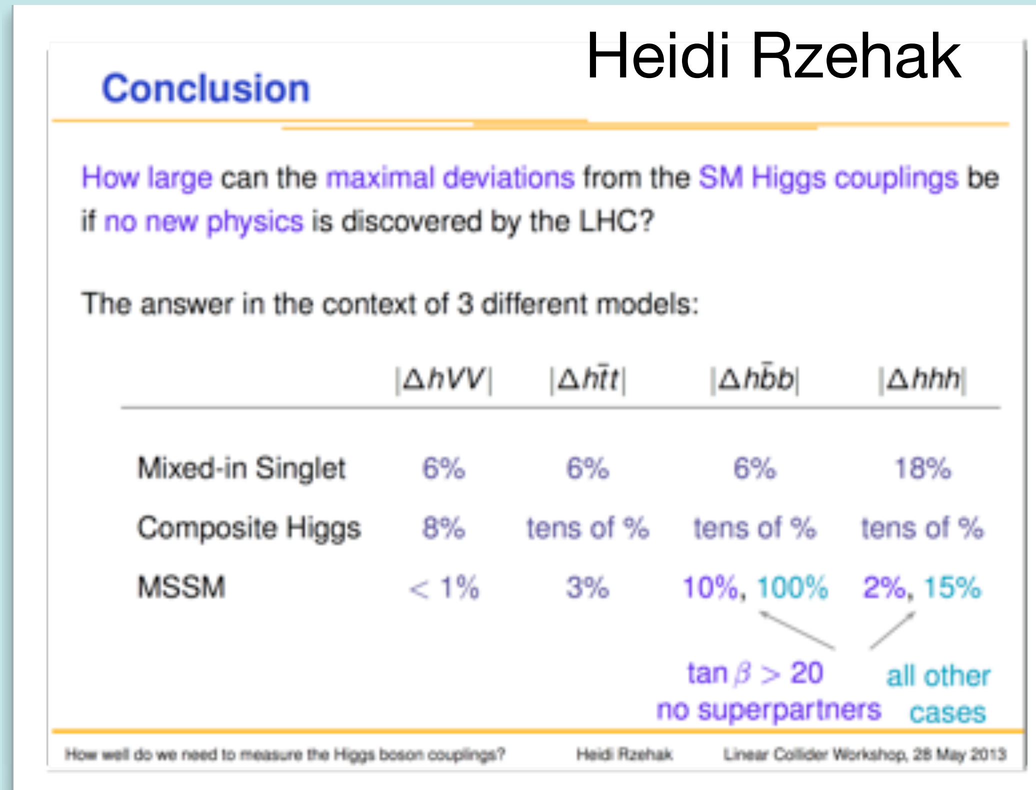
through Precision Higgs Measurements

- Multiplet structure :
  - Additional singlet?
  - Additional doublet?
  - Additional triplet?
- Underlying dynamics :
  - Weakly interacting or strongly interacting?
    = elementary or composite ?
- Relations to other HEP questions :
  - DM
  - EW baryogenesis
  - neutrino mass
  - inflation?

There are many possibilities!

Different models predict different deviation patterns --> Fingerprinting!

Model	μ	τ	b	c	t	g_V
Singlet mixing	↓	↓	↓	↓	↓	↓
2HDM-I	↓	↓	↓	↓	↓	↓
2HDM-II (SUSY)	↑	↑	↑	↓	↓	↓
2HDM-X (Lepton-specific)	↑	↑	↓	↓	↓	↓
2HDM-Y (Flipped)	↓	↓	↑	↓	↓	↓


Heidi Rzehak

Conclusion

How large can the maximal deviations from the SM Higgs couplings be if no new physics is discovered by the LHC?

The answer in the context of 3 different models:

	$\lvert\Delta hVV\rvert$	$\lvert\Delta h\bar{t}t\rvert$	$\lvert\Delta h\bar{b}b\rvert$	$\lvert\Delta hhh\rvert$
Mixed-in Singlet	6%	6%	6%	18%
Composite Higgs	8%	tens of %	tens of %	tens of %
MSSM	$< 1\%$	3%	10%, 100%	2%, 15%

$\tan\beta > 20$ no superpartners; all other cases

How well do we need to measure the Higgs boson couplings? Heidi Rzehak Linear Collider Workshop, 28 May 2013

Expected deviations are small --> Precision!

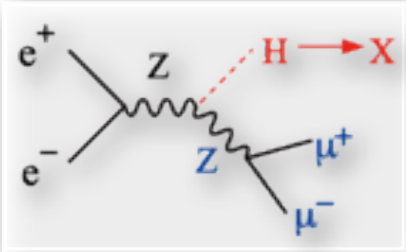
For the precision we need a 500 GeV LC.

Why 250-500 GeV?

Three well known thresholds

ZH @ 250 GeV (~MZ+MH+20GeV) :

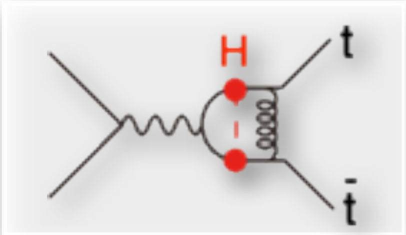
- Higgs mass, width, J^{PC}
- Gauge quantum numbers
- Absolute measurement of HZZ coupling (recoil mass) -> couplings to H (other than top)
- BR(h->VV,qq,ll,invisible) : V=W/Z(direct), g, γ (loop)

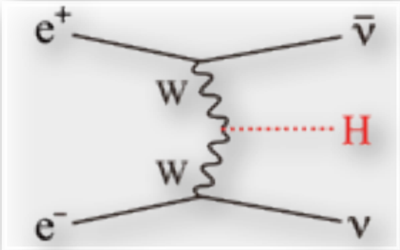


ttbar @ 340-350GeV (~2mt) : ZH meas. Is also possible

- Threshold scan --> theoretically clean mt measurement: $\Delta m_t(\overline{MS}) \simeq 100\,\mathrm{MeV}$
  --> test stability of the SM vacuum
  --> indirect meas. of top Yukawa coupling
- AFB, Top momentum measurements
- Form factor measurements

γ γ → HH @ 350GeV possibility



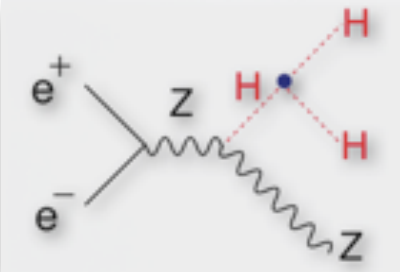


vvH @ 350 - 500GeV :

- HWW coupling -> total width --> absolute normalization of Higgs couplings

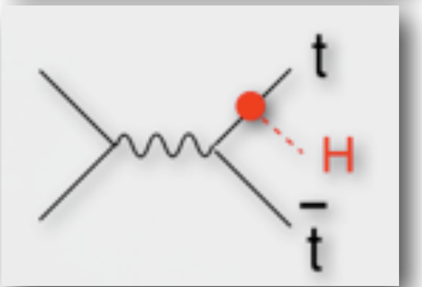
ZHH @ 500GeV (~MZ+2MH+170GeV) :

- Prod. cross section attains its maximum at around 500GeV -> Higgs self-coupling



ttbarH @ 500GeV (~2mt+MH+30GeV) :

- Prod. cross section becomes maximum at around 800GeV.
- QCD threshold correction enhances the cross section -> top Yukawa measurable at 500GeV concurrently with the self-coupling



We can complete the mass-coupling plot at ~500GeV!

BR and Coupling Measurements

H→bb,cc,gg,WW*,ττ,μμ

ILD

Hiroaki Ono

Current Higgs BR summary (ΔσBR/σBR)

E_{cm} (GeV)	250	350	500	1000	Comment
Pol (e-,e+)	(-0.8,+0.3)	(-0.8,+0.3)	(-0.8,+0.3)	(-0.8,+0.2)	
Lumi (fb^{-1})	250	250	500	1000	
Mh (GeV)	120	120	120	125	
h→bb	1.0%	1.0%	0.57%	0.39%	Eur. Phys. J. C 73, 2343 (2013) LC-REP-2013-005
h→cc	6.9%	6.2%	5.2%	3.9%	Eur. Phys. J. C 73, 2343 (2013) LC-REP-2013-005
h→gg	8.5%	7.3%	5.0%	2.8%	Eur. Phys. J. C 73, 2343 (2013) LC-REP-2013-005
h→WW*	8.1%		3.0%	2.5%	LC-REP-2013-006 250, 500 GeV to be prepared
h→ττ	3.5%				LC-REP-2013-001
h→μμ				31%	LC-REP-2013-006

Re-do with new 125 GeV full simulation samples

May 28 2013 ECFA 2013 @ DESY Higgs/EWSB session 12

SiD results are similar.

What we measure is not BR itself but σxBR.

To extract BR from σxBR, we need σ from the recoil mass measurement.

ILD

Shin-ichi Kawada

Summary & Next Plan

We evaluated the precision of the branching ratio of $H \to \tau\tau$ mode with the ILD full detector simulation.

scaled results to 125 GeV

$\sqrt{s} = 250$ GeV, $M_H = 125$ GeV, $\mathrm{Br}(H \to \tau\tau) = 6.32\,\%$,
$\int L\,dt = 250\ \mathrm{fb}^{-1}$, $P(e^-, e^+) = (-0.8, +0.3)$

precision : $\frac{\Delta(\sigma\cdot\mathrm{Br})}{(\sigma\cdot\mathrm{Br})} = 4.1\ \%$

Next : Analysis with samples with latest simulation tools & $M_H = 125$ GeV ($\sqrt{s} = 250$ GeV, 350 GeV, 500 GeV, 1 TeV)

ECFA LC 2013 @ DESY (2013/May/28) 19

Cross Section Results

Astrid Muennich

CLIC

350 GeV mh=126GeV	
Signal events (BDT>0.08)	312
Total signal events	529
Background events (BDT>0.08)	150
Signal efficiency	60%
Signal purity	67%
$\sqrt{S+B}/S$ (Method 1)	6.9%
$\sqrt{S+B}/S$ (Method 2)	6.2%

1.4 TeV mh=120GeV	
Signal events (BDT>0.05)	1227
Total signal events	2238
Background events (BDT>0.05)	1620
Signal efficiency	55%
Signal purity	43%
$\sqrt{S+B}/S$ (Method 1)	4.3%
$\sqrt{S+B}/S$ (Method 2)	3.7%

Method 2 has a slight advantage over method 1 as this is a statical error and method 2 can use the full information contained in every bin.

New method (method 2) to utilize all the BDT bins

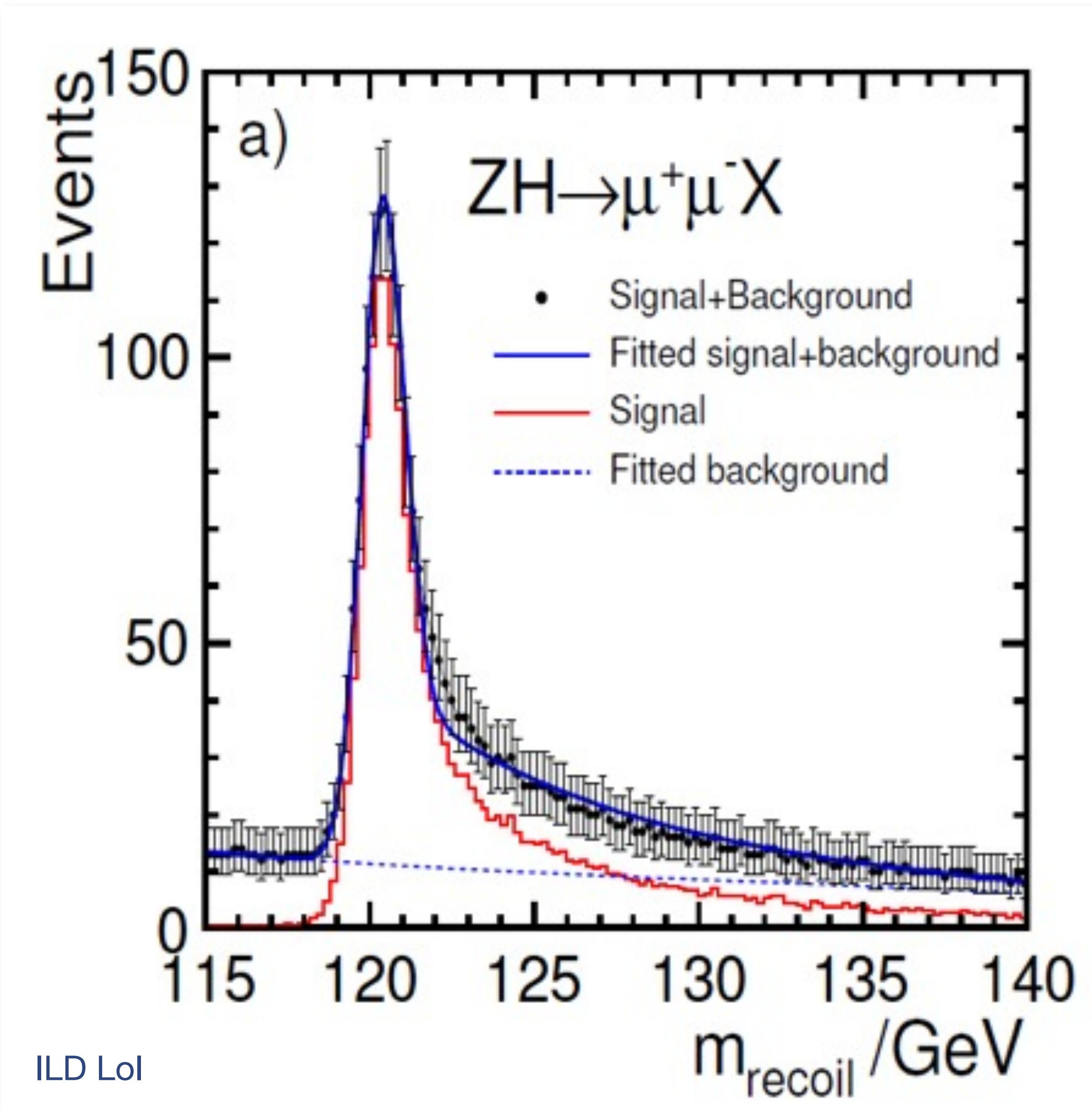
A. Münnich H → ττ 15

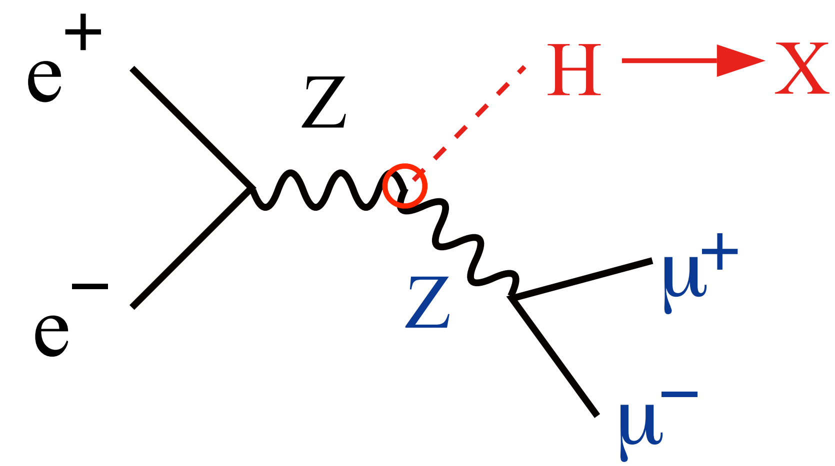
Recoil Mass Measurement

The flagship measurement of a LC

The best place to do this recoil mass measurement is at 250 GeV!

Recoil Mass





$$M_X^2 = \left(p_{CM} - (p_{\mu^+} + p_{\mu^-})\right)^2$$

Invisible decay detectable!

$250\,\mathrm{fb}^{-1}@250\,\mathrm{GeV}$ $m_H = 125\,\mathrm{GeV}$

$$\Delta\sigma_H/\sigma_H = 2.6\%$$

$$\Delta m_H = 30\,\mathrm{MeV}$$

$$BR(\mathrm{invisible}) < 1\%\,@\,95\%\,\mathrm{C.L.}$$

scaled from mH=120 GeV

Akimasa Ishikawa

Model-independent absolute measurement of σ_{ZH} (the HZZ coupling)

K.Fujii @ ECFA LCWS 2013

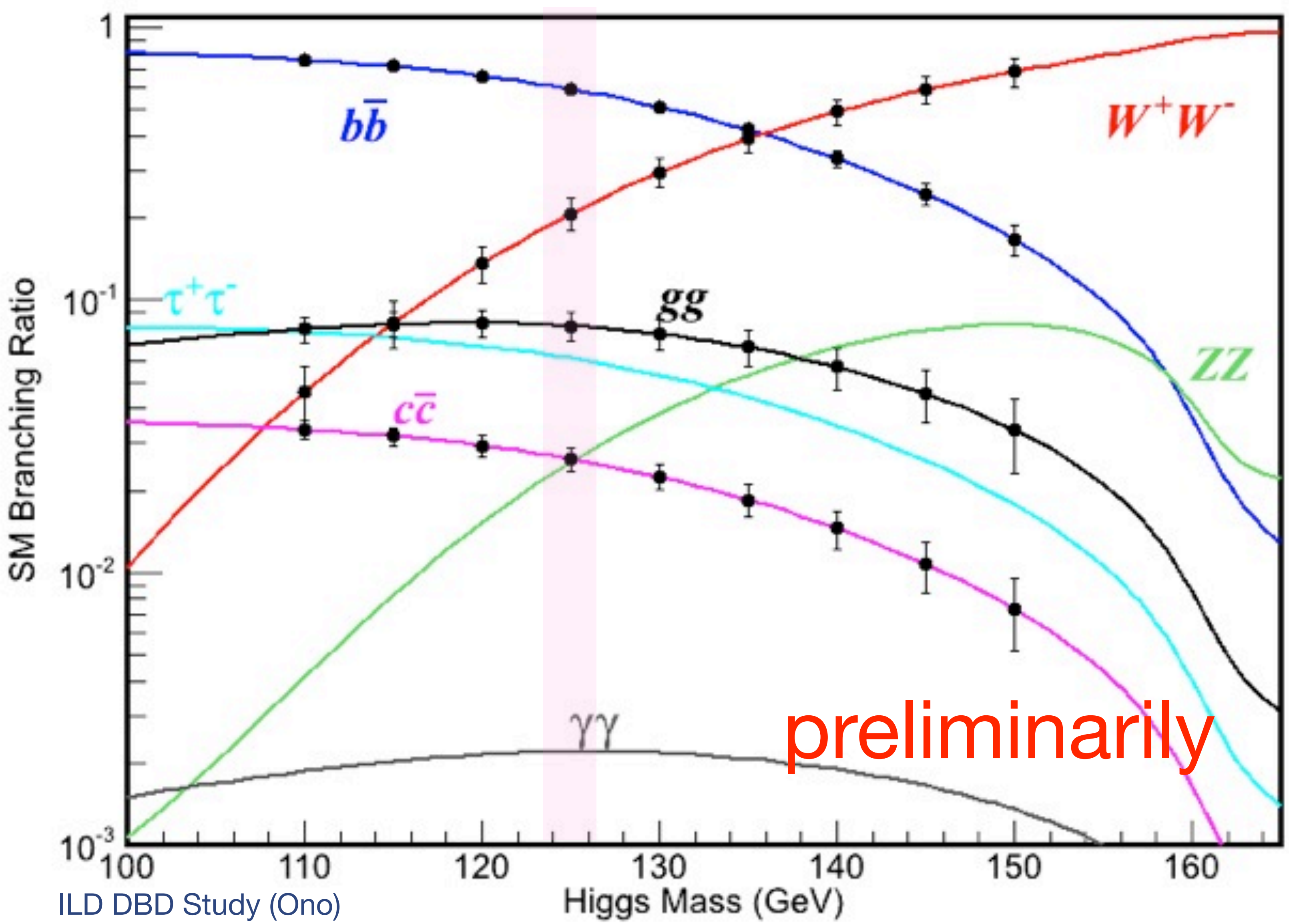
Branching Ratio Measurements

for b, c, g, tau, WW*, ...

DBD Physics Chap.

$$250\,\mathrm{fb}^{-1}@250\,\mathrm{GeV}$$
$$m_H = 125\,\mathrm{GeV}$$

scaled from mH=120 GeV



ILD DBD Study (Ono)

	@250GeV
process	ZH
Int. Lumi. [fb^{-1}]	250
Δσ/σ	2.6%
decay mode	ΔσBr/σBr
H → bb	1.1%
H → cc	7.4%
H → gg	9.1%
H → WW*	7.4%
H → ττ	4.2%
H → ZZ*	19%
H → γγ	29-38%

preliminarily

What we measure is not BR itself but σxBR.

To extract BR from σxBR, we need σ from the recoil mass measurement.
--> Δσ/σ=2.6% eventually limits the BR measurements.
--> If we want to improve this, we need more data at 250GeV.
We need to seriously think about luminosity upgrade scenario (c.f. Tim Barklow)

Total Width and Coupling Extraction

One of the major advantages of the LC

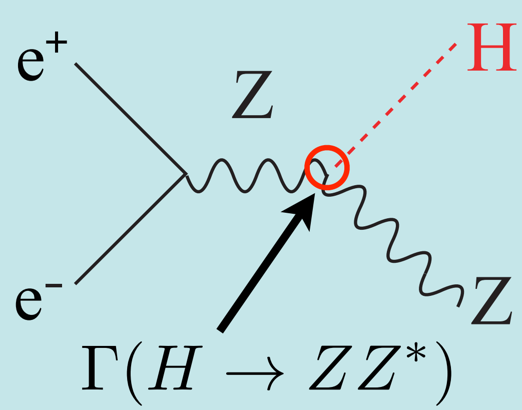
To extract couplings from BRs, we need the total width:

$$g^2_{HAA} \propto \Gamma(H \to AA) = \Gamma_H \cdot BR(H \to AA)$$

To determine the total width, we need at least one partial width and corresponding BR:

$$\Gamma_H = \Gamma(H \to AA)/BR(H \to AA)$$

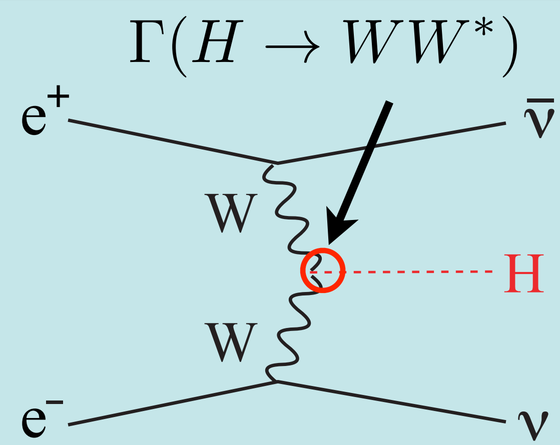
In principle, we can use A=Z, or W for which we can measure both the BRs and the couplings:



$BR(H \to ZZ^*)$

BR=O(1%): precision limited by low stat. for H->ZZ* events

$250\,\mathrm{fb}^{-1}$@$250\,\mathrm{GeV}$
$\Delta\Gamma_H/\Gamma_H \simeq 20\%$



$BR(H \to WW^*)$

More advantageous but not easy at low E

$250\,\mathrm{fb}^{-1}$@$250\,\mathrm{GeV}$
$\Delta\Gamma_H/\Gamma_H \simeq 11\%$

C.F.Durig, Helmholtz Alliance 6th WS, Dec. 2012

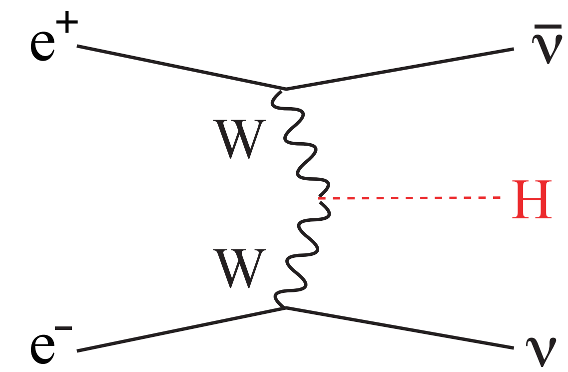
LC 500 and Higher

Width and BR Measurements at 500 GeV

Addition of 500GeV data to 250GeV data

E_{cm} [GeV]	independent measurements	relative error
250	σ_{ZH}	2.6%
	$\sigma_{ZH} \cdot Br(H \to b\bar{b})$	1.1%
	$\sigma_{ZH} \cdot Br(H \to c\bar{c})$	7.4%
	$\sigma_{ZH} \cdot Br(H \to gg)$	9.1%
	$\sigma_{ZH} \cdot Br(H \to WW^*)$	6.4%
500	$\sigma_{ZH} \cdot Br(H \to b\bar{b})$	1.8%
	$\sigma_{ZH} \cdot Br(H \to c\bar{c})$	12%
	$\sigma_{ZH} \cdot Br(H \to gg)$	14%
	$\sigma_{\nu\bar{\nu}H} \cdot Br(H \to b\bar{b})$	0.66%
	$\sigma_{\nu\bar{\nu}H} \cdot Br(H \to c\bar{c})$	6.2%
	$\sigma_{\nu\bar{\nu}H} \cdot Br(H \to gg)$	4.1%
	$\sigma_{\nu\bar{\nu}H} \cdot Br(H \to WW^*)$	2.6%

ILD DBD Full Simulation Study



comes in as a powerful tool!

$$\Delta\Gamma_H/\Gamma_H \simeq 6\%$$

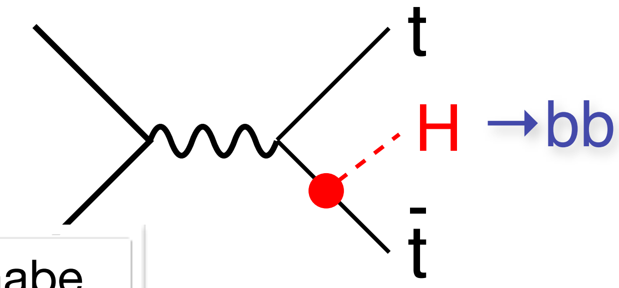
Mode	ΔBR/BR
bb	2.7 (2.7)%
cc	5.2 (7.8)%
gg	4.5 (9.5)%
WW*	3.6 (6.9)%

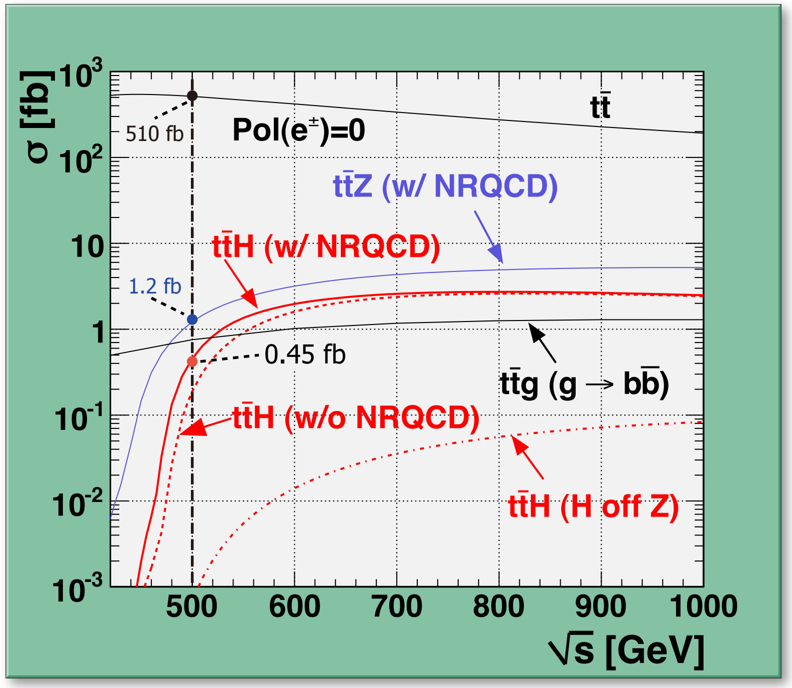
$250\,\mathrm{fb}^{-1}$@$250\,\mathrm{GeV}$
$+500\,\mathrm{fb}^{-1}$@$500\,\mathrm{GeV}$
$m_H = 125\,\mathrm{GeV}$

preliminarily

The numbers in the parentheses are as of $250\,\mathrm{fb}^{-1}$@$250\,\mathrm{GeV}$

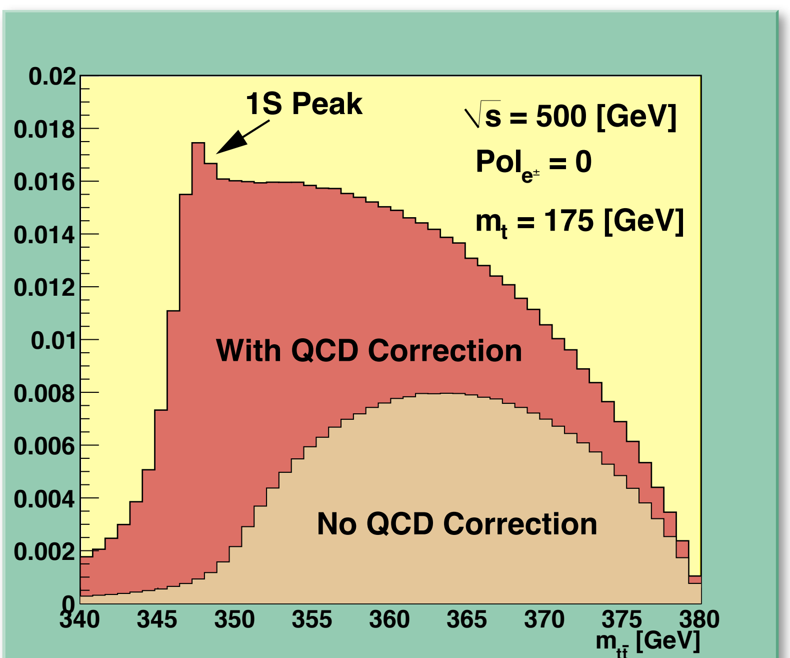
Top Yukawa Coupling





Cross section maximum at around Ecm = 800GeV

Ecm = 500GeV: near threshold

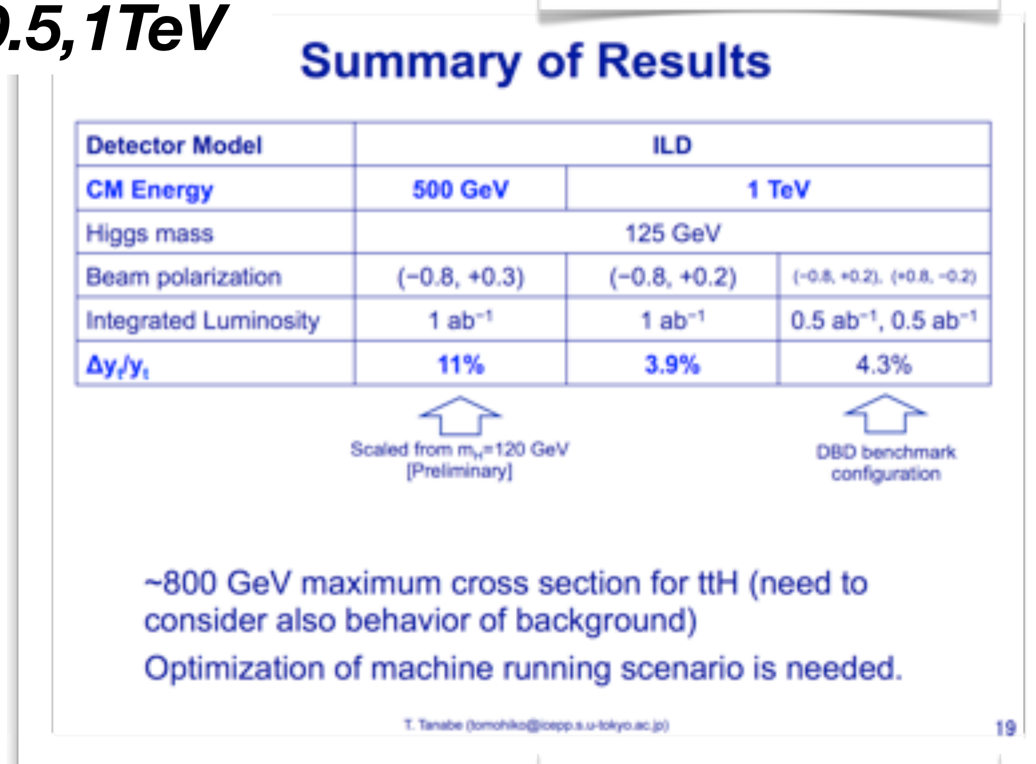


A factor of 2 enhancement from QCD bound-state effects

Notice σ(500+20GeV)/σ(500GeV) ~ 2
Moving up a little bit helps significantly!

ILD 0.5,1TeV

Tomohiko Tanabe



Summary of Results

Detector Model	ILD		
CM Energy	500 GeV	1 TeV	
Higgs mass	125 GeV		
Beam polarization	(−0.8, +0.3)	(−0.8, +0.2)	(−0.8, +0.2), (+0.8, −0.2)
Integrated Luminosity	1 ab⁻¹	1 ab⁻¹	0.5 ab⁻¹, 0.5 ab⁻¹
$\Delta y_t/y_t$	11%	3.9%	4.3%

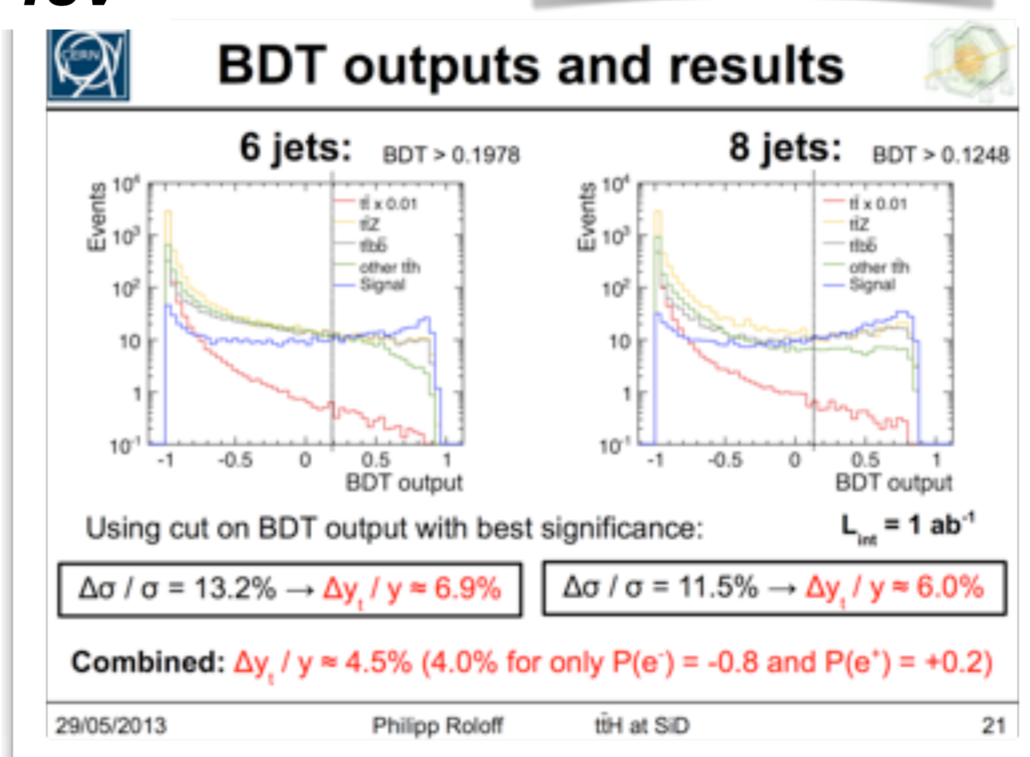
Scaled from m_H=120 GeV [Preliminary]
DBD benchmark configuration

~800 GeV maximum cross section for ttH (need to consider also behavior of background)
Optimization of machine running scenario is needed.

T. Tanabe (tomohiko@icepp.s.u-tokyo.ac.jp) 19

SiD 1TeV

Philipp Roloff

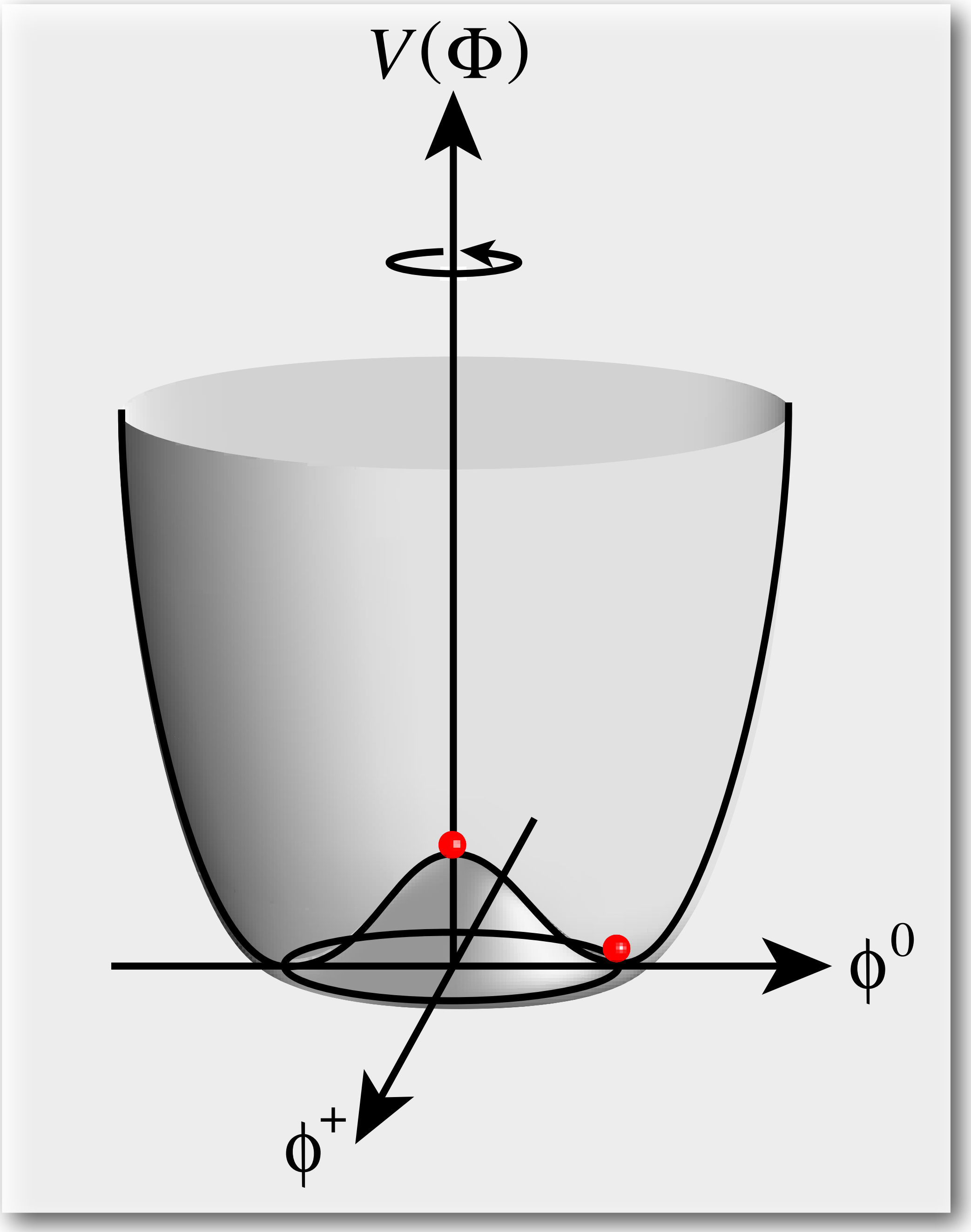


CLIC 1.4TeV

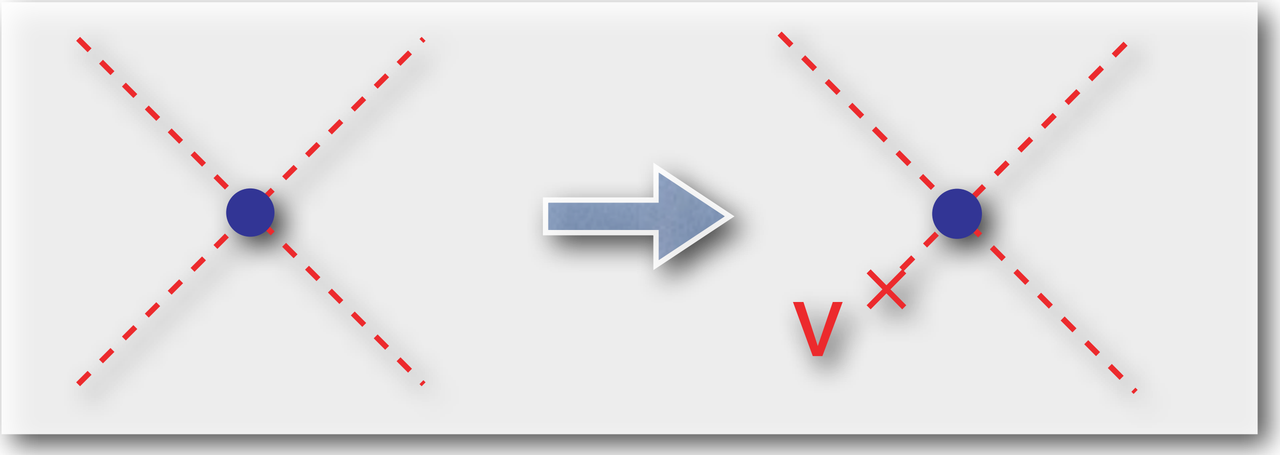
Sophie Redford

Higgs Self-coupling

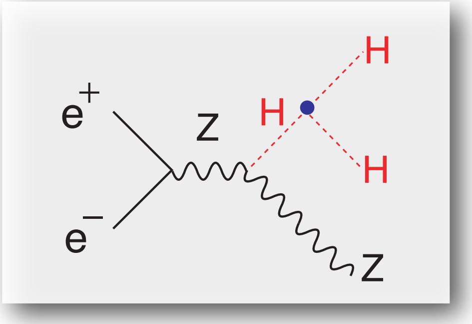
What force makes the Higgs condense in the vacuum?

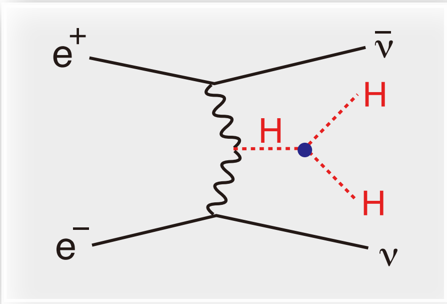


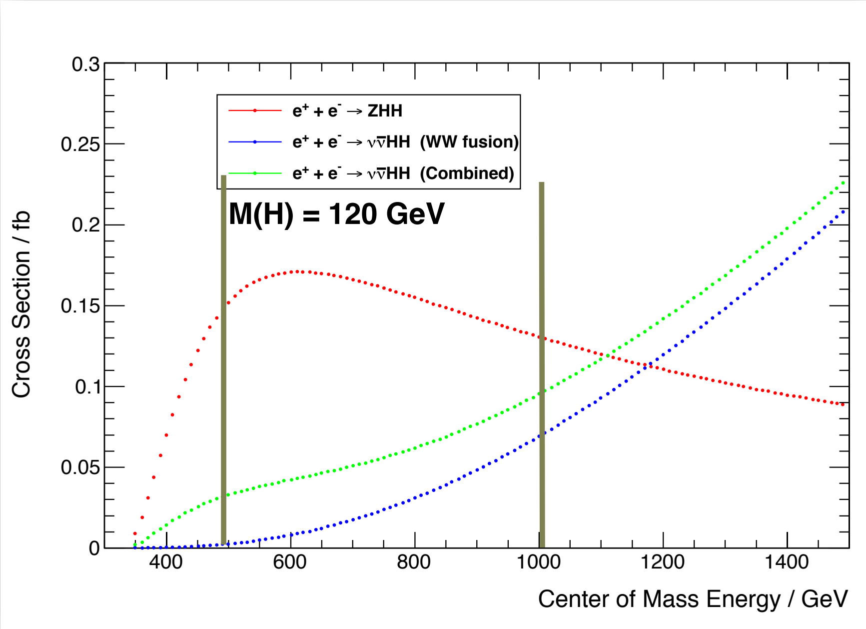
We need to measure the Higgs self-coupling



= We need to measure the shape of the Higgs potential





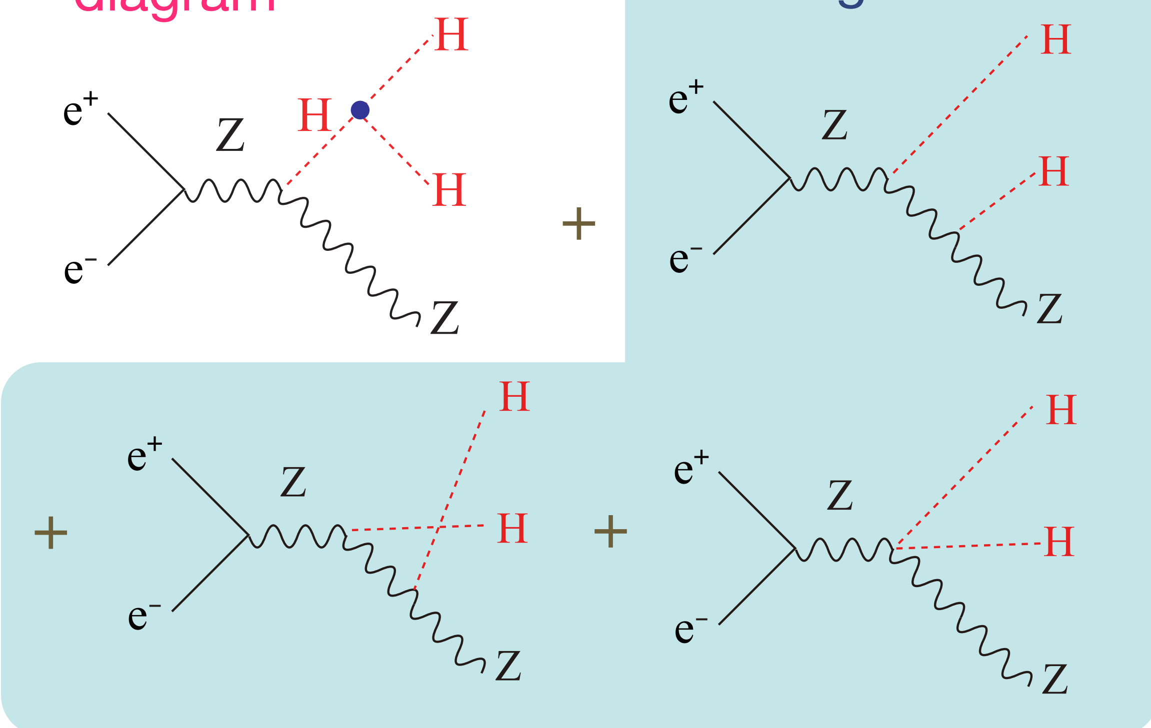


The measurement is very difficult even at a LC.

The Problem : BG diagrams dilute self-coupling contribution

Signal diagram

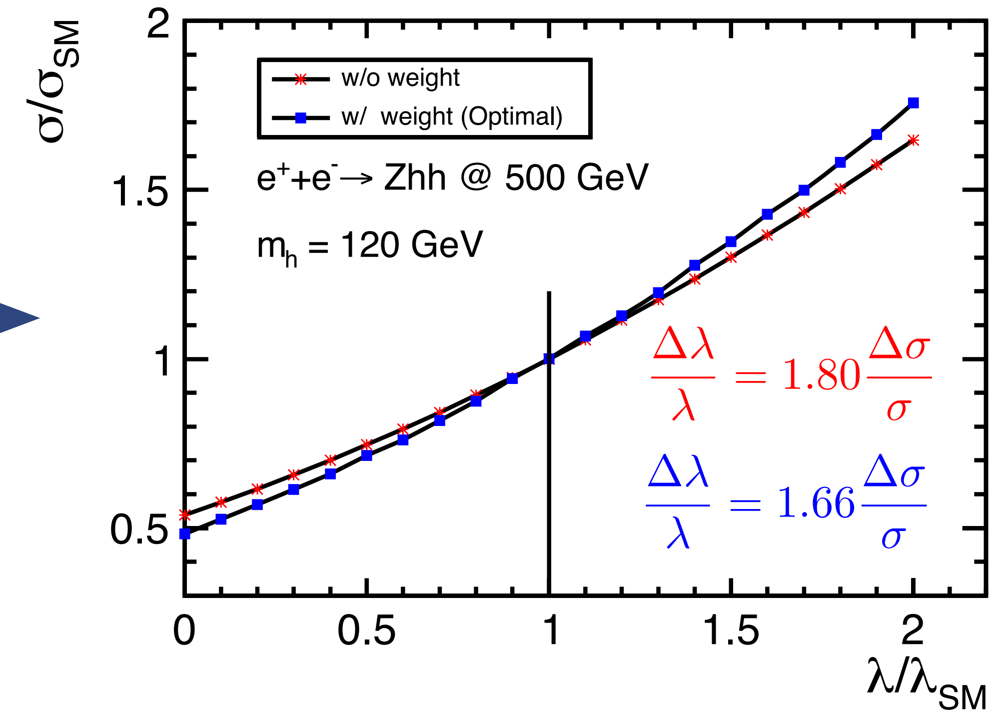
Irreducible BG diagrams



$$\sigma = \lambda^2 S + \lambda I + B$$

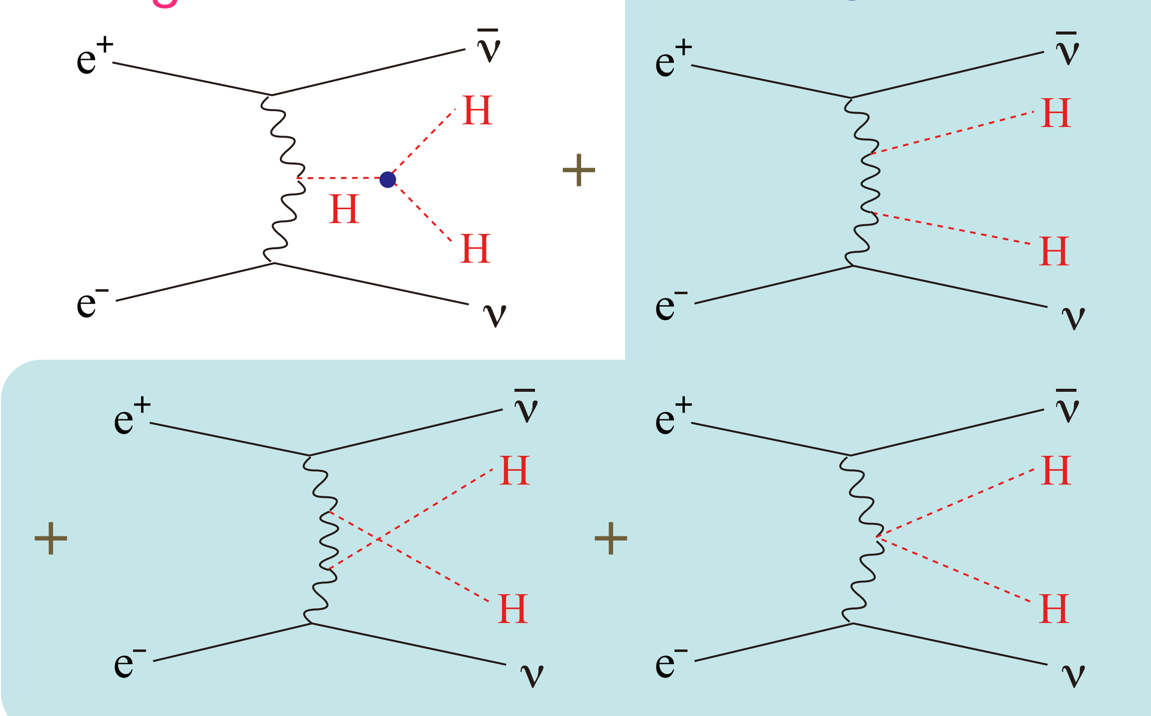
$$\frac{\Delta\lambda}{\lambda} = F \cdot \frac{\Delta\sigma}{\sigma}$$

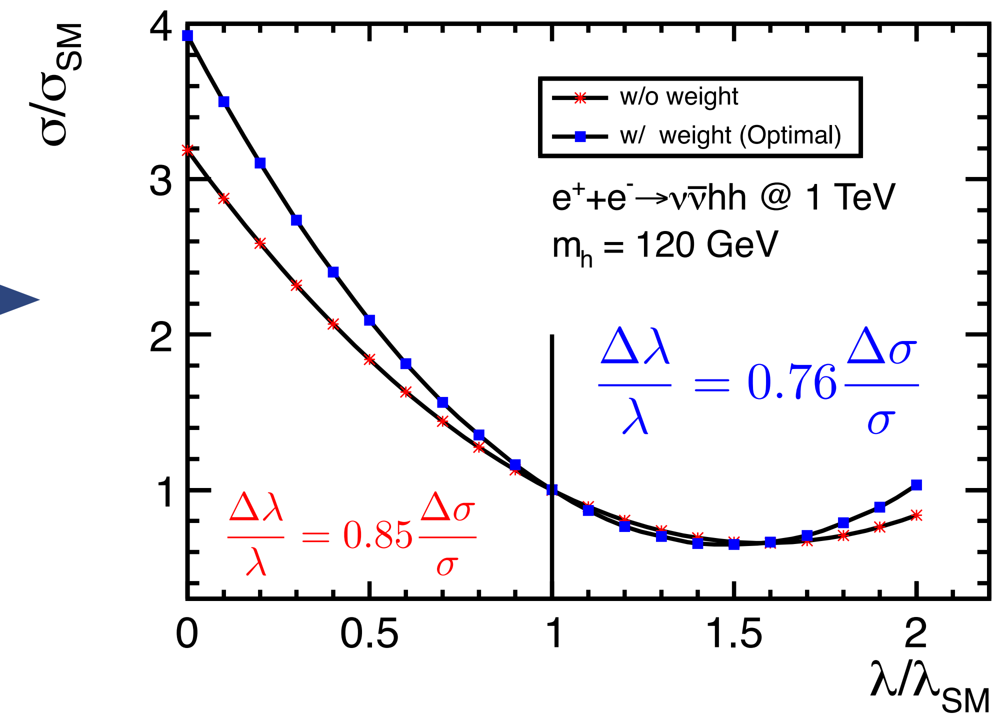
F=0.5 if no BG diagrams



Signal diagram

Irreducible BG diagrams





Junping Tian LC-REP-2013-003

Current State of the Art

ILD: HH→bbbb

Junping Tian

prospects

effect of positron polarisations

P(e⁻) = -0.8

P(e⁺)	0	+0.3 (+0.2)	+0.6 (+0.4)
ZHH @ 500 GeV	50%	44%	40%
ννHH @ 1 TeV	20%	18%	16%

ILC Luminosity Upgrade — Tim Barklow's talk

3.2 ab^{-1} ~ 6 years @ 500 GeV; 5 ab^{-1} ~ 6 years @ 1 TeV

	TDR-Upgrade
ZHH @ 500 GeV	44%--> 35%
ννHH @ 1 TeV	18%--> 11%

CLIC: HH→bbbb

Ways to increase the number of signal events

Polarization significantly increases the signal cross section e.g. from 0.63 fb (unpolarized) to 1.37 fb (-80%, +30%)

collision energy Polarization e^-/e^+	√s = 1.4 TeV unpolarized	√s = 1.4 TeV -80% / +30%	√s = 3.0 TeV unpolarized	√s = 3.0 TeV -80% / +30%
Δ σ(HHνν)	≈ 22%	≈ 18%	≈ 10%	≈ 7%
Δ λ_{HHH}	≈ 28%	≈ 22%	≈ 16%	≈ 11%

Numbers with polarized beams obtained by scaling signal and background cross sections, ignoring polarization-dependent changes to kinematic properties.

all cross section values: mH = 120 GeV

Other Channels contributing
at 1.4 TeV: ZHH cross section ~50% of HHνν
at 3.0 TeV: ZHH cross section < 10% of HHνν

Z boson fusion diagrams (electrons in final state) < 15% of W boson fusion cross section

Note:
m_H = 126 GeV results in slightly smaller signal cross sections
σ(HHνν) = 0.15 fb at 1.4 TeV
σ(HHνν) = 0.59 fb at 3.0 TeV
both with unpolarized beams

Jan Strube

ILD: HH →bbWW*

Masakazu Kurata

- Higgs self coupling analysis using the events with H→WW* is ongoing.
  - Multi variate analysis to reject the backgrounds
  - Unfortunately, c jet analysis doesn't give significant contribution
  - Total sensitivity is ~1.4σ

ILC 250+500+1000

Model-independent Global Fit for Couplings

Canonical ILC program

250 GeV: 250 fb^{-1}
500 GeV: 500 fb^{-1}
1 TeV: 1000 fb^{-1}

(M_H = 125 GeV)

P(e-,e+)=(-0.8,+0.3) @ 250, 500 GeV

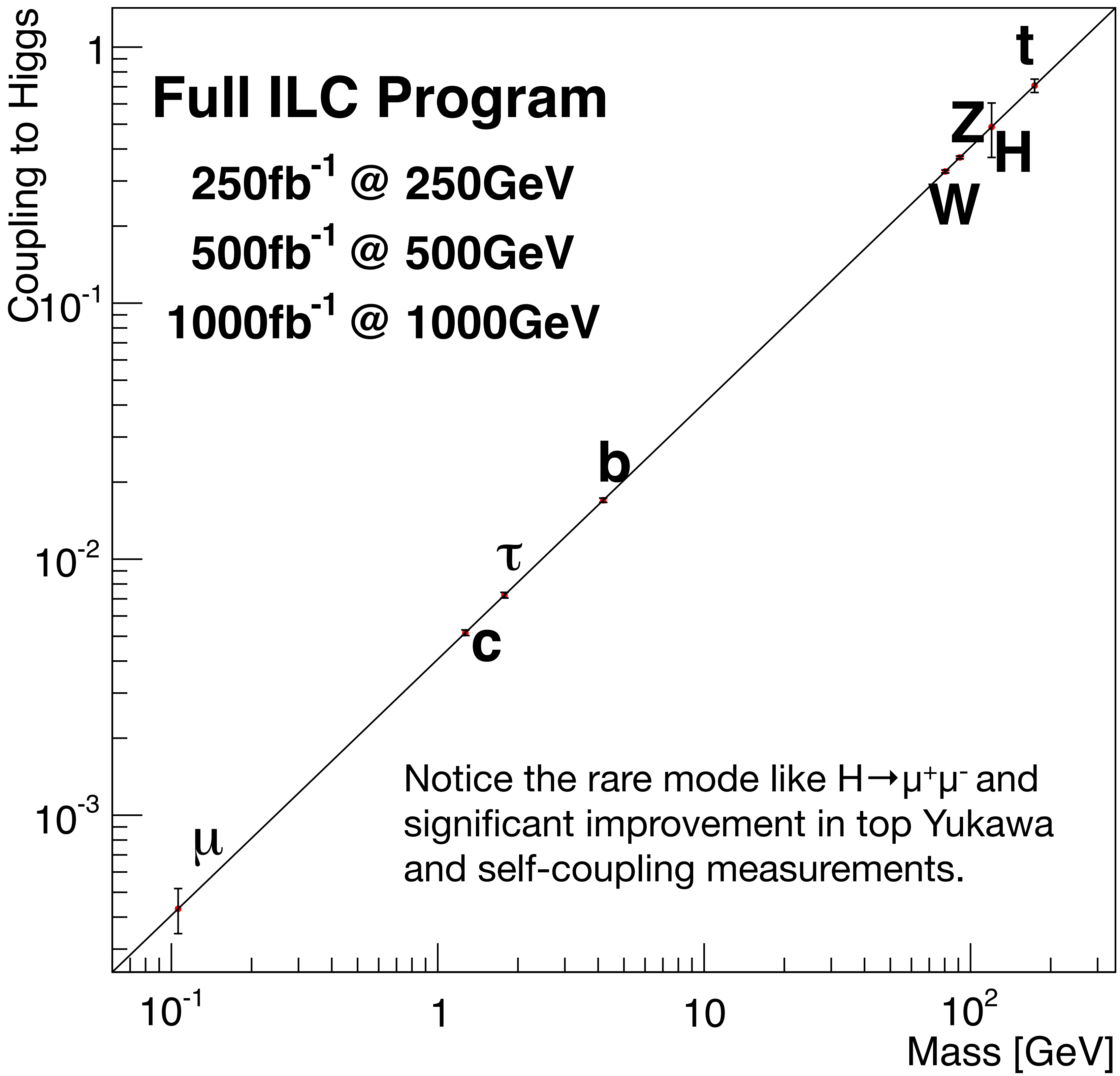
P(e-,e+)=(-0.8,+0.2) @ 1 TeV

coupling	250 GeV	250 GeV + 500 GeV	250 GeV + 500 GeV + 1 TeV
HZZ	1.3%	1.3%	1.3%
HWW	4.8%	1.4%	1.4%
Hbb	5.3%	1.8%	1.5%
Hcc	6.5%	2.9%	2.0%
Hgg	7.0%	2.5%	1.8%
$H\tau\tau$	5.7%	2.5%	2.0%
$H\gamma\gamma$	25%	12%	5.2%
$H\mu\mu$	-	-	16%
Γ_0	11%	5.9%	5.6%
Htt	-	16%	3.8%
HHH	-	104%	26%

K.Fujii @ ECFA LCWS 2013

Mass Coupling Relation

After Canonical ILC Program



H→bb,cc,gg,WW*,ττ,μμ

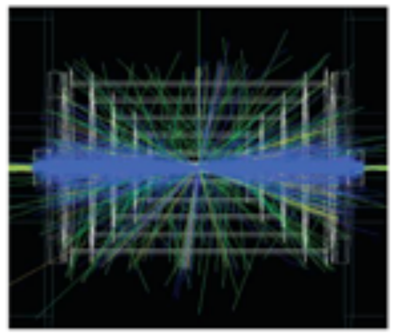
CLIC

Tomas Lastovicka

THE CLIC ACCELERATOR ENVIRONMENT

Center of mass energy	350 (500) GeV	1.4 TeV	3 TeV
Accumulated luminosity	500 fb^{-1}	1.5 ab^{-1}	2 ab^{-1}
Bunch spacing	0.5 ns	0.5 ns	0.5 ns
Bunches per train	354	312	312
Train repetition rate	50 Hz	50 Hz	50 Hz
γγ → hadrons per BX	0.3	1.3	3.2

- Challenging environment
- γγ overlay → 19TeV visible energy @ 3 TeV
  - Reduced by a factor of 16 in 10ns readout window.
  - Requires to employ "LHC-style" jet reconstruction algorithms (typically FastJet k_T).



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Astrid Muennich

Cross Section Results

mh=126GeV 350 GeV		mh=120GeV 1.4 TeV	
Signal events (BDT>0.08)	312	Signal events (BDT>0.05)	1227
Total signal events	529	Total signal events	2238
Background events (BDT>0.08)	150	Background events (BDT>0.05)	1620
Signal efficiency	60%	Signal efficiency	55%
Signal purity	67%	Signal purity	43%
$\sqrt{S+B}/S$ (Method 1)	6.9%	$\sqrt{S+B}/S$ (Method 1)	4.3%
$\sqrt{S+B}/S$ (Method 2)	6.2%	$\sqrt{S+B}/S$ (Method 2)	3.7%

Method 2 has a slight advantage over method 1 as this is a statical error and method 2 can use the full information contained in every bin.

New method (method 2) to utilize all the BDT bins

A. Münnich H → ττ 15

SUMMARY

The statistical accuracy of σ(e⁺e⁻ → $H\nu_e\nu_e$)×BR(H → XX̄) could be determined to

X = b: 0.3 % at 1.4 TeV and to 0.22 % at 3 TeV.
X = c: 2.9 % at 1.4 TeV and to 2.7 % at 3 TeV.
X = g: 1.8 % at 1.4 TeV and to 1.8 % at 3 TeV.

for m_H = 126 GeV and accumulated luminosities of 1.5 ab^{-1} and 2 ab^{-1} for 1.4 TeV and 3 TeV, respectively.

The study was performed with full simulation and reconstruction in CLIC_SiD detector, realistic beam spectrum, ISR, γγ overlay... and with unpolarized beams.

Analysis at 350 GeV is in progress.

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Eva Sicking

Summary

Summary: Higgs Couplings to Gauge Bosons at CLIC

- Higgs boson production in W^+W^--fusion
  - (1) $H \to WW^*$ at 350 GeV and 1.4 TeV
    - Analysis in progress
    - Study semi-leptonic final state and fully hadronic final state
    - Identify kinematic variables for signal/background classification
    - Simulate additional relevant background channels
  - (2) $H \to \gamma\gamma$ measured at 1.4 TeV
    - Preliminary results: Uncertainty of measurement of $\sigma_{e^+e^- \to H\nu\bar{\nu}} \times \mathrm{BR}_{H\to\gamma\gamma}$ is 17 %
    - Towards final results:
      - Increase number of simulated events
      - Study additional kinematic variables for the multivariate analysis
  - (3) $H \to Z^0\gamma$ measured at 1.4 TeV
    - Analysis in progress
    - Study quark, e, and μ channel
    - Identify kinematic variables for signal/background classification
    - Simulate additional relevant background channels

Eva Sicking (CERN) Higgs Couplings to Gauge Bosons at CLIC 29-05-2013 37 / 37

LHC + LC

Higgs couplings

Tilman Plehn

LHC including Moriond/Aspen data [SFitter: Klute, Lafaye, TP, Rauch, Zerwas]

- focus SM-like [secondary solutions possible]
- six couplings and ratios from data

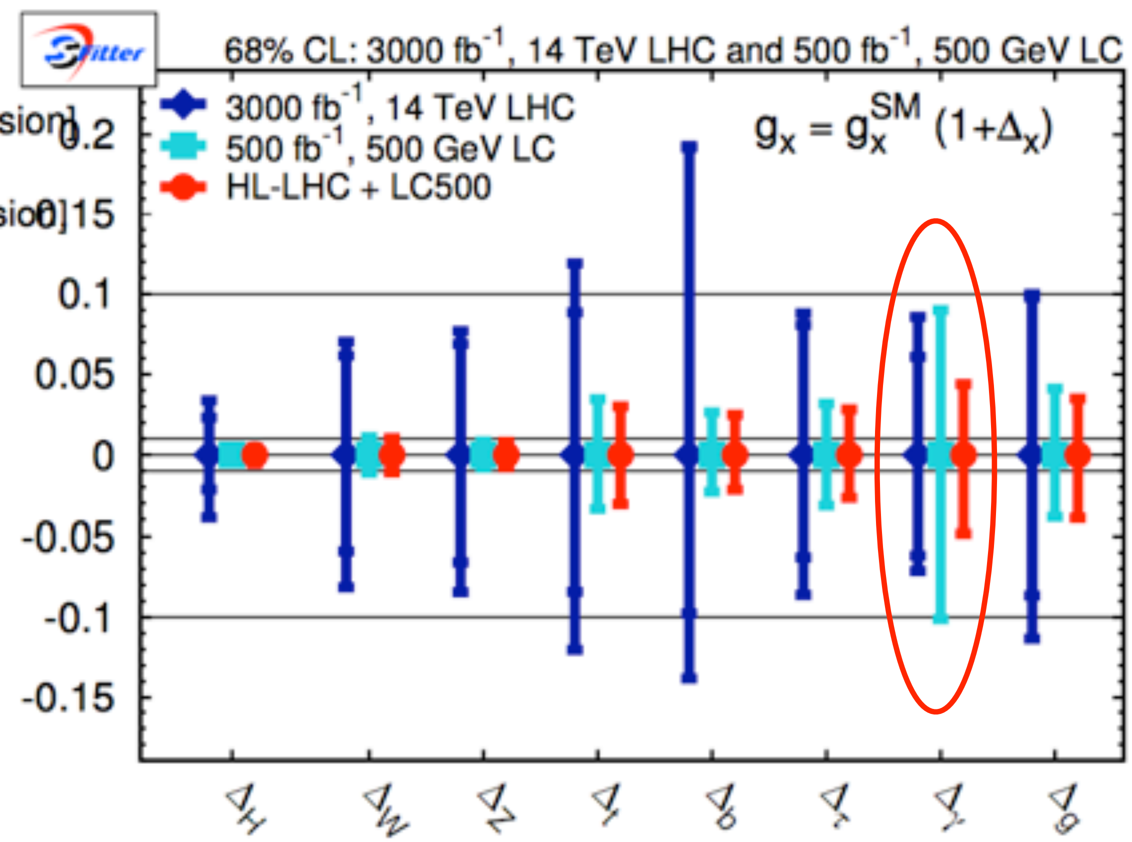
  g_b from width

  g_g vs g_t not yet possible

  [similar: Ellis etal, Djouadi etal, Strumia etal, Grojean etal]
- poor man's analyses: $\Delta_H, \Delta_V, \Delta_f$
- Tevatron $H \to b\bar{b}$ with little impact

Future dinosaurs

- LHC extrapolations unclear [SFitter version]
- theory extrapolations tricky [SFitter version]
- ILC case obvious [500 GeV for now]
- interplay in loop-induced couplings
- $t\bar{t}H$ important at LHC and ILC



LHC+LC500 Synergy!

Conclusions

- The primary goal for the next decades is to uncover the secret of the EW symmetry breaking. This will open up a window to BSM and set the energy scale for the E-frontier machine that will follow LHC and ILC 500.
- Probably LHC will hit systematic limits at O(5-10%) for most of σ×Br measurements, being not enough to see the BSM effects if we are in the decoupling regime.
  To achieve the primary goal we hence need a 500 GeV LC for self-contained precision Higgs studies to complete the mass-coupling plot
  - starting from $e^+e^- \to ZH$ at Ecm = 250GeV,
  - then ttbar at around 350GeV,
  - and then ZHH and ttbarH at 500GeV.
- The LC to cover up to 500 GeV is an ideal machine to carry out this mission (regardless of BSM scenarios) and we can do this with staging starting from 250GeV. We may need more data depending on the size of the deviation. Lumi-upgrade possibility should be always kept in our scope.
- If we are lucky, some extra Higgs boson or some other new particle might be within reach already at LC 500. Let's hope that the upgraded LHC will make another great discovery in the next run. (Note: Sven discussed SUSY decays to Higgs.)
- If not, we will most probably need the energy scale information from the precision Higgs studies. Guided by the energy scale information, we will go hunt direct BSM signals with a new machine, if necessary.

Backup

HL-ILC ?

See Tim Barklow's talk

High Luminosity ILC

- TLEP can host 4 detectors → but extra 2 detectors cost ~ $1G ⇔ x2 Luminosity upgrade of ILC
- Polarizations at LC ⇔ effective luminosity doubler
- Wall plug power: ILC < TLEP
- E_{cm} can be further optimized: e.g. tth

ILC Luminosity Upgrade

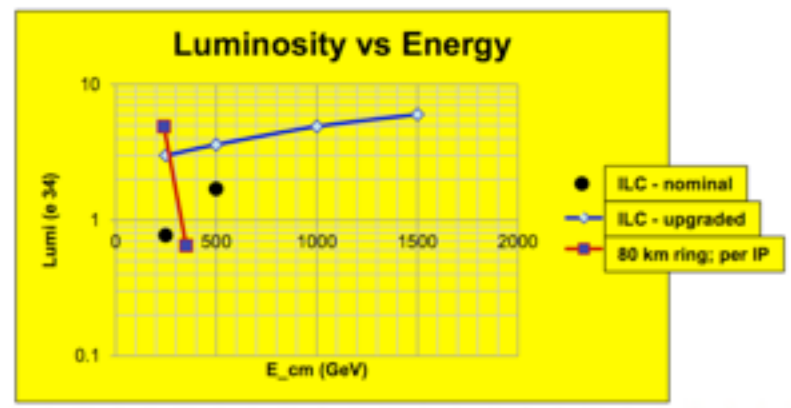
- Concept: increase n_b from 1312 → 2625
  - Reduce linac bunch spacing 554 ns → 336 ns
  - Increase pulse current 5.8 → 8.8 mA
  - Increase number of klystrons by ~50%
- Doubles beam power → ×2 L (3.6×10^{34}cm^{-2}s^{-1})
- Damping ring:
  - Electron ring doubles current (389mA → 778mA)
  - Positron ring: possible 2nd (stacked) ring (e-cloud limit)
- AC power: 161 MW → 204 MW (est.)
  - AC power increased by ×1.5
  - shorter fill time and longer beam pulse results in higher RF-beam efficiency (44% → 61%)

14 March, 2013 Marc Ross, SLAC 11

ILC at low/high Ecm

- Low E_{cm} operation of upgraded ILC:
  - L_{250} ~ 3e34; Wall plug 200 MW
  - Higgs Factory Option
- High E_{cm} ~ 1.5 TeV
  - L_{1500} ~ 6e34; Wall plug 340 MW

Assumes 2x improved efficiency; 2450 bunches



14 March, 2013 Marc Ross, SLAC 13

Snowmass e^+e^- Collider Luminosity (fb^{-1})
based on 3×10^7 s running time for ILC & LEP3/TLEP

Ecm(GeV)	ILC	ILC Lum Upgrade	LEP3	TLEP
250	250	900	300	1500
350	300	950		200
500	500	1100		
1000	1500	1500		

Independent Higgs Measurements

Hypothetical HL-ILC

250 GeV: 900 fb^{-1}
500 GeV: 2200 fb^{-1}
1 TeV: 3000 fb^{-1}

(M_H = 125 GeV)

Ecm	250 GeV		500 GeV		1 TeV
luminosity · fb	250		500		1000
polarization (e-,e+)	(-0.8, +0.3)		(-0.8, +0.3)		(-0.8, +0.2)
process	ZH	vvH(fusion)	ZH	vvH(fusion)	vvH(fusion)
cross section	1.4%	-	-		
	σ·Br	σ·Br	σ·Br	σ·Br	σ·Br
H-->bb	0.58%	5.5%	0.87%	0.32%	0.19%
H-->cc	3.9%		5.8%	3.0%	1.8%
H-->gg	4.8%		6.7%	2.0%	1.3%
H-->WW*	3.4%		4.4%	1.2%	0.93%
H-->ττ	2.2%		2.6%	6.7%	2.0%
H-->ZZ*	10%		12%	3.9%	2.4%
H-->γγ	25%		23%	16%	6.4%

250 GeV: 250 fb^{-1}
500 GeV: 500 fb^{-1}
1 TeV: 1000 fb^{-1}

→

250 GeV: 900 fb^{-1}
500 GeV: 2200 fb^{-1}
1 TeV: 3000 fb^{-1}

Coupling Measurements

Hypothetical HL-ILC

250 GeV: 900 fb^{-1}
500 GeV: 2200 fb^{-1}
1 TeV: 3000 fb^{-1}

(M_H = 125 GeV)

P(e-,e+)=(-0.8,+0.3) @ 250, 500 GeV   P(e-,e+)=(-0.8,+0.2) @ 1 TeV

coupling	250 GeV	250 GeV + 500 GeV	250 GeV + 500 GeV + 1 TeV
HZZ	0.70%	0.70%	0.70%
HWW	2.5%	0.75%	0.74%
Hbb	2.8%	0.93%	0.81%
Hcc	3.4%	1.4%	1.1%
Hgg	3.7%	1.3%	0.96%
Hττ	3.0%	1.3%	1.0%
Hγγ	13%	5.9%	2.9%
Hμμ	-	-	9.3%
Γ_0	6.1%	3.1%	3.0%
Htt	-	8.5%	2.6%

HHH	-	50%	15%