Opening Comments

2014/11/01 Keisuke Fujii

WG Objectives

- On July 4, 2012, ATLAS and CMS announced the discovery of a Higgs-like boson with a mass of about 125GeV and the data that followed strongly indicates that it is a Higgs boson indeed. The world has changed since then. The discovery has vaulted the question of its properties on the top of the list of questions in HEP. The 125GeV boson is a window to BSM physics and ILC is the best machine to use it.
  The energy upgrade of LHC will probably bring us more. It is important to stress that ILC, too, is an energy frontier machine. It will access the energy region never explored with any lepton collider. There can be a zoo of new uncolored particles or new phenomena that are difficult to find at LHC but can be discovered and studied in detail at ILC.

  We need to demonstrate that ILC will advance our understanding of particle physics qualitatively beyond the information that will be available from the results expected from the future stages of the LHC. Be prepared for LHC Run2! (longer-term goal)

- The ILC project preparation office has been formed in KEK and the MEXT's ILC Task Force started its review. In parallel, site-specific design started and a new ILC parameter WG was formed to provide information necessary to optimize the staging scenario. Make inputs to the MEXT's physics WG (monthly). The next mid-term target for us to show our activities to the LC community is ALCWS14 on Apr. 20-24 in Tsukuba.

MEXT's ILC Review (Schedule)

- 2014/06/24 1st Physics WG Mtg.
    - particle physics in general
    - Overview of ILC project and physics
- 2014/07/29 2nd Physics WG Mtg.
    - European strategy and P5 report
    - ILC's physics case discussions
- 2014/08/27 3rd Physics WG Mtg.
    - Cosmic rays, astronomy
    - ILC's physics case discussions
- 2014/09/22 4th Physics WG Mtg.
    - Flavor physics, neutrinos
    - ILC's physics case discussions (Comparison with LHC)
- 2014/10/21 5th Physics WG Mtg.
    - Interim summary
- 2014/11/14 2nd Expert Panel Mtg.

Tomohiko

Higgs
Top
BSM

27 Pages

Precis of the Physics Case for the ILC

LCC Physics Working Group†

October 2014

1 Introduction

The physics potential of the International Linear Collider has been documented in a number of reports. Most recently, it is presented in some detail in Volume 2 of the ILC Technical Design Report [1] and in a series of reports to the American Physical Society's study of the future of US particle physics (Snowmass 2013) [2–5]. However, we thought that it might be valuable to add to these a brief and accessible review of the main points of these documents. You will find that here.

The most important aspects of the ILC physics program are: (1) measurement of the properties of the newly-discovered Higgs boson with very high precision; (2) measurement of the properties of the top quark with very high precision; (3) searches for and studies of new particles expected in models of physics at the TeV energy scale. The specific capabilities of the ILC in these areas are reviewed in the various sections of this report. The physics program of the ILC is still broader, encompassing precision electroweak measurements, detailed studies of the W and Z boson couplings, tests of Quantum Chromodynamics, and other topics. A complete survey is given in Ref. [1].

Before we begin, we should make two general points about the role of the ILC in the current situation in particle physics. The first is that the discovery of the Higgs boson at the CERN Large Hadron Collider [6,7] is a milestone in the history of particle physics that changed our perspective on the goals of this field. We now have in hand the complete particle spectrum of a "Standard Model" that could be correct up to very high energies. It is possible that this theory of particle physics could be correct up to energies thirteen orders of magnitude higher than our current experiments. However, this would be unfortunate, because this model is inadequate in several important respects. First, it does not explain the most basic fact about the Higgs field, why it is that this field forms a condensate that fills space and gives rise to the masses of all known particles. Second, it has no place for the particle or particles that make up cosmic dark matter, a neutral, weakly interacting substance that, according to astrophysical observation, makes up 85% of the mass in the universe. Third, it does not explain the asymmetry in the amount of matter and antimatter in the universe. One might add to this list many more fundamental questions, for example, why the matter that we observe has precisely the quantum numbers of quarks and leptons.

However, these three question are the keys to progress through experiment. The most pressing issue in particle physics today is that of where and how the Standard Model breaks down. If the questions just listed have answers given by current theoretical proposals, new particles and forces beyond the Standard Model should appear at the leading accelerators currently operated and planned—the LHC and the ILC.

In the discussion to follow, we will compare the capabilities of the LHC and the ILC. However, it is also important to realize that the experimental programs at these accelerators differ in essential ways. The LHC gives access to high energies for direct production of new particles. However, this comes at a price. The rates of production of proposed new particles are typically $10^{-10} - 10^{-12}$ of the proton-proton total cross section. Even after selection of characteristic event types, these processes typically represent only about 10% of the total yield, over a background consisting of complex Standard Model reactions. This limits both the range of new processes that can be observed and the precision with which rates can be measured.

At the ILC, and more generally in electron-positron collisions, the situation is qualitatively different. The processes that we wish to study are large fractions of the total electron-positron annihilation cross section. Event selections give high purity, over backgrounds that are straightforward to compute. For the study of a heavy particle, all decay modes can be observed, and systematic errors on measured rates are at the 0.1% level. This is a powerful and unique capability that we can apply to the Higgs boson and top quark—the two known particles most directly connected to the questions we have listed above—and to any new particles that might appear in the energy range that the ILC will study. Precision measurements at the ILC can not only prove the existence of new particles with masses well above the e^+e^- collision energy but also can give detailed information about their properties. We will see examples of this in all three sections below.

The second point is a perspective on the longer-range future of high-energy physics. Our field's need for larger and more powerful accelerators has driven us to be more globalized than any other field of science. Today, there is one high-energy proton-proton collider in the world, the LHC. Its construction was made possible by the existing complex of tunnels and infrastructure at CERN. At the moment, a large fraction of the experimental particle physicists in the world are collaborators in the two large experiments ATLAS and CMS at the LHC. This insures CERN's current stature as the major international center of particle physics. For electron-positron collisions, any facility at energies much higher than those already realized must be a linear collider in a long, straight tunnel. The ILC infrastructure will provide a basis for collisions at 500 GeV and also, with new generations of technology, a setting for electron-positron collisions at still higher energies. It will allow Japan to host a laboratory in Asia of comparable importance to CERN on the world scene in particle physics, one that will be the global host for experiments with electron and positron beams into the longer-term future.

What we want

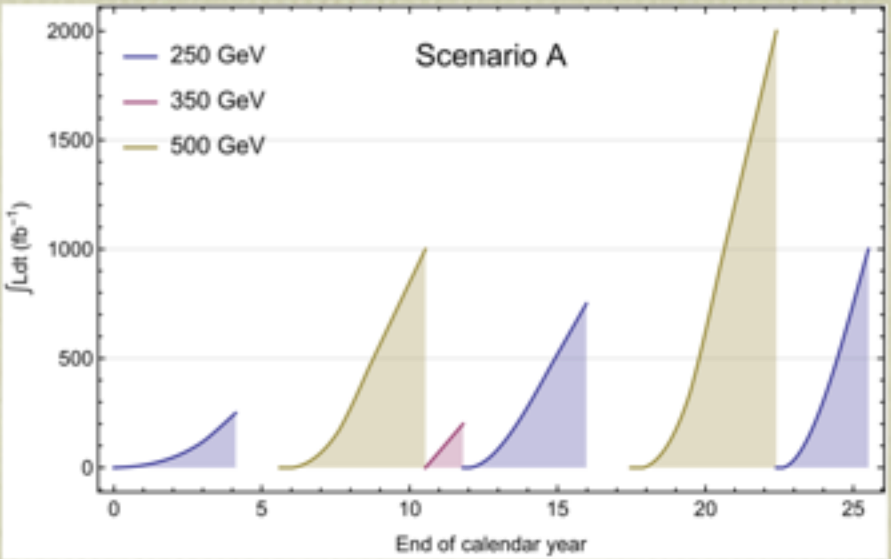
- We have the 125 GeV boson that is a powerful tool to explore the symmetry breaking sector (SBS).
  We need to invent a way to make maximal use of it.
  - Is it possible to map various BSM models in ideally a single and hopefully a small number of generic parameter spaces so as to compare the physics reach of ILC with that of the future upgraded LHC.
  - If yes, explore the possibility of fingerprinting BSM models in the generic parameter space. --> partially done in the Snowmass process
- The most important Mission of ILC = bottom-up reconstruction of the SBS and clarification of its relation to other open questions of elementary particle physics.
  - Make a strategy to reconstruct the SBS
    - Shape of SBS: Multiplet Structure (a SM-like 2-let main but what about small admixtures of 1-let?, 3-let? If there, how many?, ...)
    - Dynamics behind SBS: weakly/strongly interacting = elementary/composite
  - Clarify relation to other open questions: DM, Baryogenesis, Neutrino mass, Hierarchy, ...
- ILC is an energy frontier machine. We need to re-examine the possibilities given the existence of the 125GeV boson and their relations to the open questions.

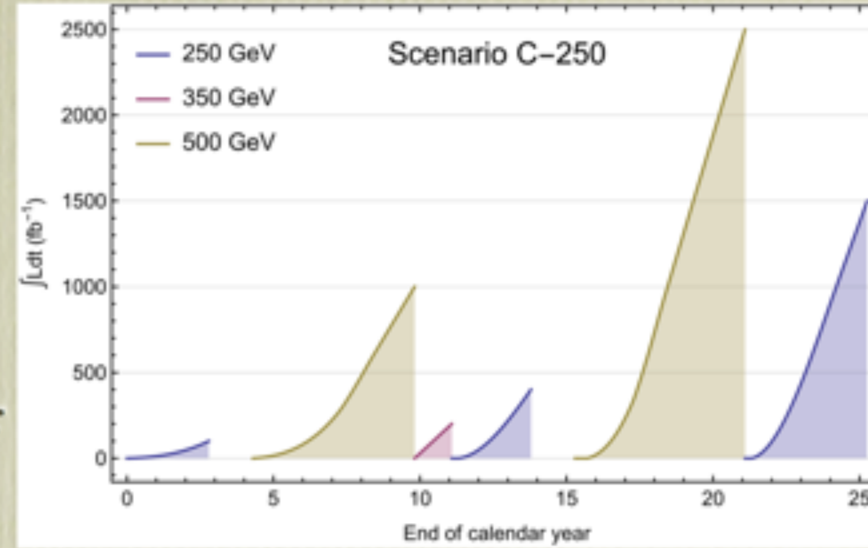
More Exercises Needed

- For theorists:
  - ILC can measure various quantities such as mh, gamma_h, ghxx, mt, etc. far better than LHC. But how accurately do we really need to measure them?
  - What will be the ultimate theoretical uncertainties in various predictions for LHC and ILC, respectively?
  - Update various ILC physics plots to accommodate LHC constraints, etc.
- For Experimentalists:
  - Update all the old analyses with mh=120 GeV to mh=125GeV: urgent!
  - Complete the analyses such as rare Higgs decays: urgent!
  - Improve the analyses such as self-coupling, H->gamma gamma, recoil mass (jets?), where the results are not yet satisfactory.
  - Studies at Ecm = 350 GeV : requests from the ILC parameter WG.
  - With the projected running scenarios described in DBD, the most measurements are still statistically limited and should improve by a luminosity upgrade or by running longer. Nevertheless, ILC, too, will hit systematics limits, eventually. It is probably the right time to start more serious studies of expected systematic errors.
    - Identify possible sources of systematic errors
    - Estimate to what degree we can control them (partially done in the Snowmass process)

Parameters for ILC Staging

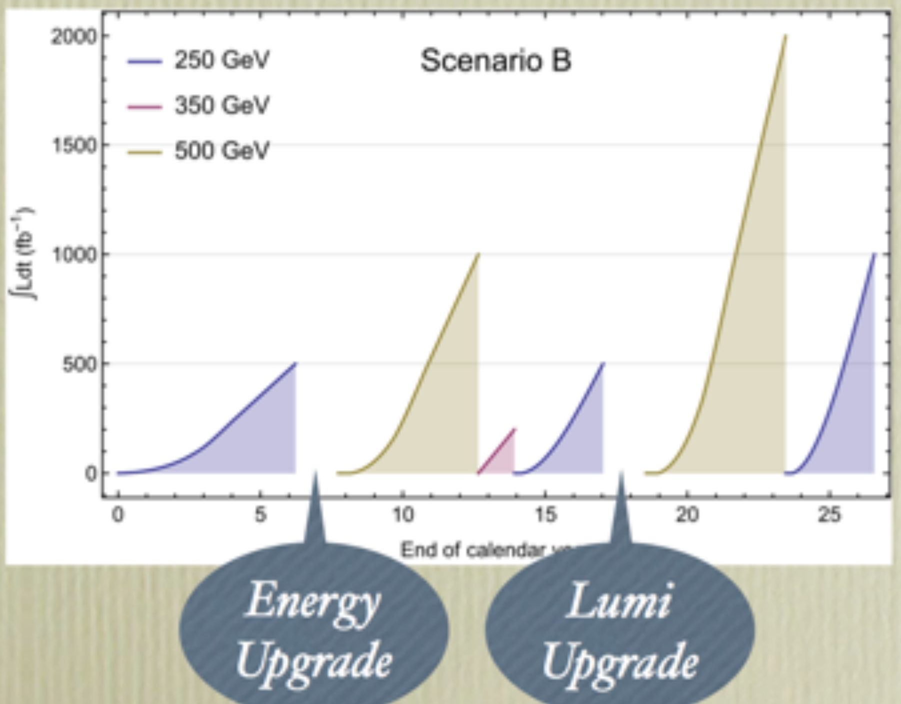
ILC Parameters Joint Working Group
(presented by Jim Brau)

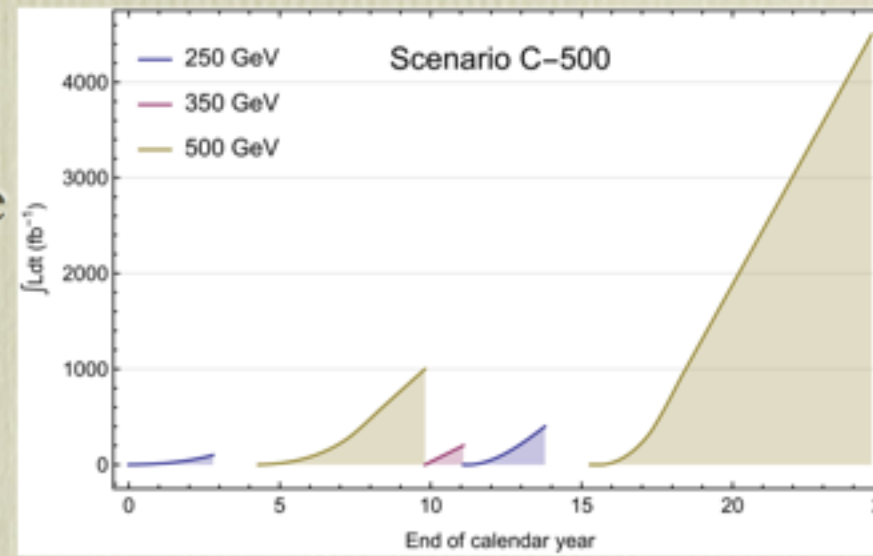




Projected evolution of integrated luminosity with realistic ramp-up and upgrade timelines

Note
- time is in <u>calendar years</u>





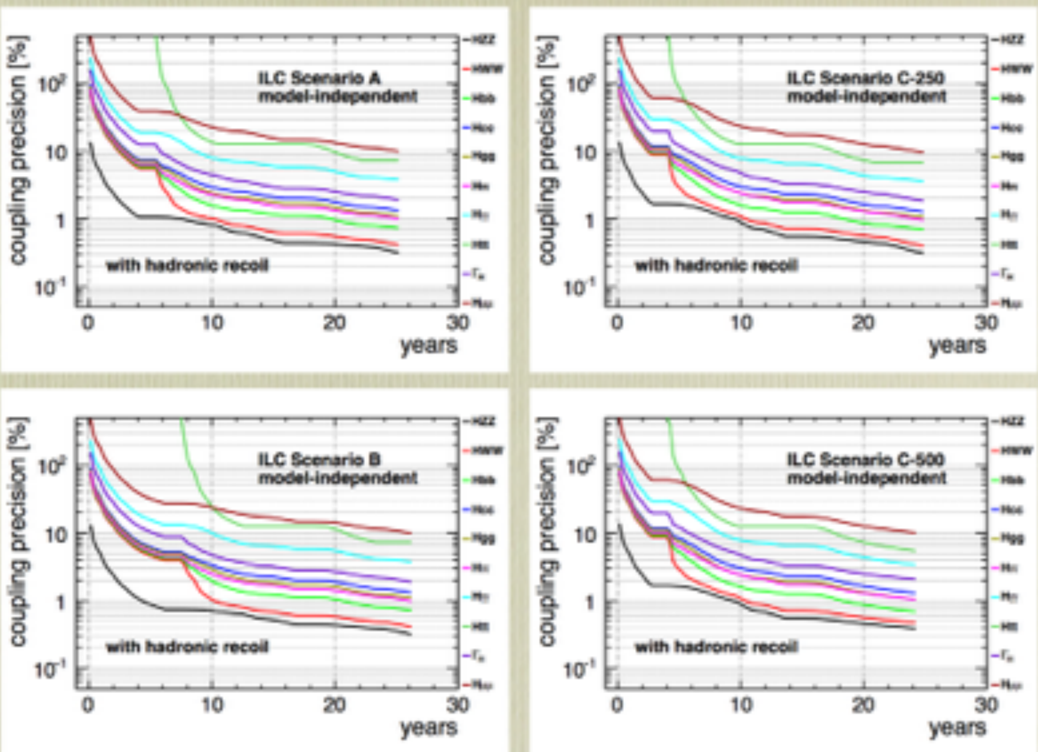
Summary of scenarios

	$\int \mathcal{L}dt$ [fb^{-1}]			
$\sqrt{s}$	A	B	C-250	C-500
250 GeV	2000	2000	2000	500
350 GeV	200	200	200	200
500 GeV	3000	3000	3500	5500

Table 1: Proposed total target integrated luminosities for $\sqrt{s} = 250, 350, 500\,\text{GeV}$.

	total run time *before*		
	500 GeV	Lumi upgrade	TeV upgrade
Scenario	[years]	[years]	[years]
A	4.1	16.0	25.5
B	6.2	17.1	26.6
C-250	2.8	13.8	25.3
C-500	2.8	13.8	24.6

Table 5: Cumulative running times for the four scenarios, including ramp-up and installation of upgrades. Not included: calibration and physics runs at Z pole and WW-threshold or scanning of new physics thresholds.



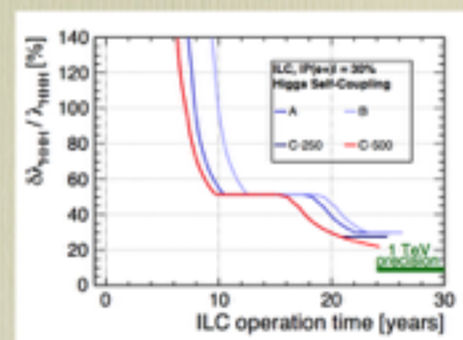
Higgs self-coupling

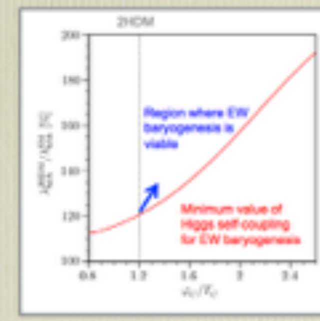
√s ≥ 450 GeV

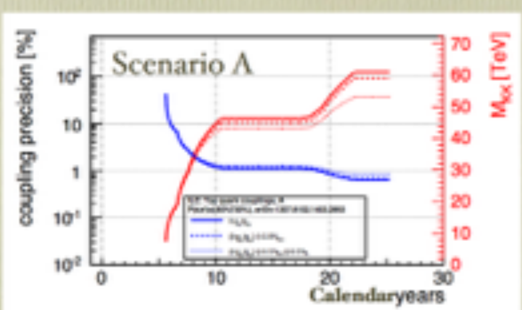
~20% precision (5σ SM) achieved at end of C-500 run

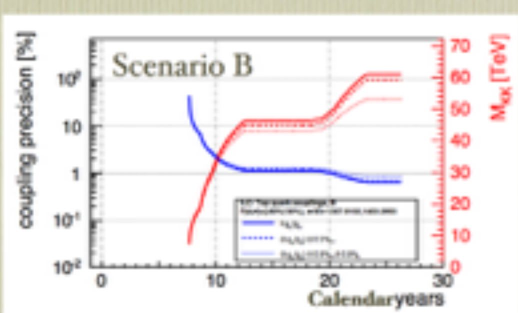
This precision is sufficient to <u>begin</u> testing BSM models, such as the EW baryogenesis model shown in Fig (arXiv:1211.5883)

1 TeV running will bring precision to ~10%



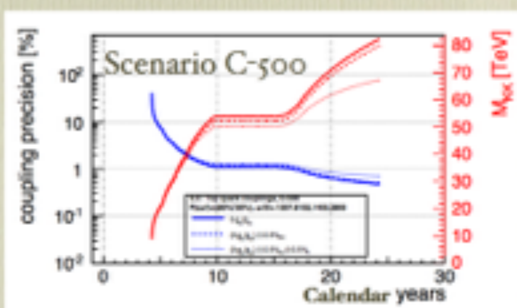






Top RH coupling & sensitivity of KK mass scale in extra dimension model

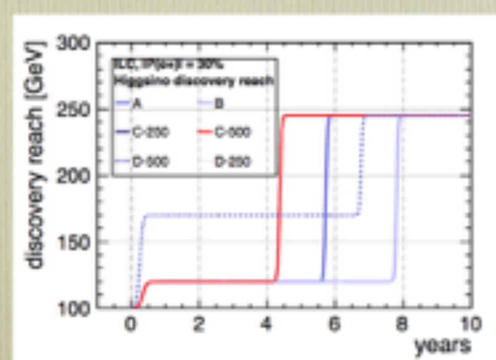
F. Richard, arXiv:1403.2893

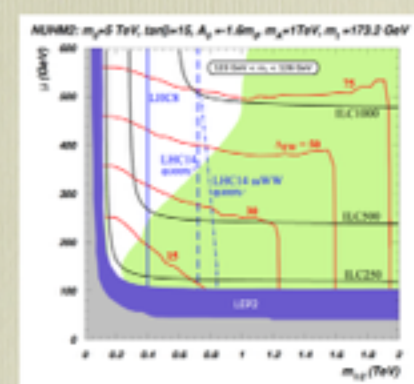


Note - the choice of this benchmark point is under recent discussion in the Physics Working Group

Discoveries

- The ILC physics program could be significantly enhanced by discoveries with the LHC or the early ILC running
- Early higher energy running increases the probability for this to happen early at the ILC
- Example: Higgsino





Accuracies in First 5 Years

	HL-LHC	ILC Scenario B	ILC Scenario D-500
$\sqrt{s}$ (GeV)	1400	250	350
L (fb^{-1})	3000	360	470
$\gamma\gamma$	2-5 %	14.8 %	10.9 %
gg	3-5 %	4.8 %	2.9 %
WW	2-5 %	3.9 %	0.63 %
ZZ	2-4 %	0.63 %	0.49 %
$t\bar{t}$ ($c\bar{c}$)	7-10 %	5.3 %	3.7 %
$b\bar{b}$	4-7 %	3.8 %	1.3 %
$\tau^+\tau^-$	2-5 %	4.3 %	2.4 %
$\Gamma_T(h)$	5-8 %	7.3 %	2.1 %

Table 7: Expected accuracies $\Delta g_i/g_i$ of Higgs boson couplings for the end of the HL-LHC program and for the first five years of ILC running assuming either Scenario B or Scenario D-500. The couplings are derived from a seven parameter fit of $g_g, g_\gamma, g_W, g_Z, g_b, g_t, g_\tau$ using the model dependent constraints described in Section 10.3.7 of the first report of the LHC Higgs Cross Section Working Group [26]. The HL-LHC coupling errors are taken from the 2013 Snowmass Higgs Working Group Report [15].

Conclusions on Staging

- For 250 GeV start optimal physics scenario is C-500, with the largest fraction of lifetime operating at the highest possible energy, optimizing the possibility of discoveries of new physics & making the earliest measurements of important Higgs properties.

- Improved early physics reach by starting at 350 GeV, rather than 250 GeV. This would optimize the Higgs measurements, open up early measurements of the top mass and electroweak couplings, and increase discovery reach for new particles.

- The physics impact of the ILC is significantly improved if the maximum energy of the 500 GeV ILC is stretched to 550 GeV where the top Yukawa precision is more than a factor of two times better than at 500 GeV.

- Report emphasizes physics that we are absolutely certain will be done with the ILC and the operational accelerator plans for achieving the best outcomes for that physics.
    - precision measurements of the Higgs boson, the top quark, and possibly measurements of the W and Z gauge bosons.

- Each scenario has compelling and impactful scientific program, but discoveries by the LHC or early running of the ILC could expand ILC's scientific impact. Discoveries of pair-produced new particles would motivation operations at or near the threshold of new physics, a capability that is one of the particular operational strengths of the ILC.

Draft of report at http://pages.uoregon.edu/jimbrau/temp/main.pdf

analysis status

Update!

ECM	@ 250 GeV		@ 350 GeV		@ 500 GeV		@ 1 TeV
luminosity/fb	250		330		500		1000
polarization (e-,e+)	(-0.8, +0.3)		(-0.8, +0.3)		(-0.8, +0.3)		(-0.8, +0.2)
process	ZH	ννH	ZH	ννH	ZH	ννH	ννH
cross section	EH	-	G		-	-	-
	σ·Br	σ·Br	σ·Br	σ·Br	σ·Br	σ·Br	σ·Br
H-->bb	EH	F	EH	EEF	EEH	F	F
H-->cc	EH		EH	EEH	EEH	EH	F
H-->gg	EH		EH	EEH	EEH	EH	F
H-->WW*	EH		EEH	EEF	EEH	F	F
H-->ττ	EH		EEH	EEH	EH	EH	EEH
H-->ZZ*	F		EEG	EEG	G	G	G
H-->γγ	G		G	EEF	G	F	F
H-->μμ	-						F
H-->Inv. (95% C.L.)	F		EEF		EEF		-
ttH, H-->bb	-				EH/EF		F

F: done by full simulation w/ mH=125GeV

EH: extrapolated from full simulation w/ mH=120GeV

EEH: extrapolated from full simulation at other ecm w/ mH = 120 GeV

EEF: extrapolated from full simulation at other ecm w/ mH = 125 GeV

G: guesstimate from old fast simulation

black: ongoing or completed

red: still missing

Our Group’s Activities

Status & Next Step

Symmetry Breaking & Mass Generation Physics

- ZH : H->bb,cc,gg -> EPJ C (2013) 73:2343, now working on mh=125 GeV case: Ono+Miyamoto
  H -> WW* anomalous coupling: analysis done -> publication: Takubo (revision done, resubmitted to P.R.D.) -> P.R.D88,013010(2013)
  H->other modes: Tino (AA,mu+mu-) + Kawada/Tanabe/Suehara (tau+tau-)
  Recoil mass: Watanuki, Jacqueline, Ogawa (ll), Tomita/Suehara (qq), CP mixing in h->tau+tau-: Yokoyama, Ogawa (TPC radius issue)
- ZHH : full simulation of the H->bb&Z->all modes, fast simulation of nunuHH: finished: Junping + Takubo (Ph.D thesis: done) -> New analysis with improved analysis tools: Junping + Claude + Suehara + Tanabe, Jet-clustering: Shaofeng Ge, LCFIPlus: Suehara
  New analysis: ZHH->ZbbWW*: Kurata (P-ID)
- nnHH : full simulation @ 1TeV, done for DBD: Junping -> publication
- nnH, eeH : precision measurements of HVV couplingsm, mh=125GeV: Junping
  BR measurements: Ono, Christian
- TTH : quick simulation studies with NRQCD corrections
  -> P.R.D84,014033(2011) -> full sim. @ 0.5 & 1 TeV: (Yonamine left) Tanabe + Sudo
- TT Threshold : Top Yukawa measurement: Horiguchi + Ishikawa + Tanabe, Theory: Kiyo + Sumino -> publicaton?
- New analysis (enW) : Koya Tsuchimoto
- AA->HH : quick simulation studies, so far H->bb and WW BG
  -> P.R.D85,113009(2012) : Kawada, Theory: Harada

Status & Next Step

Beyond the Standard Model

- SUSY : full simulation studies for LOI -> publication
  - EWkino scan: Tanabe
- Extra U(1), etc. -> Z' tail
  - TT : full simulation studies for LOI -> publication in conjunction with tau tau
  - tau tau : full simulation studies for LOI -> ditto
- Hidden Sector / XD : P.R.D78, 015008 (2008)
- LHT : P.R.D79, 075013 (2009)
- Model discrimination: Saito + Suehara .. : P.R.D84, 115003 (2011)
- R-handed neutrinos: Saito : P.R.D82, 093004 (2010)
- LHT: Kato (exp) + Harigaya (th): ZHZH finished, working on eHeH, nHnH, ..: Draft (n-1)?
- Very light gravitino: Katayama (Master's thesis), Tanabe (exp) + Matsumoto (th) --> 1st Draft --> New student: Takuaki Mori (Tokyo)
- Quasi stable stau: Yamaura (Master's thesis) + Kotera + Kasama —> reactivated
- Higgs portal/h->Invisible: Honda -> Yamamoto -> Ishikawa, Ogawa
- W-H+/W+H-: Shinzaki (exp) + Kanemura, yagyu (th)
- New projects?
  - AMSB: Tanabe
  - Single photon (DM search): Tanabe?
  - Heavier Higgs bosons?: Yokoya, Abhinav
  - Radiative correction to Higgs couplings in 2HDM: Kikuchi
  - H125->ccbar: Hidaka
  - m_nu, DM, baryogenesis: Machida

Short Term Schedule

- Weekly Meeting
  - Every Fri. at 13:30 (conf. ID: to be announced)
- General Meeting
  - 10:30 on Sat. Jan. xx, 2015 (KEK MCU2 conf. ID:864)
- Annual ILC Det. Meeting, Dec 17-19, 2014
- Toyama Meeting of New Higgs WG, Jan. 10-11, 2015
- HPNP 2014, Toyama, Jan 11-15, 2015
- ALCW 2015, Tsukubba, Apr 20-24, 2015