ILC Status

Hitoshi Yamamoto
Tohoku University

FCAL Meeting, Krakow, May 2018

Problems with Standard Model

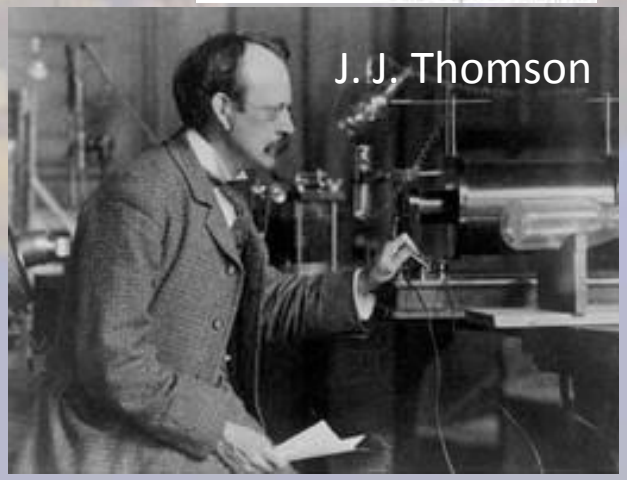
- No candidate for Dark Matter
- Cannot explain the origin of EW symmetry breaking
- Cannot explain the matter dominance of Universe
- Higgs mass correction: quadratic divergence fine-tuning problem - multiverse?
- …

All above indicate New Physics beyond SM

E. Rutherford

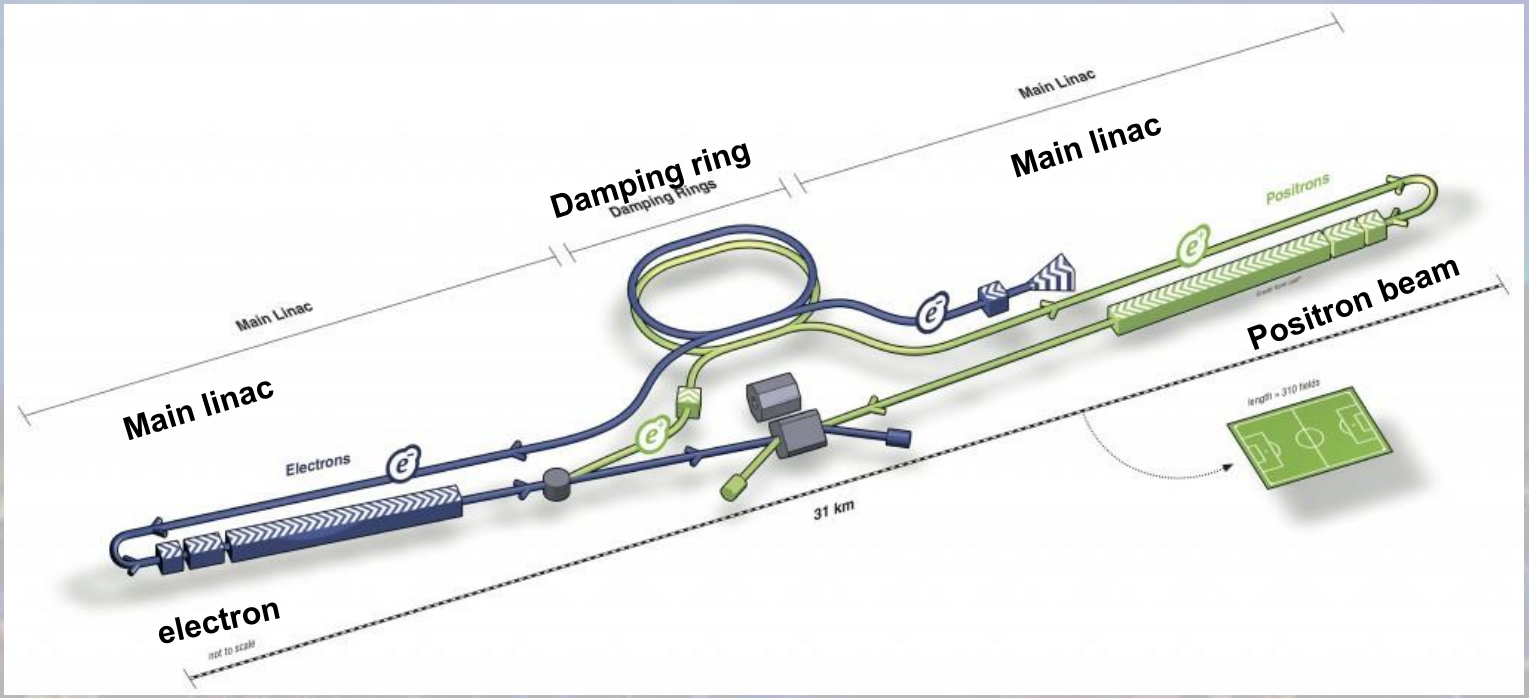
New era of particle physics has begun!

Can be compared to the discoveries of nucleus (Ratherford) and electron (J.J. Thomson) opening new era of particle physics



ILC is to lead this new era

International Linear Collider



- Electron-positron collider
- Ecm = 500 GeV TDR baseline, L = ~1 x 10^{34} /cm^2s
- Polarization (e-/e+) = ±0.8/±0.3
- 2x10^{10} particles/bunch, 1312 bunch/train, 5 trains/sec
- Beam size at IP : σy = 5.9nm, σx = 474nm, σz = 300μm
- Average accelerating gradient = 31.5 MV/m

Plan of this talk

- Movements around the European Strategy 2013
- ILC250 Higgs Factory and its physics
- Political movements surrounding ILC250
- Prospects

J. J. Thomson

Reaction of Europe

- ‘European Strategy 2013’ (March 22, 2013)
  - There is a strong scientific case for an electron-positron collider, complementary to the LHC, that can study the properties of the Higgs boson and other particles with unprecedented precision and whose energy can be upgraded … The initiative from the Japanese particle physics community to host the ILC in Japan is most welcome, and European groups are eager to participate. Europe looks forward to a proposal from Japan to discuss a possible participation.

Letter from Diet Members of Japan to DOE

Federation of Diet Members for the ILC

Jan 8, 2014

…

the Japanese government has shown a vital interest in the ILC project …

The ultimate decision to host the ILC project rests with the Japanese government and the Diet. Both houses of the Diet are strongly in support of the ILC project …

The most important issue for the realization of the ILC is whether it can become a truly global project. For this purpose, the Japanese government is currently gathering information from abroad and is starting talks with the United States and European countries about forming a partnership.

Federation of Diet Members for the ILC
Room 302 (Office of Takeo Kawamura)
Second Members' Office Building of the House of Representatives
2-1-2 Nagata-cho, Chiyoda-ku, Tokyo 100-8982, Japan

January 8, 2014

The Honorable Ernest Moniz
Secretary, U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585
United States of America

Dear Dr. Moniz:

We, the Diet members of Japan, established a multiparty federation of Diet members to realize the International Linear Collider (ILC). There are now a total of over 150 members from the House of Representatives and the House of Councillors, representing more than 2 of the policymakers in Japan.

Sincerely yours,

Takeo Kawamura 河村建夫
Chair, Federation of Diet Members for the ILC
Member, House of the Representatives of Japan

Ryu Shionoya 塩谷立
Secretary General, Federation of Diet Members for the ILC
Member, House of the Representatives of Japan

Kenji Kosaka 小坂憲次
Deputy Chair, Federation of Diet Members for the ILC
Member, House of the Councillors of Japan

Reaction of US: P5 Report

P5: Particle Physics Project Prioritization Panel (DOE)
23 May 2014

- On the scientific case for the ILC
  - ‘we emphasize most strongly that the scientific justification for the project is compelling’.

- On the US participation
  - ‘As the physics case is extremely strong, all Scenarios include ILC support at some level through a decision point within the next 5 years’.
  - If extra budget : ’Play a world-leading role in the ILC experimental program and provide critical expertise and components to the accelerator, should this exciting scientific opportunity be realized in Japan.’

P5 chair, Steven Ritz
SCIPP director, UCSC

Science Council of Japan on ILC

Requested by MEXT; Report submitted on Sep 30 2013
(MEXT: Ministry of education, culture, sports, science and technology)

The conclusion of the report included:

- The Committee suggests that the government of Japan should (1) secure the budget required for the investigation of various issues to determine the possibility of hosting the ILC, and (2) conduct intensive studies and discussions among stakeholders, including authorities from outside high-energy physics as well as the government bodies involved for the next two to three years.

- In parallel, it is necessary to have discussions with the research institutes and the responsible funding authorities of key countries and regions involved outside of Japan, and to obtain clear understanding of the expected sharing of the financial burden.

MEXT ILC Advisory Panel

- ‘ILC Advisory Panel’ was established under MEXT (May 2014)

- Four working groups under the ILC Advisory Panel
  1. Particle&Nuclear Physics working group
     - On the ILC physics case with respect to other future projects
  2. TDR validation working group
     - On the financial resources well as maturity of design
  3. Human resources working group
     - Will there be enough human resources worldwide (educated)?
  4. Governance and management working group

- Interim report: June 2015

ILC Advisory Panel Interim Report

June 25, 2015

Excerpts

‘The ILC is considered to be important because of its capability to investigate new physics beyond the Standard Model by exploring new particles and precisely measuring the Higgs boson and top quark. It should be also noted that the ILC might be able to discover a new particles which are difficult to be detected in LHC experiments.’

‘… it is necessary to closely monitor, analyze and examine the development of LHC experiments’

‘…it is important to have general understanding on the project by the public and science communities’

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J. J. Thomson

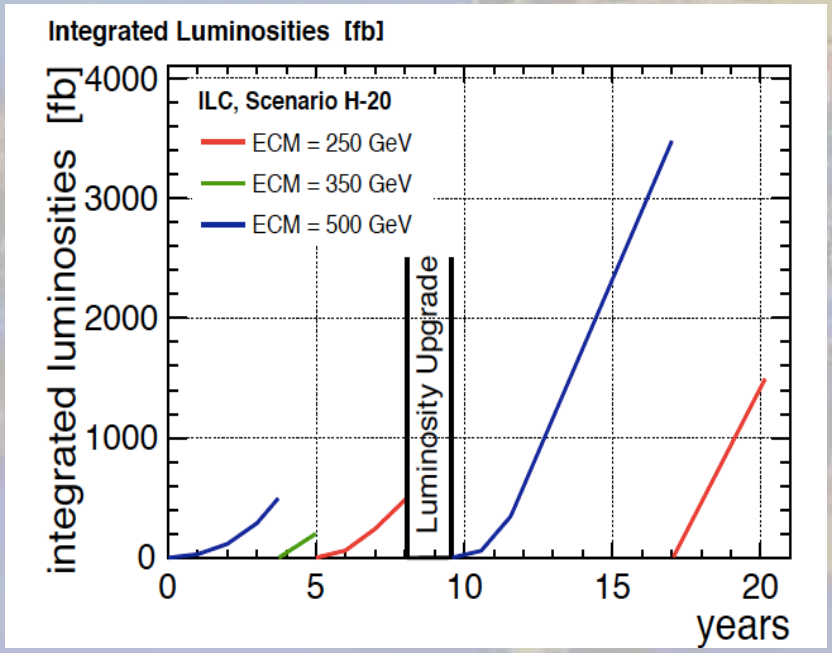
Proposal for ILC250 Higgs Factory

At LCWS2016 Morioka, it was proposed that the first stage at 250 GeV is defined as a Higgs factory that defines one whole project which should be justified by its own scientific case.

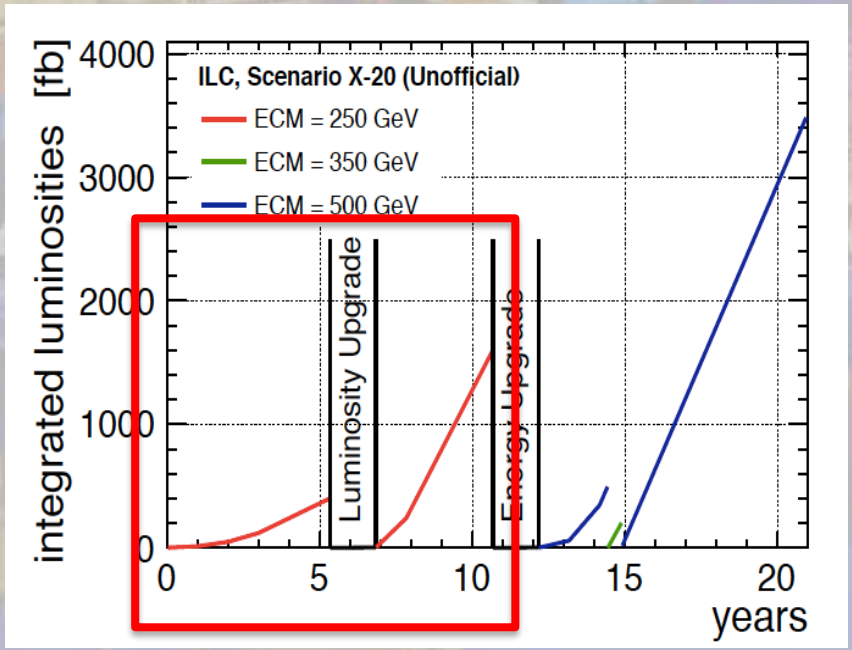
The idea was discussed and a general agreement was obtained.

Staging

Up to Dec. 2016 (LCWS Morioka)
500 GeV start sample scenario



After Dec. 2016
Generally agreed by ILC community
To be formalized this fall



ILC250 Higgs Factory

Build the ILC250 Higgs factory as the first stage ‘program’

Higgs Coupling Measurements

- κ framework
  - Assume the same interaction as SM. Vary the size of the coupling constants ('traditional' framework).

$$\frac{\Gamma(h \to ZZ^*)}{SM} = \kappa_Z^2 \,, \qquad \frac{\sigma(e^+e^- \to Zh)}{SM} = \kappa_Z^2$$

- EFT (Effective Field Theory) approach
  - Assume that deviations from SM are small.
  - Assume SU(2)XU(1) gauge symmetry of SM.
    - Radiative corrections calculable.

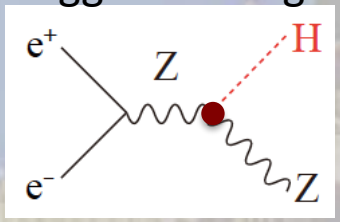
$$\delta\mathcal{L} = \frac{m_Z^2}{v}(1+\eta_Z)hZ_\mu Z^\mu + \zeta_Z \frac{1}{v} hZ_{\mu\nu}Z^{\mu\nu}$$

Not in SM

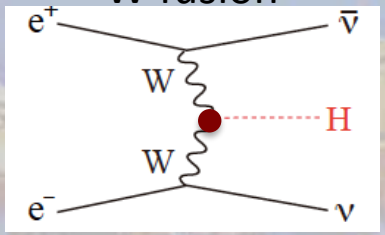
Notes on κ Framework

- For κ_Z and κ_W , production rates give high precision

Higgsstrahlung



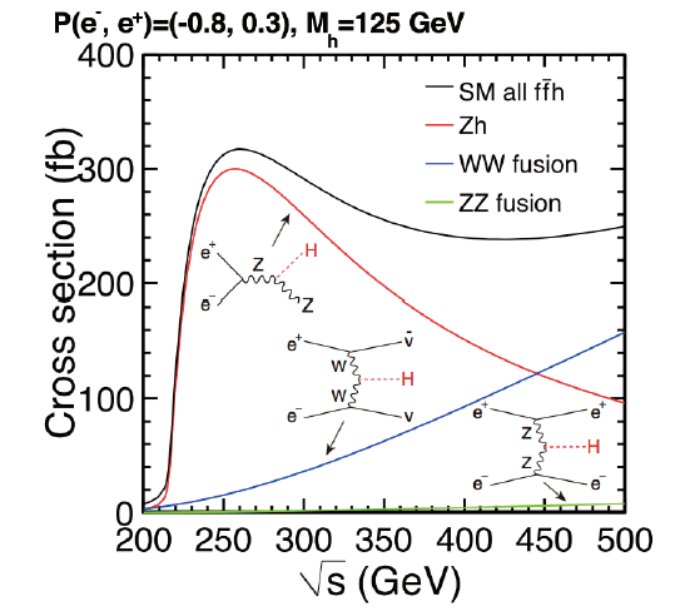
W fusion



- In general for κ_X , Γ_{tot} is necessary in addition to Br(H→x)
  - Γ_{tot} = Γ(H→ZZ)/Br(H→ZZ) with Γ(H→ZZ) from κ_Z
  - Γ_{tot} = Γ(H→WW)/Br(H→WW) with Γ(H→WW) from κ_W
  - W mode is far more powerful than Z mode

    Br(H→WW) ~ 10XBr(H→ZZ)

    Requires ~350 GeV Ecm or more



EFT (Effective Field Theory) Approach

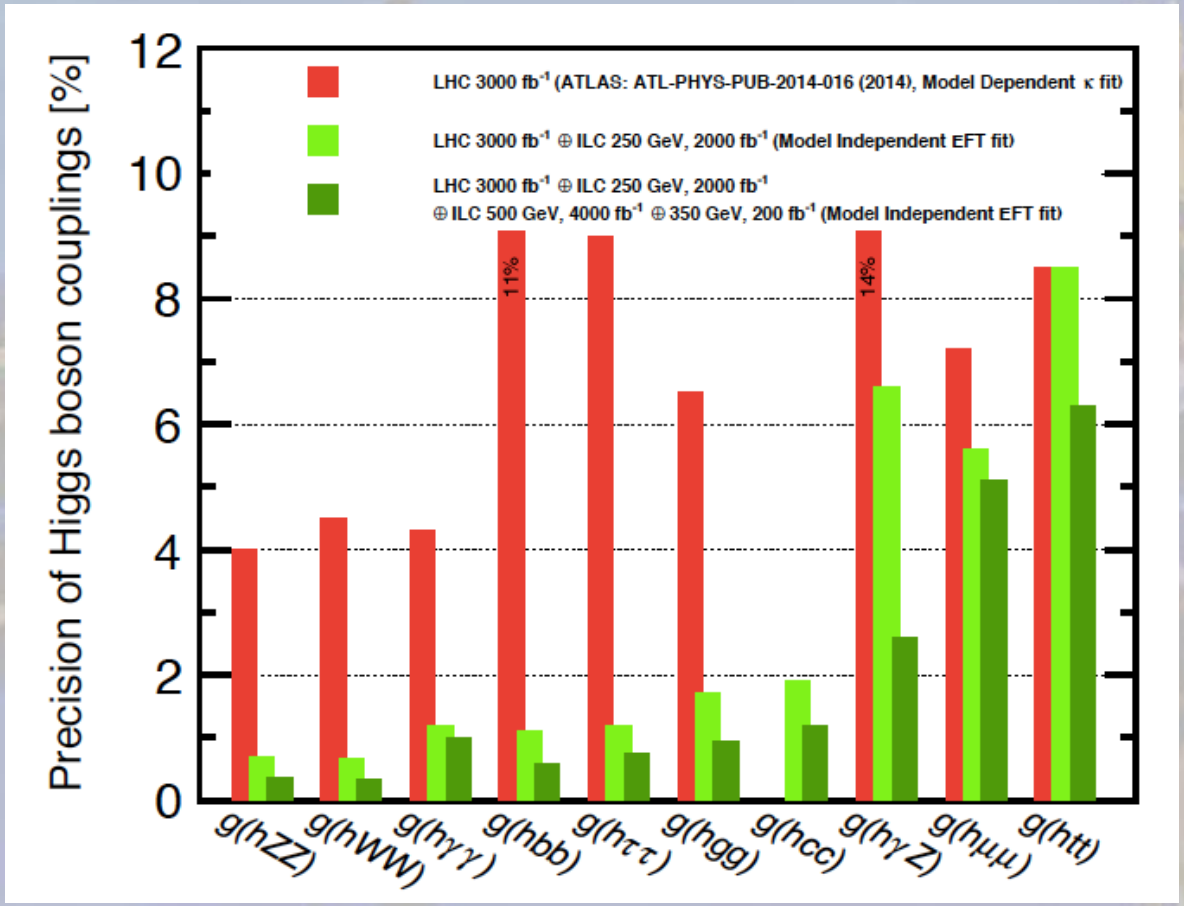
$$\Delta\mathcal{L} = \frac{c_H}{2v^2}\partial^\mu(\Phi^\dagger\Phi)\partial_\mu(\Phi^\dagger\Phi) + \frac{c_T}{2v^2}(\Phi^\dagger \overleftrightarrow{D}^\mu\Phi)(\Phi^\dagger \overleftrightarrow{D}_\mu \Phi) - \frac{c_6\lambda}{v^2}(\Phi^\dagger\Phi)^3$$
$$+\frac{g^2 c_{WW}}{m_W^2}\Phi^\dagger\Phi W^a_{\mu\nu}W^{a\mu\nu} + \frac{4gg' c_{WB}}{m_W^2}\Phi^\dagger t^a\Phi W^a_{\mu\nu}B^{\mu\nu}$$
$$+\frac{g'^2 c_{BB}}{m_W^2}\Phi^\dagger\Phi B_{\mu\nu}B^{\mu\nu} + \frac{g^3 c_{3W}}{m_W^2}\epsilon_{abc}W^a_{\mu\nu}W^{b\nu}{}_\rho W^{c\rho\mu}$$
$$+i\frac{c_{HL}}{v^2}(\Phi^\dagger \overleftrightarrow{D}^\mu\Phi)(\overline{L}\gamma_\mu L) + +4i\frac{c'_{HL}}{v^2}(\Phi^\dagger t^a \overleftrightarrow{D}^\mu\Phi)(\overline{L}\gamma_\mu t^a L)$$
$$+i\frac{c_{HE}}{v^2}(\Phi^\dagger \overleftrightarrow{D}^\mu\Phi)(\overline{e}\gamma_\mu e)\ .$$

(Before EW symmetry breaking)

- 20-parameter fit (up to dim-6)
- Br(H→ZZ, γZ, $\mu\mu$)/Br(H→$\gamma\gamma$) from HL-LHC included
- e+e- → WW included (triple gauge coupling)
- SU(2): HZZ and HWW couplings are related (→ Γ_{tot})

Higgs Coupling Measurement Precisions

EFT approach



ILC250
2000 fb-1 (~10 yrs)

Polarization:
(-+, +-, ++, --) =
(45%, 45%, 5%, 5%)

When combined with HL-LHC, ILC 250 (2000fb^{-1}) is nearly as effective as ILC500 (4000fb^{-1}) is added.

Model Discrimination

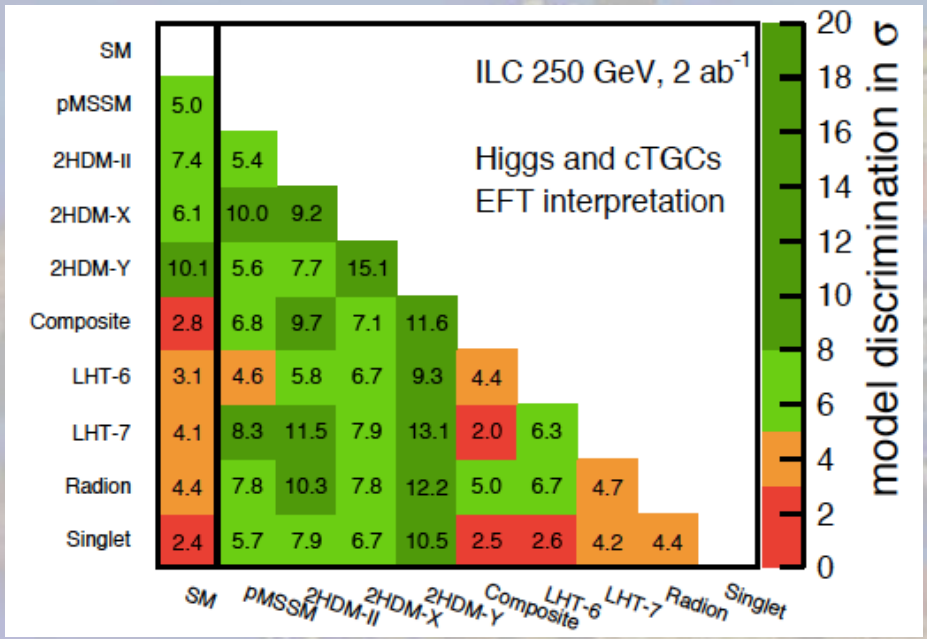
- Pick models that are not likely to be discovered at HL-LHC
- Evaluate separations between the models (incl. SM)

	Model	$b\bar{b}$	$c\bar{c}$	gg	WW	$\tau\tau$	ZZ	$\gamma\gamma$	$\mu\mu$
1	MSSM [34]	+4.8	-0.8	- 0.8	-0.2	+0.4	-0.5	+0.1	+0.3
2	Type II 2HD [36]	+10.1	-0.2	-0.2	0.0	+9.8	0.0	+0.1	+9.8
3	Type X 2HD [36]	-0.2	-0.2	-0.2	0.0	+7.8	0.0	0.0	+7.8
4	Type Y 2HD [36]	+10.1	-0.2	-0.2	0.0	-0.2	0.0	0.1	-0.2
5	Composite Higgs [38]	-6.4	-6.4	-6.4	-2.1	-6.4	-2.1	-2.1	-6.4
6	Little Higgs w. T-parity [39]	0.0	0.0	-6.1	-2.5	0.0	-2.5	-1.5	0.0
7	Little Higgs w. T-parity [40]	-7.8	-4.6	-3.5	-1.5	-7.8	-1.5	-1.0	-7.8
8	Higgs-Radion [41]	-1.5	- 1.5	10.	-1.5	-1.5	-1.5	-1.0	-1.5
9	Higgs Singlet [42]	-3.5	-3.5	-3.5	-3.5	-3.5	-3.5	-3.5	-3.5

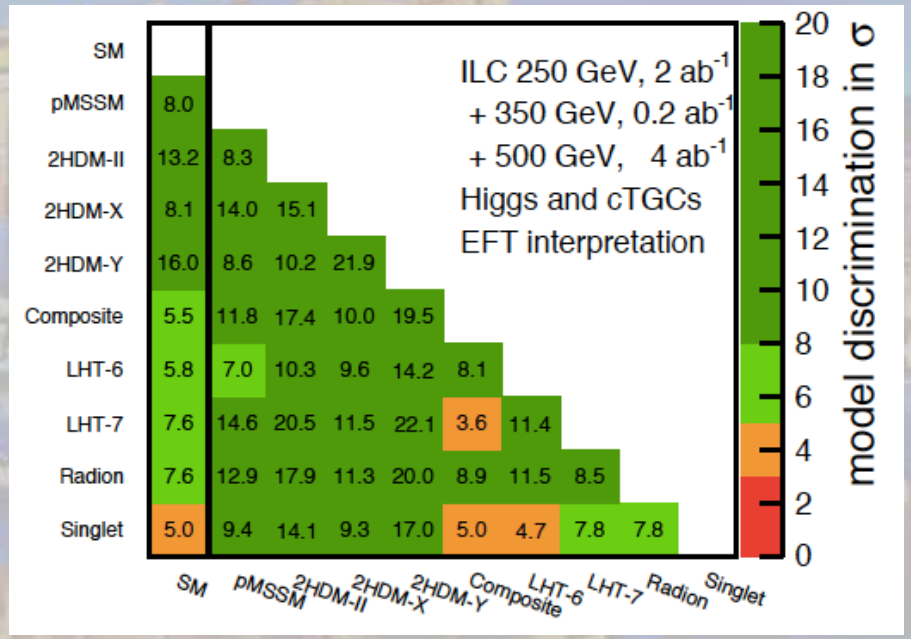
Models and deviations from SM (%)

Model Discrimination

ILC250



ILC500 (~H20)

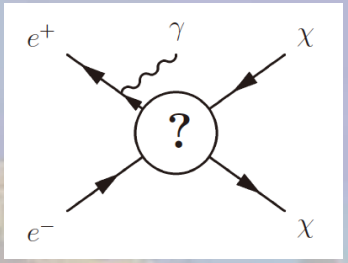


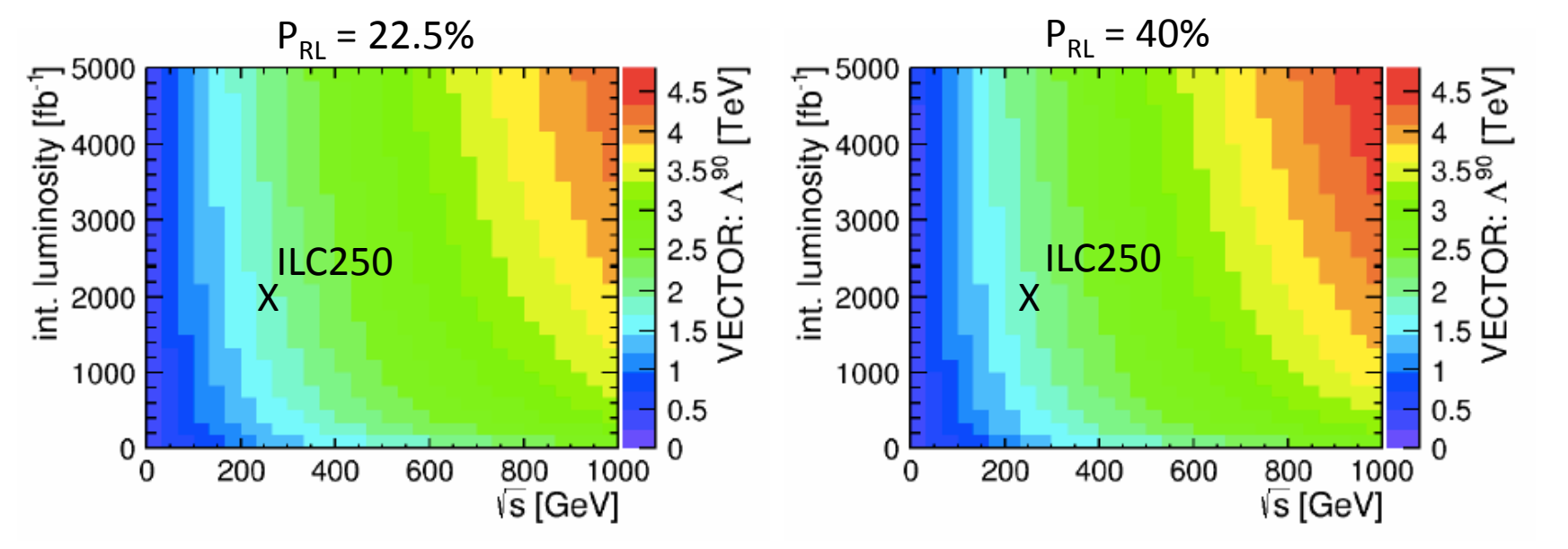
Separations among models in #sigma

ILC500 (~H20) has better separations among models that are beyond HL-LHC.
ILC250 has less sensitivities, but still quite effective in model separations.
(ILC500 takes twice as long running time)

Mono photon events (e+e- → χχγ)

Exclusion limits for Λ
EFT approach: Vector-like fermion WIMP





K. Fujii et al

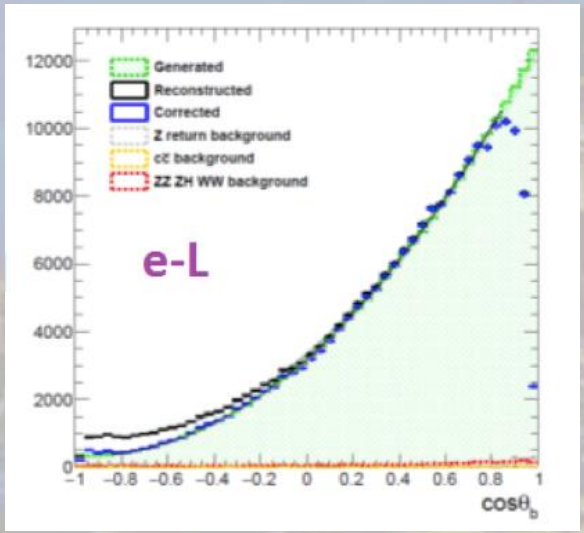
P_{RL}: fraction of data with e-(R) and e+(L)
Λ: energy scale of BSM (= $M_{mediator}(gf\ g\chi)^{-1/2}$)

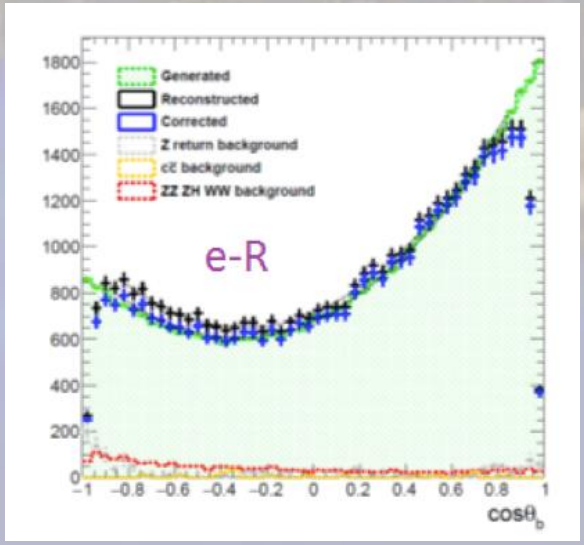
ILC250 has sensitivities ~ 2 TeV

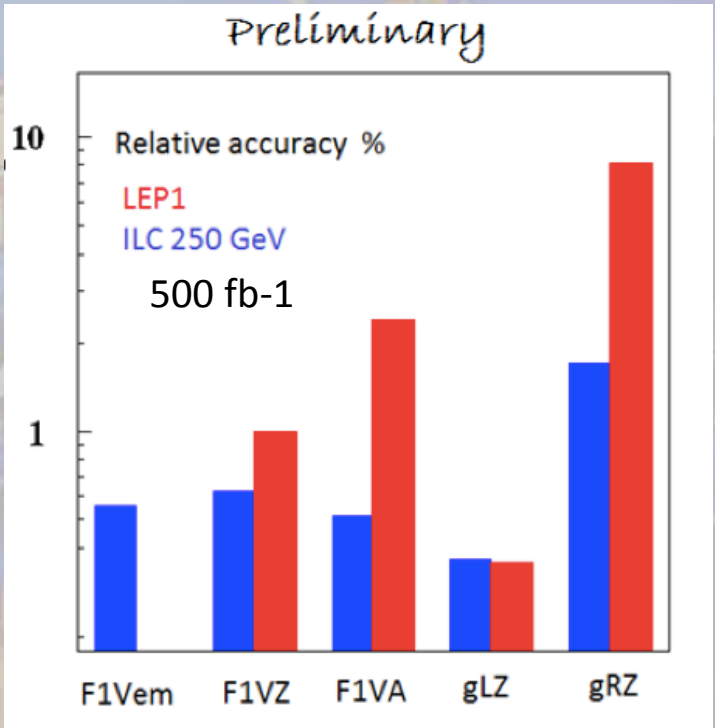
Indirect Probes: ee→bb

Poeschl et al.

Form Factor Study







Substantial improvements over LEP1
Errors reduced by ~1/2 with 2000 fb-1

Study on-going

Plan of this talk

- Movements around the European Strategy 2013
- ILC250 Higgs Factory and its physics
- Political movements surrounding ILC250
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J. J. Thomson

Committee on the Physics Significance of ILC 250 GeV Higgs Factory (JAHEP)

Conclusions (June 2017)

- ILC250 should run concurrently with HL-LHC to enhance physics outcomes from LHC.
- Given that a new physics scale is yet to be found, ILC250 is expected to deliver physics outcomes that are nearly comparable to those previously estimated for ILC500 in precise examinations of the Higgs boson and the Standard Model.
- The ILC250 Higgs factory, together with HL-LHC and SuperKEKB, will play an indispensable role in the discovery of new phenomena originating from new physics with the energy scale up to 2–3 TeV and the elucidation of the origin of matter-antimatter asymmetry.
- A linear collider has a definite advantage for energy-upgrade capability. ILC250 possesses a good potential for its upgrades to reach the higher energy of new physics that the findings of ILC250 might indicate.

JAHEP Statement on Staging

July 22, 2017

- Considering the current LHC outcomes. ILC250 should play an essential role in precision measurement of the Higgs boson and, with HL-LHC and SuperKEKB, in determining the future path of new physics. Based on ILC250's outcomes, a future plan of energy upgrade will be determined so that the facility can provide the optimum experimental environment by considering requirements in particle physics and by taking advantage of the advancement of accelerator technologies. It is expected that ILC will lead particle physics well into the 21st century.

- To conclude, in light of the recent outcomes of LHC Run 2, JAHEP proposes to promptly construct ILC as a Higgs factory with the center-of-mass energy of 250 GeV in Japan.

Linear Collider Board (LCB)

Conclusions on the 250 GeV ILC as a Higgs Factory proposed
by the Japanese HEP community
8 Nov 2017

…The cost of such a machine is estimated to be lower by up to 40% compared to the originally proposed ILC at 500 GeV [3]. …

The acceleration technology of the ILC is now well established…

One of the unique features of a linear collider is the capability to increase the operating energy by improving the acceleration technology and/or extending the tunnel length. For these reasons, the Linear Collider Board strongly supports the JAHEP proposal [4] to construct the ILC at 250 GeV in Japan and encourages the Japanese government to give the proposal serious consideration for a timely decision….

International Committee for Future Accelerators (ICFA)

Statement on the ILC Operating at 250 GeV as a Higgs Boson Factory
Nov 2017

…ICFA considers the ILC a key science project complementary to the LHC and its upgrade.

ICFA welcomes the efforts by the Linear Collider Collaboration on cost reductions for the ILC, which indicate that up to 40% cost reduction relative to the 2013 Technical Design Report (500 GeV ILC) is possible for a 250 GeV collider.

ICFA emphasizes the extendibility of the ILC to higher energies and notes that there is large discovery potential with important additional measurements accessible at energies beyond 250 GeV. ICFA thus supports the conclusions of the Linear Collider Board (LCB) in their report presented at this meeting and very strongly encourages Japan to realize the ILC in a timely fashion as a Higgs boson factory with a center-of-mass energy of 250 GeV as an international project, led by Japanese initiative.

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J. J. Thomson

MEXT ILC Advisory Panel on ILC250

- Physics case subcommittee
  - Reactivated with updated members: Evaluate the scientific case for ILC250
  - Mtgs: Jan 18, Apr 13
- TDR subcommittee
  - Reactivated with updated members: Evaluate the maturity of technical design and costing of ILC250
  - Mtgs: Jan 30, Apr 19

ILC Advisory Panel (parent committee)

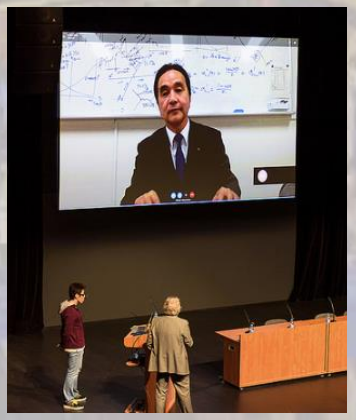
- Mtgs: May 31, (July 4)

Then back to the Science Council of Japan ?

Progress in Europe

Kauffman

Hirano



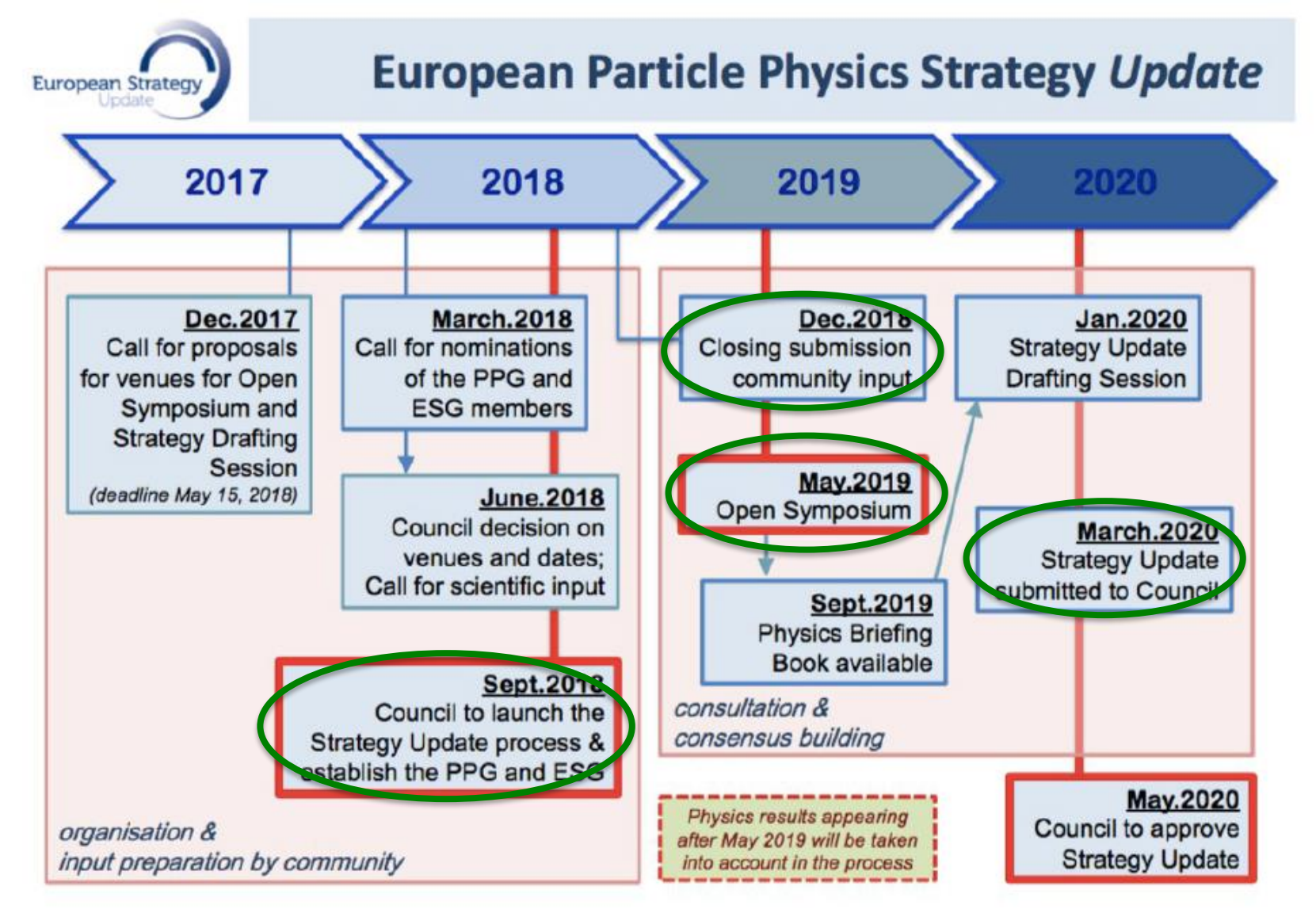
Becht

- LCWS2017 Strassburg
  - Remote joint speech by Japanese and European parliament members
    - Japan: Kawamura, Shionoya, Hirano
    - Europe: Becht, Kauffman
  - Started the next step as below
- Federation's visit to France/Germany
  - Jan 9-11, 2018
  - From Japan: 2 Ex MEXT ministers, MEXT high-level officers, Industries, researchers: ~ 20 total
  - Established links at 4 levels: parliament, funding agencies, Researchers
- More visits by the Federation planned (to Europe and US)

European Particle Physics Strategy Update (EPPSU 2020)

EPPSU Secretary:
Halina Abramovicz

- Defines which projects for Europe to promote in the field of particle physics.
- Organized by CERN.
  - EPPSU reports to the CERN council
- Last update was in 2013, next is 2020.
- Largely defines participation of each member states (France, Germany, Italy, etc.) in key projects (including ILC)
- Preparations start this year.
  - Establish PPG (Physics Preparatory Group) : produces physics briefing book
  - Establish ESG (European Strategy Group) : drafts strategy update
  - Deadline of inputs to PPG: Dec 18, 2018.



Timely Japanese government's positive 'expression of interest' is critical for ILC to be included in this process (latest by the end of this year)

Summary

- ILC will lead the new era of particle physics opened up by the discovery of Higgs.
- The discovery of Higgs propelled the ILC, supported also by the interests of Europe and North Americas.
- Compared to the old ILC500, the new ILC250 accomplishes up to 40% cost reduction.
- ILC250 has a strong physics case as a Higgs Factory alone.
- The review by the MEXT ILC Advisory Panel, and possibly by the Science Council of Japan, will be completed within 2018.
- It is critical that a positive signal from the Japanese government comes in time for the ILC to be included in the European Strategy discussion.