ILC Project

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Tohoku University

IUEP Mini Workshop 2018
Oct 7, 2018, Gwangju
Channam National U.

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 – unless multiverse?
- …

E. Rutherford

All the above indicate New Physics Beyond SM

Higgs is the probe for BSM

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

J. J. Thomson

ILC has been designed to lead this new era

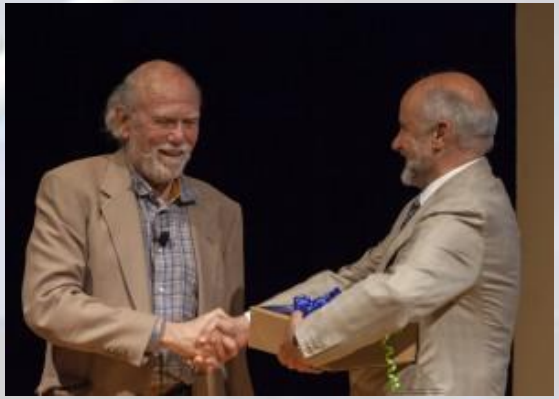
ILC TDR Completed

Ceremony: June 12, 2013

Tokyo

CERN

Fermilab



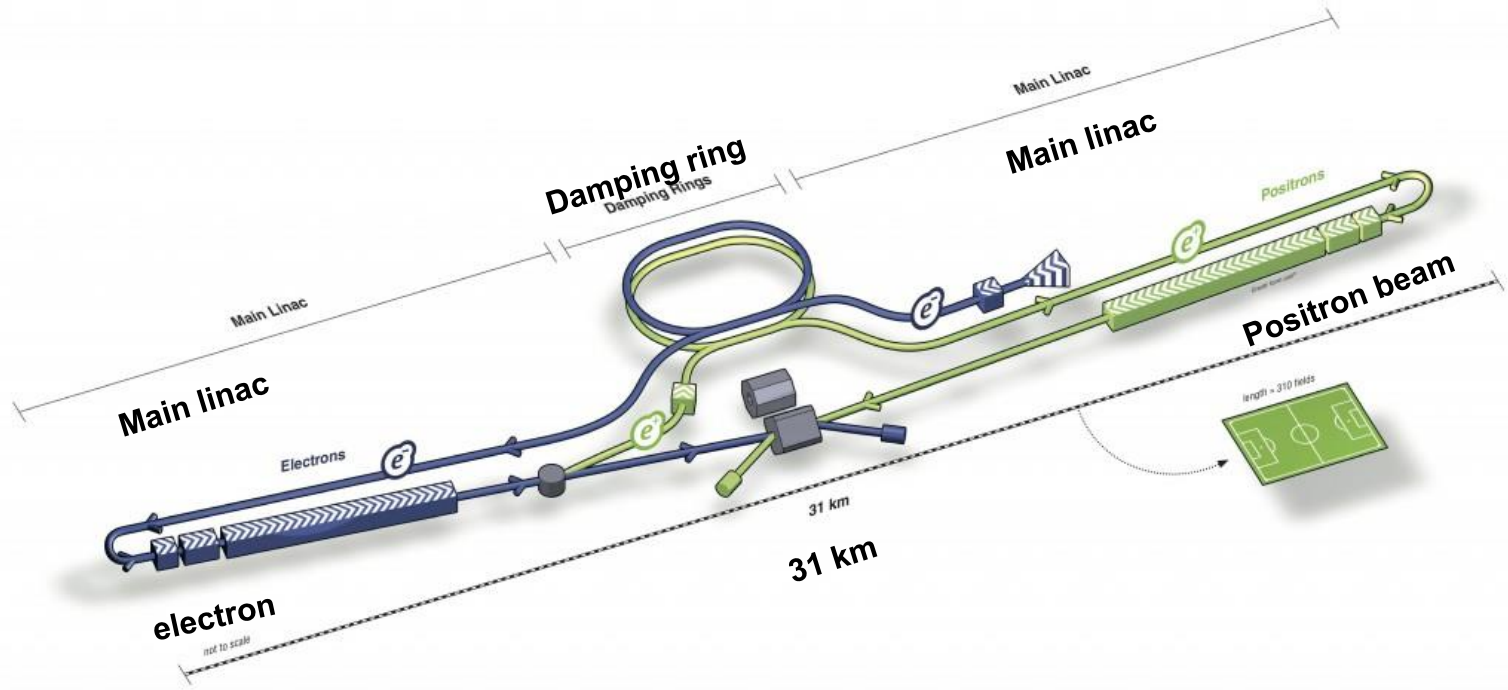
TDR 5 volumes

Culmination of many years of R&Ds

ILC is in principle ready to go technically (apart from some loose ends, cost reductions, etc.)

ILC500 (TDR) Hardwares

ILC

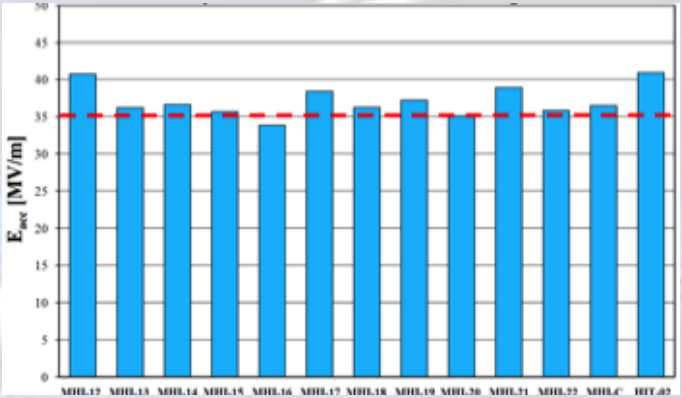


TDR 'Baseline':

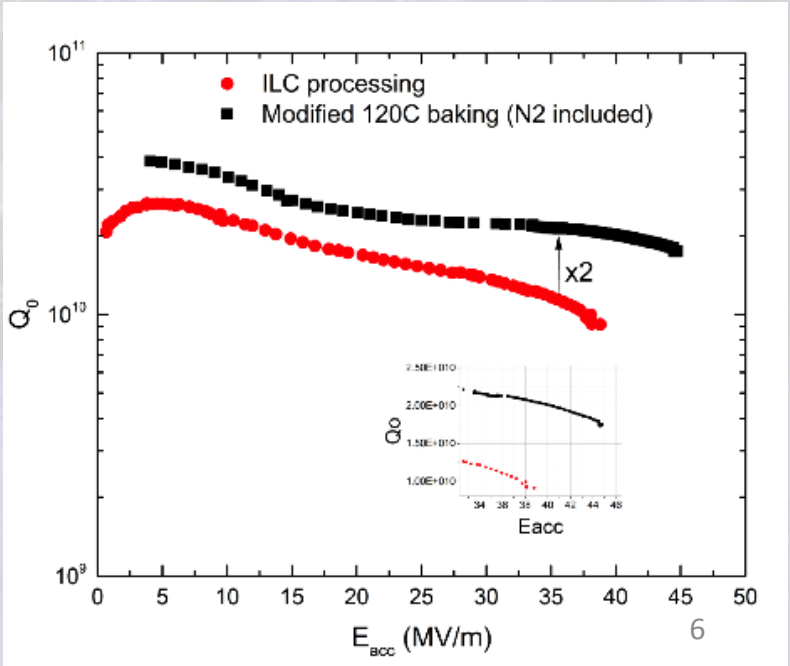
- Ecm = 500 GeV, L = 1.8 x 10^{34} /cm^2s
- Polarization (e+/e-) = ±0.3/±0.8
- 2x10^{10} particles/bunch, 1312 bunch/train, 5 trains/sec
- Beam size at IP : σy = 5.9nm, σx = 474nm, σz = 300μm
- Average accelerating gradient = 31.5 MV/m
- Wall plug power = 163 MW

Accelerating Beams

Superconducting RF cavities

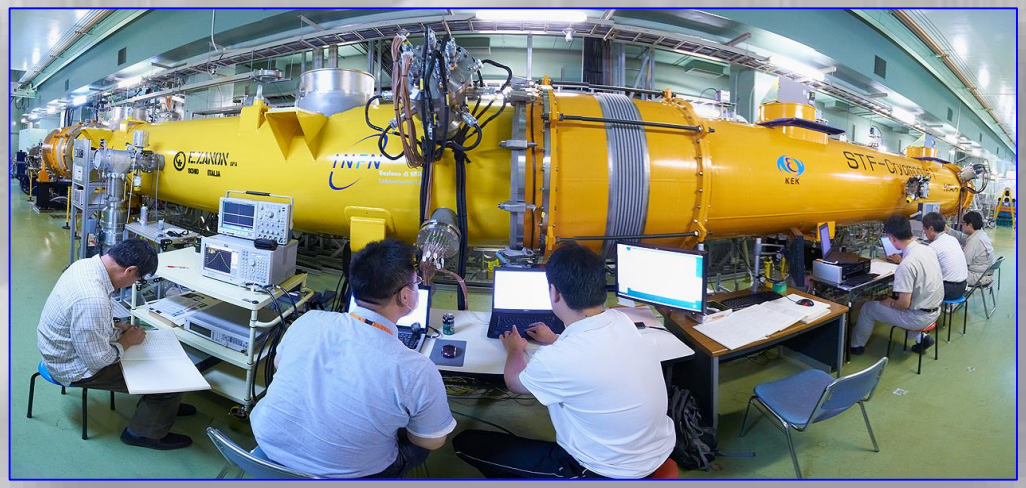


- Cavity spec:
  - 35 MV/m ±20% (‘vertical test’)
    Corresponds to~ 31.5 MV/m operation
  - 90% yield achieved
- Still improving (5 yrs from TDR)
  - e.g. N2 doping
    - Higher gradient
      - 35 MV/m operation realistic (TDR: 31.5 MV/m)
        → Fewer cavities
    - Higher Q
      - Less cryogenic power



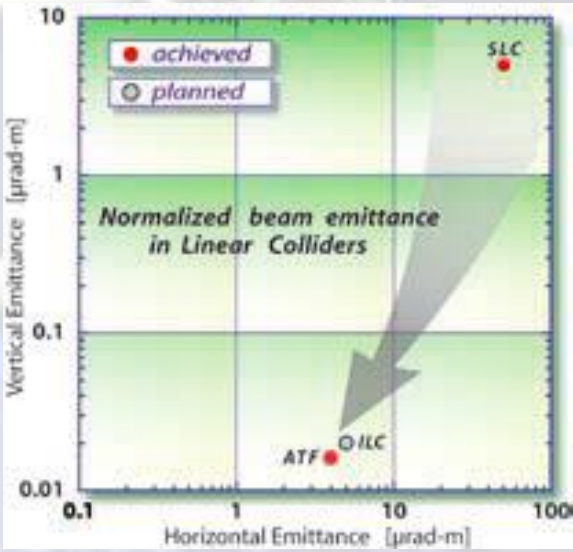
Assembling the Cryomodule

- Cryomodule assembly
  - Combine cavities from all over the world
    - Designs are not identical
    - Can they be assembled to one accelerator without degrading performance?
  - 'Plug-compatibility' design
    - KEK 'S1-global' project successful

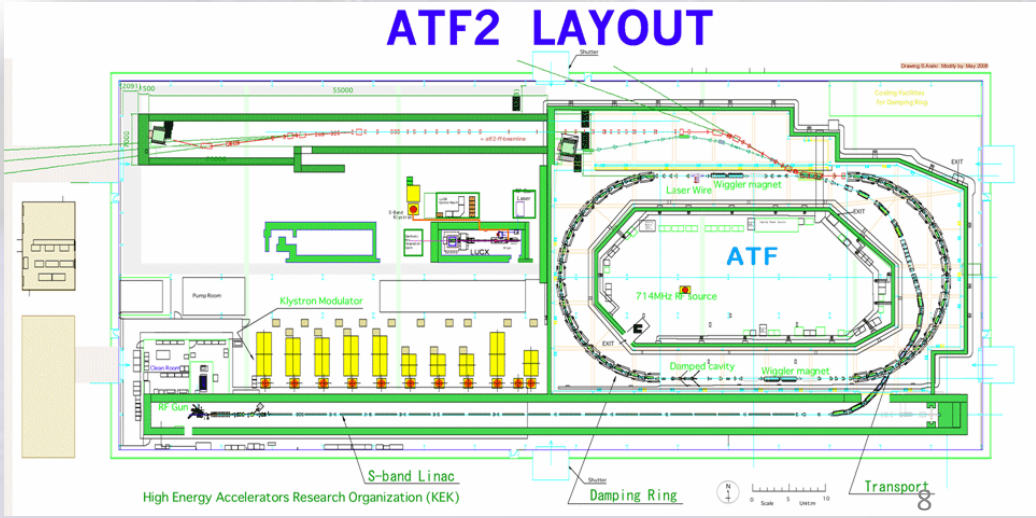


Making Beams Smaller

- ATF (Accelerator Test Facility), KEK
  - Super low emittance: achieved
- ATF2, KEK
  - Goals
    - Beam size 37 nm: 41 nm achieved:~OK
    - Keep it stable by feedback system : achieved



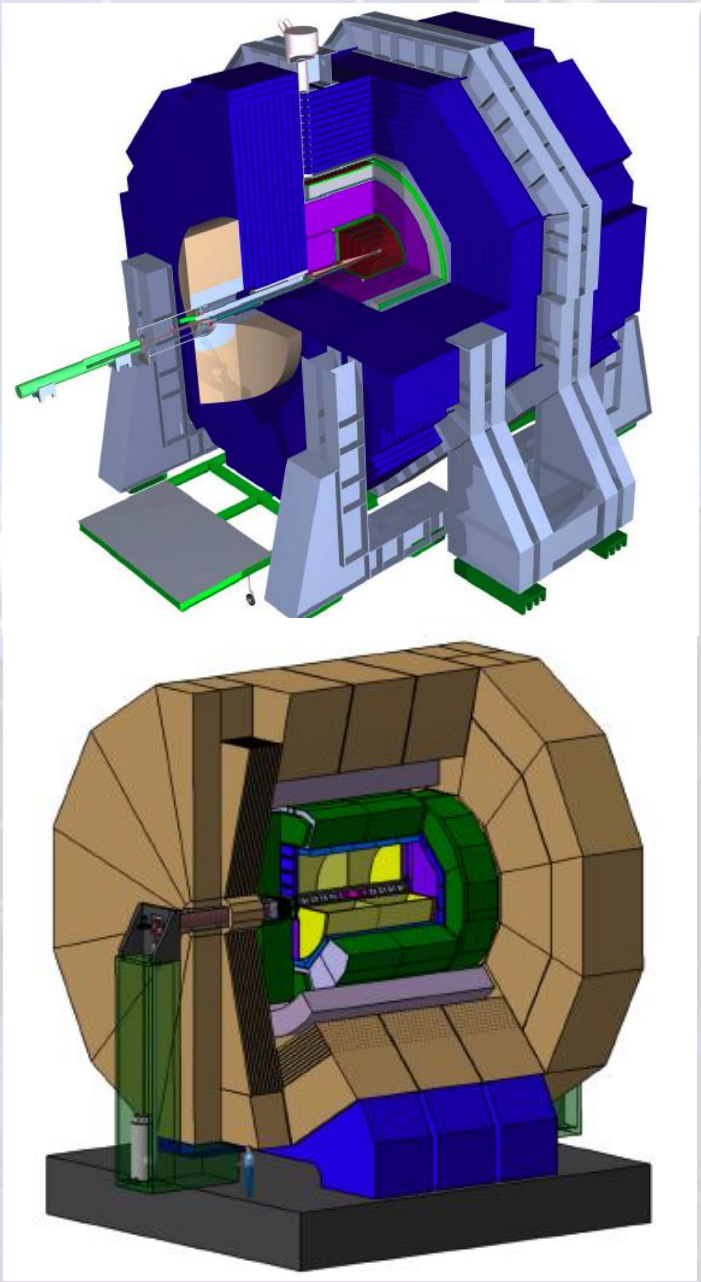
International collaboration



Two Detectors

- SiD
  - High B field (5 Tesla)
  - Small ECAL ID
  - Small calorimeter volume
    - Finer ECAL granularity
  - Silicon main tracker
- ILD
  - Medium B field (3.5 Tesla)
  - Large ECAL ID
    - Particle separation
  - TPC for main tracker

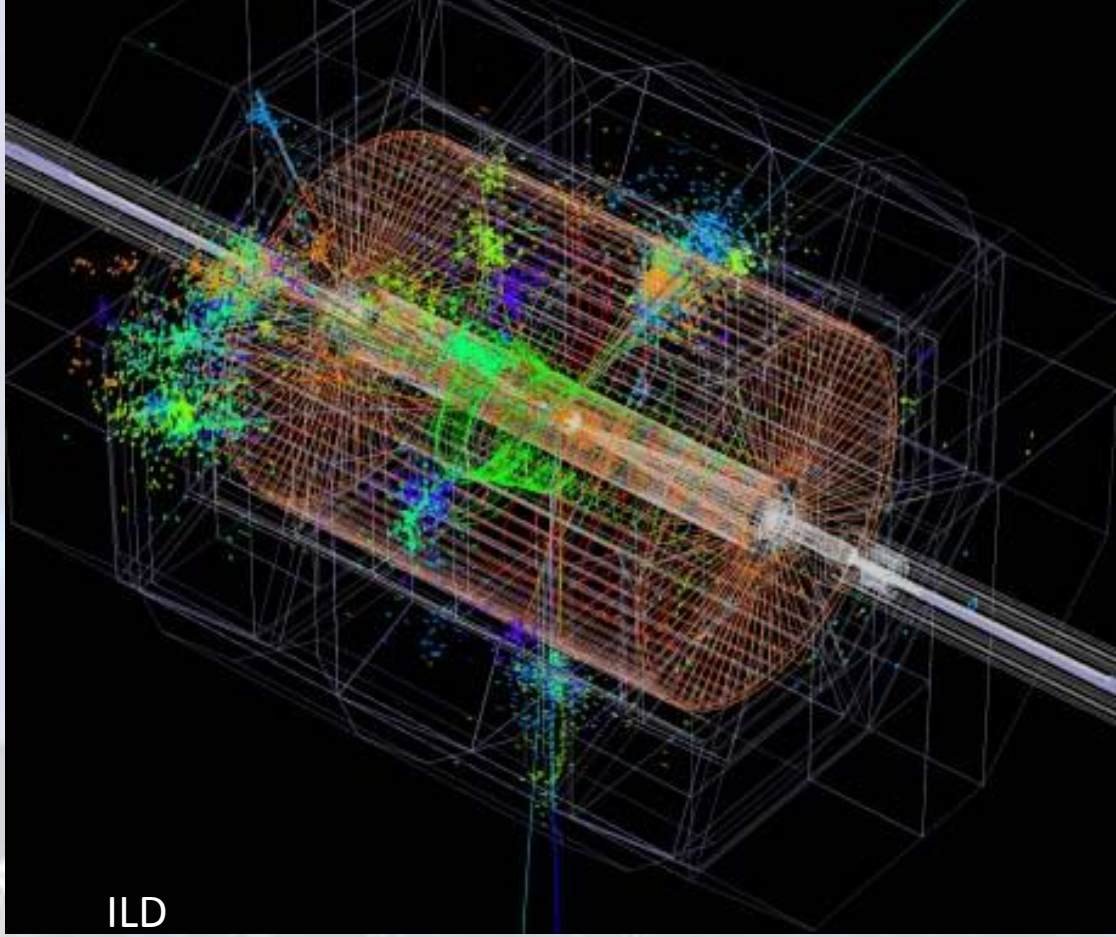
Based on PFA idea



PFA
(particle flow algorithm)

Jet Energy Measurement:

- Charged particles
  - Use trackers
- Neutral particles
  - Use calorimeters
- Remove double-counting of charged showers
  - Requires high granularity



#ch	ECAL	HCAL
ILC (ILD)	100M	10M
LHC	76K(CMS)	10K(ATLAS)

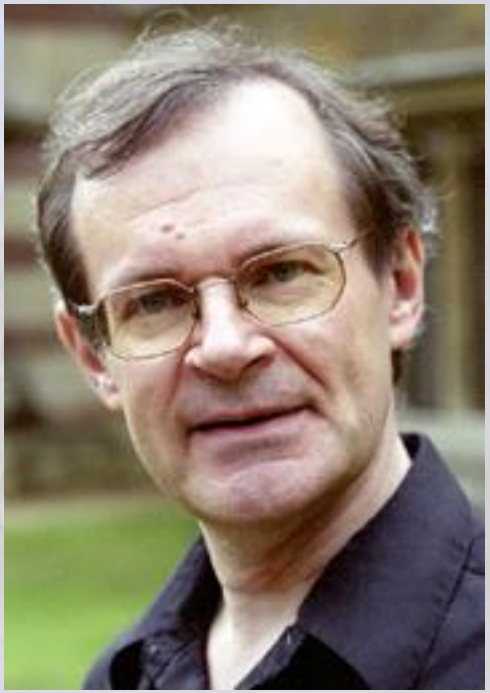
$X10^3$ for ILC
Need new technologies !
(Si pads, GEM, RPC, etc.)

Jet energy resolution ~ ½ of LHC


ILC 500 Political History

Dark Days

- In December 2007,
  - UK ceased funding for ILC
  - US ILC funding was reduced to ¼



Coined as ‘Black December’ by Brian Foster (GDE’s European regional director) in his ‘director’s corner’ of ILC newsline)

Difficult days for ILC followed

JAHEP Report
(Japan Association of High Energy Physicists)

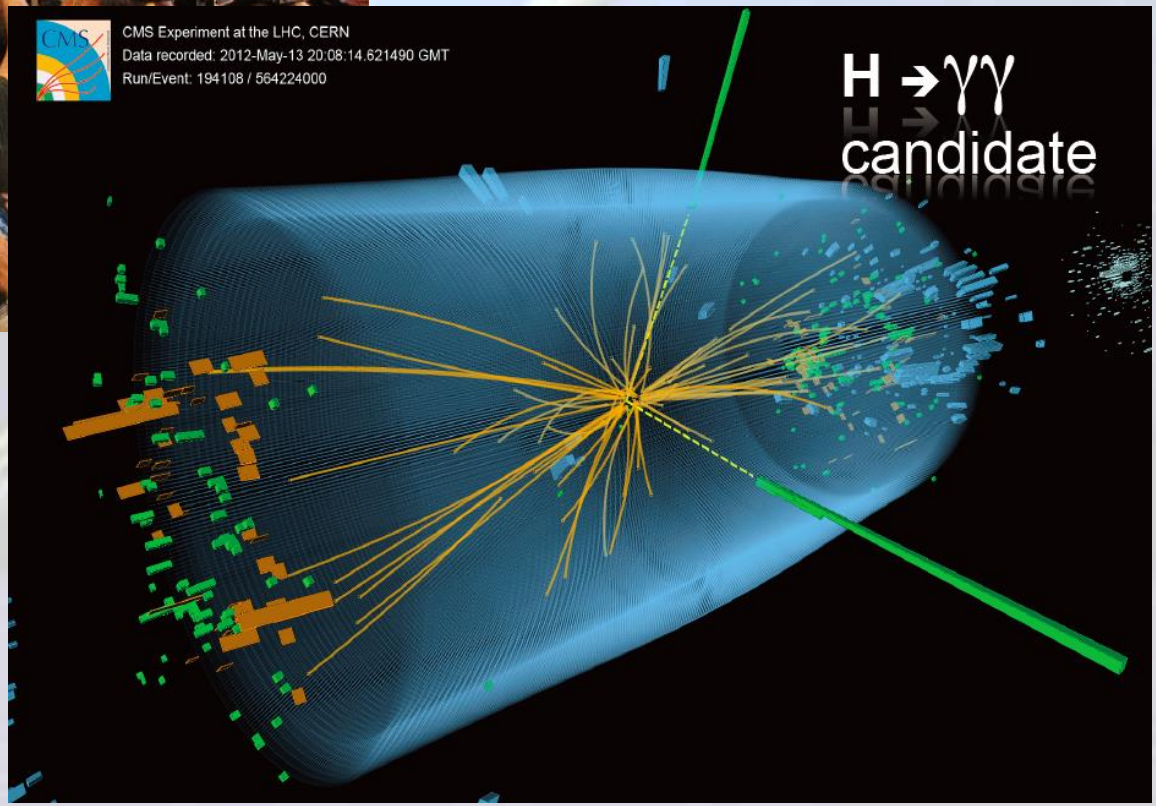
'The Final Report of the Subcommittee on Future Projects of High Energy Physics'
Feb 11, 2012

(at the top of its recommendations)

- Should a new particle such as a Higgs boson with a mass below approximately 1 TeV be confirmed at LHC, Japan should take the leadership role in an early realization of an e+e- linear collider. In particular, if the particle is light, experiments at low collision energy should be started at the earliest possible time. …

Presented at the European Strategy Update Open Symposium at Krakow, September 2012. Received with enthusiasm.

Higgs ‘Discovery’ July 4, 2012



JAHEP Proposal

'A Proposal for a Phased Execution of the ILC Project'
October, 2012

… following the subcommittee's recommendation on ILC, JAHEP proposes that ILC be constructed in Japan as a global project with the agreement of and participation by the international community in the following scenario:

(1) Physics studies shall start with a precision study of the "Higgs Boson", and then evolve into studies of the top quark, "dark matter" particles, and Higgs self couplings, by upgrading the accelerator. A more specific scenario is as follows:

(A) A Higgs factory with a center-of-mass energy of approximately 250 GeV shall be constructed as a first phase.

(B) The machine shall be upgraded in stages up to a center-of-mass energy of ~500 GeV, which is the baseline energy of the overall project.

(C) Technical extendability to a 1 TeV region shall be secured.

(2) A guideline for contributions to the construction costs is that Japan covers 50% of the expenses (construction) of the overall project of a 500 GeV machine. The actual contributions, however, should be left to negotiations among the governments.

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.

To be updated in 2020

Letter to DOE from the Federation of Diet Members for the ILC

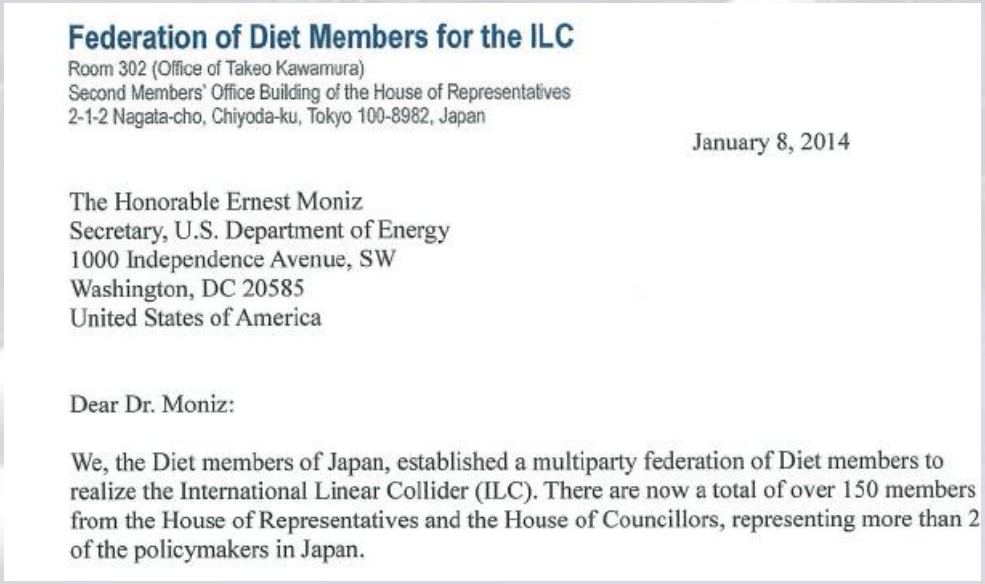
Jan 8, 2014

…

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.

All ex MEXT ministers

Sincerely yours,

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

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

Kenji Kosaka
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 scenario C : '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.'

Scenario A : constant for three years, followed by increases of 2%/year wrt the FY2013 budget. (constrained and pessimistic)

Scenario B : constant for three years, followed by increases of 3/yr wrt the FY2014 President's budget request. (constrained and optimistic)

Scenario C : 'unconstrained'

Still valid now (as of Oct 2018)


ILC 250 Higgs Factory

Proposal for ILC250 Higgs Factory

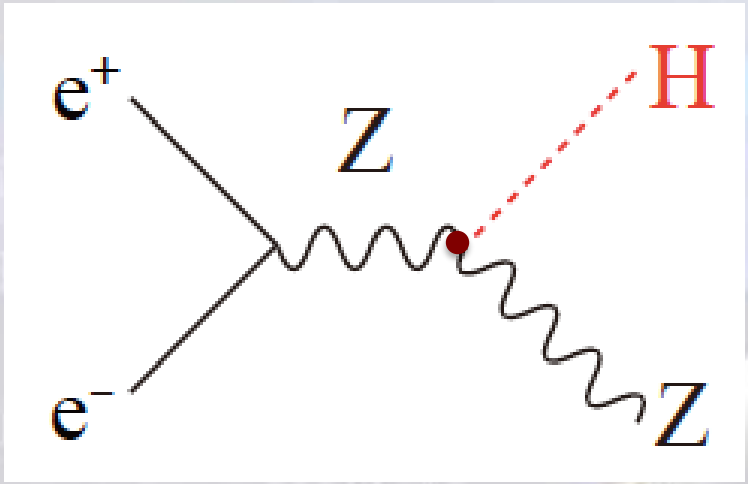
At LCWS2016 Morioka, it was proposed that the first stage at 250 GeV as a Higgs factory is defined as one whole project which should be justified by its own scientific case.

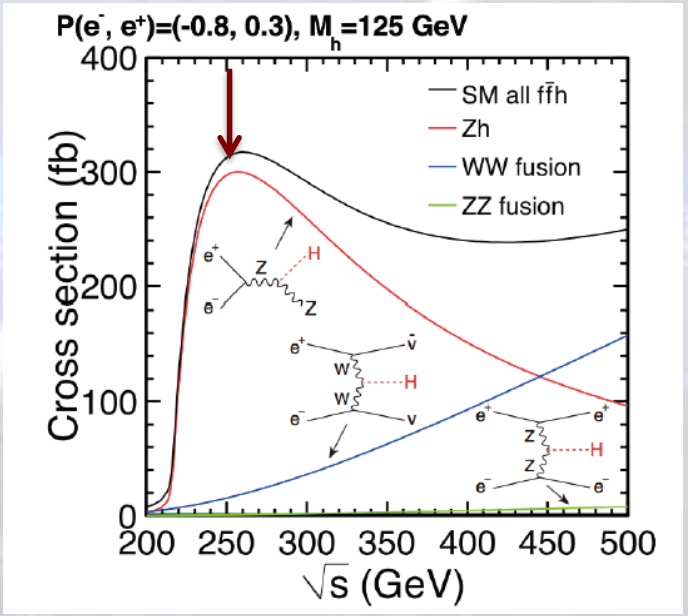
The idea was discussed and a general agreement was obtained.

ILC 250 Higgs Factory

- Optimal energy to produce Higgs in a controlled environment

Higgsstrahlung

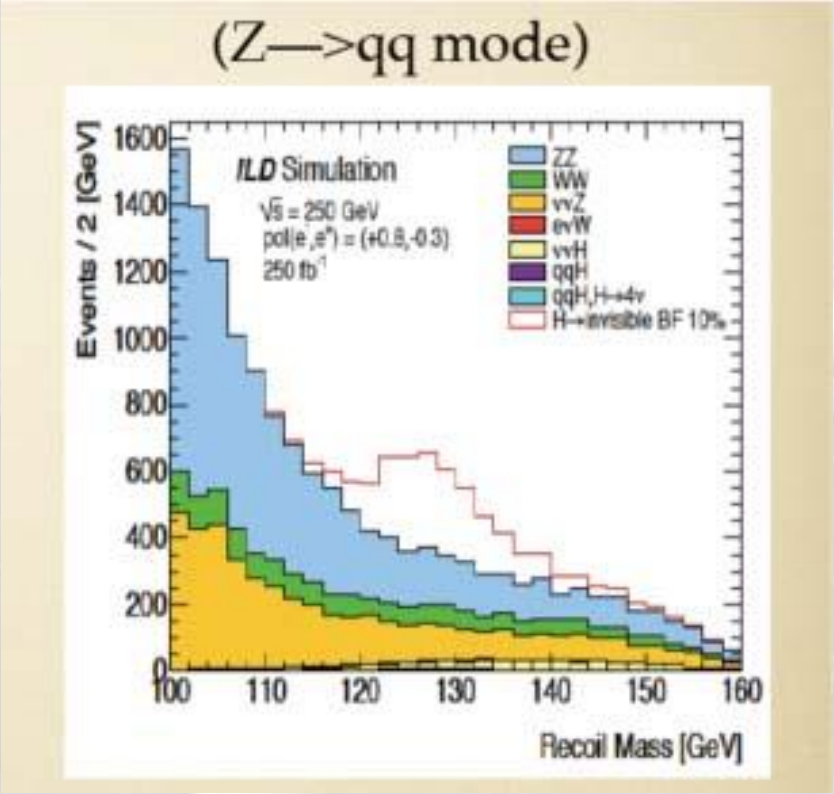




- Precise measurement of HZZ coupling by production
- Recoil mass of Z ≡ Higgs reconstruction
  - No explicit reconstruction of Higgs (Higgs tagging)
  - Powerful for invisible Higgs decays

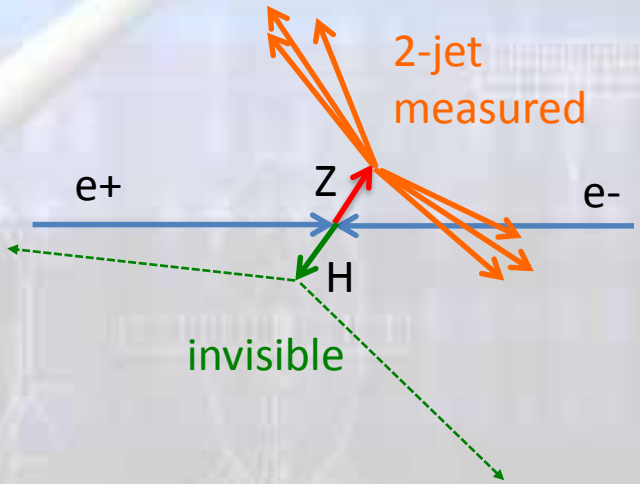
Exotic Higgs Decays by Higgs tagging

e+e- → ZH, H → invisible



250 fb-1 at Ecm = 250 GeV

Recoil mass reconstruction



Including Z → l+l- and scaling to 1500 fb-1

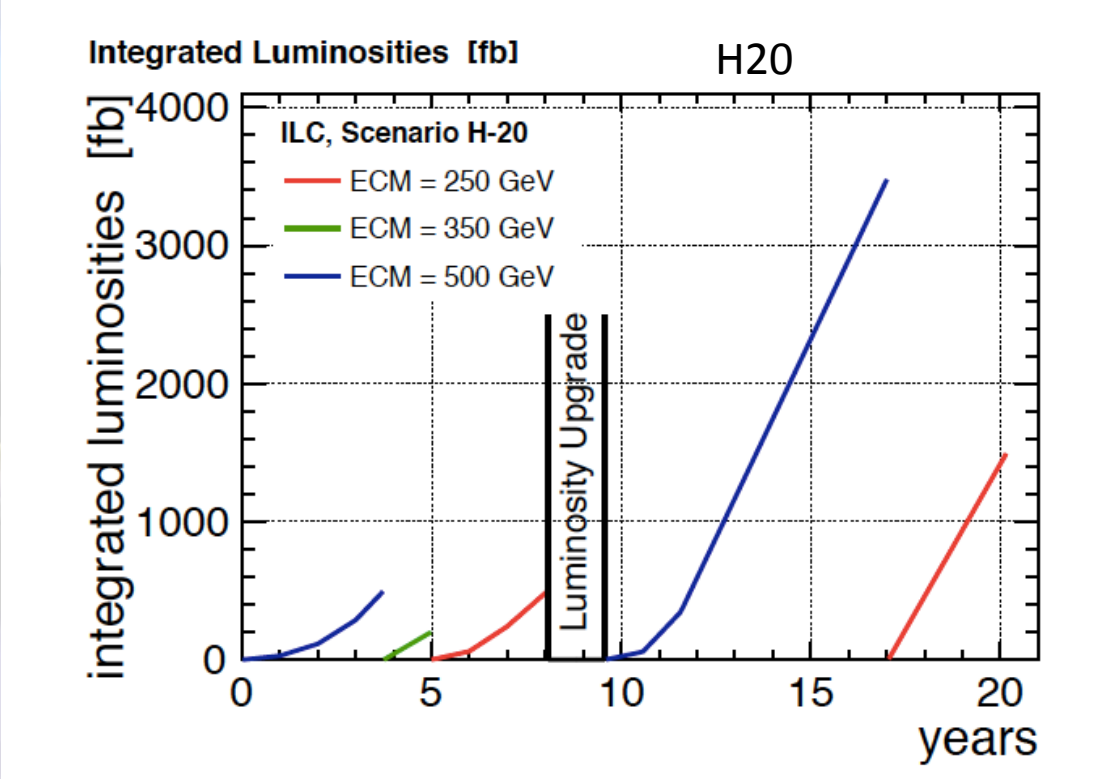
Br (H → invisible) < 0.4%

‘Standard’ Sample ILC500 Running Scenario

- Up to 500 GeV for 20 years total (~25 yrs for LHC)
- Realistic ramp up profile and shutdown time for upgrades

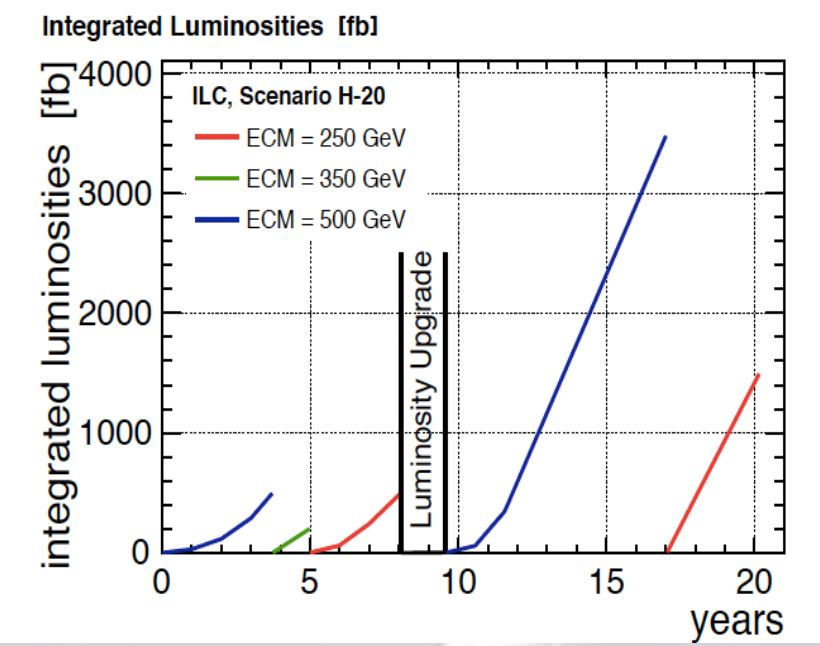
Total
250GeV 1500fb-1
350GeV 200fb-1
500GeV 4000fb-1

Actual running scenario will depend on results from LHC and early phase of ILC, etc.

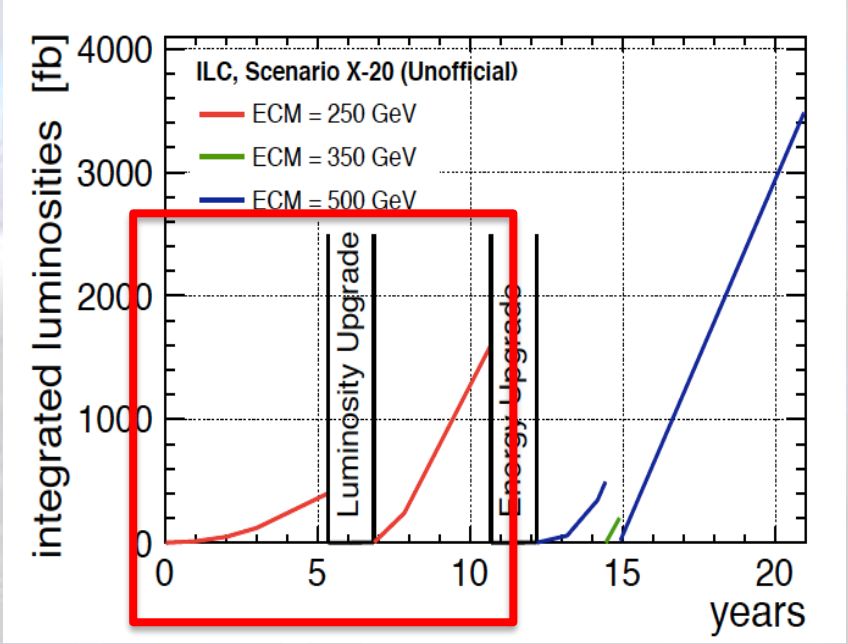


Staging：ILC250 Higgs Factory

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



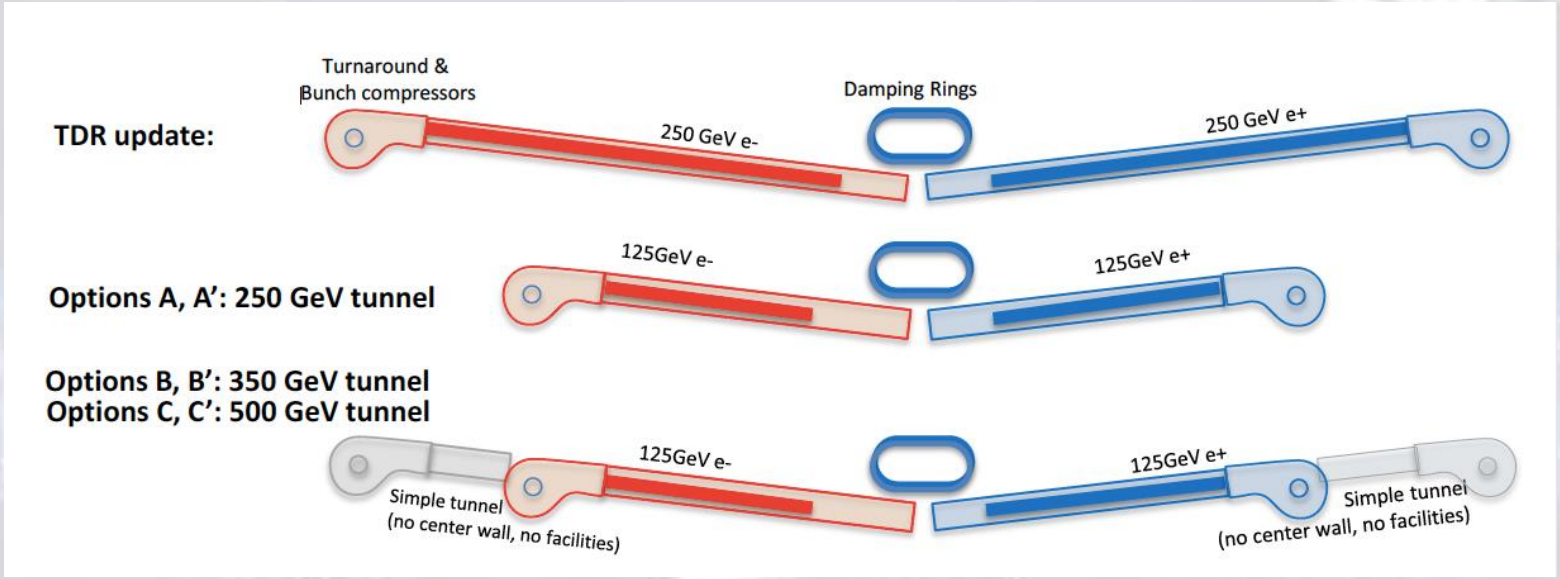
After Dec. 2016
Generally agreed by ILC community
To be formalized this fall



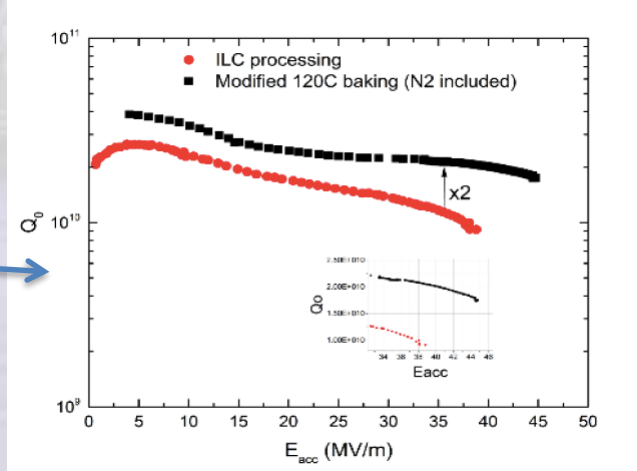
ILC250 Higgs Factory

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

Staging Options



Improvement by N2 doping



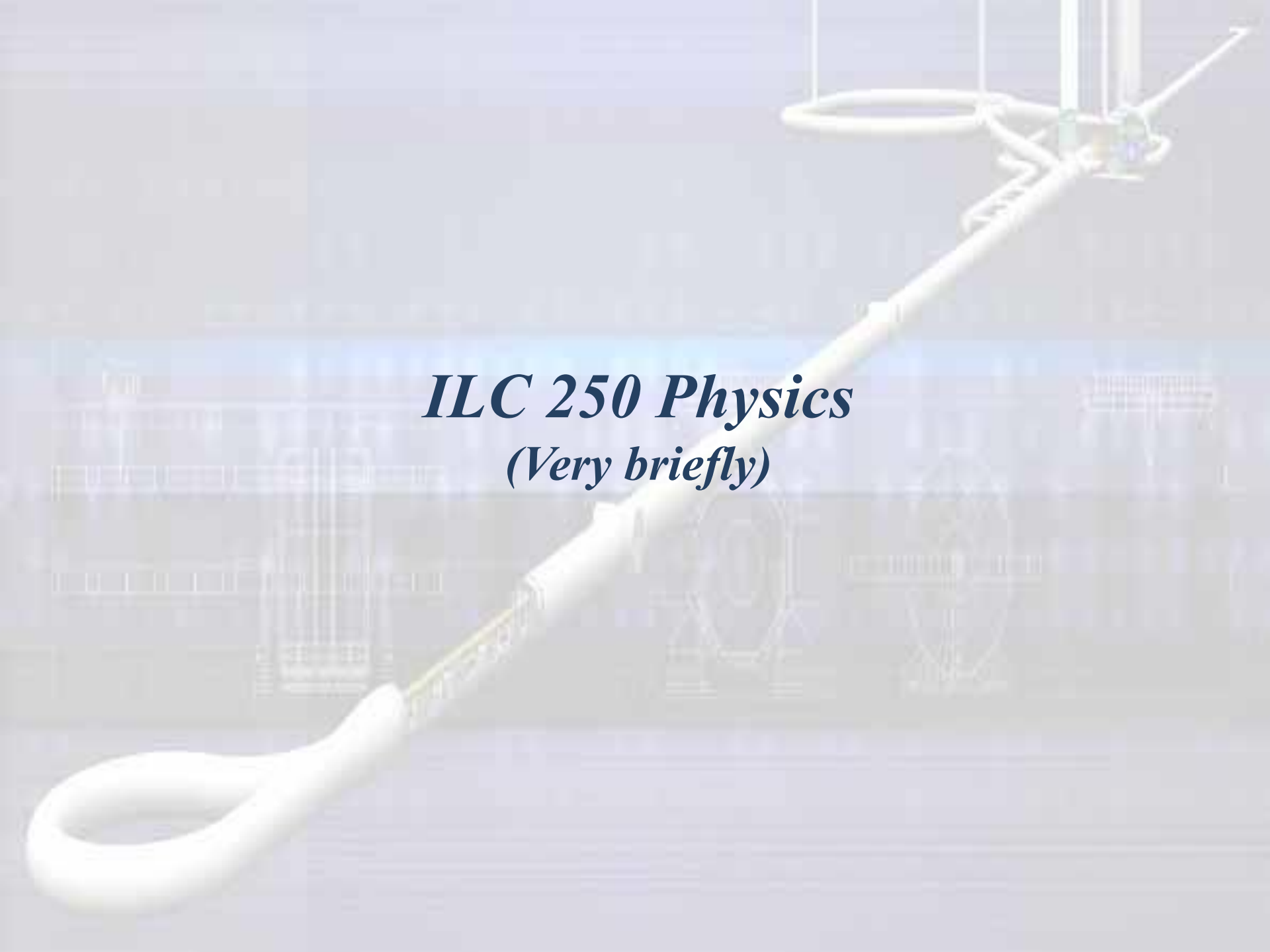
Options A, B, C : Assume 31.5 MV/m (TDR)
Options A', B', C' : Assume 35 MV/m
Now realistic, e.g.

Cost Reduction
ILC500（TDR）→ ILC250

Table 6-1: Summary of the staging cost

	e+/e- collision [GeV]	Tunnel Space for [GeV]	Value Total (MILCU)	Reduction [%]
TDR	250/250	500	7,980	0
TDR update	250/250	500	7,950	-0.4
Option A	125/125	250	5,260	-34
Option B	125/125	350	5,350	-33
Option C	125/125	500	5,470	-31.5
Option A’	125/125	250	4,780	-40
Option B’	125/125	350	4,870	-39
Option C’	125/125	500	4,990	-37.5

Up to 40% cost reduction compared to ILC500 (TDR)

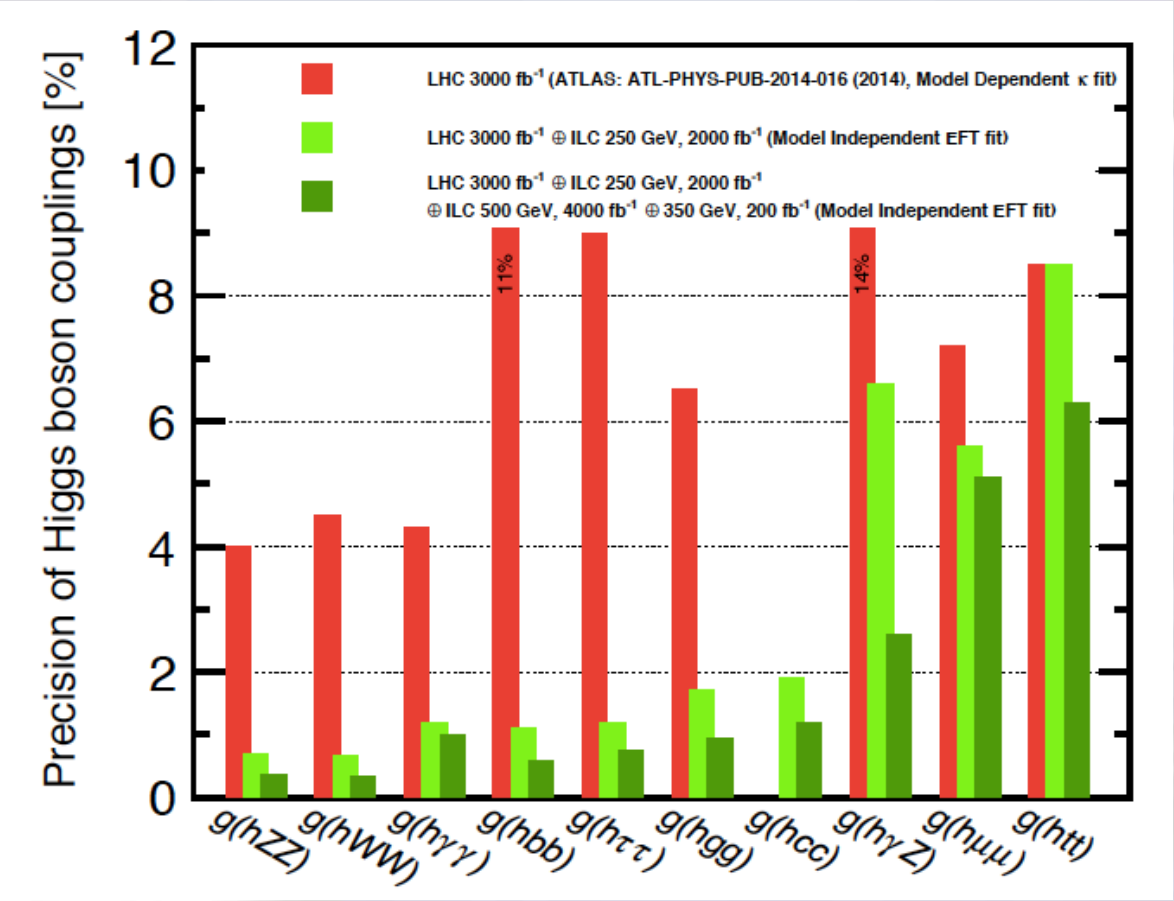


ILC 250 Physics

(Very briefly)

Higgs Coupling Measurement Precisions

EFT approach



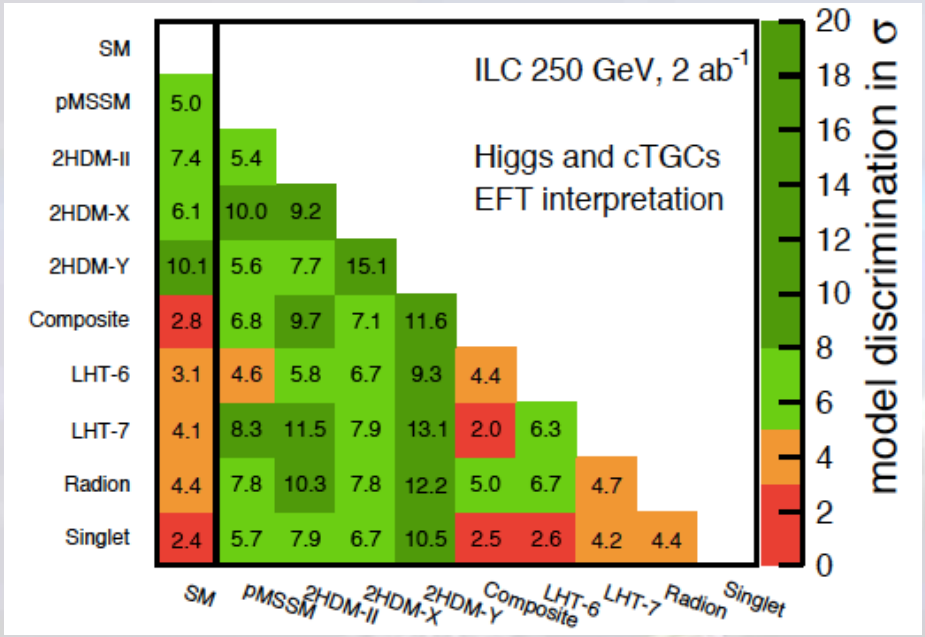
ILC250
2000 fb-1 (~10 yrs)

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

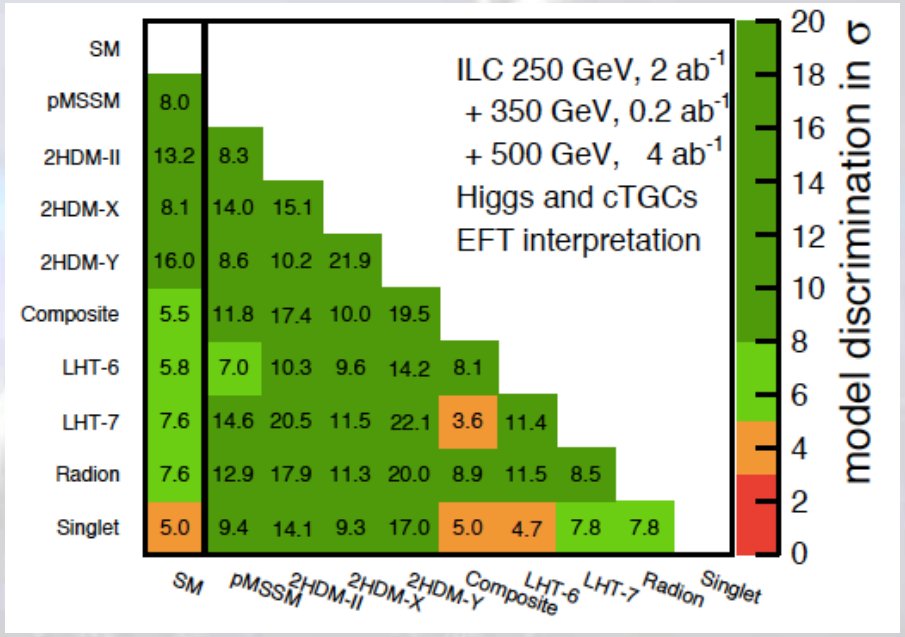
When combined with HL-LHC, ILC 250 (~10 yrs) is nearly as effective as ILC500 (~20 yrs).

Model Discrimination

ILC250



ILC500 (~H20)



Separations among models in #sigma
(9 models unlikely to be rejected by HL-LHC)

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)

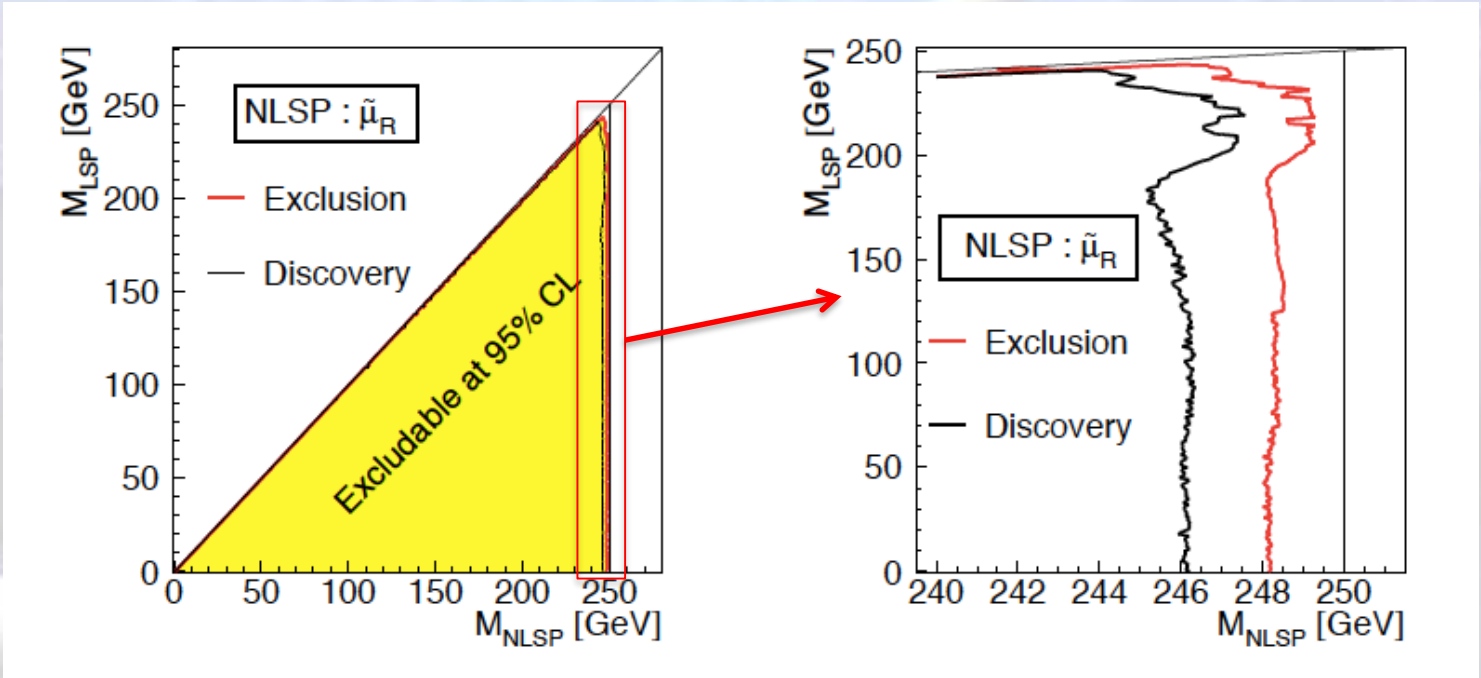
NLSP Pair Production

'Smuon' pair prodution

$$e^+e^- \to \tilde{\mu}^+\tilde{\mu}^- \quad \tilde{\mu} \to \mu\chi$$

Signal: soft muon pair

M. Berggren



Sensitivity nearly up to the kinematic limit

Possibility to find a new particle at ILC 250

ILC 250 Political Status

Scientific Significance of ILC and Proposal of its Early Realization in light of the Outcomes of LHC Run 2

Japan Association of High Energy Physicists, July 22, 2017

- …As discussed above, the scientific significance and importance of ILC has been further clarified 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 22nd 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.

MEXT ILC Advisory Panel on ILC250

Established in May 2014. 'Re-activated' to evaluate the ILC 250 GeV 'Higgs factory'.

'Re-activated' two working groups:

- Particle and nuclear physics working group
  - evaluate the scientific case for ILC250
  - First mtg: Jan 18, 2018
- TDR working group
  - evaluate design maturity and costing
  - First mtg: Jan 30

The ILC advisory panel has produced its final report on July 4, 2018.

MEXT ILC Advisory Panel on ILC250: Report

Final Report: July 4, 2018

On Scientific Merits

Based on the lack of new physics found at LHC,

. . .

'The strongest advantage of experiments at the 250 GeV ILC is their capability to precisely measure the couplings of the Higgs boson. If any coupling(s) is measured to be different from the Standard Model prediction, a particle-by-particle pattern of the deviation will elucidate the nature of new physics, suggesting a future direction of elementary particle physics. Mysteries in the Standard-Model such as the nature of dark matter and compositeness of the Higgs boson may also be clarified with this measurement.'

. . .

It also stated that going from 500 GeV to 250 GeV reduced the chance to find new particles and precluded precision top physics.

Also commented on cost estimation, technical feasibility, human resources, organization/management, and international cooperation.

Science Council of Japan (SCJ)

Committee on the Revised ILC

- Five years ago, the SCJ committee on ILC issued a report:

… 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.

… Upon completion of the above investigations, SCJ is prepared to contribute to the government's decision by presenting scientific and academic perspectives.

Now that MEXT experts' committee finished its report

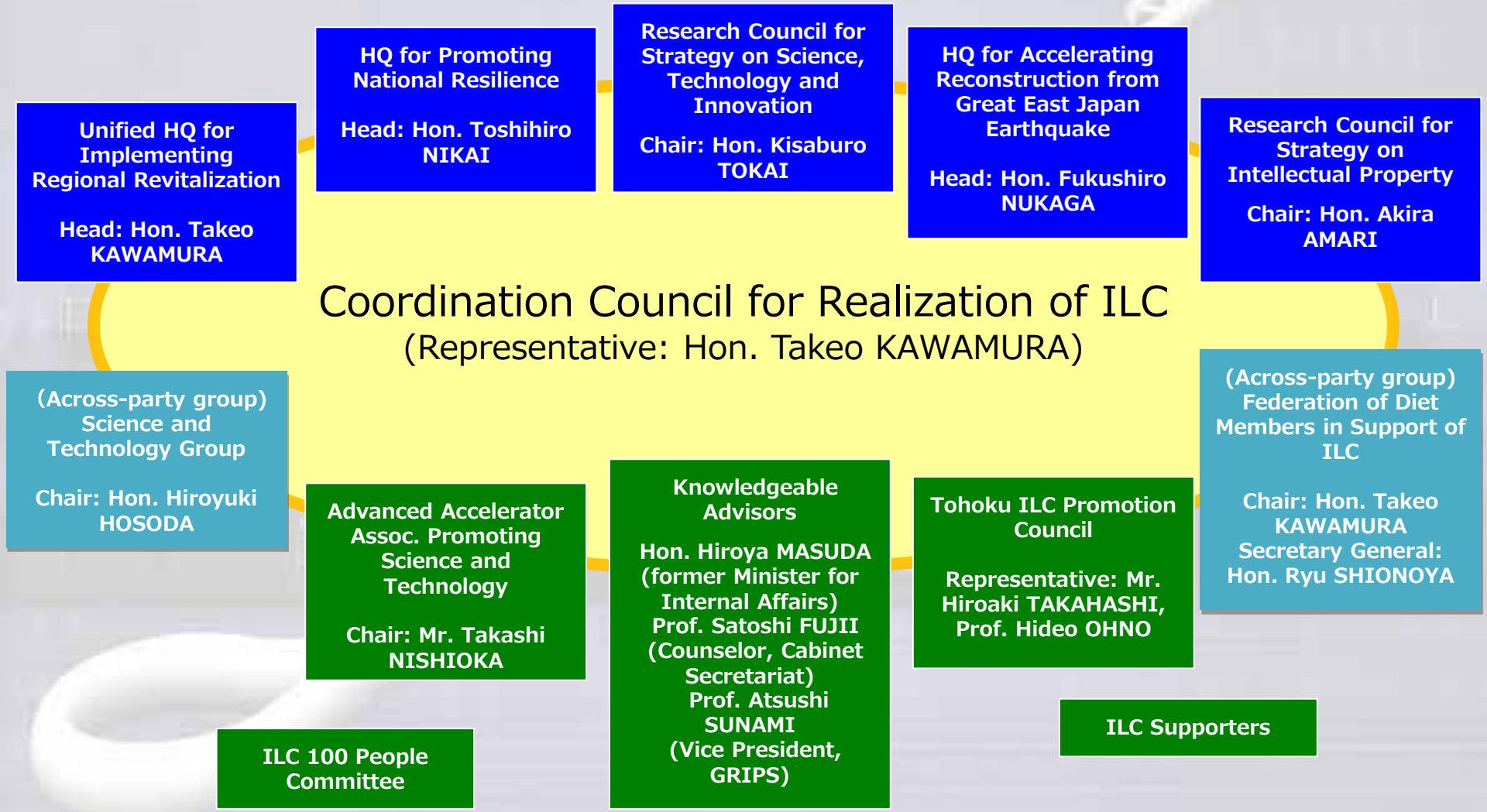
- SCJ committee was re-Established on Jul 26, 2018
  - Final Report by ~ end of 2018
  - European Strategy sets the deadline

Ruling Party（LDP）'s Coodination Council for Realization of ILC

- Established Sep 18,2018
  - Goal: realize ILC as a national project addressing cross-policy issues
  - Takeo Kawamura (chair)
  - + Chairs of committees related to science and technologies, desaster recovery.
    - Toshihiro Nikai (chair: national resiliency)
    - Akira Amari (chair: intellectual Property)
    - + …
  - + Industry organizations
    - Advanced Acceerator Assoc.
    - Tohoku ILC promotion council
  - + 'experts'
    - Hiroya Masuda
    - Satoshi Fujii
    - + …

LDP Leadership

Coodination Council for Realization of ILC



Resolution by the Coodination Council for Realization of ILC

September 18, 2018

(unofficial trasnlation)

We, requesting that ILC be realized as a national project, thereby propose as follows:

1. To position ILC as a cross-policy ”national project", covering not only science, technology and innovation but also many challenges faced by the national government;

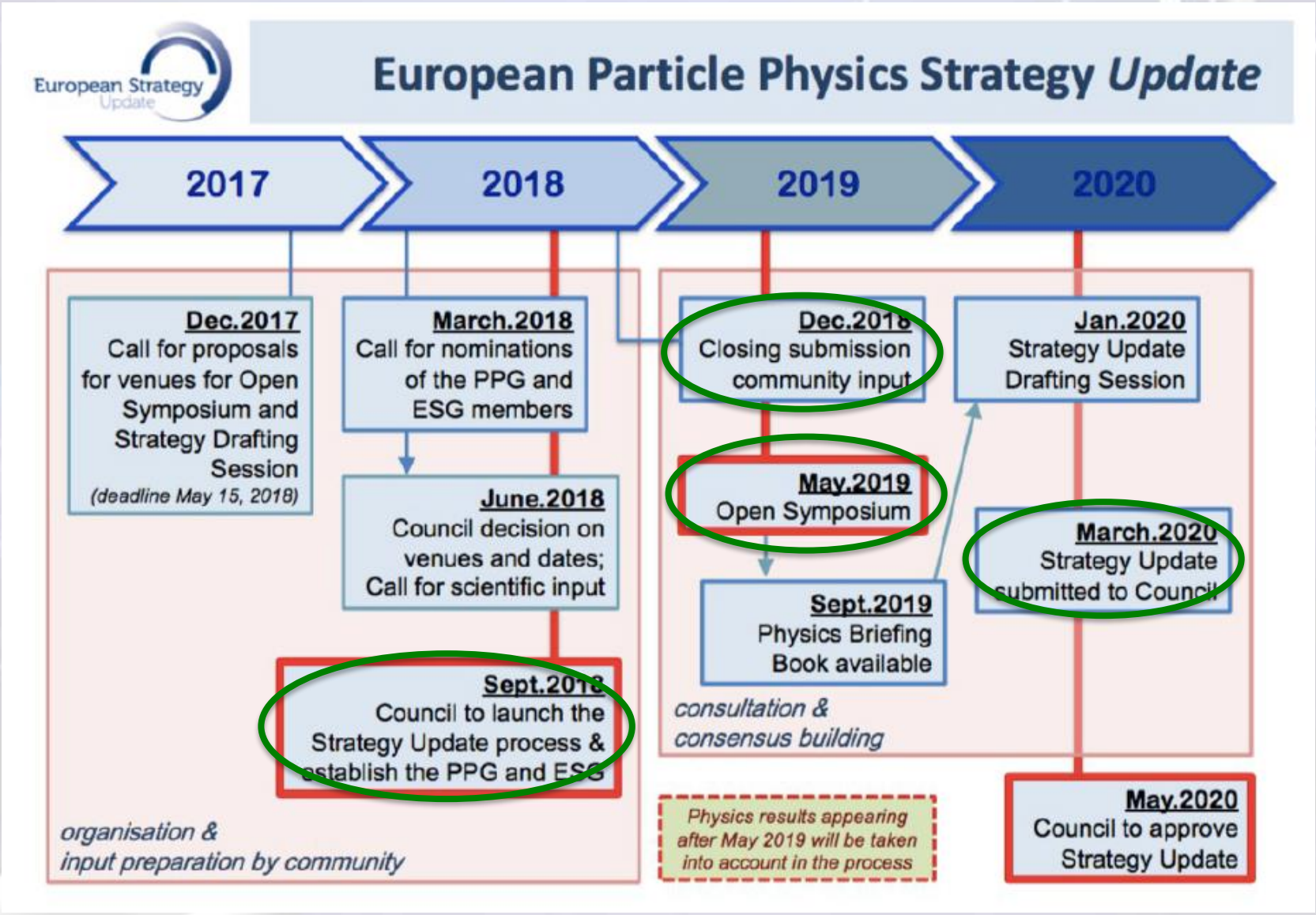
2. To secure the financial resources for the realization of ILC (beyond the Olympic Games) outside of the ordinary science and technology, academic or university budgets; and in addition,

3. To make sure that, as for the international agreement of ILC, certain critical decisions (CD’s), such as the share of investments from overseas be roughly half, be satisfied before the international agreement necessary for the start of construction of ILC is reached.

European Particle Physics Strategy Update (EPPSU 2020)

- 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 started 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.

It is critical that ILC be on the agenda!



Japanese government's positive 'expression of interest' is critical for ILC to be included in this process.

LCWS2017 Strasburg

Remote speeches by Japanese diet members (Oct 27)

Speeches were to be in person, but the general election made them remote.

Rep. Kawamura and Rep. Shionoya : from Tokyo

Rep. Hirano : from Tohoku U.

Strassburg: Rep. Olivier Becht (France), Rep. Stefan Kauffman (Germany)

LCWS2017 Strasburg

Mr. Becht (France):

…I was talking on Wednesday with my colleagues in the French parliament – colleagues from the French-Japan friendship group in the assembly national, and I am very happy to tell you that we consider this cooperation as a major subject of interest for two countries and for Europe-Japan relationship. …

Mr. Kaufman (Germany):

… And everybody here is convinced that the money for the ILC is a very good investment, to understand fundamental principles of physics which can help us to make the world better….

…I think the planned ILC is shortly named in the ESFRI roadmap as you know, but more important will be the new strategy which will be soundly established in 2019, 20, wherein Europe, therefore Germany, will state their concrete position to ILC and also possibility of cooperation and support. …

European Strategy Update

Japanese Delegation to Europe

- Jan. 8 - 11, 2018: Paris and Berlin
- 18 from Japan

  Diet members: Reps Shionoya, Ito, Otsuka +
  Administration: Itakura (MEXT vice mnister) +
  Industry: Nishioka (AAA chiar) +
  Researchers
- Met with

(France)

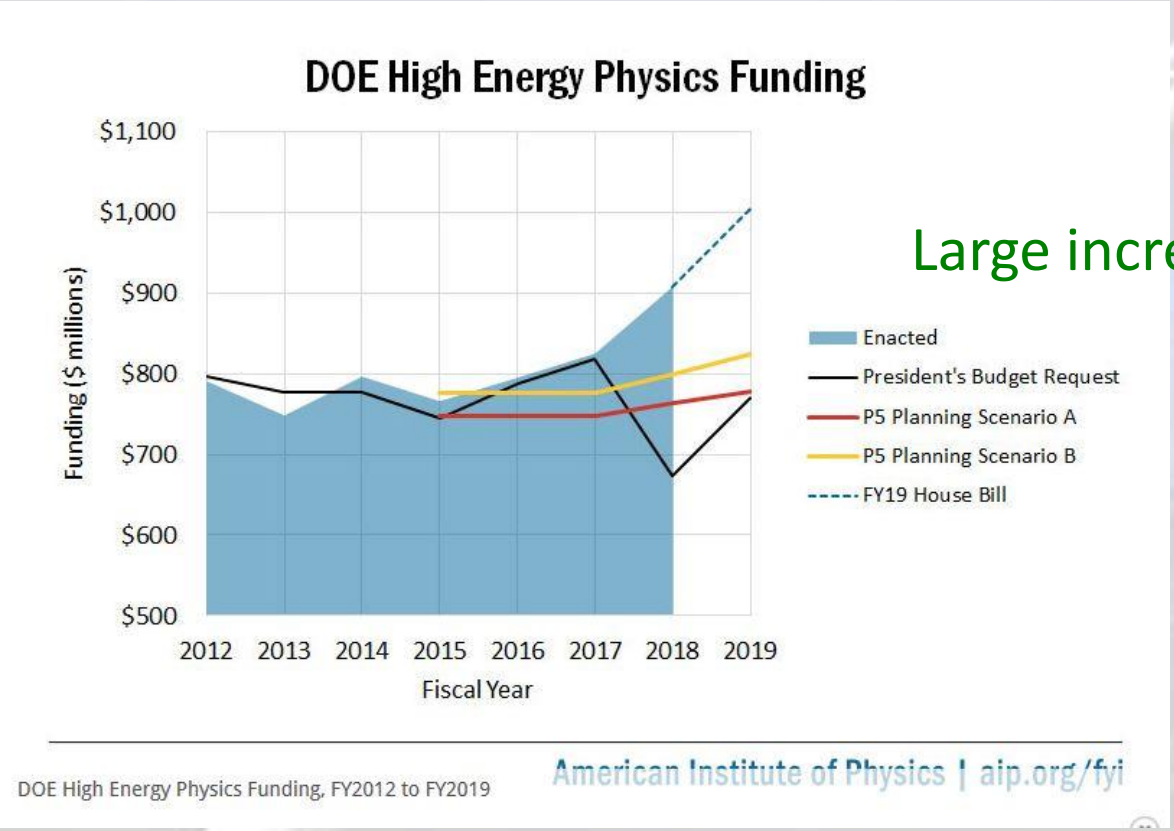
Olivier Becht (France national assembly, Council of Europe vice chair for France)
Silvain Waserman (Vice chair of French national assembly)
Georg Shutte (Undersecretary of ministry of education and research)

(Germany)

Stefan Kauffman (German Bundestag, committee on education,technology..)
Alain Beretz (Head of MESRI research and innovation office)

Established the contact points for discussions on ILC (resource sharing etc.) at government, parliament, academy, and industry levels.
Reps Becht and Kauffman: separate visits to Japan (past and future)
Ready to initiate official negotiations once a 'green sign' comes from Japan.

US HEP Budget



Large increase!

- 2018 DOE HEP budget: $908M
- 2019 projected: $1B (somewhere between scenarios B and C)

DOE is now eager to contribute to the ILC (Office of HEP)

Outreach

- ‘ILC supporters’（Apr 16, 2018 ~）
  - Promoter: Mamoru Oshii
    ‘First and last activity for the society for me’
  - Members: 20000 and increasing

- ‘Committee of 100 for iLC’（June 29, 2018~）
  - Chair: Hiroya Masuda (ex Minister of Internal Affairs)
  - 129 influential opinion leaders
    Kengo Kuma (architect), Robert Campbell (Japanology) etc.
  - Actively promoting ILC

- Lectures, seminars, classes…
  - Countless
  - But still not enough for outside Iwate prefecture (ILC site)

Search Frequency Rating: ‘ILC’

Outreach

Japan Visits by Two Nobel Laureates for ILC

- Barry Barish
  - Nobel: Gravitational Wave Detection
  - ILC GDE director 2005-2013, finish ILC TDR
- Sheldon Glashow
  - Nobel: One of fathers of SM

- Aug 5,6,7,2018
  - 5th: Symposium (Ocha-dai)
  - 6th: Individual media interviews
  - 7th: Visit Minister of Science and Tech. Press Conference (FCCJ)

Barry Barish: answering a questions at FCCJ

'ILC cost per researcher is about the same as other average facilities: ½ salary, ½ equipments'

WE NEED THE ILC NOW!

Sheldon Lee Glashow
Metcalf Professor of Science & Mathematics
Boston University, Emeritus
Higgins Professor of Physics, Harvard University, Emeritus
Honorary Einstein Professor of the Sciences,
Academy Sinica, Beijing

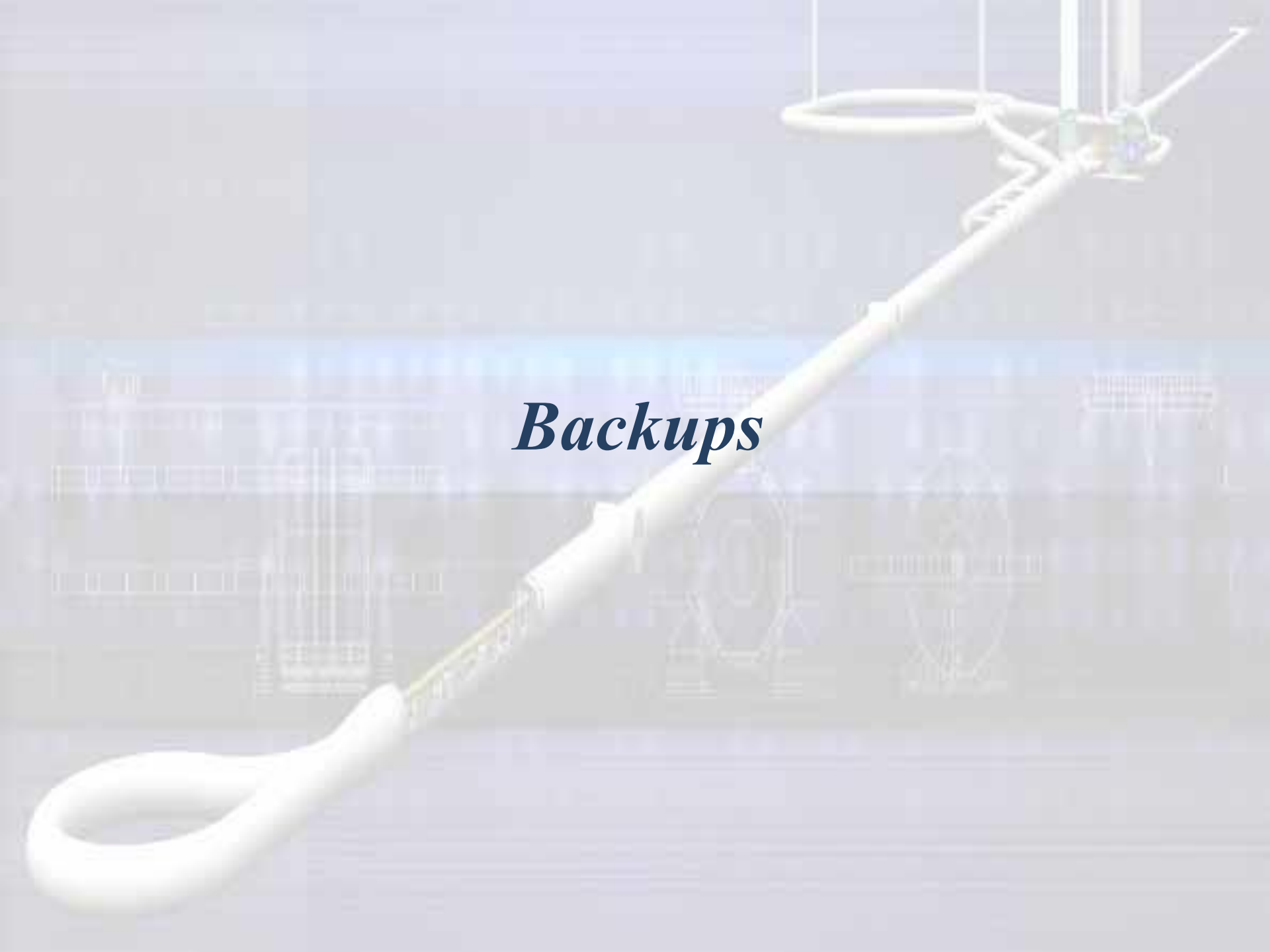
5 August, 2018

At my own initiative, I have traveled over 10,000 km solely to attend these meetings, with the hope that the Science Council of Japan promptly issue a positive assessment of the ILC, whose construction is essential to the Global Scientific Endeavor.

ILC Symposium, Tokyo

Main Points

- ILC has been designed to lead the new era of particle physics opened up by the discovery of Higgs.
- ILC250 Higgs Factory reduces the cost by up to 40%.
- For precision Higgs measurements, ILC ~ several tens of HL-LHC running simultaneously.
- New particles: at LHC, ~1 million Higgs were produced and then discovered. At ILC, a handful will do.
- Japanese government is about to finish evaluating the case for ILC (ILC 250 Higgs Factory).
- The ruling party is ‘ready to go’.
- The deadline for inputs to the European Strategy Discussion is the end of this year – important that a positive statement comes from Japanese government in that time scale.


Backups

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.
  - Interactions not in SM included

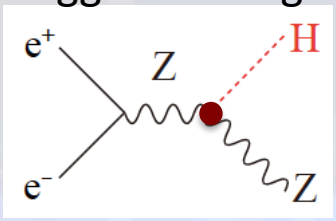
$$\delta\mathcal{L} = \frac{m_Z^2}{v}(1+\eta_Z)hZ_\mu Z^\mu + \zeta_Z \frac{1}{v} hZ_{\mu\nu}Z^{\mu\nu}$$

Not in SM

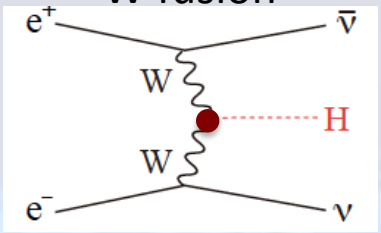
Notes on κ Framework

- For κ_Z and κ_W , production rates give high precision

Higgsstrahlung



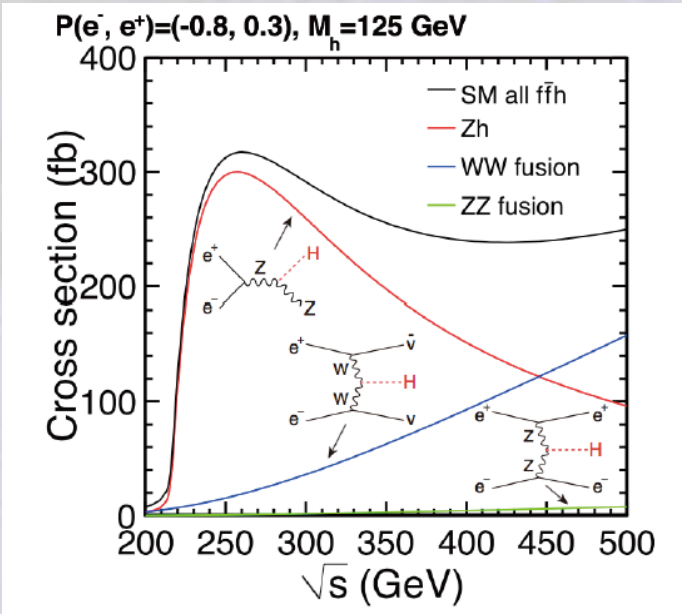
W fusion



- 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

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

(Before EW symmetry breaking)

- 20-parameter fit (up to dim-6 SU(2)xU(1))
- 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})

Model Discrimination

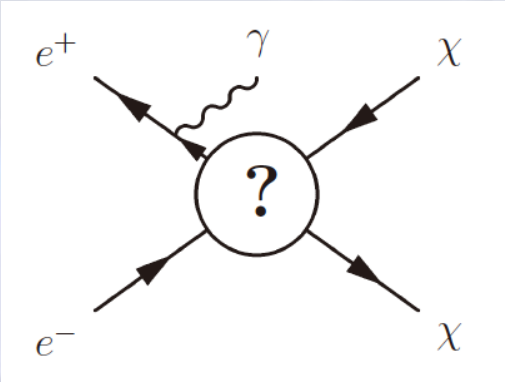
- Pick models that are not likely to be discovered at HL-LHC

	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

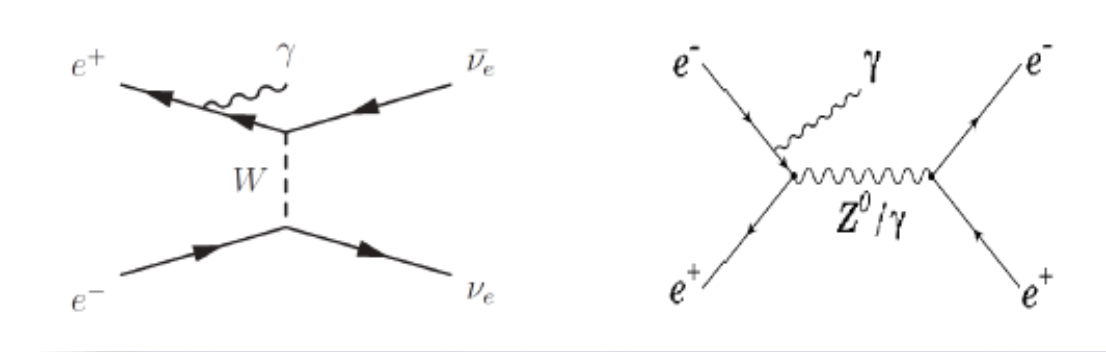
Models and deviations from SM for Higgs couplings (%)

Dark Matter Search

Mono photon events ($e^+e^- \rightarrow \chi\chi\gamma$)



Main background processes

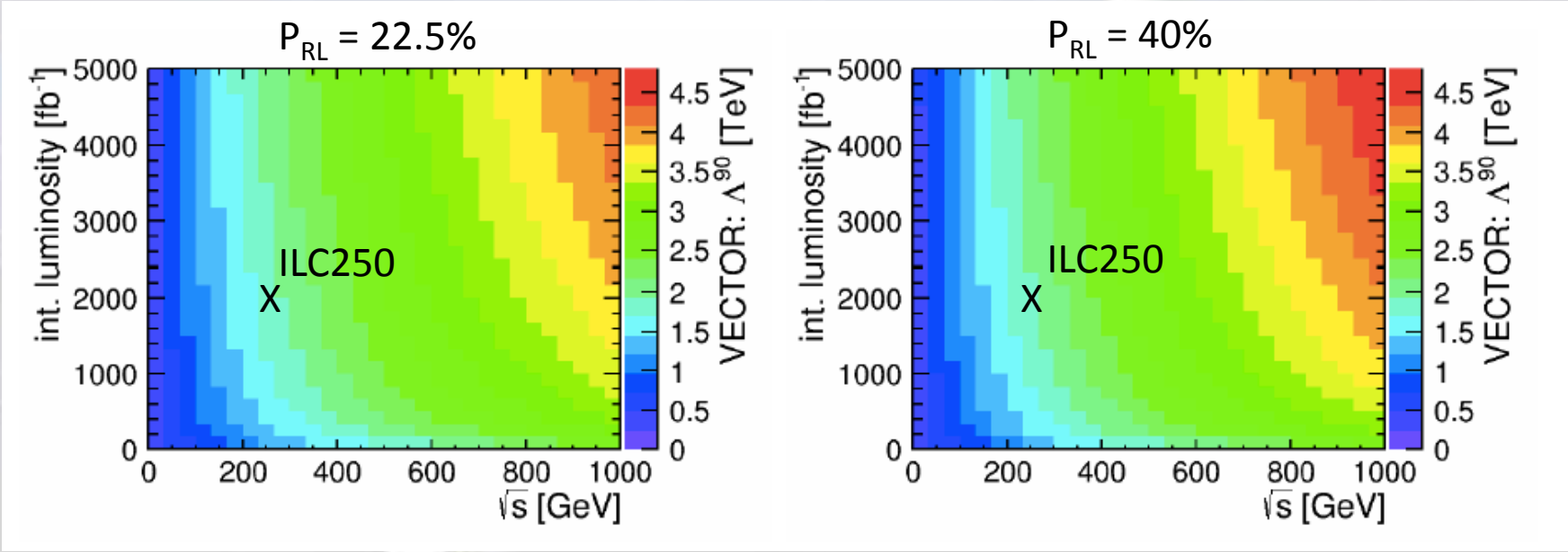


Radiative neutrino pair

Radiative Bhabha
(T channel large: forward e+e-)

Mono photon events (e+e- → $\chi\chi\gamma$)

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



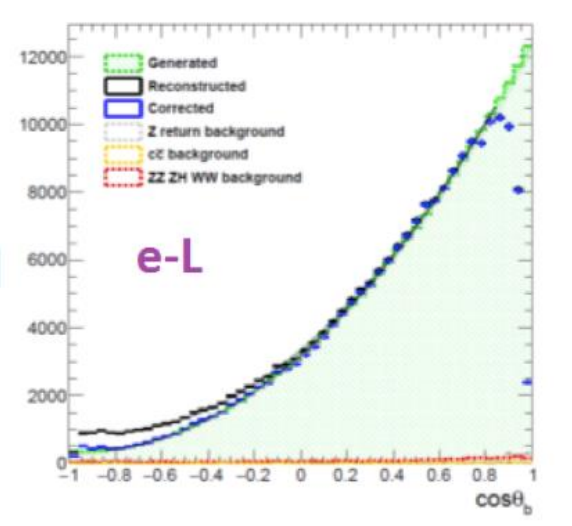
K. Fujii et al

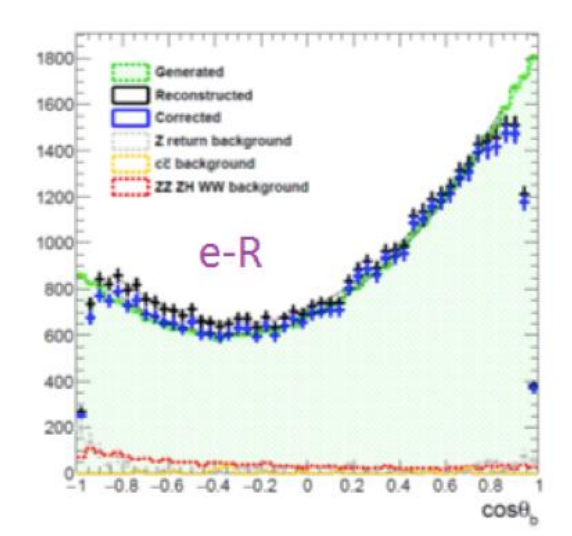
P_{RL}: fraction of data with e-(R) and e+(L)
Λ: energy scale of BSM (= $M_{mediator}(gf\, g\chi)^{-1/2}$)

ILC250 has sensitivities ~ 2 TeV

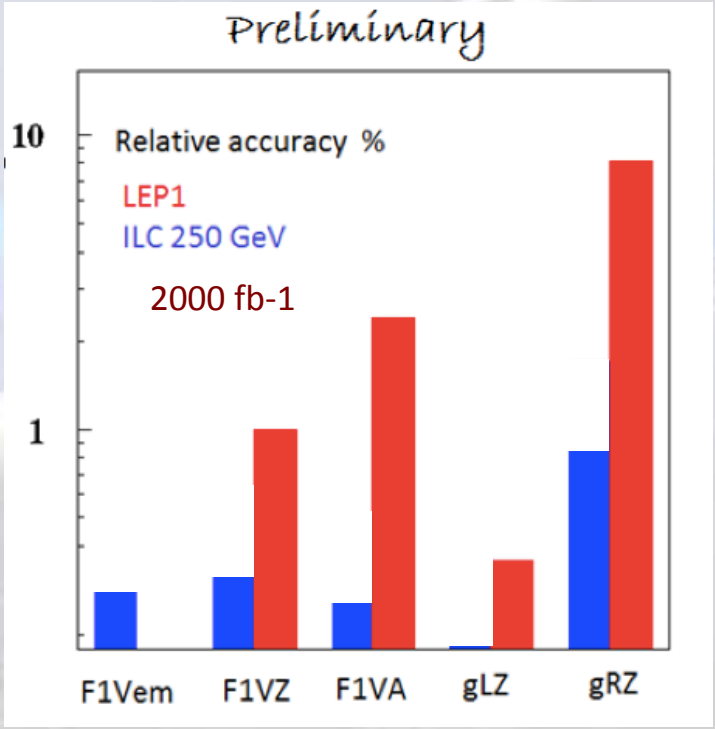
Indirect Probes: ee→bb

ILC250 does not cover top threshold, but…





Form Factor Study



Substantial improvements over LEP1

These errors will be reduced by ~1/2 for ILC250 (2000 fb-1)

Study on-going (→ EFT)

Poeschl et al.