International Linear Collider in Japan

20st July 2013
EPSHEP 2013
Stockholm, Sweden

Department of Physics, School of Science and ICEPP, the University of Tokyo
Chair: High Energy Physics Committee of Japan
Sachio Komamiya
International Linear Collider  ILC

The next major accelerator project driven by truly international efforts
Superconducting linear accelerator of ~30km length will be constructed underground
Colliding electrons and positrons face-to-face to study the universe of $10^{-12}$ second after its creation.
Specially, detailed properties of the Higgs boson, top quark, dark matter particle, … will be studied.
Advantage of linear collider
(1) No energy loss due to synchrotron radiation
(2) Extendability (length ⇒ energy )
Challenging technology of ILC

(1) Very high acceleration gradient with super-conducting linac
   ⇒ shorter length ⇒ low construction cost
   super-conducting ⇒ low running cost

(2) Face-to-face collision of very narrow (flat) beams
   ⇒ increase interaction probability ⇒ lower running cost

Both technologies are established as shown in TDR.
Very Brief History of the Linear Collider Project

1980s  LC Accel. R&D was started at DESY, KEK, SLAC
1991  First Linear Collider Workshop (Finland )
1990s  Five major accelerator technologies were under hard competition:
        TESLA , S-band, C-band, X-band, CLIC
1998  Physics and detector issues are rather accelerator independent
        World-wide-studies of physics and detector for LCs was formed (grass-roots-organization)
2002  ICFA created ILC Steering Committee (ILCSC)
2004  International Technology Recommendation Panel (ITRP) chose super-conducting RF for the main linac technology
International Technology Recommendation Panel Meeting
August 11 ~ 13, 2004. Republic of Korea
2004 KEK DG Yoji Totsuka held first workshop at KEK on LC with Superconducting RF technology

2005 Global Design Effort (GDE) was established

Snowmass Meeting
GDE Director
Barry Barish

2007 Reference Design Report (basic design with cost)

Project Managers
Regional Directors

Marc Ross  Nick Walker  Akira Yamamoto  Michael Harrison  Bryan Foster  Kaoru Yokoya

2009 LOI for detector concepts (ILD, SiD)
Research Director  Sakue Yamada
Recent Activities

2012 March  Recommendation of subcommittee for future projects of Japanese HEP (chair: Toshinori Mori)

May  ILC strategy council (chair:Satoru Yamashita)
     Site selection committee was formed under this council (cochair: K. Kawagoe, H.Yamamoto)

July  **Higgs Boson was discovered at LHC**

Oct.  A Proposal for a Phased Execution of the International Linear Collider Project
      (The Japan Association of High Energy Physicists)


2013 Feb.  ICFA creates Linear Collider Board (LCB) and Linear Collider Collaboration (LCC ) (Director: Lyn Evans)
A Proposal for a Phased Execution of the International Linear Collider Project

The Japan Association of High Energy Physicists (JAHEP) endorsed the document on 18 October 2012.

ILC shall be constructed in Japan as a global project based on agreement and participation by the international community.

Physics: Precision study of “Higgs Boson”, top quark, “dark matter” particles, and Higgs self-couplings,

Scenario: Start with a Higgs Boson Factory ~250 GeV. Upgraded in stages up to a center-of-mass energy of ~500 GeV, which is the baseline energy of the overall project. Technical extendability to a 1 TeV region shall be secured.

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.
European Strategy
Chair: Tatsuya Nakada (Swiss Federal Institute of Technology Lausanne)

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 Technical Design Report of the International Linear Collider (ILC) has been completed, with large European participation. 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.

Obviously the highest priority is for Europe is LHC and LHC Luminosity upgrade. ILC should not interfere with the LHC upgrade (the timing and the budget)
US Participation in Japanese Hosted ILC

• Science drives the need for e^+e^- collider
  – ILC addresses absolutely central physics questions and is complementary to the LHC
  – Japanese hosted ILC could be under construction before 2024

• Parameters of a potential US contribution are not known and depend on international agreements
  – The US has made substantial contributions to detector and accelerator development through the global effort
  – Should an agreement be reached, the US particle physics community would be eager to participate in both the accelerator and detector construction
31st July 2008 established a suprapartisan ILC supporters

(July 2008〜)
President Kaoru Yosano
Deputy Yukio Hatoyama
Secretary-General Takeo Kawamura
Director Norihisa Tamura

Renewed on 1st Feb 2013 lead by Takeo Kawamura

Advanced Accelerator Association of Japan (AAA)

June 2008 established an industry-academy collaboration

Industry: >90 companies (Mitsubishi HI, Toshiba, Hitachi, Mitsubishi Electric, Kyoto Ceramic et al.) Academy: 38 institutes (KEK, Tokyo, Kyoto, Tohoku, Kyushu, RIKEN, JA EA et al.)

AAA homepage http://aaa-sentan.org

Supreme advisor Kaoru Yosano
President Emeritus Masatoshi Koshiba
President Takashi Nishioka (Mitsubishi HI)
Trustee Atsuto Suzuki (KEK)
" Akira Maru (Hitachi)
" Yoshiaki Nakaya (Mitsubishi Electric)
" Yasuji Igarashi (Toshiba)
" Akira Noda (Kyoto University)
" Keijiro Minami (Kyoto ceramic)
Auditor Sachio Komamiya (University of Tokyo)
Lyn Evans visits Prime Minister Abe et al.
Apr 25-27, 2013, Tokyo

- Visited
  - Prime Minister Shinzo Abe
  - Minister of science and technology, Ichita Yamamoto:
  - Takeo Kawamura: chair of the federation of diet members for ILC, former MEXT minister
    With Koshiba, Murayama, Yamashita
  - Hakubun Shimomura: MEXT minister
  - Hiroya Masuda: former minister of interior
  - Kiyohiko Ito: managing director JACE (Japanese Association of Corporative Executives: Industry)
  - etc. etc.
Very Recent Activities

2013 April  ILC Taskforce started in MEXT Japan

2014 May  ECFA LC (DESY, Hamburg)

2013 June  ILC Event  TDR Review is completed  (Tokyo ⇒ Geneva ⇒ Chicago)

2013 June-August  In Science Council of Japan  ILC Review Committee was formed

2013 July  EPS-HEP 2013  (Stockholm, Sweden)

2013 Summer  A site in Japan will be chosen by scientists (MEXT, Politicians all agree to the process)

2013 Nov. 11-15  LCWS2013  The University of Tokyo
The new leaders (TD phase to ED phase)
Linear Collider Directorate = LCD

Michael Harrison
ILC Accelerator

Hitoshi Yamamoto
Physics and Detector

Steinar Stapnes
CLIC Accelerator

Lyn Evans
Director

Hitoshi Murayama
Deputy
The Next Step

• Move from the Technical Design Phase to the Engineering Design Phase towards the real construction of Both Accelerator and Detectors

• Reinforce Public relations as a global project

Work with governments

• Site and host country establishment

• Establish the organization of ILC laboratory refer to the “Project Implementation Plan” of TDR

• International negotiation of the cost share etc.
LHC $H \rightarrow \gamma \gamma$ mass distribution

ILC $\mu^+ \mu^- \text{ recoil mass distribution}$

$\text{Events} / 2 \text{ GeV}$

$\text{Events}$

$\text{Selected diphoton sample}$

$\text{Data 2011+2012}$

$\text{Sig+Bkg Fit (m$_{\gamma \gamma}$=126.8 GeV)}$

$\text{Bkg (4th order polynomial)}$

$\text{ATLAS Preliminary}$

$H \rightarrow \gamma \gamma$

$\text{Events - Fitted bkg}$

$\text{ILC}$

$\text{ZH} \rightarrow \mu^+ \mu^- X$

$\text{Events}$

$\text{Signal+Background}$

$\text{Fitted signal+background}$

$\text{Signal}$

$\text{Fitted background}$

$\text{m}_{\text{recoil}} / \text{GeV}$
Higgs Boson

ILC in the first phase is the Higgs Boson Factory

$O(10^5)$ such events will be collected and studied.

Precise measurement of Higgs Boson
⇒ Deduce Principal Low in the Nature

- Origin of mass
- Structure of the 'vacuum'

$$e^+e^- \rightarrow Z + H \rightarrow e^+e^- + b \bar{b}$$
Importance of Precise Measurement of Higgs Properties
Decoupling Theory     Light Higgs Boson ~ SM Higgs Boson

Just for example: Two Doublet Model (SUSY)     ILC TDR

**Coupling of h = 126GeV Higgs and weak gauge bosons**

\[ V = W, Z \]

\[ g(hVV)/g(hVV)_{SM} = \sin(\beta - \alpha) \]

\[ \sim 1 - 2c^2m_Z^4\cot^2\beta/m_A^4 \]

\[ \sim 1 - 0.3\% (200 \text{ GeV}/m_A)^4 \]

**Coupling of h and SU2(2) \ l_w=1/2 quark**

\[ g(htt)/g(htt)_{SM} = g(hcc)/g(hcc)_{SM} \]

\[ = \cos\alpha/\sin\beta = \sin(\beta - \alpha) + \cot\beta \cos(\beta - \alpha) \]

\[ \sim 1 - 2c \cdot m_Z^2\cot^2\beta/m_A^2 \]

\[ \sim 1 - 1.7\% (200 \text{ GeV}/m_A)^2 \]

Deviations from the Standard Model Higgs couplings are very small even for ILC precise measurements.
Coupling of $h$ and quarks and leptons with $l_w=-1/2$

\[
g(h\bar{b}b) / g(h\bar{b}b)_\text{SM} = g(h\tau\tau) / g(h\tau\tau)_\text{SM} \\
= -\cos\alpha / \cos\beta = \sin(\beta - \alpha) - \tan\beta \cos(\beta - \alpha) \\
\sim 1 + 2c \cdot m_Z^2 / m_A^2 \\
\sim 1 + 40\% (200 \text{ GeV}/m_A)^2
\]

The deviations must be seen at ILC even for $m_A \sim 1000\text{GeV}$.

Very difficult for LHC
Power of electron polarization at ILC

Scalar muon production

Polarized (90% $e^-_R$) vs. data

Background signal
Possibility of Japan to be a host of ILC

Some facts to believe Japan to host ILC, if we work very hard for the next few years.

1) Discovery of Higgs Boson at LHC
2) TDR of ILC project is completed.
3) CERN is expected to work on LHC upgrade
   Support from international community
   Europe, Americas, Asians
4) Supports of Political and Industrial sectors
   • Advanced Accelerator Association of Japan
5) Started site studies with dedicated funding
6) Agreement in the HEP community in Japan
   • Report from subcommittee of future
     HEP projects of Japan (March 2012)
   • Phased Execution of ILC (October 2012)
The Jump-Start Scenario
(Very optimistic but not impossible)

2013 July  Site evaluation by scientists will be completed in Japan
2013 fall  New organization within Japanese government is expected to be formed and in preparation to bid to host the ILC

2014-15  Intergovernmental negotiation
Linear Collider Collaboration (Lyn Evans and ILC sector) continue to refine the design and organization of the global lab for ILC

2015  International Review of the ILC project (LHC physics @13-14 TeV)

2016  Construction starts (accelerator + detectors)
2026  Commissioning of the ILC machine
Scientific Activities

Lepton CP Asymmetry
Power-Upgrade

Beyond Standard Physics

International Linear Collider (ILC)

Quest for Birth-Evolution of Universe

KEK DG keeps showing this ugly slide since 2008

Technology Innovation
Encouraging Human Resources

Quark CP Asymmetry
[Origin of Matter]

[Origin of Force]

Higgs Particle [Origin of Mass]

Quest for Neutrinos

Quest for 6 Quarks

Super-KEKB

J-PARC

LHC

KEK-B

Scientific Activities

Quest for Unifying Matter and Force

International Linear Collider (ILC)

KEK DG keeps showing this ugly slide since 2008
All roads lead to ILC
Until 4th July 2012, for more than 20 years, we keep agitating that a Revolution in the field of particle physics is inevitable.

⇒ Discovery of “Higgs Boson” = The July revolution has started

⇒ This is just a start of an enormous revolutionary era overwhelming the Standard Model = the Ancien Regime.
Higgs Couplings at ILC

Measurement of $\sigma \times BR \rightarrow$ Input to global fit $\rightarrow$ Extract Higgs couplings
Exploit LHC / ILC synergy.  M. Peskin hep-ph 1207.2516

Deviations from SM prediction is expected to be small  O(%) level
COBE 1990
Angular resolution = 10°
Temperature fluctuation \(10^{-5}\)K

WMAP 2003
Angular resolution = 10’
\(\tau(\text{the Universe}) = 13.69 \pm 0.13 \text{ Gyr}\)
Polarization measurement

Planck 2013
\(\tau(\text{the Universe}) = 13.796 \pm 0.058 \text{ Gyr}\)
Complementarity and synergy between hadron and \(e^+e^-\) colliders (based on the experimental facts)

Story of Top Quark and Higgs Boson

From precise electro-weak measurements at LEP, top mass was predicted

Discovery to Top

Precise Measurement of Top mass at the TEVATRON

Higgs mass is restricted into a narrow mass range using precise top mass and LEP/SLC electro-weak data

\[ 114 \text{ GeV} < M_H < 160 \text{ GeV} \]

Discovery of Higgs at LHC

Precise measurements of Higgs properties at ILC
Organization of Linear Collider Projects

ICFA

Program Advisory Committee
Norbert Holtkamp

Linear Collider Board (LCB)
Sachio Komamiya

FALC
Yasuhiro Okada

Regional Directors
Brian Foster
Harry Weerts

Directorate
Lyn Evans

Deputy (Physics)
Hitoshi Murayama

ILC
Mike Harrison

CLIC
Steinar Stapnes

Physics & Detectors
Hitoshi Yamamoto

Linear Collider Collaboration = LCC
Investigation of Higgs boson (scalar particle has the same quantum numbers as for the vacuum) can be the zeroth step to understand inflation of the universe and dark energy.
ILC Detector R&D

- **Vertex Detector:** pixel detectors & low material budget
- **Time Projection Chamber:** high resolution & low material budget, MPGD readout
- **Calorimeters:** high granularity sensors, $5 \times 5 \text{mm}^2$ (ECAL), $3 \times 3 \text{cm}^2$ (HCAL)

<table>
<thead>
<tr>
<th>Sensor Size</th>
<th>ILC</th>
<th>ATLAS</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertex</td>
<td>$5 \times 5 \text{mm}^2$</td>
<td>$400 \times 50 \text{mm}^2$</td>
<td>x800</td>
</tr>
<tr>
<td>Tracker</td>
<td>$1 \times 6 \text{mm}^2$</td>
<td>$13 \text{mm}^2$</td>
<td>x2.2</td>
</tr>
<tr>
<td>ECAL</td>
<td>$5 \times 5 \text{mm}^2$ (Si)</td>
<td>$39 \times 39 \text{mm}^2$</td>
<td>x61</td>
</tr>
</tbody>
</table>

**Particle Flow Algorithm**

- Charged particles $\rightarrow$ Tracker,
- Photons $\rightarrow$ ECAL, Neutral Hadrons $\rightarrow$ HCAL

Separate calorimeter clusters at particle level
$\rightarrow$ use *best* energy measurement for *each* particle.
$\rightarrow$ offers unprecedented *jet energy resolution*

State-of-the-art detectors can be designed for ILC
Higgs Boson mass is responsible for a big branching in the particle physics history. Higgs Boson is a window beyond the Standard Model.

~125 GeV Higgs Boson is categorized as a light Higgs Boson.

Many experimentalists could not trust the existence of the Higgs Boson, since it looks too expedient and artificial.
Limit of High Energy Circular $e^+e^-$ Colliders

Reaction is simple, experiment is clean but…

Electron and positrons loose energy due to synchrotron radiation.

Energy loss per turn $\Delta E$ is given by

$$\Delta E \propto \left(\frac{E}{m}\right)^4 / R$$

- $E$: particle energy
- $m$: particle mass
- $R$: radius

Like a bankruptcy by loan interest

Recover the energy loss and obtain higher collision energy

1. Use heavier particle ($\text{proton mass/electron mass} = 1800$) $\Rightarrow$ LHC
2. Larger radius $\Rightarrow$ $R = \infty$ $\Rightarrow$ Linear collider