The View from Japan
after the discovery of a Higgs Boson

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IOP 2013
University of Liverpool

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The University of Tokyo
Chair: High Energy Physics Committee of Japan    Sachio Komamiya
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 a 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 Boson mass is responsible for a big branching in the particle physics history.

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

Elementary Higgs Boson
Supersymmetry ?
Stabilization of Higgs mass

Composite Higgs Boson
Technicolor etc. ???
(Fermion Monism ?????)

Higgs Boson is a window beyond the Standard Model.
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.
Electron-positron collider

Electron and positrons are point-like elementary particles ⇒ Clean environment. Processes are simple.
Prediction: O(0.1-1%)
State-of-the-art detector can be built

Proton-Proton Collider

Proton is a composite particle ⇒ processes are complicated
NNLO O(10%)
High radiation
High event rate
⇒ need a high-tech detector and powerful computing system
Cross Sections

proton - (anti)proton cross sections

- Tevatron
- LHC

$\sigma_{t\bar{t}}$

- $\sigma_{W}$
- $\sigma_{Z}$

$\sigma_{\mu\mu}(E_{T}^{#mu} > \sqrt{s}/20)$

$\sigma_{j\mu}(E_{T}^{j\mu} > 100 \text{ GeV})$

$\sigma_{t}(E_{T}^{#tau} > 200 \text{ GeV})$

$\sigma_{t}(E_{T}^{#tau} > \sqrt{s}/4)$

$\sigma_{Higgs}(M_{H} = 120 \text{ GeV})$

$\sigma_{Higgs}(M_{H} = 200 \text{ GeV})$

$\sigma_{Higgs}(M_{H} = 500 \text{ GeV})$

$\sigma_{p+p}(L=500 \text{ fb}^{-1})$

$\sigma_{e^+e^-}(L=500 \text{ fb}^{-1})$

$\sigma (fb)$

$\sqrt{s} (\text{GeV})$

$\sum q\bar{q}$

$W^+W^-$

$Z\gamma$

$|\cos\theta| < 0.8$

$|\cos\theta| > 0.8$

$t\bar{t}175 \text{ GeV}$

$500 \times 10^3$

$5 \times 10^3$

$50$

# events for $L=500 \text{ fb}^{-1}$
LHC overlooks new phenomena including Higgs Boson and SUSY
Actual situation would be .......

LHC overlooks new phenomena including Higgs Boson and SUSY
Since LHC physicists are excellent, LHC overlooks new phenomena including Higgs Boson and SUSY.
**Story of Top Quark and Higgs Boson**

**Importance of interplay between hadron and e^+e^- colliders**

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:

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

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**Discovery of “Higgs” at LHC**

Precise measurements of Higgs properties at ILC.
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 ($\text{proton mass/electron mass} = 1800$) ⇒ LHC

(2) Larger radius ⇒ LEP (27km) ⇒ large radius
Electron Positron Linear Collider is inevitable

Large radius $R \Rightarrow$ Ultimate radius $R=\infty$ !

Straight beam line $\Rightarrow$ No synchrotron radiation
(Linear Collider)

Electrons are accelerated from one side positon from the other side. Collide the beams at the center

Reduce construction cost $\Rightarrow$ High acceleration gradient
Reduce running cost (electric power) $\Rightarrow$ Squeeze the beam size as small as possible at the interaction point $\Rightarrow$ round beam is unstable $\Rightarrow$ very flat beam
Tunnel design for Mountain Range site

ILC = International Linear Collider
TDR design of ILC
for Ecm = 500 GeV
Higgs Boson

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

ILC in the first phase is the Higgs Boson Factory

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

Origin of mass $\rightarrow$ Structure of the ‘vacuum’

$e^+e^- \rightarrow Z + H \rightarrow e^+e^- + b\bar{b}$
Higgs Measurements at ILC

<table>
<thead>
<tr>
<th>$\sqrt{s}$ and $\mathcal{L}$</th>
<th>$\Delta(\sigma \cdot BR)/(\sigma \cdot BR)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sqrt{s}$ and $\mathcal{L}$</td>
<td>250 fb$^{-1}$ at 250 GeV (-0.8,+0.3)</td>
</tr>
<tr>
<td>mode</td>
<td>$Zh$</td>
</tr>
<tr>
<td>$h \to b\bar{b}$</td>
<td>1.1%</td>
</tr>
<tr>
<td>$h \to c\bar{c}$</td>
<td>7.4%</td>
</tr>
<tr>
<td>$h \to g\bar{g}$</td>
<td>9.1%</td>
</tr>
<tr>
<td>$h \to WW^*$</td>
<td>6.4%</td>
</tr>
<tr>
<td>$h \to \tau^+\tau^-$</td>
<td>4.2%</td>
</tr>
<tr>
<td>$h \to ZZ^*$</td>
<td>19%</td>
</tr>
<tr>
<td>$h \to \gamma\gamma$</td>
<td>29-38%</td>
</tr>
<tr>
<td>$h \to \mu^+\mu^-$</td>
<td>100%</td>
</tr>
</tbody>
</table>

ILC TDR, $m_H=125$ GeV, BRs from LHC HXSWG assumed.
Importance of Precise Measurement of Higgs Properties
Decoupling Theory Light Higgs Boson \( \sim \) SM Higgs Boson

Just for example: Two Doublet Model (SUSY)

**Coupling of \( h = 125 \) GeV 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 \( \text{SU2}(2) \) \( l_w = 1/2 \) 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 $I_w = -1/2$

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

The deviations must be seen at ILC even for $m_A \sim 500\text{GeV}$.

Very difficult for LHC
Impact of Precise Measurement

A. Wagner

COBE 1990
Angular resolution = 10°
Temperature fluctuation $10^{-5}K$

WMAP 2003
Angular resolution = 10'
$\tau$(the Universe) = 13.69±0.13 Gyr
Polarization measurement

Planck 2013
Angular resolution ~ 4'
$\tau$(the Universe) = 13.796±0.058 Gyr
History of International LC Community
1980s  LC accelerator R&D starts at DESY, KEK, SLAC, CERN, …
1990s  5 different LC designs: TESLA, S-band, C-band, X-band, CLIC
1998  World-wide-studies of physics and detector for LCs was established
2003  ILC Steering Committee (ILCSC) formed
2004  Selected superconducting RF for the main linac
2005  Global Design Effort (GDE) formed (Barry Barish)
2007  Reference Design Report
2009  LOI process validated two detector concepts (ILD and SiD)
2012  Technical Design Report
2013  Feb.  Linear Collider Collaboration (LCC=ILC+CLIC) formed (Lyn Evans)
2013  June  TDR review will be completed

The Jump-Start Scenario (Very optimistic but not impossible)
2013  July  Site evaluation by scientists will complete 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)
2015-16  Construction starts
2026-27  Commissioning of the ILC machine
The committee makes the following recommendations concerning large-scale projects, which comprise the core of future high energy physics research in Japan.

- **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. In parallel, continuous studies on new physics should be pursued for both LHC and the upgraded LHC version. Should the energy scale of new particles/physics be higher, accelerator R&D should be strengthened in order to realize the necessary collision energy.**

- **Should the neutrino mixing angle θ₁₃ be confirmed as large, Japan should aim to realize a large-scale neutrino detector through international cooperation, accompanied by the necessary reinforcement of accelerator intensity, so allowing studies on CP symmetry through neutrino oscillations. This new large-scale neutrino detector should have sufficient sensitivity to allow the search for proton decays, which would be direct evidence of Grand Unified Theories.**
It is expected that the Committee on Future Projects, which includes the High Energy Physics Committee members as its core, should be able to swiftly and flexibly update the strategies for these key, large-scale projects according to newly obtained knowledge from LHC and other sources.

It is important to complete and start the SuperKEKB including the detector, as scheduled. Some of the medium/small scale projects currently under consideration have the implicit potential to develop into important research fields in the future, such as neutrino physics and as such, should be promoted in parallel to pursue new physics in various directions. Flavour physics experiments such as muon experiments at J-PARC, searches for dark matter and neutrinoless double beta decays or observations of CMB B-mode polarization and dark energy are considered as projects that have such potential.
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.
Support from Europe and USA

European Strategy  Chair: Tatsuya Nakada

e) 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
Union of Diet members to promote a construction of international laboratory for LC

31st July 2008 established a suprapartisan ILC supporters

(July 2008〜)
President Kaoru Yosano
Deputy Yukio Hatoyama
Secretary-General Takeo Kawamura、Yoshihiko Noda
Director Norihisa Tamura、Masamitsu Naito

Renewed on 1st Feb 2013 lead by Takeo Kawamura

Advanced Accelerator Association of Japan (AAA)

June 2008 established an industry–academy collaboration

Industry: 85 companies (Mitsubishi HI, Toshiba, Hitachi, Mitsubishi Electric, Kyoto Ceramic et al.)
Academy: 38 institutes (KEK, Tokyo, Kyoto, Tohoku, Kyushu, RIKEN, JAEA et al.)
as of December 2011

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)
27 March 2013      LCC Director Lyn Evans met our Prime minister
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 “a Higgs Boson” at LHC
2) TDR of ILC project was completed end 2012.
3) CERN is expected to work on LHC upgrade
   Support from international community
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
   • Report from subcommittee of future HEP projects of Japan (March 2012)
   • Phased Execution of ILC (October 2012)
Projects of Japan other than ILC

1) Neutrino Physics ☆
2) Super KEKB
3) J-PARK (other than neutrino)
3.2σ Evidence of $\nu_e$ appearance from $\nu_\mu$ beam

World best measurement of $\theta_{23}$

Next goals

5σ appearance observation before Summer 2013 w/ $\sim8\times10^{20}$ POT

Realize $>750\text{ kW}$

Appearance & disappearance precision measurements

Start to explore CPV and mass hierarchy
Hyper-Kamiokande project

- Exploring the full picture of neutrino mixing
  - Neutrino beam from J-PARC (≥1MW expected)
    - CP asymmetry in lepton sector
  - Atmospheric neutrino
    - Determination of mass hierarchy and $\theta_{23}$ octant
  - Search for proton decay (Sensitivity: $\tau/B(e^+\pi^0) > 10^{35}$ years)
- Measurements of solar and astrophysical neutrinos

Total mass: 1Mton
Fiducial mass: 560kton
(x25 of Super-K)

International WG
Japan, Canada, Spain, Switzerland, Russia, UK, US
CP asymmetry in lepton sector

- 3σ CPV measurement for 74% of $\delta$ ($\sin^2 2\theta_{13} = 0.1$)
- CP phase $\delta$ measurement
  - $<10^\circ$ if $\delta=0$
  - $<20^\circ$ if $\delta=90^\circ$

Search for proton decay

- $p \rightarrow e^+\pi^0$:
  - $1.3 \times 10^{35}$ yrs (90%CL)
  - $5.7 \times 10^{34}$ yrs (3σ)
- $p \rightarrow \nu K^+$:
  - $2.5 \times 10^{34}$ yrs (90%CL)
  - $1.0 \times 10^{34}$ yrs (3σ)

With 10 years data

~10 times sensitivity than current Super-K limits
What is the goal beyond $\theta_{13}$ and $\delta$?

CKM imaginary phase cannot explain the CP violation in the universe (baryon dominance over anti-baryon)
With the same reason neutrino $\delta$ may not explain the CP violation in the Universe.

$\Rightarrow$ Large neutrino detectors are also for nucleon decay searches.
Nucleon decay is a direct window of GUTs ($p \rightarrow \pi^0 e^+, p \rightarrow \nu K^+$)

$$(\text{Detector mass}) \cdot (\text{Run time}) \propto (GUT \text{ energy scale})^{1/4}$$

Size and budget of neutrino detectors (including nucleon decay) become large.
$\Rightarrow$ ICFA established neutrino panel (members are already selected)

It is very important to see the projects in Europe (CERN) and in USA (Fermilab). International cooperation may be inevitable.
**Scientific Activities**

- **Quest for Birth-Evolution of Universe**
- **Quest for Unifying Matter and Force**
- **Lepton CP Asymmetry**
- **Power-Upgrade**
- **Beyond Standard Physics**
- **Technology Innovation**
- **Encouraging Human Resources**
- **Super-KEKB**
- **J-PARC**
- **KEK-B**
- **LHC**
- **Quark CP Asymmetry**
- **Higgs Particle [Origin of Mass]**
- **Quest for Neutrinos**
- **[Origin of Matter]**
- **Quest for 6 Quarks**
- **KEK DG keeps showing this ugly slide**
All roads lead to ILC
There was a revolution in particle physics!
The 1974 November Revolution
Discovery of J/ψ (charm quark)

There was a revolution in particle physics!
The 1974 November Revolution
Discovery of J/ψ (charm quark)
R looks monotone increasing function with $s (= Ecm^2)$. Parton model must be wrong

B. Richter
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, 5x5mm² (ECAL), 3x3cm² (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 × 5 mm²</td>
<td>400 × 50 mm²</td>
<td>x800</td>
</tr>
<tr>
<td>Tracker</td>
<td>1 × 6 mm²</td>
<td>13 mm²</td>
<td>x2.2</td>
</tr>
<tr>
<td>ECAL</td>
<td>5 × 5 mm² (Si)</td>
<td>39 × 39 mm²</td>
<td>x61</td>
</tr>
</tbody>
</table>

**Particle Flow Algorithm**

Charged particles → Tracker,
Photons → ECAL, Neutral Hadrons → HCAL

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

State-of-the-art detectors can be designed for ILC