International Linear Collider Challenge on Accelerator Science

Hiroshima University
Masao KURIKI
(ILC University Caravan)
1. An historical view on accelerator and LC
2. ILC accelerator overview
3. ILC, the first global project in Asia
Livingston Plot: Evolution of Particle Accelerator

Rapid progress has been made by continuous evolution.

like a multi-stage rocket!

We need new ways to reach higher energy!

From Symmetry Magazine
Storage ring and LINAC

\[ \epsilon_x = \epsilon_{\text{cathode}} \frac{\gamma}{\beta} \]

**Emittance**

\[ \epsilon_x = C_q \frac{\gamma^2 I_5}{J_h I_2} \]

**Energy loss**

\[ \Delta E = \frac{C \gamma E^4}{\beta \rho} \]

Linac is suitable for higher energy and low emittance beam!
ILC: International Linear Collider
CME - 250-500 GeV

It is the only way to reach higher energy with e+ e- collider.
1. An historical view on accelerator and LC
2. ILC accelerator overview
3. ILC, the first global project in Asia
The leading actor: Spin polarization

- $e_L$ and $e_R$ are different particles in gauge interaction.
- To define the initial states, energy, particles, and spin are essential.

<table>
<thead>
<tr>
<th>$I_L$</th>
<th>$l_L \equiv \begin{pmatrix} \nu_{eL} \ e_L \end{pmatrix}$</th>
<th>$I_W = \frac{1}{2}, \ Y_W = -1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e_R$</td>
<td>$I_W = 0, \ Y_W = -2$</td>
<td></td>
</tr>
</tbody>
</table>

$$P = \frac{N_R - N_L}{N_R + N_L}$$

- Luminosity is effectively enhanced.
- Improving S/N ratio.

Figure 2.3: Cross sections for Standard Model physics processes in $e^+e^-$ annihilation at 500 GeV, as a function of the electron longitudinal polarization.
In 1970'

<table>
<thead>
<tr>
<th>Method</th>
<th>Pol.(%)</th>
<th>Avarage current (A)</th>
<th>Peak current(A)</th>
<th>Spin Reveral</th>
<th>Brightness</th>
</tr>
</thead>
<tbody>
<tr>
<td>NEA GaAs</td>
<td>40</td>
<td>1e-6</td>
<td>1e-1</td>
<td>Laser</td>
<td>Very High</td>
</tr>
<tr>
<td>EuO photo-emission</td>
<td>27</td>
<td>1e-6</td>
<td>1e-4</td>
<td>Mag.</td>
<td>medium</td>
</tr>
<tr>
<td>Photo Ion. Pol. Li</td>
<td>76</td>
<td></td>
<td>1e-4</td>
<td>Mag.</td>
<td>medium</td>
</tr>
<tr>
<td>Fano effect, Photo-Ion. Cs</td>
<td>90</td>
<td></td>
<td>1e-4</td>
<td>Laser</td>
<td>high</td>
</tr>
<tr>
<td>Optical pump He discharge</td>
<td>30</td>
<td>1e-6</td>
<td></td>
<td>Laser</td>
<td>high</td>
</tr>
<tr>
<td>EuS field emission</td>
<td>89</td>
<td></td>
<td></td>
<td>Mag.</td>
<td>very high</td>
</tr>
<tr>
<td>Electron scattering from Hg beam</td>
<td>27</td>
<td>2e-8</td>
<td></td>
<td>angle</td>
<td>medium</td>
</tr>
<tr>
<td>Electron scattering from W.</td>
<td>40</td>
<td>5e-8</td>
<td></td>
<td>angle, E</td>
<td>high</td>
</tr>
</tbody>
</table>

Photo-emission from GaAs

(b) Strained Ga As

Strain Axis Parallel to Incident Photon Axis

\[ E_g = 1.43 \text{ eV} \]

\[ \Delta E_{\text{strain}} = 0.05 \text{ eV} \]

\[ \Delta E_{\text{spin orbit}} = 0.34 \text{ eV} \]

Conduction mini-band

GaAs or InGaAs

AlGaAs

\[ E_{\text{th}} \]

Heavy hole mini-band

Light hole mini-band

\[ L_W \]

\[ L_B \]

so
# History of NEA GaAs

<table>
<thead>
<tr>
<th>Year</th>
<th>Type</th>
<th>Pol. (%)</th>
<th>Quantum Eff.</th>
<th>Author</th>
</tr>
</thead>
<tbody>
<tr>
<td>1976</td>
<td>Zn-GaAs</td>
<td>40</td>
<td>1e-4</td>
<td>Tech. H. Zürich</td>
</tr>
<tr>
<td>1981</td>
<td>AlGaAs-GaAs SL</td>
<td>49</td>
<td>1e-4</td>
<td>Jülich, Germany</td>
</tr>
<tr>
<td>1991</td>
<td>AlGaAs-GaAs SL</td>
<td>71</td>
<td>2e-4</td>
<td>Nagoya, KEK, NEC</td>
</tr>
<tr>
<td></td>
<td>Strained InGaAs</td>
<td></td>
<td>1e-5 ~ 1e-4</td>
<td>SLAC, UCB,</td>
</tr>
<tr>
<td></td>
<td>Strained GaAs on GaAsP</td>
<td>90%</td>
<td>1e-3</td>
<td>SLAC</td>
</tr>
<tr>
<td>2005</td>
<td>GaAs-GaAsP strained SL</td>
<td>92+-6</td>
<td>5e-3</td>
<td>Nagoya, KEK</td>
</tr>
</tbody>
</table>
Positron Source

- Positron production is a more complicated business.
- Amount of e+ is 50 times larger than that in SLC (SLAC Linear Collider, the first linear collider in the world).
- Staging approach to minimize possible risks and maximize physics potential.
  - 1st stage: Unpolarized e-driven e+ source.
  - 2nd stage: Polarized undulator driven e+ source.
To generate gamma ray from undulator radiation, >130GeV electron beam for collision is shared.

Helical undulator for polarized gamma ray generation.

The beam structure has to be identical to that in ML, i.e. 1ms pulse duration. It requires 100 m/s target rotation speed to mitigate heat load on the target.
Electron Driven Positron Source

- 6 GeV e- beam on W-Re target.
- By manipurating the beam structure, heat load on the production target is manageable. It could be 5 m/s.

Marathon runner in Vacuum
Asymmetric Beam and LC

Event rate

\[ N = \sigma \times L \]

\( \sigma_y \ll \sigma_x \) (asymmetric)

Keep luminosity and surpress Beamstrahlung and Disruption.

Luminosity

\[ L = \frac{f_{rep} n_b N^2}{4 \pi \sigma_x \sigma_y} \]

Beamstrahlung

\[ \frac{\Delta E}{E} \propto \frac{N^2 E}{(\sigma_x^2 + \sigma_y^2) \sigma_z} \]

Disruption

\[ D_{x,y} = \frac{2N r_e}{\gamma} \frac{\sigma_z}{\sigma_{x,y}(\sigma_x + \sigma_y)} \]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal size</td>
<td>640 nm</td>
</tr>
<tr>
<td>Vertical size</td>
<td>5.7 nm</td>
</tr>
<tr>
<td>Bunch length</td>
<td>300 ( \mu )m</td>
</tr>
<tr>
<td>Vertical Disruption</td>
<td>19.4</td>
</tr>
<tr>
<td>RMS energy by BS</td>
<td>2.4%</td>
</tr>
<tr>
<td>Horizontal emi.</td>
<td>10 mm.mrad</td>
</tr>
<tr>
<td>Vertical emi.</td>
<td>0.04 mm.mrad</td>
</tr>
</tbody>
</table>
Damping Ring

- DR make up the beam by radiation damping for high luminosity.
- KEK-ATF demonstrated the low emittance.
- Super-B factory will be operated in tougher conditions. It would be a good test for LC.

<table>
<thead>
<tr>
<th>Particle</th>
<th>Axis</th>
<th>Injector (µm)</th>
<th>IP (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>electron</td>
<td>Horizontal</td>
<td>1.0e-5</td>
<td>1.0e-5</td>
</tr>
<tr>
<td></td>
<td>Vertical</td>
<td>1.0e-5</td>
<td>4.0e-8</td>
</tr>
<tr>
<td>positron</td>
<td>Horizontal</td>
<td>2.0e-2</td>
<td>1.0e-5</td>
</tr>
<tr>
<td></td>
<td>Vertical</td>
<td>2.0e-2</td>
<td>4.0e-8</td>
</tr>
</tbody>
</table>
Main Linac
Super-conducting Accelerator

SCRF Procurement/Manufacturing Model

ILC Host-Lab

World-wide Industry responsible to ‘Build-to-Print’ manufacturing

Regional Hub-Lab: A

Regional Hub-Lab: B

Regional Hub-Lab: C: responsible to Hosting System Test and Gradient Performance

Regional Hub-Lab: D

Regional Hub-Lab: E, & ...

Technical Coordination for Lab-Consortium

Regional hub-laboratories responsible to regional procurements to be open for any world-wide industry participation

: Technical coordination link

: Procurement link
Industorialization

Production yield:
94 \% \geq 28 \text{ MV/m},

Average gradient:
37.1 \text{ MV/m}

Design average gradient:
35 \text{ MV/m}

It is ready for production!
What is Final Focus?

- Focus the beam size down to 5.7nm.
- Chromatic correction (correctoin on chromatic aberation) is essential.
- Demonstration of the chromatic correction and tuning method is aim of ATF2.
Final Focus Test (ATF2)

The ATF2 plan: realization of the nanobeam

Focus point (37nm beam size)

Modulator

80MeV Preinjector

Klystron

Damping ring

Damped cavity

Wiggler magnet

Synchrotron radiation interference monitor

X-ray synchrotron radiation profile monitor

The diagnostic line for the extracted low emittance beam

Double kicker System for stable beam extraction

Laser wire

Injection kicker

The linear accelerator as the injector

Photocathode RF gun

Fast feedback kicker for beam position stabilization

Optical diffraction beam size monitor

Stripline beam position monitor

Tungsten(Carbon) Wire Scanner

Cavity beam position monitor

Laser wire

276m

23 October 2013
We are approaching!

- The beamsize at the virtual IP is measured as visibility by the laser fringe monitor.
- 60nm is confirmed.
- 35nm at 1.3 GeV is goal of ATF2. This number corresponds to 5.7nm at 250 GeV beam energy.
ILC, The first global project in Asia.
Evolution of LCs

In 2013, ILC TDR is published!

THE INTERNATIONAL LINEAR COLLIDER
FROM DESIGN TO REALITY

WWW.linearcollider.org
## Evolution of LCs

<table>
<thead>
<tr>
<th>- 2004</th>
<th>GLC</th>
<th>NLC</th>
<th>TESLA</th>
<th>CLIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004-2013</td>
<td></td>
<td>ILC</td>
<td></td>
<td>CLIC</td>
</tr>
<tr>
<td>2013-</td>
<td></td>
<td>ILC</td>
<td></td>
<td>CLIC</td>
</tr>
</tbody>
</table>

LCC (Linear Collider Collaboration)

Director
Deputy Director
Accelerator
CLIC
Multilateral Lab

Laboratory A

University B

Laboratory C

University D

ILC Laboratory

Main Campus

Facility

Data Center

University A

Laboratory B

University C

Laboratory D
ILC timetable
not guaranteed, but not unrealistic

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Jpn. Cand. site</td>
<td>ILC propose</td>
<td>Site Deci.</td>
<td>int. negotiation</td>
<td>LC prep. office</td>
<td>Pre-ILC Lab.</td>
<td>ILC Lab.</td>
<td>ILC construction</td>
<td>ILC operation</td>
<td></td>
</tr>
</tbody>
</table>

TDR DBD
The ILC site evaluation committee of Japan has assessed the two candidate sites based on technical and socio-environmental criteria and unanimously concluded as follows:

The Kitakami site is evaluated to be the best domestic candidate site for the ILC.

http://ilc-str.jp/topics/2013/08281826/
ILC as a future project

- Japanese society (http://www.jahep.org/) proposes a staging approach of LC.
  - 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. ...... 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 selfcouplings, by upgrading the accelerator. (from a report of subcomittee for future projects of high energy physics)

- Very positive statements from European strategy (Europe), Snowmass process (US), Shanxian conference (China), etc. supporting the japanese leading role in ILC.
A lepton collider: a decisive asset...

..if
- can be decided/built soon
- It might start at 250 Gev, but it should be upgradable to 500 GeV, with a possible extension to 1 TeV c.m.

Best candidate: ILC
- Mature design
- TDR delivered
- Japanese community has submitted to the government a request to host it.

Japan should put something on the table and then CERN will come.
We welcome the initiative for ILC in Japan

- U.S. accelerator community is capable to contribute
  - Supported by the physics case as part of a balanced program
- ILC design is technically ready to go
  - TDR incorporates leadership U.S. contributions to machine physics & technology
    - SRF, high power targetry (e+ source), beam delivery, damping rings, beam dynamics
- Important that there is an upgrade path of ILC to higher energy & luminosity (> 500 GeV, > 10^{34} \text{ cm}^{-2}\text{s}^{-1})

We are experienced & ready to do it

Snowmass Frontier Capabilities WG William Barletta
Snowmass Energy Frontier WG
Chip Brock

**bottom line**

This Higgs Boson changes everything.
We’re obligated to understand it using all tools.

“To me, it’s the ILC.”
Social conditions

• “Japan should contribute to innovation on advanced accelerator technology” (In the policy speech of the prime minister).

• 150 diet members form ILC promotion alliance. 談員連盟

• Advanced Accelerator Science and Technology Association (AAA) is formed by companies, labs, and universities.
A report of a series of special session for ILC is published in September 2013.

Science of ILC is significant.

For the official bid by Japanese government, various issues on monetary budget sharing, human resources for detector and accelerator constructions, etc. should be well investigated within several years.

Budget for this investigation should be funded by Japanese government.

Translation by the presenter. It is not official
Host Nation

- We need to think more broadly
  - CERN was founded on the ashes of war by a set of visionary physicists
    - And today, we are beneficiaries of their foresight
So perhaps today, at the dawn of the Asian century, the world needs Japan, China, Korea, India, Vietnam all collaborating on a peaceful endeavor.
Summary

- Accelerator technology for ILC is ready to go.
- Japanese candidate site was chosen.
- Japan Science Council recommend to investigate various issues to construct ILC in Japan within several years.
- ILC would be the first global project in Asia.
- ILC would be the regional center of particle physics in Asia. It is important not only for scientists, but also for social development in Asian countries.