Asia ILC Activity Report

J. Gao

IHEP

LCB Meeting, August 7, 2016
Chicago, USA
Contents

• Japan
• China
• Korea
• India
ILC R&D Progress, in Japan/KEK
January ~ July, 2016

SRF Technology:
• STF2 SRF Accelerator Construction at KEK
  – Completion of RF distribution system installation for STF2 Cryomodules (CMs)
    • Cavity gradient: 34.9 MV/m with best 8 cavities (of 12 cavities, CM1 + CM2a)
    – Cool-down and RF power test to be realized in October, 2016.
• SRF Cavity R&D cooperation in Asia
  – A 9-cell cavity developed by IHEP processed and vertically tested at KEK, in 2016.
• “Marx” Modulator (Solid State, RF Power Supply) R&D at KEK
  – A prototype development in progress in cooperation with Japanese industry

Nano-beam Technology:
• ATF2, FF beam-size and the stability
  – A beam size of 41 nm (preliminary) achieved with FONT feed-back ON.
  – Non-linear magnetic field effect being studied.

KEK-ILC Action Plan:
• SRF Cost Reduction R&D plan proposed
  – SRF cost reduction R&D proposed in close communication b/w Fermilab and KEK
KEK-STF SRF Accelerator Plan

STF Accelerator tunnel length: 100 m
- Beam Energy: ~ 240 MeV in JFY2017
- using eight 9-cell cavities
- Charge: 2nC/bunch, 2437bunch, 0.9ms, 5Hz
- Pulse Current: 5.7mA in train
- Pulse Train: 369ns spacing

Capture CM (2 cavities)

CM-1 (8 cavities)

CM-2a (4 cavities)

Chicane 2

Beam Dump

Photo-cathode RF-gun
KEK-STF: Cavity/CM Performance, and RF-Power/Control and Beam Test Preparation

<table>
<thead>
<tr>
<th>SRF cavity Gradient (MV/m) before/after CM Assembly</th>
</tr>
</thead>
<tbody>
<tr>
<td>Module</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>Cav. #</td>
</tr>
<tr>
<td>V. Test (CW)</td>
</tr>
<tr>
<td>in CM (pulse)</td>
</tr>
</tbody>
</table>

Gradient stable | Degraded | Gradient stable

*G (av. of 12 cav.): ~ 30 MV/m
G (av. of best 8): ~ 35 MV/m

FY14: CM1+CM2a (8+4) assembly
FY15: Cavity individually tested in CM RF power system in preparation
FY16: 8-cavity string to be RF tested
FY17: Beam Acceleration anticipated (to reach > 250 MeV)
Marx Modulator Development at KEK

• A prototype “Marx” modulator being developed at KEK in cooperation with a company in Japan, based on preliminary effort between SLAC and KEK.
  – It features “parallel charging and series discharging” by using SiC devices (instead of Si) to cost-effectively generate RF high-voltage,
Progress in KEK-ATF2, 2016

- **Int’l Collaboration for “Nano-beam” Research**
  - ~25 Lab., and > 100 Collaborators

- **Modeling of ILC - BDS**
  - Same Optics: as ILC-BDS

- **Goal**
  - FF Beam Size: 37 nm (→ 5.9 nm at ILC)

- **Progress**
  - 41 nm (preliminary) reached with FONT FB ON
  - Non-linear magnetic field effect being studied.

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https://agenda.linearcollider.org/event/7014/contributions/36882/attachments/30069/44951/ATF2_okugi_20160601.pdf
KEK issues action plan for the International Linear Collider

January 6, 2016

Japan’s High Energy Accelerator Research Organization (KEK) issued an KEK-ILC action plan for how KEK should start its preparation toward the International Linear Collider when the Ministry of Education, Culture, Sports, Science and Technology (MEXT), decides to initiate negotiations with foreign countries.

KEK has been promoting the development of linear collider accelerator technology for a long time and has greatly contributed to the publication of the ILC Technical Design Report (TDR). KEK considers the promotion of the ILC project to be a strategic part of organization’s future, described in the KEK Roadmap published in May 2013. Its activities are currently centered around three facilities: the Superconducting RF Test Facility (STF), the Accelerator Test Facility (ATF), and the Cavity Fabrication Facility (CFF). In addition to the efforts in the technical development, KEK established the Planning Office for the ILC in February 2014, to promote the ILC project and the technical development activities at KEK.
KEK ILC Action Plan

- plan the technical actions, organization, human resources and training to realize formal approval of the ILC project
- ensure a smooth start of the construction phase through the preparation phase from the current status

<table>
<thead>
<tr>
<th></th>
<th>Pre-preparation Phase</th>
<th>Main Preparation Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Present</td>
<td>P1</td>
</tr>
<tr>
<td>ADI</td>
<td>Establish main parameters</td>
<td>Verify parameters w/ simulations</td>
</tr>
<tr>
<td>SRF</td>
<td>Accelerate beam with SRF cavity string and cryomodule</td>
<td>Demonstrate mass-production technology and stability</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Demonstrate Hub-lab functioning and global sharing</td>
</tr>
<tr>
<td>Nanobeam</td>
<td>Achieve the ILC beam-size goal</td>
<td>Demonstrate the nanobeam size and stabilize the beam position</td>
</tr>
<tr>
<td>Positron source</td>
<td>Demonstrate technological feasibility</td>
<td>Demonstrate both the undulator and e-driven e+ sources</td>
</tr>
<tr>
<td>CFS</td>
<td>Pre-survey and basic design</td>
<td>Geology survey, engineering design, specification, and drawings</td>
</tr>
<tr>
<td>Common technical support</td>
<td>Support engineering and safety</td>
<td>Common engineering supports (network, radiation safety, etc.)</td>
</tr>
<tr>
<td>Administration</td>
<td>Project planning and promotion Preparation for the ILC pre-lab</td>
<td>General affairs, finance, international relations, public relations Establishing the ILC pre-lab and managing the ILC preparation</td>
</tr>
</tbody>
</table>
ILC Cost-Reduction R&D Proposal

focusing on SRF in 2~3 years

The R&D proposal addresses the International Linear Collider (ILC) cost reduction feasibility, followed by industrialization R&D during the “main preparation” phase.

A-1. Nb material preparation
   - with optimum RRR and clean processing for sheeting/piping

A-2. SRF cavity fabrication for high-G and high-Q
   - with a new surface process provided by Fermilab

A-3. Power input coupler fabrication
   - using new ceramic requiring no coating

A-4. Cavity chemical treatment
   - vertical EP and easier handling w/ safer solution
Contents

- Japan
- China
- Korea
- India
Joint effort of IHEP ILC Group and HE-Racing Technology Corporation (IHEP workshop) for ILC cavity technology transfer and industrialization study.

First 1.3 GHz TESLA 9-cell cavity (HERT001) has been completed on July 28th, 2016 and passed vacuum test.

Expect to surface-process by EP and test at KEK in Autumn.
HE-Racing Technology (HERT)

• Rich experience in accelerator components manufacture:
  – S-band and C-band accelerator tubes, SLED, RFQ, magnets …
  – SRF cavities (spoke and elliptical) and high power input couplers

• Cavity fabrication facilities:

Press Machine  CNC Turning Center  Vertical Machining Center
CMM Machine  Vacuum Furnace  EBW Machine
Cavity Fabrication

- Optimized manufacturing process, welding parameters and structures
- Accurate frequency, shape and length control; careful surface cleaning
- More cavities to further improve the welding quality, simplify the manufacturing process, and reduce cost for mass-production
## IHEP 1.3 GHz Cavity R&D

<table>
<thead>
<tr>
<th>Year</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016</td>
<td><strong>9-cell TESLA, fine grain</strong> cavity with HOM, by High-Energy Racing</td>
</tr>
<tr>
<td>2014</td>
<td><strong>9-cell TESLA-like, fine grain</strong> cavity with HOM, max. 48 MV/m by EP</td>
</tr>
<tr>
<td>2012</td>
<td><strong>9-cell Low Loss, large grain</strong> cavity with HOM, 20 MV/m by EP</td>
</tr>
<tr>
<td>2010</td>
<td><strong>9-cell low-loss, large grain</strong> cavity without HOM, 20 MV/m by CP</td>
</tr>
<tr>
<td>2008</td>
<td>single cell low-loss large and fine cavity, max. 40 MV/m by CP</td>
</tr>
<tr>
<td>2006</td>
<td>single cell ICHIRO large grain cavity, max. 48 MV/m by EP</td>
</tr>
</tbody>
</table>
1. Frequency and field flatness measurement
2. Inspection of inner surface by Kyoto-camera
3. Local grinding around defect area
4. Pre-EP (5 um) & EP-I (100 um)
5. Annealing
6. Inspection of inner surface by Kyoto-camera
7. Pretuning
8. EP-II (10 um), HPR
9. Clean room assembly, baking
10. Set-up of VT system with T-map
11. Vertical Test
12. Frequency and Field flatness measurement
13. Inspection of inner surface by Kyoto-camera after VT
EP Preparations

Ultrasonic cleaning
π-mode Field Flatness after pre-tuning

π-mode (1303.167MHz) Field Flatness = 92.95%
Cavity assembly, Baking

leak test

Baking (48h)
IHEP-03 Vertical Test Result

CBP(80 \, \mu m@IHEP), Pre-EP(5 \, \mu m), EP-I(100 \, \mu m), Annealing(750 \, ^\circ C, 3h)
EP-II(20 \, \mu m), HPR(1.5h+3.5h), baking(140 \, ^\circ C, 48h)

\[ \pi(\text{initial}) \]
\[ 16.85 \text{MV/m} \]
\[ Q:1.08E10 \]
# Cell Gradient by Passband Modes Test

<table>
<thead>
<tr>
<th>Cell 1&amp;9</th>
<th>Cell 2&amp;8</th>
<th>Cell 3&amp;7</th>
<th>Cell 4&amp;6</th>
<th>Cell 5</th>
<th>Quench Location/Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>π(initial)</td>
<td>16.85</td>
<td>16.85</td>
<td>16.85</td>
<td>16.85</td>
<td>16.85</td>
</tr>
<tr>
<td>π(final)</td>
<td>16.64</td>
<td>16.64</td>
<td>16.64</td>
<td>16.64</td>
<td>16.64</td>
</tr>
<tr>
<td>2 π / 9</td>
<td>8.10</td>
<td>19.44</td>
<td>22.28</td>
<td>14.90</td>
<td>---</td>
</tr>
<tr>
<td>5 π / 9</td>
<td>18.85</td>
<td>12.82</td>
<td>22.24</td>
<td>3.77</td>
<td>23.94</td>
</tr>
<tr>
<td>4 π / 9</td>
<td>13.00</td>
<td>17.03</td>
<td>7.41</td>
<td>18.85</td>
<td>---</td>
</tr>
<tr>
<td>3 π / 9</td>
<td>12.32</td>
<td>24.64</td>
<td>12.32</td>
<td>12.32</td>
<td>&gt;24.64</td>
</tr>
<tr>
<td>(E_{\text{acc, max}})</td>
<td>18.85</td>
<td>24.64</td>
<td>22.28</td>
<td>18.95</td>
<td>24.64</td>
</tr>
</tbody>
</table>

Cell3 >22MV/m, Cell4 >19MV/m, Cell8>24.6MV/m, Cell9 >16.85MV/m
Quench location

1-cell equator, $\theta = 130$ deg.

6-cell equator, $\theta = 279$ deg.

3-cell equator, $\theta = 301$ deg.

7-cell equator, $\theta = 297$ deg.

9-cell equator, $\theta = 297$ deg.

Surface Inspection
Acknowledgement

Eiji Kako, Kensei Umemori, Mineyuki Asano, Motoaki Sawabe, Kouichi Nakamura, Fumihiko Tukada, Jun Sakai, Taisuke Yanagimachi, Shinichi Imada, Hiroki Yamada......
IHEP T-mapping System

- T-mapping is the most common diagnostic tool for SRF cavities
- We will develop a fixed T-mapping systems
- With Carbon Resistor (200 AB sensor at first step)
- Sampling time: < 100ms
- Data logger: Not determined
- Labview
T-mapping : Resistors

Temperature sensor
Vertical test of 1.3GHz cavity N-doped

- 1.3 GHz single-cell cavities were N-doped after Nb sample experiments.
- Several vertical tests were finished, but Q Value didn’t increase. Key reason: **NO EP**, just received BCP. Other reasons are also under research.

![Graph showing Q₀ vs. E_acc (MV/m)](image)

- **Before N-doping**
- **After N-Doping**

Magnetic shielding around cavity
# IHEP EP Schedule

<table>
<thead>
<tr>
<th>2016</th>
<th></th>
<th>2017</th>
<th>2018</th>
</tr>
</thead>
</table>

## Key Time Points:
- **Oct. 2016**: Finish the Conceptual Design
- **Dec. 2016**: Finish Review and Administrative process for choosing company
- **Feb. 2017**: Finish Engineering Design and Review
- **Oct. 2017**: Finish Critical Units fabrication or Purchase
- **Dec. 2017**: Finish Assembly
- **Apr. 2018**: Finish Commissioning and Acceptance

![Layout of Critical Units for Electropolishing facility](image-url)
Slotted cavity development time line

BBU threshold:

\[ I_{th} = -\frac{2c^2}{e^{(\frac{R}{Q})}Q_2^\omega T_{12} \sin \omega t_1} \]

To lower HOMs’ Qe

Funded by NSFC


4.2K test (1st)

2K test (2nd, 3rd)
### Slotted Cavity HOMs’ Damping Comparison

<table>
<thead>
<tr>
<th>Measured Value</th>
<th>Calculated Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>F (GHz, with covers)</td>
<td>Q&lt;sub&gt;L&lt;/sub&gt; (with covers)</td>
</tr>
<tr>
<td>1.524</td>
<td>560</td>
</tr>
<tr>
<td>1.5312</td>
<td>714</td>
</tr>
<tr>
<td>1.5926</td>
<td>624</td>
</tr>
<tr>
<td>1.5979</td>
<td>606</td>
</tr>
<tr>
<td>1.677</td>
<td>1037</td>
</tr>
<tr>
<td>1.68</td>
<td>995</td>
</tr>
<tr>
<td>1.713</td>
<td>94</td>
</tr>
<tr>
<td>1.7526</td>
<td>1192</td>
</tr>
<tr>
<td>1.7492</td>
<td>1280</td>
</tr>
<tr>
<td>1.794</td>
<td>1312</td>
</tr>
<tr>
<td>1.8405</td>
<td>2047</td>
</tr>
<tr>
<td>1.9</td>
<td>445</td>
</tr>
<tr>
<td>1.973</td>
<td>714</td>
</tr>
<tr>
<td>2.052</td>
<td>470</td>
</tr>
<tr>
<td>2.086</td>
<td>615</td>
</tr>
<tr>
<td>2.184</td>
<td>531</td>
</tr>
<tr>
<td>2.1985</td>
<td>321</td>
</tr>
<tr>
<td>2.254</td>
<td>1450</td>
</tr>
<tr>
<td>2.324</td>
<td>1990</td>
</tr>
<tr>
<td>2.365</td>
<td>1224</td>
</tr>
<tr>
<td>2.4</td>
<td>1071</td>
</tr>
<tr>
<td>2.437</td>
<td>800</td>
</tr>
</tbody>
</table>

*Notes on TABLE III: Many HOMs disappeared in the network analyzer when opening the waveguide port as the Q<sub>L</sub> of these mode decreased below 10 or so. These modes are depicted by “x”. Since there are several calculated modes around the measured frequency or the frequency shift between measured frequency and calculated frequency is large, we use “-” to depict. * depicts quadruple mode.
Vertical test

- First test: 4.2K vertical test, limited by power, the accelerating gradient of the cavity reached 2.4MV/m \((Q_0=1.4\times10^8)\).
- Second & third test: 2K vertical test, the \(Q_0\) of slotted cavity were limited by the coupler flange (stainless steel). Maximum \(Q_0\) is \(1\times10^8\). \(\pi\) mode gradient is 1.4MV/m. Maximum \(B_{pk}\) of \(2/3\pi\) mode(with a lower field in beam pipe) is 24.5mT. It is equal to the \(B_{pk}\) of \(\pi\) mode with a gradient of 4.3MV/m.
- A longer Nb beam pipe is needed to increase \(Q_0\). Next step, we will add the beam pipe length.
Contents

• Japan
• China
• Korea
• India
Fabrication of Low-Q IP-BPM

• Made by Aluminum (2kg for double block)
  – Precise surface machining within 4um.
  – IPBPM A & B are fabricated together in same block.
  – IPBPM C was fabricated to single block.
Installation of IP-BPM system
IP-BPM resolution test in KEK-ATF2 (Mar. 2016): position resolution of 8nm

Residual value = measured position – predicted position

Norm. Resolution = Geo. factor x RMS of residual
Calibration factor x Measured charge
Nominal charge

Calibration factor = 8.1586nm

Measured resolution = 9.3811nm
Measured beam charge = 0.869x1.6nC
~86.9% beam charge

Measured charge = 0.869x1.6nC

Current Accelerator Activities in Korea (2016)

- PLS-II (3.0-GeV Light Source)
- 10-GeV PAL-XFEL
- Rare Isotope Science Project
- Synchrotron for Carbon Therapy
- KOMAC, 100-MeV Proton Linac
Status of Accelerator R&D in Korea

- **PAL-XFEL (10 GeV):** Commissioning is under progress smoothly. SASE Lasing was achieved officially on June 27, 2016.

- **Construction of RISP (Rare Isotope Science Project) & KHIMA (Carbon Therapy) Project** are on-going as planned.

- **PLS-II (3.0 GeV light source) and KOMAC (100 MeV proton linac)** are in users’ service.
PAL-XFEL Tunnel
First Lasing at 0.5 nm on 14 June, 2016

Spontaneous Radiation

SASE Radiation

SASE Radiation

June 12, 2016

14 June 2016

16 June 2016
Scan method: 100 shots/point

- $E_e = 4.0 \text{ GeV}$
- $G = 9.5 \text{ mm}$
- $\Delta E/E \sim 0.5\%$

Photons per Shot

PD Current per Shot (nA)

Energy (keV)
The brightest 0.5-nm FEL
(Achieved on June 27, 2016)
Contents

- Japan
- China
- Korea
- India
Development for SCRF Cavity at RRCAT

Raja Ramanna Centre for Advanced Technology
Machining facility

Machined half cells of five-cell SCRF cavity

Dumbell Machining fixture development

Machining of dumbells on precision lathe

Inspection of machined components
### Laser Scanning Confocal Microscope

**Imaging Method**: 3-D Laser Scanning Confocal system

<table>
<thead>
<tr>
<th><strong>Z - Resolution (Depth)</strong></th>
<th>1 nm</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Z - Measurement repeatability</strong></td>
<td>12 nm</td>
</tr>
<tr>
<td><strong>X-Y Resolution</strong></td>
<td>0.12 μm</td>
</tr>
</tbody>
</table>

![Confocal image of replica](image1.jpg)

![Measurement of bead profile](image2.jpg)

<table>
<thead>
<tr>
<th>No.</th>
<th>Result</th>
<th>Width [μm]</th>
<th>Height [μm]</th>
<th>Length [μm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>1806.831</td>
<td>252.657</td>
<td>1824.410</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>1689.145</td>
<td>212.954</td>
<td>1702.516</td>
</tr>
</tbody>
</table>
Cavity Processing Facility

Centrifugal Barrel Polishing (single Cell)

Main features of CBP machine

- Turret and Barrel rotate in opposite direction
- Turret speed – 0 – 200 rpm (variable)
- Barrel speed – 0 – 200 rpm (variable)
- Barrel size – 320 X 320 X 500 mm

Barrel Polishing Machine
Electro-polishing setup for 1.3 GHz & 650 MHz Cavities
Cavity Processing Facility

High Pressure Rinsing Setup

Ultra Pure Water Plant
Low Temperature Baking & Pilot Cleanroom Facilities

Low temperature baking facility for 650 MHz

Pilot clean room facility
EBW Machine Installed at RRCAT, INDORE
Development of 1.3 GHz Five-cell cavity

A five-cell 1.3 GHz SCRF cavity was Fabricated with IUAC. The cavity was sent to Fermilab for processing under IIFC. The cavity was tested in October 2014.

The cavity achieved the accelerating gradient \( (E_{\text{acc}}) \) of 20.3 MV/m at 2 K and 42 MV/m at 1.5-1.7 K with \( Q_0 \) of 2 \( \times \) 10\(^{10} \).
First beam accelerated to 22 MeV on 29th Sept 2014 at TRIUMF. e-gun (300 keV) ACM2 (not installed) 300 kV supply ICM klystrons cold box ACM1 (one 9-cell cavity)

12 MV/m (cw) 10 MV/m (cw)

23 MeV, 10 microAmp

1.3 GHz 5-Cell Cavity

Two halves of the 5-Cell Cavity.

First multi-cell niobium cavity built in India.

Result of the cold test performed at Fermilab. The cavity reached 20.3 MV/m @ 2 K, and 42 MV/m @ 1.5-1.7 K.
2K Vertical Test Stand Facility

The 2K cryostat & electronics was developed in collaboration with Fermilab under IIFC

Cryostat & Cavity Insert Assembly

Transfer of liquid helium

RF testing in progress

$Q_c$ vs $E_{acc}$ @ 2K

Quench at 38.7 MV/m

$Q_c \times 10^{10}$
Niobium Cavity development at TRIUMF

Cavities for VECC will come from TRIUMF
Conclusions

Asian countries continue to work and collaborate on ILC related technologies in 2016

- Japan: KEK continue to work on SCRF and Nanobeam technology for ILC with 41nm achieved at ATF2

- China: IHEP continue its effort on 1.3GHz SCRF technologies with great progress with the first IHEP Factory made 1.3GHz 9cell TESLA cavity completed and collaborate actively with KEK on ILC SCRF and positron source. Financial support for ILC ATF2 and positron source collaboration with ILC has been quaranteed in the nex five years.

- Korea: Korea University collaborate actively on ATF2 BPM and home accelerator projects goes well with PAL-XFEL SASE laseing on June 27, 2016.

- India: BARC progresses well on 1.3GHz SC technology and laboratory deveoplments.

Thanks go to Profs. S. Michizono, A. Yamamoto, W. Namkung, E.S. Kim and D. Datta for their providing progress information fron their countries.