International Linear Collider:
- Technical Status and Readiness -

Akira Yamamoto and Shin Michizono
(KEK/LCC)

Presented at IAS Conference, Hong Kong, 24 Jan., 2017
Outline

• Introduction

• Technical Progress and Status
  – Nano-beam technology
  – SRF technology
  – Civil engineering

• Readiness for the Project
  – Further effort for the cost reduction and the R&Ds

• Summary
ILC GDE to LCC

1980’ ~ Basic Study

2004 2006 '07 '08 '09 '10 '11 '12 '13 '14 '15 '16 '17

Ref. Design (RDR)

Technical Design Phase

ILC-GDE

LCC

TDR publication

126 GeV

Higgs discovered

2012.12.15

2013.6.12

Selection of SC Technology

A. Yamamoto, 170123
Important Energies in ILC

125 GeV Higgs discovery reinforcing the ILC importance

Physics confident:
- Higgs and Top Quark
- Learn “everything” about H (125)
- Probe dynamics of EWSB

New Physics beyond SM:
- Direct or indirect DM searches
- Evidence for BSM physics
- Hints of a new mass scale

Integrated Luminosity (ab⁻¹)

LEP reached →

E_{cm} (GeV)

200 300 400 500 600
ILC Acc. Design Overview (TDR)

**Item Parameters**

<table>
<thead>
<tr>
<th>Item</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>C.M. Energy</td>
<td>500 GeV</td>
</tr>
<tr>
<td>Length</td>
<td>31 km</td>
</tr>
<tr>
<td>Luminosity</td>
<td>$1.8 \times 10^{34}$ cm$^{-2}$s$^{-1}$</td>
</tr>
<tr>
<td>Repetition</td>
<td>5 Hz</td>
</tr>
<tr>
<td>Beam Pulse Period</td>
<td>0.73 ms</td>
</tr>
<tr>
<td>Beam Current</td>
<td>5.8 mA</td>
</tr>
<tr>
<td>Beam size (y) at FF</td>
<td>5.9 nm</td>
</tr>
<tr>
<td>SRF Cavity G. Q$_{0}$</td>
<td>31.5 MV/m</td>
</tr>
<tr>
<td></td>
<td>$Q_{0} = 1 \times 10^{10}$</td>
</tr>
</tbody>
</table>
Nano-beam Technology

- Electron and Positron Sources (e-, e+):
  - Damping Ring (DR):
  - Ring to ML beam transport (RTML):
  - Main Linac (ML): SCRF Technology
  - Beam Delivery System (BDS)

Nano-beam technology advanced by ATF Collaboration, hosted at KEK.
SRF Technology

- Electron and Positron Sources (e-, e+):
- Damping Ring (DR):
- Ring to ML beam transport (RTML):
- **Main Linac (ML)**: SCRF Technology
- Beam Delivery System (BDS)
Advantage of Superconducting RF

- **Ultra-high** ($Q_0 = 10^{10}$):
  - small surface resistance $\rightarrow$ nearly zero power (heat) in cavity walls

- **Long beam pulses** ($\sim$1 ms)
  $\rightarrow$ intra-pulse feedback

- **Larger aperture**
  $\rightarrow$ better beam quality w/ larger aperture - lower wake-fields

- Work necessary on engineering for:
  - Cryomodule (thermal insulation)
  - Cryogenics

$\textbf{Luminosity:}$

$$L \propto \frac{\eta P_{RF}}{E_{CM}} \sqrt{\frac{\delta_{BS}}{\epsilon_y}}$$

- Luminosity proportional to RF efficiency ILC
  - $\sim$160MW @ 500GeV

- Capable of efficiently accelerating high beam currents

- Low impedance aids preservation of high beam quality (low emittance)
Outline

Introduction

Technical Progress and Status
- Nano-beam technology
- SRF technology
- Civil engineering

Readiness for the Project
- Further effort for the cost reduction and the R&Ds

Summary
Progress in Acc. Technology for the ILC, in ~ 2016

Two Key Technologies matured for the project realization!

• Nano-beam Technology:
  KEK-ATF2: FF beam size (v): 41 nm at 1.3 GeV (to go 37nm, equiv. to 6 nm at ILC)

• SRF Technology:
  European XFEL: SRF Cavity completion, 100% (800) reaching $<G> \approx 30$ MV/m.
  – Cryomodule (CM), 100% (100) reaching $<G> \approx 28$ MV/m
  – Installation into acc. Tunnel completed, and cool-down just started,
  Fermilab: CM (8 cavity string) reaching ILC gradient: $<G> > 31.5$ MV/m
  – New Surface process “N2 Infusion” demonstrated for High-Q and High-G
  KEK: CM (8-cavity string) reaching : $<G> > 31$ MV/m
  US-Japan: Cost Reduction R&Ds started, reflecting recent technical advances

Issue and Prospect:

• Cost-reduction to start the project with the staging at C.E. 250 GeV, Higgs Factory, is to be studied, in addition to the cost-reduction R&D efforts
To develop the nanometer beam technologies for ILC

- Key for the luminosity
- 6 nm beam at IP (ILC)

**ATF/ATF2: Accelerator Test Facility**

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**Layout of ILC**

**ATF2: Final Focus Test Beamline**

Goal 1: establish “small beam” tech.

Goal 2: stabilize “beam position”

- 1.3 GeV S-band Electron LINAC (~70m)
- Damping Ring (~140m)
- Low emittance electron beam
ATF International Collaboration

relatively independent R&D teams

アメリカ(USA)
SLAC国立加速器研究所
ローレンス・バークレー国立研究所(LBNL)
フェルミ国立加速器研究所(FNAL)
ローレンス・リバモア国立研究所(LLNL)
ブルックヘブン国立研究所(BNL)
コーネル大学(Cornell Univ.)
ノートルダム大学(Notre Dome Univ.)

日本(Japan)
高エネルギー加速器研究機構(KEK)
東北大学(Tohoku Univ.)
東京大学(Univ. of Tokyo)
早稲田大学(Waseda Univ.)
名古屋大学(Nagoya Univ.)
京都大学(Kyoto Univ.)
広島大学(Hiroshima Univ.)

イギリス(UK)
Univ. of Oxford
Royal Holloway Univ. of London
STFC, Daresbury
Univ. of Manchester
Univ. of Liverpool
Univ. College London

イタリア(Italy)
INFN, Frascati

スペイン(Spain)
IFIC-CSIC/U

ロシア(Russia)
Tomsk Polytechnic Univ.

中国(China)
中国科学院高能物理研究所(IHEP)

韓国(Korea)
ポハン加速器研究所(PAL)

インド(India)
Raja Ramanna Centre for Advanced Technology

Education of the Young Researchers at ATF

Number of PhD/Master Thesis

Year


Master

PhD
Progress in FF Beam Size and Stability at ATF2

Goal 1:
Establish the ILC final focus method with same optics and comparable beamline tolerances
- ATF2 Goal: \(37 \text{ nm} \rightarrow \text{ILC 6 nm}\)
- Achieved \(41 \text{ nm}\) (2016)

Goal 2:
Develop a few nm position stabilization for the ILC collision by feedback
- FB latency \(133 \text{ nsec}\) achieved (target: < 300 nsec)
- Position jitter at IP: \(410 \rightarrow 67 \text{ nm}\) (2015) (limited by the BPM resolution)

We continue efforts to achieve goal 1 and goal 2.

T. Okugi, ECFA-LCW, June, 2016

K. Kubo

A. Yamamoto, 170123
1965  HEPL (Stanford U.), S-band. 3-cell, Pb plated cavity
       Beam acceleration up to 1mA
1978  ATLAS (Argonne NL), Heaviy Ion Acc. with CW SRF
1988  TRISTAN (KEK)
       509 MHZ, 5-cell, x32 cavity, 5 MV/m, 200 MV
       LEP-II (CERN), 352 MHz, 4-cell x300 →3 GV
1990  Plan for TESLA (TeV Energy SC Linear Accelerator).
       TDR (2001)
1995  CEBAF (TJNAF), 1.5 GHz, 5-cell, 336 cavities
       CW-4GeV,1mA。
1997  CESR (Cornell), KEKB (KEK)
2004:  ILC: SC technology selected
       1.3 GHz, 31.5MV/m (pulse)
2016  EURO-XFEL (TESLA type :pulse, 23.6MV/m)
TBD    realization of ILC
## Major Accelerators Under Construction 2010 ~

<table>
<thead>
<tr>
<th>Project</th>
<th>Notes</th>
<th># cavities</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEBAF-JLAB (US)</td>
<td>Upgrade 6.5 GeV =&gt; 12 GeV electrons</td>
<td>80</td>
</tr>
<tr>
<td>XFEL-Hamburg (EU)</td>
<td>18 GeV electrons – for Xray Free Electron Laser – Pulsed</td>
<td>840</td>
</tr>
<tr>
<td>LCLS-II – SLAC (US)</td>
<td>4 GeV electrons –CW XFEL (Xray Free Electron Laser)</td>
<td>300</td>
</tr>
<tr>
<td>SPIRAL-II (France)</td>
<td>30 MeV, 5 mA protons -&gt; Heavy Ion</td>
<td>28</td>
</tr>
<tr>
<td>FRIB – MSU 8US)</td>
<td>500 kW, heavy ion beams for nuclear astrophys</td>
<td>340</td>
</tr>
<tr>
<td>ESS (Sweden)</td>
<td>1 – 2 GeV, 5 MW Neutron Source ESS - pulsed</td>
<td>150</td>
</tr>
<tr>
<td>PIP-II–Fermilab (US)</td>
<td>High Intensity Proton Linac for Neutrino Beams</td>
<td>115</td>
</tr>
<tr>
<td>ADS- (China, India)</td>
<td>R&amp;D for accelerator drive system</td>
<td>&gt; 200</td>
</tr>
<tr>
<td>Globally Int. Effort</td>
<td></td>
<td>&gt; 2000</td>
</tr>
</tbody>
</table>
Global SRF Collaboration

- **Europian Collab.**
  - DESY, INFN
  - CEA-Saclay, LAL-Orsay

- **Asian Collab.**
  - IHEP, PKU
  - KEK
  - IUAC, RRCAT

- **America(s) Collab.**
  - FNAL/ANL
  - TRIUMF
  - SLAC, LCLS-II
  - Cornell
  - JLAB
  - DESY, INFN
  - CEA-Saclay, LAL-Orsay
  - IHEP, PKU
  - KEK
  - IUAC, RRCAT
  - FNAL/ANL
  - TRIUMF
  - SLAC, LCLS-II
  - Cornell
  - JLAB
European XFEL: SRF Completed

Progress:
2013: Construction started
2015: SRF cav. (100%) completed
CM (70%) progressed

Further Plan:
2016: E- XFEL acc. completion
2016/E: E-XFEL beam to start

1.3 GHz / 23.6 MV/m
800+4 SRF acc. Cavities
100+3 Cryo-Modules (CM)

Acc. : ~ 1/10 scale to ILC-ML
SRF system: ~ 1/20 scale to ILC-SRF

1 km SRF Linac

XFEL site

Media.xfel.au, Dec. 2015
**E-XFEL: SRF Cavity Performance (as received)**

SRF cavity production/test;

# RI Cavities, 373 (as of Sept. 2015)
- Final process: 40 µm EP.
- w/ same recipe to ILC-SRF’s
- Tested at DESY-AMTF

Notes:
- “Ultra-pure water rinsing as the 2nd process improving the gradient performance (> ~10%) for lower-performed cavities (not shown here).

<table>
<thead>
<tr>
<th>G-usuable (Q₀ &gt; 10¹⁰)</th>
<th>G-max (ILC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;G&gt; MV/m</td>
<td>29.4</td>
</tr>
<tr>
<td>Yield at 28MV/m</td>
<td>66%</td>
</tr>
</tbody>
</table>
47 of 420 (> 10%) of RI cavity production exceed 40 MV/m
Cryomodule Performance: VT vs. MT

Average gradient gain (HT-VT, MV/m) for individual cavity RF distribution

1\textsuperscript{st} sample of 34 series CM
\[ \Delta E_{op} = -2.1 \text{ MV/m} \]

2\textsuperscript{nd} sample of 19 series CM
\[ \Delta E_{op} = -1.7 (-0.9) \text{ MV/m} \]

Last 42 series CM
\[ \Delta E_{op} = +0.4 \text{ MV/m} \]

- Significant gradient degradation from XM6 to XM23, while CEA and Alysom put all their effort in achieving production goal of 1 CM/week: an audit of string and module assembly was conducted by CEA on XM26
- A simplification of the clean room procedures was introduced at XM54: no degradation after

No degradation, after \(~\text{XM54}\)
Fermilab: CM2 reached <31.5 MV/m >

CERN Courier December 2014

ILC-type cryomodule makes the grade

For the first time, the gradient specification of the International Linear Collider (ILC) has been achieved on average across an entire ILC-type cryomodule made of ILC-grade cavities. A team at Fermilab reached the milestone in early October. The cryomodule, called CM2, was developed to advance superconducting radio-frequency technology and infrastructure at laboratories in the Americas region, and was assembled and installed at Fermilab after initial vertical testing of the cavities at Jefferson Lab. The milestone—an achievement for scientists at Fermilab, Jefferson Lab, and their domestic and international partners in superconducting radio-frequency (SRF) technologies—has been nearly a decade in the making, from

Cryomodule test at Fermilab reached < 31.5 > MV/m, exceeding ILC specification

Comparison of CM-2/RFCA002 Cavity Gradients

ILC Milestone
31.5 MV/m

Cavity Location/Serial #
New Surface Process recently demonstrated at Fermilab, “N$_2$ Infusion at 120 C”

- N2 infusion at 120 C directly after heat treatment at 800 C,
- Same cavity, sequentially processed, no EP in b/w
- Achieved: 45.6 MV/m
  Q at ~ 35 MV/m : ~ 2.3e10
KEK-STF: Cavity/CM Performance, and RF 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>Cav. #</td>
</tr>
<tr>
<td>V. Test (CW)</td>
</tr>
<tr>
<td>in CM (pulse)</td>
</tr>
<tr>
<td>Gradient stable</td>
</tr>
</tbody>
</table>

*<G>: 30 MV/m (12 Cav.), 35 MV/m (best 8)

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 expected (to reach > 250 MeV)

Y. Yamamoto, E. Kako, H. Hayano
8 Cavities were tuned on resonance by piezo, and vector-sum operation was done at 31MV/m.
Effort to lead industrialization technology at KEK

**EBW**

SST EBOCAM KS-110 – G150KM Chamber (St. St. chamber)

**Press**

AMADA digital-survo-press SDE1522
150t, 50stroke/min, 225mmstroke

**Trim**

MORI VKL-253 Vertical CNC lathe

Chemical process

A. Yamamoto, 170123
KEK 9-Cell Cavity (KEK-01/02) reached 36/38 MV/m

KEK-01 (Rolled, FG, 2014): Reached 36 MV/m
KEK-02 (Ingot-sliced, LG, 2016): Reached 38 MV/m
<table>
<thead>
<tr>
<th>Year</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016</td>
<td>9-cell <strong>TESLA</strong>, <strong>fine grain</strong> cavity with HOM, by High-Energy Racing, process and test at KEK</td>
</tr>
<tr>
<td>2014</td>
<td>9-cell <strong>TESLA-like</strong>, fine grain cavity with HOM, 16.8 MV/m by EP, process and test at KEK</td>
</tr>
<tr>
<td>2012</td>
<td>9-cell <strong>Low Loss</strong>, <strong>large grain</strong> cavity with HOM, 20 MV/m by EP, process and test at FNAL</td>
</tr>
<tr>
<td>2010</td>
<td>9-cell low-loss, large grain cavity without HOM, 20 MV/m by CP, test at KEK and JLAB</td>
</tr>
<tr>
<td>2008</td>
<td>single cell low-loss large and fine cavity, max. 40 MV/m by CP, process and test at KEK</td>
</tr>
</tbody>
</table>
Quality control and cost reduction:

- **Niobium**: OTIC (EXFEL 35% 7 t, FRIB 50% 5 t, LCLS-II 50% 5.6 t …)
- **Cavity**: OTIC, HERT, BIAM (ILC, CADS, FRIB, HEPS, CEPC …)
- **Coupler**: HERT (ILC, CADS, RISP …), JNT
- **Cryomodule**: **WXCX** (EXFEL 60, LCLS-II 33, FRIB), HFJN (CADS)
  - LCLS-II cryomodule quality control (IHEP & SLAC-FNAL-JLAB collaboration)
A SCRF Industrialization Model

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

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

China has been already modelling/functioning as an industrialization partner
ILC Candidate Location: Kitakami, Tohoku

- Oshu
- Ichinoseki
- Ofunato
- Kesen-numa
- Sendai

High-way
Express-Rail
IP Region
ARUP Tunnel Optimisation Tool (TOT) for 100km Circular Lake Geneva Rhone Les Usses
Common Mountainous Condition in FCC and ILC

Future Circular Collider (FCC)

Elevation along the Circular candidate site

International Linear Collider (ILC)
TOT: Automatic searching for the best access route
Visualization of TOT-ILC

Panel-1: Map Plan View

Panel-2: Candidate Site Constraints
- Tunnel Length
- Tunnel Gradient
- Distance to Roads
- Distance to Buildings
- Distance to Rivers

Panel-3: Cross Section Profile

Panel-4: Output of Access Tunnel

A. Yamamoto, 170123
New Baselining of Civil-engineering,

Beam Line

- Assembly Place: Surface Building/AH
- Access way to DHI underground
  - only Inclined Access Tunnel (AT)
  - Transport. by special long trailer

- Assembly Place: Underground/DH
- Access way to DH underground
  - mainly Vertical Shaft (VS)
  - Transport. by Gantry Crane
Cryogenics Layout with Further Safety and Conserving He Resource
Outline

Introduction

Technical Progress and Status
- Nano-beam technology
- SRF technology
- Civil engineering

Readiness for the Project
- Further effort for the cost reduction and the R&Ds

Summary
Status and Prospect for ILC

We are here,
In 2017

(Pre-Preparation and) Preparation Phase

(~2+) 4 year

ILC Organization (ILC Lab.)

Construction Operation

(9 year)


<table>
<thead>
<tr>
<th>Topics</th>
<th>Pre-Preparation Stage</th>
<th>Main Preparation Stage</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ADI</strong></td>
<td>Present (we are here)</td>
<td>P1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P4</td>
</tr>
<tr>
<td><strong>SRF</strong></td>
<td>Establish main parameters</td>
<td>Verify parameters w/ simulations</td>
</tr>
</tbody>
</table>
|                 | Beam acc. with SRF cavity string, 
|                 | Cost Reduction R&D (proposed) | Demonstrate mass-production technology, 
|                 |                        | stability, hub-lab functioning, and global sharing |
| **Nano-beam**   | Achieve the ILC beam-size goal | Demonstrate the nanobeam size and stabilize the beam position |
| **e+**          | Demonstrate technological feasibility | Demonstrate both the undulator and e-driven e+ sources |
| **CFS**         | Pre-survey and basic design | Geology survey, engineering design, specification, and drawings |
## ILC SRF ML Parameters

<table>
<thead>
<tr>
<th>Component</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.3 GHz Nb 9-cell Cavities</td>
<td>16,024</td>
</tr>
<tr>
<td>Cryomodules</td>
<td>1,855</td>
</tr>
<tr>
<td>SC quadrupole pkg</td>
<td>673</td>
</tr>
<tr>
<td>10 MW MB Klystrons &amp; modulators</td>
<td>~400</td>
</tr>
</tbody>
</table>
A plan for ILC Cost-Reduction R&D in Japan and US focusing on SRF Technology, in 2~3 years

Based on recent advances in technologies;

- **Nb material** preparation
  - w/ optimum RRR and clean surface
- **SRF cavity fabrication** for high-Q and high-G
  - w/ a new baking recipe provided by Fermilab
- **Power input coupler** fabrication
  - w/ new (low SEE) ceramic without coating
- **Cavity chemical process**
  - w/ vertical EP and new chemical (non HF) solution
- **Others**
FG-Nb rolled or LG-Nb sliced from Ingot

Fabrication process of Nb sheets for Superconducting Cavities
Tokyo Denki Co., Ltd.

1. Mother Material
2. Pressing
3. Outgassing and Sintering
4. EB Melting(1st)
5. Sintering
6. Cutting
7. Forging
8. Mechanical grinding
9. Rolling
10. Polishing
11. Rolling
12. Cutting
13. Annealing
14. Testing
15. Polishing
16. Packing

Note

Cleanliness highly secured

Courtesy: G. Myneni

A. Yamamoto, 170123
G. Reached with Nb-Ingot Sliced

Result from DESY
# Standard Procedure Established

<table>
<thead>
<tr>
<th>Standard Fabrication/Process</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fabrication</strong></td>
</tr>
<tr>
<td>Nb-sheet purchasing</td>
</tr>
<tr>
<td>Component Fabrication</td>
</tr>
<tr>
<td>Cavity assembly with EBW</td>
</tr>
<tr>
<td><strong>Process</strong></td>
</tr>
<tr>
<td>EP-1 (~150um)</td>
</tr>
<tr>
<td>Ultrasonic degreasing with detergent, or ethanol rinse</td>
</tr>
<tr>
<td>High-pressure pure-water rinsing</td>
</tr>
<tr>
<td>Hydrogen degassing at &gt; 800 C</td>
</tr>
<tr>
<td>Field flatness tuning</td>
</tr>
<tr>
<td>EP-2 (~20um)</td>
</tr>
<tr>
<td>Ultrasonic degreasing or ethanol (or EP 5 um with fresh acid)</td>
</tr>
<tr>
<td>High-pressure pure-water rinsing</td>
</tr>
<tr>
<td>Antenna Assembly</td>
</tr>
<tr>
<td>Baking at 120 C</td>
</tr>
<tr>
<td><strong>Cold Test (vertical test)</strong></td>
</tr>
<tr>
<td>Performance Test with temperature and mode measurement</td>
</tr>
</tbody>
</table>

## Key Process

### Fabrication
- Material
- EBW
- Shape

### Process
- Electro-Polishing
- Ethanol Rinsing or
- Ultra sonic. + Detergent Rins.
- High Pr. Pure Water cleaning
# Standard Procedure Established

<table>
<thead>
<tr>
<th>Fabrication</th>
<th>Component Fabrication</th>
<th>Cavity assembly with EBW</th>
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<td></td>
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<td></td>
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</table>

- **N2 infusion at 120 C directly after heat treatment at 800 C**

<table>
<thead>
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<th>Cold Test (vertical test)</th>
<th>Performance Test with temperature and mode measurement</th>
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## Key Process

### Fabrication
- Material
- EBW
- Shape

### Process
- Electro-Polishing
- Ethanol Rinsing or Ultra sonic. + Detergent Rins.
- High Pr. Pure Water cleaning
New Surface Process recently demonstrated at Fermilab, “N₂ Infusion at 120 C”

- N₂ infusion at 120 C directly after heat treatment at 800 C,
- Same cavity, sequentially processed, no EP in b/w
- Achieved: 45.6 MV/m Q at ~ 35 MV/m : ~ 2.3e10
LCC, Next-term Organization
2017 ~ 2019
Cost reduction

- All of these measures will reduce the cost by 10-20%, but that is not enough for a realistic project funding.
- The beauty of a linear collider is that it can be staged.
- Serious discussions must now start on realistic staging scenarios to bring the cost of the first stage down.
<table>
<thead>
<tr>
<th>Project</th>
<th>SRF Cavity</th>
<th>Assoc.</th>
<th>CM</th>
<th>RF</th>
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<td>Fermilab</td>
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<td>Marx M.</td>
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<td>CERN</td>
<td>HL-LHC Thin-film (Nb on Cu)</td>
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<td>(Cornell)</td>
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# ILC Staging to be studied

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<tr>
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A. Yamamoto, 170123

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• **ILC** prepared for an e+e- collider, CE 500 GeV, extendable to 1 TeV.
• Nano-Beam technology demonstrated at **ATF hosted at KEK**
• SRF Technology advanced, and, particularly, demonstrated at E-XFEL for mass-production, and at Fermilab for High-Q and High-G.
• Cryogenics & Civil Eng/ works advanced, reflecting CERN-LHC exp.

• **Cost Reduction R&D work** required for SRF technologies, reflecting recent technology progress,
• **Study of the energy staging**, starting at C.E. 250 GeV, to be studied for realizing the project sooner.
reserved
Progress

\[ E_{\text{acc}} > 50 \text{ MV/m} \] is yet to be achieved in “low \( B_p \)” multi-cell cavities

Average gradient specification of current and future projects is \( \sim 20 \text{ MV/m} \)