Industrialization of the ILC Project

Marc Ross, SLAC
Linear Collider Collaboration - ILC
Prepared for IPAC 2013, Shanghai, 13-17 May, 2013
Keywords:

• High Technology
• Technology transfer
  – ‘valley of death’
  – ‘Galapagos syndrome’
• Global partnership
• Infrastructure development
• Plug Compatibility
  – Integration and modularity
• Intellectual Property
ILC Industrialization:

• **Introduction**
  – Scale of mass production for ILC
  – Preparing for ILC – Cost Model and Interface Definitions

• **Technical progress**
  – Cavity R&D

• **Technology Transfer**
  – Processing and testing recipe
  – Lab infrastructure

• **Working with Industrial partners**
  – Industrial infrastructure
  – Outreach, Workshops, Contracts

• **Summary**
From the outset ILC was conceived to be of such scientific scope that no single institution or region would be able to provide the needed resources for construction.
### SCRF Linac Technology

<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 / correction / BPM package</td>
<td>673</td>
</tr>
<tr>
<td>10 MW Multi-Beam Klystrons &amp; modulators</td>
<td>436</td>
</tr>
</tbody>
</table>

→ **Mature technology** ←

Above items ready for industrialization
ILC GDE: A Truly Global Effort

No “host” laboratory

- Design team(s) remain at their home institutes
- Funding via local agencies
- Global coordination by core management team

No precedence for a global project of this scale
• Distributed resources: **but Common Goals** → (and useful overlap with ongoing programs)

• Parallel activities in each region → *Promotes involvement of regional industry*

• Key performance parameters and interfaces defined and agreed to by Global Design team

• Cross-calibration
### European XFEL (DESY):
- **Construction complete in 2015**

### European XFEL vs. ILC (single linac)

<table>
<thead>
<tr>
<th>European XFEL</th>
<th>ILC (single linac)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum beam energy</td>
<td>GeV</td>
</tr>
<tr>
<td>Accelerating gradient</td>
<td>MV/m</td>
</tr>
<tr>
<td>Charge per bunch</td>
<td>nC</td>
</tr>
<tr>
<td>Number of bunches</td>
<td></td>
</tr>
<tr>
<td>Number of load cavities</td>
<td></td>
</tr>
<tr>
<td>Number of cryomodules</td>
<td></td>
</tr>
<tr>
<td>CAVities per klystron</td>
<td></td>
</tr>
<tr>
<td>Average beam power per klystron</td>
<td>MW</td>
</tr>
</tbody>
</table>

- **6% scale of ILC** – *most important industrial demo*

**12.5 m long cryomodule**

![Diagram of European XFEL and ILC](image)
Goal: Cost Effective Production

- Emphasize global approach
  - Multiple-region mass-production

1: R&D

2: Build-to-print scheme

3: Factory Floor plan...

4: Intellectual Property

5: Global Project Implementation

Cost Effective Mass-Production

- Develop realistic models on which to base cost estimate
  - With participating industry & institutions

- In-kind contribution models

- Plug Compatible Interfaces

- Cavity Specs. / Yield

- Vendor models

- Production process models
ILC Cost Model

• Allows funding agencies to assess needed resources

• A tool for further cost optimization and iteration
  – *Specific production plans studied and evaluated for Technology Drivers:* by experienced, Qualified Vendors
  – ‘Learning Curve’ mass-production scaling for others

• Project Planning:
  – Consideration of governance and procurement models

• Qualified Industrial Partners help to create a defendable ILC cost estimate by providing detailed, understandable basis
ILC Cost Model: Basis type

<table>
<thead>
<tr>
<th>Item</th>
<th>TDR Cost Basis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superconducting material</td>
<td>EXFEL procurement †</td>
</tr>
<tr>
<td>Cavity resonator</td>
<td>industrial study †</td>
</tr>
<tr>
<td>Power coupler</td>
<td>EXFEL procurement †</td>
</tr>
<tr>
<td>Tuner</td>
<td>EXFEL procurement †</td>
</tr>
<tr>
<td>Helium vessel</td>
<td>EXFEL procurement †</td>
</tr>
<tr>
<td>Magnet package</td>
<td>vendor quote †</td>
</tr>
<tr>
<td>Cryostat materials</td>
<td>EXFEL procurement †</td>
</tr>
<tr>
<td>Cryomodule assembly</td>
<td>industrial study †</td>
</tr>
</tbody>
</table>

† discount based on a 95% learning curve

Cost Basis type for ENTIRE ILC estimate

SC Linac: 35% Value estimate

15.05.2013
BN* Learning Curve – LHC dipoles

- “...the learning percentage for the LHC dipole production lies, not surprisingly, between shipbuilding and aerospace production”


* Babcock Noell Group 15.05.2013
‘Plug-Compatibility’

≡ *Functional interface definition for key components*

• Promote diversity and innovative contributions within specified interface
  – Effective inter-lab tech transfer; many examples
  – Strengthens overlap with partner lab programs by providing technical flexibility

• Take the lowest cost ‘demonstrated component’ for the estimate but expect

• Plug-Compatibility to be applied for both R & D *and construction phase*
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- **Technology Transfer**
  - Processing and testing recipe
  - Lab infrastructure

- **Working with Industrial partners**
  - Industrial infrastructure
  - Outreach, Workshops, Contracts

- **Summary**
**ILC SCRF R&D Chronology**

<table>
<thead>
<tr>
<th>Year</th>
<th>Cavity</th>
<th>Cryomodule</th>
<th>Dedicated BeamTests</th>
<th>Industrialization and Communication with Industry</th>
<th>Path to qualification: Actually building cavities</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>Cavity Gradient (CW vertical test)</td>
<td>~ 100 cavities (total) from the 3 regions for:</td>
<td>Integration test: the ‘global cryomodule’</td>
<td>1st Visit Vendors (2009), Organize Workshop (2010)</td>
<td>15.05.2013, IPAC 13, Marc Ross, SLAC</td>
</tr>
<tr>
<td>2010</td>
<td></td>
<td></td>
<td></td>
<td>2nd visit and communication, Organize 2nd workshop (2011)</td>
<td></td>
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<tr>
<td>2013</td>
<td></td>
<td></td>
<td></td>
<td>3rd communication and study contracts (2011-2012)</td>
<td></td>
</tr>
</tbody>
</table>

- **Cavity Gradient (CW vertical test)**: 
  - Integration test: the ‘global cryomodule’
  - 1st Visit Vendors (2009), Organize Workshop (2010)
  - 2nd visit and communication, Organize 2nd workshop (2011)
  - 3rd communication and study contracts (2011-2012)

- **Cryomodule** – (tested without beam)

- **Dedicated BeamTests**

- **Industrialization and Communication with Industry**
A Global Cavity Test Result Database:

- to help define process and assess performance
- “One sheet to plot them all”

Production yield: Limit of 2 chemical processing cycles
Primary result of a given cavity vertical test: **6 pathologies**

\[ I \approx (\beta E_{SP})^{2.5} \exp \left( -\frac{\alpha}{\beta E_{SP}} \phi^{1.5} \right) \]
Vertical Cavity Test Results at DESY: 1995-2006 – the great decade of SRF R&D

DESY: Establishing the basic recipe

ACID ETCH
ElectroPolish

2012 ILC Average: 37 MV/m

103 cavities / 434 tests
4.2 tests/cavity average

IPAC 13, Marc Ross, SLAC

DESY: Establishing the basic recipe
12 GeV cavities: overall performance

Vertical Test; 1500 MHz 7 cell; 10% gradient correction

Cavities made by RI (Germany); Followed ILC Process

Reported 11.2012 by F. Pilat

CEBAF 12 GeV upgrade

72/86 @ admin limit (85%)
Global Progress in ILC Cavity Gradient Yield

(94+/−6)% pass: Mass Production trial

15/16 > 28 MV/m
12/16 > 35 MV/m

- Followed Standard Process
- NOT MORE THAN 2 Process/Test CYCLES
- Mimic industrial strategy

2nd pass yield - established vendors, standard process

>28 MV/m yield
>35 MV/m yield

KILC 2012

2010-2012(16)

2006-2007(3)
2008(10)
2009(9)

Yield [%]

0
20
40
60
80
100

test date (#cavities)
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• **Working with Industrial partners**
  – Industrial infrastructure
  – Outreach, Workshops, Contracts

• **Summary**
Cavity/ Cryomodule Fabrication

- Niobium sheets / tubes
- Deep drawing half-cells / end groups
- HOM antenna

**He Tank**

- Acceptance Test (Lab.)
- Helium Tank (EB) Welding
- Mechanical Tuner assembly
- Cryostat and "cold-mass"

**Mechanical fabrication (EB welding)**

- Optical inspection, leak checking, RF tuning
- Surface treatment (EP, HPR, baking)

**Surface Process**

- String assembly (clean room)
- Cryomodule assembly

**LHe-Tank Assembly**

- Vertical Test = Cavity RF Test
- Cryomodule Assembly and RF Test

**Cavity Fabrication**

- Material/ Sub-component
As-delivered XFEL cavity:
Cavity Surface Processing and testing recipe adopted by EU-XFEL (pg 1)
Reference for Cavity Specification except for Tuner

- Technical guideline for ILC-GDE TDR and the cost estimate:
  - referring Specifications for E-XFEL SCRF 1.3 GHz Cavity, issued by DESY
    - EXFEL/001 and associated documents: Rev.B, June 2009, by courtesy of W. Singer (DESY-XFEL),
    - The reference specification is available with ILC-GDE PMs, under permission of W. Singer (DESY-XFEL)
    - URL: http://ilcagenda.linearcollider.org/event/ILC-SCRF-TR

From European XFEL (DESY):
- **Full Cavity specification as a basis for cost / industrial studies**
- Starting-point document
Cryomodule Development & Test

- KEK: STF (S1-Global)

- FNAL: NML Facility

- DESY: XFEL
  - including prototype module ACC7 in FLASH (~30MV/m)
• Supported through Chinese innovation initiative ‘973’
A first real test of ‘Plug- Compatibility’
Saclay Cryomodule Assembly:

cavity strings assembly
cryomodules assembly
BPMs system
DESY Cavity/Cryomodule Test Facility

- XFEL Module testing at DESY
- ILC cavity/cryomodule production testing can be done with ~ 3 such test facilities.
- A factor of 3: 20 X more CM / 2 period of time / 3 regions
Fermilab: RF Unit Test Facility

1st Cryomodule tested
2nd Cryomodule connected
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  – Lab infrastructure

• **Working with Industrial partners**
  – Industrial infrastructure & Sharing responsibilities
  – Outreach, Workshops, Contracts

• **Summary**
Electron Beam Melting

As a result of the increasing demand for refractory metals in the last few decades, the electron-beam furnace has been developed to a reliable, efficient apparatus for melting and purification.

Critical industrial Infrastructure 1: Vacuum Smelter for purifying Nb
6 such moderate size vacuum smelting plants operating at capacity for 2 to 3 yrs. (Similar Nb total for LHC; specs are different for magnet conductor)

Heraeus, Germany (others: ATI-WahChang, Tokyo Denkai, OTIC Ningxia)

500KW electron beam cold hearth furnace
Electron Beam Welding at KEK:

- Goal: Develop welding parameters and tooling openly, at an institution, and share with industrial partners
- Cost of tooling development absorbed by institution

Critical industrial Infrastructure 2: Electron Beam Welder
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, & …
<table>
<thead>
<tr>
<th>Step hosted</th>
<th>Industry</th>
<th>Industry/Laboratory</th>
<th>Hub-laboratory</th>
<th>ILC Host-laboratory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regional constraint</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Accelerator</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>- Integration, Commissioning</td>
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<tr>
<td>SCRF Cryomodule</td>
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<td></td>
<td></td>
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<tr>
<td>- Performance Test</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Cryomodule/Cavity</td>
<td></td>
<td>Coupler, tuner, cav-string/cryomodule assembly work</td>
<td>As partly as hub-lab</td>
<td></td>
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<tr>
<td>- Assembly</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cryomodule component</td>
<td>V. vessel, cold-mass ...</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Manufacturing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9-cell Cavity</td>
<td></td>
<td>Cold, gradient test</td>
<td>As partly as hub-lab</td>
<td></td>
</tr>
<tr>
<td>- Performance Test</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9-cell Cavity</td>
<td></td>
<td>9-cell-cavity assembly, Chem-process, He-Jacketing</td>
<td>As partly as hub-lab</td>
<td></td>
</tr>
<tr>
<td>- Manufacturing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sub-comp/material</td>
<td>Nb, Ti, specific comp. ...</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Production/Procurement</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
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• **Summary**
• Is there a viable SCRF business model?
  – **Maybe!** (applications presented at IPAC13)

• Scale of production needed for ILC is too large and could not be part of that but…
  – IP gained along the way definitely would be
  – And must be vigorously protected

• Plant development and business scheme different character from LHC experience
Niobium Superconducting Cavities
1.3 GHz 9-Cell ILC/TESLA

Niobium in stock for quick delivery!

$49,999*

*Entry level niobium cavity delivered in 3 months (other options available).

Let us help you customize the exact niobium structure you need from 28 MHz to 3.9 GHz and beyond.

www.niowaveinc.com
sales@niowaveinc.com
517.999.3475

Contact us to discuss your needs
Communication w/ Industry

- multiple ~½ day visits and
- open workshops

Visits to SC Cavity Manufacturers in Global Industry: 2009

Europe:
- RI (ACCEL)
- ZANON

Americas:
- AES
- NIOWAVE
- PAVAC

Asia:
- MHI
- HITACHI (expected)
- TOSHIBA (expected)

A Satellite Meeting at IPAC-2010

SCRF Cavity Technology and Industrialization

Date: May 23, 2010, a full-day meeting, prior to IPAC-2010
Place: Int. Conf. Center, Kyoto, Japan
Organized by: ILC-GDE Project Managers,

The 2nd workshop on SCRF Technology and Industrialization for the ILC

as a satellite meeting of SRF 2011
- Date: July 24, 2011
- Place: Chicago
- Agenda:
  - Introduction
  - Reports from SCRF cavity/cryomodule industry
  - Reports from SC material vendor
  - Comments from Potential Regional Hub-laboratory
  - Discussions on the ILC SCRF industrialization model
- Note:
  - Open for everybody,
  - Many Industrial participations acknowledged
ILC Global Design Effort Project Manager visit to SCRF cavity-cryomodule manufacturers

February - March 2011

In the ILC-GDE Technical Design Phase 2, we intend to seek for cost-effective mass-production scenarios for the SCRF cavity and cryomodule systems. As the primary cost driver for the ILC, establishing a defendable and realistic cost for the industrial manufacture with a level of 2,000 cryomodules will be by far the most critical issue facing the GDE as it prepares for the Technical Design Report at the end of 2012.

This webpage is intended to capture the material presented to vendors and to include key references.

ILC-SCRF Status and Preparation for Industrialization of Cavity and Cryomodule (pdf, English)  
Akira Yamamoto, Marc Ross, Nick Walker - Project Managers for the ILC Global Design Effort, Prepared for visiting SCRF cavity/cryomodule manufacturers, Revised May 2011

Preparation for ILC SCRF Cavity and Cryomodule Industrialization (pdf)  
Akira Yamamoto, Marc Ross, Nick Walker - Project Managers for the ILC Global Design Effort, Revised May 2011.

~½ day visits: use of common presentation material
<table>
<thead>
<tr>
<th>#</th>
<th>Date</th>
<th>Company</th>
<th>Place</th>
<th>Technical subject</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2/8, 2011</td>
<td>Hitachi</td>
<td>Tokyo (JP)</td>
<td>Cavity/Cryomodule</td>
</tr>
<tr>
<td>2</td>
<td>2/8</td>
<td>Toshiba</td>
<td>Yokohana (JP)</td>
<td>Cavity/Cryomodule, SCM</td>
</tr>
<tr>
<td>3</td>
<td>2/9</td>
<td>MHI</td>
<td>Kobe (JP)</td>
<td>Cavity / Cryomodule</td>
</tr>
<tr>
<td>4</td>
<td>2/9</td>
<td>Tokyo Denkai</td>
<td>Tokyo (JP)</td>
<td>Material (Nb)</td>
</tr>
<tr>
<td>5</td>
<td>2/18</td>
<td>OTIC</td>
<td>NingXia (CN)</td>
<td>Material (Nb, NbTi, Ti)</td>
</tr>
<tr>
<td>6</td>
<td>(3/3), 9/14</td>
<td>Zanon</td>
<td>Schio (IT)</td>
<td>Cavity/Cryomodule</td>
</tr>
<tr>
<td>7</td>
<td>3/4,</td>
<td>RI</td>
<td>Koeln (DE)</td>
<td>Cavity</td>
</tr>
<tr>
<td>8</td>
<td>(3/14), 4/8</td>
<td>AES</td>
<td>Medford, NY (US)</td>
<td>Cavity</td>
</tr>
<tr>
<td>9</td>
<td>(3/15), 4/7</td>
<td>Niowave</td>
<td>Lansing, MI (US)</td>
<td>Cavity/Cryomodule</td>
</tr>
<tr>
<td>10</td>
<td>4/6</td>
<td>PAVAC</td>
<td>Vancouver (CA)</td>
<td>Cavity</td>
</tr>
<tr>
<td>11</td>
<td>4/25</td>
<td>ATI Wah-Chang</td>
<td>Albany, OR (US)</td>
<td>Material (Nb, Nb-Ti, Ti)</td>
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<tr>
<td>12</td>
<td>4/27</td>
<td>Plansee</td>
<td>Ruette (AS)</td>
<td>Material (Nb, Nb-Ti, Ti)</td>
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<tr>
<td>13</td>
<td>5/24</td>
<td>SDMS</td>
<td>Sr. Romans (FR)</td>
<td>Cavity</td>
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<td>14</td>
<td>7/6</td>
<td>Heraeus</td>
<td>Hanau (DE)</td>
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<td>15</td>
<td>10/18</td>
<td>Babcock-Noell</td>
<td>Wurzburg (DE)</td>
<td>CM assembly study</td>
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<tr>
<td>16</td>
<td>11/11</td>
<td>SST</td>
<td>Maisach (DE)</td>
<td>Electron Beam Welder</td>
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</tbody>
</table>
## The 3rd Cycle Communication with Companies

Further studies with contracts in 2011-2012

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</table>
### Mass-Production Study

#### Contracts:

<table>
<thead>
<tr>
<th>Company</th>
<th>Mass production model</th>
<th>Contract funded/hosted by</th>
</tr>
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<tbody>
<tr>
<td>Cavity</td>
<td>RI</td>
<td>DESY</td>
</tr>
<tr>
<td>AES</td>
<td>20%</td>
<td>DOE/Fermilab</td>
</tr>
<tr>
<td>MHI</td>
<td>20, 50, 100%</td>
<td>KEK</td>
</tr>
<tr>
<td>Quadrupole</td>
<td>Toshiba</td>
<td>KEK</td>
</tr>
<tr>
<td>CM and assembly</td>
<td>Hitachi</td>
<td>KEK</td>
</tr>
<tr>
<td>AES</td>
<td>25%</td>
<td>DOE/Fermilab</td>
</tr>
<tr>
<td>CM assembly</td>
<td>BN</td>
<td>CERN</td>
</tr>
</tbody>
</table>

*In parallel, EXFEL experience communicated by DESY, INFN, CES/Saclay*
Summary

• Communication w/ Industry on many topics
  – We continue to seek cost effective production strategies by:
    • Widening cooperation with industry
    • also emphasize in-house mass-production studies
  – Industry provided cost information; various models (20 ~ 100 %).

• Cost study in Communication with Laboratories
  – Communication with potential regional hub-laboratories to establish
cryomodule assembly and test schemes; esp. required infrastructure

• Further Study required
  – Cost effective industrialization studies for:
    • Couplers, cryomodule assembly and test, etc
  – Industrialization models for a world-wide cooperative project
Acknowledgments:

- **Industrial Partners for ILC:**
  - (Cannot name them all…)

- **NingXia OTIC, CX Wuxi, Tokyo Denkai, Toshiba (Nasu and Keihin), MHI, AES, RI, BN, Zanon, CPI, DTI, Mega, Niowave, Pavac, ATI-Wah Chang, Hitachi, Heraeus, Thales, …**