Industrialization of the ILC Project

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Linear Collider Collaboration - ILC

Prepared for IPAC 2013, Shanghai, 13-17 May, 2013

Keywords:

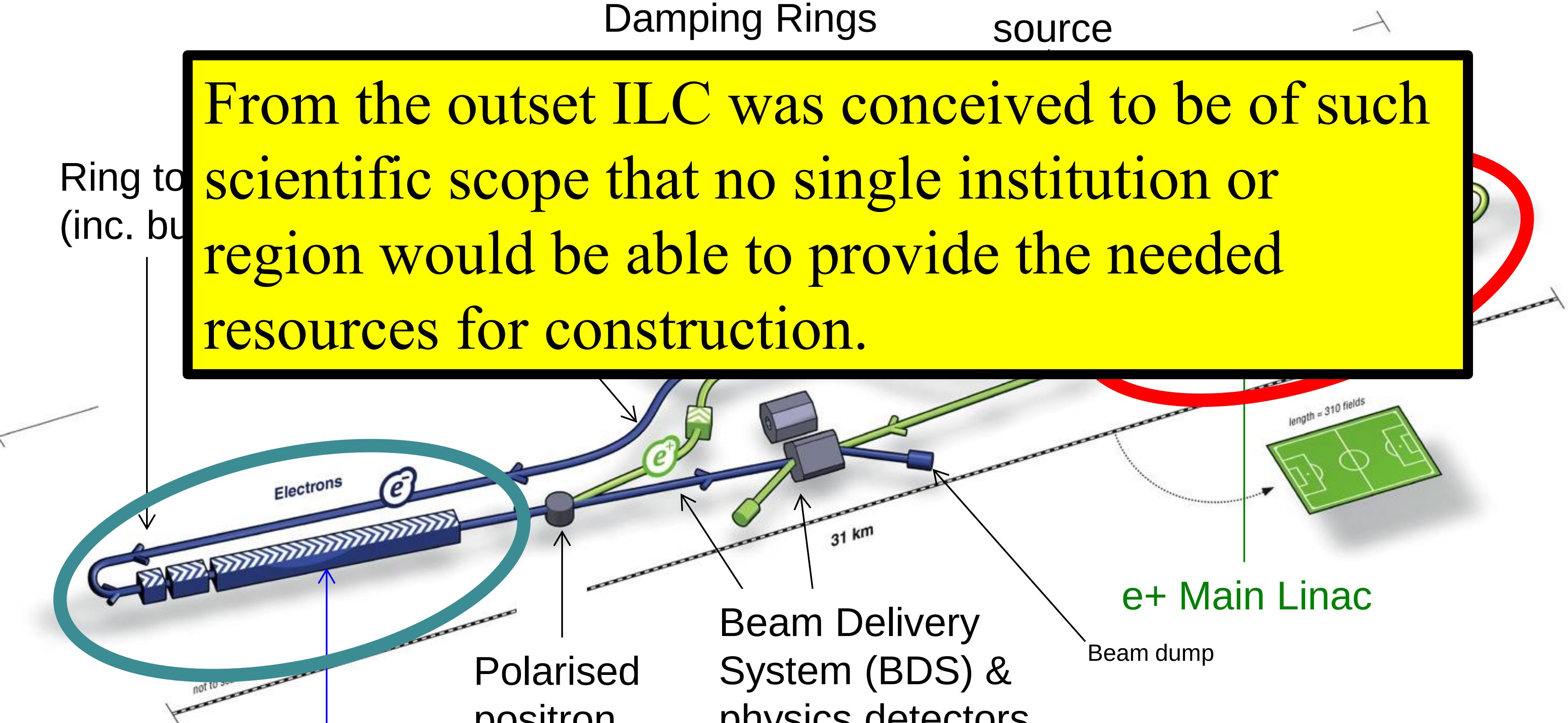
- **High Technology**
- **Technology transfer**
  - ‘valley of death’
  - ‘Galapagos syndrome’
- **Global partnership**
- **Infrastructure development**
- **Plug Compatibility**
  - Integration and modularity
- **Intellectual Property**

8-track tape
(ca 1968)

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**

ILC in a Nutshell

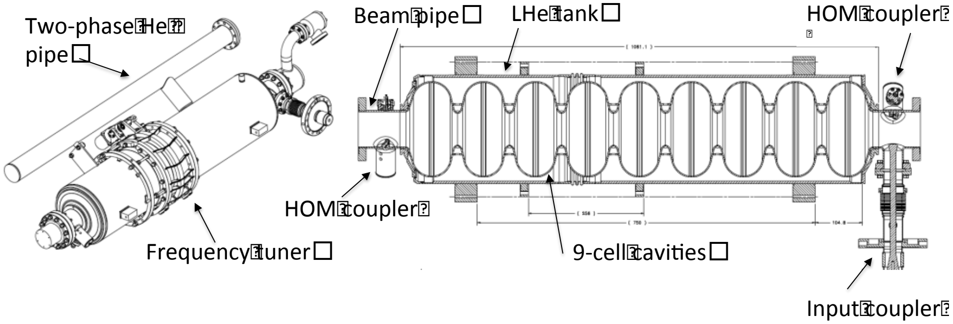


From the outset ILC was conceived to be of such scientific scope that no single institution or region would be able to provide the needed resources for construction.

not too scale

ILC Scheme | © www.form-one.de

SCRF Linac Technology

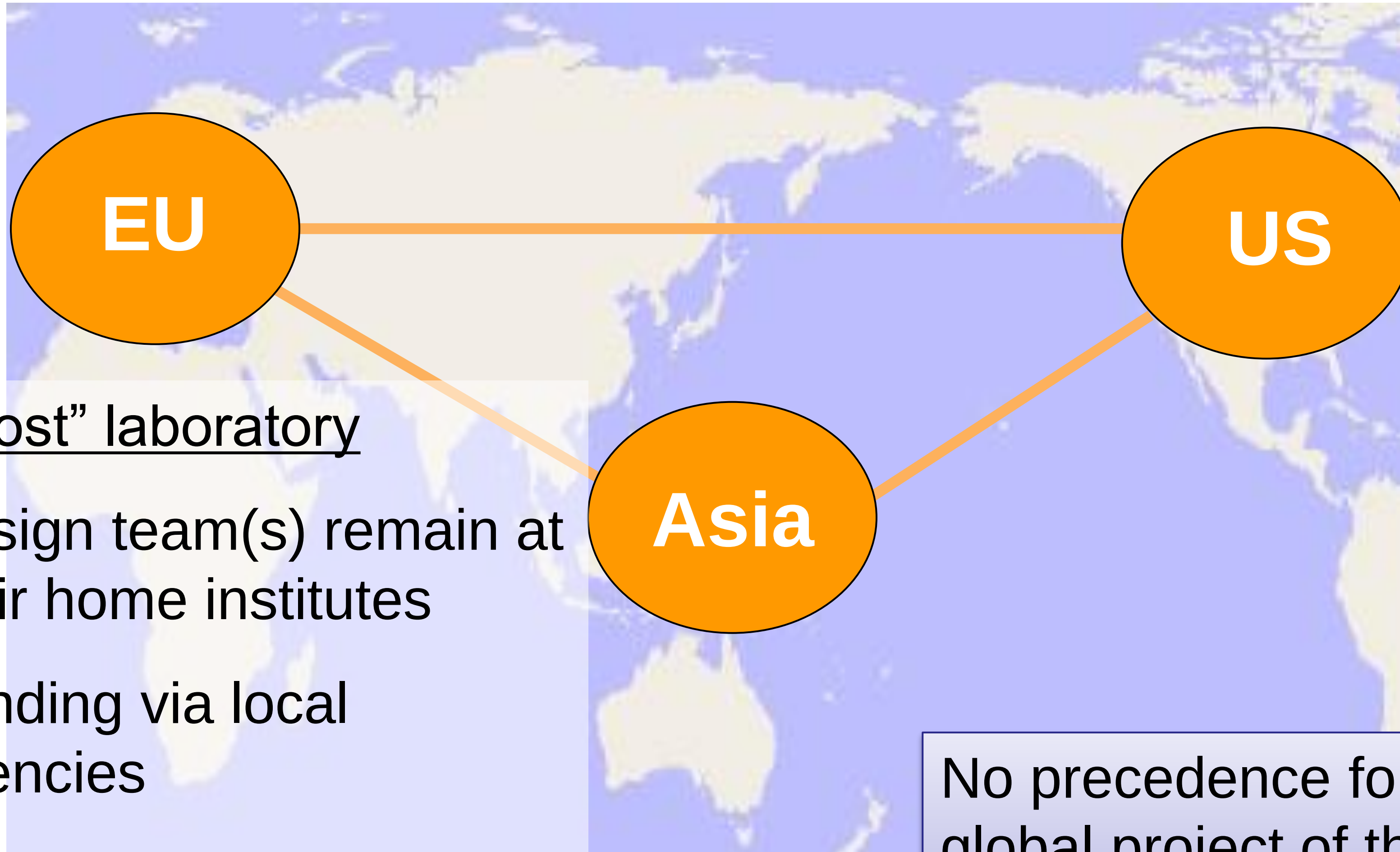


1.3 GHz Nb 9-cell Cavities	16,024
Cryomodules	1,855
SC quadrupole / correction / BPM package	673
10 MW Multi-Beam Klystrons & modulators	436

→ Mature technology ←

Above items ready for industrialization

ILC GDE: A Truly Global Effort



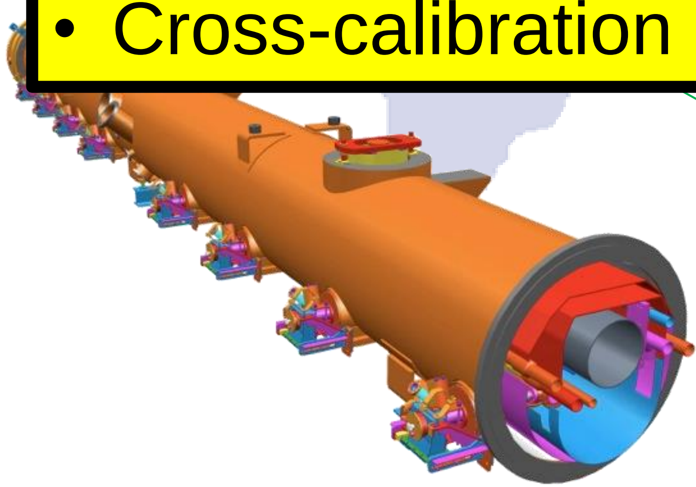
<u>No "host" laboratory</u>

- 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

Global ILC SCRF Technology

- Distributed resources: ***<u>but Common Goals</u>*** → (and useful overlap with ongoing programs)
- Parallel activities in each region → ***Promotes <u>involvement of regional industry</u>***
- Key performance parameters and interfaces defined and agreed to by Global Design team
- Cross-calibration



		European XFEL	ILC (single linac)
Maximum beam energy	GeV	17.5	250
Accelerating gradient	MV/m	23.6	31.5
Charge per bunch	nC	1	3.2
Nu[illegible]	[illegible]	[illegible]	[illegible]
Re[illegible]	[illegible]	[illegible]	[illegible]
Bu[illegible]	[illegible]	[illegible]	[illegible]
Be[illegible]	[illegible]	[illegible]	[illegible]
Be[illegible]	[illegible]	[illegible]	[illegible]
Matched loaded Q		4.7×10^6	5.5×10^6
Fill time	µs	803	927
RF pulse length	ms	1.45	1.65
Number of klystrons		29	188/205
Number of cavities		800	7332
Number of cryomodules		100	846
Cavities per klystron		32	39/36
Average beam power per klystron	MW	3.92	7.37/6.80

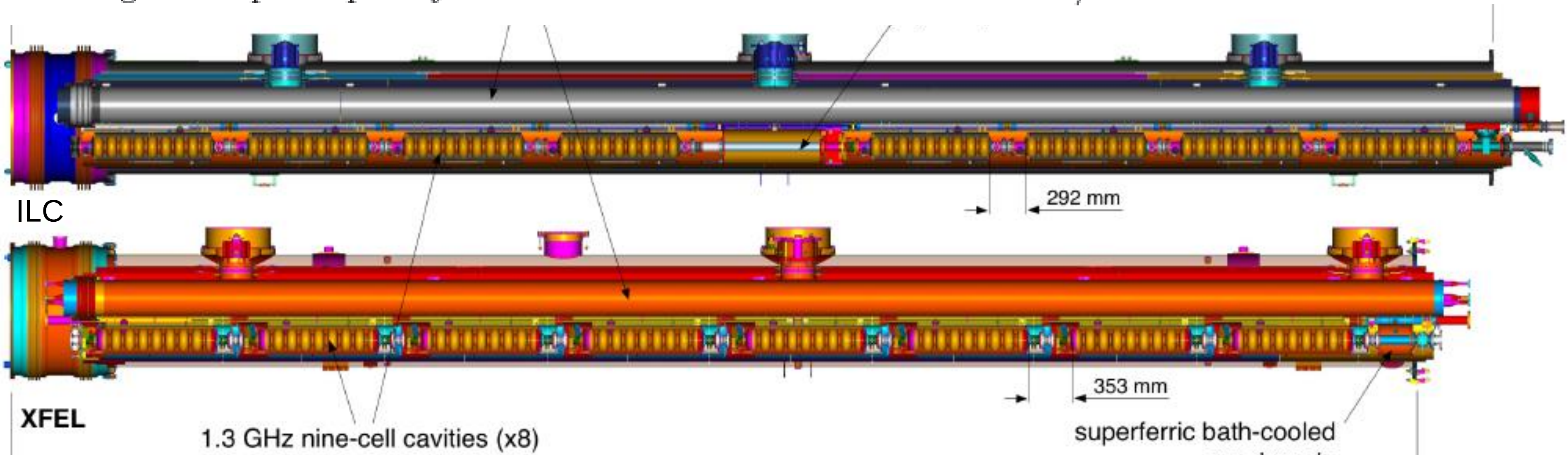
European XFEL (DESY):

- ***Construction complete in 2015***

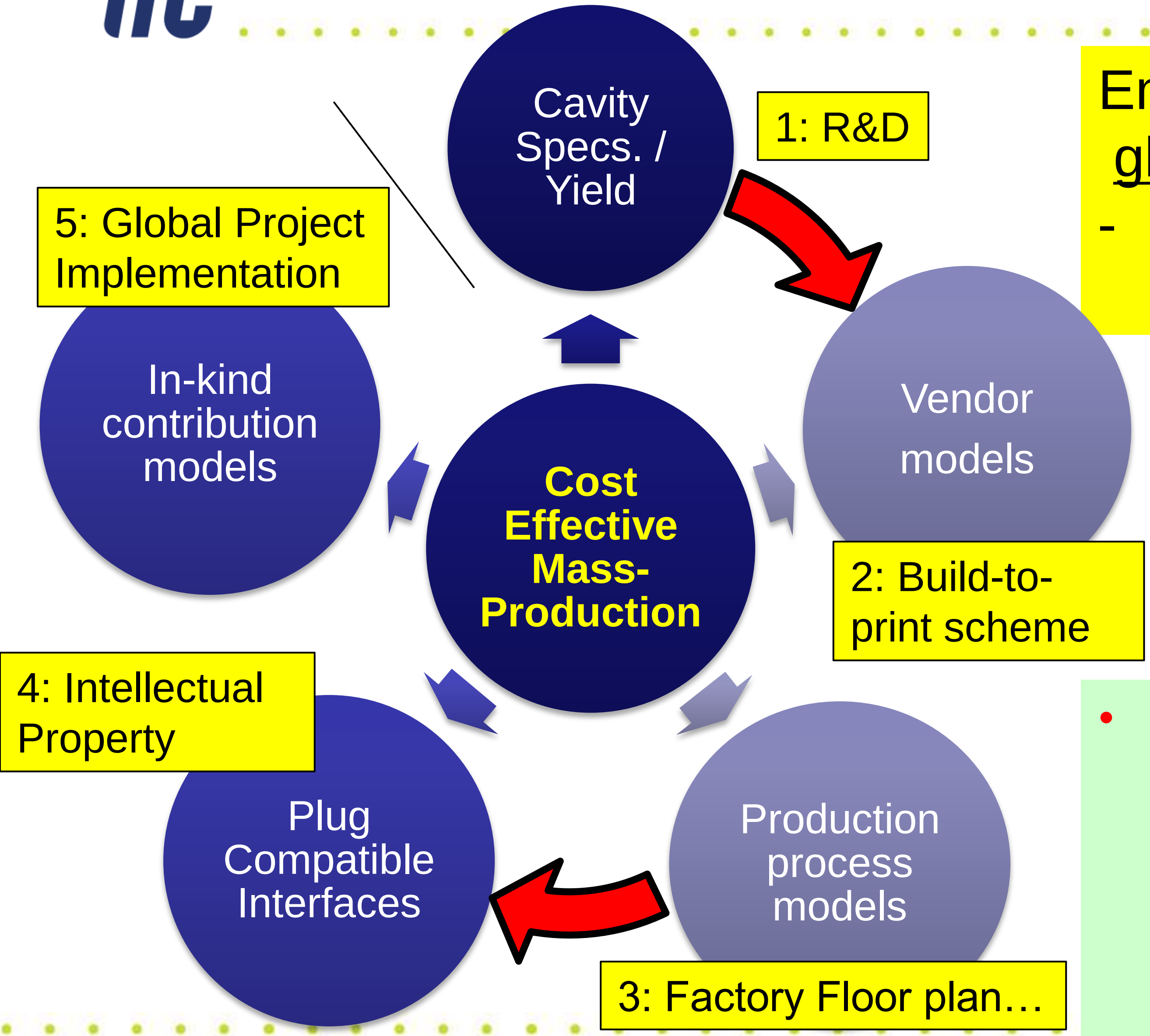
EU-XFEL

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

12.5 m long cryomodule



Goal: Cost Effective Production



Emphasize <u>global approach</u>
- Multiple-region mass-production

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

ILC Cost Model

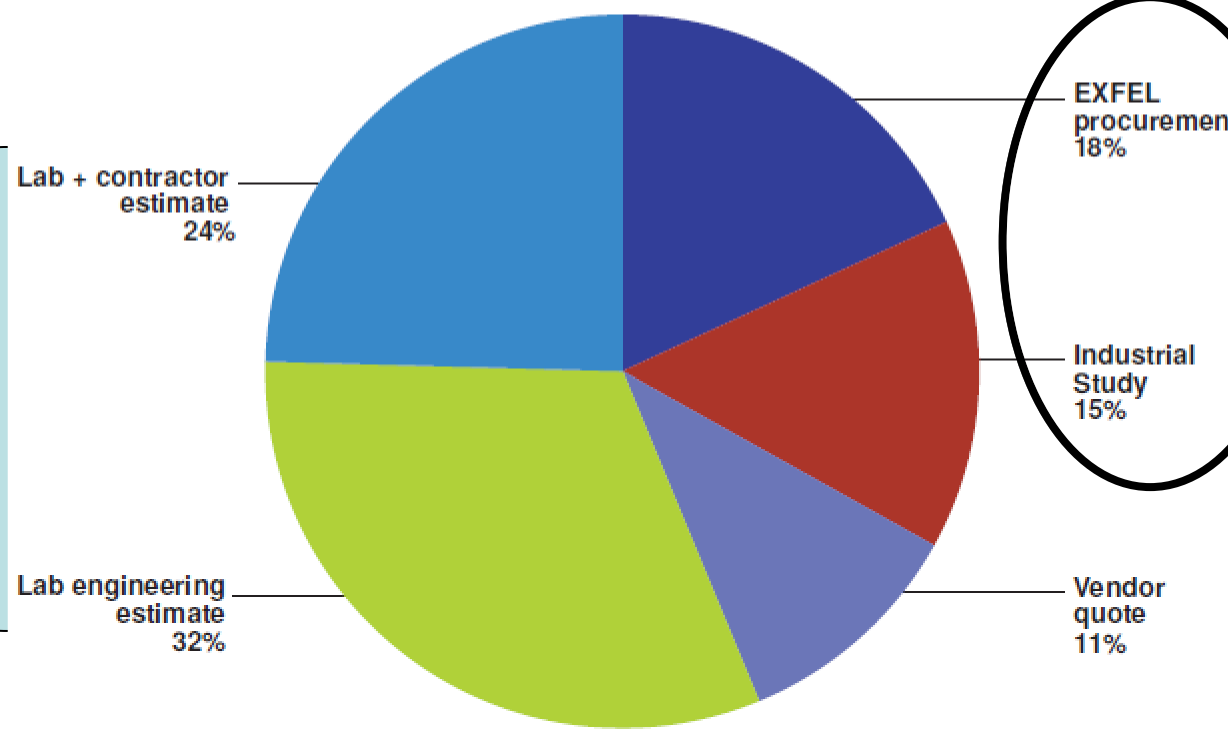
- **Allows funding agencies to assess needed resources**
- **A tool for further cost optimization and iteration**
  - ***Specific production plans studied and evaluated for*** ***Technology Drivers***: by experienced, Qualified Vendors
  - ‘Learning Curve’ mass-production scaling for others
- **Project 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***

Item	TDR Cost Basis
Superconducting material	EXFEL procurement[†]
Cavity resonator	industrial study
Power coupler	EXFEL procurement[†]
Tuner	EXFEL procurement[†]
Helium vessel	EXFEL procurement[†]
Magnet package	vendor quote
Cryostat materials	EXFEL procurement[†]
Cryomodule assembly	industrial study

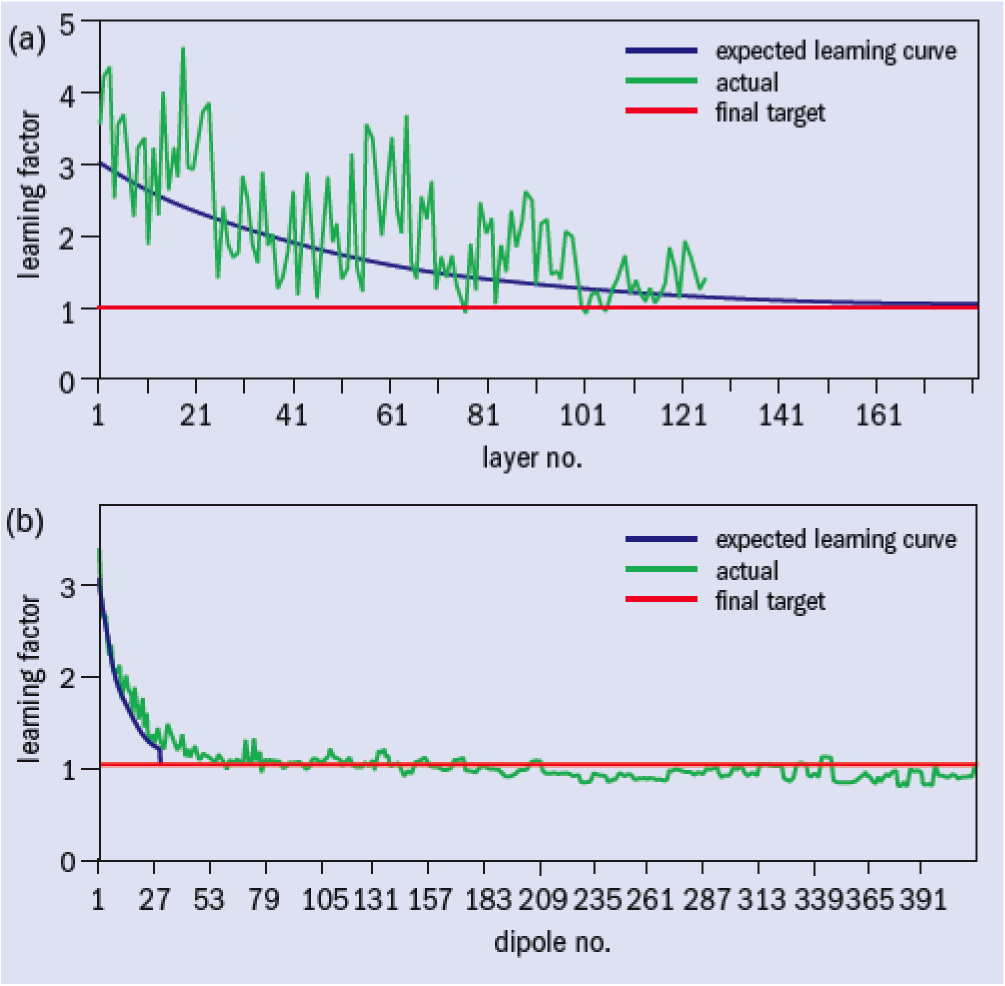
[†] discount based on a 95 % learning curve

SC Linac: 35% Value estimate



Cost Basis type for ENTIRE ILC estimate

BN* Learning Curve – LHC dipoles



- "…the learning percentage for the LHC dipole production lies, not surprisingly, between shipbuilding and aerospace production"

"The Longest Journey – The LHC dipoles arrive on time" L. Rossi, CERN Courier 10.2006

* Babcock Noell Group

‘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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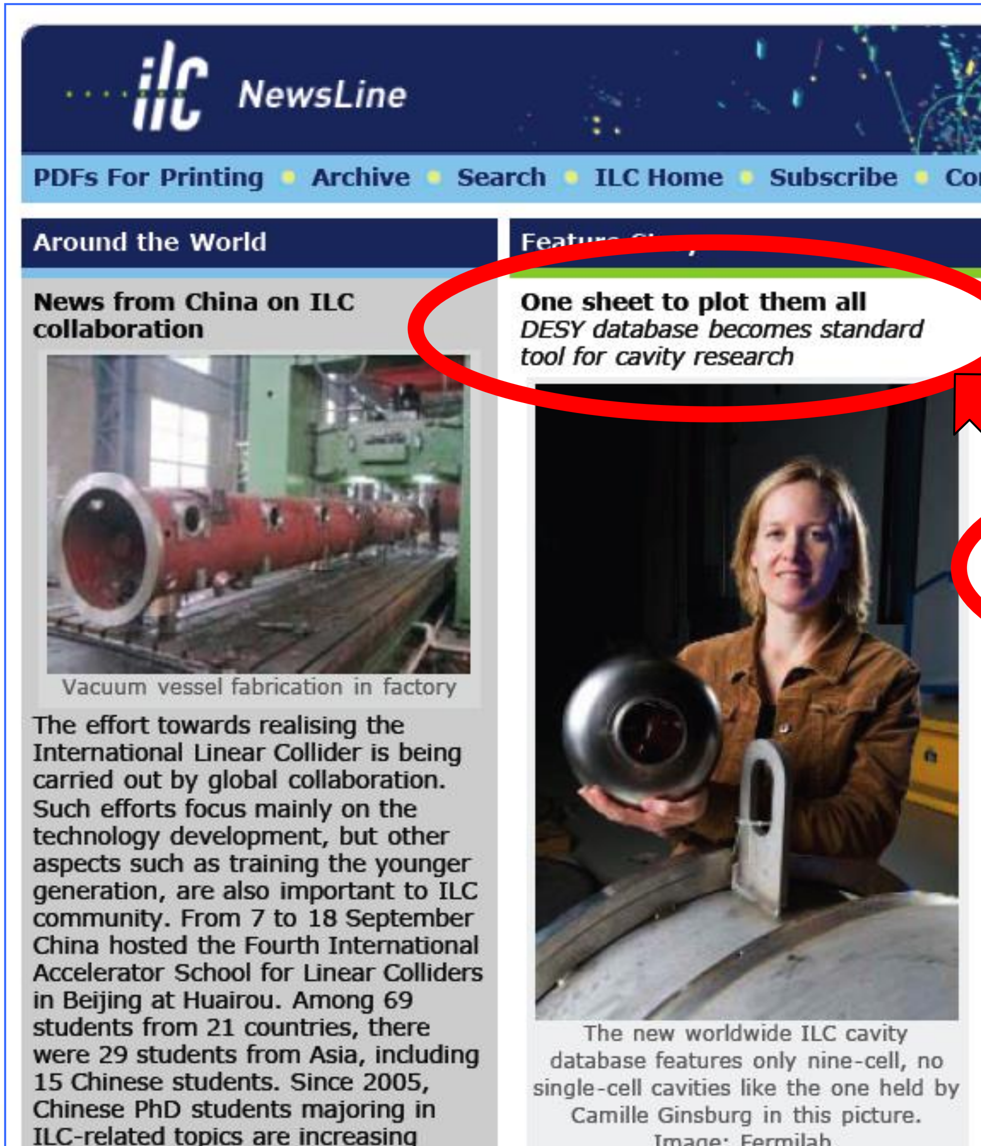
ILC SCRF R&D Chronology

	2006	2010	2013 →
Cavity Gradient (CW vertical test)	~ 100 cavities (total) from the 3 regions for:		'production yield', process development, vendor development and R&D
Cryomodule – (tested without beam)		**Integration test: the '*global cryomodule*'**	XFEL AMTF
Dedicated BeamTests		**FLASH - DESY (mainly)**	
Industrialization and ***Communication*** with Industry:		1st Visit Vendors (2009), Organize Workshop (2010) 2nd visit and communication, Organize 2nd workshop (2011) 3rd communication and study contracts (2011-2012)	

Path to qualification:

Actually building cavities

A Global Cavity Test Result Database: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Around the World

News from China on ILC collaboration

Vacuum vessel fabrication in factory

The effort towards realising the International Linear Collider is being carried out by global collaboration. Such efforts focus mainly on the technology development, but other aspects such as training the younger generation, are also important to ILC community. From 7 to 18 September China hosted the Fourth International Accelerator School for Linear Colliders in Beijing at Huairou. Among 69 students from 21 countries, there were 29 students from Asia, including 15 Chinese students. Since 2005, Chinese PhD students majoring in ILC-related topics are increasing

One sheet to plot them all

DESY database becomes standard tool for cavity research

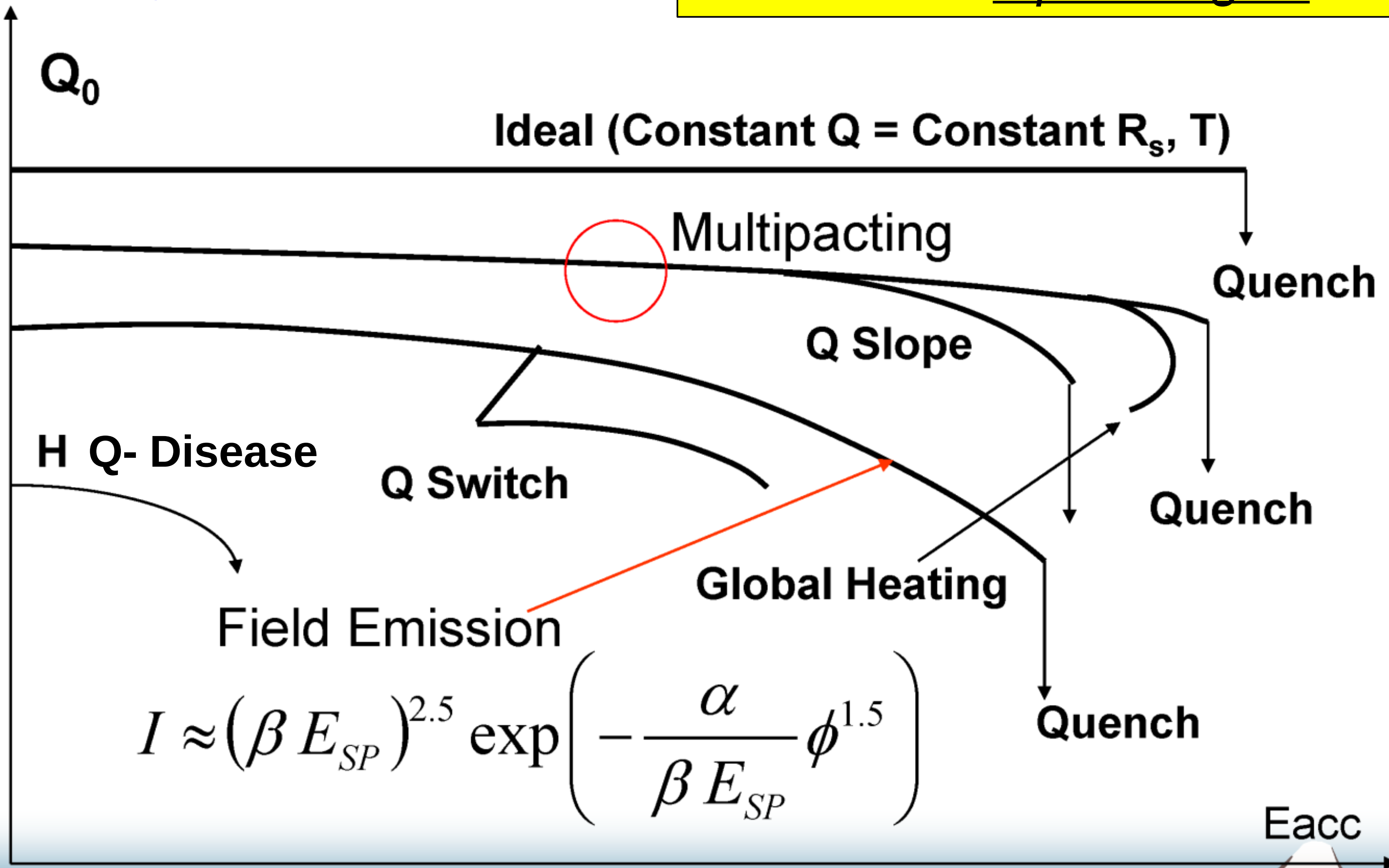
The new worldwide ILC cavity database features only nine-cell, no single-cell cavities like the one held by Camille Ginsburg in this picture. Image: Fermilab.

- **to help define process and assess performance**
- **"One sheet to plot them all"**

<u>Production</u> yield:
Limit of 2 chemical processing cycles

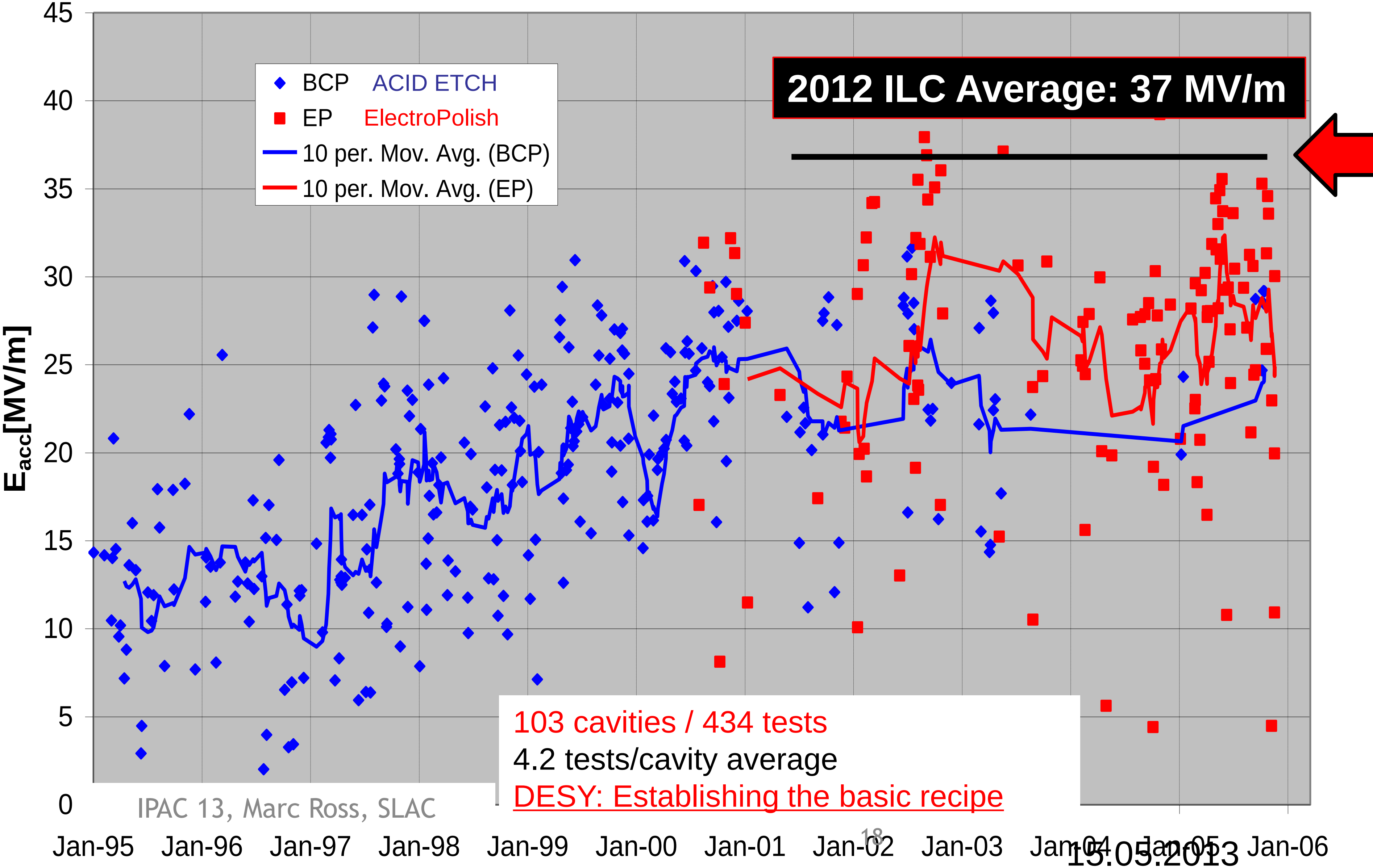
Q-E Curves

Primary result of a given cavity vertical test: ***6 pathologies***



Shuichi Noguchi、KEK 6-th ILC School, November 2011 12

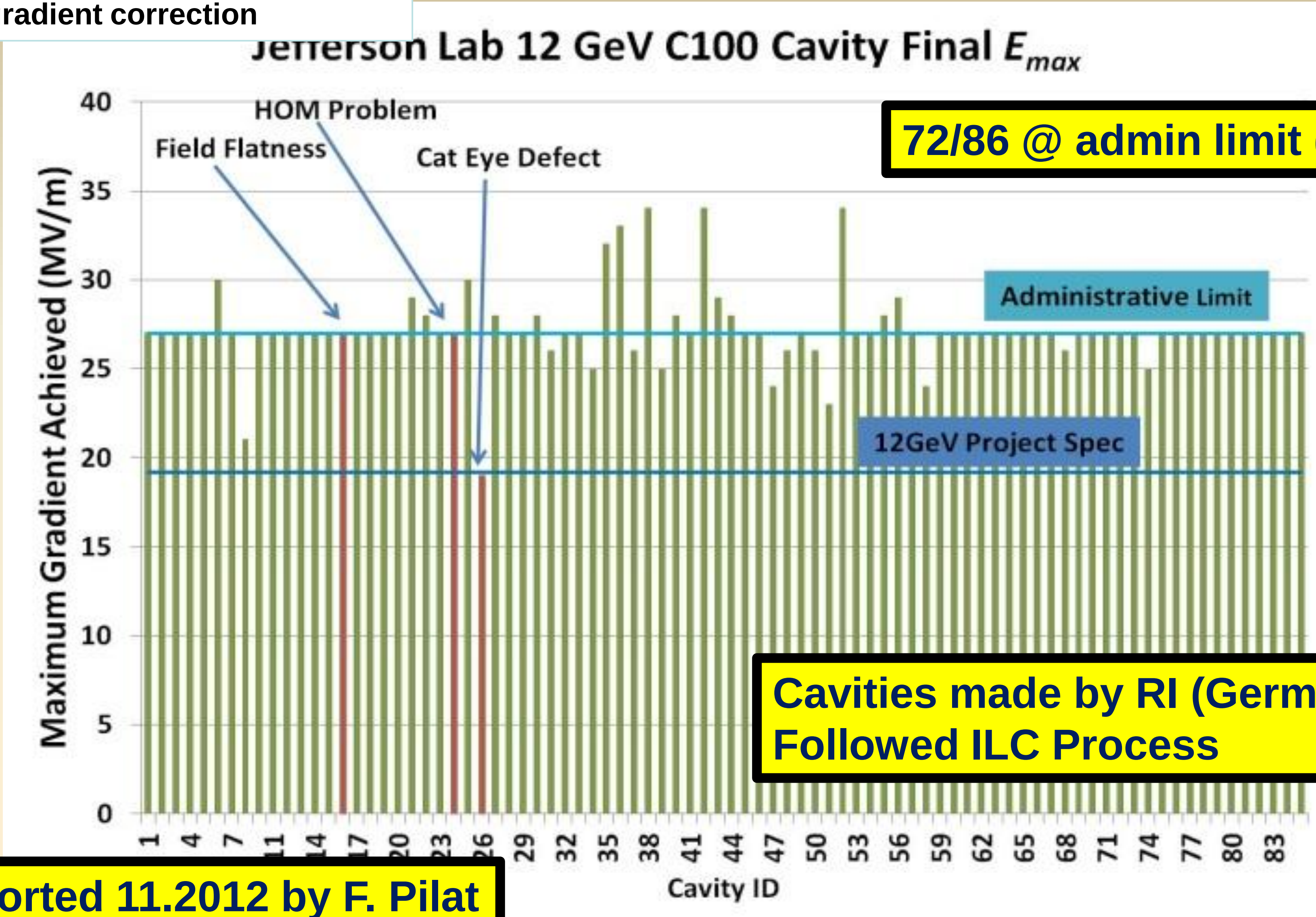
Vertical Cavity Test Results at DESY: 1995-2006 – the great decade of SRF R&D



CEBAF 12 GeV upgrade

12 GeV cavities: overall performance

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

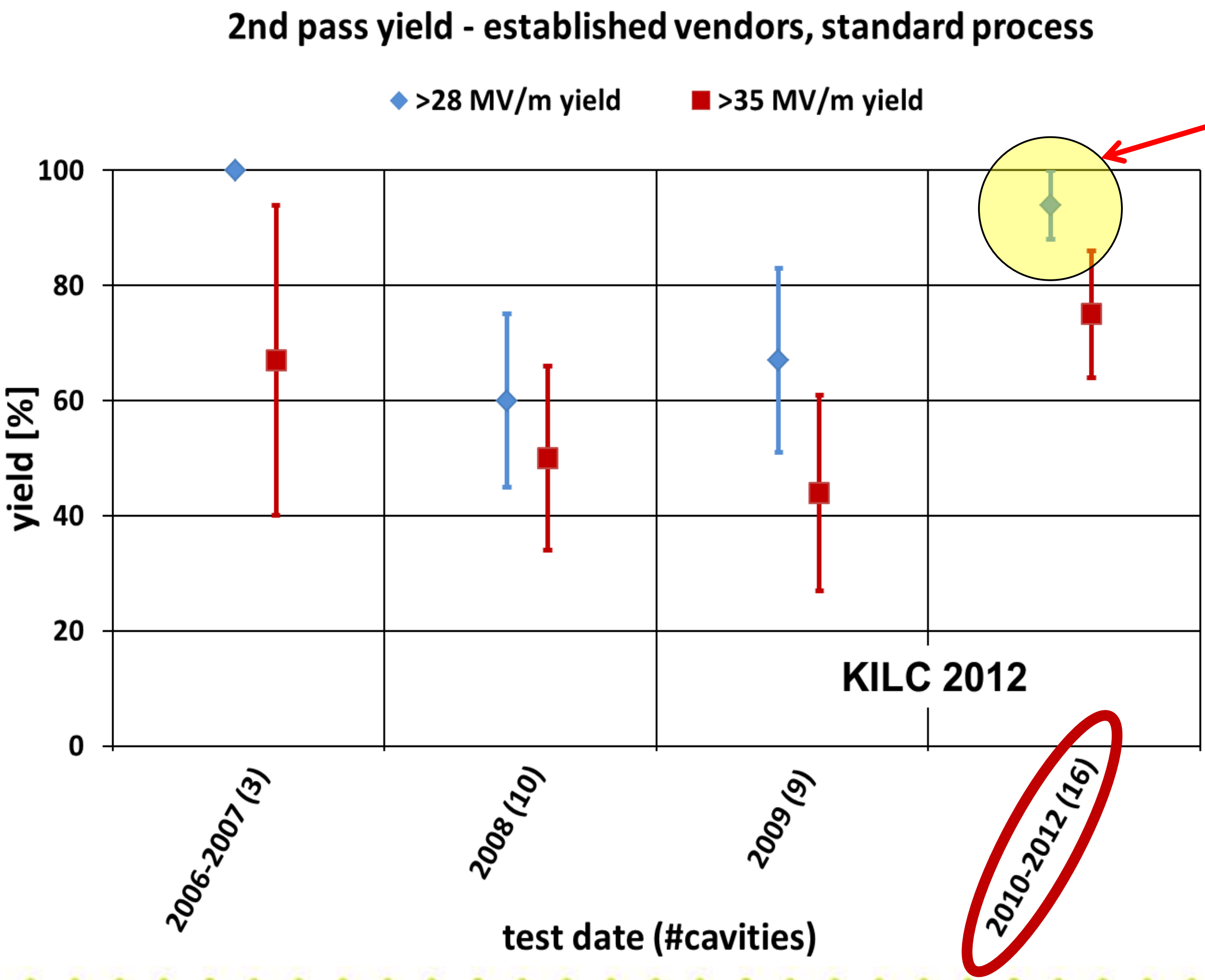


72/86 @ admin limit (85%)

Cavities made by RI (Germany); Followed ILC Process

Reported 11.2012 by F. Pilat

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

15.05.2013
Marc Ross, SLAC
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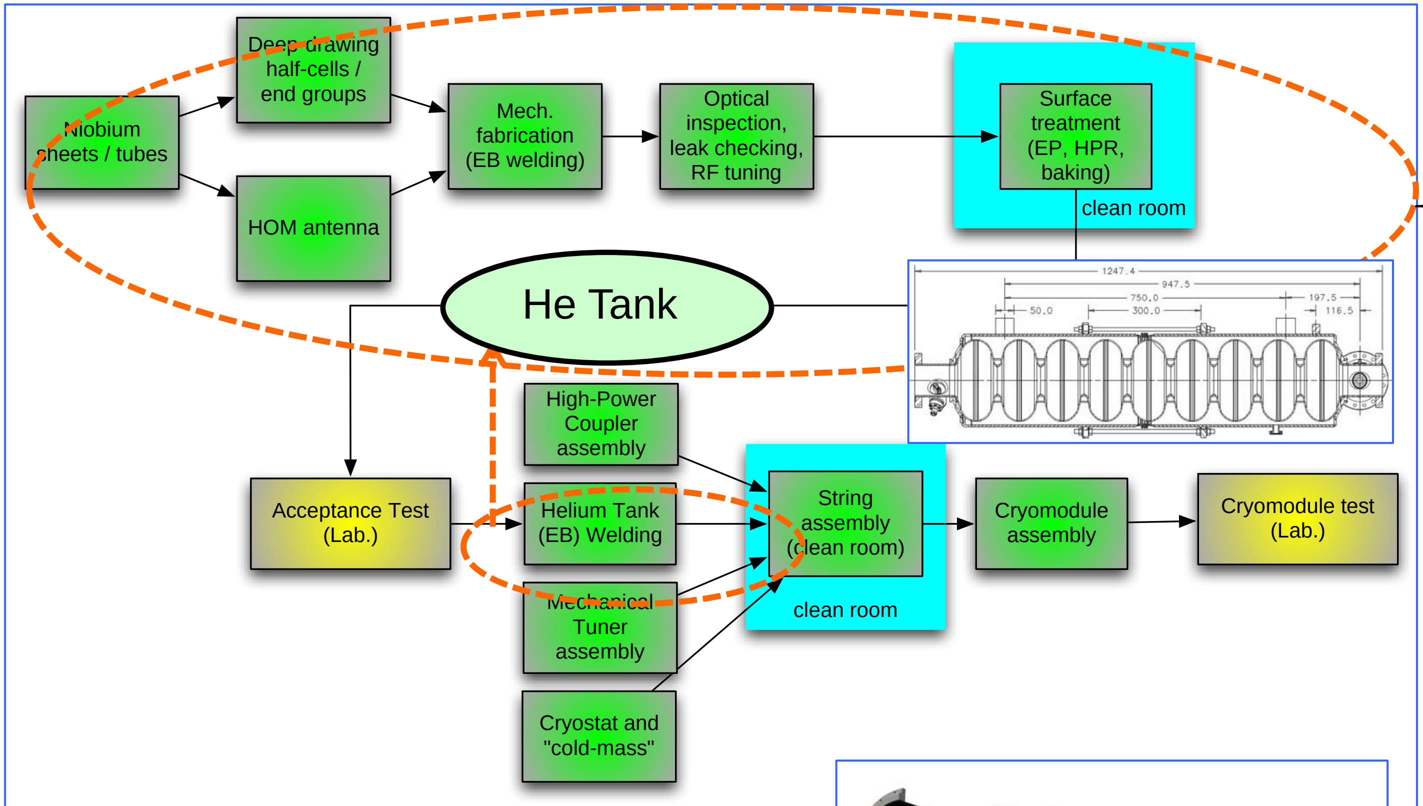
Cavity/ Cryomodule Fabrication



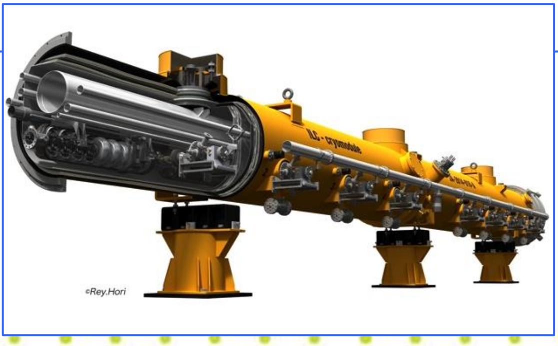
Material/ Sub-component

Cavity Fabrication

Surface Process

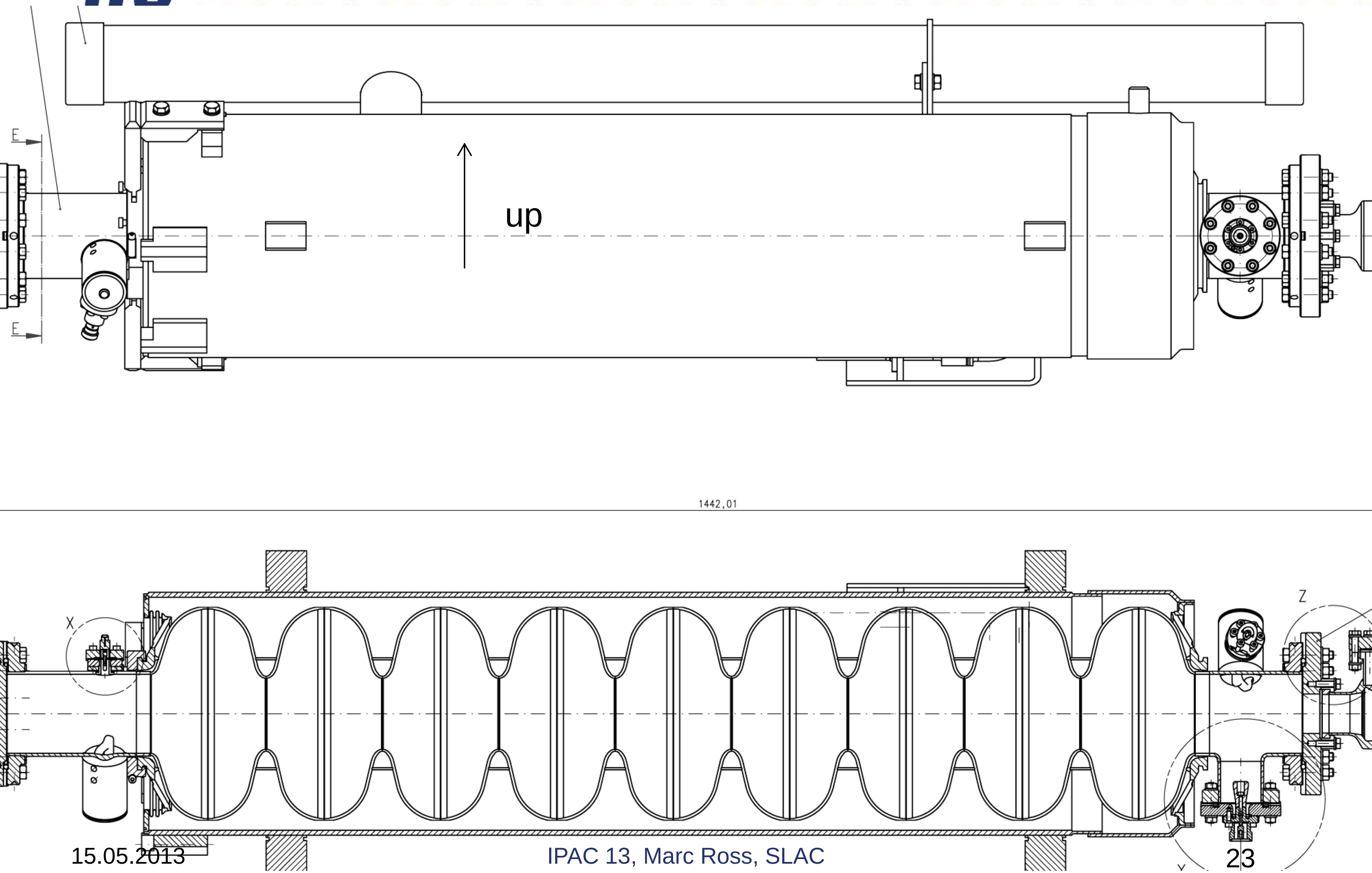
LHe-Tank Assembly

Vertical Test = Cavity RF Test

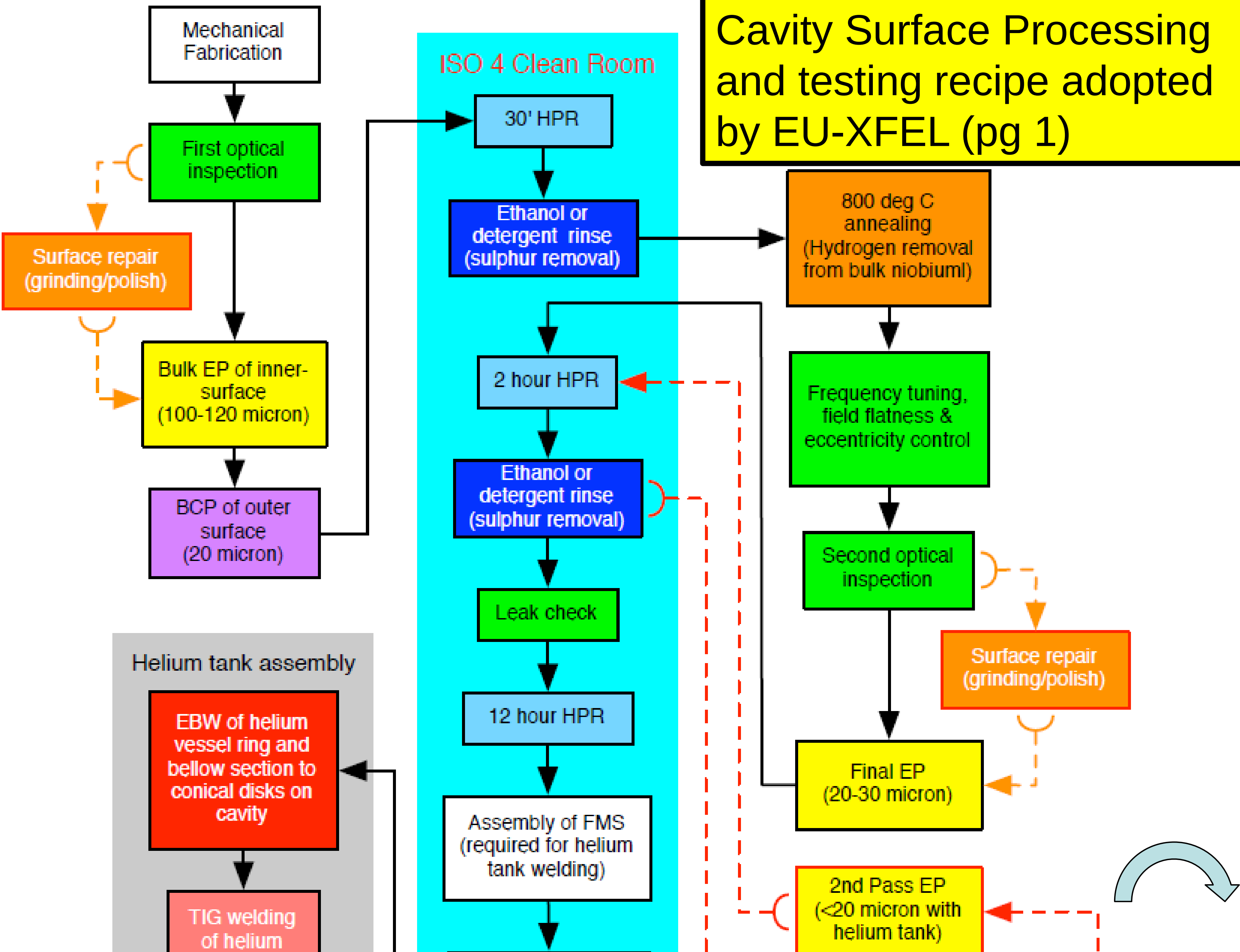


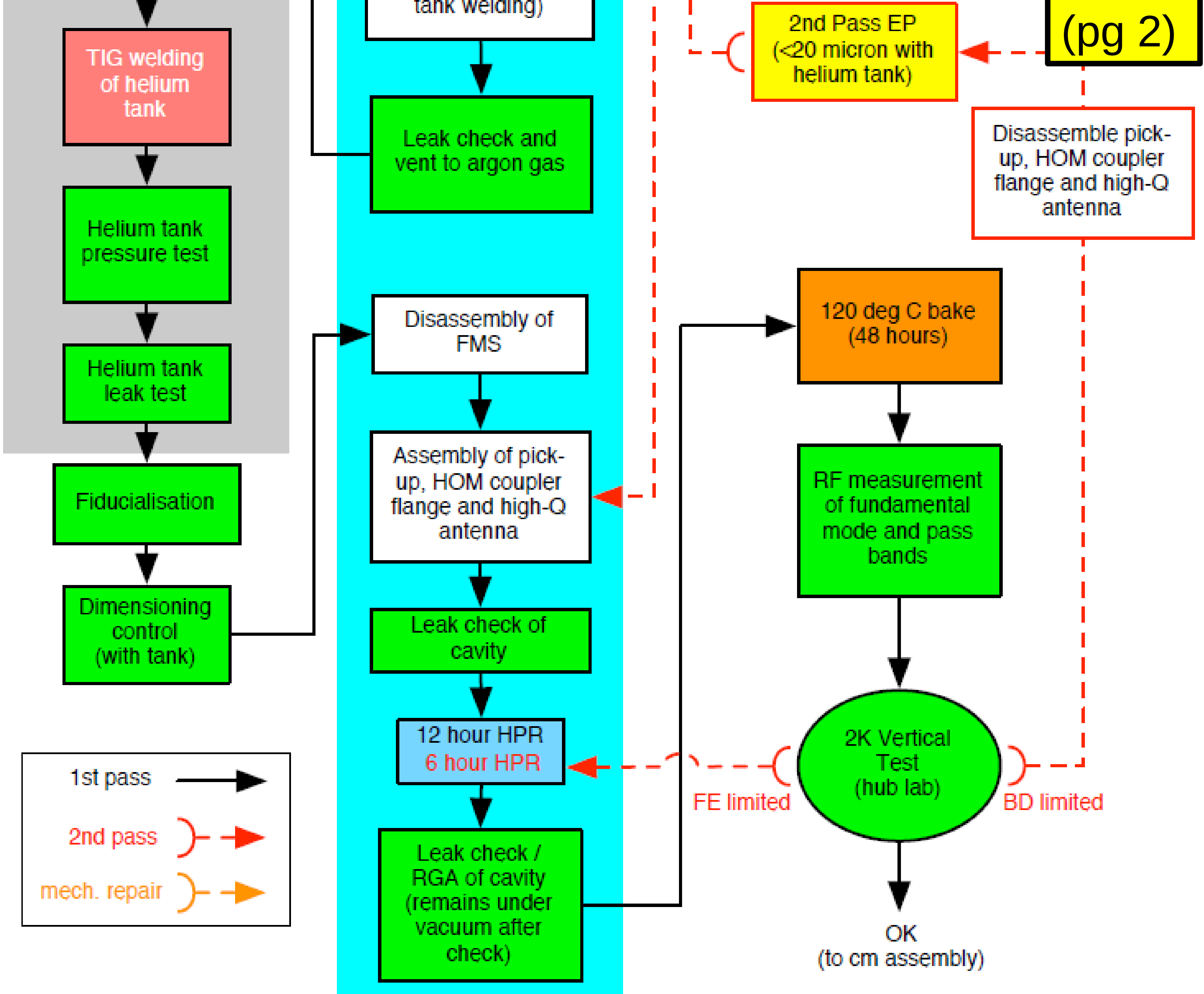
Cryomodule Assembly and RF Test

As-delivered XFEL cavity:



Cavity Surface Processing and testing recipe adopted by EU-XFEL (pg 1)





tank welding)
TIG welding of helium tank
Leak check and vent to argon gas
2nd Pass EP (<20 micron with helium tank)
(pg 2)
Disassemble pick-up, HOM coupler flange and high-Q antenna
Helium tank pressure test
Helium tank leak test
Disassembly of FMS
120 deg C bake (48 hours)
Fiducialisation
Assembly of pick-up, HOM coupler flange and high-Q antenna
RF measurement of fundamental mode and pass bands
Dimensioning control (with tank)
Leak check of cavity
12 hour HPR
6 hour HPR
2K Vertical Test (hub lab)
FE limited
BD limited
1st pass
2nd pass
mech. repair
Leak check / RGA of cavity (remains under vacuum after check)
OK (to cm assembly)

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* (or soon to be)

Reference for Cavity Specification

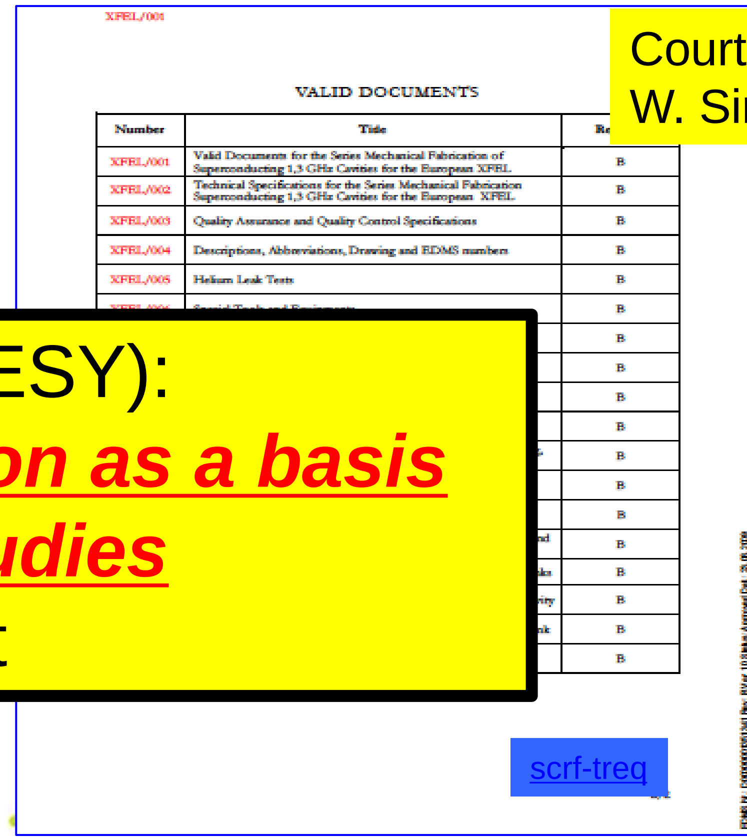
except for Tuner

- **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


W. Singer

VALID DOCUMENTS
FOR THE
SERIES MECHANICAL

1/2


XFEL/001

VALID DOCUMENTS

Number	Title	Re
XFEL/001	Valid Documents for the Series Mechanical Fabrication of Superconducting 1,3 GHz Cavities for the European XFEL	B
XFEL/002	Technical Specifications for the Series Mechanical Fabrication Superconducting 1,3 GHz Cavities for the European XFEL	B
XFEL/003	Quality Assurance and Quality Control Specifications	B
XFEL/004	Descriptions, Abbreviations, Drawing and EDMS numbers	B
XFEL/005	Helium Leak Tests	B

Courtesy: W. Singer

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

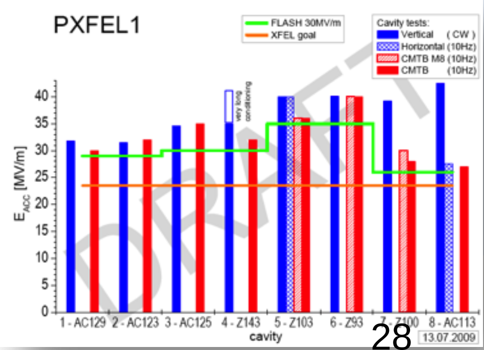
scrf-treq

Cryomodule Development & Test

- **KEK: STF (S1-Global)**

- **FNAL: NML Facility**

- **DESY: XFEL**
  - including prototype module ACC7 in FLASH (~30MV/m)



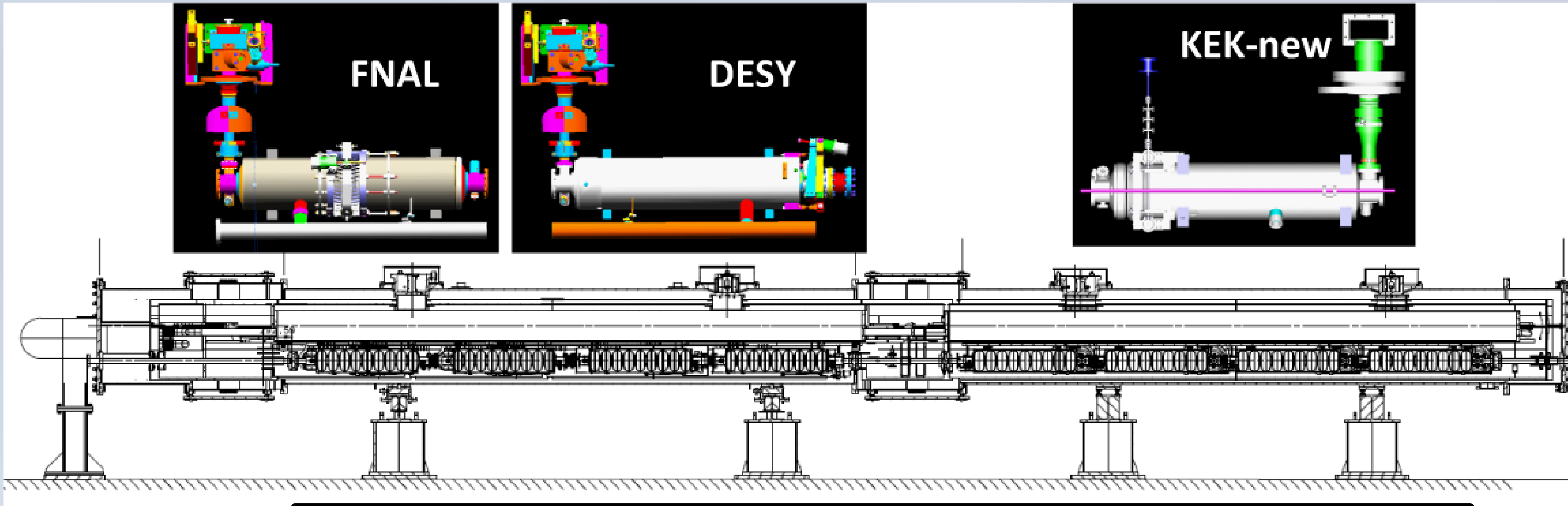
EU-XFEL Cryostat / Cold-Mass

WUXI CITY CREATIVE CHEMICAL EQUIPMENT CO.,LTD.
无锡市创新化工设备有限公司

科技部973重点科研项目：低温恒温器

- **Supported through Chinese innovation initiative ‘973’**

S1-Global Cryomodule at KEK



A first real test of ‘Plug- Compatibility’

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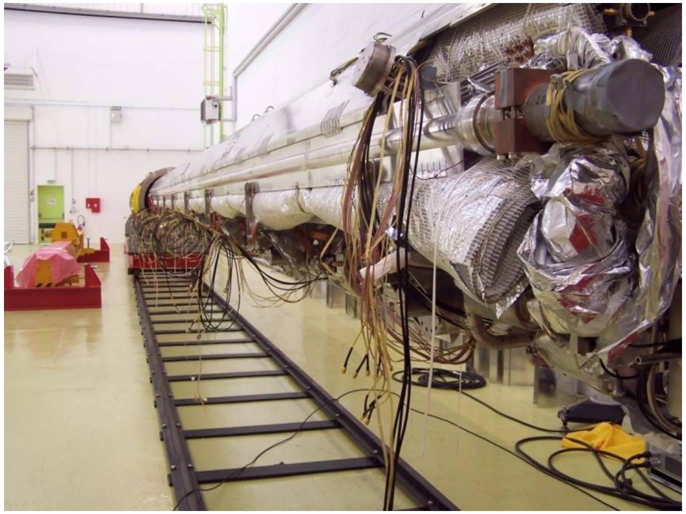
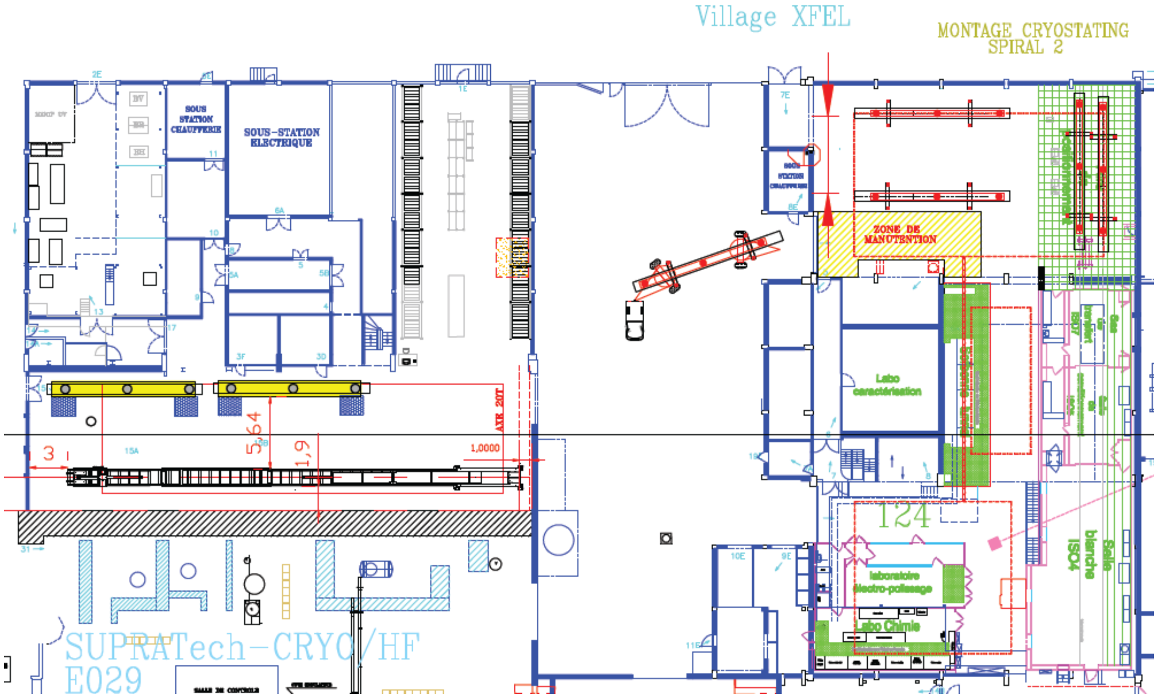
Courtesy: H. Weise (DESY), O. Napoli (Saclay)

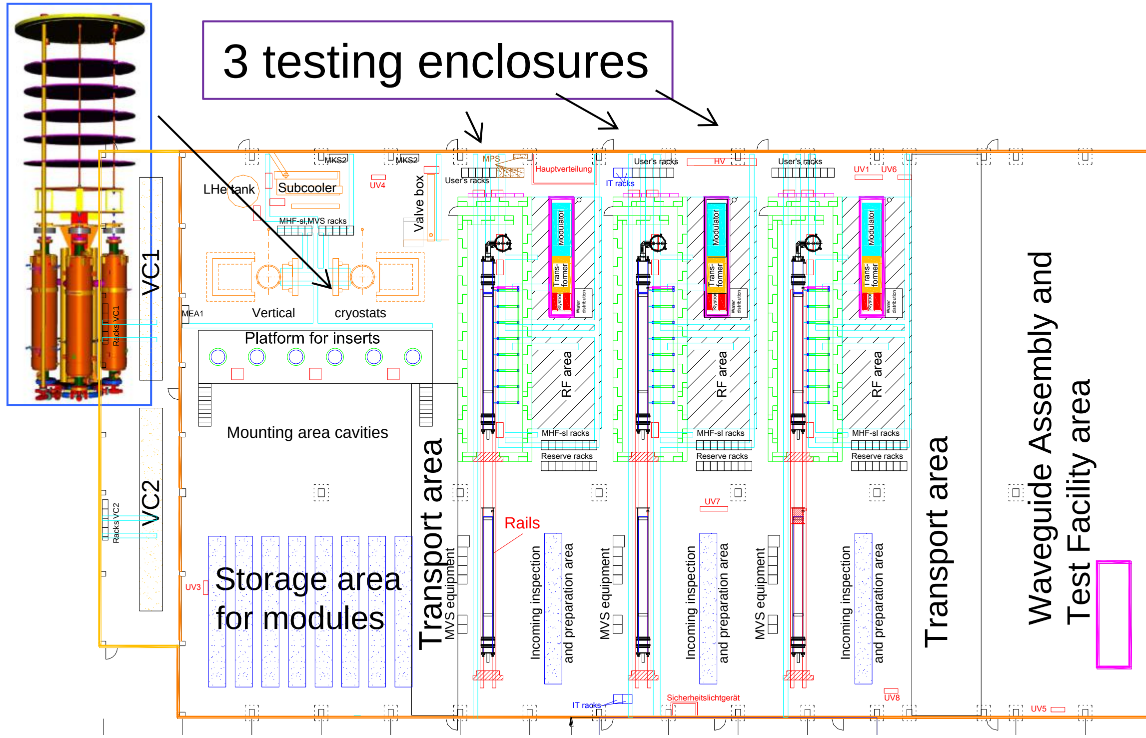
Saclay Cryomodule Assembly:

cavity strings assembly
cryomodules assembly
BPMs system



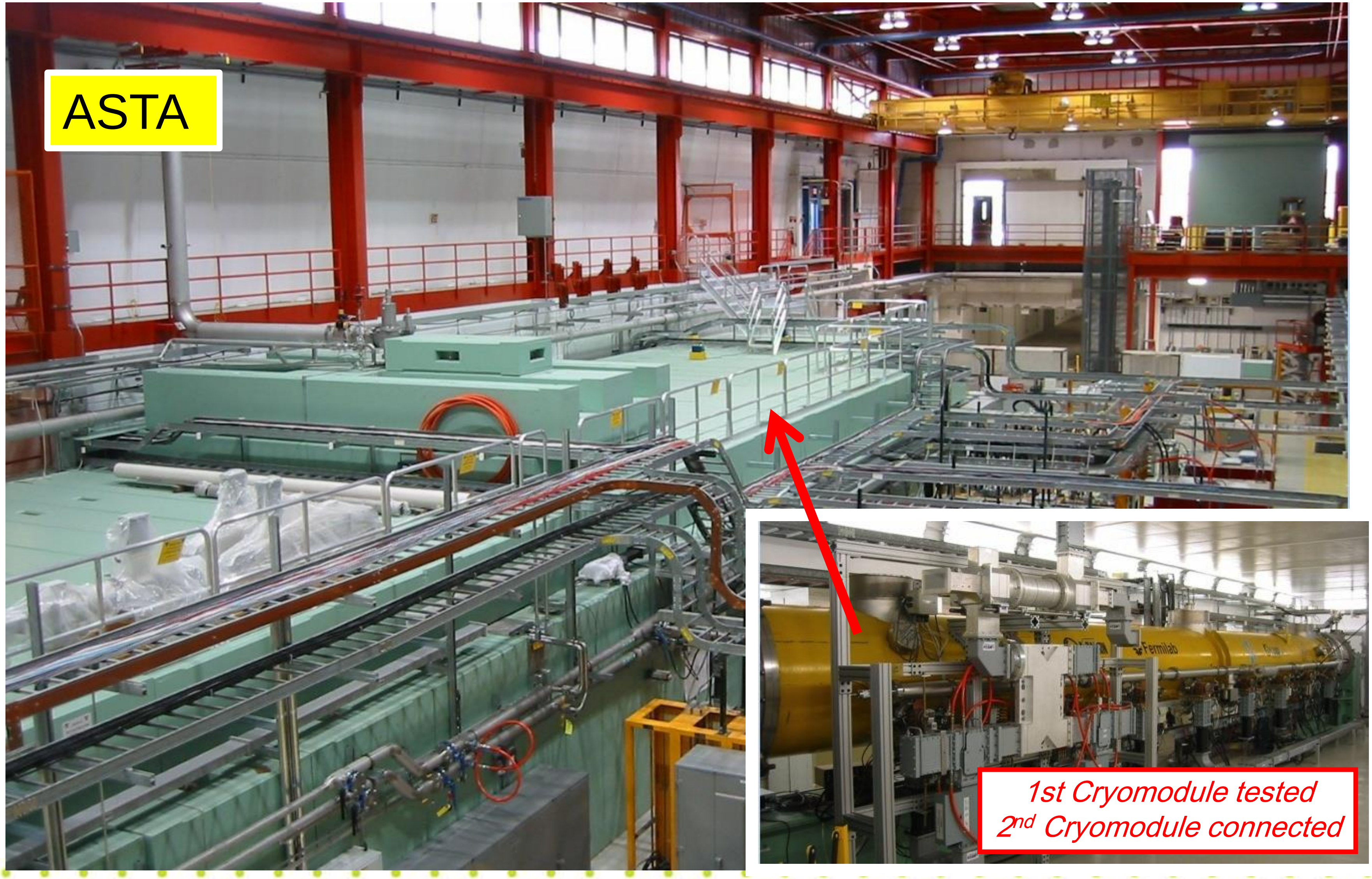


DESY Cavity/Cryomodule Test Facility



- 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



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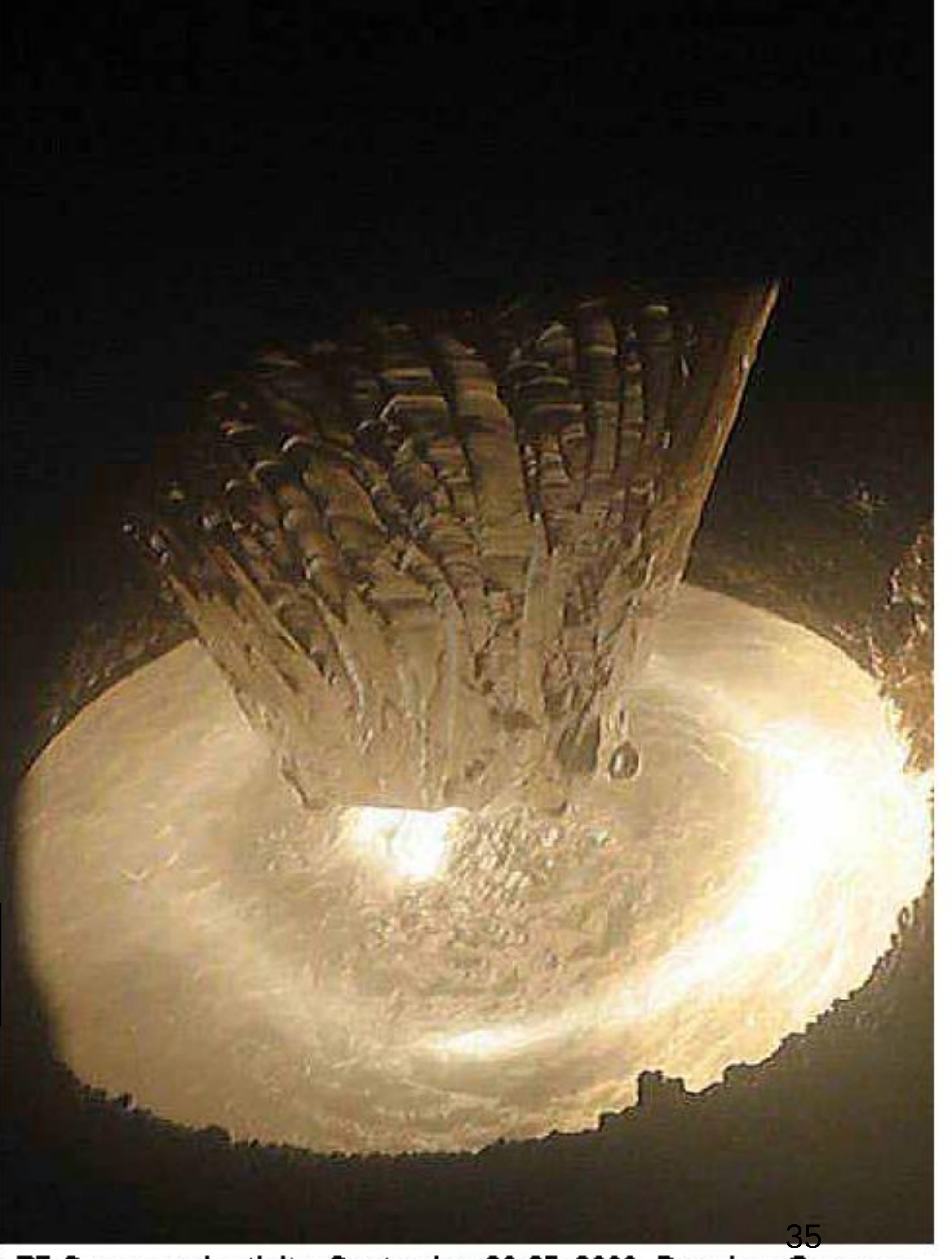
Electron Beam Melting

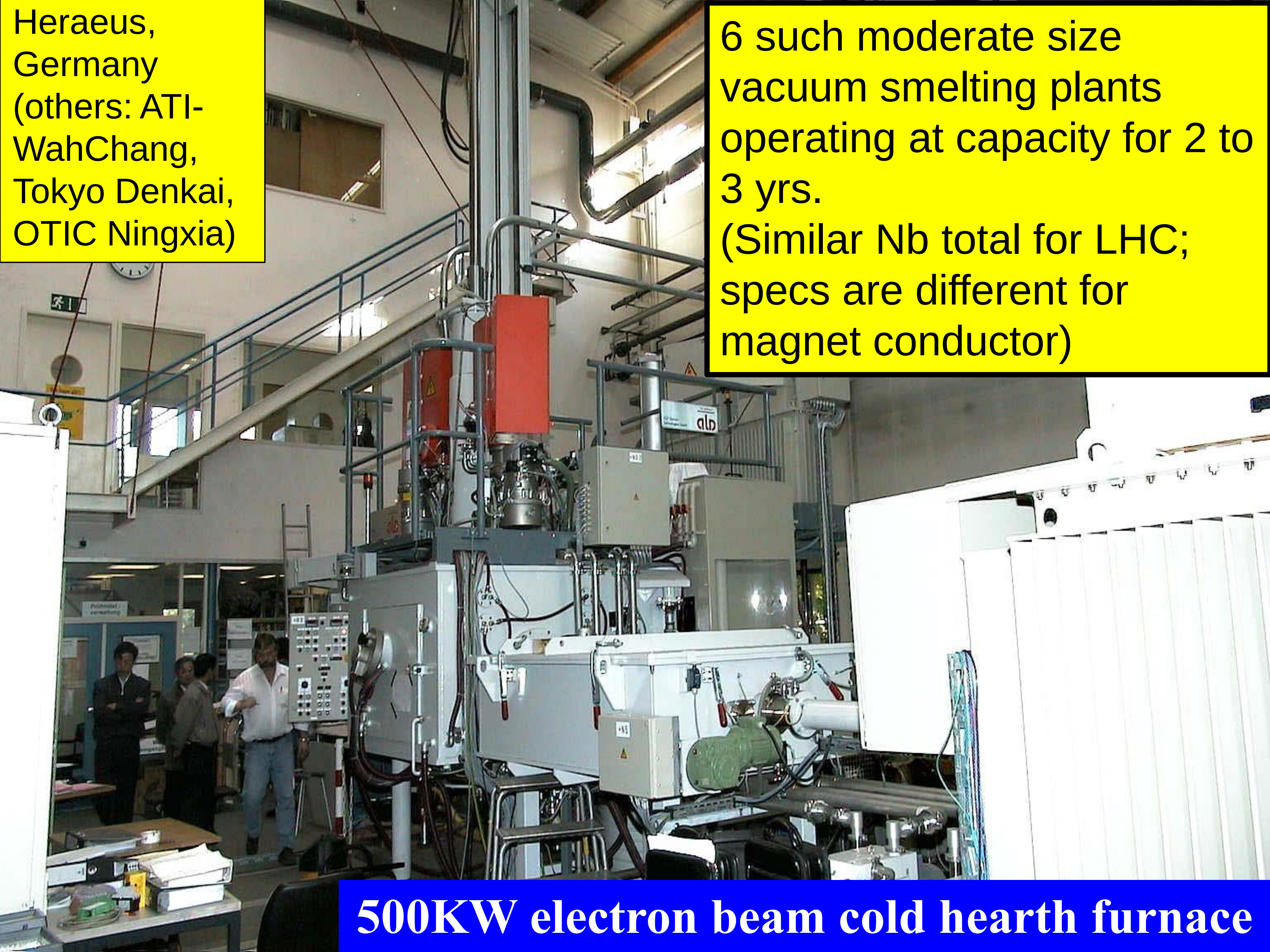
As a result of the increasing demand for refractory metals in the last few decades, the electron-beam furnace has been developed to a reliable, efficient apparatus for melting and purification.



Critical industrial Infrastructure 1: Vacuum Smelter for purifying Nb

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

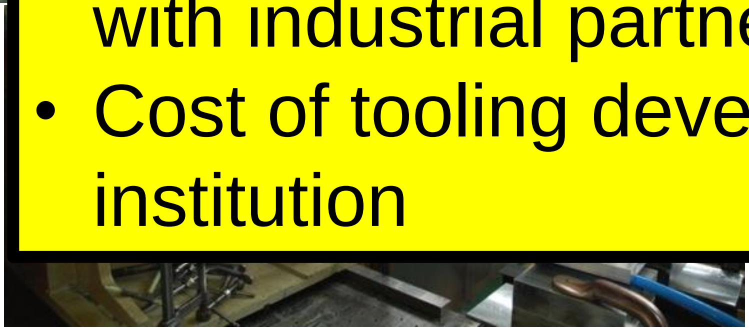
6 such moderate size vacuum smelting plants operating at capacity for 2 to 3 yrs.
(Similar Nb total for LHC; specs are different for magnet conductor)

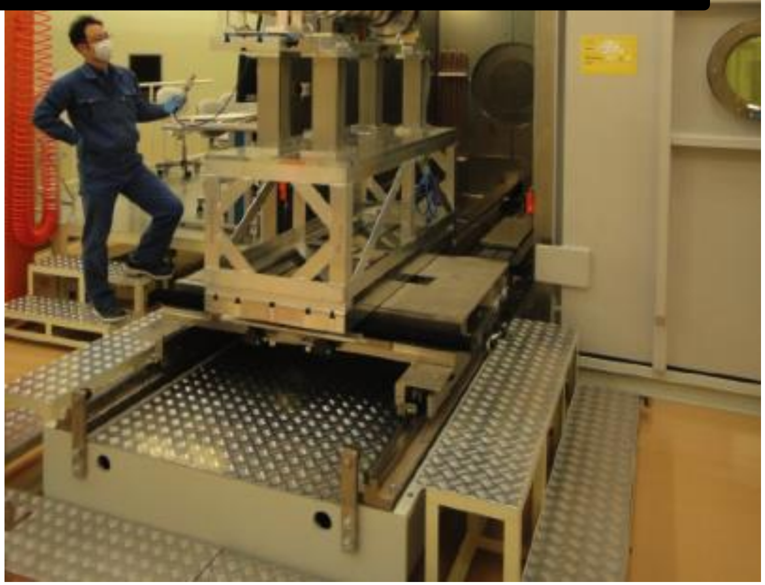


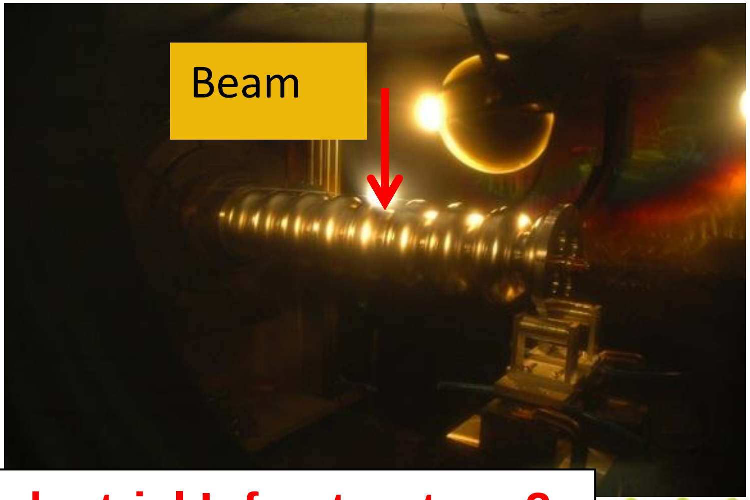
500KW electron beam cold hearth furnace

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





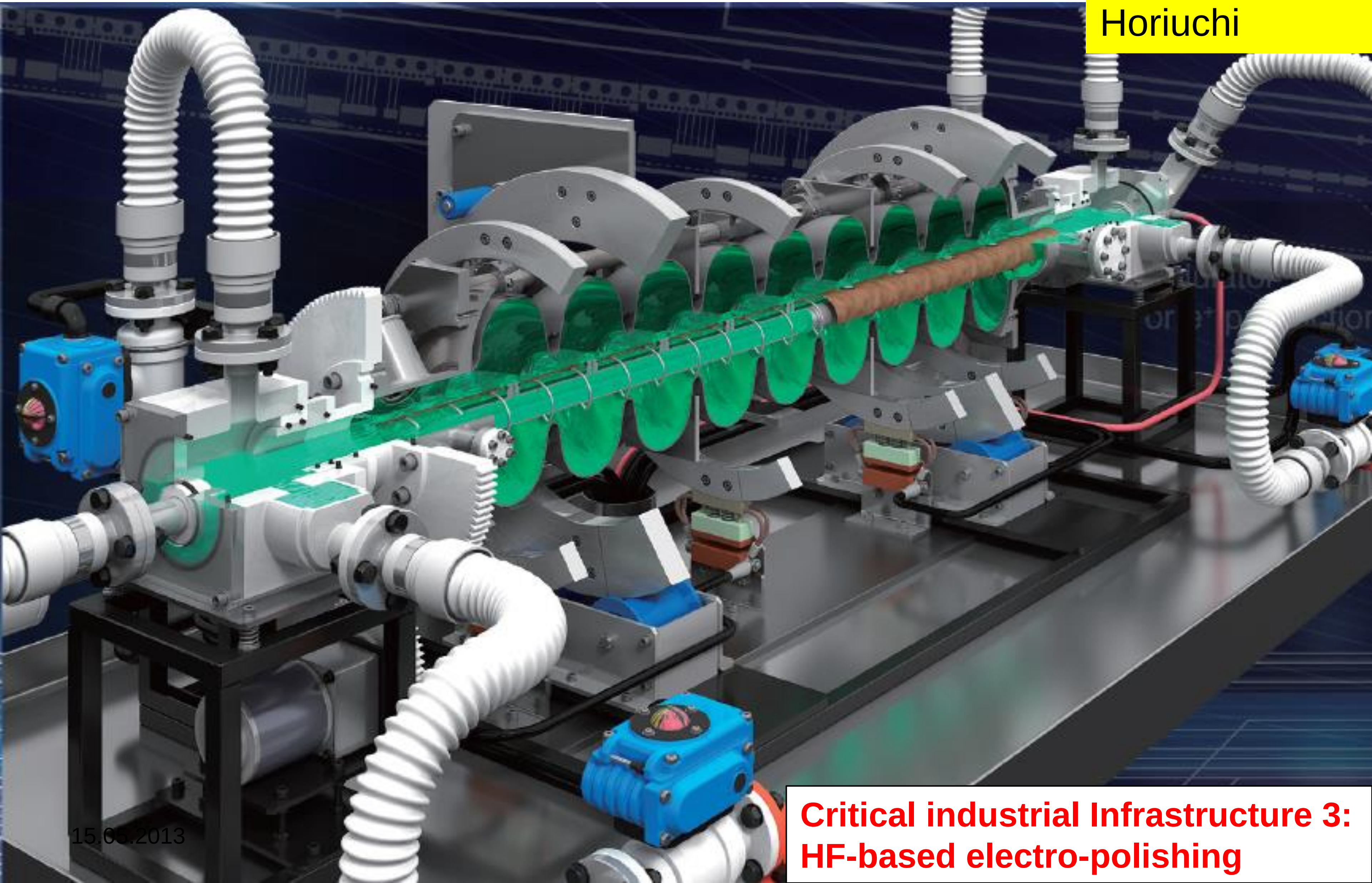


8 July 2011

Critical industrial Infrastructure 2: Electron Beam Welder

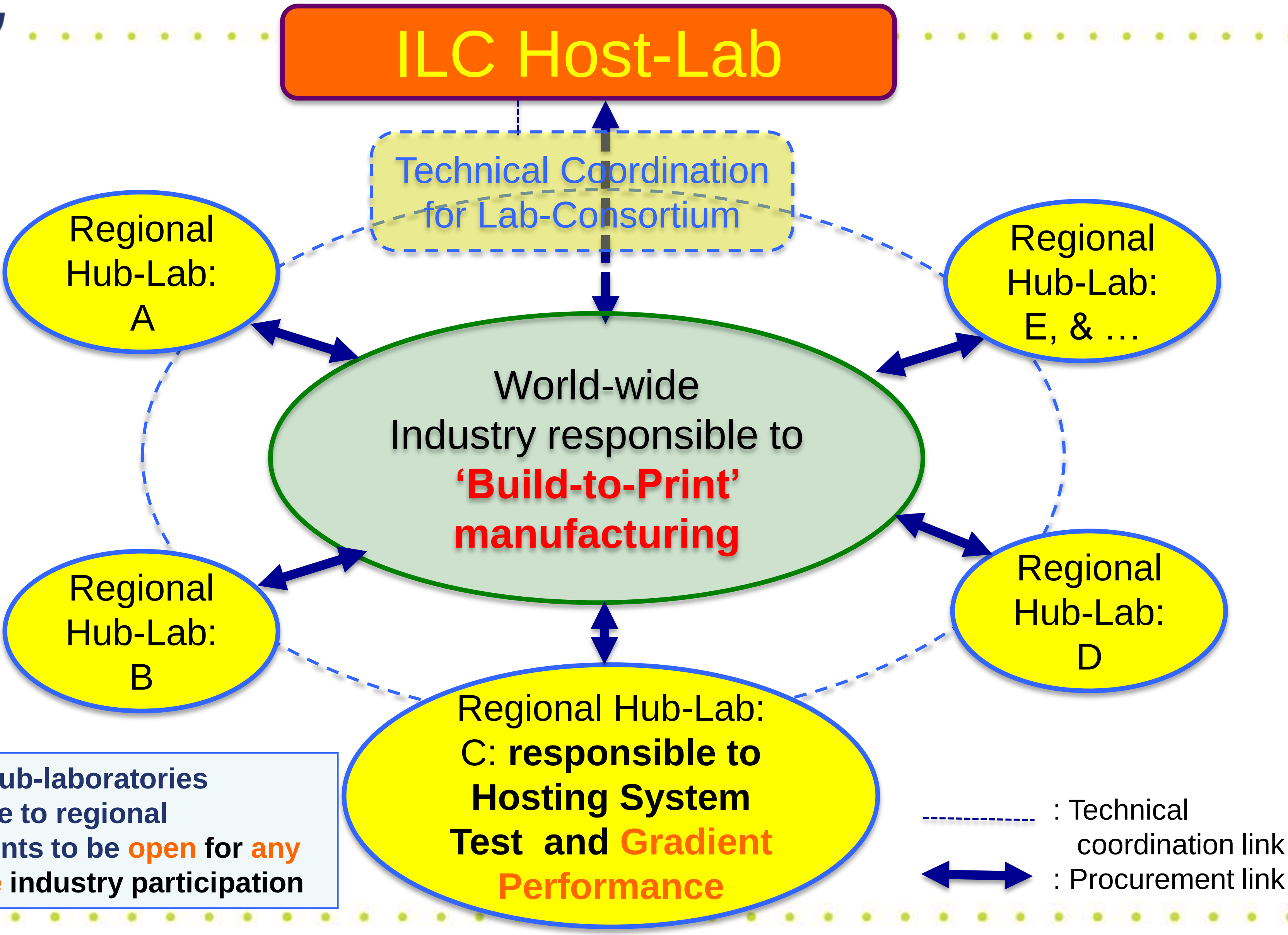
Electro-polishing

Graphics by Rey Hori / Mamoru Horiuchi



Critical industrial Infrastructure 3: HF-based electro-polishing

SCRF Procurement/Manufacturing Model



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

Production Process/Responsibility

Step hosted	Industry	Industry/Laboratory	Hub-laboratory	ILC Host-laboratory
Regional constraint	no	yes	yes	yes
Accelerator - Integration, Commissioning				Accelerator Integration
SCRF Cryomodule - Performance Test			Cold, gradient test	As partly as hub-lab
Cryomodule/Cavity - Assembly		Coupler, tuner, cav-string/cryomodule assembly work		As partly as hub-lab
Cryomodule component - Manufacturing	V. vessel, cold-mass ...			
9-cell Cavity - Performance Test			Cold, gradient test	As partly as hub-lab
9-cell Cavity - Manufacturing	9-cell-cavity assembly, Chem-process, He-Jacketing			
Sub-comp/material - Production/Procurement	Nb, Ti, specific comp. …		Procurement	

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SCRF Industry

- **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.

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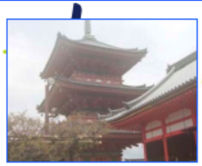
Communication w/ Industry

Visits to SC Cavity Manufacturers in Global Industry: 2009

Notes:
AES: Advanced Energy Systems
RI: Research Instruments (previously, ACCEL)
MHI: Mitsubishi Heavy Industries



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

- multiple ~½ day visits and
- open workshops

ILC Global Design Effort Project Manager visit to SCRF cavity-cryomodule manufacturers

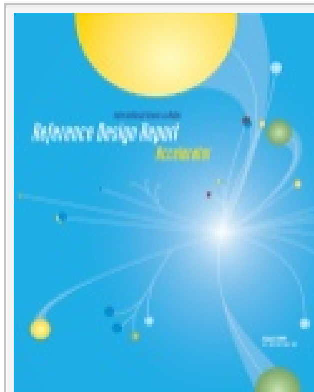
February - March 2011

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 web page 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/cromodule 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.



Reference Design Report

Download the full report

Volume 3 - Accelerator: Download the pdf (20MB)

ILC Research and Development Plan for the Technical Design Phase

~½ day visits: use of common presentation material

(Last updated: 1 March 2011)

The 2nd cycle Communication with Companies

SC Material Cavity /Cryomodule Manufacturers

	Date	Company	Place	Technical sbject
1	2/8, 2011	Hitachi	Tokyo (JP)	Cavity/Cryomodule
2	2/8	Toshiba	Yokohana (JP)	Cavity/Cryomodule, SCM
3	2/9	MHI	Kobe (JP)	Cavity / Cryomodule
4	2/9	Tokyo Denkai	Tokyo (JP)	Material (Nb)
5	2/18	OTIC	NingXia (CN)	Material (Nb, NbTi, Ti)
6	(3/3), 9/14	Zanon	Schio (IT)	Cavity/Cryomodule
7	3/4,	RI	Koeln (DE)	Cavity
8	(3/14), 4/8	AES	Medford, NY (US)	Cavity
9	(3/15), 4/7	Niowave	Lansing, MI (US)	Cavity/Cryomodule
10	4/6	PAVAC	Vancouver (CA)	Cavity
11	4/25	ATI Wah-Chang	Albany, OR (US)	Material (Nb, Nb-Ti, Ti)
12	4/27	Plansee	Ruette (AS)	Material (Nb, Nb-Ti, Ti)
13	5/24	SDMS	Sr. Romans (FR)	Cavity
14	7/6	Heraeus	Hanau (DE)	Material (Nb, Nb-Ti, Ti)
15	10/18	Babcock-Noell	Wurzburg (DE)	CM assembly study
16	11/11	SST	Maisach (DE)	Electron Beam Welder

The 3rd Cycle Communication with Companies

Further studies **with contracts** in 2011-2012

	Date	Company	Place	Technical sbject
1	2/8, 2011	**Hitachi**	Tokyo (JP)	Cavity/Cryomodule
2	2/8	**Toshiba**	Yokohana (JP)	Cavity/Cryomodule, SCM
3	2/9	**MHI**	Kobe (JP)	Cavity / Cryomodule
4	2/9	Tokyo Denkai	Tokyo (JP)	Material (Nb)
5	2/18	OTIC	NingXia (CN)	Material (Nb, NbTi, Ti)
6	(3/3), 9/14	Zanon	Schio (IT)	Cavity/Cryomodule
7	3/4,	**RI**	Koeln (DE)	Cavity
8	(3/14), 4/8	**AES**	Medford, NY (US)	Cavity
9	(3/15), 4/7	Niowave	Lansing, MI (US)	Cavity/Cryomodule
10	4/6	PAVAC	Vancouver (CA)	Cavity
11	4/25	ATI Wah-Chang	Albany, OR (US)	Material (Nb, Nb-Ti, Ti)
12	4/27	Plansee	Ruette (AS)	Material (Nb, Nb-Ti, Ti)
13	5/24	SDMS	Sr. Romans (FR)	Cavity
14	7/6	Heraeus	Hanau (DE)	Material (Nb, Nb-Ti, Ti)
15	10/18	**Babcock-Noell**	Wurzburg (DE)	CM assembly study
16	11/11	SST	Maisach (DE)	Electron Beam Welder

Mass-Production Study

Contracts:

	Company	Mass production model	Contract funded/hosted by
Cavity	RI	100% (50%)	DESY
	AES	20 %	DOE/Fermilab
	MHI	20, 50, 100%	KEK
Quadrupole	Toshiba	100 %	KEK
CM and assembly	Hitachi	20, 50, 100%	KEK
	AES	25%	DOE/Fermilab
CM assembly	BN	100, 33 %	CERN

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, …**