Course B: Superconductive RF

T. Saeki (KEK)

LC school 2013

5 - 15 Dec. 2013, Antalya, Turkey

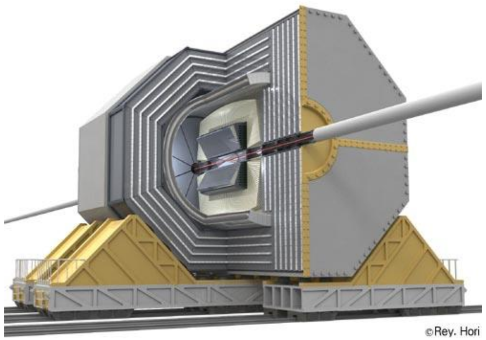
Course B: Superconductive RF Industrialization and Challenges

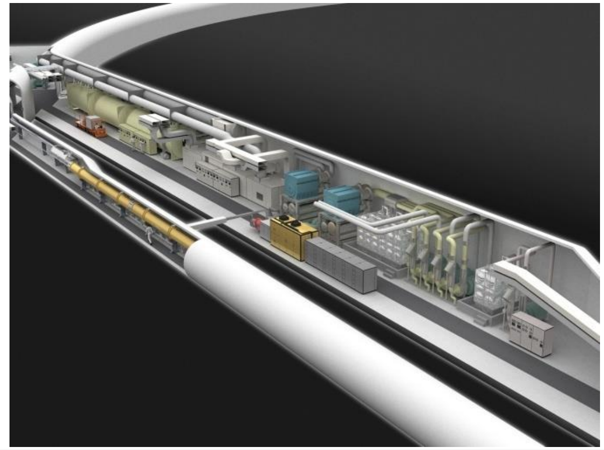
T. Saeki (KEK)

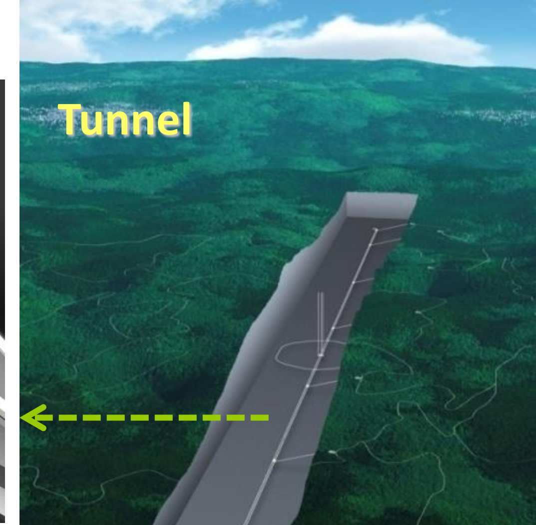
LC school 2013

12 Dec. 2013, Antalya, Turkey

ILC Overview

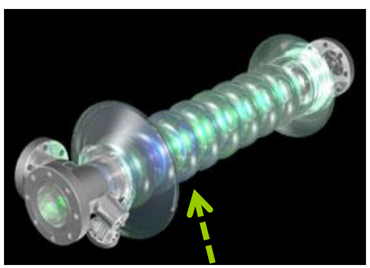


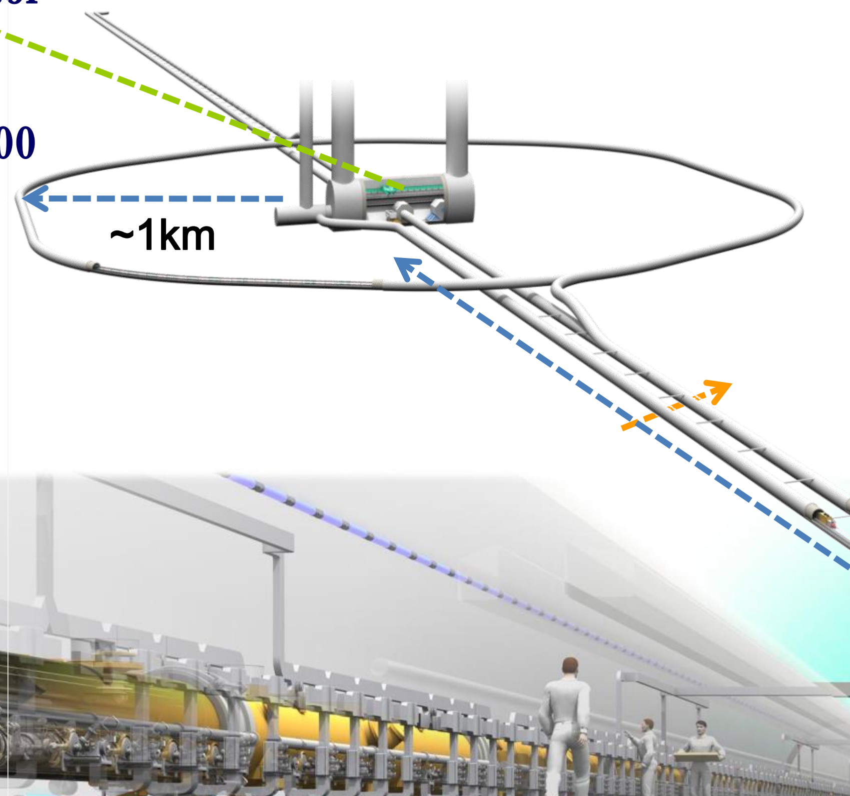


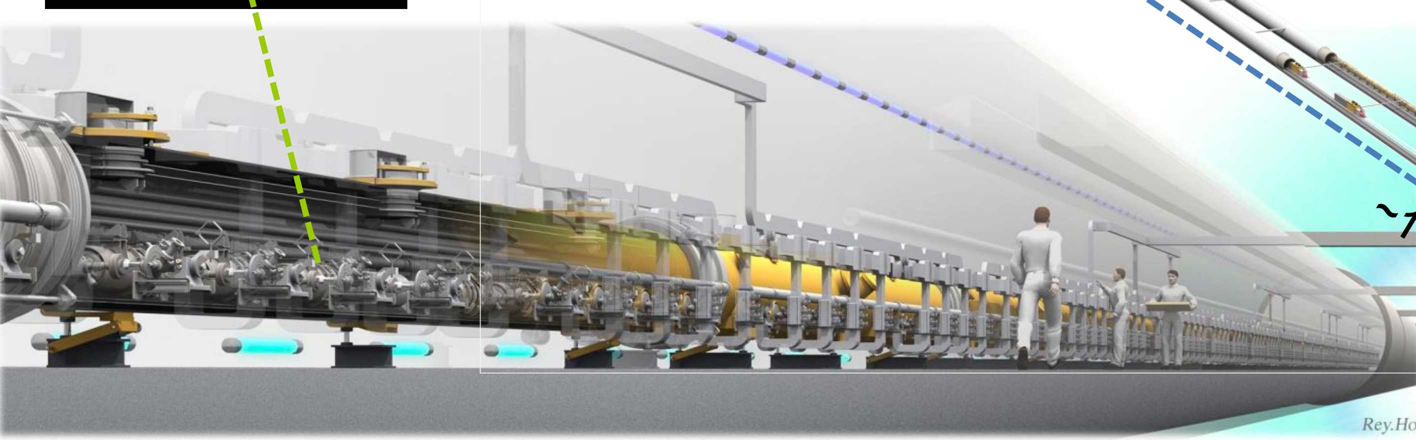


Detector

# of SRF cavities ~16000







Superconducting RF accelerator

ILC Cost Breakdown (RDR)

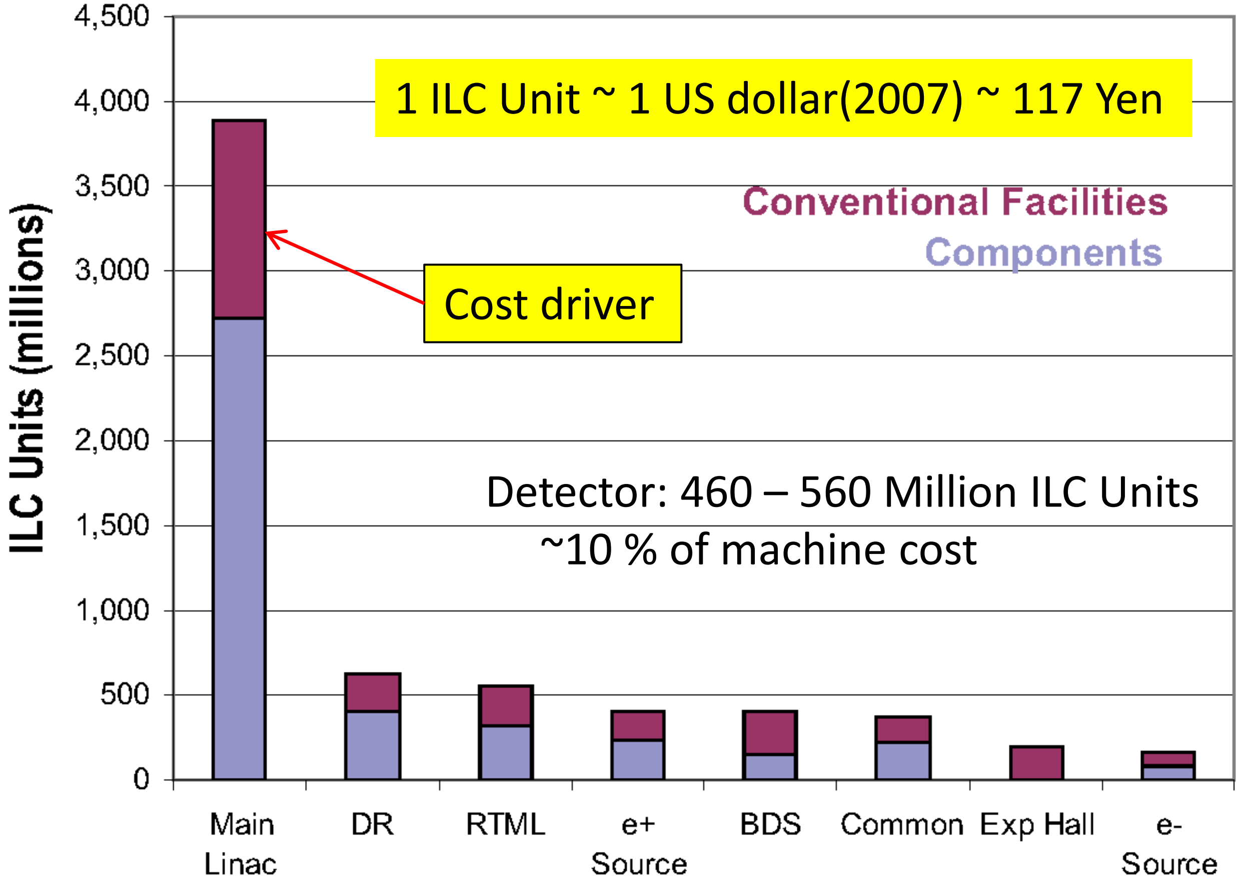
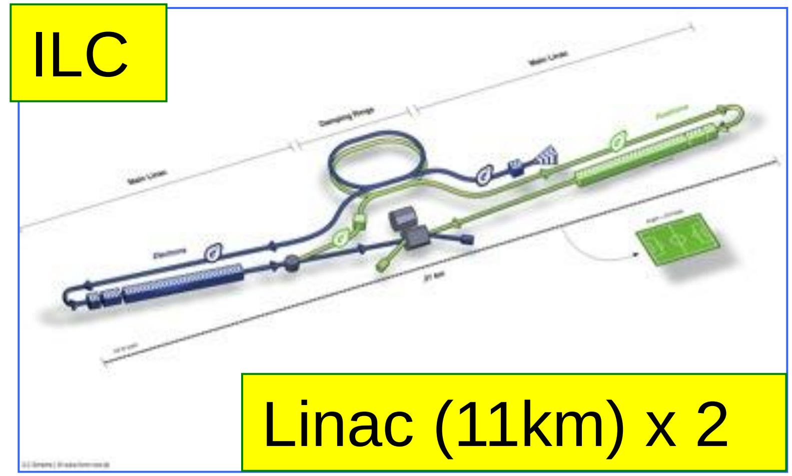
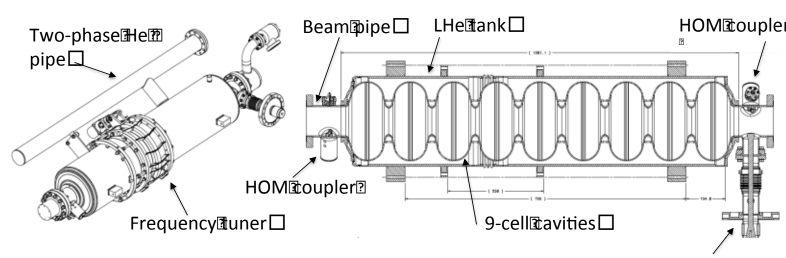


FIGURE 6.2-1. Distribution of the ILC value estimate by area system and common infrastructure, in ILC Units. The estimate for the experimental detectors for particle physics is not included. (The Conventional Facilities estimates have been averaged over the three regional site estimates.)

SCRF Industrialization required for ILC

Parameters	Value
C.M. Energy	500 GeV
Peak luminosity	1.5 x10^{34} $cm^{-2}s^{-1}$
Beam Rep. rate	5 Hz
Pulse duration	0.73 ms
Average current	5.8 mA (in pulse)
Av. field gradient	31.5 MV/m +/-20% Q_0 = 1E10
# 9-cell cavity	16,024 (x 1.1)
# cryomodule	1,855
# Klystron	~400

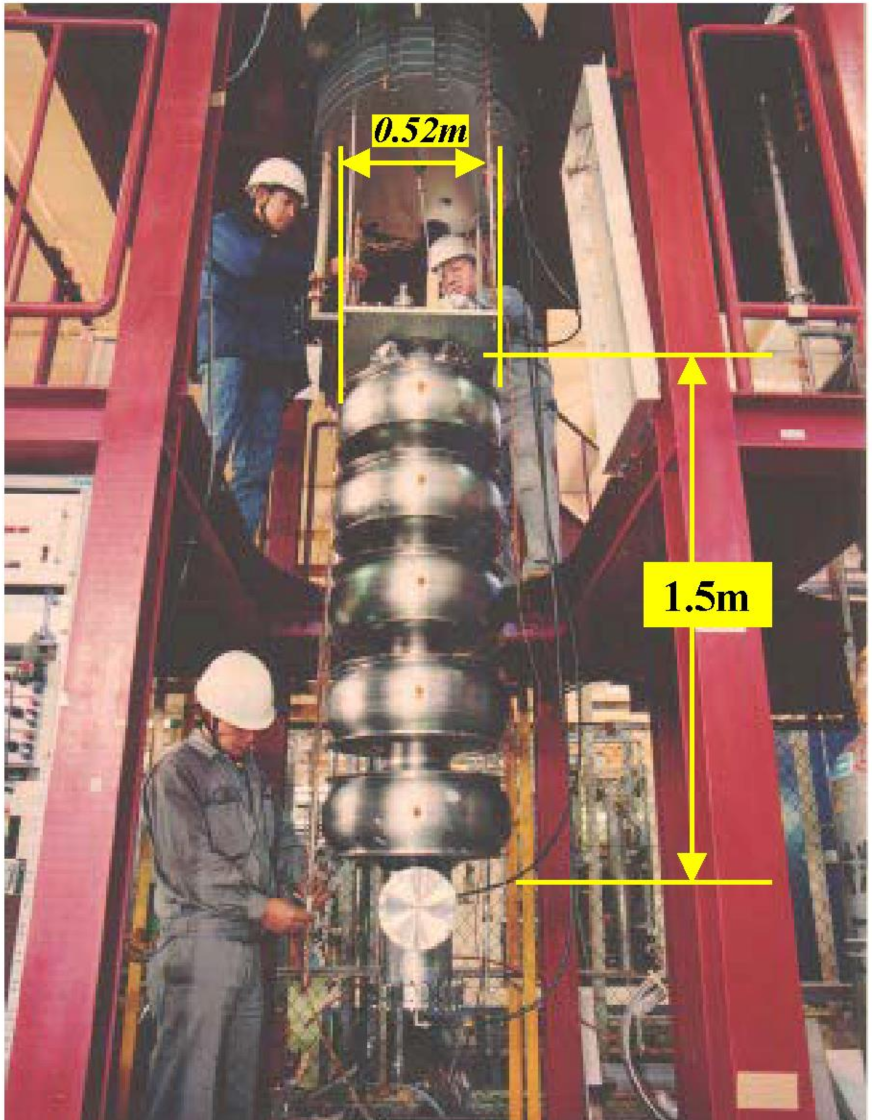




High quality

16024 x 1.1(Yield = 90%)
~ 17600 cavities of mass-production

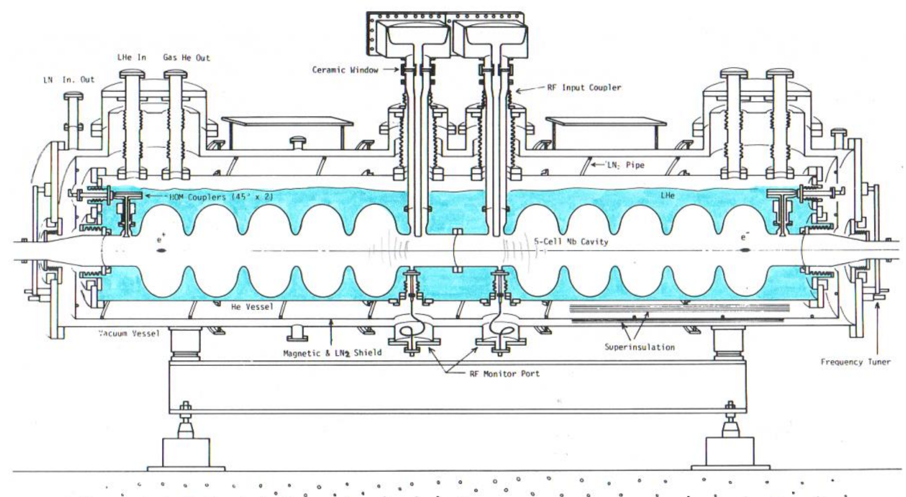
History of SRF Cavity
TRISTAN @ KEK (1988 – 1995)



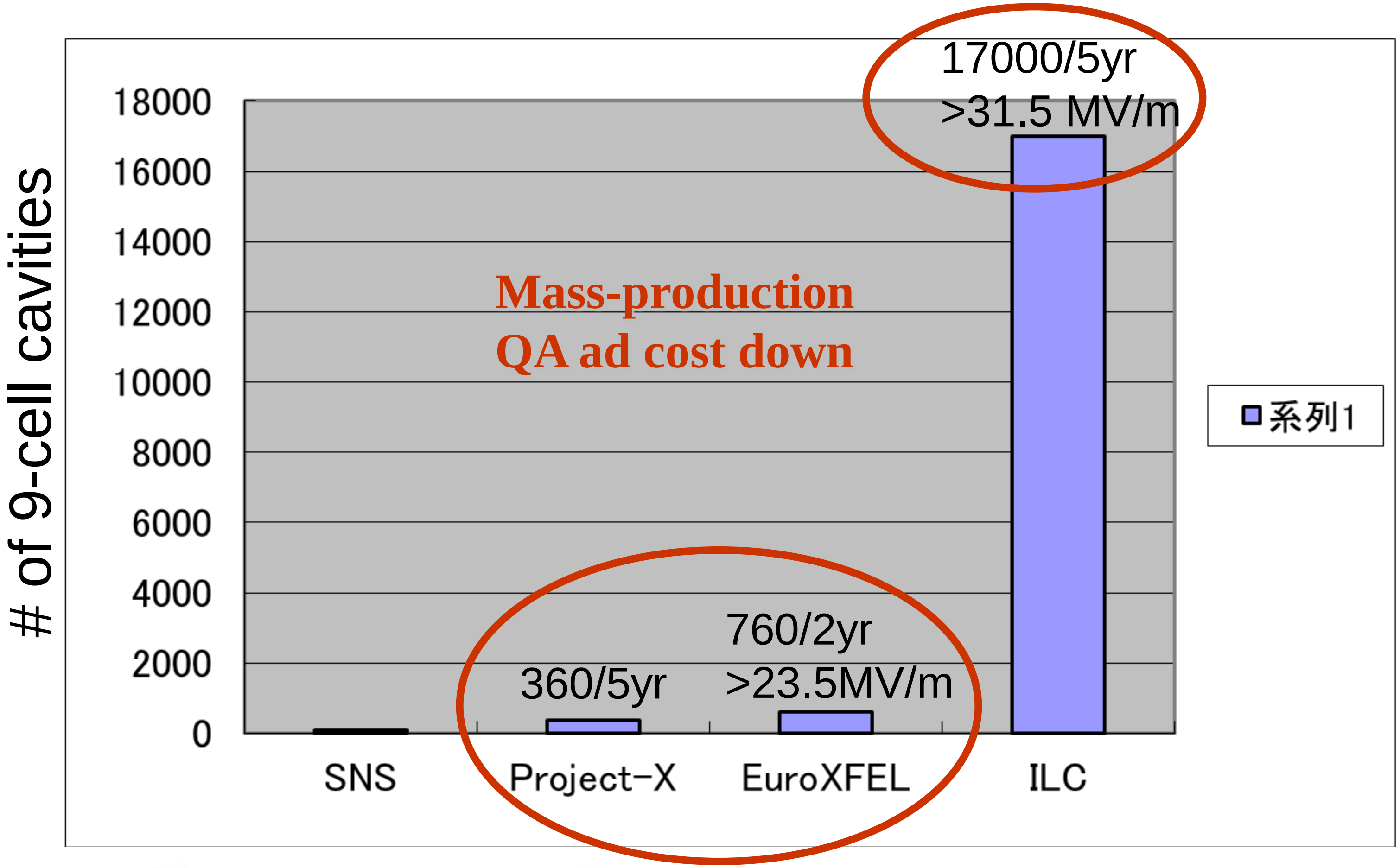
History of SRF cavity at KEK

SRF Cavity in TRISTAN
Bulk-Nb 508MHz 5-Cell Cavity

The first mass-production of SRF Cavities in the world.
32 SRF cavities were fabricated and operated in TRISTAN.



Fabrication of cavities in ILC

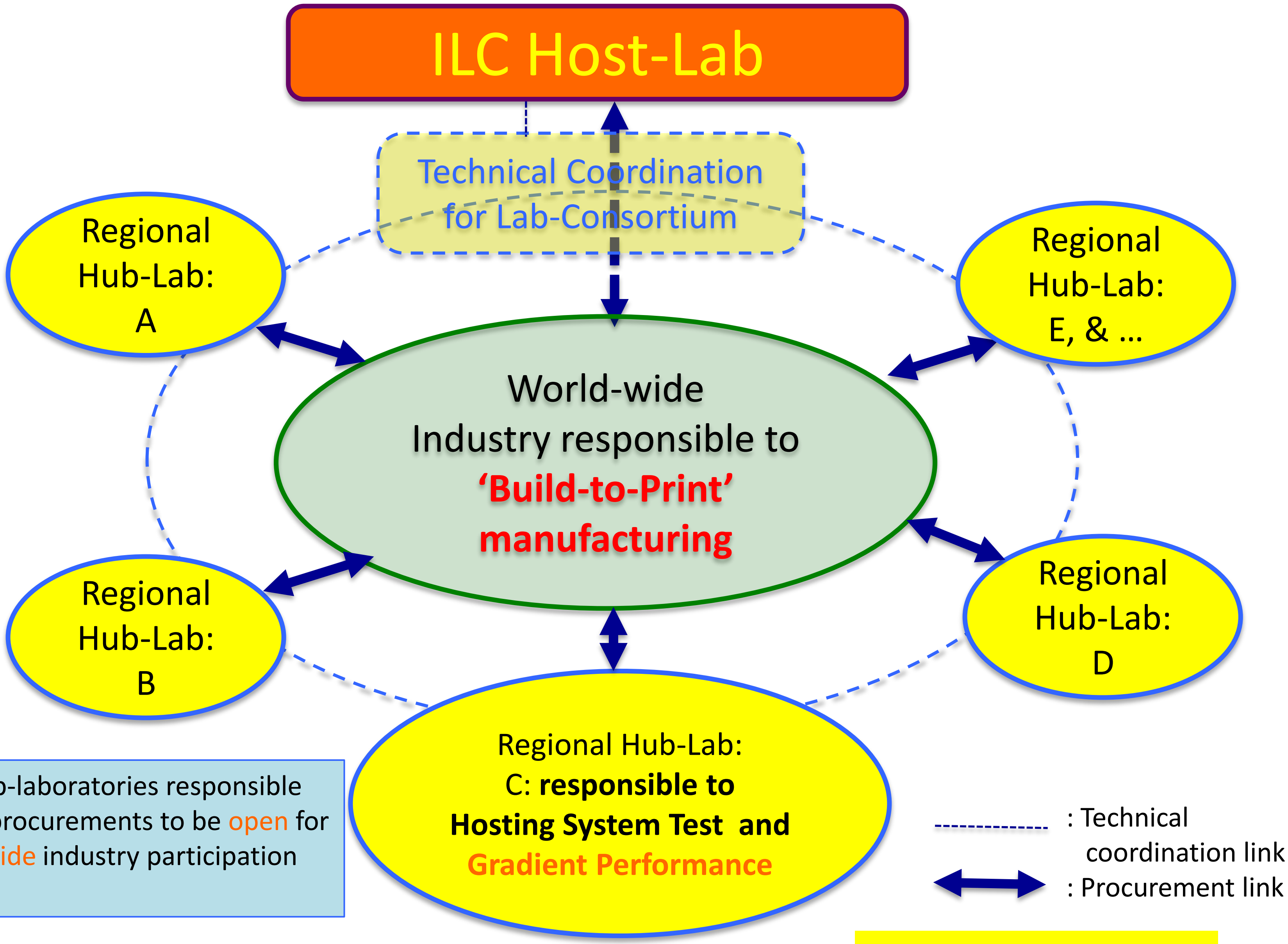


Toward Industrialization

- Global status of Industries
  - Research Instruments (ACCEL) and Zanon in Europe
  - AES, Niowave, Roak, PAVAC in Americas
  - MHI, Hitachi, Toshib, and others in Asia

Project Scope	# of Cav.		Assuming 200 work-days/yr
SNS	~ 110	3years	< ~ 1 cavity / week
XFEL → ÷ 2 vendors	~760	2 years	380/yr : ~ 1.9 cavity/day → 0.95 /day/vendor
Project X	~360	4-5 years	72/yr : 1.8 cavity / week
ILC			
Single vendor model	~15,500 + spare	5 years	~3100/yr → 16/day ~3400/yr → 17/day
6 vender model (3 regions x 2)	same	same	→ ~ 570/yr → 2.8/day/vendor

SCRF Procurement/Manufacturing Model



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

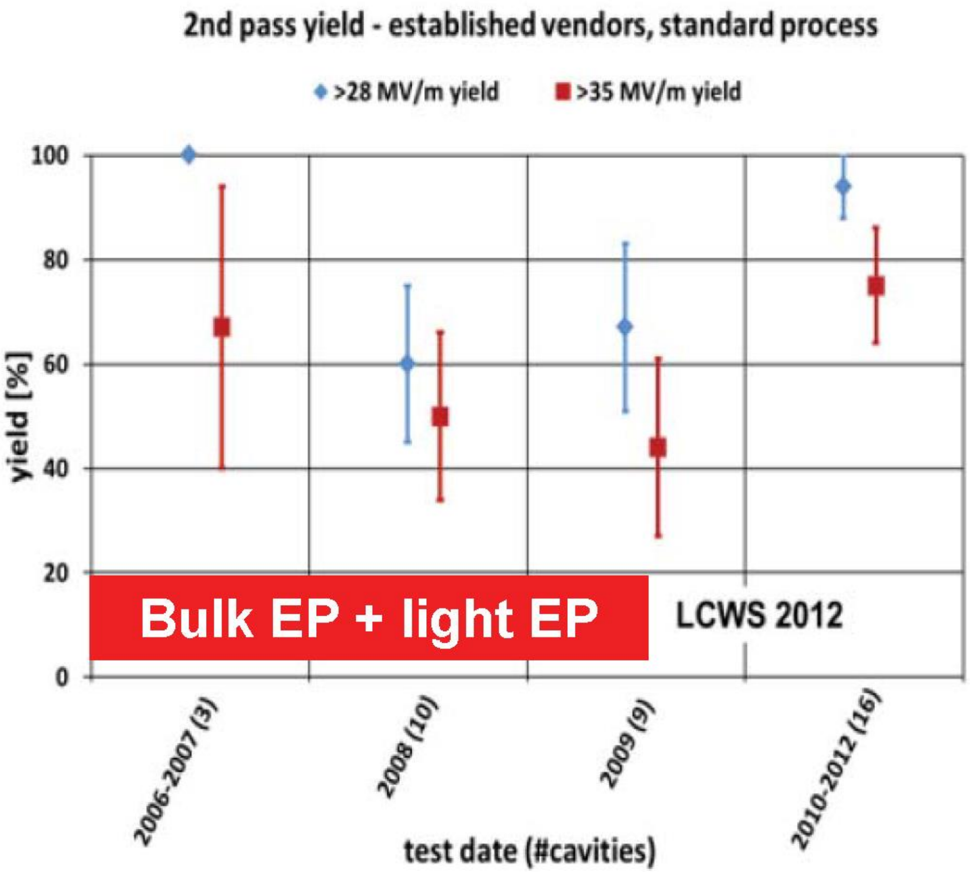
Slide by A. Yamamoto

Visiting Companies in Progress
(and further plan)

	Date	Company	Place	Technical sbject
1	2/8	**Hitachi**	Tokyo (JP)	Cavity/Cryomodule
2	2/8	**Toshiba**	Yokohana (JP)	Cavity/Cryomodule, Magnet
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	**(Zanon) mtg at INFN**	Verona (IT)	Cavity/(Cryomodule)
7	3/4	**RI**	Koeln (DE)	Cavity (Cryomodule)
8	3/14, (4/8)	**AES**	Medford, NY (US)	Cavity (Cryomodule)
9	3/15, (4/7)	**Niowave**	Lansing, MI (US)	Cavity/ (Cryomodule)
10	4/6	**PAVAC**	Vancouver (CA)	Cavity, EBW-machine
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, Vessel, joint
14	7/6	**Heraeus**	Hanau (DE)	Material (Nb, Nb-Ti, Ti)
15	9/14	**Zanon**	Verona (IT)	Cryomodule
16	11/16	**SST**	Munchen (DE)	EBW-machine

Slide by A. Yamamoto

Progress in SCRF Cavity Gradient



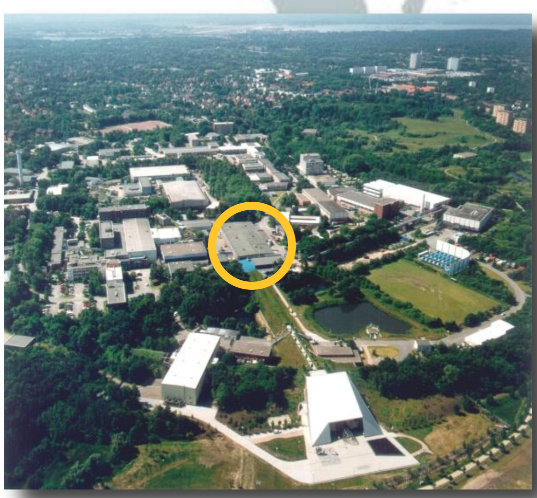
Production yield:
94 % at > 28 MV/m,

Average gradient:
37.1 MV/m

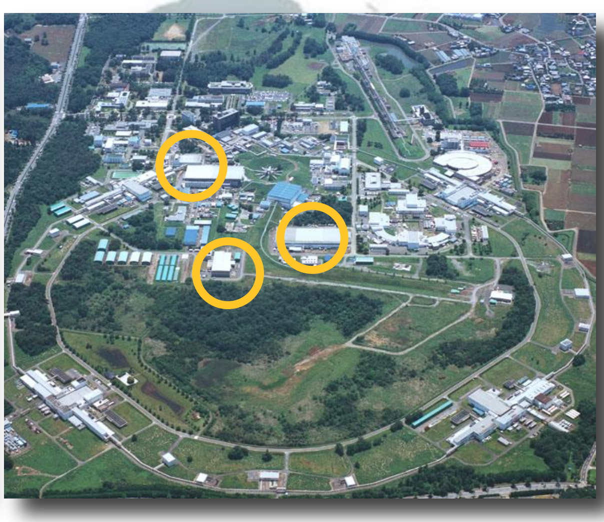
reached (2012)

Presented by A. Yamamoto, IPAC13

Main Laboratories for ILC R&D in the world



FLASH@DESY



STF@KEK

ILCTA@FNAL

Accelerator technology - collaborative effort

Industrial study module assembly (M6 done, M8 autumn 2007)

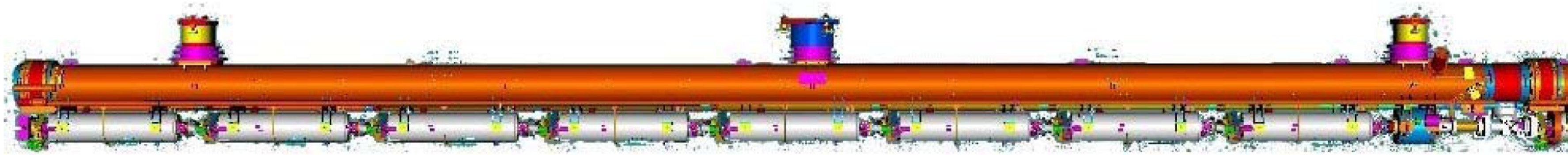
2 more cryostats (TTF3/INFN) delivered

Superferric magnet (CIEMAT)

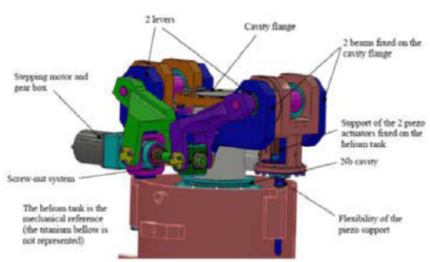
BPM (Saclay)

# of 9-cell cavities = 760

Integrated HOM absorber

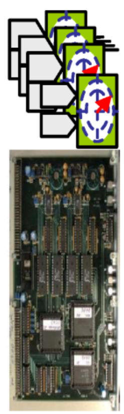


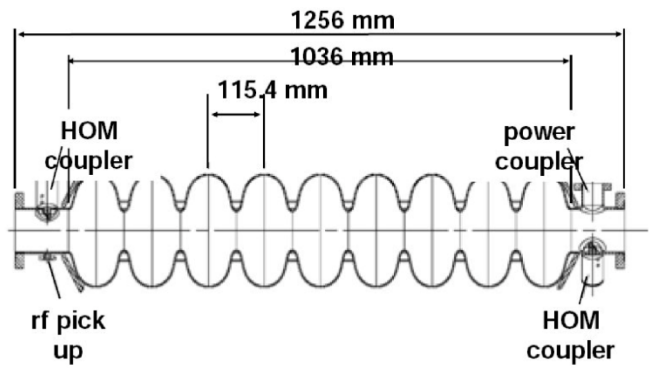
Length quantized n·λ/2 (possibility of ERL)



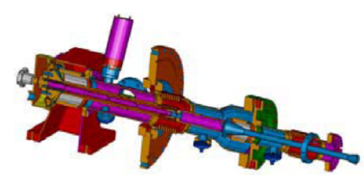
Tuner w/piezo (Saclay)

Industrialization in preparation





LLRF development (collab. Warsaw/Lodz)



TTF3-type coupler

Industrialization launched (Orsay)

Almost the same technology as ILC

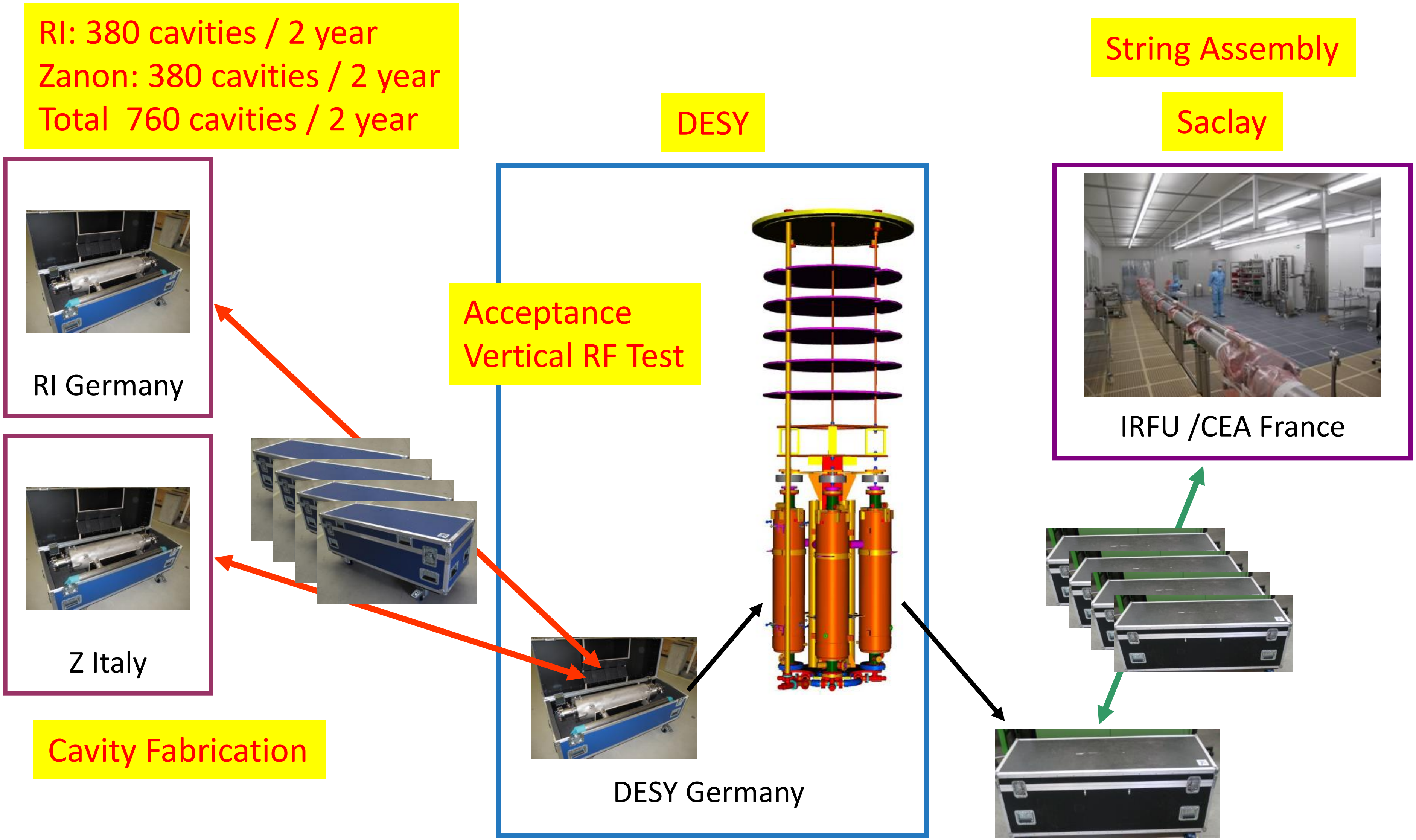
European XFEL

Civil Construction for the European XFEL

Slide by H. Weise

Civil Construction

Slide by H. Weise



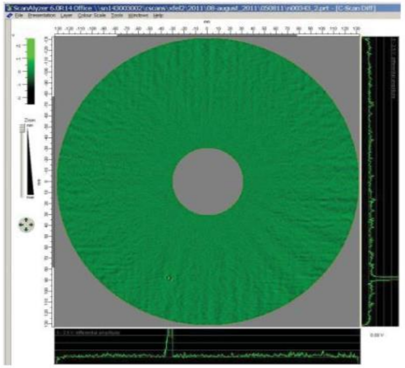
DESY takes care of installation / dismounting of cavities into / from test insert
Transport to CEA in transport boxes as well

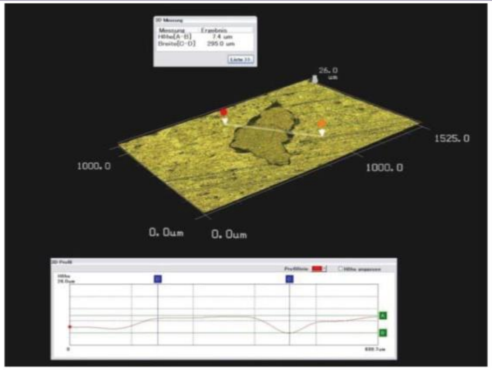
Slide by H. Weise

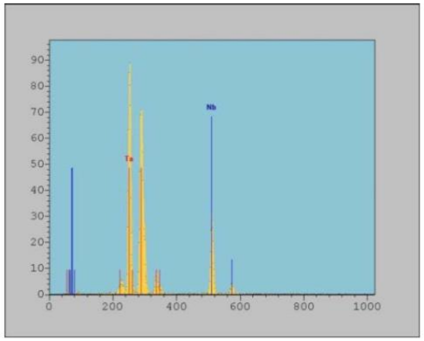
Status of Euro-XFEL (E.U.)

European XFEL

One example of foreign material inclusion (Ta) in the Nb sheets. For details see MOP050, MOP032

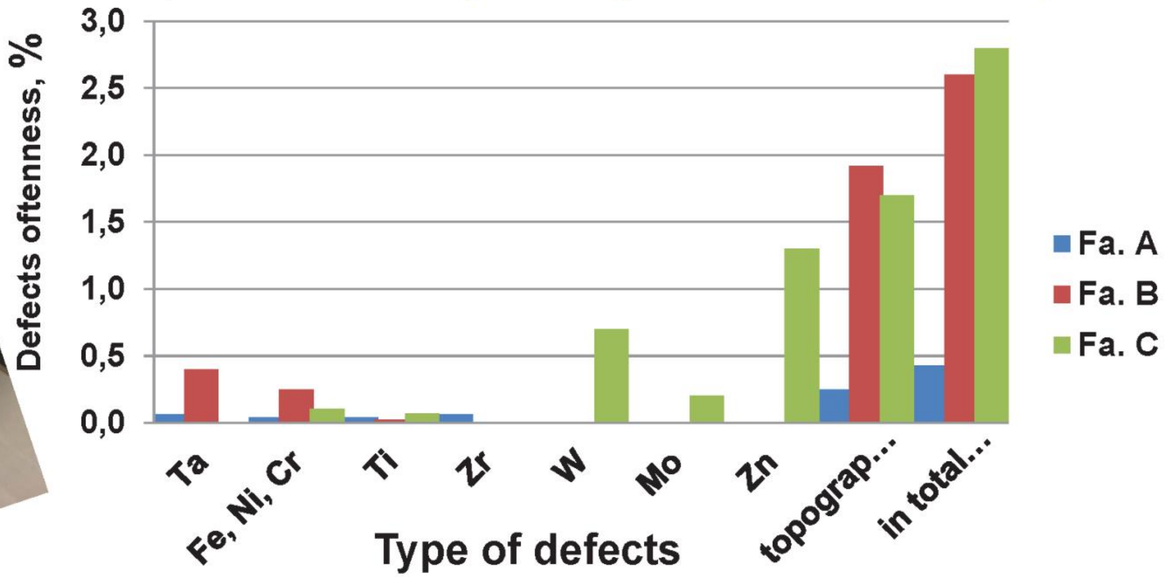






Example: Eddy-Current scan, 3D -Microscope image and element analysis

Statistic: Comparison of detected defects in Nb-sheets for different suppliers



Slide by W. Singer / DESY

Status of Euro-XFEL (E.U.)

European XFEL

DESY developed, build and installed at both companies the Cavity Tuning Machine CTM and Equipment for RF measurement of half-cells, dumb-bells and end-groups HAZEMEMA

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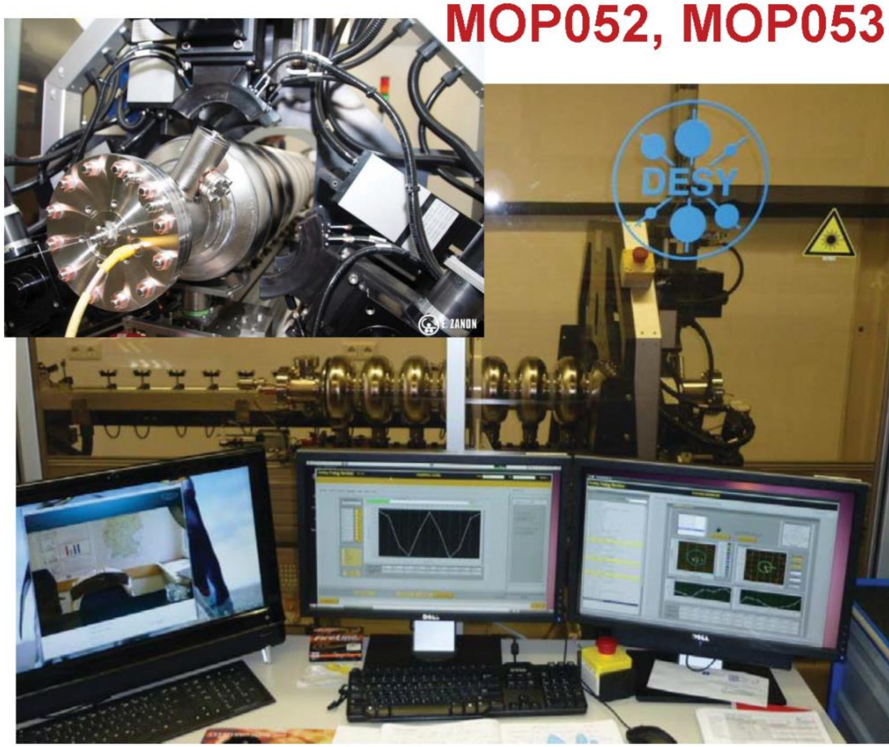
Service is in DESY responsibility. Equipment has to be robust, required trained personal that has special background. **MOP051, MOP052, MOP053 A. Sulimov et al**



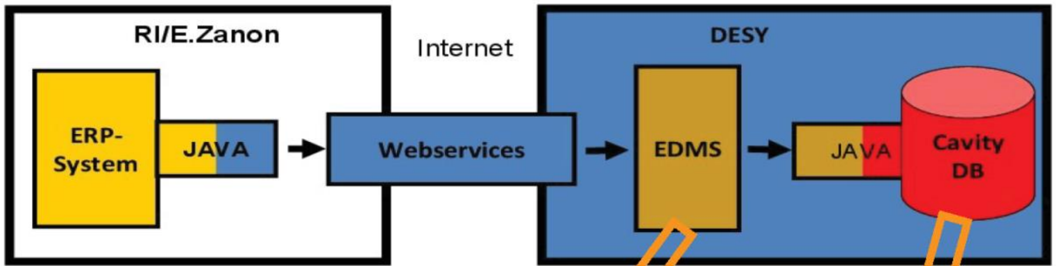
Cavity Tuning Machine CTM installed at RI

HAZEMEMA installed at EZ

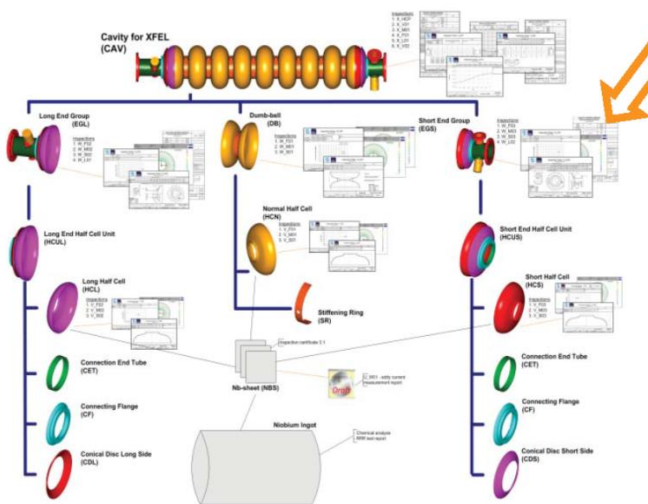
Status of Euro-XFEL (E.U.)

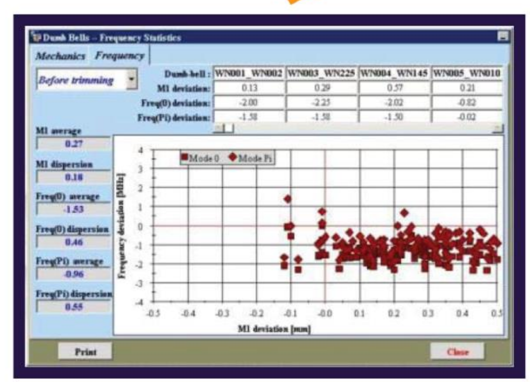
European XFEL

QM and Documentation : EDMS, Data Bank for statistic.
Automated transfer of documents/data from System to System.
Paperless documentation



EDMS product breakdown structure for XFEL cavity





XFEL Cavity Data Bank for statistical analysis

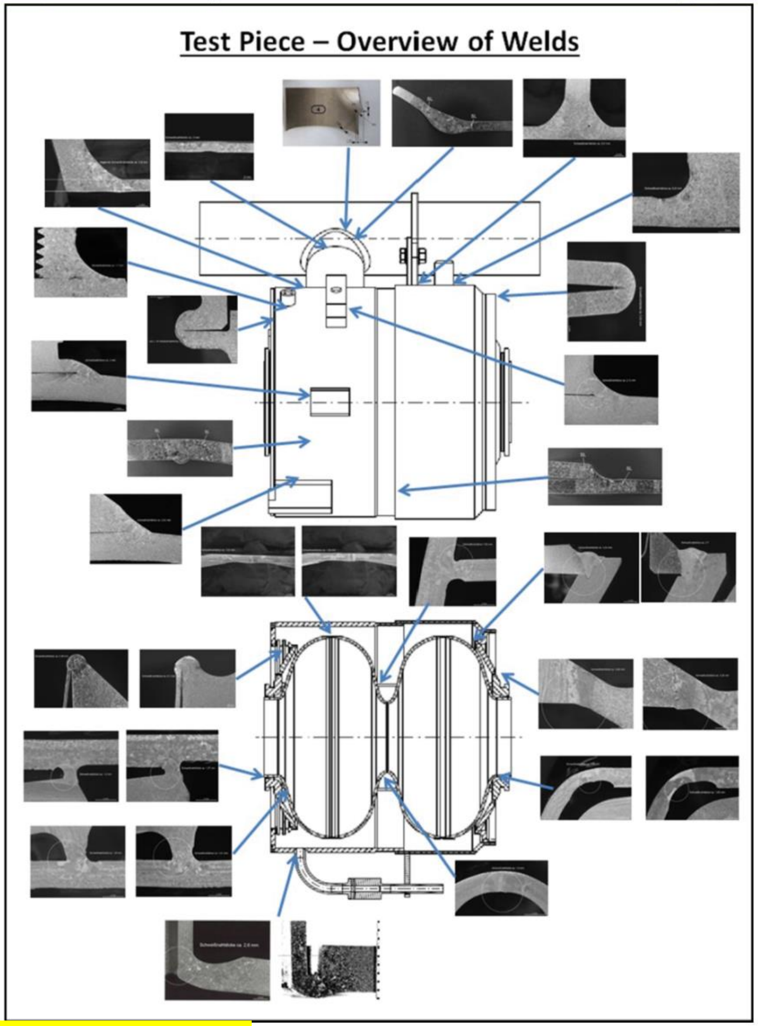
All XFEL SC cavity documents (specifications, protocols, PED data etc.) recorded in EDMS. RI and E. Zanon have an access (to relevant data only).
For more see poster MOP035, J. Iversen et al.

Status of Euro-XFEL (E.U.)

European XFEL

Test piece represents all pressure bearing parts: Destructive notified body analysis. MOP048

- Test piece (TP) is composed by 2 cell with helium vessel, representing all pressure bearing parts and welding seams.
- It is built using the same welding parameters that will be used in the series production.
- Two EBW machines/company. Consequently two test pieces had been built per company and destructively tested by TUEV NORD.
- Previously DESY has done similar tests on real cavities and gave the feed back to companies



Slide by W. Singer / DESY

Status of Euro-XFEL (E.U.)

European XFEL

Treatment: European XFEL treatment recipe was worked out on prototype cavities

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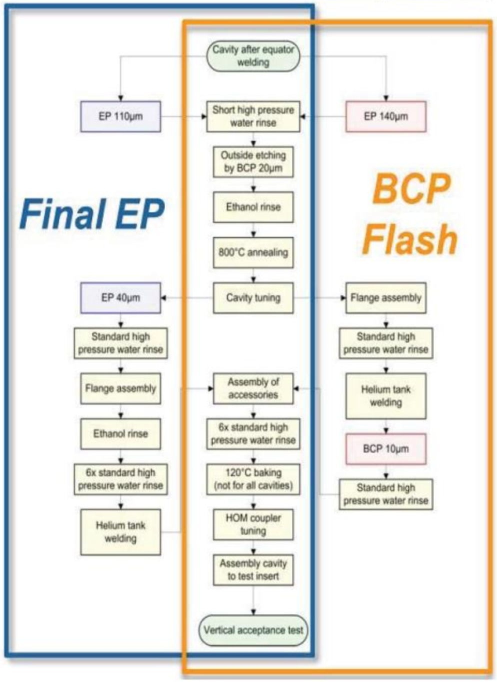
Prior surface treatment.

EP 110-140 μm (main EP), outside BCP, ethanol rinse, 800° C annealing, tuning

Final surface treatment - two alternative options

1. Final EP of 40 μm, ethanol rinse, high pressure water rinsing (HPR) and 120° C bake
2. Final BCP of 10 μm (BCP Flash), HPR and 120° C bake.



Integration of the helium tank, assembly of HOM, pick up and high Q antennas and shipment to DESY for 2K RF acceptance test

Slide by W. Singer / DESY

Status of Euro-XFEL (E.U.)

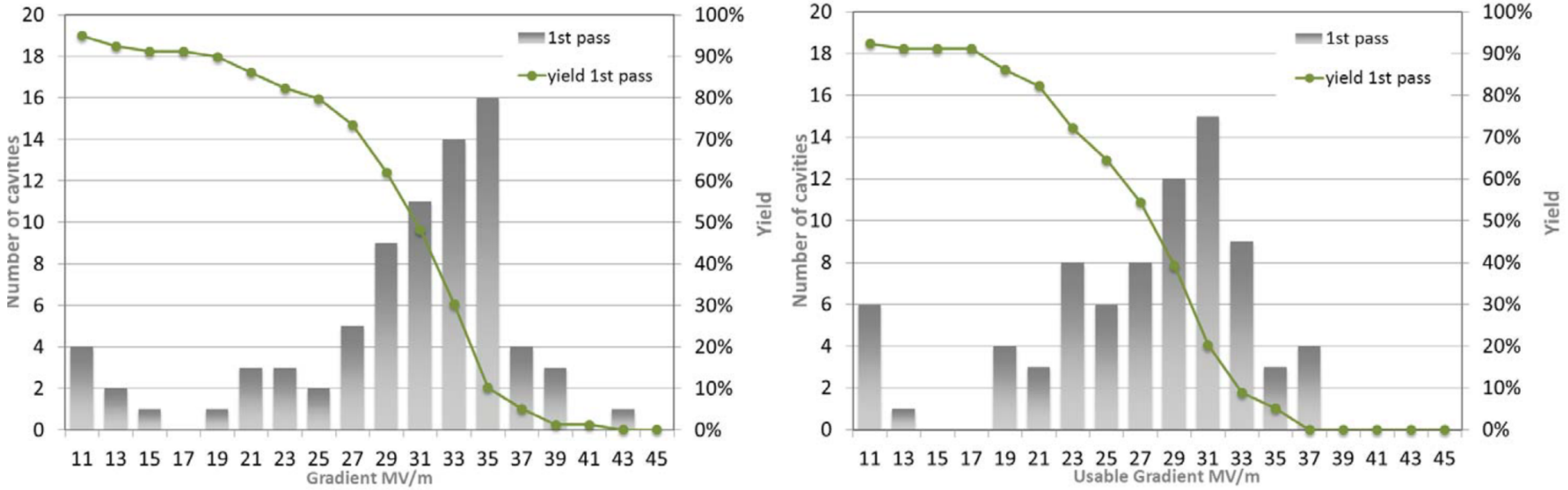
European XFEL

Infrastructure, Methods and Test Results for the Testing of 800 Series Cavities for the European XFEL

Yield of gradients: As received / 1. Pass

13

- Yield of usable and maximum gradient of **79 cavities as received**



Average **maximum** gradient:

(28.1 ± 7.8) MV/m

EZ: (27.6 ± 7.7) MV/m

RI: (29.2 ± 8.2) MV/m

Average **usable** gradient:

(25.0 ± 7.7) MV/m

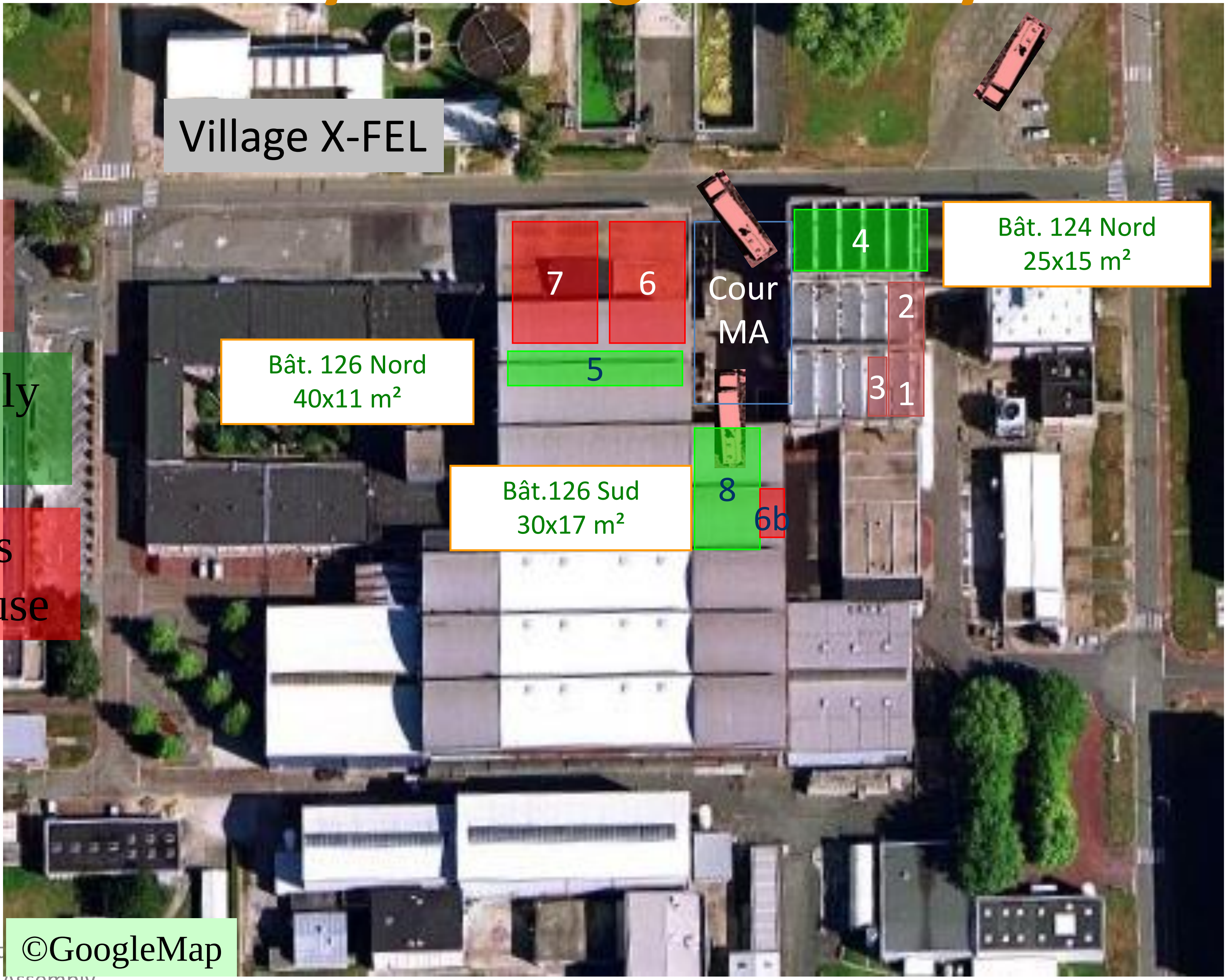
EZ: (24.5 ± 7.6) MV/m

RI: (26.1 ± 7.8) MV/m

given errors are standard deviation

Slide by D. Reschke / DESY (E.U.)

Assembly Buildings at Saclay

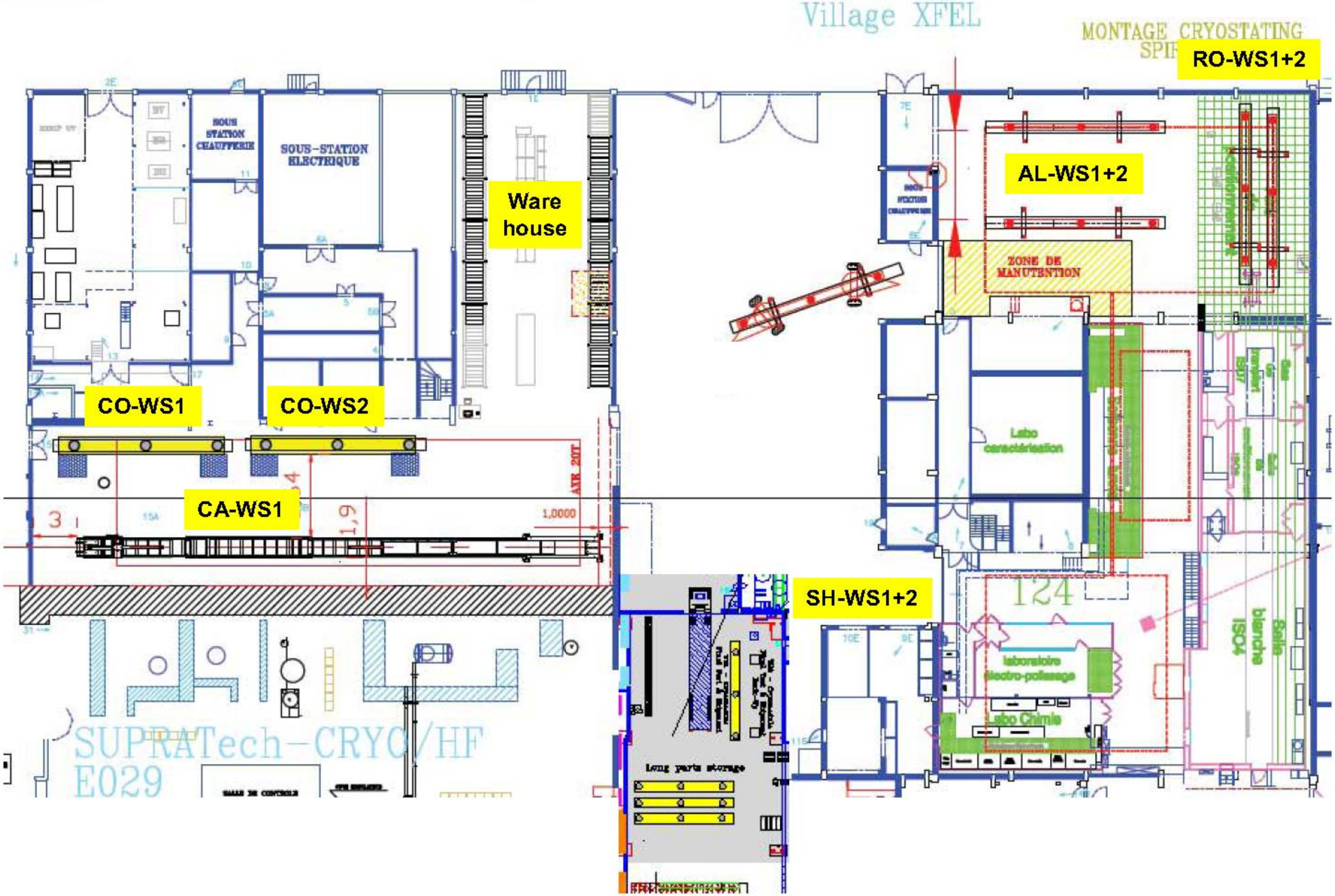


Clean Romm

Assembly Halls

Offices Warehouse

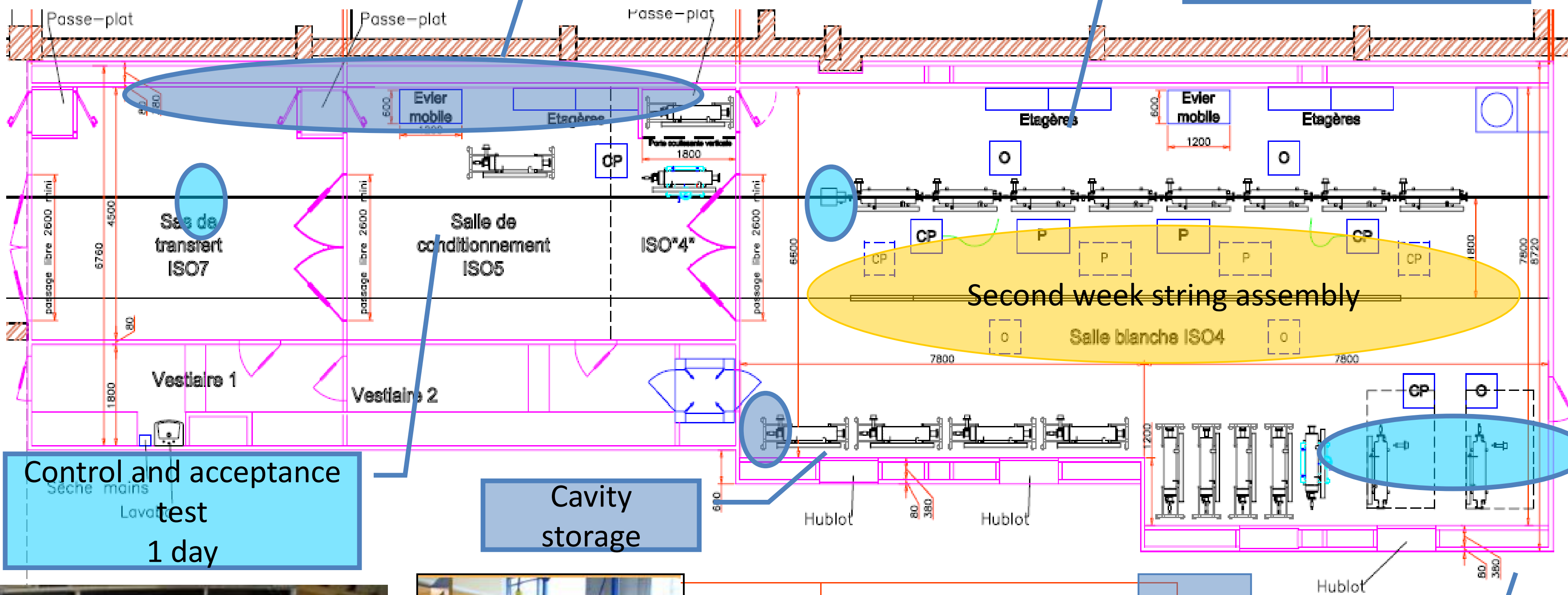
Assembly Hall : Workstations



Clean Room Workstations at Saclay

Unpacking / packing and cleaning pieces

Cavity string assembly
(1 string / week)



Control and acceptance test
1 day

Cavity storage

Cavity washer

Coupler cold part assembly
(8 cavities / week)

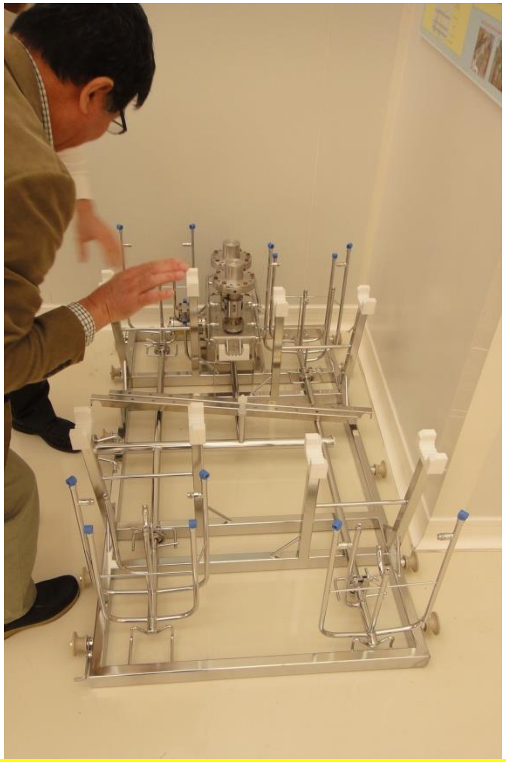
Clean Room constructed (Sept'09)

Saclay

5 Mar. 2012

Saclay(March 2011)

Clean room and low-pressure rinsing system



Platform with many nozzles for
Low-pressure rinsing system

High-pressure rinsing system for Spiral-2 cavity

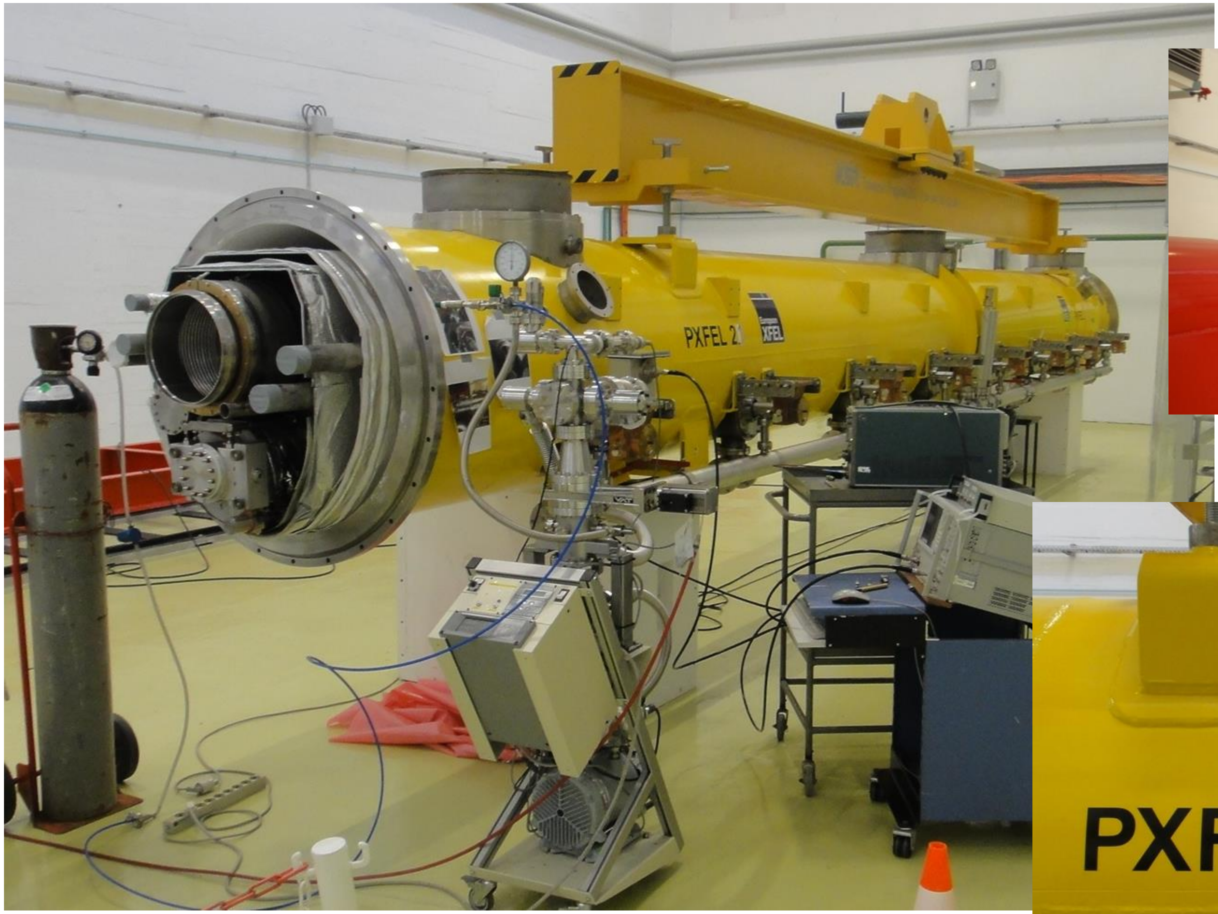
Saclay

5 Mar. 2012

Saclay(March 2011)

Cold-mass carrier with electric motor with wireless-controller

Saclay (March 2011)



7 March 2011 at Saclay

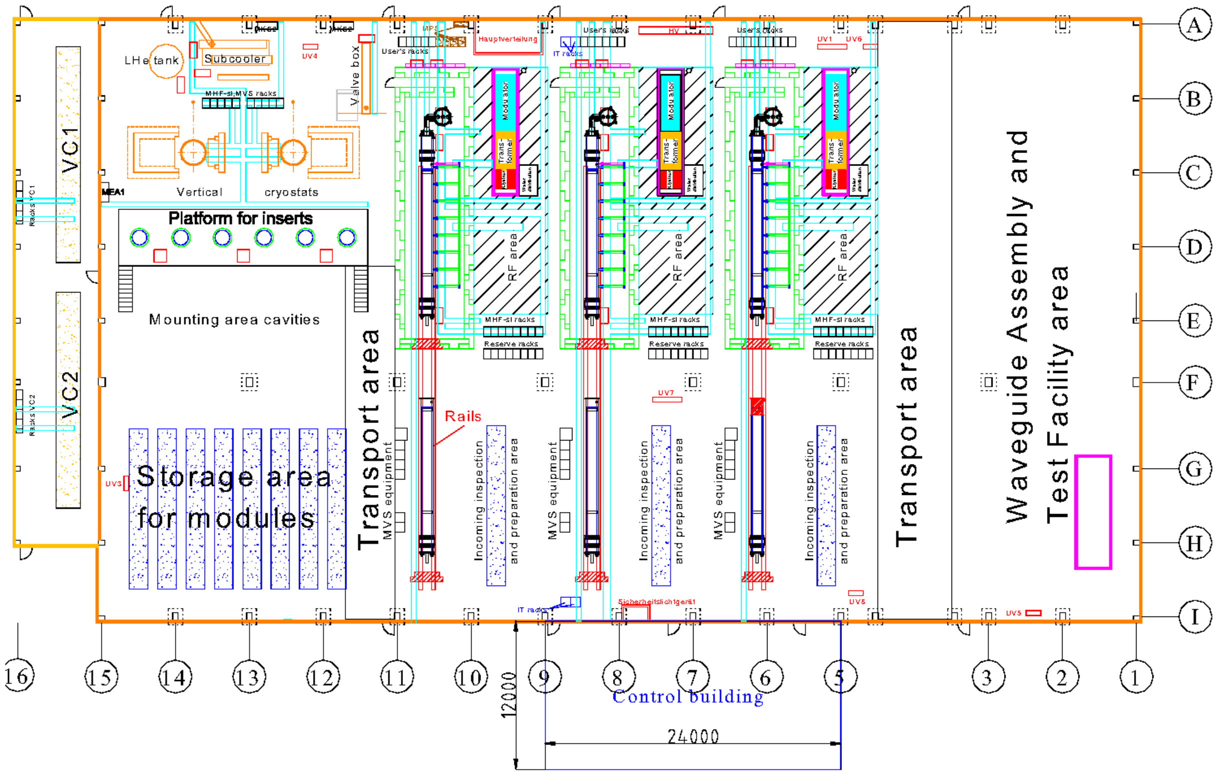
PXFEL 2.1 (DESY >>> Saclay >>> transportation to DESY within a few weeks)

DESY (March 2011)

Construction of Accelerator Module Test Facility (AMTF) hall is on going.

Three cryomodule test stands.

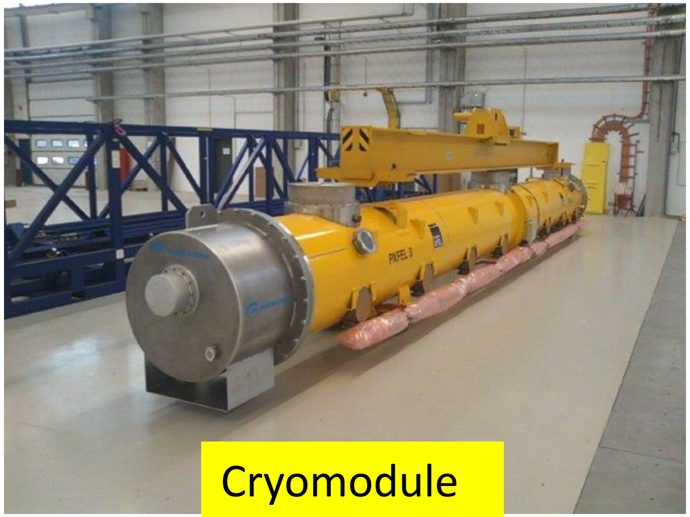
Accelerator Module Test Facility (AMTF) Including Single Cavity Tests



- Warm cryogenic piping 10/2010
- ISO- and UH Vacuum equipment 10/2010
- Vacuum compressors commissioning 11/2010
- cryo components (LHe sub cooler & He storage tank main transfer line & vertical cryostats) **are late** – fall 2011

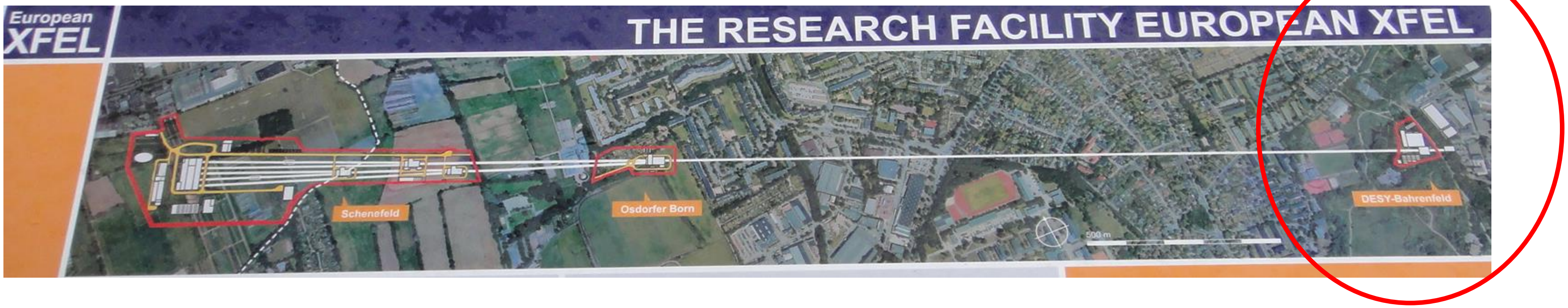
- **Commissioning**
  - **- vertical tests late fall 2011**
  - **- horizontal tests end 2011**

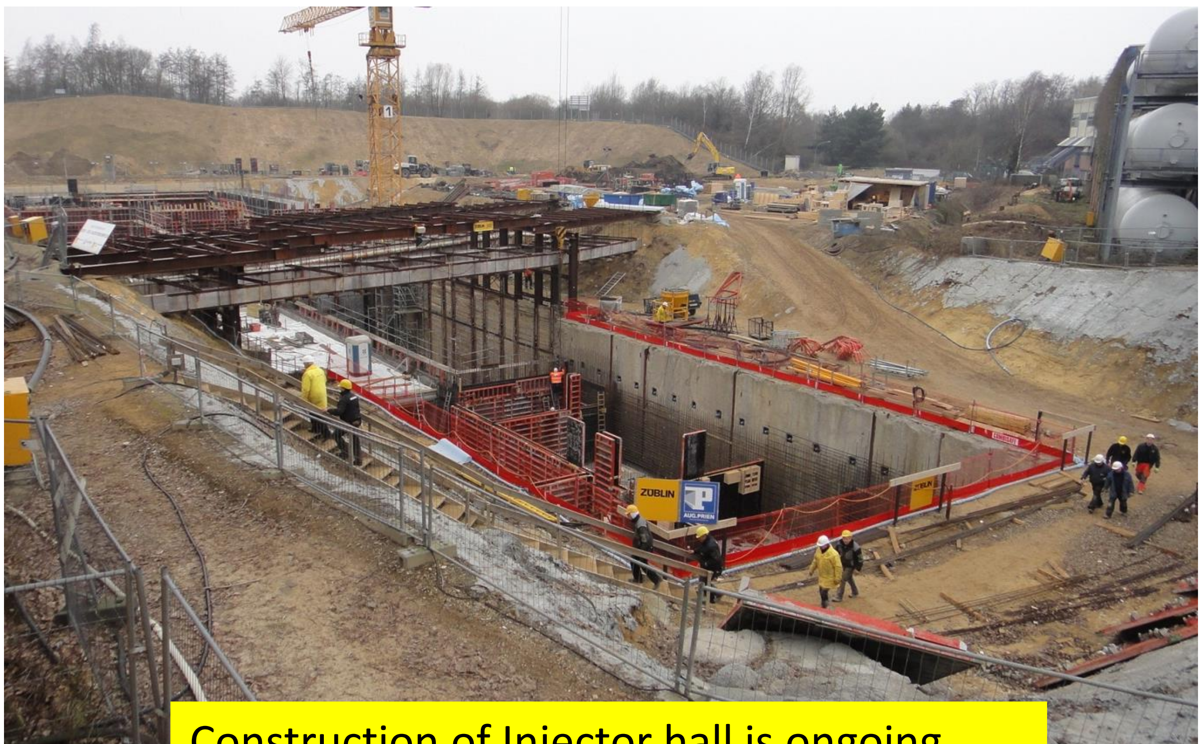
DESY(March 2011)



Construction of Accelerator Module Test Facility (AMTF) hall is on going.

DESY (March 2011)



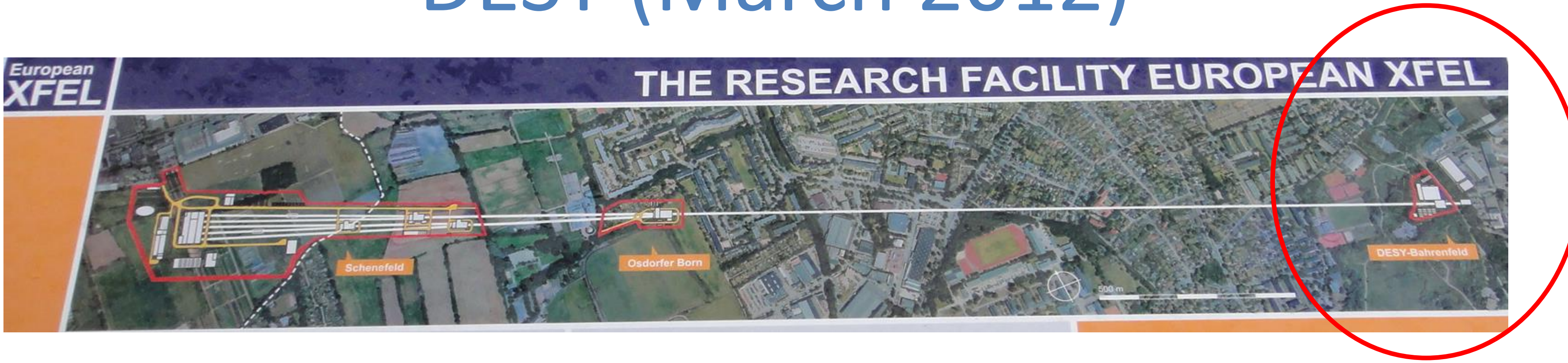


Construction of Injector hall is ongoing.

He tanks

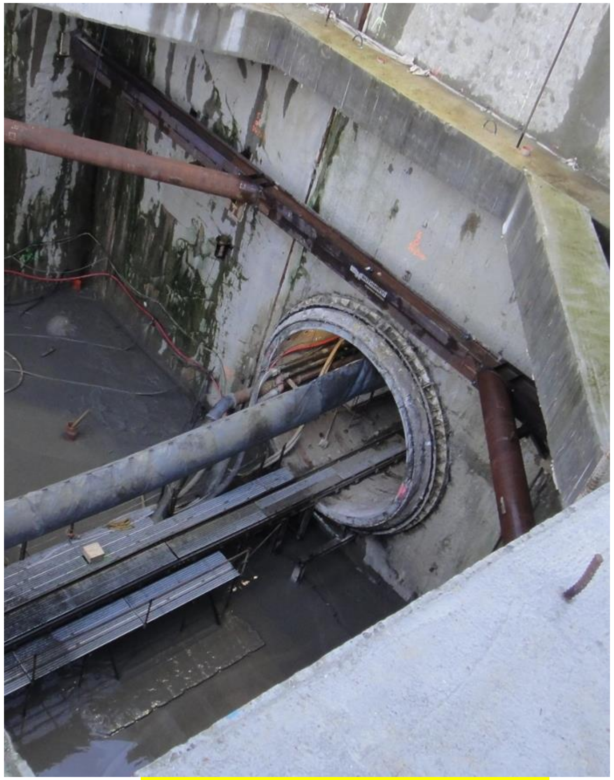
Spring 2011

DESY (March 2012)



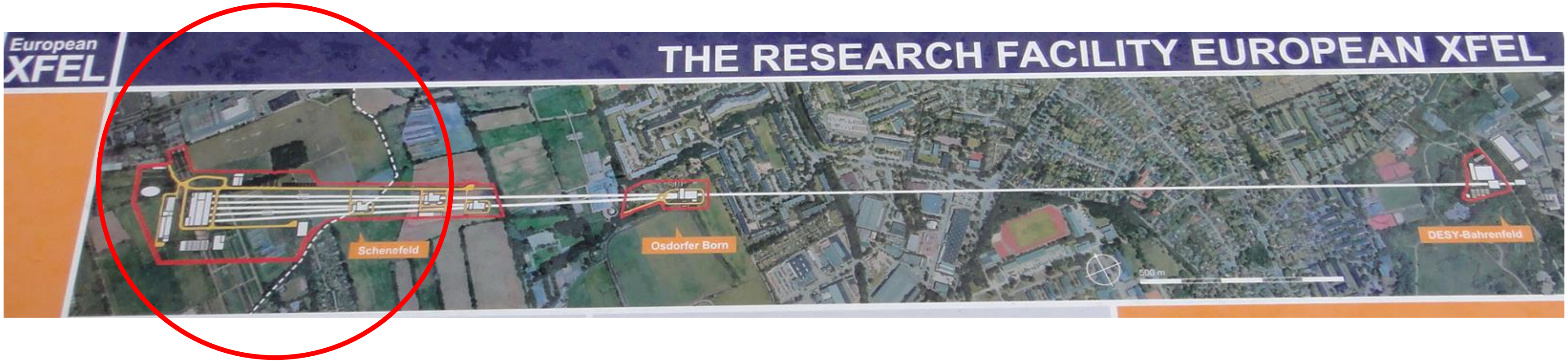
DESY (March 2011)

End of SRF linac. Entrance of tunnel bawling machines.



End of SRF linac

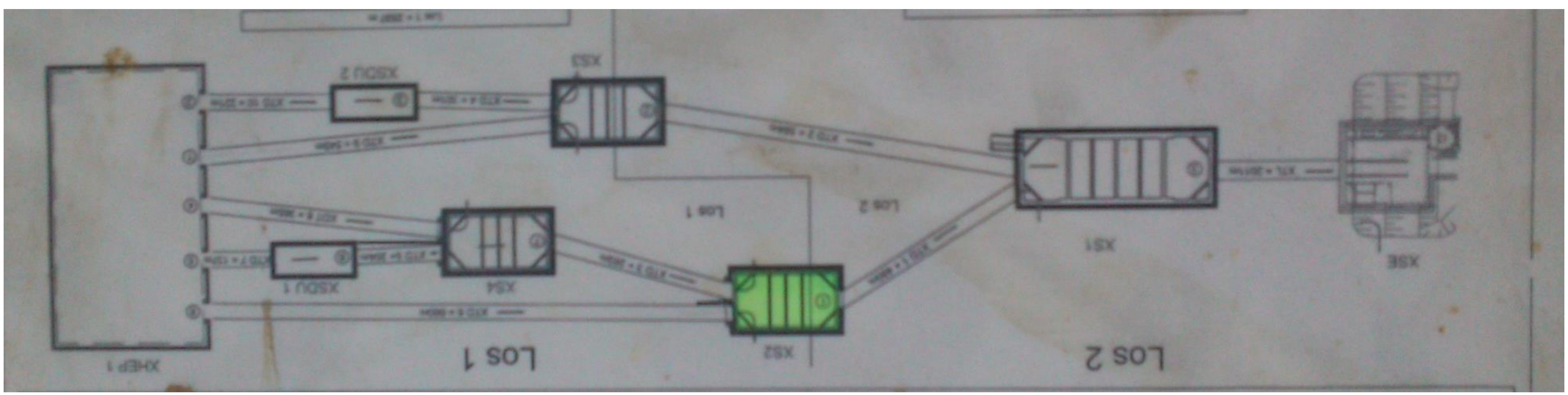
DESY (March 2011)



DESY is in this direction

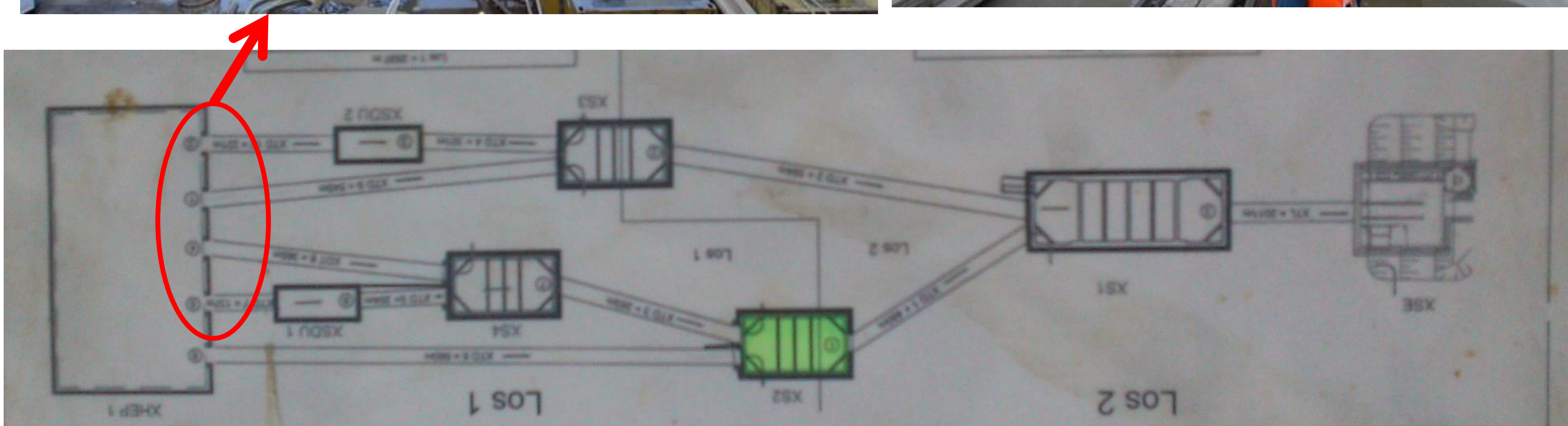
Construction of experimental halls is ongoing.

DESY (March 2012)

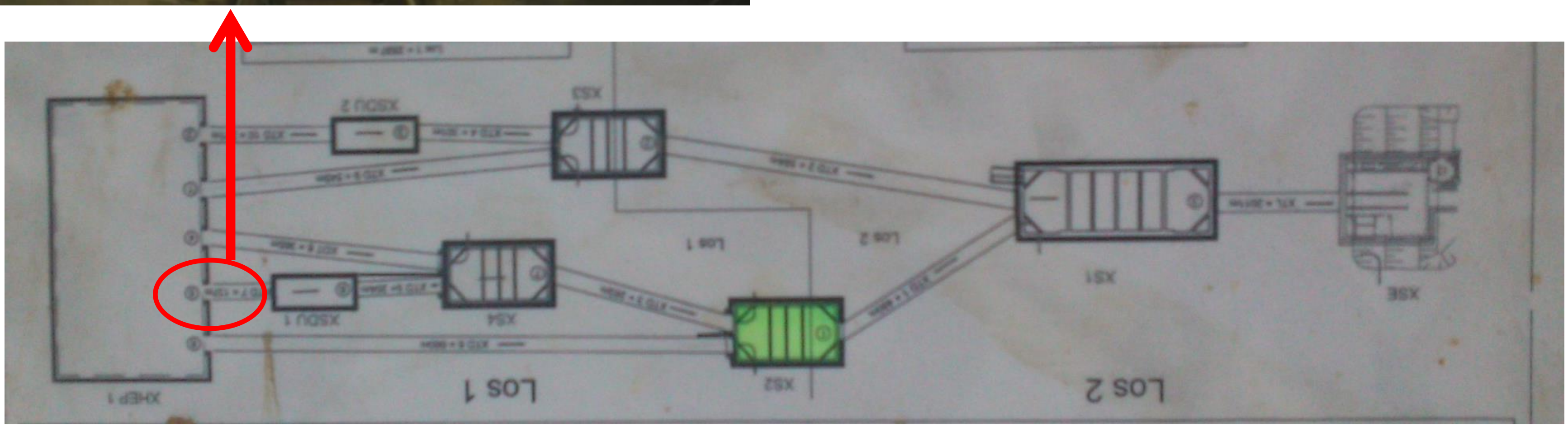


DESY (March 2012)

8 Mar. 2012

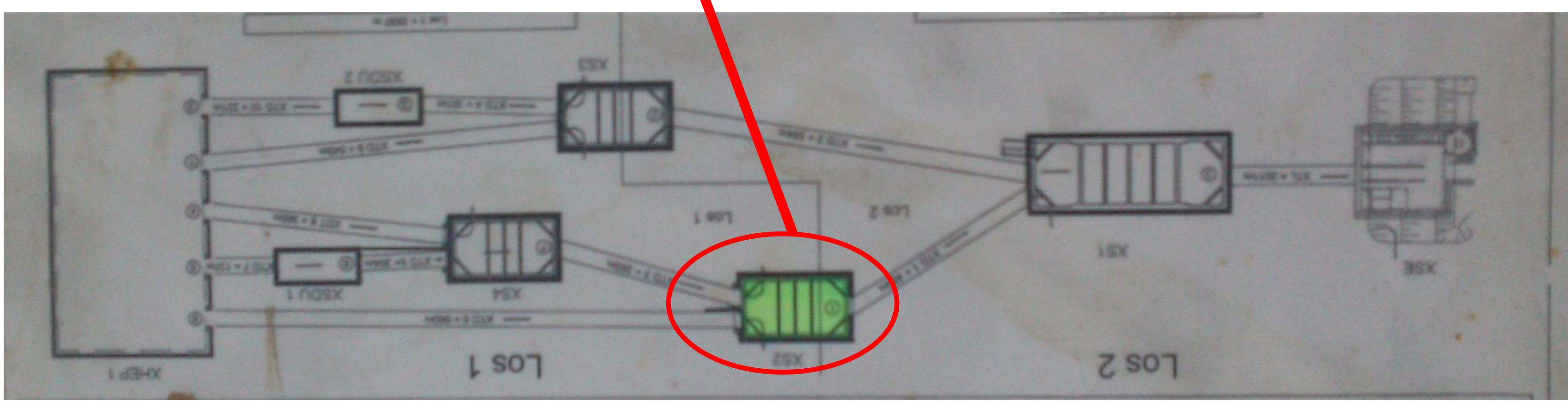


DESY (March 2012)



DESY (March 2012)

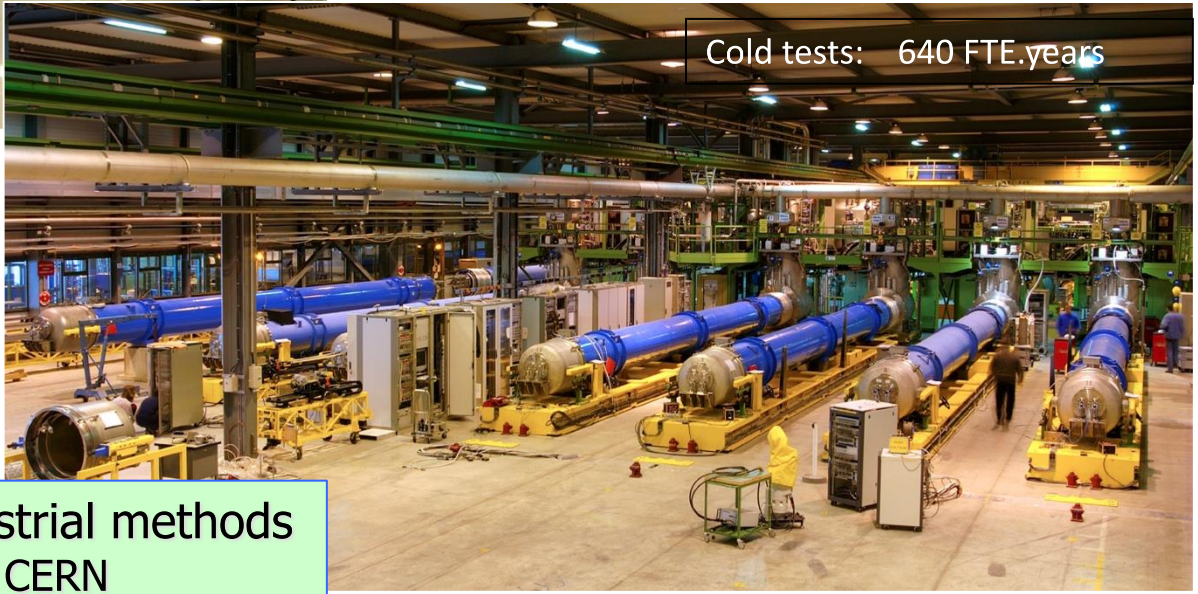
8 Mar. 2012



Courtesy: P. Lubrun (CERN), 1st WS, 2010

CERN's Experience from LHC Cryostating and Test

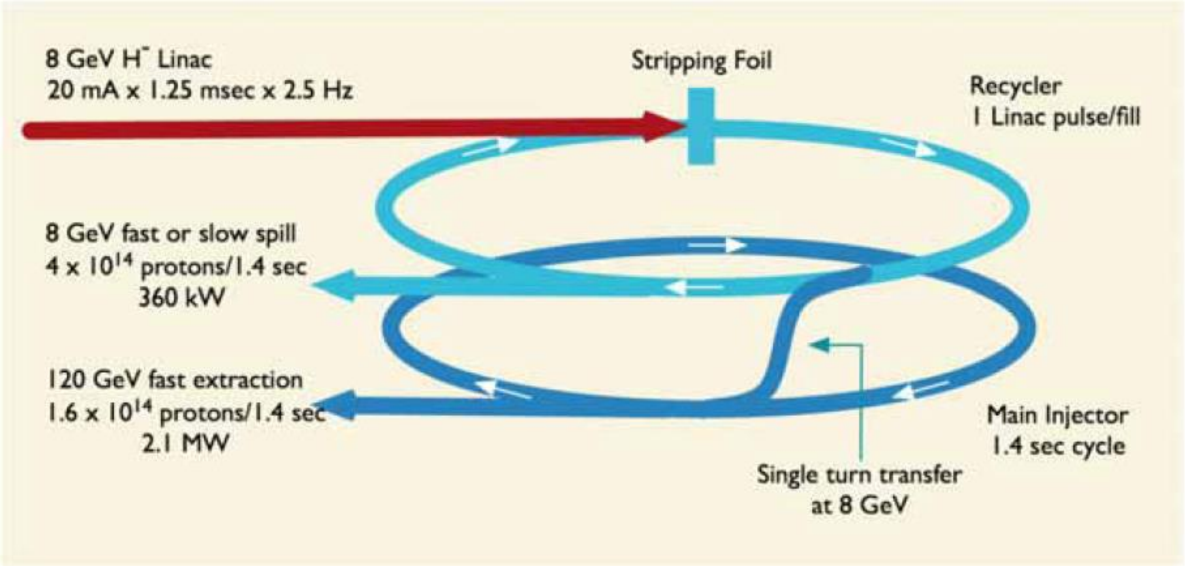
Bringing industry to the laboratory
Cryostat assembly by industry on CERN site



Producing in-house with industrial methods
Cryogenic magnet test station at CERN

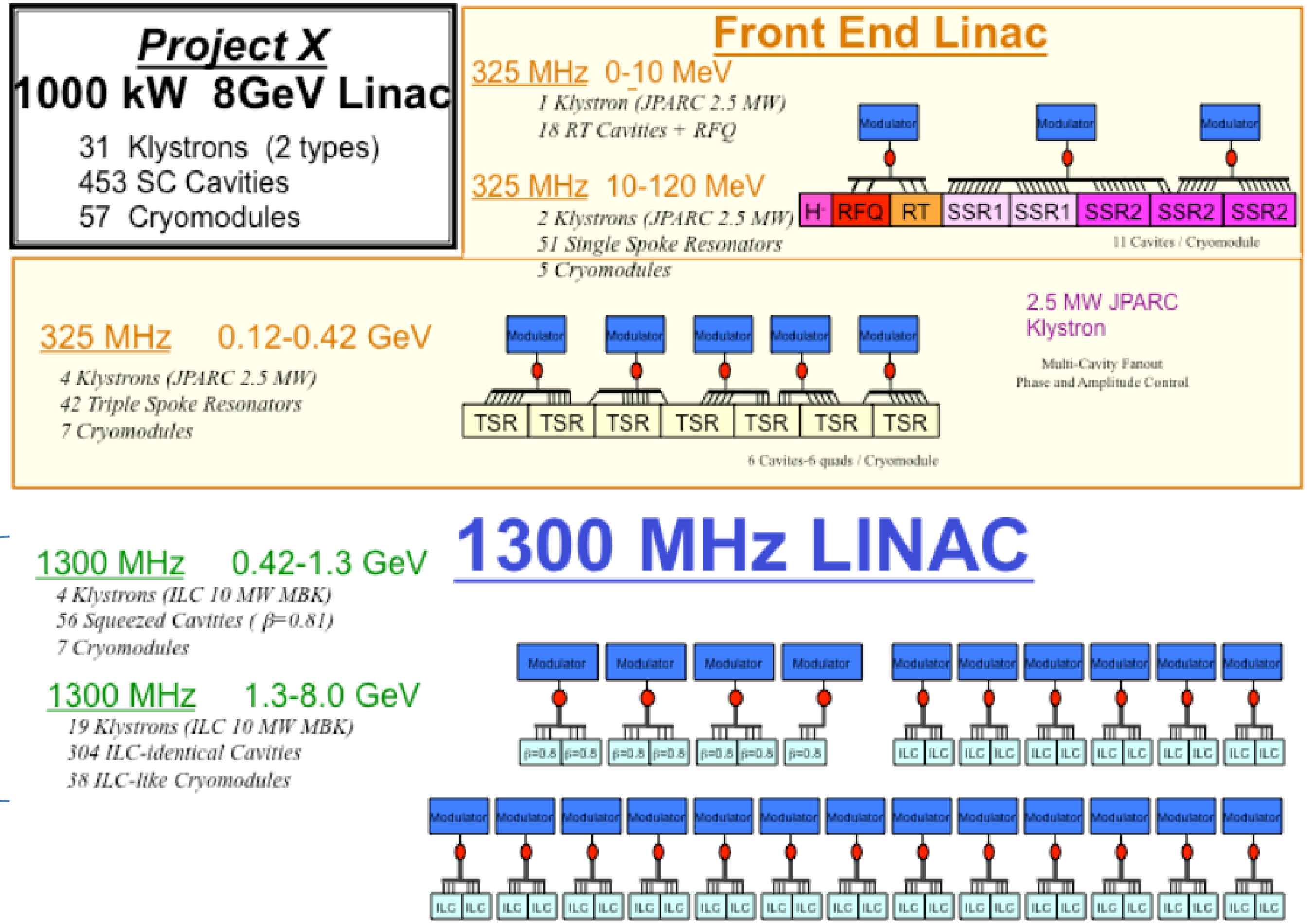
Initial Configuration-1

- Initial Configuration-1



- Strong alignment with ILC technologies
- Initial Configuration Document-1 V1.1 released March 2009
  - Accompanying cost estimate ~$1.5B

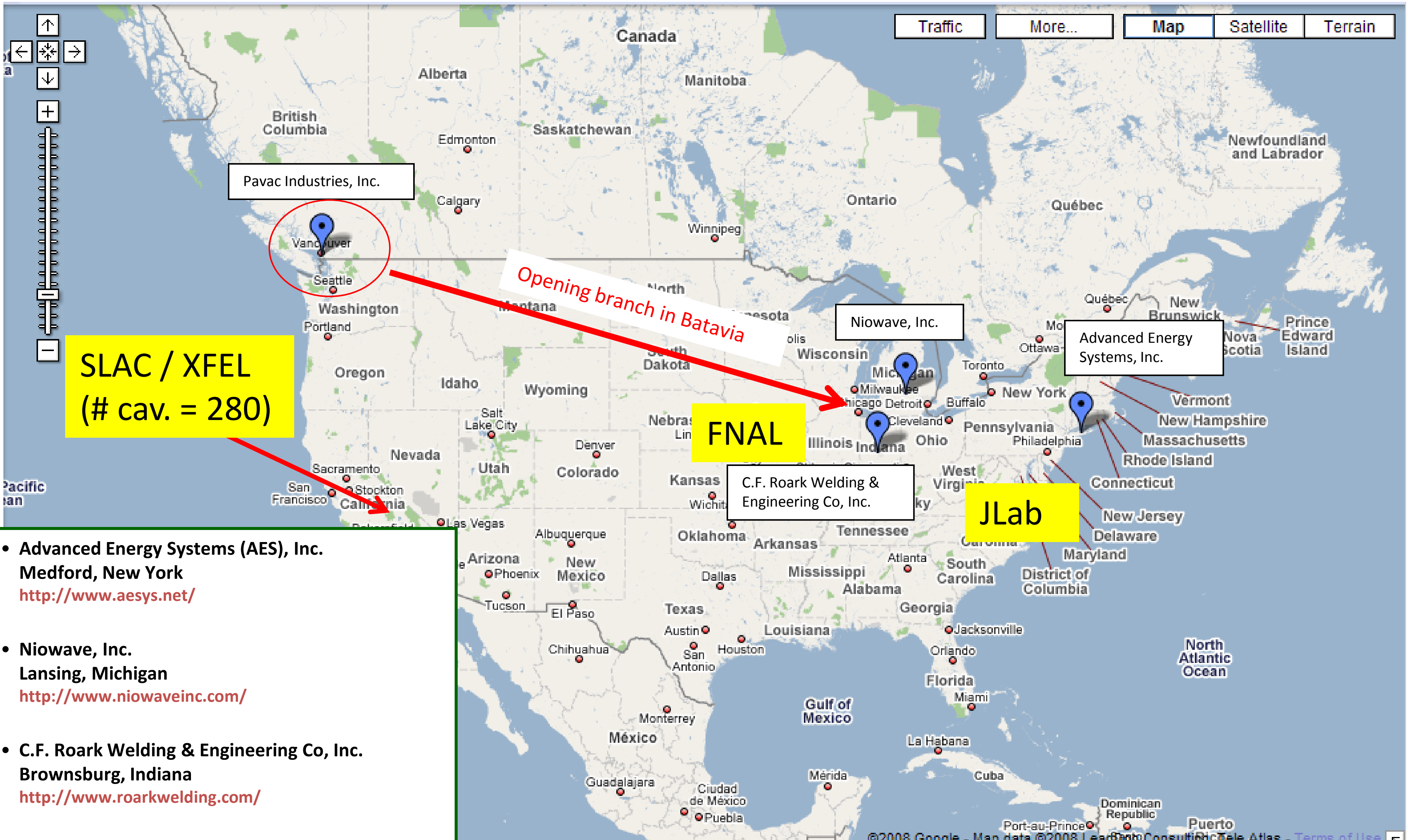
Project X Linac Configuration



360 Cavities

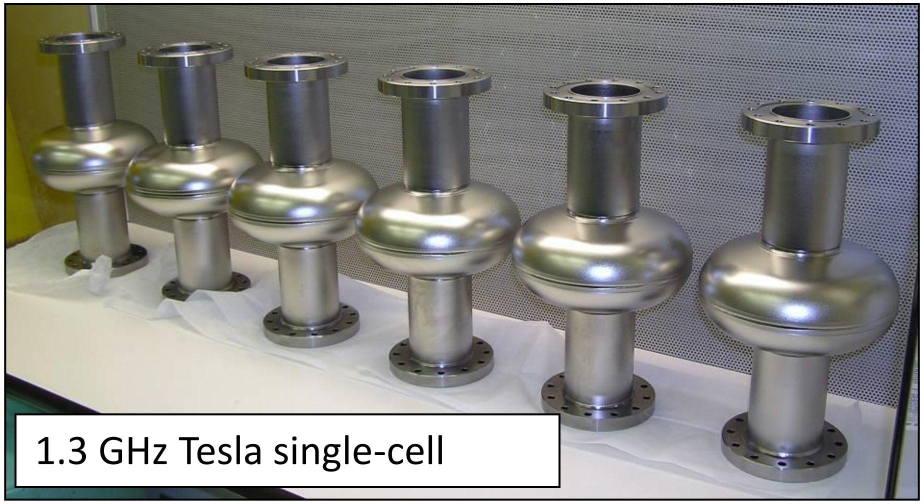
Figure III-3 : Layout and component counts for the initial Project X linac configuration

North American Cavity Vendors and laboratories

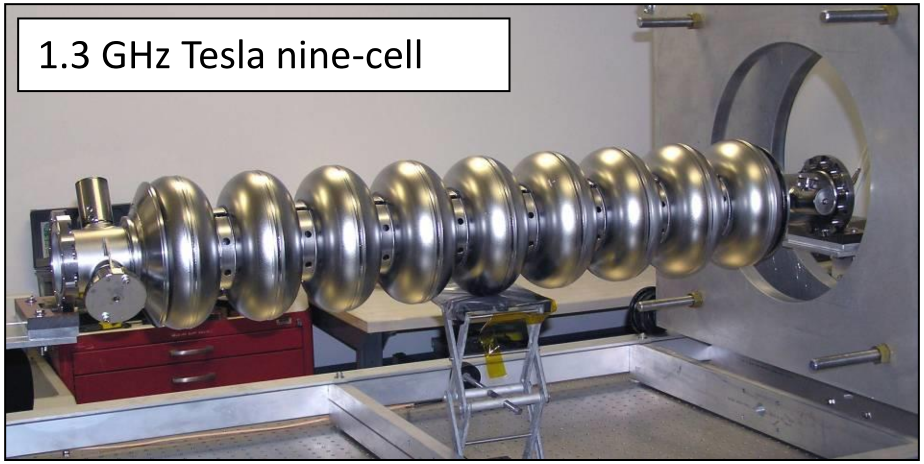


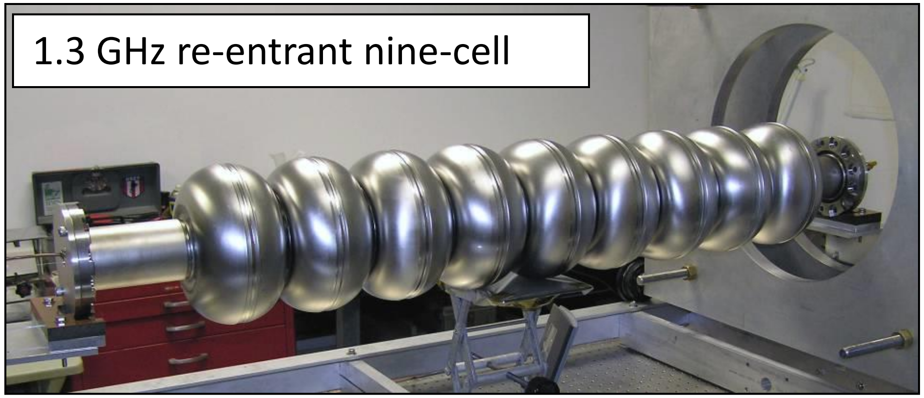
- **Advanced Energy Systems (AES), Inc.**
  Medford, New York
  http://www.aesys.net/
- **Niowave, Inc.**
  Lansing, Michigan
  http://www.niowaveinc.com/
- **C.F. Roark Welding & Engineering Co, Inc.**
  Brownsburg, Indiana
  http://www.roarkwelding.com/
- **Pavac Industries, Inc.**
  Richmond, British Columbia
  http://www.pavac.com

AES has complete production capability on-site
10 nine-cells delivered; 6 more in April, 20 more ordered (ARRA)


1.3 GHz Tesla single-cell

Electron-beam welding facility


1.3 GHz Tesla nine-cell


1.3 GHz re-entrant nine-cell

Cryomodule activities at FNAL

CM1 String Assembly

MP9 Clean Room

Final Assembly

CM1

Move to NML

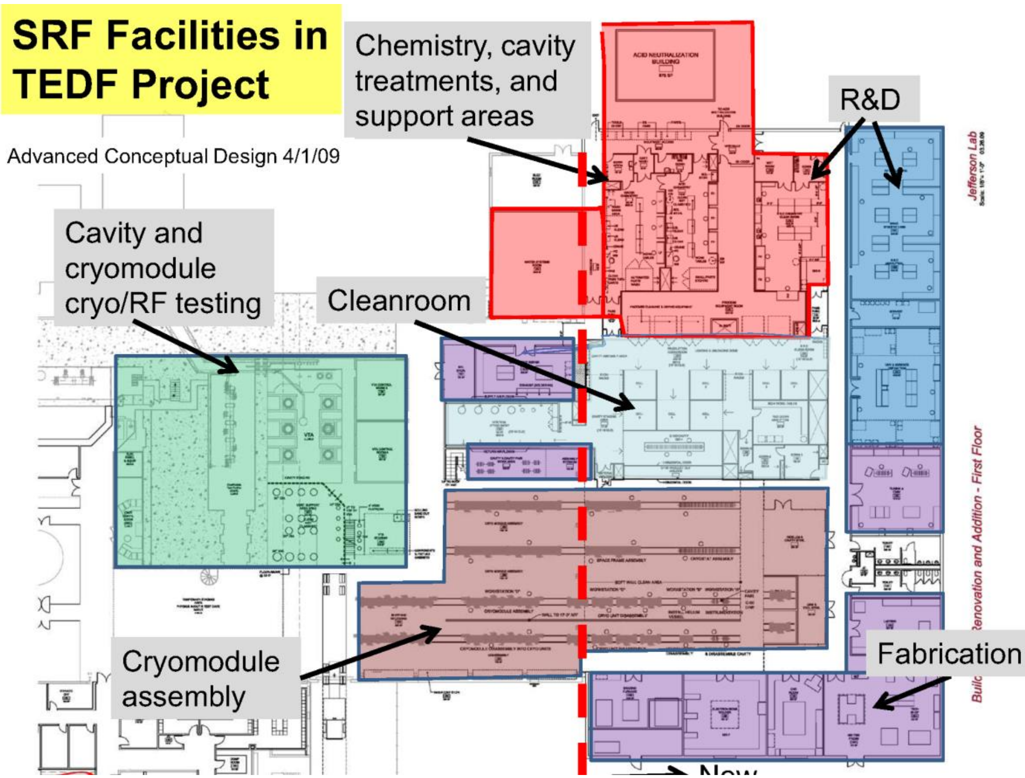
CM1 installed

Dressing cavities for CM2

FNAL S1 global
Cavities @ KEK

Jefferson Lab Technology and Engineering Development Facility Project (TEDF)

Presented by C. Reece at TTC(March 2011)

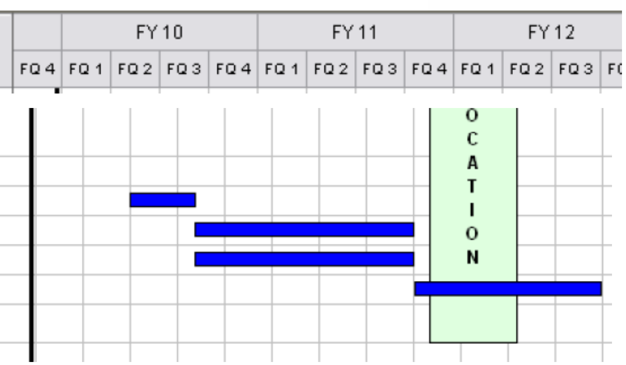


TEDF Summer 2010

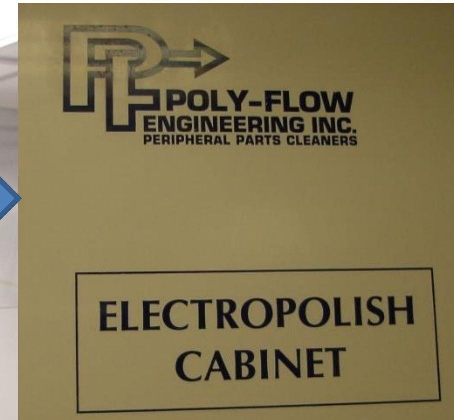
TEDF Feb 2011

Only the VTA and Cryo-module Test Facility will be unchanged!

	Activity Name	Start Date	Finish Date
13	TEDF Schedule		
14	**Early Start/Finish**		
15	6.3.1.1 Civil/Site & Early Procurements	3/31/10	8/3/10
16	6.3.1.2 TED Building Construction	8/4/10	9/30/11
17	6.3.1.3 TL Addition Construction	8/4/10	9/30/11
18	6.3.1.4 TL Renovation	10/3/11	9/28/12
19			
20			



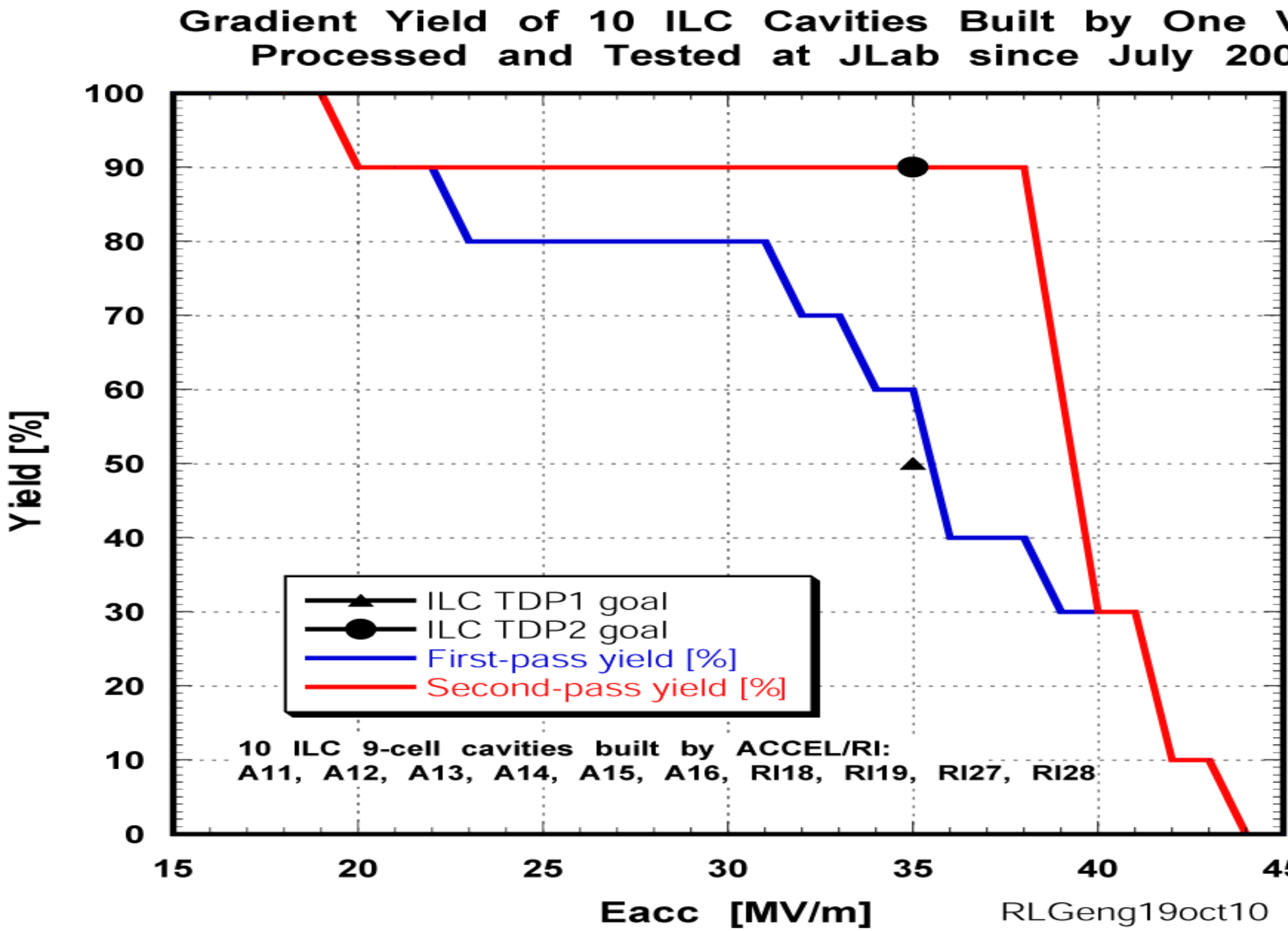
EP facility at JLab



Sleeve design
Nomura plating

+

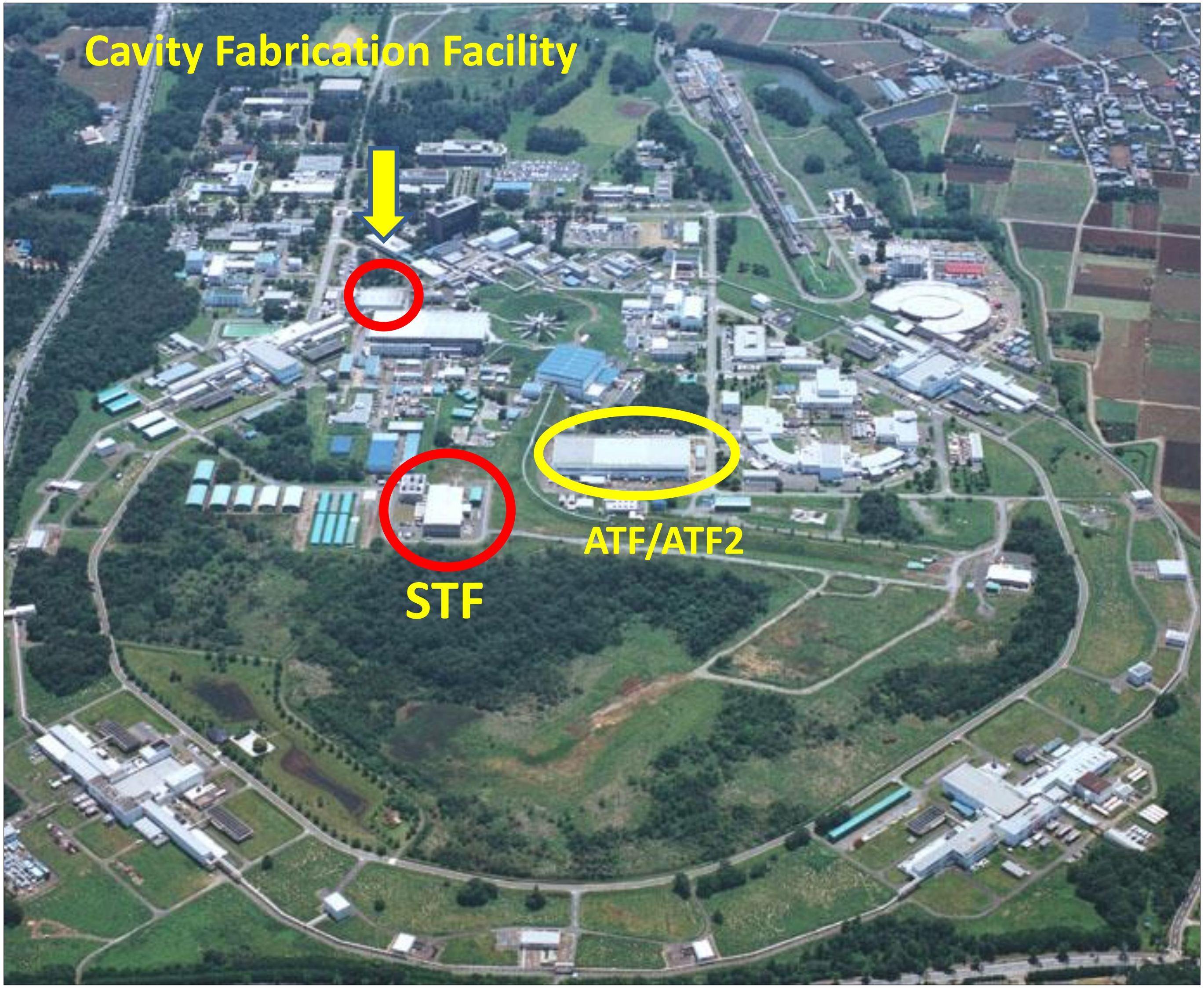
System design
J. Mammosser and Poly Flow Engineering



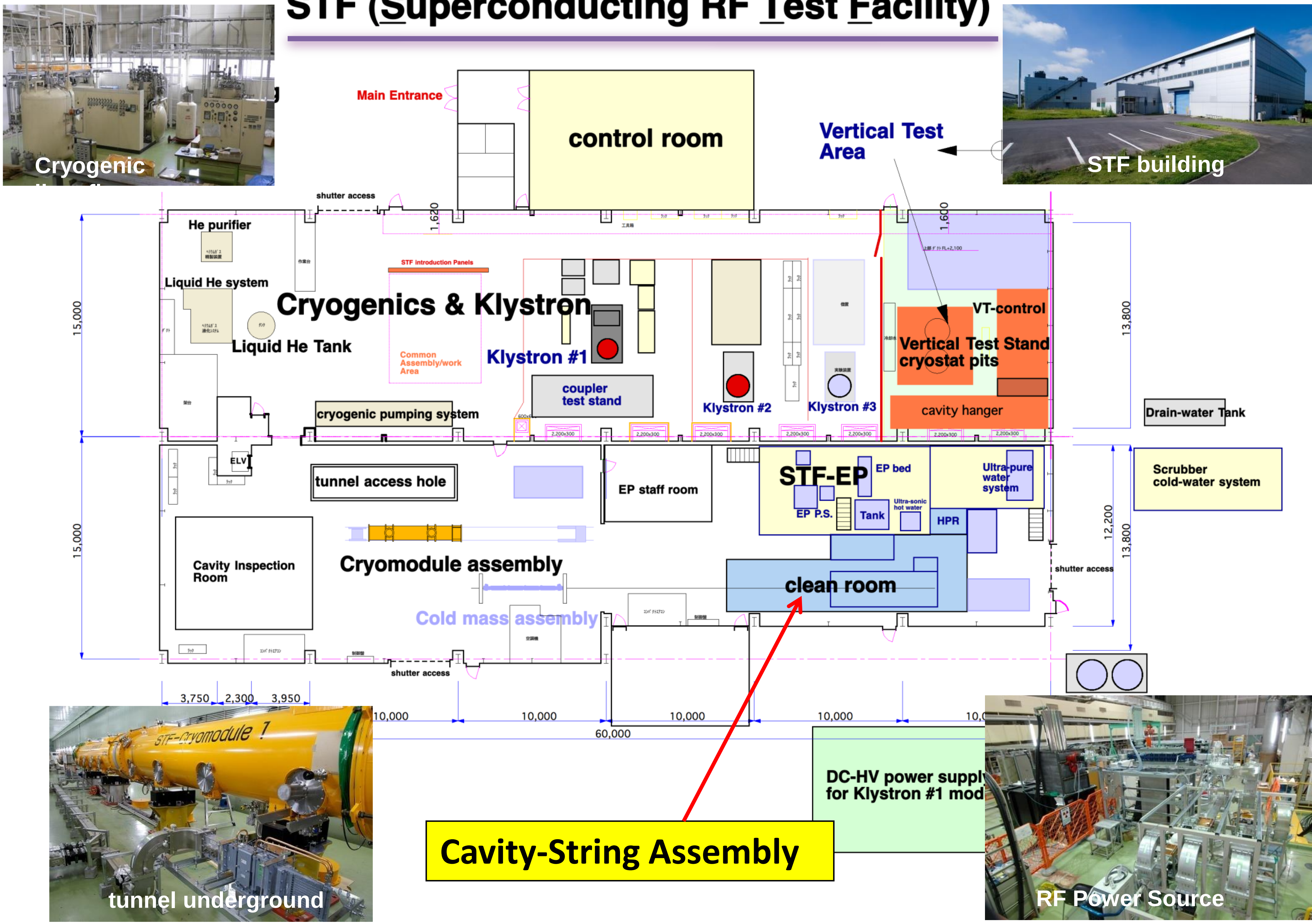
Gradient data of 9-cell cavities processed by using JLab standard ILC electropolishing procedure suggest 90% gradient yield at > 38 MV/m is within reach as long as cavities are free from genetic defects due to fabrication or material

Slide by R. Geng

ILC Test Facilities at KEK



STF (Superconducting RF Test Facility)



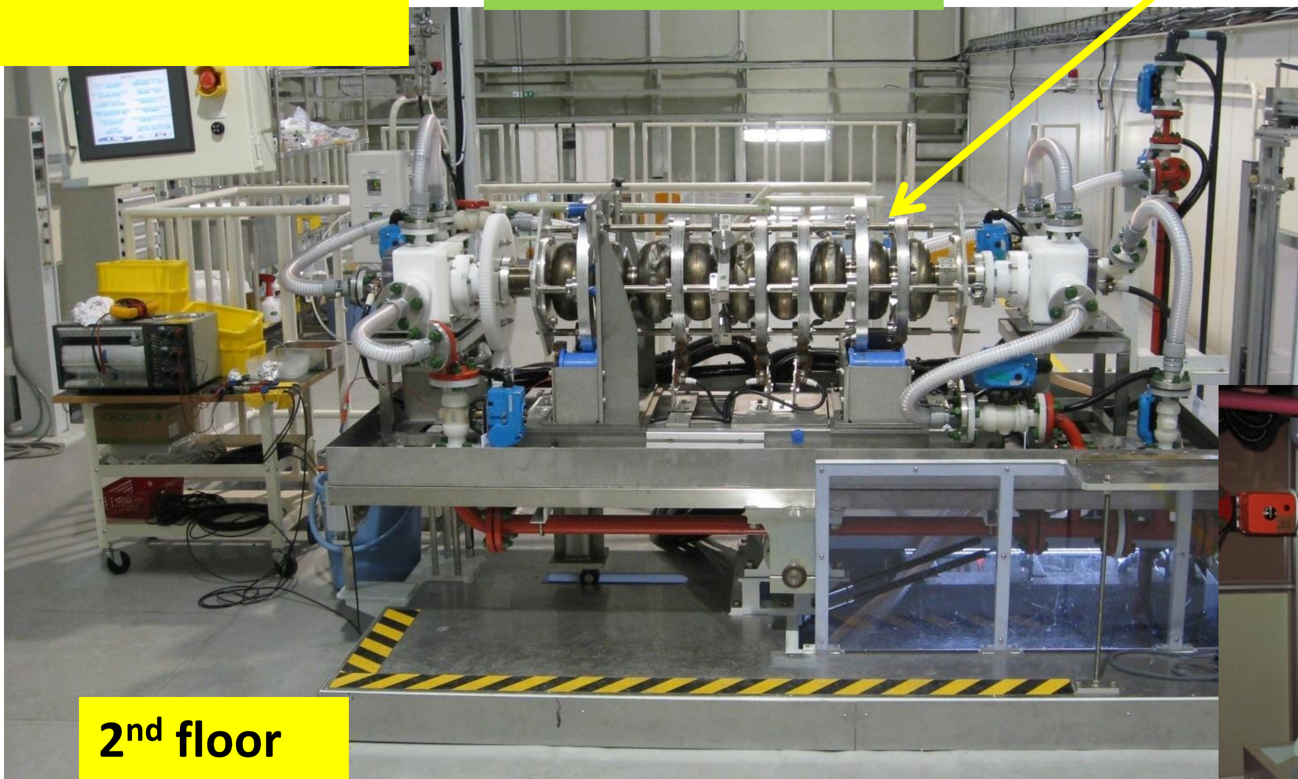
EP facility at STF/KEK

Automatic Operation Console

1st EP bed

9-cell cavity

EP acid: HF + H_2SO_4
Aluminum anode,
surface removal speed: 20μm/hour,
~18V ~270A ~30degC (for 9-cell)
cavity rotation: 1 rpm



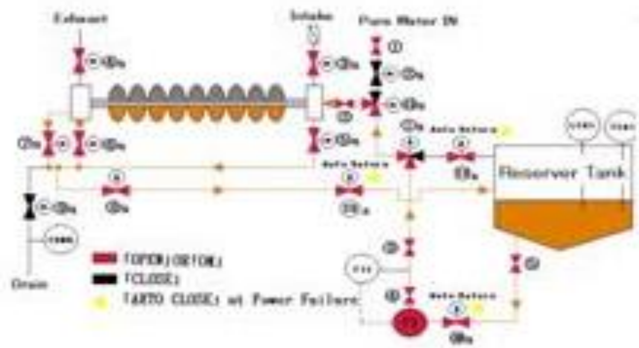
2nd floor

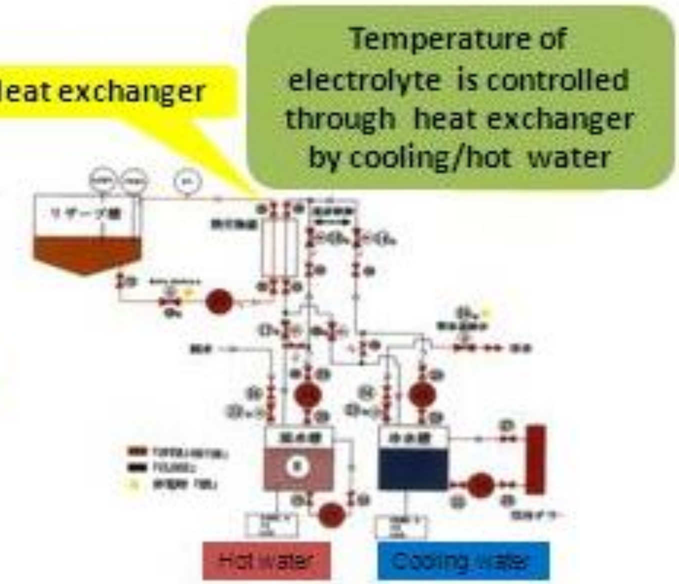
1st floor

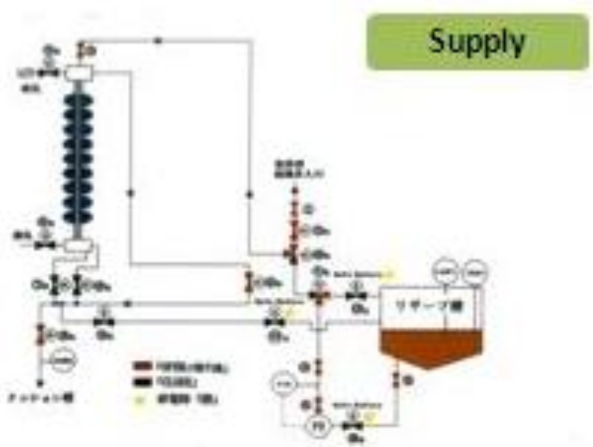
EP solution reservoir tank

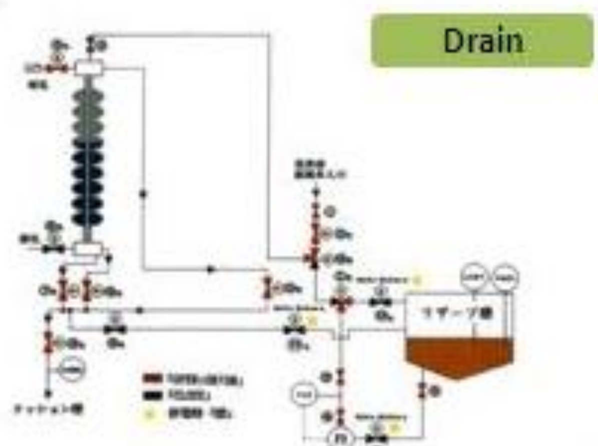
New EP facility at KEK was constructed in 2008, instead of old Nomura EP facility.

EP process at STF-KEK

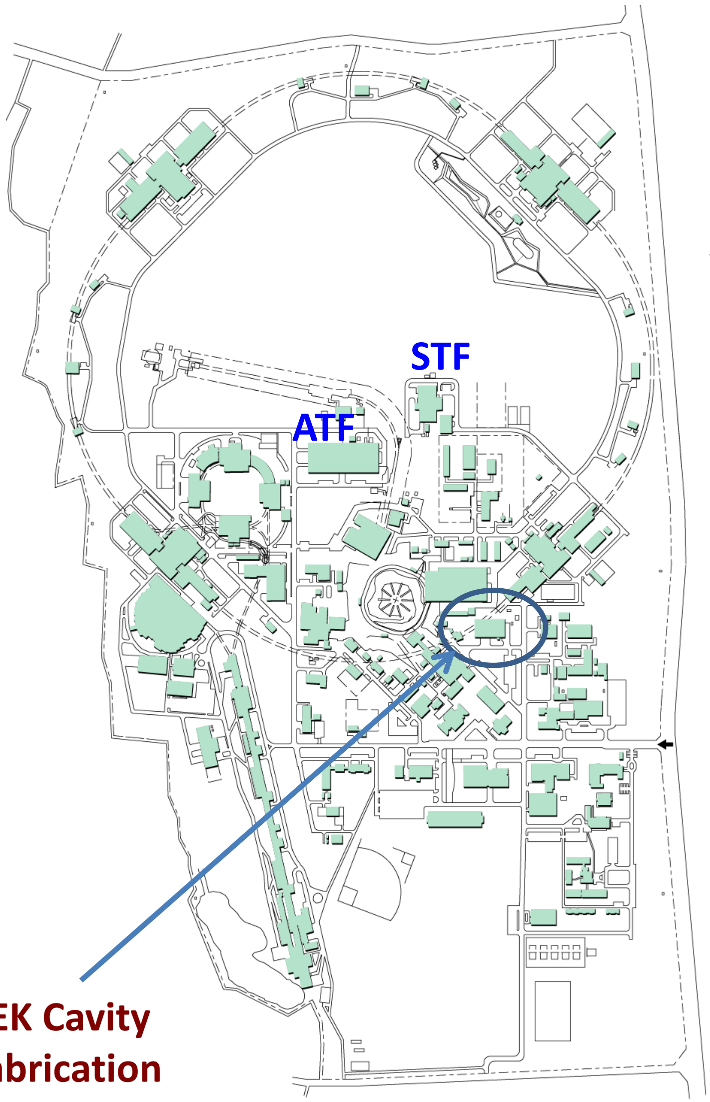




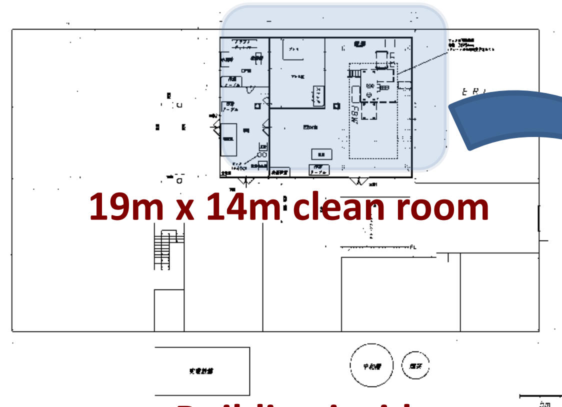




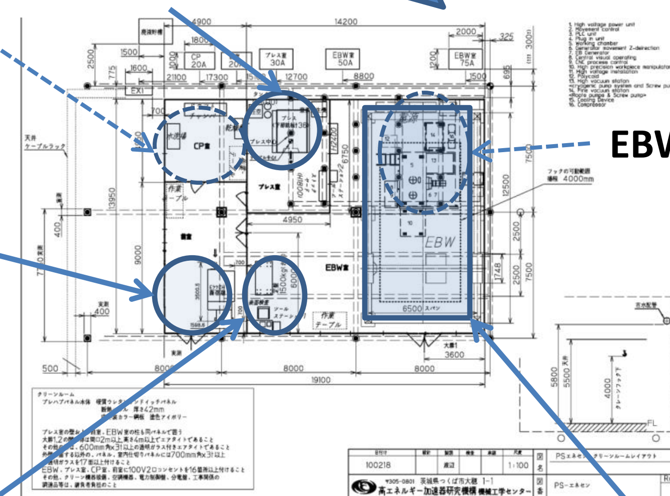
KEK Cavity Fabrication Facility



KEK Cavity Fabrication Facility



Building inside

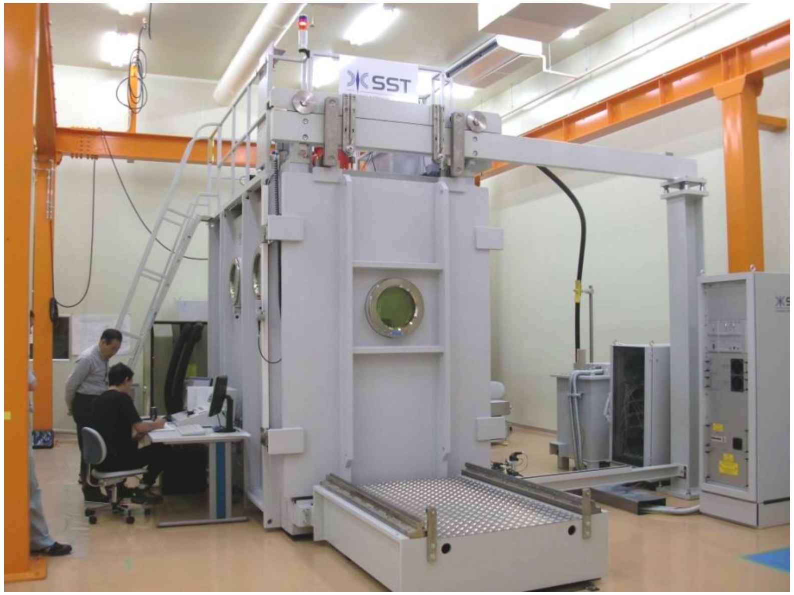


Slide by Hayano

Slide by Hayano

Main Machines in the facility

EBW



SST EBOCAM KS-110 – G150KM
Chamber (Stainless Steel chamber)

Press

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

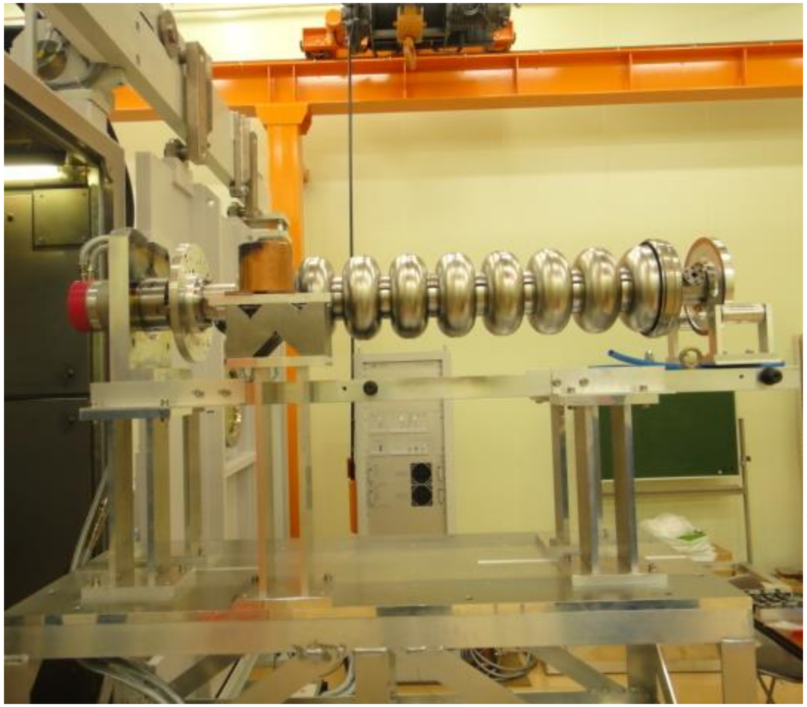
Trim

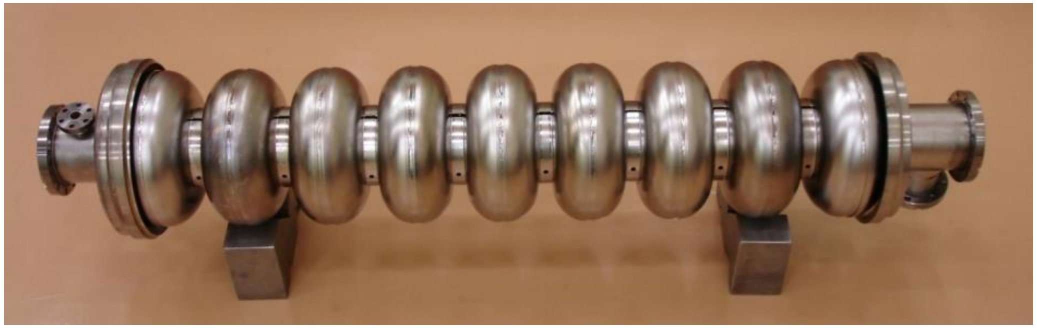
MORI VKL-253
Vertical CNC lathe

Tape-cut Ceremony on
July 13,2011
for
EBW operation start.

Chemi-room

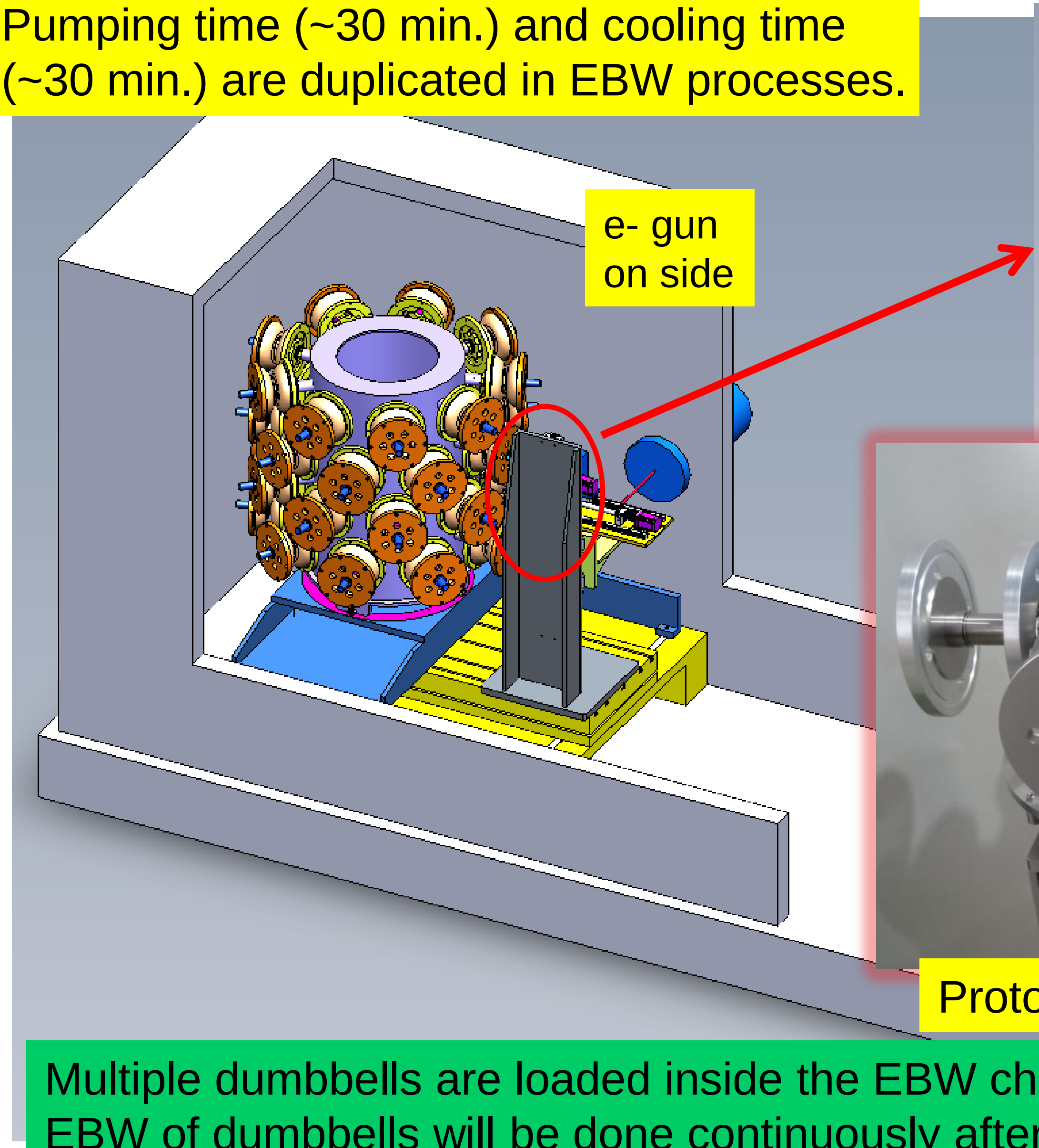
EBW assembly in CFF/KEK

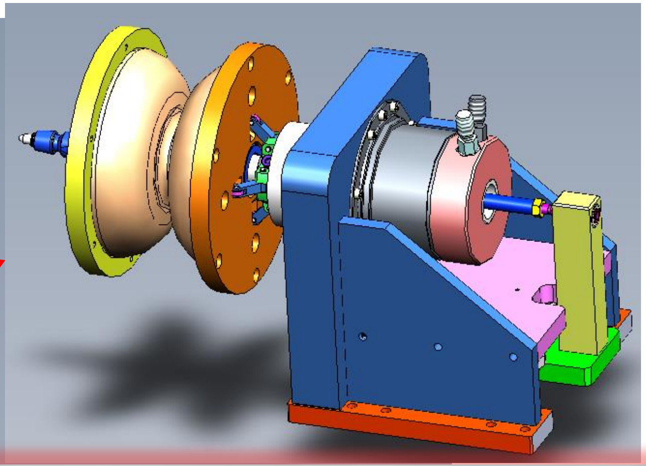


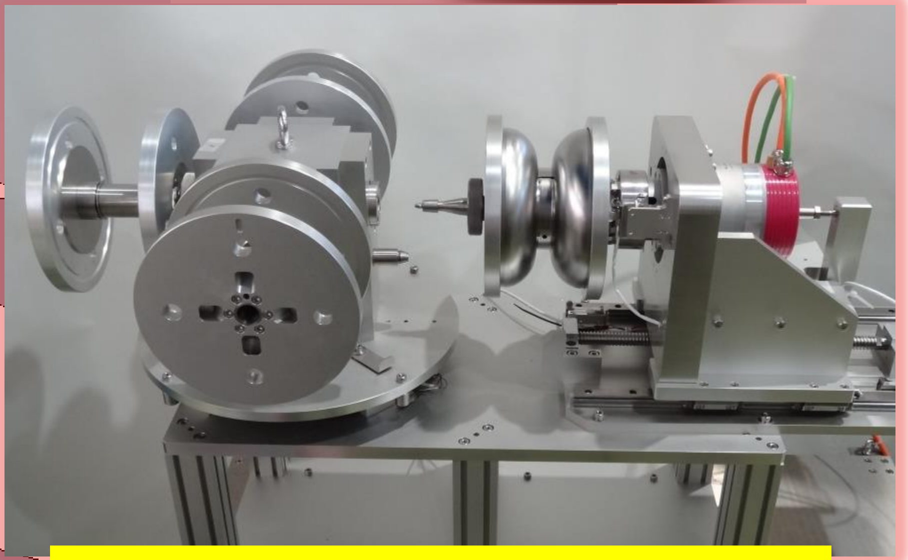


Design of loader for multiple dumb-bells

Pumping time (~30 min.) and cooling time (~30 min.) are duplicated in EBW processes.



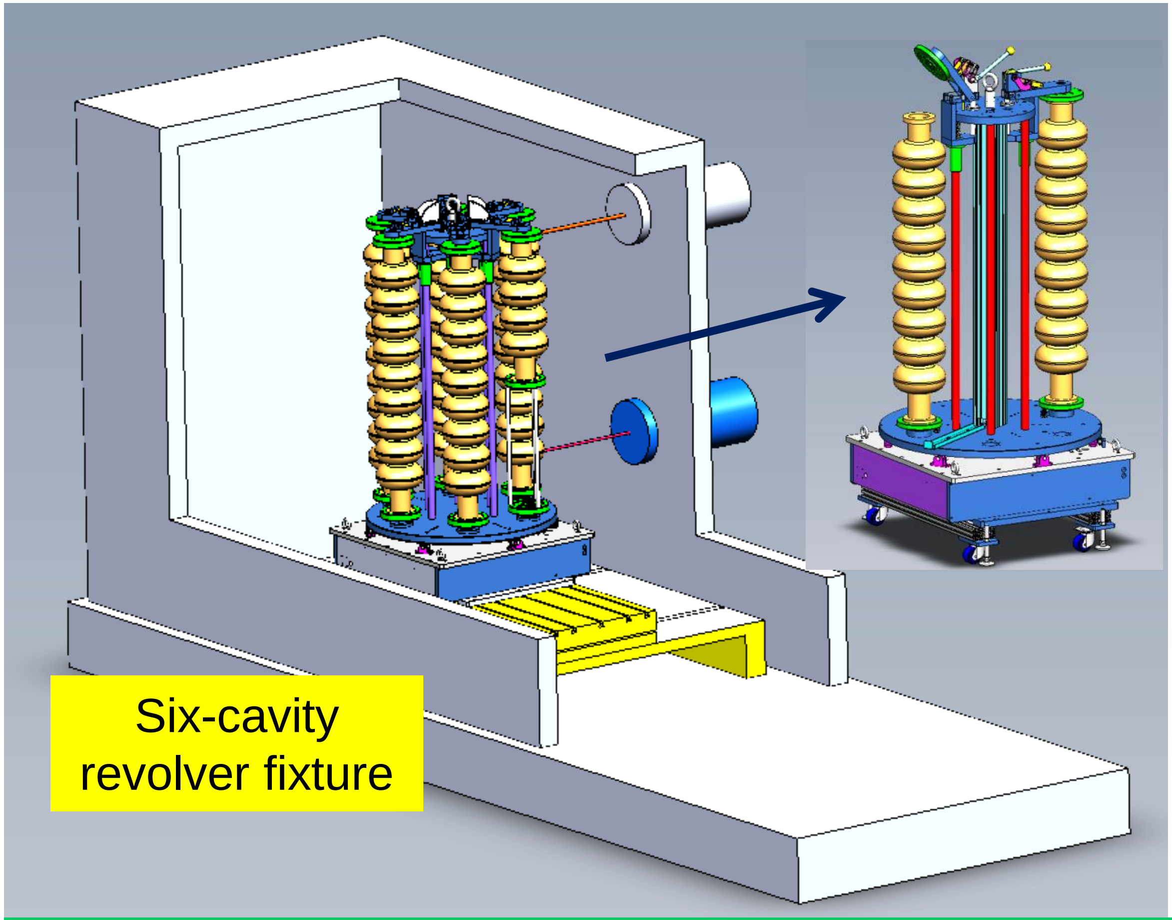




Proto-type of four-dumbbell loader

Multiple dumbbells are loaded inside the EBW chamber at once and the EBW of dumbbells will be done continuously after pumping down.

Design of 9-cell cavity fixture for EBW machine

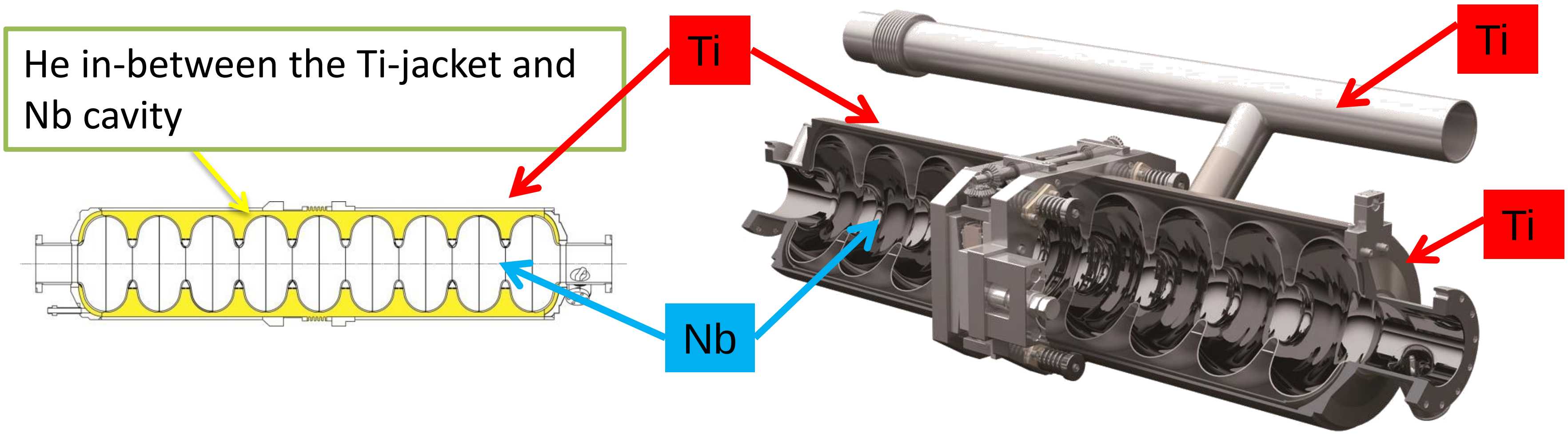


Six-cavity revolver fixture

Proto-type of revolver fixture

Pumping time (~30 min.) and cooling time (~30 min.) are duplicated in EBW process. The time is reduced if multiple-seams are welded in one pumping cycle.

Japanese High-Pressure Gas safety act



One must fabricate cavities complying with Japanese High-Pressure Gas (J-HPG) safety act if we use the cavities in accelerators.

For cavities by venders,
Manufacturer: KEK
Applicant: venders

For cavity KEK-03 in CFF,
Manufacturer: KEK
Applicant: KEK/CFF

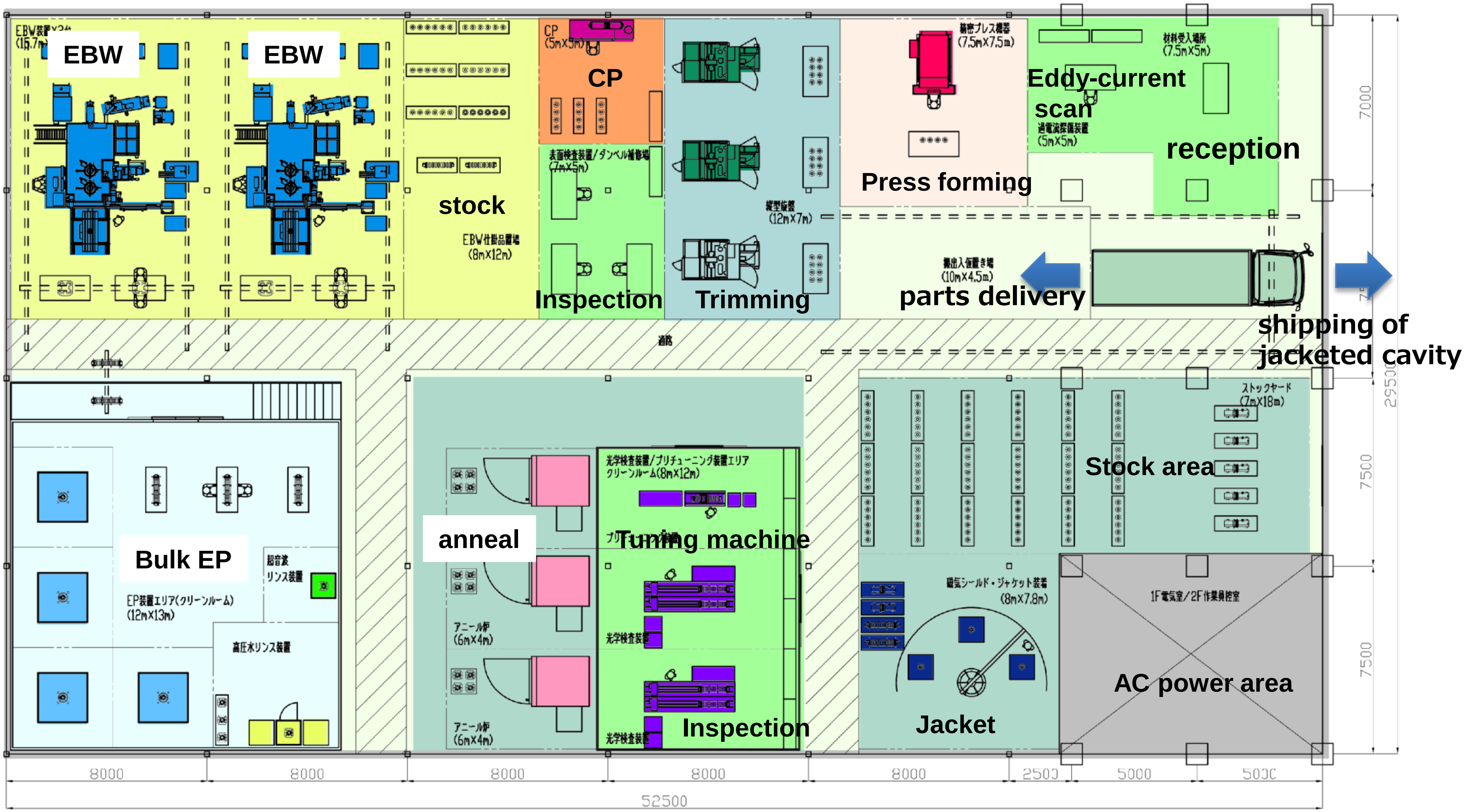
In case of ILC in Japan, a significant fraction of cavities might be imported from foreign vendors. KEK/CFF can guide them for the procedures of J-HPG safety act.

Estimation of cavity production plant

Slide by Hayano

KEK-MHI

Plant Simulation study using CFF housing area（53m x 30m）



Assuming Nb plates for cell, fabricated end-group parts are input,
200 working days/year, 2 shifts/day with 30 people times 2 shifts

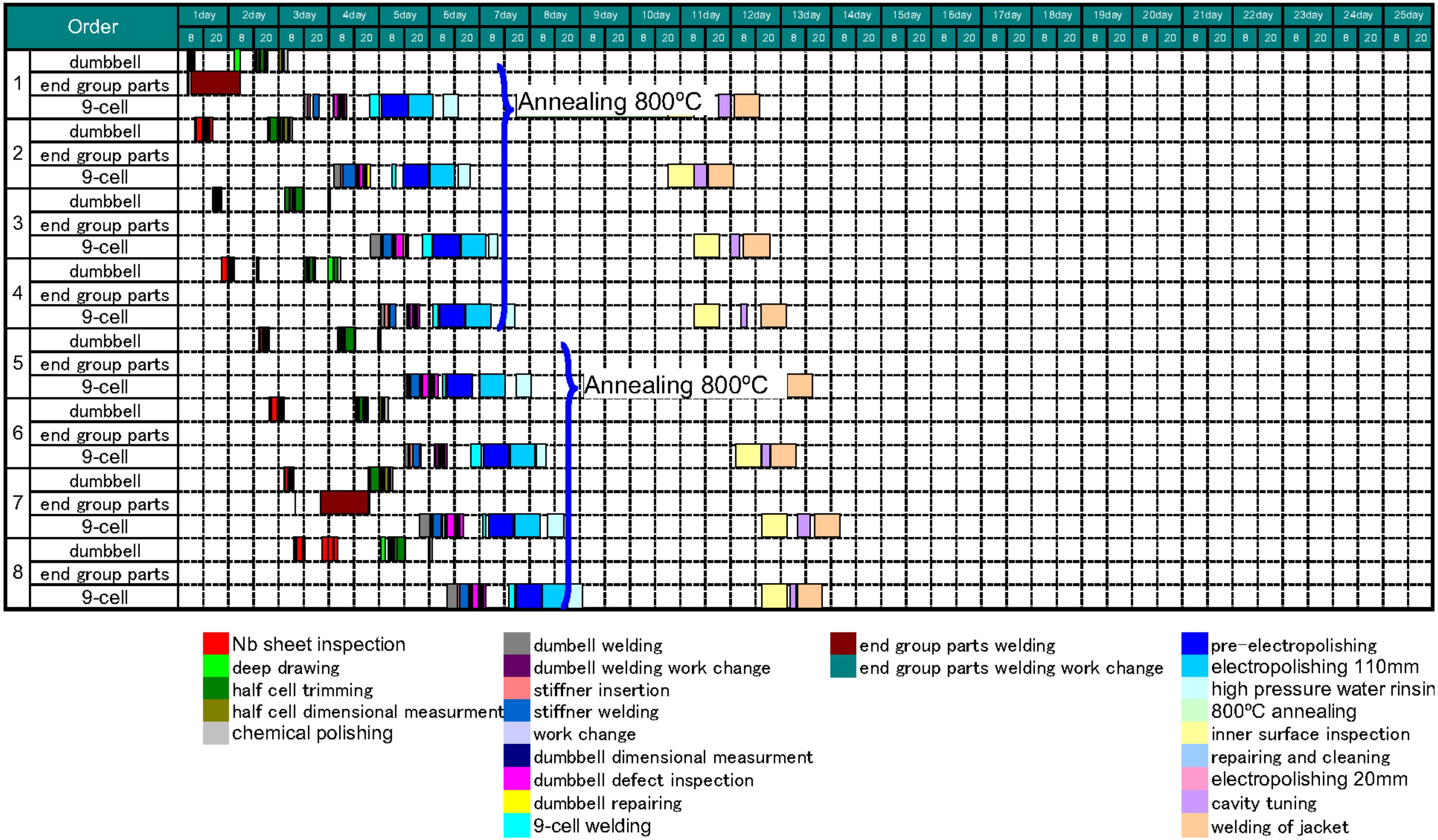
Max. production rate will be ~530 cavities/year, ~2650 cavities for 5years.

Assuming that final treatment and vertical test will be done in other place.

Cavity production Gantt chart

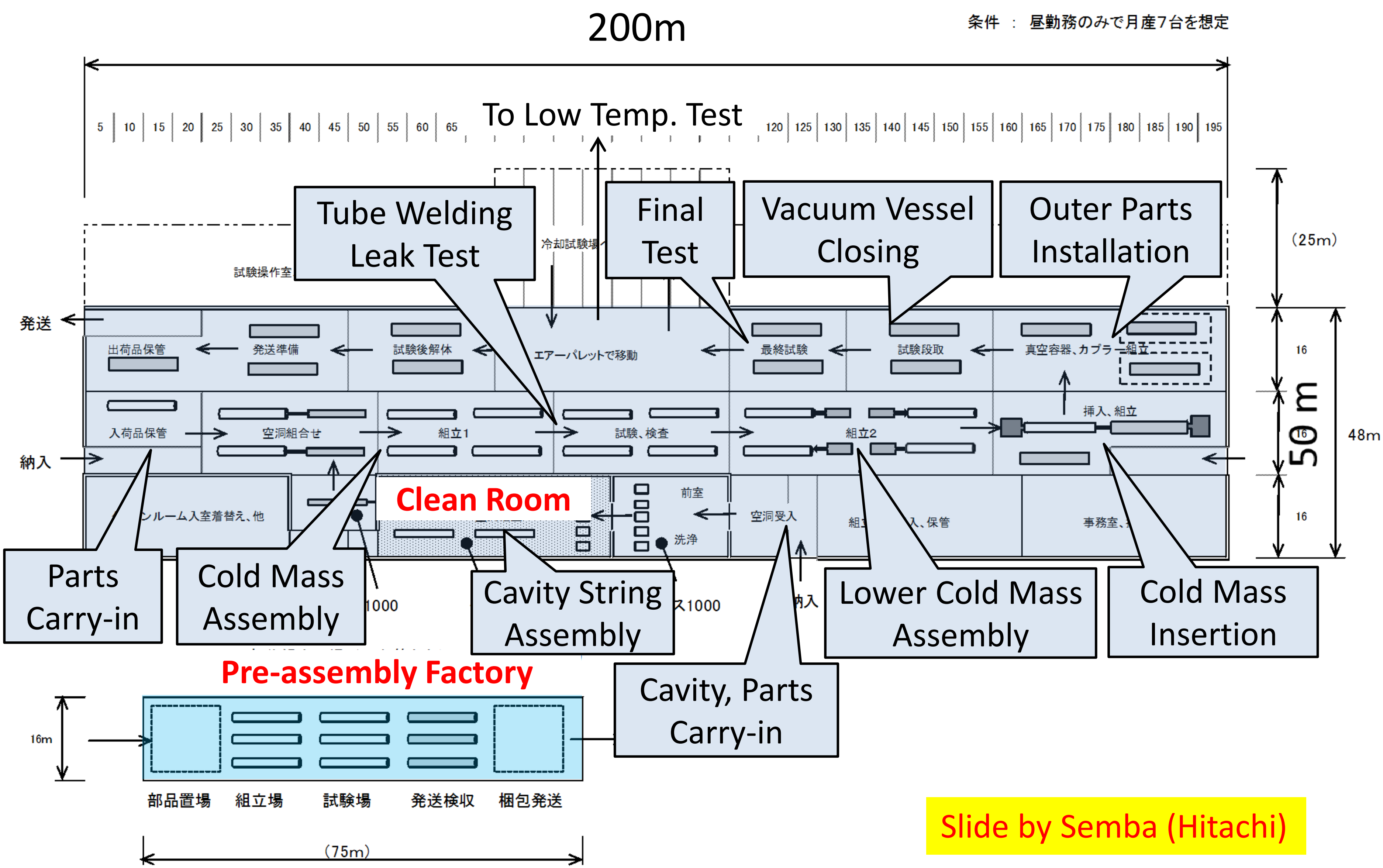
Slide by Ishii (MHI)

MITSUBISHI HEAVY INDUSTRIES, LTD.
TECHNOLOGY & INNOVATION HEADQUARTERS



5-3 New Assembly Building

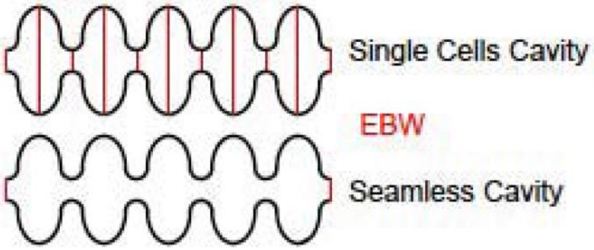
Day shift only



Slide by Semba (Hitachi)

Challenges

Study of seamless cavities

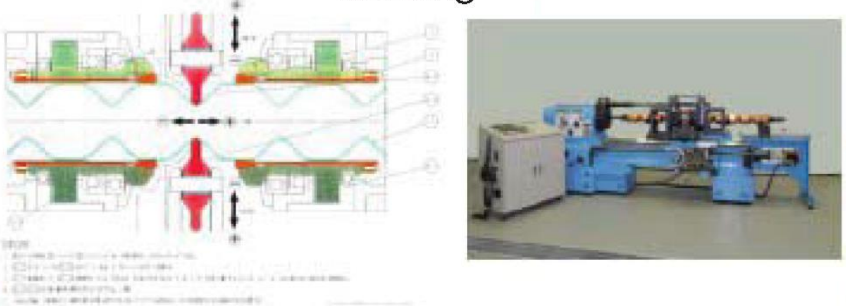


Reducition of EBW

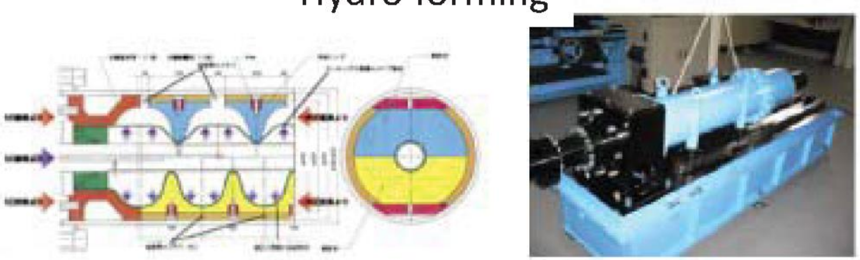
Low cost
High reliability

Approch:
- Development of Nb tube
- Improvement of forming and heat treatment

Necking



Hydro forming

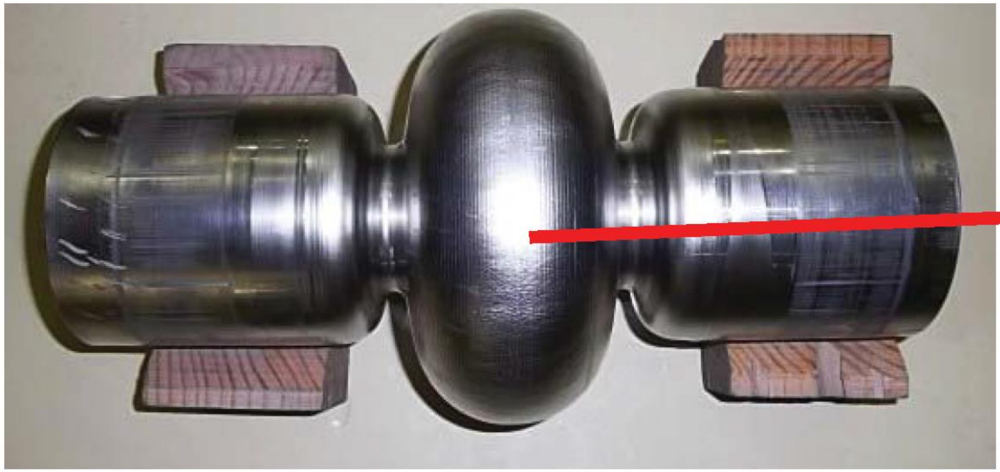


Collaboration with FNAL and LANL

Success of forming with Nb tube

After necking

After hydroforming (1/2 stage)



Finished hydroforming (1-cell)

Equator

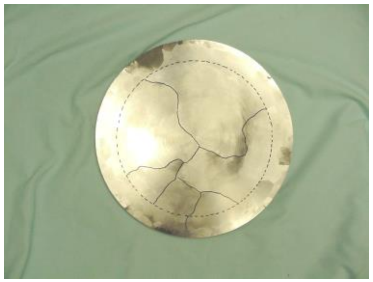
Cross view at equator area (inside)

Nb tube was manufactured by ATI Wah Chang and provided by FNAL

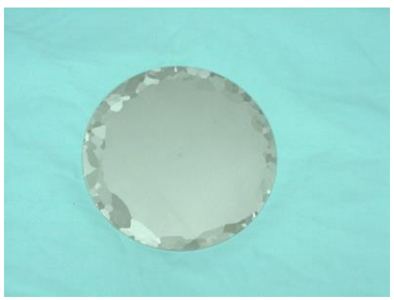
Slide by Yamanaka / KEK

Large Grain/Single Crystal Niobium

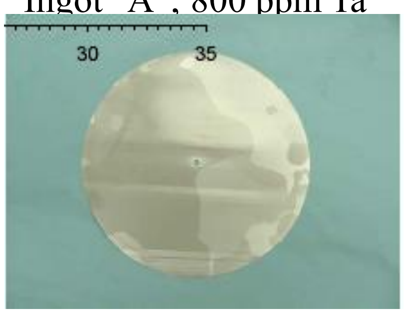
CBMM



Ingot "D",800 ppm Ta



Ingot "A", 800 ppm Ta



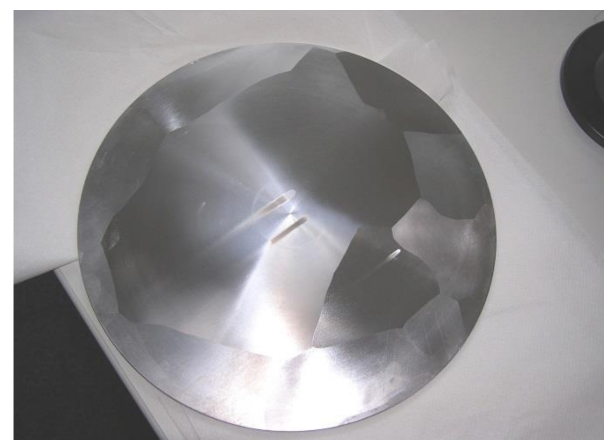
Ingot "B", 800 ppm Ta

Ninxia

Ingot "C", 1500 ppm Ta

Wah Chang

Heraeus



Slide by P. Kneisel / JLab

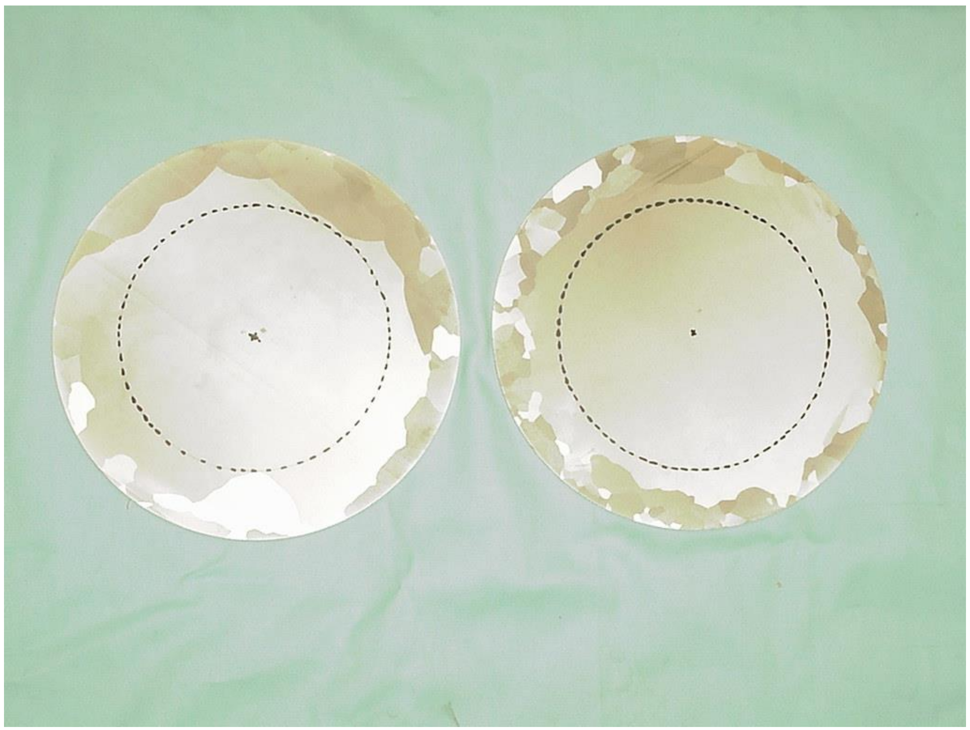
Large Grain/Single Crystal Niobium

Discs from Ingot

Cavity

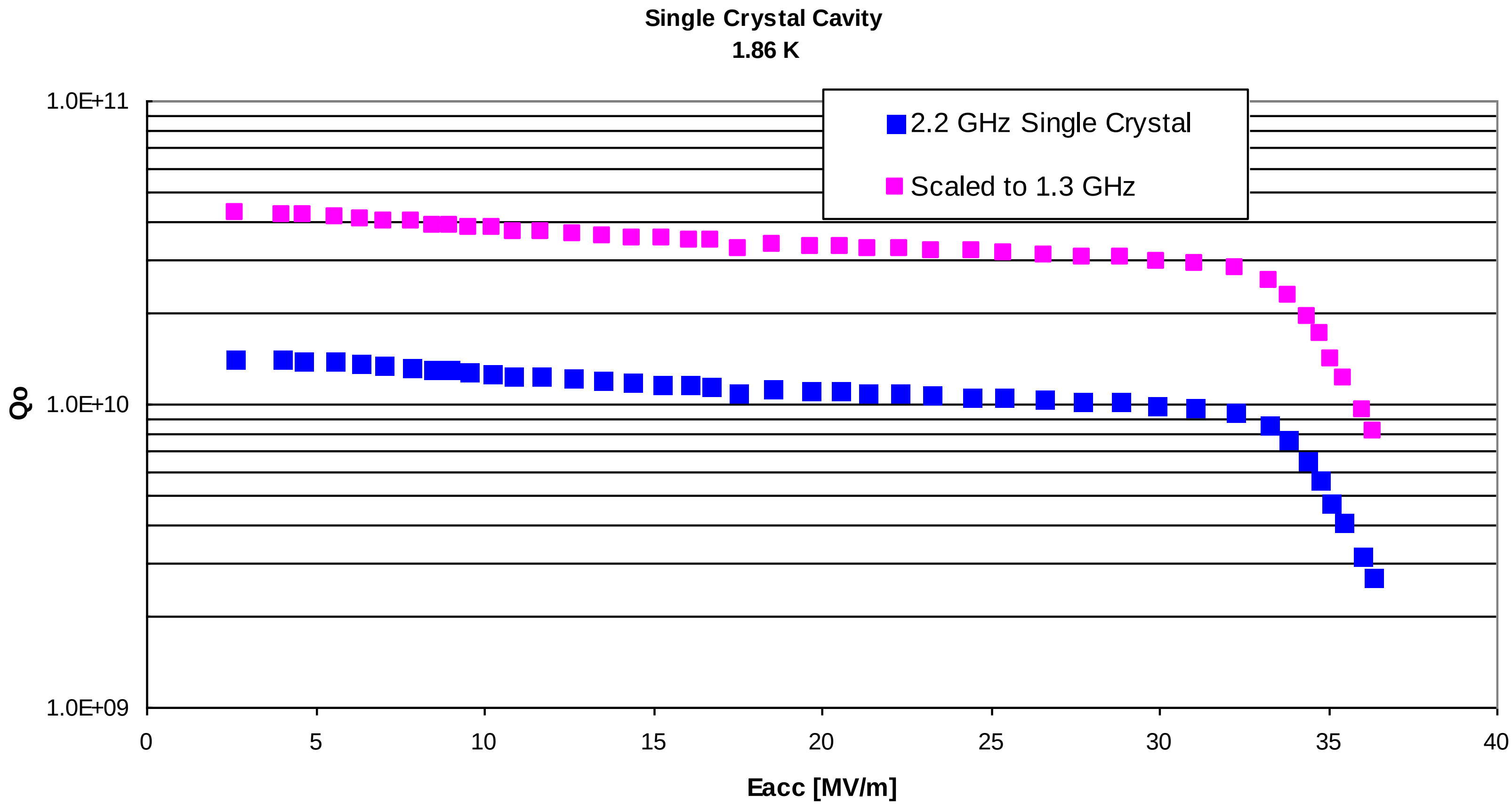
$E_{peak}/E_{acc} = 1.674$

$H_{peak}/E_{acc} = 4.286$ mT/MV/m



Slide by P. Kneisel / JLab

Single Crystal Cavity (2)



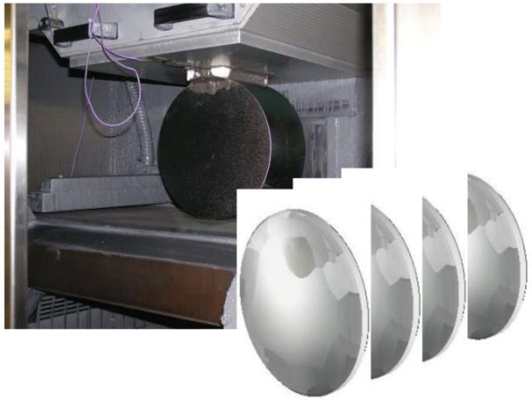
Slide by P. Kneisel / JLab

Large Grain Cavity (DESY)

European XFEL

Large Grain LG cavity R&D: 11 LG 9-cell cavities from HERAEUS material fabricated at RI

Development of LG disc production was done within the framework of the XFEL R&D program of DESY and the W. C. HERAEUS.



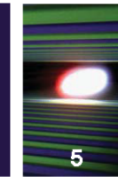
Fabrication similar to fine grain cavities: Deep drawing, Machining, EB welding
Very smooth (shiny) surface in grain areas after BCP
The steps at grain boundaries are more pronounced as in polycrystalline material. More in **TUP041, X. Singer et al.**

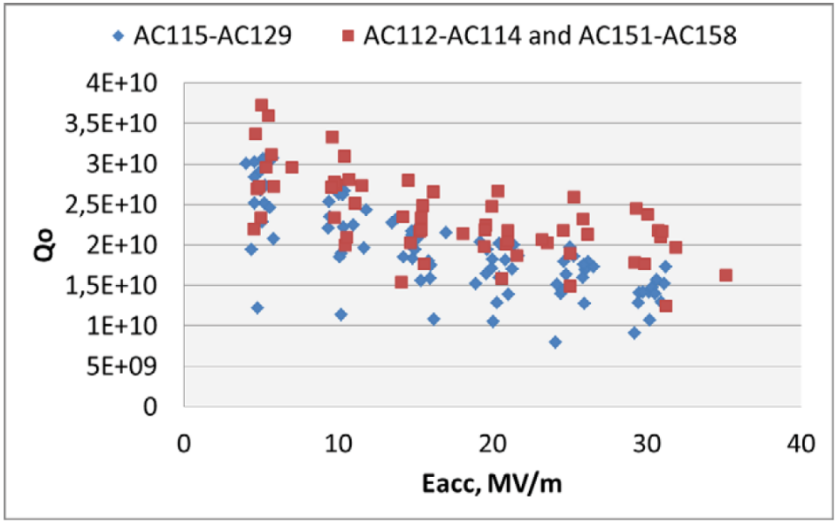
Slide by W. Singer / DESY

Large Grain Cavity (DESY)

European XFEL

European XFEL Large Grain Cavities
(or LG advertisement for future projects)



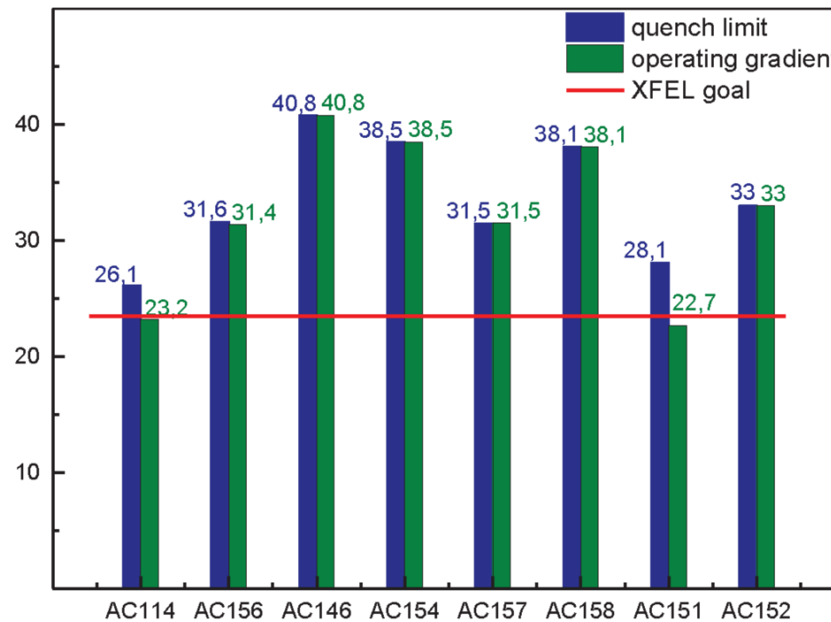


Comparison of Q_0 at 2 K for 11 EP-treated LG cavities (red) with Q_0 at 2 K of XFEL prototype cavities (AC115–AC129, best result) treated according to XFEL recipe (blue).

E_{acc} performance of LG cavities in EXFEL cryomodule XM-3.

The cryomodule has ca. 60% lower cryogenic losses in CW, compared to all 4 previously tested cryomodules (J. Sekutowicz).

For details see presentation of C. Madec THIOA02

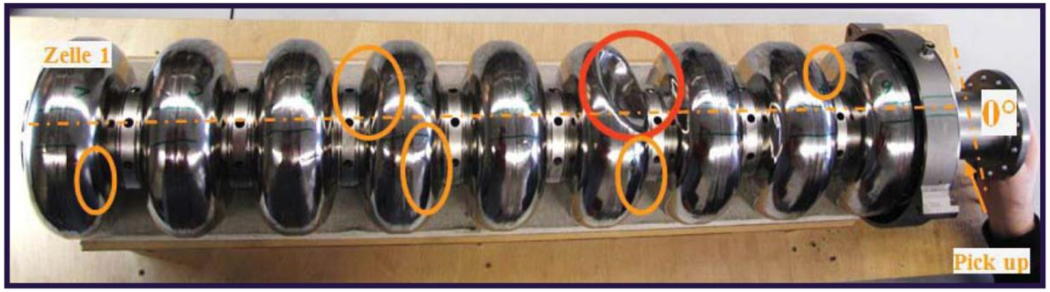


Slide by W. Singer / DESY

Large Grain Cavity (DESY)

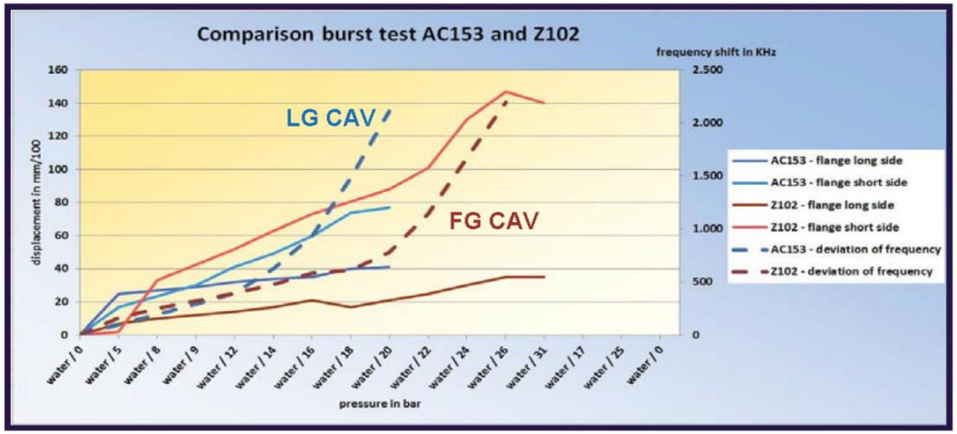
European XFEL

Cavity burst test. LG Cavity and Fine Grain Cavity. Poster MOP048, A. Schmidt et al



LG cavity after burst test. **How painful for us was to look on this.**

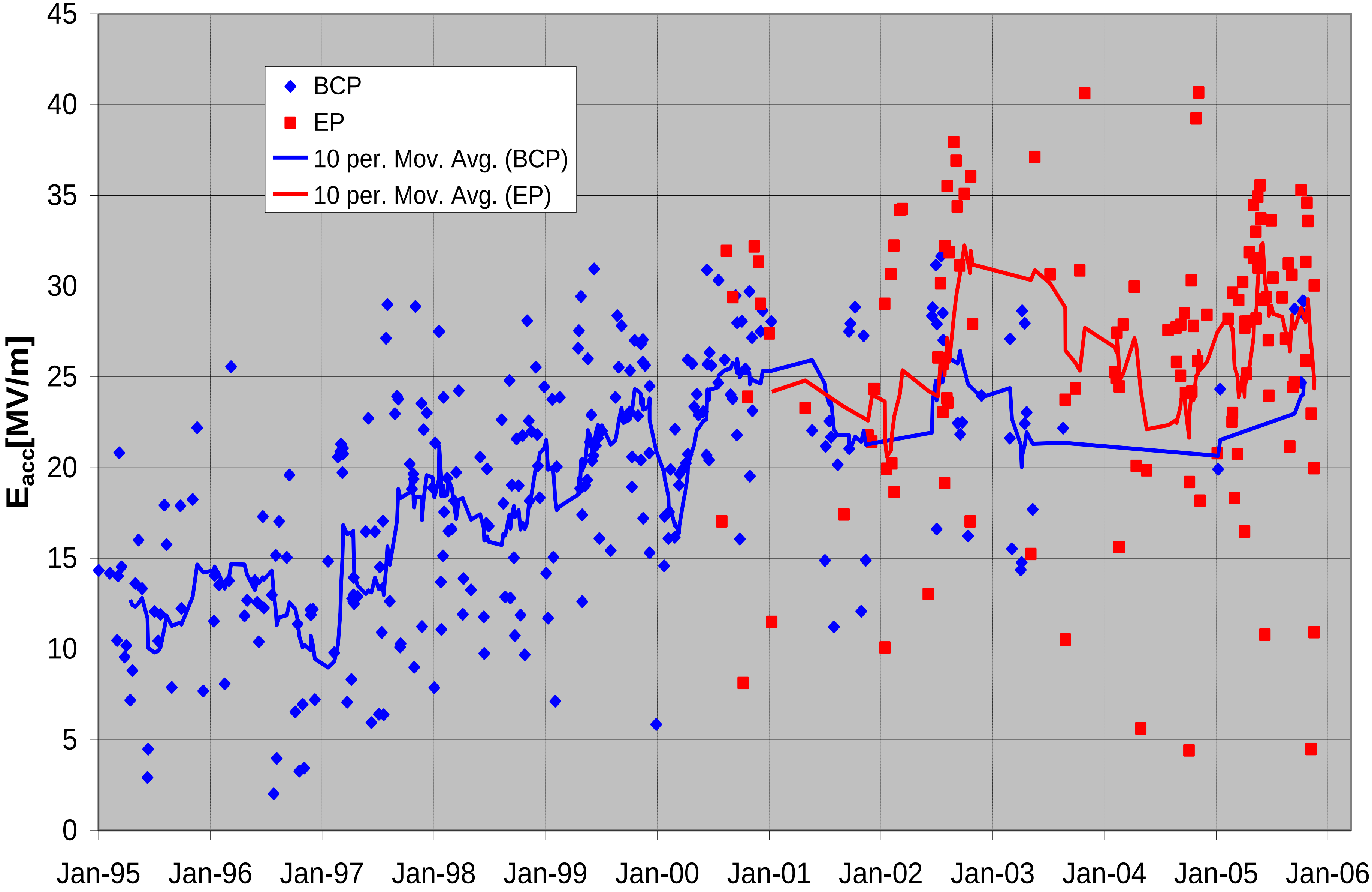
Burst happened at the connection of stiffening ring to half cell



The burst test on a Fine Grain and Large Grain cavity could approve the sufficient stability of both types for European XFEL Linac

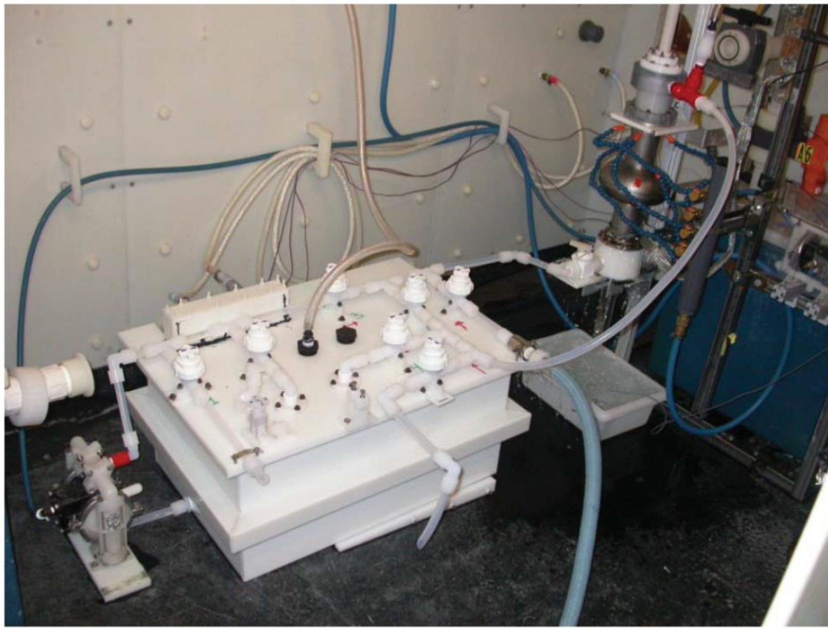
Slide by W. Singer / DESY

E_{acc} vs. time



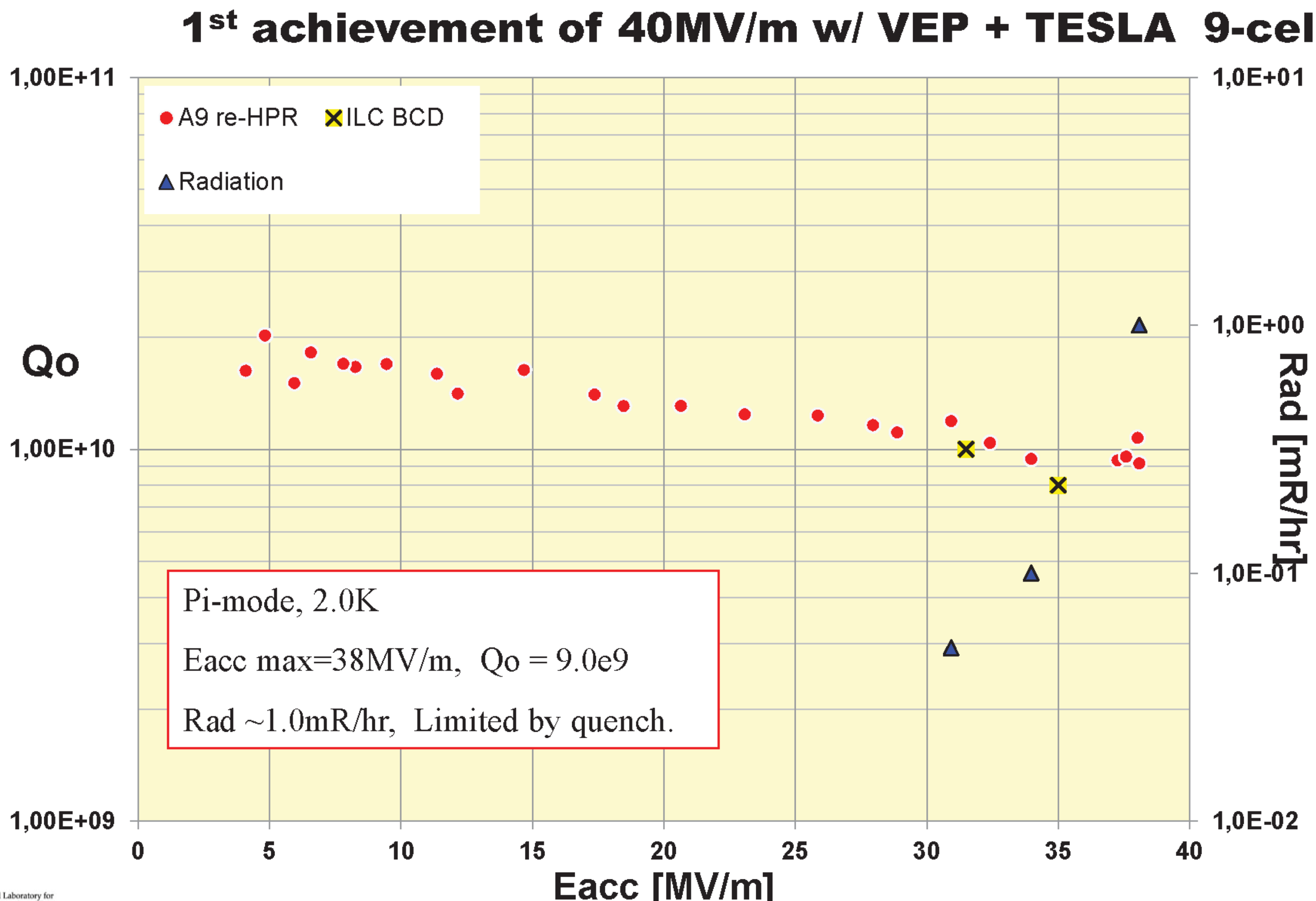
Eacc[MV/m]
0
5
10
15
20
25
30
35
40
45
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Jan-00
Jan-01
Jan-02
Jan-03
Jan-04
Jan-05
Jan-06
BCP
EP
10 per. Mov. Avg. (BCP)
10 per. Mov. Avg. (EP)

Cornell, Vertical EP



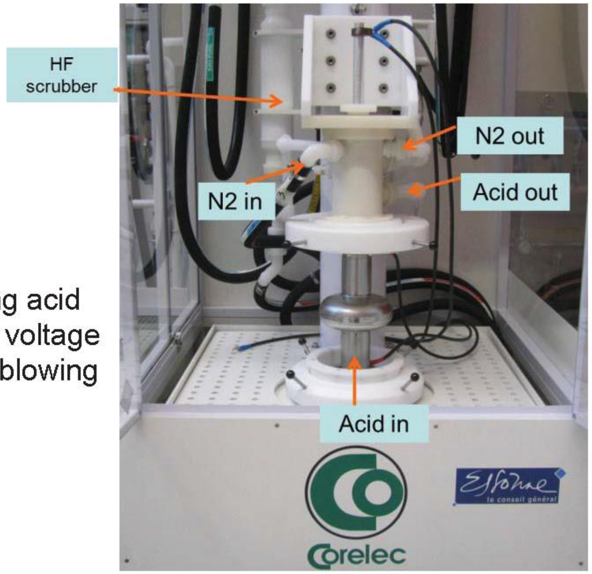
Slide by F. Furuta /Cornell (U.S.)

Cornell VEP, 40MV/m w/ ILC 9-cell



Slide by F. Furuta /Cornell (U.S.)

Vertical EP at Saclay (France)



- Circulating acid
- Constant voltage
- Nitrogen blowing

Fermilab
TB9RI025 cavity
Prior to VEP

- VEP of 1Cell and 9Cell cavities
- Focus on parameters: low voltage (~ 6V) – high acid flow (25L/min)
  - Improved degassing (H_2 , O_2)
  - Lower heating
- Four 1-Cell cavities and 1 nine-cell cavity prepared by VEP
- But delay in results: Field Emission problems (cleanroom's water)

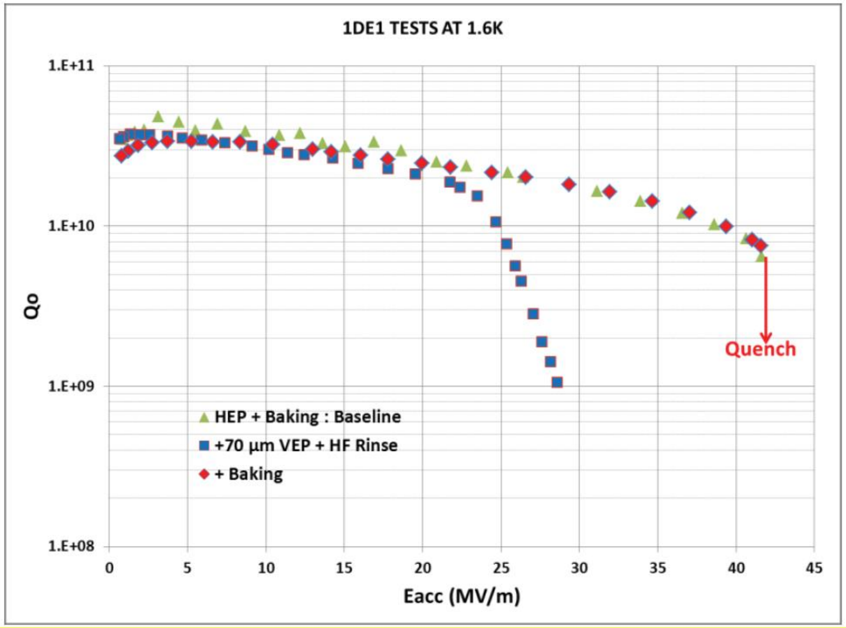
Presented by F. Eozénou, 1st LCC/ILC cavity group meeting, 2013

Vertical EP at Saclay (France)

1DE1: Horizontal EP + 70 µm VEP
•Parameters: 6V & >24L/min
•Bright and smooth surface

•Performance before/after baking similar to HEP
•High gradient maintained after VEP

1DE1 after HEP + 70 µm VEP



Aspects to improve:

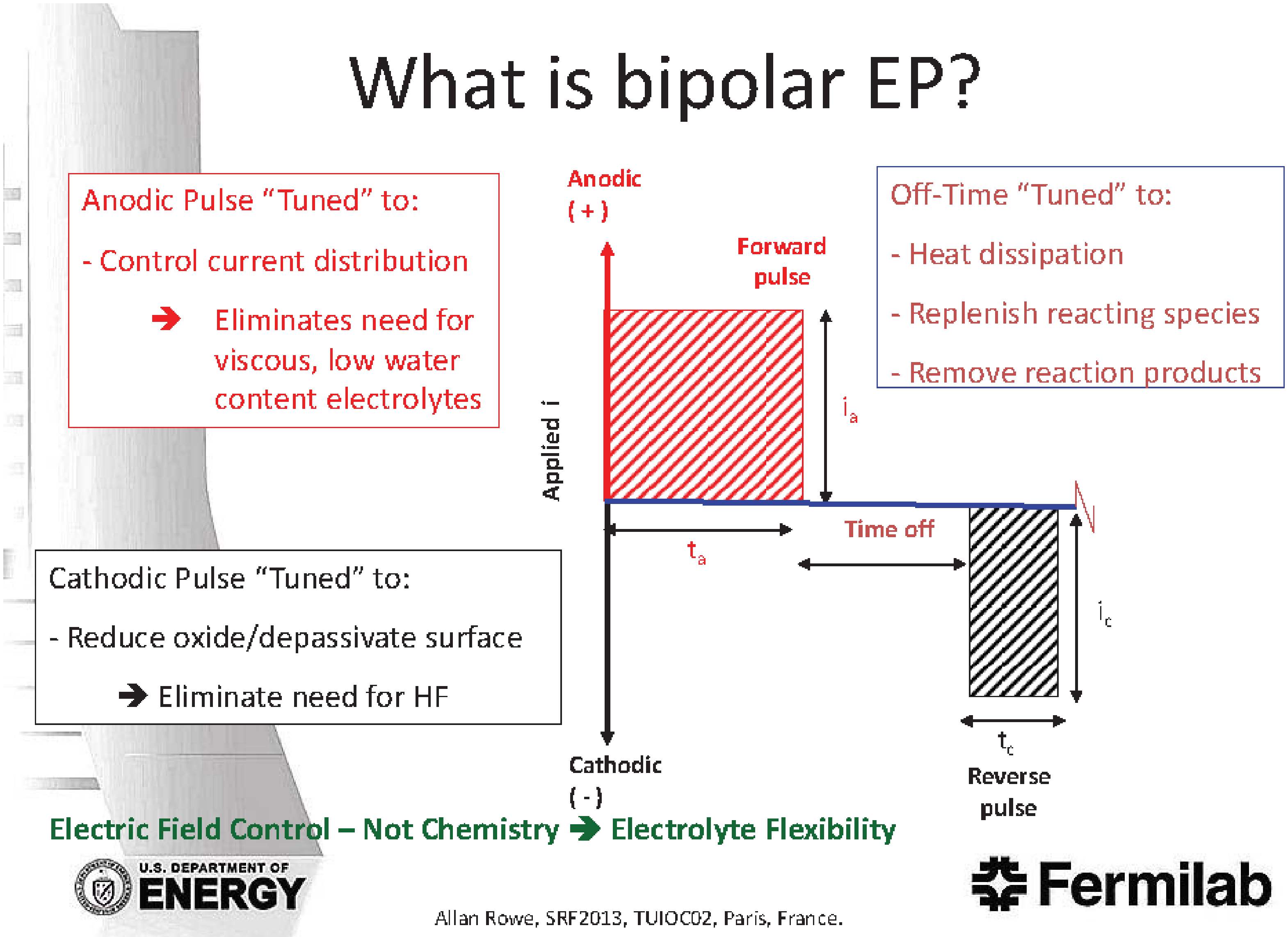
-Low removal rate at 19° C: 0.2µm/min

- asymmetry: removal rate higher in the upper part of the cell (x 3)

higher local

Presented by F. Eozénou, 1st LCC/ILC cavity group meeting, 2013

Bipolar EP at FNAL (U.S.)



Slide by A. Rowe /FNAL

Bipolar EP at FNAL (U.S.)

Why pursue bipolar EP?

- Electropolishing without HF
  - Labs strongly dislike **HF** due to safety issues
  - Ecological footprint can be reduced
- Potential 'Drop-in' EP technology that may replace traditional HF-based EP.
- Potential industrial scalability improvement over traditional EP (vertical orientation).
- Electrolyte modification from 9:1 solution of 95% H_2SO_4:49% HF to dilute H_2SO_4. Working concentration is 5-10 wt% H_2SO_4.
  - Relatively safe and ecologically superior
- Potential improvement of EP parameter control.

U.S. DEPARTMENT OF ENERGY

Allan Rowe, SRF2013, TUIOC02, Paris, France.

Fermilab

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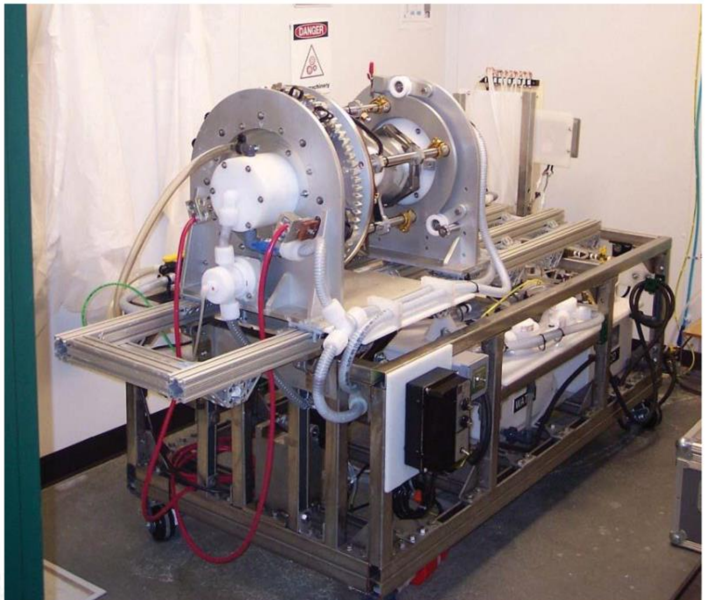
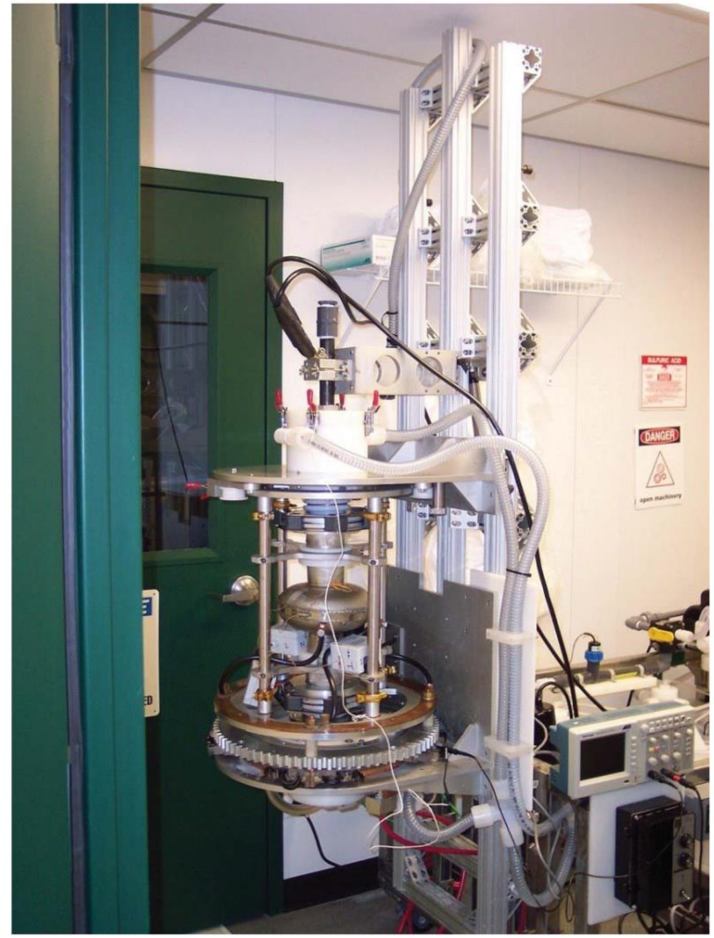
Bipolar EP at FNAL (U.S.)

‘Drop-in’ (replacement) EP?



Horizontal EP tool at Faraday Technology, Inc. Initial trials were performed horizontally, but transitioned to vertical with dramatically improved performance.



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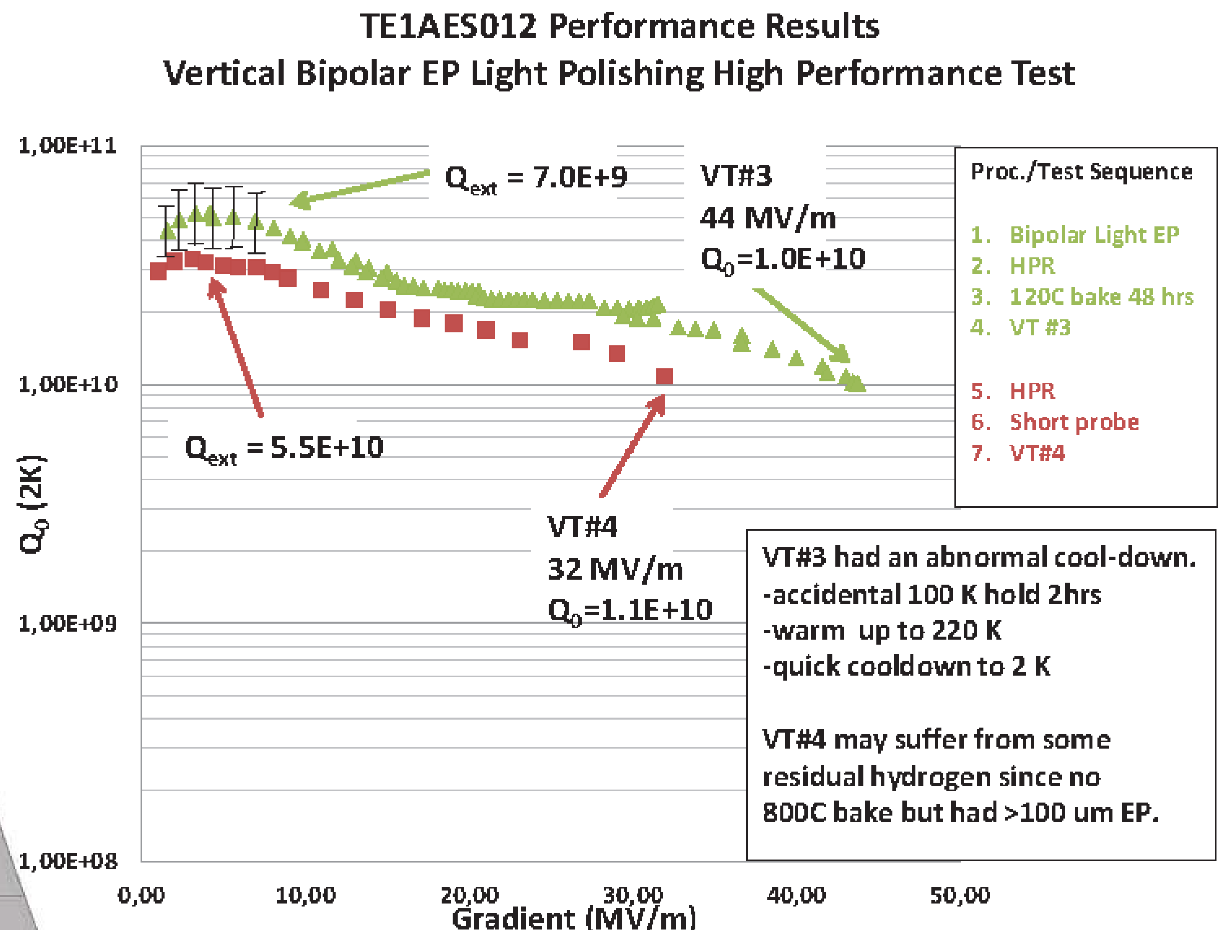
Bipolar EP at FNAL (U.S.)



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