深圳综合粒子设施研究院

Institute of Advanced Science Facilities, Shenzhen

Cycle of Seminars by Carlo Pagani

Seminar # 6

QA, QC and Data Management Tools in SRF Accelerators

Shenzhen, 25 November 2022 / INFN LASA, 27 November 2024

Institute of High Energy Physics
Chinese Academy of Sciences

Carlo Pagani

carlo.pagani@mi.infn.it

INFN LASA

Contents

Contents

Production and exchange of any type of goods are naturally based on the application QA & QC at a certain level.

For complex object and apparatus specific rule and qualification patents have been developped do make possible both: the assurance of the expected quality and its indirect control through properly documeted production steps.

Whoever produces something for a certan function or use has every interest in producing items that are attractive in terms of quality and cost. The experience demostrated that the strict application of specific rules and controls, **QC**, during the production assures the quality, **QA**, of the final product.

Whoever buys something for a certan function or use is asking items that are attractive in terms of quality and cost. The certified application of all the codified rules and controls during the production and the use of materials and subcomponents also certified are the guarantee for the buyer.

Preamble

QA (Quality Assurance) is process oriented and focuses on defect prevention,

QC (Quality Control) is product oriented and focuses on defect identification

Prior to the extensive division of labor and mechanization resulting from the Industrial Revolution, **it was possible for workers to control the quality of their own products**.

The Industrial Revolution led to a system in which large groups of people performing a specialized type of work were grouped together under the supervision of **a foreman** who **was appointed to control the quality** of work manufactured.

Some Historical References - 1

From the time of the First World War, manufacturing processes typically became more complex, with larger numbers of workers being supervised. Following this experience a few new concets have been introduced:

- **Taylor**, utilizing the concept of **scientific management**, helped **separate production tasks into many simple steps** (the assembly line) and limited quality control to a few specific individuals, **limiting complexity**.
- **Ford** emphasized **standardization of design and component standards** to ensure a standard product was produced, while quality was the responsibility of machine inspectors,
- **Shewhart** at Bell Laboratories developed in 1924 the **control chart and the concept of of statistical control,** equivalent to **exchangeability.** With comtributions from others **sampling inspection** was put **on a rational statistical basis**

Some Historical References - 2

- After World War II, **Deming and Juran promoted the collaborative concepts of quality** and these concepts were **used in the extremely fast re-development of the Japanese economy**
- In spite of these important developments, **the US continued to apply the old Quality Control (QC)** concepts of inspection and sampling to remove defective products from production lines, **essentially unaware of or ignoring advances in QA for decades**
- The inroduction of some new concepts and procedures started worldwide
  - **Failure test and stress test** in all the extreeme operational conditions
  - **Statistical control on parts or on the process** that made the part, ideally eliminating the defect before more parts can be made like it
  - **Total quality management** that includes the processes which are managed with QA.
  - **Models and standards** like what specified in the **ISO 17025 international standard** that specifies the general requirements for the competence to carry out tests and or calibrations.

The Company Quality concept

During the 1980s, the concept of "company quality" with the focus on management and people came to the force also in the U.S. It was considered that, if all departments approached quality with an open mind, success was possible if management led the quality improvement process.

The **company-wide quality approach** places an emphasis on four aspects (enshrined in standards such as **ISO 9001**):

- Elements such as controls, **job management**, adequate processes, performance and integrity criteria, and **identification of records**
- **Competence** such as knowledge, skills, experiences, qualifications
- Soft elements, such as personnel integrity, confidence, organizational culture, **motivation, team spirit** and quality relationships
- **Infrastructure** (as it enhances or limits functionality)

The quality of the outputs is at risk if any of these aspects is deficient.

QA attitude and organization

The importance of actually measuring Quality Culture throughout the organization is illustrated by a survey that was done by *Forbes Insights* in partnership with the American Society for Quality. A survey of more than 60 multinational companies found that those companies whose employees rated as having a low quality culture had increased costs of $67 million/year for every 5000 employees compared to those rated as having a high quality culture.[30]

Quality Assurance is not limited to manufacturing, and can be applied to any business or non-business activity, including: design, consulting, banking, insurance, computer software development, retailing, investment, transportation, education, scientific institution, national and international research laboratories, scientific infrastructures and enterprises.

The realization of large scientific projects, like the moon program or a SRF based accelerator strongly benefit from well establisced QA culture and organization.

Quality Management Practice

QA comprises a quality improvement process, which is **generic** in the sense that it can be **applied to any activity** and it establishes a quality culture, which supports the achievement of quality.

This in turn is **supported by quality management practices** which can include a number of business systems and which are usually specific to the activities of the business unit concerned.

In manufacturing and construction activities, these business practices can be equated to the models for quality assurance defined by the International Standards contained in the **ISO 9000 series** and the specified specifications for quality systems.

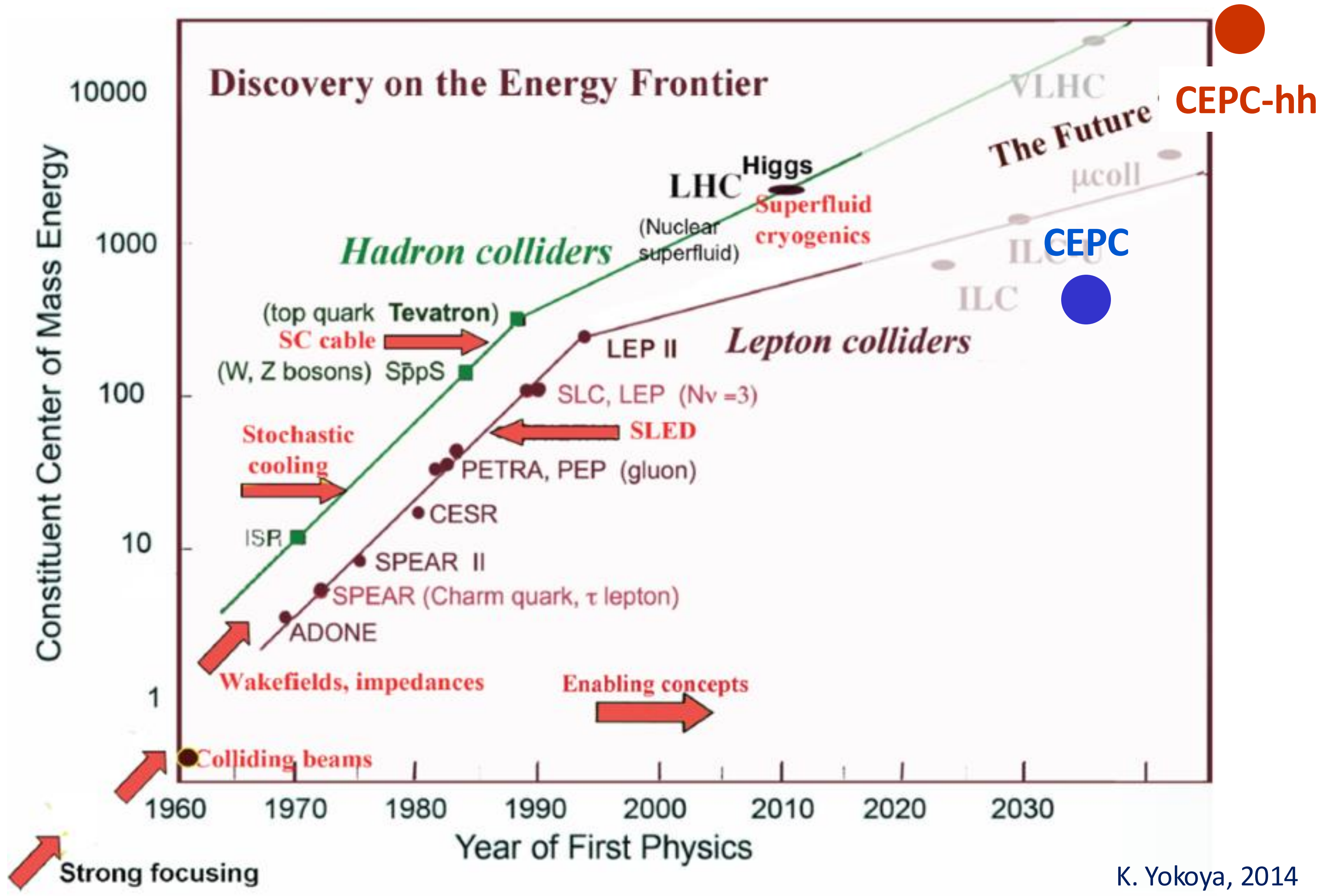
In the system of **Company Quality**, the work being carried out was shop floor inspection which **did not reveal the major quality problems.** This led to quality assurance or **total quality control,** which **has come into being recently.**

From Industrial Production to Science

- **QA/QC concepts and procedure** were among the main drivers of the **unprecedented economic development** after the 2nd World War
- **Japan and West Germany** were the first to widely adopt these procedures and benefit from them, followed by most of other Countries with different delays and speeds, according to their status and desire for redemption.
- The **benefits** introduced by the application to the industrial productions of QA/QC rules and procedures became evident from the sixties and seventies, **starting from electronics**.
- The impressive impact of the **highly reliable custom electronics** and its consequent impact on instrumentation and industrial automation pushed all the world economy toward **reliable production and global commerce**
- **Science has greatly benefited** from the availability of high quality industrial manufacturing, **integrated QA/QC** concets in its behavior, invested in **industrialization** and contributed **spin-offs** and **start-ups**.

Contents

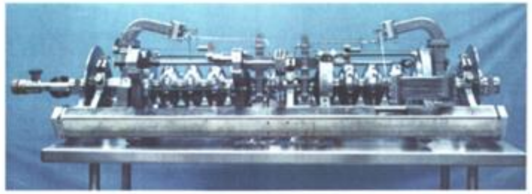
From 1979 HEP drives Accelerators R&D

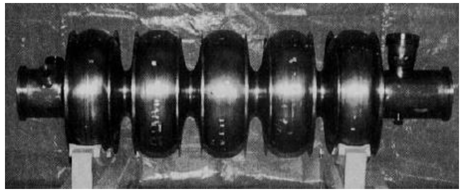


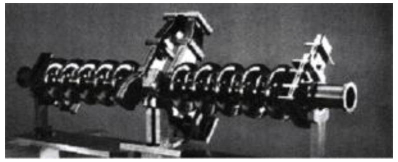
K. Yokoya, 2014

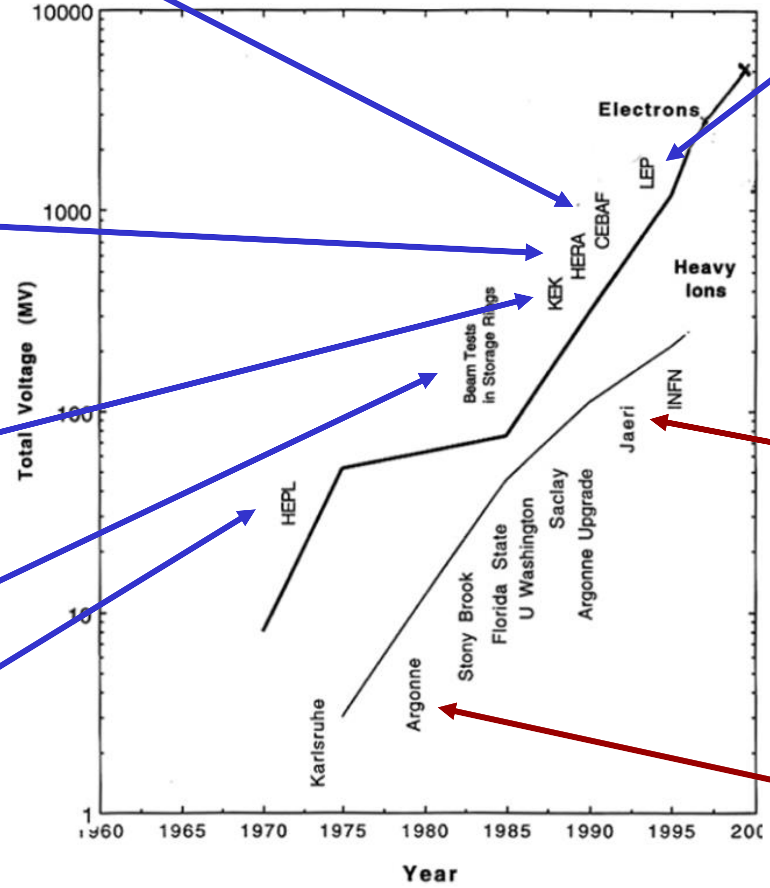
SCRF From HEPL to year 2000

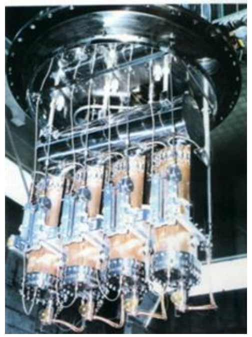
"Livingston Plot" **from Hasan Padamsee**









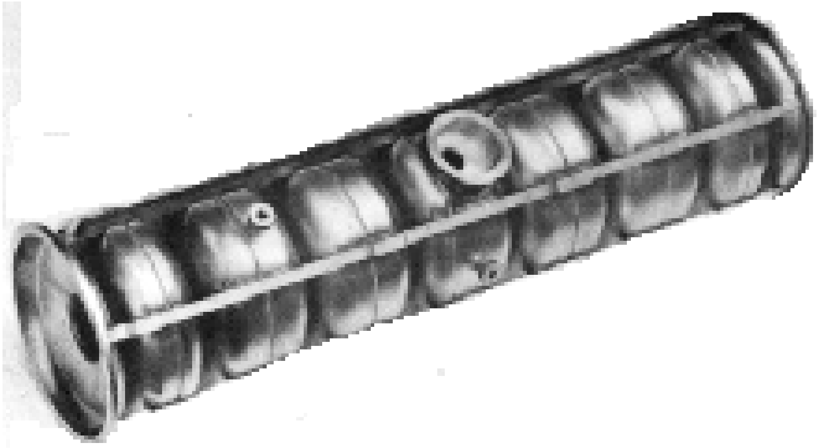


SRF at the pioneering age in the seventies

Argonne National Labs

ATLAS: Heavy-ion Linac

- Originated at Caltech
- Implementd and used in other labs for β ~ 0.1



Stanford University

HEPL: Electron Linac for FEL

- First multicell electron cavity: β = 1

Limiting Problems

Material properties

- Moderate Nb purity (Niobium from the Tantalum production)
- Low Residual Resistance Ratio, RRR → Low thermal conductivity
- Normal Conducting inclusions → Quench at moderate field

Cavity treatments and cleanness

- Cavity preparation procedure at the R&D stage
- High Pressure rinsing and clean room assembly not yet introduced

Microphonics

- Mechanical vibrations in low beta structures → High RF power required

Multipactoring

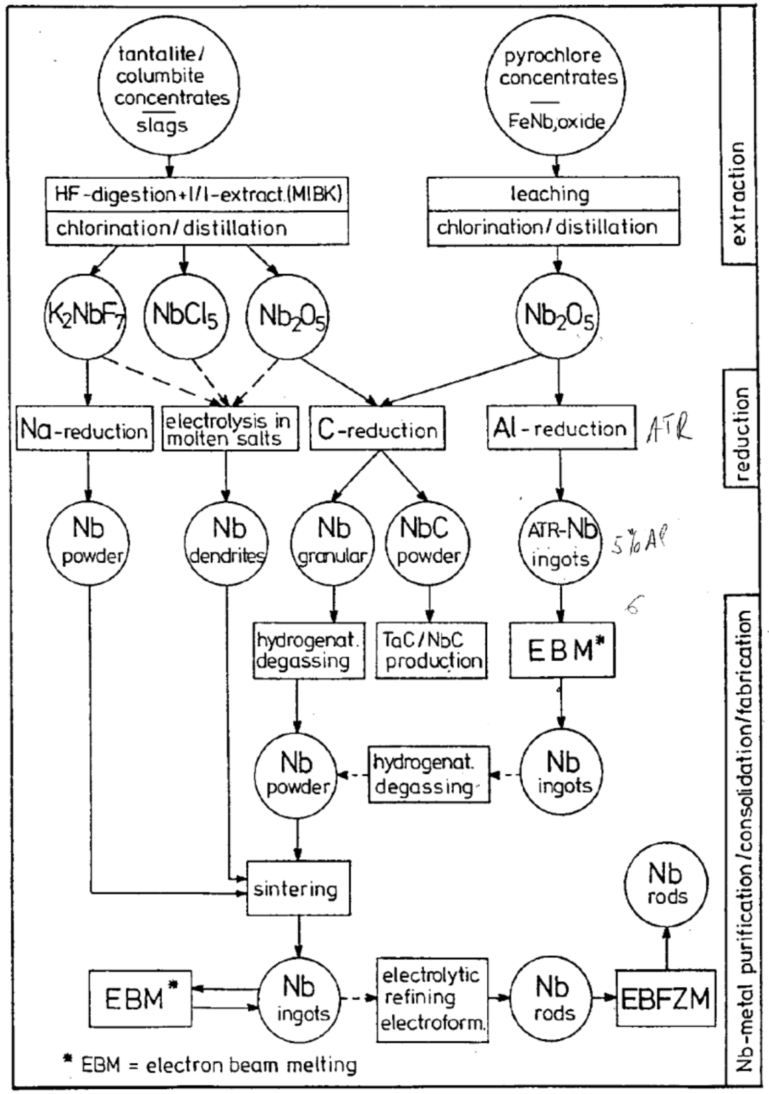
- MP has been the major limit for HEPL, and electron linacs to 1984
- Pill-box like geometry: higher shunt impedance but higher MP problems

Quenches/Thermal breakdown → low RRR and NC inclusions

Field Emission

- General limit at those time because of poor cleaning procedures and material

Main routes of Nb fabrication process



Classical routes for Nb, consist of the carbothermic reduction of Nb_2O_5 and the aluminothermic reduction of Nb_2O_5 followed by EBM.

$$Nb_2O_5 + 7C \rightarrow 2NbC + 5CO$$

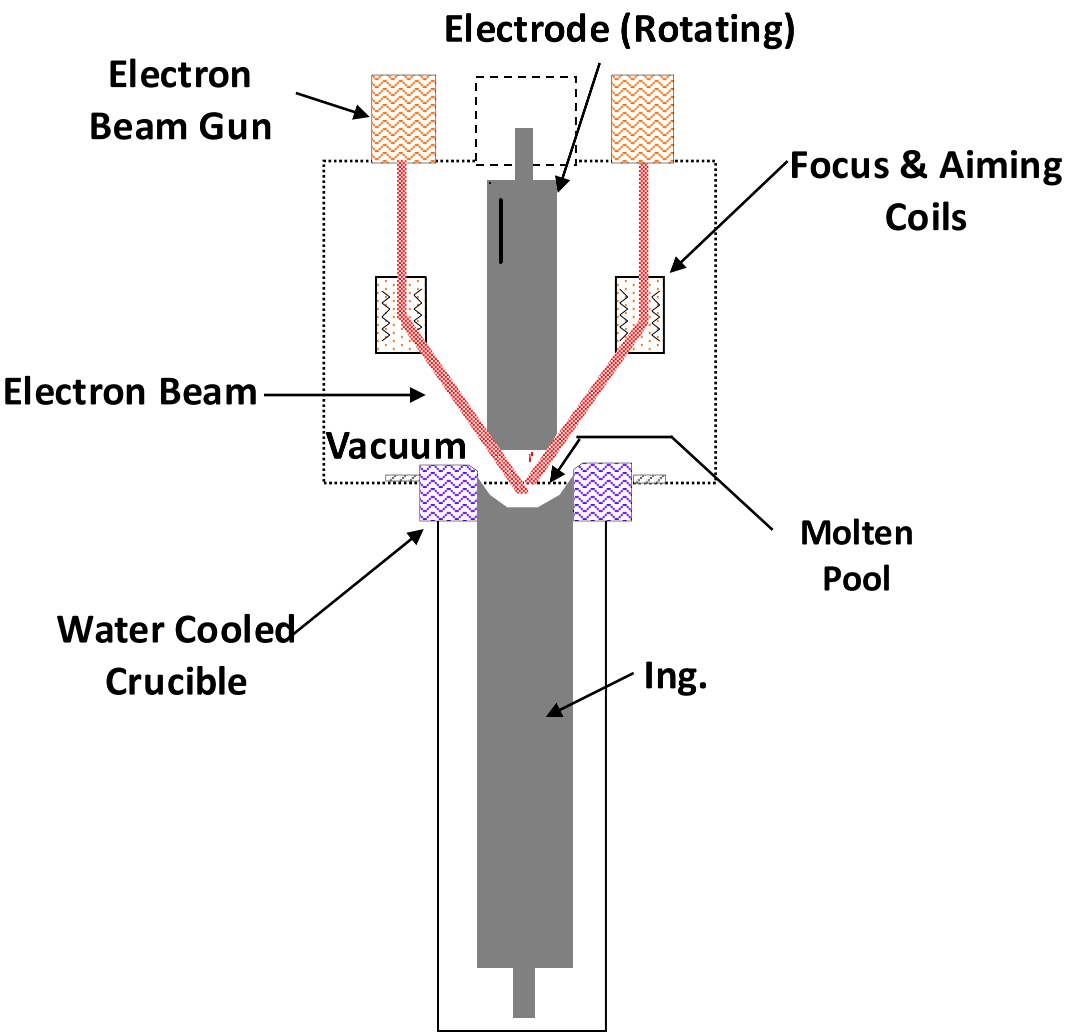
$$5NbC + Nb_2O_5 \rightarrow 7Nb + 5CO$$

$$3Nb_2O_5 + 10Al \rightarrow 5Al_2O_3 + 6Nb$$

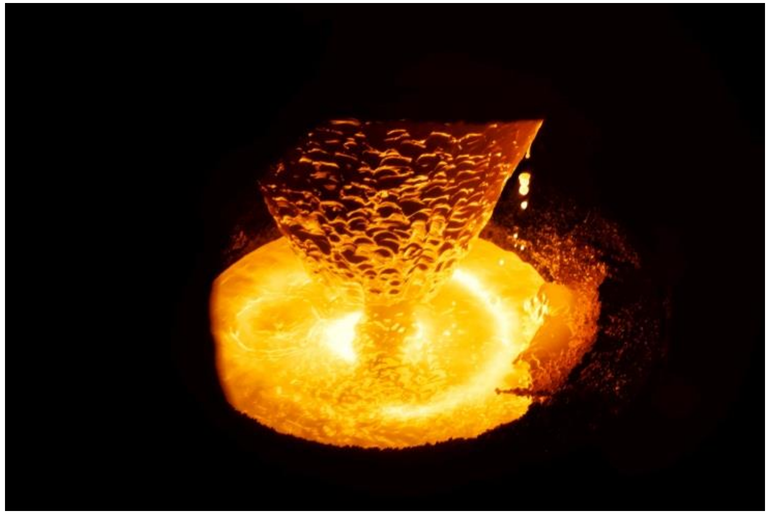
An alternative route of niobium fabrication and alloying is powder metallurgy. For special applications it may be convenient to produce powder with high purity hydriding. The production of high-grade niobium with small Ta-concentration can be performed via the sodium reduction of purified K_2NbF_7.

$$K_2NbF_7 + 5Na \rightarrow Nb + 2KF + 5NaF$$

Electron Beam Melting of Niobium



During of the ingot melts, molten metal globules **fall into a pool** on the ingot which is contained in a water cooled copper crucible. Impurities are evaporated and pumped away. Power impact is maintained to keep the pool molten out to within a few mm of the crucible wall. During melting the ingot formed is **continuously withdrawn** through the crucible.

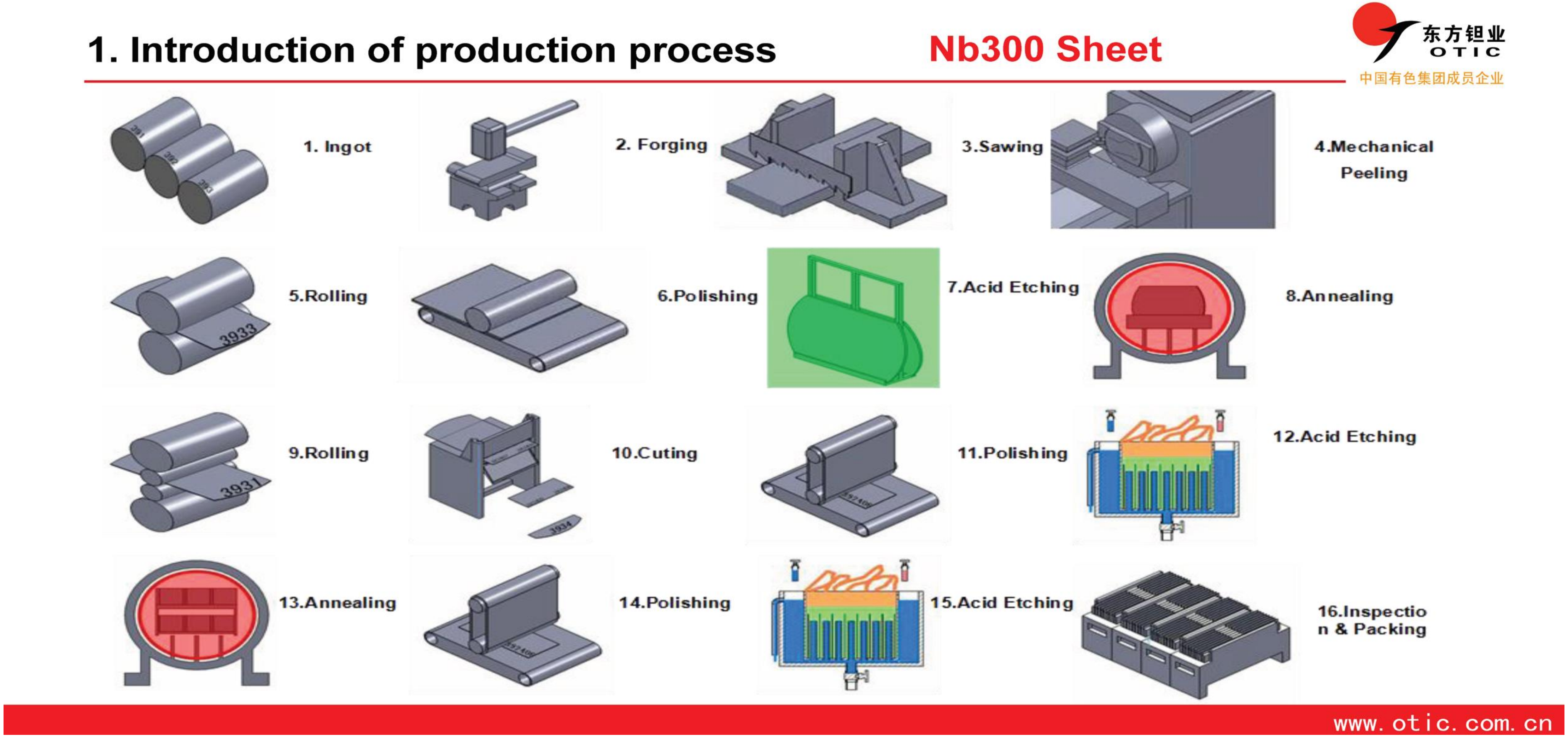


Electron Bem Melting

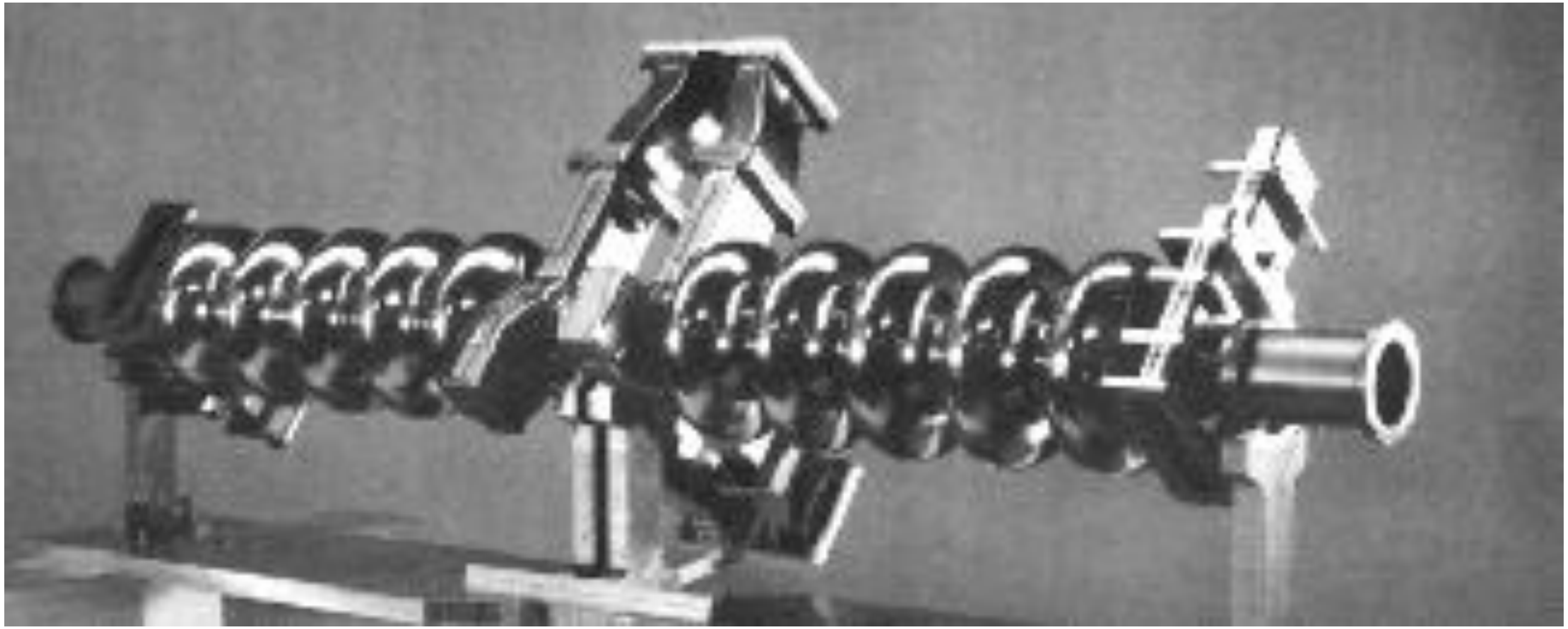
As a result of the increasing demand for refractory metals in the last few decades, the electron-beam furnace has been developed to a reliable, efficient apparatus for melting and purification.

One problem sometimes observed with e-beam melted ingots is the nonhomogeneous distribution of impurities. The **skin** of the ingot contains more impurities than the inside. **Top to bottom inhomogeneity**.

Nb Sheets Fabrication at OTIC



1884/85 The Cornell Brake-throug

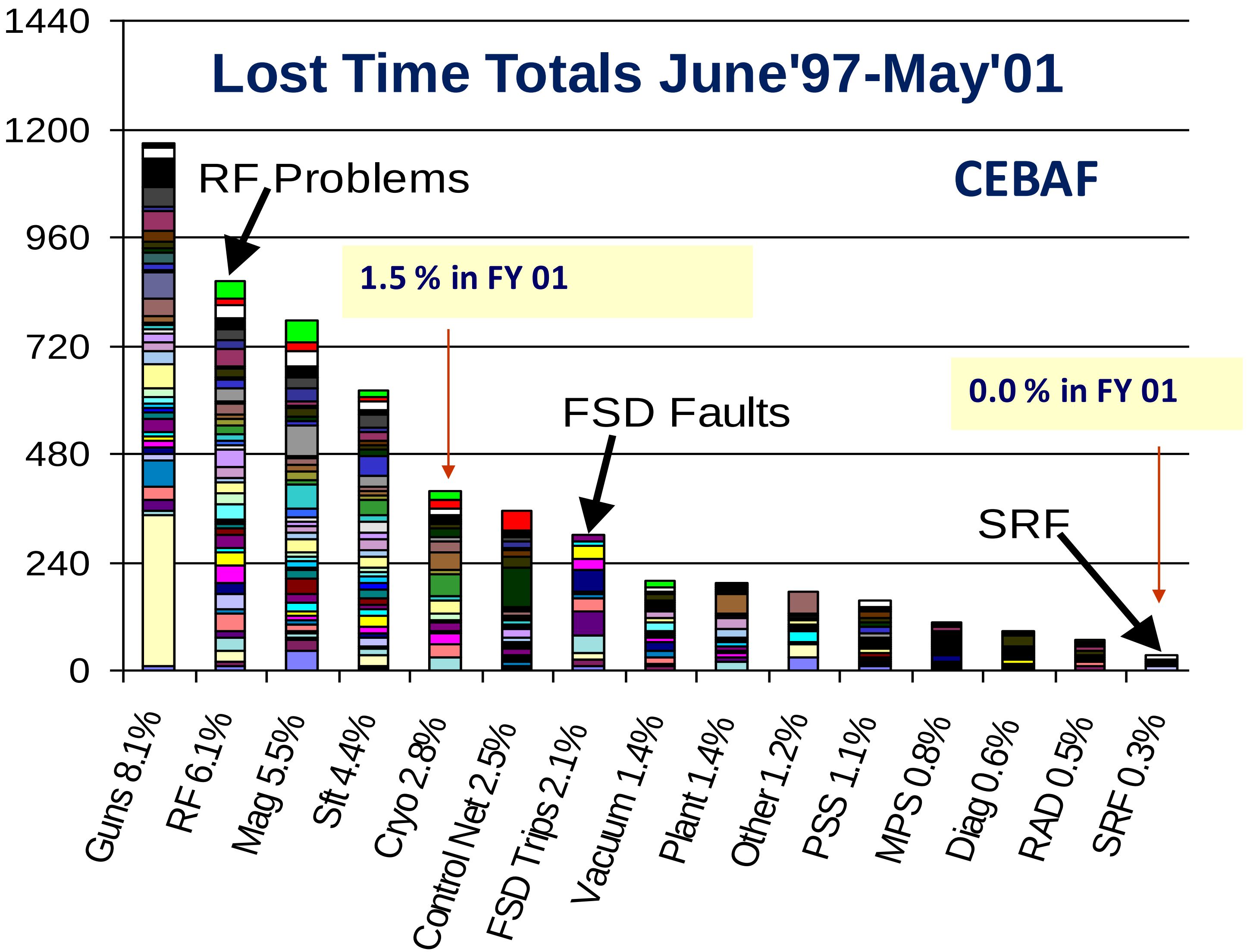


First great success

A pair of 1.5 GHz cavities developed and tested at Cornell: 4.5 MV/m
Chosen for CEBAF at TJNAF for a nominal E_{acc} = 5 MV/m

330 Cavities produced in industry but treated and tested at TJNAF

A great success for CEBAF



Excellent reliability of SRF technology

Moderate field > 5 MV/m

The only warm-up for the **Isabelle Hurricane**

TRISTAN SRF from KEK to MHI

KEK 1981

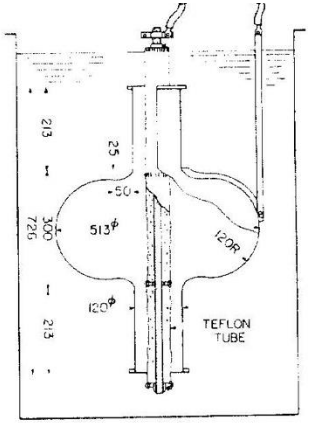


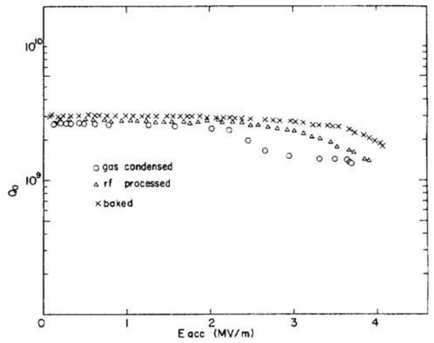
Fig. 1 Set up of the electropolishing.

Major impurities in the niobium used for the 500 MHz cavity.

Tantalum	1700 ppm
Tungsten	800 ppm
Zirconium	800 ppm
Silicon	500 ppm

T. Furuya, S. Hiramatsu, T. Nakazato, T. Kato
P. Kneisel*, Y. Kojima and T. Takagi

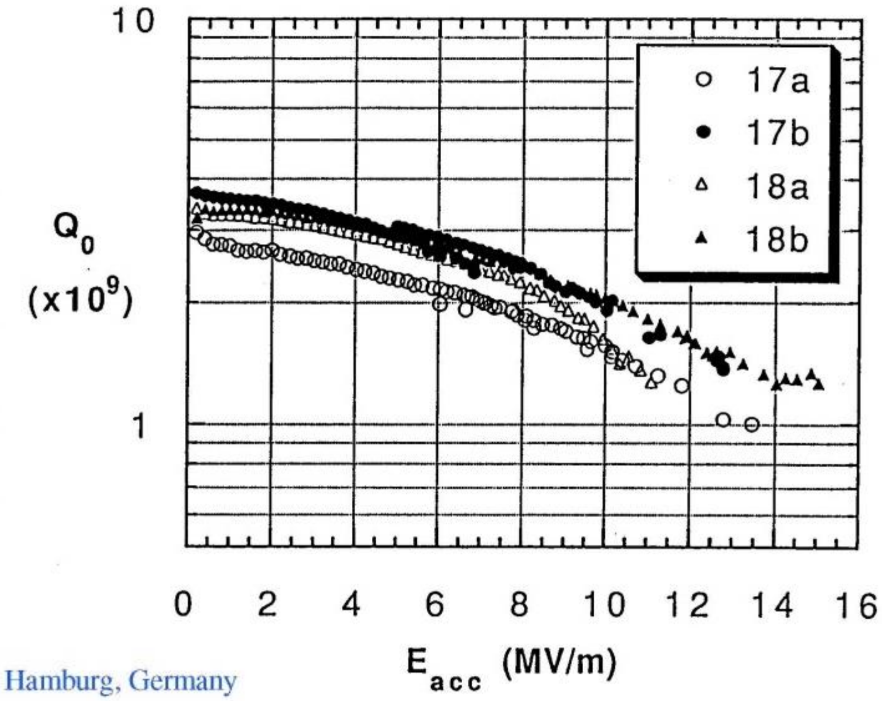
IEEE Transactions on Nuclear Science, Vol. NS-28, No. 3, June 1981



1995

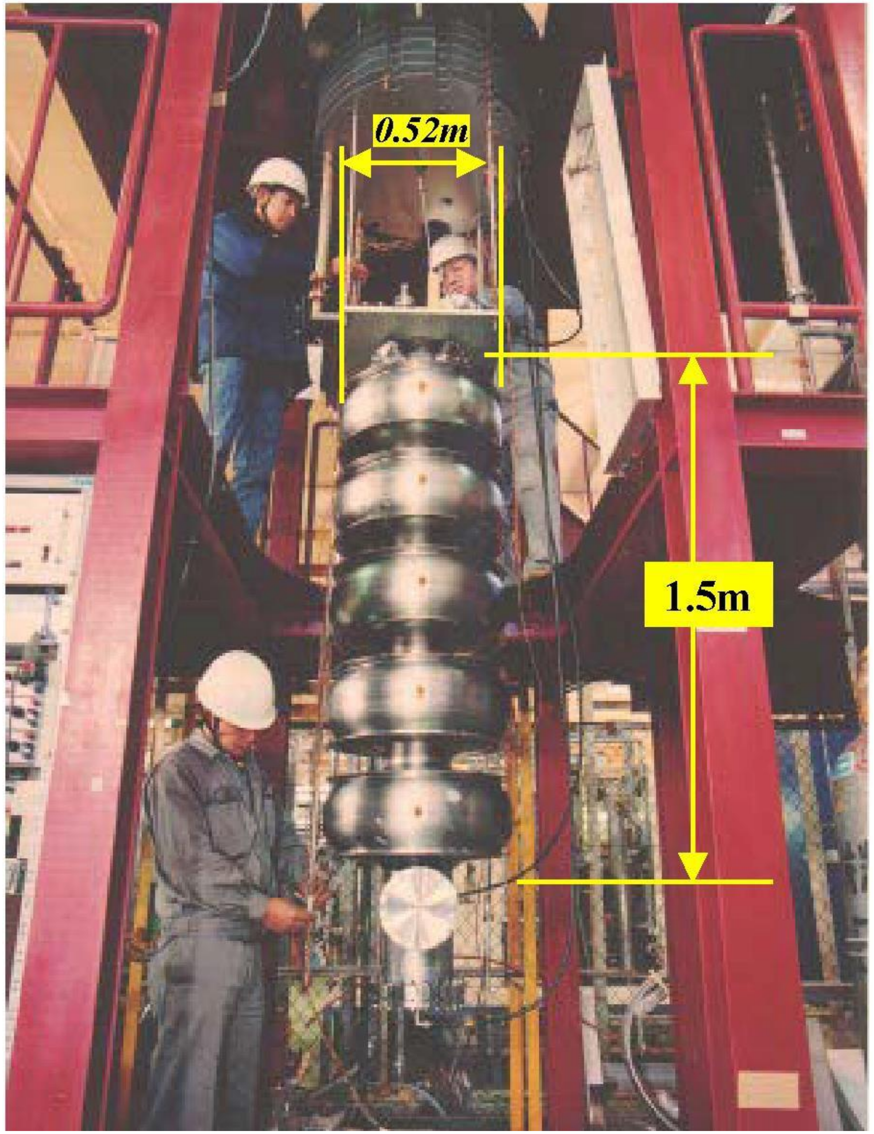
Table 1. Results of final vertical measurements of spare cavities.

Cavity #	17a	17b	18a	18b
Meas. date	28 June 91	12 June 91	30 Jan. 91	7 Feb. 91
f_0 (MHz)	508.240	508.178	508.204	508.218
Q_{15D} 1) ($\times 10^{11}$)	3.33	2.57	2.49	3.03
Q_0 at low field ($\times 10^9$)	2.8	3.6	3.3	3.4
$E_{acc,max}$ (MV/m)	13.5	12.8	11.1	15.1



Proceedings of the Fifth Workshop on RF Superconductivity, DESY, Hamburg, Germany

First Industrial Production in Japan (1988 – 1995)

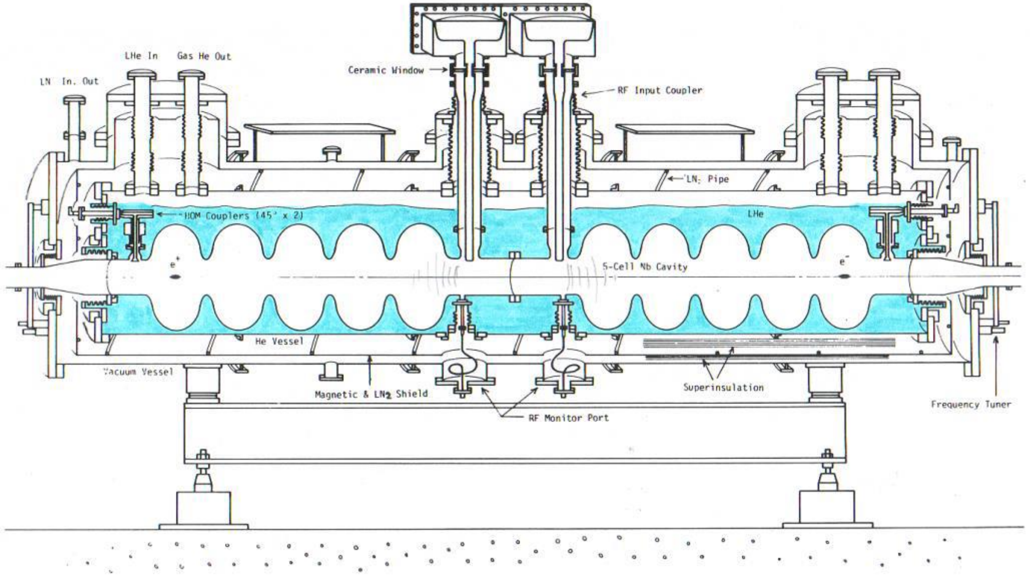


The **first mass-production** of SRF Cavities in the world

SRF Cavity **for TRISTAN** at **KEK**

Bulk-Nb - 508MHz - 5-Cell Cavity

32 SRF cavities were fabricated by Mitsubishi and operated in TRISTAN



LEP-2 as the first QA/QC Industrialization

- **Complete inftrastructure set up at CERN** collecting resources and competences:
  - Compelete **chemical plant**
  - Big (6-8 m^3) **Electron Beam Welding** machine cryo-pomped
  - Availability of the main **CERN mechanical workshop** with new machinary
  - Special support from scientists of 3 member Countries (France, Germany and Italy) to prepare in parallel a **QA/QC based industrialization**
- Moderate results with bulk Niobium but
- Oustandig resuts with the new CERN tecnology of **Nb coating of Cu by magnetron sputtering**
- **All aquipments and receipts trasferred to 3 industryies** for mass production. **QA/QC procedures and EDMS included**

LEP 2 Cavities and Modules

4-cell, 352 MHz,

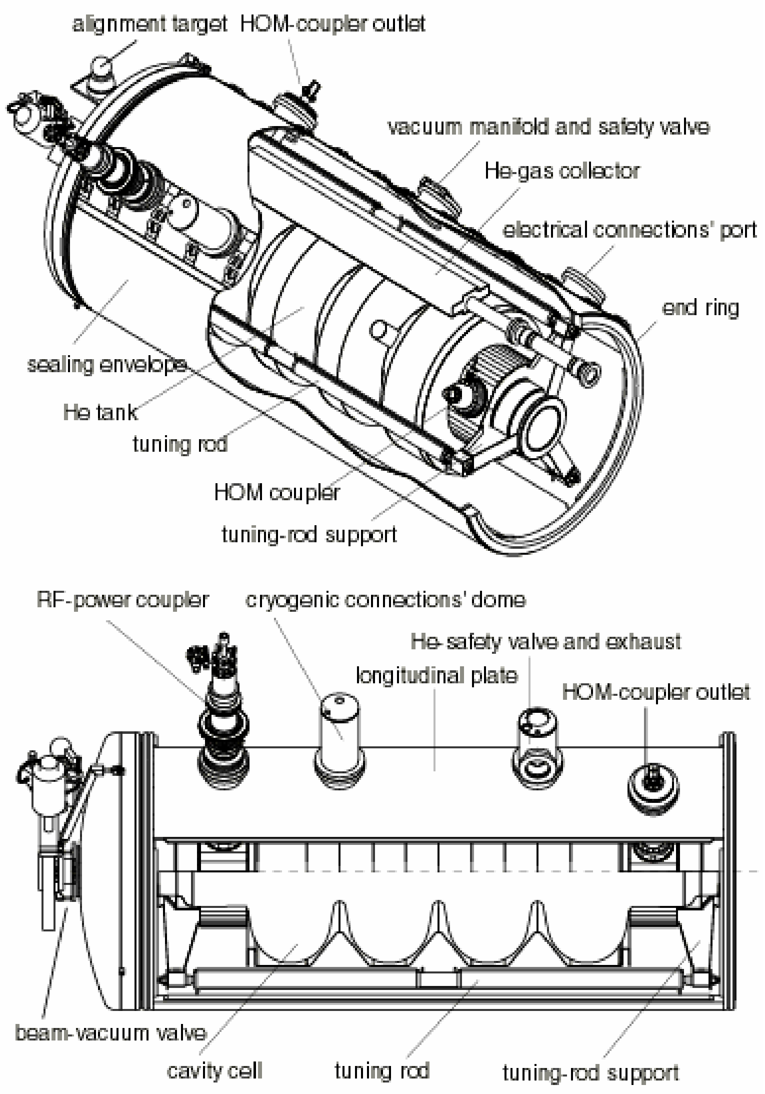
L_{act}=1.7 m

32 bulk niobium

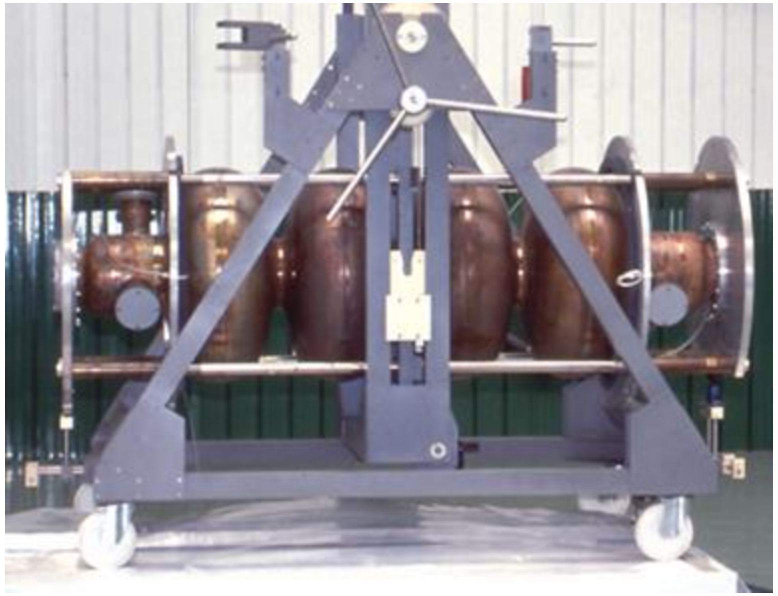
- Limited to 5 MV/m
- Poor material and inclusions

256 Nb sputtered on Cu

- Magnetron-sputtering of Nb on Cu
- Completely done by industry
- Moderate Q-slope at 350 MHz
- Field emission above 8 MV/m
- Average E_{acc} = 7.8 MV/m – cryo-limited



LEP-2 Cavities in Industry

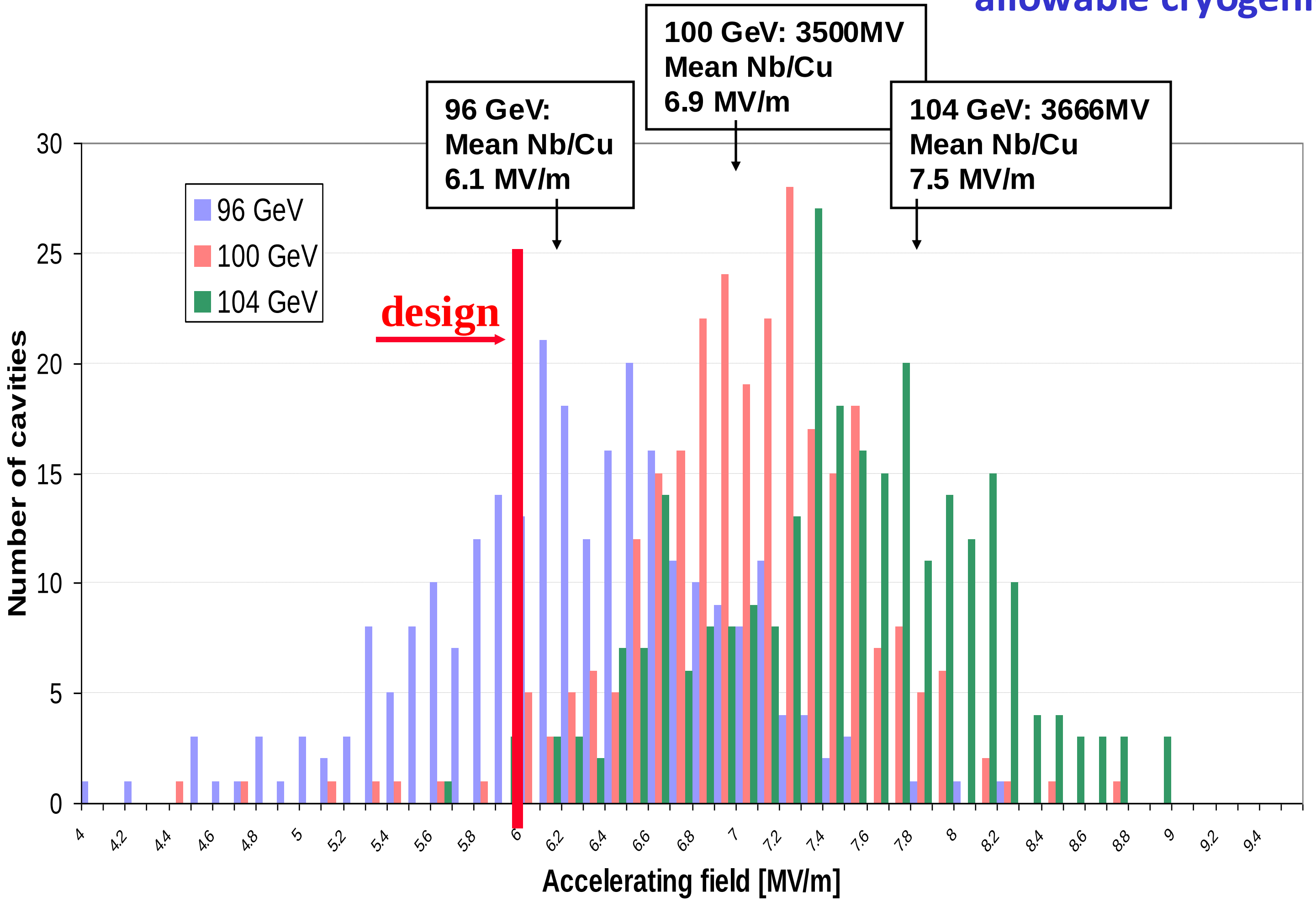


A great success for LEP II

Accelerating Field Evolution with time

from G. Geschonke's Poster for the ITRP visit to DESY

Final energy reach limited by allowable cryogenic power

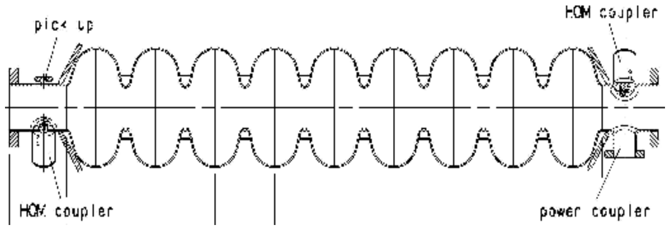


Contents

First Steps of the TESLA Game

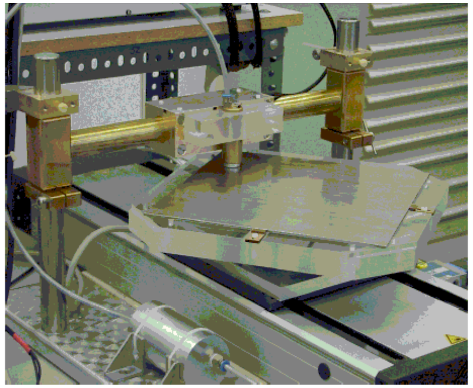
Major contributions from: CERN, Cornell, DESY, CEA-Saclay, INFN-LASA

9-cell, 1.3 GHz



TESLA cavity parameters

R/Q	1036	W
E_{peak}/E_{acc}	2.0	
B_{peak}/E_{acc}	4.26	mT/(MV/m)
$\Delta f/\Delta l$	315	kHz/mm
$K_{Lorentz}$	$\approx$ -1	$Hz/(MV/m)^2$



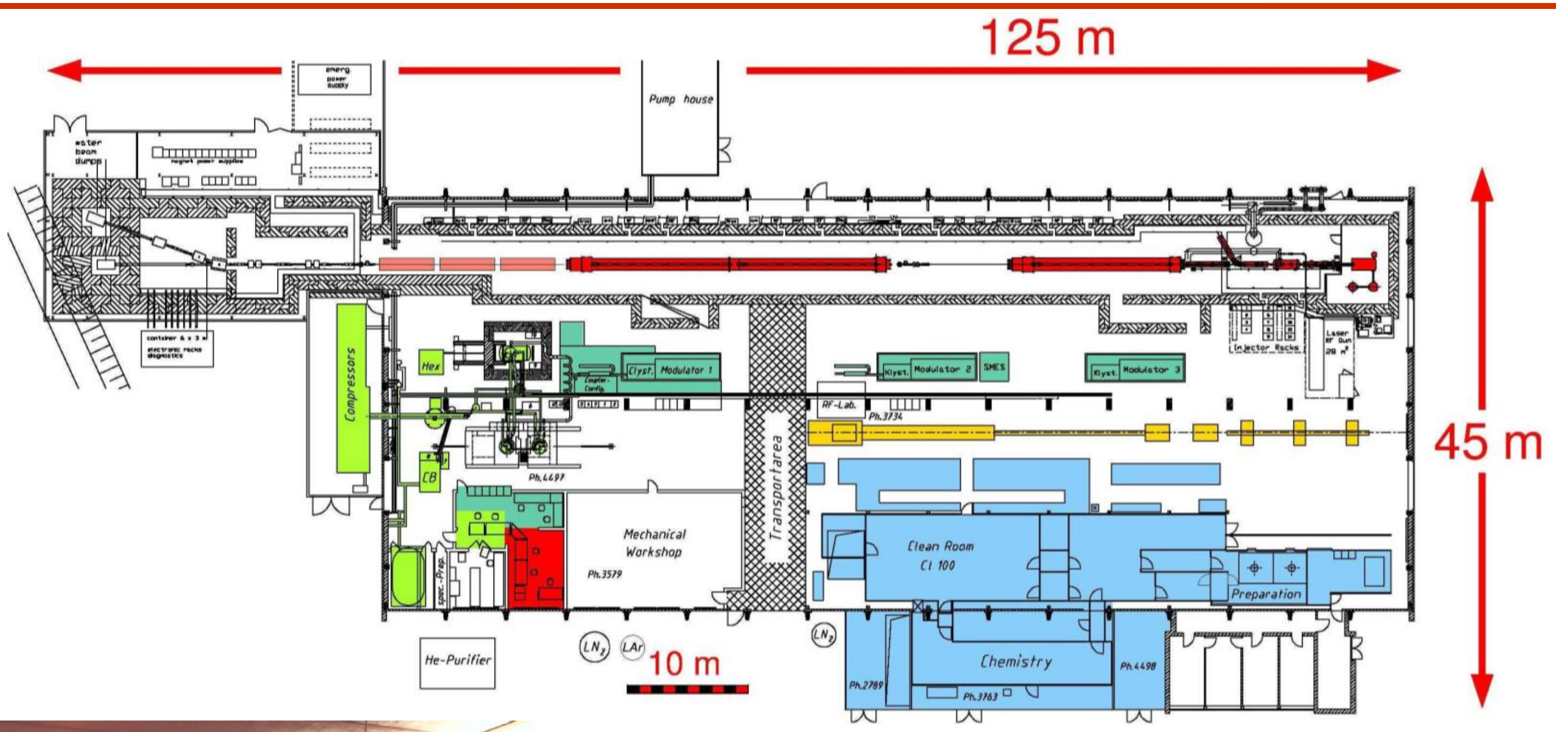
Eddy-current scanning system for niobium sheets

Cleanroom handling of niobium cavities

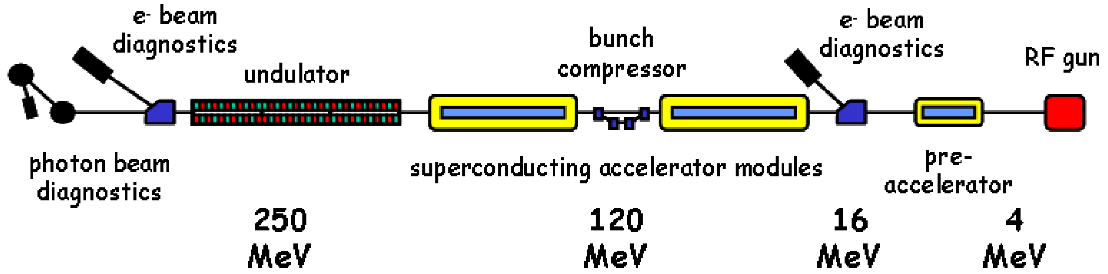
Preparation Sequence

- Niobium sheets (RRR=300) are scanned by eddy-currents to detect avoid foreign material inclusions like tantalum and iron
- Industrial production of full nine-cell cavities:
    - Deep-drawing of subunits (half-cells, etc.) from niobium sheets
    - Chemical preparation for welding, cleanroom preparation
    - Electron-beam welding according to detailed specification
- 800 °C high temperature heat treatment to stress anneal the Nb and to remove hydrogen from the Nb
- 1400 °C high temperature heat treatment with titanium getter layer to increase the thermal conductivity (RRR=500)
- Cleanroom handling:
    - Chemical etching to remove damage layer and titanium getter layer
    - High pressure water rinsing as final treatment to avoid particle contamination

TTF: a new infrastructure at DESY



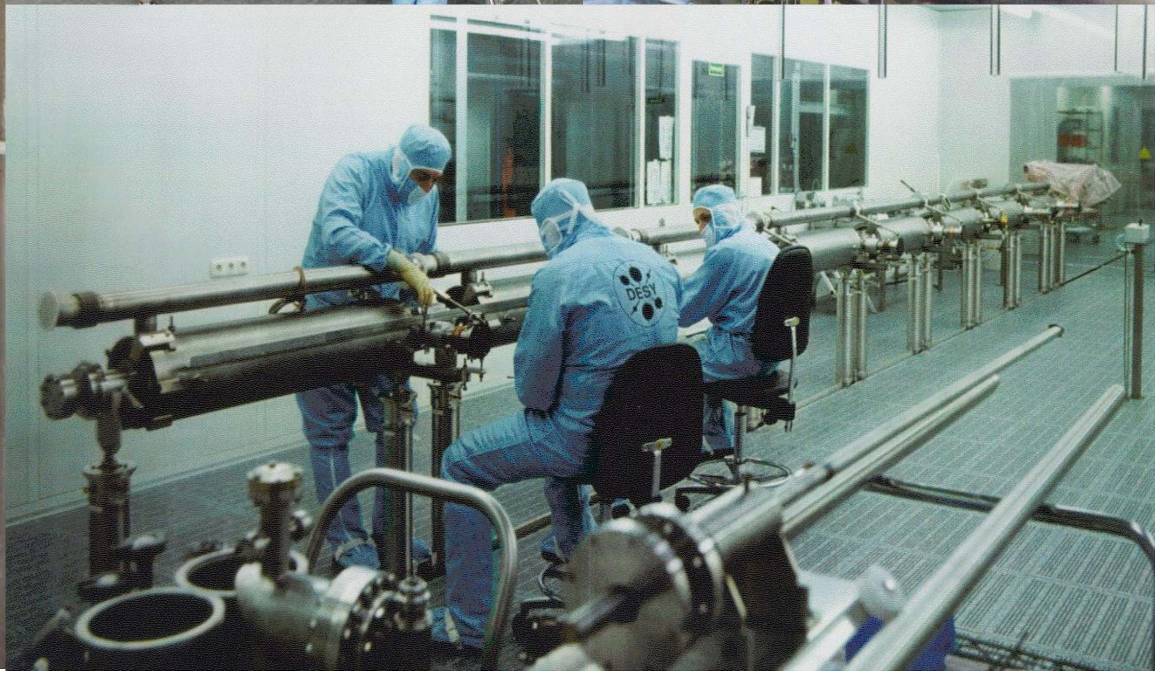
TTF as operated for SASE FEL



The way to improve SRF Performances

- In parallel with the machine design, **all major TESLA sub-components have been conceived, designed and protopyped for TTF**.
- Most of the process has been performed in **strict collabotration with industry**.
- Concerning SRF cavities, all the technology already mastered by industry have been further improved with the help of Labs experience. **All the mechanical fabrication done in industry**.
- The acquisition of an EB Welding machine at DESY had the strong opposition by the Director Biorn Wiik
- The matured experience on the **Niobium welding** has been transferred directly **from Labs to industry**
- Clean room operation and special surface treatments were developped at the DESY infrastructure and promptly tranferred to Industry

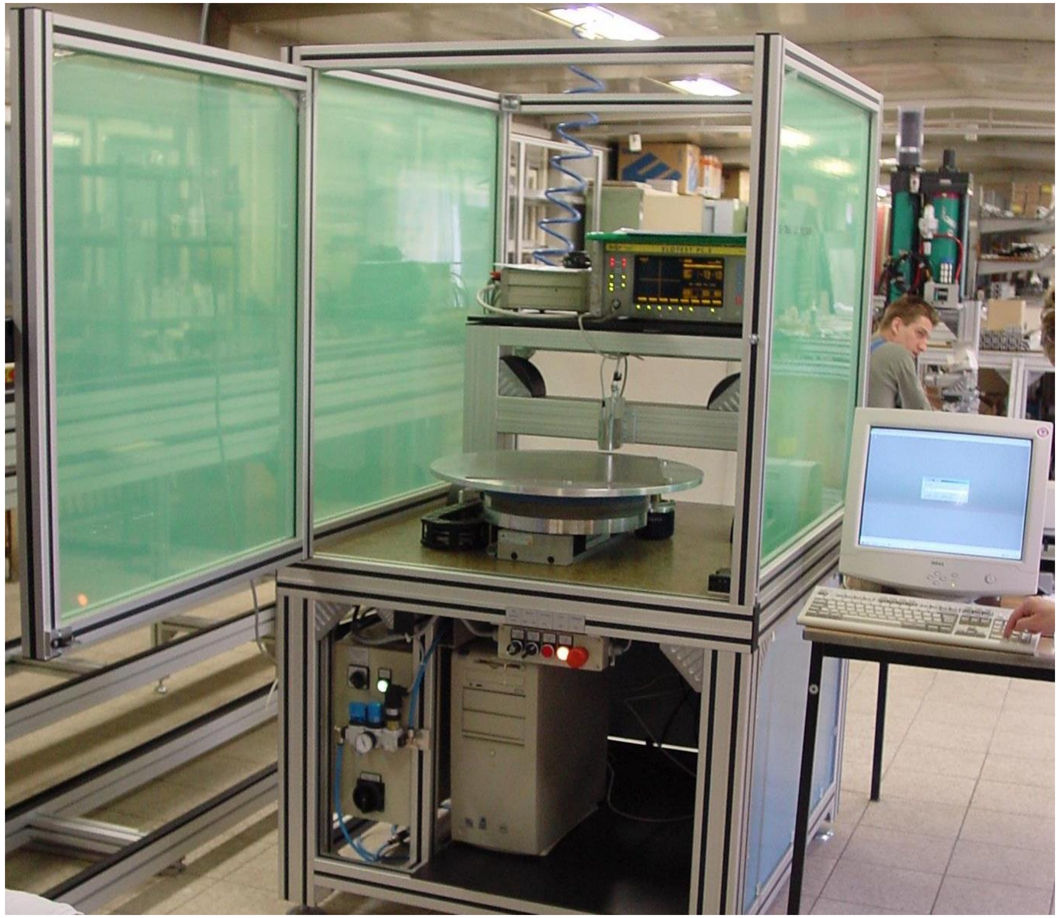
Preparation of TESLA Cavities



HT Furnace and Eddy Current Scanner

High Temp. Furnace to improve RRR reproduced at DESY from Jlab (1400C)

Eddy Current Scanner of Nb Sheets to detect foreign inclusions

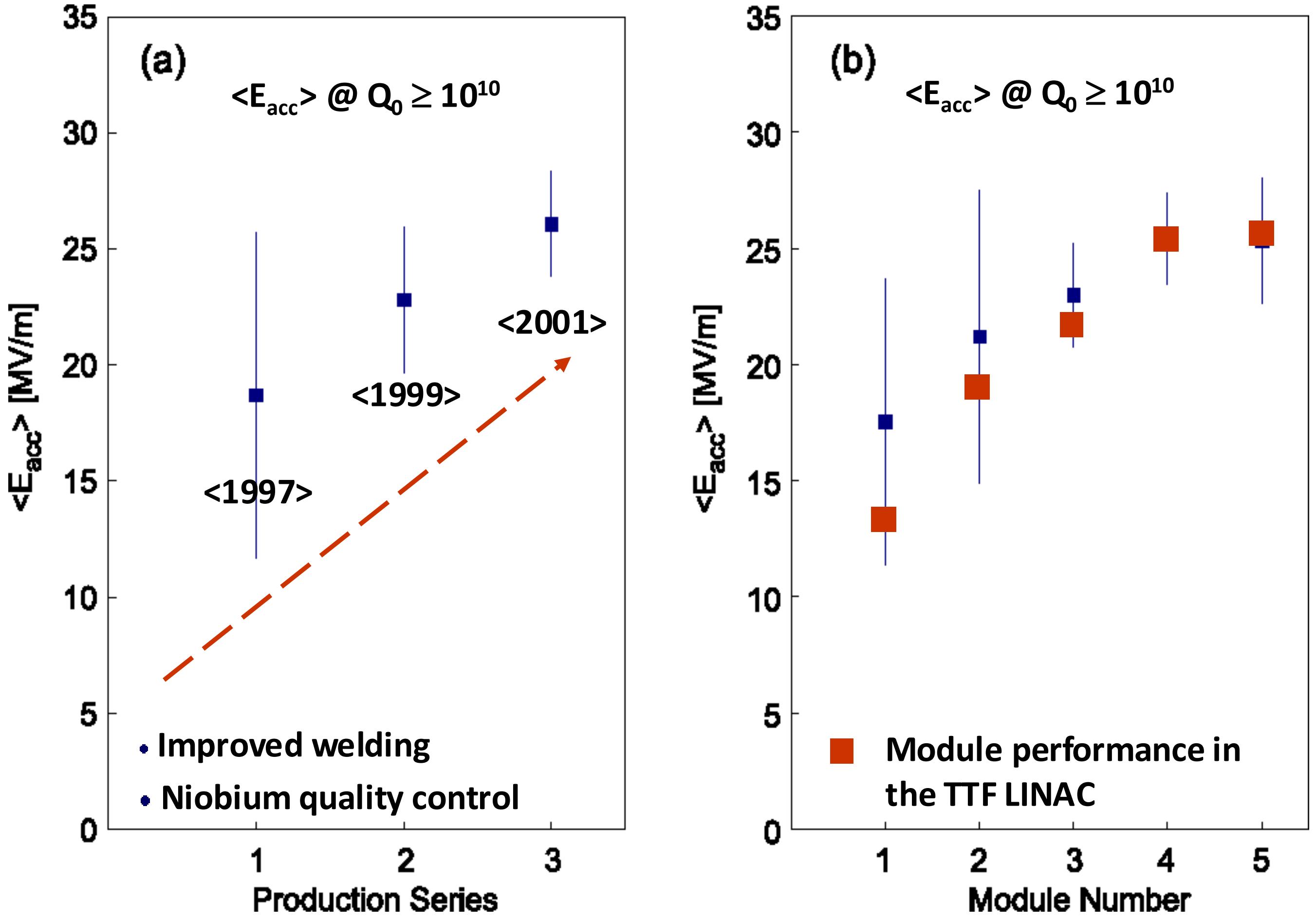


Learning Curve with BCP

BCP = Buffered Chemical Polishing

3 cavity productions from 4 European industries: Accel, Cerca, Dornier, Zanon

4th production of 30 cavities to define Quality Control for Industrialization



Two major contributions to rise the limits

In-Situ Baking (120-140 °C) from CEA-Saclay (Bernard Visentin)

Cures Q-drop at High Field

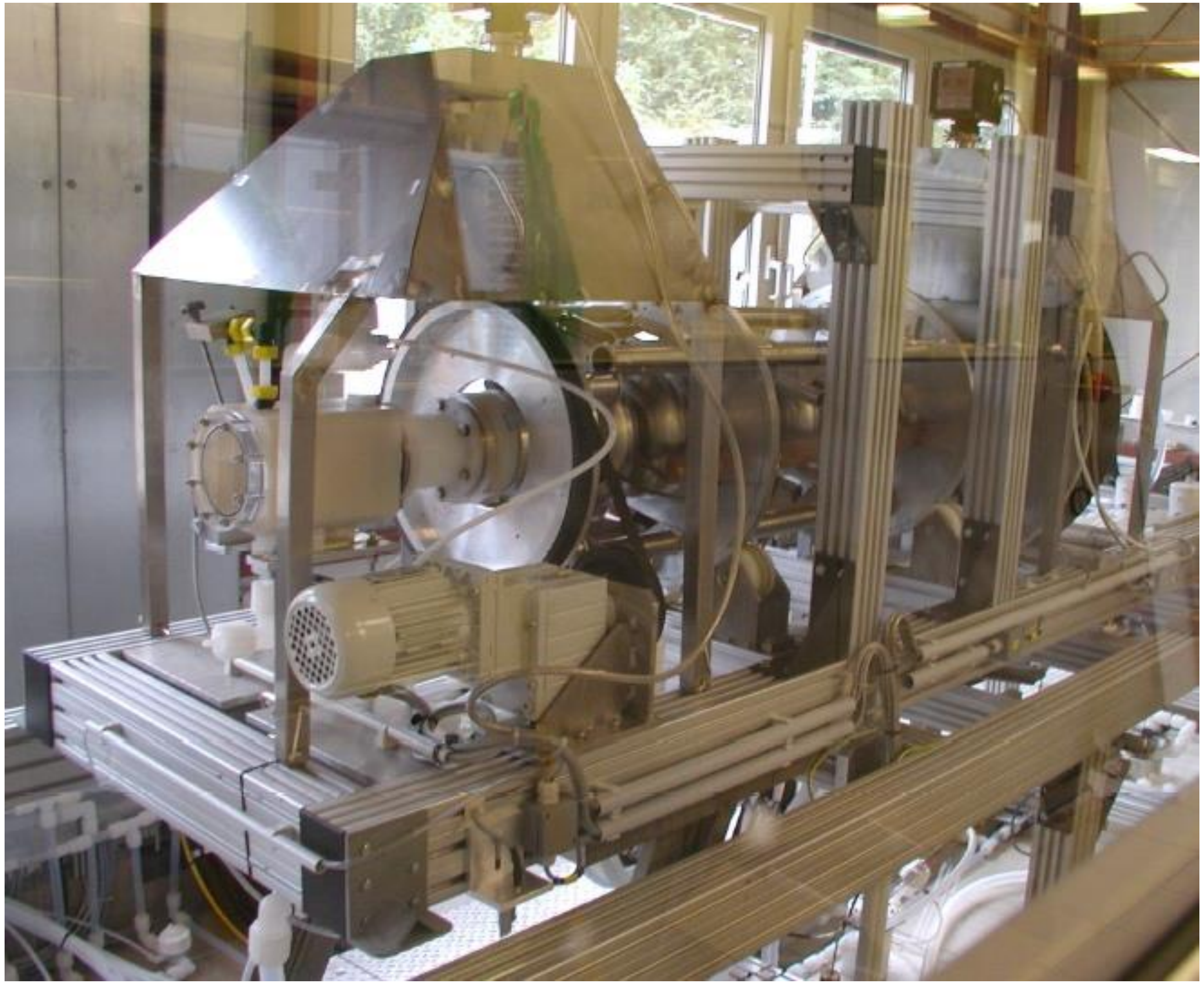
- Formation of a uniform Nb_2O_5, dielectric, layer on the surface
  - Reduction of the normal conducting dissipation from NbO and NbO_2
- Diffusion of the high oxygen concentration in the superconducting layer
  - Better BCS performances, i.e. lower surface resistance

Electro-polishing (EP) from KEK (Kenji Saito)

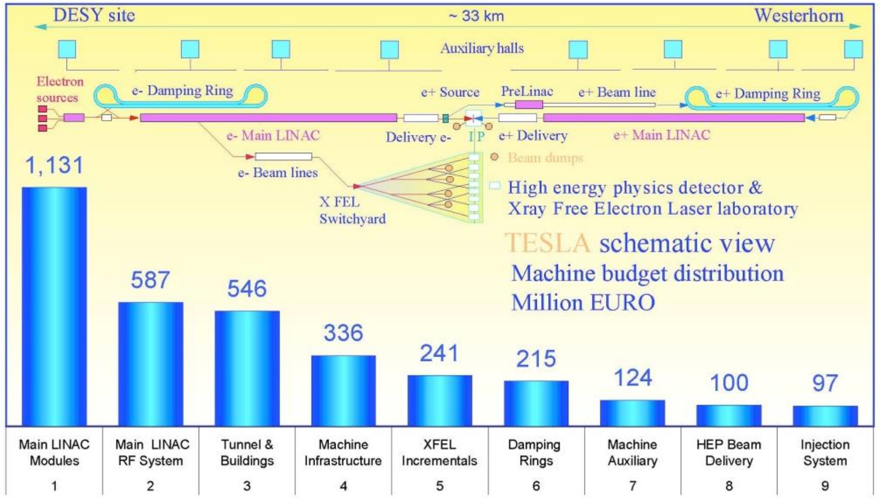
Improves field emission and maximum field

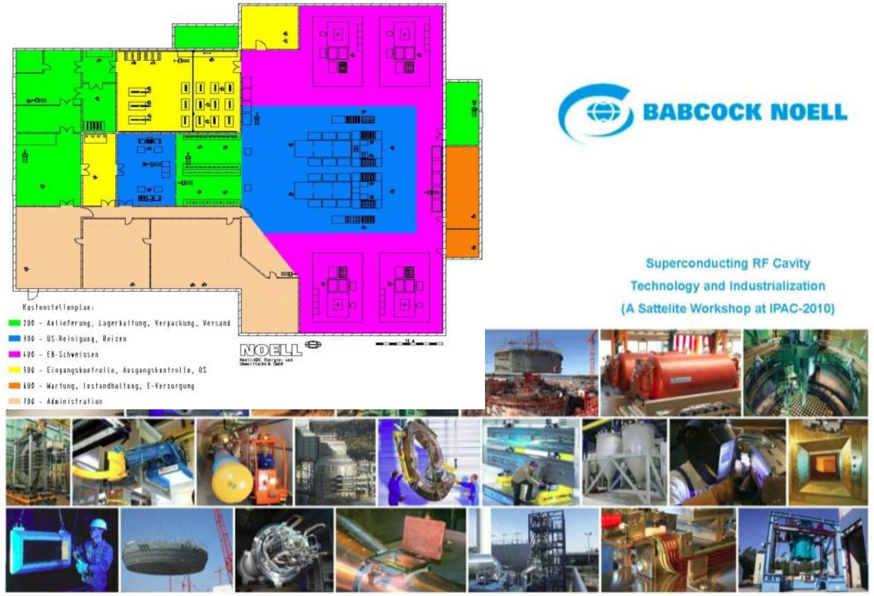
- Much smoother surface, less local field enhancement
  - Better cleaning with high pressure water rinsing
  - Q-drop cure by in-situ baking more efffective
  - High temperature (1400 °C) heat treatment avoidable

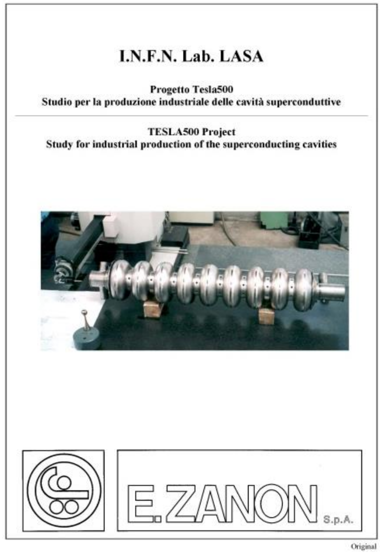
EP at DESY from the KEK Experience



Industrial Studies for TESLA TDR & E-XFEL







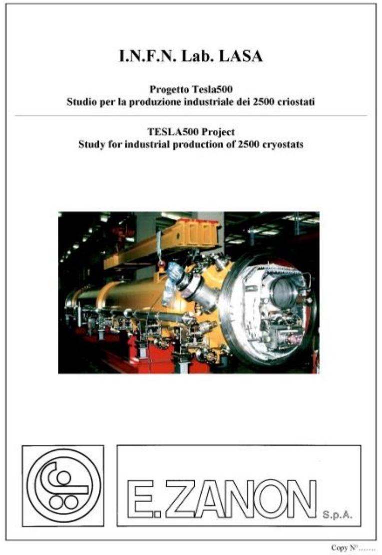
I.N.F.N. Lab. LASA

Progetto Tesla500
Studio per la produzione industriale delle cavità superconduttive

TESLA500 Project
Study for industrial production of the superconducting cavities

E.ZANON S.p.A.

Original



I.N.F.N. Lab. LASA

Progetto Tesla500
Studio per la produzione industriale dei 2500 criostati

TESLA500 Project
Study for industrial production of 2500 cryostats

E.ZANON S.p.A.

Copy N°.......

Overview on industrial studies for superconducting linacs (TESLA, XFEL,CARE), status dec.05, D.Proch

#	Subject	main issues	design	fabrication	cost	Contract	Status
1	Nb RRR 300	500 to of Nb sheet production		X	X	DESY	finished
2	Cavity fabrication	20000 cavities, welding		X	X	DESY	finished
3	Cavity fabrication	1000 cavities, welding		X	X	DESY	finished
4	Cavity fabrication	20000 cavities, hydroforming		X	X	DESY	finished
5	Cavity processing	20000 cavities, VT test, 1400°C, BCP		X	X	DESY	finished
6	Module assembly I	Assembly of 20000 cavities		X	X	DESY	finished
7	Cavity processing	Substitute BCP by EP, 1000 cavities		X	X	XFEL	in preparation
8	Module assembly II	Improvements to study 6, 1000 cavities	X	X	X	XFEL	started
9	Input coupler	improvement to TTF3 design, 1000 couplers	X	X	X	XFEL	in preparation
10	EP	Industrial aspects of EP		X	X	CARE	in preparation
11	Improvement of components	Reliability aspects of critical components	X	X		CARE	in preparation
12	Squid scanner	Principle layout, prototype	X	X		CARE	finished

European XFEL Cavity Production - 1

At the end of the long prequalification process (TTF, FLASH, ILC,…)

Ettore **Z**anon, **EZ** & **R**esearch **I**nstruments, **RI**

were contracted at the **end 2010** to produce each

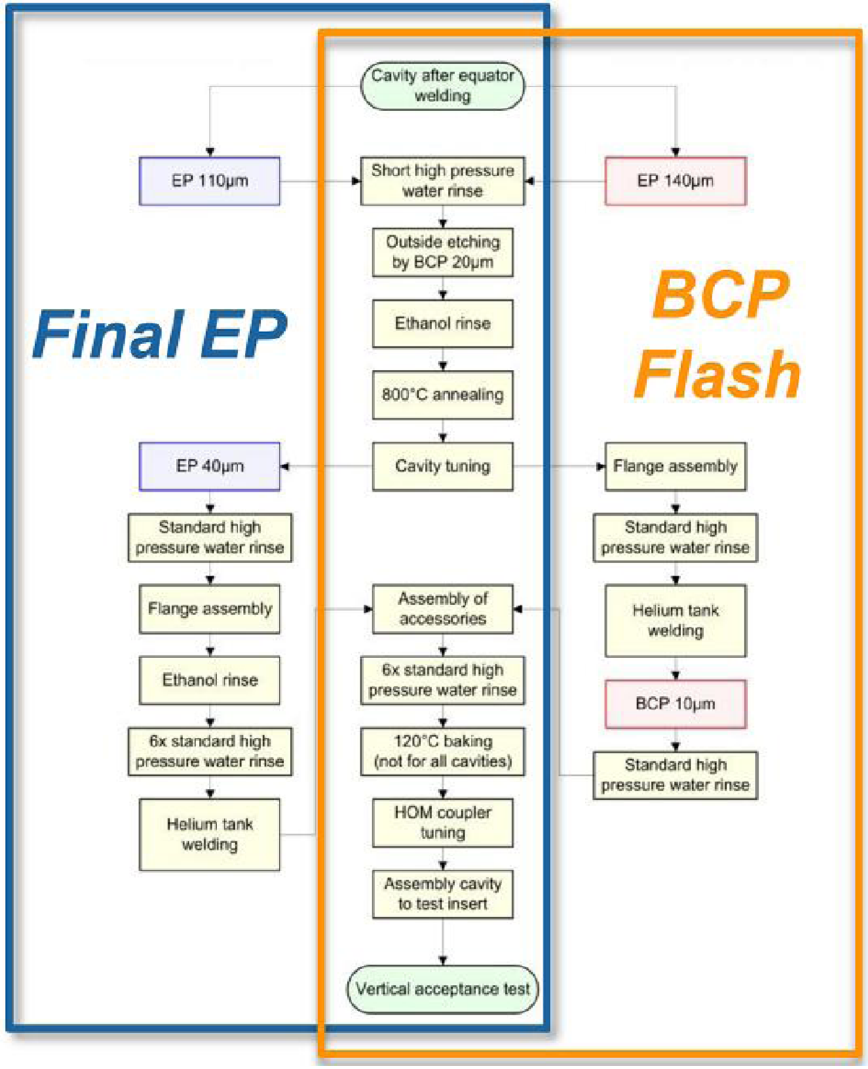
- **8 Cavities** for infrastructure rump/up and qualification
  4 Dummy CVs (DCV), 4 Reference CVs (RCV)
- **280 XFEL type series cavities (first 8 are PCV)**
  12 ILC HiGrade cavities

- **Additional 120 cavities allocated end 2012 to each companiy**
  Nb & NbTi supplied by DESY
- Production precisely following **detailed specifications** which also include the **exact definition of infrastructure** to be used (**build to print**)
- Final treatment after main EP: final **EP** for **RI** / flash **BCP** for **EZ**

European XFEL Cavity Production - 2

- **No performance guaranty by the vendors**, i.e. the risk of unexpected low gradient or field emission is taken over by XFEL/DESY (responsibility for re-treatment).
- **Goal**: average usable XFEL gradient **23.6 MV/m** at $Q_0=1x10^{10}$, X-Rays <1x10^{-2}mGy/min)
- First series cavities (PCV) **to be delivered end 2012 – begin 2013**
- All cavities to be delivered till **end 2014 – begin 2015**
- Delivery rate: about **8 CVs/week** (4/each vendor)
- Supervision of the CV production: **DESY & INFN/LASA**

Treatments as from Experience on Prototype



Prior surface treatment.

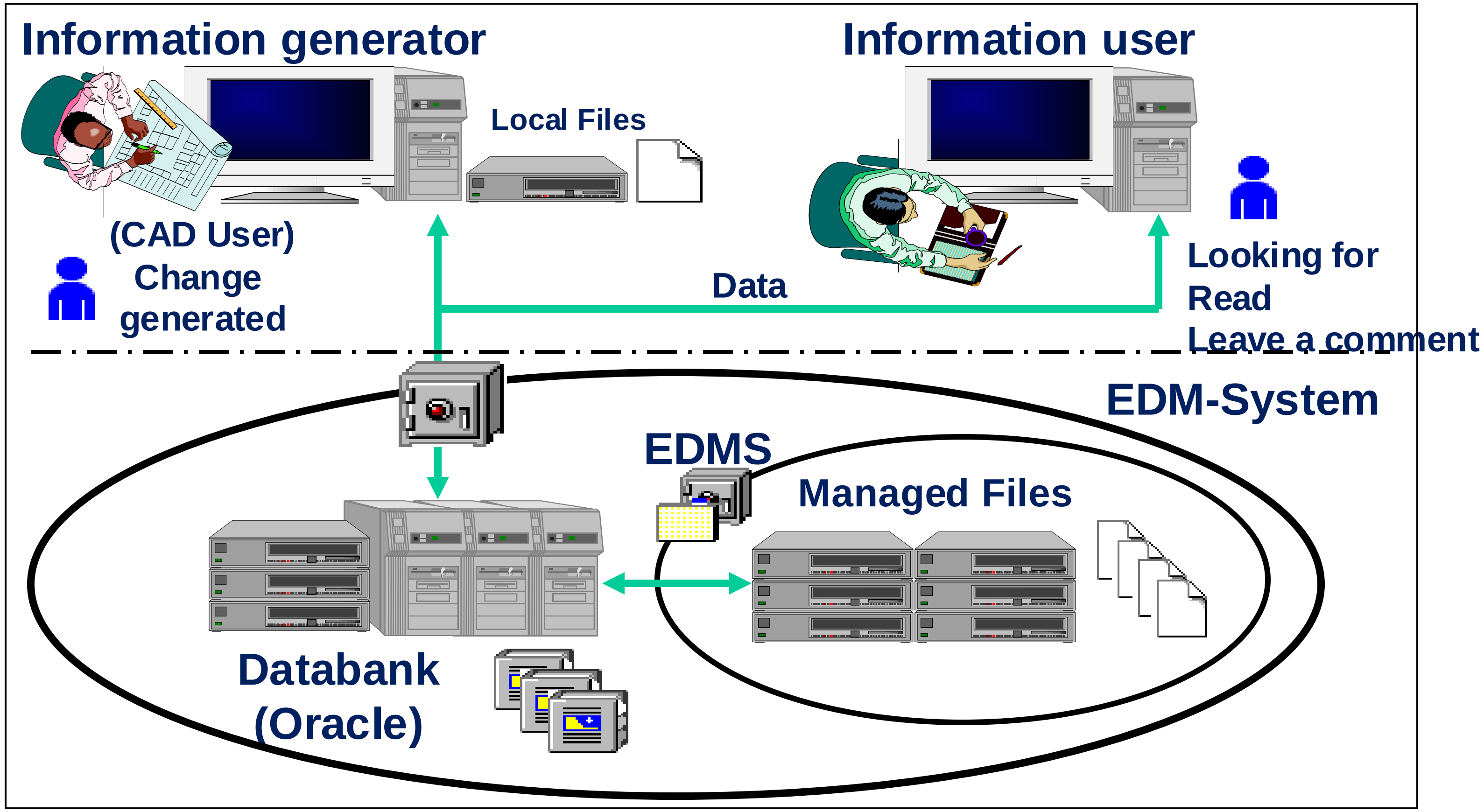
EP 110-140 µm (main EP), ethanol rinse, outside BCP, 800°C annealing, tuning

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 before vertical RF test

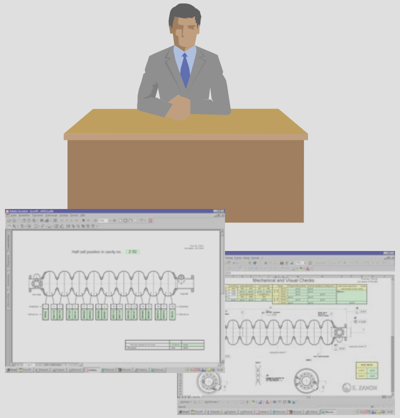
Engineering Data Management System



Application of EDMS for cavity fabrication. Aim: - paper less documentation, up to date information, tracking the trends.

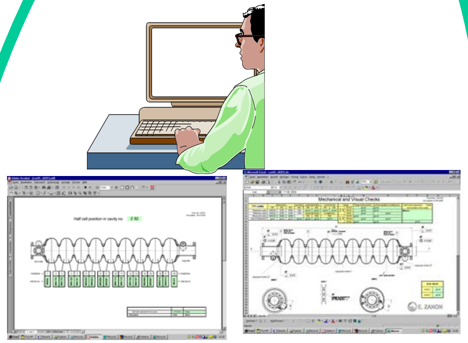
Involvement of cavity producer

DESY



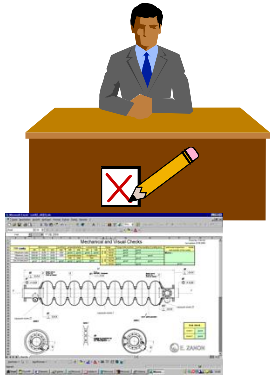
- create the work description (in EDMS).
- create the protocol template (in EDMS).
- message to Producer.

Producer



- log in EDMS.
- open the Inbox.
- read work description
- produce accordingly cavity part
- fill out the template of protocol.
- submit the protocol to release - life-cycle.

DESY



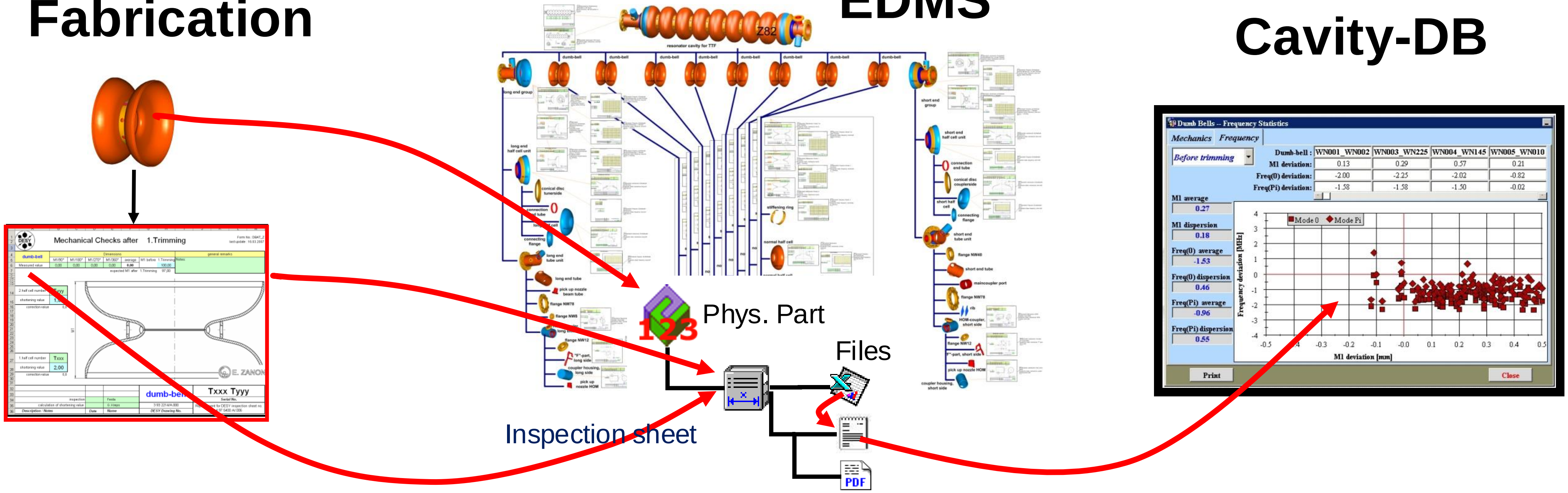
- check and release the protocol.
- message to Producer (in EDMS).

Fabrication, EDMS & Cavity Data Bank

Fabrication

EDMS

Cavity-DB



Inspection sheets for quality management

Fabrication structure. Subassembly parts related. Procedure related

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)

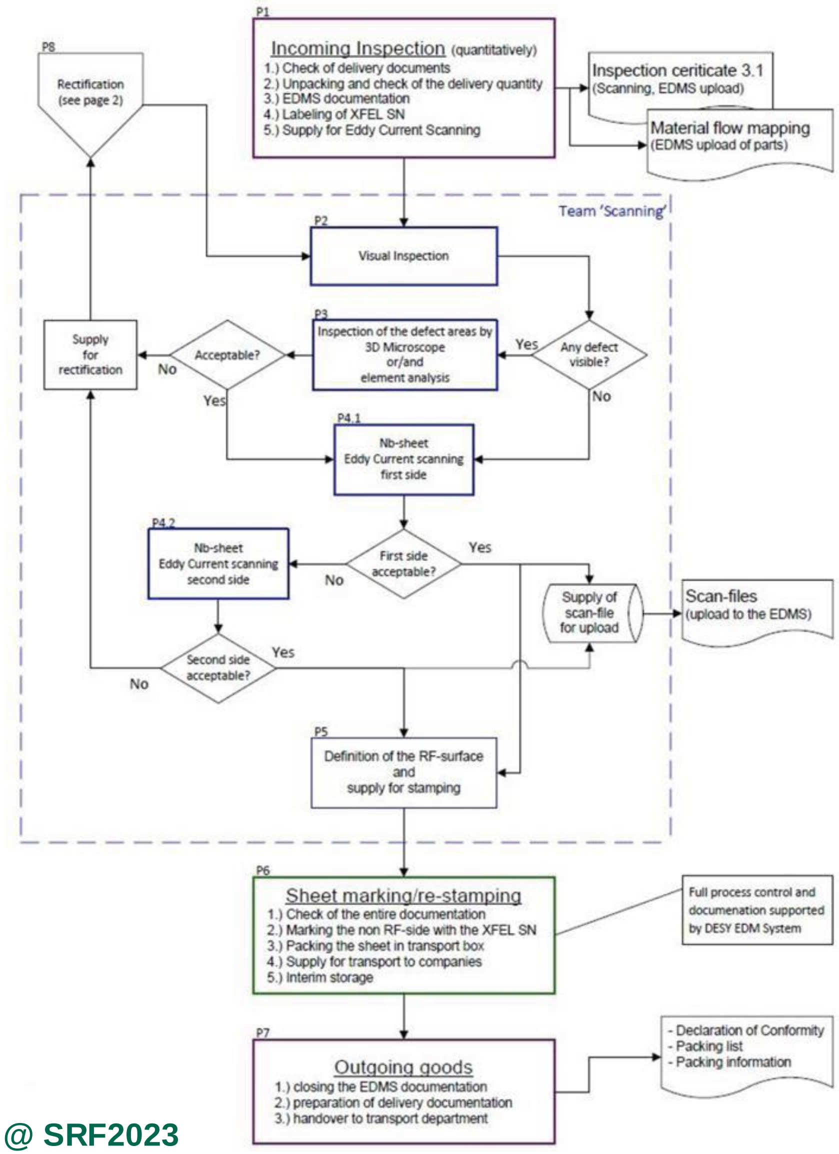
QC of Niobium Shsets via EDMS

More than 15000 niobium sheets for cell fabrication ordered and delivered to DESY

A fully EDMS controlled process was developed by DESY, with a QC team, in order to fulfill all requirements for PED, QA and logistics

The process is connected to the EDMS at three work team stations:

- Team **“Labelling”** for incoming inspection, certificate examination and sheet labelling
- Team **“Scanning”** for visual examination and eddy current scanning
- Team **“Stamping”** for permanent marking of the sheets and preparation for its supply to the cavity producer.



From MOP035 @ SRF2023

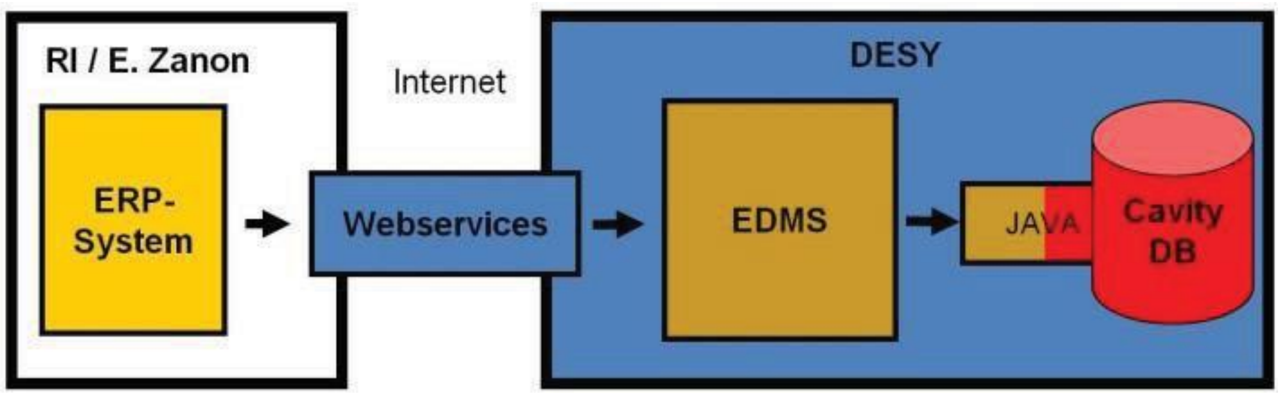
Cavity Fabrication and EDMS

XFEL cavities are part of a pressure equipment according to **PED regulations**.

Main requirement is to ensure **full traceability** of the finished cavity through the whole fabrication history back to the raw material and its inspection certificates.

Because of the non conventional production, it was decided to perform an **external QC** procedure **in addition to the QA at the manufacturer**. Namely:

- fast flow of QM documents to DESY.
- structured and well organized repository of documents.
- an acceptance procedure for checking the quality and releasing the cavity for treatment processes after fabrication.



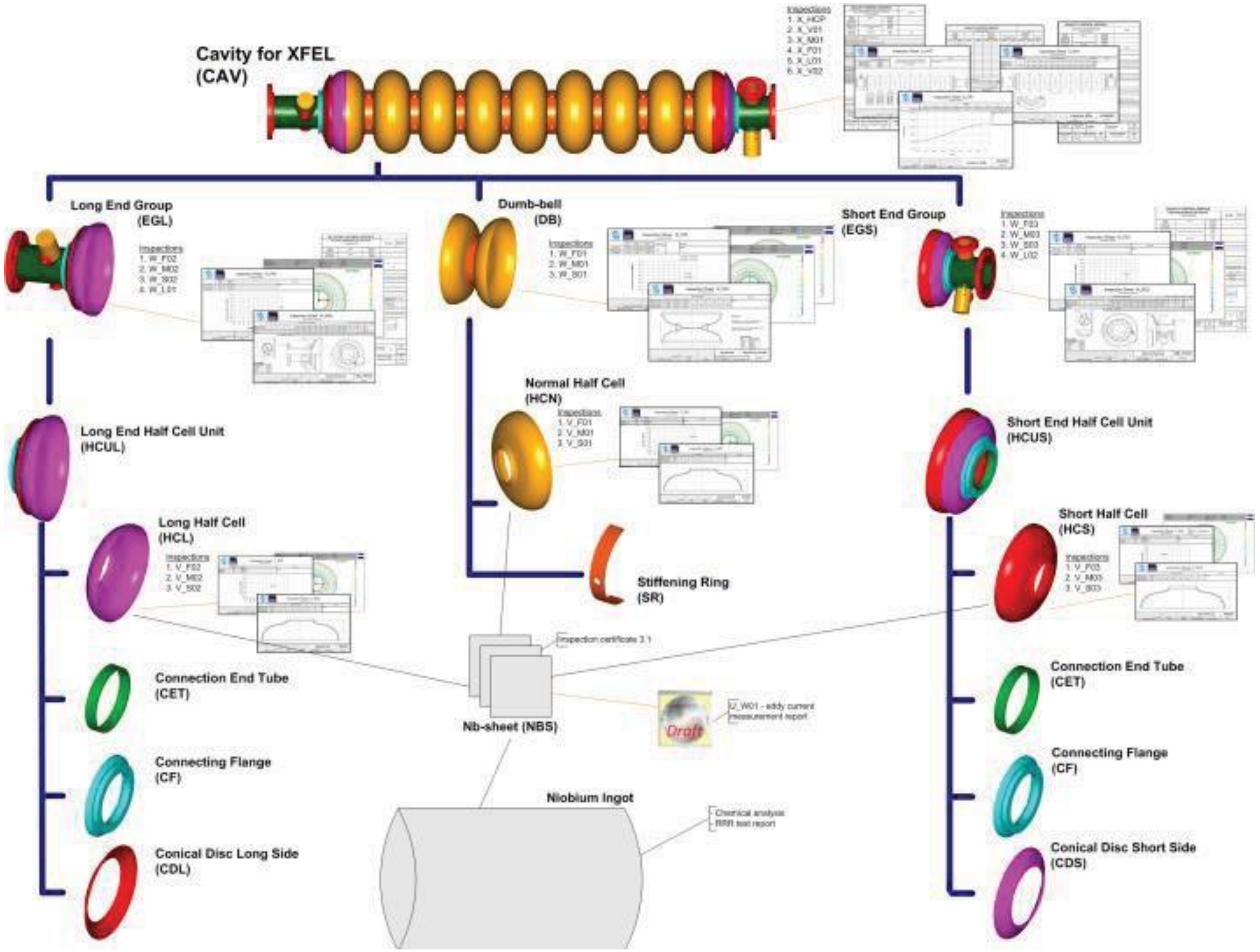
From MOP035 @ SRF2023

Cavity Document Structure in the EDMS

The product breakdown structure (PBS) of the cavity for XFEL is the representation for each part of the cavity and the cavity itself

With the receipt of QM all the cavity documents are generated by the supplier and put in the EDMS:

- physical parts are created, and the complete structure of each cavity is built step by step following the fabrication progress
- QM documents are created and directly linked to the physical part.



From MOP035 @ SRF2023

Some details: Dumb-bell fabrication steps

1) Mechanical and Visual Checks,
2. Check of frequency,
3. Calculation of trimming,
4. “1.trimming“
5. Mechanical and Visual Checks,
6. Check of frequency,
7. **Decision** :
   - “accepted to use for a cavity“ or
   - “trimming necessary“ or

➔ **If decision „Accepted to use for a cavity**

7. Calculation of position in cavity and prognoses of cavity length and frequency after welding,

➔ **If decison “trimming necessary”**

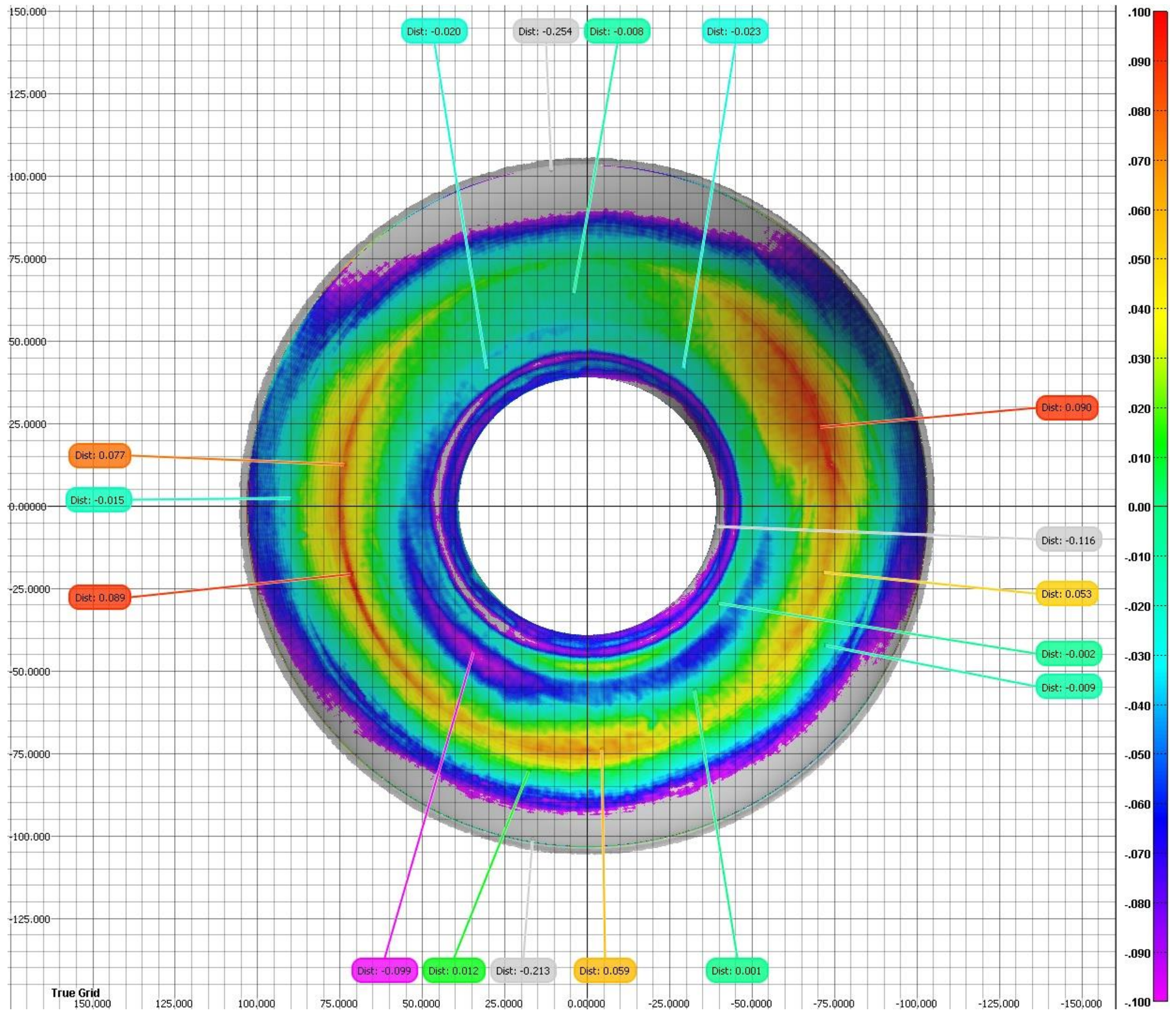
8. Calculation of trimming
9. “trimming“
10. Mechanical and Visual Checks,
11. Check of frequency,
12. **Decision** :
   - “accepted to use for a cavity“ or
   - “trimming necessary“ or

➔ **If decision “Accepted to use for a cavity”**

➔ **If decision “trimming necessary”**

13. Calculation of trimming,
14. “trimming“
15. Mechanical and Visual Checks,
16. Check of frequency
17. **Decision** :
   - “accepted to use for a cavity“
   - “Bad quality, don’t use this dumb-bell for a cavity“

➔ **If Decision „Accepted to use for a cavity**

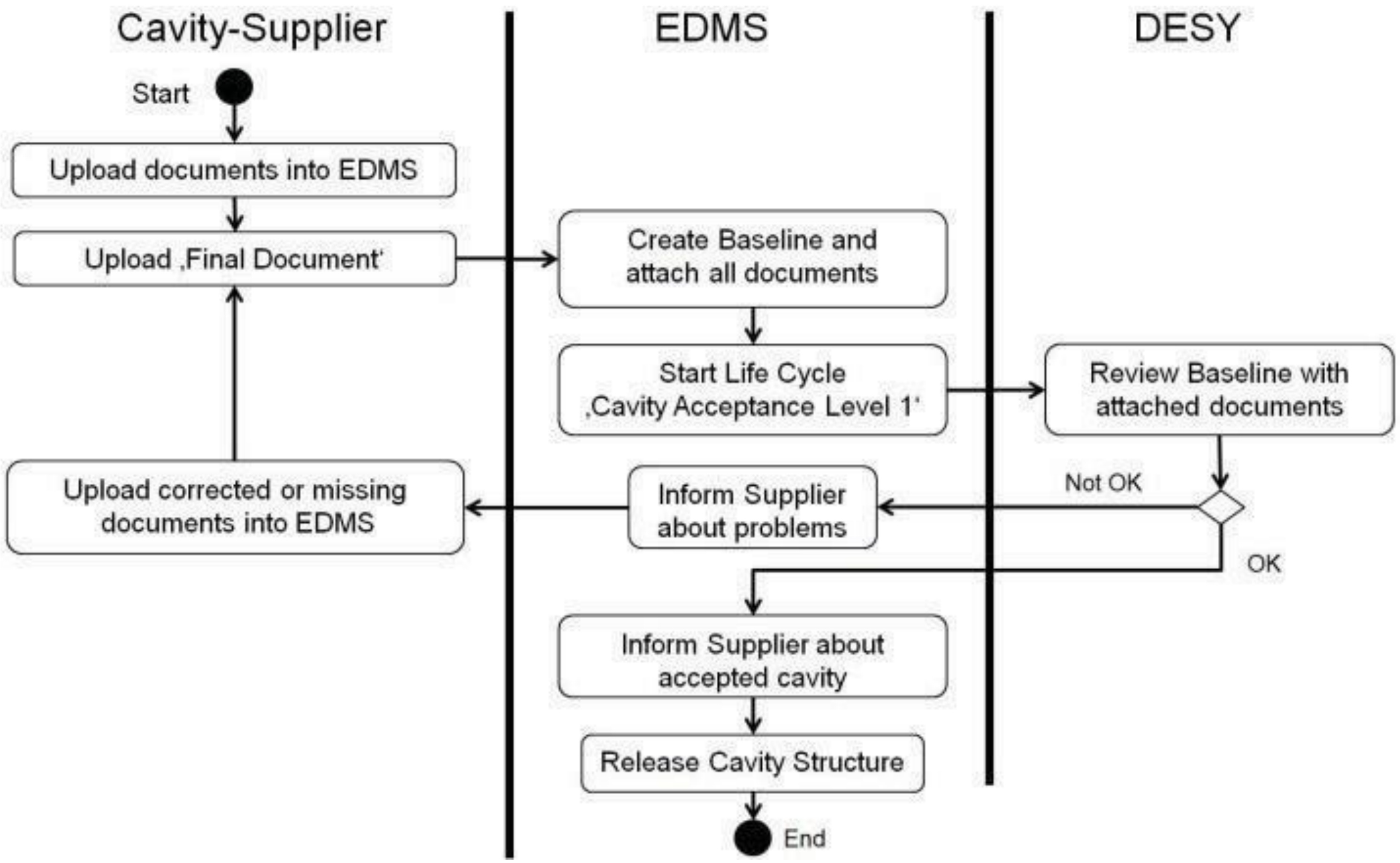


Acceptance Procedure before Treatments

Once the cavity fabrication is completed, a contractual hold point is reached, and the customer performs a **release procedure for acceptance**.

The procedure is completely supported and processed by **using the EDMS**.

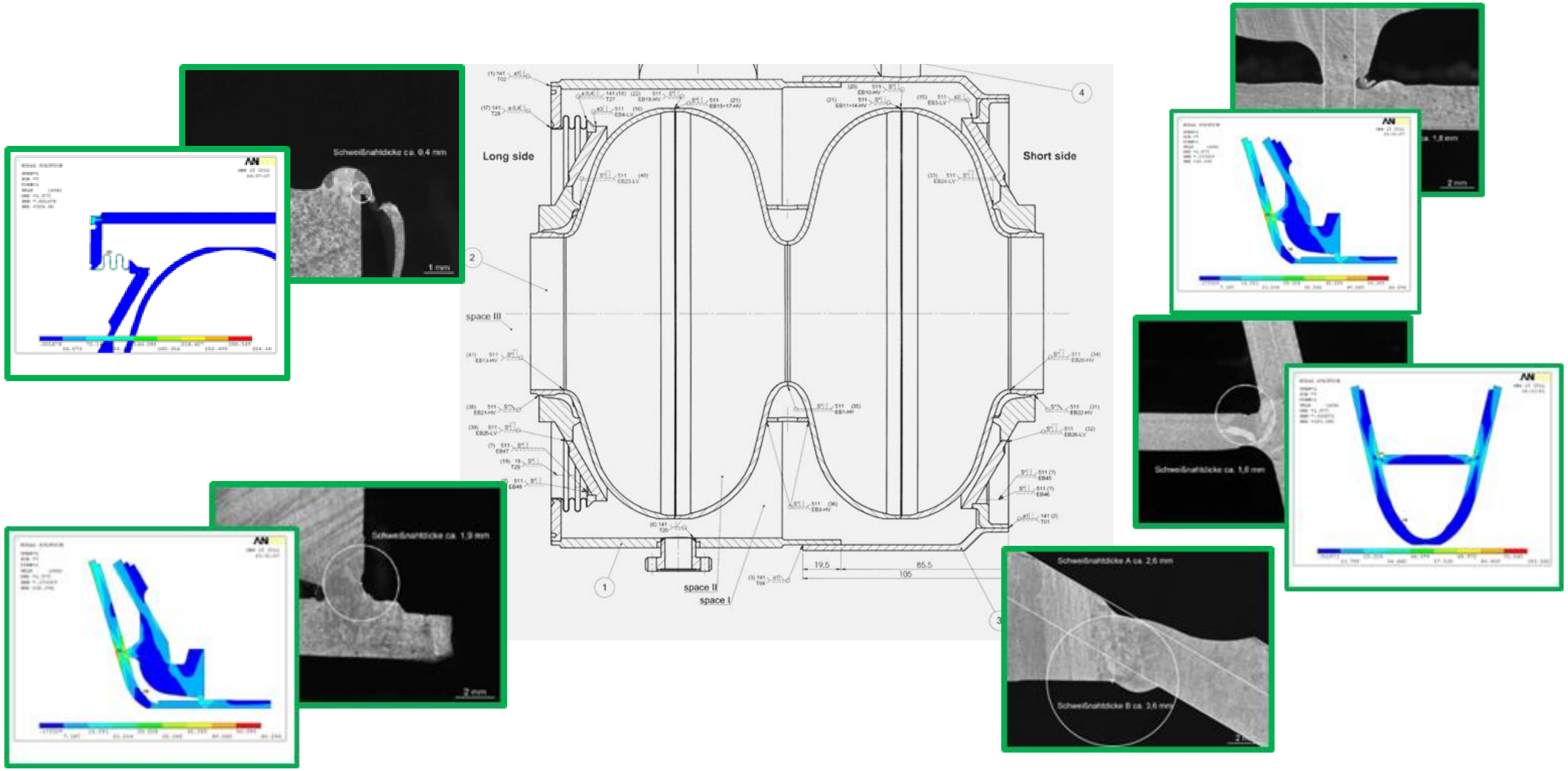
- Based on QM documentation the producer ask the **final document**
- **All documents** for the QC are already collected **in the EDMS**
- The inspection report Is delivered to the supplier via EDMS



From MOP035 @ SRF2023

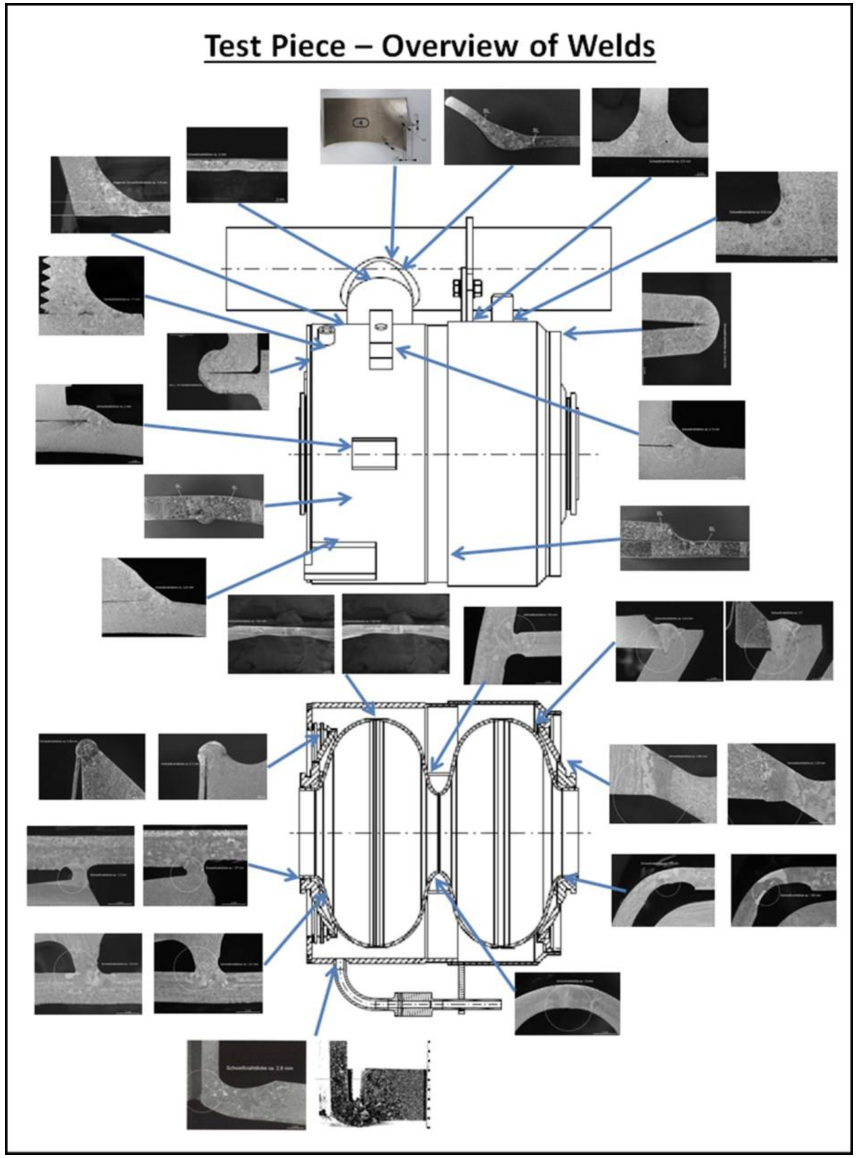
PED Activities and TUEV Control

Test piece (TP) is composed by 2 cell with helium vessel, without end groups, representing all pressure bearing parts and welds. It is built using exactly the same manufacturing methods and welding parameters that will be later used for production. **Two EBW machines/company. Then two test pieces had been built.**



Test Piece for PED Destructive Test

- 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

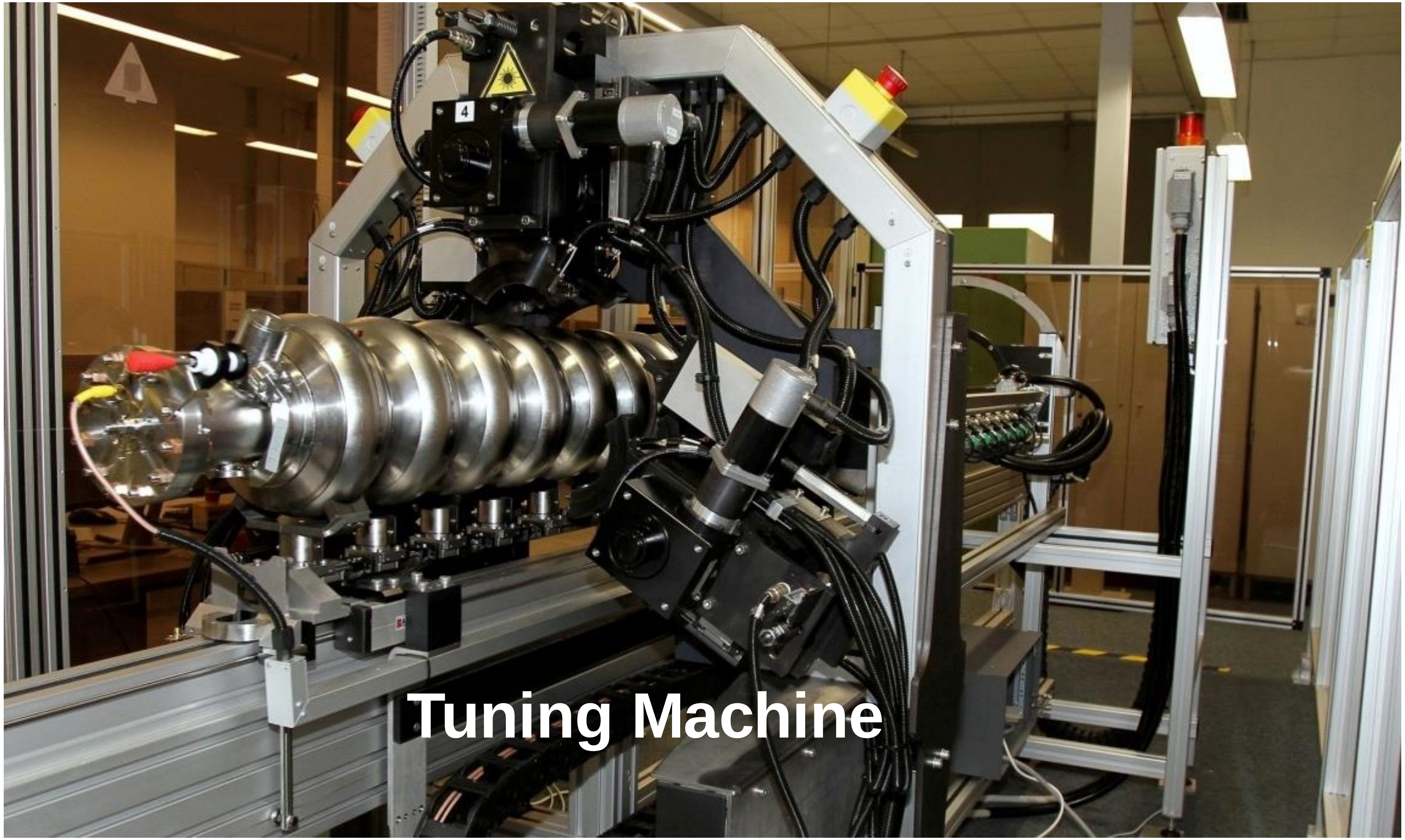


From MOP048 @ SRF2023

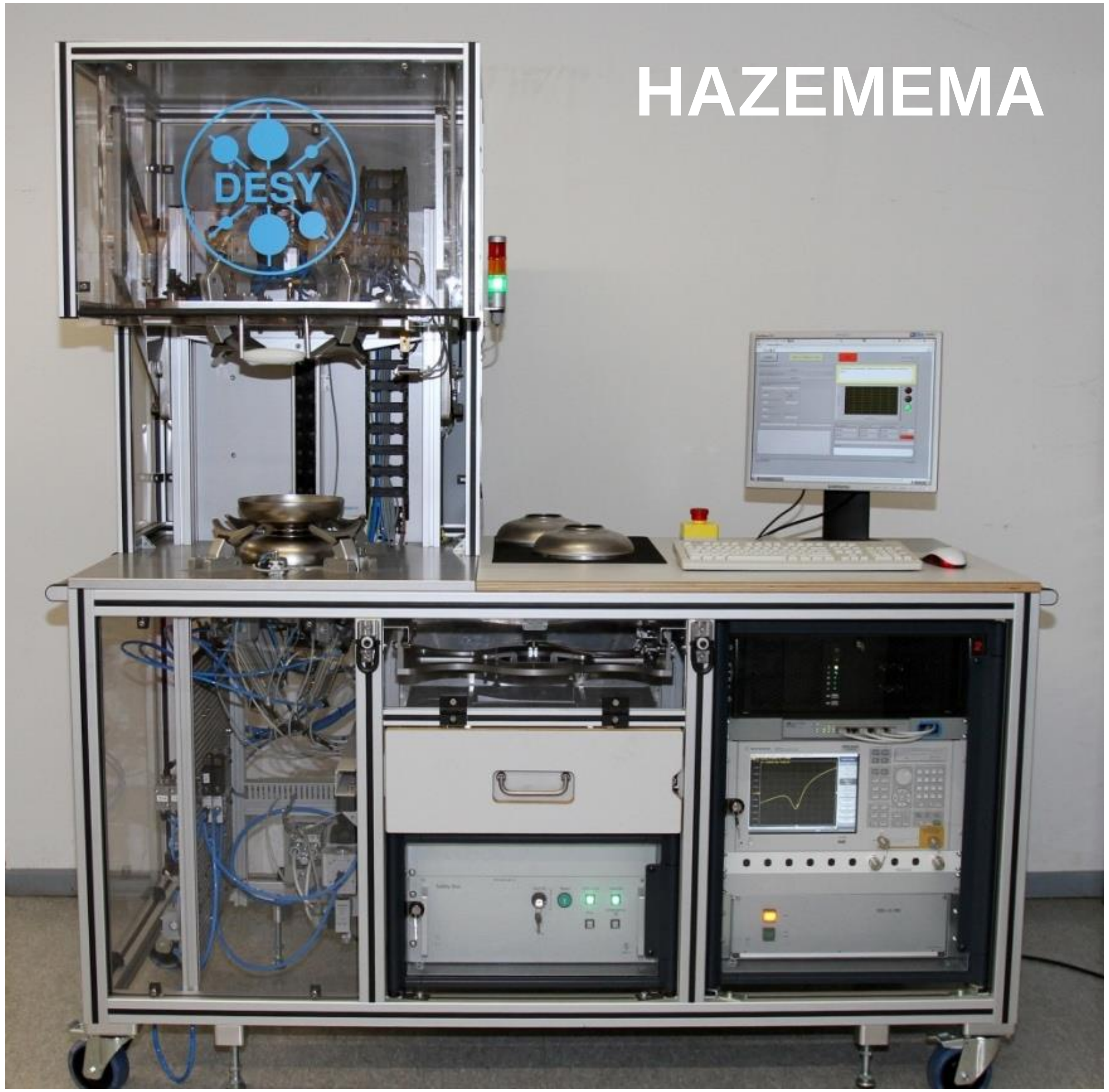
Major Infrastructures at EZ & RI

- 2 **EBW** (Electron Beam Welding) plants, equipped with cryo-pumps
- ISO 7 and ISO 4 **Clean Rooms** with cleaning and rinsing facility
- **UPW** (Ultra Pure Water - 18 MΩ·cm) production system (>3000 l/h)
- **HPR** (High Pressure Rinsing – 100 bar) apparatus
- **800 °C** and **120 °C ovens** operating with High Vacuum.
- Cavity Tuning Machine, **CTM**, provided by DESY
- **RF tests** set up (for **H**alf**C**ell, **D**umb**B**ells and **E**nd**G**roups), provided by DESY
- **US** (Ultra Sonic) cleaning baths
- Complete **chemical processing** plants (**EP**, **BCP** or both)
- Cavity internal **visual inspection** systems

Equipment supplied by DESY to RI & EZ



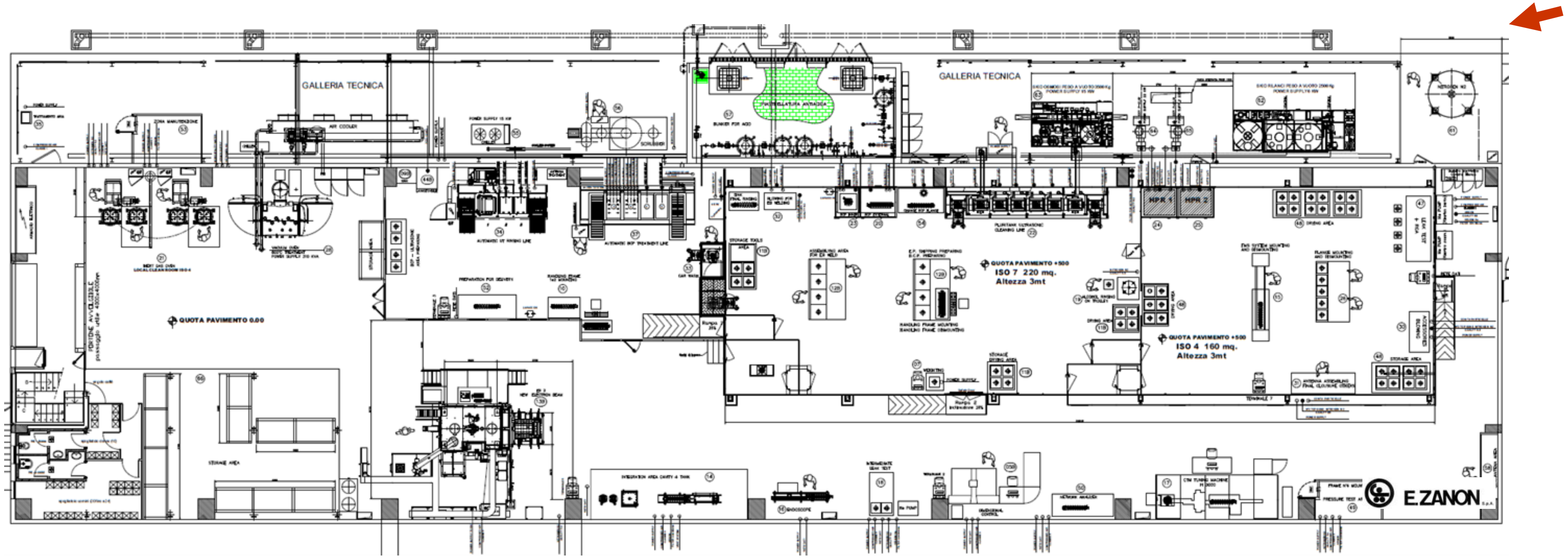
Equipment supplied by DESY to RI & EZ



Equipment for RF measurement of half cells, dumb bells and end groups called HAZEMEMA

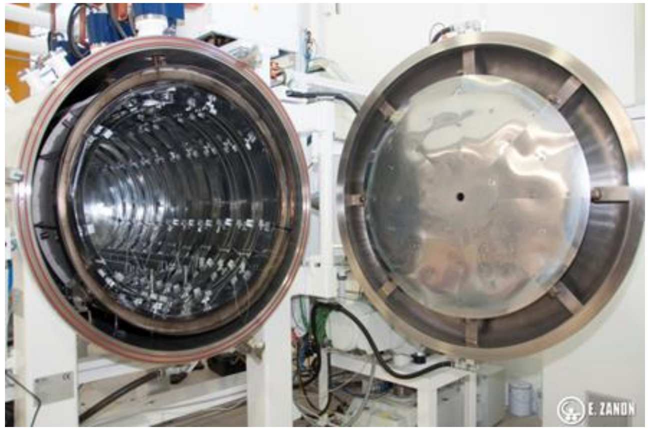
All equipments Provided with CE certification according EU regulations

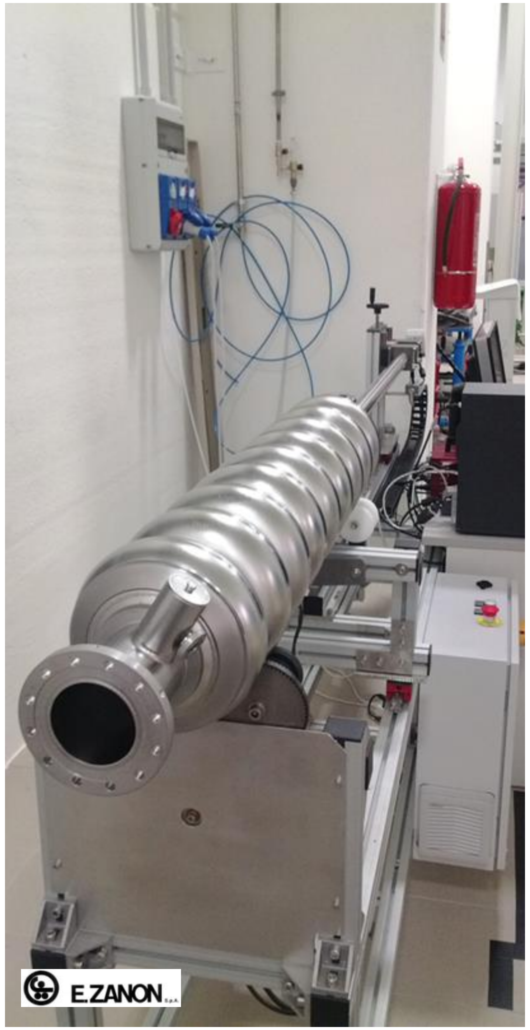
Cavity Infrastructure Layout at EZ



Building layout: clean rooms ISO10, ISO7, ISO4, US and BCP treatment, 120°C baking, 800°C oven, EBW, tuning machine etc.

Examples of EZ Infrastructure *(courtesy of EZ)*





New EBW machine

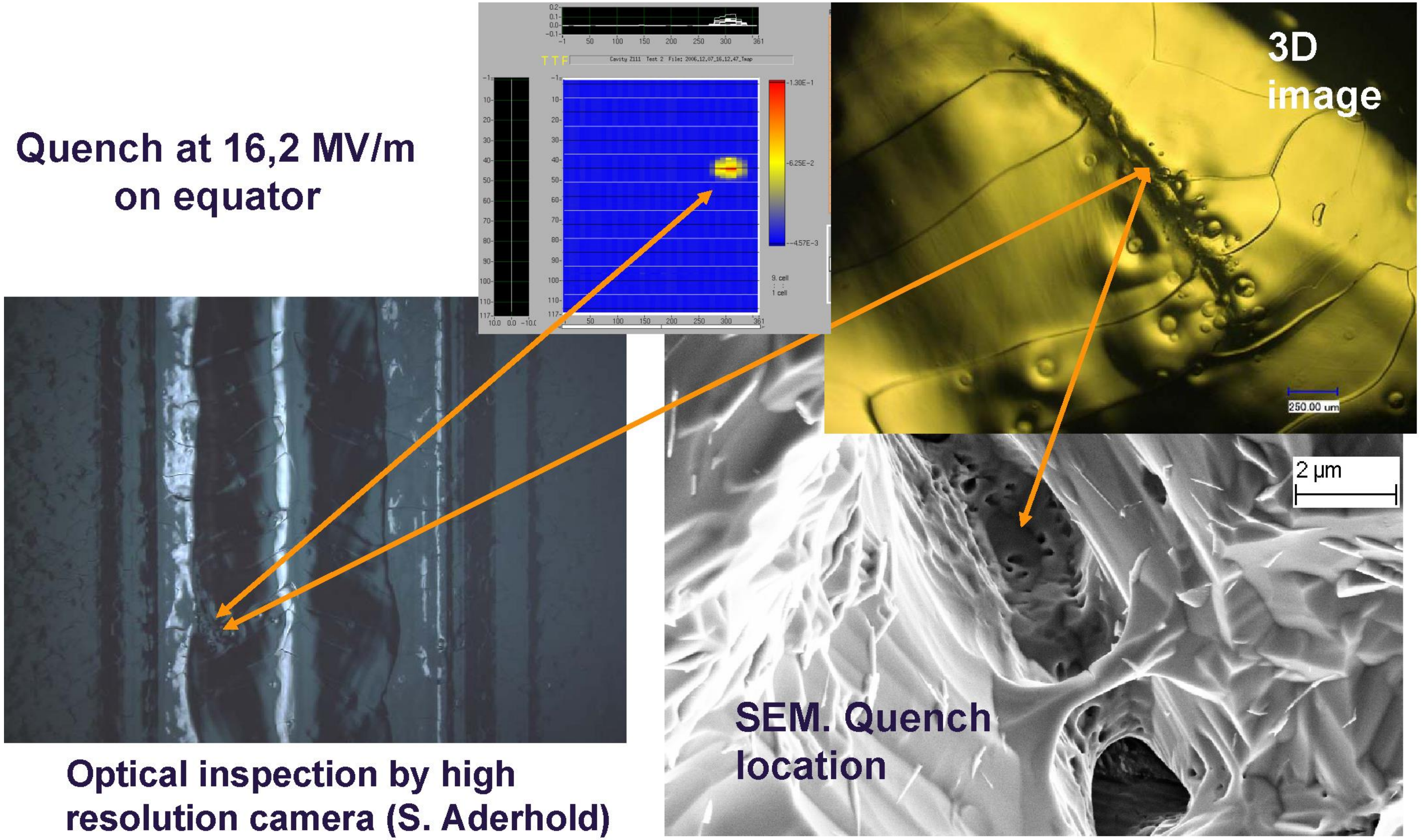
New oven for 800°C treatment

Borescope for optical inspection

Deep Defect Analysis Capability @ Labs - 1

Topographical defects at the welding seams

Quench at 16,2 MV/m
on equator

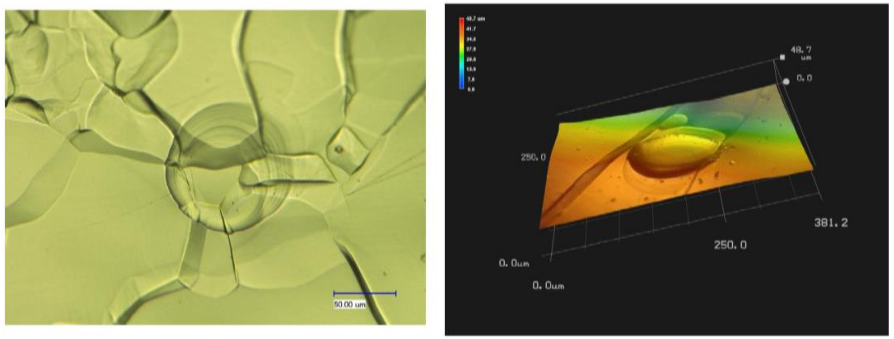


Optical inspection by high
resolution camera (S. Aderhold)

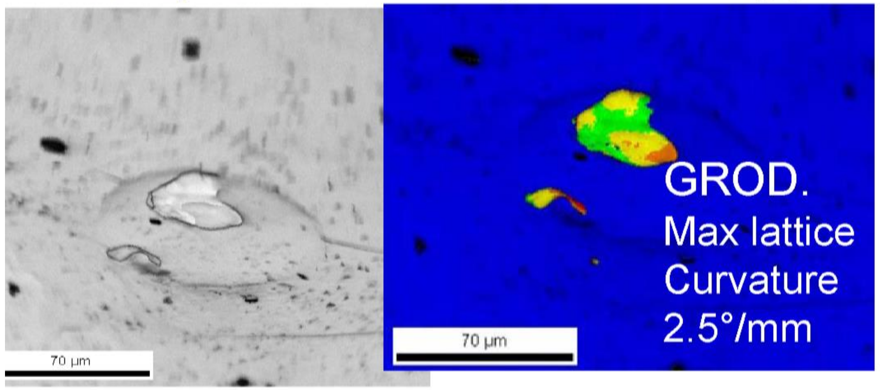
SEM. Quench
location

Deep Defect Analysis Capability @ Labs - 2

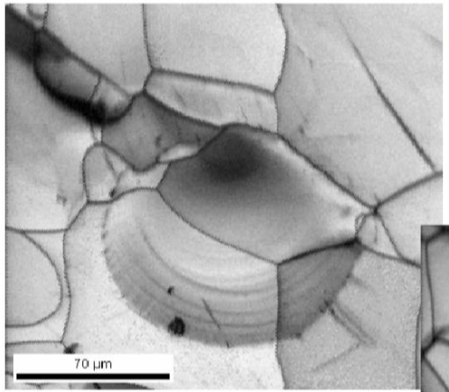
Etching pits: EBSD with strain maps via grain reference orientation deviation (GROD)



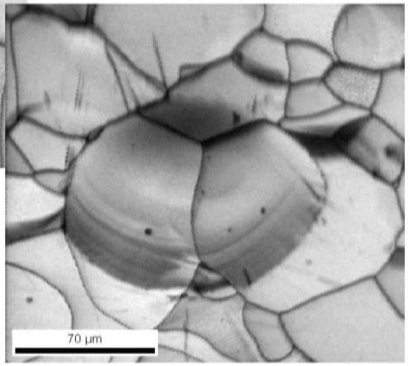
Cavity Z111: 3D Images of etching pits



Z111: Pit in heat affected zone HAZ of weld, enclosing region of strain, all within one grain (R. Croocs)



Pits away from the weld, with grain boundary triple junctions

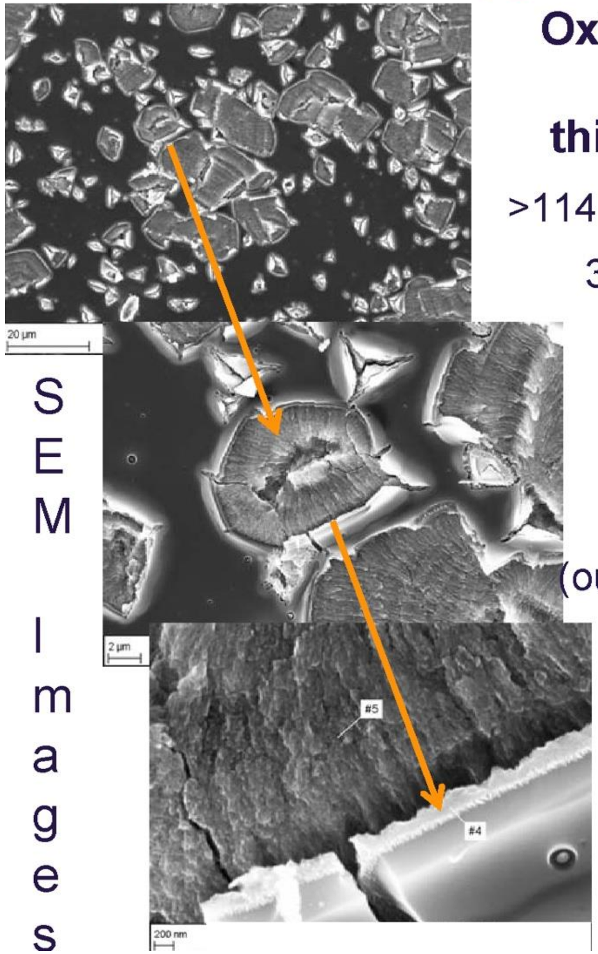


- **Pits don't seem to be related to grain orientation**
- **Pits in weld HAZ are near areas of remaining cold work (high dislocation density)**
- **Pits away from the weld, in fine grain area tend to be centered on grain boundary triple junctions**

Deep Defect Analysis Capability @ Labs - 3

Dangerous surface defects generated by bad HPR (Hihg Pressure Water rinsing)

Auger spectrums indicates very high presence of oxygen.



S E M Images

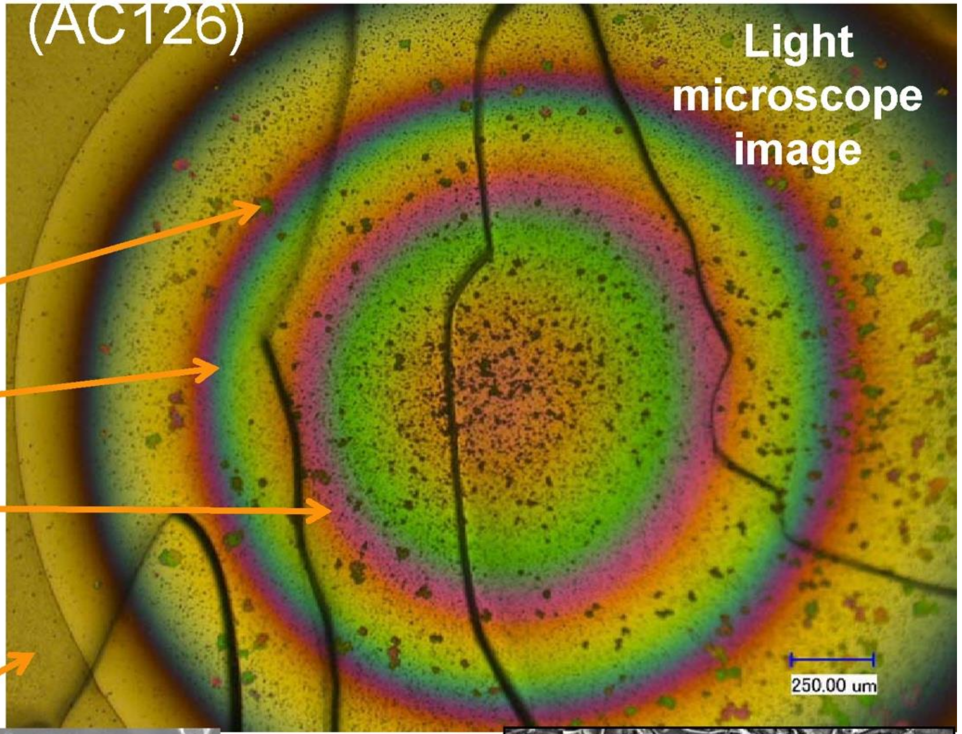
Oxide layer with thickness:

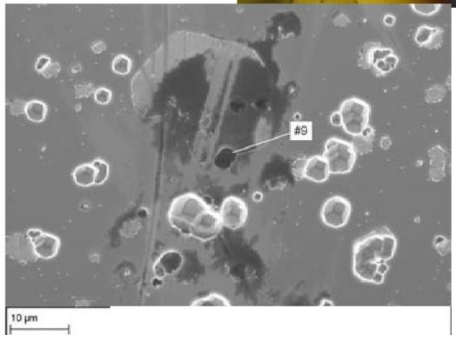
>114 nm (spot)

32.5 nm (blue)

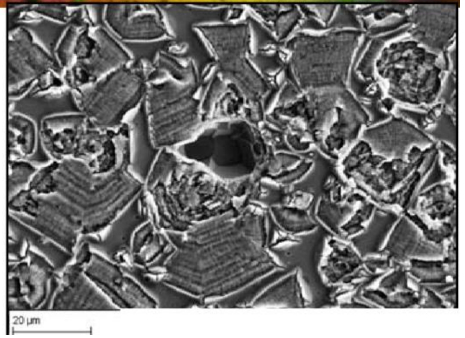
195 nm (red)

13 nm (outside rings)





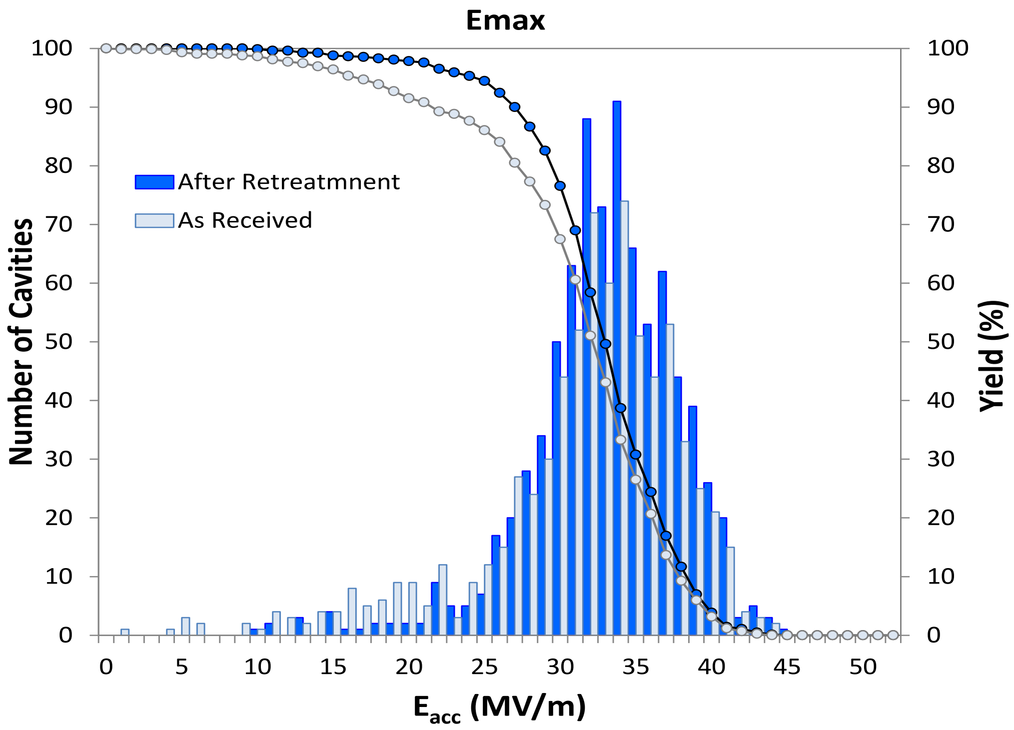
SEM image of the black spots EDAX indicates carbon

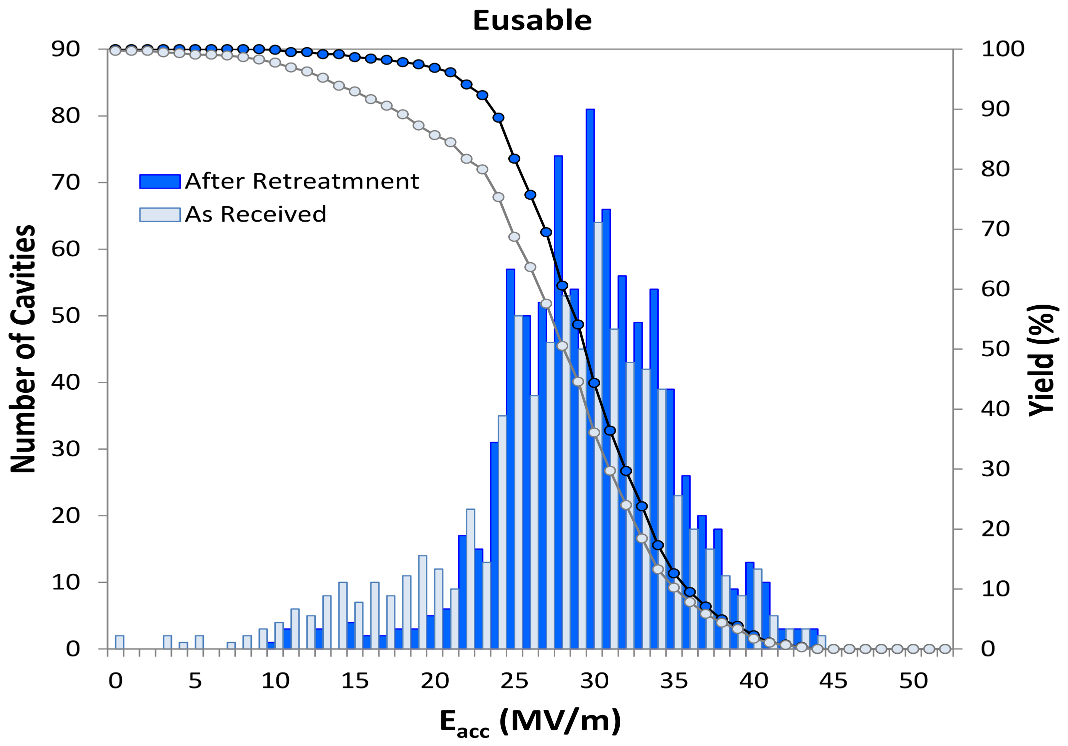


Contents

Final performance: Eacc

Total after 313 retreatments performed on 237 of the 831 cavities





Before:

E max 31.4 ± 6.8 [MV/m]

(RI): E max 33.0 ± 6.5 [MV/m])

(EZ): E max 29.8 ± 6.6 [MV/m])

After:

E max 33.0 ± 4.8 [MV/m]

(RI): E max 34.7 ± 4.4 [MV/m])

(EZ): E max 31.5 ± 4.9 [MV/m])

Before:

E usable 27.7 ± 7.2 [MV/m]

(RI): E usable 29.0 ± 7.3 [MV/m])

(EZ): E usable 26.4 ± 6.6 [MV/m])

After:

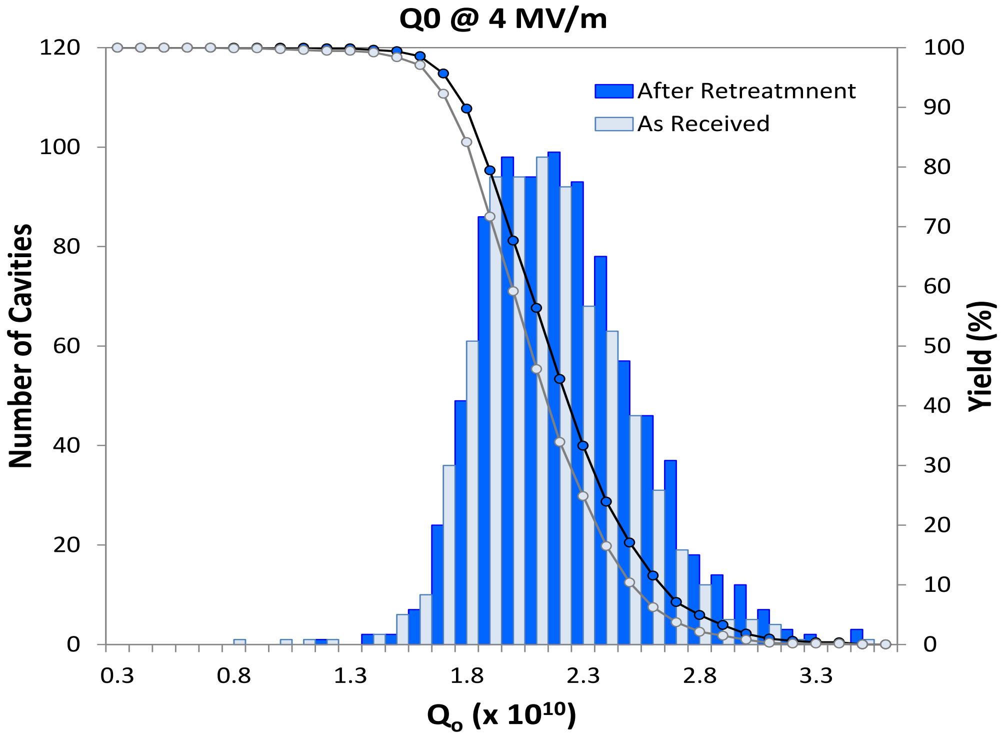
E usable 29.8 ± 5.1 [MV/m]

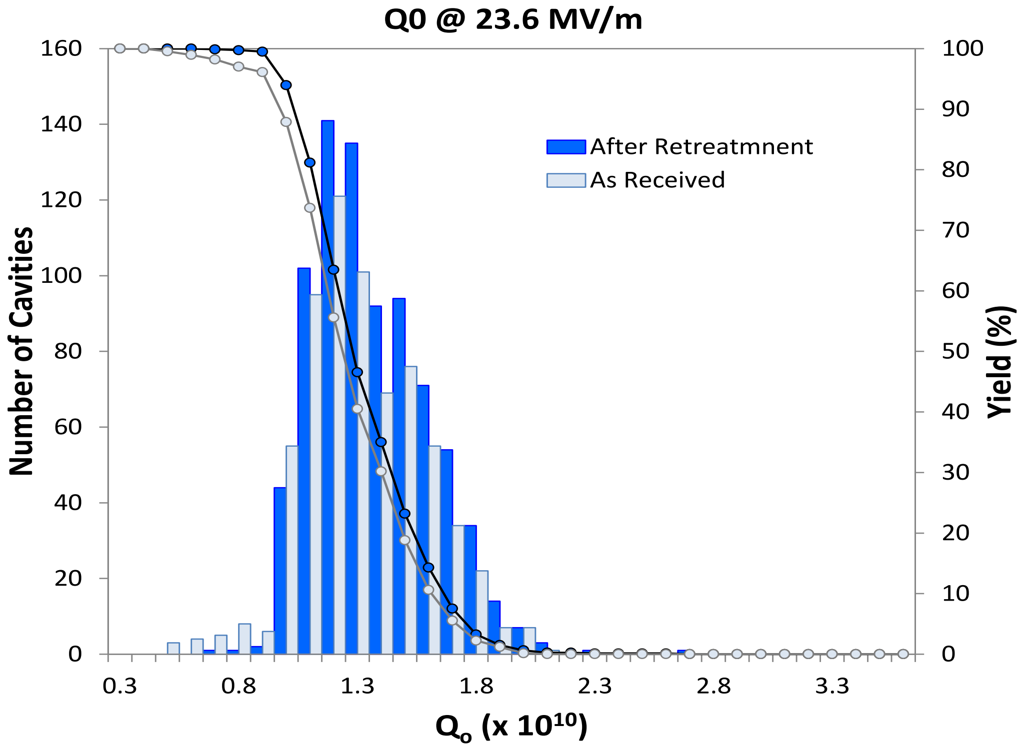
(RI): E usable 31.2 ± 5.2 [MV/m])

(EZ): E usable 28.6 ± 4.8 [MV/m])

Final performance: Q_0

Total after 313 retreatments performed on 237 of the 831 cavities





Before :

Q0 @ 4 MV/m 2.15 ± 0.32 [$1 \cdot 10^{10}$]

(RI): Q0 @ 4 MV/m 2.11 ± 0.32 [$1 \cdot 10^{10}$])

(EZ): Q0 @ 4 MV/m 2.18 ± 0.32 [$1 \cdot 10^{10}$])

After:

Q0 @ 4 MV/m 2.23 ± 0.34 [$1 \cdot 10^{10}$]

(RI): Q0 @ 4 MV/m 2.21 ± 0.34 [$1 \cdot 10^{10}$])

(EZ): Q0 @ 4 MV/m 2.26 ± 0.33 [$1 \cdot 10^{10}$])

Before:

Q0 @ 23.6 MV/m 1.31 ± 0.26 [$1 \cdot 10^{10}$]

(RI): Q0 @ 23.6 MV/m 1.29 ± 0.24 [$1 \cdot 10^{10}$])

(EZ): Q0 @ 23.6 MV/m 1.34 ± 0.28 [$1 \cdot 10^{10}$])

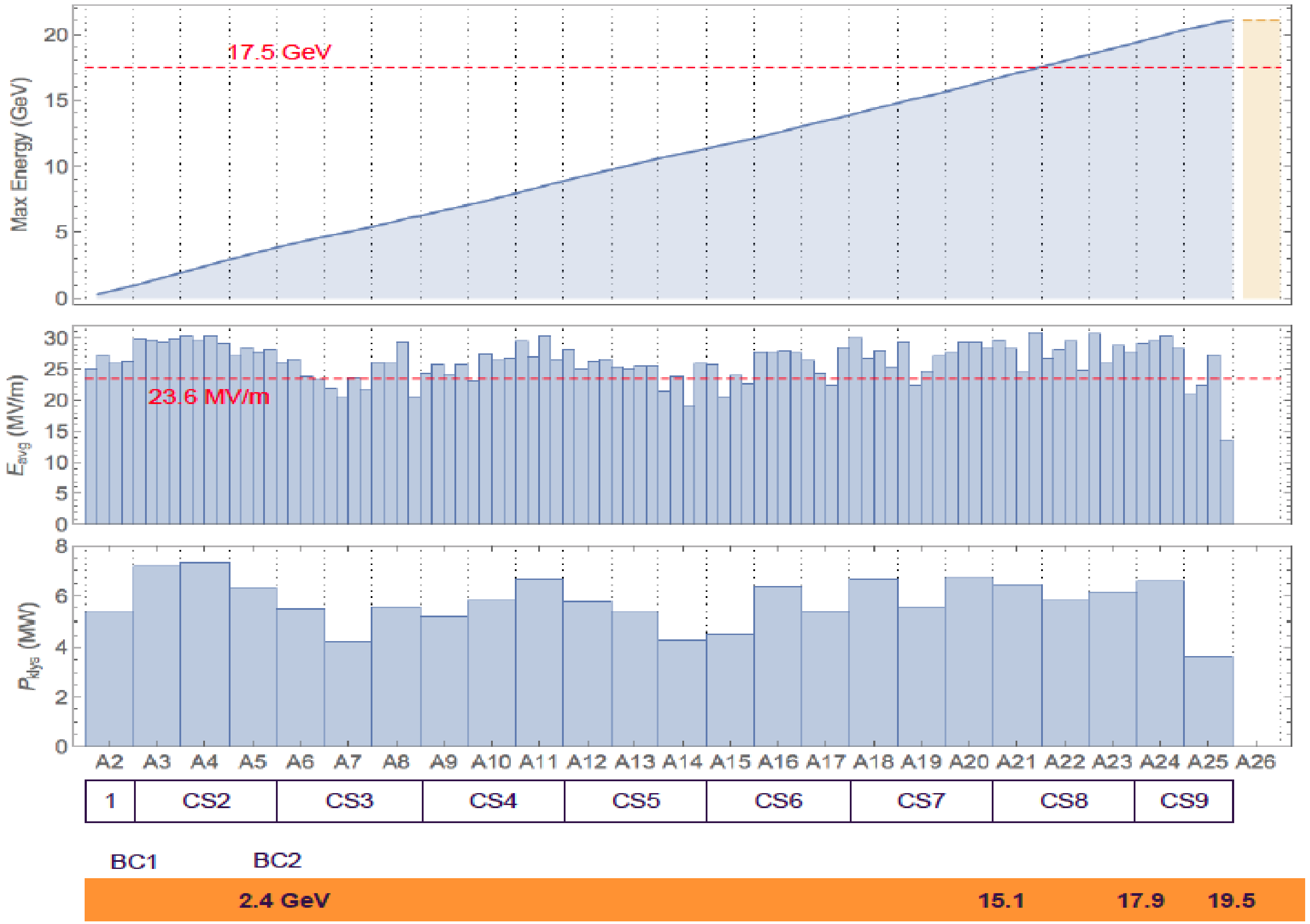
After:

Q0 @ 23.6 MV/m 1.37 ± 0.25 [$1 \cdot 10^{10}$]

(RI): Q0 @ 23.6 MV/m 1.34 ± 0.22 [$1 \cdot 10^{10}$])

(EZ): Q0 @ 23.6 MV/m 1.41 ± 0.26 [$1 \cdot 10^{10}$])

E-XFEL: Usable Installed Voltage



Lessons Learned from EuXFEL production

- **Industry**, once trained, **did as well as the labs behind**.
- **Results obtained** were very **close to the best available** 13 years before, at the time of the ITRP, **but much more stable**
- **Results depend on**: the technology applied + **QA/QC & EDMS**
- The complete cycle in **industry improves the yield**
- A **second treatment was crucial** to improve the yield
- HPR was usually sufficient, flash BCP required in few cases, EP excluded becaude of the He tank
- The possibility of **a second treatment improves the yield**, both for high field and field emission onset

A Few General Concepts to be Followed

- **The success of a new large research infrastructure** must have a number of obvious but crucial characteristics:
  - **Respect and deliver the design specifications**
  - **Service and maintenece** time limited and **precisely scheduled**
  - **Availability very close to 100%**
- **An accelerator based user facility asks the accelerator** to be designed and built fullfilling all the requirements specified above. Namely:
  - **All components** must be sufficiently **overdesigned** to garantee a **suffuciently long MTBF** (Mean Time Between Failures)
  - A **perfect balance** must be calculated **between redundancy and MTBF + MTTR** (Mean Time To Repair) to limit the number of unscheduled shutdown
  - The production of each component must follow the best practice, being **manufactured by industry stricly following the QA/QC practice**
  - An **efficient and complete EDMS system must be on place since the beginning**

Goog practices

- Use as much as possible components that are **standard** and produced by industry. Always ask and verify all the available documentation. When designing balance redundany and **MTBF**.
- Develop the new components in **dedicated infrastructures** designed and built, possibly **with industry**, to be adequate to the task. The **number and expertise** of people is crucial.
- For special components start as soon as possible the selection of **possible manufacturers** and include them **in the R&D process**.
- **Select an EDMS system** and use it extensively from the beginnig
- **Train personal** to the **QA/QC** paractices and to the use of **EDMS**

Thank you for your attention