Innovative Accelerator Technologies

Qualification of a company by a facility

LEAPS INNOVATION

LEAPS-INNOV Annual Meeting 2022

Casa Convalescència, Barcelona, Spain

Hans Weise
DESY, May 4th, 2022

HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES

European XFEL

DESY.

Facilities and Technology Transfer

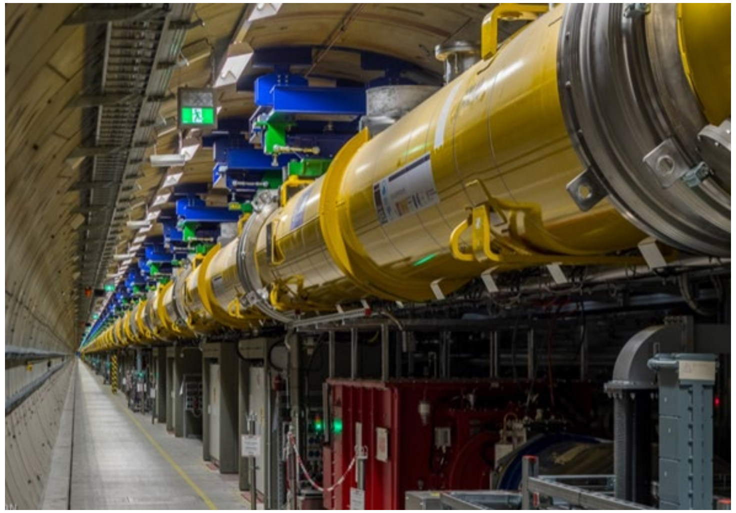
Qualification of partners and industry

- **Facilities** are often located at and thus connected with smaller or larger research laboratories.

- The particle accelerator community starts projects based on
  - the scientific needs
  - the innovative ideas
  - the collaborating partners
  - the available technologies
  - the existing infrastructure
  - the funding

- The real work usually
  - starts with an **R&D phase**, continues with **prototyping**,
  - requires **qualification of partners and industry**,
  - goes on with **pre-series** production which is followed by sometimes **large series**,
  - and if construction is finished, the commissioning ends in **facility operation**.

The success finally calls for **technology transfer** to other projects and/or companies.



Facilities qualify through the people and needs

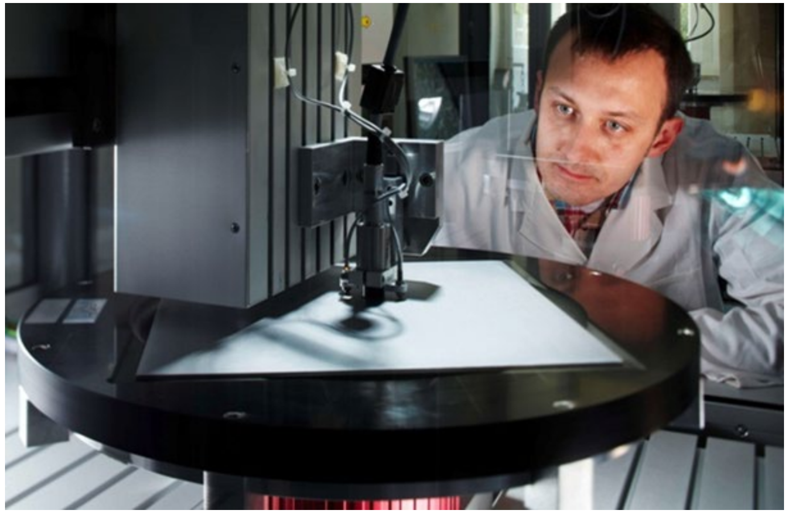
Cutting-edge technogy requires specialized companies

- **Modern accelerators** are often based on **cutting-edge technology**. Due to high cost we see the tendency of **operating the facilities at the limit or with highest reliability**.

  In consequence,

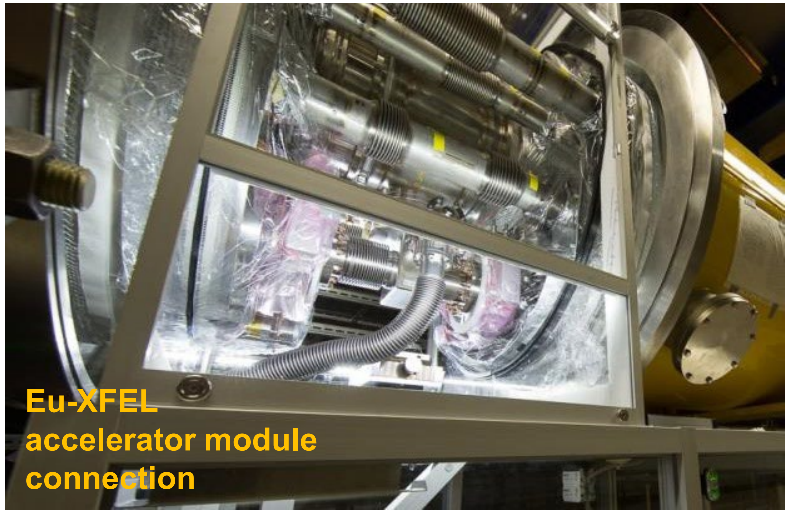
  - **specialized companies** need to **learn the technology** from research laboratories; they either **take over** or **become close partner**
  - the **number of sources** remains often **very low**, sometimes we live with one or two qualified vendors only
  - we are used to **work with spin-off companies** or see well educated and trained **young researchers and engineers** first in the **research lab,** and later at the **company** (usually beneficial for all sides)

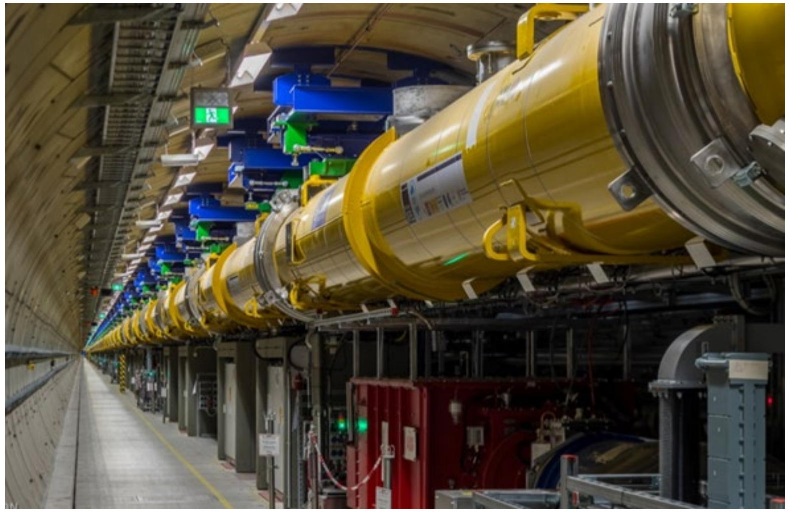
  Facilities qualify companies through their people and needs.



Innovative Accelerator Technologies

Particle clean vacuum and superconducting magnets



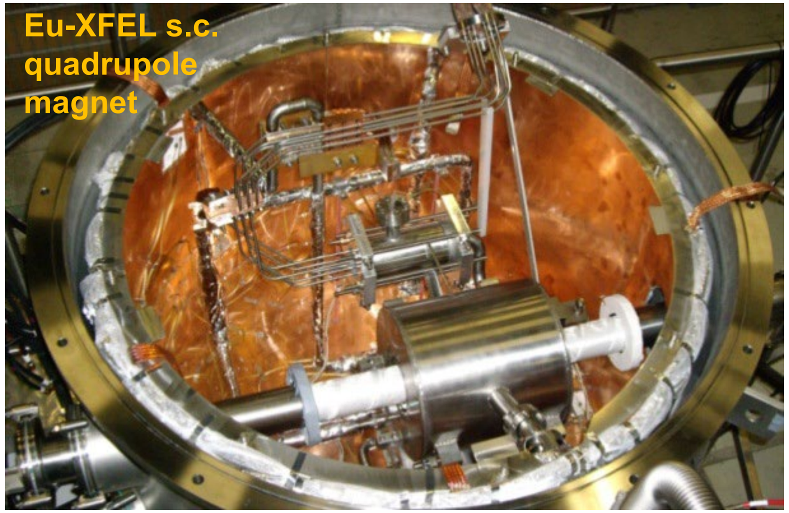


Particle-clean vacuum is indispensable for the success of modern accelerator technology.

- This holds for all beam line sections next to SRF cavities and modules. Including beam diagnostics. And becomes more and more standard also for normal-conducting structures.

Superconducting magnets can be small units or become very large and can have extremely high fields.

- The European XFEL uses a series of approx. 100 magnets. Other FELs, currently built worldwide, are comparable.
- CERN and FAIR are using and still developing (with partners) large high field superconducting magnets.

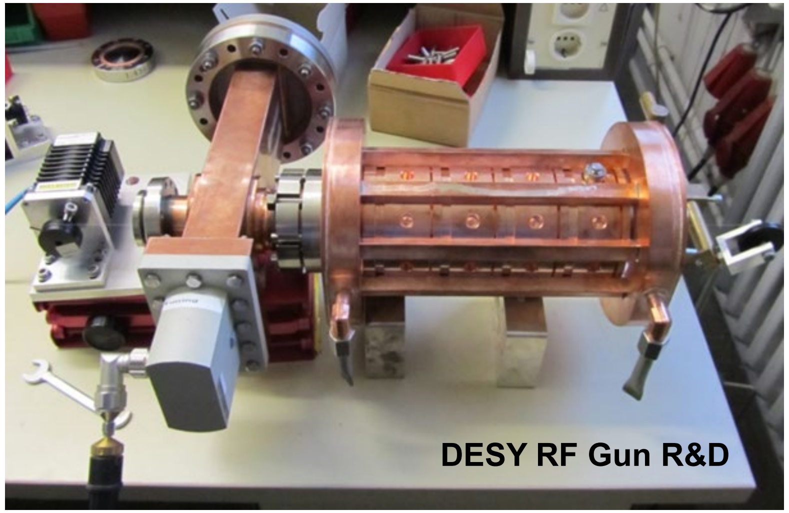


Innovative Accelerator Technologies

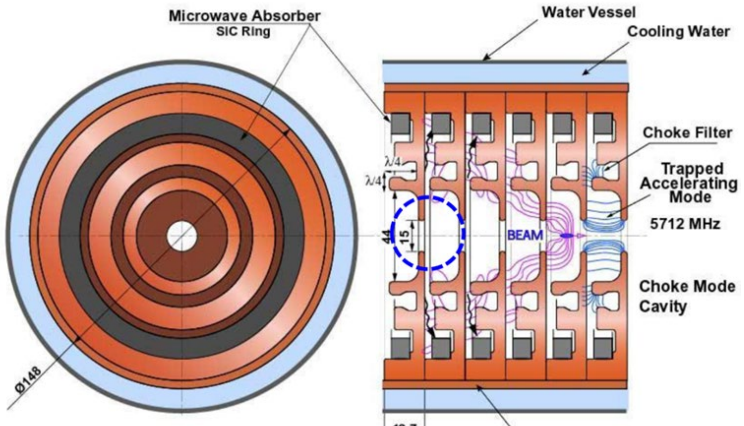
Normal conducting magnets and accelerator sections

Normal conducting beam line magnets are produced at a number of well qualified companies.

- Most laboratories work with selected partners on a regular basis. But constraints can impact long time relations, be it availability of material causing changes in technology, or even political constraints.



DESY RF Gun R&D

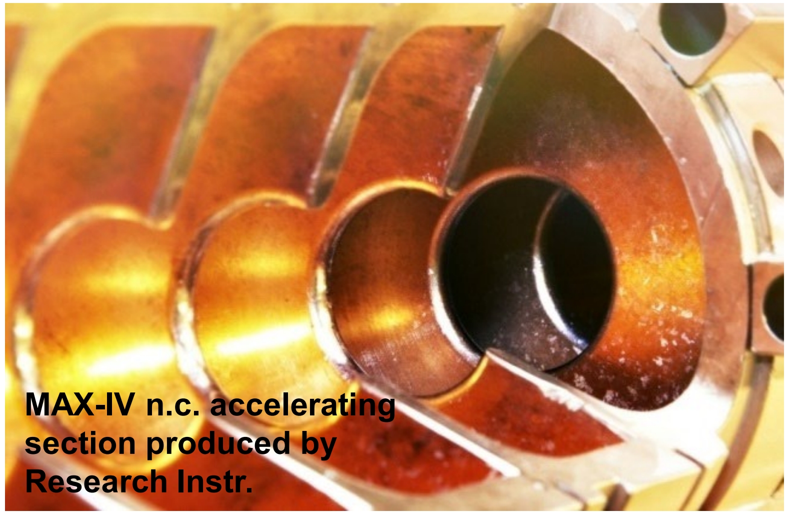


MITSUBISHI HEAVY INDUSTRIES, LTD.

$2a \sim 14$ mm for SCSS structure
$2b \sim 40$ mm
period $p \sim 16.7$ mm, $t \sim 2.5$ mm

Normal conducting accelerator sections are available from qualified companies, but some laboratories are still producing them in-house.

- Established gradients / accel. fields are covered by standard procurement.
- New developments are connected with lab-industry partnership and technology transfer.



MAX-IV n.c. accelerating section produced by Research Instr.

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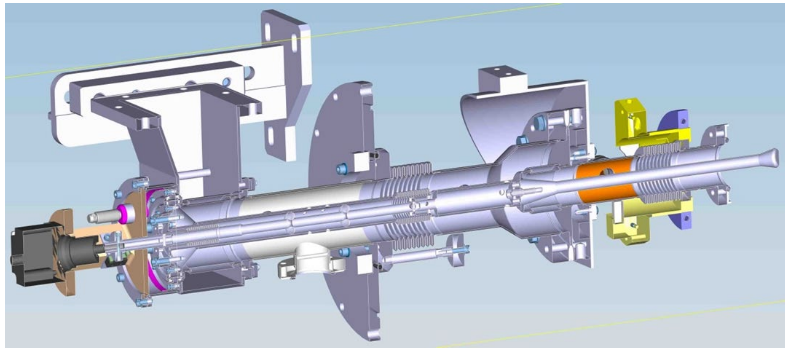
RF power sources and power couplers

Klystron development and in fact the complete RF power systems are often done in cooperation between laboratories and industry.

- With de-emphasizing radar and transmitter technology the development of klystrons became challenging. Some projects need special R&D, e.g. multi-beam klystrons at the European XFEL.

RF power couplers are critical auxiliaries. The knowledge transfer from the lab to companies is of utmost importance.

- There is the risk that technologies get lost if the time between projects becomes too long.
- RF power conditioning usually happens at the facilities or the project in-kind partner.

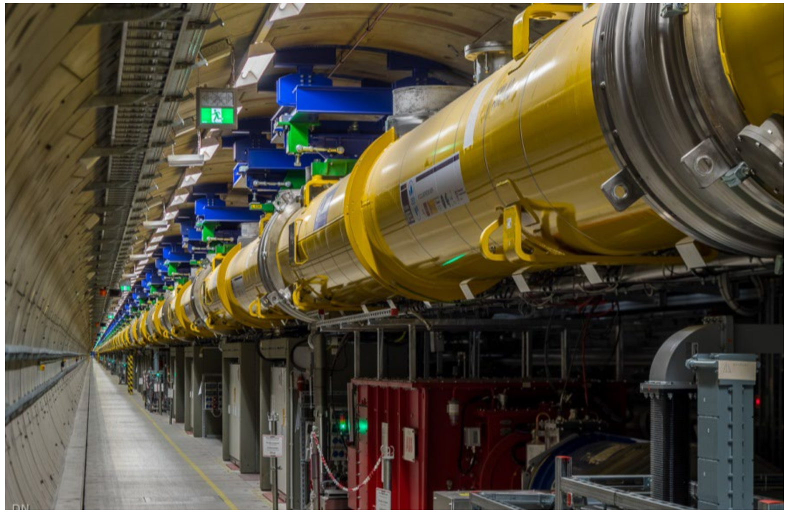


Superconducting Technology

A worldwide community with strong European partners

- Superconducting radiofrequency **(SRF) accelerators are today seen as state-of-the-art and industry is able to deliver the respective components.**
- **The European XFEL** with DESY‘s and its partners’ engagement in the design, construction and operation of the accelerator is setting the standard.
- The European XFEL is **the longest SRF linac worldwide**.
- The **fully successful technology transfer** to industry reached a point where other worldwide projects (LCLS-II, ESS, new SRF based FELs at e.g. SINAP, China) are profiting greatly from the efforts.

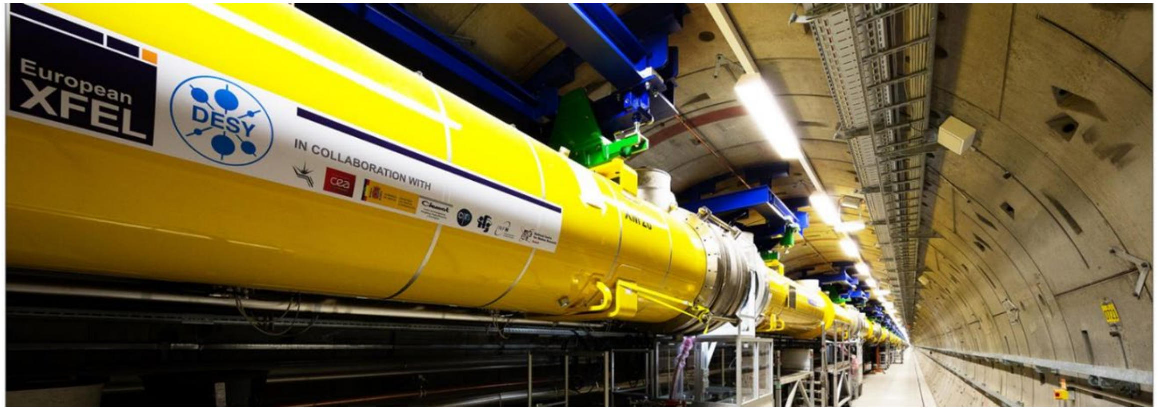
European XFEL high energy linac section



Sustainable Infrastructure

Collaborative use of European infrastructure

- In the labs highly developed infrastructure is **operated by skilled teams** to the benefit of
    - **Accelerator R&D** (in Germany: DESY and partner laboratories e.g. HZDR, HZB, HIM Mainz)
    - **European XFEL** and DESY‘s **FLASH** facility
    - Major **research facilities worldwide** (LCLS-II, ESS, new FELs)
- Access to existing distributed infrastructure guarantees
    - Sharing of **expertise**
    - Participation in new and recent **developments**
    - **Sustainability** by keeping **highly motivated teams**

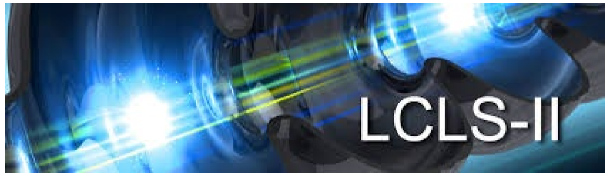


HZDR HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

HZB Helmholtz Zentrum Berlin

DESY.

HIM Helmholtz-Institut Mainz



Fermilab

Jefferson Lab Thomas Jefferson National Accelerator Facility

ess EUROPEAN SPALLATION SOURCE

INFN MILANO

cea

UPPSALA UNIVERSITET

Science & Technology Facilities Council

cnrs

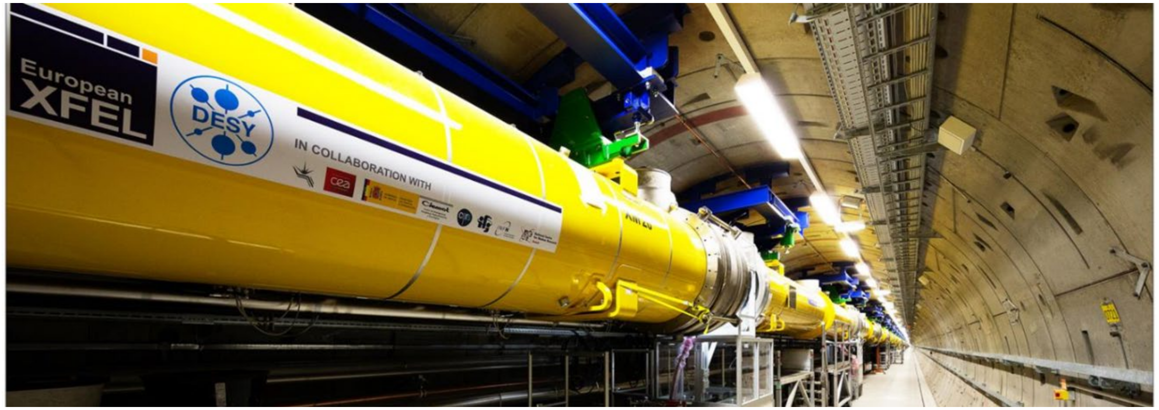
SINAP

PEKING UNIVERSITY

Sustainable Infrastructure

European infrastructure and AMICI / I.FAST

- The success of the **European XFEL** constructed in the in-kind model triggered the wish to sustain the highly developed infrastructure and its **well trained teams** to the benefit of new projects and facilities.
  - **AMICI being Accelerator and Magnet Infrastructure for Cooperation and Innovation was started as an EU sponsored activity.**
  - **https://eu-amici.eu**
  - **The activities are continued within the new EU program IFAST, here as work package WP13.**
  - **https://ifast-project.eu/wp13-technology-infrastructure**



European Commission

ACCELERATOR AND MAGNET INFRASTRUCTURE FOR COOPERATION AND INNOVATION

iFAST

WP13

PARTNERS

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Superconducting Accelerators

60 years history, and 30 years of TESLA Technology

TESLA'S HIGH-GRADIENT MARCH

Established 30 years ago with a linear electron–positron collider in mind, the TESLA Technology Collaboration has played a major role in the development of superconducting radio-frequency cavities and related technologies for a wide variety of applications.

Standing tall *Superconducting radio-frequency cavities at DESY.*

Energetic beams of charged particles are essential for high-energy physics research, as well as for studies of nuclear structure and dynamics, and deciphering complex molecular structures. In principle, generating such beams is simple: provide an electric field for acceleration and a magnetic field for bending particle trajectories. In practice, however, the task becomes increasingly challenging as the desired particle energy goes up. Very high electric fields are required to attain the highest energy beams within practical real-estate constraints.

The most efficient way to generate the very high electric fields in a vacuum environment required to transport a beam is to build up a resonant excitation of radio waves inside a metallic cavity. There is something of an art to shaping such cavities to "get the best bang for the buck" for a particular application. The radio-frequency (RF) fields are inherently time-varying, and bunches of charged particles need to arrive with the right timing if they are to see only forward-accelerating electric fields. Desirable very high resonant electric fields (e.g. 5–40 MV/m) require the existence of very high currents in the cavity walls. These currents are simply not sustainable for long durations using even the best normal-conducting materials, as they would melt from resistive heating.

Superconducting materials, on the other hand, can support sustainable high-accelerating gradients with an affordable electricity bill. Early pioneering work demonstrating the first beam-acceleration using superconducting radio-frequency (SRF) cavities took place in the late 1960s and early 1970s at Stanford, Caltech, the University of Wuppertal and Karlsruhe. The potential for real utility was clear, but techniques and material refinements were needed. Several individual laboratories began to take up the challenge for their own research needs. Solutions were developed for electron acceleration at CESR, HERA, TRISTAN, LEP II and CEBAF, while heavy-ion SRF acceleration solutions were developed at Stony Brook, ATLAS, ALPI and others. The community of SRF accelerator physicists was small but the lessons learned were consistently shared and documented. By the early 1990s, SRF technology had matured such that complex large-scale systems were credible and the variety of designs and applications began to blossom.

The TESLA springboard

In 2020, the TESLA Technology Collaboration (TTC) celebrates 30 years of collaborative efforts on SRF technologies. The TTC grew out of the first international TESLA (TeV

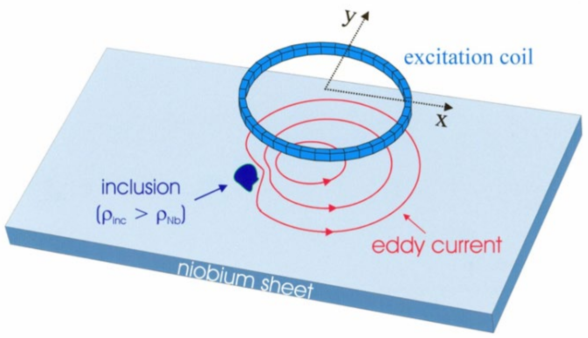
THE AUTHORS
Eiji Kako *KEK*, **Paolo Pierini** *ESS* *and* **Charles E Reece** *JLab*.

- SRF Cavities have a long history of about 60 years
- With the start of TESLA's High Gradient March the **industrial production was emphasized**.
- At that time, the **mechanical fabrication** was already done by companies but lab supervision was common.
- The **surface treatment** was an R&D issue, and the industrial treatment was started much later.
- The European XFEL construction included the DESY & INFN supervised set-up of **new infrastructure at cavity vendors**.
- The now existing infrastructure is used for many projects worldwide.

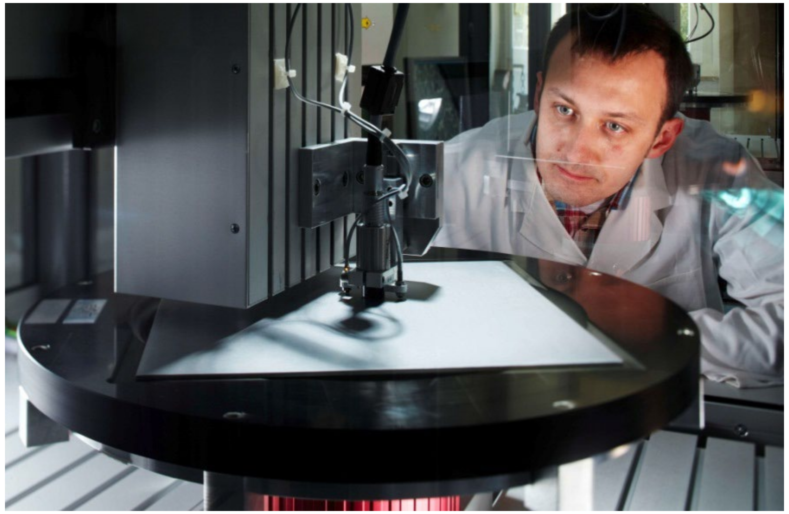
SRF Cavity Production

Niobium scanning and surface analysis

- **Detailed examination** of niobium sheets is a *sine qua non* condition for large series production of superconducting cavities.
- DESY operates a specially developed **eddy current device** to search for inclusions. For the European XFEL more than 16,000 sheets were scanned. Different vendors were qualified.
- The SRF community aims for **highest performance** and **highest quality factor SRF cavities.** Thus cavity production starts with the niobium specification.
- Over the years, DESY has been responsible for the scanning QC for the complete production of LCLS-II cavities. ESS cavity material followed, also SHINE, and PIP-II is next.



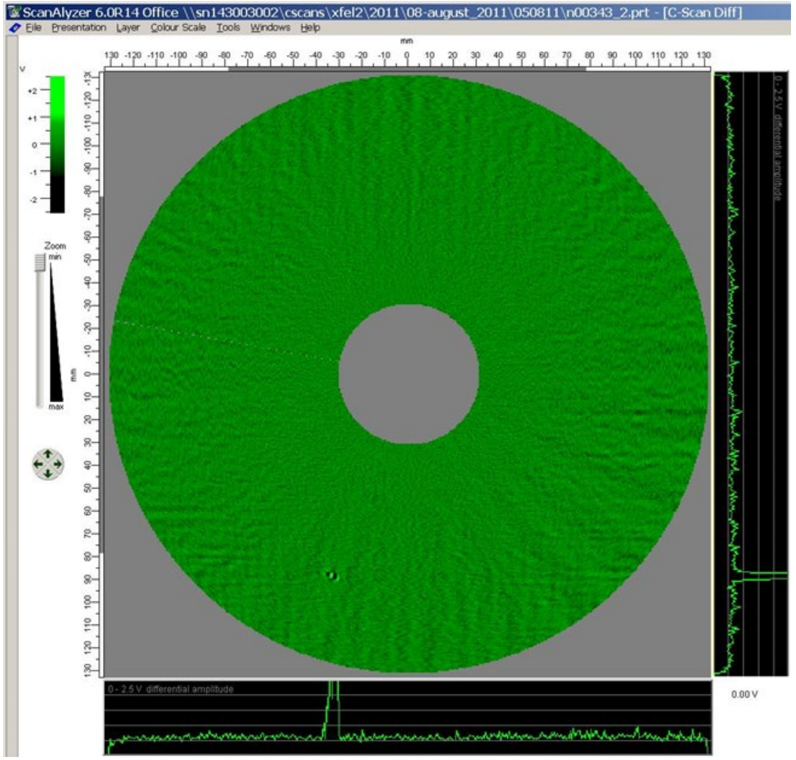
- The achieved visible sheet's depth is approximately 500 µm, and the minimal detectable inclusion size is about 80 µm. The scanning result is used to decide on the RF active surface i.e. the later inner side of the accelerating structure.
- Identified defects are studied in a well equipped metallurgy laboratory at DESY.



SRF Cavity Production

Quality control

- For the European XFEL all Nb / NbTi material (24,420 single parts!) was procured by DESY.
- Detailed quality inspection was developed and carried out.
- All material was made available to the cavity vendors.

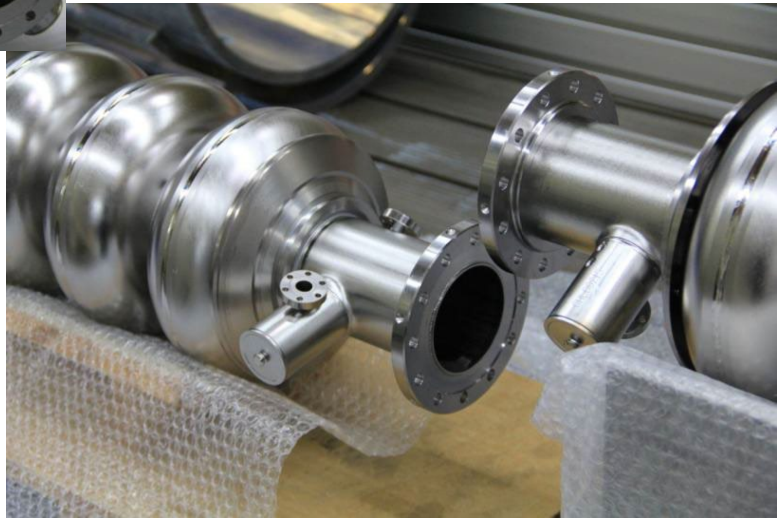


- Today we see both, the procurement by the projects and by the cavity vendor.
- In the majority of cases the **sheets are still scanned** at DESY. For small series production and for lower cavity frequency it is sometimes skipped.
- In general, the **production quality** turns out to be higher if the Niobium vendor knows about DESY QC being applied.

Cavity Production

Large series production at Research Instruments and ZRI Zanon

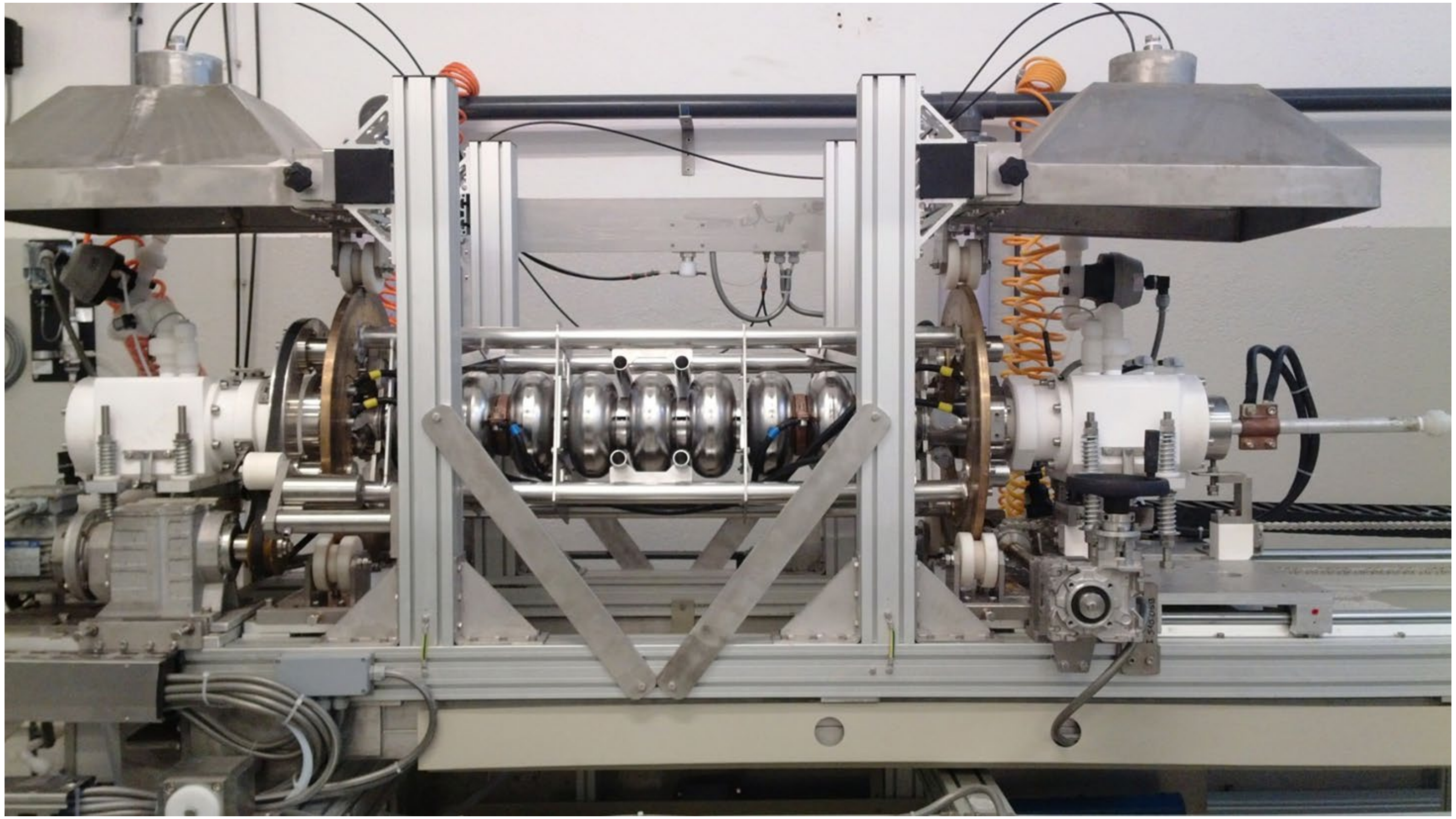
all pictures courtesy
Research Instruments and E. Zanon



- SRF Cavity production is in the **portfolio of two well-qualified European companies**.
- The largest series is a 1.3 GHz 9-cell cavity built from fine grain bulk Niobium.
- The standard specification was developed for the European XFEL. Project specific adaptation was done.

Cavity Production

Electropolishing as essential technology



picture courtesy
E. Zanon

- The **Electropolishing** of SRF cavities was established by several laboratories.
- The **Eu-XFEL cavity procurement** included the **technology transfer** to the cavity vendors.
- **Detailed description of process parameters** incl. QC measures were given.

Cavity Production

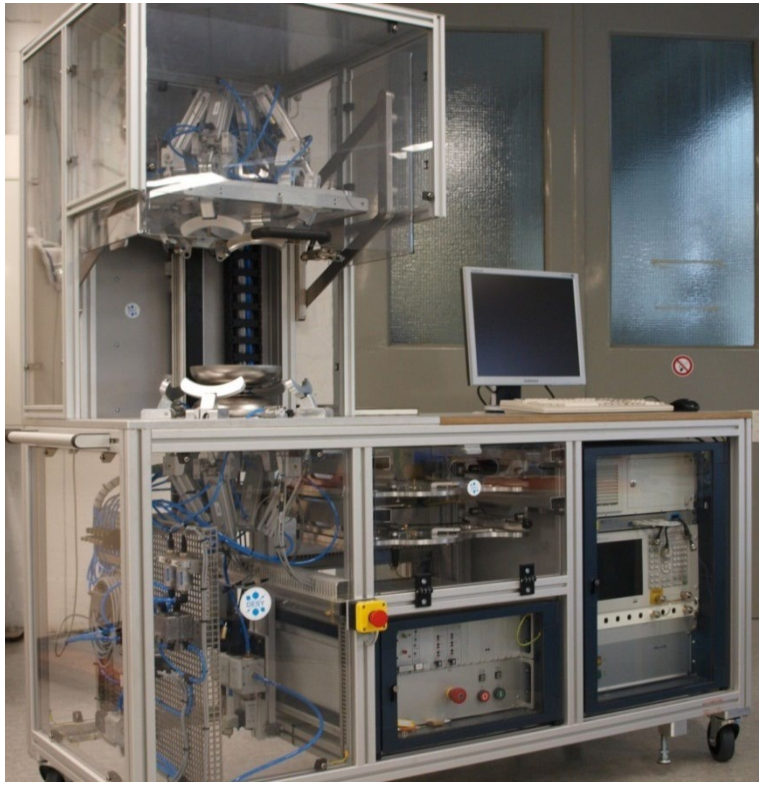
Electropolishing as essential technology

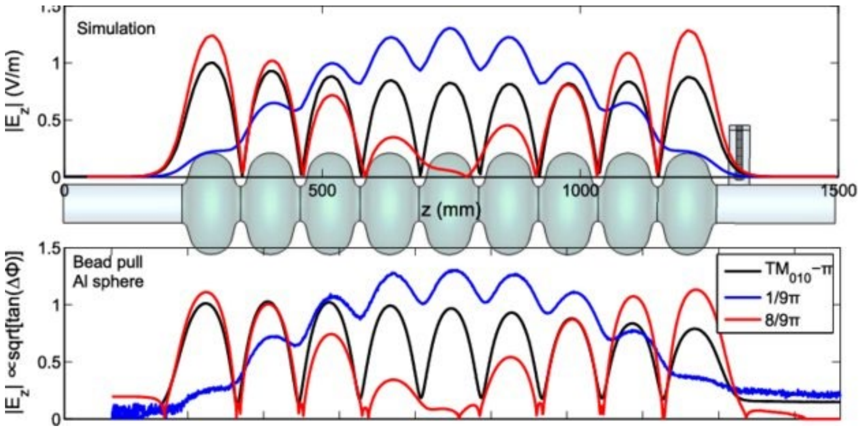
picture courtesy
Research Instruments

- Both cavity vendors set-up **new clean room infrastructure.**
- The successful commissioning of the overall production site was a results of **strong collaboration between the cavity vendors and the supervising laboratories** DESY and INFN LASA.

Cavity Production

Frequency and field flatness tuning





- Special **CE certified machines** were developed in the laboratories and given to industry.
- The **HAZEMEMA** is used to determine the required trimming before welding.
- The **Tuning Machine** is used to guarantee field flatness at the correct RF frequency.
- DESY efforts to develop these two machines were supported by FNAL and KEK.
- **Both machines are still in operation at the cavity vendors.**

Vertical Cavity Testing at DESY

Testing in a quasi industrial fashion

- Due to the missing cryogenic infrastructure **vertical cavity testing is done in the laboratories**.
- The DESY / XFEL infrastructure is used to offer service to projects and facilities, either directly or via the cavity vendors.
- Test capacities are usually limited in order to **not challenge the R&D** projects at the infrastructure owner.

SRF Cavity Testing

RF testing after surface treatment is a must

- Vertical test infrastructures profit from professional and regular use. DESY operates several **vertical test stands** / dewars **to characterize cavities.** In total 6 inserts are used to take either up to 4 standard 1.3 GHz cavities, or **other structures like SRF guns** into the cryostat.
- Adaptations to other cavities e.g. ESS medium and high beta were made.

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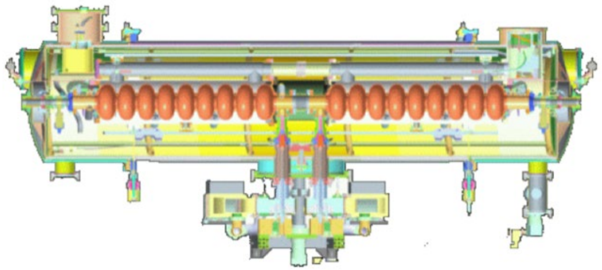
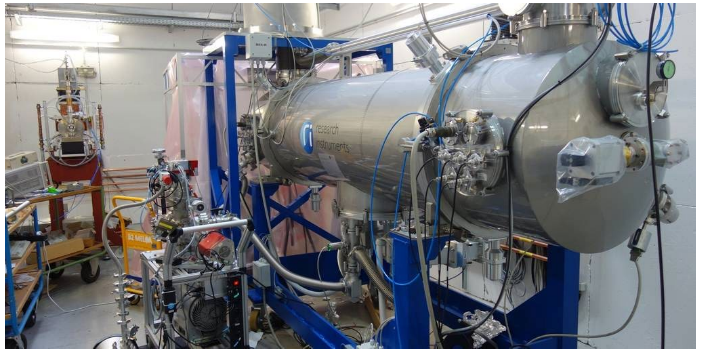
- For the European XFEL over 1200 cavity tests were carried out.
- Now, DESY's R&D program emphasizes **single cell R&D, SRF guns, and sample tests** (Quadrupole resonator).
- **Education of young scientists plays a major role in order to guarantee sustainability of SRF technology.**

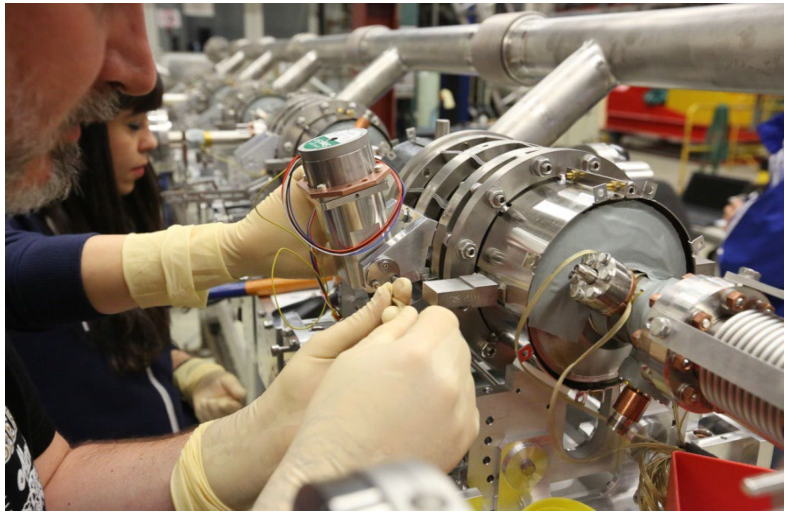
Accelerator Module Assembly

From the cavity string to the finished module

- At DESY **dedicated assembly infrastructure** for the assembly / dis-assembly and repair of superconducting accelerator modules is in operation.
- **This infrastructure is used** for standard European XFEL or FLASH facility modules. **Other infrastructures worldwide** e.g. at CE Saclay but also Fermilab and KEK mimic the DESY facilities, with adaptations to their needs.
- Most facilities are taking advantage of **trained personal from industry**.
- Some laboratories set-up and commissioned smaller infrastructure to deal with shorter modules or single cavities.
- **Technology transfer from FZ Dresden**, Rossendorf, to the company Research Instruments allowed for the production of **a two 9-cell cavity module**, to the benefit of a number of projects worldwide.



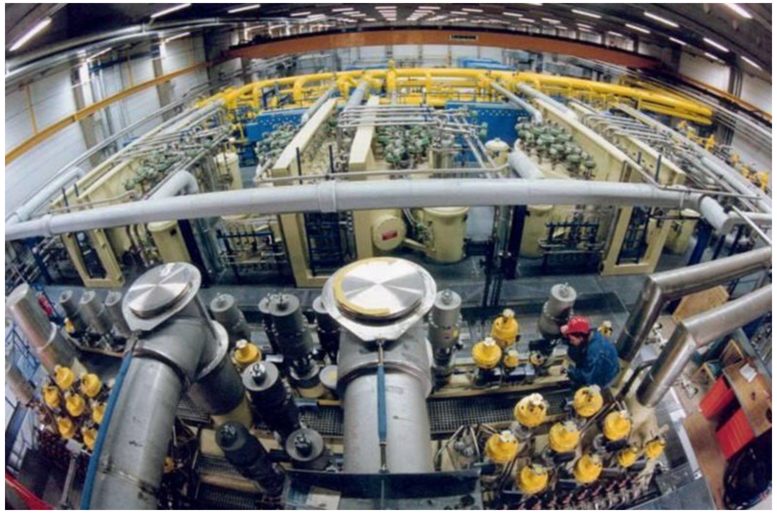




Accelerator Module Testing

Module R&D includes extensive testing

- **Module testing** is done at the facilities or by the project in-kind contributors. Also here the cryogenics infrastructure is **too challenging for industry**. Also RF power system are **not easily available at companies**.
- **In the community several horizontal test stands** are available for the characterization of completely assembled superconducting accelerator modules. Three test stands were used for the European XFEL series testing.
- It is unlikely that industry will be able to invest in its own testing infrastructure. In case industrial projects require such infrastructure, a direct liaison with existing test facilities could be investigated.



Summary

Innovative brains and facilities

There is a long tradition of innovative accelerator design, construction and operation. Consolidated knowledge is the basis for new R&D ideas.

Highly motivated teams operate existing and create new R&D infrastructures.

Facilities and companies act together to the benefit of both.

The European XFEL SRF activities led to an extremely successful technology transfer between partners and industry.

The healthy lab / facility environment includes

- **Enthusiastic brains – old stagers and young scientists**
- **Technical platforms – material studies and component development**
- **Facilities – treatment, testing and beam**

Industry can profit and the existing infrastructure should be used – perhaps after some required adaptation – to the benefit of future projects.

EU supported networks like LEAPS, AMICI, I.FAST will clearly help.

Innovation is our future!

European Commission

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