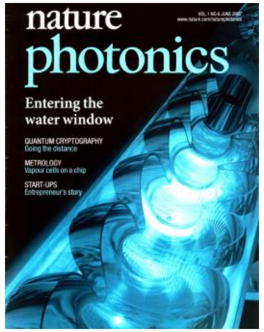
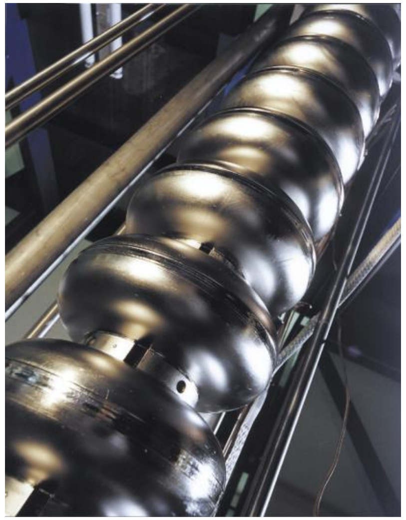


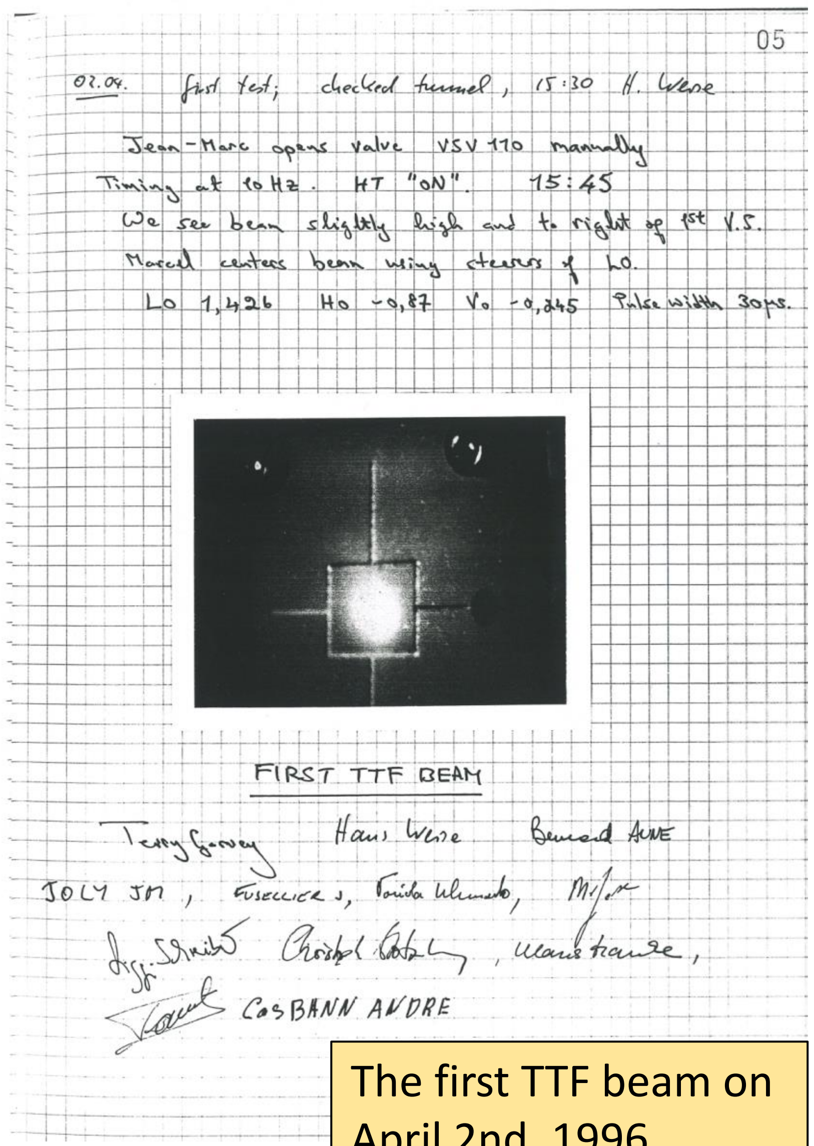


Superconducting RF Linacs and FELs - a Successful Partnership

Hans Weise / DESY

25th Anniversary of the First Lasing at TTF (now FLASH) – International Symposium

A little bit of history…. Let‘s go to the mid 90ies


05

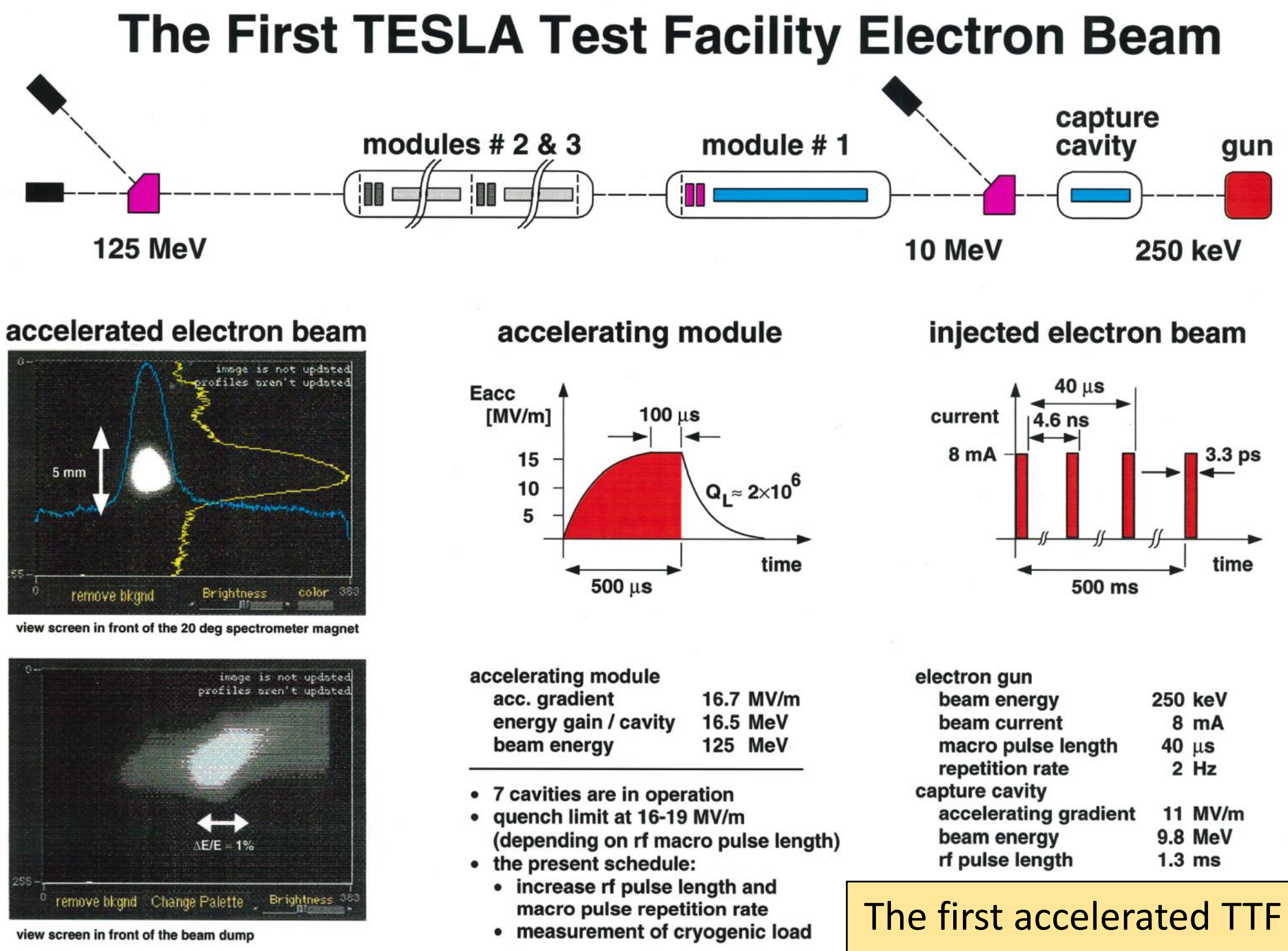
02.04. first test; checked tunnel, 15:30 H. Weise

Jean-Marc opens valve VSV 110 manually
Timing at 10 Hz. HT "ON". 15:45
We see beam slightly high and to right of 1st V.S.
Marcel centers beam using steerers of L0.
L0 1,426 H0 -0,87 V0 -0,245 Pulse width 30μs.

FIRST TTF BEAM

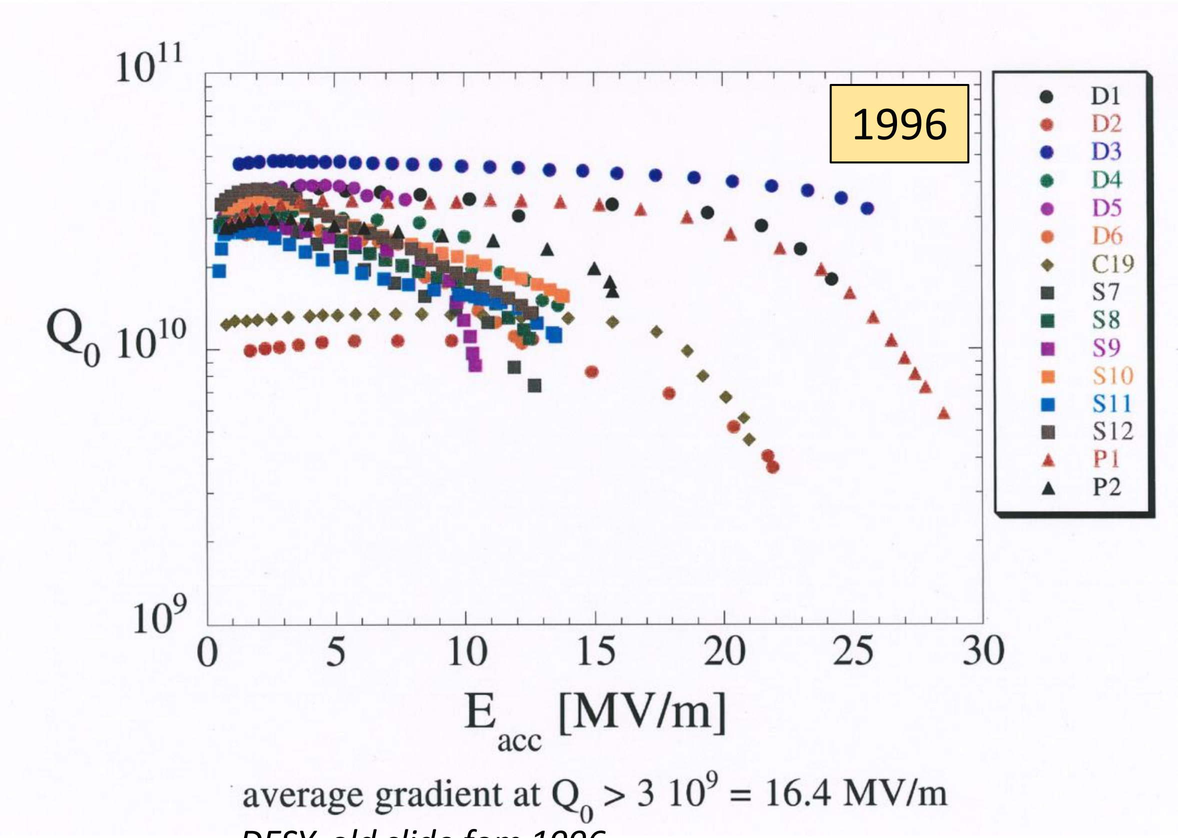
Terry Garvey, Hans Weise, Bernard Aune
JOLY JM, Fusellier J, Toida Ulmeda, [illegible]
[illegible], Christof [illegible], [illegible],
[illegible] COSBANN ANDRE

The first TTF beam on April 2nd, 1996

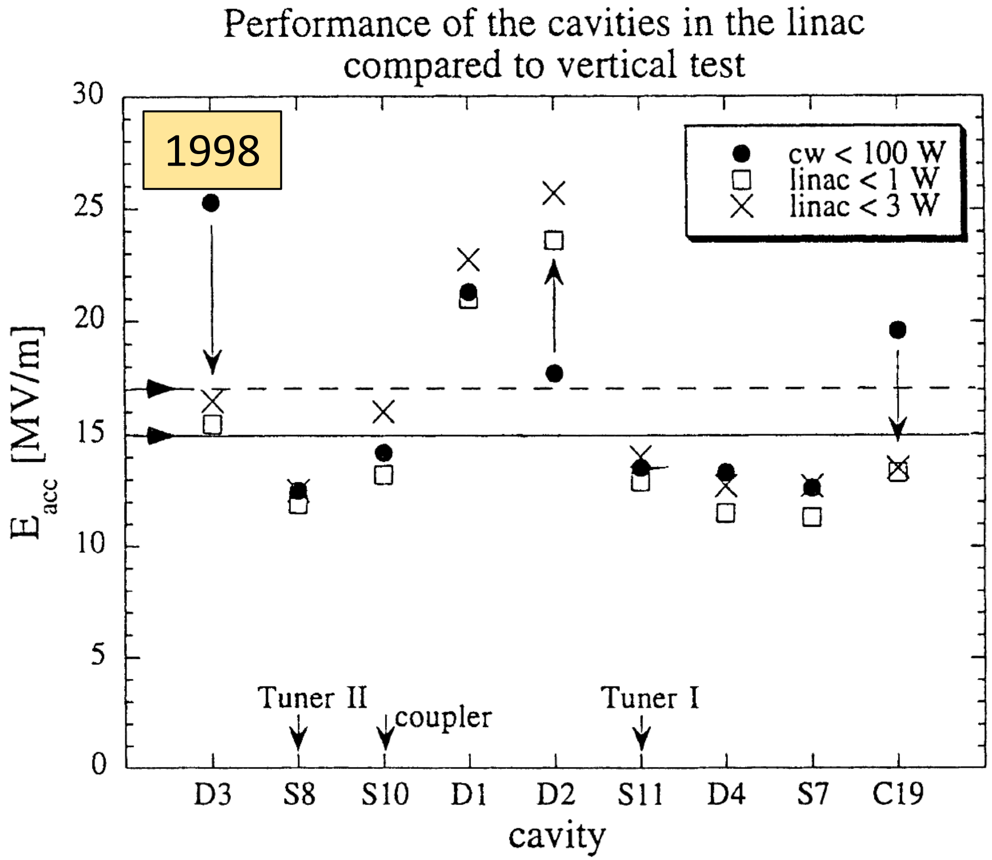


The first accelerated TTF beam in June 1997

First cavities and first module at TTF / FLASH



DESY, old slide fom 1996



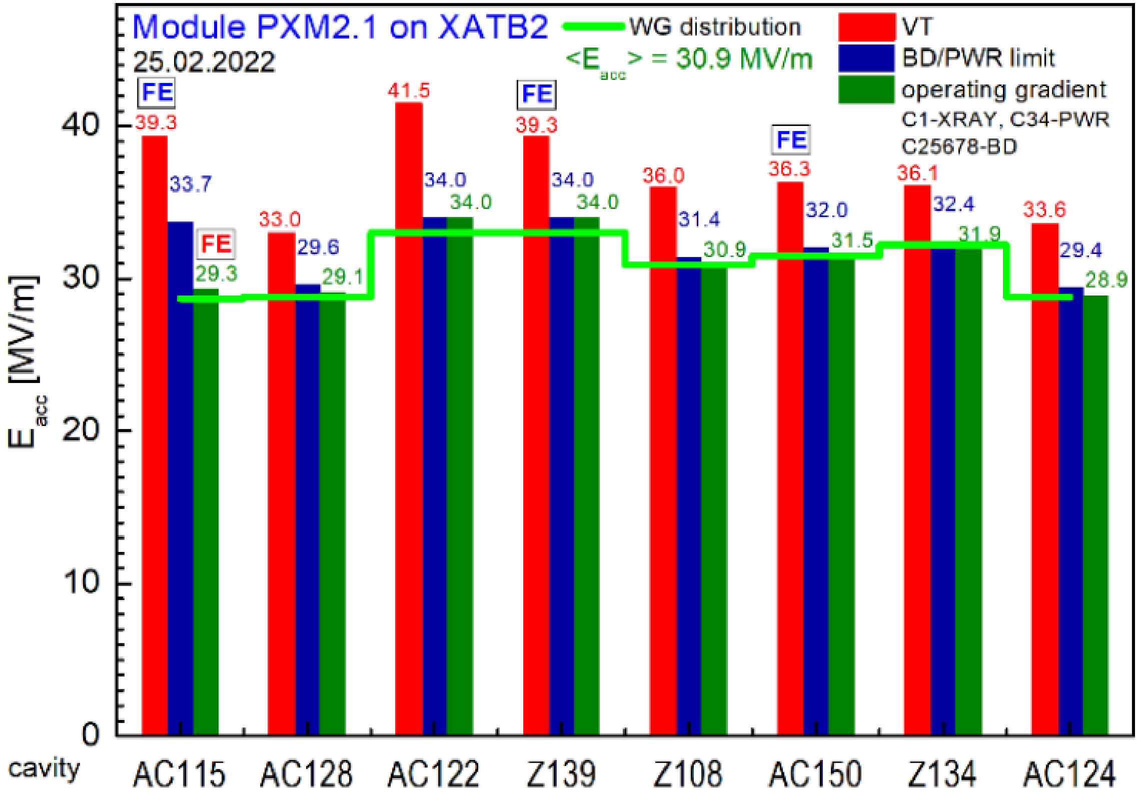
linac: 10 Hz rep. rate, 305 μs rise time, 800 μs constant gradient

Particle Accelerators, Vol. 60, pp. 53-72

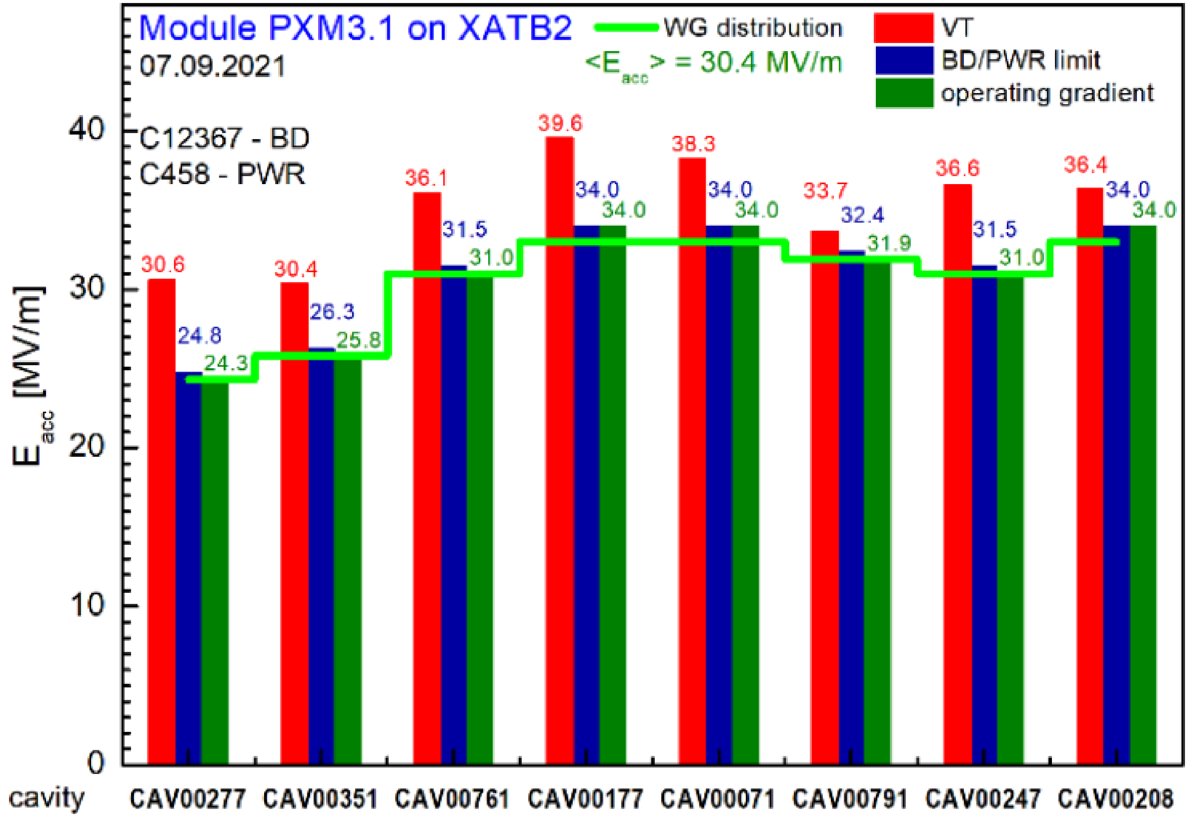
Our famous Q vs. E curves – here @1.8K

The first comparison between vertical test and linac operation – again @1.8K

Most recent FLASH modules offer 30 MV/m



2021/2022



we still compare vertical and module tests – now @2K

accelerating gradients increased by roughly a factor 2

Other historical annotations - SRF for FELs

First Operation of a Free-Electron Laser*

D. A. G. Deacon,† L. R. Elias, J. M. J. Madey, G. J. Ramian, H. A. Schwettman, and T. I. Smith
High Energy Physics Laboratory, Stanford University, Stanford, California 94305
(Received 17 February 1977)

A free-electron laser oscillator has been operated above threshold at a wavelength of 3.4 μm.

Ever since the first maser experiment in 1954, physicists have sought to develop a broadly tunable source of coherent radiation. Several ingenious techniques have been developed, of which the best example is the dye laser. Most of these devices have relied upon an atomic or a molecular active medium, and the wavelength and tuning range has therefore been limited by the details of atomic structure.

Several authors have realized that the constraints associated with atomic structure would not apply to a laser based on stimulated radiation by free electrons.[1-5] Our research has focu... teraction between radiation ... in a spatially periodi... Of the schemes whic... approach appears the ... of coherent radiation i... and the ultraviolet, and ... yielding very high avera... viously described the re... of the gain at 10.6 μm.[6] ... the first operation of a fre... laser oscillator.

Our apparatus is shown schematically in Fig. 1. A superconducting helix generates a periodic transverse magnetic field of 2.4 kG. A 43-MeV electron beam from the superconducting accelerator is fired along the axis of the helix. Radiation passing through the helix with the electron beam is amplified and a pair of mirrors at the ends of

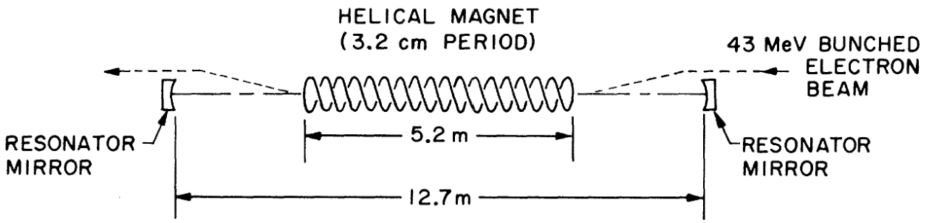


FIG. 1. Schematic diagram of the free-electron laser oscillator. (For more details see Ref. 6.)

Phys. Rev. Lett. **38**, 892 – **Published 18 April, 1977**
DOI: https://doi.org/10.1103/PhysRevLett.38.892

Other historical annotations - SRF for FELs in 1999

ELSEVIER

Nuclear Instruments and Methods in Physics Research A 429 (1999) 21–26

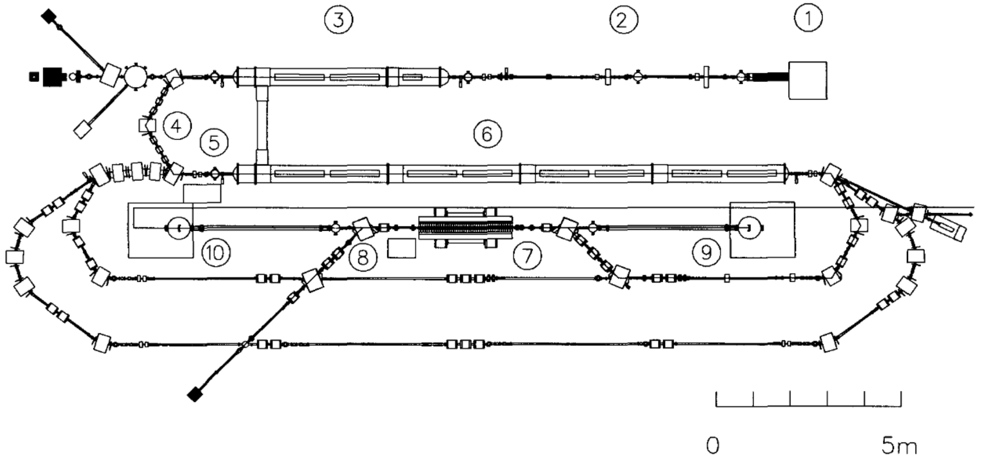
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

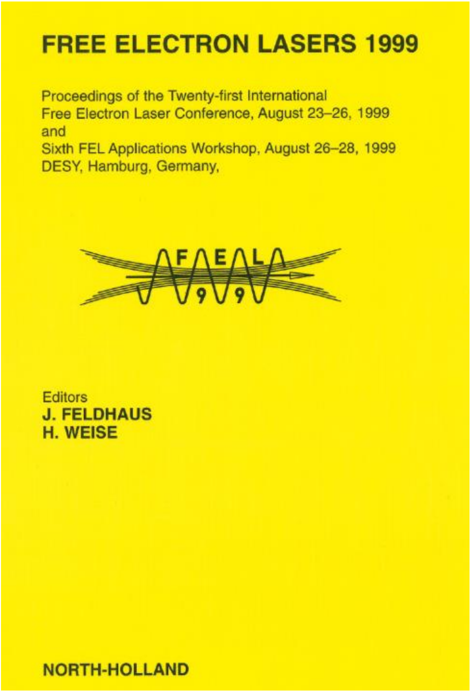
www.elsevier.nl/locate/nima

First lasing of the Darmstadt cw free electron laser

M. Brunken*, S. Döbert, R. Eichhorn, H. Genz, H.-D. Gräf, H. Loos, A. Richter, B. Schweizer, A. Staschek, T. Wesp

Institut für Kernphysik, Technische Universität Darmstadt, D-64289 Darmstadt, Germany





ELSEVIER

Nuclear Instruments and Methods in Physics Research A 429 (1999) 27–32

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

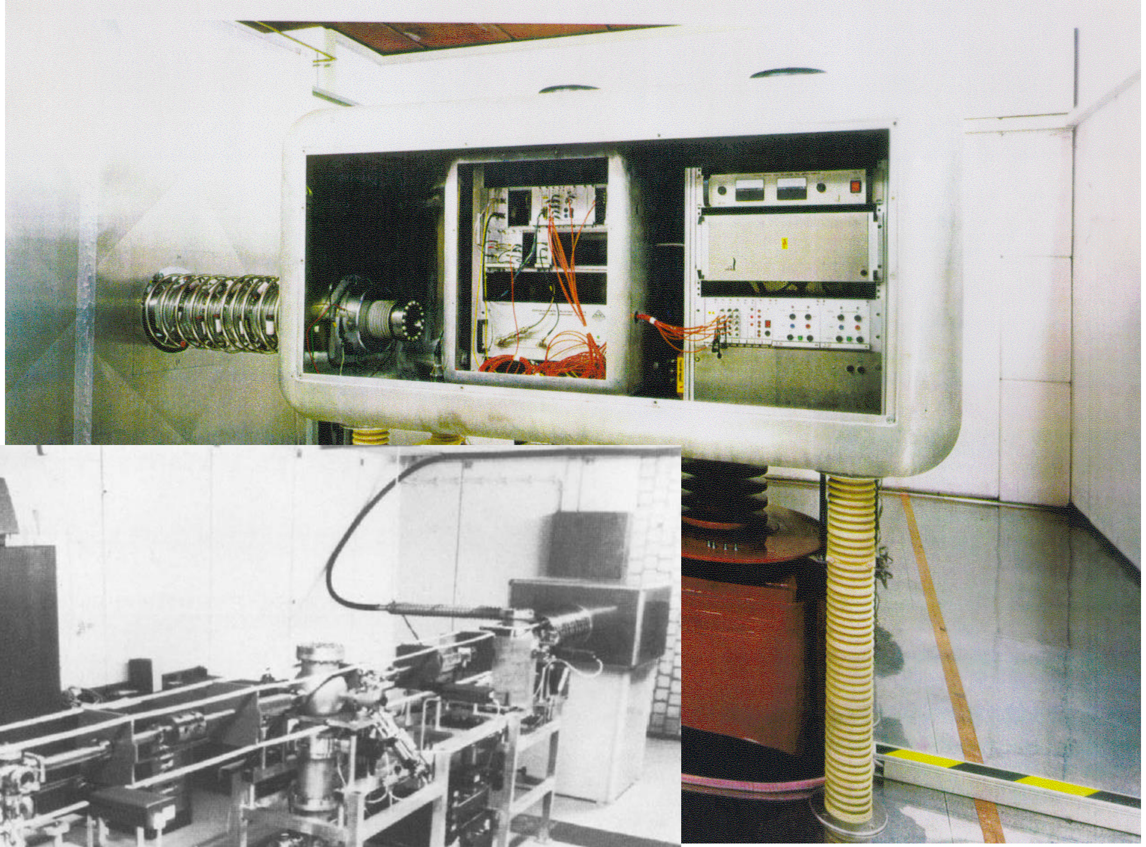
www.elsevier.nl/locate/nima

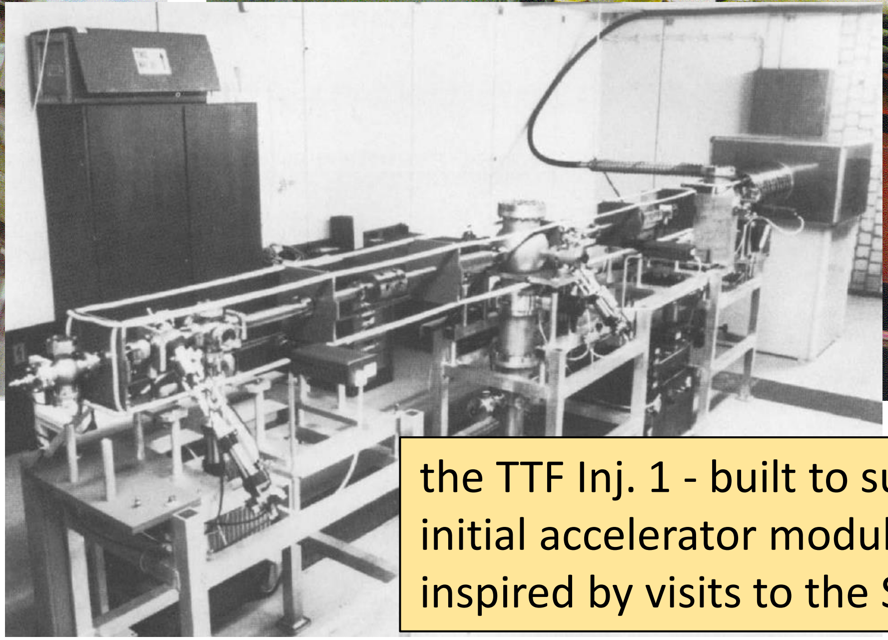
First lasing of the Jefferson Lab IR Demo FEL

S. Benson*, G. Biallas, C. Bohn, D. Douglas, H.F. Dylla, R. Evans, J. Fugitt, R. Hill, K. Jordan, G. Krafft, R. Legg[1], R. Li, L. Merminga, G.R. Neil, D. Oepts, P. Piot, J. Preble, M. Shinn, T. Siggins, R. Walker, B. Yunn

Thomas Jefferson National Accelerator Facility, 12000 Jefferson Avenue, Newport News, VA 23606, USA

Setting the scene – reminder and memories





LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE

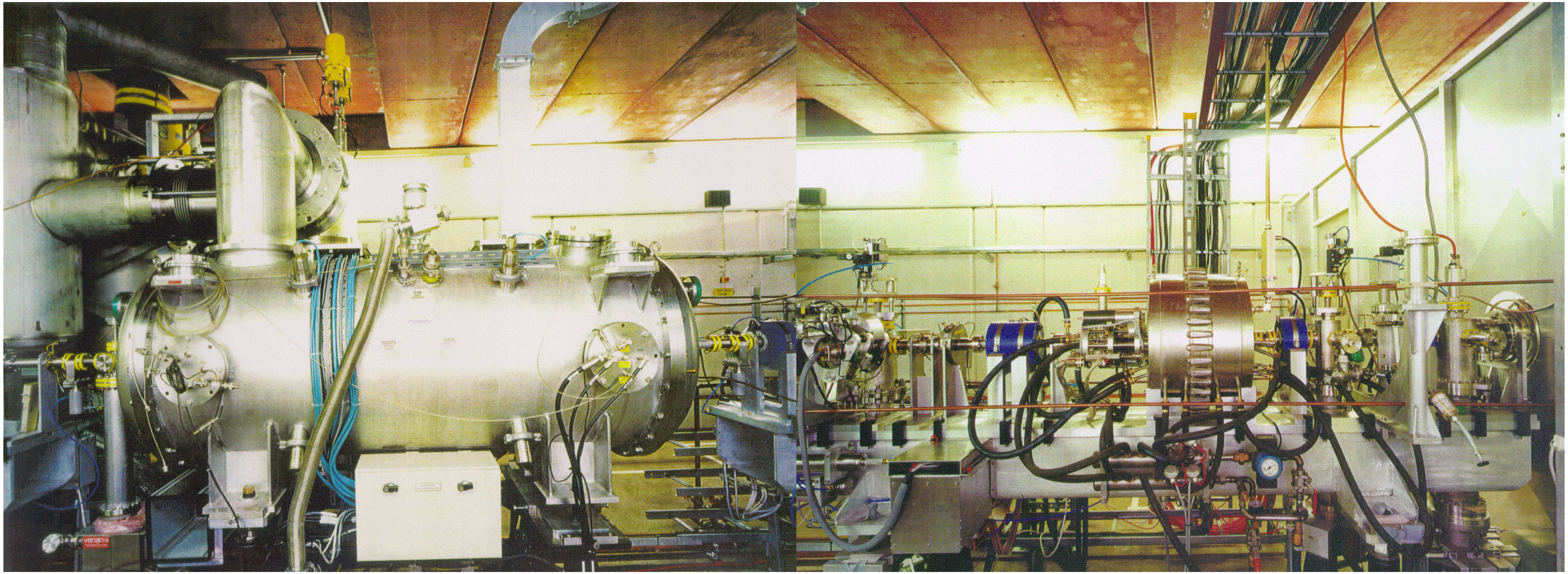
IPN-LAL 1956-2016

Irfu

cea SACLAY

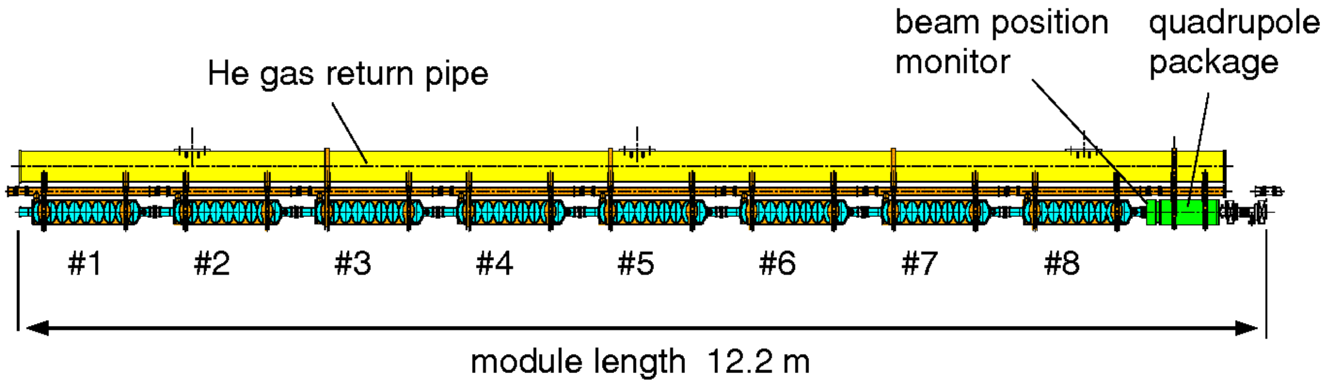
the TTF Inj. 1 - built to supply e- beam for initial accelerator module testing
inspired by visits to the S-DALINAC

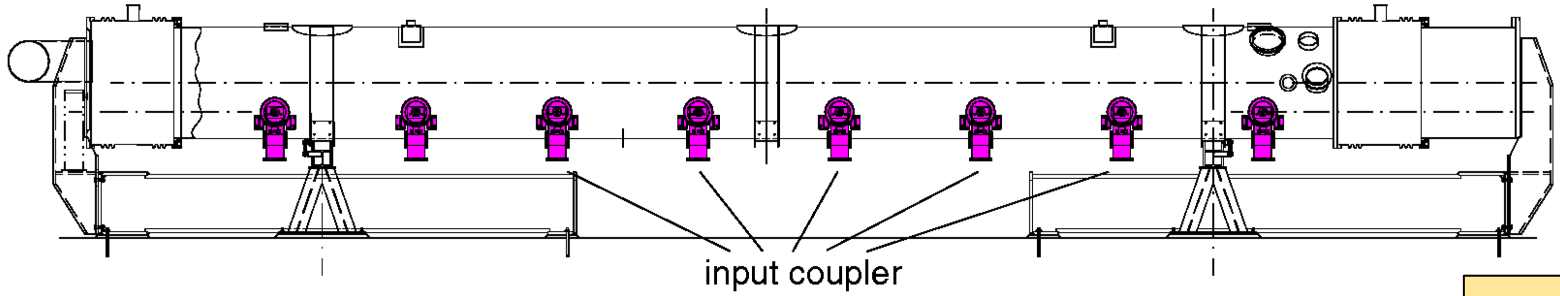
Setting the scene – reminder and memories

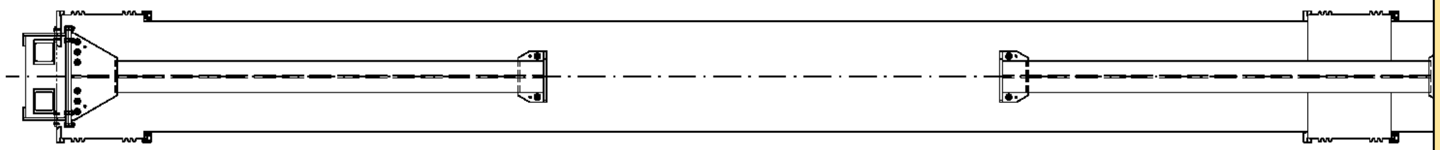


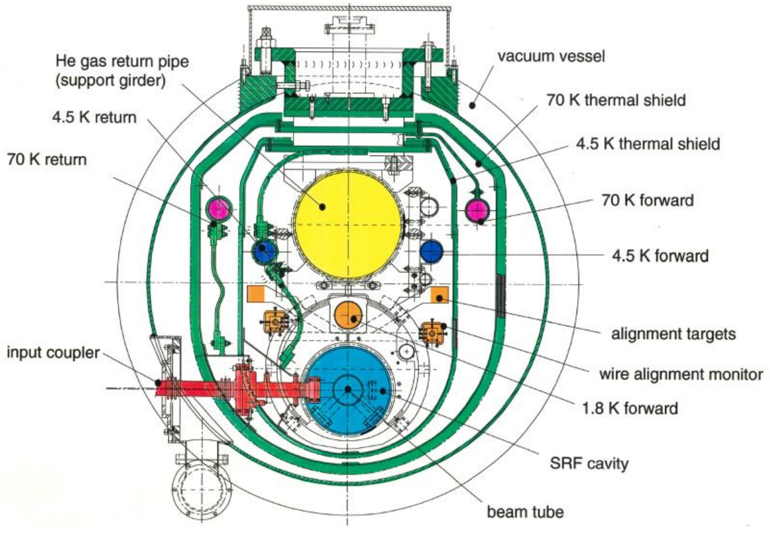
the TTF Inj. 1 - built to supply e- beam for initial accelerator module testing

Setting the scene – reminder and memories

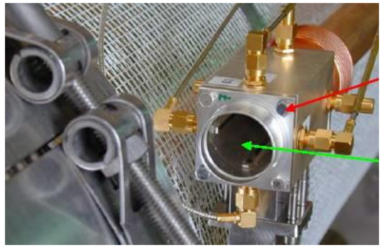








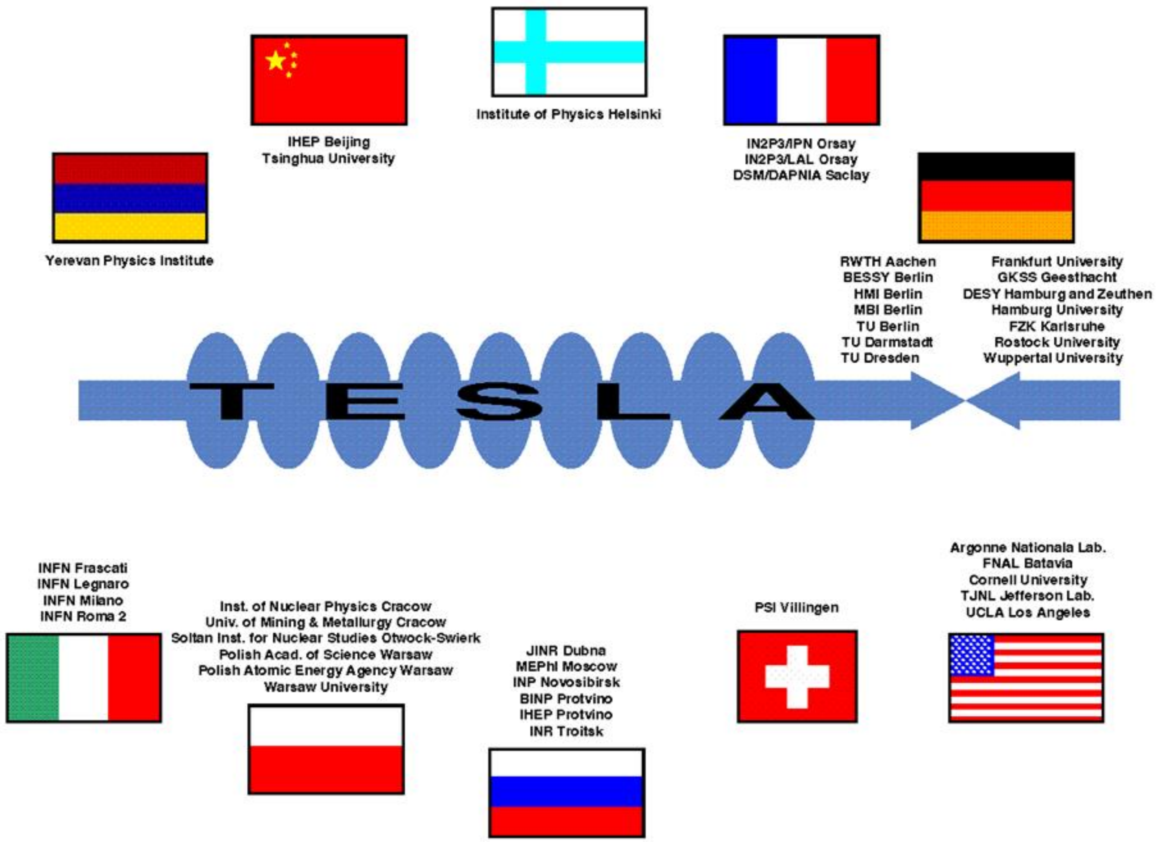
. . . Istituto Nazionale di Fisica Nucleare – LASA – Laboratorio Acceleratori e Superconduttività Applicata



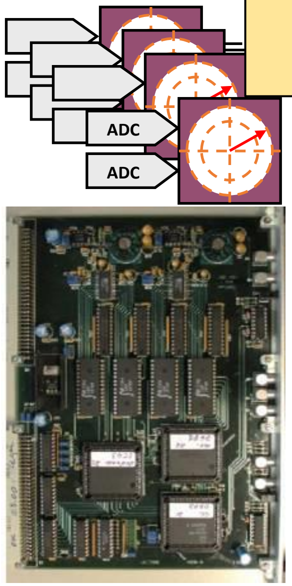
First modules differed in design and included e.g. essential diagnostics like wire alignment monitor, different RF input coupler ….
Later:

- changed concept wrt. longitudinal shrinkage
- major cryogenic modifications

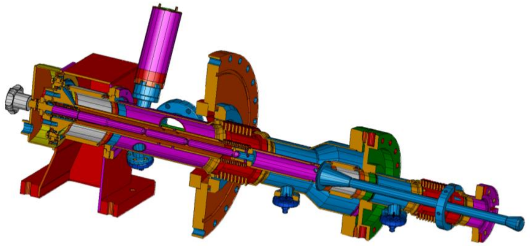
FLASH would not exist w/o TESLA Collaboration



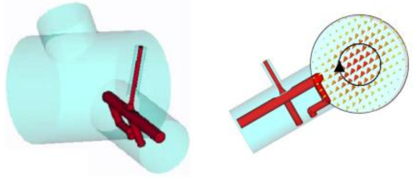
- Many of the TESLA Collaboration members had essential contributions to the SRF technology.
- If not directly to the cavities, RF power Couplers and modules then to the TTF set-up in areas like diagnostics, magnets, RF supply etc.



RF pick up & LLRF



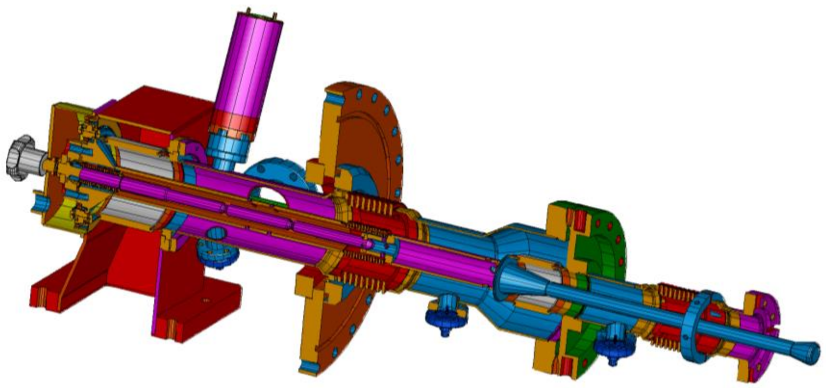
RF power coupler

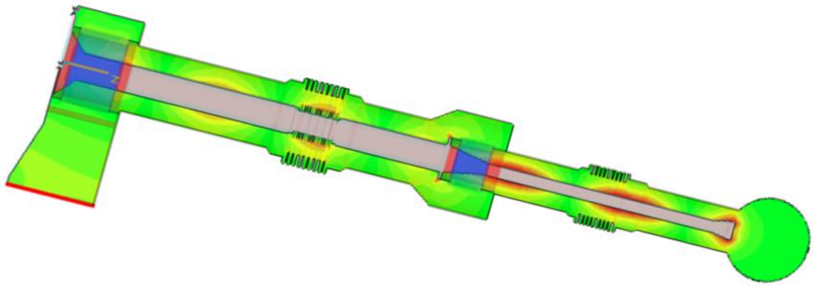


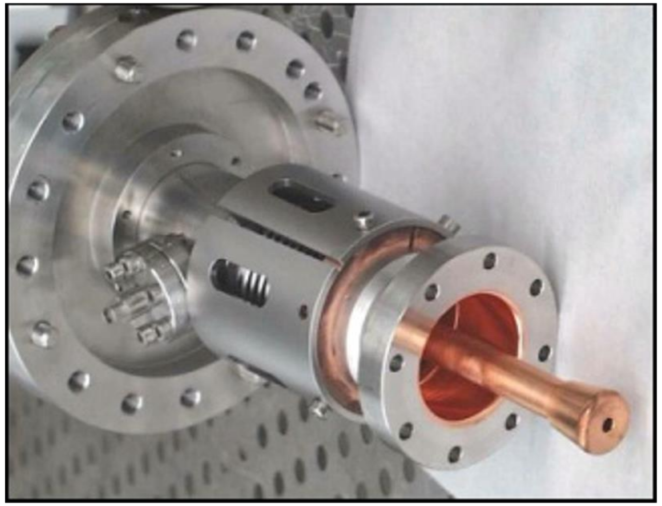
HOM coupler

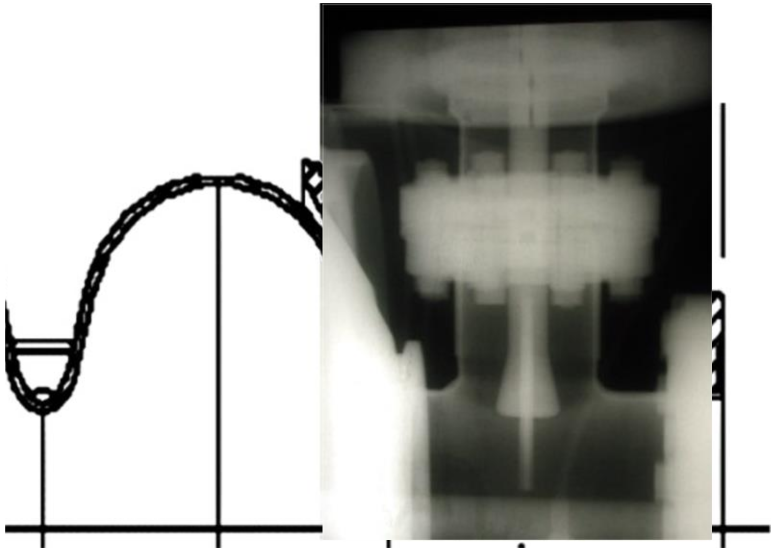
TTF/FLASH technology for EuXFEL (RF power couplers)

2000+







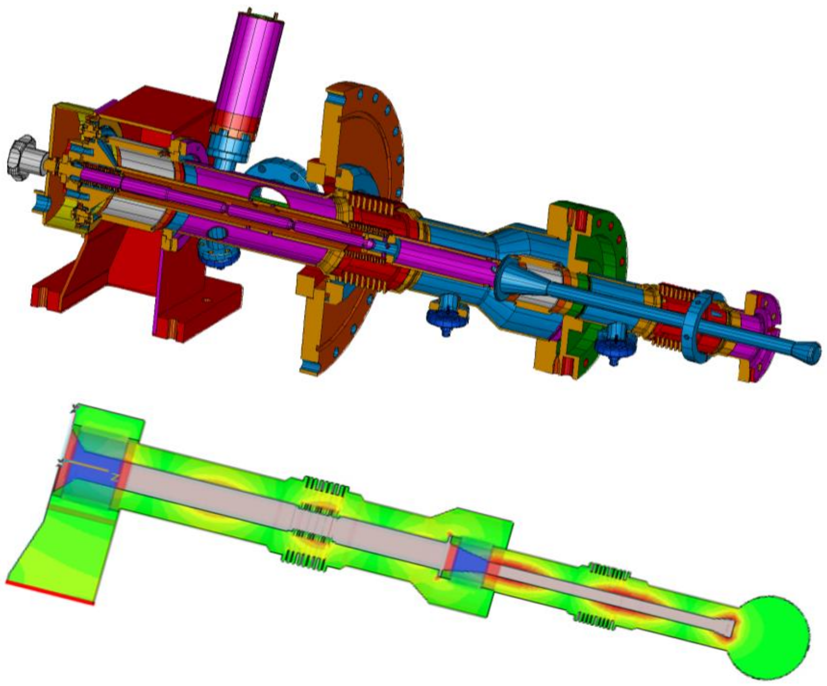


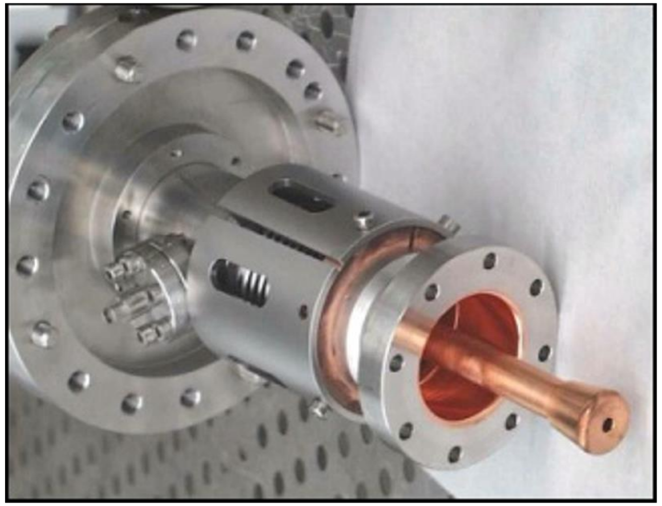
Two types and **three generations of couplers** were used at the TTF Linac.

All couplers were cold conditioned to a power level corresponding to accelerating gradients of at least 25 MV/m **(>200 kW, 1.3 ms, 10 Hz).**

Coupler type III was the base for the EuXFEL (≈1000 couplers). **Only minor modifications were needed to allow for large scale production.**

TTF/FLASH technology for EuXFEL (RF power couplers)





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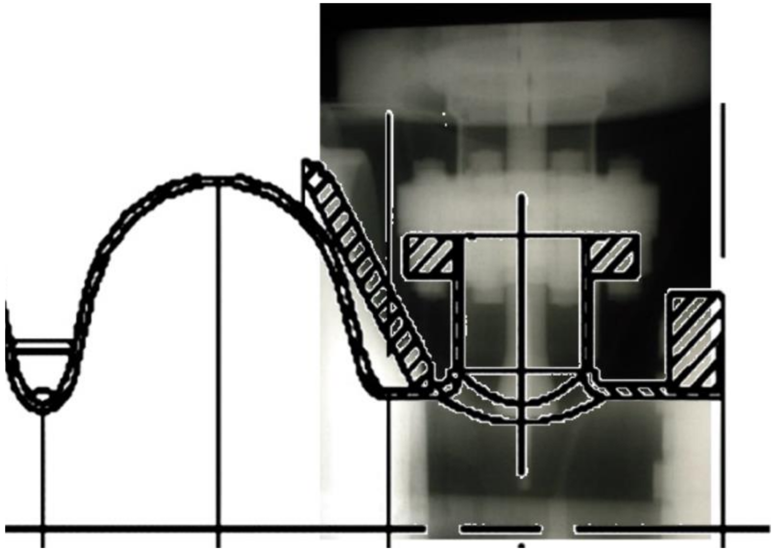
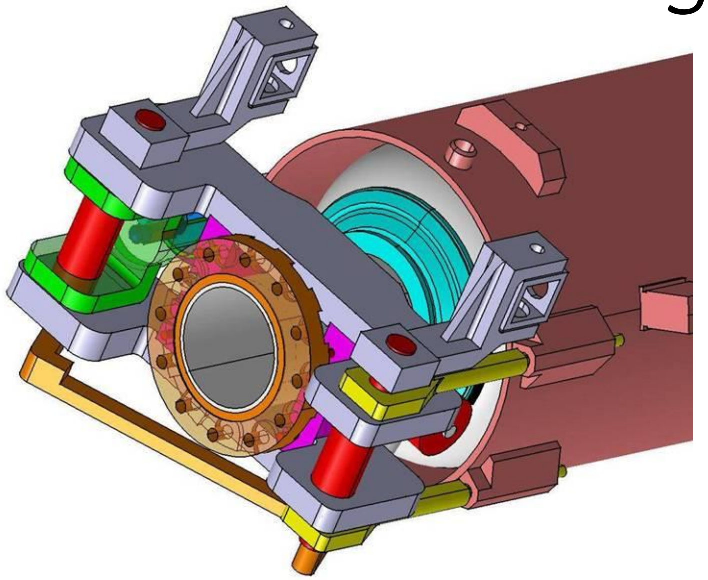
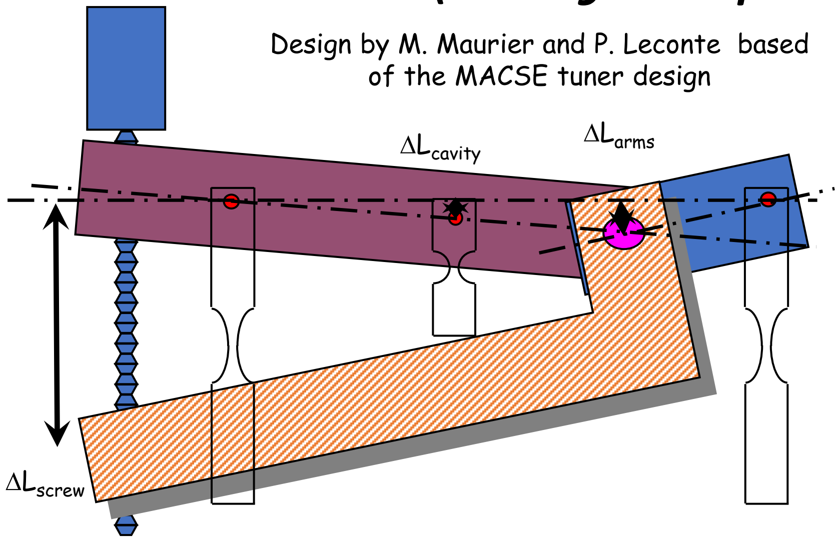
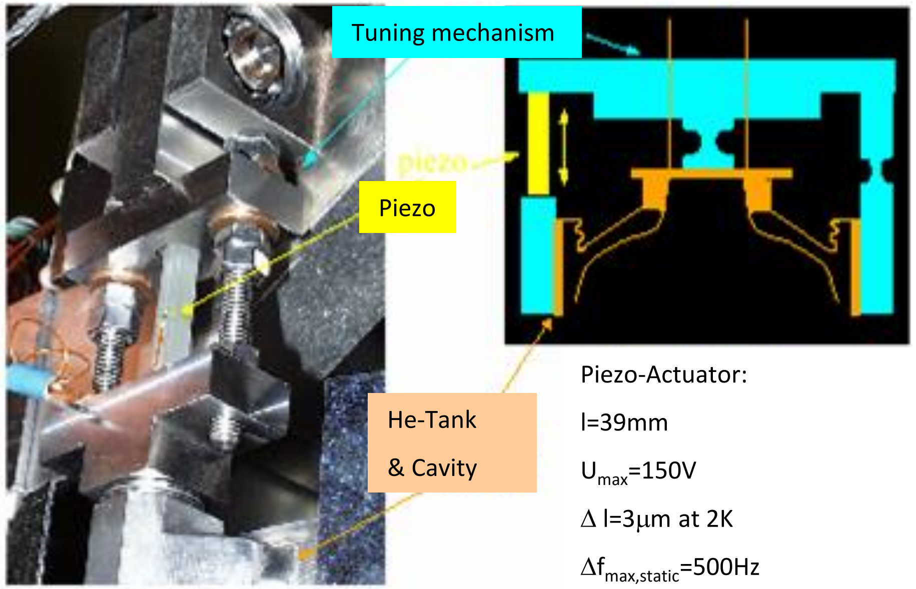


TTF/FLASH technology for EuXFEL (RF frequency tuners)

2000+







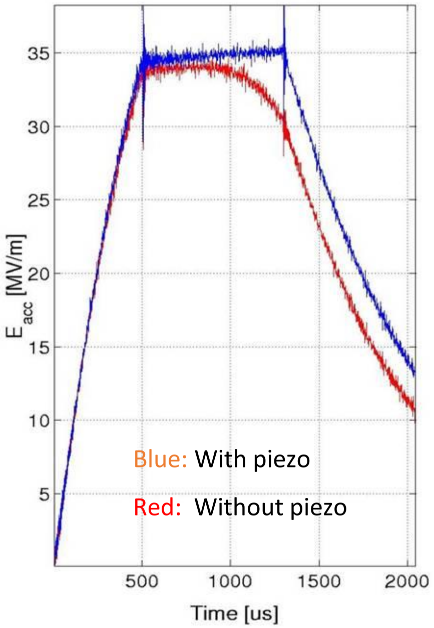
Piezo-Actuator:

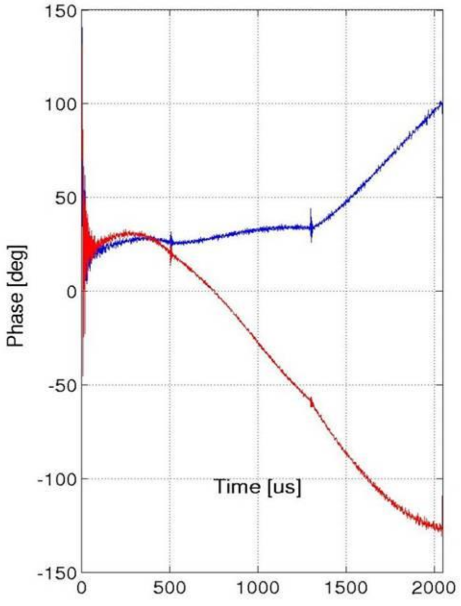
l=39mm

U_{max}=150V

Δ l=3μm at 2K

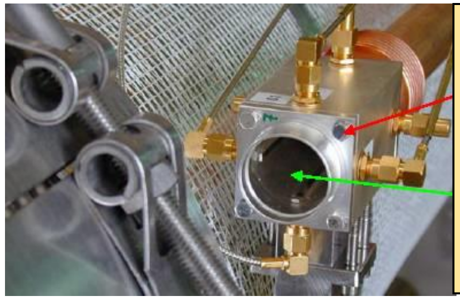
$\Delta f_{max,static}$=500Hz





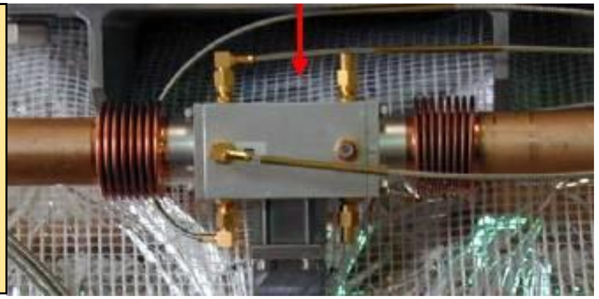
TTF/FLASH technology for EuXFEL (module alignment)

2000+

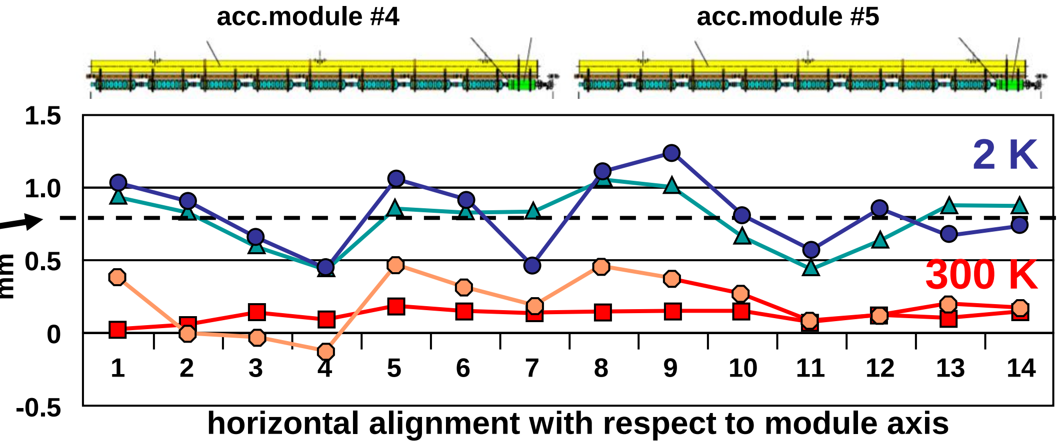


cavity / quad string alignment is measured using a stretched wire system

at warm and at cold temperature



corresponds to a perfectly aligned cavity / quad string



TDR specifications (RMS):

cavities	x/y:	+/- 0.5 mm
	z:	+/- 1 mm
quad/dip	x/y:	+/- 0.3 mm
	z:	+/- 1 mm
	roll:	+/- 0.1 mrad

Results (peak):

cavities	x:	+/- 0.35 mm
	y:	+/- 0.25 mm
quad/dip	x:	+ 0.1 / - 0.4 mm
	y:	+ 0.2 / - 0.5 mm

overall module tilt ≈ 0.1 mrad

- 20-Jun-03 300 K
- 22-Jul-03 2 K
- 06-Oct-03 300 K
- 31-Mar-04 2 K

TTF/FLASH technology for EuXFEL (string assembly)

2000+

The assembly of an 8 cavity string

- **is a standard procedure**
- **is done by technicians from the TESLA Collaboration**
- **is well documented using the cavity database as well as an Engineering Data Management System**
- **was the basis for two industrial studies.**

We are ready to transfer this well known and complete procedure to industry.

The inter-cavity connection is done in class 10 cleanrooms

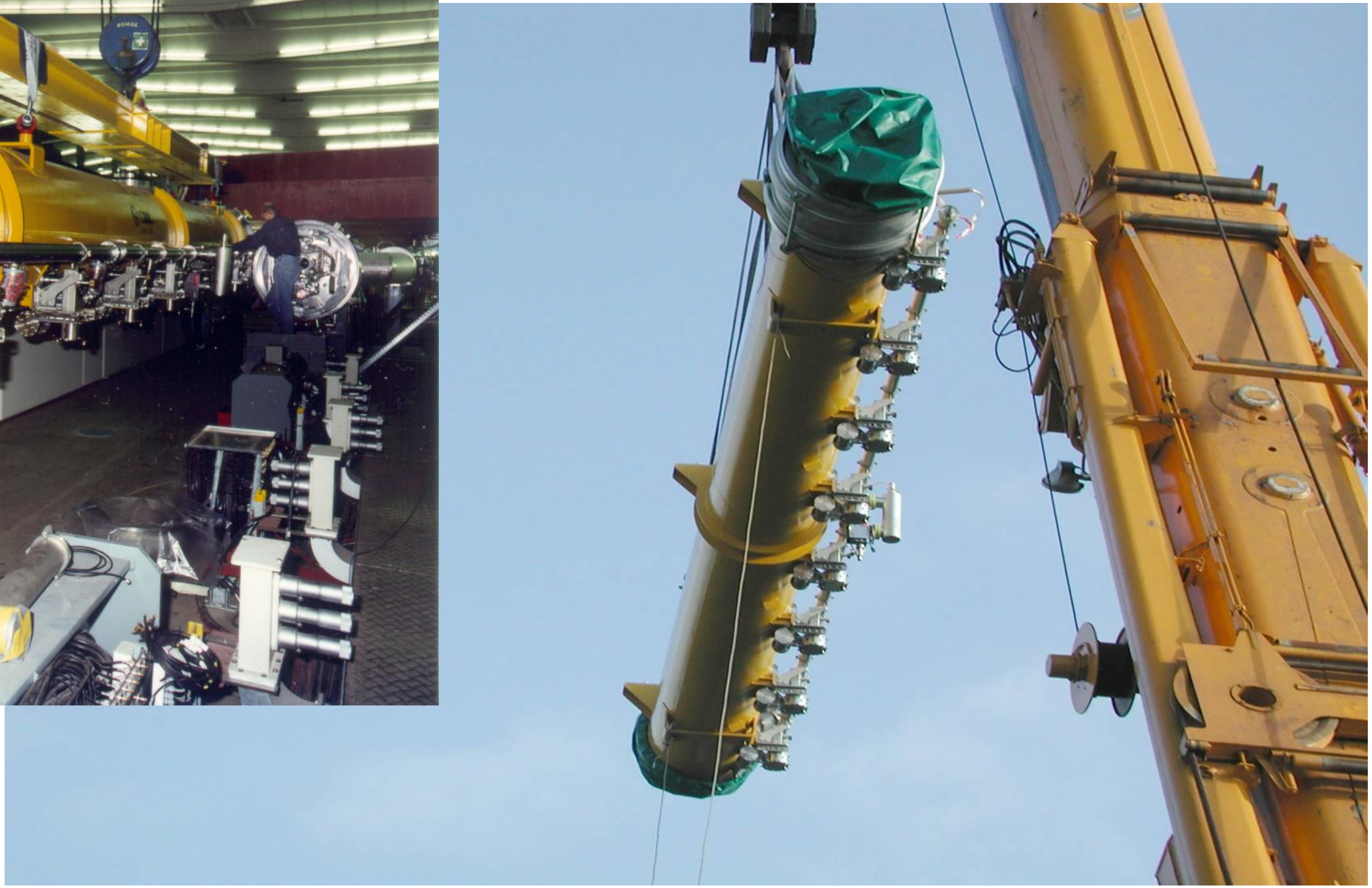
TTF/FLASH technology for EuXFEL (module assembly)

2000+

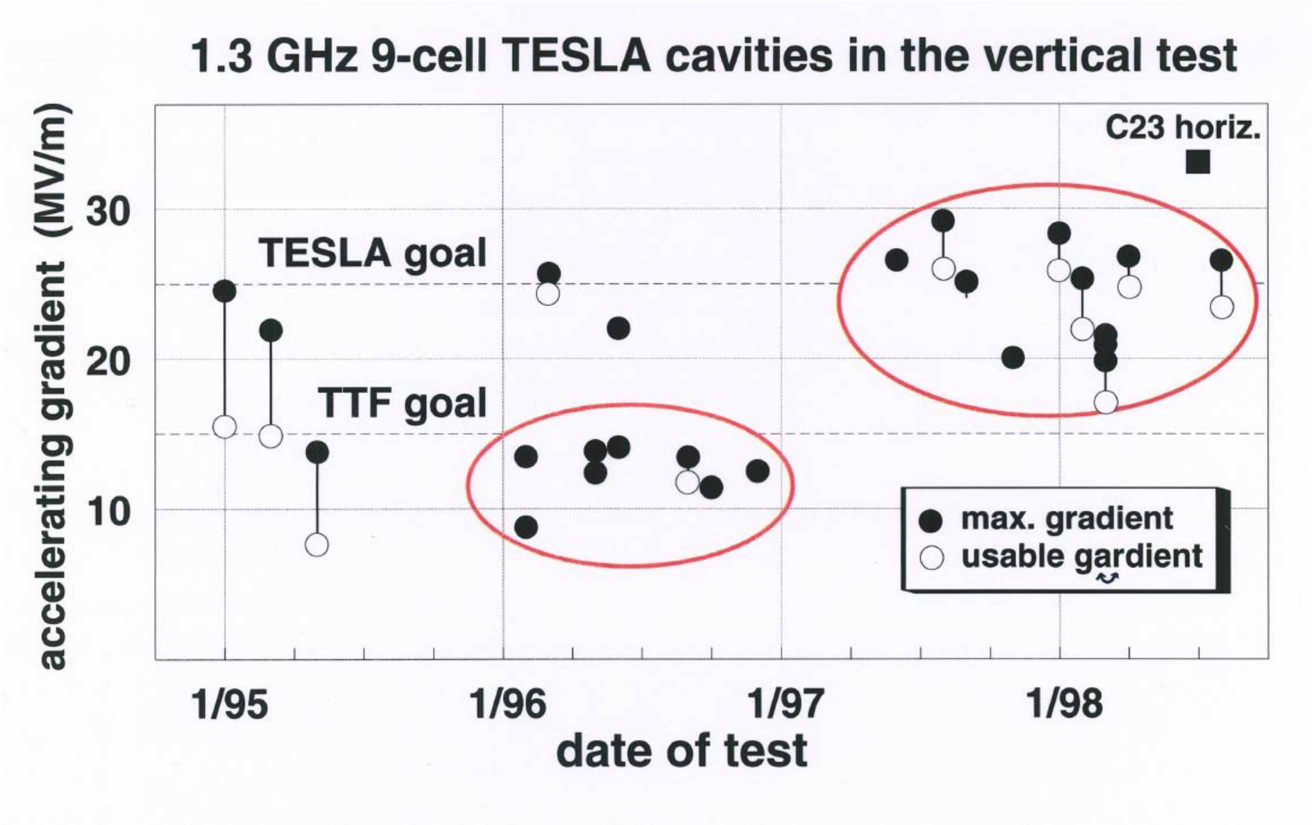
The module assembly is a well defined and standard procedure.

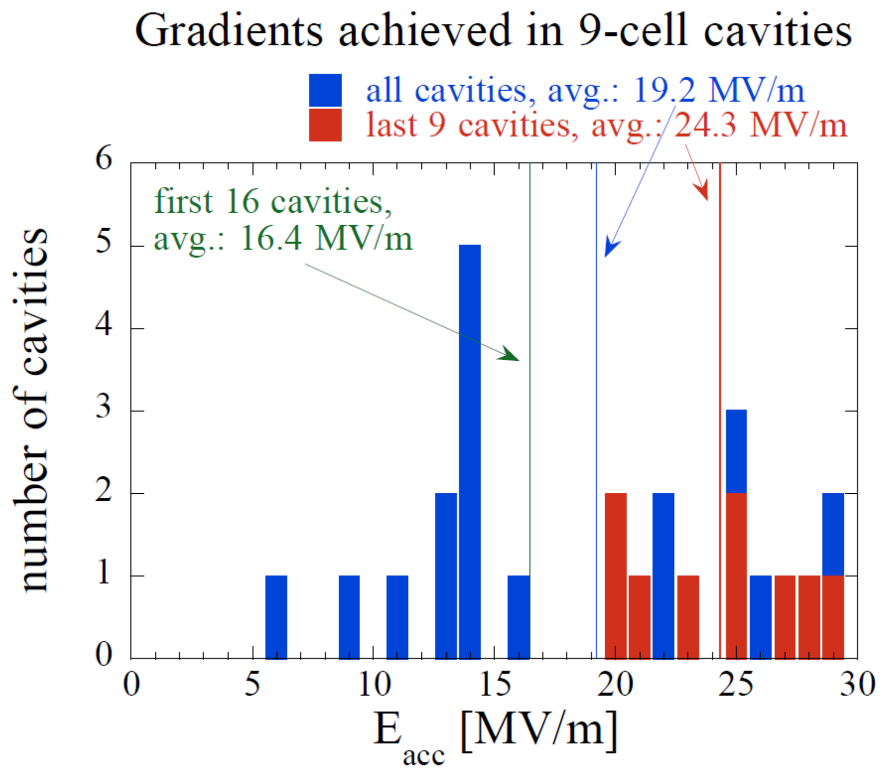
- **experience of 10 modules exists**
- **the latest generation (type III) was used for series production (XFEL requires 120 modules)**
- **several cryogenic cycles as well as long time operation were studied**
- **the assembly problems occurred are well understood and cured**

TTF/FLASH technology for EuXFEL (module installation)

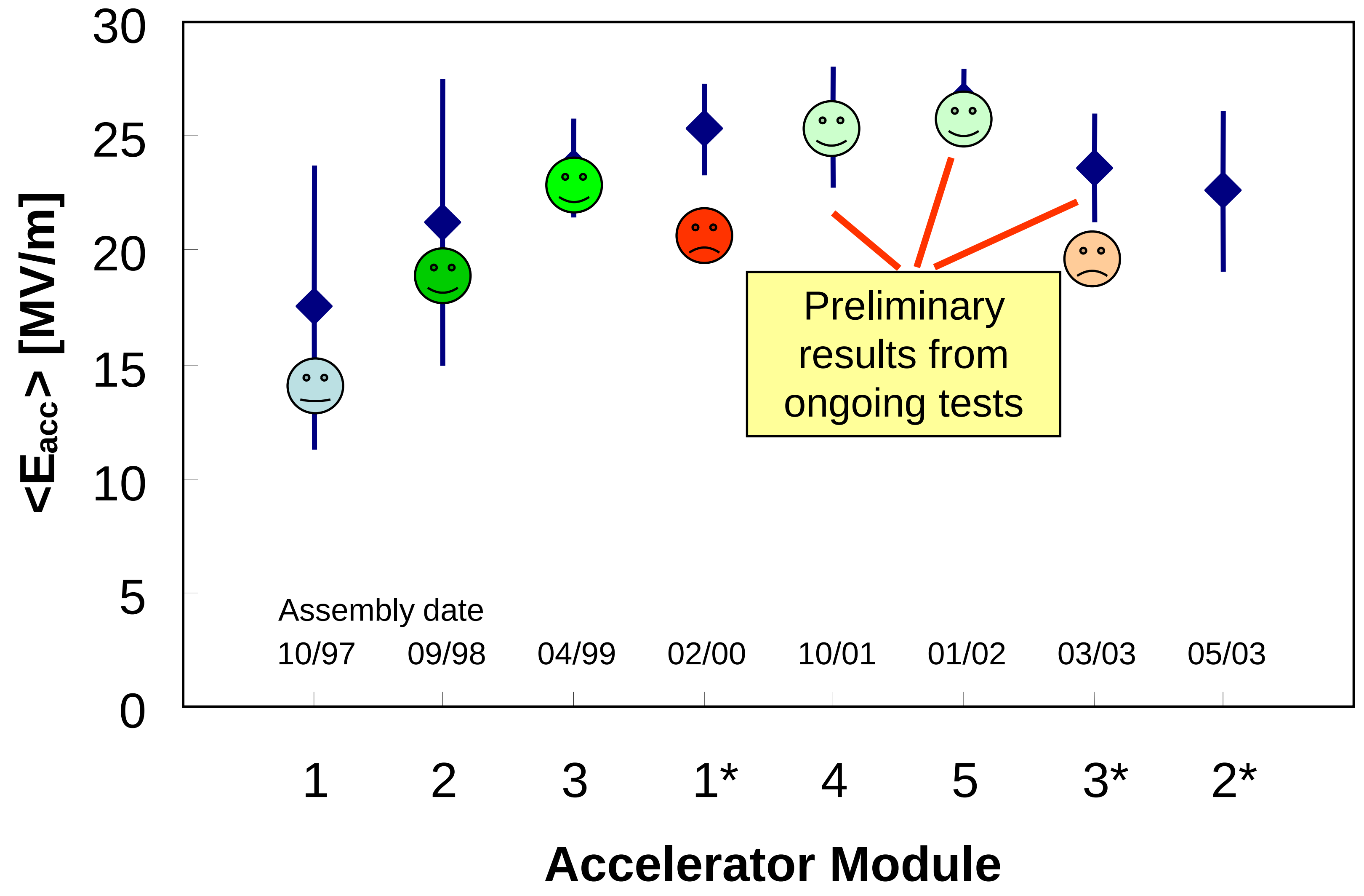


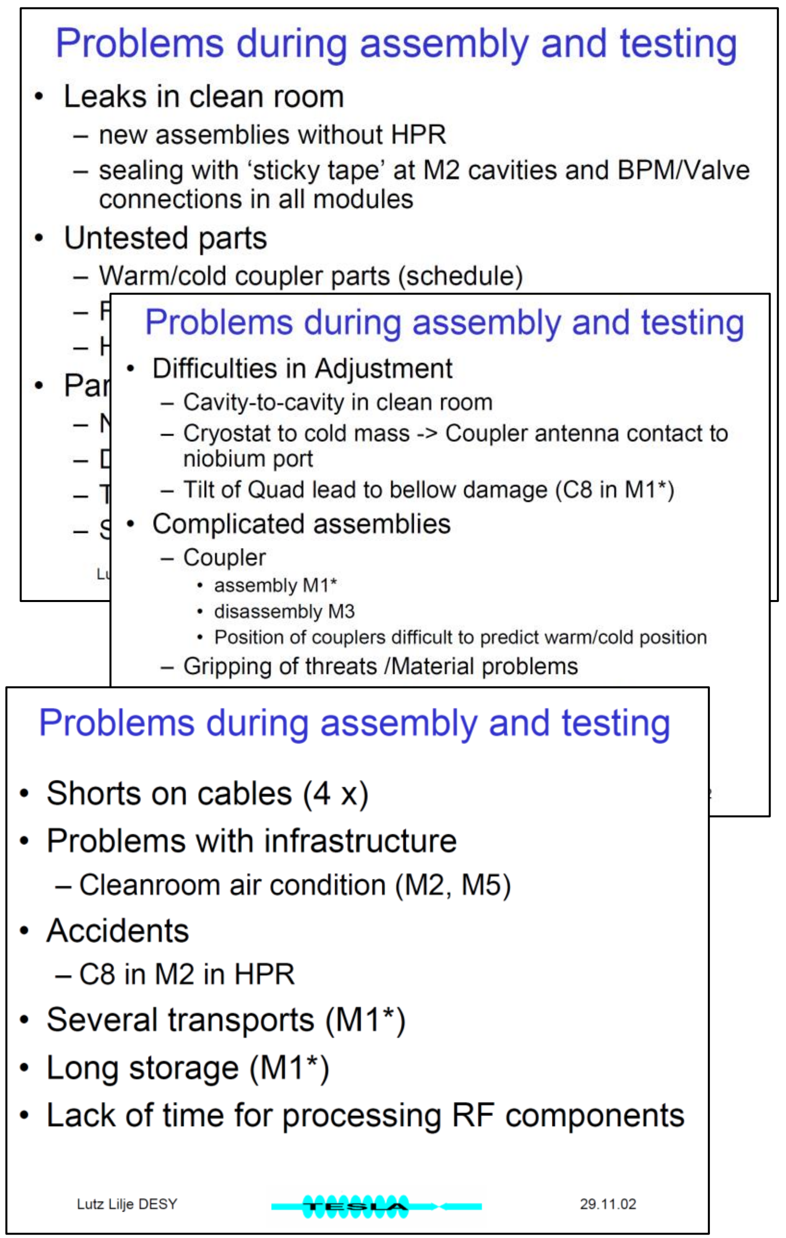
TTF/FLASH technology around year 2000





TTF/FLASH as a module test bed





Problems during assembly and testing

- Leaks in clean room
  - new assemblies without HPR
  - sealing with 'sticky tape' at M2 cavities and BPM/Valve connections in all modules
- Untested parts
  - Warm/cold coupler parts (schedule)
  - F
  - H
- Par
  - N
  - D
  - T
  - S

Problems during assembly and testing

- Difficulties in Adjustment
  - Cavity-to-cavity in clean room
  - Cryostat to cold mass -> Coupler antenna contact to niobium port
  - Tilt of Quad lead to bellow damage (C8 in M1*)
- Complicated assemblies
  - Coupler
    - assembly M1*
    - disassembly M3
    - Position of couplers difficult to predict warm/cold position
  - Gripping of threats /Material problems

Problems during assembly and testing

- Shorts on cables (4 x)
- Problems with infrastructure
  - Cleanroom air condition (M2, M5)
- Accidents
  - C8 in M2 in HPR
- Several transports (M1*)
- Long storage (M1*)
- Lack of time for processing RF components

Lutz Lilje DESY 29.11.02

Exotic and fascinating technology byways

DESY TELEGRAMM

vom 6. Februar 1998

Erster Niob-Resonator ohne Schweißnähte bei DESY gefertigt

Zum ersten Mal wurde im Rahmen der TESLA-Entwicklungen ein einzelliger supraleitender Niob-Resonator durch „Innenhochdruck-Umformung" aus einem nahtlosen Rohr gefertigt. Diese Weltpremiere gelang einer russisch-deutschen Gruppe, die an der Entwicklung nahtloser Resonatoren für den TESLA-Linearbeschleuniger arbeitet.

In Zusammenarbeit mit dem GKSS-Forschungszentrum in Geesthacht, der Universität der Bundeswehr in Hamburg und der Universität Wuppertal wurden die Materialeigenschaften des Niobs eingehend untersucht. Der Umformungsprozeß wurde per Computer simuliert und optimiert und anschließend an einer von dem INR-Institut in Moskau gebauten Maschine bei DESY durchgeführt. Das nahtlose Rohr aus reinem Niob wurde dabei mit Öl gefüllt und unter hohem Druck von innen in eine Form gepreßt – ohne zusätzliche Wärmebehandlung.

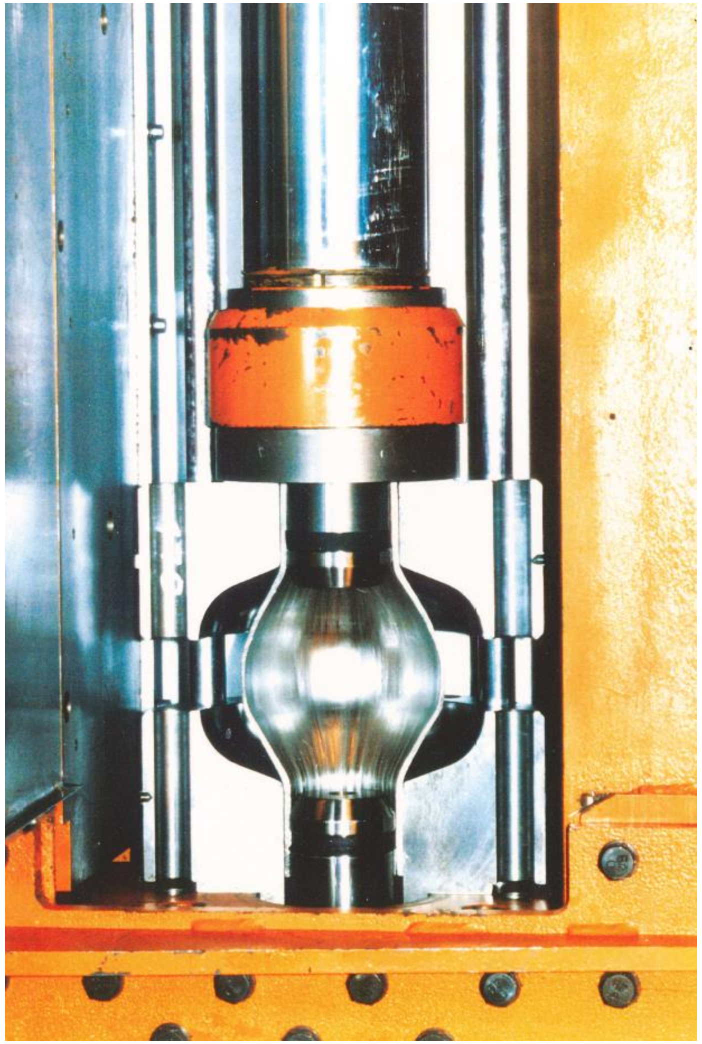
Erklärtes Ziel dieser Entwicklung ist es, durch Vermeiden der bisher notwendigen Schweißnähte an den Resonatoren nicht nur die Material- und Produktionskosten deutlich zu senken, sondern auch die Beschleunigungseigenschaften zu verbessern. Als nächstes steht neben weiteren Verbesserungen des Umformungsprozesses auch die Fertigung von mehrzelligen Resonatoren auf dem Programm.

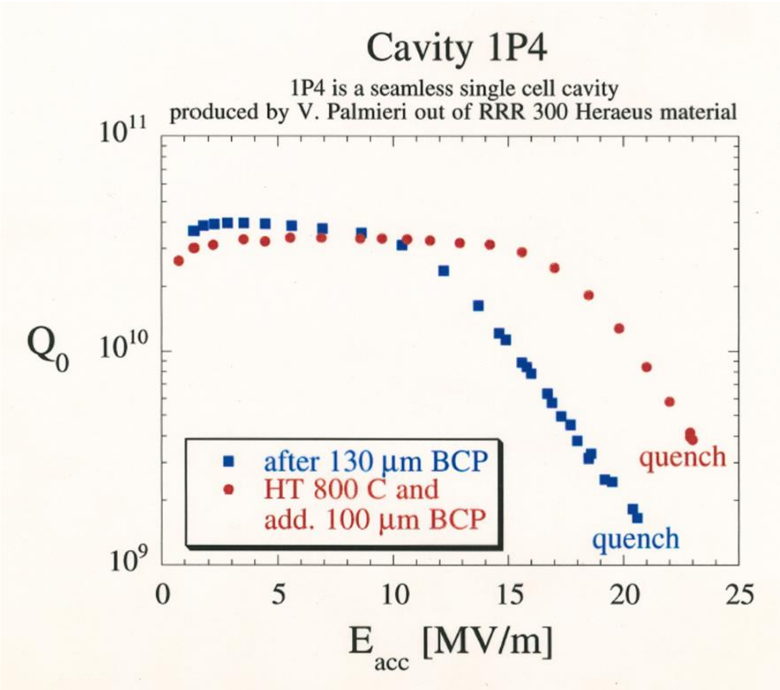
Successful Production of Seamless Niobium Cavity at DESY

For the first time, a single-cell superconducting cavity has been „hydroformed" from a seamless niobium tube at DESY. This world premiere was accomplished by a Russian-German team working on the development of seamless resonators for the planned TESLA linear collider – a technology which is expected not only to reduce material and production costs compared to the current welding technique, but also to improve the accelerating performances.

Development work included studies of the pure niobium's forming properties as well as computer simulations and optimization of the hydroforming process itself, which was then realized on a machine built at the Moscow INR institute. The oil-filled tube was expanded into a mold by the internal oil pressure. Further development plans now comprise improvement of the tubes' forming properties as well as the production of multi-cell cavities.

Herausgegeben von DESY/PR, Aushang bis 16.02.1998





Hydroforming and Spinning were tried out quite extensively by DESY & partners as well as at INFN Legnaro.

Exotic and fascinating technology byways

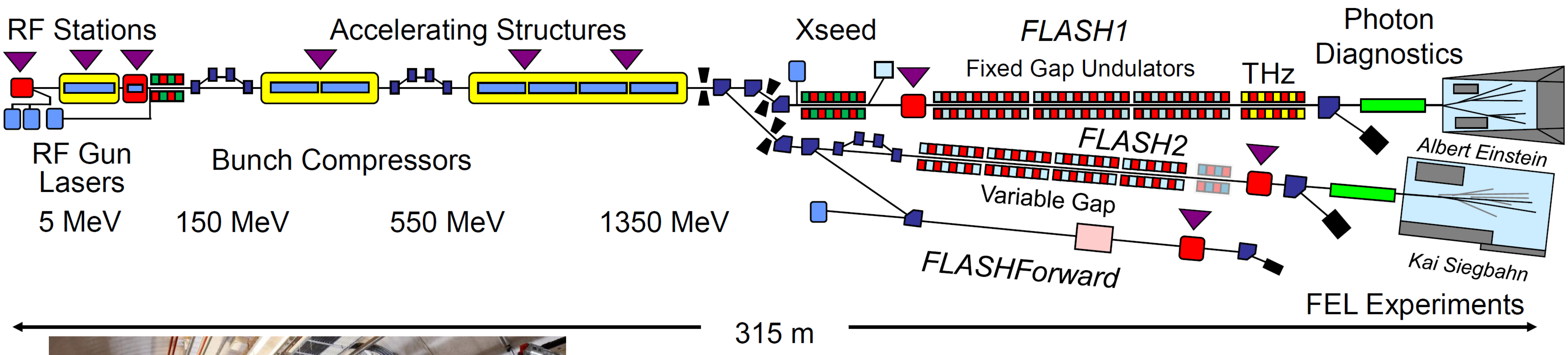
Proceedings of EPAC08, Genoa, Italy MOPP136

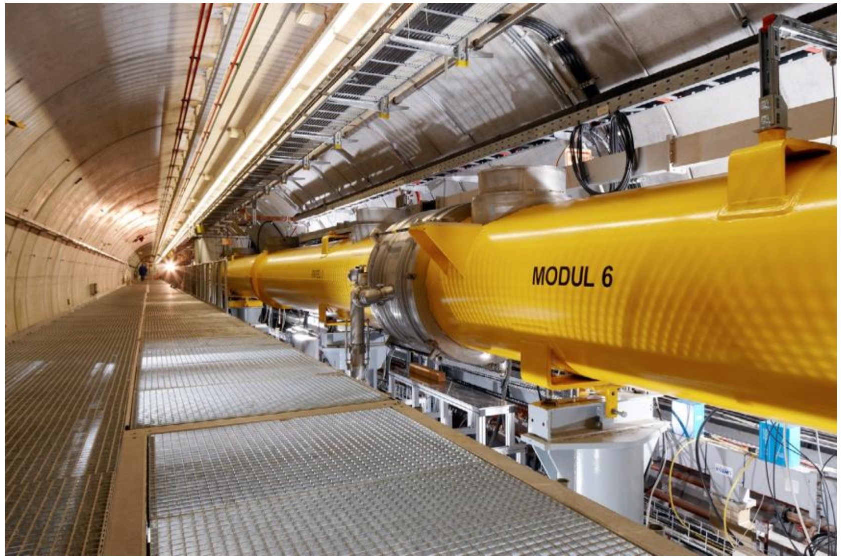
PERFORMANCE OF SINGLE CRYSTAL NIOBIUM CAVITIES*

P. Kneisel[#], G. Ciovati, TJNAF, Newport News, VA 23606, U.S.A.
W. Singer, X. Singer, D. Reschke, A. Brinkmann, DESY, 22603 Hamburg, Germany

Single Crystal SRF cavities made from a special Nb ingot.

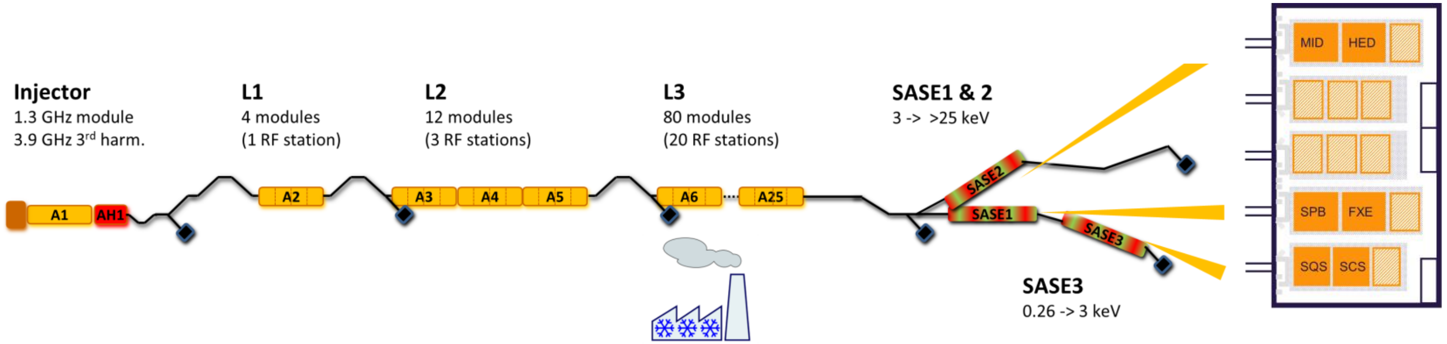
SRF Technology facilitates Science at User Facilities

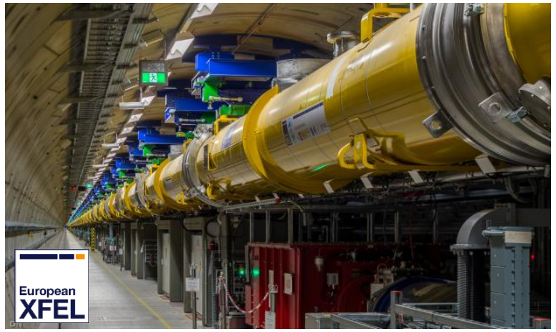


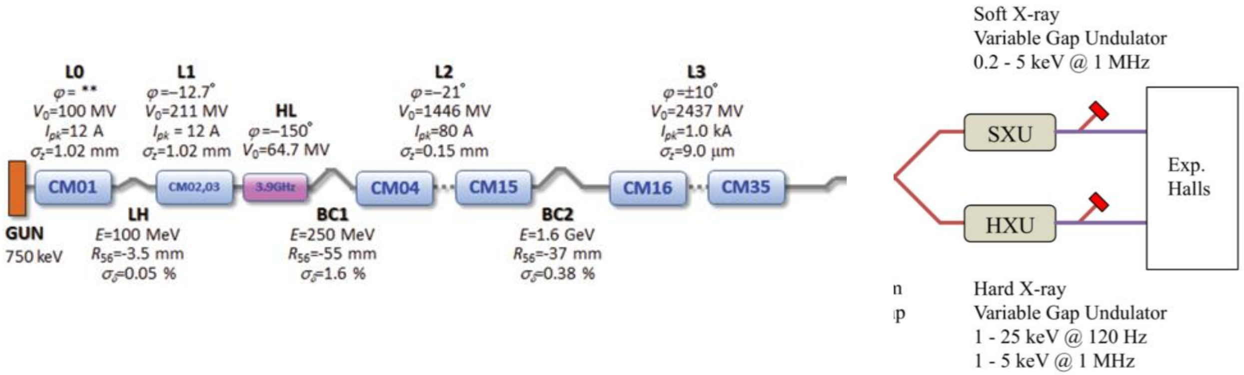


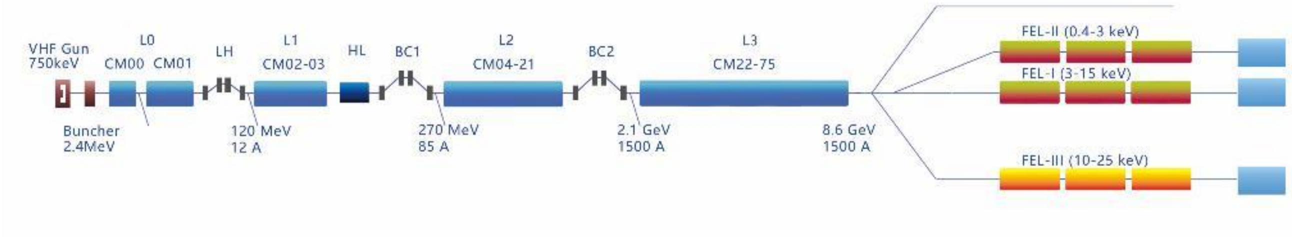
- FLASH paved the way towards large scale facilities.
- The SRF linac technology developed by the TESLA / TTC community is a solid foundation for many research facilities worldwide. With more to come…
  https://tesla.desy.de

FLASH R&D led to so far three large FELs worldwide



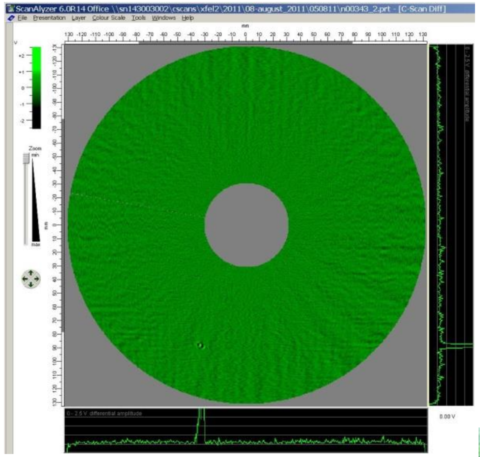


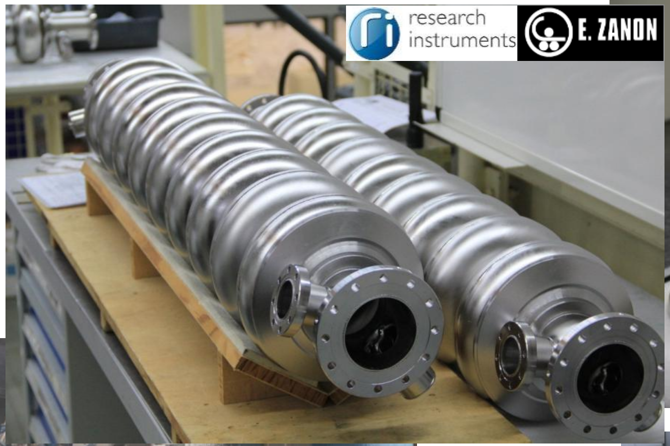




Construction of large XFELs requires industrialization

Industrialization, logistics AND quality management is a must





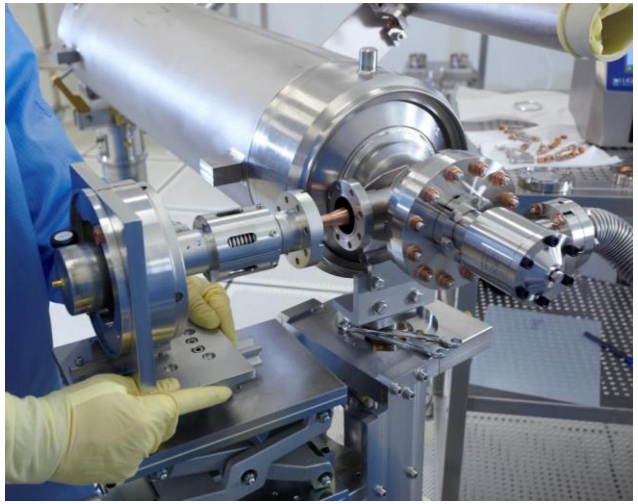
QS of Niobium sheets
(developed for EuXFEL, now done at DESY for very many SRF based (large) scale facilities)

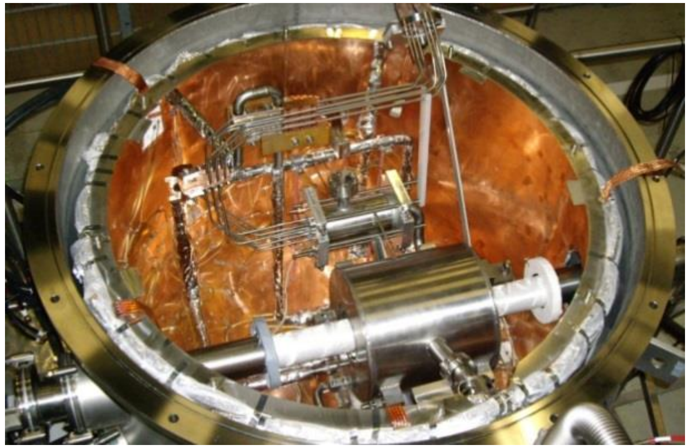
Tools for **successful cavity fabrication in industry** were developed and handed over, and are still maintained by DESY.

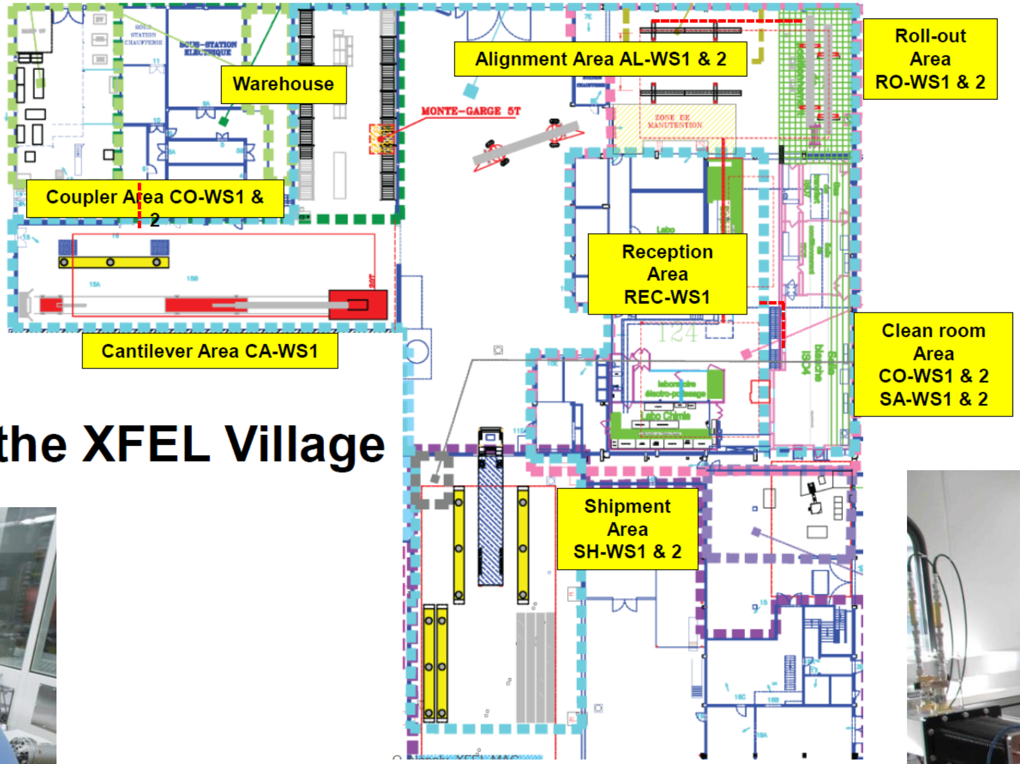
Cavity tuning machine (developed (w/ FNAL support) and handed over, and still maintained by DESY).

Construction of large XFELs requires strong labs

Infrastructure at DESY, CE Saclay, and IJCLab Orsay





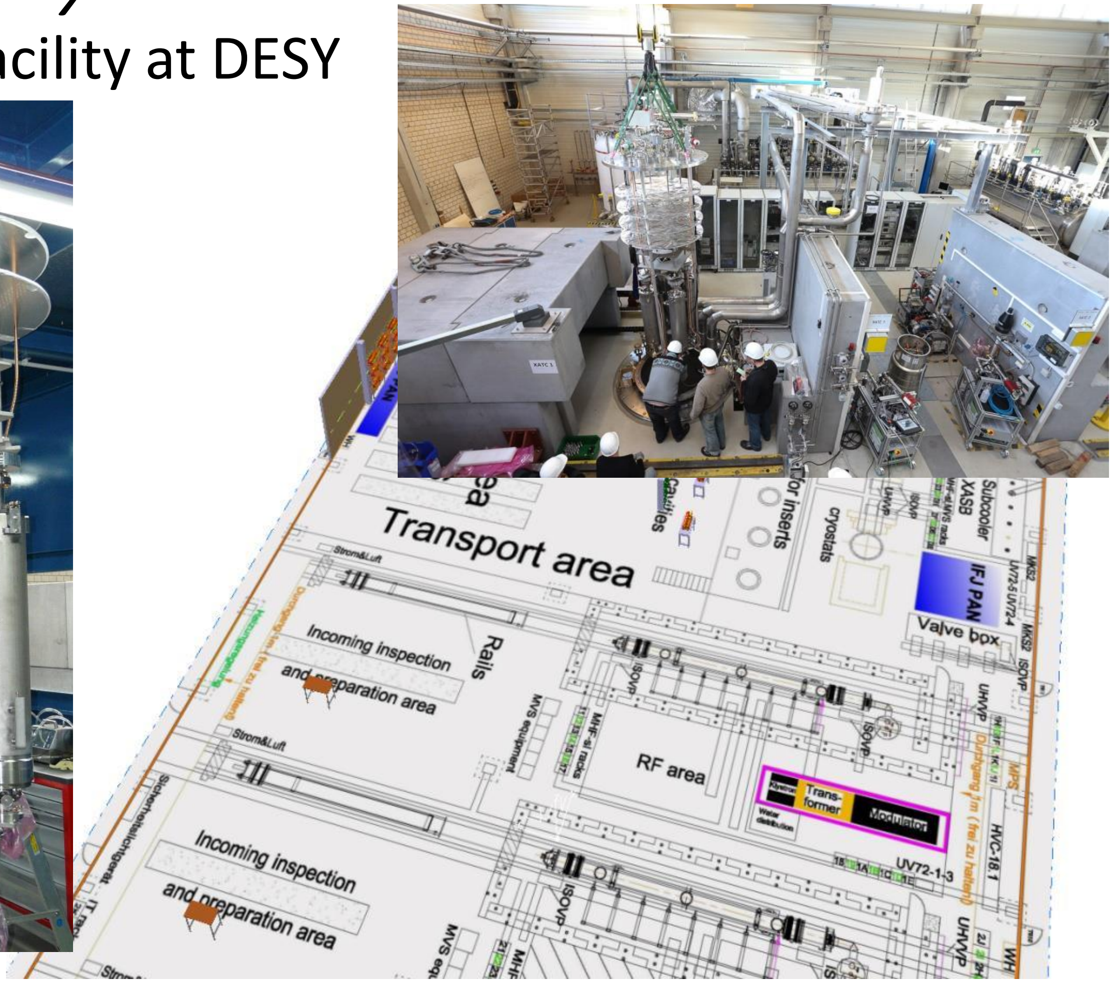


the XFEL Village

Remarkable SRF infrastructure was set-up by several partners of the EuXFEL Accelerator Consortium.

Component testing and quality assurance

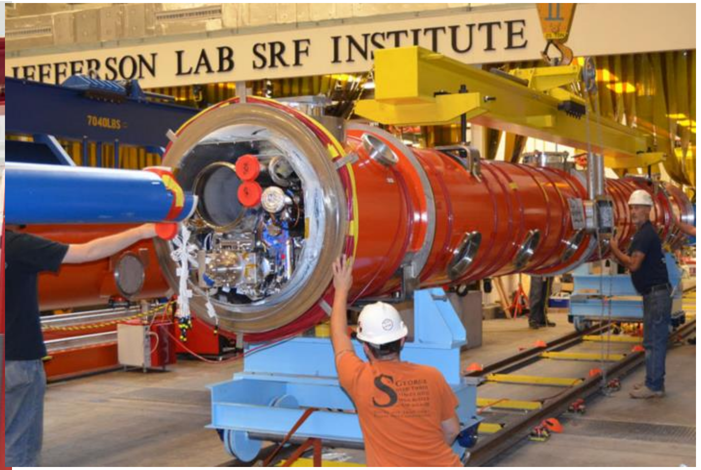
The Accelerator Module Test Facility (AMTF) Facility at DESY



Test stands (cavity & module), for the EuXFEL designed, built and operated, with the help of major in-kind contributions.

New infrastructure at U.S. labs and SHINE

Labs worldwide mimic the DESY / EuXFEL installations with adaptations



LCLS-II

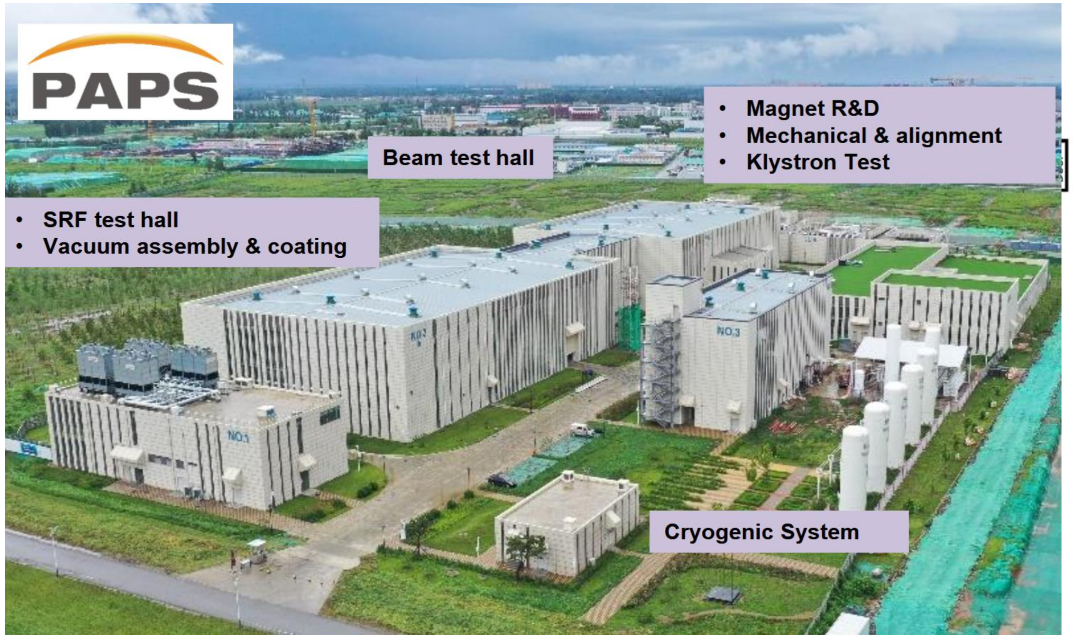
Fermilab

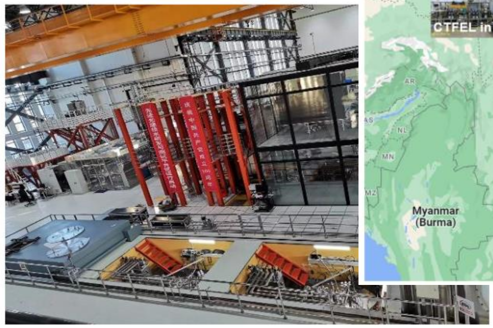
Jefferson Lab

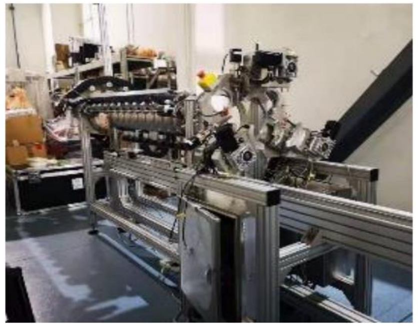
SHINE

… *and more*

Chinese Labs and industry are developing quickly







The FLASH success will continue

As key partner in the TESLA R&D effort

- **we started a great development**
- **we have built FLASH, and are successfully operating a worldwide very visible FEL facility**
- **we established SRF linac technology at large**
- **we were setting the scene for SRF based hard X-ray FELs**
- **we successfully operate the longest SRF linac worldwide to drive the European XFEL with highest reliability**
- **we are further developing SRF technology, well embedded in the SRF community**
- **we are looking forward to seeing even more benefit from our 30+ year R&D**

- **we enjoyed working with partners and friends**
- **we can all be happy and proud of what we have reached during the last 25+ years**
- **we still have excellent ideas**