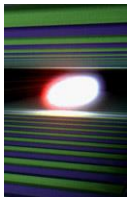
THE EUROPEAN XFEL

HOW TO PRODUCE 100 SUPERCONDUCTING MODULES IN COLLABORATION AND WITH INDUSTRY

Winni Decking, for the Accelerator Consortium

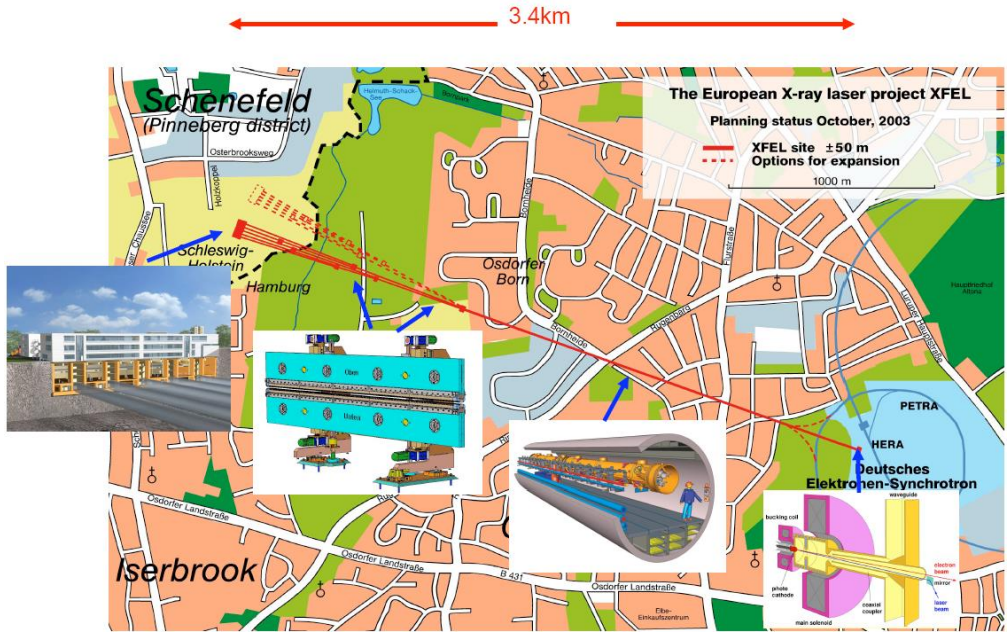
Courtesy: based on talk given by Hans Weise at IPAC14
with many pictures from D. Noelle / DESY & others
incl. E. Zanon & Research Instruments

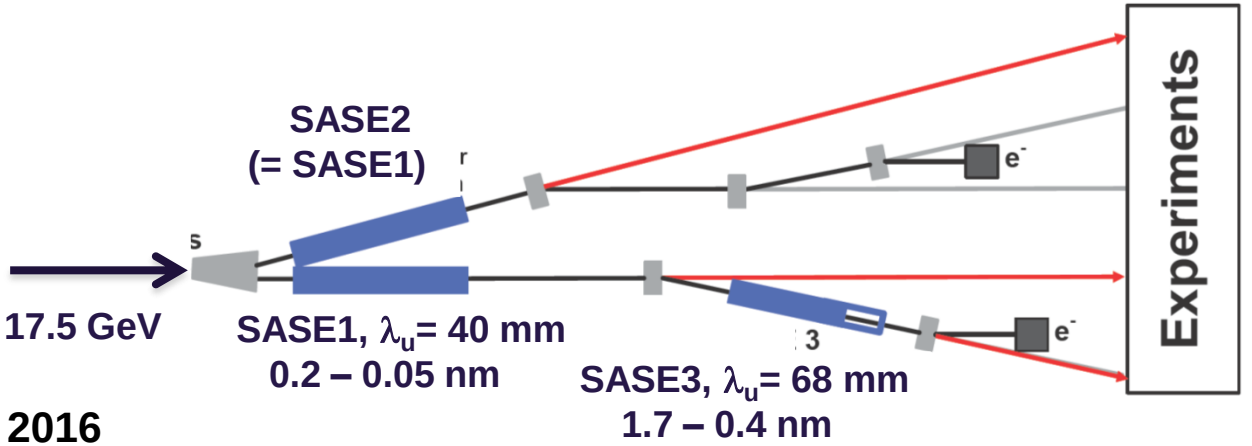
The European XFEL
Built by Research Institutes from 12 European Nations



Some specifications

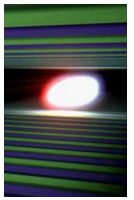
- Photon energy 0.3 - 24 keV
- Pulse duration ~ 10 - 100 fs
- Pulse energy few mJ
- Superconducting linac. 17.5 GeV
- 10 Hz (27 000 b/s)
- Max. beam power 600 kW
- 5 beam lines / 10 instruments
  - Start version with 3 beamlines and 6 instruments
- Several extensions possible:
  - More undulators
  - More instruments
  - …….
  - Variable polarization
  - Self-Seeding
  - CW operation



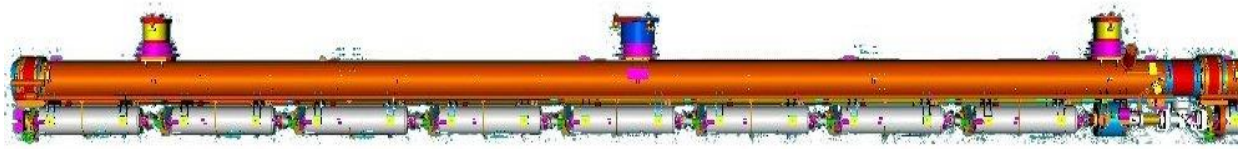


First electron beam 2nd half of 2016

An Accelerator Complex for 17.5 GeV

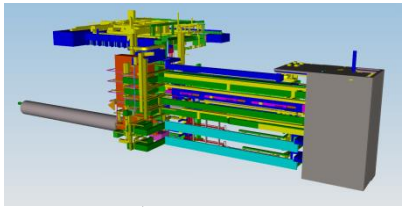


100 accelerator modules

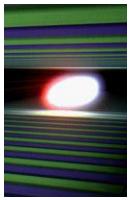


800 accelerating cavities
1.3 GHz / 23.6 MV/m

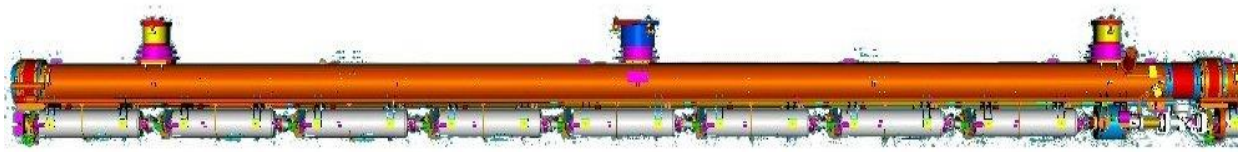
25 RF stations
5.2 MW each



Contributors to the XFEL Accelerator



100 accelerator modules



800 accelerating cavities

1.3 GHz / 23.6 MV/m

DESY

HELMHOLTZ ASSOCIATION

INFN Istituto Nazionale di Fisica Nucleare

irfu cea saclay

cnrs In2p3

MINISTERIO DE EDUCACIÓN Y CIENCIA

Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

Wrocław University of Technology

ncbj

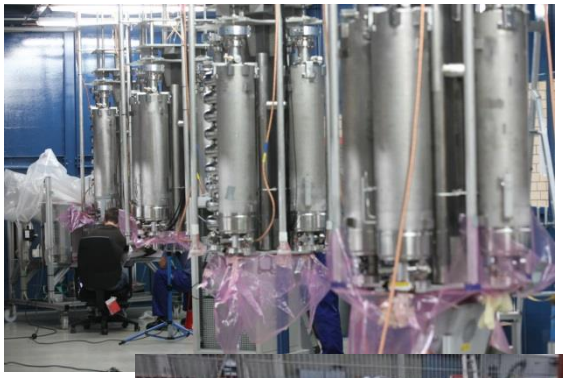
UPPSALA UNIVERSITET

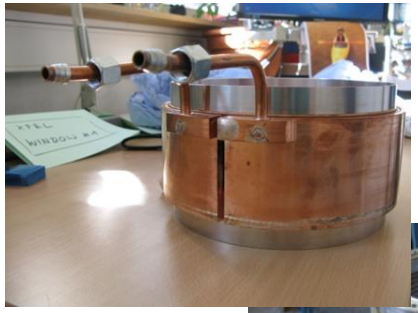
Stockholm University

PAUL SCHERRER INSTITUT PSI

European XFEL

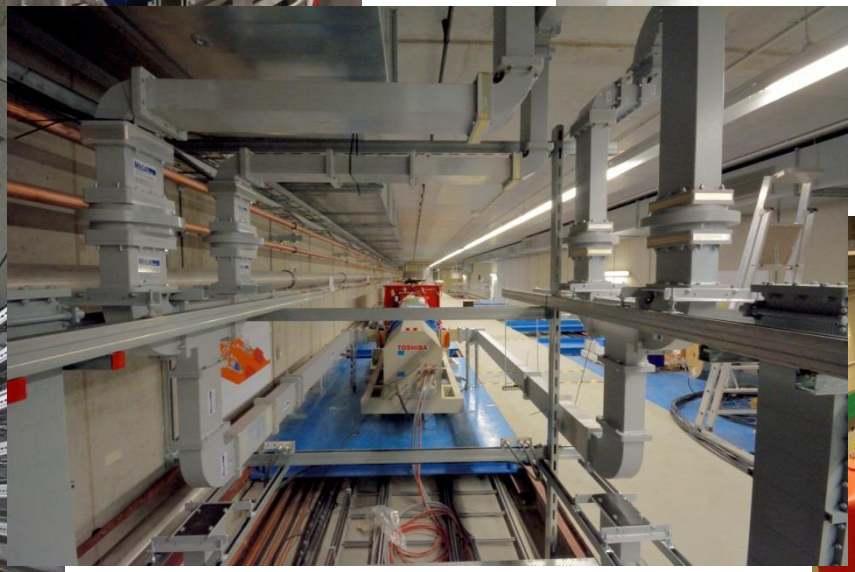
Production of Accelerator Components





European XFEL

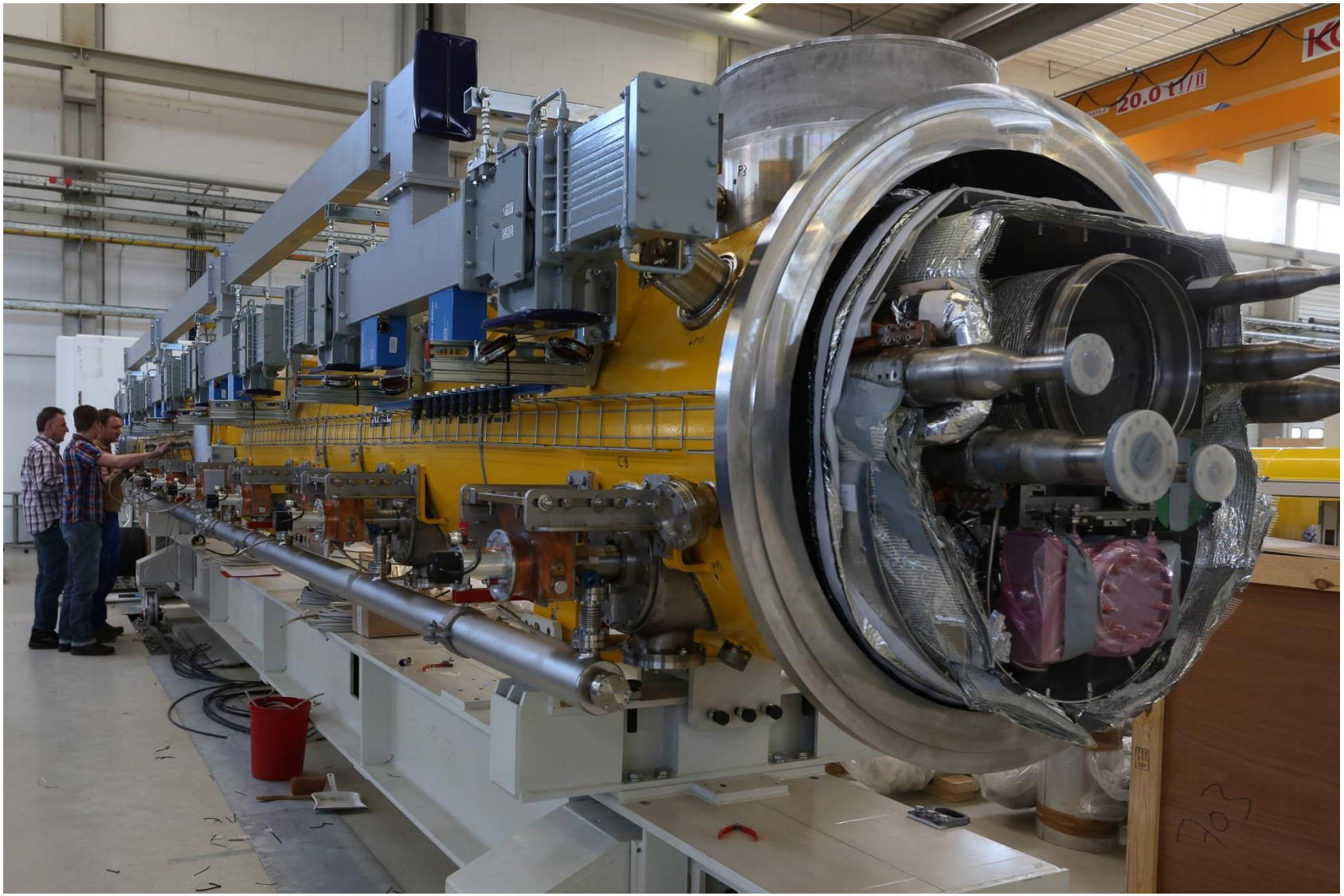
Installation



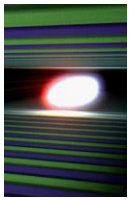
European XFEL

Installation Test

XFEL Accelerator Module with Tailored Waveguide System



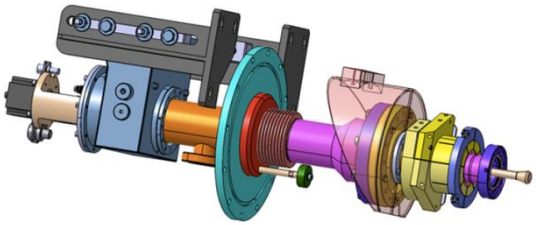
Contributions to the European XFEL Modules

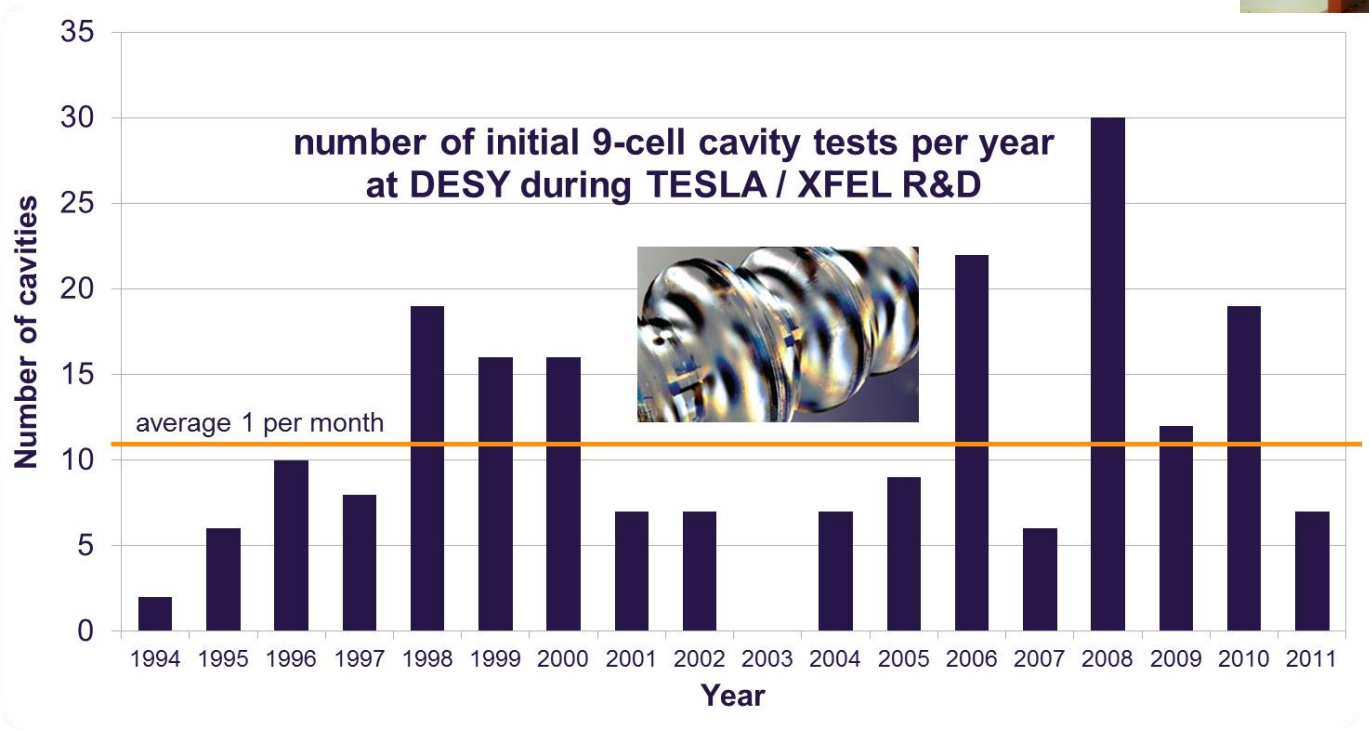


BINP Novosibirsk, Russia	• cold vacuum bellows • coupler vacuum line
CEA Saclay / Irfu, France	• cavity string and module assembly • cold beam position monitors • magnetic shields, superinsulation blankets
CIEMAT, Spain	• Superconducting magnets
CNRS / LAL Orsay, France	• RF main input coupler incl. RF conditioning
DESY, Germany	• cavities & cryostats • contributions to string & module assembly • coupler interlock • frequency tuner • cold vacuum system • integration of superconducting magnets / current leads • cold beam position monitors
INFN Milano, Italy	• cavities & cryostats • contributions to frequency tuners
Soltan Institute, Poland	• Higher Order Mode coupler & absorber

Production Rate of Key Components

European XFEL requires **8 cavities & couplers** to build **1 module per week**





monthly average was to increased by approximately

x 30

Cavity Production (here at Company RI)

all pictures courtesy Research Instruments

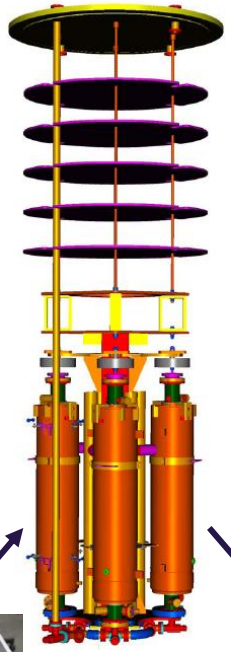
Cavity Production (here at Company E. Zanon)

800 XFEL Cavities Travel Through Europe

research instruments

E. ZANON

DESY



DESY Germany

CEA / Irfu France

irfu cea saclay

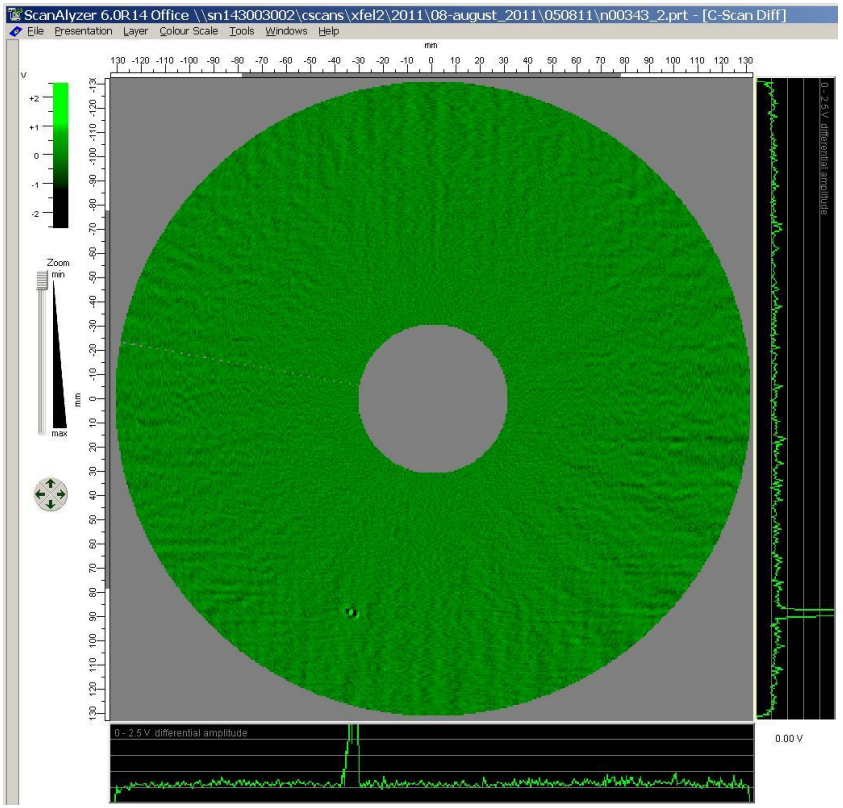
- two cavity vendors were contracted to produce 400 cavities each
- slight variation in final surface treatment

- all cavities are tested and partly re-treated / re-tested in collaboration of IFJ / DESY

- further assembly takes place at CEA Saclay / Irfu

Niobium Material Bought and QC-ed by DESY

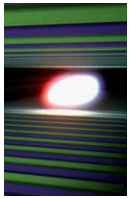
- All Nb / NbTi material (24,420 single parts!) was procured by DESY.
- Detailed quality inspection was developed and carried out.
- All material available to cavity vendors.

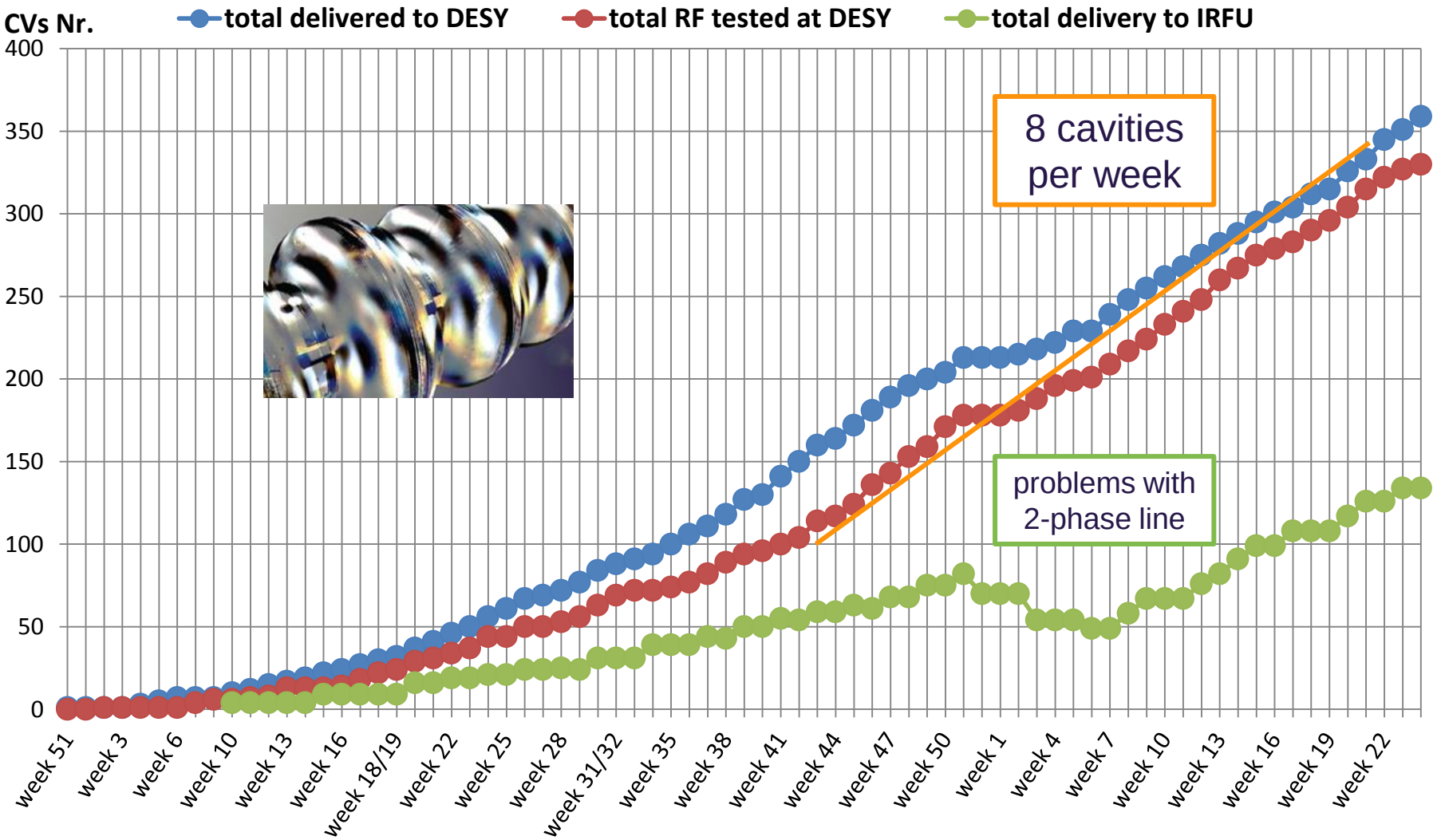


Industrial Cavity Production Relies on DESY & INFN Supervision

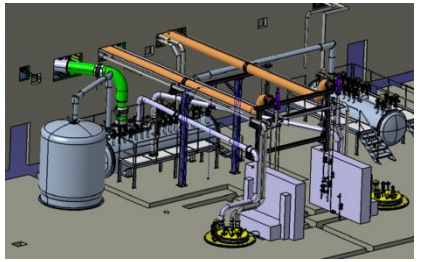
- Special CE certified machines were developed and given to industry.
- Since accelerator cavities are delivered without performance guarantee, very detailed specifications are used.
- Many productions steps are supported and partly supervised by DESY & INFN.
- Several QC steps are established. Very detailed documentation.

Cavity Delivery Status as of 6/2014





AMTF Test Stand Infrastructure

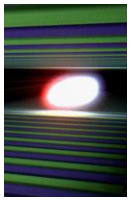


European XFEL

Vertical Cavity Testing at DESY

DESY HELMHOLTZ ASSOCIATION

Cavity Results



- **Mechanical production + surface treatment** in full + standard operation
- **Vertical cavity testing** and all work flows at AMTF are well established

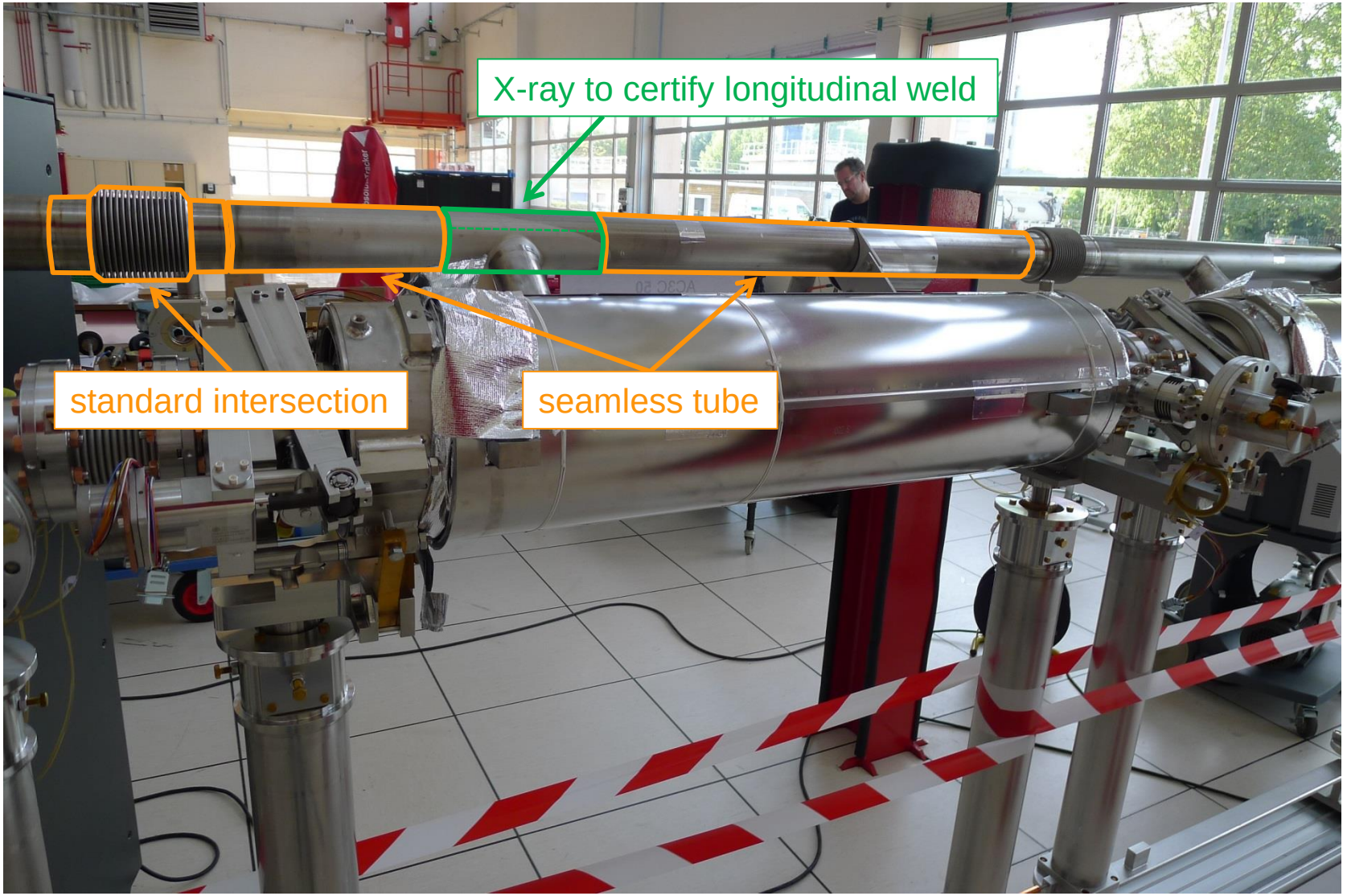
- **Gradients** in average above specification (almost 300 cavities tested)
  - Average usable gradient after delivery (26.8 ± 7.1) MV/m
  - 2/3 of cavities can be used w/o further treatment
  - 1/3 is getting additional treatm. -> usable grad. increased to (29.6 ± 5.1) MV/m
- **Re-treatment gives significant improvement**
  since ~100 additional treatments / tests for initial gradients < 20MV/m give a projected **energy gain of approx. 1300 MeV**

- Vertical testing incl. re-treatment & re-testing can be finished in time with realistic assumptions based on experience gained so far

European XFEL

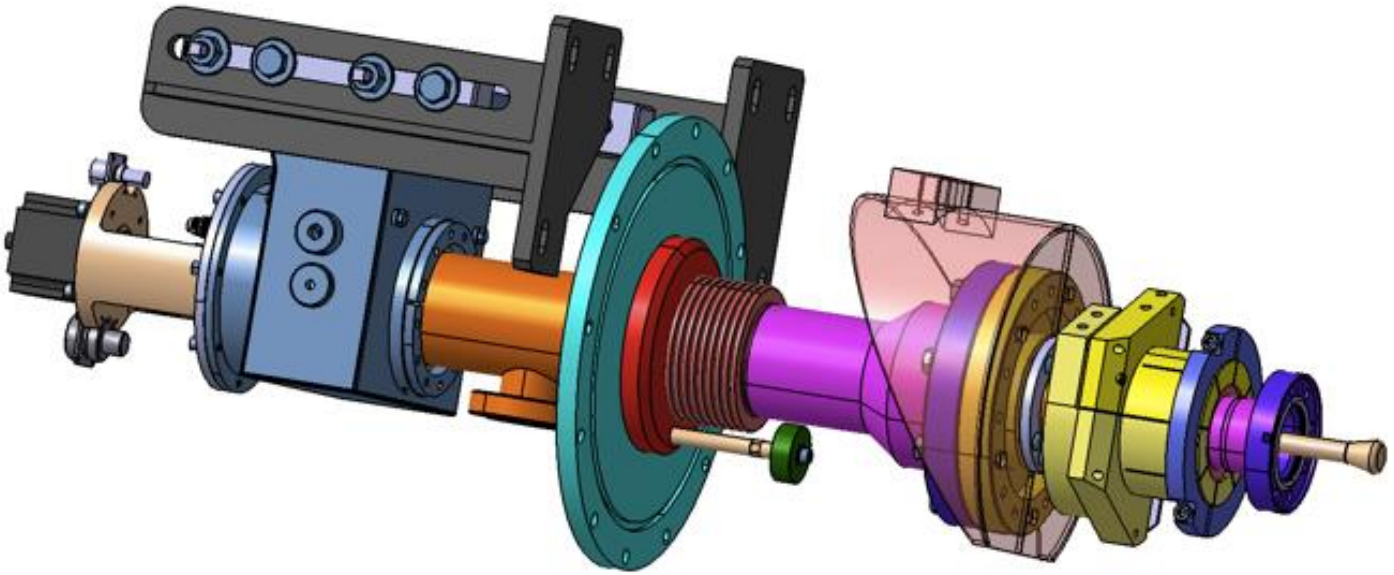
Cavities (Ready for Transport to IRFU)

2-Phase Line (Service Pipe) Needs and Gets Systematic Repair Work

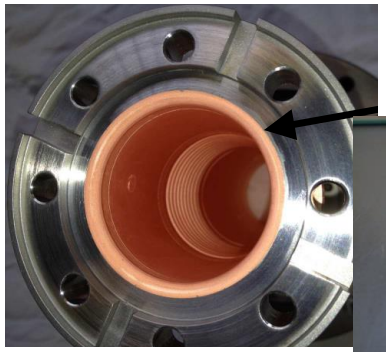
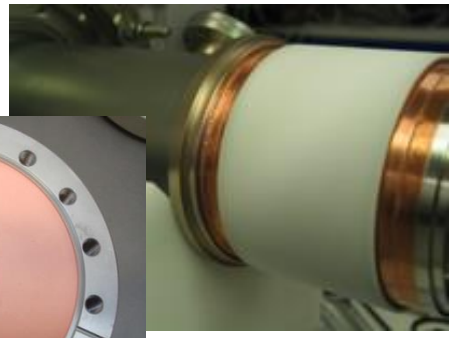
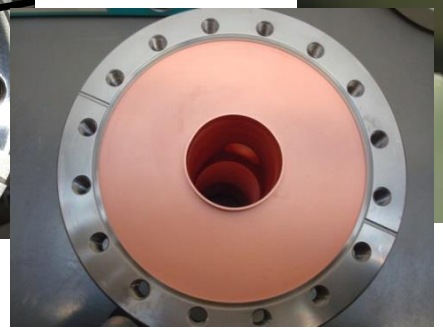


RF Power Couplers

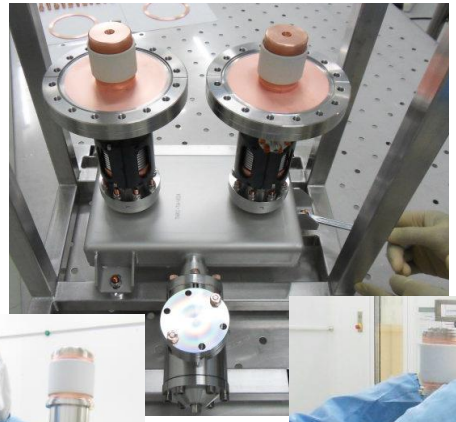
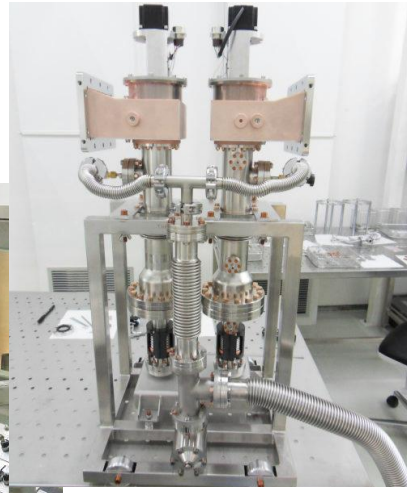
- Ramp-up of RF power coupler production at Thales / RI needed more time than assumed.
- The problem was the copper plating which requires perfect cleanliness of stainless steel surfaces.
- Reproducibility of copper plating remains challenging.
- In general excellent quality control is required to reject bad parts early during production.

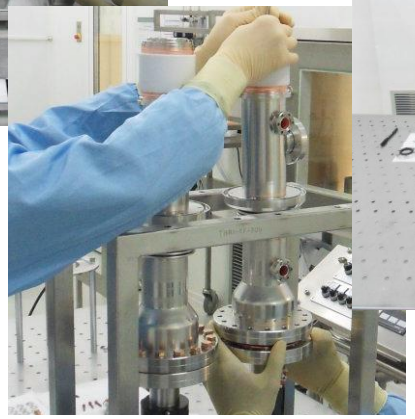


Coupler Fabrication

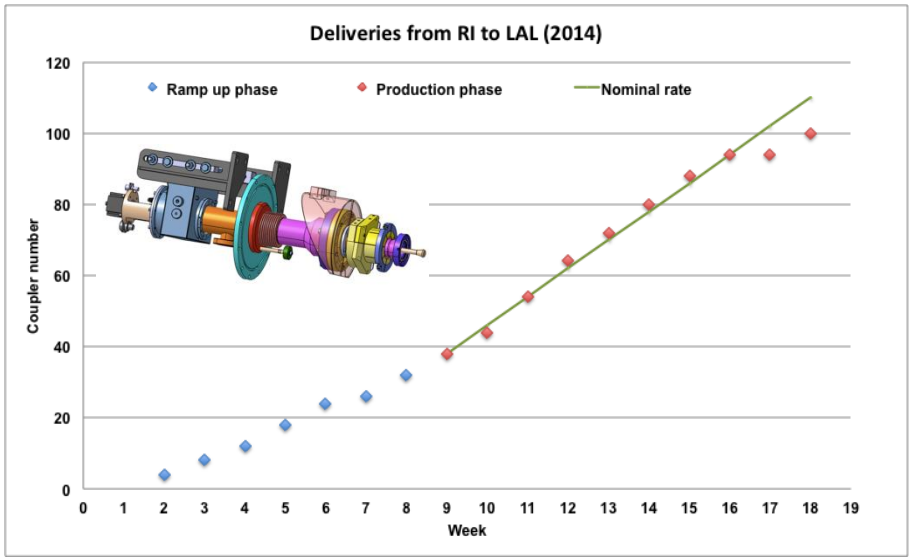


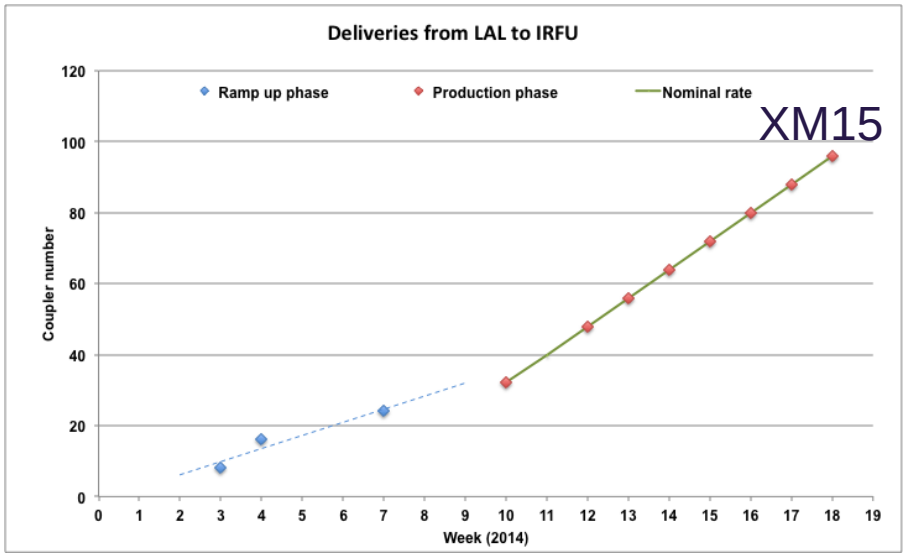



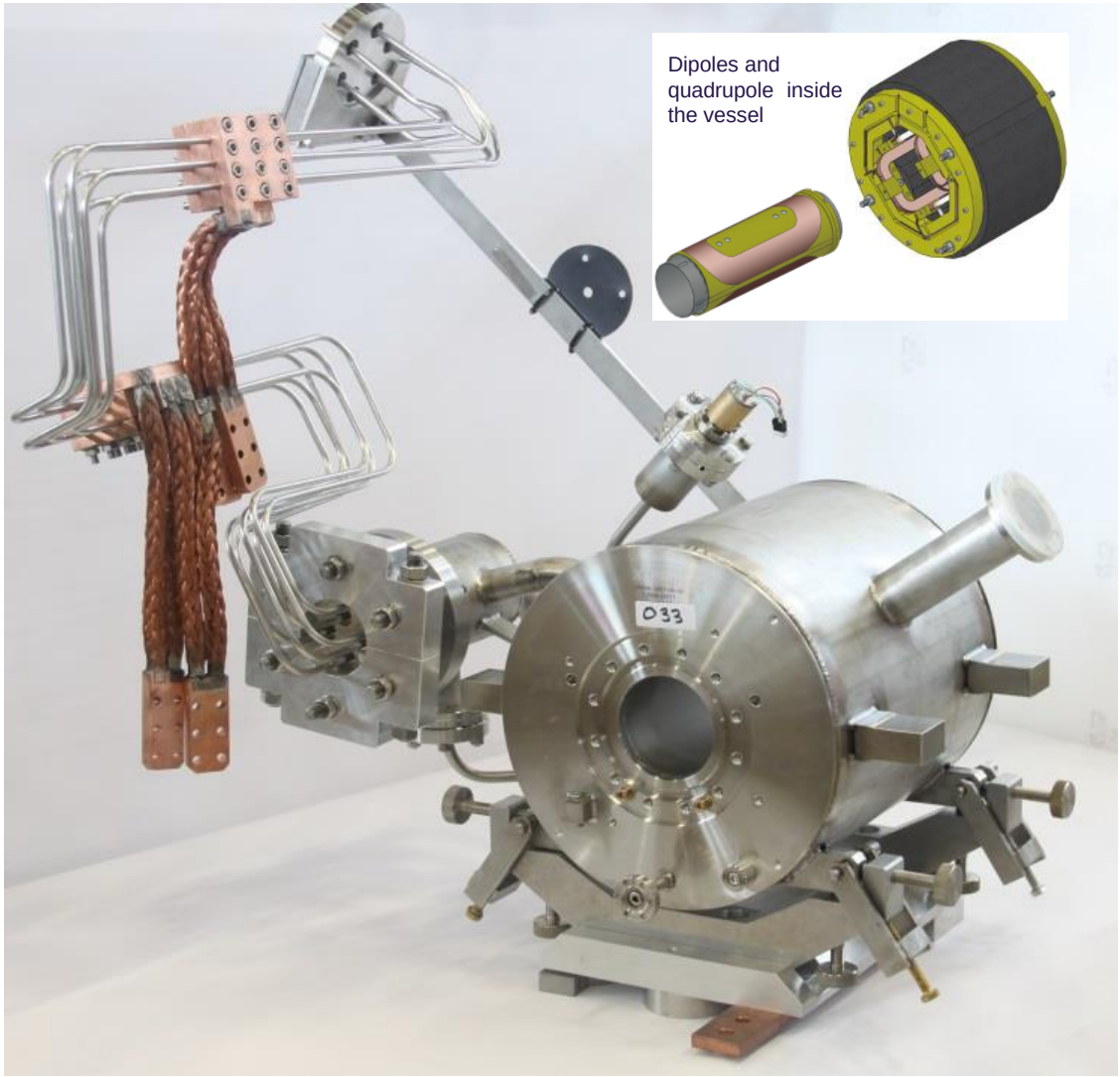
Coupler Pairs Installation in the RF Test Stands

RF Power Coupler Delivery Status as of 4/2014



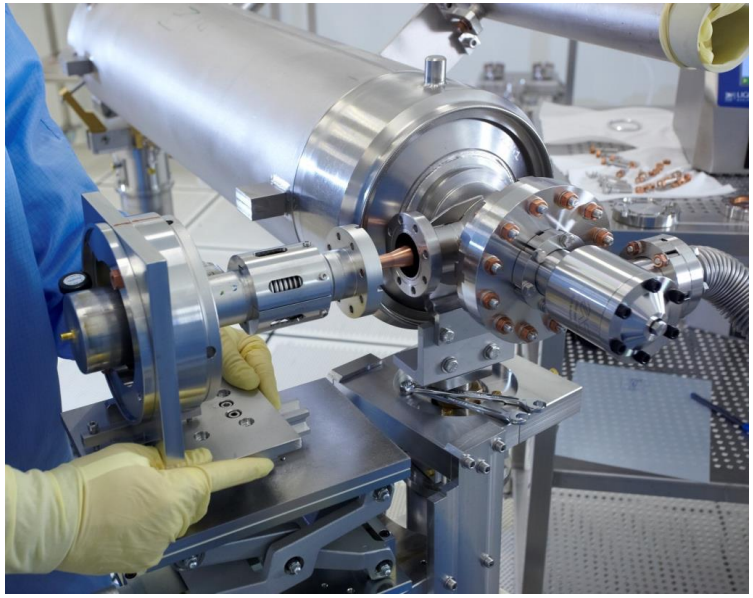


Cold Magnets

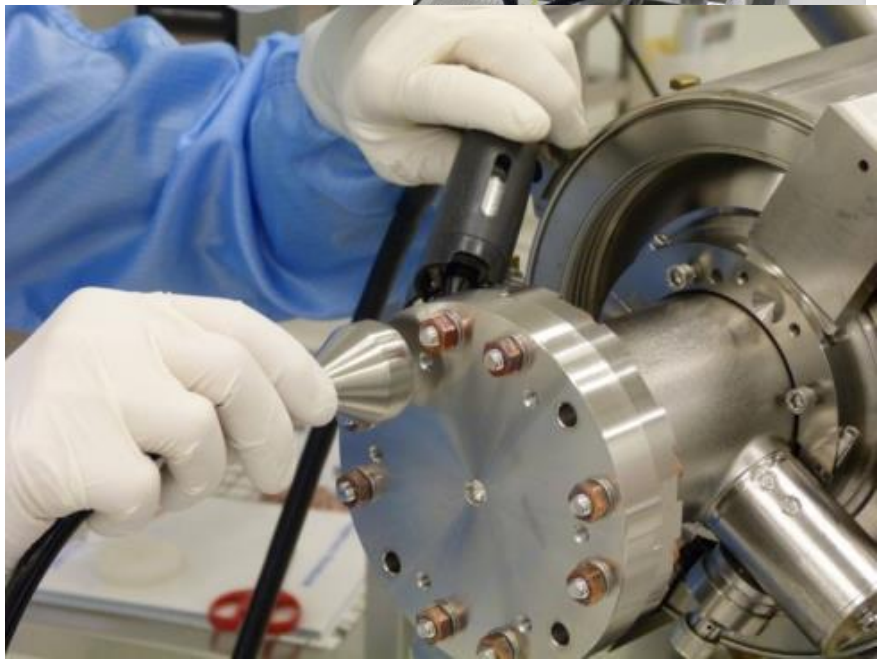


- 80 (of 100) magnets at DESY
- 67 cold tested
- 48 copper plated
- 20 BQU assembled
- 10 BQU's shipped

Cavity String Assembly at CEA Saclay / Irfu



Assembly is performed by external company (ALSYOM) under CEA supervision

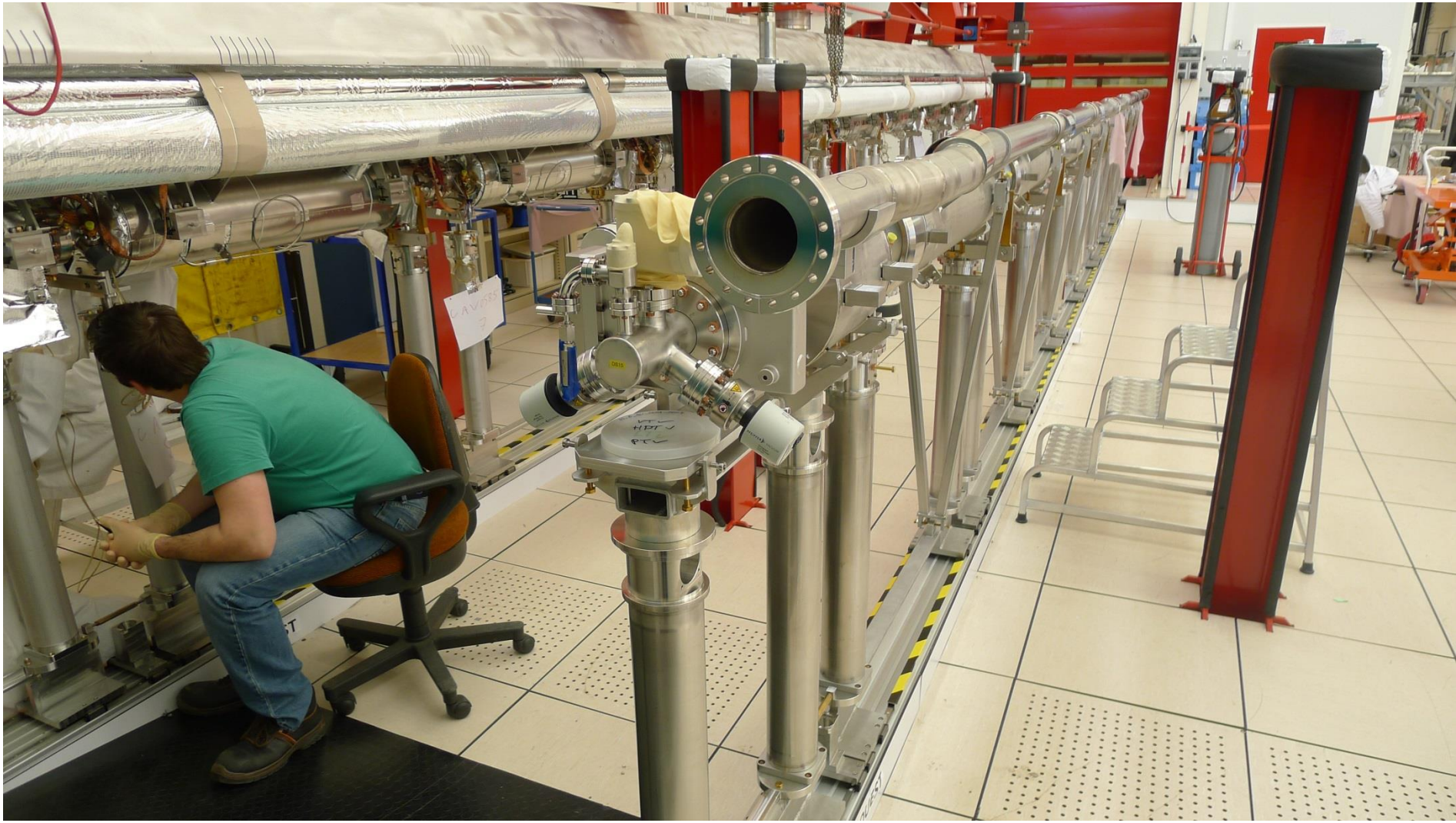


European XFEL

Accelerator Cavity String Assembly at Irfu (XM4)

European XFEL

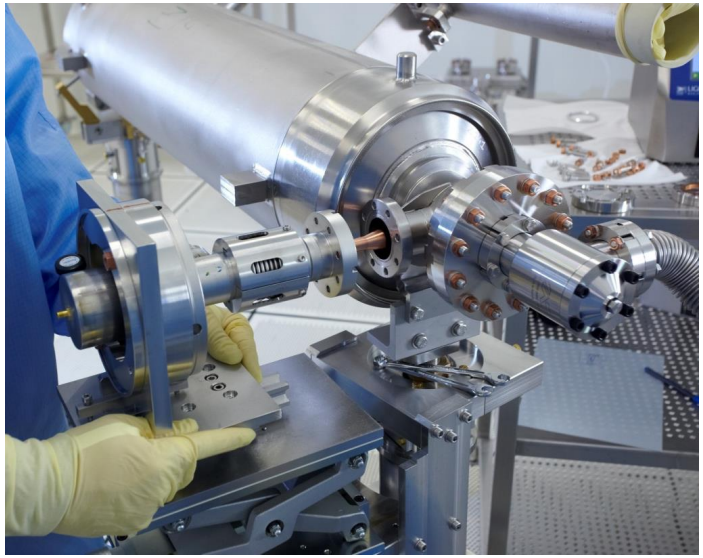
String / Cold Mass Marriage (XM3 & XM4)



cea SACLAY DESY HELMHOLTZ ASSOCIATION

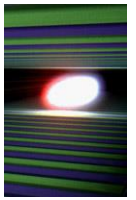
RF Power Coupler Assembly
Transport Caps / Final Checks / Shipment

Module Assembly – Buffers are Filled



- string and module assembly relies on sufficiently filled buffers for all parts
- at present parts available at CEA for at least the next 4 modules
  - Cavities
  - Couplers
  - BQU
  - Vacuum parts (bellows / gate valves)
  - Cryostats
  - Magnetic shielding
- transportation boxes and parts-in-circulation are an issue; quick return is a must

Accelerator Module Assembly Chart



	WBS	Nom de la tâche	Duration	Start	Finish
107	4	Series Modules	344 days?	Tue 03.09.13	Tue 03.05.16
108	4.1	XM1 Assembly	131 days	Tue 03.09.13	Tue 25.03.14
118	4.2	XM2 Assembly	116 days	Wed 16.10.13	Wed 16.04.14
128	4.3	XM3 Assembly	96 days?	Thu 21.11.13	Wed 23.04.14
140	4.4	XM4 Assembly	78 days	Tue 07.01.14	Wed 30.04.14
150	4.5	XM5 Assembly	56 days	Mon 24.02.14	Mon 19.05.14
160	4.6	XM6 Assembly	50 days	Mon 17.03.14	Fri 30.05.14
170	4.7	XM7 Assembly	45 days	Mon 31.03.14	Fri 06.06.14
180	4.8	XM8 Assembly	40 days	Mon 14.04.14	Fri 13.06.14
190	4.9	XM9 Assembly	35 days	Tue 29.04.14	Fri 20.06.14
200	4.10	XM10 Assembly	35 days	Mon 12.05.14	Fri 27.06.14
210	4.11	XM11 Assembly	35 days	Mon 19.05.14	Fri 04.07.14
220	4.12	XM12 Assembly	35 days	Mon 26.05.14	Fri 11.07.14
230	4.13	XM13 Assembly	35 days	Mon 02.06.14	Mon 21.07.14
240	4.14	XM14 Assembly	35 days	Mon 09.06.14	Mon 28.07.14
250	4.15	XM15 Assembly	35 days	Mon 16.06.14	Mon 18.08.14
260	4.16	XM16 Assembly	35 days	Mon 23.06.14	Mon 25.08.14
270	4.17	XM17 Assembly	35 days	Mon 30.06.14	Mon 01.09.14
280	4.18	XM18 Assembly	35 days	Mon 07.07.14	Mon 08.09.14
290	4.19	XM19 Assembly	35 days	Tue 15.07.14	Mon 15.09.14
300	4.20	XM20 Assembly	35 days	Tue 22.07.14	Mon 22.09.14
310	4.21	XM21 Assembly	35 days	Tue 29.07.14	Mon 29.09.14
320	4.22	XM22 Assembly	35 days	Tue 19.08.14	Mon 06.10.14
330	4.23	XM23 Assembly	35 days	Tue 26.08.14	Mon 13.10.14
340	4.24	XM24 Assembly	35 days	Tue 02.09.14	Mon 20.10.14
350	4.25	XM25 Assembly	35 days	Tue 09.09.14	Mon 27.10.14
360	4.26	XM26 Assembly	35 days	Tue 16.09.14	Mon 03.11.14
370	4.27	XM27 Assembly	35 days	Tue 23.09.14	Mon 10.11.14
380	4.28	XM28 Assembly	35 days	Tue 30.09.14	Mon 17.11.14
390	4.29	XM29 Assembly	35 days	Tue 07.10.14	Mon 24.11.14
400	4.30	XM30 Assembly	35 days	Tue 14.10.14	Mon 01.12.14
410	4.31	XM31 Assembly	35 days	Tue 21.10.14	Mon 08.12.14
420	4.32	XM32 Assembly	35 days	Tue 28.10.14	Mon 15.12.14
430	4.33	XM33 Assembly	35 days	Tue 04.11.14	Mon 22.12.14
440	4.34	XM34 Assembly	35 days	Tue 11.11.14	Mon 05.01.15
450	4.35	XM35 Assembly	35 days	Tue 18.11.14	Mon 12.01.15
460	4.36	XM36 Assembly	35 days	Tue 25.11.14	Mon 19.01.15
470	4.37	XM37 Assembly	35 days	Tue 02.12.14	Mon 26.01.15
480	4.38	XM38 Assembly	35 days	Tue 09.12.14	Mon 02.02.15
490	4.39	XM39 Assembly	35 days	Tue 16.12.14	Mon 09.02.15
500	4.40	XM40 Assembly	35 days	Tue 23.12.14	Mon 23.02.15
510	4.41	XM41 Assembly	35 days	Tue 06.01.15	Mon 02.03.15
520	4.42	XM42 Assembly	35 days	Tue 13.01.15	Mon 09.03.15
530	4.43	XM43 Assembly	35 days	Tue 20.01.15	Mon 16.03.15
540	4.44	XM44 Assembly	35 days	Tue 27.01.15	Mon 23.03.15
550	4.45	XM45 Assembly	35 days	Tue 03.02.15	Mon 30.03.15

Gantt Chart

2014

September October November December January February March April May June July August September October November December

Q2/2014 being a decisive quarter

XM5

XM10

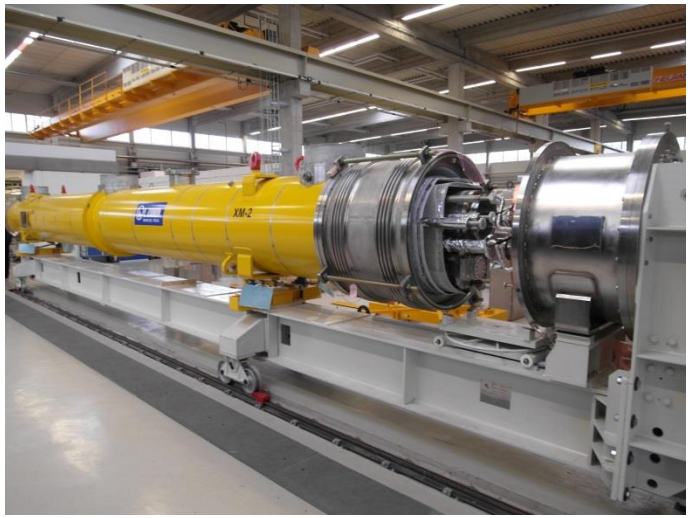
XM20

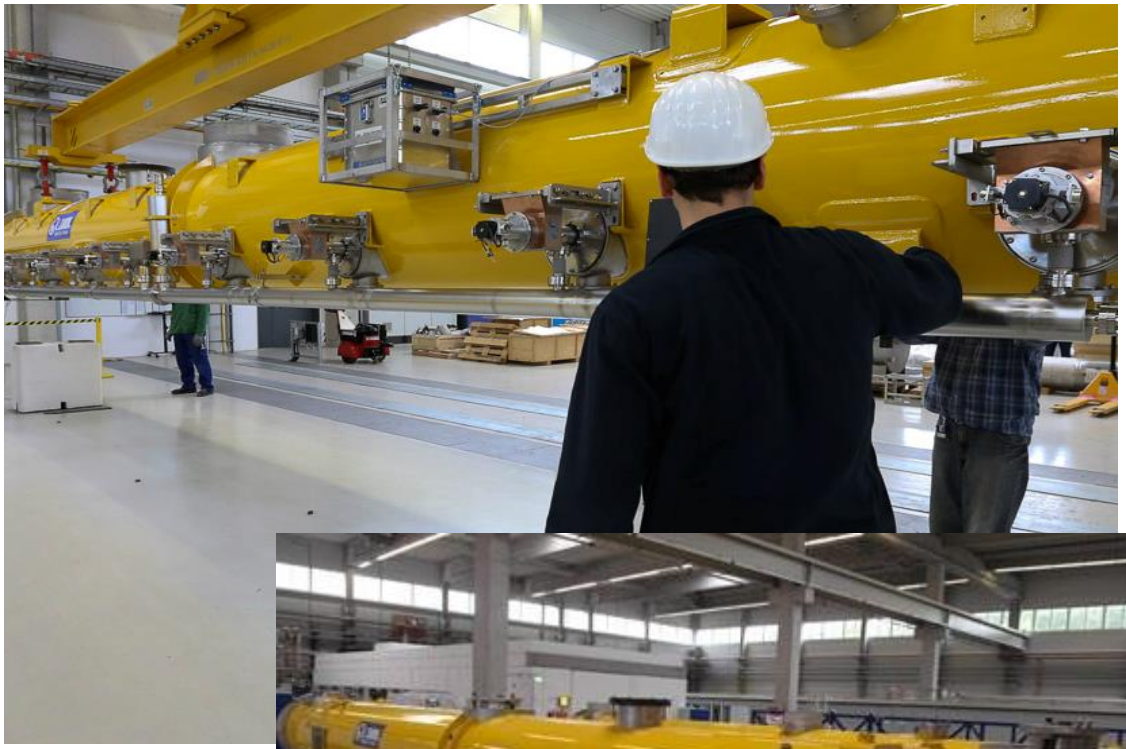
Re-open **AMA** discussion

Accelerated **M**odule **A**ssembly

Module Transport (XM1 arriving at DESY)

So far 9 modules delivered to AMTF



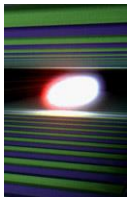


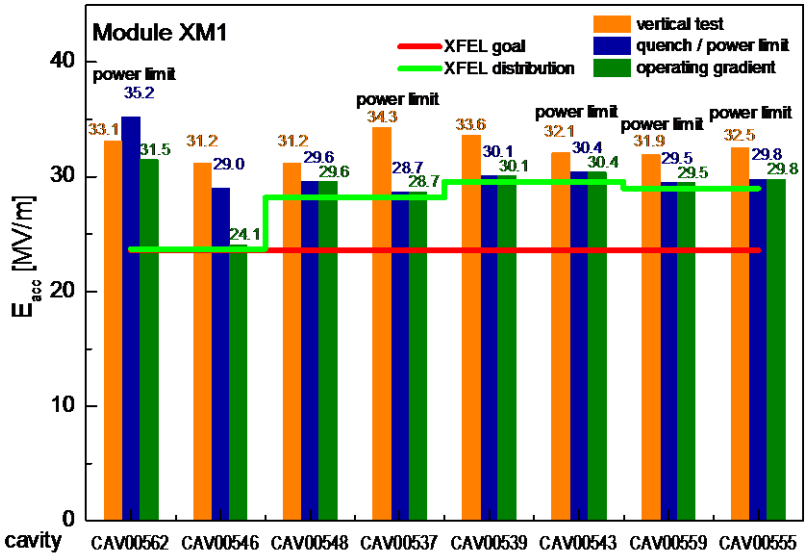
Accelerator Module Testing at DESY

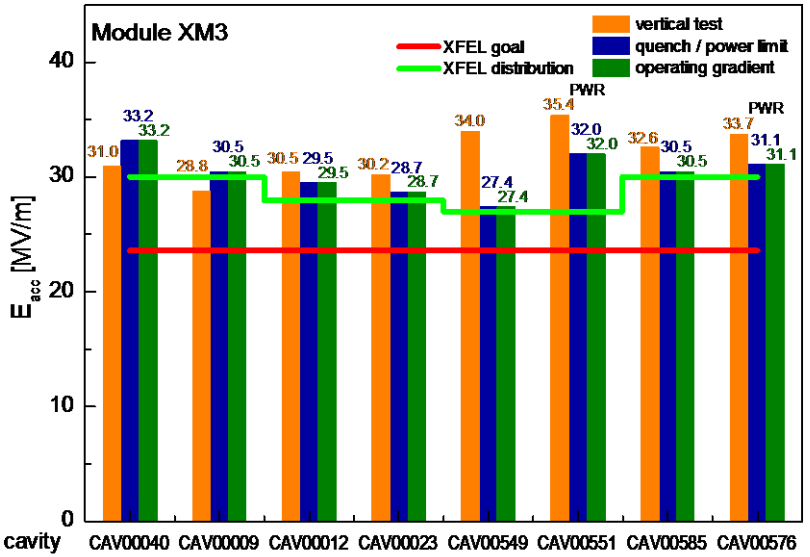
- first results: XM-2, XM-1 and XM1 are all above XFEL specs. of 23.6 MV/m
- some non-conformities exist but lead to final improvements of series production; feedback to CEA / Irfu and others

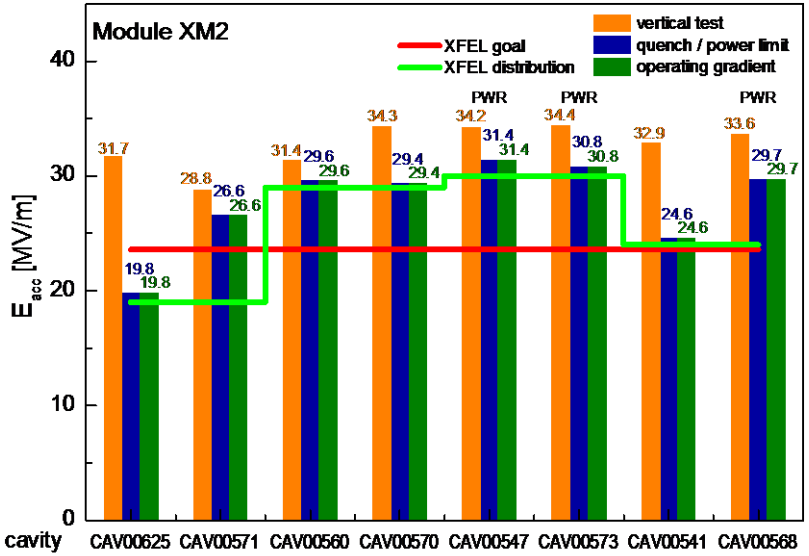
European XFEL

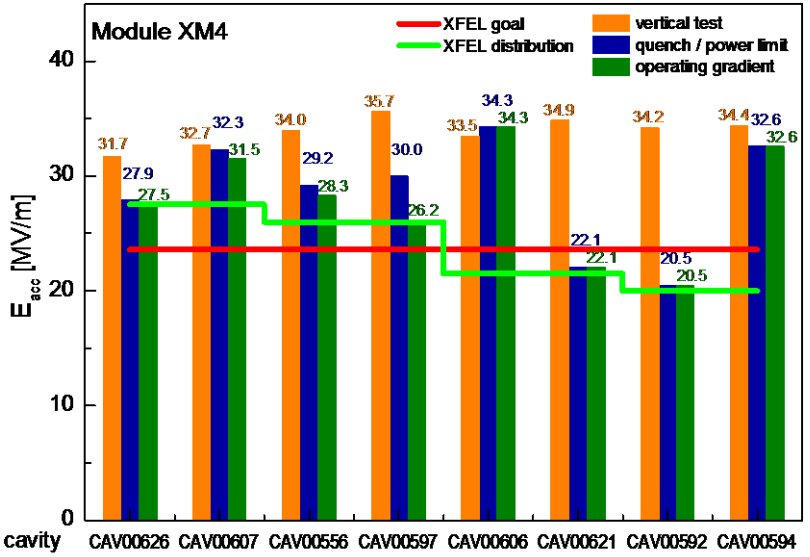
Module Test Results



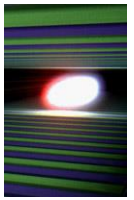








SRF Experience



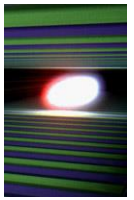
- Major key-player already working together in the TESLA linear collider R&D phase joined the European XFEL in an early phase.

- DESY has the role as coordinator of the accelerator complex including the superconducting linac. At the same time large in-kind contributions in the field of SRF technology are coming from DESY.

- Work packages contributing to the cold linac are in all cases co-led by a DESY expert and a team leader from the institutes contributing. Integration into the linac installation and infrastructure is a DESY task.

- The European XFEL clearly profits from the long-time experience of DESY in SRF technology, and from the history in building and operating large scale accelerator facilities.

Industrial Contracts



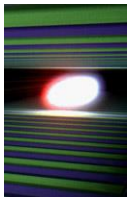
- Large series production in industry requires pre-qualification.

- While in some cases vendors were qualified already during the TESLA R&D phase, in some other areas a careful multistep qualification was done.

- There was a strong effort to always have at least two qualified vendors, and where possible the overall production was split accordingly.

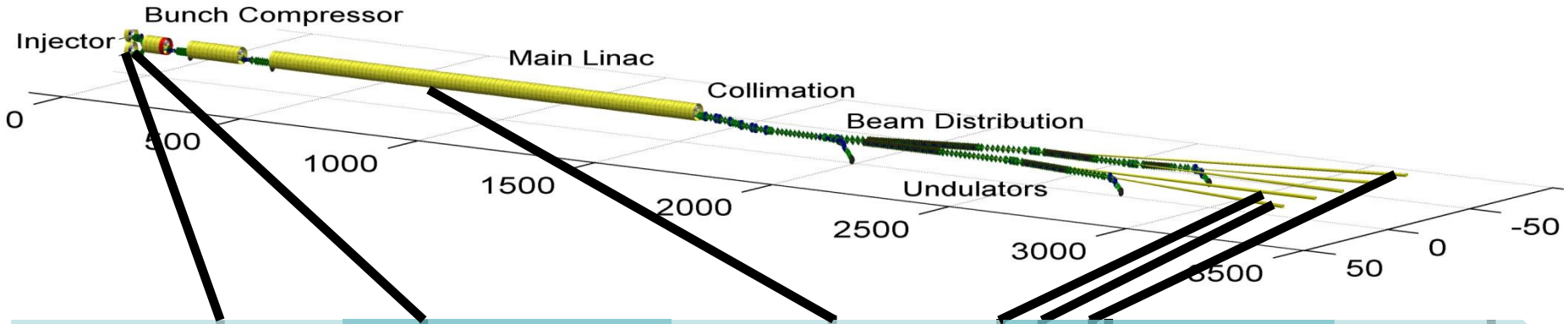
- After contract award a continuous close cooperation with vendors is needed. Many of the used components remain challenging, and non-conformities can be reduced only in fruitful discussions. SRF technology does not allow real compromises, i.e. problems have to be smoothened out in a common effort.

In-kind Contributions



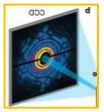
- European XFEL is built based on in-kind contributions. This includes technology transfer between the different institutes and also industry. In such a model the coordination effort should not be underestimated. The original budget estimate needs to take care of this.
- Difficult to handle are also the duties defined by dependencies, e.g. in the supply chain. In a technically ambitious project the responsibilities in terms of work sharing may be clear but in case of sudden and unexpected technical problems the collaborative spirit is needed and of utmost importance.
- Coordination and integration of in-kind contributions requires not only additional resources but also relies on the possibilities of a strong laboratory. Expecting turn-key systems is an incorrect approach. Both partner, the receiving party but also the in-kind contributor need expertise and excellent communication skills.
- **The superconducting linac of the European XFEL can only be built due to the great collaborative effort accompanied by an immense team spirit of the involved partners**

Outlook into commissioning and operation



2014 | 2015 | 2016 | 2017 | 2018

- First e-beam out of RF gun installed at XFEL
- Injector cooldown
- Linac cooldown
- SA1
- SA3
- SA2
- 1st lasing possible
- Start user operation
- Full TDR performance

e^-	Gun and injector laser com.	Injector com. up to full XFEL performance (varying charges and bunch patterns, laser heater, slice diagnostics, intra-train feedbacks, automated procedures)	Initial linac com. with reduced performance	Continued accelerator com. to full performance (high beam power, bunch length flexibility, multiple bunch properties per rf-pulse, full wavelength tuneability, ….)
γ				Beam line and experiment com.
				. First user operation