100 SUPERCONDUCTING MODULES FOR THE EUROPEAN XFEL

IN COLLABORATION AND WITH INDUSTRY

DESY

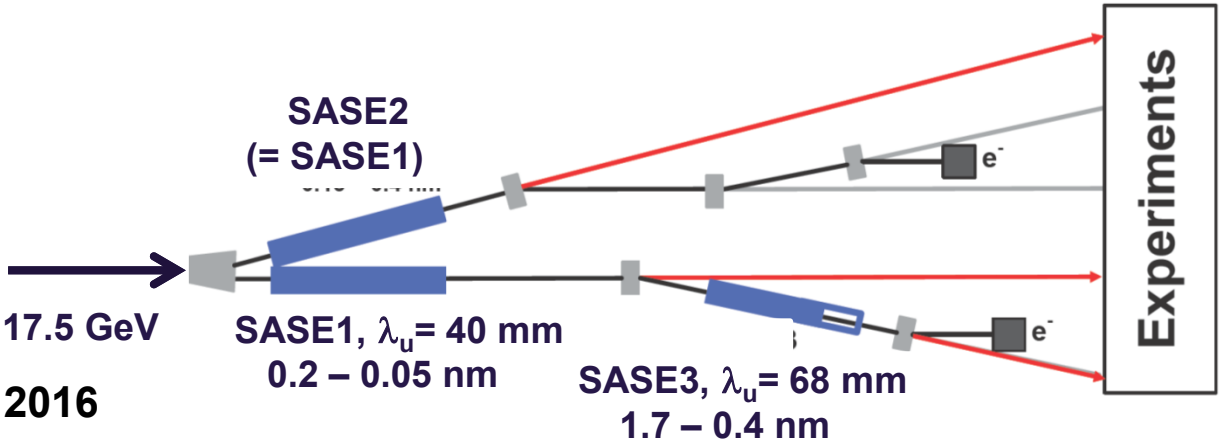
HELMHOLTZ ASSOCIATION

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)
- 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



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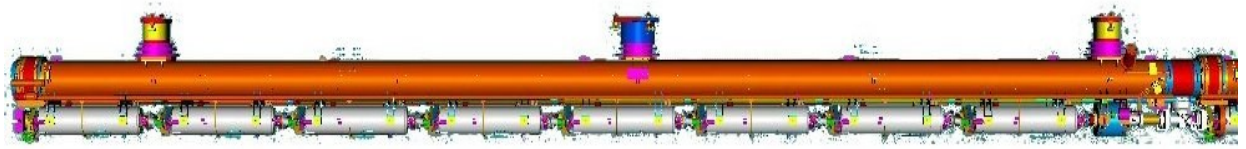
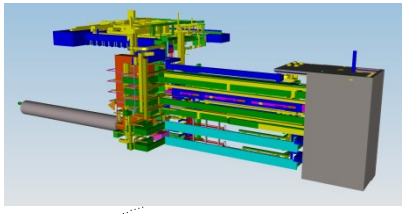
An Accelerator Complex for 17.5 GeV

100 accelerator modules



800 accelerating cavities
1.3 GHz / 23.6 MV/m

25 RF stations
5.2 MW each



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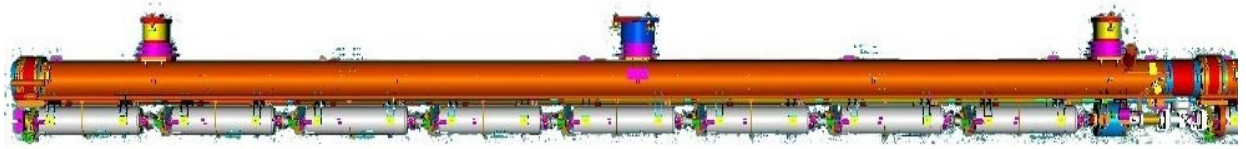
Contributors to the XFEL Accelerator

100 accelerator modules



800 accelerating cavities
1.3 GHz / 23.6 MV/m

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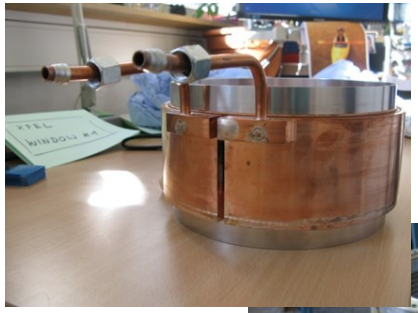
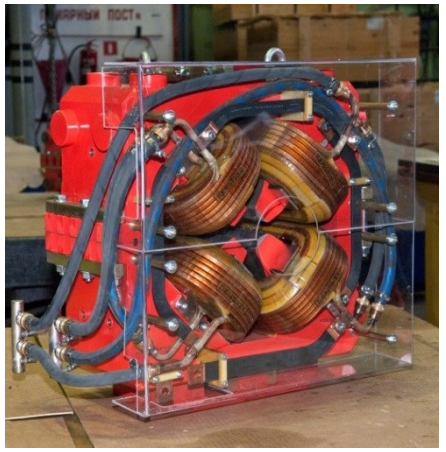
Production of Accelerator Components





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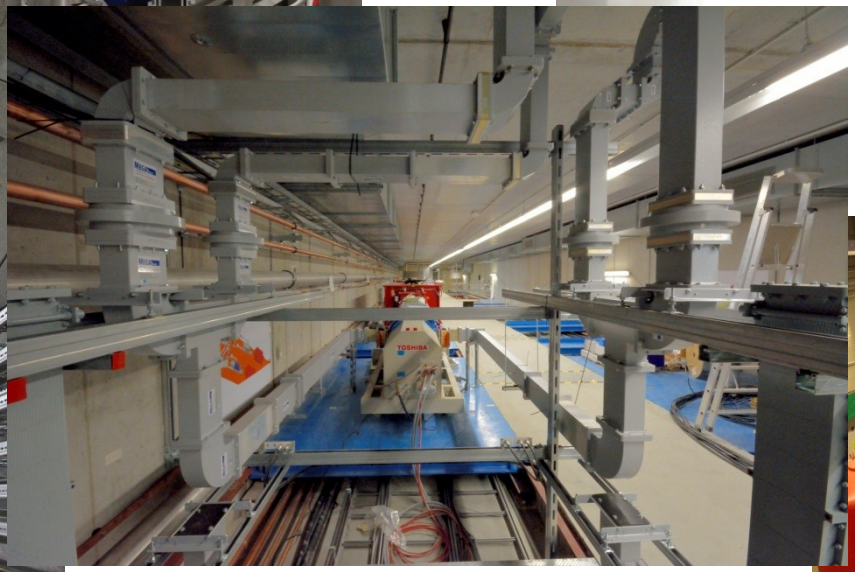
Installation



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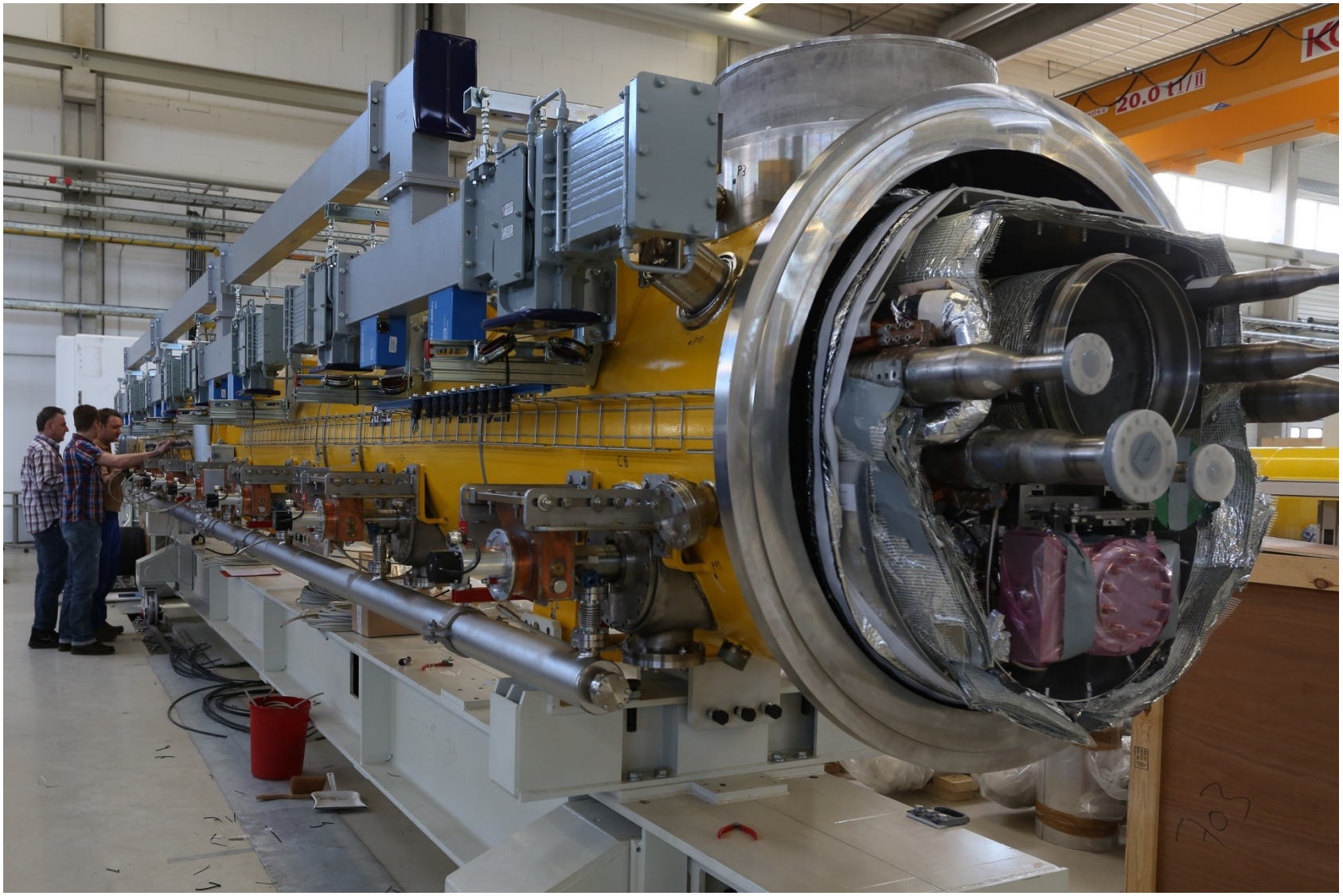
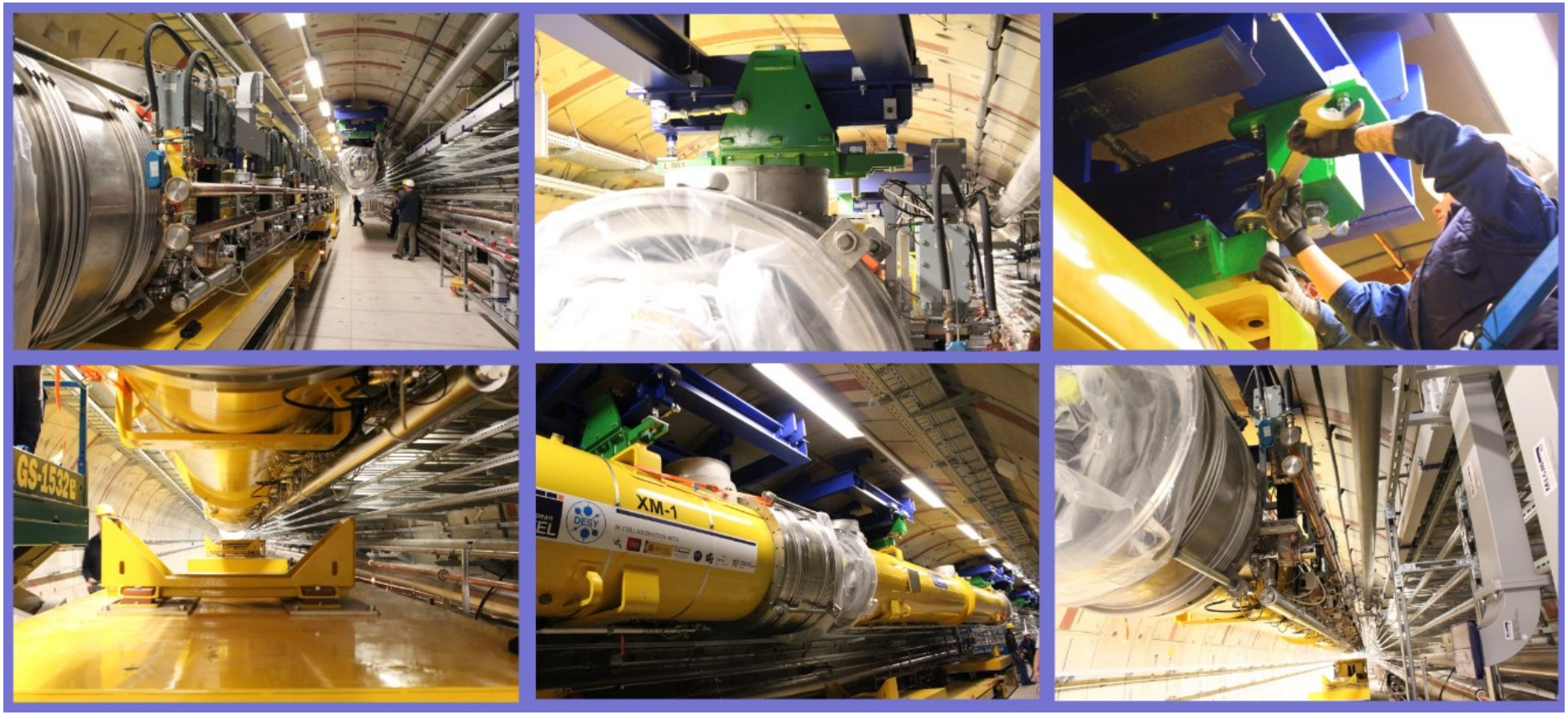
First Modules are Installed in the Linac Tunnel

XFEL Accelerator Module with Tailored Waveguide System



XFEL Accelerator Module being Transported into the XFEL Main Linac Tunnel

- the tested and with all accessories completed modules are transported into the main linac tunnel; approx. 2 hours are needed between AMTF loading and final attachment to the tunnel ceiling
- the accessories include the tailored wave guide system



- the suspension frames are welded to steel bands being part of the tunnel tuebbings
- certified welding and welds are a must; safety simulations were done to analize failure scenarios; a Helium blow-out was studied

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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

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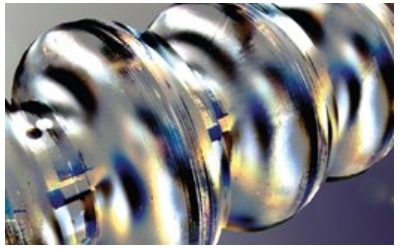
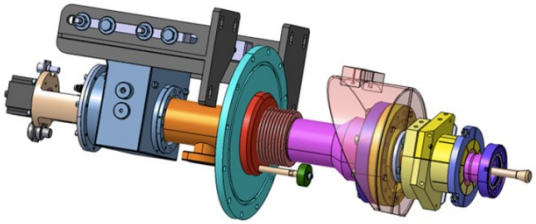
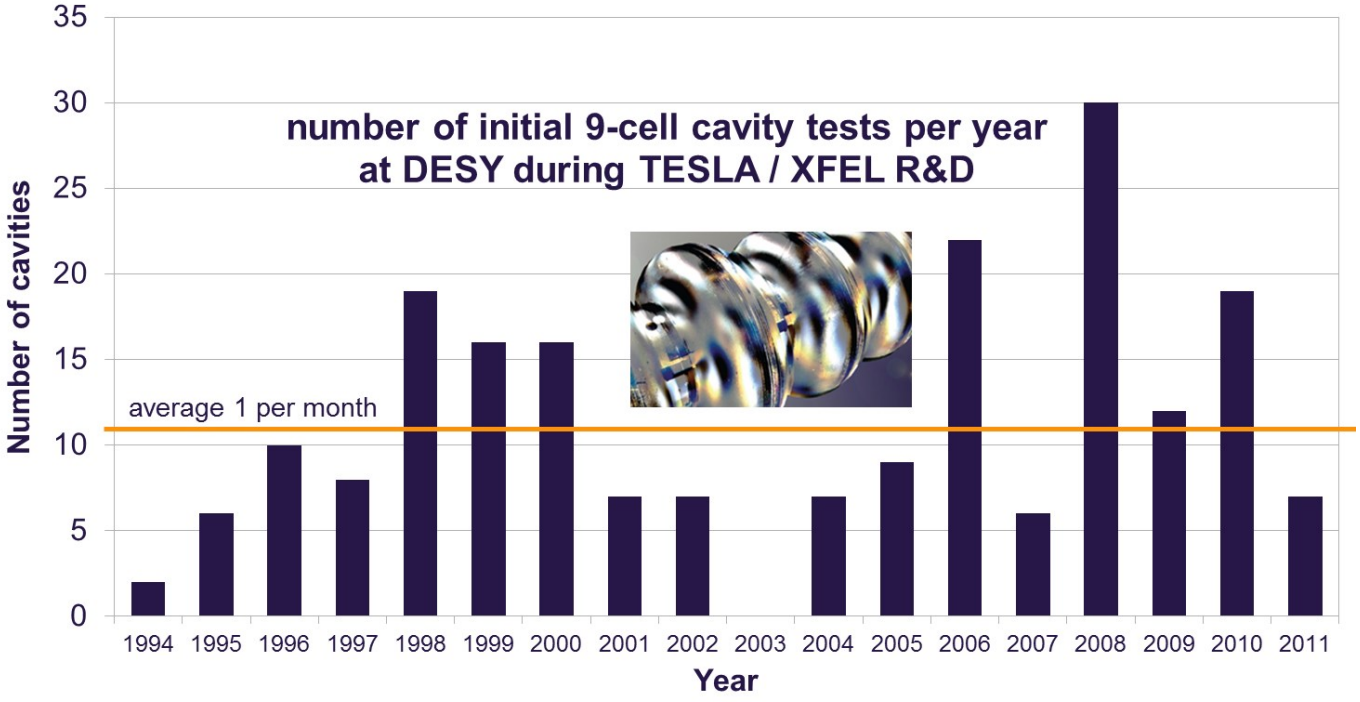
Production Rate of Key Components

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







monthly average was to increased by approximately

x 30

European XFEL

Cavity Production (here at Company RI)

all pictures courtesy Research Instruments

European XFEL

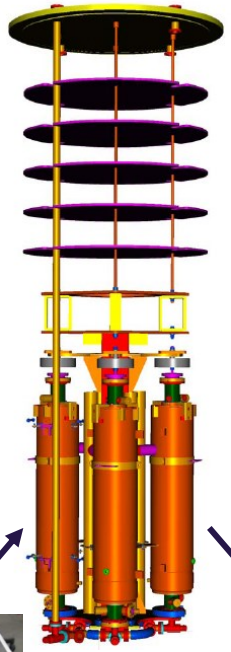
Cavity Production (here at Company E. Zanon)

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

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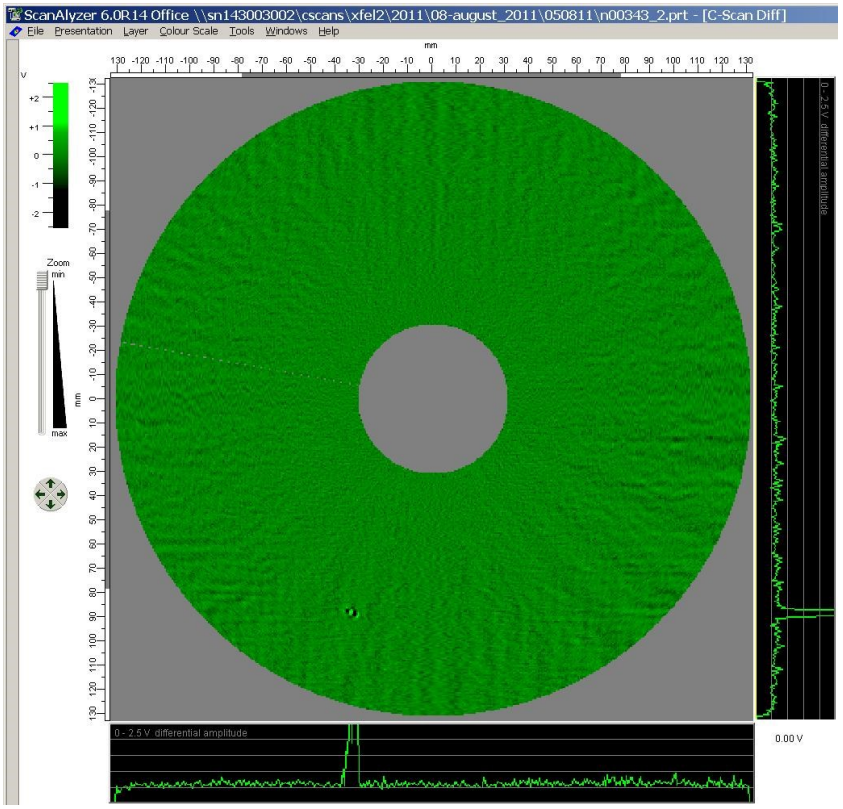
Niobium Material Bought and QC-ed by DESY

- 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.

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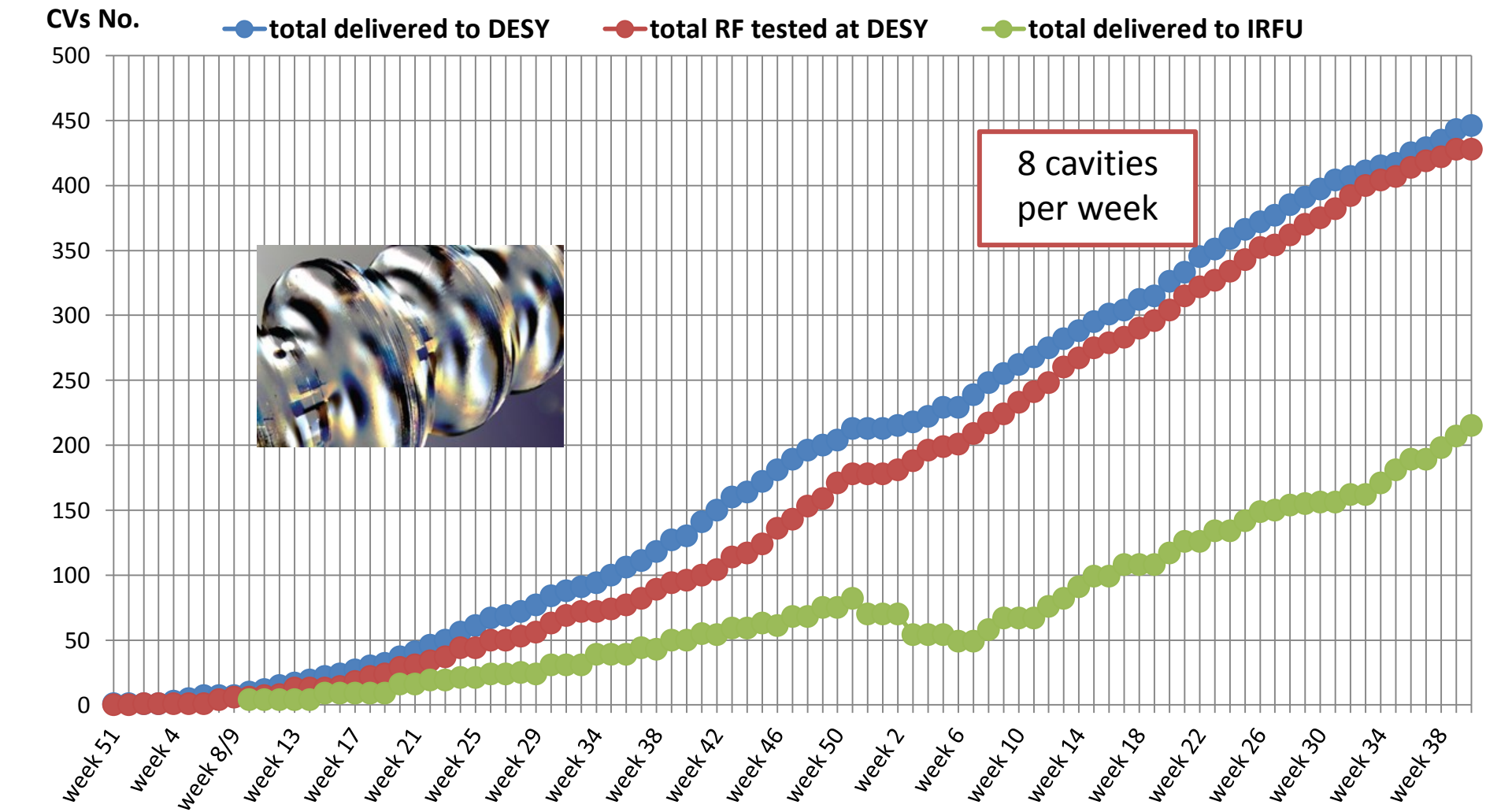
Cavity Delivery Status as of 9/2014



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Vertical Cavity Testing at DESY

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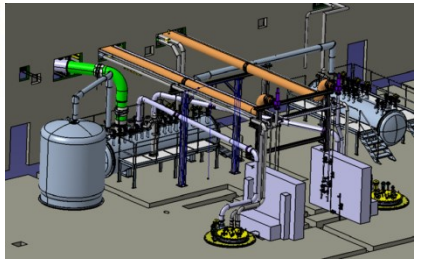
AMTF Test Stand Infrastructure



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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 (more than 400 cavities tested)
  - Average usable gradient after delivery (26.6 ± 7.6) 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

- Cavities up to **XM24** are shipped for module assembly at CEA Saclay

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Cavities (Ready for Transport to IRFU)

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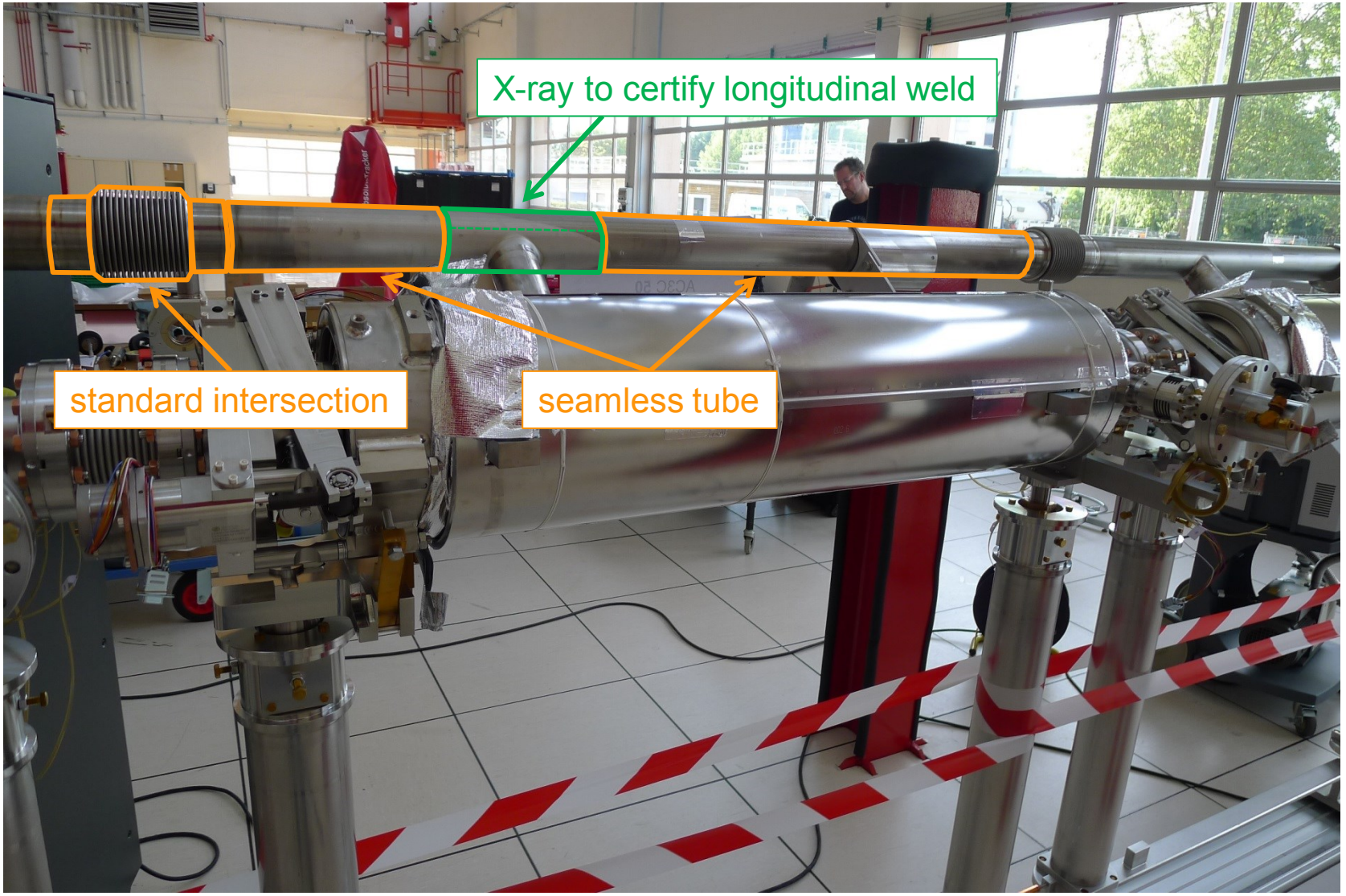
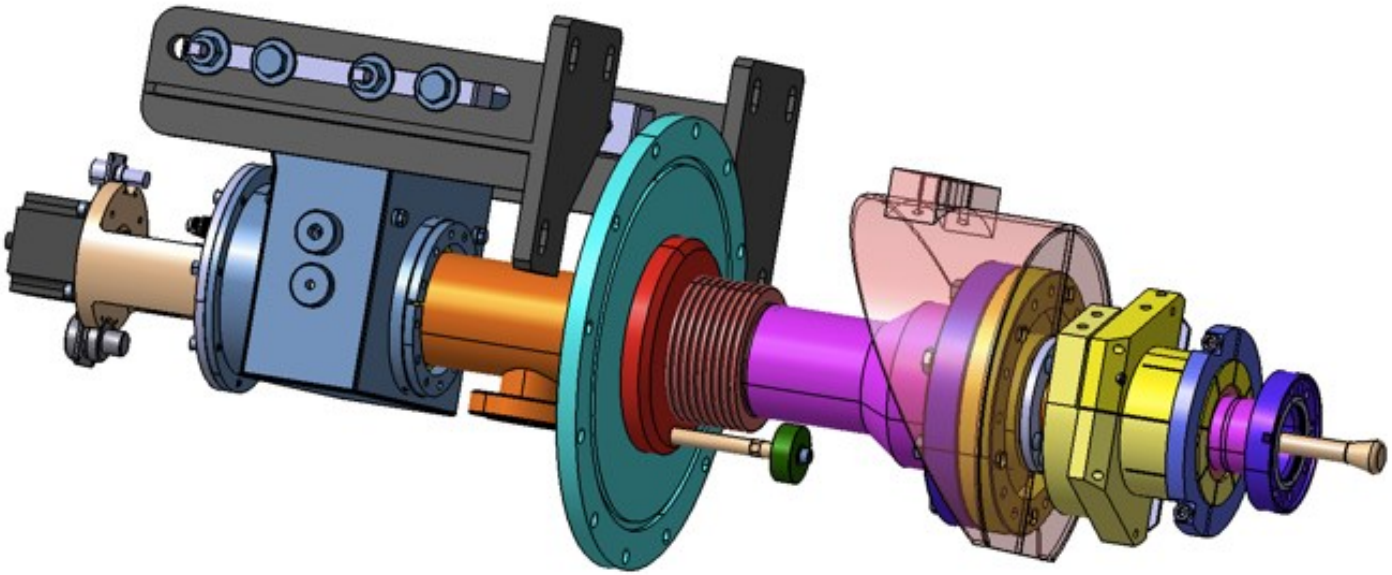
2-Phase Line (Service Pipe) Needs and Gets Systematic Repair Work



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.



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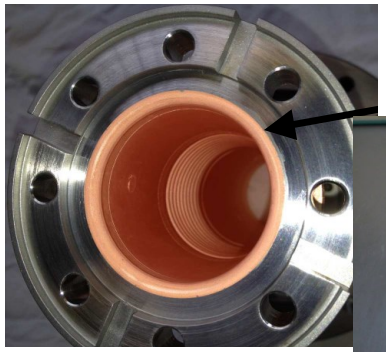
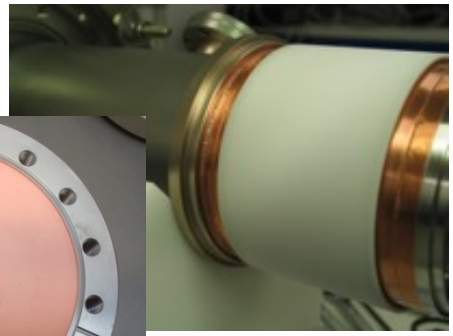
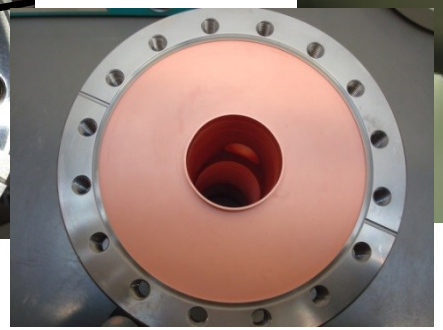
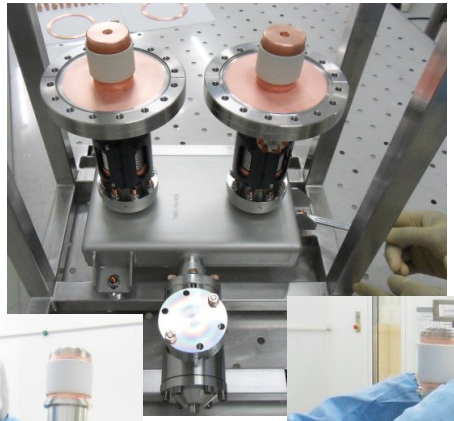
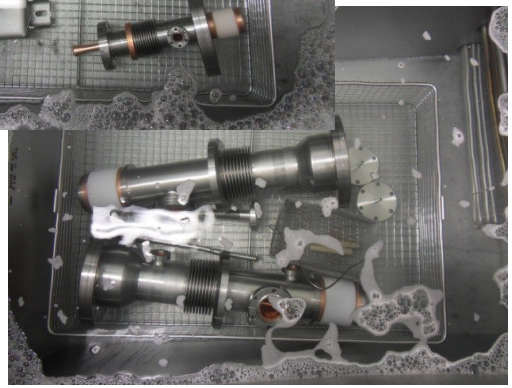
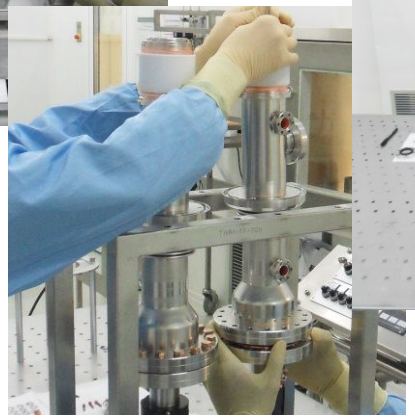
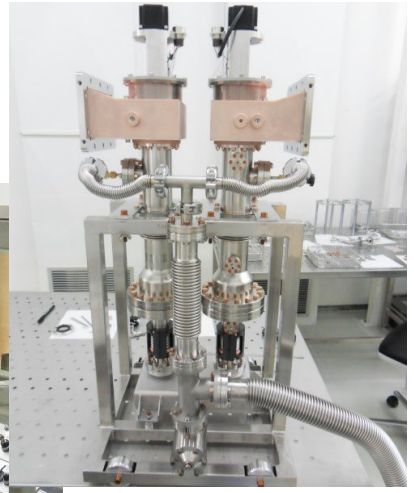
Coupler Fabrication



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Coupler Pairs Installation in the RF Test Stands

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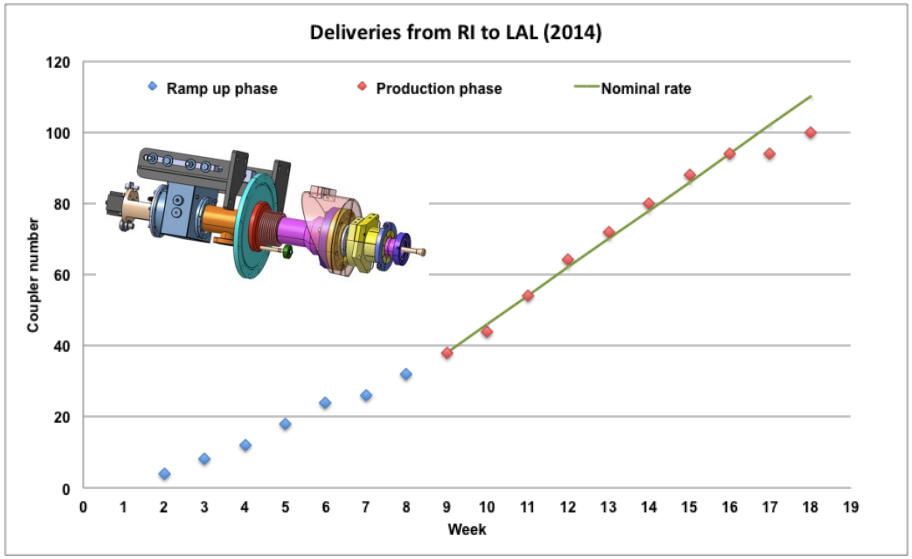
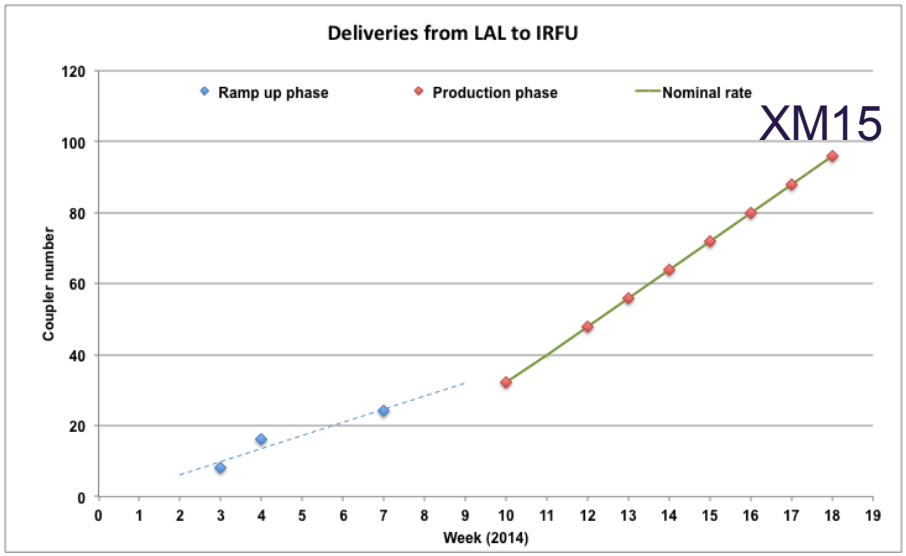
RF Power Coupler Delivery Status as of 4/2014





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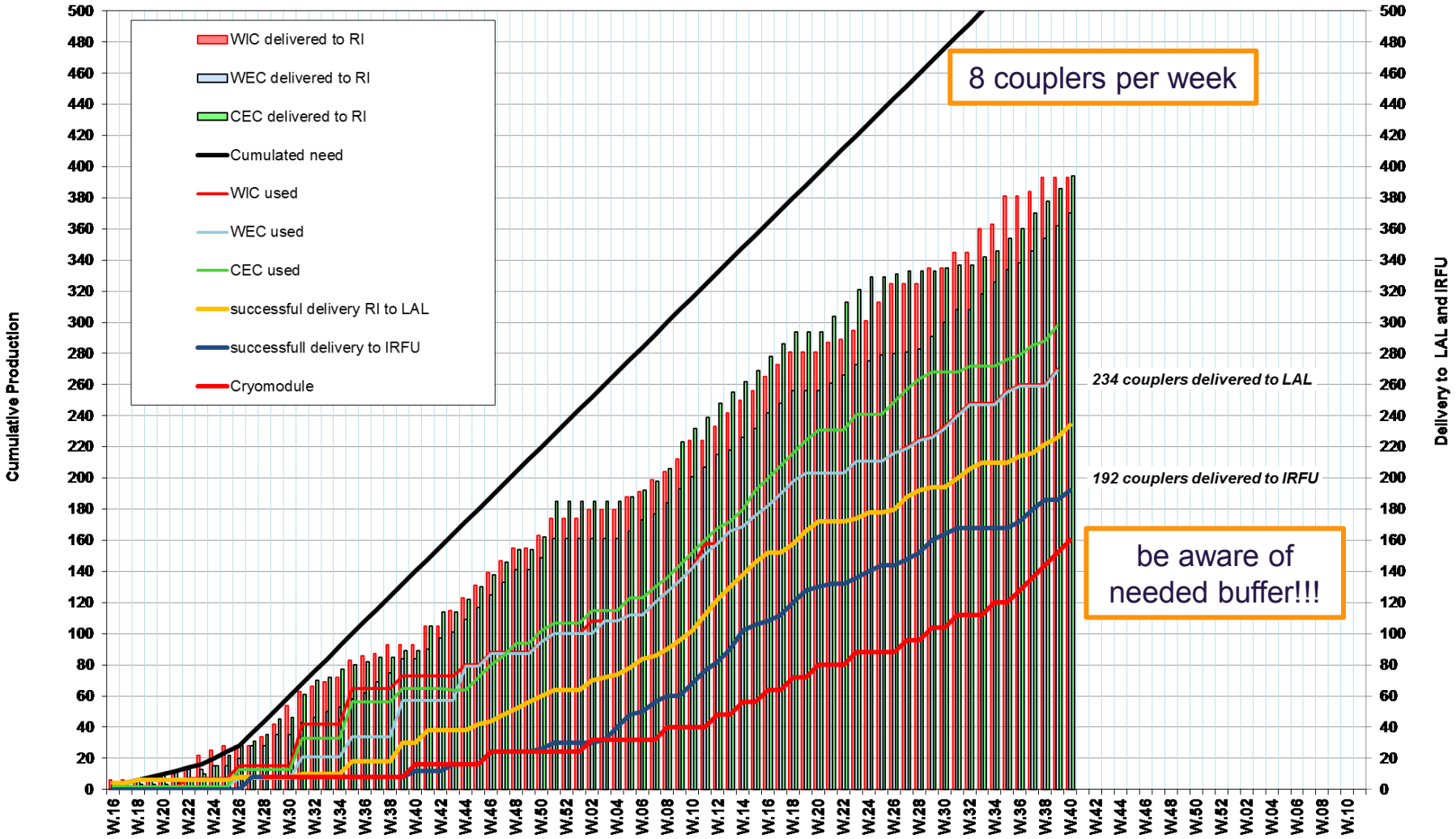
XFEL Power Coupler Production Chart



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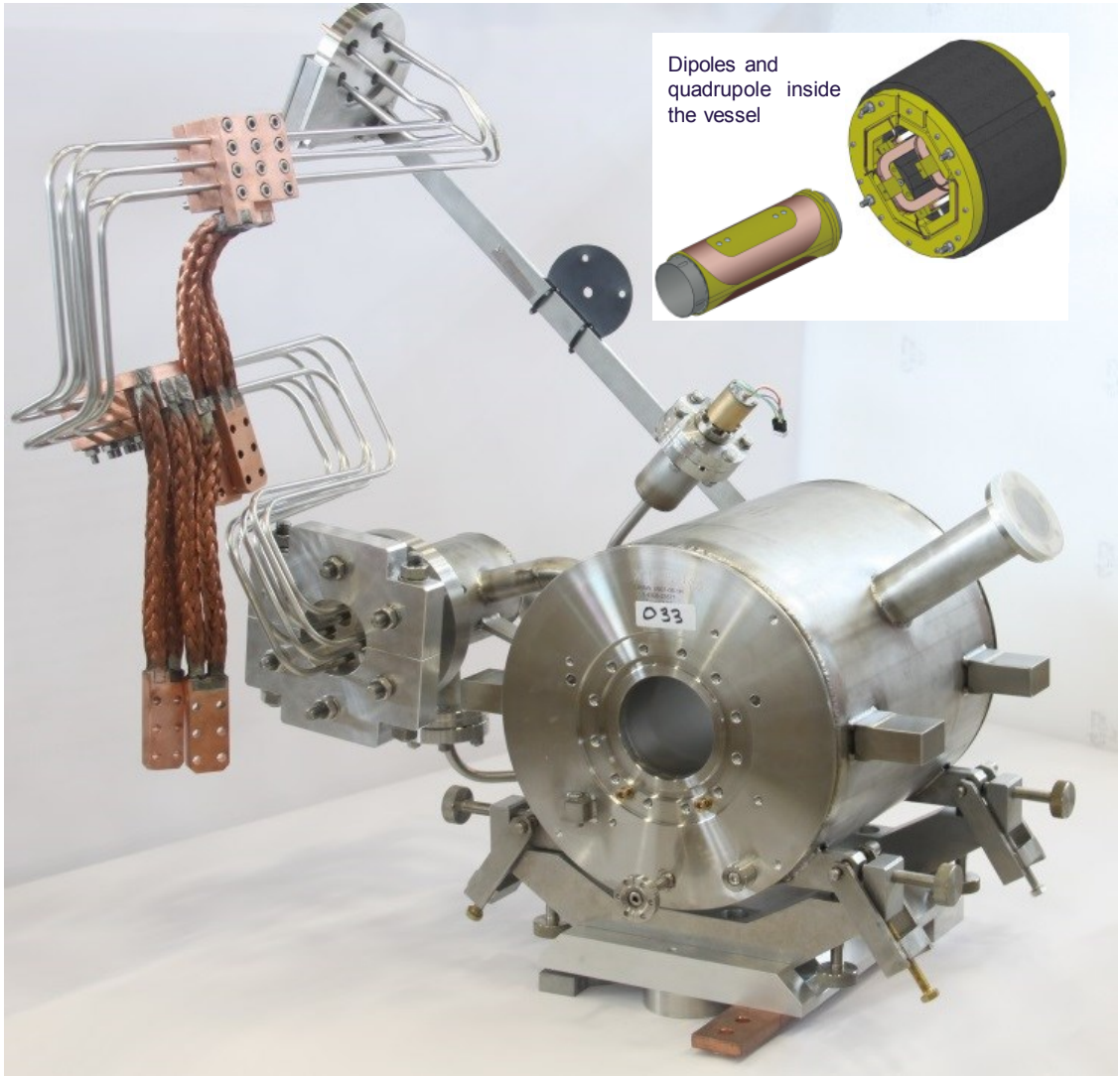
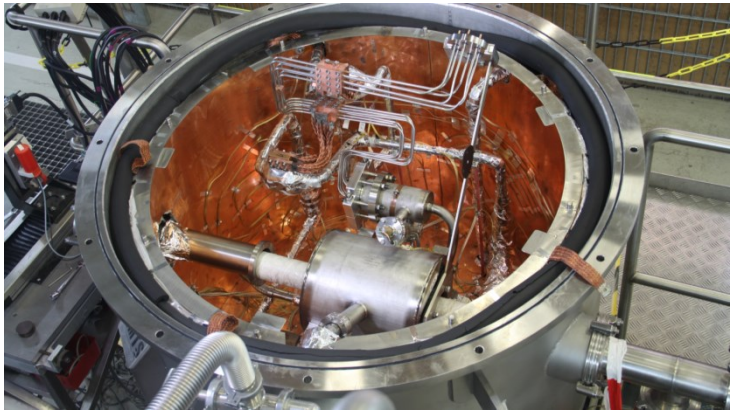
Cold Magnets



- almost all 100 magnets delivered to / accepted by DESY
- approx. 80 cold tested
- approx. 60 copper plated
- approx. 25 BQU assembled
- 20 BQU's shipped



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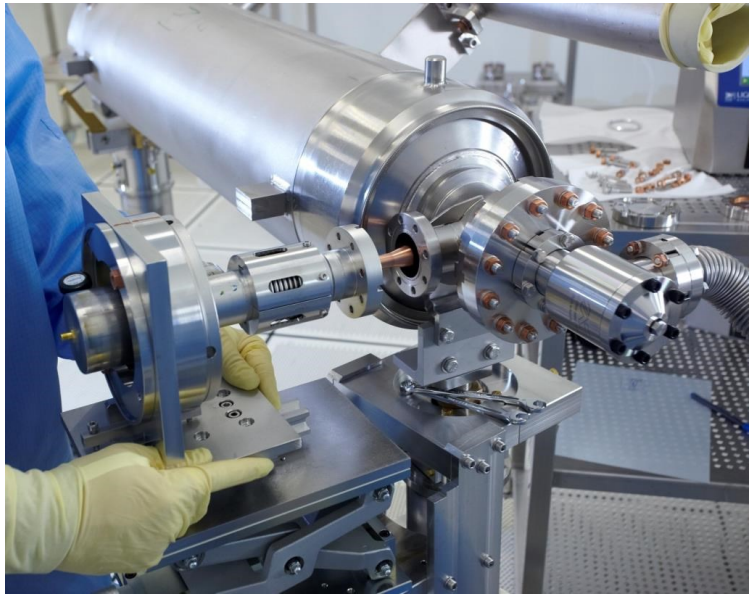
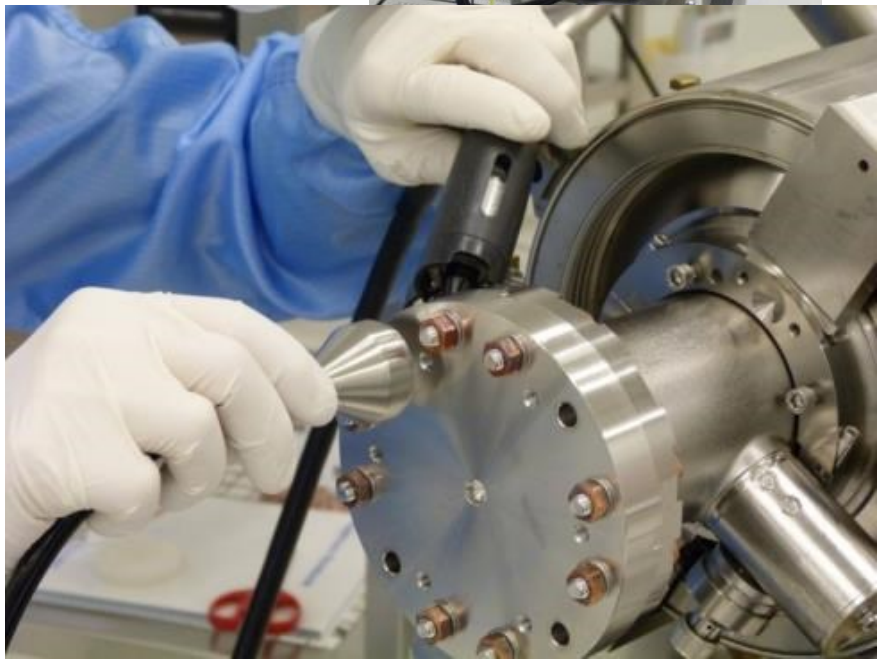
Cavity String Assembly at CEA Saclay / Irfu



- actual work is done by the company Alsyom
- supervision by Irfu
- support by DESY



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Accelerator Cavity String Assembly at Irfu

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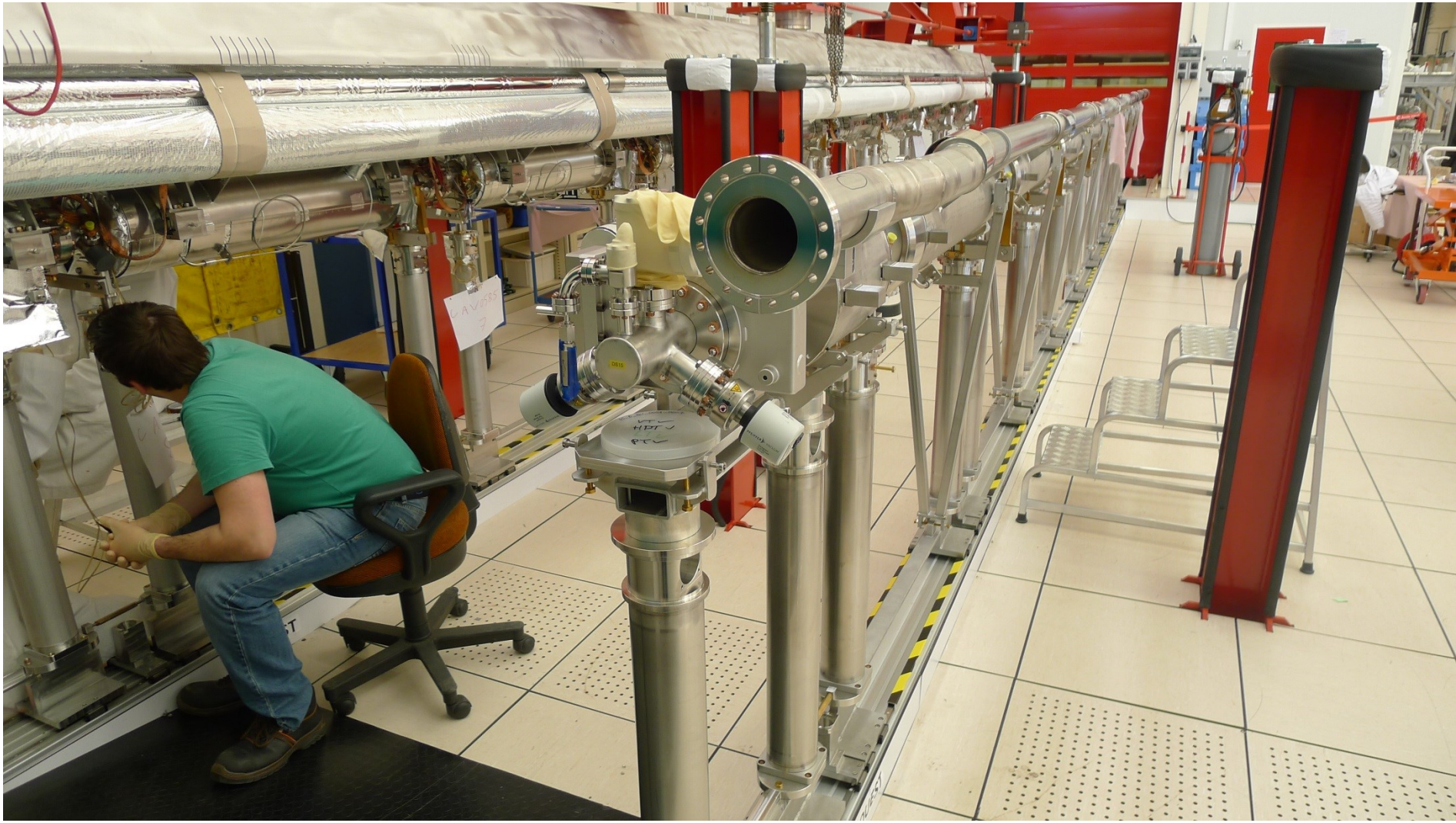
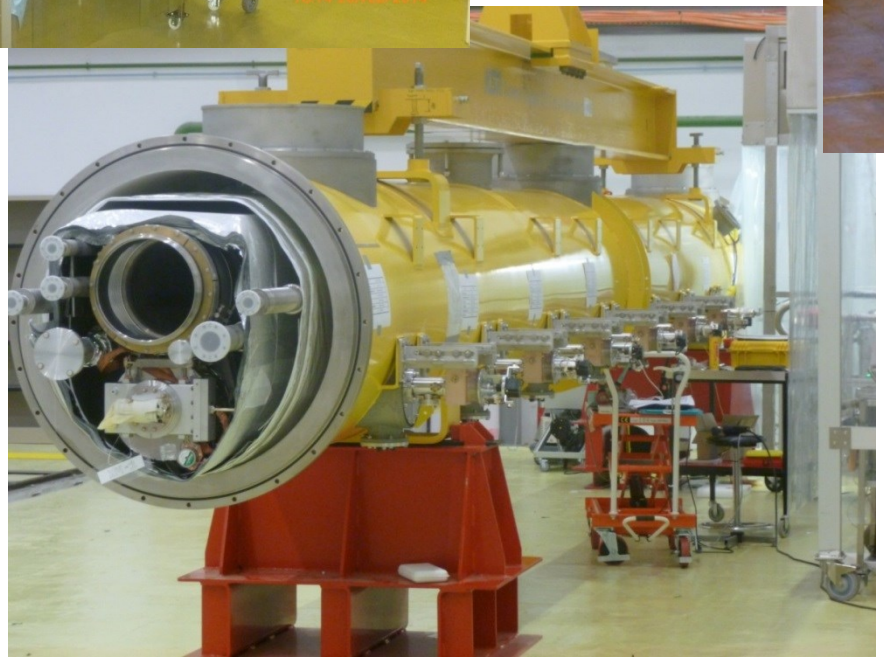
String / Cold Mass Marriage



RF Power Coupler Assembly
Transport Caps / Final Checks / Shipment



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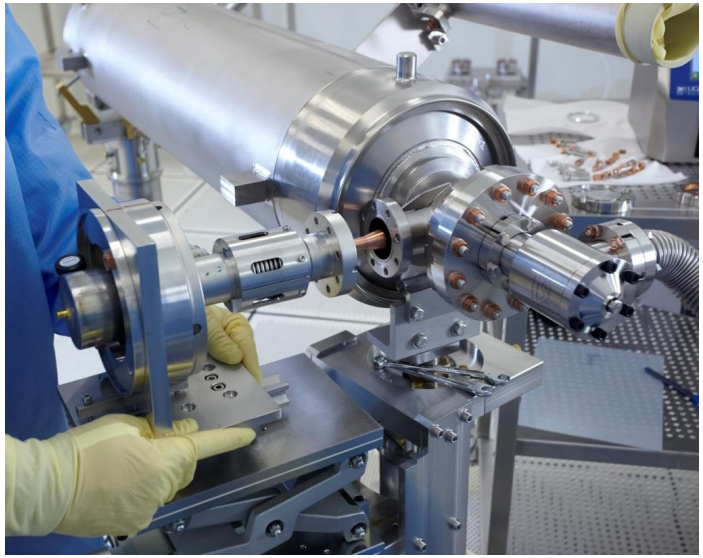
Module Assembly – Buffers are Filled



- 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

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Module Assembly – Output Rate

Component availability at CEA	XM10	XM11	XM12	XM13	XM14	XM15	XM16	XM17	XM18	XM19	XM20	XM21	XM22	XM23	XM24
Cavities	09.04.14	23.04.14	14.05.14	28.05.14	04.06.14	17.06.14	25.06.14	02.07.14	06.08.14	20.08.14	27.08.14	03.09.14	17.09.14	24.09.14	30.09.14
Couplers	25.03.14	03.04.14	10.04.14	17.04.14	25.04.14	07.05.14	16.05.14	23.05.14	18.06.14	11.07.14	23.06.14	01.08.14	12.09.14	19.09.14	0
BQU	23.04.14	06.05.14	14.05.14	17.06.14	25.06.14	09.07.14	06.08.14	20.08.14	17.09.14	24.09.14	30.09.14	0			
Gate valve	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
Cryostat	27.05.2014	03.06.2014	11.06.14	27.06.14	22.07.14	05.08.14	1	30.09.14	1	1	1	1	0		
Magnetic shields	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Assembly Schedule															
past position current position prediction	XM10	XM11	XM12	XM13	XM14	XM15	XM16	XM17	XM18	XM19	XM20	XM21	XM22	XM23	XM24
CC (cold couplers)	27.05.14	16.06.14	04.07.14	24.07.14	04.08.14	26.08.14	08.09.14	12.09.14	24.09.14	01.10.14	W41	W42	W43	W44	W45
SA (string assembly)	19.06.14	04.07.14	22.07.14	07.08.14	26.08.14	10.09.14	15.09.14	25.09.14	01.10.14	W41/3	W42	W43	W44	W45	W46
RO (roll-out)	30.06.14	21.07.14	31.07.14	27.08.14	04.09.14	16.09.14	23.09.14	30.09.14	W41/2	W41	W43	W44	W45	W46	W47
AL (alignment)	21.07.14	06.08.14	25.08.14	10.09.14	16.09.14	24.09.14	02.10.14	W41/3	W42/3	W43	W44	W45	W46	W47	W48
CA (cantilever)	29.07.14	28.08.14	05.09.14	16.09.14	24.09.14	02.10.14	W41/2	W42/2	W43/2	W44	W45	W46	W47	W48	W49
CO (warm couplers)	26.08.14	05.09.14	11.09.14	22.09.14	01.10.14	W41/3	W42/1	W43/1	W44/1	W45	W46	W47	W48	W49	W50
SH (shipment)	01.09.14	11.09.14	19.09.14	26.09.14	06.10.14	W41/2	W43/5	W43/5	W44/5	W46	W47	W48	W49	W50	W51
Shipment to DESY	03.09.14	16.09.14	24.09.14	01.10.14	08.10.14	15.10.14	21.10.14	28.10.14	04.11.14	W46	W47	W48	W49	W50	W51

- goal: 7 work station – one week each should lead to 1 module per week
- ramp-up of string and module assembly needed more time
- challenges were
  - successful knowledge transfer
  - non-conformities
  - work organization / shop floor management

cea SACLAY DESY HELMHOLTZ ASSOCIATION

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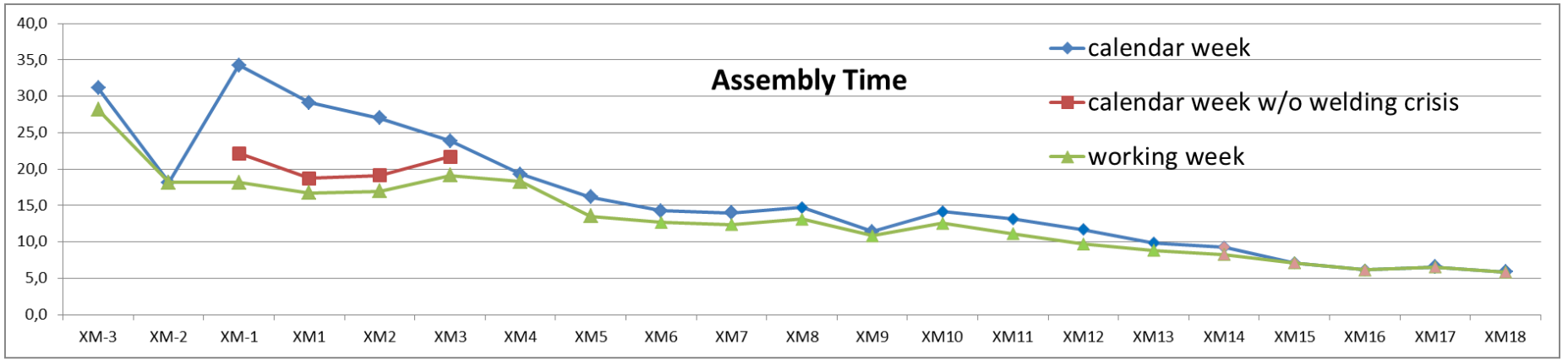
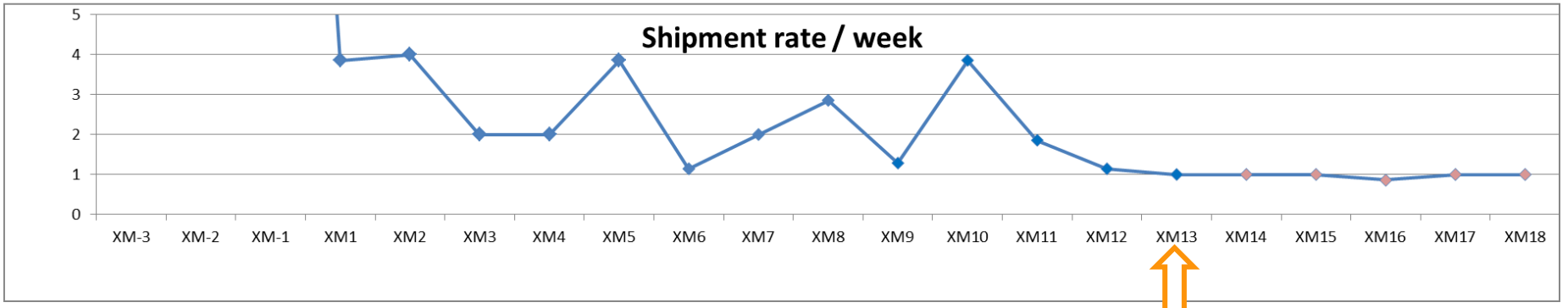
Module Assembly – Reached Output Rate





- the late success of the ramp-up requires further acceleration of the module assembly
- studies are scheduled for Q4/2014
- acc.scheme to be realized asap

delivered last week (W40)

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Module Transport (XM1 arriving at DESY)

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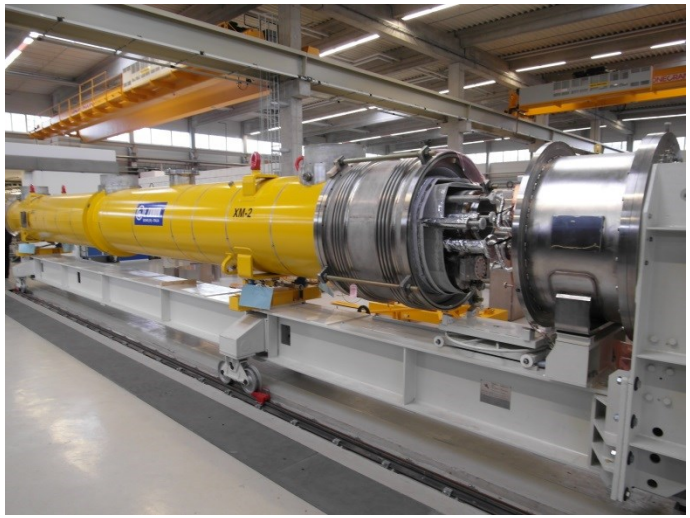
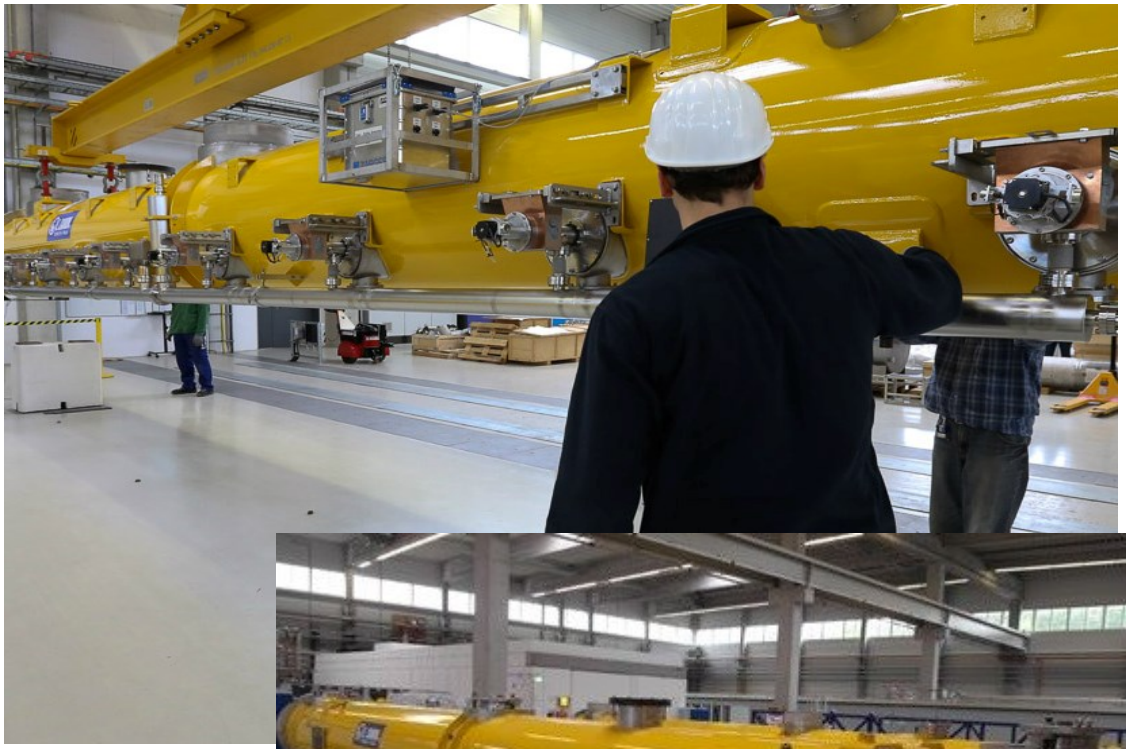
Many Modules at AMTF





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Accelerator Module Testing at DESY

- first results: all above XFEL specs. of 23.6 MV/m
- some non-conformities led to final improvements of series production; feedback to CEA / Irfu

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

- The European XFEL is built based on in-kind contributions. The project 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. Discussion of legal constraints is often of no avail, even if necessary.

- 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. A well-developed team spirit is of large benefit.

- 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.

Thank you!!!