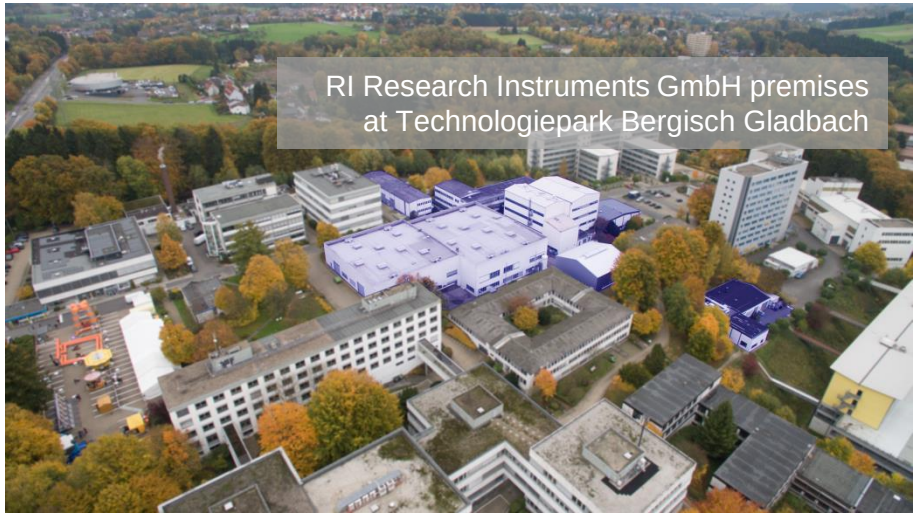
Production of 420 SRF cavities for XFEL

Michael Pekeler
RI Research Instruments GmbH
Friedrich-Ebert-Str. 1
51429 Bergisch Gladbach
Germany

RI Research Instruments GmbH

• Mid 80'ies	Activities started at Interatom/Siemens
• 1994 – 2007	ACCEL Instruments GmbH (Management buyout)
• 2007 – 2009	ACCEL is 100% daughter of Varian Medical Systems
• 2009 – today	RI Research Instruments GmbH (51% owned by Bruker EST)
• Jan. 2015	Acquisition of Bruker ASC Beamline, Vacuum and Endstation business (now "Photon Instrumentation")



RI Research Instruments GmbH premises at Technologiepark Bergisch Gladbach

- RI management hold significant equity stakes of the company
- About 180 employees,
  30% engineering & project management,
  60% manufacturing

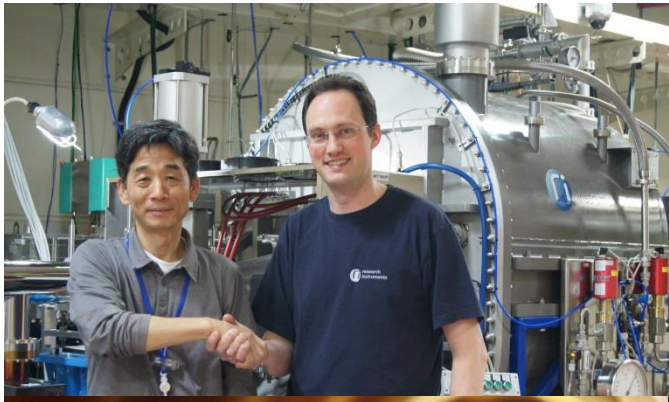
Worldwide renowned as "Advanced technology engineering and manufacturing specialist"

Solutions
Manufacturing
Performance

As a project oriented company we are running about 80 projects with order volumes between 100 kEUR and > 10 MEUR in parallel.

The XFEL cavity project was the largest project in our history.

The main challenge is to distribute the resources of the company in such a way to the projects, that they can all be finished in time and with the required quality.



XFEL cavity production project

Order for 300 cavities received from DESY in September 2010
Order for additional 120 cavities received in March 2013
Project will be finished in December 2015

Niobium and
helium vessel supplied by DESY

RI scope:

- Mechanical manufacturing of cavity, respecting the pressure vessel code
- Complete Surface preparation and helium vessel welding
- Shipping to DESY under vacuum and “ready for cold RF test”
- Extensive documentation and QA is crucial and will ensure that cavities are manufactured and treated according to detailed DESY specification. No performance guarantee.

- Erection of new infrastructure and PED qualification: 2 years,
- Qualification of new infrastructure with reference cavities: 0,5 years
- Series production: 2,5 years

Analysis of needed resources for mechanical manufacturing

	XFEL				post XFEL			
Recources (mechanical)	**Shifts**	**Working days**	**For 200 cavities/year**	**Installed at RI for XFEL**	**Shifts**	**Working days**	**For 600 cavities/year**	**Additional needed at RI**
Turning machine	2	5	5	5	3	7	7,5	3
Milling machine	2	5	1	3	3	7	1,5	-
Dimensional control place	2	5	1	3	3	7	1,5	-
Metal working station	2	5	1	3	3	7	1,5	-
BCP barrel	2	5	1	1	3	7	1,5	1
Degreasing bath	2	5	1	3	3	7	1,5	-
EB welding machines	2	5	1,5	1,5	3	7	2,5	1
Leak checker	2	5	0,5	3	3	7	1	-
RF control	2	5	0,5	1	3	7	1	-
Grinding place	2	5	0,5	2	3	7	1	-
Press	2	5	0,5	2	3	7	0,5	-

Basis : 75% on time

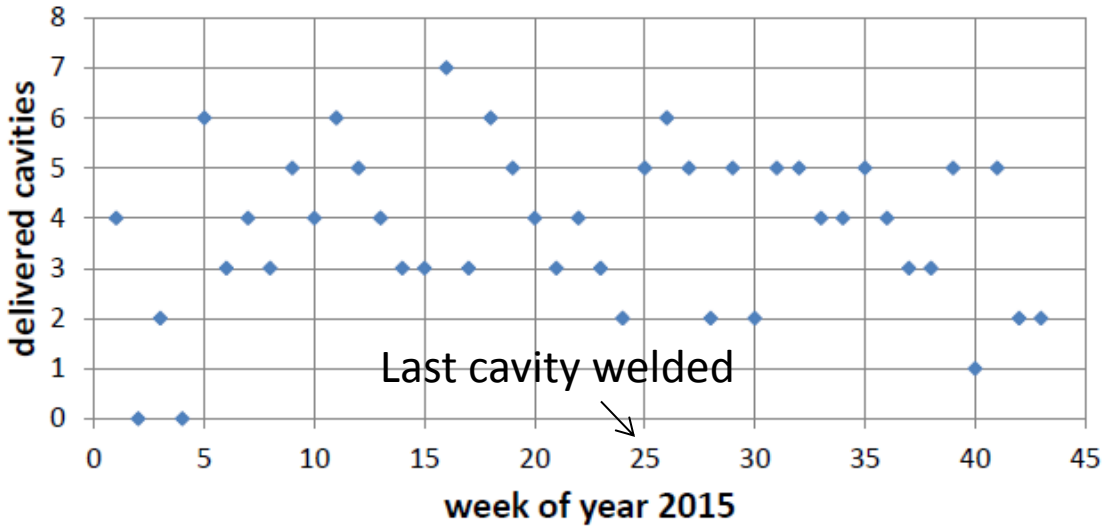
For the XFEL mechanical production a new EB welder was installed.

All other infrastructure was available already at RI in 2010

New EB welder at RI for XFEL production

- 60 kV EB welder from Pro Beam
- Replaces our old small EB welder
- Pallet system
- Lock chamber (1E-3 mbar)
- Weld chamber (1E-6 mbar)
- Turbo pumps

Delivered cavities in 2015



In 2015 the average delivery rate was 3.9 cavities per week

- The delivery was limited by the mechanical production, challenging to reach a constant delivery rate as we were not able to built up a buffer of mechanically finished cavities
- Limited resources of EB welding machine did limit the production, conflict with other projects that also need the EB welding resources (beside the XFEL cavities, we also welded XFEL couplers, other niobium cavities and a lot of copper cavities in our EB welding machines)
- No back-up when the EB welding machine has failure

Challenges in mechanical fabrication

- The shape tolerances (+/- 0.2 mm) of the endcells after deepdrawing and welding the endgroup was not always achieved, re-work of the endgroups was needed and did disturb the series production, niobium too expensive to just discard out of tolerance pieces
- We are designing now a re-shaping tool that hopefully will allow final calibration of the endgroup after final welding, first results expected within 3-4 month
- Behavior of different material (Plansee, Tokio Denkai, Ninxia) similar during deepdrawing, same tools used for three materials
- Meeting all dimensional tolerances on end groups is challenging

EB welding

- EB welding of niobium: Parameters quite stable and defined through the experience gained at RI within the last decade; EB parameters were qualified with the test piece.

- Only one cavity lost by EB welding (operator accidentally programmed much too high current, hole through ring and bellow weld and through cavity cell)

- 4 cavities with EB un-regularities at equator:
  - 1 cavity: parameters were not programmed correctly and 7 out of 9 equator welds had unsmooth appearance, but welded through, cavity was finished and showed good RF performance
  - 3 cavities: HV shut off for a short time, resulting in small area with thinner under-bead for 2 cavities and not welded through for one cavity (for this cavity the equator weld was re-welded immediately after inspection), cavities reached specification

- No hole blown into any equator weld by EB welding during the production of 420 cavities

Analysis of needed resources for surface preparation

	XFEL				post XFEL			
Recources (preparation)	**Shifts**	**Working days**	**For 200 cavities/year**	**Installed at RI for XFEL**	**Shifts**	**Working days**	**For 600 cavities/year**	**Additional needed at RI**
Degreasing bath (clean room	2	5	1,5	2	3	7	2,5	1
Ethanon rinse	2	5	0,5	1	3	7	1	-
BCP outside bath	2	5	0,5	1	3	7	1	-
Leak check station, clean room	2	5	1	1	3	7	1,5	1
Tuning machine	2	5	0,5	1	3	7	1	-
Clean room assembly	2	5	2	2	3	7	3	1
EP station	2	5	1	1	3	7	1,5	1
800 ° C oven (4 cavities per run)	3	7	0,5	1	3	7	1,5	1
HPR	2	5	2	2	3	7	3	1
Drying places	2	5	4	8	3	7	12	4
EB welding	2	5	0,5	0,5	3	7	0,5	-
120° C Oven	3	7	2	3	3	7	4	1
Leak check, pressure check	2	5	0,5	2	3	7	0,5	-
TIG welding	2	5	1	2	3	7	1,5	-

Basis : 75% on time

Only EP plant available at RI at the beginning of the project in 2010

Tuning machine free issued by DESY

XFEL cavity project – specification and erection of new infrastructure

- Clean room (120 m^2): Decided to have ISO 4 in all areas to make clean room simple and flexible, no detergent used in clean room, special ISO7 clean room at EP plant used to degrease the cavities, special transport of clean cavities from EP plant to clean room

- 800 C annealing furnace: Integrated in the RI brazing and EB welding work shop with separate housing to keep the surrounding area more clean, cavities are treated in vertical direction

- Slow venting and pumping systems:
  Pumps stand: Half automatic design for easy use,
  mass spectrometer: challenging to achieve and maintain reliable operation

RI cleanroom for XFEL cavities

XFEL cavity project – specification and erection of new infrastructure

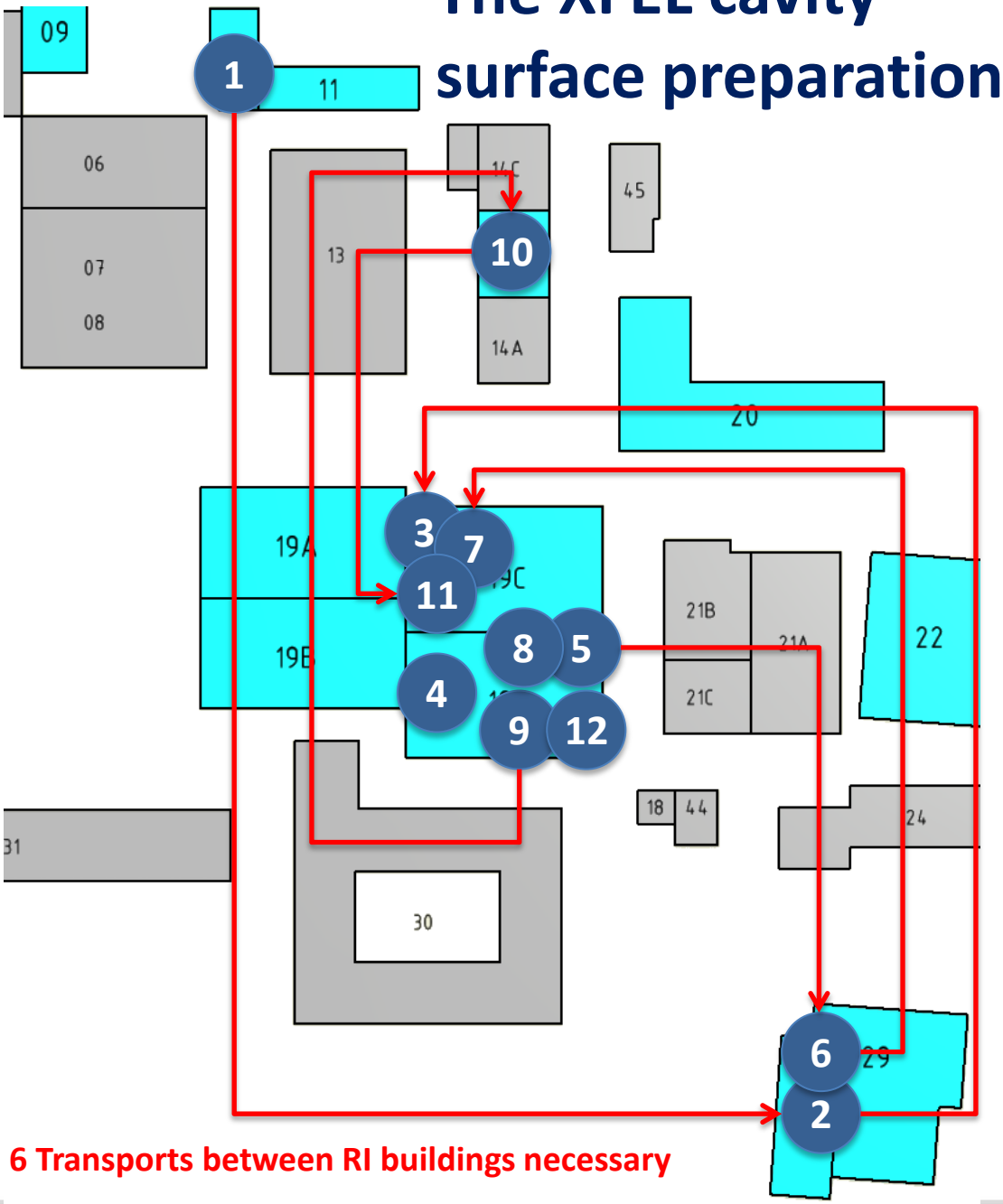
- 120 C baking oven: 3 oven are operated with one pumping system, temperature control of the cavity is challenging (max allowed gradient: 10 C within the cavity)

- Had to learn that cavities can be bended or deformed easily when filling them with water and degrease them, due to different thermal expansion of water and niobium.

- The amount of DI water and nitrogen used during the cavity production is remarkable




The XFEL cavity surface preparation at RI



6 Transports between RI buildings necessary

1. Outside etching (BCP)
2. Weighting, US-degreasing, Electropolishing (110 µm), rinsing
3. Cleanroom (1 x HPR, ethanol rinse, drying, weighting)
4. 800 ° C annealing
5. Tuning
6. Electropolishing (40 µm), rinsing
7. Cleanroom (1 x HPR, ethanol rinse, assemble blank flanges, leak check, 6 x HPR, drying, install FMS (field measurement system), leak check)
8. Check field profile (ev. tuning)
9. EB welding of ring and bellow
10. TIG welding of helium vessel
11. Cleanroom (disassemble FMS, install antennas (pick-up, HOM. High Q for vertical testing), leak check, 6 x HPR, assemble last flange, leak check and RGA
12. 120° C baking, leak check
13. Transport under vacuum to DESY for vertical test

XFEL cavity project – qualification of infrastructure

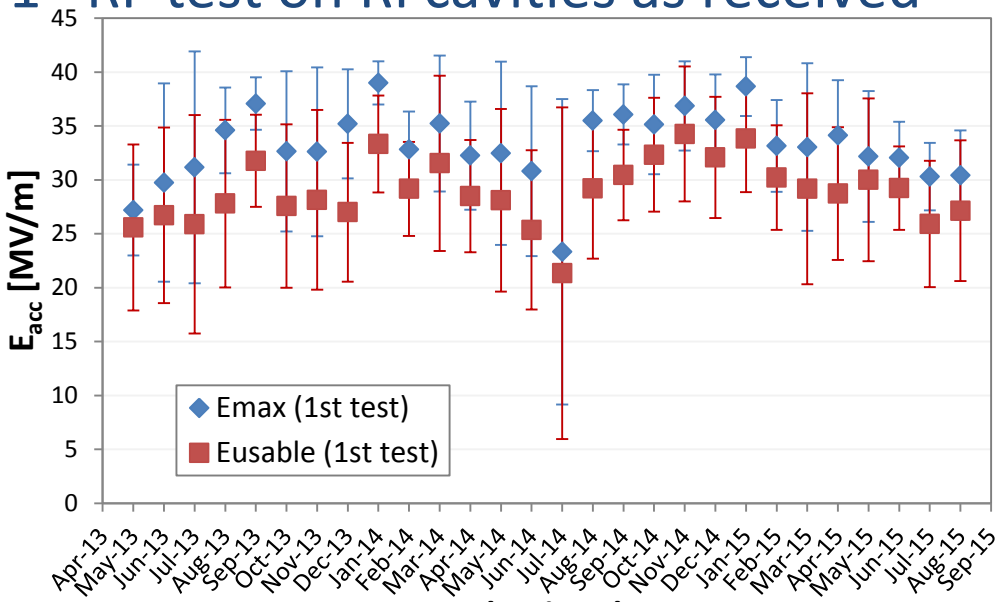
- Most difficult part of the project
- Qualification was done by the reference cavities, first treated by DESY and then retreated by RI
- Very useful to define the correct handling of the cavities at all stations
- Good collaboration between RI and DESY/INFN experts necessary, don't panic when first bad results are there
- Training by DESY/INFN experts key for success
- Have to remember: First reference cavity showed only 4 MV/m after just slow venting and pumping

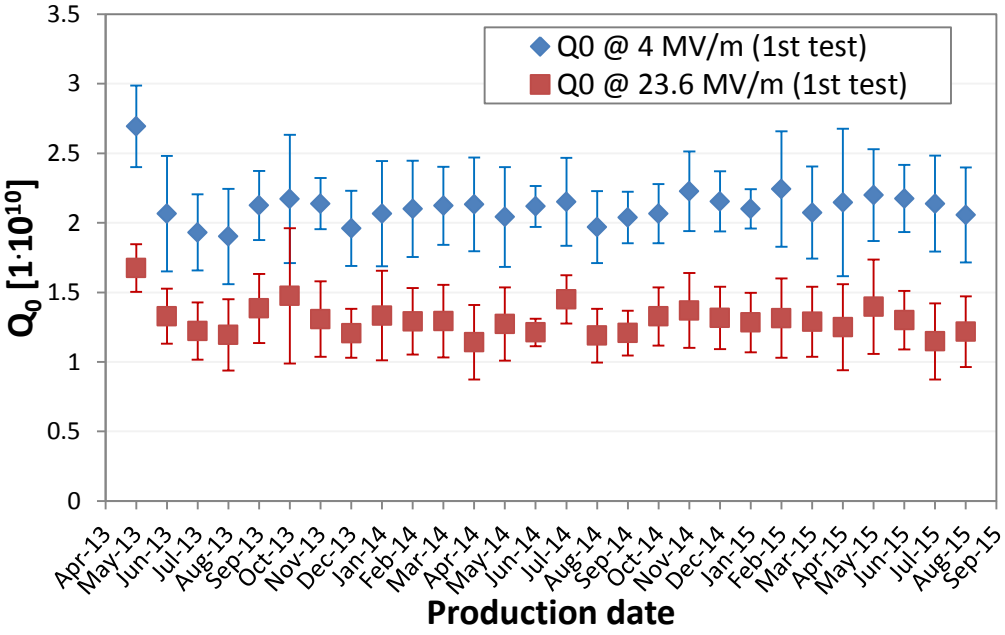
XFEL cavity project – Hiring and qualification/training of personnel

- Have made good experience to find good operators for all tasks
- Training of the operators together with DESY/INFN experts at the beginning of the project was key for success
- During 2,5 years series production, the preparation process was reviewed by DESY/INFN experts 2 times
- During series production, quality of work is remarkably stable, even in two shift operation without the engineers being present all the time

SOME NUMBERS (ONLY FIRST TEST)

1st RF test on RI cavities as received





Total tests: 327, test Ok: 259, Ok at 1st: 79.2%

E_{max}: 33.2 +/- 6.5 [MV/m]

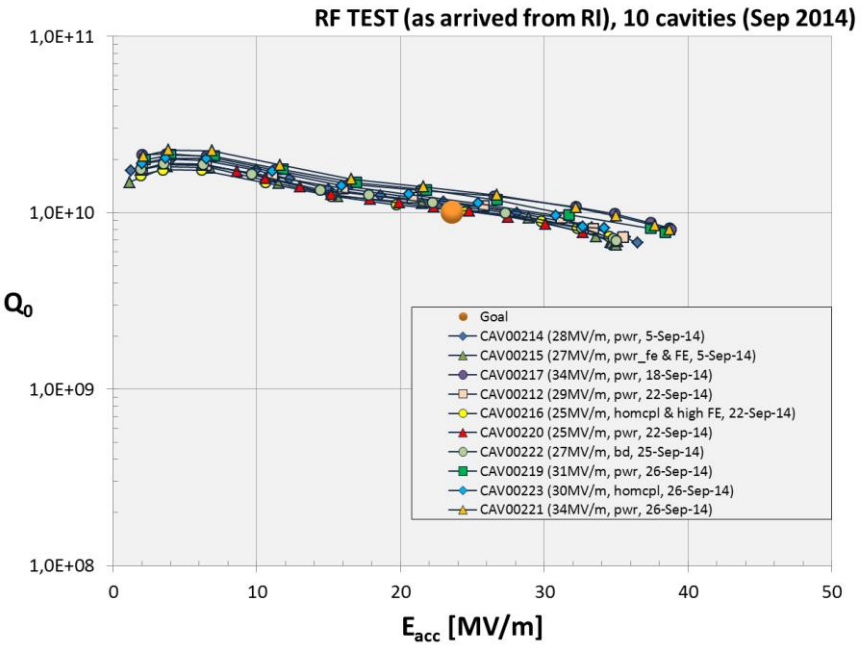
E_{usable}: 29.1 +/- 7.3 [MV/m]

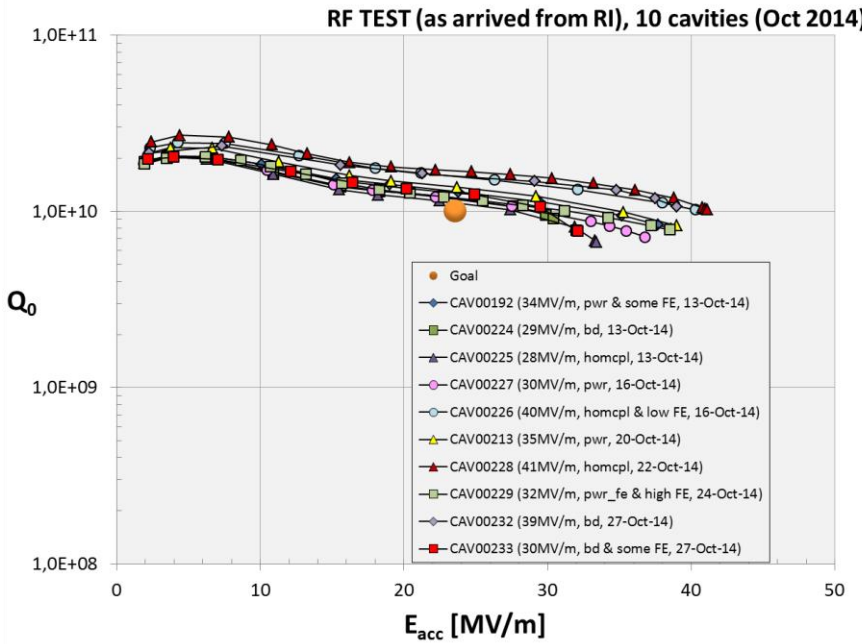
Q_0 @ 4MV/m: 2.12 +/- 0.33 [$1 \cdot 10^{10}$]

Q_0 @ 23.6MV/m: 1.30 +/- 0.27 [$1 \cdot 10^{10}$]

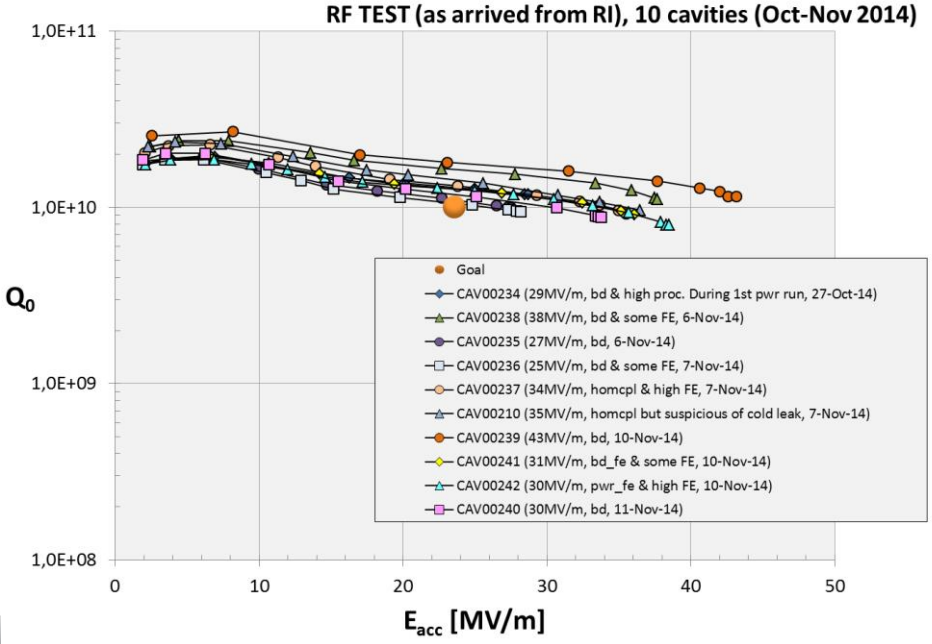
When you follow the specification, the XFEL recipe will produce excellent cavities

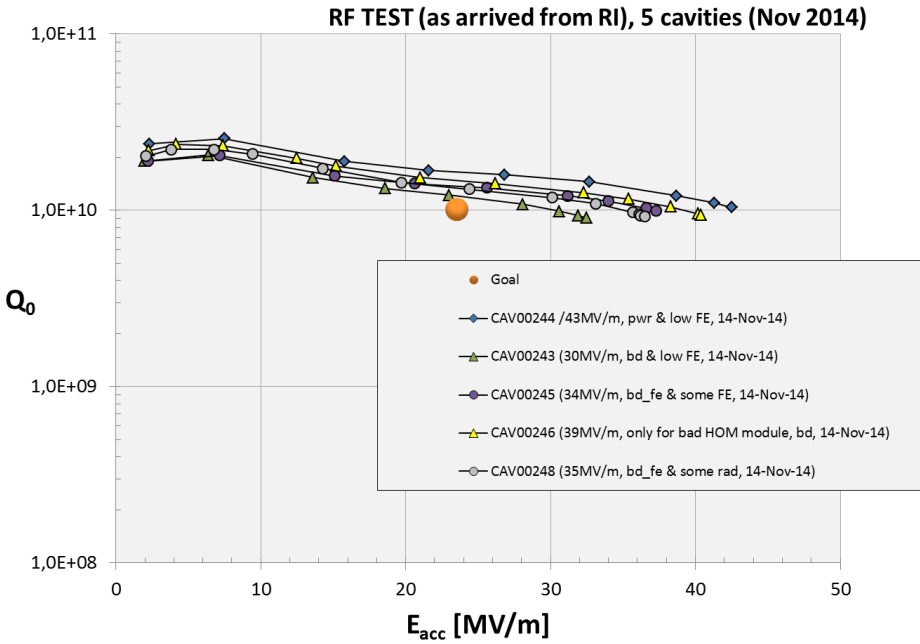
courtesy of D. Reschke/L. Monaco





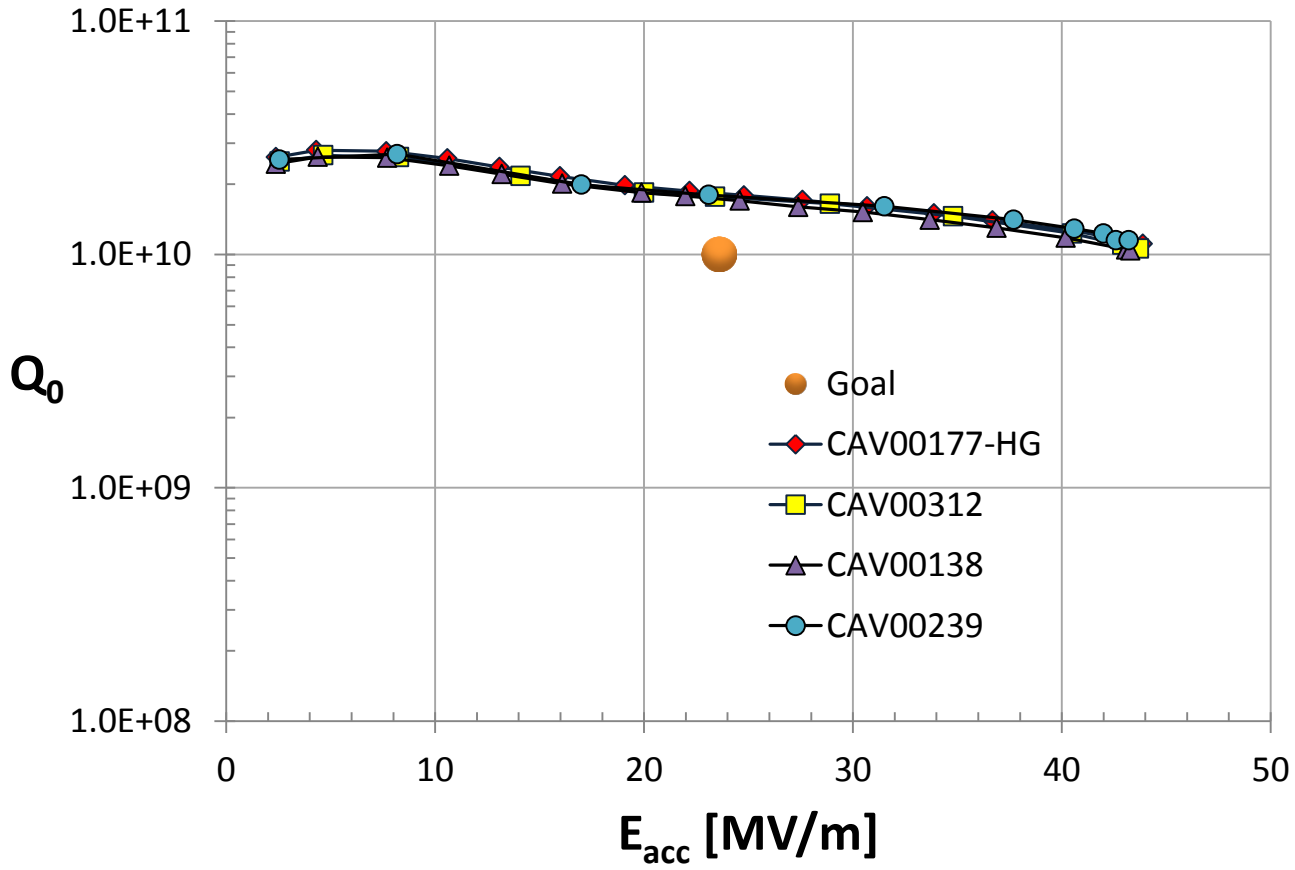
monthly cavity test results





BEST CAVITIES: AS RECEIVED

research instruments



Why are some cavities better than the others? (personal opinion)

- In case a cavity is limited by FE it is most probably caused by a human error during assembly process in the clean room. We can retreat it by additional HPR which is a very fast process that can be done within a week

- In case the cavity is limited by earlier quenches or lower Q, we do not believe it is caused by the EB welding. We learned that N2-doping is not only influencing the Q but also the quench field. Some minor variation of oxygen or other impurities content in the RF surface layer from EP or 120 C baking process might influence the Q and the quench field (just a speculation)

Summary

- The production of the XFEL cavities has been a big success for RI
- Due to logistics the mechanical production at the end is more challenging for us than the surface preparation which runs independently from other projects
- Mechanical tolerances (end groups) are still tough to meet

- When strictly following the XFEL recipe, the resulting cavity performance is well above the XFEL specification

- Many thanks to the cavity project team of DESY/INFN for the excellent collaboration