Superconducting RF cavity system production for particle accelerators in scientific and industrial applications

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RI Research Instruments GmbH, Germany

- 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)

- **About 180 employees, 30% engineering & project management, 60 % manufacturing**
- Located in Bergisch Gladbach, a town 20 km away from the center of Cologne


RI Research Instruments GmbH premises at Technologiepark Bergisch Gladbach

Worldwide renowned as **"Advanced technology engineering and manufacturing specialist"**

World map of science customers and partners

Markets:

- Big Science
- Medical/ Particle Therapy
- Energy/ Nuclear
  (incl.Fusion, ADS, Transmutation)
- Advanced Technology Industry
  (incl. Life Science, Semiconductor)

In house manufacturing capabilities

On about 6000 m^2, we have a very deep manufacturing capability and are producing key components of our products in house

- Forming, milling and turning
- Certified welding and brazing
  - Electron beam welding
  - Vacuum and induction brazing
  - TIG welding
- Electro-chemical and physical and surface preparation and coating
- Heat treatments
- Clean room assembly
- State-of-the-art test facilities
  - RF measurements
  - Vacuum and Cryogenics
  - Dimensional inspection
- System integration
- ISO 9001 certification

From built to print manufacturing up to turn key system delivery with guaranteed performance

Particle accelerators, Energy and Fusion technology, EUV systems, Cryogenic equipment, Undulators, beam lines

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RI is working in parallel on 80 projects with contract values above 100 k€ each

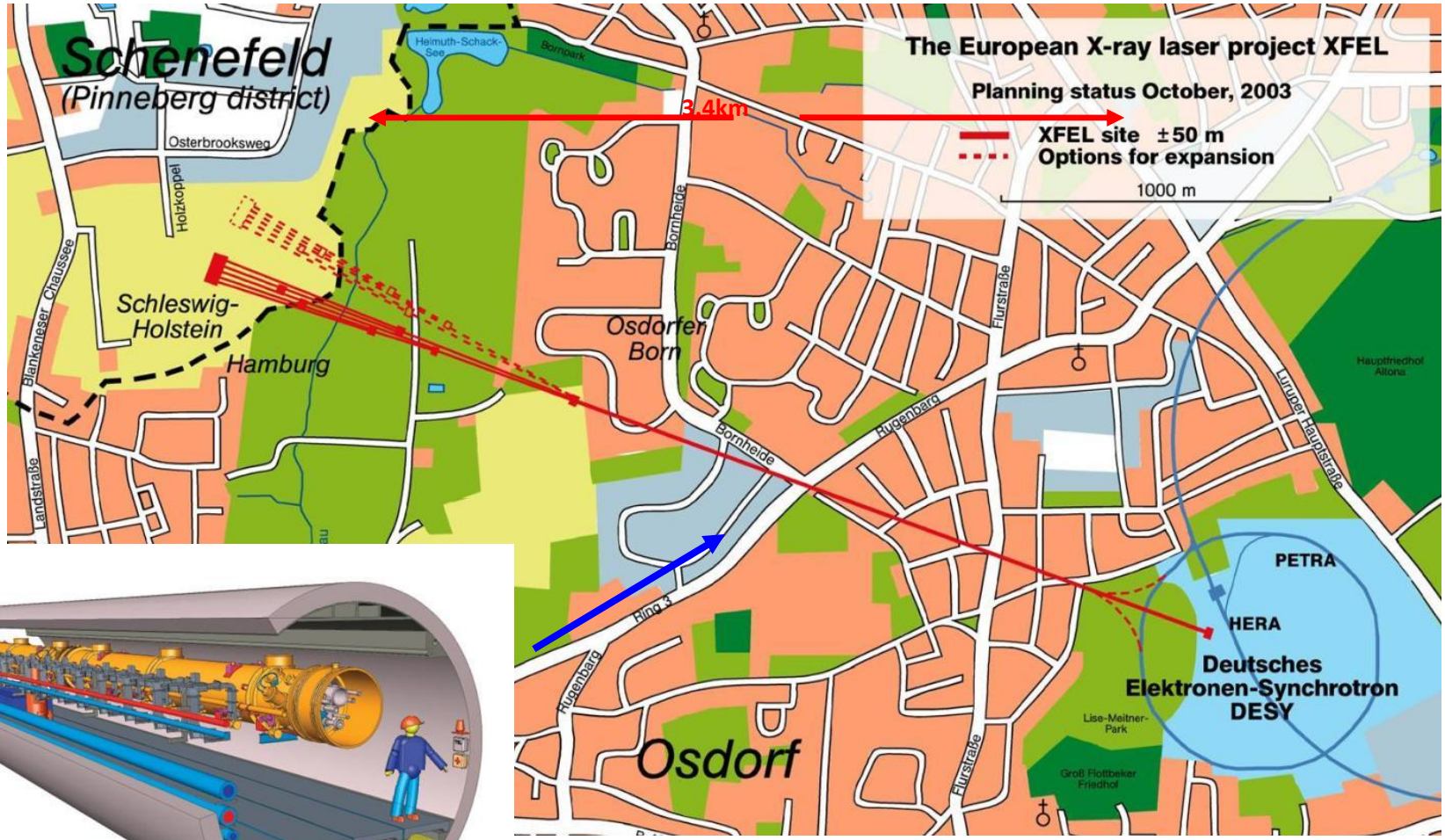
Superconducting RF business: contributes about 25% of turnover of RI

Delivered SRF cavities

RI is world leading company in manufacturing SRF cavities

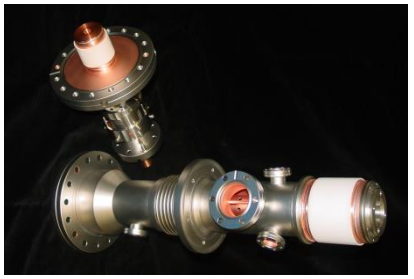
In total more than 1500 SRF cavities produced at our premises within the last 30 years

European XFEL Superconducting Linac



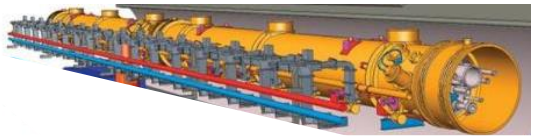
key components of linac:
800 superconducting RF cavities, 800 RF couplers

RI contribution to the E-XFEL project



420 Nb 9 cell cavities (1.3 GHz)		670 RF couplers (consortium with TED)	
Manufacturing	**Surface preparation**	**TED**	**RI**
Forming Nb sheets	Electro-polishing	Turning and milling	Brazing of ceramics
Turning , milling	High pressure rinsing	Brazing stainless steel	TiN coating of ceramics
Acid treatment (BCP)	Vacuum anneal (800 C)	Copper coating →	EB welding
Electron beam welding	ISO 4 clean room assembly		Cleaning
RF control	RF tuning		Assembly in ISO 4
Vacuum control	Titanium He-vessel welding		Vacuum control

Qualification testing at/by DESY ↘ ↙ Qualification testing at/by LAL



Module assembly at CEA (company Alsyom, France)

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Module testing at/by DESY → Installation into XFEL tunnel

XFEL cavity mechanical manufacturing

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- Order for 420 received in September 2010 from DESY
- Series production from Mid 2012 - Mid 2015 (3 years)
- Achieved a production rate of up to 180 cavities per year, 0.7 cavities each working day

2 shifts (06:00 – 22:00) at 5 working days, Saturday used to accelerate the schedule

Resources (Occupation):

- **5 turning machines (75 %)**
- **1 press (10 %)**
- **1 milling machine (30 %)**
- **2 EB welding machines (75 %)**
- **1 RF control place (20 %)**
- **3 dimensional control spaces (60 %)**
- **1 BCP barrel (75 %)**
- **2 metal working place (60 %)**
- **1 leak checker (70%)**
- **1 grinding place (50%)**

Challenges:

- shape accuracy (0.2 mm) of cells
- constant output of cavities

EB welding:

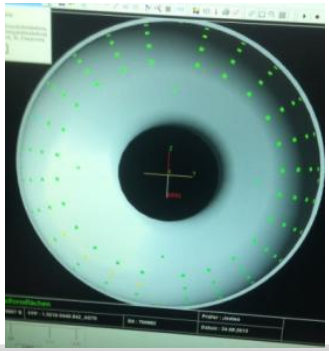
- very stable, almost no errors

RI had large experience in producing SRF cavities through the last 20 years

XFEL cavity manufacturing impressions

End tubes,
HOM couplers

Metrological
inspection of
dumbbells



Dumbbells and stiffening rings, welded dumbbells

XFEL cavity surface preparation

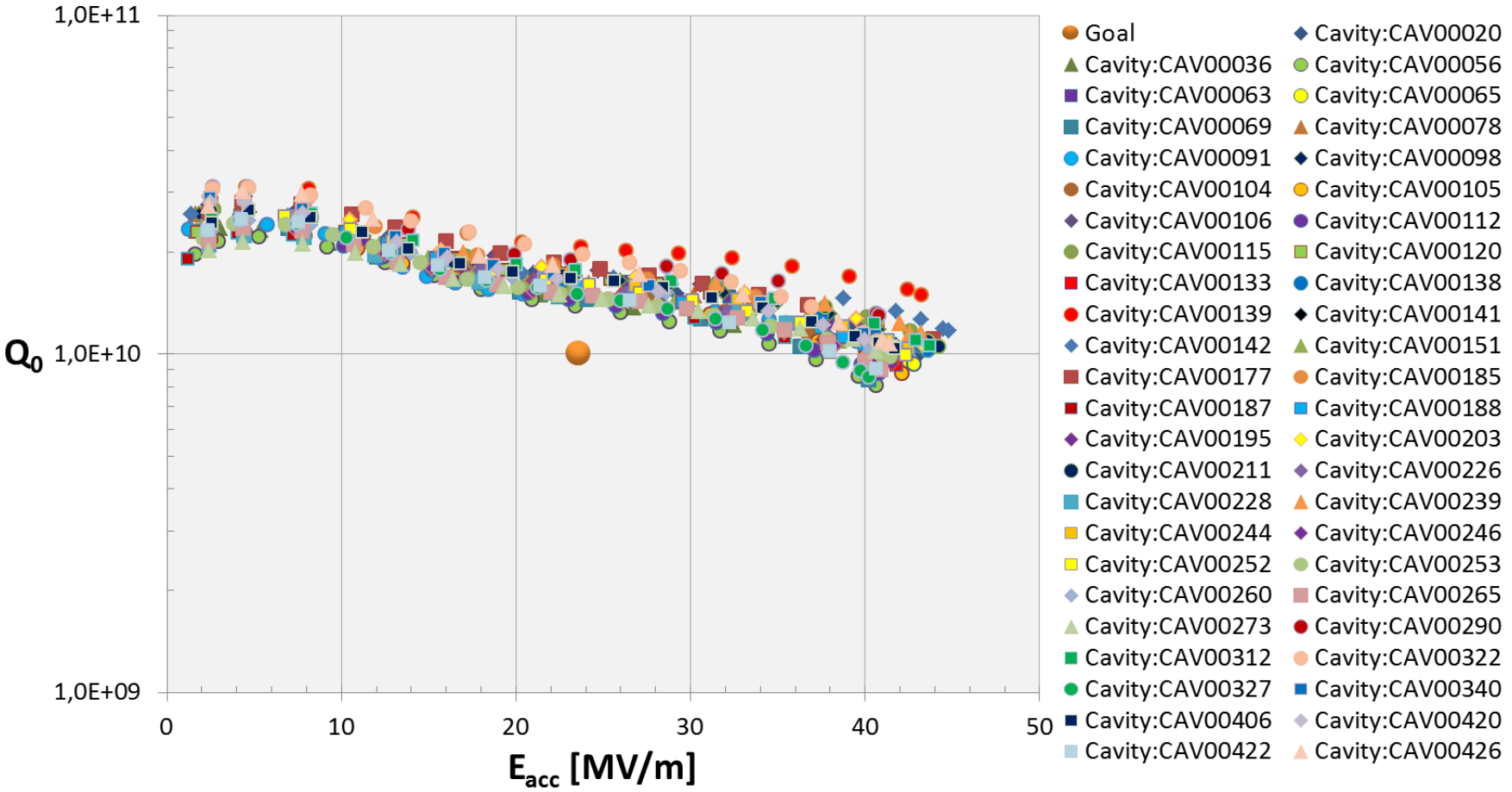
- The EXFEL Cavities had to be delivered to DESY ready for cold RF tests
- Sophisticated surface treatment was applied to the SRF cavities in order to generate a dust free and clean surface layer inside the cavity needed for cavity operation at highest accelerating gradients and quality factors
- The treatment steps (the XFEL-recipe) to generate such high performance cavity surface was developed within a 15 years long R&D phase at DESY and other various world leading SRF labs
- The cavity treatment according to the XFEL recipe requires erection of special Infrastructure (electro-polishing plant, ISO4 clean room, all metal vacuum annealing furnace, etc)
- Technology transfer of the XFEL recipe to RI was done by DESY and INFN experts within a trustful and cooperative partnership

Infrastructure for surface preparation

- Electro-polishing plant
- Buffered chemical polishing plant
- 800 C annealing furnace
- 120 C baking station
- TIG welding and pressure testing of titanium helium vessel
- 120 m2 ISO 4 clean room with high pressure water rinsing stations, special vacuum pumping system

RI cleanroom for XFEL cavities

RI XFEL cavity results



47 of 420 cavities of RI EXFEL cavity production exceeding **40 MV/m**

More than half of the 420 cavities exceeded **35 MV/m**

Average accelerating gradient of all RI cavities was **33 MV/m (RMS 6.5 MV/m)**

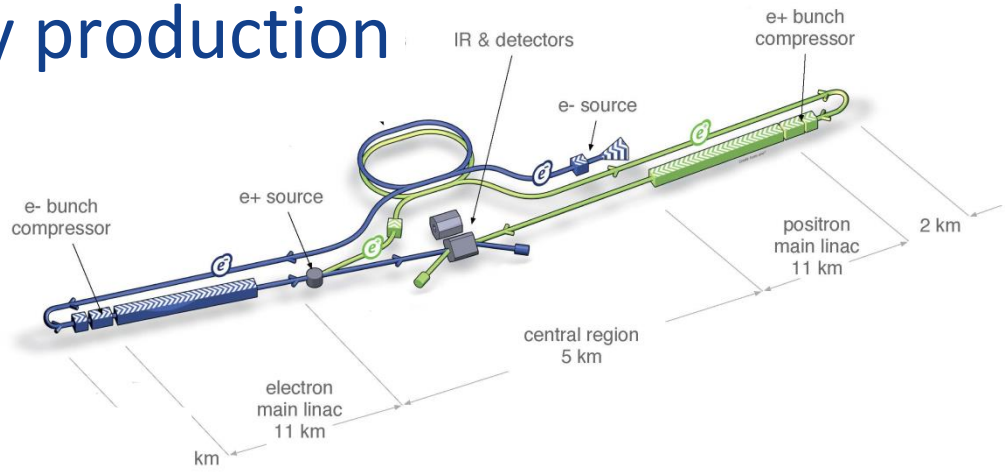
Ongoing and future SRF cavity series production for scientific application

- After XFEL, the series production of almost identical LCLS-II cavities has started and is ongoing until Mid 2017
- Infrastructure can be easily adopted to allow quarter-wave (QWR), half-wave (HWR), or other kind of elliptical cavities for future projects like ESS in Lund, Sweden or RISP at IBS, South Korea.
- The aim of RI is, to deliver those cavities ready for cold RF test like it was done for the EXFEL project

First LCLS-II cavities ready to ship

Prototype QWR für IBS RISP project in cleanroom, at high pressure water rinse (HPR) and 120 C bake

ILC cavity production



- ILC needs 18,000 EXFEL type SRF cavities in total for 500 GeV
- 6,000 cavities to be produced in the three regions Asia, Americas and Europe each
- 2 production sites in each region: 3,000 cavities per production site
- 7.5 years series production: 400 cavities per year, each site
- Doubling the working time per week by going from 2 shift at 5 days to 3 shifts at 7 days and with some minor modification, RI would be able to produce with the currently installed EXFEL infrastructure about 400 cavities per year
- RI almost achieved the ILC design parameters already during EXFEL production

Delivered SRF accelerator modules

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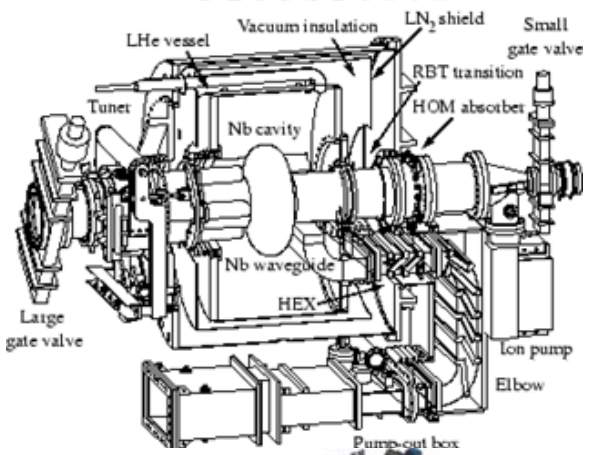
500 MHz accelerator modules

Technology transfer from Cornell University, USA

2000:	**2 SRF modules**	**for NSRRC,**	**Taiwan**
2000:	**2 SRF modules**	**for CORNELL,**	**USA**
2000:	**2 SRF modules**	**for CLS,**	**Canada**
2003:	**3 SRF modules**	**for DLS,**	**Great Britain**
2005:	**3 SRF modules**	**for SSRF,**	**PR China**
2010:	**3 SRF modules**	**for PAL,**	**Korea**
2012:	**1 SRF module**	**for DLS**	**Great Britain**



- Cavity production and cavity surface preparation
- Cavity vertical test
- Coupler production and conditioning
- Ferrite style HOM loads
- Module assembly
- **Installation on customer site**
- Commissioning, guarantee on cavity voltage and Q
- **Valve boxes and transfer lines**
- **SRF Electronics**
- **Interlock and data acquisition system**

Factory testing, shipping, installation

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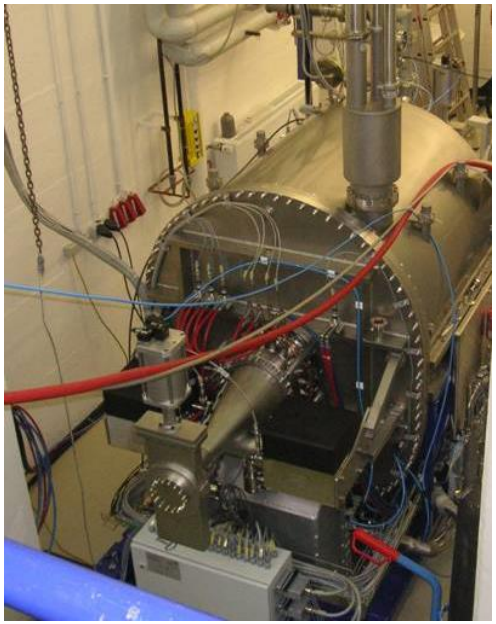


Twin Cavity Accelerator Module as Turn-Key System for FEL and ERL Application

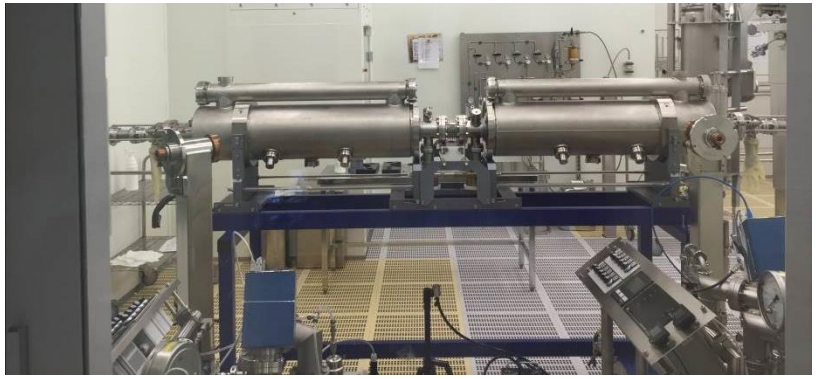
- RI has produced in 2006 already 2 such modules to Daresbury
- 2 Modules for Ankara University (2016)
- 2 Modules for Mainz University (2017)

License Agreement on the Twin Cavity Module with FZ Rossendorf

Target Values (cw operation):

Eacc > 15 MV/m @ Cavity Q > 1 E10

Prf > 8 kW per Coupler



String assembly recedntly done with consultation/review of DESY experts

Future SRF module production

- The XFEL module production was performed by industry (Alsyom) using infrastructure at CEA, France

- Investment in infrastructure for module assembly (clean room, tooling) is lower than the investment in infrastructure for cavity surface preparation

- Shipping of SRF modules can be done

- **SRF module production technology could be transferred completely to industry**

Outlook for ILC:

- ILC needs 2,250 XFEL like modules, 750 per region, 375 per production site
- The XFEL module assembly infrastructure at CEA allows assembly of 1 module every week (50 per year) in one shift 5 working days operation.
- With 2 such production sites in each region (Asia, Americas, Europe), 100 modules would be assembled per year, the ILC production would be finished in 7.5 years.

SRF modules for Industrial application

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SRF technology might be the choice for future industrial application of accelerators:

- **EUV light source for lithography (ERL or FEL)**
- **Driver (linac) for an accelerator driven system (ADS) or accelerator driven sub-critical nuclear reactor**

Each such machine would need about 40 (EUV) up to 160 (ADS) SRF cavities housed in 10 to 50 SRF modules

For both applications SRF modules are required operating in cw mode with highest reliability

SRF modules for Industrial application

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For a fast and economic SRF module production for a industrial application like ADS or EUV light source a collaboration between institute and industry could be best and as follows:

Task	Performed at
Design in view of reliable operation	Industry (consultation from institute)
Manufacturing of cavities	Industry
Manufacturing of couplers	Industry
Surface preparation of cavities and couplers	Industry
Test of cavities and couplers	Laboratory
Assembly of SRF modules	Industry
Test of SRF modules	Laboratory
Installation and commissioning of SRF modules	Industry

The cold testing of cavities and SRF modules in industry would need large investment in cryo-plant, RF power sources and test bunkers and should/could be done after the SRF technology has break through for industrial application

Summary

- High performance SRF cavity production ready for cold RF test and at large numbers is already available in industry
- SRF module assembly feasible to be carried out completely in industry
- Collaboration between institute and industry proven to work for challenging scientific projects using SRF and could be extended for first industrial application using SRF technology