Injection Systems for Synchrotron Light Sources

Monday 22 Nov 2010 at 13:10 (00h50')

Primary authors : Dr. VOGEL, Hanspeter (RI Research Instruments GmbH)

Co-authors :

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RI Research Instruments GmbH

Contribution to the II Mexican Workshop on Accelerator Physics: A Light Source

Hanspeter Vogel

RI Research Instruments GmbH

Content

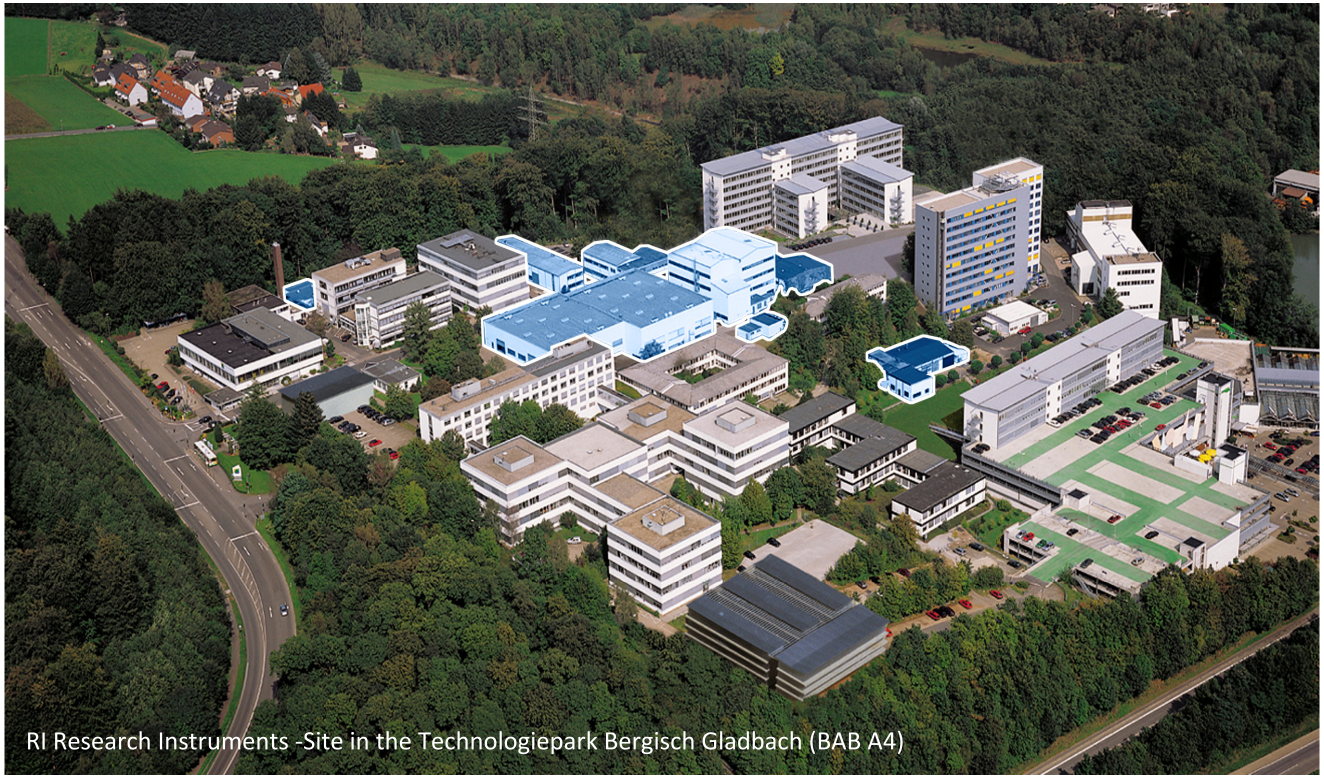
Injection Systems for Synchrotron Light Sources

RF Accelerating Systems for Synchrotron Light Sources

- Overview on RI Research Instruments/ACCEL Instruments history and background
- Overview on RI activities in accelerator technology
- Injection systems for Synchrotron Light Sources
  - Sources and Linear Accelerators
  - Booster Rings
- RF Accelerating Systems for Synchrotron Light Sources
  - room temperature RF
  - superconducting RF
- Summary
  - Industrial capabilities to supply subsystems for synchrotron Light Sources
  - Requirements for the Synchrotron Light Source in case of industrial supplies

RI Research Instruments GmbH

Advanced Technology Equipment and Turn-Key System Supplier for Research, Industry and Medical worldwide



Linear Accelerators

RF Cavities, Couplers, Auxiliaries

Superconducting Accelerator Modules

Electron and Ion Sources

Beam Diagnostic Elements and Particle Beamlines

Accelerator Equipment for Particle Therapy

Specialized Manufacturing Projects

A former activity of ACCEL Instruments GmbH

51% of shares by Bruker ASC, Inc.

Management holding a significant equity stake of the company

Overview on RI's company history

research instruments

1970:

Interatom GmbH, 100 % owned by Siemens, about 2000 people

Research Nuklear Power plant development

1989:

Siemens, about 2000 people

Research Nuklear Power plant development

Magnet and accelerator group
60 people

1993

ACCEL Instruments GmbH (Staff developed 30 -> 270 p)

RF cavities and special products	Optical beam lines	Superconducting magnets	Proton therapy

2007

ACCEL Instruments GmbH owned by Varian Medical Systems

RF cavities and special products	Optical beam lines	Superconducting magnets	Proton therapy

2009

RI Research Instruments GmbH	BASC GmbH	Varian Proton Therapy GmbH
51% Bruker	100% Bruker	100% Varain Meical Systems
RF cavities and special products	Optical beam lines and SC magnets	Proton therapy business
90 people		

BEST (Bruker Energy and Supercon Technology)

Bruker EST Corp
Billerica, USA

Hydrostatic Extrusions Ltd. (100 %)
Perth, Scotland, UK
Cuponal, tolling

Bruker EAS GmbH (100 %)
Hanau, Germany
LTS and PIT wire: MRI, NMR, FTMS

Bruker HTS GmbH (100 %)
Alzenau, Germany
1G and 2G HTS Superconductors

Bruker Advanced SuperCon GmbH: Supercon Magnets & Devices; Beamlines (100 %)
Bergisch-Gladbach, Germany
HTS Supercon Devices, New Magnet Types, Beamline Projects, EUV and XAM Technologies

RI GmbH: Accelerators & Special Products (51 %)
Bergisch-Gladbach, 45% investment by RI GmbH management
Project business & Specialized Manufacturing for Accelerators, Fusion research/ITER, VMS

Company Organisation

Operational Safety
S. Bauer

Managing Directors Dr. M. Peiniger, Dr. B. Prause
Secretary H. Lohmar

Quality Management
B. Göge

Technical Management
H. Vogel

Business SC RF, Cryogenics, Clean Surfaces
Dr. M. Pekeler
- Marketing
- Sales
- Engineering
- Project Management

Business NC RF, Accelerator Systems, Special Products
Dr. C. Piel
- Marketing
- Sales
- Engineering
- Project Management

Technology, Development, Project Engineering OEM VMS
Dr. P. vom Stein
- Technology
- Development
- Design
- Supply, Service Varian PT

Manufacturing
S. Bauer
- Manufacturing Logistics/ Dimensional Control
- Turning
- Milling
- Electrical
- Surface Treatment
- Joining Technology
- Assembly

Finance
T. Börner
- Accounting
- Financial Project Management
- Human Resources
- IT/Systems

Core Competences and Markets

Quality Management according to DIN EN ISO 9001:2000, KTA

Technologies

- RF, Accelerator
- Superconductivity
- Cryogenics
- Vacuum
- Integr. System Control
- Specialized Manufacturing
- Surface Treatment
- System Integration

Products / Services

- Linear Accelerators,
- RF Cavities, Couplers
- SRF Accelerator Modules
- Electron and Ion Sources
- Beam Diagnostic Elements
- Particle Beamlines
- Precision Manuf. Components

Markets

- Fundamental Physics
- Applied Research
- Medical/ Particle Therapy
- Energy/ Nuclear
- Advanced Technology Industry

  Including:

  Inspection,

  Solar,

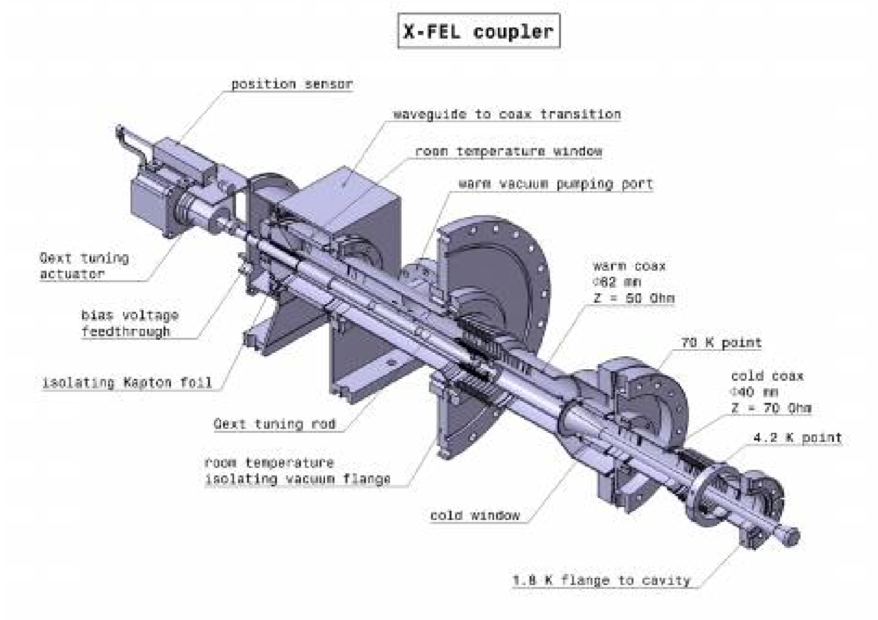
  Live Science

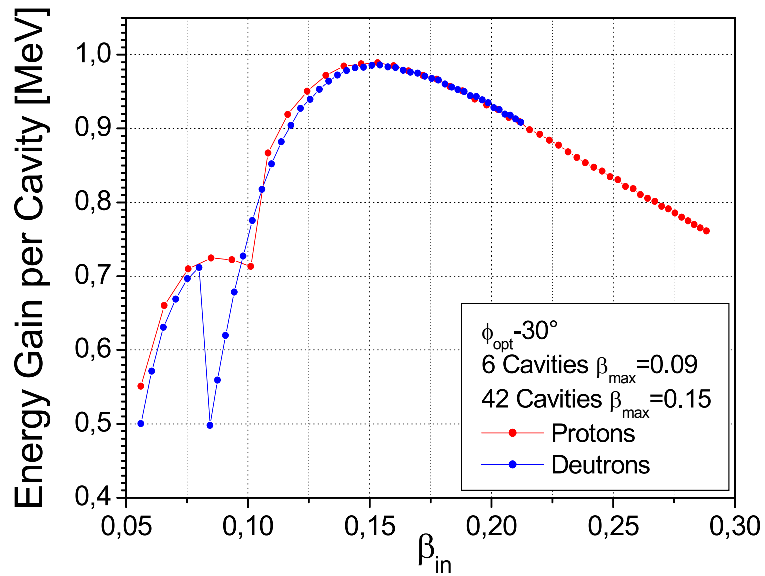
physics layout – engineering – design – manufacturing – assembly – testing – service

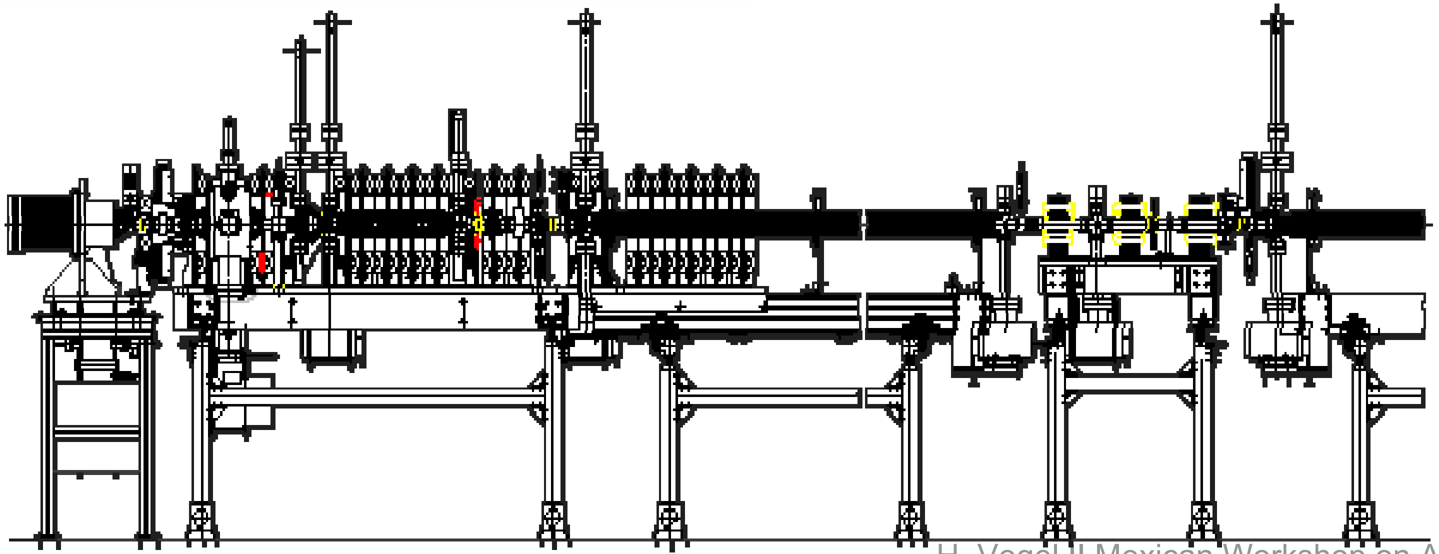
World Map of Customers and Partners in Fundamental and Applied Research (not complete)

RI is a Global Player in an expanding worldwide Business

RI scope: **Engineering** <> Manufacturing <> System Integration







research instruments

RI scope: Engineering <> **Manufacturing** <> System Integration

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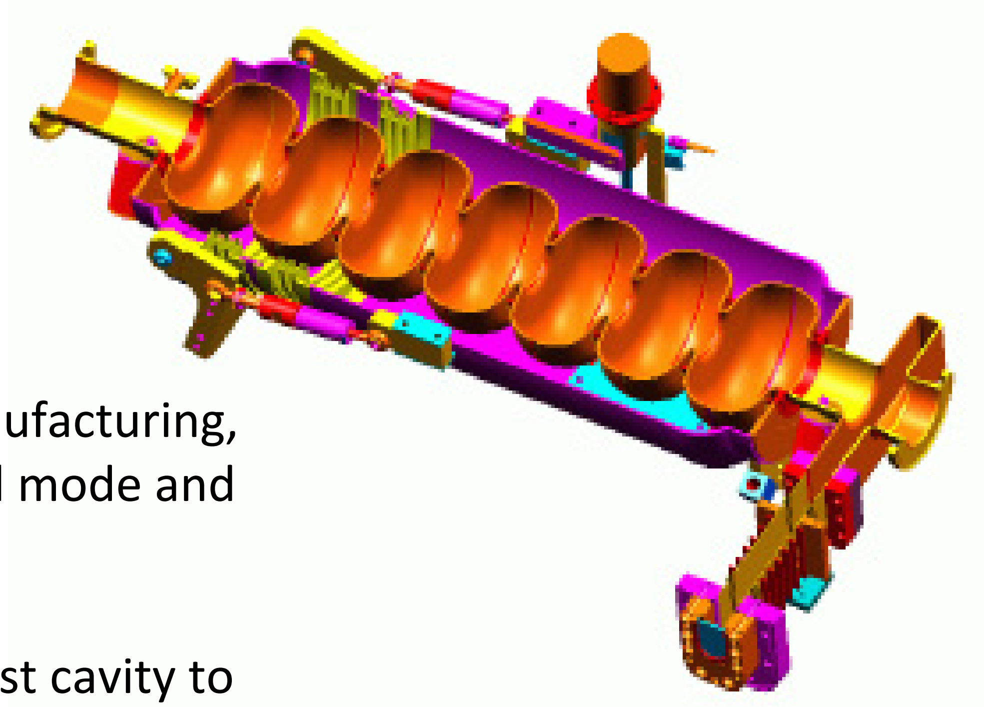
Overview on RI activities in accelerator technology
Superconducting RF

We manufactured e.g. 360 CEBAF, 109 SNS and more than 100 ILC Type Cavities

(Technology Transfer DESY, JLAB, Cornell, University Wuppertal)

Superconducting cavities – CEBAF upgrade cavities



86 pieces 1.5 GHz 7-cell cavities
contracted in July 2009.

Scope includes material procurement, manufacturing, bulk chemistry and RF tuning (fundamental mode and HOM couplers).

First article to be delivered in June 2010, last cavity to be delivered middle of 2011 (current planning last cavity November 2010).

First cavities tested at Jefferson Lab with accellerating gradients in the range of 40 MV/m

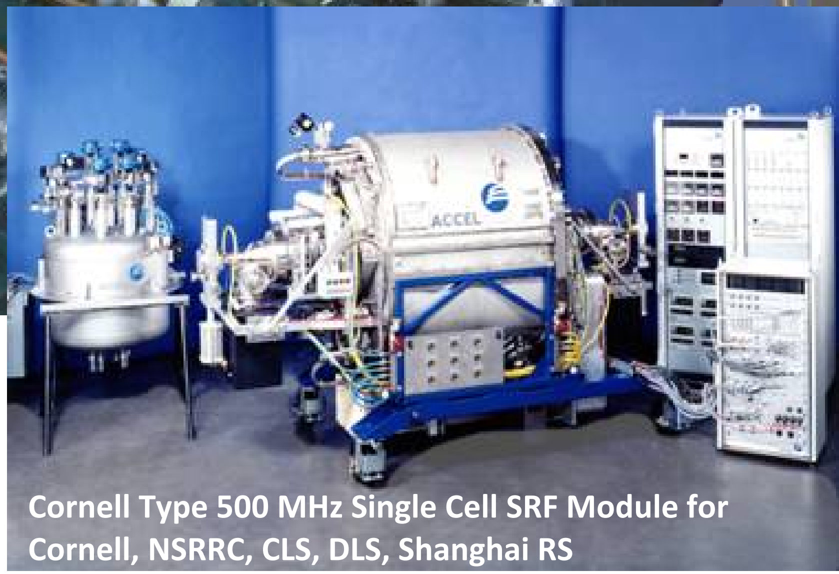
research instruments

Superconducting RF Accelerator Modules

LEP 200 Nb/Cu, 352 MHz

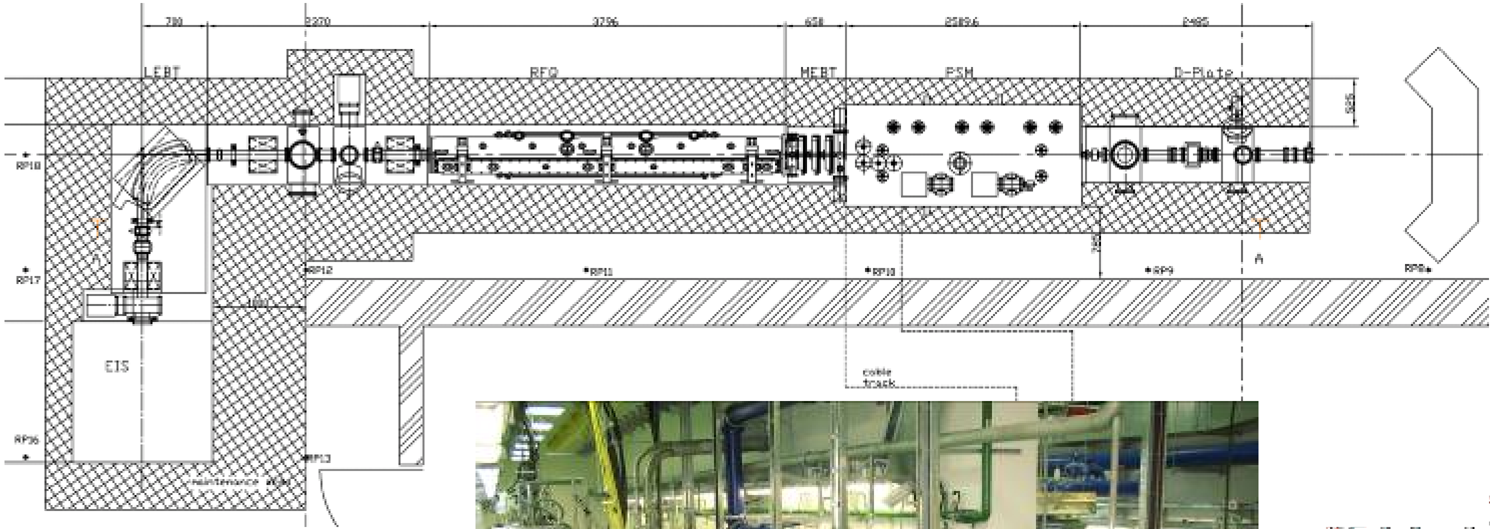
3rd harmonic, 1500 MHz Landau Module for BESSY (Inhouse Development)

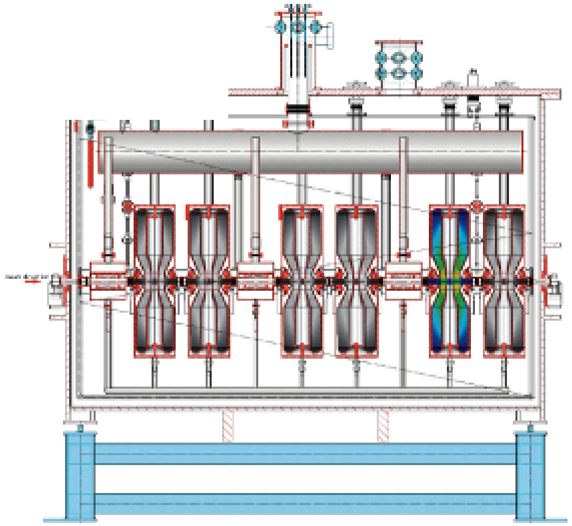
Technology Transfer from CERN and Cornell



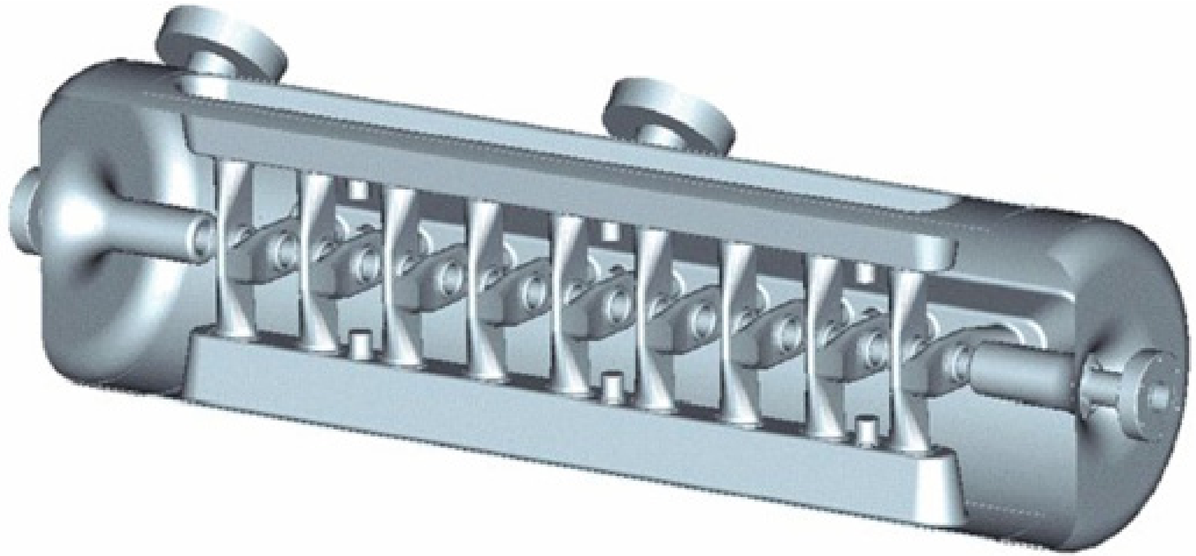
Cornell Type 500 MHz Single Cell SRF Module for Cornell, NSRRC, CLS, DLS, Shanghai RS

40 MeV Superconducting linear accelerator for Protons and Deuterons based on Half Wave Resonators





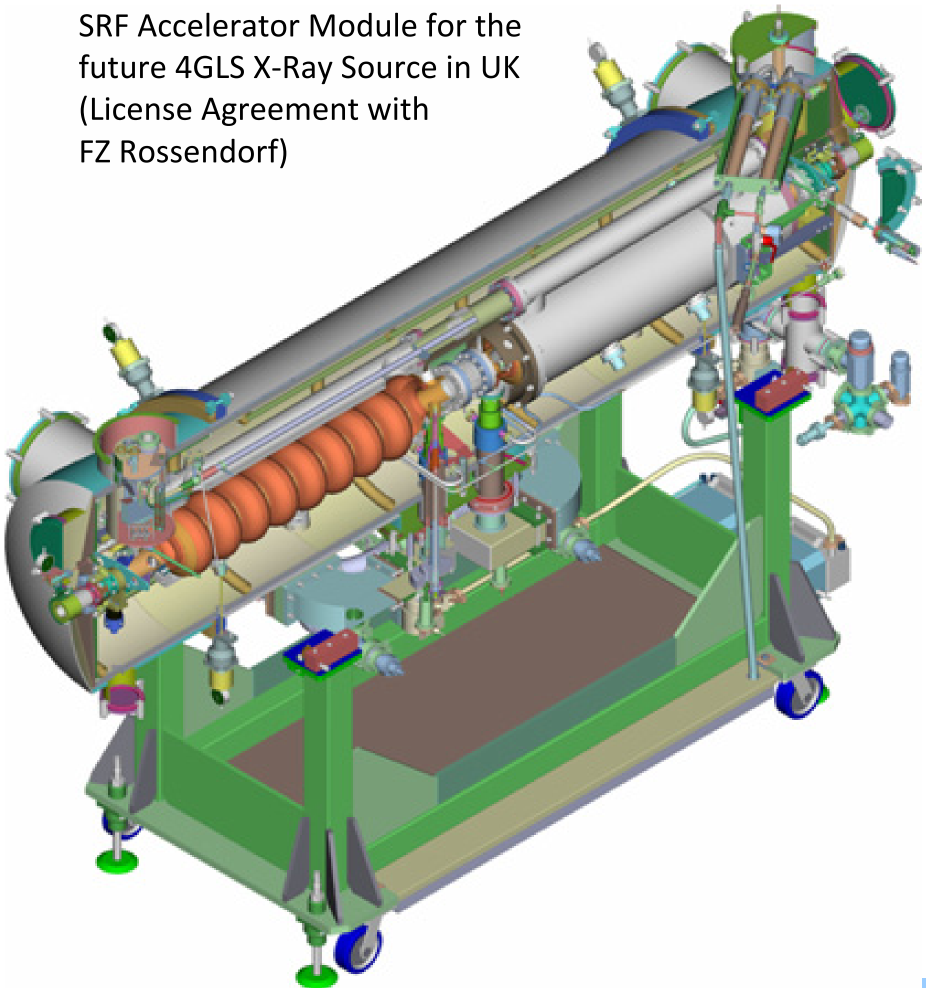
SRF Cavities, Prototyping



CH-Mode Cavity for Ion-acceleration (Design: Univ. Frankfurt)

Superconducting Linear Accelerators for FEL/ERL Applications and the Future ILC

SRF Accelerator Module for the future 4GLS X-Ray Source in UK (License Agreement with FZ Rossendorf)



SRF Cavities and Modules for the future projects X-FEL/DESY (800 Units) in Hamburg und ILC (20000 Units)

Courtesy DESY

Delivery on Sept. 09, 2005, to FNAL for ILC

RI is the World‘s leading Company in SRF Technology

Overview on RI activities in accelerator technology
normalconducting RF

CCL Modules for SNS in Oak Ridge/USA

Complete CCL-Module during RF Test at RI

CCL Linac at SNS

We manufactured, assembled, aligned and rf tuned 4 CCL Modules as a Special Equipment Supplier (Co-operation with LANL)

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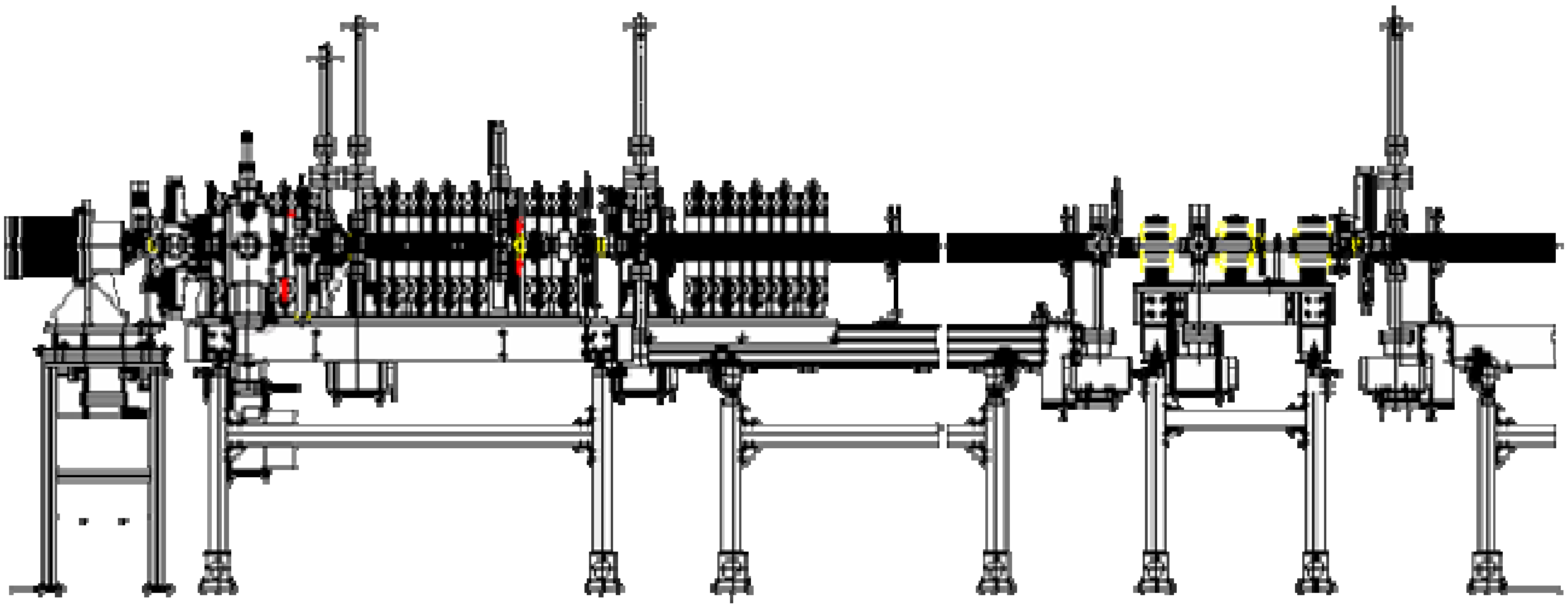
3 rd Generation Light Source Injector Linac



design, manufacturung, installation, operation by RI:
Gun, Bunching System, Focussing System, Accelerating Sections, RF-supply, vacuum-, control-system,

research instruments

Turn-Key S-Band Electron Linear Accelerators for Synchrotron Light Sources and Medical Applications

Delivered:

SLS/PSI, CH	100 MeV
DLS, UK	100 MeV
ASP, Australia	100 MeV
PTB, Germany	0,5-50 MeV

In Production:

Taiwan Light Source	150 MeV
Uni Nijmegen	15 MeV

NSLS-II. Brookhaven National Lab) 200 MeV

Technology Transfer from DESY (Dortmund Univ.)

License Agreement on S-Band Lin. Collider Components with DESY

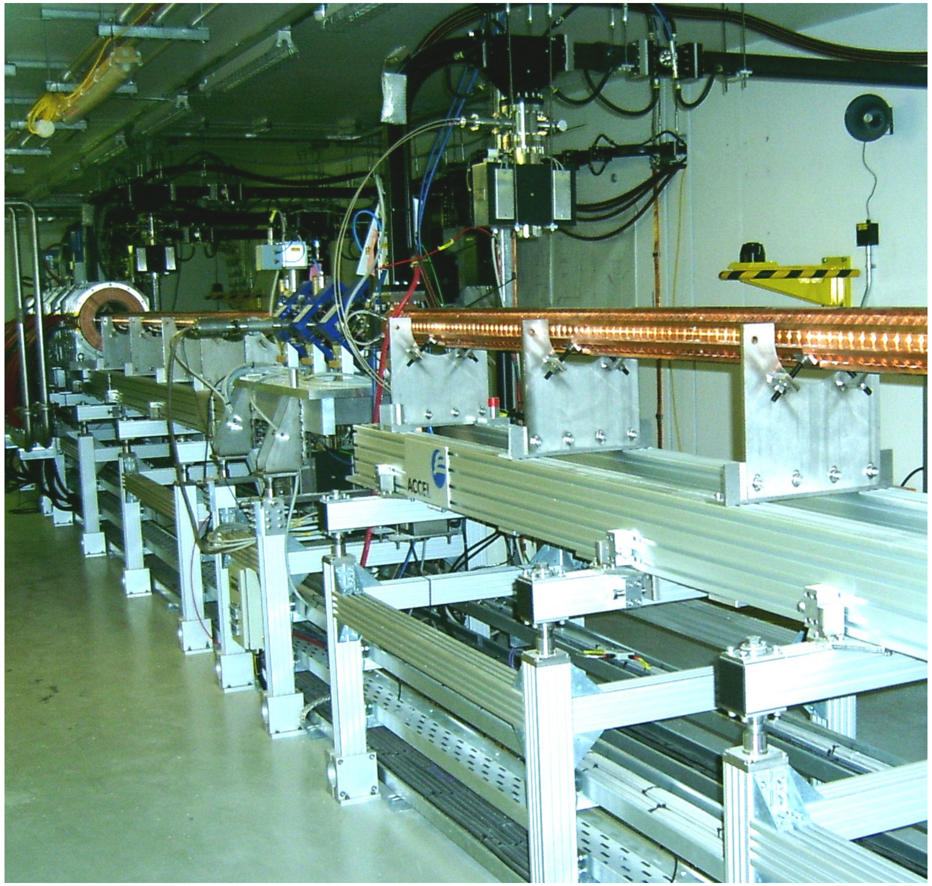
S-Band Structures for injection linacs

Parameter:

• mode 2p/3	
• frequency	2.9983 GHz
• length	5.2 m
• no. of cells including absorber cells:	150 + 6
• shunt imp.	51 MW/m
• Q	14000
• filling time	0.74 ms

Electron Injection Linacs for Synchrotron Light Sources

Swiss Light Source 100 MeV Linac



Diamond Light Source 100 MeV Linac

Electron Injection Linacs for Synchrotron Light Sources, detailed parameters

research instruments

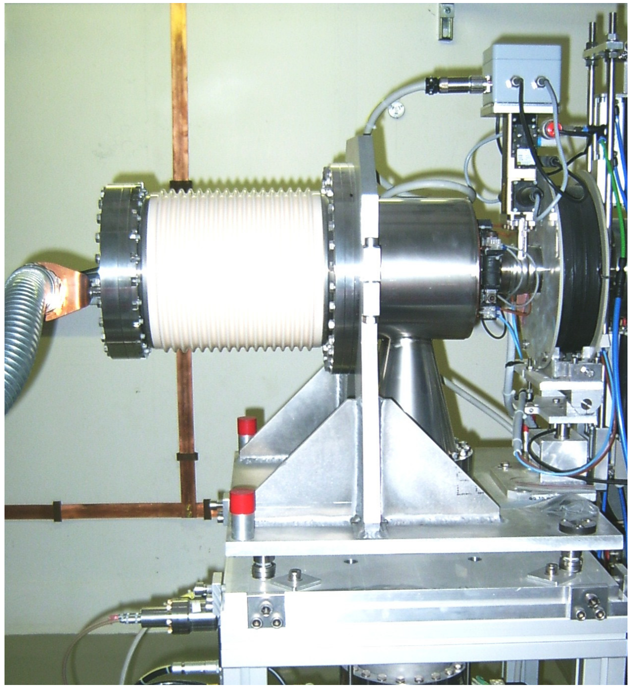
Project (year)	Energy	Pulse structure / repetition rate	Charge	Emittance (1σ) / energy spread (rms)
Swiss Light Source (2000)	100 MeV	a) Single bunch < 1 ns / 10 Hz b) Multi bunch 200 – 900 ns, 2 ns bunch spacing / 10 Hz	a) > 1.5 nC b) > 1.5 nC total	$\varepsilon_n < 50\ \pi\cdot$mm$\cdot$mrad / $\sigma_E/E < 0.5$ %
Diamond Light Source (2005)	100 MeV	a) Single bunch < 1 ns / 5 Hz b) Multi bunch 300 – 1000 ns, 2 ns bunch spacing / 5 Hz	a) > 1.5 nC b) > 3.0 nC total	$\varepsilon_n < 50\ \pi\cdot$mm$\cdot$mrad / $\sigma_E/E < 0.5$ %
Australian Synchrotron Project (2006)	100 MeV	a) Single bunch < 1 ns / 5 Hz b) Multi bunch 150 ns, 2 ns bunch spacing / 5 Hz	a) > 0.3 nC b) > 3.1 nC total	$\varepsilon_n < 50\ \pi\cdot$mm$\cdot$mrad / $\sigma_E/E < 0.5$ %

Electron Injection Linacs
for Synchrotron Light Sources (under construction)

Project (year)	Energy	Pulse structure / repetition rate	Charge	Emittance (1σ) / energy spread (rms)
Taiwan Photon Source (2011)	150 MeV	a) Single bunch < 1 ns / 5 Hz b) Multi bunch 200 – 1000 ns, 2 ns bunch spacing / 5 Hz	a) > 1.5 nC b) > 5.0 nC	$\varepsilon_n < 50\ \pi\cdot mm\cdot mrad$ / $\sigma_E/E < 0.5\ \%$
NSLS II / BNL (2012)	200 MeV	a) Bursts of single bunches, ***n***·2 ns bunch spacing / 10 Hz b) Multi bunch 160 – 300 ns, ***n***·2 ns bunch spacing / 10 Hz	a) > 0.5 nC/bunch b) > 15 nC total	$\varepsilon_n < 15\ \pi\cdot mm\cdot mrad$ / $\sigma_E/E < 0.5\ \%$

NSLS II 200 MeV Linac

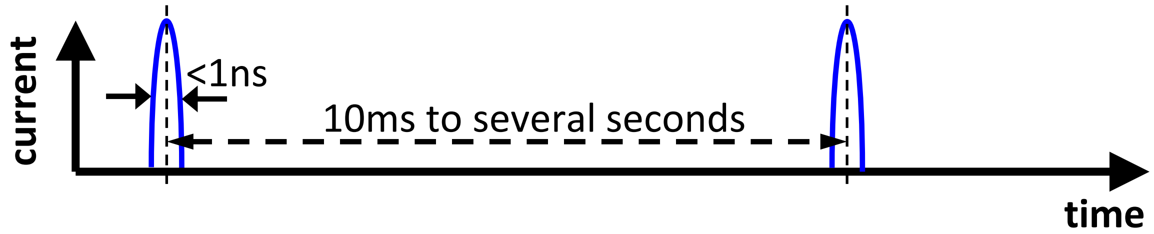
Electron Source / Pulse Structure



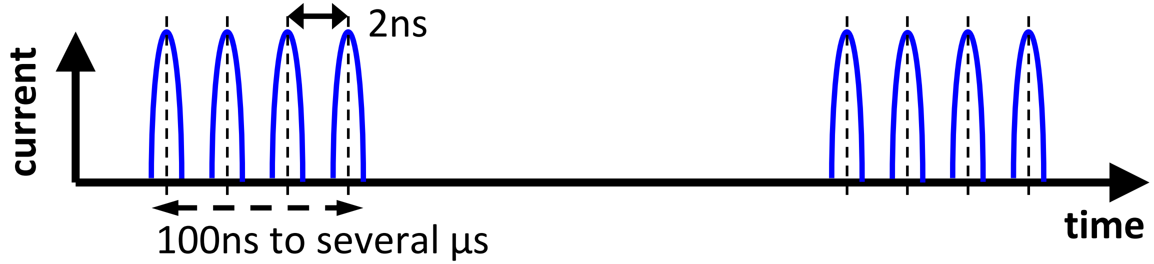
Electron source 90 keV

Single bunch:	FWHM < 1ns
Peak current:	> 3 A
Multi bunch:	0.1 µs to 10 µs
Grid modulation:	500 MHz
Repetition rate:	up to 100 Hz

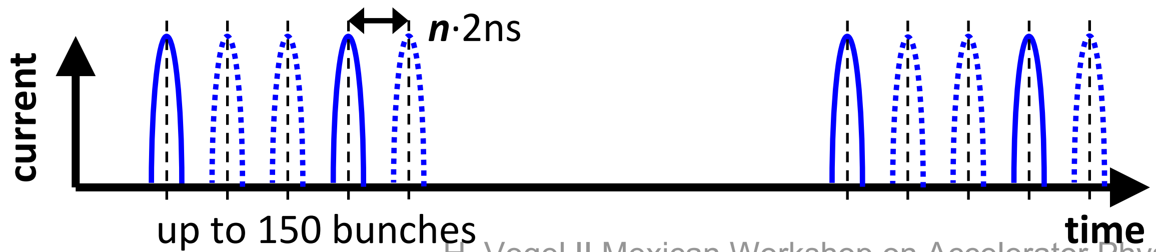
single bunch:



multi bunch with 500 MHz modulation:

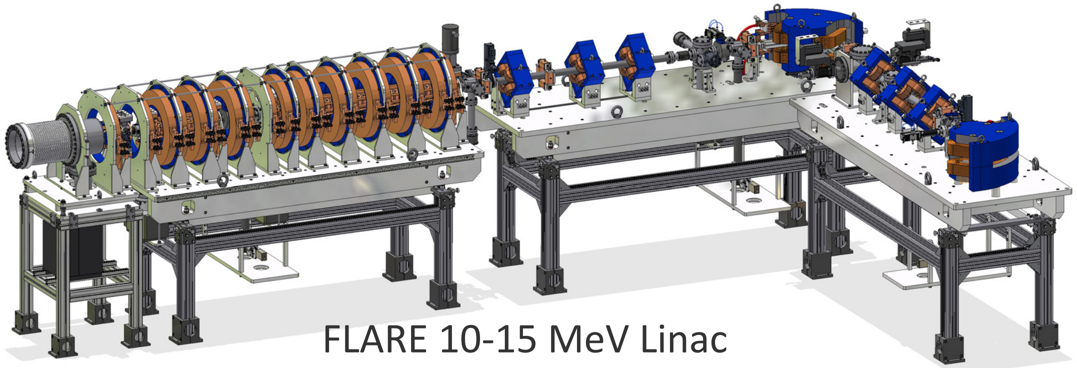


single bunch bursts and multi bunch
with flexible bunch pattern (NSLS II 200MeV Linac)



Electron Injection Linacs for Special Applications

Project (year)	Energy	Pulse structure / repetition rate	Charge	Emittance (1σ) / energy spread (rms)
PTB Germany (2009)	Range 0.5 MeV – 50 MeV	Multi bunch 3 µs, 333 ps bunch spacing / 100 Hz	Up to 400 nC per macro pulse	$\varepsilon_n < 50\ \pi\cdot mm\cdot mrad$ / $\sigma_E/E < 0.1$ %
FLARE IR-FEL driver Netherland (2011)	Range 10 MeV – 15 MeV	Multi bunch 10 µs, 333 ps bunch spacing / 10 Hz	> 0.2 nC per bunch, 6000 nC per macro pulse	$\varepsilon_n < 50\ \pi\cdot mm\cdot mrad$ / $\sigma_E/E < 0.3$ %



FLARE 10-15 MeV Linac

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500 MHz Five Cell Cavities for Boosters

500 MHz Five Cell cavities used at DESY, Hamburg and in a number of booster rings:

DIAMOND Light Source

Canadian Light Source

Australian Synchrotron Project

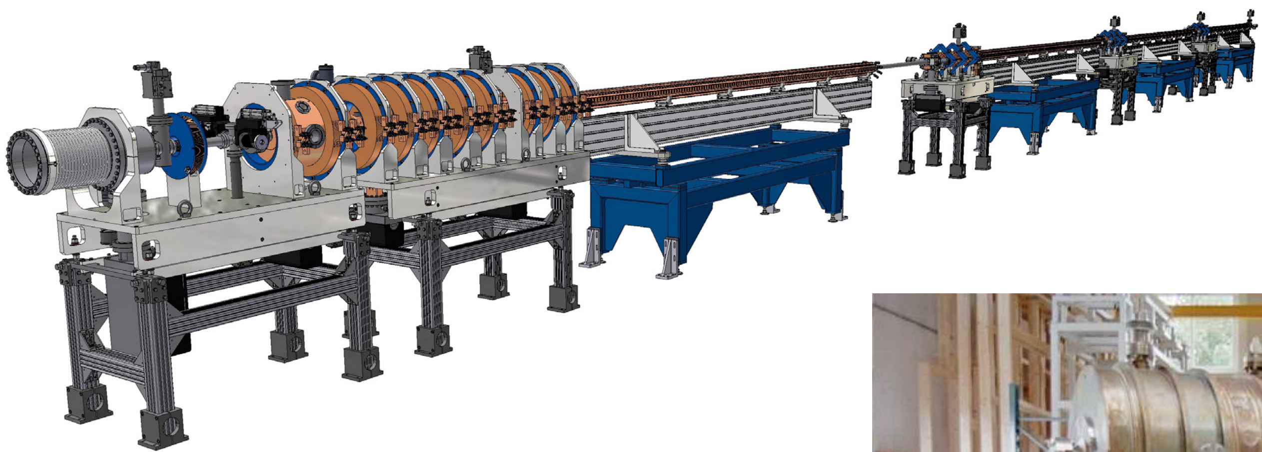
Shanghai Light Source

CELLS

Complete with power coupler, tuner, vacuum system, low power rf, vacuum baked, ready for high power operation

Complete Injection System

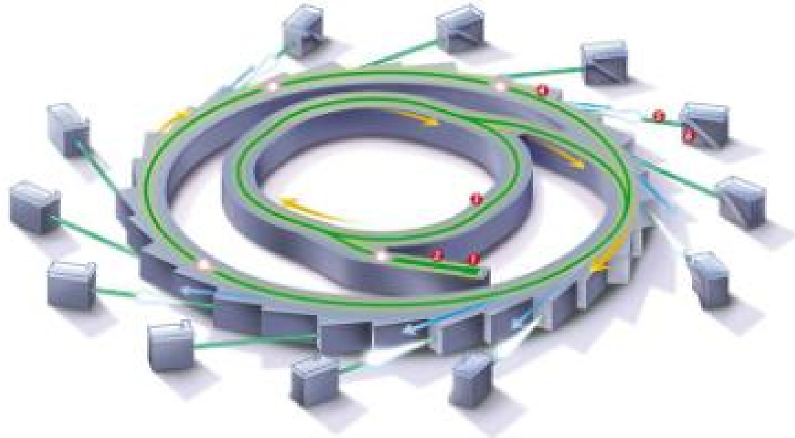
research instruments



A complete injection system consisting out of a 100 MeV Linac and a complete booster ring including our 500 MHz rf cavity has been designed, built and delivered to the Australian Synchrotron Project (ASP).
RI is partnering with other companies or institutes experienced in magnet and circular accelerators

DANFYSIK - Accelerator systems

Australian Synchrotron Project – 2004-2006
100 MeV Linac, LEBT, 3.0 GeV Synchrotron, HEBT



Lattice:	*Combined function*
Booster circumference:	*130m*
Injection energy:	*100MeV*
Peak energy:	*3.0GeV*
Beam current (multi bunch train):	*5mA*

Conclusions on injection systems

1. Electron Linear Accelerators (linacs) as injectors for Synchrotron Light Sources are available in various variants. All linacs delivered so far are based on the same principles and well proven components, nevertheless individual parameters (energy, puls patterns, etc.) have been realized with every project and we are ready to be flexible for future projects.

2. Booster rings are based on a reliable 5cell cavity, designed by DESY. Such cavities may still be available at DESY. When building a booster possibilities for realization may vary from complete in house (customer) solutions to turn-key industrial supplied solutions.

Content (continued, second talk)

research instruments

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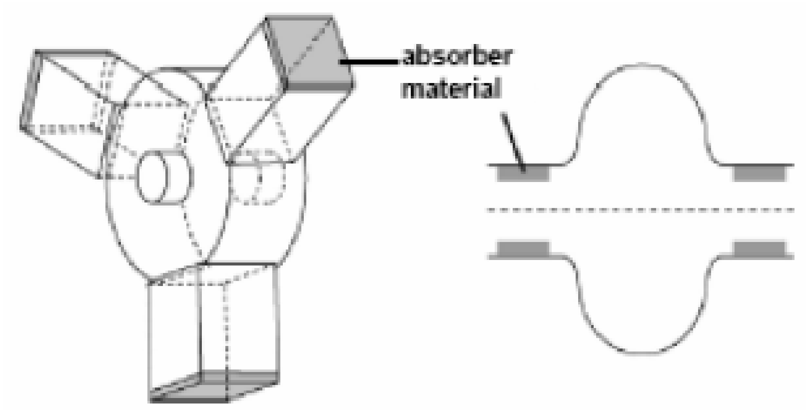
Several concepts for HOM free or HOM damped nc cavities are existing

PEP (476 MHz)
ASP (500 MHz)
BESSY (500 MHz): applied in Willy Wien
CELLS: a further developed BEESY design applied at CELLS
ESRF (350 MHz), a scaled version of the BESSY/CELLS concept
(not mentioning other concepts with lower frequencies)



Principles of nc vs. sc HOM damping

The HOM free 500 MHz cavity developed by BESSY

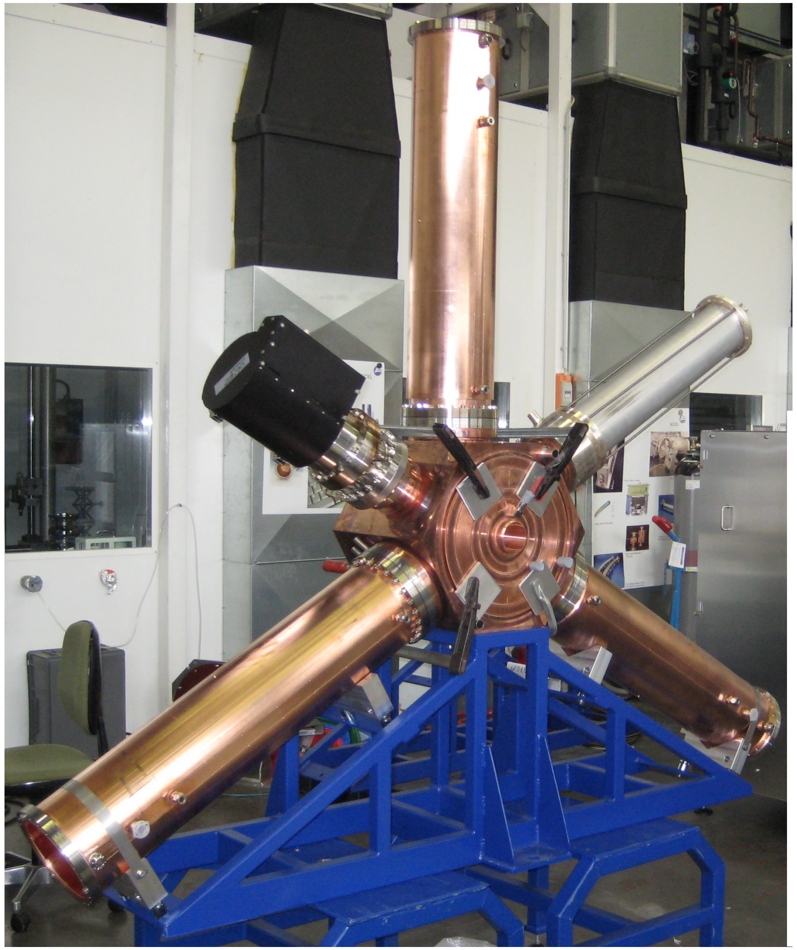


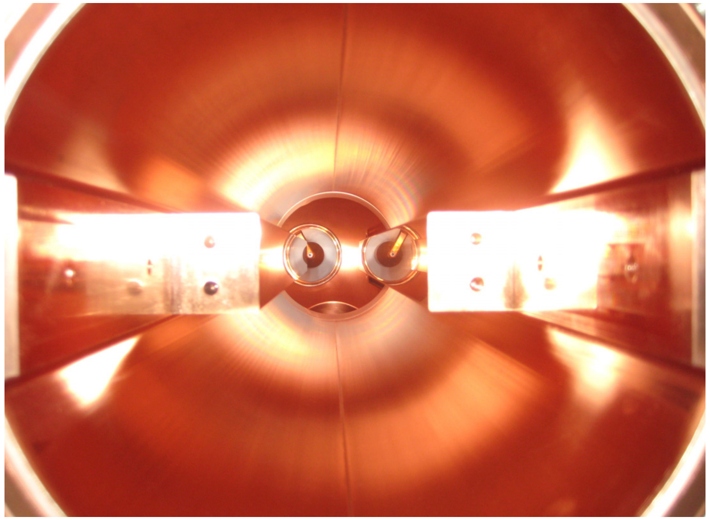
Table 2: Fundamental Mode Performance Parameters

Shunt impedance	3.4 MΩ
Quality factor	29600
Coupling (adjustable)	0.1 -8
Cavity power / rf-voltage	
reached	40 kW / 520 kV
expected with modifications	80 kW / 735 kV
expected without gaps	100 kW / 825 kV

Ref.: E. Weirether, EPAC 2008, THXM03, Patent by BESSY

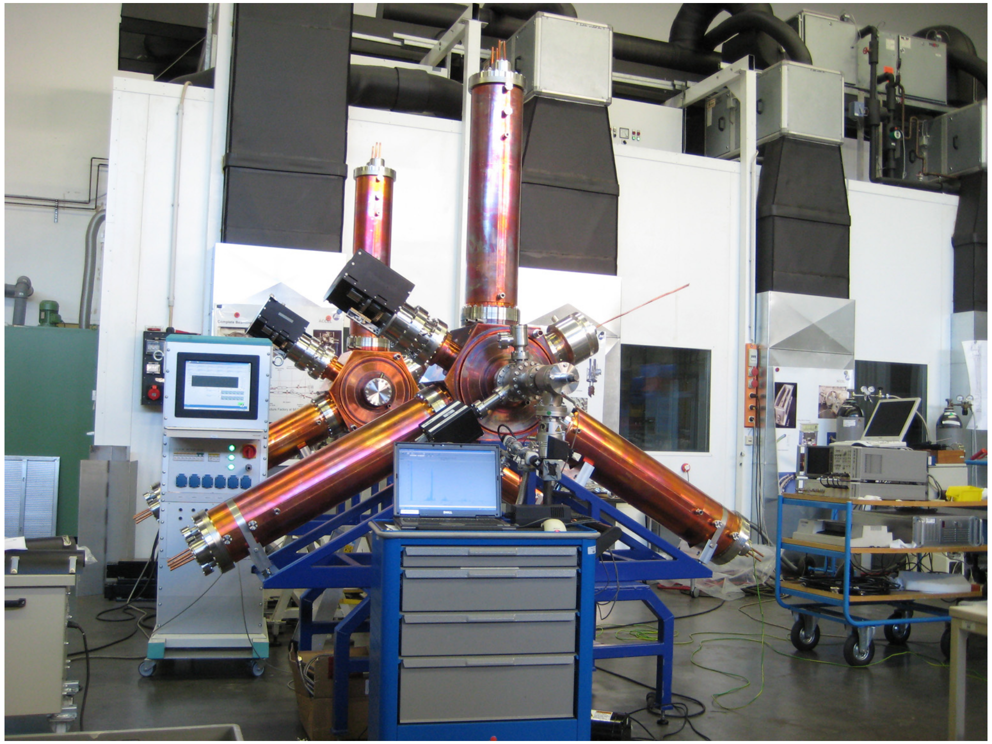
The HOM free 500 MHz cavity developed by BESSY

Status:
One cavity operating at the German Metrology Light Source (Willy Wien, Berlin) at 520 kV (40 kW)
6 cavities produced with design modifications for CELLS (Spain)..



Based on the performance of the Willy Wien cavity and the first tested cavity for CELLS improvements at the HOM waveguide connection have been implemented and successfully tested (end of 2008).
(825 kV and 100 kW)

HOM damped cavities for CELLS, Spain



CELLS is operating 6 cavities in the storage ring (+1 'hot spare')

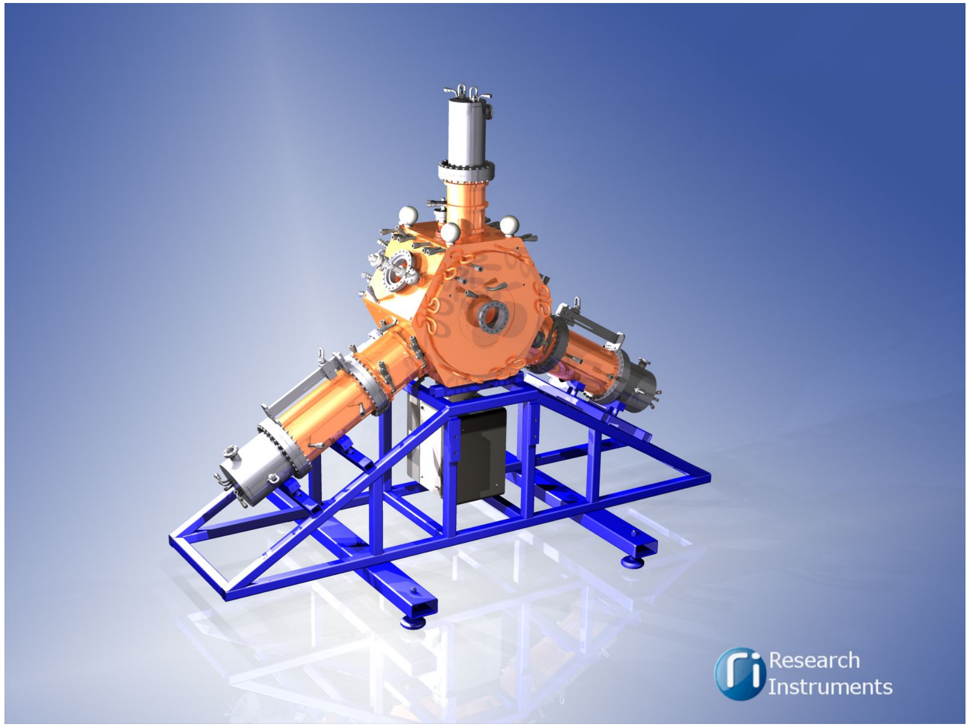
F_0=500MHz

U_{acc}= 825 kV

P= 100 kW (80 kW rf power)

Cavities have been fully equipped (power couplers, tuner, vacuum), low power rf tests (fundamental mode, coupling factors) and vacuum-baked ready for high power test at CELLS

HOM damped cavity for ESRF, France



ESRF is planning an upgrade of their storage ring rf by replacing 5 cell cavities with HOM-damped single cell cavities

The design is similar to the CELLS/BESSY design at 352 MHz

Prototypes are under fabrication for delivery in early 2011 and subsequent high power testing

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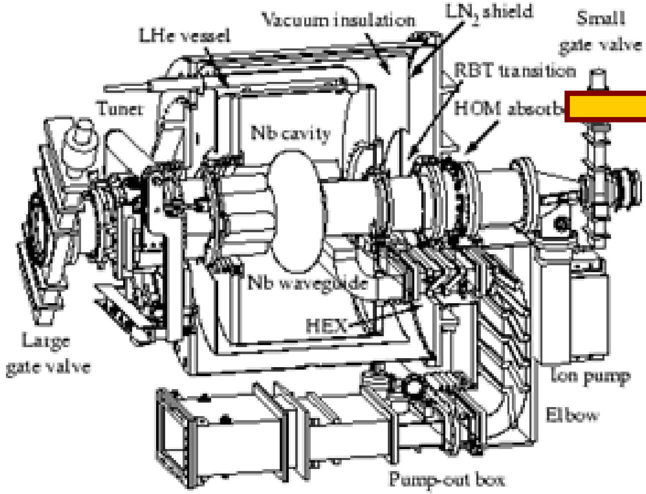
Cornell modules (500 MHz): technology transfer to ACCEL

research instruments

CORNELL UNIVERSITY

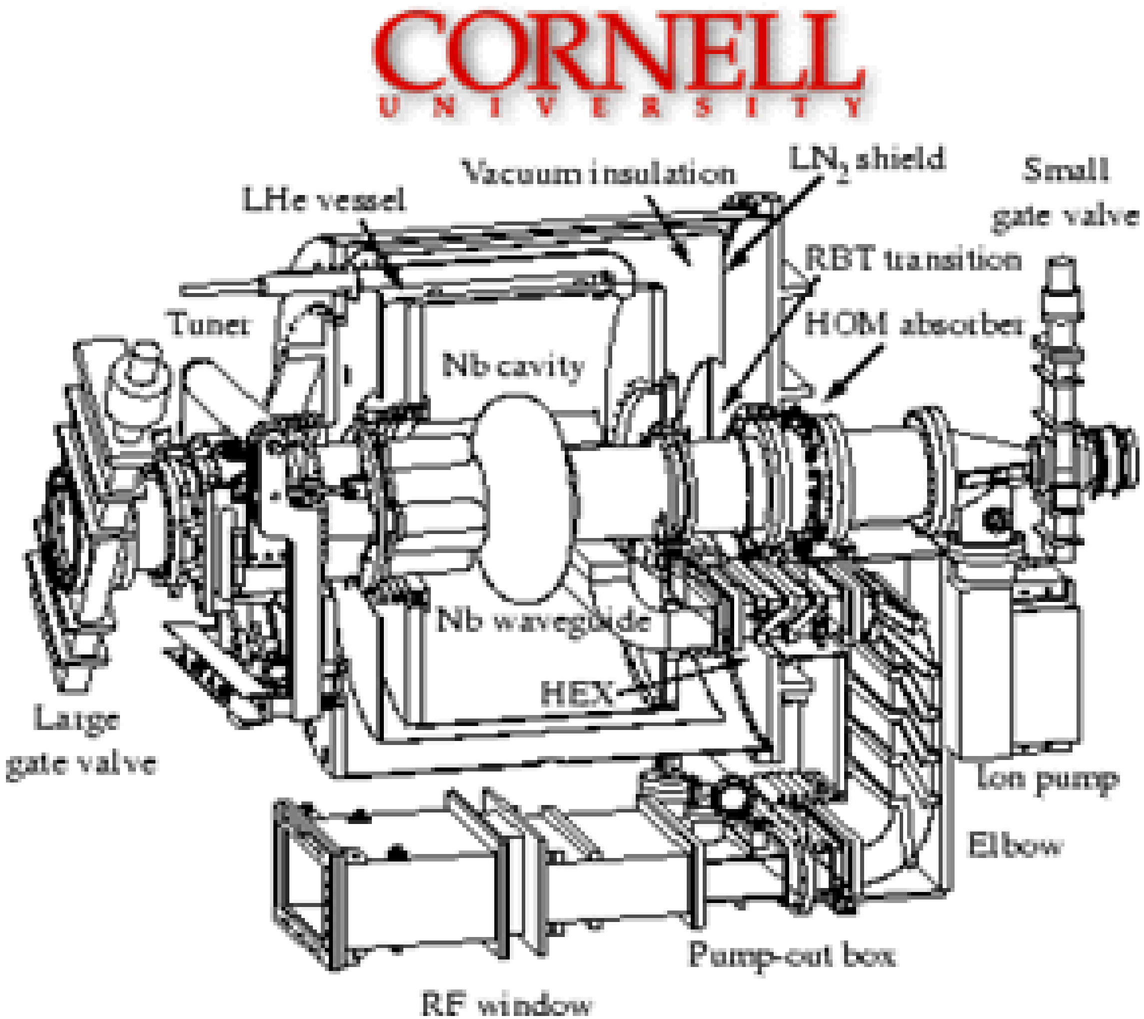


Technology transfer

In **1999 Cornell University and ACCEL agreed on a technology transfer of the 500 MHz SRF module**
Technology developed for CESR II.
NSRRC had decided to use the Cornell modules in their Light Source and were looking for an industrial supplier that could deliver the modules as a turn key system including valve boxes, transfer lines and SRF electronics.
The following contracts have been concluded meanwhile, making this technology transfer most successful:

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, China
2010: 2 SRF Modules for the Pohang Light Source upgrade **in total 14 SRF modules delivered, under contruction**
2011: 2 (3) SRF Modules are planned for NSLS II at Brookhaven

Cornell modules (500 MHz): technology transfer to ACCEL/RI



Main Components:

- srf cavity
- power coupler
- HOM loads (at room temperature)
- Cryostat, cryo system
- vacuum system
- control system (RF, cryo)

Turn key Cornell style SRF modules

research instruments

Scope can cover

- Cavity production
- Surface preparation
- Vertical test
- Coupler production
- Coupler conditioning
- HOM loads
- Module assembly
- Installation
- Commissioning
- Valve boxes
- transfer lines
- SRF Electronics
- Interlock and data acquisition system
- LLRF

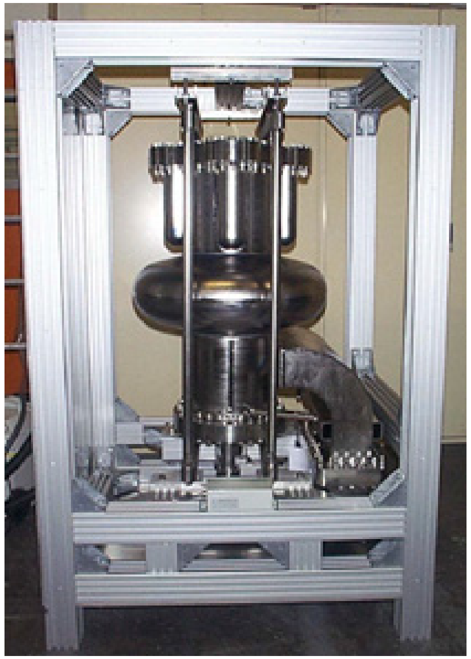
Module performance:
V_{acc} > 2 MV, Q_0 > 5 x 10^8
is the basis for cryoplant layout

Cavity preparation for vertical test at RI

Closed loop BCP →

HPR

Assembly in clean room



Packing and shipping for vertical test

Bulk Nb Cavity preparation and test results

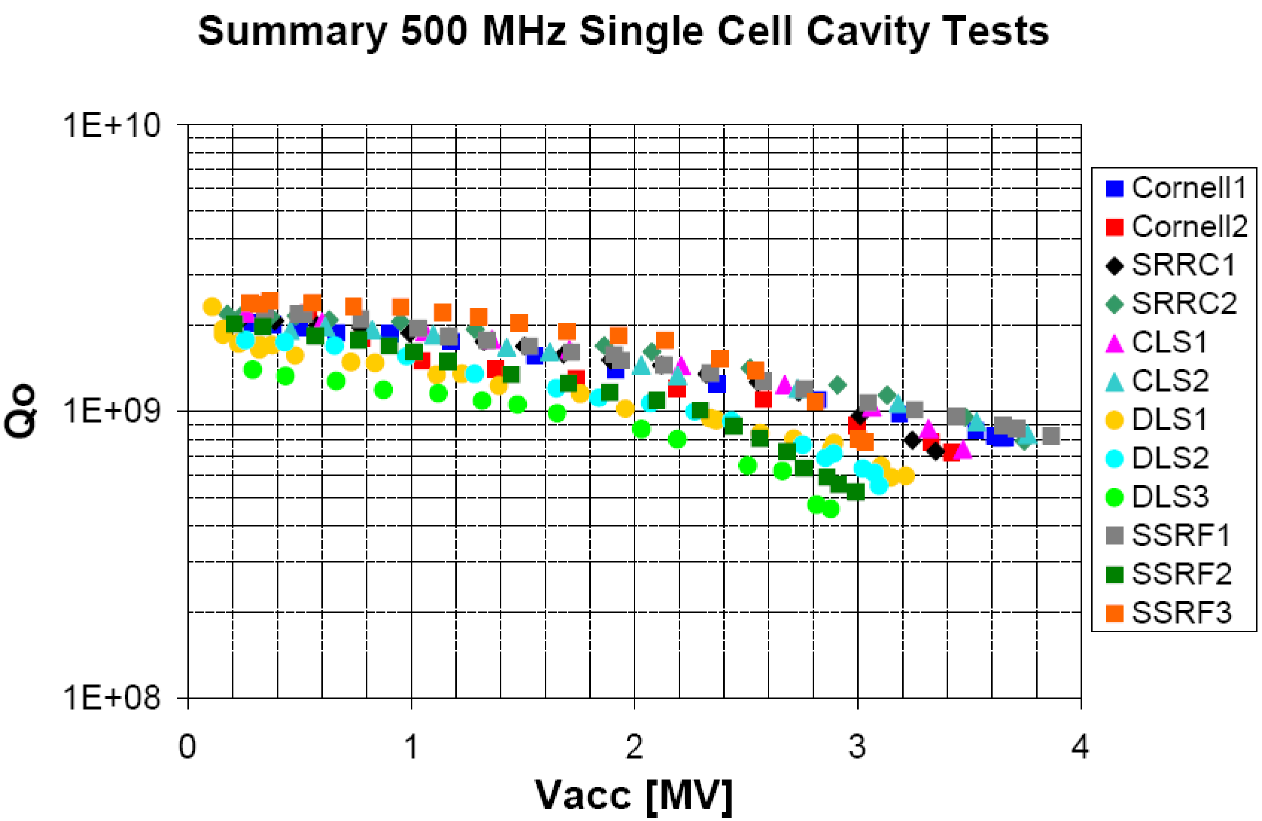
research instruments

Preparation is done at RI Research Instruments as follows:

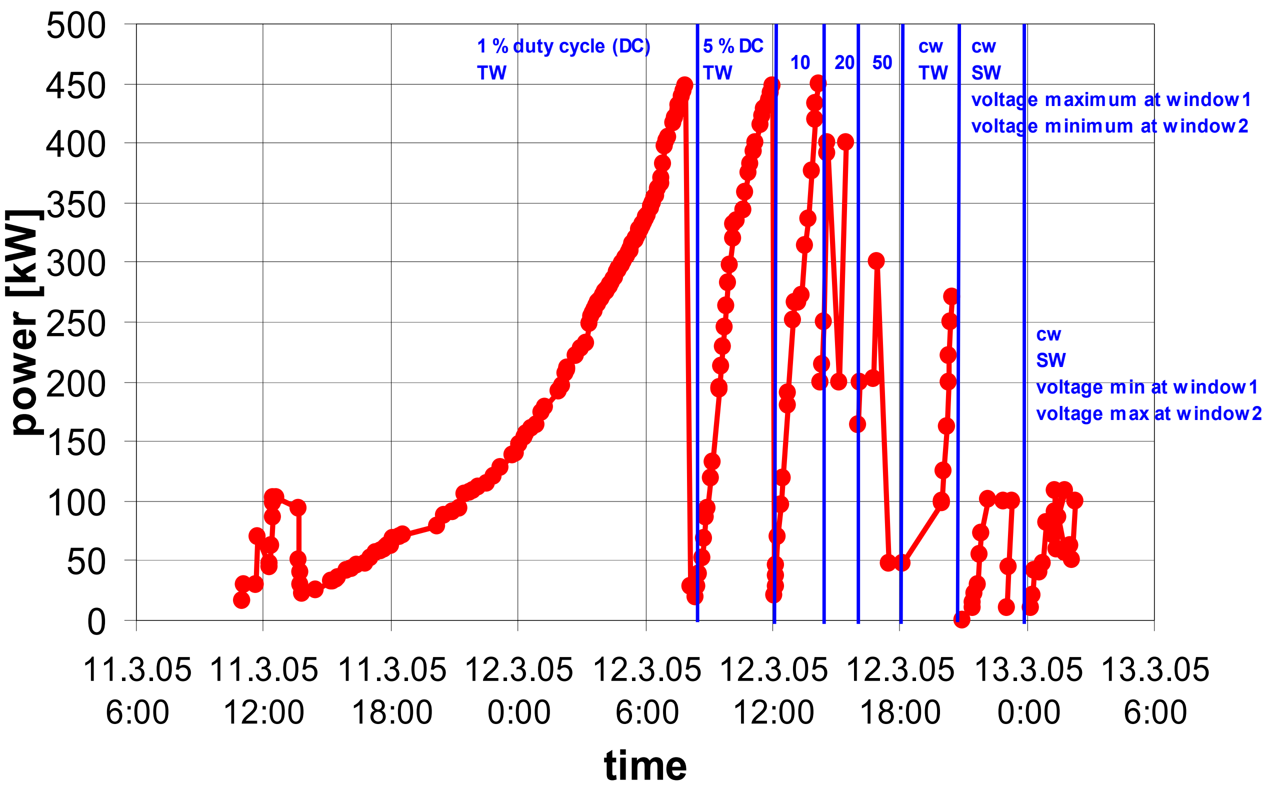
- **Degreasing**
- **Buffered chemical polishing** **(1:1:2), in closed loop chemistry, acid actively cooled to temperatures below 15 °C**
- **Water Rising > 17 MWcm**
- **High pressure water rinsing (100 bar)**
- **Drying by pumping**
- **Assembly in class 100 clean room**

- **All test results achieved in consecutive preparations / tests**
- **All field values limited by available RF power**

Cavities are accepted after cold test for module assembly with Eacc at 2,5 MV and Q0 > 1 E09



Waveguide Window conditioning



Windows cleaned, assembled and baked at RI
Shipped to Cornell or other research labs for RF conditioning by RI technicians, customer participation welcome.
Windows are accepted for module assembly with:
250 kWatt cw operation
120 kWatt cw operation full reflection

Factory acceptance test with valve box and SRF electronics

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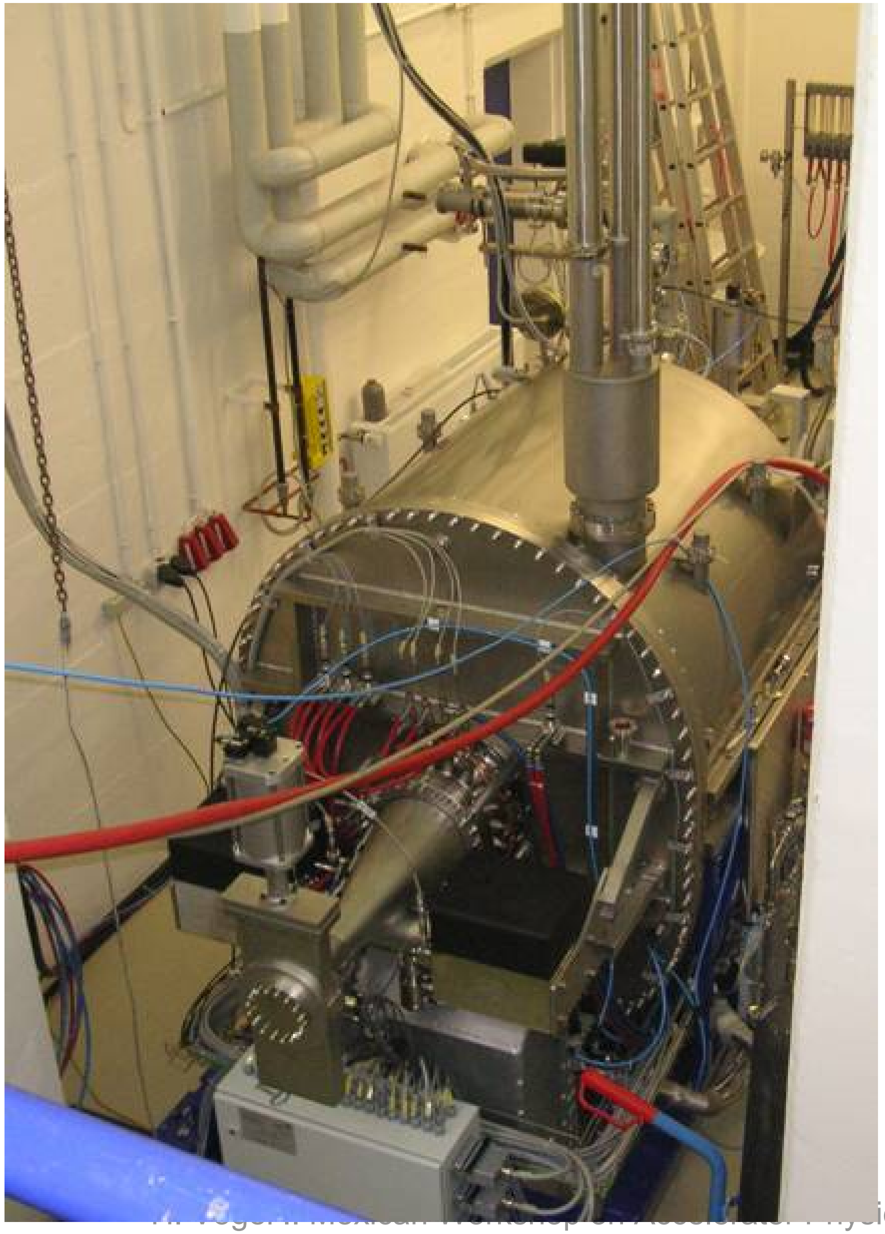

Overseas transport

Installation and taking into operation at customers site, here the SSRF storage Ring (Shanghai)

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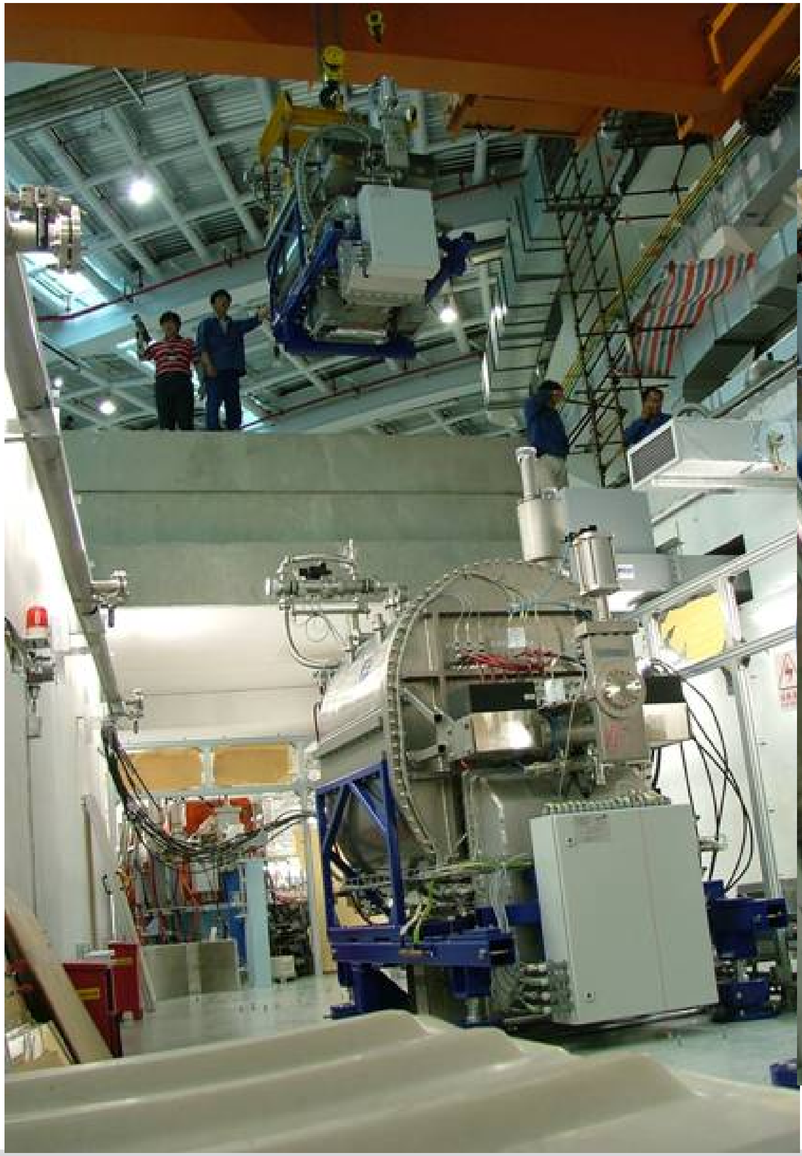
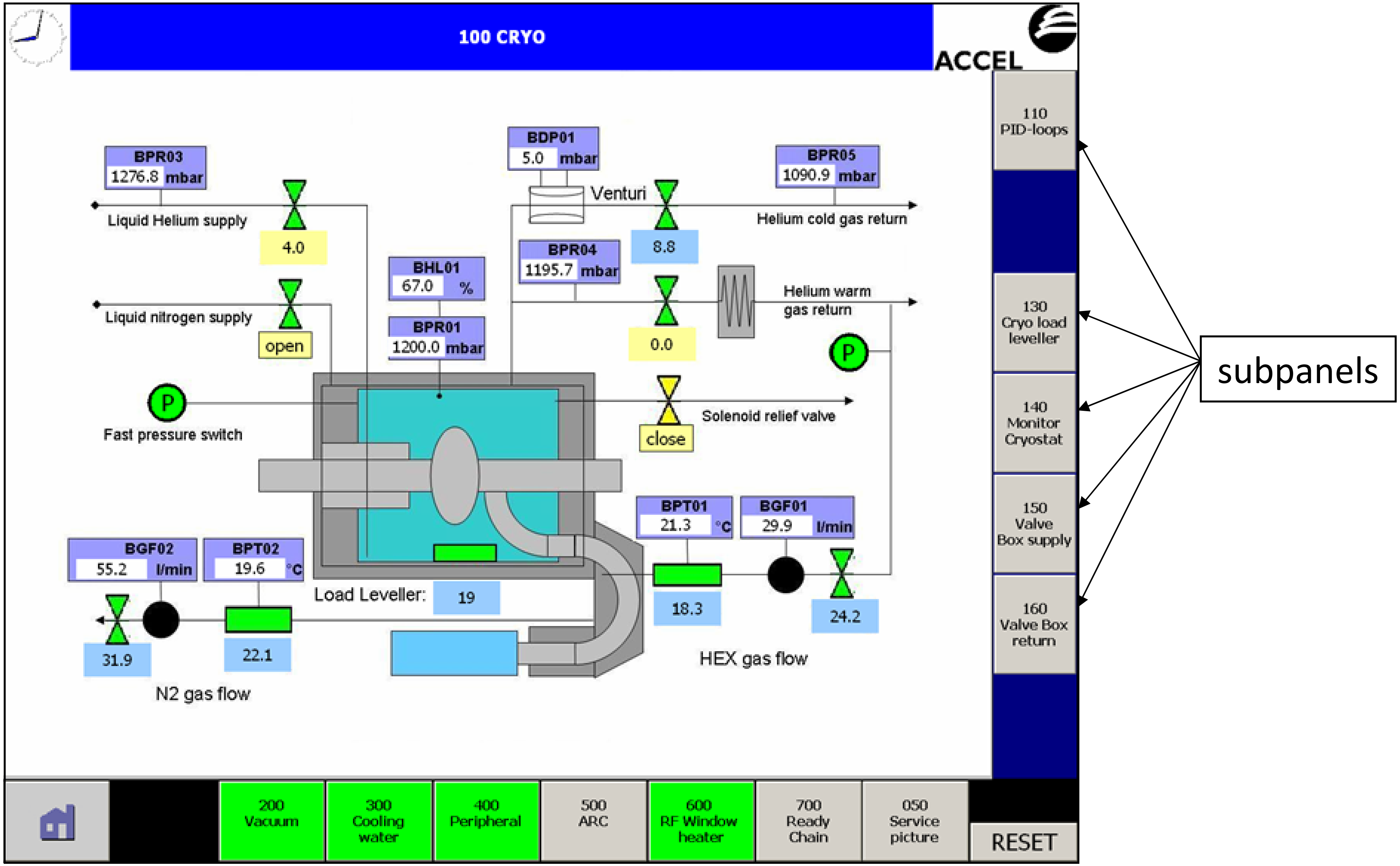


Main panel for cryogenic operation
(a control system example)



Commissioning of SRF modules on site

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Commissioning of a SRF module takes normally about 4-6 weeks

First week: Unpacking, Installation into the storage ring, alignment
Second week: Pumpdown and leak check
Third week: Connection to the interfaces: cryoplant, RF plant, LLRF, control system
Fourth week: Cooldown, check of cryogenic performance and interlock check
Fifth week: RF conditioning and RF test

Requirements from customer side:

- Water supply ready
- Commissioning of RF plant finished
- Some helping hands during module installation
- Alignment group for installation
- Cryogenic plant commissioned
- Low power RF equipment like network analyzer, power meter for RF calibration
- Training of RF operators during commissioning and acceptance test

Conclusions on storage ring RF (1)

1. superconducting rf systems are available from Industry based on proven designs like CORNELL Modules and 500 MHz modules from KEK (Japan)
applied in a number of storage rings as shown here in this presentation plus KEK (Japan), IHEP (Beijing, China), New Taiwan Light Source

2. Proven designs and working room temperature rf systems are available from industry also in various applications like BESSY/CELLS design, ASP design, MaxLab (Sweden), ESRF (France, 352 MHz), NSLS (Brazil), Poland, etc.

Conclusions on storage ring RF (2)

1. For sc systems we deliver “turn-key” modules with cavities tested to specification and power handling capability shown for the rf window in a high power testing (as well as other parameters like tuning, coupling, vacuum, thermal properties) . The final testing of the completed srf module requires the cryogenic and rf supplies of the customers installation

2. For nc systems we deliver rf cavity systems complete with auxiliaries and low power measurements performed (frequency, tuning range, coupling etc.). High Power RF Testing to be discussed with partners (DESY…) or finally performed with the customers installation

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Industrial Supplies / User provided Infrastructure

Summary of possible industrial supplies and required infrastructure:
nc storage ring rf

Supplier

rf cavity: fully equipped with

- power/window
- tuner, field probe
- HOM dampers
- vacuum systems
- vacuum baked
- low power rf

User

- high power rf supplies and distribution
- cooling water and other utilities
- technicians experience in rf and vacuum

Industrial Supplies / User provided Infrastructure

Summary of possible industrial supplies and required infrastructure: superconducting storage ring rf

Supplier

srf accelerating module fully equipped with

- cavity, tested separately before integration
- rf window tested separately before integration
- module leak-checked at cryogenic temperature
- valve box for distribution and control of cryoliquids

User

- high power rf supplies and distribution
- cryogenic plant and distribution (transfer lines)
- utilities
- technicians experience in srf cryogenic operations, vacuum rf

Industrial Supplies / User provided Infrastructure

Summary of possible industrial supplies and required infrastructure:
injection systems

Supplier

turn key linear accelerator with guaranteed
parameters to be agreed with customer

- turn key linac
- alternative: turn key injection system

User

- beam transport systems
- kicker systems
- infrastructure
- utilities

Industrial Supplies: support in design

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To reflect the Pohang Light Source upgrade requirements tow options have been discussed:
sc option: 2 Modules in operation, one spare
operating gradient: 1,5 MeV (moderate)
power to beam: 270 kW per coupler (limit)
total rf power needed: app 0.5 MW
nc option: 6 cavity systems in operation, one "hot" spare
operating gradient 500 keV (moderate)
power to cavity and beam: app. 130 kW per coupler (limit)
total RF Power needed: app 0.8 MW

Design Requirements for PLS 3.0 SRF Cavity

Budget Information:*1

sc option: 4,5 Mill €
nc option: 2.5 Mill €

*1 subject to escalation, scope of supplies, fees, and commercial/contractual conditions, 2010 cost factors

- **PLS 3.0;**
  - Energy: 3.0 GeV
  - Current: 400 mA

Bending Radius [m]	BM radiation loss [keV]	ID radiation loss [keV]	Gap Voltage [MV]	Total RF power @ 3 GeV, 400 mA [kW]
6.3 (PLS3.0)	1137.3	213.3	3	540
10	716.5	213.3	3	372
15	477.7	213.3	3	272

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