SRF in Storage Rings

Michael Pekeler

ACCEL Instruments GmbH
51429 Bergisch Gladbach
Germany

SRF in Storage Rings

Michael Pekeler

ACCEL Instruments GmbH
51429 Bergisch Gladbach
Germany

TESLA type cavity: racing horse, >25 MV/m

This talk cavity: working horse, ~8 MV/m
but ~250 kW cw power to the beam

Advantages of SRF versus NC for storage rings

ACCEL

- Operation at high voltage possible (typical value: 2 MV per cavity)
- Operation at high power possible (up to about 250 kW per cavity)
- HOM free design possible, all HOMs can propagate through the beam tubes to HOM dampers, ferrite beam pipe HOM loads or loop HOM couplers

This are the three main reasons, why new high current storage rings are more and more considering SRF for their RF system

First installations:	**TRISTAN, HERA, LEP**
B-Factories:	**KEK-B, CESR**
New Installations:	**IHEP, NSRRC, CLS, DLS, SSRF, SOLEIL, LHC**
higher harmonic cavities:	**SLS, ELLETRA, BESSY**

TRISTAN at KEK

- 32 superconducting 5-cell cavities (509 MHz)
- 16 cavities installed in 1988, 16 cavities installed in 1999
- 200 MV provided to the beam, operation untill 1995

Two cavities inside one vacuum vessel

LEP at CERN

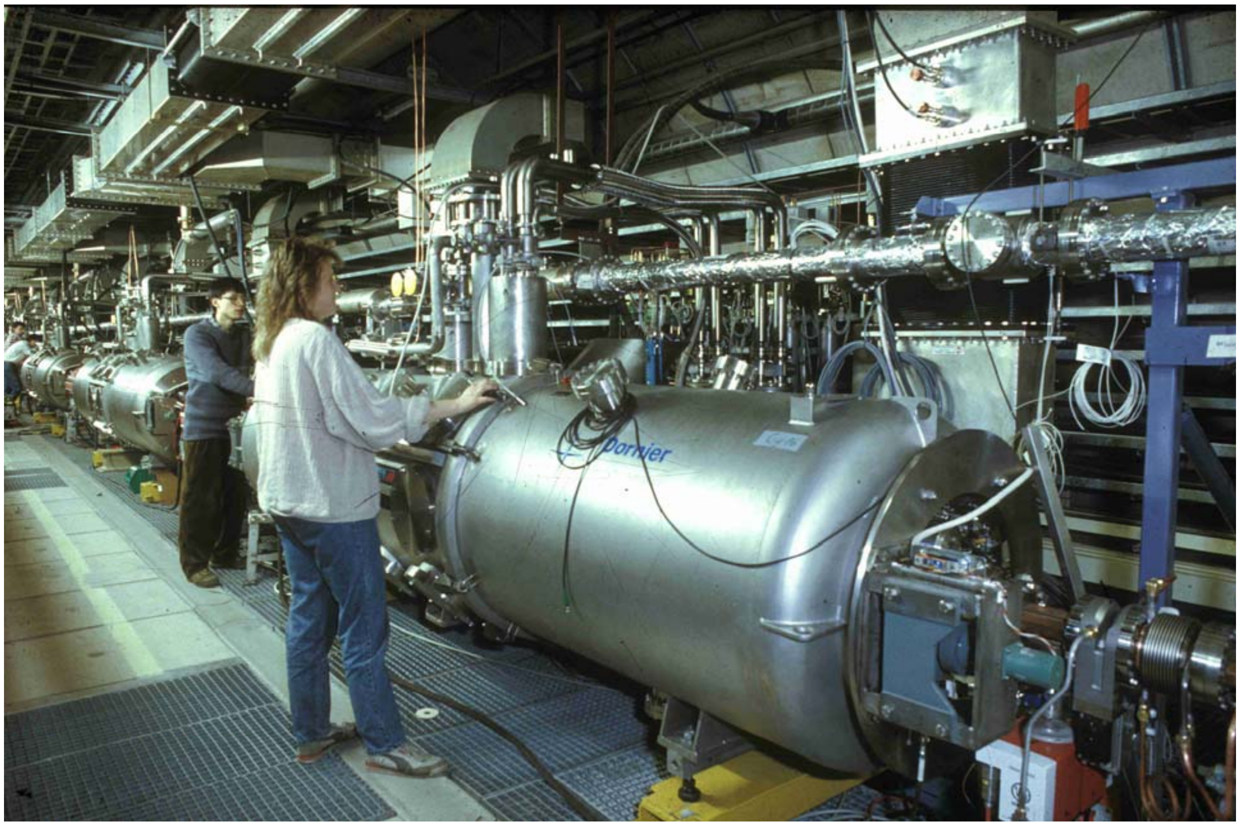
- 288 superconducting 4-cell cavities (352 MHz)
- Installation completed 1999
- More than 3600 MV provided to the beam, operation until 2002

Development of Nb/Cu deposition technology and transfer of technology to European industry

Four cavities inside one vacuum vessel

HERA at DESY

- 16 superconducting 4-cell cavities (500 MHz)
- Installation in 1991
- 30 MV provided to the beam, operation will stop probably in 2007

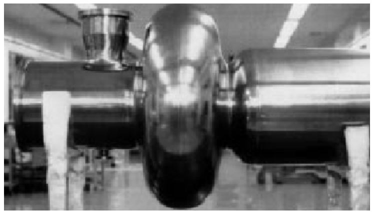


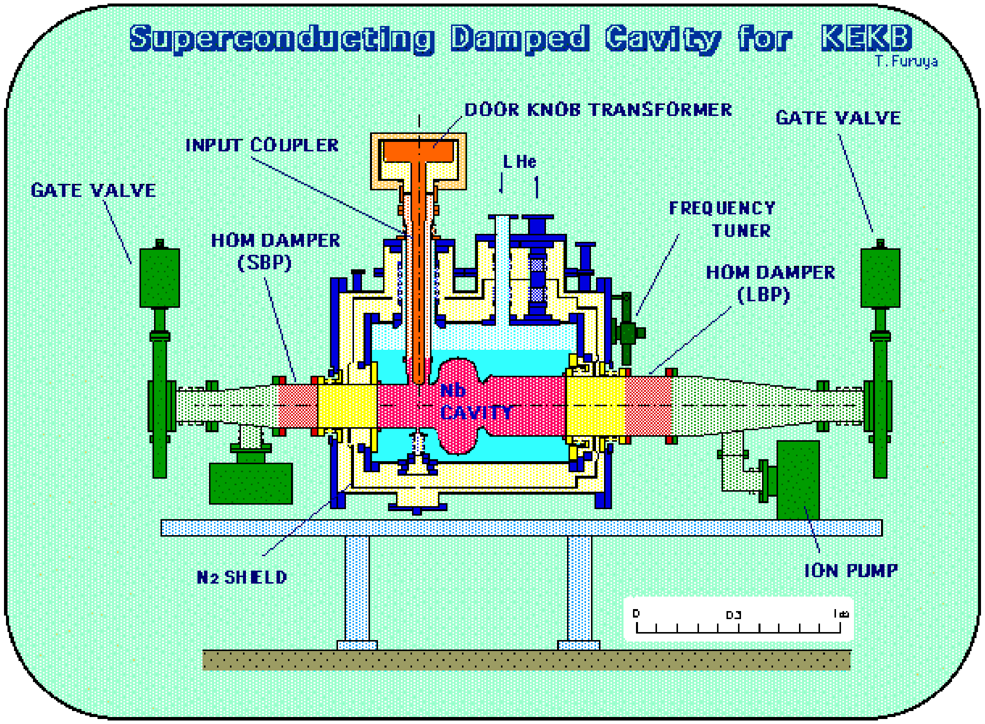
Two cavities inside one vacuum vessel

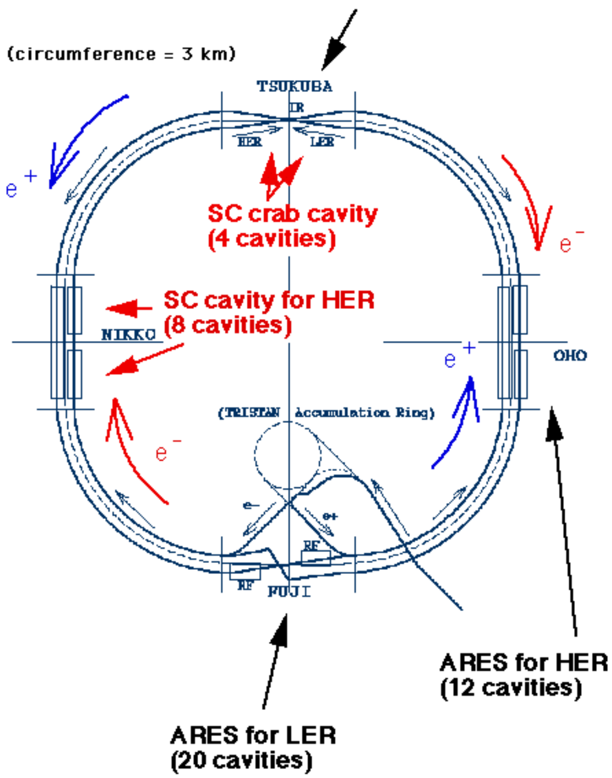
KEK B-factory High Energy Ring (HER)

ACCEL

Resonant frequency	508.887 MHz
R/Q	93 Ohm
Q_0	10^9
Q_{ext}	7×10^4
Operating temperature	4.5 K
Accelerating voltage	1.5 MV







KEKB HER:
8 GeV e^- storage ring

KEK B achievements

	Design	achieved
Number of SC cavities	8	4 at the commissioning 8 since Sept. 2000
Beam intensity	1.1A in 5000 bunches	1.34 A in 1389 bunches
Bunch length	4 mm	6 - 7 mm
Max RF voltage w/o beam	-	> 2.5 MV/cavity (2 – 2.8 MV/cavity)
RF voltage with beam	1.5 MV/cavity	1.2 – 2 MV/cavity
Q-value	1×10^9 at 2 MV	$0.5 – 2 \times 10^9$ at 2 MV
RF power transferred to the beam	> 250 kW/cavity	300 - 350 kW/cavity 400 kW/cavity in max.
HOM power	5 kW at 1.1 A	14 - 16 kW at 1.34 A

RF Power at 1.27 A:

RF power of 2.4 MW was transferred to the beam by 8 SC cavities.

KEK B Luminosity records

1998 Commissioning with 4 SC

1999 **380** kW to the beam.
Physics run start.

2000 Installation of next 4 SC

2001 L_{peak}= **6.9 x 10^{33} cm^{-2}s^{-1}**
HOM of each SC: **5 kW.**

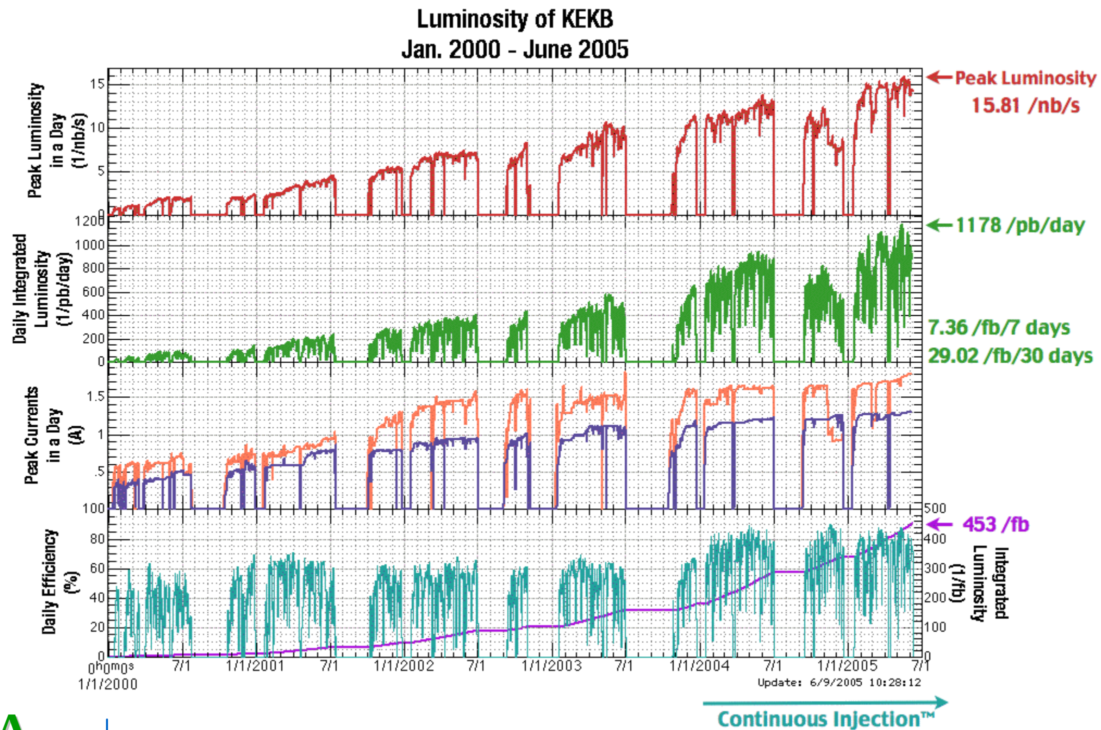
2002 L_{peak} = **8.2 x 10^{33} cm^{-2}s^{-1}** .
Beam of HER reached **1 A.**

2003 L_{peak} = **1.06 x 10^{34} cm^{-2}s^{-1}**
Beam of HER reached **1.1 A**
HOM of each SC: **10 kW.**
L_{peak} = **1.13 x 10^{34} cm^{-2}s^{-1}**
Beams of HER reached **1.18A**

2004 Continuous Injection mode
1.25A, **16kW** of HOM.

2005 L_{peak} = **1.58 x 10^{34} cm^{-2}s^{-1}**
with **1.27A**(HER)

…. still growing up …..

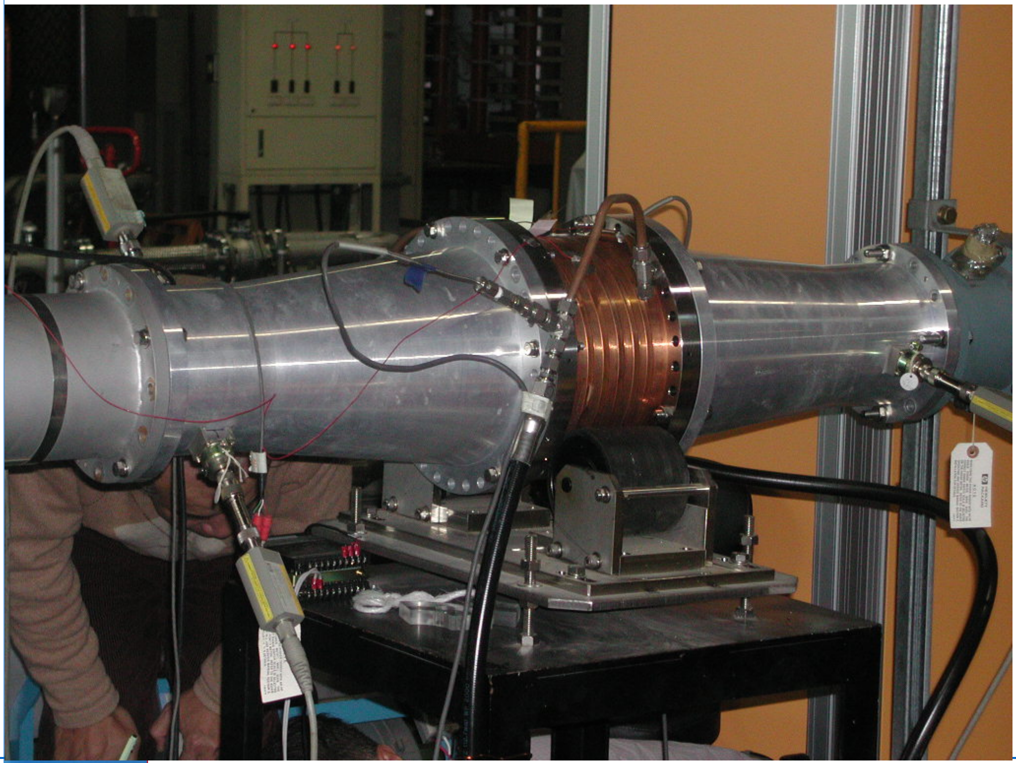


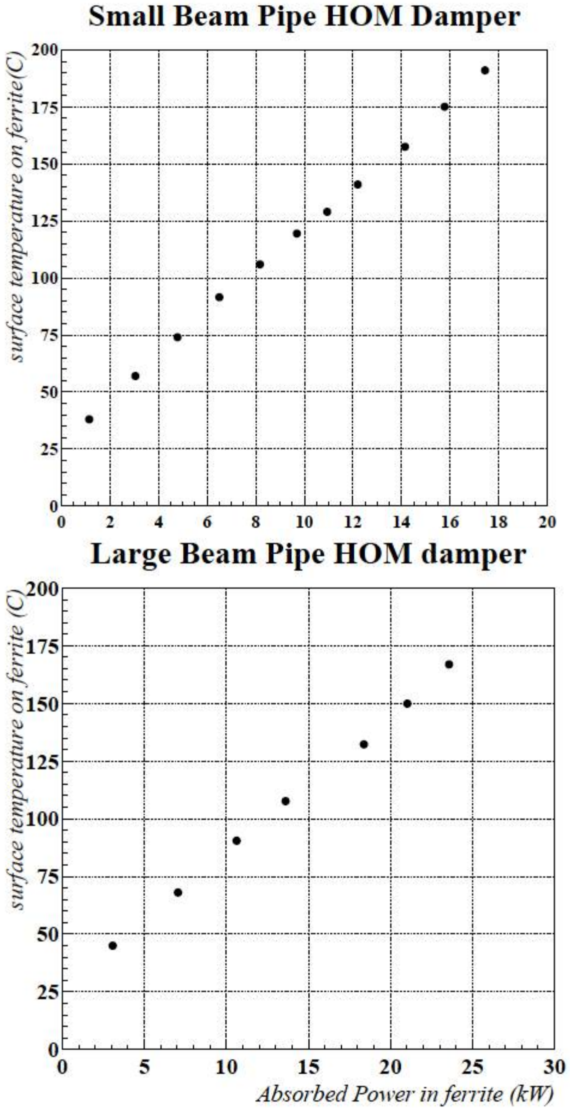
Future plans: Super KEK B

- Required RF power: 460 kW/cavity.
- Traveling wave of 500 kW demonstrated at a module test stand in 2003
- Spare module built and installation planned

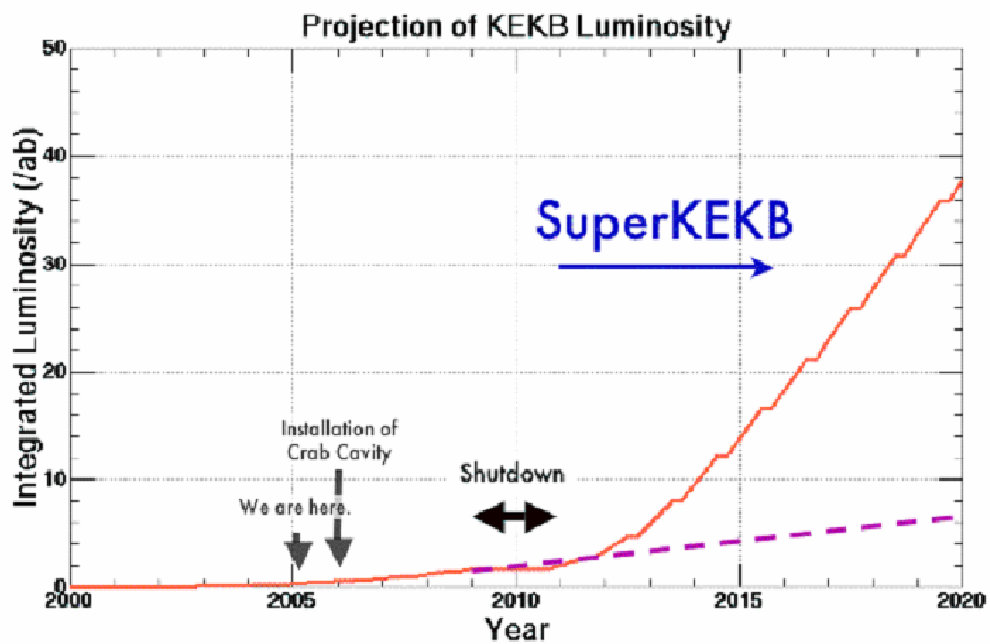
KEK B HOM dampers

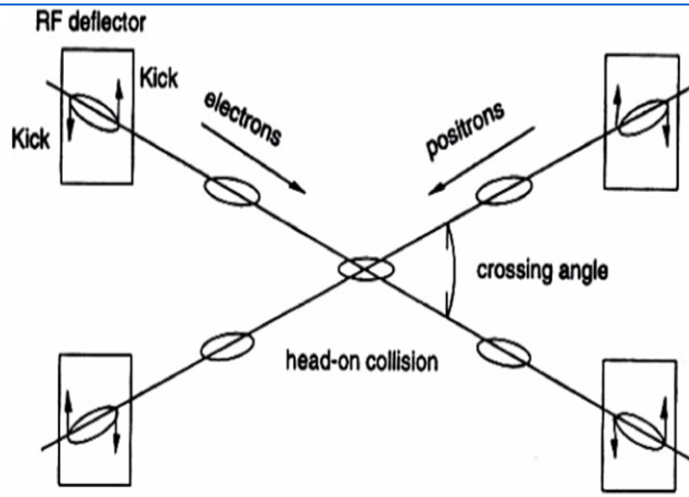
- Absorbed power up to 18 kW for SBP damper and 25 kW for LBP damper (good for 2 A operation)
- The surface temperature reached near 200 C.
- Out gas rate to be measured next

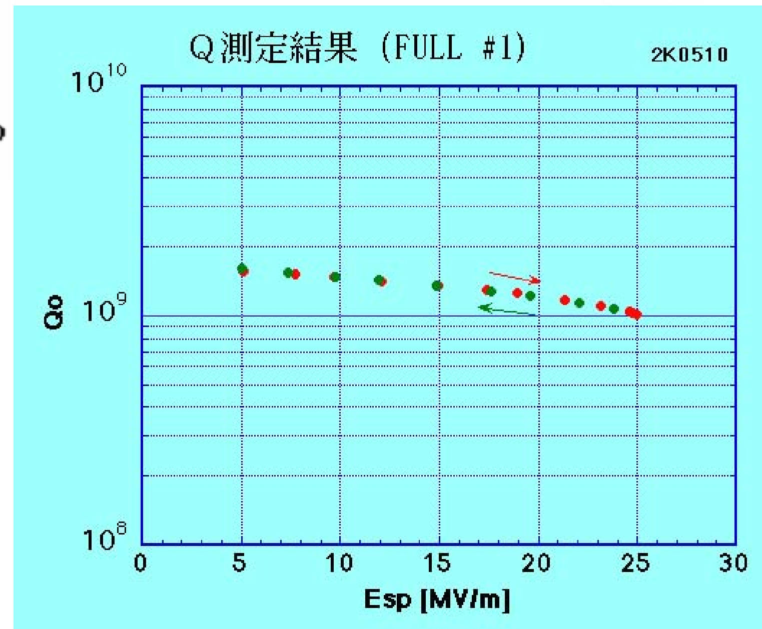




Super KEK B dreams





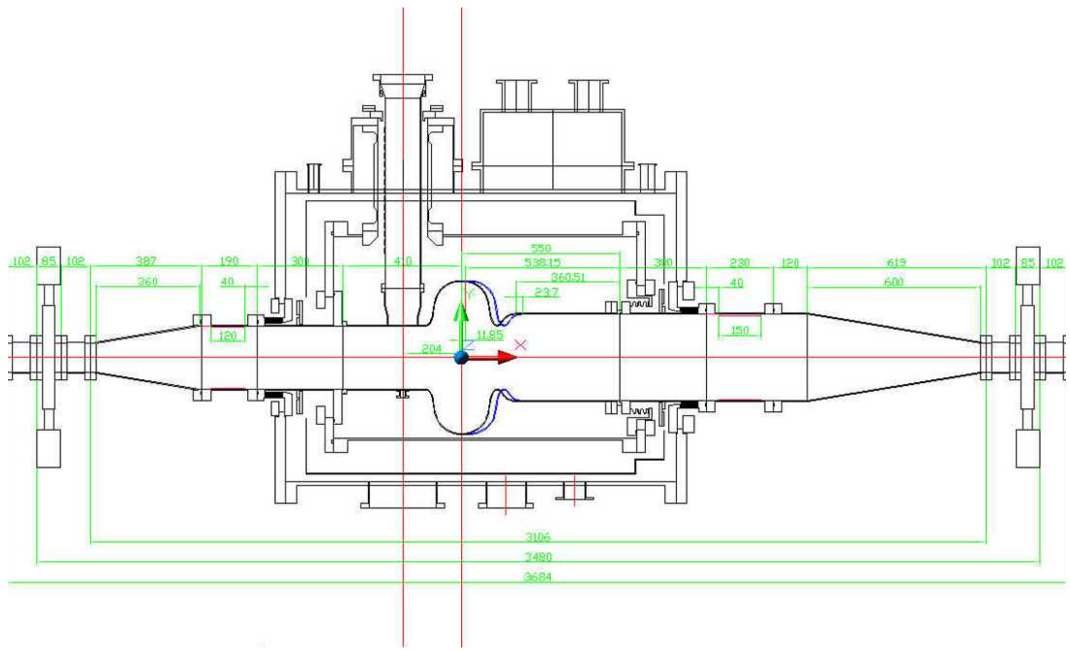


KEK B technology cooperation with MELCO

KEK together with MELCO currently produces two SRF modules for the BEPII two ring e+e- collider for τ–charm physics at IHEP, Beijing, China

- Two modes of operation: collider and SR facility
- Required voltage: 1.5-2 MV per cavity

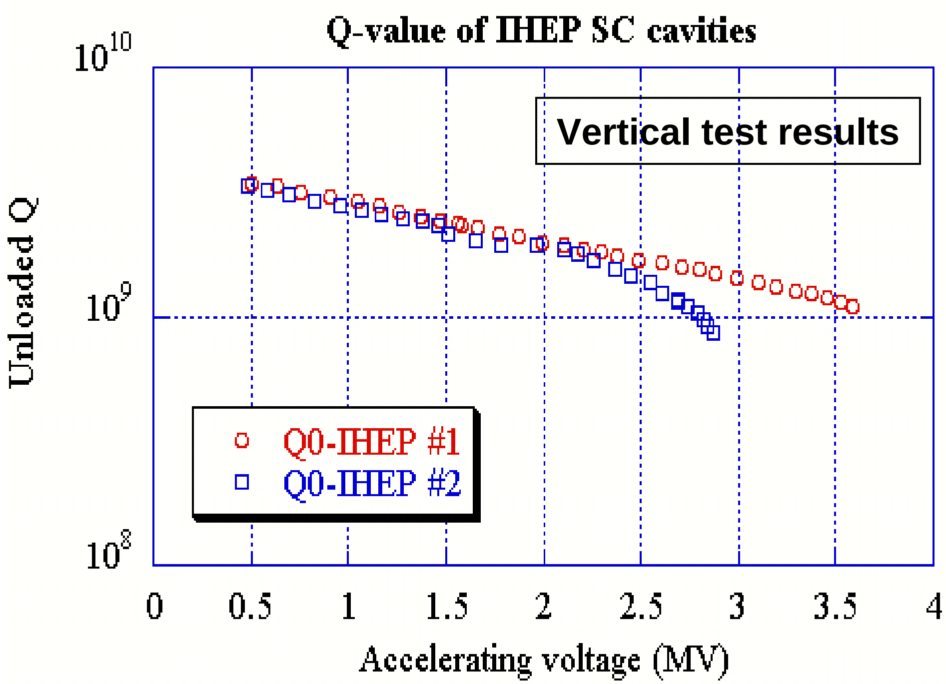
Redesign of cavity from 509 MHz to 500 MHz was necessary

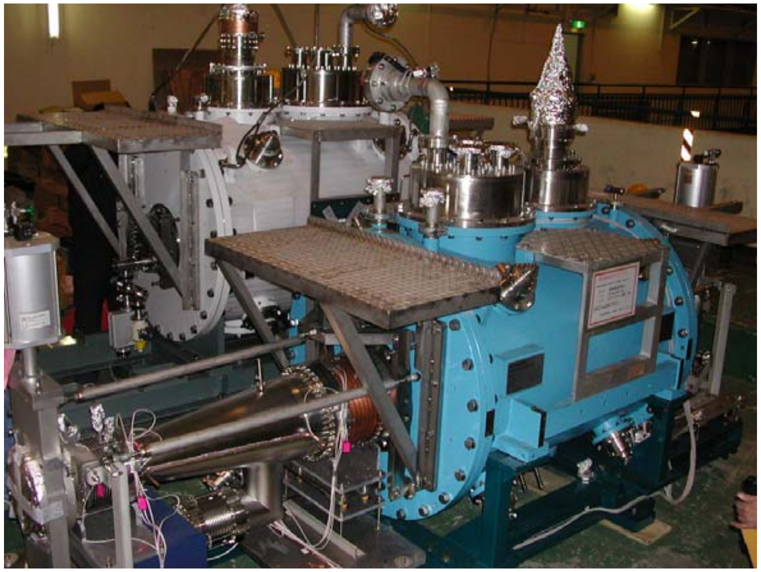


500 MHz module

KEK B, IHEP modules

ACCEL





KEK spare module (blue)
IHEP module (white)

- Contract (Sep/2003)
- Vertical cold test (Dec/2004)
- Delivering of cavity modules (April/2005)
- Vacuum design and fabrication (IHEP, Sep/2005)
- Final assembling (Oct/2005)
- Horizontal power test (Dec/2005)
- Installation (Jan/2006), Commissioning (Jun/2006)

LHC modules: Nb/Cu technology

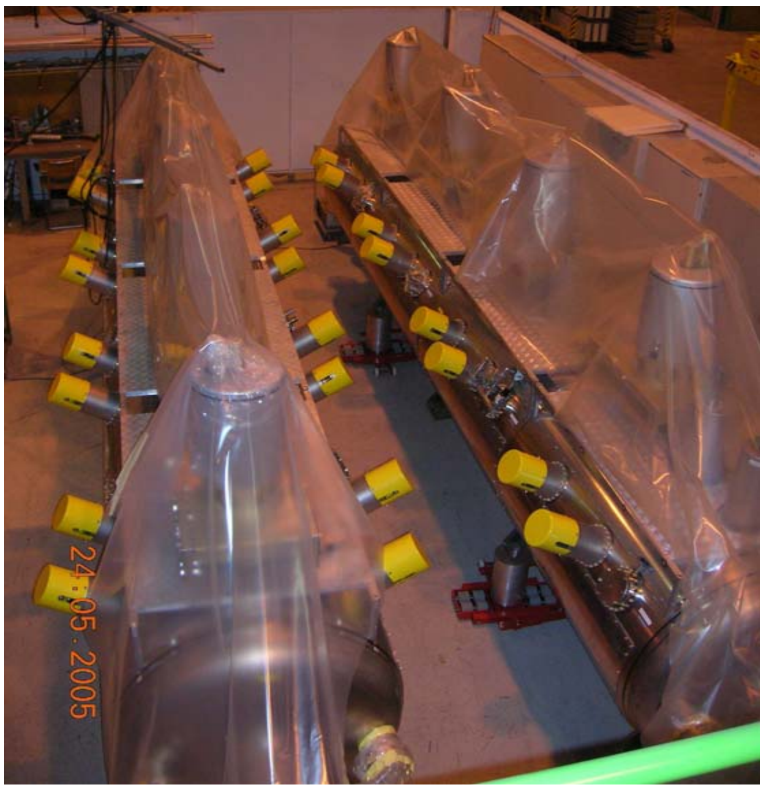
- Design field is 2MV per cavity, installation planned for April 2006
- 16 MV required per beam => 2 modules per beam needed
- 4 modules or 16 cavities needed for operation of LHC
- 21 cavities ordered from industry => one spare module + one spare cavity

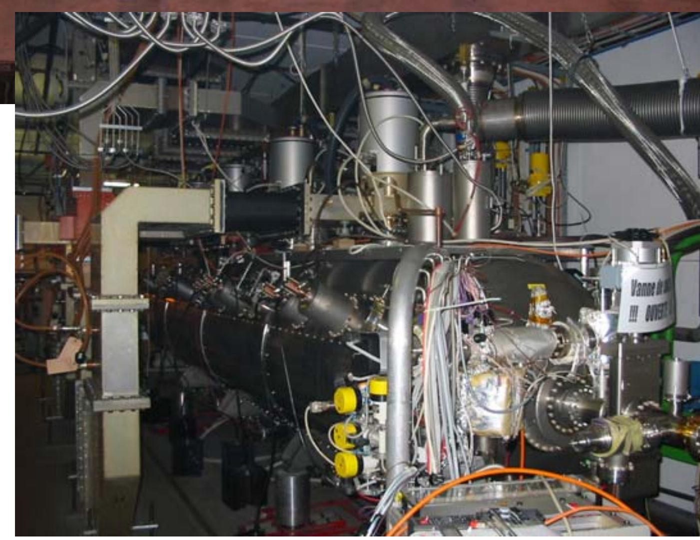
Four single cell cavities (400 MHz) in one vacuum vessel

LHC modules: assembly status and horizontal test

ACCEL

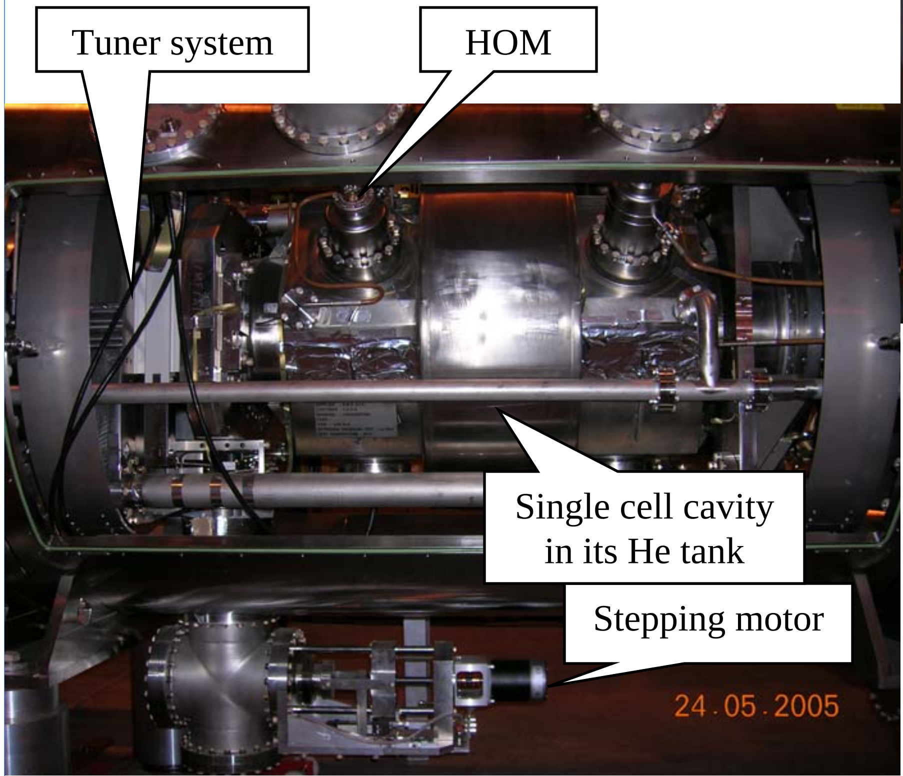
- Two modules assembled and high power test finished
- Each cavity: > 3 MV reached
- Two more modules at assembly





LHC modules: spare cavity

Spare cavity can be tested in Horizontal test cryostat as well

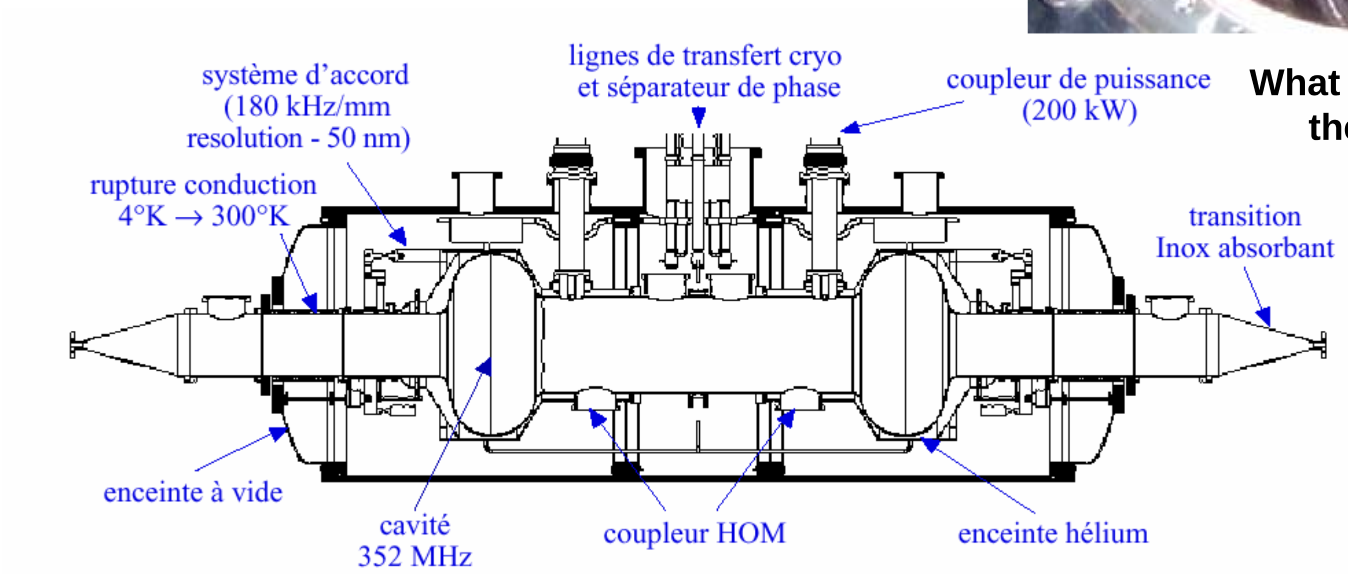


SOLEIL: Nb/Cu technology

SOLEIL: 2.75 GeV, 500 mA light source

- **Nb/Cu single-cell HOM damped cavities**
- **Designed and built by Saclay/CERN collaboration**
- **352 MHz**
- **1.5 MV/cavity**
- **LEP input couplers @ 200 kW**
- **loop HOM couplers**

What the beam sees from the SOLEIL module



Two single cell cavities (352 MHz) in one vacuum vessel

SOLEIL: test results and refurbishment

ACCEL

High power test at CERN 1999
- 2.5 MV reached in each cavity
- 120 kW SW operation of the couplers

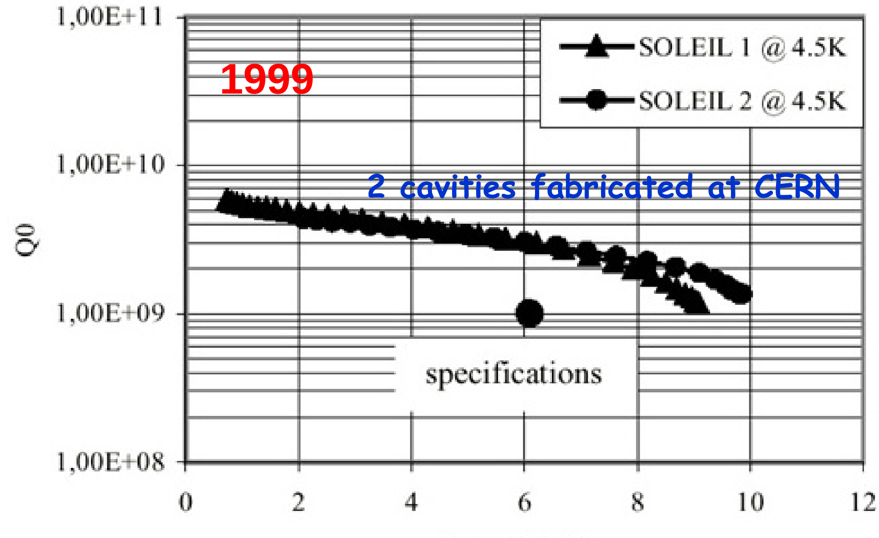
Beam test in ESRF in 2001
- 3 MV provided to the beam
- 190 kW transferred to the beam through each coupler

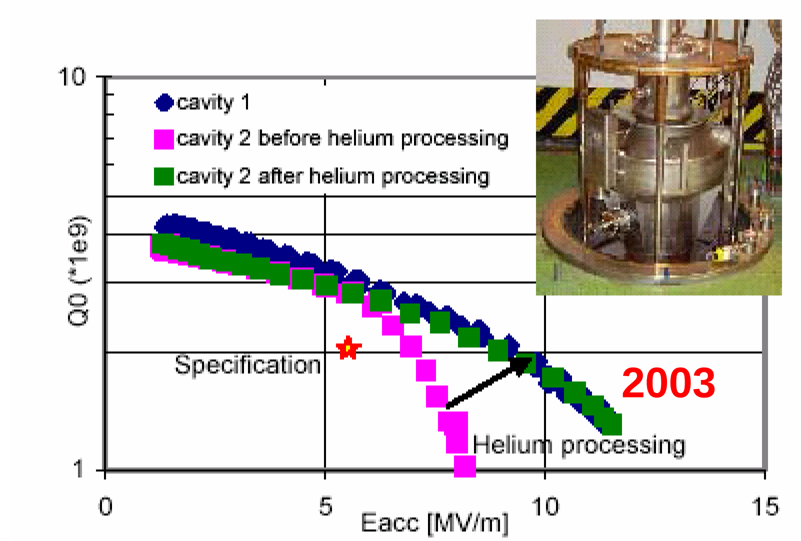
Weak points observed:
- too much HOM power (2 kW) from fundamental mode
- too high thermal losses

Decision 2002:
- improve HOM coupler design
- introduce thermal shield

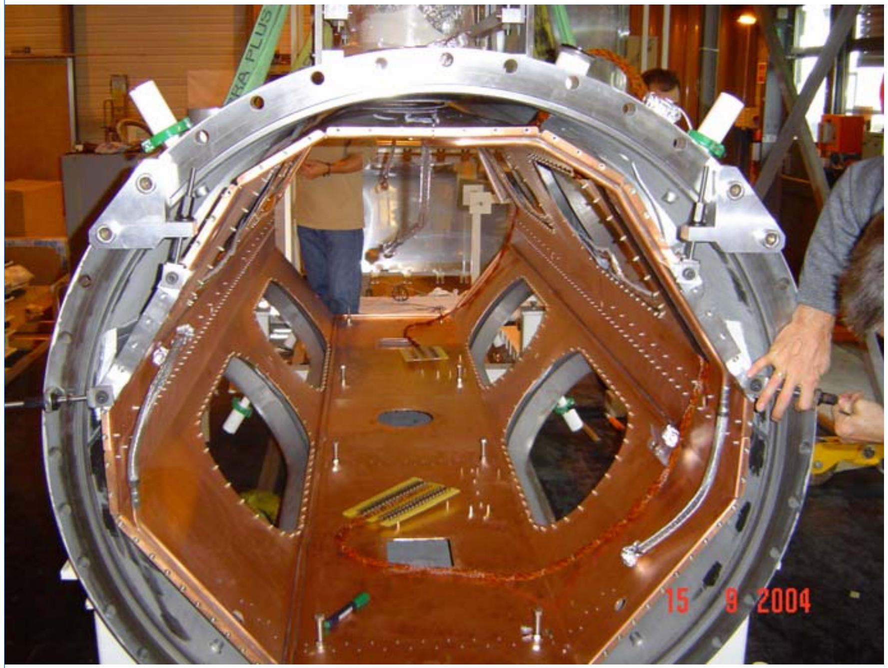
Refurbishment: new rinsing of cavities
- new vertical test in 2003

New high power test at CERN in 2005
- 2.5 MV reached in each cell (spec is 1.5 MV)
- 200 kW full reflection through each coupler (spec is 150 kW TW)
- rejection of fundamental mode ok (now –34 dB, 1999: -19 dB)
- thermal losses reduced to 51 W (1999: 117 W)





SOLEIL: future plans



Thermal shield

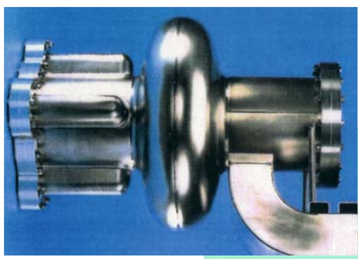
Refurbished cryomodule prior horizontal test

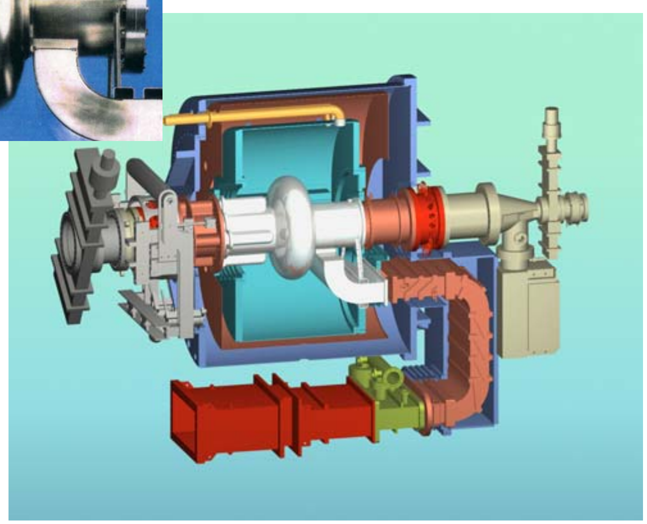
SOLEIL decided to order one more module from industry,
offers are received already
decision on supplier within one or two months from now

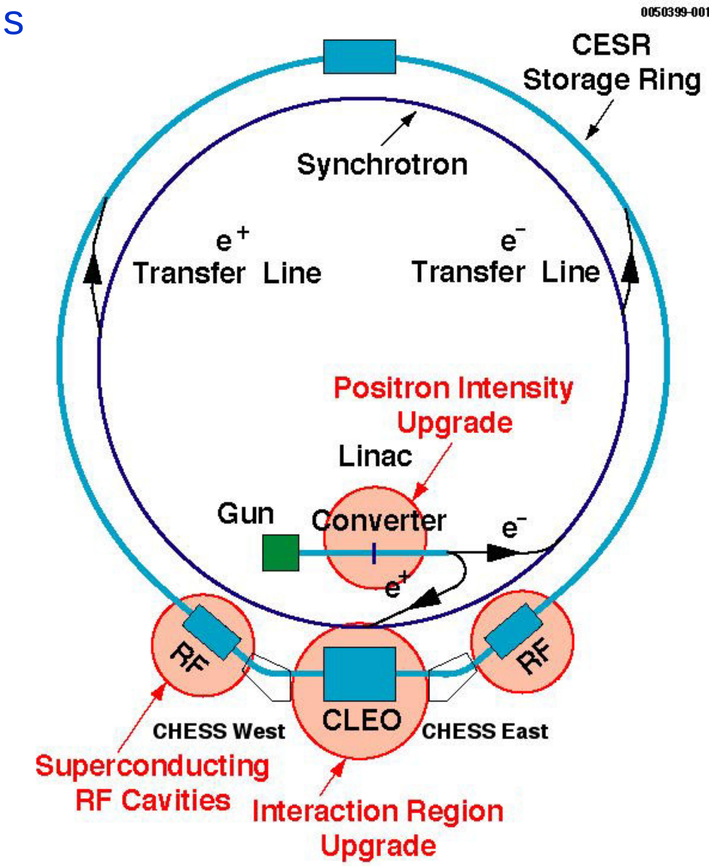
Cornell: CESR III modules

4 superconducting B-cell cavity cryomodules

Resonant frequency	499.765 MHz
R/Q	89 Ohm
Q_0	10^9
Q_{ext}	2×10^5
Operating temperature	4.5 K
Accelerating voltage	up to 3 MV
Static heat leak	30 W





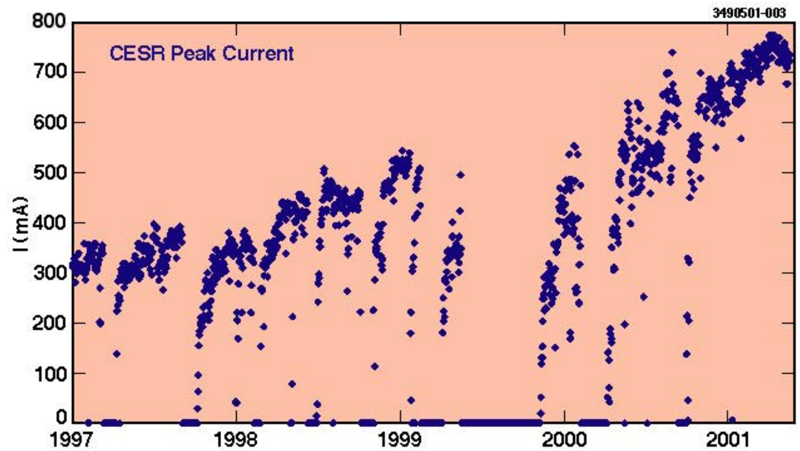


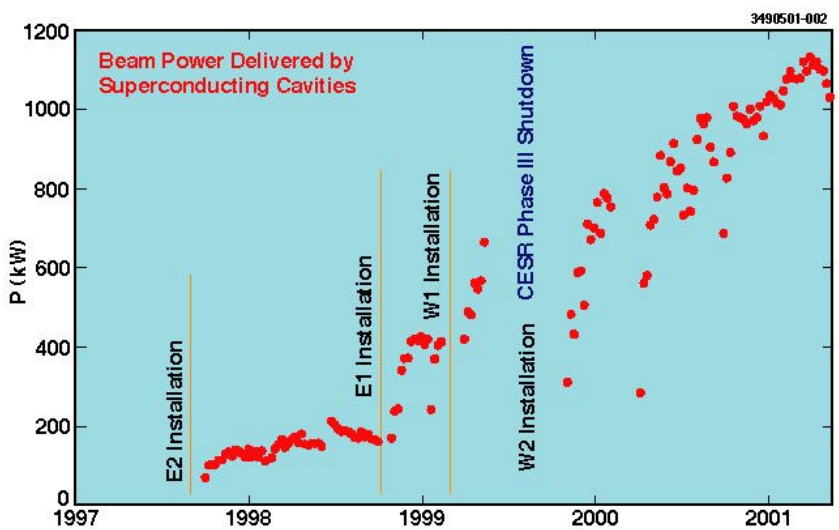
Highlights:

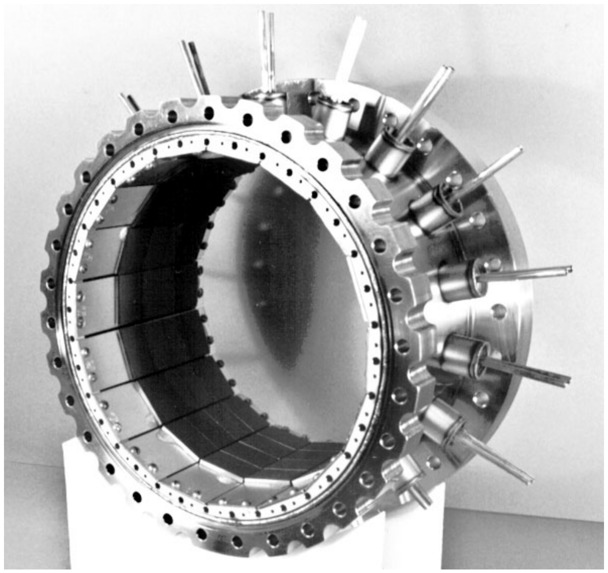
- **1994:** Beam test, demonstration of high current operation
- **1997:** First SRF cavity installed and routine operation
- **1999:** First storage ring to run entirely on SRF cavities

Cornell: CESR III performance

Peak luminosity	1.3×10^{33} cm^{-2}s^{-1}
Beam current	0.78 A
RF voltage with beam	1.85 MV/cavity (1.6 – 2)
Q_0	1×10^{9} at 2 MV 0.3 – 1 $\times10^{9}$ at 2.7 MV
Max. power transferred to beam	300 kW/cavity (360 kW forward power)
HOM power	5.7 kW/cavity at 0.75 A







Cornell: CESR c and CESR chess

ACCEL

CESR-CHESS light source (E=5.3 GeV, Ibeam=500 mA)

- similar though somewhat relaxed requirements
  as for CESR-III due to lower beam current
- emphasis on long beam lifetime, short bunches are not required
  hence high RF voltage is not needed (1.65 MV/cavity)

CESR-c tau/charm factory (E=1.55…2.5 GeV)

- high luminosity
  strong IR focusing and short bunch length (1 cm)
  high RF voltage (1.85…3 MV/cavity)
- high luminosity
  high RF voltage
- low energy
  low beam energy loss per turn & lower beam current
  low RF power (40…160 kW)

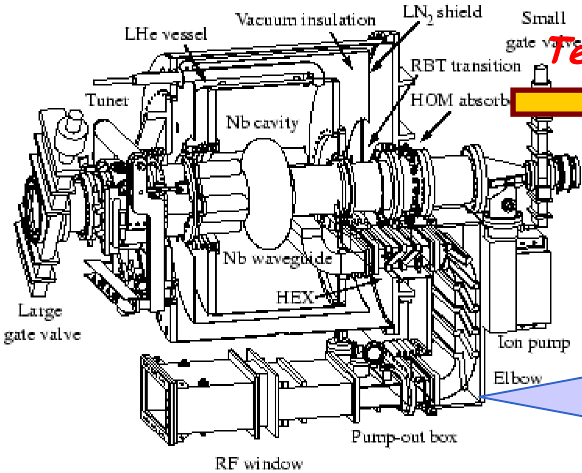
passive cavities

Sucessful operation since 2003

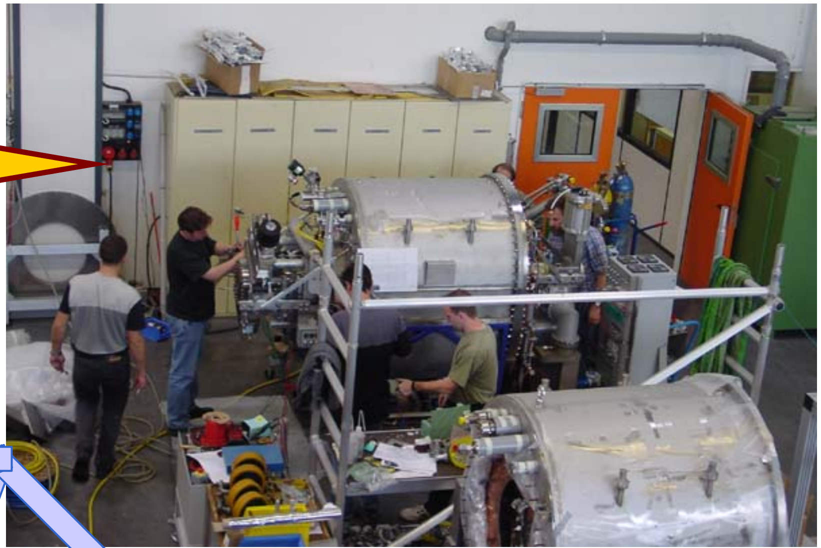
Cornell: technology transfer to ACCEL

ACCEL

CORNELL UNIVERSITY



Technology transfer



2 modules

Turn-Key Systems

Taiwan Light Source

2 modules

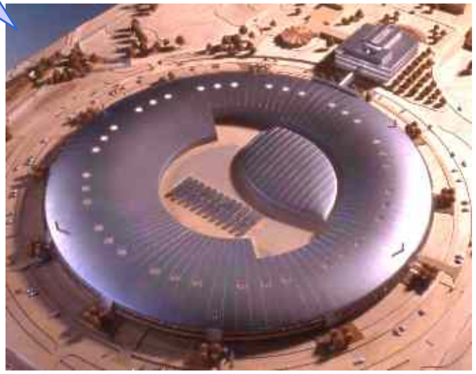
National Synchrotron Radiation Research Center

2 modules

Canadian Light Source Inc.

3 modules

diamond



Turn key Cornell style SRF modules

Guaranteed module performance: V > 2 MV, Q > 5 x 10^8

Scope can cover

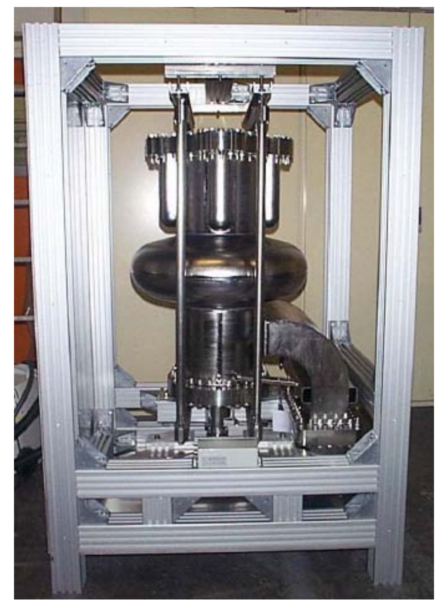
- Cavity production
- Surface preparation
- Vertical test
- Coupler production
- Coupler conditioning
- HOM loads
- Module assembly
- Installation
- Commissioning
- Valve boxes
- transfer lines
- SRF Electronics
- LLRF

Cavity preparation for vertical test

Closed loop BCP

HPR

Assembly in clean room



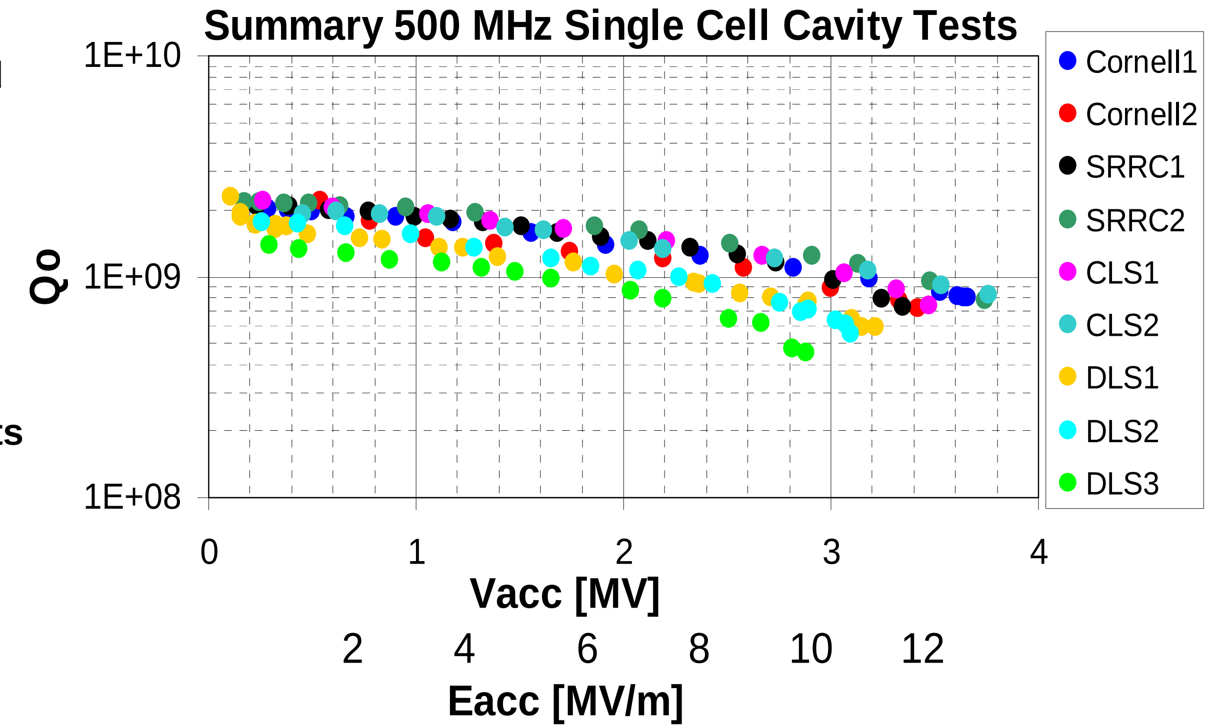
Packing and shipping
for vertical test

Bulk Nb Cavity preparation and test results

Preparation is done at ACCEL as follows:

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

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



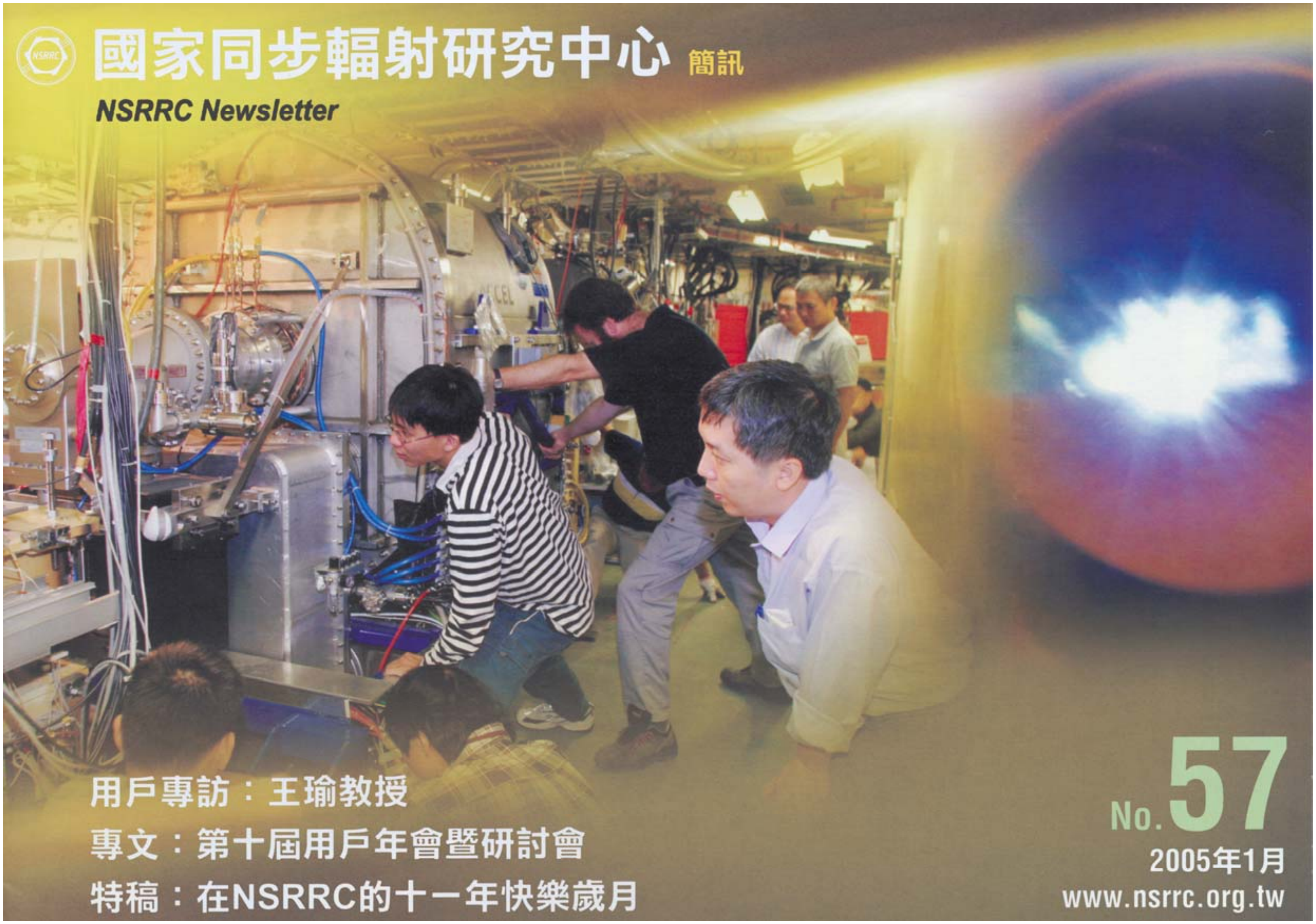
Transport/Logistics

Special transport frame for shock absorption

Transport in air ride truck

Overseas transport

Installation into the NSRRC storage ring



Two modules for Cornell, two modules for Taiwan Light Source and two modules for Canadian Light Source

ACCEL

Cornell

- delivered in winter 2002 and summer 2003
- both modules are operating in CESR at up to **2.4 MV/m and up to 160 kW**

Canadian Light Source

- delivered in summer 2003 and summer 2004
- first Light Source that was commissioned with superconducting RF
- both modules operated in the machine, first one operated for more than one year, then removed in order to install second one. First one now serves as hot spare.
- first one operated at up to **2.5 MV and above 200 kW**, second one up to **2.4 MV and 160 kW,** maximum beam current so far **205 mA.**

Taiwan Light Source at NSSRC

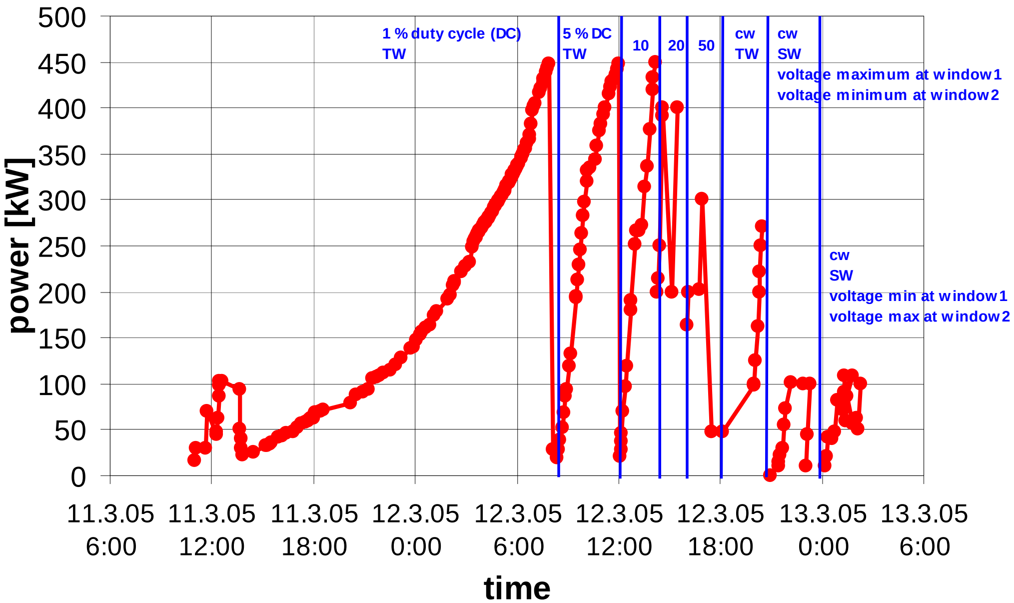
- delivered in spring 2004 and winter 2004
- one module operating in the machine since fall 2004 at **1.6 MV and** up to **85 kW**
- **400 mA stored in the ring**, upgrade goal achieved
- second module commissioned on test stand at NSRRC to **1.6 MV**: hot spare

All modules achieved guaranteed performance

Three modules for Diamond Light Source

ACCEL

- all three cavities tested
- four windows conditioned
- first module will be delivered this month
- installation starts in August
- second module under assembly
- third module: assembly starts in September



Super 3HC modules for SLS and ELETTRA

ACCEL

Scaled version (1.5 GHz) of SOLEIL module, HOM damping by loop couplers, developed from collaboration of CEA, PSI, Sinchrotron Trieste and CERN,

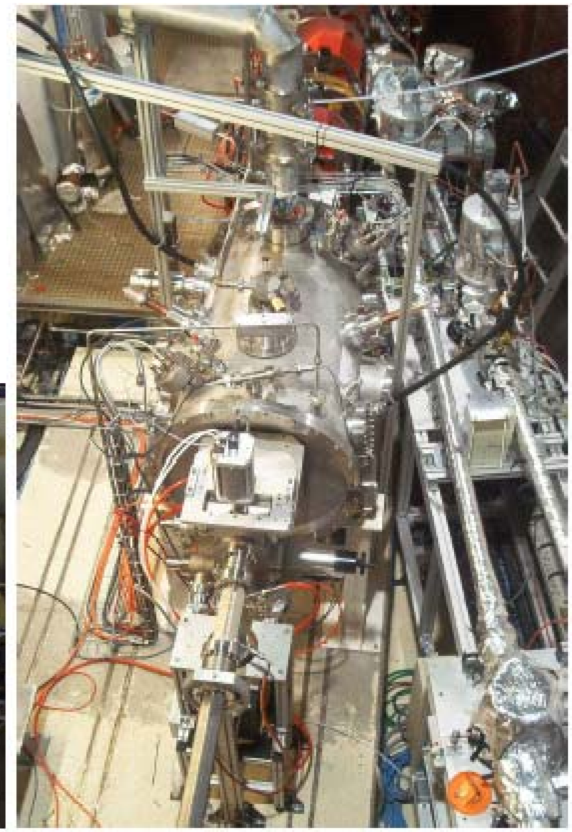
1 MV @ Q > 1x 10^8, operated at 4.5 K

- factor of 3 on bunch lengthening achieved
- factor of 2 on beam life time achieved

Cold mass assembly at CEA

In class 100 clean room

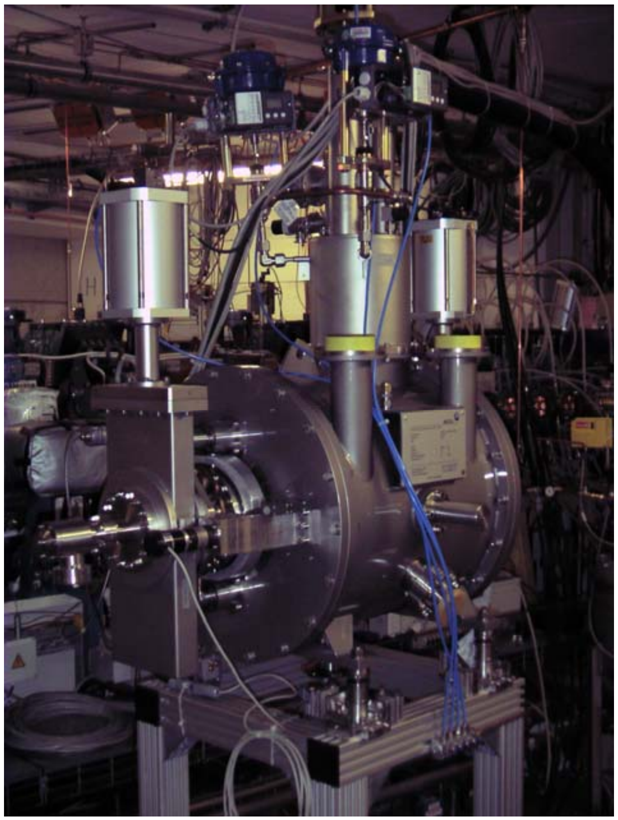
SLS cryomodule

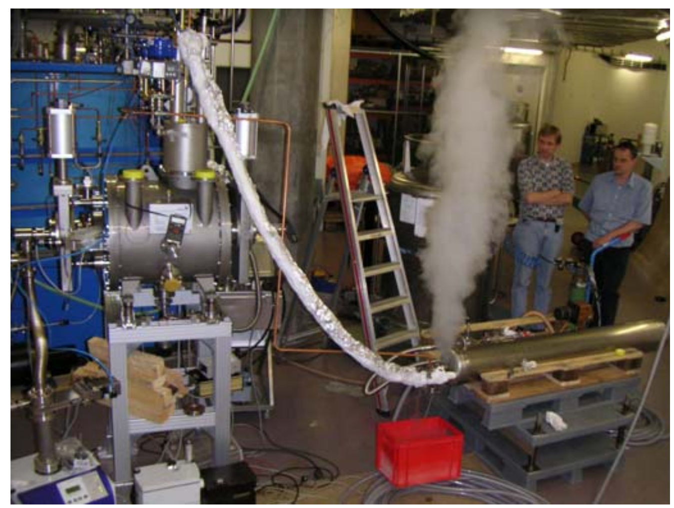


ELETTRA cryomodule

Landau module for BESSY

- Scaled CESR type cavity (1.5 GHz)
- ferrite type beam tube HOM dampers
- 0.5 MV at $Q=8x10^7$ achieved at 4.5 K
- up to now only off line test





Family trees of superconducting RF systems

ACCEL

LEP
Nb/Cu technology,
loop HOM couplers

→ SOLEIL → SLS S3HC cavity; ELETTRA S3HC cavity

→ LHC

CESR B-cell
WG input coupler
Ferrite HOM load

→ TLS, CLS, DIAMOND

→ BESSY II Landau cavity

→ or SSRF

KEKB SC cavity
Ferrite HOM load

→ or SSRF

→ BEPC II

Summary / New projects

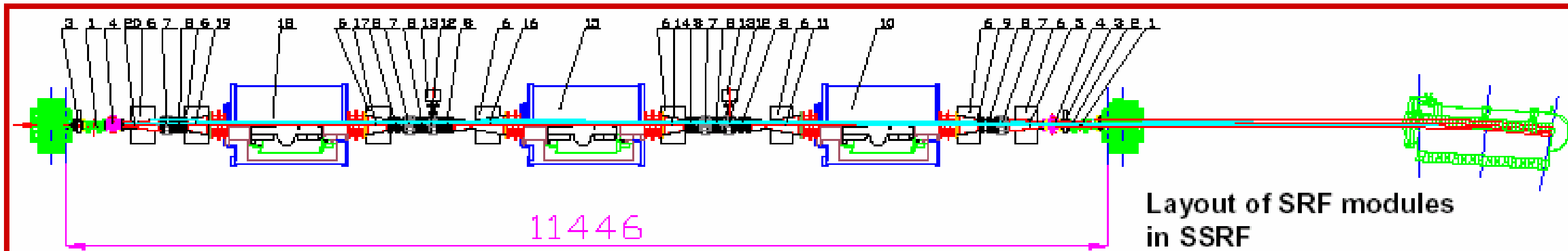
Three different reliable and proven superconducting RF design for high current storage ring RF systems can be purchased from industry,
Voltage around 2 MV per cavity, power transferred to the beam around 250 kW

SSRF (Shanghai Light Source) will decide this month on industrial supplier for their storage ring RF system, future potential projects: NSLS II, PETRA III, TPS, ILC-DR

Three SRF Modules for Storage Ring of Shanghai Synchrotron Radiation Facility (SSRF)

Requirements to RF System		
	Phase I (4IDs)	Phase II (IDs full)
RF Frequency	499.654 MHz	499.654 MHz
Beam current	200 ~300 mA	300 mA
Total loss per turn	~1.64MeV/500 kW	~2.08MeV/620 kW
V_{acc}	≥4 MV	≥4 MV
RF stability	≤±1%	≤±1%
RF phase stability	≤±1°	≤±1°

Basic parameters of each set SRF module	
RF Frequency/Tuning range	499.654 MHz/±200KHz
Eacc in vertical test	>12 MV/m
Q_0 (@Eacc=8MV/m)	1×10^9
Accelerating voltage	2 MV
Dynamic loss/Total cryogenic loss	70W/100W
Qext	$1.8 \pm 0.2 \times 10^5$
Power transferable to the beam	250 KW



Layout of SRF modules in SSRF

Acknowledgements

I would like to thank:

Wolfgang Anders (BESSY)
Sergey Belomestnykh (Cornell)
Pierre Bosland (CEA)
Takaaki Furuya (KEK)
Morten Jensen (DLS)
Liu Jianfei (SSRF)
Mark de Jong (CLS)
Pierre Maesen (CERN)
Catherine Thomas-Madec (SOLEIL)
Chaoen Wang (NSRRC)
for helping me preparing the talk

Many thanks to the staff of Cornell, Canadian Light Source and NSRRC for their help, support and hospitality during module commissioning and installation