Cornell SRF Overview
- focusing on ERL fraction of SRF group -

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Georg Hoffstaetter
Cornell Physics Dept. / CLASSE

1) ERL Injector R&D, prototyping, and operation
2) ERL main linac R&D, prototyping, and technology transfer
3) Low Loss Research (For CW linacs, mostly ERL and Project-X)
4) High Voltage Research (Mostly for ILC)
5) New SRF materials with potential for high voltage and low loss.
6) Fundamental SRF properties – theory and experiment
7) Storage ring SRF cavities operation and technology transfer
8) SRF related Beam Research:
    a) Dark current in SRF linacs
    b) X-ray background outside SRF linacs
    c) Cavity focusing and ERL linac optics

Superconducting RF 1964 – present

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1975: First Test of SRF Cavities in a HEP Accelerator
(2.86 GHz, Ea= 4 MV/m, 110 mA, 4 GeV)

1982: First Test of SRF in a Storage Ring
(1500 MHz, Ea = 2 MV/m, 12 mA)

1987: CEBAF Adopted Cornell SRF Technology and Cavity Design

1990: First International Workshop on SRF Linear Collider

1994: First Demonstration of 500 MHz High Current Operation
(Ea = 5 MV/m, 200 mA)

1995: First Demonstration of Eacc > 25 MV/m for LC 5-cell cavity, first TESLA cavity

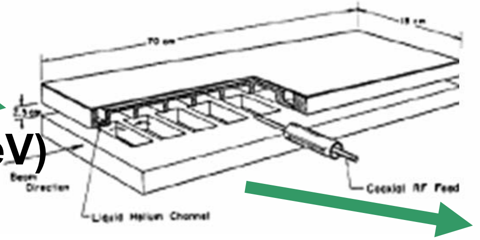
2000: First Storage Ring to Run Entirely on SRF Cavities, Ea = 7 MV/m, I = 700 mA

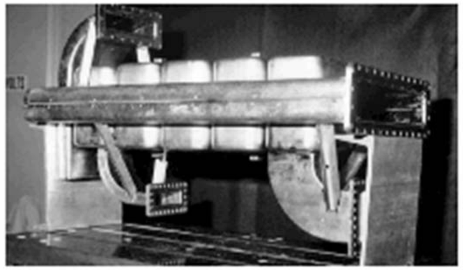
2002: First Test of 200 MHz Cavity (11 MV/m)

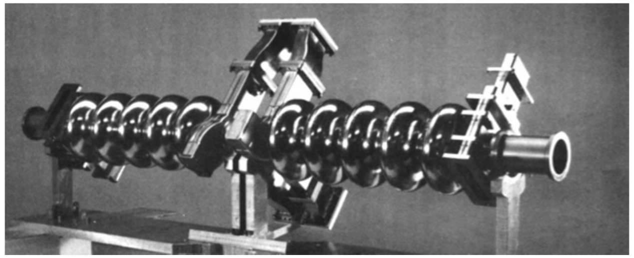
2004: First ultra-high gradient cell => 59MV/m

2009: First high-current SRF-ERL injector

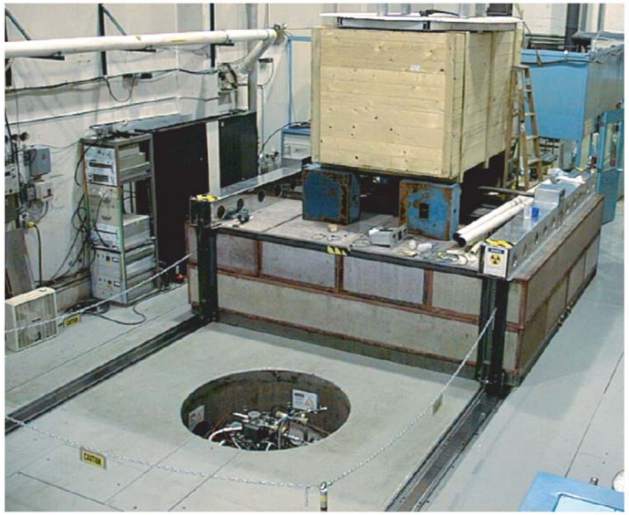
2011: First ERL cavity specs in vertical test







Cornell's SRF R&D facilities -1-



Cornell's SRF R&D facilities -2-

- **Strong research team:**

  3Prof, 4PhD, 7Eng/Tech, 4Grads

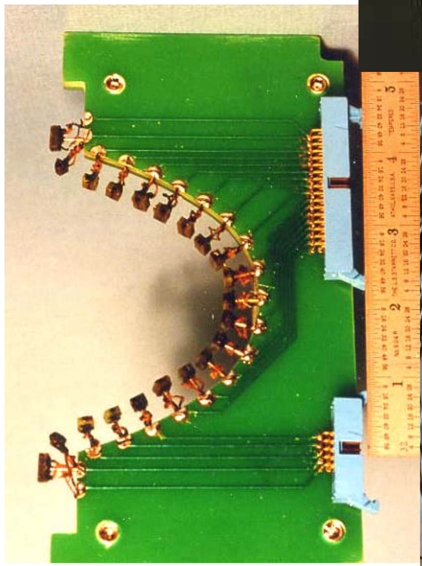
- **RF measurement lab**

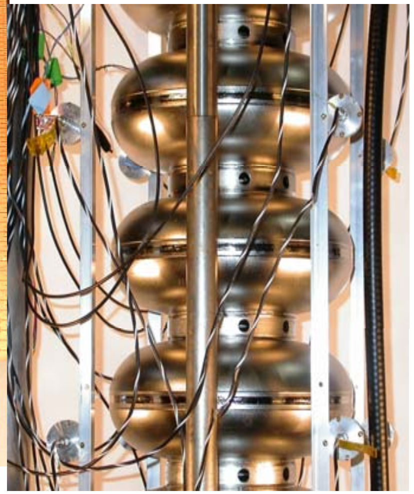
- **Clean room**

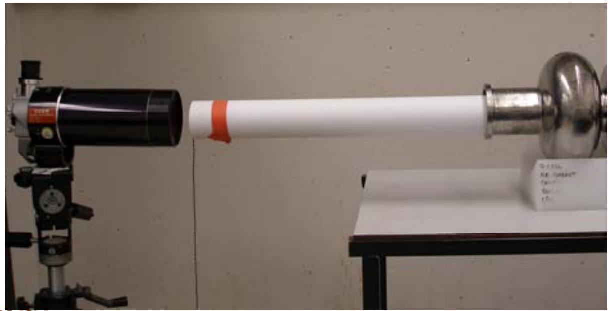
- **Chemical handling**

Cornell's SRF R&D facilities -3-

- Precision coordinate measurement
- Scanning electron microscope, Auger analysis, SIMS
- Advanced m-Kelvin thermometry
- OST quench locator
- Questar optical inspection
- Helium recovery system
- Large 1450C high-vacuum furnaces







SRF-ERL injector-linac prototype

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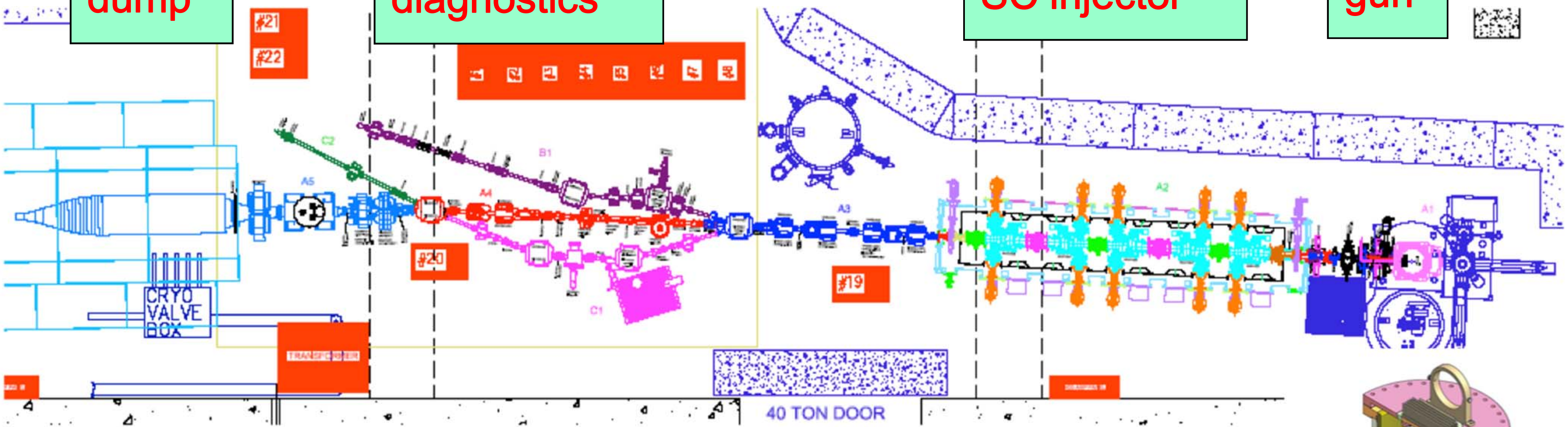
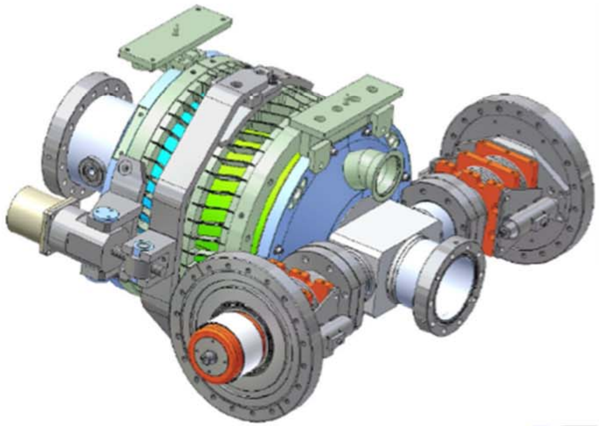


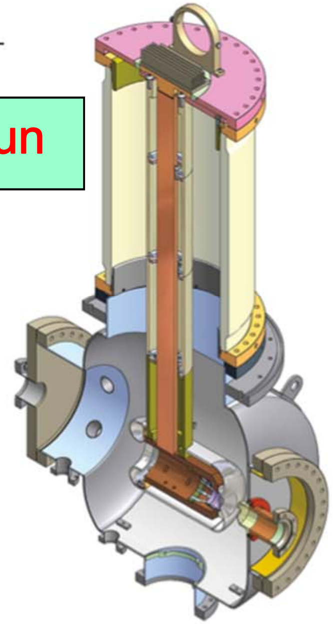
HOM absorb.

CW coupler

Dressed cavity



gun



Cavity Production at Newman Lab

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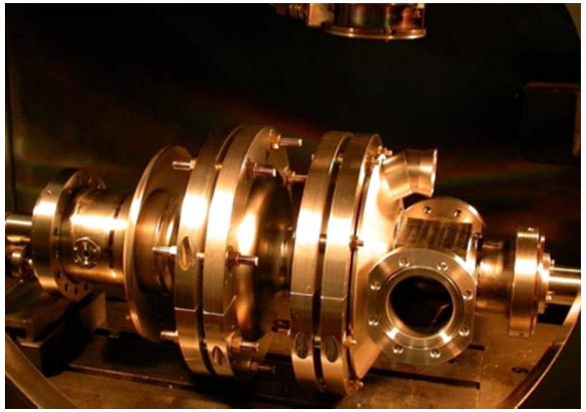
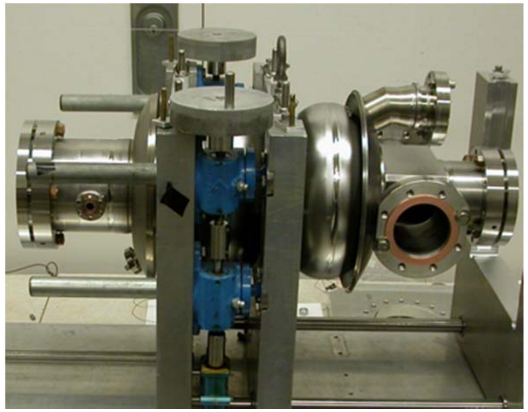
Pressed Nb cups for cavities

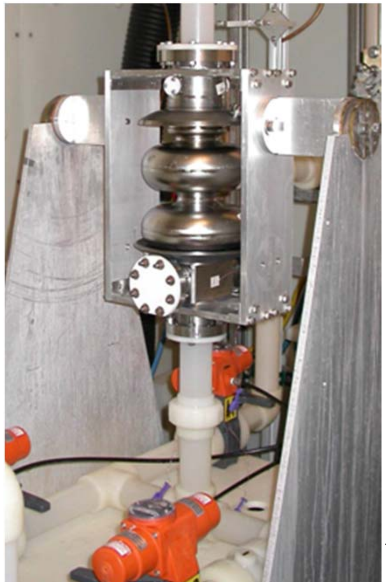
E-beam welding of cavities



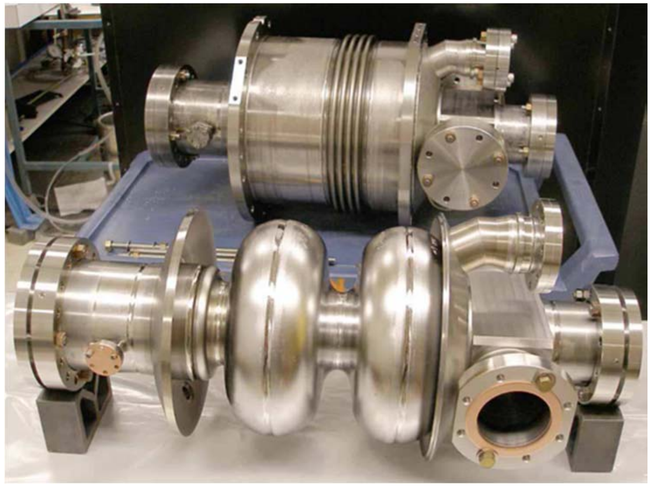
Tuning of cavities



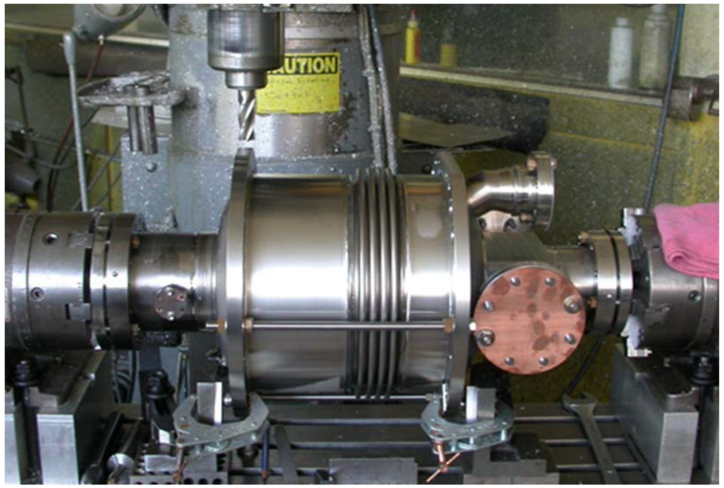
BCP cavity etch



Cavity with and w/o He vessel



Final matching of He vessel



All constructed at Cornell, except coupler, absorber, and vessel

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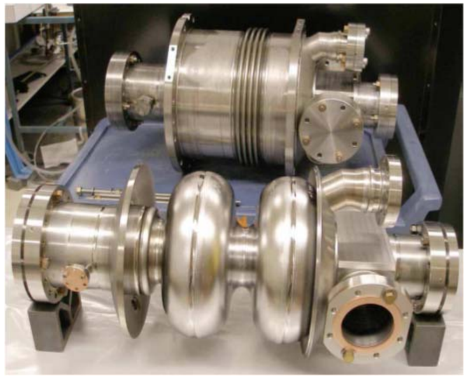
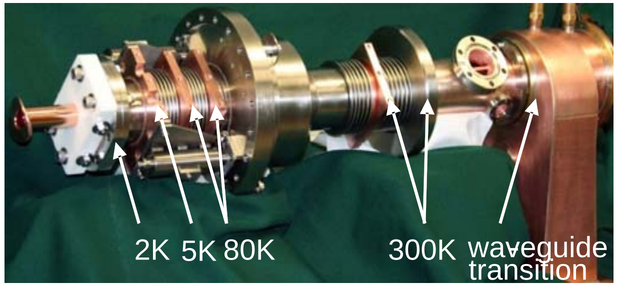
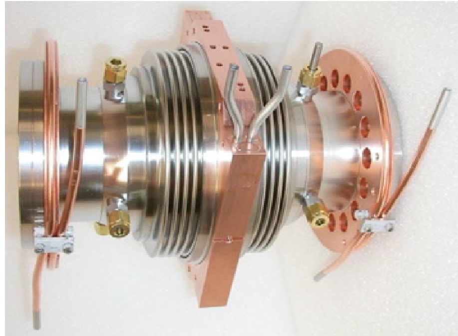
Pushing the Envelope in Many Ways



SRF cavity: design for high beam current

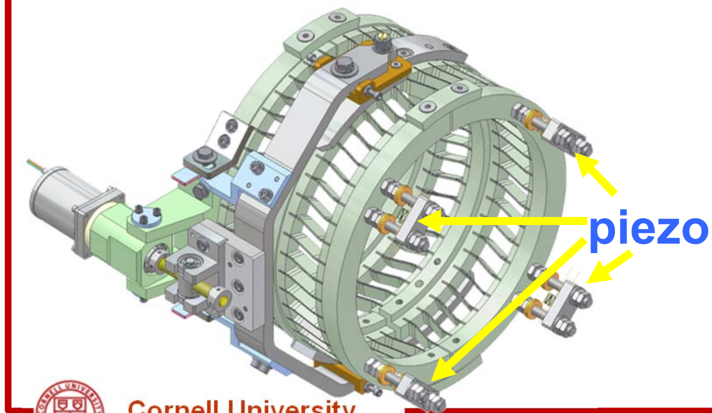


RF input coupler: design for high power

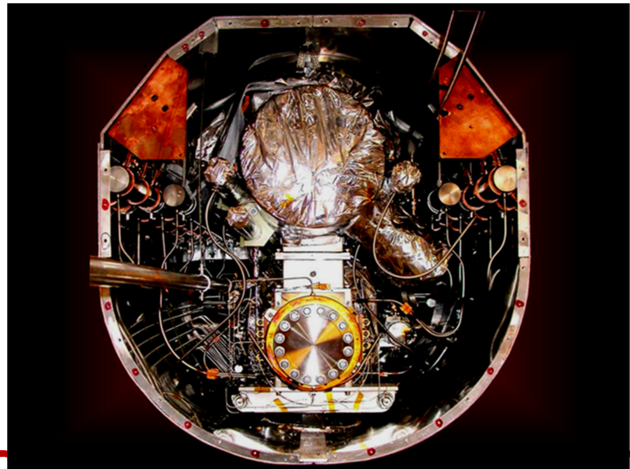


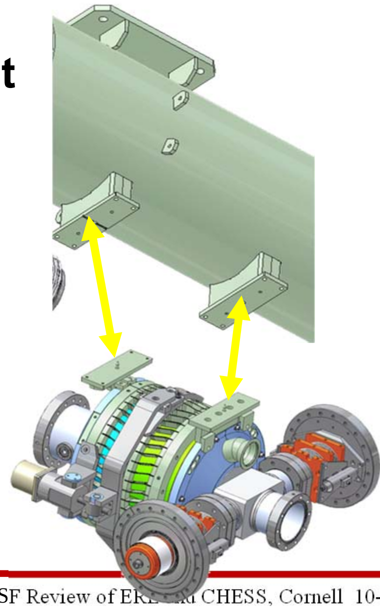
HOM damper: design for strong HOM suppression

Frequency tuner: stabilize cavity length on nm scale



Module design: support high cryo loads and provide excellent alignment





ERL Injector Module Assembly in Cornell's SRF group

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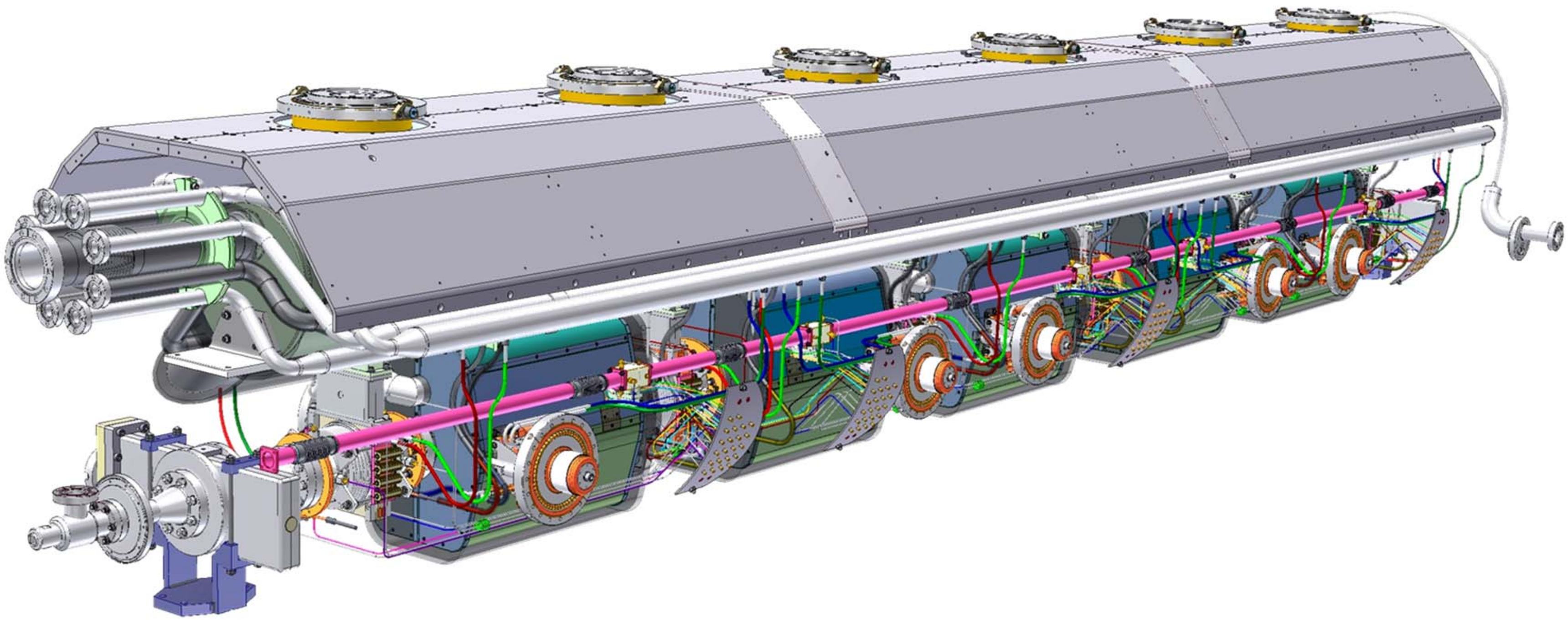

All done at CLASSE – No company could do this today !

ERL Injector Module Assembly in Cornell's SRF group

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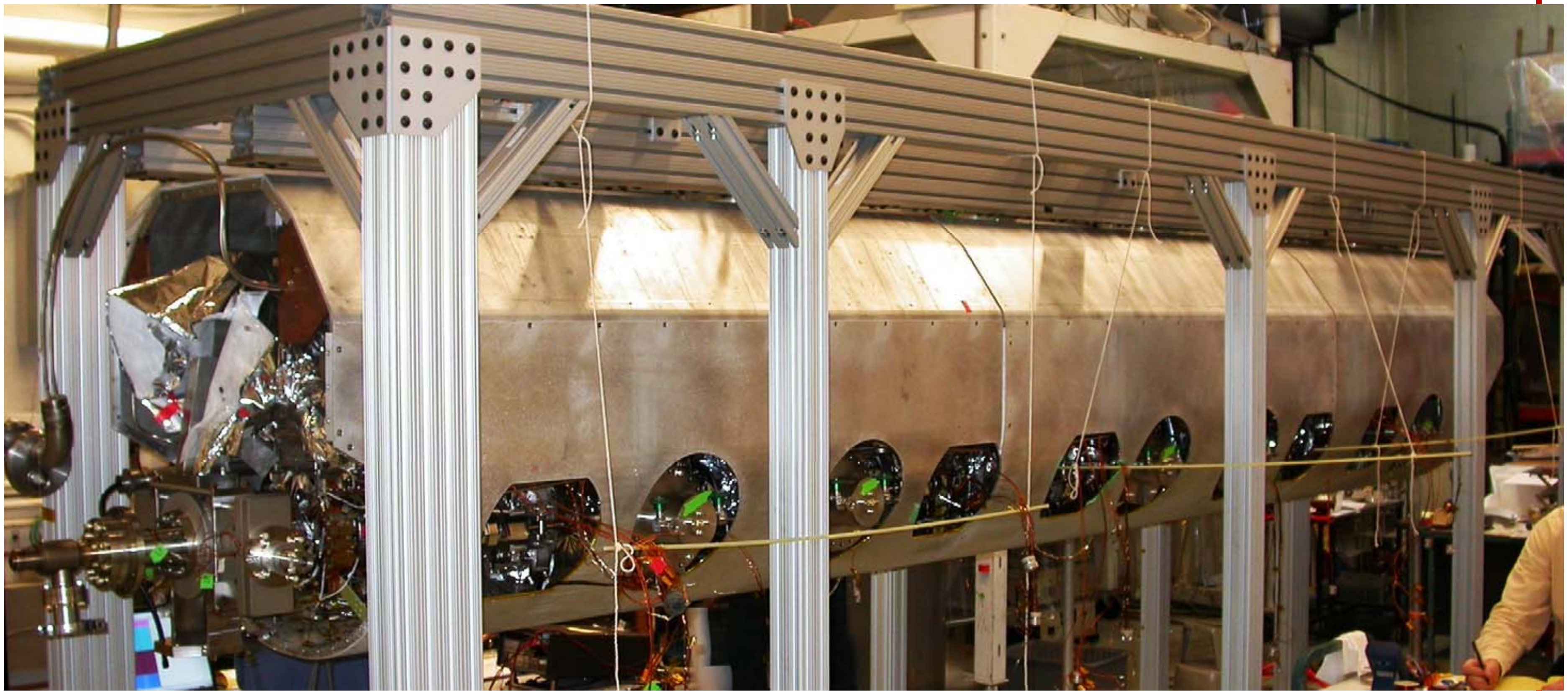
ERL Injector Module Assembly in Cornell's SRF group



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ERL Injector Module Assembly in Cornell's SRF group

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Rebuilding and Improving the ERL Injector

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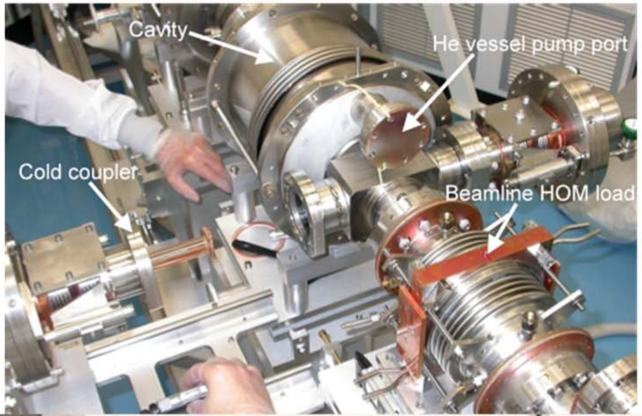
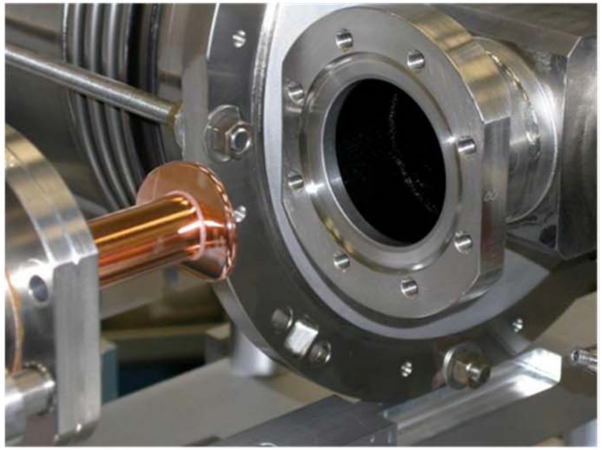
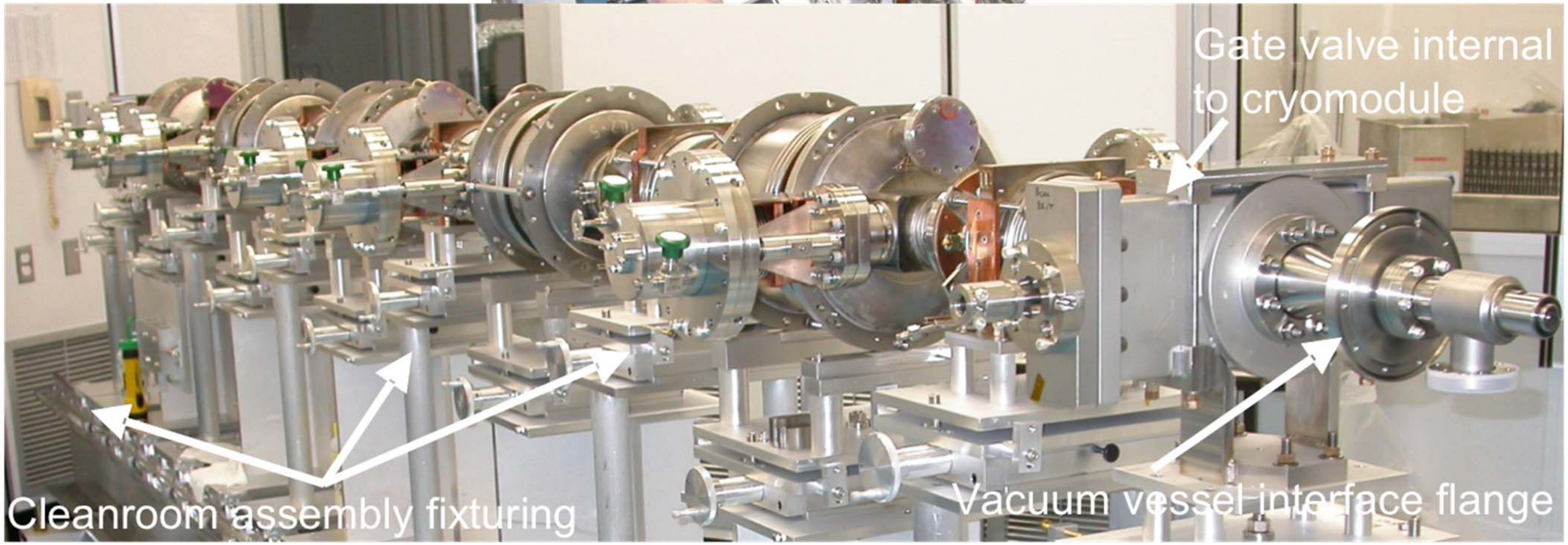
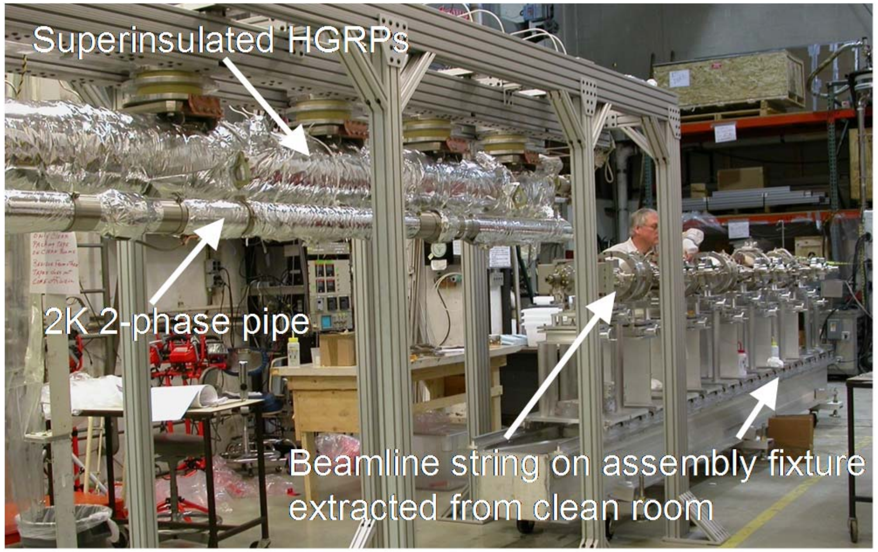
Attach cold couplers to beamline string

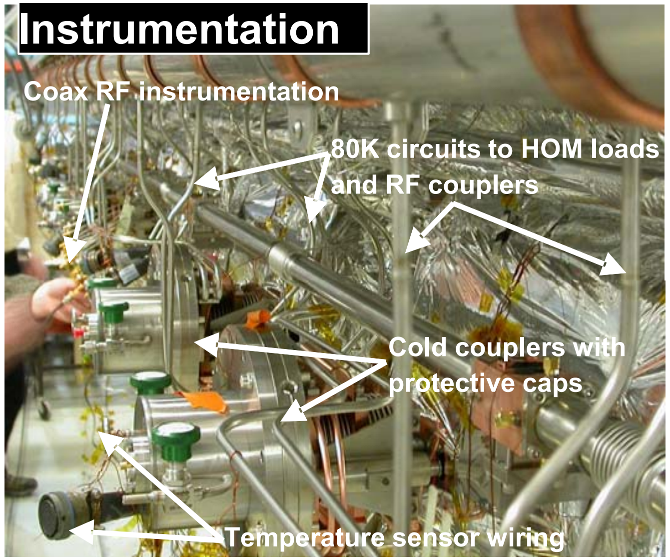


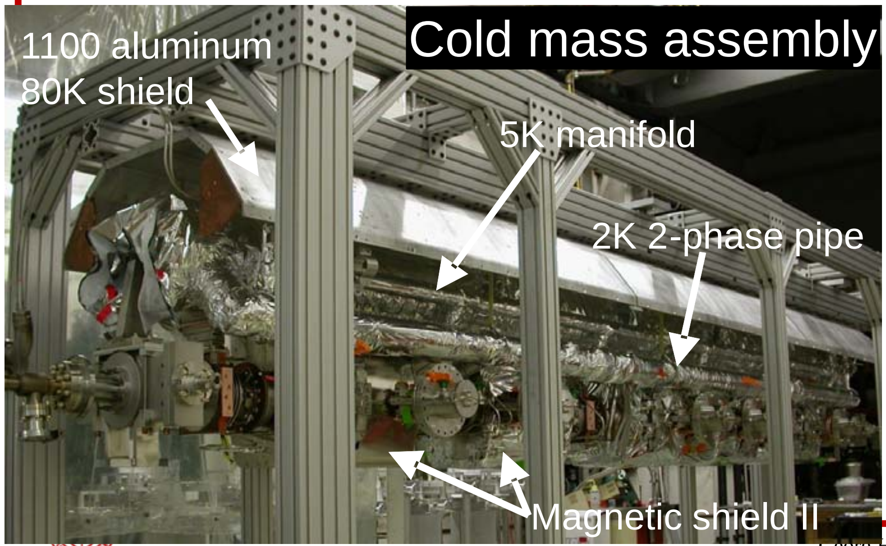


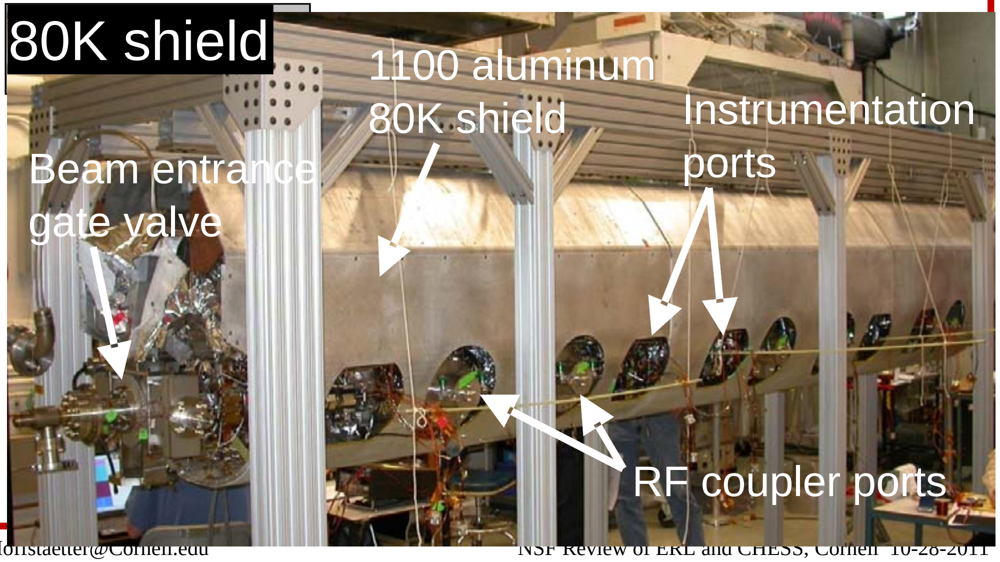


Module Assembly at Newman Lab









Does is cold alignment correct ?

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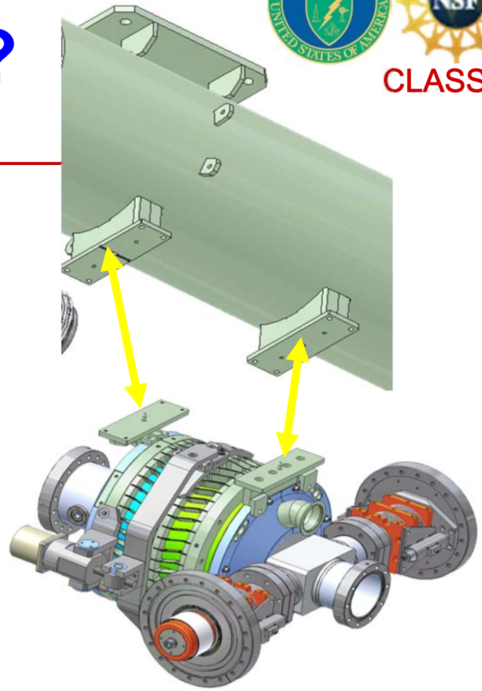
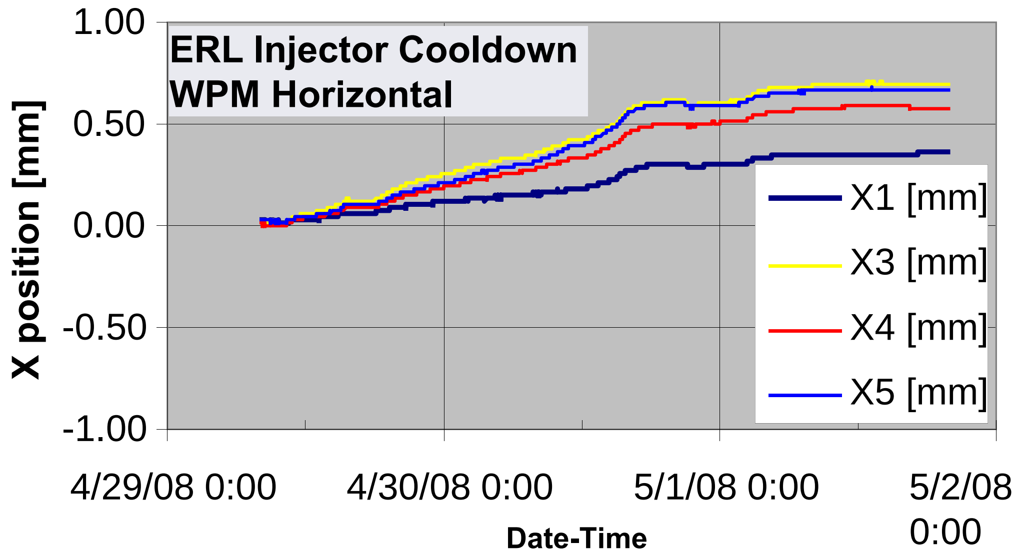
✓ Required ERL cavity alignment: transverse offset < 0.5 mm (for beam emittance preservation)



- Challenge: Movements during cool-down. Cavities are inside of vacuum vessel at 2K
- Solution: Individual alignment concept
- Result: Cavity string is aligned to □0.2 mm after cool-down (previous best module: □1 mm)!



Localization and elimination of magnetic error

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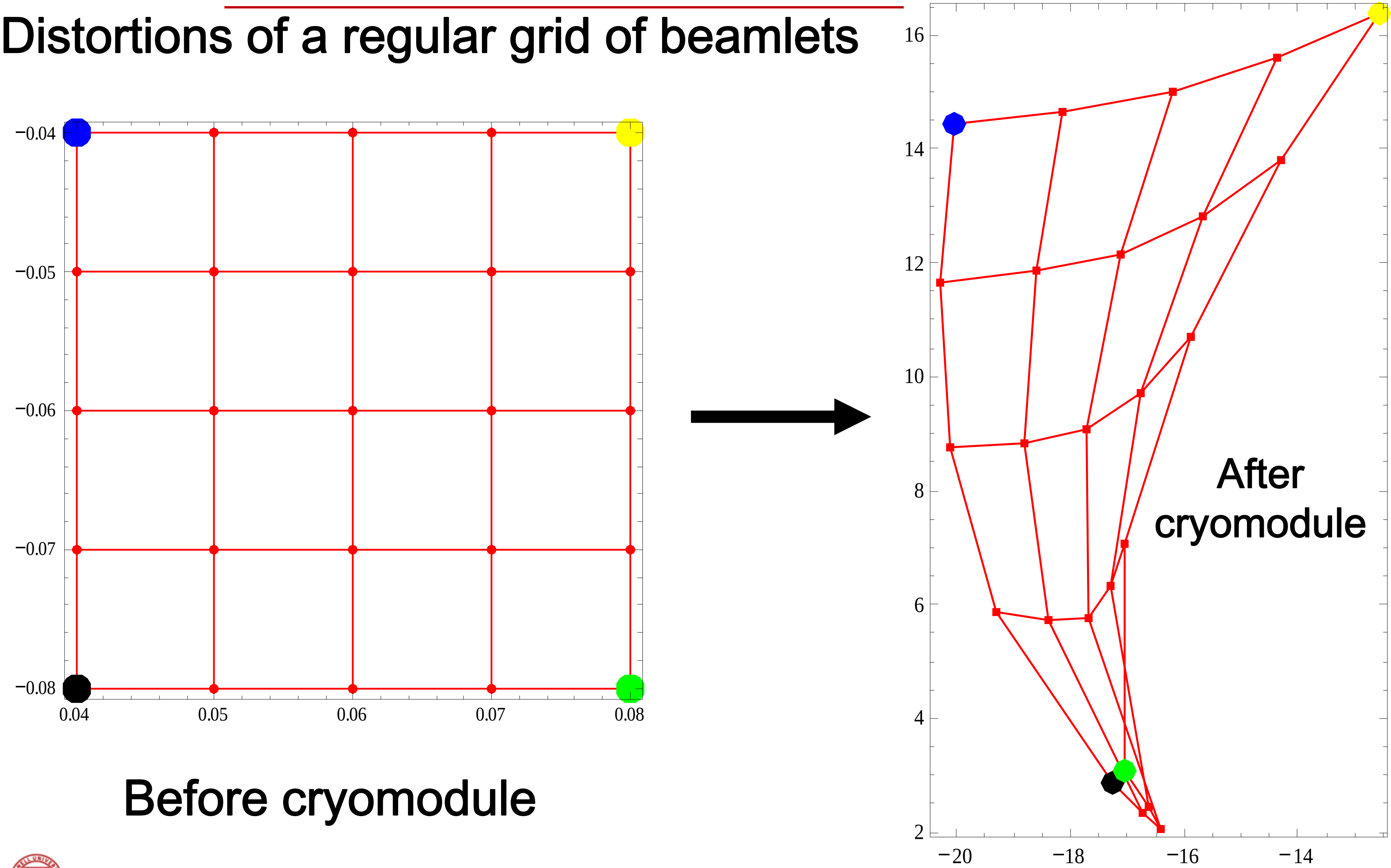
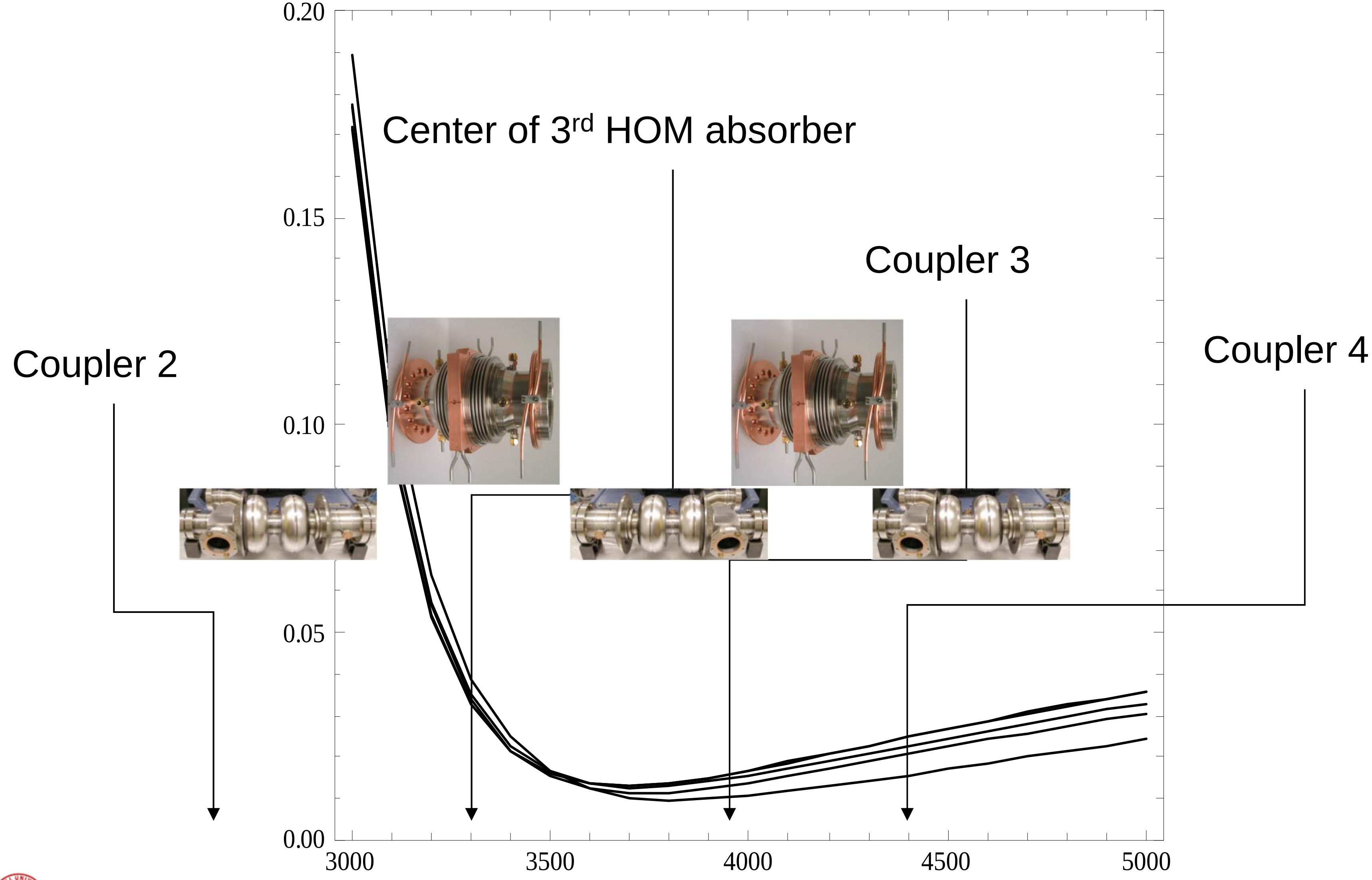
Distortions of a regular grid of beamlets



Before cryomodule

After cryomodule

Does is cold alignment correct ?



SRF ERL Injector Cryomodule Re-Work (fall 2009 – spring 2010)

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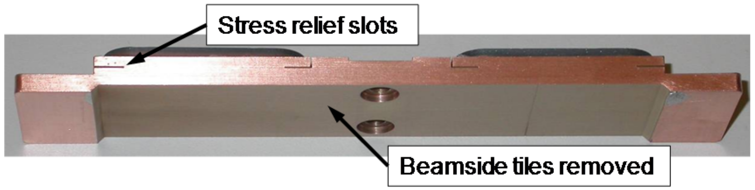
The first run period (July 2008 – August 2009) revealed lower than expected cavity Q_0 and HOM load absorber tiles charging -> beam steering.

September 2009

Module disassembly

- **Re-processed SRF cavities**
- **Fixed absorber charging problem (removed beamside RF absorber tiles)**

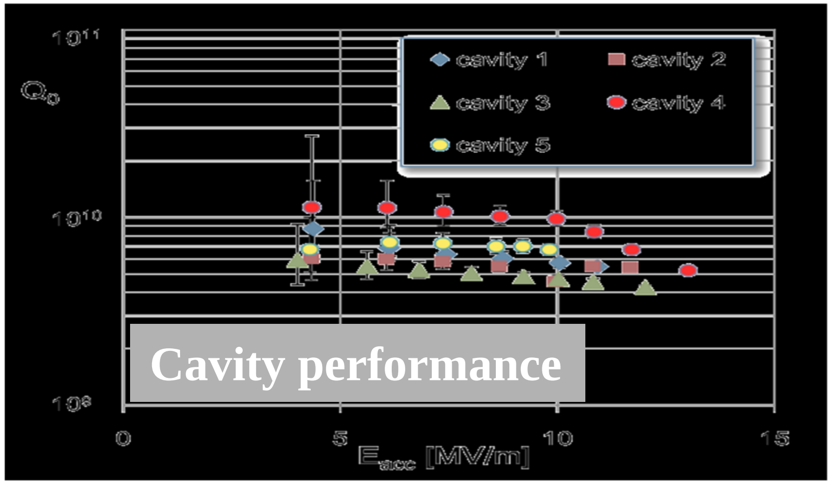


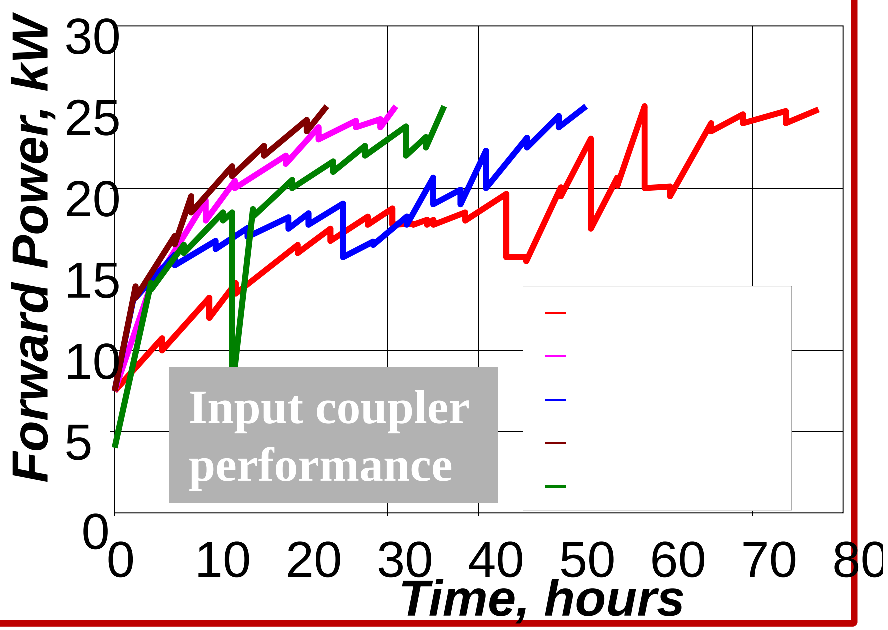
February 2010

Module reassembly

Does the injector work?

- ✓ **All components work well (after some initial hitches)**
- ✓ **Successfully accelerated beam currents of 25 mA**
  - ✓ **Transferred > 125 kW of RF power to the beam**
  - ✓ **Performance projected indicates that operation at >100 mA is possible**





Milestones at Cornell's injector

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Peak DC-power supply voltage: 750kV
Peak DC-gun voltage: 440kV (of 500kV required with beam)

Peak DC-beam current: 25mA (up to brilliance mode spec)
Peak bunched-beam current: 25mA with GaAs / 20mA with CsK_2Sb for 8h

Peak charge per bunch: 200pC (more than needed)

Typical bunch length: 2ps (up to spec)

Smallest normalized thermal emittance: 0.25 mm mrad/mm radius
Smallest normalized emittance after injector at 80pC: 0.8 mm mrad
For this gun, 0.5 mm mrad is theoretical limit !
This bunch in a 5GeV ERL would produce X-rays brighter than any ring today.

Largest SRF-injector cavity Q0: 1.e10 (of 2.e10 required)
Largest injector-coupler power: 60kW (of 100kW required)
Largest SRF-cavity voltage: 13MV/m (up to spec)

HOM Damping Workshop at Cornell

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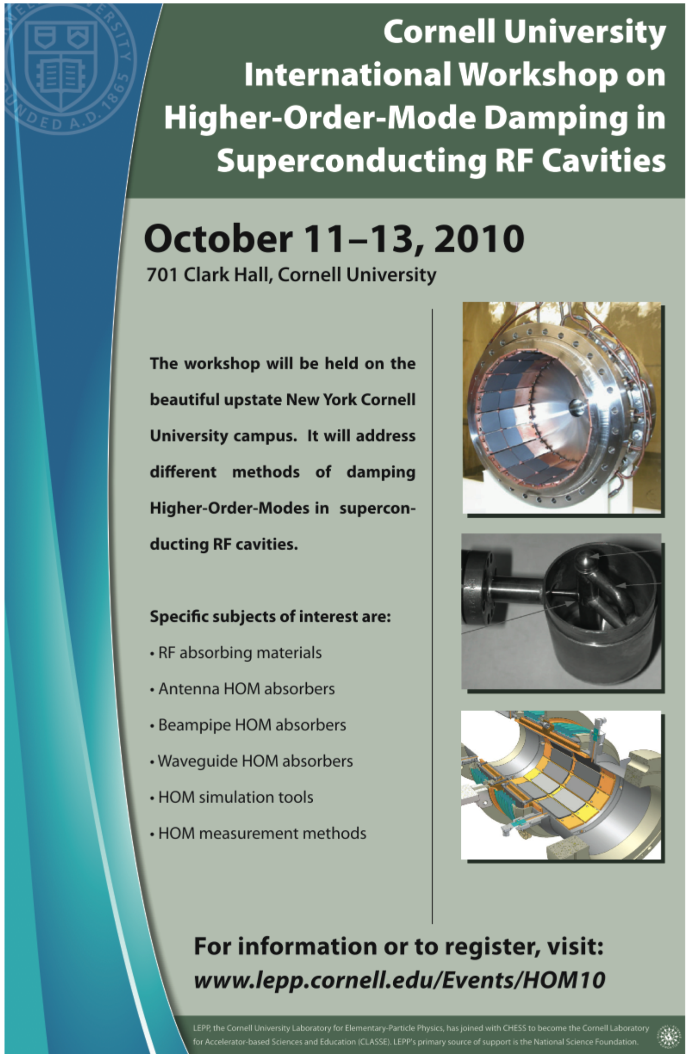


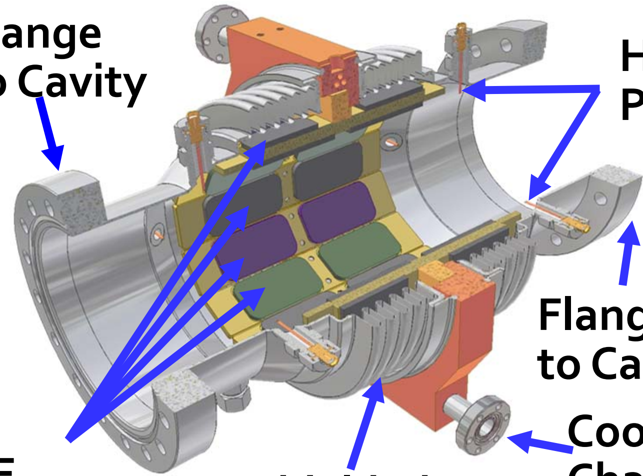
- ~40 participants
- From 15 different labs/ universities from Asia, Europe and U.S.

Cornell's HOM Beamline Absorber

Extensive research program to find absorber materials which

- **are effective at 80 K**
- **and_absorb over the required wide frequency range (1 GHz to >100 GHz)**
- **Be vacuum compatible and radiation hard**
  - Ferrites
  - Graphite loaded SiC
  - Carbon-nanotube loaded ceramics

Carbon-Nanotube Absorber



Spherical carbon inclusions vs. CNTs

HOM Results from the Injector SRF Module

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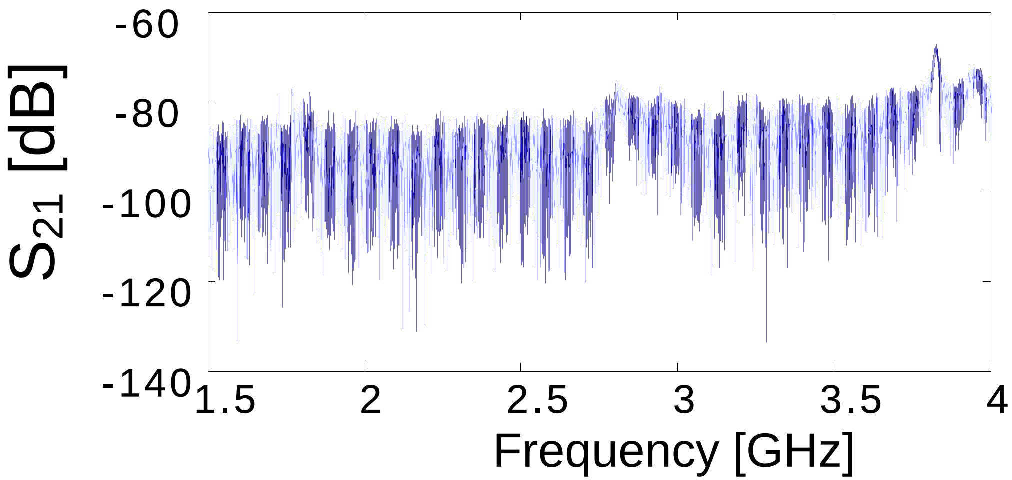
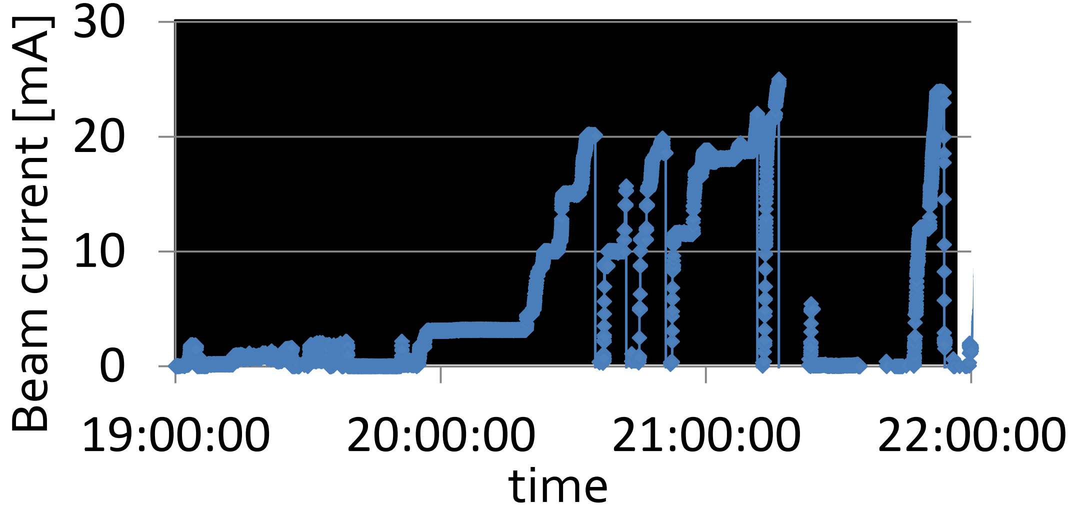
Yes, very well…

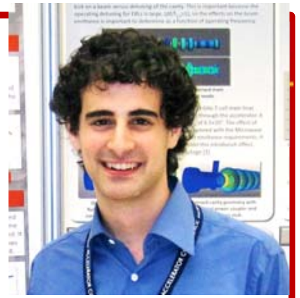
- ✓ **HOM spectra measurements confirm excellent damping with typical Qs of a few 1000**



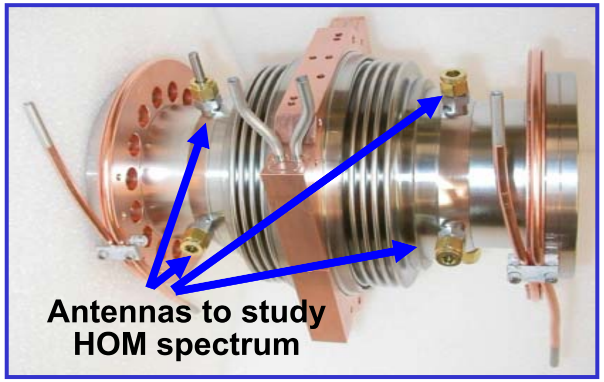
- ✓ **Operated injector SRF module with beam currents of 25 mA**
  - **Measured ΔT very small. → operation at >100 mA feasible (>10* previous record!)**

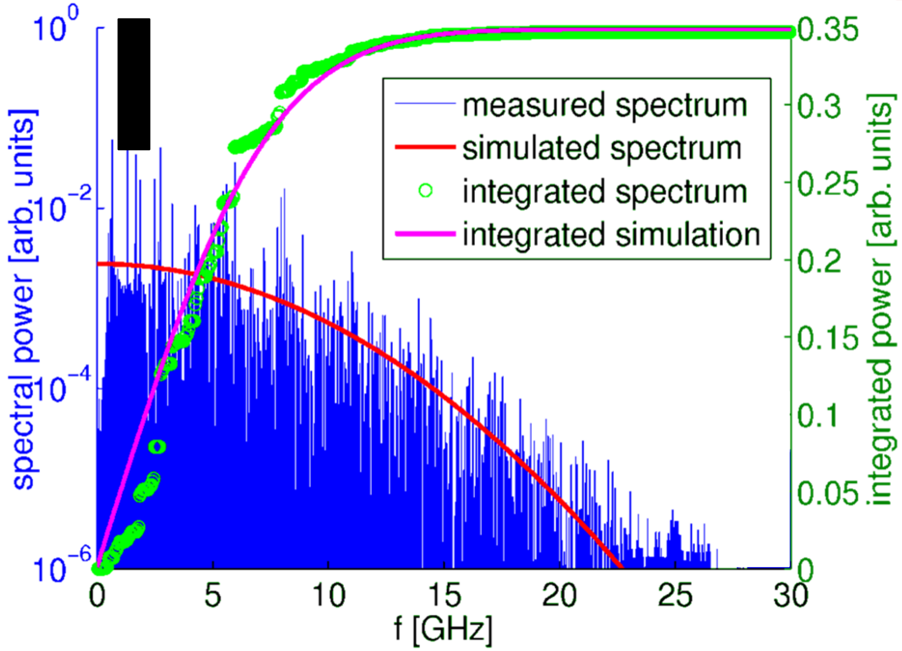


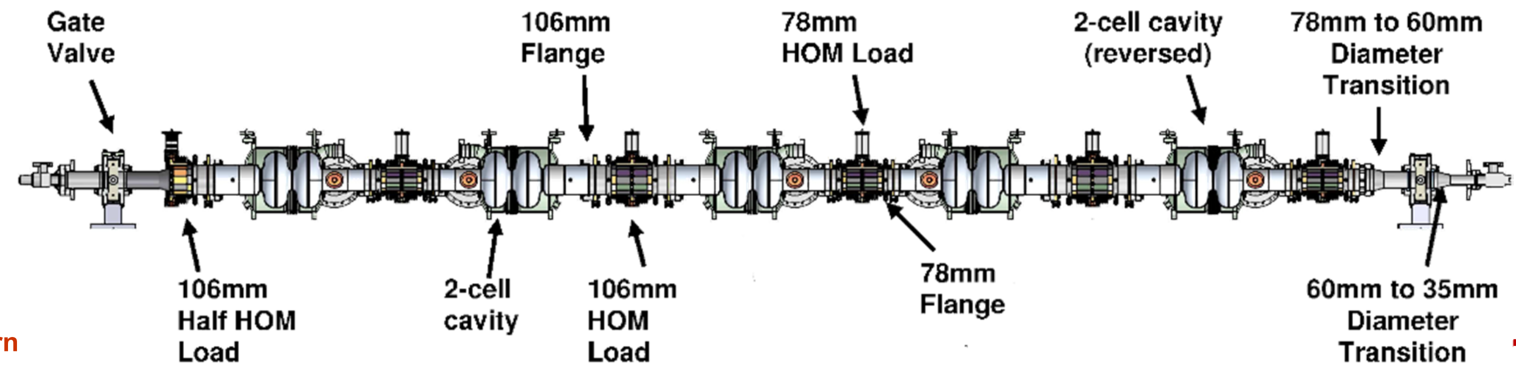
HOM Science



- **What is the spectrum of the beam driven HOMs?**
  - **Simulation and measurements**



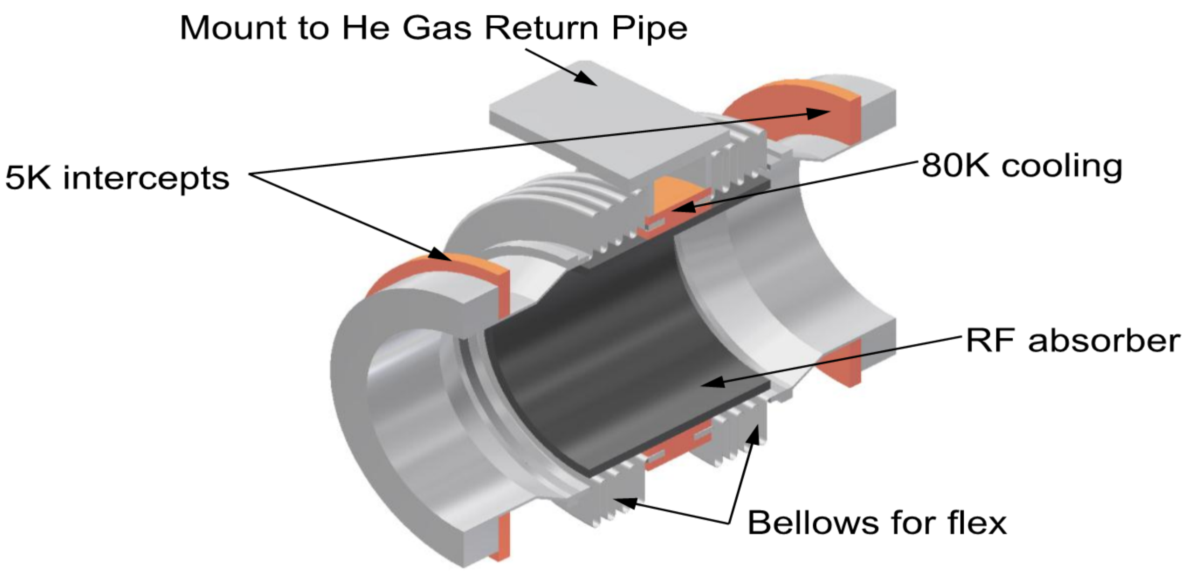




ERL Phase1B progress for SRF

- Engineering design of 7-cell cavity, dumbbells ready, v-test of 1st cavity in Sept.
- Engineering design of 8 HOM absorber, parts ready for brazing
- Concept design and quote for SC quadrupole/corrector/BPM package

- Horizontal test to evaluate midfield Q in early 2012
- Horizontal test with beam for HOM measurements in 2013
  - Incorporate a full-circumference heat sink to allow >500W dissipation @ 80K
  - New beamline flanges, variations of the “Zero Impedance Flange”



Phase 1B ERL protoyping: 2010-2014
Technology development for ERLs (anywhere)

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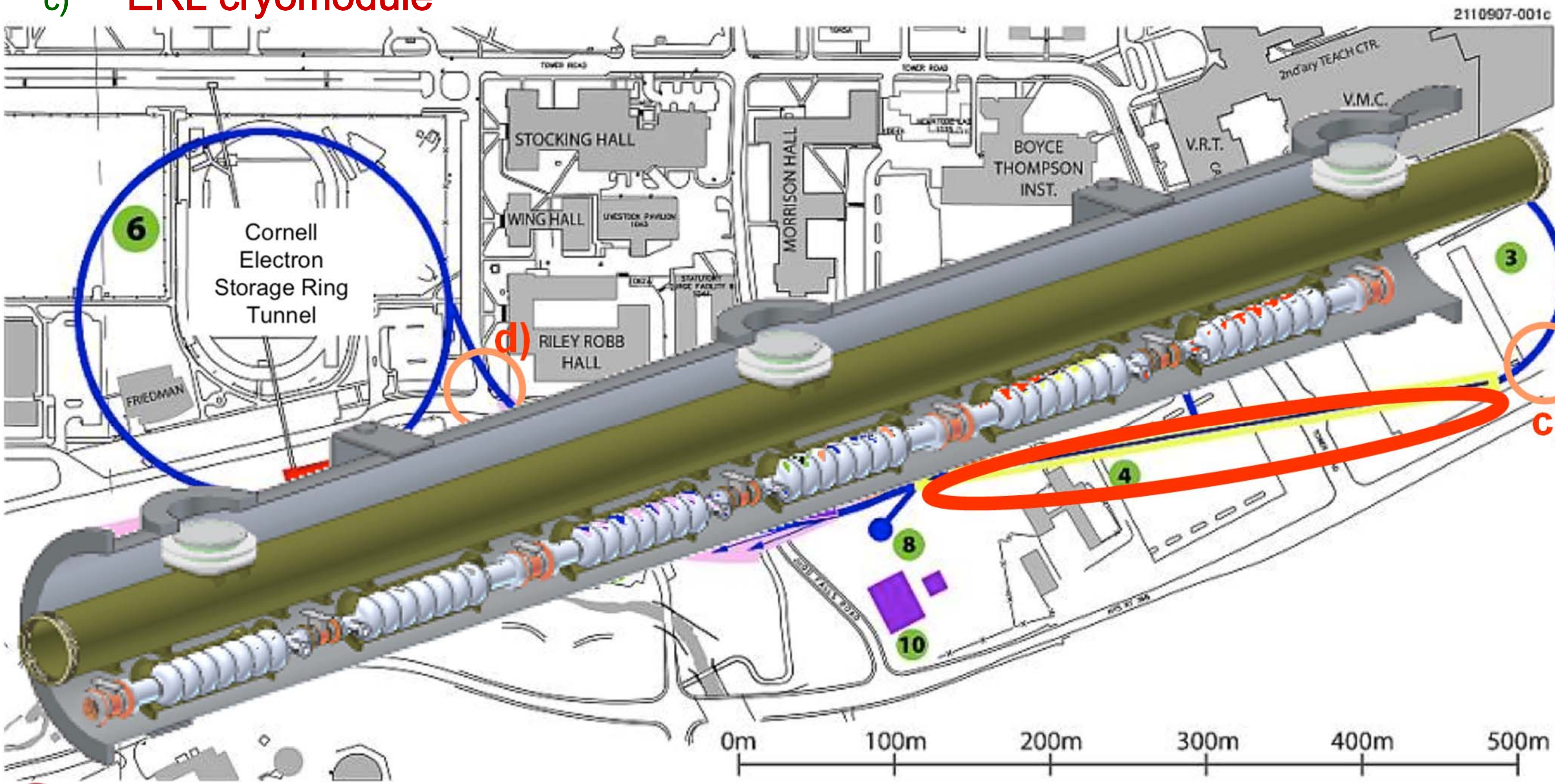
a) Continued Gun R&D
b) High-brightness beam physics
c) ERL cryomodule
d) ERL Undulators
e) Other X-ray beamline R&D



ERL cavity fabrication and measurement

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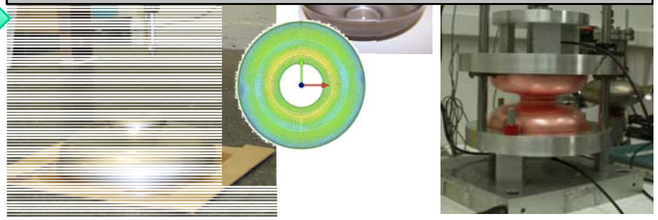
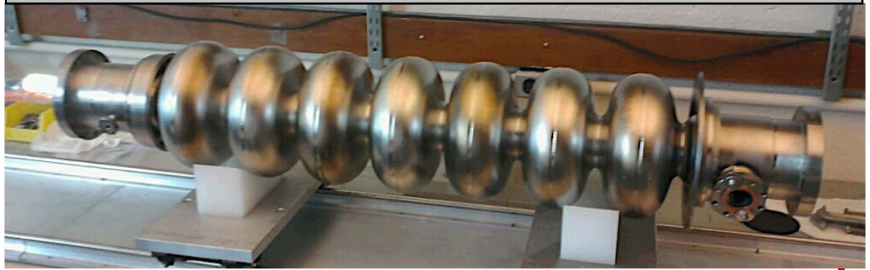
Electron Beam Welding

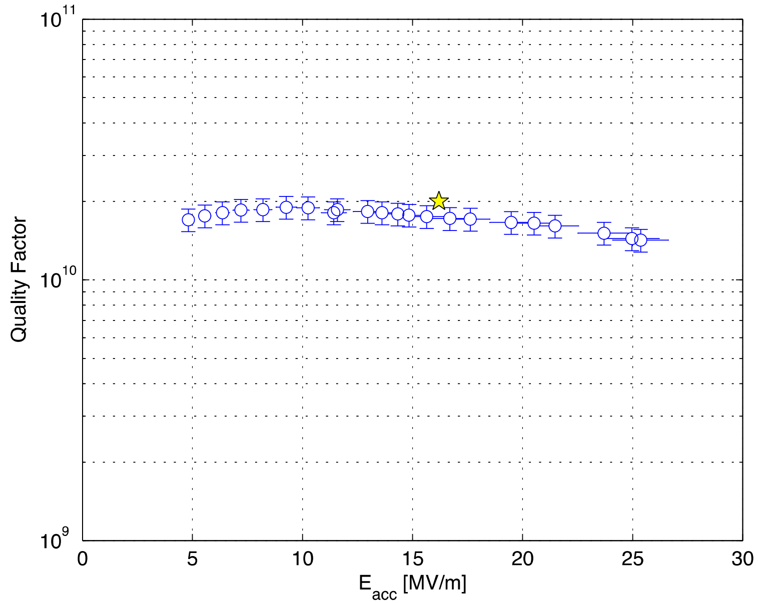
Quality control: CMM and frequency check



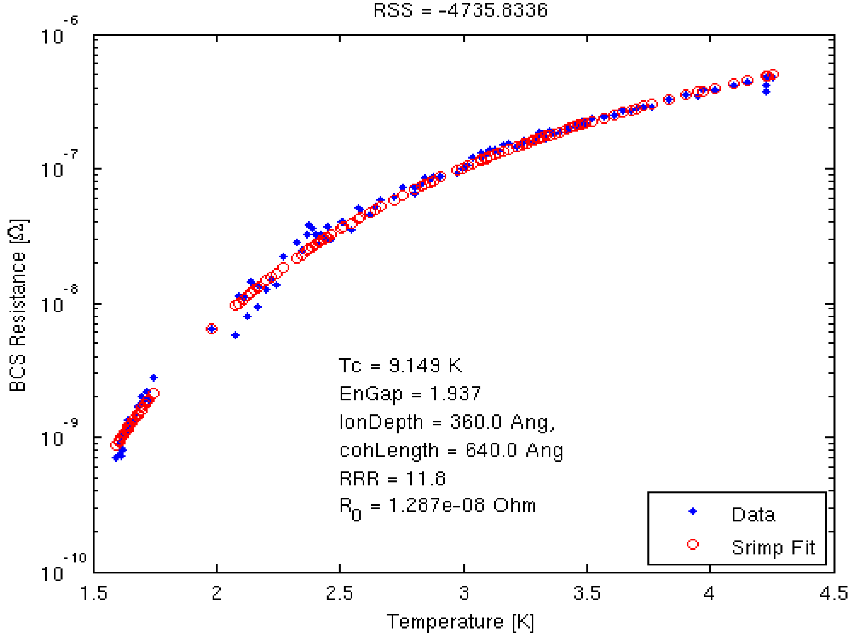
Finished main linac cavity with ±0.25 mm shape precision



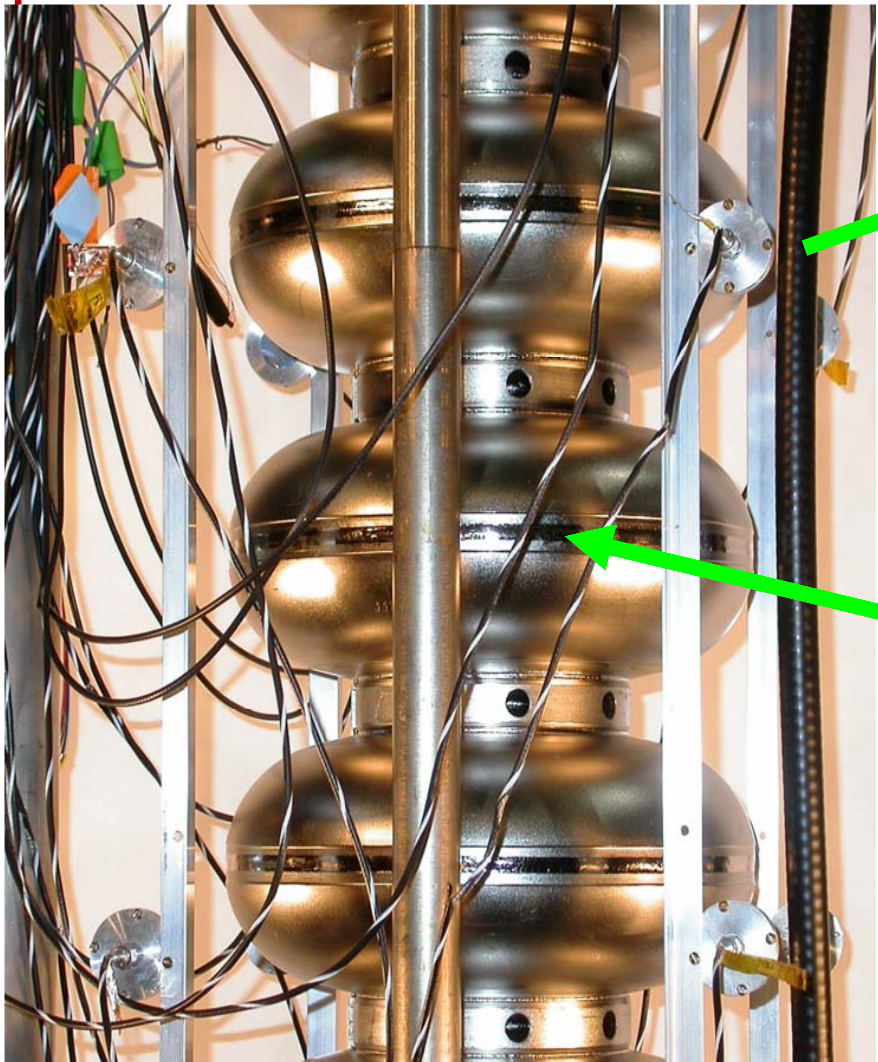
Q vs. E for 1st prototype Cornell ERL cavity

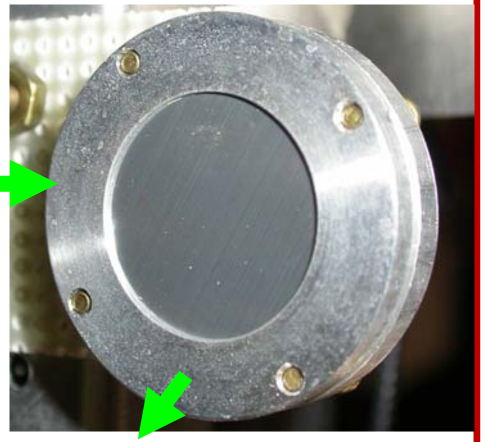


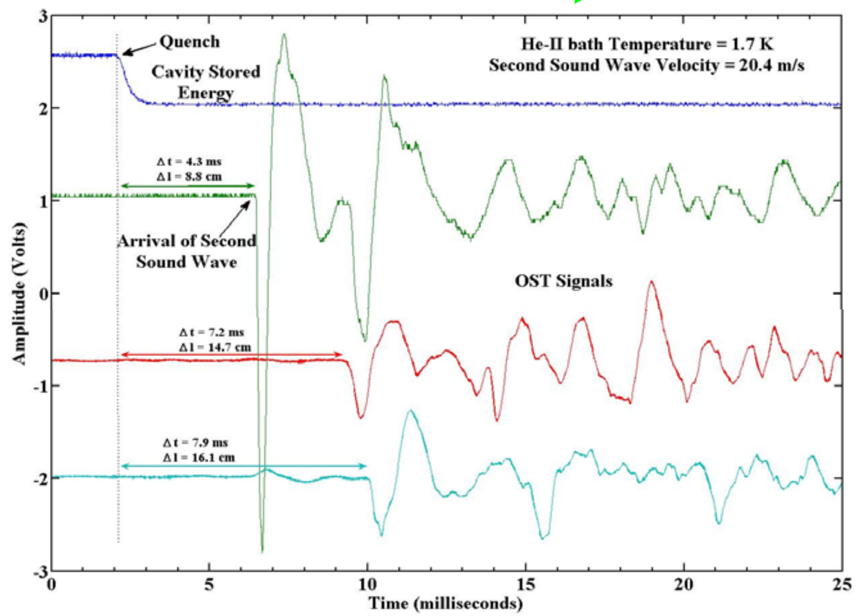
Shrimp fit for Residual resistivity of 13 nOhm



Second Sound Quench Location







From Specs to Finished Cavity

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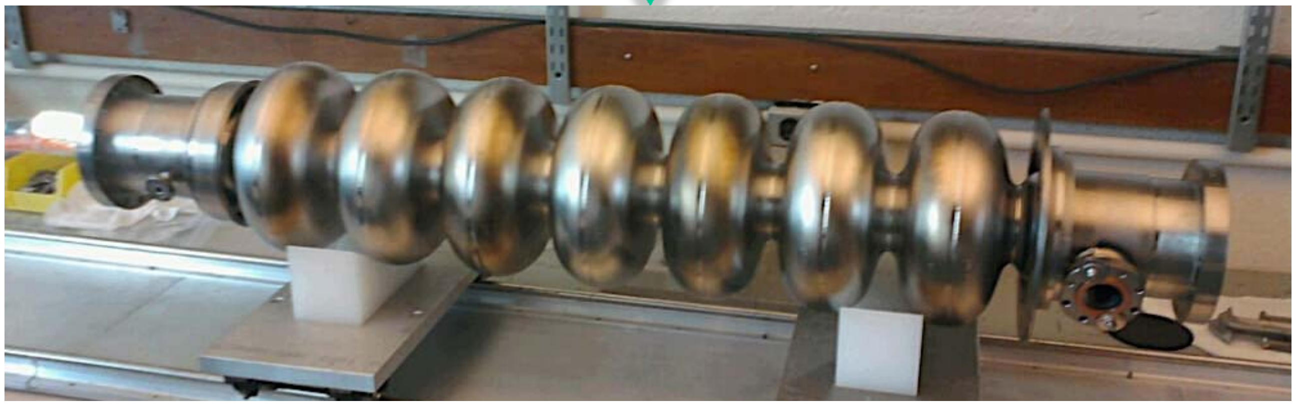
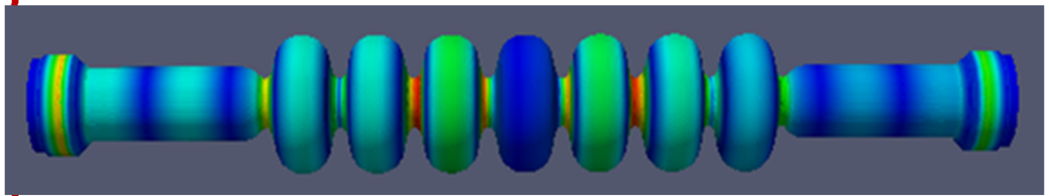
ERL operation with >100 mA, minimize cryogenic wall losses, minimize cavity microphonics (modulation of cavity frequency by mechanical vibrations)

RF design
Mechanical design
Cavity fabrication



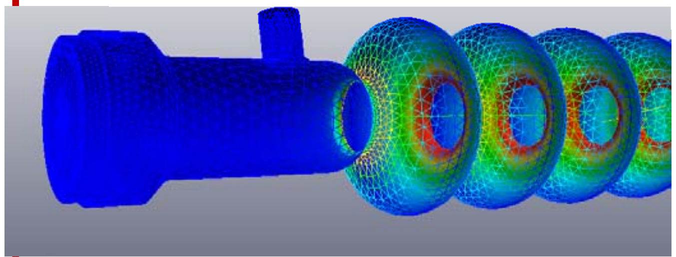
RF Optimization

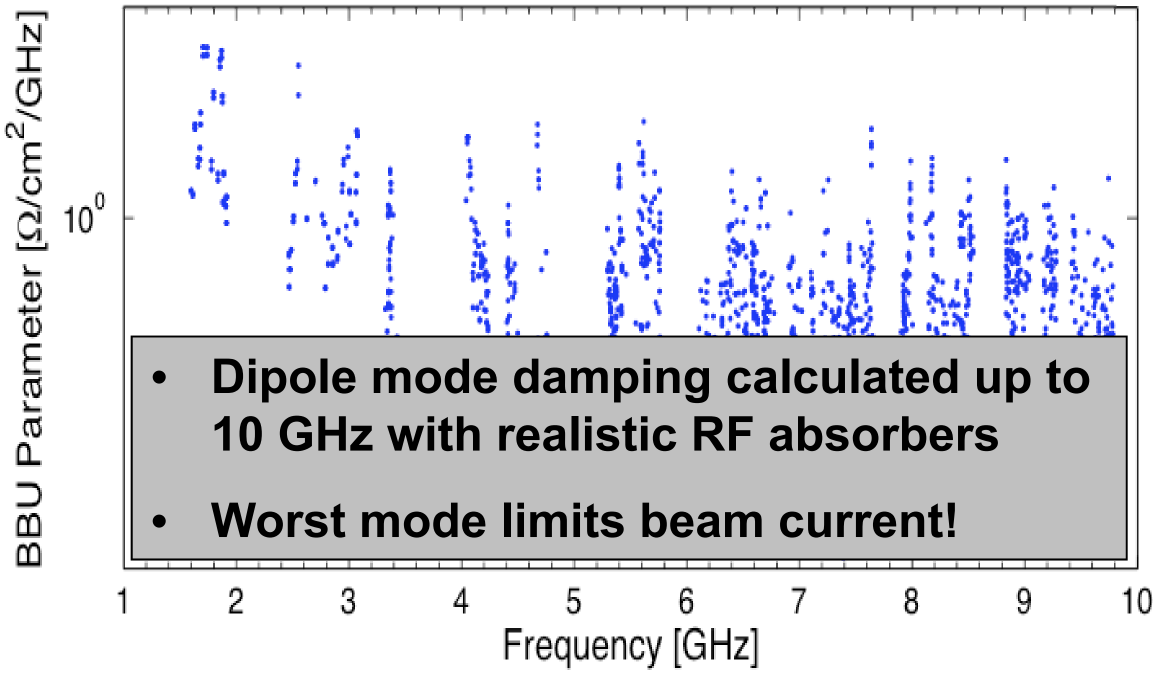


Cell shape optimization

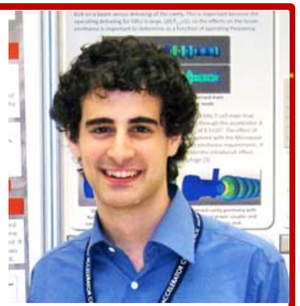
- ~20 free parameters
- 1000's of eigenmodes
- Impact of cell shape errors

-> Supports beam current >400 mA (previous record: 10 mA)

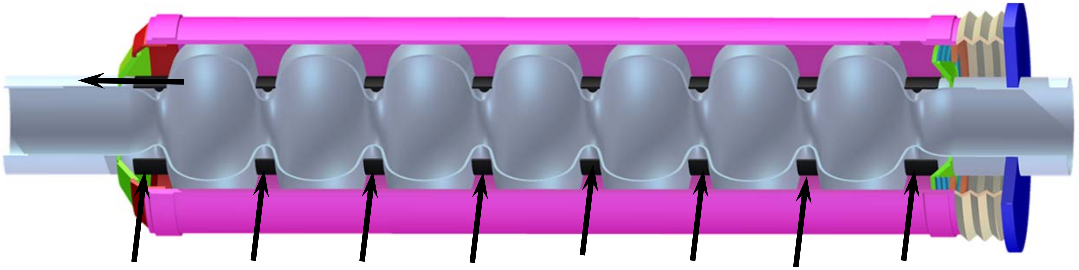




Mechanical Design



Model of Cornell ERL Main Linac Cryomodule

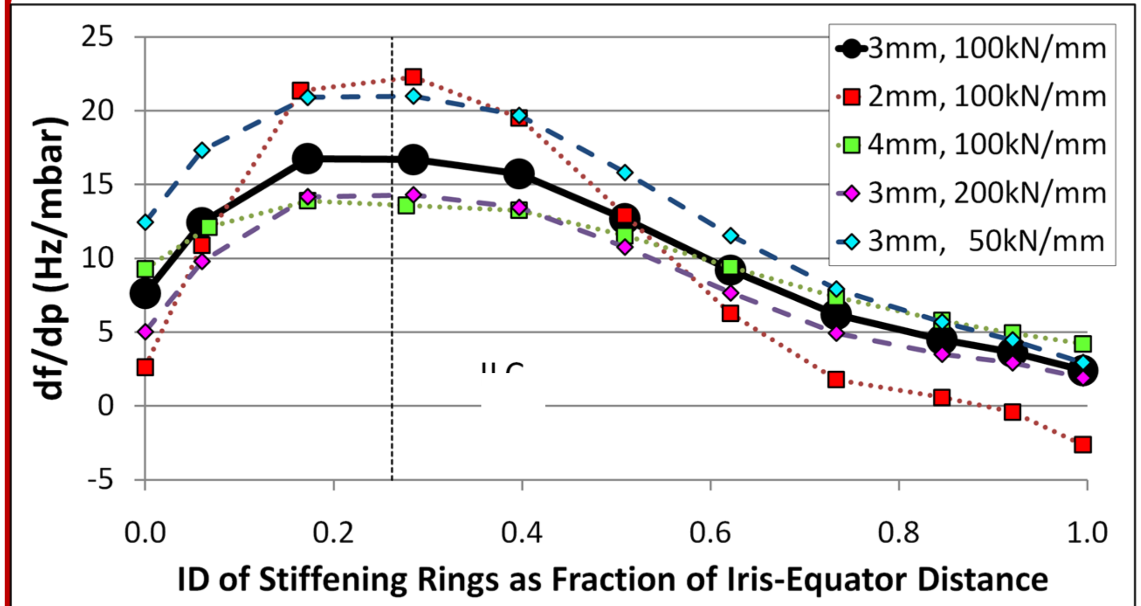


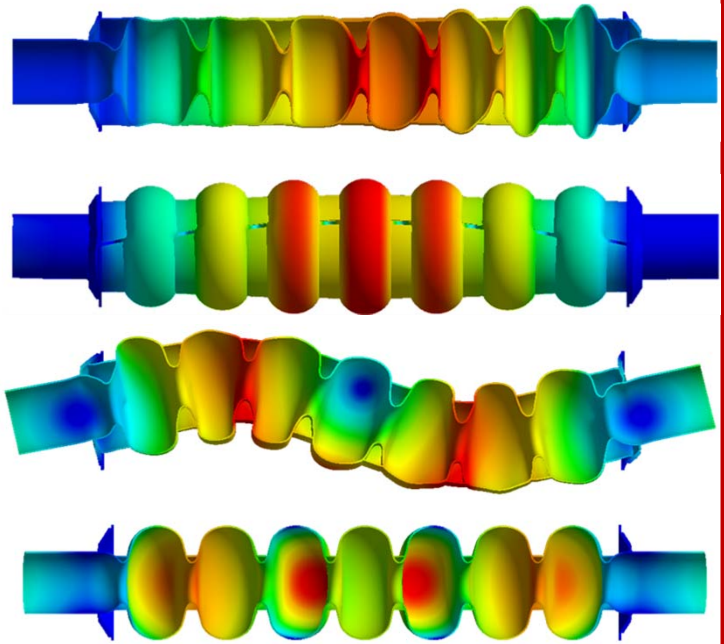
Stiffening rings can vary from ID at iris to OD at equator

Mechanical optimization

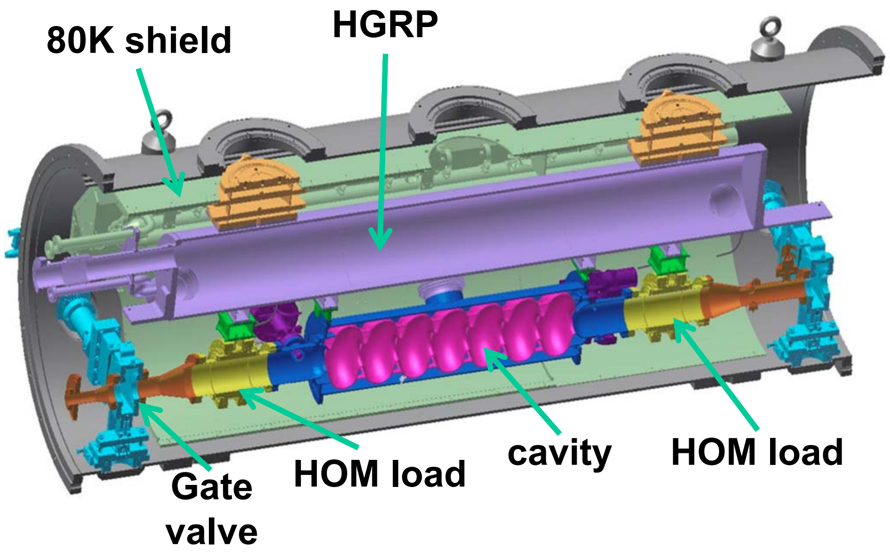
- stiffness and mechanical vibration modes

  -> modulation of f_{RF}

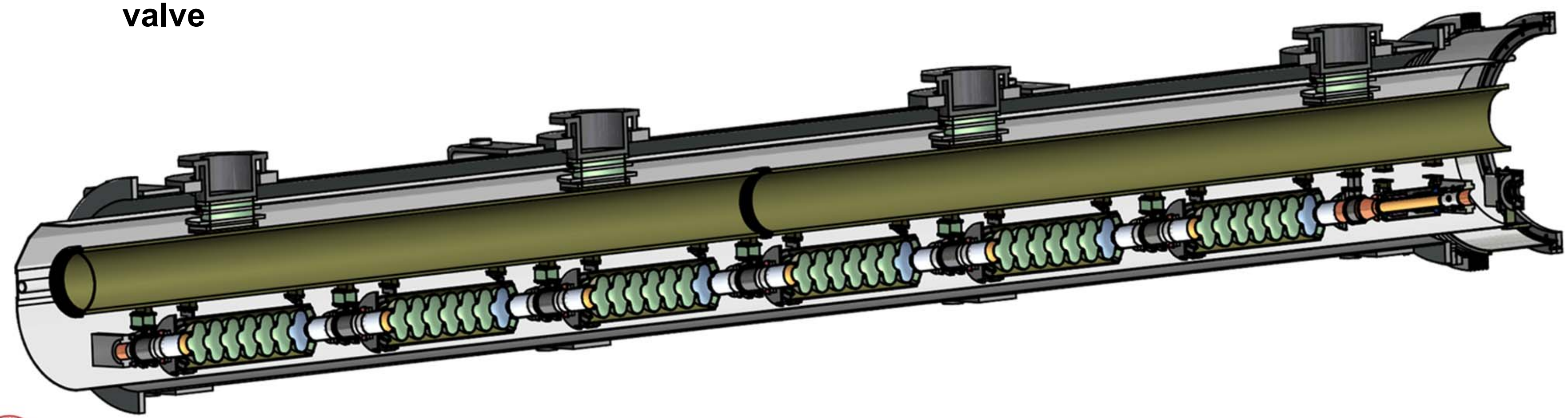




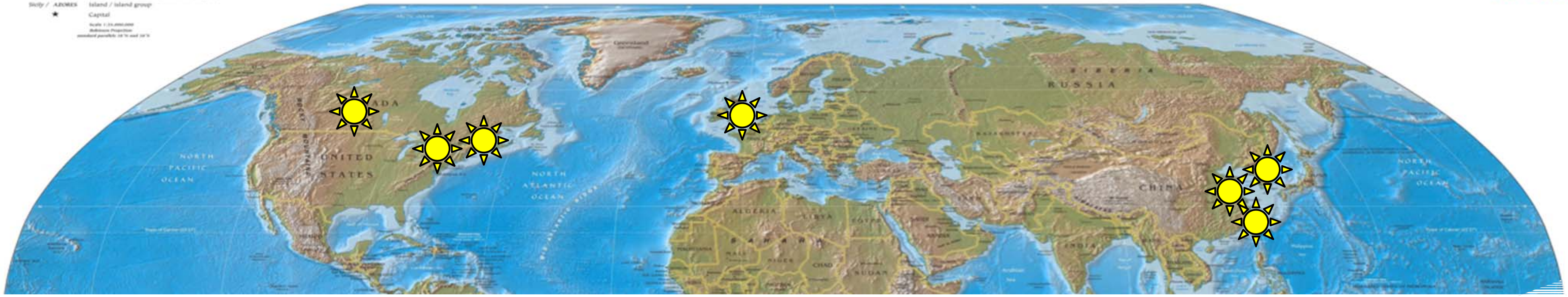
Next Steps: 2011 – 2014



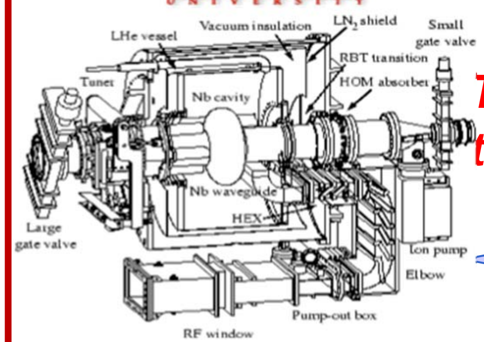
- Test of prototype cavity without and with beam (up to 100 mA)
- Build and test full main linac SRF cryomodule



Example of Industry Connection: Cornell 500MHz cavities



Technology transfer to industry



Technology transfer

Canadian Light Source

TPS Taiwan Photon Source

diamond

SINAP SSRF

1999: Cornell University and ACCEL agreed on technology transfer of the 500MHz SRF module

2000: 2 SRF modules for NSRRC, Taiwan; delivered operational

2000: 2 SRF modules for Cornell, USA; delivered operational

2000: 2 SRF modules for CLS, Canada; delivered operational

2003: 3 SRF modules for DLS, Great Britain; delivered operational

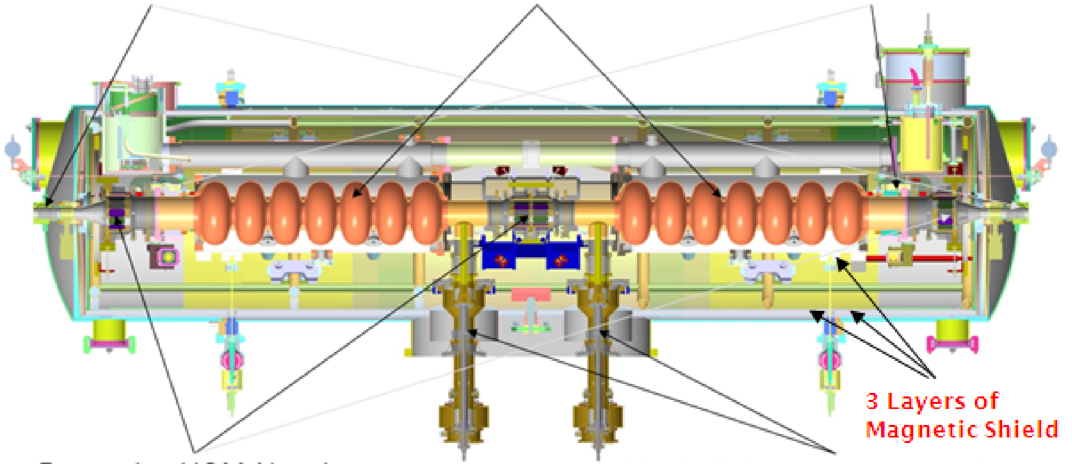
2005: 3 SRF modules for SSRF, China; delivered operational

2010: 2 SRF modules for Pohang light source, Korea; under contract

2010: SRF modules for NSLS-II, USA; bidding won by AES / New York, in technology transfer from Cornell

Intern. CW Cryomodule Collaboration
Host lab: Daresbury

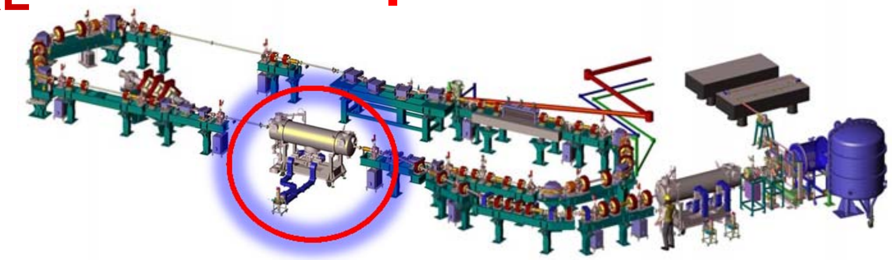
CLASSE



Parameter	Target
Frequency (GHz)	1.3
Cryomodule Length	3.6m
R/Q (Ω)	762
E_{acc} (MV/m)	>20
E_{pk}/E_{acc}	2.23
H_{pk}/E_{acc}	46.9
CM Energy Gain	>32MeV
Q_o	$>10^{10}$
Q_{ext}	4×10^6 - 10^8

- **Collaboration formulated in early 2005 to design and fabricate new CW cryomodule and validate with beam**
- **Dimensioned to fit on the ALICE ERL facility at Daresbury:**
  - **Same cryomodule footprint**
  - **Same cryo/RF interconnects**
  - **'Plug Compatible' with existing cryomodule**

See poster: TUPO013



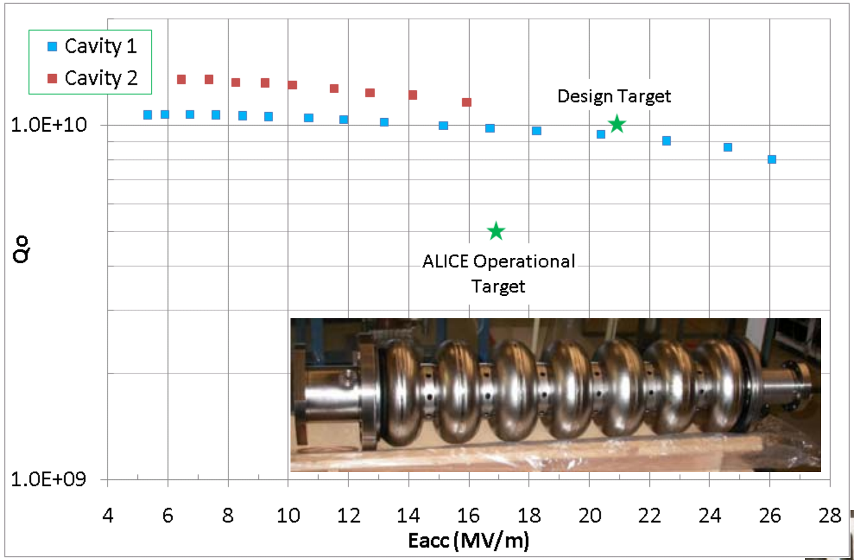
Science & Technology Facilities Council ASTeC

Cornell University

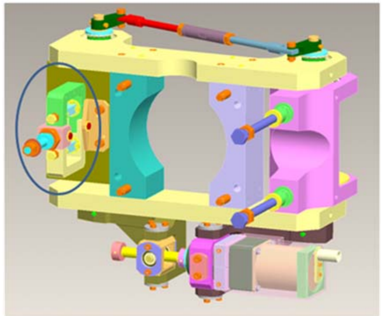
Assembly preparations at Daresbury for the intern. CW cryomodule

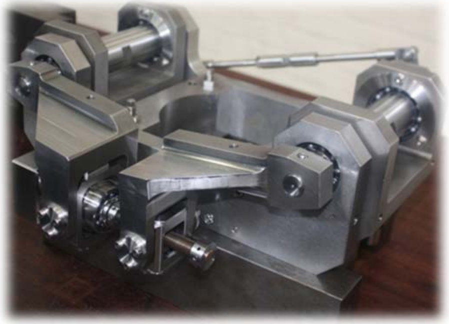
CLASSE

DESY superstructures modified, changed to optimised end groups by Cornell

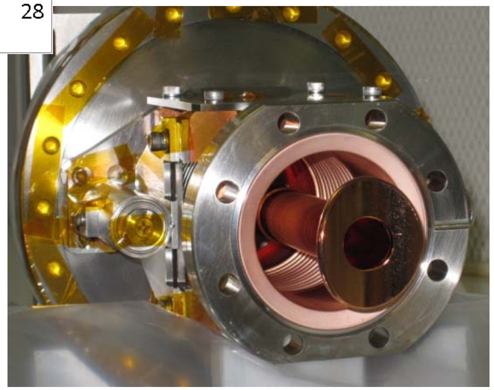


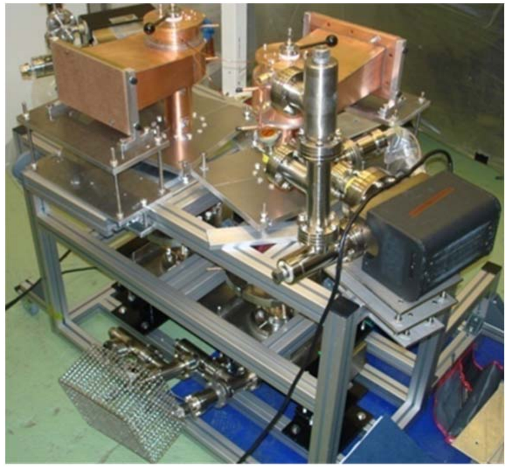
Modified Saclay-II tuner with wider aperture and low voltage piezo cartridges.

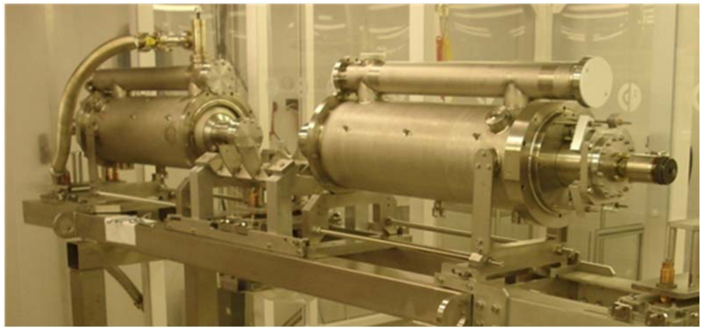




Modified Cornell ERL injector coupler with a shortened cold section.







Cold couplers installed ⇒ awaiting HOM absorbers.
Cryomodule to be ready later this year.

Collaborations

1) MOU with KEK (Tsukuba) who have adopted many of our parameters and designs for their hard x-ray ERL plans – includes SRF collaboration

2) MOU with HMZ (Berlin) on the development of LLRF control for ERLs and exchange of ERL SRF-injector designs.

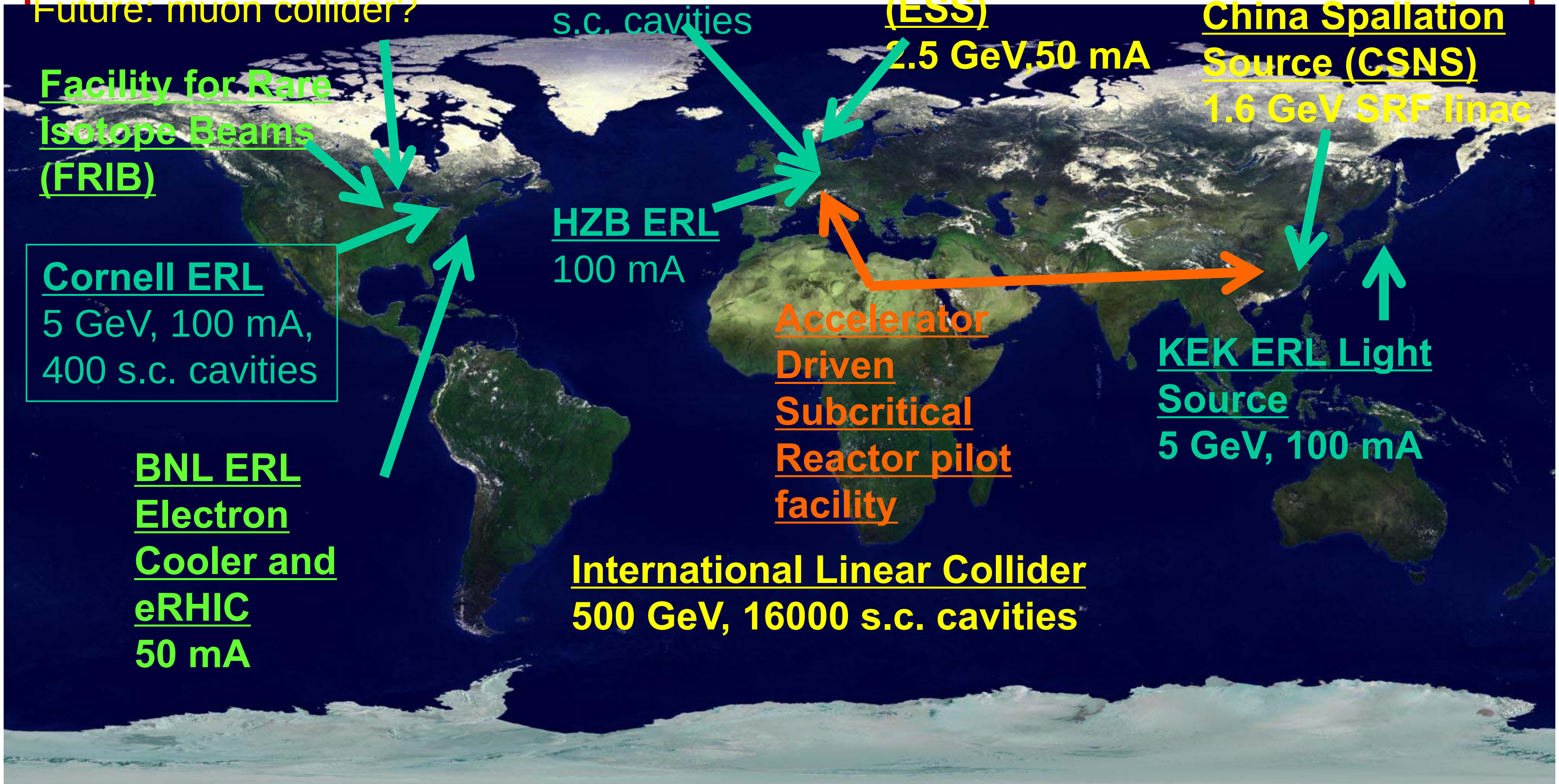
3) Daresbury (UK): International SRF ERL cryomodule collaboration.

4) LBNL: Upcoming collaboration meeting on SRF for the NGLS soft x-ray FEL

5) JLAB: Joint measurements and exchange of students (SRF control and BBU)

6) TRIUMF (Vancouver): Exchange of ERL SRF hardware and injector designs.

Future SRF Driven Accelerators



END