Developing Facilities For SNS Cryomodule Performance Improvements

J. Mammosser

Managed by UT-Battelle
for the Department of Energy

Outline:

- **History of SRF Facilities at SNS**
- **Current Facility Status**
- **Linac Component Activation**
- **Results of Cryomodule Repairs**
- **Near Term Plans**
- **Addressing Pressure Vessel Code**

SNS SRF Facilities History

- **During the construction phase**
  - **Cryomodules were fabricated by Thomas Jefferson National Accelerator Facility (JLab), shipped to SNS, installed and commissioned in the linac**
  - **Plans at that time were to build full SRF facilities**
    - **This was delayed due to funding**
    - **Focus was on commissioning and gaining operational experience**
  - **RF test facility building completed**
    - **RF test facility test cave was installed but not operational**
    - **Di water plant**
    - **Portable cleanroom installed and subcomponent cleaning work area**

SNS SRF Facility History

- **Operating the Superconducting Linac (SCL)**
  - **Several limitations became known from operational experience**
    - **HOM coupler multipacting, strange signals**
    - **High fundamental power coupling out HOM ports**
    - **Field emission and multipacting in cavities**
  - **Focus was now on understanding operational set points**
    - **Need was to develop an understanding of the cavities collective behavior**
  - **Operational knowledge was gained**

Cryomodules are now one of the most stable elements in the accelerator!!

SNS SRF Facility History

- **Now that the SCL was operating fine**
  - **Focus was on repairing some cavities that were identified with operational problems**

→ Some typical type repairs and others more difficult to address

3 Cavities with HOM coupler issues

1 Cavity with tuner showing excessive motor movement

1 Cavity with noisy field probe signal

- **New facilities Were Installed at This Time**
  - **Cleanroom installed**
  - **RF test facility becomes operational**

SNS SRF Facility History

- **Focus now on In-situ Repairs to Cryomodules**

  Removal from tunnel

  - **Cryomodule 19 (Fundamental Power → HOM) removed, repaired and installed**
  - **Cryomodule 12 (Beamline Leak) removed, repairs underway**

  Repairs in Tunnel

  - **Cryomodule 10 July 08**
  - **Cryomodule 09 July 08**
  - **Cryomodule 11 January 09**

- **Spare Cryomodules Now Underway**
  - **JLab collaboration → qualification of first HB cavities completed**
  - **Need for facilities is aimed at supporting installed Linac Cryomodules**

SRF Facility Status:

- **New DI water plant procured**
- **HPR System Design Completed**
  - **Pump / electronics procured**
- **Vertical Test Pit civil design complete**
- **Power Upgrade Plan (PUP) Facilities**
  - **Test Cave cryogenic support facility identified**
    - **Separate refrigerator to support test cave and vertical dewar operations**
    - **Return transfer line**
- **Cavity plasma cleaning system fabricated**

SRF Facility - Cavity Qualification	Classification	Details
Cleanroom		
Small part cleaning/degreasing Cleanroom- String assembly Cleanroom – Cavity assembly	ISO 7 (M 5.5) ISO 5 (M 3.5) ISO 4 (M 2.5)	$58m^2$ $58m^2$ $2.5m^2$
	RF tuning station	Received Cavity tooling needed
*DI water Plant		
	E-1	2268 liter storage, 38 liter makeup Installation November!
*High Pressure Rinse Station		
	Wand Nozzles Pump	Rotates and translates Water Fanjets - 2 opposed Nitrogen gas Fanjets 2 opposed LEWA Teflon diaphragm -15 lpm Design Complete!
*Vertical Test Facility		
	Dewar Cryogenic source	Depth -3.35m Diameter – 71.1cm **Separate helium refrigerator Design Complete!

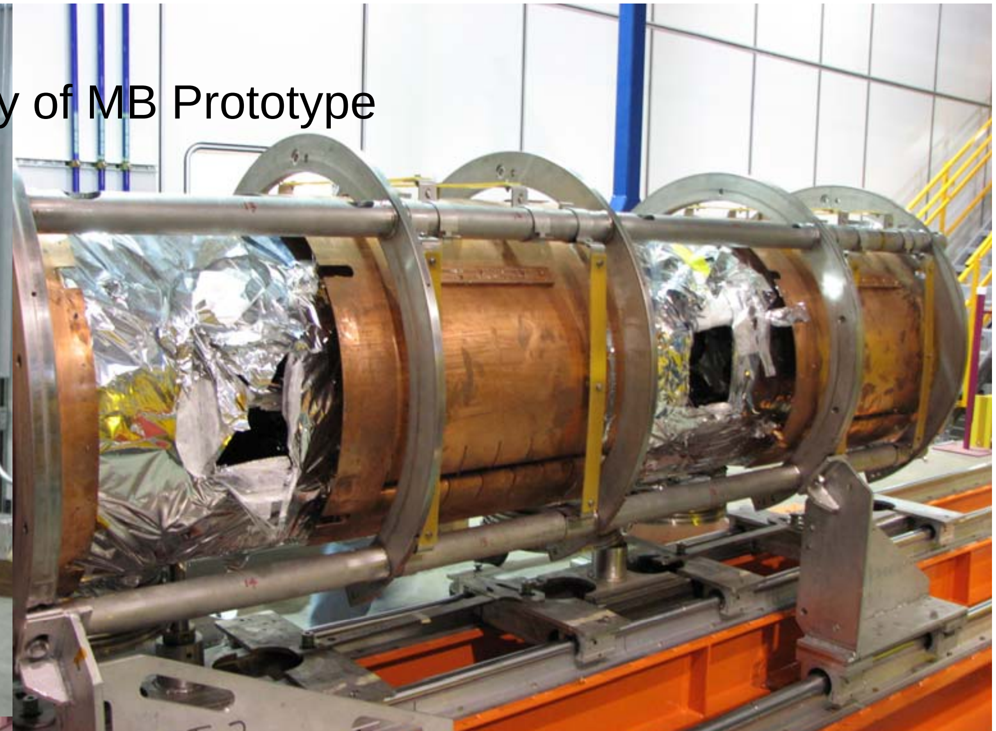
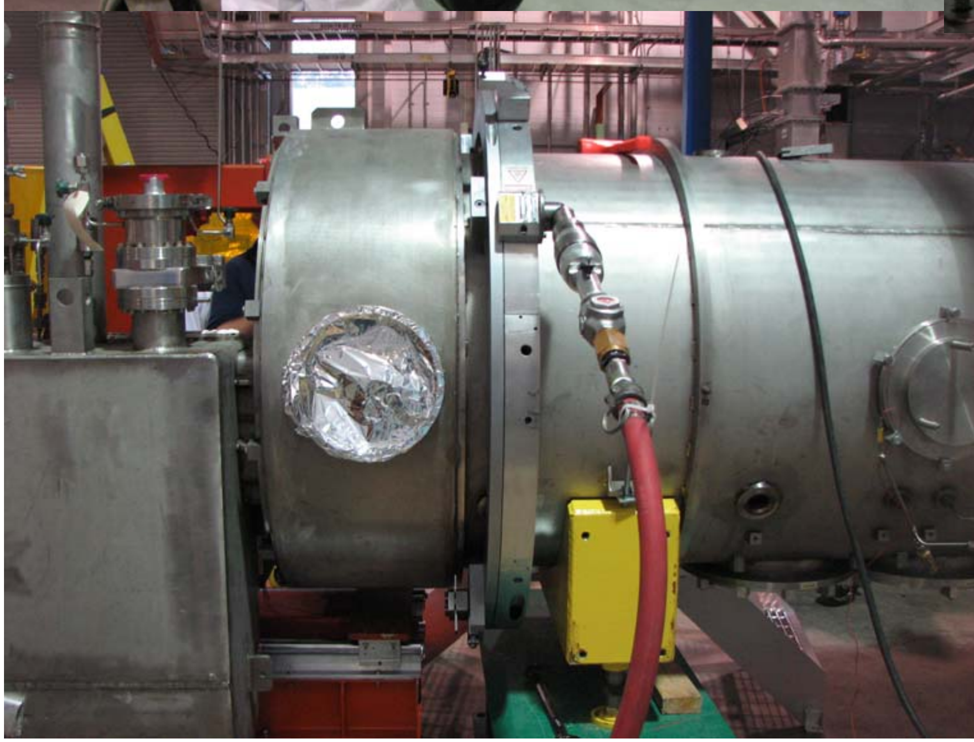
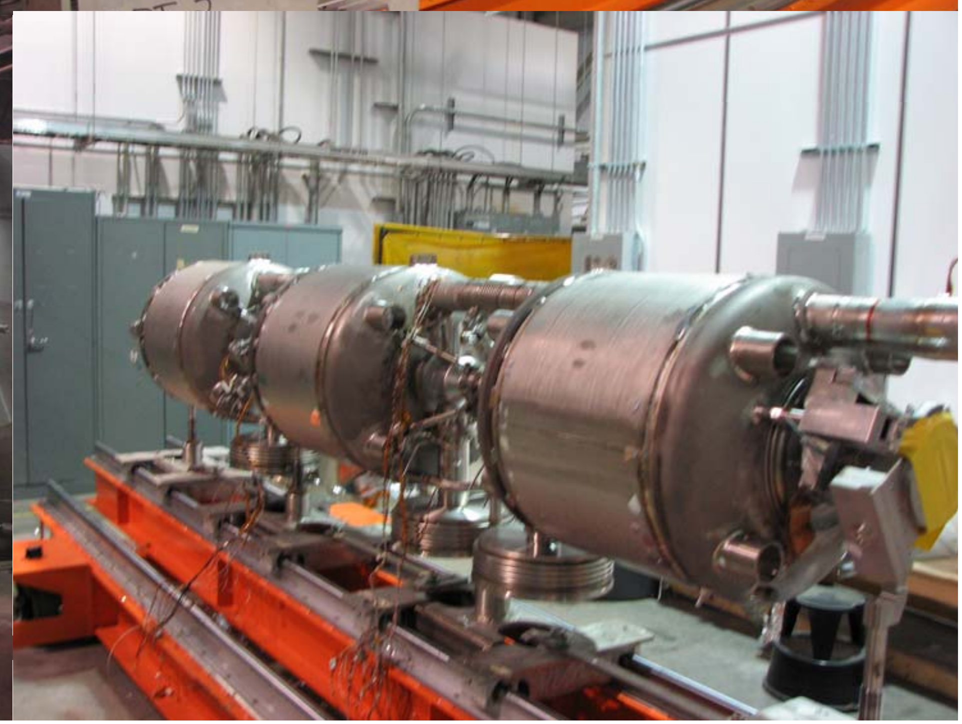
SRF Facility - Cryomodule Fabrication	Classification	Details
Module Fabrication		
Assembly Tooling	String tooling Transfer tooling Module tooling	All tooling in-house
Cryomodule Test Facility		
	Space Cryogenic Connections	11m x 4m Supply transfer line Shield transfer line **Return transfer line
	**Test Facility Refrigerator	200W 2K 200W Shield

Power Upgrade Plan!

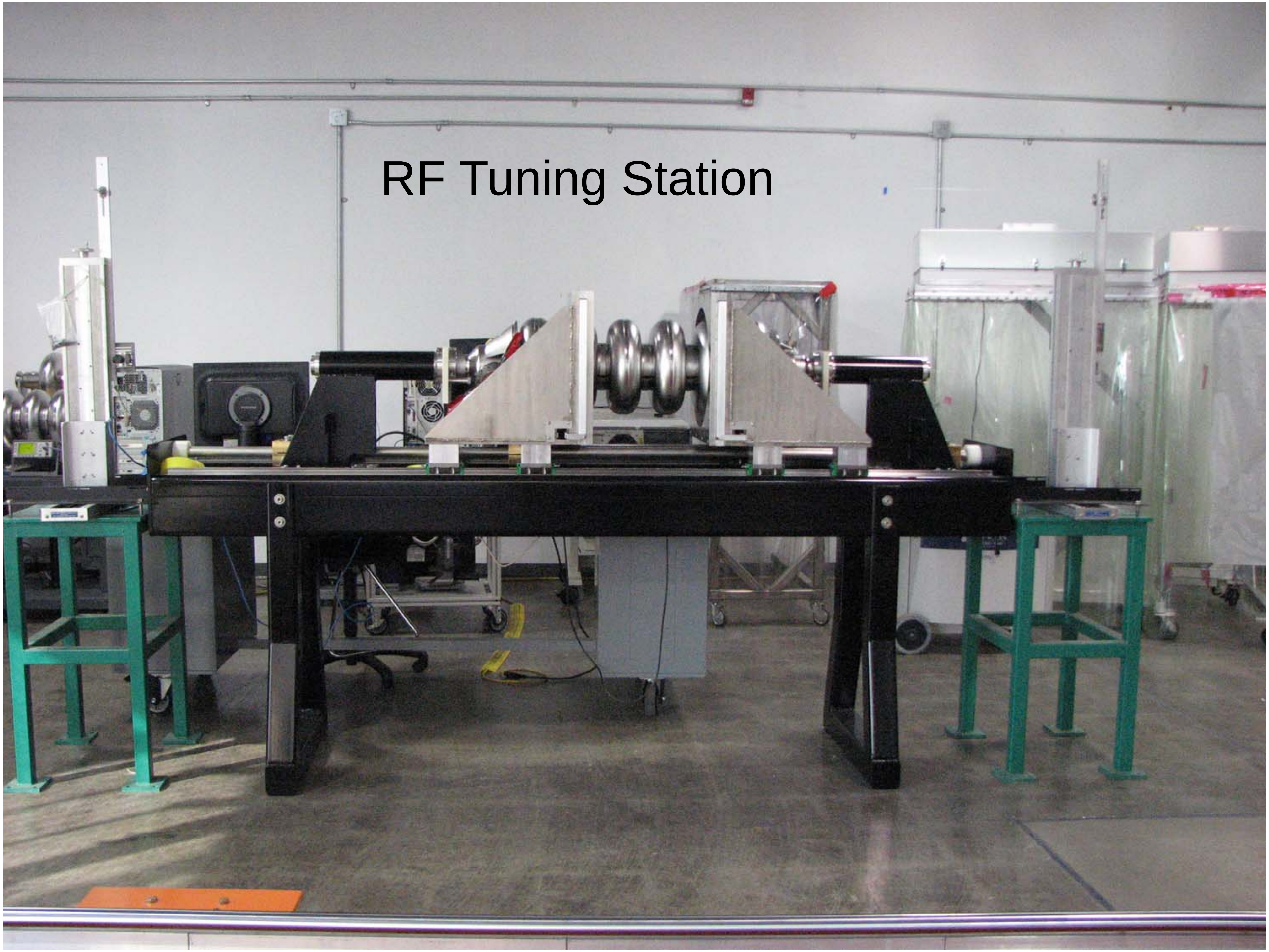
- **Cleanroom entry**
- **Class 10,000 area**
- **Small part cleaning**
- **Ultrasonic cleaning**


Class 100 area used for
Cryomodule repairs

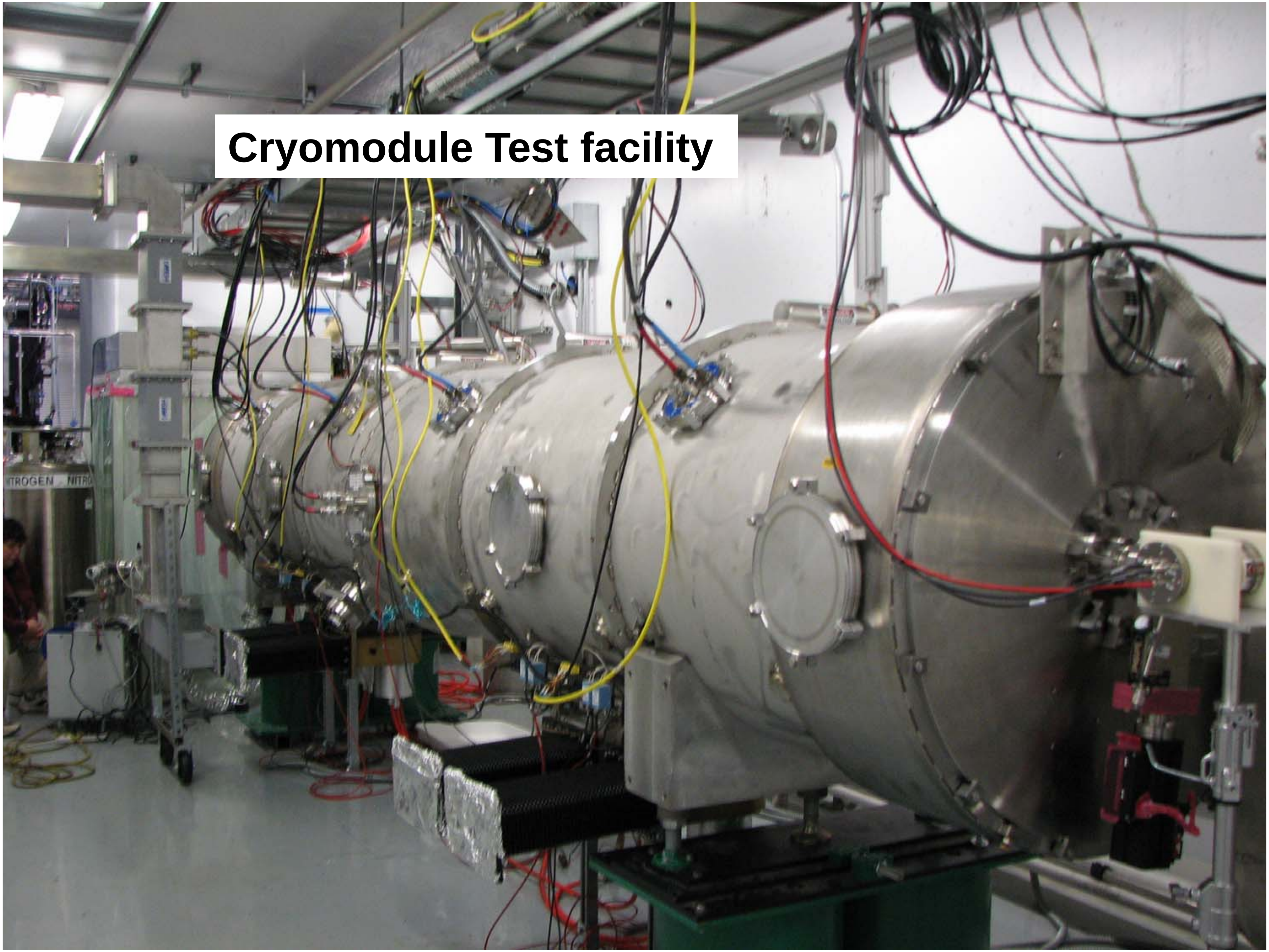
Cryomodule Disassembly of MB Prototype

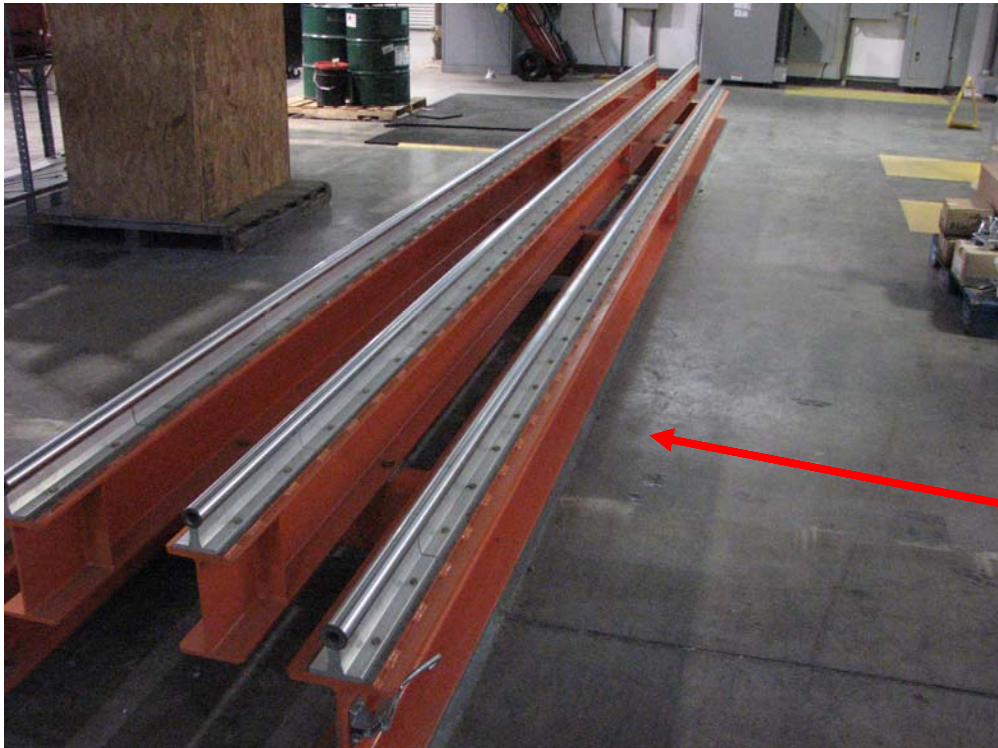





RF Tuning Station



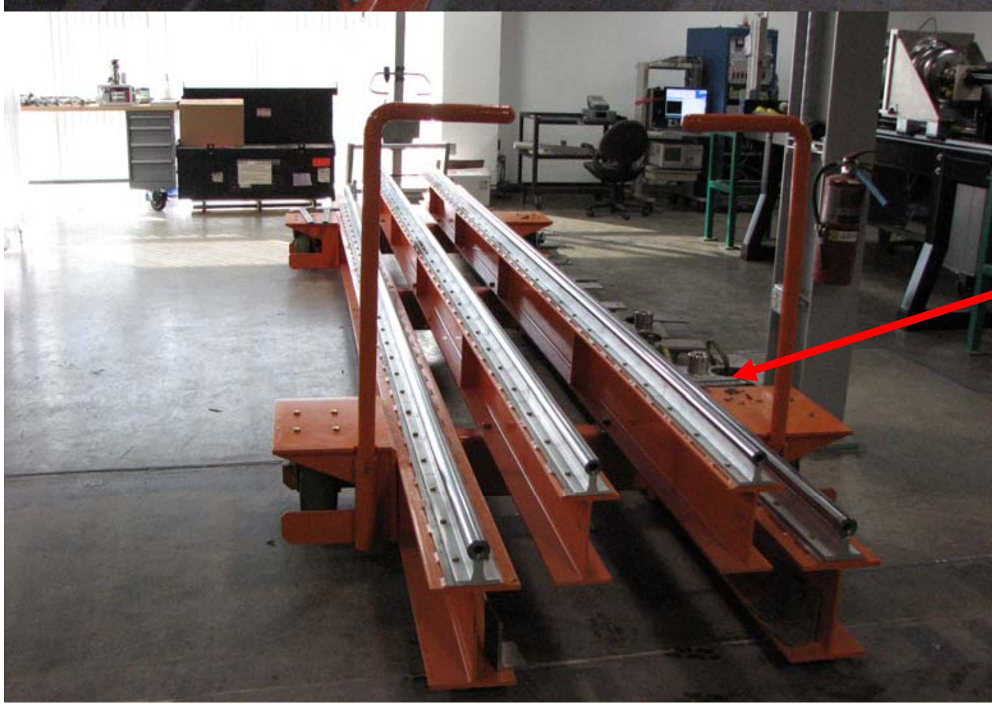
Cryomodule Test facility





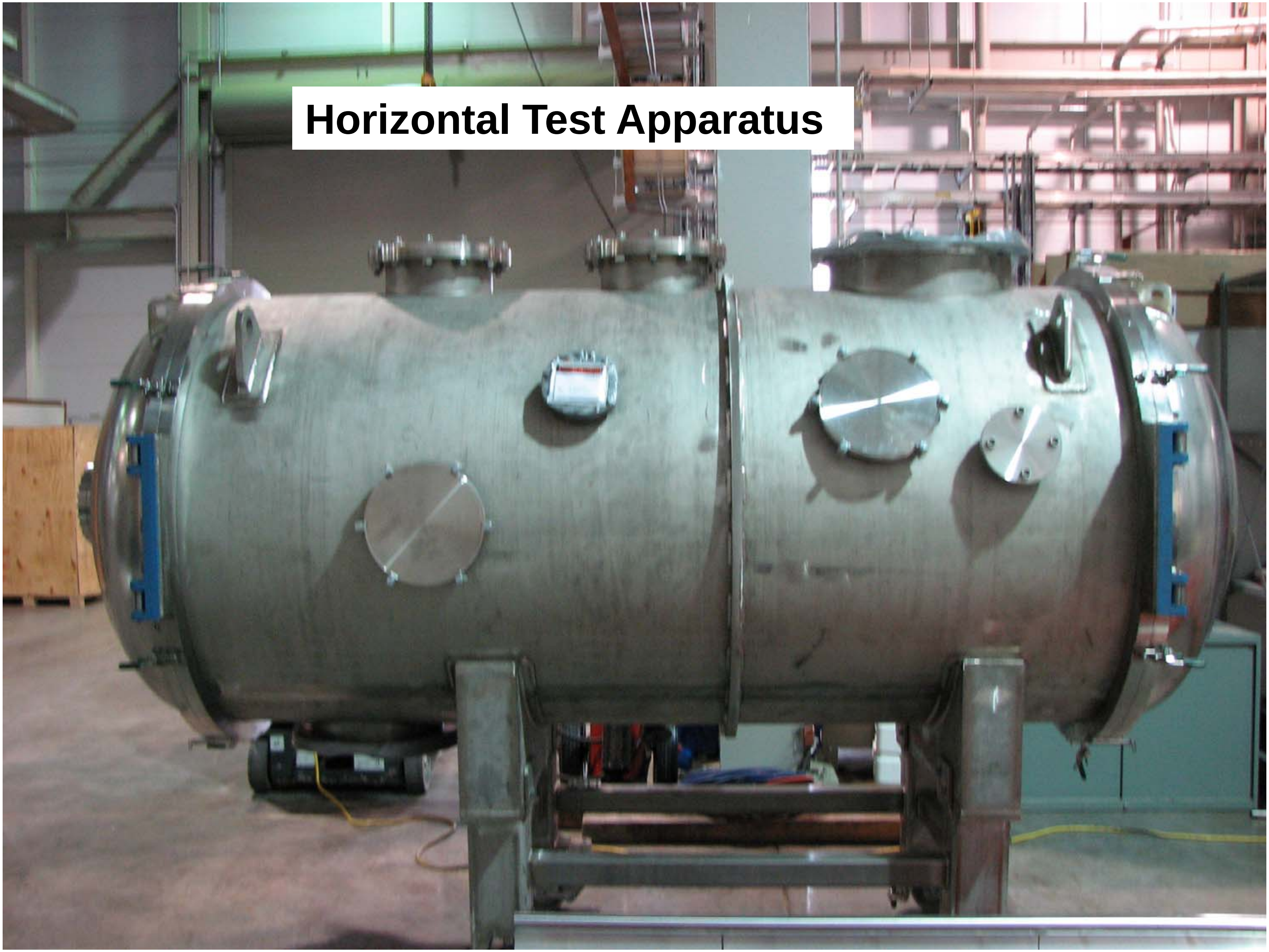
- **Tooling for building spare Cryomodules**

Fixed Rail

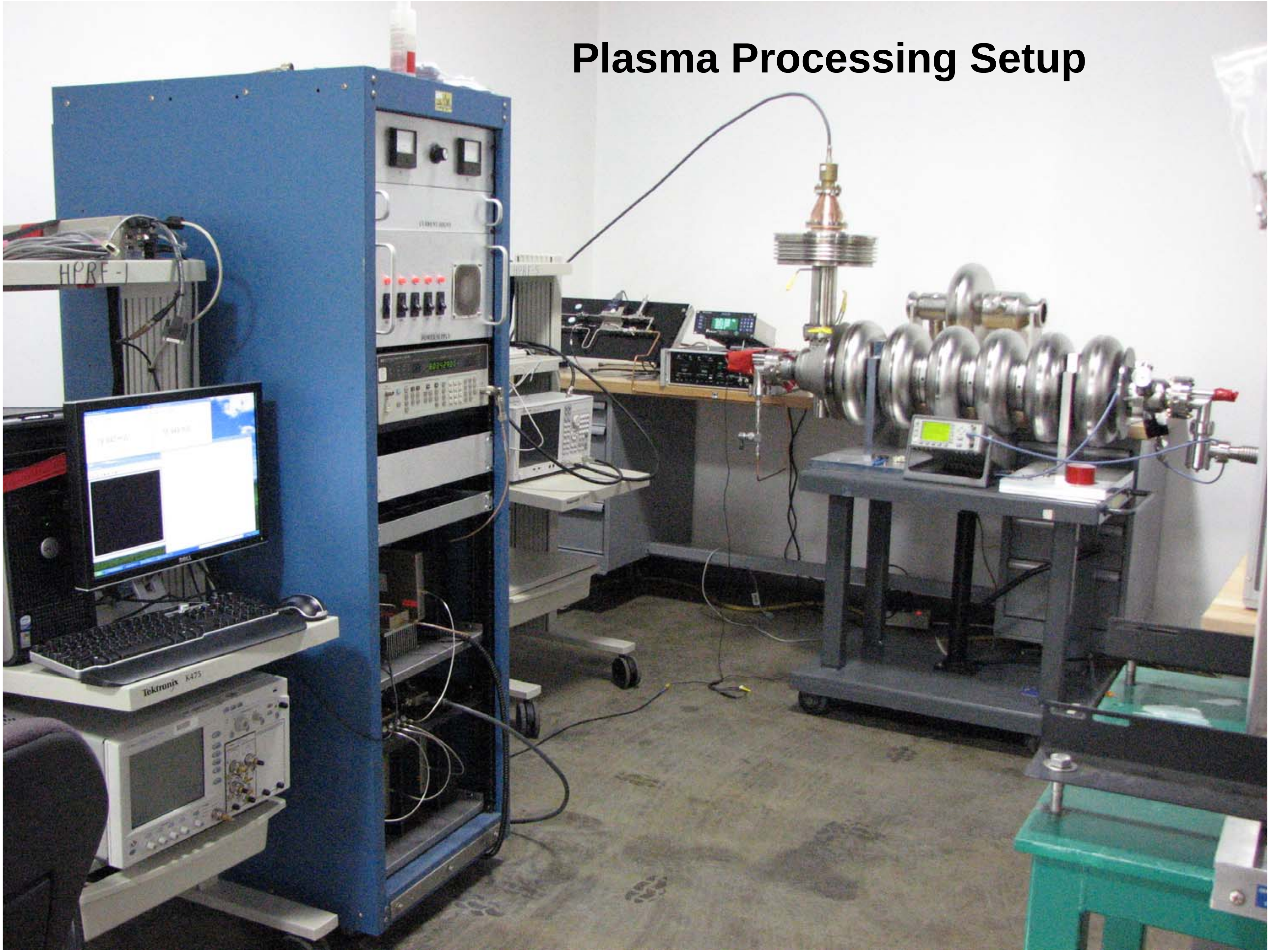


Transfer Cart

Horizontal Test Apparatus

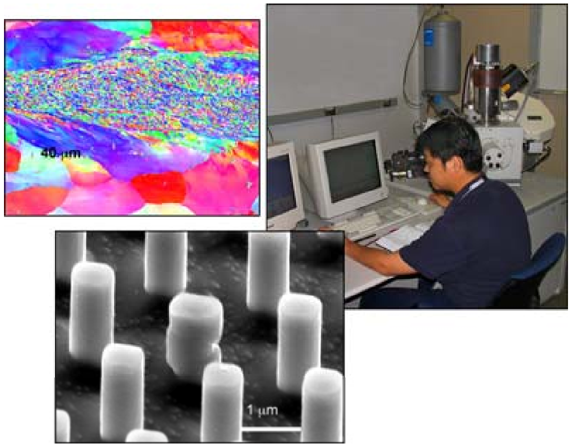


Plasma Processing Setup



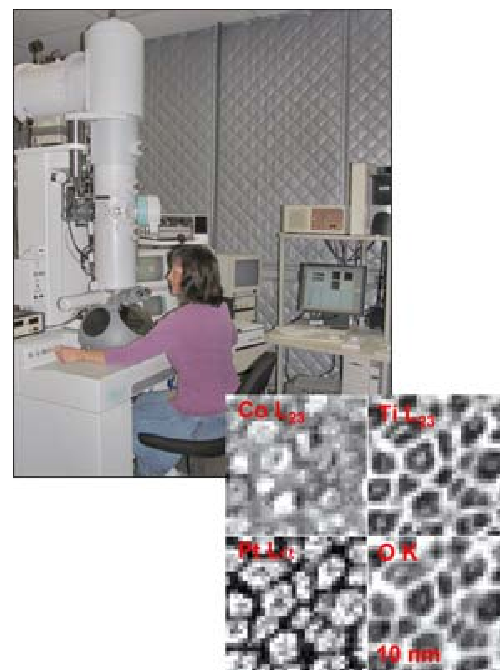
ORNL SHARE Program

Philips XL30 FEG-SEM

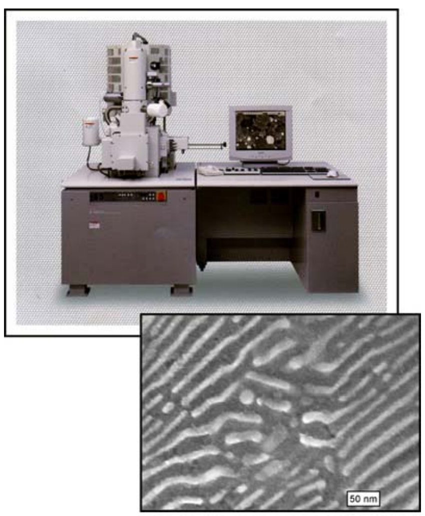


Thermo Scientific K-Alpha X- Ray Photo XPS1

CM200-FEG TEM-STEM



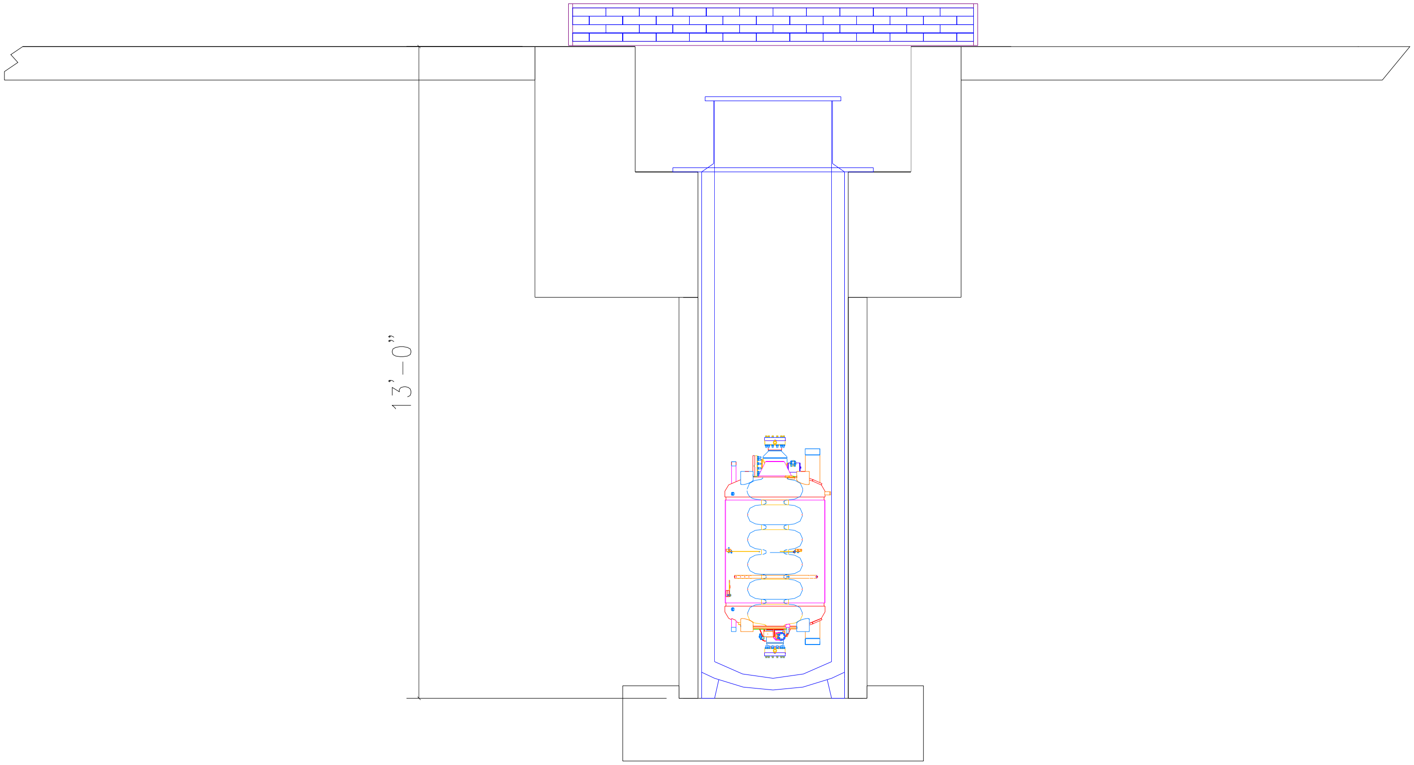
Hitachi S4800 high resolution SEM



Y_2O_3 platelets in an internally oxidized $Fe_{17}Y_2$ alloy

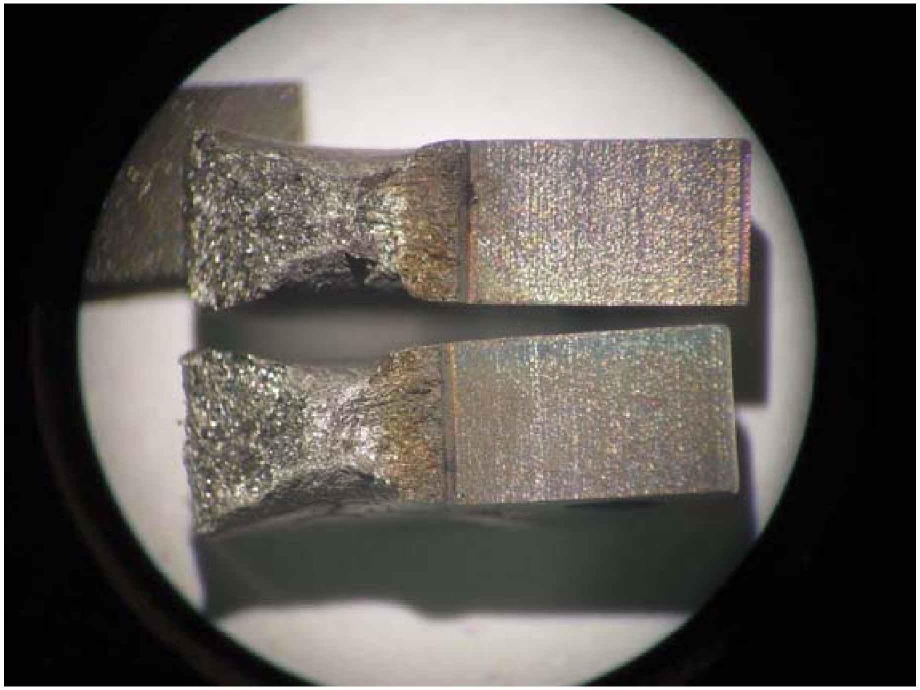
Vertical Dewar Concept

- **Civil Construction Design Completed !!**

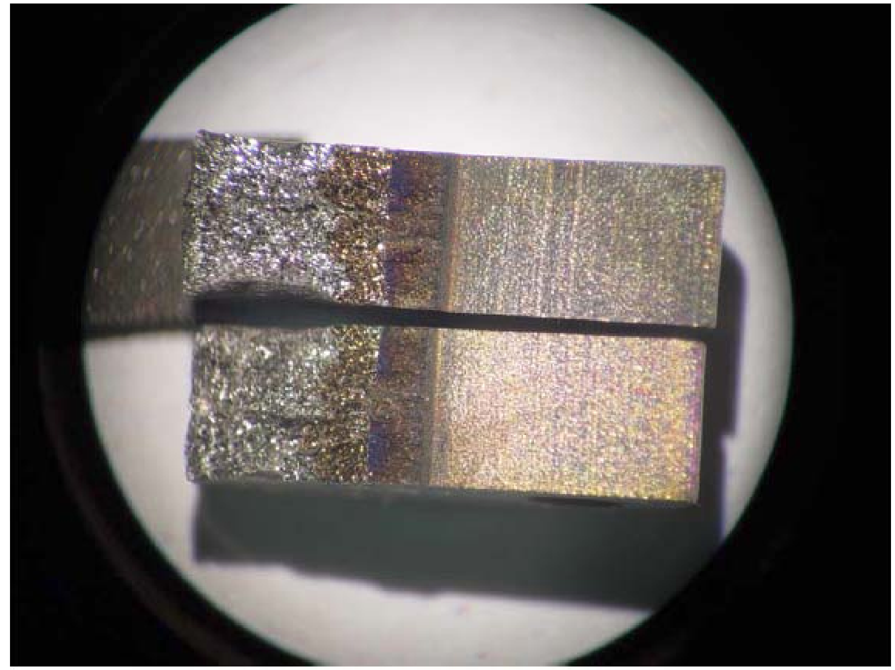


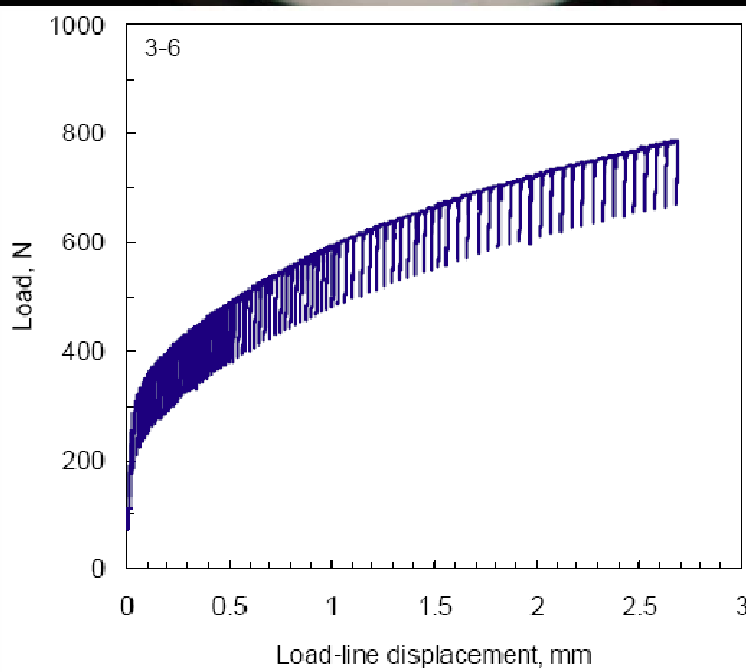
Materials Testing ORNL

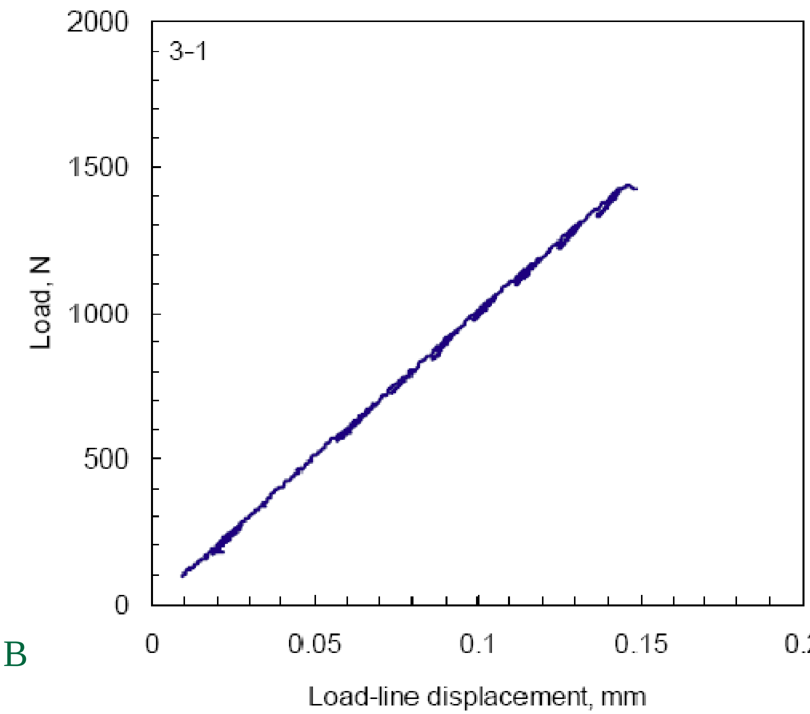
3-6



3-1





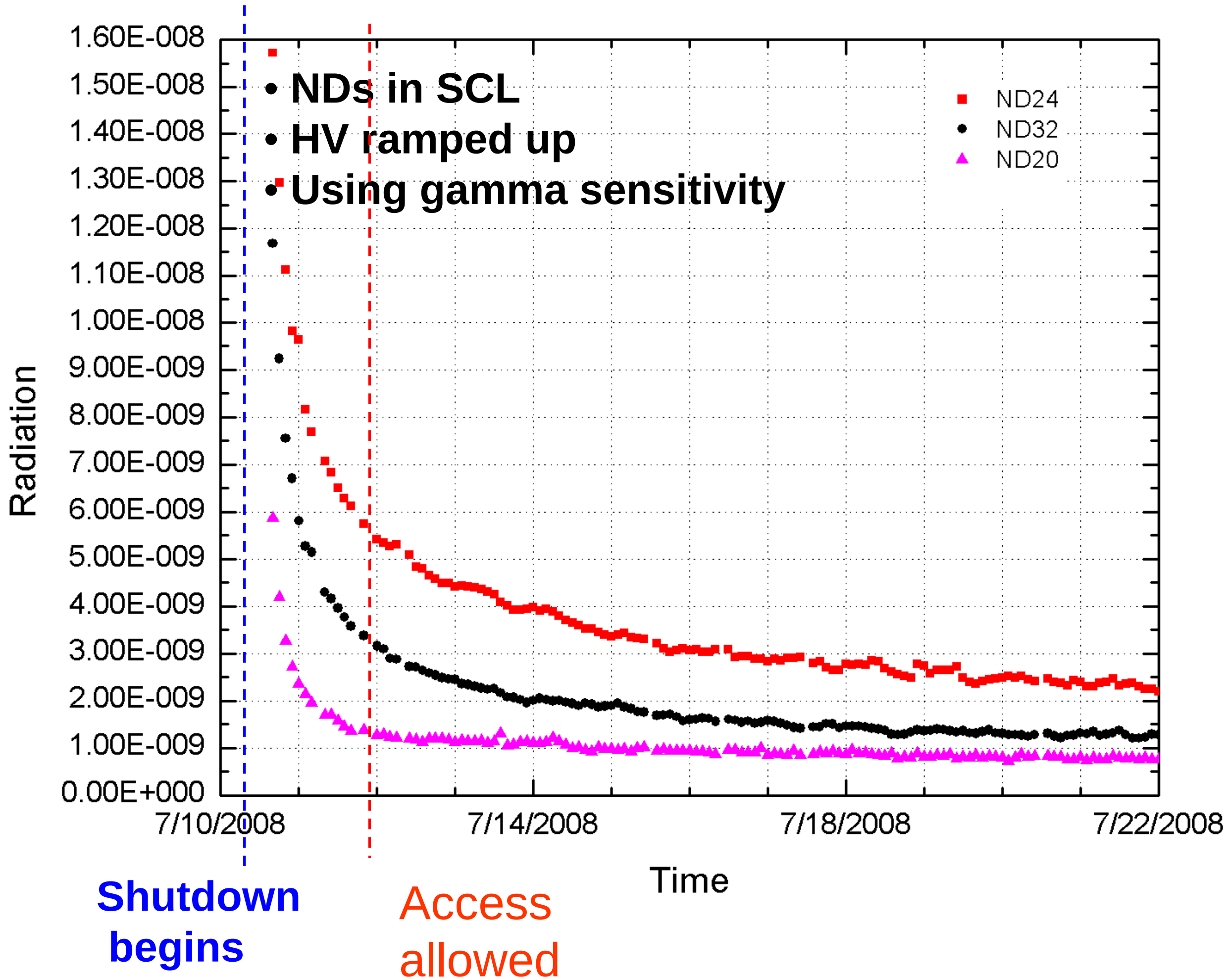


ctoria B

Linac Activation

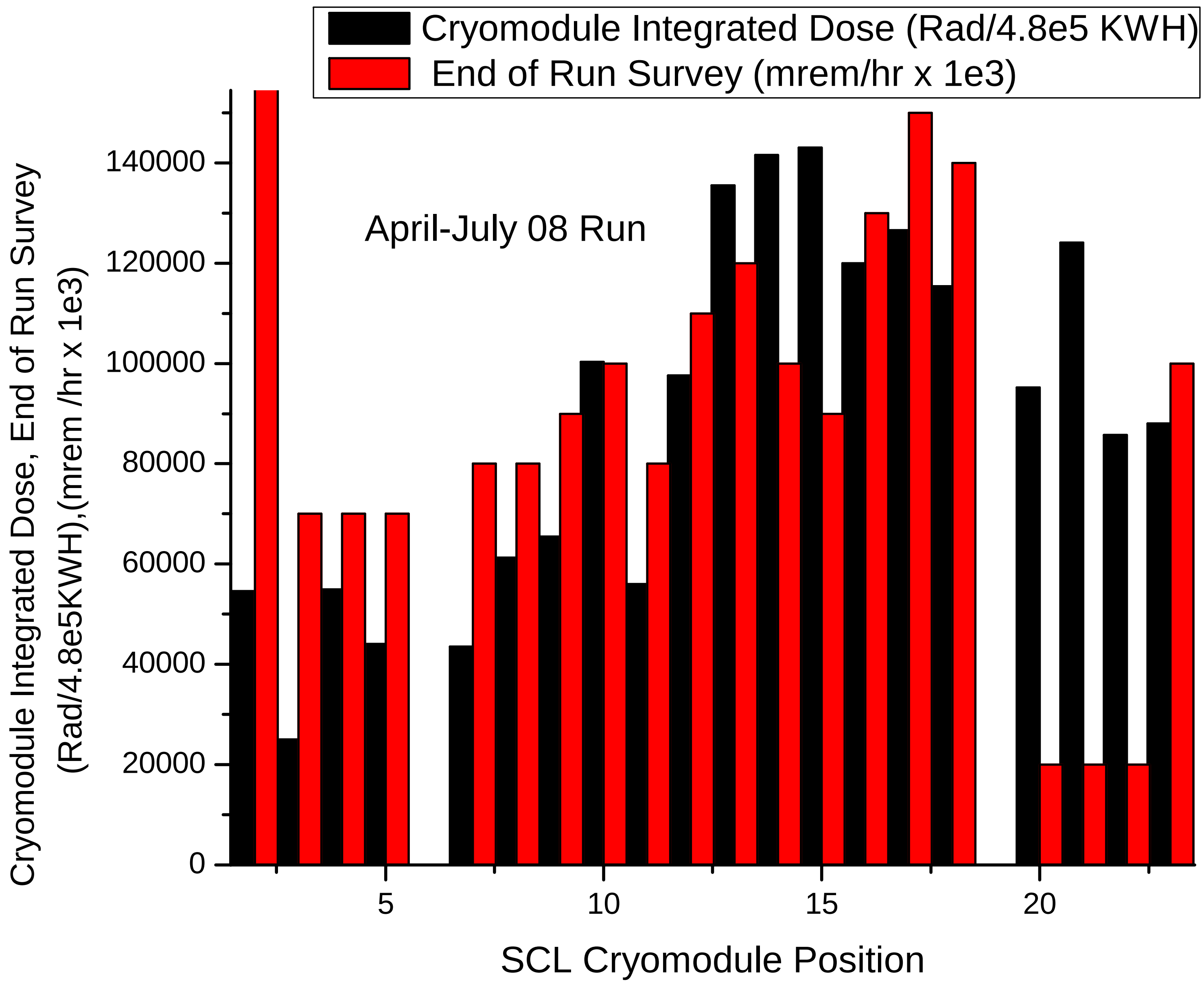
- **All Cryomodules Are Now Activated**
  - **Activation levels are still low, but will increase with beam power**
  - **Repairs take significant planning in advance and controlled areas to work**
  - **Radiation Measurements Were Made in Tunnel**
    - **Decay of radiation after beam shutdown**
    - **SCL Radiation Spectrum in Tunnel**
    - **SCL Integrated Radiation Dose Measured**

Activation Decay Measurements



Radiation Spectrum Measured in SCL

uCi	Isotope	Range	(keV)
1.31	Mn-52	1329.23	1338.73
1.26	Mn-52	1429.77	1439.27
1.01	Cr-51	317.3	324.43
0.88	Ni-57	1914.11	1924.39
0.82	Na-24	2745.68	2758.32
0.78	Sc-44m	269.35	276.48
0.77	Co-56	2590.73	2602.59
0.75	Mn-52	931.32	940.03
0.67	Nb-90	2311.6	2323.46
0.64	Nb-90	2179.91	2190.98


Cryomodule Integrated Dose (Rad/4.8e5 KWH)
End of Run Survey (mrem/hr x 1e3)
April-July 08 Run
Cryomodule Integrated Dose, End of Run Survey
(Rad/4.8e5KWH),(mrem /hr x 1e3)
0
20000
40000
60000
80000
100000
120000
140000
5
10
15
20
SCL Cryomodule Position

Near Term Plans (FY09-FY11)

- **Urgent need is to increase linac gradients to meet the power ramp-up plan**

MB Linac:

- Need to repair/recover one disabled cavity (CM11b), during Feb 09 maintenance down
- Armed with experience gained from repair of CM19, CM10, shows repairs can be done without degrading performance on assembled cryomodules
  - Procedures we developed worked!
- Build 1 Spare MB Cryomodule

Near Term Plans (FY09-FY11)

HB Linac:

- **Repair CM12 Helium Circuit Leak**
  - **CM12 Is the lowest operating HB cryomodule due to end group quenching (Field Emission)**
  - **CM12 Is typical of HB CM performances, field emission limited and therefore represents the best opportunity to develop surface processing techniques (Helium Processing)**
- **Install CM19, Feb maintenance down**
- **Redesign HB Cryomodule to Meet 10CFR851**
  - **Start the fabrication of 2 HB spare cryomodules in-house**

Recent Successes (CM19):

- **CM19 cavity b suffered from erratic/high power transmission from the HOM b probe**
  - Cavity was operated several months with a blown attenuator on this port

- **Repair of CM19**
  - Cryomodule was moved to cleanroom and beamline vacuum was letup
  - Both HOM probes were removed and blanked off
  - Careful repair procedures were developed and implemented
  - Full monitoring of particulates recorded

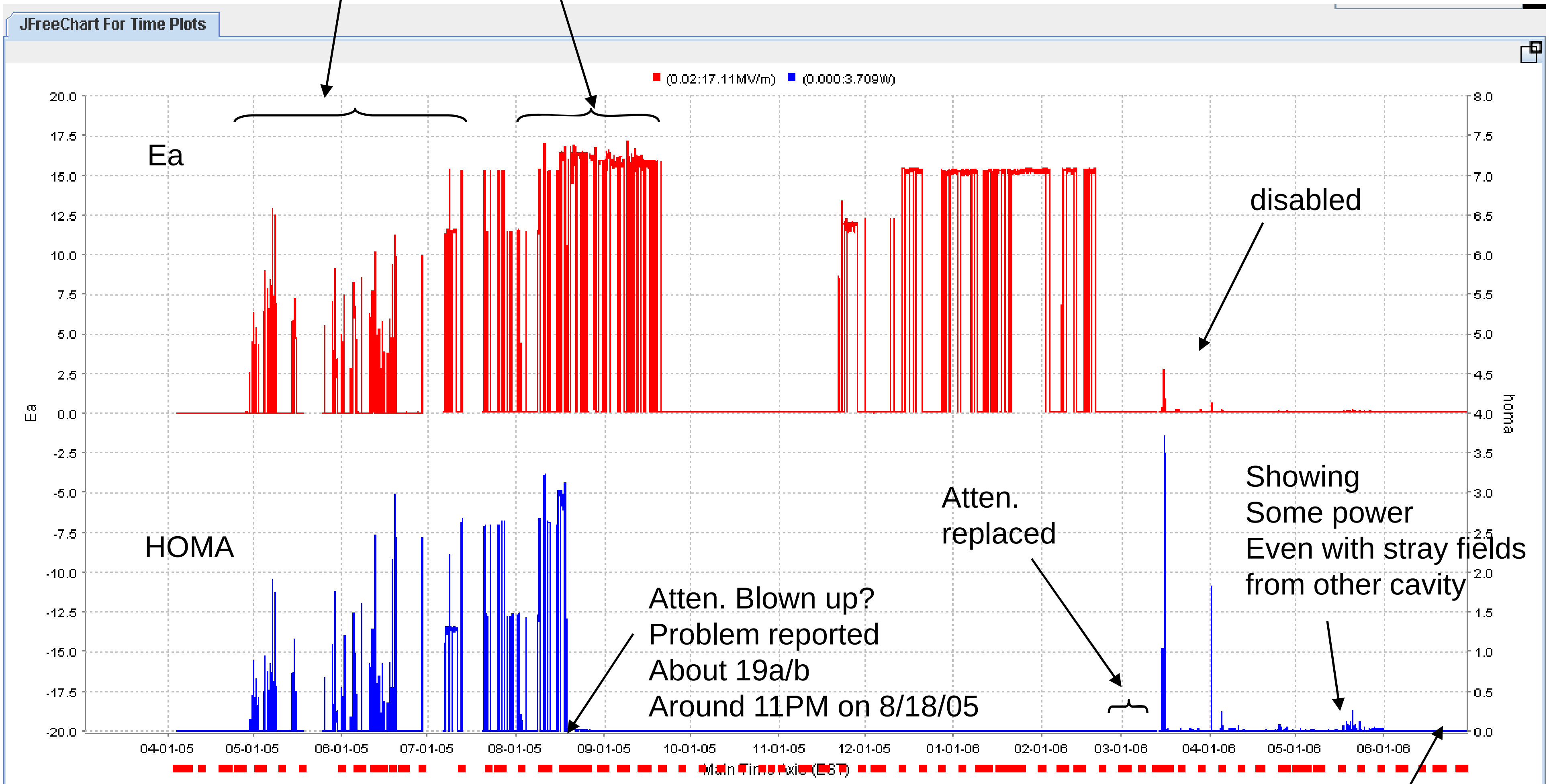
- **Repair of CM10**
  - Field probe signal noise

Data from

Sung-Ho Kim

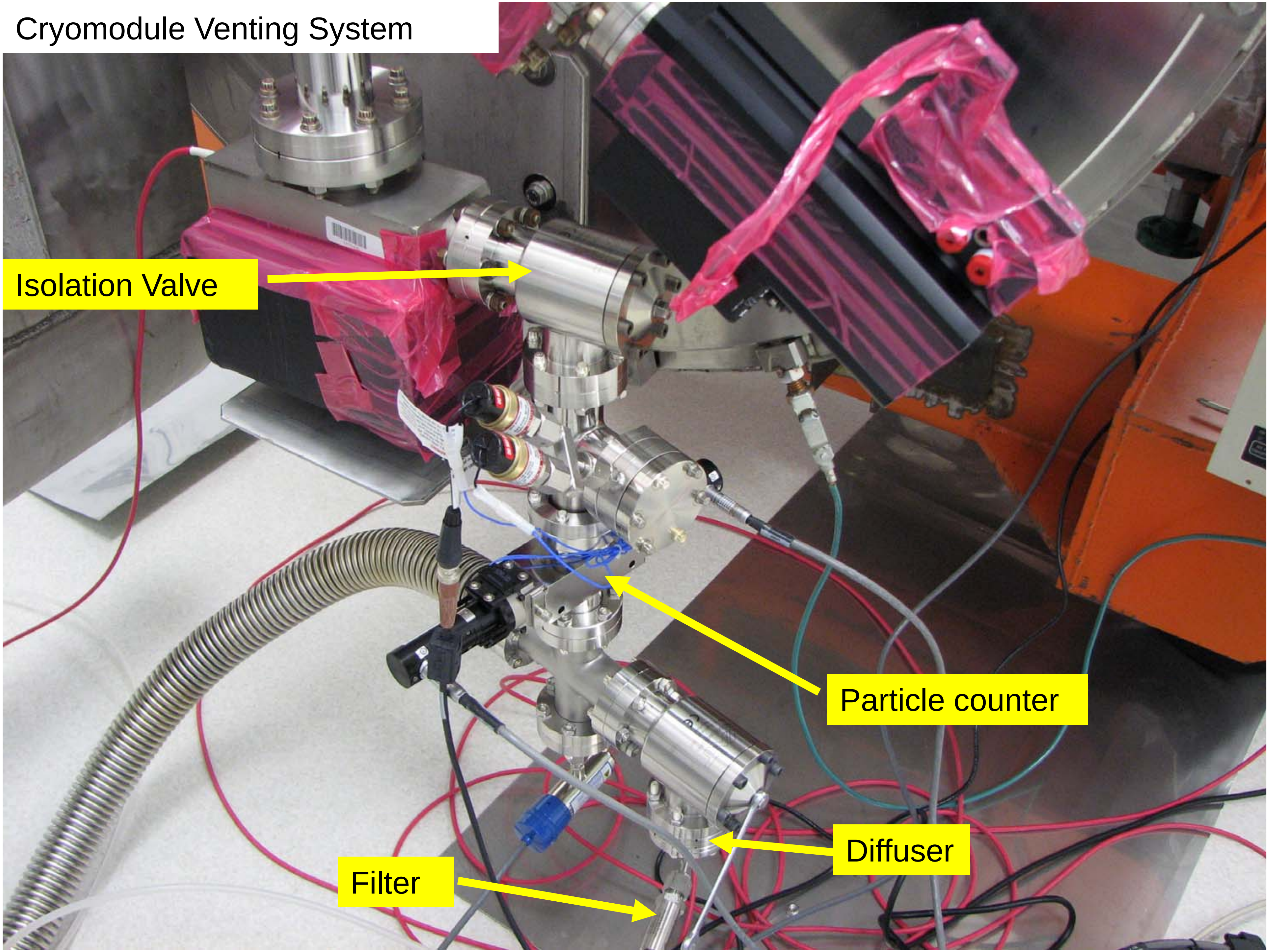
Cryomodule Commissioning
19b Ea, limit~18 MV/m
; Qhoma (high power)~1.5e11
Qhoma (low power)~ 1.4e11

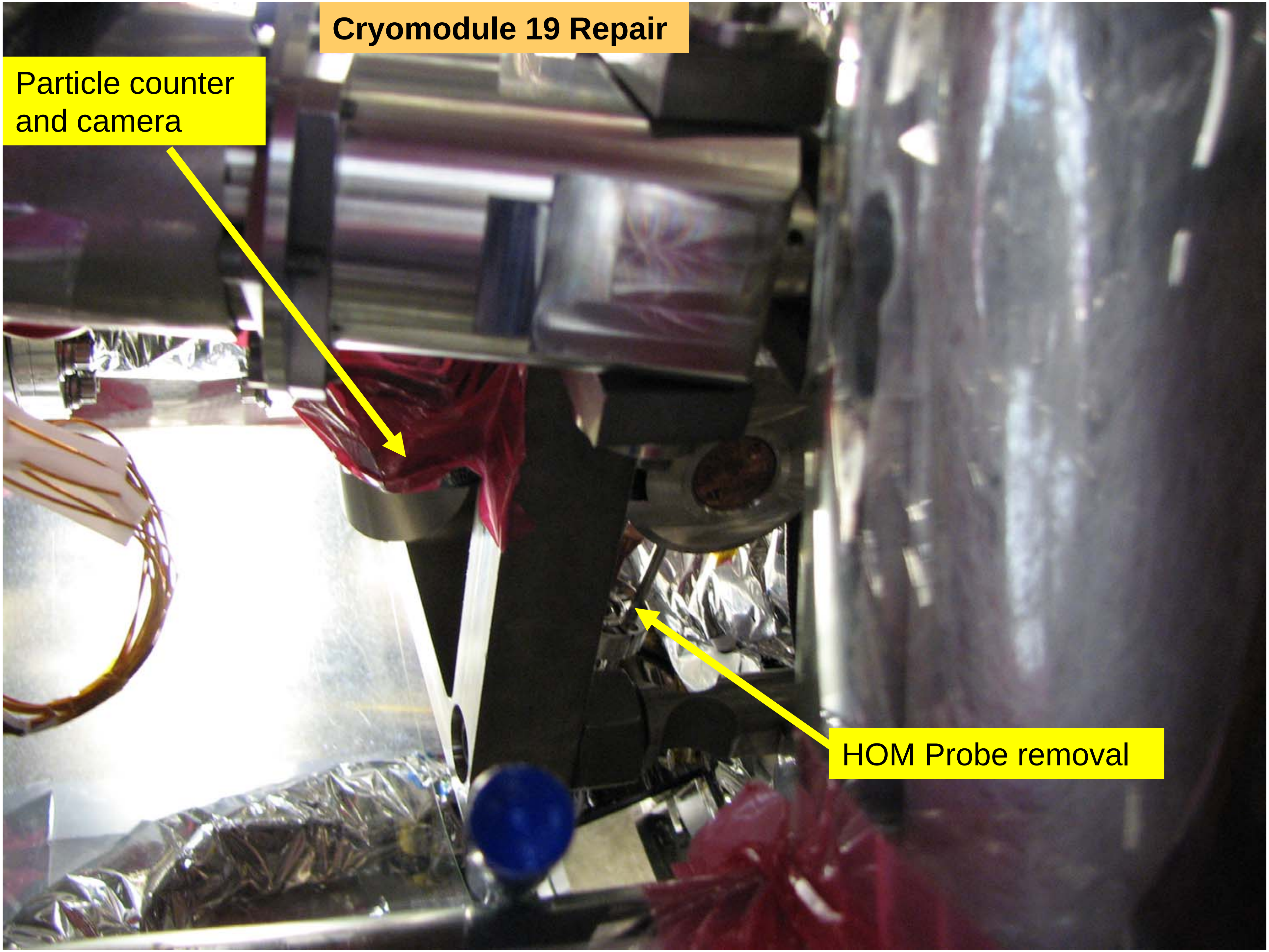
SCL beam commissioning

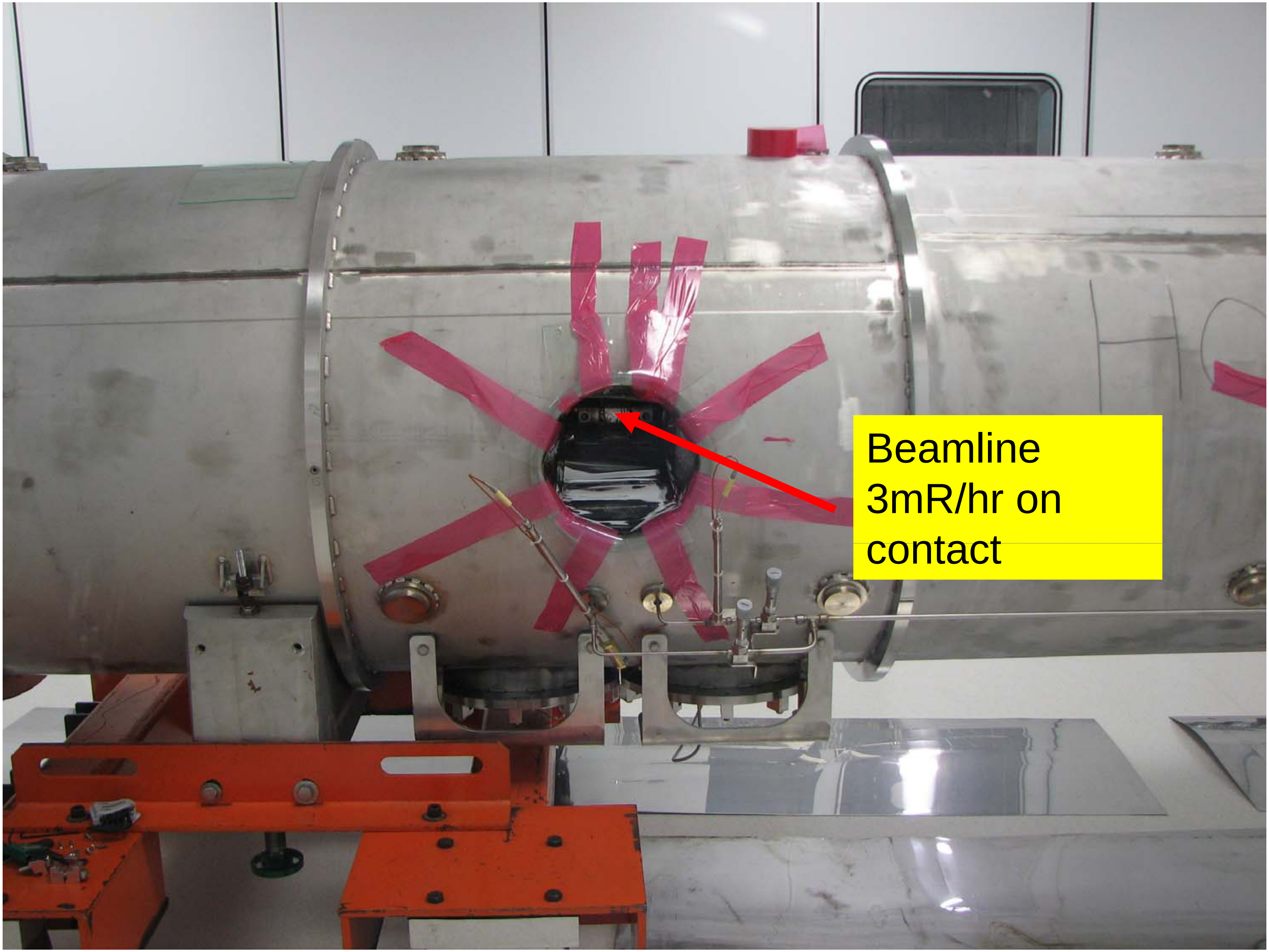


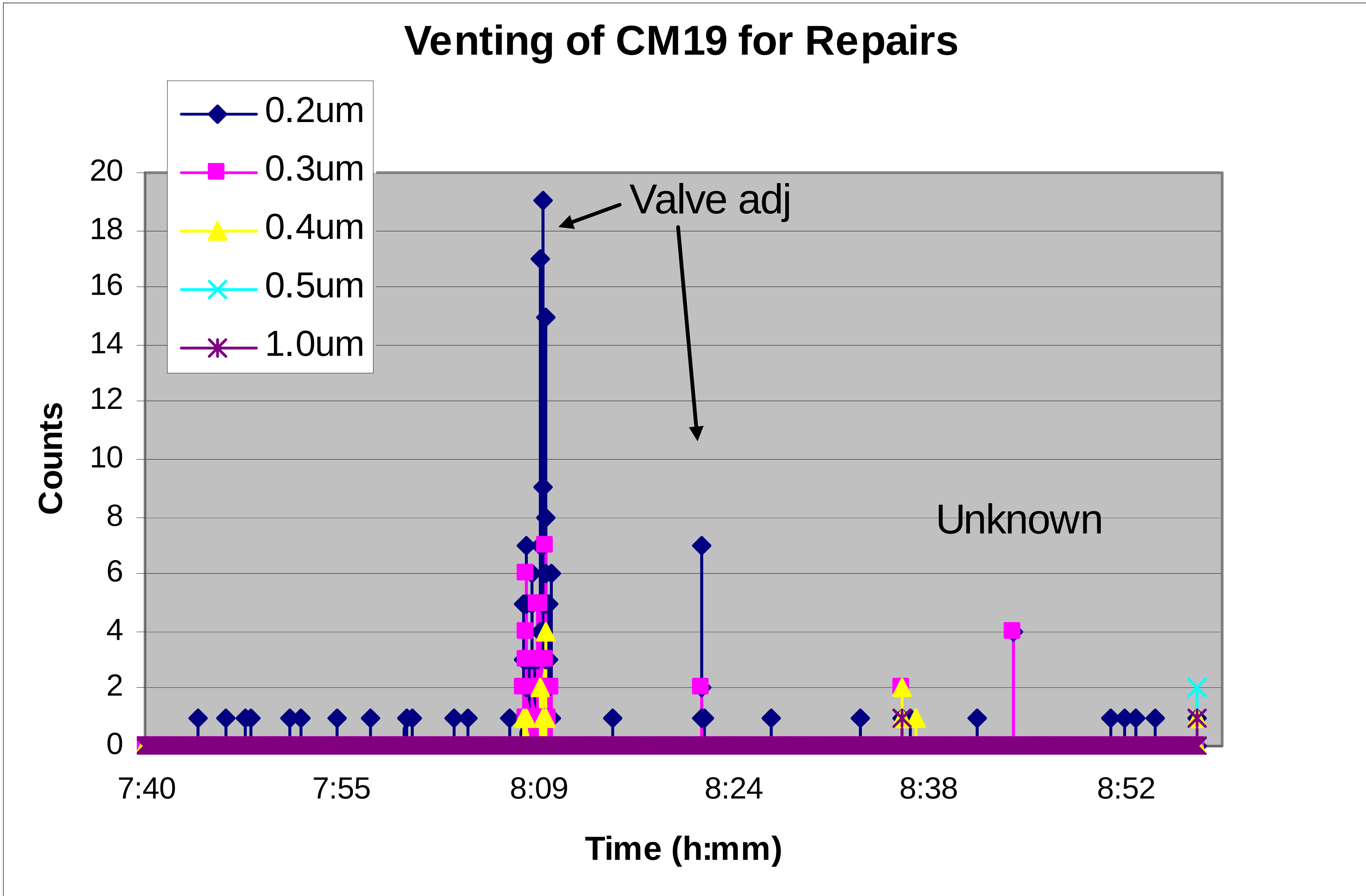
Low power measurement
At 4K in the tunnel
Qhoma~3.8e8 (+25 dB)

Cryomodule Venting System




Cryomodule 19 Repair
Particle counter and camera
HOM Probe removal


Beamline
3mR/hr on
contact


Venting of CM19 for Repairs
0.2um
0.3um
0.4um
0.5um
1.0um
Valve adj
Unknown
Counts
20
18
16
14
12
10
8
6
4
2
0
7:40
7:55
8:09
8:24
8:38
8:52
Time (h:mm)

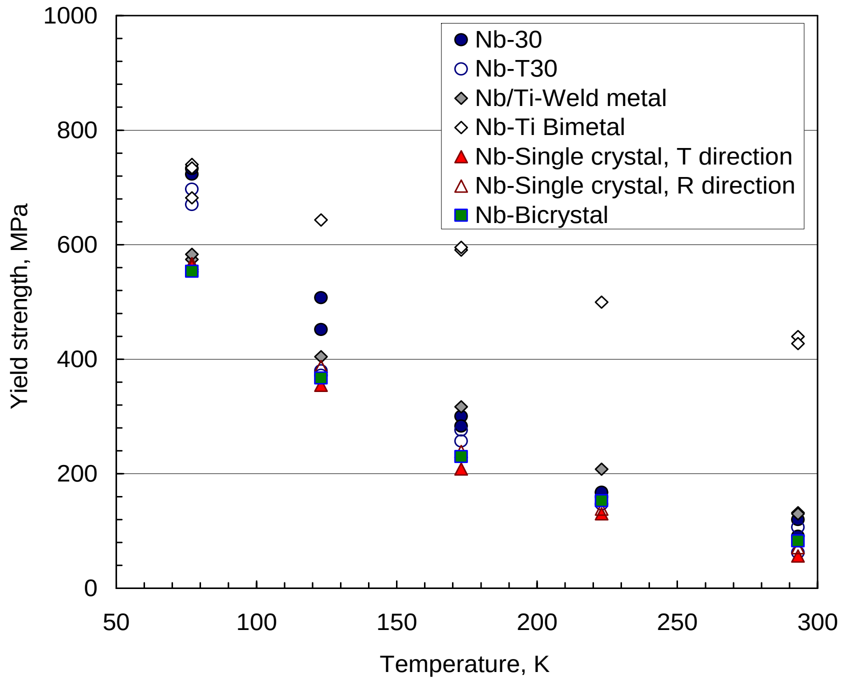
CM19 Test Results :

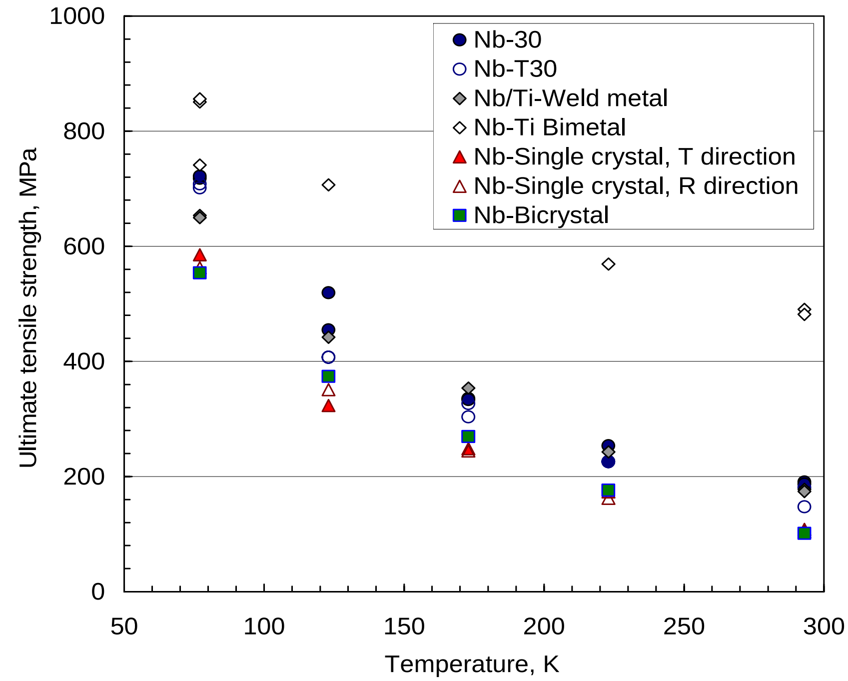
- **All cavities were tested individually at 4.2K, 30Hz 1ms pulse**
  - All cavities achieved > 15MV/m showing no degradation of performance from past data
    - **Collective limits were determined in Feb 08, confirmed results, best performing HB Cryomodule in Linac**
  - Additional diagnostics installed in cryomodule led to further understanding of HOM filters during commissioning phase
    - HOMa - filter showed strong multipacting (MP) which affected many other signals including vacuum, HOMb temperature, electron probe, coupling factors ect.
    - MP was processed away and signals returned to normal

Addressing Pressure Vessel Requirements

- **To better understand the problem we decided to:**
  - **Build data on pressure circuit materials at various temperatures**
    - **RRR Nb**
    - **NbTi**
    - **SS**
    - **Ti**
    - **Welds and weld transitions**
  - **Perform pressure tests on all subcomponents to understand safety margins**
    - **Feed-thrus**
    - **Conflat joints**
    - **Bellows**
    - **Transition joints**
    - **Weld joints**

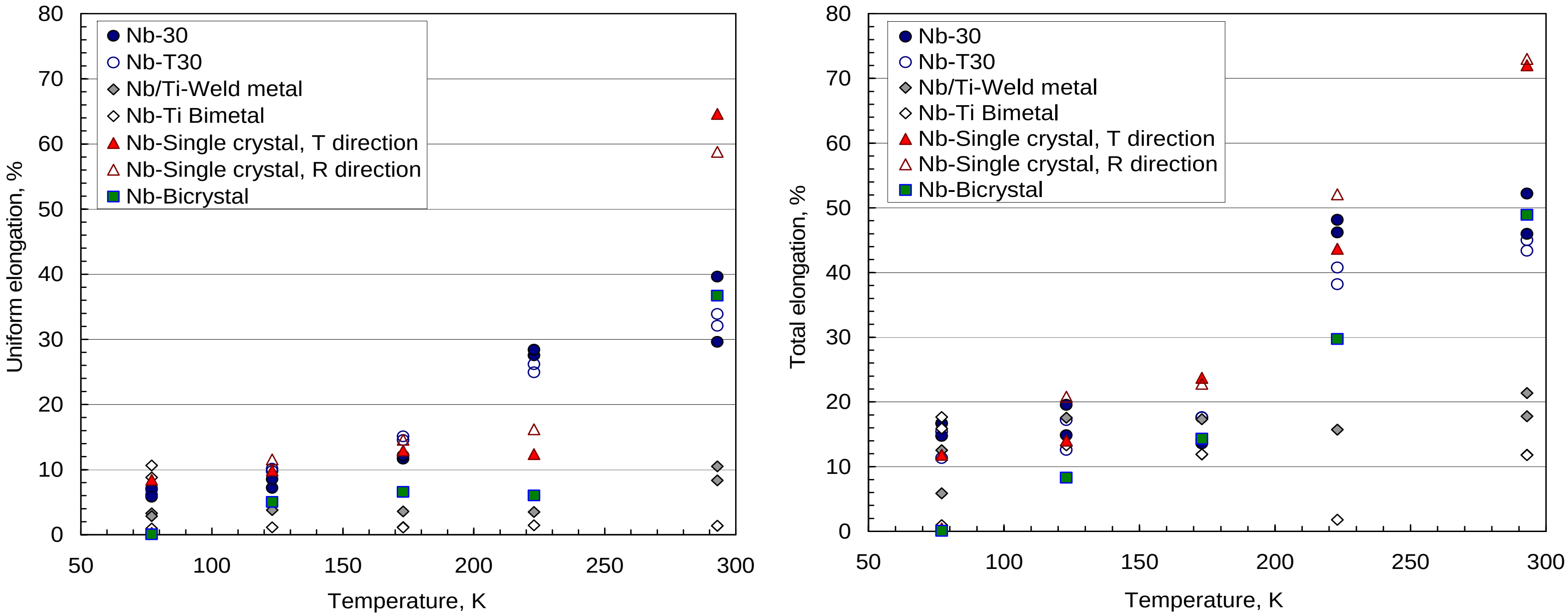
Strength of cryogenic vessel materials





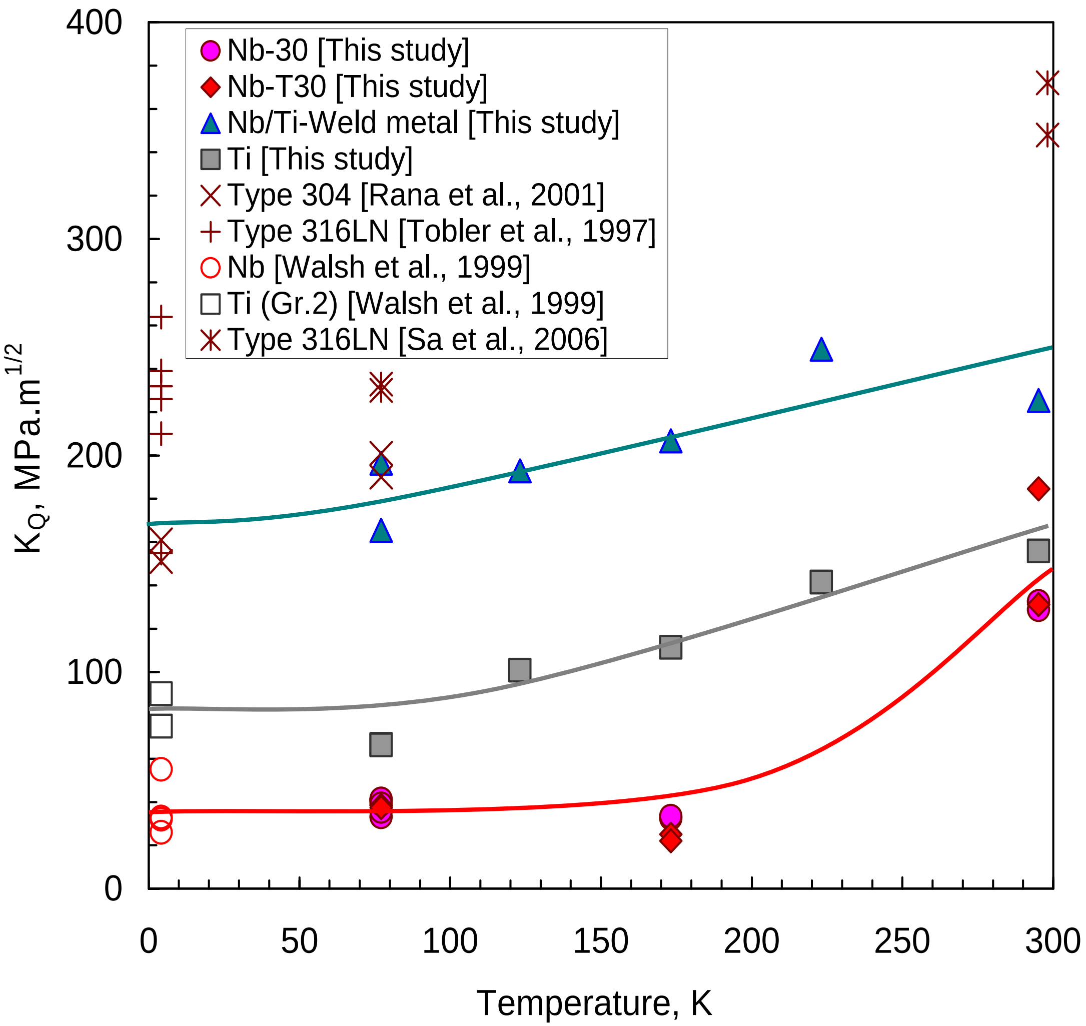
- **The strengths of Nb metals (Nb-30, Nb-T30, weld metal, single crystals, bicrystals) display strong temperature dependence, while they are similar at a given temperature.**
- **The Nb-Ti bimetal (explosion welded) shows the highest strength among the metals tested. This indicates that, assuming there is no influential defect formed by the welding process, the weld will not fail prior to a failure at adjacent softer material part.**

Ductility of cryogenic vessel materials



- **The ductility of Nb metals increases with test temperature. It displays larger variation at higher temperatures.**
- **Both base metals, Nb-30 & 30T, retain at least 5% uniform elongation and 11% total elongation at the lowest temperature.**
- **The single crystal specimens show higher elongations than the Nb-Ti bicrystal specimens, indicating that the grain boundaries are weakened by a mechanism. (Loading direction was perpendicular to the grain boundary.)**
- **The Nb-Ti bimetal and Nb/Ti weld metal retain relatively low elongations over the test temperature range. The bimetal broke always at the weld joint.**

Fracture toughness of helium vessel materials



- **The fracture toughness of Nb (30 & T30) decreases with decreasing test temperature and reaches the lower shelf values (30 – 40 MPam$^{1/2}$).**
- **The Nb/Ti weld metal shows much higher fracture toughness than the base metal (Nb). The fracture toughness of Ti is also higher than that of Nb.**
- **Among the metals compared the stainless steels (304 & 316LN) show the highest fracture toughness values over the temperature range.**
- **For Nb and Ti, the fracture toughness data from this study are consistent with those from earlier studies (when extrapolated to 4 K).**
- **Fracture toughness tests at 4 K is expected to confirm these findings.**


EAST
FRAGILE

Conclusion:

- **SCL operation is well understood and stable**
- **In-situ repairs to cryomodules successful**
- **Redesign of HB cryomodule for PV code underway**
  - **Two HB and one MB cryomodule spares will be built in-house**
- **Plans are to complete the SRF facilities**