325 MHz Superconducting Spoke Resonator Development at Fermilab

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TTC Meeting
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Spoke Cavity History at Fermilab

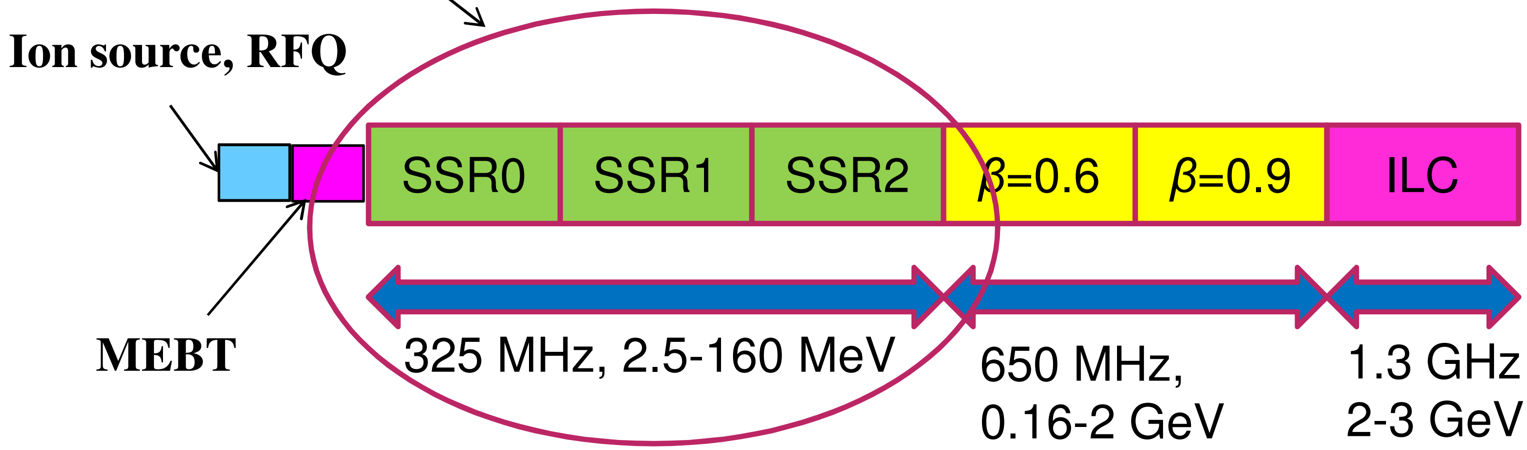
- Fermilab efforts on superconducting spoke resonator (SSR) accelerating cavities began about five years ago
- Development of SC spoke cavities at 325 MHz was an enterprise of the Fermilab HINS program apart from the larger 1.3/3.9 GHz efforts
- The context was for a pulsed, high-intensity proton/H- linac
  - Up to 3 msec pulse length and 1% duty factor
  - 4°K operation
  - 27 mA pulsed beam current
- The frequency was chosen to be 325 MHz
  - 4^{th} subharmonic of ILC 1.3 GHz
  - JPARC klystron is available at 324 MHz

Spoke Cavities in Present Context of Project X

- Within the past year Project X concept has morphed
  - Linac operating CW
  - 2°K operation to reduce cryo load
  - 1 mA continuous accelerated beam current
- Threshold energy for application of SSR cavities has been lowered from 10 MeV to 2.5 MeV requiring design of a β=0.11 structure
- Triple-spoke cavities in the earlier machine design are replaced in favor of more efficient β=0.6 650 MHz elliptical cavities
- Now there are plans to tightly integrate the whole Fermilab SRF program to include Project X, ILC, and 3rd harmonic (3.9 GHz) activities

Project X 3 GeV CW Linac

- **Low-energy SRF 325 MHZ linac (2.5-160 MeV)**
  - 3 families of single-spoke cavities *(β=0.11, β=0.22, β=0.4)*
  - 1 mA CW accelerated beam current



Technical Progress on Cavities

- Two β = 0.22 spoke cavities are fabricated and processed
- Both have tested successfully (bare) in the Fermilab VTS to beyond design accelerating gradient:
  – Pre-CW design requirement was 10 MV/m @ Q_0 > 5E8 at 4°K
  – >30 MV/m has been achieved in one HINS cavity at 2°K
- The first cavity manifested symptoms of Q-disease and has since undergone a 600°C bake at TJNL
  – That cavity is now welded into helium vessel
  – First post-bake test will be in the new horizontal test cryostat by this summer
- The second cavity was cooled down and tested only one time
- Cavity end-wall spring constant (~20 N/micron) and tuning sensitivity (~550 Hz/micron) have been measured to set cavity tuner design parameters
- Cavity resonant frequency has been successfully tuned by in-elastically deforming the end-walls

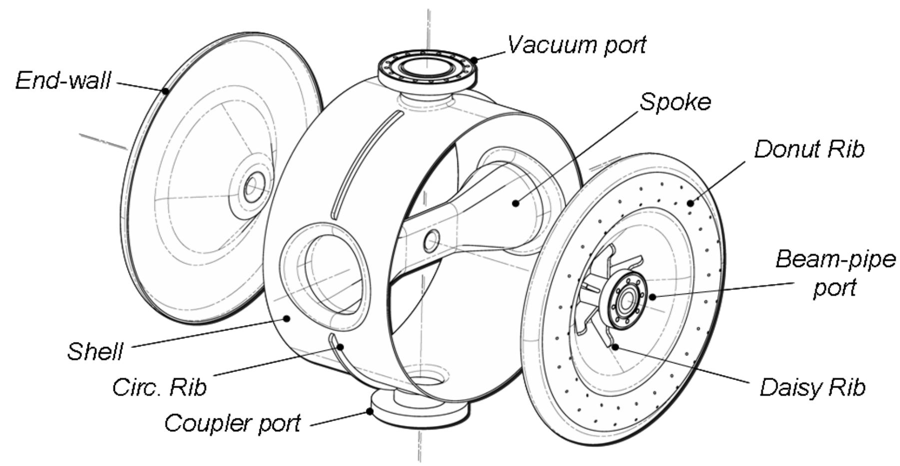
Project X 325 MHz Testing Facilities

- Fermilab VTS
  - Design and construction of a 1300 ↔ 325 MHz frequency convertor and procurement of a 200W 325 MHz amplifier has allowed spoke cavity testing using the full complement of facilities and software at VTS developed for 1300 MHz elliptical cavities
- 325 MHz Superconducting Spoke Cavity Test Facility
  - Pulsed RF power from 2.5 MW 325MHz J-PARC type klystron
  - Horizontal test cryostat for dressed spoke cavities at 4°K operation
  - Cryostat without cavity will begin first test cool down in Meson Detector Building within days
  - Allows low power, full-gradient CW VTS-like testing for cavities w/high-Q_{ext} drive antenna
  - Allows full pulsed-power testing with 400kW 325 MHz RF source for cavities w/ 'real' power input coupler installed
  - Modifications of the cryostat for 2°K operation are being designed

HINS 325 MHz Single Spoke Design Parameters

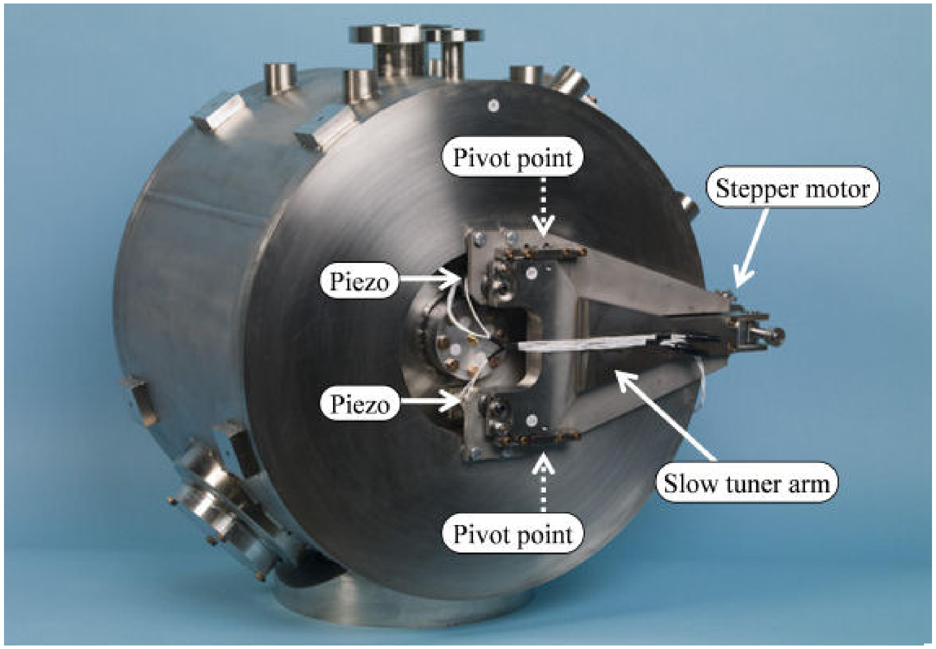
Quantity	Value
Operating temperature	4.4 K
HINS accelerating gradient, E_{acc} *	10 MV/m
Q_0 at accelerating gradient	> 0.5×10^9
Beam pipe, Shell ID	30 mm, 492 mm
Lorenz force detuning coefficient	3.8 Hz/(MV/m)^2 (with He vessel)
E_{peak}/E_{acc} *	2.56
B_{peak}/E_{acc} *	3.87 mT/(MV/m)
G	84 Ω
R/Q_0	242 Ω
Geometrical Beta, β_g	0.21

SSR1-02, the 2nd SSR1 prototype. Fabricated by Roark.



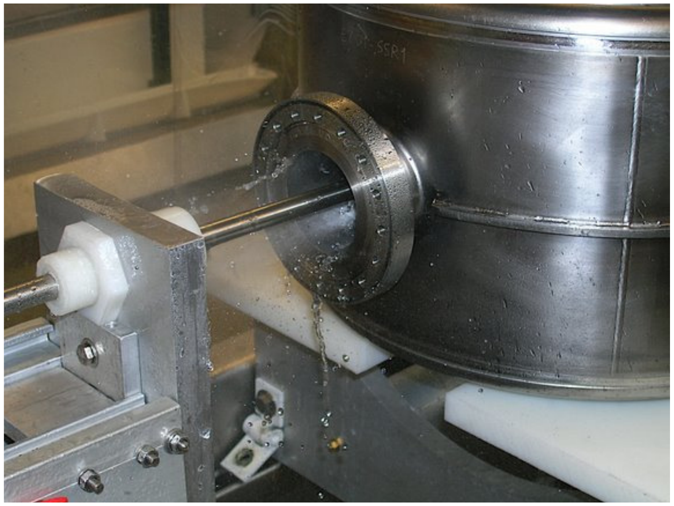
* E_{acc} is the total accelerating voltage divided by L_{eff}, where $L_{eff} = (2/3)\beta\lambda = 135$ mm, the distance between the edges of the accelerating gaps at the two endwalls.

SSR1 Cavity – Bare and with Helium Vessel and Tuner



BCP and HPR Infrastructure at the ANL G150 Facility

BCP Set-up

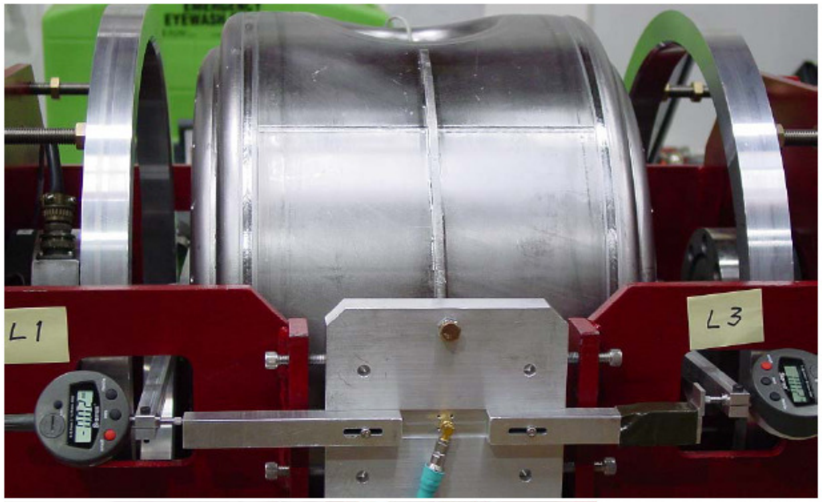


Spoke Cavity in HPR Set-up

Project X

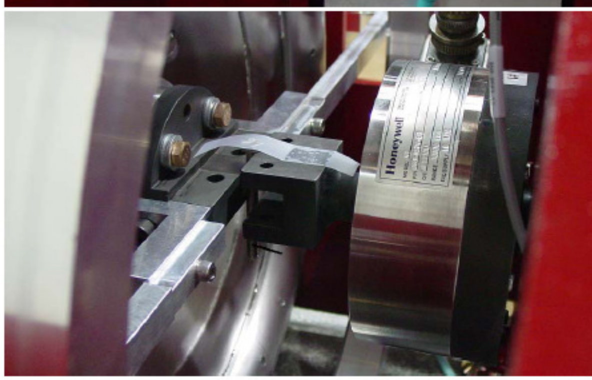
SSR Cavity Tuning Fixture

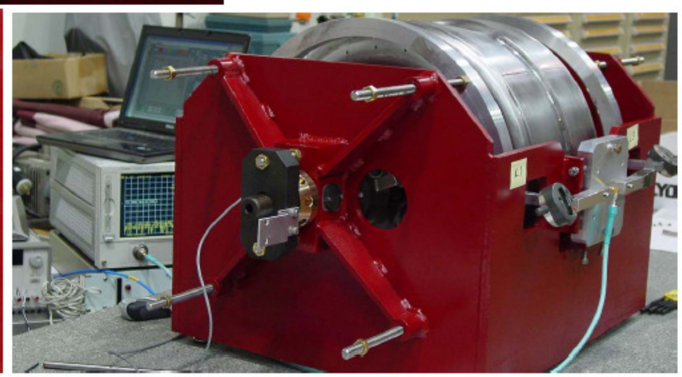
SSR cavity tuning fixture with cavity SSR1-01.



4 Position Sensors and 2 Dynamometers. Cavity can be hold on coupler and vacuum port flanges or by 2 rings on equator near C-shape stiffening rings.

MHz/mm	lb/mm	N/mm
566	4507	20053

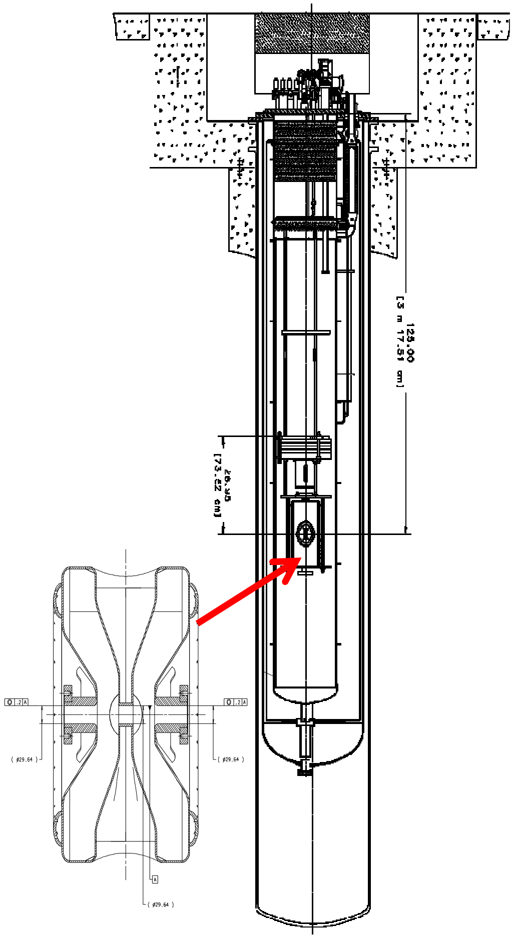




SSR Cavity Testing

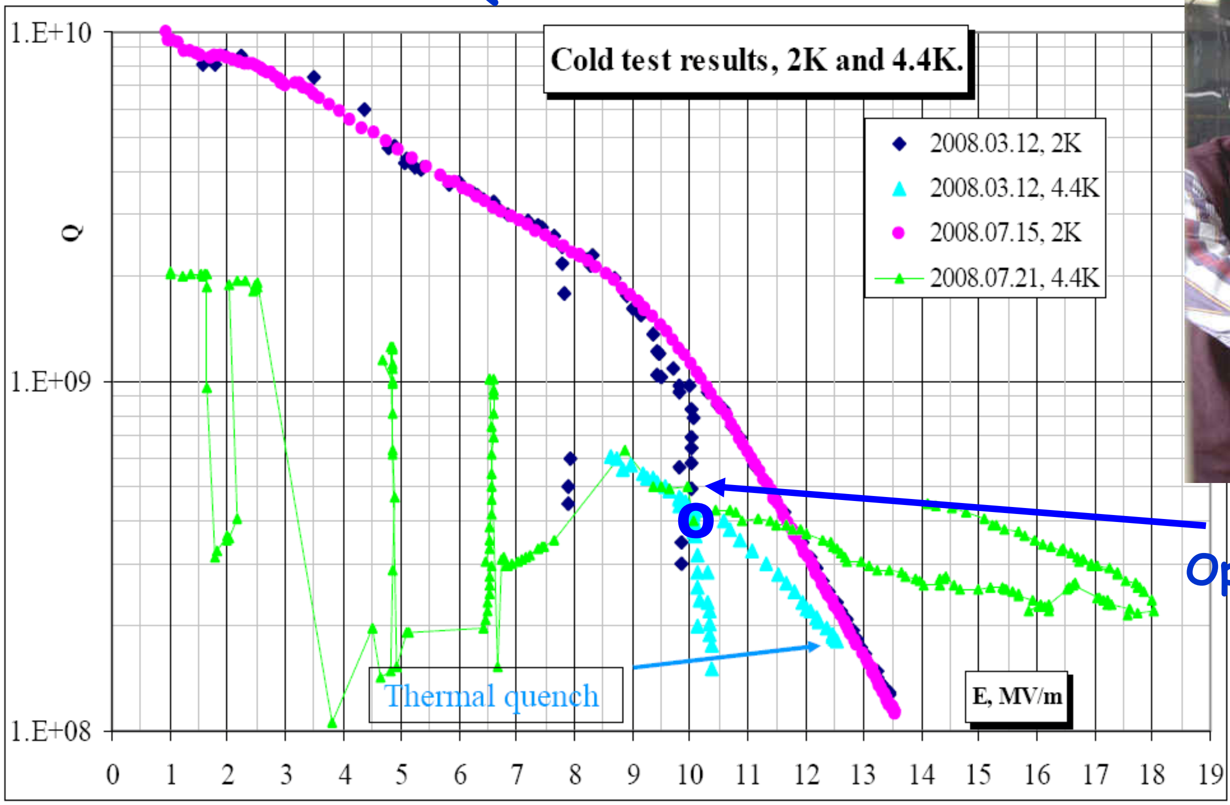
- SSR1-1
  - Four VTS tests between March 2008 and March 2009
  - Vacuum problems in first two tests
  - Active pumping added to VTS before 4th test
  - 4th test included cool-down dwell at 100° K in attempt to induce Q-disease
  - Cavity subsequently baked at 600° C at JLAB, welded into He jacket and dressed with tuner
  - Will next be tested in new test cryostat in coming months
- SSR1-2
  - One VTS test in 2009
  - Reached very high gradient – 33MV/m

Spoke Cavity Prepared for VTS



SSR1-1 Early VTS Results

SSR1-01 Vertical Test
Q vs. E

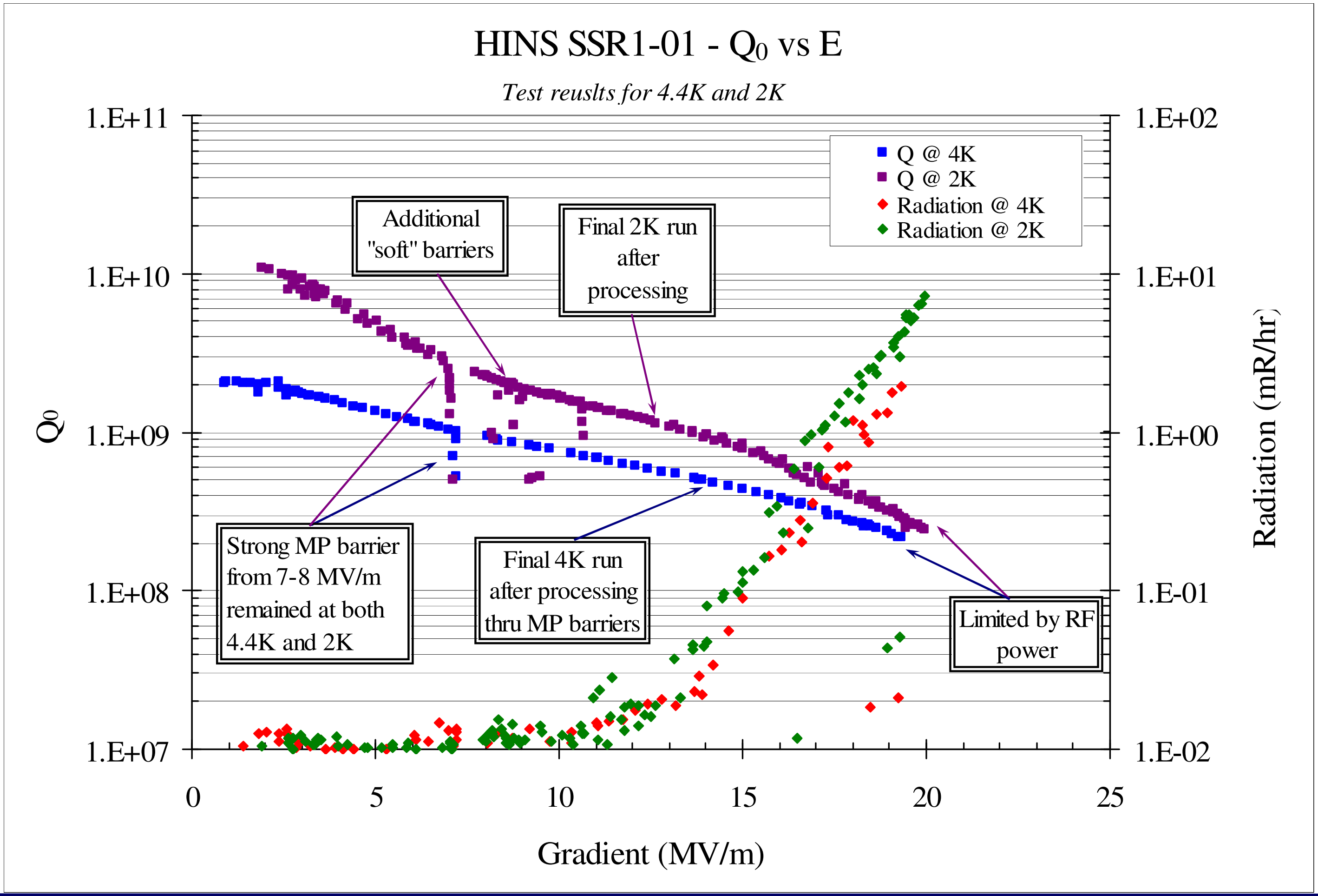


Dressed Cavity
Operating Goal @ 4K

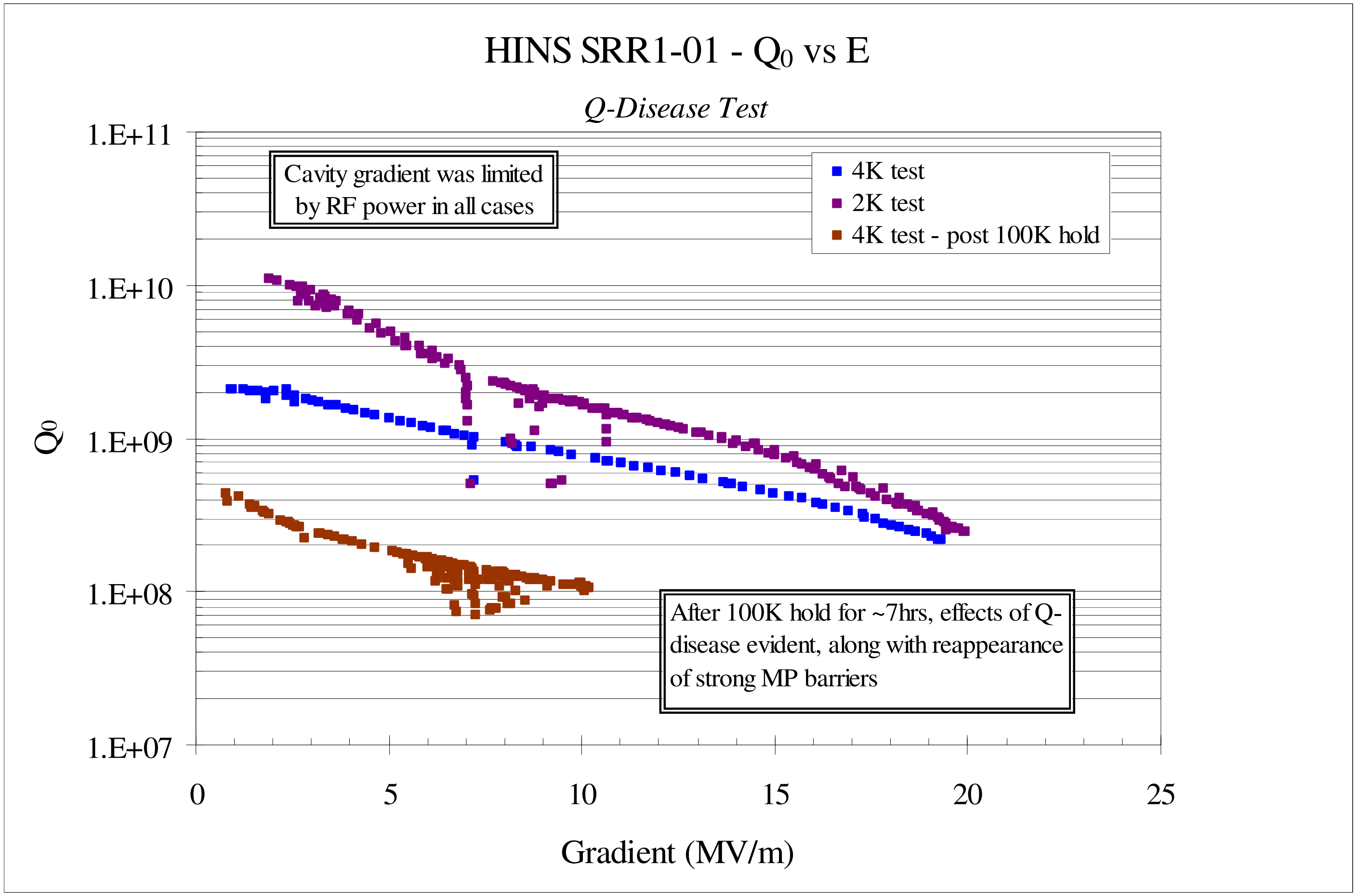
This test ended when multipacting due to poor cavity vacuum became unacceptable.

Accelerating Gradient MV/m

SSR1-1 Final Test Results

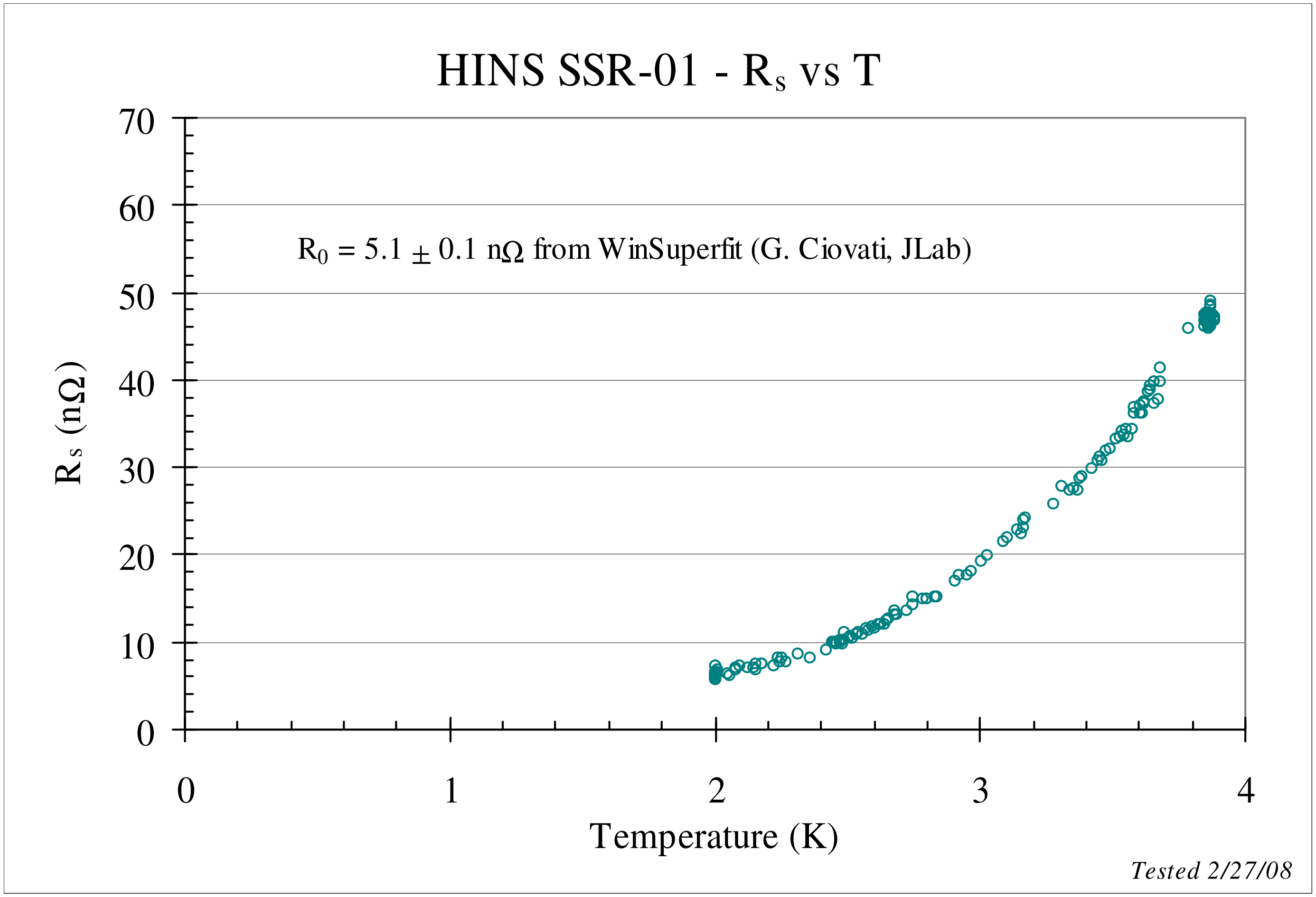


SSR1-1 Final VTS Test Inducing Q-disease



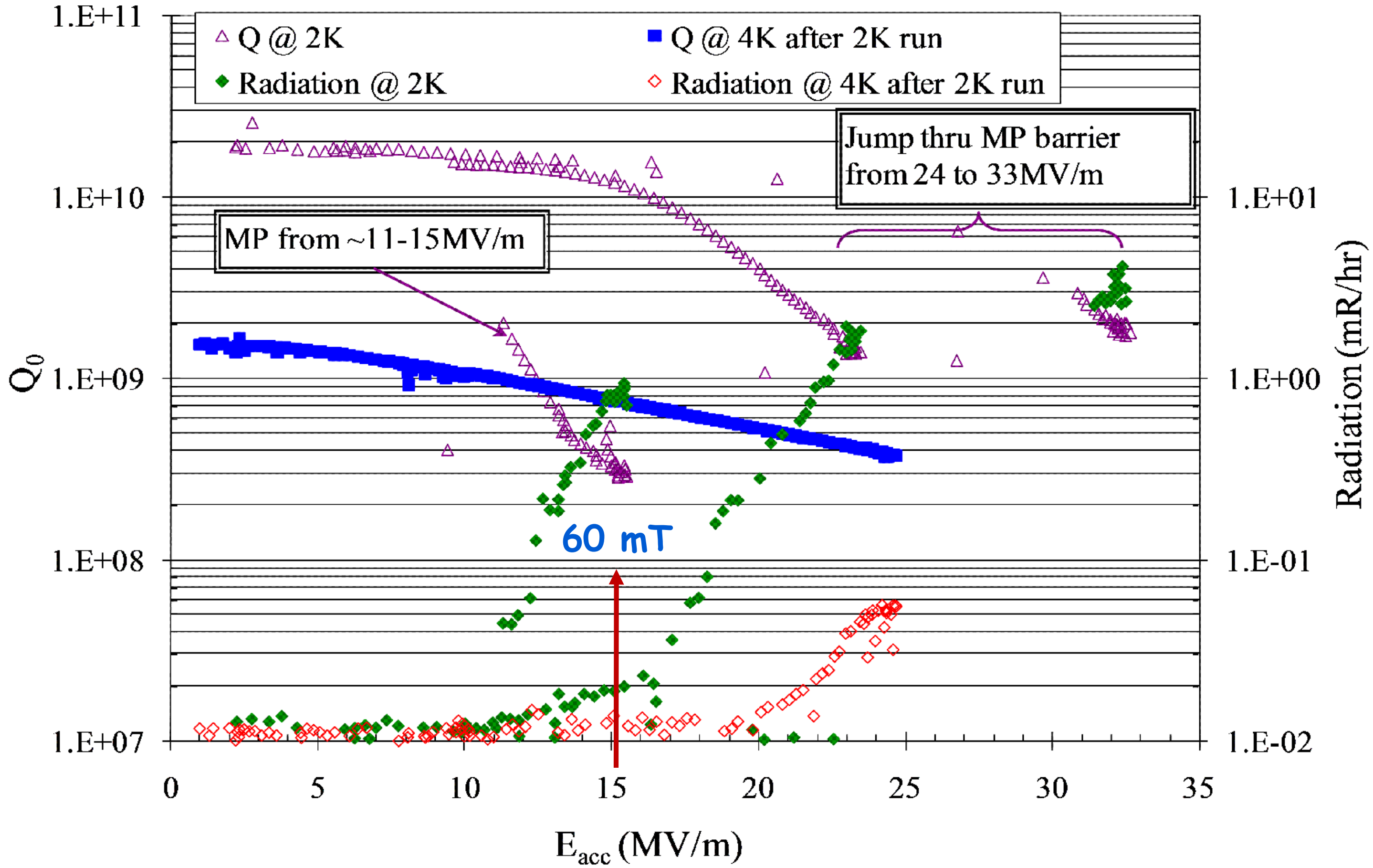
Ozelis Jan 2009

SSR1-1 R_s vs T



HINS SSR-01 - R$_s$ vs T
$R_0 = 5.1 \pm 0.1$ nΩ from WinSuperfit (G. Ciovati, JLab)
70
60
50
40
30
20
10
0
R$_s$ (nΩ)
0
1
2
3
4
Temperature (K)
Tested 2/27/08

SSR1-2 First Cool-down VTS Test Results

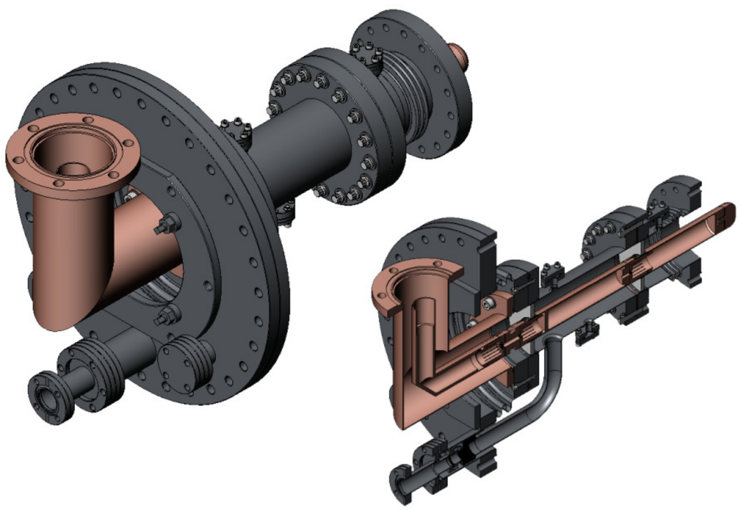


SSR1 Dressed with Tuner

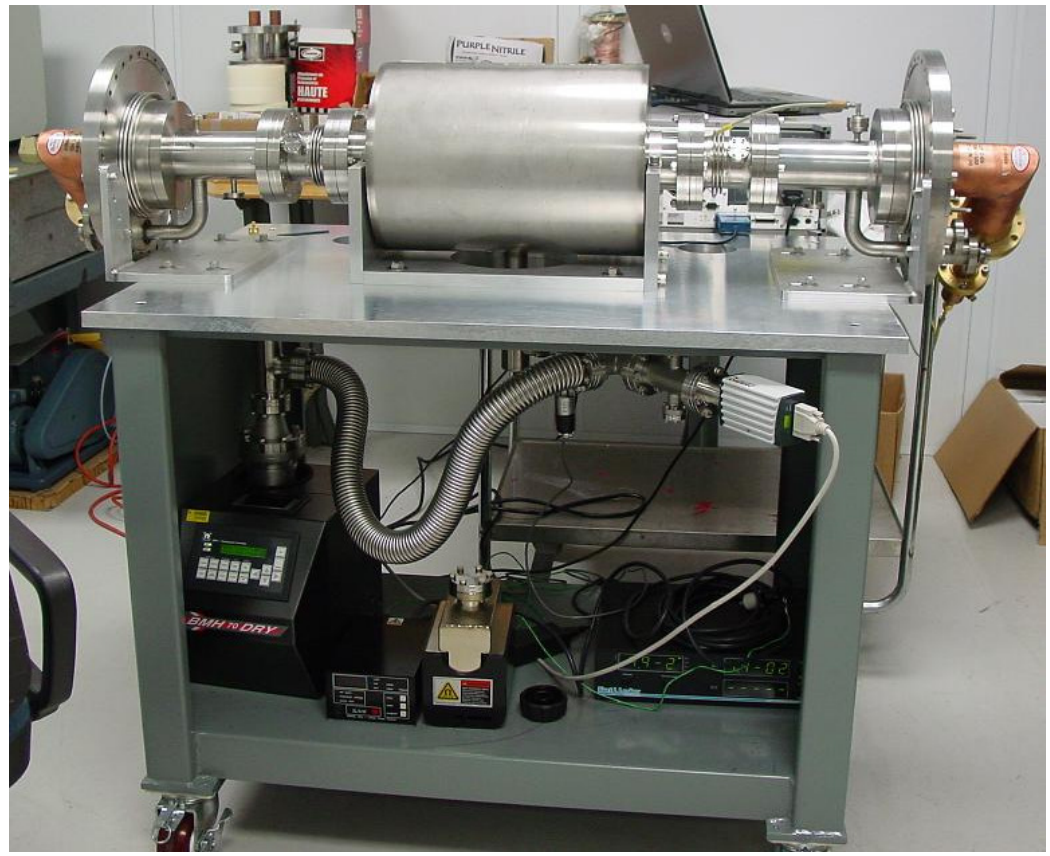
Parts for 2 helium vessels are in-house, one of which is welded. One prototype tuner has been tested warm.

Project X

Input Coupler High Power Test Fixture

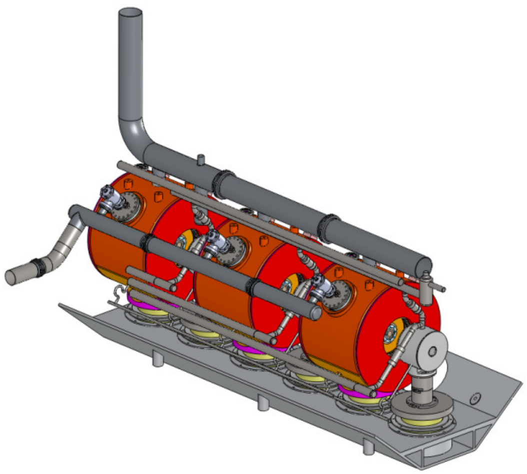


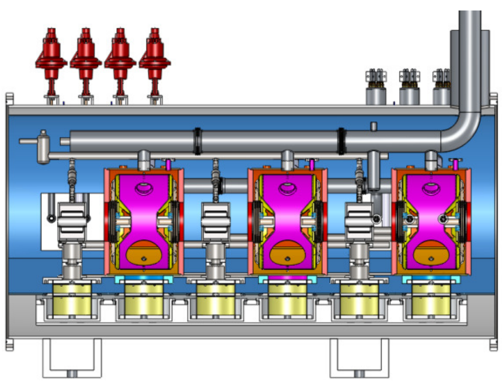
Three Fermilab-designed couplers and one SBIR-produced coupler are in-house. First full-power tests have been successfully completed.

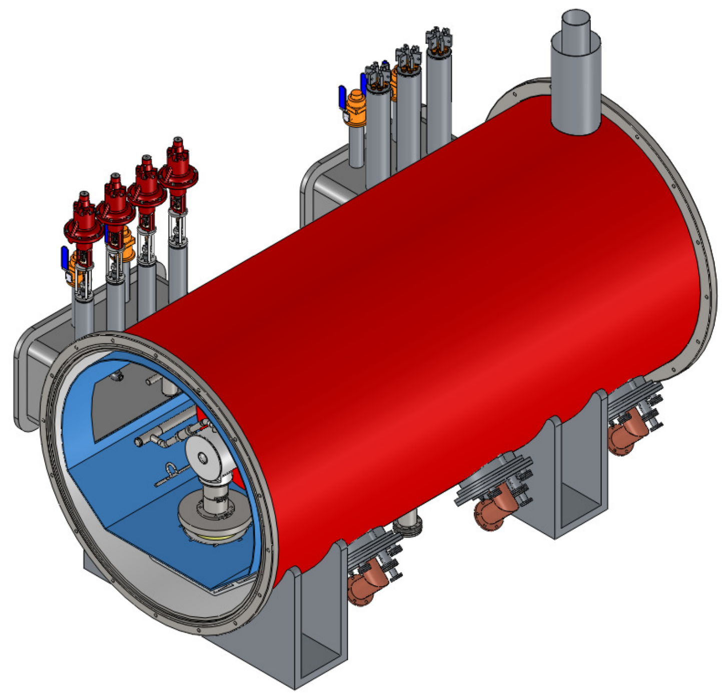


Spoke Cavity Horizontal Test Cryostat in MDB

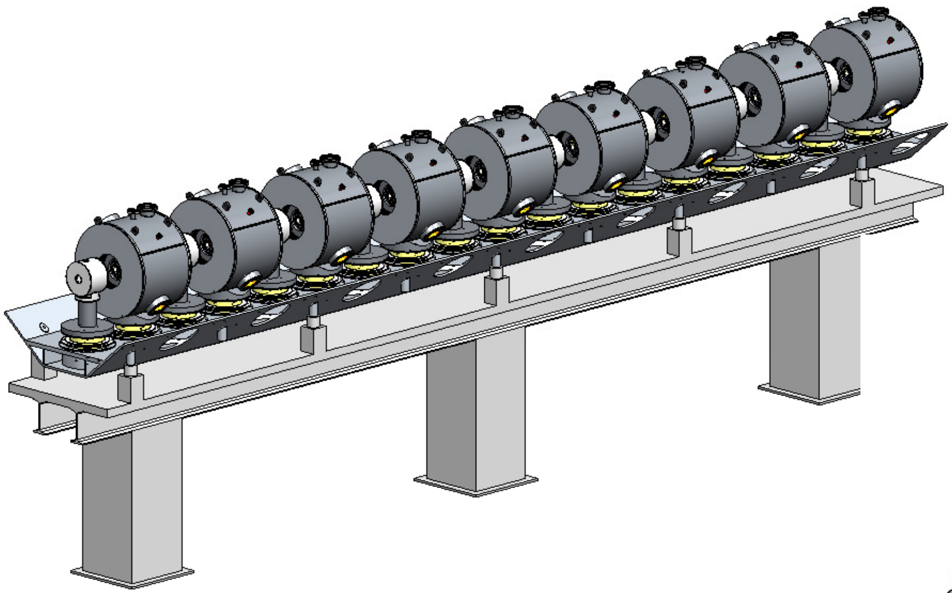
3-Cavity Cryomodule Concept

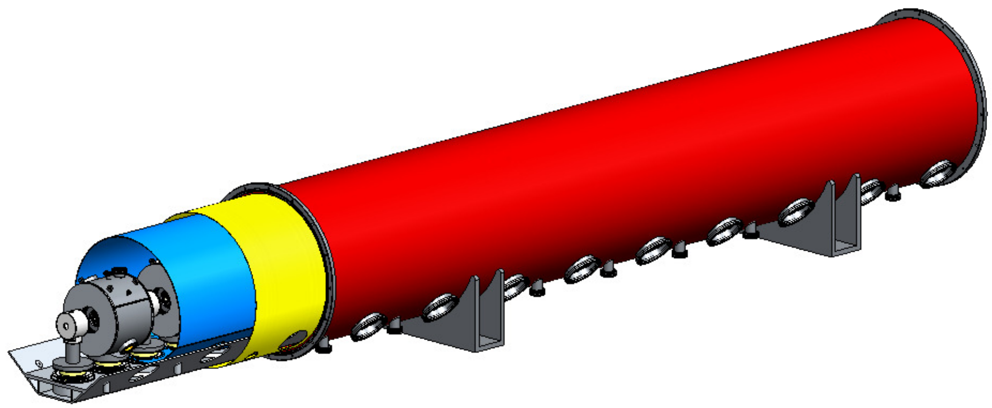






Cryomodule Assembly

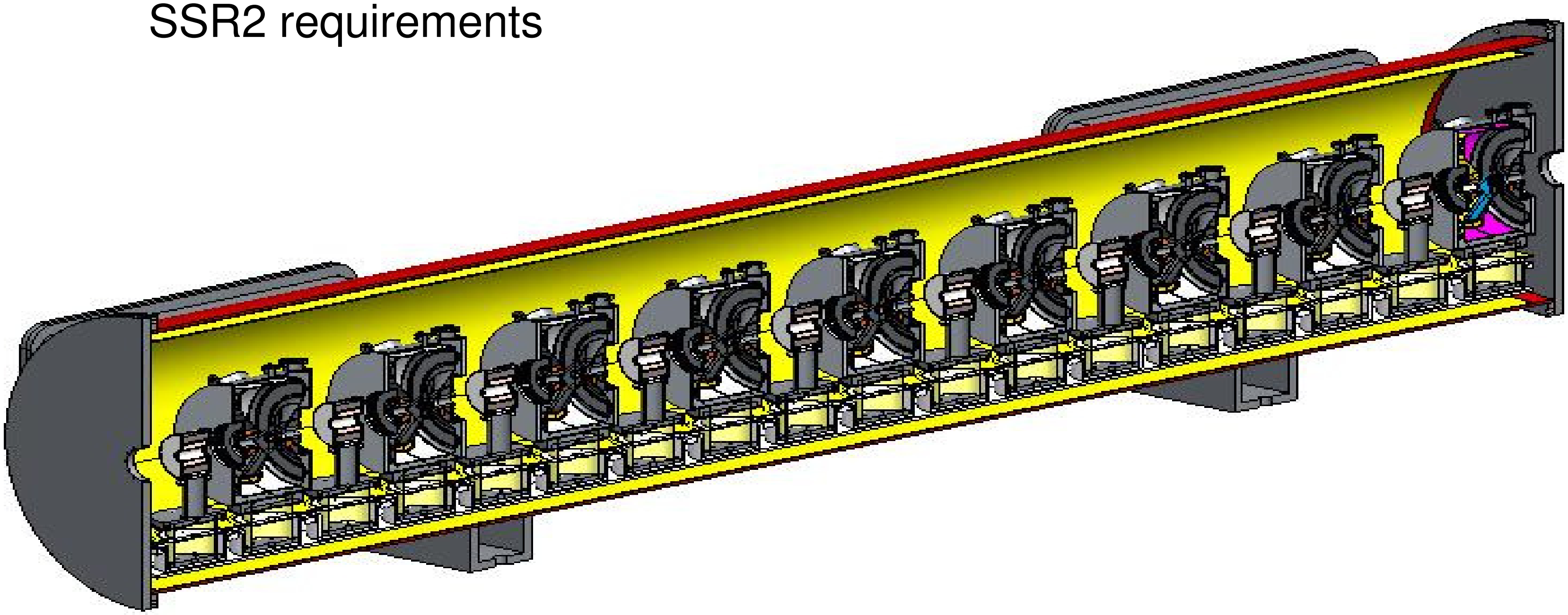




Assemble using the same or similar tooling to that used for ILC final assembly.

SSR1 Cryomodule Model

- Present conception of SSR1 Cryomodules
  - Contain 9 SSR1 cavities and 9 solenoids
  - Project X expects that these designs could be extended to SSR0 and SSR2 requirements

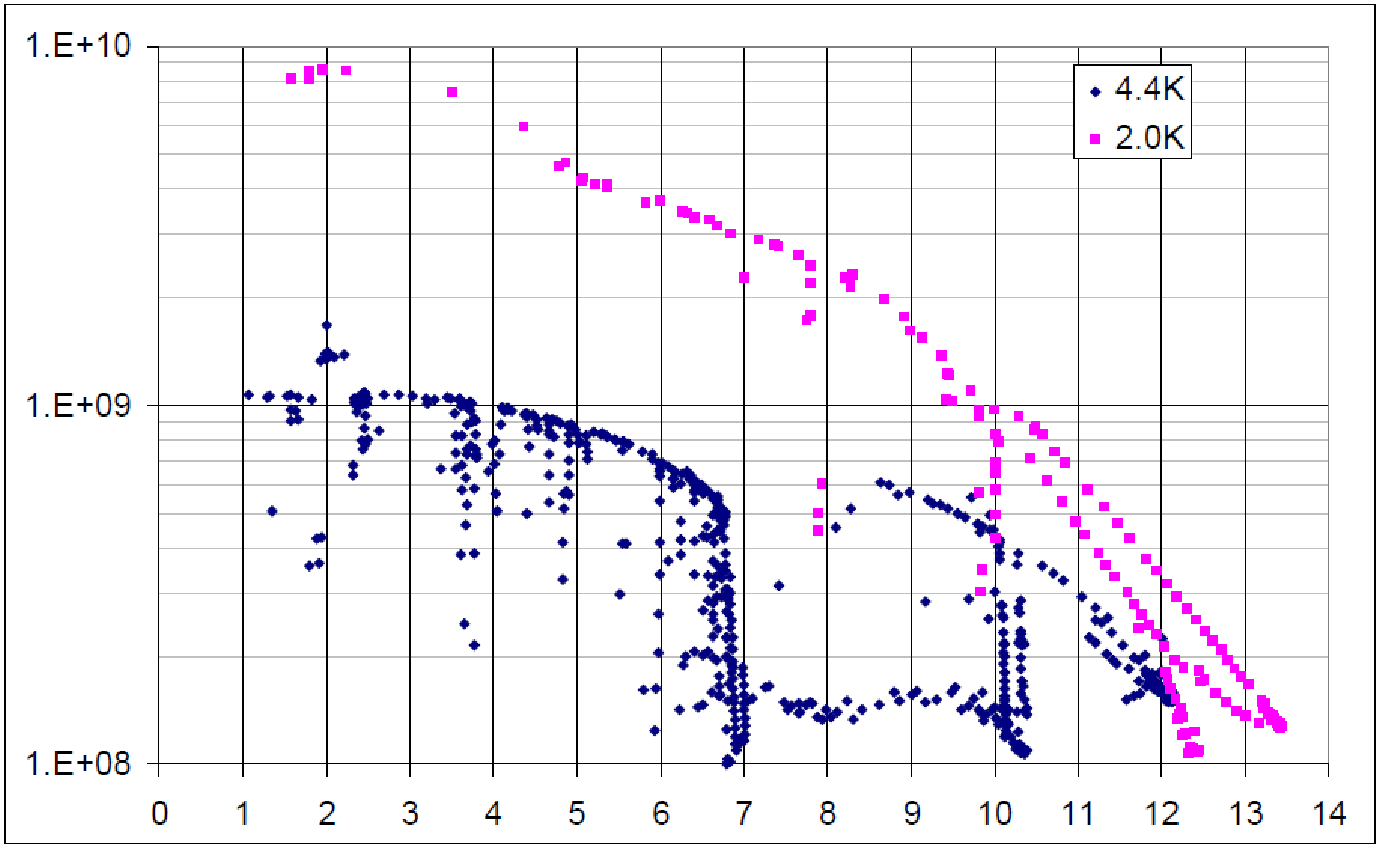


What's Next?

- First tests of SSR1 with tuners in new cryostat with full pulsed power
- Two SSR1 cavities are being fabricated in India at IUAC
- Ten SSR1 cavities are being fabricated by Niowave/Roarke
- Make plans to process these cavities
- Address issues relevant to 2°K CW operation
- Design of SSR0 is beginning
- Cryomodule design work continues
- First beam acceleration through spoke cavities??? – 2012-13-??

Back-Ups

Very early Tests



2008.03.13. 4 hours of work at 2K. Maximum of accelerating gradient reached 13.5MV/m limited by field amplifier power 200 W and field emission.

3rd test history of the cavity SSR1-1 on July 14-17 and 21, 2008.

July 14. Vacuum vessel cooling down started.

July 15. RF test started. Cavity power processed a little at 4K and then cooled down to 2K. Power processing finished at 2K. Results very similar to results of March test.

July 16. "Multipacting/breakdown" in the cavity. About 5 hours in this regime, about 20-50 kV/m

July 17 cavity warmed up.

July 21 cavity cooled to 4.4K and tested. After about 3 hours processing cavity reached 18MV/m. Limited by "Multipacting/breakdown" due to bad vacuum in the cavity, may be caused by leak.

2008.07.24 SSR1-1 3rd cold test results. T.Khabiboulline.