Low Beta Cavity Development for an ATLAS Intensity Upgrade THIOC01

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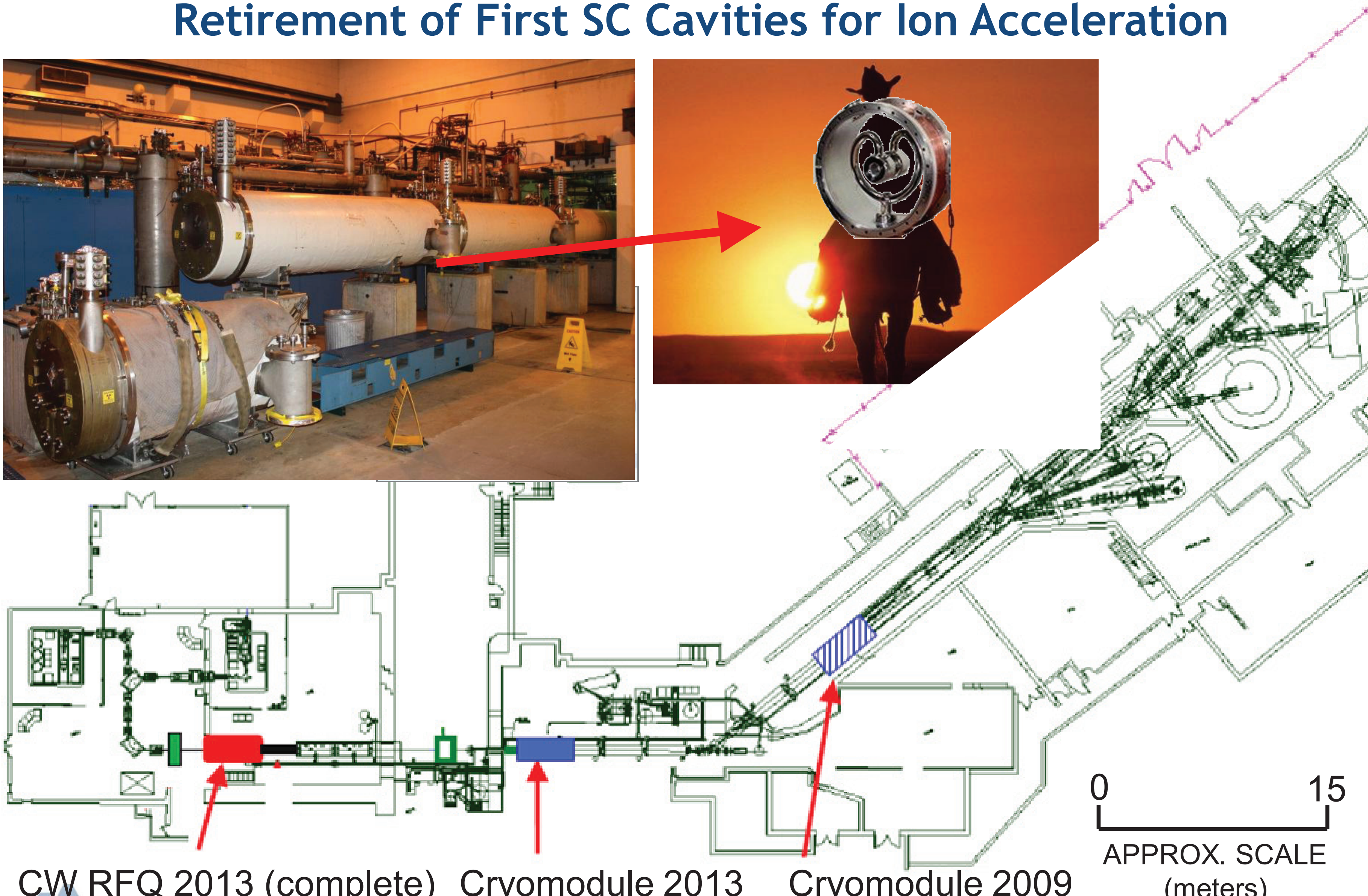
Speaker: Michael Kelly

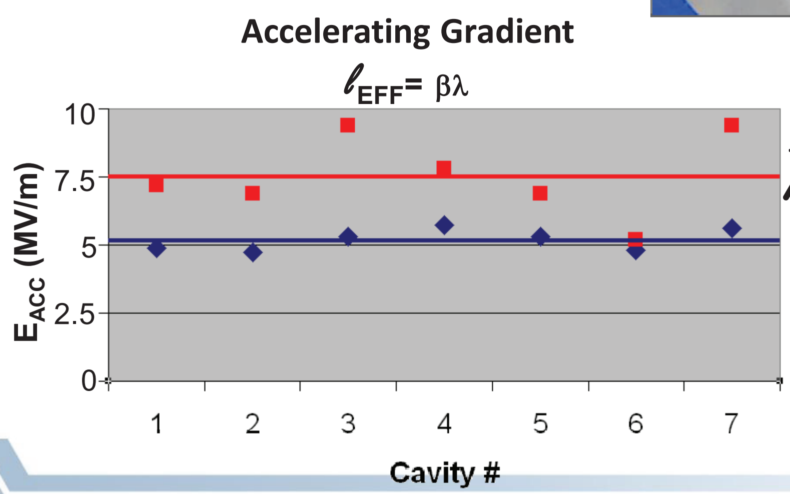
On behalf of: Peter Ostroumov, Zachary Conway, Scott Gerbick, Tom Reid, Ryan Murphy , Mark Kedzie, Sang-hoon Kim, Brahim Mustapha , Sergey Kutsaev

2013 ATLAS Intensity Upgrade
Retirement of First SC Cavities for Ion Acceleration



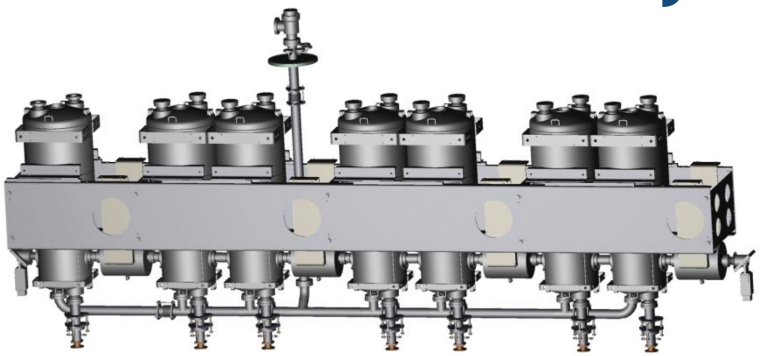
ATLAS Energy Upgrade Cryomodule (2009)

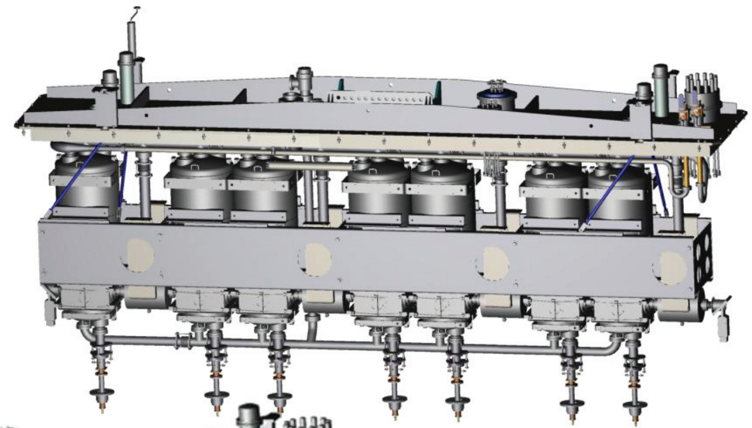
- Seven **β=0.15 quarter-wave cavities** added to the end of the ATLAS linac
- Separate cavity vacuum plus clean room techniques for the first time with low beta module
- Cavities stable at B_{PEAK} (Ave)= 60 mT, B_{PEAK}(Max)=88 mT
- 36 Experiments; 3192 Acceleration hours (~100% availability) for June 2011-June 2013; **14.5 MV in 4.6 m module length** is most SC module voltage per unit length for this beta

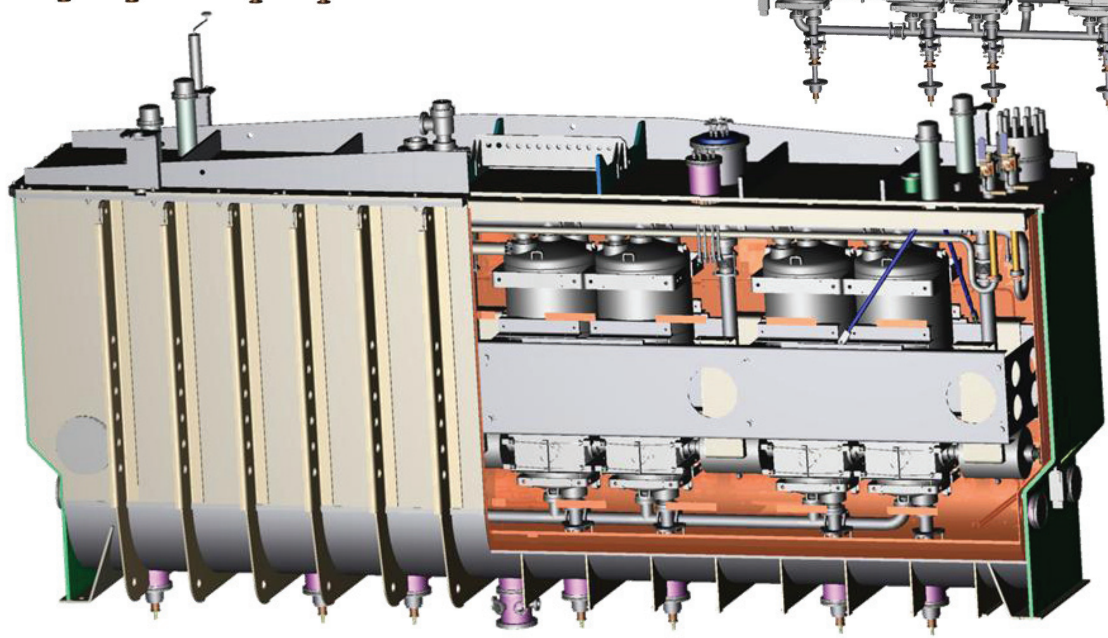


Further +50% with a ↑ coupler upgrade

ATLAS *Intensity* Upgrade Cryomodule (2010-2013)



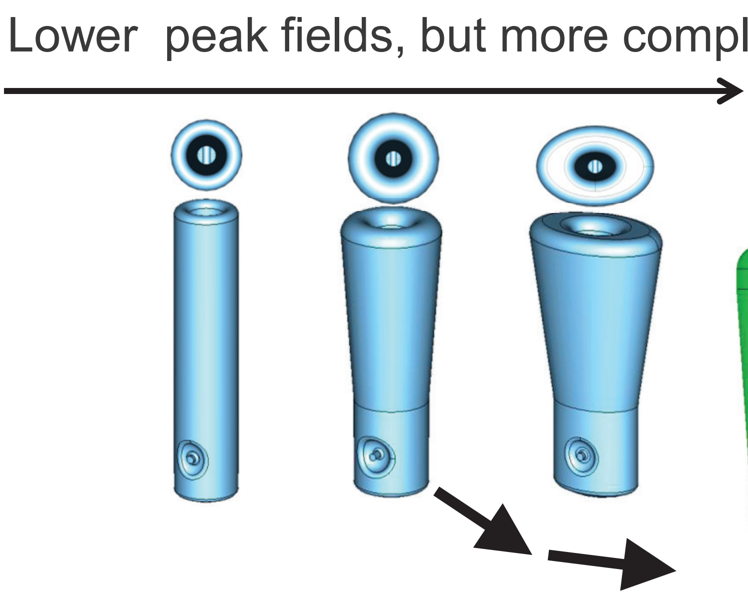


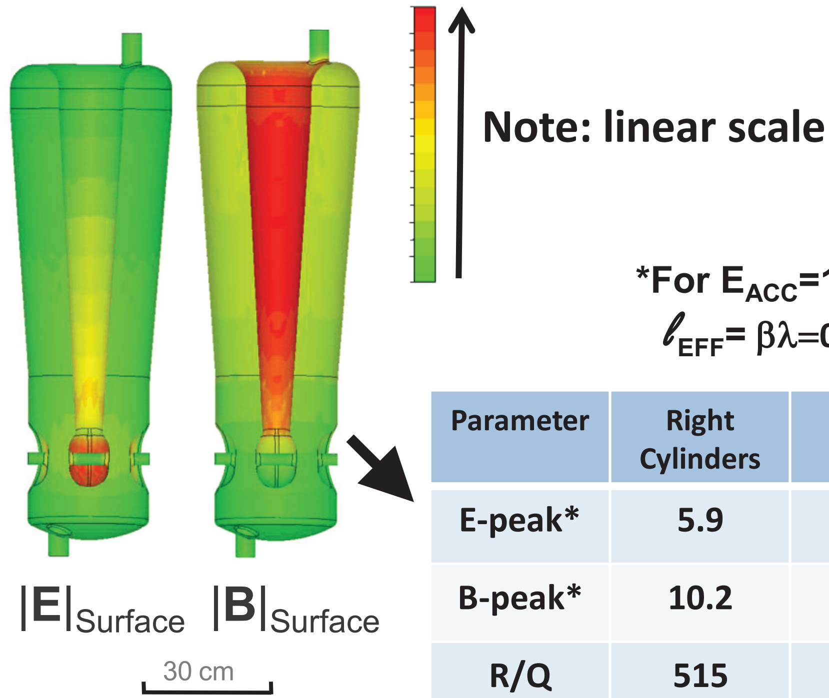


- **7 cavity, 4 SC solenoids, 5-meter long cryomodule, f_0=72.75 MHz, β_G=0.0775**
- **Performance goal: Compared to 2009, achieve overall module voltage 20% higher, 17.5 MV, *even while building for β_G one half value of 2009 cryomodule***

Key Technology Development for ATLAS Intensity Upgrade

New Electromagnetic Design for a Quarter-wave Cavity





*For E_{ACC}=1 MV/m
$\ell_{EFF} = \beta\lambda = 0.31$ m

Parameter	Right Cylinders	Conical shape	Unit
E-peak*	5.9	5.1	MV/m
B-peak*	10.2	7.6	mT
R/Q	515	575	Ohm
QR_S	16.8	26.4	Ohm

The addition of a tapered outer housing allows possibility to gain the equivalent voltage of 2 additional cavities in a 7-cavity module with *no increase in cryomodule length*

Beam Steering Suppression in Quarter-wave Cavities

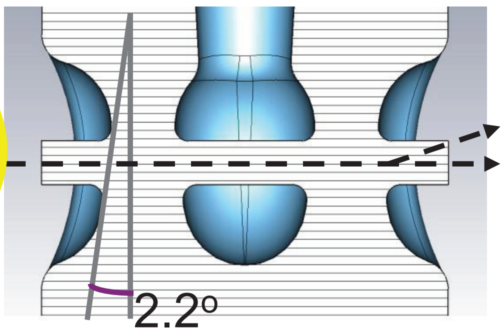
Non-zero B-field on beam axis→steering → emittance growth →beam loss

Remedy: Modify the transverse E field so that its effect cancels magnetic field steering

$$\Delta p_y \sim \frac{1}{\beta^2} \int_{L/2}^{-L/2} E_y \sin(kz+\varphi) + \beta c \cdot B_x \cos(kz+\varphi) dz$$

The correction of the steering and the large 30 mm aperture are key features of 'Intensity' upgrade

Steering Correction



Beam steering angle reduced 10 times from ~1 mrad → ≤0.1 mrad over full velocity range

Central conductor halves with steering corrected faces; correction comes with no additional fabrication cost

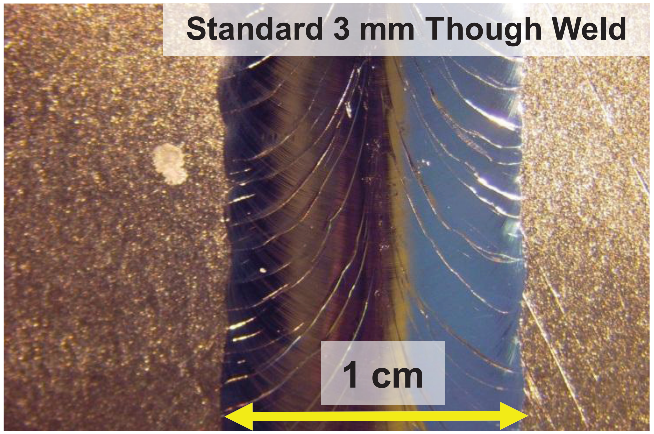
Significant Aspects of Cavity Fabrication

To remove the reliance on a highly skilled machinist, for Nb cuts were made using standard wire electric discharge machining (EDM); little or no possibility for inclusions

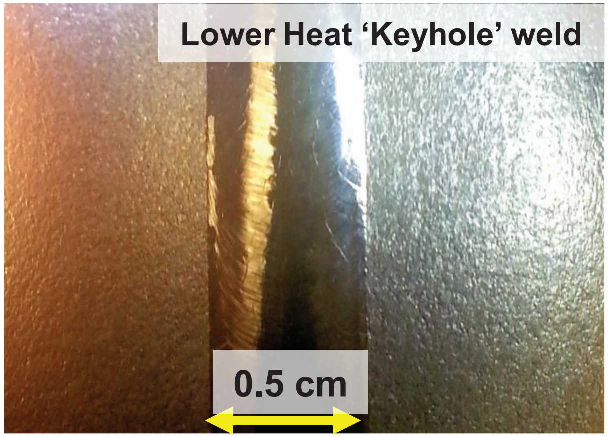

Cavity Bottom Dome


Center Conductor

All welds in regions where $B_{Surface} \geq \frac{1}{2} B_{PEAK}$ are 'keyhole' welds with ¼ total heat as standard 3 mm through weld



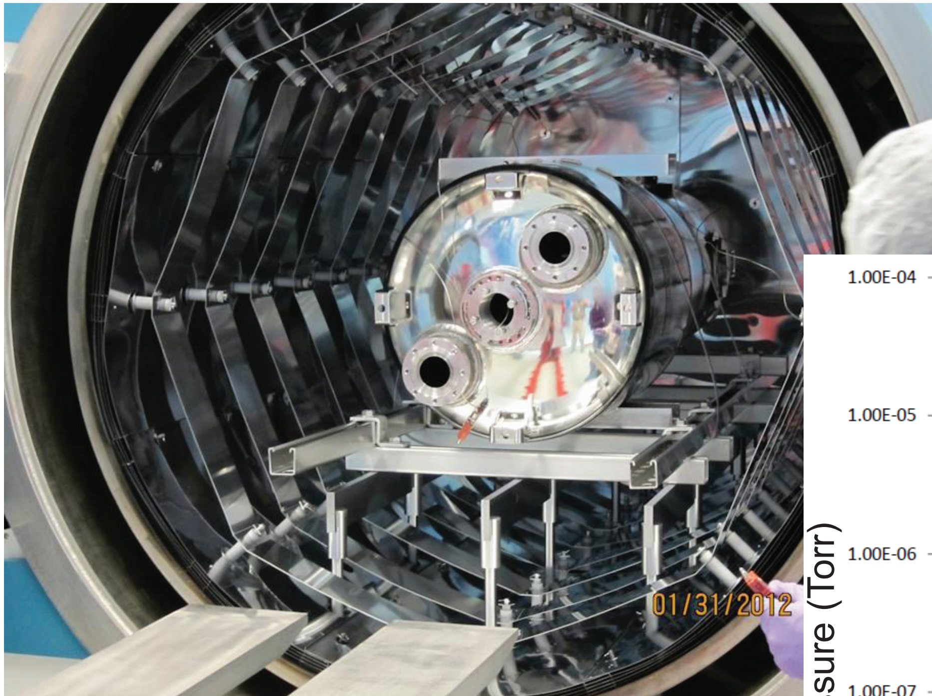
Standard 3 mm Though Weld

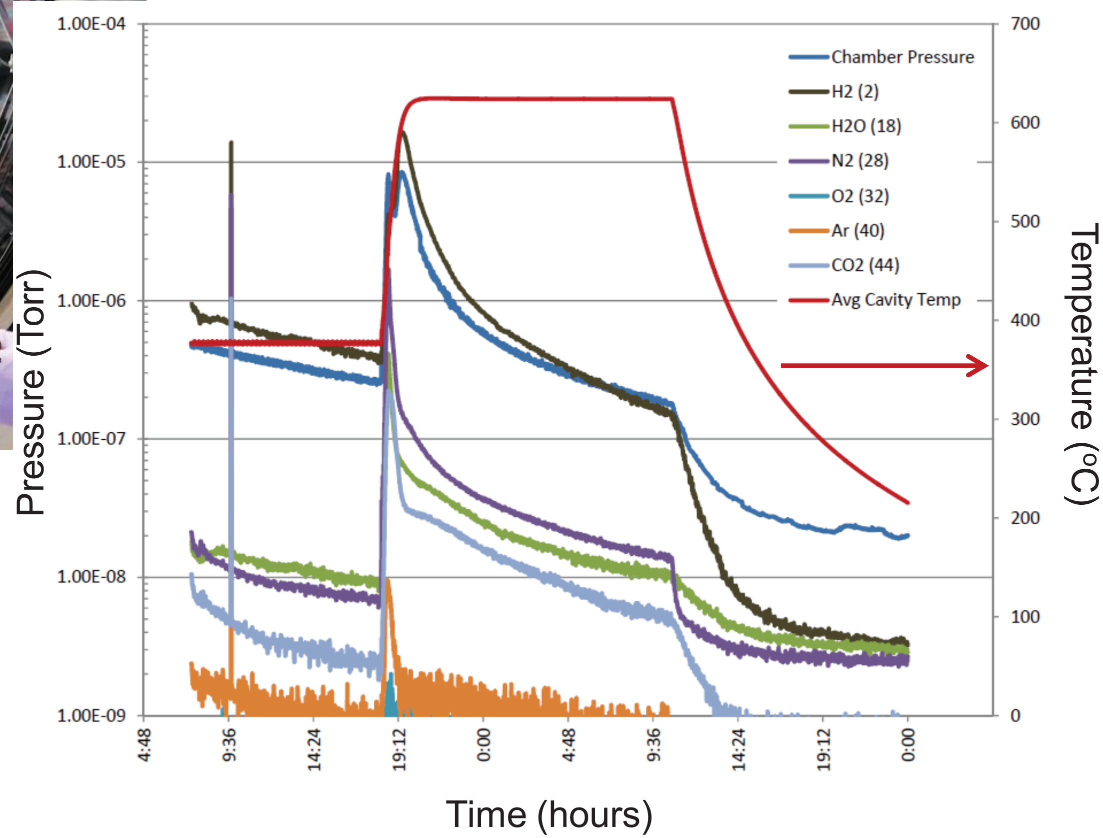


Lower Heat 'Keyhole' weld

Hydrogen Degassing at 625°C for New QWR's

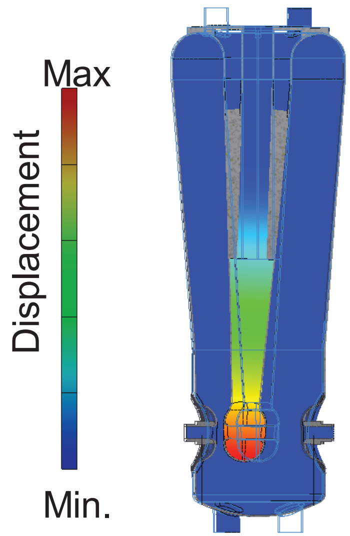
Through Argonne-Fermilab collaboration on SRF





Centering of the QWR Central Conductor

Greatly reduces microphonics from ‘pendulum’ mode in this class of cavities. This is passive, permanent, generally applicable, low risk, and simple



Freq. vs. displacement $f(x) = -1.643x^2 - 0.831x$

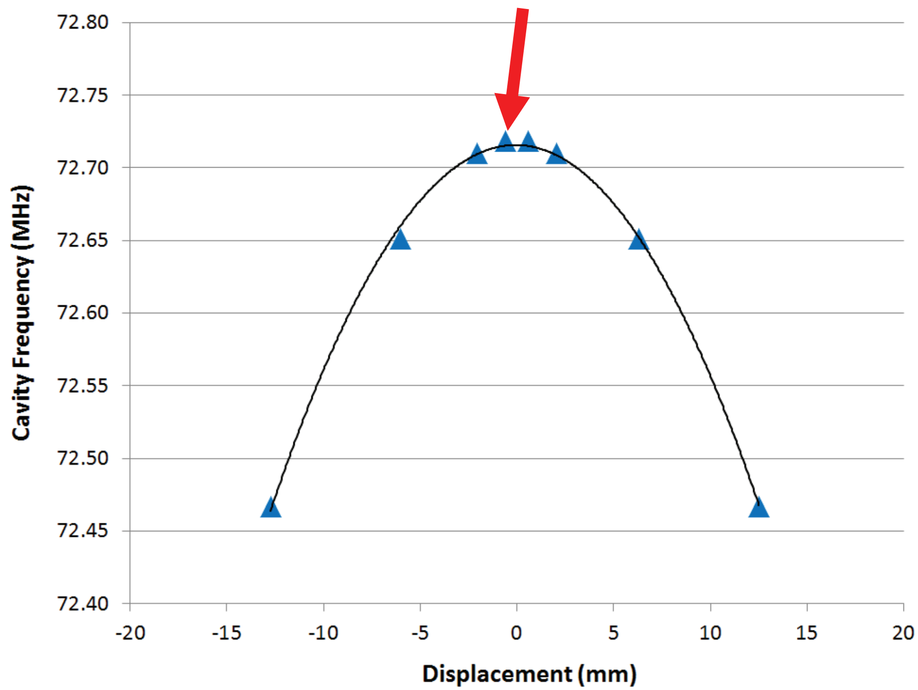
Change in Freq. vs. displacement

$$\frac{\partial f}{\partial x} = -3.286x - 0.831$$

Minimum given by:

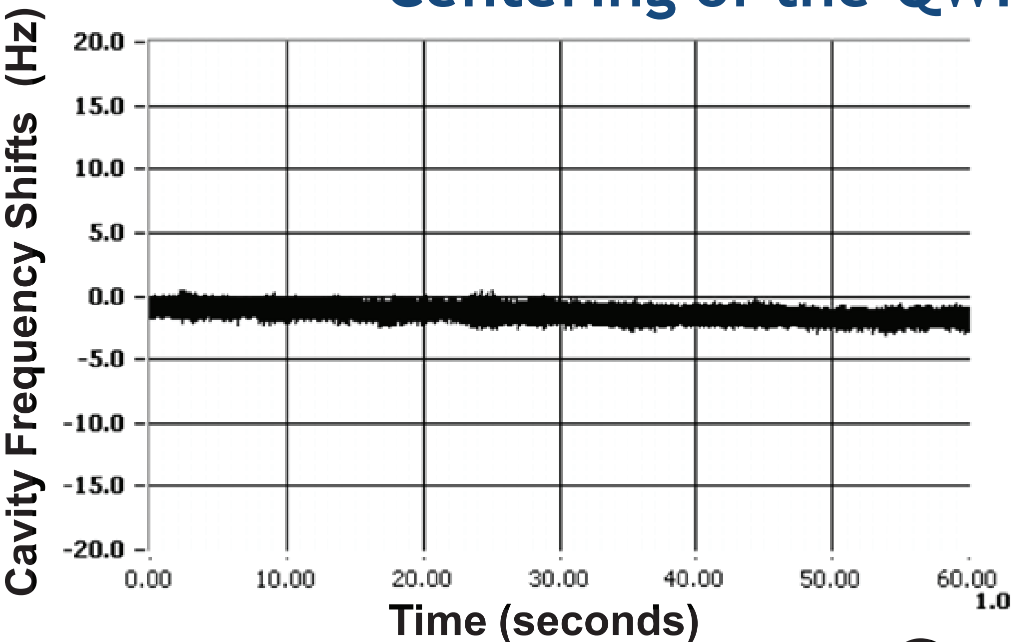
$$\frac{\partial f}{\partial x} = 0 \qquad x_0 \cong 0.25 \text{ mm}$$

Bend the central conductor (inelastically) so it rests at the maximum frequency (minimum of capacitance); microphonics become 2nd order with respect to pendulum vibrations



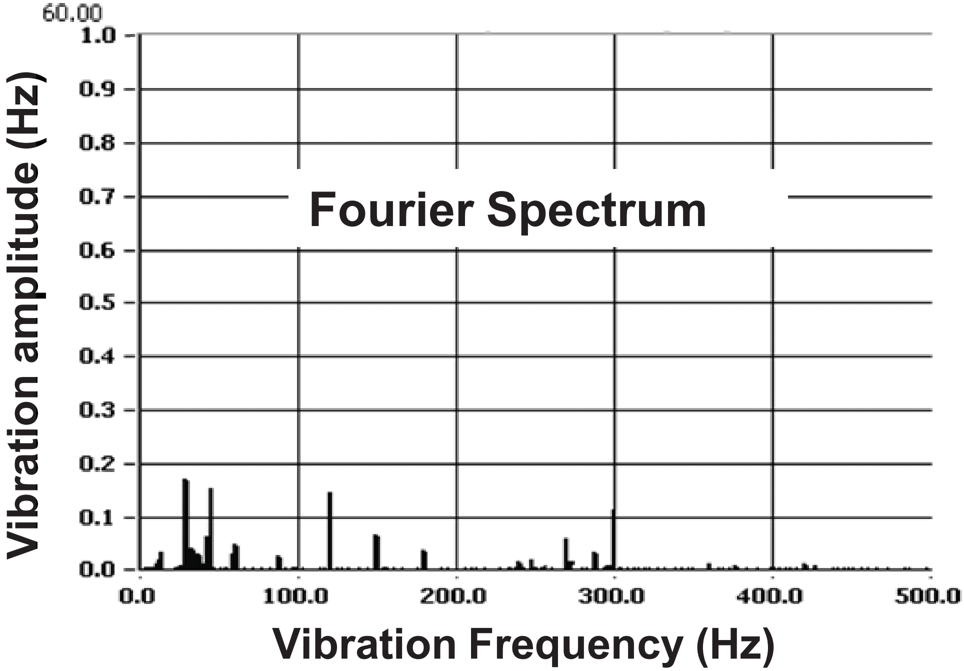
Acknowledge advice from J.R. Delayen, ~2000

Centering of the QWR Central Conductor



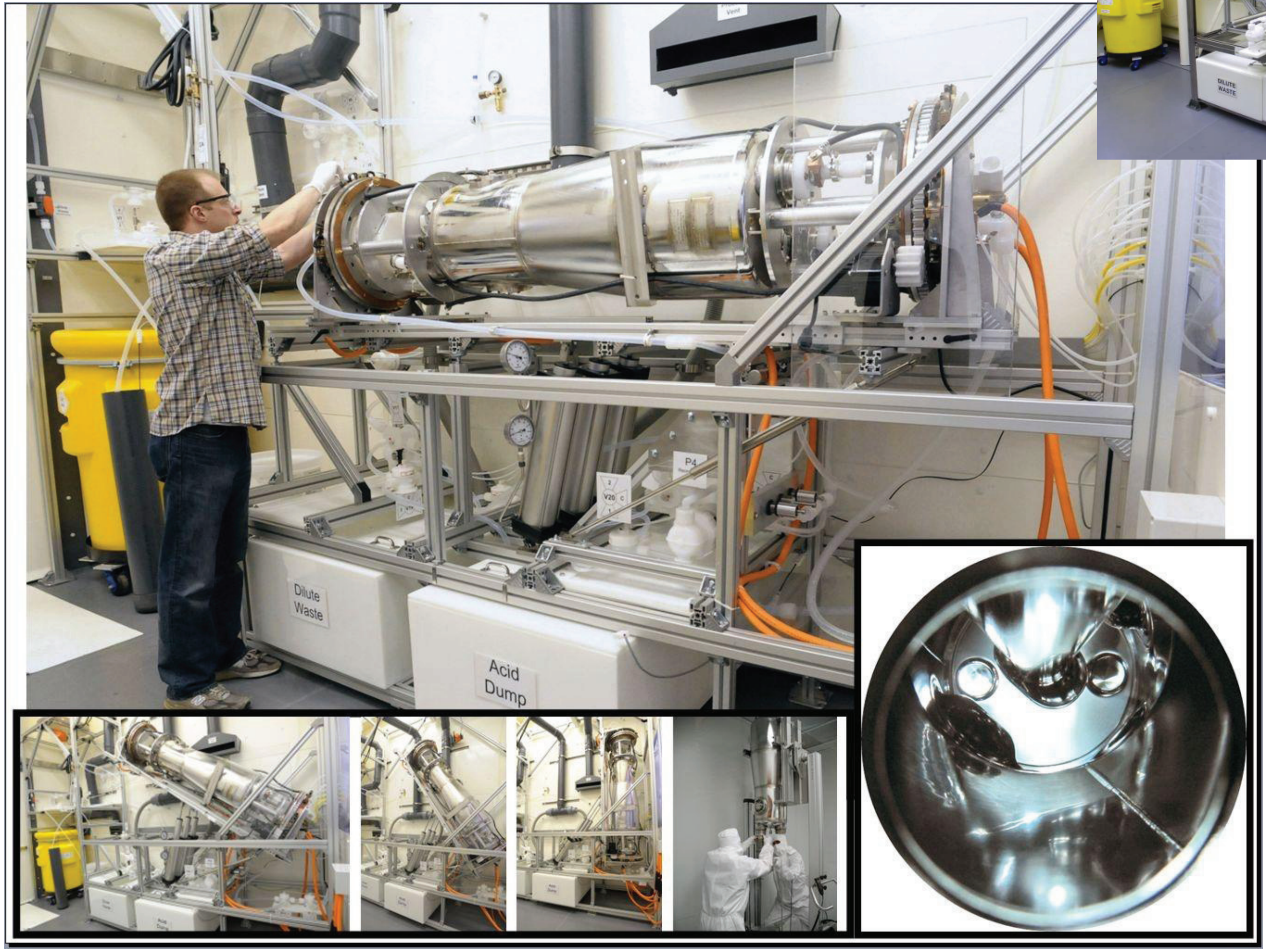
After centering observed microphonics span only 5% of planned fast tuning window

Total microphonics from pendulum mode (~50 Hz mechanical frequency) is small



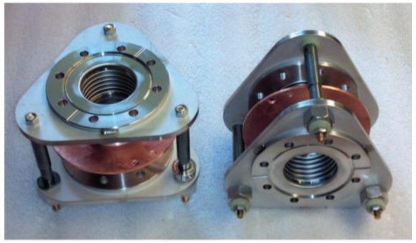
Electropolishing for Co-axial TEM Cavities

Provides the unique capability to electropolish the cavity after all fabrication is complete (including Helium vessel)

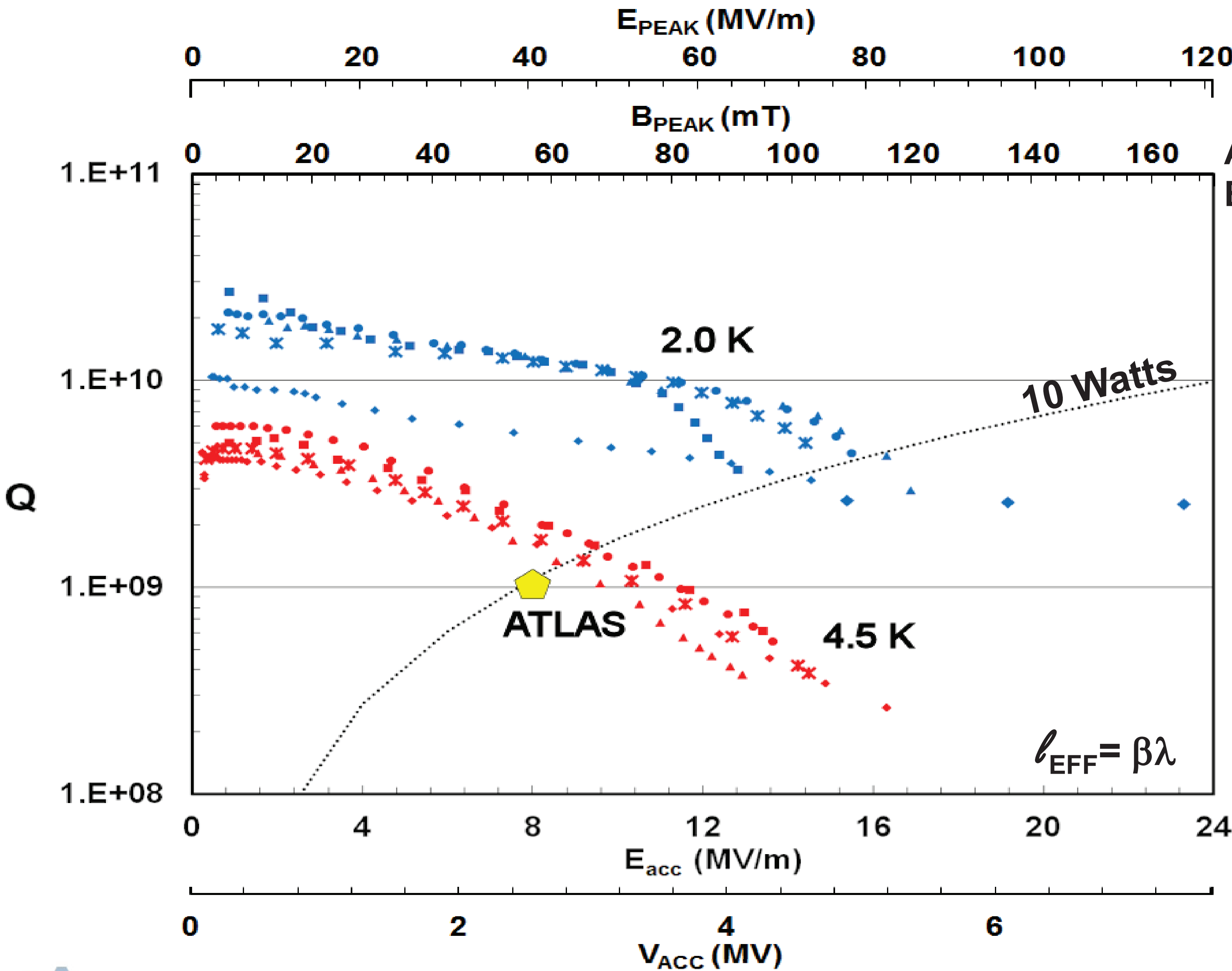


4 kW CW RF Couplers for RF Phase Stabilization

Two ceramic windows (one 80 Kelvin one room temp) with center conductor effectively cooled to 80 Kelvin through the 40 mm diameter, 6 mm cold window. Tested stable at 4 kW with little or no conditioning or multipacting for 72 MHz.

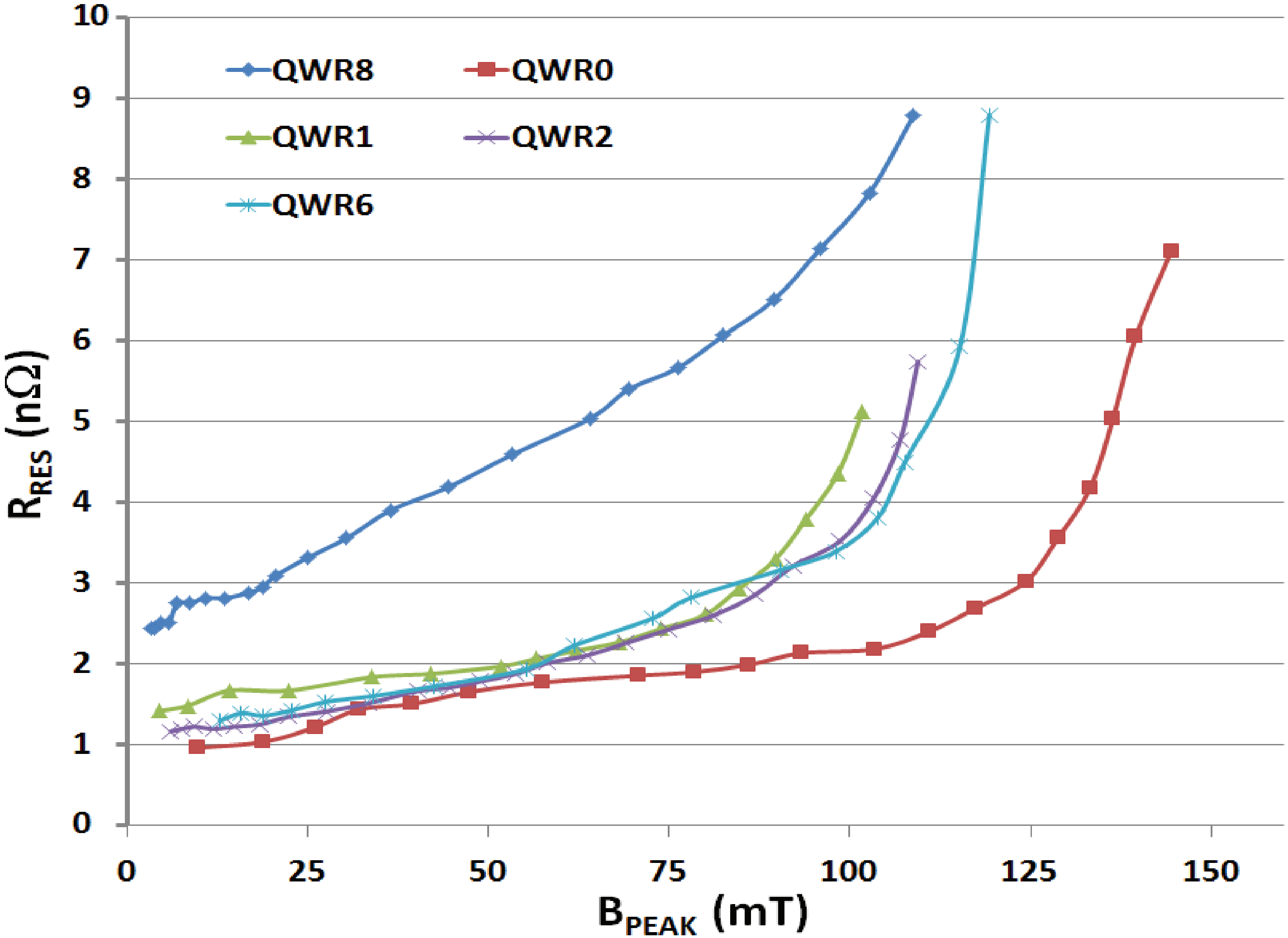


5 of 8 Cavities in Single Cavity Tests



Ave Cavity Max at B_{PEAK}=129.6 mT

Resistivity, G/$Q_{measured}$, Taken From 2 K Data

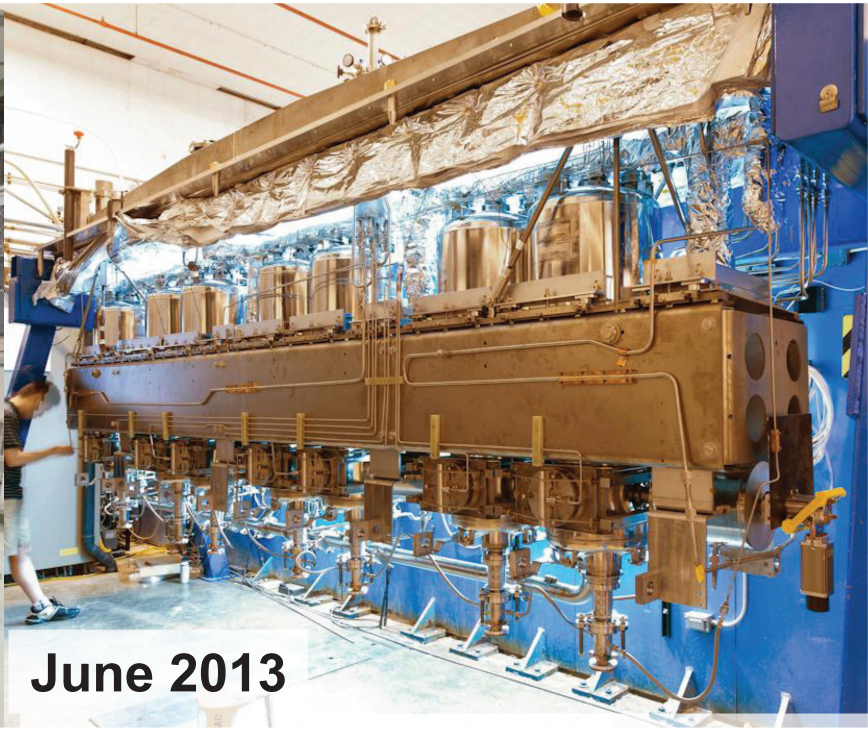


Test Conditions

- T = 2.0 Kelvin (BCS negligible)
- CW operation
- B_{EXT} = 15 mG in the region of the cavity
- Cool down rate ≈ 1 K/min through 9.2 K

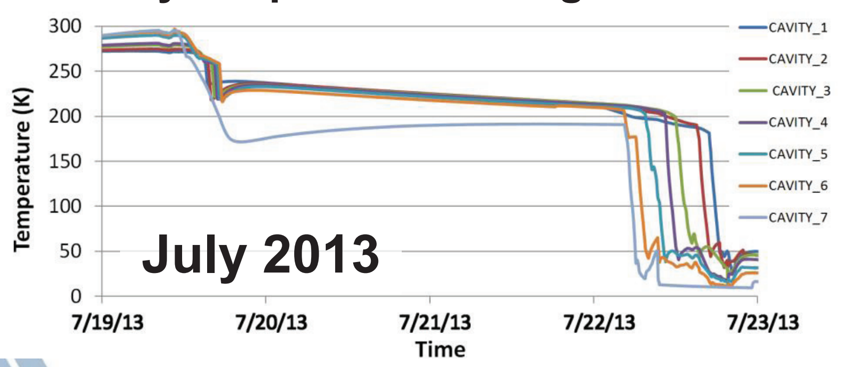
Cavity String Assembly and Cooldown

Jan. 2013



June 2013

Cavity temperature during 1st cool down



August 2013 (Test for 2 wks)

- All cavities $E_{ACC}\geq 10$ MV/m
- Tuners cycled through full range
- Low microphonics, +/- 2 Hz for periods of minutes up to days
- Solenoids aligned to 120 μm RMS

October 2013

- Need to place string in stand (above) and
- Replace pickup loops (too much coupling)
- Squeeze one cavity by +5 kHz

Summary

Technology improvements for TEM-mode cavities (some difficult or impossible without modern simulation codes) are built into new ATLAS cavities

- Low surface fields and higher accelerating gradient than for cylindrical geometries
- Little or no sensitivity to external Helium pressure changes or pendulum mode vibrations
- Magnetic steering correction using a transverse E-field (correction is relatively insensitive to beam velocity with no sacrifice of aperture)

Fabrication and processing have substantially improved since ATLAS 2009 upgrade

- Electropolishing for new quarter wave cavities (or any coaxial TEM cavity with proper ports) is an improved version of ILC system and was used for all seven complete cavities

Technology improvements are general in nature may be applied to most future TEM cavities