Production 72 MHz Beta=0.077 Superconducting Quarter-wave Cavities for ATLAS

2012 Heavy-Ion Accelerator Technology Conference

Speaker: Mike Kelly
Physics Division

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Outline and SRF Group

Outline

I. Overview of recent ATLAS SC cryomodules

II. Key developments for ATLAS and other ion linacs

Team working for SC ion linacs at ANL

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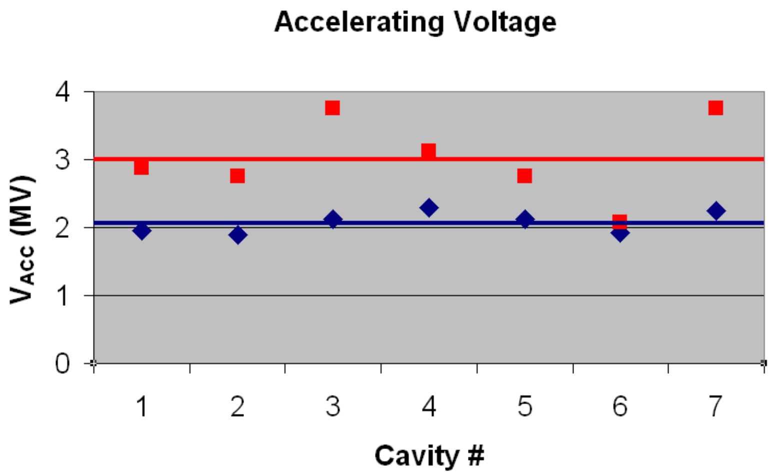
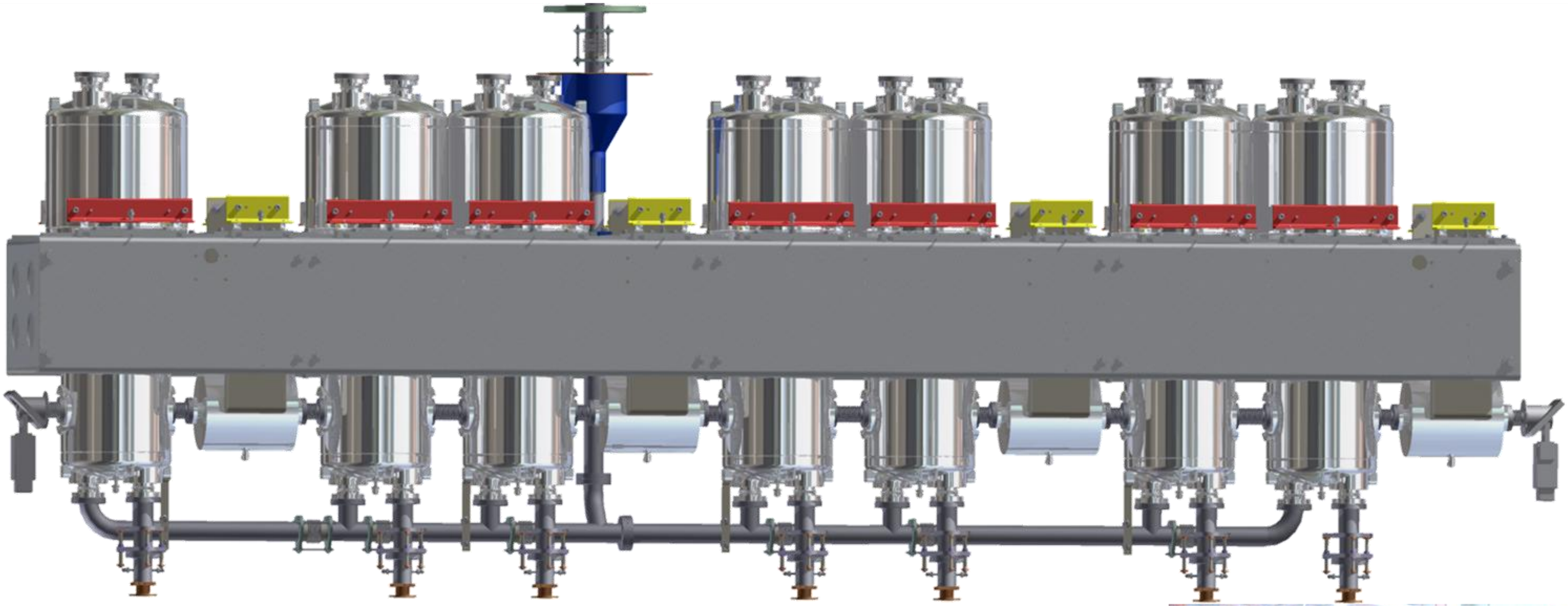
I. Present Low-β Technology for ATLAS

- 2009 Cryomodule; seven **β=0.15 quarter-wave cavities** added to the ATLAS heavy ion linac
- Separate cavity vacuum space
- Maximum voltages of **3.75 MV per cavity** have been achieved (E_{PEAK} = 48 MV/m, B_{PEAK} = 88 mT)
- Real gradient for operational cavities of **14.5 MV in 4.6 m module length**; highest for any SC linac in this range of beta



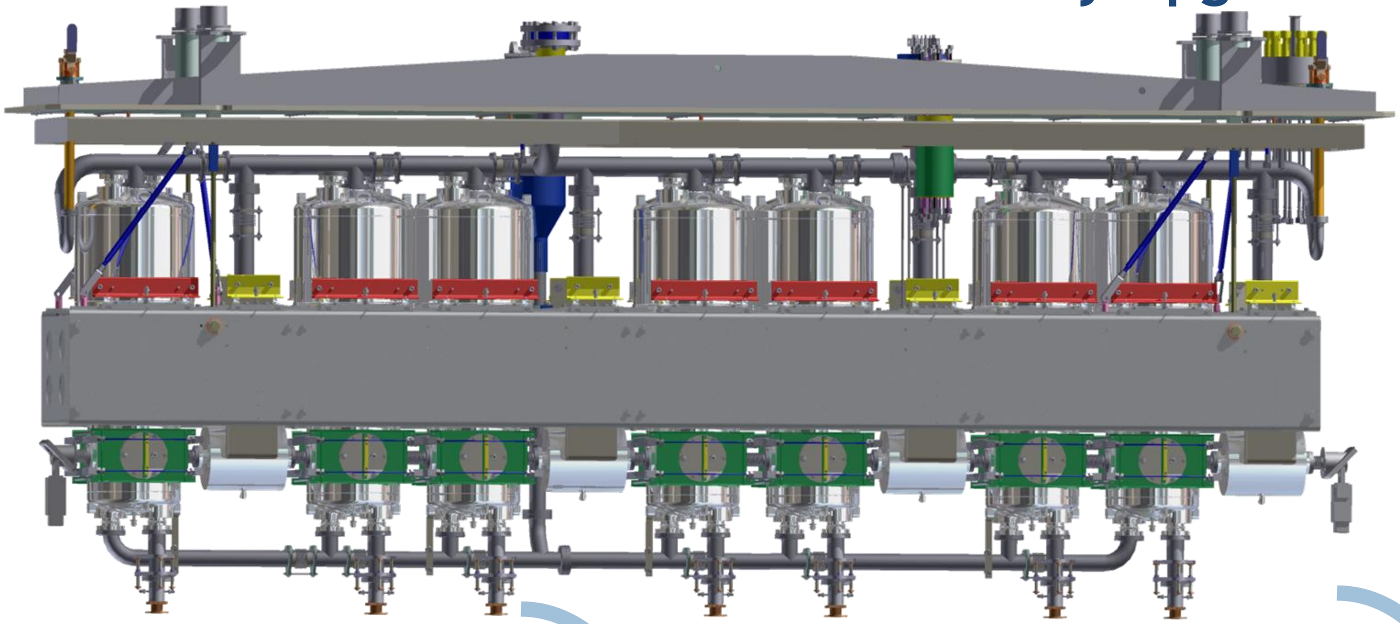
I. 2012 ATLAS Intensity Upgrade Cryomodule



Clean Room Assembly

- **Seven β=0.077 quarter-wave cavities, four 9-Tesla SC solenoids**
- **17.5 MV in 5 meter module length**
- **1st ANL module with 4 kW cw high-power rf coupler (already tested at full power)**

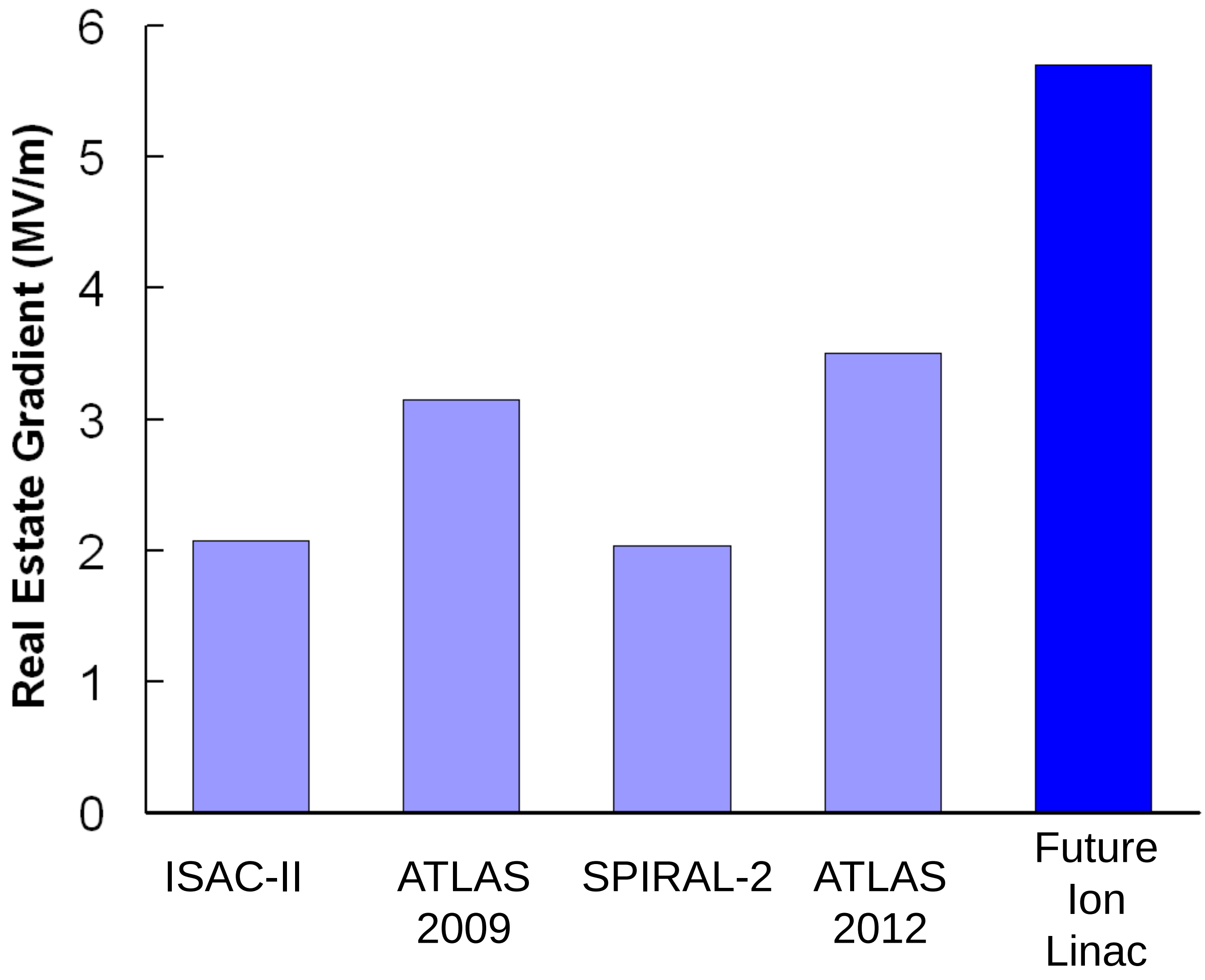
I. 2012 ATLAS Intensity Upgrade Cryomodule



Complete sealed string assembly

Vacuum vessel + magnetic + thermal shielding

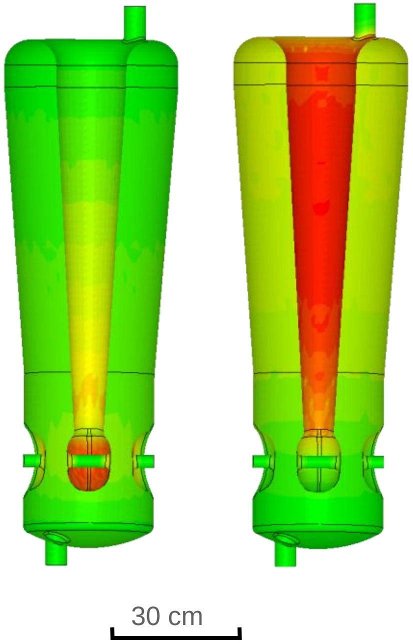
I. Real Estate Gradient for Today's State-of-the-Art (β~0.6-.15)



Part II. Key Technical Developments for ATLAS Low-β SC Cavities

II. Electromagnetic Design for a Quarter-wave Cavity

Surface Fields



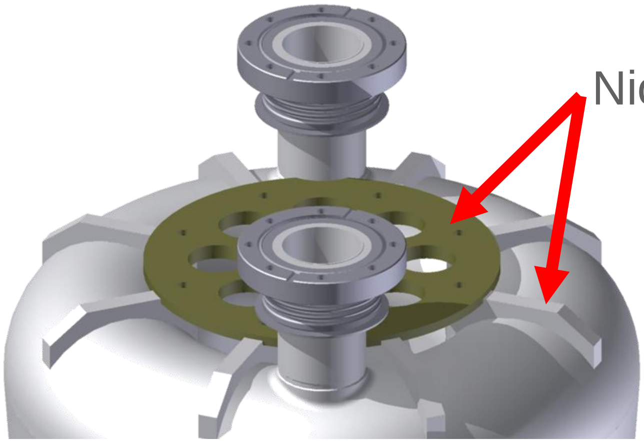
Die formed center conductors

Parameter	Value	Units
Frequency	72.750	MHz
Peak Beta	0.077	
QRs	26.4	Ohm
R/Q	576	Ohm
$\beta\lambda$	31.75	cm
Design Voltage	2.5	MV
$\Delta f / \Delta E^2_{acc}$	-1.9	$Hz/(MV/m)^2$
$\Delta f / \Delta P$	-2.6	Hz/Torr
Tuning Sensitivity	~8	kHz/mm
At Eacc= 1 MV/m		
Stored Energy	0.375	Joule
E_{peak}	5.16	MV/m
B_{peak}	7.62	mT

Electromagnetic Design

- Low surface fields consistent with fabrication/processing/cleaning
- Steering corrected drift-tube face to eliminate beam steering
- Tapered outer housing reduces B_{PEAK} by ~20% compared to cylindrical outer housing

II. Mechanical Design for a Quarter-wave Cavity



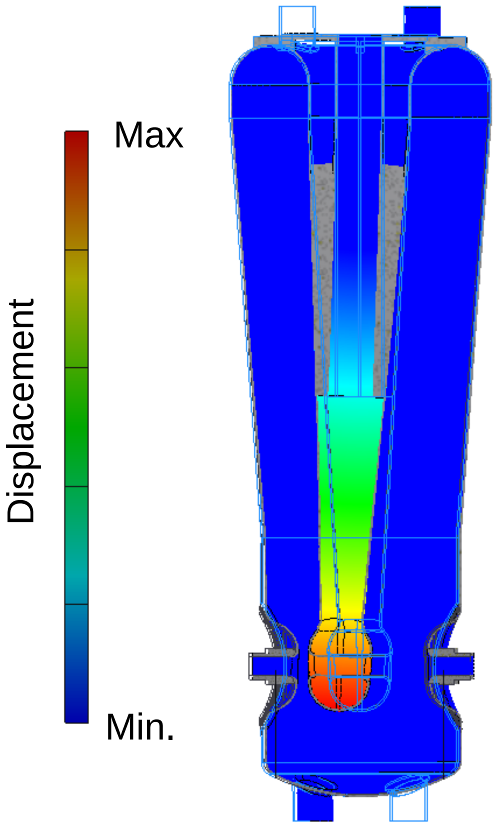
Niobium reinforcing ribs and a titanium plate to stiffen center conductor

Stiffening in E-field region, in part, to reduce $\Delta f/\Delta p$

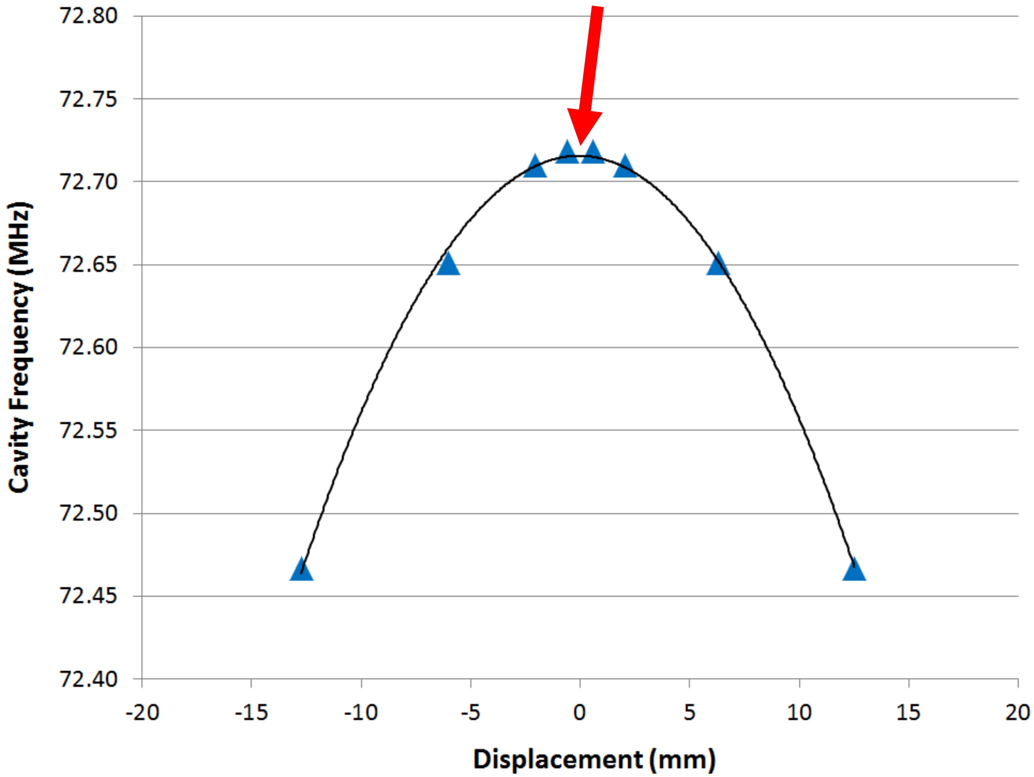
ATLAS operates at 4 Kelvin:

- ***Very small helium pressure sensitivity by design*** $\Delta f/\Delta p$ = -2.6 Hz/Torr
- ***Enabled through modern FEA simulations (ANSYS)***

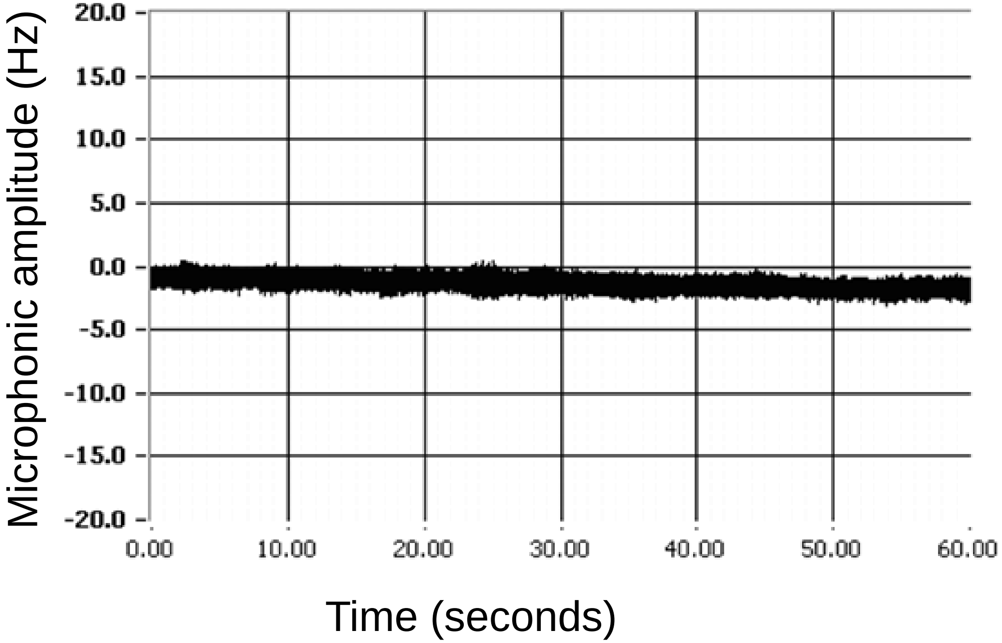
II. Mechanical Design: Cavity Frequency Versus Displacement of the Center Conductor

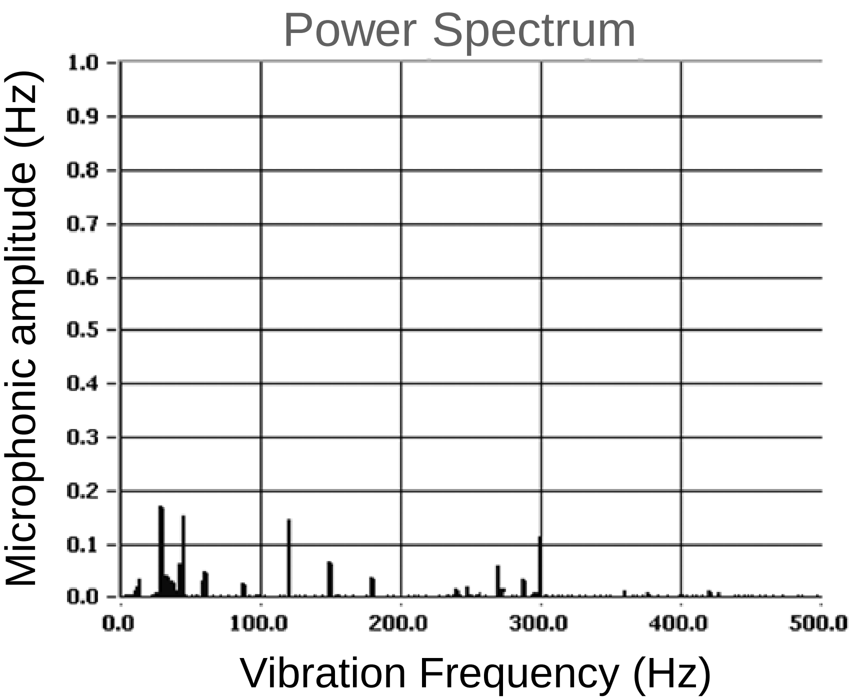


Maximum cavity frequency when center conductor is electrically centered (vibration here cause only 2nd order frequency shifts!)



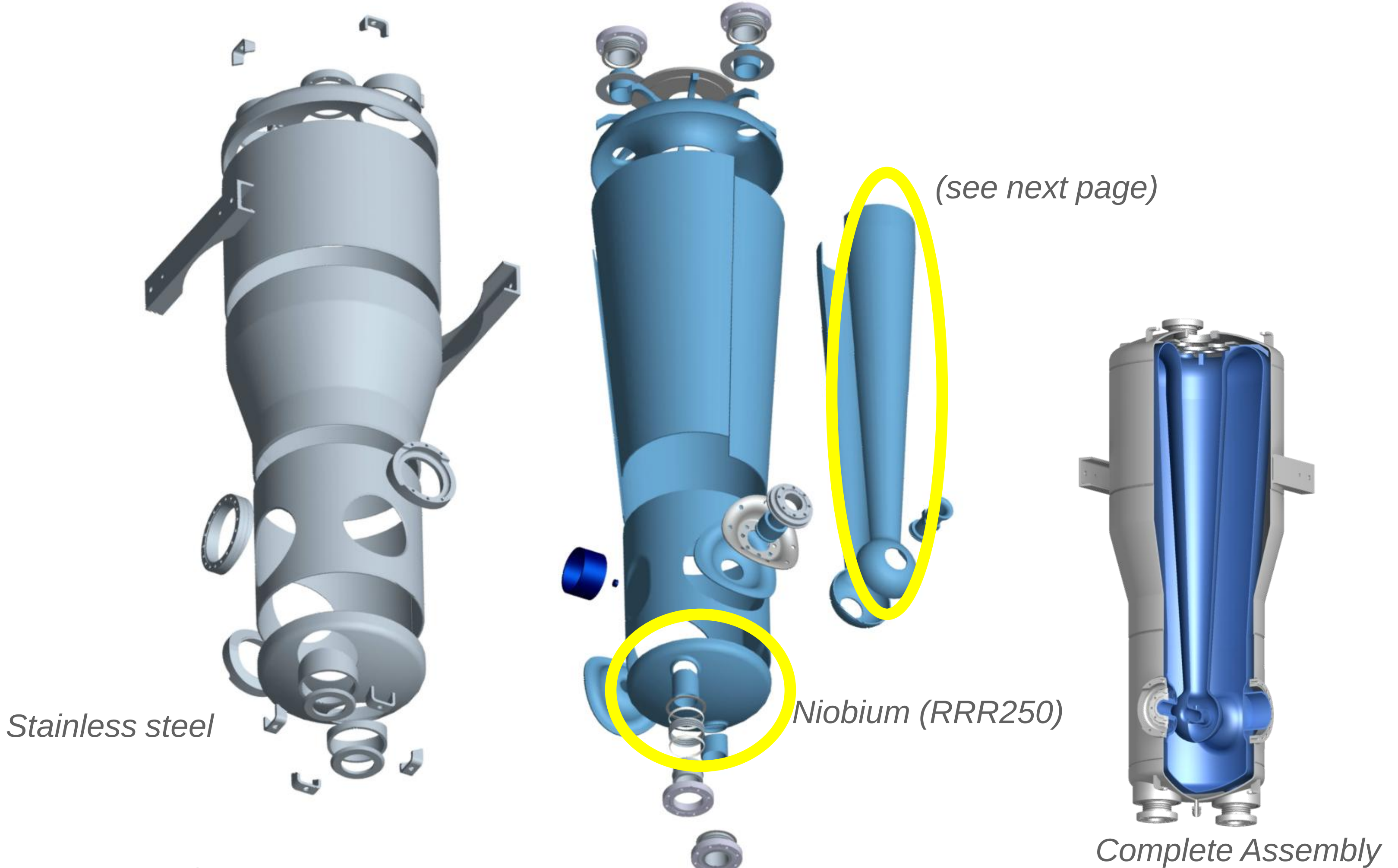
II. Mechanical Design: Near Elimination of Microphonics in 72 MHz Quarter-wave Cavity





- Electrical centering of center conductor plus small $\Delta f/\Delta p$ nearly eliminates microphonic detuning

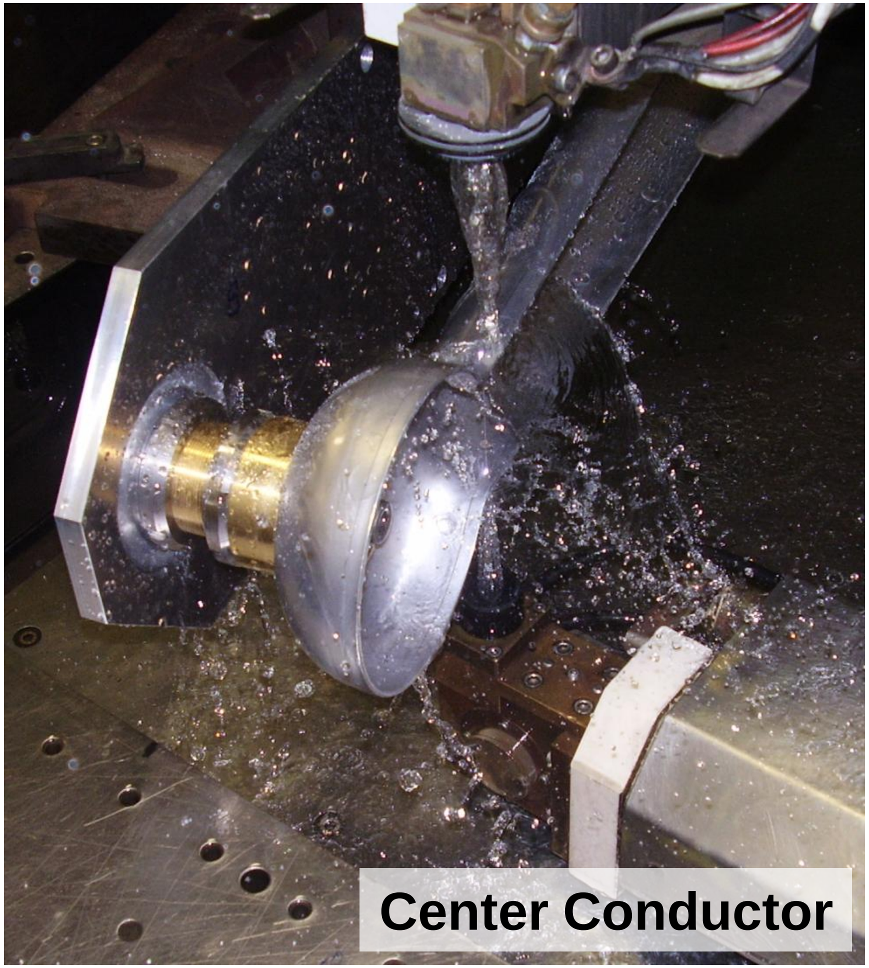
II. Parts design for ANL Low-Beta SC Cavity



- Niobium is hydroformed or deep drawn all with blended transitions
- Stainless steel helium vessel assembled around the e-beam welded niobium cavity
- Ports at ends of cavity specifically for electropolishing

II. Cavity Fabrication by Wire EDM


Cavity Bottom Dome


Center Conductor

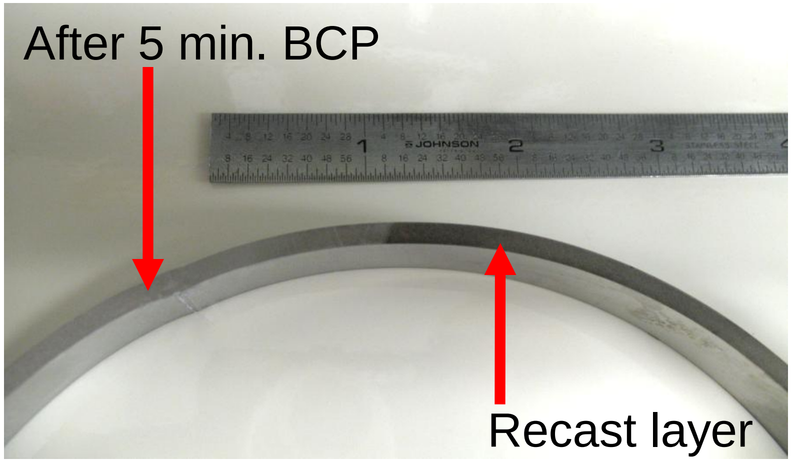
Wire EDM at Adron

II. Cavity Fabrication by Wire EDM

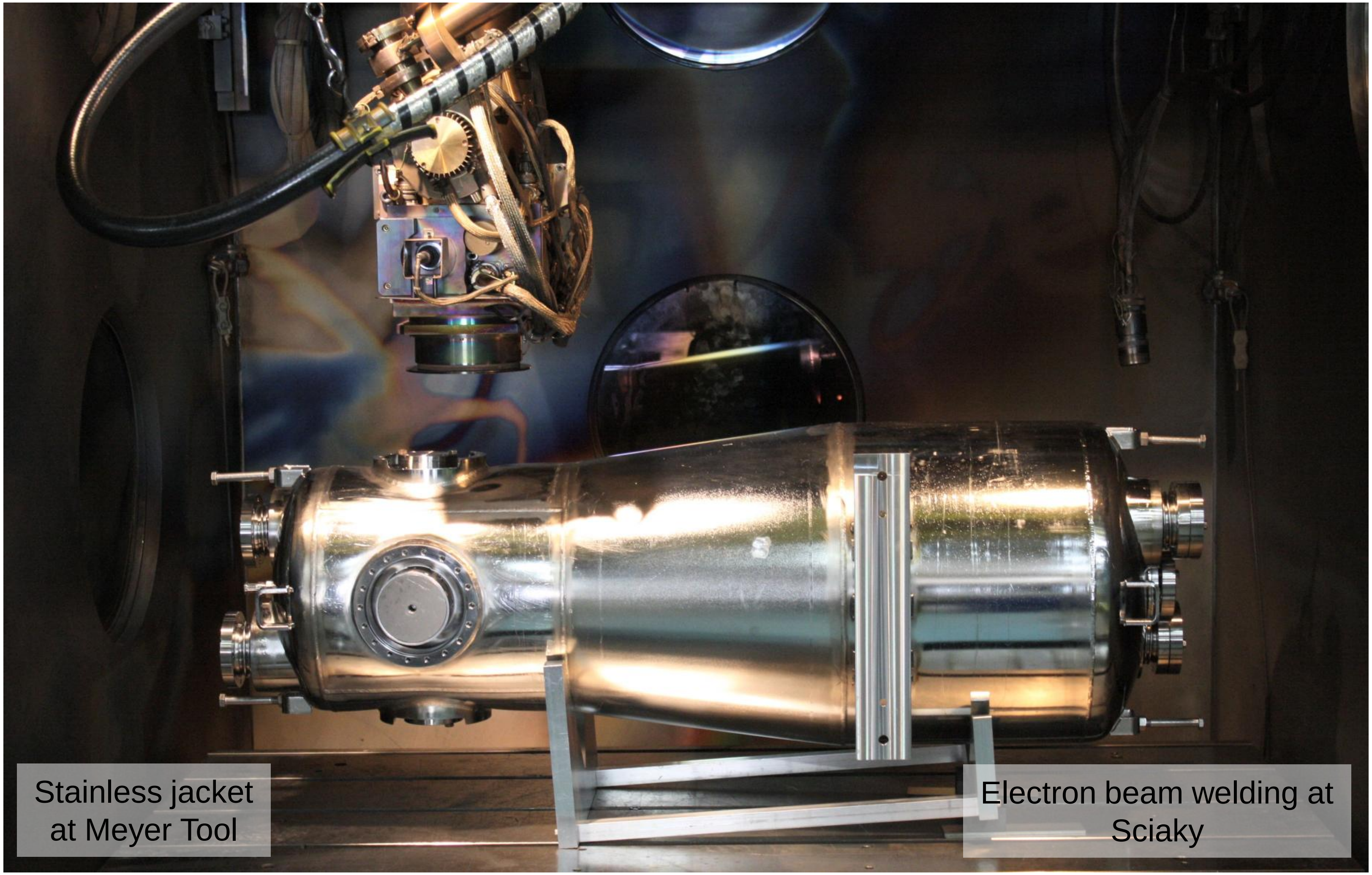
- ***Essentially no possibility for inclusions***
- ***No expert or special EDM techniques needed (traditional niobium machining requires a machinist highly skilled in niobium machining)***
- ***Nothing to support the notion that*** "Wire EDM is a filthy process"
- Recast layer 5 microns thick
  - Oxide of brass and niobium
  - Completely removed with a 5 minute buffered chemical polish (not so with EP)

Other Features of Wire EDM:

- 25 micron tolerances
- Can slice (like bread machine) or drop down from above with "sinker EDM"
- Example: Cuts a 30 cm diameter 3 mm thick niobium cylinder in 3 hours

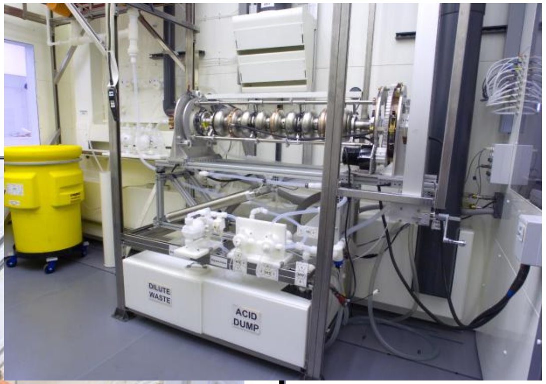


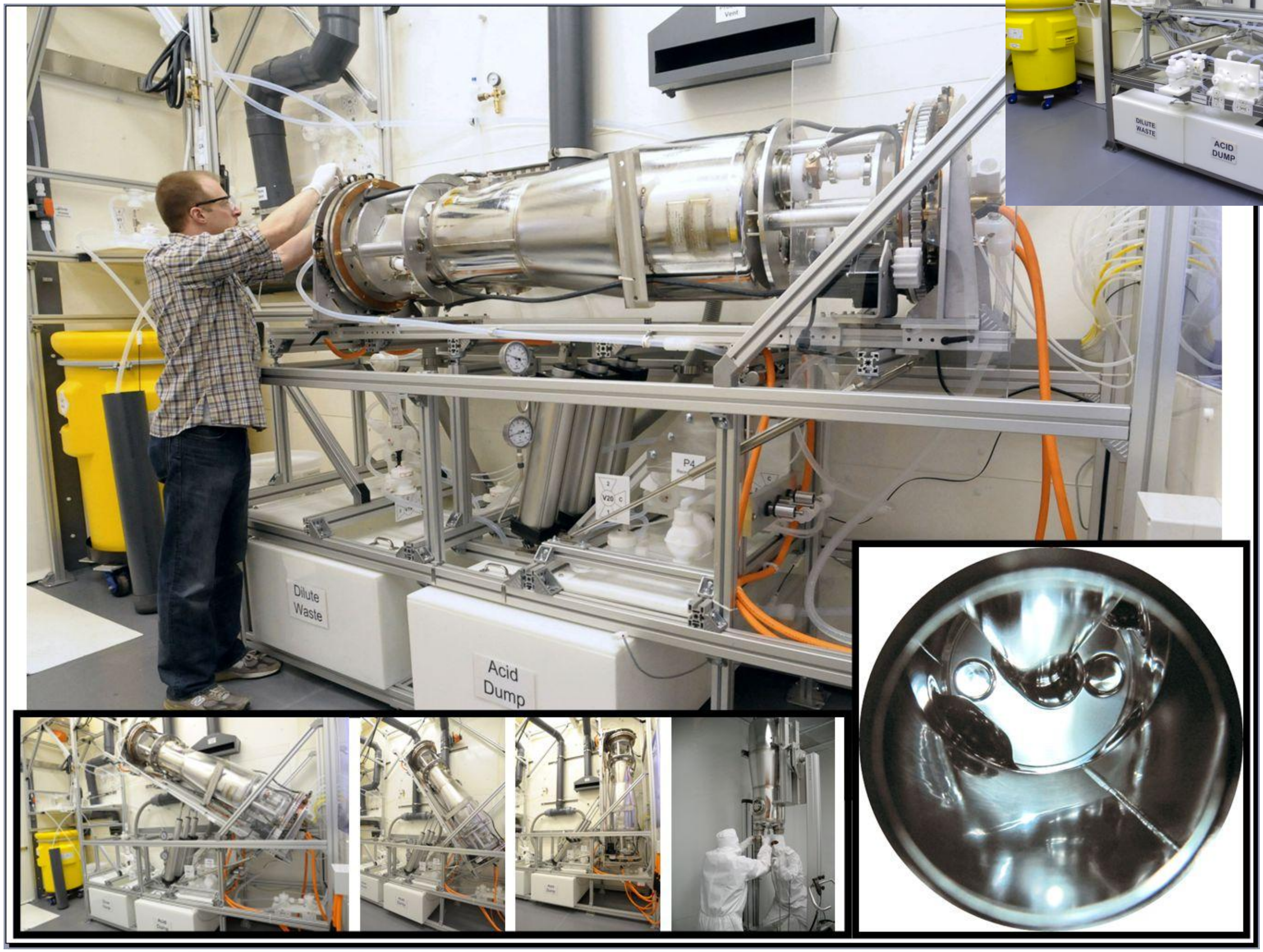
II. Final Weld on Helium Vessel (ASME stamped)



II. Key Technical Development for a Low-Beta SC Cavity

A new electropolishing system for complete low-β SC cavities

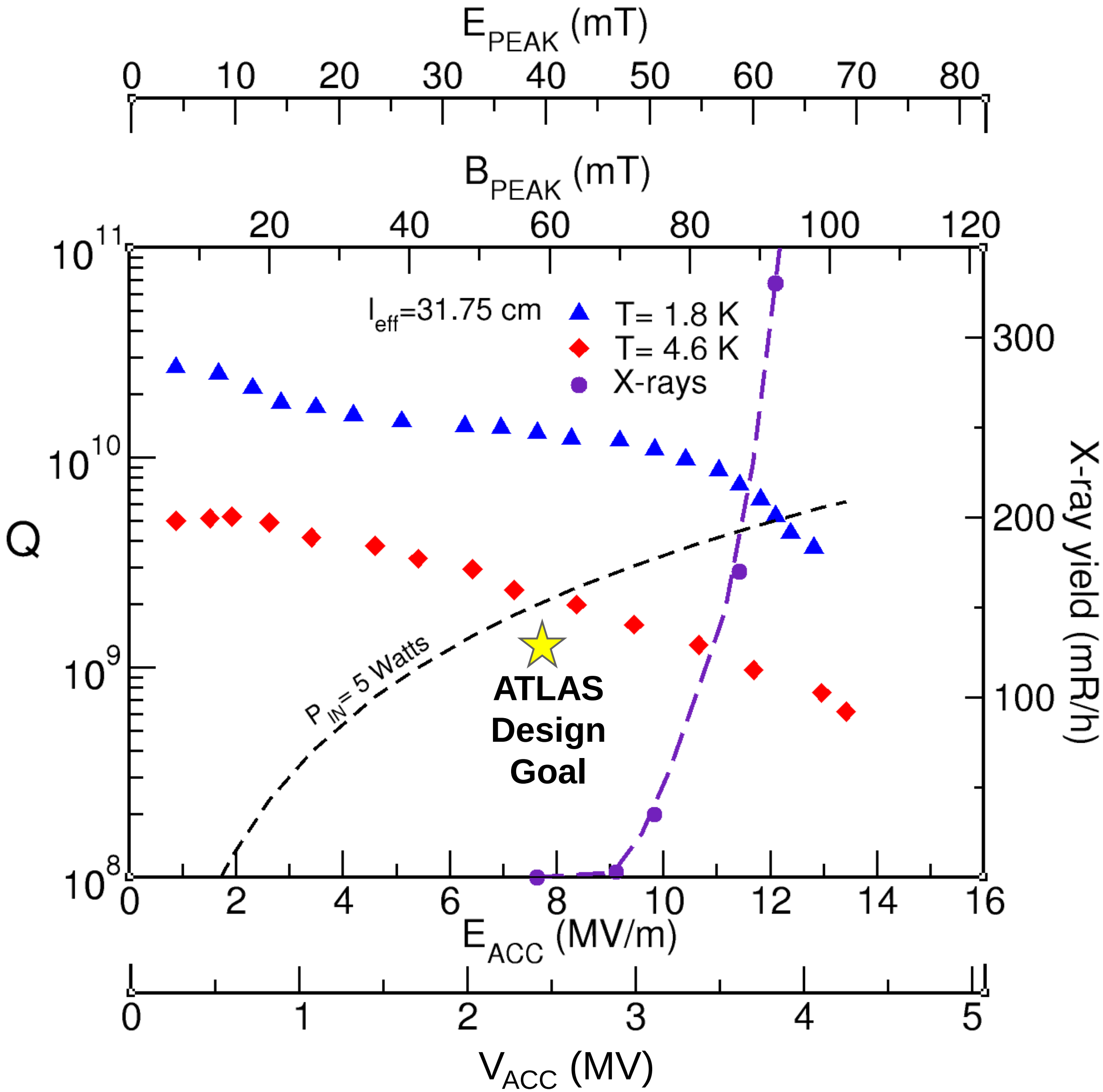




II. ANL Recipe for Quarter- (Half-)wave Cavity Cavities

- Welding
  - BCP weld preparation – 5-8 minutes, T<18°C
  - Exterior BCP 5 minutes on all niobium surfaces, T<18°C
  - Pre-weld manual HPR on weld surfaces, class 1000 bag; un-bag in chamber
- Ultrasonic cleaning
  - 1 hour in DI water with 60°C Liquinox
- Electropolishing
  - 150 microns in two 6-hour procedures
- High-pressure water rinsing
  - ~4 hours total @ 11 lpm using 0.04 micron filtered DI water (1 hour per coupling port)
- Drying and Clean Assembly
  - 24 hours drying @ class 100
  - Assembly in class 100 area
- *In-situ 120°C bake (no benefit observed yet at ANL)*
- *Bake at 600°C for 10 hours for hydrogen degassing*

II. Test Results for 1st 72 MHz QWR



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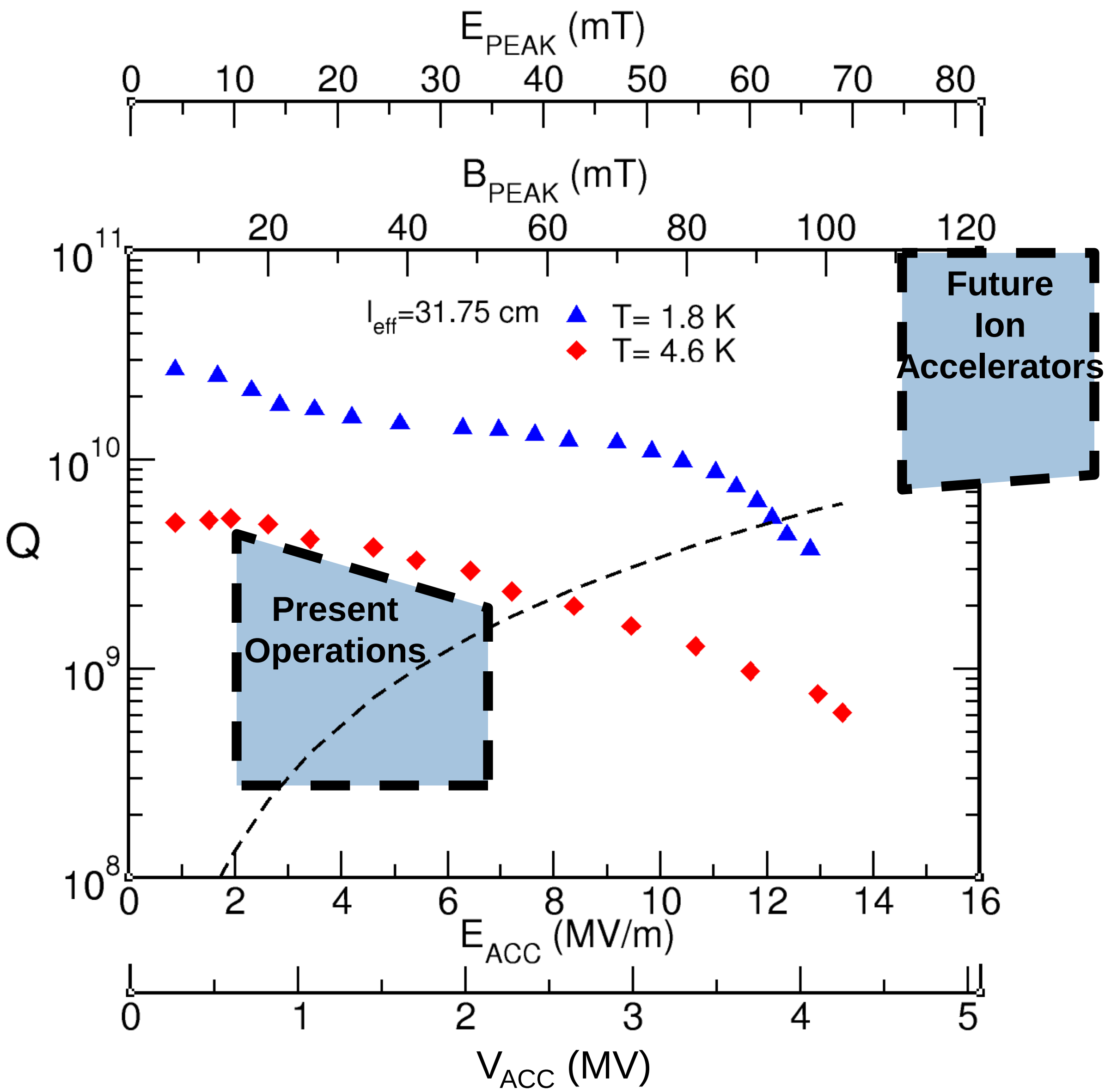

Summary

- Major improvements in SRF technology for ion linacs in the last decade
  - Sophisticated designs
  - Clean room techniques; high-quality EP
  - Improved cavity performance
- New directions for SC ion linacs
  - **Upgrades and new machines for basic science**
  - **Very high intensity CW light ion drivers for medicine and accelerator driven systems**
- The ANL approach
  - Low frequency optimized cavities
  - Large voltage gain per cavity, low rf losses
  - High real estate gradient
- High-performance SC cavities well positioned for many new high-current CW ion linacs