SRF Advances for ATLAS and Other β<1 Applications

15th International Conference on RF Superconductivity

Speaker: Mike Kelly
Physics Division

July 28, 2011

Outline and SRF Group

Outline

I. Background (Where are we now?)

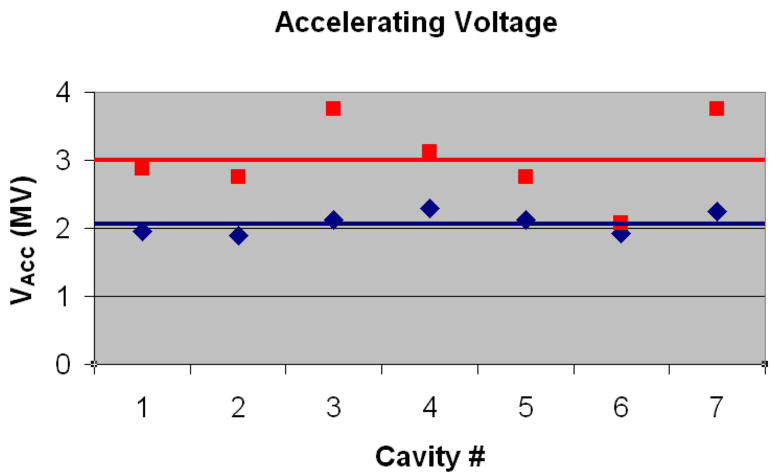
II. Key developments at ANL for β<1 Applications

Reduced β SRF Team at ANL

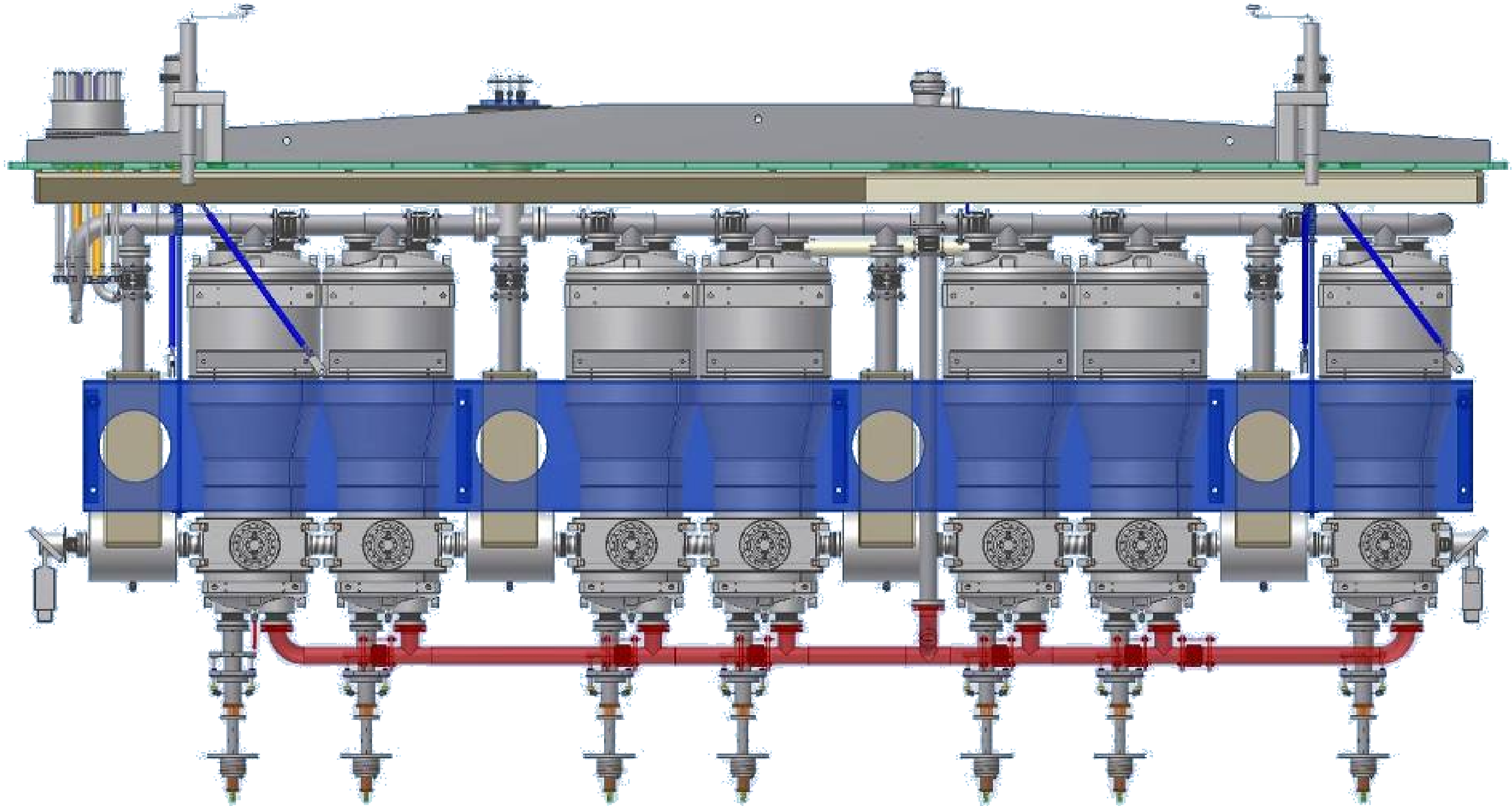
Scott Gerbick – **WEIOA03,** Electropolishing
Zachary Conway – **FRIOA02,** Tuners for low-β
Peter Ostroumov - **MOPO026,** Half-wave for FRIB
Tom Reid - **TUPO021,** EP at ANL
Ryan Murphy - **TUPO034,** ANL HPR for various cavities
Brahim Mustapha **- MOPO044,** HWR Optimization
Mark Kedzie
Michael O'Toole

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

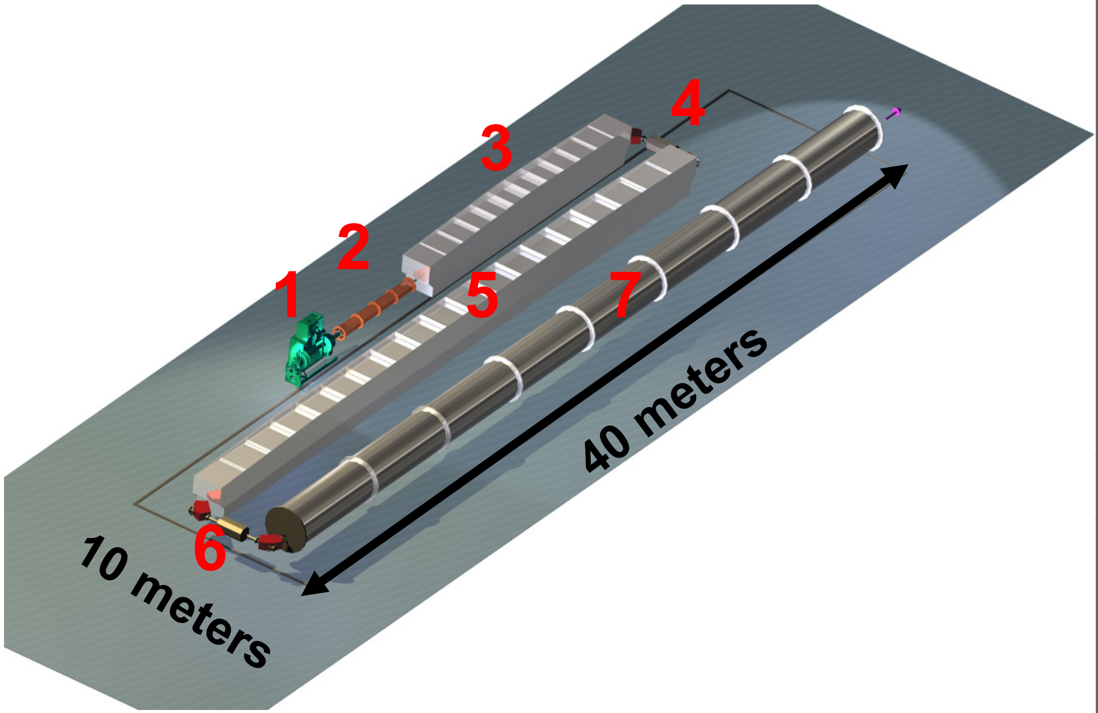


- Seven β=0.077 quarter-wave cavities, four 9-Tesla SC solenoids, (Plus one R&D cavity!)
- 17.5 MV in 5 meter module length – replaces 3 split-ring modules
- High voltage per cavity + compact lattice → Most accelerator/$ for ATLAS
- 4 kW cw high-power rf coupler (essentially no heating in initial tests to 3 kW)

I. Compact Proton Linac Using High-performance SC Cavities

1 GeV Proton Linac - 40 meter footprint

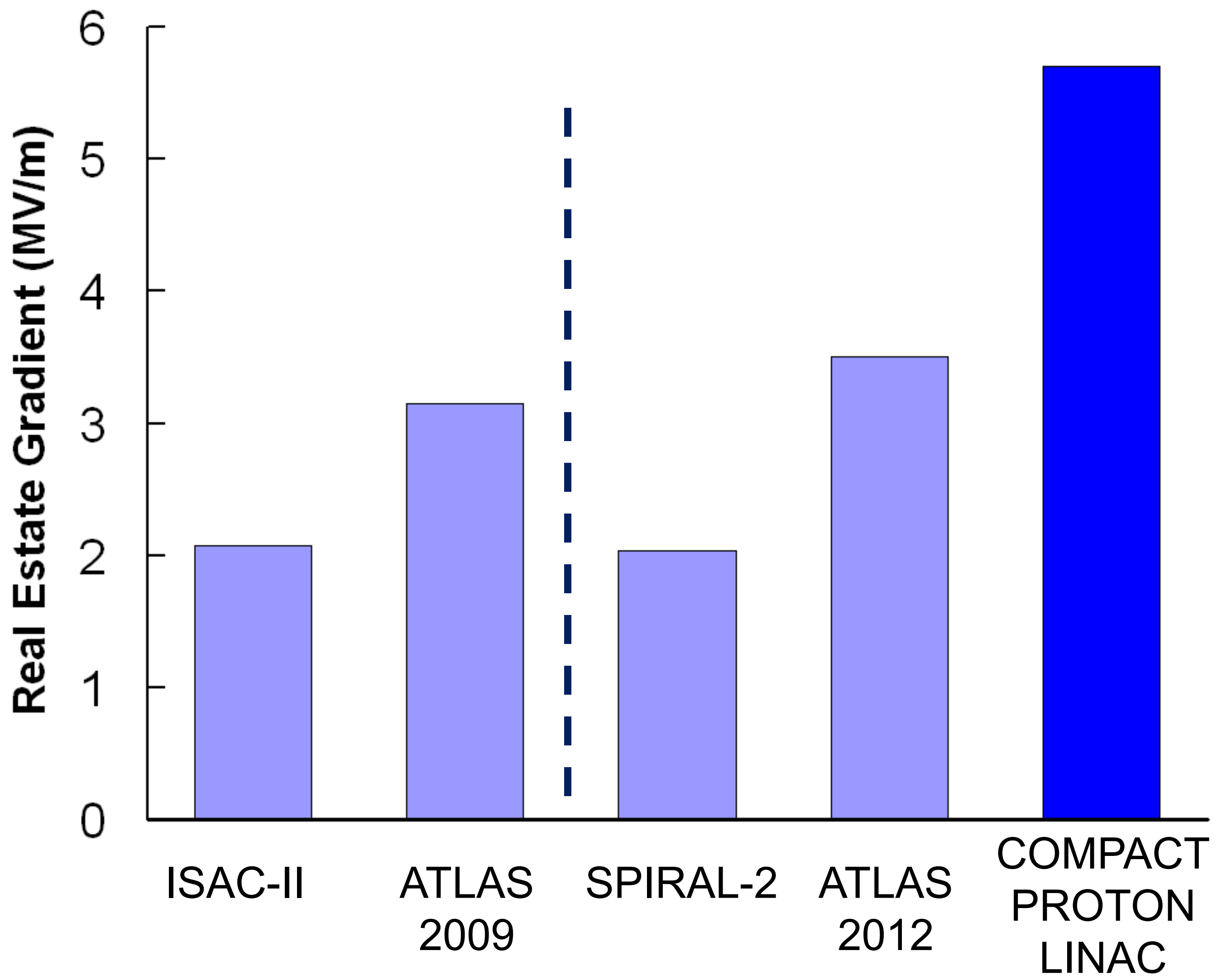
Key assumption: all cavities with B_{PEAK}=120 mT



Section	Description	Length	Proton beam energy
1	Ion Source	1 m	25 keV
2	RFQ	4.0 m	1.5 MeV
3	*3 QWR, 20 HWR*	11.5 m	144 MeV
4	Bend 1	1.2 m	144 MeV
5	*21 Spoke*	27.1 m	461 MeV
6	Bend II	1.2 m	461 MeV
7	*24 E-cell (650 MHz)*	32.9 m	1016 MeV

Application to: ADS, Medicine, National Security, Basic Science

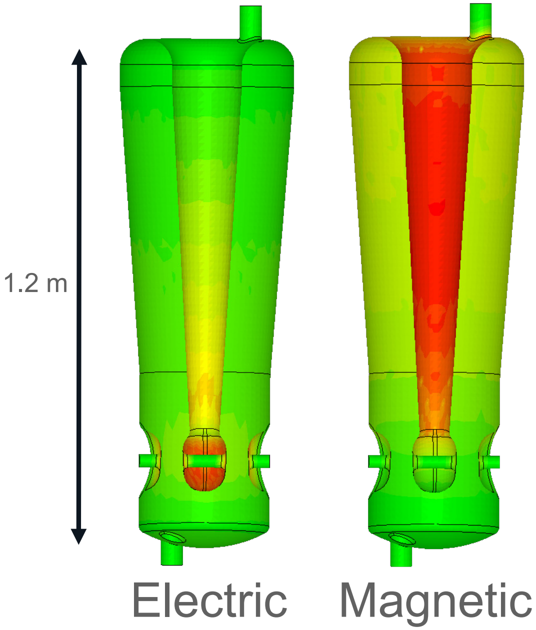
I. Real Estate Gradient for Today's State-of-the-Art (β~0.6-.15)



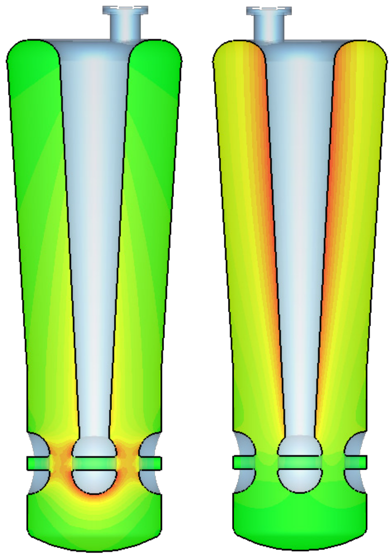
Part II. Key Technical Developments at ANL for Low-β SC Cavities

II. Electromagnetic Design for a Quarter-wave Cavity

Surface Fields



RF Volume Fields



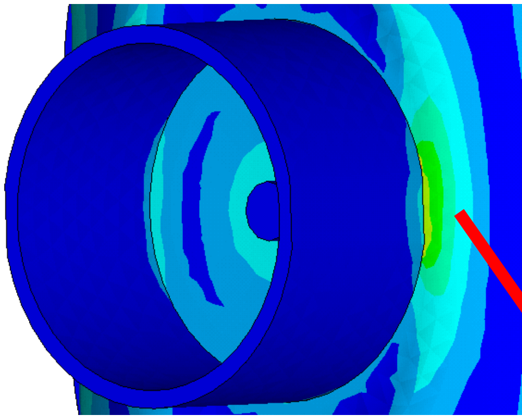
Parameter	Value	Units
Frequency	72.750	MHz
Peak Beta	0.077	
QRs	26.4	Ohm
R/Q	576	Ohm
$\beta\lambda$	31.75	cm
Design Voltage	2.5	MV
$\Delta f / \Delta E^2_{acc}$	-1.9	$Hz/(MV/m)^2$
$\Delta f / \Delta P$	-2.6	Hz/Torr
Tuning Sensitivity	~8	kHz/mm
At Eacc= 1 MV/m		
Stored Energy	0.375	Joule
E_{peak}	5.16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

Electromagnetic Design

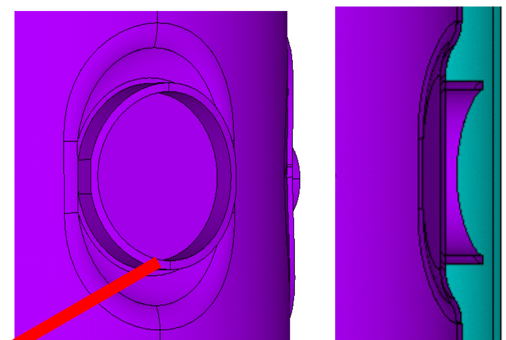
- Minimize surface fields consistent with fabrication/processing/cleaning
- Steering corrected drift-tube face to eliminate beam steering
- Tapered outer housing reduces B_{PEAK} by ~20% compared to cylindrical outer housing

II. Mechanical Design for a Quarter-wave Cavity

Niobium reinforcing ribs to stiffen center conductor



Niobium ring to mount piezoelectric tuner



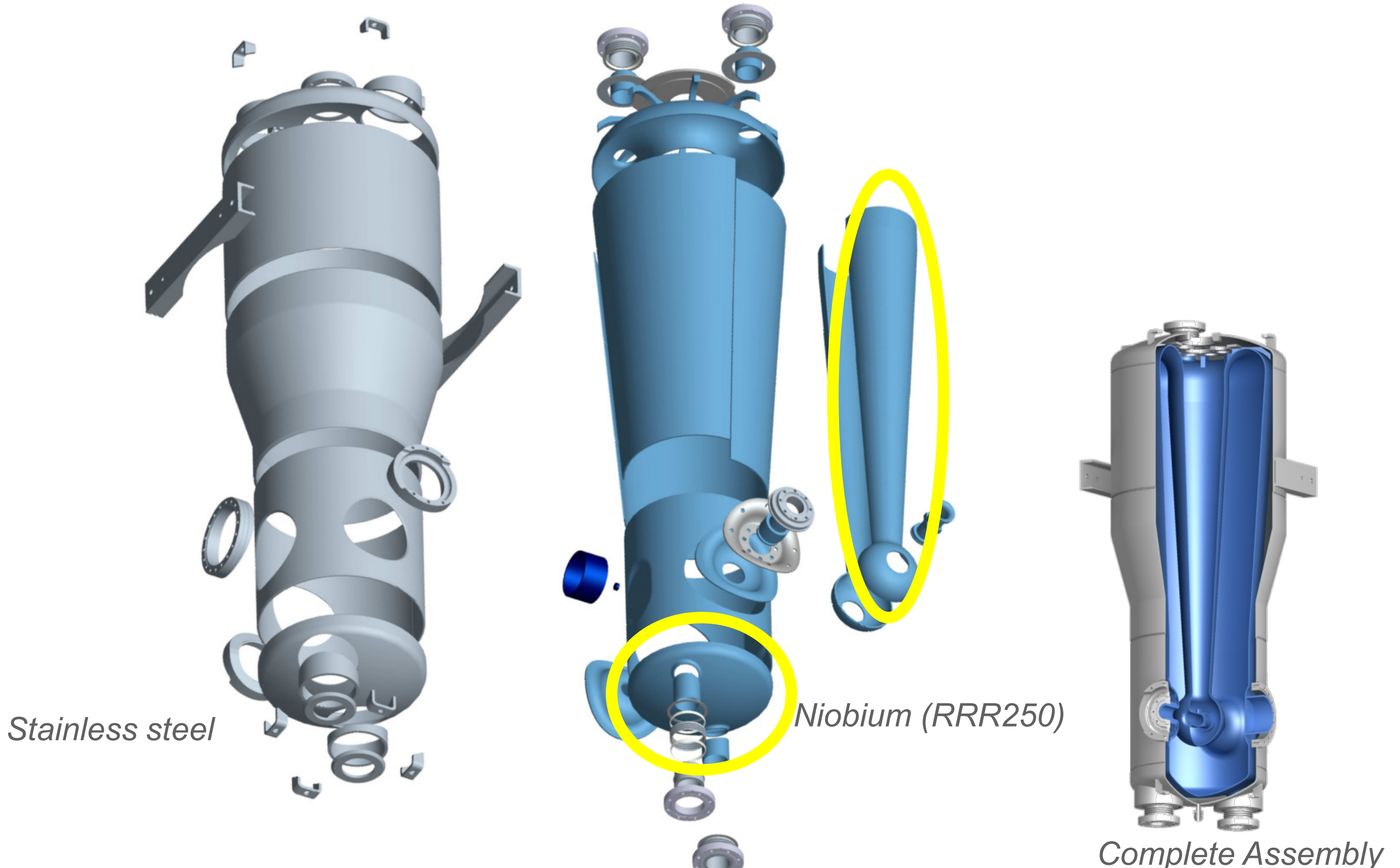
Balancing ring to reduce $\Delta f/\Delta p$

Collaboration with Advanced Energy Systems

Mechanical Design

- ATLAS operates at 4 Kelvin, therefore should:
  - ***Nearly eliminate helium pressure sensitivity by design*** $\Delta f/\Delta p$ = -2.6 Hz/Torr
  - Increase pendulum mode frequency with appropriate stiffening
  - Essentially eliminate pendulum mode by tuning, Zachary Conway – **FRIOA02**

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
- No demountable flanges; ports at ends of cavity for electropolishing and cleaning

II. Cavity Fabrication by Wire EDM

Cavity Bottom Dome

Center Conductor

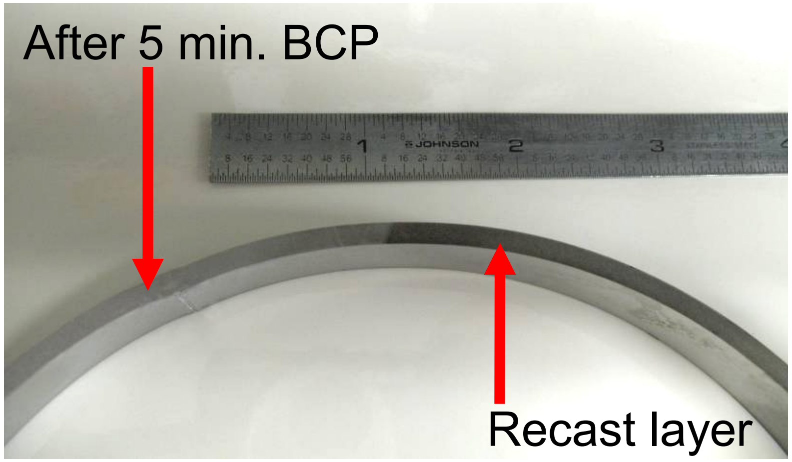
Wire EDM at
Adron

II. Cavity Fabrication by Wire EDM

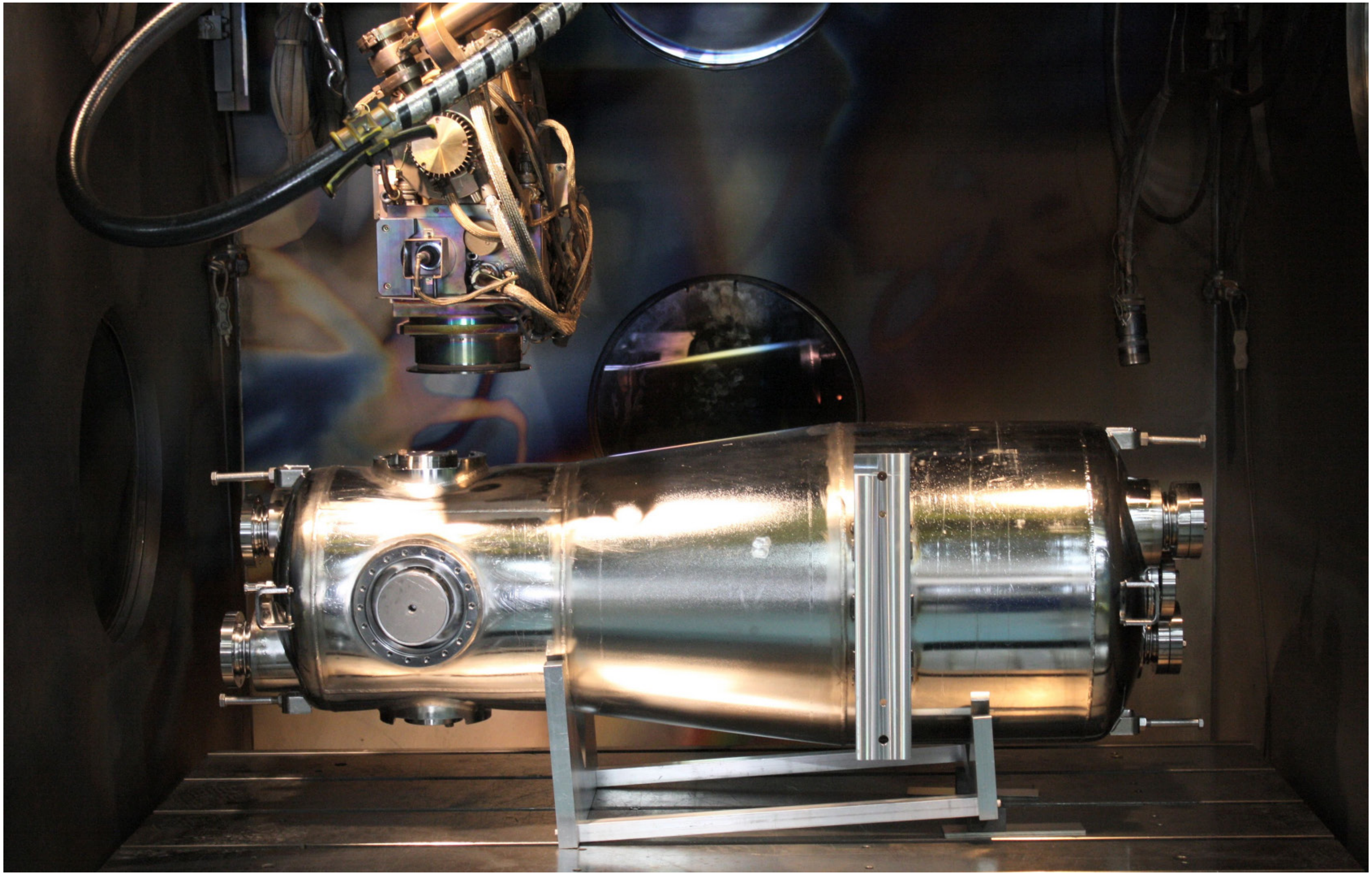
- ***Essentially no possibility for inclusions – eliminate source of weld problems***
- ***Nothing to support the notion that*** "Wire EDM is a filthy process"
- Recast layer only 5 microns thick
  - Oxide of brass and niobium
  - Completely removed with a 5 minute BCP; not removed easily by EP
- Hydrogen degassing is necessary anyway

Other Features of Wire EDM:

- 300 micron thick wire; 350 micron curf (width of cut)
- 25 micron dimensional tolerances
- Can slice (like bread machine) or drop down from above with "sinker EDM"
- Various brass alloys with different cutting speeds
- Example: Cuts a 30 cm diameter 3 mm thick niobium cylinder in 3 hours



II. Final Weld on Helium Vessel (ASME stamped)

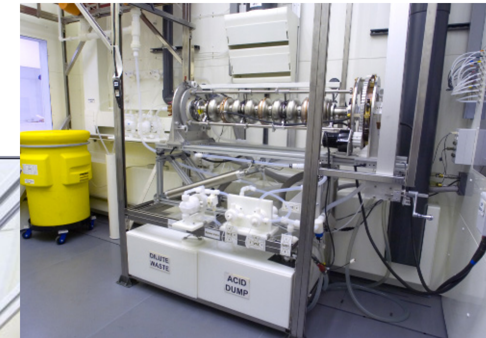


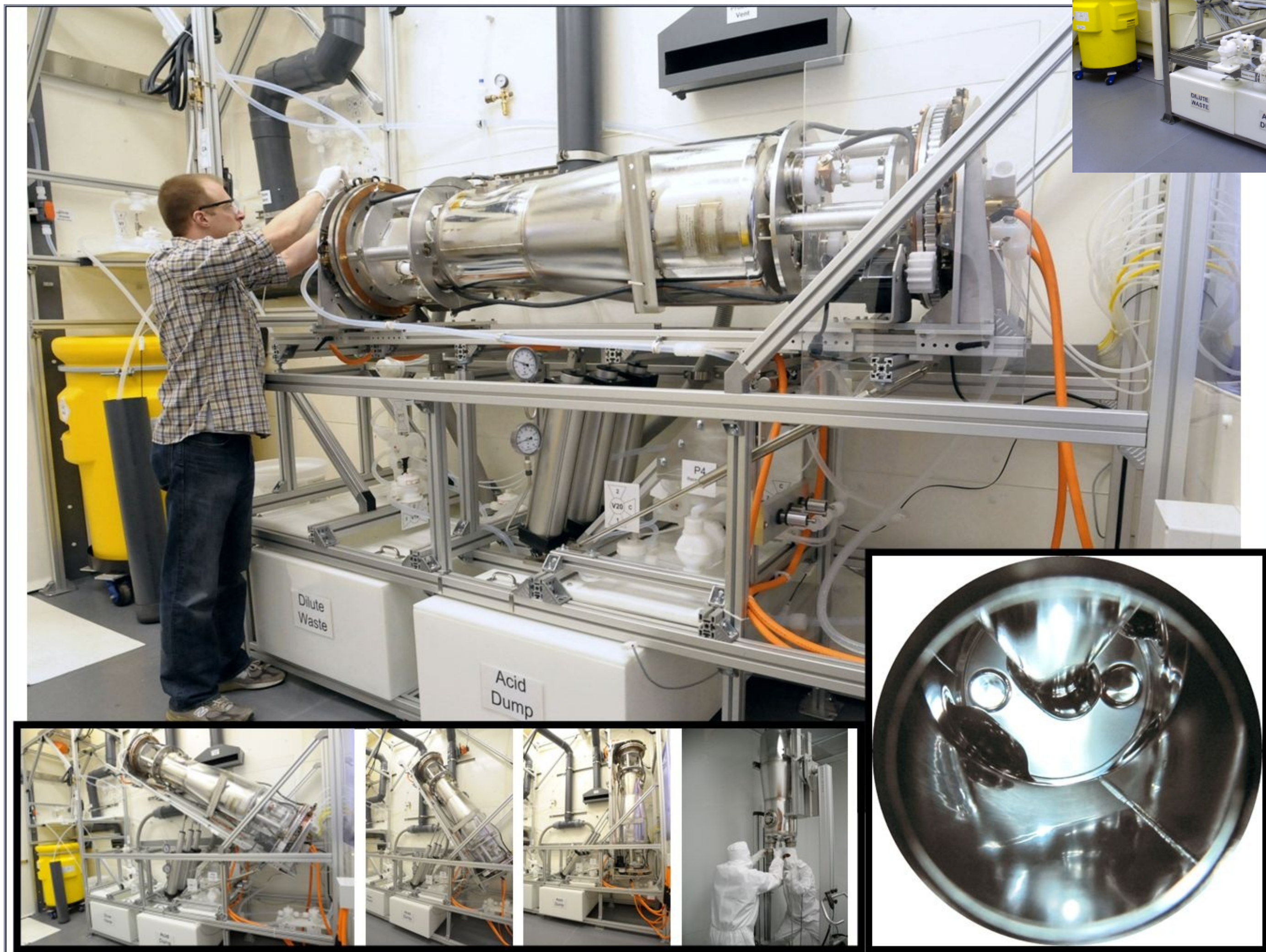
Stainless jacket at Meyer Tool

Welding at Sciaky

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

- A New Electropolishing System For Low-Beta SC Cavities - **WEIOA03,** S.M. Gerbick (ANL)

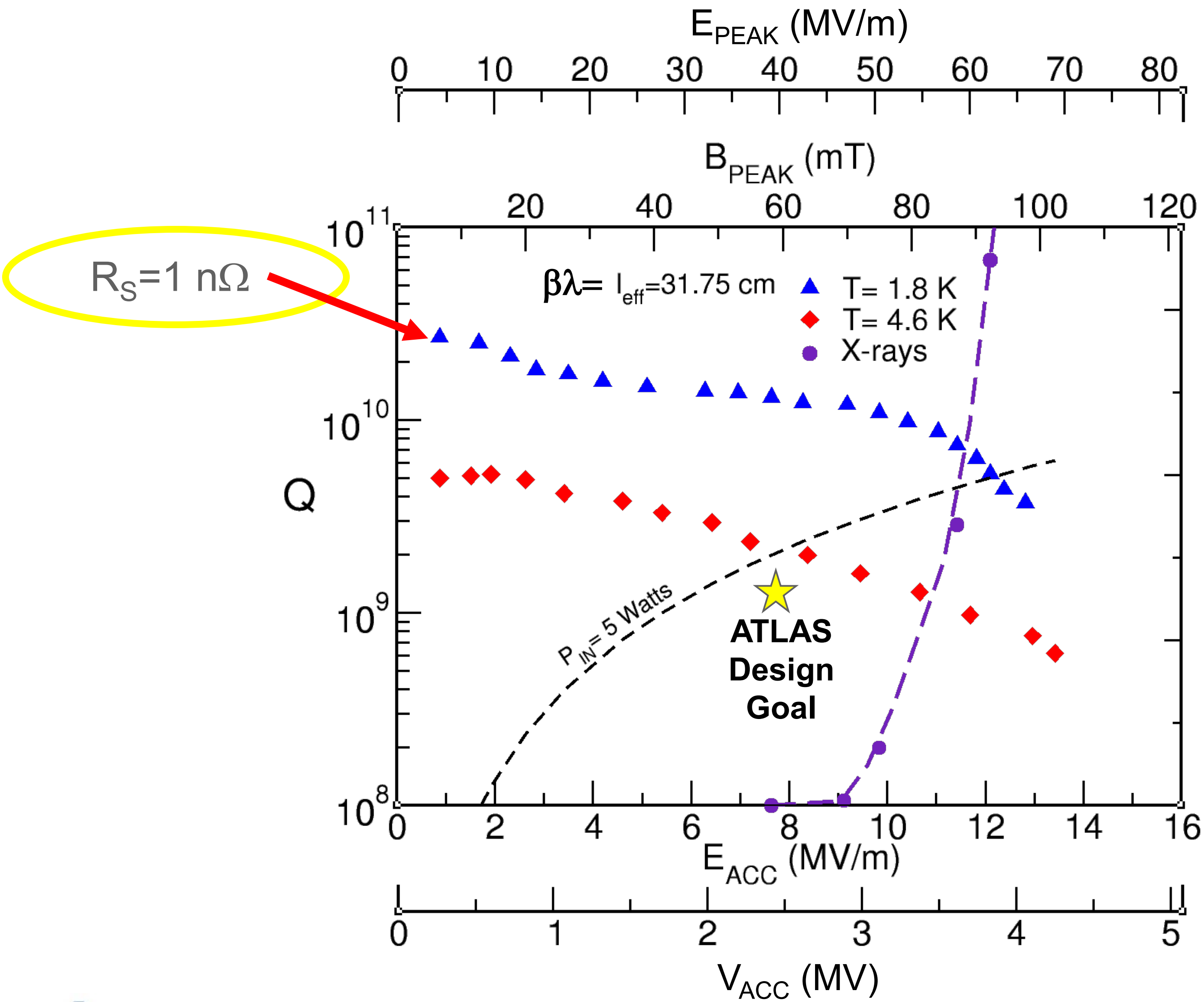




II. ANL Recipe for Prototype Low-β Cavity Surface Processing

- Welding
  - BCP weld preparation – 5-8 minutes, T<18^{o}C
  - Exterior BCP of 5 minutes on all niobium surfaces, T<18^{o}C
  - Pre-weld manual HPR on weld surfaces, class 1000 bag; un-bag in chamber
- Ultrasonic cleaning
  - 1 hour in DI water @ 60 ^{o}C 1% 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^{o}C bake (complete but not yet tested)*
- *Bake at 600^{o}C for 10 hours for hydrogen degassing/light EP (to be performed)*

II. Test Results for Prototype 72 MHz QWR



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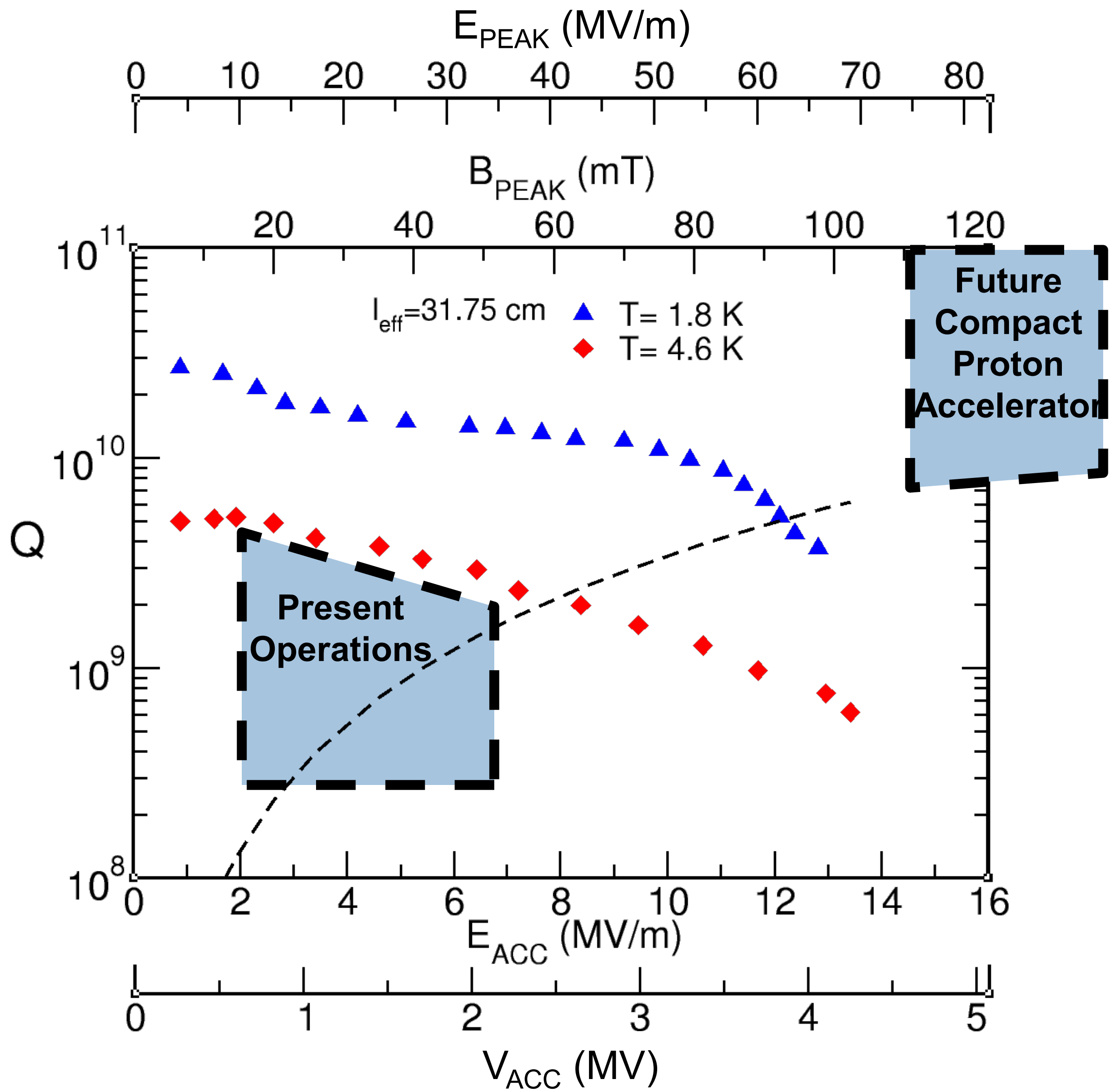

Summary

- Major improvements in SRF technology for β<1 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, national security, 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 next generation of high-current CW ion linacs