SRF CAVITIES FOR FUTURE ION LINACS

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Collaborators (Short Version)

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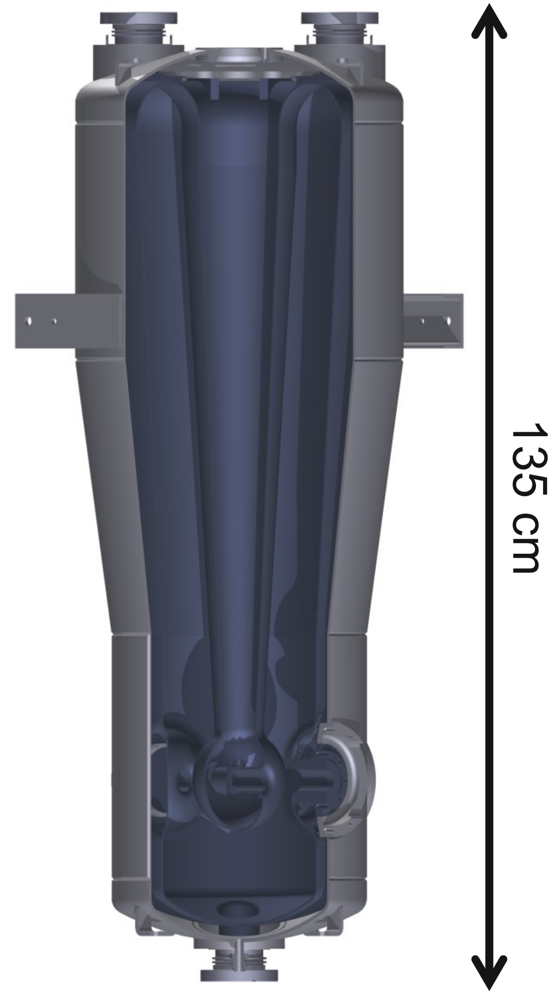
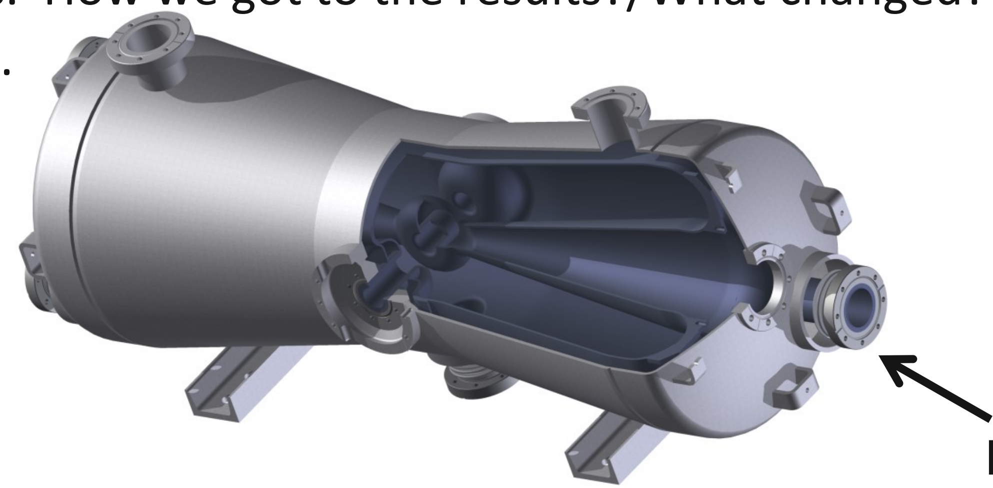
  - HEP Division: R. Murphy and T. Reid.
  - NE Division: A. Barcikowski, G. Cherry, R. Fischer and J. Morgan.
- FNAL Project-X Personnel: D. Bice, I. Gonin, A. Klebaner, V. Lebedev, A. Lunin, T. Khabiboulline, T. Nicol, T. Peterson, R. Kephart, L. Ristori, A. Rowe, R. Stanek, M. White and more.
- Soreq-NRC SARAF Personnel: D. Berkovits, I. Mardor, A. Perry, J. Rodnizki and more.
- J. Delayen, ODU-JLAB.
- R. Laxdal, TRIUMF.
- G. Olry, GANIL.
- A. Facco, INFN-Legnaro/MSU-FRIB
- Many Vendors:
  - Advanced Energy Systems.
  - Meyer Tool and Manufacturing.
  - Sciaky.
  - ATI Wah Chang.
  - Numerical Precision.
  - Adron Tool.
  - ATI Wah Chang.
  - And many more…

Introduction

- Low-beta cavities (0.05 < $\beta = v/c$ < 0.6) & applications
- Want to reduce the length and cost of low-beta accelerators.
- The approach is two-fold:
  - Substantially increase the performance of low-β cavities.
    - Geometry optimization for both processing and electromagnetics.
    - Quality control; apply/improve upon methods developed for β = 1 cavities
  - Optimize the accelerator lattice geometry for maximum real-estate gradient.
- Applications of reduced beta cavities.
- Results. How we got to the results?/What changed?
- Impact.



72.75 MHz, β = 0.077
Quarter-Wave Resonator



162.5 MHz, β = 0.11
Half-Wave Resonator

Low-Beta Cavity Applications

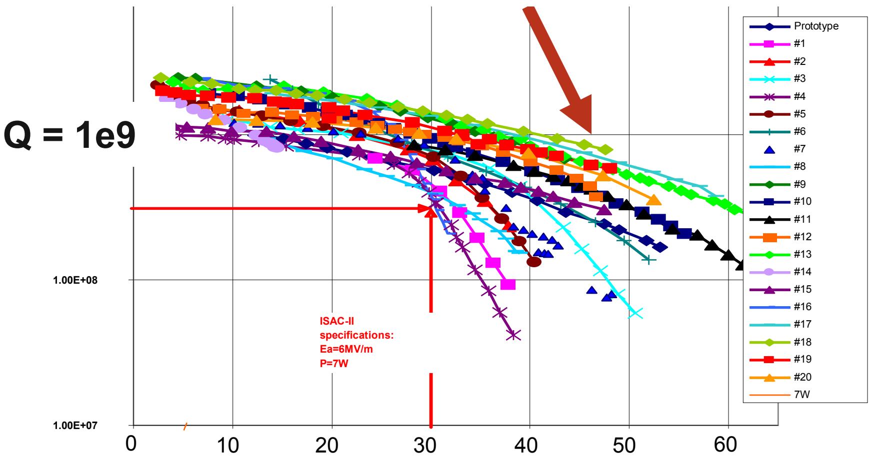
- Originally used as booster linacs fed by electrostatic accelerators: Karlsruhe, ATLAS @ ANL, , JAERI, ALPI @ INFN-Legnaro, U. of Canberra, etc.
- Applications Include:
  - Basic Science
  - National Security
  - Nuclear Medicine (Medical Isotope Production)
  - Waste Transmutation
  - Accelerator Driven Systems
- Projects:
  - ISAC – II @ TRIUMF
  - Spiral2 @ GANIL
  - FNAL & Project-X
  - FRIB and ReA @ MSU
  - ATLAS Upgrades @ ANL
  - European Spallation Source, IFMIF,…
  - Many more (e.g., RISP, China ADS)

Quarter-Wave Resonator (QWR)
72 MHZ, β = 0.077 (Back)

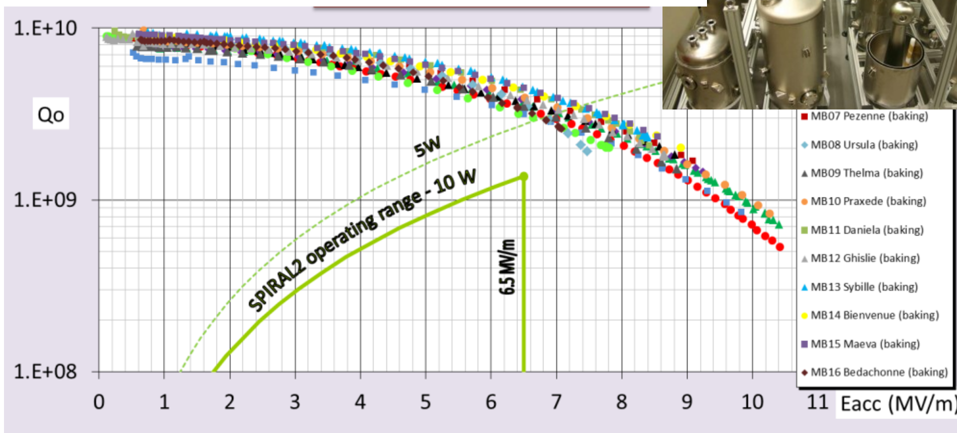
Half-Wave Resonator (HWR)
325 MHZ, β = 0.285 (Front)

Applications

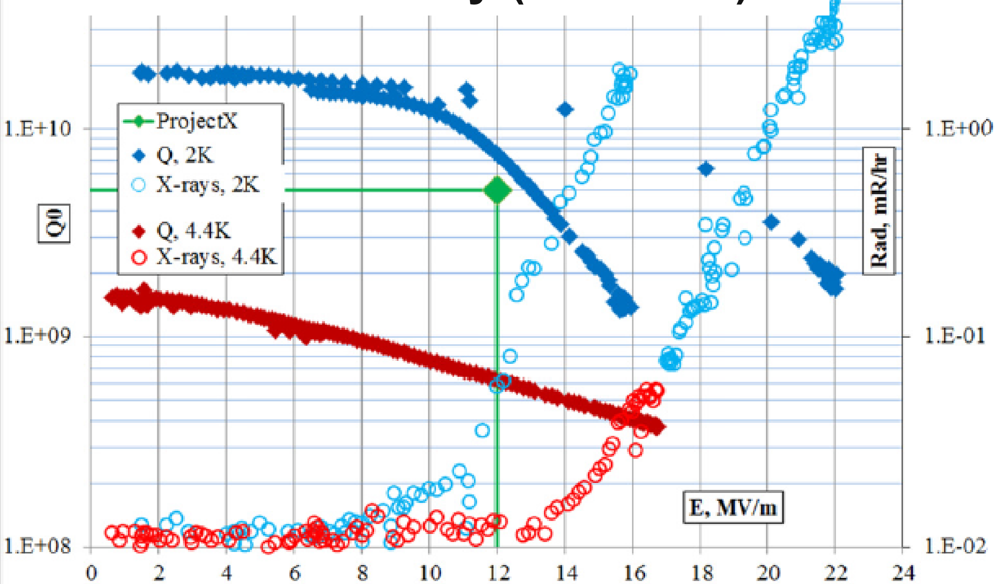
TRIUMF QWRs, 4 K, E_{acc} > 10 MV/m



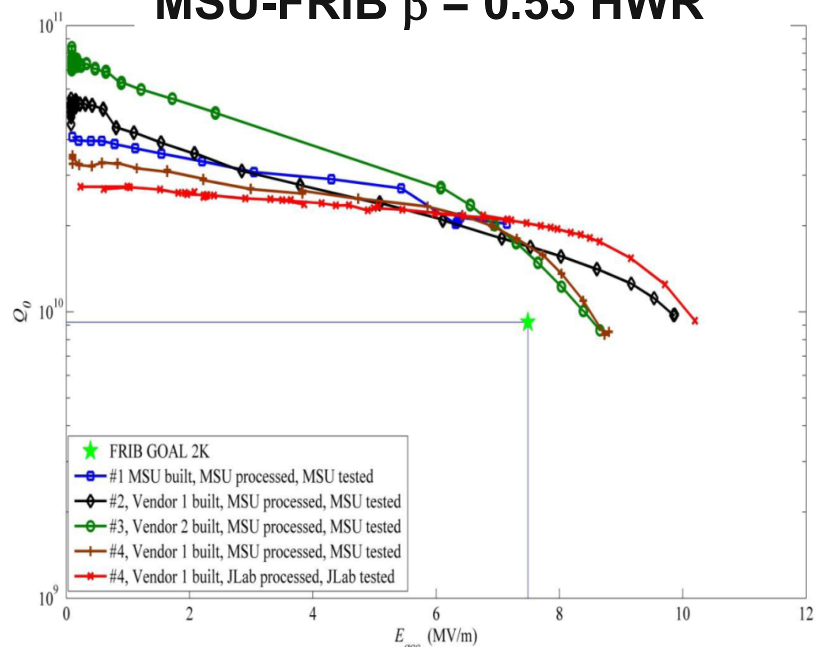
Spiral2 β = 0.12 QWRs @ 4 K



FNAL SSR1 Cavity (Next Talk)



MSU-FRIB β = 0.53 HWR



Pictures courtesy of R. Laxdall (TRIUMF), L. Ristori (FNAL), and G. Olry (IPNO)

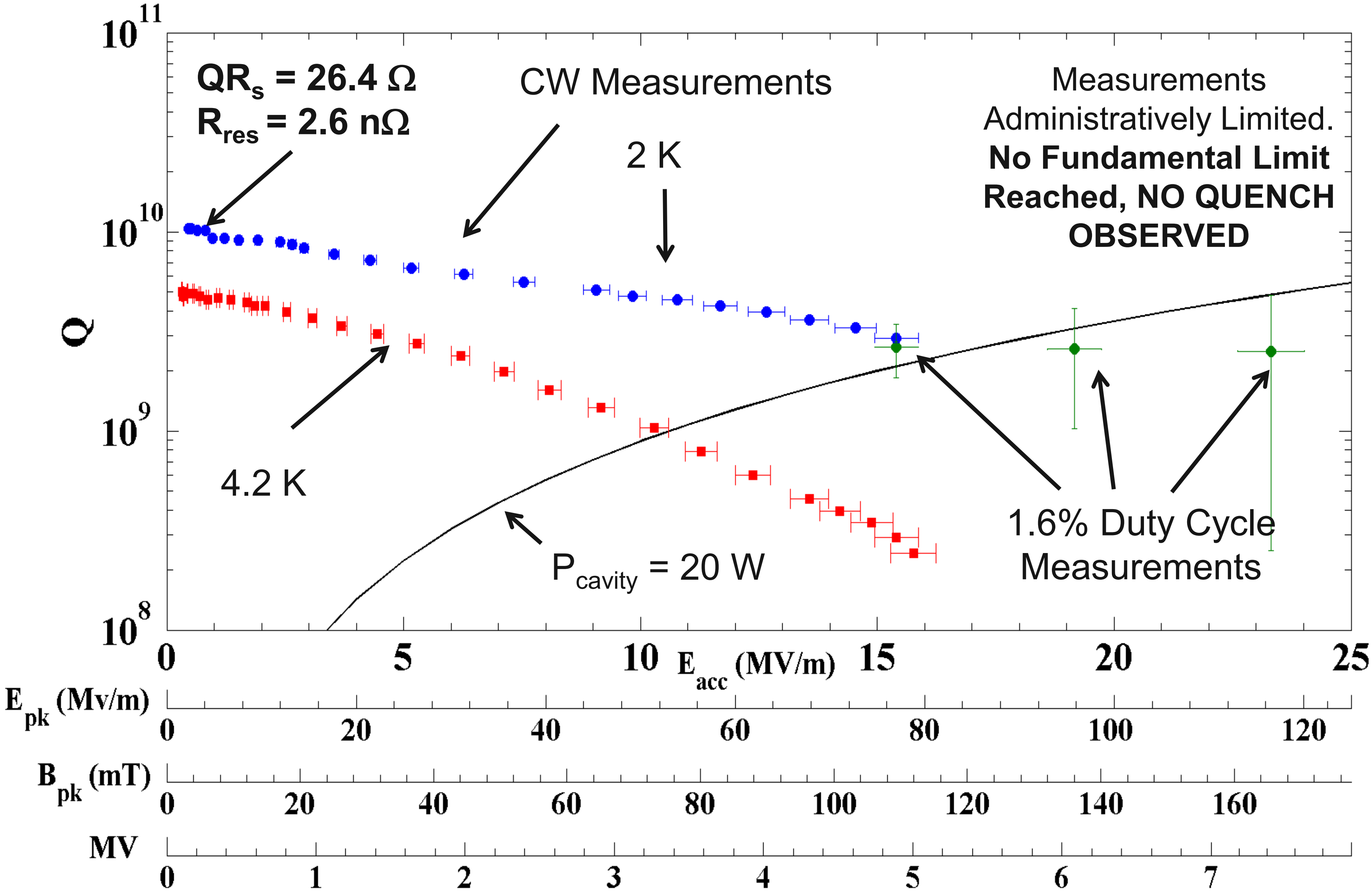
Cavity Fabrication

- Learned a lot from TESLA/ILC development.
- The additions to the fabrication for the QWR are:
  - Final EP.
  - Electrostatic discharge machining.
  - Very careful attention to weld joint preparation.
  - Significantly more surface inspection and QA.
  - Reduced temperature of chemical polishing for all pre-weld preparations and for final polishing steps of the finished cavity, T < 30^{0}C.
  - 600^{0}C bake to degas hydrogen.

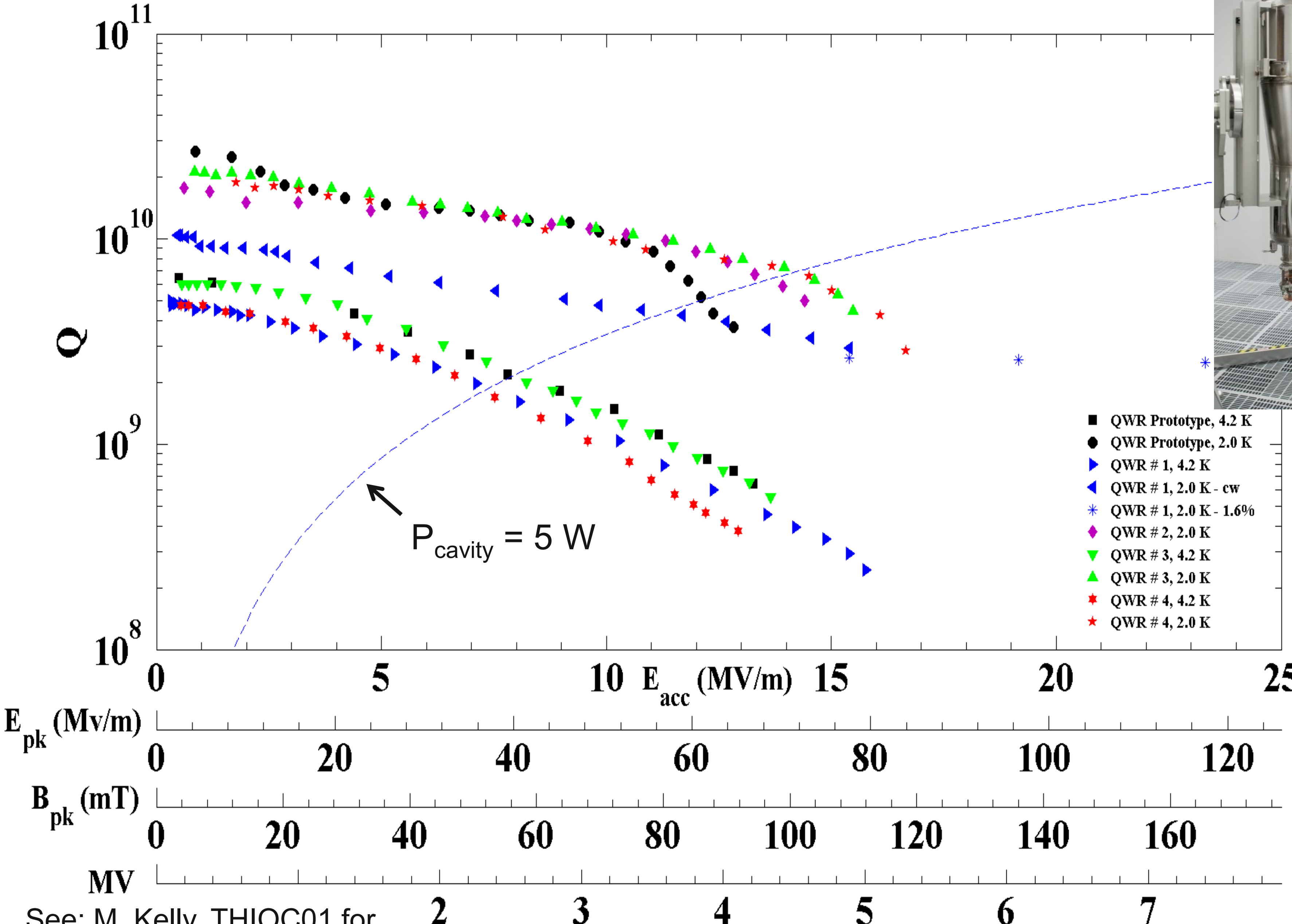
ANL Low-β Electropolishing Tool

Cavity Type	QWR
Freq. (MHz)	72.75
β	0.077
l_{eff} (cm, βλ)	31.75
E_{pk}/E_{acc}	5.2
B_{pk}/E_{acc} (mT/(MV/m))	7.6
QR_s (Ω)	26.4
R_{sh}/Q (Ω)	587

72 MHz QWR Results - I

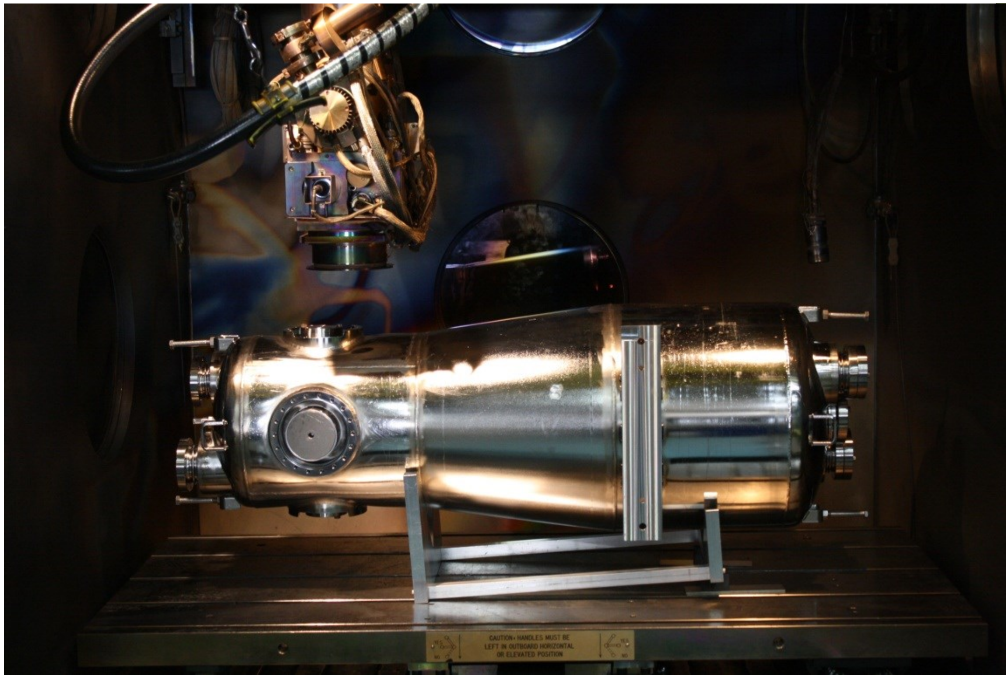


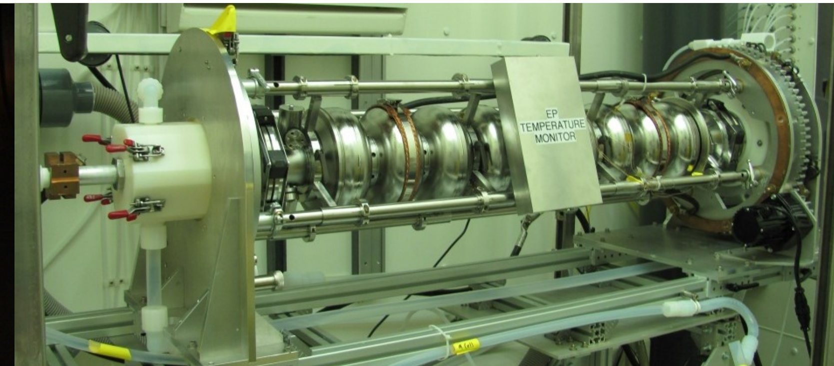
72 MHz QWR Results - II



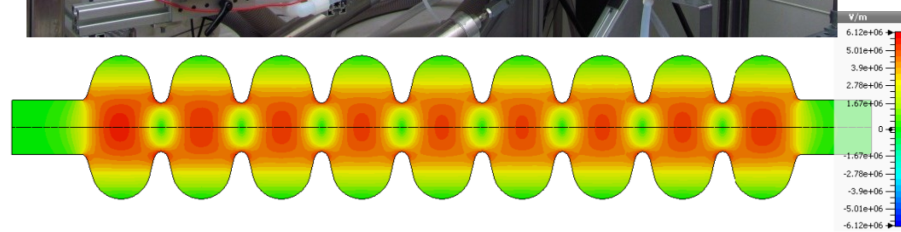
See: M. Kelly, THIOC01 for additional results.

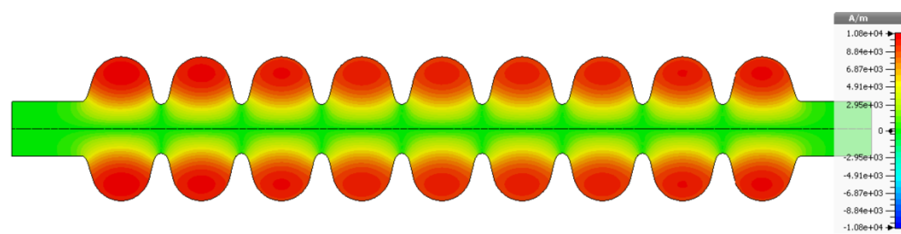
How does this result compare to the best β = 1 cavities?





	72 MHz QWR	Really Good ILC 9-Cell
Peak Surface Magnetic Field	166 mT	175 mT
Peak Surface Electric Field	117 MV/m	84 MV/m





See: R.L. Geng, SRF11, Pg. 74.

Impact

- **High Performance Resonators = Shorter Cheaper Accelerators.**

- **Work is proceeding to simultaneously increase the peak fields, quality factors and power coupler rating of reduced-beta cavities.**

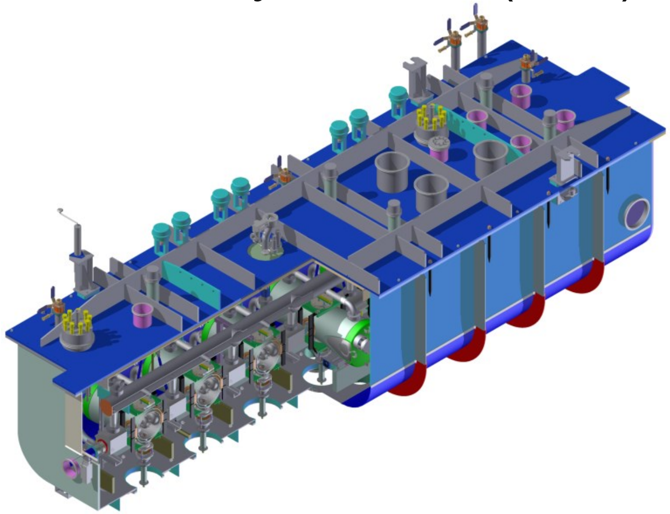
- **Enables new applications where SC Linac technology was too expensive to support in the past:**
  - Basic Science.
  - National Security.
  - Nuclear Medicine (Medical Isotope Production).
  - Waste Transmutation.
  - Accelerator Driven Systems.

- **Improved techniques for all SC niobium accelerator cavities.**
  - Weld preparations
  - EDM
  - Final EP after fabrication is finished

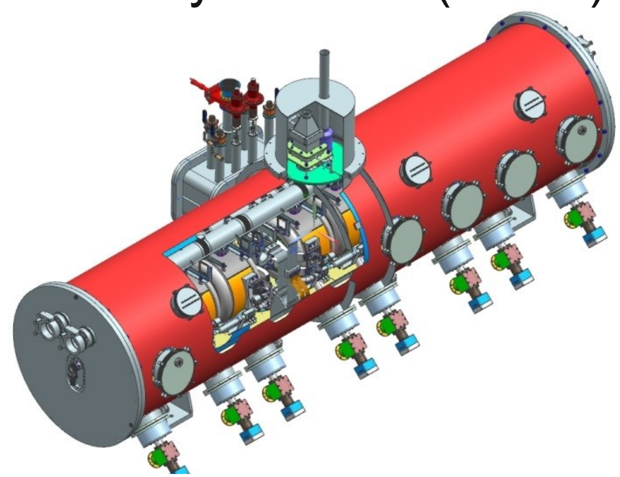
Future Application: Project – X @ FNAL (PXIE)

Cavity Type	HWR	SSR1	SSR2
Freq. (MHz)	162.5	325.0	325.0
β	0.11	0.22	0.47
l_{eff} (cm, $\beta\lambda$)	20.7	20.3	43.4
Operating Voltage (MV)	1.5/+2.0	2.0	TBD
E_{pk}/E_{acc}	4.6	3.8	3.4
B_{pk}/E_{acc} (mT/(MV/m))	5.4	5.8	6.6
QR_s (Ω)	48	84	82
R_{sh}/Q (Ω)	262	242	310
# of Cavities Required	8	8	TBD

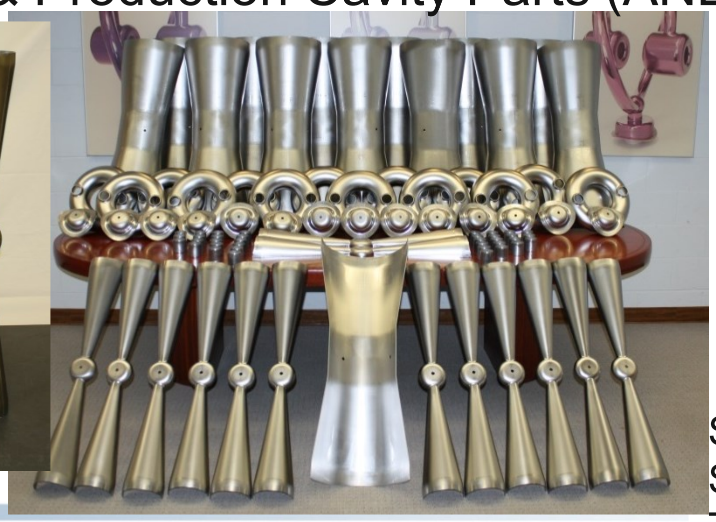
HWR Cryomodule (ANL)



SSR1 Cryomodule (FNAL)

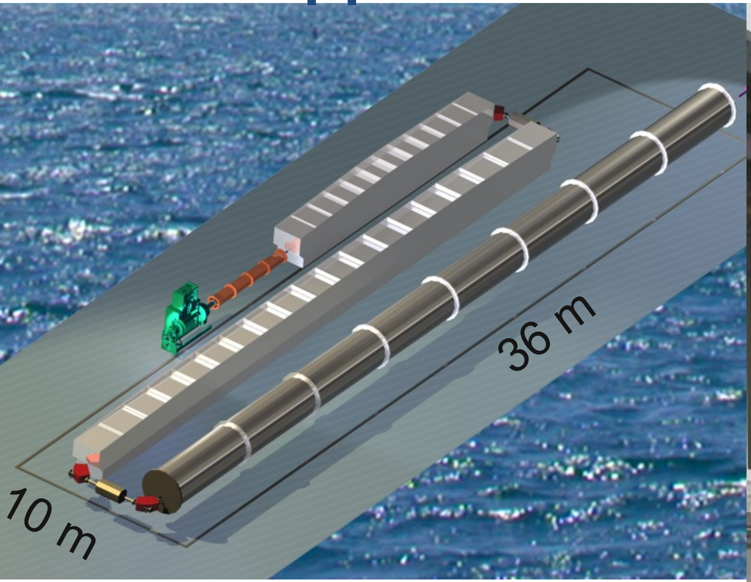


HWR Prototype & Production Cavity Parts (ANL)



SSR1 picture courtesy of T. Nicol, FNAL.
See: S. Nagaitsev et al, IPAC12, Pg. 3874.
T. Nicol et al, PAC13, To Be Published

Future Application: 1 GeV, 1 mA Proton Linac



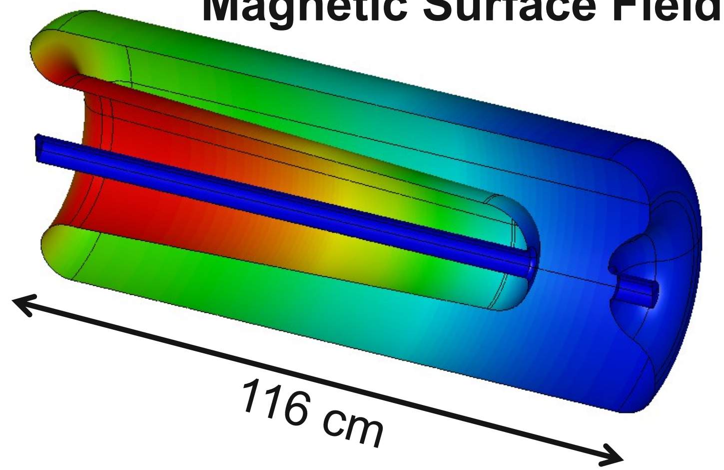
- Low-beta real-estate gradients of >5 MV/m are achievable.
- This enables major cost reductions for the front end of future heavy-ion linacs.

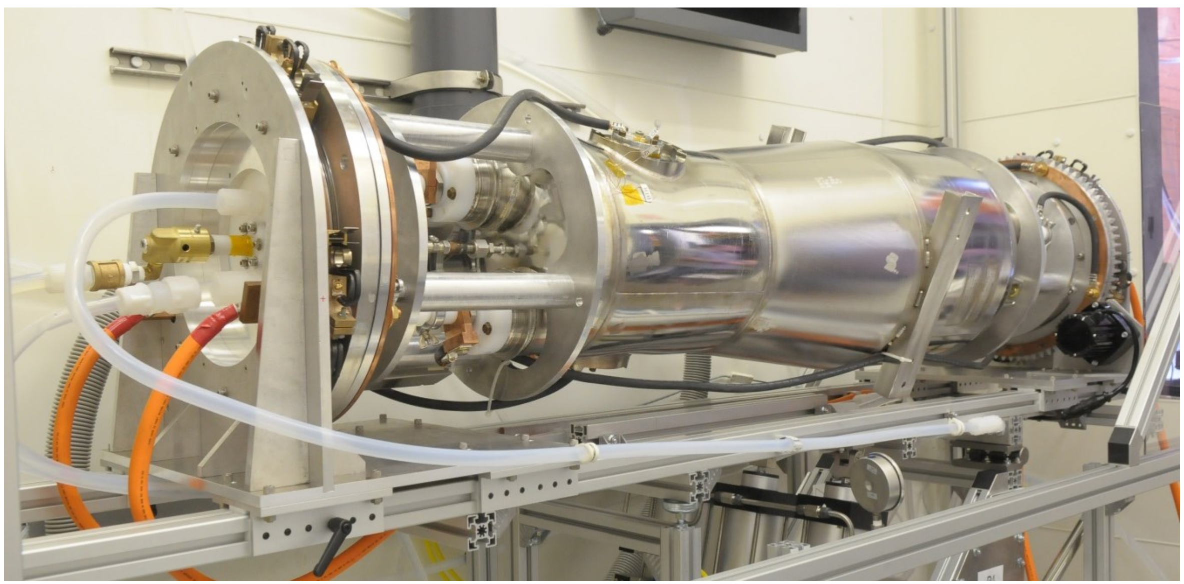
Future Application - IV: Low-β in High-β Territory

Typical low-β cavity geometries do not have to be limited to low-β applications.

- 84.48 MHz, 2.5 MV QWR BNL Electron Gun for >35 mA: S. Belomestnykh MOP017
- High-β Spokes: J.R. Delayen, LINAC12 and PRST-AB to be published.
- RF Deflecting Cavities: S.U. De Silva and J.R. Delayen, PRST-AB 012004 & 082001 (2013).

Example: BNL QWR





Cavity Type	QWR
Frequency	84.48 MHz
Voltage	> 2.5 MV
E_{peak} @ 2.5 MV	39 MV/m
B_{peak} @ 2.5 MV	80 mT
R/Q	123 Ω
G	35 Ω

Conclusions

- New ion linac front ends greatly benefit from investment in low-beta resonators (Higher E_{acc} and Q).
  - Building from the development work done for the ILC.
  - New innovations for low-beta enhance this.
- There is no fundamental reason why low-beta resonators should not perform at the limits of Nb as do velocity of light structures.
  - Greater fabrication complexity is no excuse.

ODU, JLAB, Niowave β = 1 Double Spoke Resonator

Picture courtesy of J.R. Delayen (ODU/JLAB)