Argonne NATIONAL LABORATORY

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Superconducting RF Cavities Development at Argonne National Laboratory

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U.S. DEPARTMENT OF ENERGY

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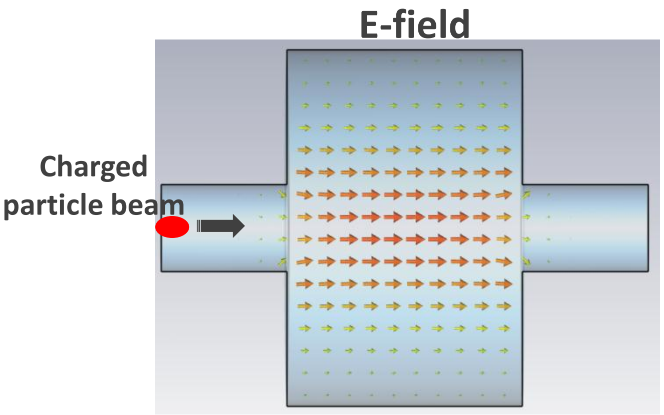
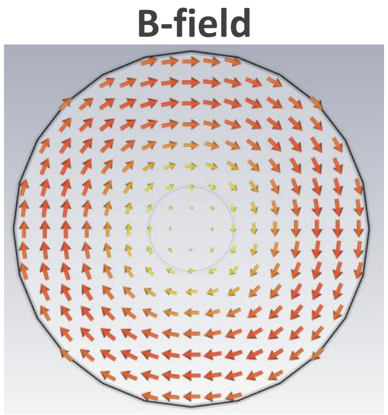
- Introduction to Superconducting RF (SRF) Accelerating Cavity
- SRF Quarter-Wave Resonators (QWR) for Argonne Tandem Linear Accelerator System (ATLAS) Intensity Upgrade
- Summary

Why Superconducting RF Cavity?

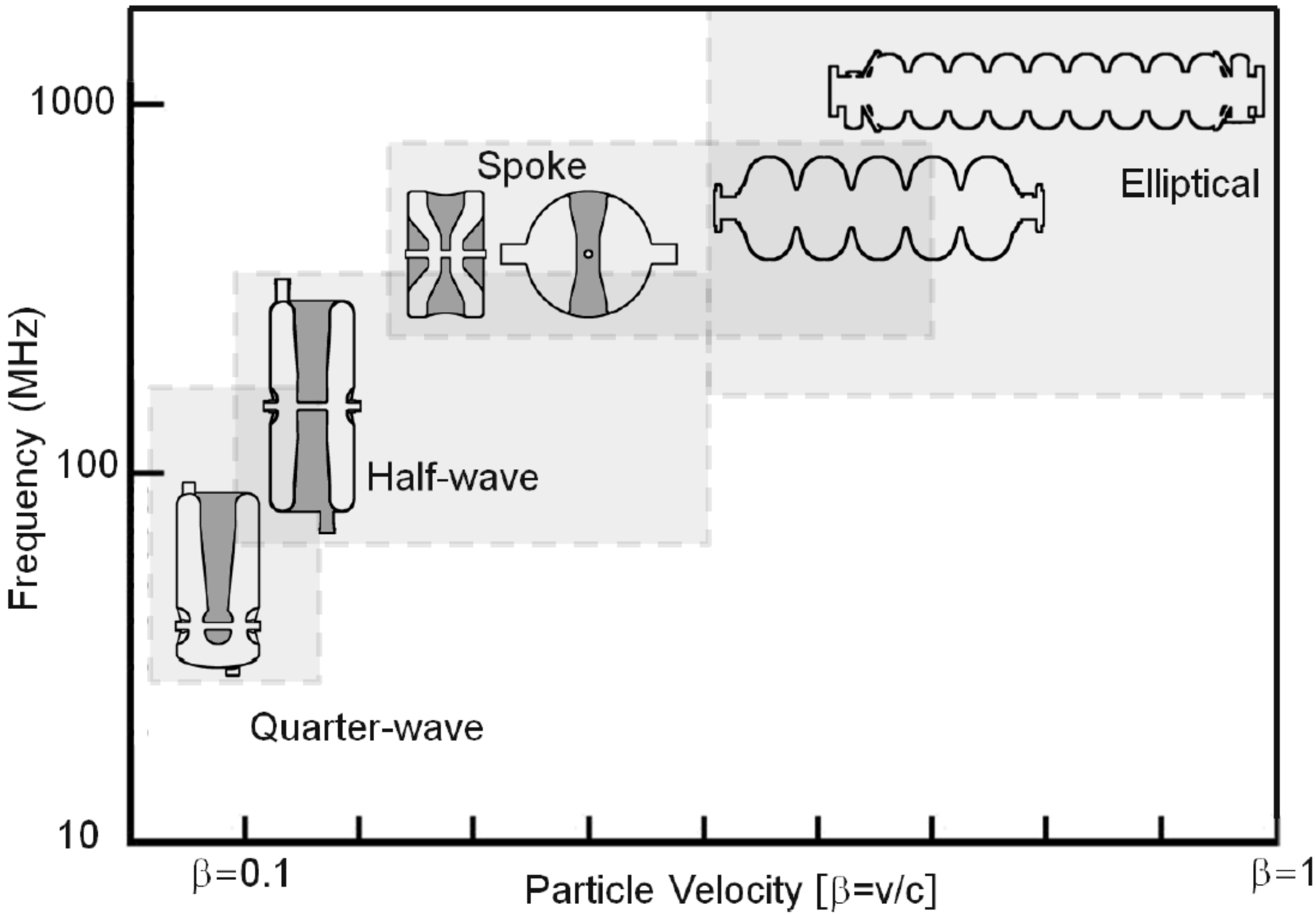
- Particle Acceleration using Resonant Cavity





- Accelerators for high intensity beams ⇒ CW operation
  - **Normal Conducting: high wall loss so extremely high cooling power**
  - **Superconducting: low wall loss then cost efficient**

Which Type of Accelerating Structure?

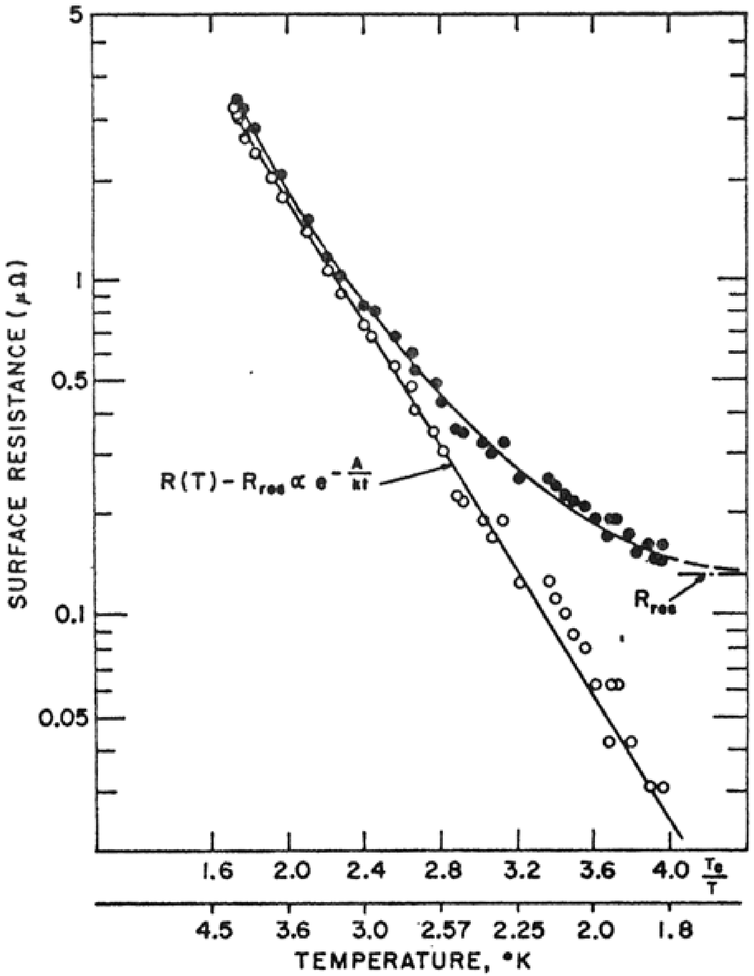


RF Loss on Superconductor Surface

- Resistance in SC
  - DC: zero resistance
  - RF(AC): finite resistance

- Surface Resistance
  - BCS resistance: material property
  - Residual resistance:
    Damaged layer, defects,
    foreign materials, hydrides/oxides,
    trapped magnetic flux, …

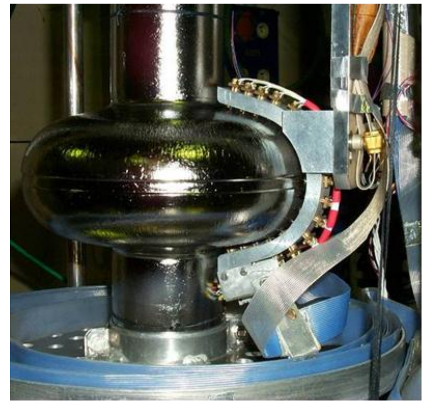
Pure and Clean Surface

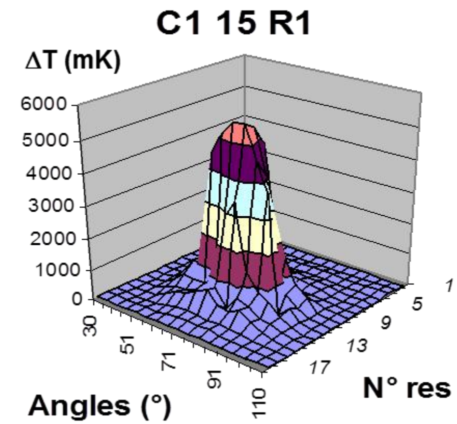


(Courtesy of S. Calatroni)

Limitation of Peak Fields

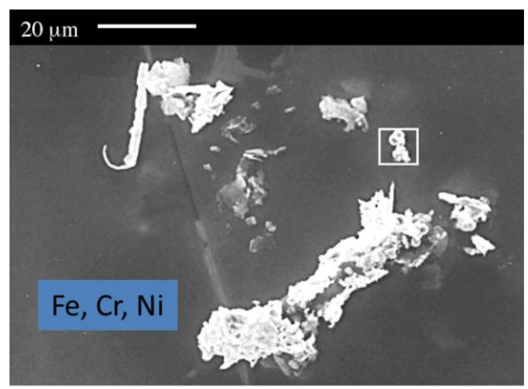
- Thermal Breakdown
  - Defects in the surface
  - Heated then quenched
  - Limiting B_{peak}

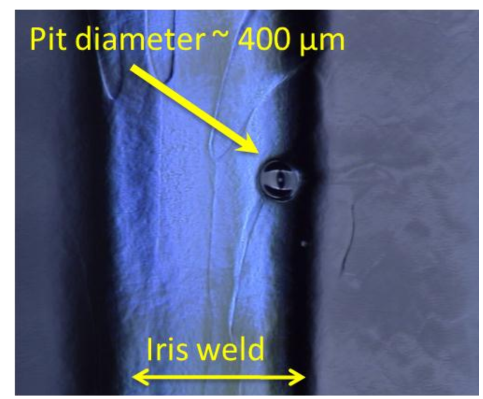




(Courtesy of C. Z. ANTOINE)

- Field Emission
  - Defects in the surface and foreign particles on the surface
  - Q degraded and strong X-ray emission
  - Limiting E_{peak}



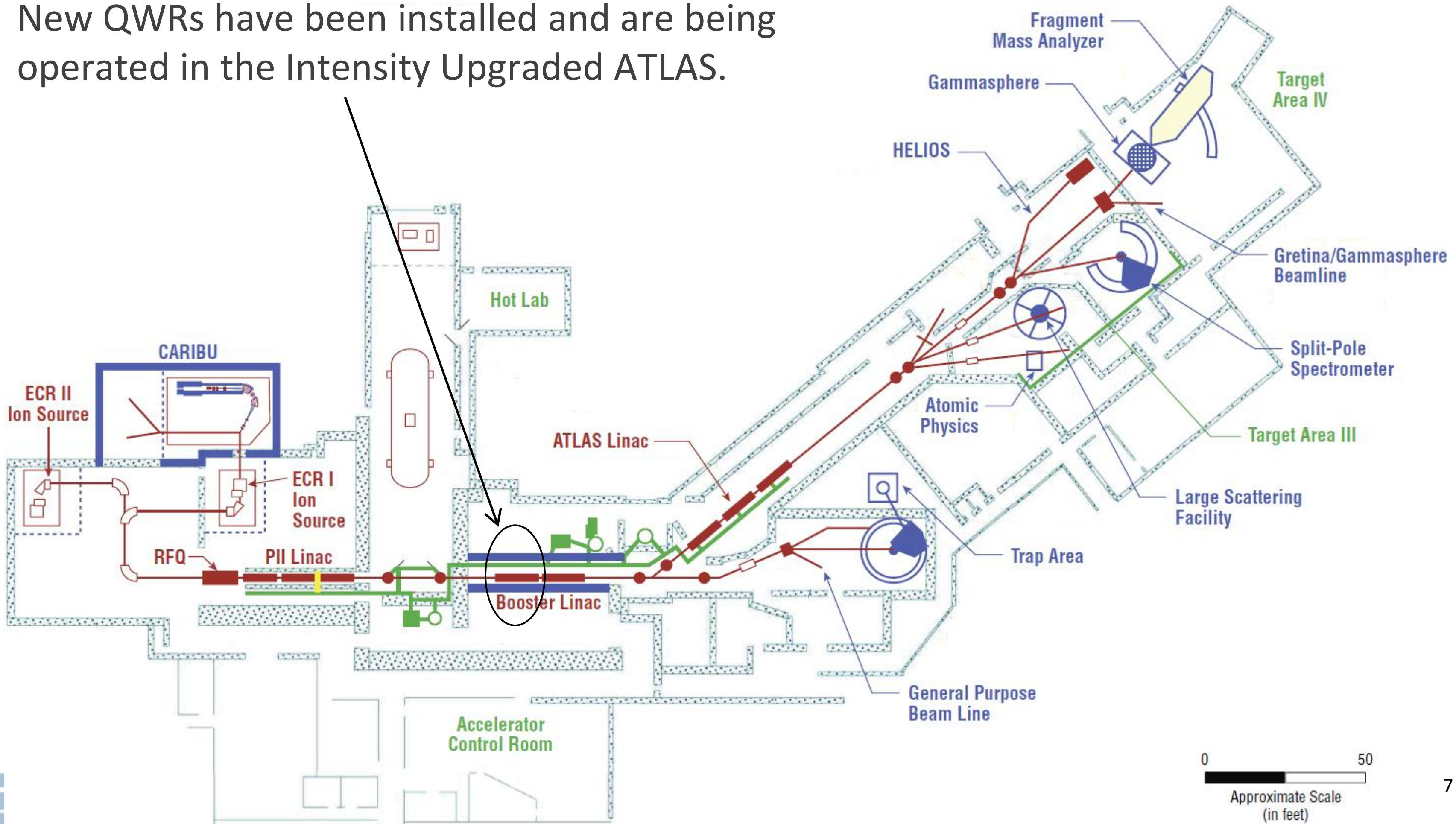


(Courtesy of R. Geng)

Pure, Clean, and Smooth Surface

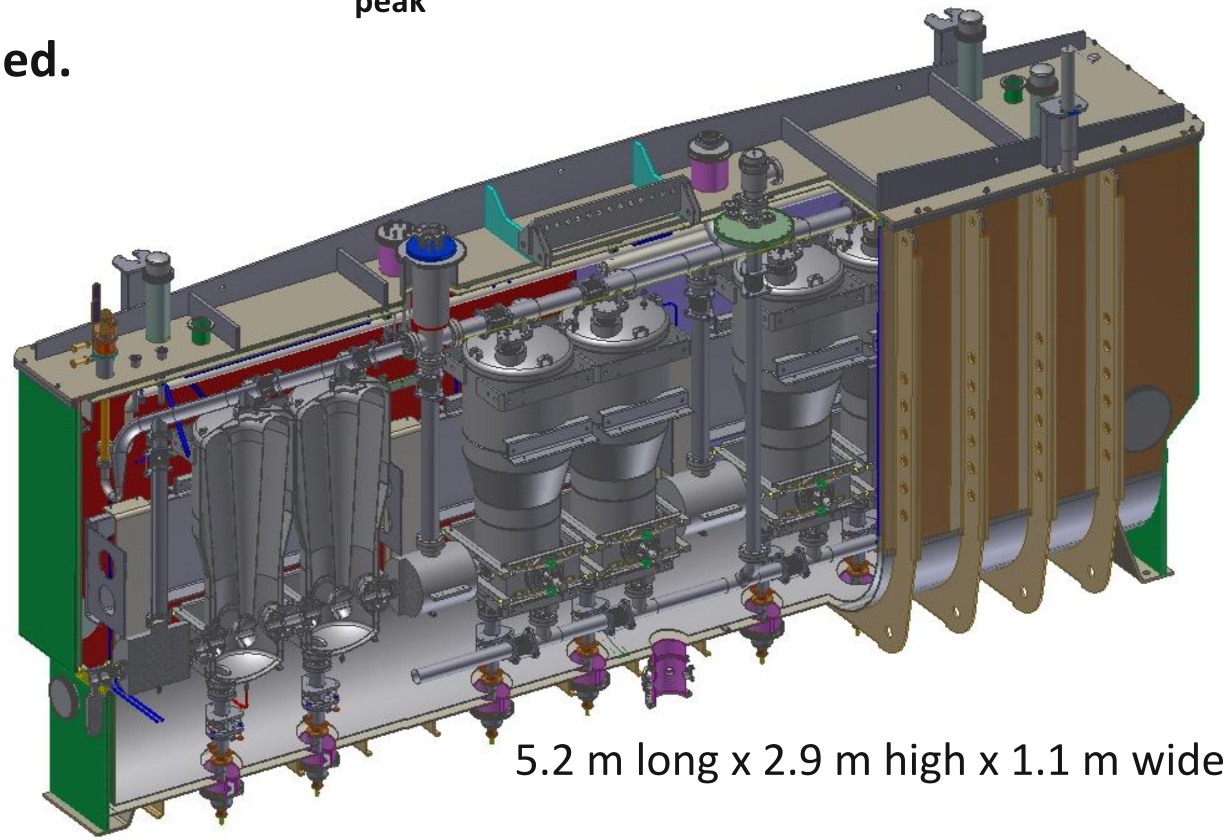
ATLAS: Facility for Nuclear Physics Experiments

- The world's first superconducting linear accelerator for heavy ions since 1978.
- Accelerating rare isotopes as well as heavy ions
- For low- and medium-energy nuclear physics such as the physical properties of the nucleus, the core of matter, the fuel of stars.
- New QWRs have been installed and are being operated in the Intensity Upgraded ATLAS.



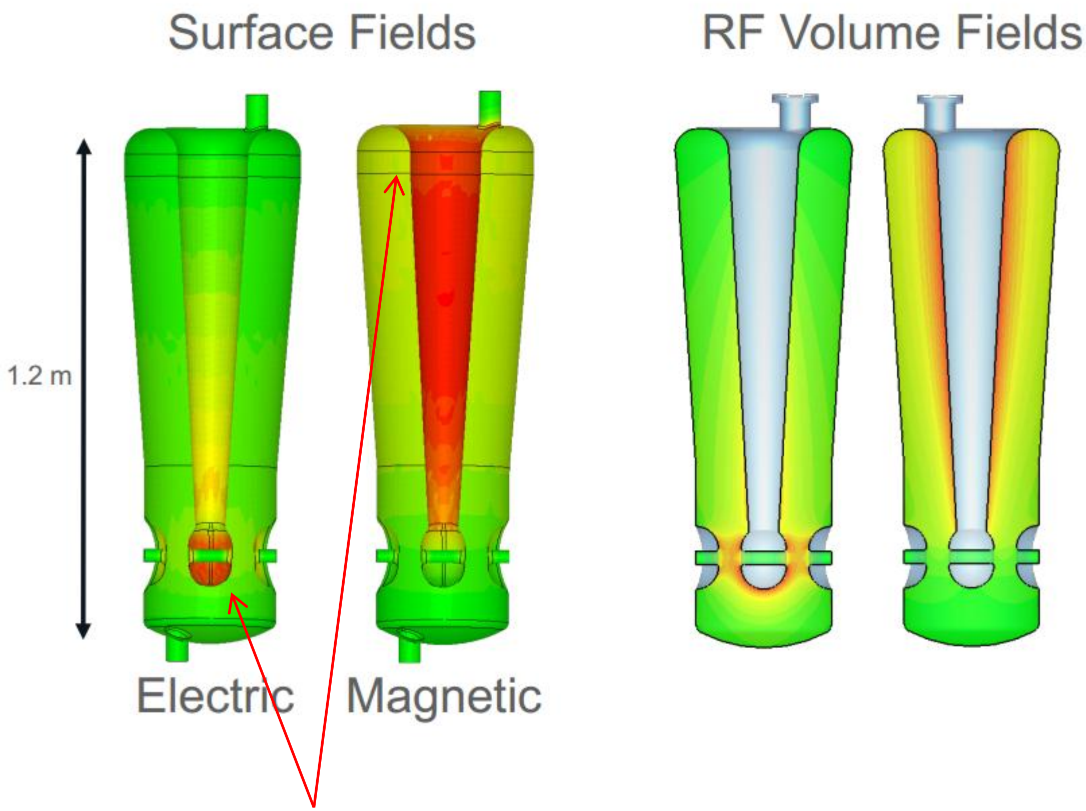
QWR Cryomodule for ATLAS Intensity Upgrade

- Cryomodule: Modularized cryostat containing multiple SRF cavities (and SC magnets).
- Seven $\beta = 0.077$, 72.75 MHz QWRs and Four 9 T SC solenoids.
- Unique features compared with other coaxial cavities
  - **Novel geometries to reduce B_{peak}.**
  - **Electro-polished.**



5.2 m long x 2.9 m high x 1.1 m wide

Electromagnetic Design of the QWR



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

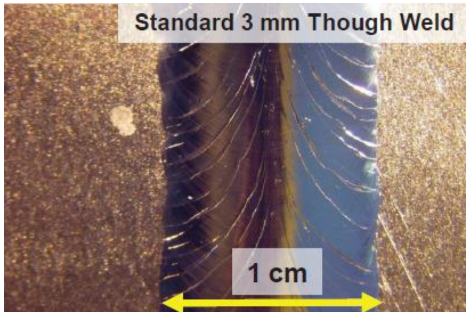
Peak surface electric and magnetic fields are minimized,
e.g. tapered sections of inner and outer conductors reduce
the peak magnetic field by 20% compared with cylindrical shape.

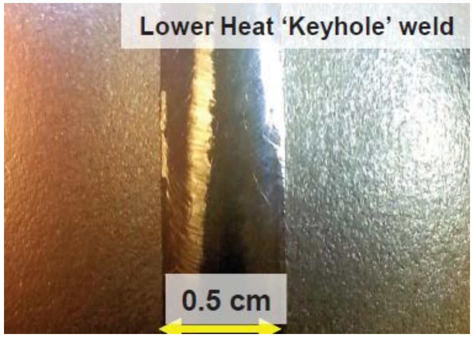
Fabrication and Treatment of the QWR

- Fabrication
  - Soaking and inspection
  - Hydroforming
  - Electrical Discharge Machining (EDM) cut
  - Etching after EDM cut
  - Electron Beam Welding (EBW)
  - LHe Jacket Welding
- Treatment
  - Electro polishing
  - Ultrasonic cleaning
  - High pressure rinsing
  - Baking

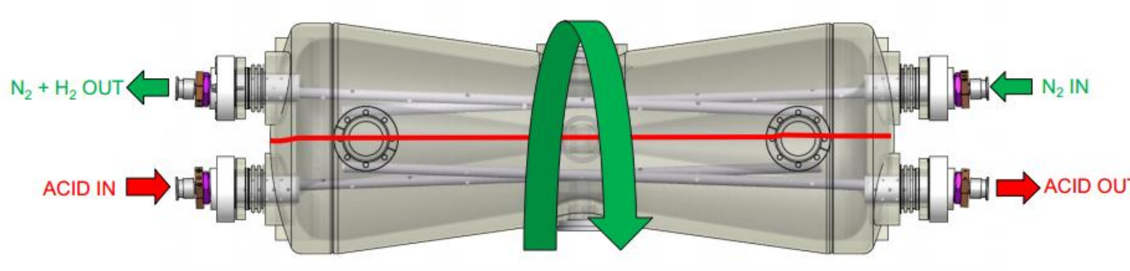
EDM

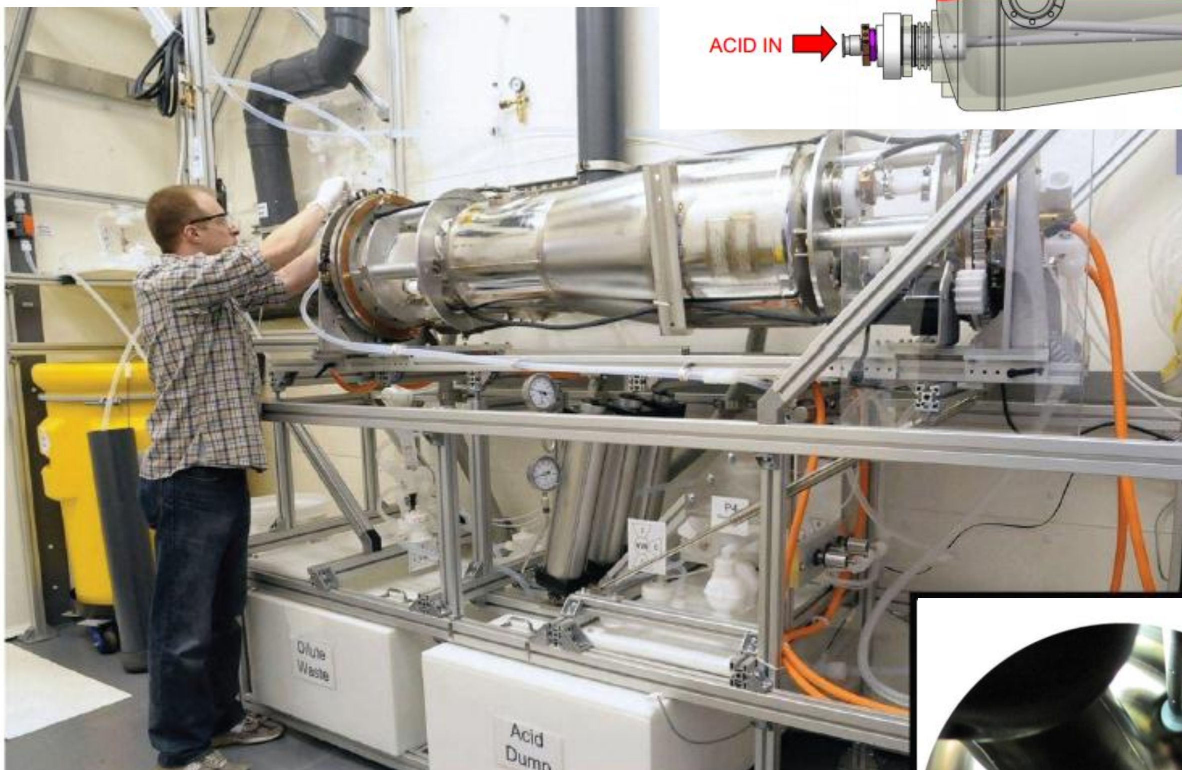
EBW





Electro-Polishing

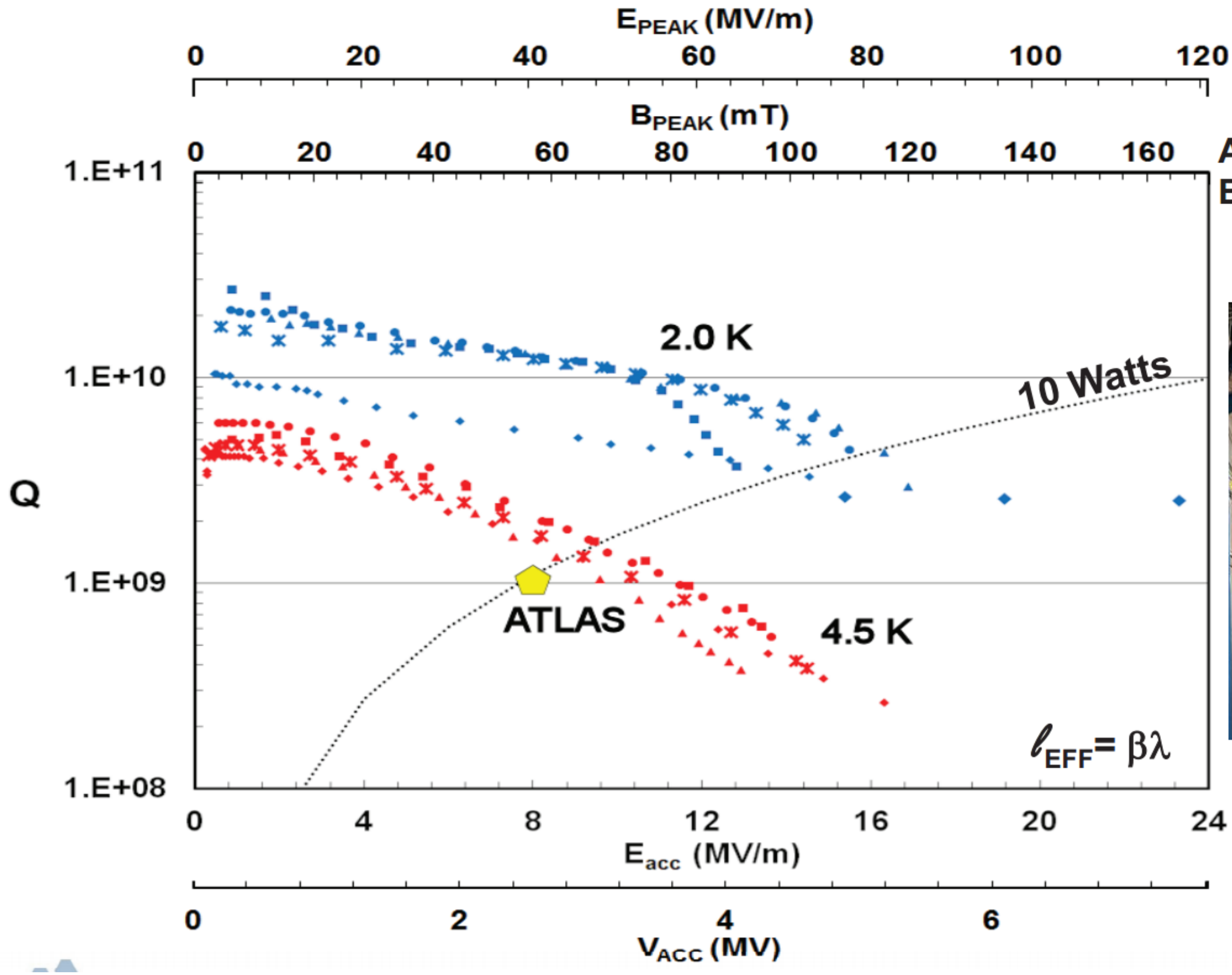




BEFORE EP

AFTER 12HRS OF EP
150μm Nb REMOVED

Performance of the QWRs



Ave Cavity Max at B_{PEAK}=129.6 mT

We achieved higher Q factors than design values, moreover, it is capable of producing 3~4 MV at this beta and frequency (β = 0.077, 72.75 MHz QWR).

Assembly

Cavity string assembly in cleanroom

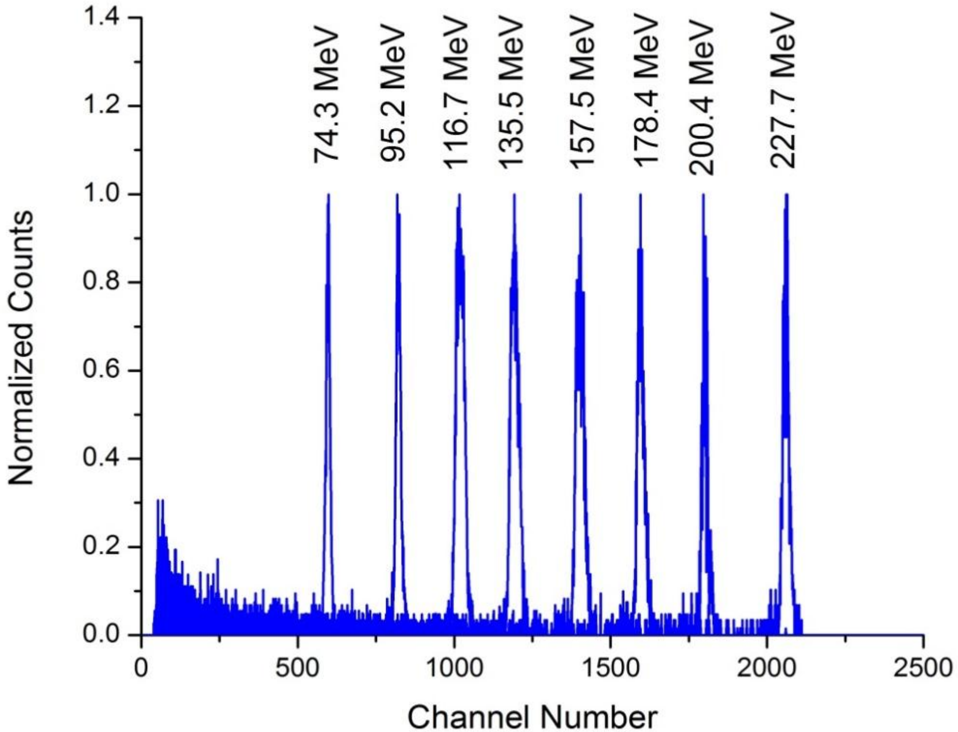
Lid assembly outside of cleanroom

Box assembly

Performance of the QWRs in ATLAS

- Accelerating voltage was average 2.5 MV/cavity as per beam measurements and the 4.5 K LHe consumption was 40 W (cf. design ~ 85 W):
  The cavities also show good performance in the cryomodule installed in ATLAS.

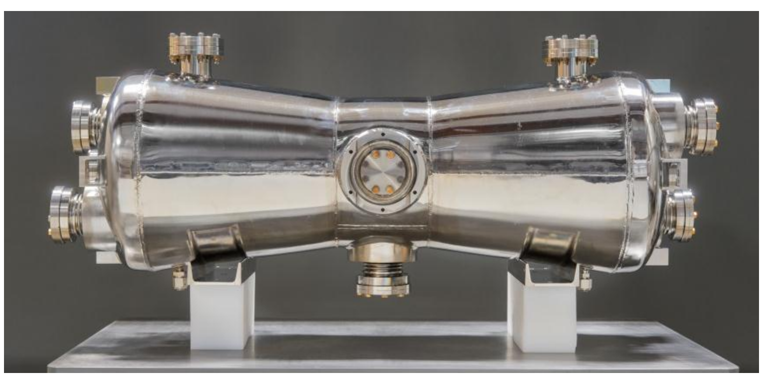
$^{45}Sc^{11+}$ ion beam energy spectrum,
(synchronous phase ~ -35°)



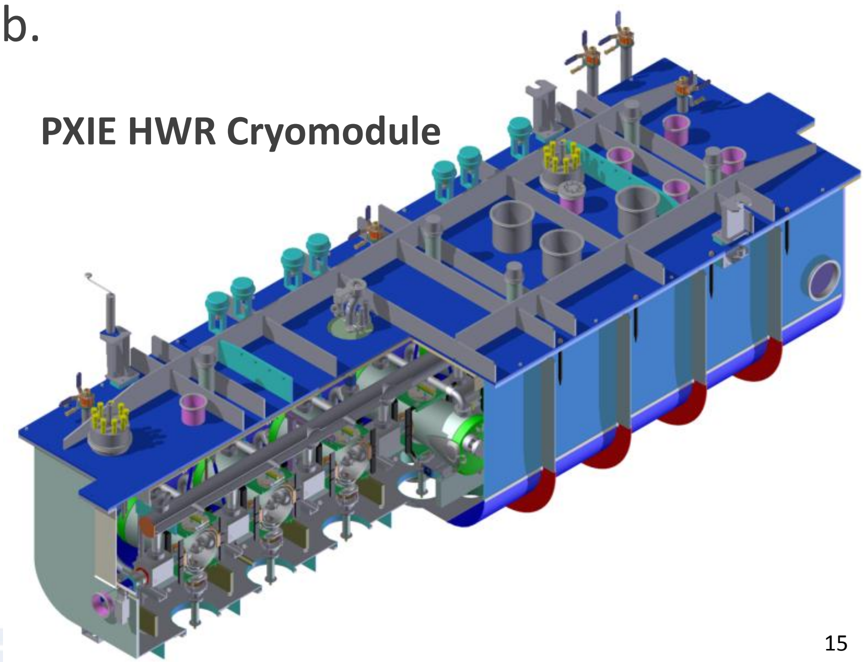
Summary

- We have completed development of β = 0.077, 72.75 MHz Quarter-Wave Resonators Cryomodule for ATLAS Intensity Upgrade.
- With the novel geometry and EP as well as many other careful steps in fabrication and treatment, we achieved record high accelerating voltages with relatively low cryogenic loads: 2.5 MV per cavity and total cryogenic load is 40 W.
- We are now developing PXIE Half-Wave Resonators Cryomodule for Proton Improvement Plan-II at Fermilab.

First prototype HWR



PXIE HWR Cryomodule



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