POTENTIAL ARGONNE NATIONAL LABORATORY CONTRIBUTIONS TO THE ELECTRON ION COLLIDER

5.4 m long β = 0.077 72.75 MHz Quarter-Wave Resonator Cryomodule String Assembly.

ZACHARY A. CONWAY
Argonne National Laboratory
Physics Division
Accelerator Development Group

5 April 2017
JLEIC Collaboration Meeting Spring 2017
Thomas Jefferson National Accelerator Facility
Newport News, VA 23606

ANL-PHY DIVISION ACCELERATOR PERSONNEL

Accelerator Development

- **Group Leader:**
  - **M.P. Kelly (PHY).**
- **Physicists:**
  - **Z. Conway (PHY).**
  - **S.H. Kim (PHY).**
  - **B. Mustapha (PHY).**
- **Engineers:**
  - **A. Barcikowski (NE).**
  - **B. Guilfoyle (HEP).**
  - **M. Kedzie (PHY).**
  - **T. Reid (HEP).**
- **Designers:**
  - **G. Cherry (NE).**

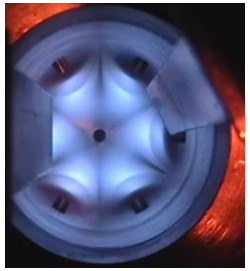
ATLAS Operations

- **ATLAS Strategic Development Group Leader:**
  - **C. Dickerson (PHY).**
- **Physicist:**
  - **R.C. Pardo (PHY).**
- **Ion Source Engineers:**
  - **R.C. Vondrasek (PHY).**
  - **R.H. Scott (PHY).**

Many thanks to contributions from M. Kelly, B.Mustapha, S.H. Kim and R. Vondrasek in this presentation.

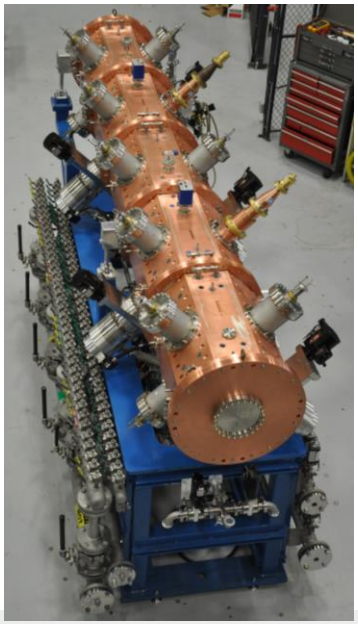
ANL WORK RELEVANT TO THE ELECTRON ION COLLIDER

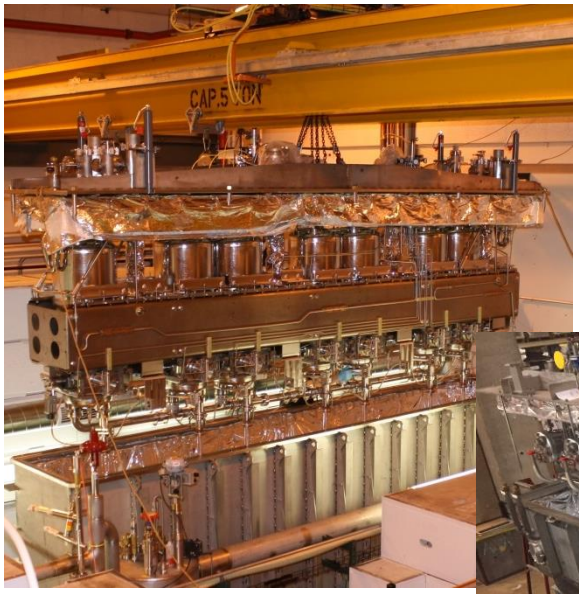
ANL ION ACCELERATOR HARDWARE SIMILAR TO JLEIC



ECR2 High Intensity Source, Regularly Delivers >25 beam species a year to ATLAS

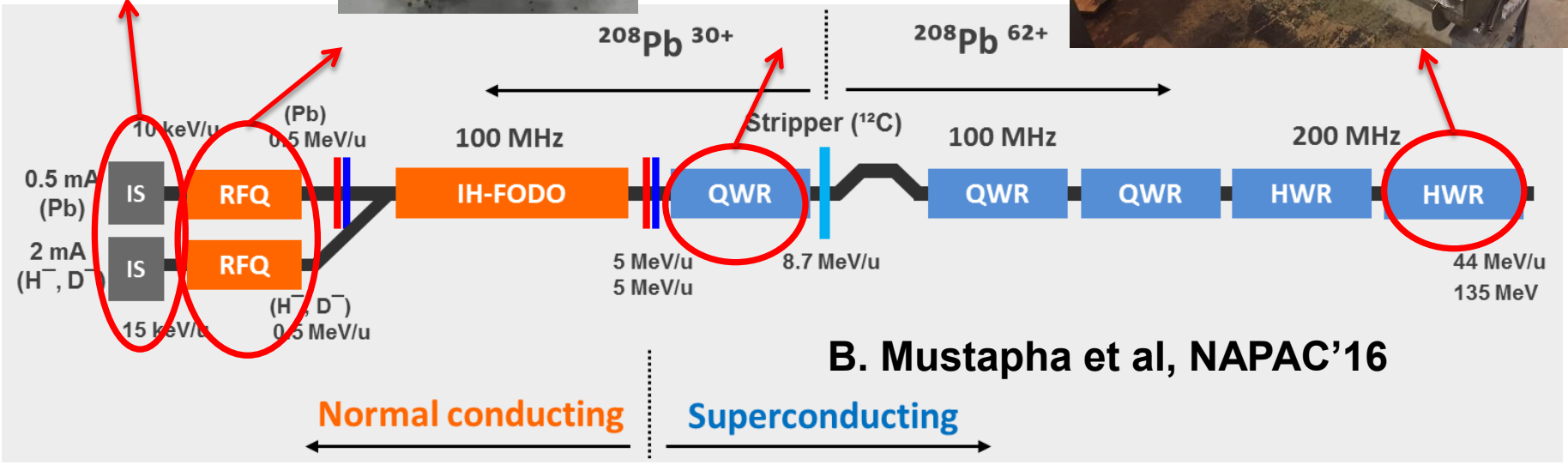
60.625 MHz
RFQ Q/A > 1/7
H - Pb





QWR Cryomodule
72.75 MHz β = 0.77

HWR Cryomodule
162.5 MHz β = 0.11



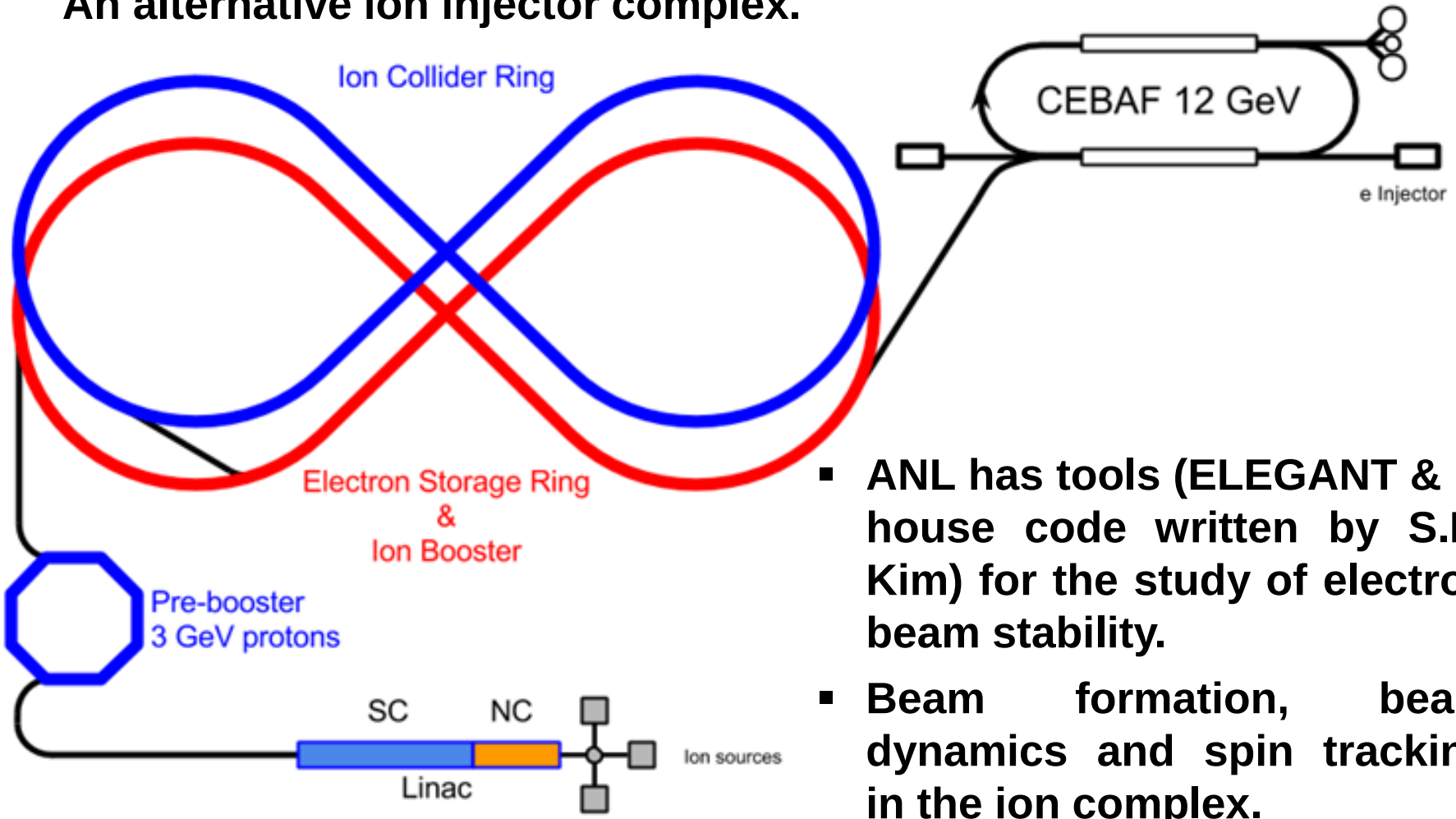
SRF ION ACCELERATOR COMPLEX R&D

COMMUNITY REVIEW OF EIC ACCELERATOR R&D FOR THE OFFICE OF NUCLEAR PHYSICS

R&D ACTIVITIES 12, 37, 60, 61 & 67

ION ACCELERATOR R&D (R&D # 12, 37, 60, 61 & 67)

An alternative ion injector complex.



- **ANL has tools (ELEGANT & in house code written by S.H. Kim) for the study of electron beam stability.**
- **Beam formation, beam dynamics and spin tracking in the ion complex.**
- **Code benchmarking with several different beam simulation tools, e.g., COSY.**

See Monday's presentation by B. Mustapha and S.H. Kim, and B. Mustapha et al, NAPAC'16.

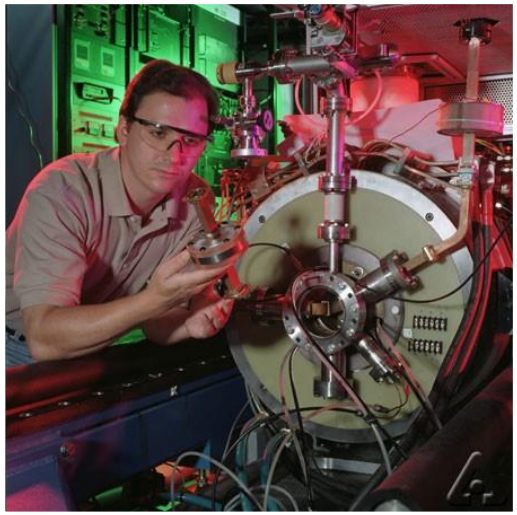
TOOLS FOR END-TO-END SIMULATION OF JLEIC ION COMPLEX

- ANL and NIU has been part of the JLab EIC collaboration for several years. During this time we developed several beam simulation tools.
- Most of the Ion Complex in the JLEIC baseline design was developed using an updated version of COSY Infinity
- This new version of COSY Infinity, mainly developed using EIC R&D funds, is capable of:
  - Linac simulation
  - Synchrotron design and simulation
  - Interaction region design and simulation
  - 3D beam dynamics, space charge effects and spin tracking
- MADX(CERN) was used to design a more compact octagonal 3 GeV pre-booster and benchmark COSY's original results
- TRACK is being used for the Linac design and detailed beam dynamics simulations including error simulations

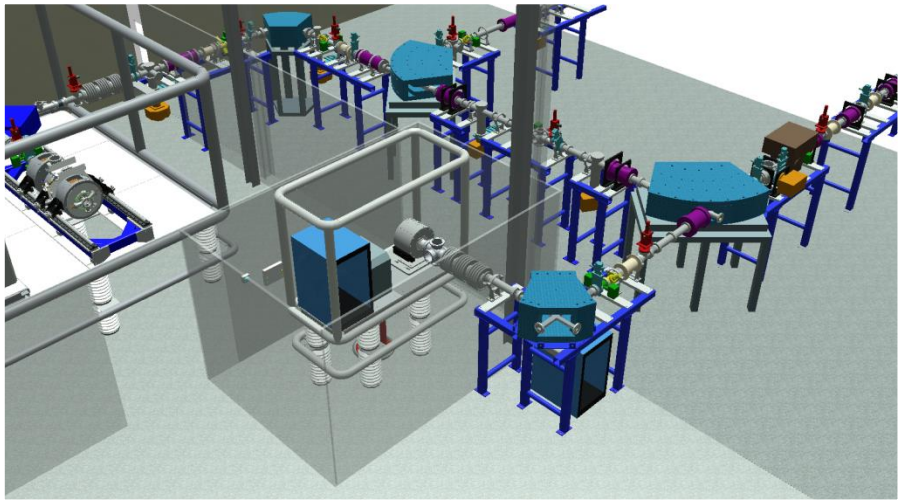
HIGH INTENSITY ION SOURCES FOR THE EIC

R&D ACTIVITIES 6 AND 69

ATLAS ION SOURCE DEVELOPMENT (R&D # 6 & 69)

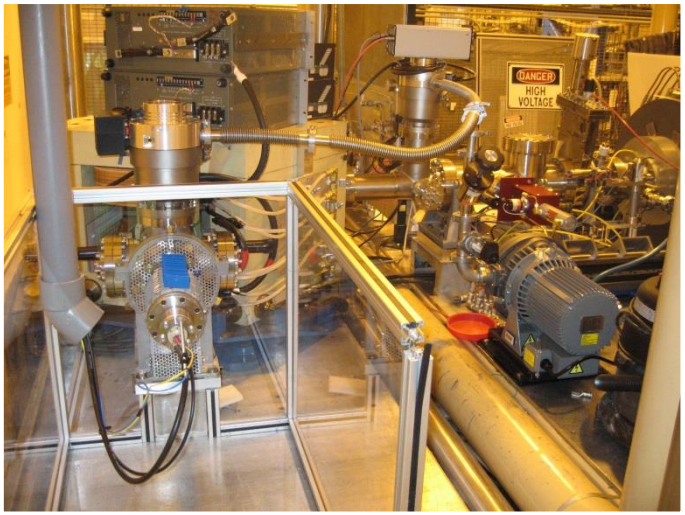


ECR2 – stable beams



ECR3 – C-14 and hazardous beams

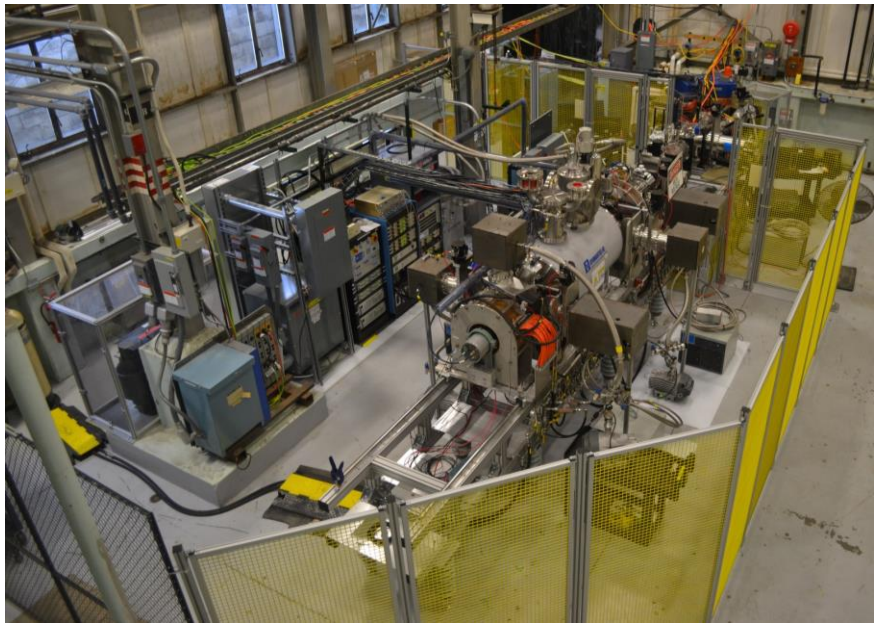
EBIS charge breeder – high efficiency and purity for radioactive beam production since 2014



ECR charge breeder – world record efficiency for both stable and radioactive beam production – 2015 Brightness Award R. Vondrasek (ANL)

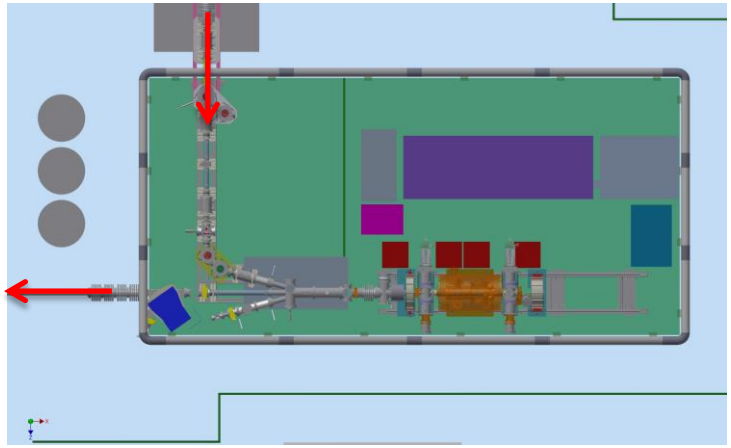
ATLAS DEVELOPMENT WORK APPLICABLE TO POLARIZED SOURCES (R&D # 6)

ATLAS EBIS



Ionization of polarized $^3He^+$ ions in EBIS trap with slanted electrostatic mirror, Pikin (BNL) et al, PSTP2007

Polarized Ions

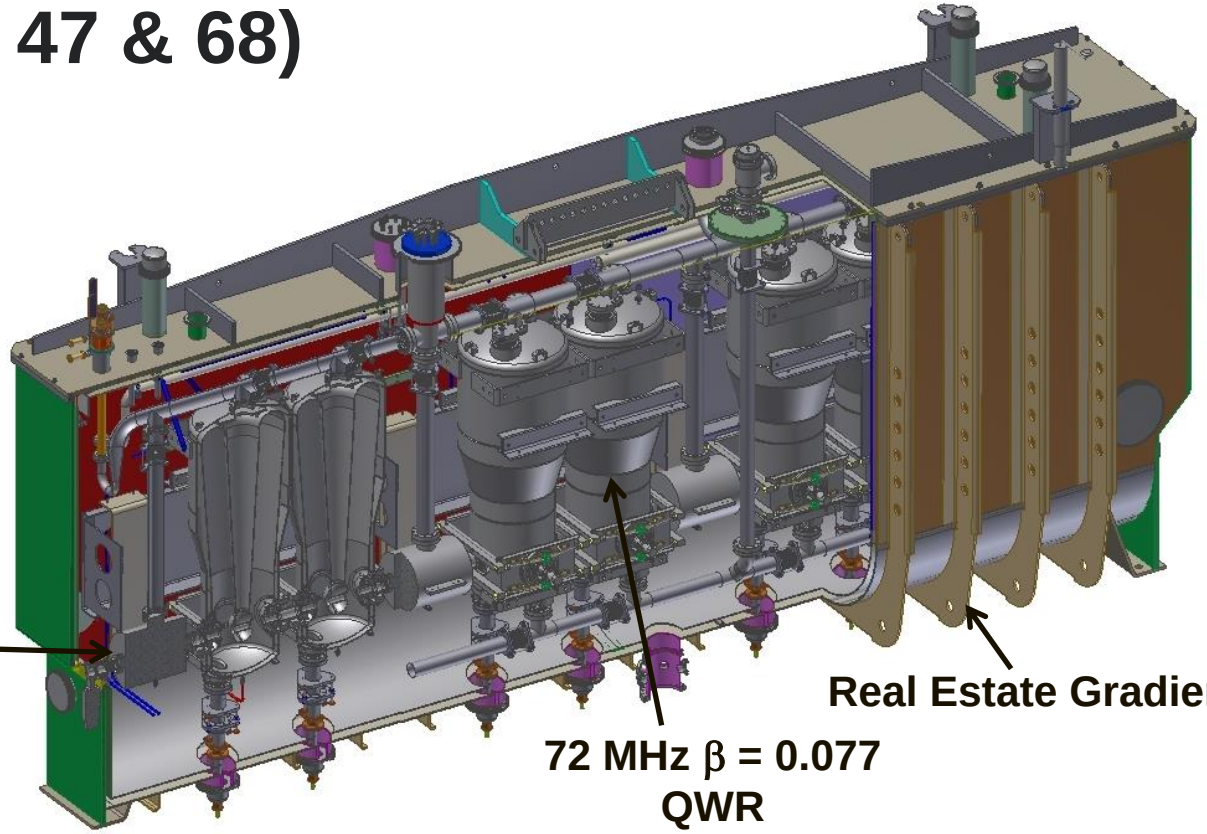


- **EBIS in operation at ATLAS since 2016.**
- **Polarization preserved in EBIS solenoid field during charge breeding.**
- **Couple ATLAS EBIS to a polarized ion beam source to generate fully stripped $^3He^{++}$, Lithium, etc.**

SUPERCONDUCTING RADIO FREQUENCY ACCELERATOR DEVELOPMENT

R&D ACTIVITY 8, 10, 27, 47, 48 & 68

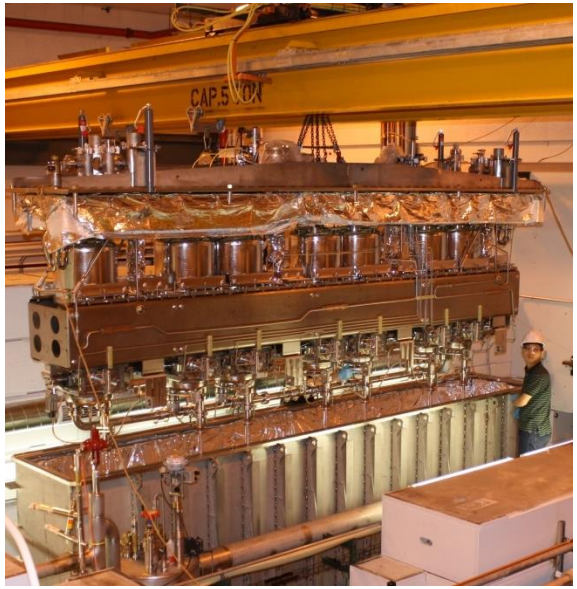
ATLAS INTENSITY UPGRADE CRYOMODULE (R&D # 47 & 68)



5.2 m long
2.9 m high
1.1 m wide

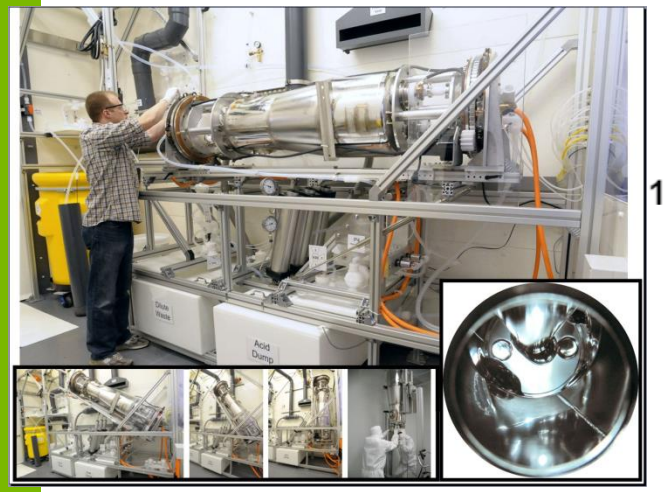
- **The new cryomodule contains 7 SC 72.75 MHz, β = 0.077, quarter-wave cavities (QWR) and 4 superconducting 9T solenoids, all operating at 4.5 Kelvin.**
- **First SRF cryomodule where cavities are completely processed after all fabrication is complete in addition to advanced electromagnetic design and fabrication techniques.**
- **In ~continuous operation since 2014, kept at T<5 K during maintenance periods.**

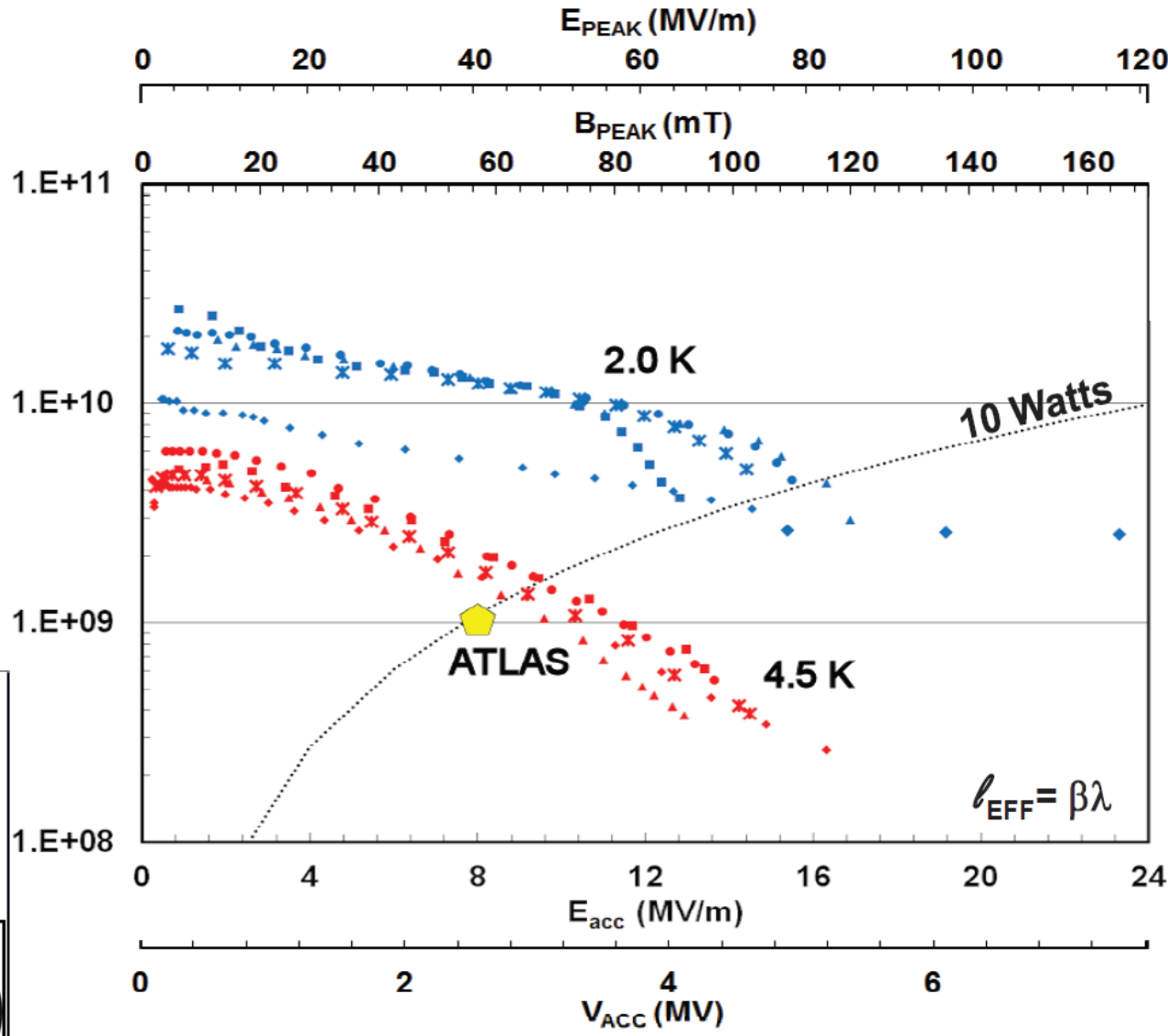
QWR MEASURED PERFORMANCE - OFFLINE



Q

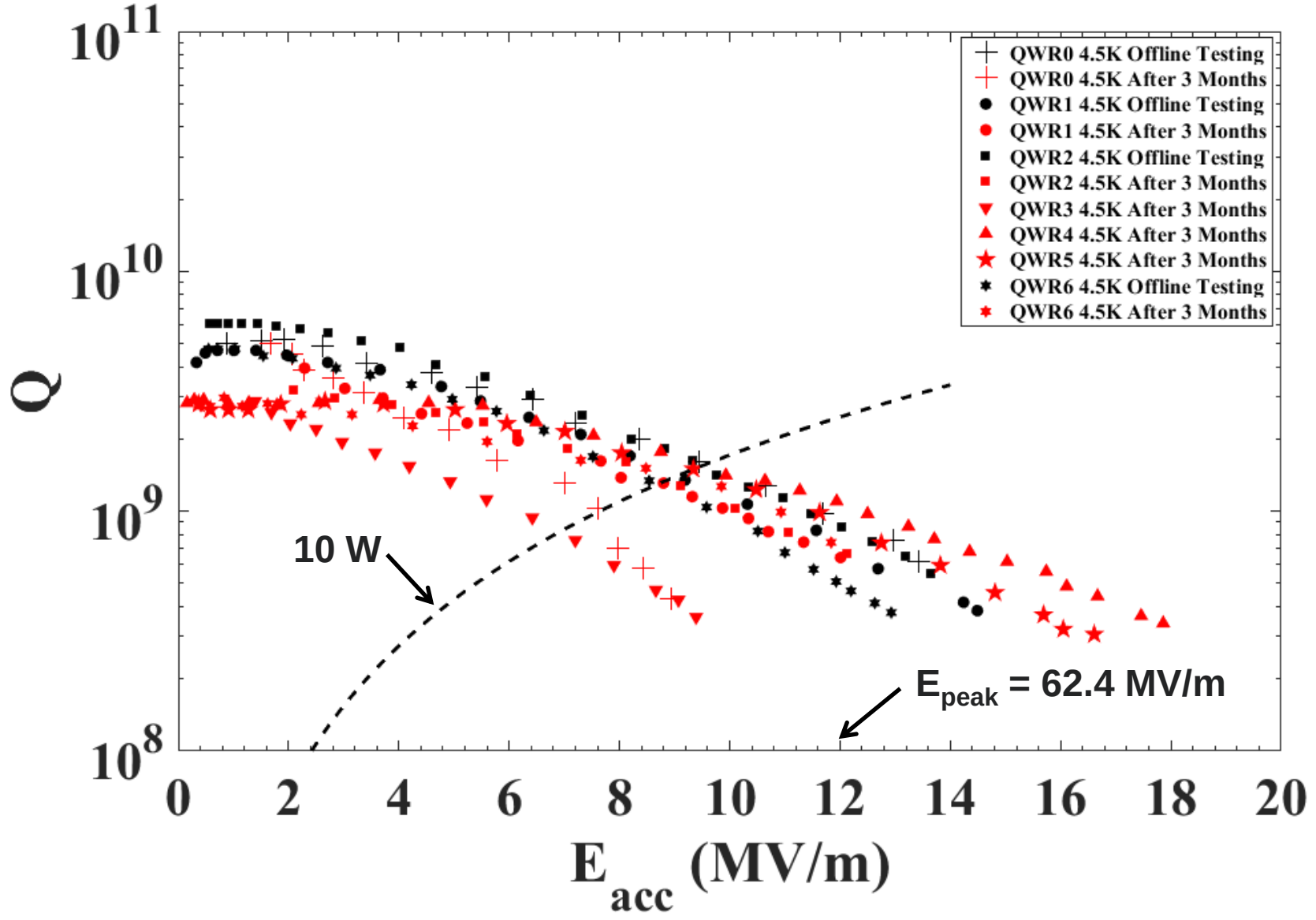
ANL Low-β Cavity EP Tool



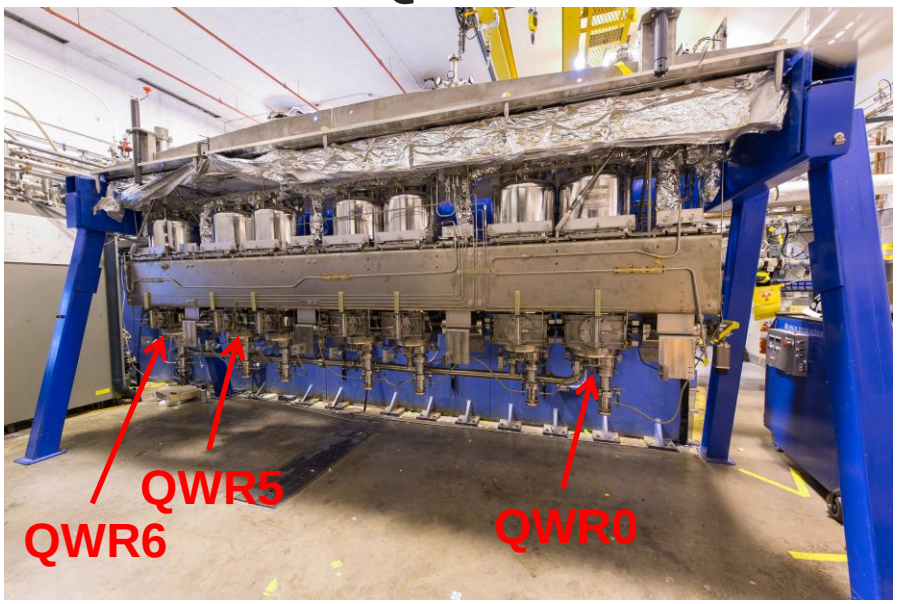


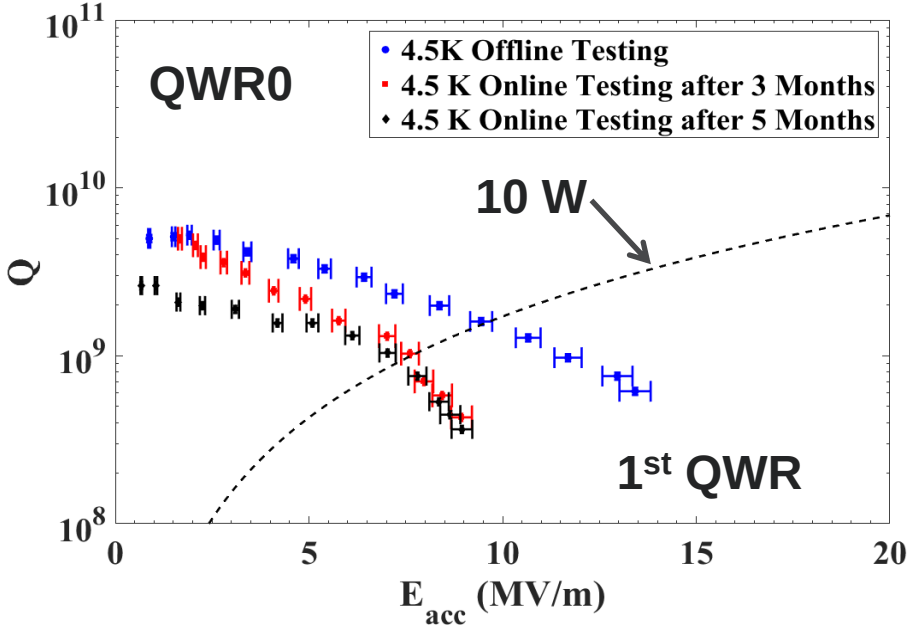
M. Kelly, SRF'13

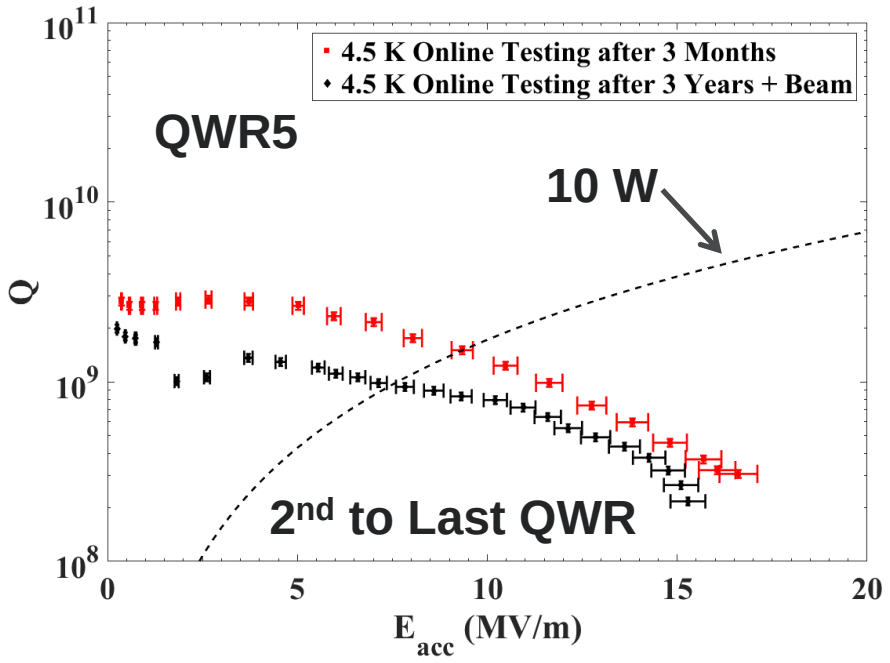
QWR PERFORMANCE AFTER 3 MONTHS ONLINE (R&D 47 & 68)

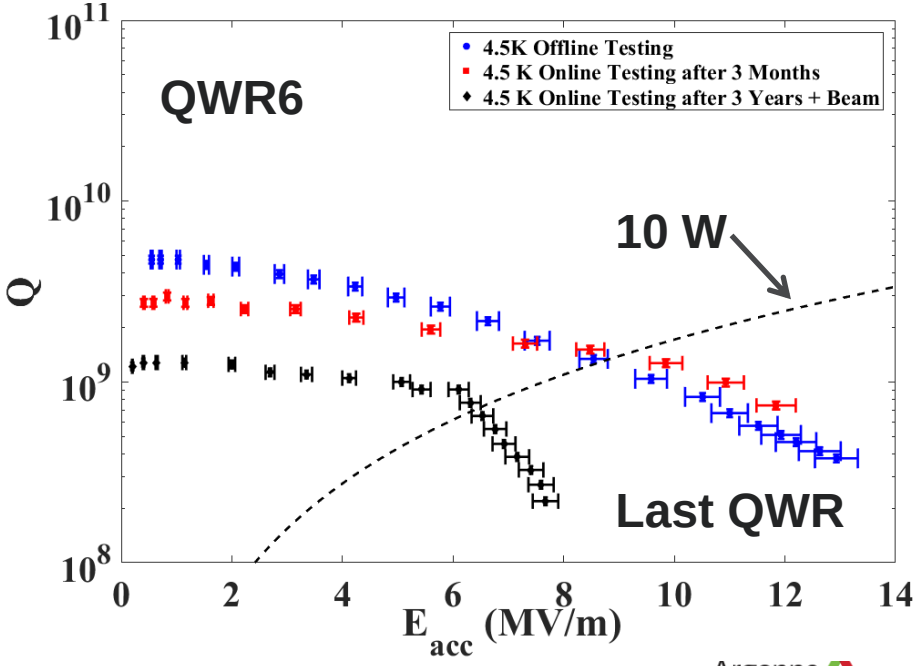


72.75 MHZ QWR CRYOMODULE PERFORMANCE

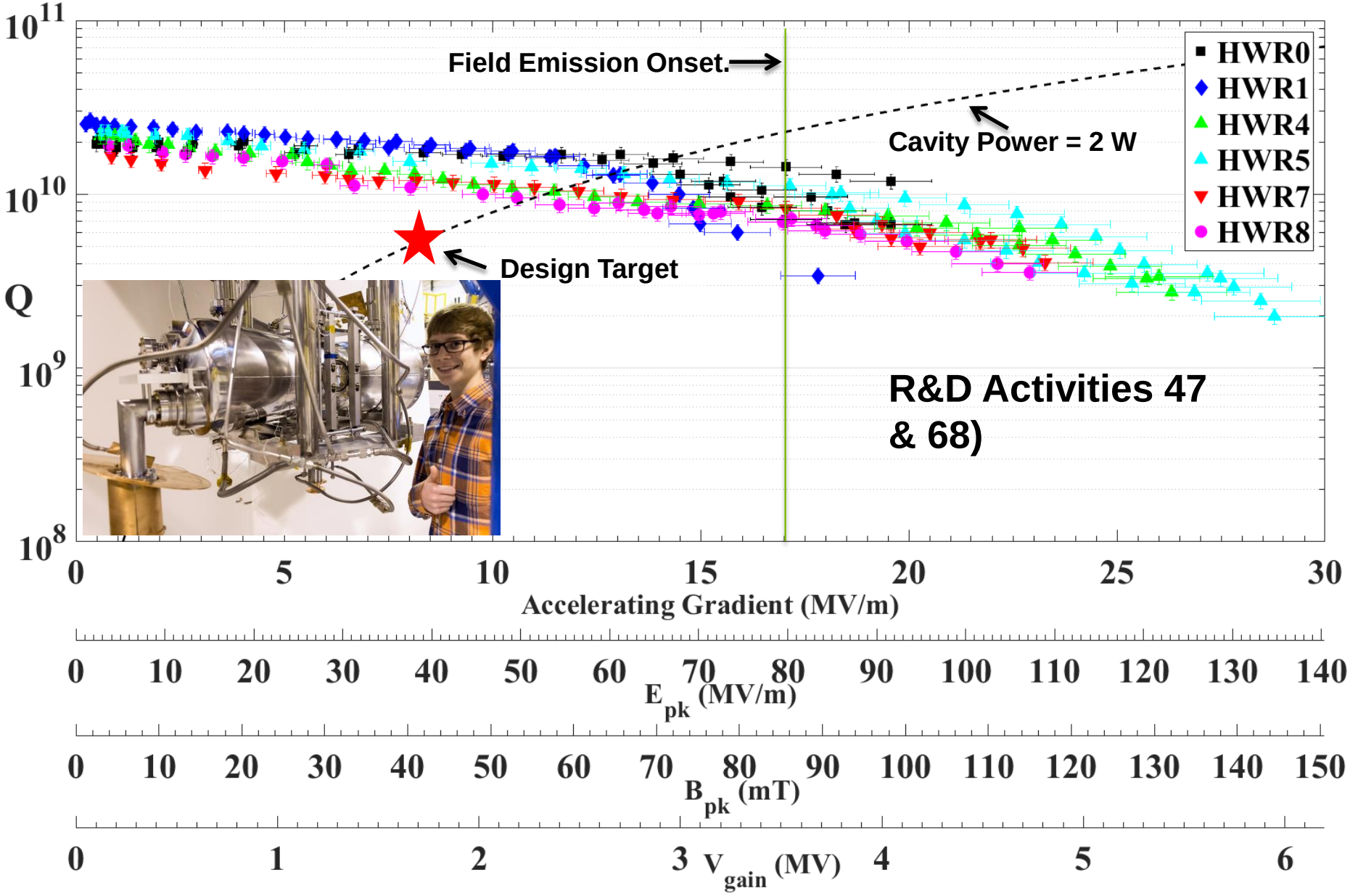








2.0 K HALF-WAVE RESONATOR PERFORMANCE

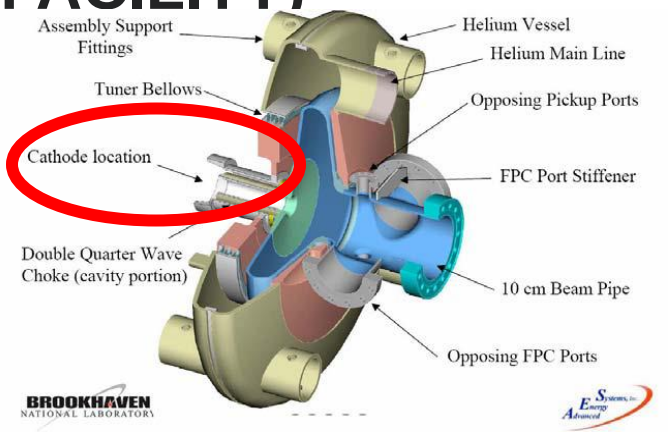


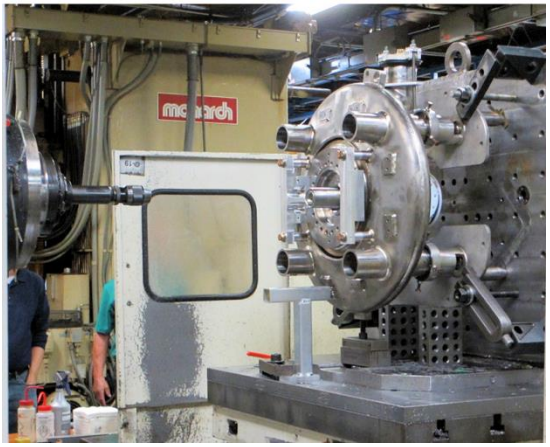
ANL/FNAL SRF SURFACE PROCESSING FACILITY @ ANL

325 MHz Spoke Cavity BCP

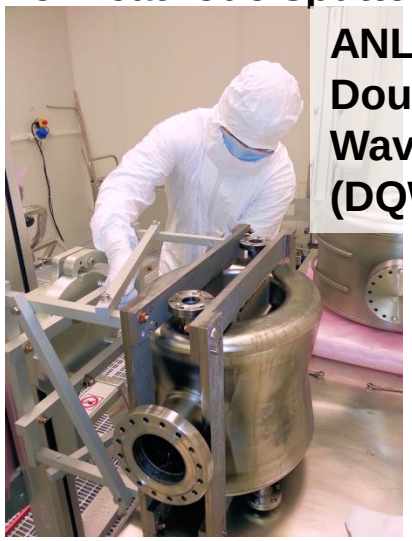
650 MHz Cavity Electropolishing

ANL CAVITY R&D SUPPORTING ELECTRON COOLING (R&D # 8, 10, 27, 47, 48 & 68; ANL'S UNIQUE PROCESSING FACILITY)



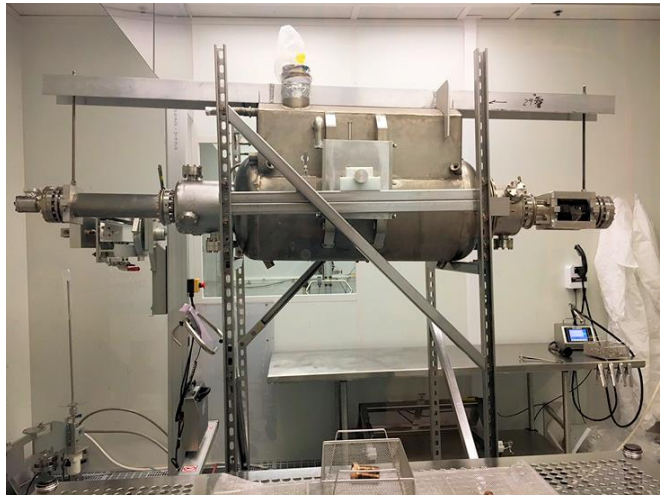


Conversion of the electron gun cavity into a low energy booster cavity: (1) modifications to the niobium and helium vessel to increase cooling (2) reprocessing to remove residues from cathode sputtering



ANL processing of Double Quarter Wave Crab Cavity (DQW-CC)

704 MHz 5-cell Superconducting RF BNL3 Cavity for the Coherent Electron Cooling Proof of Principle Project



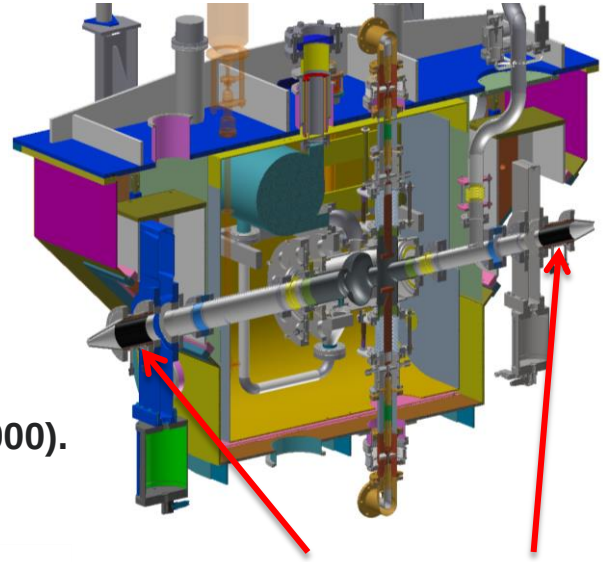
HIGH POWER SRF FOR ELECTRONS
R&D ACTIVITIES 9, 11, 26 & 50

HOM DAMPING IN HIGH CURRENT SRF CAVITY: APS UPGRADE HARMONIC CAVITY

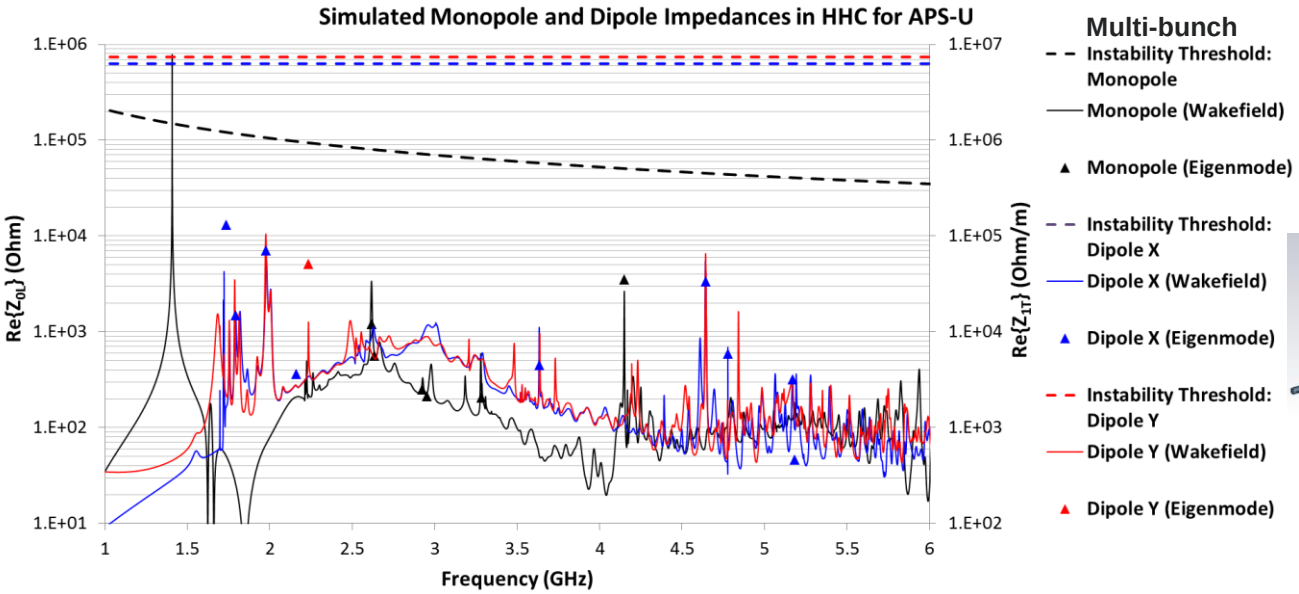
R&D Activities 9 & 11

- **Superconducting Harmonic Cavity in the APS Upgrade**
  - To increase Touschek lifetime and reduce collective effects
  - 1.4 GHz (4th harmonic) single-cell SRF cavity, 1 MV norm.
  - **Beam current: 200 mA, Single bunch charge: 15 nC, Bunch repetition rate: 13 MHz**
  - **Beam pipe silicon carbide (SiC) HOM absorbers**
- **Analysis of HOM Impedances**
  - Fully analyzed HOM Impedance spectra in Wakefield simulations.
  - **The SiC HOM absorbers strongly damp all HOMs (Q: 100 – 1000).**
  - Estimated dissipation power: 1 kW max. per absorber.

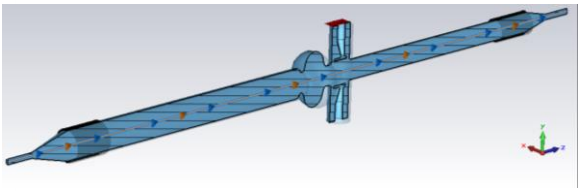
APS-U Harmonic Cavity Cryomodule



SiC HOM Absorbers
at Room Temperature



CST Wakefield Simulation Model



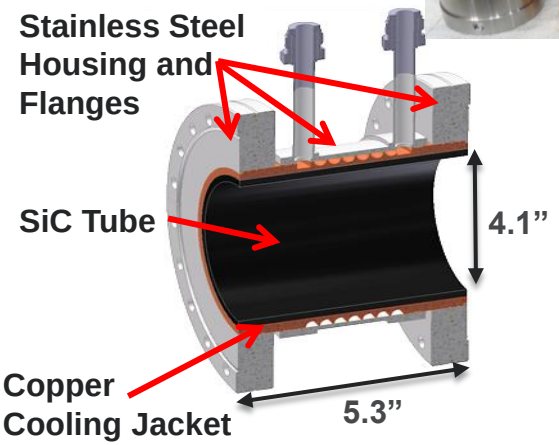
Argonne NATIONAL LABORATORY

SIC HOM ABSORBER ASSEMBLY FOR APS UPGRADE HARMONIC CAVITY

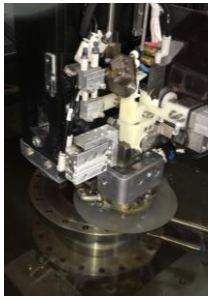
R&D Activities 9 & 11

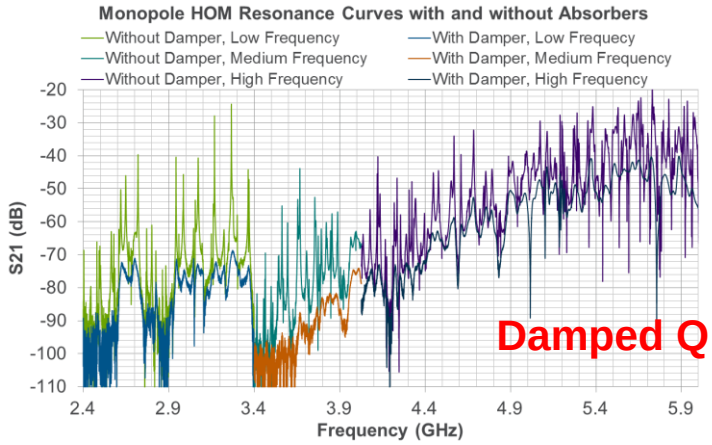
- **Designed and Built the Absorber Assemblies**
  - Material: graphite-direct-sintered silicon carbide, Coorstek SC-35 based on Cornell's experience
  - **Shrink fit** with 0.1 mm interference in diameter
- **Thermal Test**
  - Temperature rise on the SiC inner surface: 2°C at 1 kW radiative heat source
  - **Applicable to ~10 kW heat load**
- **HOM Damping Test at Room Temperature**
  - **Demonstrated HOMs are successfully damped**

Machine Parts



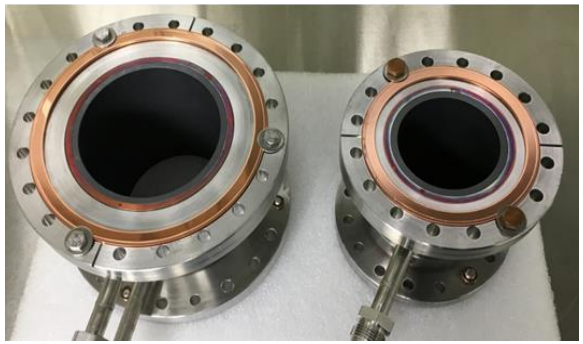
Wire EDM



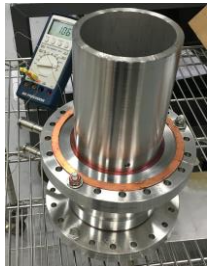


Damped Q: 100 – 1000

Finished Assemblies



Shrink Fit

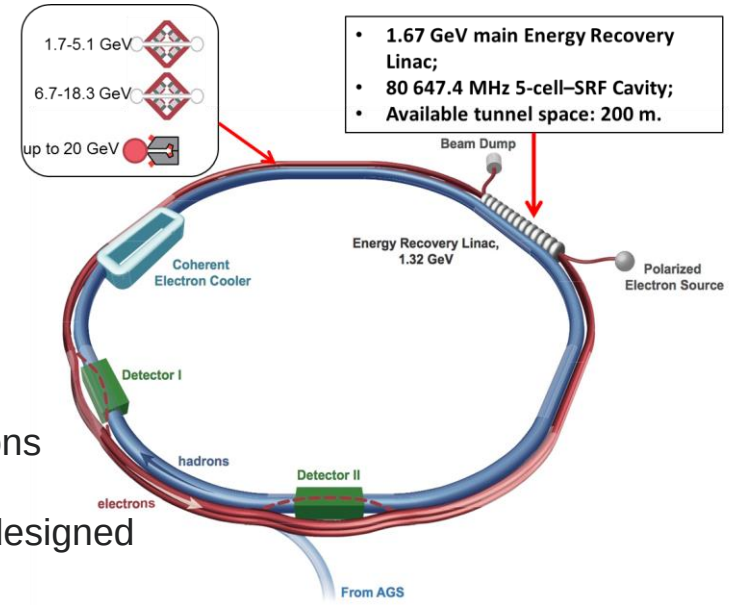


HOM DAMPING STUDY FOR HIGH CURRENT SRF CAVITIES IN THE PROPOSED ERHIC

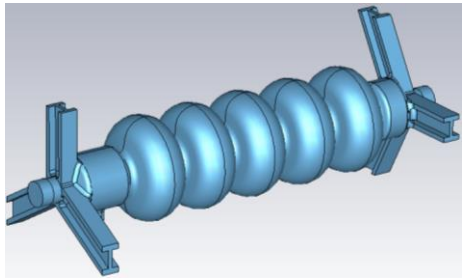
R&D Activities 9, 11, 26 & 50

- **ERL Cavity in the Proposed eRHIC**
  - **647 MHz 5-cell elliptical cavity**
  - Total 80 cavities for 1.67 GeV/pass
  - **Beam current**: 50 mA per pass and 5 passes either for acceleration or deceleration, so **total 0.5 A**
  - **Dipole impedance limit to avoid beam break up (BBU): 10^7 Ohm/m**
- **ANL's Contribution**
  - Finding an efficient way to damp HOMs from RF simulations run on the ANL Physics Division's workstation
  - **Baseline: double ridge waveguide HOM couplers**, as designed by BNL, **with warm SiC HOM absorbers**
  - **Alternative: enlarged beam pipes with warm and cold SiC HOM absorbers**

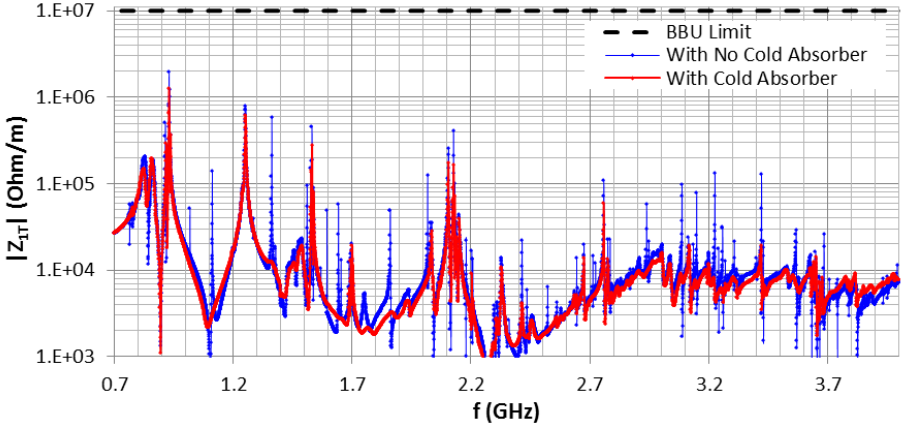
eRHIC Conceptual Layout (Courtesy of W. Xu)



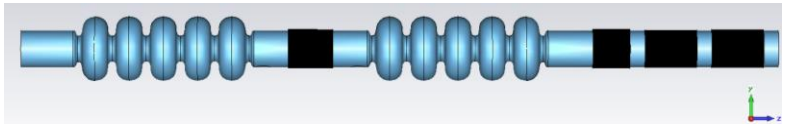
The ERL Cavity with HOM Couplers



Dipole Impedance in the Alternative HOM Damping Option



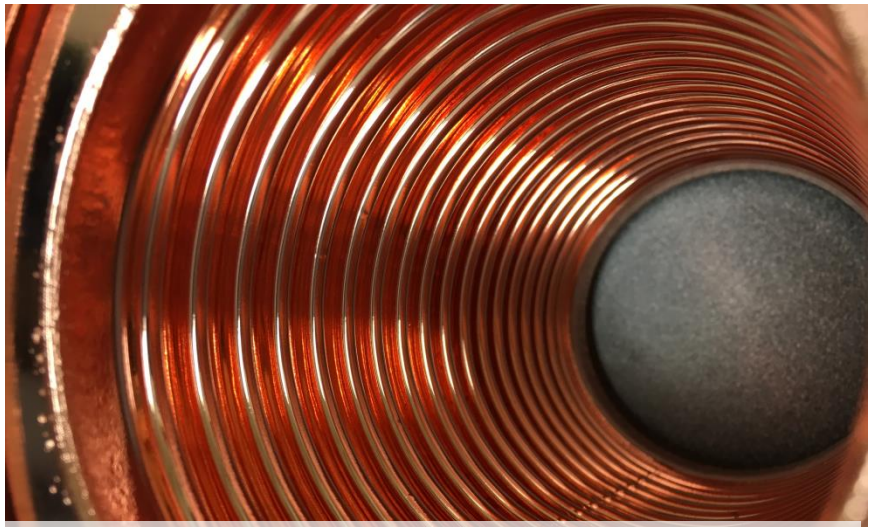
An alternative with only beam pipe HOM absorbers



ACCELERATOR HARDWARE COPPER COATING R&D ACTIVITIES 15 & 35

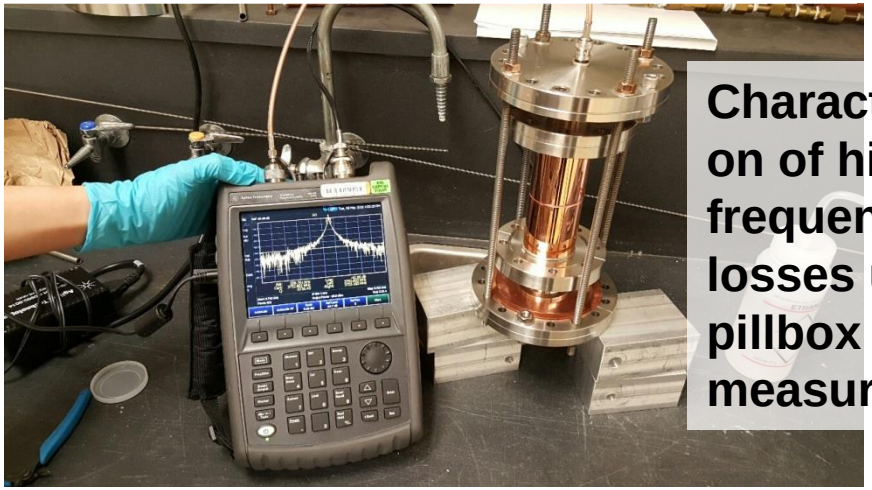
HIGH PURITY COPPER COATINGS FOR ACCELERATOR COMPONENTS (R&D # 15 & 35)

ANL collaboration with US industry to develop low-rf loss/low SEM coatings



20 microns of high-purity copper on interior of rf power coupler bellows

ATLAS 4 kW Couplers



Characterization of high-frequency rf losses using pillbox mode measurements

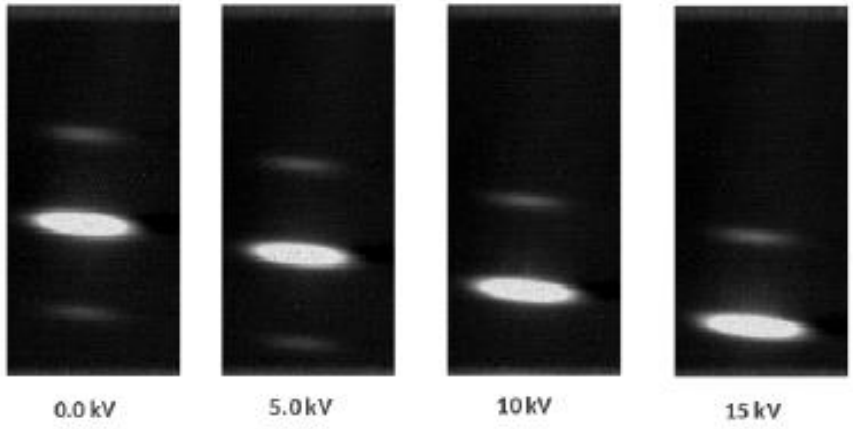
Non-destructive characterization using XRF (x-ray fluorescence spectroscopy)

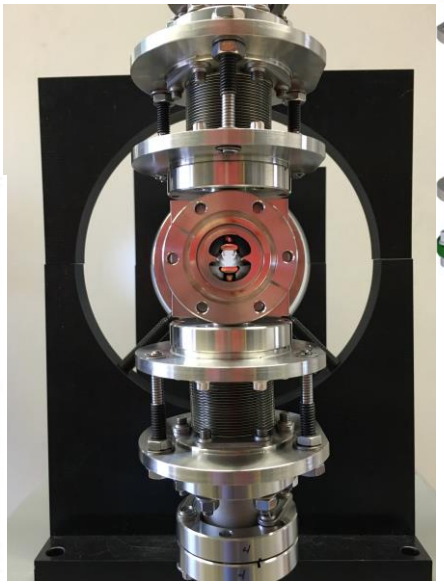
HIGH VOLTAGE FAST KICKERS
R&D ACTIVITIES 19, 42 & 52

ANL PHY/APS COLLABORATION ON FAST KICKERS (R&D ACTIVITIES 19, 42 & 52)

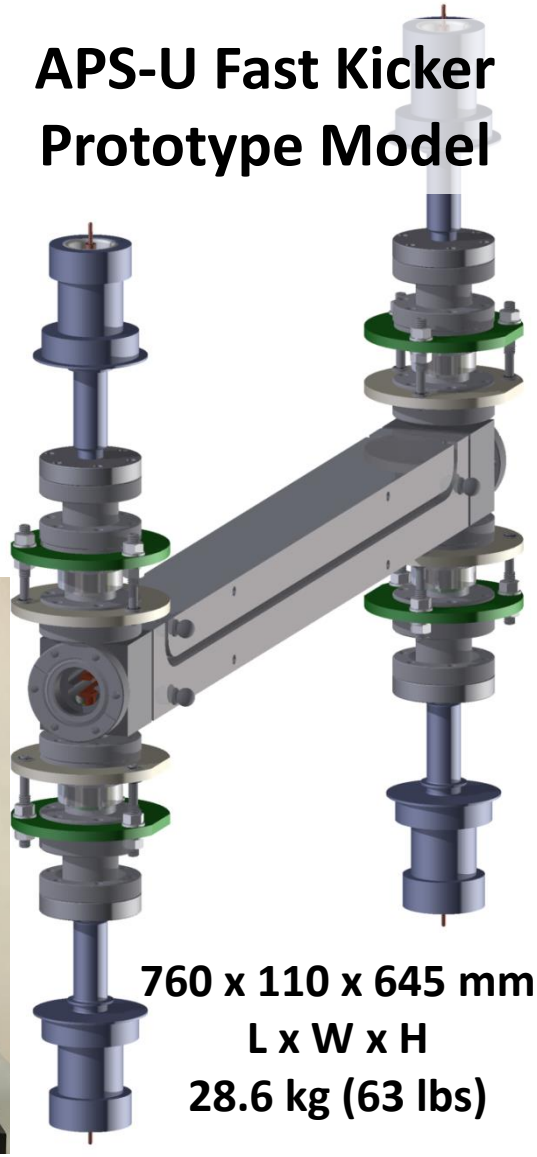
- Demonstrated rise/fall times of 6-7 ns, limited by pulser
  - Power supply R&D required.
  - Recycle pulses for high rep rate (up to ~1 MHz).
    - ANL patent on RF power recovery feedback circulator. US # 7,915,840
- High voltage ready:
  - Tested to 30 kV.
  - Straightforward to upgrade to 60 kV.
- Successfully tested with beam in the APS injector test line.
- Transverse beam feedback.

Beam Deflection Measurments





APS-U Fast Kicker Prototype Model



760 x 110 x 645 mm
L x W x H
28.6 kg (63 lbs)

SUMMARY

- **ANL is ready and willing to collaborate on projects which genuinely benefit the EIC.**
- **ANL has expertise in many high priority R&D items:**
  - **Ion beam simulations and code benchmarking,**
  - **Collective effects and electron beam instabilities,**
  - **Superconducting RF accelerator cavities, cryomodules and processing,**
  - **High intensity ion sources,**
  - **Fast kickers,**
  - **HOM loads, and**
  - **High purity copper coatings.**

- **Thank you!**