Argonne NATIONAL LABORATORY 75 1946–2021

ADVANCES IN THE ATLAS ACCELERATOR

MICHAEL KELLY

Accelerator Development Group Leader
Physics Division

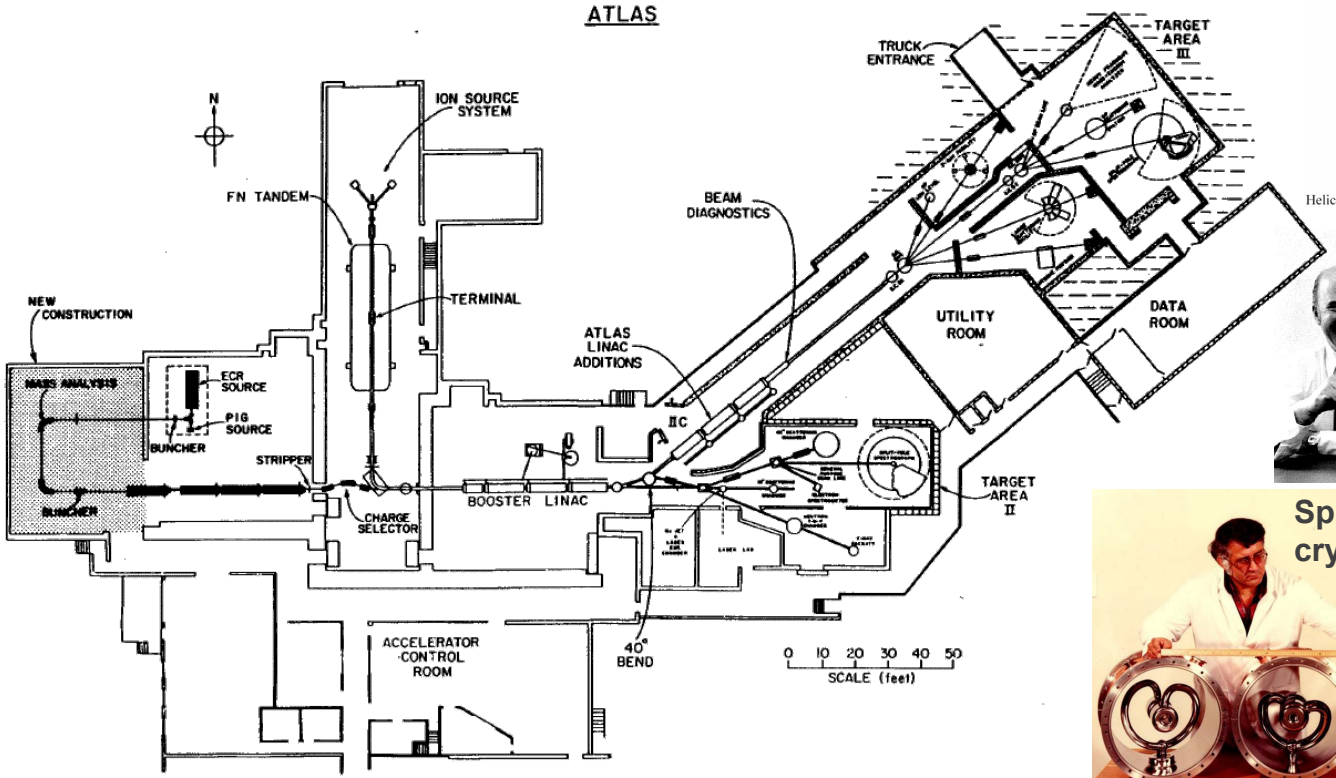
North American Particle Accelerator Conference
Hotel Albuquerque
Albuquerque, New Mexico
7-12 August 2022

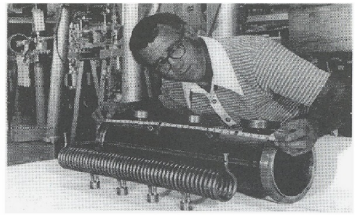
OUTLINE

- Background/context
- (Briefly on) ATLAS source and detector advances
- Aspects of the ATLAS superconducting linac
- Technology for future ion accelerators

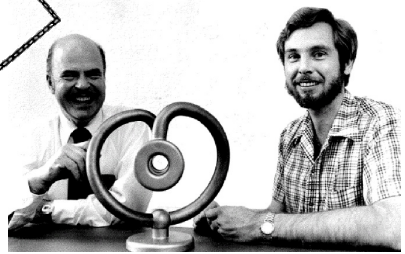
ATLAS 1978-1985 Worlds first superconducting linac for heavy-ions

Conceived in early 1970's; a bold vision to use superconducting niobium cavities as a post accelerator to the TANDEM

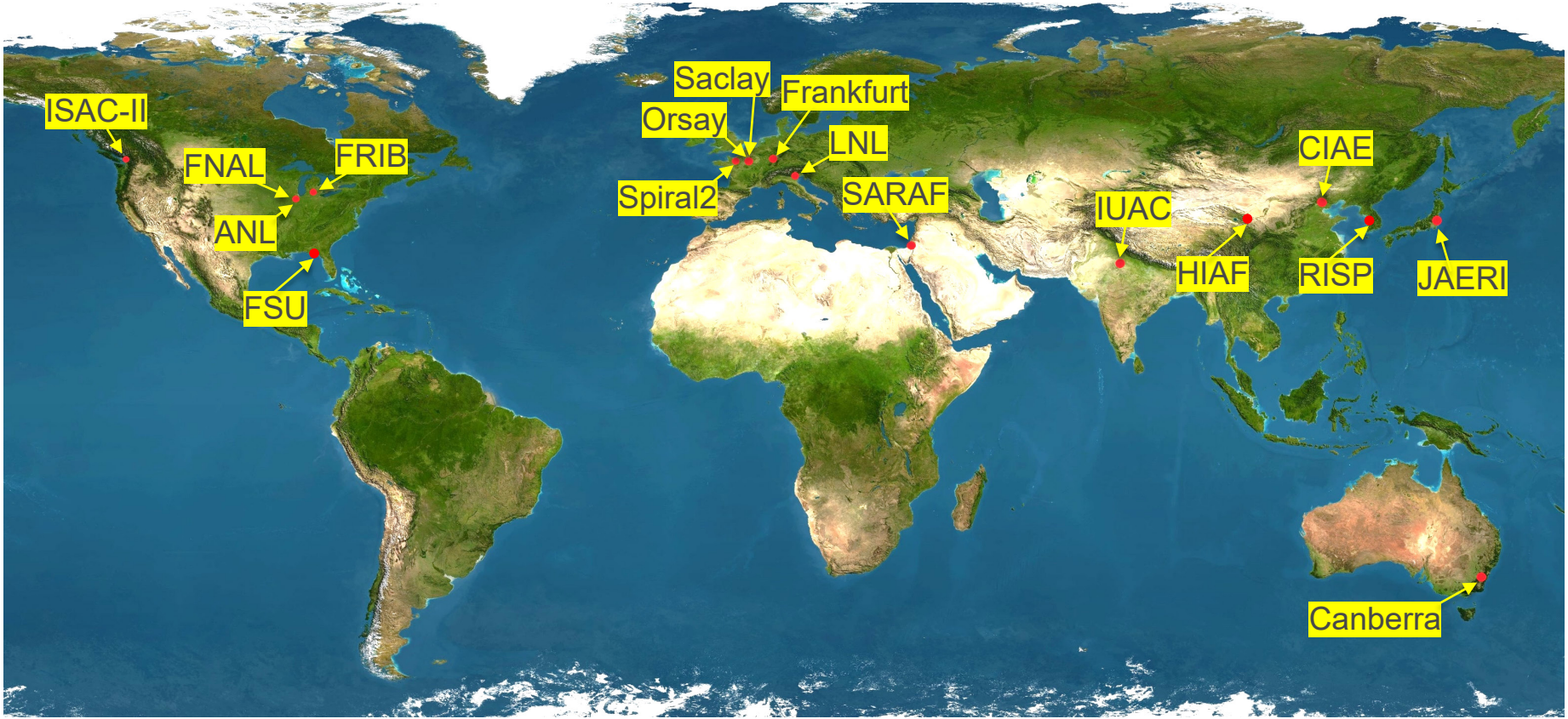




Helical Nb resonator developed at ANL for a heavy-ion linac.

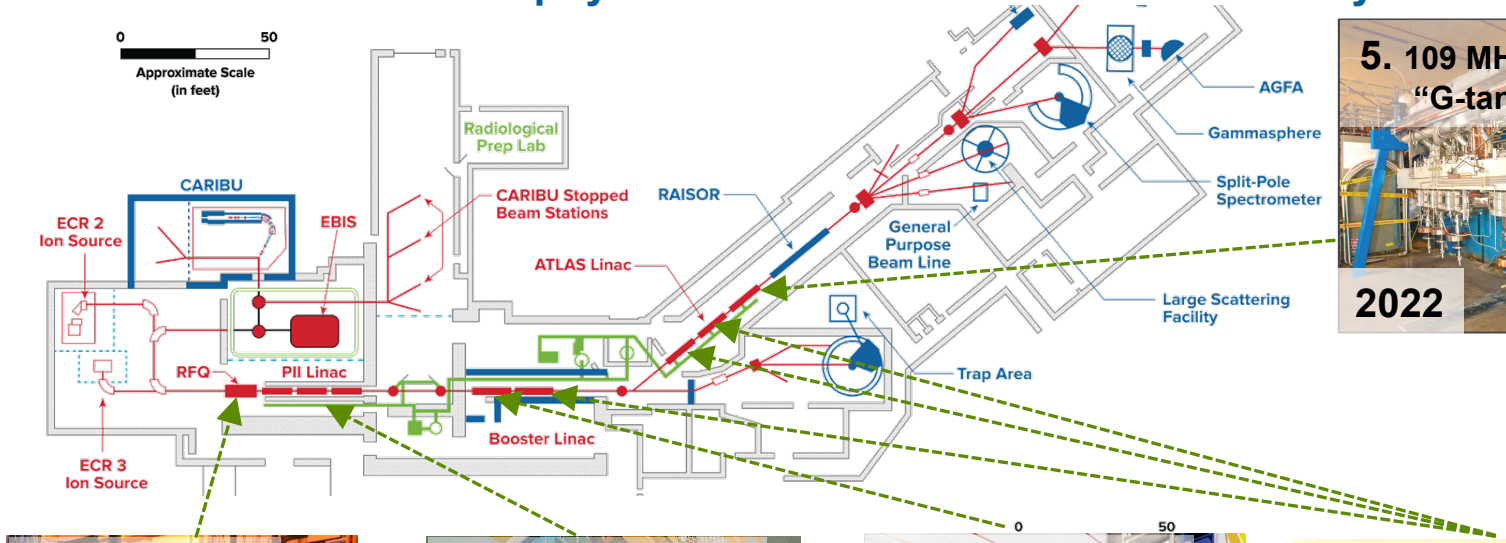


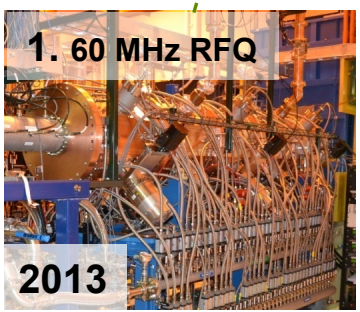
SUPERCONDUCTING HEAVY ION LINACS AND R&D

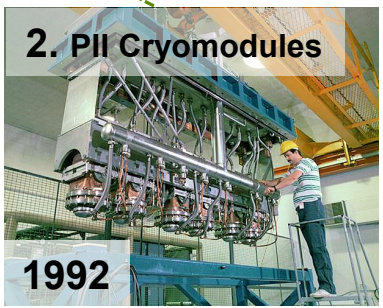


ATLAS 2022 Nearly entire accelerator is new or upgraded

ATLAS is the DOE nuclear physics stable beam national user facility







ATLAS BEAMS

Stable beams (protons to Uranium), rare isotopes from ^{252}Cf fission source (CARIBU) and in-flight beams (RAISOR)

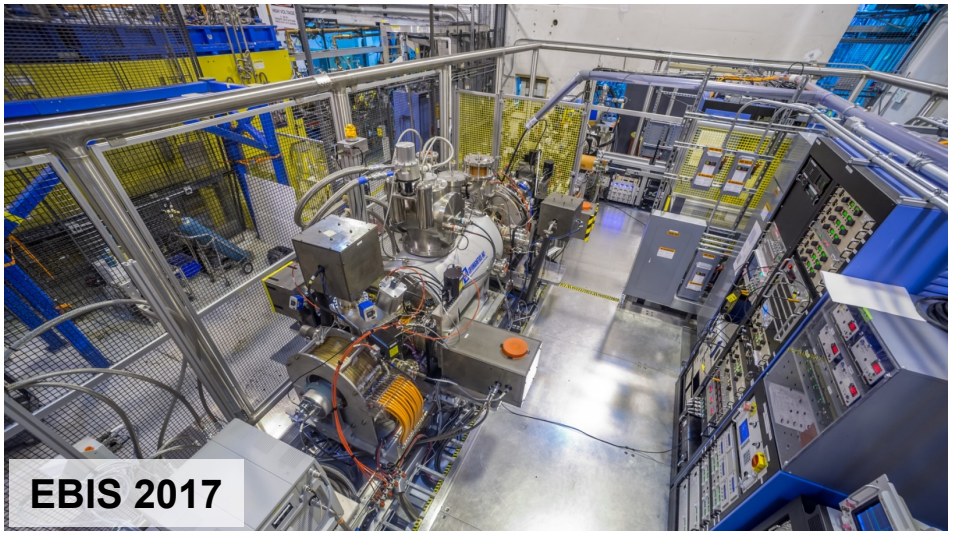
- CARIBU: **"ion source" for neutron rich rare isotopes**; ^{252}Cf source inside of a *helium gas catcher*; fission fragments are thermalized and quickly extracted into low emittance beam

  https://accelconf.web.cern.ch/HIAT2012/papers/moc04.pdf

- EBIS: **charge breeder for rare isotopes**; suppression stable ion background; high charge states with fast breeding time

  P Ostroumov et al 2010 JINST 5 c07004

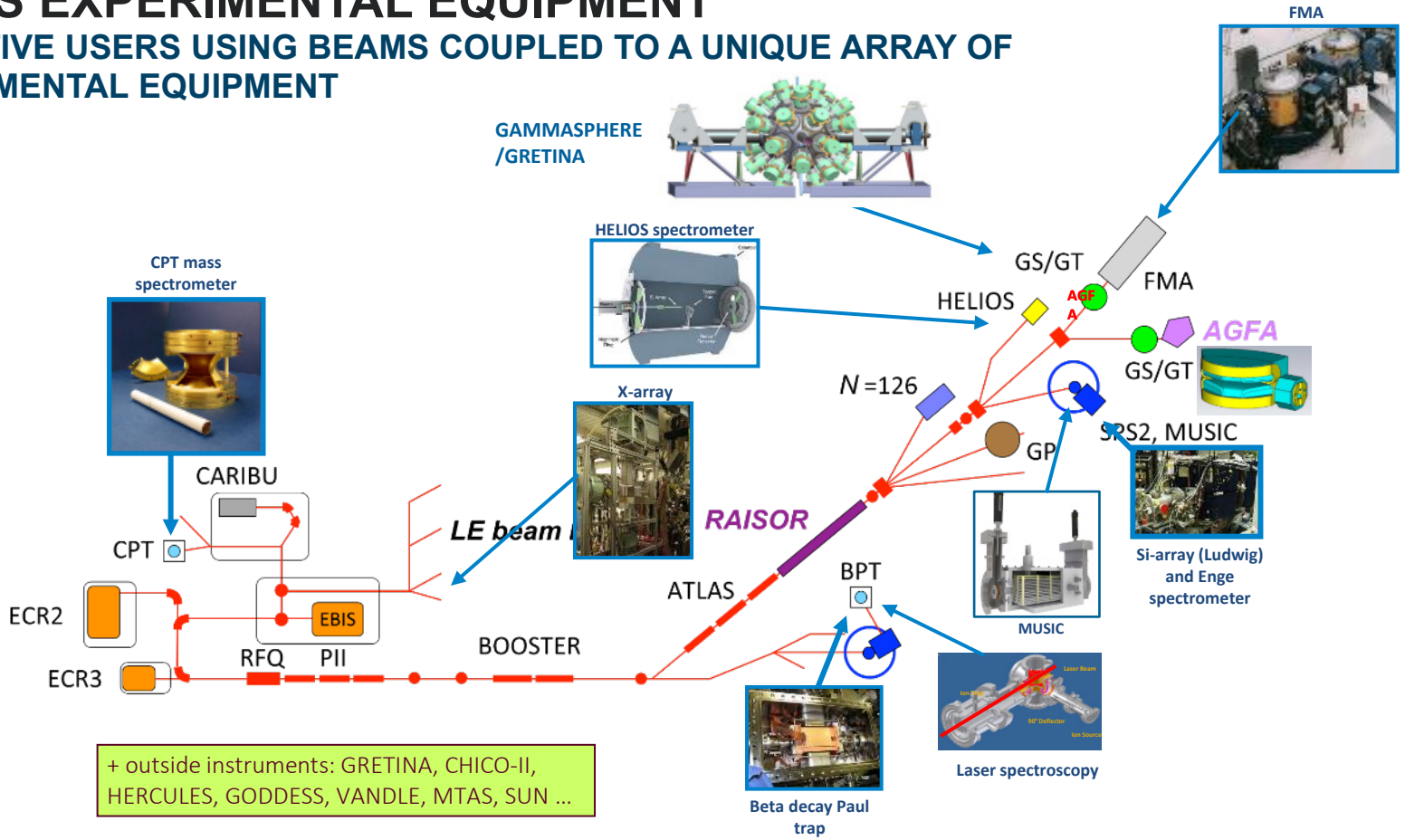
- RAISOR: **a system of selecting and purifying rare isotopes created via the in-flight process**; consists of a target, magnetic chicane separator and an RF sweeper



https://accelconf.web.cern.ch/hiat2018/talks/tuxaa01_talk.pdf

ATLAS EXPERIMENTAL EQUIPMENT

600 ACTIVE USERS USING BEAMS COUPLED TO A UNIQUE ARRAY OF EXPERIMENTAL EQUIPMENT



PRIORITIES & STRATEGIC PLAN

PHY, ATLAS AND ACCELERATOR GROUP

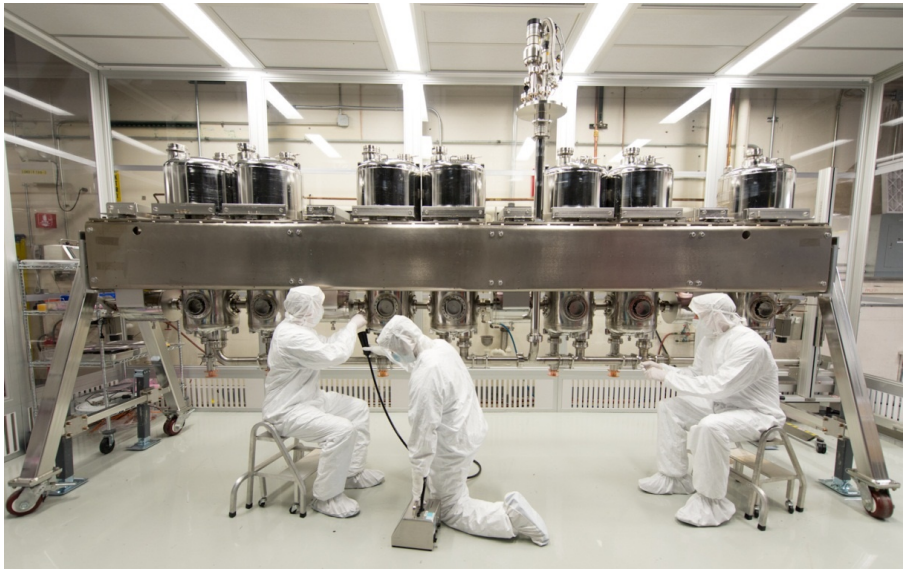
- Ensure ATLAS continues to provide unique, **high-impact science and accelerator technology** that is relevant to the mission of NP
- Oversee robust, healthy, and safe operation with **multi-user capabilities** to better serve the low-energy community
- Address diversity, equity, and inclusion within the Physics Division and User community
- Work with the community to develop new capabilities and **state of the art instrumentation**
- Strong partnership with **FRIB**: science & instrumentation (e.g., SOLARIS)
- Develop a Fundamental Symmetries Group focused on NLDBD and Quantum Information Science (QIS), together with additional support from the Theory Group
- Enhance the experimental component of the **nuclear data program**
- Support the development of an **isotope program at Argonne**

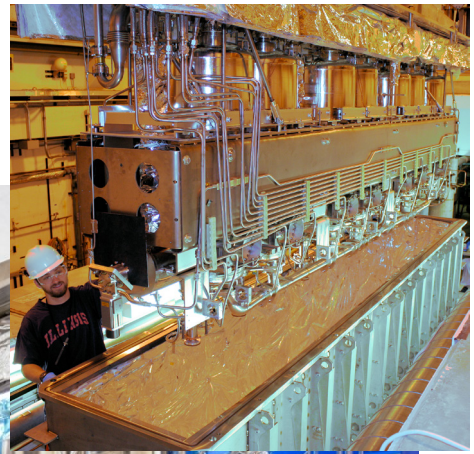
https://www.anl.gov/phy/physics-division-strategic-plan

2014 ATLAS INTENSITY UPGRADE CRYOMODULE

LATEST SRF TECHNIQUES; REPLACED 3 ATLAS SPLIT-RING MODULE

- 5-meter module of seven 72 MHz quarter-waves, v/c ≈0.8
- 'Fully' optimized RF design, high-purity niobium, electropolishing, baking, clean room assembly
- Overcoupling for phase stabilization (rather than reactive tuner)
- Large aperture (3 cm) and steering correction for high-intensity beams

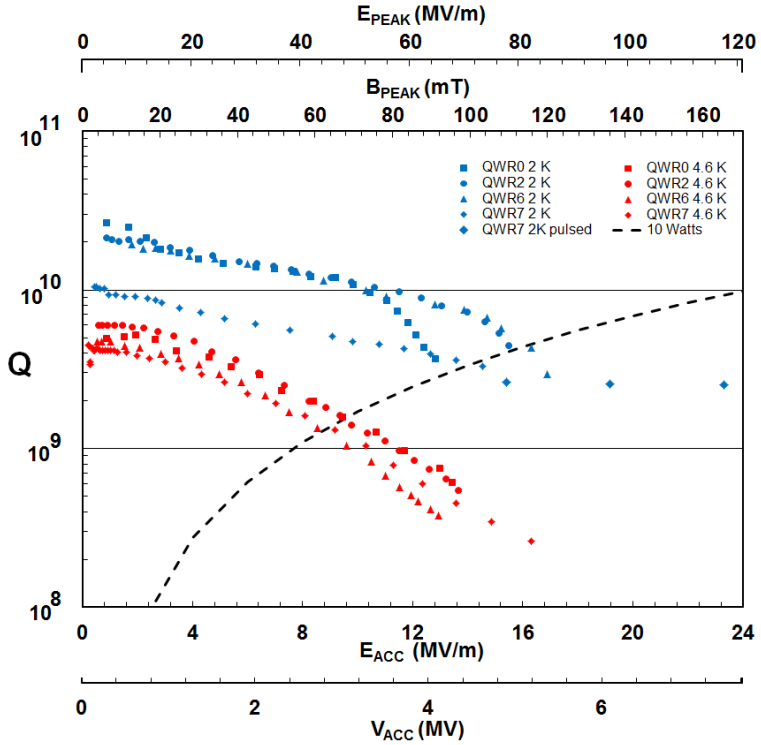




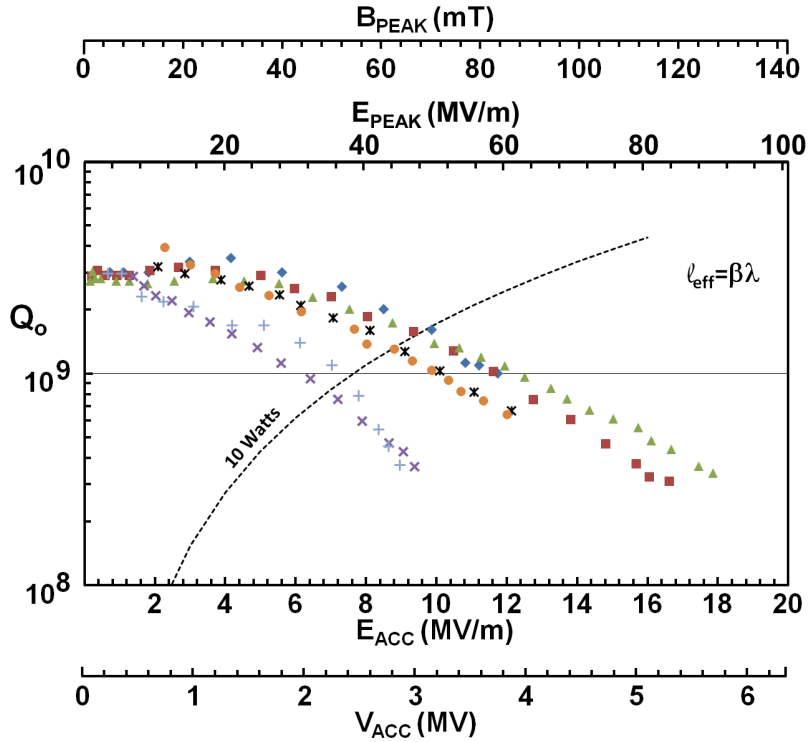
PERFORMANCE OF 2014 INTENSITY UPGRADE CRYOMODULE

HIGH Q AND GRADIENT IN OFFLINE TESTING AND INSTALLED INTO ATLAS

Test cryostat performance (2 K and 4 K)



ATLAS online performance (4 K only)



2022 REFURBISHMENT OF THE 2009 ENERGY UPGRADE CRYOMODULE

Upgrades to position ATLAS for delivery of high intensity stable beams

- Complete disassembly and rebuild of module
- A new (8^{th}) SRF cavity, v/c≈0.15
- Reactive fast tuners replaced→
- With 8 new high-power couplers (coupler technology is a big deal)
- All 8 cavities electropolished in modern EP system
- New 4 kW CW amplifiers and digital LLRF controllers
- Upgrade: ***equivalent voltage of half an additional cryomodule for ~1/5 cost of new module, (20 MV total from 8 cavities)***

Brookhaven National Laboratory

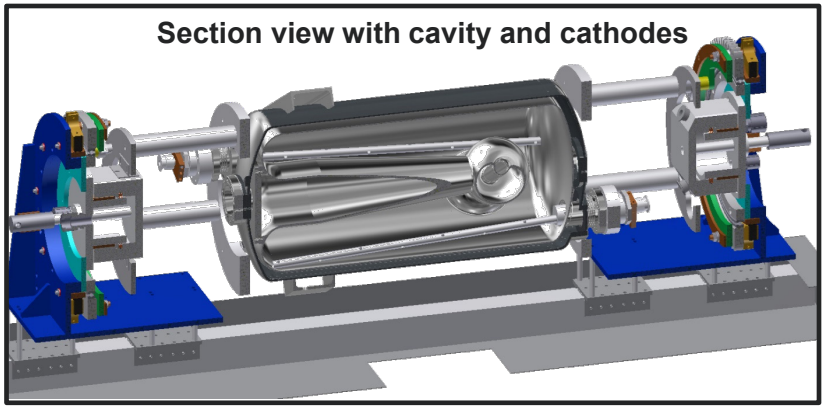
Initial 2009 clean assembly

2022 post- clean room

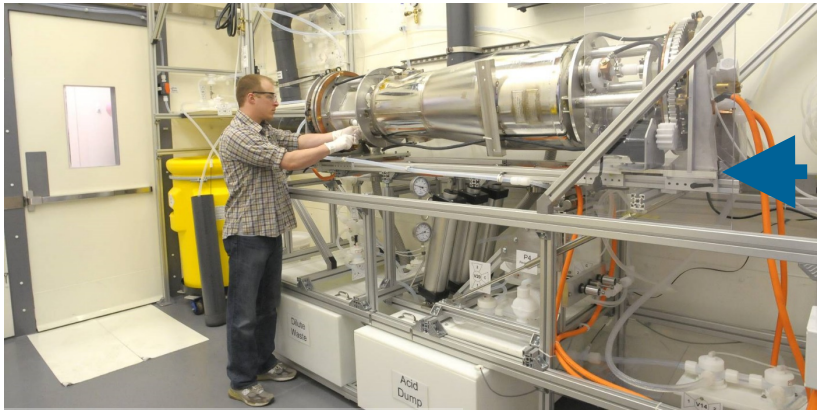
ATLAS FACILITY FOR PROCESSING TEM-MODE CAVITIES

Unique cavity electropolishing system for production quarter-wave, half-wave, spoke cavities

- Electropolishing: surface treatment of choice for SRF cavities esp. where high gradient is important
- TEM cavity EP is an evolution of that from ILC e-cell R&D
- Modern electropolished TEM cavities achieving gradients similar as for e-cell
- Long learning curve: process optimization continues (cold 'final' electropolishing to reduce surface defects)



2022 refurbishment of 109 MHz (After electropolishing)



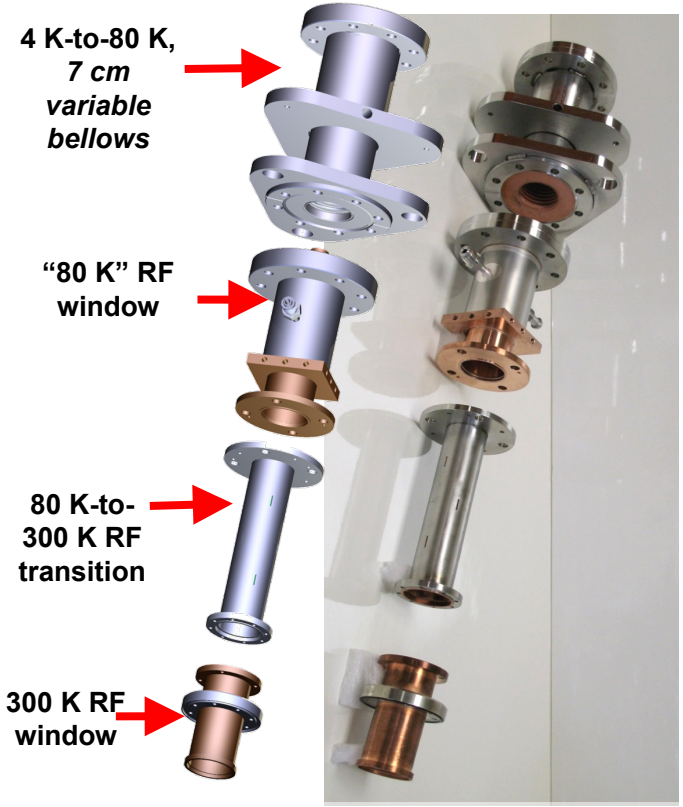
2013 Quarter-wave at Argonne

2007 ILC R&D at Argonne

1. Crawford in **NIM in Phys. Res. A 849 (2017), Crawford**
2. **Chouhan, "Study on Electropolishing Conditions for 650 MHz Niobium SRF Cavity", NAPAC 2022**

HIGHLY ADJUSTABLE ATLAS COUPLERS

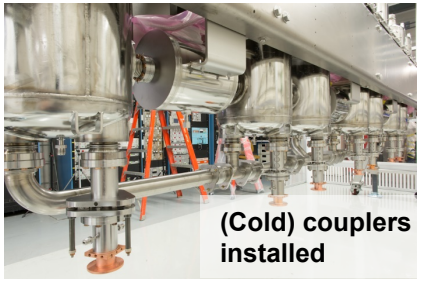
50 W COAXIAL 2-RF WINDOW CAPACITIVE COUPLING



Couplers used in ATLAS 72 and 109 MHz modules

Features/Issues

- Adjustable coupling → operational flexibility, RF phase control, *but also for initial conditioning or recurrent multipacting*
- Two planar window design → compact clean assembly
- Materials: ceramic, thin-wall stainless, copper plating (issue is fragility in fab., handling, and Ops.)
- DC bias on center conductor for suppression of multipacting → *requirement depending on frequency*

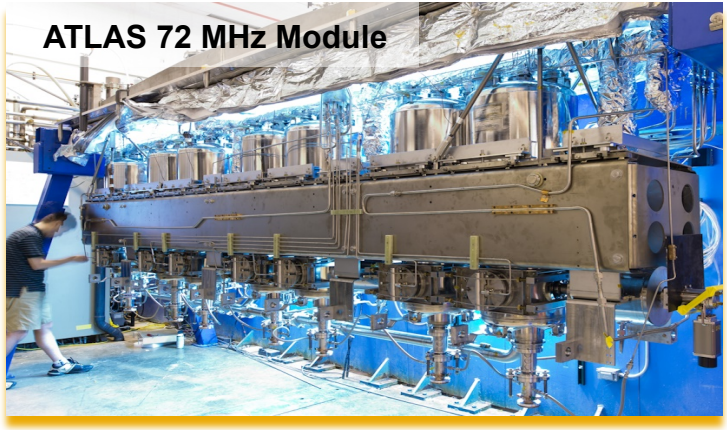


(Cold) couplers installed

Production Couplers

COAXIAL POWER COUPLERS FOR ATLAS AND OTHER PROJECTS

FREQUENCIES FROM 72 MHZ TO 1.4 GHZ AND RF POWER TO 20 KW CW

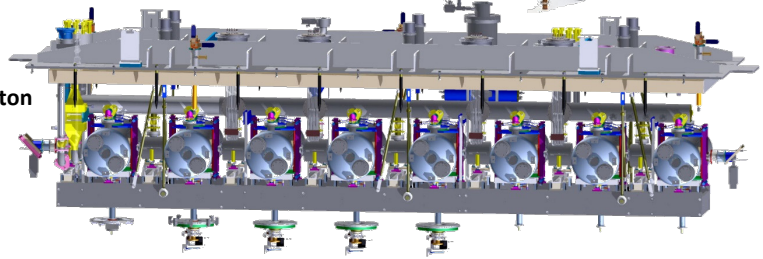


FRIB QWRs

https://accelconf.web.cern.ch/LINAC2012/papers/tupb093.pdf

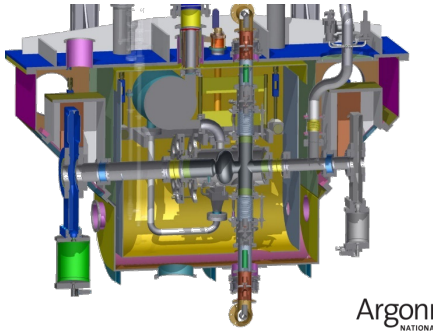
PIP-II HWRs

"Half-wave Cryomodule for Proton Improvement Project 2 at Fermilab", SRF17



Advanced Photon Source Upgrade

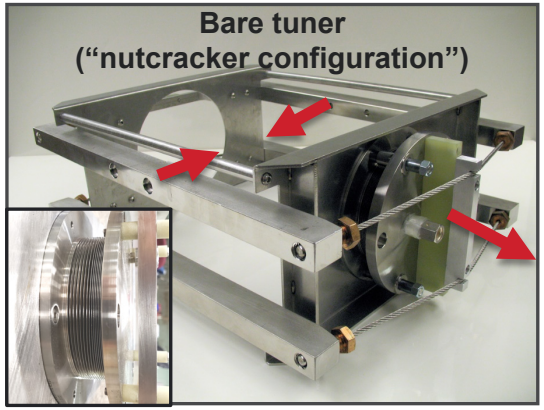
"A Superconducting Harmonic Cavity System for the ANL Advanced Source" SRF17

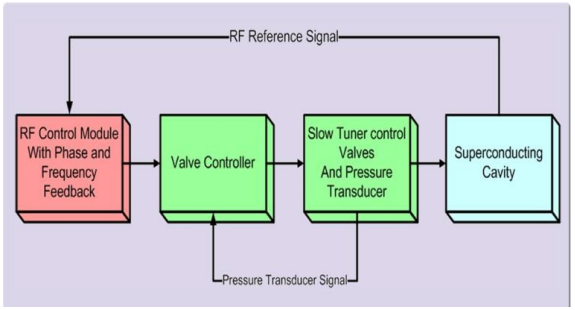


ATLAS PNEUMATIC SLOW TUNER

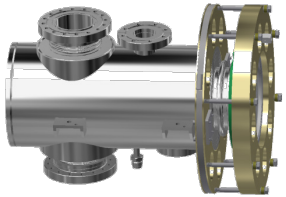
SUCCESSFUL 40+ YEAR OLD CONCEPT APPLIED TO LATEST TEM AND E-CELL CAVITIES

- Reliable concept refined over 4 decades
- Helium gas at ~80 K expands a bellows to squeeze the cavity
- Only connection a ~3 mm gas line
- Essentially no sliding parts, no friction, no hysteresis
- Can be actuated w/o vibrations, no "out-of-lock"

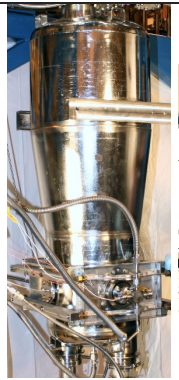




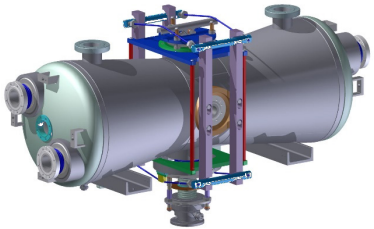
Tuner pressure controlled in closed loop LLRF system



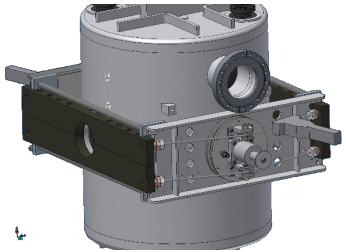
1.4 GHz e-cell w/ tuner (installation 2023 in APS-U)



ATLAS QWRs w/ tuner (~48 in use)



PIP-II HWR w/ tuner (8 in use)



FRIB HWR w/ tuner (~220 in use)

ACCELERATOR R&D (INTEGRATED INTO 2018 ATLAS LONG-RANGE PLAN)

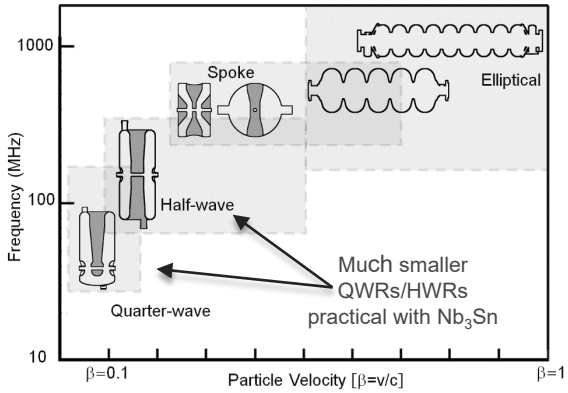
ATLAS Upgrades, Niobium-tin R&D for Future ATLAS/NP, High impact work for others

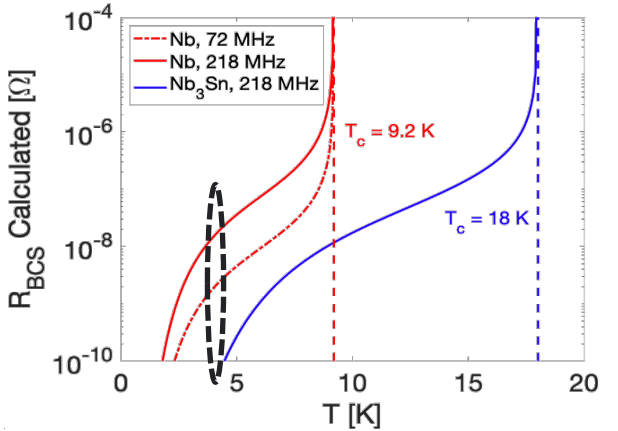
- **Major refurbishment of the last module in ATLAS**; 50% improvement in module performance using latest SRF techniques; essential for future ATLAS N=126 factory
- **Niobium-tin (Nb_3Sn) R&D**: Next generation cavity technology; New PHY cavities to be coated this year; established a new US industrial cavity manufacturing company (niobium hydroforming)
- **Commissioning new cavity vacuum furnace**: Supports DOE Nuclear Physics, High Energy Physics, and Basic Energy Sciences for DOE/SC R&D and projects
- ATLAS capabilities have outsized positive impact on other DOE projects/national priorities (**Advanced Photon Source Upgrade Bunch Lengthening System**)

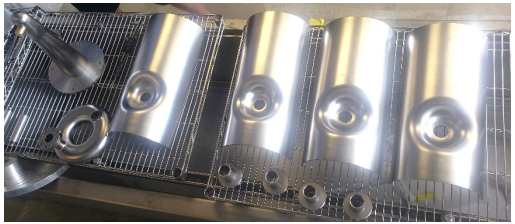
NIOBIUM-TIN CAVITY R&D FOR ATLAS/LOW-BETA

Aim for practical use of niobium-tin in ATLAS

- Nb_3Sn by vapor diffusion is by far the most promising next generation technique for SRF cavities
  - ***Paradigm shift for low-beta accelerators***
  - Small cavities operated without large central cryoplants
  - Enables higher frequency for low-beta → much smaller accelerators
- Applications
  - ATLAS upgrades, new isotope facility, re-buncher
- Challenges
  - Fundamental challenge is to grow high quality Nb_3Sn without defects
  - Niobium-tin by vapor diffusion is performed at 1100°C
  - Some fabrication techniques precluded
  - Niobium-tin is brittle like ceramic







CONCLUDING REMARKS

- ATLAS technology: sources, the superconducting linac to the experimental equipment have been continuously upgraded
  - Also provide impactful benefits to other DOE/NP/HEP/BES projects
- ATLAS is the DOE nuclear physics stable beam national user facility
  - High availability with 5000-6000 beam-hours annually, over 600 active users
- Upgrades planned over the next decade (AMUU – multi-user capability, nuCARIBU upgrade, N=126 Factory) to provide unique ATLAS capabilities now and in the FRIB era
- We are pursuing transformative SRF technologies tailored to ATLAS and the low-beta accelerator community

THANK YOU TO MANY COLLEAGUES


Argonne
NATIONAL LABORATORY
1946
75
2021