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The ATLAS Energy Upgrade Cryomodule

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MOOCAU04

Introduction

- A new cryomodule containing 7 **β=0.15 quarter-wave cavities** is now operating with beam in the ATLAS heavy ion linac, increasing energy by 30-40%.
- This represents the first successful demonstration of **separate cavity and insulating vacuum systems** for a low-β cryomodule.
- Maximum voltages of **3.75 MV** per cavity have been achieved. ~1 MV/cavity is today's state-of-the-art for operations.

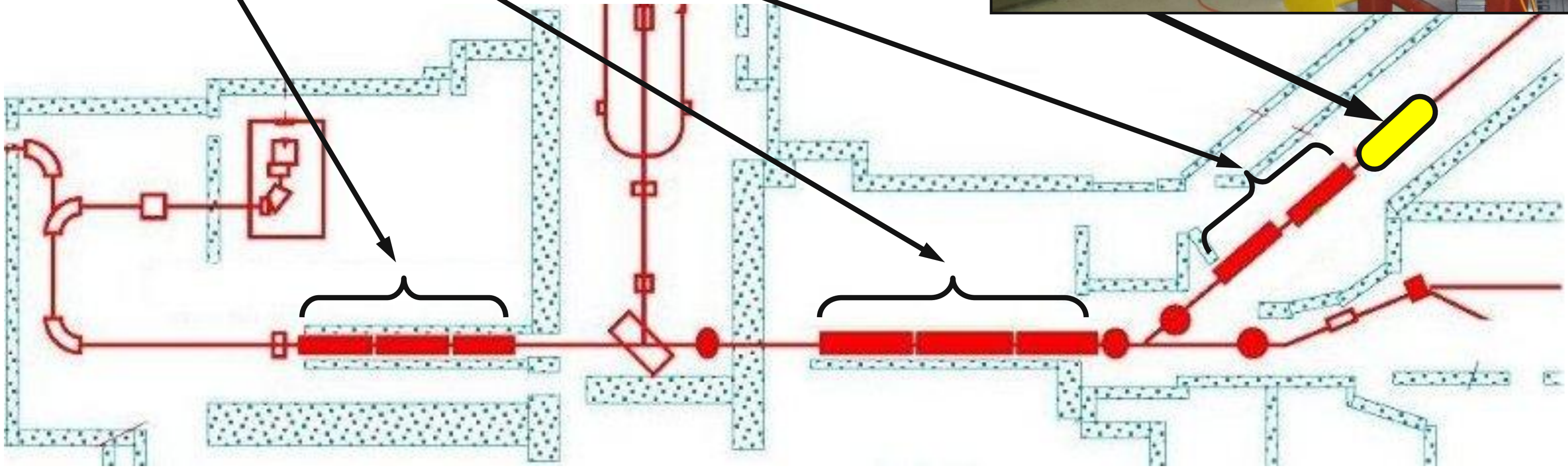
Features

- Optimized electromagnetic and structural design of the cavities
- Cancellation of beam steering effect due to the RF field in the QWR
- State-of-the-art surface processing, clean-room assembly, low-particulate pumping and venting systems *(THPPO029)*
- Top-loaded cryomodule design which minimizes components involved in clean assembly

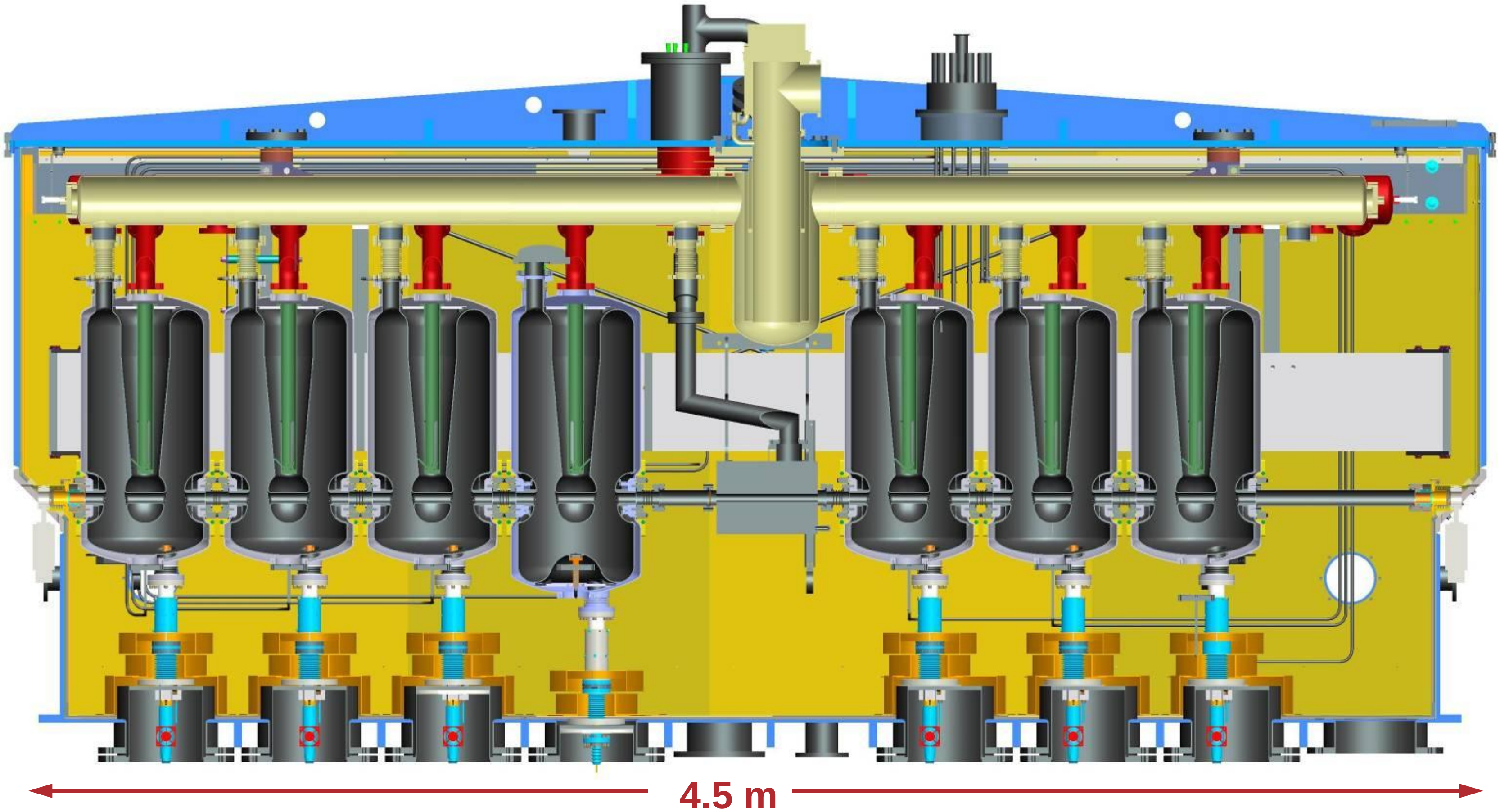
Location in the ATLAS Tunnel

30 m
40 MV

4.5 m
14.5 MV



Section View

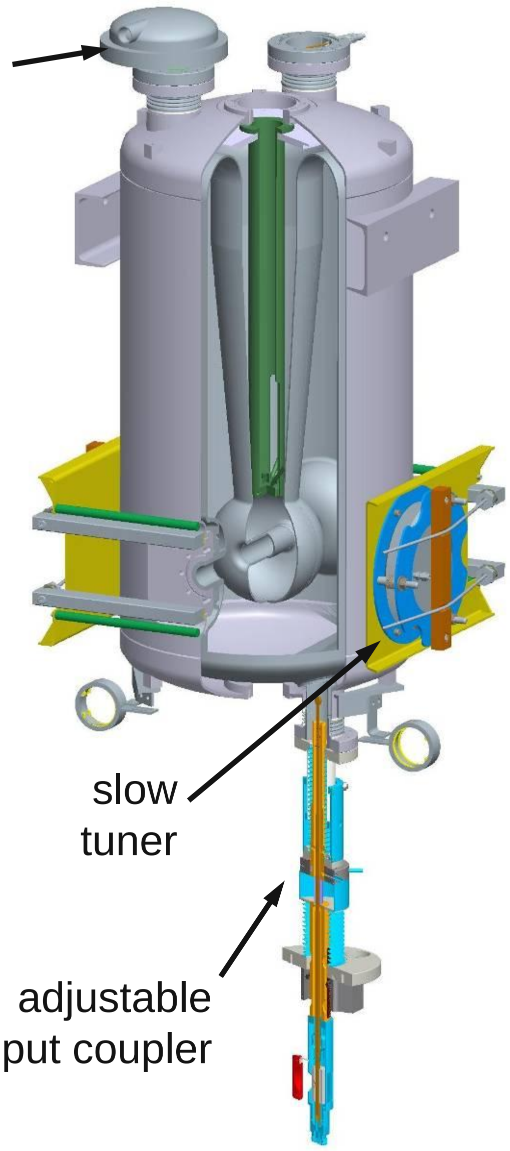


- 7 cavities installed
- Beam valves pass through angled endwalls of box

Cavity Parameters

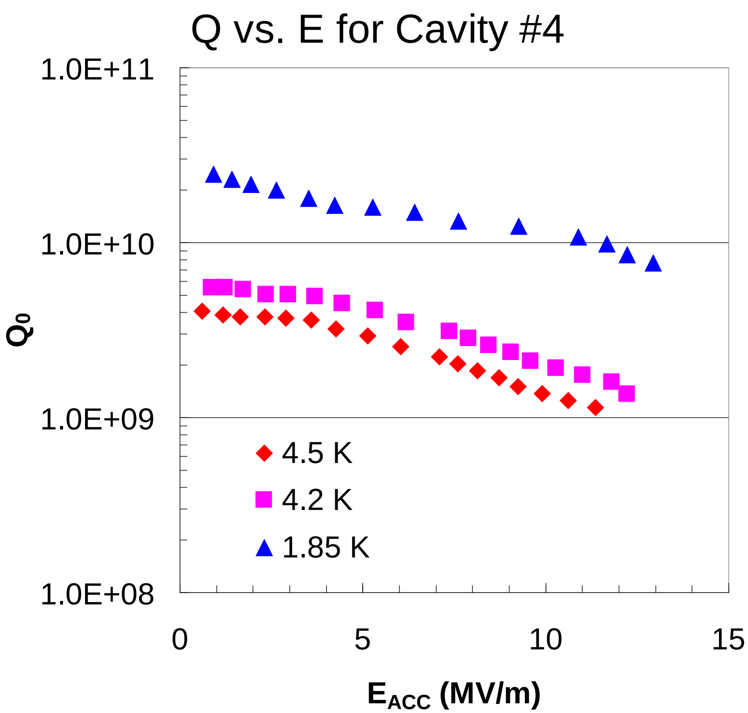
Frequency	109.125	MHz
beta	0.15	
U_0	37*	J
Active length	25	cm
E_{PEAK}	48*	MV/m
B_{PEAK}	88*	mT
G	40	Ohm
R_{sh}/Q	548	Ohm

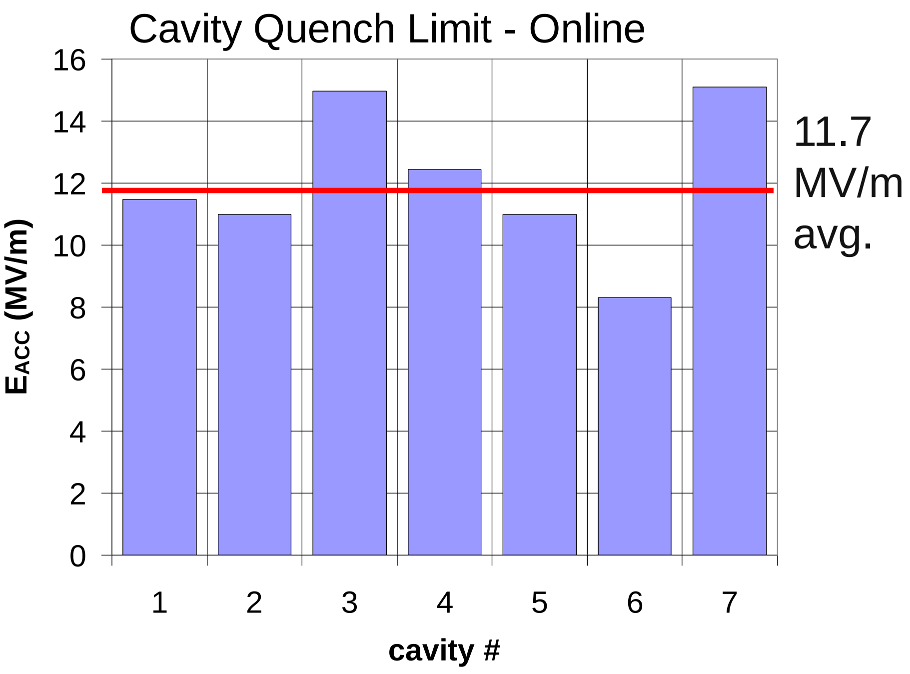
*at 3.75 MV/cavity = 15 MV/m



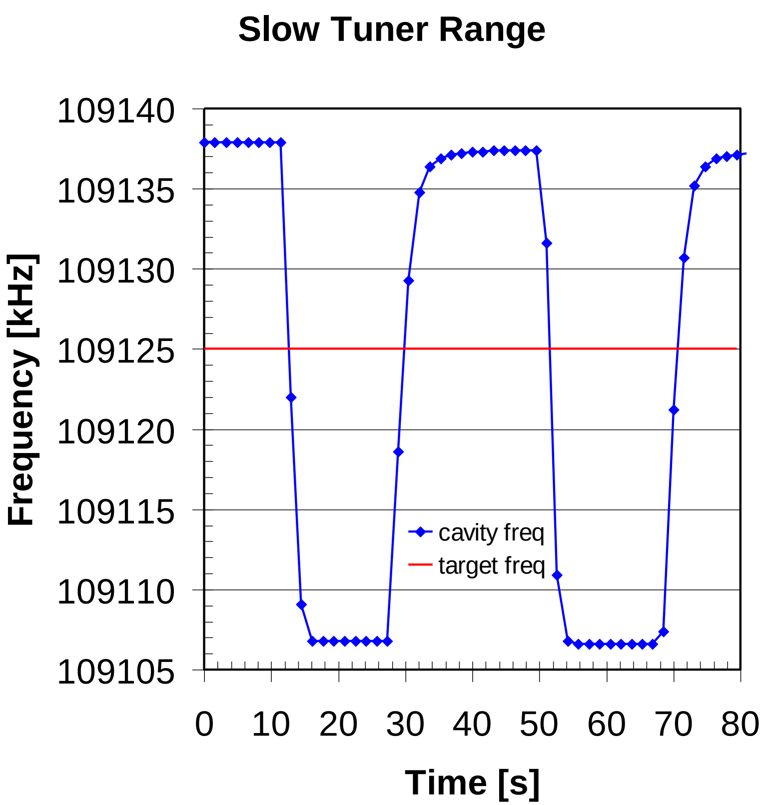
Accelerating Fields

- 15 MV/m achieved on-line in 2 cavities:
  – V_{MAX} = 3.75 MV, E_{PEAK} = 48 MV/m, B_{PEAK} = 88 mT





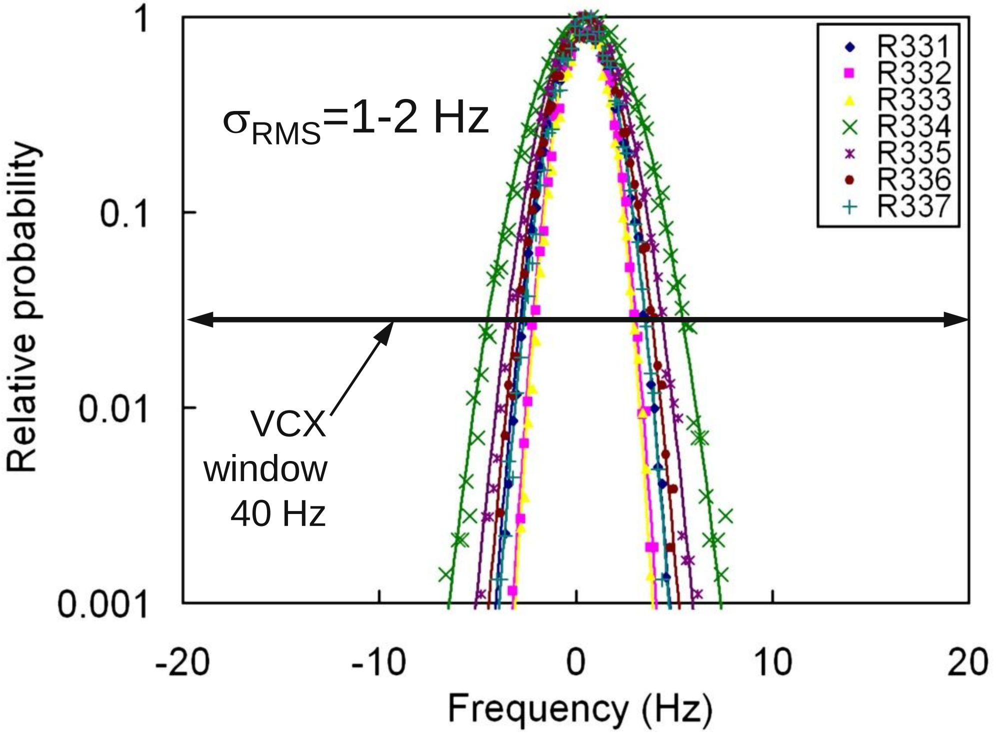
Tuners & Microphonics



- *1.2 kHz/s slew rate on-line*

Measured cavity microphonics – simultaneous operation at 2 MV/cavity (avg.)

- *to date no cavities have lost lock due to microphonics*



(TUPPO031)

Beam-Based Performance Data

- Accelerate Carbon +6 beam through the cryomodule
- Measure beam energy via time-of-flight
- Use TRACK code to fit accelerating voltage to TOF data
- Power dissipation to LHe measured at the refrigerator (dynamic load):
  - **55W** at 14.5 MV ($Q = 1.0 \times 10^9$)

Cavity Number	Beam Energy [MeV]	Cavity Voltage [MV]
1	174.0	1.96
2	184.5	1.89
3	196.1	2.13
4	208.5	2.29
5	219.7	2.12
6	229.9	1.92
7	241.5	2.24
Total voltage		**14.5**

Maximizing Performance

- VCX fast tuner is 30-year old technology
- VCX limit = 2.3 MV/cavity (avg.)
- Cavity performance has outstripped VCX capability
- VCX will not be part of future designs
- Performance increase possible:
  - Low measured microphonics
  - Reduce VCX tuning window

Cavity Number	Cavity Voltage [MV]	Max. Achievable Voltage [MV]
1	1.96	2.88
2	1.89	2.75
3	2.13	3.75
4	2.29	3.13
5	2.12	2.75
6	1.92	2.08
7	2.24	3.75
Total voltage	**14.5**	**21.1**

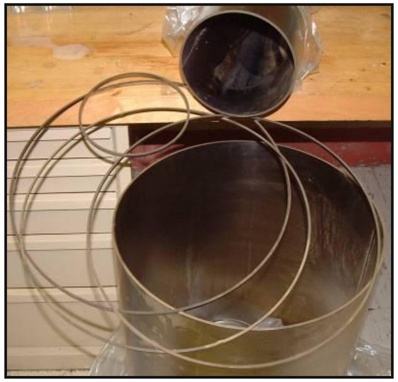
RF System

- 109 MHz, 250 W solid-state water-cooled amplifiers + LLRF for 8 cavities in 1 rack
- I&Q type LLRF controller has the following feedback loops:
  - frequency - use slow tuner
  - amplitude - adjust input drive power
  - phase - use VCX
- Slow and Fast tuner controllers
- Voltage pulsers are used to switch VCX diodes

Cavity Fabrication

hydroforming

- Die hydroformed RRR300 niobium
- Conventional machining/wire EDM
- EBW, electropolish, flash BCP
- HPWR, clean handling



Wire EDM

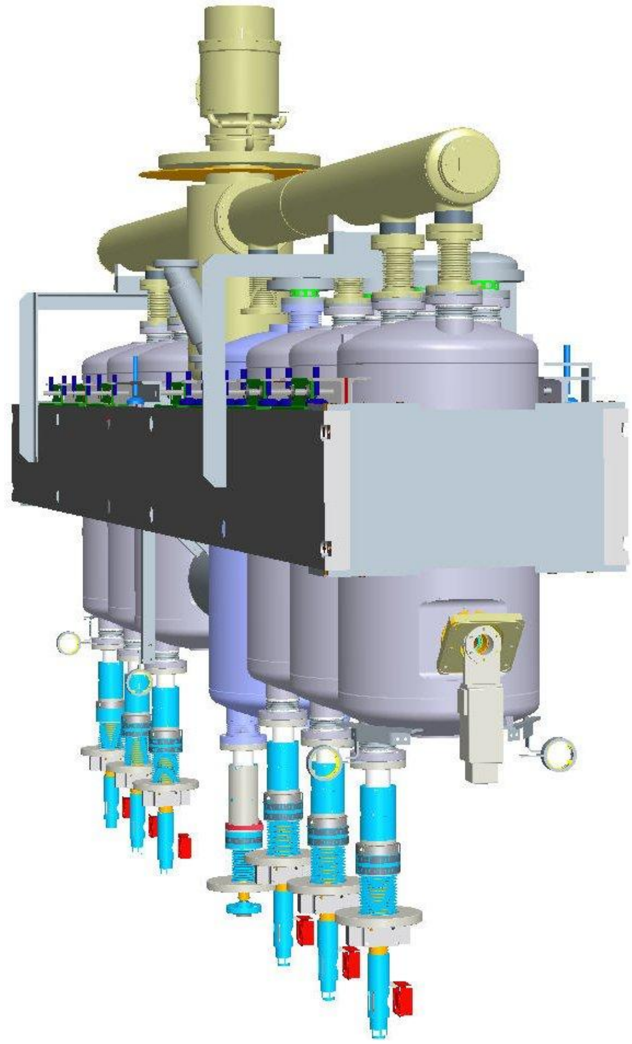
(THPPO066)

electron beam welding

electropolish

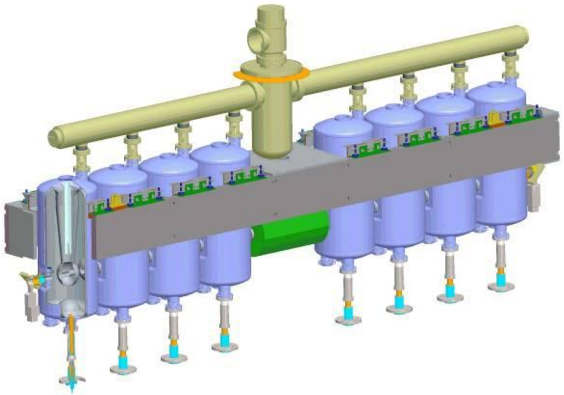
flash BCP

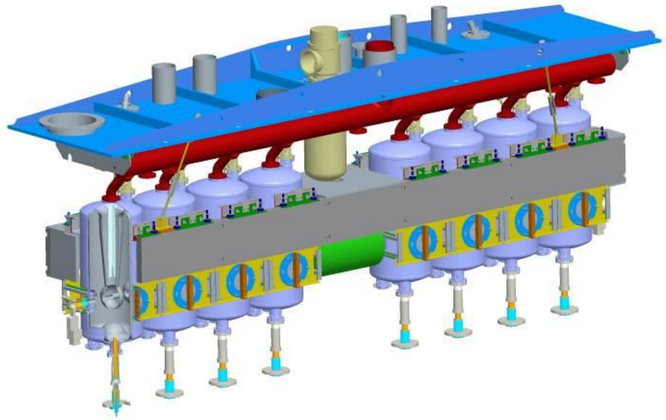
String Assembly (inside clean room)

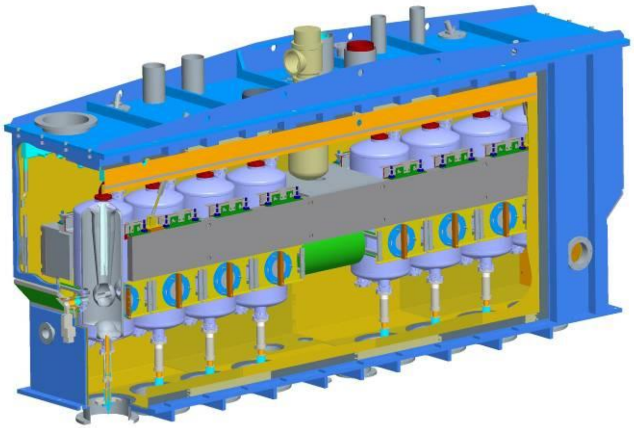


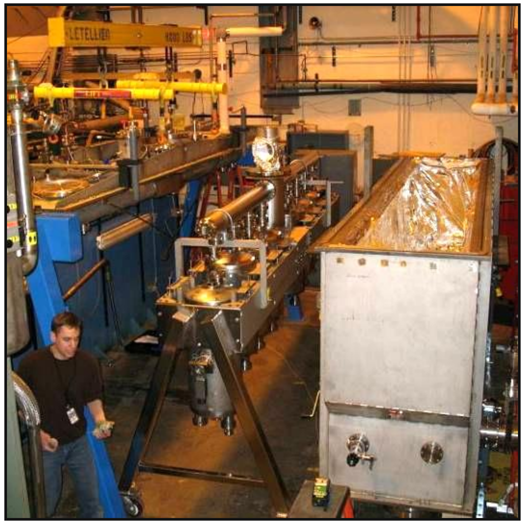
- Cavities pre-assembled w/coupler & VCX
- Cavity assemblies installed on support frame
- Inter-cavity bellows & vacuum manifold installed
- Beam valve spools installed
- 2 people, 1 month to complete

Final Assembly (external to clean room)









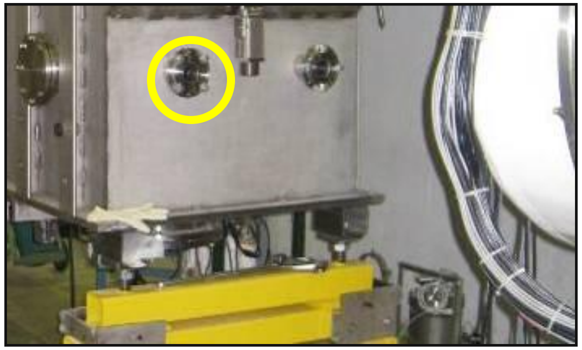
clean cavity string

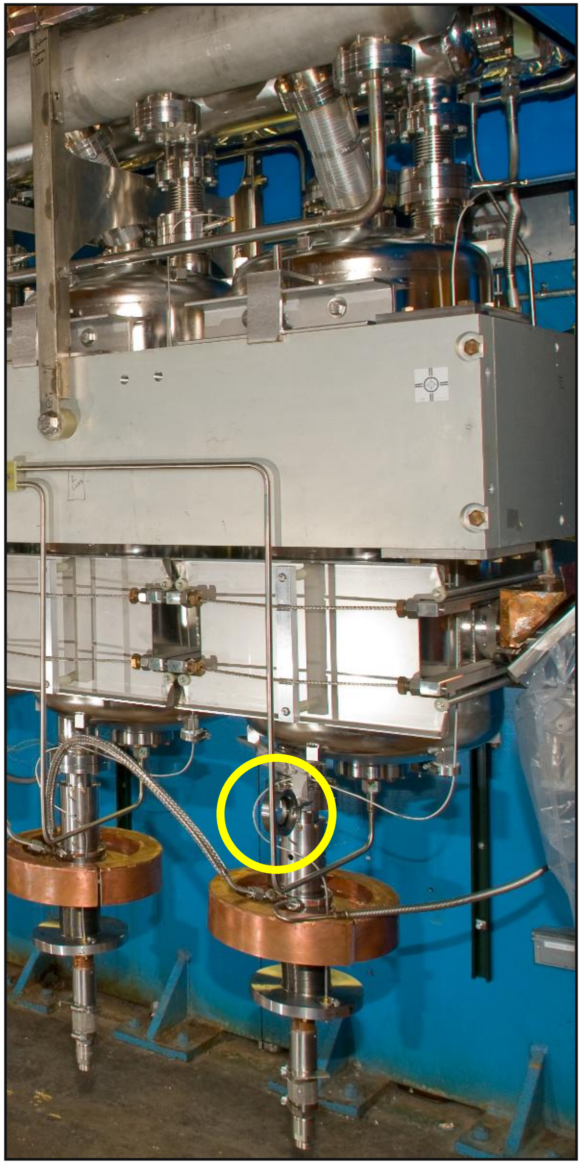
dressed string suspended from lid

module closure

Alignment

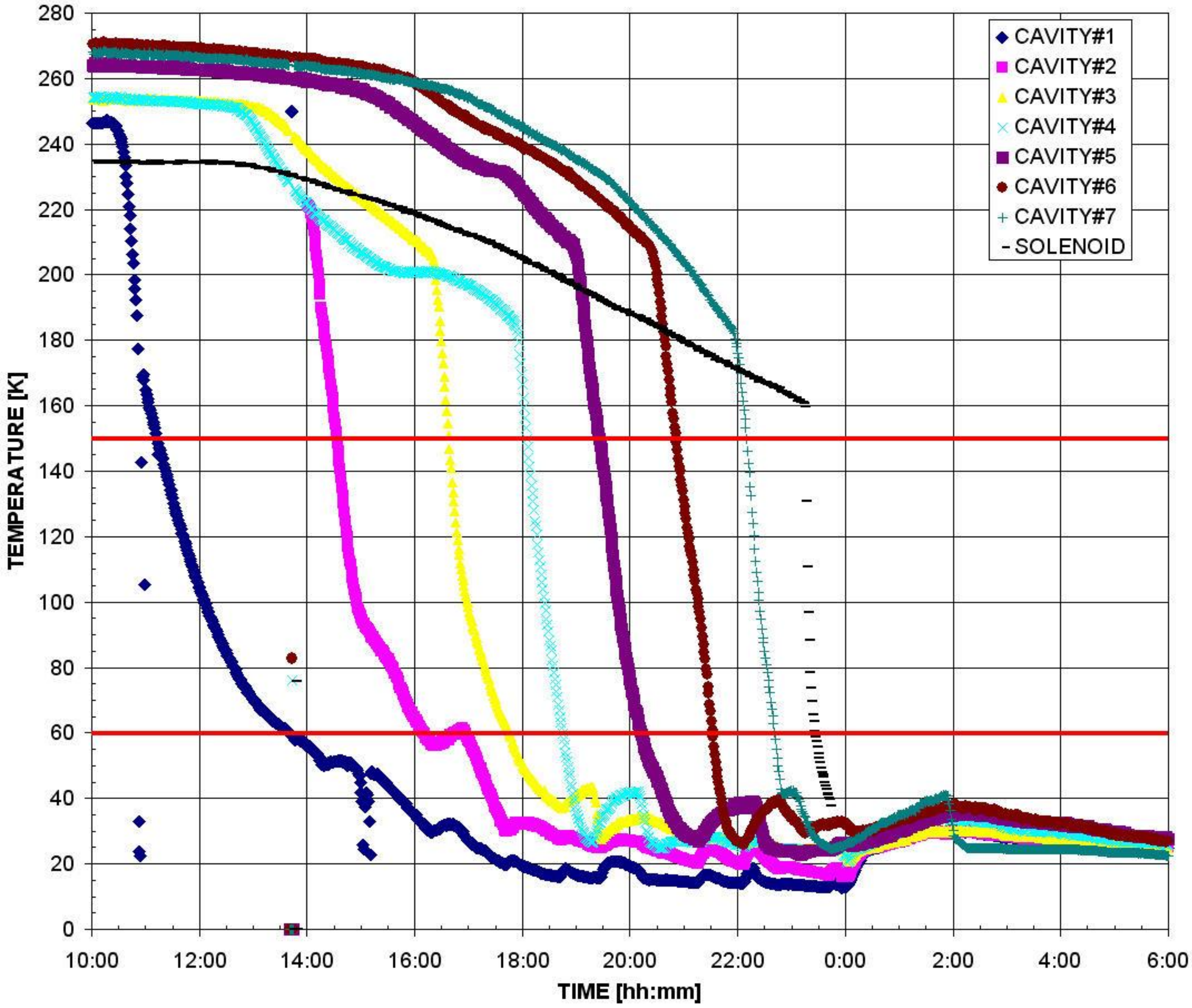
- Tolerances not critical for ATLAS
- Installation alignment in the tunnel: ± 0.5 mm
- Alignment crosshairs referenced to beam centerline
- Viewports on vacuum vessel endwalls
- Check with beam: no observed losses





Cooldown

- LHe:
  - Cavities
  - Solenoid
  - **15W static**
- LN2:
  - Thermal shield
  - Coupler intercepts
  - Beam valve intercepts
  - VCX fast tuners
  - **200W static**



Summary

- Represents the first full implementation of clean techniques for low-β cavities
- Provides a factor 3 performance gain over existing ATLAS technology
- Cryomodule design is a strong basis for next generation ion linacs
- Further developments will maximize the potential of state-of-the-art QWRs
  - TUPPO016