the Current Status of LLRF at ATLAS and New Upgrade

*Y. Luo, S. Sharamentov, D. Novak
M.P. Kelly, C. Dickerson, M. Hendricks
ANL, Argonne, IL 60439, USA

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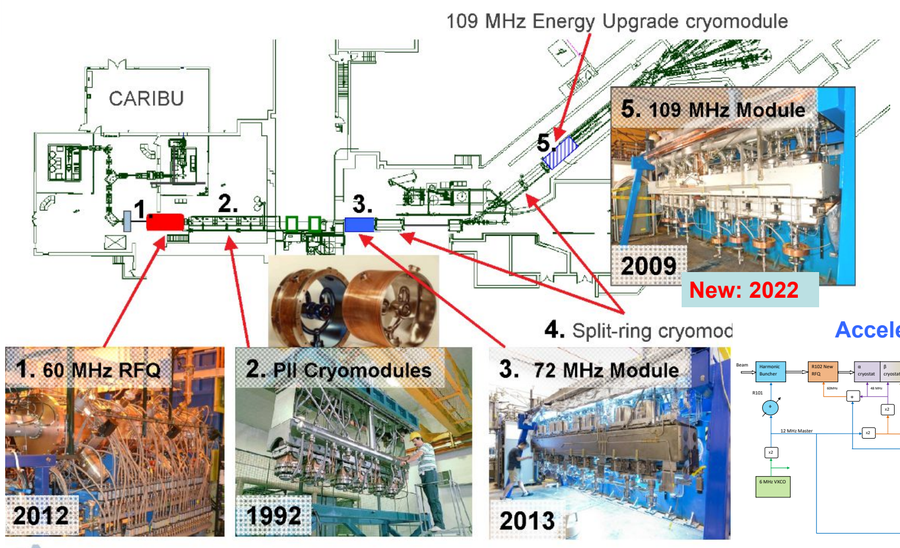
ANL Physics Division

ABSTRACT

ATLAS, the world's first accelerator to use RF superconductivity for ion acceleration has undergone a major upgrade to increase the beam transmission efficiency and intensity. A first of its kind, the new CW RF quadrupole (RFQ) was built to replace three superconducting (SC) resonators (β=0.008 and 0.016). In addition, a new cryomodule of seven 72.75 MHz (β=0.077) SC quarter-wave resonators has also been developed and put into the operation since 2014. The new SC cavities demonstrated world-record accelerating fields (operated at 2.5MV/cavity) for similar type of cavities. This year, an upgraded 109 MHz cryomodule of 8 quarter-wave SC resonators is installed. New RF systems have been developed and installed for the RFQ and the new SC cavities. For upgraded 109 MHz cryomodule, a digital low level RF (LLRF) system developed by Brookhaven National Laboratory (BNL) is installed and configured. Numerous modifications have been developed to improve the operational reliability and performance of both SC cavities and RFQ. In this paper, the current status of ATLAS RF systems and LLRF control systems will be presented.

ATLAS Accelerator Cryomodules



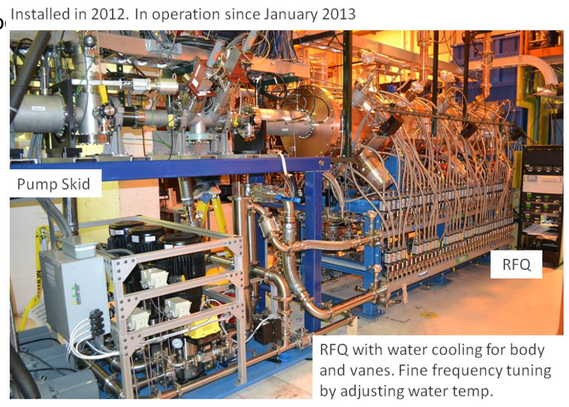
Present: 8 Cryomodules; 48 SC Accelerating Cavities

SC Split-ring cryomodules were built about 30 years ago.

ATLAS Efficiency and Intensity Upgrade

- **Increase beam transmission efficiency**: Radioactive beams from CARIBU (from Proton to Uranium)
- **Increase intensity of ion beams**: Stable ion beams up to 10 pμA, hundreds of electrical microAmps
- **This upgrade requires new RF system**: Two 60 KW amplifiers for 60 MHz RFQ, Seven 4 KW solid state amplifiers for the New 72 MHz Cryomodule, plus new control system

Installed in 2012. In operation since January 2013

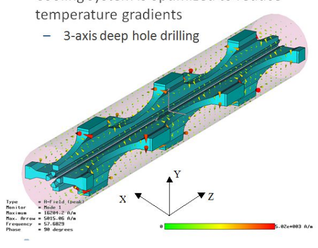


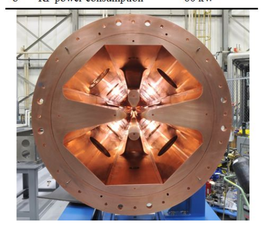
RFQ with water cooling for body and vanes. Fine frequency tuning by adjusting water temp.

ATLAS CW RFQ

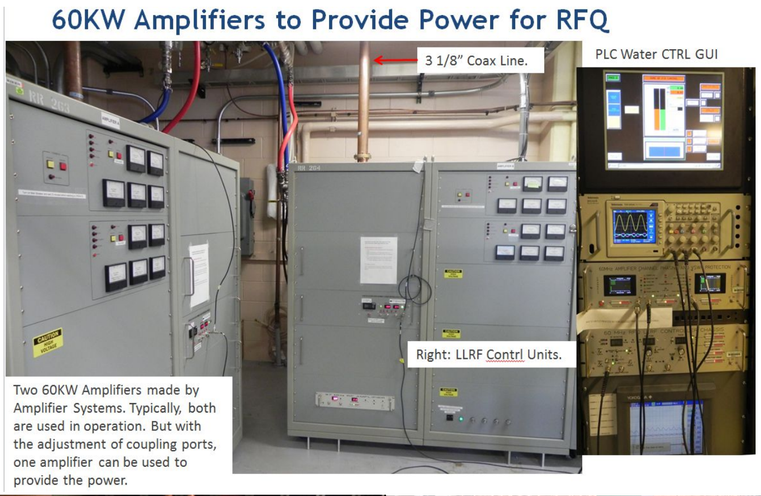
- Total voltage is 2.1 MV
- Novel multi-segment split-coax structure
  - Internal size is 19" only for 60 MHz
  - Strongly coupled segments
  - Reduced number of tuners
  - Bead pull measurements are not required
- Cooling system is optimized to reduce temperature gradients
  - 3-axis deep hole drilling

	Parameter	Value
1	Duty cycle	100%
2	q/A	1/7 to 1
3	Input Energy	30 keV/u
4	Output Energy	295 keV/u
5	Average radius	7.2 mm
6	Vane Length	3.81 m
7	Inter-Vane Voltage	70 kV
8	RF power consumption	60 kW



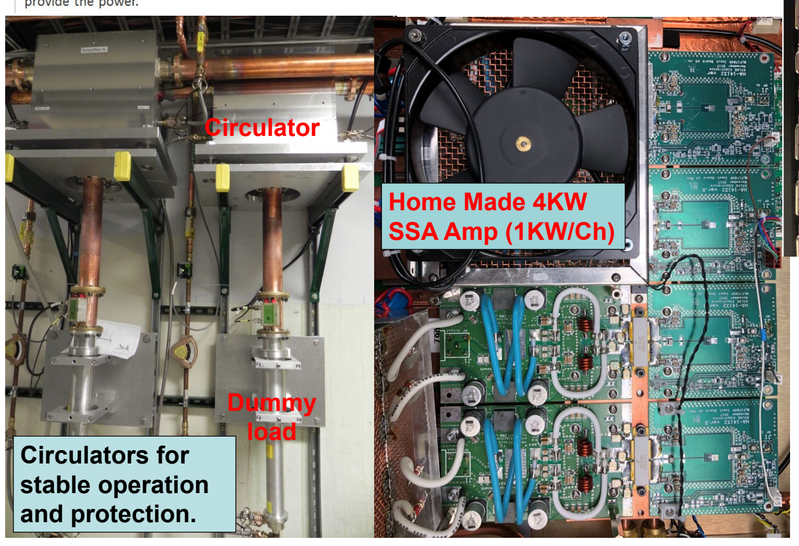


60KW Amplifiers to Provide Power for RFQ



Two 60KW Amplifiers made by Amplifier Systems. Typically, both are used in operation. But with the adjustment of coupling ports, one amplifier can be used to provide the power.

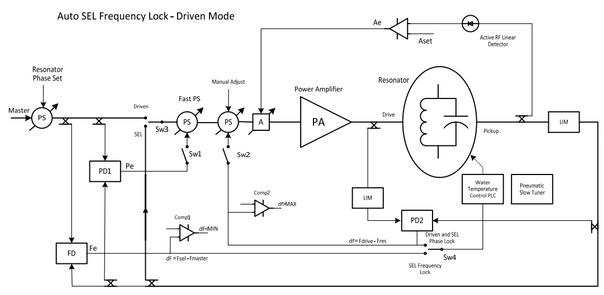
Home Made Two 48 KW (Total 96 KW) solid SSA (2022 upgrade!)



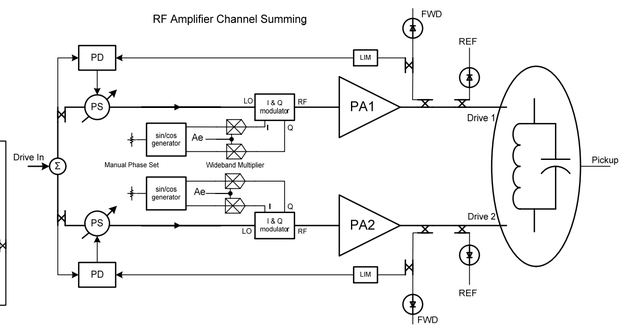
Circulators for stable operation and protection.

SSA Power Supply 2022

RFQ LLRF Control



Freq. error is used to adjust the temp. of water



Phase adjustment for two channels mode

72 MHz Cryomodule

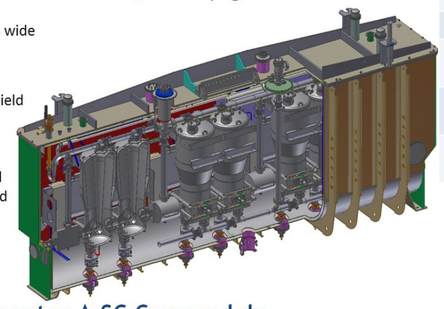
Cryomodule of 7 QWRs and 4 SC Solenoids

- Seven β = 0.077, 72.75 MHz quarter-wave cavities
- Four 9-Tesla superconducting solenoids
- Replaces 3 old cryomodules with split-ring cavities
- Total design voltage is 17.5 MV, 4.5K cryogenic load is 70 W
- Will be operated to provide ~20 MV, 4.5K cryogenic load is 85 W

5.2 m long x 2.9 m high x 1.1 m wide

Vacuum Vessel
Room Temperature Magnetic Shield
Aluminum Heat Shield
(MLI not shown)

Compact design, focusing period
Includes 2 cavities and 1 solenoid



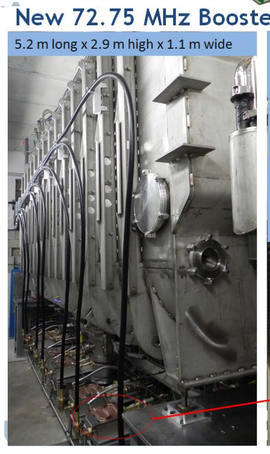
	New	Old G	
	Beta=0.077	Beta=0.15	Comment
Number of Cavities	7	7	
Number of Solenoids	4	1	
Operating Temperature	4.5 K	4.5 K	
Voltage per Cavity in Cryomodule	>2.5 (4.1) MV	>2.0 (3.0) MV	Cavity limit in parentheses
Performance Limiting System	?	VCX fast tuner	
E_{PEAK} in Cryomodule	40 (70) MV/m	26 (39) MV/m	Cavity limit in parentheses
B_{PEAK} in Cryomodule	57 (100) mT	47 (69) mT	Cavity limit in parentheses
Power to Helium/Cavity	5 W @2.5 MV	8 W @ 2 MV	

Stored Energy @1MV/m of the new Cryomodule: 0.15 J

Comparison between 72 MHz and 109 MHz G Cryomodules

New 72.75 MHz Booster A SC Cryomodule

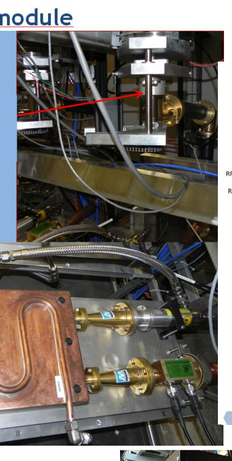
5.2 m long x 2.9 m high x 1.1 m wide



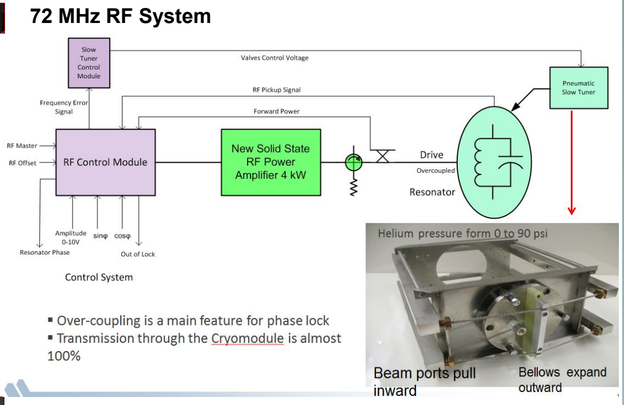
Left: Cryomodule A

Right Upper: RF Coupling Port

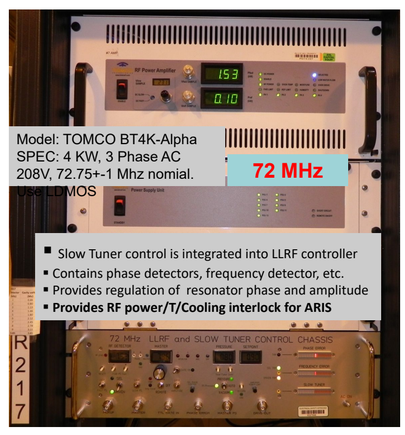
Right Bottom: Circulator and Dummy Load with Water Cooling.

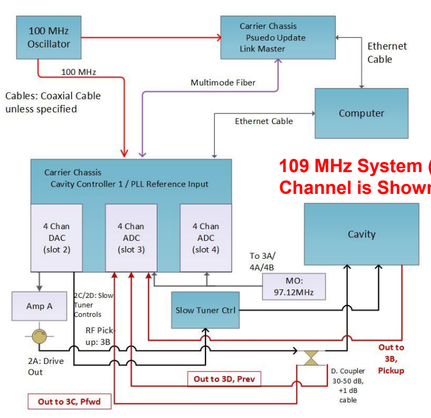


72 MHz RF System



- Over-coupling is a main feature for phase lock
- Transmission through the Cryomodule is almost 100%

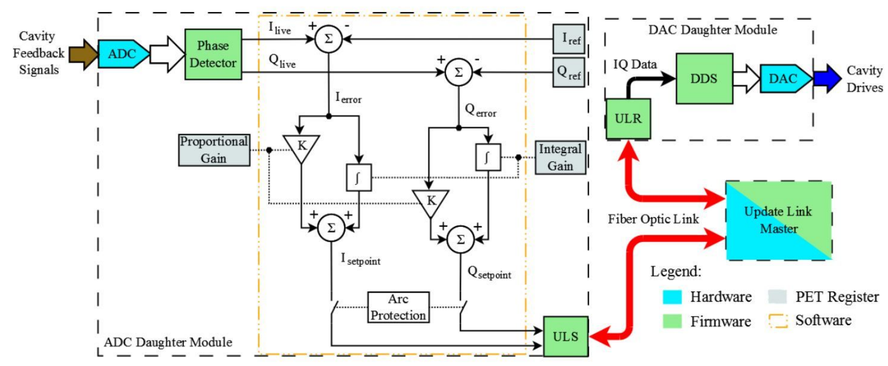




109 MHz System (1 Channel is Shown)

New 109 MHz Cryomodule Upgrade

- Goal of the upgrade to enable high intensity beams for N=126. **10 MV** → post-refurbishment 20 MV
- **New Digital LLRF-Joint with Brookhaven National Lab (BNL)**
- New 5KW/each cavity Solid State Amplifiers from Rhode & Schwarz



IQ Feedback Loop (BNL LLRF)

Recent upgrade and Future Upgrade

- **Digital LLRF Control System from BNL with Modifications for 109 MHz Cryomodule**
- **Other: Two 48 KW (Total 96 KW) Home Made SSA for RFQ application**

Future: Digital LLRF control system design for other cryomodule. SC quarter-wave resonators to replace several split-ring cavities and some bunchers.

Acknowledgements

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Author: Y. Luo, yluo@anl.gov