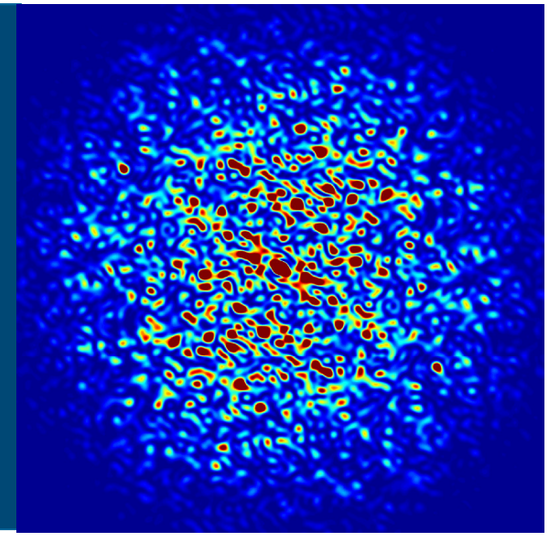
Stand-Alone Cryocooler-Based Module for the ATLAS Multi-User Upgrade



Michael Kelly
Accelerator Development Group Leader, Physics Division, Argonne National Laboratory
Sergey Kutsaev, Robert Berry, Ronald Agustsson
RadiaBeam Systems, LLC.

TTC Collaboration Meeting
WG-4: New techniques for fabrication of SRF components & CM assembly and design
Thursday February 5, 2020

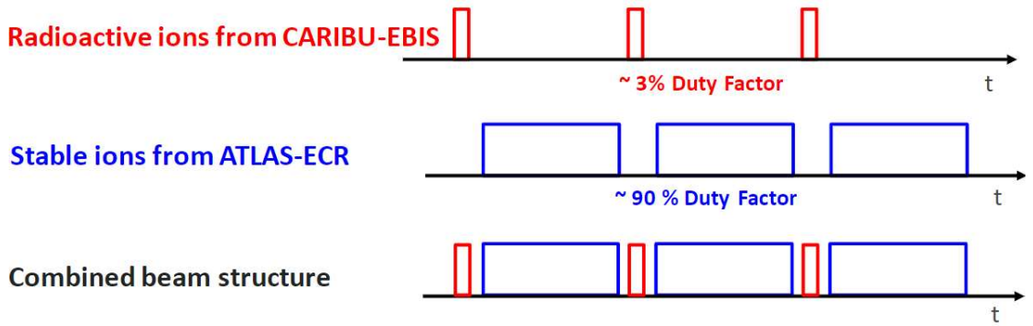
Project Background

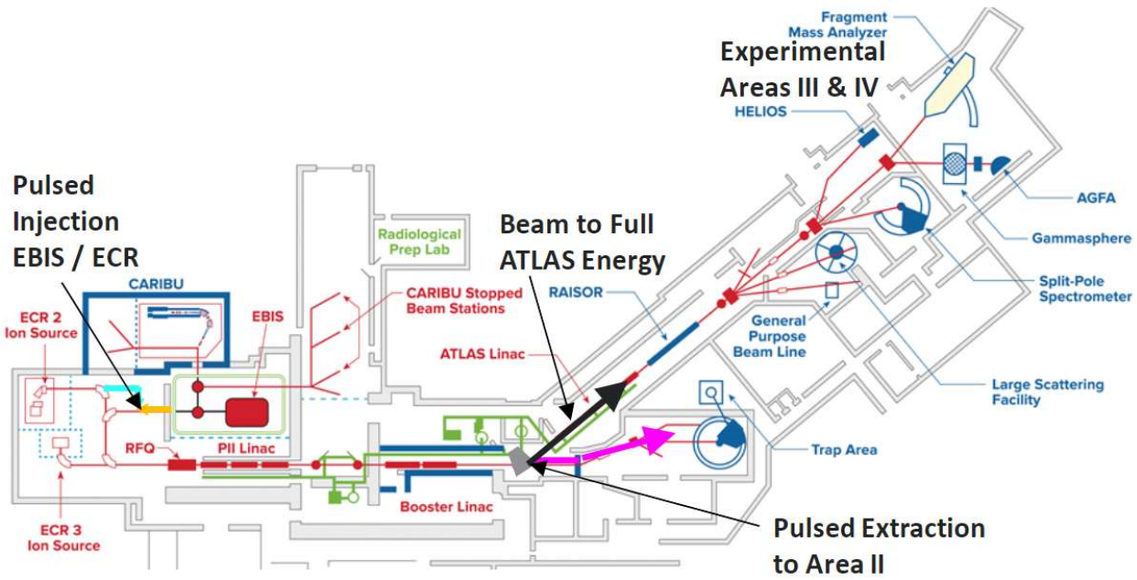
- **Technical Concept:** New high-capacity 5 Watt cryocoolers combined with one or more low RF loss superconducting cavities/cryostats are practical solutions for sources, accelerating sections or de-buncher/re-bunchers or for industrial applications, material processing, food irradiation
- **Enabling new technology, high-cooling capacity cryocoolers**, is led by PI, Dr. Sergey Kutsaev, RadiaBeam Systems, LLC and Sumitomo Heavy Industries
- **Argonne will provide:** Superconducting cavity, tuner, power coupler, RF power, cold testing
- **Funding:** U.S. Department of Energy SBIR program Office of Nuclear Physics, Topic 33: Nuclear Physics Accelerator Technology
- **Question:** Will these begin to replace conventional helium refrigerators?

Application: ATLAS Multi-user Upgrade

Increased beamtime availability of 2000-3000 hours per year

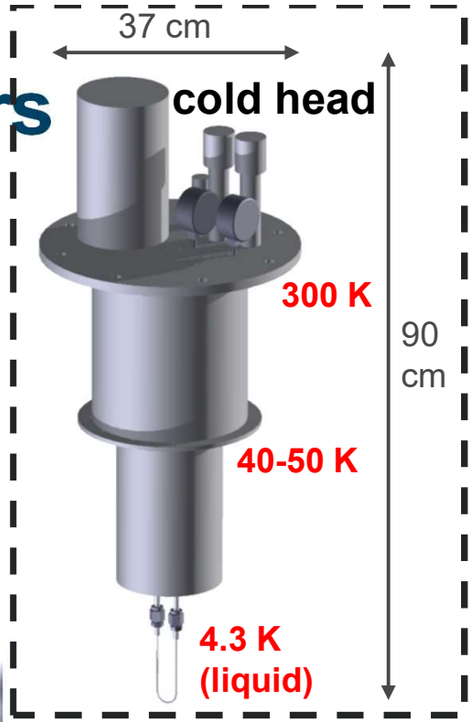
- **Beyond the commissioning of FRIB, ATLAS will address the needs of the low-energy nuclear physics community as the only national stable beam user facility and as a complement to FRIB in specific areas of rare isotope science**
- **Present radioactive beams from ATLAS CARIBU are short macropulses filling 3% of RF buckets**
- **The ATLAS multi-user upgrade will enable the simultaneous acceleration of a CARIBU beam and a stable beam by filling the remaining >90% of the RF duty cycle**
- **A stand alone cryomodule will allow the independent adjustment of beam properties (energy, time focus) to a second set of ATLAS users**

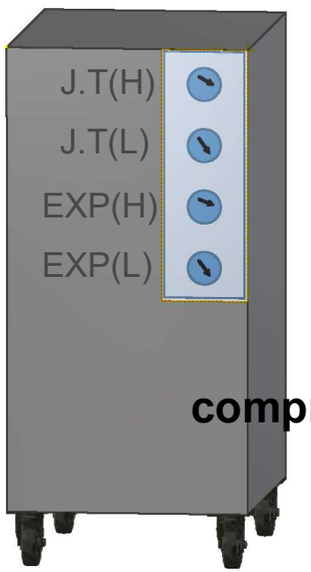




Two 5-Watt Sumitomo Cryocoolers

- Planned Phase II SBIR purchase by Radiabeam from Sumitomo Heavy Industries
- **Cycle:** Two-stage Gifford–McMahon (GM) cycle coupled to a Joule-Thomson (JT) refrigerator (schematic in supplemental slides)
- **Cooling capacity:** 5.0 Watts/cooler at 4.3 K, together with, 12.0 Watts/cooler at 40-50 K for the cooler radiation shield
- **Hardware:** 50 kg cold head, each head has a 6.4 kW compressor (60Hz 3-phase, 200 VAC)





compressor

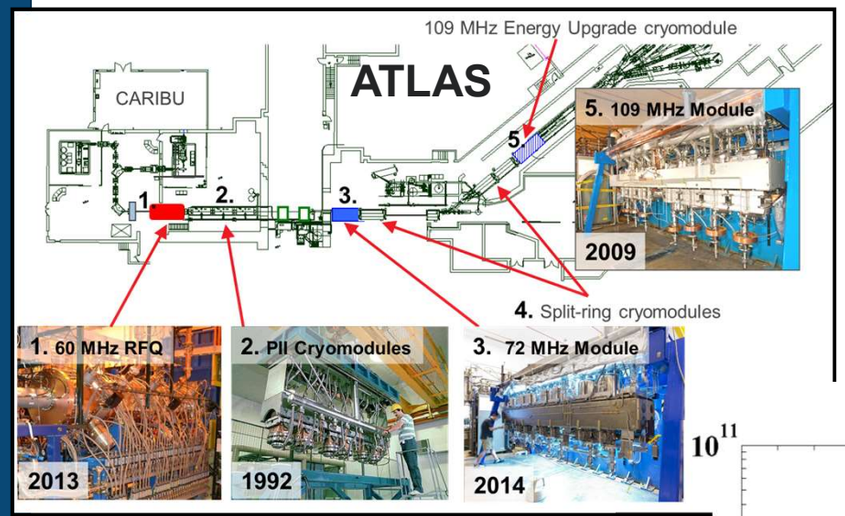
Assembly and Integration of Cavity/Cryomodule

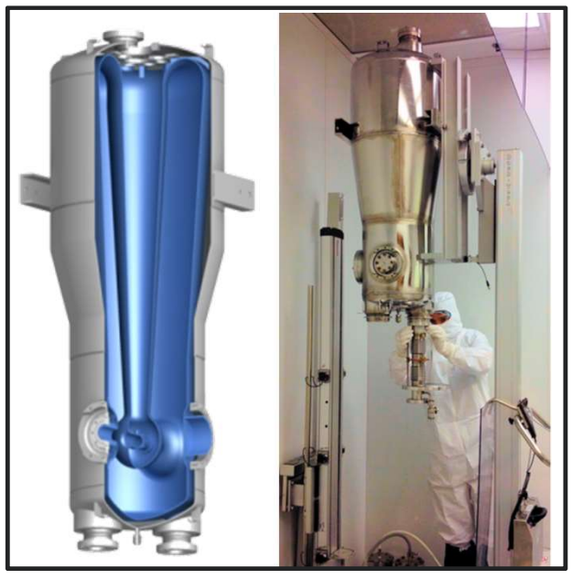
Single cavity module similar to small ANL test cryostat

Clean assembly

Vacuum vessel w/ magnetic and 80 K shields

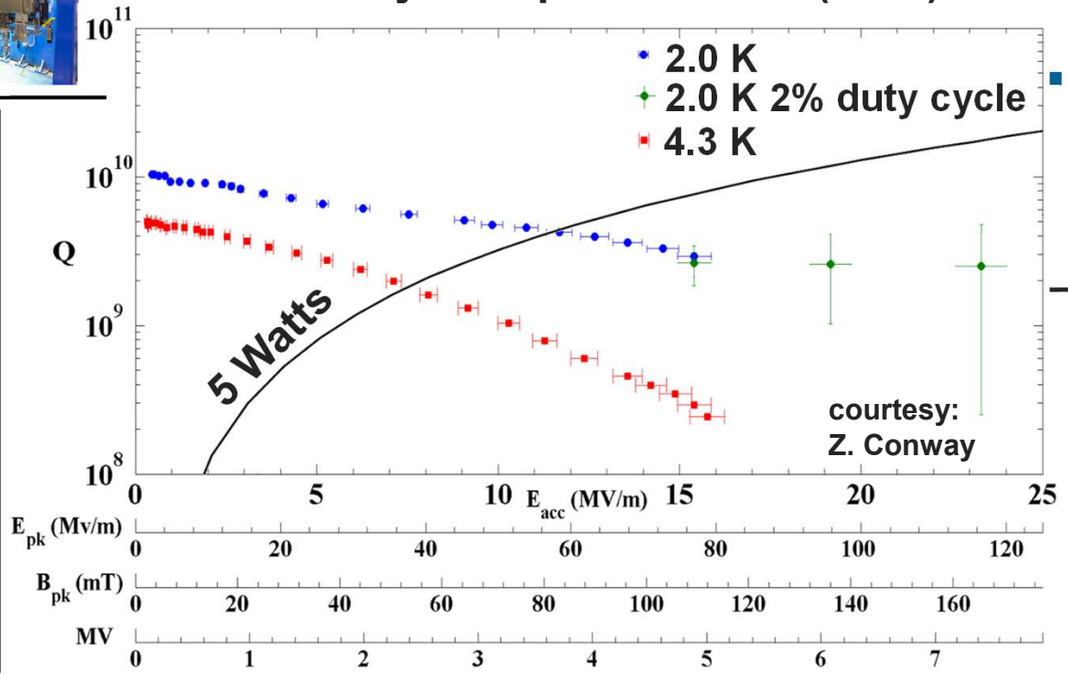
SC Quarter-wave Accelerating Cavity f_o=72 MHz, β=0.077





- Same cavity type as for 2014 ATLAS cryomodule
- This QWR was separately funded 2011 R&D to achieve highest possible gradient
- Fab./Prep. ⇨ EP, 625°C bake, light EP
- Planned operation here: V_{ACC}=2 MV for 5 W input power at 4.3 K (key is R_{BCS}~2 nΩ at 4.3 K)

Test cryostat performance (2013)



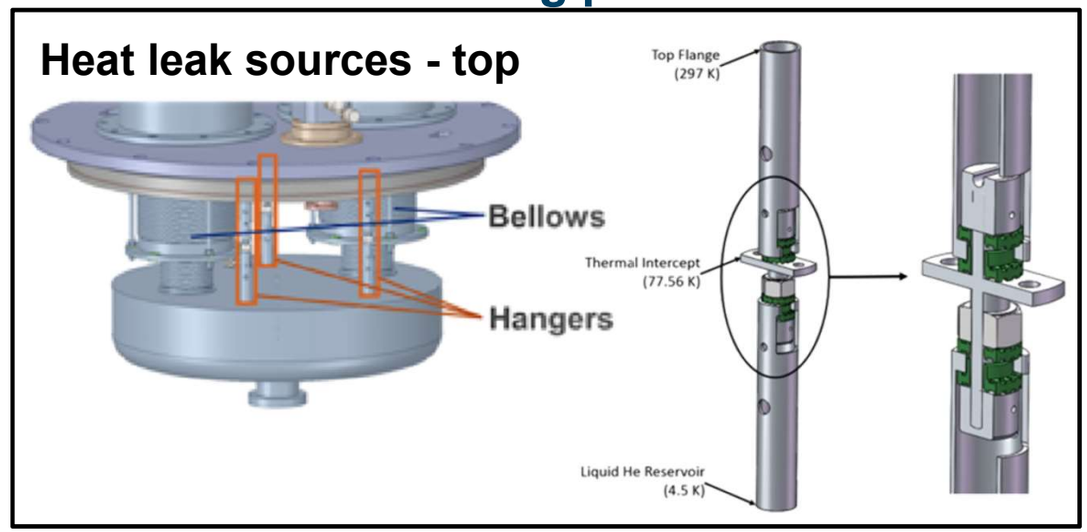
4.3 K Cryomodule Heat Budget

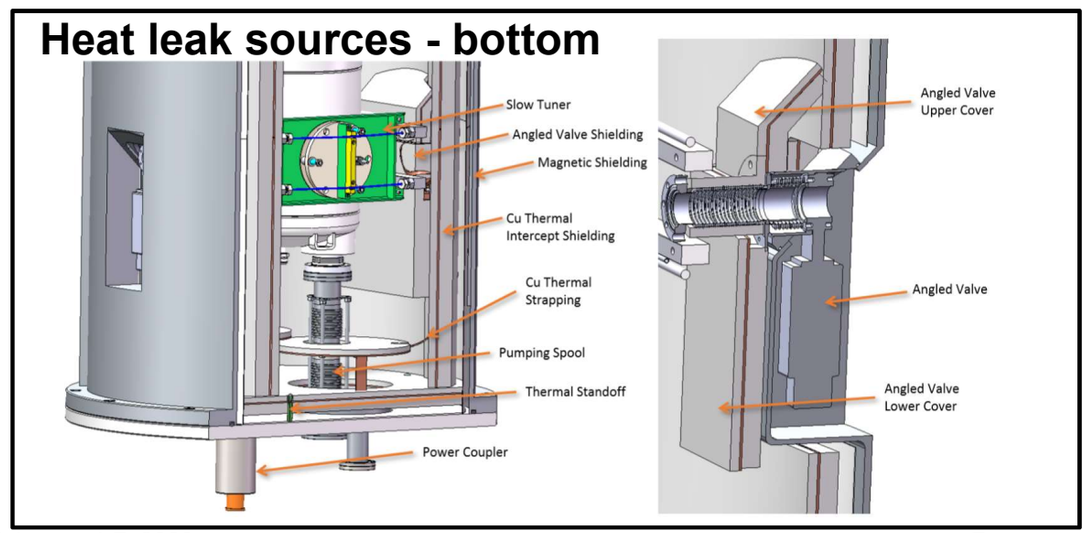
Reasonable to run single cavity cryostat with 10 Watts cooling power

Component	Heat load (W)
Cavity dynamic RF*	5
Power coupler* (static + dynamic)	0.5
Radiation to 4.3 K*	0.084
Bayonet#	0.5
Instrumentation#	1
Beamline conductive load*	0.03
Cold mass hangers*	0.18
Burst disk assembly#	1
Pumping spool*	0.6
Total	**9.4**

*Detailed engineering designs

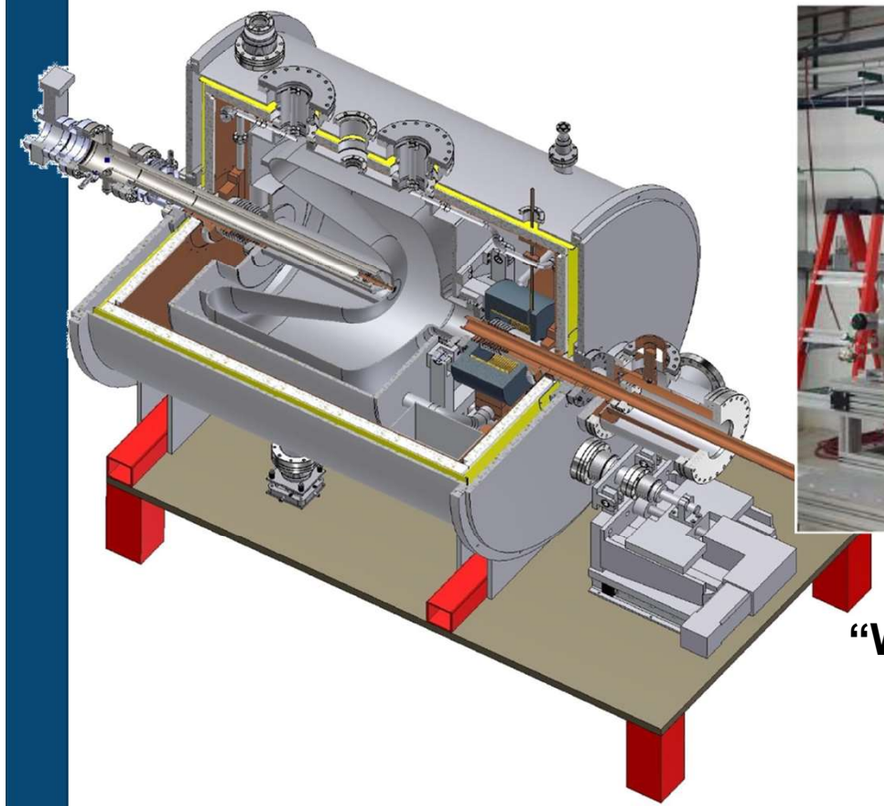
#"Conservative guestimates"





Other Applications: 200 MHz Quarter-wave SRF Gun

At this frequency and 4.3 K, single-cavity cryocoolers can be considered



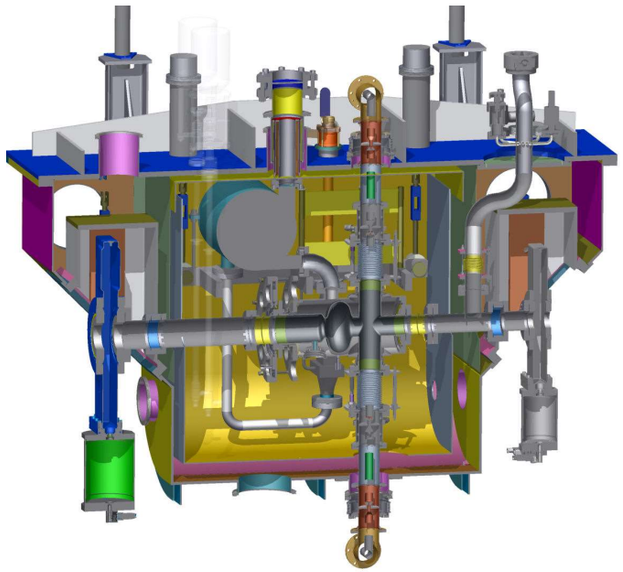
“WIFEL Gun” commissioning at U. Wisc.
Measured static loss = 6 Watts

R_{BCS}	1.36E-08	Ohm
T	4.3	K
f GHz	0.2	GHz
Rres	2.00E-09	Ohm
RoQ	147	Ohm
G	85	Ohm
At Vacc	3	MV
Ep	40.1	MV/m
Bp	60.9	mT
P_{diss}	11.2	Watts

Calculated dynamic load
= 11 Watts

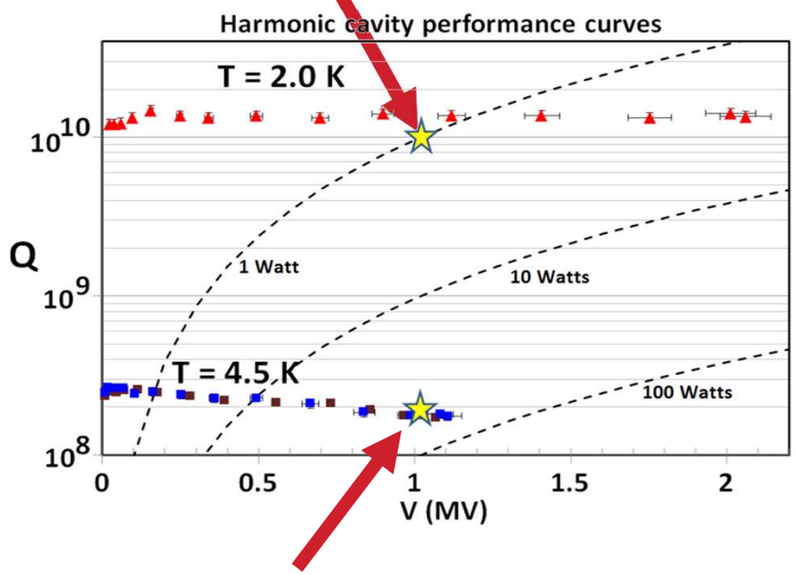
Other Applications:1.4 GHz “Bunch Lengthening Cavity”

Not as well suited to applications requiring 2 K operation *i.e.* relatively higher frequencies



Advanced Photon Source Upgrade Bunch Lengthening Cryomodule

Cryocoolers capacity low at 2 K



Cavity heat load high at 4 K

$$P_{in} = \frac{V^2_{ACC} \cdot Rs}{(R_{SH}/Q)(Q \cdot Rs)}$$

$$R_s = R_{BCS}(T, \omega) + R_{Res}$$

Summary: Issues/outlook

- **Stand alone cryomodule based on new 5 W cryocoolers is a practical and valuable application of new cryocooler technology to an SRF accelerating cavity for the ATLAS Multi-user Upgrade**

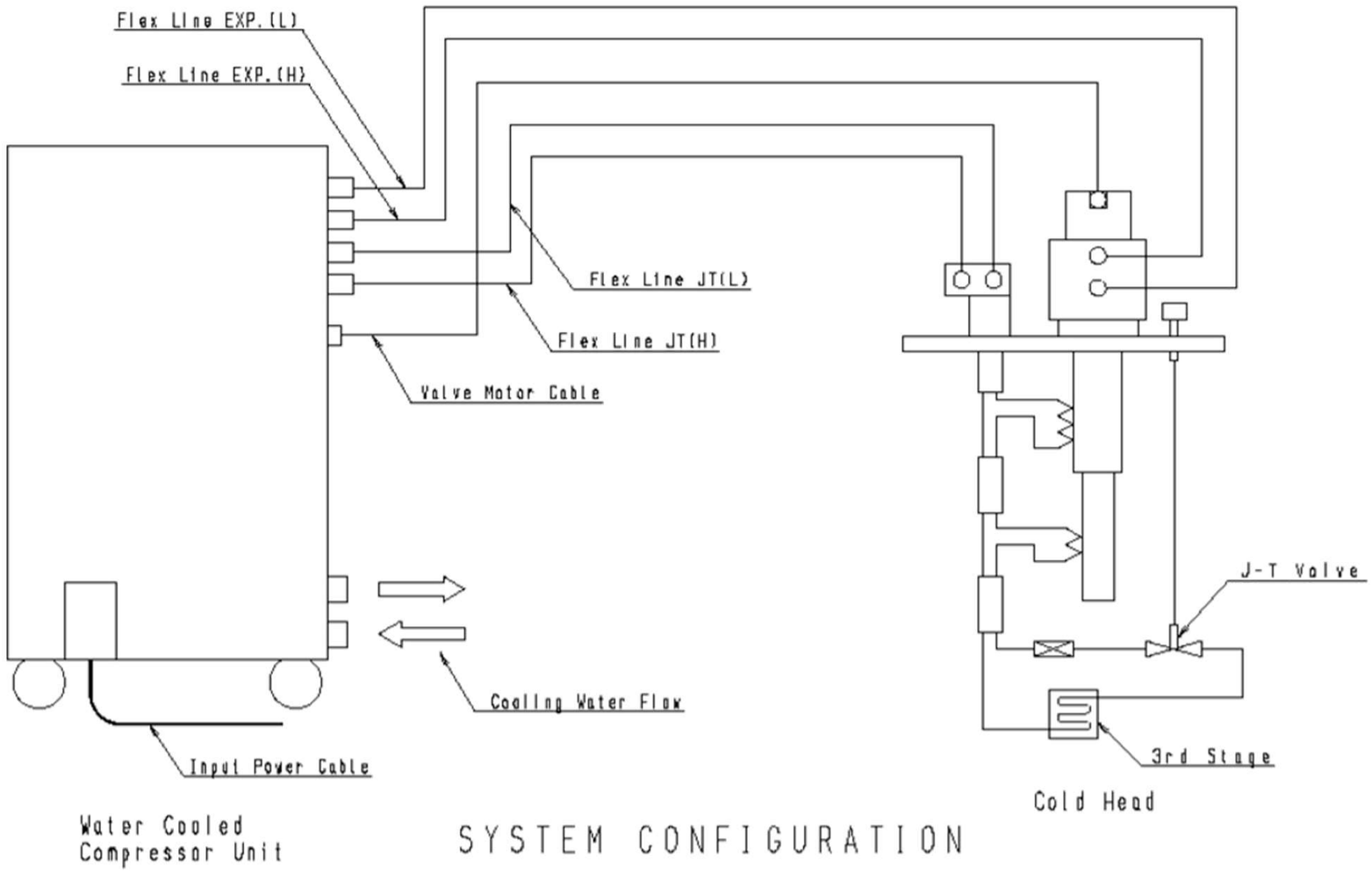
- **Key development: Commercial 5 Watt two-stage Gifford–McMahon (GM) cycle coupled to a Joule-Thomson (JT) refrigerator from Sumitomo**

- **Issues: Microphonics?, 10,000 hour maintenance on cold head (displacer)**

- **Future: Are there techniques to reduce 4.3 K surface resistance in SRF cavities**
  - **Nitrogen doping, Nb_3Sn**

- **Are we close to using stand alone cryocoolers rather than central helium refrigerators for large accelerating cryomodules/accelerators?**
  - **Not yet, unit cost per Watt still several times higher and wall plug efficiency lower**

Supplemental Slides



Courtesy: Sumitomo