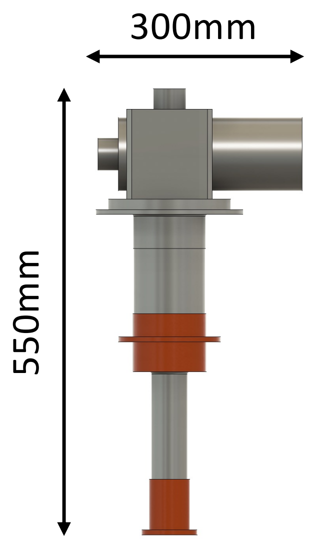
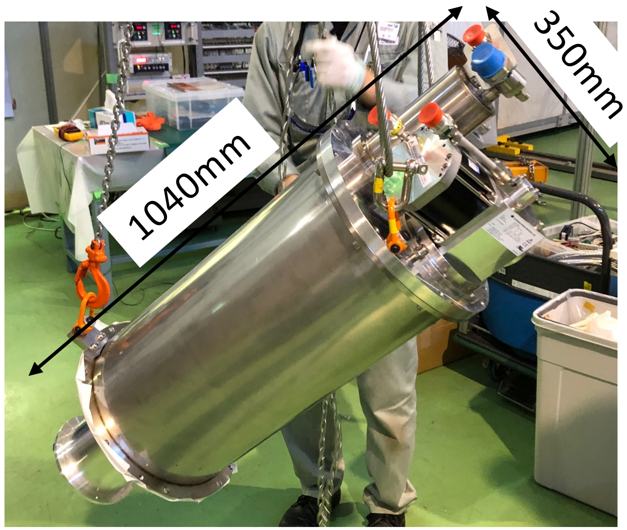
Hot Topic Session: Speaker's List

Cagetory	Name	Institute	Speaker confirmed
• Introduction	Gianluigi Ciovani	JLab	yes
1. Choice of cryocoolers	1a) Tomohiro Yamada	KEK	yes
	1b) Ram Dhuley	FNAL	yes
	1c)Roman Kostin	Euclid Tech.	yes
	1d) Ziqin Yang	IMP	J. Hao
2. Thermal Link design	2a) Neil Stilin	Cornell U.	yes
	2b) Tomohiro Yamada	KEK	yes
	2c) Ram Dhuley	FNAL	yes
	2d) Roman Kostin	Euclid	yes
	2e) Thomas Proslier	CEA-Saclay	yes
3a. Nb3Sn on Cu thin-film performance	3aa) Cristian Pira	INFN	yes
	3ab) Shawn McNeal	Ultramet	yes
3b. Nb3Sn on Nb thin-film performance	3ba) Uttar Pudasaini	JLab	yes
	3bb) Jiankui Hao	PKU	yes
	3bc) Liana Shpani	Cornell	N. Stilin
4. Tunability / robustness of Nb3Sn	4a) Grigory Eremeev	FNAL	yes

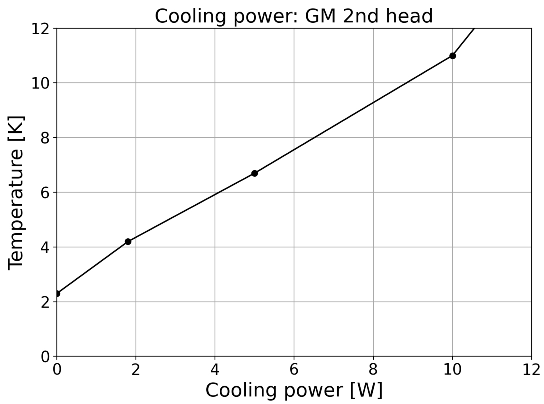
1a

GM and GM-JT cryocoolers (by Tomohiro Yamada, KEK)

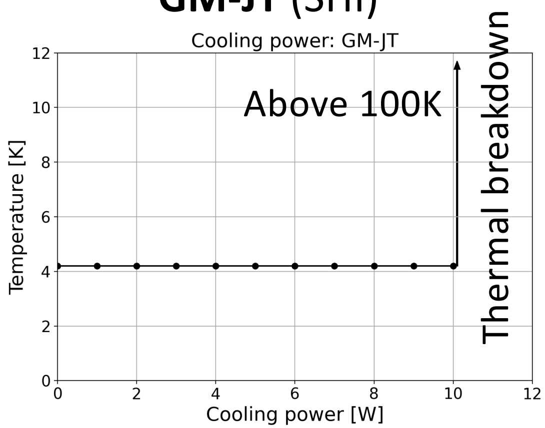


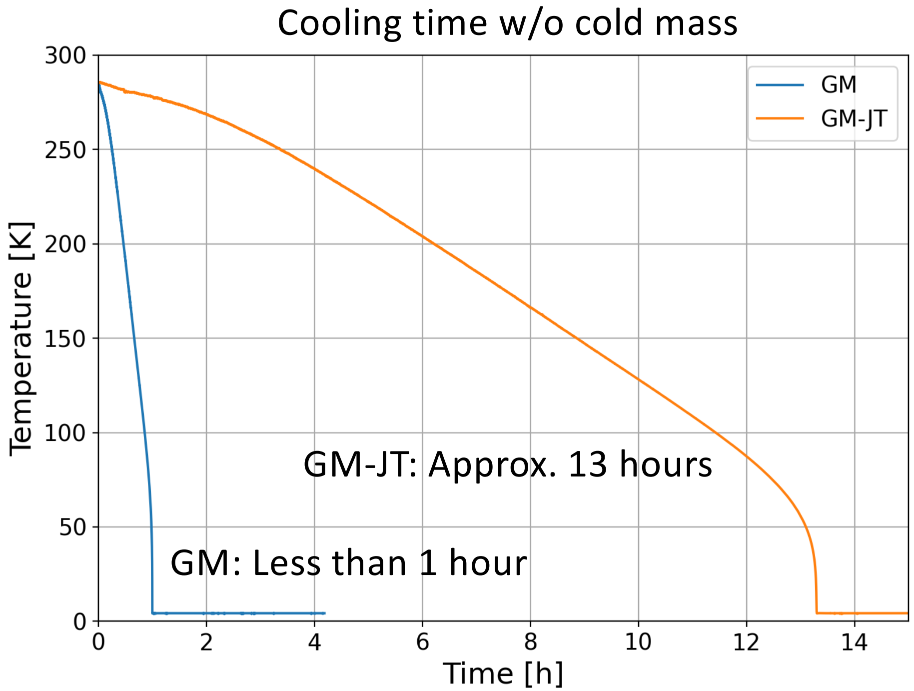


GM: RDE-418D4 (SHI)



GM-JT (SHI)

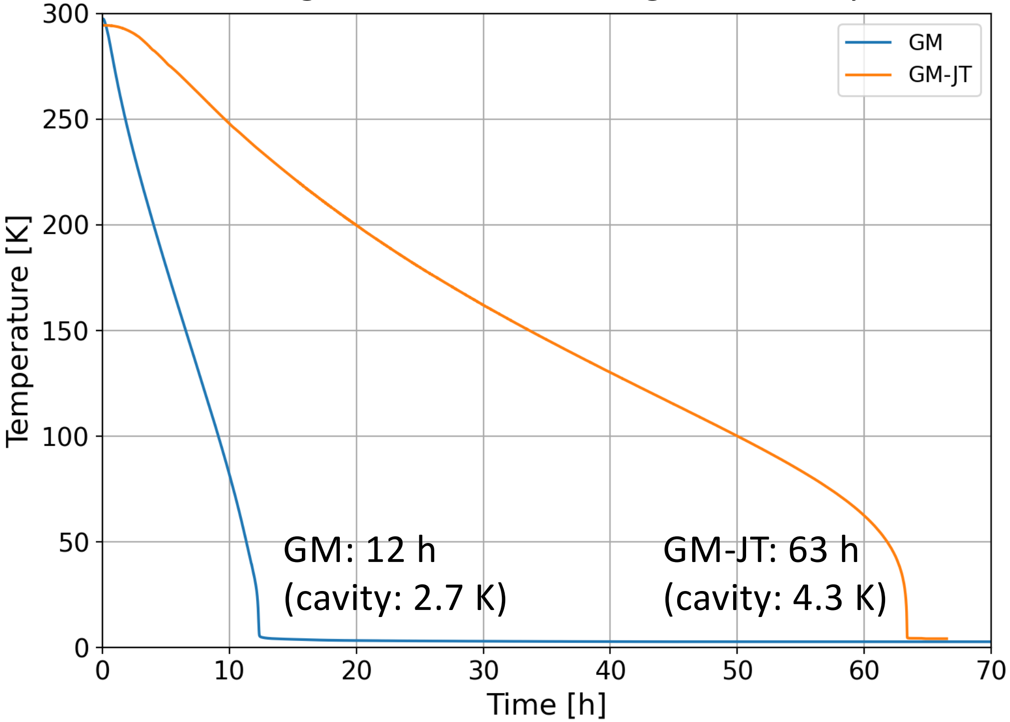




- The GM doesn't have thermal breakdown, whereas the GM-JT will be thermally broken above allowable heat input (9-10W).
- The GM-JT takes long cooling time because of its poor cooling capacity in high temperature region.

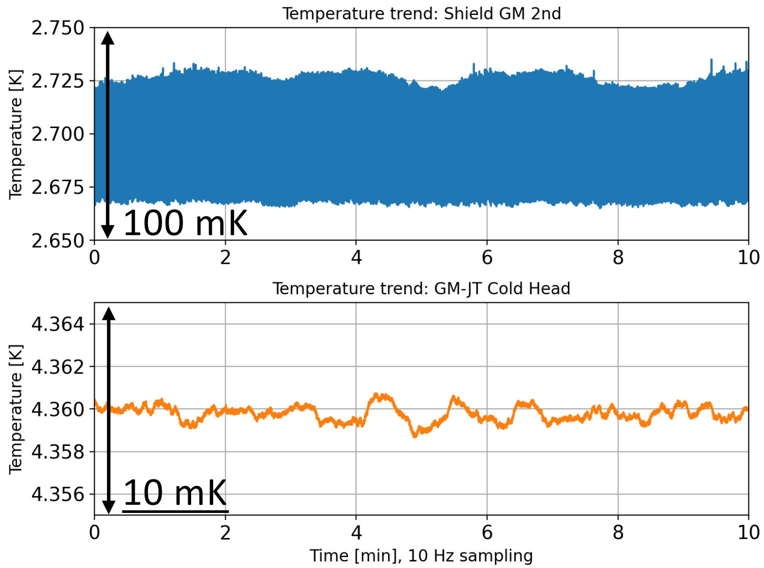
Cavity cooling (1.3GHz)

Cooling time of 1.3 GHz single cell cavity



- GM-JT takes almost 5 times long time to cool down the cavity.
- Minimum temperatures for cases of GM and GM-JT were 2.7 K and 4.3 K, respectively.

Cold heads' temperature oscillation



Max	Min
2.735K	2.664K

Δ=70mK

Max	Min
4.361K	4.359K

Δ=2mK

GM-JT temperatures were quite stable.

- We saw several hundreds Hz of frequency fluctuation in the GM case. <- Due to vibration or temperature?
- Considering thermal resistance in the thermal link and RF heating at the cavity, the cold head temperature needs to be as low as possible to keep the cavity temperature near 4.2K.

1b

Fermilab U.S. DEPARTMENT OF ENERGY Office of Science

The use of pulse tube cryocoolers for conduction cooling of SRF cavities

Ram C. Dhuley on behalf of Fermilab's conduction-cooled SRF project team

2023 TTC Meeting at Fermilab

07 December 2023

Fermilab's conduction-cooled SRF demonstration used a Cryomech PT420 pulse tube cryocooler

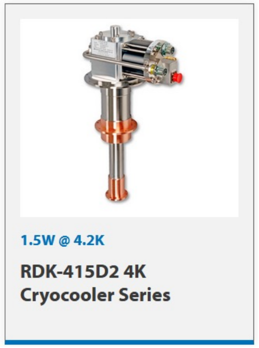
Approach for selecting the cryocooler

Estimation of 4 K cooling power requirement

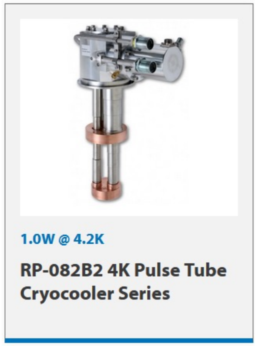
Single cell, beta ~1, Nb3Sn 650 MHz cavity, ~4 K operation			
Parameter	**Value**	**Unit**	**Expression**
Rs	1.00E-08	ohm	
G	265	ohm	
Q0	2.65E+10		G/Rs
Eacc	1.00E+07	V/m	
R/Q	150	ohm	
Lacc	0.23	m	
P-diss	***1.33***	***W***	***(Eacc*Lacc)^2/(Q0*R/Q)***

- We needed at least 1.33 W @ ~4 K
- Further buffer to account for:
  - Cavity showing higher Rs
  - Static heat leak
  - Dynamic heat leak from RF cables
- Approach: get a cryocooler with highest available unit 4 K cooling capacity.

Market survey in 2016-2017



Sumitomo GM



Sumitomo PT

5 W @ 4.3 K
CG310SC

Sumitomo GM-JT

Cryomech PT

GM-JT coolers:

- Limited field data
- More suitable for isothermal cooling at the JT stage (liquefaction vs. conduction load)
- "JT cooling loop" suddenly stops working above a certain temperature – (intermediate warmup to >18 K, uniform slow cooldown for Nb_3Sn cavities?)
- All GM capacity is used for precooling the JT stage

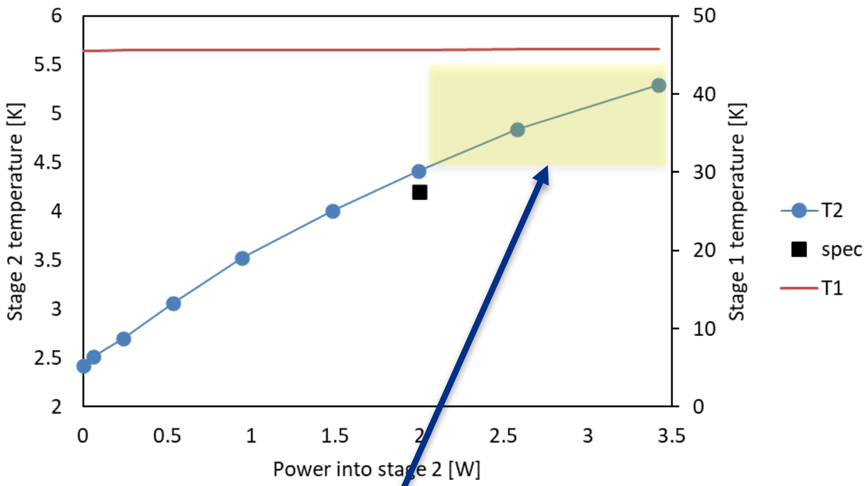
Pulse tube coolers:

- Very good response to non-isothermal load all the way to room temperature
- Excellent temperature control can be established using a heater
- 55 W @ 45 K available in the same unit for thermal radiation and conduction leak interception

Fermilab

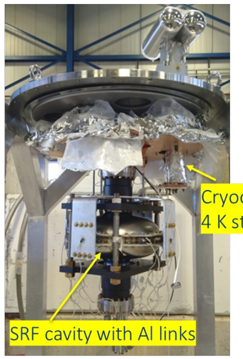
Fermilab's conduction-cooled SRF demonstration used a Cryomech pulse tube cryocooler

In-house measured performance of Cryomech PT420

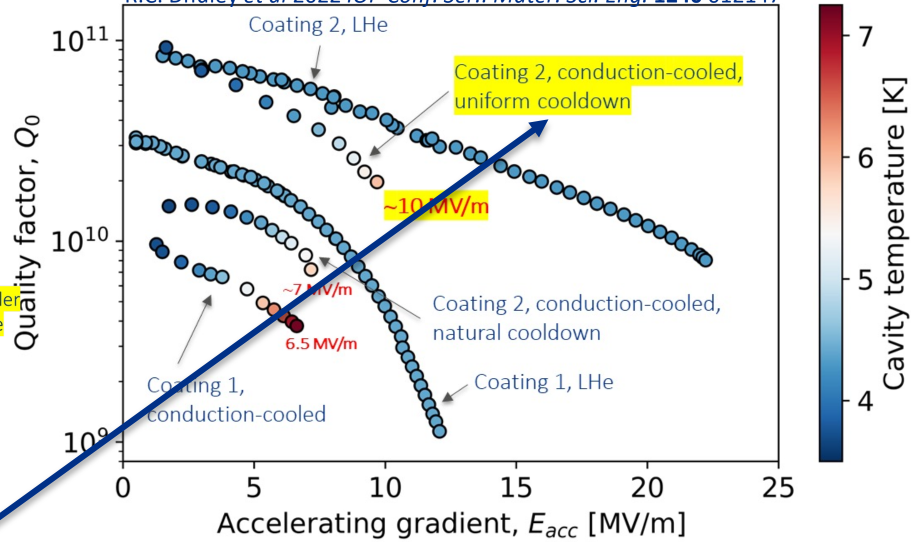


This "smooth Q vs. T" feature of a PT cryocooler is particularly useful when the cavity dissipates more than the expected heat.

Results obtained on the single cell, 650 MHz, Nb_3Sn cavity cooled using 1x PT 420 cryocooler



R.C. Dhuley *et al* 2022 *IOP Conf. Ser.: Mater. Sci. Eng.* **1240** 012147



Uniform cooldown was achieved by first warming the cryocooler-cavity to >25 K using a heater; then very slowing powering down the heater The "smooth Q vs. T" feature of the PT cryocooler made this quite convenient.

1c

Closed cycle cryocoolers for conduction cooling of SRF cavities

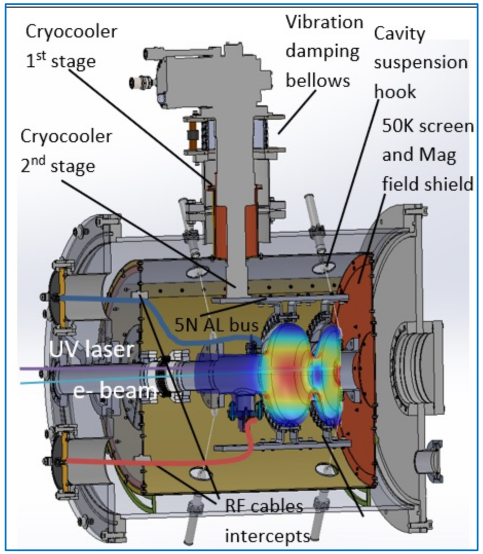
Roman Kostin, Euclid BeamLabs, Bolingbrook, IL, USA

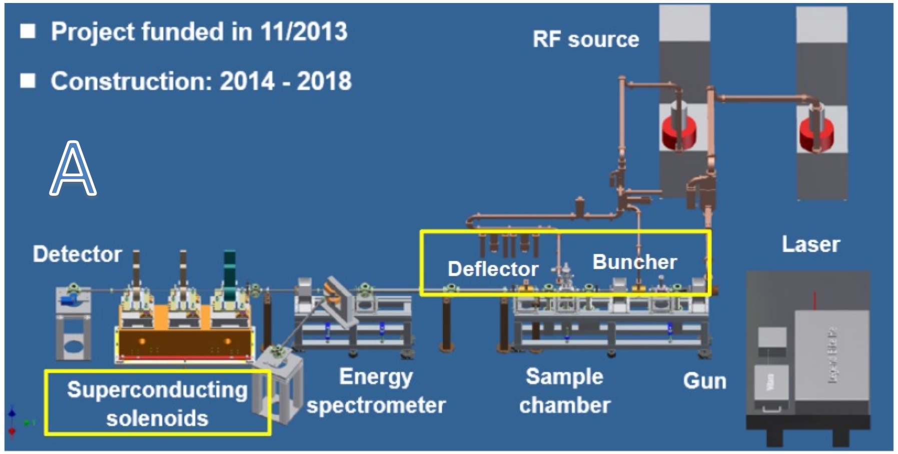
Why do we need cryocooler and what we are doing?

Conduction cooled Nb_3Sn SRF photo-gun for UED/UEM:

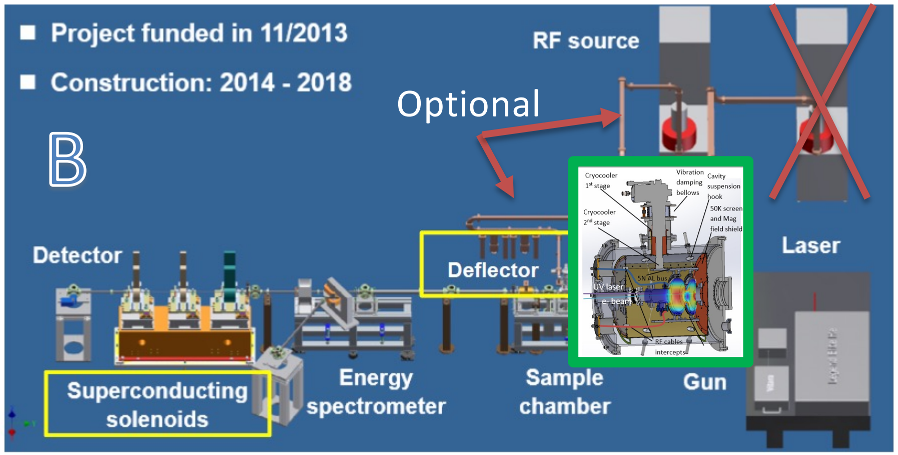
- 4K operation temperature (Nb_3Sn)
- 2W cryocooler is required ($50K, relatively cheap)
- CW operation
- Smaller footprint, 10W RF power only
- Higher stability

Parameter	Value
Frequency	1.3 GHz
Length	1.45cell (166.54mm)
Q0 at 4° K (Rs = 20 nΩ)	1.16×10^{10}
R/Q	176.9 Ω
Geometry factor	232 Ω
Wall Power dissipation	0.9 W
E on axis	20 MV/m
E max	23.5 MV/m
B max	43.3 mT
E acc	10 MV/m





Courtesy of Dao Xiang, talk at IPAC19



Closed-cycle cryocoolers: intro

- Cryocooler consist of a cold head and a compressor
- Most widely used cold heads: Gifford-McMahon (**GM**) and Pulse Tube (**PT**)
- Pulse Tubes Cooling Capacity (**CC**) goes to 0 in horizontal orientation
- Pulse Tubes have a remote valve option (less vibrations, but CC-10%)
- Compressors types: air cooled, water cooled - chiller req-d (more $ and Power Consumption X1.5)
- Sumitomo 4.2 [K] options: indoor/outdoor air/water cooled compressors, PT and GM cold heads
- Cryomech 4.2 [K] options: water cooled compressors only, PT only

CRYOMECH

SUMITOMO

Pulse Tube (PT) | Remote valve PT | PT | Remote valve PT | GM

Cryomech water cooled compressor

Sumitomo water cooled compressor

Indoor air cooled

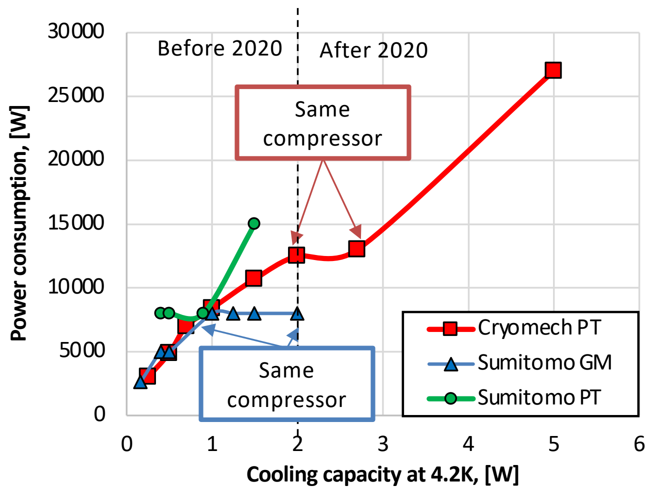
Outdoor air cooled

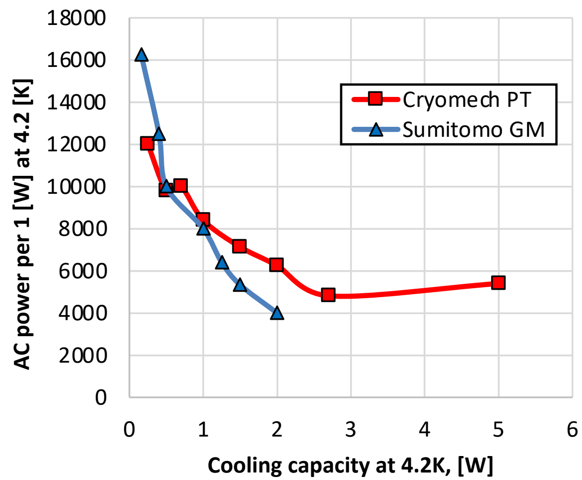
Closed-cycle cryocoolers: specs

- Things to consider
  - **PRICE**
  - **Efficiency**
  - **Power and cooling supply**
  - Maintenance: PT 20k hrs, GM 10k hrs
  - Cooler scheme: pulse-tube of Gifford Mc Mahon
  - Cooling capacity
  - Operation conditions (vertical or not)
  - Vibrations
  - Sizes
- **Interesting correlation:**
  - Power consumption is driven by compressor
  - Cooling capacity is driven by cold head
- Euclid choice was **Sumitomo air cooled** because of price and no cooling water supply.

Table.1 Closed cycle cryocooler cost based on quotes collected in 2020

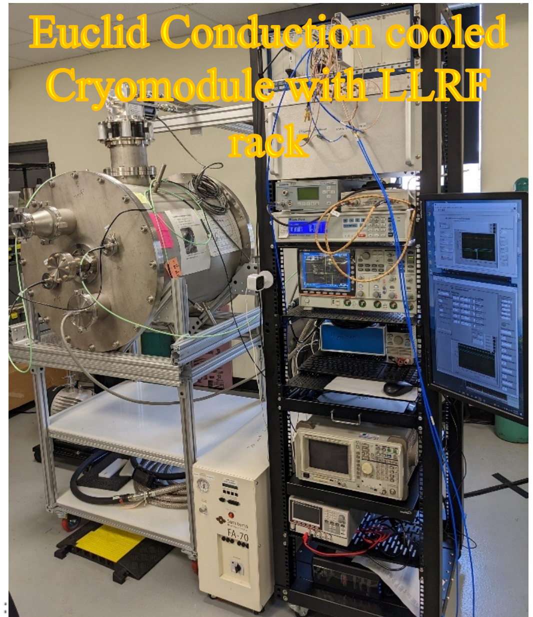
	Cryomech Water Cooled PT	Sumitomo Water Cooled GM	Sumitomo Air Cooled GM
Cold head	$30k (PT420RM)	$36k (RDE-418)	$36k (RDE-418)
Compressor	$25k (CP1114)	$7k (F-70L)	$13k (FA-70L)
Misc.	$8k	$2k	$6k
Chiller	$20k	$20k	NA
Total	**$83**	**$65k**	**$55k**

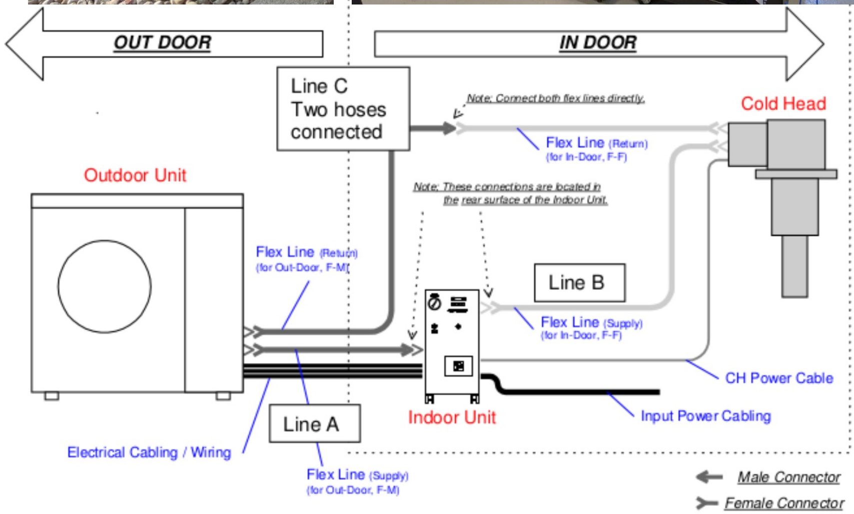




Summary

- Cryomech and Sumitomo had only 2 [W] systems back in 2020
- Cryomech offered only PT cold heads and water-cooled compressors:
  - Water cooled compressors require chiller:
    - Increases power consumption x1.5, 20 [kW] total
    - Increases price by $20k - $83k total.
  - PT
    - Can operate vertically only
    - Maintenance in 20k [hrs]
    - Lower vibrations for **remote valve option only**
- Sumitomo offered GM/PT with air/water cooled compressors
- **Euclid choice was Sumitomo air cooled GM system:**
  - Power: 8 [kW]: 40 [Amp], 200 [V] 3 phase.
  - Price: $55k
  - Can operate upside down if needed
  - Maintenance in 10k [hrs]
  - Vibration is not an issue: Euclid cavity was locked despite 5 [Hz] bandwidth.





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-updated, 231206

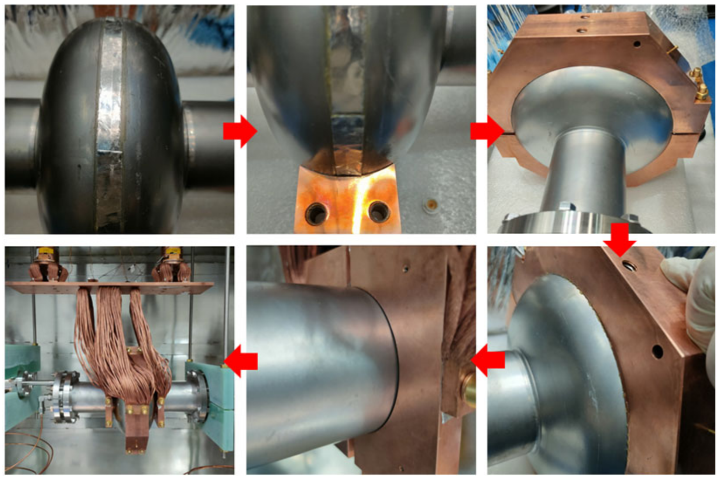
Hot-topic Session at TTC-Fermilab Meeting

Topic 1、Topic 2

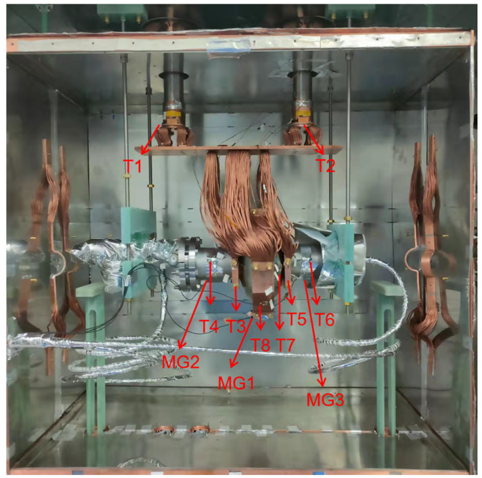
Ziqin Yang (yzq@impcas.ac.cn), Yuan He
Jiankui Hao (Peking University, On behalf of Ziqin Yang)

Institute of Modern Physics, Chinese Academy of Sciences

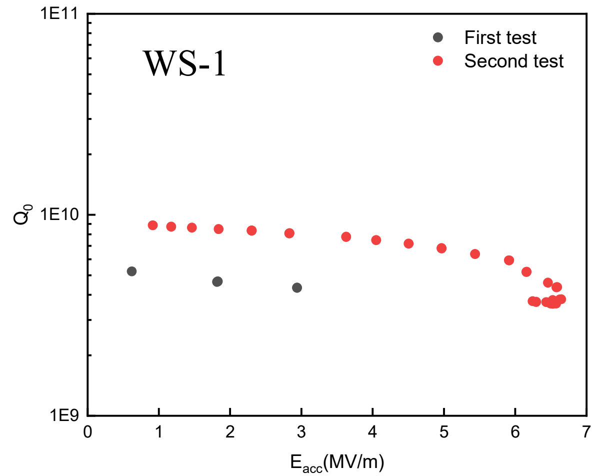
Thermal cycle effect of conduction-cooled Nb_3Sn SRF cavity



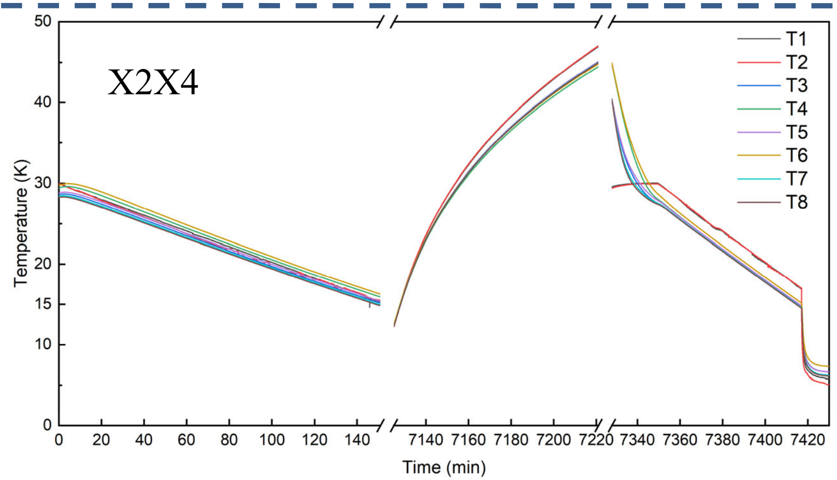
Assembly of conductive cooling anchor



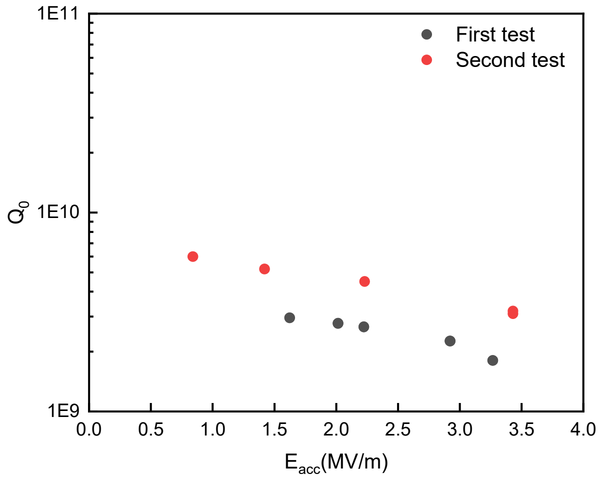
Cernox sensors and magnetic flux gates



Thermal effect **verification experiment** carried out on another Nb_3Sn cavity



Two cooldown processes crossing Tc



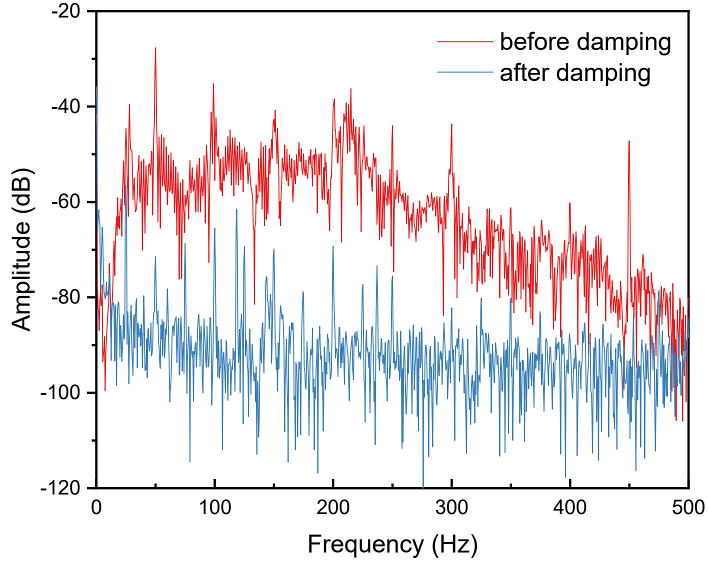
Improvement of RF performance after repeated cooldown process

1. Uneven temperature distribution in the first slow-cooldown due to the local contact between the copper strip and the cavity?
2. Repeated cooldown has been shown to reduce non-uniformity, but what is the physical picture?

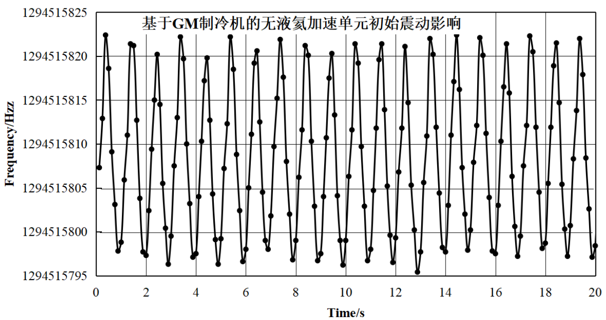
Frequency vibration caused by GM cryocoolers and suppression

Initial design: Vibrations transmitted to the top of module

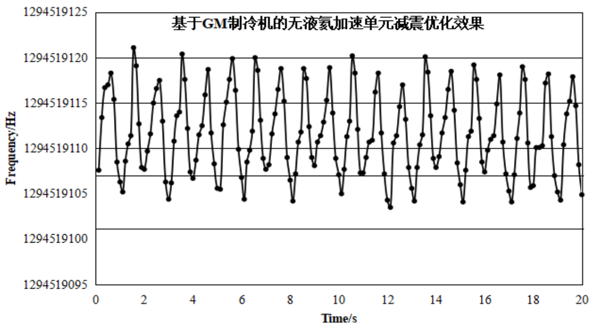
Optimized design: Vibrations transmitted to the ground



The mechanical vibration of the cavity is obviously suppressed after optimization



Frequency vibration~27Hz measured by frequency meter



Frequency vibration decreased to~15Hz

1. GM cryocoolers can cause frequency vibration of conduction cooled SRF cavity, and their impact on particle acceleration is being further evaluated.
2. Reasonable damping structure design can significantly reduce the impact of GM cryocoolers.