Status of Polarization Modulation Unit

Agenzia Spaziale Italiana

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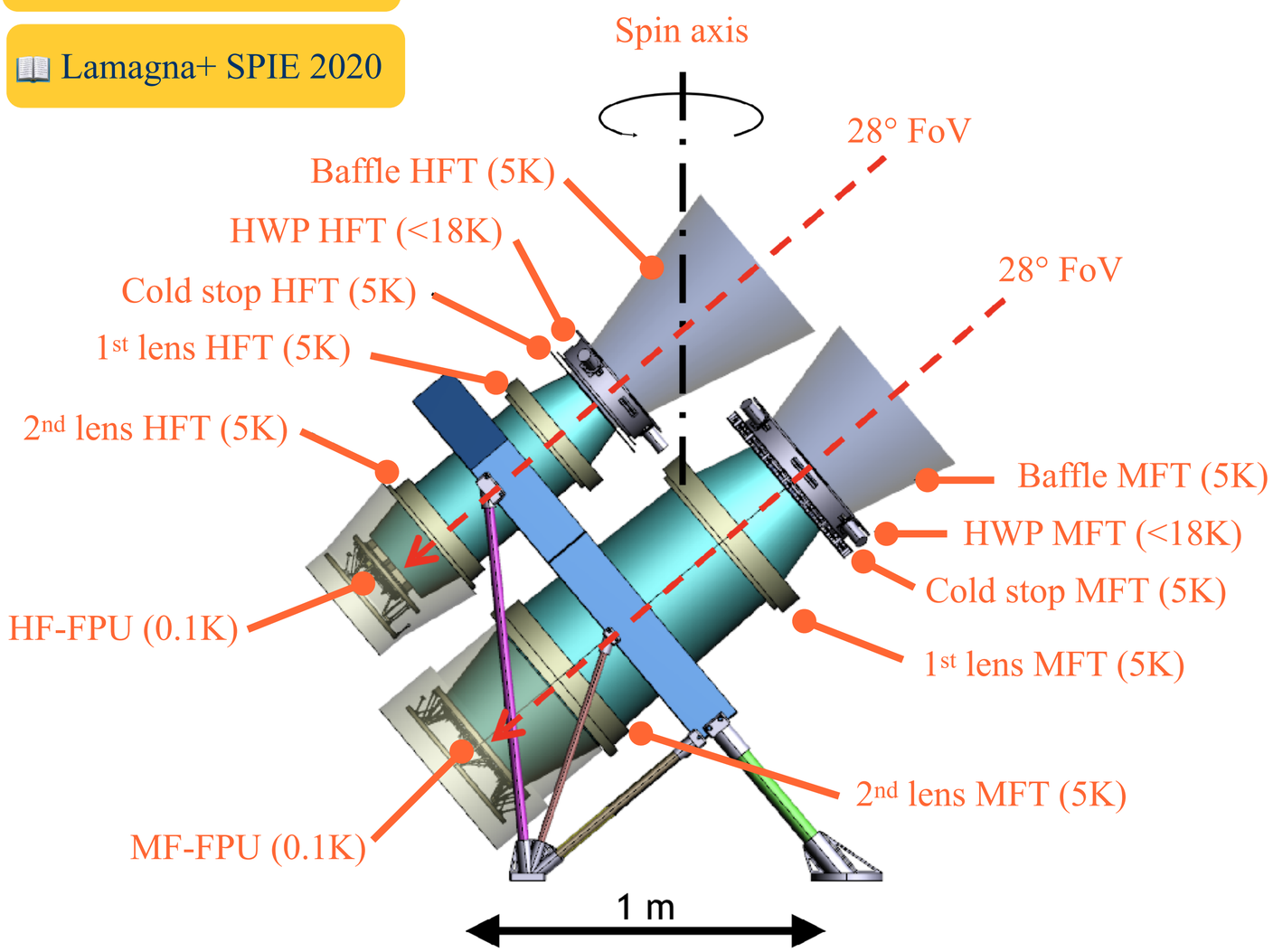
SAPIENZA
UNIVERSITÀ DI ROMA

Middle-High Frequency Telescopes (MFT/HFT)

📖 Montier+ SPIE 2020

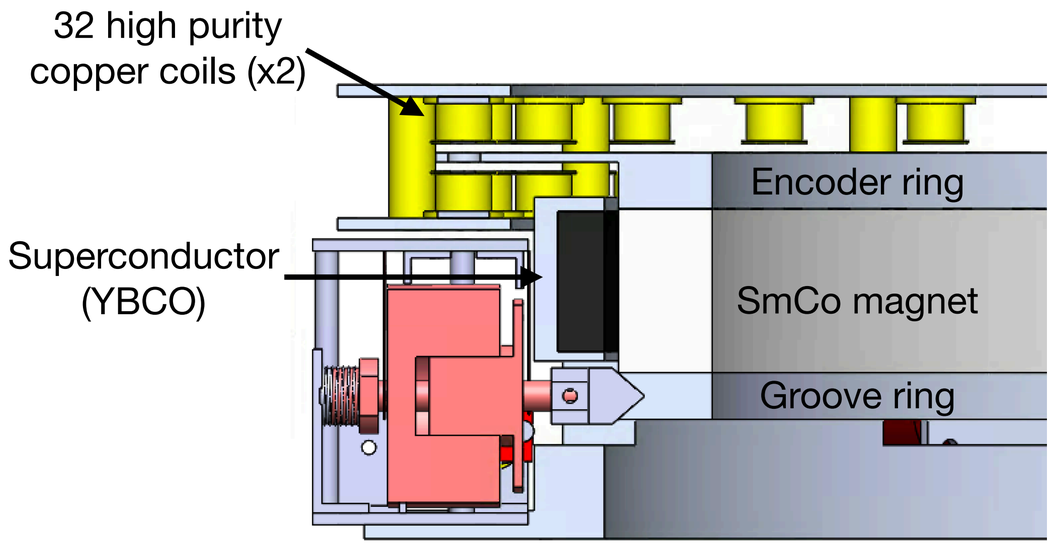
📖 Lamagna+ SPIE 2020

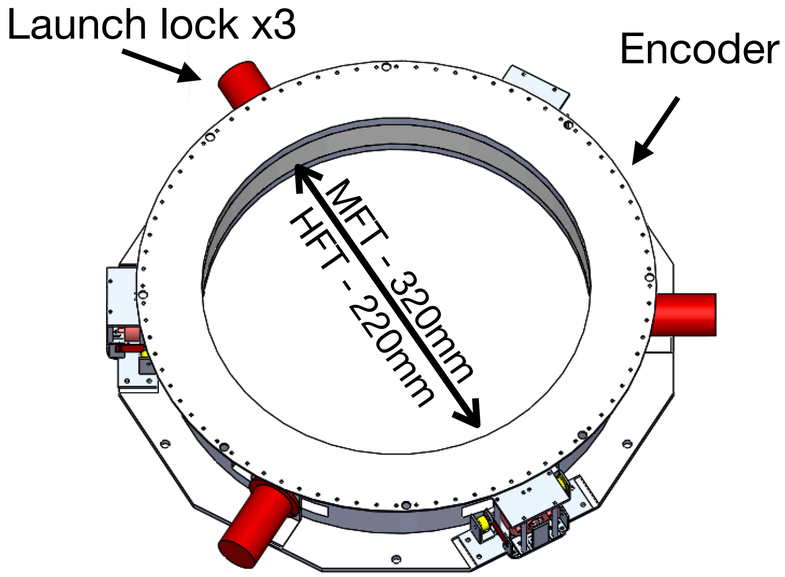


- Refractive optics
- Each telescope has PMU with a half-wave-plate (HWP)
- Optics at **5 K**
- Field of view: **28°**
- Simple and high heritage from ground experiments
- Compact (mass & volume)
- Simplified design for filtering scheme
- PP lenses + ARC
- Weight 180 kg

	MFT	HFT
ν (GHz)	**100-195**	**195-402**
Ap. diameter (mm)	**300**	**200**
Ang. res. (arcmin)	**38-28**	**29-18**

PMU - Overview

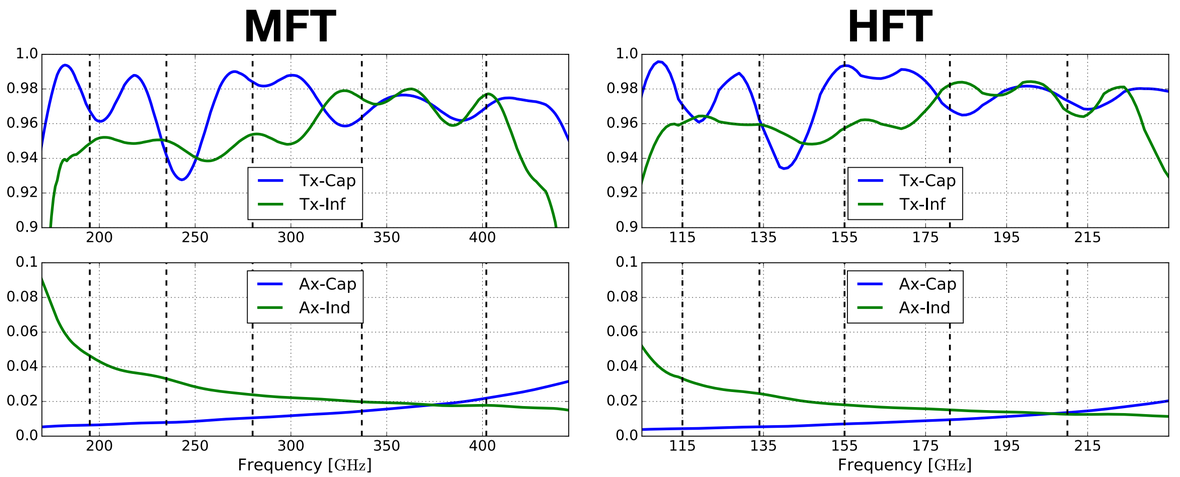




Metal-mesh HWP
located in the center

PMUs requirements

	MFT	HFT
HWP diameter	320 mm	220 mm
HWP temperature	< 20 K	< 20 K
PMUs dissipation	< 4 mW	
Rotation frequency	39 rpm	61 rpm
Angular accuracy	< 1’	< 5’
Lifetime	> 3 years	> 3 years
Total mass	< 20 Kg	



Phase-A study (Thales)

- **Delivered Documents**:

- DEL01_PMU —> PMU Requirement Specification
- DEL02_PMU —> PMU Development Plan with AIV Plan, Deliverable and Schedule
- DEL03_PMU & DEL08_PMU —> PMU Design Definition and Justification File with Budgets
- DEL04_PMU & DEL05_PMU —> PMU Mechanical and Thermal Preliminary Analyses
- DEL06_PMU & DEL07_PMU —> PMUs Electrical and Mechanical ICD

2.2.1 M/HFT PMU Hardware Tree

In order to easy the requirement understanding, an Hardware Product Tree of the M/HFT PMU in line with its requirement is detailed in Figure 2.2-2 (the cryogenic section represented in Figure 2.2-1 is in red).

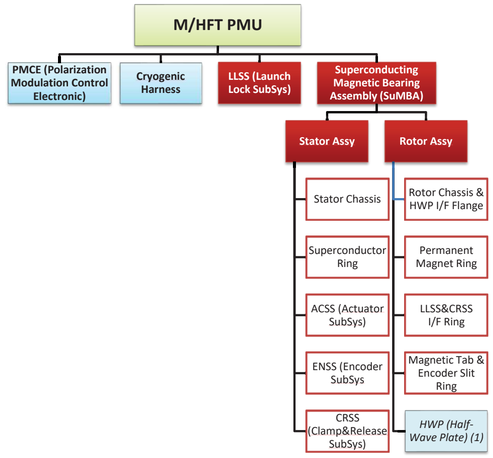


Figure 2.2-2: Possible HFT/MFT PMU Hardware Tree (Cryogenic Part in Red)

(1) Not part of the PMU, it is included for completeness because the item is constrained to the Rotor Chassis with a dedicated mechanical I/Fs. The HWP shall be replace by a dedicated and representative mechanical and thermal dummy HWP during all the PMU qualification, acceptance, performance and environmental test campaigns (cf. §3.3, §**Errore. L'origine riferimento non è stata trovata.**, §**Errore. L'origine riferimento non è stata trovata.**).

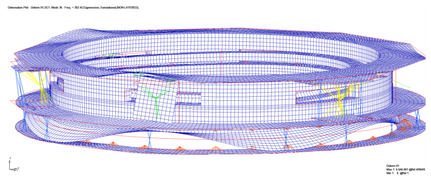


Figure 2.4-2: mode 36 – 262.5 Hz – ROTOR ENCODER + STATOR SUPPORT (with LLSS)

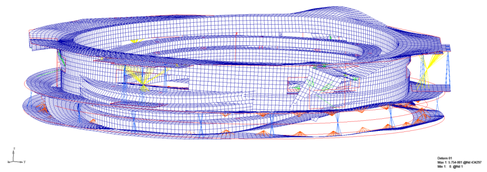


Figure 2.4-3: mode 49– 348.9 Hz – ALL STRUCTURE – Z axis and rotation on X,Y axis

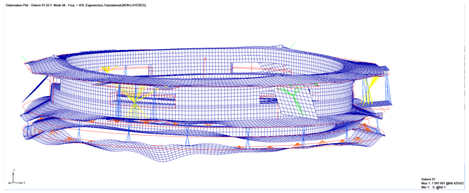


Figure 2.4-4: mode 66 – 795.2 Hz – ALL STRUCTURE – Z axis

3.4 PMU BLOCK DIAGRAM

The block diagram of the whole PMU is represented below (this is the same for both the MFT and the HFT).

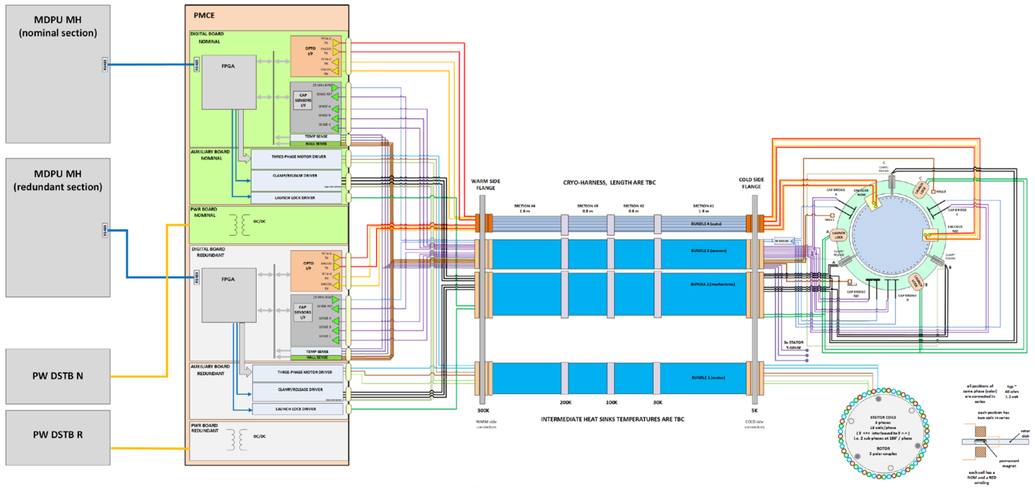
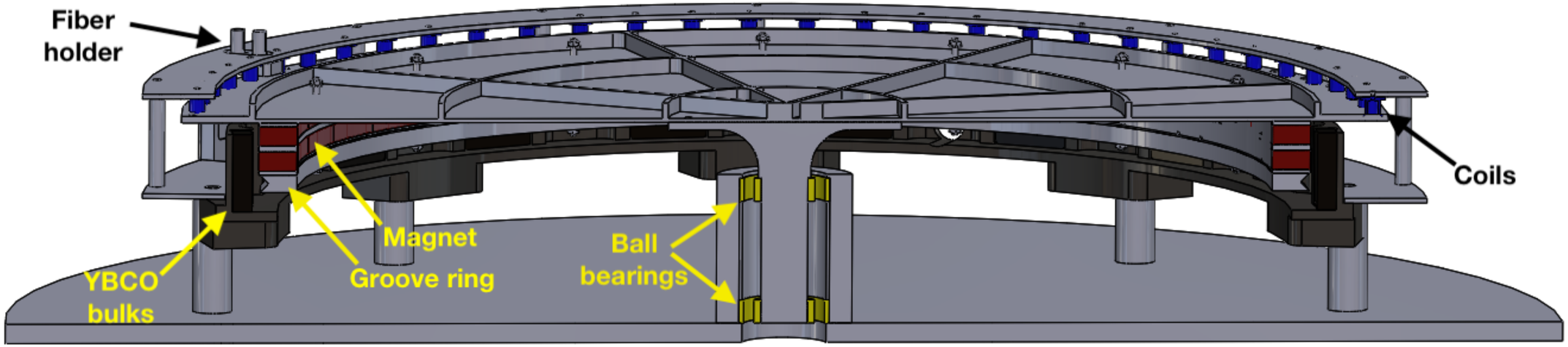
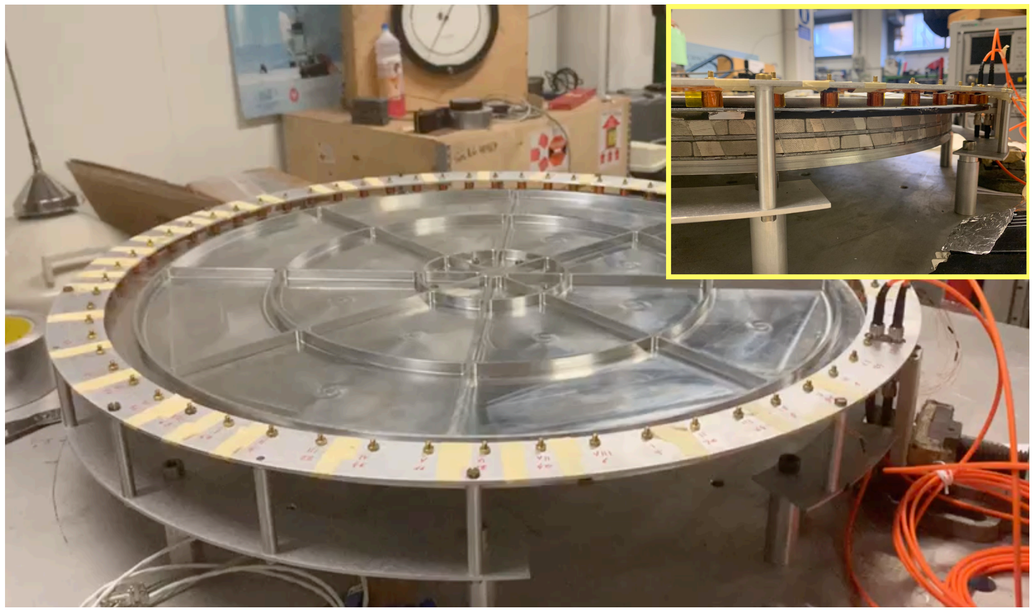


Figure 3.4-1: M/HFT PMU Block Diagram

Room temperature mockup

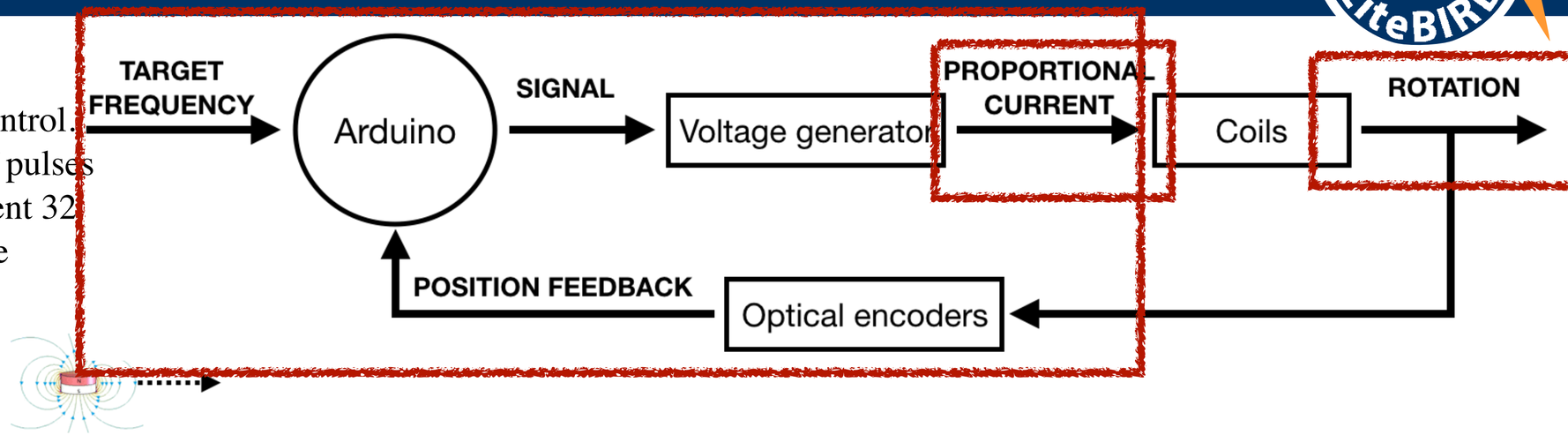


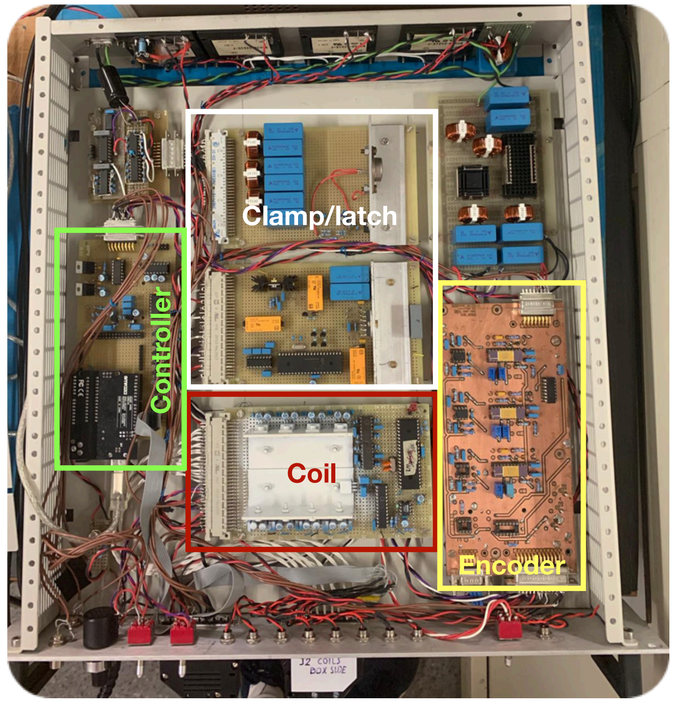


	300K	Cryo	
Power Load	✓		Critical
Motor	✓		Efficiency
Encoder	✓	✓	Same behaviour
Clamp/release system	✓	~	Tested, to be optimized
Sensors	✓	✓	Same behaviour

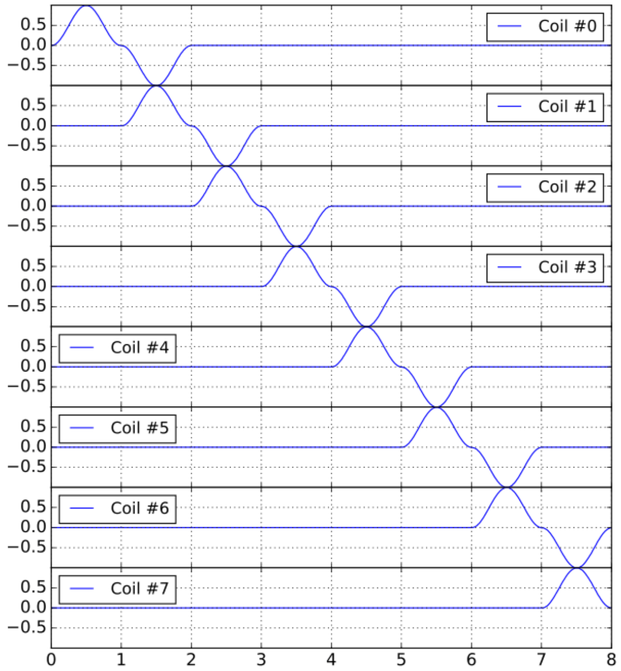
Room temperature mockup - Drive system

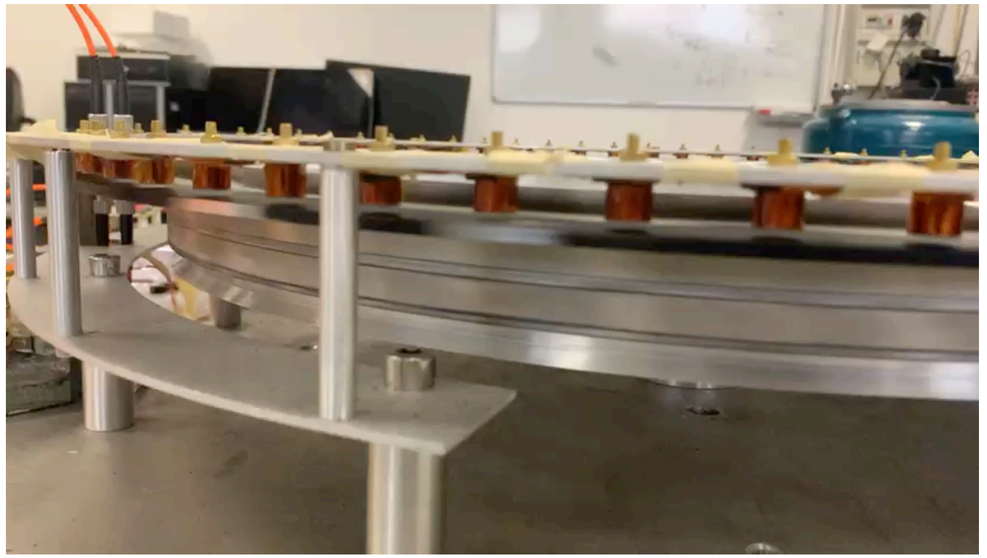
The rotation is stabilized by means of a PID (Proportional-Integrated-Derivative) feedback control. The PID feedback controls both the frequency of pulses (16-bit resolution) and the magnitude of the current 32 times per round (12-bit resolution) to stabilize the rotation when the right frequency is reached.





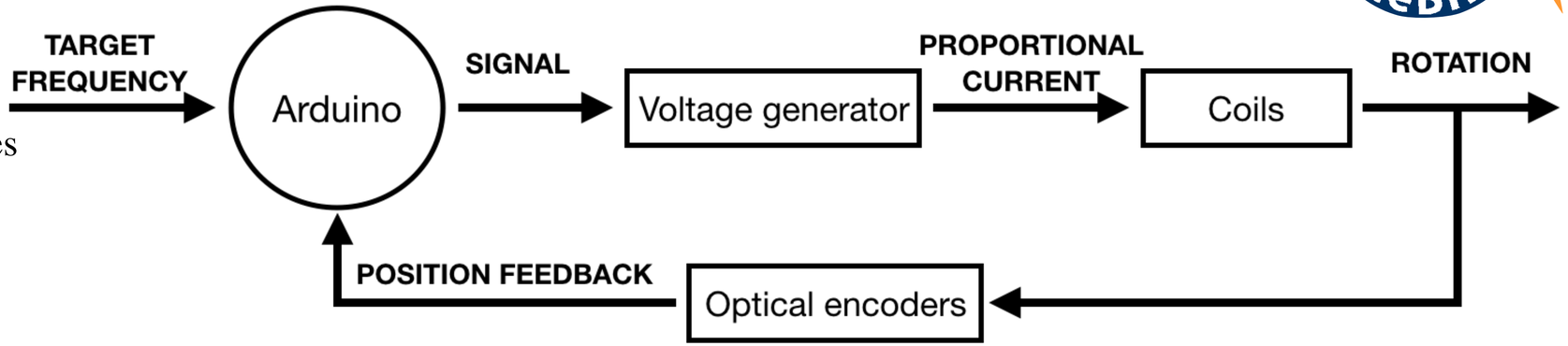
P. de Bernardis

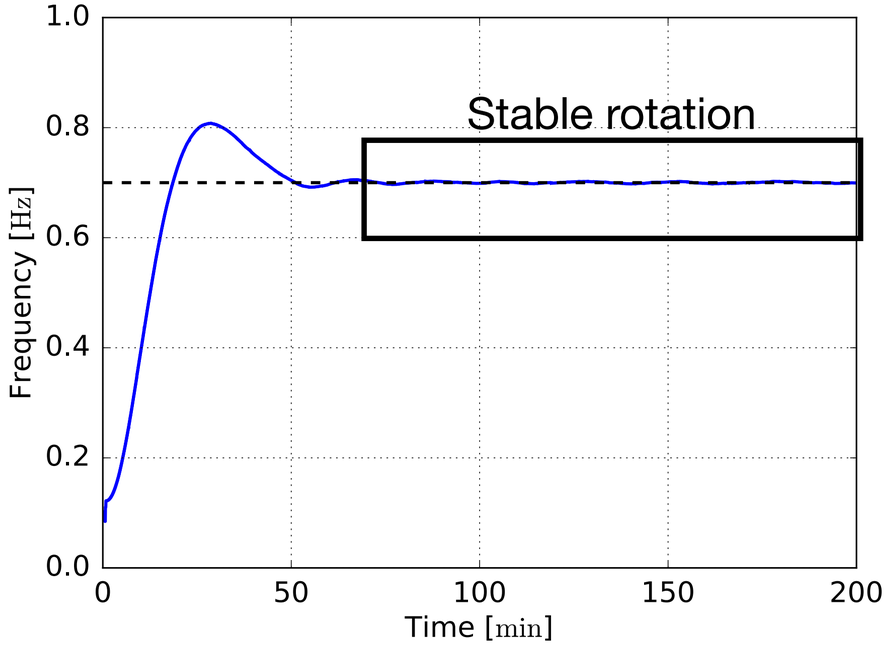


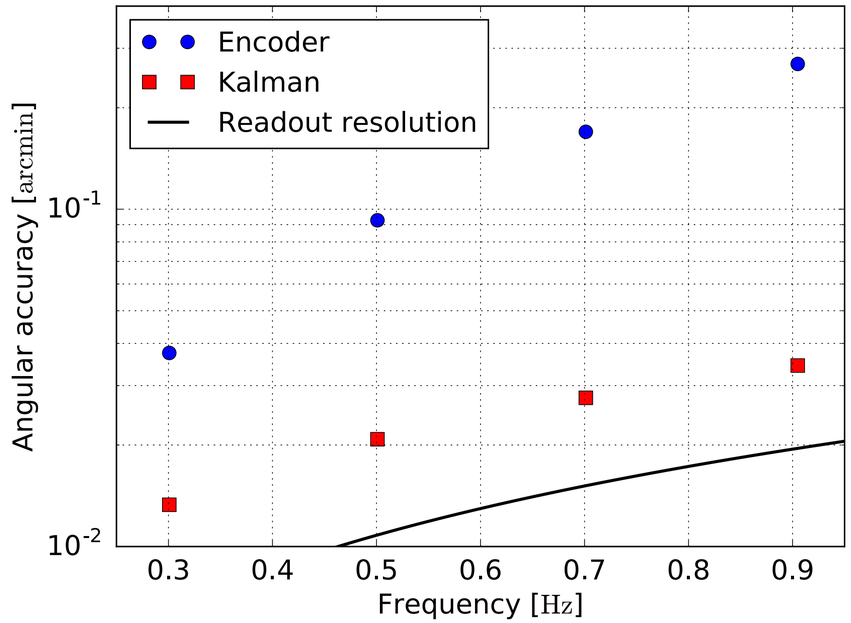


Room temperature mockup - Drive system

The rotation is stabilized by means of a PID (Proportional-Integrated-Derivative) feedback control. The PID feedback controls both the frequency of pulses (16-bit resolution) and the magnitude of the current 32 times per round (12-bit resolution) to stabilize the rotation when the right frequency is reached.







The accuracy was improved thanks to the using of a Kalman filter which combines system's dynamic model, system's physical properties and multiple sequential measurements to make an estimate of the system's varying quantities that is better than the estimate obtained by using only one measurement alone.

Room temperature mockup - Friction

LSPE-PMU will be used to measure the loss, validating the model and allowing to (down)scale to the LiteBIRD systems (5mW).

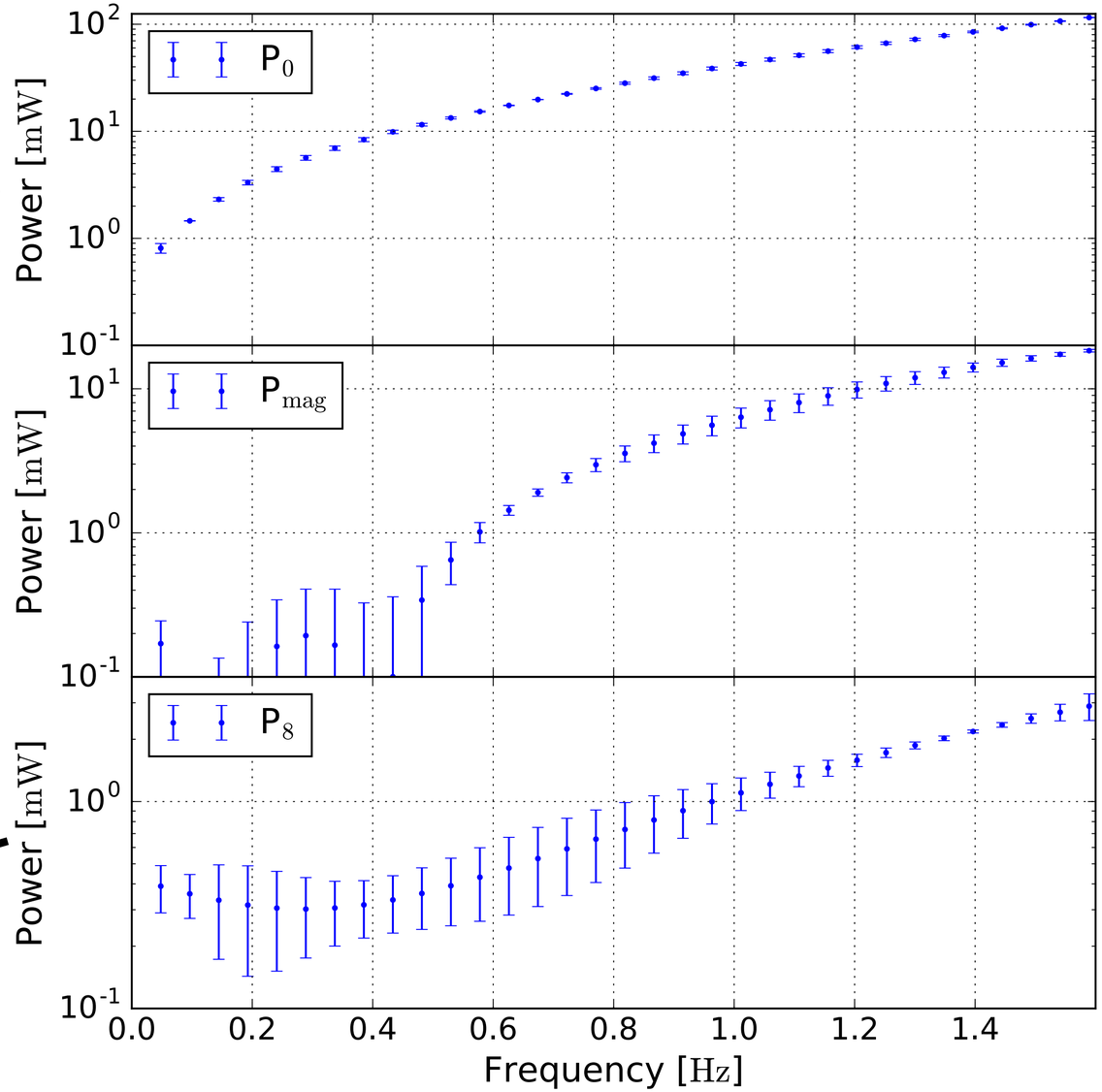
LiteBIRD forecast based on room temperature measurements

	MFT	**HFT**
	[mW]	[mW]
8 magnets	0.59	0.88
Main magnet	<0.41	<0.57
Hysteresis	<0.50	<0.50
Joule	0.09	0.05
Harness	0.22	0.22
Rotor emission	0.09	0.07
Total	< 1.90	< 2.29

Ball bearings contribution

The minimization of this contribution is one of the most critical point in the modulator design (magnet inhomogeneity and stator material choice)

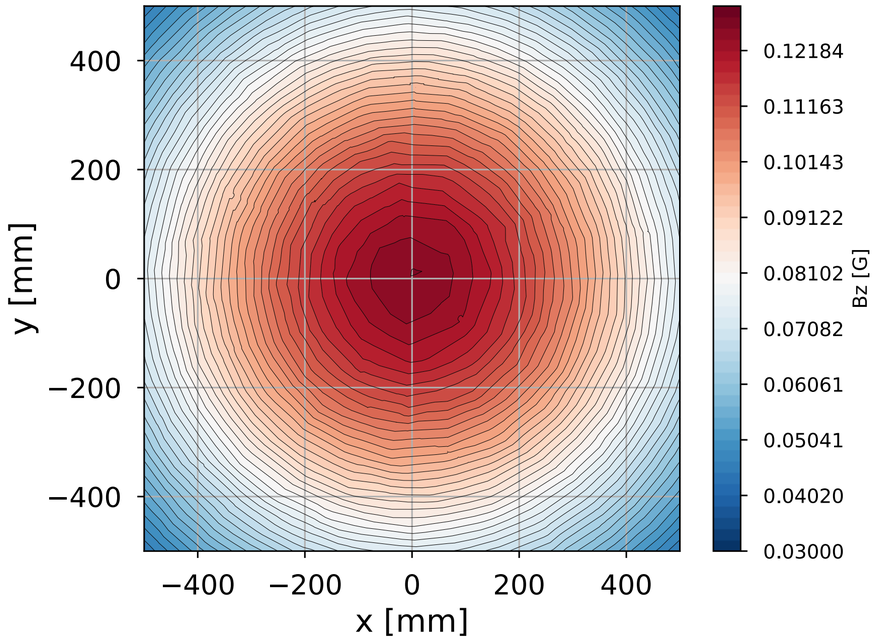
Motor magnets contribution

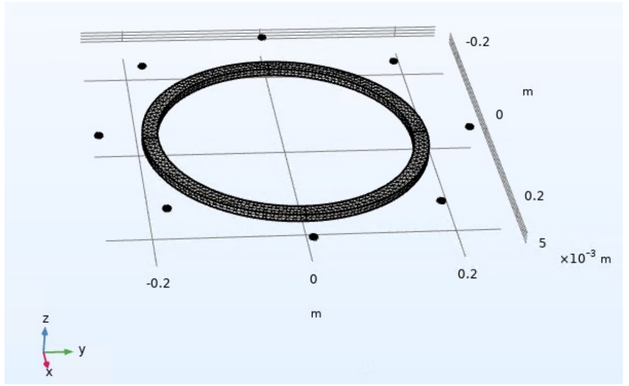


PMU - Magnetic field

	Simulated		Requirement
	MFT	**HFT**	
DC	< 0.15 G	< 0.35 G	2G
0.8 mHz	TBD	TBD	20 uG / sqrt(Hz)
Stability (low f)	< 0.1 mG	< 0.3 mG	2.4 mG
4f (3f-5f)	< 4 uG	< 20 uG	2 uG/sqrt(Hz)

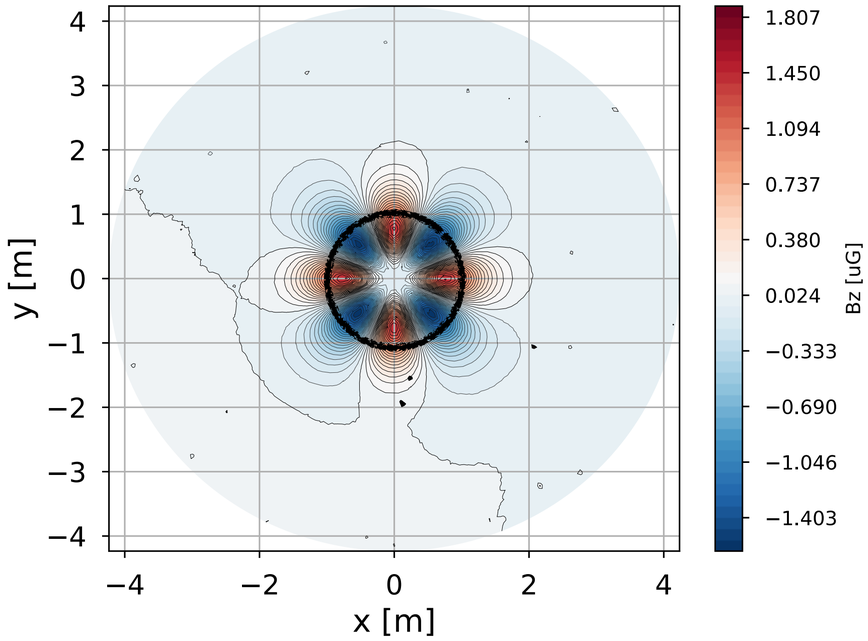
PMU magnetic field is **NOT** fully compliant with the requirements.
A magnetic shield is mandatory.





Main magnet:
- B_r = 0.5 T
- h = 10 mm
- dR = 20 mm
- z_{FP} = 1.1 m

8x magnets
- B_r = 1.0 T
- d = 10 mm
- h = 2 mm

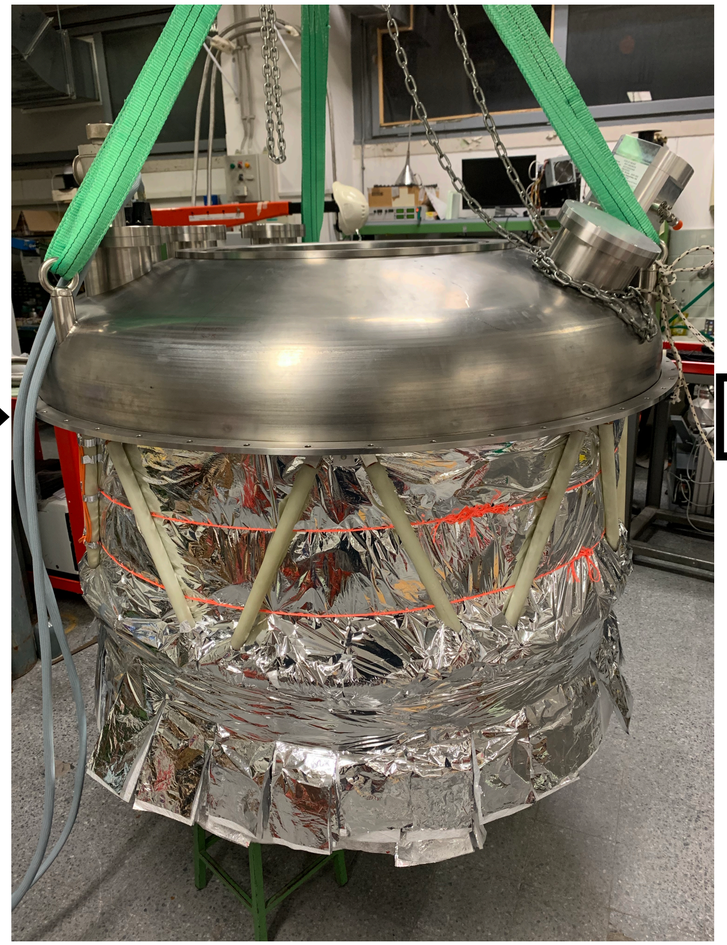


Cryogenic facility

The development of the cryogenic facility required lot of months and lot of effort (many people involved).

Assembly test

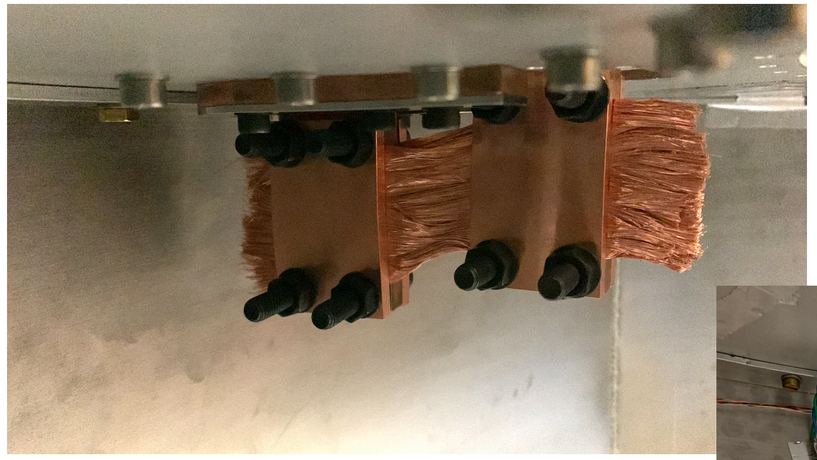
Multi-layer insulation



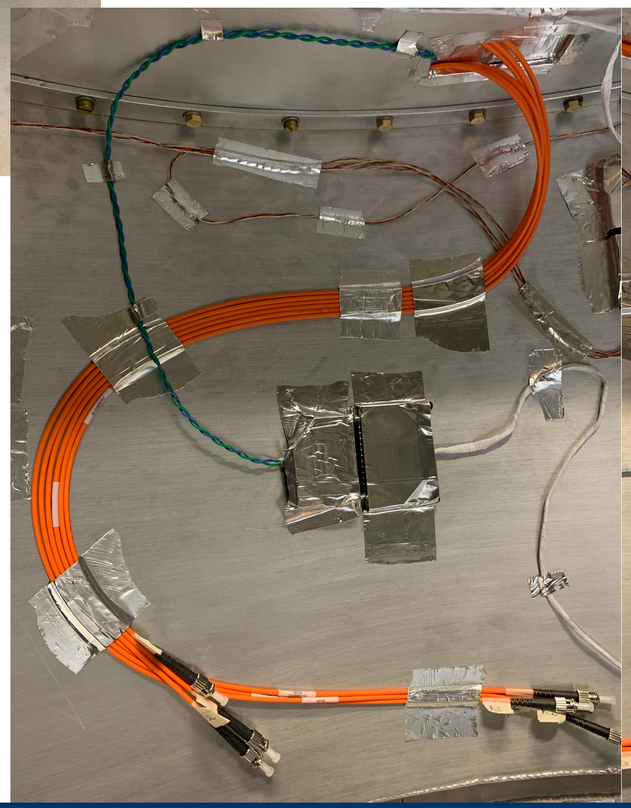
Ready to cooldown

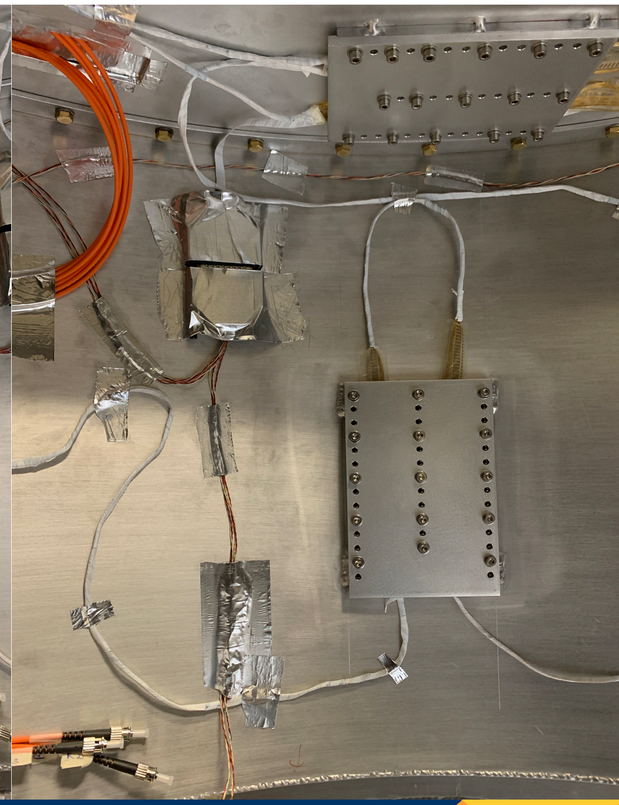
Cryogenic facility

Thermal straps

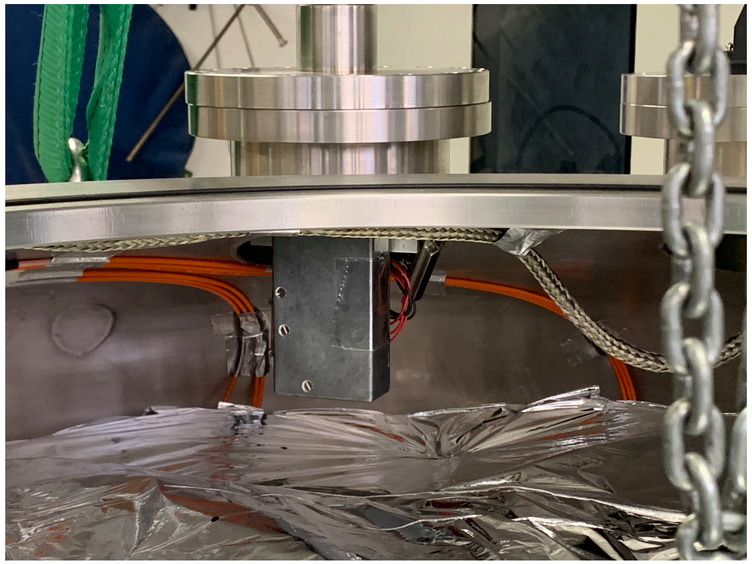


2nd stage sensors wiring





Encoder readout electronics

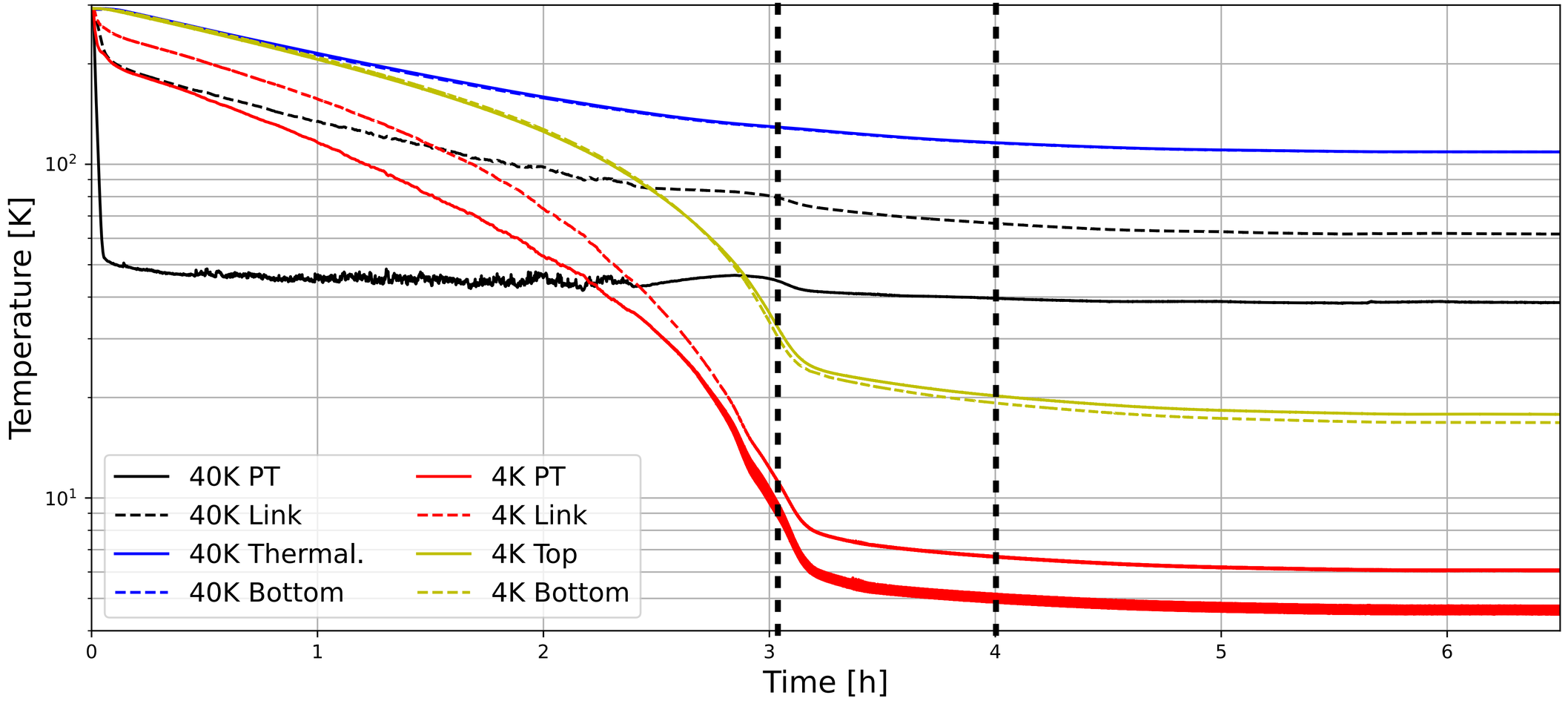


Cryogenic facility - 1st cooldown

Only the temperature sensors and the harness were installed

~ 72h
< 30K

~ 96h
< 20K

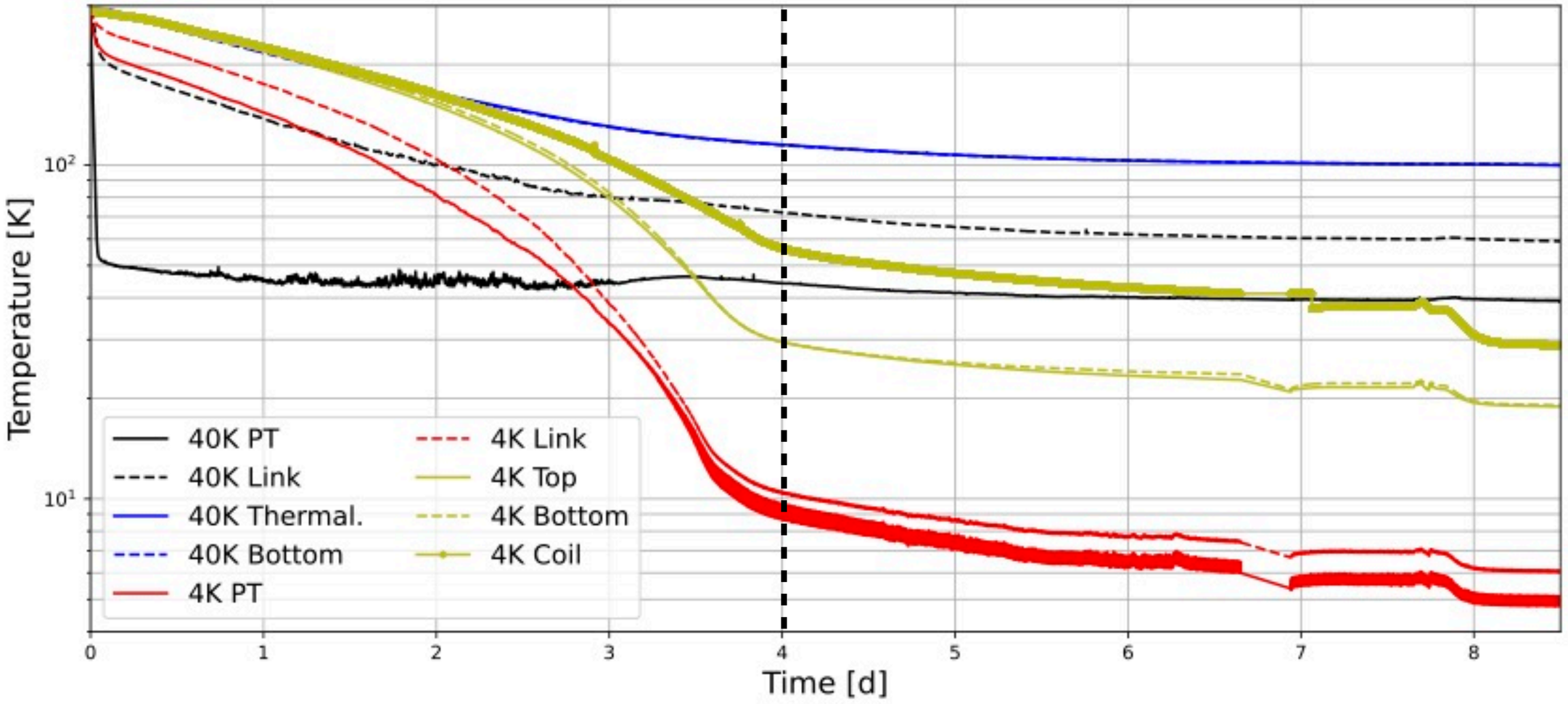


Cryogenic facility - 2nd cooldown

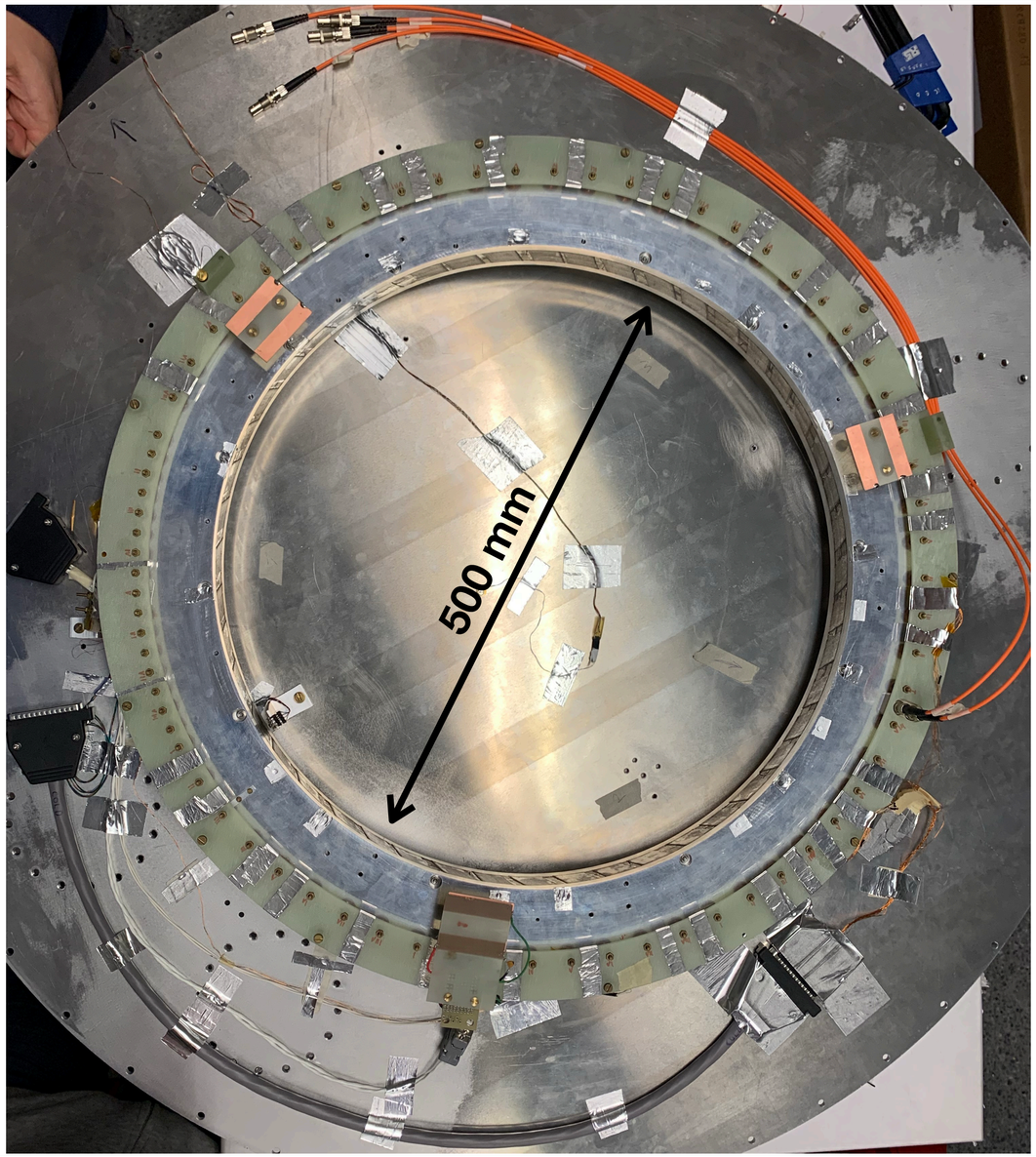
PMU fully installed

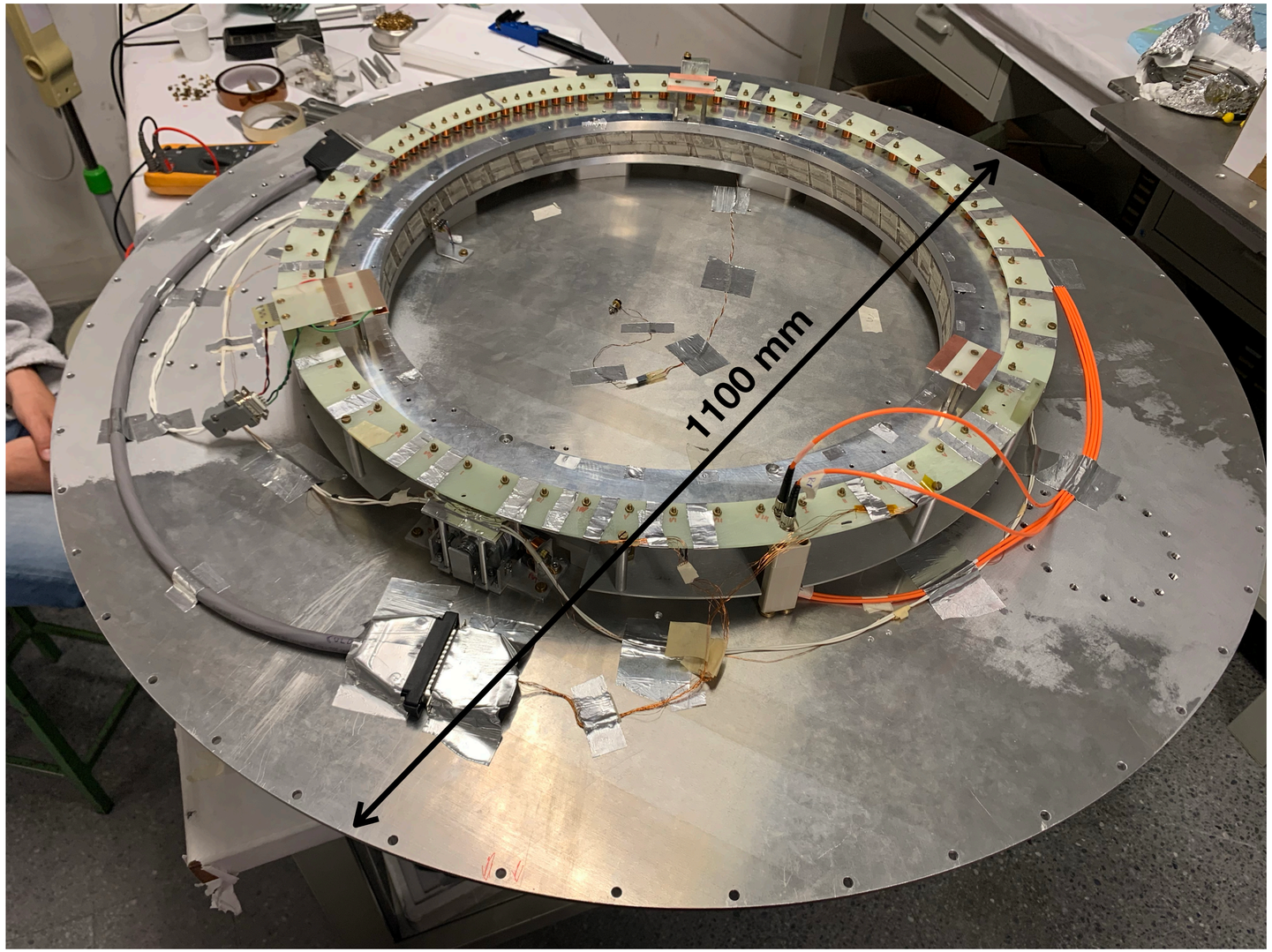
~ 96h

< 30K

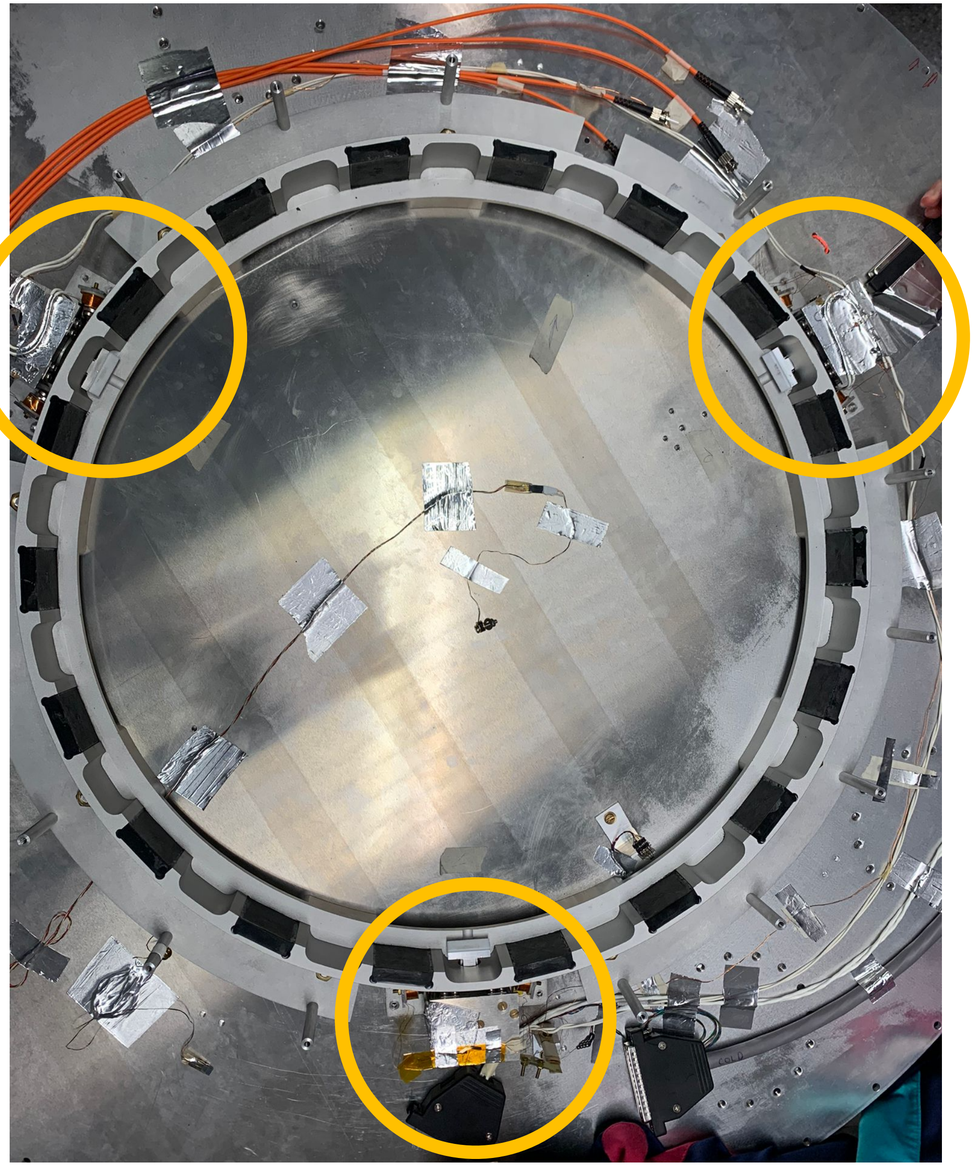


PMU - Overview



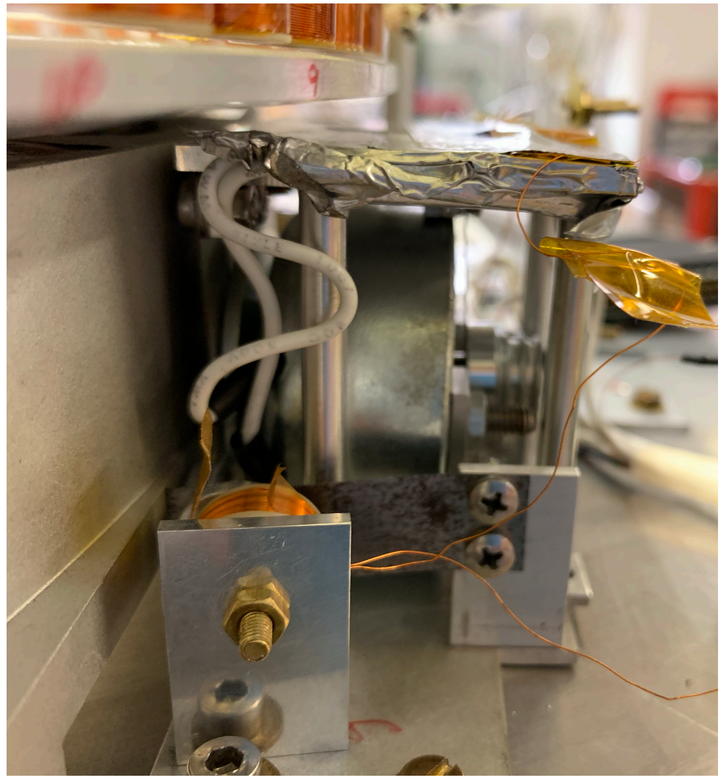


PMU - Overview

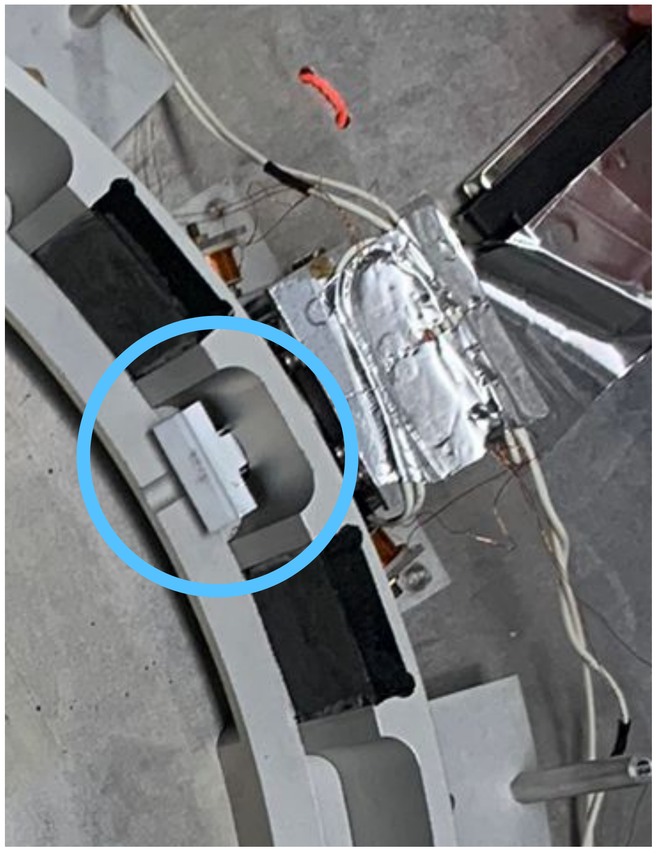


Superconductive bearing —> 18 YBCO bulks
(transition temperature ~90K)

3x Clamp / Release system



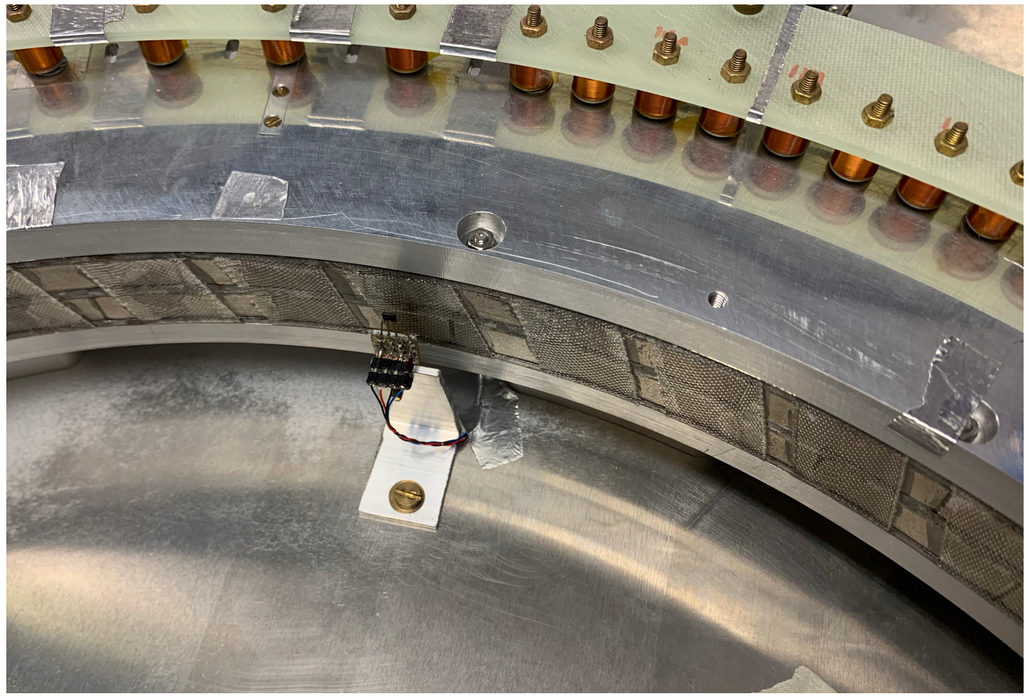
Teflon head



PMU - Overview

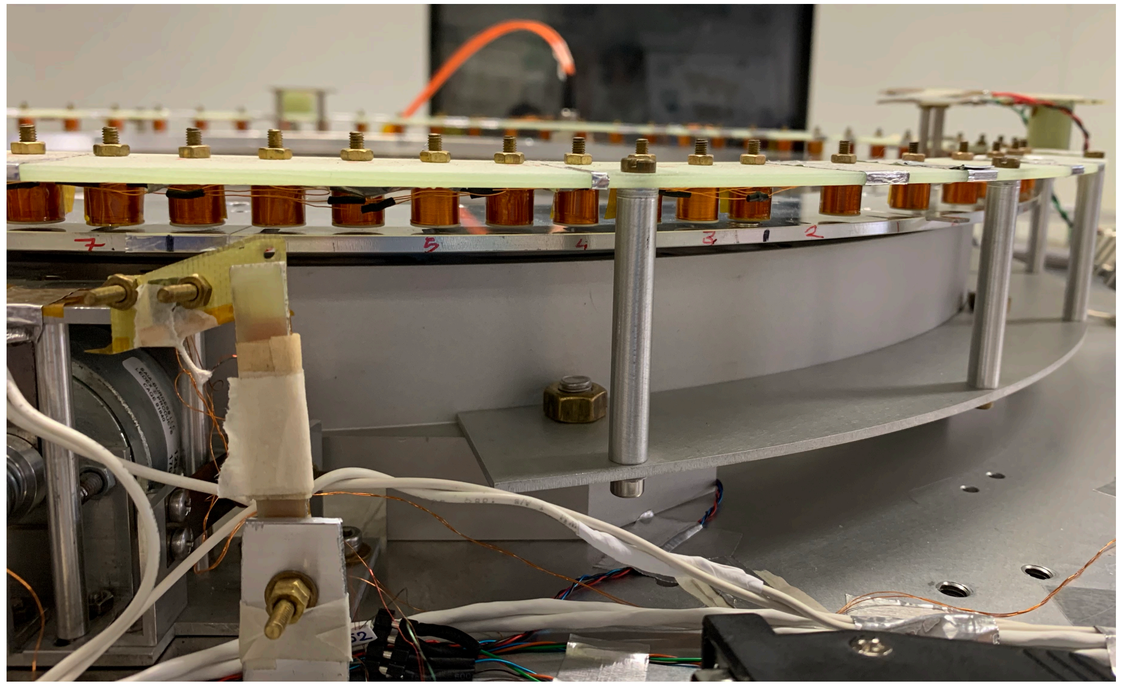
Rotor

NdFeB permanent magnet
(2 segmented rings, 32 sectors each)



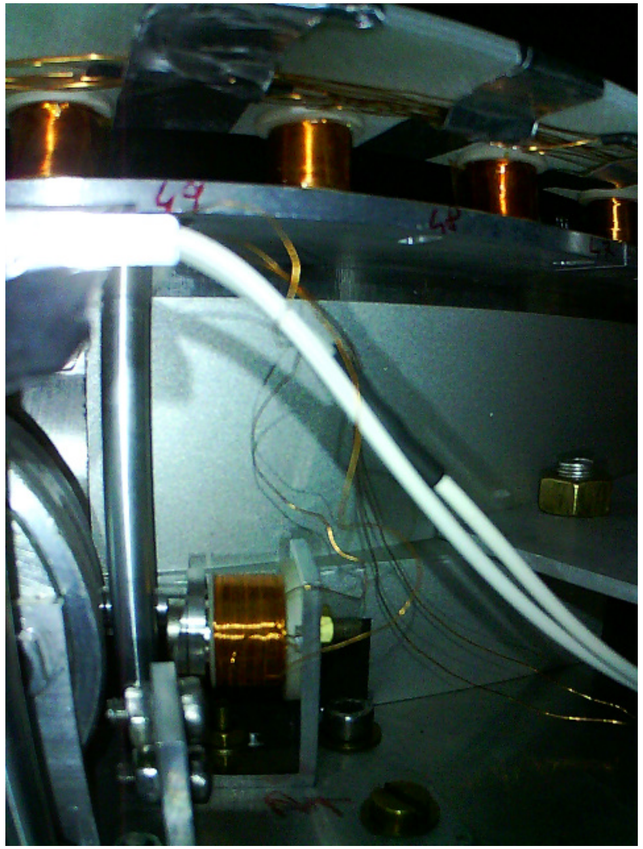
Motor

64 coils (8-phase) + 8 coils (start)
8 magnets

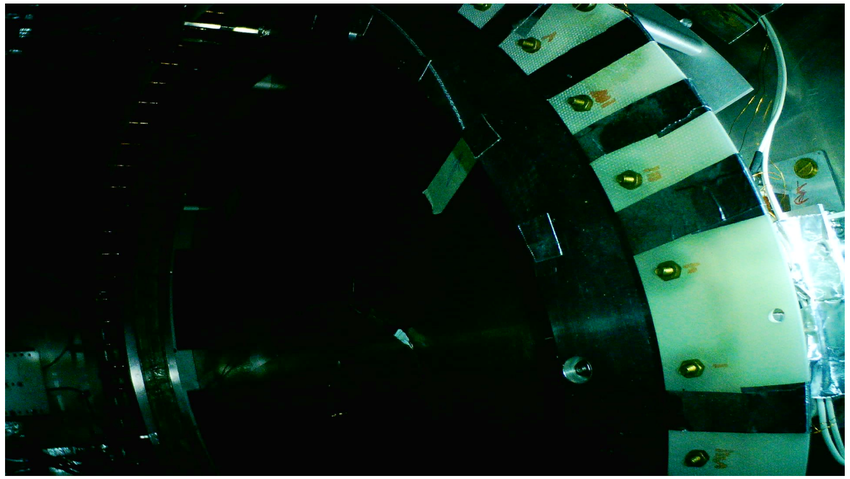


PMU - Webcams

2 “cryogenic” webcams.
The webcams are attached to the 1st stage and are looking inside the 2nd stage volume.



~1W load for each webcam
(180 mA at 5 VDC)



Summary

The modulator was released and moved.

Magnetic levitation fully demonstrated!

Lot of work has to be done during the next months:

- Spin the rotor and stabilize the rotation
- Measure the friction
- Optimize the PMU configuration
- Characterize the HWP properties (temperature, emissivities, …)