Attività di R&D criogeniche in Sezione

Istituto Nazionale di Fisica Nucleare

Retreat di Sezione

Assisi, 13-15 Giugno 2022

Angelo Cruciani

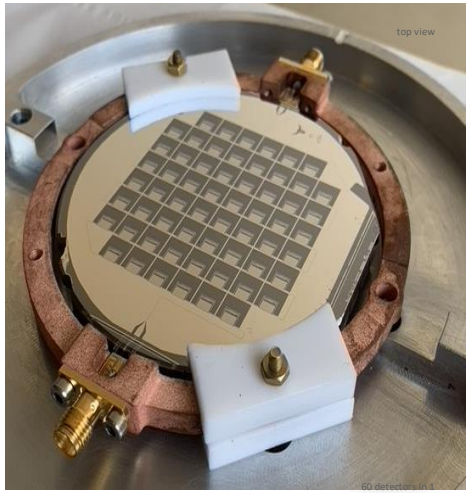
Cryogenics @ RM1

QUBIC

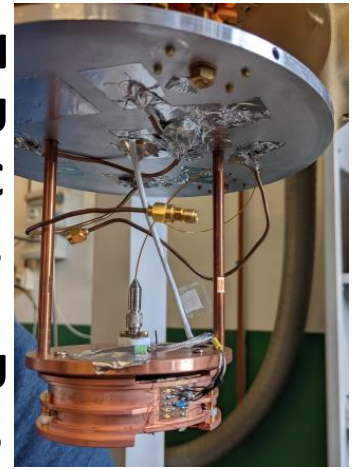
CUPID

ARCHIMEDES

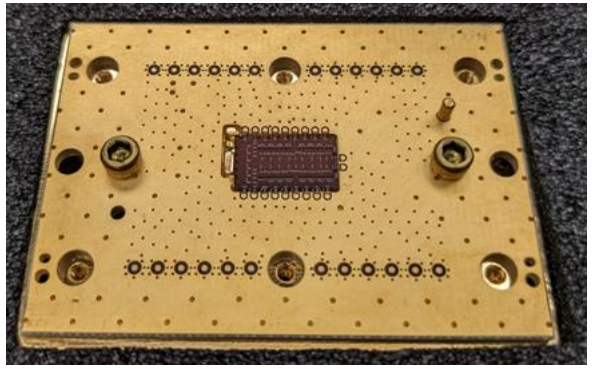
BULLKID



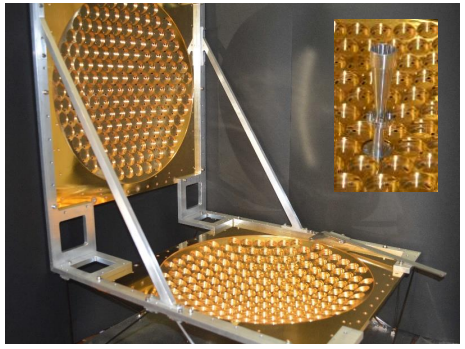
NUCLEUS

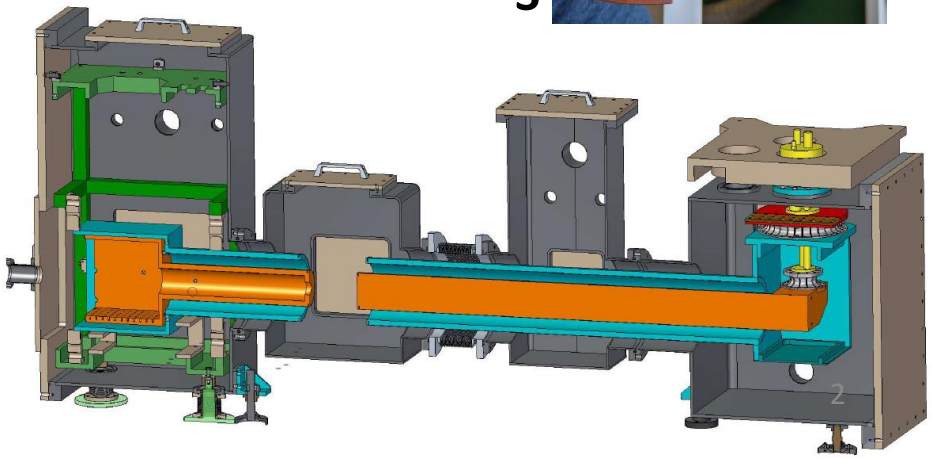


SQMS



LSPE/LITEBIRD





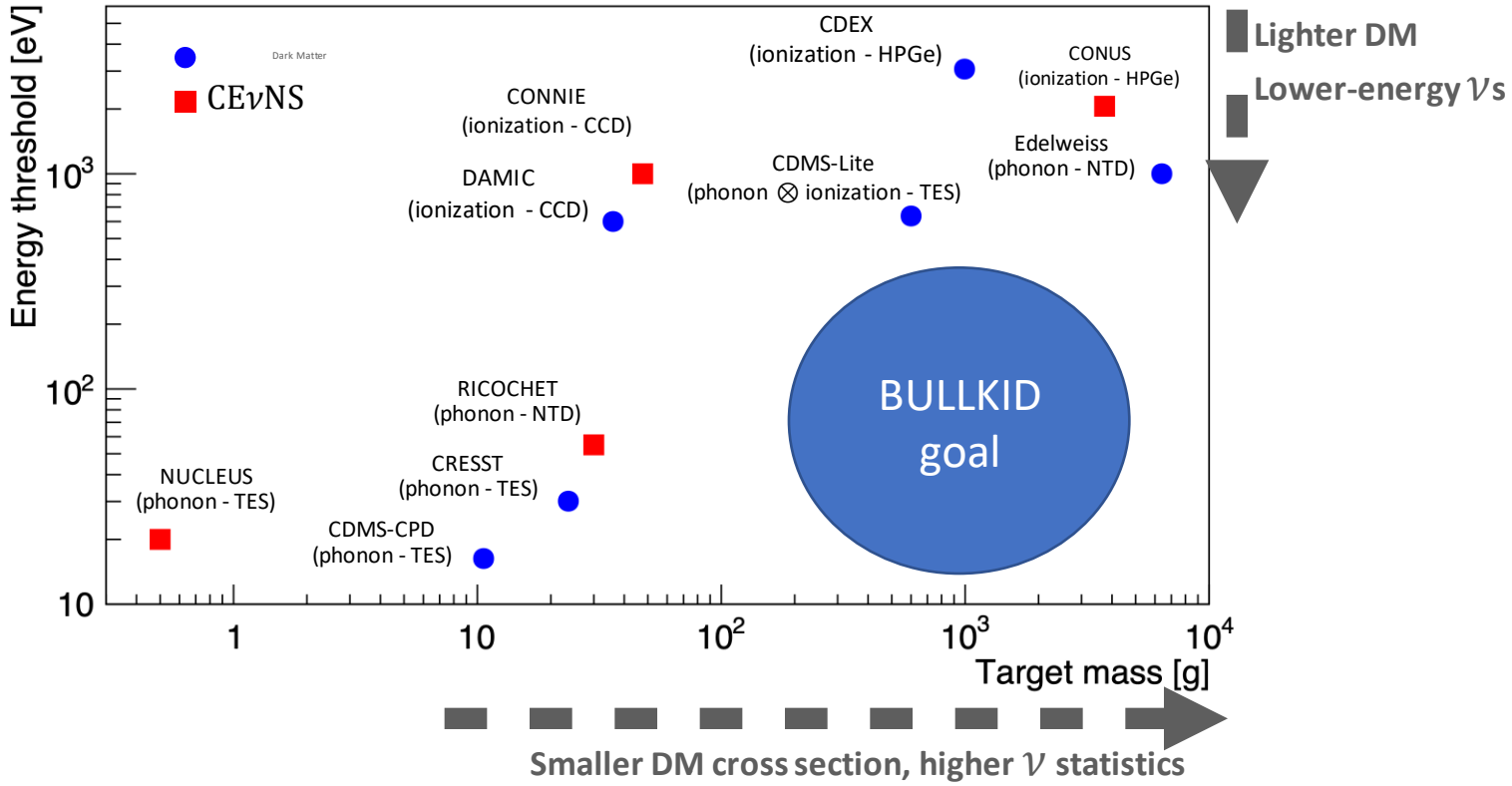
ET

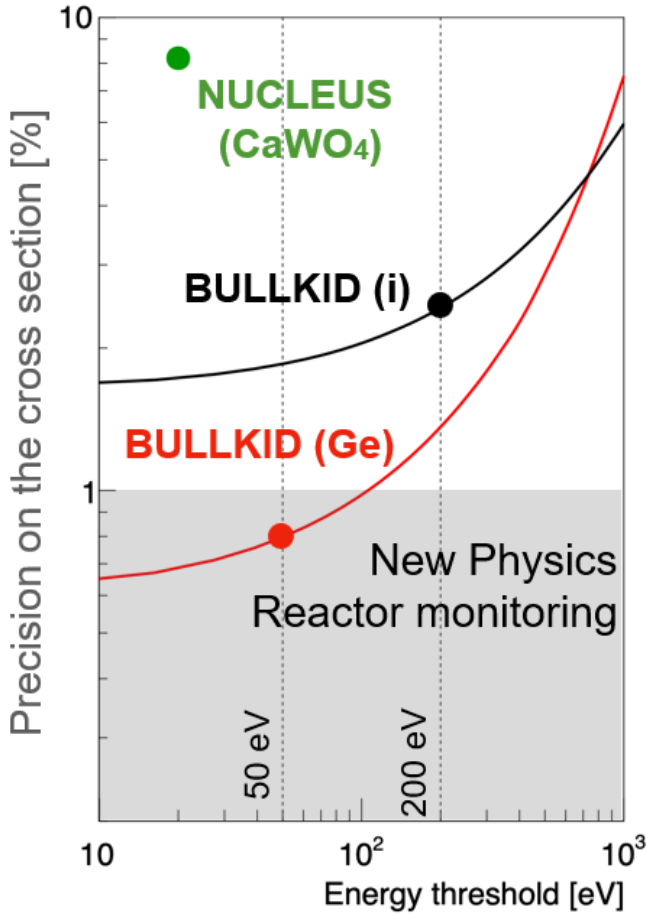
Facilities

- **Laboratorio rivelatori criogenici** (*M. Vignati*)
  Principali attività: Nucleus (CSN2), Bullkid (CSN 5)
- **Ultra Lab** (*F. Bellini*)
  Principali attività: CUPID (CSN 2), SQMS (CSN 5)
- **Experimental Cosmology Group** *(P. de Bernardis)*
  Principali attività INFN: QUBIC, LSPE e LITEBIRD (CSN 2)
- **Laboratorio Rivelatori di onde gravitazionali** (*E. Majorana*)
  Principali attività: ET e Archimedes (CSN 2)

BULLKID motivation

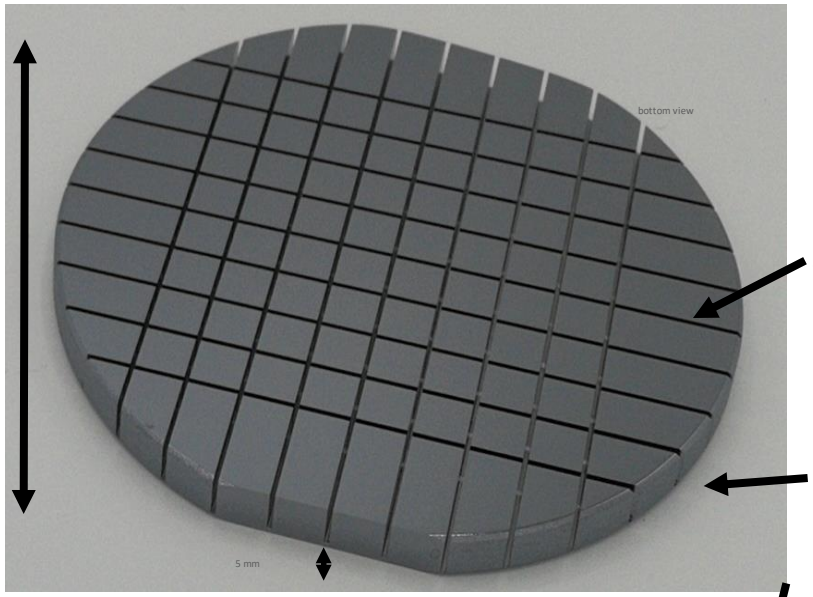
BULLKID aims to develop a KIDs based detector able to combine large mass and low threshold for CNS and light WIMPs



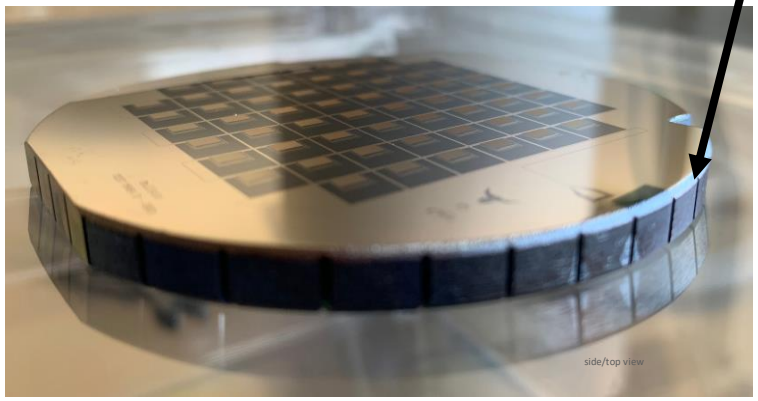


Credits: M. Vignati

BULLKID detector



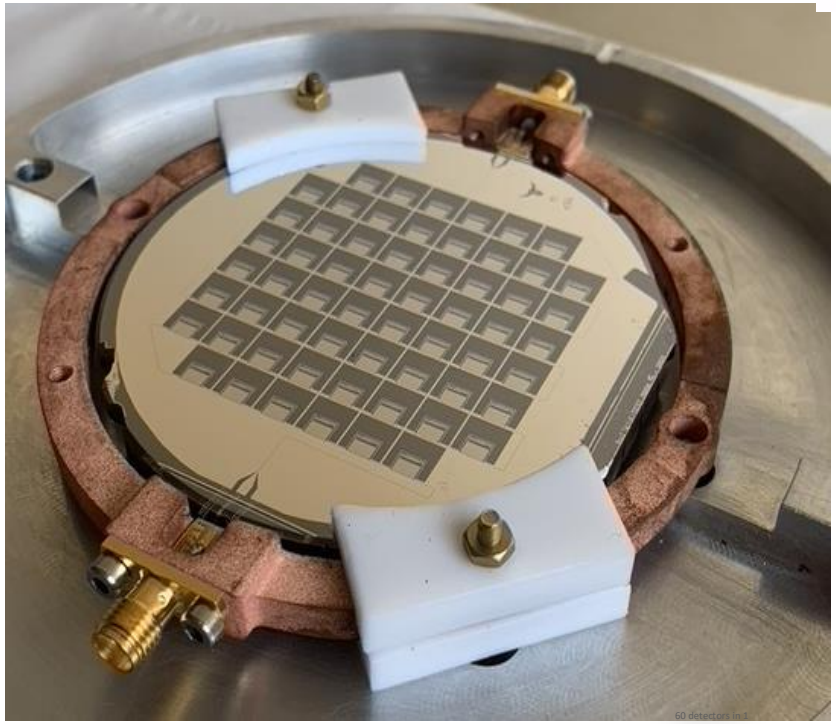
2. lithography of multiplexed KID array



4.5 mm deep grooves
- 5.5 mm pitch
- chemical etching

0.5 mm thick surface:
- holds the structure
- hosts the KIDs

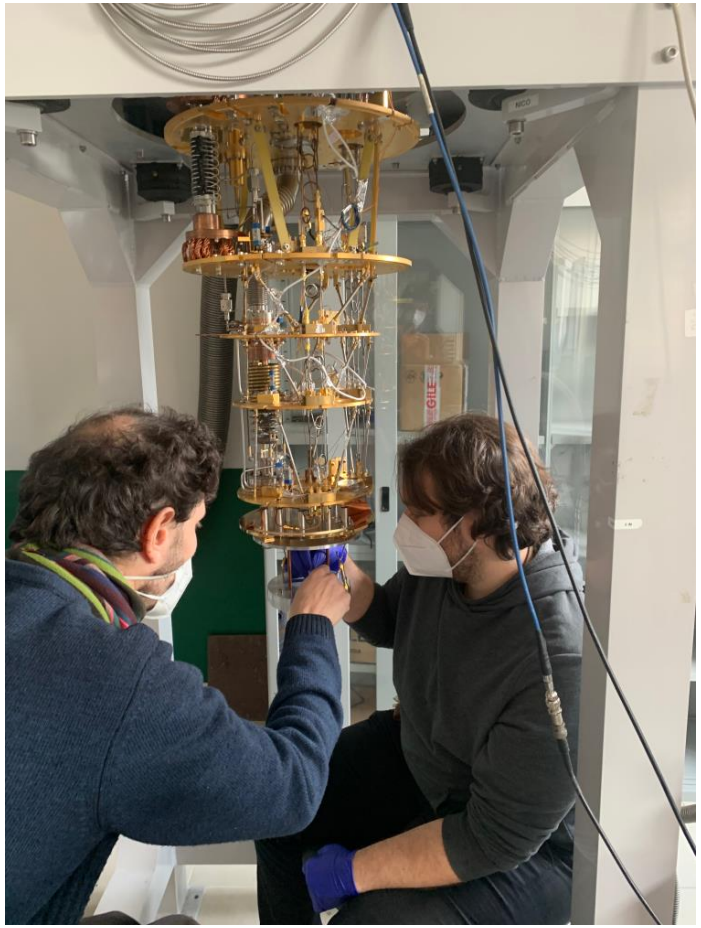
KID array
- 60 nm aluminum film
- 60 KIDs lithography

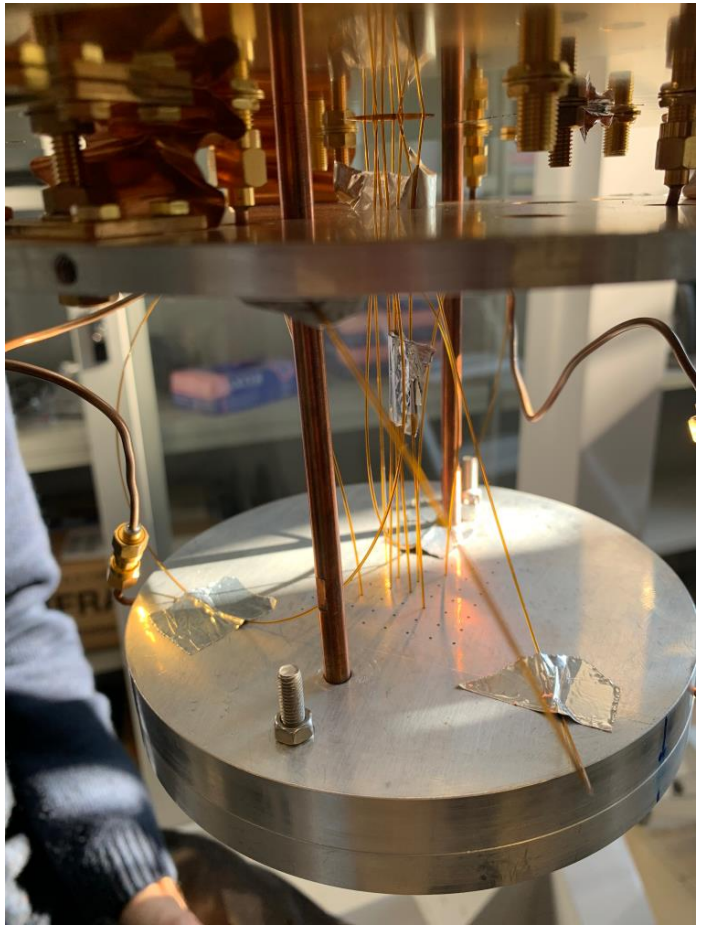


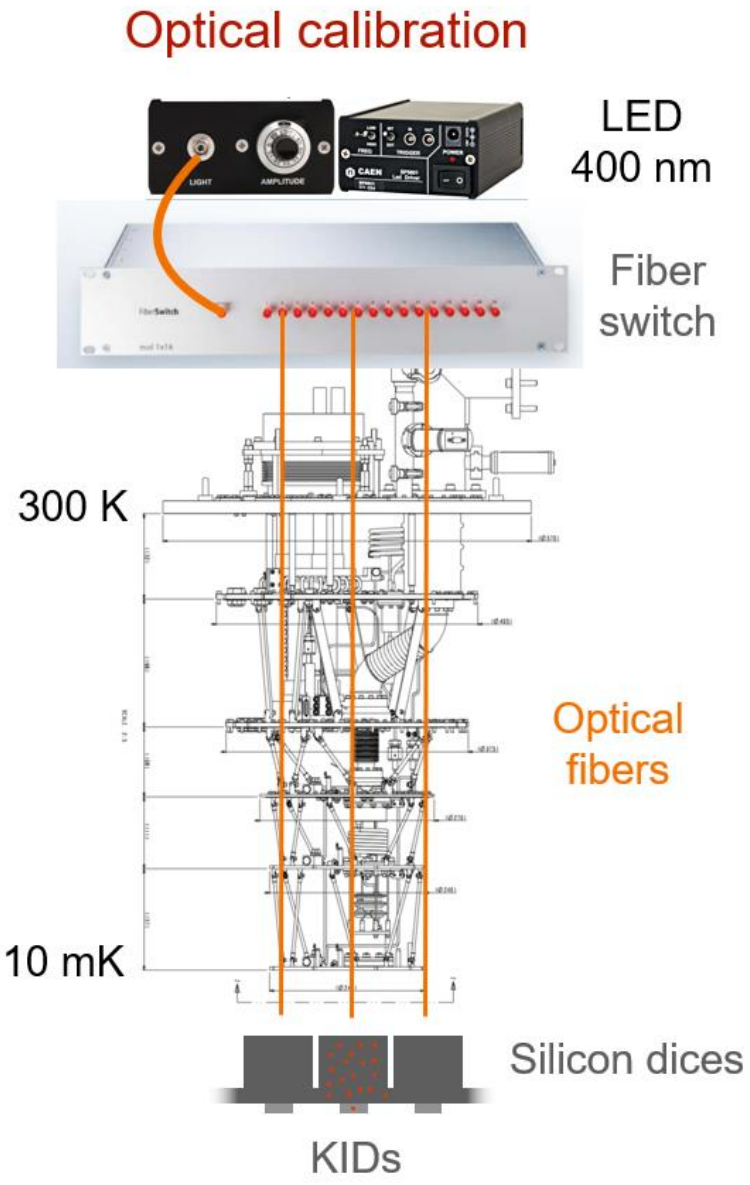
60 dices 0.3 g each
1 readout line

Design and assembly
- 3D-printed Cu holder
- Aluminum case

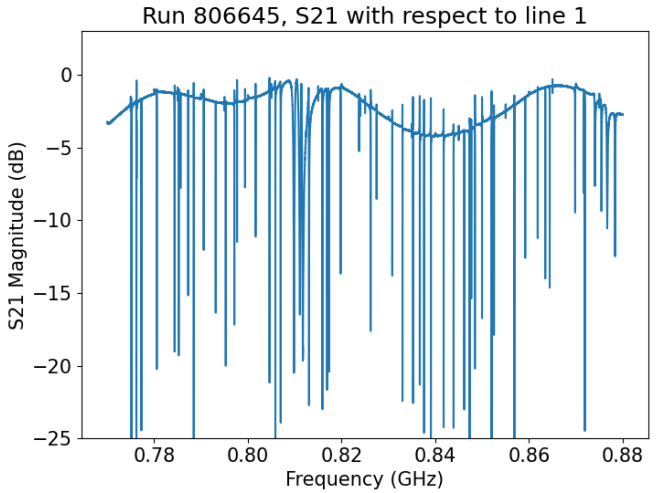
Experimenal setup

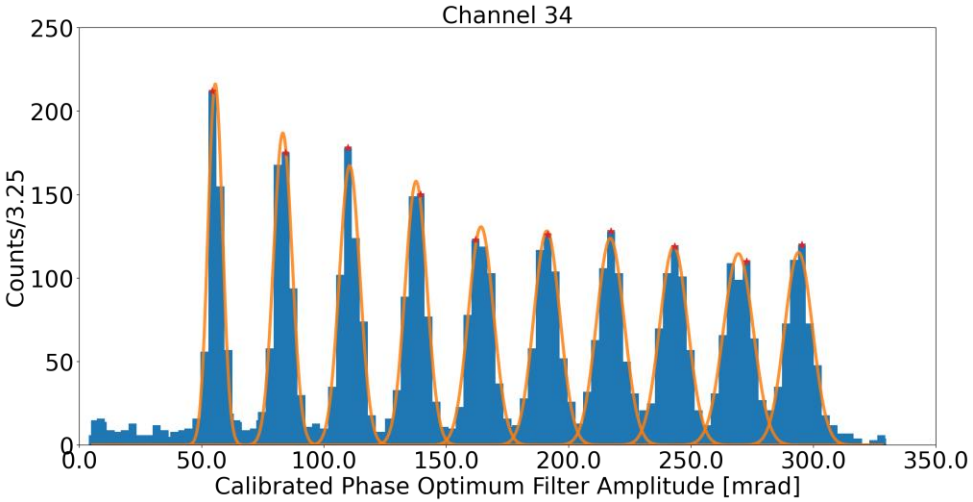


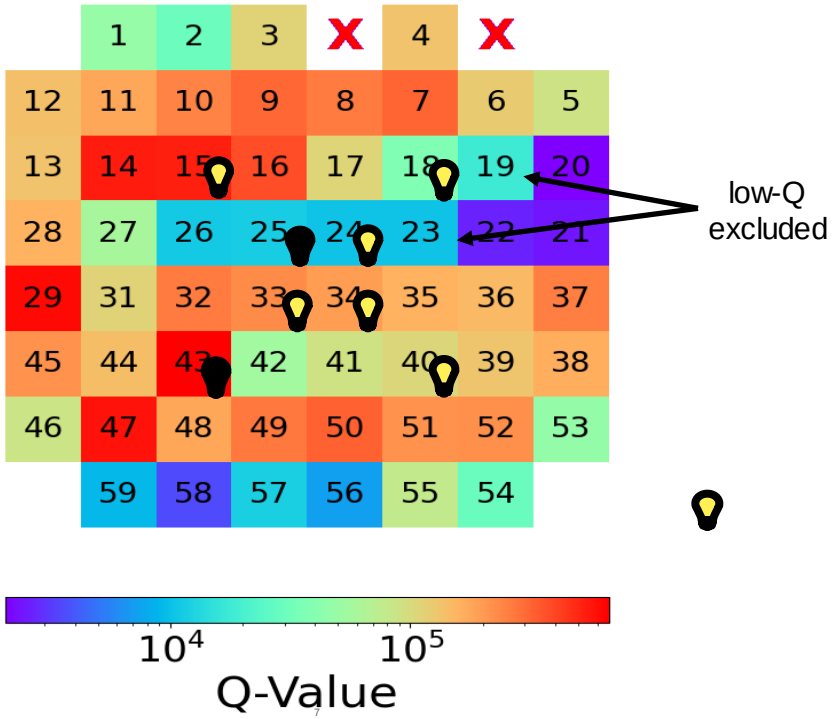




Preliminary results







KID	σ_0 [mrad]	σ_0 [eV]
15	3.4±0.1	*25.0±1.2*
33	1.78±0.03	*22.9±0.8*
34	1.14±0.02	*25.4±0.5*
40	0.73±0.01	*20.6±0.9*

optical cal

threshold ~120 *eV*

Current cool-down:
cross-check with x-ray calibration, light on other channels

Effects of radioactivity on QUBITs

Ideal Qubit: strongly coupled to other qubit (*entanglement*), but decoupled from the world (*coherence*)

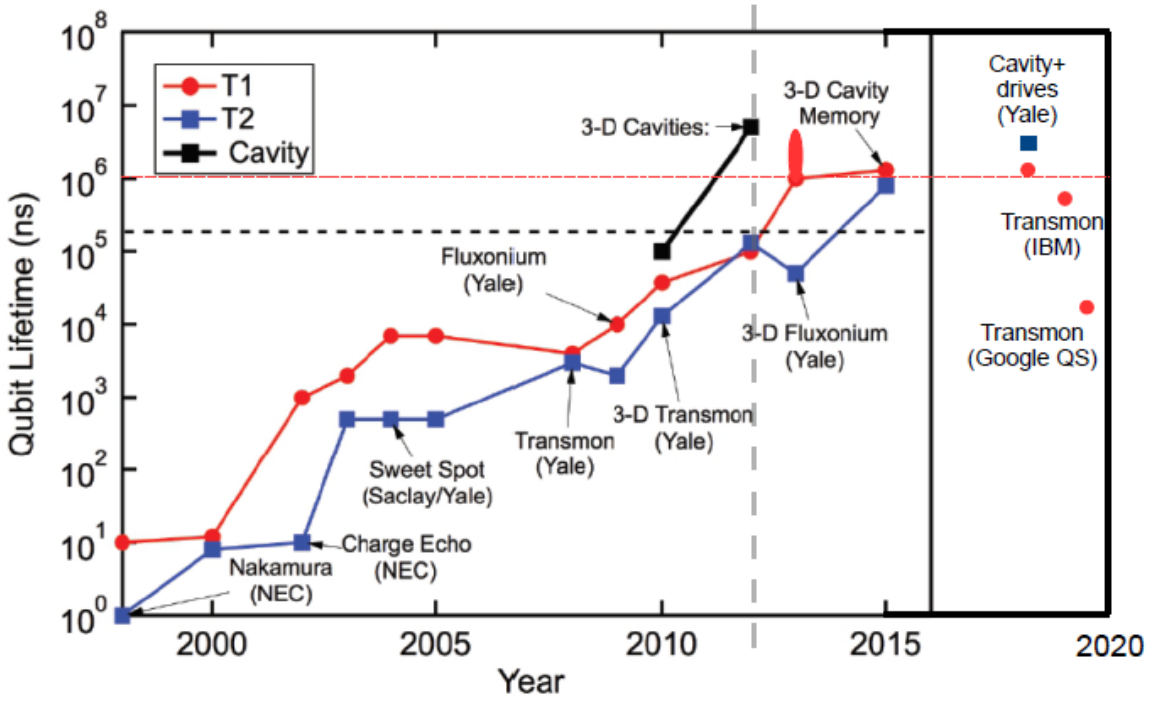
Cohernce: the longer, the better → goal: scale of ms

Many sources of decoherence under investigation, mainly related to TLS noise and excess of QPs

Possible mecanism for excess of QPs:

- Infrared detection
- Thermal/mechanical stress
- ….

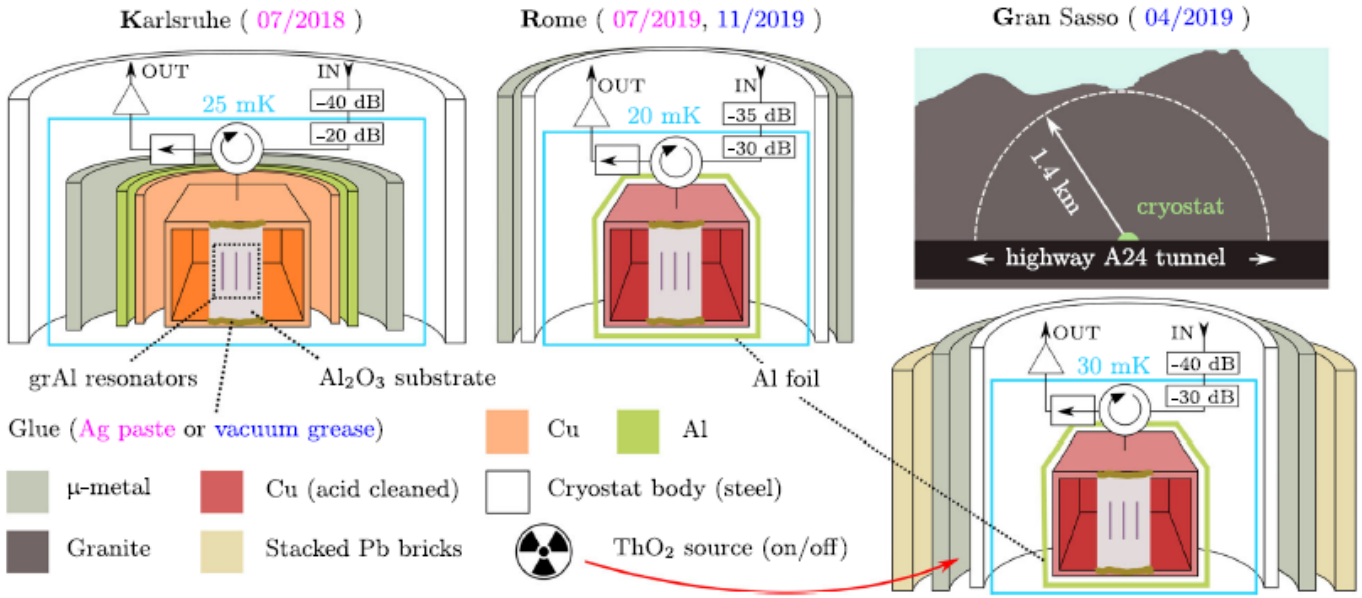
Cosmic Rays and enviromental radioactivity

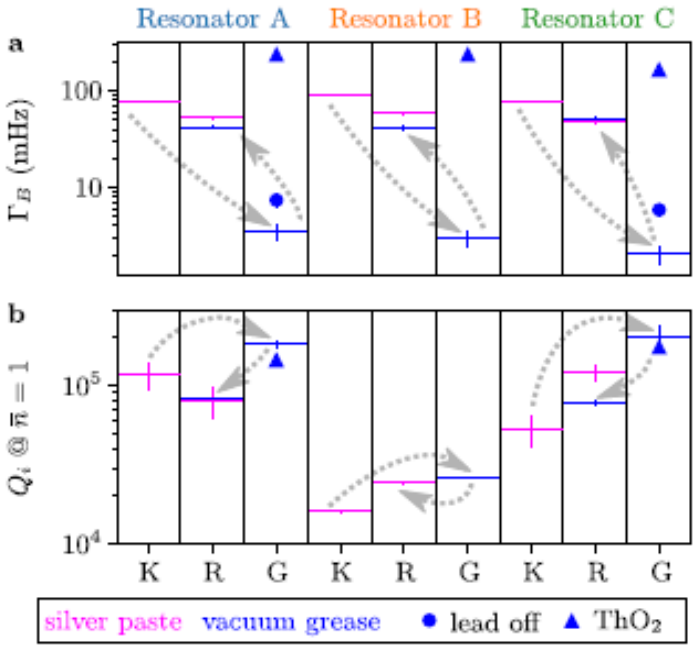


original plot (up to 2012): M.H. Devoret & R.J. Schoelkopf, Science **339**, 1169 (2013)
extension (up to 2015): M. Reagor, PhD thesis (Yale)

Effects of radioactivity on QUBITs

Tests of superconducting resonator similar to fluxonium qubits in 3 different sites to assess effects of Cosmic particles and natural radioactivity

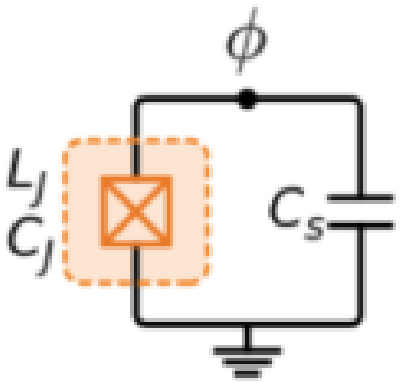


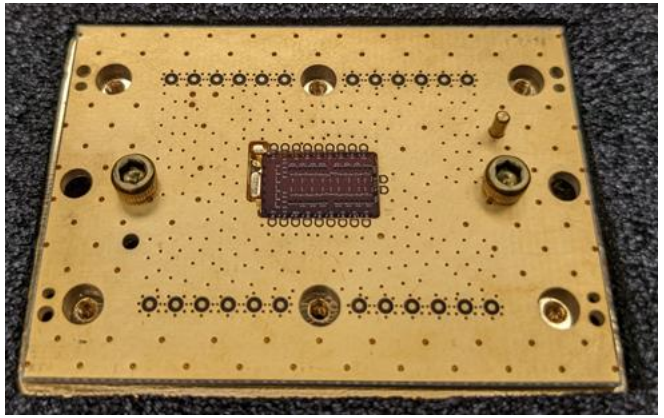


- Cardani et al., Nature Communications 2021
- Gusenkova et al., Appl. Phys. Lett. 2022.

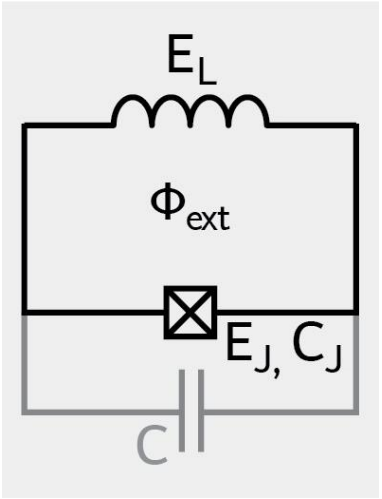
Next measurements

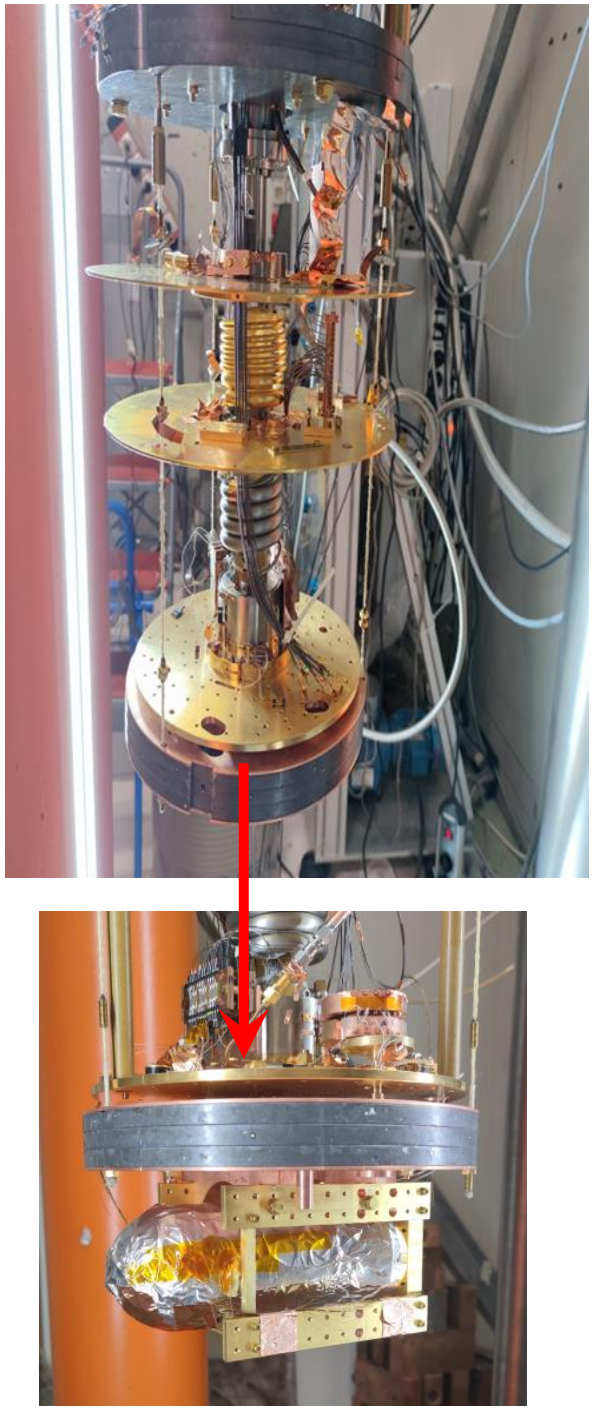
- Test of Transmon QUBITs (summer) in the context of SQMS





- Test of Fluxonium QUBITs (before the end of the year)





- LNGS radiopure facility equipped for QUBIT characterization

- RF electronics operating at a noise temperature of around 2 K

Pulse Tube Cooling Station prototype for Rome1 Test Facility

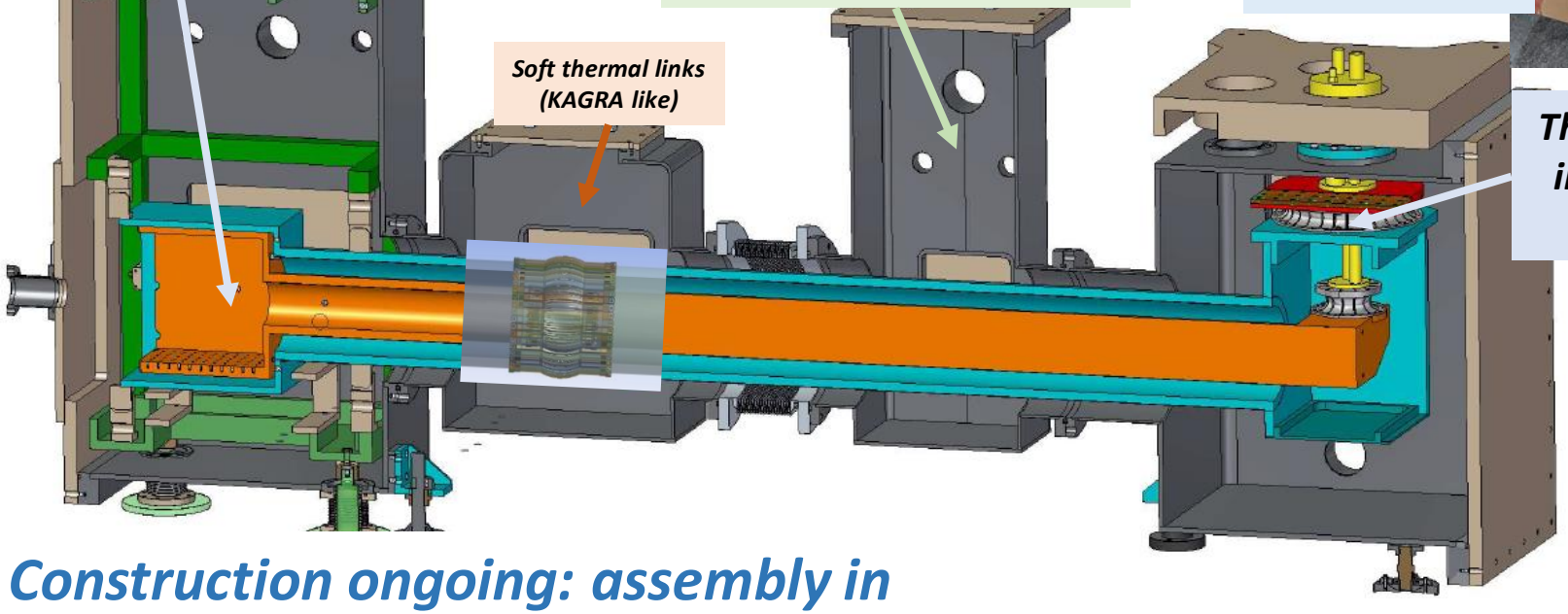
Cryogenic test Chamber:
- Dissipation Measurements,
- Residual vibrations,
- Sensing and actuators testing

Cryogenic cooling lines suspensions (GW Interferometers technology)

2 Pulse Tubes Cryomech PT400 (1.8 W @ 4.2 K) in counterphase

Soft thermal links (KAGRA like)

Thermal links in Al5N and Al6N



Construction ongoing: assembly in summer 2022

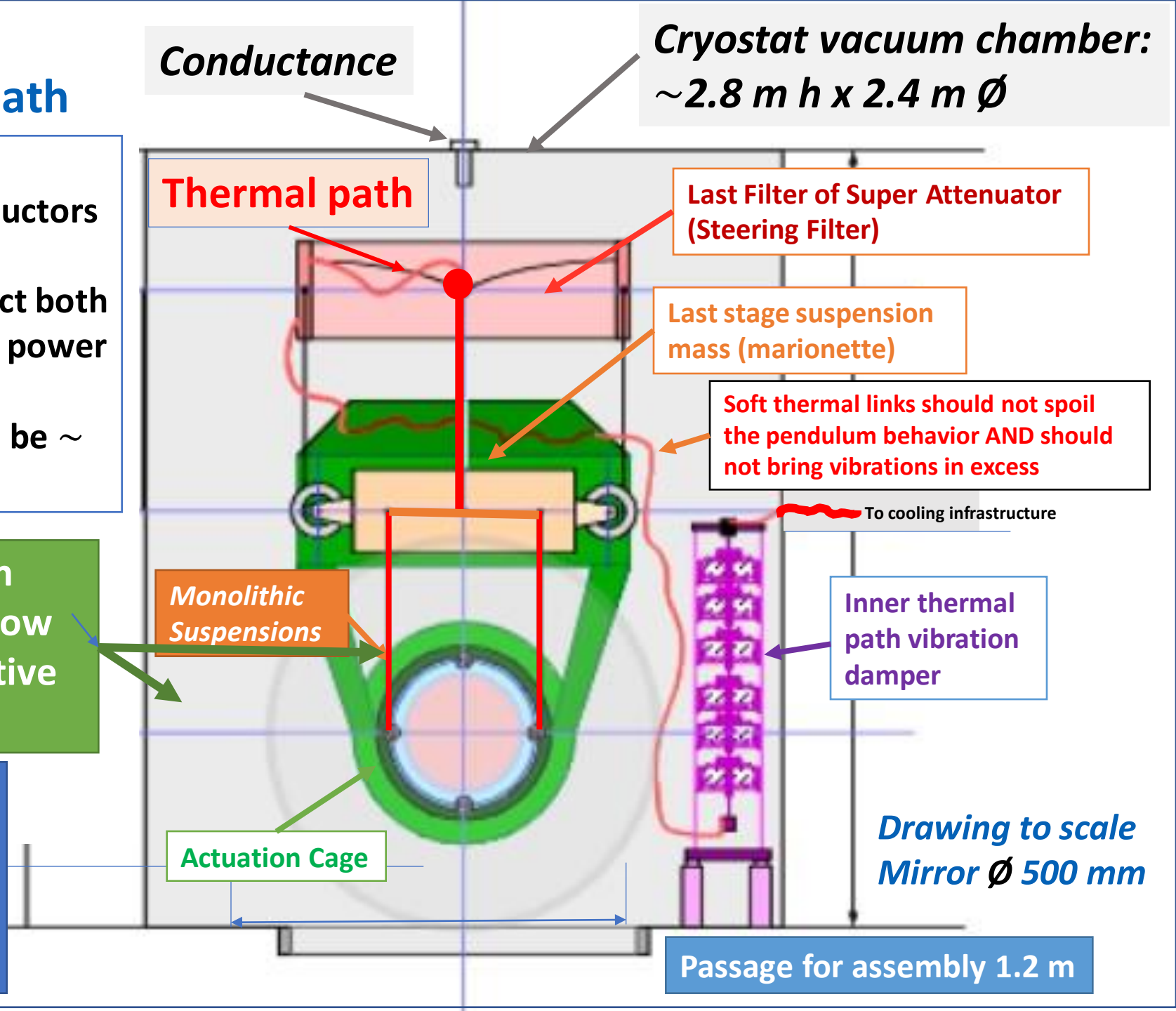
Design by Antonio Marra, Franco Bronzini:

ET-LF Cryo Payload:
A closer look to the thermal path

In order not to spoil thermal noise, suspension wires should be good conductors AND with very low dissipations: e.g. Marionette calbe could be chosen to act both as a suspension element and a cooling power carrier.
In this case, Q of the pendulum should be ~ 10^6

The inner shield and the actuation cage should be at a temperature low enough to have an efficient radiative cooling

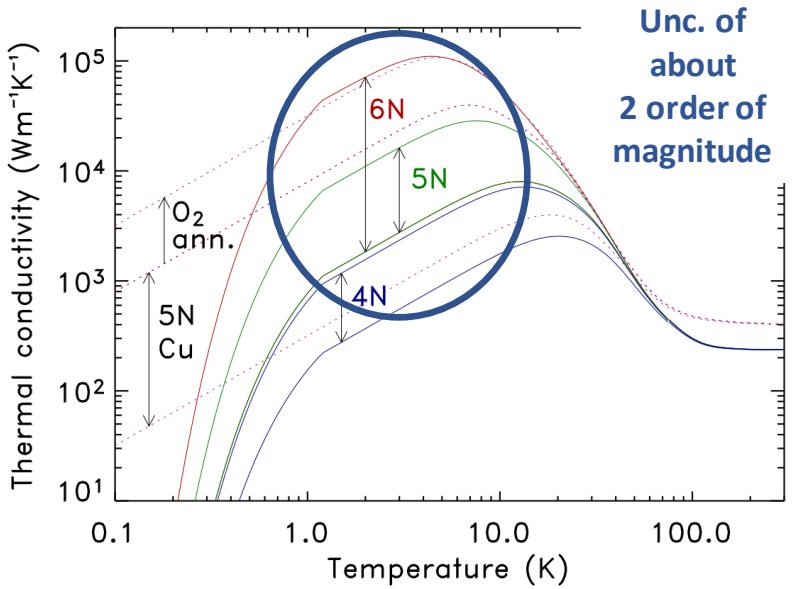
Tradeoff between:
- Thermal noise
- Control Strategies
- Cooling Efficiency

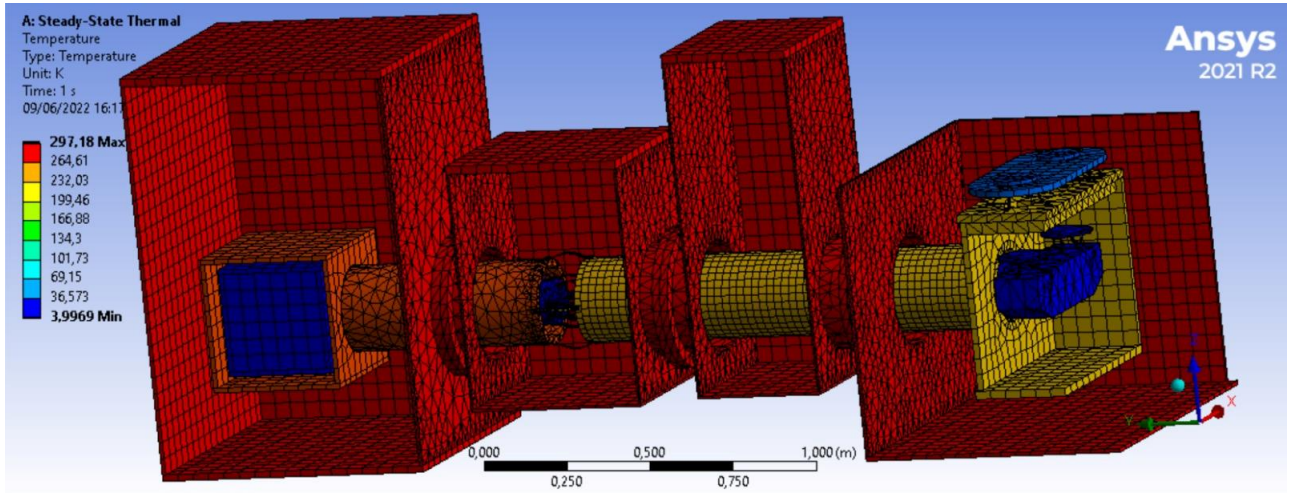


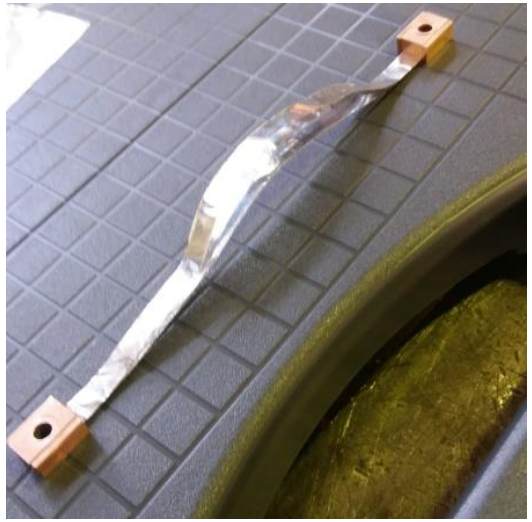
6N Al Heat link studies

The activity includes:

- FEM simulations to assess the needs of the cryogenic system
- Project of very efficient soft thermal links
- Characterisation of Al6N thermal links at cryogenic temperature

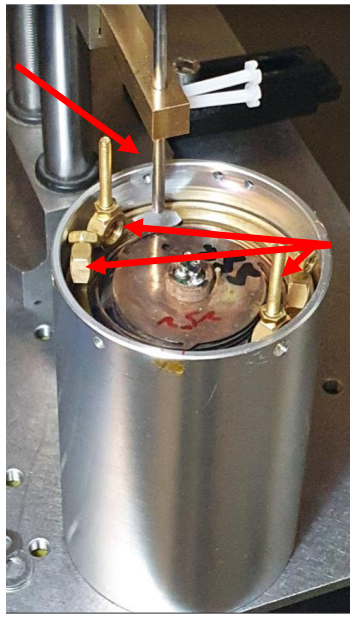




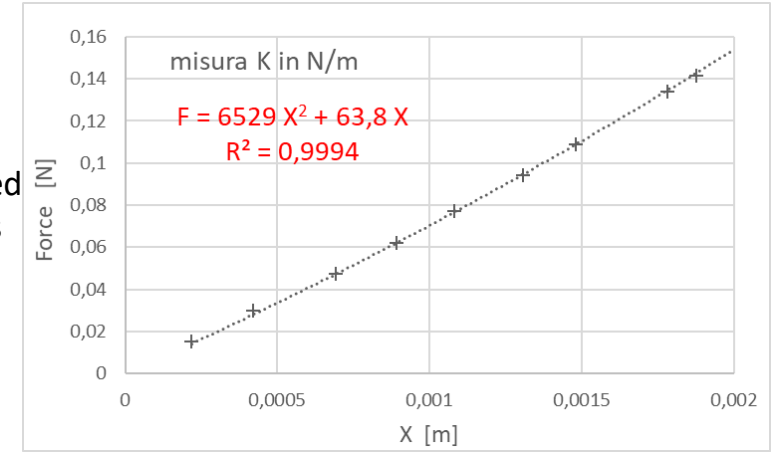


Operation of geophones at low temperature

Bundle fiber

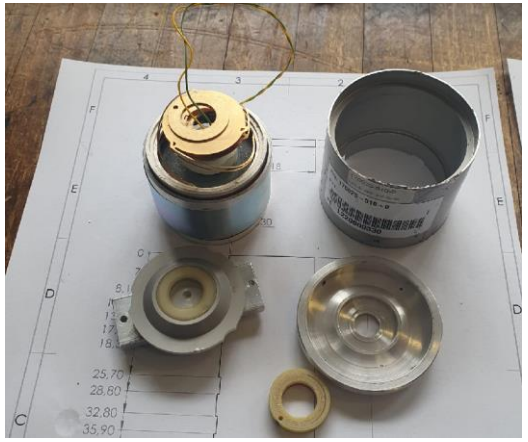


Added “calibrated weights

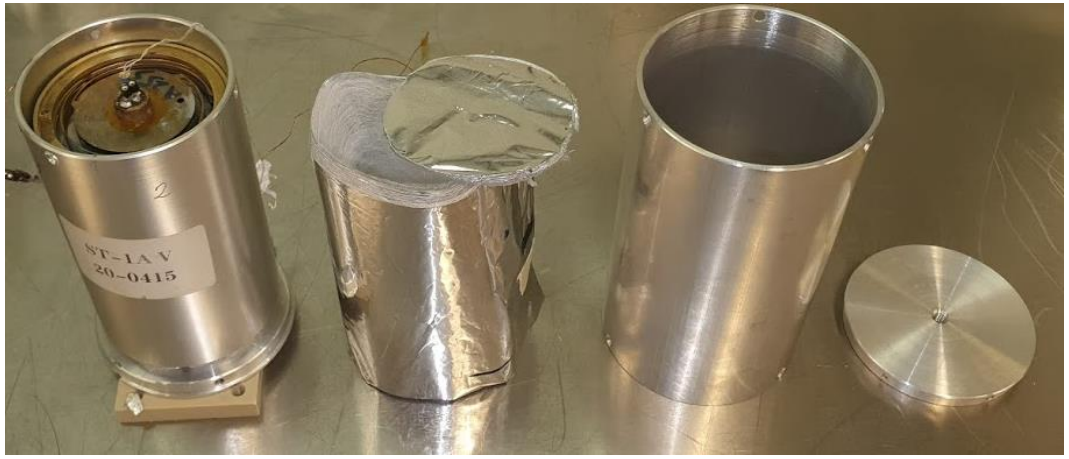


Evaluation of the Elastic Constant K Geo-1

Different weights are “added” on the moving mass. The corresponding displacement Is evaluated by the bundle fiber (calibrated EACH TIME with the micrometer)

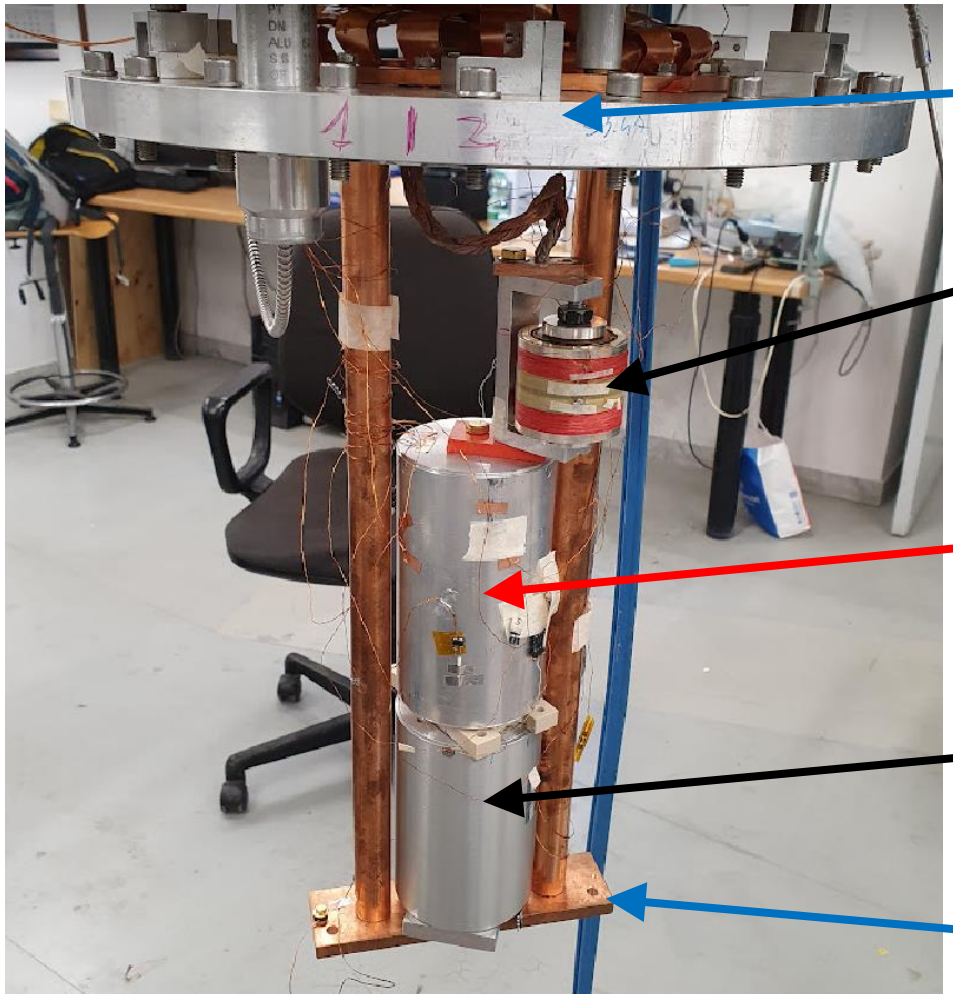


Brand new 2 Hz geophone (1.2 Keuro), modified to operate at low temperature



With (only) 0.8 Watt the geophone works @294 K within a 15 Kelvin cryostat

Calibration in the VFC Cryostat (20-300 K)



≈ 15 Kelvin

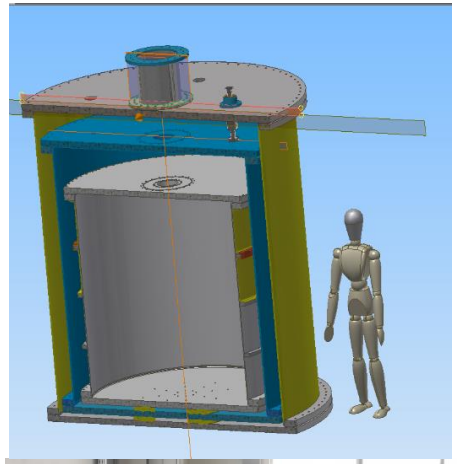
Cold 2-Hz Geophone (to be calibrated @ 20-100 K)

Calibrated Geophone operated @ 294 Kelvin

Cold 1-Hz Geophone (to be calibrated @ 20-160 K)

≈ 15 Kelvin

Costruzione del criostato di Archimedes



Trasportata presso il laboratorio di superficie SARGRAV in Sardegna all'inizio di quest'anno

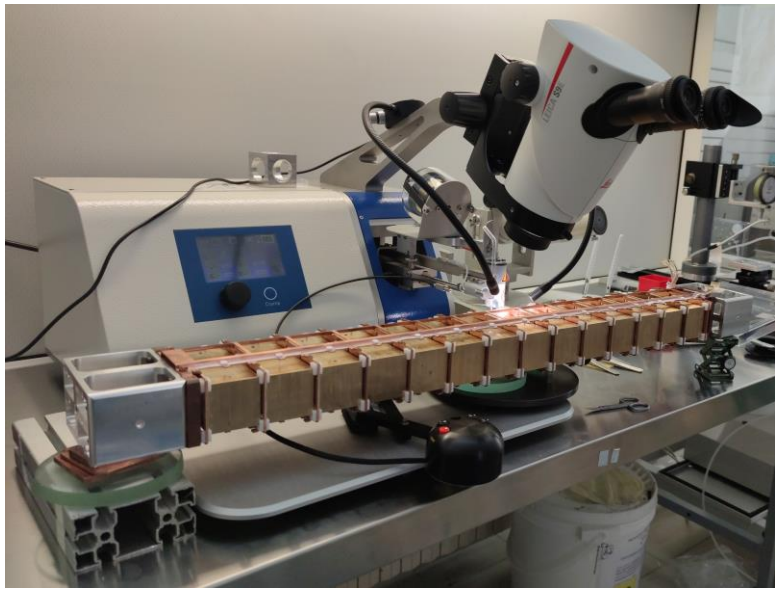
Seconda camera in costruzione

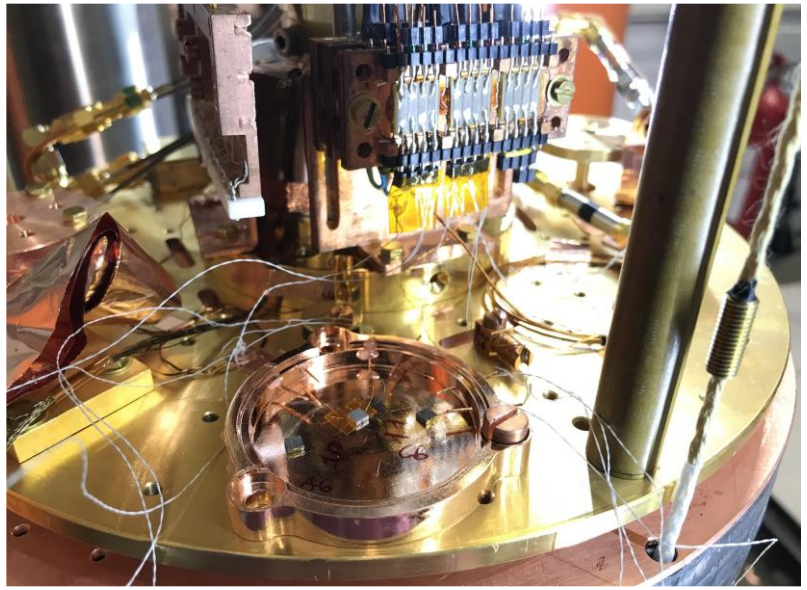
Avviata gara per la terza camera

Camera sperimentale, collaudata nel luglio 2020

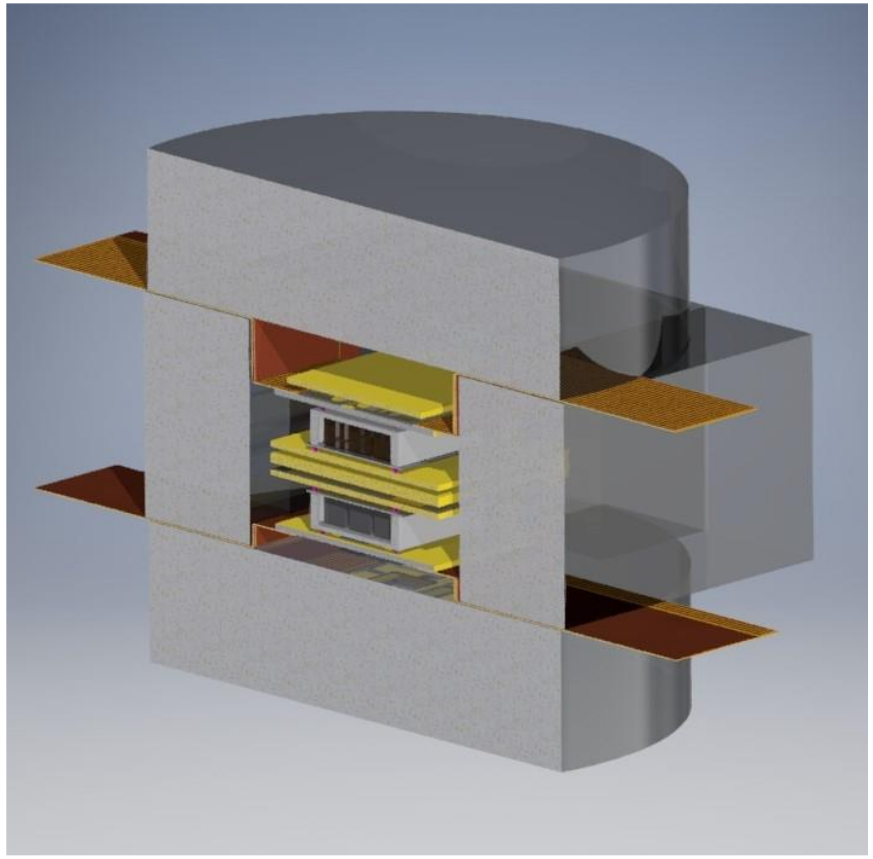

Camera sperimentale, collaudata nel luglio 2020
ARCHIMEDES

CUPID: Assembly, bonding and NTD characterisation

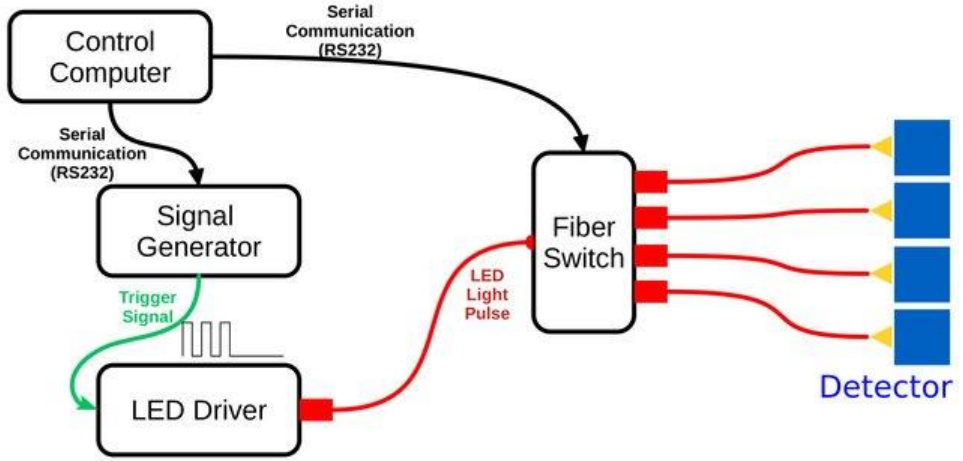


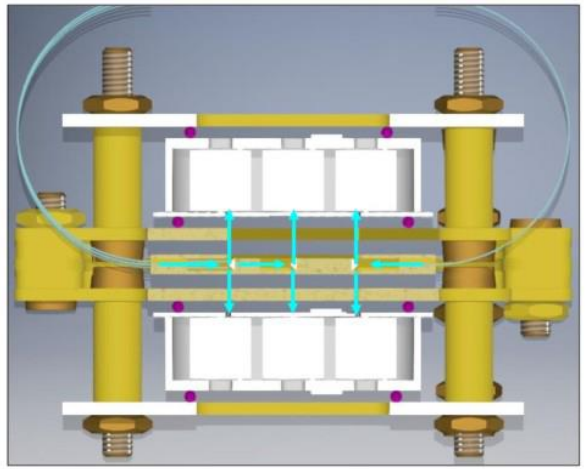


Nucleus: calibration of the experiment



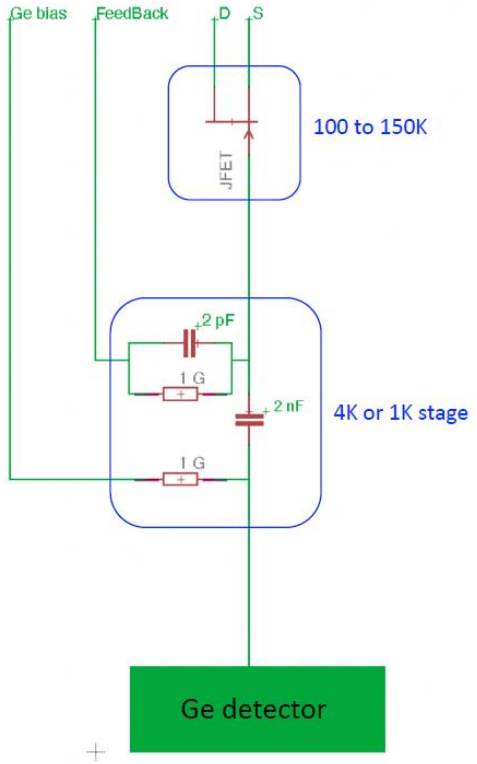
The core of the experiment is represented by an array of 18 low threshold TES detectors sorrounded by an inner veto (Si) and a Outer Veto (Ge)

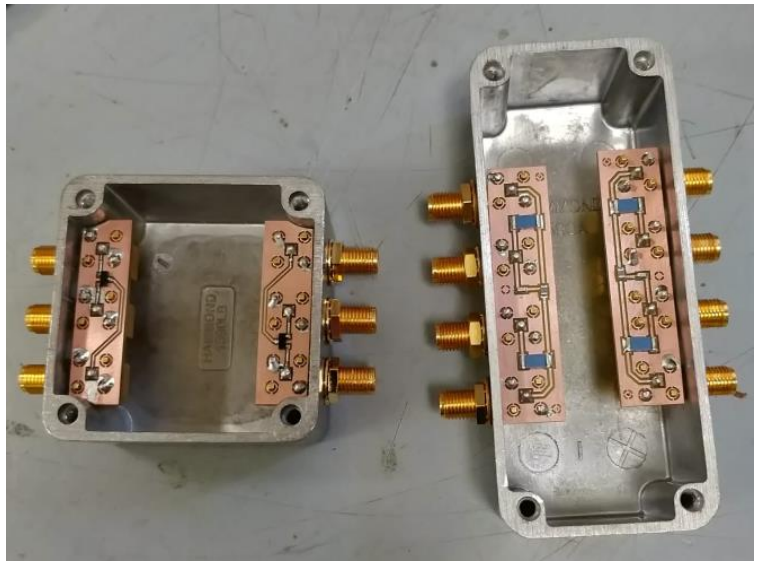




The calibration is made by means of a system of optical fibers, coupled to a fast lamp at RT

Nucleus: Germanium Outer Veto detector assembly and charcterisation





- Operation of a Germanium detector @ 10 mK with a threshold energy around 1 keV
- Prototyping of the read-out electronics for the direct application in the experiment

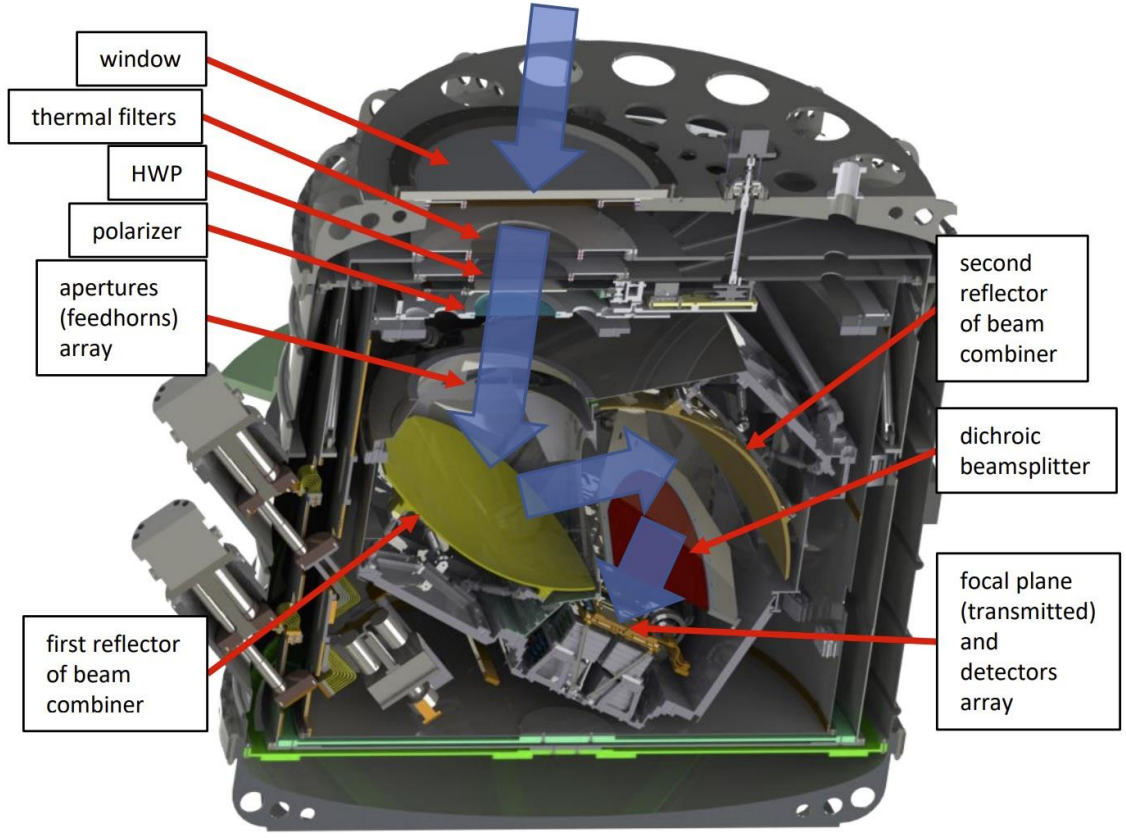
nucleus EXPERIMENT

Polarimeter development, Cryogenic System and Detectors calibration for the QUBIC experiment

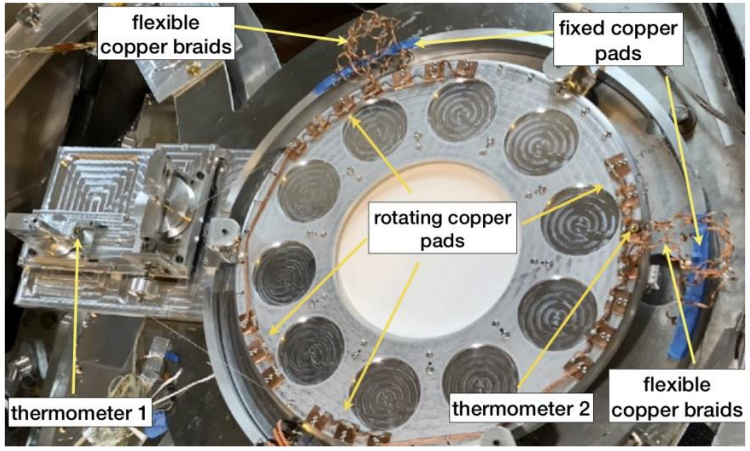
- The QUBIC experiment aims at measuring CMB polarization from the 5200 m Alto Chorillo (Argentinian Andes), with an innovative bolometric interferometer.
- International experiment lead by J.C. Hamilton (APC Paris).
- Important INFN contributions (Coordinator S. Masi, Roma1):
- Cryogenic system and cryogenic polarization modulator (Roma1), feedhorns array (Mi), beam combiner and optical switches array (MiB), data analysis (Roma2).
- Currently in Salta for last calibrations. Shipment to the observation site by September/october 2022.

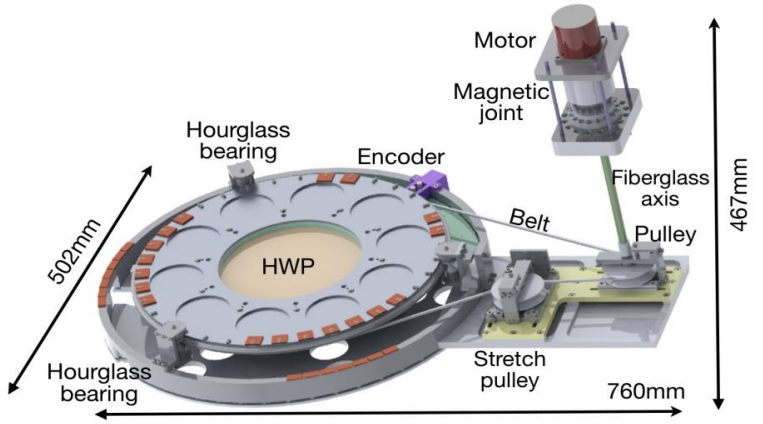
Polarimeter development, Cryogenic System and Detectors calibration for the QUBIC experiment

• The cryogenic system is described in depth in Masi et al. JCAP 04 038 (2022).



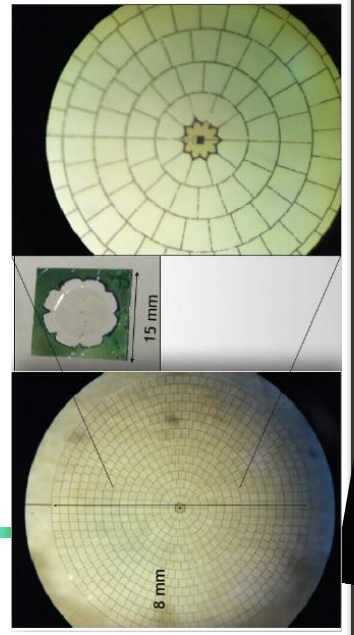
• The cryogenic polarization modulator is described in depth in D'Alessandro et al. JCAP 04 039 (2022).

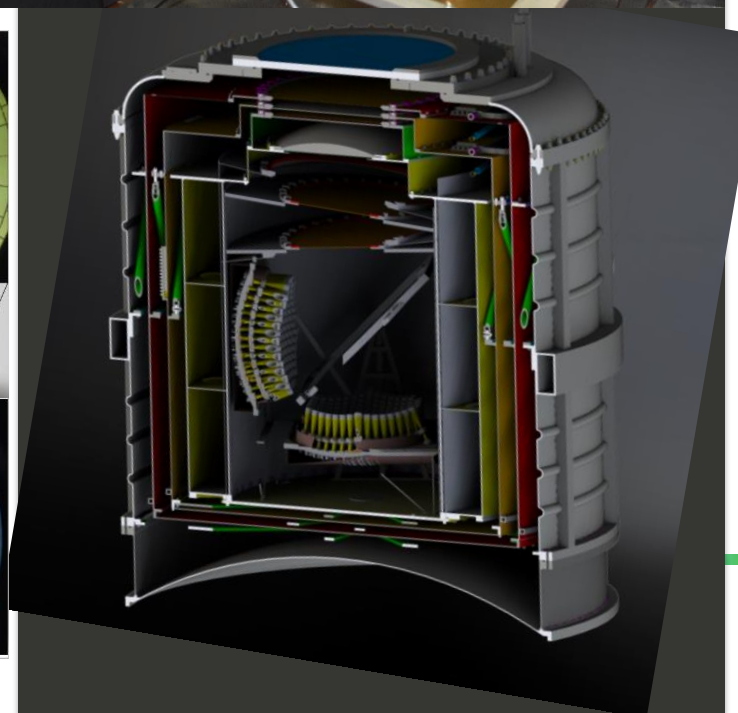




Polarimeter development, Detectors Integration and Calibration for LSPE-SWIPE

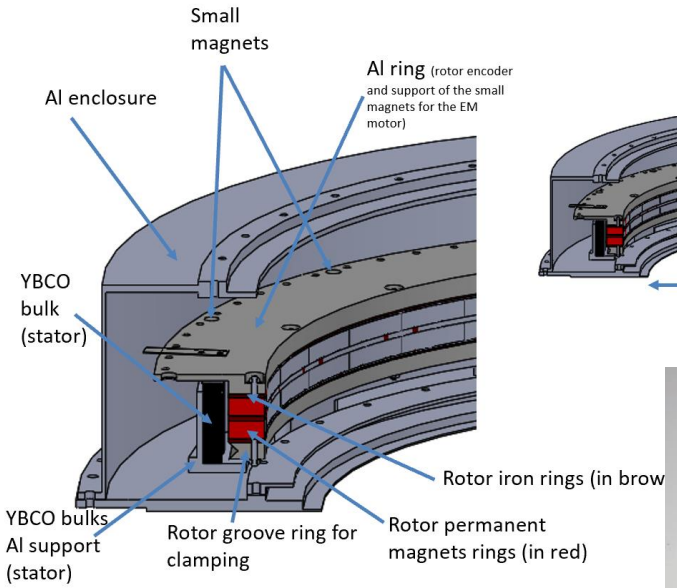
- The SWIPE instrument of the Large-Scale Polarization Explorer is a CMB polarimetry mission on a stratospheric balloon, to be flown in the Arctic night in 2023.
- Funded by ASI, Sapienza, and INFN
- Mission PI in Roma1 (de Bernardis).
- The cryostat, telescope, polarization modulator, multimode feedhorns and the focal plane are developed in Roma1, while the spider-web absorbers and the TES thermistors are developed in INFN Genova (F. Gatti). Readout electronics developed in INFN Pisa (G. Signorelli).
- Dedicated focal-plane integration facility in Roma1. Dedicated polarimetry test facility in Roma1 (G31).
- The cryogenic system is described in Piacentini et al.

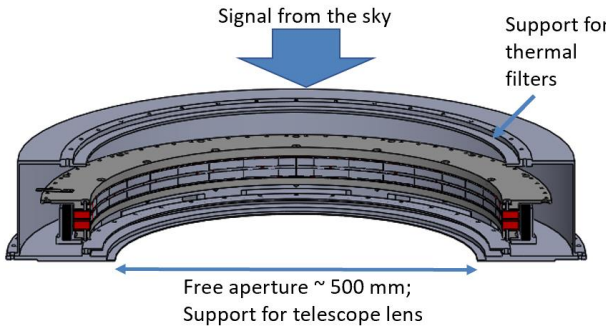




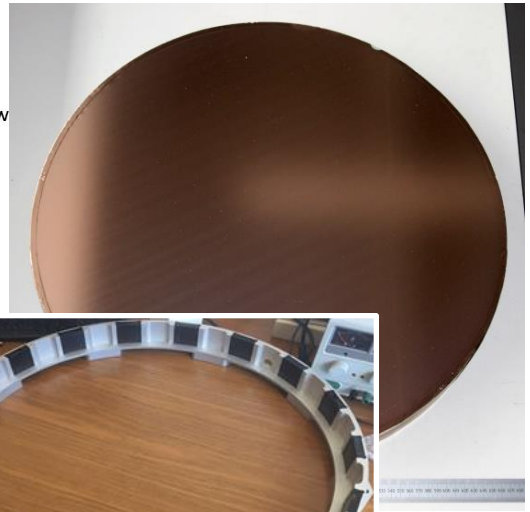
LiteBIRD/LSPE polarization modulators

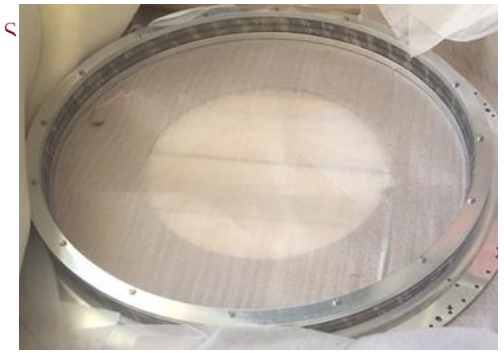
- The polarization modulators for the CMB missions LSPE an LiteBIRD are based on a cryogenic spinning metamaterials half-wave plate.
- To avoid friction, we have developed a large (50 cm diameter) hollow superconducting magnetic bearing
- The rotator is able to spin the HWP at 30 rpm with negligible (<5 mW) power dissipation on the 2K cryogenic stage.
- See arXiv:2101.05188 for details.





1T field strength in the gap. Total mass 9 kg.





LiteBIRD/LSPE testbed cryostat (Obelix)

- The large cryogenic polarization modulators of LSPE/SWIPE and LiteBIRD require a 1 m^3 cryogenic volume to be operated and optimized.
- To save on the cost of liquid helium we have developed a cryogenic test facility, called Obelix, which is based on Pulse-tube refrigerators.
- The facility is being installed in the G31 laboratory in Sapienza.