COLD LAB ACTIVITY REPORT

CLAUDIO GATTI

64nd LNF Scientific Committee – November 2022

COLD - Cryogenic Laboratory for Detectors

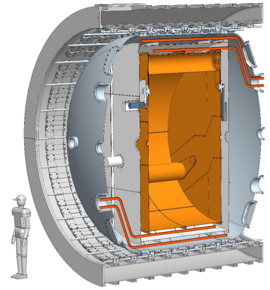
- Axion Experiments
- Superconducting Quantum Devices
- Superconducting Cavities
- Magnetic Measurements

COSMIC WISPERS
CA 21106

EXPERIMENTS

QUAX – QUest for AXions

Search for galactic axions with Sikivie's Haloscopes at 10 GHz (Ongoing experiments at LNL and LNF).



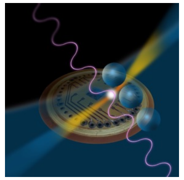
(K)FLASH

Search for galactic axions with a Sikivie's Haloscope at 100 MHz (Design Study).

Superconducting Devices

DART WARS (Detector Array Readout with Travelling Wave AmplifieRS)

Development of wide band quantum amplifiers for multi-channel detector readout (Ongoing).



SIMP (Single Microwave Photon detectors)

Development of single-microwave photon detector (Ends 2021)

Qub-IT Quantum Sensing with superconducting qubits (Started 2022).

Supergalax FET H2020 Project

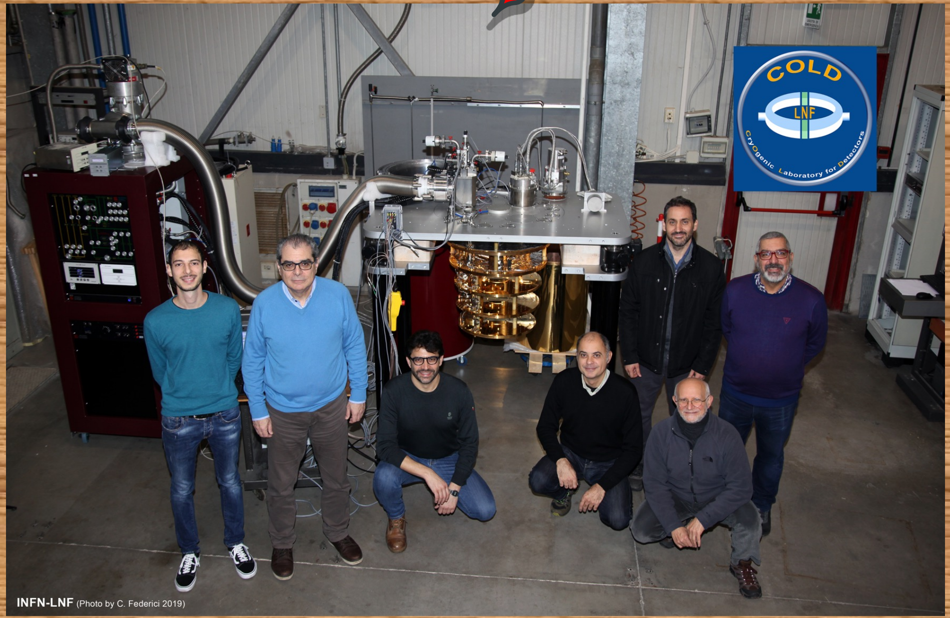
SC-qubits array photon-detector for axion experiments

SQMS USA DOE Project

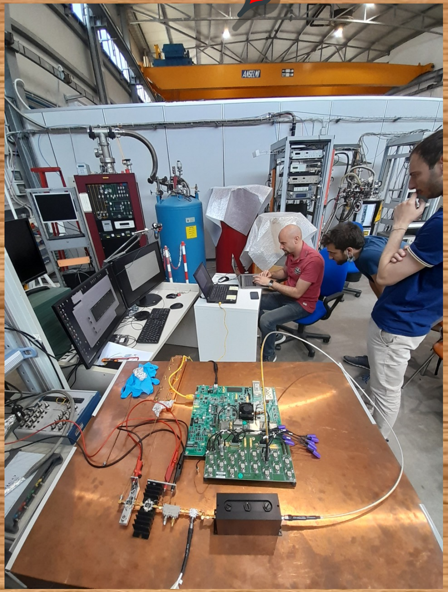
Superconducting Quantum Materials and Systems

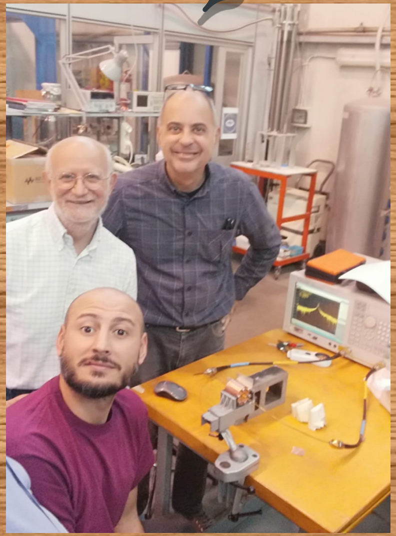
SAMARA

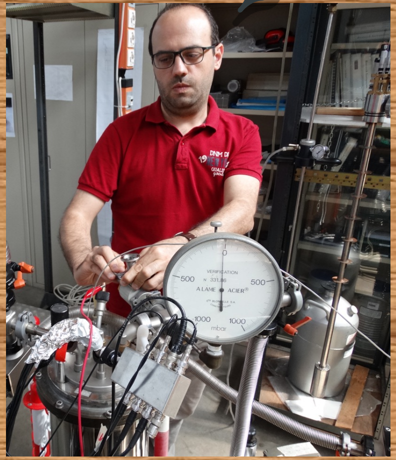
SC materials for cavities

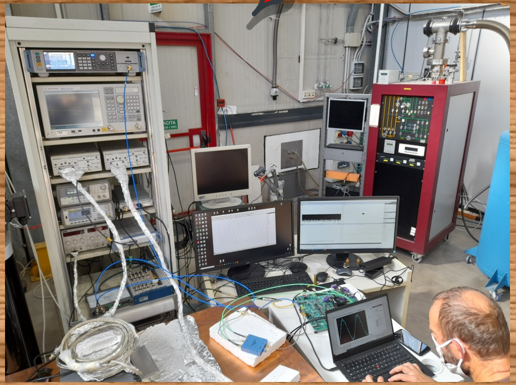


INFN-LNF (Photo by C. Federici 2019)



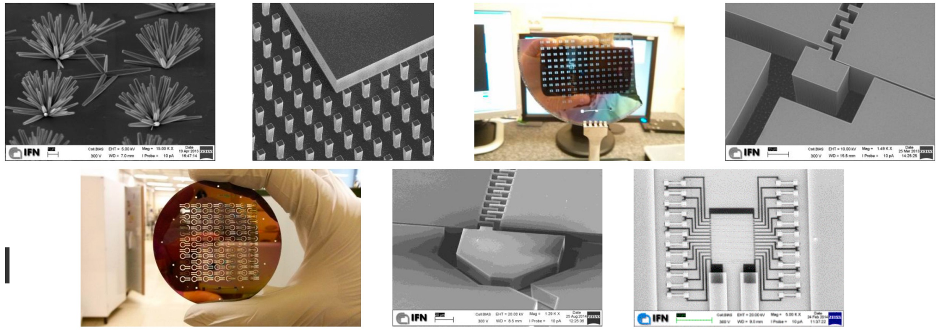






Consiglio Nazionale
delle Ricerche

NANOMICROFAB
ADVANCED LAB



CNR, National Research Council

INRiM
ISTITUTO NAZIONALE
DI RICERCA METROLOGICA

PiQuET
PIEMONTE QUANTUM ENABLING TECHNOLOGY

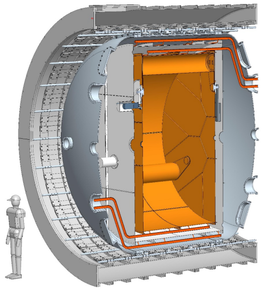
INRiM, Italian Metrology Institute

FBK, Fondazione Bruno Kessler

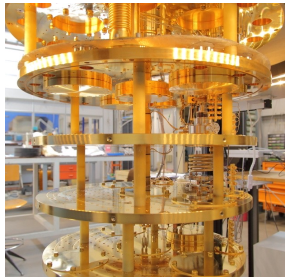
FONDAZIONE
BRUNO KESSLER

COLD Lab activity in 2022

Experiments



- Operations for the test of the FINUDA Magnet
- Update of FLASH CDR



- First run with QUAX-LNF Haloscope
- QUAX-LNL data analysis and paper submission (PRD)

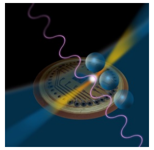
SC devices

SUPERGALAX

- Test of 10 Flux-Qubits device

Qub-IT

- Flux JPA
- Qubit design



- Stub-tuner JJ device

DARTWARS

- Multicavity DAQ for TWPA

SC resonant cavities

SQMS

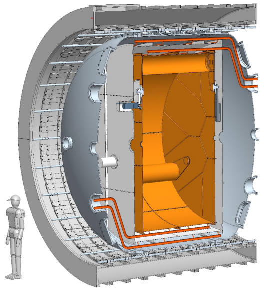
- Design, fabrication and vacuum test of a 4 GHz cavity for FNAL
- Mechanical Design of 9GHz Nb_3Sn cavity

SAMARA

- Test of NbTi cavities
- Characterization of YBCO tapes

COLD Lab activity in 2022

Experiments



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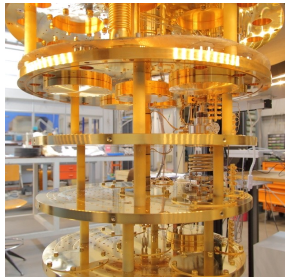

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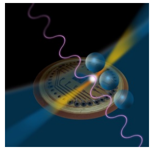

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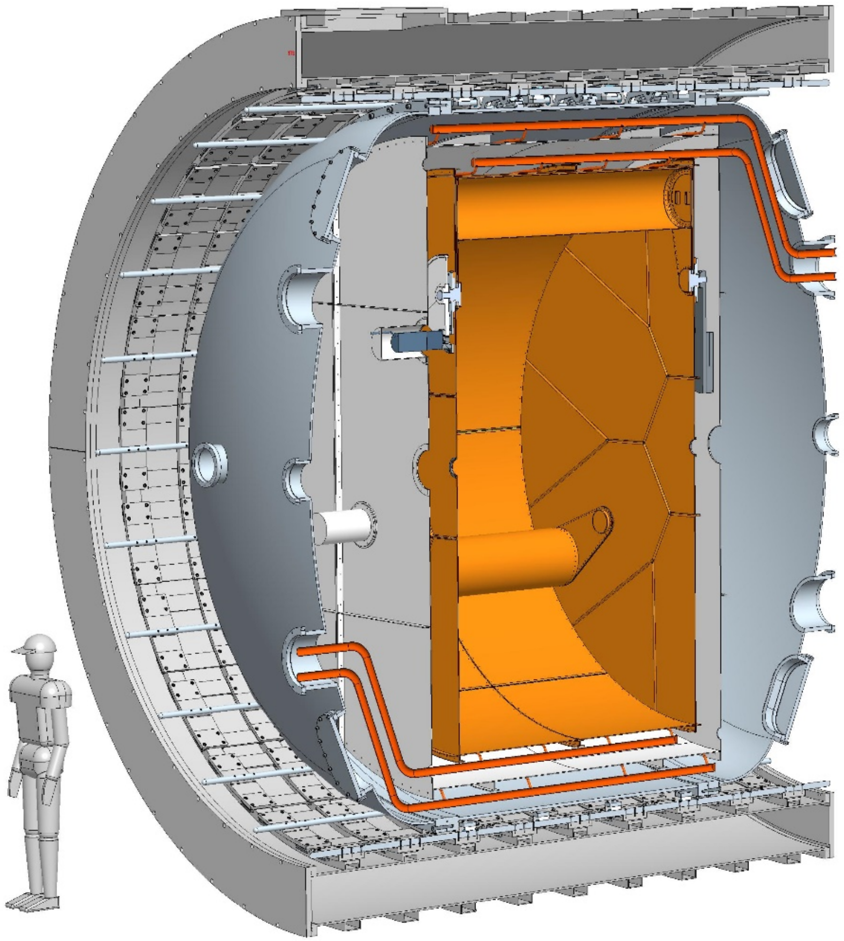


FLASH FINUDA MAGNET FOR LIGHT AXION SEARCH

GALACTIC AXION SEARCH AT 100 MHZ (0.4-1.1 MEV)

FLASH - PREPARATION FOR THE TEST OF THE FINUDA MAGNET

- The FINUDA Superconducting Solenoid was shut down in 2007. Since then, it wasn't switched on again and it must now be tested for operation before considering it for the FLASH experiment.
- Some work needs to be done in order to cool and energize the magnet again:
  1. modification and reconnection of the transfer line between FINUDA and the cryogenic plant
  2. maintenance and restarting of the cryogenic plant (stopped since 2018)
  3. revamping of the control system of the FINUDA cryogenics
  4. replacement of the FINUDA/cryogenic plant safety valves
  5. check of the magnet Power Supply operation
  6. check for the ancillary systems operation
  7. check for the operation of the closing system of the magnet iron-endcaps
  8. check and update of the safety procedures

Thanks to the collaboration of the LNF divisions (DA, DT, DR) and to the LNF-service managers and staff.

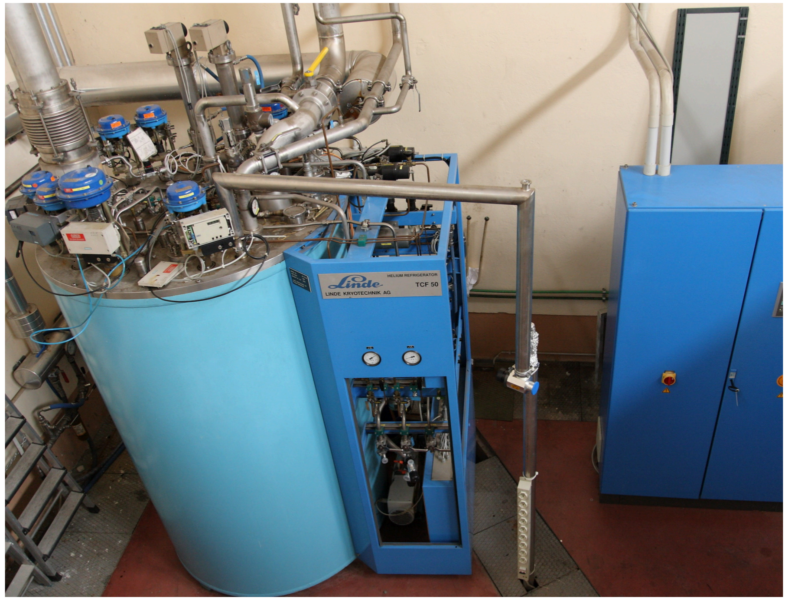
Modification and Reconnection of the Transfer Line Between FINUDA and the Cryogenic Plant

- FINUDA was supplied with liquid/gaseous Helium from the cryogenic Valve Box using a cryogenic transfer line which was dimensioned to reach the FINUDA position in the 2nd DAFNE interaction region. Now it is moved about 5 meter far from there, so the TL must be dismounted, prolonged and remounted to reach the new placement.

1. Two companies will do the work: the first one will dismount and remount the line; the second will modify it.
2. We are making the order and we expect to finish the work before the DAΦNE restarting (Jan or Feb 2023)

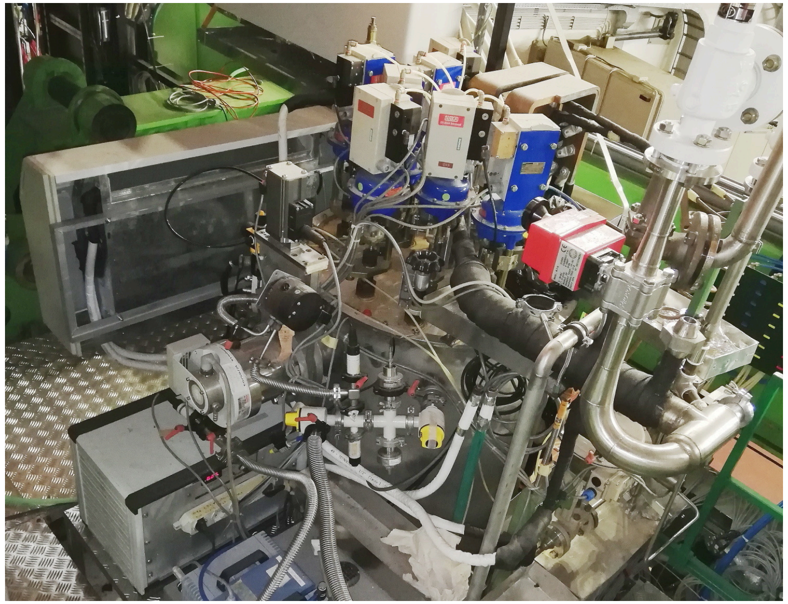
Maintenance and Restarting of the Cryogenic Plant

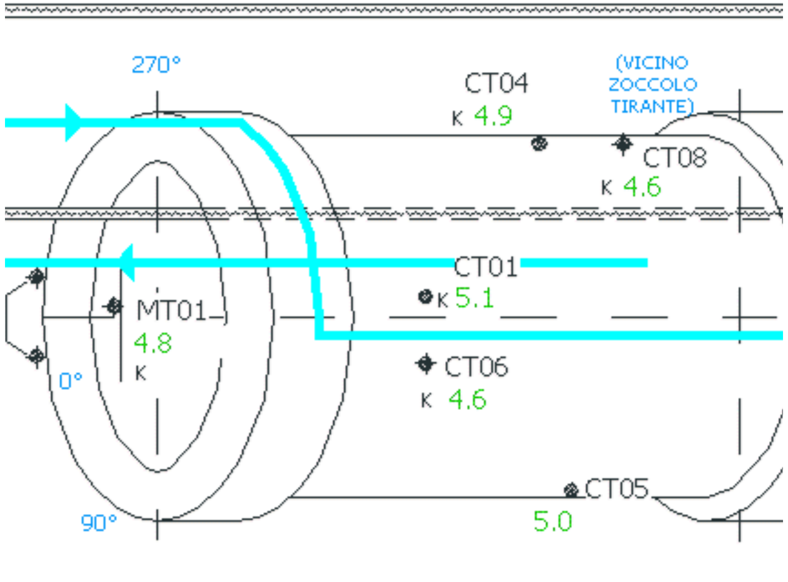
- The DAFNE cryogenic plant is based on a LINDE TCF50 Helium refrigerator/liquefier. It kept cold the SC magnets during the KLOE and FINUDA runs. It was stopped in 2018
- We restarted the PLC, but it losts its memory due to a backup-battery fault, so we must reload the software before checking the hardware (already done by an external company in the past).
- Warning: we need about 300 m^3 of Helium to cool FINUDA, but on the next months a global Helium shortage is foreseen
- Test of cryo plant foreseen on Feb 2023

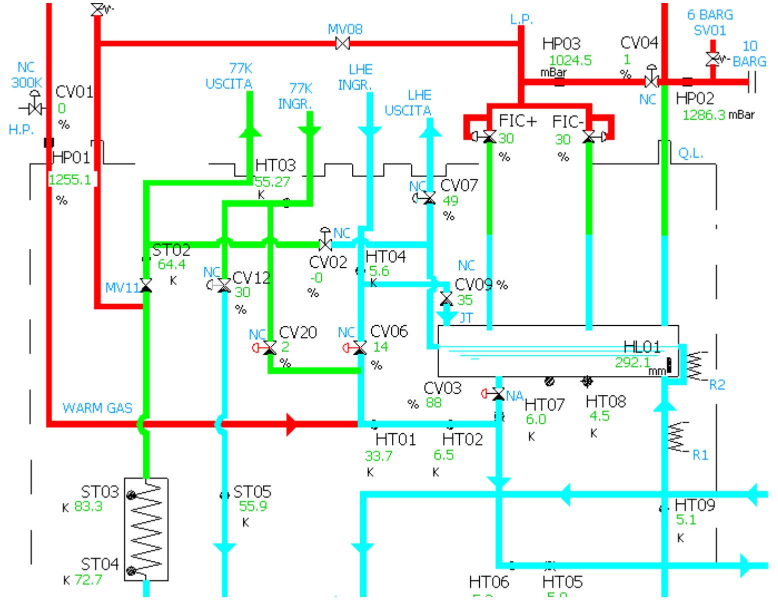


Revamping of the Control System of the FINUDA Cryogenics

- The control system of the FINUDA cryogenics is based on an old hardware for valve control, which has been checked for operation and found no more reliable.
- The control system is a Labview 5-based program running on a Windows-2000 NI PXI
- We are planning to revamp all this system with a new control hardware/software, replacing the hardware PIDs and 4-20 mA controls with a new Labview-based program and DACs.
- We are discussing the involvement of LNF experts in these days. Timing to be understood yet.





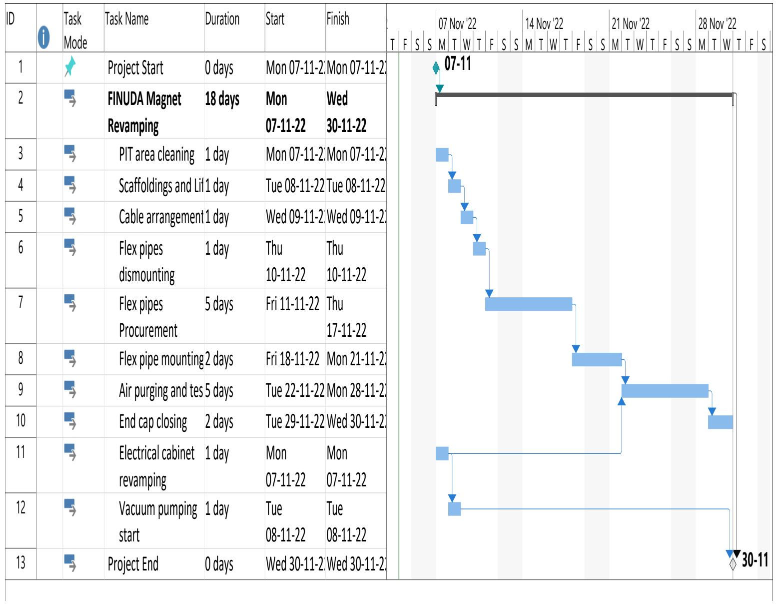


Check of the Operation of the Magnet Power Supply

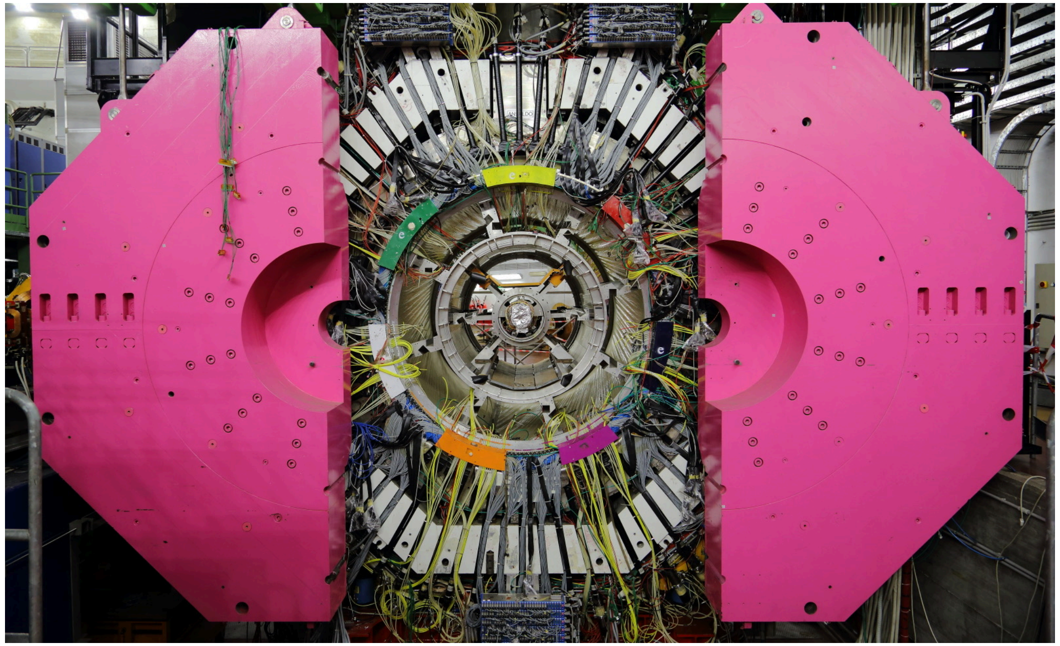
- The FINUDA magnet Power Supply has been preliminary checked and it seems all is working correctly.
- An internal battery pack must be replaced, we're going to buy a new one.
- Connection with the water cooling system was dismounted and must be remounted. Some solutions have been proposed to do it.

Check of the Closing System of the Magnet Iron-Endcaps

- We planned the operations to check for the operation of the endcaps hanling. They have been indicated in a Gantt diagram and will be done in the next weeks



ID	Task Mode	Task Name	Duration	Start	Finish
1		Project Start	0 days	Mon 07-11-2	Mon 07-11-2
2		**FINUDA Magnet Revamping**	**18 days**	**Mon 07-11-22**	**Wed 30-11-22**
3		PIT area cleaning	1 day	Mon 07-11-2	Mon 07-11-2
4		Scaffoldings and Lif	1 day	Tue 08-11-22	Tue 08-11-22
5		Cable arrangement	1 day	Wed 09-11-2	Wed 09-11-2
6		Flex pipes dismounting	1 day	Thu 10-11-22	Thu 10-11-22
7		Flex pipes Procurement	5 days	Fri 11-11-22	Thu 17-11-22
8		Flex pipe mounting	2 days	Fri 18-11-22	Mon 21-11-2
9		Air purging and tes	5 days	Tue 22-11-22	Mon 28-11-2
10		End cap closing	2 days	Tue 29-11-22	Wed 30-11-2
11		Electrical cabinet revamping	1 day	Mon 07-11-22	Mon 07-11-22
12		Vacuum pumping start	1 day	Tue 08-11-22	Tue 08-11-22
13		Project End	0 days	Wed 30-11-2	Wed 30-11-2



Others

The connection between the FINUDA cryogenic valves and the compressed air system has been restored

The safety valves of FINUDA and Cryogenic Plant have been dismounted and we asked for an offer for their replacement

The magnet’s Quench Detector must be checked for functioning.

Preparing FLASH CDR

Article

FLASH

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† Current address: Affiliation 3.
‡ These authors contributed equally to this work.

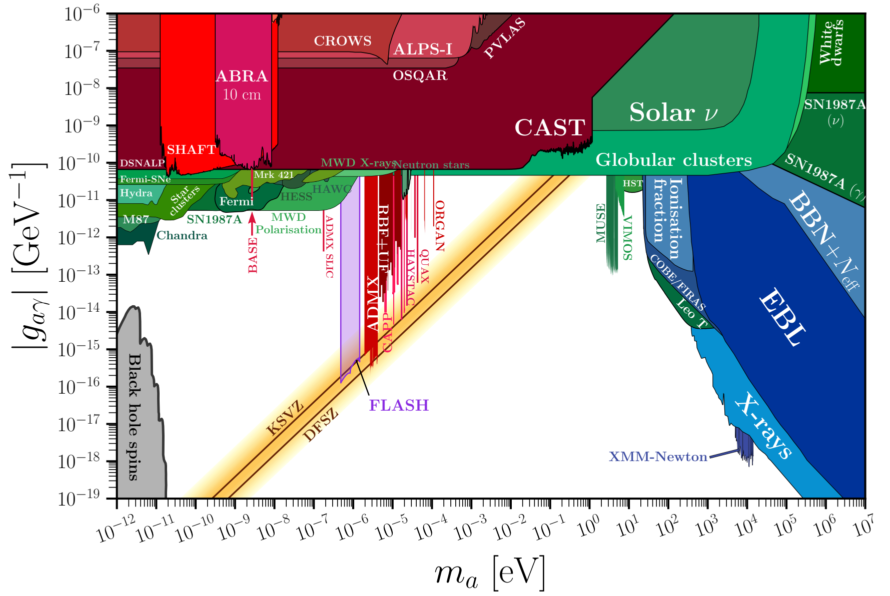
Abstract: abstract goes here

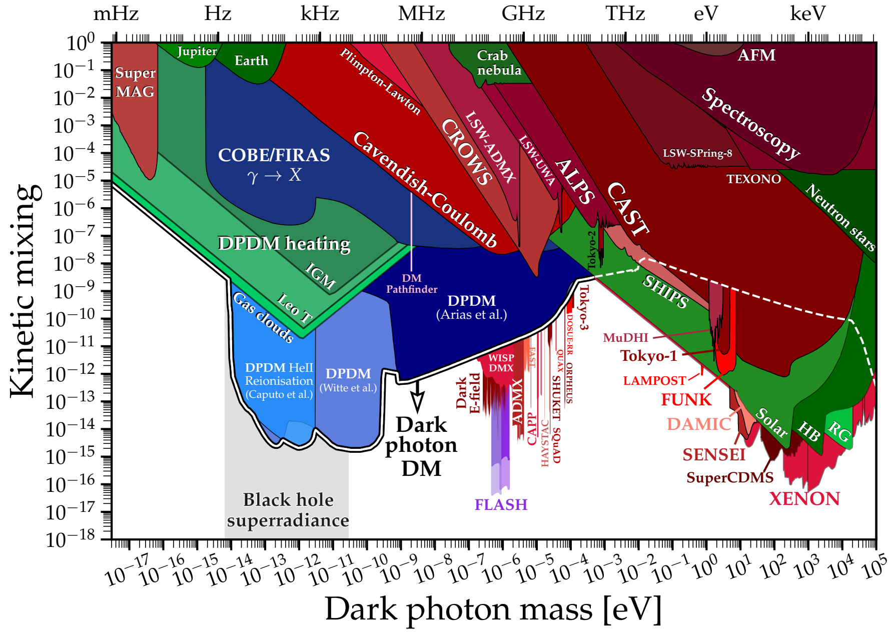
Keywords: keyword 1; keyword 2; keyword 3 (List three to ten pertinent keywords specific to the article; yet reasonably common within the subject discipline.)

1. Introduction

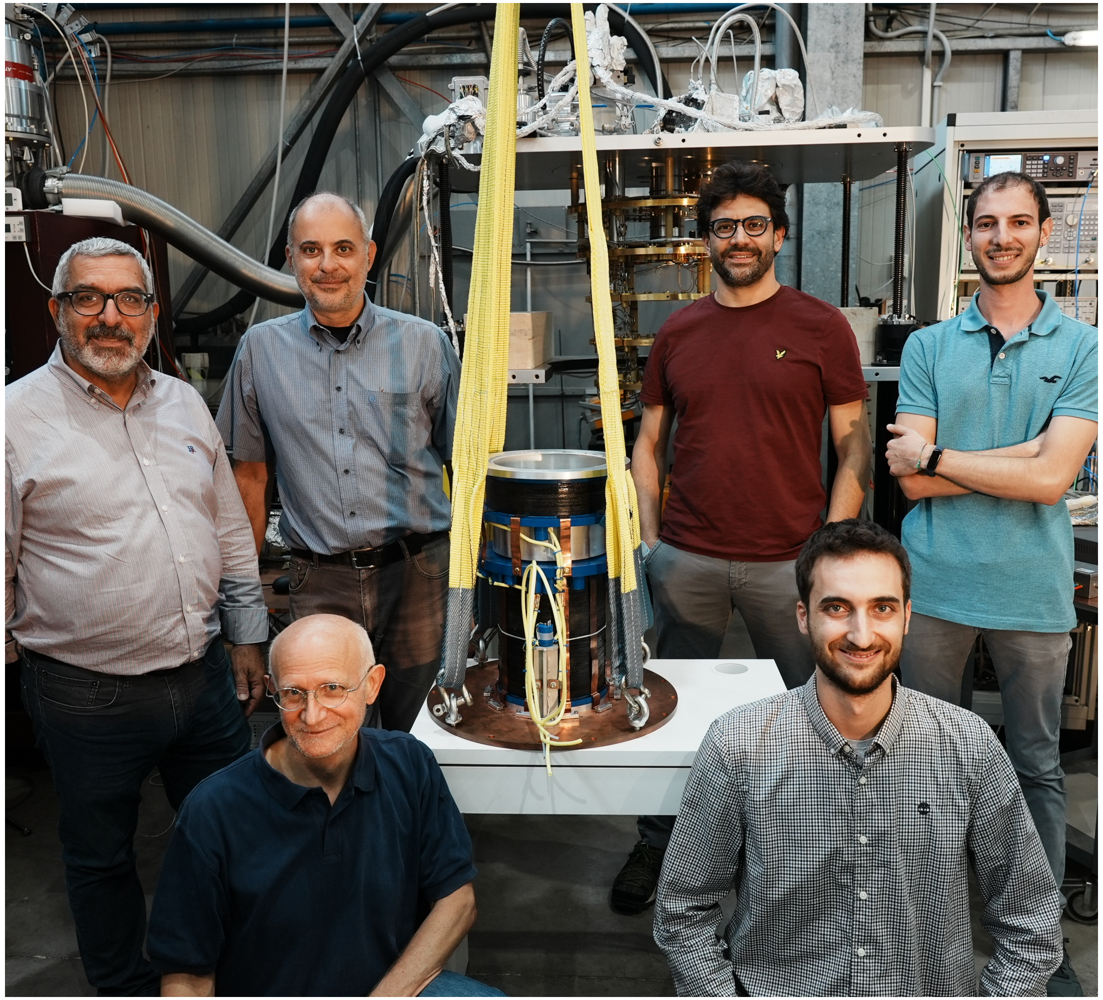
2. Brief review on axion cosmology

The "invisible" QCD axion [1,2] is a light Goldstone boson arising within the solution to the strong CP problem proposed by Peccei and Quinn [3,4], and a possible dark matter candidate [5–7]. In the standard cosmological scenario, refined cosmological simulations yield a narrow range in which the QCD axion would be the CDM particle, with an axion mass in the range $m_A \approx (10 - 100)\,\mu$eV, as recently proven by refined cosmological simulations [8–13]. Along with the QCD axion, a set of particles which share the same phenomenology would arise from string compactification and form the so-called "axiverse" [14–16]. These possibilities have been proven interesting for a number of experiments that are planned to explored the parameter space of the QCD axion and other axion-like particles away from the preferred region [17–19], as discussed in depth in various



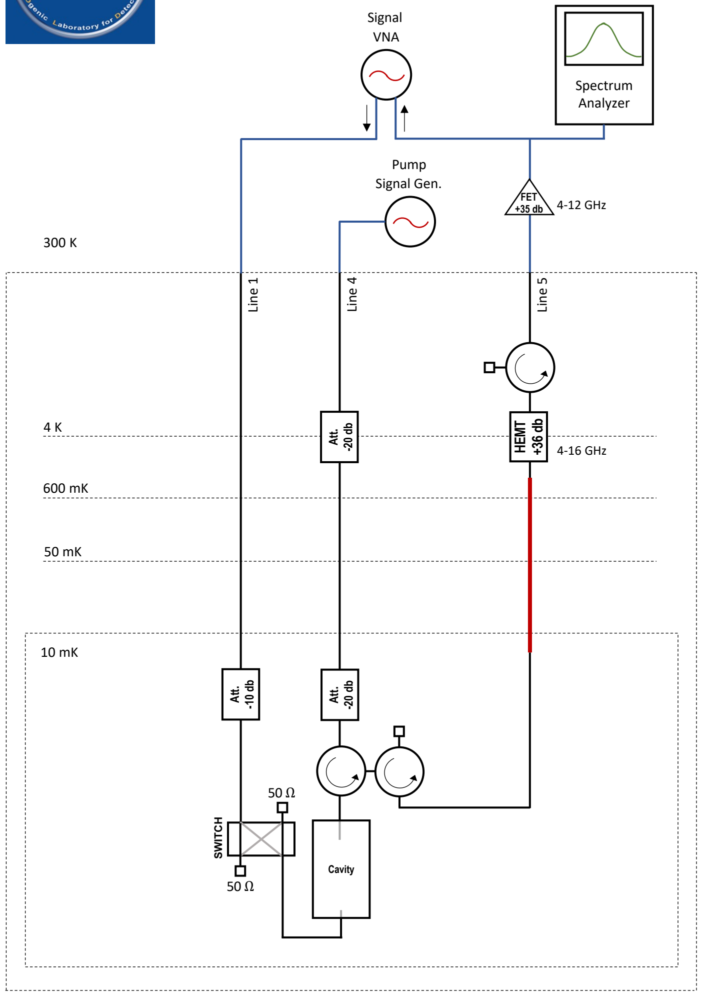


KLASH CDR https://arxiv.org/abs/1911.02427



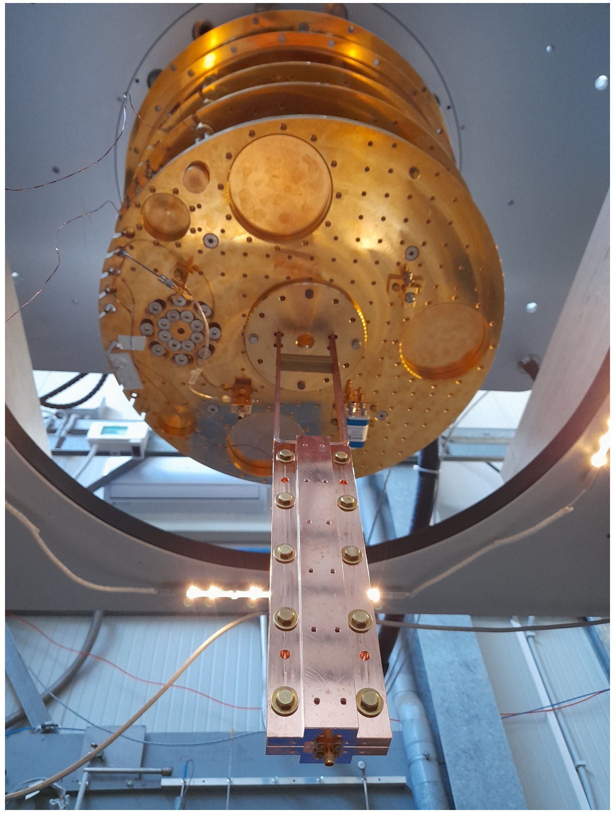
QUAX-LNF

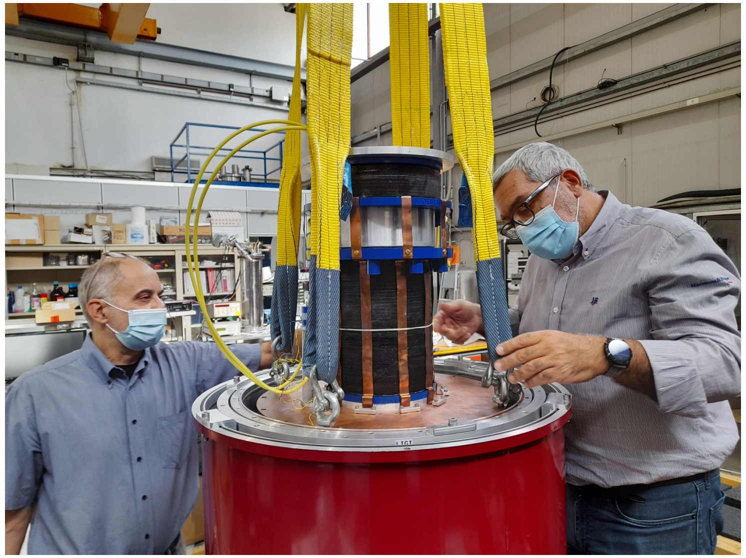
First Run of LNF Haloscope

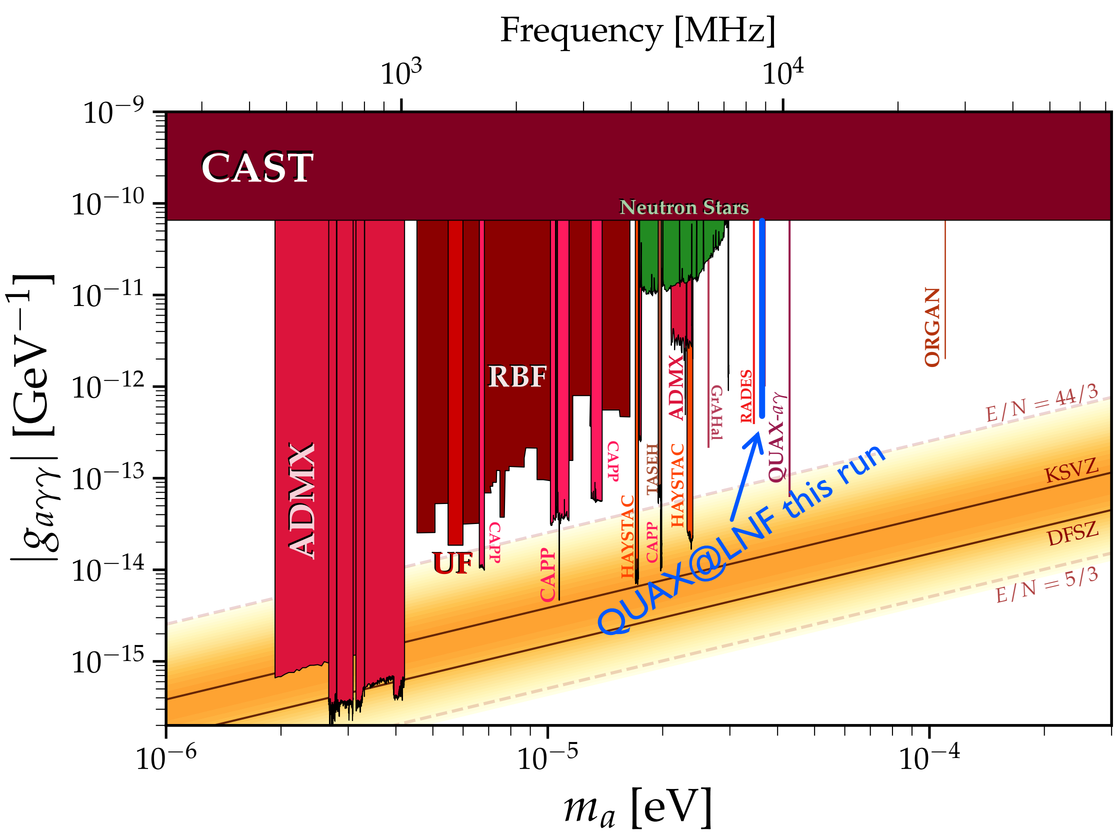


Frequency	8.5 GHz
Volume	0.14 L
Q_0	100,000
B	9 T
Tcavity	20 mK

Leiden Cryogenics CF-CS110-1000







First Run of LNF Haloscope

Problems during cooldown:

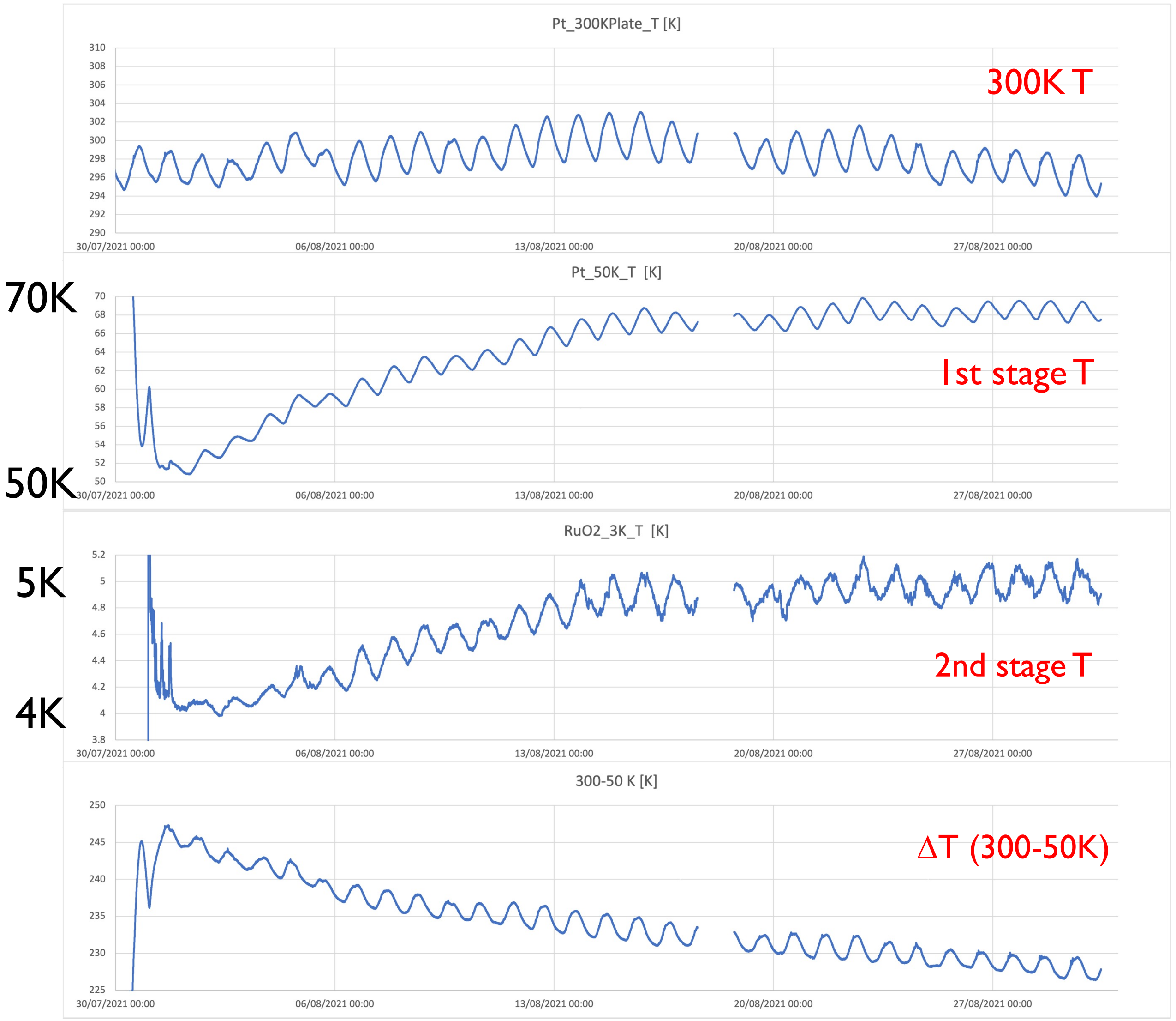
- We operated with HEMT at 5.5 K and 50K plate at 70K.
- Operated with lower B field (2.5 instead of 9 T)
- Higher cavity temperature than expected (150 instead of 10mK)
- Pick up noise due to bad grounding (solved)

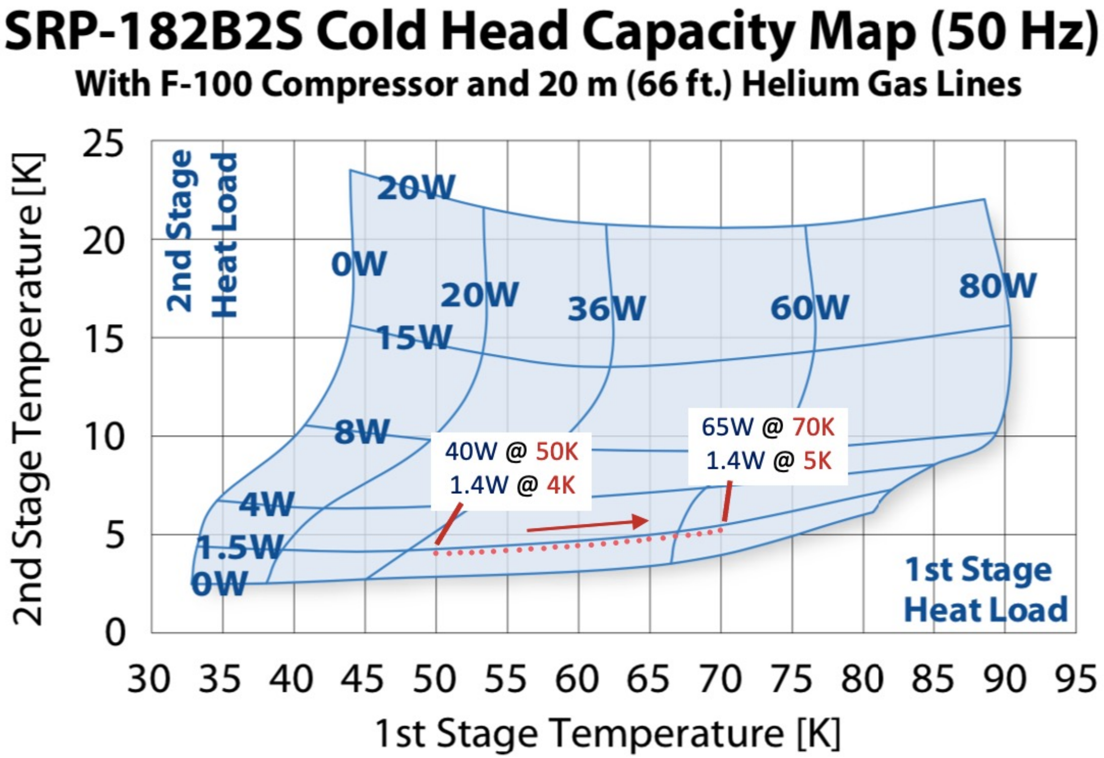
$$g^{KSVZ} = 1.35 \times 10^{-14}$$ @ m_a=35 μeV

	Gagg 90% cl	T_{noise}	Q	B(T)
Current status	3.3×10^{-13} (2h)	8 K (HEMT)	100,000 Cu Cavity	2.5
2nd pulse tube and HEMT expected noise	6.6×10^{-14}	3 K (HEMT)	100,000 Cu Cavity	9
With JPA	2.5×10^{-14}	SQL (JPA)	100,000 Cu Cavity	9
With JPA and SC cavity	1.6×10^{-14}	SQL (JPA)	250,000 SC Cavity	9

1h data taking

PT TEMPERATURE DRIFT ON COLD LAB CF-CS110 CRYOSTAT

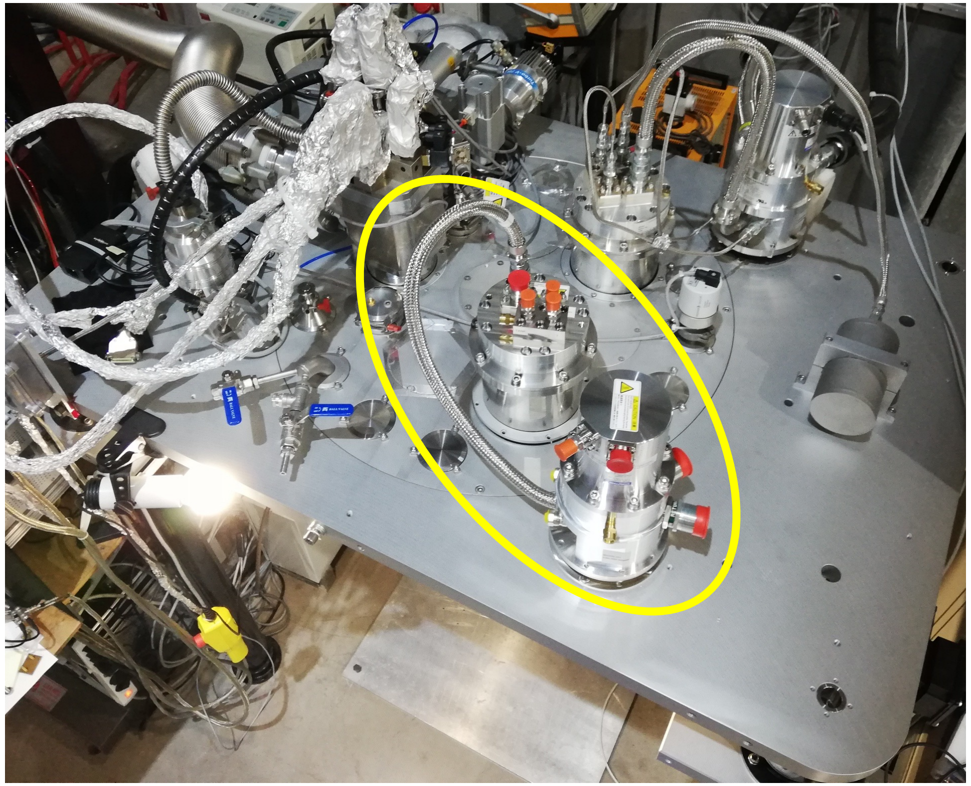


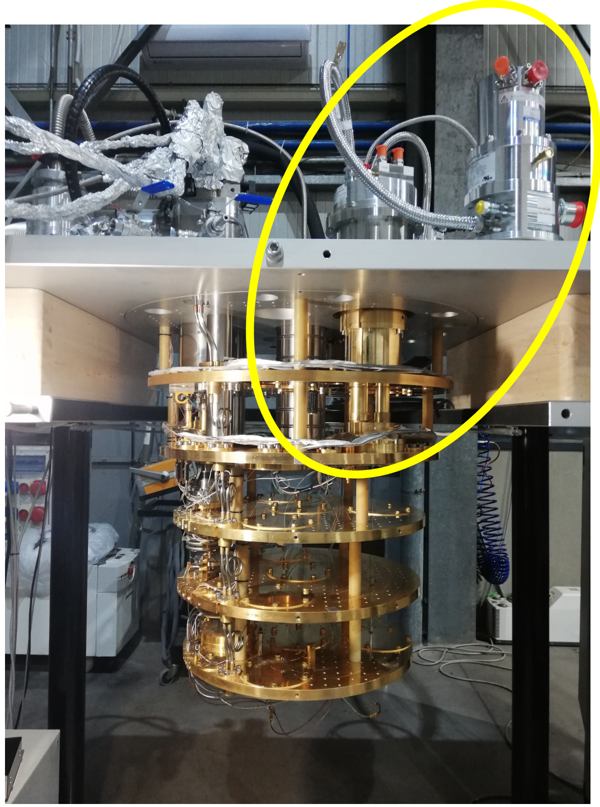


- 1st stage T rise from 50 to 70 K in 3 weeks
- 25W of extra heat input on the 50K stage
- 2nd stage follows the 1st one (4 to 5 K)
- cause not yet clear

Second Pulse Tube Arrival and Mounting on the 10 mK Cryostat

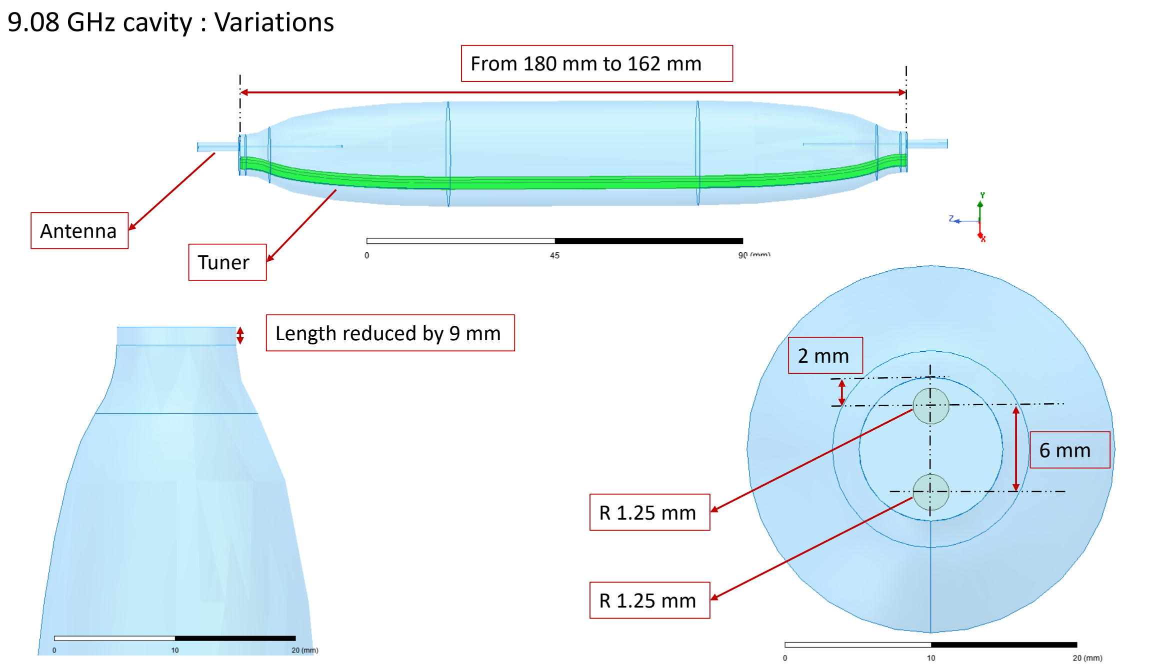
- A 1.5 W Pulse Tube refrigerator was procured and is currently being assembled on the COLD Lab cryostat with dilution refrigerator
- It is identycal to the one already mounted (Sumitomo SRP-182B2S) and will work as a booster for the cooling capacity at 4 K and 50 K
- This update will overcome the problem in the SC magnet supply above 5 T

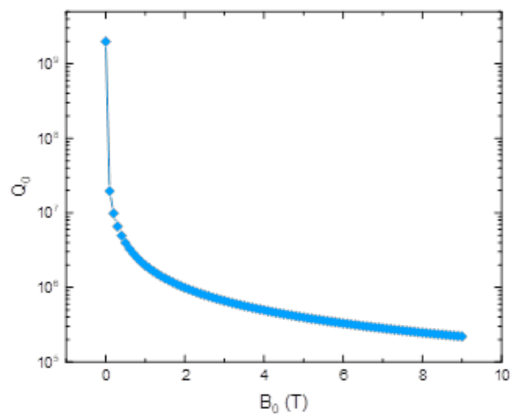


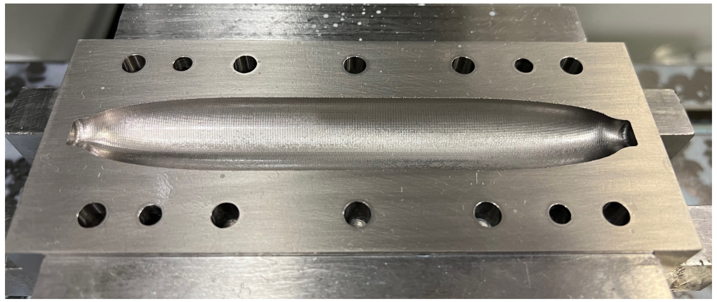


SUPERCONDUCTIVE CAVITY: NB_3SN

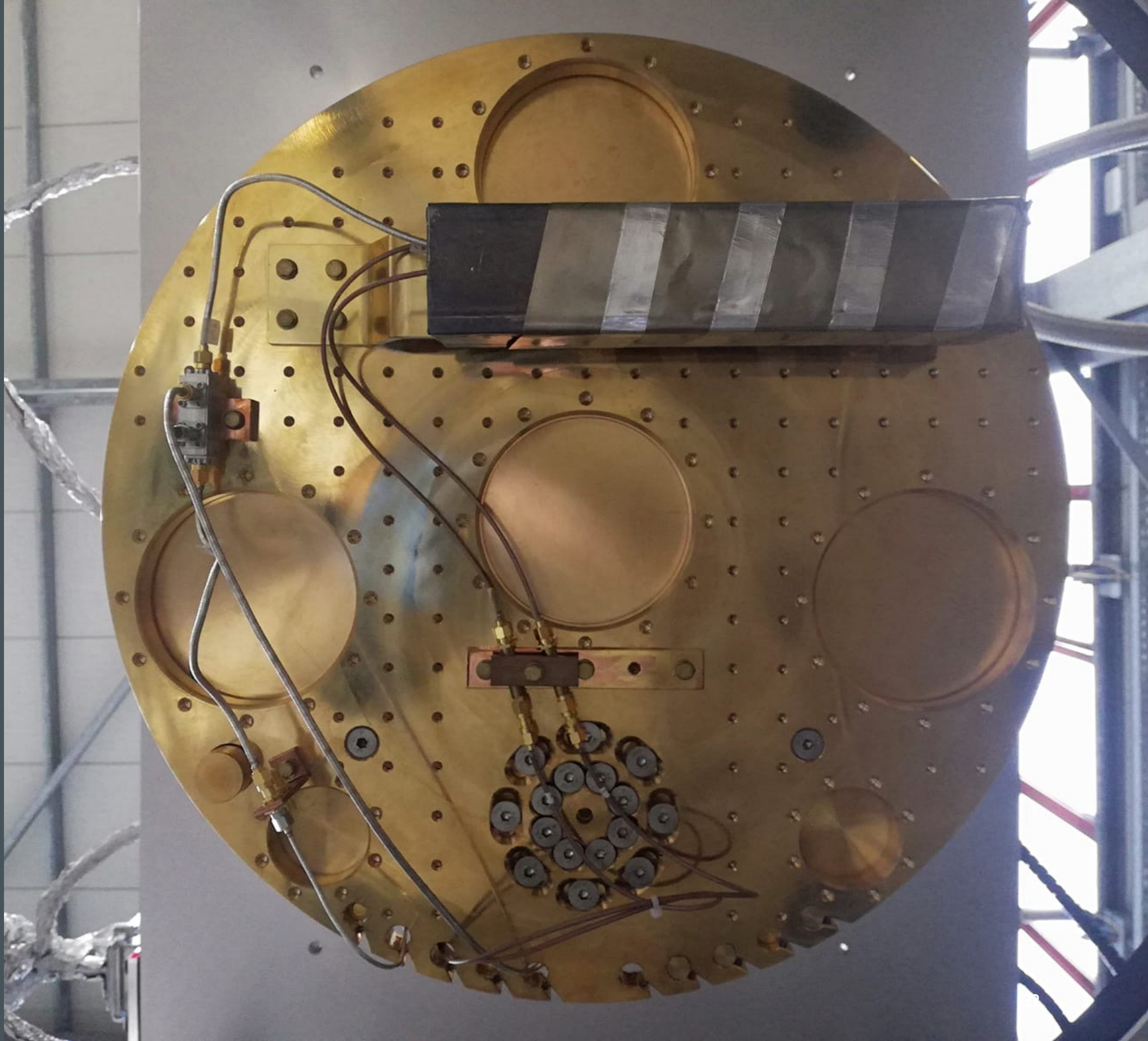
- Fabrication in progress at FNAL



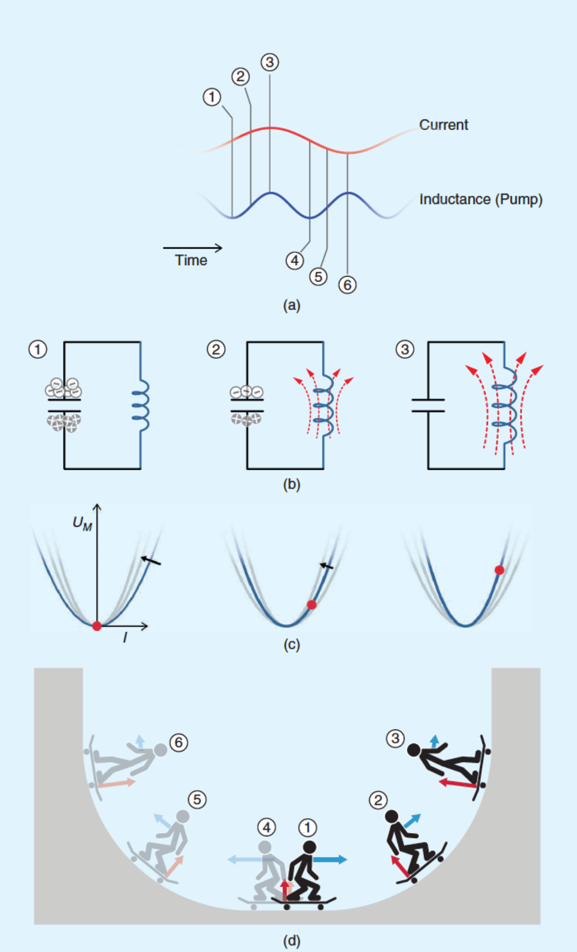




QUANTUM LIMITED AMPLIFIERS

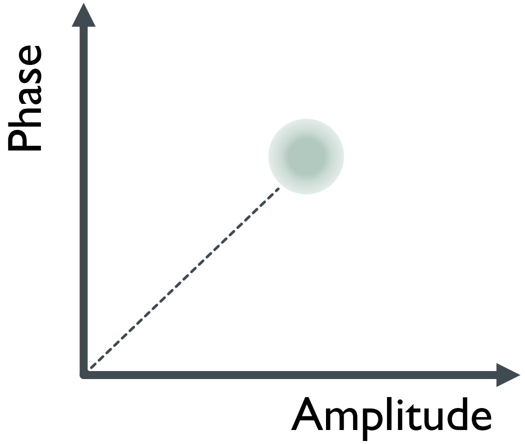


Parametric Amplification



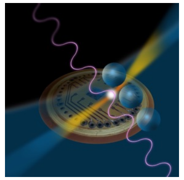
J. Aumentado IEEE Microwave Magazine

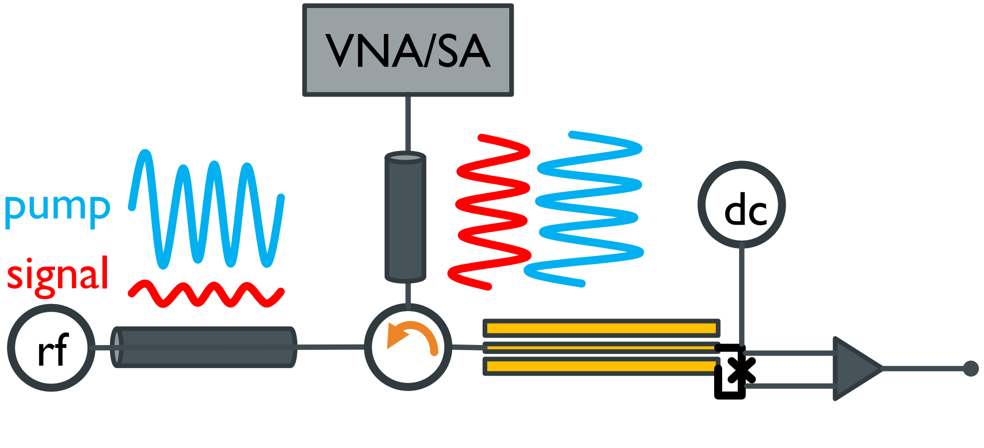
- Parametric amplification is obtained by modifying the parameters of an oscillating system.
- In electrical circuits is obtained by modulating capacitances or inductors with "pump" currents.
- In lossless superconducting circuits parametric amplification allows to reach the noise at the quantum limit.

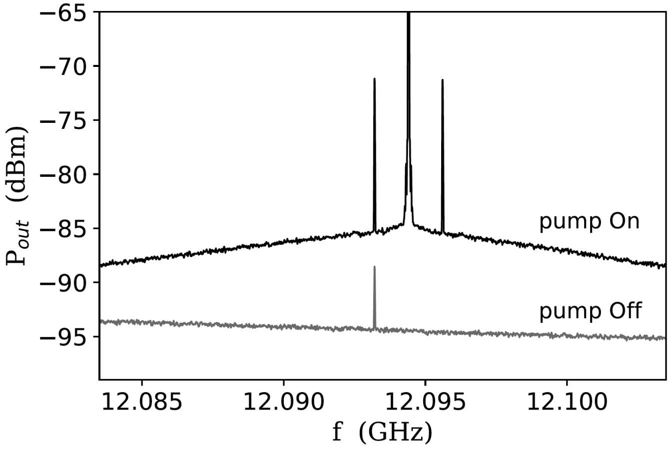


$$k_B T_{noise} = \hbar\omega$$

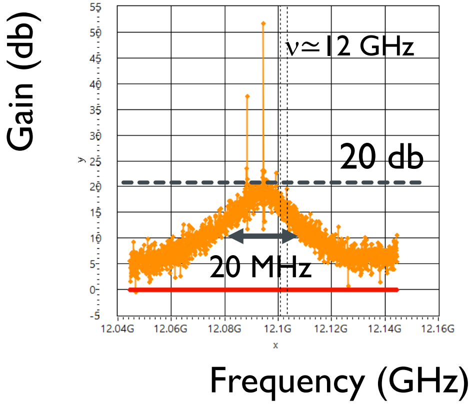
First result on a Josephson Parametric Amplifier based on single junction



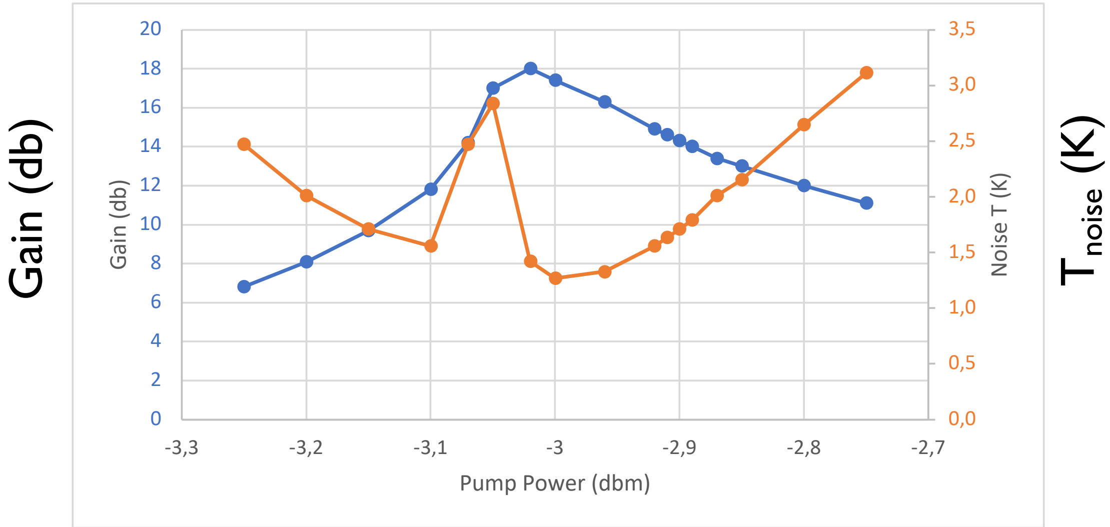


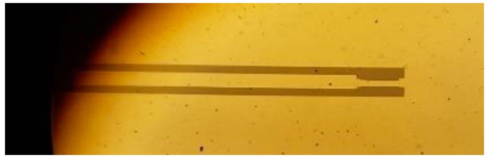


20 db Gain and 10 MHz bandwith



Noise reduced from 8K (HEMT) to about 1.3K

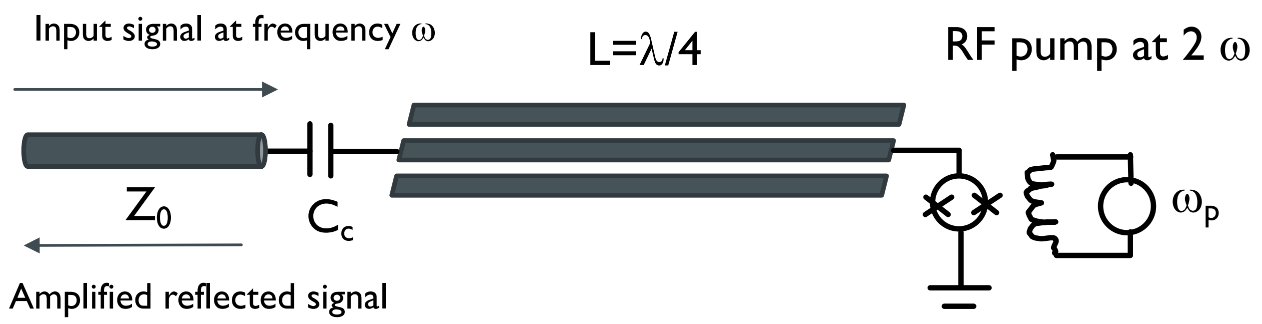


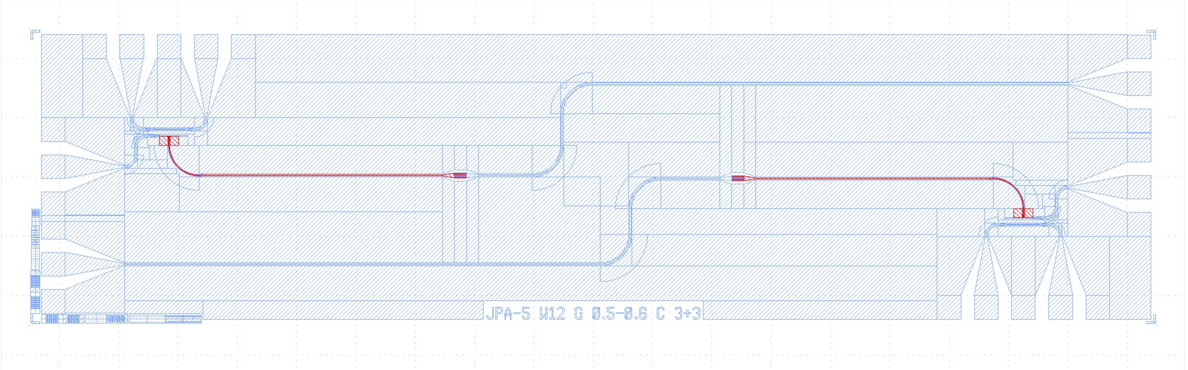


Collaboration with

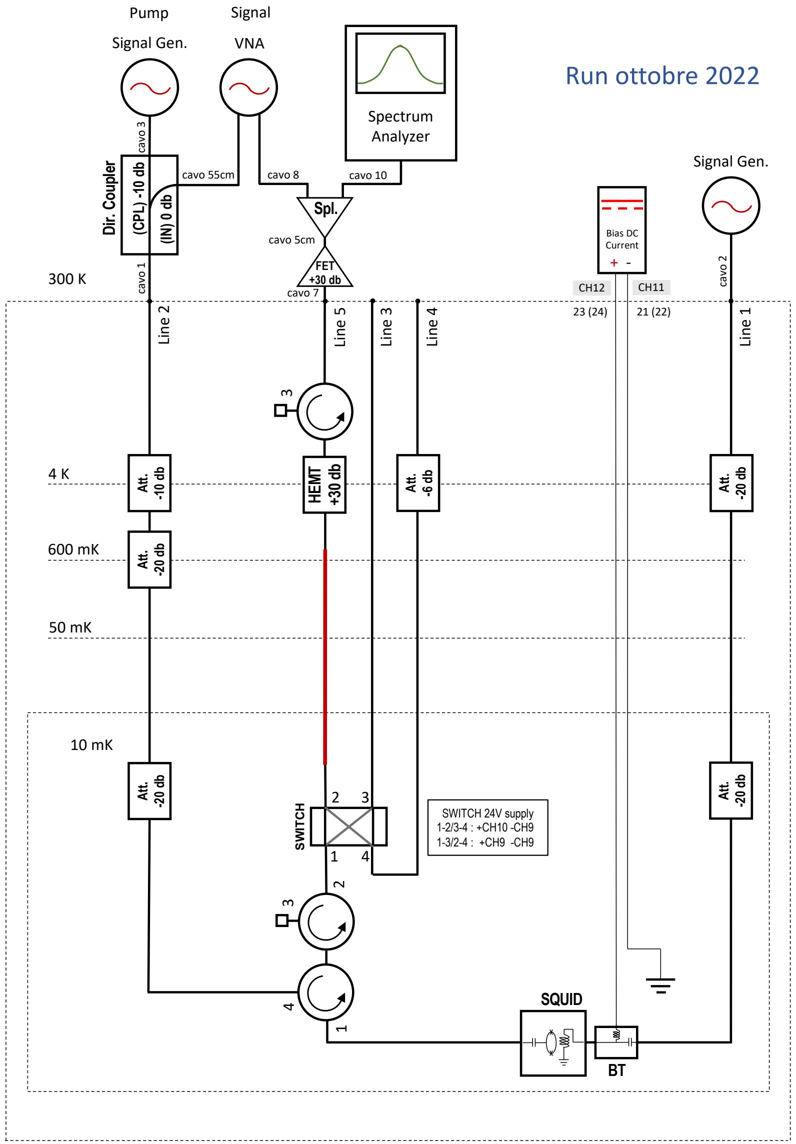
IFN
Consiglio Nazionale delle Ricerche
Istituto di Fotonica e Nanotecnologie

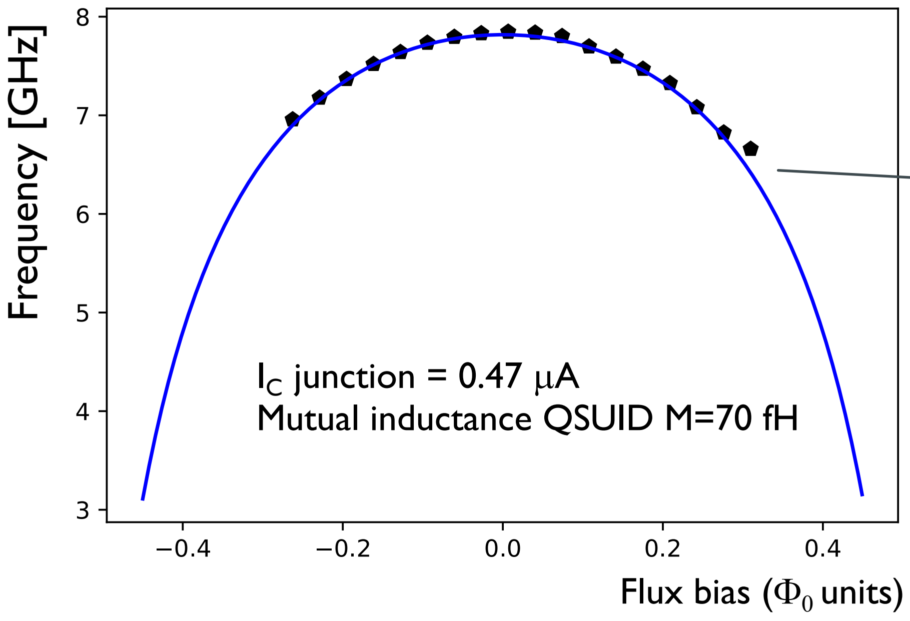
Realization and test of a Flux JPA

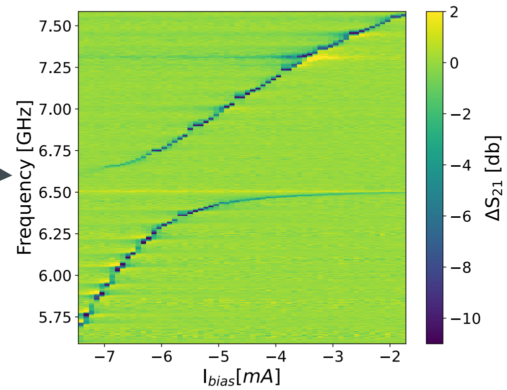




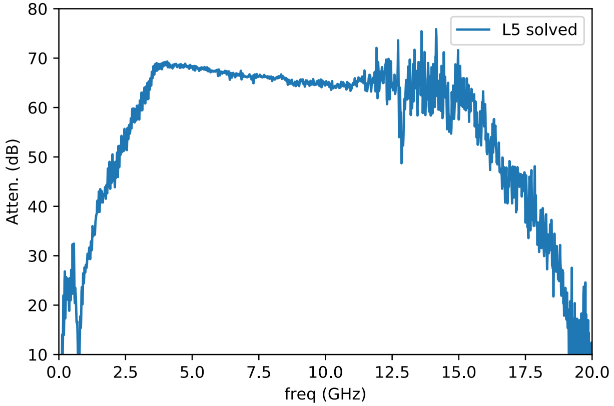
Chip realized at FBK with submicrometric optical lithography and Al shadow evaporation technique.







Hybridization with spurious mode



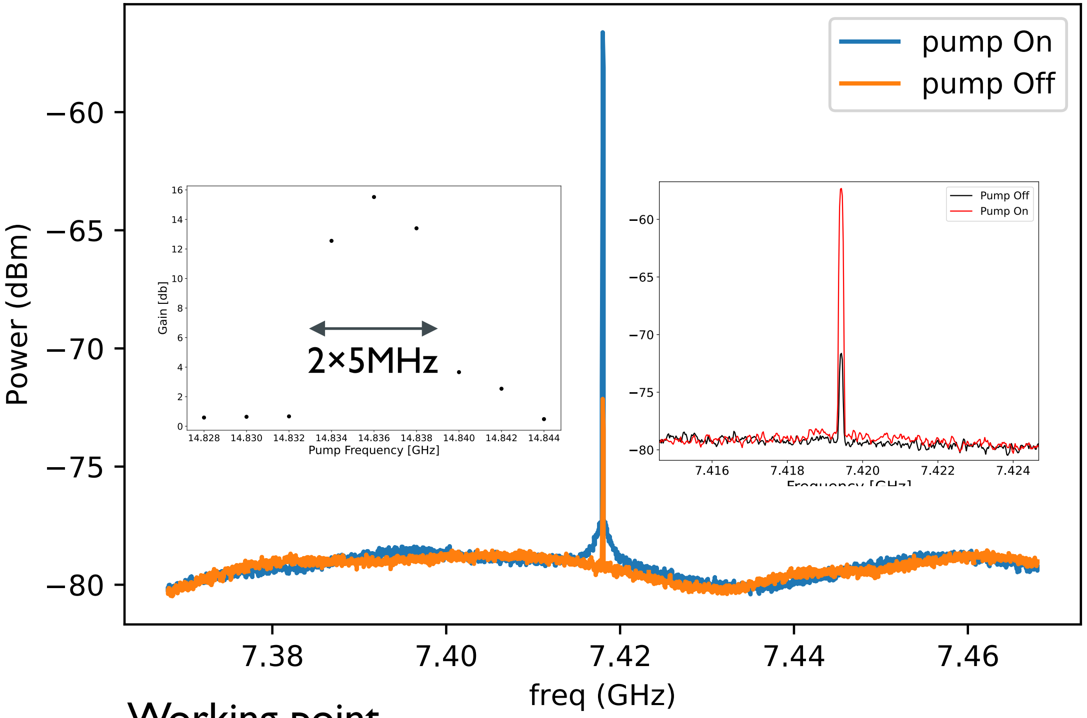
HEMT line gain calibration:

$$Gain = (64.5 \pm 2.0)\ \text{dB}$$

$$T_n^{HEMT} = \frac{P_n}{k_B\ \Delta\nu\ G5} = (3.3 \pm^{1.9}_{1.2})\ K$$

~3K from Low Noise Factory datasheet

Degenerate JPA Gain and Noise



Working point

f_{signal}=7.418 GHz

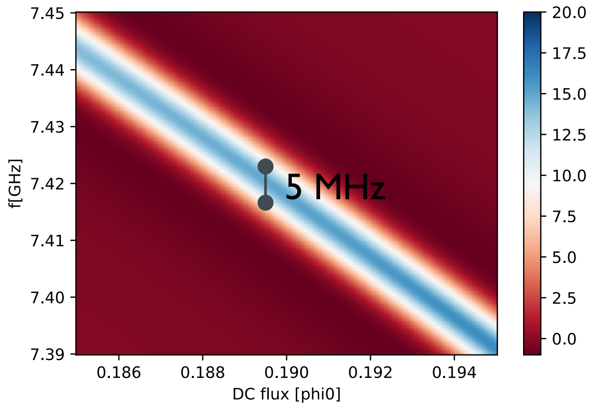
f_{pump}=$2f_{signal}$

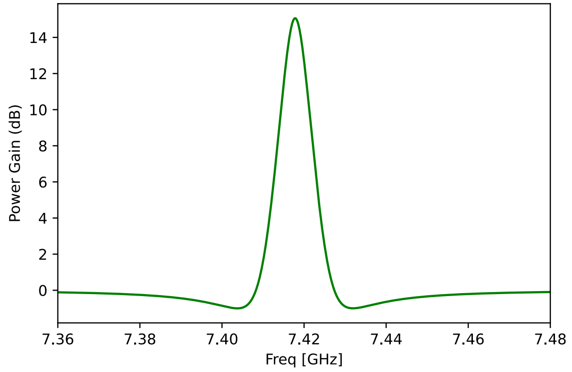
P_{signal}= -135 dbm

P_{pump}= -45 dbm

Φ=0.19 Φ_0

Theoretical expectation





Measured Gain

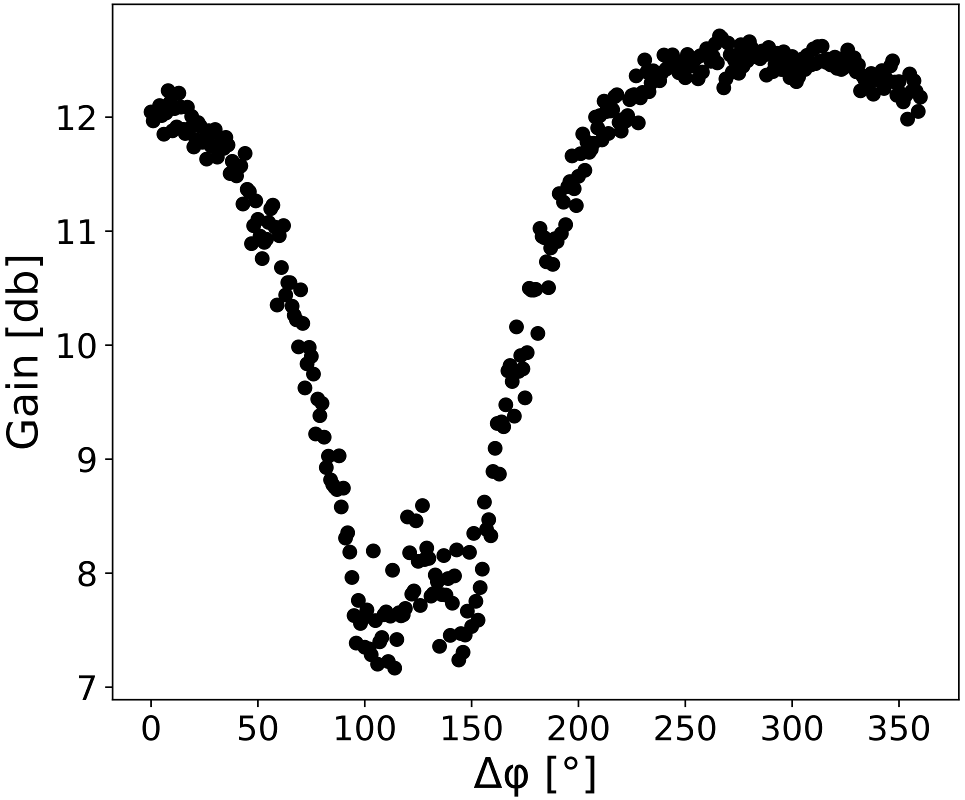
$$G_{JPA} = 15.5 \text{ dB}$$

Measured Noise

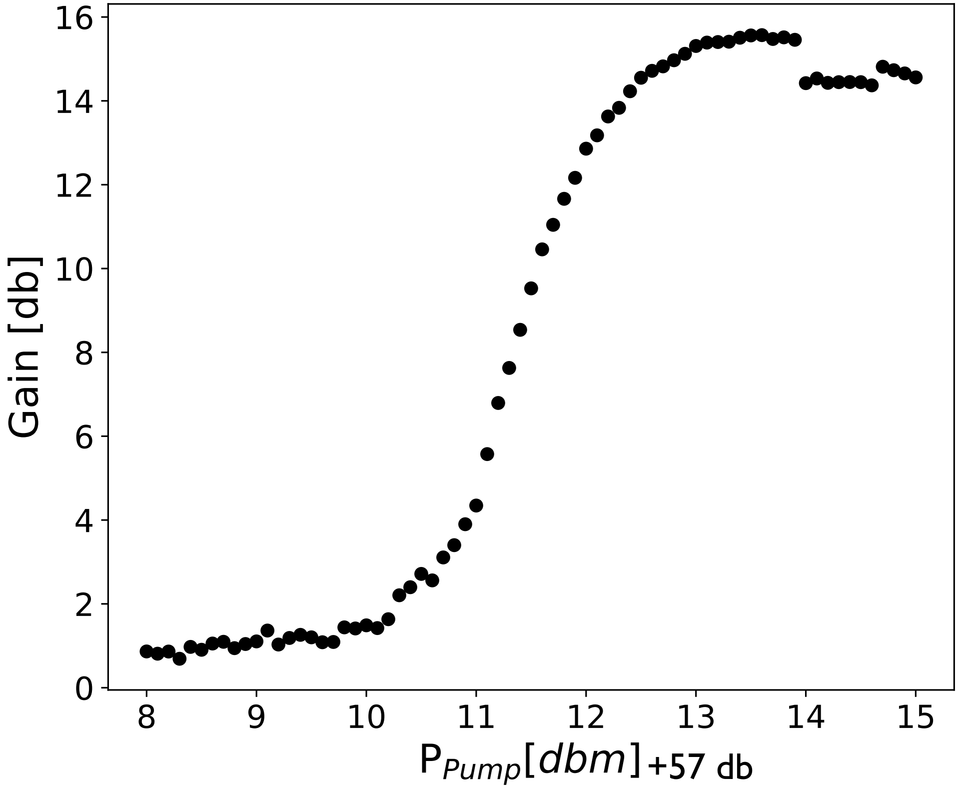
$$T_n^{JPA} = \frac{P_n}{k_B\, \Delta\nu\, (G5 + G_{JPA})} = \left(0.130 \pm^{0.075}_{0.049}\right) K$$

Expected quantum noise ½ $h\nu/k_B$ T=0.174 K

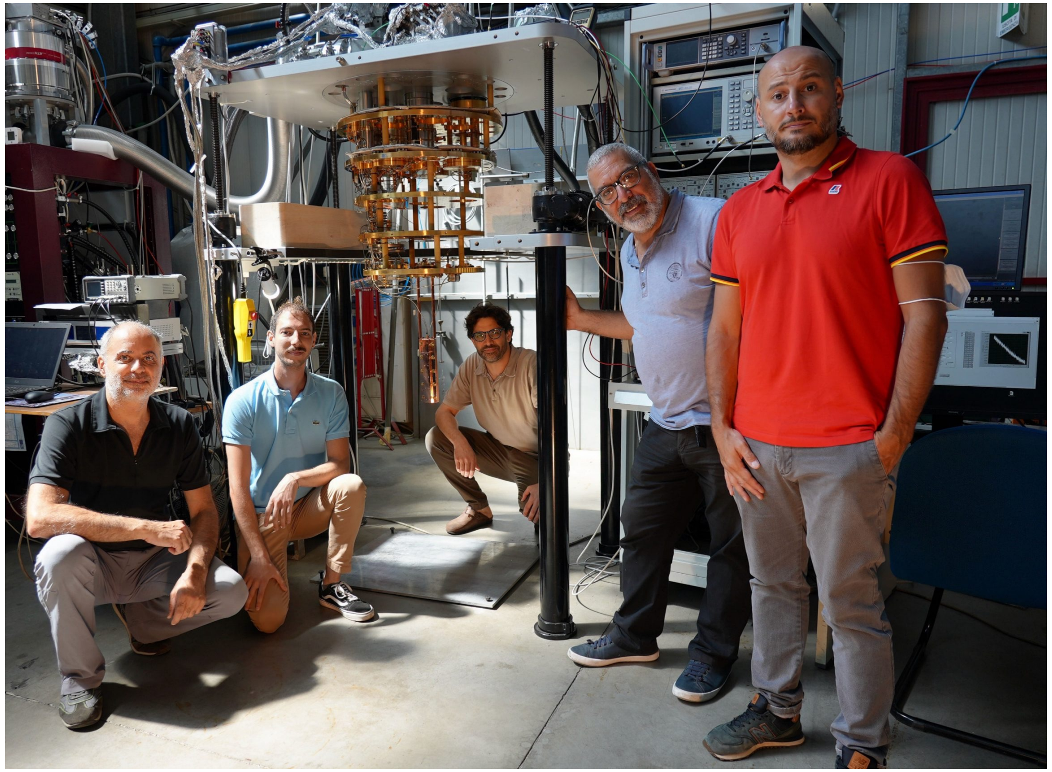
Scan in pump phase



Scan in pump power



SUMMARY



- Ongoing work for the operation of the FINUDA magnet in 2023
- FLASH CDR under writing with sensitivity to HFGW
- First Run with Quax-LNF haloscope done in July 2022
- 2^{nd} pulse tube now installed (→9T)
- First Flux JPA fabricated (→SQL noise)
- Nb_3Sn cavity in fabrication at FNAL (→ higher Q_0)