Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

SEARCH FOR AXION AND AXION-LIKE-PARTICLES AT LNF

CLAUDIO GATTI, LABORATORI NAZIONALI DI FRASCATI - INFN

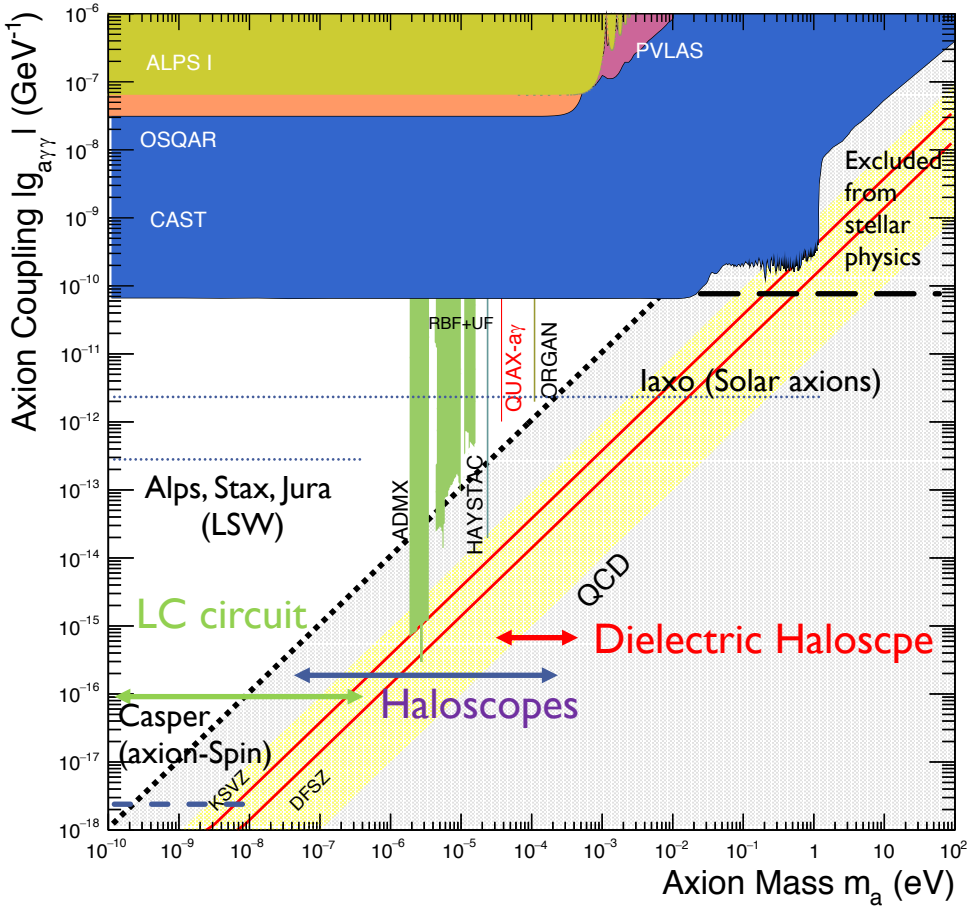
58th Scientific Committee Meeting, LNF November 11th 2019

OUTLINE

- Overview of Axion Searches
- Axion Research at LNF
  1. Haloscopes
     a. KLASH
     b. QUAX
  2. Single microwave photon detection
     a. SIMP
     b. SUPERGALAX (Fet Open H2020)
- Collaborations
- Conclusion

DM-AXION SEARCHES trhough gaγγ

The last decade witnessed an increasing interest in axions and axion-like particles with many theoretical works published and many new experimental proposals that started a real *race* towards their discovery.
In 10-20 years we'll probably explore most of the region of the parameter space predicted by QCD-axion models.



m_a(eV)

MADMAX (Dielectric Haloscpe) — 10^{-4}

ADMX
HAYSTAC
CAPP
QUAX
KLASH
ORGAN
RADES
(Haloscopes) — 10^{-5}

ABRACADABRA
DMRadio
(LC circuit) — 10^{-6}

AXION RESEARCH AT LNF

Ongoing Activities at LNF

QUAX (CSN2) (2017-)
QUest for AXions

Search for QCD-axion Dark Matter with Haloscopes:
QUAX-ae: Looks for axion-spin coupling in the mass region m_a= 40-50 μeV
QUAX-aγ: standard haloscope in mass region m_a= 40-50 μeV

KLASH (CSN2) (?)
KLoe magnet for Axion SearcH

Proposal for a large haloscope to serach axions in the mass range 0.1-1 μeV

SIMP (CSN5) (2019-2021)
SIngle Microwave Photon detection

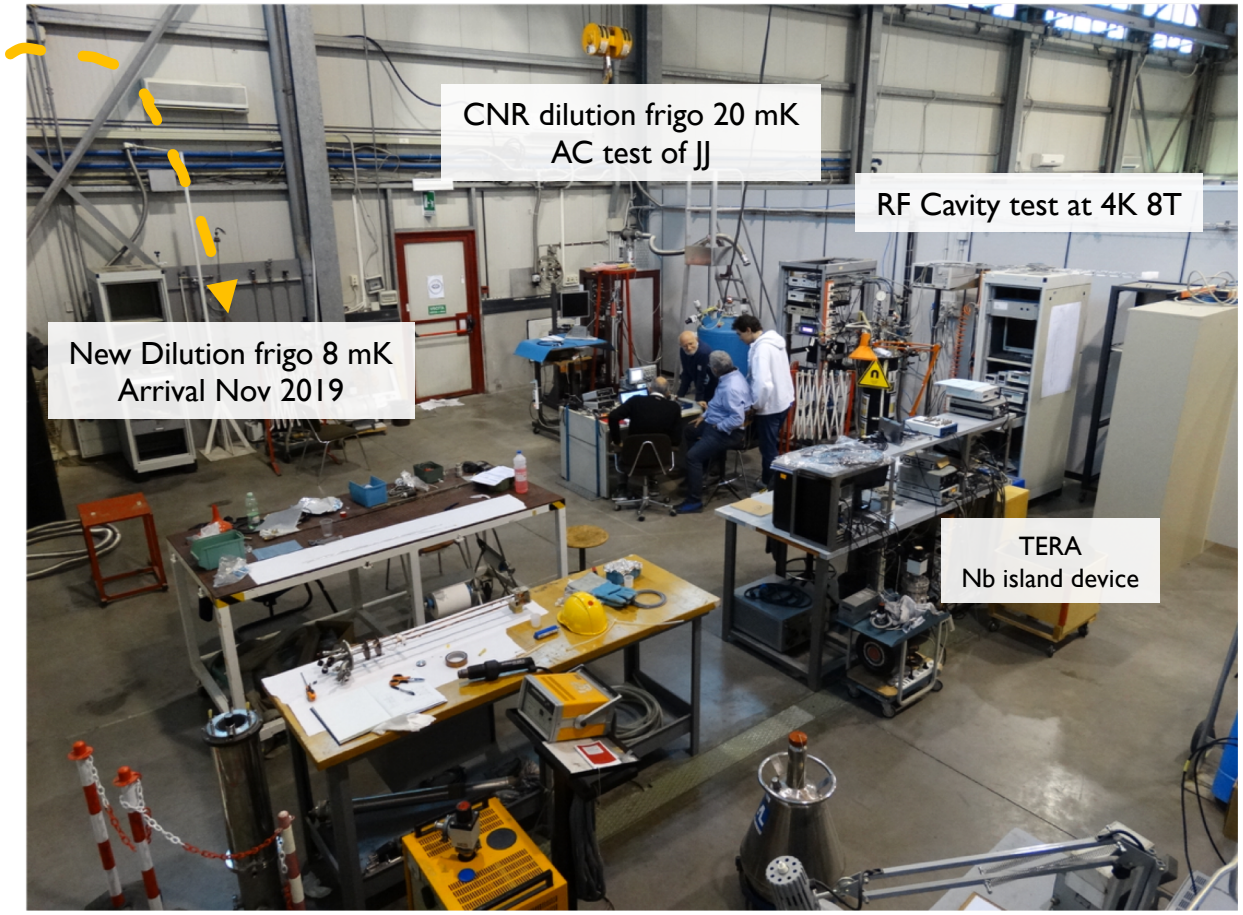
R&D activity on the detection of single microwave photon counters (10-100 GHz)

Supergalax (H2020 project) (2020-2022)
Single microwave photon detection for axion searches

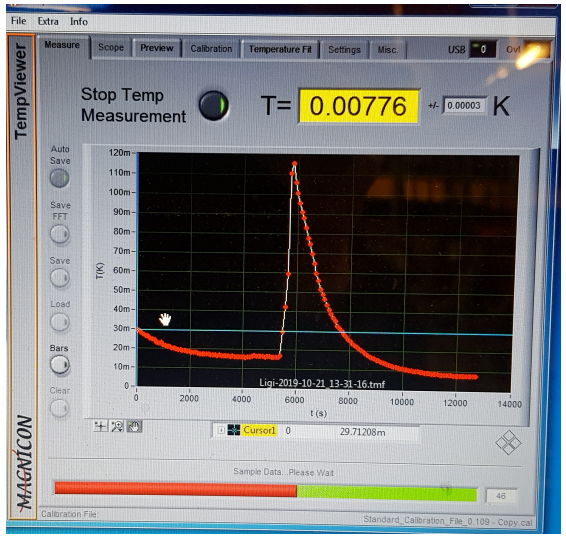
H2020 project FET OPEN

CryOgenic Laboratory for Detectors

LNF 2020 SIMP-QUAX	FTE
Ricercatori LNF	3.2
Ricercatori CNR associati	0.9
Tecnologi	1.6
PhD Student	1
Tot	6.7

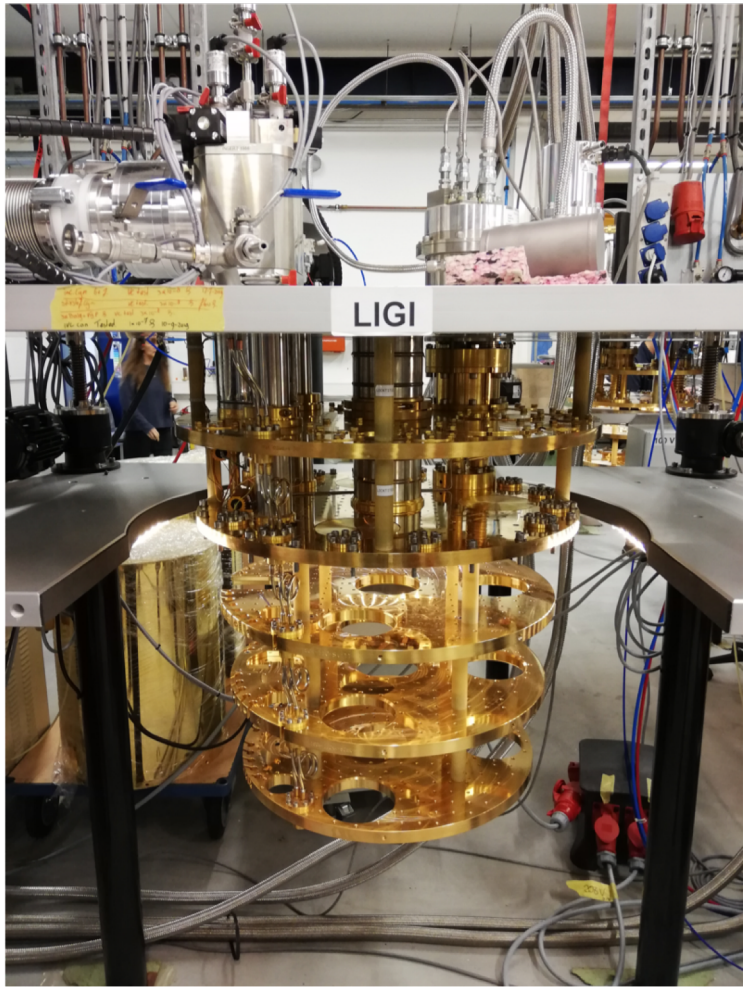


DILUTION REFRIGERATOR



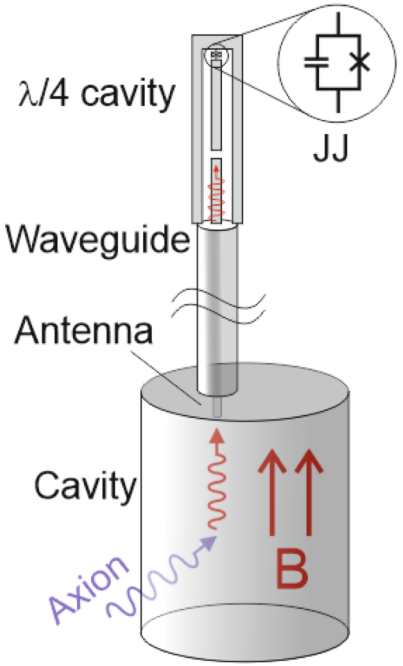
- *CF-CS110-1000* with Sumitomo 1.8 W PT
  (T = 8 mK – Q = 1 mW @ 120 mK)
- GHS refurbished
  - new pressure sensor rack
  - new LCR meter (+ CMN thermometer)
  - new compressor
- 4 coax 20 GHz cables for RF tests installed

Successfully cooled in Leiden!



Shipping to LNF on November the 15th!

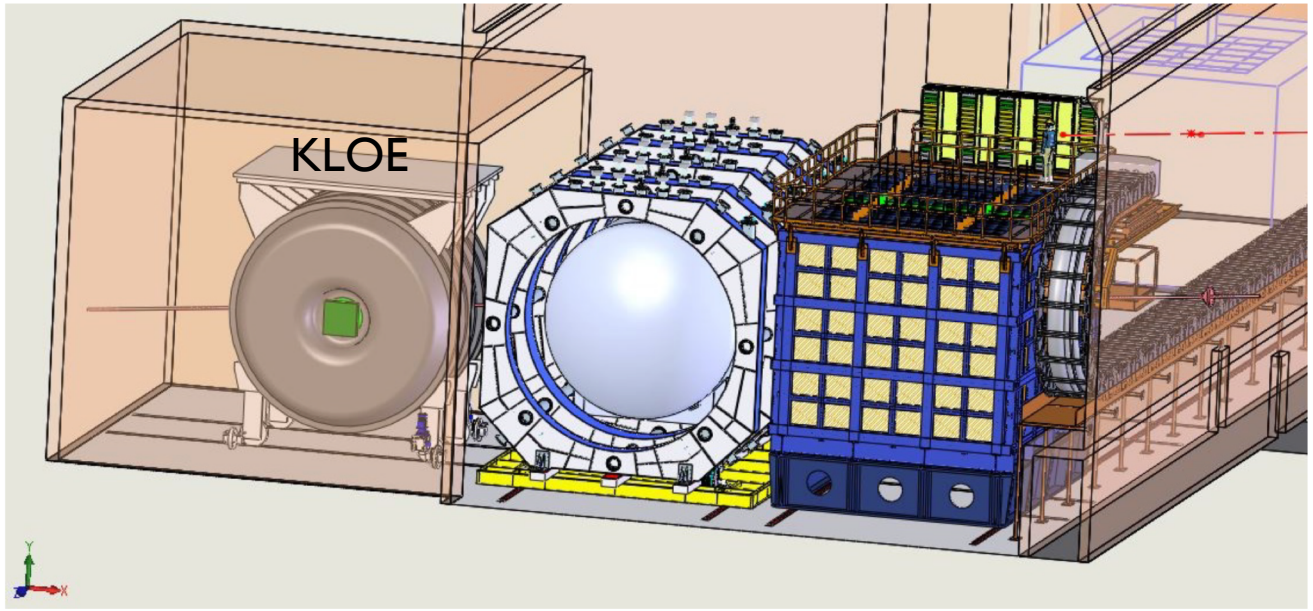
HALOSCOPES



KLASH

KLASH – BAD NEWS

- The KLOE magnet will be used for the DUNE Near Detector at Fermilab



DUNE Near Detector layout

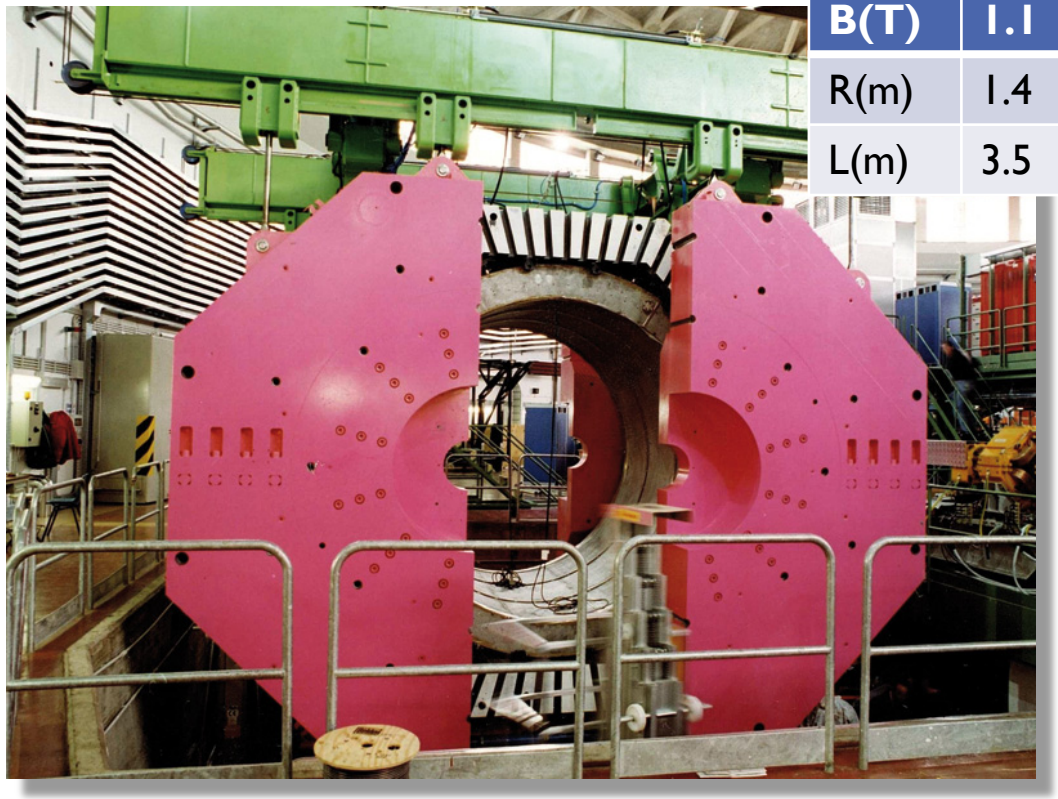
KLASH → FLASH: Finuda magnet for Light Axion SearcH

- SC magnet built by Ansaldo Italia (ASG Supeconductors) for FINUDA experiment
- Similar sensitivity to galactic axions of KLASH

Several aspects to be investigated:

1. Timeline for KLOE shipping to Fermilab if KLOE Hall has to be used as experimental Hall (where else?)
2. Move of the magnet to the KLOE Hall
3. Interference with DAFNE operations
4. Commissioning of the magnet ten years after its shutdown
5. Mechanical robustness of the magnet to withstand the weight of the cryostat

At best, we estimate a delay of at least two years…



B(T)	1.1
R(m)	1.4
L(m)	3.5

KLASH CONCEPTUAL DESIGN REPORT – GOOD NEWS

Physics > Instrumentation and Detectors

KLASH Conceptual Design Report

D. Alesini, D. Babusci, P. Beltrame S.J., F. Björkeroth, F. Bossi, P. Ciambrone, G. Delle Monache, D. Di Gioacchino, P. Falferi, A. Gallo, C. Gatti, A. Ghigo, M. Giannotti, G. Lamanna, C. Ligi, G. Maccarrone, A. Mirizzi, D. Montanino, D. Moricciani, A. Mostacci, M. Mück, E. Nardi, F. Nguyen, L. Pellegrino, A. Rettaroli, R. Ricci, L. Sabbatini, S. Tocci, L. Visinelli

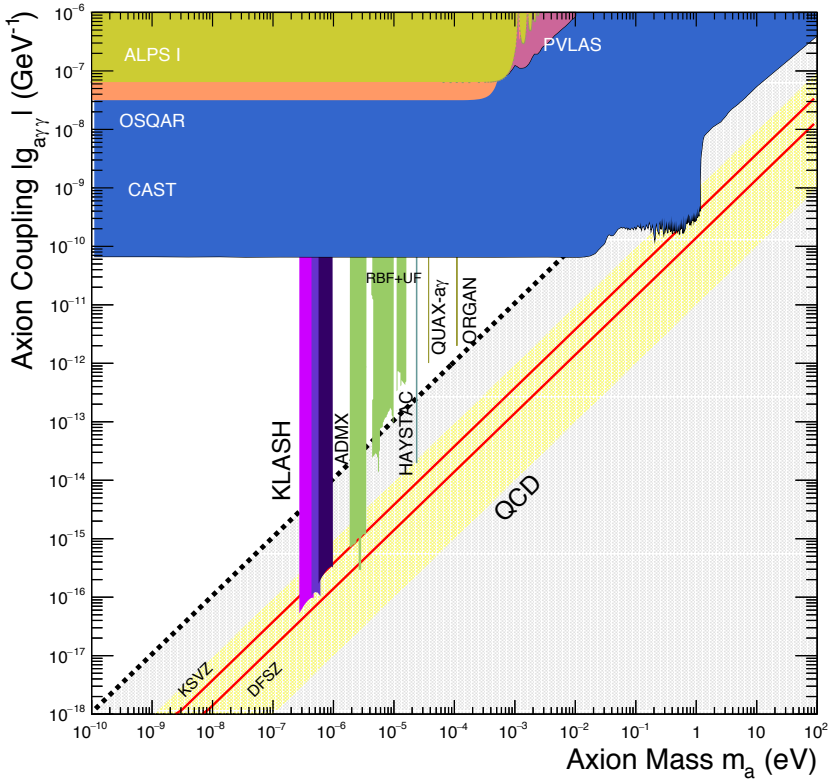
(Submitted on 6 Nov 2019)

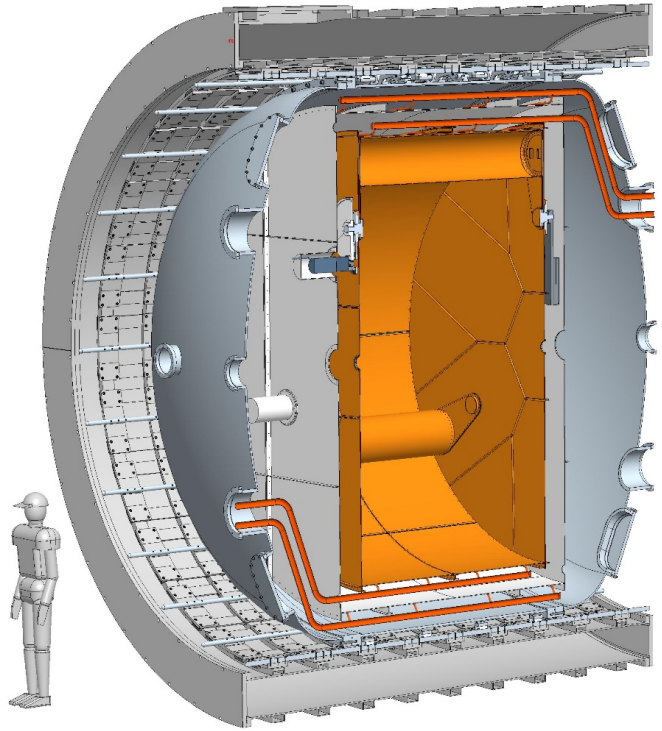
The last decade witnessed an increasing interest in axions and axion-like particles with many theoretical works published and many new experimental proposals that started a real race towards their discovery. This paper is the Conceptual Design Report of the KLASH (KLoe magnet for Axion SearcH) experiment at the Laboratori Nazionali di Frascati (LNF). The idea of this experiment has been stimulated by the availability of the large volume superconducting magnet, with a moderate magnetic field of 0.6 T, used in the KLOE detector at the DAFNE collider. The main conclusion we draw from this report is the possibility to build and put in operation at LNF in 2–3 years a large haloscope with the sensitivity to KSVZ axions in the low mass range between 0.2 and 1 μeV, complementary to that of other experiments. Timeline and cost are competitive with respect to other proposals in the same mass region thanks to the availability of most of the infrastructure, in particular the superconducting magnet and the cryogenics plant.

CDR (80 pp) covers: Physics Case; Physics Reach; Mechanical Design; Cryogenics; RF Design; Signal Amplification; Analysis. Strong effort from everybody and great collaboration with LNF Theory Group!

KLASH CONCEPTUAL DESIGN REPORT – GOOD NEWS

KLASH sensitivity to axions in 3.5 years of data taking

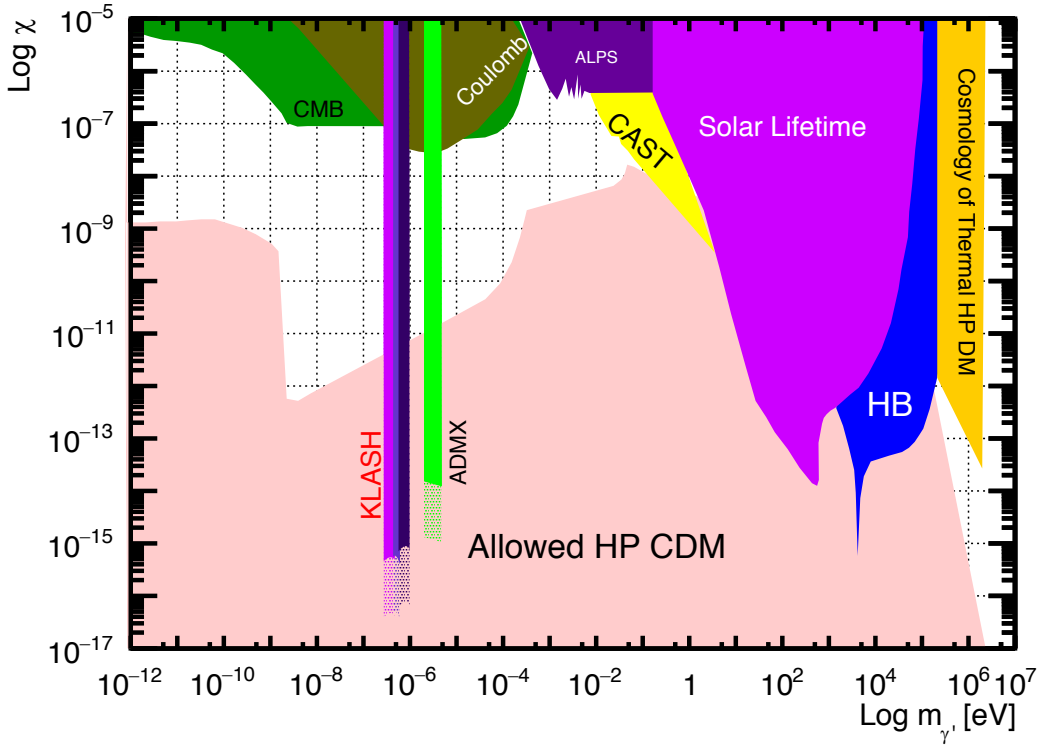


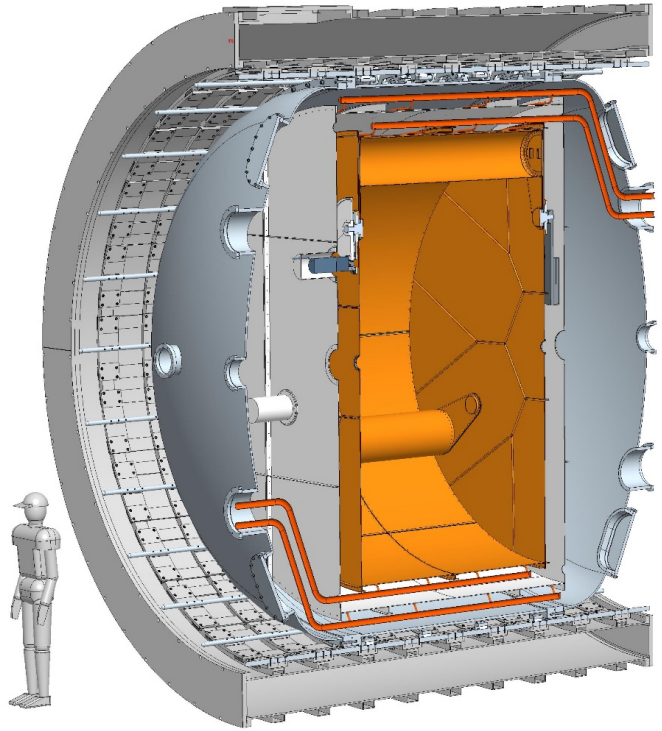


KLASH layout

KLASH CONCEPTUAL DESIGN REPORT – GOOD NEWS

KLASH sensitivity to Hidden Photons in 3.5 years of data taking





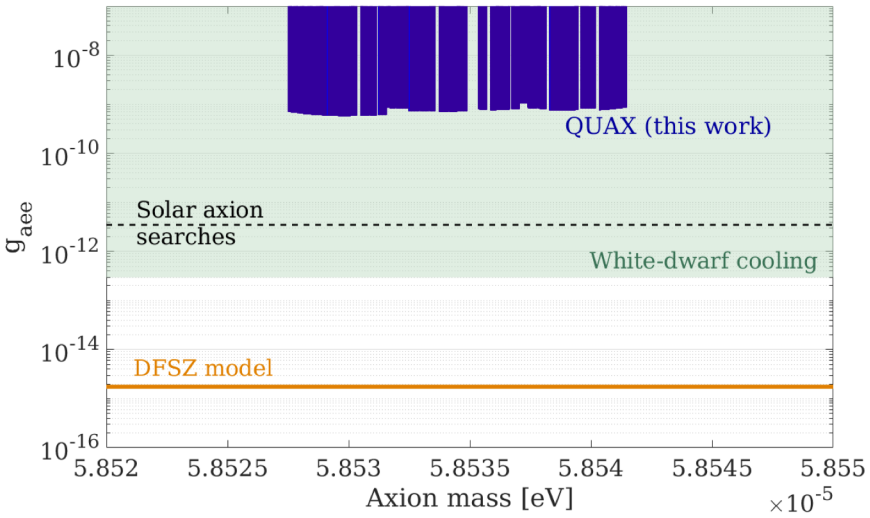
KLASH layout

QUAX


Palmer
Making Candy Fun
QUAX
The Yummy Ducky
HOLLOW MILK
FLAVORED
Candy Duck
NET WT
2 OZ (56g)

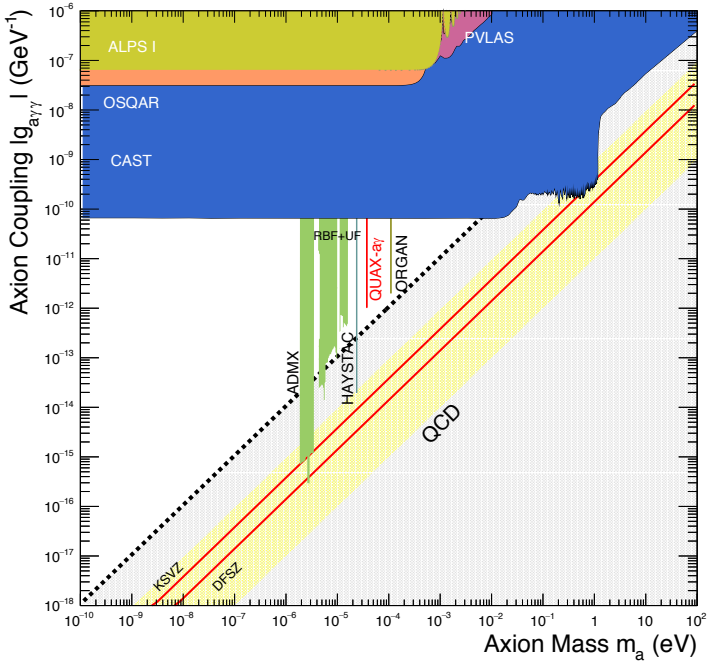
QUAX: Quest for Axions

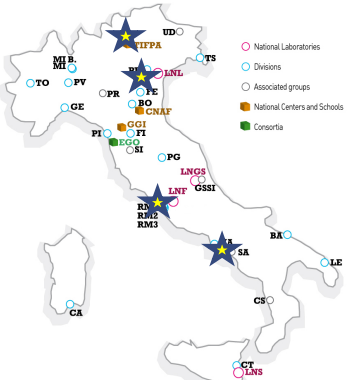
QUAX-ae



EPJC (2018) 78:703

QUAX-aγ





Research Units
Padova (Nat Resp)
LNL (experiment site)
LNF (experimental site)
TIFPA FBK
Salerno

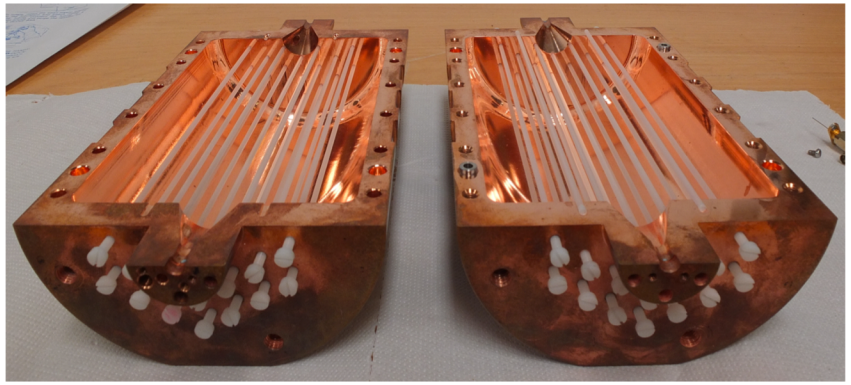
"Axion Search with Superconductive resonant cavity"

Phys. Rev. D **99**, 101101(R) (2019)

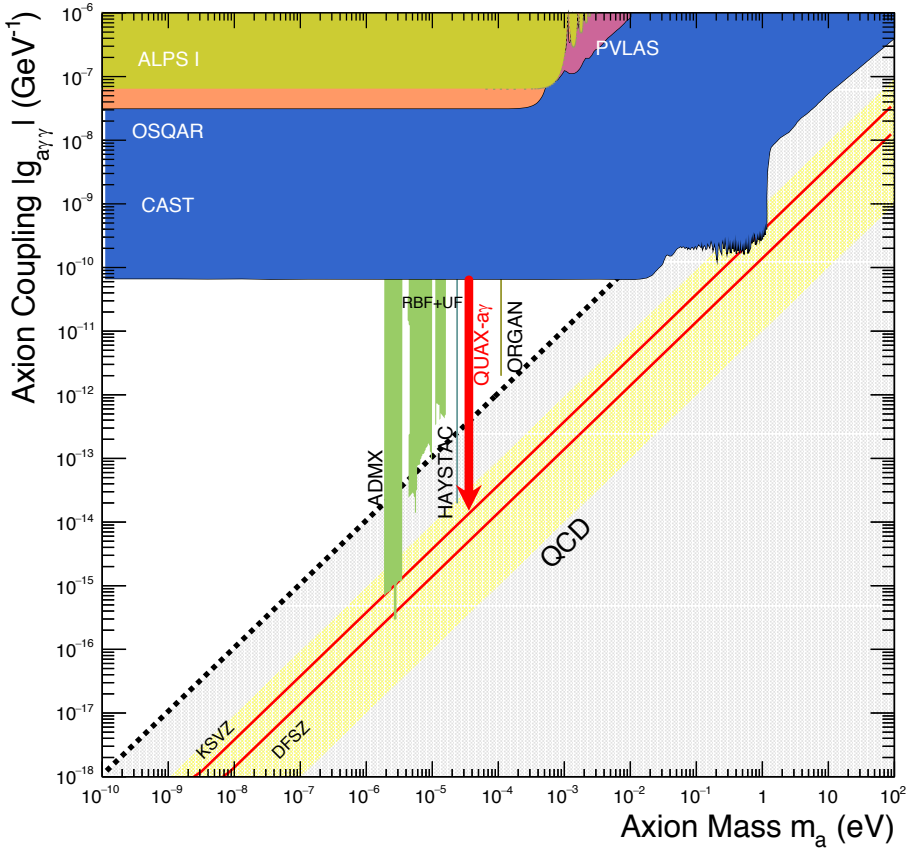
Sensitivity Improvements Expected for QUAX-aγ

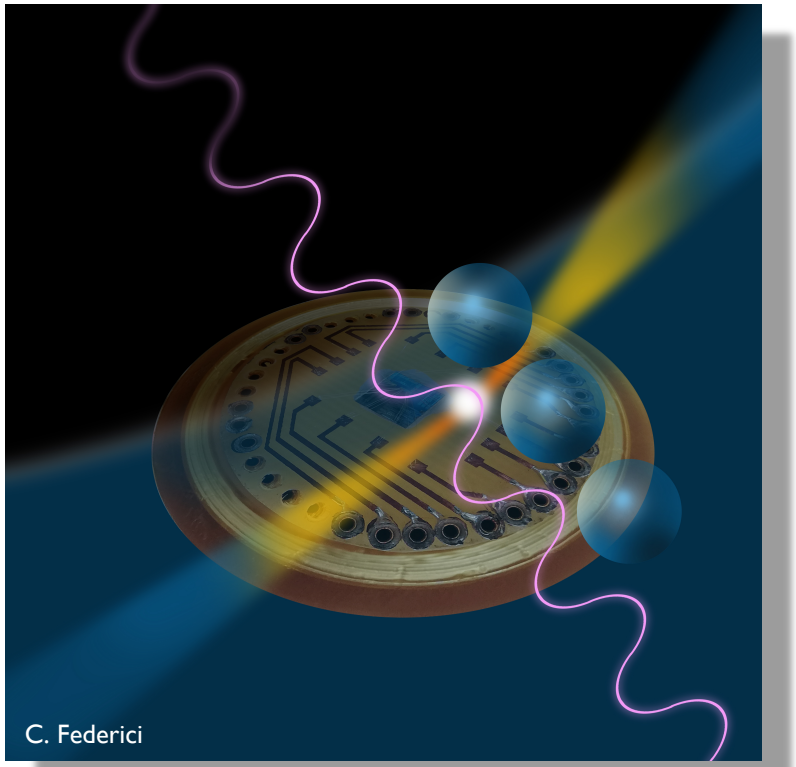
We plan to reach axion band next year, with the following improvements:

1. 2 Haloscopes (LNL and LNF): first measurement at LNF in Sept. 2020
2. Dilution refrigerator: T=50 mK
3. Quantum Limited Amplifier (JPA): T_{noise}=500 mK
4. Stronger Magnet: 10 T
5. New resonant cavities: SC; Photonic; Dielectric, etc.



PBG cavity: paper in preparation



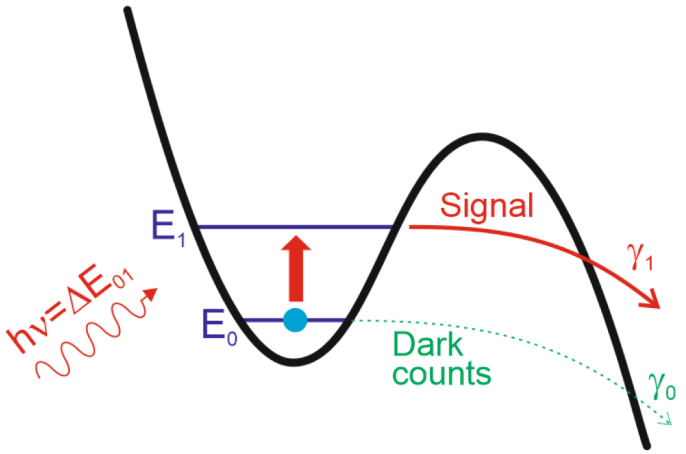


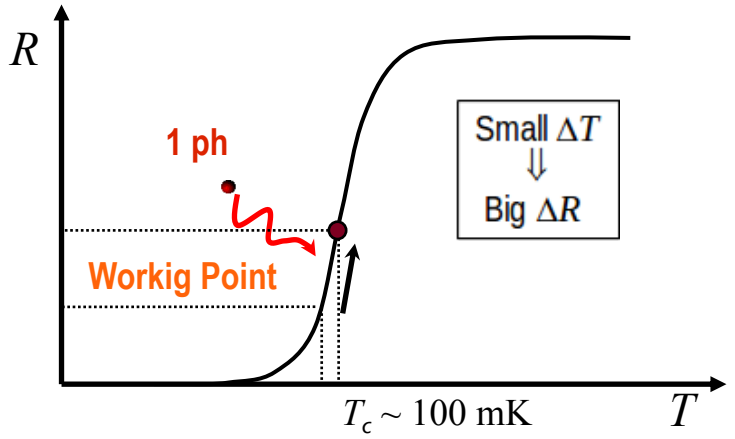
SINGLE MICROWAVE PHOTON DETECTION

SIMP: SIngle Microwave Photon detection

Development of single microwave photon counter (10-100 GHz) with two technologies:

1. Current biased Josephson Junction (LNF, Salerno, CNR-IFN)
2. Transition Edge Sensor (INFN-Pi, CNR Nano-NEST, TIFPA, INRIM)



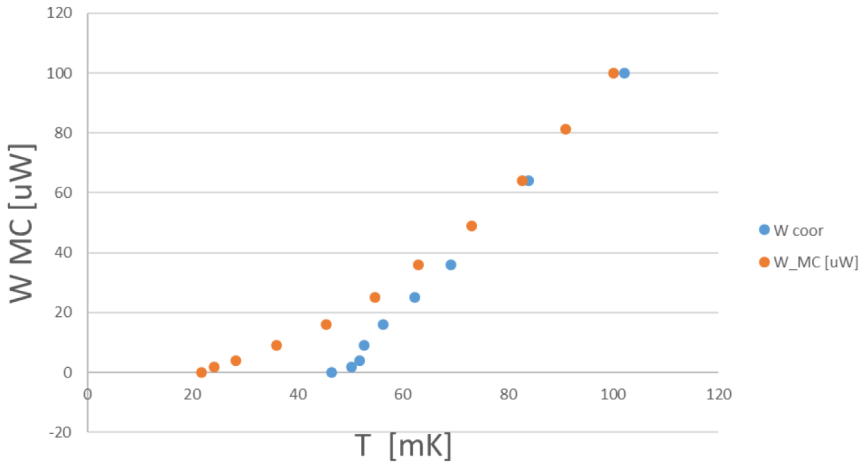


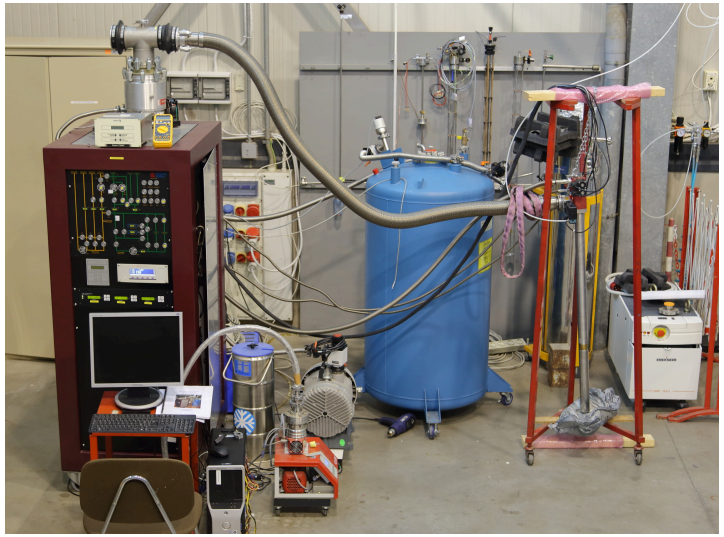
Unità
LNF (Nat Resp)
INFN Pi
INFN Sa
TIFPA-FBK
CNR Nano NEST
CNR IFN
INRIM

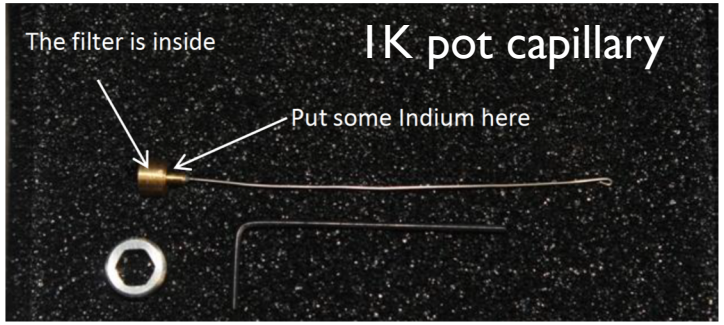
Test of Josephson Junctions at LNF

Leiden Cryogenics MCK50-100

- CNR dilution refrigerator put in operation after fixing problems with 1K Pot and Sorption Pump.

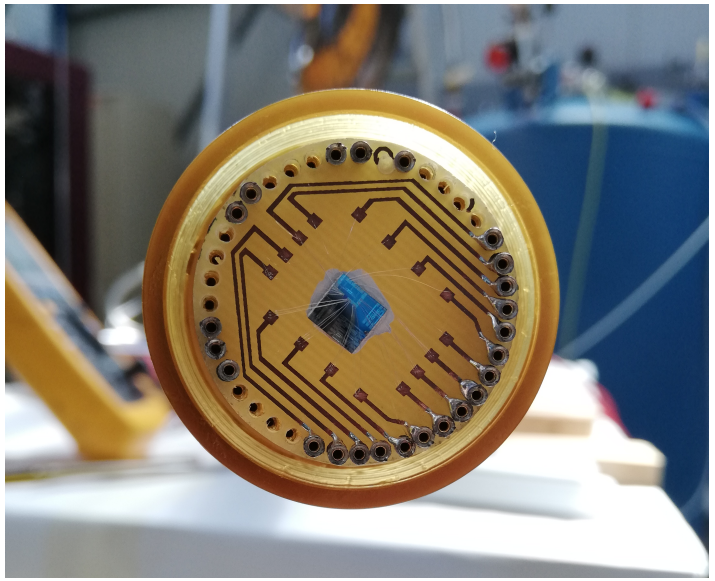


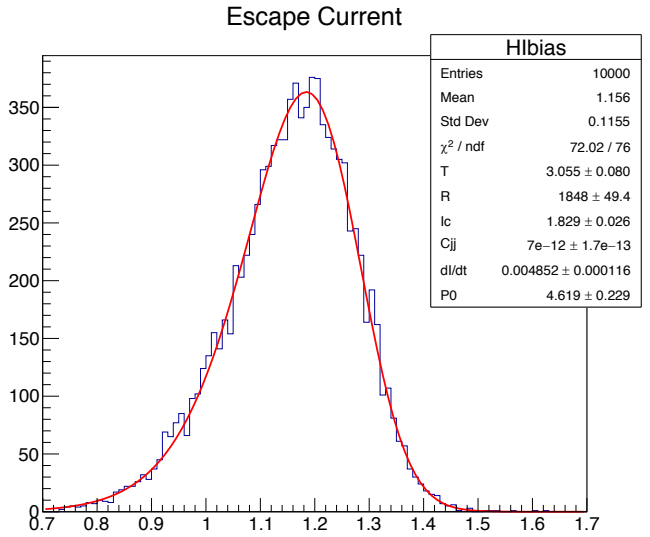


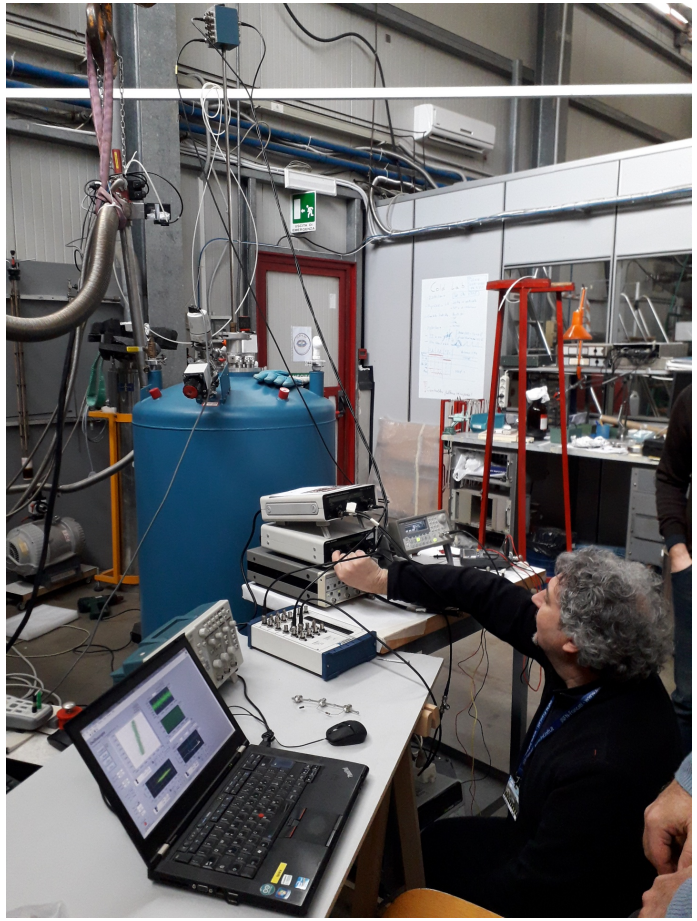


Test of Josephson Junctions at LNF

- CNR dilution refrigerator put in operation after fixing problems with 1K pot and sorption pump.
- Measurement of Escape Currents of a Nb JJ at 4 K

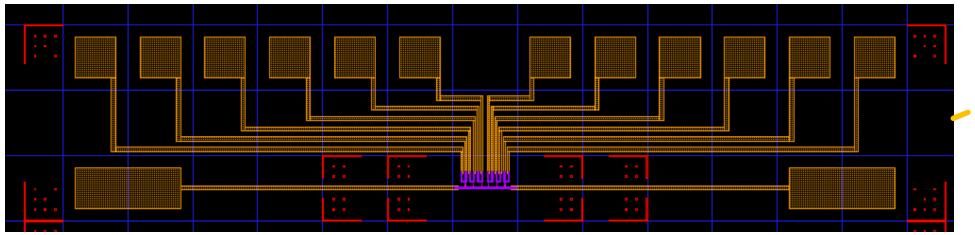






Test of Josephson Junctions at LNF

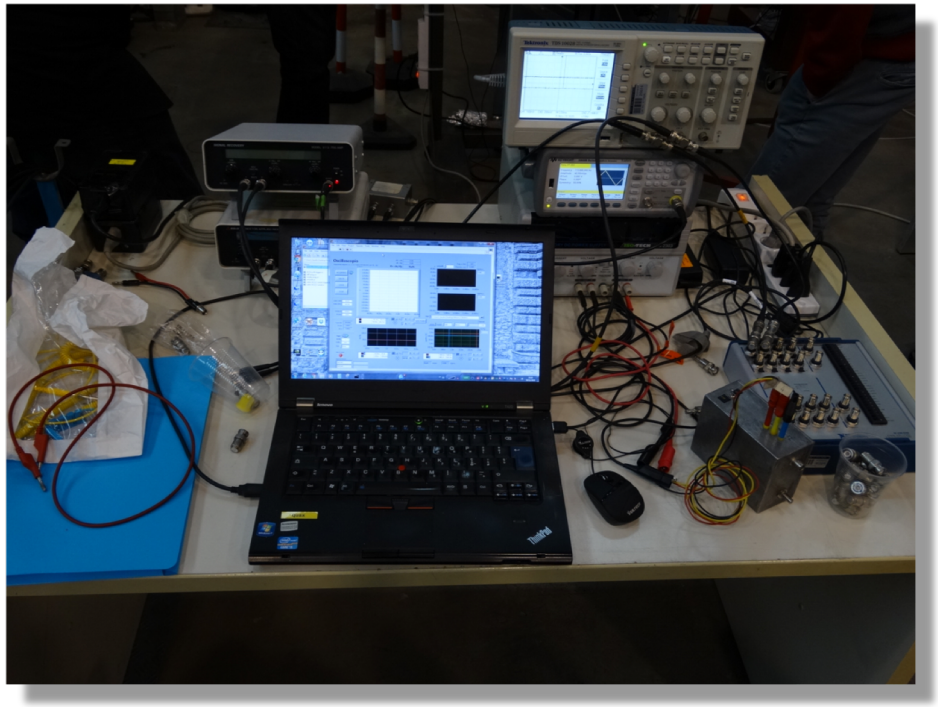
- CNR dilution refrigerator put in operation after fixing problems with 1K pot and sorption pump.
- Measurement of Escape Rates of a Nb JJ at 4 K
- Fabrication at CNR-IFN of chips with Al Junctions.



Test of Josephson Junctions at LNF

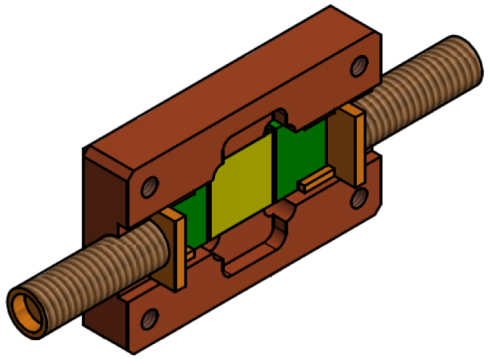
- CNR dilution refrigerator put in operation after fixing problems with 1K pot and sorption pump.
- Measurement of Escape Rates of a Nb JJ at 4 K
- Fabrication at CNR-IFN of chip with Al Junctions.

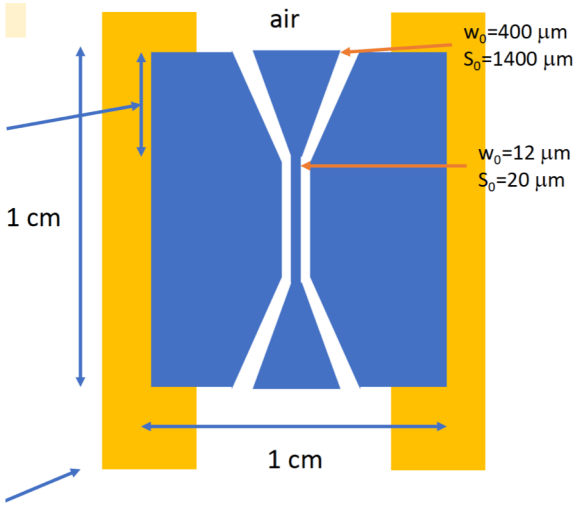
Test of Al chip at 20 mK this week!

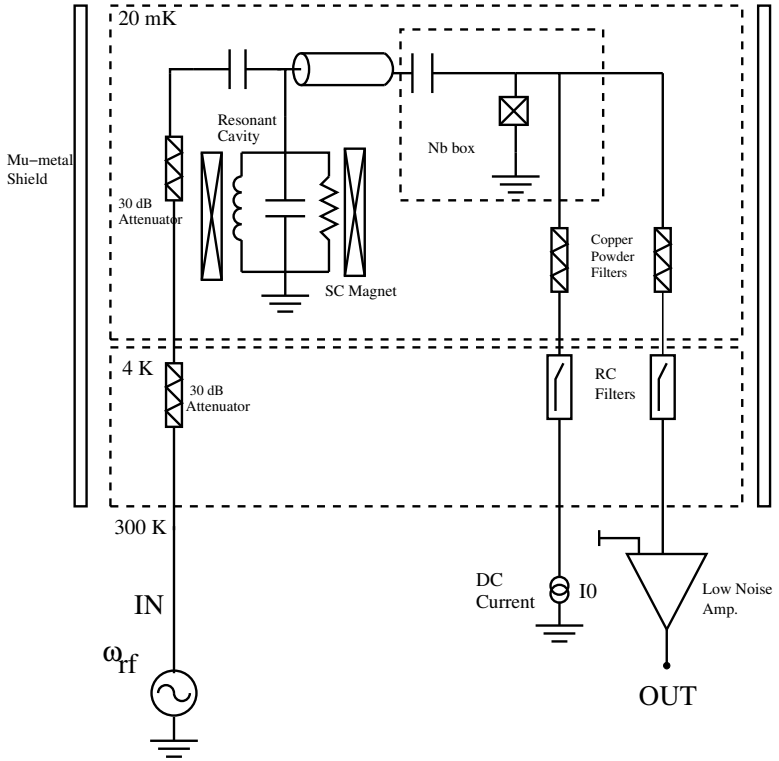


Getting Ready for RF Measurements

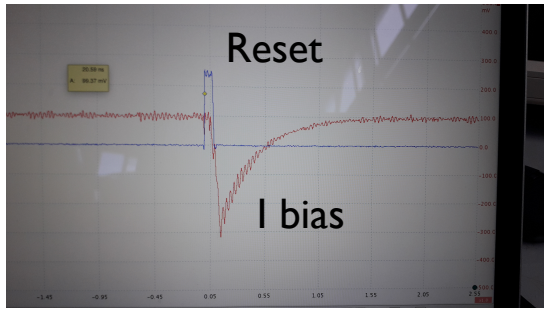
Sample holder for RF chip







Electronics for biasing JJ



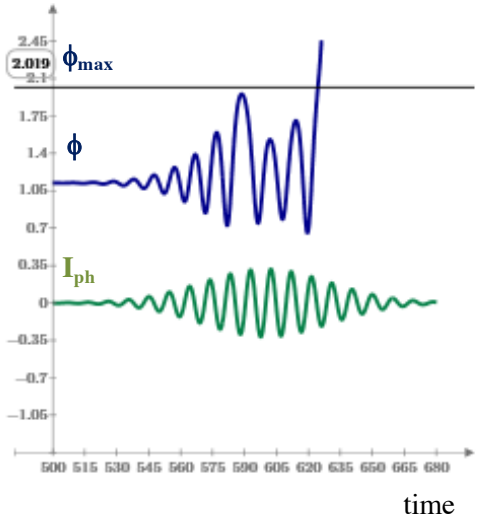
Purchases made for RF measurements:

1. Wave function generator 20 GHz
2. Cryogenic Low Noise Amplifier 8-12 GHz
3. Room T Low Noise Amplifier 8-12 GHz
4. Cryogenic Circulator 8-12 GHz
5. Room T Mixer 10-12 GHz
6. NI ADC board
7. SC coax cables
8. Metal powder Filters
9. Microwave connectors, attenuators etc.
10. SR 560 LF Low Noise amplifier
11. Wavefunction generator 30 MHz
12. Power supply
13. ….

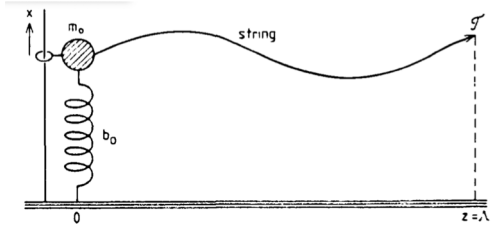
JJ SIMULATION

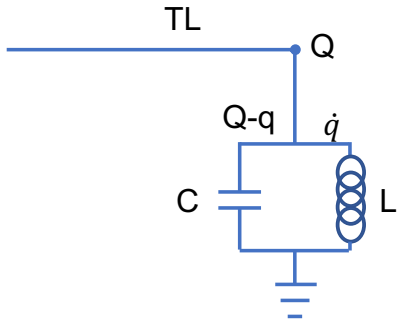
Strong effort in collaboration with CNR-IFN and Salerno group to describe and simulate JJ device (next project milestone) and define the best junction parameters.

Classical description of a driven JJ



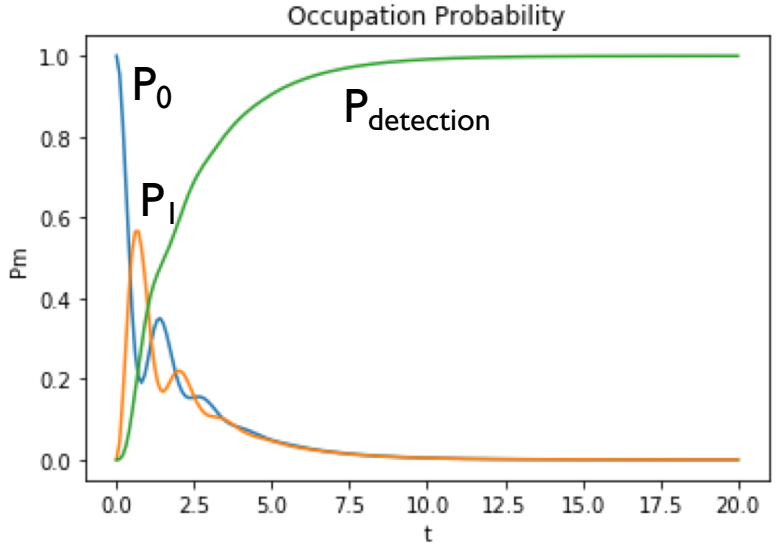
Transmission Line terminated with JJ





$$L = \frac{1}{2}\int_0^d dz\left[C_0\dot{\phi}(z,t)^2 - \frac{1}{L_0}\phi'(z,t)^2\right] + \frac{1}{2}C_J\dot{\phi}(0,t)^2 - \frac{1}{2L_J}\phi(0,t)^2 + \frac{1}{6}I_0\left(\frac{2\pi}{\Phi_0}\right)^2\phi(0,t)^3$$

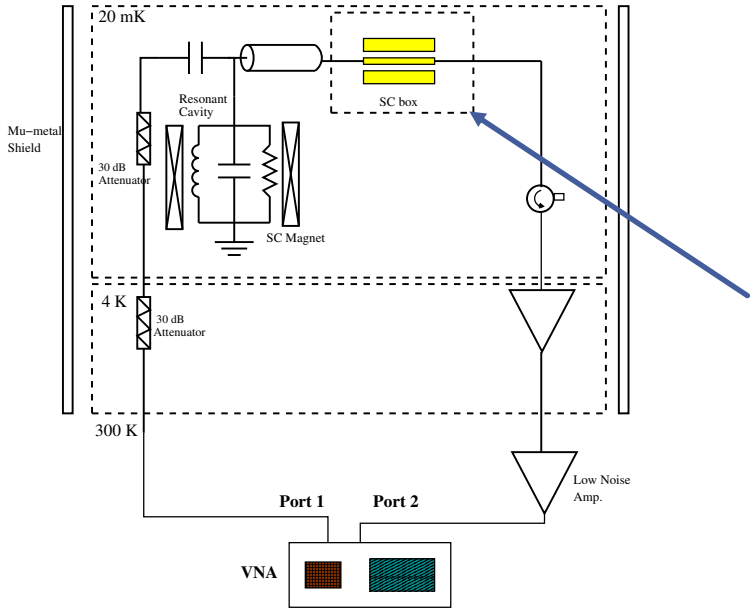
Simulation of quantum system TL+JJ

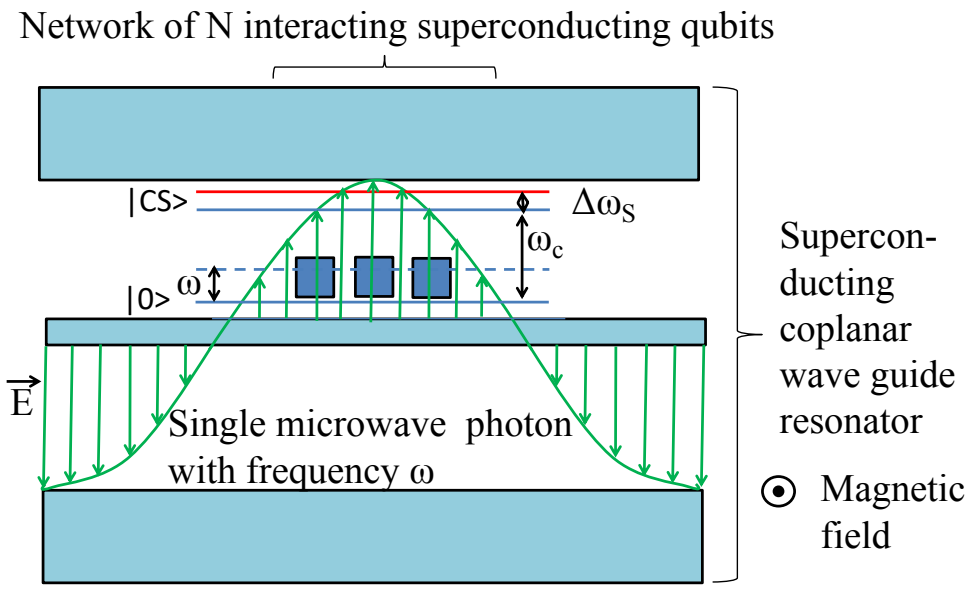


Simulation based on Schondorf et al. arXiv:1609.08887

SUPERGALAX: Highly sensitive detection of single microwave photons with coherent quantum network of superconducting qubits for searching galactic axions

Budget 2.7 M€
CNR (IT, PI, exp)
INRIM (IT, exp)
INFN (IT, axion exp)
KIT (DE, exp)
Leibniz IPHT (DE, exp)
RUB (DE theory)
LU (UK, theory)





Measure a shift of cavity resonance peak (Stark shift) when there's a photon

The LNF group will test the device in a Haloscope and search axions in the mass range 40-50 μeV (QUAX range)

INFN and IBS-CAPP Agreement for Cooperation in Axion Physics

ISTITUTO NAZIONALE DI FISICA NUCLEARE
CONSIGLIO DIRETTIVO
DELIBERAZIONE N. 15141
Maggio 2019

The Parties agree that the collaboration shall include as priority activities the following:
1. Development of high quality factor resonant cavities, including superconducting cavities
2. Development of cavity design for high frequencies, including multi-cavity detectors (photonics band gap technique)
3. Development of quantum-limited noise amplifiers
4. Development of single photon counters
5. Development of high-field large-volume superconducting magnets
6. Participation in axion experiments at both bases

IMPLEMENTING ARRANGEMENT N . 1
TO THE FRAMEWORK AGREEMENT

BETWEEN

THE ISTITUTO NAZIONALE DI FISICA NUCLEARE (INFN), ITALY

AND

THE INSTITUTE OF BASIC SCIENCE - CENTRE FOR AXION AND PRECISION PHYSICS (IBS-CAPP), KOREA

FOR COOPERATION IN THE AREAS OF AXION PHYSICS

CONCLUSIONS

- In few years we:
  1. set up a new cryogenic and RF laboratory
  2. joined the QUAX R&D and helped make it an experiment
  3. started a new R&D project in CSN V (SIMP)
  4. joined the H2020-project Supergalax

  this was also done with the help of LNF
- We are developing frontier technologies to improve the sensitivity of axion experiments
- We are ready to setup our own haloscope for axions in the mass range 40-50 μeV
- KLASH will not be done … maybe FLASH will be, but with a less aggressive timescale …
- In any case, the search for axions at LNF started!