AXION Searches - FLASH

Claudio Gatti - LNF

Physics Beyond Colliders Annual Workshop, CERN 27 Mar 2024

COLD@LNF

CryOgenic Laboratory for Detectors:

- Axion Dark Matter Experiments
- Quantum Sensing with Superconducting Devices
- Type II and HTC Superconducting Cavities

COSMIC WISPERS
CA 21106

ICSC
Centro Nazionale di Ricerca in HPC,
Big Data and Quantum Computing

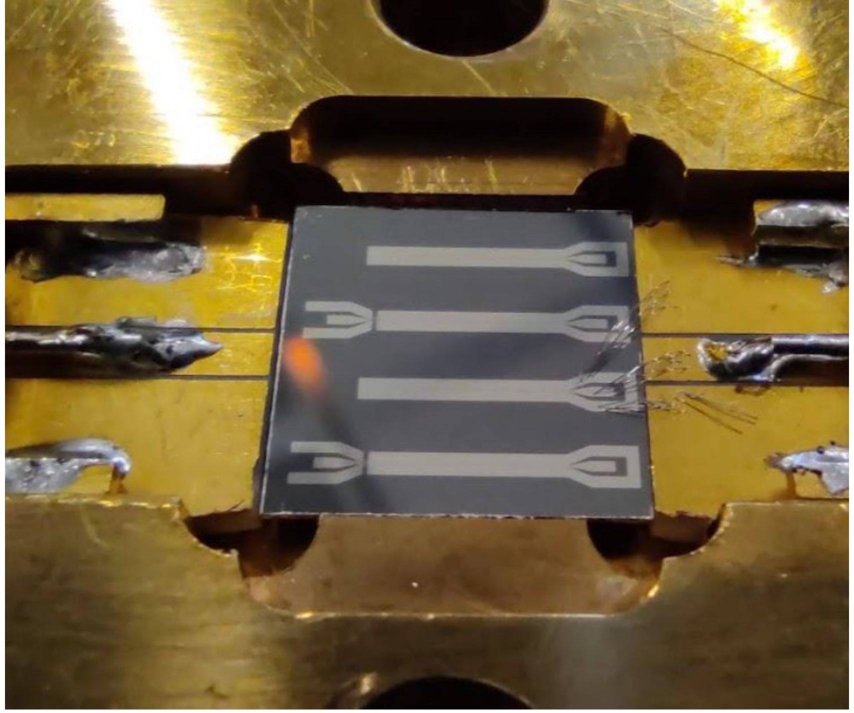
DART WARS

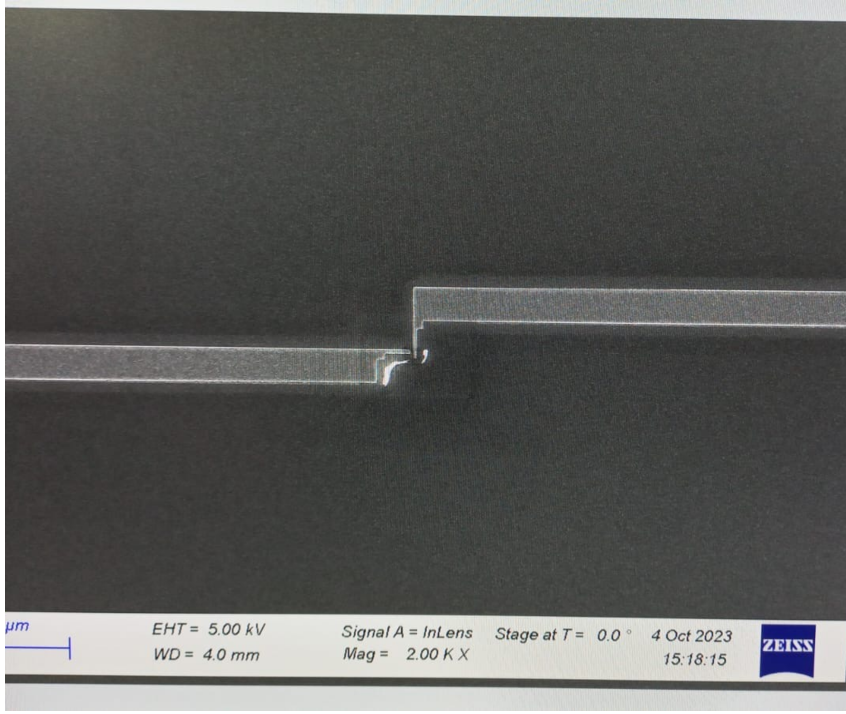
Qub-IT

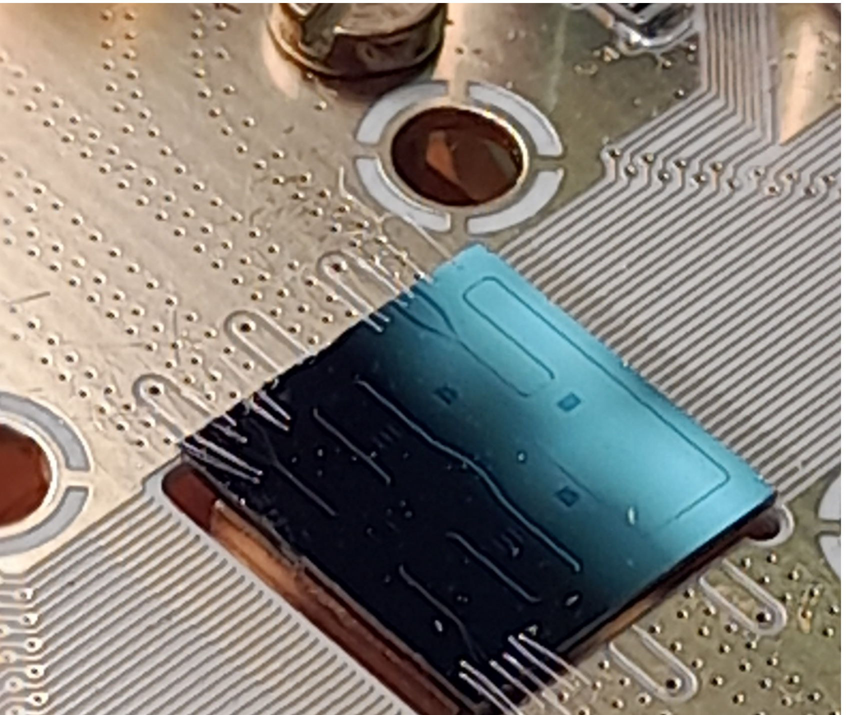
NQSTI
National Quantum Science and Technology Institute

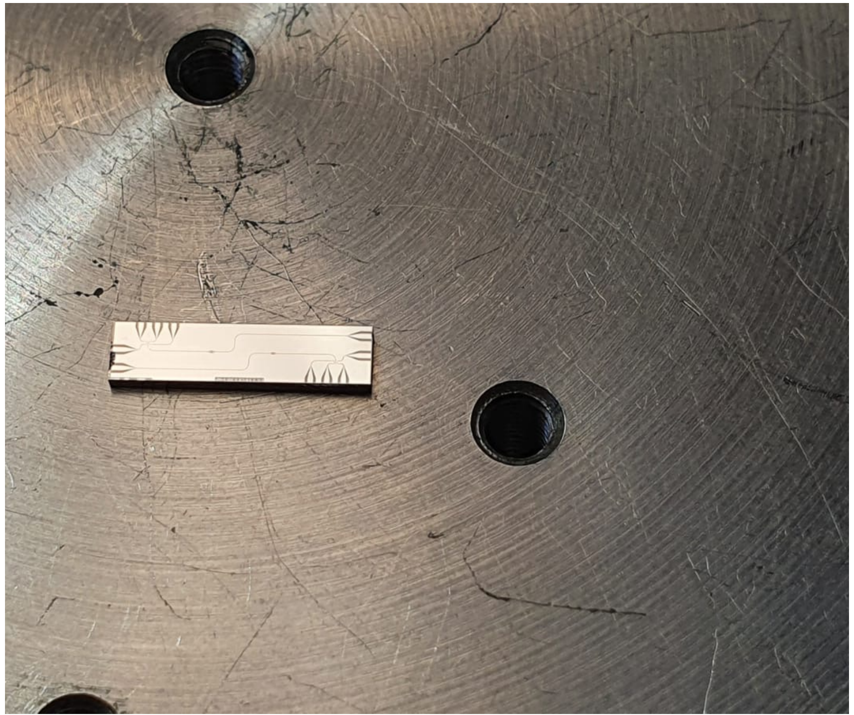
SUPERGALAX

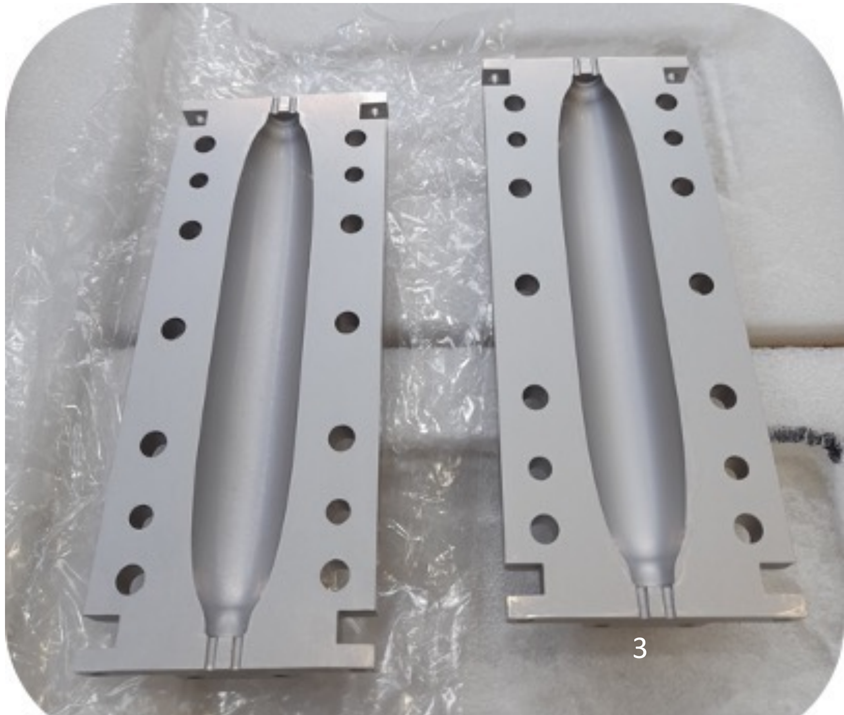
SQMS




µm
EHT = 5.00 kV
WD = 4.0 mm
Signal A = InLens
Mag = 2.00 K X
Stage at T = 0.0 °
4 Oct 2023
15:18:15





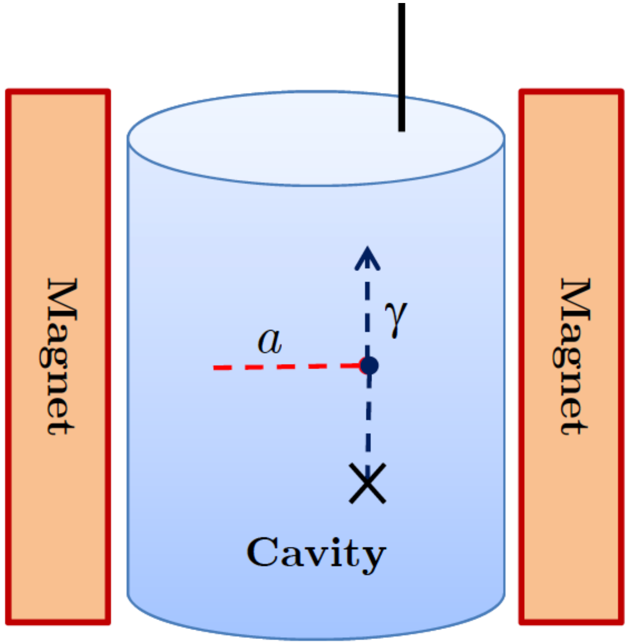


Sikivie's Haloscope

$$\nabla^2 E - \partial_t^2 E = -g_{a\gamma\gamma} B_0 \partial_t^2 a$$

Solving the equation inside a cylindrical resonant cavity, the signal power is

$$P_{\text{sig}} = \left(g_\gamma^2 \frac{\alpha^2}{\pi^2} \frac{\hbar^3 c^3 \rho_a}{\Lambda^4} \right) \times \left(\frac{\beta}{1+\beta} \omega_c \frac{1}{\mu_0} B_0^2 V C_{mnl} Q_L \right)$$



β antenna coupling to cavity

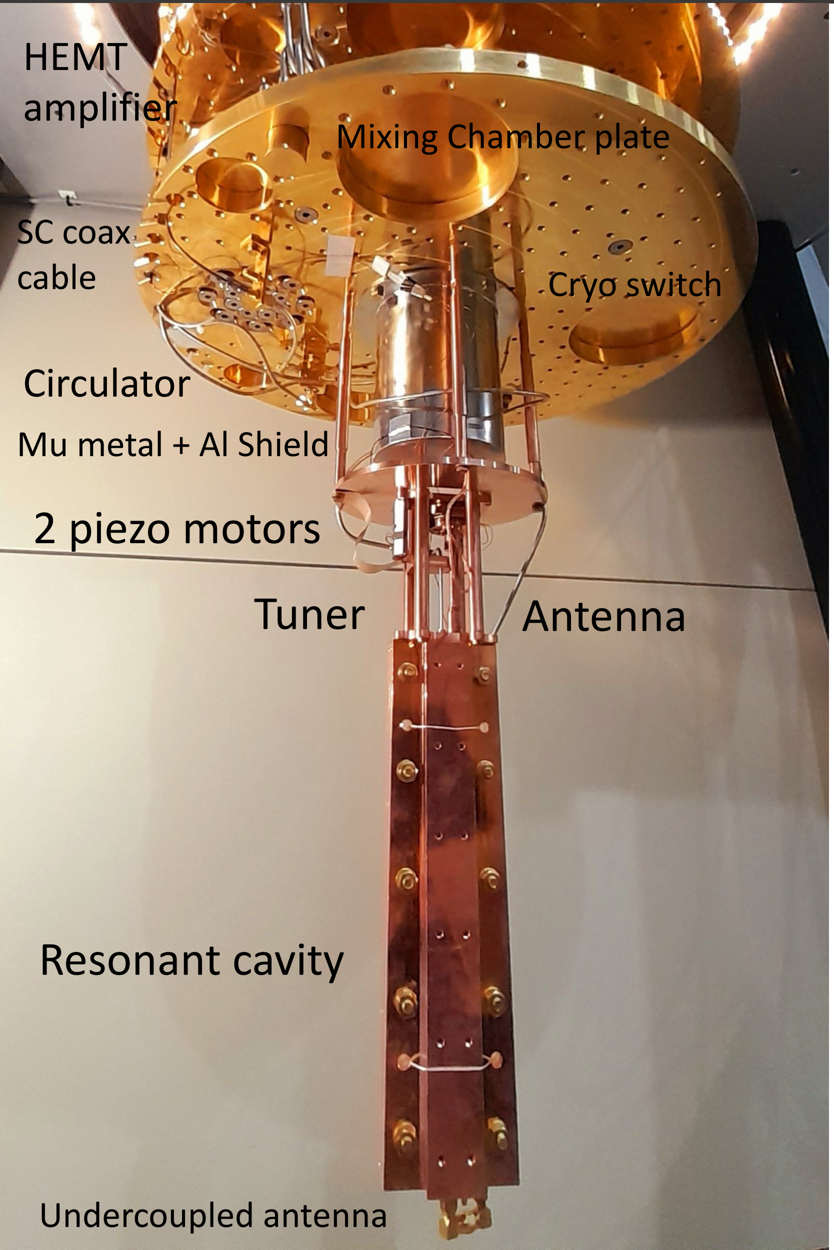
V cavity volume

C_{mnl} mode dependent factor about 0.6 for TM010

Q_L cavity "loaded" quality factor

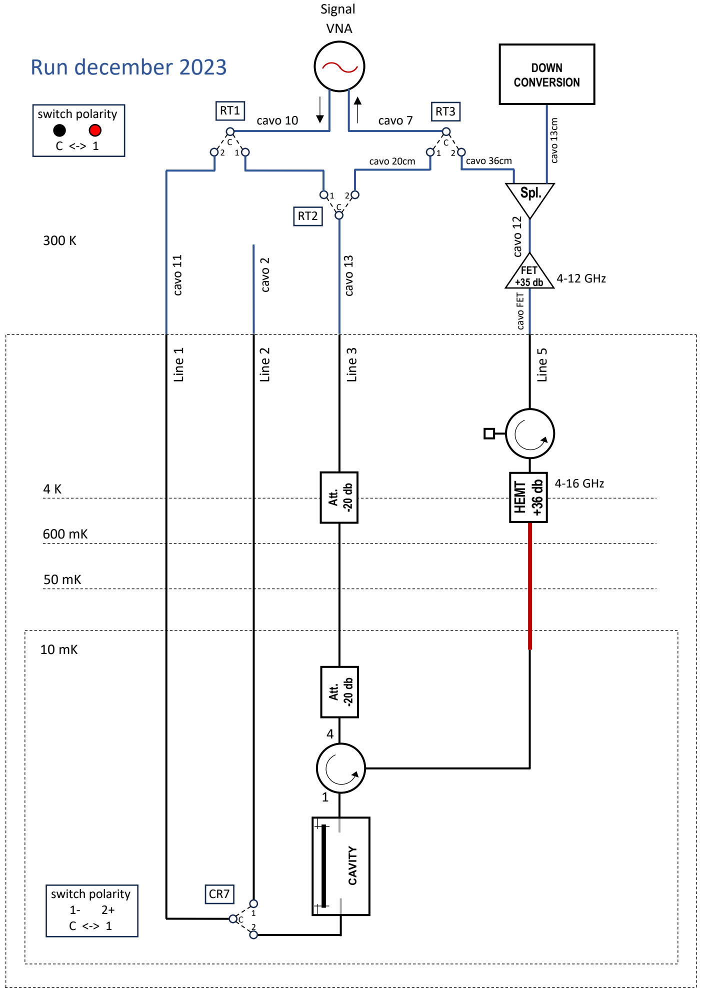
Sikivie Phys. Rev. D 32,11 (1985)

QUAX@LNF: The LNF Axion Haloscope



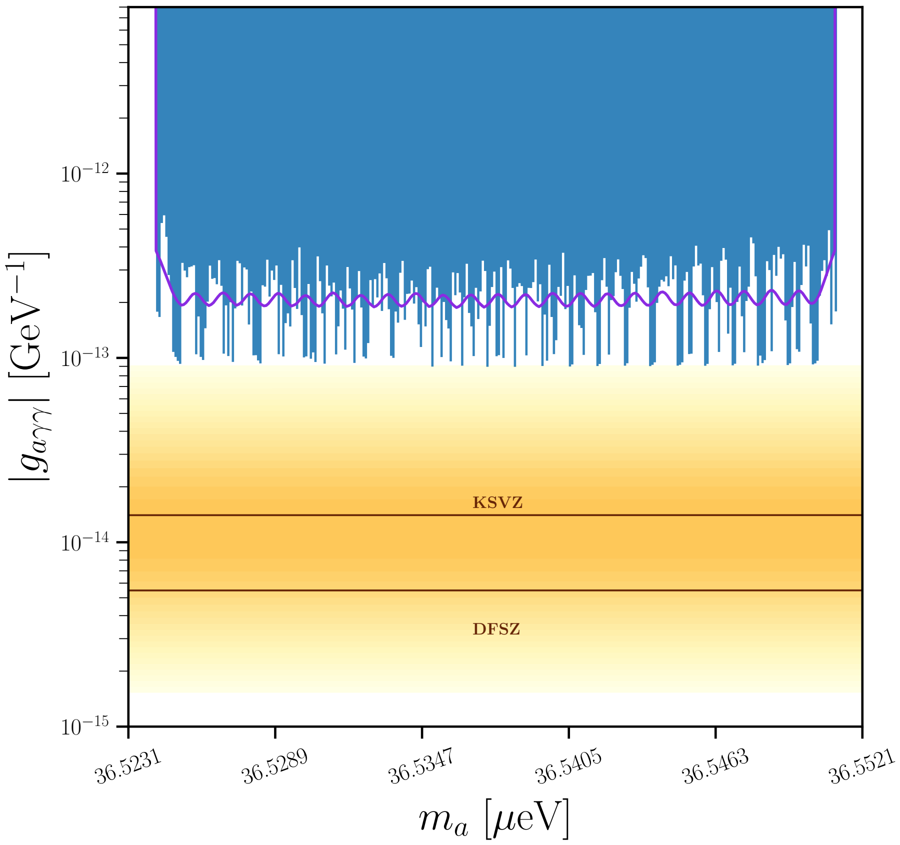
December 2023 Run

- Cavity temperature 30 mK
- Magnetic Field B=8 T
- Frequency 8.8 GHz
- Copper cavity Q_0=50,000 with tuner
- HEMT amplifier
- Tnoise 4K
- 2 weeks data taking
- 6 MHz scan



QUAX@LNF Results for 2023 Run

- 24 runs, 1 hour each, 250 kHz of frequency steps
- Average exclusion 90% c.l. $g_{a\gamma\gamma} = 2\times10^{-13}\ GeV^{-1}$
- Preprint arXiv:2404.19063

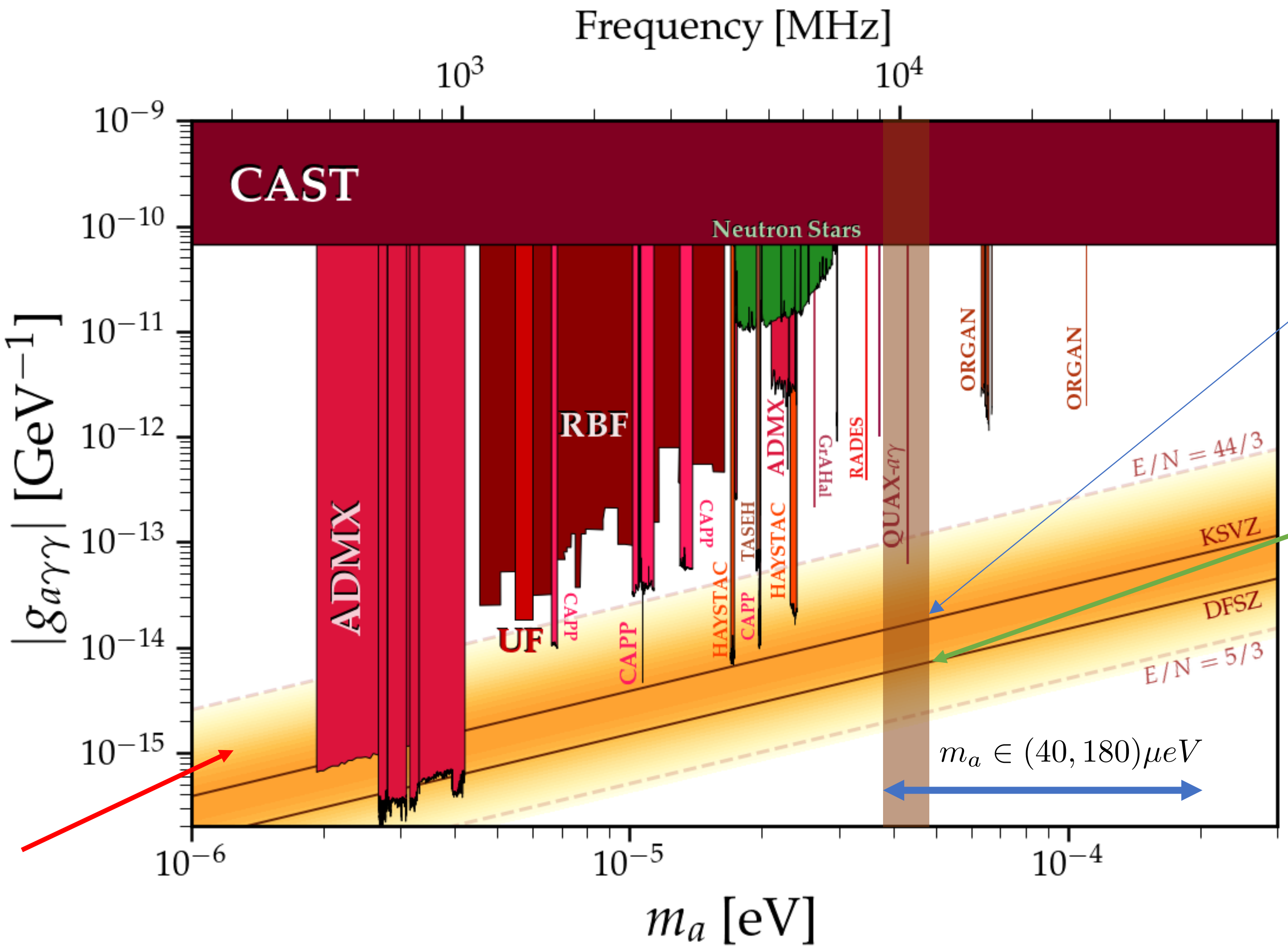


ν_c [GHz]	Q_L	β
8.83176900	32345	0.5206
8.83203080	32228	0.519
8.83229550	32273	0.5082
8.83255580	32332	0.5141
8.83282190	32387	0.5097
8.83307310	32401	0.5078
8.83334500	32300	0.5097
8.83360070	32503	0.5058
8.83386200	32540	0.5075
8.83412790	32752	0.5014
8.83438580	32573	0.5026
8.83464620	32904	0.5005
8.83490660	32957	0.4984
8.83516350	32863	0.4951
8.83542850	32872	0.4947
8.83568970	33326	0.4881
8.83594630	33051	0.489
8.83620570	33056	0.4894
8.83646975	33104	0.4857
8.83672330	33584	0.4823
8.83698660	33529	0.4803
8.83724500	33659	0.4823
8.83750860	33639	0.4793
8.83776640	33450	0.4793

QUAX LNF&LNL 2023-2025

LNF:
- Superconducting cavity $Q_0 > 2\times10^5$
- B=9T
- Multicavity

LNL:
- Dielectric cavity $Q_0>10^6$
- B=14 T
- Single cavity



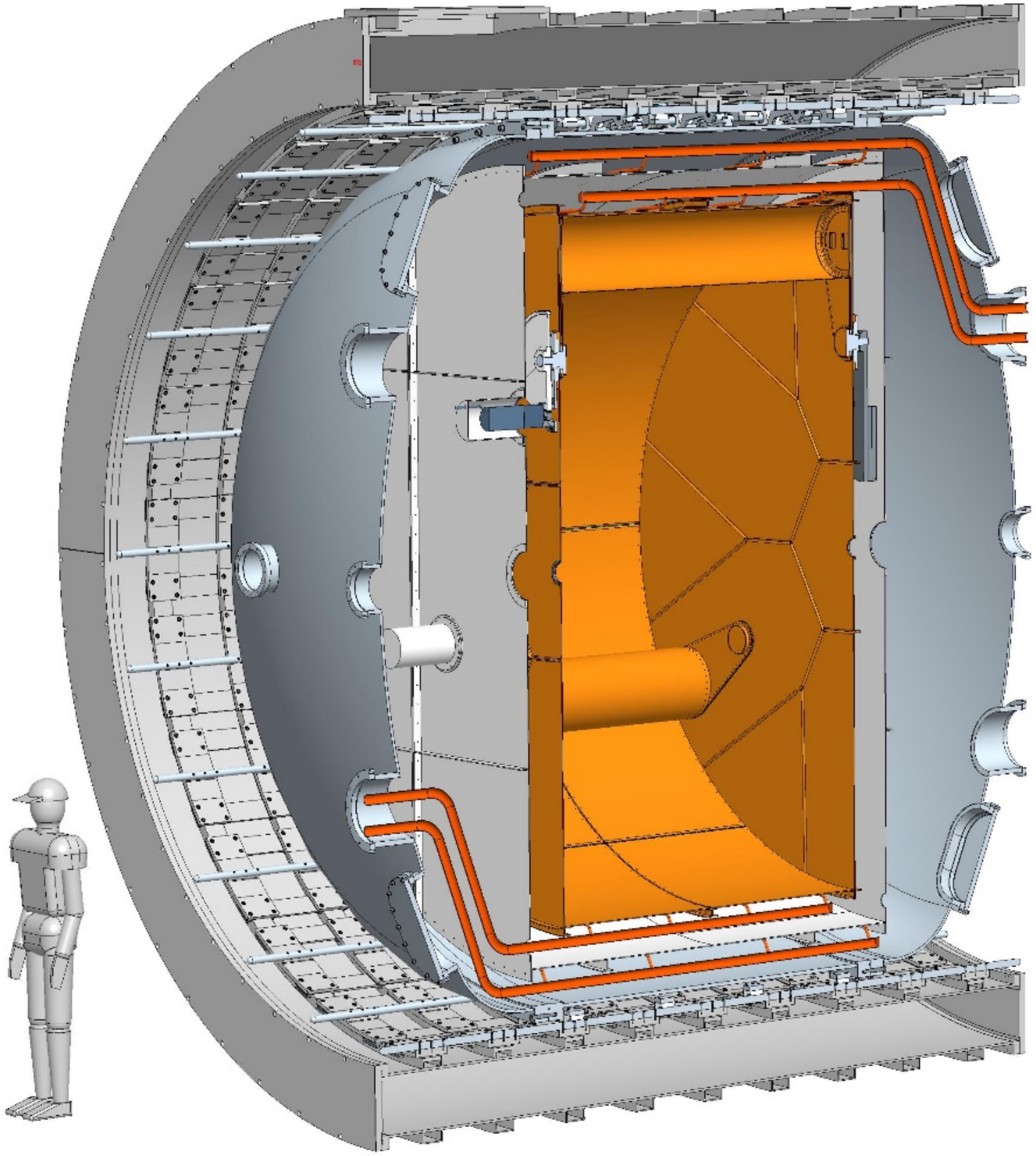
Next years with noise at Quantum Limit

Beyond Quantum Limit with photon counter (ongoing R&D)

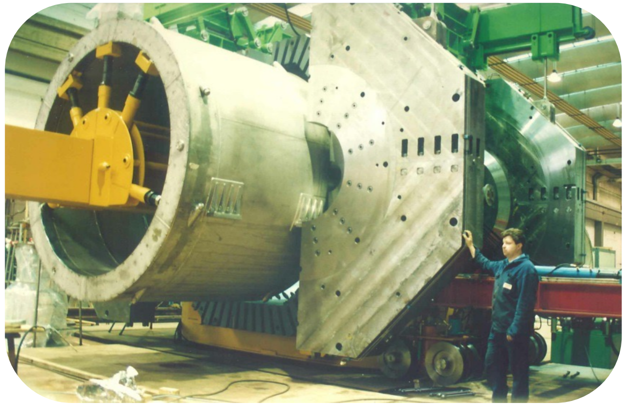
What about the low mass limit?

FLASH
Finuda magnet for Light Axion SearcH

Galactic axion search at 100 MHz (0.5-1.5 μeV)



Large Superconducting Magnets at LNF



FINUDA→FLASH

B(T)	1.1
I(A)	2845
R(m)	1.4
L(m)	2.2

KLOE→KLASH

B(T)	0.6
I(A)	2300
R(m)	2.43
L(m)	4.4


Laboratori Nazionali di Frascati

INFN-18-09-LNF
September 18, 2018

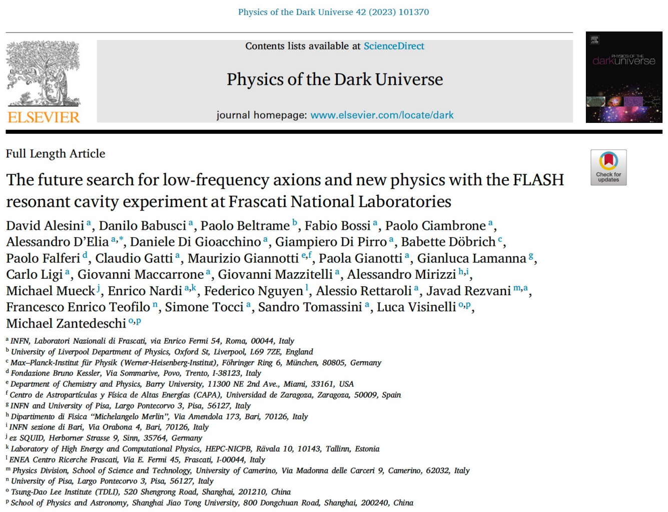
The KLASH – Letter of Intent

D.Alesini[1], D.Babusci[1], F.Bossi[1], P.Ciambrone[1], G.Corcella[1], D.Di Gioacchino[1], P.Falferi[2], C.Gatti[1], A.Ghigo[1], G.Lamanna[3], C.Ligi[1], G.Maccarrone[1], A.Mirizzi[4], D.Montanino[5], D.Moricciani[1], A.Mostacci[6], E.Nardi[1], A.Paoloni[1], L.Pellegrino[1], A.Rettaroli[1], R.Ricci[1], L.Sabbatini[1], S.Tocci[1].


INFN-19-18/LNF
November 7, 2019

KLASH

Conceptual Design Report


Physics of the Dark Universe 42 (2023) 101370

Contents lists available at ScienceDirect

Physics of the Dark Universe

journal homepage: www.elsevier.com/locate/dark

Full Length Article

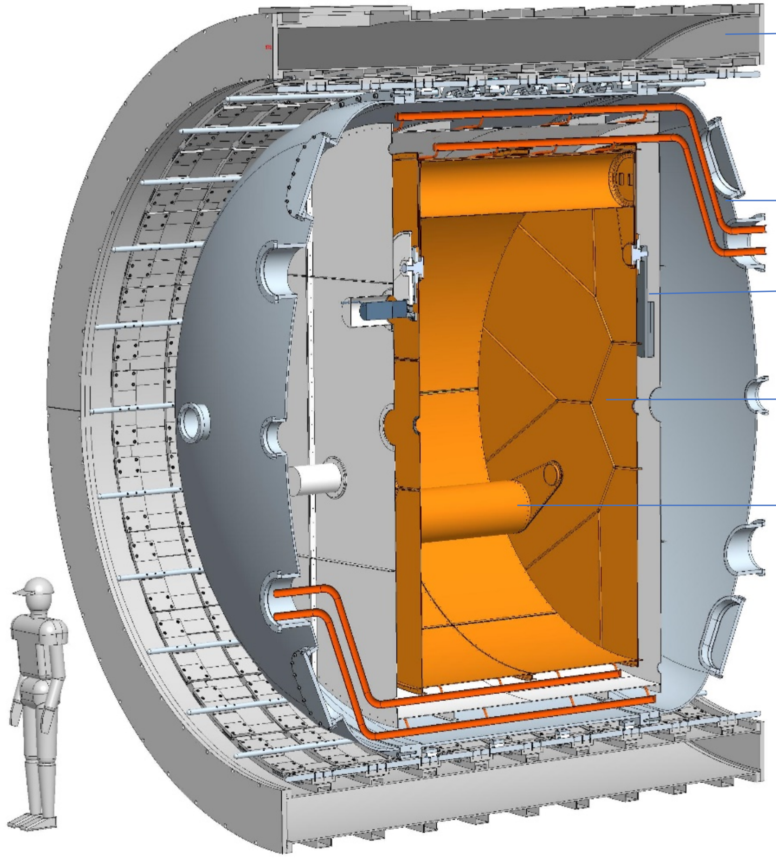
The future search for low-frequency axions and new physics with the FLASH resonant cavity experiment at Frascati National Laboratories

David Alesini [a], Danilo Babusci [a], Paolo Beltrame [b], Fabio Bossi [a], Paolo Ciambrone [a], Alessandro D'Elia [a,*], Daniele Di Gioacchino [a], Giampiero Di Pirro [a], Babette Döbrich [c], Paolo Falferi [d], Claudio Gatti [a], Maurizio Giannotti [e,f], Paola Gianotti [a], Gianluca Lamanna [g], Carlo Ligi [a], Giovanni Maccarrone [a], Giovanni Mazzitelli [a], Alessandro Mirizzi [h,i], Michael Mueck [j], Enrico Nardi [a,k], Federico Nguyen [l], Alessio Rettaroli [a], Javad Rezvani [m,a], Francesco Enrico Teofilo [n], Simone Tocci [a], Sandro Tomassini [a], Luca Visinelli [o,p], Michael Zantedeschi [o,p]

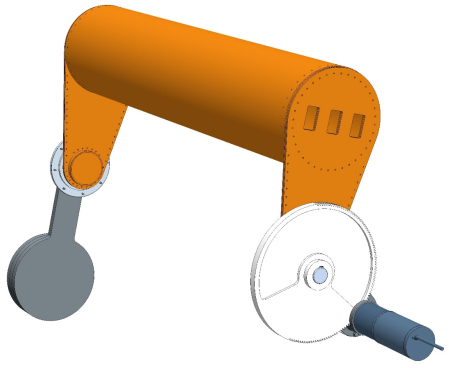
[a] INFN, Laboratori Nazionali di Frascati, via Enrico Fermi 54, Roma, 00044, Italy
[b] University of Liverpool Department of Physics, Oxford St, Liverpool, L69 7ZE, England
[c] Max–Planck-Institut für Physik (Werner-Heisenberg-Institut), Föhringer Ring 6, München, 80805, Germany
[d] Fondazione Bruno Kessler, Via Sommarive, Povo, Trento, I-38123, Italy
[e] Department of Chemistry and Physics, Barry University, 11300 NE 2nd Ave., Miami, 33161, USA
[f] Centro de Astropartículas y Física de Altas Energías (CAPA), Universidad de Zaragoza, Zaragoza, 50009, Spain
[g] INFN and University of Pisa, Largo Pontecorvo 3, Pisa, 56127, Italy
[h] Dipartimento di Fisica "Michelangelo Merlin", Via Amendola 173, Bari, 70126, Italy
[i] INFN sezione di Bari, Via Orabona 4, Bari, 70126, Italy
[j] ez SQUID, Herborner Strasse 9, Sinn, 35764, Germany
[k] Laboratory of High Energy and Computational Physics, HEPC-NICPB, Rävala 10, 10143, Tallinn, Estonia
[l] ENEA Centro Ricerche Frascati, Via E. Fermi 45, Frascati, I-00044, Italy
[m] Physics Division, School of Science and Technology, University of Camerino, Via Madonna delle Carceri 9, Camerino, 62032, Italy
[n] University of Pisa, Largo Pontecorvo 3, Pisa, 56127, Italy
[o] Tsung-Dao Lee Institute (TDLI), 520 Shengrong Road, Shanghai, 201210, China
[p] School of Physics and Astronomy, Shanghai Jiao Tong University, 800 Dongchuan Road, Shanghai, 200240, China

KLASH CDR arXiv:1911.02427
FLASH paper Phys. Dark Univ. 42 (2023)

THE F(K)LASH Cryostat and Resonant Cavity

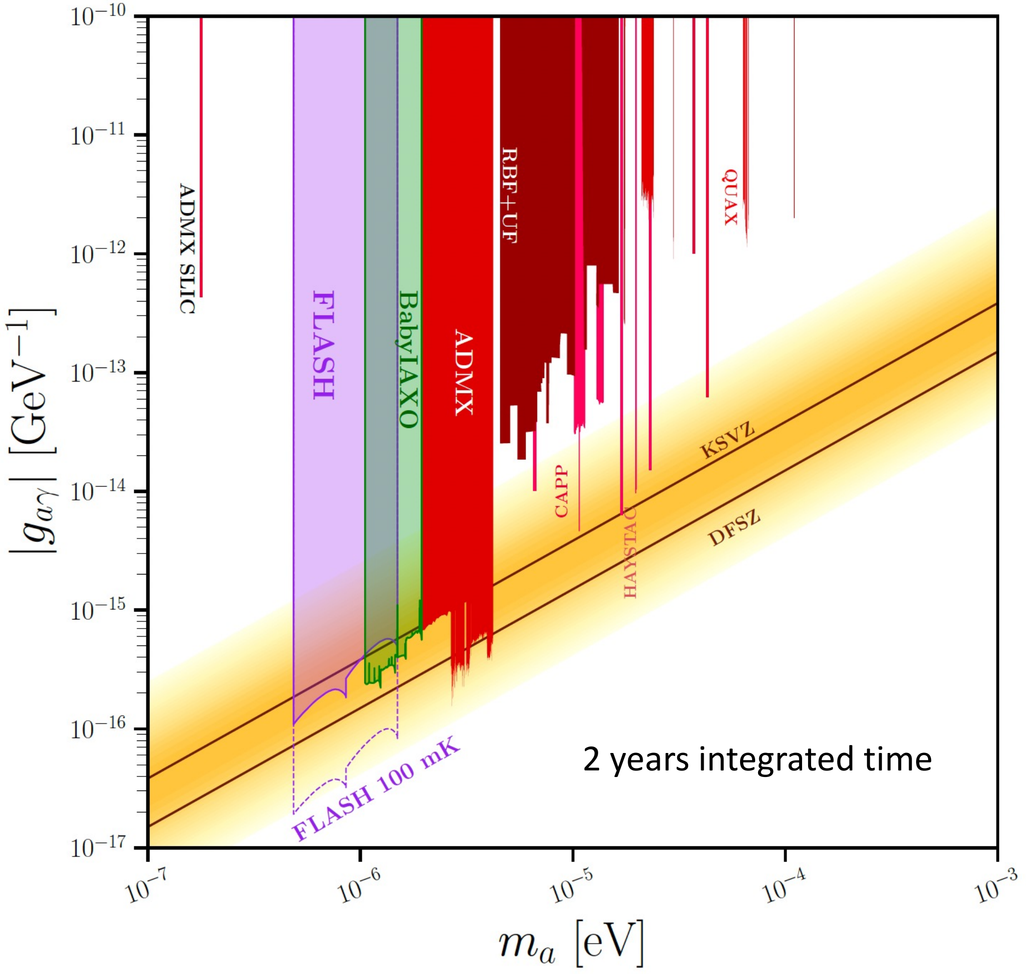


- KLOE/FINUDA Magnet
- Vacuum vessel made by a-magnetic stainless steel
- Shield in aluminum alloy, to be cooled to 70 K by gaseous Helium
- OFHC Cu resonant cavity, cooled to 4.6 K by saturated liquid Helium
- 3 OFHC Cu tuning bars mounted on eccentric cranks with reduction gearboxes

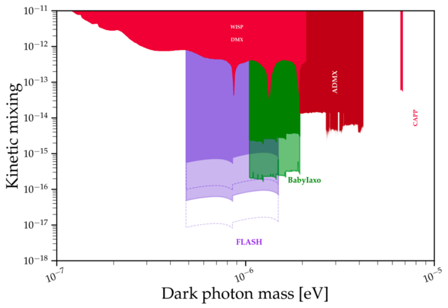


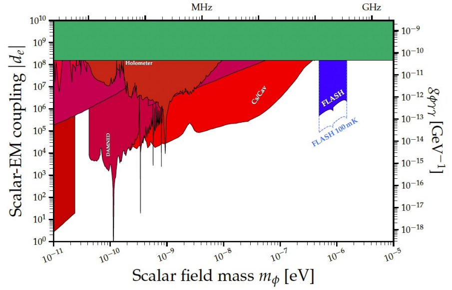
Design by FANTINI Sud Mechanical Div.

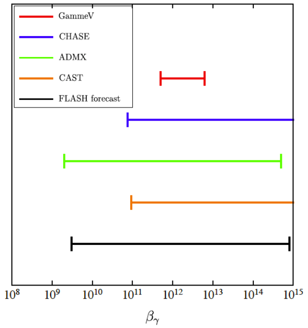
Sensitivity to Axions and ALPS



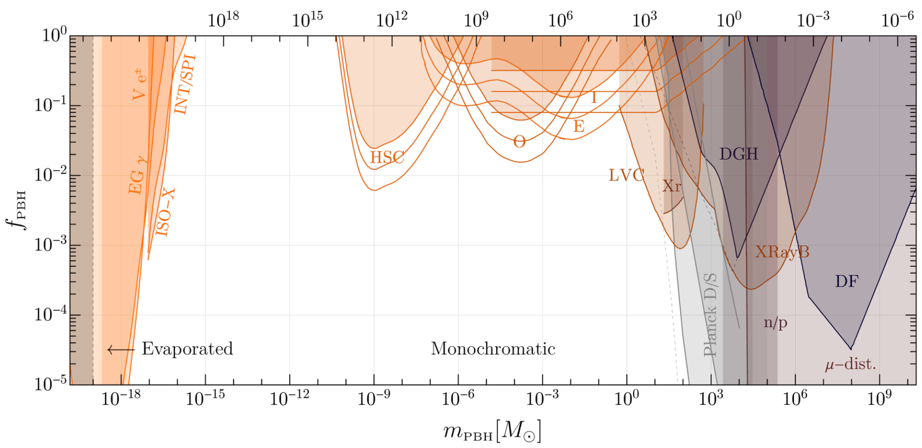
Parameter	Value
ν_c [MHz]	150
m_a [μeV]	0.62
$g_{a\gamma\gamma}^{\mathrm{KSVZ}}$ [GeV^{-1}]	2.45×10^{-16}
Q_L	1.4×10^5
C_{010}	0.53
B_{max} [T]	1.1
β	2
τ [min]	5
T_{sys} [K]	4.9
P_{sig} [W]	0.9×10^{-22}
Scan rate [Hz s^{-1}]	8
m_a [μeV]	0.49 - 1.49
$g_{a\gamma\gamma}$ 90% c.l. [GeV^{-1}]	$(1.25 - 6.06) \times 10^{-16}$

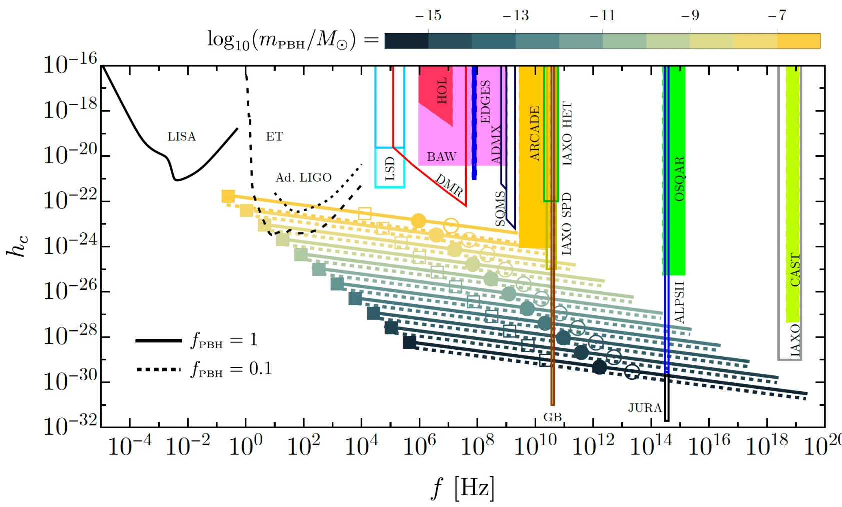


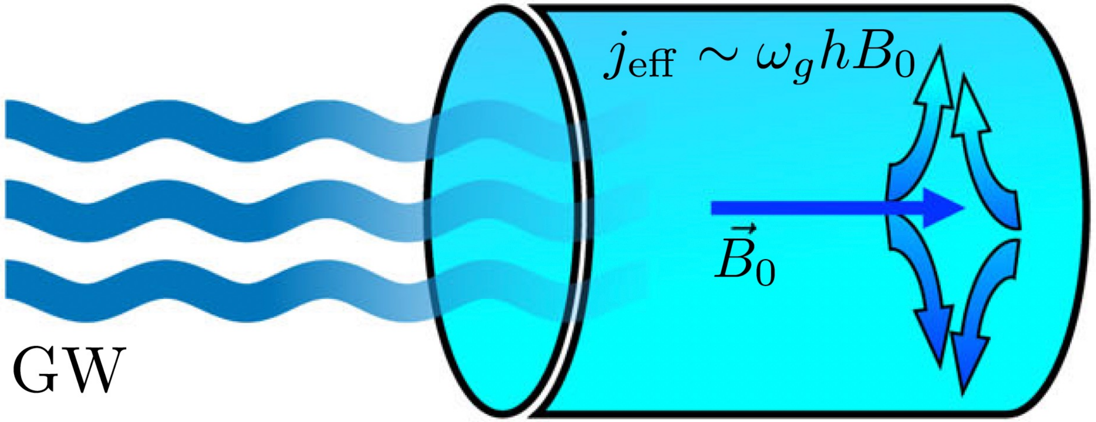




Light Primordial Black Hole Dark Matter with Ultra-high-frequency Gravitational Waves







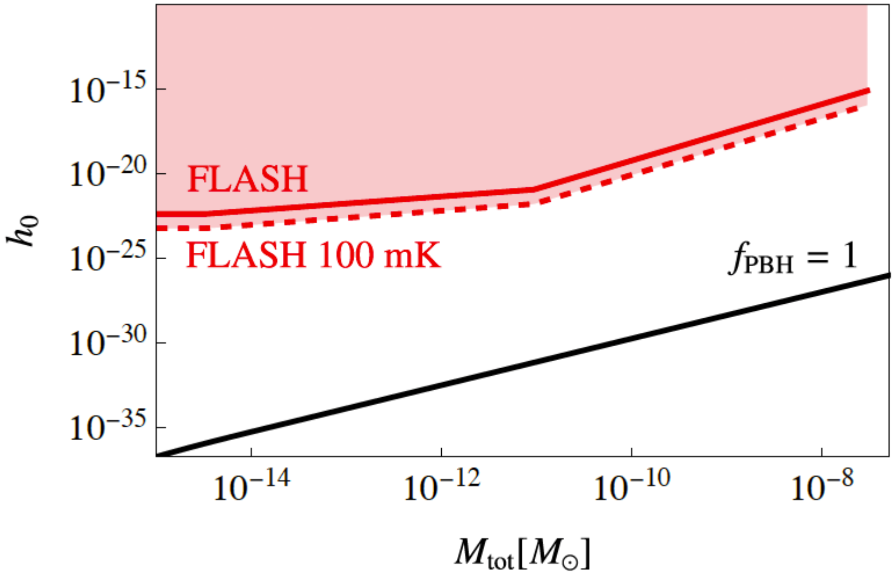
A. Berlin Phys. Rev. D 105, 116011

Franciolini Phys. Rev. D 106, 103520 2022

FLASH Sensitivity to HFGW

Sensitivity limited also by short duration time of the HFGW from PBHs. Gain 1 or 2 order of magnitudes wrt GHz cavities:

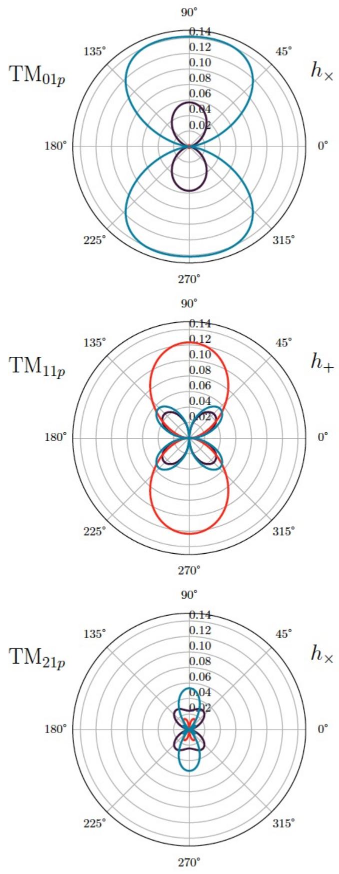
- Signal power scales as Radius^2
- Q factor effective as long as Ncycles~Q



$$t_{int} \simeq 2.72 \cdot 10^{-14}\ \mathrm{s} \times \left(\frac{M_c}{10^{-5} M_\odot}\right)^{-5/3} \left(\frac{\nu}{200\ \mathrm{MHz}}\right)^{-8/3} \left(\frac{10^6}{Q}\right)$$

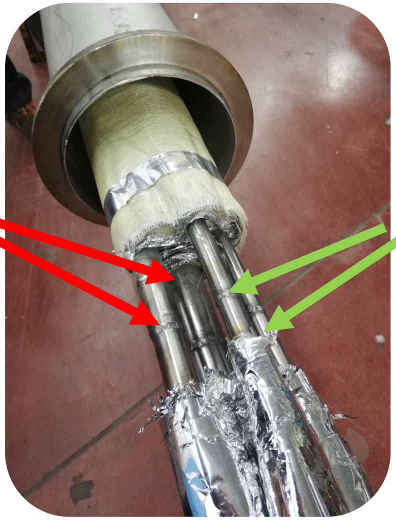
Mode	Resonant Frequency [MHz]	Q factor (@4°K)
TM010	109.5	626e3
TM011	166.1	526e3
TM012	272.3	752e3
TM110	174.4	790e3
TM111	214.5	598e3
TM112	304.7	712e3
TM210	233.7	915e3
TM211	264.9	664e3
TM212	342.1	755e3

$p = 0$ $p = 1$ $p = 2$



Commissioning of the FINUDA Magnet – Last Operated in 2007

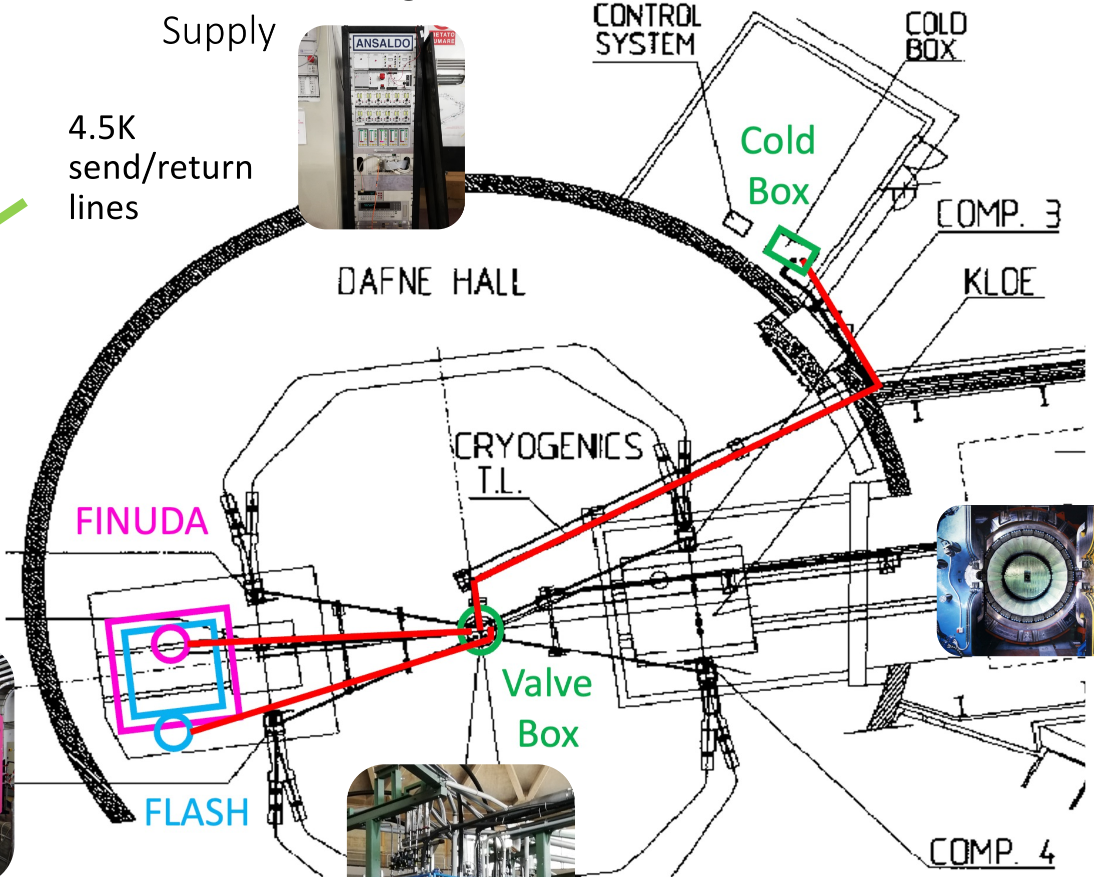
70K send/return lines

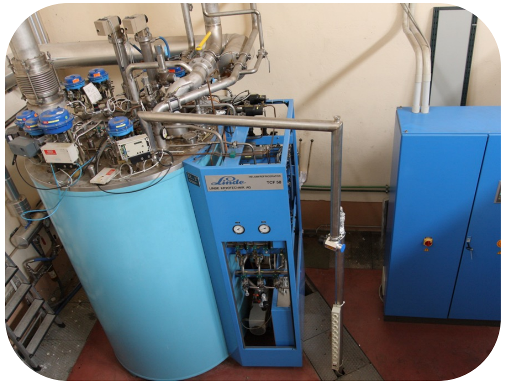


4.5K send/return lines

Reconnection of He transfer line

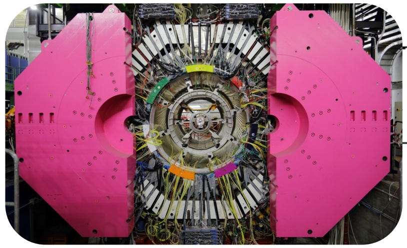
Control of Magnet Power Supply





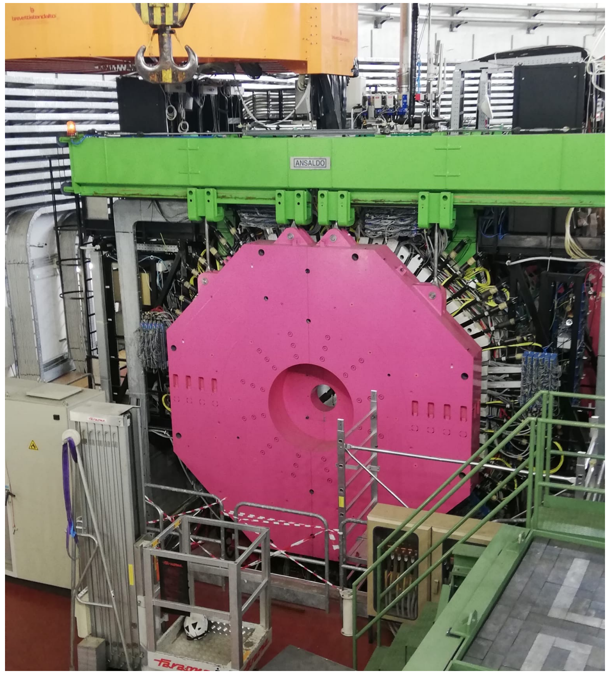
Cryogenic plant

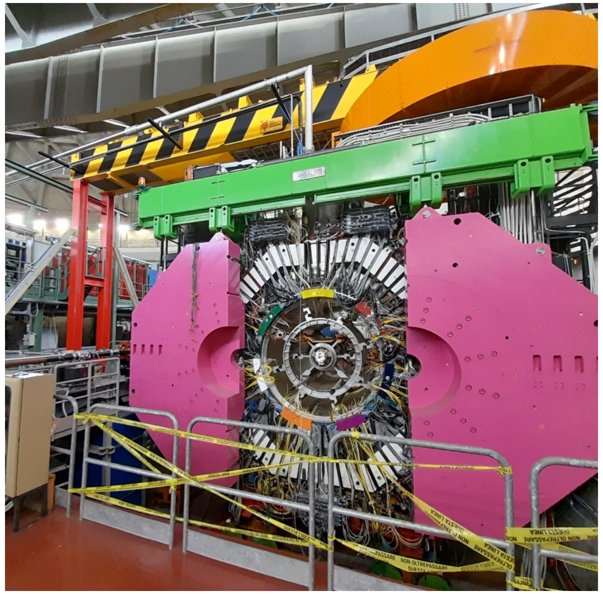
KLOE



FINUDA/FLASH


LOXAM
199.177.155

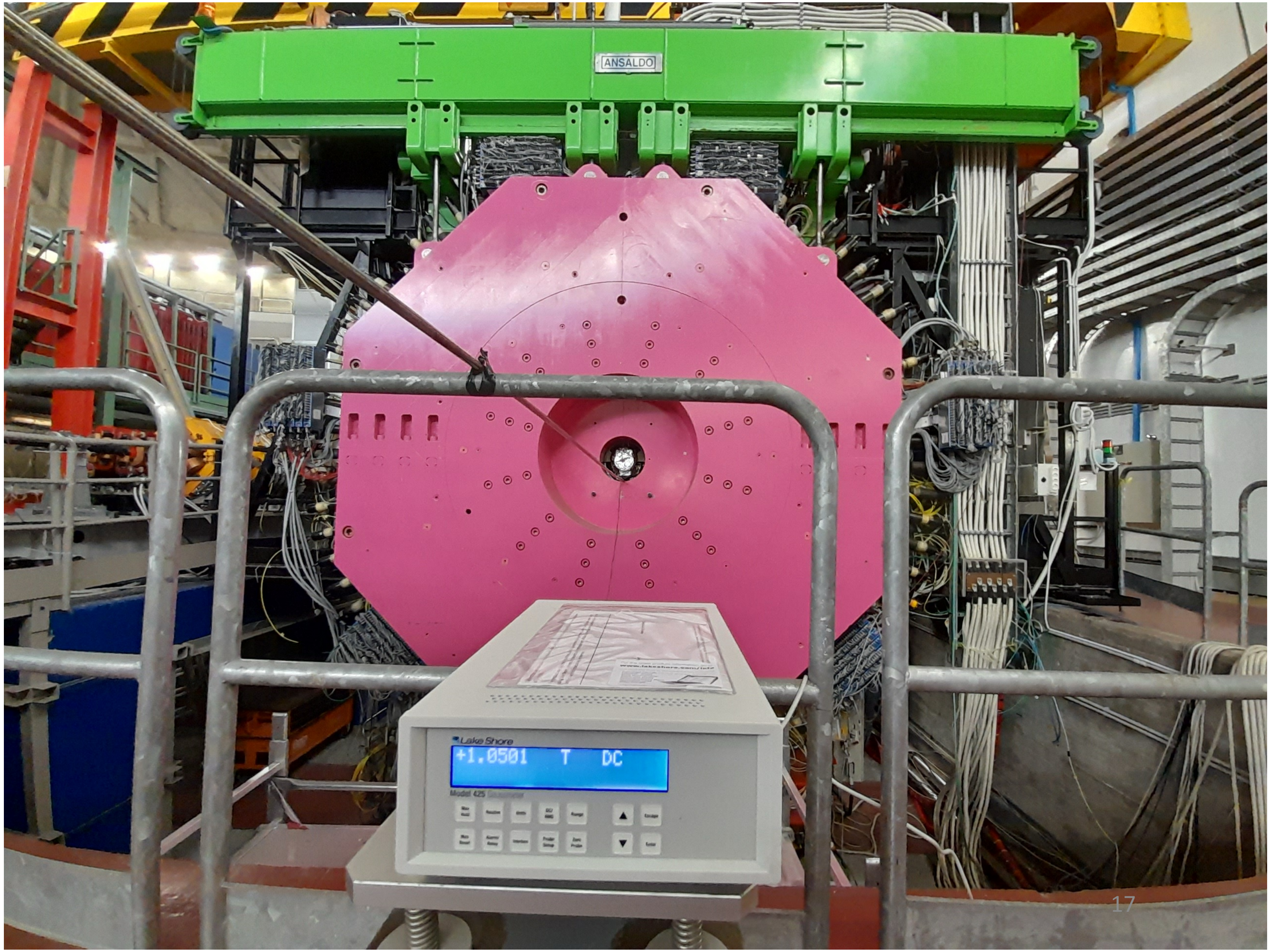

ANSALDO

VIETATO
FUMARE


CONVERTITORE CLTS
CHIUSURA
BREAKER

Successful Test of the FINUDA Magnet

After a series of operations, the cryogenic plant was finally put back into operation. On Jan the 19th 2024, FINUDA was cooled down to 4 K and energized with a current of 2706 A, generating a magnetic field of 1.05 T.



CONCLUSIONS

FINUDA Magnet successfully tests in January 2024 after 20 years from last operation.

Next steps: Technical Design Report, INFN approval, construction and commissioning. About 5 years from now.

For the TDR we need to fully design mechanical cryogenics and RF components:

Vacuum vessel

Cryostat support

Service Turret

Radiation screens

RF Cavity and pick up antennas

Tuning System

Assembly Tools

Signal amplification and DAQ

SQUID multiplexing

B field shields

Computing

Setting up a Collaboration with both theory and experimental groups

Experimental groups:

LNF, INFN and Uni Pisa, INFN Trento, Uni Camerino

Ongoing discussion with INFN Milano

Groups are joining from Spain and Germany