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SERAPH: Wavelike Dark Matter Searches with SRF Cavities and Transmon Qubits

Patras 2024 Sept. 16, 2024

Raphael Cervantes

SQMS and Fermilab

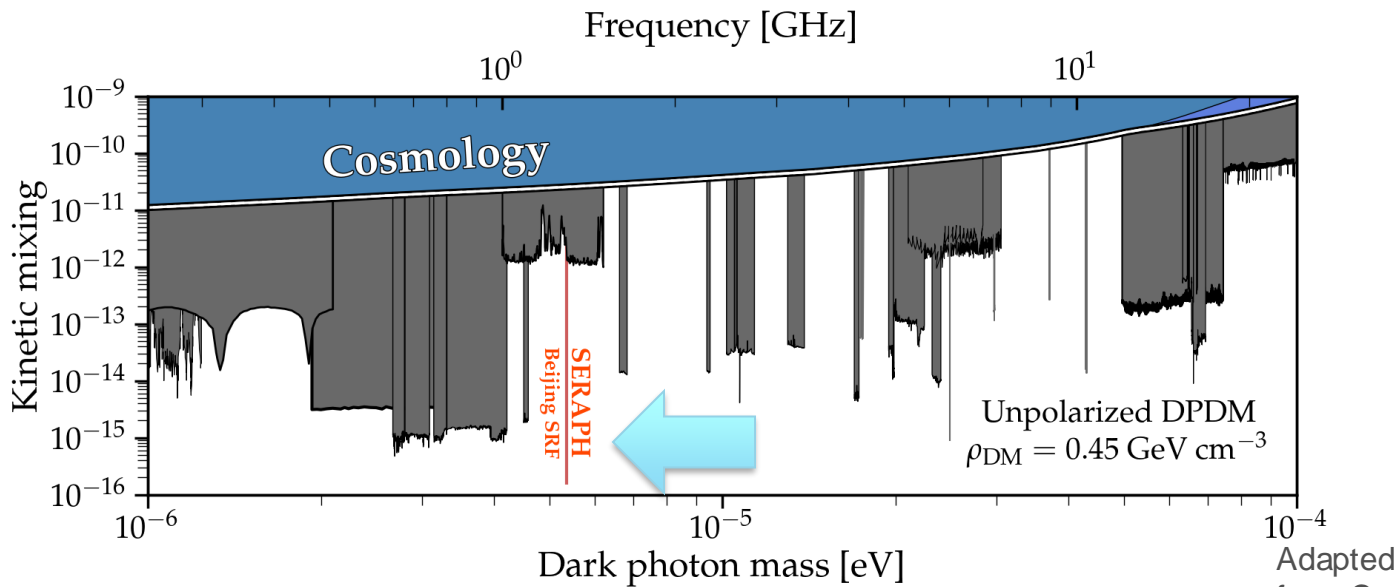
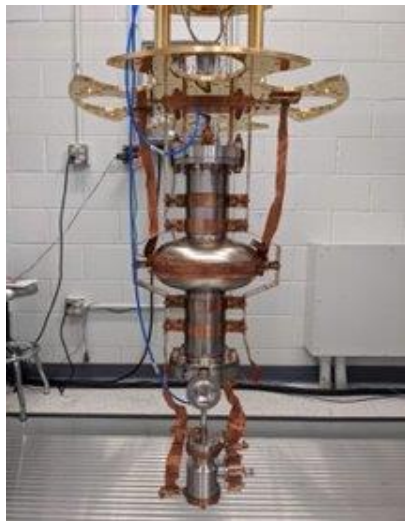
The Quantum Garage



Interdisciplinary QIS center comprising of experts in materials quantum devices, HEP, and algorithms.

Credit: A. Grasselino

Review: Deepest Exclusion to Wavelike DPDM with SRF Cavities



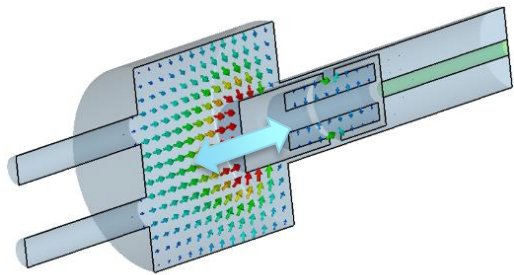
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Deepest sensitivity to wavelike dark photon dark matter with superconducting radio frequency cavities

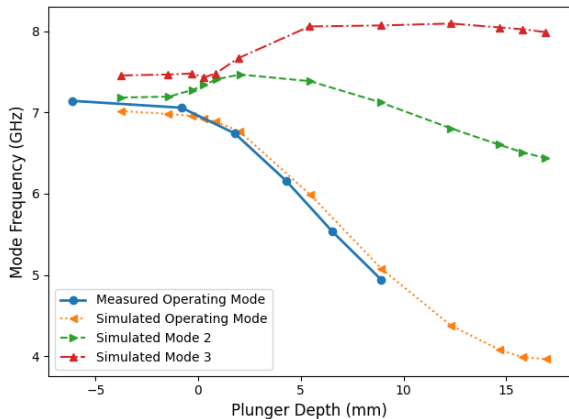
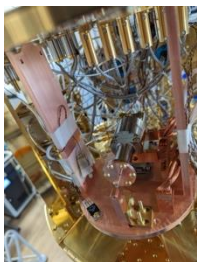
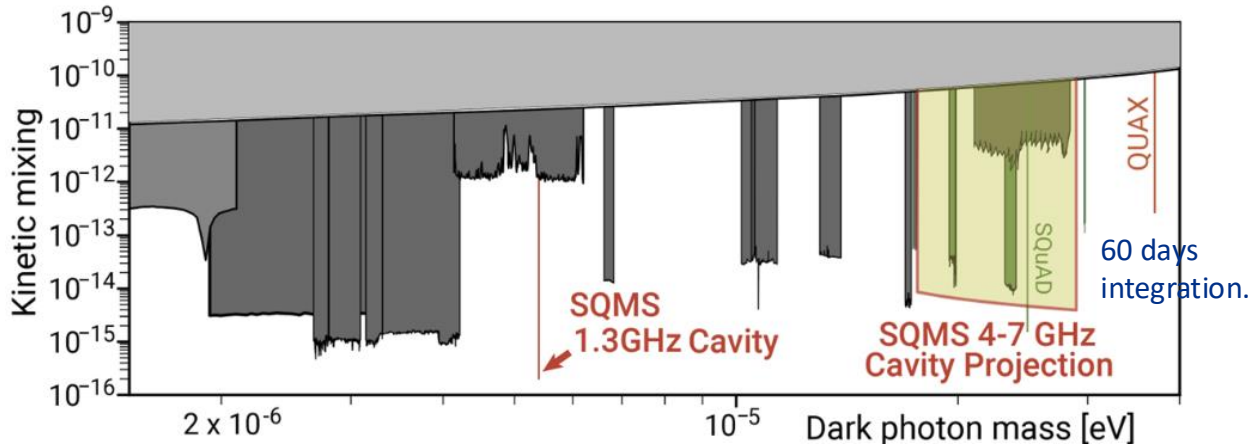
R. Cervantes, J. Aumentado, C. Braggio, B. Giaccone, D. Frolov, A. Grassellino, R. Harnik, F. Lecocq, O. Melnychuk, R. Pilipenko, S. Posen, and A. Romanenko
 Phys. Rev. D **110**, 043022 – Published 12 August 2024

For virialized dark matter,
 instantaneous scan rate $\propto Q_L$,
 even if $Q_L \gg Q_{DM}$.

Next Step: Widely tunable SRF cavity.



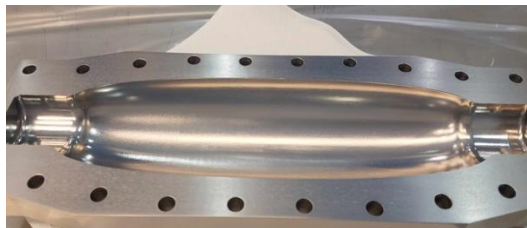
“plunger” cavity
4-7 GHz



- Tunable DPDM search from 4-7 GHz.
- Measured $Q \sim 10^8$ at both 20 mK and 1.4 K.
- Working towards mechanical modifications to reduce microphonics from 8 kHz to 100 Hz.
- Need to increase volume to increase sensitivity at cost of mode crossings.

FNAL Nb₃Sn Cavities for ADMX and INFN

Initial R&D at Fermilab



Q_0 of 5×10^5 at 6 T, 4.2 K, 3.9 GHz

PHYSICAL REVIEW APPLIED

Highlights Recent Subjects Accepted Collections Authors Referees Search

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High-Quality-Factor Superconducting Cavities in Tesla-Scale Magnetic Fields for Dark-Matter Searches

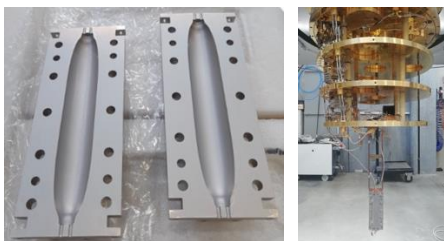
S. Posen, M. Checchin, O.S. Melnychuk, T. Ring, I. Gonin, and T. Khabiboulline
Phys. Rev. Applied 20, 034004 – Published 5 September 2023

Q can improve with alignment and heat treatment.

Prototypes sent to Partners

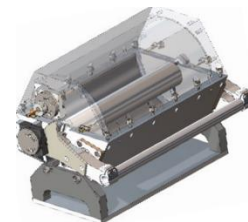


Nb₃Sn tuning rod for ADMX Sidecar sent to U. Washington (w/ LLNL)



9 GHz Nb₃Sn cavity sent to INFN Frascati for testing in 8 T fridge

Potential Future Experiments

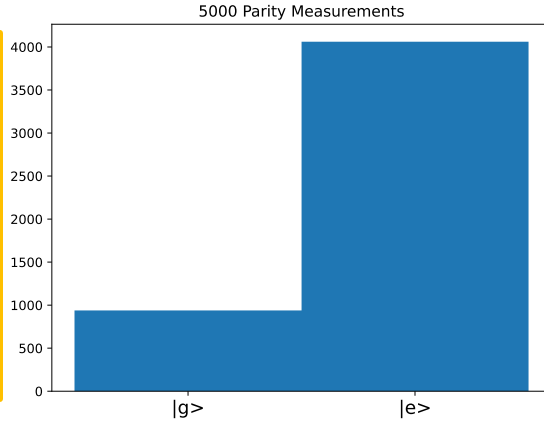
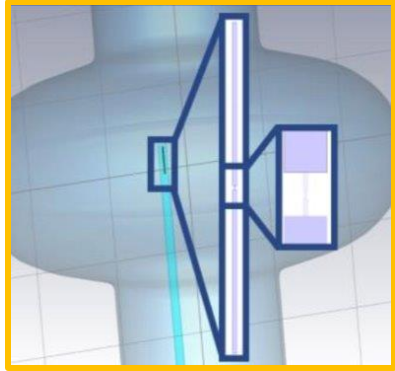


ADMX-EFR at Fermilab



Hybrid dielectric-Nb₃Sn cavity for INFN QUAX haloscope

Photon counting at SQMS



Qubit with $T_1 \sim 150 \mu\text{s}$. Readout rate is 1/ms. Fidelity is $\sim 80\%$. Storage cavity at 5 GHz.

Parity measurement where qubit is prepared in ground state and we apply two $+\pi/2$ pulses.

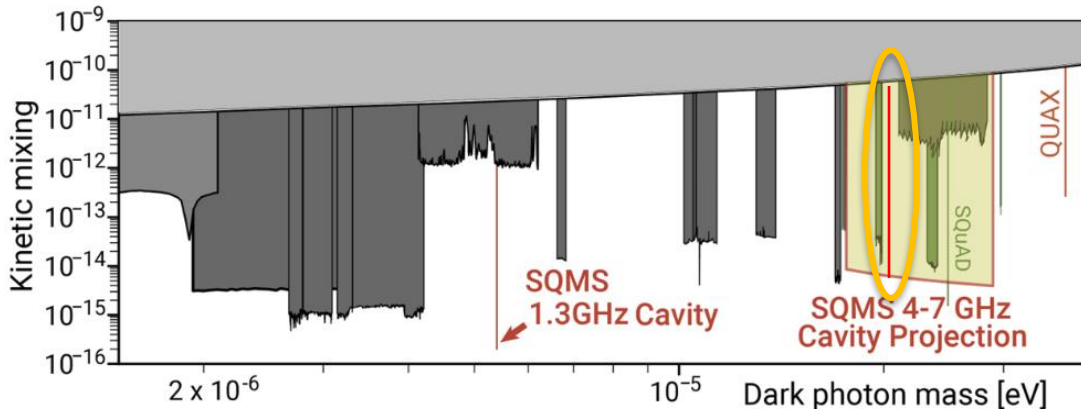
With perfect readout:

$|g\rangle$ corresponds to 1 photon.

$|e\rangle$ corresponds to 0 photon.

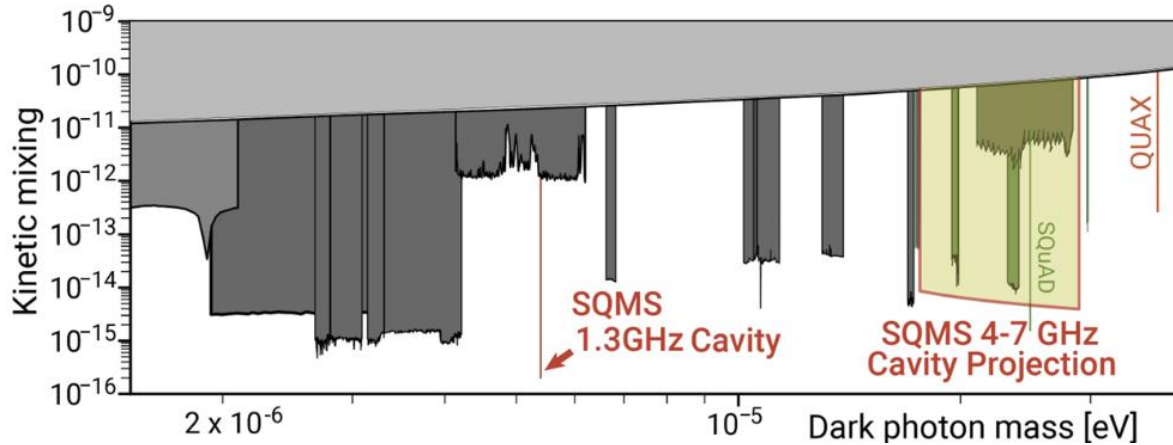
DPDM search with nonidealities in quantum protocols that reduce sensitivity. Preliminary dark photon limit $\chi = 8e-15$.

Better system under wraps. Itinerant photon counters for axion searches in near future.

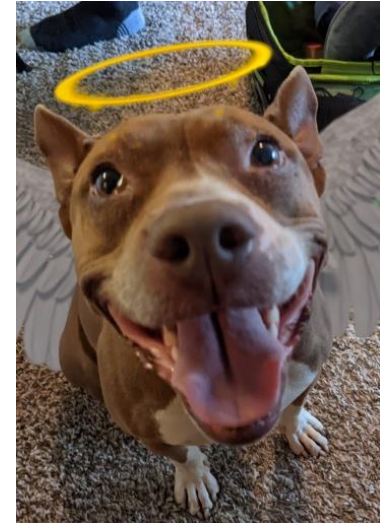


Summarize

- Ultra-high Q cavities have achieved unprecedented sensitivity to wavelike DPDM and can boost by scan rate by orders of magnitude.
- Progress towards widely tunable SRF cavities, Nb_3Sn cavities, and photon counting for axion searches.



Edited by slimemoldgrappling



Seraphine
the mascot.