Towards a Cavity Haloscope with a GHz Tuning System Using Galvanically Contacted Transmon Qubits

20th Patras workshop on Axion, WIMPs and WISPs
09/23/2025
Speaker: Kan Nakazono (the University of Tokyo)
DarQ Collaboration

Outline

- Main idea (based on Patras 19th talk, arXiv:2505.15619)
- Status for the next run
- Introduction of DarQ experiment

arXiv:2505.15619

Search for Dark Photon Dark Matter with a Mass around 36.1 μeV Using a Frequency-tunable Cavity Controlled through a Coupled Superconducting Qubit

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(DarQ Collaboration)

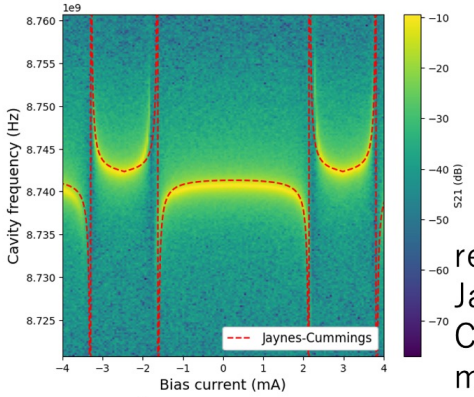
DarQ-Lamb experiment

Using a superconducting qubit as a cavity frequency tuner

Lamb shift (dispersive shift) $\propto \frac{g^2}{\Delta}$ ...coupling constant $g \sim \mu E$

...detuning $\Delta = \omega_q - \omega_c$

Bias current tuning test (2024)



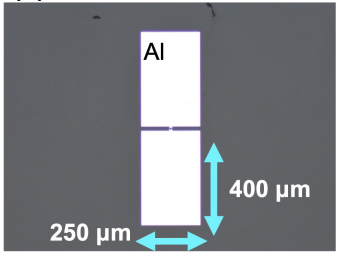
y-axis: frequency of cavity

z-axis: Transmission amplitude

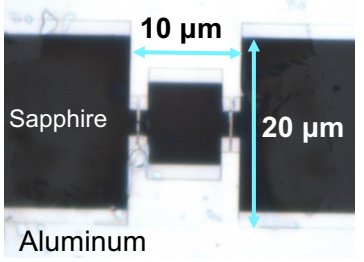
red line: Jaynes-Cummings model fitting

x-axis : current ∝ magnetic flux

(a)



(b)



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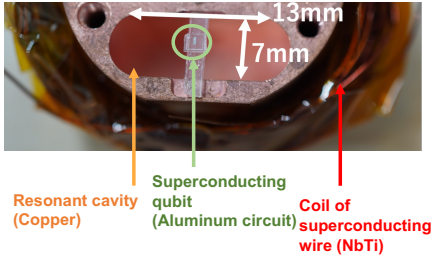

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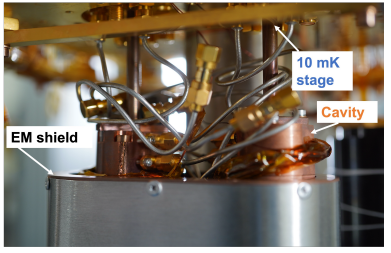
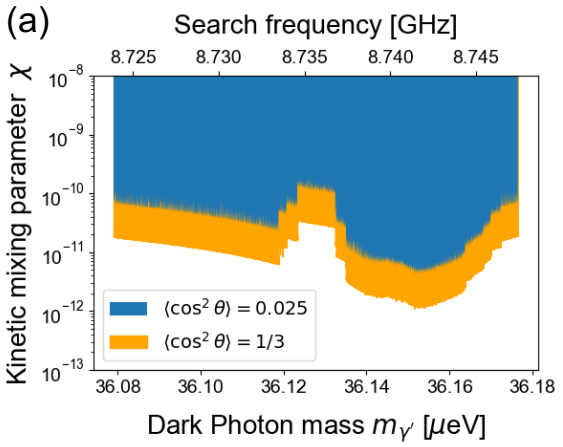
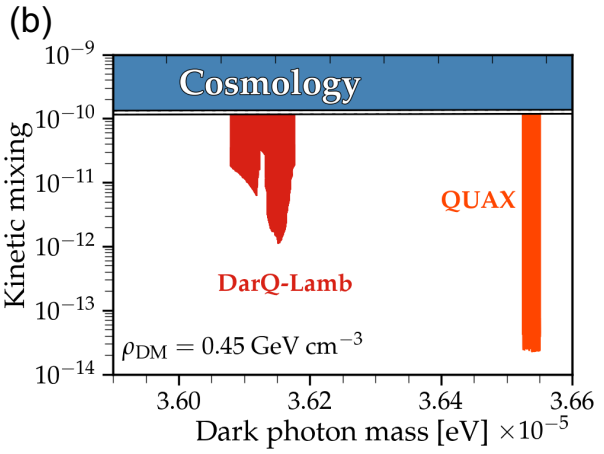


Dark photon DM search around 36.1 μeV in 2024





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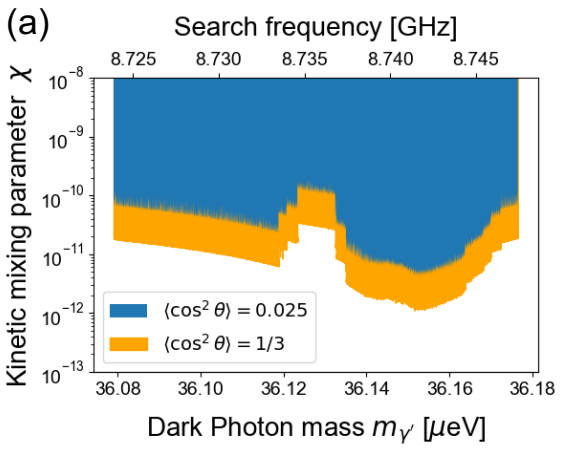
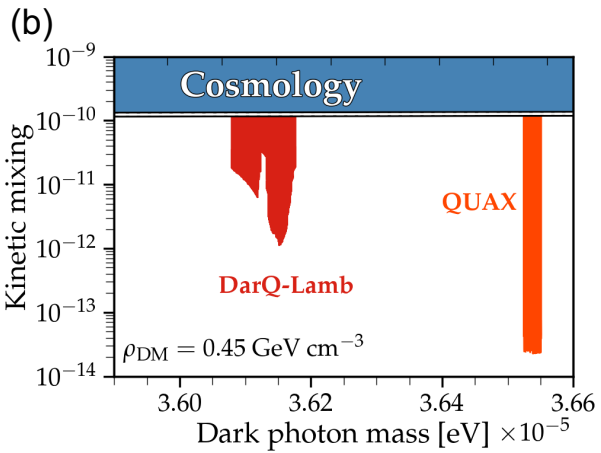




arXiv:2505.15619

For the Next run…

①high sensitivity or ②broaden frequency tuning range

This poster

Status

Wider frequency tuning range ↔ Stronger the qubit-cavity coupling

(physically)

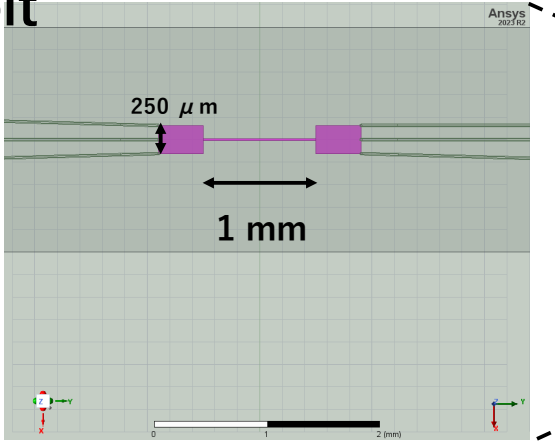
Galvanically contacted qubit-cavity system

$\omega_c \sim 7$ GHz

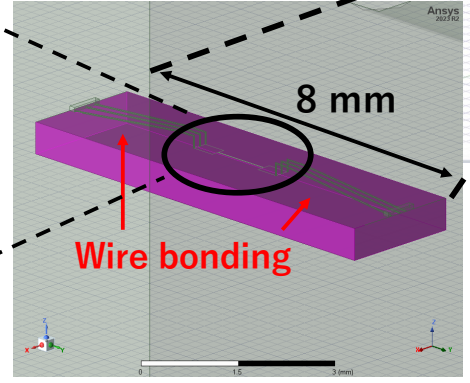
Contact SRF cavity and qubit's pad with wire bonding

Ansys HFSS FEM simulation…

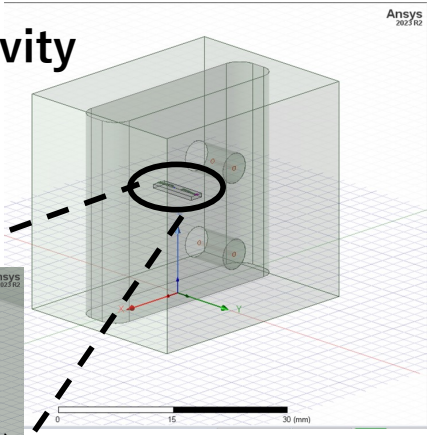
Qubit



Chip



Cavity



Simulation... chip position sweep

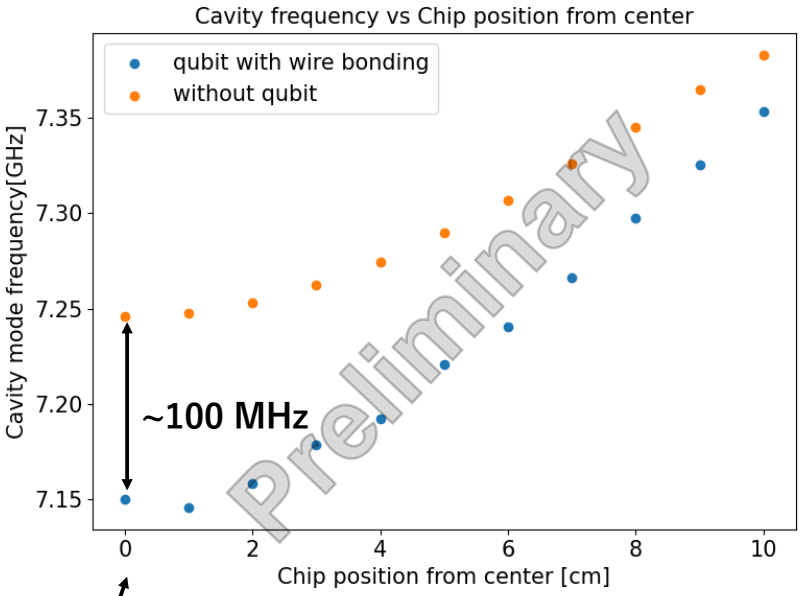
Outputs... Cavity frequency and Form factor

Form factor...

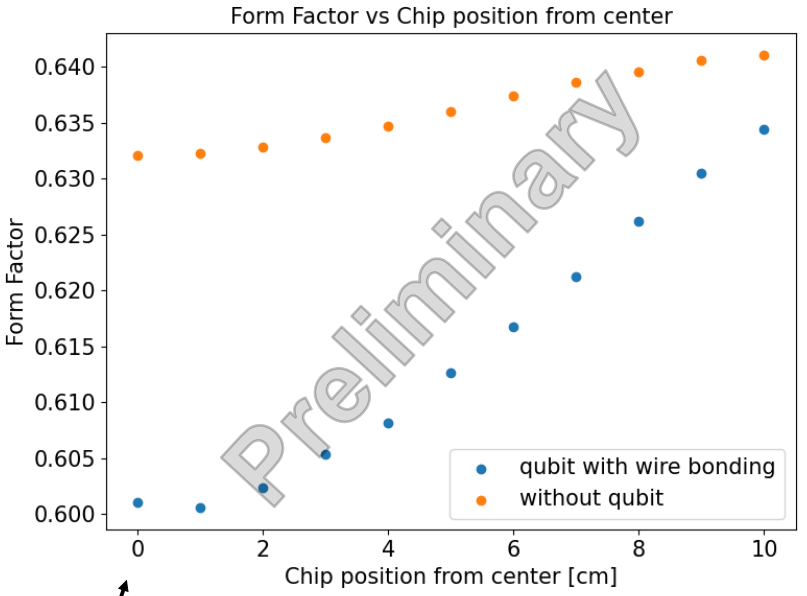
$$C_y = \frac{\left|\int dV \vec{E}\cdot\vec{X}\right|^2}{V\int dV|\vec{E}|^2|\vec{X}|^2}$$

(dark photon detection efficiency depends on the E-field distribution)

$$= \frac{\left|\int dV \vec{E}\cdot\vec{n}_y\right|^2}{V\int dV|\vec{E}|^2}$$



Center of the cavity (Maximum interaction)



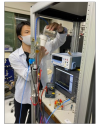
Center of the cavity (Maximum Energy loss)

Introduction: DarQ collaboration

DarQ collaboration

"Dark matter search using Qubits"

UTokyo ICEPP


Toshiaki Inada

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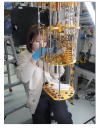
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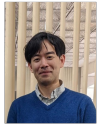
Ryu Sawada

Junichi Tanaka

UTokyo Moroi Lab

Takeo Moroi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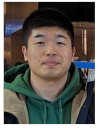
Atsushi Noguchi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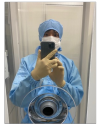
KyotoU HE Lab


Shion Chen

Tetsuro Nakagawa

KEK QUP

Tatsumi Nitta

+1 researcher
+2 graduate school student

Officially starting this year (The first meeting was held this March)

URL: https://sites.google.com/view/darq-experiment

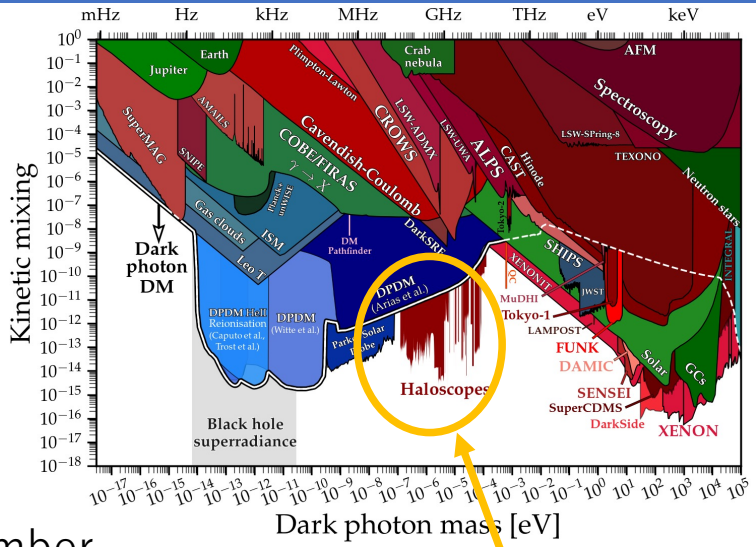
Thank you for listening!

Back Up

Search for dark photon

Dark photon

- Mixed with photon by kinetic mixing parameter χ
- Converted to the ordinary photon
  - Frequency of photons corresponds to dark photon's mass $\hbar\omega \approx m_{DM}c^2$



In the μeV to meV range...

- Long de Broglie wavelength and high number density

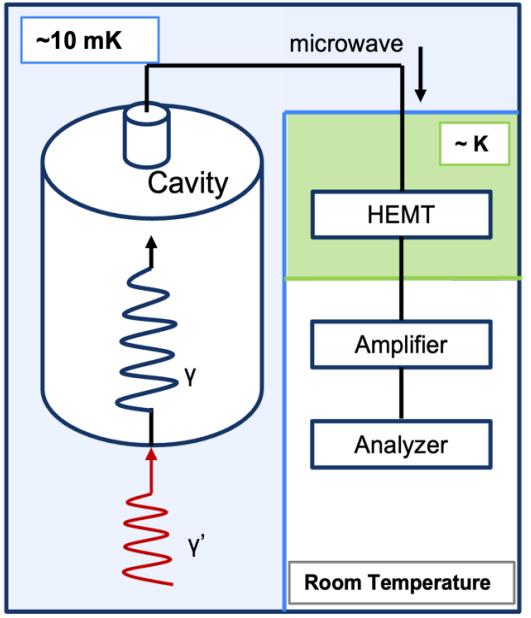
→Phase is coherent (like classical wave)

→Enable to apply coherent weak electric field detection technology!

- Overlapping mass range with well-motivated QCD axions

Cavity haloscope

- Accumulating powers and enhancing signals near the resonance frequency of a cavity
- Cooling down the resonator to cryogenic temperatures (Dilution Refrigerator: ~10mK)
- Reducing background noise (blackbody radiation)



Goal: Broadband Frequency Search ↔ Wide frequency tuning of a cavity

Signal power, noise power and variables

$$P_s = \eta\chi^2 m_{\gamma'} \rho_{DM} V_{eff} Q_L \frac{\beta}{1+\beta} L(f, f_0, Q)$$

$$P_{noise} = k_B b T_{sys} / \sqrt{N}$$

Variable	explanation	value	others
$m_{\gamma'}$	frequency	$\sim 8.74\,\mathrm{GHz}$	each measurement
ρ	DM density	$0.45\,\mathrm{GeV/cm^3}$	from (Asztalos et al., 2001)
β	coupling constant	~ 0.3	each measurement
T_{sys}	system noise	$7.9\,\mathrm{K}$	Y-factor measurement
V_{eff}	effective volume	$3.14\,\mathrm{cm^3}$	$V \times formfactor$
Q_L	(Loaded) Quality factor	~ 5000	each measurement
η	attenuation factor	1.02	SG filtering
N	number of data	100	per measurement
b	bandwidth	$200\,\mathrm{Hz}$	bandwidth of spectrum analyzer

χ : kinetic mixing parameter $\propto$ sensitivity of the detector