20th Patras workshop

Feasibility Study of Axion Searches with an Itinerant Single Microwave Photon Detector

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(DarQ collaboration)

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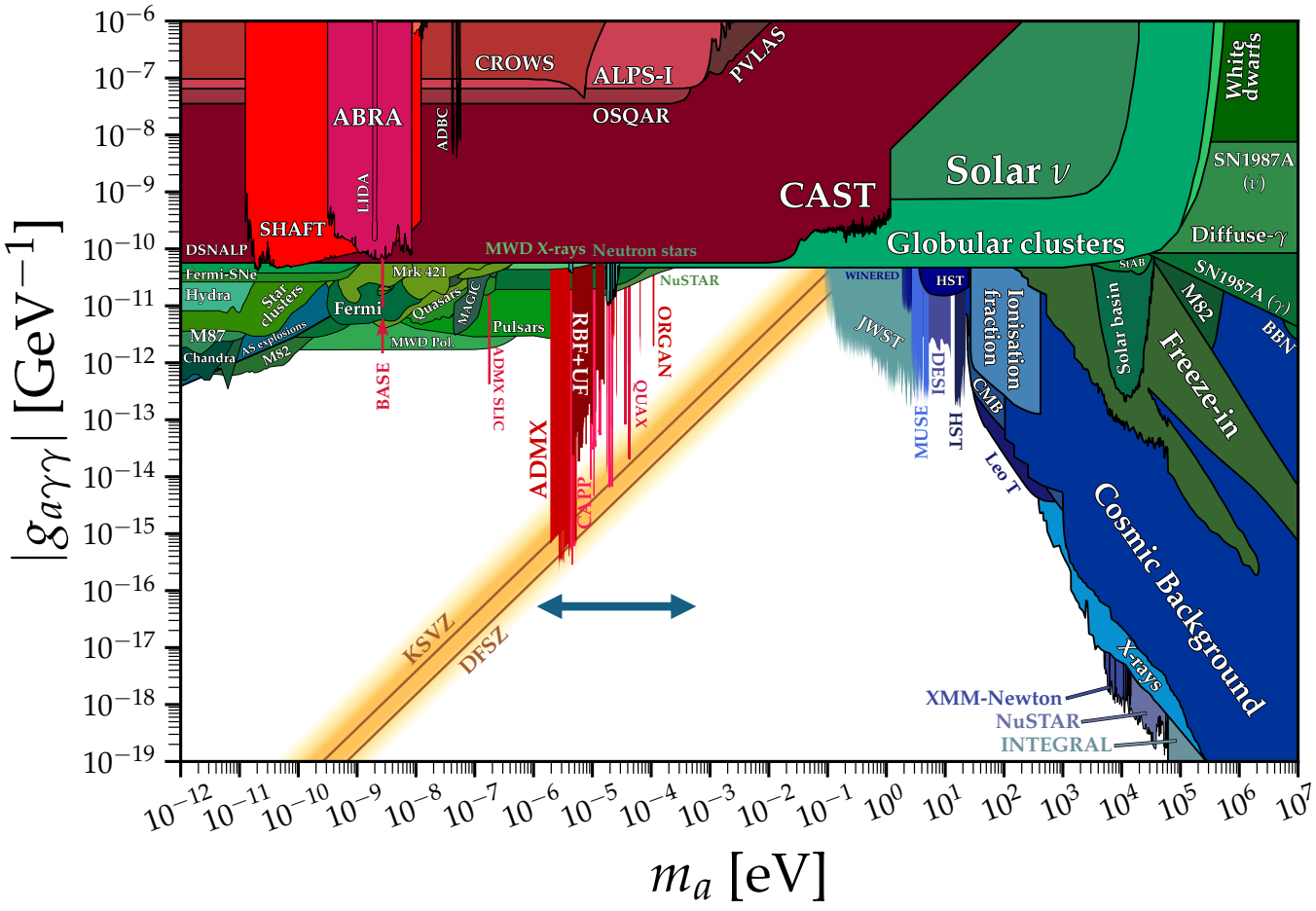
Motivation

- **Axion : well-motivated candidate for dark matter**
- **The vast majority of the theoretically motivated parameter space** (yellow shaded region & $\mathcal{O}(1)\ \mu$eV ~ $\mathcal{O}(100)\ \mu$eV mass) **has not yet been explored.**
- Very weak coupling strength

→ The expected event rate is extremely low.

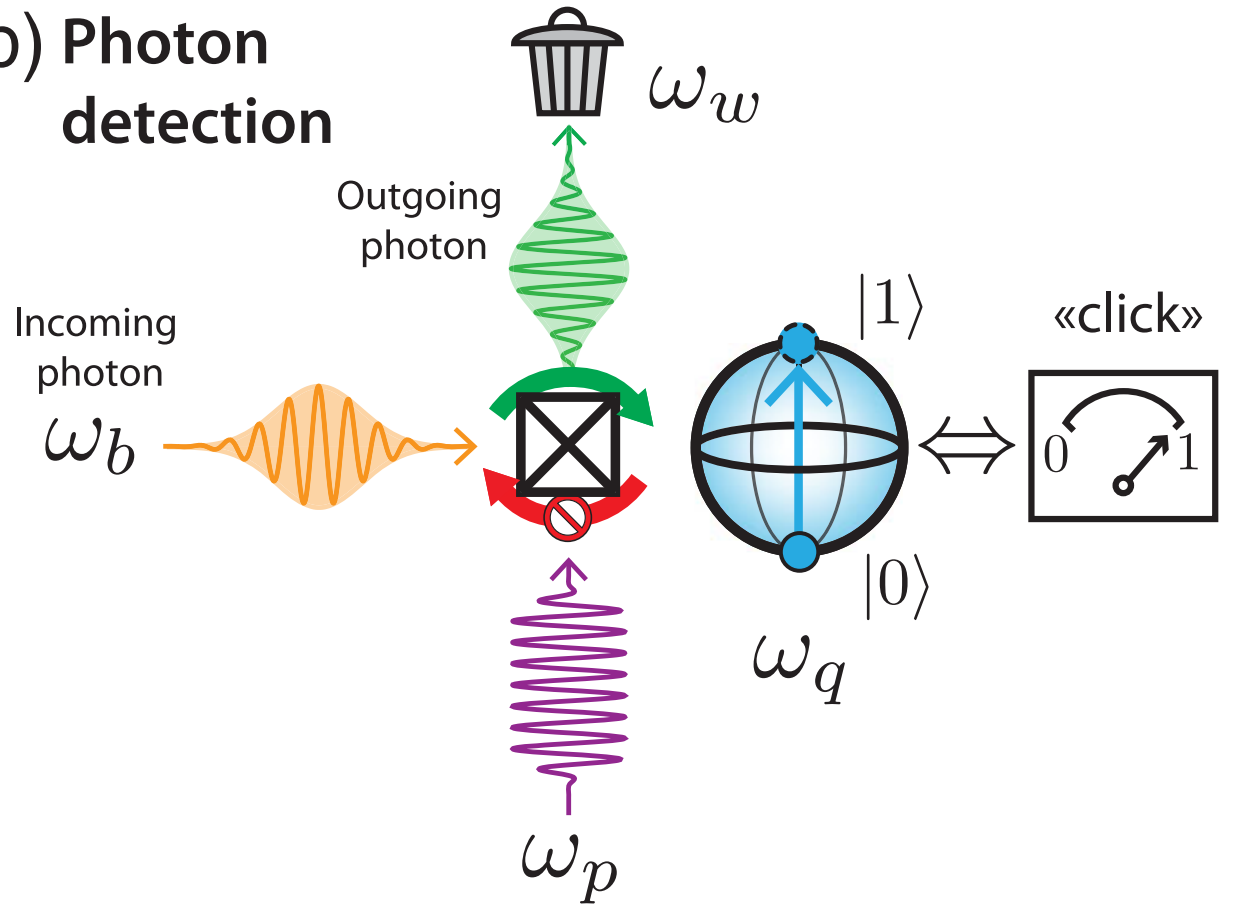
→ **Requires measurement beyond the Standard Quantum Limit (SQL).**



Current upper bound on axion-photon coupling. (O'HARE, C. cajohare/AxionLimits: AxionLimits. Zenodo https://doi.org/10.5281/ZENODO.3932430 (2020).)

Working Principle of SMPD realized using a transmon qubit

- Transmon qubit : Artificial two-level system realized by the nonlinear LC circuit.
- Input photon entering through the resonator (ω_b) → transmon switches to the excited state ($|0\rangle \rightarrow |1\rangle$) via four-wave mixing process. (Lescanne et al. Phys. Rev. X 10, 021038 (2020))
- **Photon counter frequency is swept to search for signal peaks induced by axion-converted photons.**



Lescanne *et al. Phys. Rev. X* **10**, 021038 (2020)

Axion Search with SMPD

- A photon converted from an axion in a cavity is transmitted through a coaxial cable to the SMPD. (→The cavity and the SMPD are **spatially separated.**)

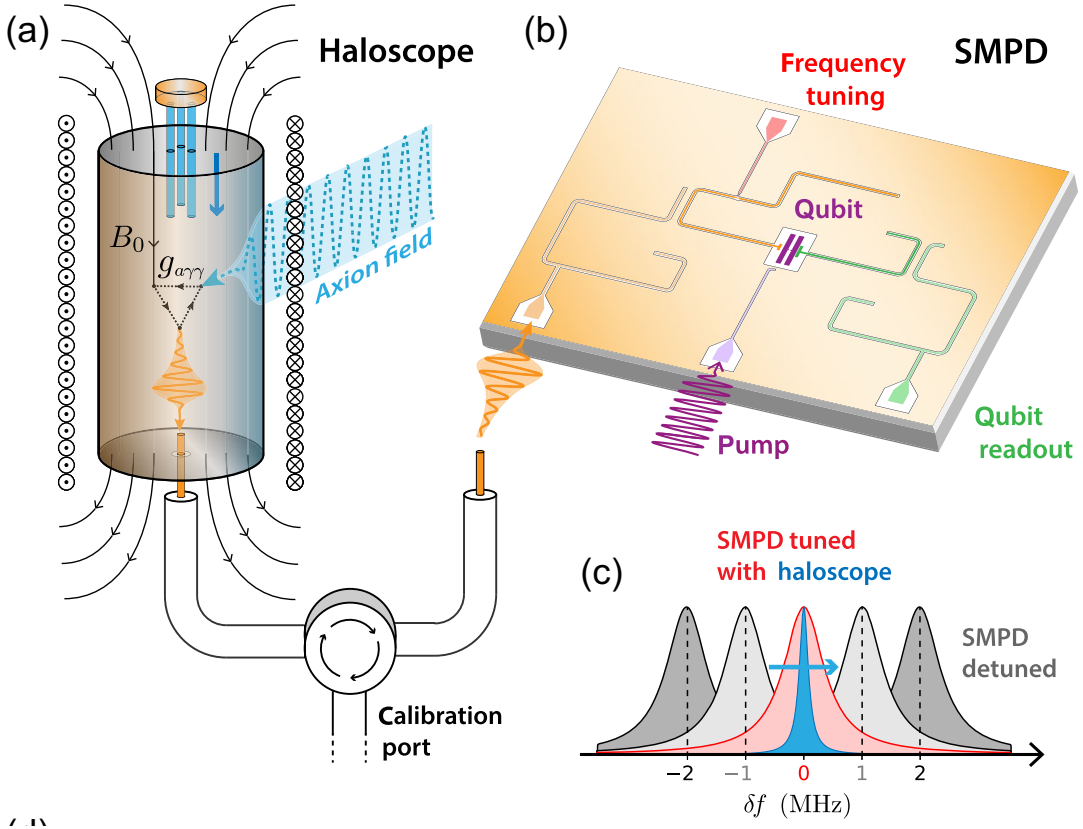
- **Proposals for improvement**

Connecting to a dish antenna

→ enabling wide-band Axion search

Multiple qubits

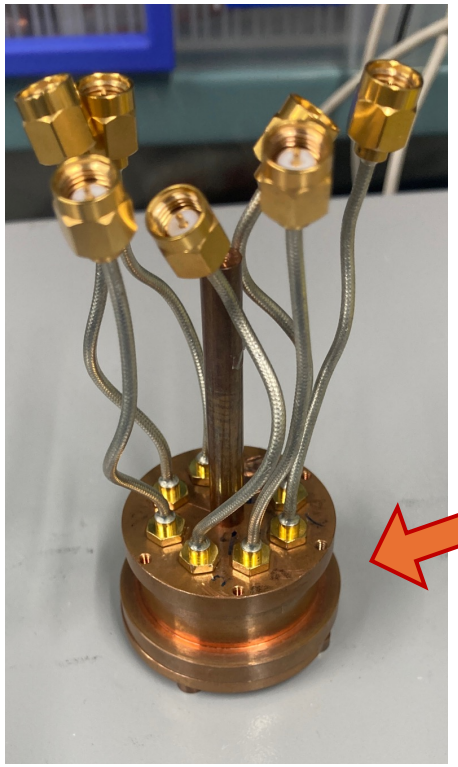
→ higher detector sensitivity



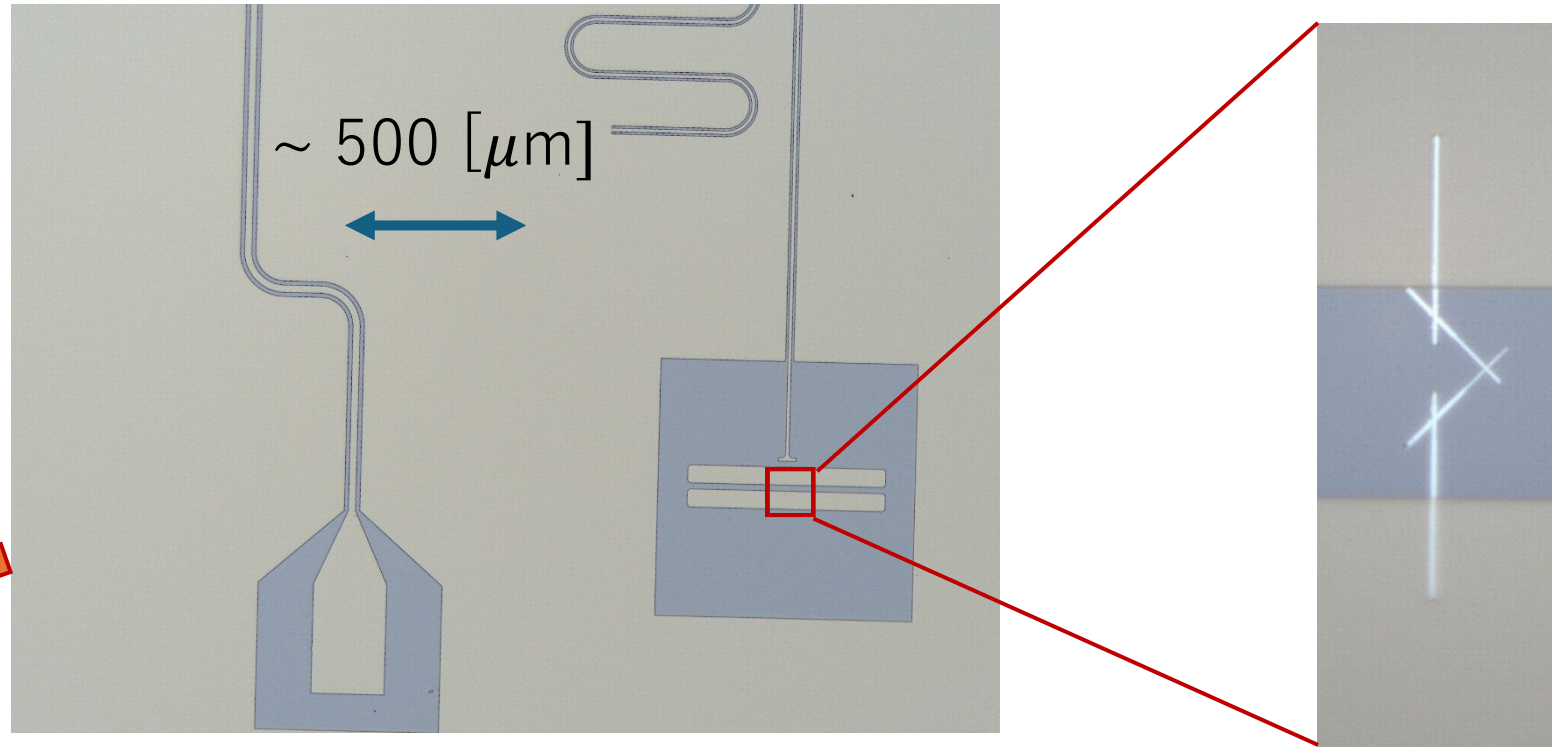
C. Braggio *et al. Phys. Rev. X* **15**, 021031 (2025)

Test Chip Fabrication

Transmon qubit : the **key component** of the SMPD
→ Fabricating a high-performance transmon is important.

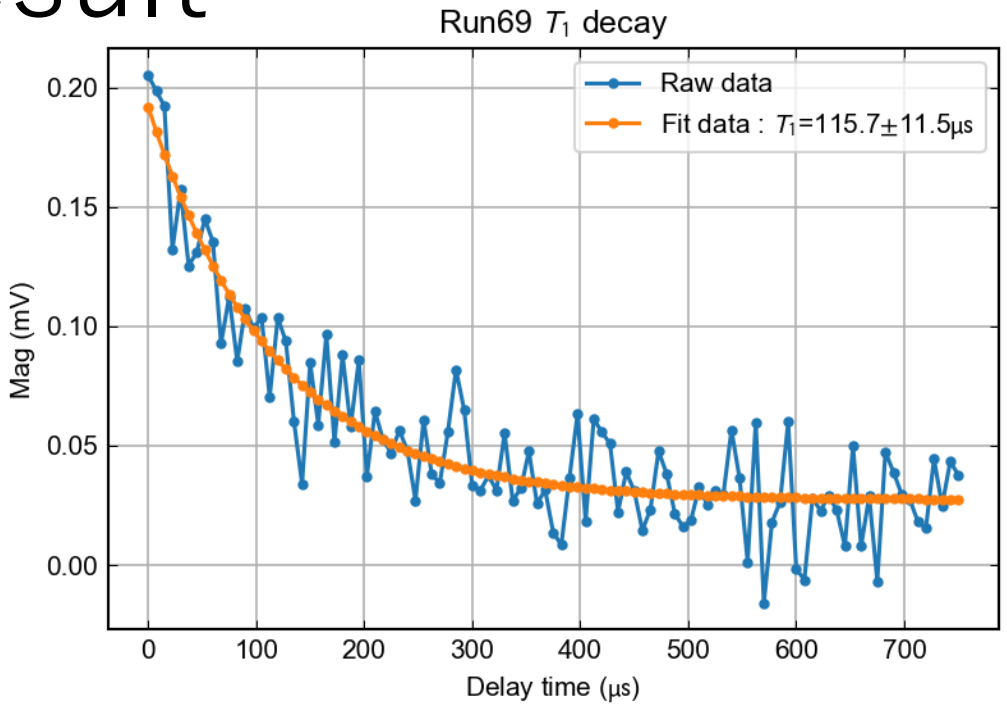


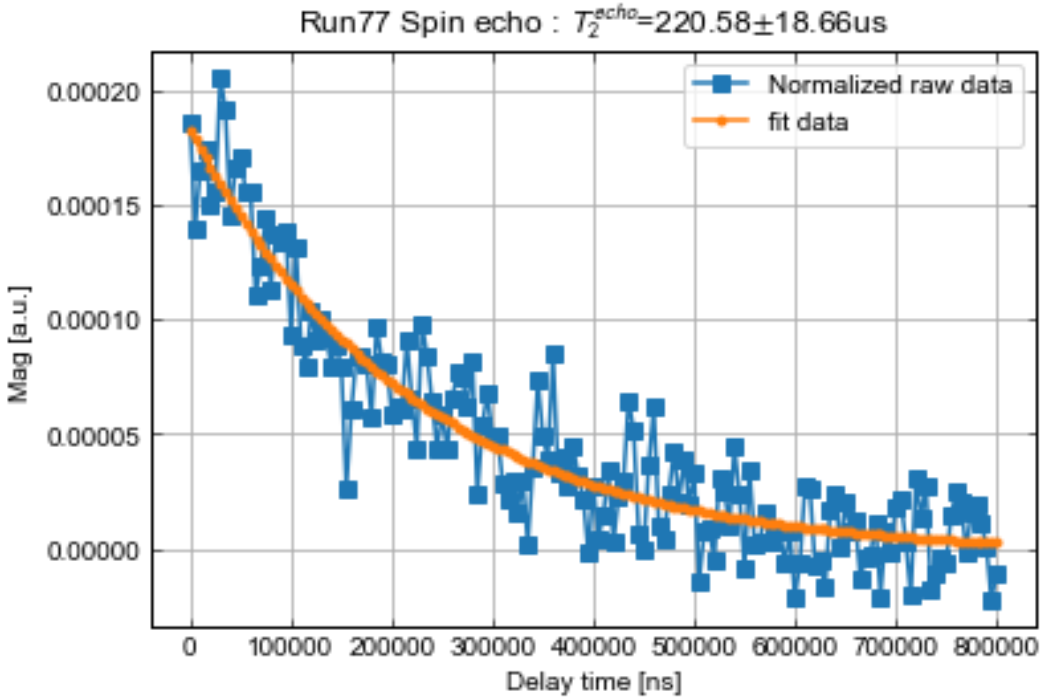
Sample holder



Optical microscope image of our transmon qubit, resonator (central figure) and Josephson junction (right figure)

Result





- Energy relaxation time : typical timescale over which an excited state loses its energy and returns to its ground state.

→**Improving T_1 is crucial for better SMPD performance.**

- By optimizing the fabrication process, the maximum energy relaxation time and echo dephasing time of our 2D transmon **exceeded 100 μs and 200 μs,** respectively

Future Plan

- **Future Plan**

Short-term prospect : Building a prototype device and carry out proof-of-principle experiments.

Long-term prospect : Modifying the experiment setup and detector design, from the prior research.

I would be very happy to receive your questions and comments during the poster session.