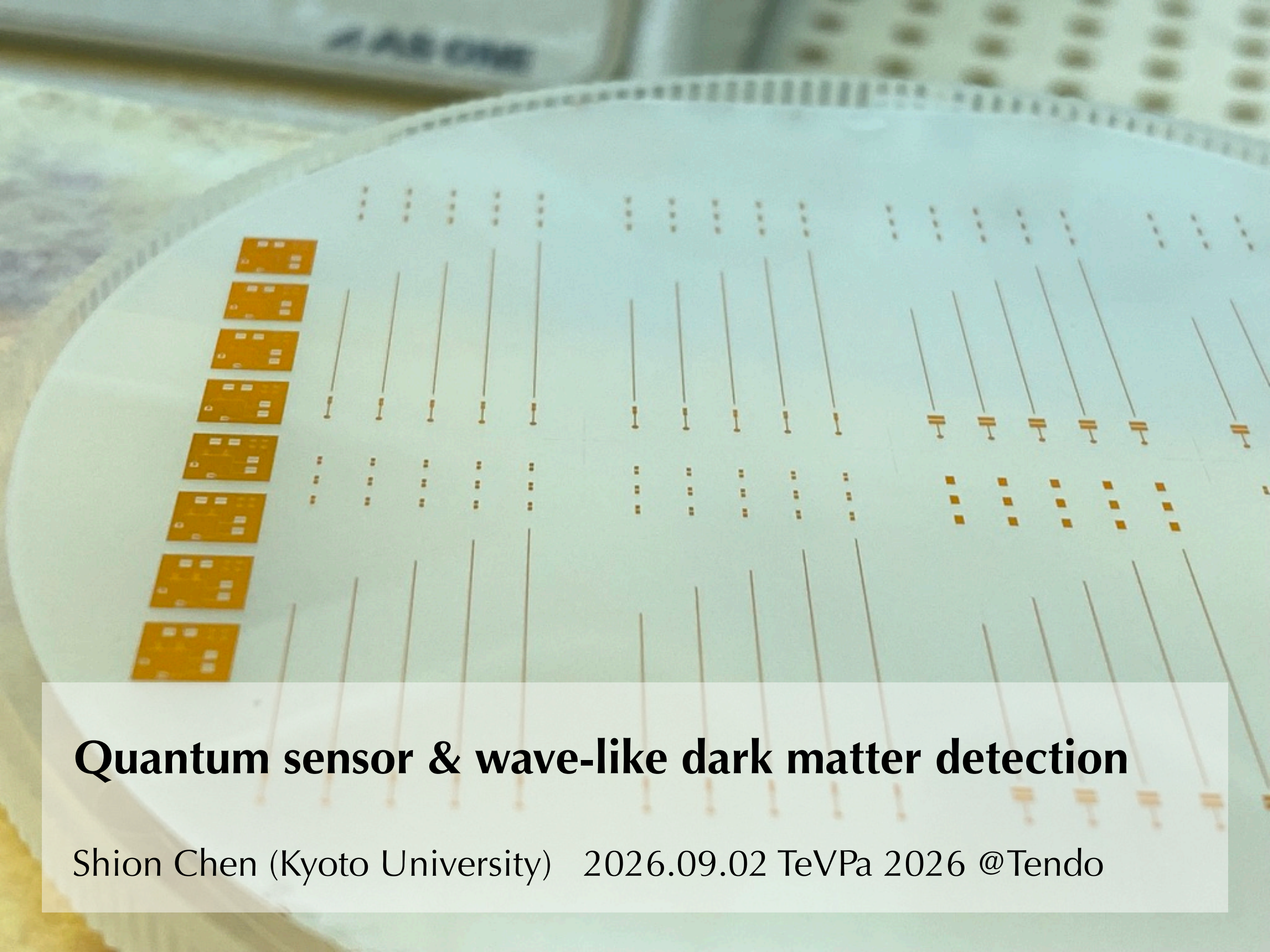




Quantum sensor & wave-like dark matter detection

Shion Chen (Kyoto University) 2026.09.02 TeVPa 2026 @Tendo

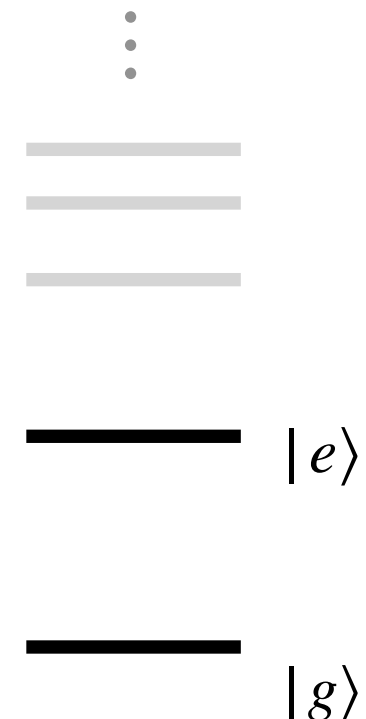
Qubits are sensors

Intrinsic trade off of quantum computers

- Fast control → Strong coupling preferred
- Long coherence time required → Small coupling preferred

Qubits: any two-level systems

- Photon (polarization state)
- Ion (spin or vibrational state)
- Neutral atom (electronic orbital state)
- Single electron (Landau levels)
- Diamond NV center (spin state)



Qubits are sensors

Intrinsic trade off of quantum computers

- Fast control → Strong coupling preferred
- Long coherence time required → Small coupling preferred

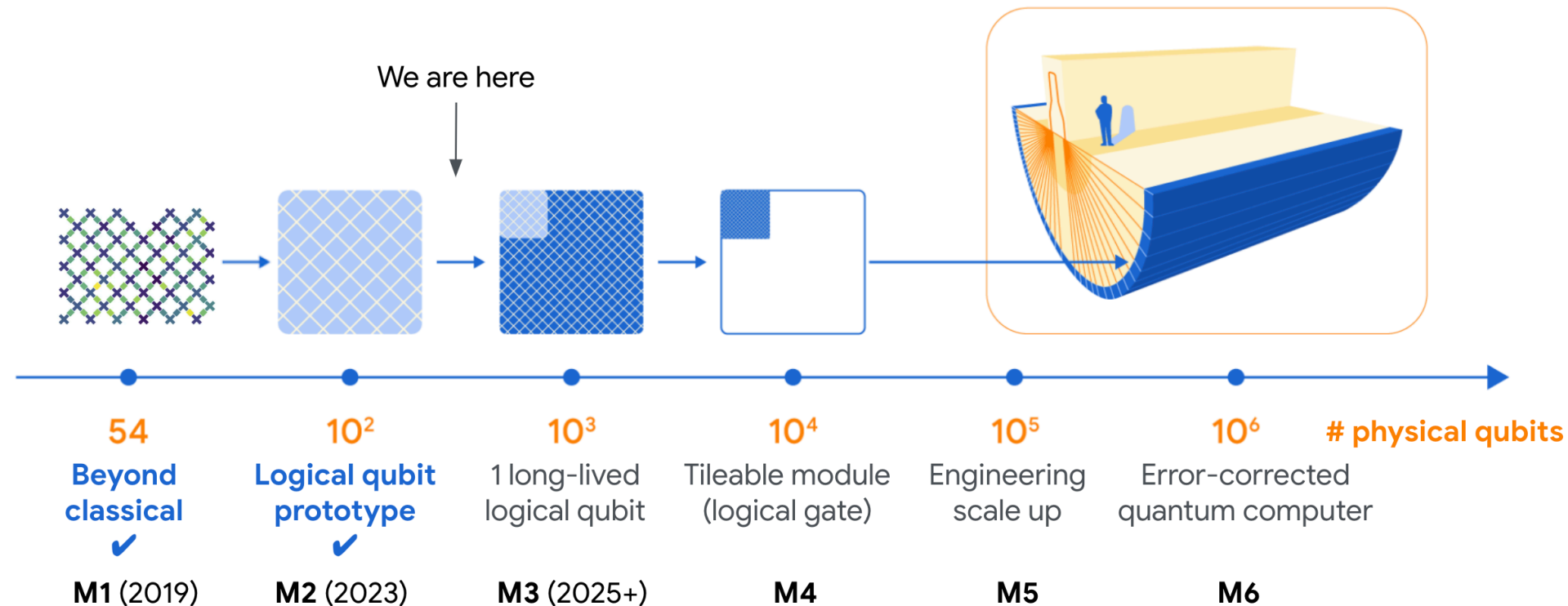
Same requirements for good sensors

- Sensitivity to weak signal → Strong coupling preferred
- Low noise level → Small coupling preferred

Good qubits = Good sensors

Good qubits are becoming available

Google Quantum AI



IBM Quantum



- ✓ **Long coherent time** ($T_{1,2} > 1 \text{ ms}$), **high gate fidelity** ($> 99.99/99.95\%$ for 1/2 bit gate)
- ✓ Breakthrough on **scale-up** ($> 10\text{k}$ bits) and **error correction**

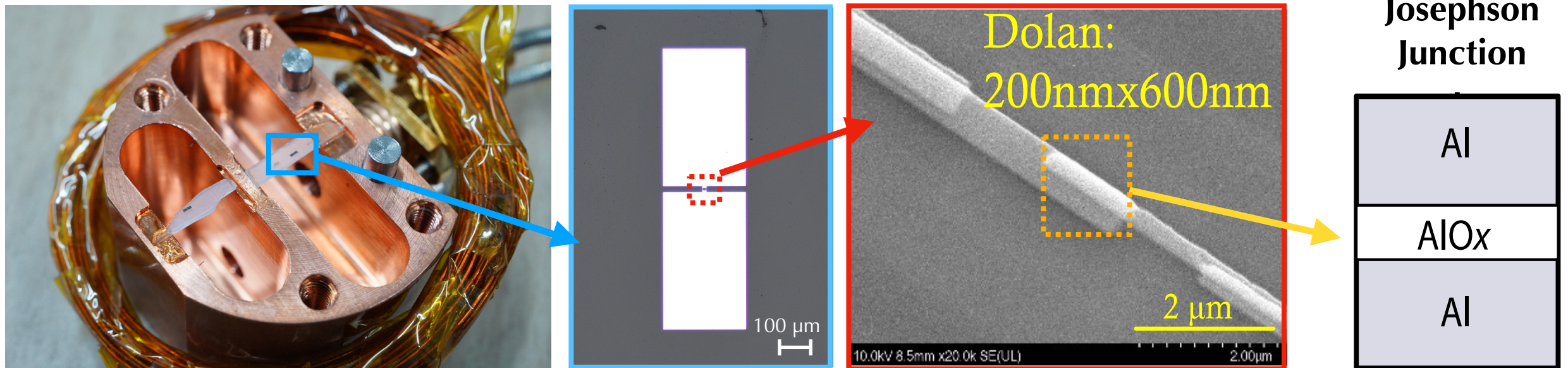
Still many challenges to go, but quantum computers are no longer a pipe dream

Today's talk

- How we can take advantage of the fast advance in the QC ?
- "Quantum computer as dark matter detector"

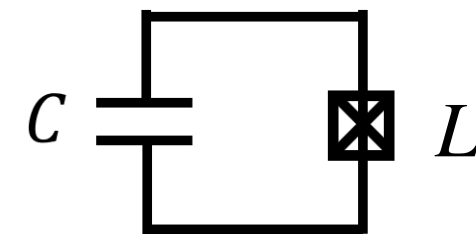
Focus on **superconducting qubit** platform today

Superconducting qubits



○ Non-linear LC circuit

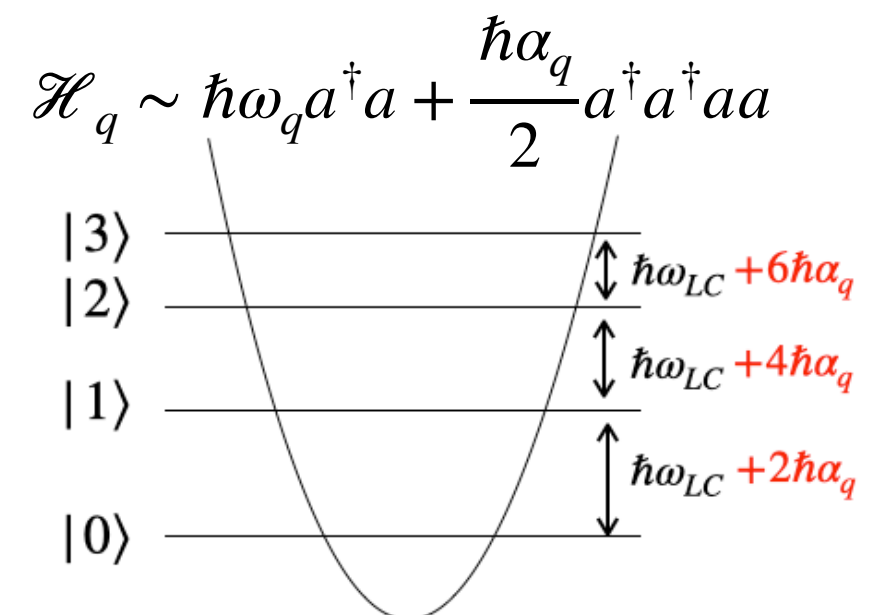
- Josephson junctions : non-linear inductance
- Anharmonic energy levels for state control



○ Thin-film superconductor : low loss

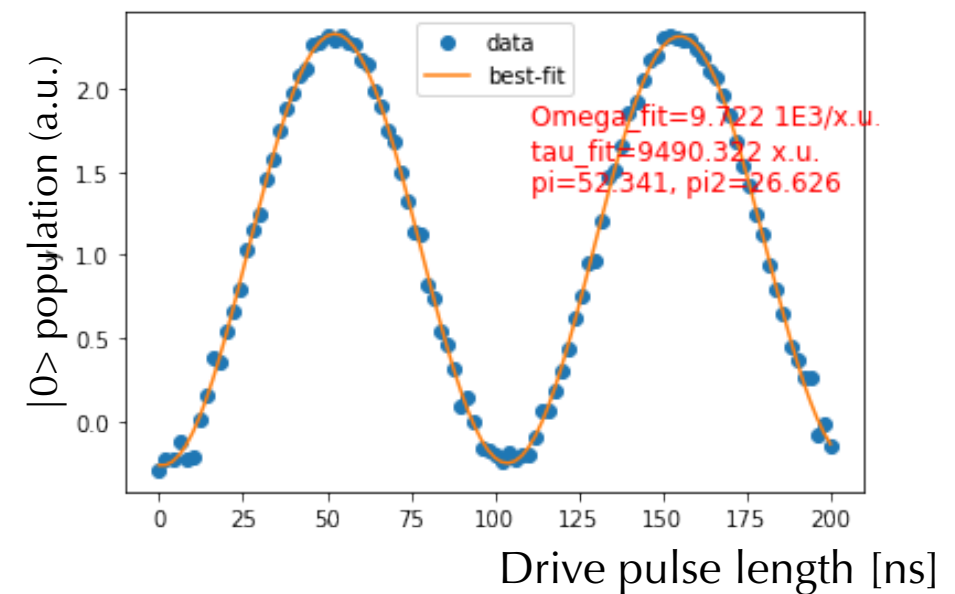
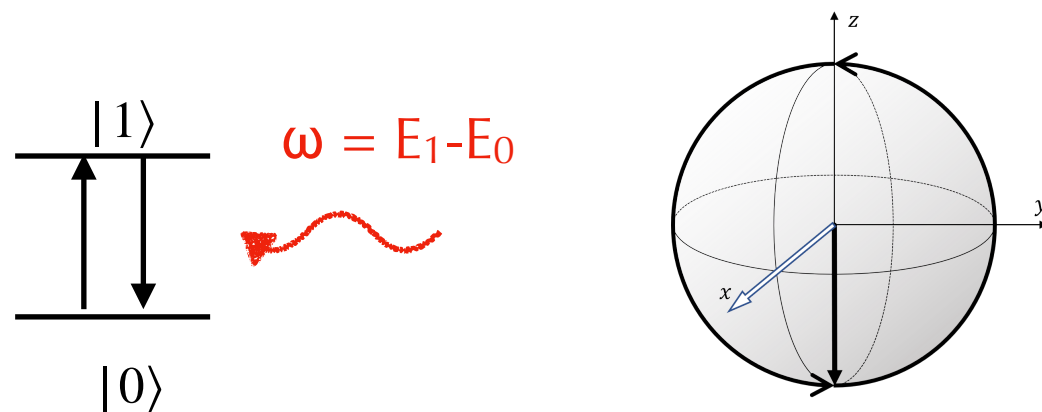
○ $E_1 - E_0$: 4-8 GHz **microwave frequency**

○ Operate at 10-20 mK

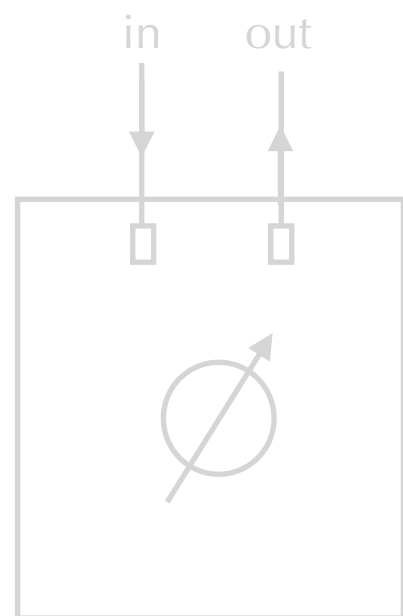


Superconducting qubits

State control : Resonant microwave drive (Rabi oscillation)



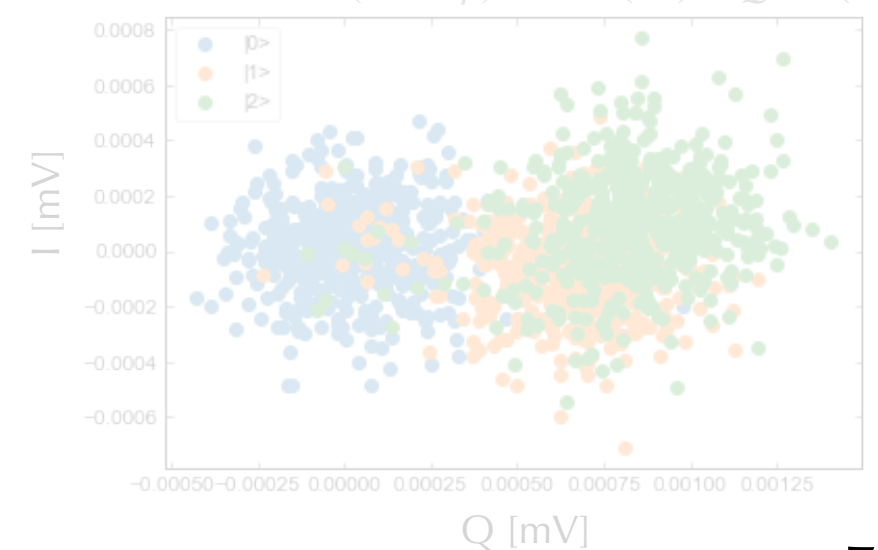
State readout : Transmission of coupled cavity (Dispersive readout)



$|g\rangle$ $|e\rangle$

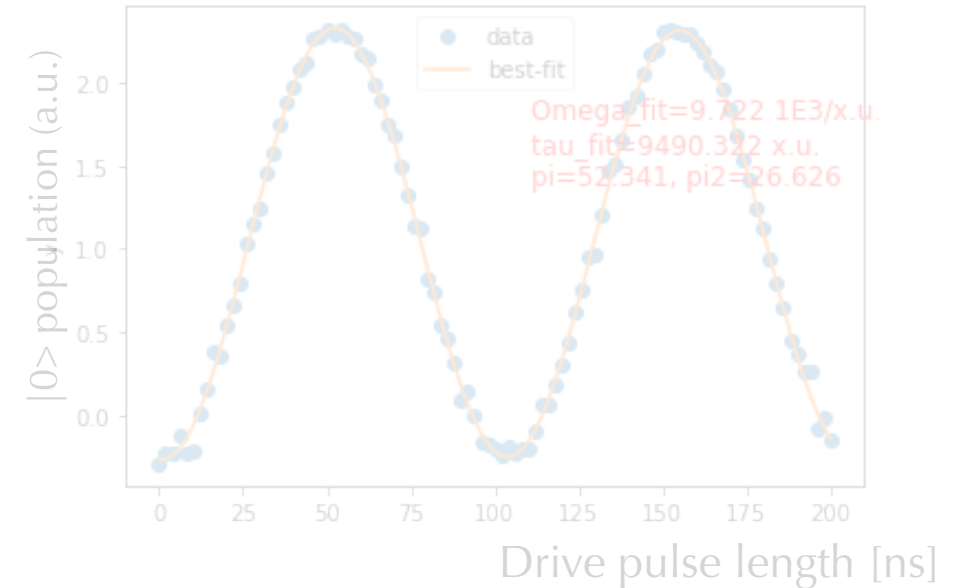
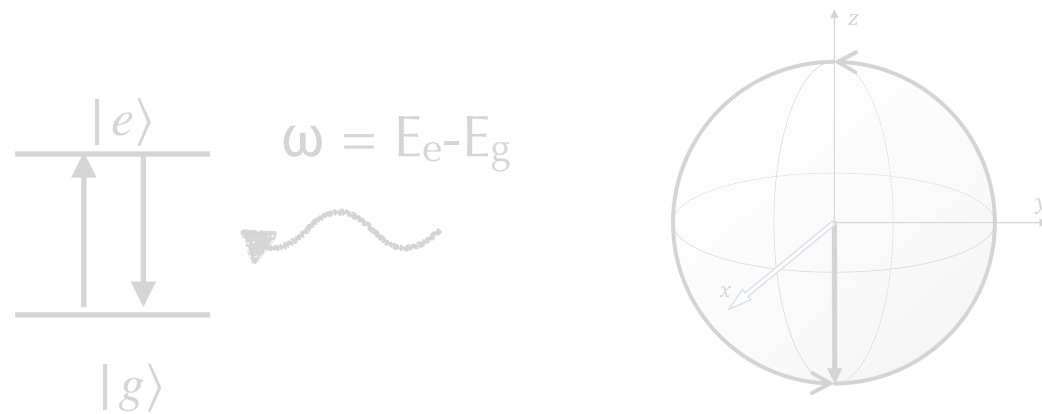
Phase of the transmitted wave

$$A \sin(\omega t + \phi) = I \sin(\omega t) + Q \cos(\omega t)$$

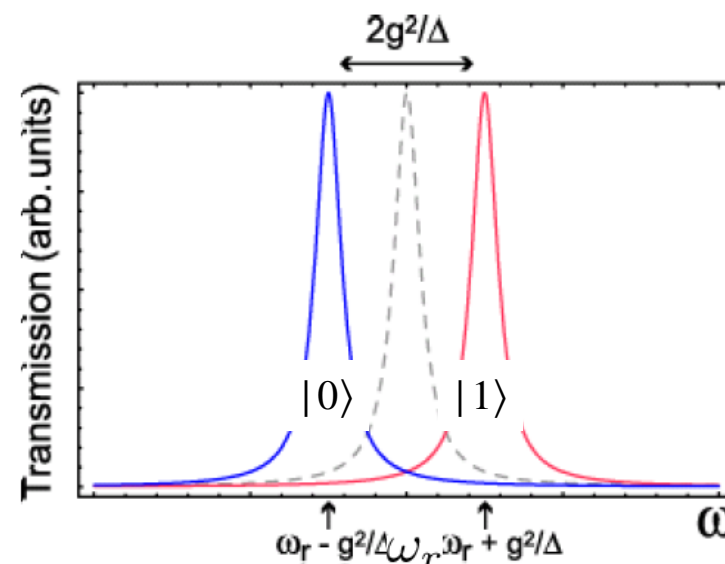
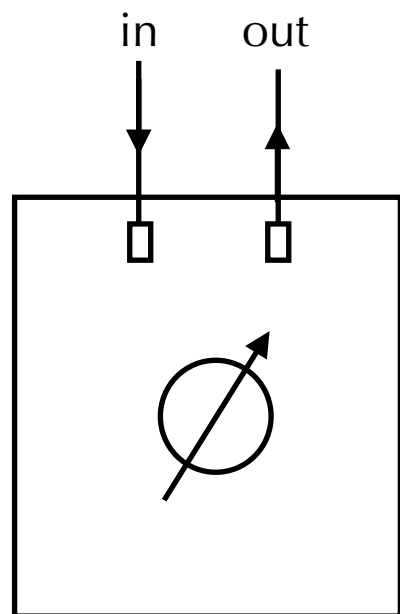


Superconducting qubits

State control : Resonant microwave drive (Rabi oscillation)

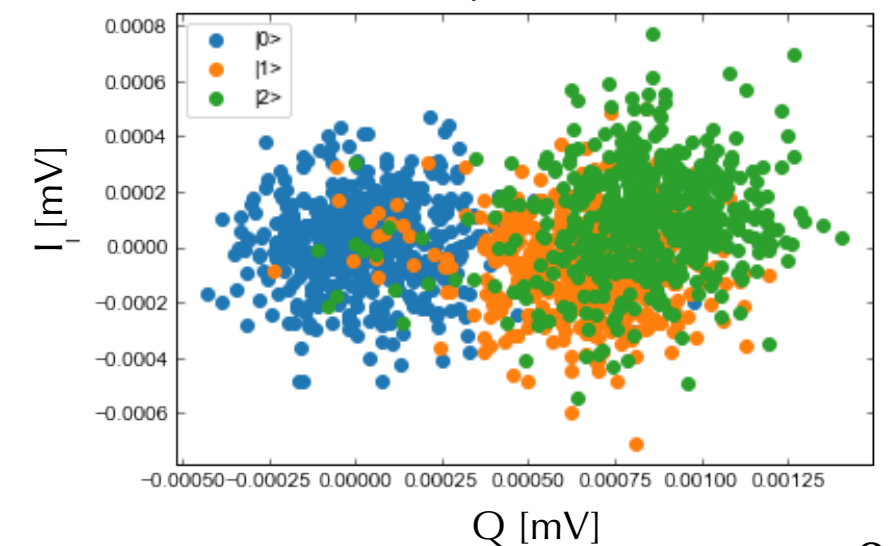


State readout : Transmission of coupled cavity (Dispersive readout)



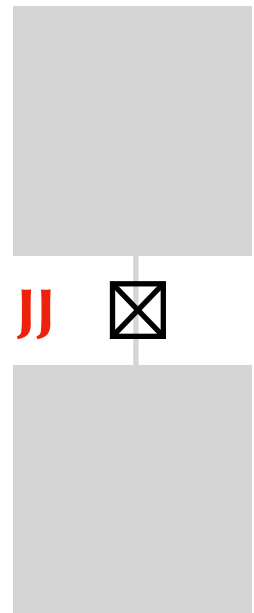
Phase of the transmitted wave

$$A \sin(\omega t + \phi) = I \sin(\omega t) + Q \cos(\omega t)$$



Superconducting qubits as photon sensors

Strong coupling to photon



EDM: $\mu \sim Qd$

$d = O(0.1 \text{ mm})$

macroscopic

$\times O(10^6)$ vs single atom

Superconducting qubits as photon sensors

Strong coupling to photon



EDM: $\mu \sim Qd$

$d = O(0.1 \text{ mm})$

macroscopic

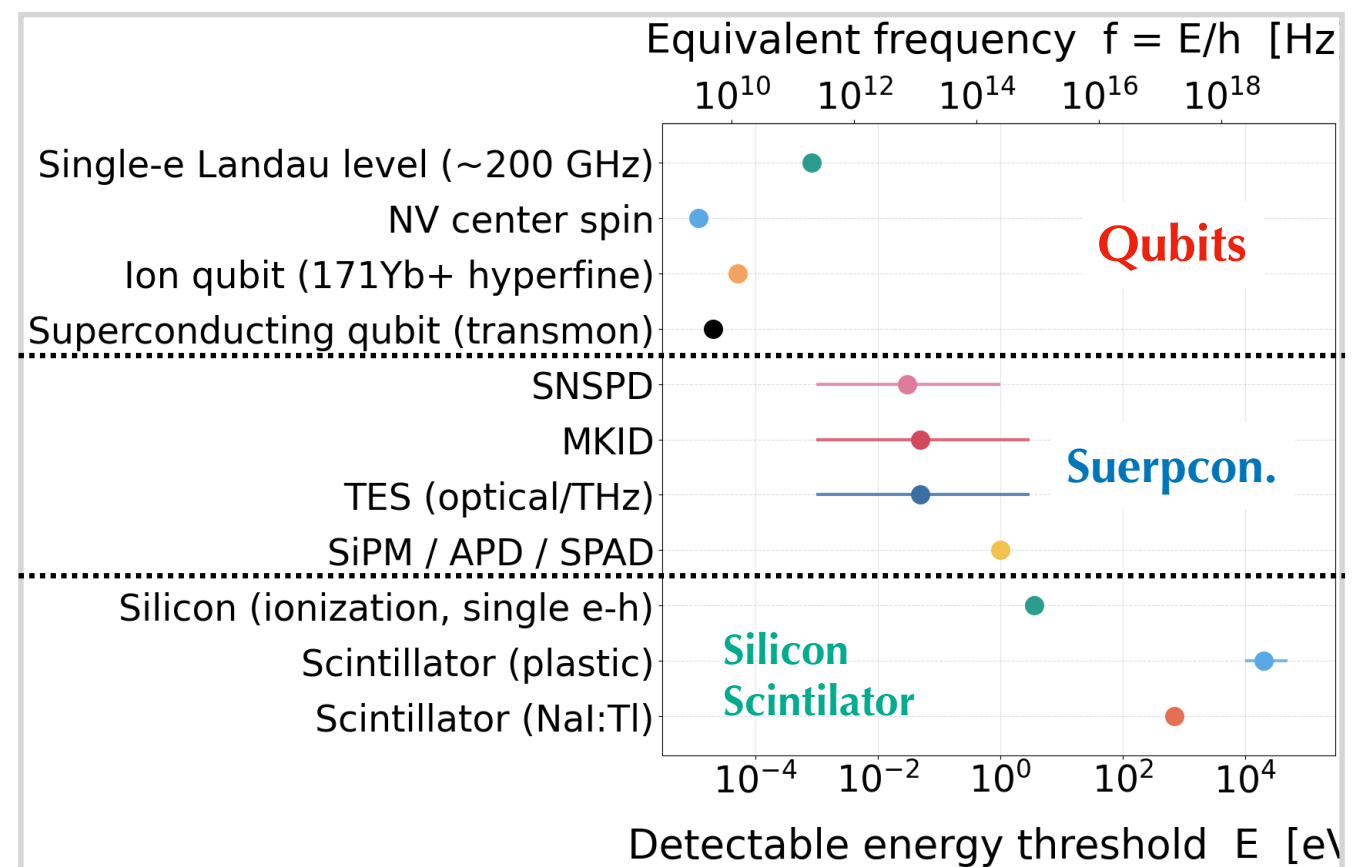
$\times O(10^6)$ vs single atom

Low threshold

Typically μeV (GHz)

c.f. Superconductor detector $\sim \text{meV}$

Scintillator / Silicon $\sim \text{eV}$



Superconducting qubits as photon sensors

Strong coupling to photon



EDM: $\mu \sim Qd$

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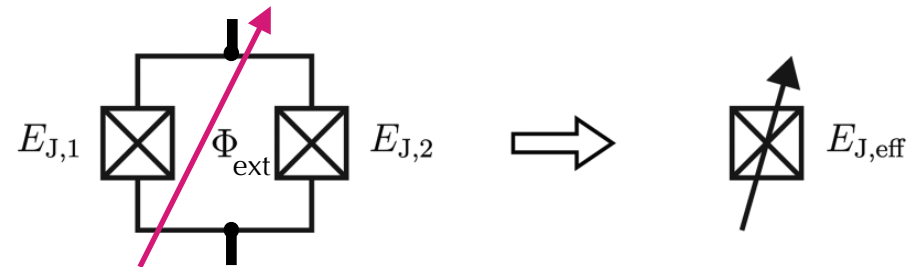
Low threshold

Typically μeV (GHz)

c.f. Superconductor detector $\sim \text{meV}$

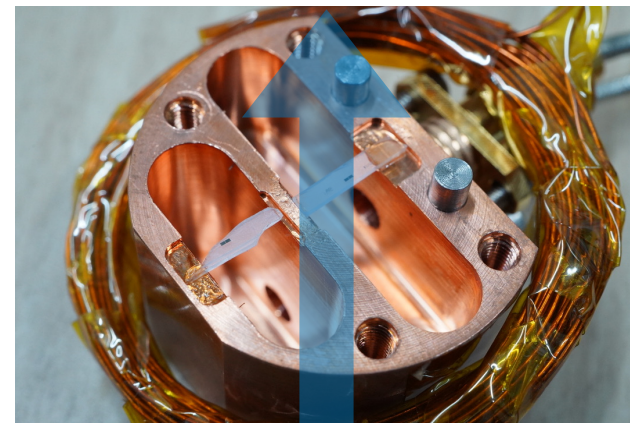
Scintillator / Silicon $\sim \text{eV}$

Wide frequency tunability

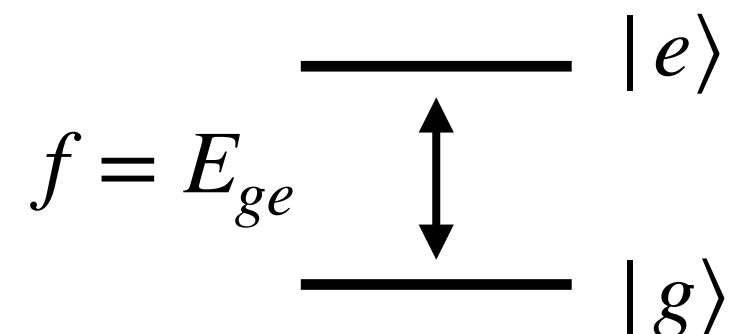


$$E_{J,\text{eff}}(\varphi_{\text{ext}}) = \sqrt{E_{J,1}^2 + E_{J,2}^2 + 2E_{J,1}E_{J,2} \cos \varphi_{\text{ext}}}$$

B-field ($\sim \mu\text{T}$)

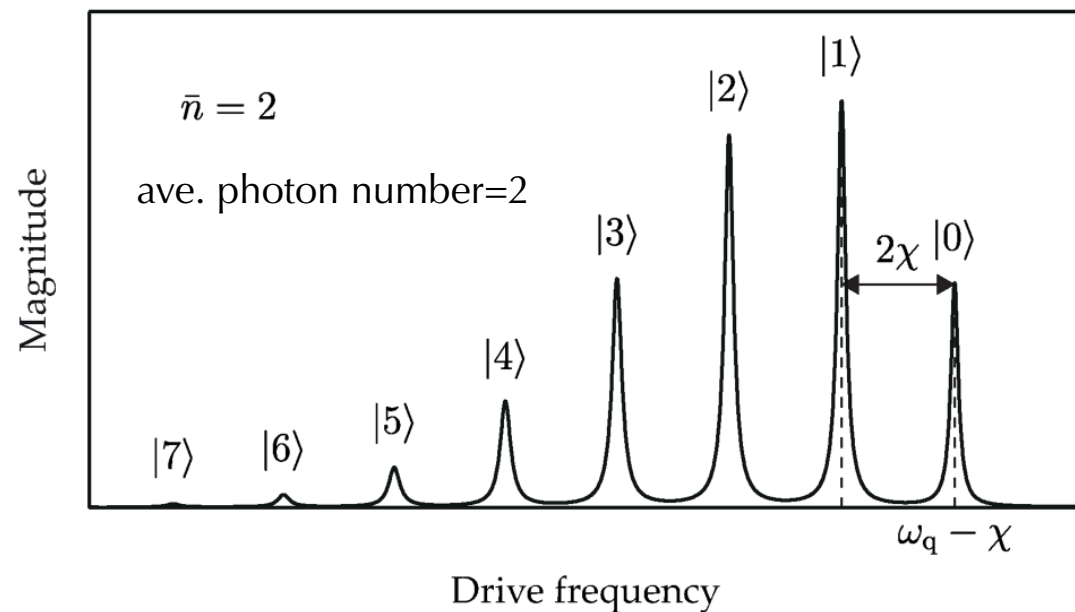


Tuning range
 $> \text{GHz}$

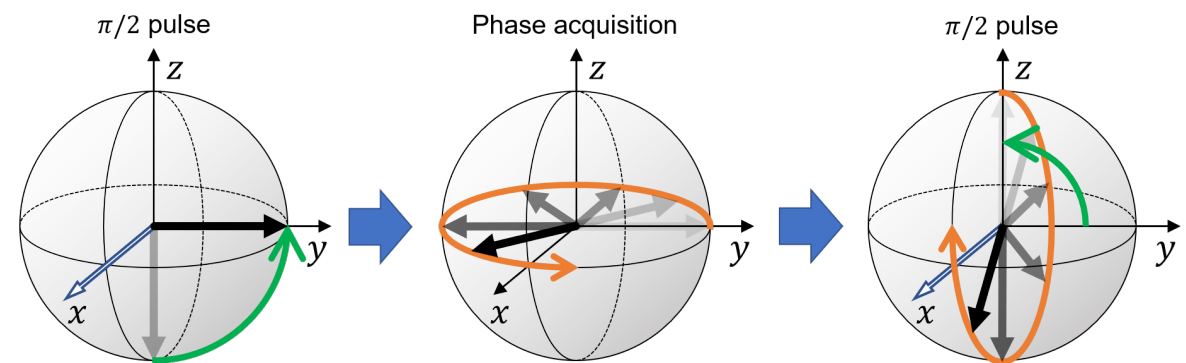


Single microwave photon counting

(b) Shift in qubit frequency: number splitting



Ramsey spectroscopy sequence



- Ambient photon $\rightarrow$ qubit detune ("ac Stark shift")

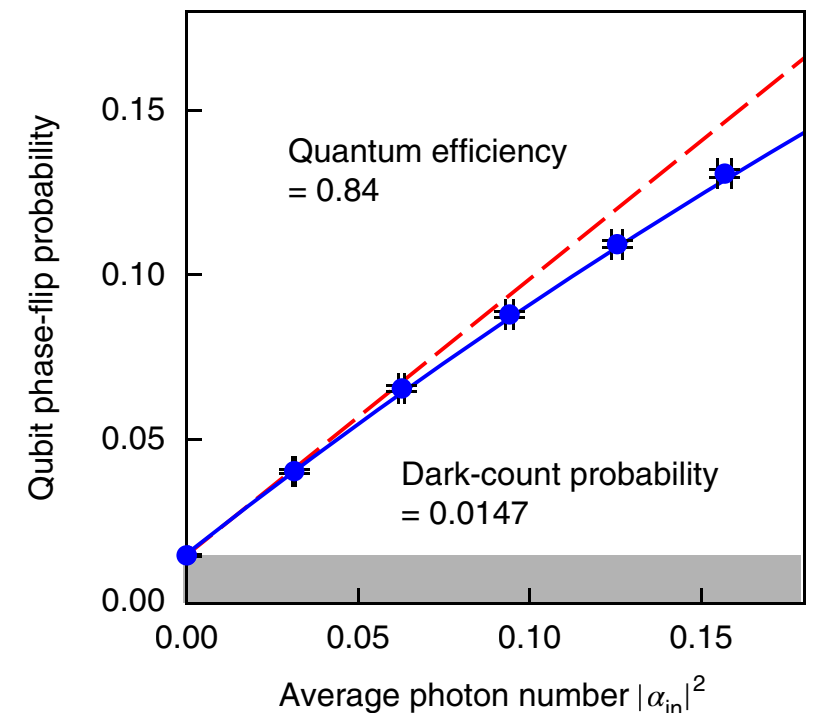
- Ramsey spectroscopy to detect the detune

Single-photon sensitivity for standing wave modes

- Itinerant photons? $\rightarrow$ R&D in progress

Lescanne et al. (2020)

Kono et al. (2018)



Physics targets : EM-interacting Wave-like dark matter

Axion

Strong CP problem

→ PQ mechanism → NG boson

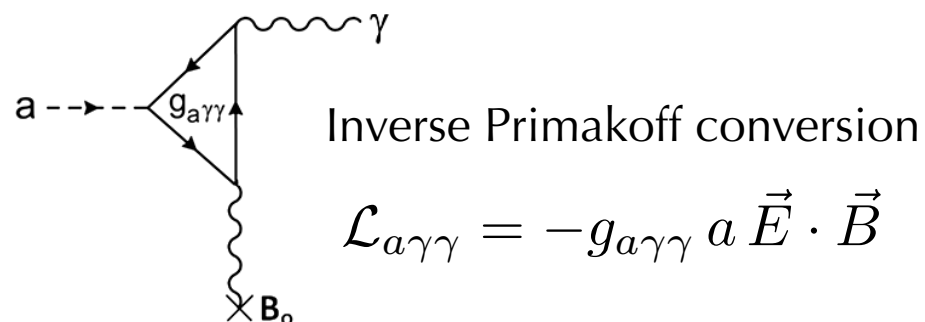
QCD axion condition

$$m_a = 5.691 \left(\frac{10^9 \text{ GeV}}{f_a} \right)$$

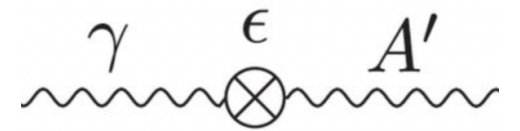
Axions that don't satisfy this are "Axion-Like Particle".
Cool thing still but won't solve the strong CP problem.

Axion-photon coupling

B-field → Photons emerge



Dark photon



mixing parameter

ordinary photon

$$X^\mu = \tilde{X}^\mu - \epsilon A^\mu$$

Dark photon
(mass eigen st.)

Dark photon
(interaction eigen st.)

Fake photon with a bit of ordinary photon

Gauge boson of a new $U(1)_{Q'}$

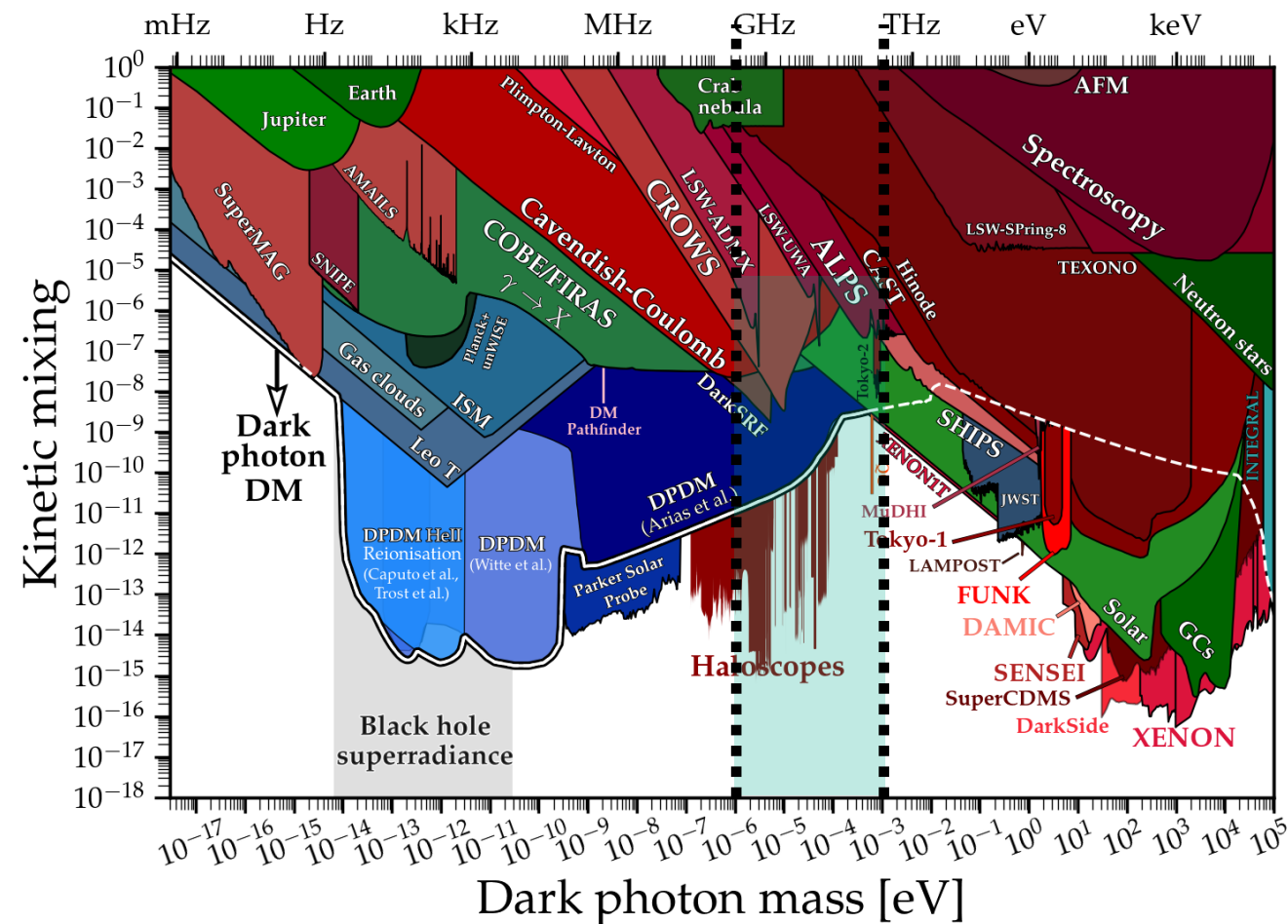
More motivation claimed recently in the context of string

Photon conversion w/o B-field

Tend to be the benchmark of axion search
experiments before installing the magnet.

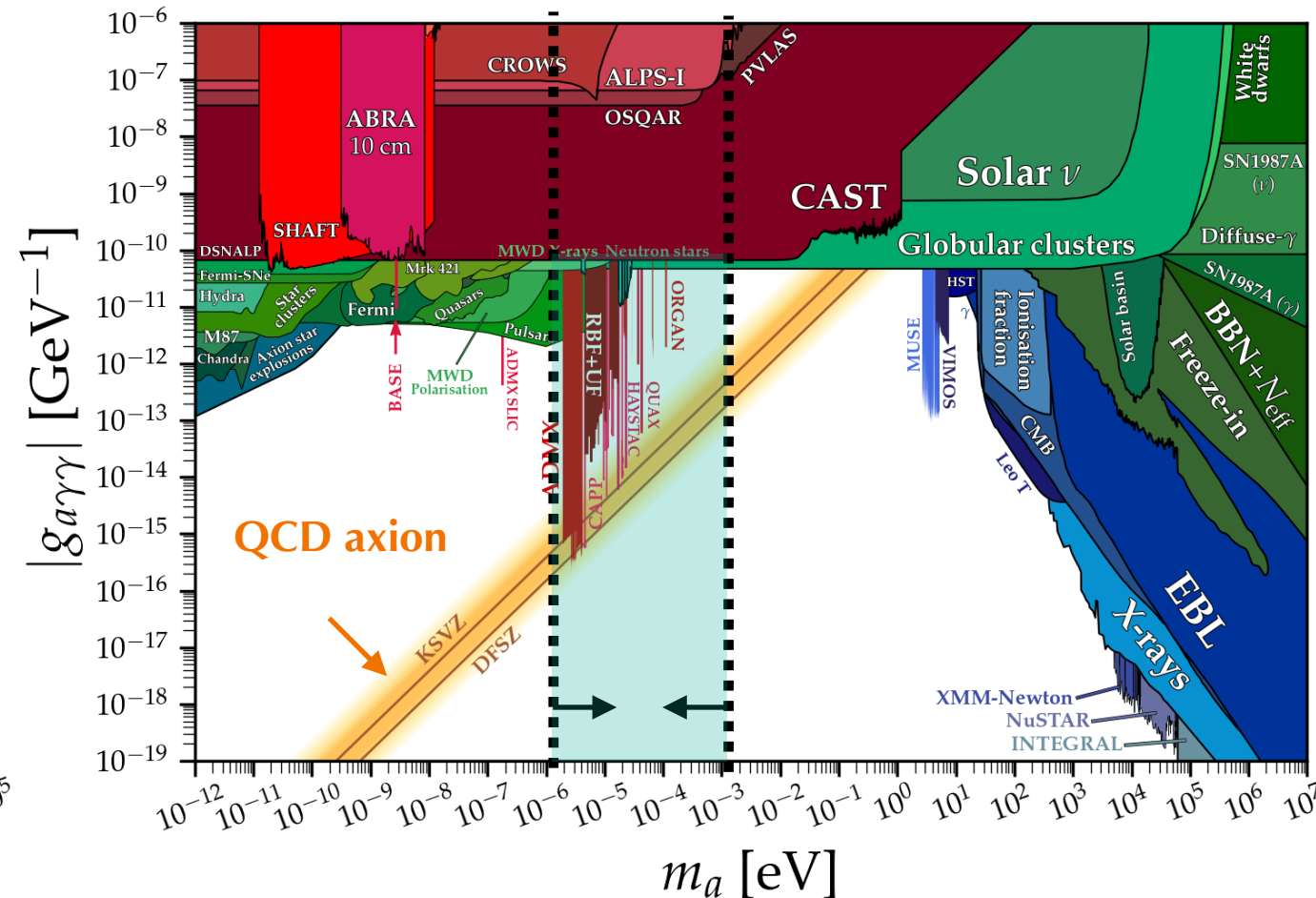
Physics targets : EM-interacting Wave-like dark matter

Dark photon



Axion

Planned in the future

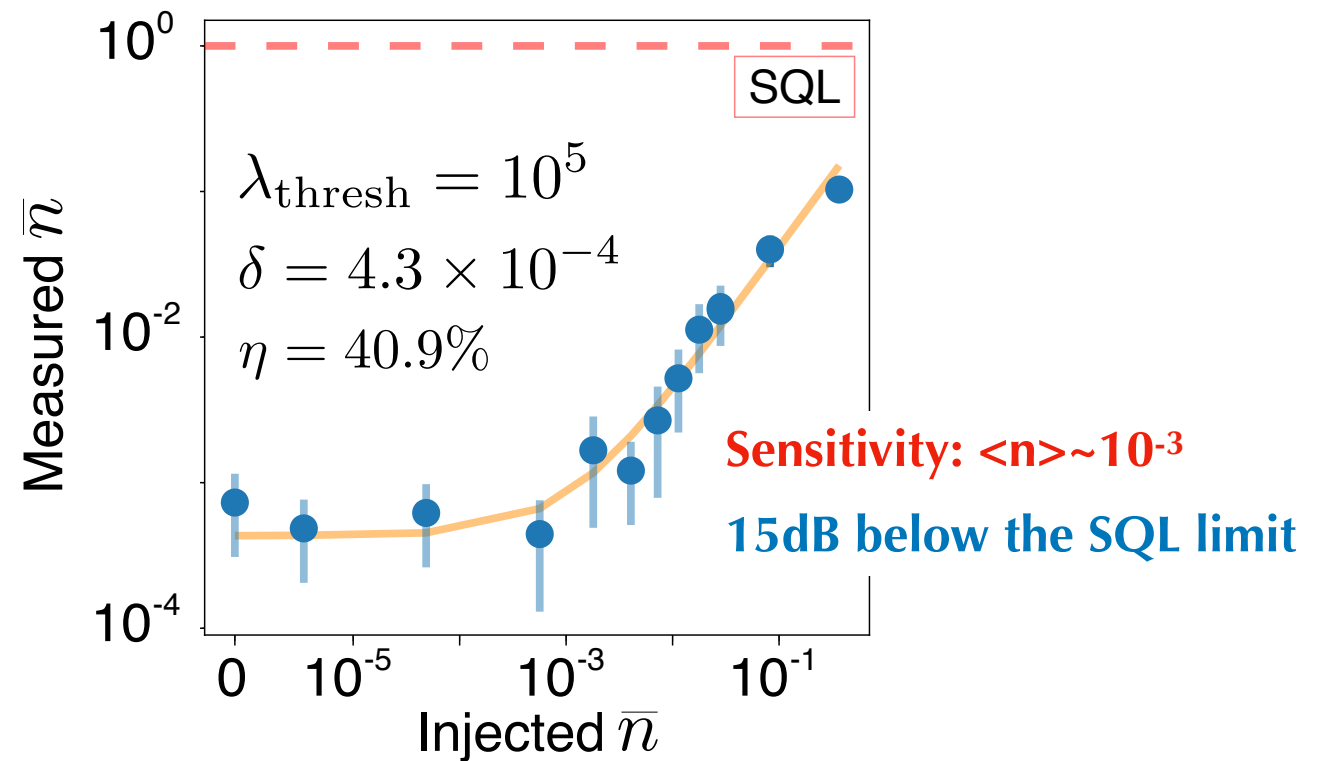
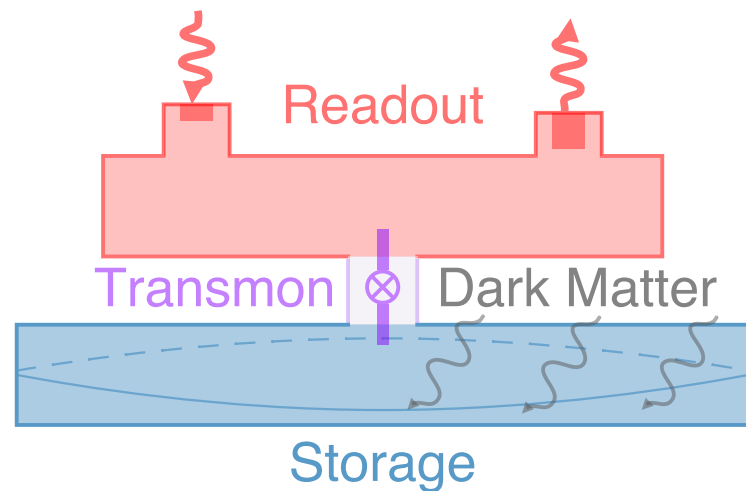


- Signal : feeble converted coherent EM field
- Microwave-Milliwave regime : μeV - meV (GHz-THz)

- Non-relativistic $\rightarrow$ mono-chronic $m_{\text{DM}}c^2 = h \frac{c}{\lambda_{\text{Compton}}}$

First application to dark photon DM search (SQuAD)

A. Dixit et al. arXiv: [2008.12231](https://arxiv.org/abs/2008.12231)

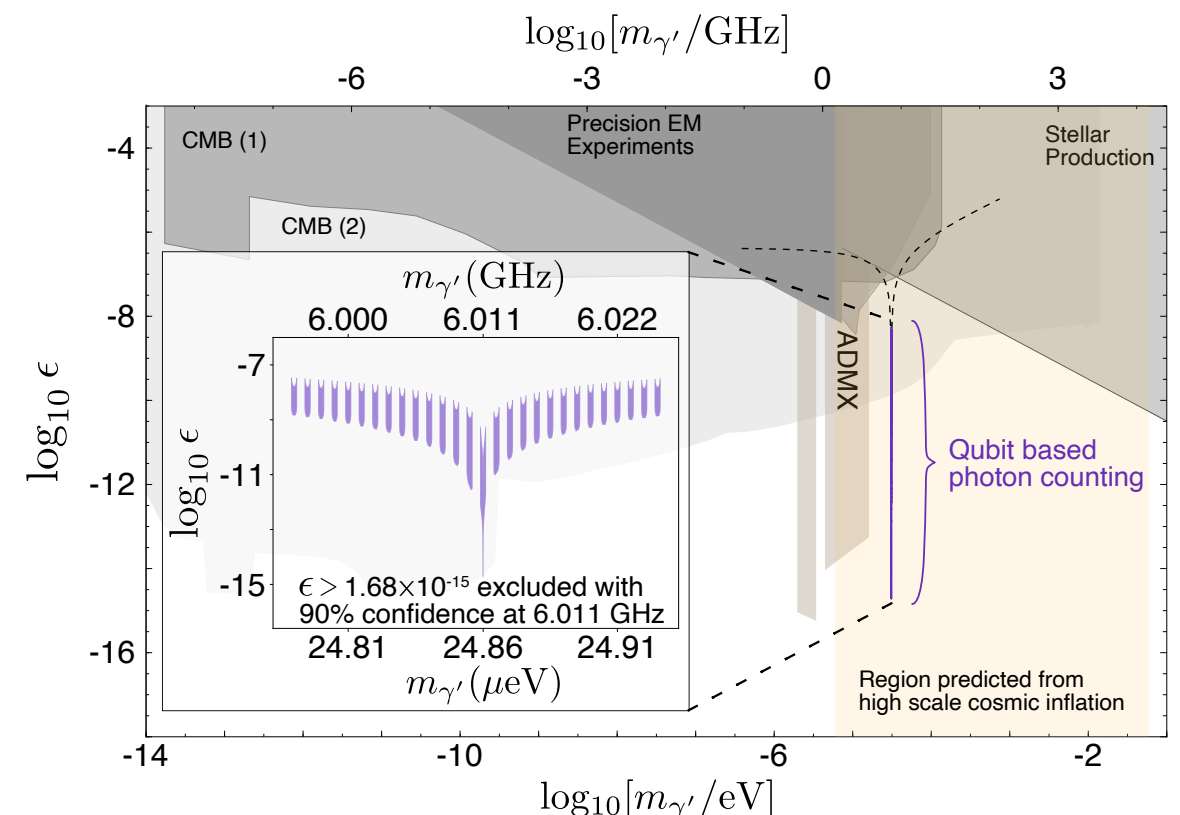


Cavity haloscope

- DM photons accumulated in the "storage"
- Read the "power" using antenna (e.g. ADMX)
- Start to suffer from Standard Quantum Limit (SQL)

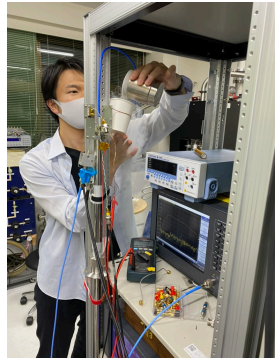
Qubit SPD to read the standing mode

- Projection to n-Fock state $\rightarrow$ no SQL
- BG level: $\langle n \rangle = 10^{-3}$
- Deep but narrow sensitivity



More direct usage of qubits? - *DarQ* experiment (2024-)

UTokyo ICEPP

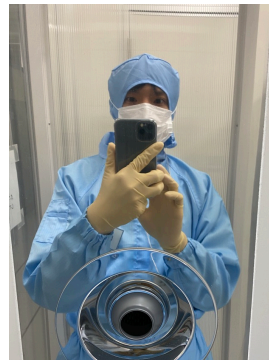


Toshiaki Inada



Yuya Mino

KyotoU HE Lab



Shion Chen



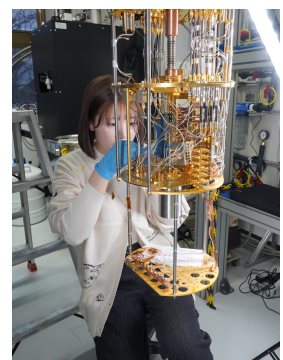
Kosuke Nakamura



Koki Aoyanagi



Koki Aoyanagi



Karin Watanabe



Kan Nakazono



Chikara Kawai

KEK QUP

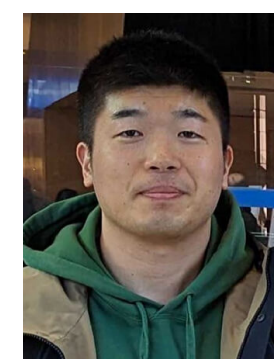


Tatsumi Nitta

UTokyo Noguchi Lab / RIKEN RQC



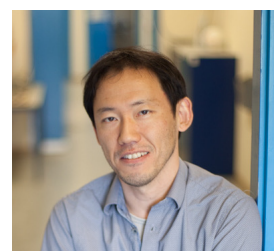
Atsushi Noguchi



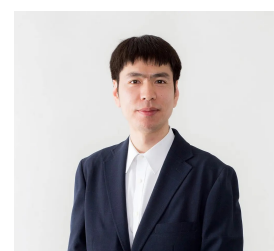
Shotaro Shirai



Yutaro Iiyama



Koji Terashi



Ryu Sawada

UTokyo Moroi Lab



Takeo Moroi



Hajime Fukuda



Thanaporn Sichanugrist

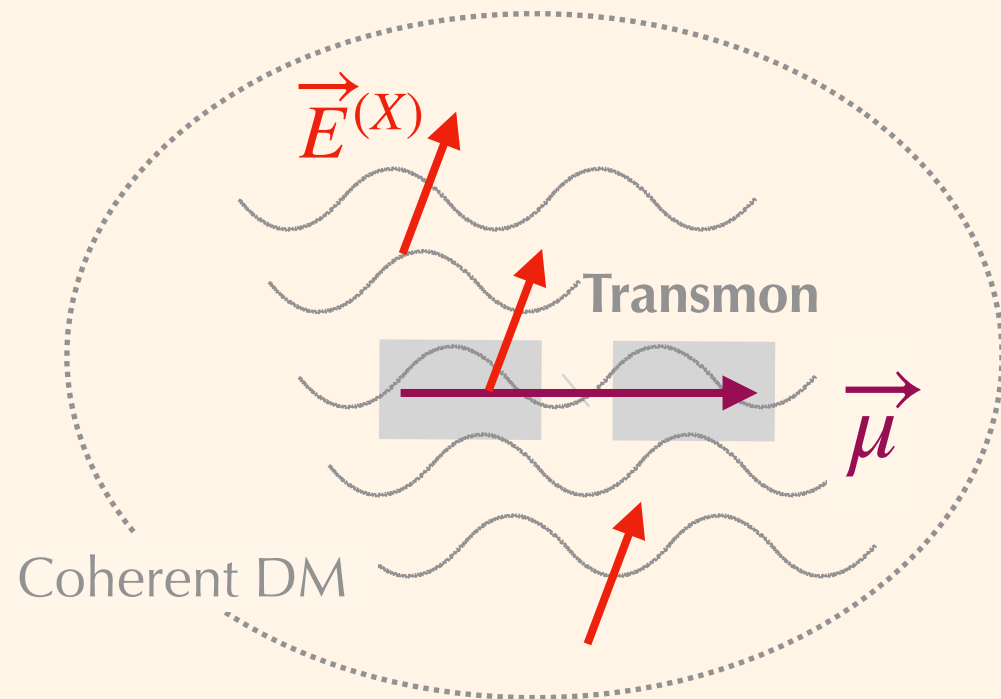
[Link](#)



"Direct excitation" by dark photon

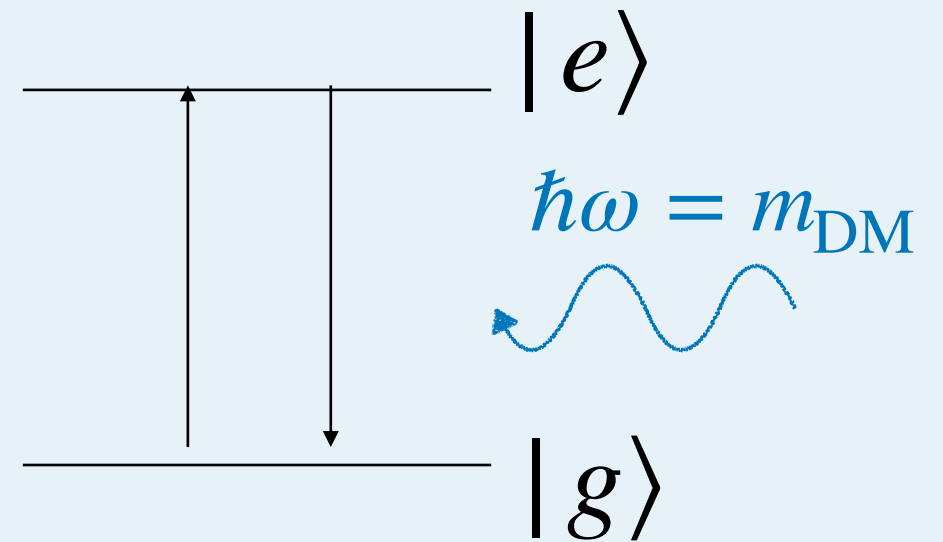
Moroi et al. PRL 131, 211001 (2023)

E-field from the DM



=

Qubit drive pulse



Excitation rate after τ :

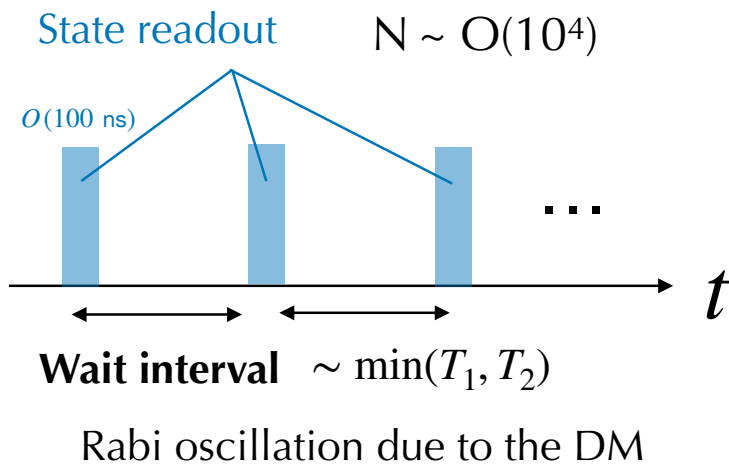
$$p \simeq 0.12 \times \kappa^2 \cos^2 \Theta \left(\frac{\epsilon}{10^{-11}} \right)^2 \left(\frac{f}{1 \text{ GHz}} \right) \left(\frac{\tau}{100 \text{ } \mu\text{s}} \right)^2 \left(\frac{C}{0.1 \text{ pF}} \right) \left(\frac{d}{100 \text{ } \mu\text{m}} \right)^2 \left(\frac{\rho_{\text{DM}}}{0.45 \text{ GeV/cc}} \right)$$

0.1-10% for $\epsilon=10^{-12} \sim 10^{-11}$

Search protocol

Moroi et al. PRL 131, 211001 (2023)

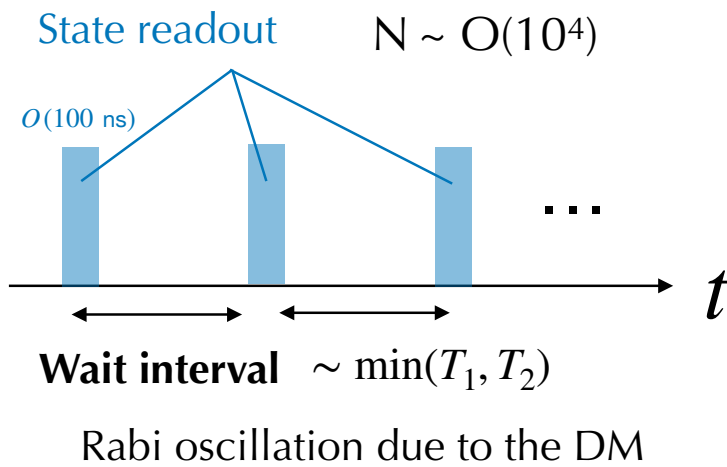
(Wait→Read)^N



Search protocol

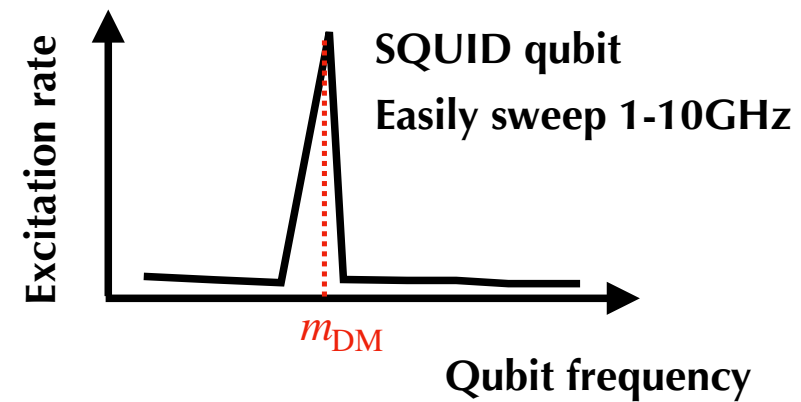
Moroi et al. PRL 131, 211001 (2023)

(Wait→Read)^N



Frequency scan→bump hunting

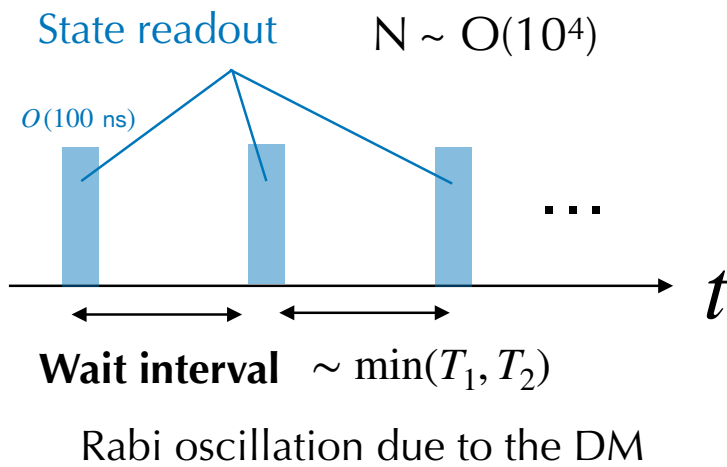
Excitation rate = fraction of $|e\rangle$ readout



Search protocol

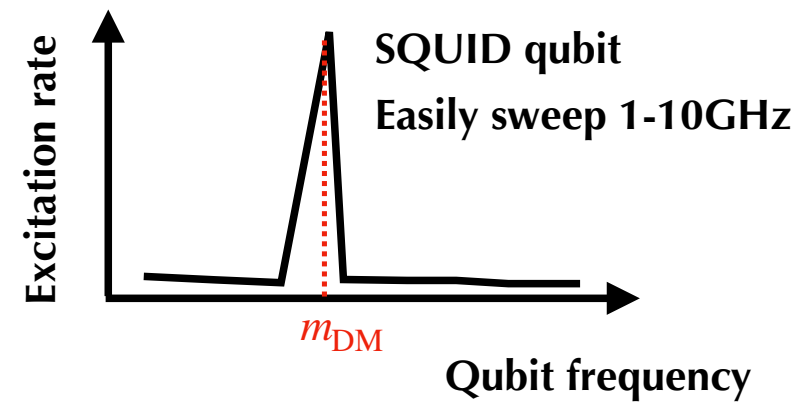
Moroi et al. PRL 131, 211001 (2023)

(Wait→Read)^N

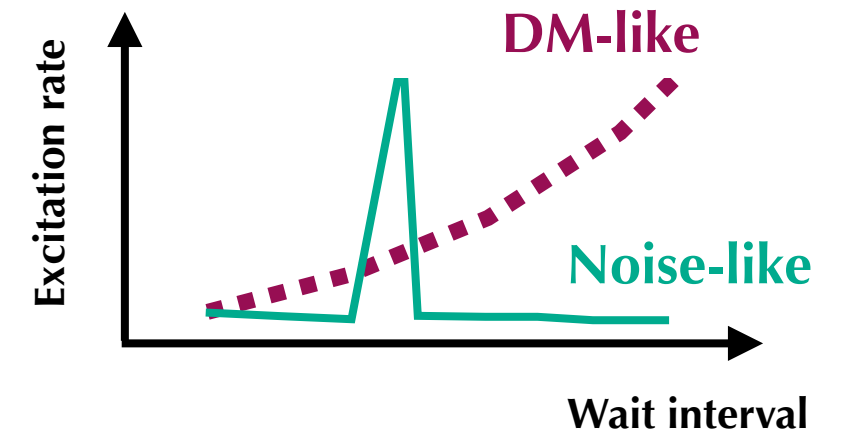


Frequency scan→bump hunting

Excitation rate = fraction of $|e\rangle$ readout



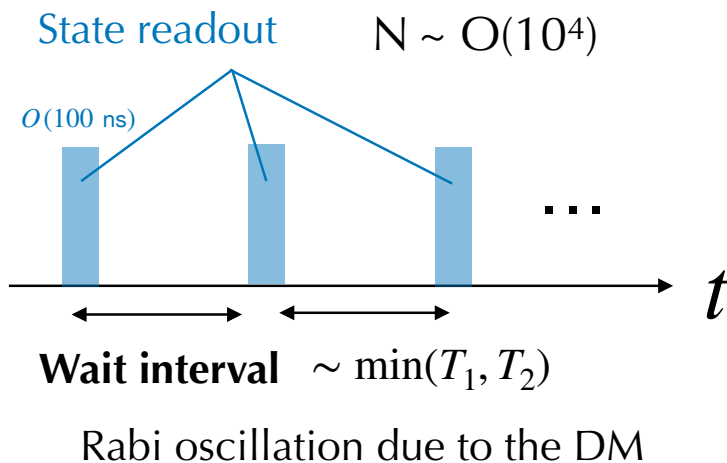
Revisit the suspicious freq.



Search protocol

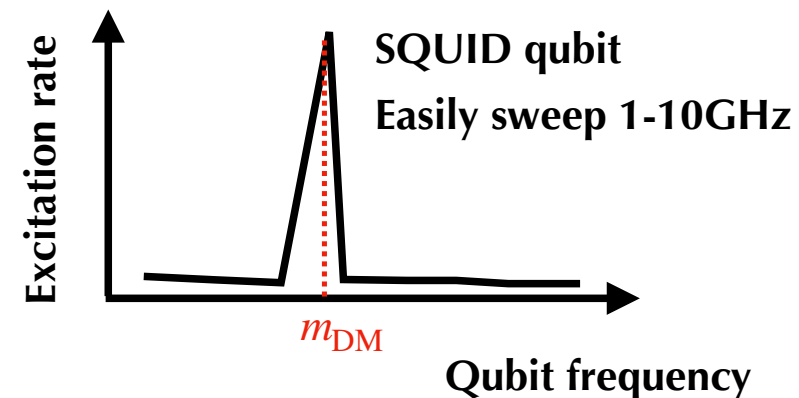
Moroi et al. PRL 131, 211001 (2023)

(Wait→Read)^N

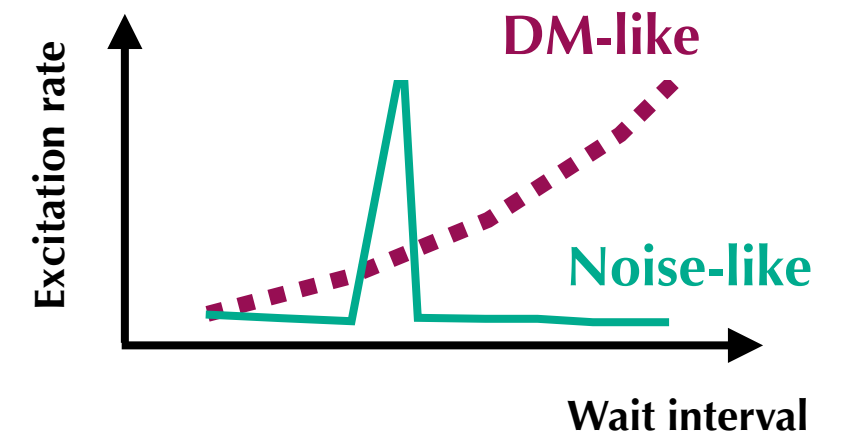


Frequency scan→bump hunting

Excitation rate = fraction of $|e\rangle$ readout



Revisit the suspicious freq.



Not many noises can cause $|g\rangle \rightarrow |e\rangle$

Thermal: $p \sim e^{-\hbar\omega/kT}$ 0.01-1% @30mK

Readout error : ~0.1%

Sensitivity not strongly bounded by coherence time

Short $T_1 \rightarrow$ Faster cycle

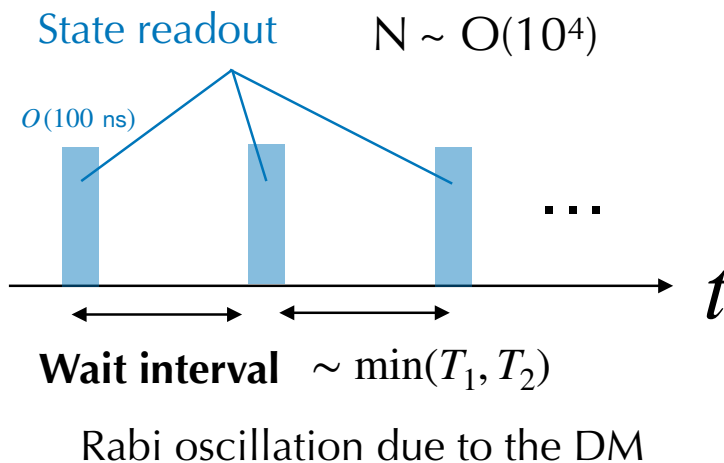
Larger width (fewer step to scan)

- ✓ Relax the fabrication requirement
- ✓ Pursuit of qubits with stronger coupling

Search protocol

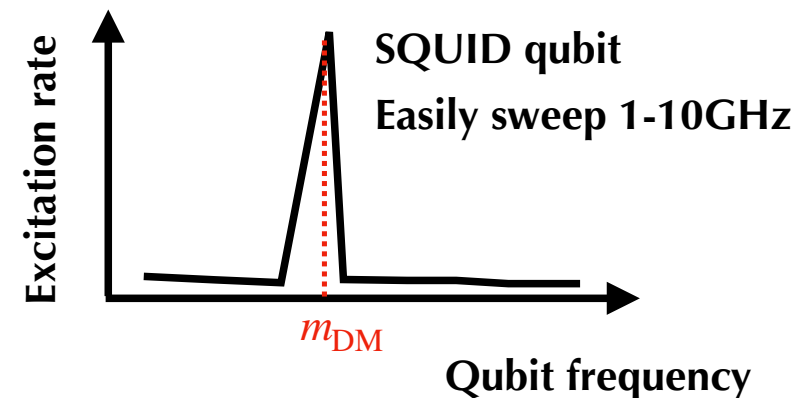
Moroi et al. PRL 131, 211001 (2023)

(Wait→Read)^N

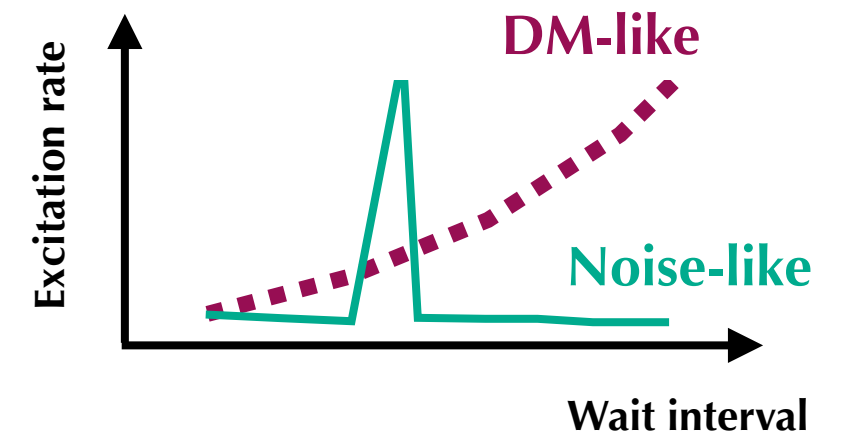


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Readout error : ~0.1%

Distinguishing from the noises?

- Different response against the packaging tightness
- Cross-checking by the other experiments
- "Per-search" for the suspicious frequencies

Sensitivity not strongly bounded by coherence time

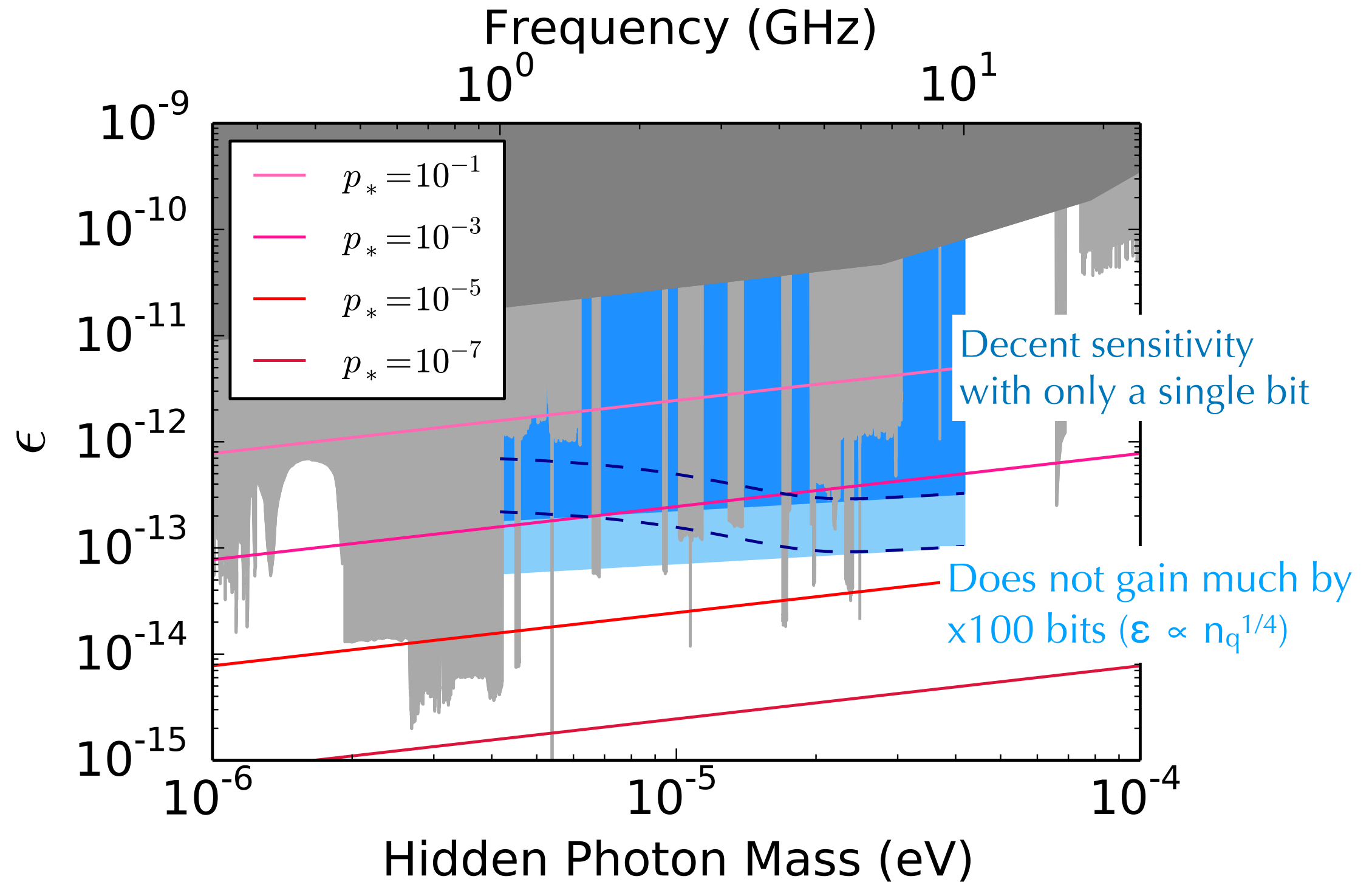
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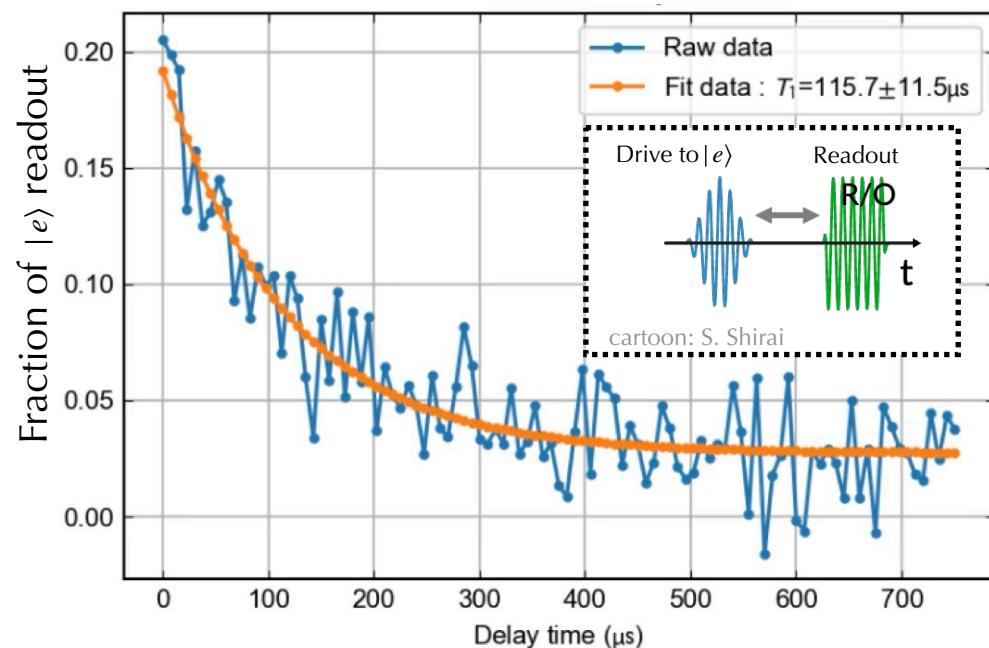
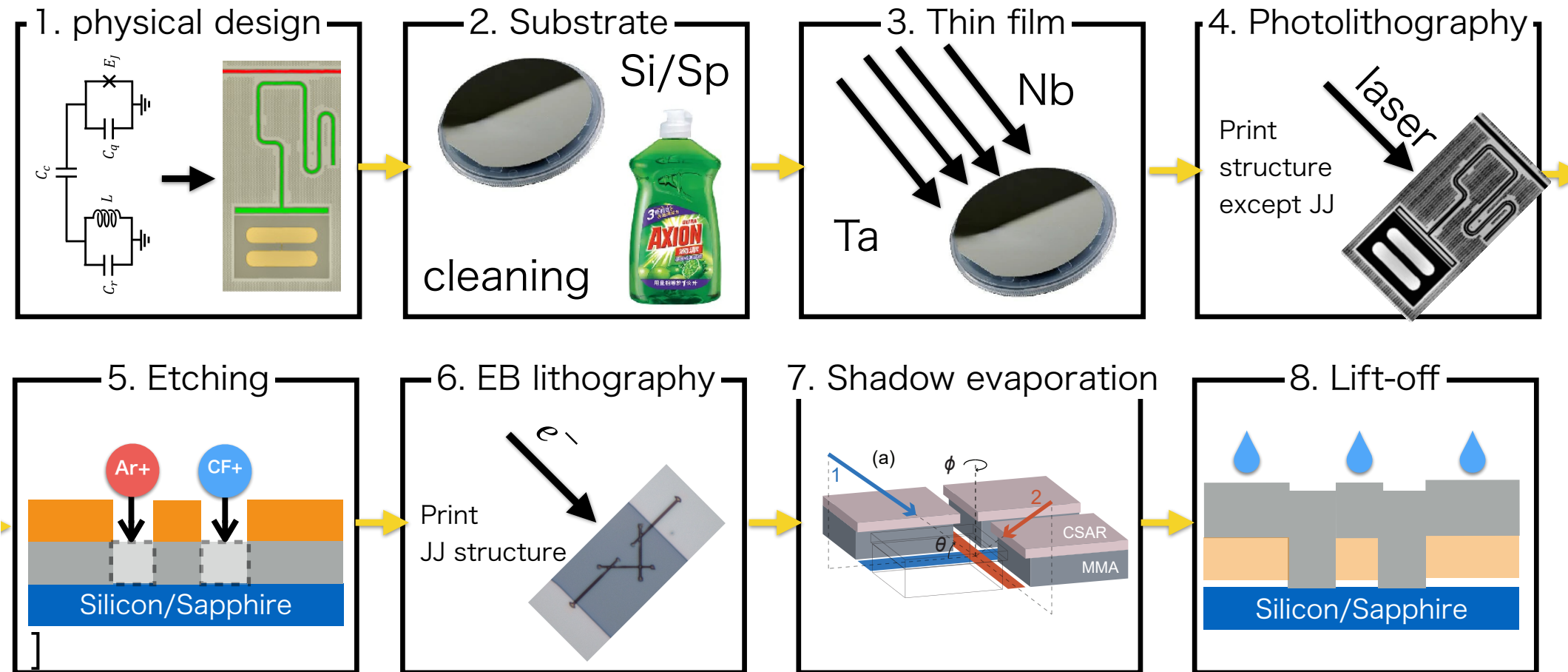
- ✓ Relax the fabrication requirement
- ✓ Pursuit of qubits with stronger coupling

Sensitivity projection

Moroi et al. PRL 131, 211001 (2023)



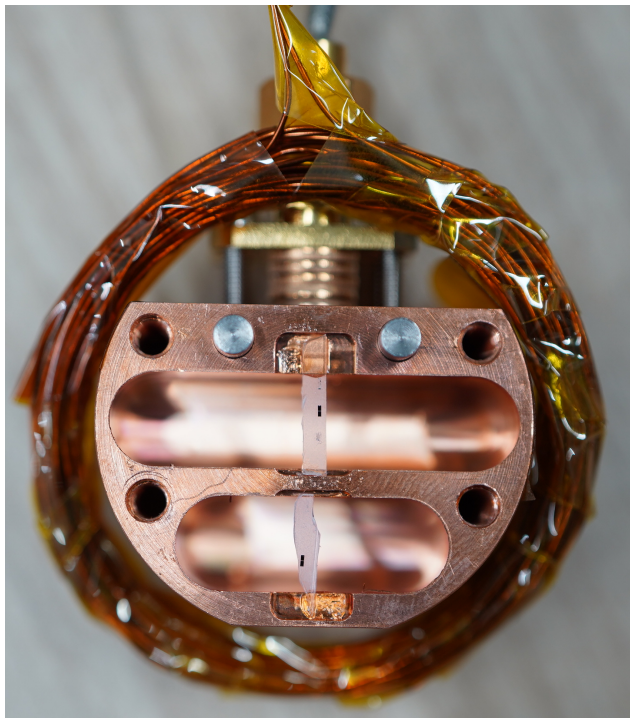
Qubit fabrication



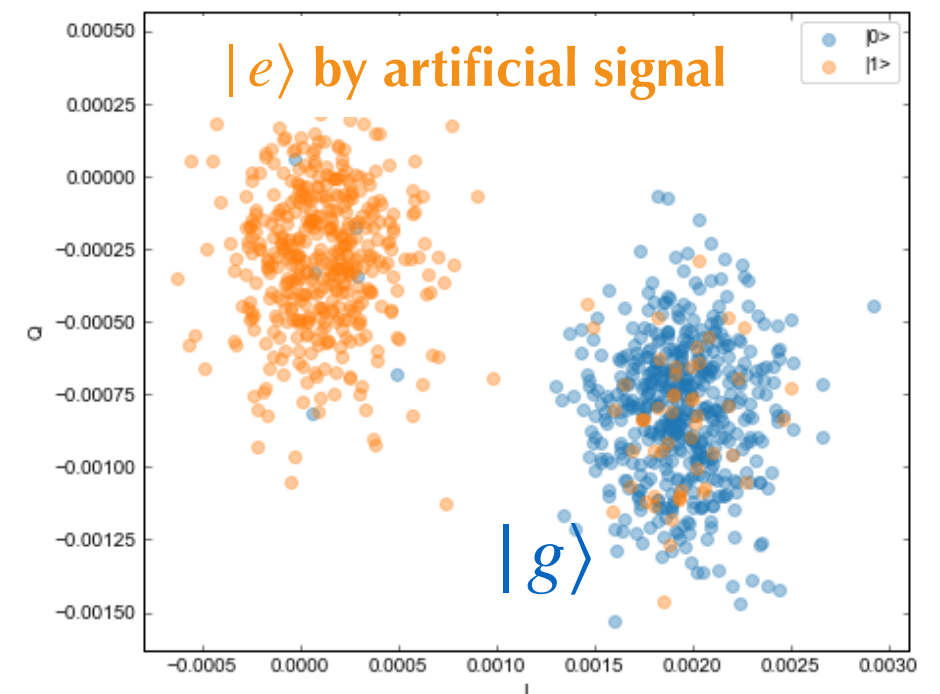
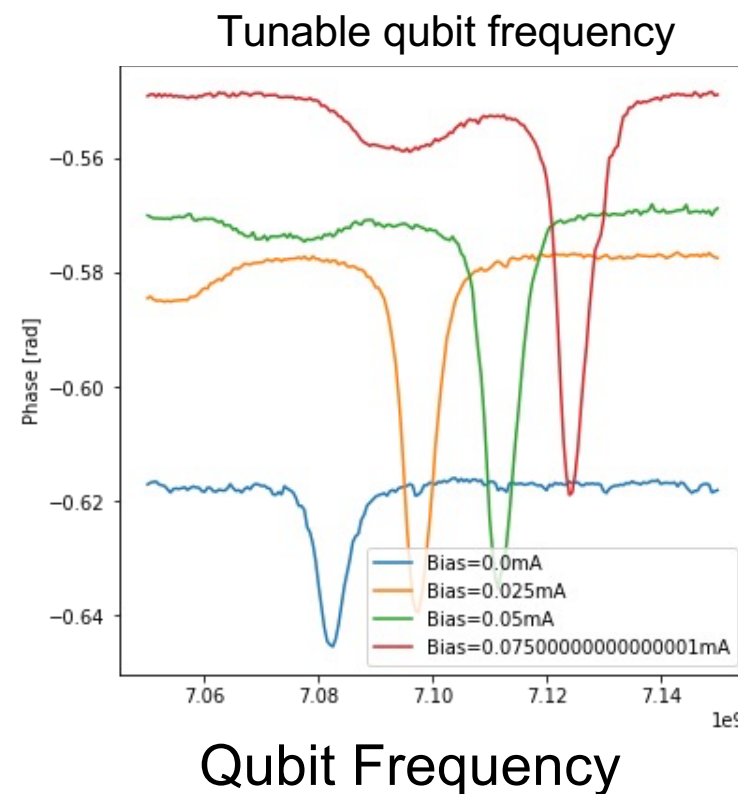
- In-house qubit fabrication in the collaboration
- * Nowadays one can buy qubits e.g. QuantWare
- Lithography + shadow evaporation
- Achieved coherence :
 - 3D: $T_1 \sim 10\text{-}30 \mu s$, $T_2 \sim 5 \mu s$
 - 2D: $T_1 > 100 \mu s$, $T_2^* > 200 \mu s$**

1 order behind the cutting-edge qubits for QC but good for sensor purpose

Demonstration experiment using the 3D implementation



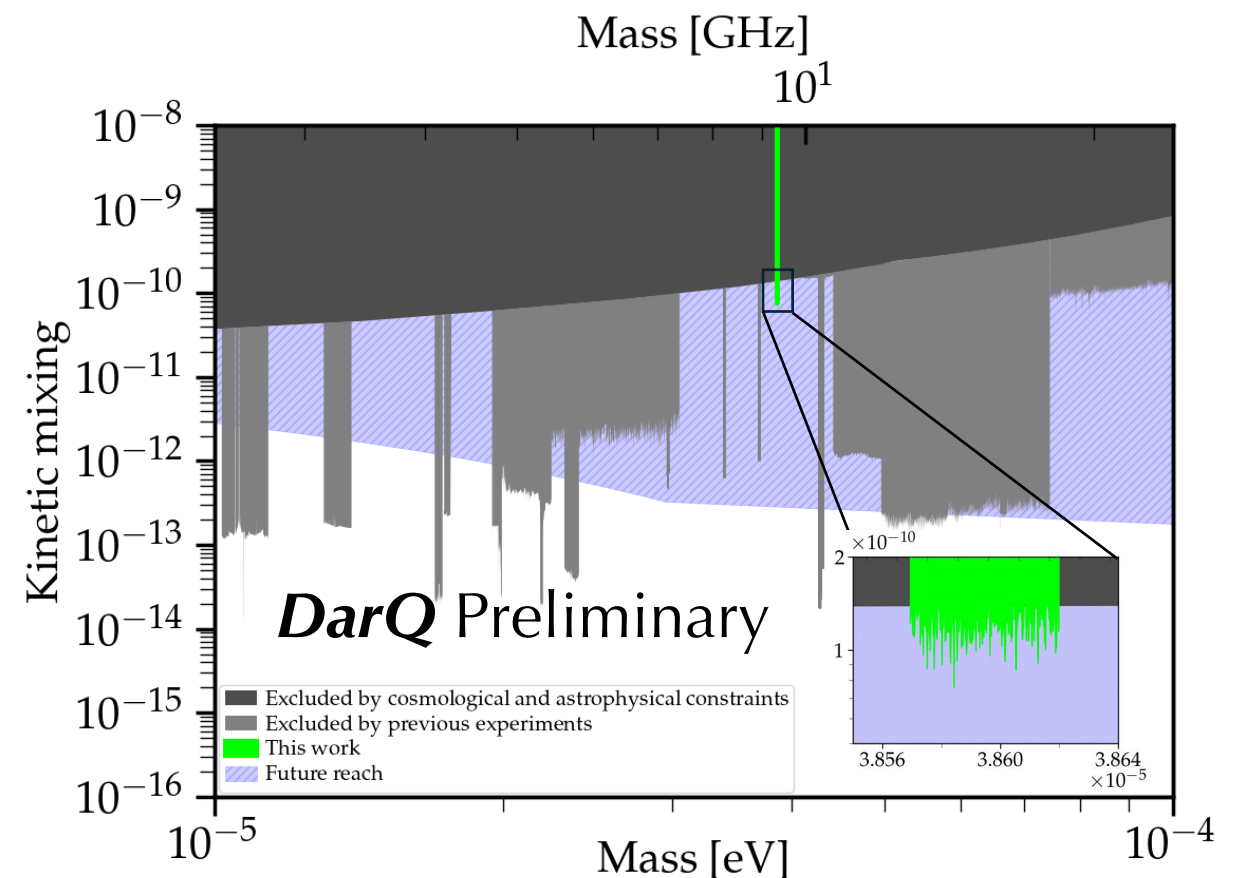
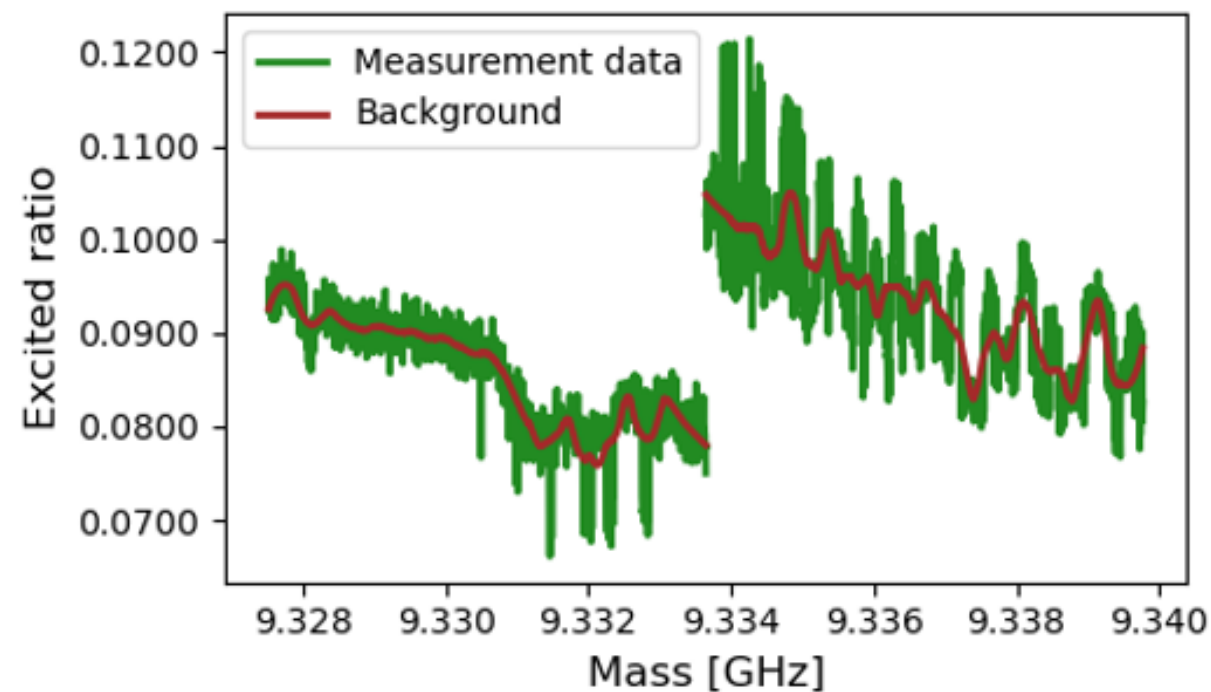
Encapsulated in a readout cavity surrounded by a bias coil



- Experiment sites : UTokyo CRC mili-kelvin quantum platform / KEK-QUP
- Validated the frequency tuning using bias coil
- Readout fidelity / thermal residual characterization
 - > 95% fidelity for $|0\rangle$ readout
- Other considerations: signal shielding by the package, non-thermal CP breakings

Demonstration experiment using the 3D implementation

12MHz / 22hrs



Planned improvements for the next runs

- Better noise / heat treatment etc.
- Introduction of high quality qubit ($T_1 > 300 \mu\text{s}$, fabricated in RIKEN's CR)

DAQ challenges

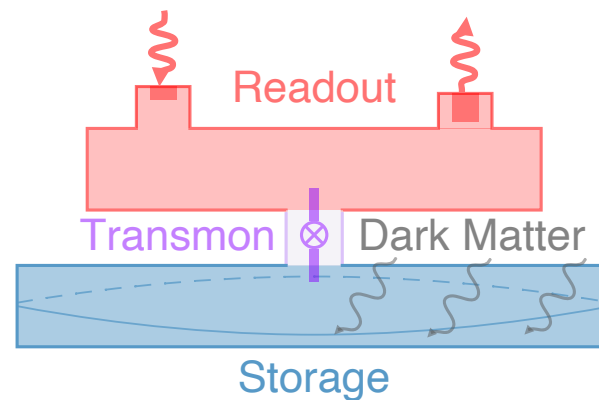
- T_1/T_2 unstable: Need T_1/T_2 measurement on each freq step $\rightarrow$ stabilization?
- Varying pi-pulse, I/Q profile etc. according to freq scan $\rightarrow$ dynamic state determination

Free space photon $\rightarrow$ Accumulated/focused photons



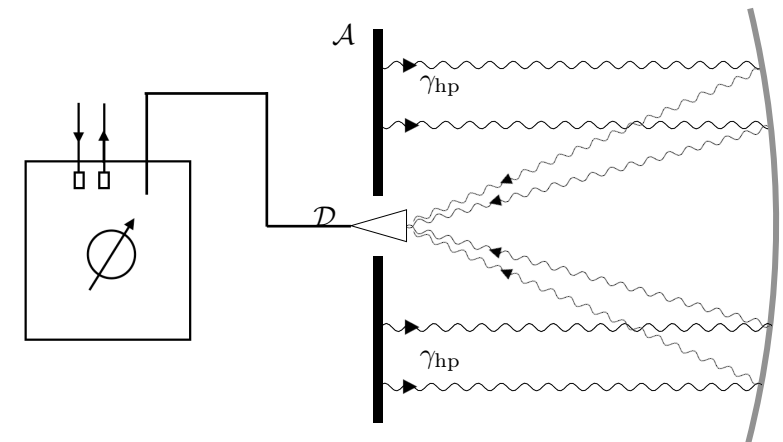
Free space

- $Q=1$
- Easy f tuning (SQUID)



Cavity

- $Q=10^{4-6}$
- Complicated tuning (bar)
- Devastating mode crossings

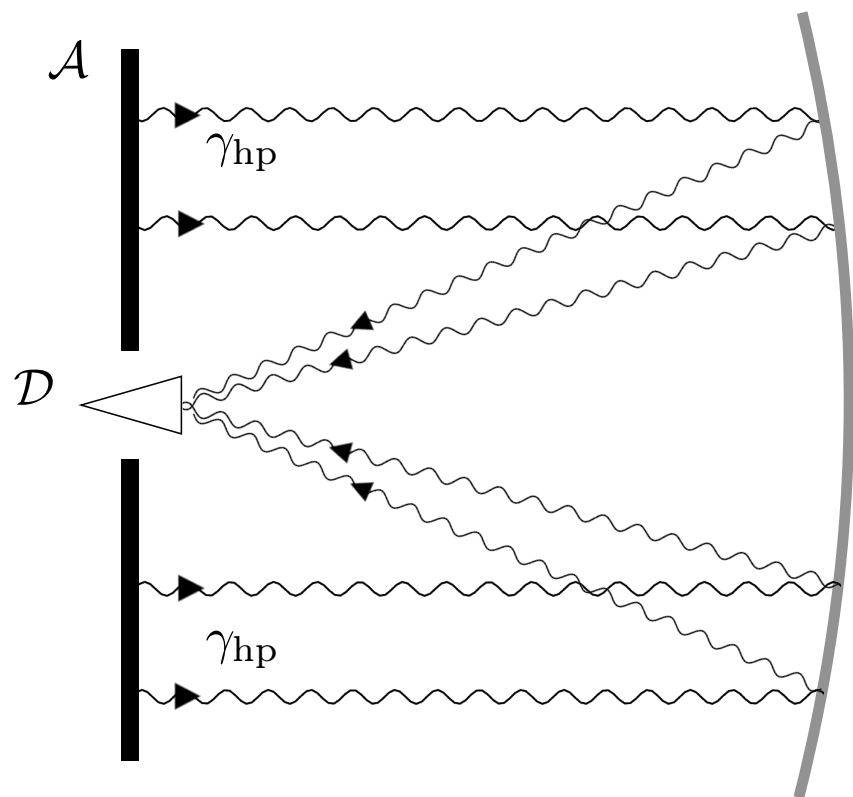


Dish antenna

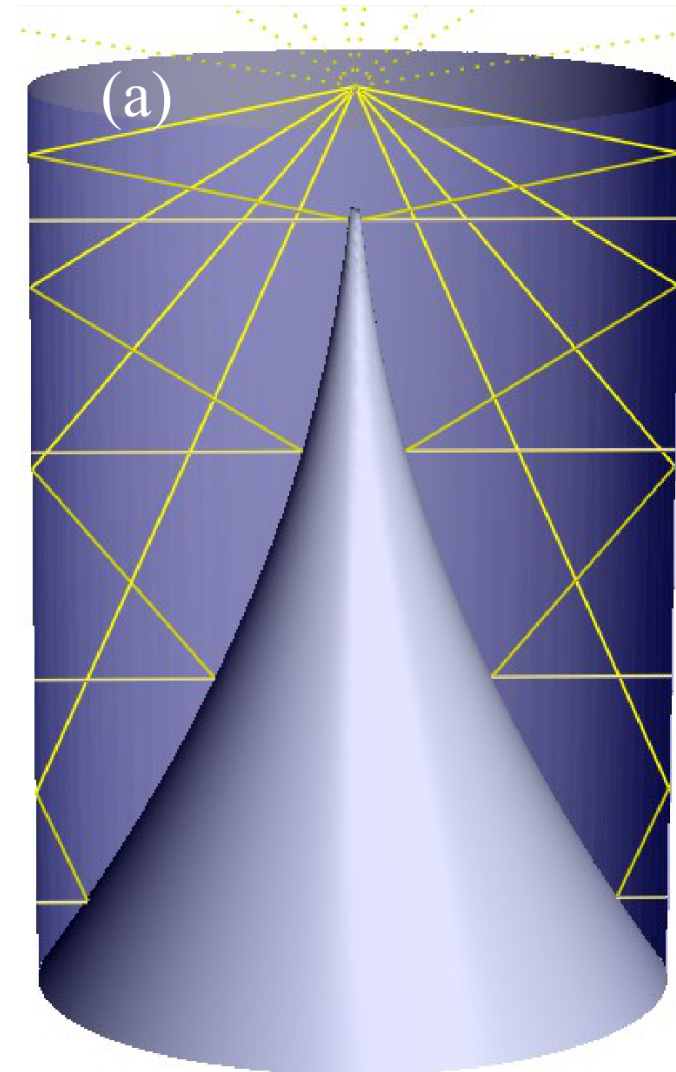
- $Q=10^{2-3}$
- Easy f tuning (SQUID)

Dish antenna idea - Radiation can be "focused"

BRASS-p/DOSUE-RR : RT reflectors



BREAD

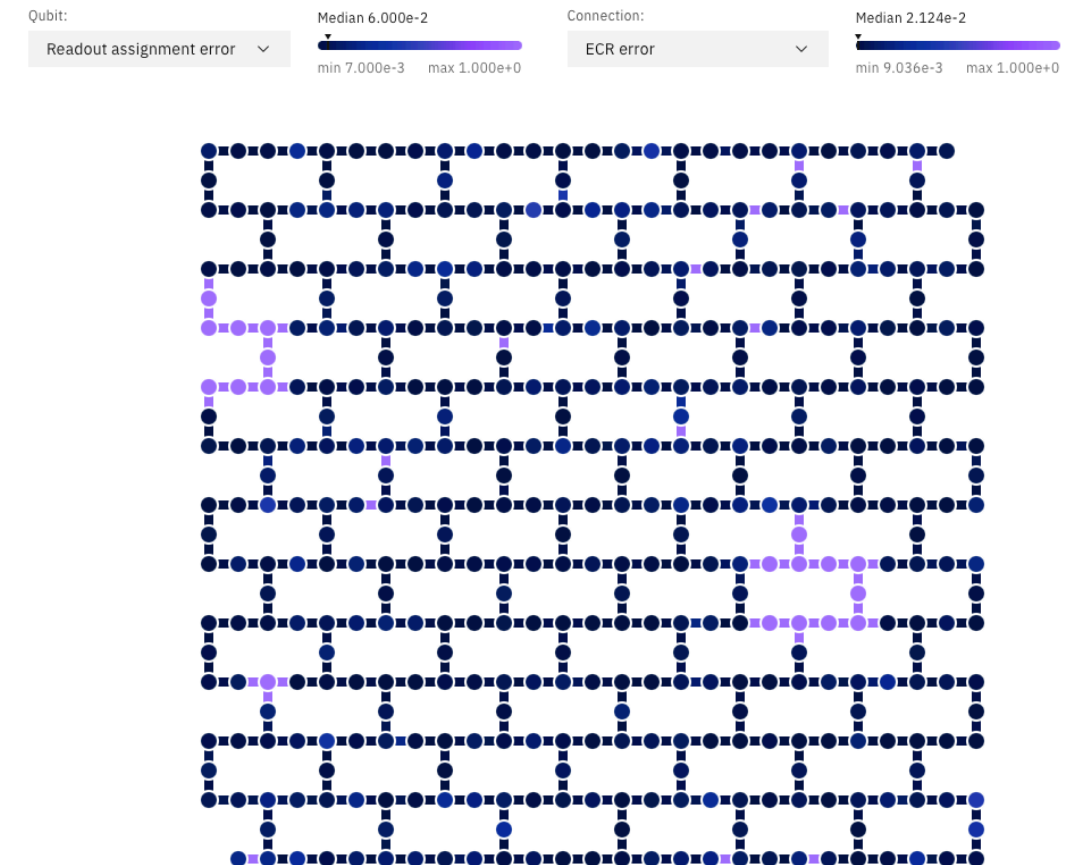


Cryogenic reflector inside the fridge

Search in an actual quantum computer?

IBM-Quantum ([link](#))

Search by system or simulator name				Your systems & simulators (26)		
Name	Qubits ↓	QV	CLOPS	Status	Total pending jobs	Processor type
ibm_seattle	433	-	-	● Online	0	Osprey r1
ibm_washington	127	64	850	● Online	4	Eagle r1
ibm_sherbrooke	127	32	904	● Online	104	Eagle r3
ibm_brisbane	127	-	-	● Online	512	Eagle r3
ibm_nazca	127	-	-	● Online	10	Eagle r3
ibm_algiers	27	128	2.2K	● Online	58	Falcon r5.11
ibmq_kolkata	27	128	2K	● Online	40	Falcon r5.11
ibmq_mumbai	27	128	1.8K	● Online	472	Falcon r5.10
ibmq_kawasaki	27	128	-	● Online	120	Falcon r5.11
ibmq_cairo	27	64	2.4K	● Online - Queue paused	673	Falcon r5.11
Items per page: 10				1-10 of 26 items		1 of 3 pages



😊 Array of high quality qubits

😊 Regular calibration

😊 Optimal readout & control

😞 Fixed frequency

😞 No B-field (→ dark photon only)

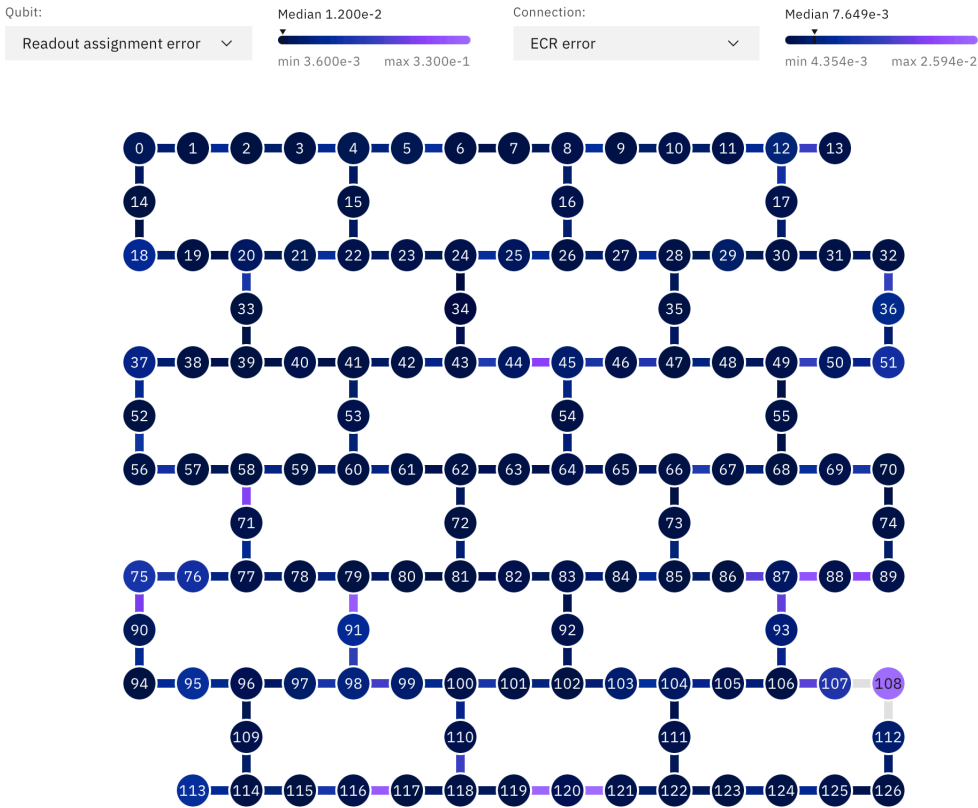
😞 Qubit parameter unknown

Discovery only, no limits

Our DM detector



Kawasaki



as of 16th Sep 2024

127

Qubits

3.2%

EPLG

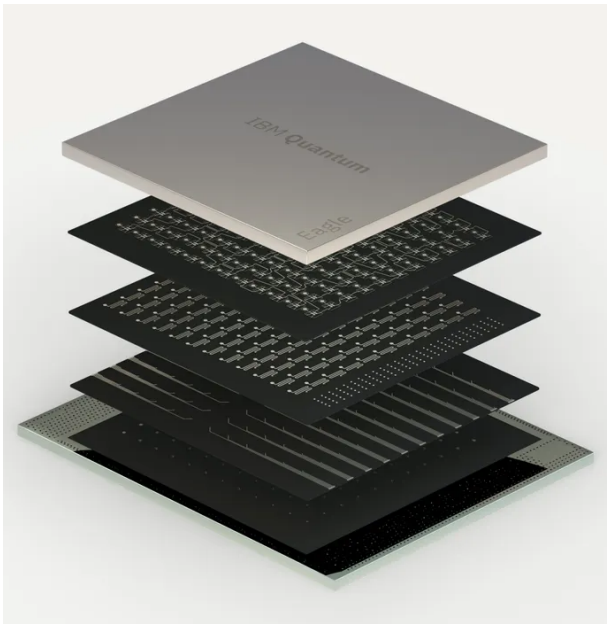
29K

CLOPS

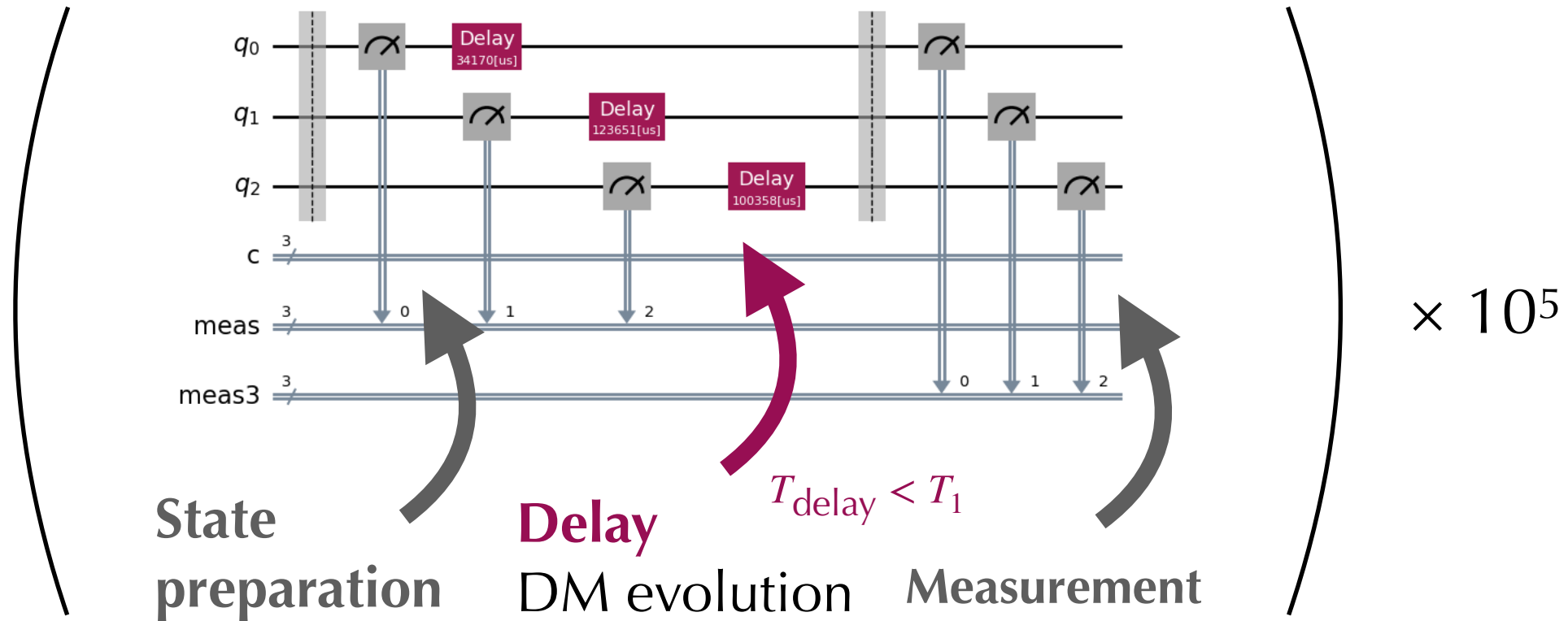
Status:	● Online
QPU region:	us-east
Total pending jobs:	1222 jobs
Processor type ⓘ:	Eagle r3
Version:	2.1.37
Basis gates:	ECR, ID, RZ, SX, X
Your instance usage:	157 jobs

Median ECR error:	7.134e-3
Median SX error:	2.449e-4
Median readout error:	1.130e-2
Median T1:	197.19 us
Median T2:	140.62 us

127-bit Eagle processor



e.g. $n_q=3$ $n_q=127$ in actual experiment



```
def submit(delay, shots=100000, ncircuits=600, session=None, batch=None):
    circuits = []
    for i in range(ncircuits):
        qr = QuantumRegister(nq)
        cr0 = ClassicalRegister(nq)
        cr1 = ClassicalRegister(nq)
        # Create a quantum circuit with 3 qubits and 3 classical bits
        qc = QuantumCircuit(qr, cr0, cr1)
        qc.measure(qr, cr0)
        # Add a delay of T1/2 to each qubit
        for iq in range(nq):
            qc.delay(int(T1[i]/2*1000*delay_factor), iq, 'qs')
            qc.delay(int(delay), iq, 'us')
        # Measure each qubit
        qc.measure(qr, cr1)
        # Visualize the circuit
        qc.draw('mpl')
        circuits.append(qc)
    circuits[0].draw('mpl')
    qc_compiled = transpile(circuits, backend, initial_layout=list(range(nq)), optimization_level=0, scheduling_method='asap')
    sampler = None
    if session:
        sampler = Sampler(session=session)
    elif batch:
        sampler = Sampler(mode=batch)
    job = sampler.run(qc_compiled, shots=shots)
```

ID / Name	Status	Created	Completed	Usage	Type	Compute resource	Tags
cvhtxdxkmd10008...	Completed	13 Sep 2024	13 Sep 2024	1m 8s	sampler	ibm_kawasaki	
cvhtx14z17rg008d...	Completed	13 Sep 2024	13 Sep 2024	1m 7s	sampler	ibm_kawasaki	
cvhtwm2vawwg00...	Completed	13 Sep 2024	13 Sep 2024	1m 6s	sampler	ibm_kawasaki	
cvhtw7gkmd10008...	Completed	13 Sep 2024	13 Sep 2024	1m 6s	sampler	ibm_kawasaki	
cvhtvtq8w2g0008e...	Completed	13 Sep 2024	13 Sep 2024	1m 8s	sampler	ibm_kawasaki	
cvhtve5p7drg008m...	Completed	13 Sep 2024	13 Sep 2024	1m 12s	sampler	ibm_kawasaki	
cvhtv1cp7drg008m...	Completed	13 Sep 2024	13 Sep 2024	1m 10s	sampler	ibm_kawasaki	
cvhttm8w2g0008e...	Completed	13 Sep 2024	13 Sep 2024	1m 9s	sampler	ibm_kawasaki	

Items per page: 10 1-8 of 8 items 1 of 1 pages

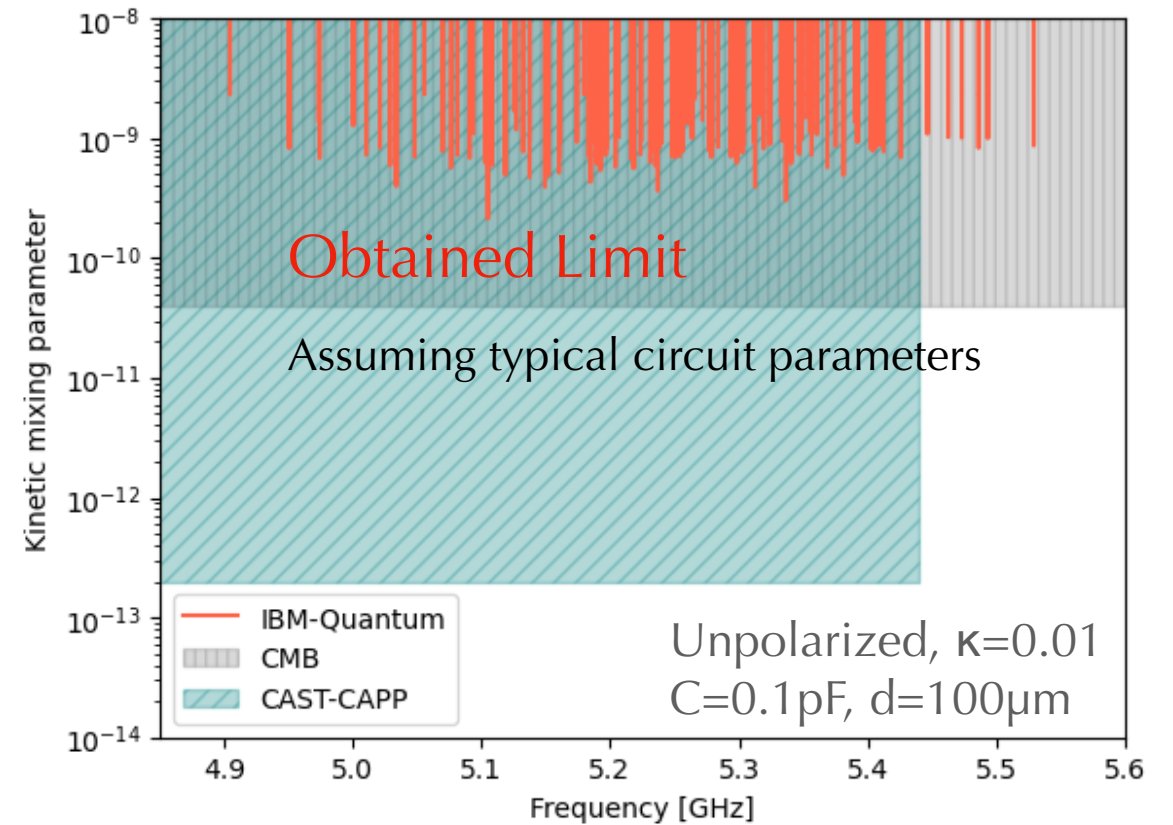
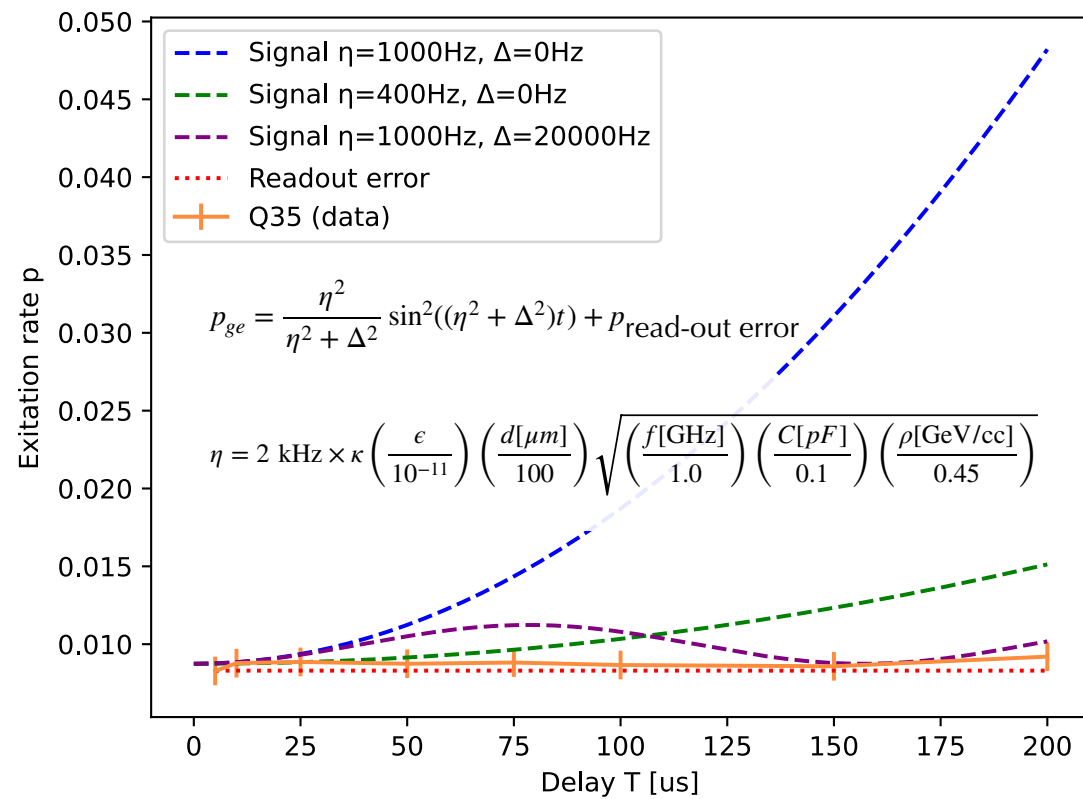
Submit a script like this

5min queue, 1min run time

✓ Script-based dark matter search

Results

Y. Iiyama & S. Chen (Preliminary)



- No spectacularly high excitation rate found
 - Pulse-level control in IBM-Quantum has been obsolete
- Started collaboration with IQM since 2025 with frequency tunability**

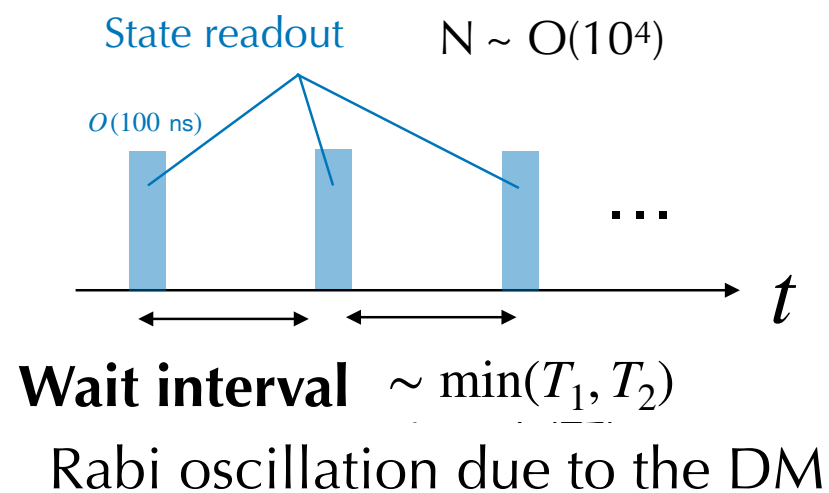
Future extension: Multi-bit interference

Sichanugrist et al. PRL **133** (2), 021801
Ito et al. [arXiv: \[hep-ex\] 2311.11632](#)

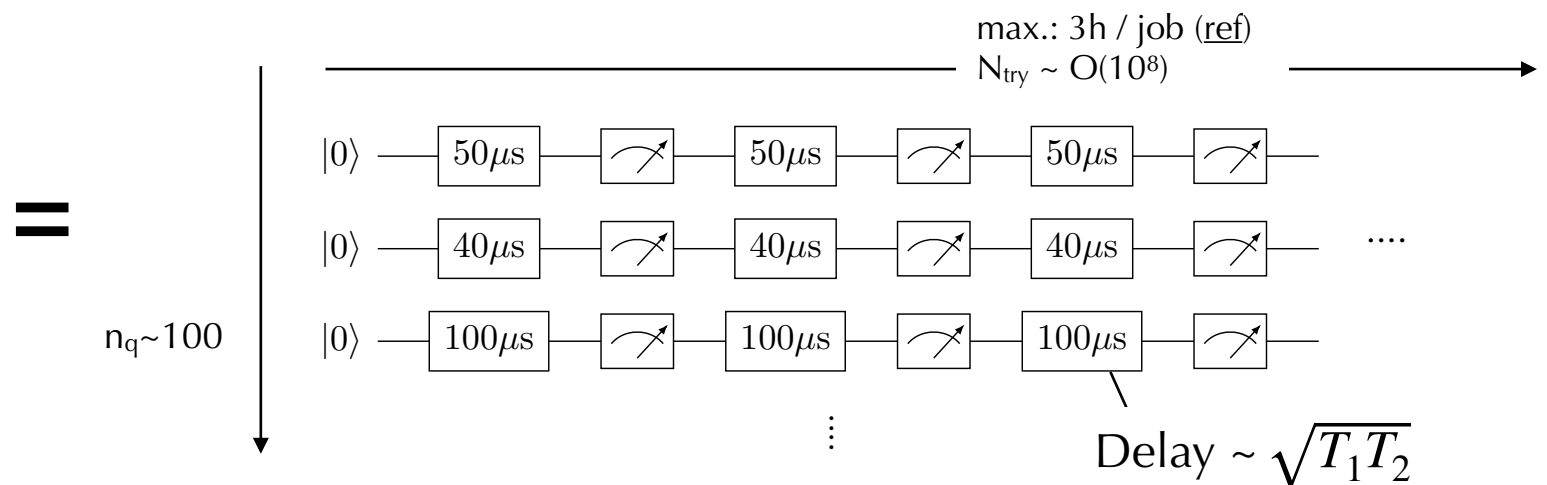
Single bit experiment : nothing quantum

Signal rate $\propto n_q^2$

(Wait $\rightarrow$ Read)^N



Correspond to this boring circuit operation

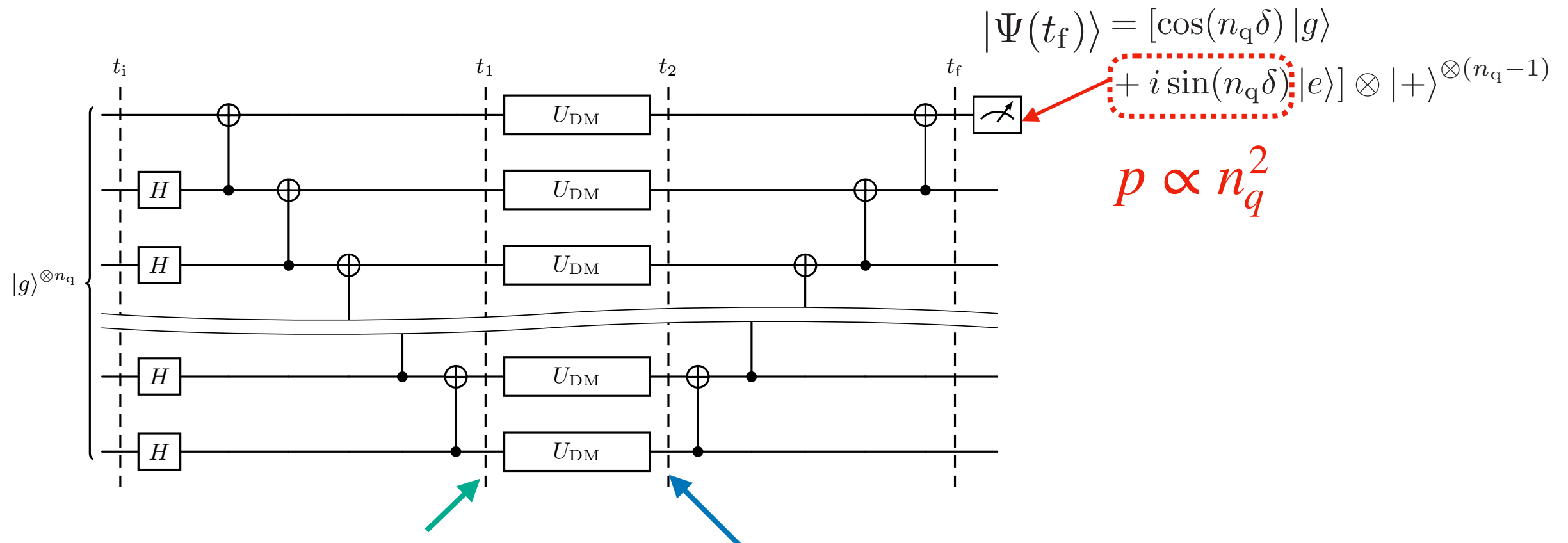


Future extension: Multi-bit interference

Sichanugrist et al. PRL **133** (2), 021801
Ito et al. arXiv: [hep-ex] 2311.11632

Multibit entanglement → **signal rate $\propto n_q^2$**

"Decoded" state to be measured



GHZ state: Maximally entangled state

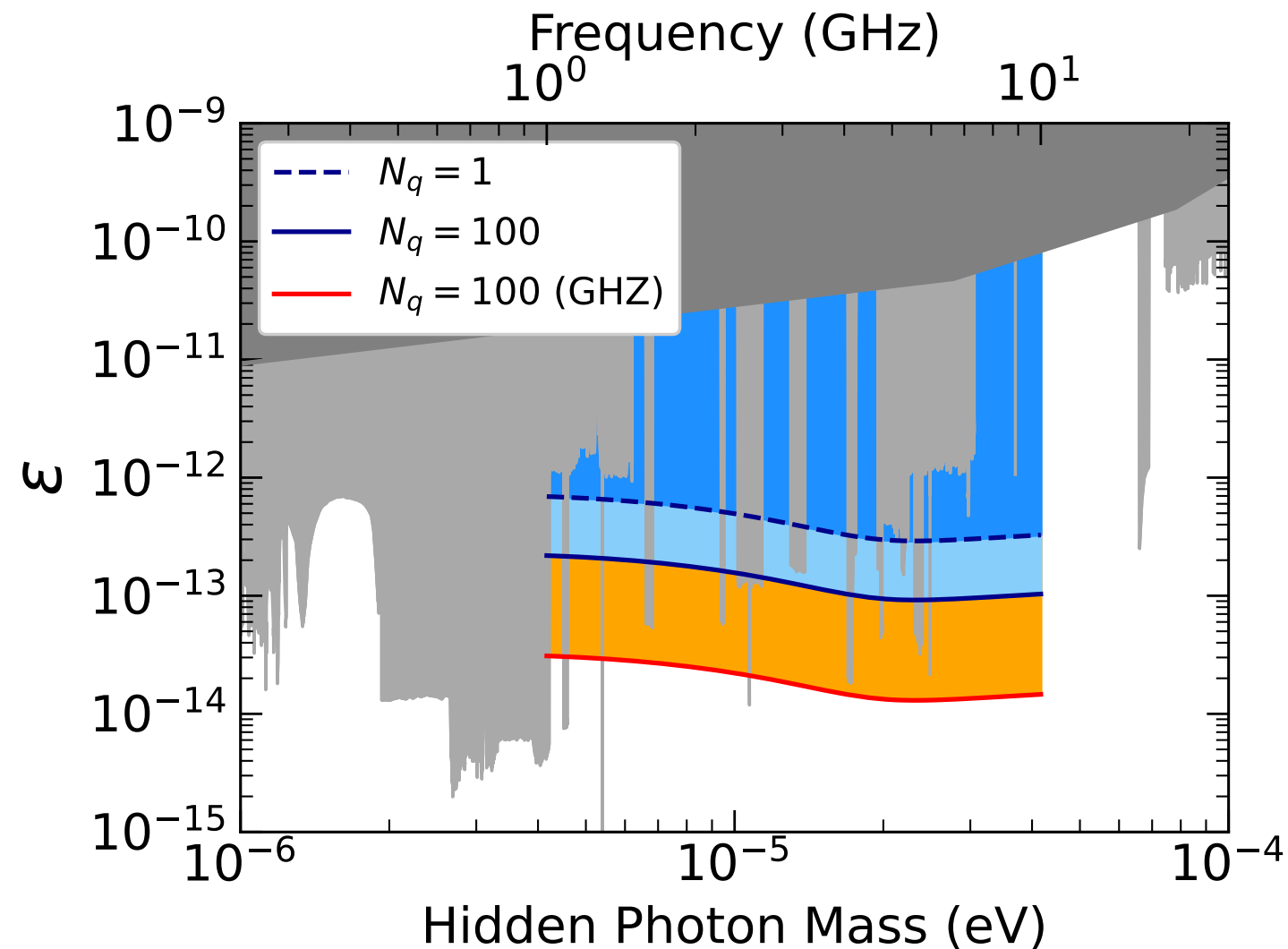
$$|\Psi(t_1)\rangle = \frac{1}{\sqrt{2}} \left(|+\rangle^{\otimes n_q} + |-\rangle^{\otimes n_q} \right)$$

DM evolution: Rabi oscillation

$$|\Psi(t_2)\rangle = \frac{1}{\sqrt{2}} \left(e^{in_q\delta} |+\rangle^{\otimes n_q} + e^{-in_q\delta} |-\rangle^{\otimes n_q} \right)$$

Future extension(2) Multi-bit interference

Sichanugrist et al. PRL **133** (2), 021801
Ito et al. [arXiv: \[hep-ex\] 2311.11632](#)



Many caveats at this point:

- Coherence time of n-entangled state : $T_n \sim T/n$
- In-situ quantum error correction needed to avoid the dephasing contribution

Many variations actively proposed recently

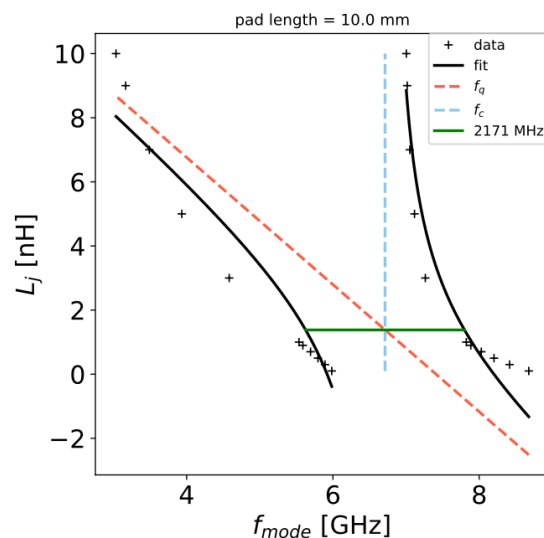
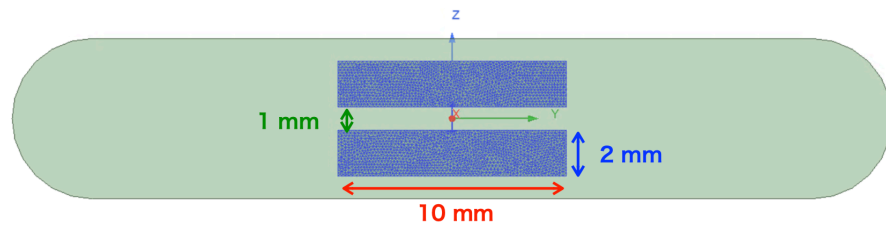
- W state : Fukuda et al. [arXiv: 2510.01816](#)
- CAT state : Zheng et al. [arXiv: 2507.23538](#)
- Q-network : Santoso et al. [arXiv: 2505.21188](#)

Same challenges for the future FTQCs

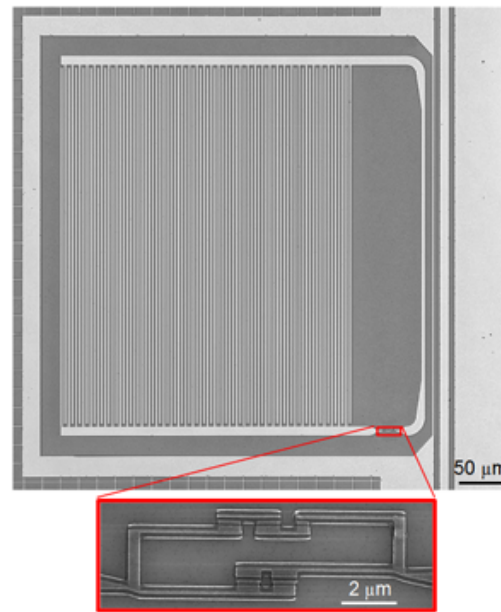
Tailored qubits for sensing purpose

Stronger coupling

Even larger capacitance pads



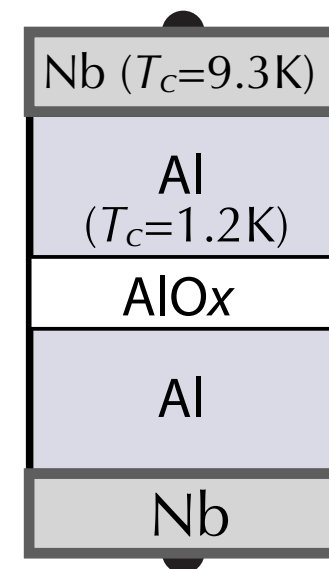
Galvanic coupling



Yoshihara et al (2018)

Higher frequency qubit

Al/Nb bilayer → Lift T_c using the proximity effect



$$E_1 - E_0 \sim \sqrt{8E_C E_J}$$

$$E_J = \frac{\pi}{2} \frac{\Delta}{R}$$

Δ : superconducting gap

All superconducting qubits so far are devised in the context of QCs

- Vastly unexplored circuit parameter space - coupling, frequency etc. ultimate limit unknown

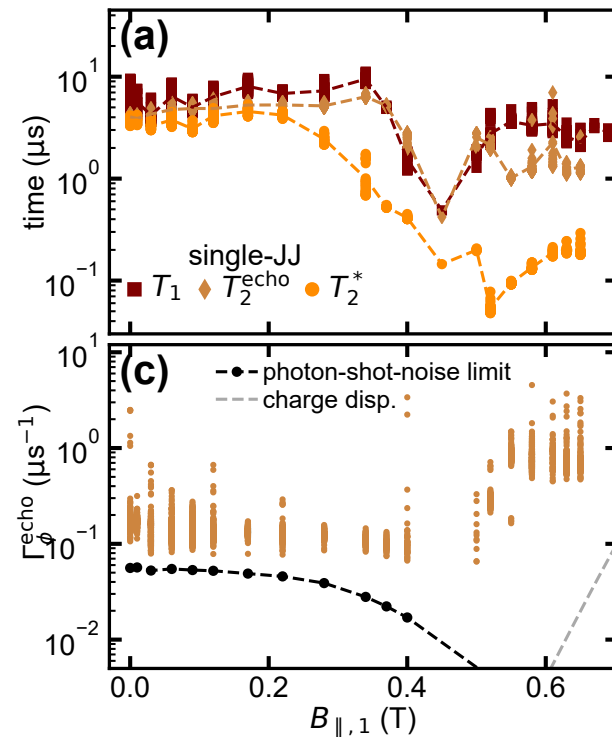
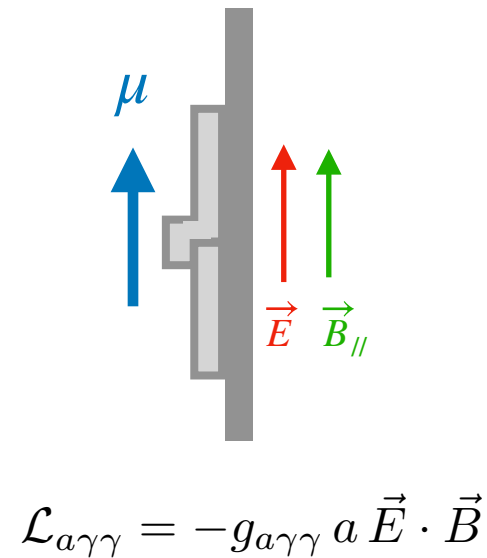
Looser limitation of coherence time can open many new paths for qubit design

- Bad coherence but maximal potential as sensors

Towards axion searches

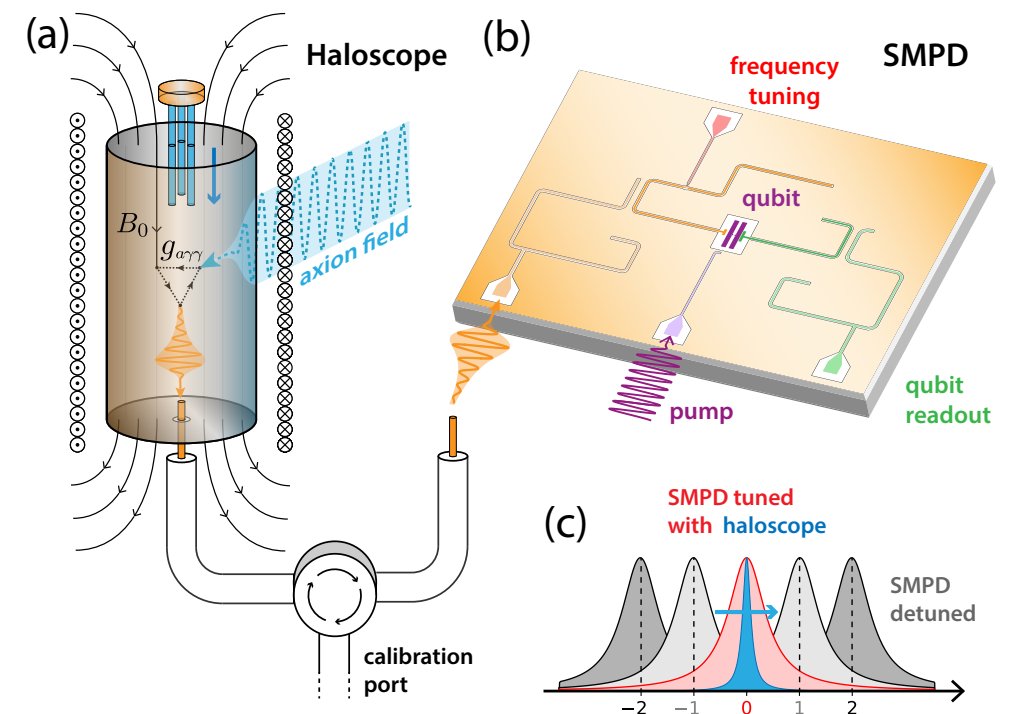
How to apply B-field?

1. Perfect alignment



Krause et al.

2. Geometrically isolate the qubit sensor



Braggio et al.

Generally strong B-field is bad for superconductor and of course to qubits too

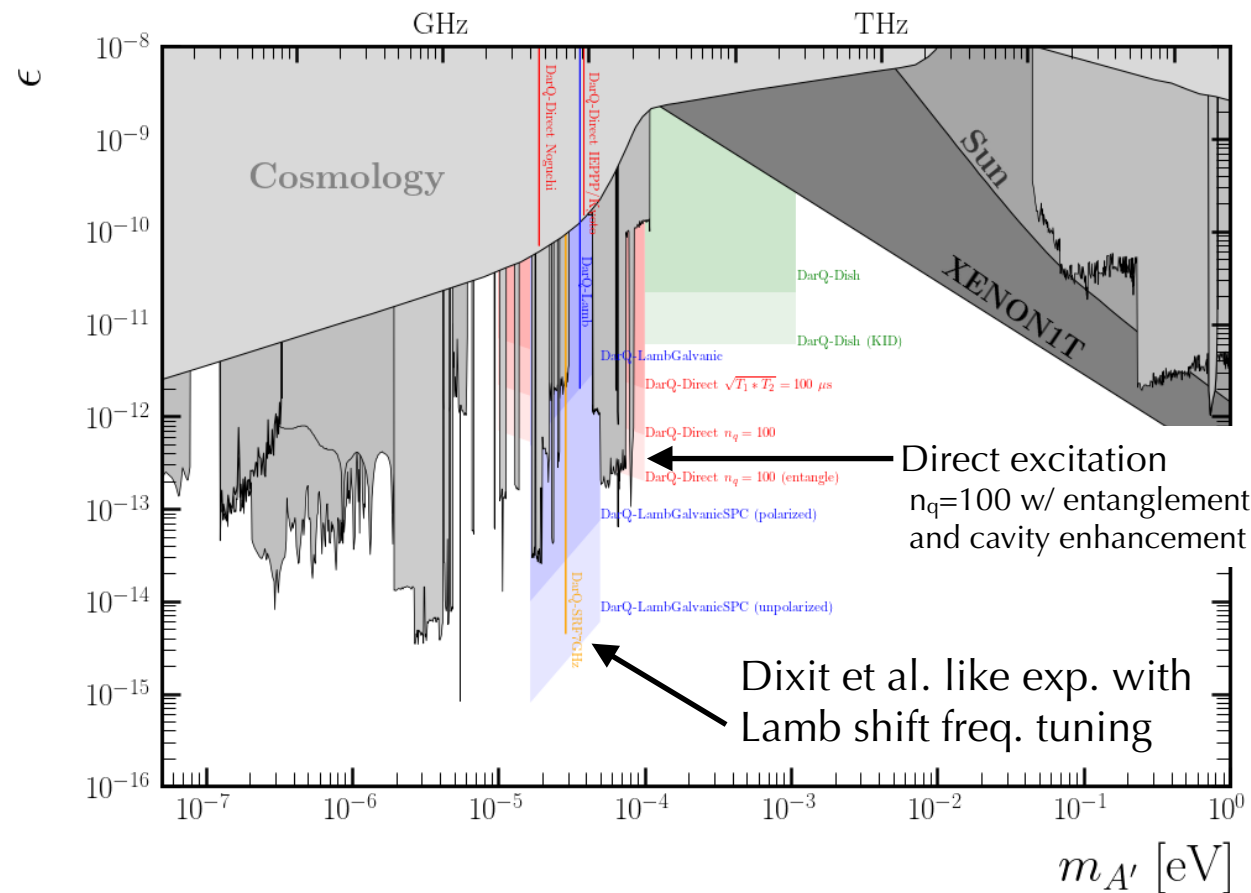
- Qubit inductively couple to flux → decoherence
- Out-of-plane is particularly bad for superconducting thin films

Possible solution

- Precise in-plane alignment of B-field
- Qubits using Nitride-based JJ
- Physical isolation from the B-field

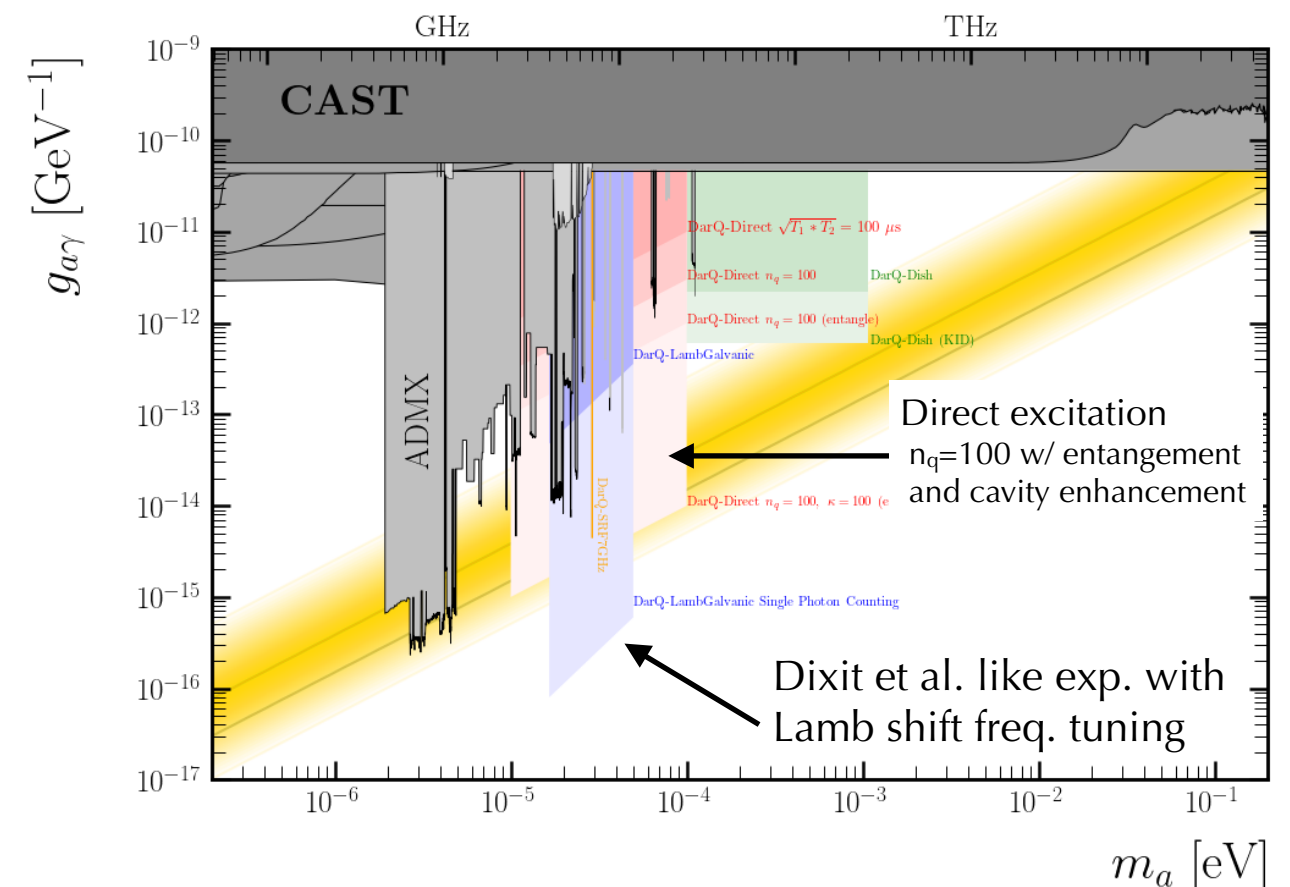
DarQ experiment Sensitivity projection

Dark photon



Axion

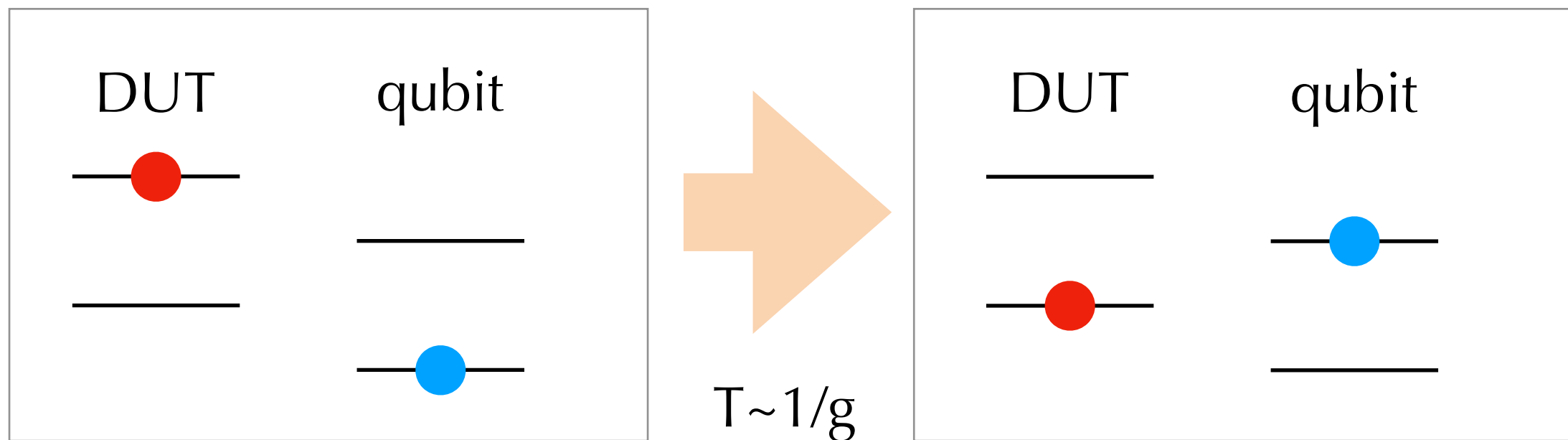
Sichanugrist et al. [arXiv: 2407.19755](https://arxiv.org/abs/2407.19755)



- One year operation time
- Long road to go, but ultimately wideband DFSZ sensitivity

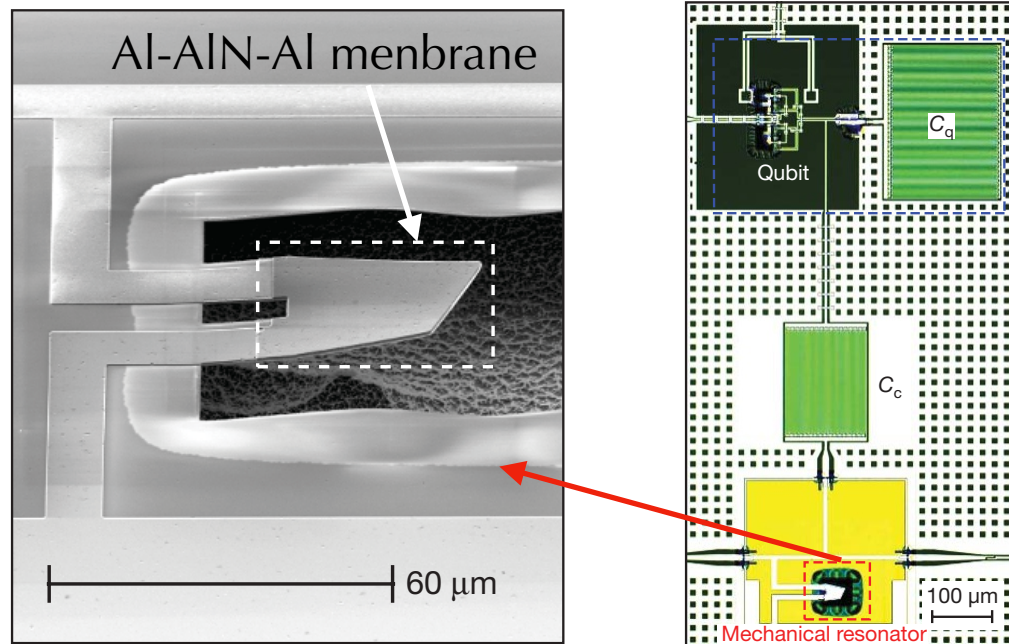
Beyond just photon sensing - Hybrid quantum system

In a the two two level system w/ a coupling constant g ,
excitation swaps after $T \sim 1/g$ (if no decoherence)



Beyond just photon sensing - Hybrid quantum system

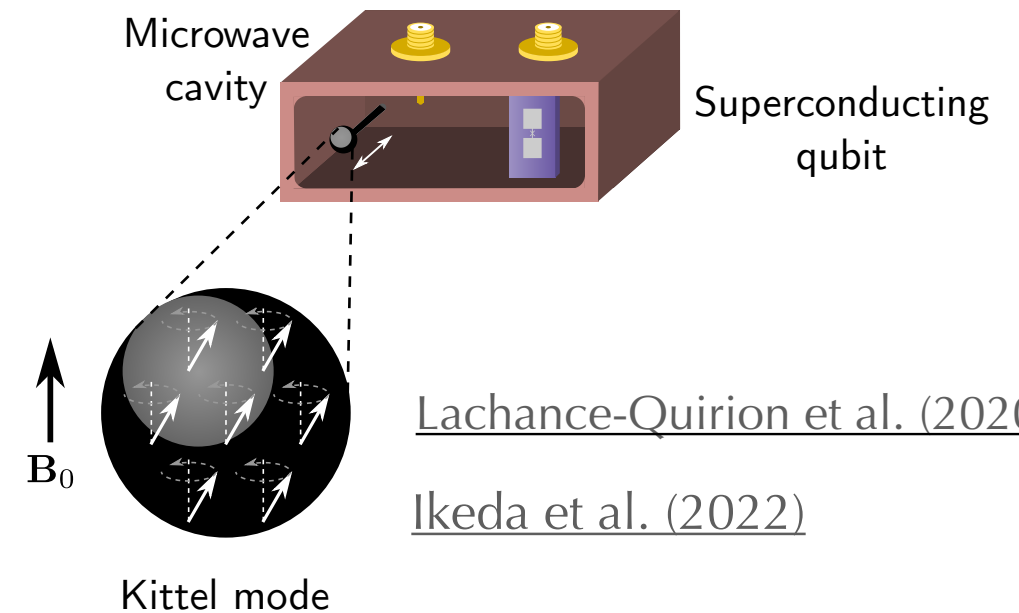
Single-(static)phonon detection



couple to qubit
for detection

O'Connell et al. (2010)

Single magnon detection



Lachance-Quirion et al. (2020)

Ikeda et al. (2022)

Potential target

- Light WIMP (2410.17308)
- High freq. GW (2306.09726)
- Axion-electron (spin) coupling

Single spin excitation detection

Z. Wang et al. (2023)

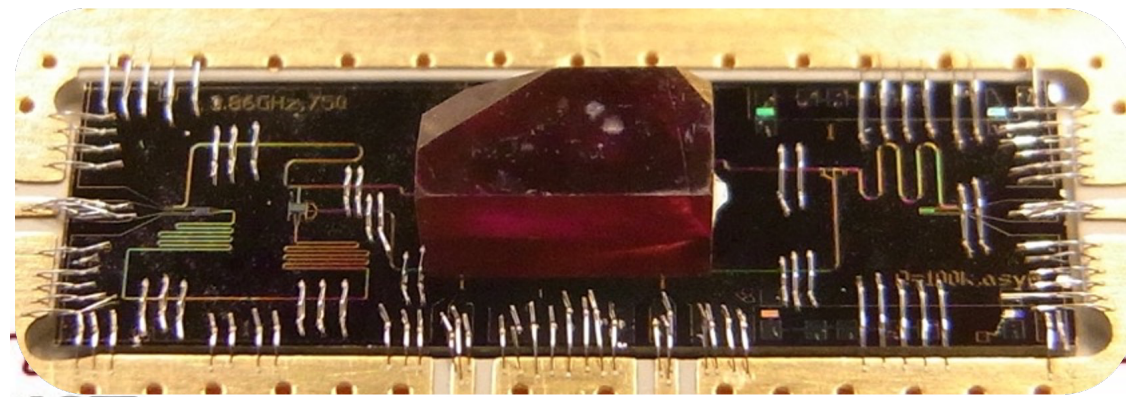
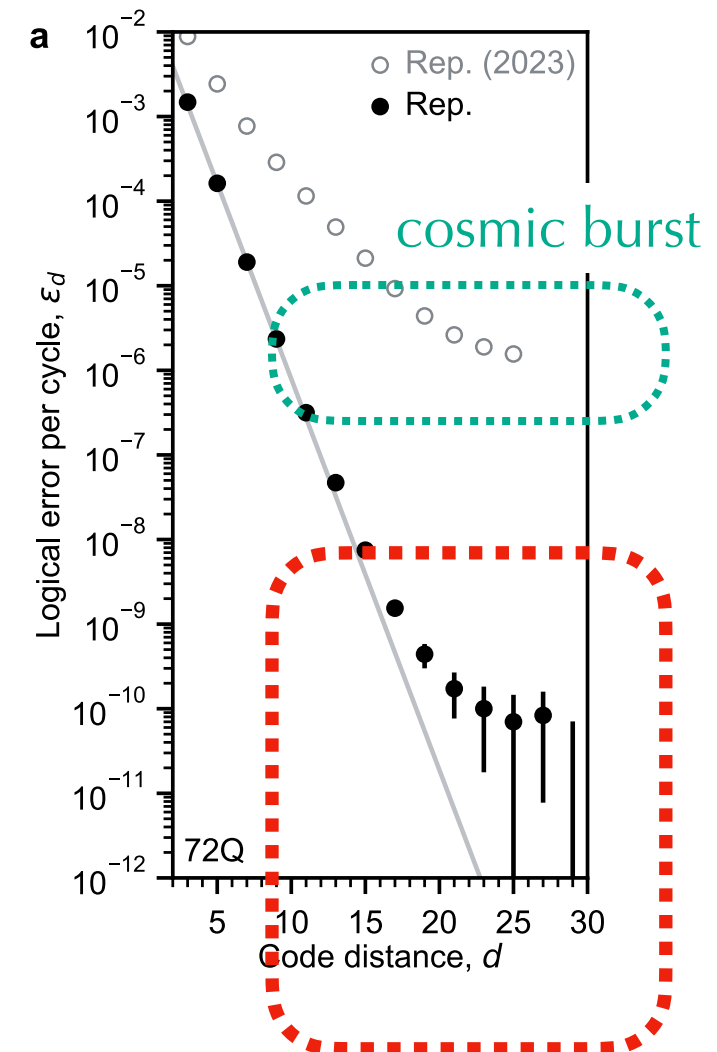
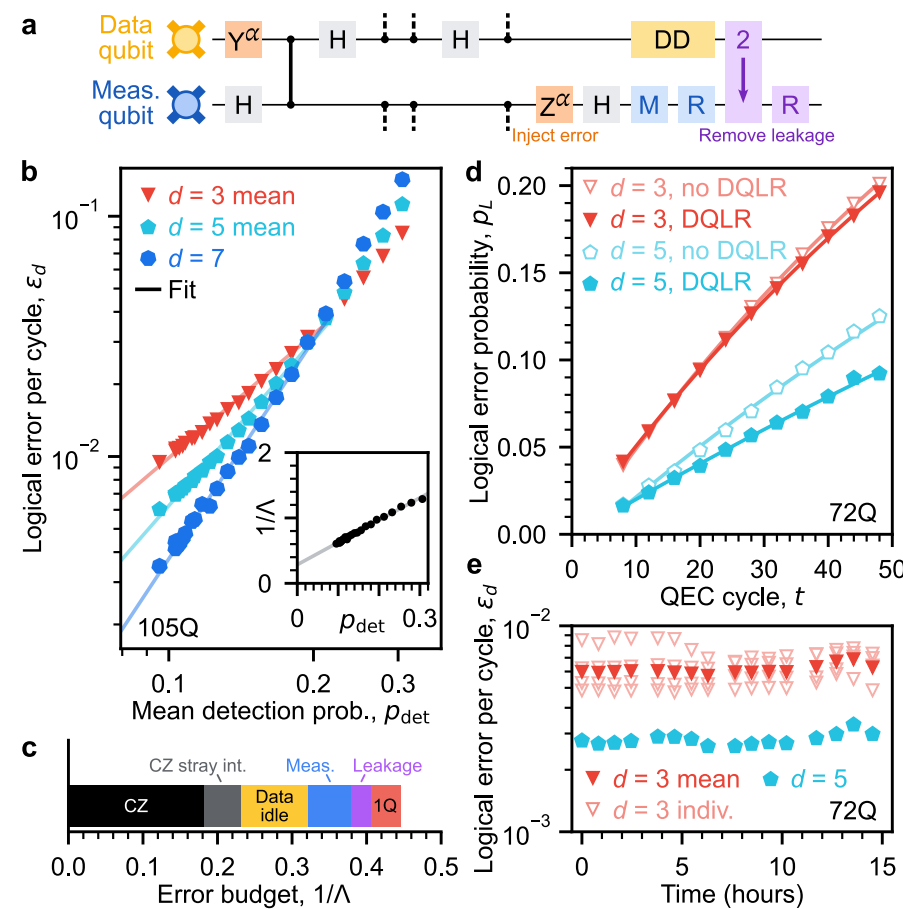
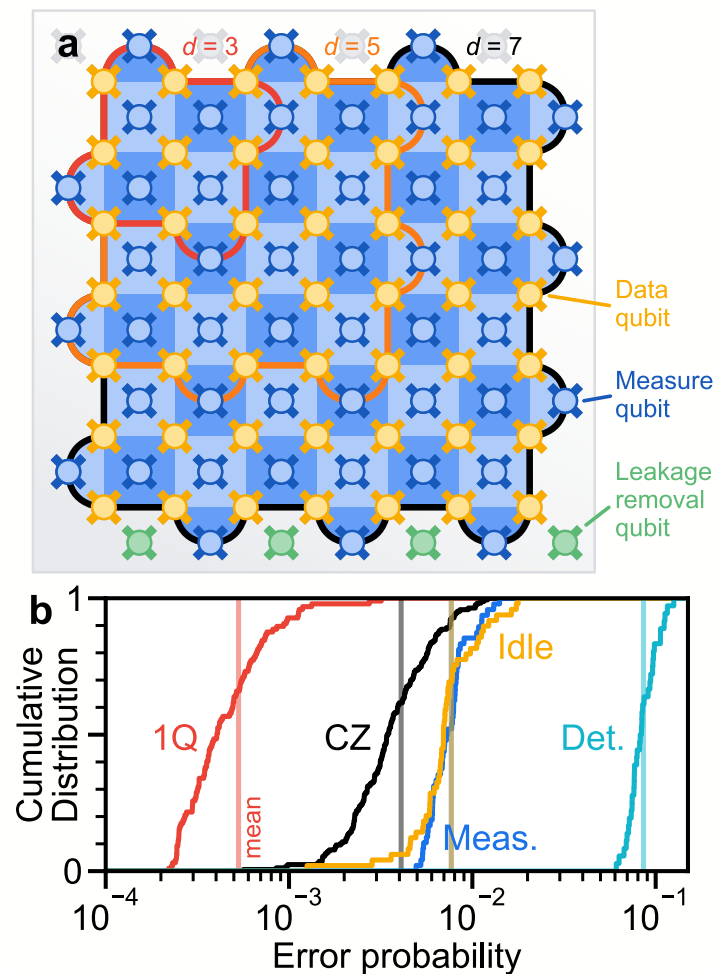


Photo: Y. Kubo's

We may already start seeing something...

Google q-AI (2024)

Quantum error correction using surface code



- Rare sources 10^{-6} - 10^{-8} understood / protection implemented
- Now, unaccounted residual error rate: $\sim 10^{-10}$ "burst" continuing $\sim 400\mu\text{s}$
- Can interpret into very stringent limit to some sort of new physics models

Summary

Superconducting qubits = powerful photon sensor

- Strong coupling
- 1-2 order of magnitude frequency tunability
- Low threshold (μeV)

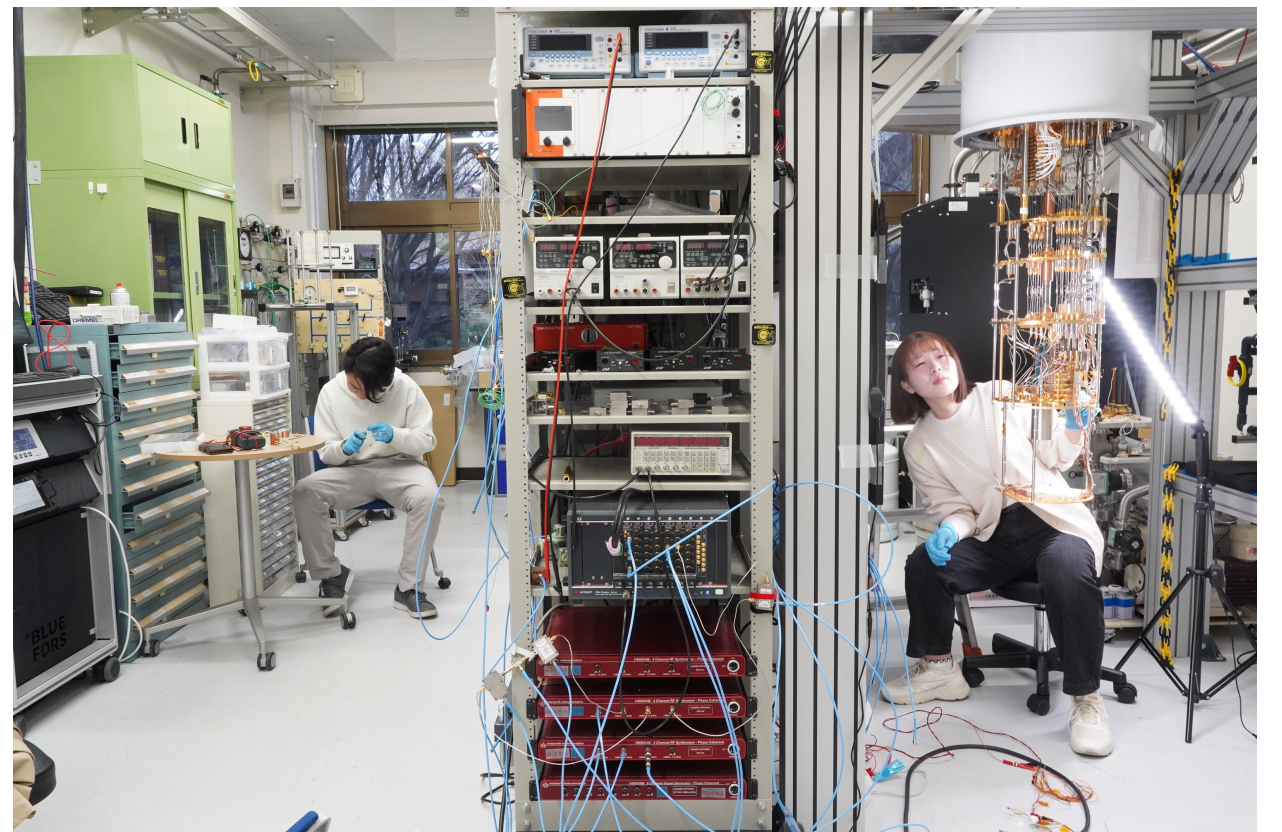
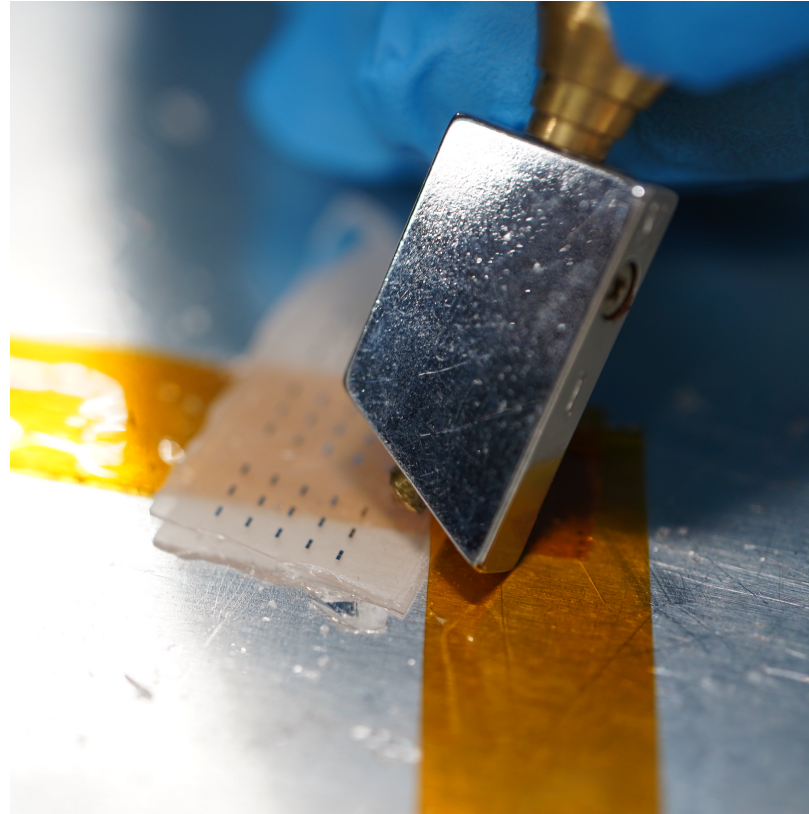
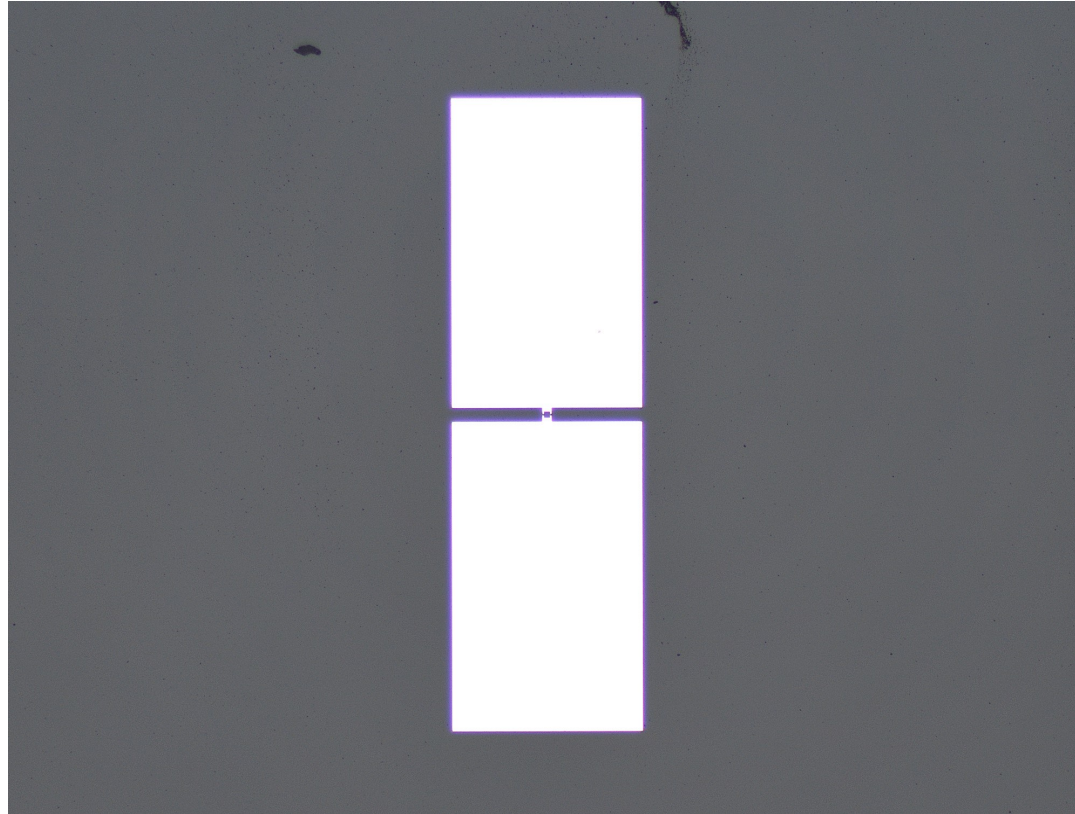
Applied for dark photon searches

- SQuAD (FNAL), DarQ (Tokyo/Kyoto/KEK) promising wideband sensitivity
- "Quantum computers are dark matter"

Sensor development - from a computing unit to a dark matter sensors

- Stronger coupling, higher frequency, B-field resilience etc.
- Hybrid quantum sensor for transducing other excitations

Backup

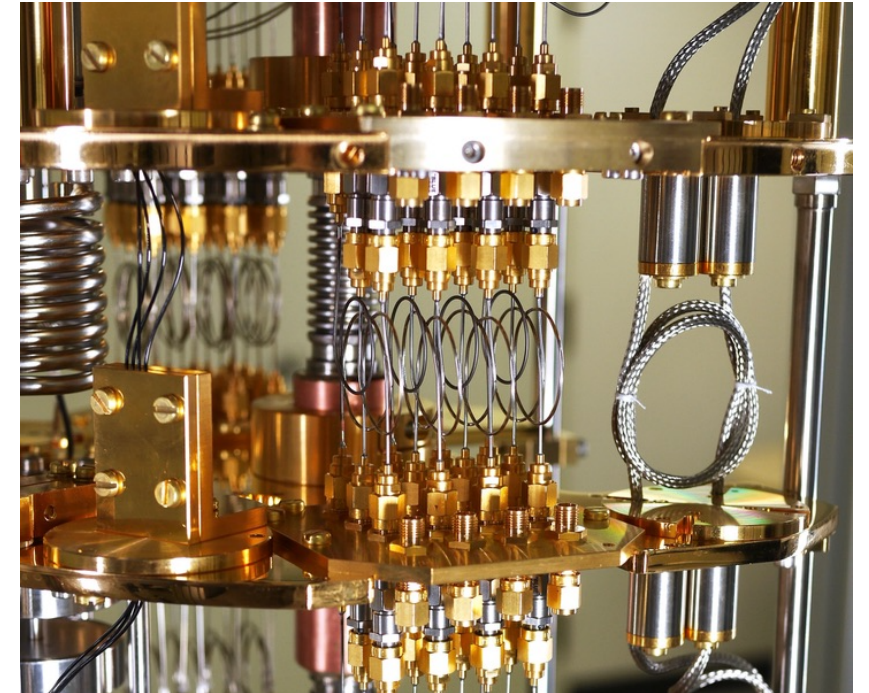
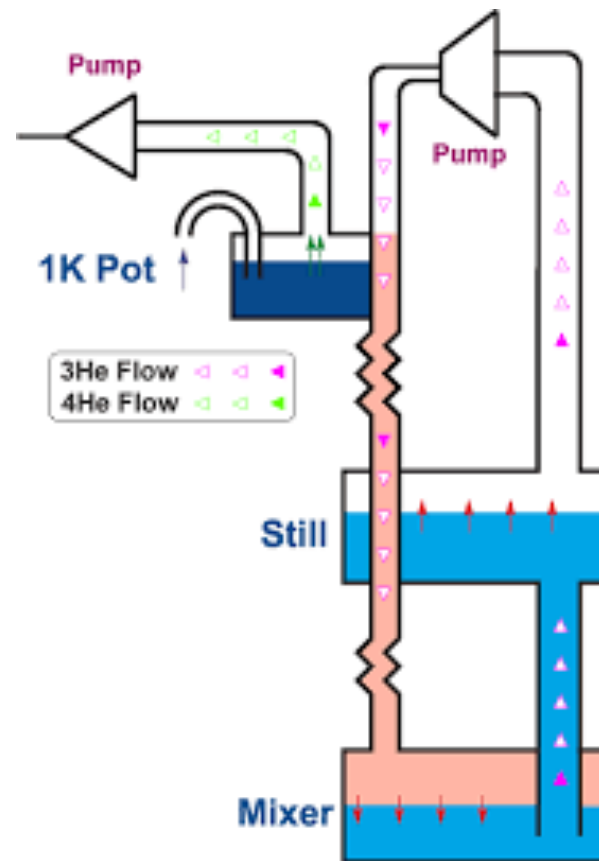
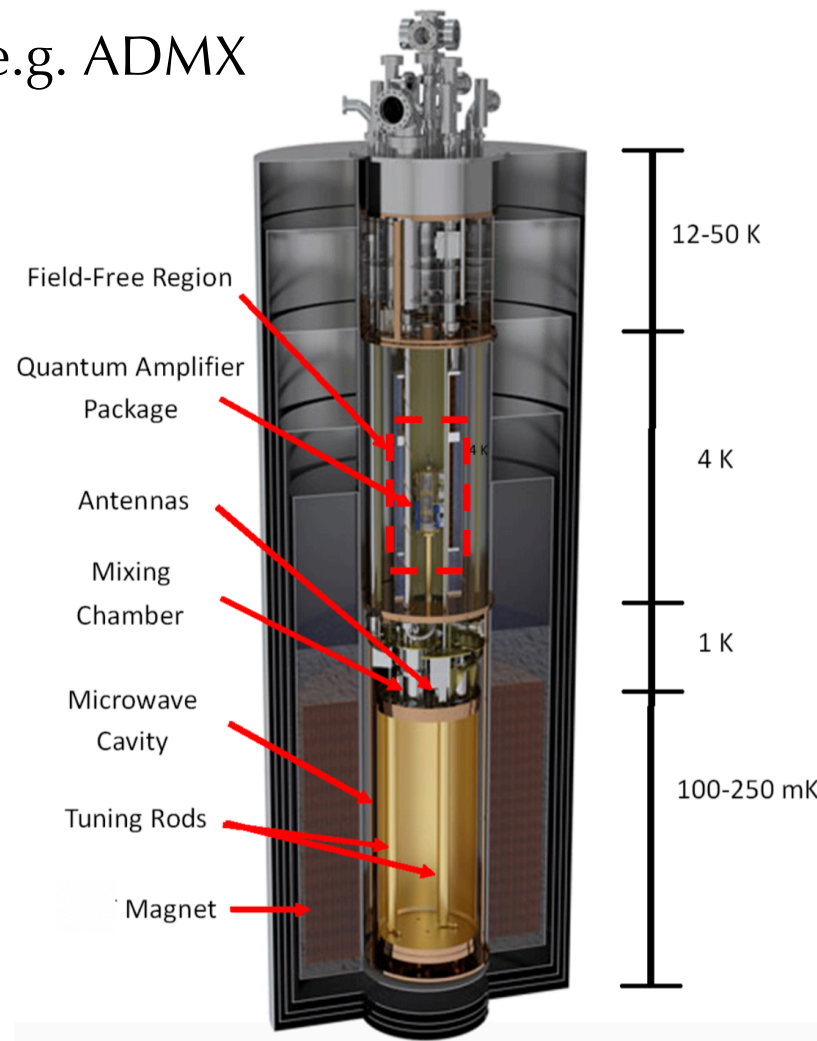


Cryostat

Dilution refrigerator:

Coldest available large-volume fridge ($\sim 10\text{mK}$)

e.g. ADMX



He^3 soaks into He^4
→ evaporation heat ❄️

Heat sources ("big-3"):

- Conduction (via pipes/cables) → make them long, low conducting materials
- Convection (via gases in the fridge) → high vacuum
- Radiation (from outside) → metal shielding

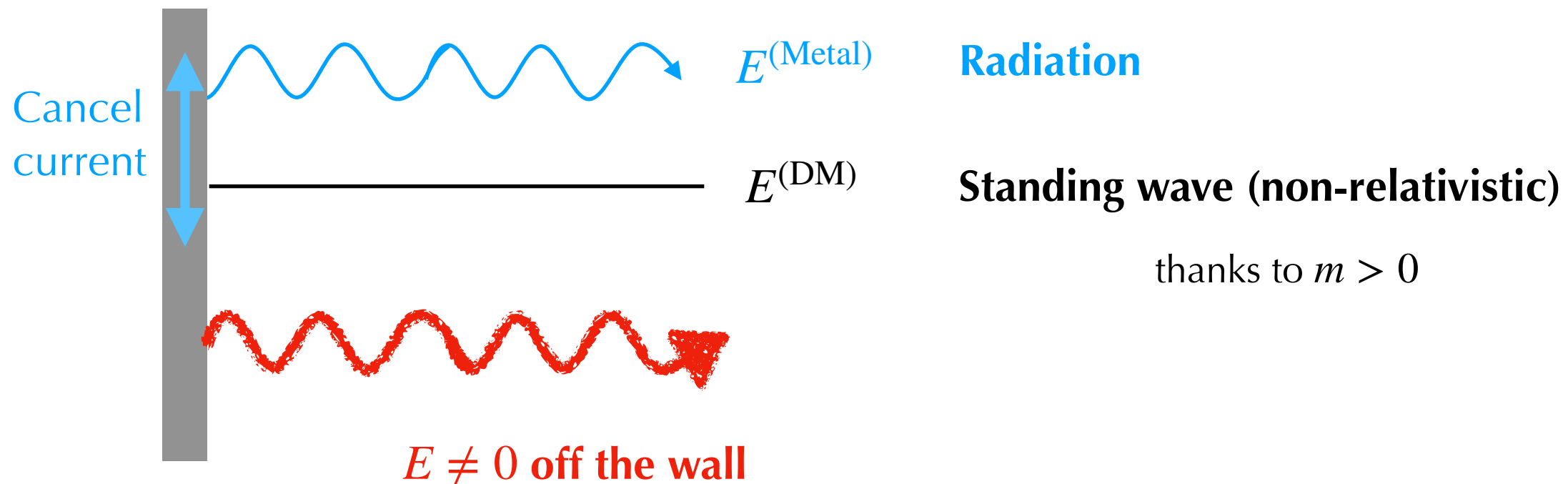
<< Cooling power: $100\text{-}1000\mu\text{W}$

Takes 2-10 days to reach the lowest temperature

Dish antenna idea

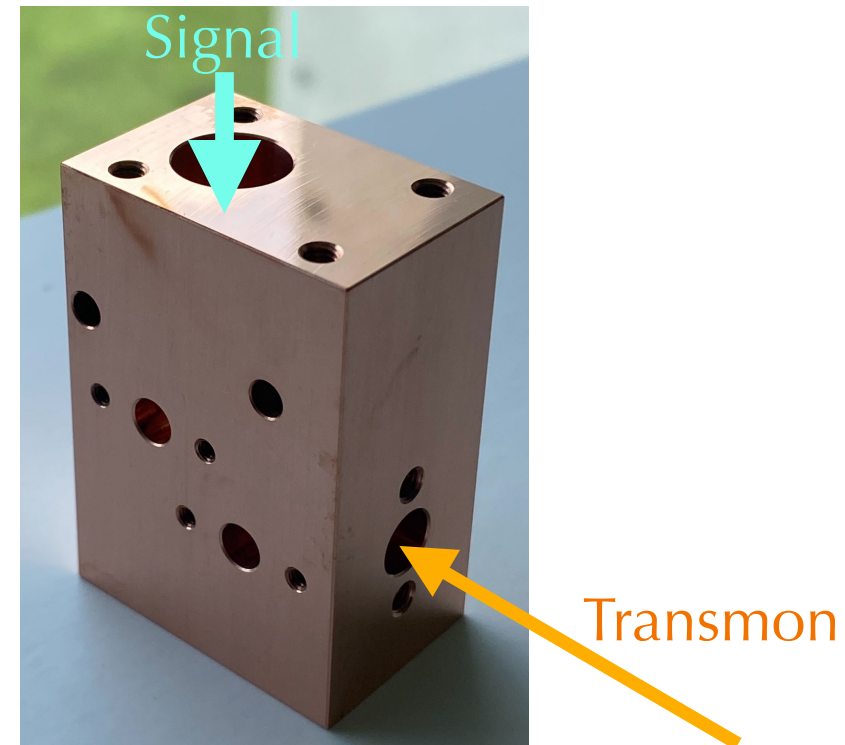
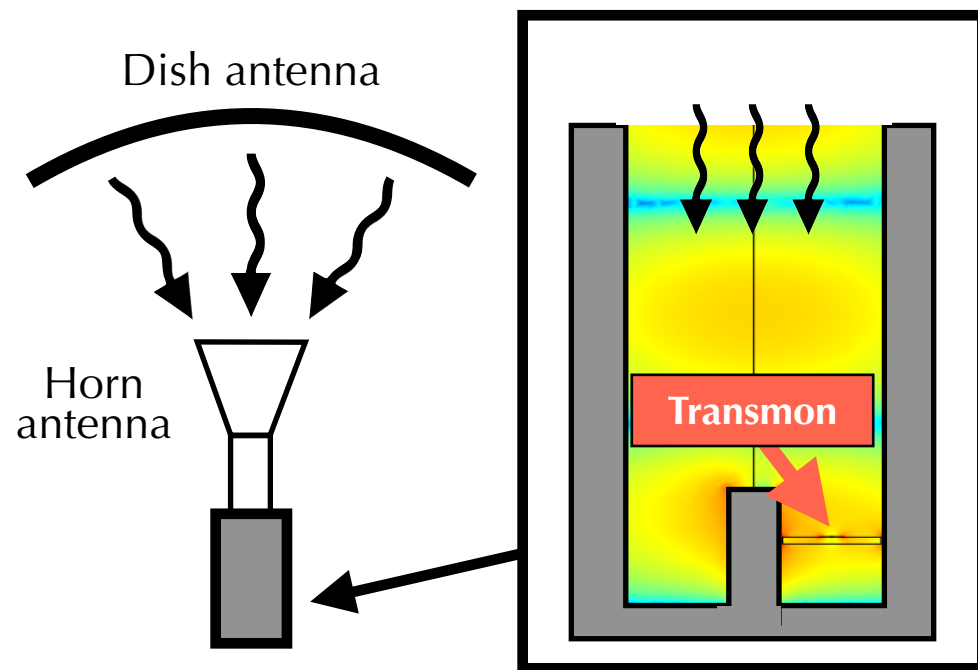
$$\begin{pmatrix} \mathbf{E} \\ \mathbf{E}_{\text{hid}} \end{pmatrix}_{\text{total},||} = \mathbf{E}_{\text{DM},||} \left[\begin{pmatrix} 1 \\ \chi \end{pmatrix} \overbrace{\exp(-i(\omega t - \mathbf{k}\mathbf{x}))}^{E^{(\text{Metal})}} + \frac{1}{\chi} \begin{pmatrix} -\chi \\ 1 \end{pmatrix} \overbrace{\exp(-i\omega t)}^{E^{(\text{DM})}} \right]_{x=0}$$

Strictly $E = 0$ inside the wall

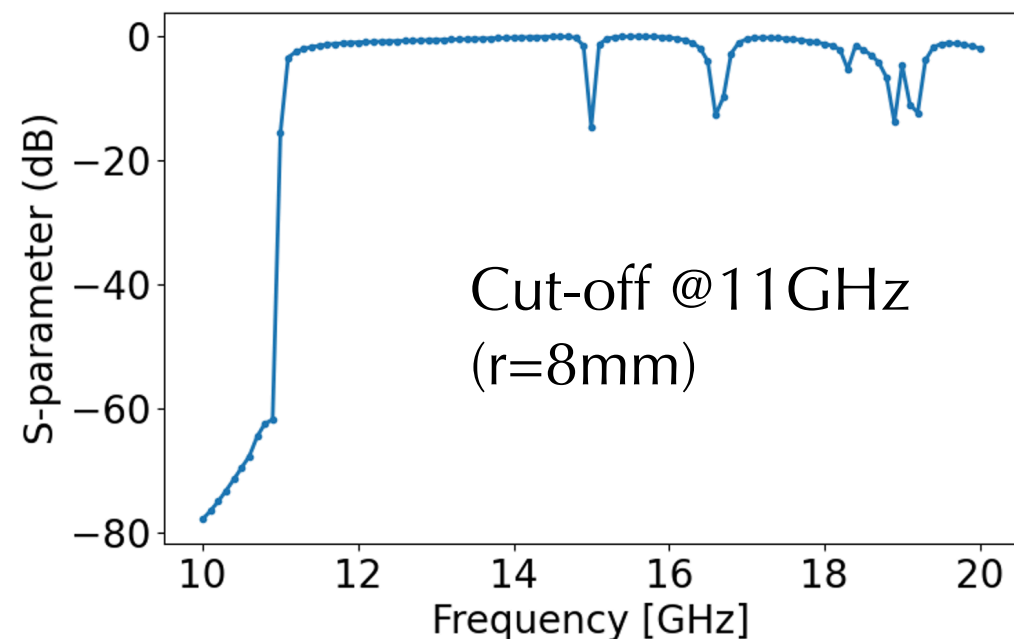


Feeble photon cloud in vacuum, feeble photon "wind" from the wall

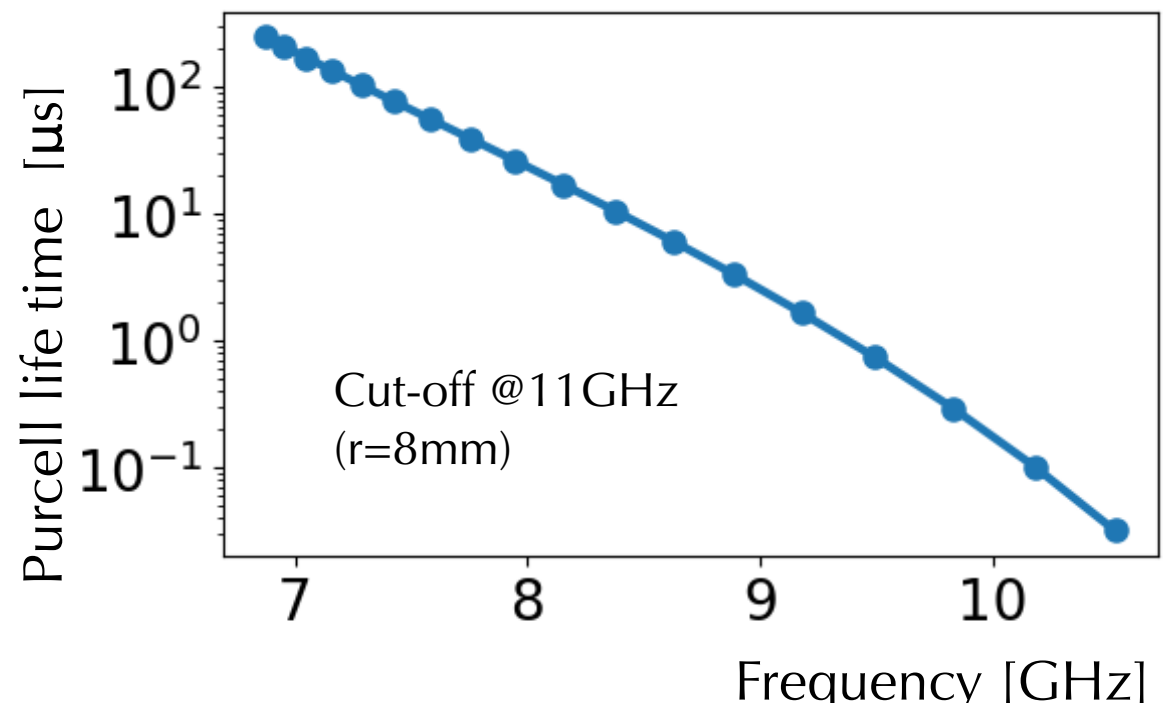
Dish antenna idea - How to introduce the field?



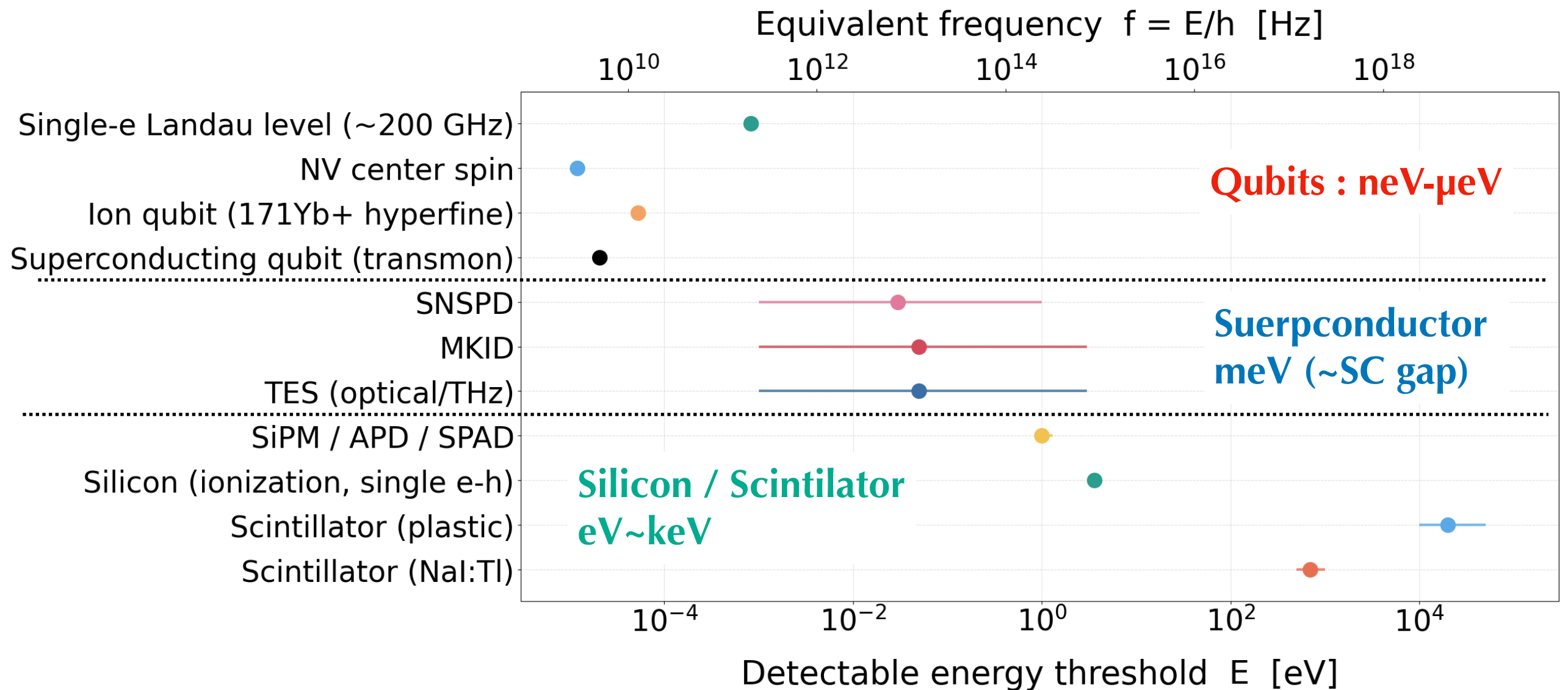
Signal introduction rate vs Purcell trade-off



Off-resonant readout regime being considered
e.g. ac Stark shift based single photon detection



Low threshold as detectors



- **Sensitive to small energy deposits**
- Typically microwave range thresholds (neV-μeV) : requirement of the phase control

Today : focus on **superconducting qubits**

Issue of package shielding

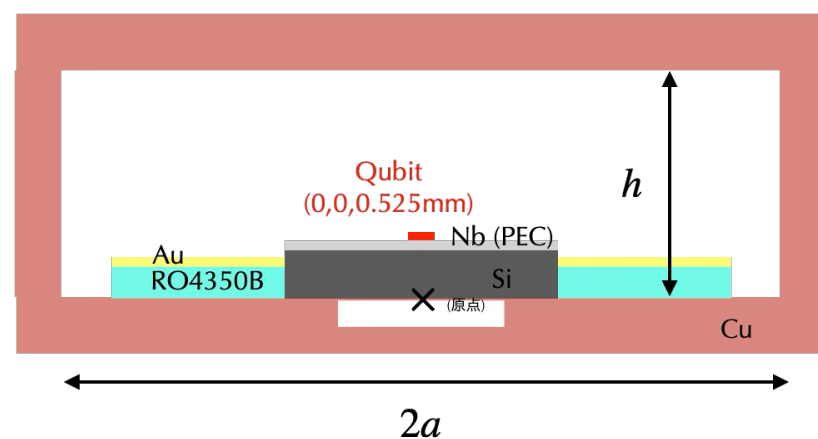
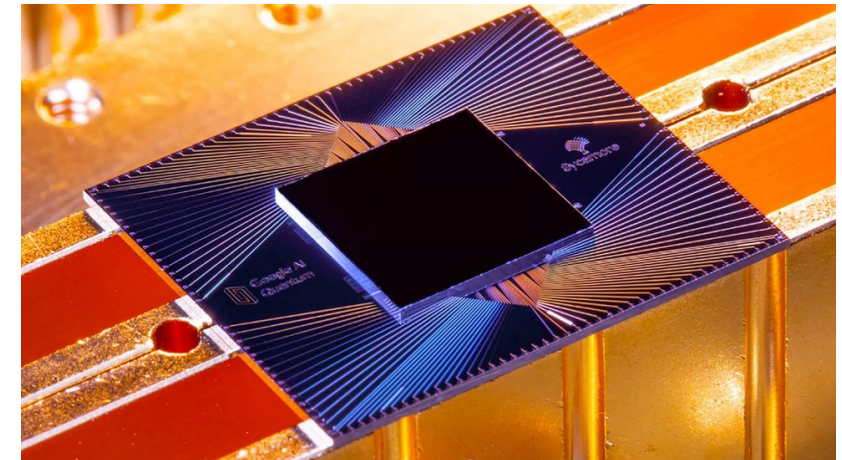
- As said, $E^{(EM)} + E^{(X)} \sim 0$ near the wall
- Tightest possible chip packaging is commonly used in 2D implementation for noise Shielding

Typical suppression factor $\kappa \sim O(10^{-3})$

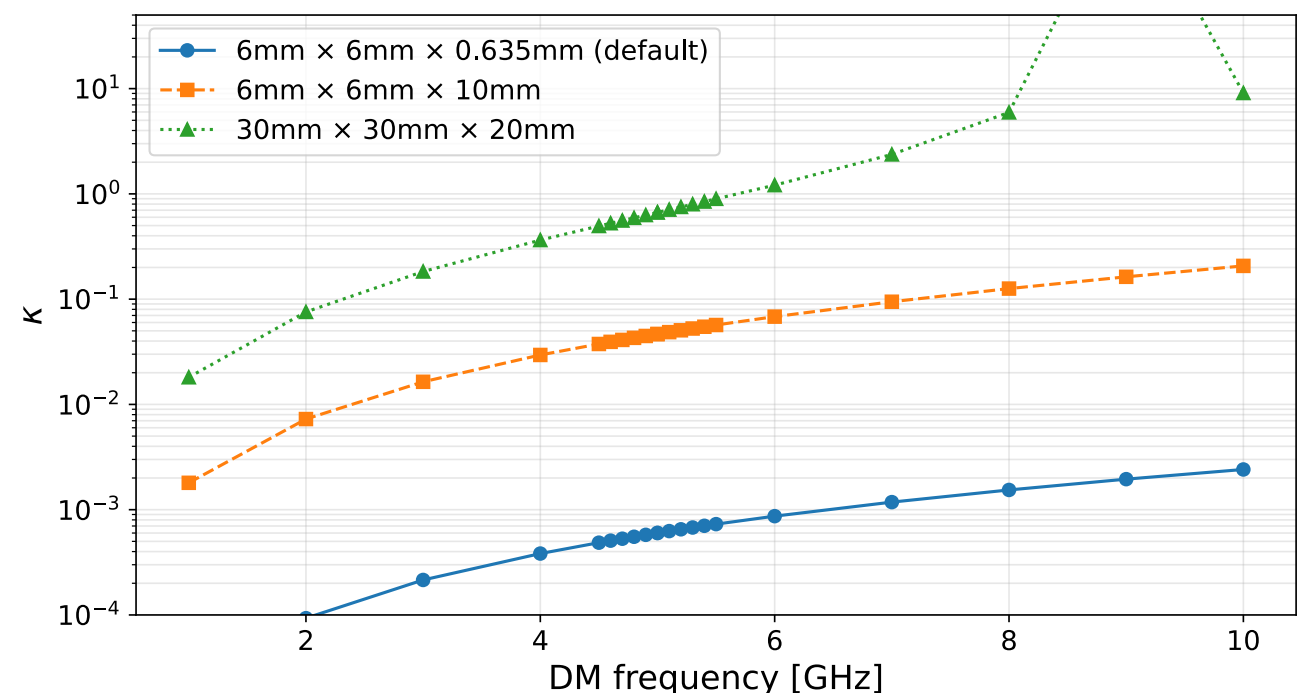
- Loosening the package? → **DM signal vs Purcell limit**

$$\kappa \sim \frac{g^2}{\Delta^2} \quad \Gamma_{\text{Purcell}} \sim \frac{g^2 \gamma}{\Delta^2 + \gamma^2}$$

- Large / high-Q 3D cavity turns out to be an ideal package for the search



US-Japan collaboration started this year to develop a custom package



Target : Wave-like dark matter

Axion

Strong CP problem

→ PQ mechanism → NG boson

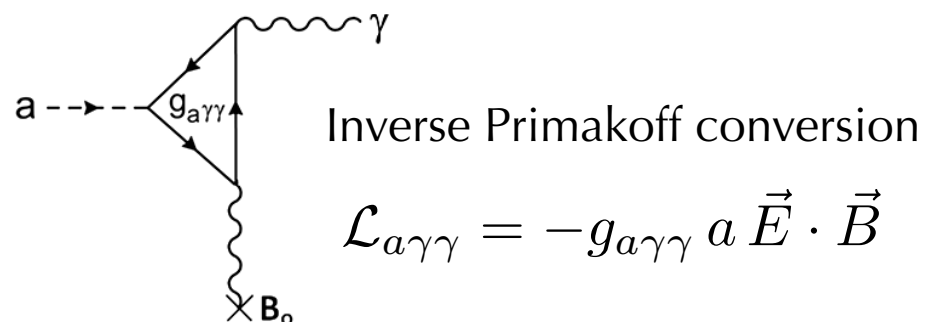
QCD axion condition

$$m_a = 5.691 \left(\frac{10^9 \text{ GeV}}{f_a} \right)$$

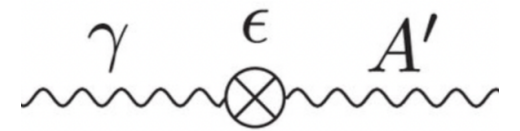
Axions that don't satisfy this are "Axion-Like Particle".
Cool thing still but won't solve the strong CP problem.

Axion-photon coupling

B-field → Photons emerge



Dark photon



mixing parameter

ordinary photon

$$X^\mu = \tilde{X}^\mu - \epsilon A^\mu$$

Dark photon
(mass eigen st.)

Dark photon
(interaction eigen st.)

Fake photon with a bit of ordinary photon

Gauge boson of a new $U(1)_{Q'}$

More motivation claimed recently in the context of string

Photon conversion w/o B-field

Tend to be the benchmark of axion search experiments before installing the magnet.