Leakage Detection in Integer Fluxonium Qubits

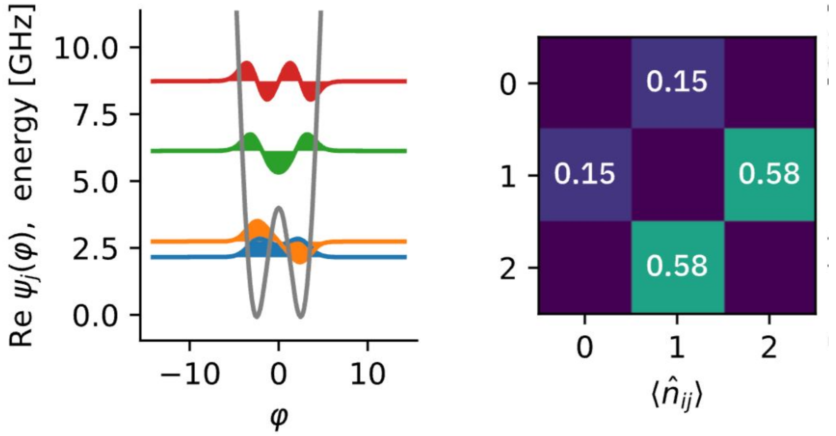
Jiakai Wang, Vlad Manucharyan, Maxim Vavilov

UNIVERSITY OF WISCONSIN–MADISON

EPFL

Property of fluxoniums

	Long coherence qubit?
half integer fluxonium, ge	✅



PHYSICAL REVIEW LETTERS

Highlights Recent Accepted Collections Authors Referees Search Press Ab

Featured in Physics Editors' Suggestion

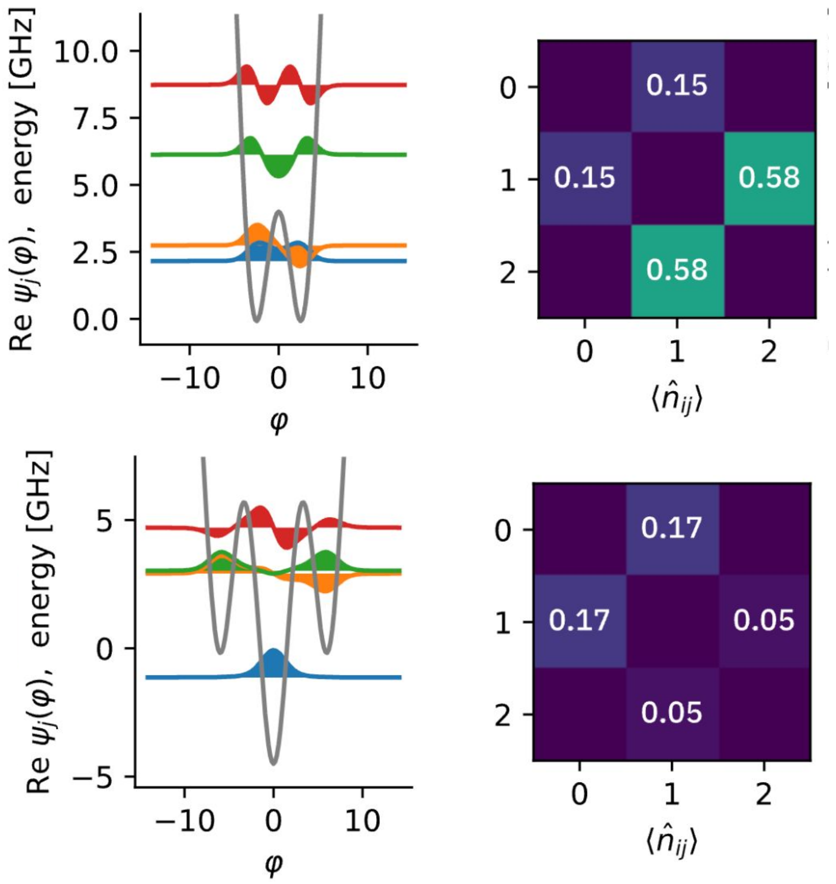
Millisecond Coherence in a Superconducting Qubit

Aaron Somoroff, Quentin Ficheux, Raymond A. Mencia, Haonan Xiong, Roman Kuzmin, and Vladimir E. Manucharyan

Phys. Rev. Lett. **130**, 267001 – Published 29 June 2023

Property of fluxoniums

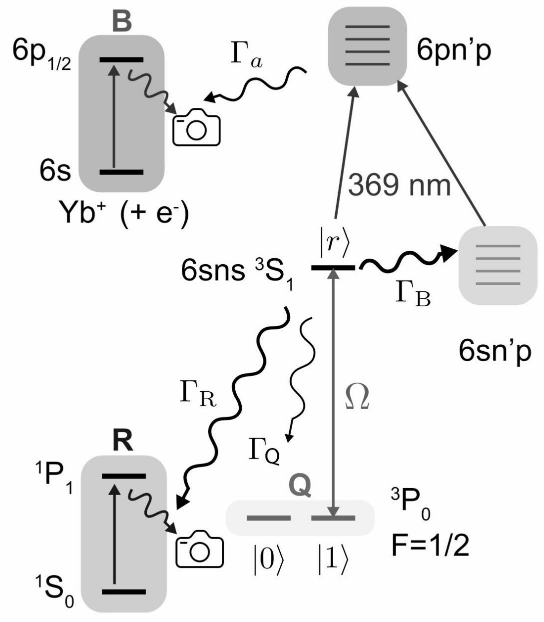
	Long coherence qubit?
half integer fluxonium, ge	✅
integer fluxonium, ge	✅ (preliminary data)
integer fluxonium, ef	✅



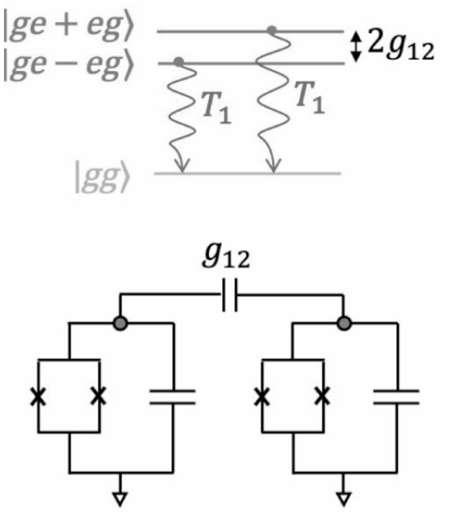
Similarity in error structure

1) **Highly coherent computational subspace**
2) **Convert most of the leakage to erasure error**

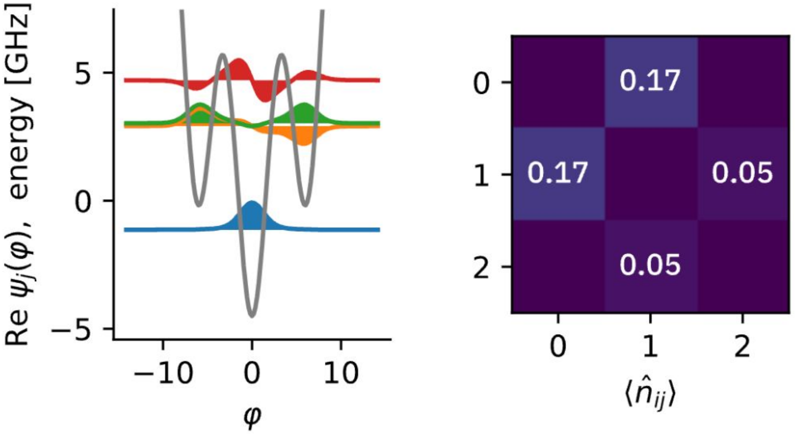
(Note that we are not claiming to have a high erasure ratio Re = P(erasure)/P(total).)



Nature Commun volume 13, 4657 (2022)

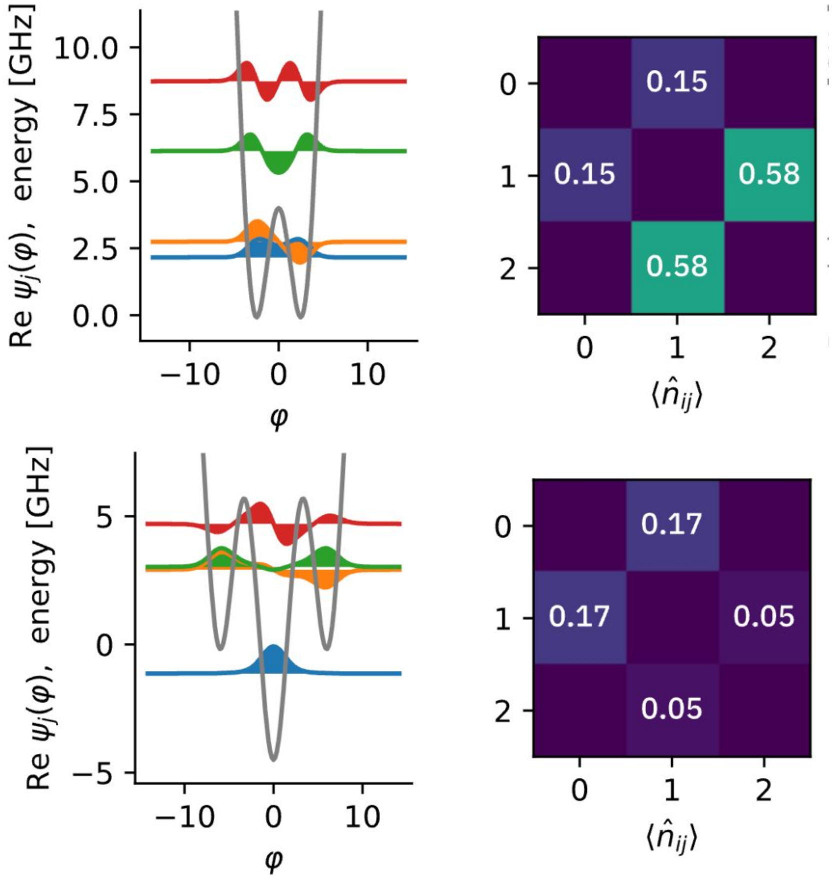


Phys. Rev. X **13**, 041022 (2023)

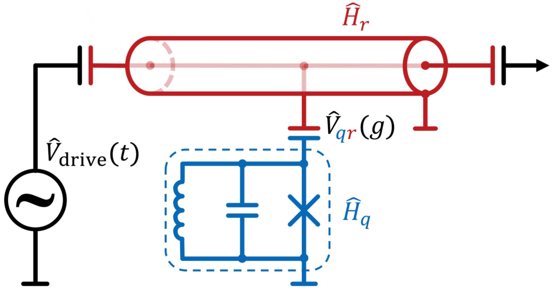


Property of fluxoniums

	Long coherence qubit?	Potential for erasure conversion?
half integer fluxonium, ge	✅	
integer fluxonium, ge	✅	
integer fluxonium, ef	✅	✅



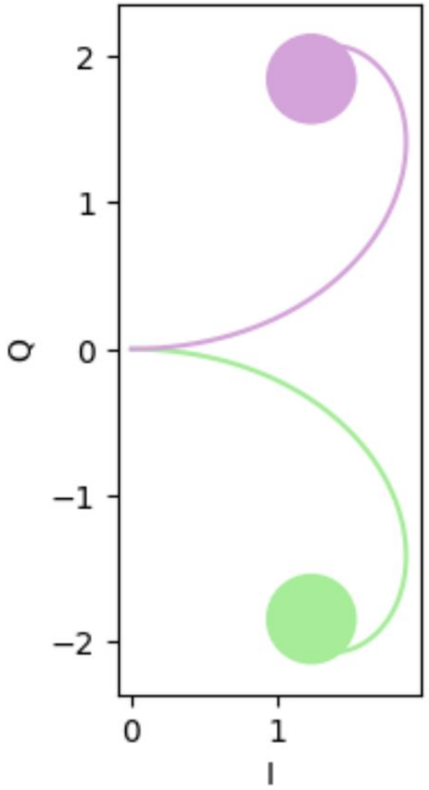
Minimal cQED readout model



Plot credit : arXiv:2402.07360

$$\mathcal{H} = \mathcal{H}_{\mathrm{r}} + \mathcal{H}_q + \mathcal{H}_{\text{interaction}}$$

$$\mathcal{H}_{\text{interaction}} = g\hat{n}_r\hat{n}_q$$

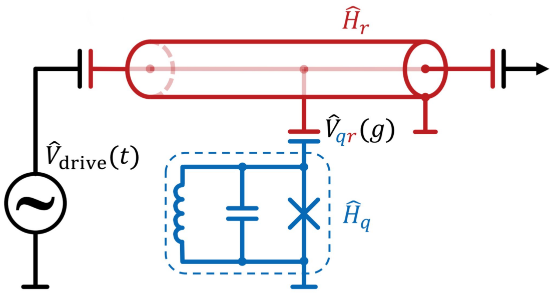


Signal of leakage

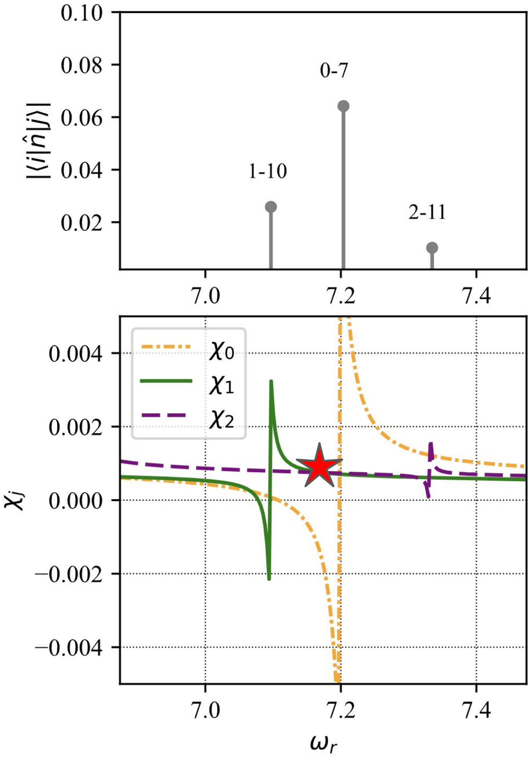
Signal of computational states

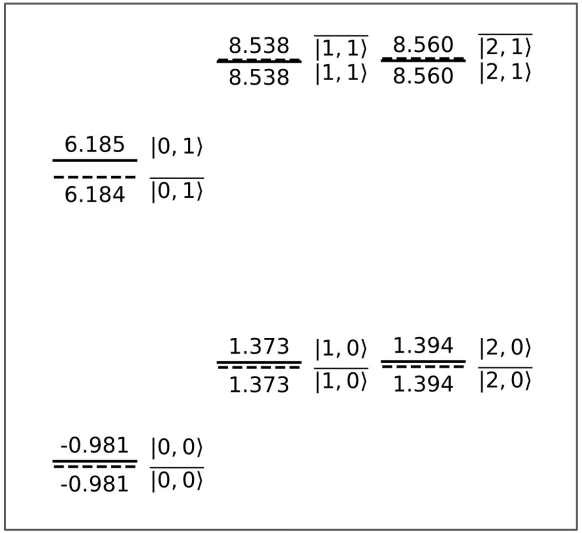
We want χ_1, χ_2 the same but distinguishable to χ_0

Tuning $\omega_{\text{resonator}}$



Plot credit : arXiv:2402.07360





$$\mathcal{H} = \mathcal{H}_{\text{r}} + \mathcal{H}_q + \mathcal{H}_{\text{interaction}}$$

Contribution to resonator frequency shift in approximation:

$$|\langle i|\hat{n}|j\rangle|^2/\Delta_{ij}$$

(Coupling strength g ≈ 100MHz)

Simulation results

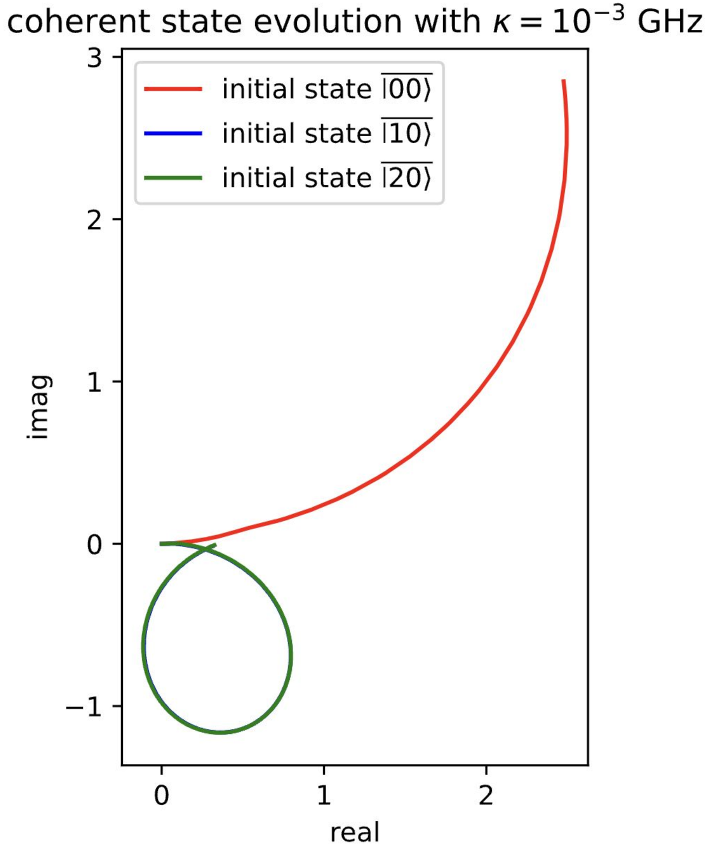
$$\mathcal{H} = \mathcal{H}_{\mathrm{r}} + \mathcal{H}_q + \mathcal{H}_{\mathrm{interaction}} + \mathcal{H}_{\mathrm{drive}}$$

$$\mathcal{H}_{\mathrm{drive}} = \Omega(t)(\hat{a} + \hat{a}^\dagger)$$

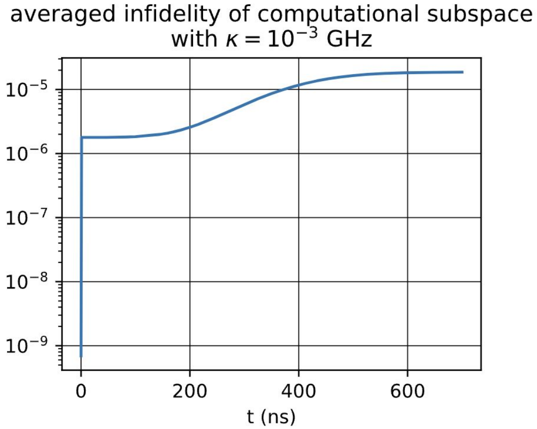
$$\mathcal{D}[\hat{a}]\rho = \kappa\left(\hat{a}\rho\hat{a}^\dagger - \frac{1}{2}\hat{a}^\dagger\hat{a}\rho - \frac{1}{2}\rho\hat{a}^\dagger\hat{a}\right)$$

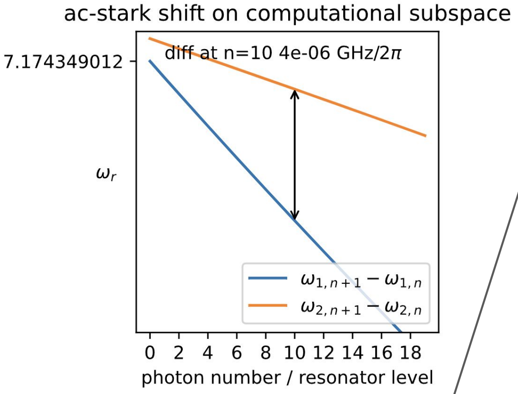
Criterion for good distinguishability:

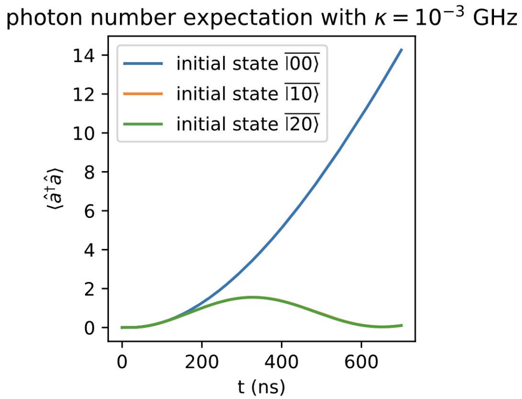
$$\sqrt{\kappa}\int_{t_0}^{t_{stop}} dt' \left|\langle\hat{\alpha}^l\rangle - \langle\hat{\alpha}^{1,2}\rangle\right|^2 \gg 1$$ ✅

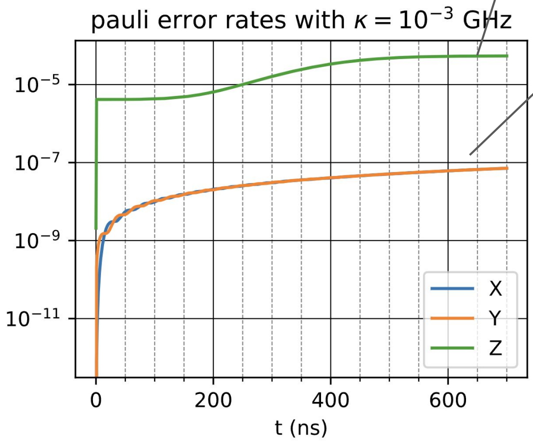


Photon shot dephasing on computational subspace









Photon shot dephasing

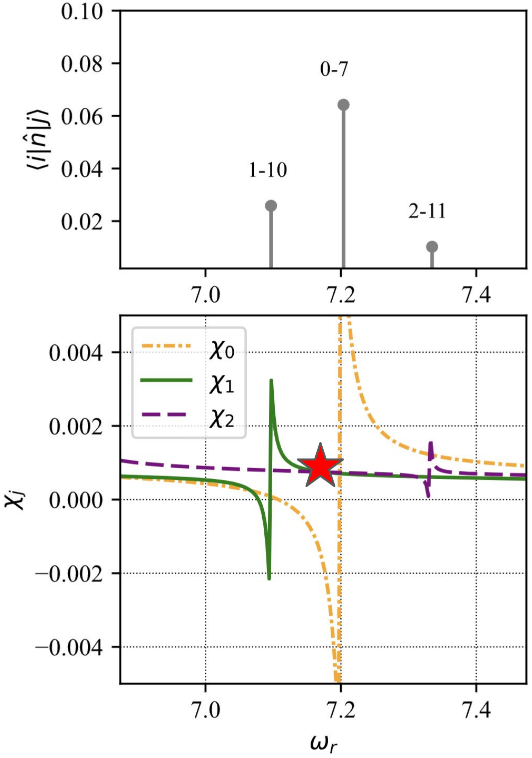
Purcell decay, non-dispersive contribution beyond linear resonator response

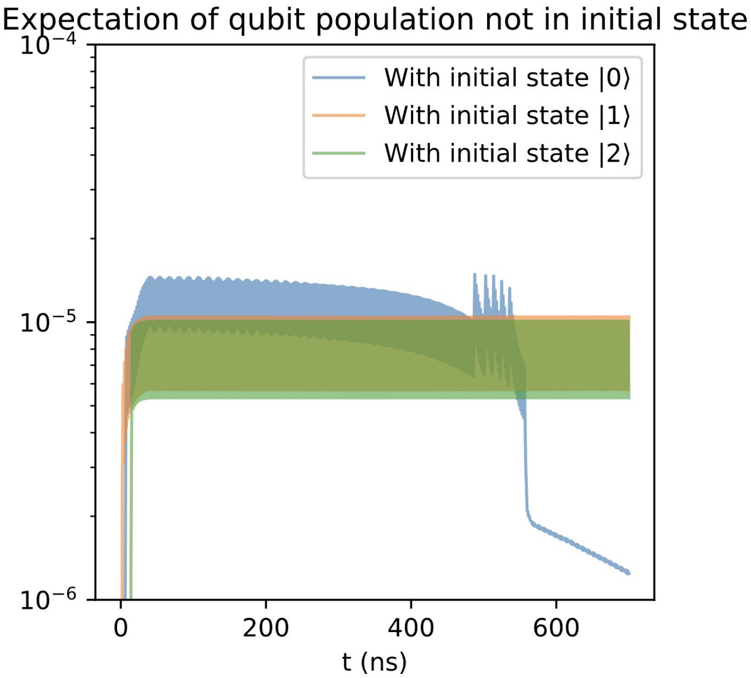
A short note on effective Pauli noise models
Michael A. Perlin
arXiv:2311.09129

Leakage to higher levels

Minimal additional leakage,

May be handled by QEC decoder





Is the detection worth it?

Assume a g-e T1 of 300μs (preliminary data), then 300 ns would accumulate leakage on the order of 10^{-3},

A 10^{-5} fidelity cost of leakage detection is worth doing to remove that 10^{-3} leakage population

Conclusion

1) We propose e-f Integer Fluxonium Qubit with highly coherent computational subspace
2) The dominant leakage population can be converted into biased erasure, via high-accuracy, high fidelity dispersive detection

Outlook

1) Experimentally calibrate the lifetime of e-f subspace of Integer Fluxonium,
2) Demonstrate the dispersive leakage detection
3) Explore architectural design space of this qubit