

Encoded Cat qubit in a high spin nucleus in Silicon

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The demonstration of Schrödinger cat states on the nuclear spin of an Antimony (Sb) donor in Silicon [1] has opened the door to cat-based quantum error correction codes in spin qubits. In this work we present an encoded cat qubit with a universal logical gate set. Applying correction in post-analysis reduce the gate error rates to below the error correction threshold.

The logical basis states are the spin coherent states of a spin-7/2 nuclear spin pointing along an axis (x) perpendicular to the Zeeman field (z), making an arbitrary logical superposition state a cat state along the spin projection operator I_x . In this basis, logical bit flips can be done virtually through a change of the global rotating frame [1]. Logical phase flips require a change in the parity along the I_z projection axis. We demonstrate how this can be done transversally through covariant $SU(2)$ rotations and a virtual gate.

The dominant errors in this system show up on the I_z operator and, through the nuclear

quadrupole moment, on the I_z^2 operator. These introduce rotation and squeezing operations respectively as shown as spin Wigner function plots in figure 1. Upon rotation to the I_z basis both kinds of errors are detectable through an ancillary electron spin qubit (figure 2) and in post-analysis can be corrected, leading to high state - and gate fidelities.

References

- [1] Yu, X., Wilhelm, B., Holmes, D. *et al* *Nat. Phys.* (2025)

Figures

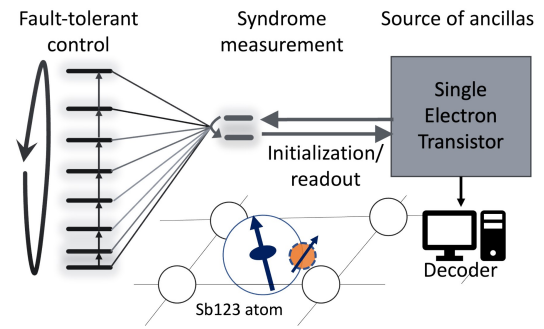


Figure 1: Physical system, the Sb123 donor has a spin-7/2 nucleus which supplies the 8 level qudit on which the cat qubit is encoded. The donor electron functions as an ancillary qubit for syndrome measurement.

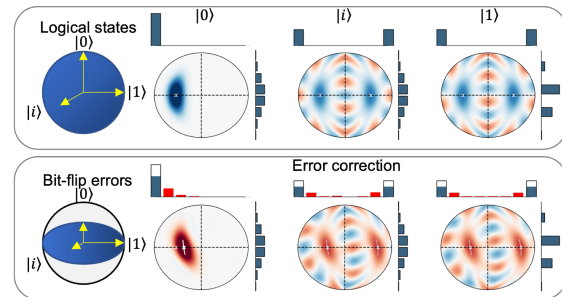


Figure 2:

Spin Wigner function plots of three logic states and the same states after an error has occurred.