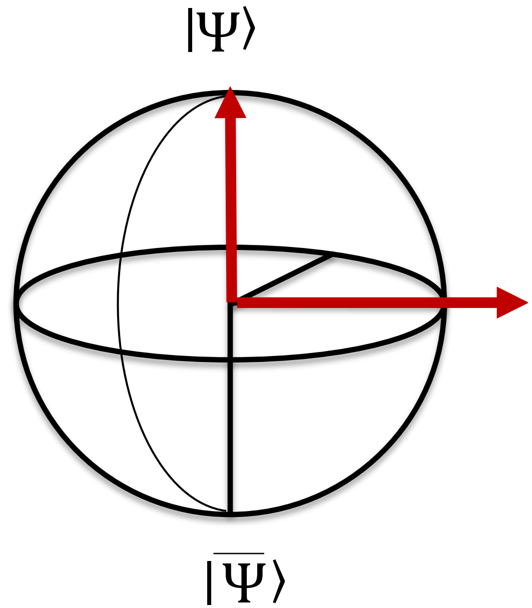
Stabilizers: $S_1 = ZZX\,;S_2 = ZXZ$

Gates:

$\tilde{X}$	$\tilde{Z}$
XXX	ZII
YYI	IZX
YIY	IXZ
XZZ	ZYY

Code words: $|\Psi\rangle = \frac{1}{\sqrt{4}}[\,|\uparrow\uparrow\uparrow\rangle + |\uparrow\uparrow\downarrow\rangle + |\uparrow\downarrow\uparrow\rangle - |\uparrow\downarrow\downarrow\rangle]$

$|\bar{\Psi}\rangle = \frac{1}{\sqrt{4}}[\,|\downarrow\downarrow\downarrow\rangle + |\downarrow\downarrow\uparrow\rangle + |\downarrow\uparrow\downarrow\rangle - |\downarrow\uparrow\uparrow\rangle]$



Requires SM entangling gates + single qubit addressing

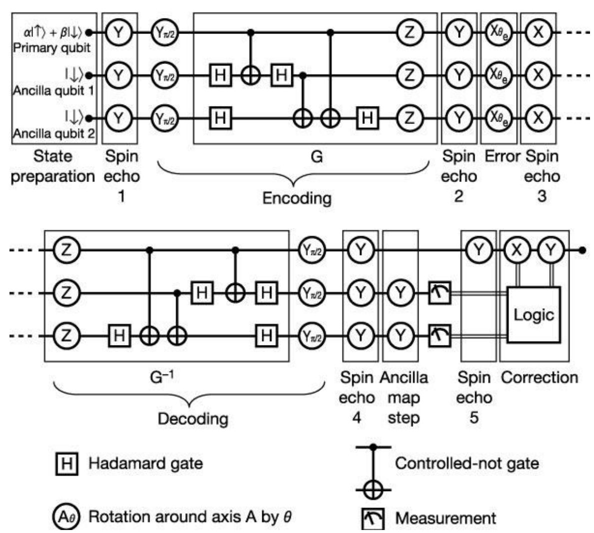
Realization of quantum error correction

J. Chiaverini[1], D. Leibfried[1], T. Schaetz[1*], M. D. Barrett[1*], R. B. Blakestad[1], J. Britton[1], W. M. Itano[1], J. D. Jost[1], E. Knill[2], C. Langer[1], R. Ozeri[1] & D. J. Wineland[1]

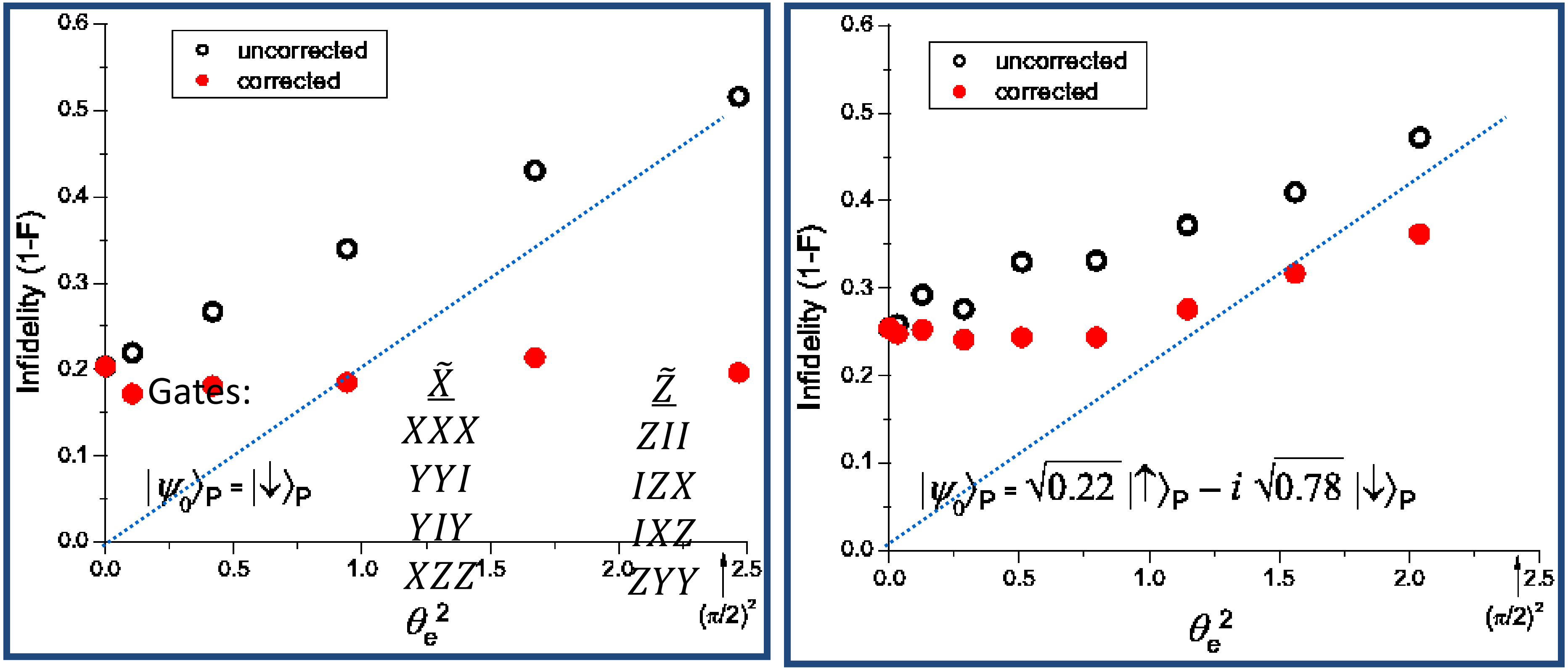
[1]*Time and Frequency Division,* [2]*Mathematical and Computational Sciences Division, NIST, Boulder, Colorado 80305, USA*

* Present addresses: Max Planck Institut für Quantenoptik, Garching, Germany (T.S.); Physics Department, University of Otago, Dunedin, New Zealand (M.D.B.)

Nature, ***432***, *602* (2004)



Results



- Uncorrected infid. ~ θ_e^2, corrected infid. ~ θ_e^4
- Qubits genuinely protected for θ_e ~ 1 rad.

(J. Chiaverini *et al*. Nature 2005)

Experimental Repetitive Quantum Error Correction

Philipp Schindler,[1] Julio T. Barreiro,[1] Thomas Monz,[1] Volckmar Nebendahl,[2] Daniel Nigg,[1] Michael Chwalla,[1,3] Markus Hennrich,[1]* Rainer Blatt[1,3]

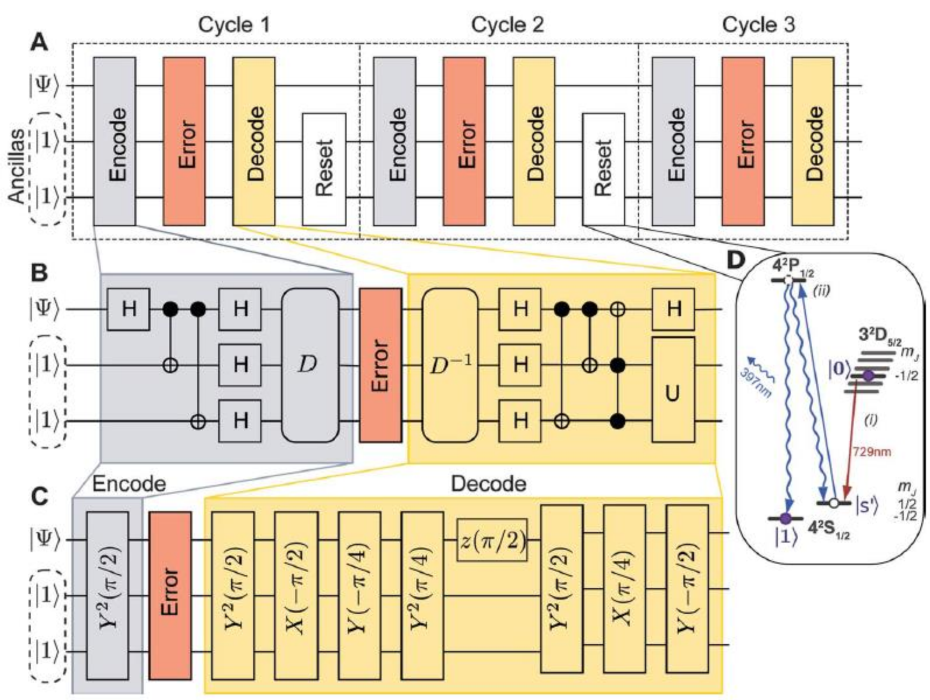
The computational potential of a quantum processor can only be unleashed if errors during a quantum computation can be controlled and corrected for. Quantum error correction works if imperfections of quantum gate operations and measurements are below a certain threshold and corrections can be applied repeatedly. We implement multiple quantum error correction cycles for phase-flip errors on qubits encoded with trapped ions. Errors are corrected by a quantum-feedback algorithm using high-fidelity gate operations and a reset technique for the auxiliary qubits. Up to three consecutive correction cycles are realized, and the behavior of the algorithm for different noise environments is analyzed.

ancillas. Initially, the qubit to be protected is in the state $|\Psi\rangle = \alpha|+\rangle + \beta|-\rangle$, where $|\pm\rangle = 1/\sqrt{2}(|0\rangle \pm |1\rangle)$, and the two ancilla qubits are both prepared in the state $|1\rangle$. In the encoding stage, they are mapped into the entangled state $\alpha|+++\rangle + \beta|---\rangle$. Next, a single-qubit phase-flip error may change $|\pm\rangle$ to $|\mp\rangle$. In the decoding and correction stage, the error is identified by a simple majority vote, and the system qubit is corrected accordingly. It should be noted that this protocol maps the information in and out of the protected state between QEC cycles. Each cycle is concluded by resetting the ancilla qubits while preserving the information on the system qubit.

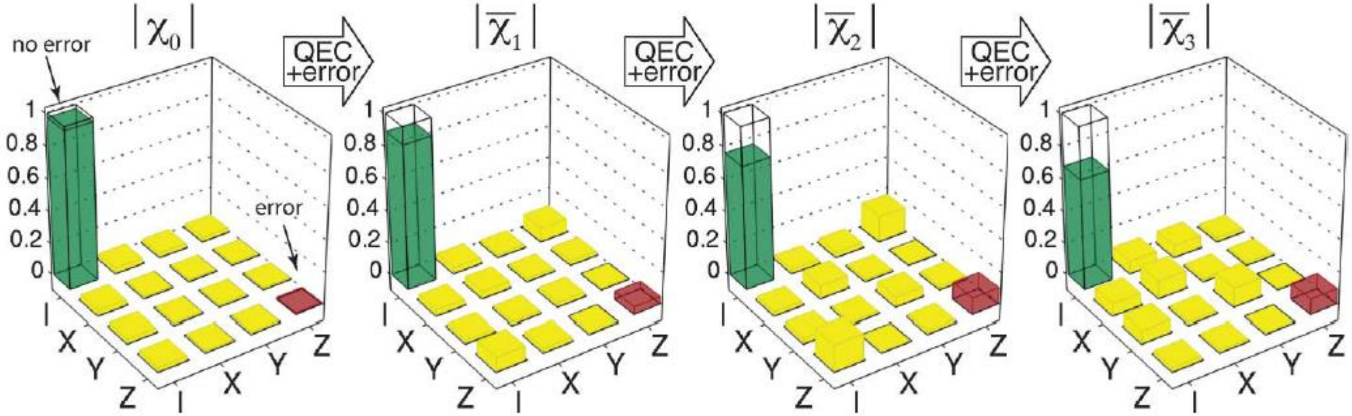
The textbook implementation of a single cycle of this QEC procedure would consist of a circuit using four controlled-NOT (CNOT) and one con-

Science, ***332***, *1059* (2011)

Stabilizers: $S_1 = YZY$; $S_2 = YYZ$



Results



|χ0|
no error
error
QEC +error
|χ̄1|
QEC +error
|χ̄2|
QEC +error
|χ̄3|
1
0.8
0.6
0.4
0.2
0
I
X
Y
Z