Testing quantum systems with entanglement

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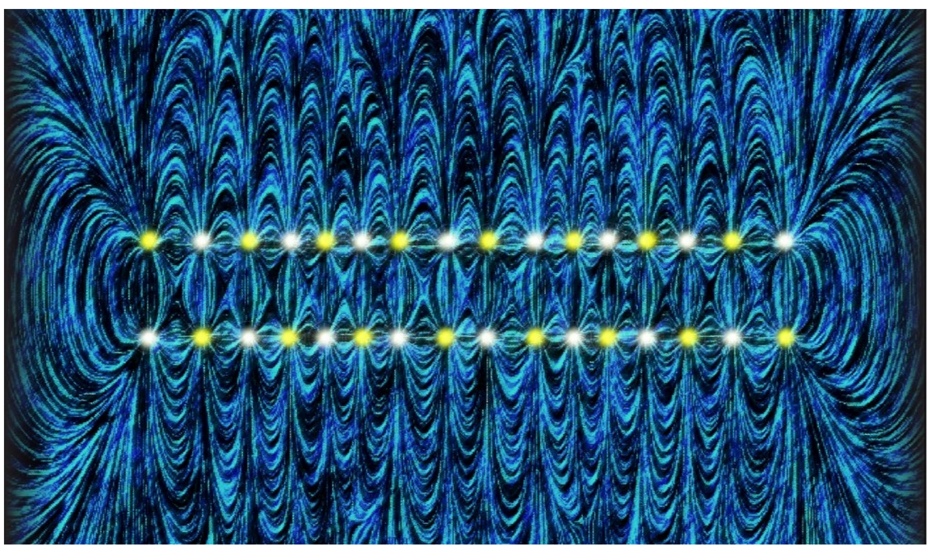
Testing a quantum black box

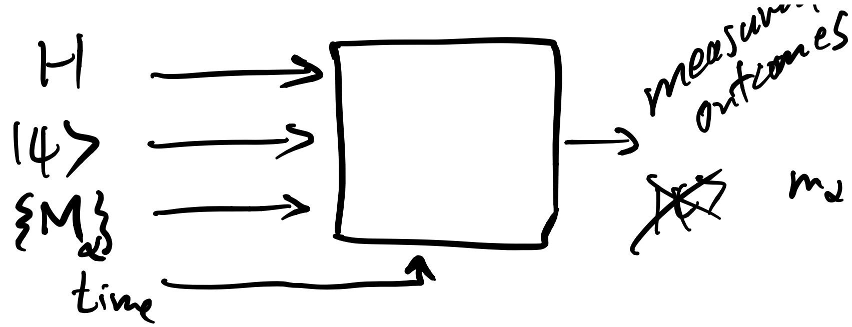
Tran, Mathew, JMT, in prep

Kafri, JMT, arxiv:1504.01187

What properties of a system can we test for/understand with limited access?



Q simulator



M_α measmt

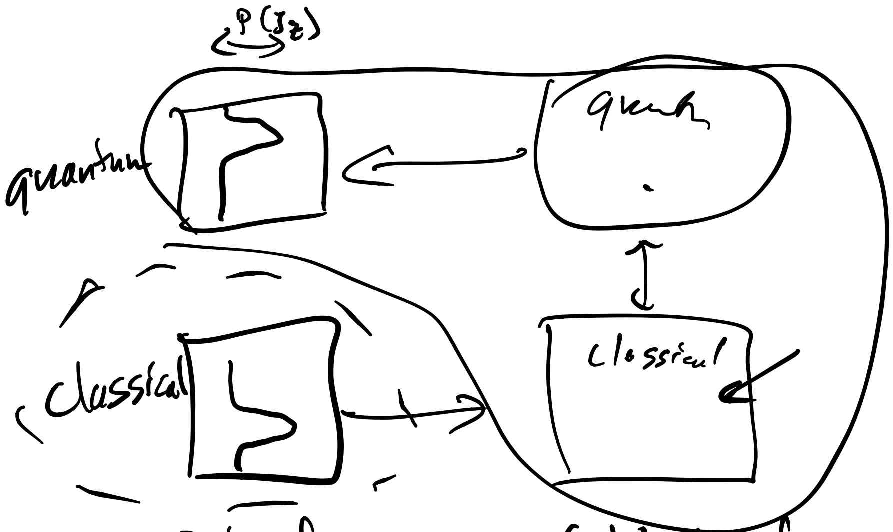
~~m_α~~ m_α w/ prob $Tr[M_\alpha^\dagger M_\alpha \rho]$

Compare $P(m_\alpha)$ for quantum evol (e^{-iHt})

vs. classical evol : evol of S.E. restricted to product states

$$H = \sum_{j=1}^{N} \frac{S^0 \cdot S^j}{\gamma_j - \gamma_0} + h_0 S_z^0 + h J_z$$

$$V = \lambda \sum \hat{n}_j \cdot \hat{S}^j \qquad \left(h_0 \gg \frac{1}{\gamma_j - \gamma_0} N \right)$$

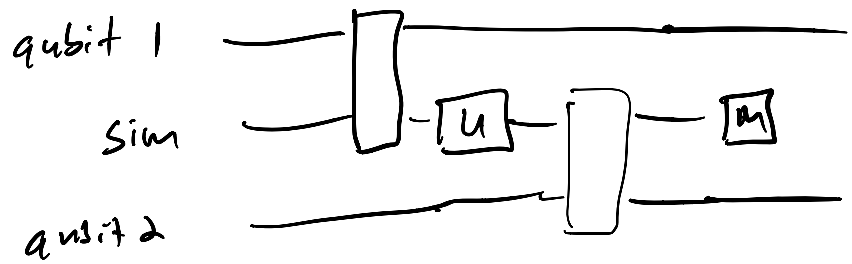


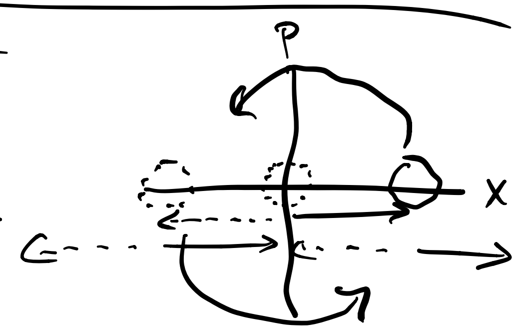
orig frame → S-W transform

$$\sum S_+^{j} S_-^{j'} + \dots$$

$$h_0 \gg h_{j,r_j} \frac{1}{}$$

$$\text{Disturb} = 1 - \lambda^{\text{poly}(N)}$$





$$\exp(-i\eta p\sigma_z^2)\,U(t)\,\exp(-i\eta p\sigma_z^1)$$

↑↑ or ↓↓ $\quad \underbrace{\exp(\mp 2i\eta p)\, U_{x\to x\pm\eta}}_{W_\pm}|\psi_s\rangle$

↑↓ or ↓↑ $\quad \underbrace{U_{x\to x\pm\eta}}_{X_\pm}|\psi\rangle$

measure $|vac\rangle\langle vac|$ or $\mathbb{1} - |vac\rangle\langle vac|$

↓ this only ↑ P

instead $|++\rangle$ state → Bell state $|\uparrow\downarrow\rangle + |\downarrow\uparrow\rangle$

$$|\langle\psi_s|\underbrace{X_-^\dagger P X_+}|\psi_s\rangle|^2 > \langle\psi_s|W_-^\dagger P W_-|\psi_s\rangle\langle\psi_s|W_+^\dagger P W_+|\psi_s\rangle$$

out-of-time-order correlation function

$$X_{\sigma_z}|\psi_s\rangle|+\rangle \to X_-|\psi\rangle|0\rangle + X_+|\psi\rangle|1\rangle$$

$$\langle\, |0\rangle\langle 1|\, \rangle$$

Witness gravity's quantum side in the lab

Physicists should rethink interference experiments to reveal whether or not general relativity follows classical theory, argue **Chiara Marletto** and **Vlatko Vedral**.

Sixty years ago, physicists congregated to discuss gravity in a seminal conference at the University of North Carolina in Chapel Hill. Richard Feynman proposed a thought experiment to analyse a deep problem: the incompatibility of quantum theory and general relativity[1]. We think that his argument needs revisiting.

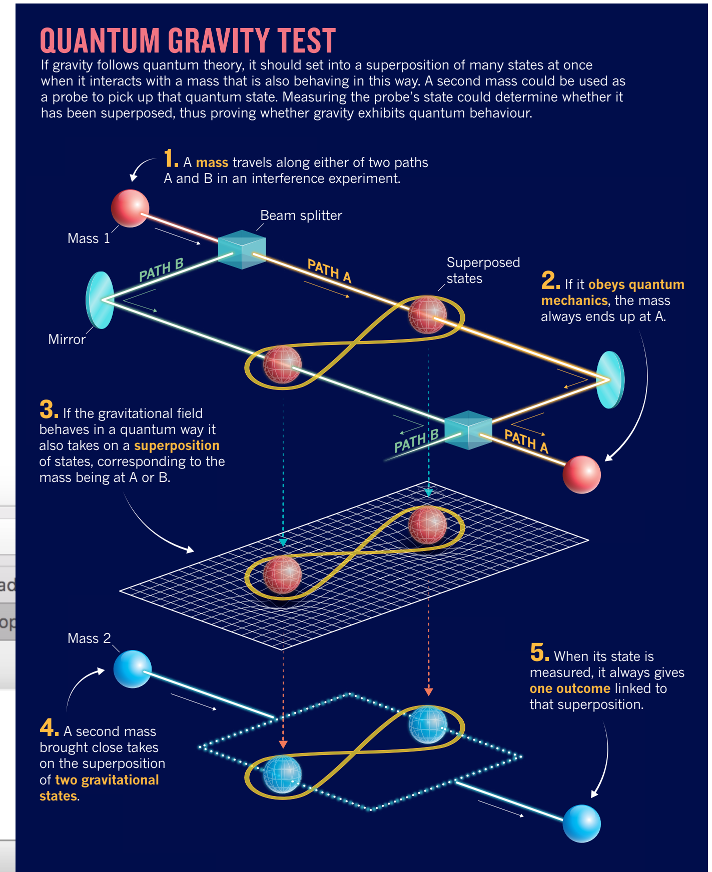
Gene... that any... as the gr... that car... quantu... such as... definite... may exi... in two p... measur... but you... uremen...

story of Schrödinger's cat. According to quantum theory, one can set up an experiment where a cat hidden in a box with deadly poison is in a superposition of being alive or dead until someone opens the box and reveals its fate.

Feynman's imagined experiment goes to the heart of this clash. First, he consid-

words, takes on a quantum nature when it interacts with a mass that is also behaving in a quantum way.

Feynman identifies two ways to solve this contradiction. Either quantum theory prevails and gravity too is 'quantized'; or general relativity prevails and quantum theory applies only at certain scales. Some principle



BackReAction

Thursday, July 13, 2017

Nature magazine publishes comment on quantum gravity phenomenology, demonstrates failure of editorial oversight

For about 15 years, I have worked on quantum gravity phenomenology, which means I study ways to experimentally test the quantum properties of space and time. Since 2007, my research area has its own conference series, "Experimental Search for Quantum Gravity," which took place most recently September 2016 in Frankfurt, Germany.

I have a headache and blame Nature magazine for it.

Extrapolating from whom I personally know, I estimate that about 150-200 people currently work in this field. But I have never seen nor heard anything of Chiara Marletto and Vlatko Vedral, who just wrote a comment for *Nature* magazine complaining that the research area doesn't exist.

Recent Comments

The gravitational coupling constant is dimensionfu... - Sabine Hossenfelder

Sabine Hossenfelder (2:15 AM, July 20, 2017) What... - AYVlasov

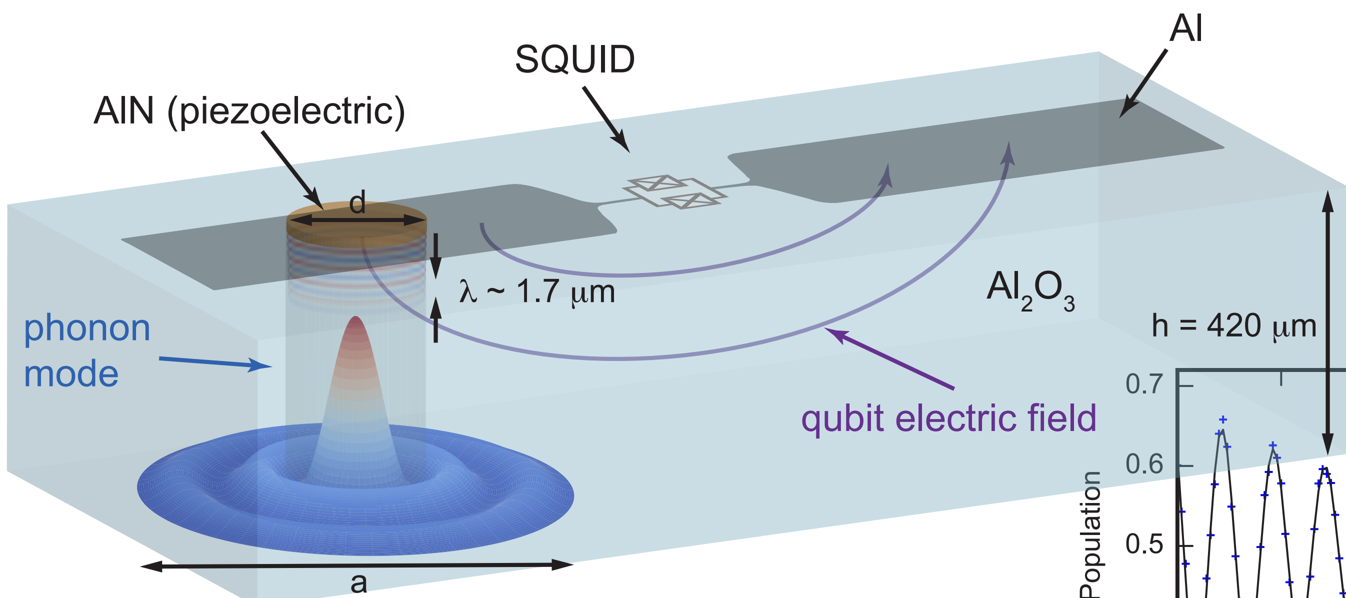
Tim Maudlin wrote: By a "Holographic hypothe... - Arun

Creating a non-classical massive superposition

Quantum acoustics with superconducting qubits

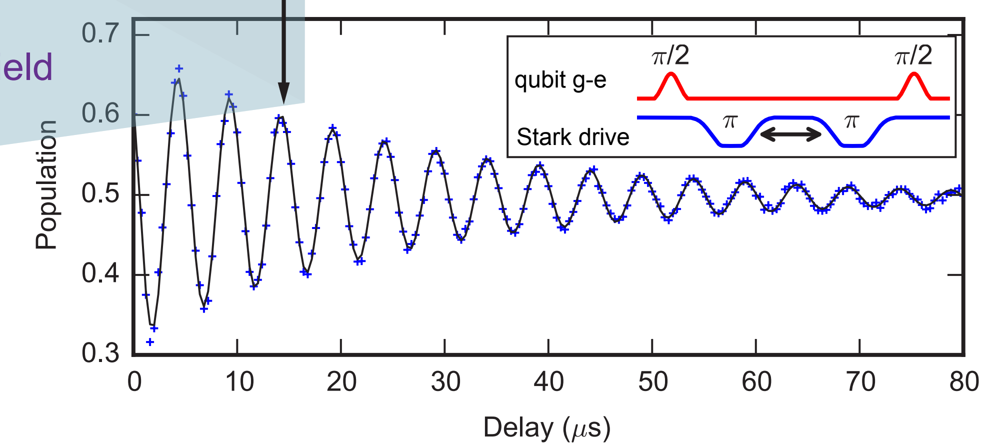
Yiwen Chu[1], Prashanta Kharel[1], William H. Renninger[1], Luke D. Burkhart[1], Luigi Frunzio[1], Peter T. Rakich[1], & Robert J. Schoelkopf[1]

$$(|0\rangle + |1\rangle)\,|\mathrm{vac}\rangle \rightarrow |0\rangle\,(1 + e^{i\phi}a^{\dagger})\,|\mathrm{vac}\rangle \rightarrow (|0\rangle + e^{i\phi}\,|1\rangle)\,|\mathrm{vac}\rangle$$



M ~ 0.1 mg

Quantum Q ~10^5**!**



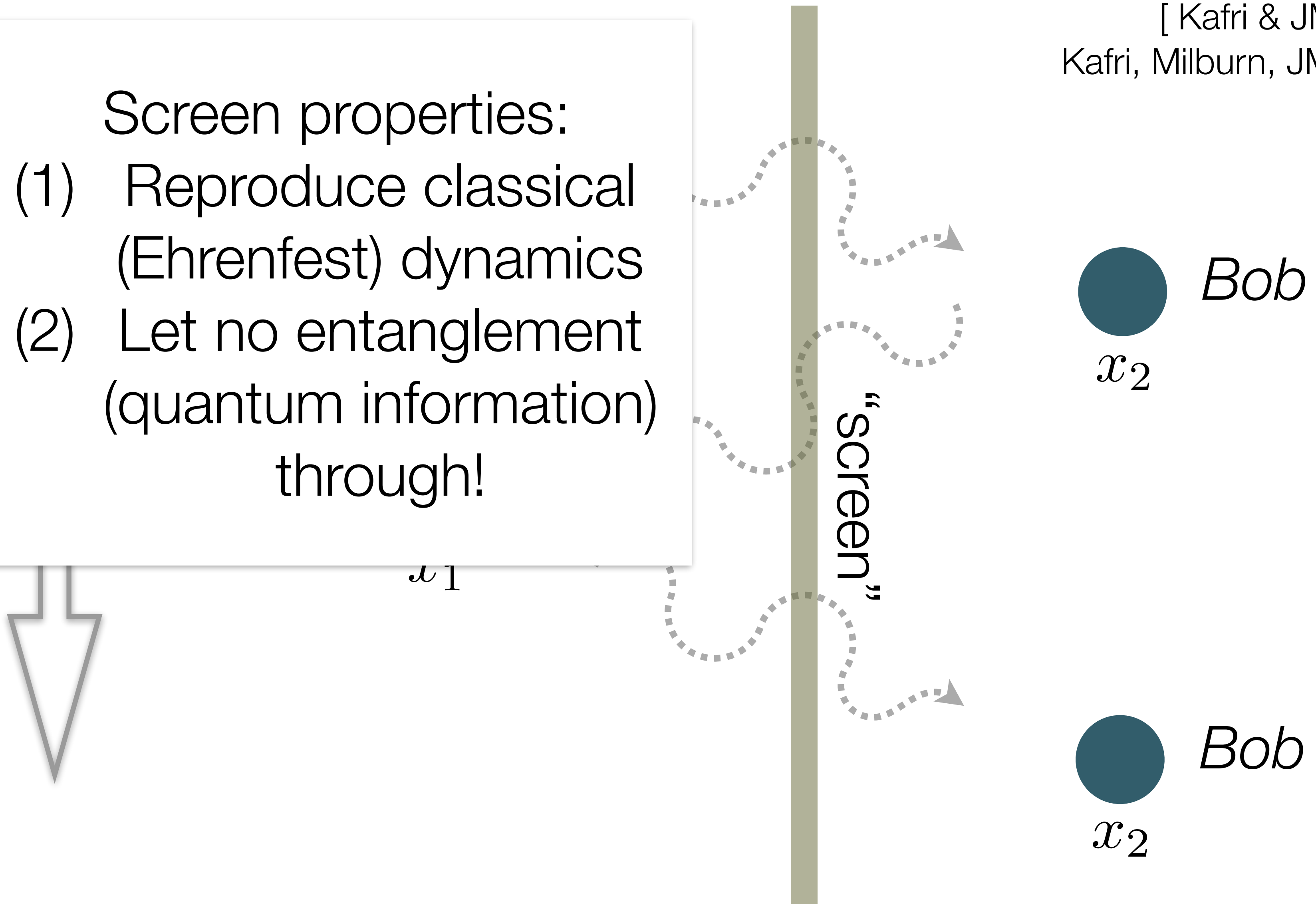
Classical force? No entanglement allowed

[Kafri & JMT, 2013,
Kafri, Milburn, JMT 2014, 2015]

Screen properties:

(1) Reproduce classical (Ehrenfest) dynamics

(2) Let no entanglement (quantum information) through!



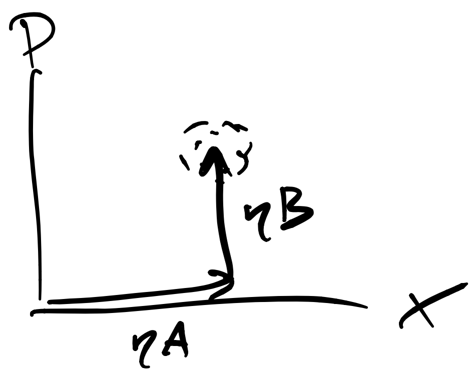
M. Wolf: the best adversary is the heterodyne channel

$V = g \hat{A}\hat{B}$

$\exp(i\eta x B)\exp(i\eta p A)$ (screen) $\exp(-i\eta x \hat{B})\exp(-i\eta p \hat{A})$

$\exp(-i\eta(x+\eta\hat{A})\hat{B})$

$\exp(-i\eta^2 \hat{A}\hat{B}) \longleftrightarrow \exp(-i\tau V)$



Simulator

$\rho_s \leftarrow$ classical

$G_{\mu\nu} = 8\pi \, \mathrm{Tr}[\hat{T}_{\mu\nu} \rho_s] \to g$

$\tilde{\rho}_s = U_g \rho_s U_g^\dagger$

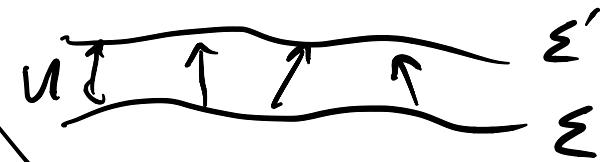
measurements $\{M_\alpha\}$

$\rho_s = m_\alpha \tilde{\rho}_s m_\alpha^\dagger$

Univ

$|\psi\rangle$

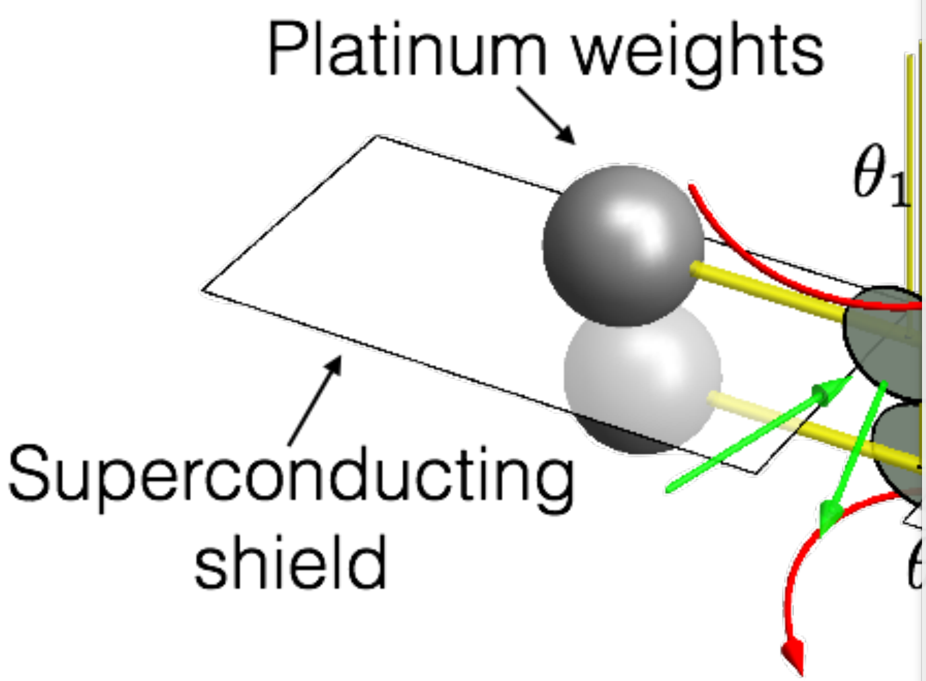
define $U_g(t+\delta t, t)$



$|\tilde{\psi}\rangle = U_g |\psi\rangle$

m_α $\quad |\psi\rangle \propto m_\alpha |\tilde{\psi}\rangle$

Testing entanglement generation via gravity: coupled Cavendish-style torsional oscillators



Procedure

(1) Verify *g* is due to gravity

(2) Estimate heating rate over 3000 s

(3) Repeat 10^7 times

Hard experiment *but* embarrassingly parallel

$$g \leq Gn/\omega \sim \frac{10^{-6}\mathrm{Hz}^2}{\omega}$$ => one phonon every 3,000 s

Thermal background at 10 mK ~ one phonon every 10 s

Testing the concept: NIST’s big-G apparatus

D. Carney, J. Stirling, C. Speake, S. Schlamminger