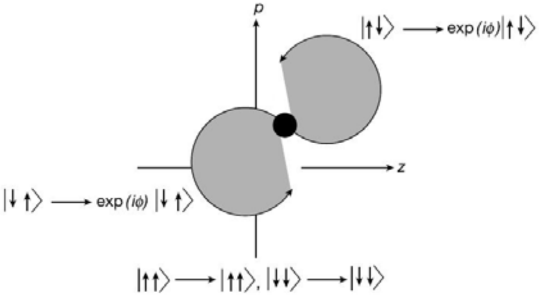
30.11.2009
QSIT lecture – student presentation

Geometric phase gate

D. Leibfried et al.

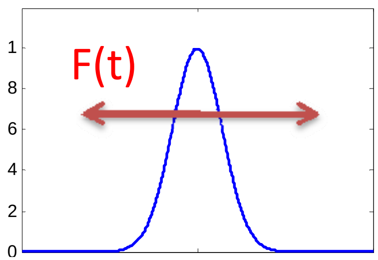
Nature **422**, 412 (2003)



Geometric phase

Apply a force F(t) to a harmonic oscillator in resonance with its frequency ω:

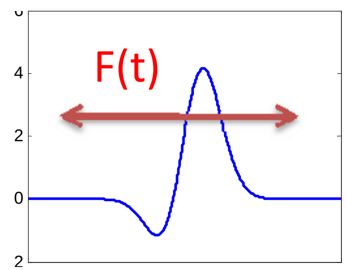
t = 0



$$|0\rangle$$

$$\langle E\rangle = \hbar\omega/2$$

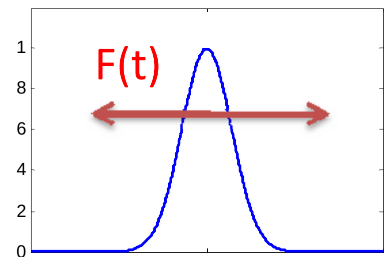
t > 0



$$\sum c_n |n\rangle$$

$$\langle E\rangle > \hbar\omega/2$$

t = T



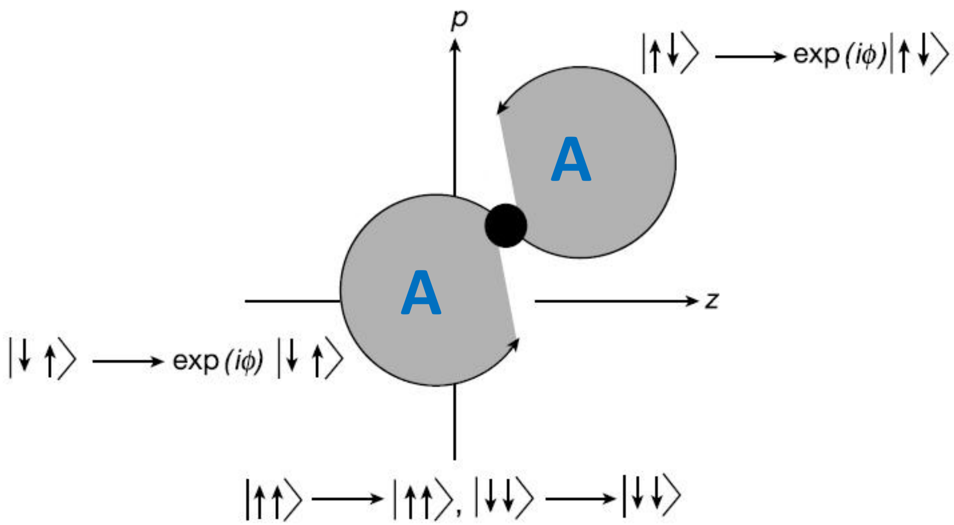
$$e^{i\phi}|0\rangle$$

$$\langle E\rangle = \hbar\omega/2$$

After time T, state oscillator returns to original state **up to phase ϕ**

Geometric phase

Oscillator state describes a **closed curve** in phase-space



Phase change proportional to area and independent of initial state: **ϕ=A/ħ**

A depends on the the **strength of F(t)**

Geometric phase gate

Goal: Gate changing the **relative phases** of two-qubit states

In the basis $|00\rangle, |10\rangle, |01\rangle, |11\rangle$:

$$\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & e^{i\pi/2} & 0 & 0 \\ 0 & 0 & e^{i\pi/2} & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

Here: Harmonic oscillator is the **stretch mode** of two trapped ions

Same state → no force

Ion A Ion B

Different state → differential force → phase

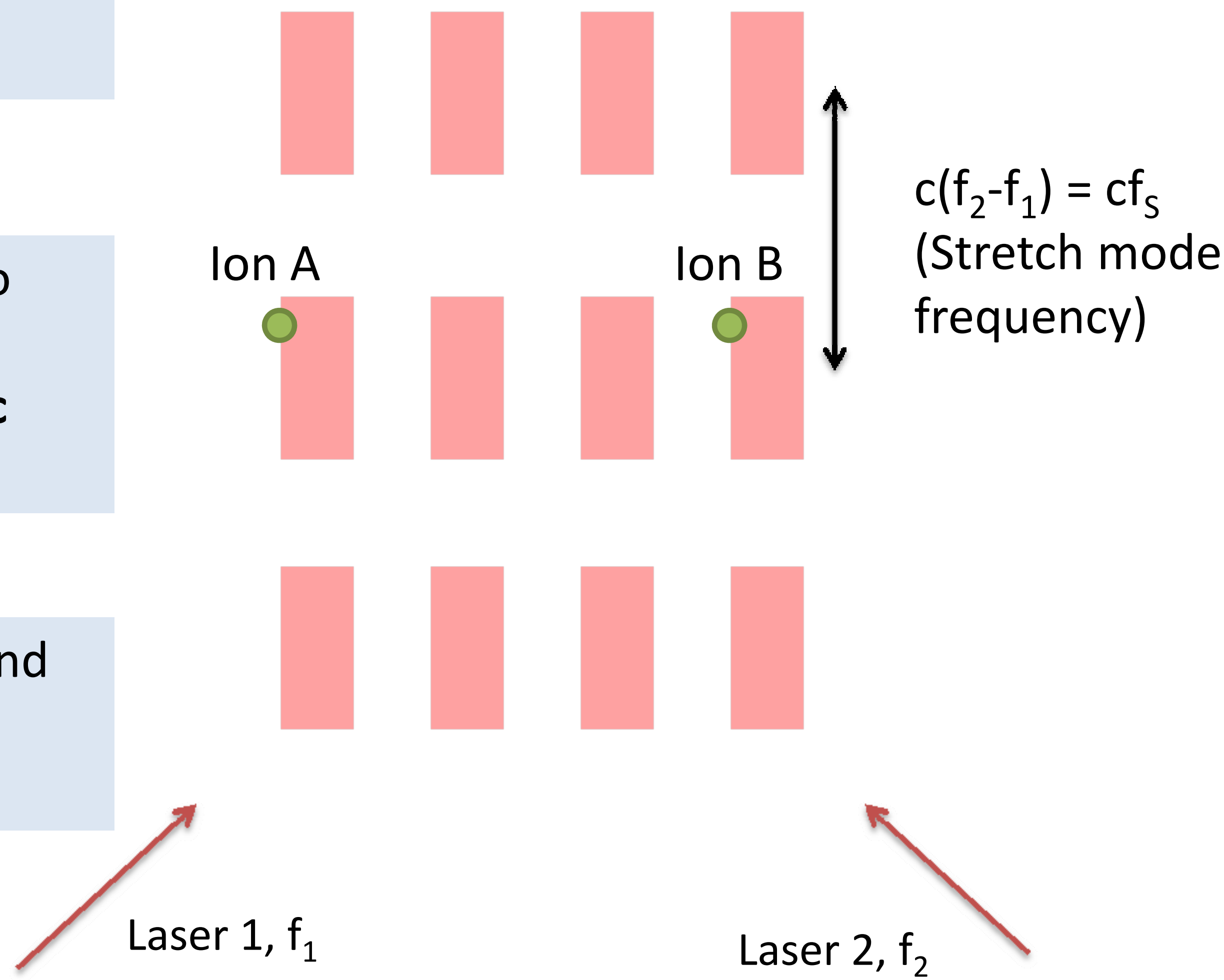
Ion A Ion B

Experimental principle

Qbit states: Two $^2S_{1/2}$ **hyperfine states**

Lasers are tuned close to the $^2S_{1/2} \leftrightarrow {}^2P_{1/2}$ dipole transition – generates **ac Stark shift** (= force)

Fine-tune **laser power** and **pulse length** to achieve $\phi = \pi/2$

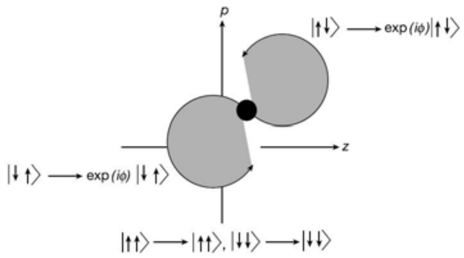


Comparison to Cirac-Zoller

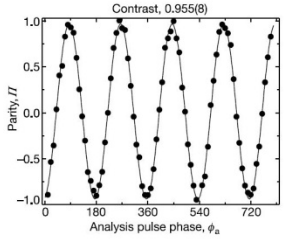
Cirac-Zoller gate	Geometric phase gate
Single-ion addressing (i.e., laser deflection) is necessary	Ions are addressed simultaneously, laser beam is fixed in space
Phase stability of the laser is very crucial	Gate phase ϕ is not directly linked to laser phase
Oscillator has to be in the ground state (it represents an auxiliary qubit state)	Gate phase ϕ is independent of initial oscillator state

Conclusions

Geometric phase gate is attractive as universal gate



Already first experimental demonstration very successful (fidelity 97%)



Room, and ideas, for improving gate performance