Integrated entangling quantum logic gate in a scalable surface-electrode ion trap

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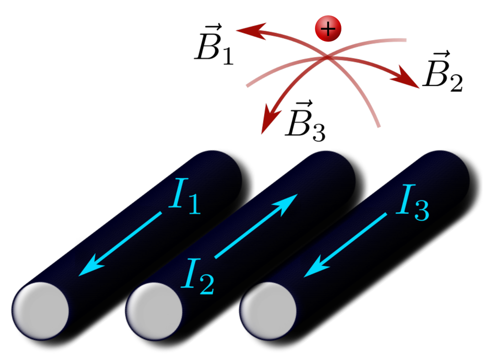
CRC1227 DQ-mat Designed Quantum States of Matter

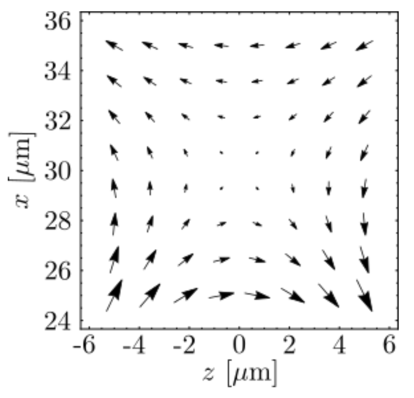
Microwave near-field approach

Goal
- High-fidelity universal gate set by using microwave fields only

Requirements
- Drive carrier and sideband transitions

Advantages
- No spontaneous emission
- Less hardware required
- Potentially better scalability

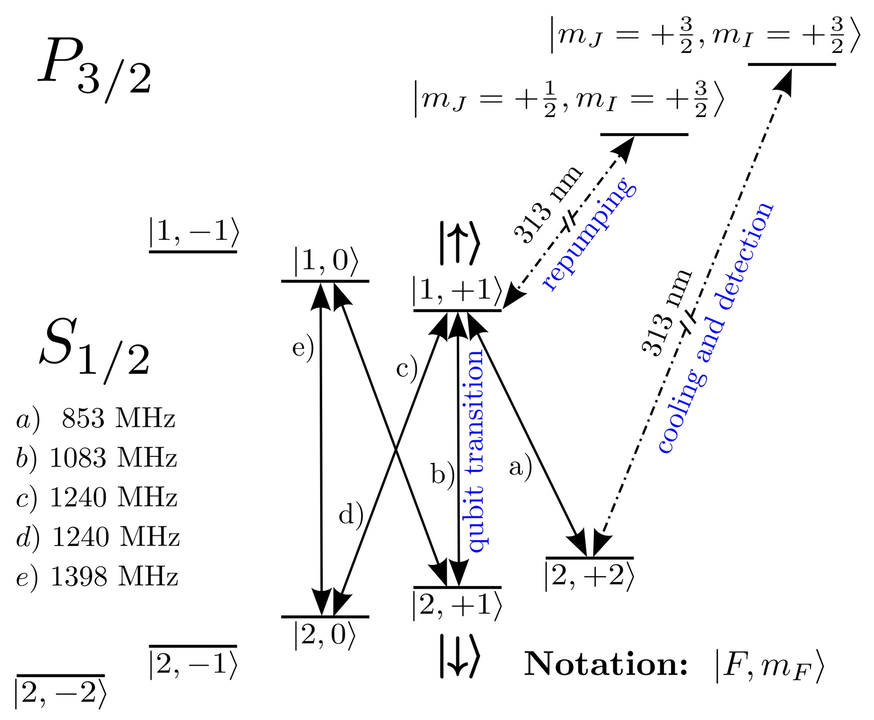




carrier	sidebands
$\Omega_C \propto \tilde{B}\ \langle\downarrow\vert\mu_m\vert\uparrow\rangle$ (driven by field)	$\Omega_{SB} \propto x_{wp}\ \tilde{B}'\ \langle\downarrow\vert\mu_m\vert\uparrow\rangle$ (driven by gradient)[1,2]

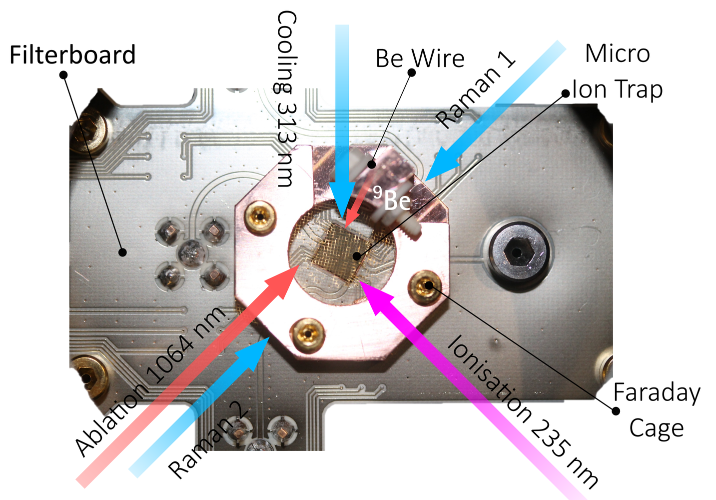
Experimental setup

Atomic transitions of $^9Be^+$



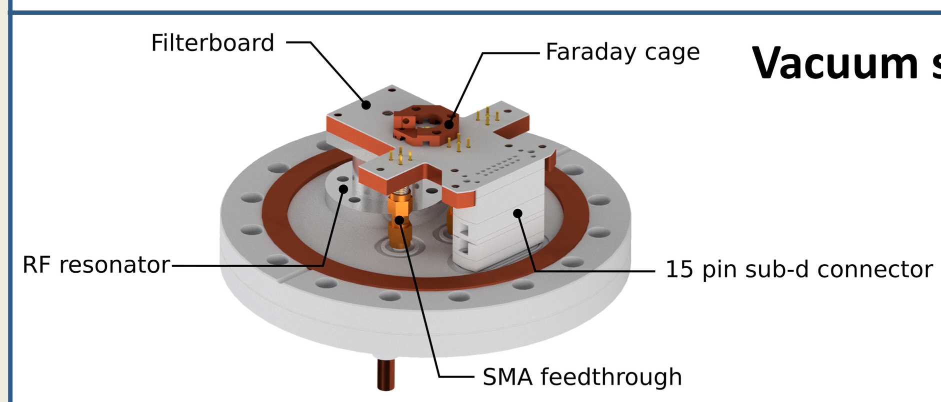
- Qubit to 1st order magnetic-field indep. at B_0=22.3 mT

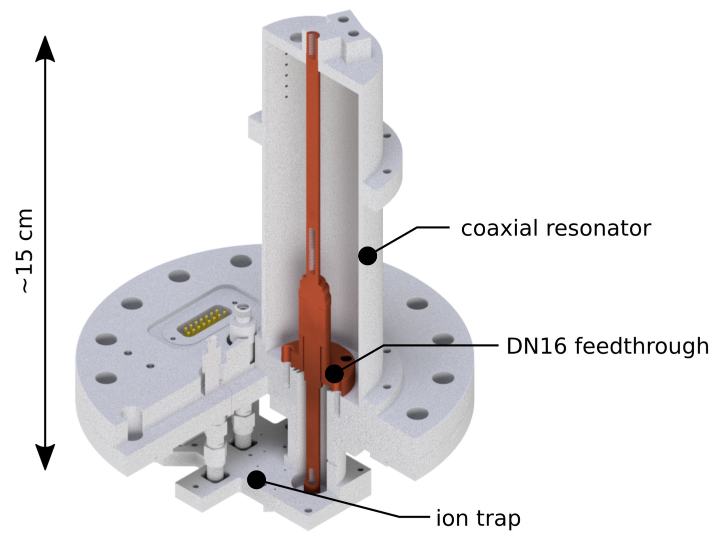
Beam configuration



- Efficient photoionisation loading from ablation plume caused by pulsed laser
- Minimal charging by reduced 235 nm exposure of surfaces

Vacuum system

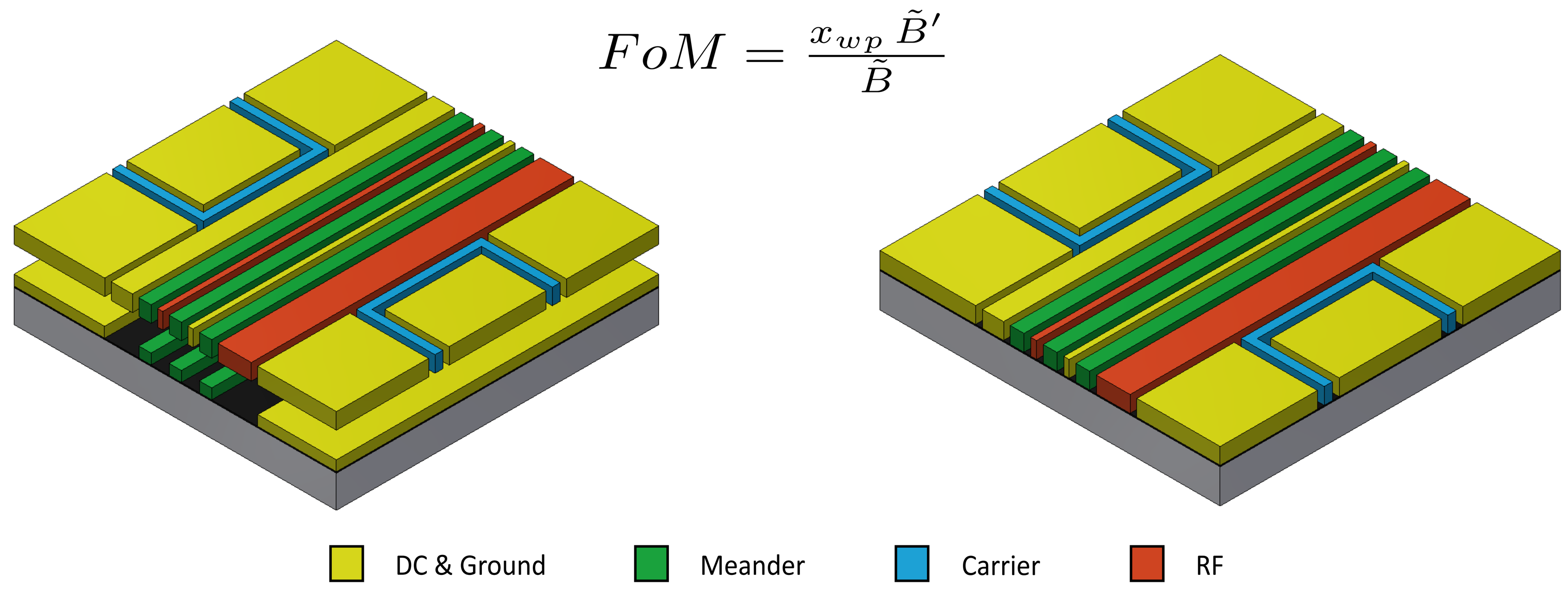




- Modular air and in-vacuum coaxial resonator
- Easy tuning of drive frequency 80-200 MHz
- Permanent magnets (long-coherence times) > 0.5 s

Ion trap designs

$$FoM = \frac{x_{wp}\tilde{B}'}{\tilde{B}}$$

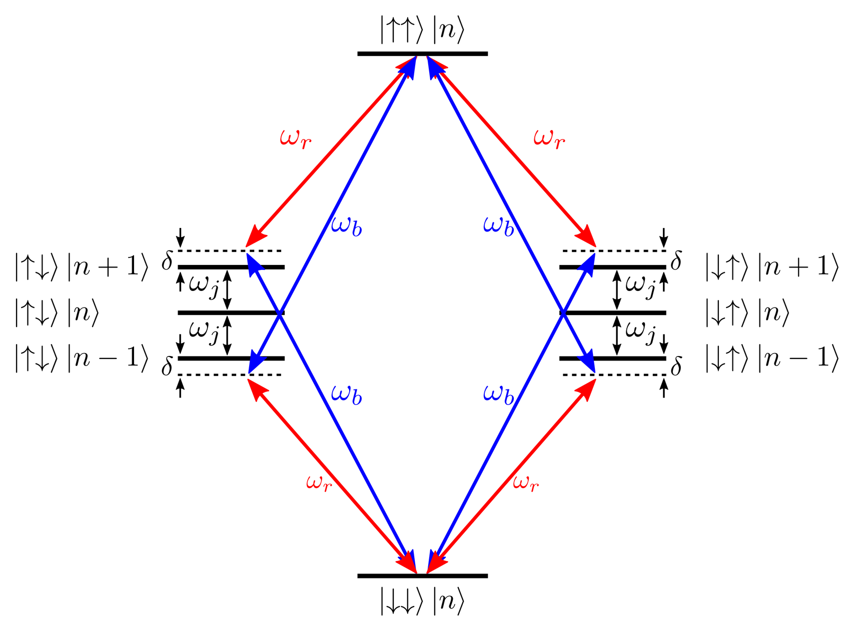


Multilayer design features[4,5]
- Substrate: Si/SiN
- Ion-electrode distance: 35 µm
- 10 DC electrodes
- 2 carrier electrodes
- Figure of Merit: > 0.3
- RF electrode length: 1.6 mm
- Carrier coupling: -28 dB

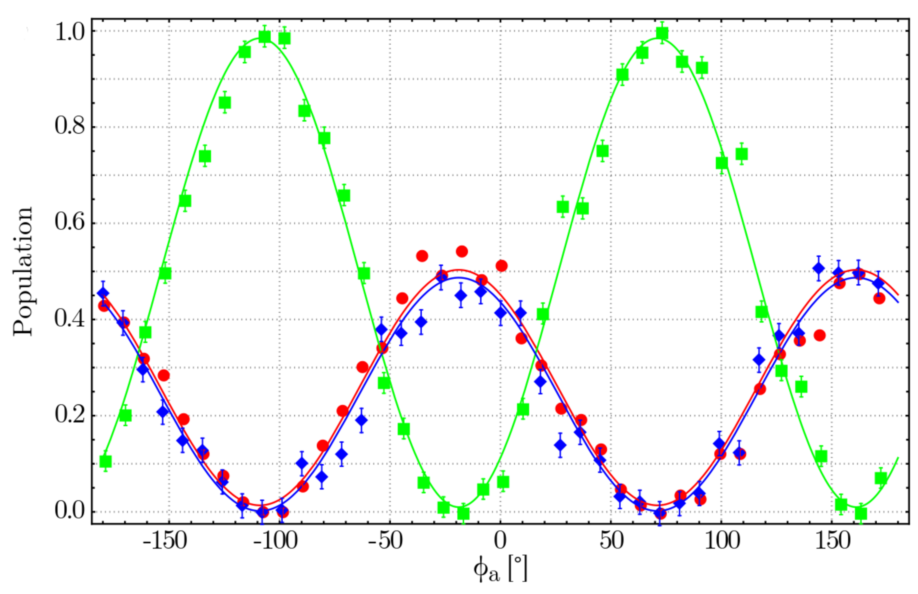
Single layer design features
- Substrate: AlN
- Ion-electrode distance: 70 µm
- 10 DC electrodes
- 2 carrier electrodes
- Figure of Merit: 0.005
- RF electrode length: 1.45 mm
- Carrier coupling: -19 dB

Classical Mølmer-Sørensen

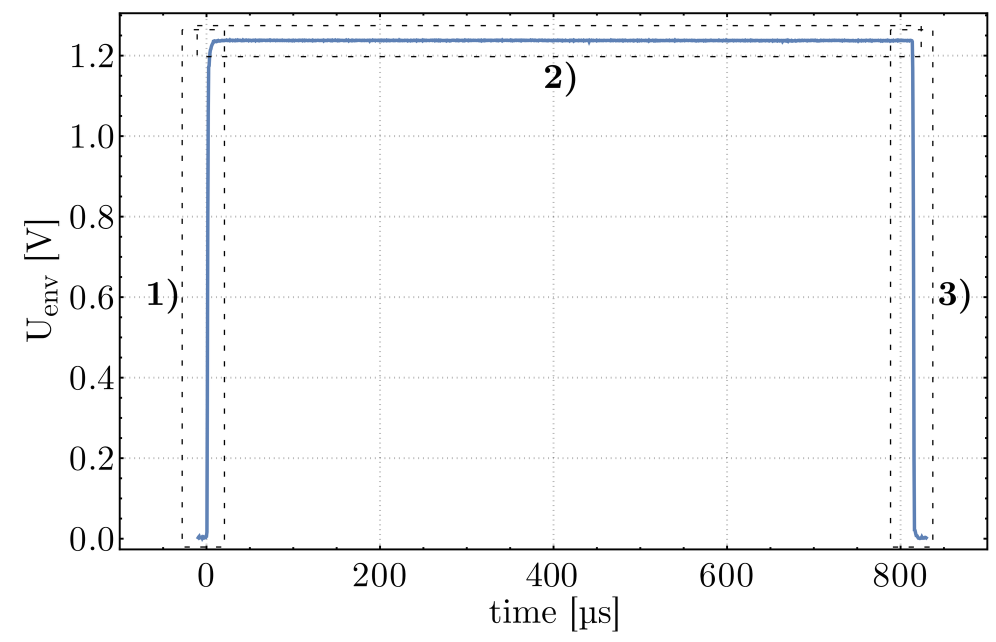
- Mølmer-Sørensen gate scheme

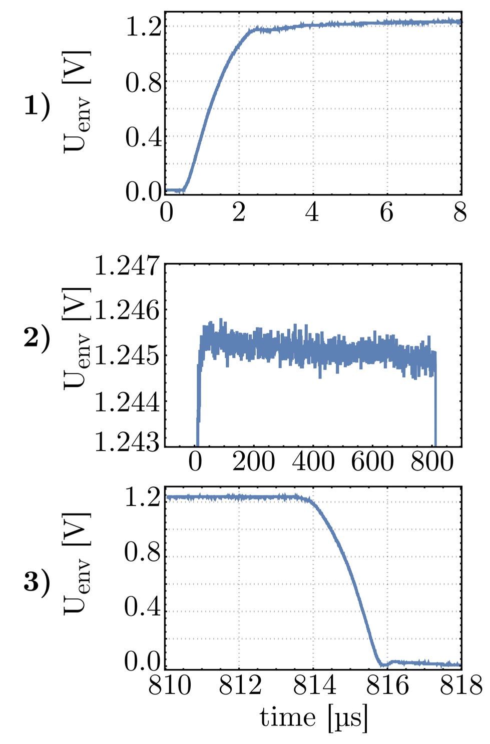


Entangling gate [3]: F=98.2(1.2)%



- Microwave amplitude is stabilized to obtain a square pulse

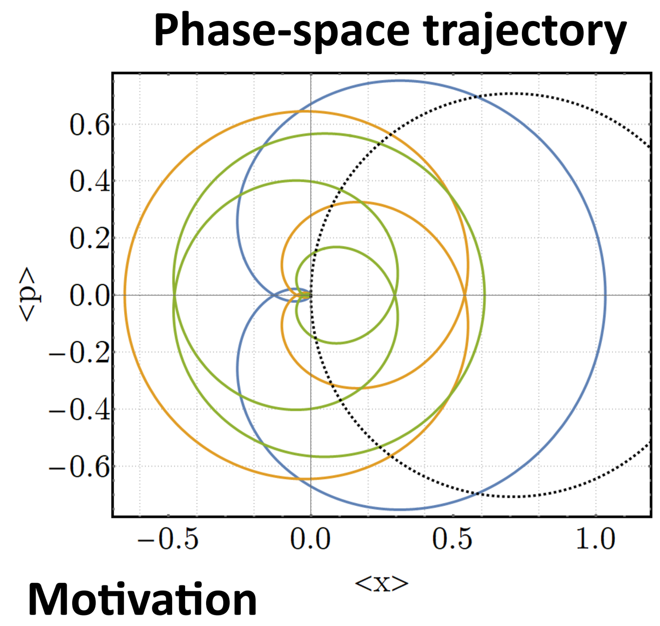




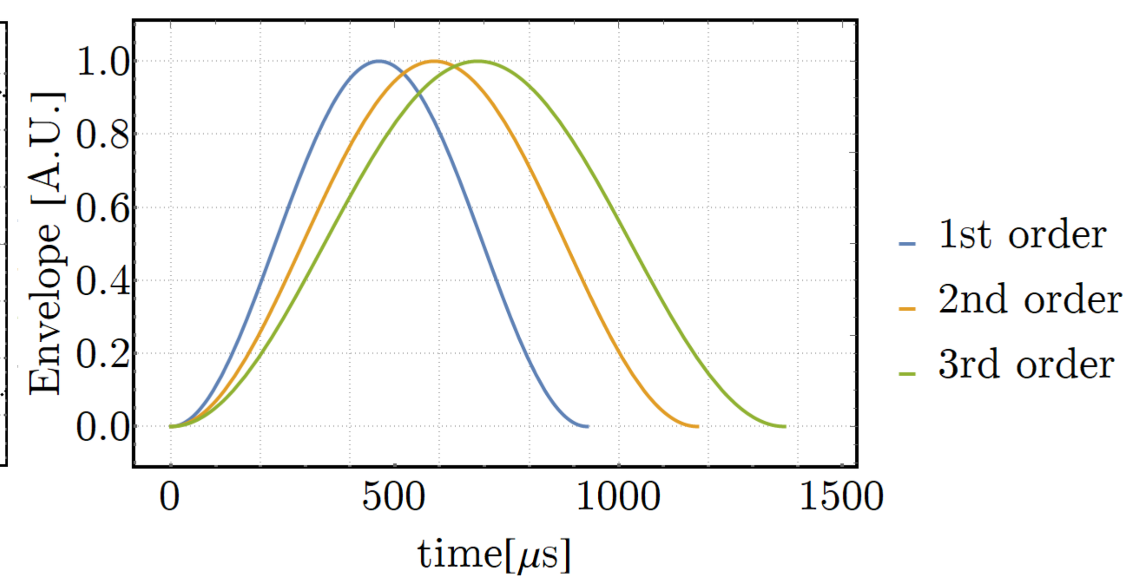
Error budget:
- Motional instability: 1.3%
- Spectator modes: 0.5%
- Heating rate: 0.4%
- Decoherence: <0.1%
- Off-resonant carr. exc. : <0.1%
- Microwave pulse shape : <0.1%

Amplitude-Modulation

Phase-space trajectory



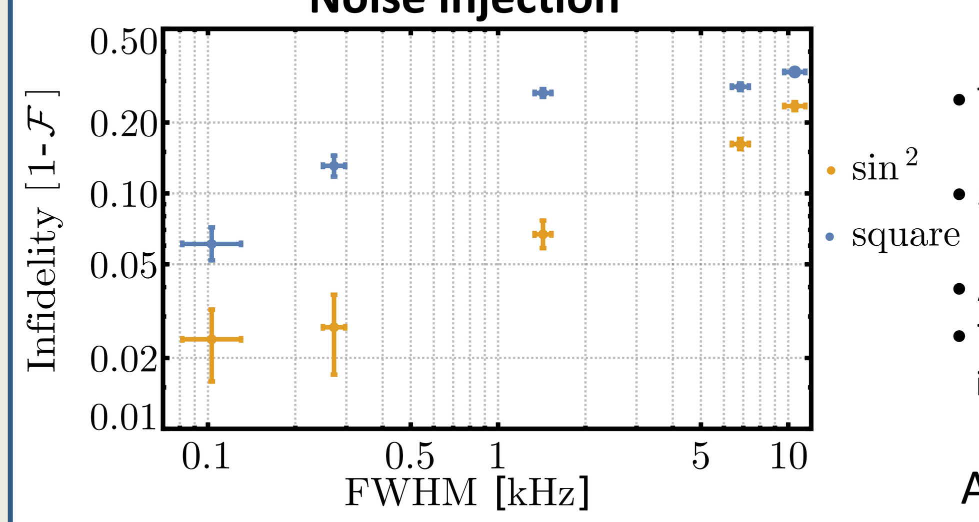
Sin^2 modulation



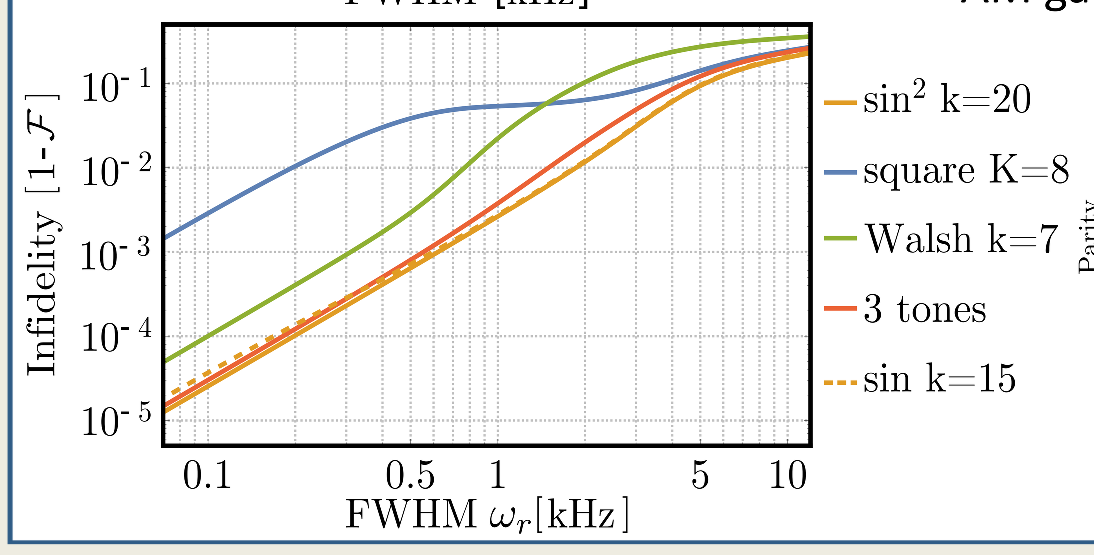
Motivation

Amplitude modulation open the possibility to change the classical circular trajectory in phase space
- Specific trajectories can be more resistant against residual spin-motion entanglement
- Provides insensitivity against motional mode fluctuations
- Dissipates less energy in the trap microstructures

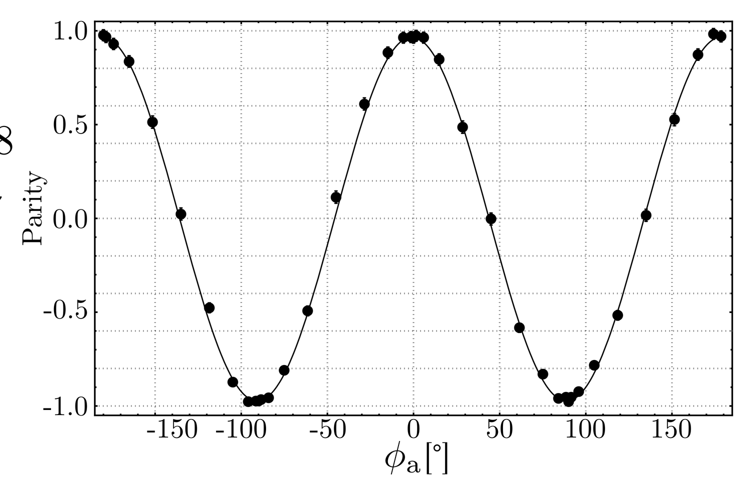
Noise injection



Gate scheme comparison
- To demonstrate resilience we artificially inject noise in the pseudopotential which affects the radial modes
- sin^2 modulation of 17th order vs 7 loop square pulse chosen because they dissipate the same energy
- All measurements are SPAM corrected
- Theoretical comparison of different schemes shows improvement of about two orders of magnitude



AM gate with 17th order [9]: F=99.7(1)%



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[9] G. Zarantonello *et al.*, PRL 123, 260503 (2019)

Outlook

Future plans
- Characterization of the in situ Ar+ cleaning [6]
- Include dynamical decoupling schemes and perform randomized benchmarking.
- Develop next generation multilayer trap system [7,8]

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