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Adiabatically-controlled two-qubit gates using quantum dot hybrid qubits

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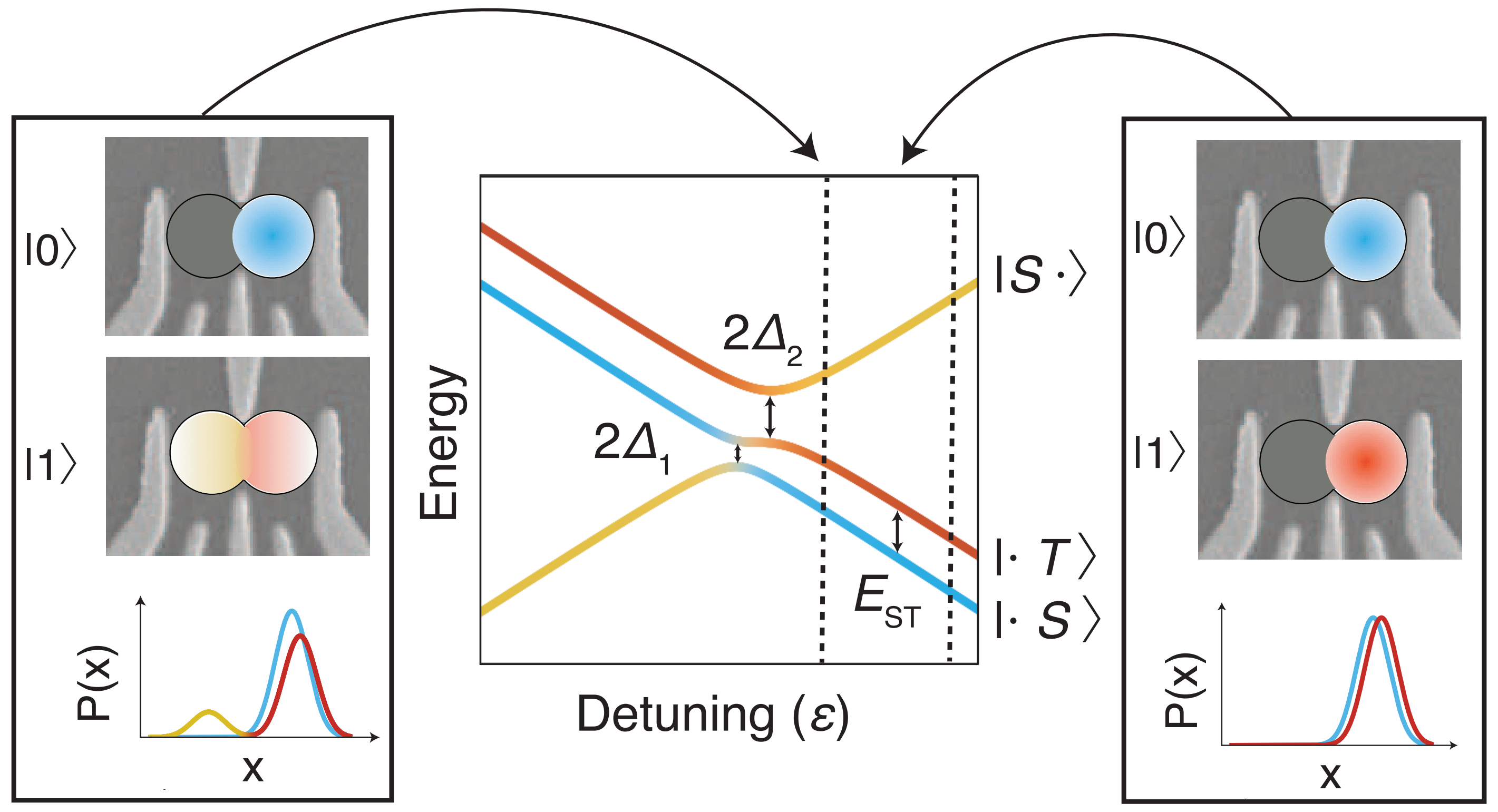
MOTIVATIONS

- Capacitive coupling is an intuitive choice of mechanism for entanglement between electrically-controlled semiconductor-based quantum bits.[1]
- Quantum Dot Hybrid Qubits (QDHQs) have the attractive feature that the effective coupling between qubit pairs are highly tunable, so that the long-range nature of electrostatic couplings does not lead to unwanted interqubit interactions.
- While the pulse sequences proposed here require less experimental overhead to implement than quickly varying pulses, it is conceivable that they would be more susceptible to charge noise, an inherently fast process.

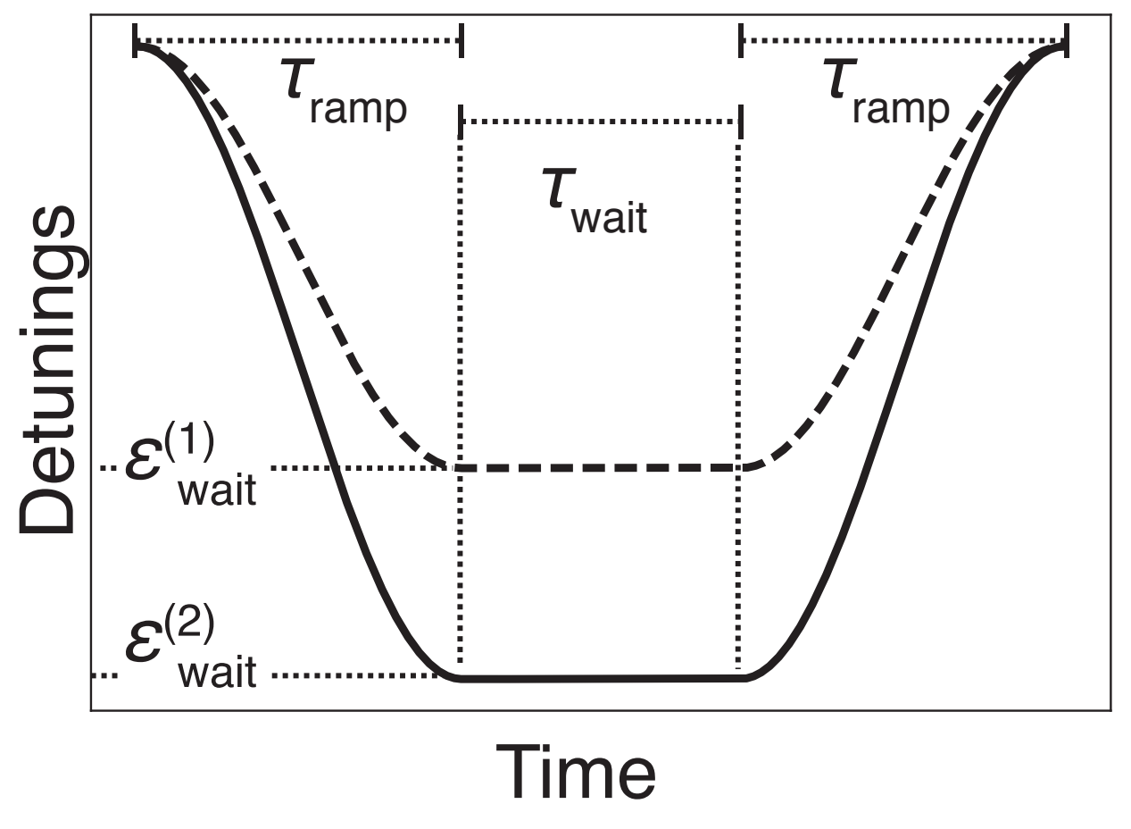
CAPACITIVELY COUPLED QDHQs

The dynamic charge character of the QDHQ leads to a tunable coupling between qubits, which can be leveraged into a CZ gate.



The dispersion of a single QDHQ as a function of the detuning ε. In the far detuned regime (right-most dashed line in center plot), the ground state is approximately $|\cdot S\rangle$, indicated in the schematics in blue, and the first excited state is approximately $|\cdot T\rangle$, indicated in the schematics in red. Closer to the charge transition point (left-most dashed line in center plot), the first excited state begins to mix with the $|S\cdot\rangle$ state, indicated in the schematics in yellow.

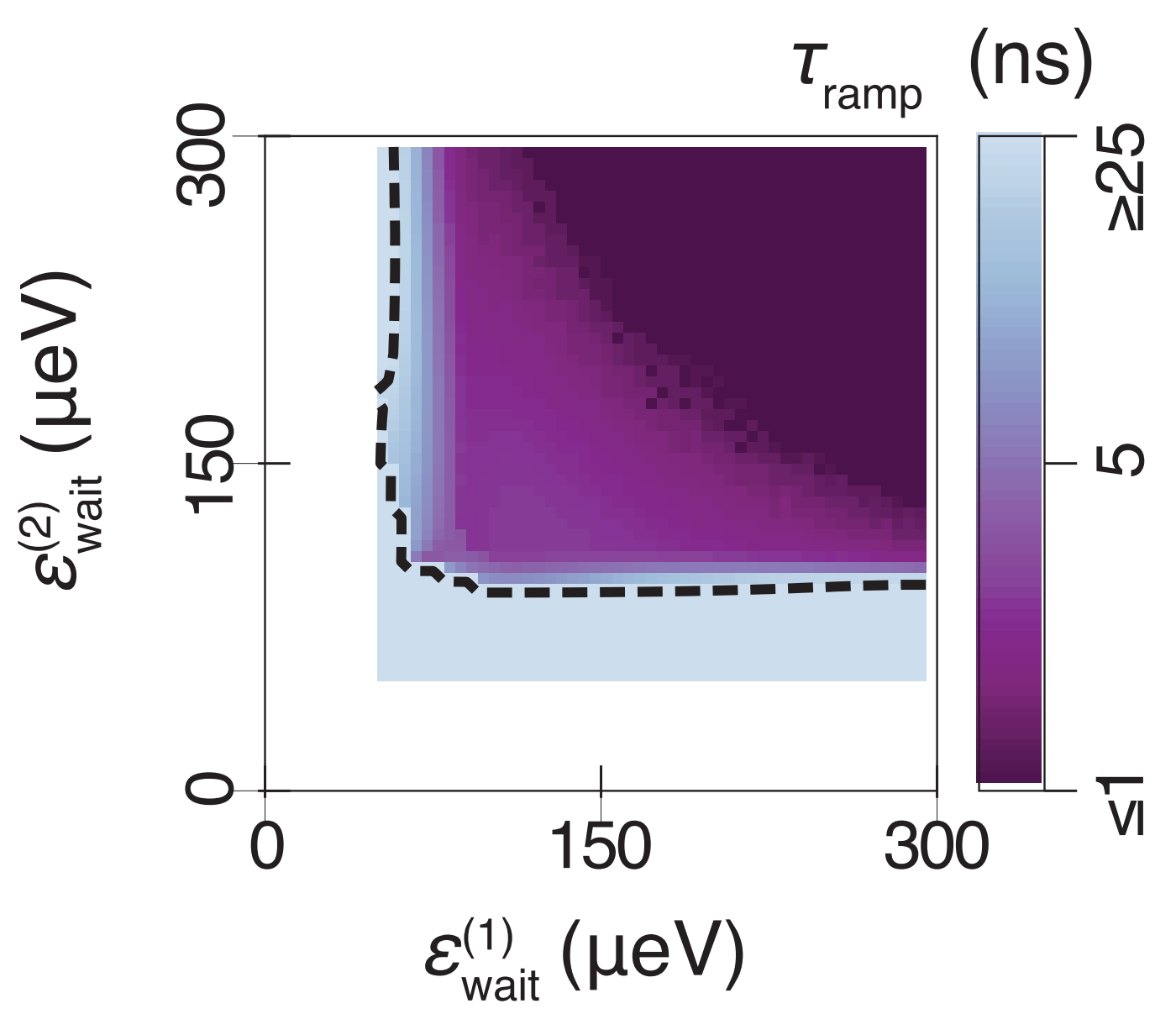
Schematic of pulse sequence on the detuning of qubit 1 ($\varepsilon^{(1)}$, dashed line) and the detuning of qubit 2 ($\varepsilon^{(2)}$, solid line). $\varepsilon^{(1)}$ and $\varepsilon^{(2)}$ begin at a large detuning and are lowered to $\varepsilon^{(1)}_{\mathrm{wait}}$ and $\varepsilon^{(2)}_{\mathrm{wait}}$ respectively over a time τ_{ramp}. The detunings are held at these values for a time τ_{wait}, and are then raised back to their starting values over a time τ_{ramp}.

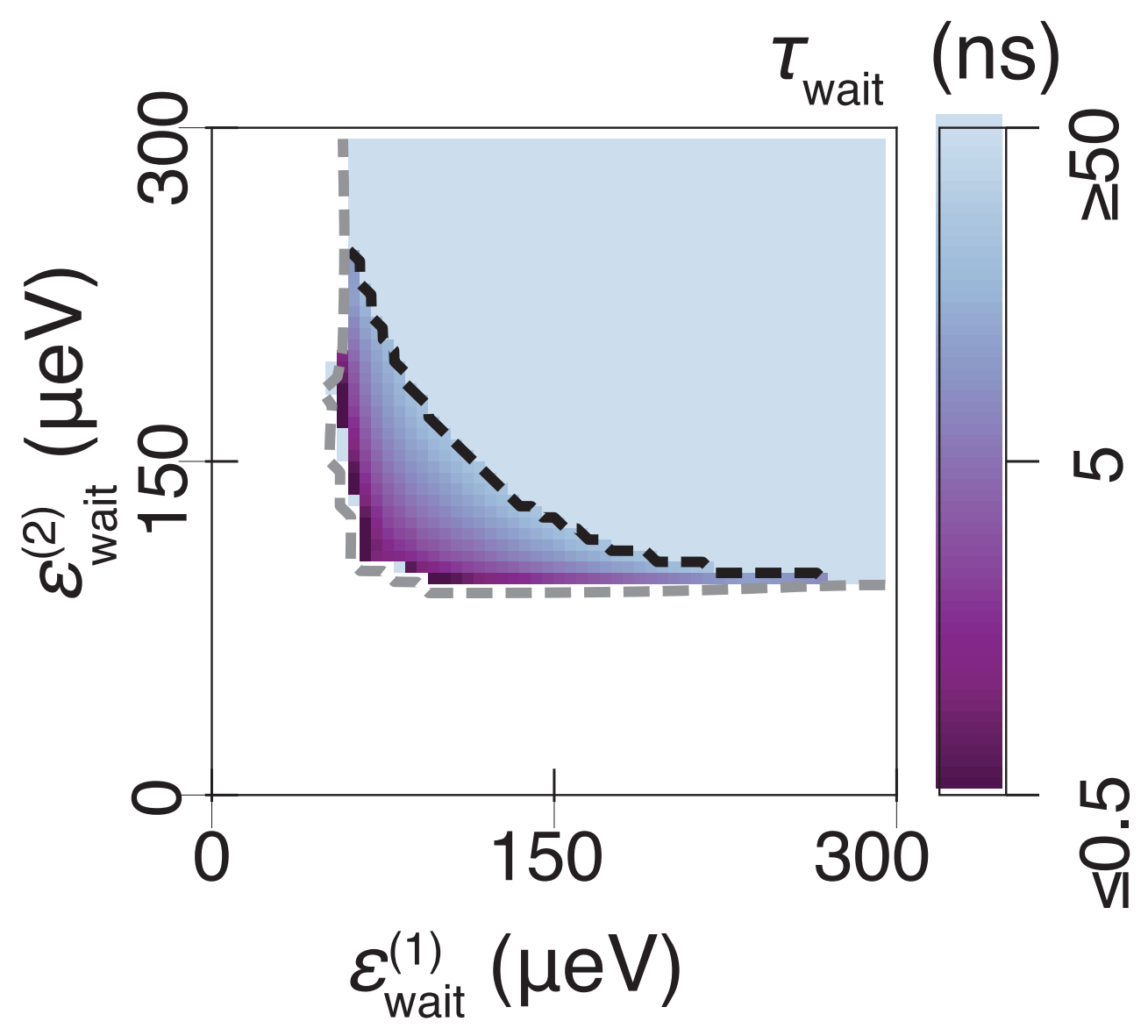


OPTIMIZING TWO-QUBIT PULSES

To find the pulse sequence that yields the highest fidelity CZ gate, we must explore the parameter space spanned by $\varepsilon^{(1)}_{\mathrm{wait}}$, $\varepsilon^{(2)}_{\mathrm{wait}}$, τ_{ramp}, and τ_{wait}. To estimate the fidelity of these gates, we will be assuming uncorrelated quasistatic charge noise on both detunings. We will be limiting the total gate time to 50 ns, ensuring that entangling gates can be performed on a timescale comparable to single-qubit gates in these systems[2].

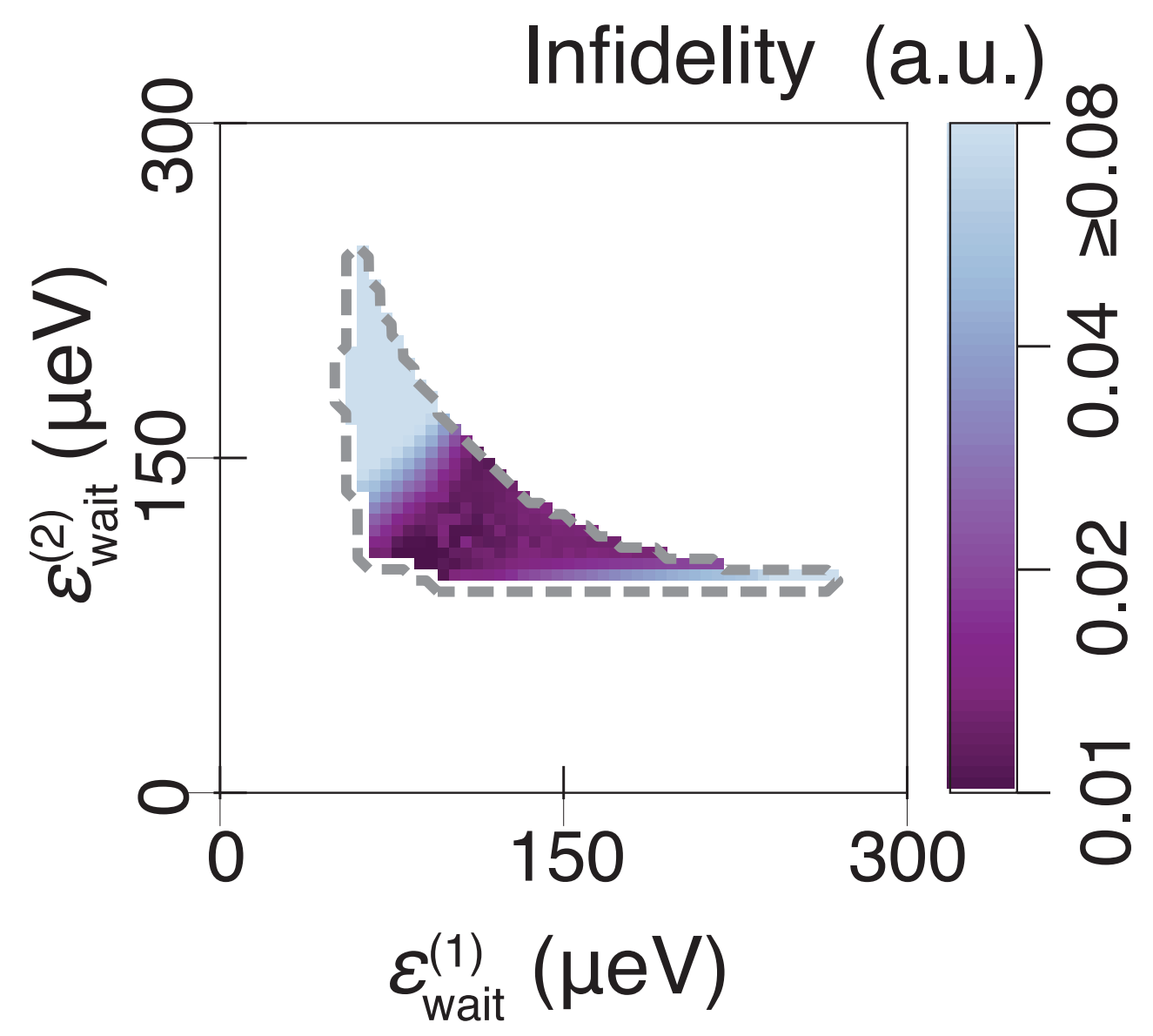
The smallest τ_{ramp} that is still consistent with the adiabaticity criterion, defined as adiabatically pulsing $\varepsilon^{(1)}$ and $\varepsilon^{(2)}$ from 500 μeV to $\varepsilon^{(1)}_{\mathrm{wait}}$ and $\varepsilon^{(2)}_{\mathrm{wait}}$, respectively. Pairs of $\varepsilon^{(1)}_{\mathrm{wait}}$ and $\varepsilon^{(2)}_{\mathrm{wait}}$ with $\tau_{\mathrm{ramp}} \geq 25$ ns (points under dashed black line) are omitted from further steps in the analysis.

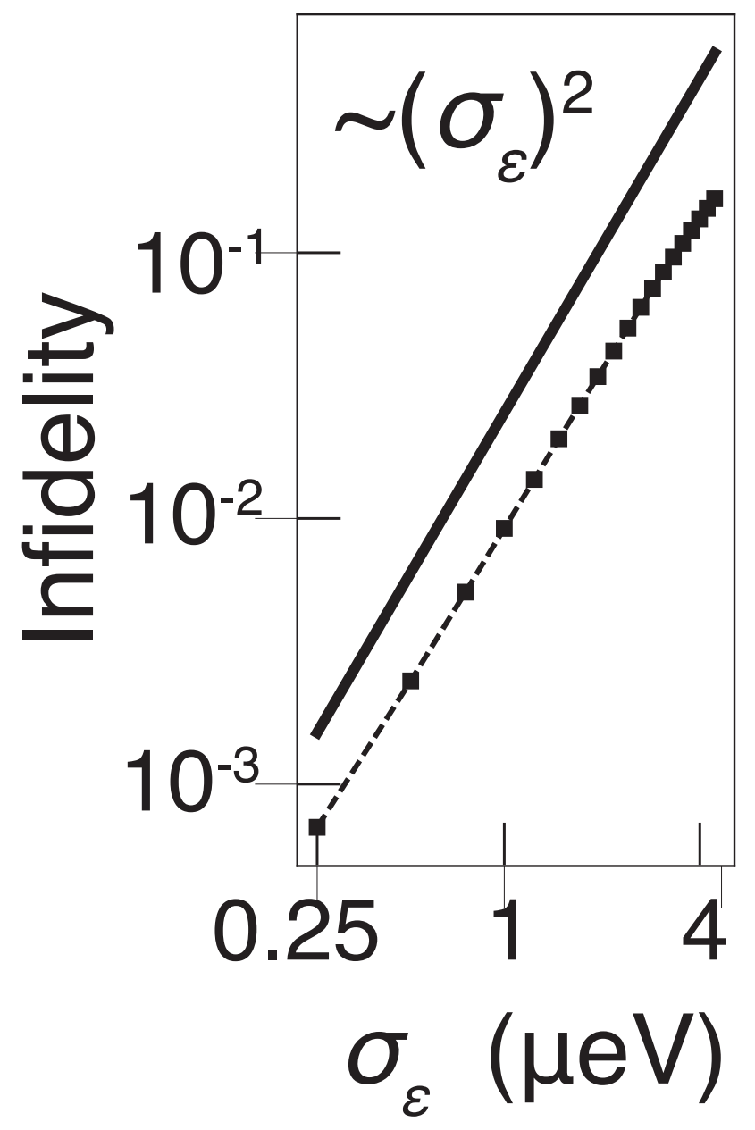




For each pair of $\varepsilon^{(1)}_{\mathrm{wait}}$ and $\varepsilon^{(2)}_{\mathrm{wait}}$ the gate fidelity is optimized over possible values of τ_{wait}, using the associated fastest τ_{ramp}, found above. Pairs with $\tau_{\mathrm{ramp}} \geq 25$ ns (points under dashed gray line) are neglected, and pairs with $\tau_{\mathrm{total}} = 2\tau_{\mathrm{ramp}} + \tau_{\mathrm{wait}} \geq 50$ ns (points above dashed black line) are omitted from further steps in the analysis.

The process infidelity of pulse sequences with optimal τ_{ramp} and τ_{wait}, here assuming quasistatic charge noise with a standard deviation of $\sigma_\varepsilon = 1$ μeV. Pulse sequences longer than 50 ns ($\tau_{\mathrm{total}} \geq 50$ ns, outside gray dashed shape) are neglected.

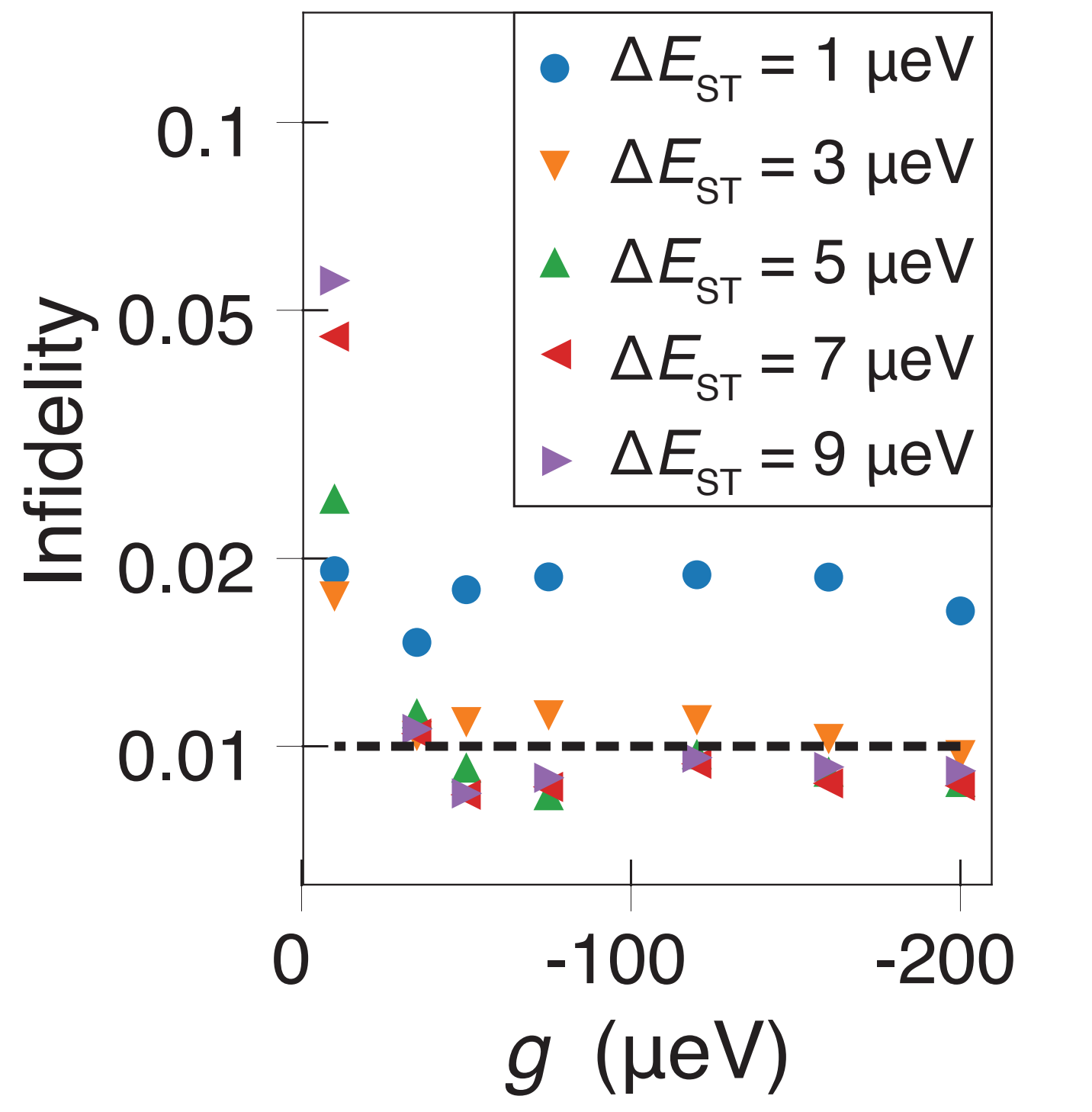


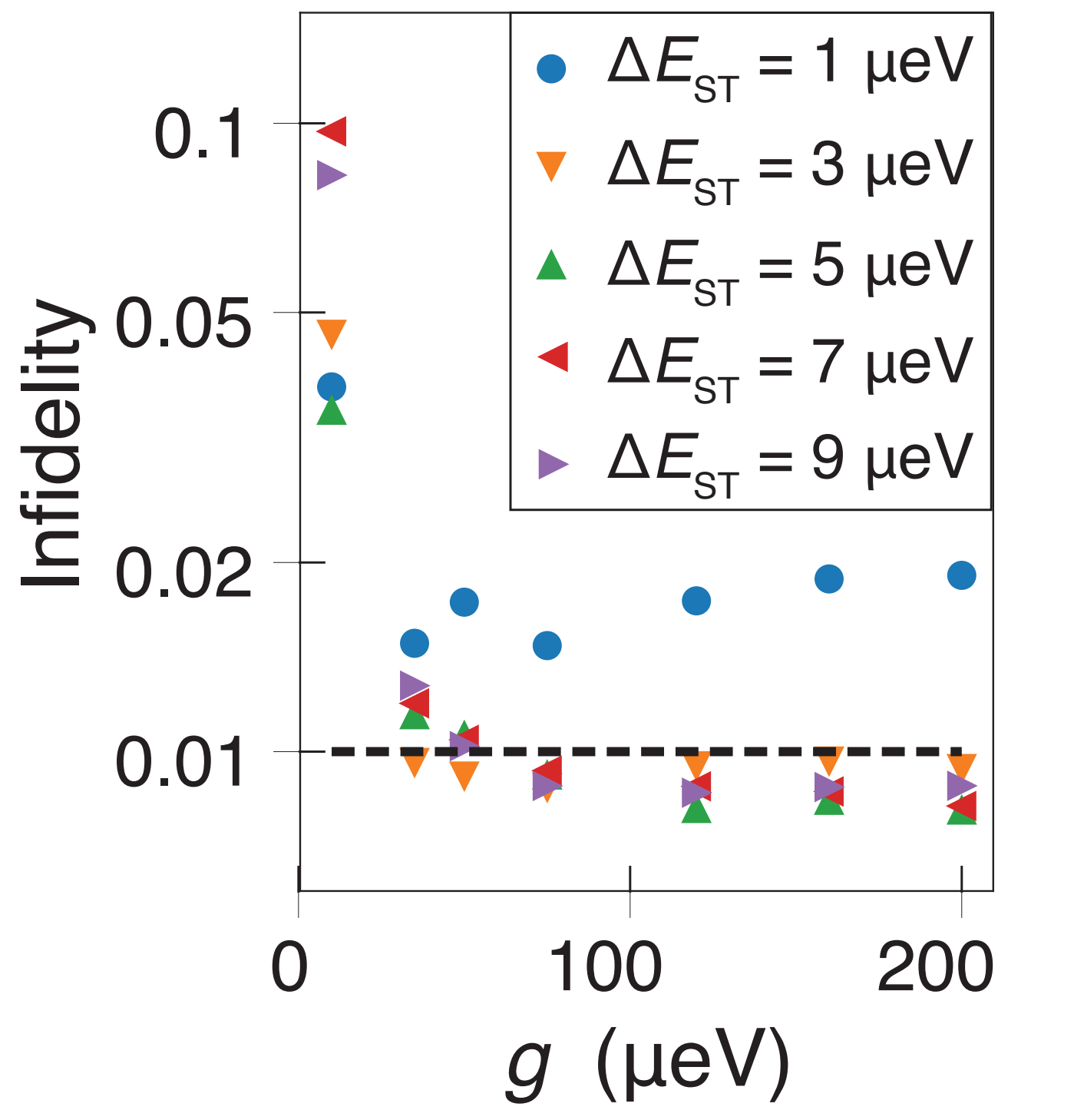


Minimum entangling gate infidelity (black squares connected with dashed black line) plotted as a function of charge noise standard deviation (σ_ε). The infidelity falls off as roughly $\sim(\sigma_\varepsilon)^2$ solid black line.

VARYING SYSTEM PARAMETERS

In the analysis presented in the section "*optimizing two-qubit pulses*", g was chosen to be +75 μeV, as this was an experimentally measured value[3]. However, capacitive couplings as large as 200 μeV have been measured as well[4]. Additionally, by switching the orientation of the QDHQs relative to each other can also result in g switching sign, which affects the effective coupling. Here we perform the same pulse optimization as before for multiple values of the coupling g, positive and negative. We additionally vary $\Delta E_{ST} = E_{ST}^{(1)} - E_{ST}^{(2)}$, keeping $E_{ST}^{(1)}$ fixed at 52 μeV.





METHODS

To calculate the process fidelity in the absence of charge noise, we first found the unitary evolution U_0 associated with a pulse sequence by performing a numerical integration. The ideal unitary U_{ideal} was then constructed as

$$U_{\mathrm{ideal}} = Z_1(\varphi_1)Z_2(\varphi_2)CZ$$

where φ_1 and φ_2 were the single qubit phase accumulations in U_0. Using the Choi-Jamiolkowski representation[5] for the process $\boldsymbol{E}(\rho)$, we calculated the process matrices χ_{actual} and χ_{ideal}, from which we found the process fidelity

$$\boldsymbol{F} = \mathrm{Tr}(\chi_{\mathrm{ideal}}\chi_{\mathrm{actual}}).$$

The fidelities were calculated for a range of possible values of quasistatic charge noise, and the average was taken over a two-dimensional Gaussian distribution with a standard deviation σ_ε. For more details, see:

http://arxiv.org/abs/ARXIVLINK.

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