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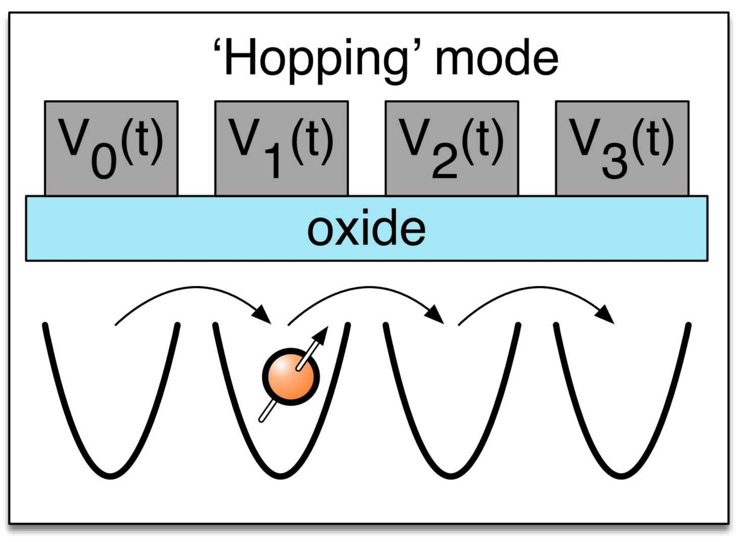
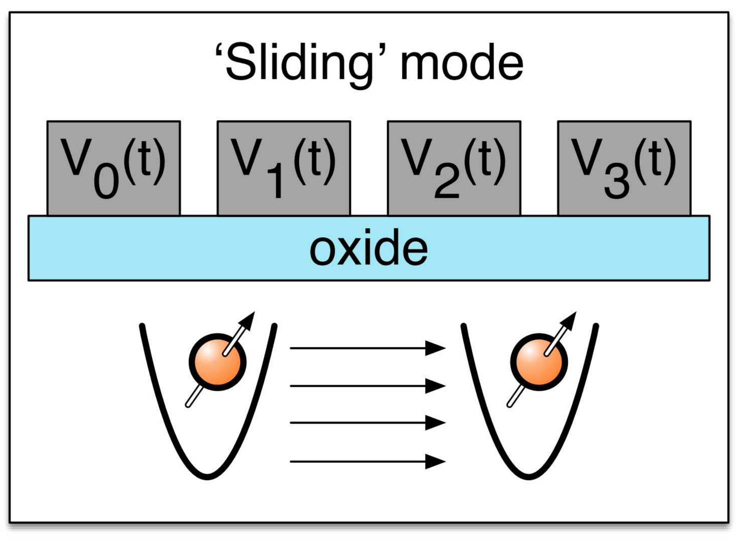
Designing a flying qubit at a silicon interface

Sandia National Laboratories
John King Gamble, N. Tobias Jacobson, Andrew D. Baczewski, Malcolm S. Carroll
Center for Computing Research, Sandia National Laboratories, New Mexico 87185

Problem description

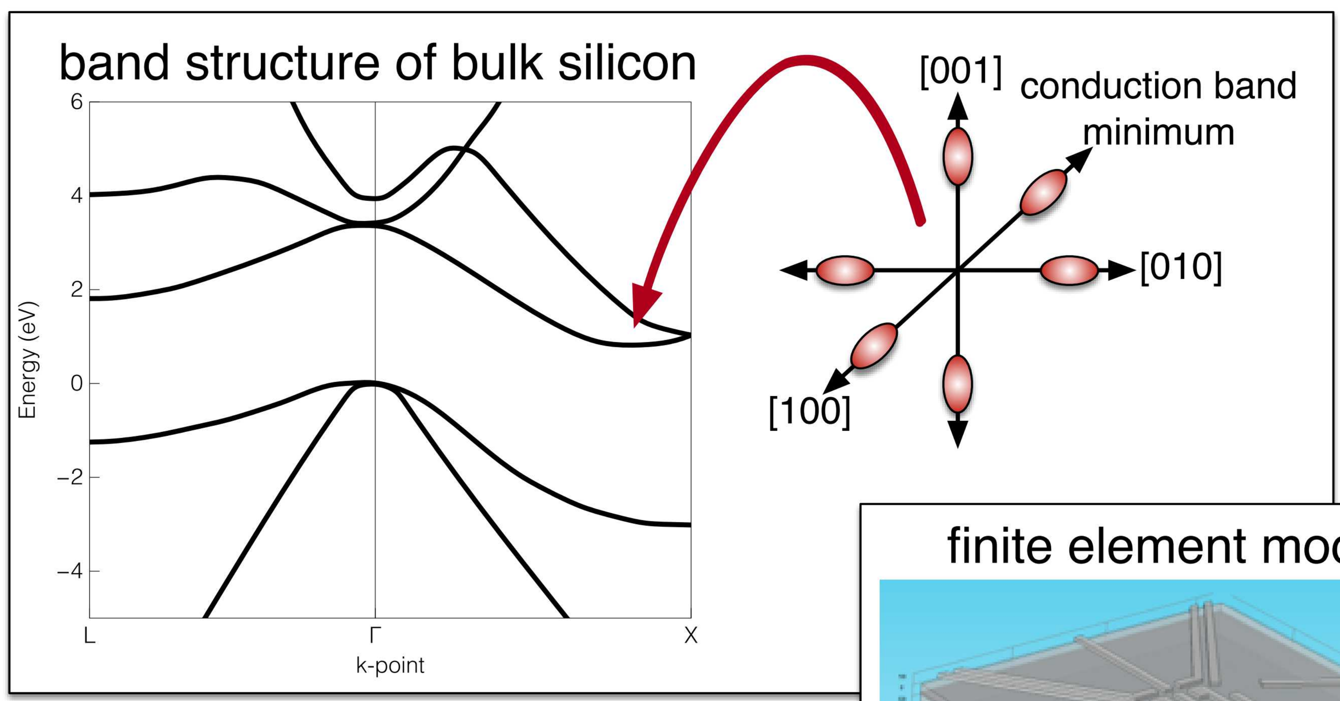


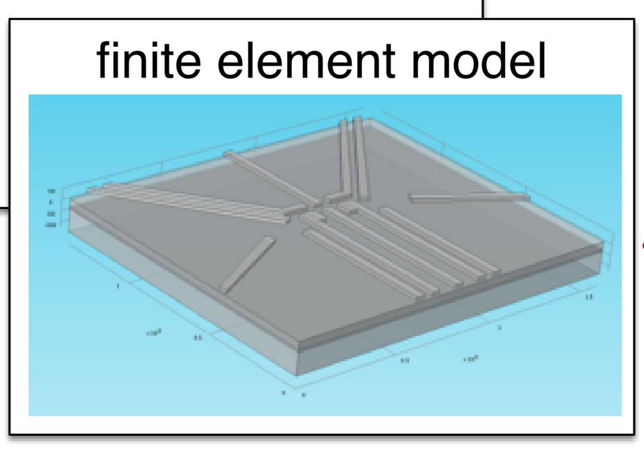


- Transporting semiconducting qubits is challenging, since most schemes are intrinsically spatially fixed.
- Possible solutions include spin buses [1], CTAP [2], cavity coupling [3], direct exchange [4], and capacitive coupling [5].
- Single-electron CCD is a possible solution [6,7], and has recently been demonstrated in quantum dots in GaAs [8].
- Applying this scheme to low-temperature silicon quantum dots poses a challenge due to low-lying valley states and larger effective mass.
- We study transport fidelity and disorder robustness as a function of geometric parameters.

Theoretical approach

- We use a non-perturbative multi-valley effective mass theory to accurately and efficiently capture the physics of quantum dots.

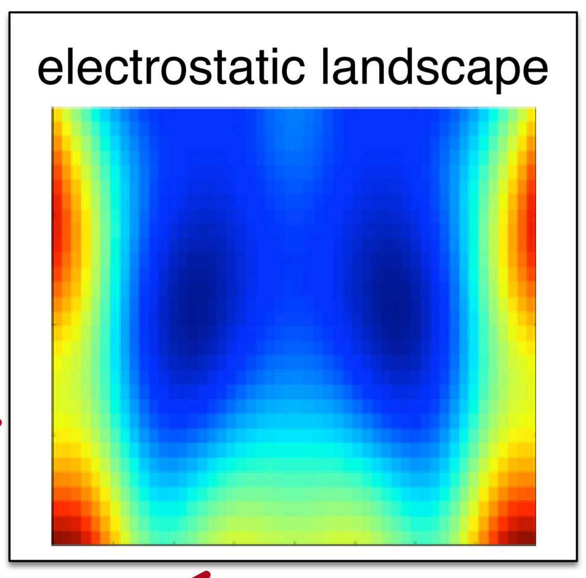




- The wave function is indexed by conduction band valley:

$$\psi(\mathbf{r}) = \sum_j F_j(r) e^{i\mathbf{k}_0^j\cdot\mathbf{r}} u_{\mathbf{k}_0^j}(\mathbf{r})$$

$$u_{\mathbf{k}_0^j}(\mathbf{r}) = \sum_{\mathbf{G}} A_{j,\mathbf{G}} e^{i\mathbf{G}\cdot\mathbf{r}}$$

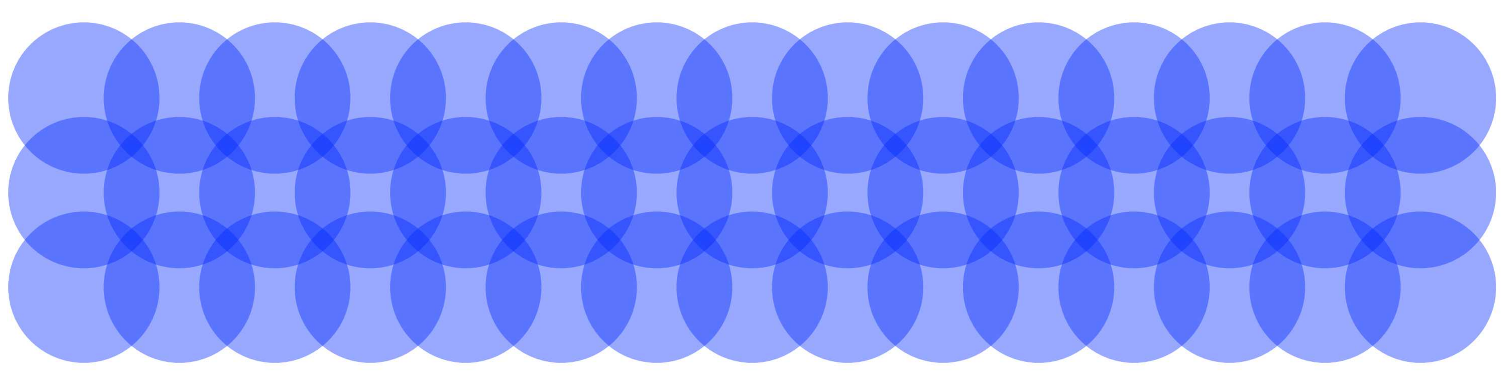


- To solve for eigenstates and energies, we need to solve a coupled system of Schrödinger-like equations, which include the valley orbit coupling:

$$EF_l(\mathbf{r}) = \left(\hat{T}_l + U(\mathbf{r})\right) F_l(\mathbf{r}) + \sum_j V_{lj}^{VO}(\mathbf{r}) F_j(\mathbf{r})$$

$$V_{lj}^{VO}(\mathbf{r}) = \sum_{\mathbf{G},\mathbf{G}'} (1 - \delta_{\mathbf{G},\mathbf{G}'}\delta_{j,l}) A_{l,\mathbf{G}'}^* A_{j,\mathbf{G}} e^{i\mathbf{r}\cdot(\mathbf{G}-\mathbf{G}'+\mathbf{k}_0^j-\mathbf{k}_0^l)} U(\mathbf{r})$$

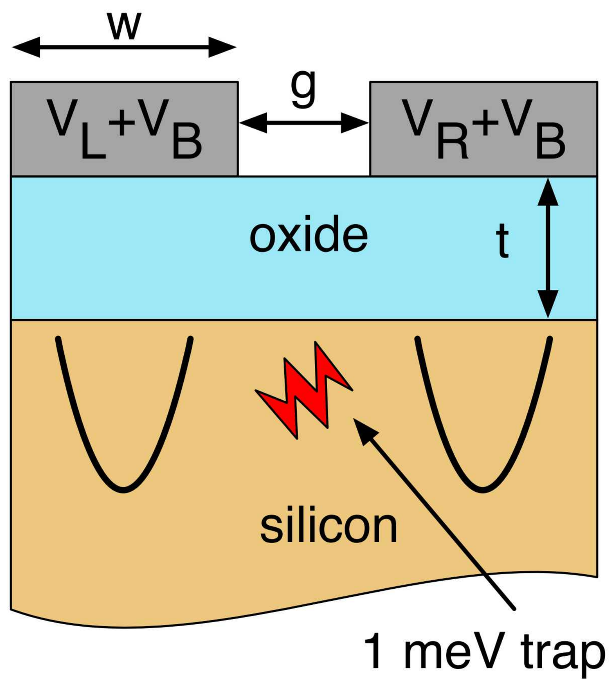
- We use a finite element model to solve for the electrostatic landscape, which is then directly substituted into the coupled system of equations and solved.

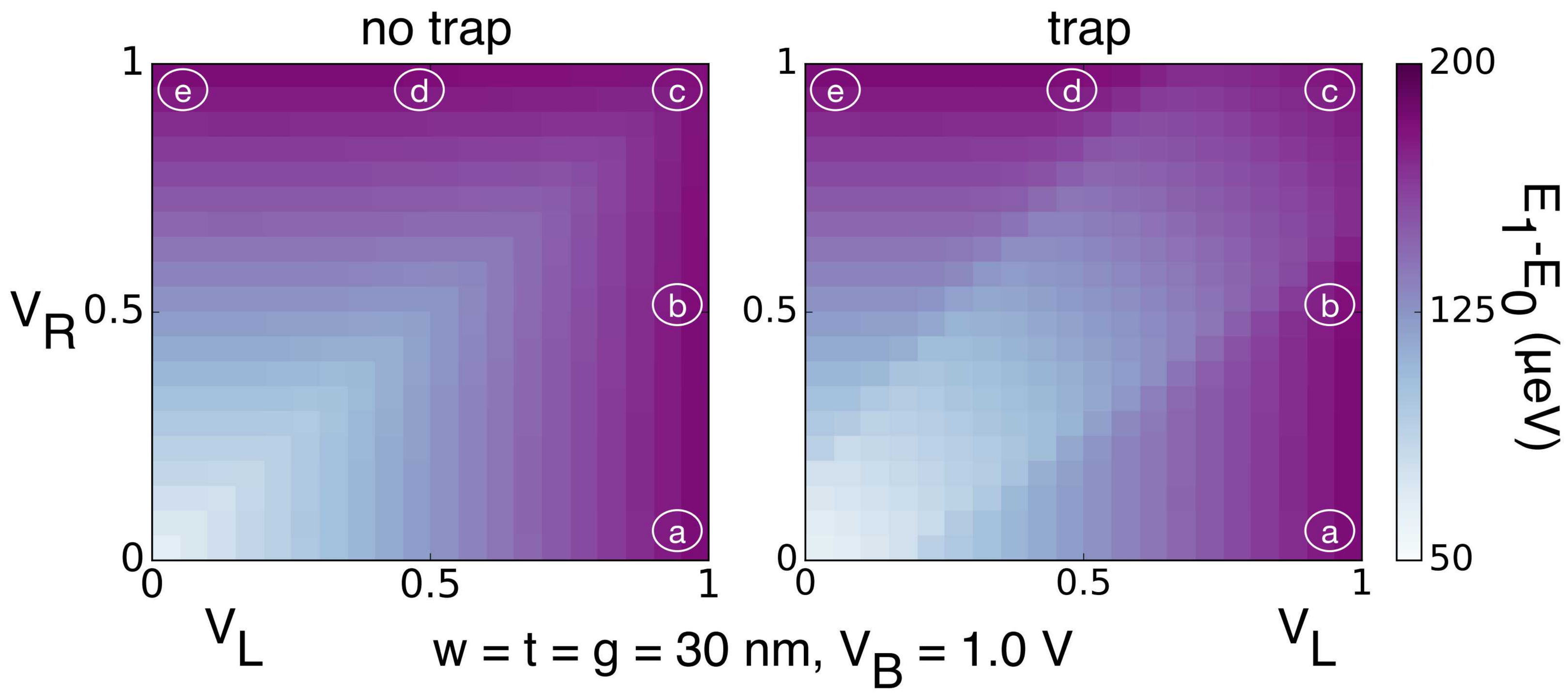


- To solve this system, we represent the envelope equations on an overlapping grid of 3D Gaussians.

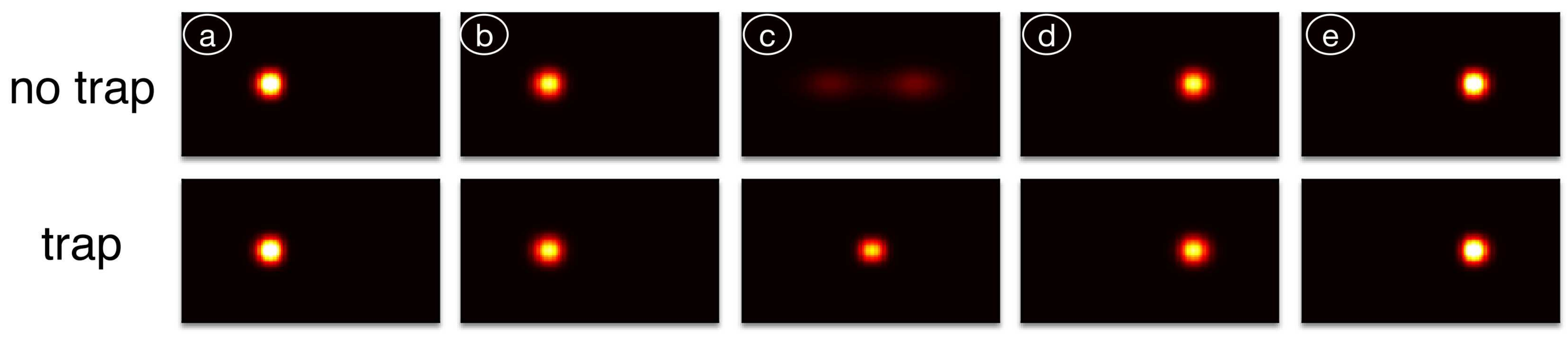
Results

- We performed numerical simulations that varied five parameters: gate width (w), oxide thickness (t), gate gap (g), variable control voltages (V_L & V_R), and background voltage (V_B).
- To assess disorder robustness, we compared the effects of a 1 meV trap in the middle of the tunnel barrier.

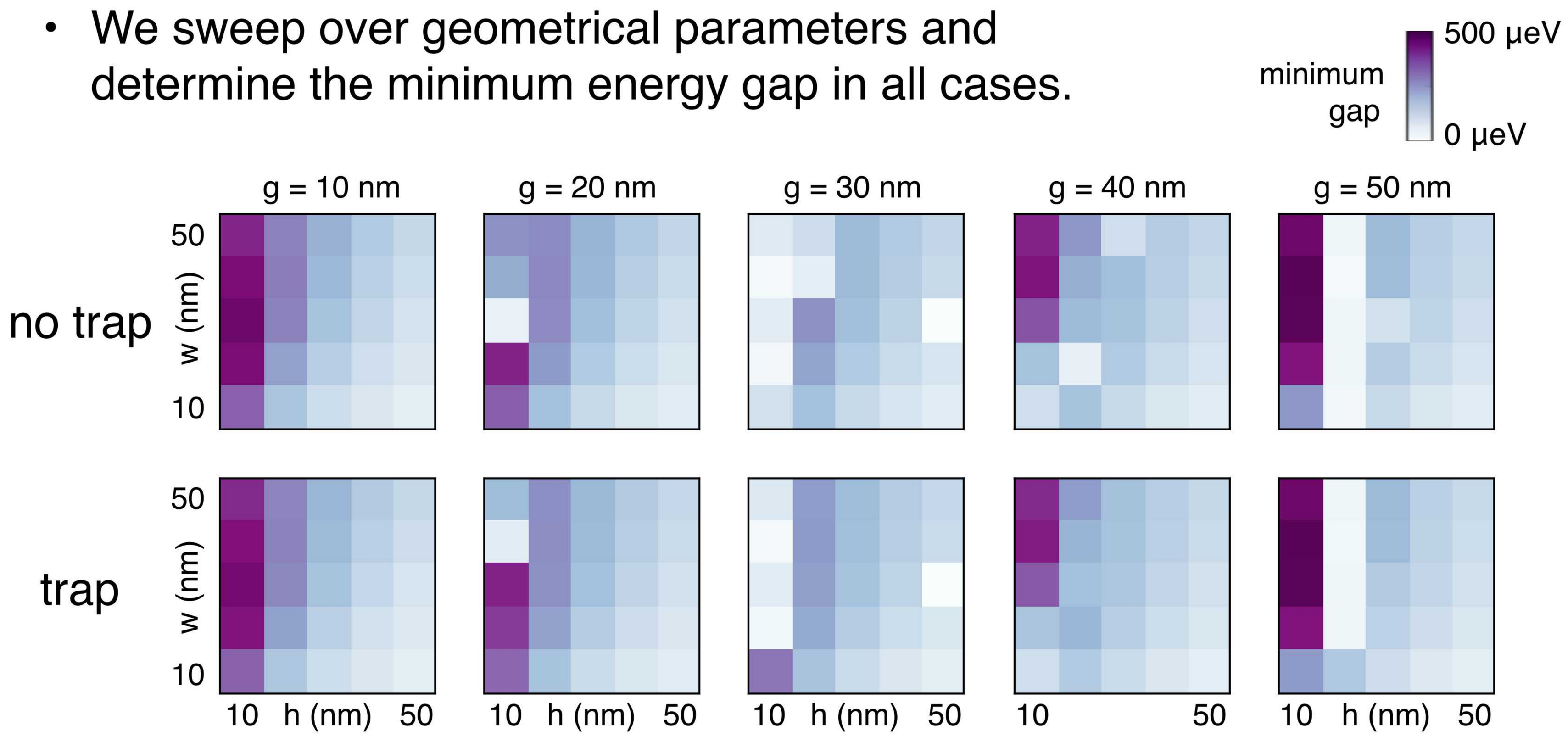




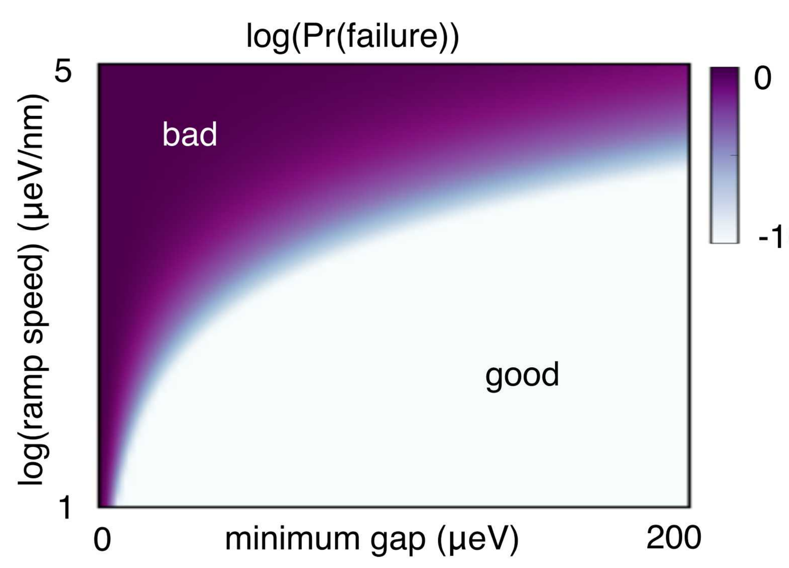
- The trap increases localization when the gates are set at equal voltages.
- In both cases, the outer path maintains the largest gap, since maintaining large vertical electric field is important to maintain high valley splitting.



- We sweep over geometrical parameters and determine the minimum energy gap in all cases.



- Our results indicate that the trap in the tunnel barrier doesn't substantially disrupt the energy gap.
- Hence, large energy gaps lead to robust, shuttles.



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