

Multi-level spectral navigation with geometric diabatic-adiabatic control

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The efficient navigation of complex multi-level energy spectra is paramount for the development of quantum technologies. Control techniques that go beyond black box optimization are required to provide high-fidelity and interpretable results [1].

We introduce a geometric framework for efficient single-parameter pulse shaping in multi-level quantum systems, enabling high-fidelity state transfer beyond the adiabatic limit. Our method interpolates smoothly between adiabatic and diabatic dynamics to minimize unwanted excitations [2] and maximize desired transitions. Crucially, the optimization complexity reduces to solving a first-order ordinary differential equation.

We showcase the flexibility of our diabatic-adiabatic protocols through two key examples in quantum information processing: state initialization [3] and shuttling [4, 5].

References

- [1] Katirae-Far, S. *et al.* *arXiv:2503.12256* (2025)
- [2] Guéry-Odelin, D. *et al.* *Rev. Mod. Phys.*, 4 (2019) 045001
- [3] Ventura-Meinersen, C. *et al.*, *EPJ Quantum Technology*, 1 (2025) 125
- [4] Ginzel, F. *et al.*, *Phys. Rev. B*, 19 (2020) 195418
- [5] Németh, R. *et al.*, *arXiv:2412.09574*, (2024)

Figures

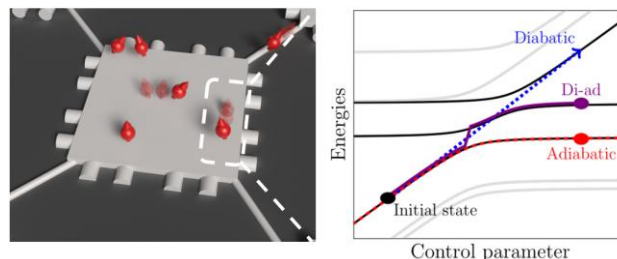


Figure 1: Schematic of a generic material platform, here, qubit shuttling, and the emergent dense energy spectrum as a function of the relevant control parameter.

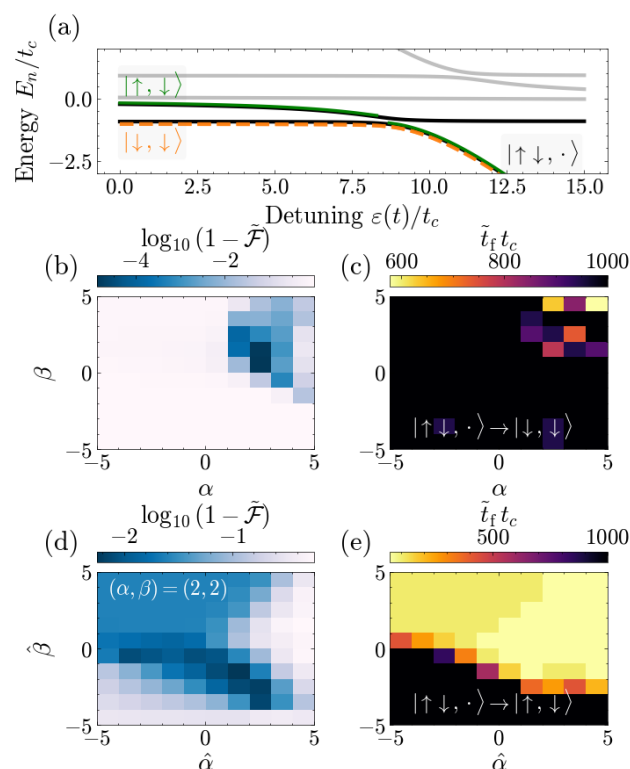


Figure 2: (a) Versatile qubit initialization of a semiconducting quantum processor using diabatic-adiabatic control. From a singlet state we can do a single-step initialization of different parity sectors. (b, c) and (d, e) show the optimal infidelity and corresponding pulse times for the initialization of the different computational states.