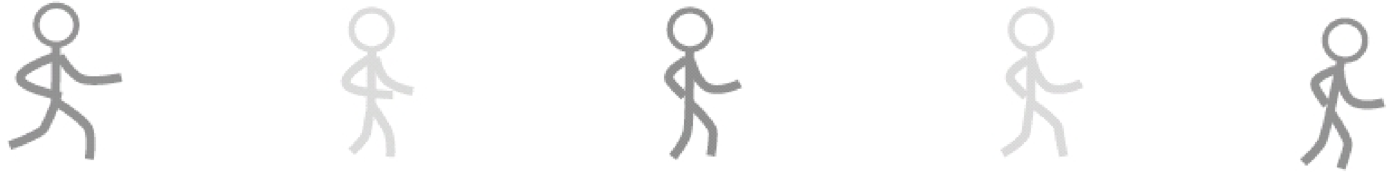
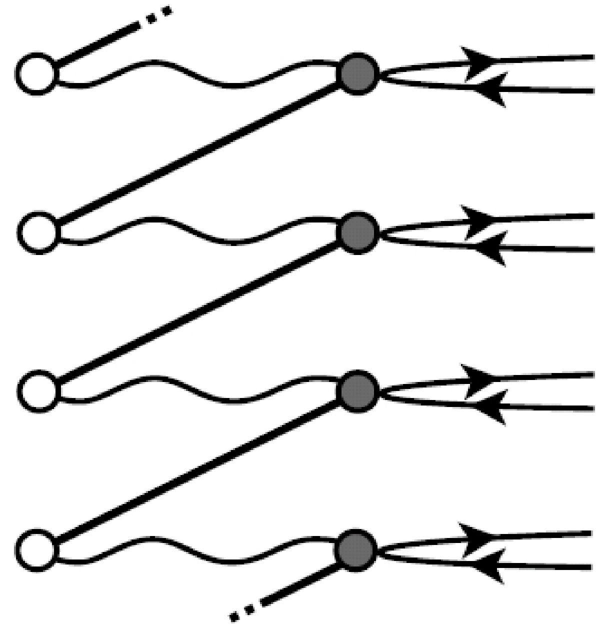


Topological transition in a non-Hermitian quantum walk

Leonid Levitov (MIT)

Chernogolovka

19 February, 2010



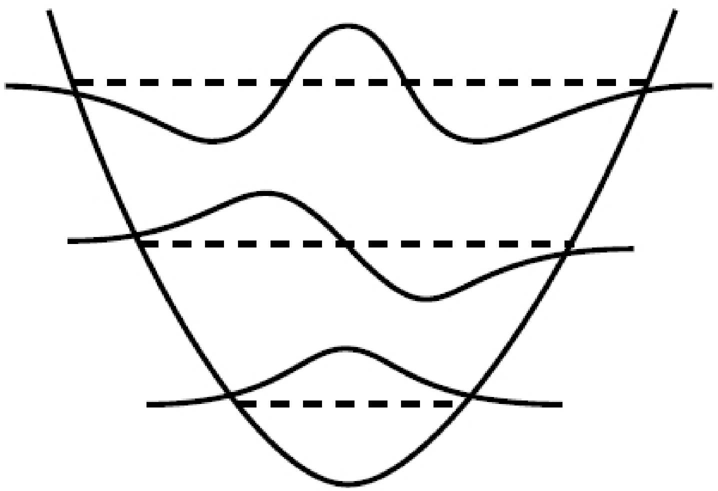
Collaboration:
Mark Rudner
(MIT, now Harvard)

Journal Reference: M. S. Rudner, L. S. Levitov, Phys. Rev. Lett. **102**, 065703 (2009).

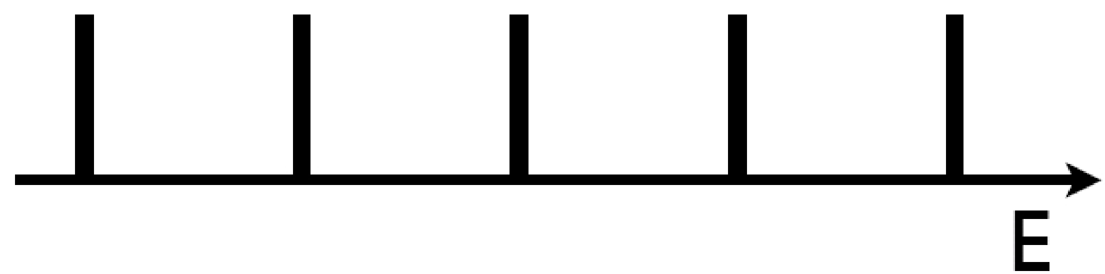
Motivation of this work:

- Identify a simple system in which quantum behavior is robust and can be probed;
- A new kind of topological transition;
- Straightforward to realize in experimental systems of current interest

QMHO energy levels quantized as integers



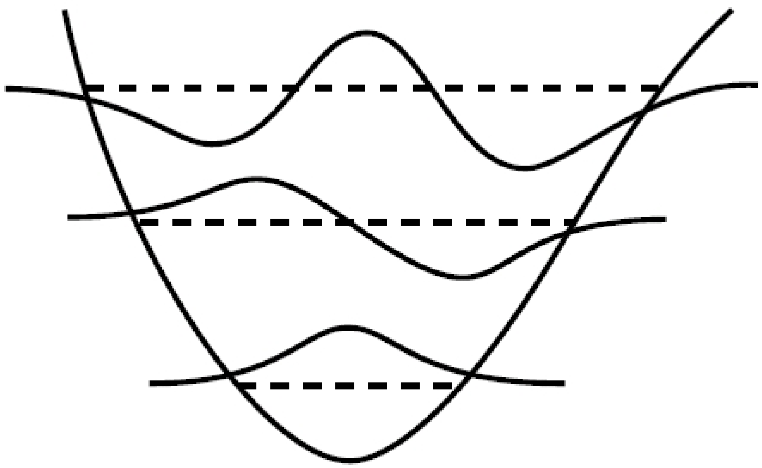
$$E = \left(n + \frac{1}{2}\right)\hbar\omega$$



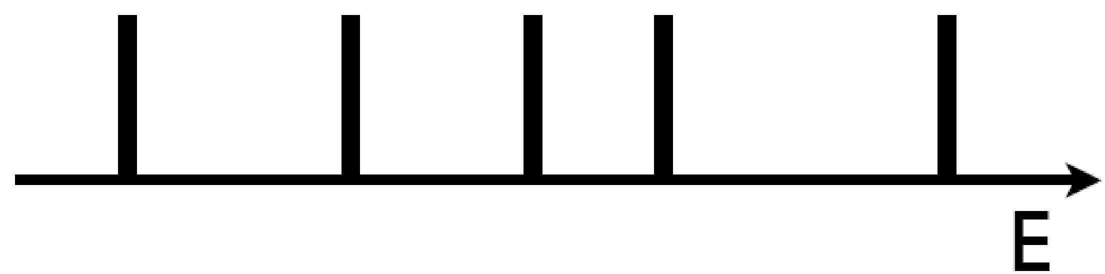
Harmonic Oscillator

Spectrum

Deformation destroys integer quantization



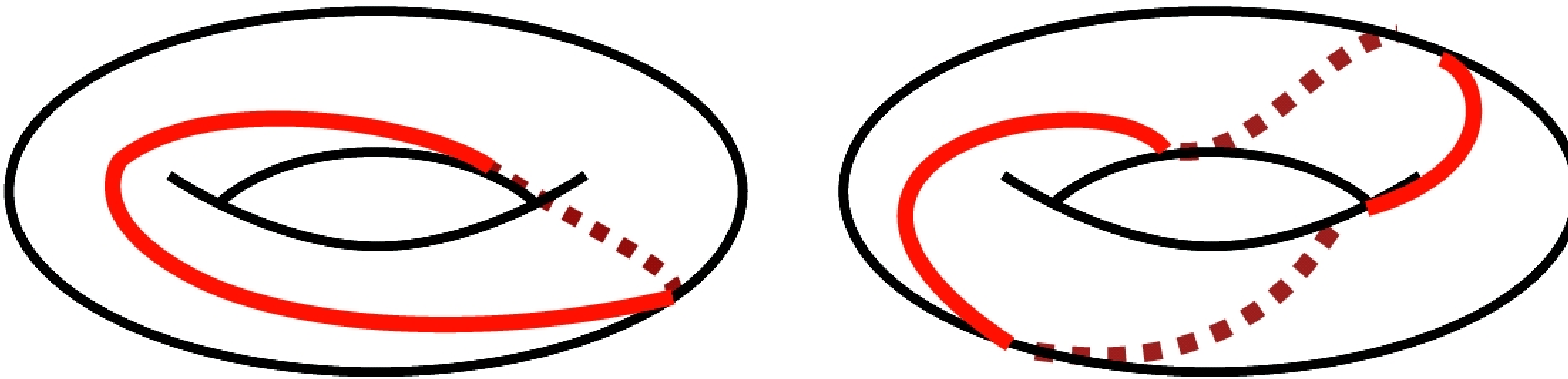
$$\cancel{E = \left(n + \frac{1}{2}\right) \hbar\omega}$$



Anharmonic Oscillator

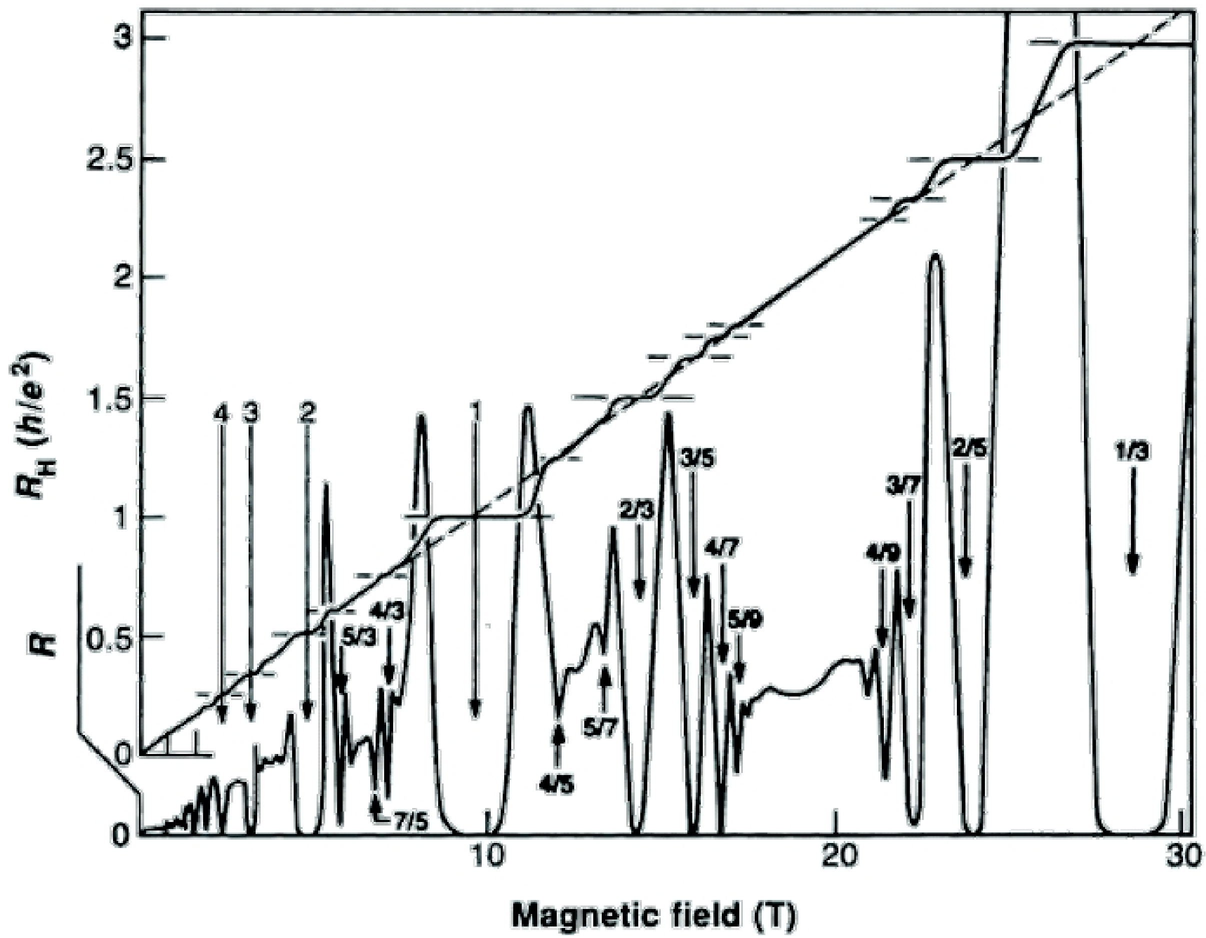
Spectrum

Topological transitions and quantization



Two phases distinguished by topological invariant

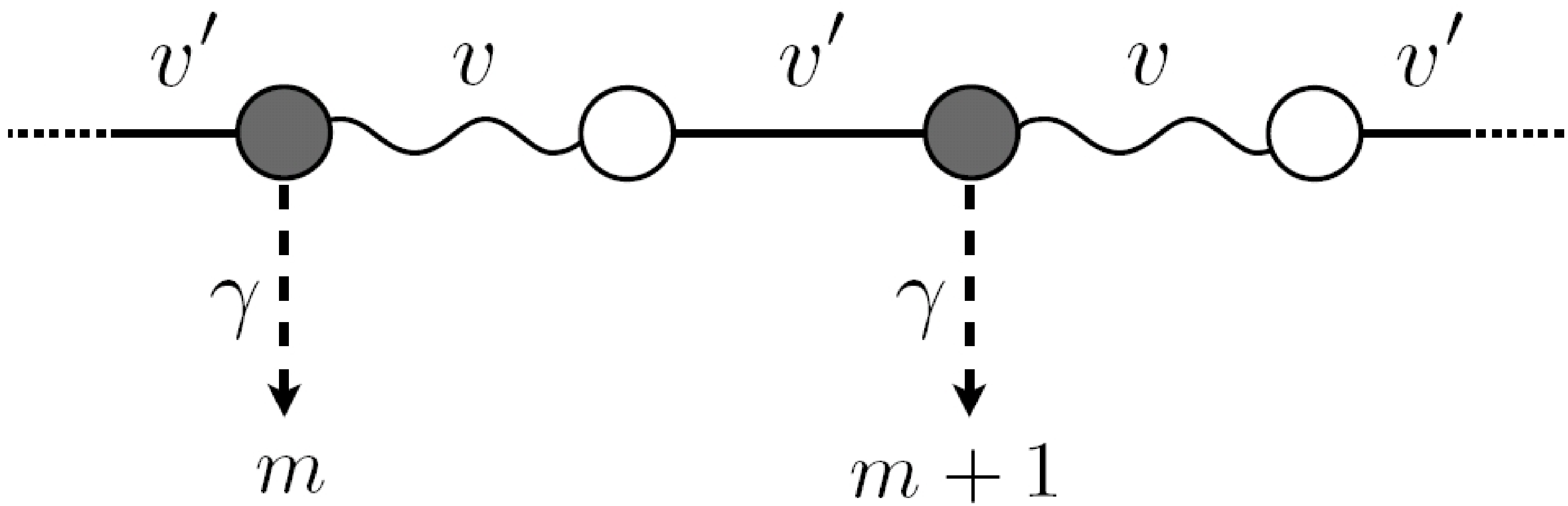
Hall plateaus insensitive to shape, disorder, ...



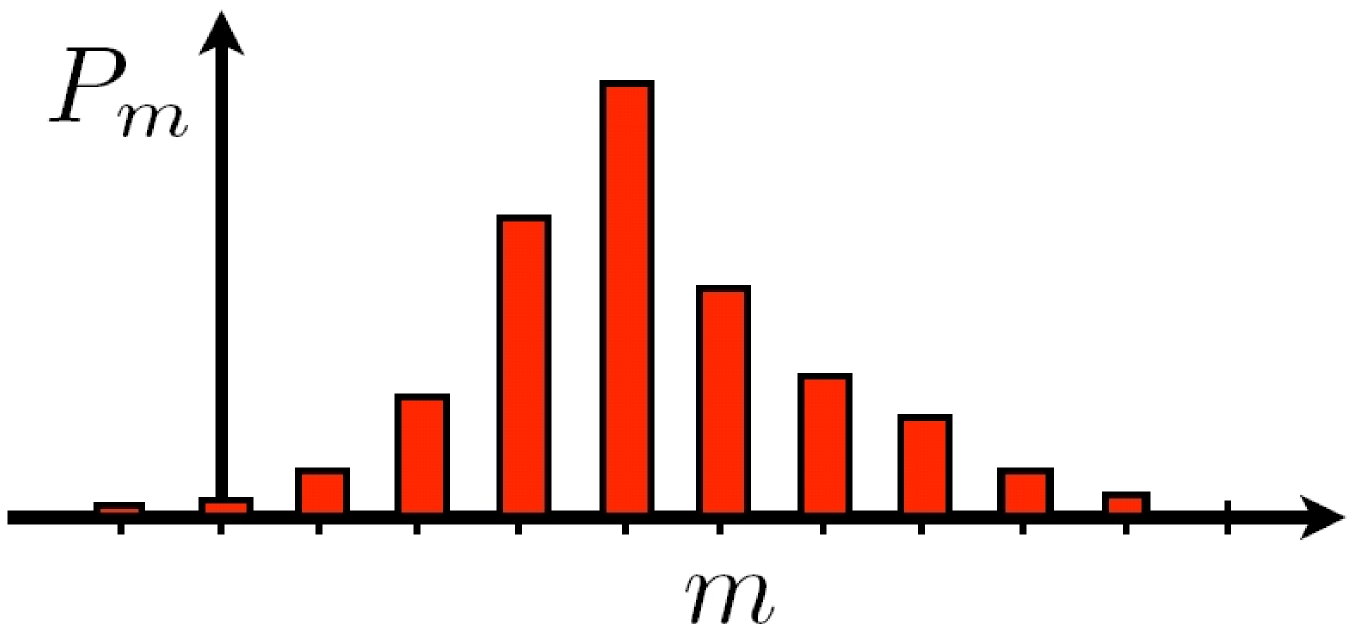
Quantum Hall Effect

Non-hermitian quantum walk

Study displacement in 1D quantum walk with decay



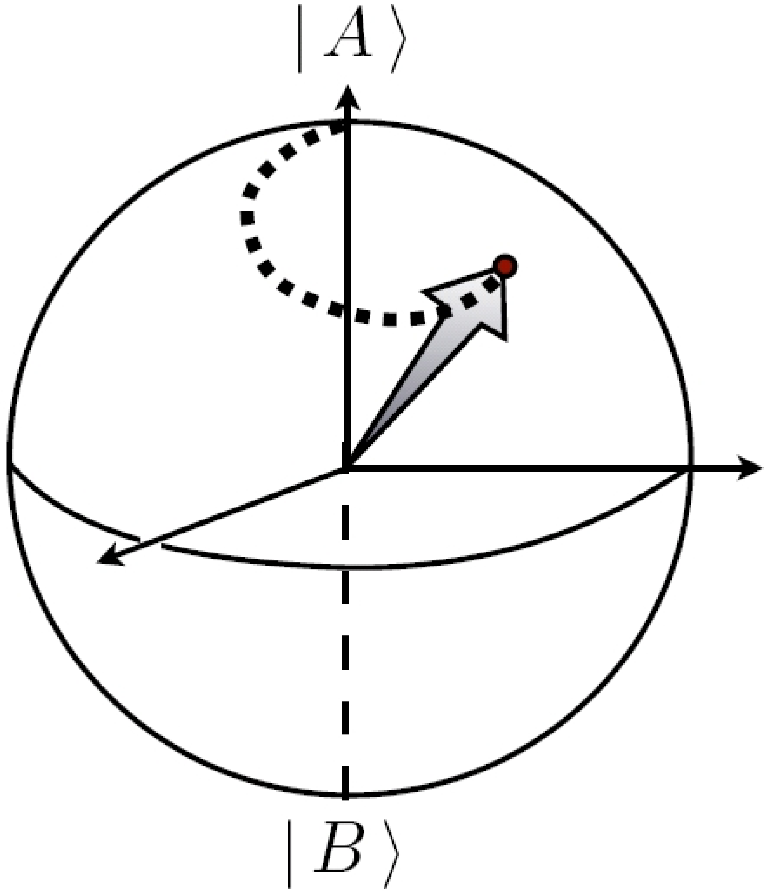
Total decay probability is sum over local terms



$$\langle\, \Delta m \,\rangle \equiv \sum_m m\, P_m; \quad P_m = \int_0^\infty \gamma |\psi_m^B(t)|^2\, dt$$

Time evolution block-diagonal in Fourier space

$$i\hbar \frac{d}{dt} \begin{pmatrix} \psi_k^A \\ \psi_k^B \end{pmatrix} = \begin{pmatrix} \varepsilon_A & v_k \\ v_k^* & \tilde{\varepsilon}_B \end{pmatrix} \begin{pmatrix} \psi_k^A \\ \psi_k^B \end{pmatrix}$$



$$v_k = v + v' e^{ik}$$

$$\tilde{\varepsilon}_B = \varepsilon_B - i\gamma/2$$

Expected displacement related to winding number

Use decomposition: $\psi_k^B(t) = u_k(t)e^{i\theta_k(t)}$

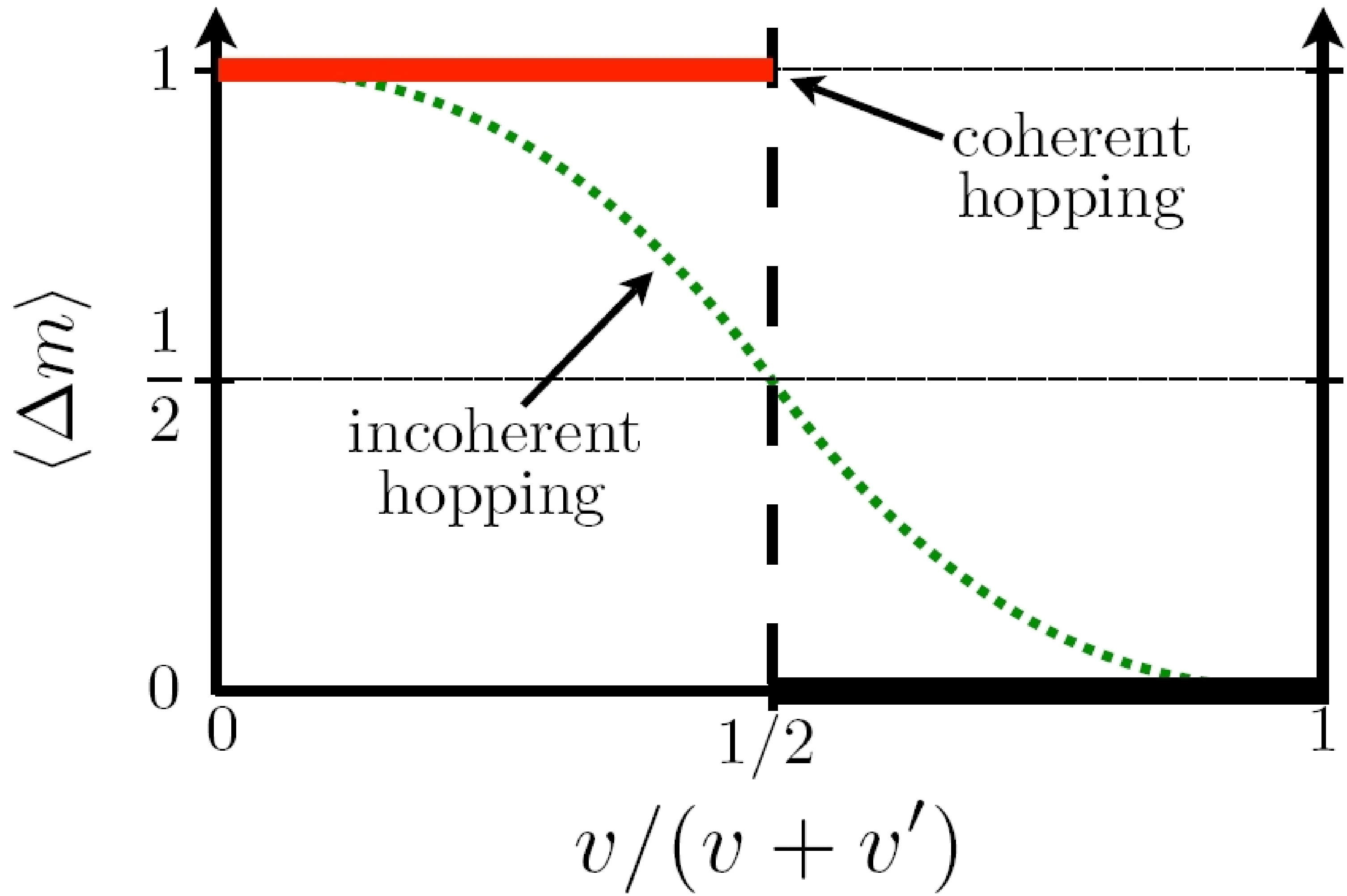
$$\langle \Delta m \rangle \equiv \sum_m m \, P_m$$

Integration by parts

$$\langle \Delta m \rangle = -\oint \frac{dk}{2\pi} \frac{\partial \theta_k^0}{\partial k}$$

$$\theta_k^0 \equiv \lim_{t \to 0^+} \theta_k(t)$$

Quantum result shows non-analytic behavior

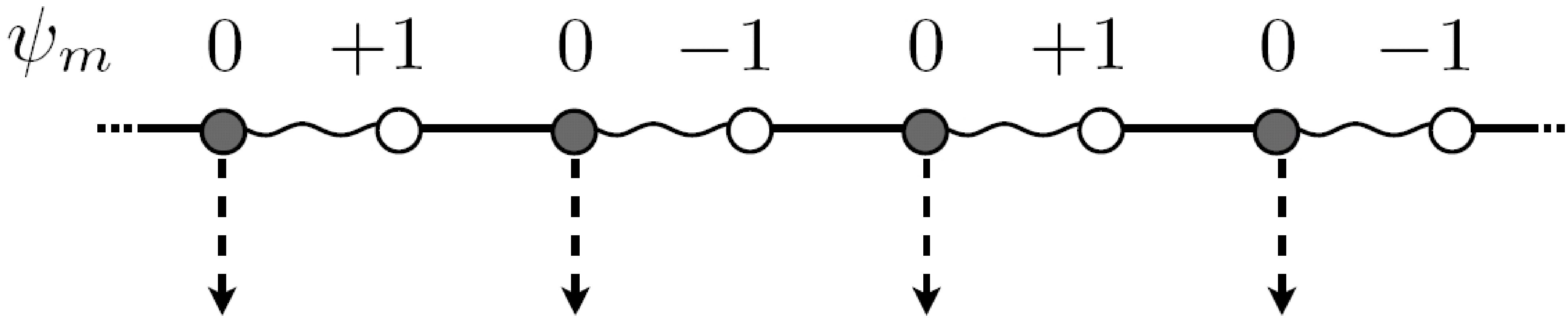


$\psi_k^B(dt) = -iv_k^* dt/\hbar$

$\theta_k^0 = \arg\{-i(v + v' e^{-ik})\}$

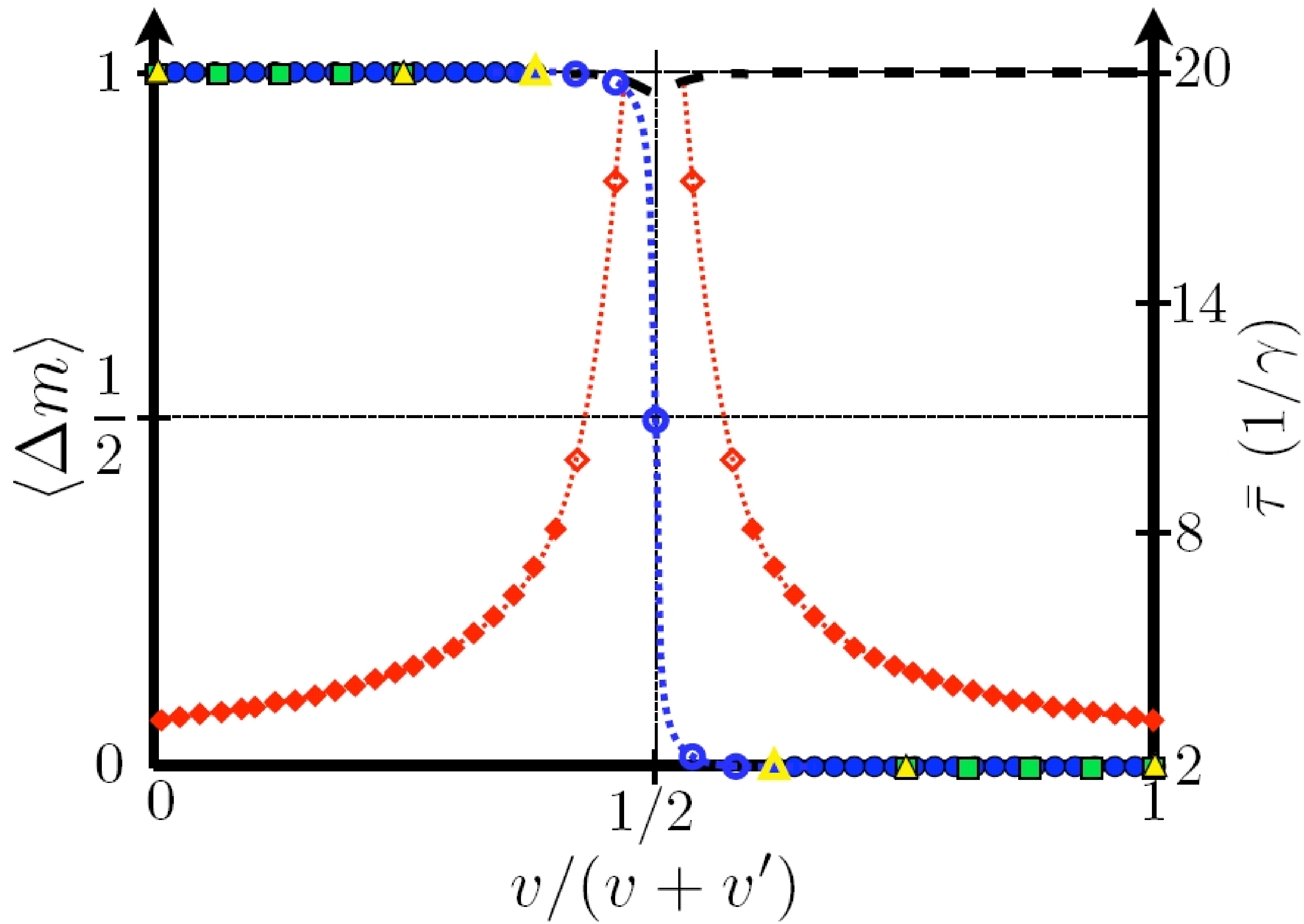
System supports dark state for $v = v'$

$$k = \pi$$



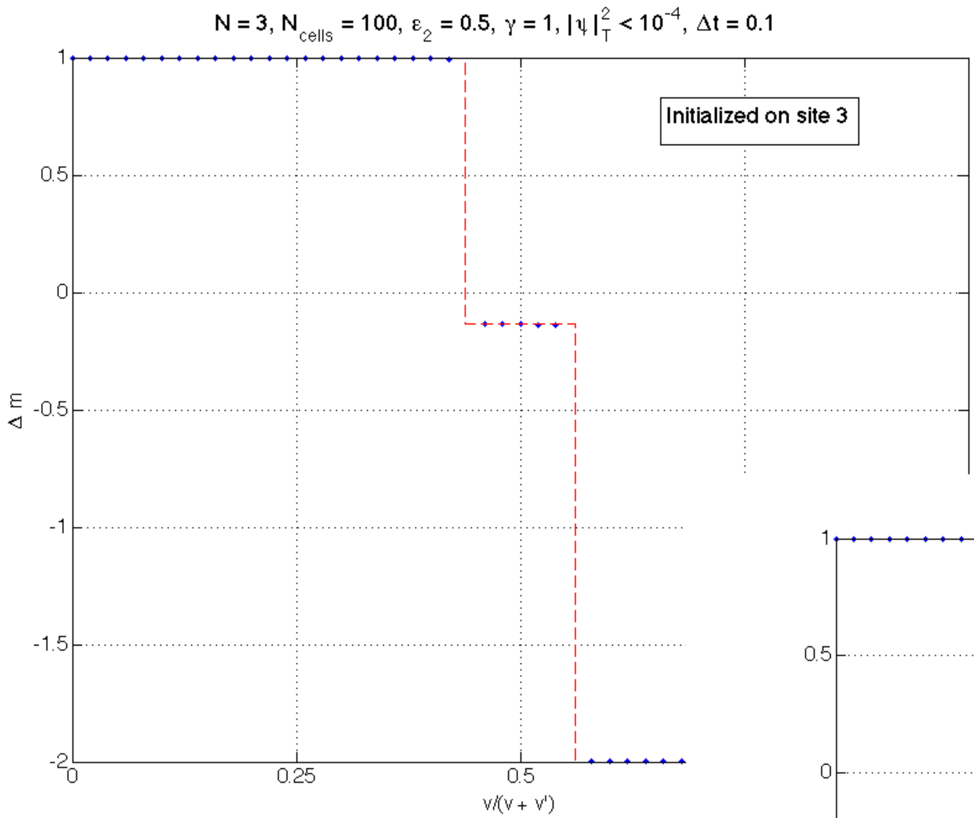
Lifetime diverges at the transition

Simulation: robustness to noise and decoherence

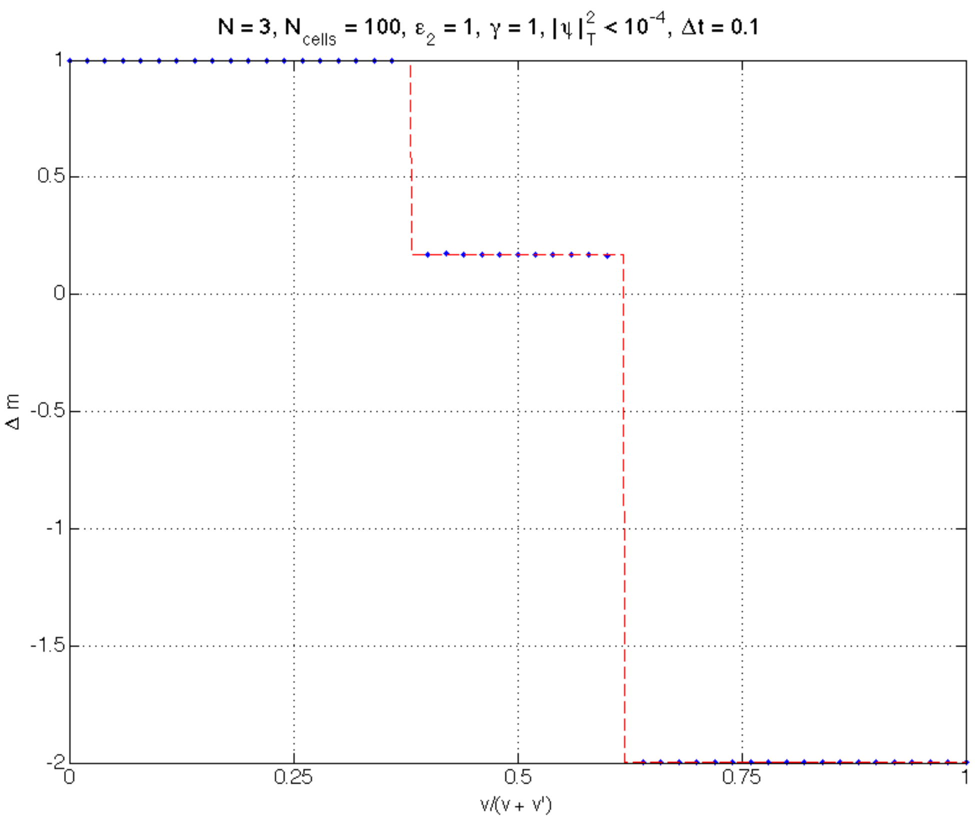


Transition unaffected by time dependent Δ, projection

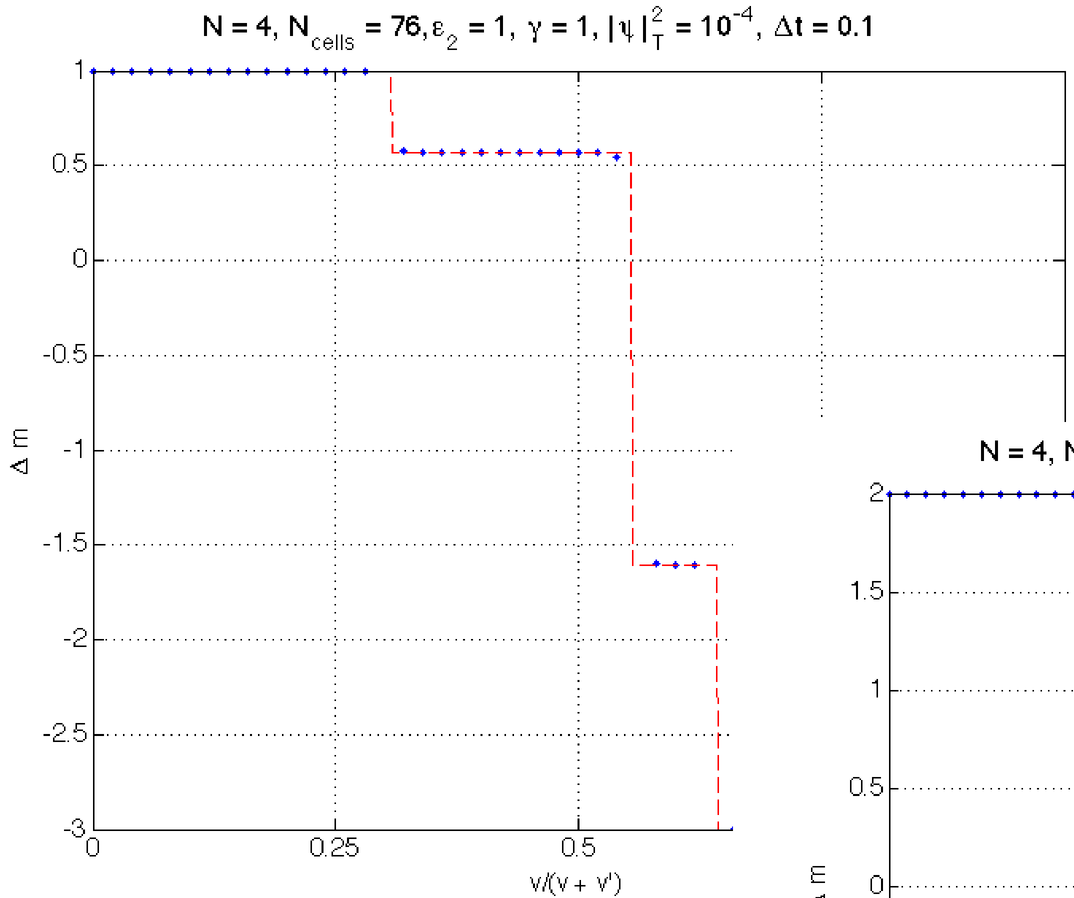
Generalization to N>2



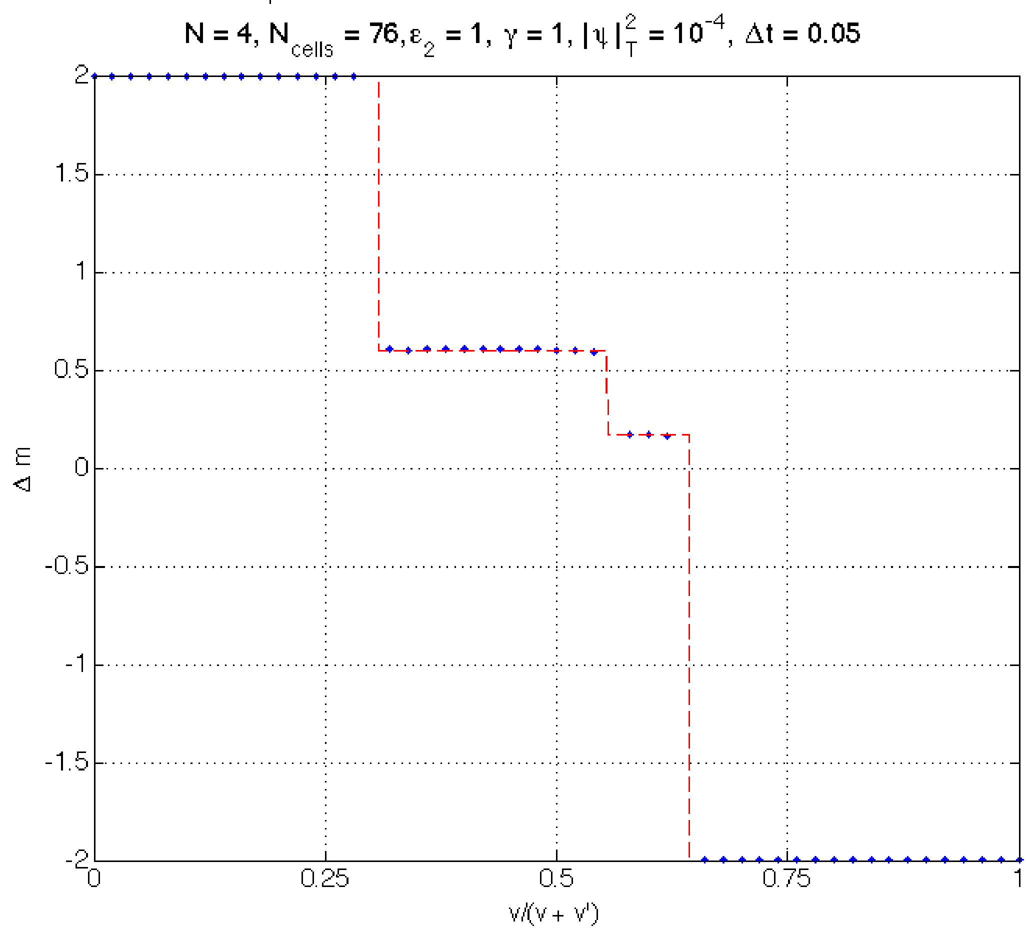
Decay from every 3rd site



Generalization to N>2

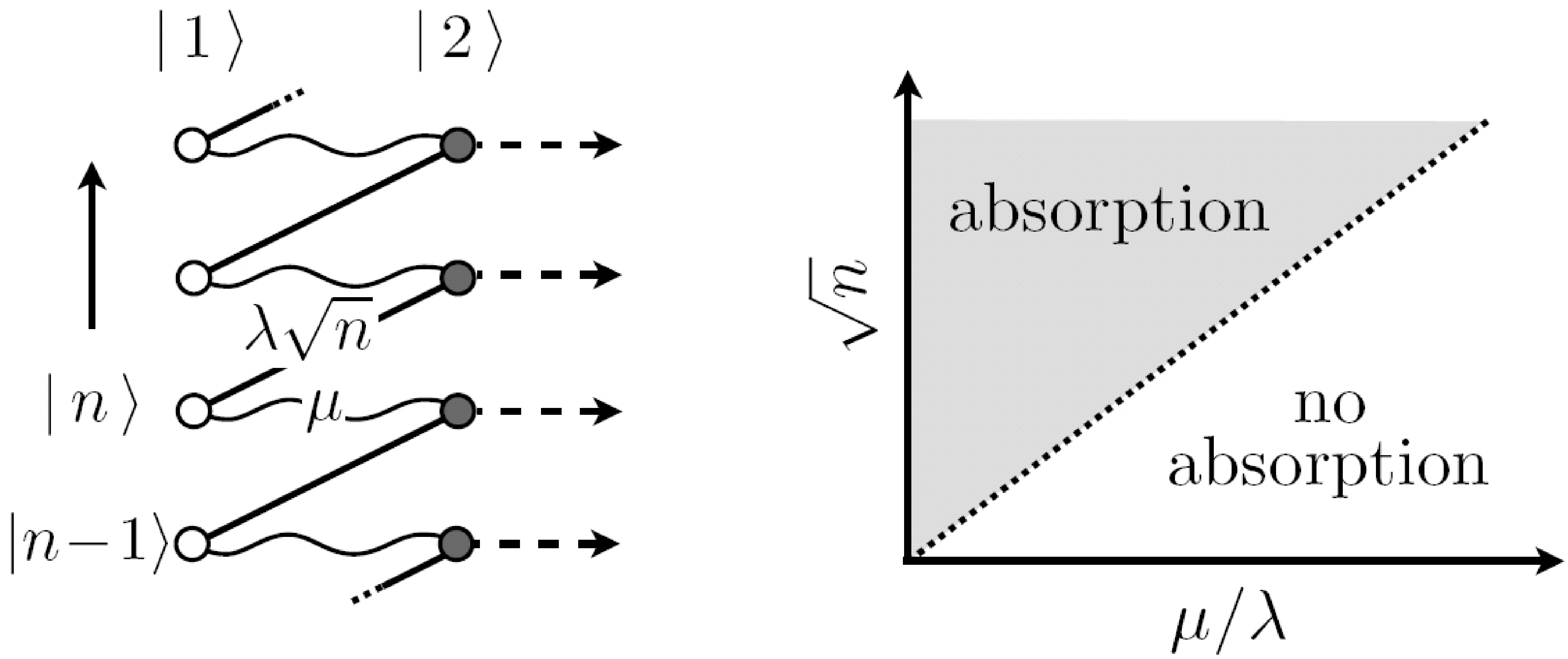


Decay from every 4th site



This slide intentionally left blank

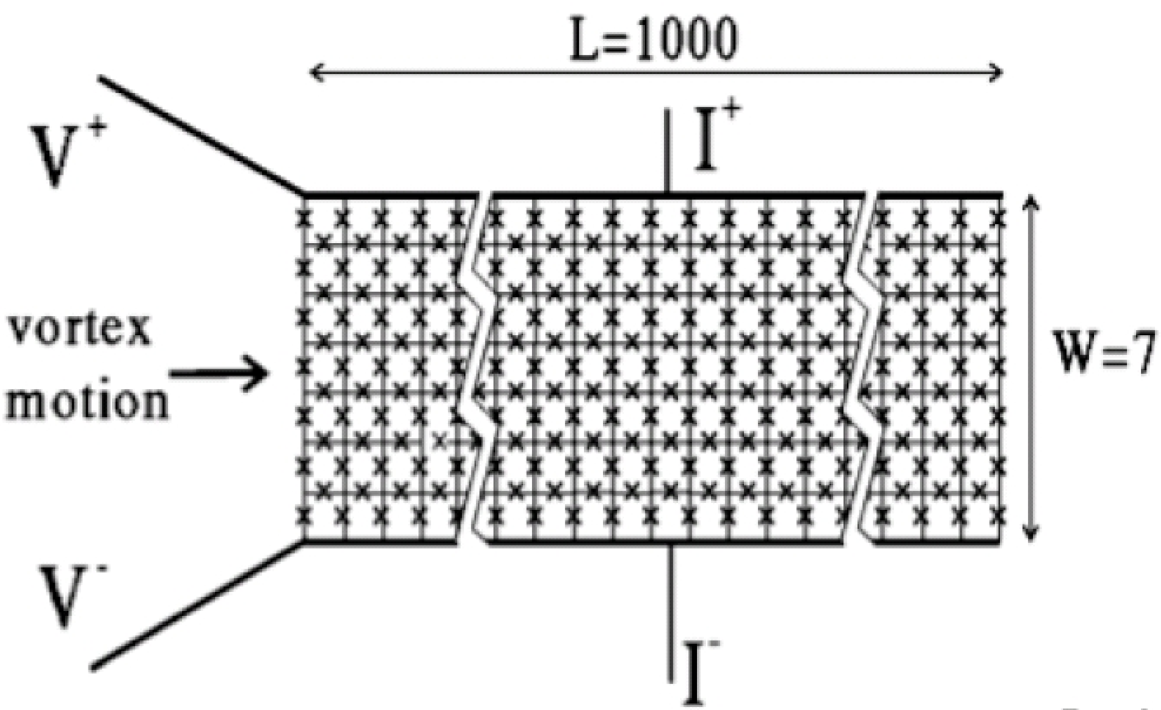
Absorption threshold for Jaynes-Cummings system

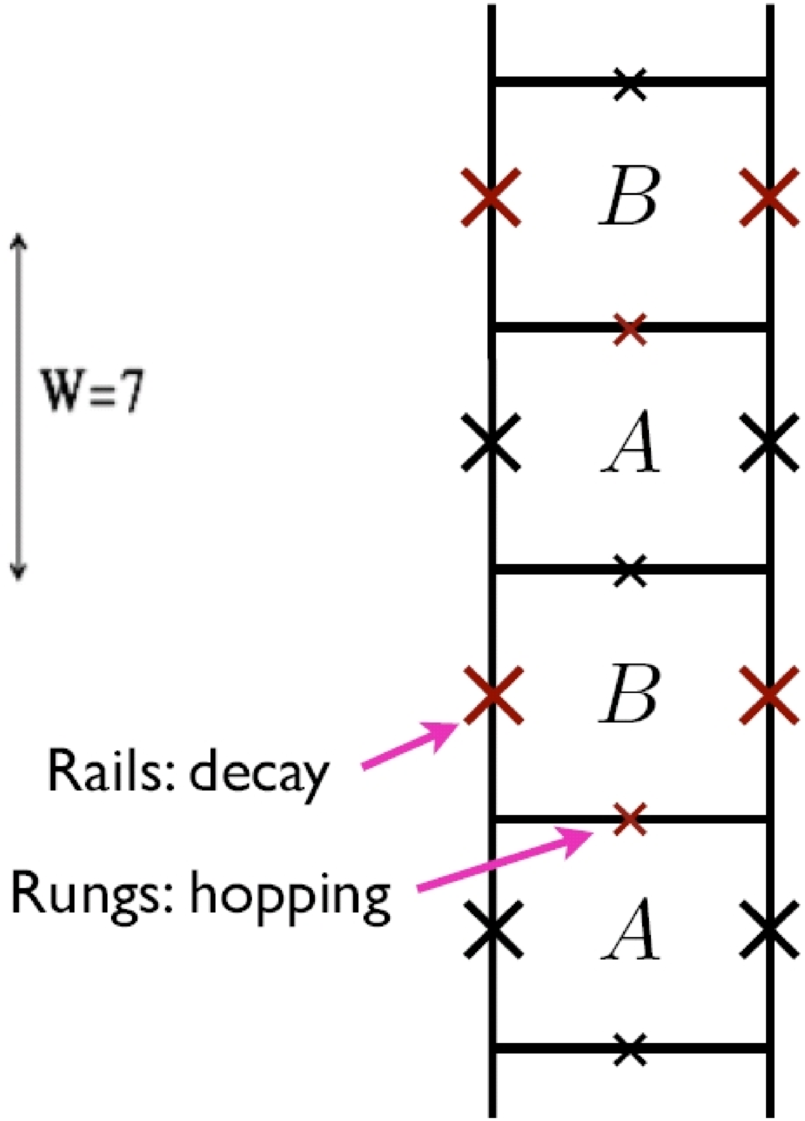


$$\hat{H}_{\mathrm{JC}} = \hbar\Omega\,\hat{a}^\dagger\hat{a} + \frac{1}{2}\Delta\,(\hat{\sigma}^z - 1) + (\lambda e^{i\omega t}\hat{\sigma}^+\hat{a} + \mu e^{i\omega' t}\hat{\sigma}^+ + h.c.)$$

$\tilde{\sigma}^+ = e^{i\omega' t}\hat{\sigma}^+, \quad \tilde{a} = e^{i(\omega-\omega')t}\hat{a}; \quad \Omega = \omega - \omega'$ (two-photon resonance)

Quantum vortex transport in Josephson arrays

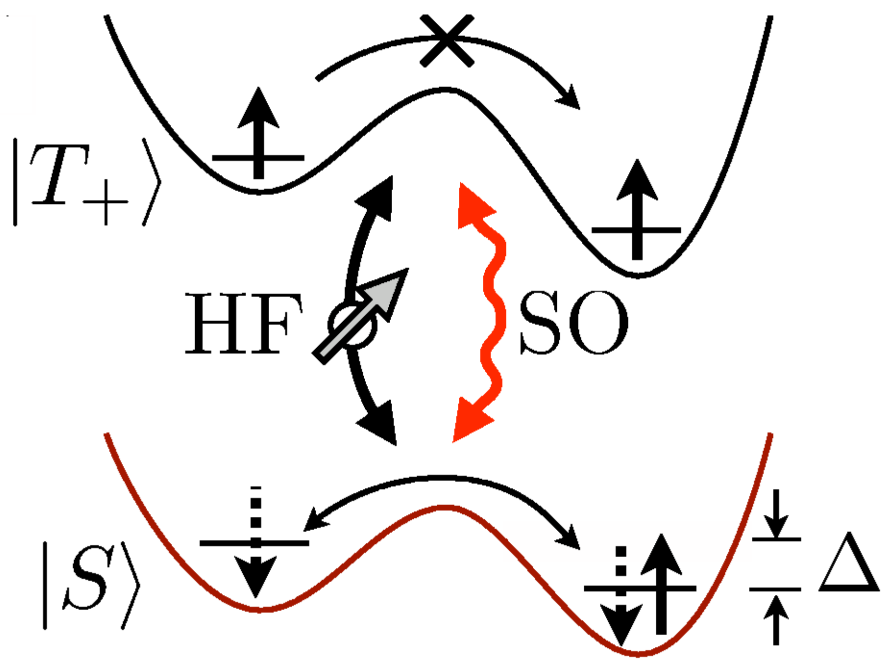


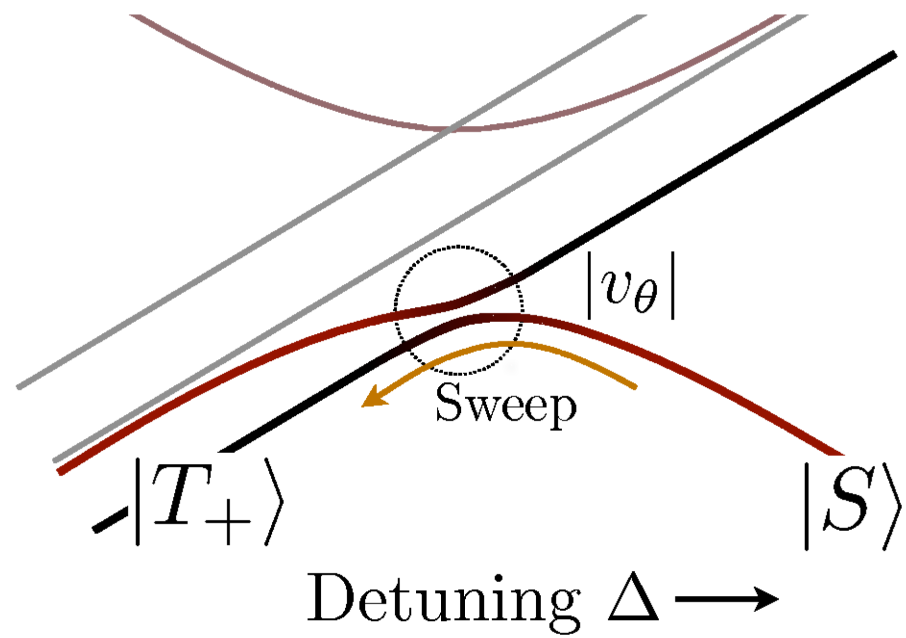


Alexander van Oudenaarden and J. E. Mooij, Phys. Rev. Lett. **76**, 4947 (1996).

Nuclear polarization and electron transport in spin-blockaded quantum dots

- Two-electron singlet and triplet levels positioned so that electron can move only by flipping spin
- Spin flips by sweeping through S-T level crossing
- Combined effect of hyperfine and spin-orbital interaction





Coherent competition between SO and HF: Landau-Zener transition for static nuclear field

$$v_\theta \equiv \langle T_+ |H| S \rangle = v_{\rm SO} + v_{\rm HF} e^{i\theta},$$

nuclear polarization XY component described by angle θ

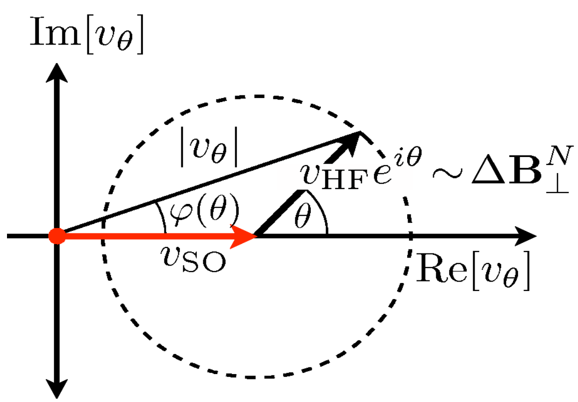
$e^{i\theta}$ obtained by factoring $I^- = \sum_i I_i^-$

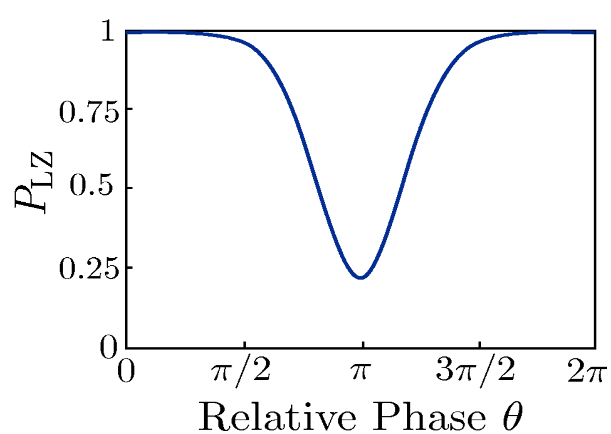
B || Z axis

$$H_{ST_+} = \begin{pmatrix} 0 & v_\theta \\ v_\theta^* & \Delta(t) \end{pmatrix}, \quad \Delta(t) = \varepsilon_S(t) - \varepsilon_{T_+}(t)$$

$$P_{\rm LZ} = 1 - \exp\left(-2\pi |v_{\rm SO} + v_{\rm HF} e^{i\theta}|^2 / \beta\right)$$

the velocity at level crossing



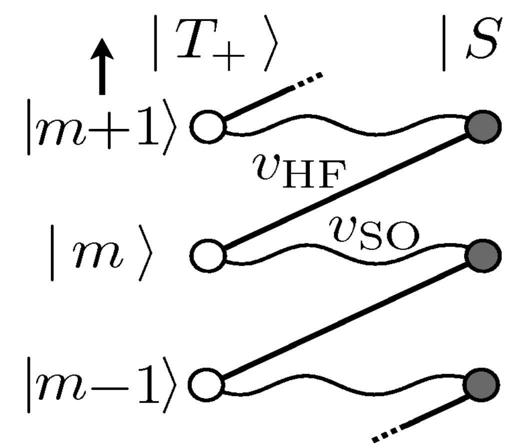


Dependence on transverse nuclear polarization

Nuclear pumping: dynamics, backaction?

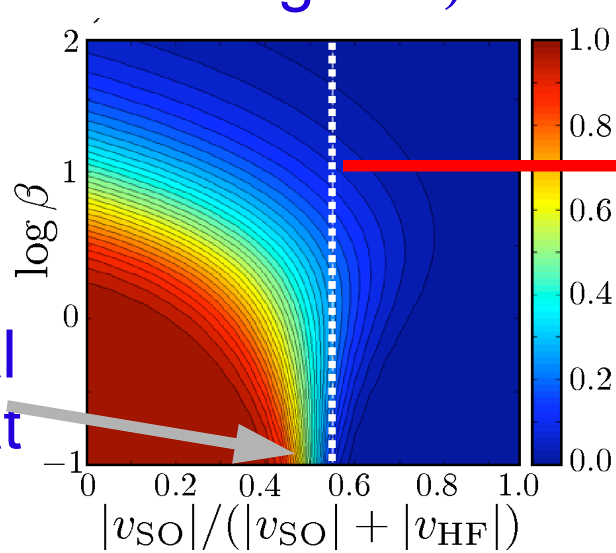
Mapping to nonhermitian walk

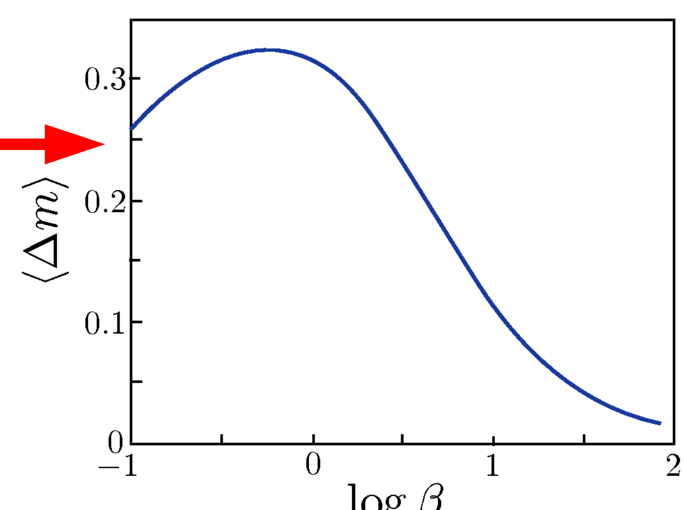
- Nuclear polarization buildup?
- The nuclear and electron spin-flip rates are **not the same** due to SO;
- Landau-Zener transitions for Bloch states on a 1D bipartite lattice



Nuclear spin-flip rate for a state with constant m_z ("averaged over angle θ")

Nonmonotonic dependence on the sweep velocity β



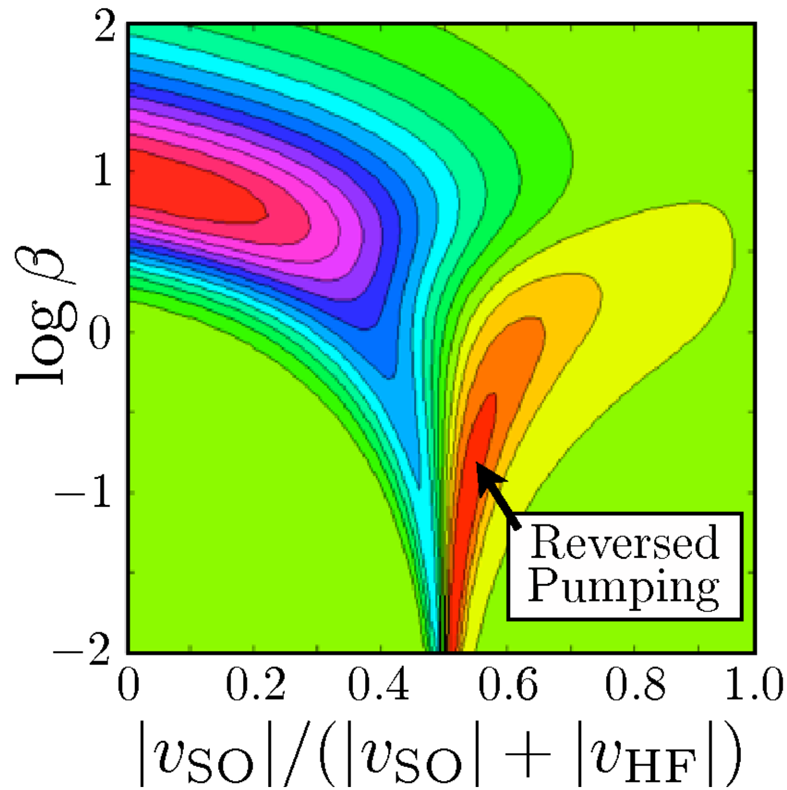


Topological transition at 0.5

Resembles results by Foletti et al 2008

New phenomena in nuclear spin pumping in the presence of SO interaction

- Electron spin flips depend on the **transverse** nuclear polarization; influence on pumping seen by Foletti et al 2008
- Nonmonotonic dependence on the sweep velocity
- Oscillations and reverse pumping under periodic sweeping back and forth
- Agrees with experiment (Foletti et al arXiv:0801:3613)



Rudner, Neder, LL & Halperin
arXiv:0909:0660

This slide intentionally left blank