

FINITE-SIZE EFFECTS OF THE SPINLESS LONG-RANGE BCS KITAEV CHAIN

Majorana zero mode localizations and energies
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$$H = H_0 + H_{\text{int}}$$

Tunneling Hamiltonian

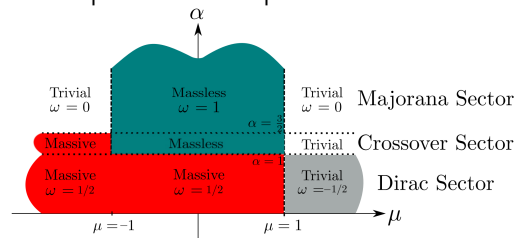
$$H_0 = -\frac{1}{2} \sum_{x=1,2,\dots,n} \tau c_x^\dagger c_{x+1} + \mu \left(c_x^\dagger c_x - \frac{1}{2} \right) + h.c.$$

Pairing Hamiltonian

$$H_{\text{int}} = \frac{1}{2} \sum_{x,x'} V_{\text{eff}}(|x - x'|) c_x^\dagger c_{x'}^\dagger + h.c.$$

$$V_{\text{eff}}(|x - x'|) = \begin{cases} -\frac{U_0}{|x-x'|^\nu} & x - x' \neq 0 \\ 0 & x - x' = 0 \end{cases}$$

$\alpha = \nu$ power-law exponent



Phase diagram of a long-range Kitaev chain, Phys. Rev. B **94**, 125121 (2016)

Interaction Hamiltonian

$$H_{\text{int}} = \frac{1}{2} \sum_{x,x'} c_x^\dagger c_{x'}^\dagger V_{\text{eff}}(|x - x'|) c_{x'} c_x$$

Mean-field approximation

$$H_{\text{int}} \approx \frac{1}{2} \sum_{x,x'} [\Delta(x, x') c_x^\dagger c_{x'}^\dagger + h.c. + \Delta(x, x') \langle c_x^\dagger c_{x'}^\dagger \rangle]$$

Superconducting gap

$$\Delta(x, x') = V_{\text{eff}}(|x - x'|) \langle c_{x'} c_x \rangle$$

Fermionic anticommutation relation

$$\Delta(x, x') = -\Delta(x', x)$$

Self-consistent gap solution

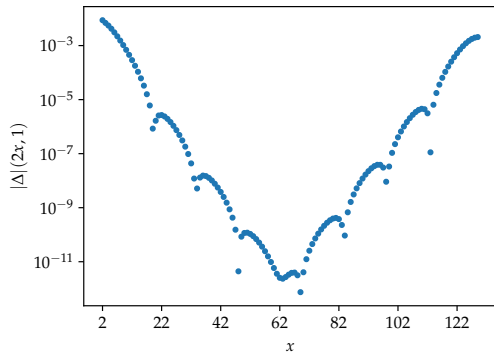
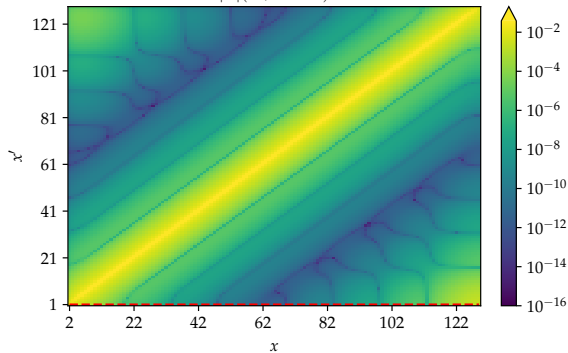


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$$\tau = 1, \mu = 0, U_0 = 0.5, \nu = 0.5, n = 256$$

$$|\Delta|(2x, 2x' - 1)$$



$$\Delta(x, x') = V_{\text{eff}}(|x - x'|) (\alpha_{\text{bulk}}(x, x') + \alpha_{\text{edge}}(x, x'))$$

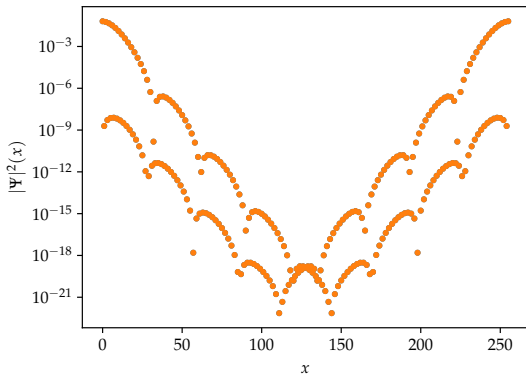
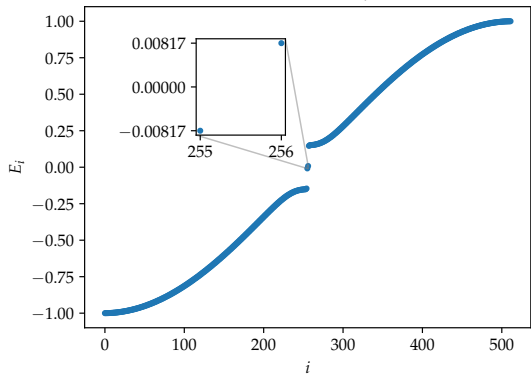
Correlation function of the bulk

$$|\alpha_{\text{bulk}}(x, x')| = g_1 e^{\frac{-|x-x'|}{\lambda_1}} (x - x' \mod 2)$$

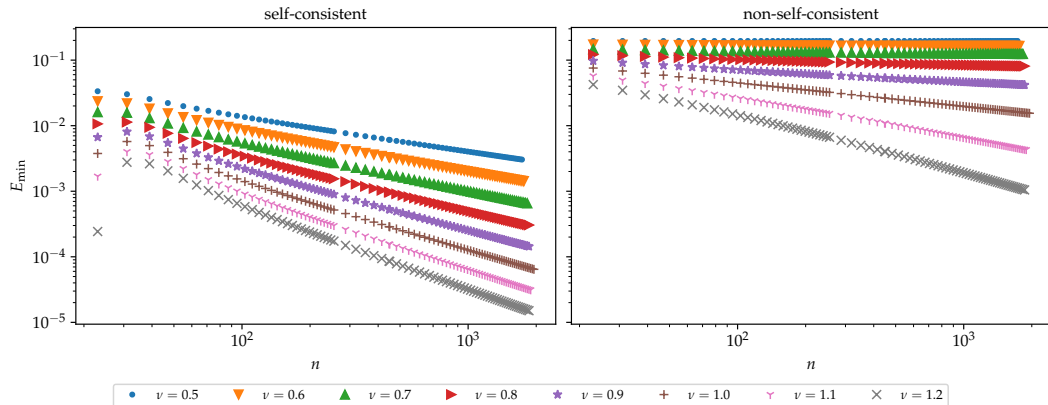
Correlation function of the edge

$$|\alpha_{\text{edge}}(x, x')| = g_2 e^{\frac{-(n-|x-x'|)}{\lambda_2}} (n - |x - x'| \mod 2)$$

$$\tau = 1, \mu = 0, U_0 = 0.5, \nu = 0.5, n = 256$$



$$\tau = 1, \mu = 0, U_0 = 0.5$$



- $\Delta(x, x') \propto e^{-|x-x'|/\lambda}$
- $\Delta(1, n) \propto n^{-\nu}$
- $\Rightarrow E_{\text{edge}} \propto n^{-\nu}$
- There are no massive Dirac edge modes
- FSE may be relevant experimentally for mesoscopic systems
- Potential impact on various predictions if self-consistency is taken into account: Phys. Rev. Lett. **113**, 156402 (2014); Phys. Rev. B **94**, 125121 (2016); Annals of Physics **374**, p. 35-66 (2016); Phys. Rev. B **96**, 125113 (2017); Phys. Rev. B **95**, 195160 (2017); Phys. Rev. Lett. **120**, 017001 (2018); Journal of Physics A **53**, 013001 (2019); Phys. Rev. Res. **3**, 013148 (2021); New Journal of Physics **25**, 033030 (2023);...(+70)

THANK YOU!