Quantum walks in optical lattices

Dariusz Wiater[1]

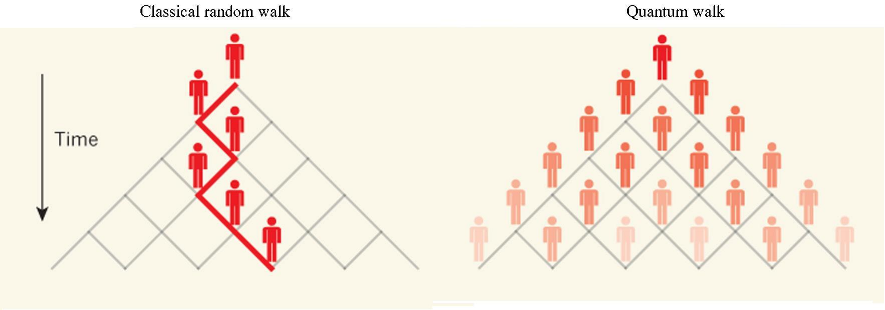
[1] Jagiellonian University

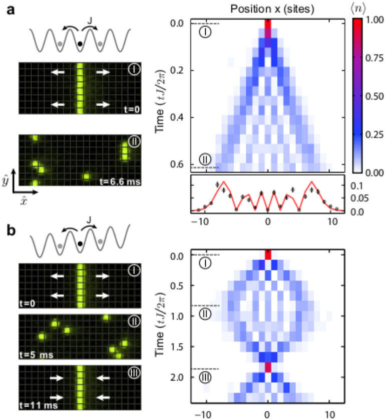
Cracow School of Theoretical Physics,
LVII Course, 2017 Entanglement and Dynamics

June 16, 2017

Outline

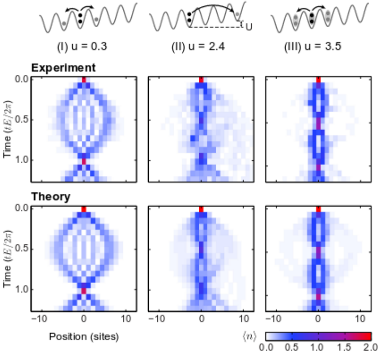
- Classical case refers to the standard random walk with gaussian probability distribution
- Quantum walks can be discrete (which are quantum version of coin flipping) or continuous (which are govern by hamiltonian)





- Experimental realization in optical lattices:

  Science 347, 1229 (2015) - Greiner Lab



$$\hat{H}_{\texttt{BH}} = -J \sum_i \left(\hat{a}^\dagger_{i+1} \hat{a}_i + h.c. \right) + \frac{U}{2} \sum_i \hat{n}_i (\hat{n}_i - 1), \tag{1}$$

external perturbations of the model:

$$\hat{H}_{\texttt{ext}} = \hat{T} + \hat{V} + \hat{D}, \tag{2}$$

where

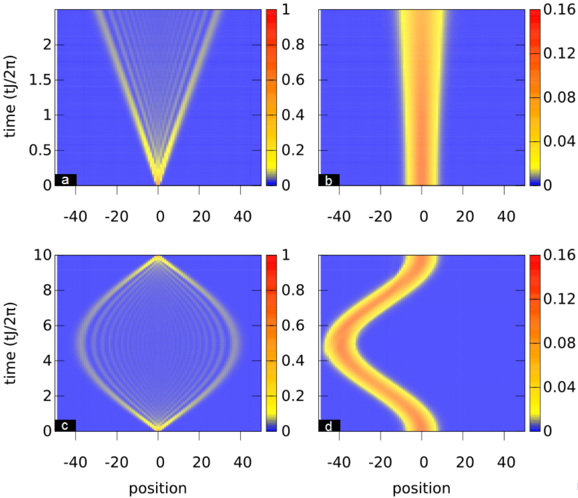
$$\hat{T} = F \sum_i i \, \hat{a}^\dagger_i \, \hat{a}_i, \tag{3a}$$

$$\hat{V} = V \sum_i \sum_{k \neq 0} k^{-\alpha} \, \hat{n}_i \hat{n}_{i+k}, \tag{3b}$$

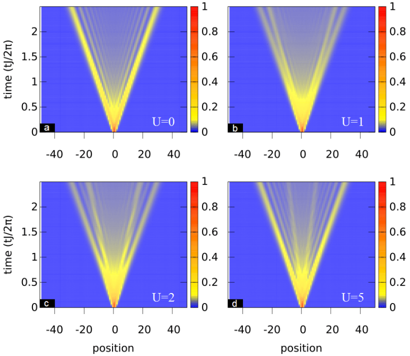
$$\hat{D} = \lambda \sum_i \cos \left[2\pi(\tau i + \phi) \right] \hat{a}^\dagger_i \hat{a}_i. \tag{3c}$$

All results: D. Wiater, T. Sowiński, J. Zakrzewski, arXiv:1705.11009

One particle quantum walk evolution:



Evolution with standard Bose-Hubbard Hamiltonian for a few on-site interaction values:

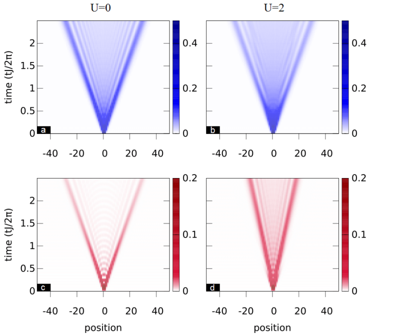


$$n(i) = \langle \psi(t) | \hat{a}_i^\dagger \hat{a}_i | \psi(t) \rangle. \tag{4}$$

We divide $n(i)$ into two sectors:

$$n_2(i) = \langle \psi(t) | \hat{a}_i^\dagger \hat{a}_i^\dagger \hat{a}_i \hat{a}_i | \psi(t) \rangle, \tag{5a}$$

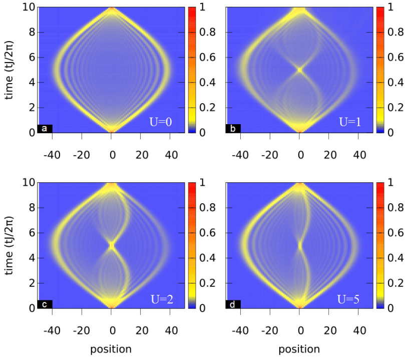
$$n_1(i) = n(i) - n_2(i). \tag{5b}$$



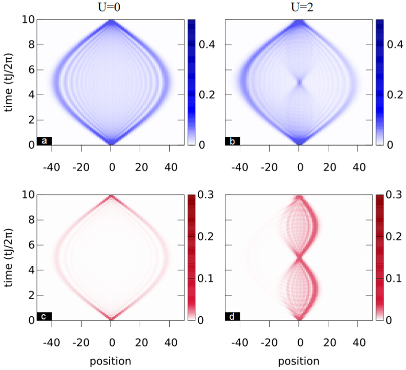
R. Khomeriki, D. O. Krimer, M. Haque, and S. Flach, Phys. Rev. A 81, 065601 (2010): Effective tunneling for paired bosons: $t_2 = (\sqrt{U^2+16} - U)/4$

$$\hat{H} = \hat{H}_{BH} + \hat{T}$$

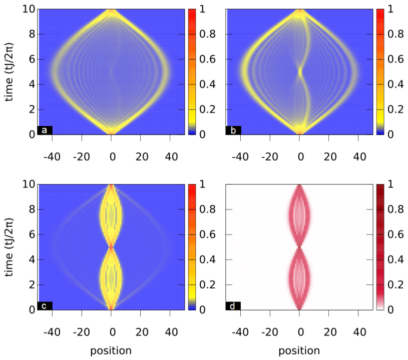
In tilted lattices system reveals Bloch oscillations:



We again divide density distribution into two sectors:

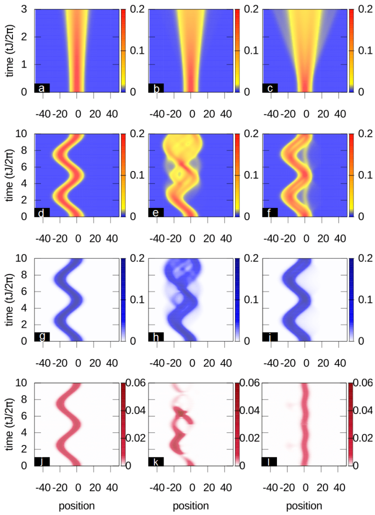


How evolution depends on the initial state?



Evolution for gaussian initial states:

U=0 U=1 U=10

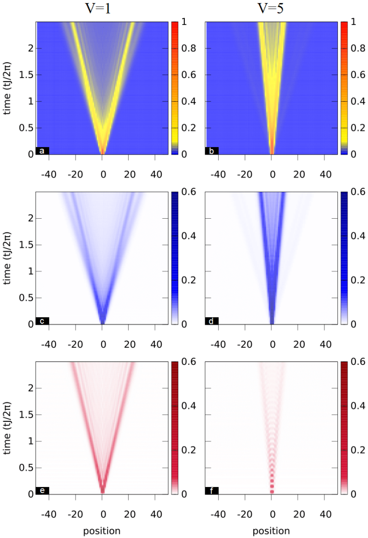


Evolution with long-range interactions:

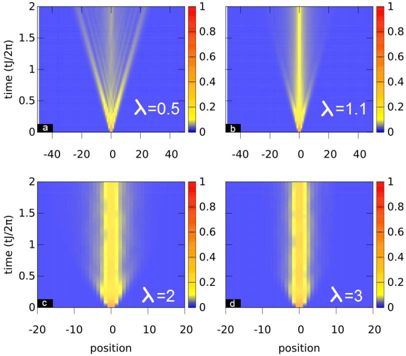
- Hamiltonian:
  $\hat{H} = \hat{H}_{BH} + \hat{V}$

  The lattice is not tilted !

- Long-range interactions speeds down expansion

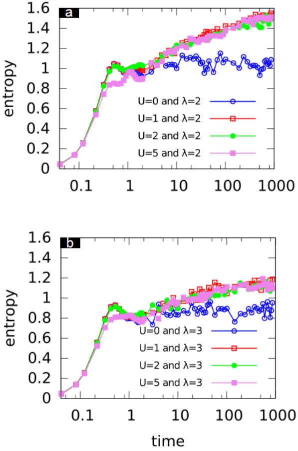


One-particle localization:



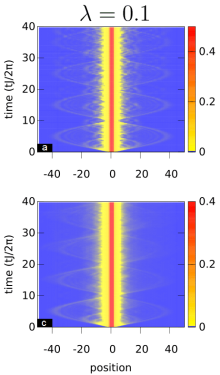
Aubry-Andre localization above threshold $\lambda = 2$

Entanglement entropy (two particle system) - logarithmic growth - signature of the MBL



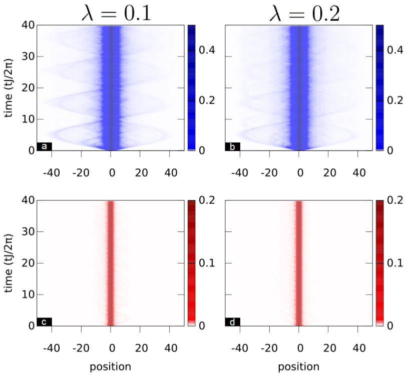
Experimental observation of MBL - Science 349, 842 (2015)

$$\hat{H} = \hat{H}_{BH} + \hat{T} + \hat{D}$$



Bloch oscillations in disordered media are damped!

Comparison between one-particle and two-particle sector:



- Quantum walks were successfully implemented in optical lattices (Greiner Lab)
- They reveal general quantum features like: Bloch oscillations, one-particle localization, MBL
- Evolution strongly depends on the initial state and parameters of the lattice
- Division of the density distribution into one-particle and two-particle shows explicitly different character of the evolution