Bose-Einstein condensate in time-dependent optical lattices

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cnrs dépasser les frontières

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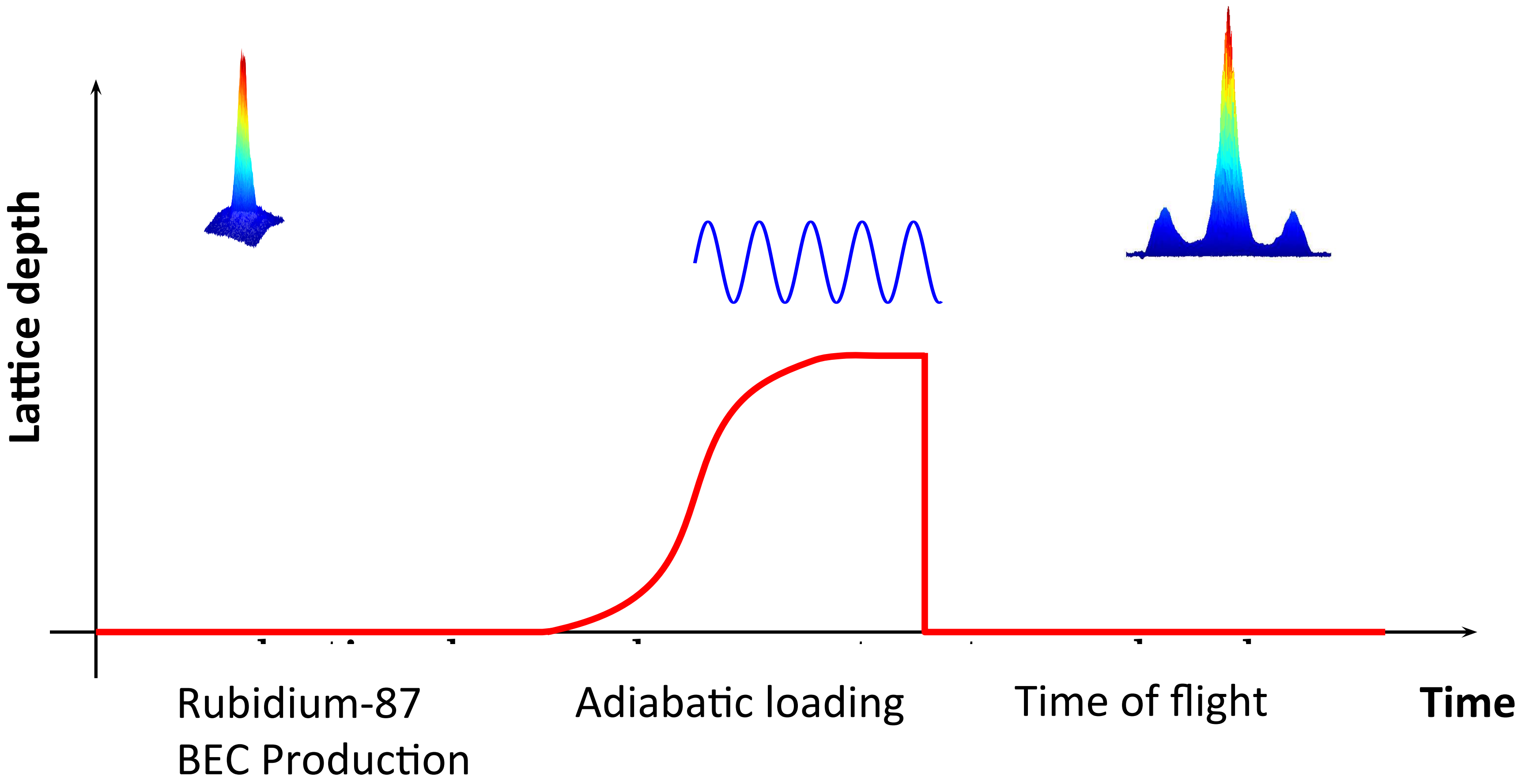
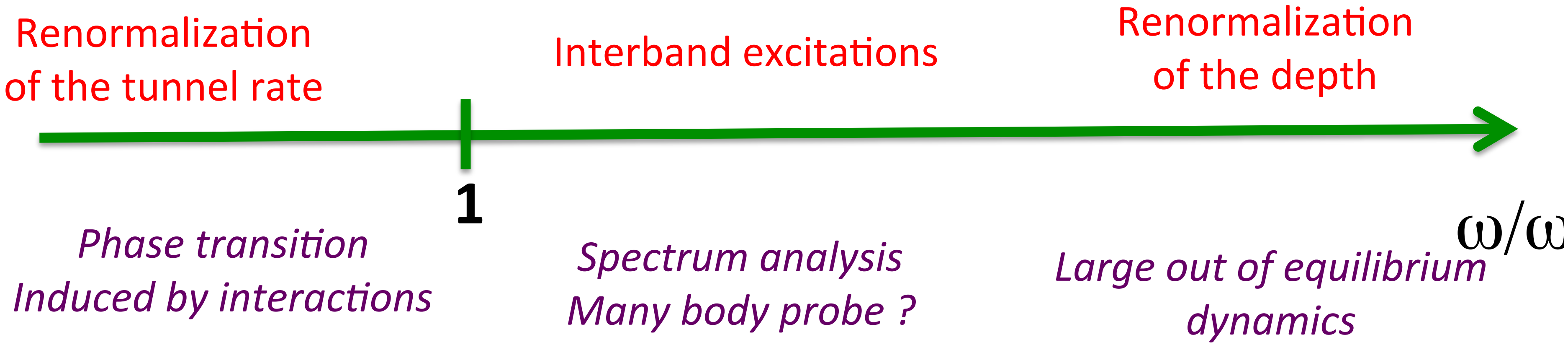
Workshop: **Quantum-Classical Transition in Many-Body Systems: Indistinguishability, Interference and Interactions** (Dresden)

Loading procedure of a 1D horizontal lattice



Outline

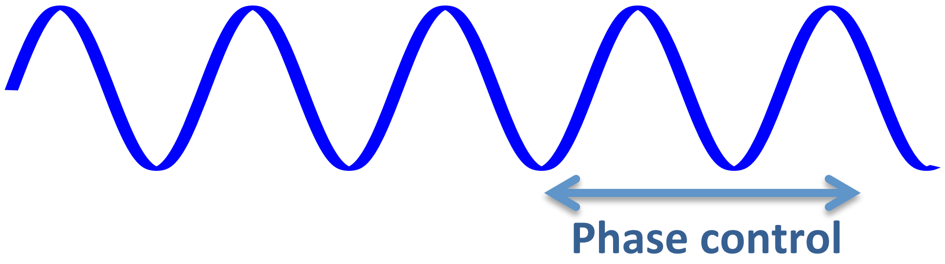


Fast sinusoidal phase shift → Renormalization of the potential

Sudden phase shift → Tunnel time delay, a micronsize Mach Zehnder interferometer

Slow sinusoidal phase shift → Phase transition induced by interactions triggered by a dynamical instability

Phase control of the optical lattice



$d = \lambda/2$ =532 nm

$$V(x) = \frac{1}{2} m\omega_{\text{ext}}^2 x^2 - sE_L \cos^2\left(\frac{\pi x}{d} + \theta(t)\right)$$

$$E_L = \hbar^2/(2md^2)$$

Renormalization of the tunnel rate

Interband excitations

Renormalization of the depth

Phase transition Induced by interactions

Spectrum analysis Many body probe ?

Large out of equilibrium dynamics

Outline

Renormalization of the tunnel rate

Interband excitations

Renormalization of the depth

1

ω/ω_0

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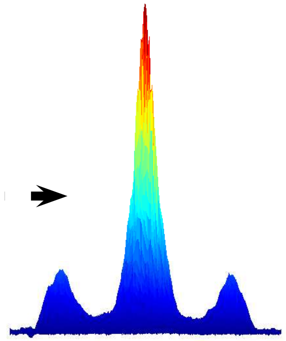
Fast sinusoidal modulation of the phase

Renormalization of the lattice depth

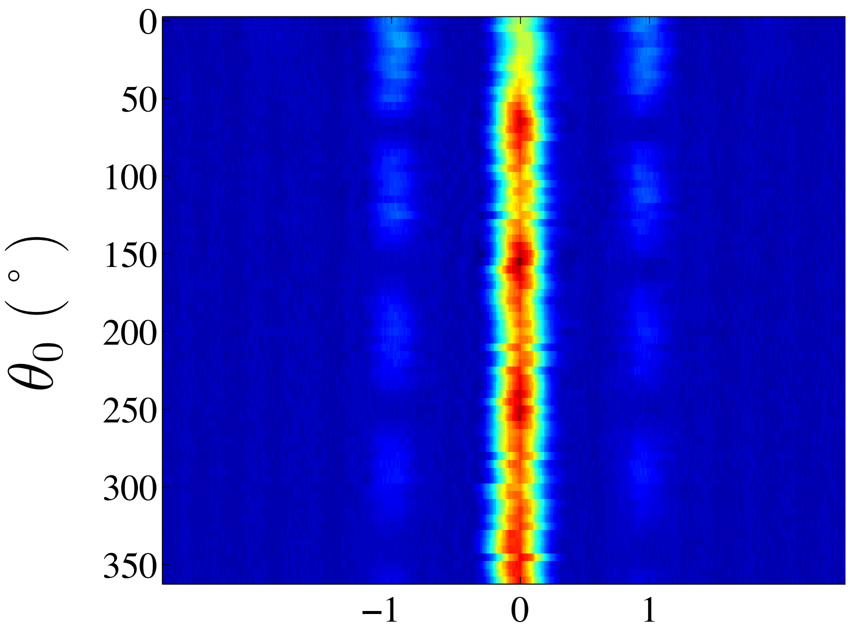
$$\theta(t) = \theta_0 \sin(\omega t) \qquad \omega \gg \omega_0$$

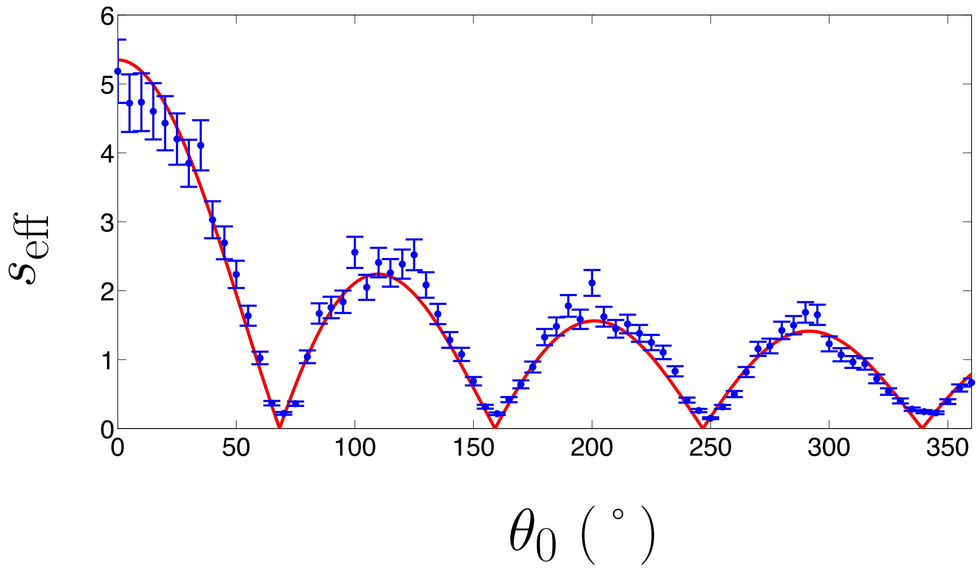


ency of modulation >> frequency of the micromotion

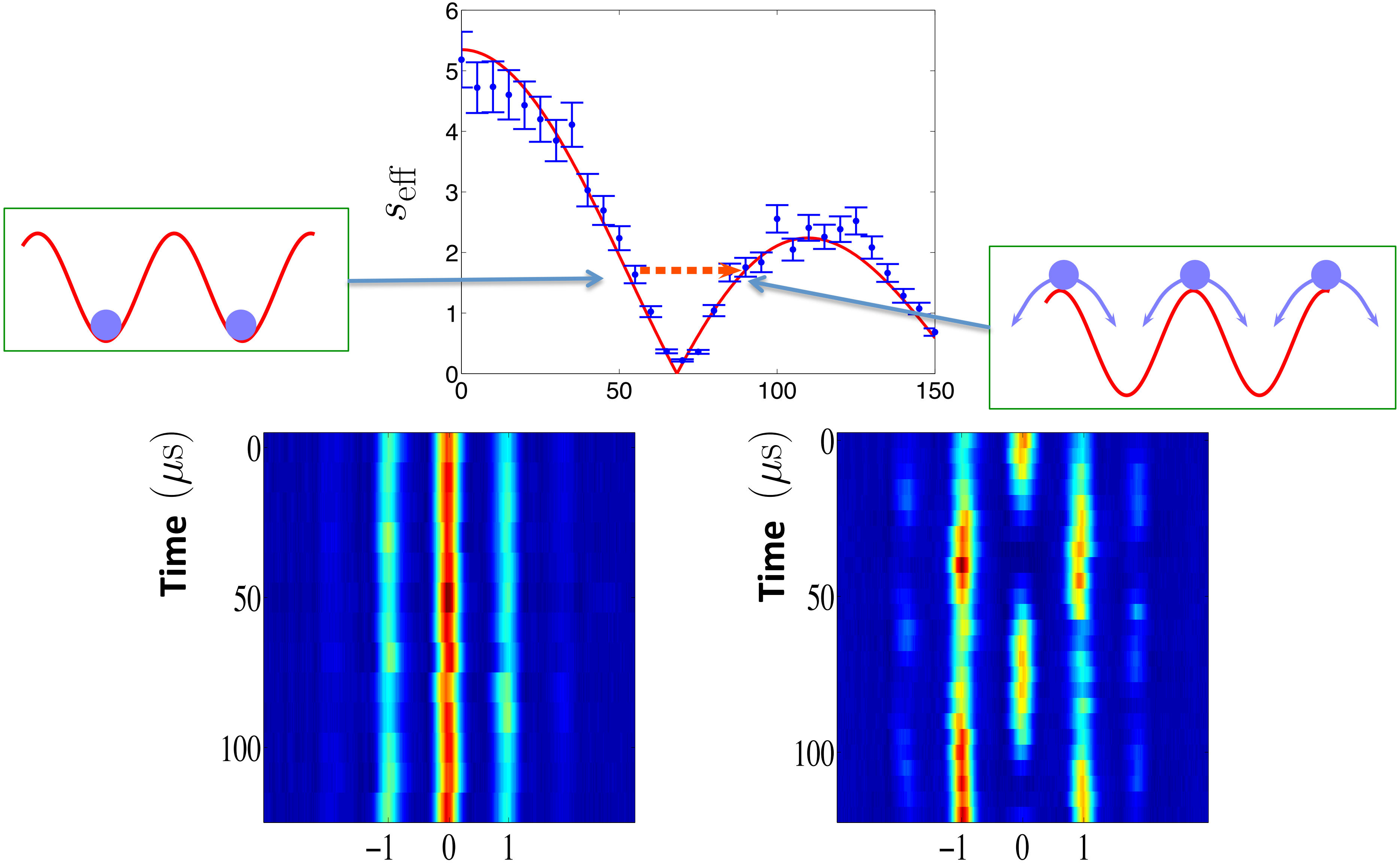
$$\langle V(x,t)\rangle = -sE_L\left(1 + \mathcal{J}_0(2\theta_0)\cos(k_L x)\right)$$

where $\mathcal{J}_0(2\theta_0)$ Bessel function order 0

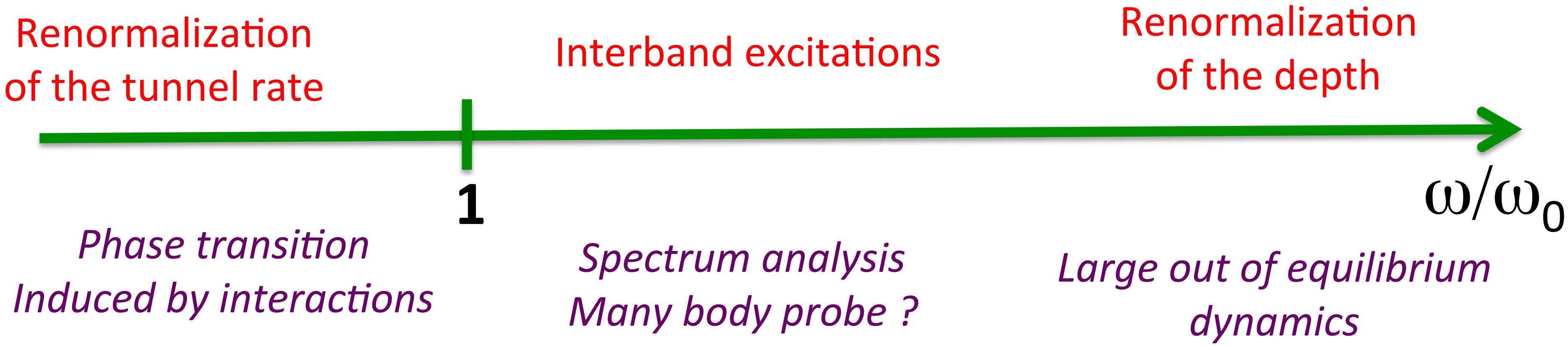




Phase reversal



Outline



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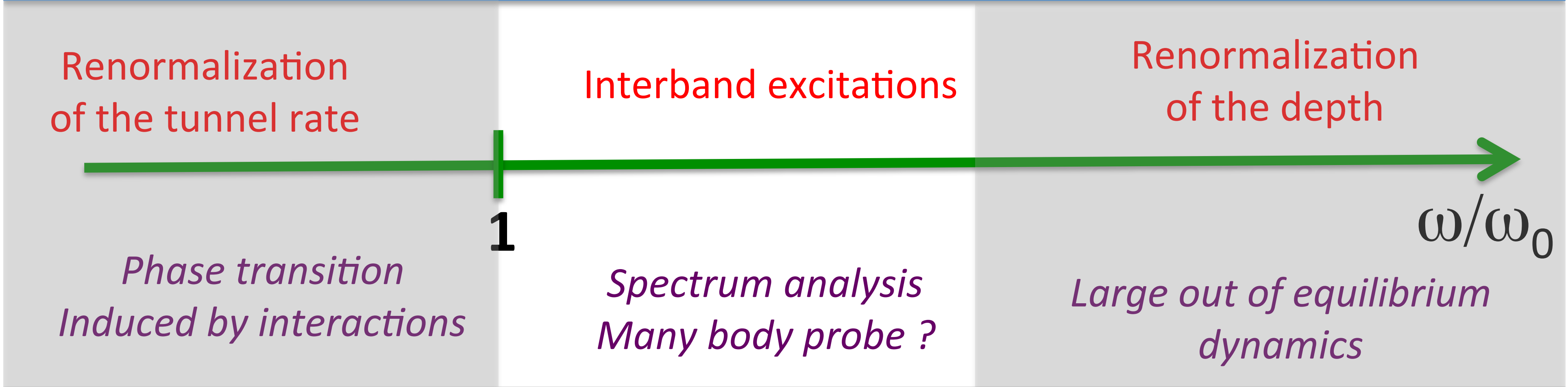
Outline



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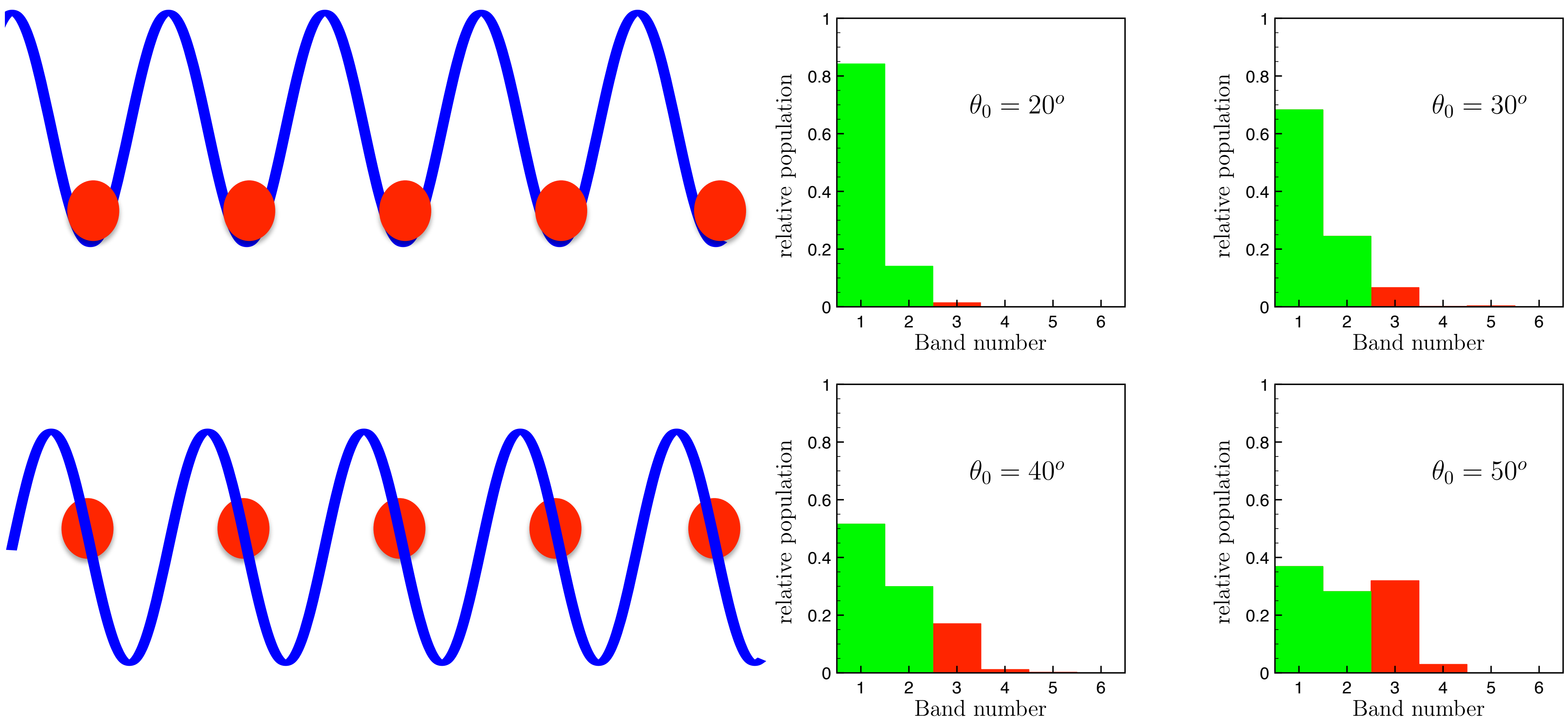
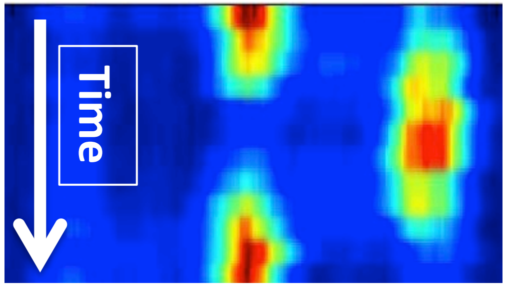
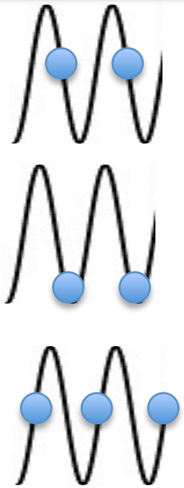
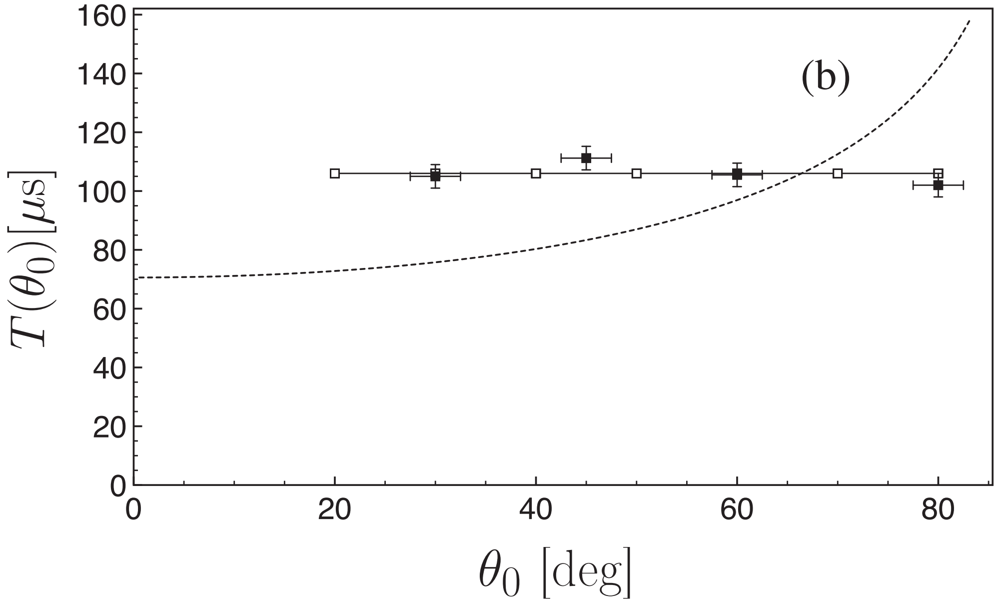
Initial state preparation: sudden phase shift



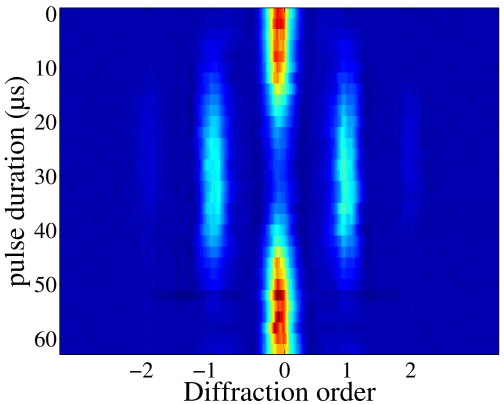
Oscillation period associated to the micromotion

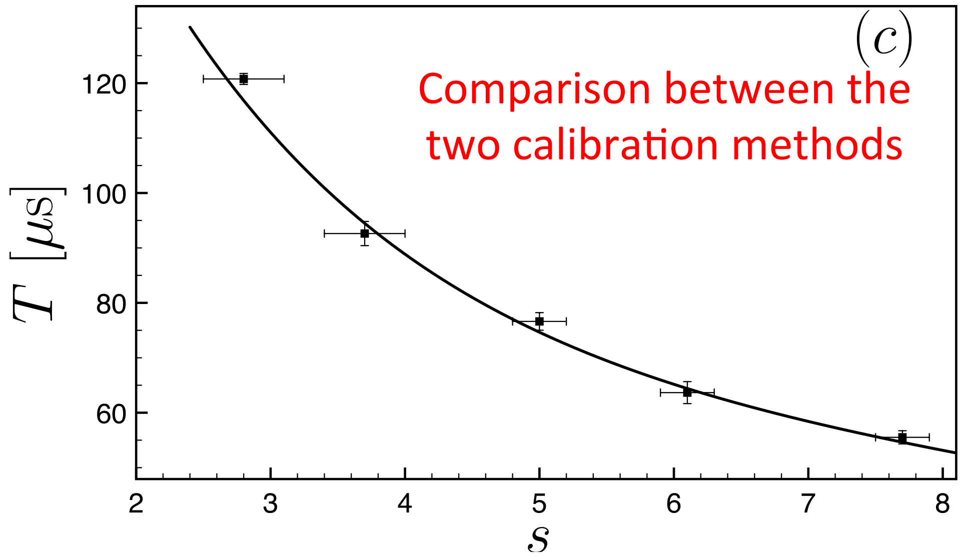




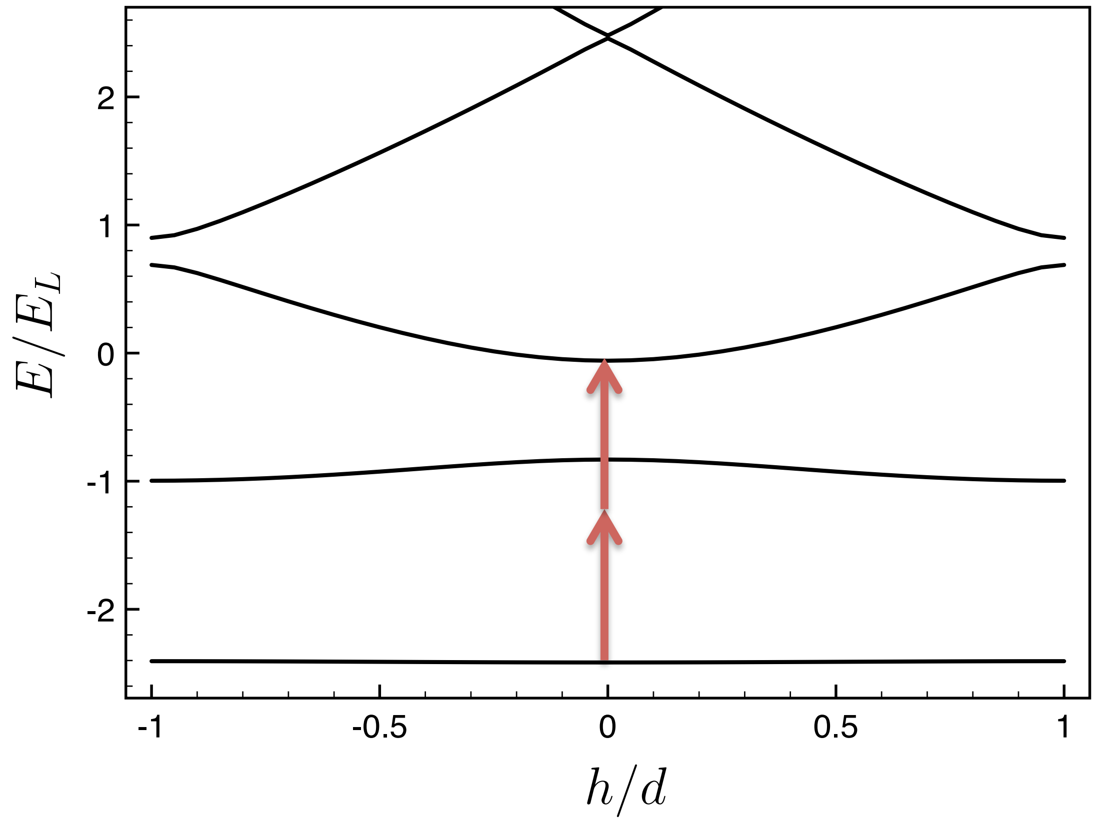


Calibration of the optical lattice depth
Kapitza Dirac





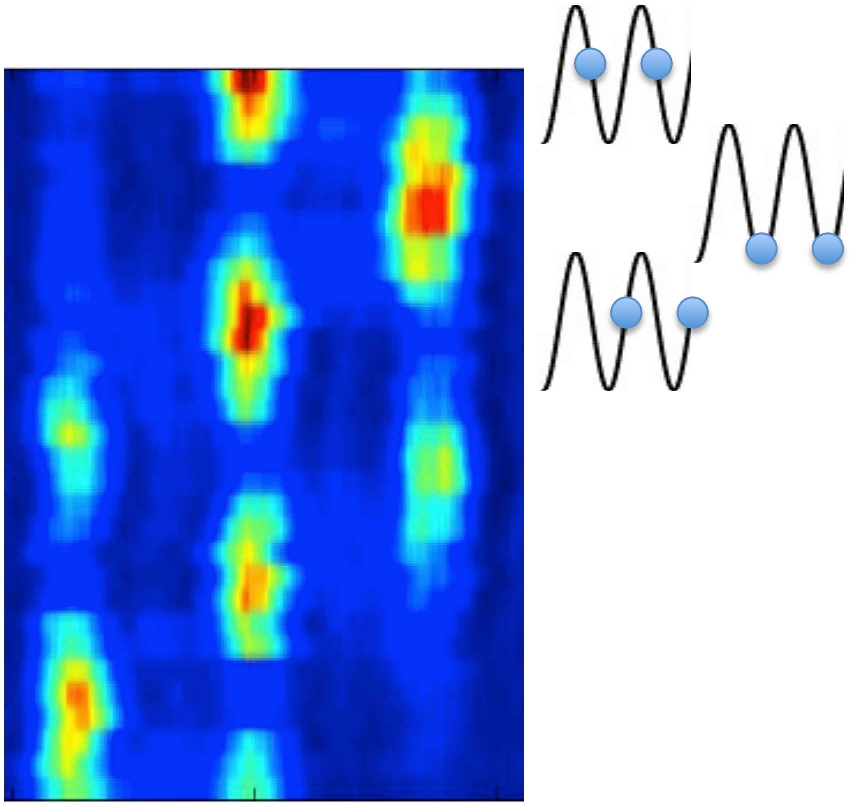
Interpretation of the intrasite dynamics



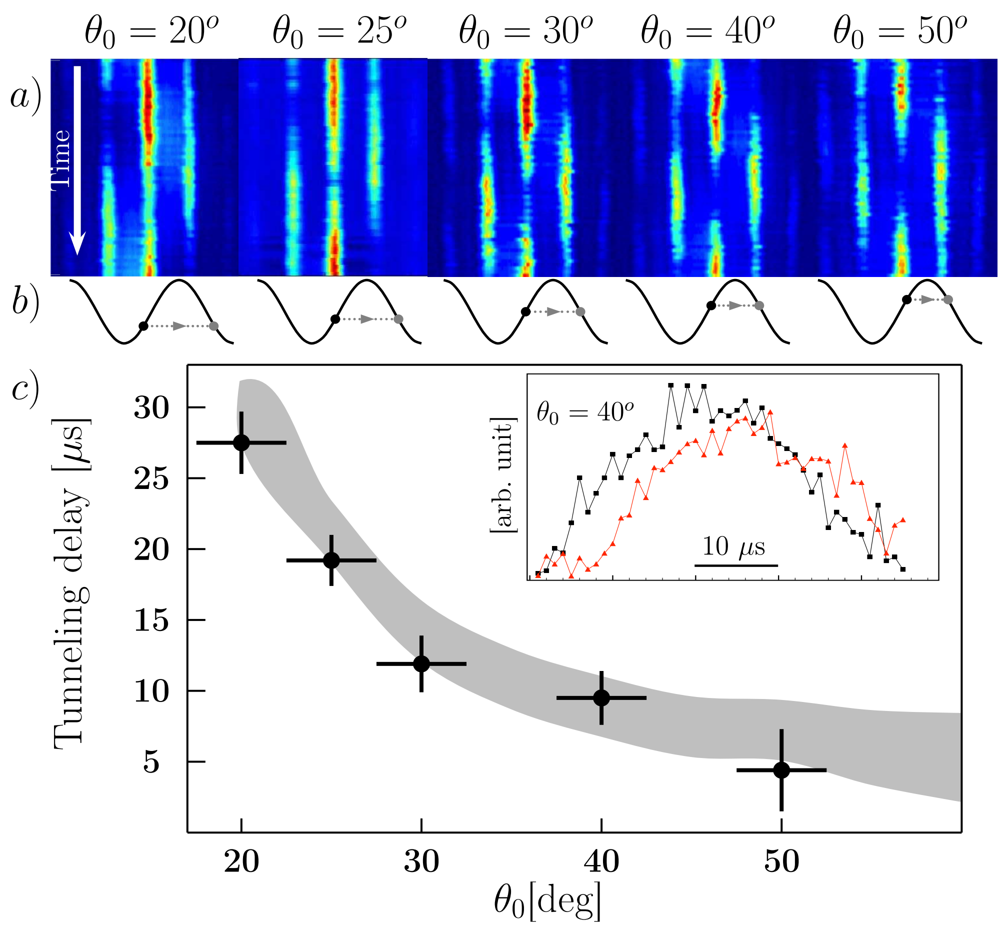
The two-phonon transition is coupled to the intrasite center of mass motion. This is the reason why the frequency of the dipole mode does not depend on the initial offset angle neither on interactions.

Direct tunneling time delay measurement

Time-of-flight
Information in velocity space



Experimental data



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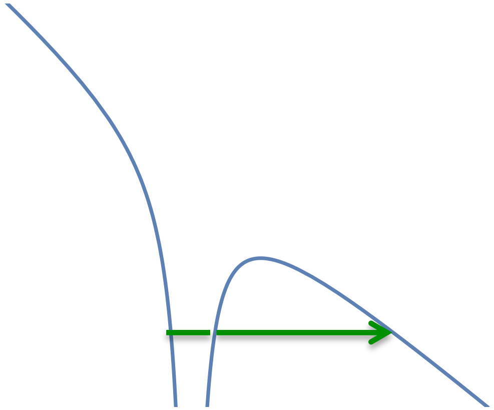
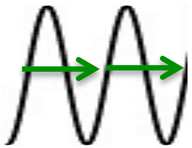
Tunneling time

Electron (strong field ionization process)



Mass	Barrier thickness	Tunneling time
10^{-30} kg	10^{-11} m	10^{-16} s

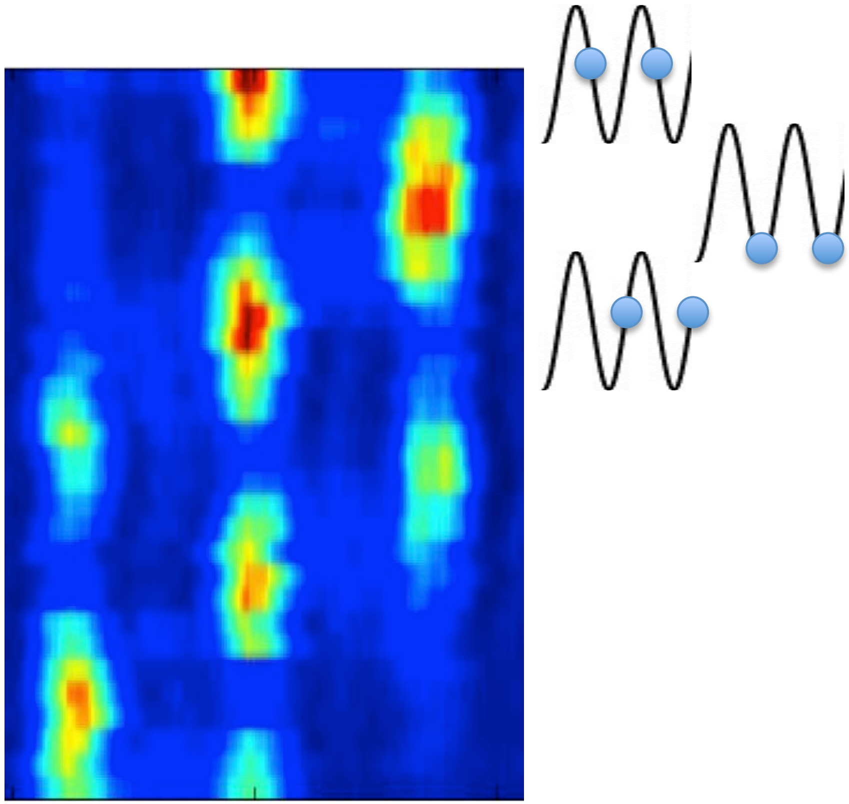
Atoms in optical lattice



Mass	Barrier thickness	Tunneling time
1.45 10^{-25} kg	10^{-7} m	10^{-5} s

Direct tunneling time delay measurement

Time-of-flight
Information in velocity space



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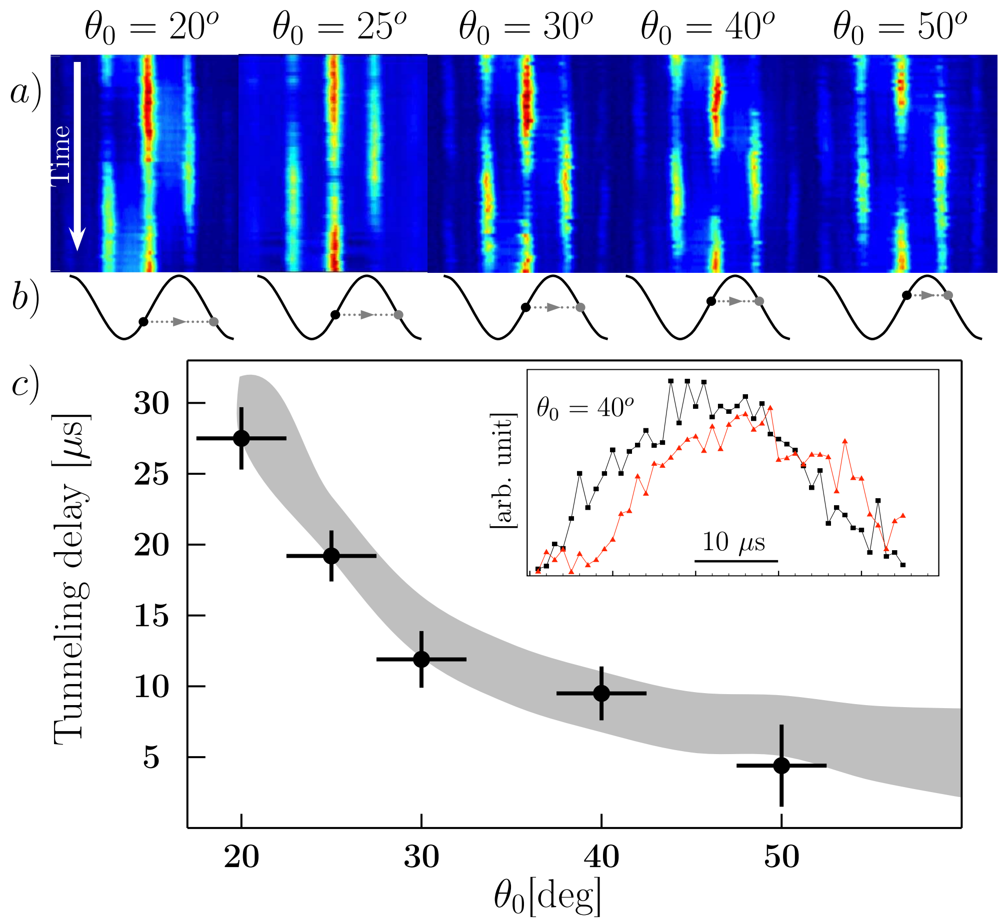


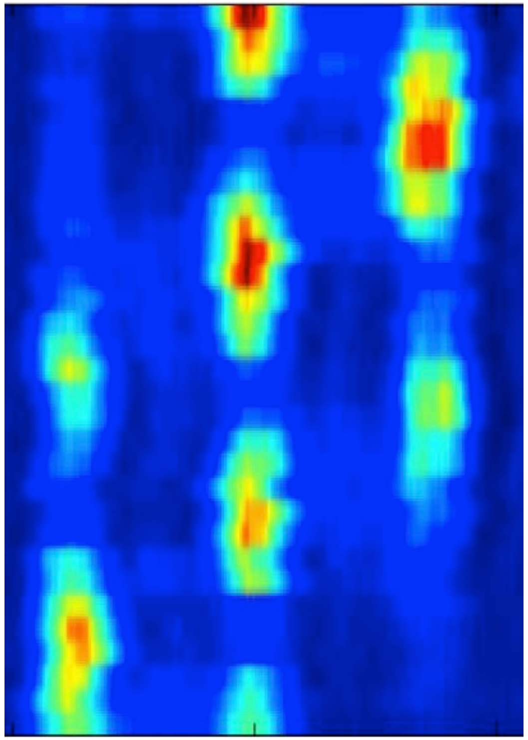
Beam splitter

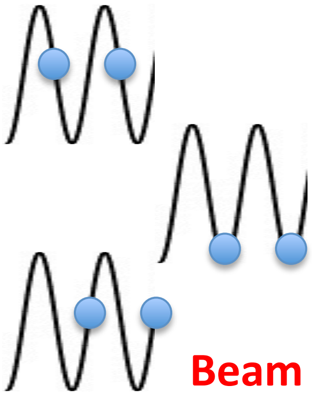
$$|D\rangle = \cos\varphi|p_0\rangle + i\sin\varphi|-p_0\rangle$$

PRL **107**, 010401 (2016)

Chain of micronsize Mach-Zehnder interferometer

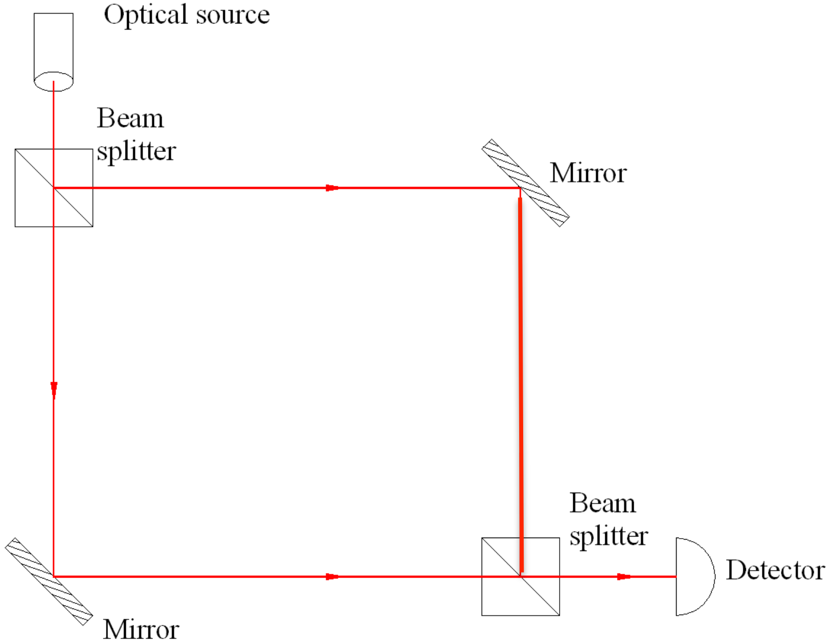
Time-of-flight
Information in velocity space





Beam splitter

Mach-Zehnder
Constructive
interference



First beam splitter

$$|D\rangle = \cos\varphi|p_0\rangle + i\sin\varphi|-p_0\rangle$$

Second beam splitter

$$\begin{aligned}|F\rangle &= \cos\varphi(\cos\varphi|p_0\rangle + i\sin\varphi|-p_0\rangle) \\ &+ i\sin\varphi(\cos\varphi|-p_0\rangle + i\sin\varphi|p_0\rangle) \\ &= \cos(2\varphi)|p_0\rangle + i\sin(2\varphi)|-p_0\rangle \\ &= i|-p_0\rangle \quad \text{for} \quad \varphi = \pi/4\end{aligned}$$

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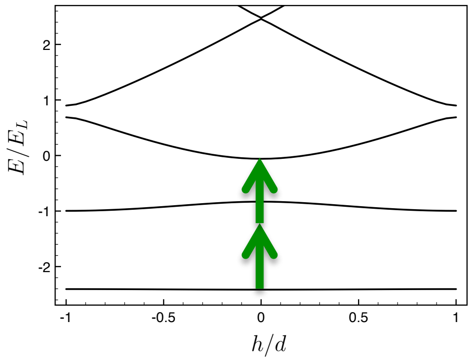
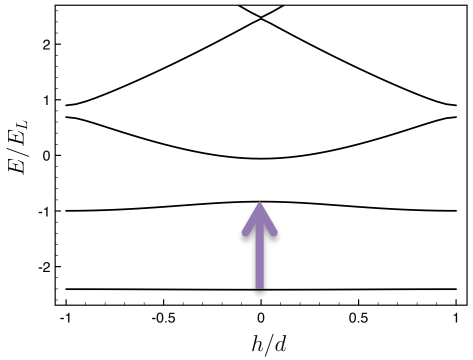
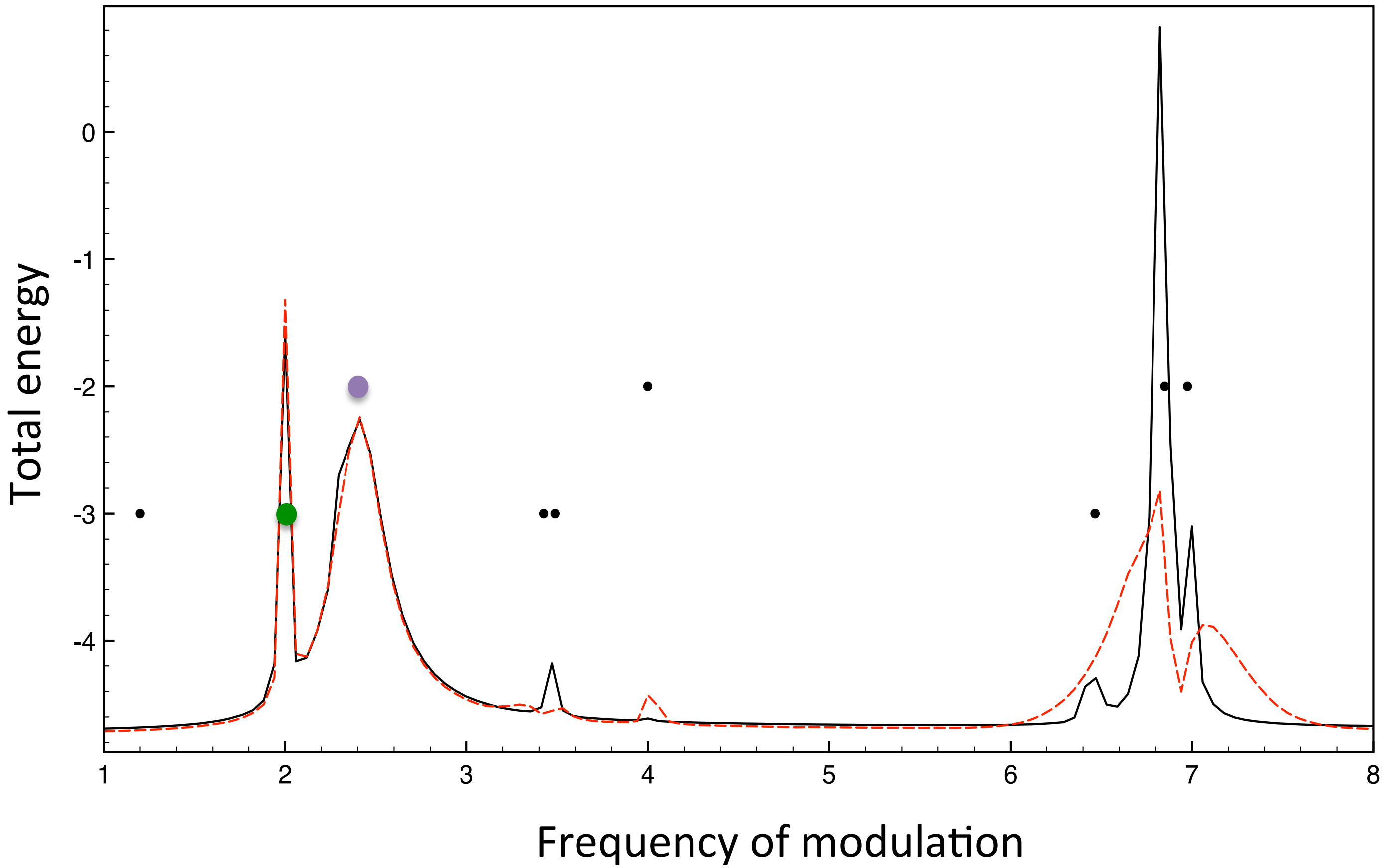
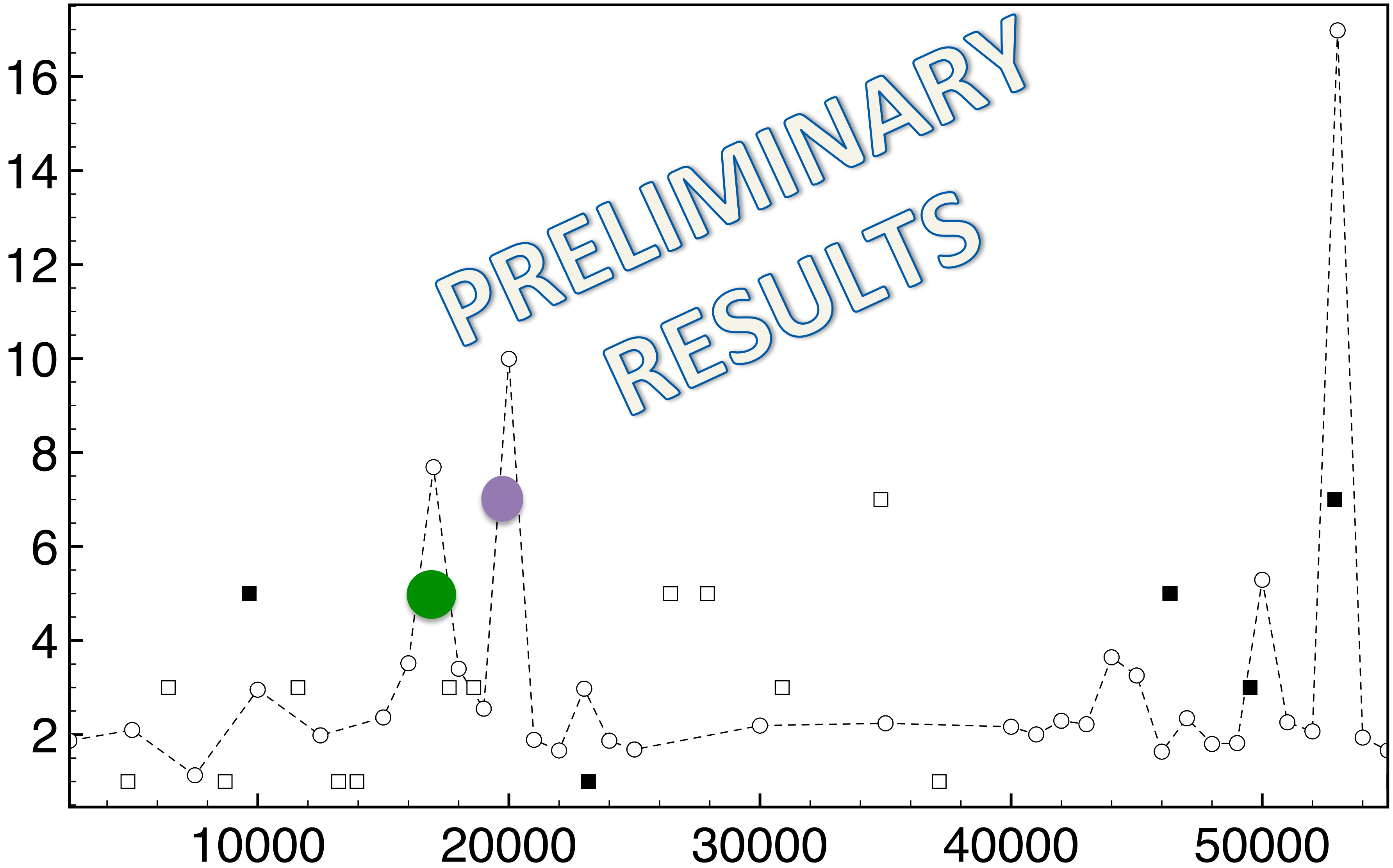
Spectroscopy as a probe of interactions (numerical results)







Spectroscopy as a probe of interactions (Experimental results)

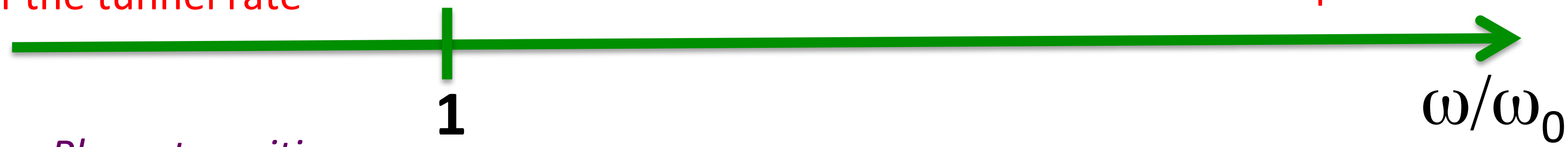


Outline

Renormalization of the tunnel rate

Interband excitations

Renormalization of the depth



Phase transition Induced by interactions

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Large out of equilibrium dynamics

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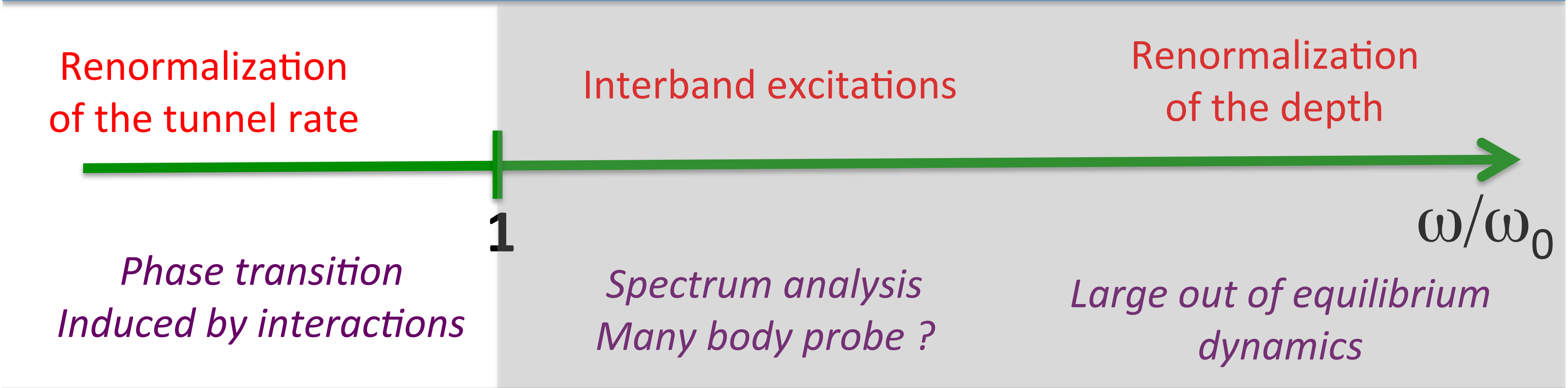

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Slow sinusoidal modulation of the phase

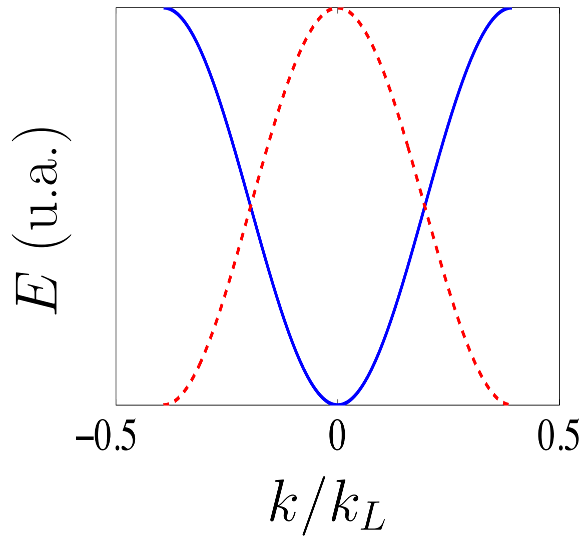
Renormalization of the tunnel rate (Chu, Arimondo, Oberthaler, Sengstock)

Frequency of modulation (2 kHz) $\varphi(t) = \varphi_0 \sin(\omega t)$ < frequency of the micromotion (10 kHz)

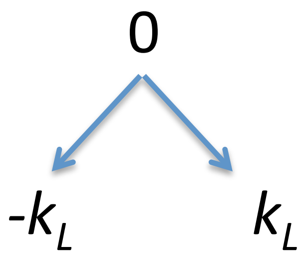
$$J \longrightarrow J J_0\left(\frac{2\pi m \omega \varphi_0}{\hbar k^2}\right) \qquad k = 2\pi/d$$

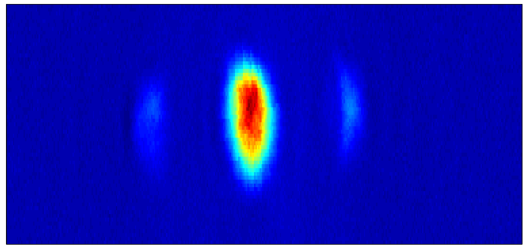
Qualitative picture

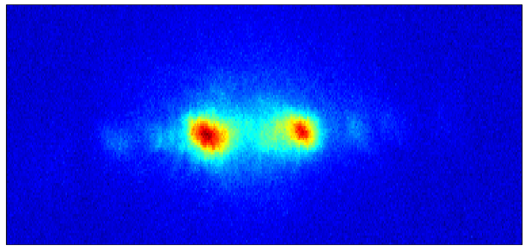
$$E_0(k) = -2J_{\text{eff}}\cos(kd)$$



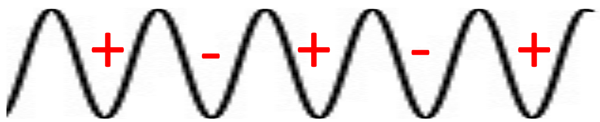
Spontaneous degenerate four wave mixing triggered by a dynamical instability







Staggered states

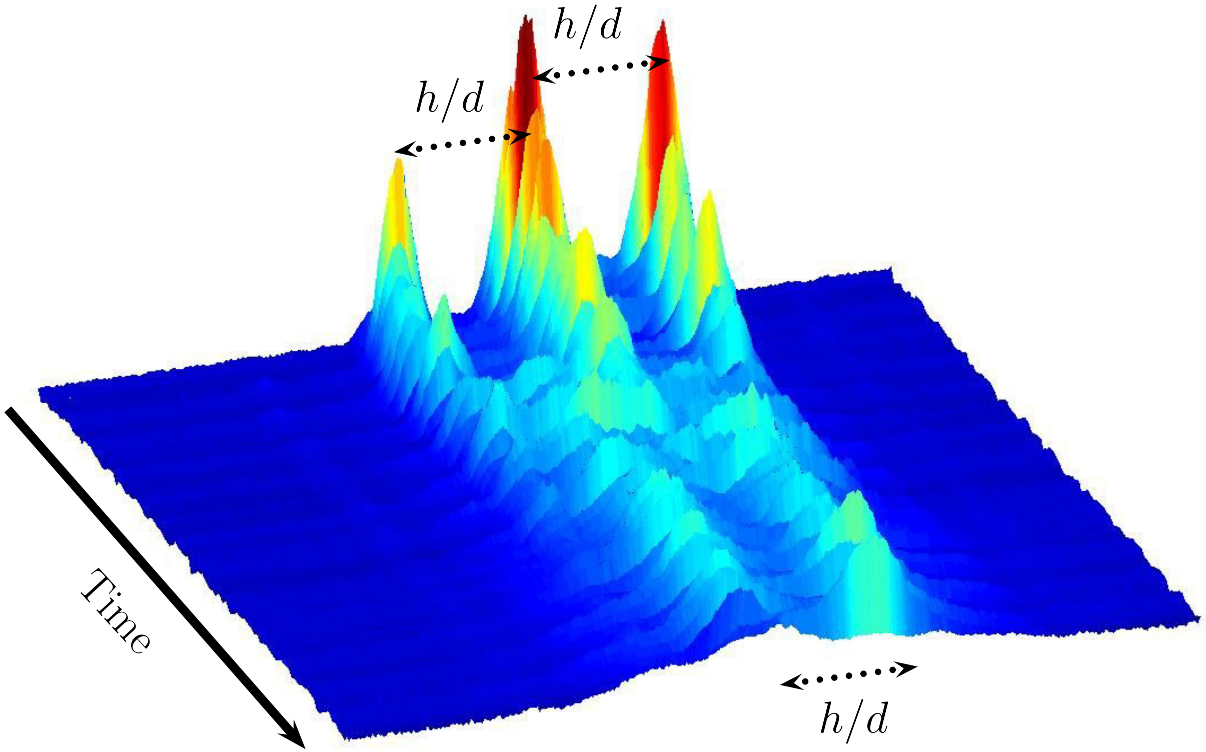


Systematic study of the kinetics

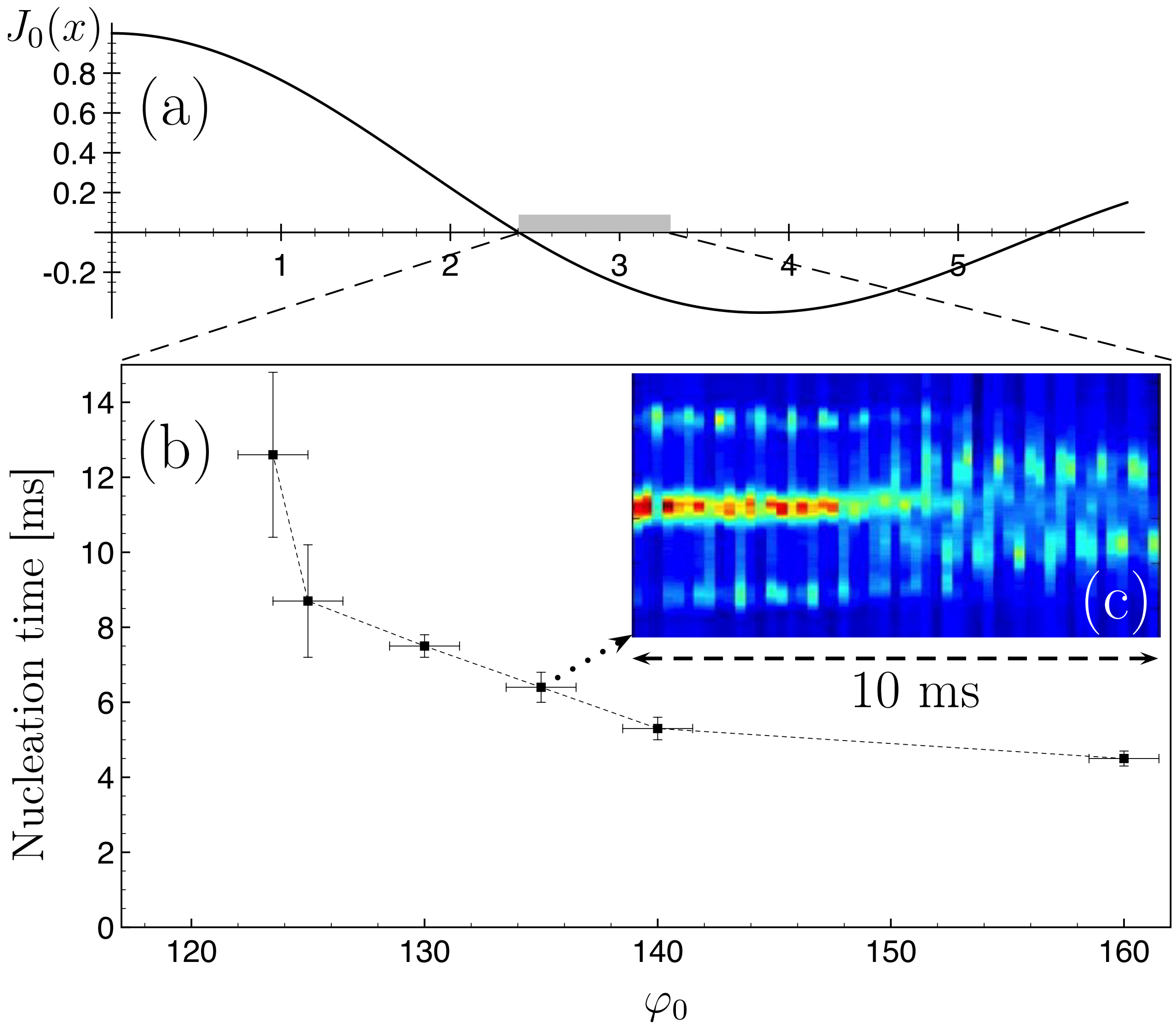
Bogolubov spectrum

$$(\hbar\omega)^2 = 4\bar{J}(1-\cos kd)(\bar{J}(1-\cos kd)+nU)$$

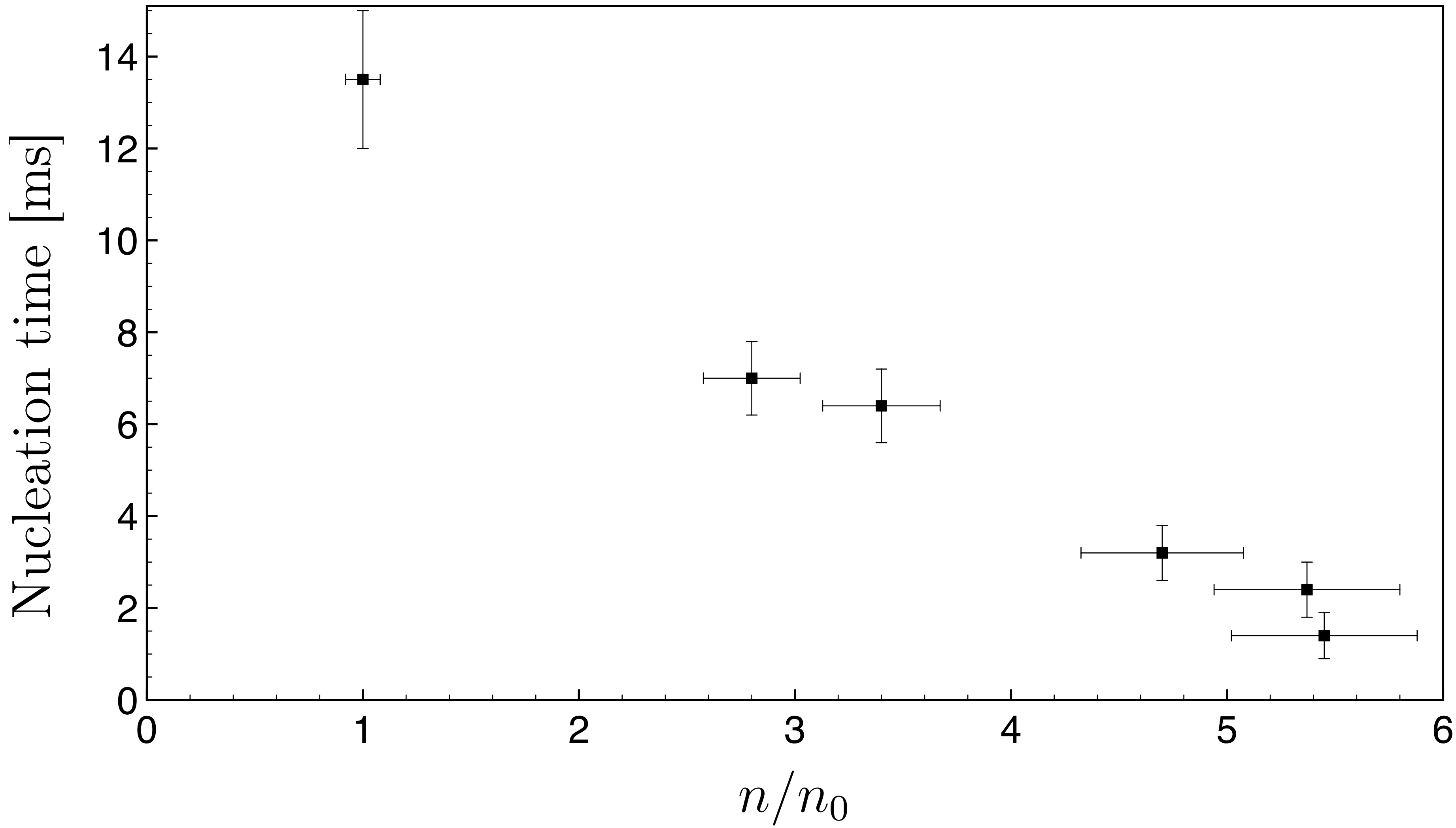
dependence in tunnel rate, J, and in the density



Nucleation of staggered states (1)

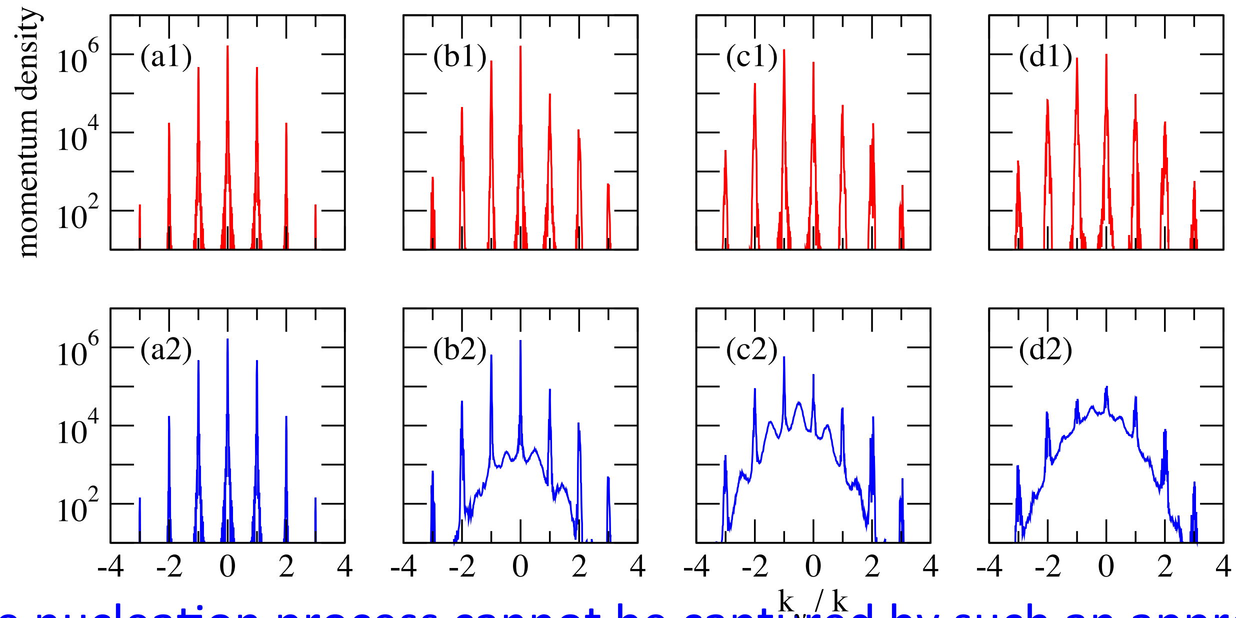


Nucleation of staggered states (2)



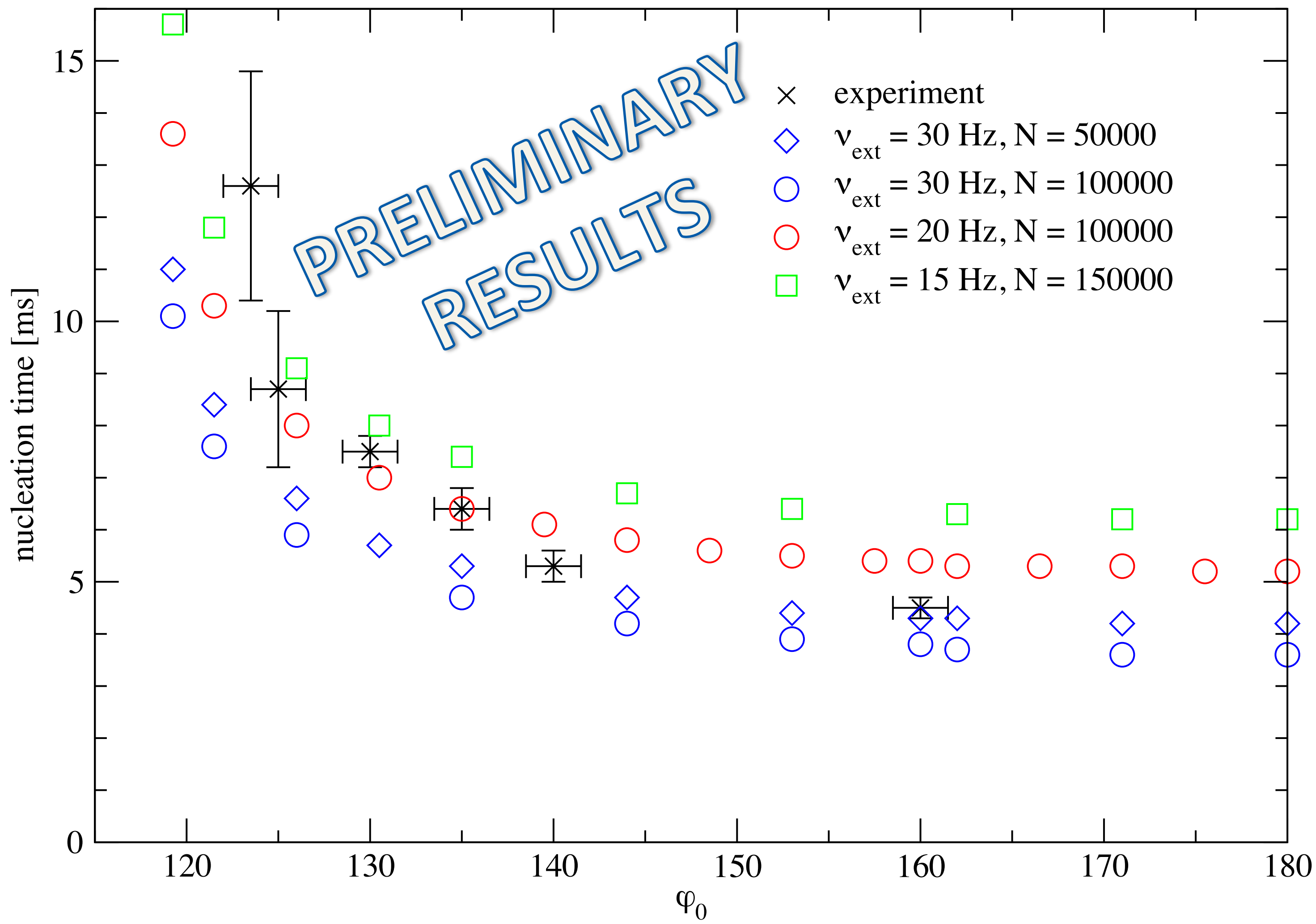
Comparison with theory

The traditional approach consists in using the Gross-Pitaevskii equation to account for the dynamics of Bose-Einstein condensates. This corresponds to a mean field approach.



The nucleation process cannot be captured by such an approach.
We are obliged to use beyond mean field approaches.
We setup a collaboration with the group of **Peter Schlagheck (université de Liège)** to develop such simulations within the Truncated Wigner approach.

Comparison with theory



Conclusion

Phase modulation →

- Renormalization of the potential
- Tunneling time delay
- Mach-Zehnder interferometer
- Quantum phase transition triggered by interactions

In situ probing of interactions ?

What about amplitude modulation ?

1 → ω/ω_0

Chaos assisted Tunneling regime
G. Lemarié
B. Georgeot
PRA **94**, 043621 (2016)

CBS-CFS
G. Lemarié
C. Muller
C. Miniatura
Arxiv:1612.02091v1 [cond-mat.quant-gas]

The Kapitza pendulum revisited
D. Shepelyansky
B. Georgeot
J. Martin