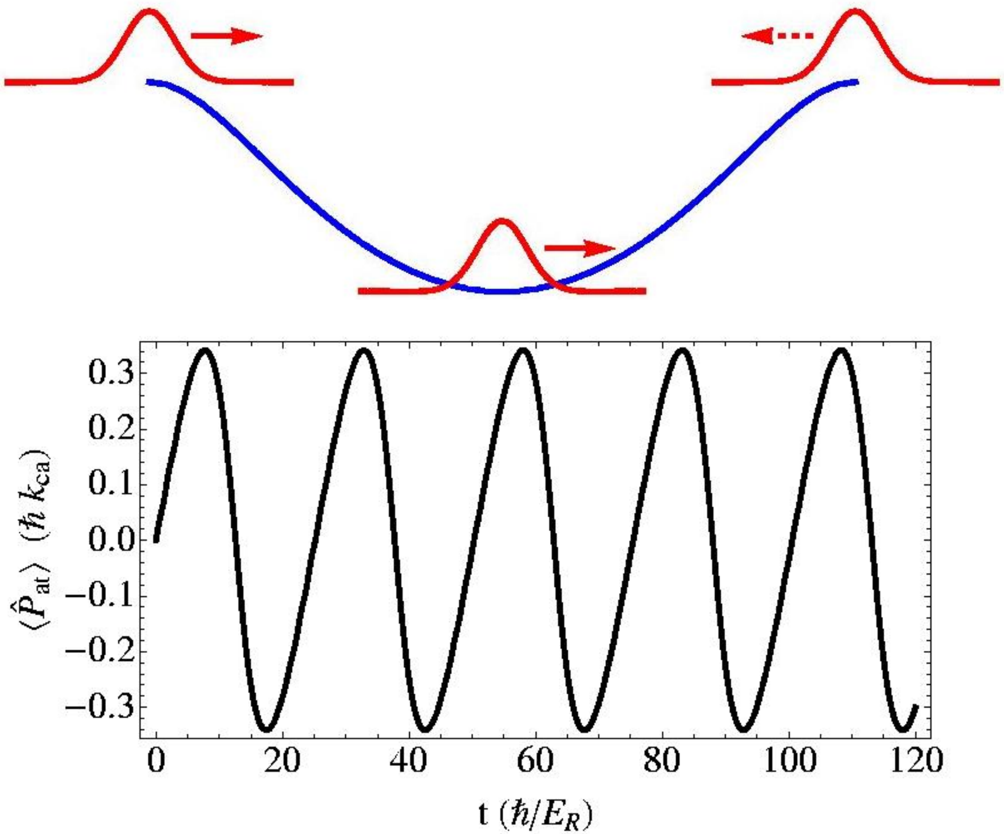
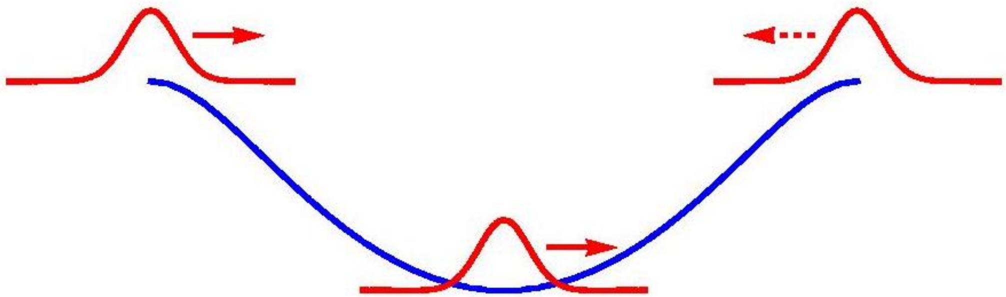
Testing the scheme: Bloch oscillations

Bloch oscillations: general



- **Initial wavepacket localized in quasimomentum**
- **Average quasimomentum changes linearly in time** $\langle q \rangle(t) = \langle q_0 \rangle + mgt$
- **Average atomic momentum oscillates in time @ frequency mgd**
- **Bragg reflection occurs at Brillouin-zone boundary** $v_g(t) = \frac{1}{\hbar}\frac{dE}{dk}$

Bloch oscillations: Signal

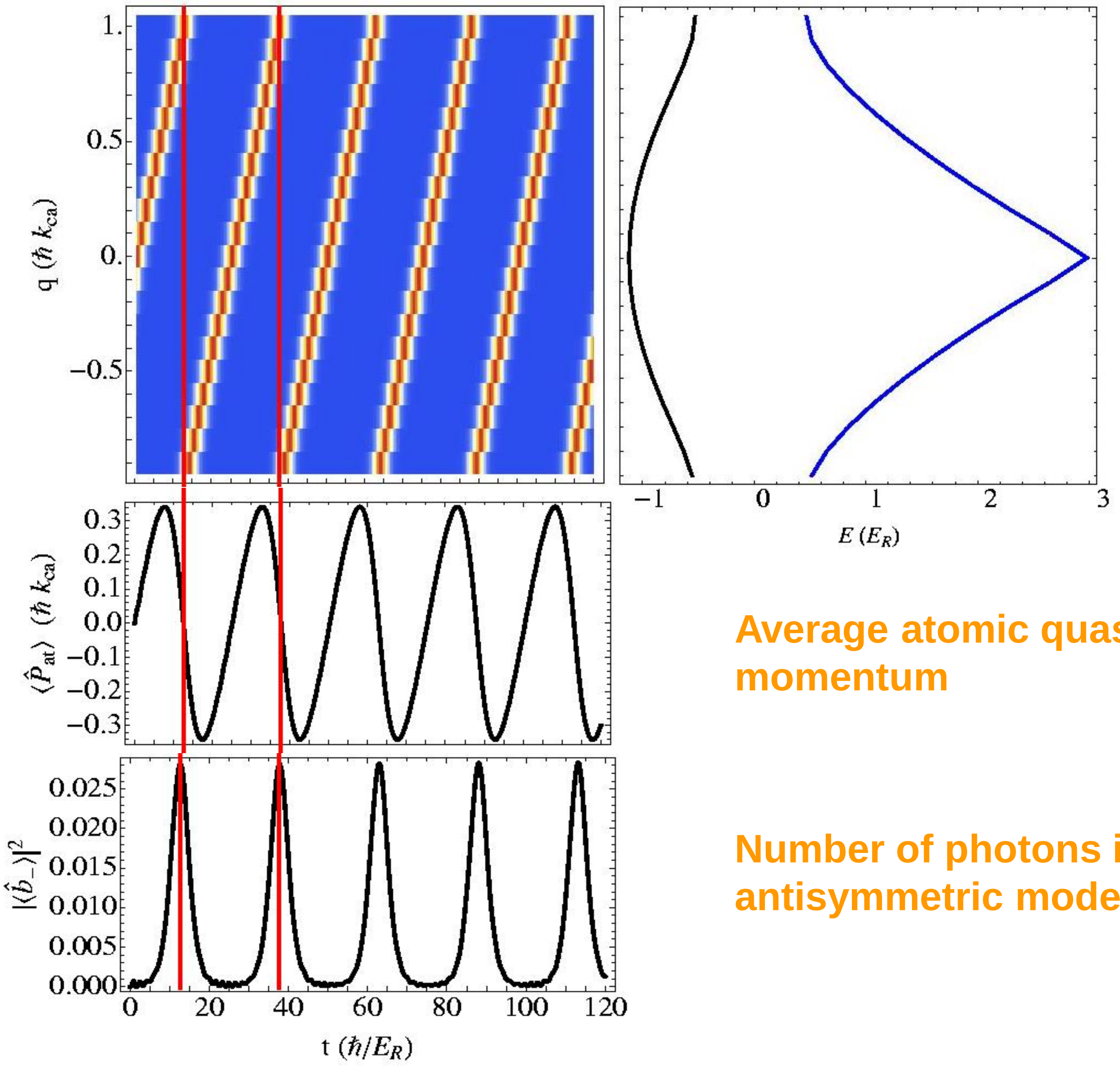


$$\langle \hat{b}_-(t) \rangle = \frac{-ig_0\beta}{\Delta_p + i\kappa/2} N_a \langle \psi | \overbrace{\sin(2k_{ca}\hat{z})}^{e^{i2k_{ca}\hat{z}} - e^{-i2k_{ca}\hat{z}}} | \psi \rangle$$

- **Photons are exchanged between lattice beams**
- **Momentum change of atoms is reflected in the amplitude of the sin mode**

Results

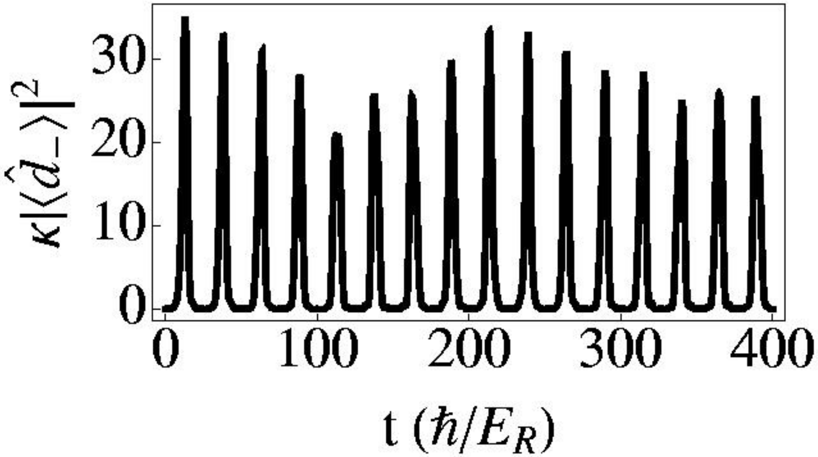
Atomic density vs. (q,t)

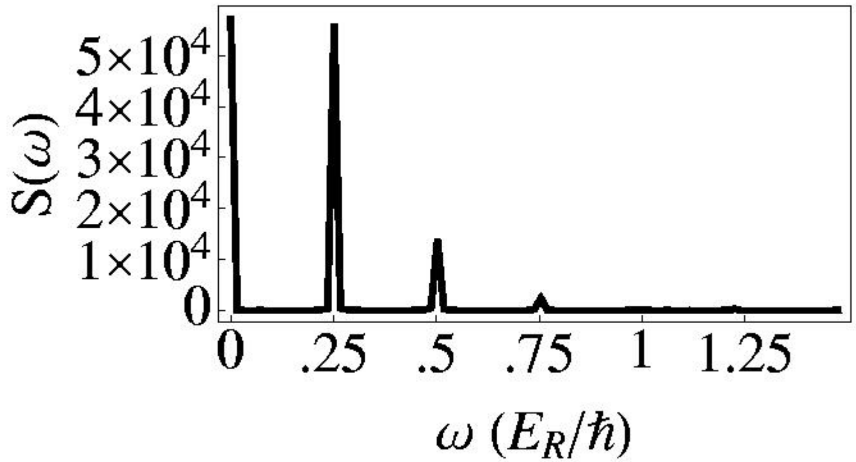


Average atomic quasi-momentum

Number of photons in the antisymmetric mode

Results: Signal





- **System parameters:**
  - -- $N_a = 10^4$
  - -- k = 100 E_R (linedewidth)
  - -- $\omega_B = 0.25\ E_R$
  - -- Interrogation time = 1 s

- **Bloch oscillation signal persists**

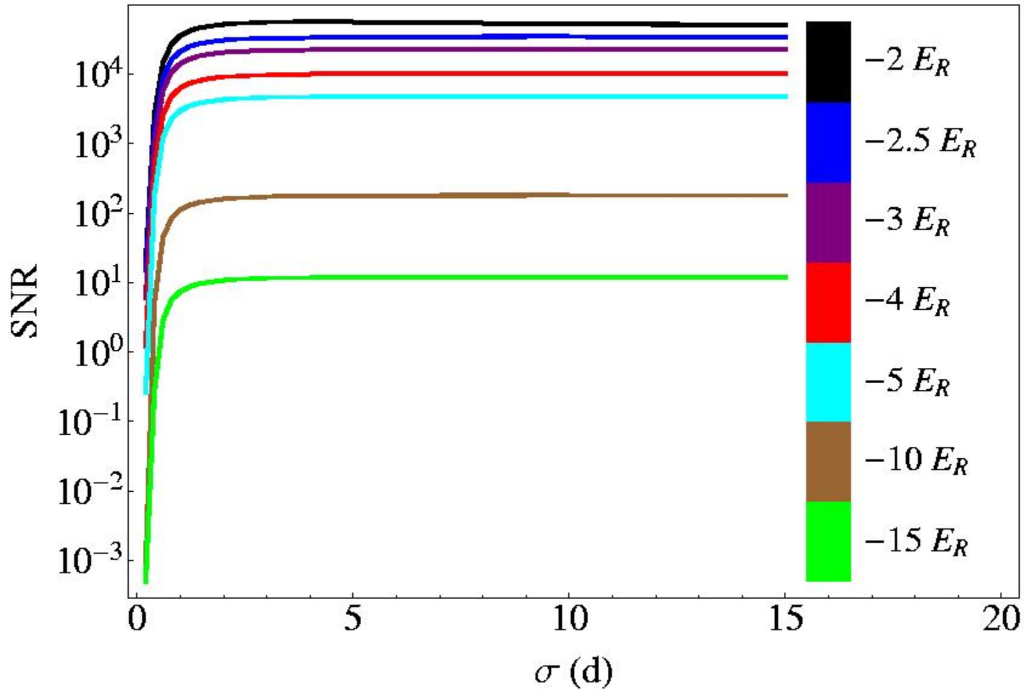
- **Power spectrum has peaks at harmonics of ω_B**

Results: SNR

$$SNR \sim \int d\omega \left| \sqrt{\kappa} \langle \hat{b}_- \rangle (\omega) \right|^2$$

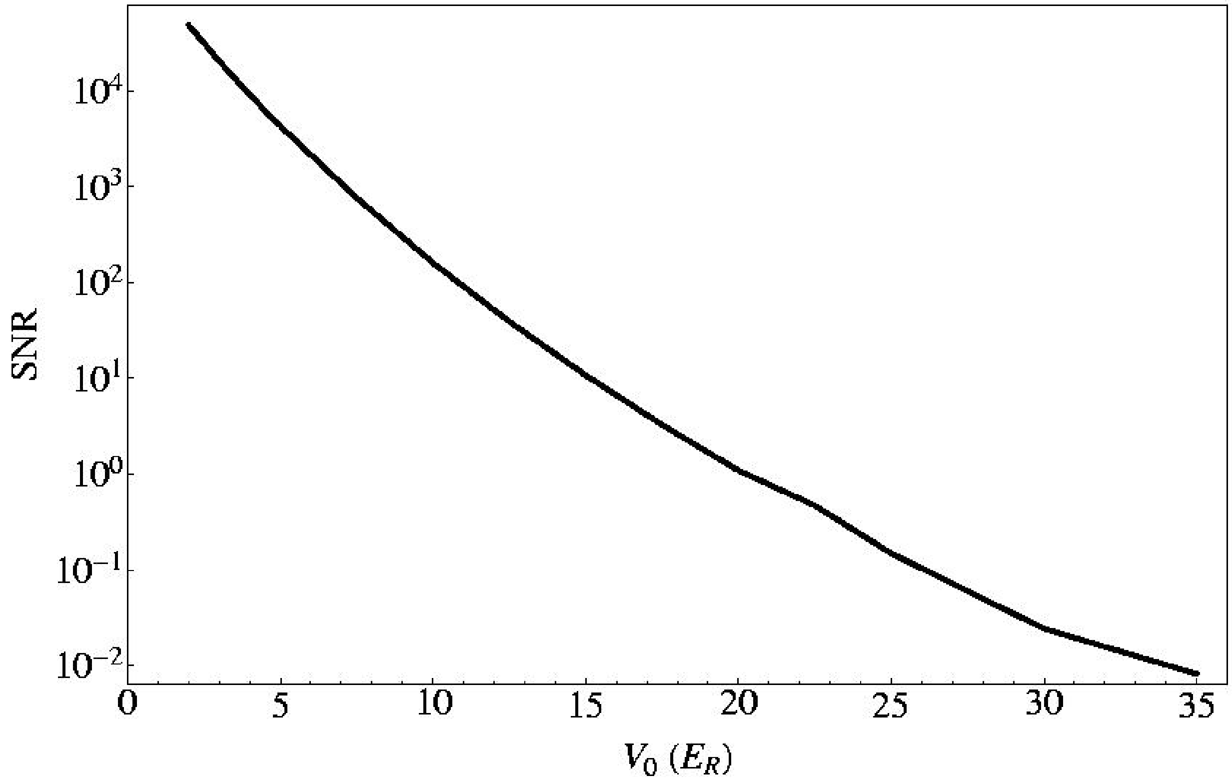
- **SNR goes as the number of outcoupled antisymmetric photons**
- **We integrate only over a single peak, after applying a notch filter**
- **SNR is influenced by wavepacket initial width, by lattice depth, by coherence of Bloch oscillations**

Results: SNR vs. Wavepacket width σ



- **SNR saturates for σ approximately 2d**
- **SNR for σ < 2d : wavepacket is continually crossing BZ boundary**

Results: SNR vs. Lattice depth V_0



- **SNR decreases exponentially with V_0**
- **SNR is of order 10 @ V_0 of order 15 E_R**
- **SNR below V_0 =2 E_R dominated by LZ tunneling**

Summary: Summary

- **Proposed an optical detection scheme for atomic dynamics in an external potential**

- **Advantages: non-destructive, real-time, minimum apparatus needed**

- **Possibility to address single atoms by appropriate tuning of lattice constant with respect to cavity size**

- **Tested the scheme to detect weak Bloch oscillation signal with SNR as high as 10^4**

- **Future: applications to characterization of many-body, strongly correlated states and dynamics**

Summary: Future

- **Use of Bloch oscillation breakdown as a way to characterize strongly-correlated atomic systems**

- **Beyond the DC-nature of Bloch oscillations: setting of AC probes such as lattice shaking or amplitude modulation techniques [Tino& Inguscio groups @ Florence] for determination of static and dynamic structure factors**

- **Possibility of improving SNR by:**

  --- Decreasing linewidth (while remaining in bad-cavity limit though!)

  --- Increasing atom-cavity field coupling g_0

  --- Increasing number of atoms N_a while working with narrow momentum distribution so to make SNR scaling with N_a^2

Acknowledgements

Conversations with Jun Ye, Ana Maria Rey, Victor Gurarie