Coherence and decay within Bose-Einstein condensates – beyond Bogoliubov

N. Katz[1], E. Rowen[1], R. Pugatch[1], N. Bar-gill[1] and **N. Davidson[1]**,

I. Mazets[2] and **G. Kurizki[2]**

(R. Ozeri and J. Steinhauer)

1. Department of Physics of Complex Systems,
2. Department of Chemical Physics,

Weizmann Institute of Science, Rehovot 76100, Israel

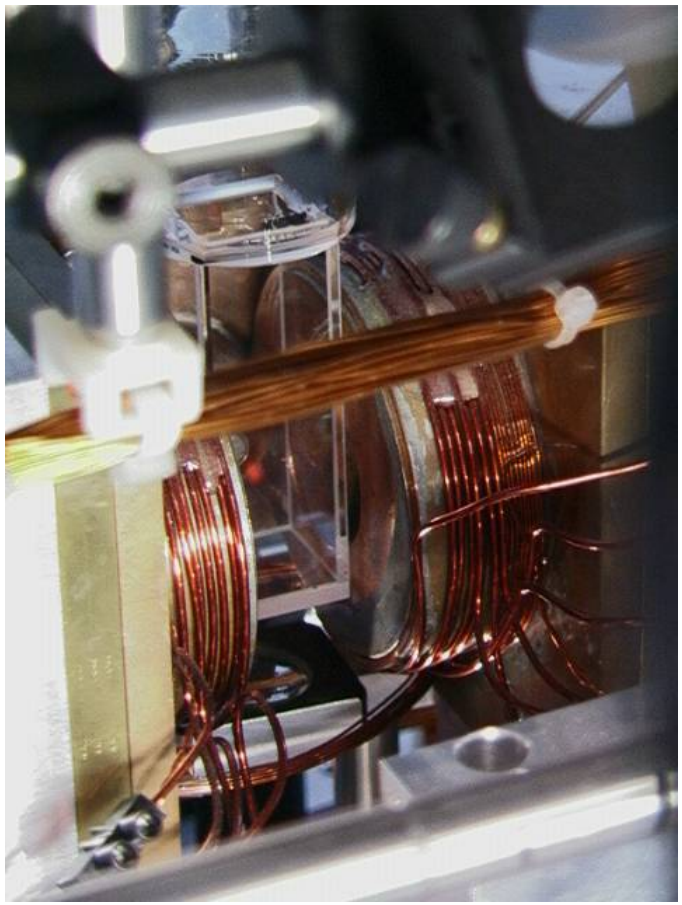
For more information – see my webpage: **www.weizmann.ac.il/home/katzn**

Outline

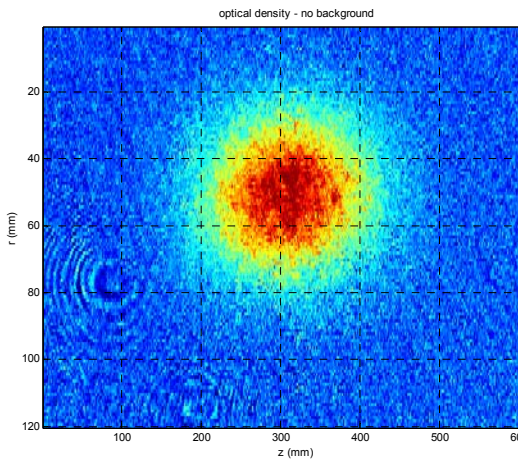
- Weak Bogoliubov excitations
  - Fringe spectroscopy
- Strong Excitations
  - Spectrum of BEC oscillating in a lattice
  - Time domain – suppression of dephasing
  - Decay of these states
- Probing many-body correlation times (theory)

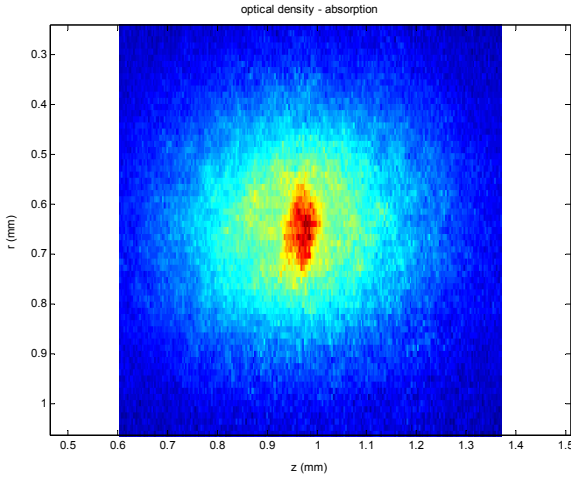
Experimental set-up

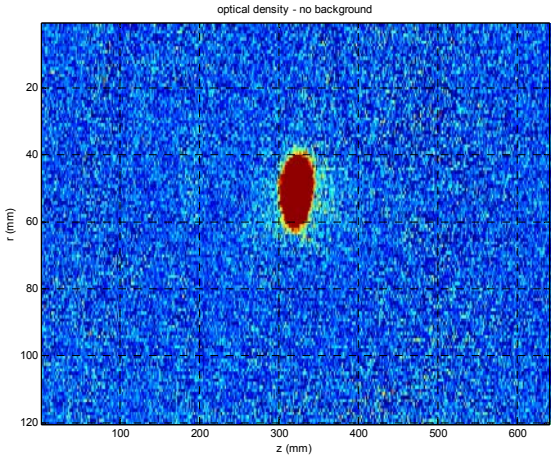
- ^{87}Rb atoms in the $|F, m_F\rangle = |2,2\rangle$ ground state.
- *N_0 = 1-5x10 ^{5} atoms*.
- *$T \sim 0.3\ T_c \sim 100$ nK*
- *~95% of atoms in the ground state*
- *Chemical potential μ/h = 2 – 4 kHz*

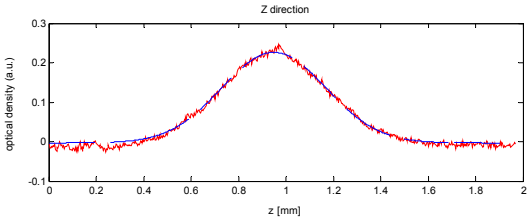


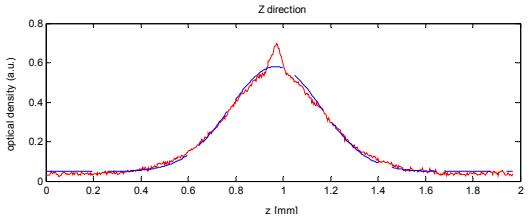
Time of flight (absorption imaging)

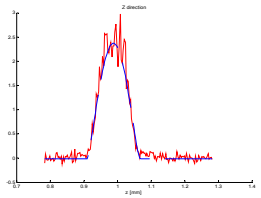












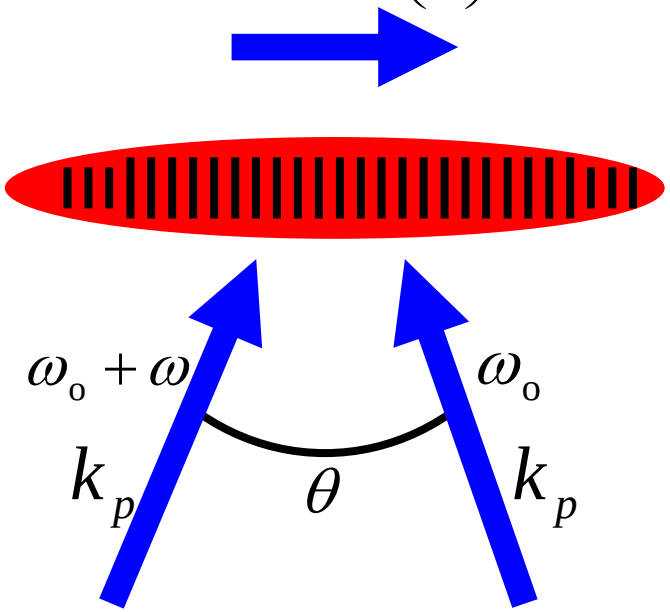
T>Tc

T=Tc

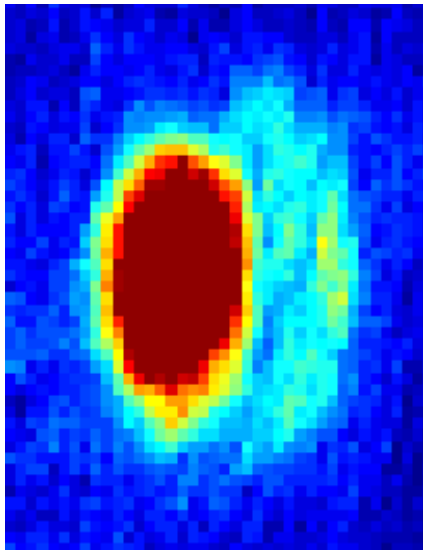
T<Tc

Bragg Spectroscopy

$$k = 2k_p \sin\left(\frac{\theta}{2}\right)$$



TOF image of an excited condensate



J. Stenger et al., PRL 82, 4569 (1999) (Ketterle); M. Kozuma et al., PRL 82, 871(1999) (Phillips); J. Steinhauer et al., PRL 88, 120407 (2002) (Davidson).

Bogoliubov spectrum

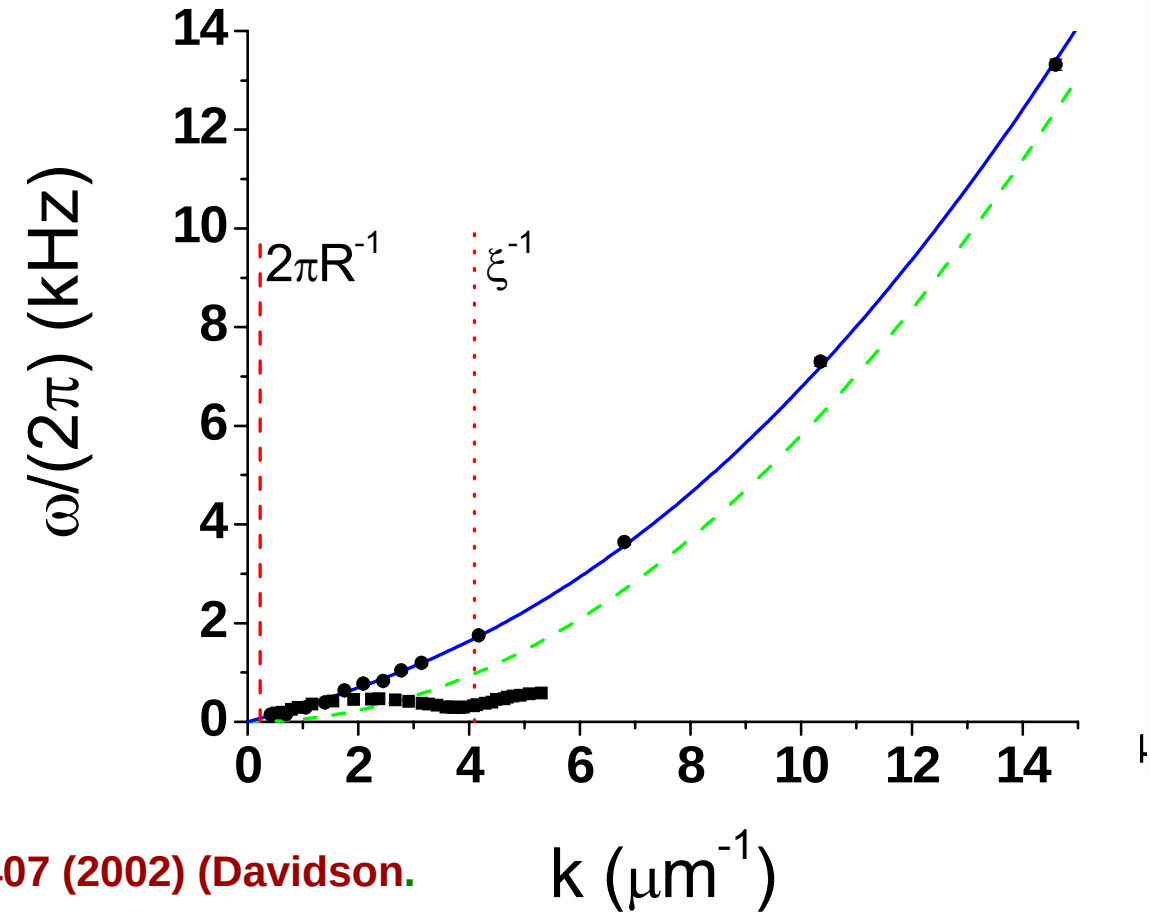
$$\varepsilon_k = \sqrt{\varepsilon_k^0\left(\varepsilon_k^0 + 2gn\right)}$$

low k limit: *Phonon regime*

$$\varepsilon_k = ck$$

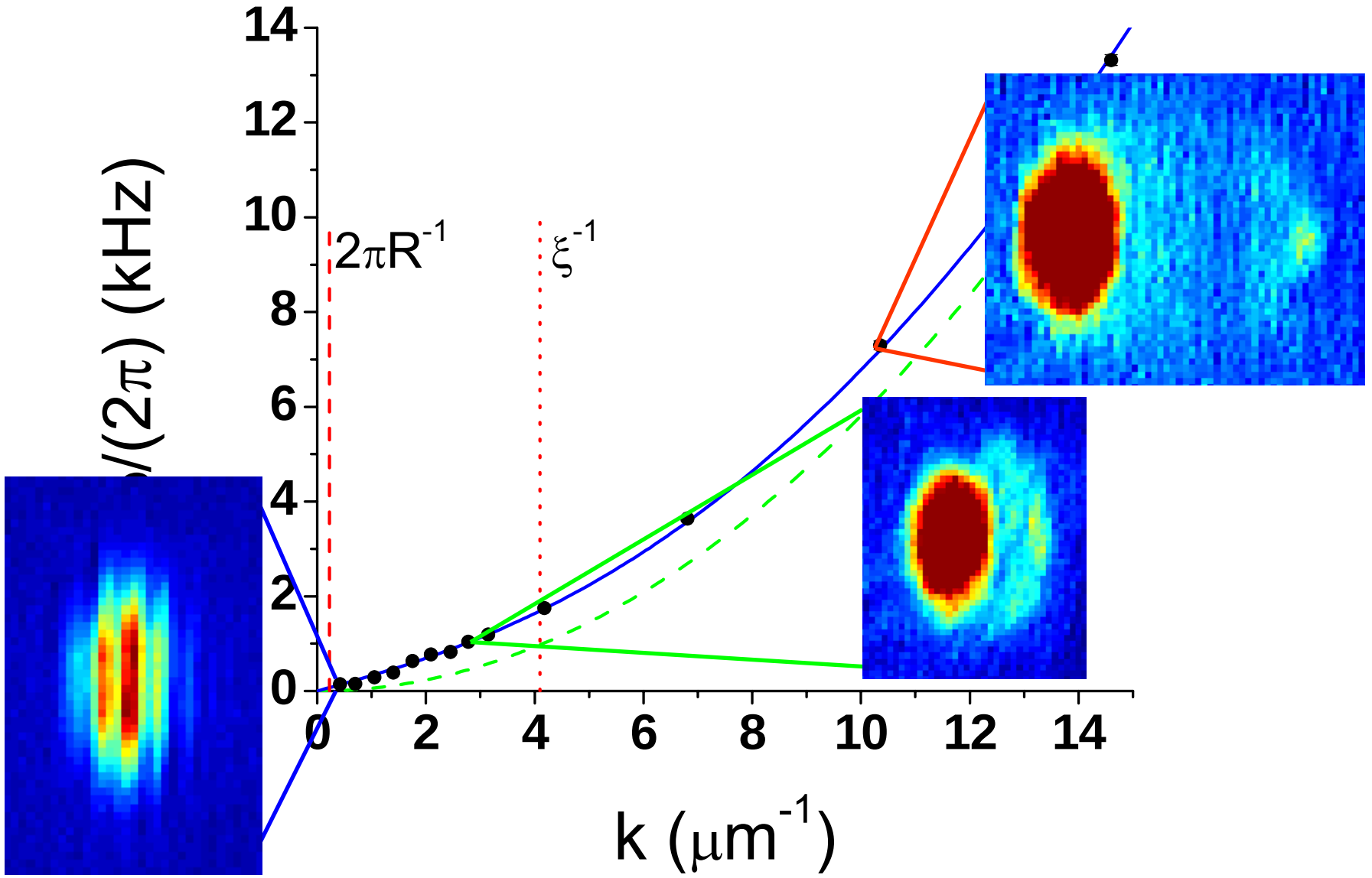
high k limit: *Free particle regime*

$$\varepsilon_k = \varepsilon_k^0 + \mu$$



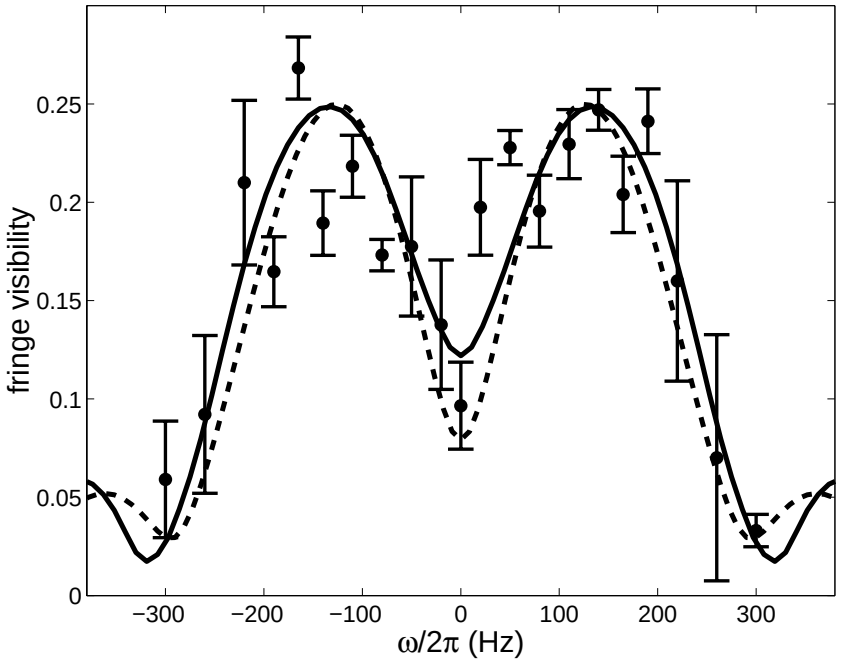
J. Steinhauer et al., PRL 88, 120407 (2002) (Davidson.

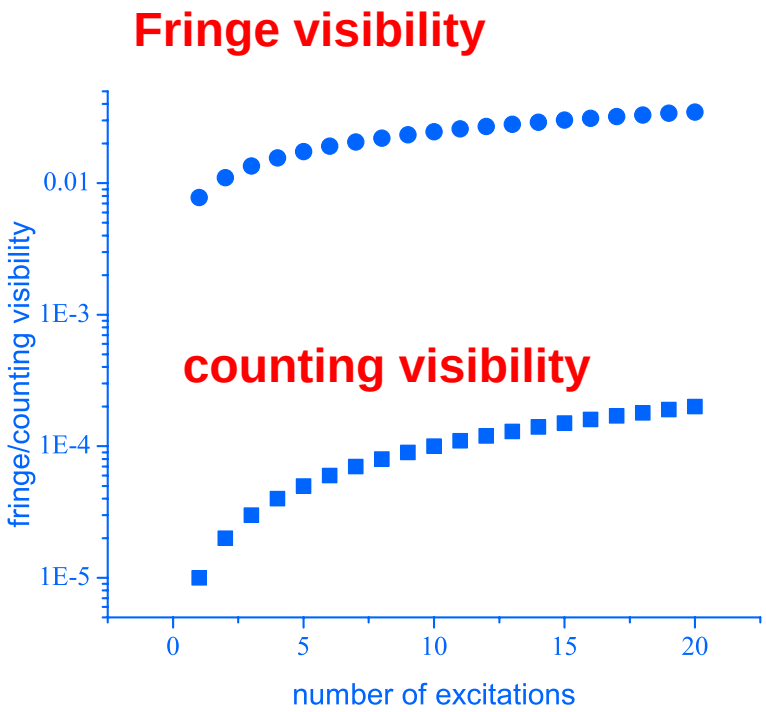
Excitation Spectrum: a roadmap



Fringe visibility: a spectroscopic tool

Heterodyne detection – matter wave interference

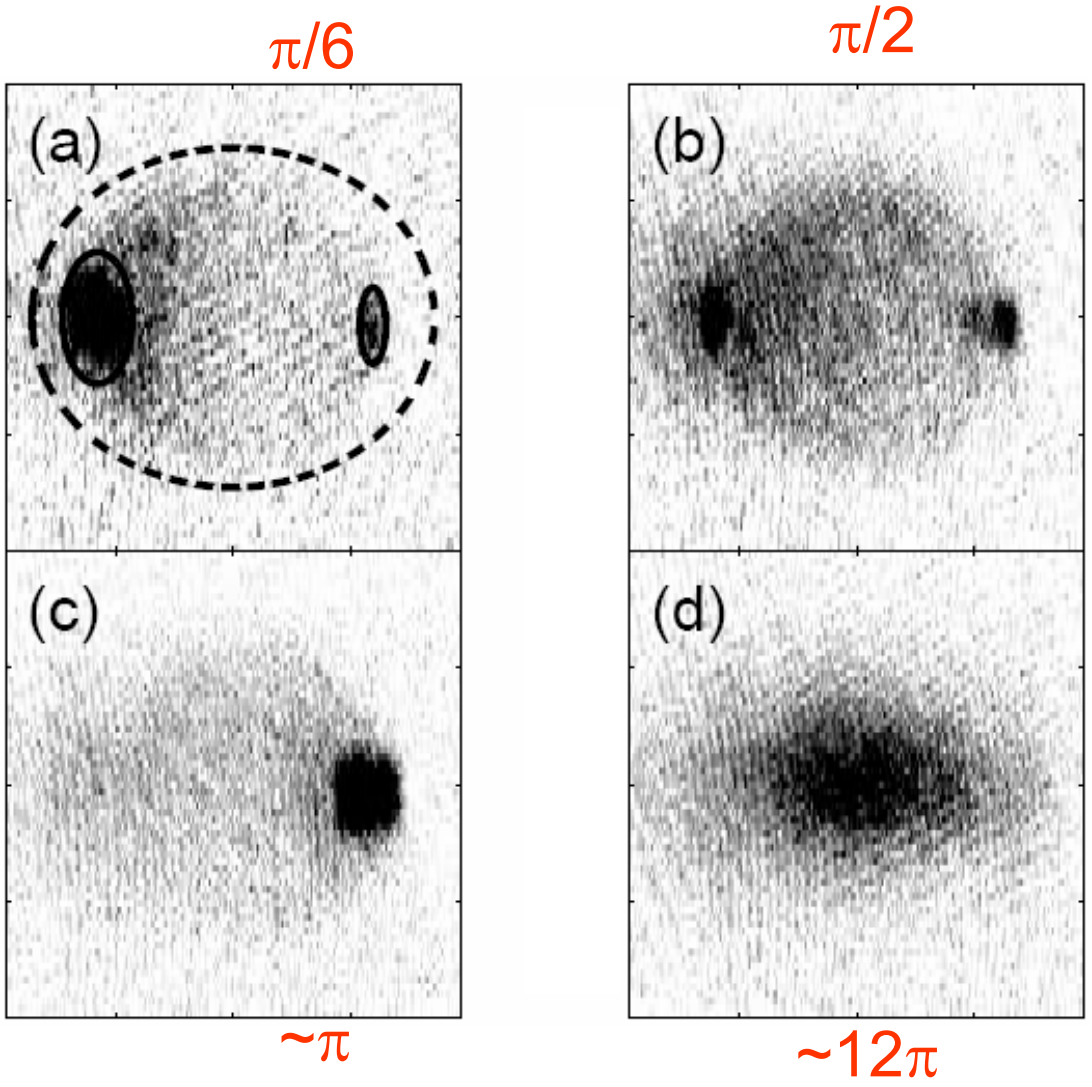




Can possibly observe single particle excitations!

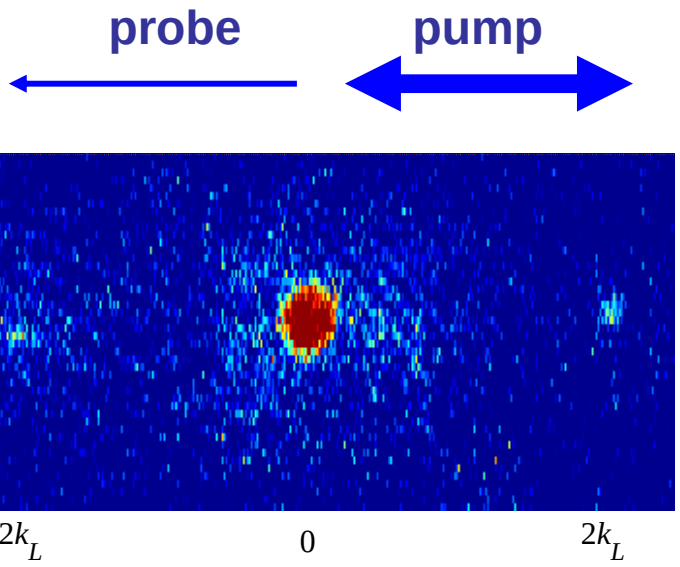
N. Katz, R.Ozeri, J. Steinhauer, N. Davidson, C. Tozzo and F. Dalfovo, PRL 93, 220403 (2004).

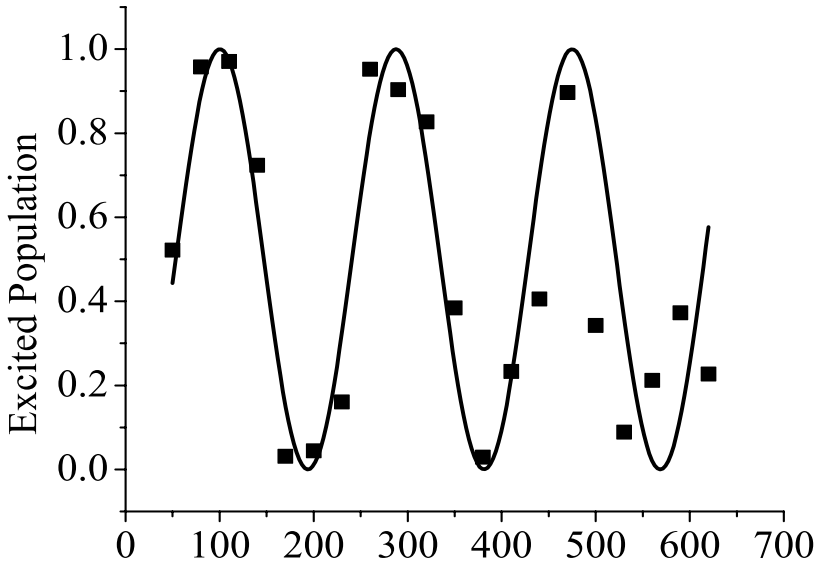
Strong excitations at high momenta



N. Katz, R. Ozeri, E. Rowen, E. Gershnabel and N. Davidson, Phys. Rev. A 70, 033615 (2004)

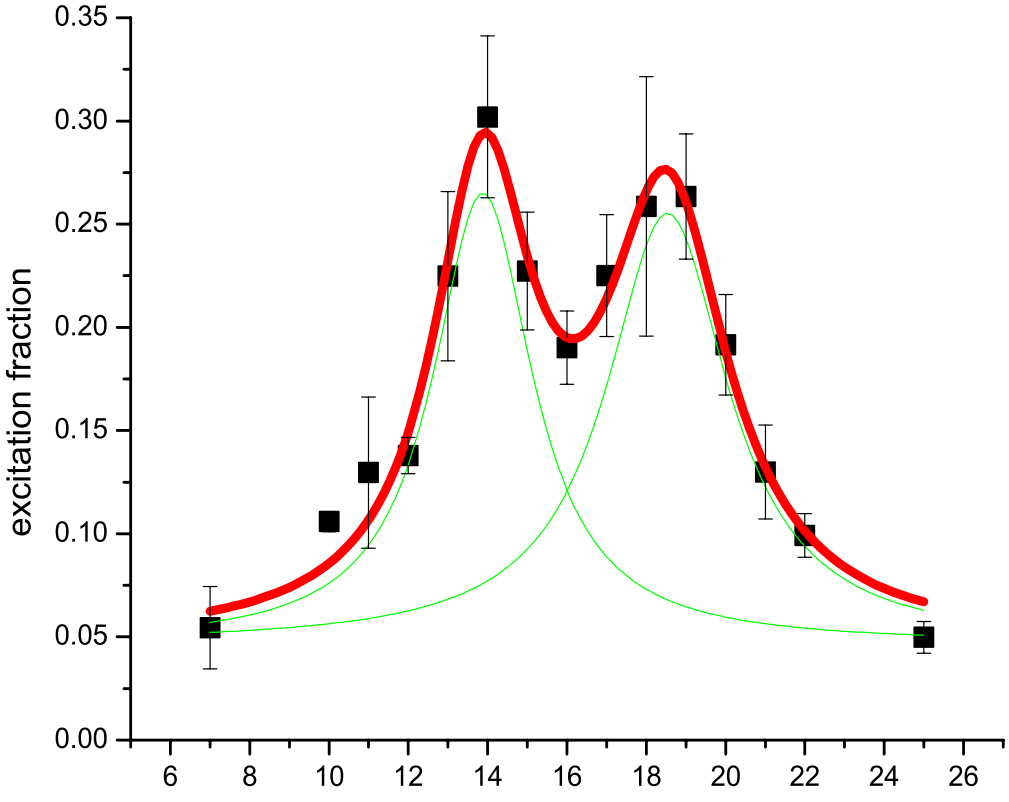
Strong excitation – splitting in spectrum





time (μsec)

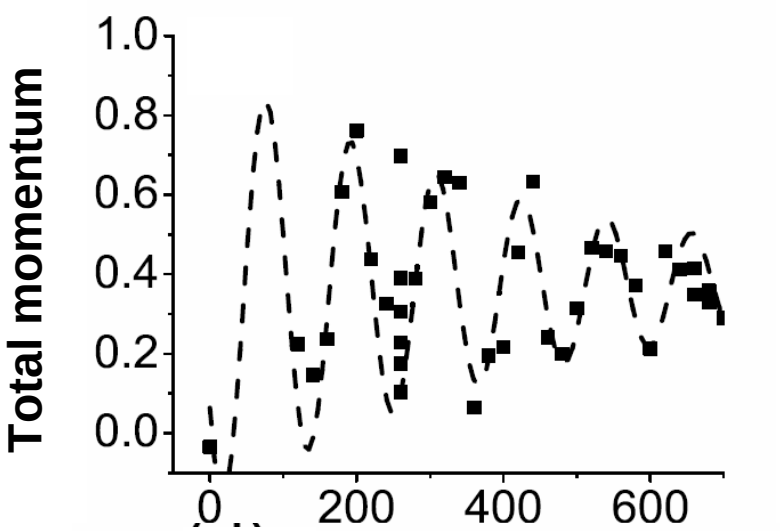
For a dressed state view of atomic mode mixing –
see Eitan Rowen's poster (Mo-15)

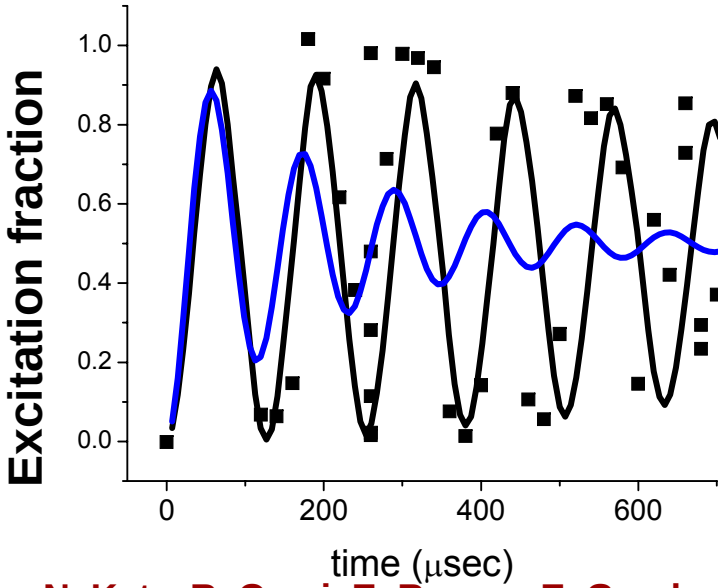


frequency (kHz)

E. Rowen, N. Katz, R. Ozeri, E. Gershnabel and N. Davidson, cond-mat/0402225 (2004).

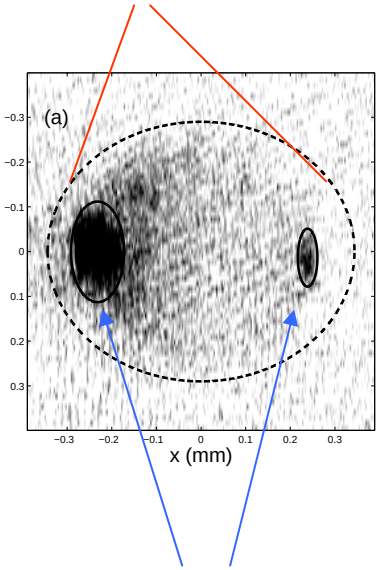
Dynamics: decoherence vs. dephasing





Momentum measurement

Decoherence+dephasing



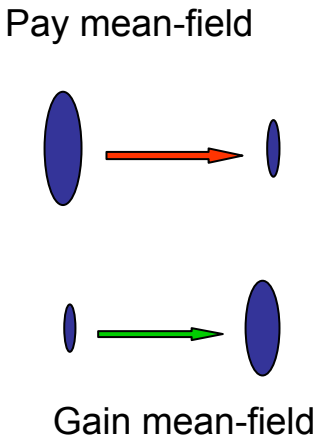
Population measurement:

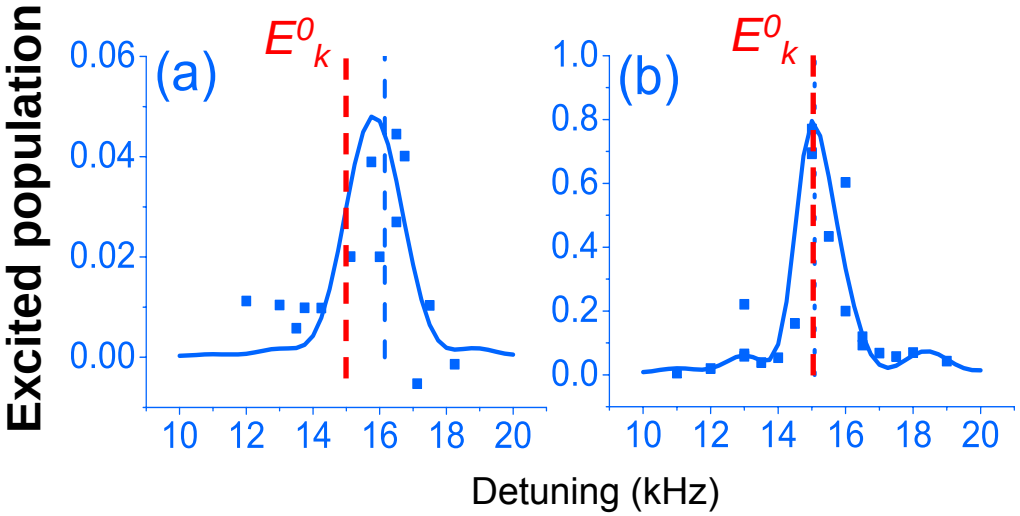
Only dephasing

Agrees with Gross-Pitaevskii!!

N. Katz, R. Ozeri, E. Rowen, E. Gershnabel and N. Davidson, Phys. Rev. A 70, 033615 (2004)

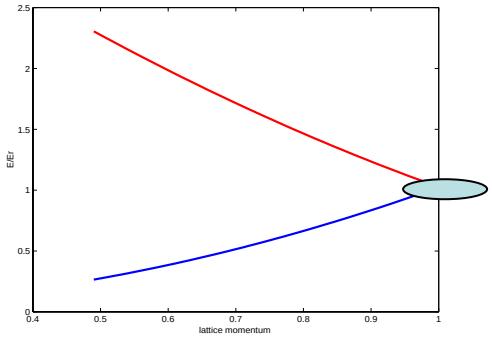
Suppression of mean field and Doppler broadening

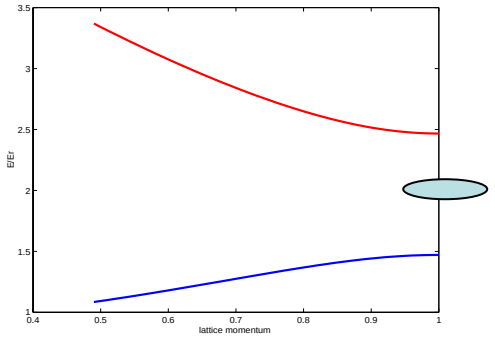




Result:

Coherence enhanced by more than a factor of 10.

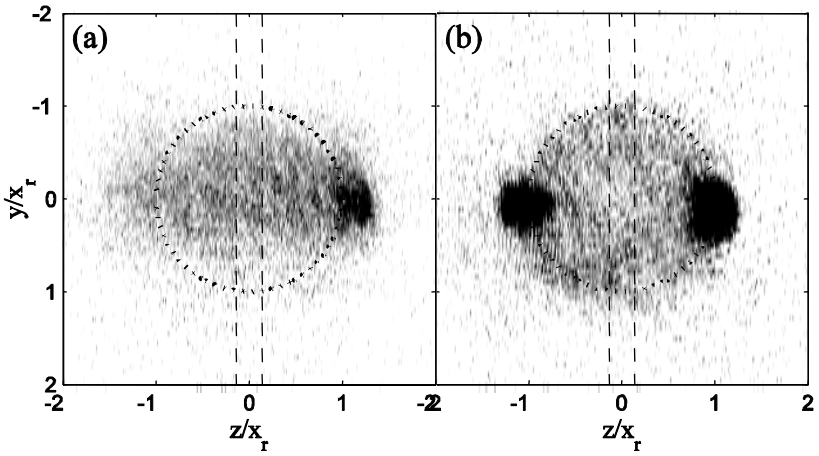




Weak **Strong**

Collisions in the lattice

experiment



E. Rowen, N. Katz, R. Ozeri, E. Gershnabel and N. Davidson, cond-mat/0402225 (2004).

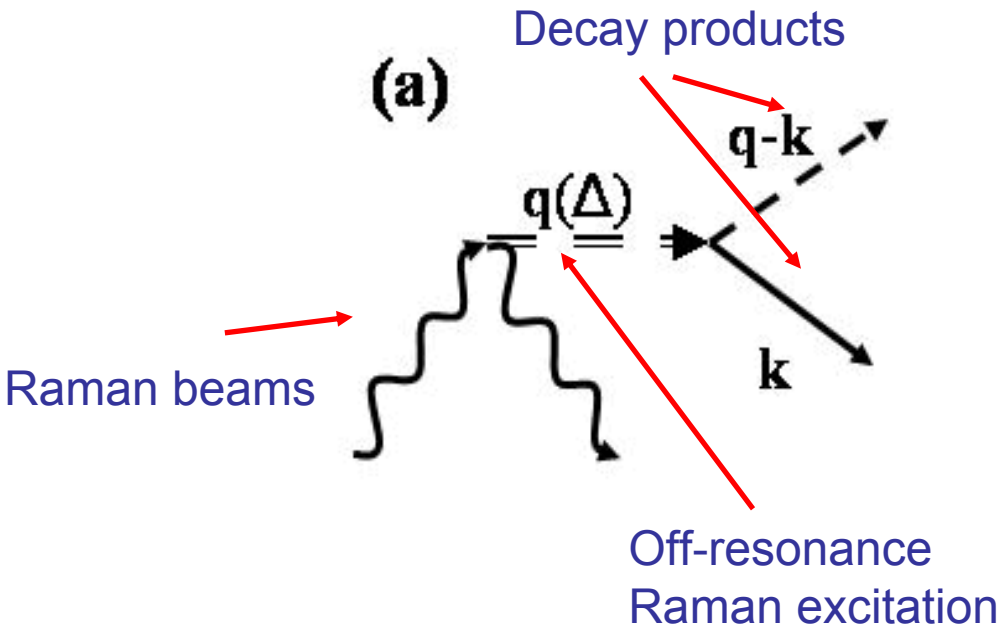
A.A. Norie, R. J Ballagh and C.W. Gardiner, cond-mat/0403378

Coupling to a nontrival continuum…

Probing correlations - Raman

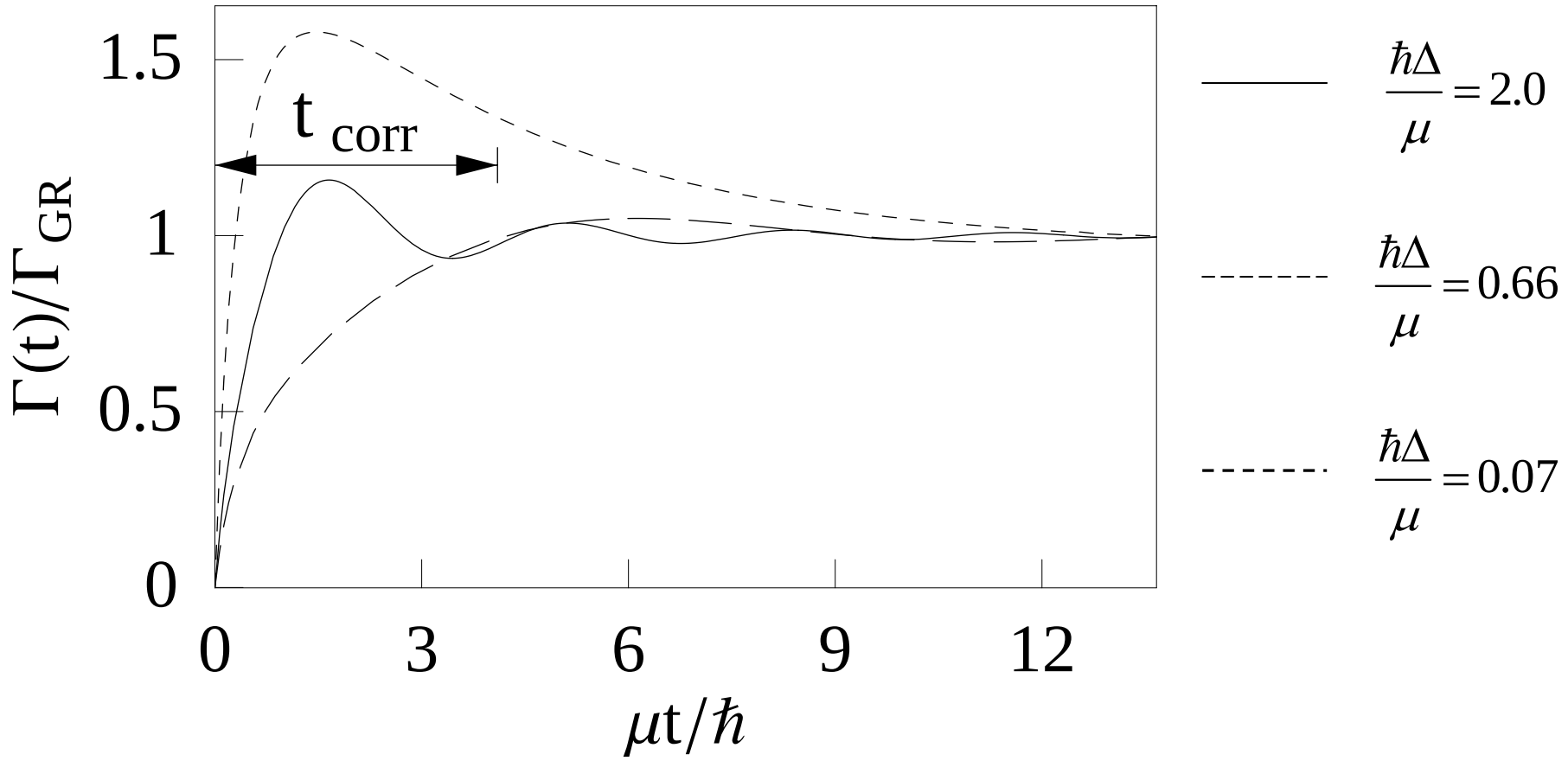
Scheme:

- Excite off resonance (positive detuning Δ) Raman momentum states (**q**),
- Monitor the decay products of these states as a function of time

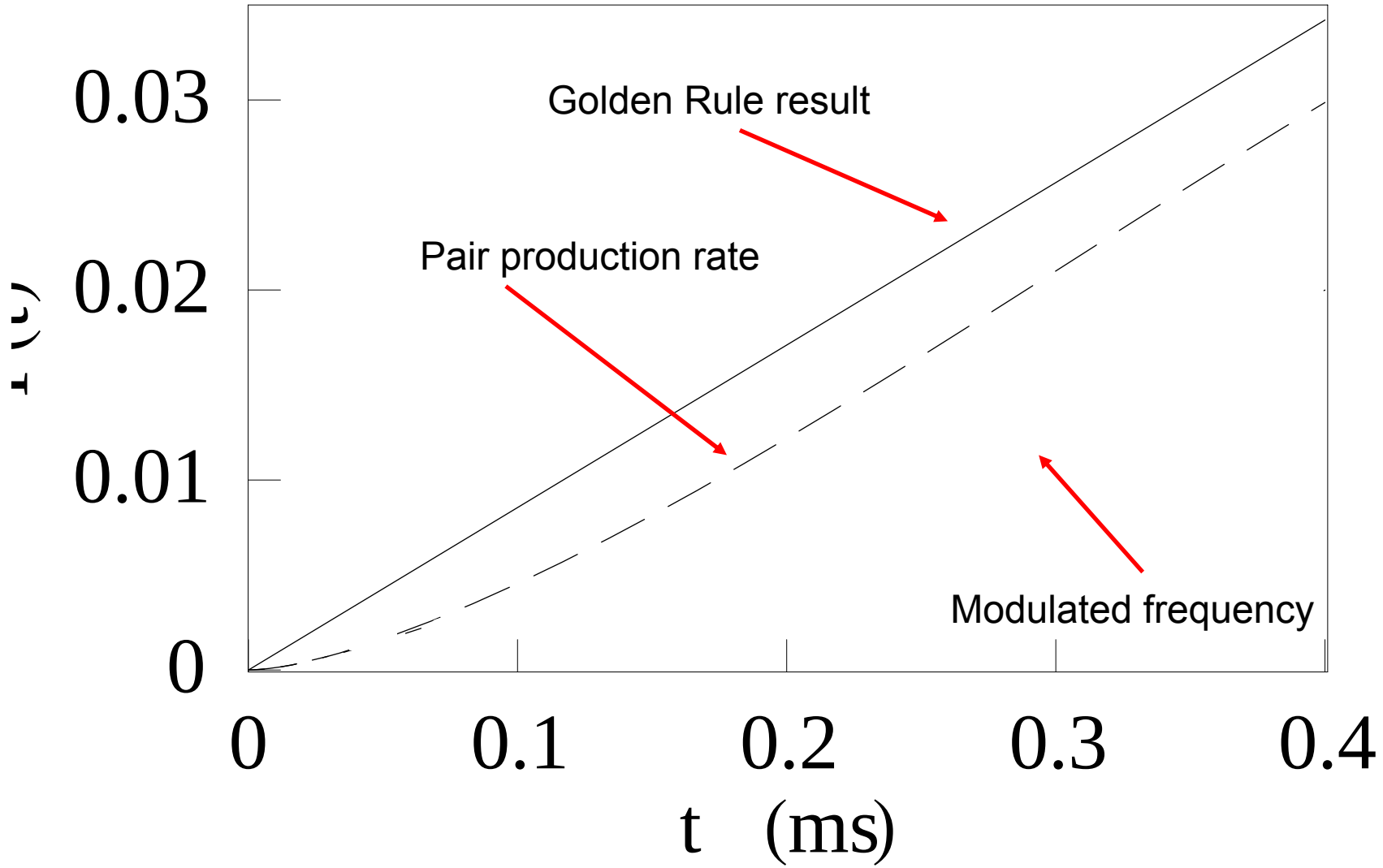


I. Mazets, G. Kurizki, N. Katz and N. Davidson, cond-mat/0411301

Zeno effects in BEC



Observing Zeno effects



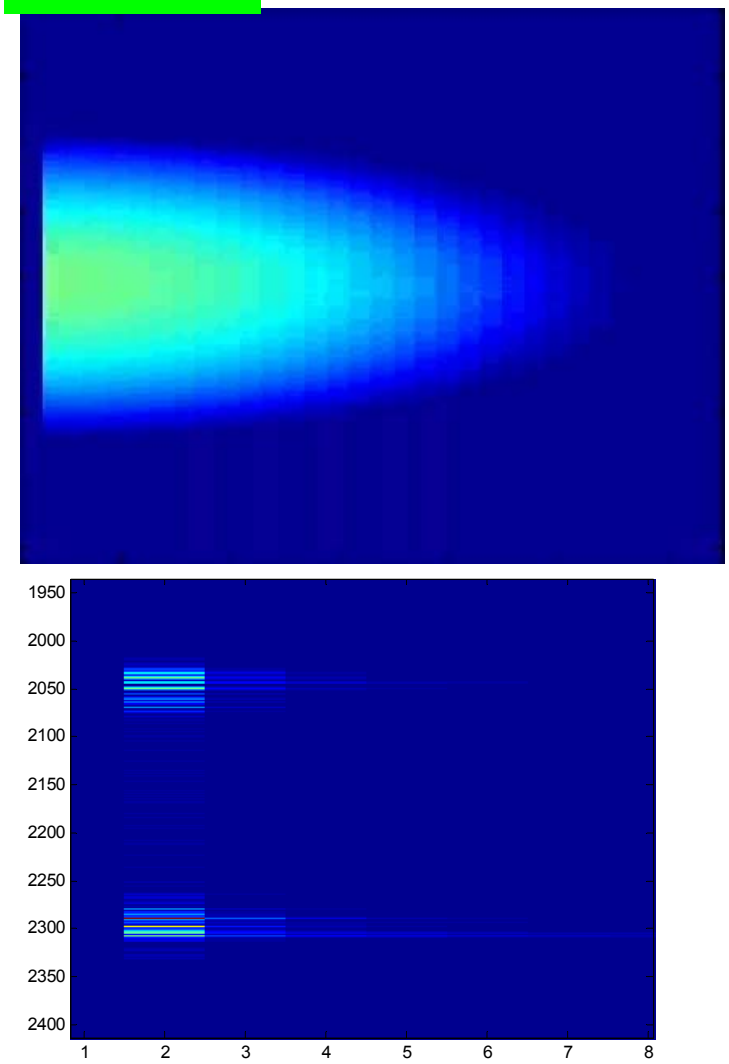
Summary - physics beyond Bogoliubov

- Heterodyne detection of few excitations
- Strong excitations – spectra and decay
- Many-body correlation time for Raman excitations

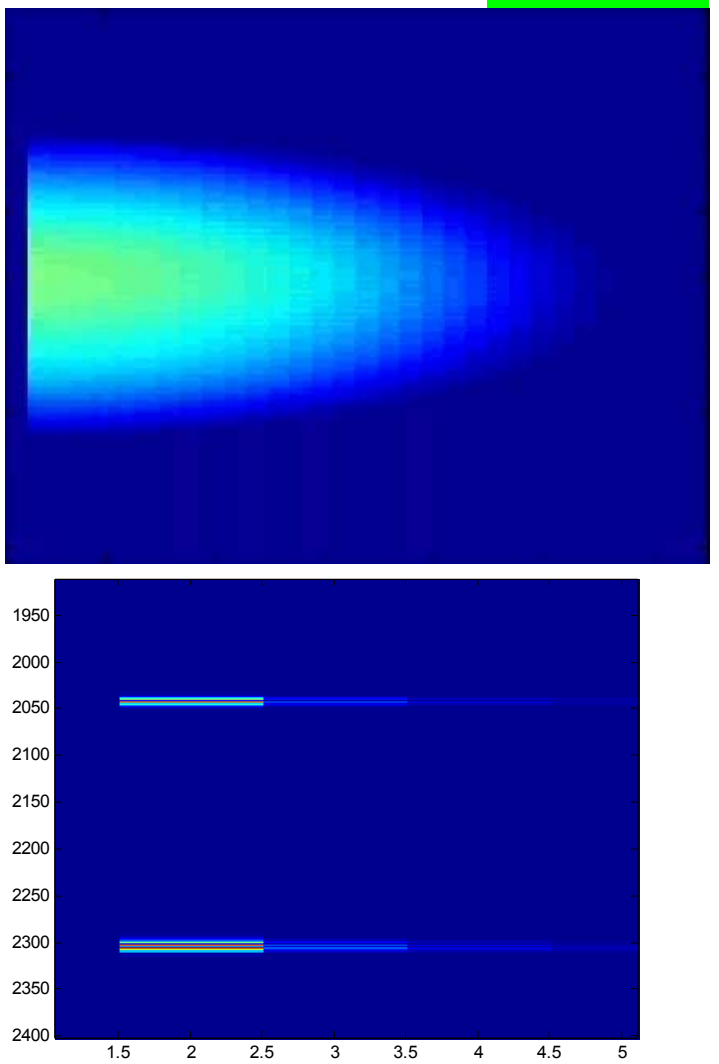
Dynamical instabilities (simulations)

What happens when the Bragg pulse is at intermediate intensity (comparable to the mean-field)?

$\hbar\Omega \approx \mu / 2$



$\hbar\Omega \approx 2\mu$



A. Vardi and J. R. Anglin, Phys. Rev. Lett. **86**, 568 (2001).