Atom Chips:

Matter Waves in Tailored Micro Potentials

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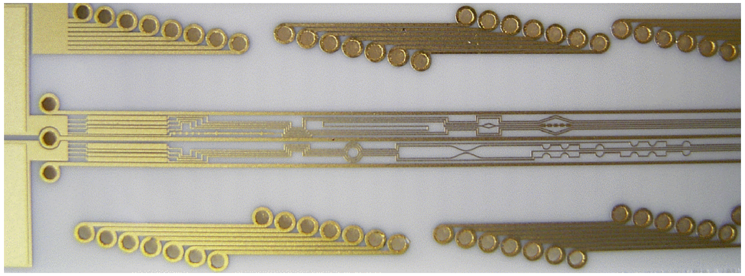
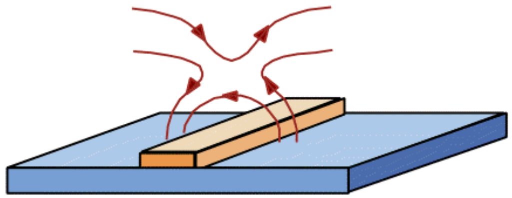
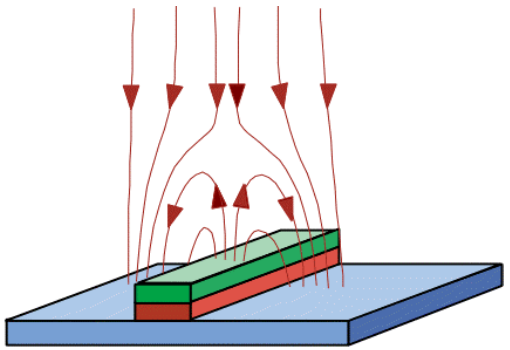


József Fortágh
Sebastian Kraft
Andreas Günther
Christian Trück
Philipp Wicke

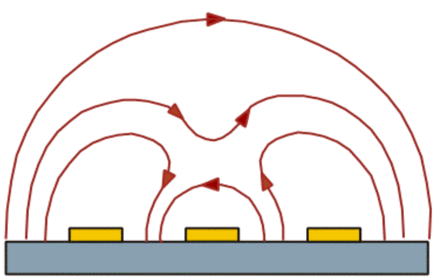
Micro fabricated surface traps

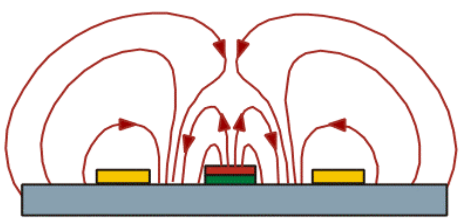
external bias field:



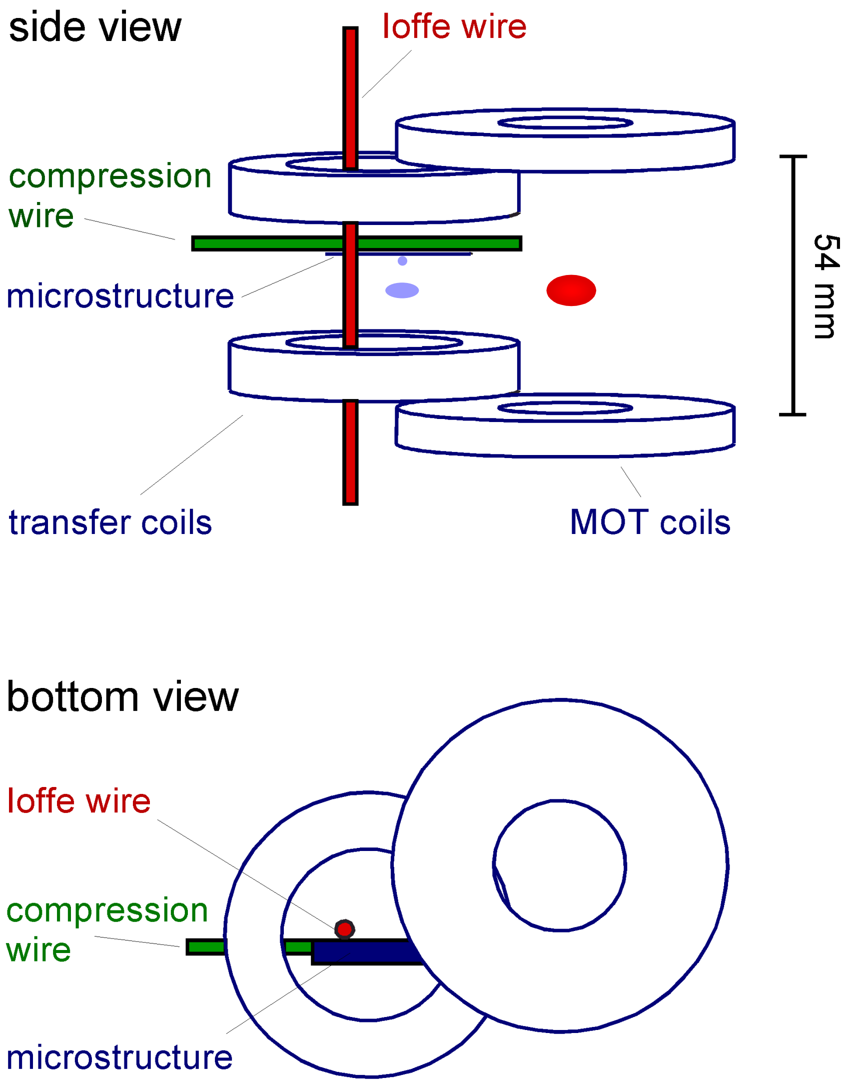


on chip bias field:





Loading scheme for the micro trap



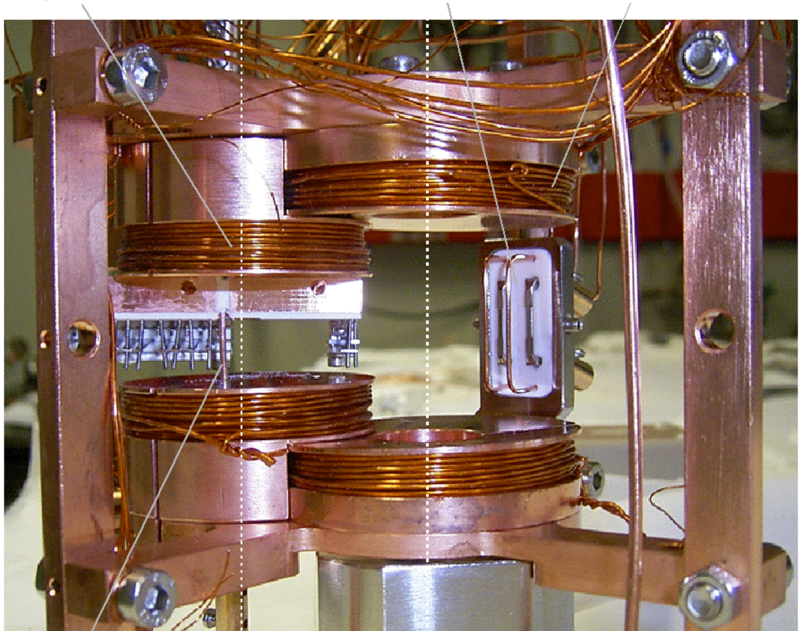
- **six-beam magneto-optical trap**
  20 mm beam diameter, 20 mW power in each beam, 3×10^8 atoms

- **adiabatic magnetic transfer**
  of ^{87}Rb atoms (F=2, m_F=2) to the microstructure

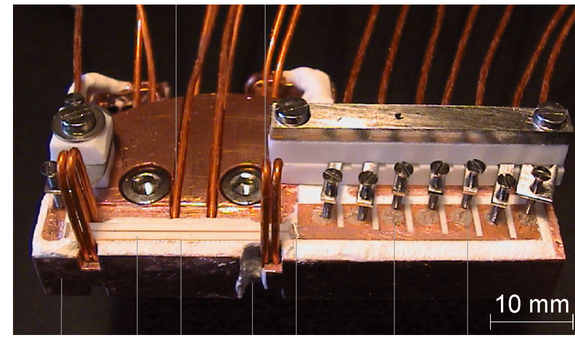
- **large atom number**
  in the microtrap up to 2×10^7,
  in the condensates up to 5×10^5

Magnetic hardware

trap setup inside the vacuum

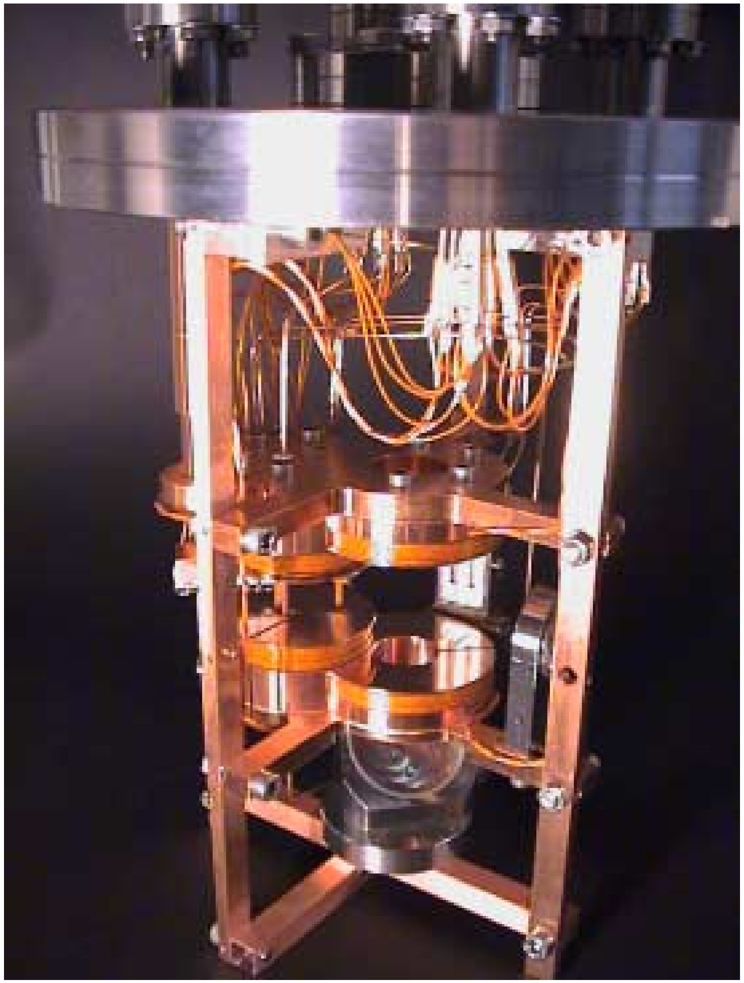


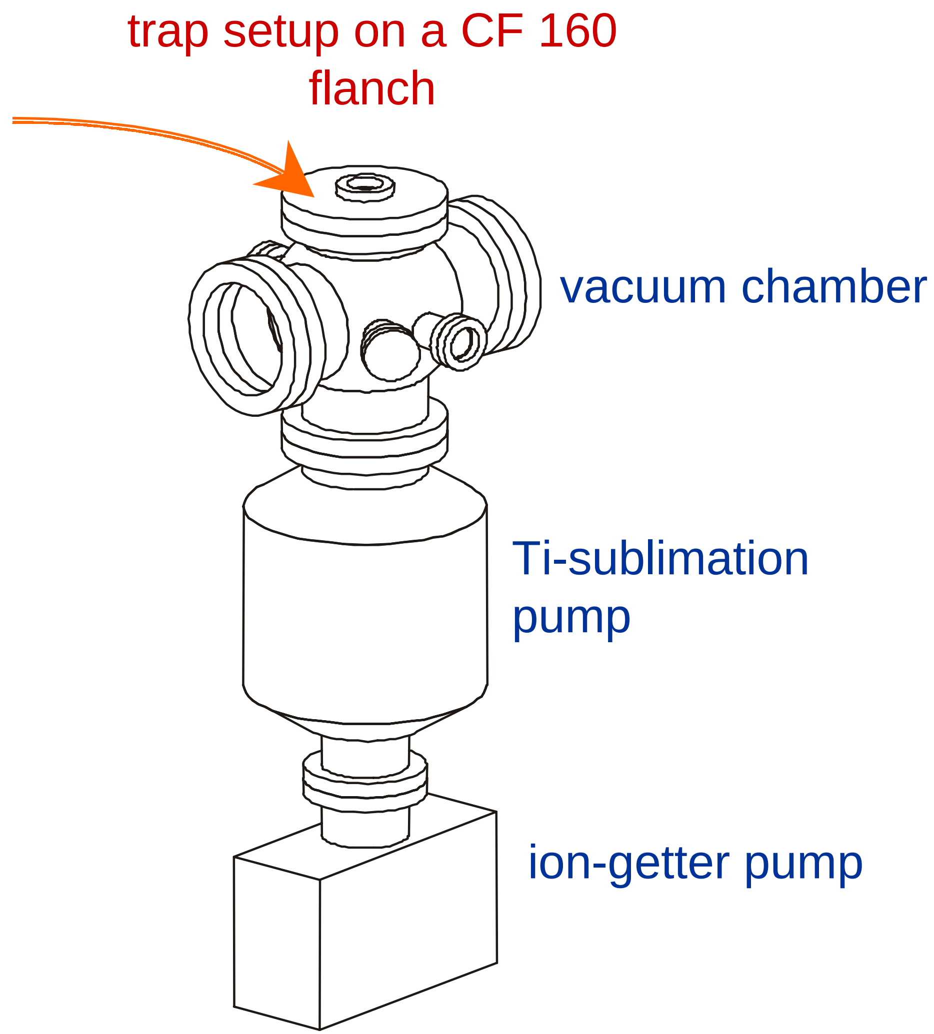
mounted microstructures



background pressure= 1×10^{-11} mbar

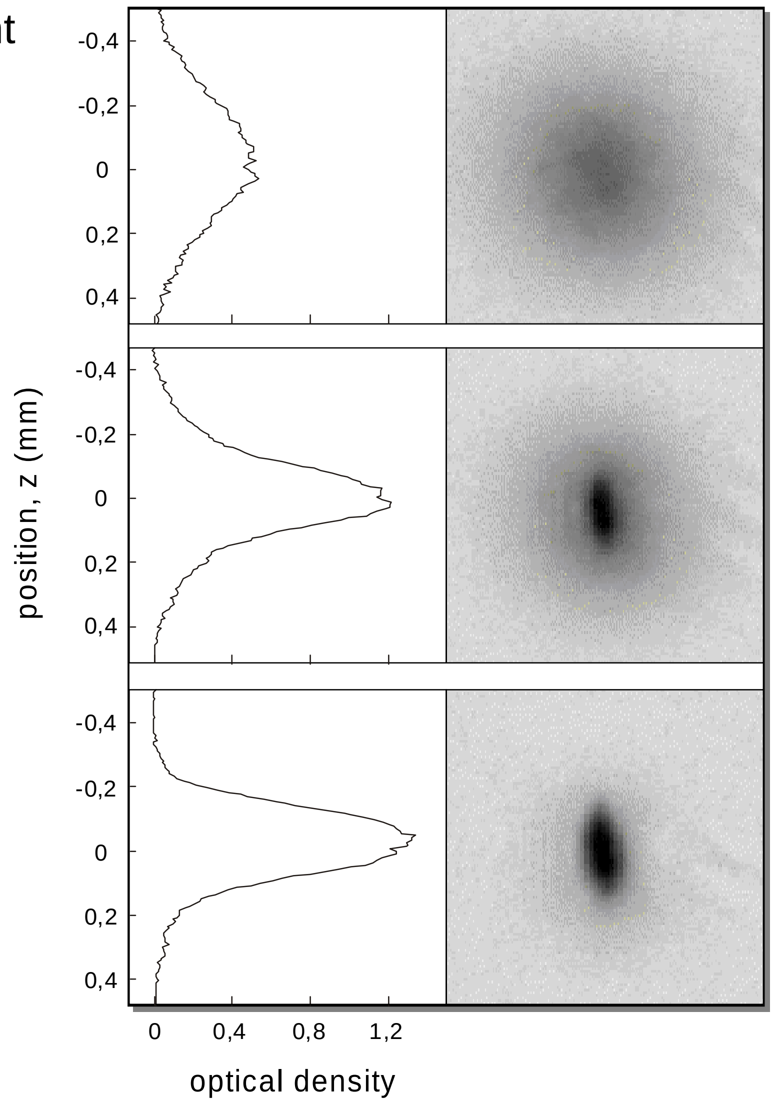
Vacuum setup





Condensation of ^{87}Rb (F=2, m_F=2)

20 ms time of flight



$\omega_{axial} = 2\pi \times 14\ Hz$

$\omega_{radial} = 2\pi \times 840\ Hz$

$\mu/k_B = 400\ nK$

$N_0 = 500\ 000$

$n_0 = 10^{15}\ cm^{-3}$

$T_C = 1\ \mu K$ @ 10^6 atoms

H. Ott, J. Fortágh, G. Schlotterbeck, A. Grossmann and C.Zimmermann, Phys. Rev. Lett. 87, 230401 (2001)

Fragmentation of a thermal cloud (1 μK)

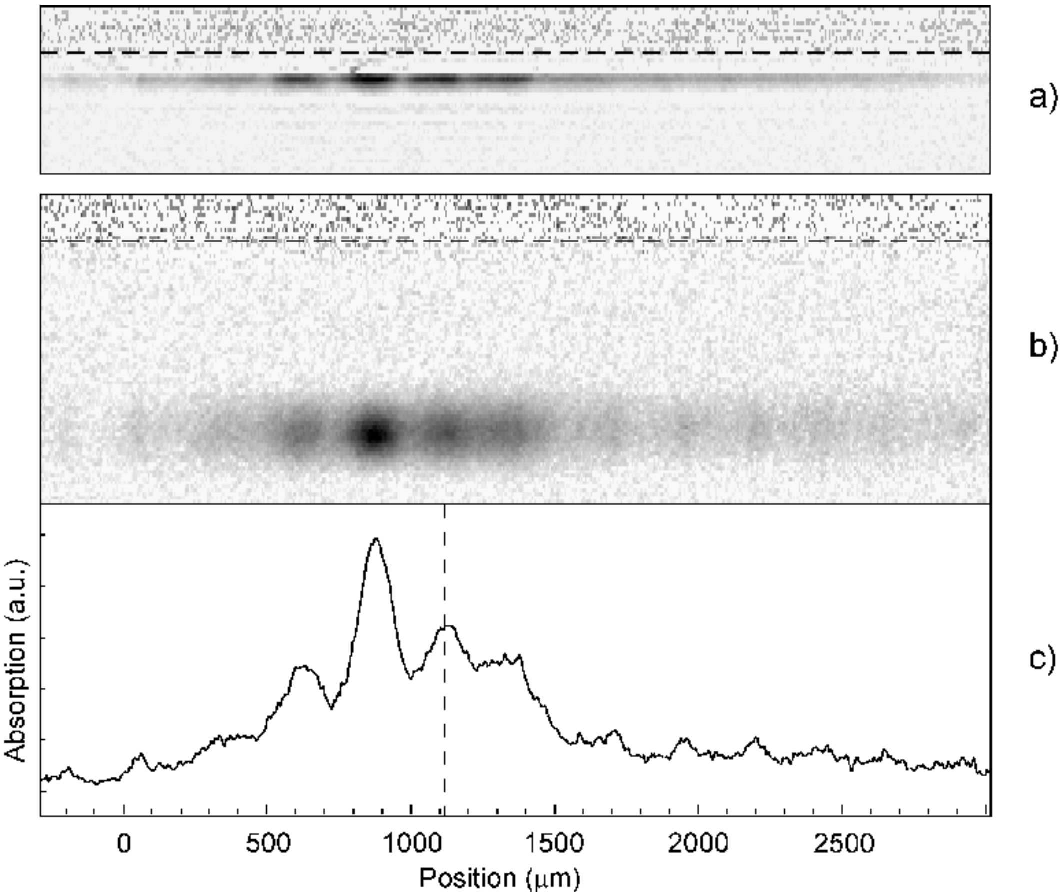
radial trap frequency $\omega_{radial} = 2\pi \times 840\ Hz$

axial trap frequency ω_{axial} is ramped to zero within 400 ms

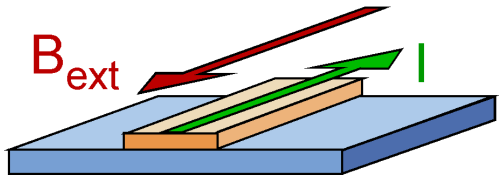
after 100 ms free expansion inside the trap

after 100 ms free expansion inside the trap and 10 ms time of flight

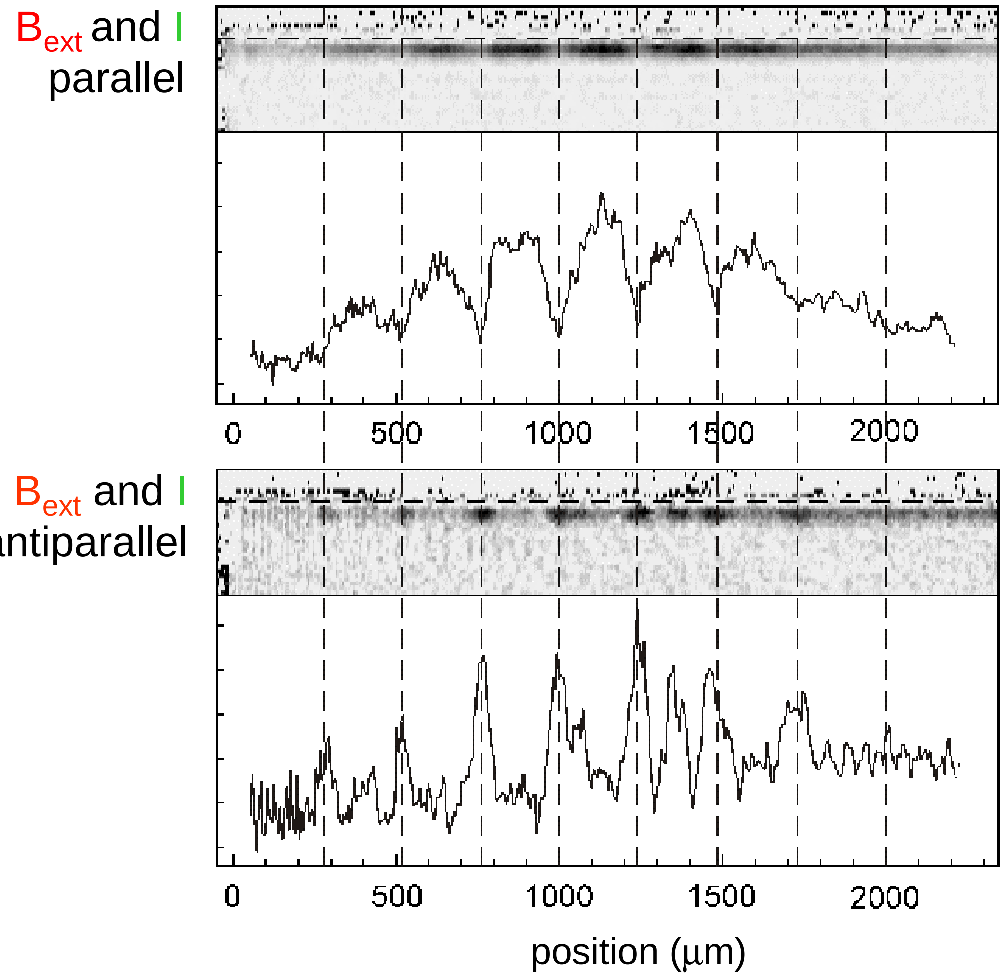
effective potential with spatial fluctuations at a scale of 260 μm



Fragmentation due to unwanted magnetic field

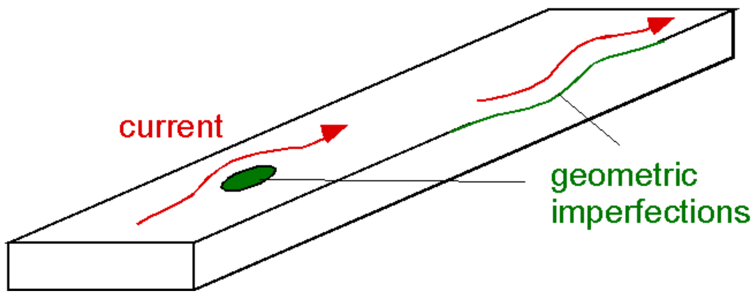


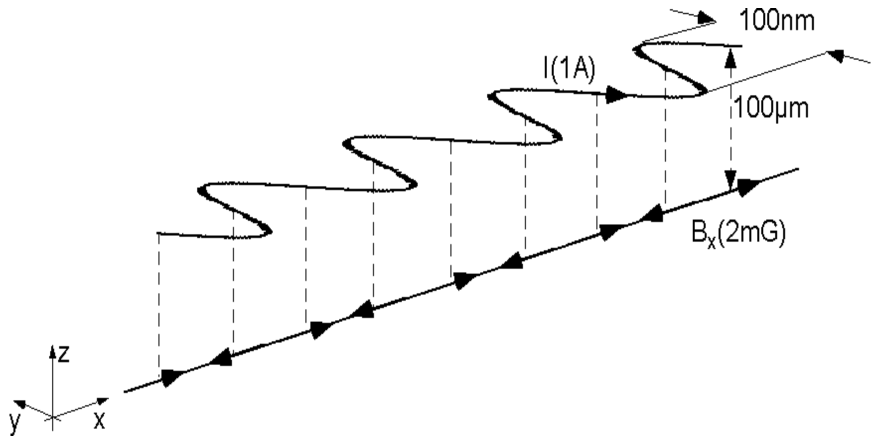
$$U = \mu \, |B(x) \pm B_{ext}| \;=\; \mu \, |\pm B(x) + B_{ext}|$$



S. Kraft, A. Günther, H. Ott, D. Wharam, C. Zimmermann and J. Fortágh J. Phys. B: At. Mol. Opt. Phys. **35,** L 469-L 474 (2002)

Geometric imperfections





numbers for a meandering model current:

- Fragmentation due to unwanted axial magnetic field component:
S. Kraft, et.al J. Phys. B: At. Mol. Opt. Phys. 35**,** L 469-L 474 (2002).

- SEM image of the conductor maps the density distribution of the atomic cloud:
Esteve et al., physics/0403020.

- Correct distance dependence:
M.P.A. Jones et al., Phys.B:At.Mol.Opt.Phys. 37, L15 (2004)

- Theoretical study assuming white noise fluctuations of the wire width:
D.-W. Wang et al., cond-mat/0307402

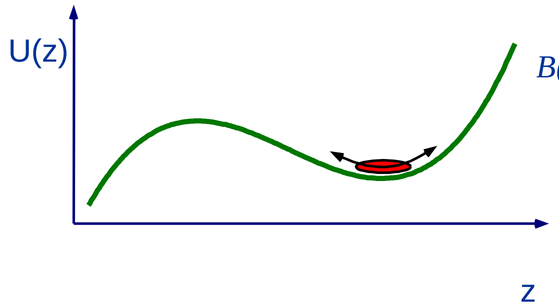
Condensate oscillation in anharmonic traps

initial displacement:

A: 0.45 mm

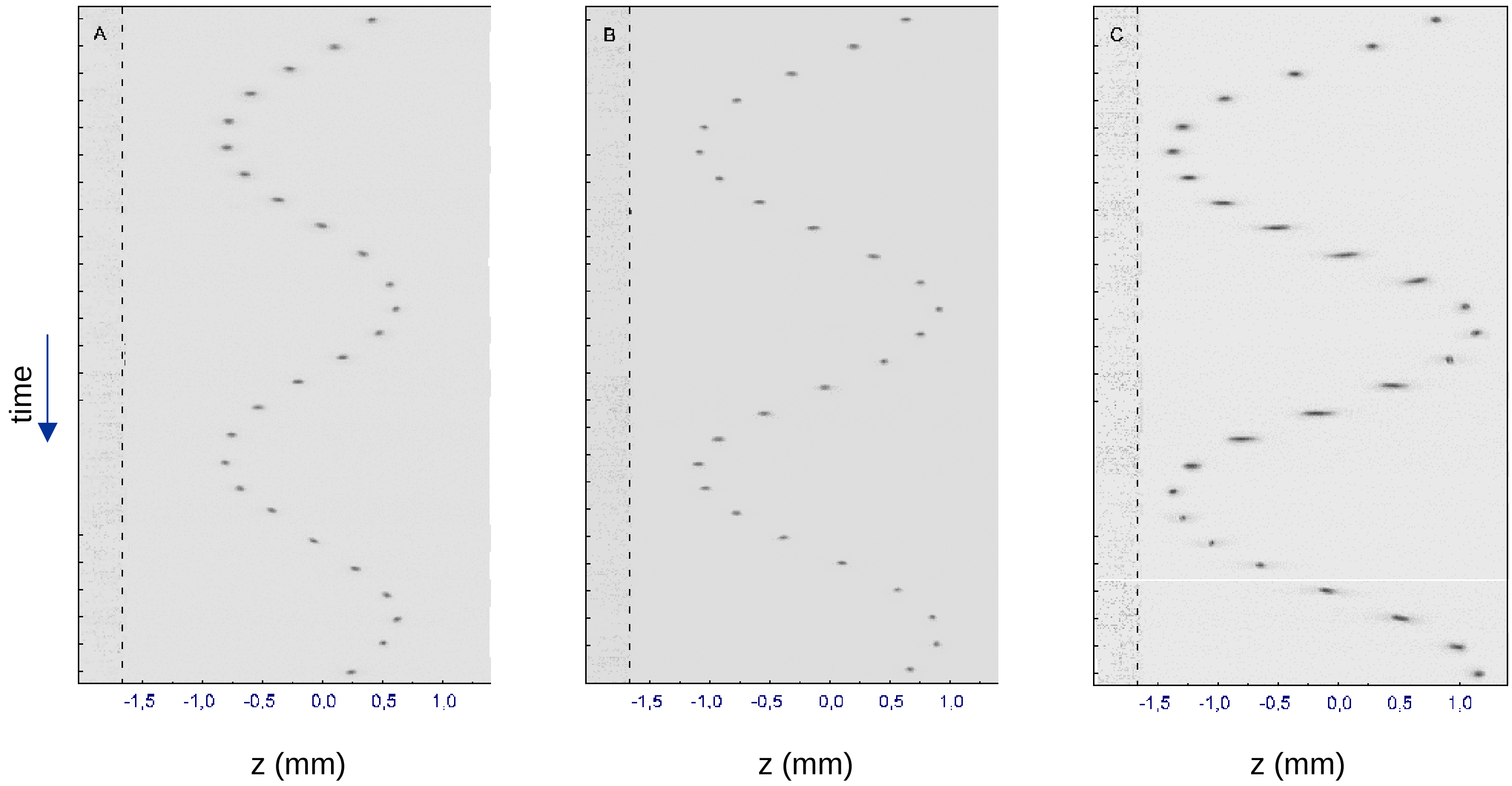
B: 0.63 mm

C: 0.79 mm



$B(z) = 3.879 + 0.219\, z^2 - 0.011\, z^3 - 0.026\, z^4$

15 ms time of flight

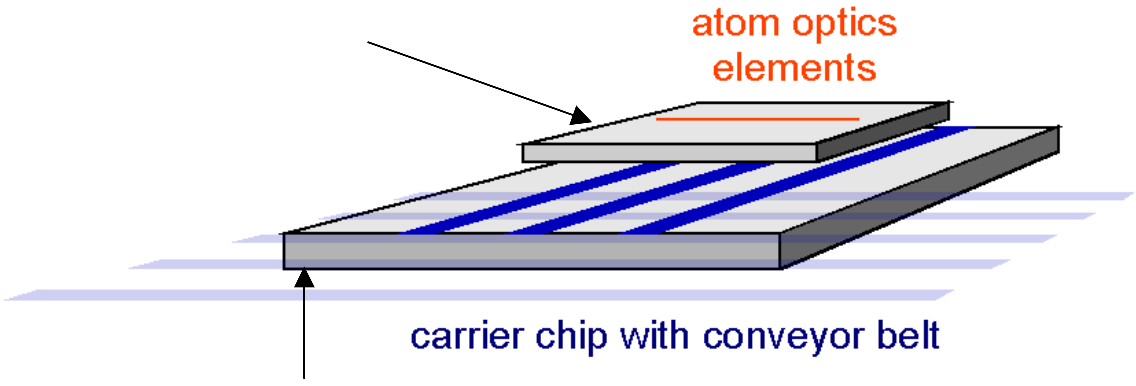


H. Ott, J. Fortágh, S. Kraft, A. Günther, D. Komma, C. Zimmermann PRL 91, 040402 (2003)

Combined chips

small scale micro structure:

Atom optic elements close to the atoms.

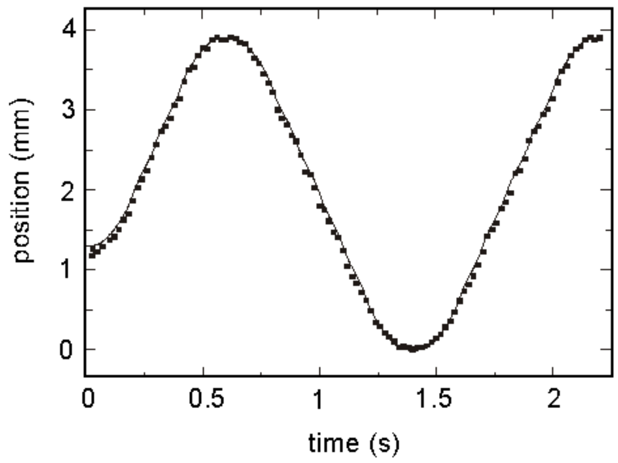


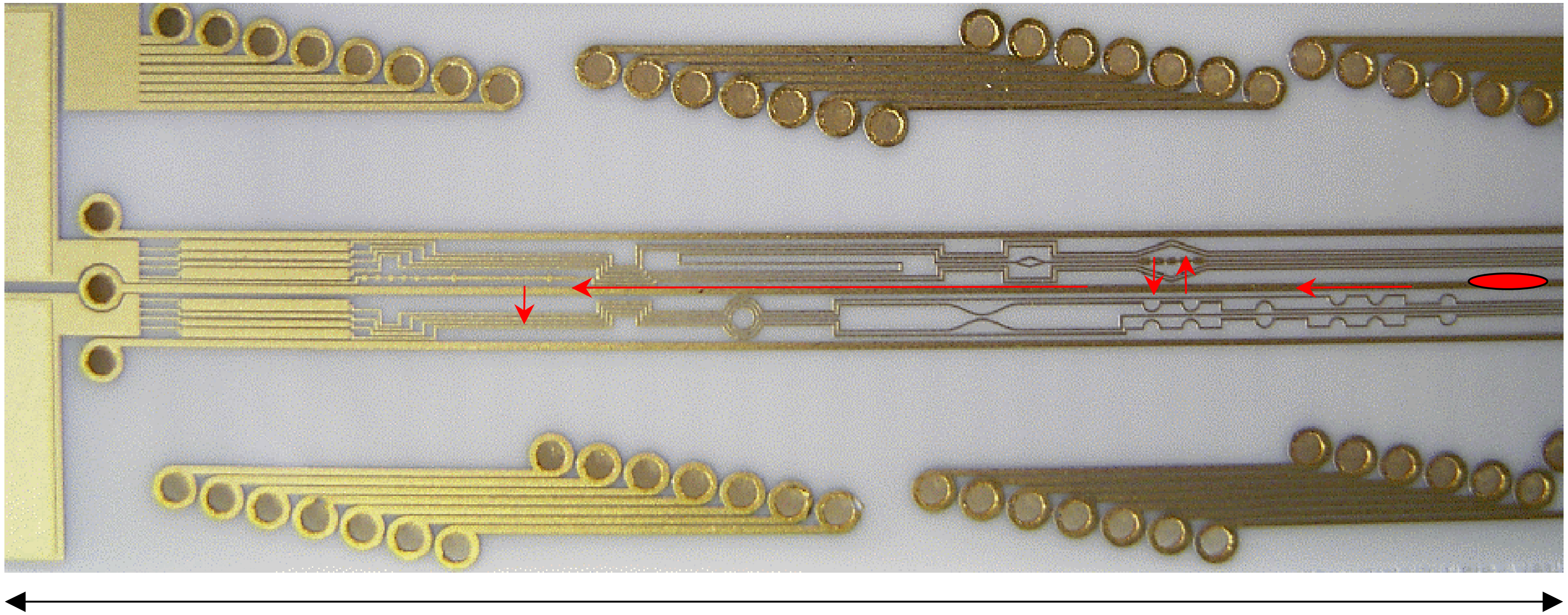
large scale carrier chip:

Quiet motion with a conveyor belt.

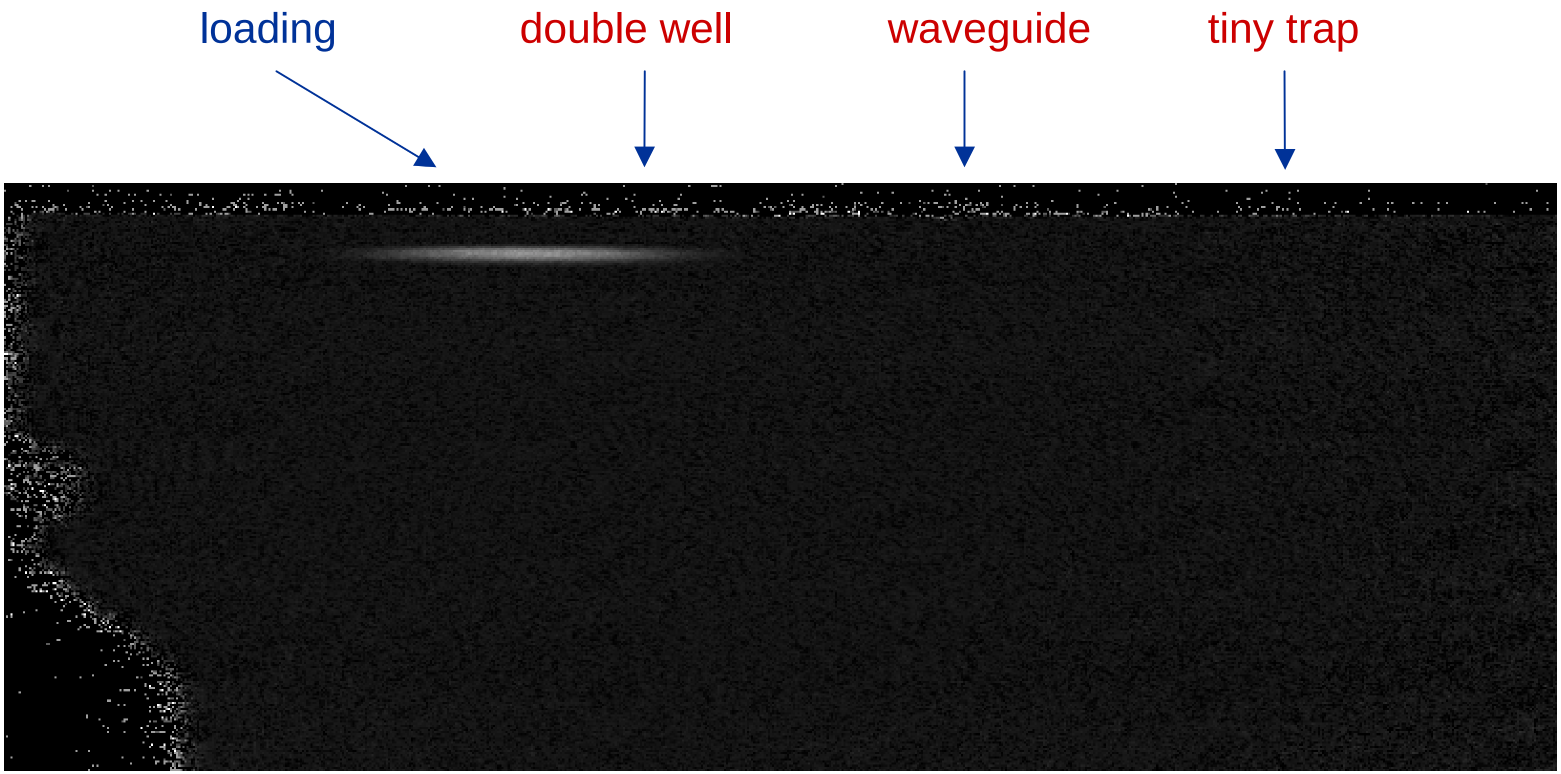
Quiet transport with a conveyor belt

- dual-layer microstructure supports a set of various microtraps
- loading the microtraps from a central waveguide
- 3D-positioning at the chip, exchange of atoms between microtraps

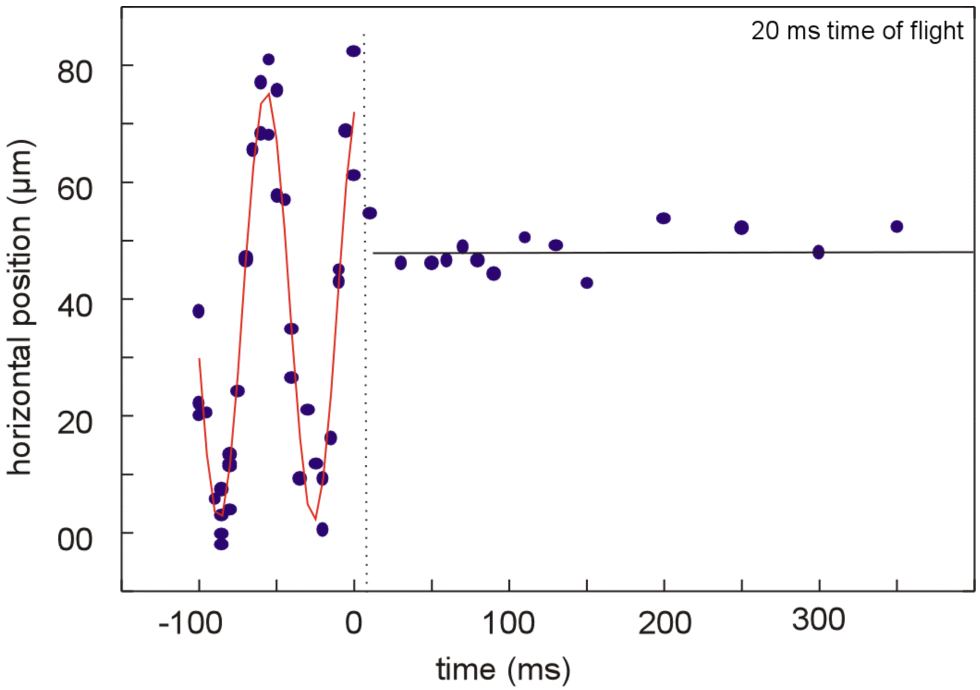




Positioning of a thermal cloud



Transport and stopping of a condensate



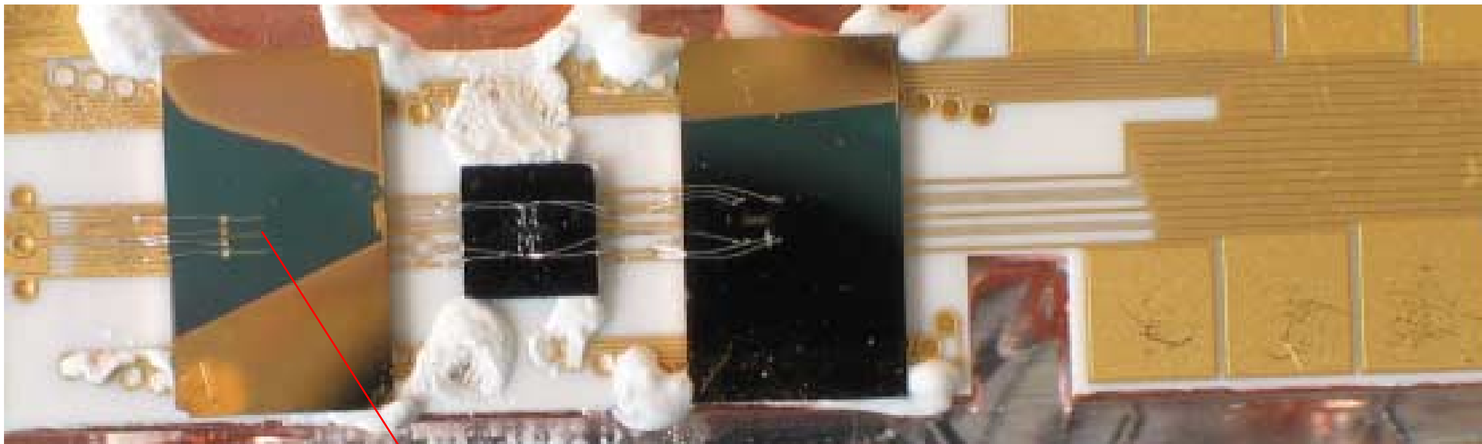
Oscillation due to excitation during transport

Stopping by sudden shift of the trap

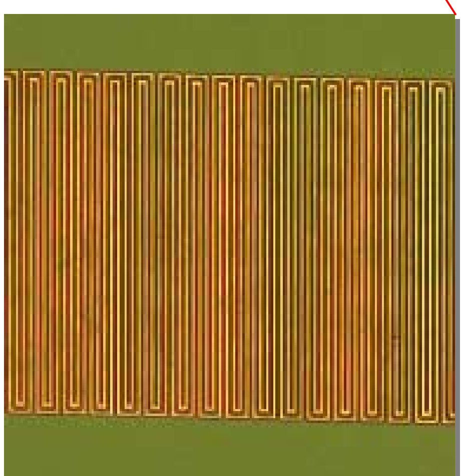
Residual velocity spread: Δv=0.1mm/s (3nK)

Chip with magnetic lattice

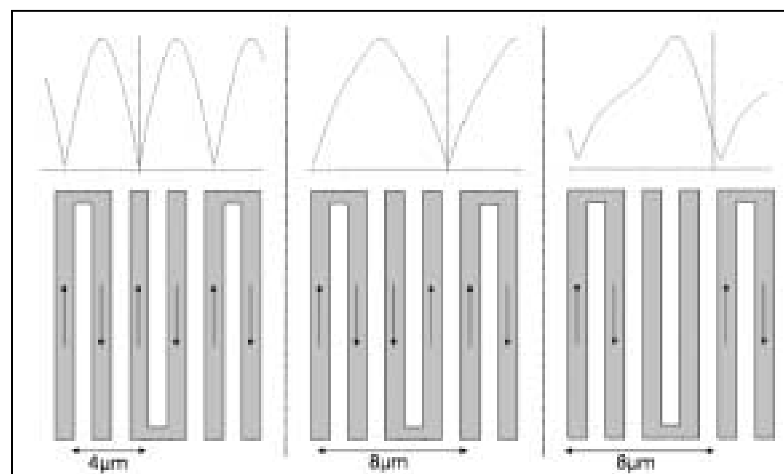
meandering conductors generate periodic potential in the wave guide



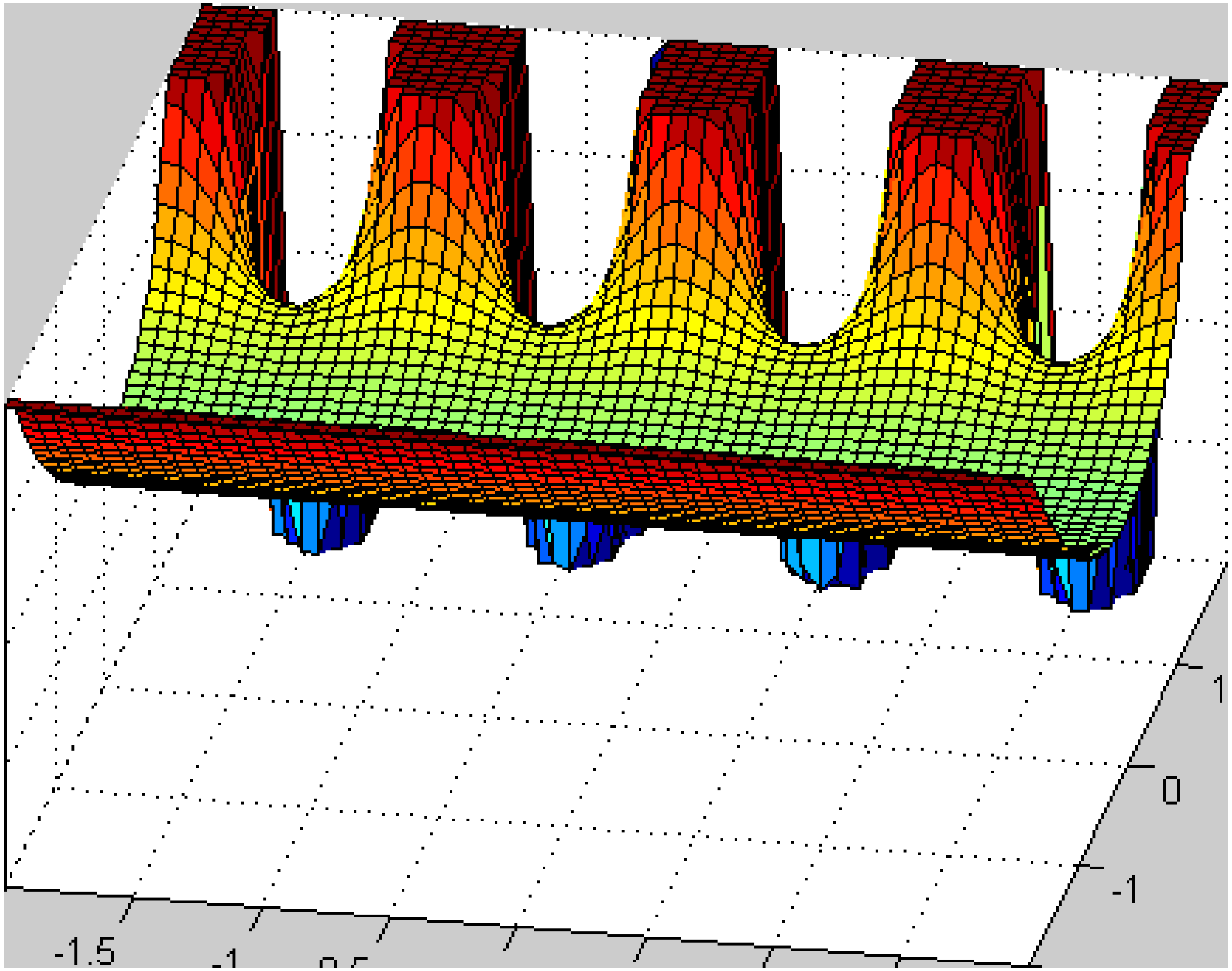
3 mm



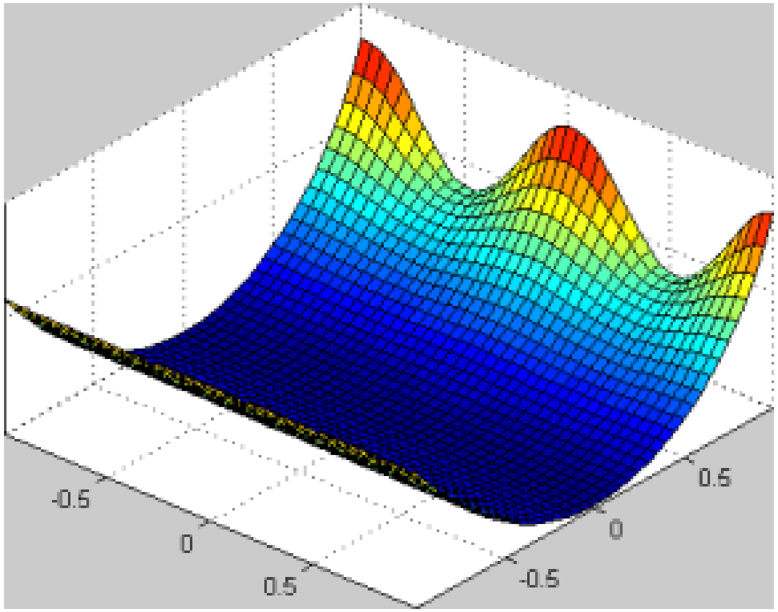
132 µm

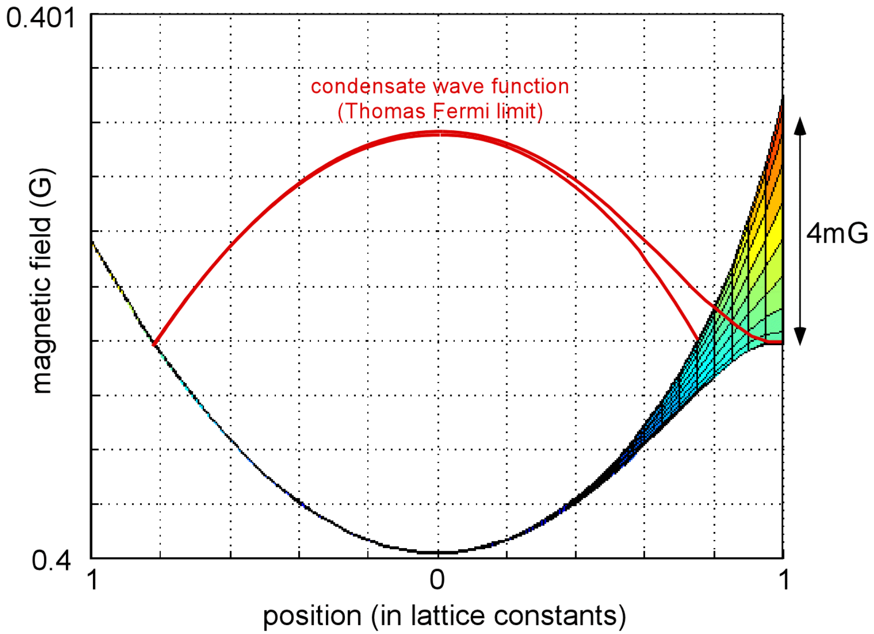


Magnetic lattice

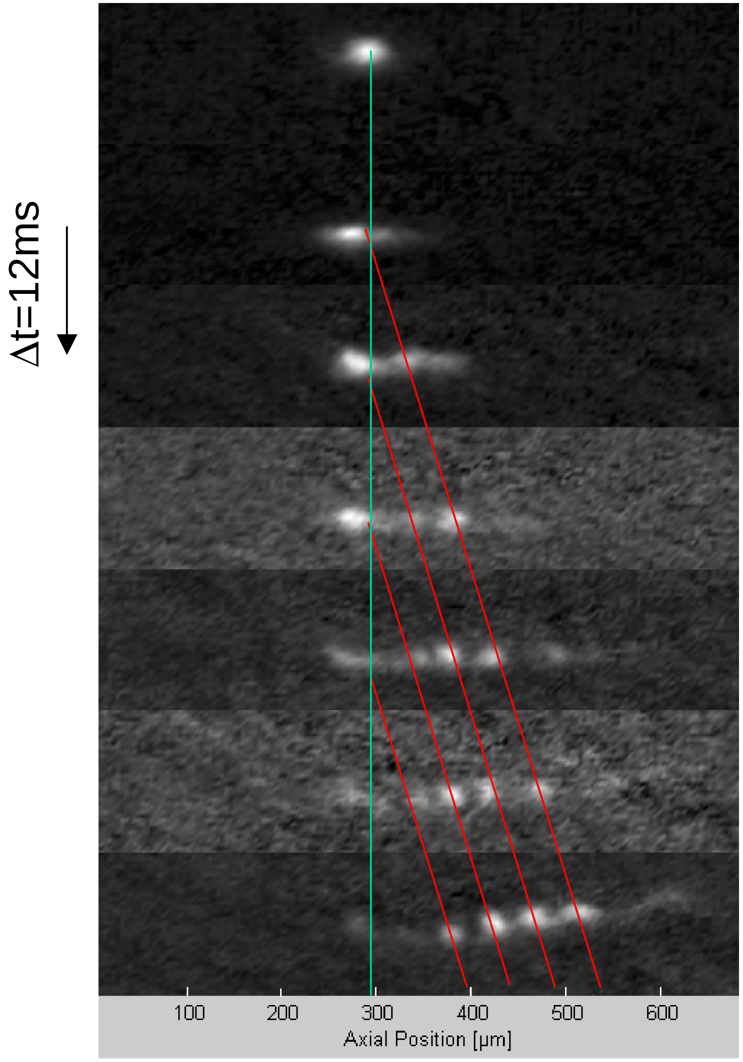


Magnetic lattice

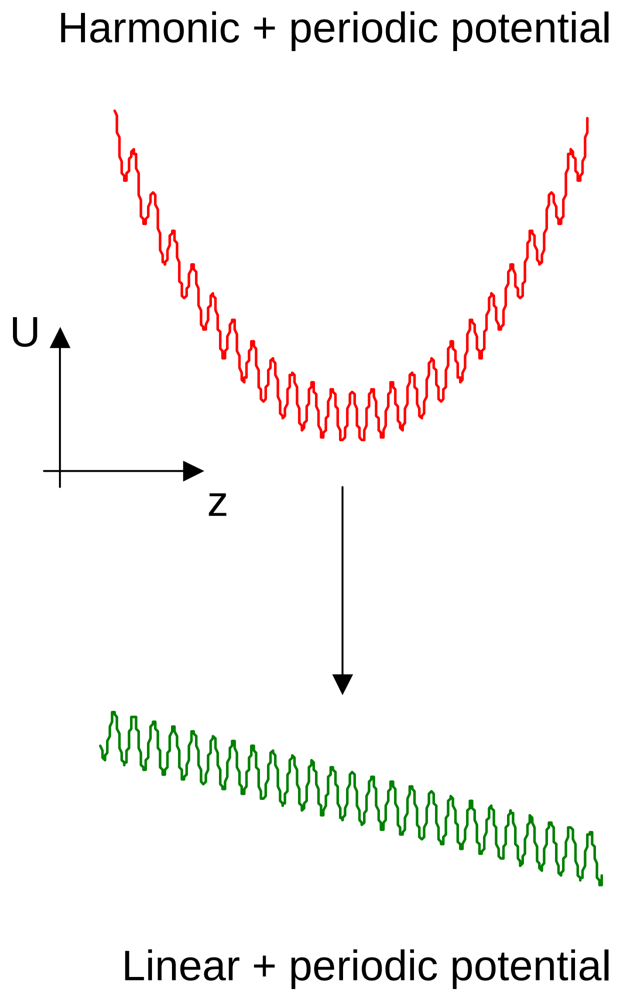




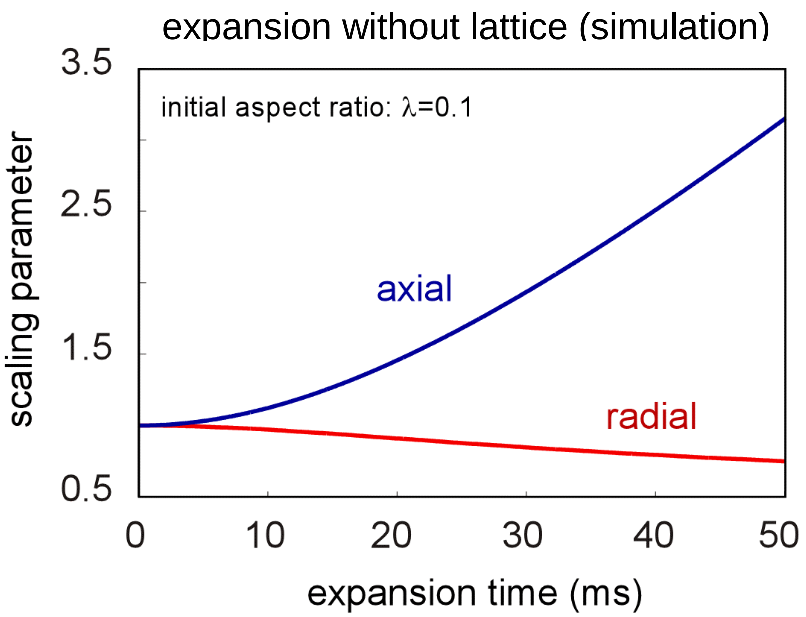
Applying a gradient

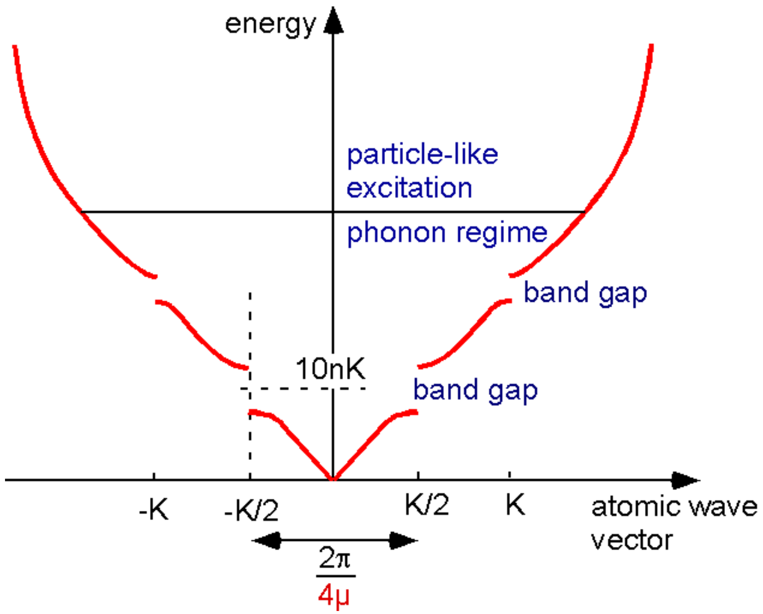


Bloch Oscillation with 80 Hz



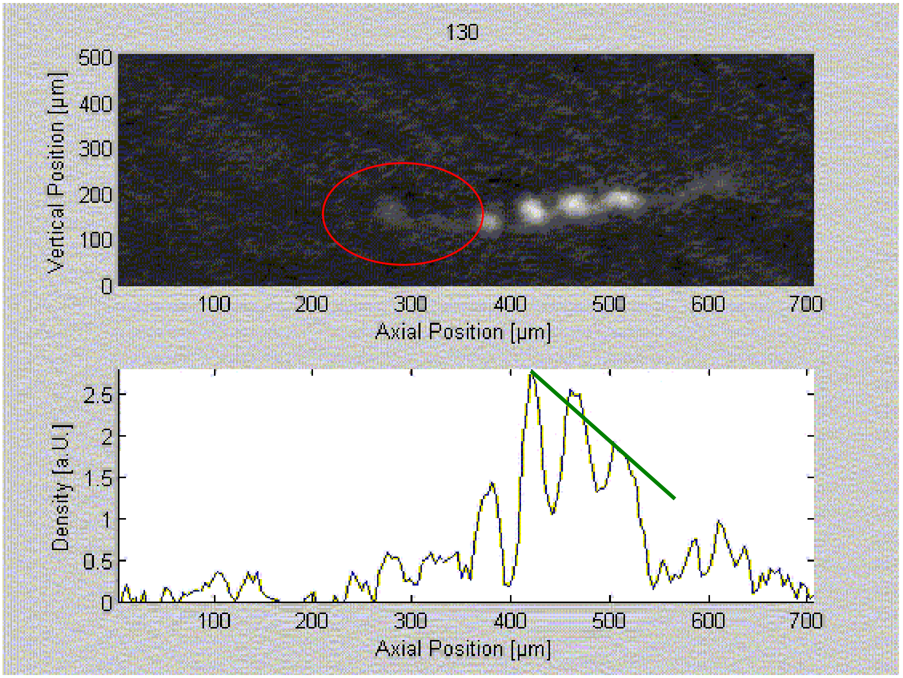
Bragg-reflection in the interaction regime ?

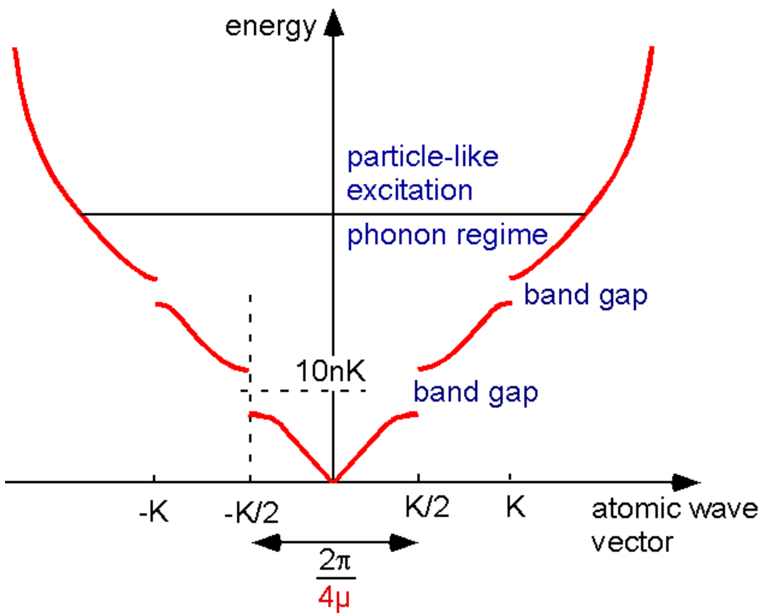




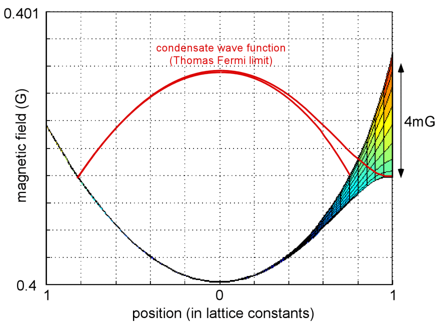
- lattice constant 10 times larger than in optical lattices
- Bragg velocity (single atom): 0.57mm/s
- recoil energy (single atom): 35Hz (1.7nK)
- initial chemical potential: 250Hz
- Lattice depth: 3.5Hz...35 Hz (s=0.1...1)

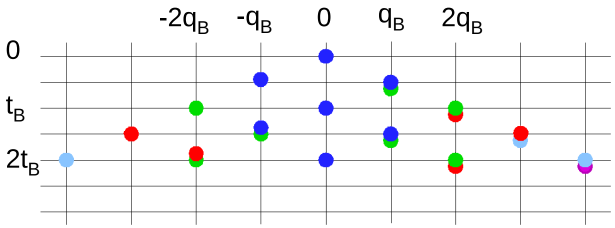
What else is different?





Number dependent lattice depth

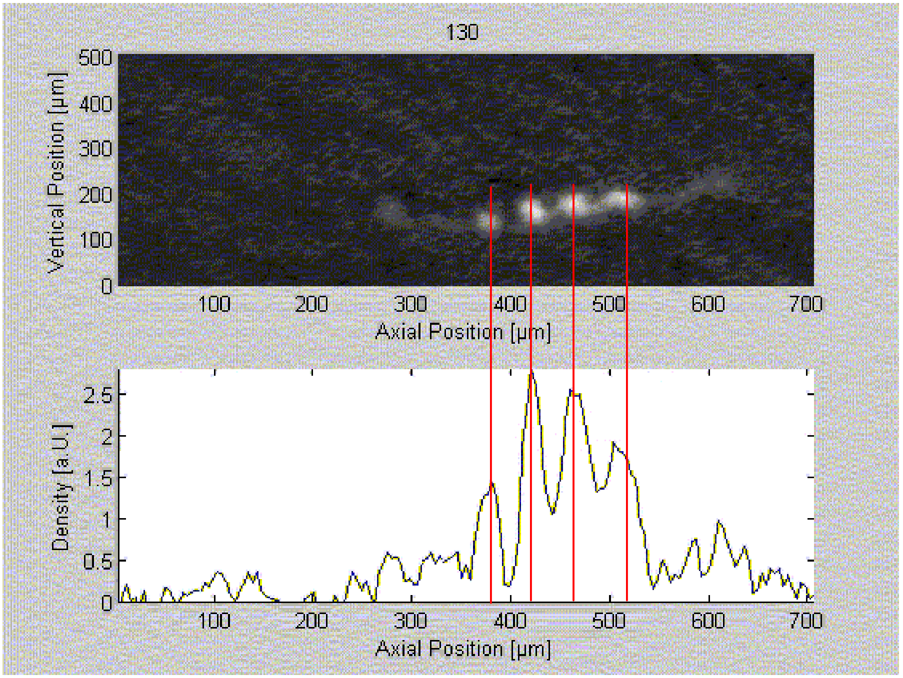




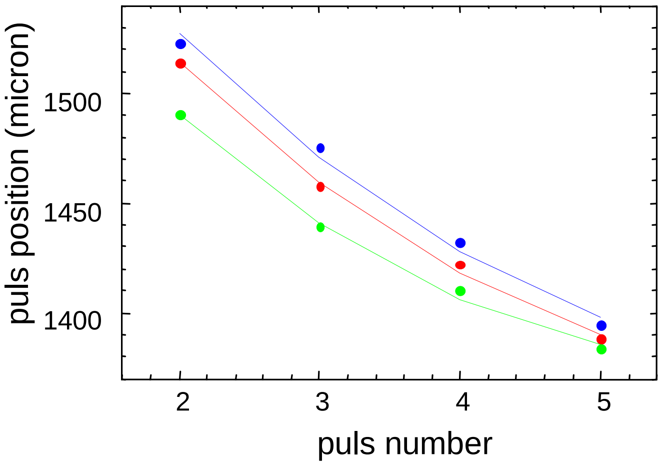
LZ tunneling and Bloch oscillation in higher bands ?

An interferometric force detector

50 ms evolution in the lattice and 19 ms time-of-flight



Force measurement



$s_n = A - Bn + 1/2\, Cn^2$

$a=0.0974 \pm 0.0023\ m/s^2$

$a=0.0959 \pm 0.0013\ m/s^2$

$a=0.0901 \pm 0.0012\ m/s^2$

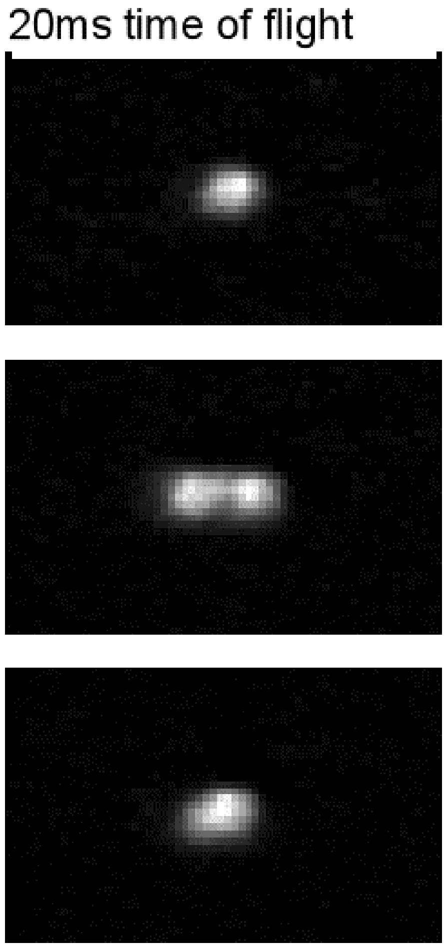
- Position of the pulses depends only on the gradient and the lattice constant.
- Better resolution for larger lattice contant.
- Already sensitive to $\sim 10^{-4}$ g = 0.1gal = 0,1cm/s^2 (statistical error)

$$t_B = \frac{h}{m\,\lambda a}$$

Bragg beam splitter

1) prepare Bloch state by slowly turning on the lattice

2) project it onto momentum states by suddenly switching off the lattice

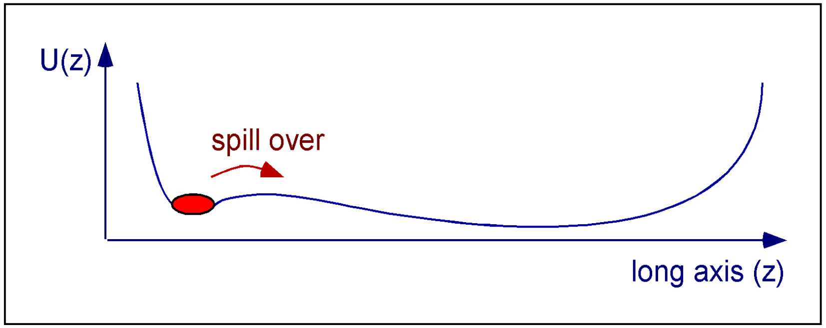


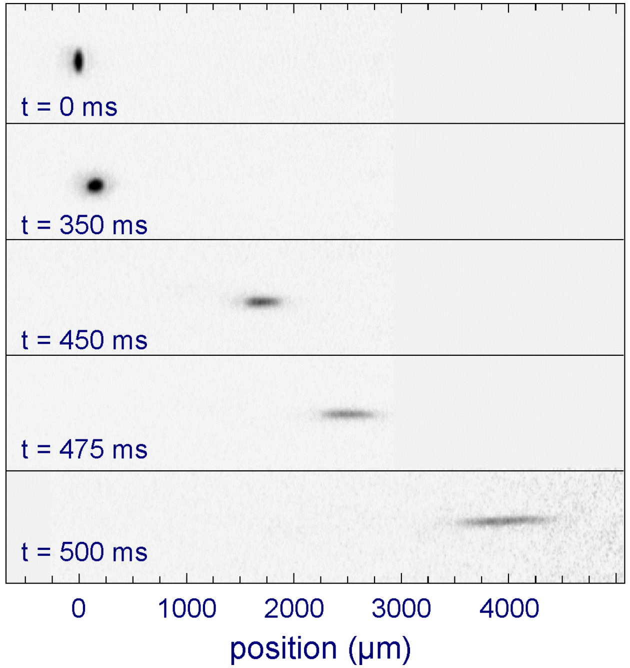
without lattice

adiabatic activation (200ms)
60 ms hold
sudden switch off (1ms)

adiabatic activation (200ms)
60 ms hold
adiabatic switch off (100ms)

Condensate as reservoir



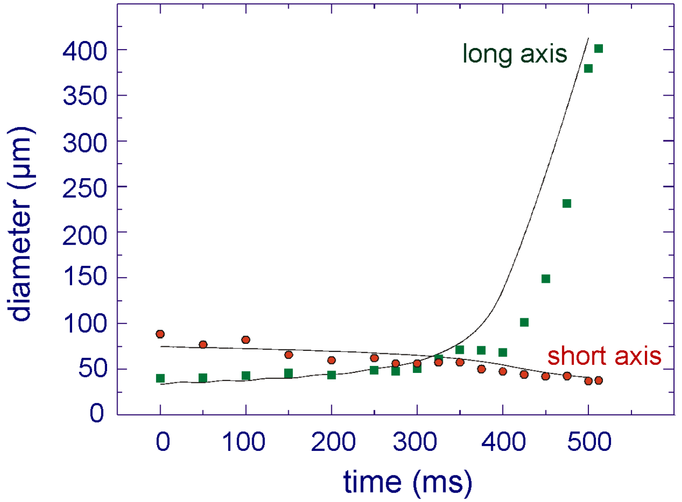


axial relaxation reduces interaction energy

↓

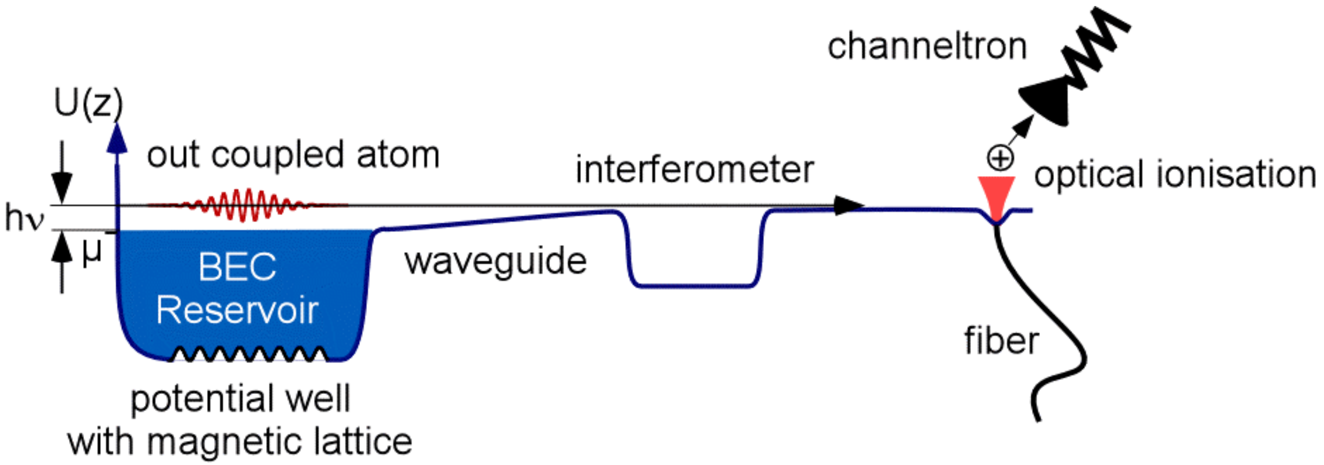
"quasi-1D condensate" without excitations

$$i\hbar \frac{\partial}{\partial t}\phi(r,t) = \left(-\frac{\hbar^2\nabla^2}{2m} + V_{ext}(r) + g|\phi(r,t)|^2\right)\phi(r,t)$$



wave packet propagating in
transverse ground state
v=50 mm/s, Δv=5 mm/s

Future: an atom spectrometer



Atom-Quantumoptics:

correlation of many particle states

entanglement

Matter wave spectroscopy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