A9 Ultracold Bose Gases With Variable Interactions

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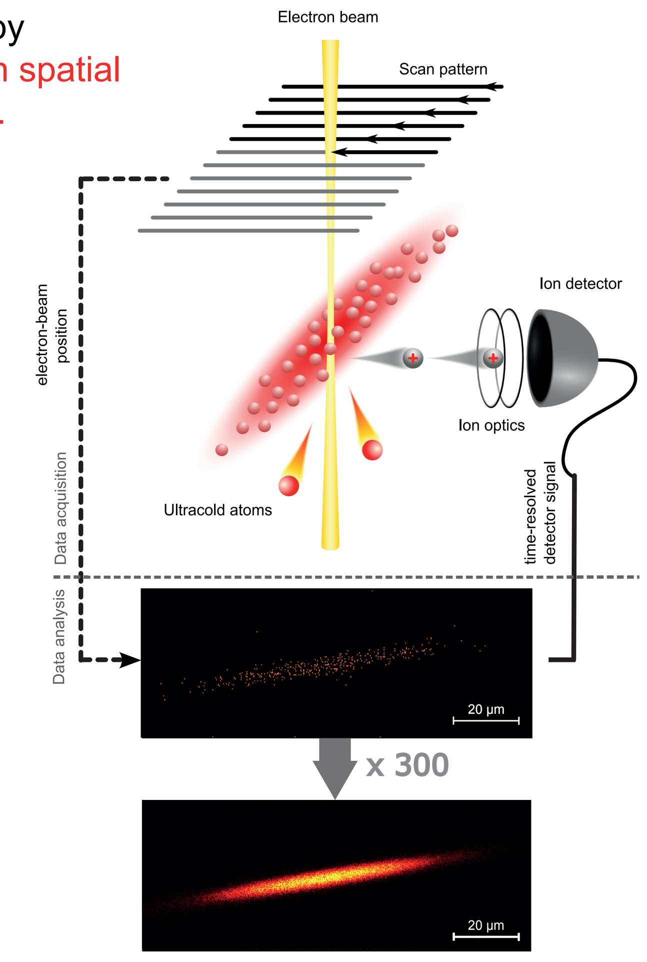
Scanning electron microscopy

High Resolution Microscopy of an Ultracold Quantum Gas

With the technique of Scanning Electron Microscopy we detect and manipulate ultracold atoms with high spatial and temporal resolution and single atom sensitivity.



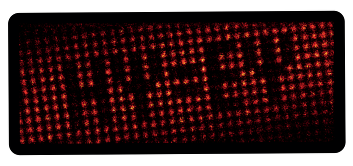
Working Principle

Interaction mechanism:

- ionization: 40%
- inelastic scattering: 55%
- elastic scattering: 5%

Physics Inside

- correlation functions
- low-dimensional systems
- selective dissipative manipulation
- tunneling dynamics in optical lattices
- addressing and manipulating optical lattices



Experimental Setup

Electron Column

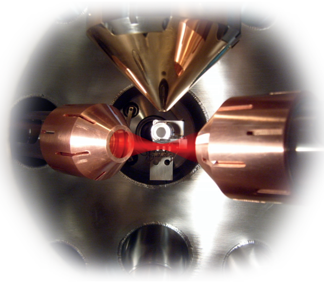
- beam diameter: 50 - 1000nm (FWHM)
- beam energy: 6keV
- depth of focus: 30µm

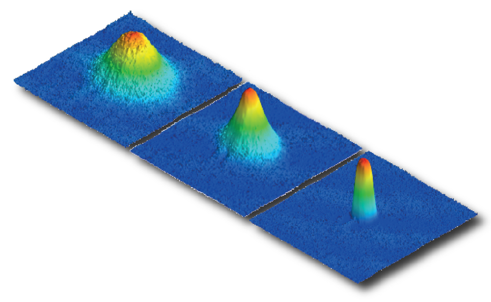
Dipole Trap

- CO_2: 10W power, 10.6µm wavelength
- trap depth: $\omega_r = 2\pi \cdot 2700$Hz, $\omega_a = 2\pi \cdot 215$Hz
- beam waist 30µm

Bose-Einstein Condensate

- evaporation time of 6 seconds
- N = 80.000 atoms
- F = 1 spinor condensate
- $\omega_r = 2\pi \cdot 178$Hz, $\omega_a = 2\pi \cdot 13$Hz

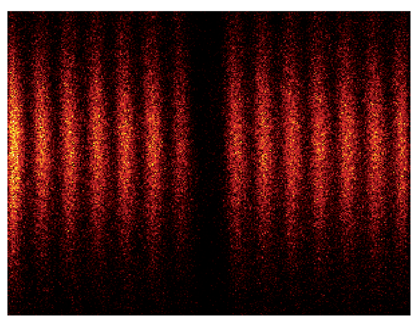




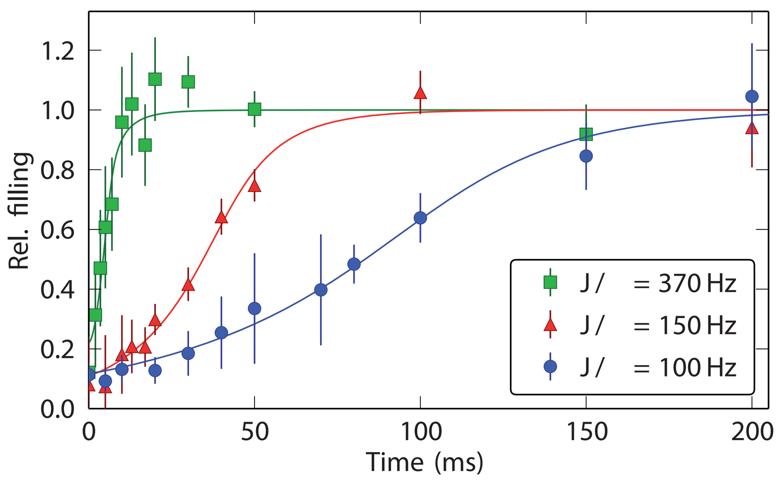
Negative differential conductivity

Measuring Configuration

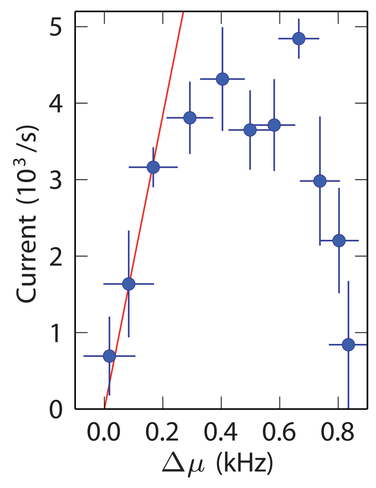
- N = 45k atoms in a BEC ⟶ $\omega = 2\pi \cdot (13, 165, 165)$Hz
- transfer to 1D optical lattice ⟶ N = 500 - 1000 atoms per site
- crossed laser beams at 90°: λ = 774nm ⟶ d = 547nm
- removal of atoms from the central site
  ⟶ observe filling status after variable time



Appearance negative differential conductivity



Derivative of data (here: J/ħ = 100Hz) leads to current-voltage characteristic



R. Labouvie *et al.* arXiv:1411.5632

- for low voltages (Δµ) the current increases linearly ⟶ Ohmic behavior
- ater that the current bends over and decreases for increasing voltage
  ⟶ negative differential conductivity in a system of ultracold atoms!
- explanation: density dependent tunneling coupling: $J_{eff}(\Delta\mu)$

3D, 1D and in between

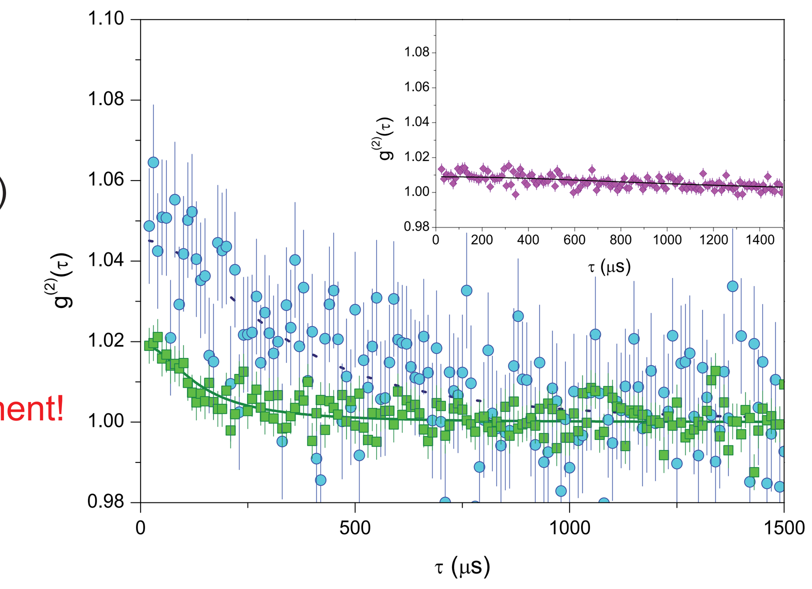
Local temporal correlation functions

Measurement in 3D

- N = 250k atoms in a thermal cloud (inset: N = 100k in a BEC in F = 1)
- extract correlation function from time resolved ion signal

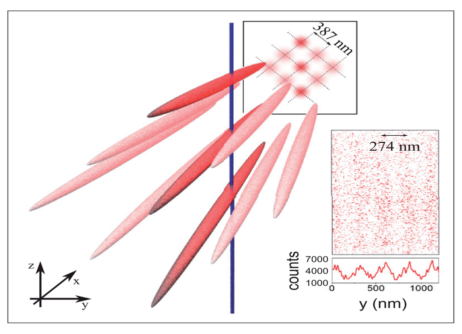
⟶ thermal bosonic bunching effect!

- theoretically predicted correlation time: $\tau_c = \frac{\hbar}{k_B T}$ ⟶ good agreement!



V. Guarrera *et al.* PRL **107**, 160403 (2011)

Measurement in 1D



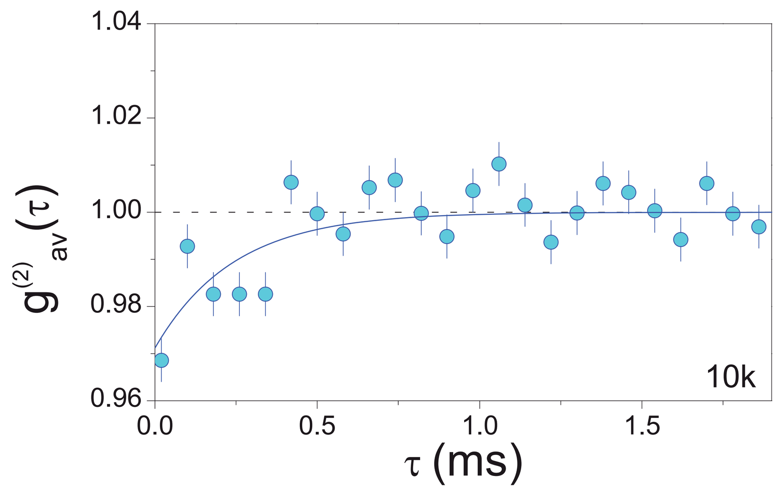
- 2D optical lattice: λ = 774nm, w = 630nm
- change atom number to adjust interaction strength
- interaction parameter in central tube: γ(0) = 1.5 / 0.5

⟶ fermionization of the bosonic particles!

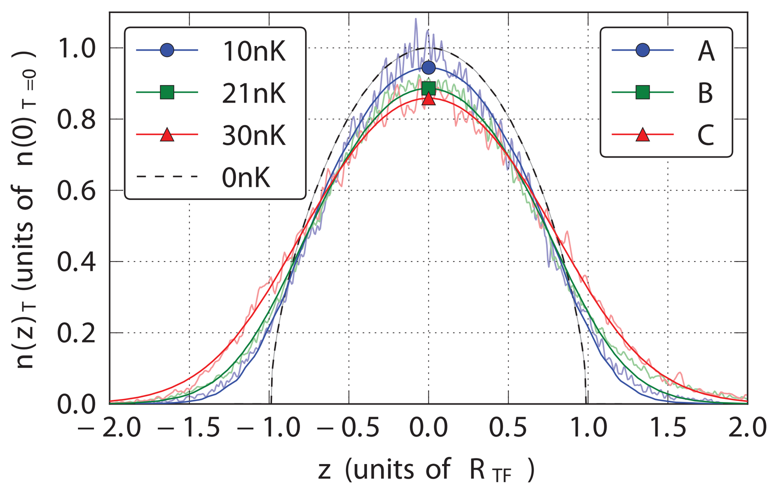
visible particle anti-bunching!

- correlation time and amplitude are compared with calculations performed using the Time Evolving Block Decimation algorithm

Collaboration between **A9** **A5**



V. Guarrera *et al.* PRA **86**, 021601(R) (2012)



A. Vogler *et al.* PRA **88**, 031603(R) (2013)

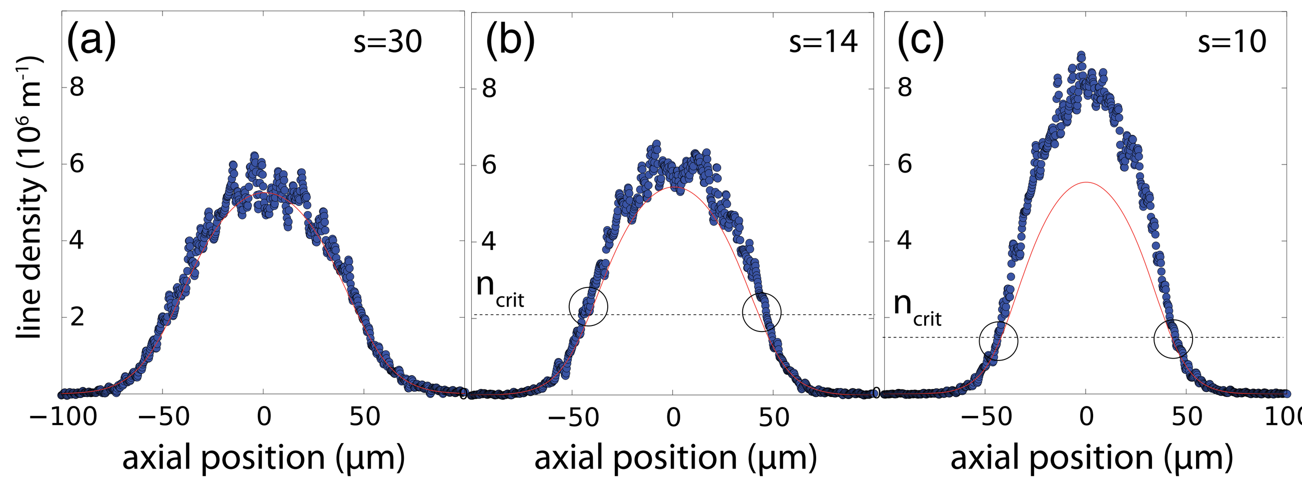
Measuring 1D density distributions:

- use electron beam for high resolution imaging
- make Abel inversion to get averaged single-tube density-profiles
- direct comparison with Yang-Yang theory for different temperatures

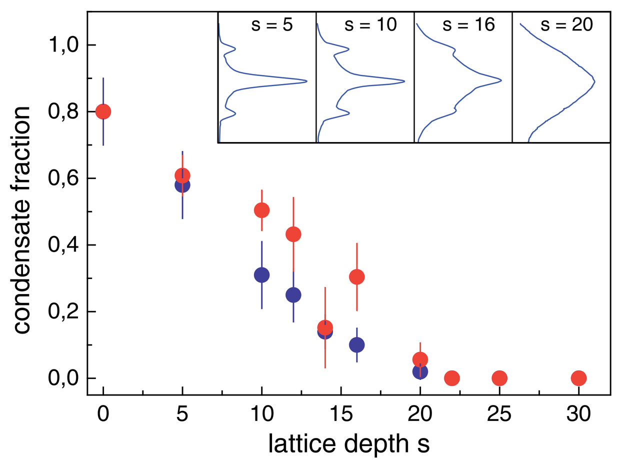
⟶ find good agreement between experiment and theory

Dimensional phase transition

- change 2D lattice height to vary interactions (from s = 30 to 0)
- use Yang-Yang theory to extract condensation fraction out of density distributions



A. Vogler et al. PRL 113, 215301 (2014)



- compare result with condesante fraction extracted from time-of-flight pictures

  ⟶ map out phase diagramm in s - µ plane

- get critical chemical potential at which the phase transition takes place

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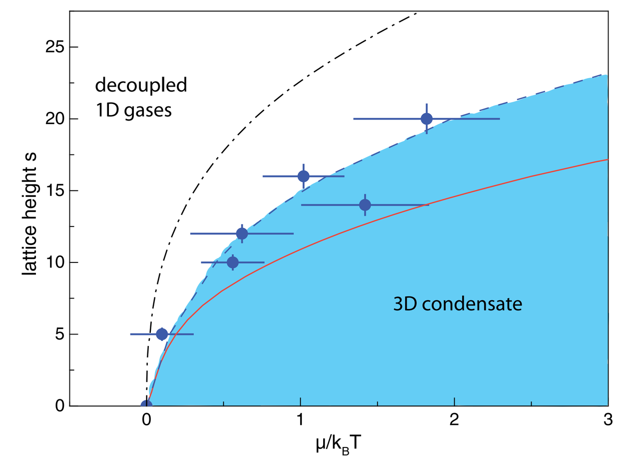
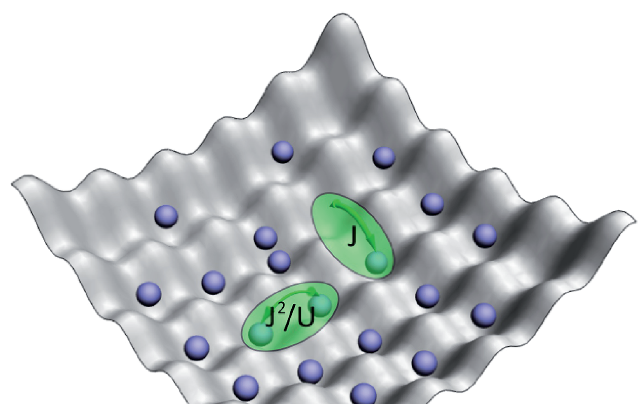


Ongoing and future work

Mass transport of strongly correlated bosons



- prepare atomic Mott insulator
- shift trapping potential
- study subsequent dynamics

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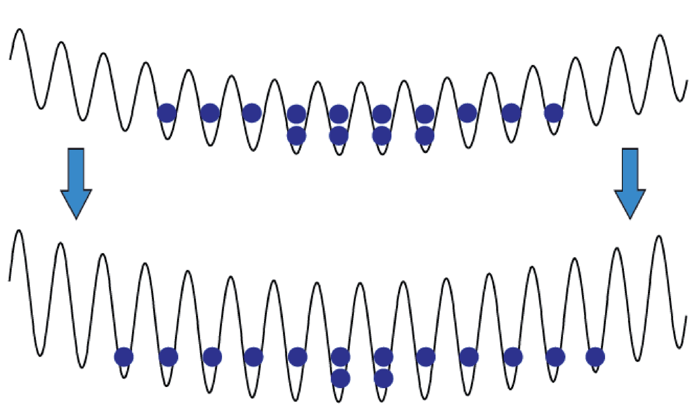
Dynamical arrest and quench dynamics



- start from atomic Mott insulator
- quench or slow change of interaction strength
- investigate relaxation dynamics to ground state

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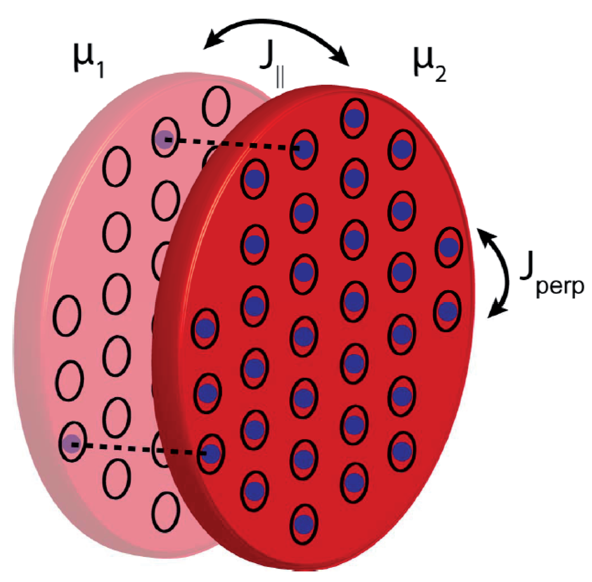
Current-voltage characteristics of strongly correlated bosons



- prepare non-equilibirum initial conditions
- adopt procedure form NDC measurement
- insulating plateaus should be visible in current-voltage relation

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Transport in mixed dimensions

- By exchanging the role of $J_{||}$ and J_{perp}, we want to study the transport in coupled 1D systems

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