Homogeneous 2D Fermi gases

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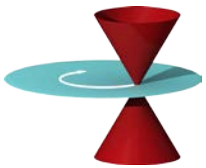
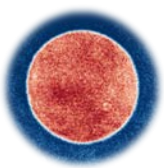
T. Lompe, H. Moritz
University of Hamburg

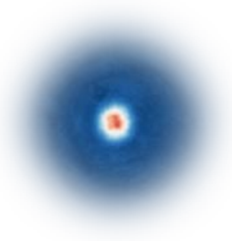
Outline



Critical velocity in BEC-BCS crossover

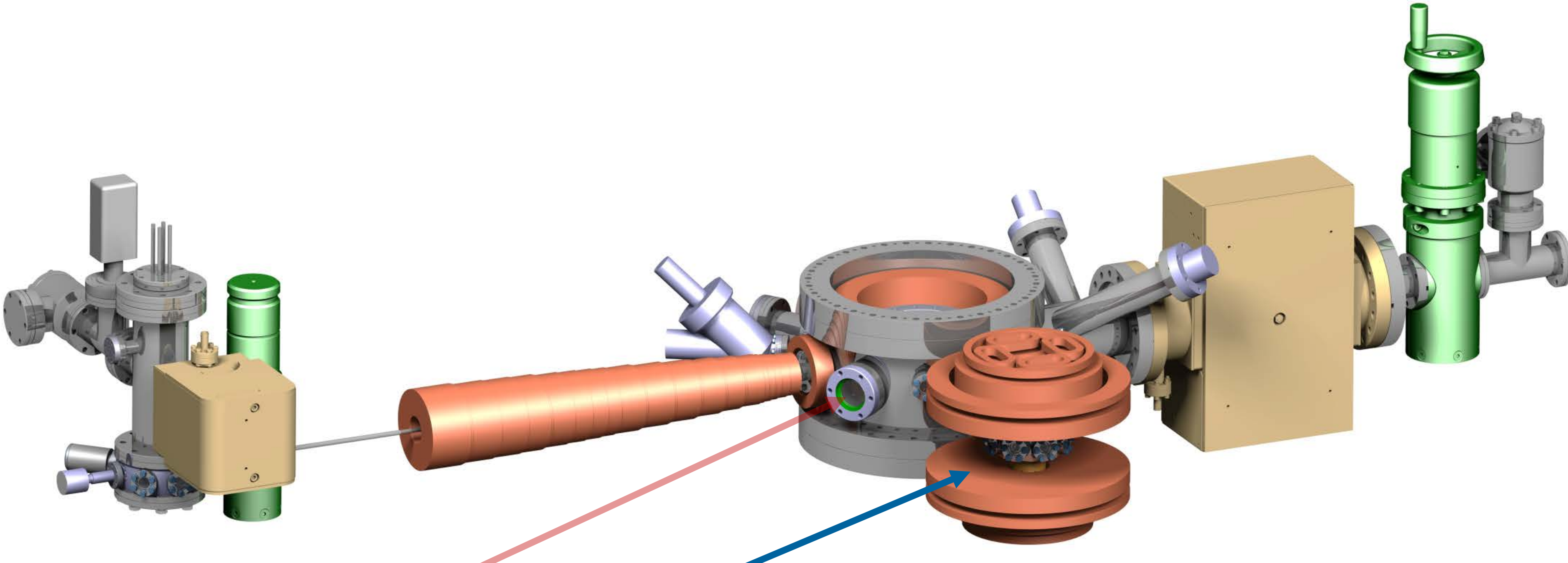


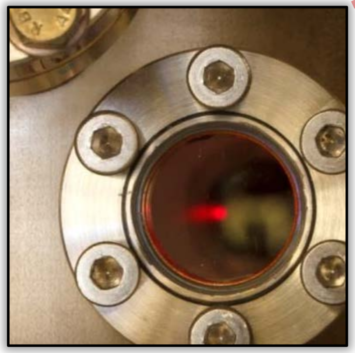
Homogeneous 2D Fermi gases

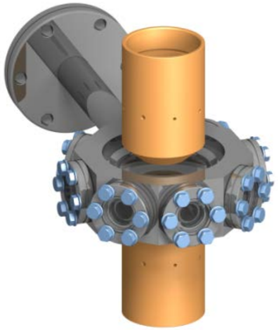


Momentum Distribution

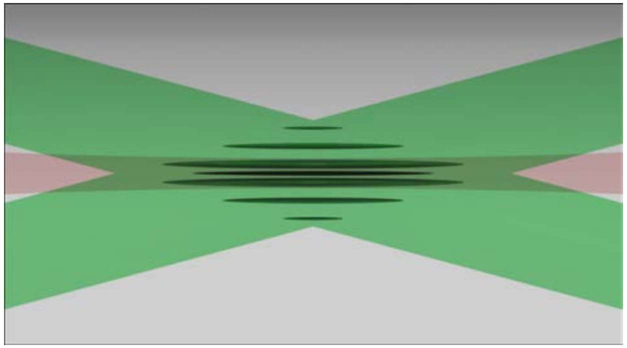
Producing Fermi gases

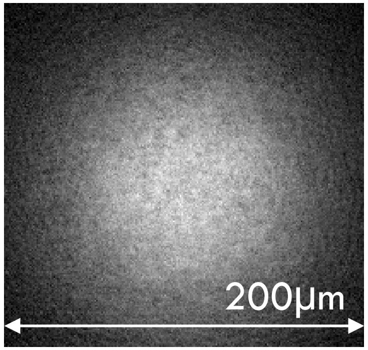






NA=0.6

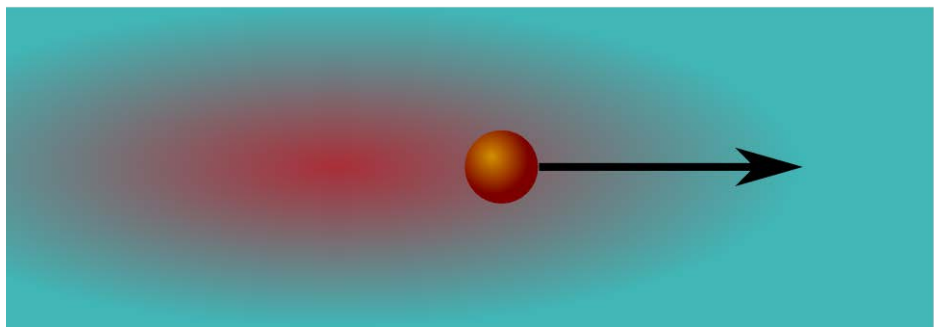




$E_F/h\nu_z \approx 4, N \approx 10^4$
$T/T_F < 10\%$
$d = n^{-1/3} \approx 1\ \mu\mathrm{m}$

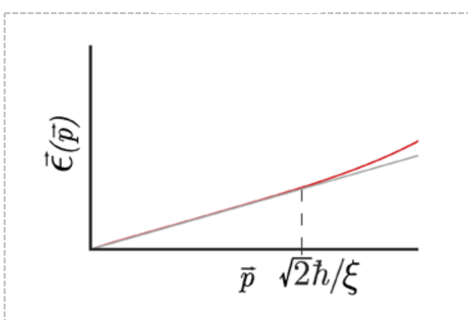
Landau's critical velocity

v<vc



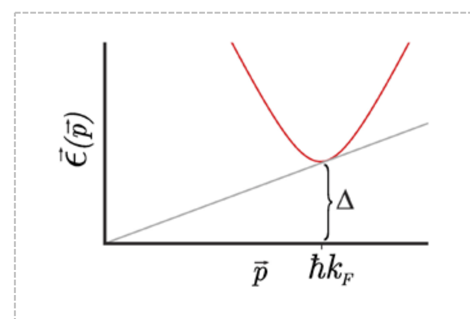
v>vc

BEC

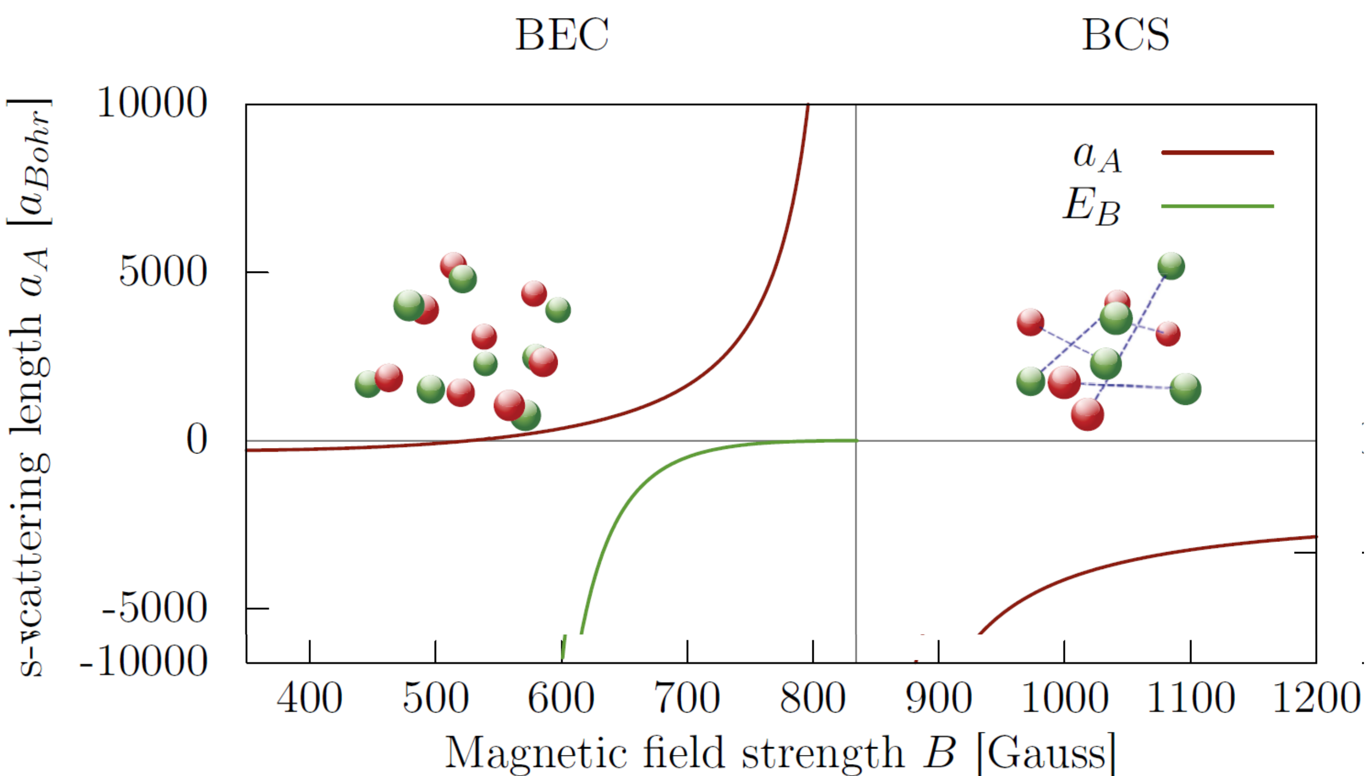


$$v_c = \min_k \left(\frac{\epsilon(k)}{\hbar k} \right)$$

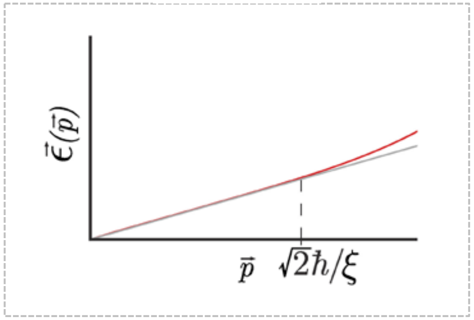
BCS



BEC-BCS crossover in ^{6}Li

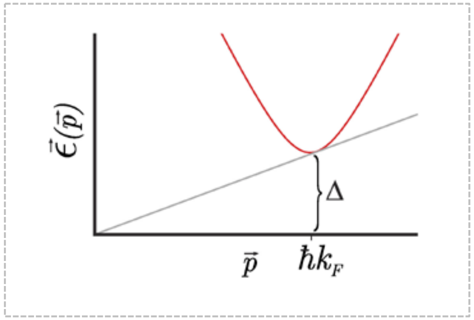


BEC

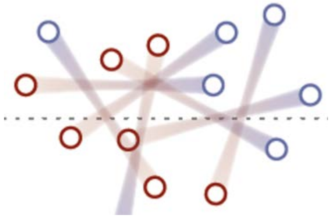


?

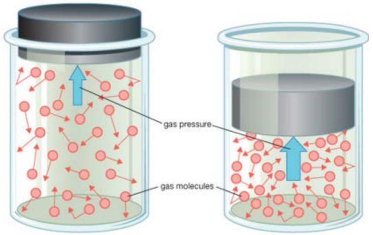
BCS



The critical velocity



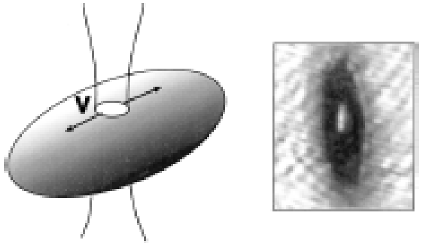
strong correlations



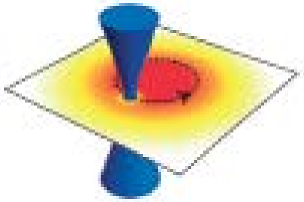
knowing ground state not enough

→ phonons, pair breaking, vortices

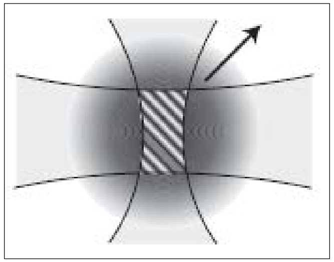
performative aspect: v_c and T_c matter



3D BEC



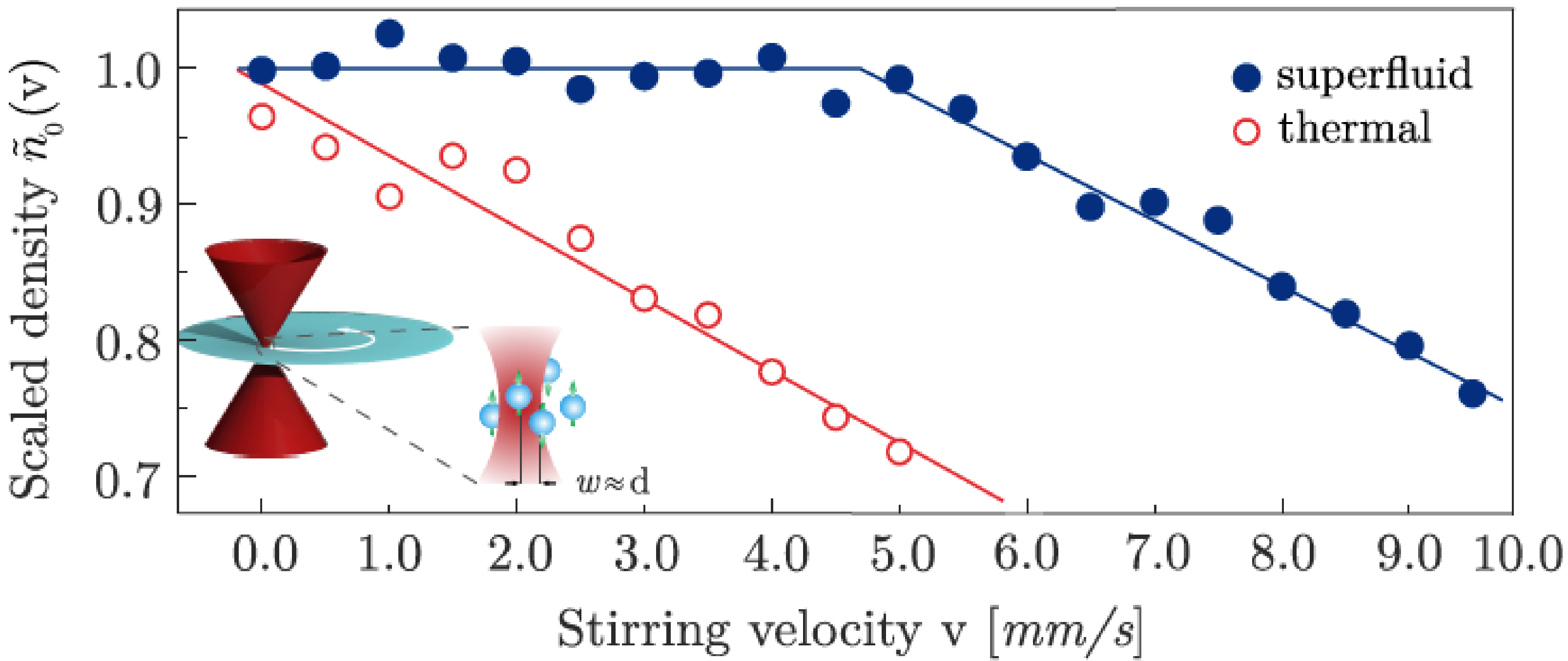
2D Bose/BKT



3D Fermi

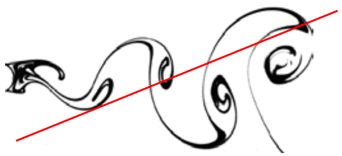
3D BEC: C. Raman et al., Phys. Rev. Lett. 83, 2502 (1999)
2D BKT: R. Desbuquois et al., Nature Phys. 8, 645 (2012)
3D Fermi: D. E. Miller et al., Phys. Rev. Lett. 99, 070402 (2007)
3D Fermi+Bose: M. Delehaye et al., Phys. Rev. Lett, 115, 265303 (2015)
BEC rings A. Ramanathan et al., Phys. Rev. Lett. 106, 130401 (2011)

Critical velocity

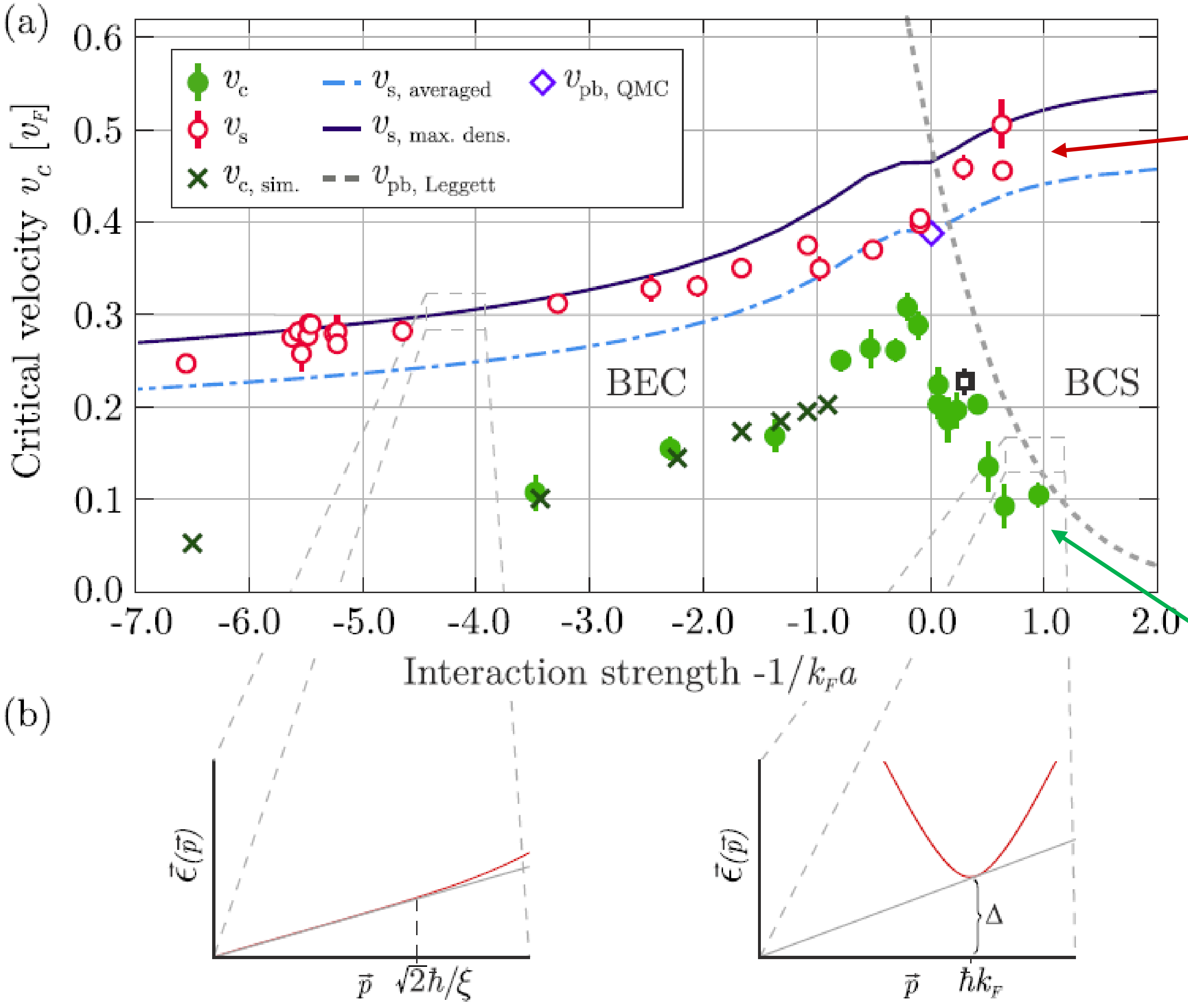


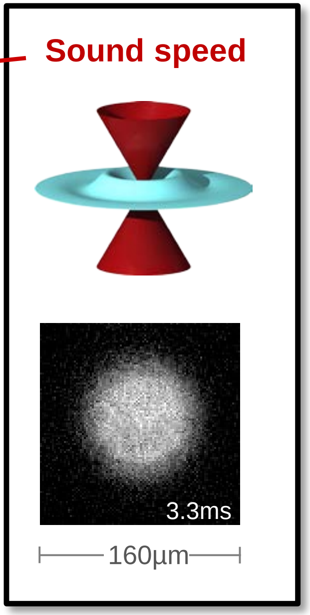
interparticle distance d ≈ 1.5µm ≈ waist of attracitve stirrer

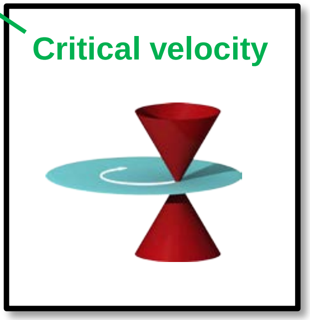
3D: $\frac{E_F}{h\,\nu_z} \approx 4,$



Critical velocity and speed of sound



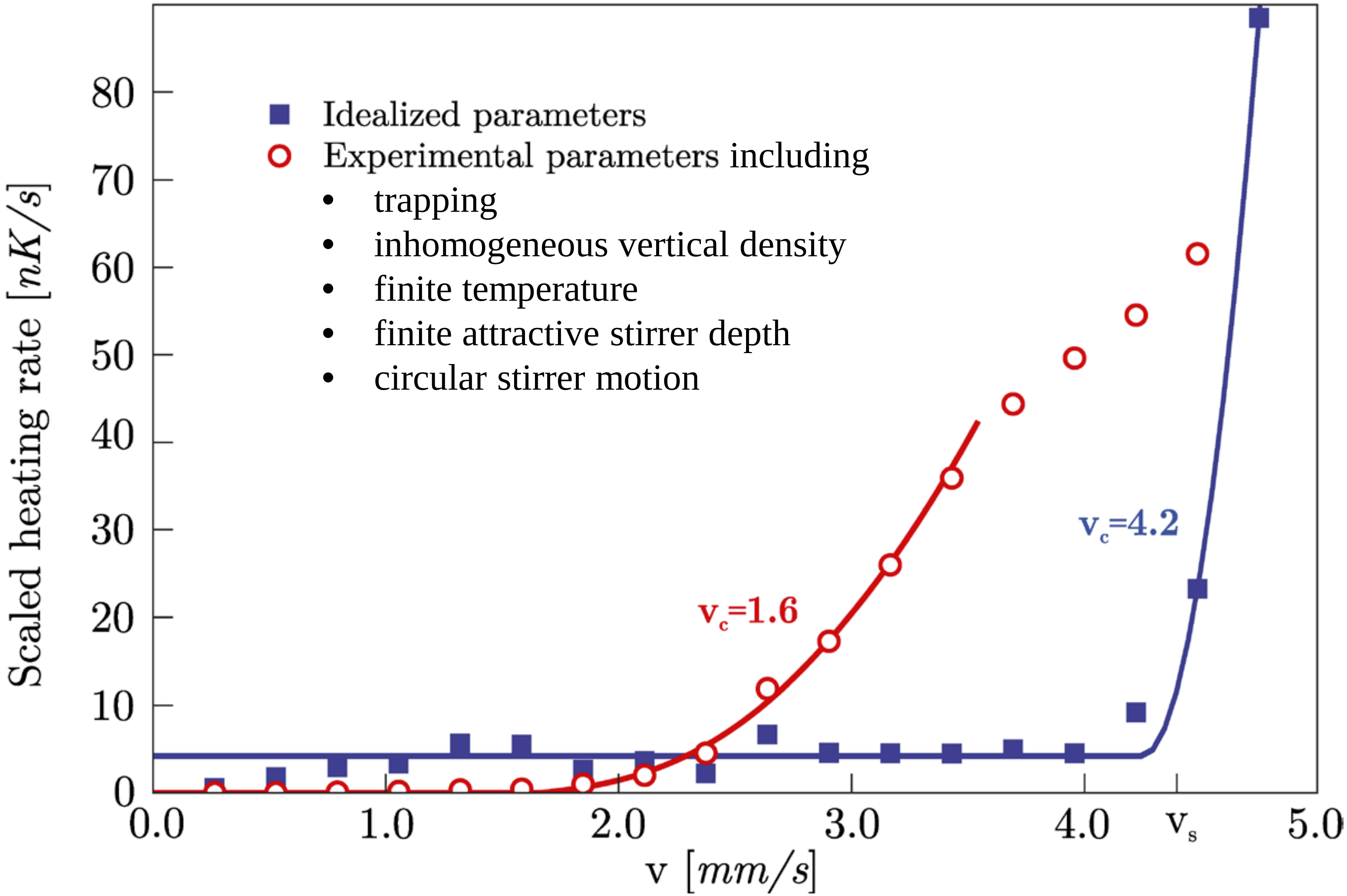




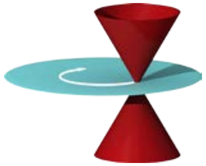
W. Weimer et al., PRL 114, 095301 (2015); V. Singh et al. PRA 93, 023634 (2016)

Simulations by Vijay Singh & Ludwig Mathey

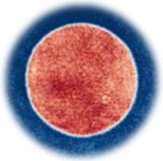
Ground state from Monte Carlo, dynamics with truncated Wigner method,



Outline



3D Critical velocity



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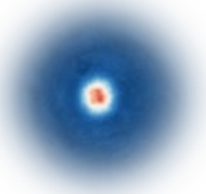
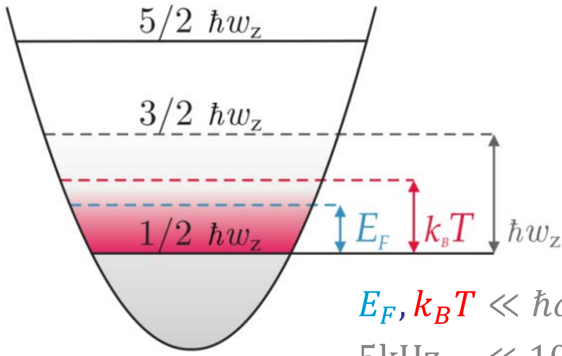


Momentum Distribution

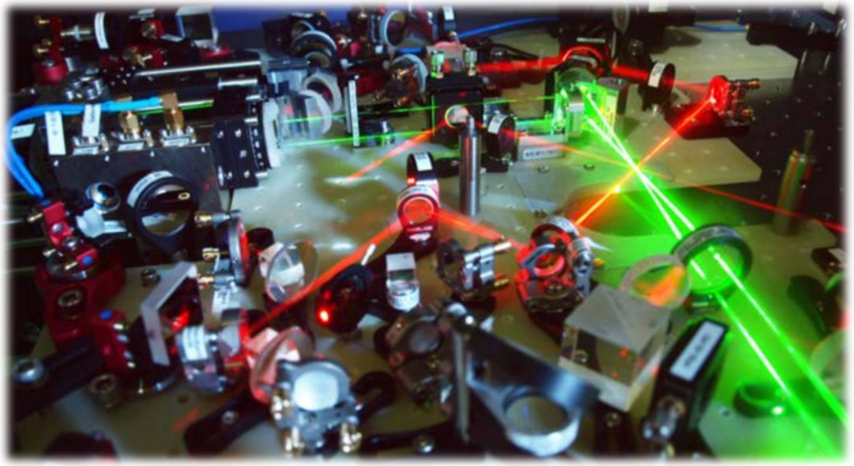
Reducing dimensions

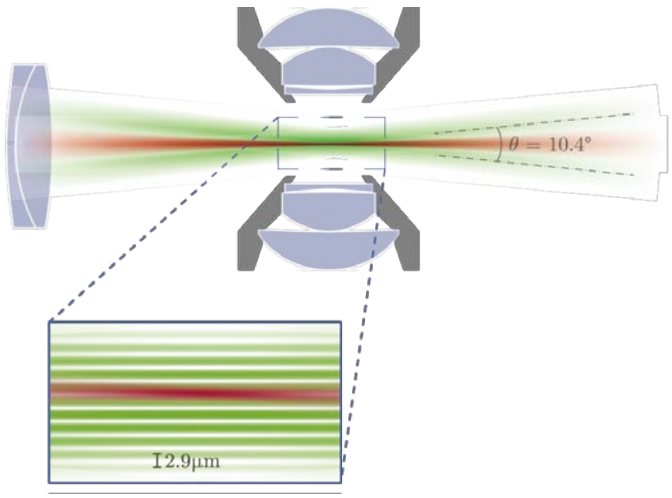


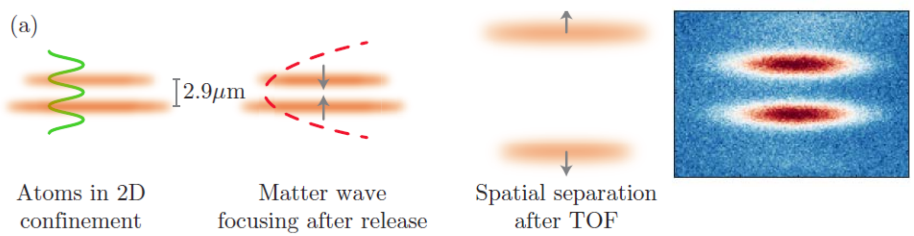
$E_F, k_BT \ll \hbar\omega_z$

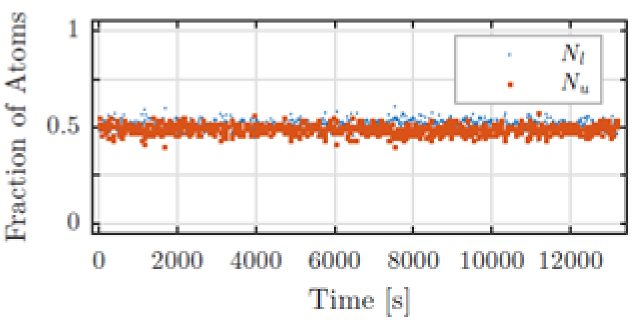
5kHz $\ll$ 10 kHz

2D Fermi: Turlapov, Vale, Köhl,
Zwierlein, Thomas, Jochim, Bakr, …



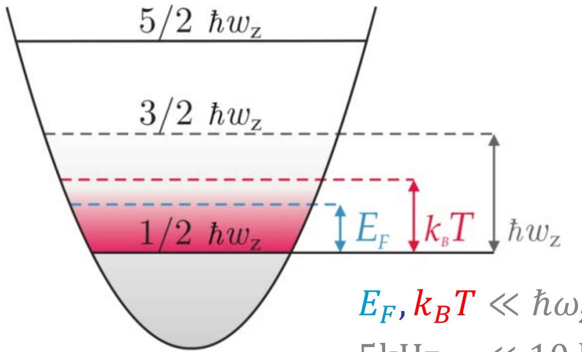






Single or double layer
stable over hours, central layer >90%

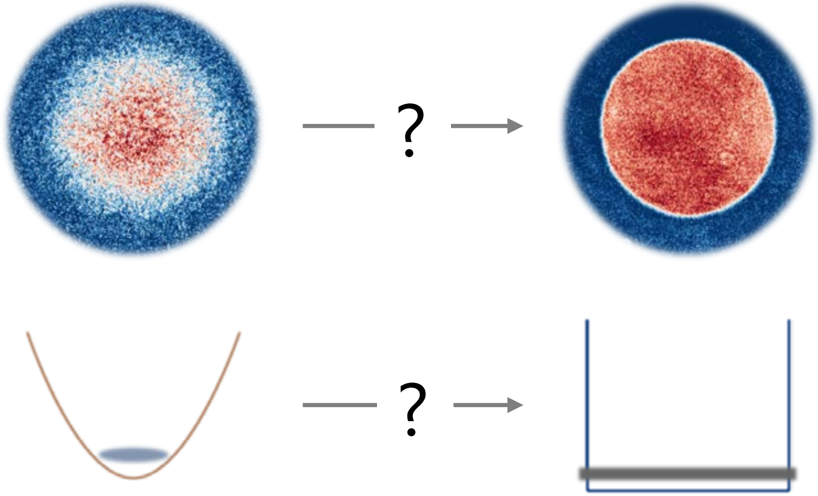
Reducing dimensions



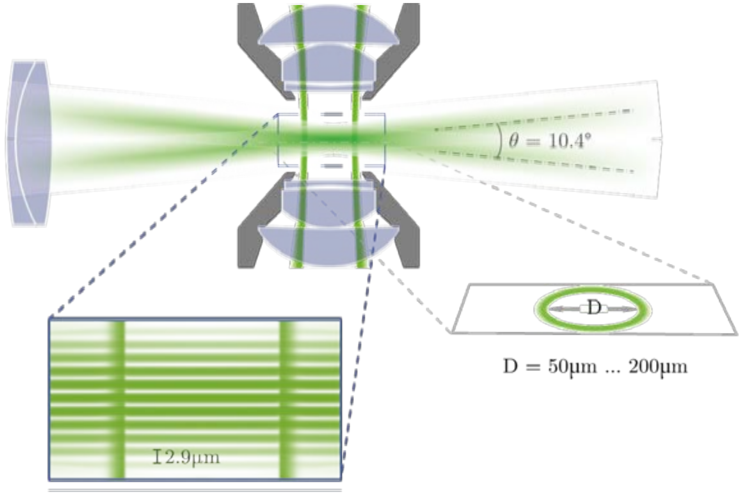
$E_F, k_B T \ll \hbar\omega_z$

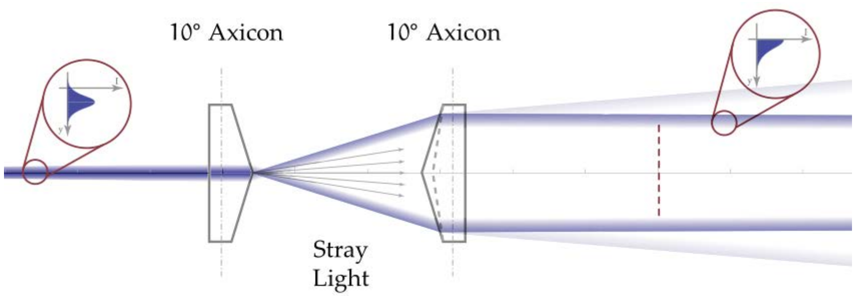
5kHz $\ll$ 10 kHz

2D Fermi: Turlapov, Vale, Köhl, Zwierlein, Thomas Jochim, Bakr, …



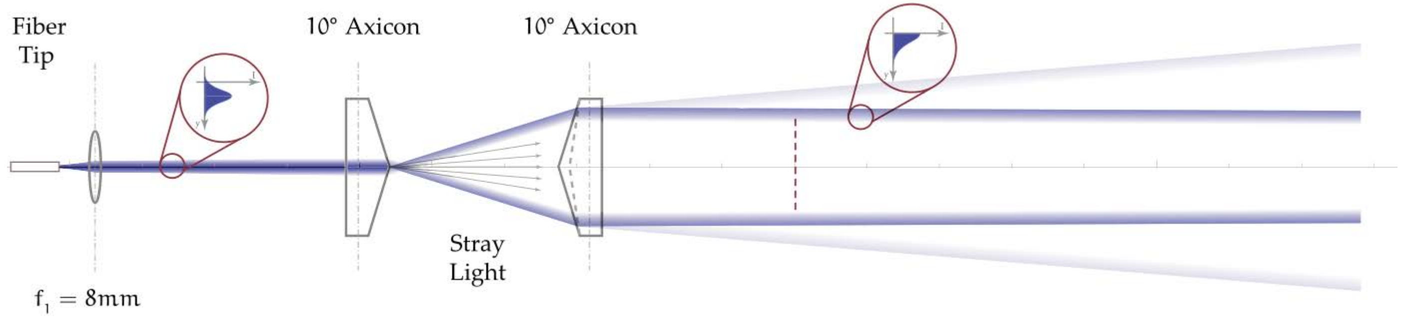
3D Fermi in box: Zwierlein Group



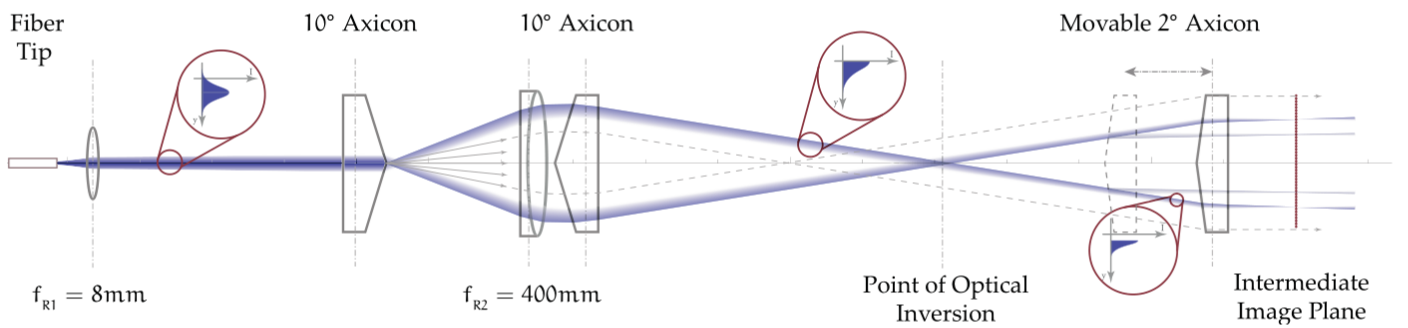


Creating a steep ring without disorder inside

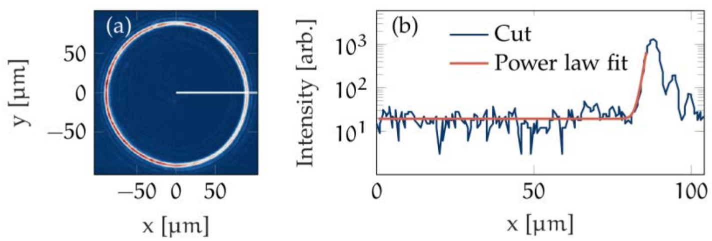
Simplest setup



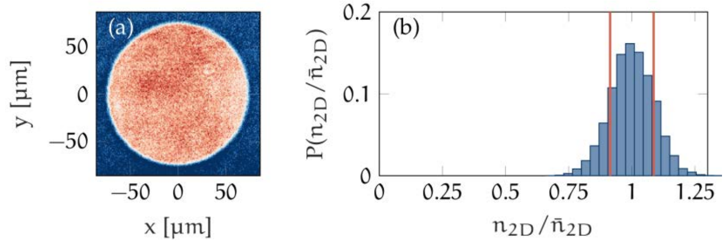
Steeper, less stray light inside



Flatness and steepness



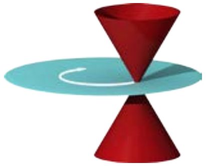
$V(x) = Ax^{\xi} = Ax^{87\pm5}$



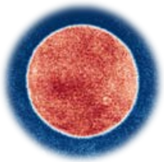
75 img's averaged

$\sigma_n = 8.6\,\%$

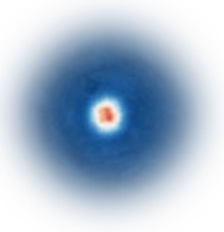
Outline



3D Critical velocity



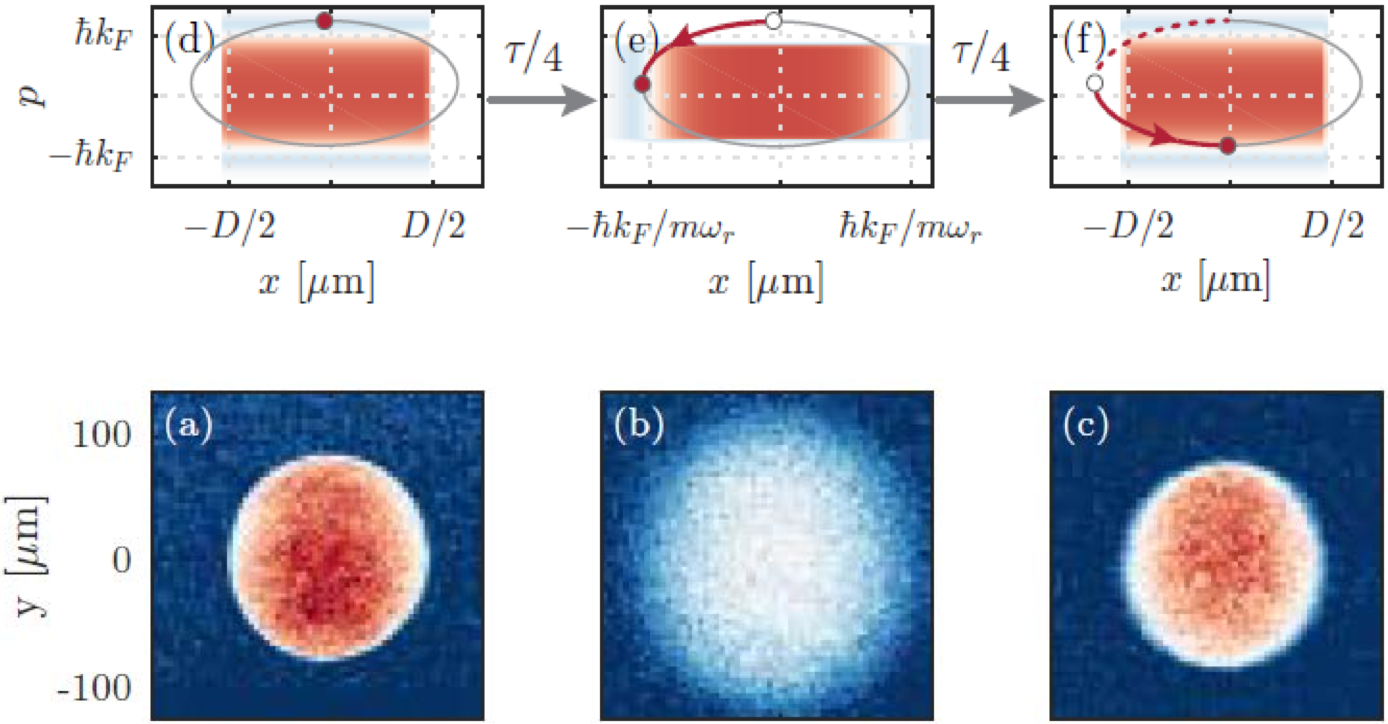
Homogeneous 2D Fermi gases

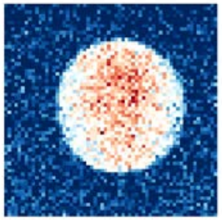


Momentum Distribution – a nonlocal probe

To momentum space and back …

free evolution in HO = rotation in phase space

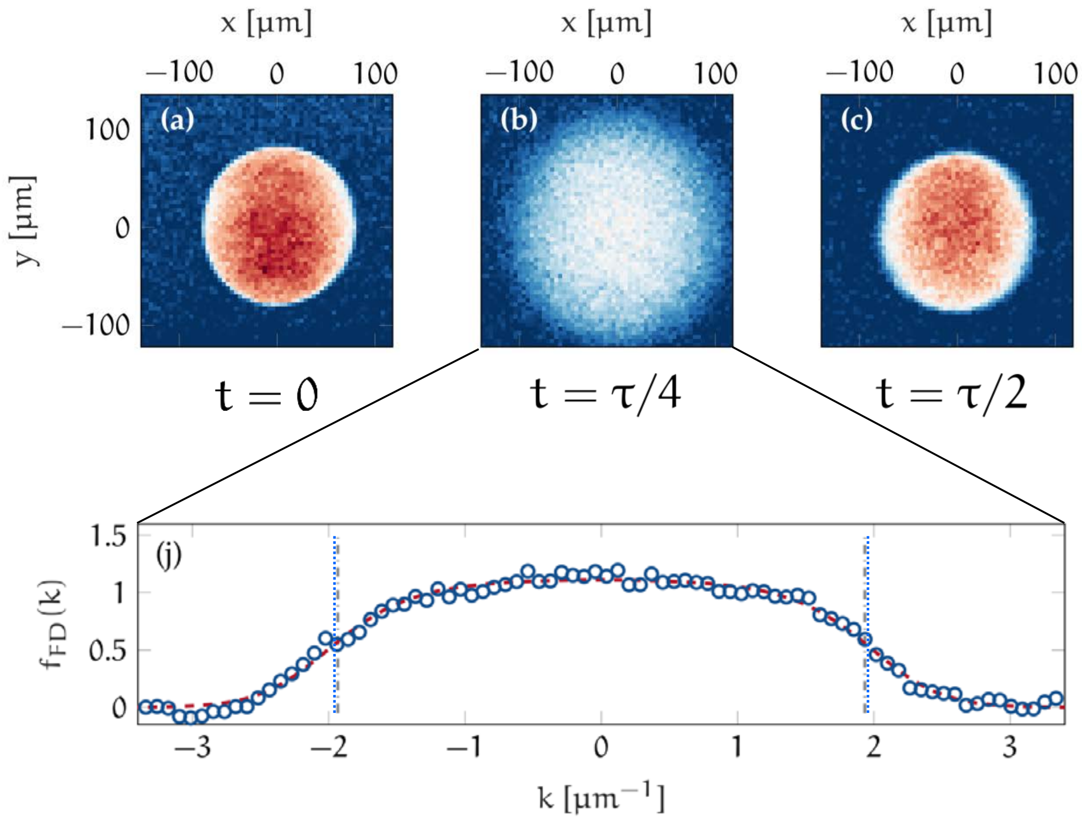




Matter wave focussing: Bose: Walraven, Cornell, Bouchoule, van Druten groups
Fermions: Jochim group

K. Hueck et al., PRL 120, 060402 (2018)

Thermometry: $n(k) = f(k, T, \mu)$



$$f_{FD}(k) = \frac{1}{1 + \exp\left[\beta\left(\frac{\hbar^2 k^2}{2m} - \mu_0\right)\right]}$$

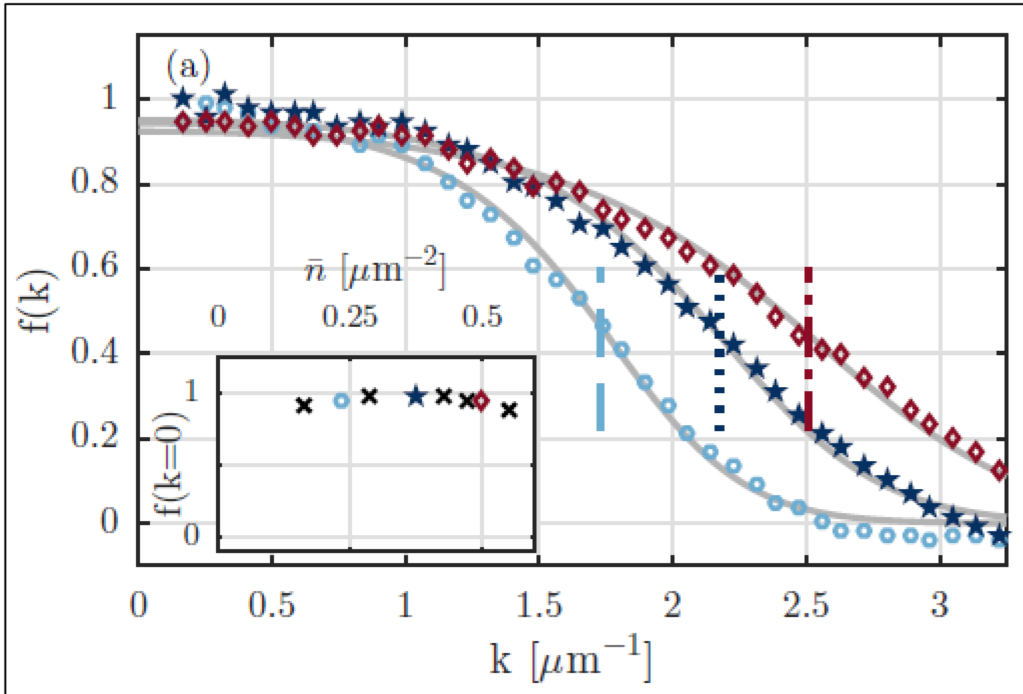
$T/T_F = 0.31 \pm 0.02$

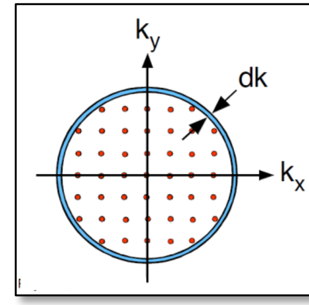
$$k_{F,dens} = \sqrt{4\pi n_{2D}}$$

K. Hueck et al., PRL 120, 060402 (2018)

Pauli blocking in momentum space

box diameter D ⇒ single k-mode occupies area $A_k = 16\pi/D^2$
Measure n(k): If one atom per A_k ⇒ unit occupation $f(k) = 1$

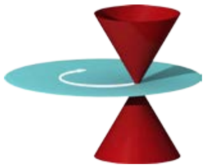




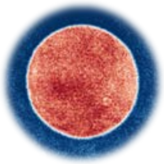
$f(k)$ saturates for increasing n ⇒ evidence for Pauli blocking

Pauli blocking in momentum space: B. Mukherjee (Zwierlein group), PRL 118, 123401 (2017)
K. Hueck et al., PRL 120, 060402 (2018)

Summary



3D Critical velocity



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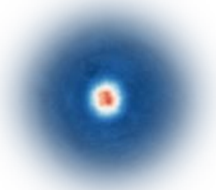
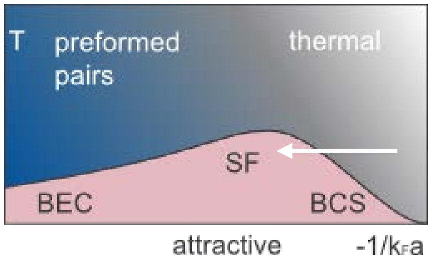


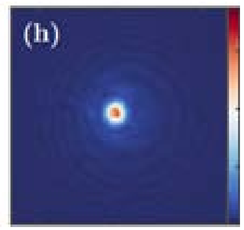
Momentum Distribution – a nonlocal probe

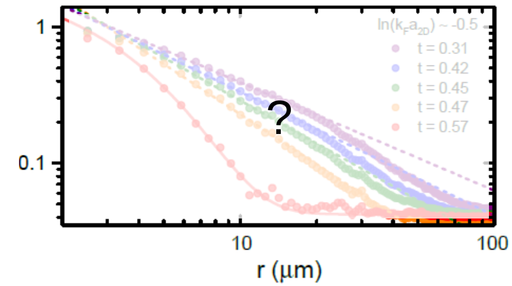
Outlook

Quench

wait → measure n(k) *Fourier* → $g_1(r,t)$

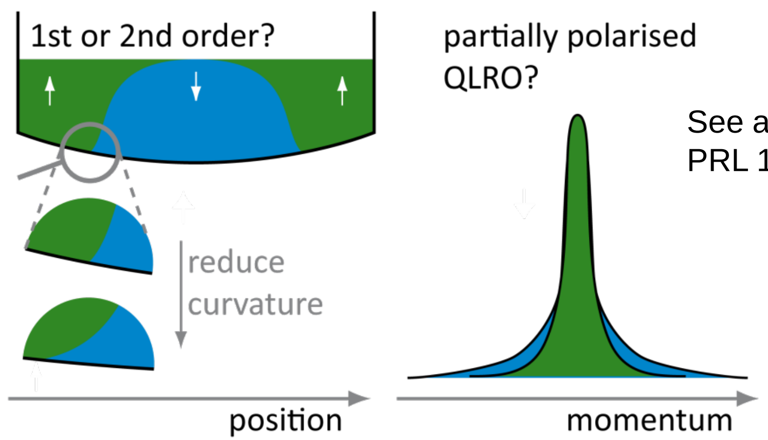






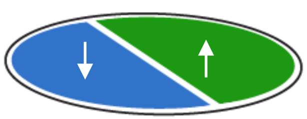
See also: P. A. Murthy et al., PRL 115, 010401 (2015), N. Navon et al., Science 347, 167 (2015)

Imbalanced gases

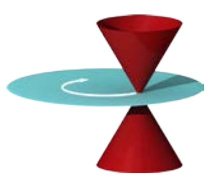


See also: D. Mitra et al. PRL 117, 093601 (2016)

Others:



Spin-diffusion



In 2D

Collaboration: Vijay Singh, Ludwig Mathey

Previous members: Wolf Weimer, Kai Morgener

SFB

SFB 925: Light induced dynamics and control of strongly correlated quantum systems

erc

Mesoscopic Fermi Gases

MesoFermi

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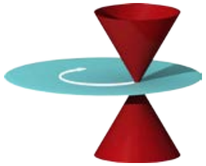
THE HAMBURG CENTRE FOR ULTRAFAST IMAGING

Outline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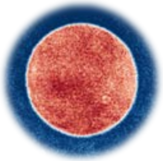
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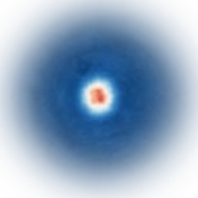
Equation of state


Momentum Distribution