

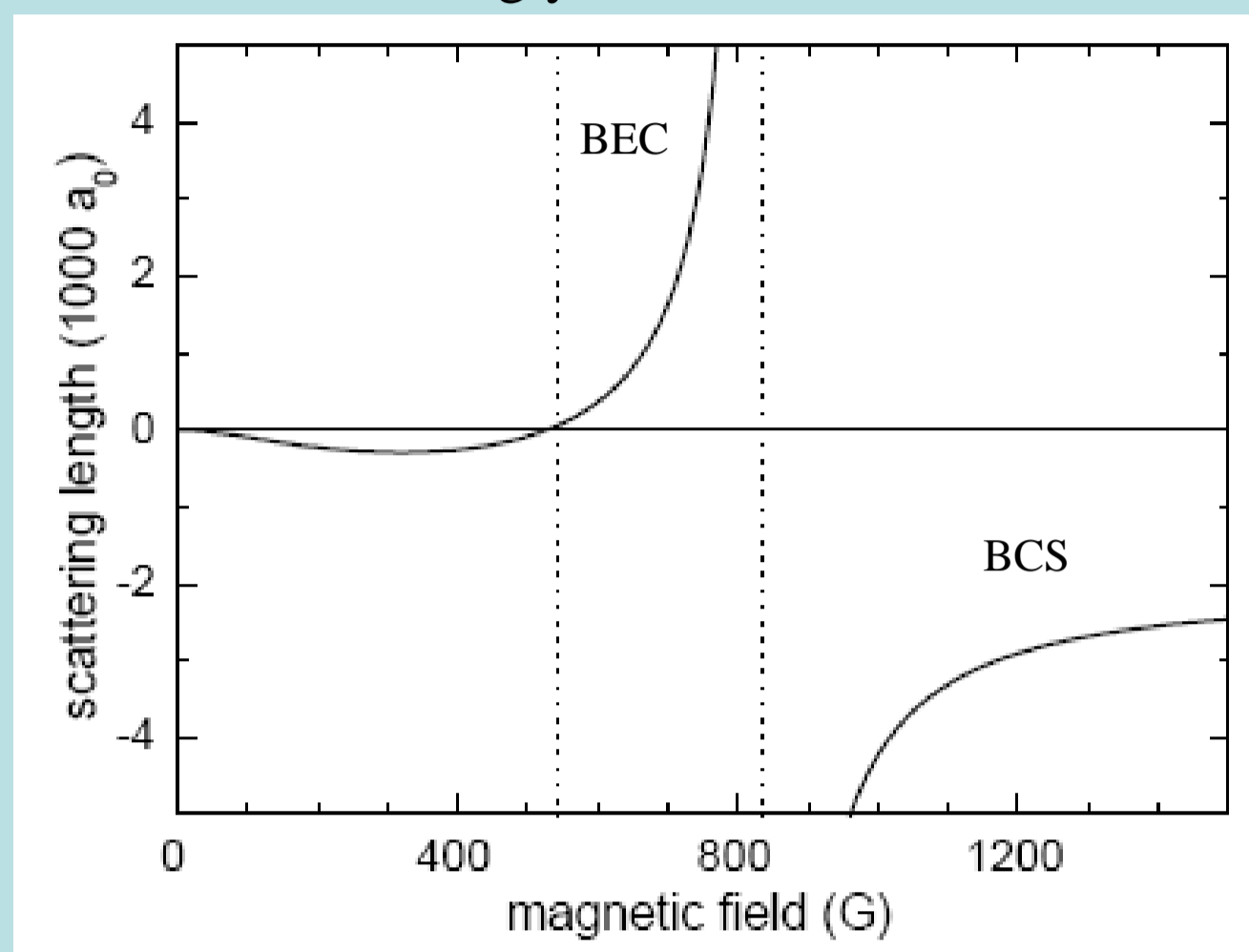
## BEC-BCS transition in Fermionic Gases

### Superfluid transition

Weak interactions: two well-understood regimes:

- $a > 0$ : Bose-Einstein Condensation of Molecules
- $a < 0$ : BCS (Bardeen-Cooper-Schrieffer) transition similar to electron pairing in superconductors

In the crossover region between the two: strongly correlated fermions

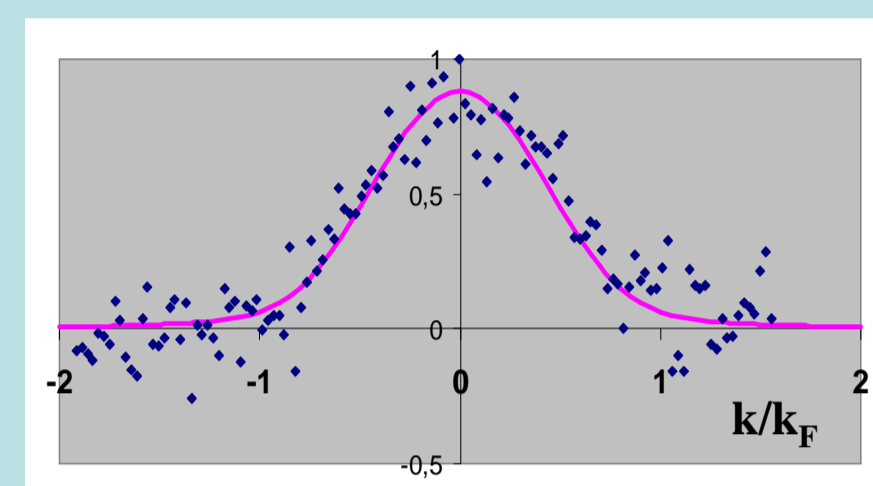
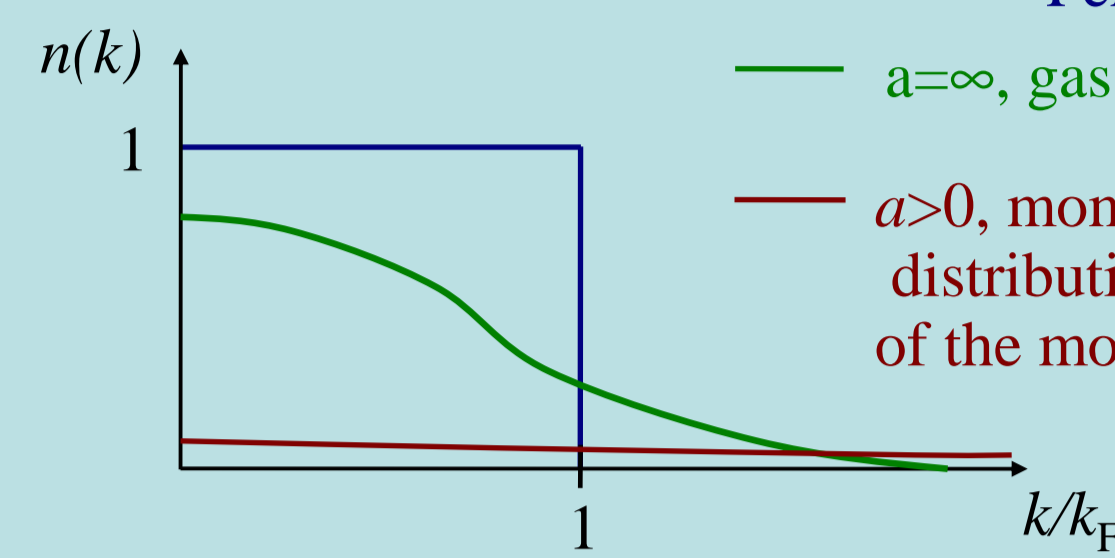


Near resonance: universal regime: a new high  $T_c$  superfluid

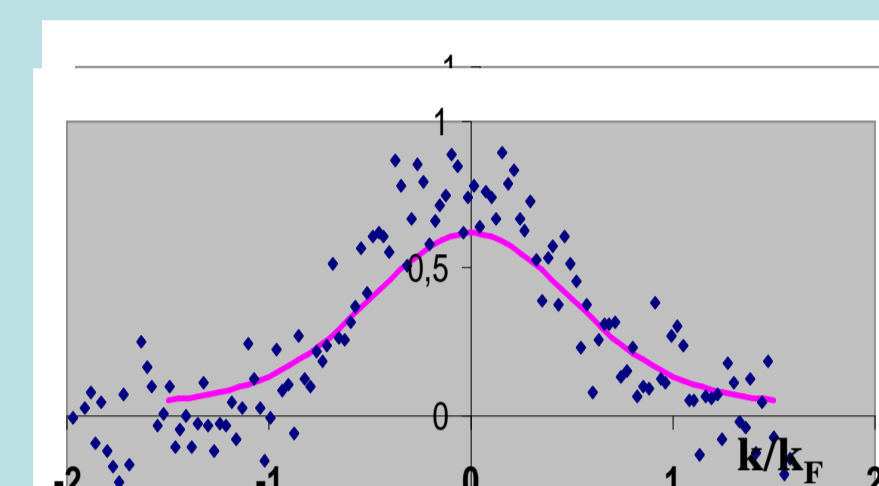
### Momentum Distribution Measurements

Theory\*

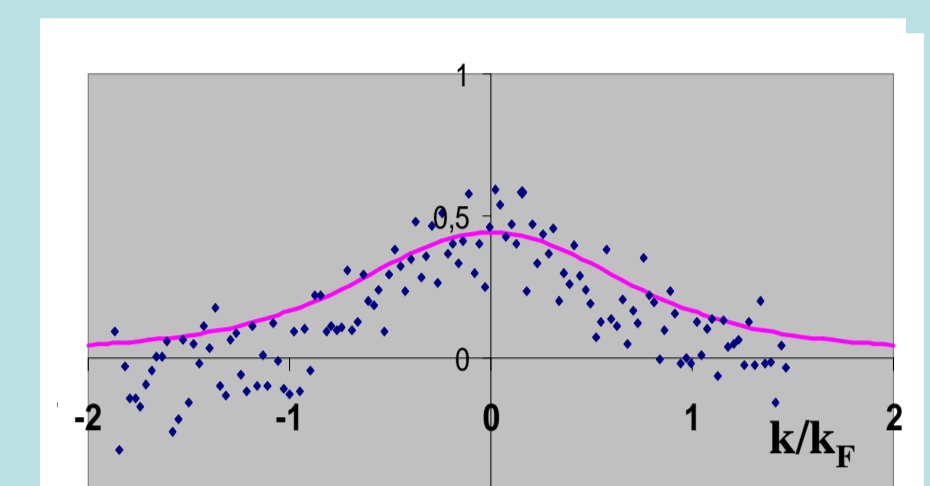
- $a < 0, T=0$  Non-interacting Fermi gas
- $a = \infty$ , gas at unitary limit
- $a > 0$ , momentum distribution of the molecules



BCS side  
 $1/k_F a = -0.42$   
1038 G  
 $3 \cdot 10^5$  atoms



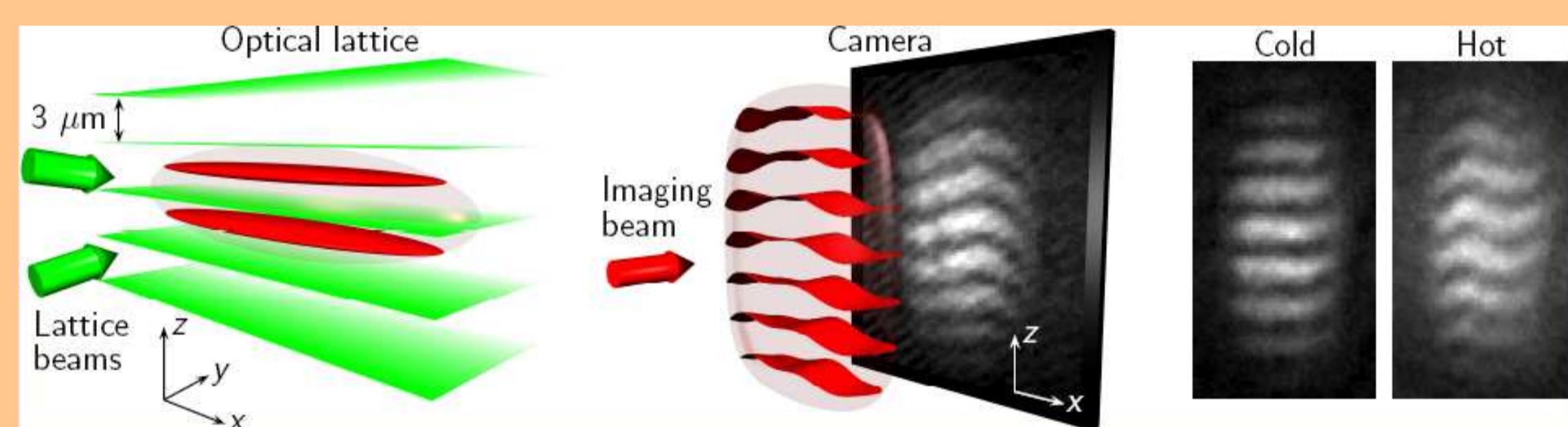
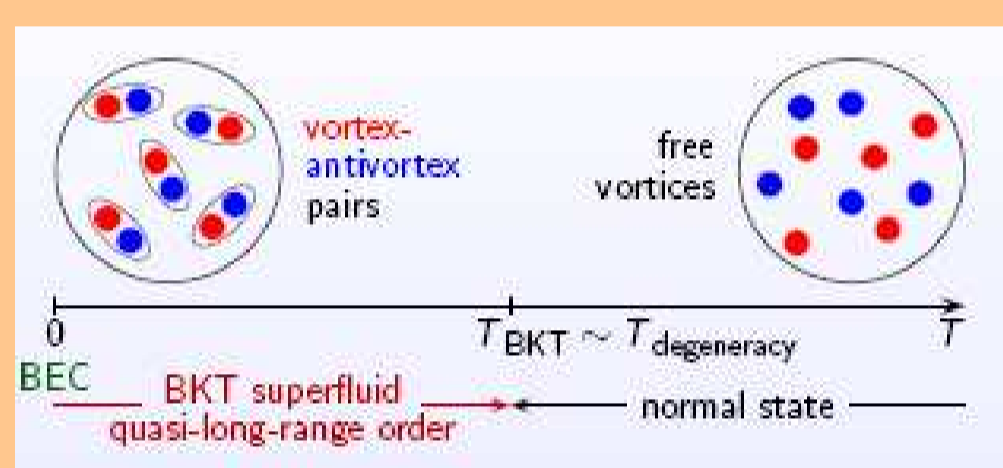
Unitarity limit  
 $1/k_F a = 0$   
854 G  
 $3 \cdot 10^5$  atoms



BCS side  
 $1/k_F a = +0.40$   
779 G  
 $3 \cdot 10^5$  atoms

## Berezinski-Kosterlitz-Thouless transition in 2D gases

No Bose-Einstein condensation at finite temperature  
Transition to quasi-long range order at  $n_{2D} \Lambda^2 \sim 1$

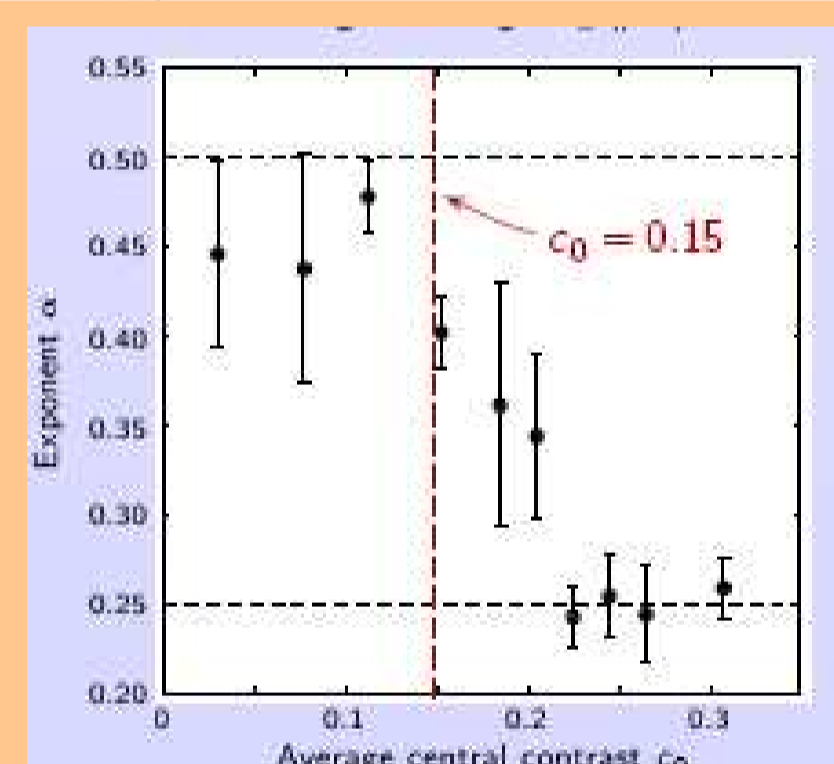


Fringe profile

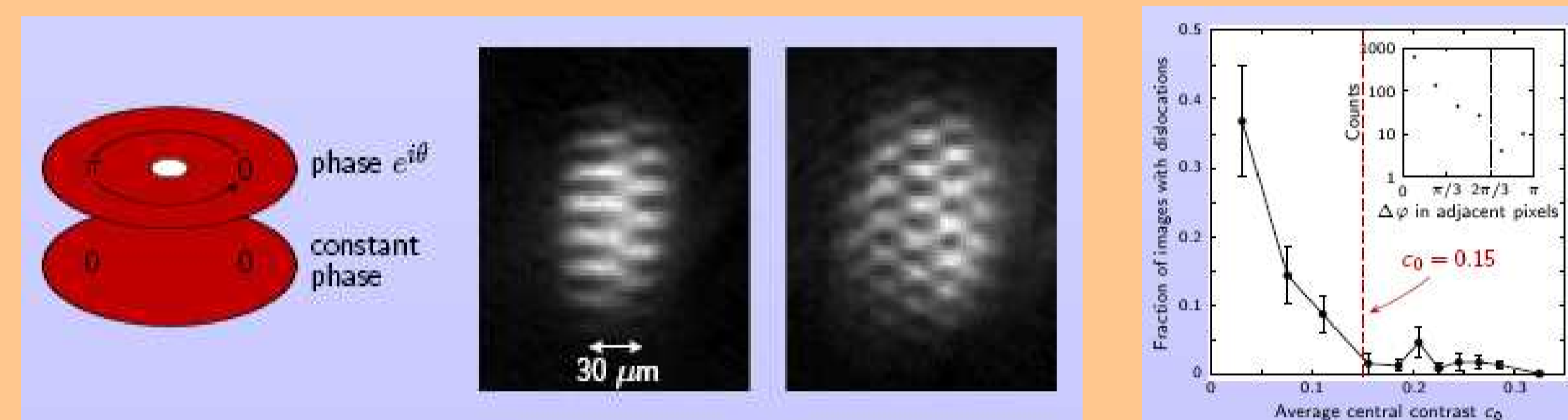
$$F(x, y) = G(x, y)[1 + c(x) \cos(kz + \phi(x))]$$

Integrated contrast

$$C(L) = \frac{1}{L} \int_{-L/2}^{L/2} c(x) e^{i\phi(x)} dx \sim L^{-\alpha}$$



### Observation of vortices as dislocations in the interference pattern

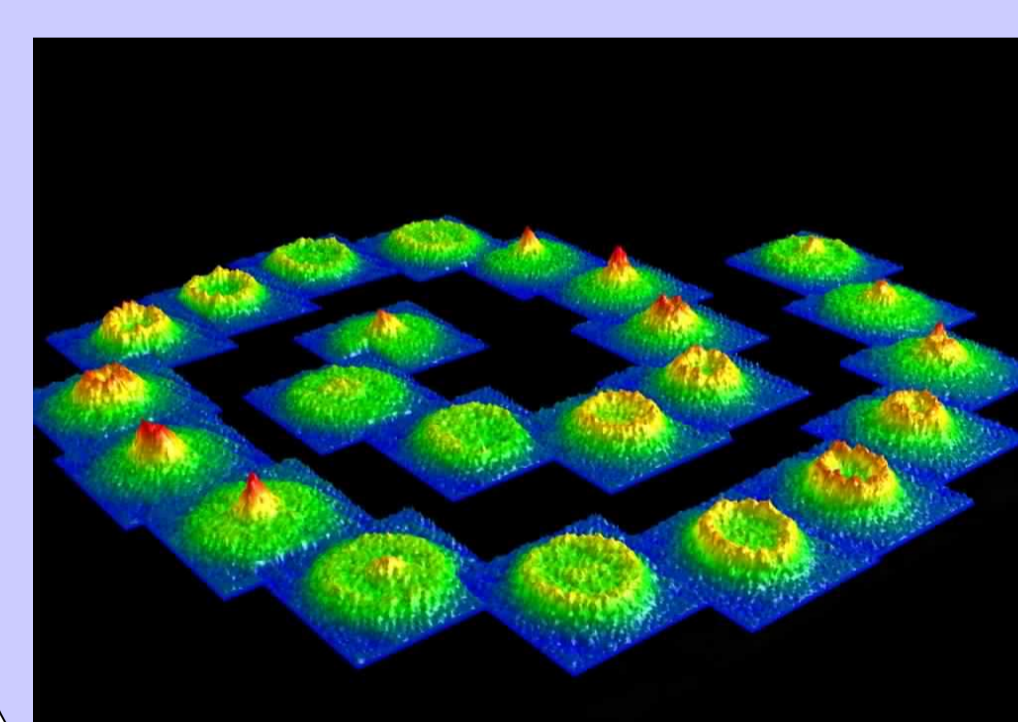


## Fast rotating bosons

Trapping frequency = rotation frequency: quantum Hall regime

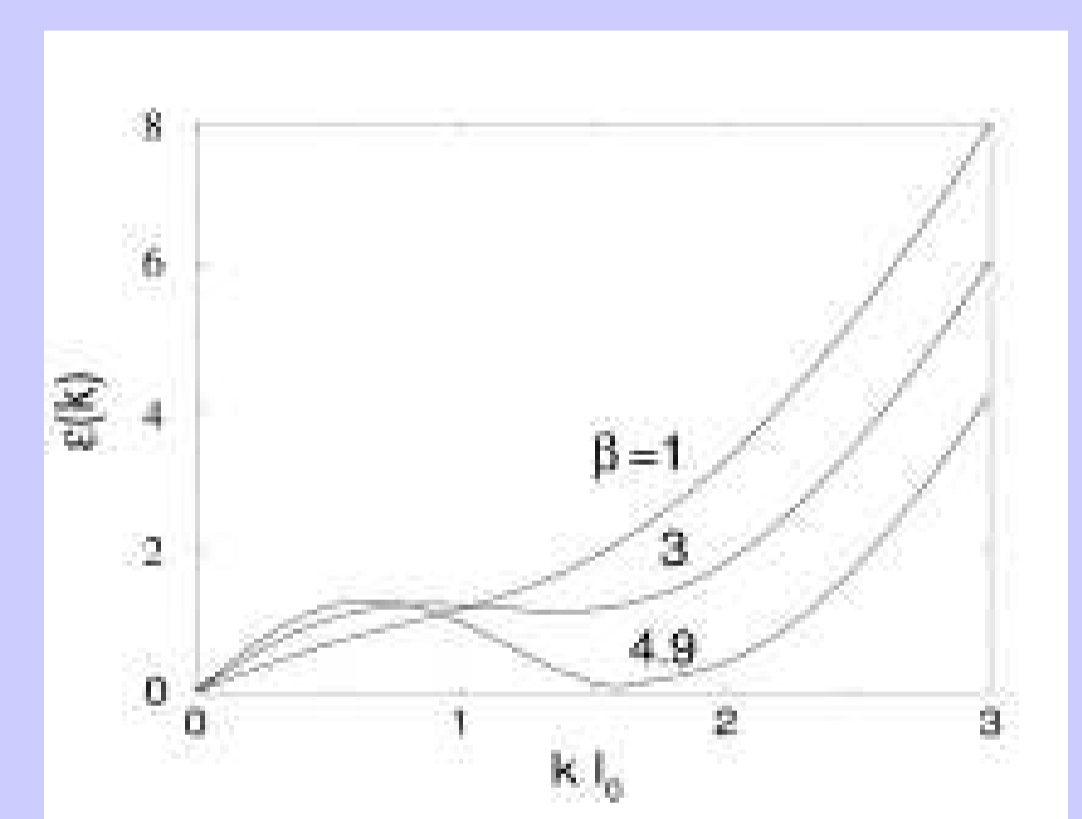
Monopolar oscillation of a fast rotating condensate

Theoretical study of the excitation spectrum for homogeneous systems



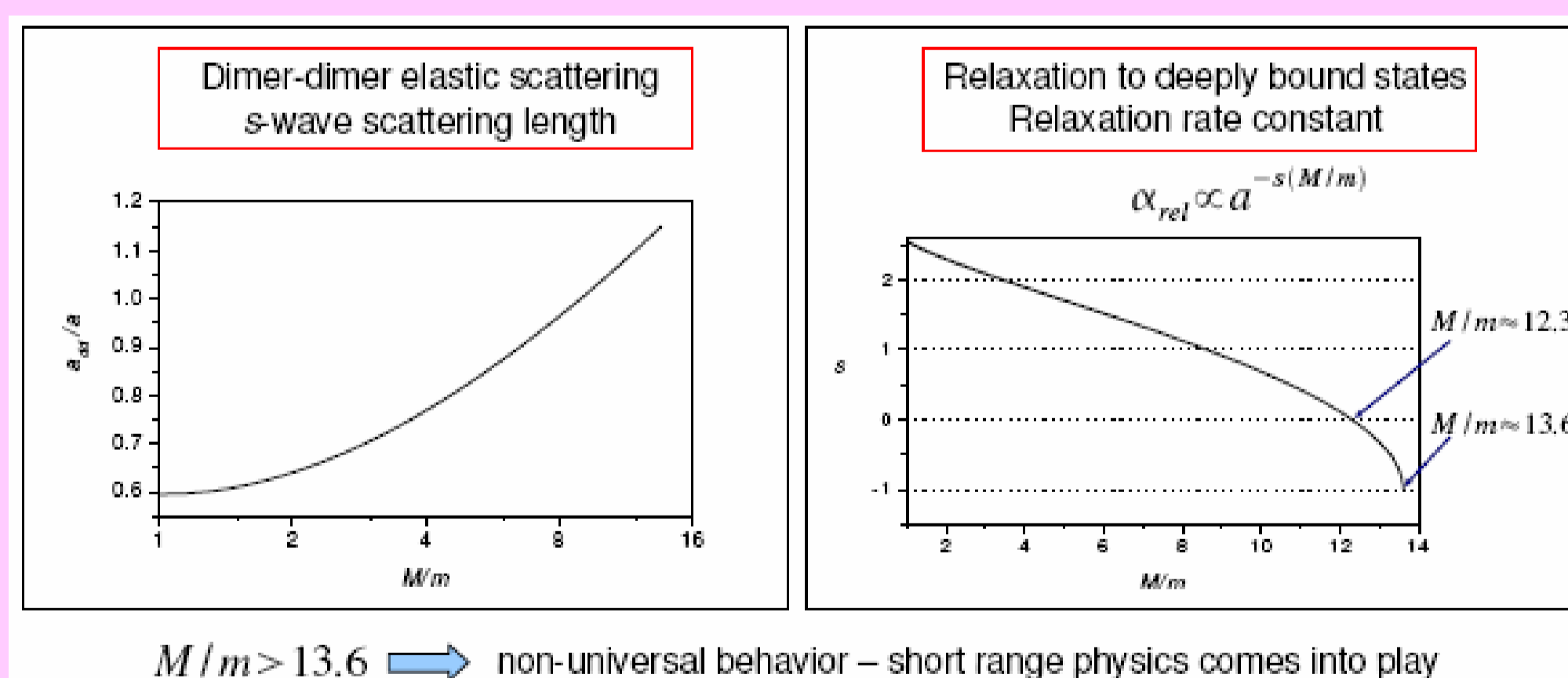
$$\beta = \frac{8_{2D} n_{2D}}{\hbar^2 / 2ma_{oh}^2}$$

$\beta < 4.9$  roton maxon spectrum  
 $\beta > 4.9$  system unstable  
Nucleation of vortex lines



## Weakly bound dimers of fermions

Study of heteronuclear dimer scattering properties



$M/m > 13.6$  non-universal behavior – short range physics comes into play

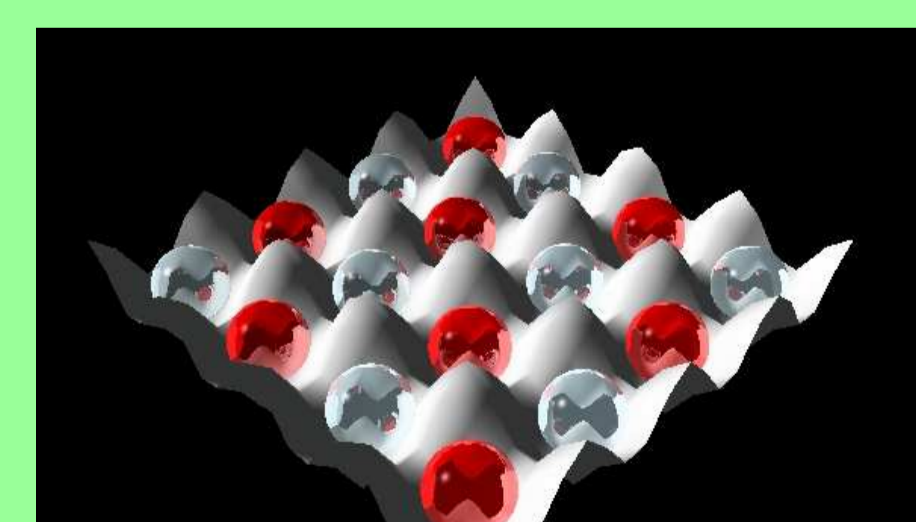
Large mass ratio: Born-Oppenheimer approach, long range effective interaction



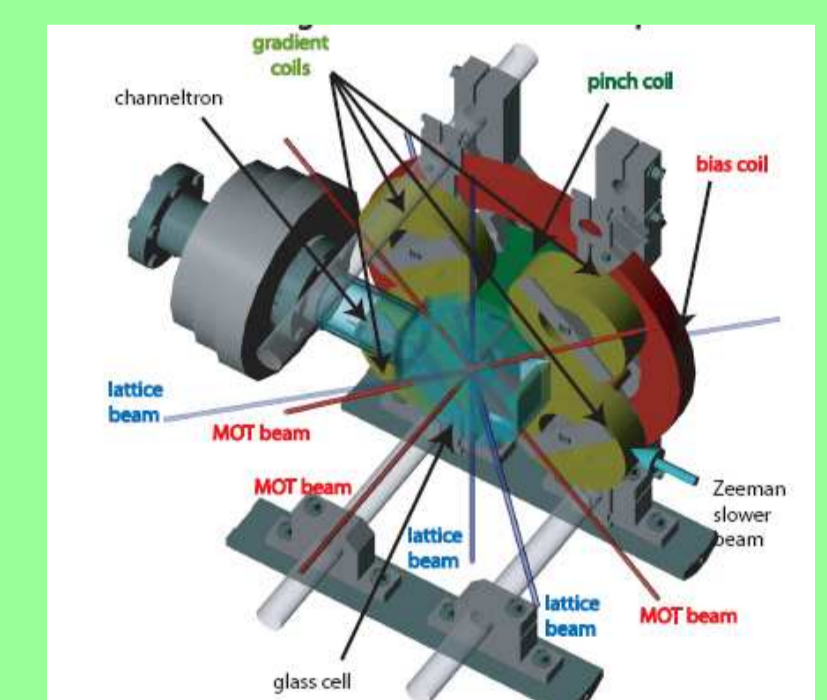
$$U_{eff}(R) = \frac{2\hbar^2}{maR} e^{-2R/a}$$

## Perspectives: ANR Gascor and Fabiola

Fermions and bosons in optical lattices: Antiferromagnetism and frustration



Néel transition to antiferromagnetic order (CPHT)  
Pairing with different species  
New quantum phases



New  $^4\text{He}$  setup  
Dynamics of Mott insulator transition

## Selected references

### Fermionic superfluids (ENS)

- T. Bourdel, *et al.*, PRL **93**, 050401 (2004), *Experimental Study of the BEC-BCS Crossover Region in Lithium 6*.  
J. Zhang *et al.*, PRA, **70**, 030702 (2004), *P-wave Feshbach resonances of ultracold  $^6\text{Li}$* .  
F. Chevy *et al.*, PRA **71**, 062710 (2005), *Resonant scattering properties close to a p-wave Feshbach resonance*.  
F. Chevy, PRL **96**, 130401 (2006), *Density profile of a trapped strongly interacting Fermi gas with unbalanced spin populations*.

### BKT Transition (ENS)

- V. Bretin *et al.*, PRL **92**, 050403 (2004) *Fast Rotation of a Bose-Einstein Condensate*.  
Z. Hadzibabic *et al.*, PRL **93**, 180403 (2004), *Interference of an Array of Independent Bose-Einstein Condensates*.  
S. Stock *et al.*, PRL **95**, 190403 (2005), *Observation of Phase Defects in Quasi-Two-Dimensional Bose-Einstein Condensates*.  
Z. Hadzibabic *et al.*, Nature **441**, 1118 (2006), *Berezinskii-Kosterlitz-Thouless Crossover in a Trapped Atomic Gas*

### Interactions in $^4\text{He}$ (ENS)

- J. Léonard *et al.*, EPL **70**, 90 (2005), *rotationally induced Penning ionization of ultracold photoassociated helium dimers*.  
J. Kim *et al.*, EPL **72**, 548 (2005), *Frequency shifts of photoassociative spectra of ultracold metastable helium atoms: a new measurement of the s-wave scattering length*.  
S. Moal *et al.*, PRL **96**, 023203 (2006), *Accurate determination of the scattering length of metastable helium atoms using dark resonances between atoms and exotic molecules*

### Fast rotating bosons (LPTMS)

- S. Sinha *et al.*, PRL **94**, 150401 (2005), *Two-dimensional Bose-Einstein condensate under extreme rotation*.  
**Dimers of fermionic atoms (LPTMS)**  
D. S. Petrov *et al.*, J. Phys. B **38**, S645 (2005), *Diatomic molecules in ultracold Fermi gases – novel composite bosons*.  
**Atoms in optical lattices (CPHT)**  
F. Werner *et al.*, PRL **95**, 056401 (2005), *Interaction-Induced Adiabatic Cooling and Antiferromagnetism of Cold Fermions in Optical Lattices*

