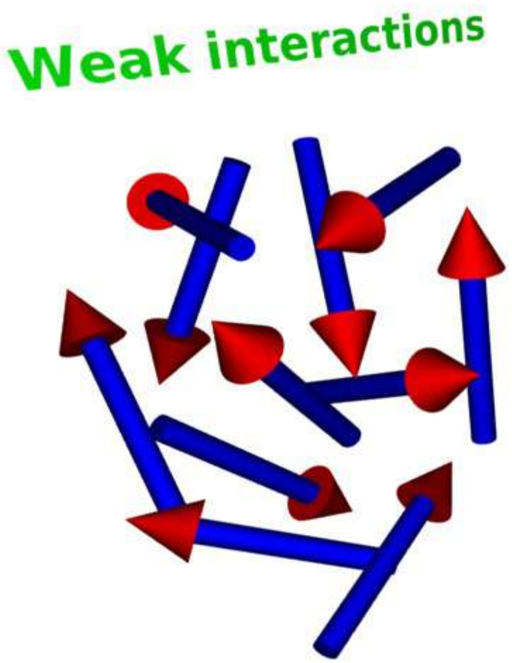
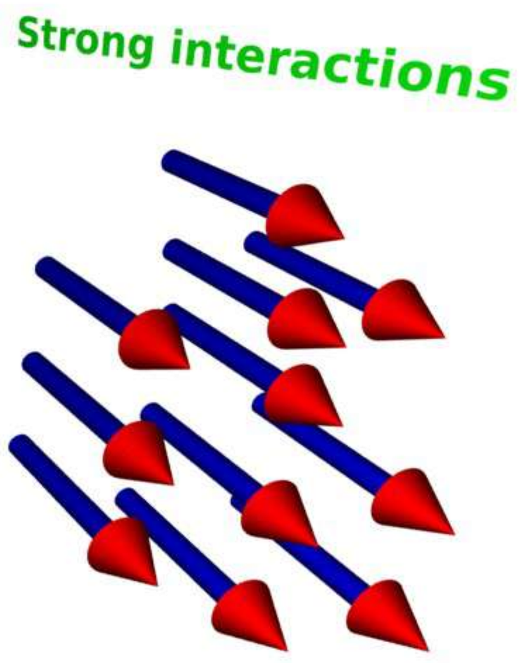
Ferromagnetism in an atomic Fermi gas





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2. St Andrews University
3. Weizmann Institute of Science
4. University of Cambridge

G.J. Conduit & B.D. Simons, Phys. Rev. A **79**, 053606 (2009)

G.J. Conduit, A.G. Green & B.D. Simons, Phys. Rev. Lett. **103**, 207201 (2009)

G.J. Conduit & B.D. Simons, Phys. Rev. Lett. **103**, 200403 (2009)

G.J Conduit & E. Altman, arXiv: 0911.2839

Ferromagnetism in iron and nickel

- The Stoner model predicts a *second order* transition

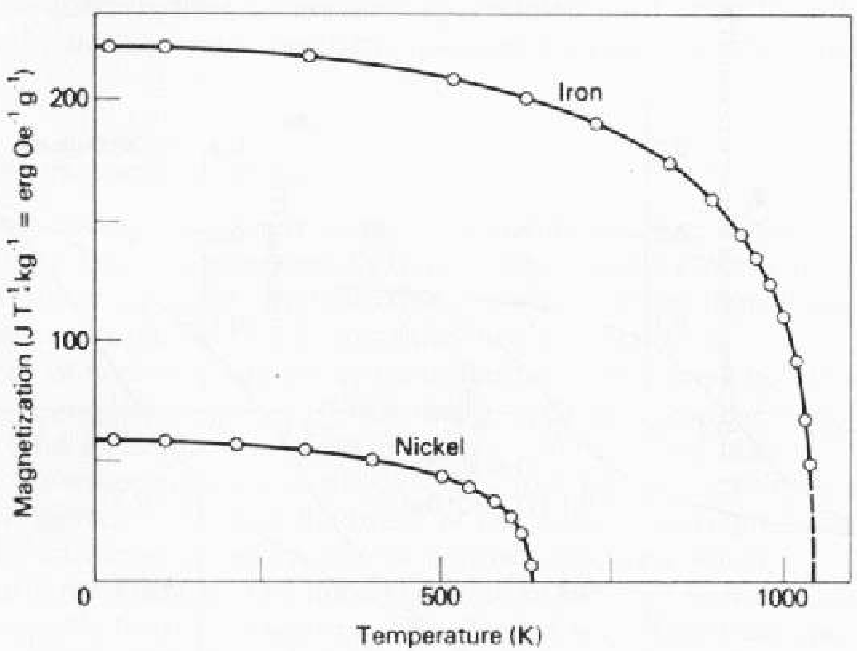


Figure 1.2 Spontaneous magnetization plotted against temperature for iron and nickel.

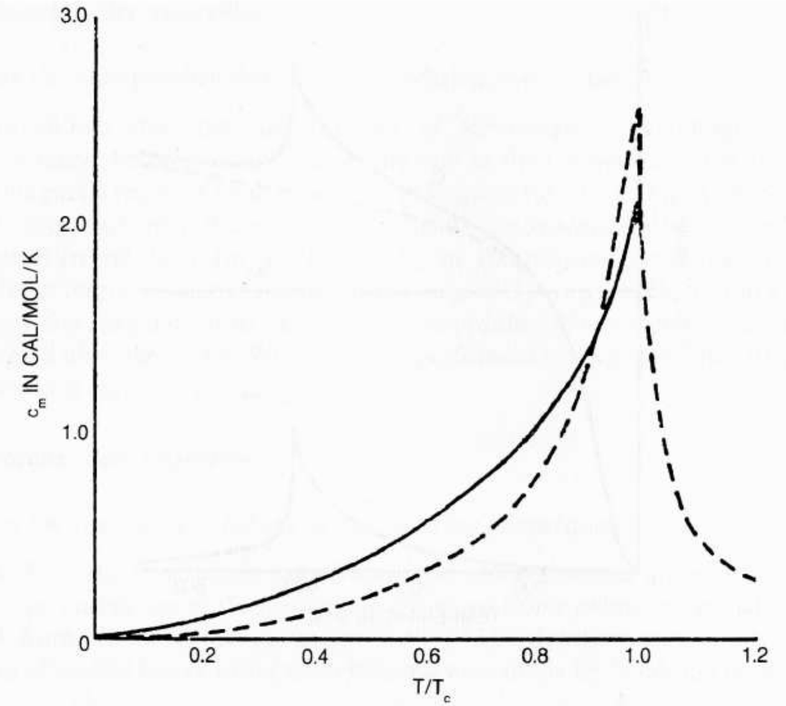
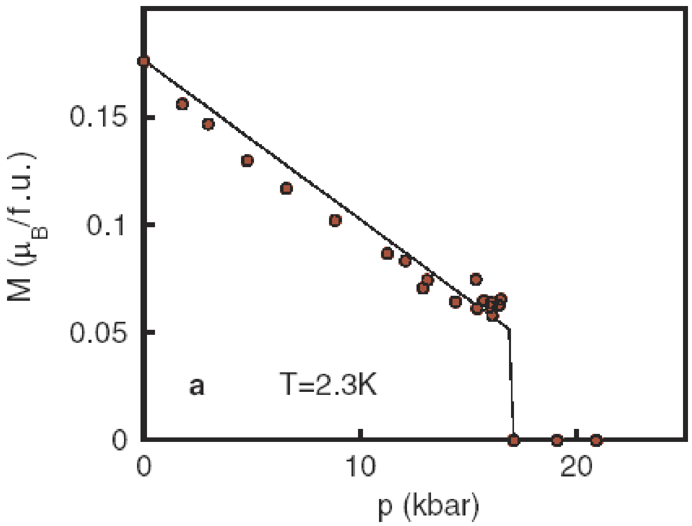


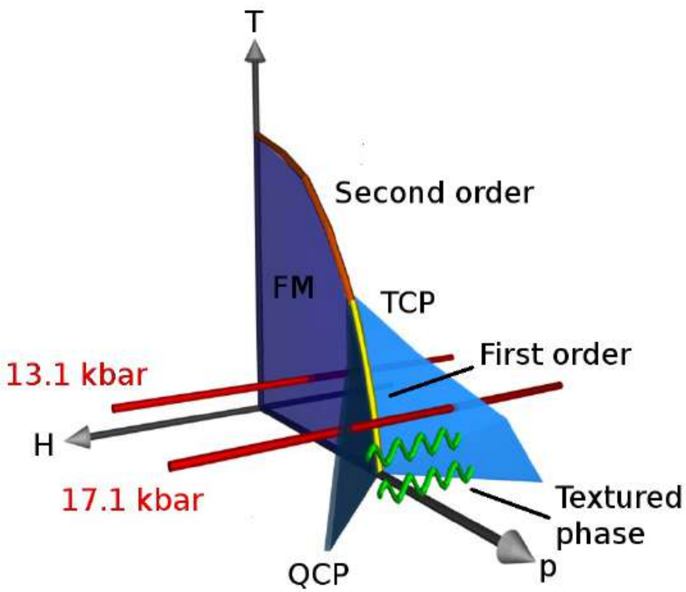
Fig. 9.20 Specific heat anomaly for nickel at its Curie point compared with the theoretical prediction.

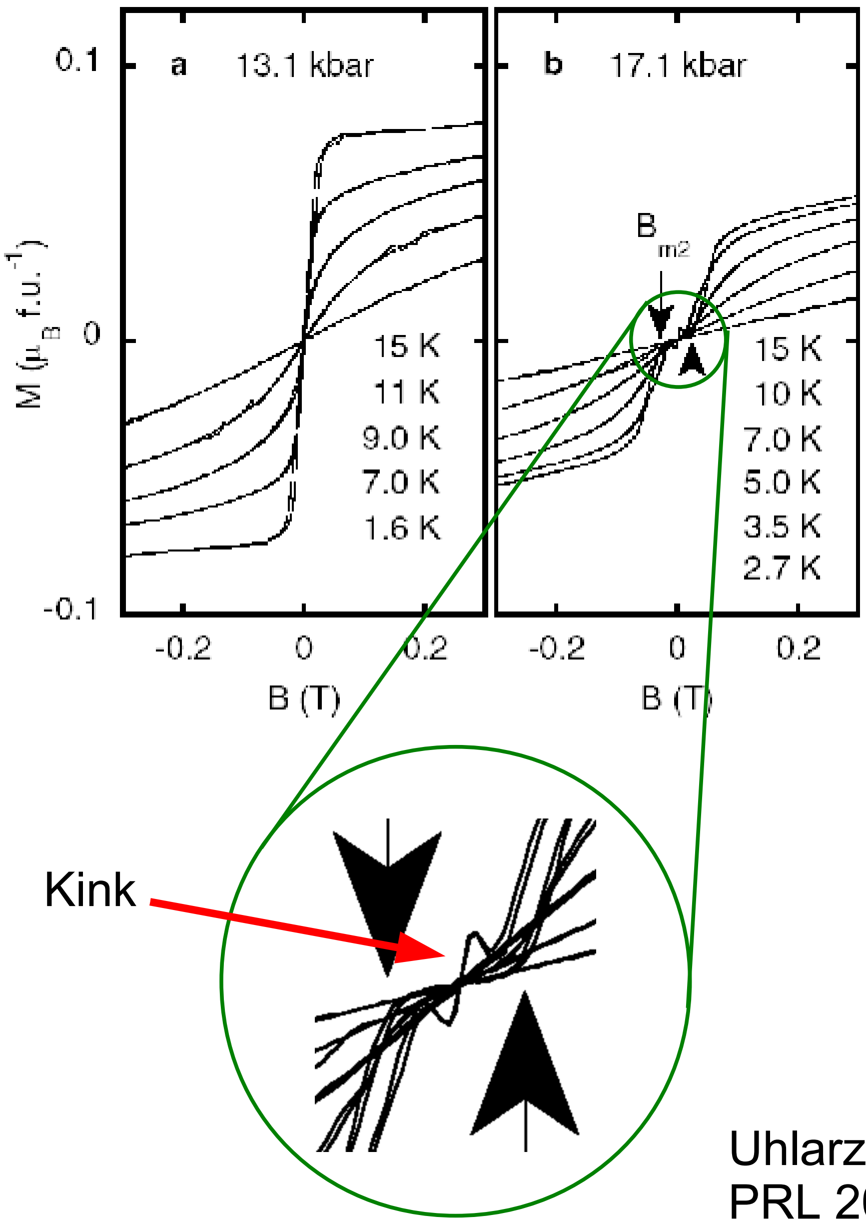
that is characterised by a divergence of length-scales (peaked heat capacity and susceptibility)

Breakdown of Stoner criterion — $ZrZn_2$

- At low temperature and high pressure $ZrZn_2$ has a first order transition



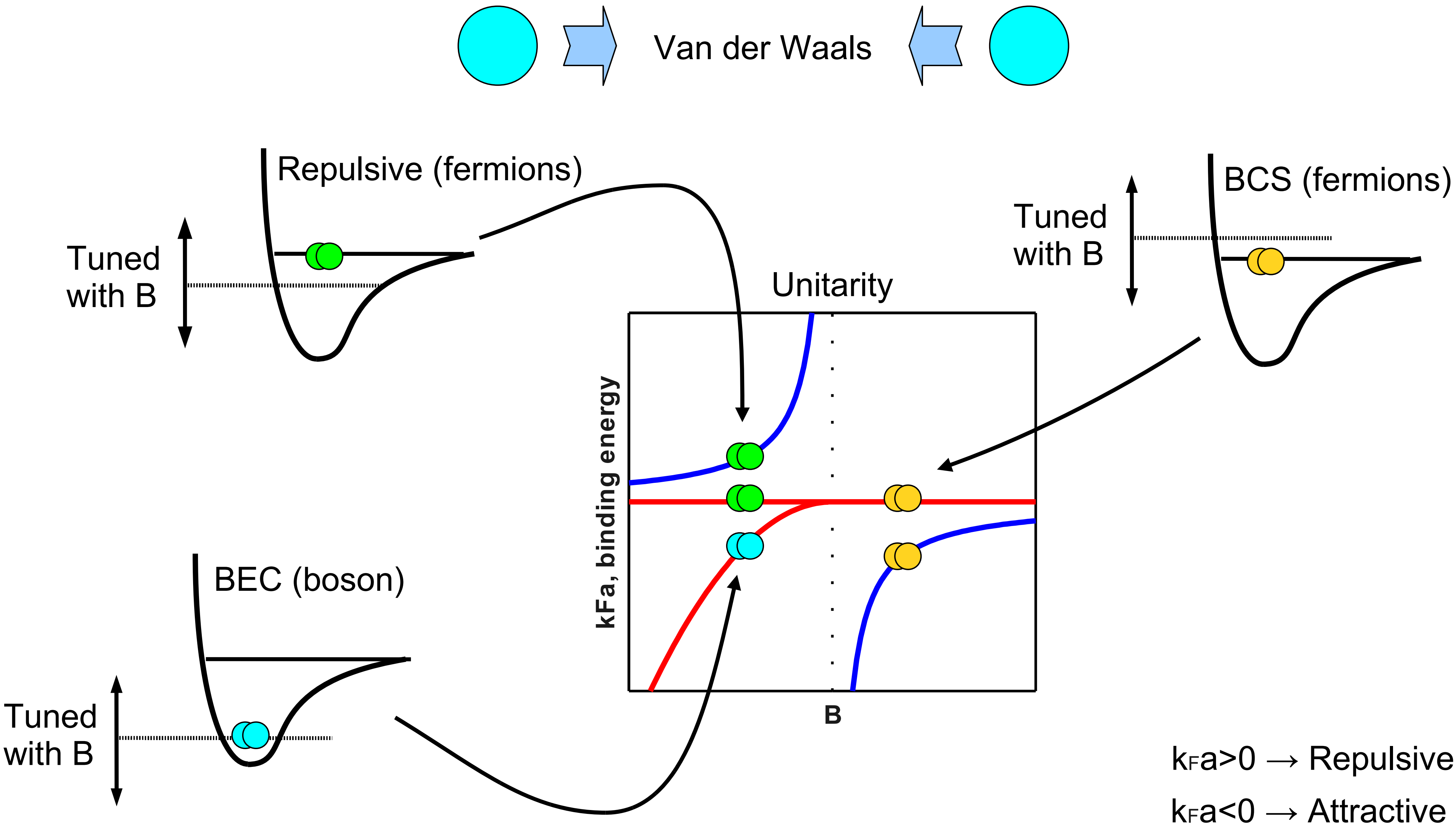




Uhlarz *et al.*, PRL 2004

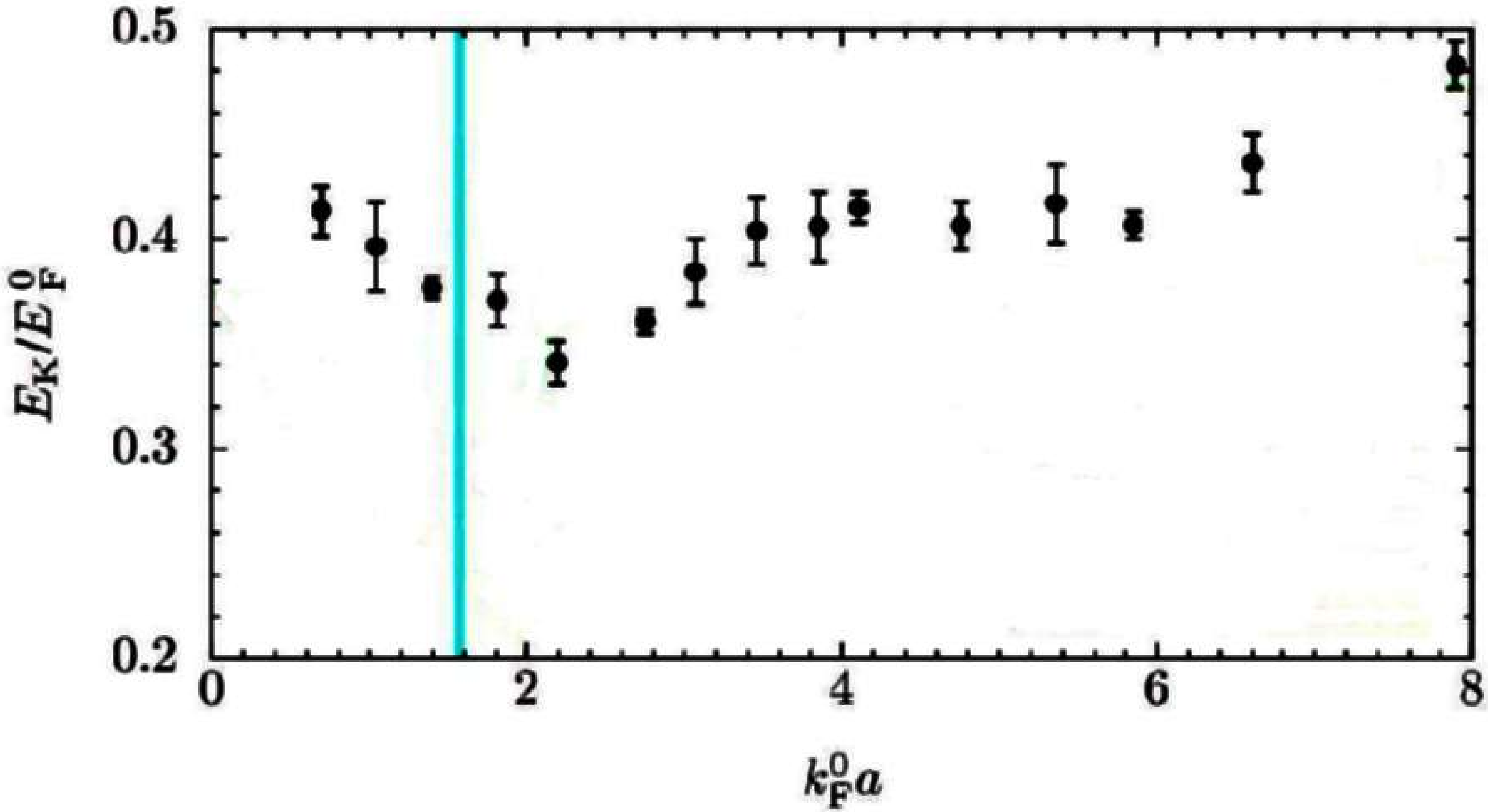
Feshbach resonance

- Control the relative energy level of the states with a magnetic field



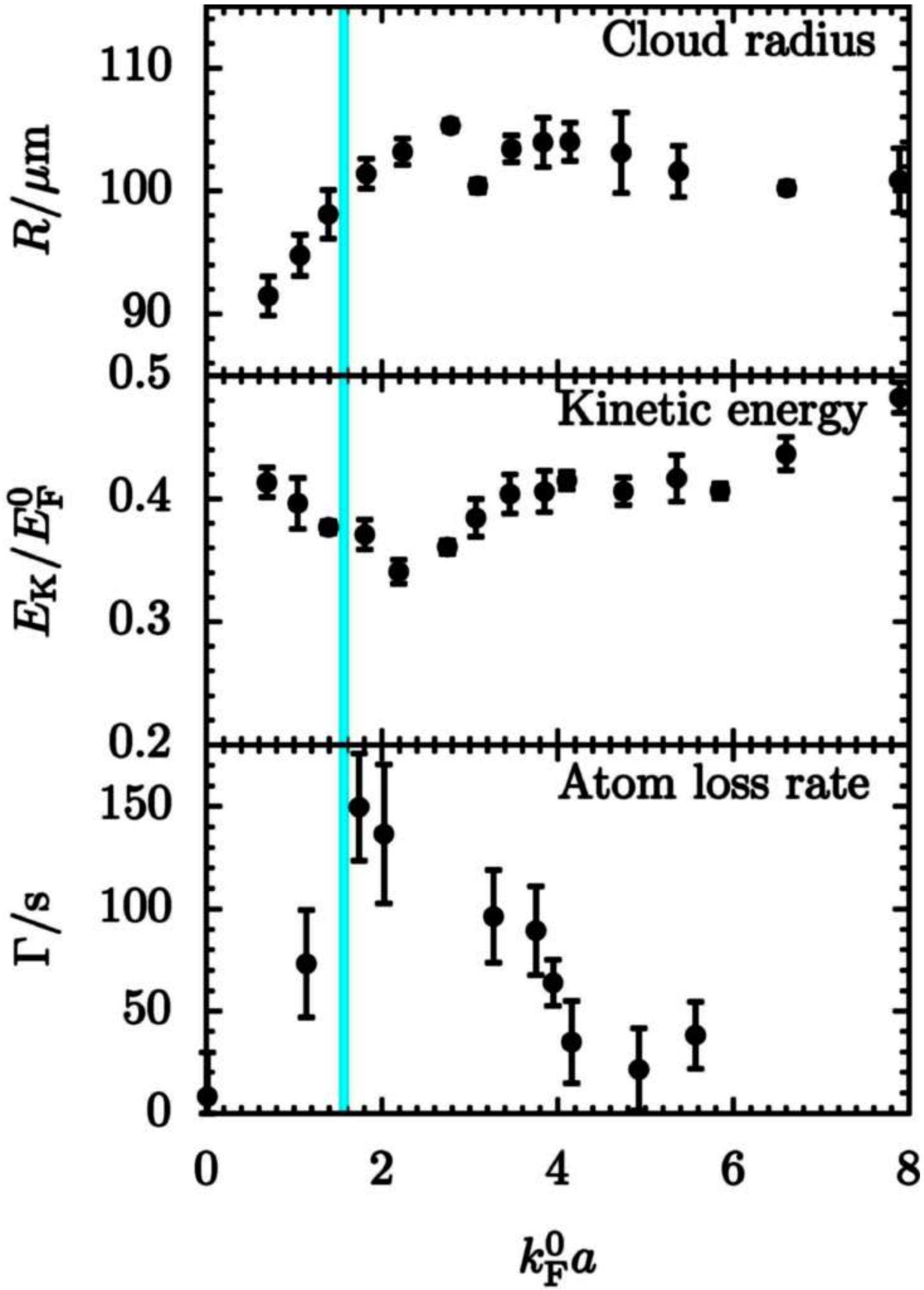
Experimental evidence for ferromagnetism

- Rise in kinetic energy at $k_F a \approx 2.2$



Jo, Lee, Choi, Christensen, Kim, Thywissen, Pritchard & Ketterle, Science **325**, 1521 (2009)

Further key experimental signatures



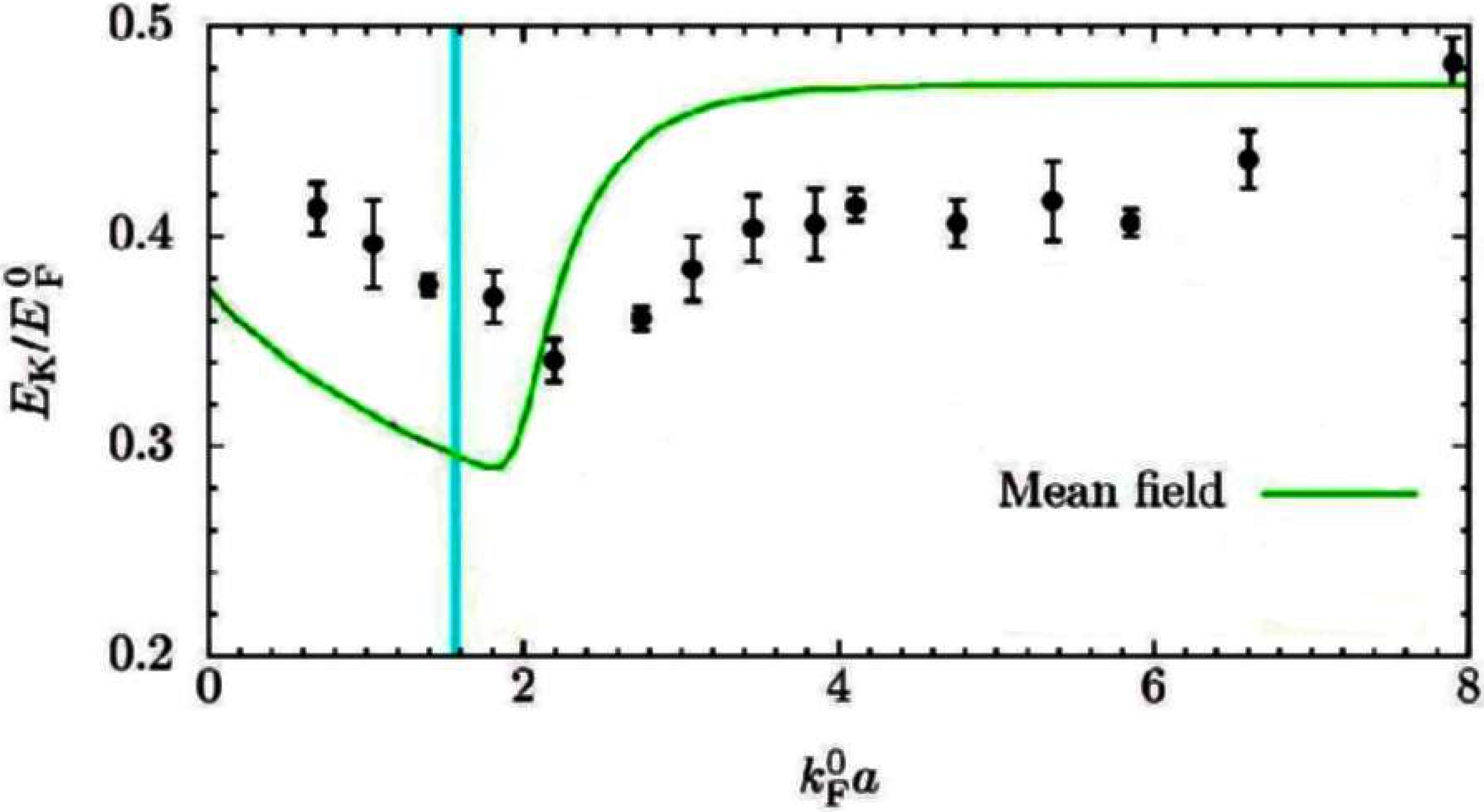
$$E_K \propto n^{5/3}$$

$$\Gamma \propto (k_F a)^6 n_\uparrow n_\downarrow (n_\uparrow + n_\downarrow)$$

Jo, Lee, Choi, Christensen, Kim, Thywissen, Pritchard & Ketterle, Science **325**, 1521 (2009)

Mean-field analysis & consequences of trap

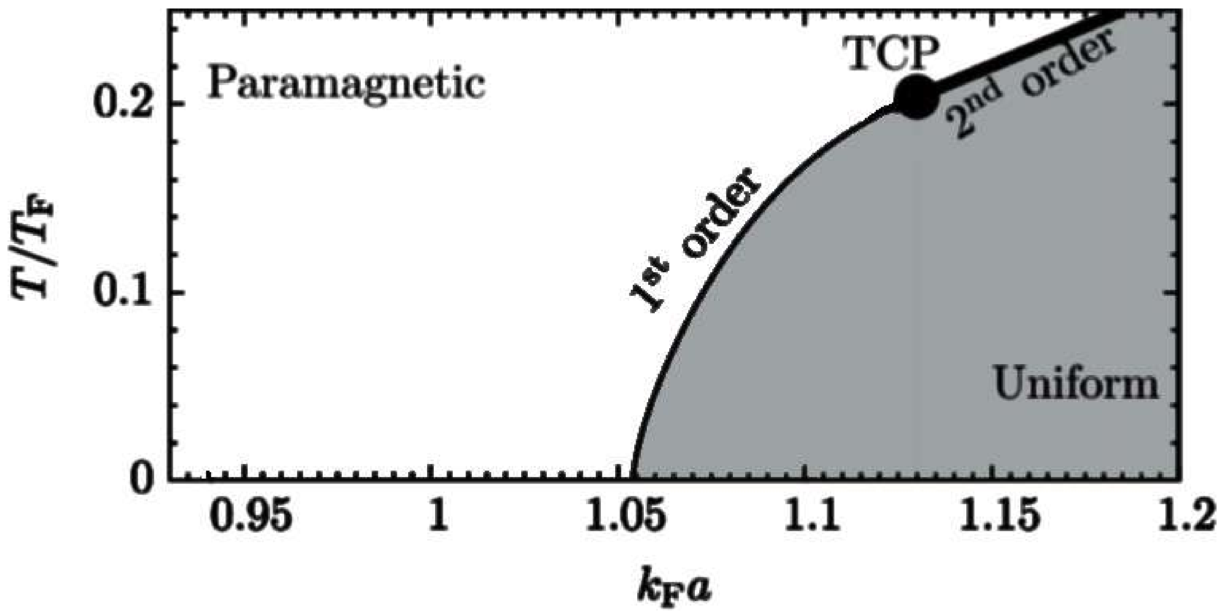
- Recovers qualitative behavior[1] but transition at $k_F a$=1.8 instead of $k_F a$=2.2

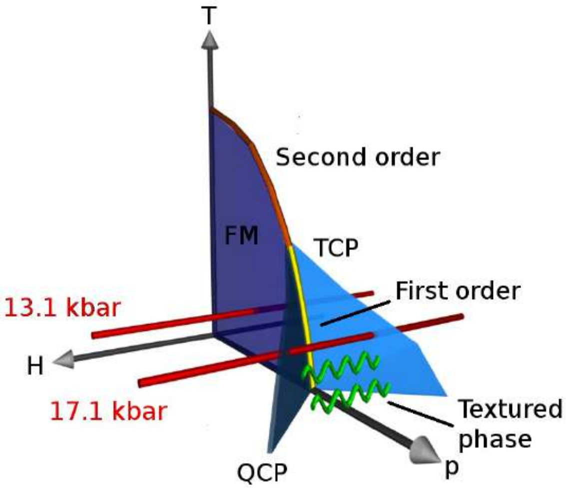


[1]LeBlanc, Thywissen, Burkov & Paramekanti, Phys. Rev. A **80**, 013607 (2009) & Conduit & Simons, Phys. Rev. Lett. **103**, 200403 (2009)

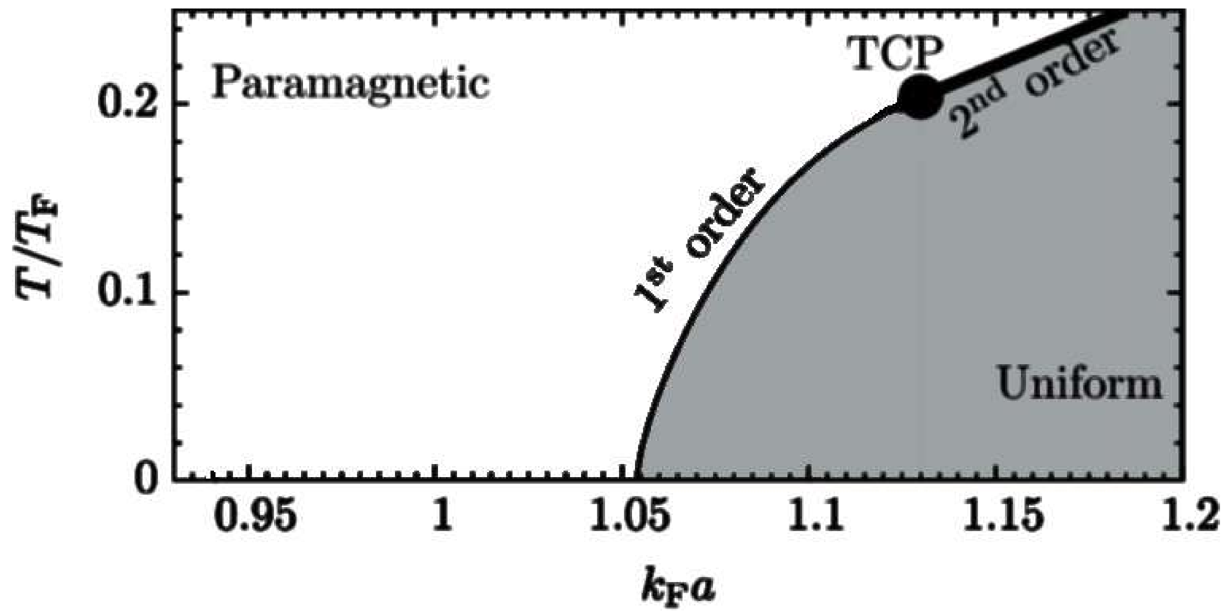
Results

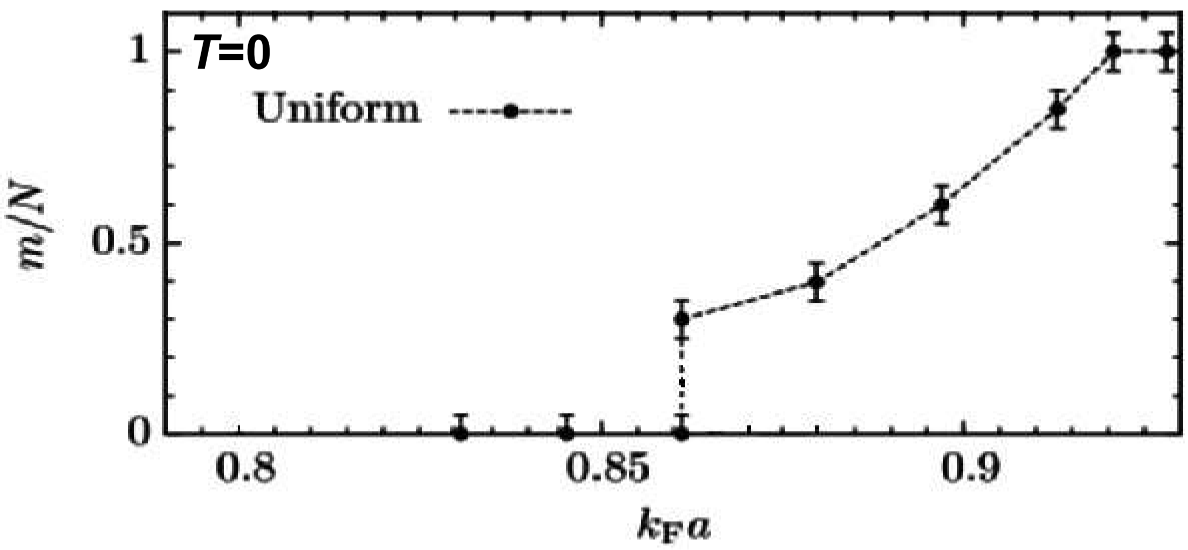
- First order ferromagnetic phase transition



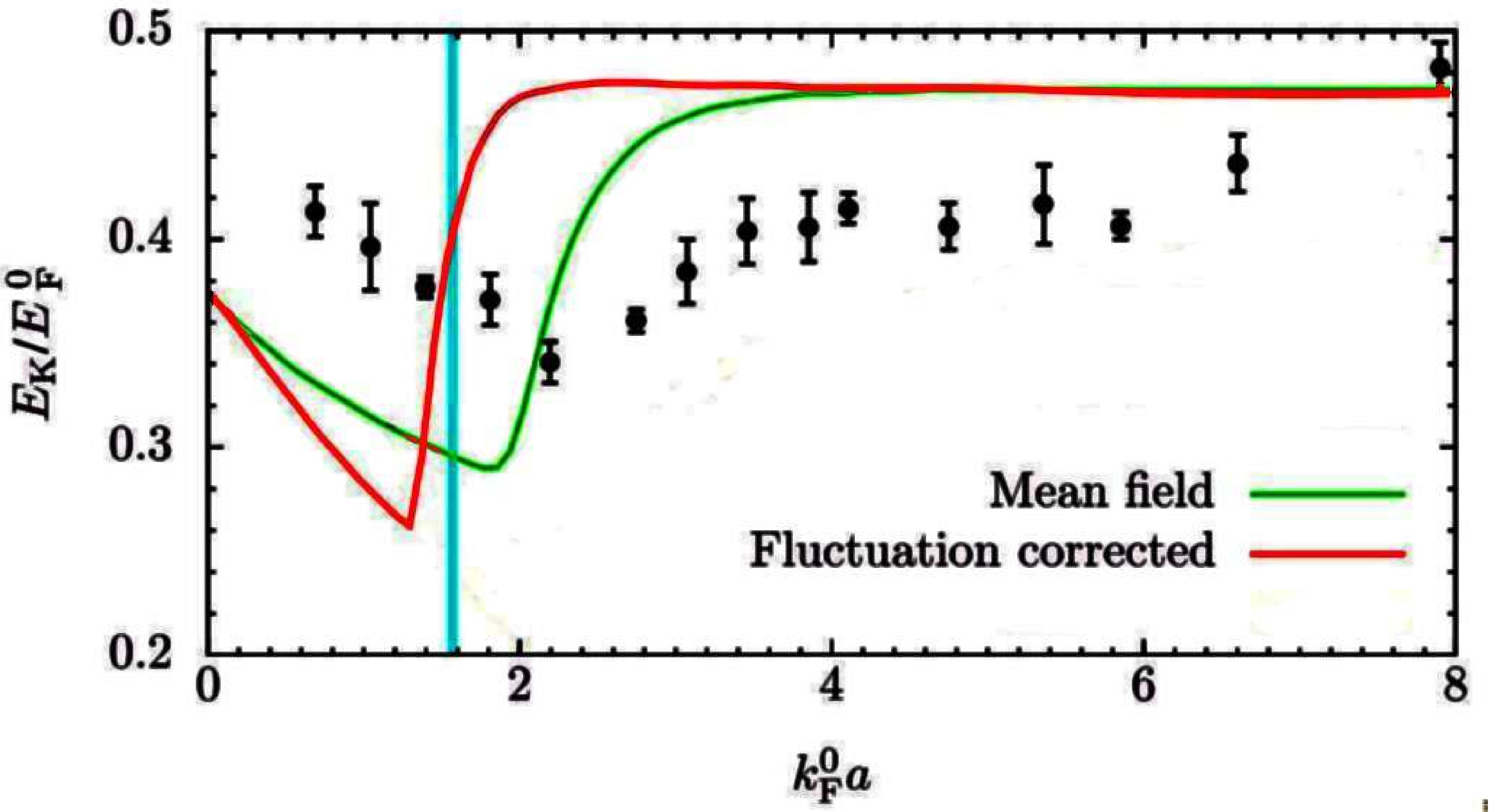


Quantum Monte Carlo verification



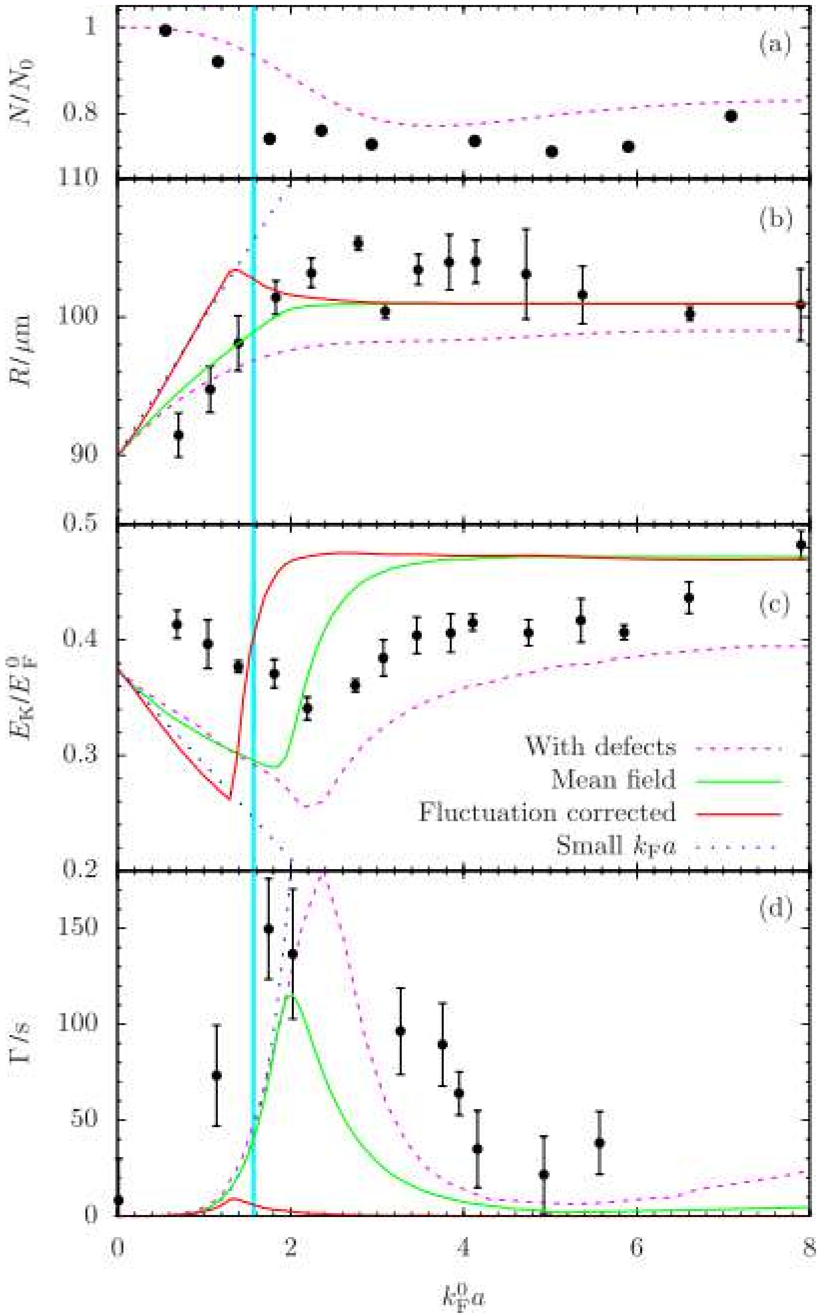


Theoretical prediction of the kinetic energy

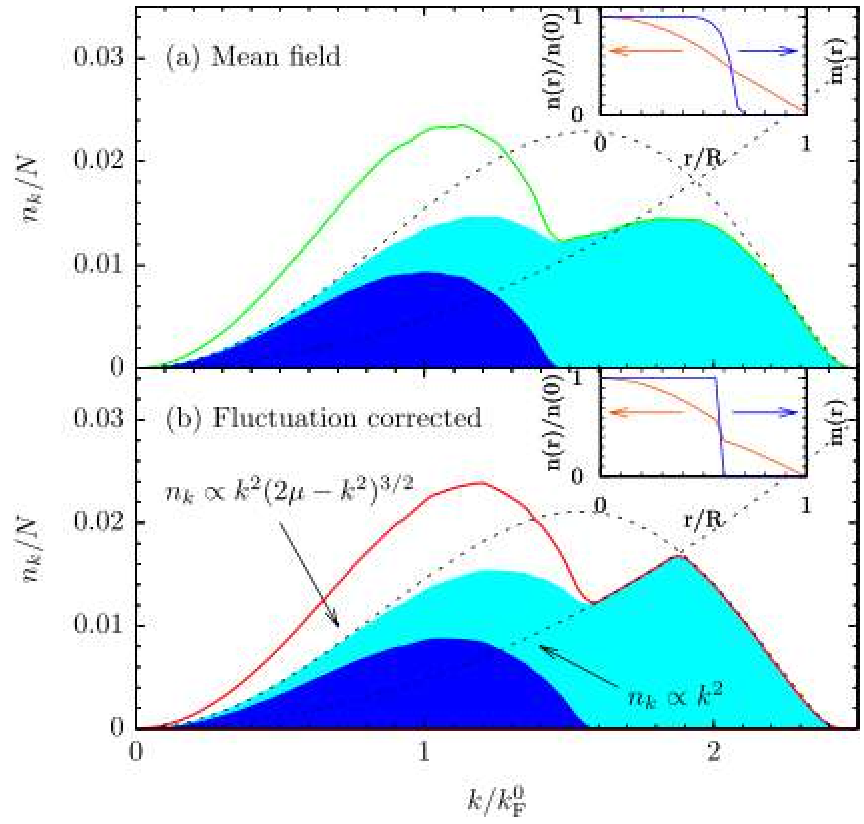


Conduit & Simons, Phys. Rev. Lett. **103**, 200403 (2009)

Ferromagnetism out of equilibrium

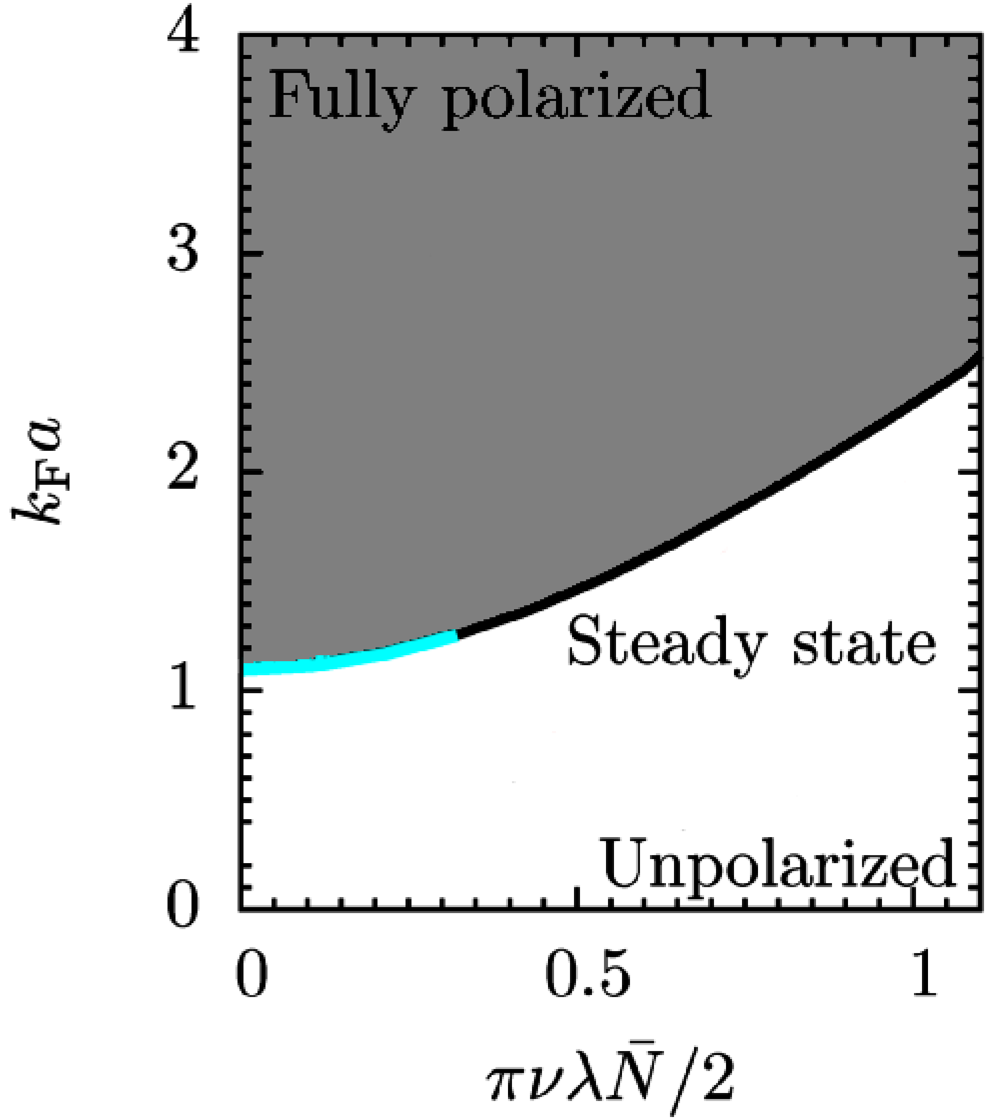


Momentum distribution



Phase boundary with atom loss

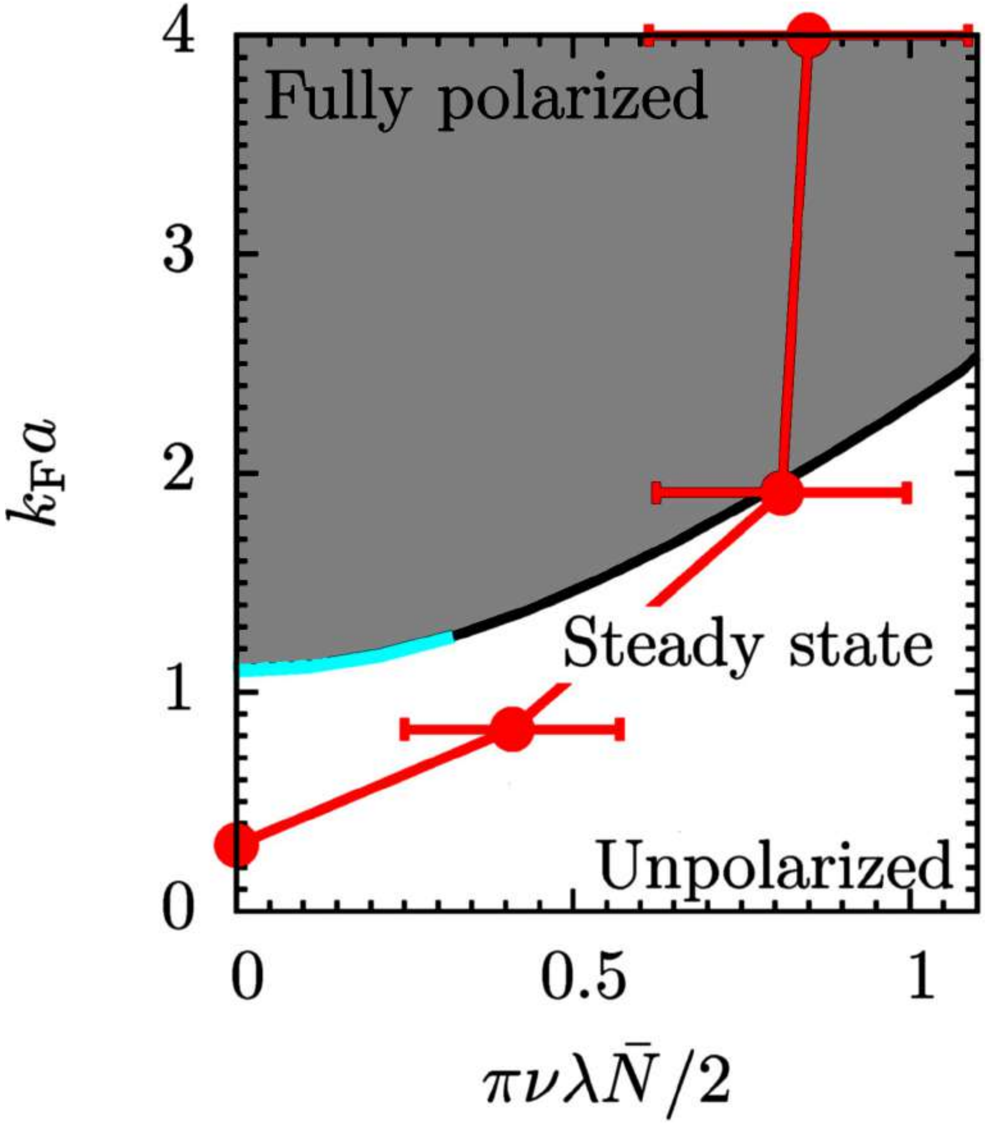
- Atom loss raises the interaction strength required for ferromagnetism



Conduit & Altman, arXiv: 0911.2839

Interaction renormalization with atom loss

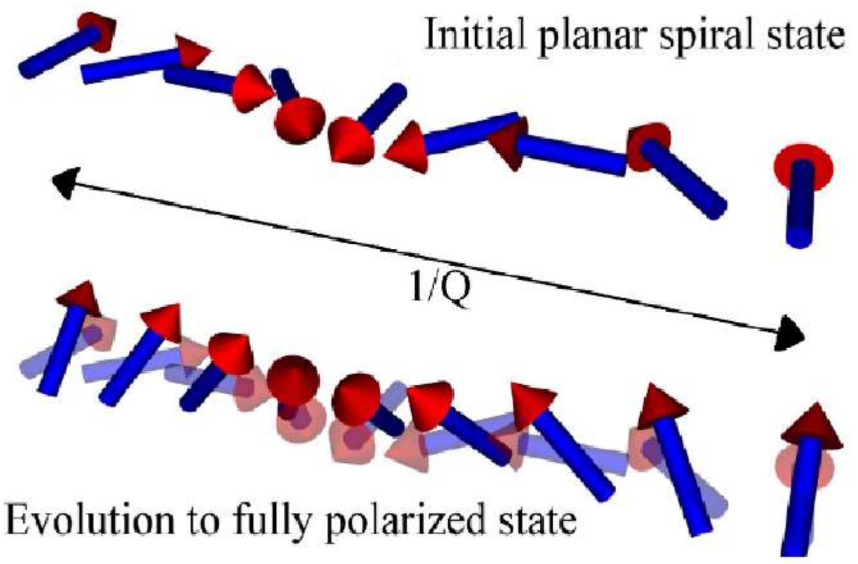
- Comparing to experimental atom loss indicates transition at $k_F a \approx 2$

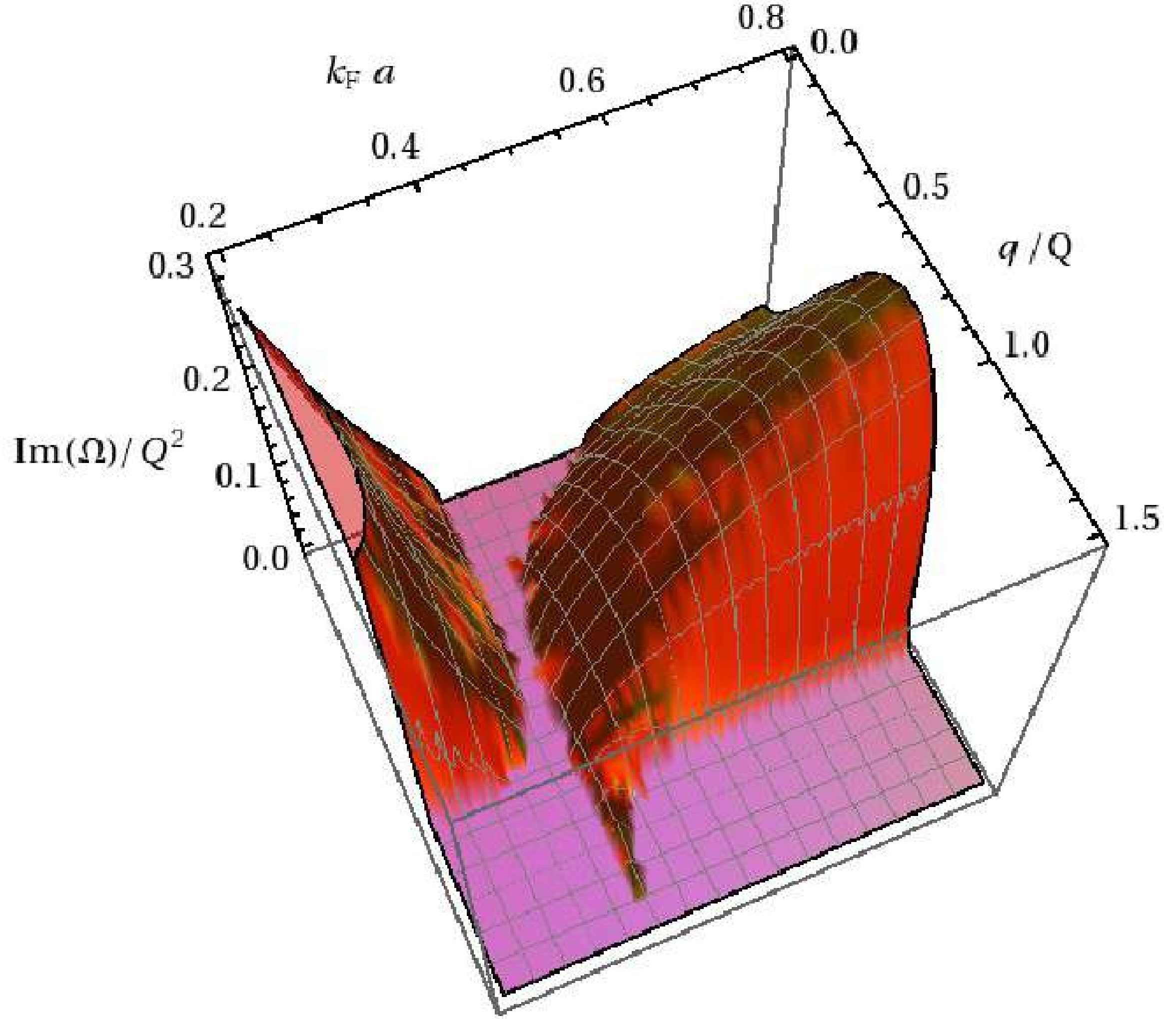


Conduit & Altman, arXiv: 0911.2839; Huckans *et al*. PRL **102**, 165302 (2009)

Alternative strategy: spin spiral

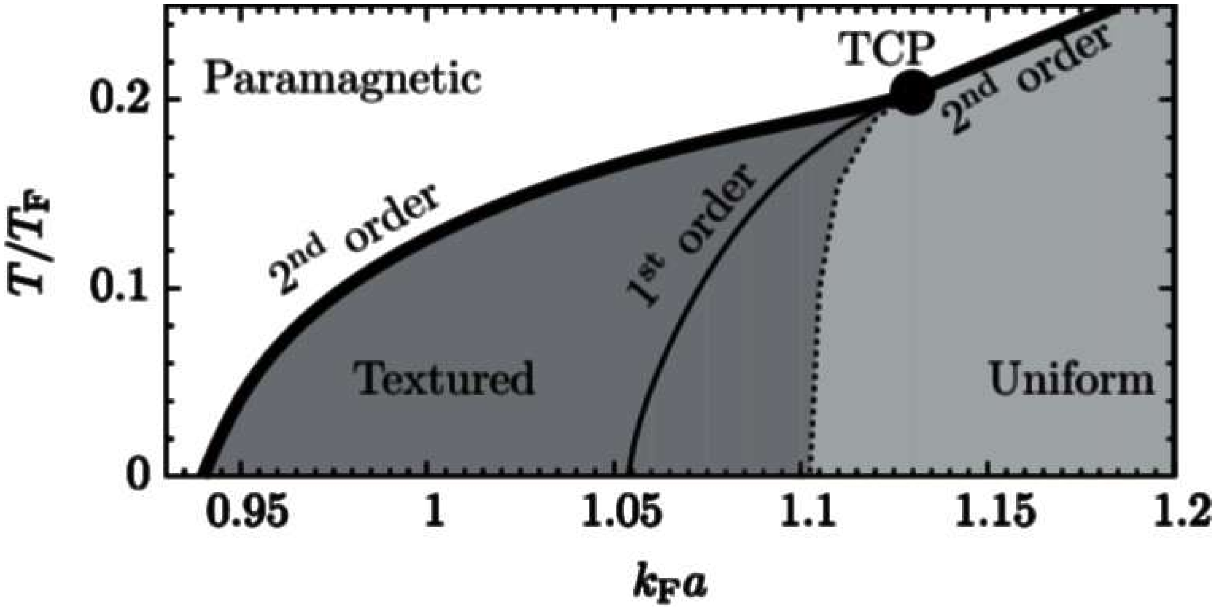
- Prepare gas in spin spiral and follow evolution into fully polarized state





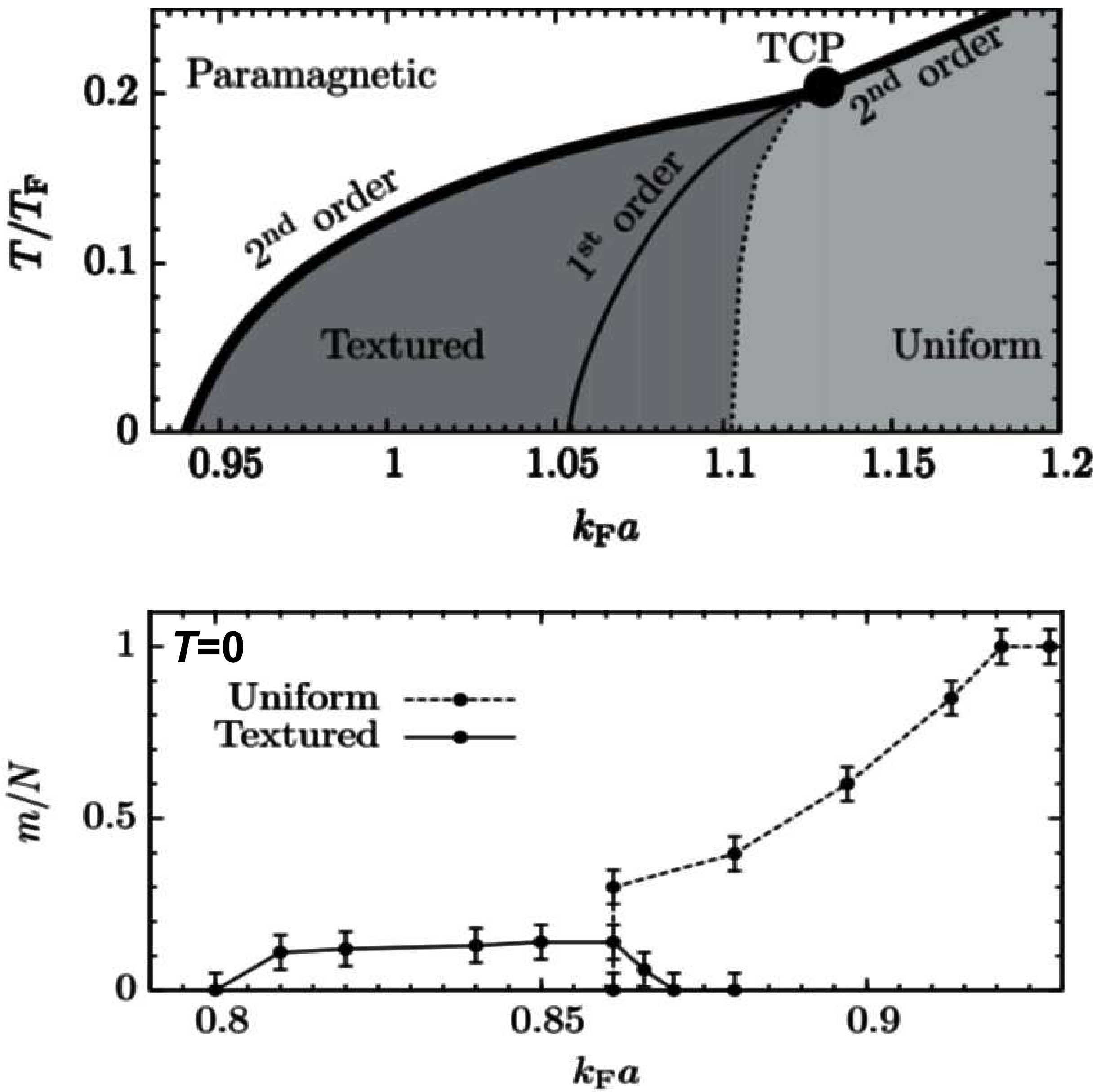
Results

- Textured phase preempts transition



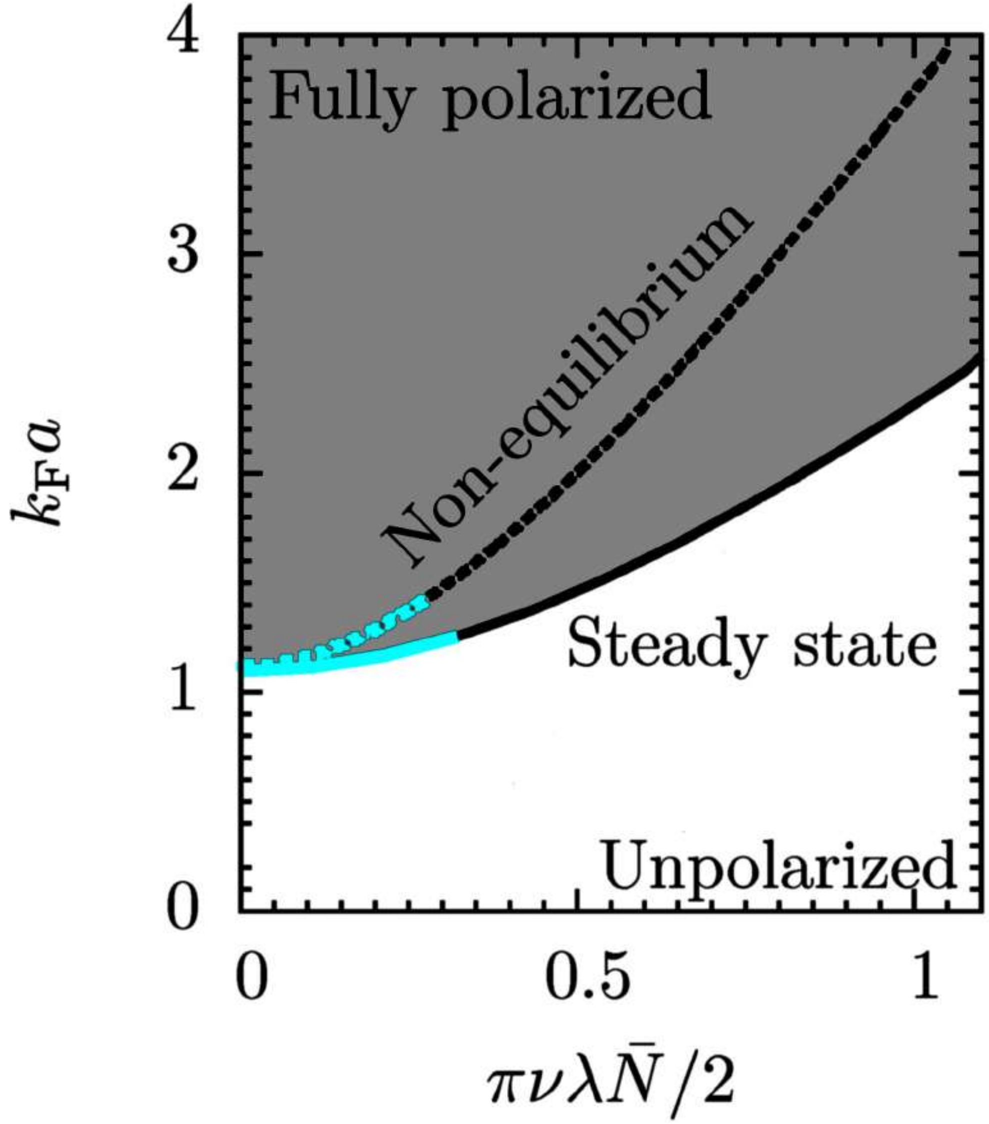
Quantum Monte Carlo: textured phase

- QMC verifies presence of textured phase



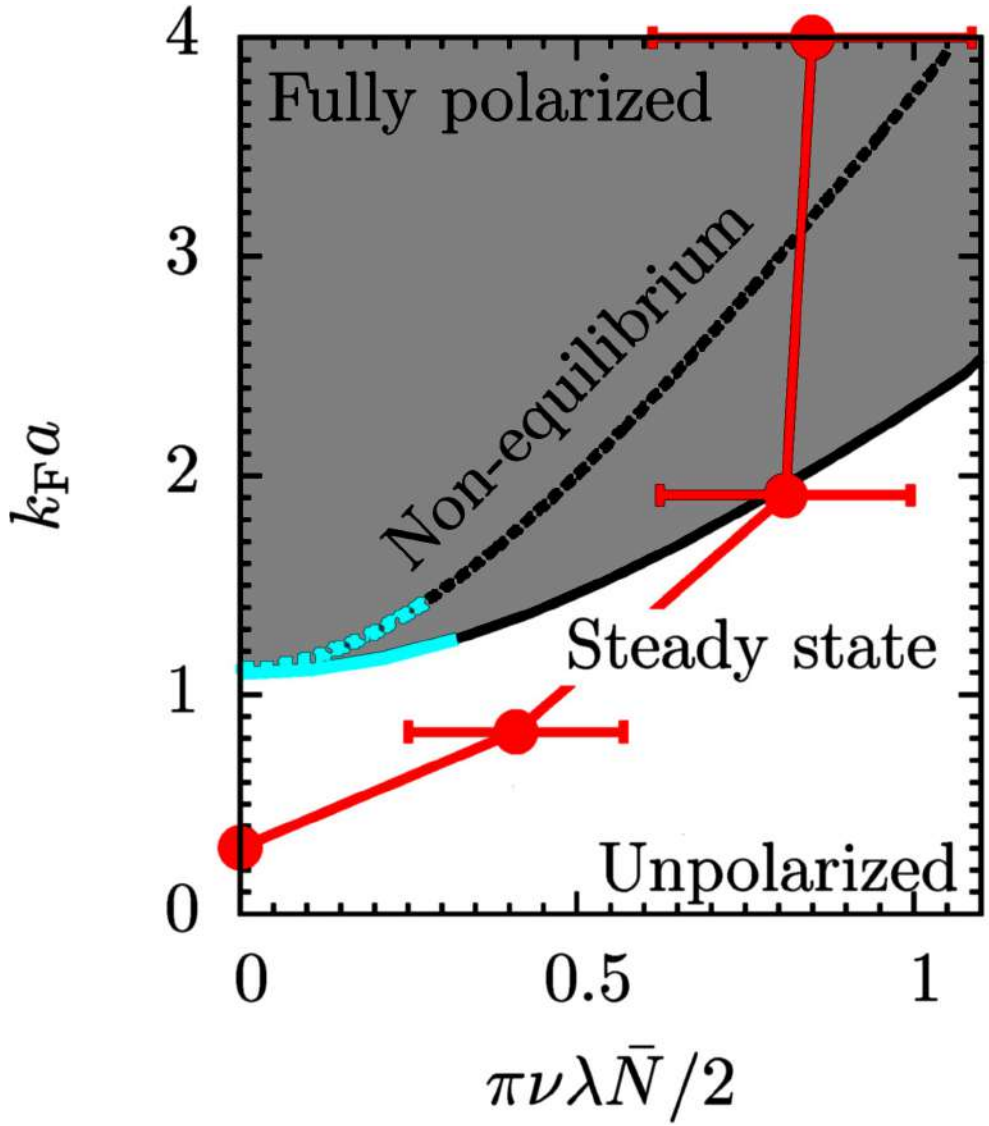
Phase boundary with atom loss

- Atom loss raises the interaction strength required for ferromagnetism



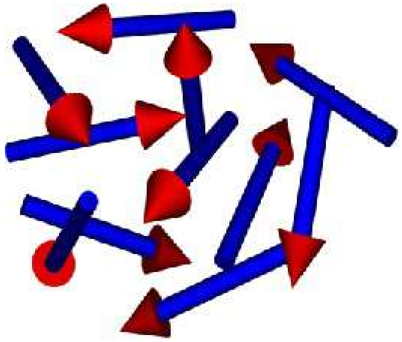
Conduit & Altman, arXiv: 0911.2839

Interaction renormalization with atom loss



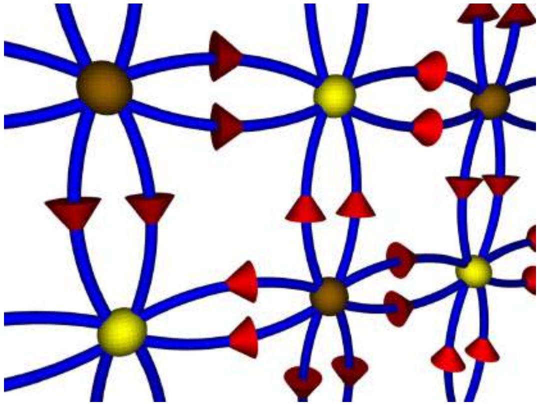
Conduit & Altman, arXiv: 0911.2839; Huckans *et al*. PRL **102**, 165302 (2009)

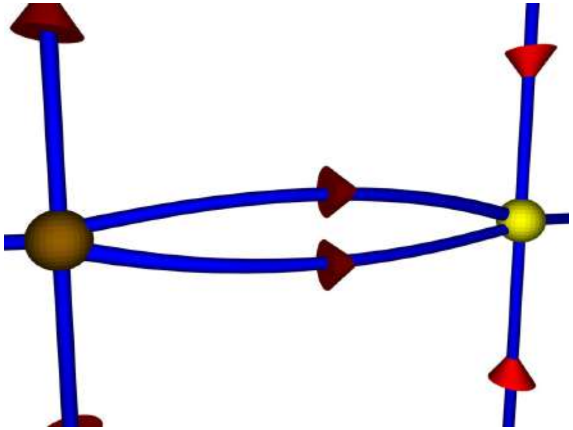
Condensation of topological defects



Start in paramagnetic state and ramp up interaction strength

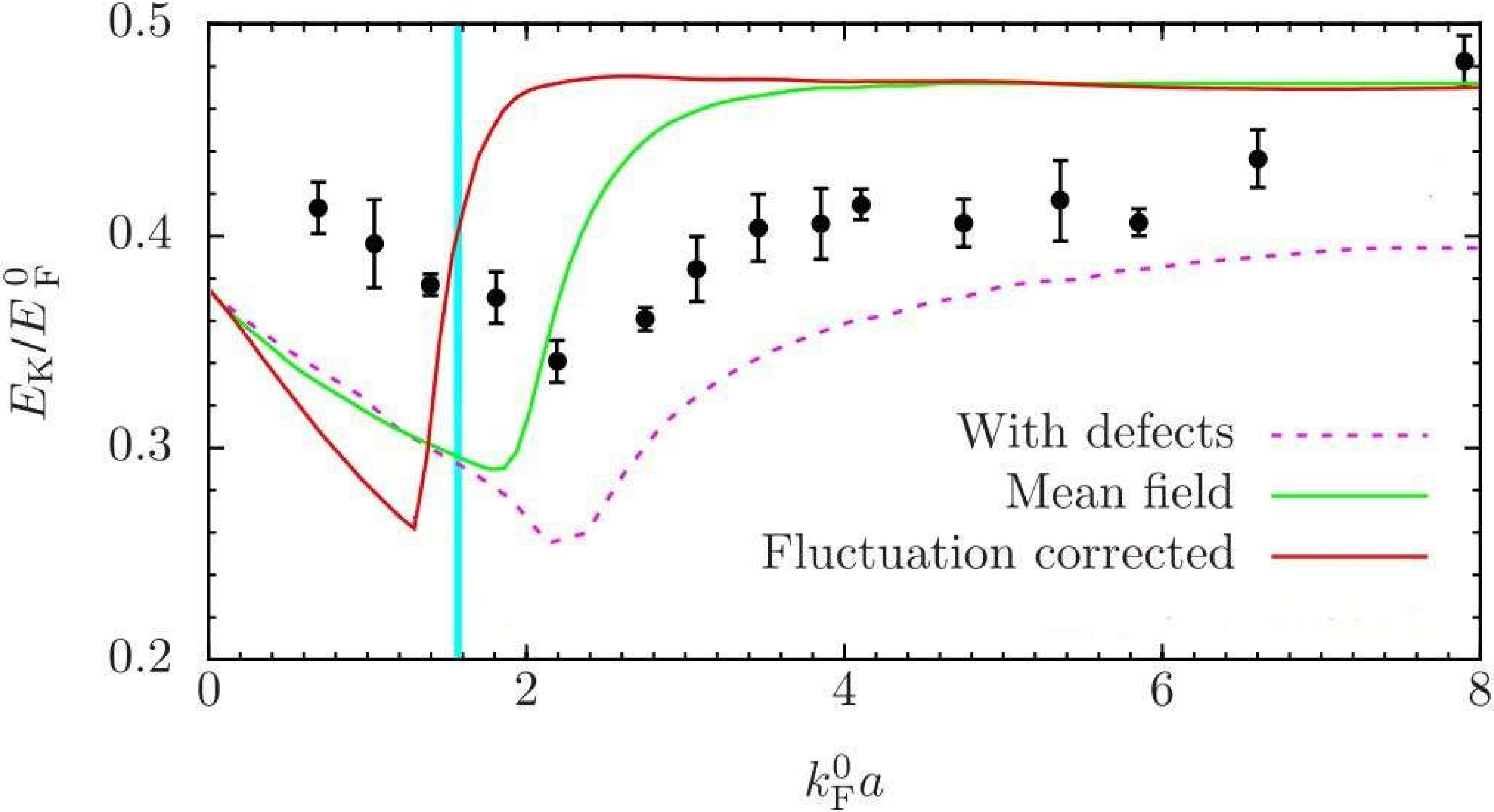
- Defects freeze out from disordered state
- Defect annihilation hinders the formation of the ferromagnetic phase thus raising the required interaction strength
- Defect radius $L \sim t^{½}$ [Bray, Adv. Phys. **43**, 357 (1994)]





Condensation of topological defects

- Condensation of defects inhibits the transition



Conduit & Simons, Phys. Rev. Lett. **103**, 200403 (2009)

Notes

- Localized vs itinerant ferromagnet
- Stoner model
- Solid state experiments for both first and second order
- Generic phase diagram
- Source(s) of first order transition – phonons [Larkin Pikin], electrons
- Disentangle with cold atoms
- Feshbach resonance
- Spin mapping
- Experimental results
- Compare with theory
- Fluctuation corrections
- QMC
- Other aspects: textured phase, loss driven ferromagnetism, collective modes

Ferromagnetism in an atomic Fermi gas

Alongside superfluidity, itinerant (Stoner) ferromagnetism remains one of the most well-characterized phases of correlated Fermi systems. A recent experiment has reported the first evidence for novel phase behavior on the repulsive side of the Feshbach resonance in a two-component ultracold Fermi gas. We perform a detailed critique of this realization by developing a formalism that extends the Hertz-Millis approach. Though the theory gives a reasonable qualitative account for the experimental findings there are crucial quantitative discrepancies. We search for possible sources of these quantitative discrepancies and explore what we could learn about solid state ferromagnetism from the cold atoms experiment.

G.-B Jo *et al*. Science **325**, 1521 (2009)
G.J. Conduit, A.G. Green & B.D. Simons, Phys. Rev. Lett. **103**, 207201 (2009)
G.J. Conduit & B.D. Simons, Phys. Rev. Lett. **103**, 200403 (2009)