Probing the BCS-BEC crossover with persistent currents

Giovanni Pecci[1], Piero Naldesi[1], Luigi Amico[2345], Anna Minguzzi[1]

1, Univ. Grenoble Alpes, CNRS, LPMMC, 38000 Grenoble, France

2. Dipartimento di Fisica e Astronomia 'Ettore Majorana', Via S. Sofia 64, 95127 Catania, Italy

3, CNR-IMM INFN-Sezione di Catania, Via S. Sofia 64, 95127 Catania, Italy

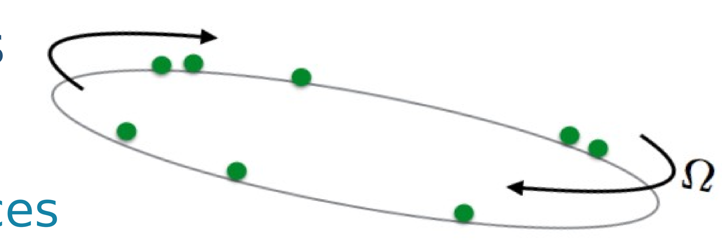
4. Centre for Quantum Technologies, National University of Singapore, 3 Science Drive 2, Singapore 117543, Singapore

5. LANEF Chaire d'excellence, Univ. Grenoble-Alpes & CNRS, F-38000 Grenoble, France

Abstract

We study the persistent currents of an attractive Fermi gas confined in a tightly-confining ring trap and subjected to an artificial gauge field all through the BCS-BEC crossover. At weak attractions, on the BCS side, fermions display a parity effect in the persistent currents, ie their response to the gauge field is paramagnetic or diamagnetic depending on the number of pairs on the ring. At resonance and on the BEC side of the crossover we find a doubling of the periodicity of the ground-state energy as a function of the artificial gauge field and disappearance of the parity effect, indicating that persistent currents can be used to infer the formation of tightly-bound bosonic pairs.

Rotating systems simulate gauge fields



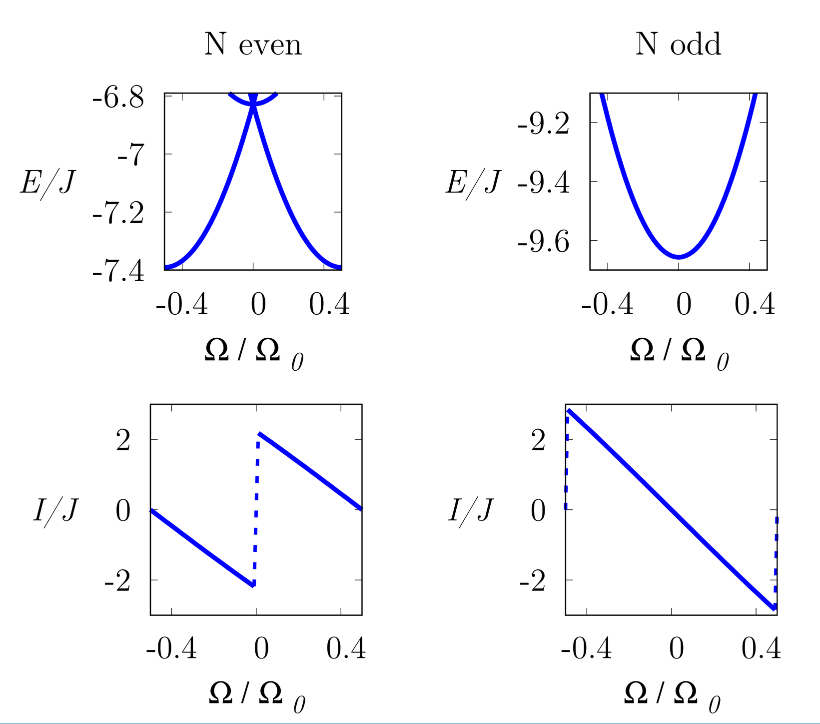
- Analogy between Coriolis and Lorentz forces
- Induced persistent mass currents as probe of different phase of the system

$$V_c = m\Omega\; \hat{p} \times \hat{r}$$

Parity effect $\Omega = 0$

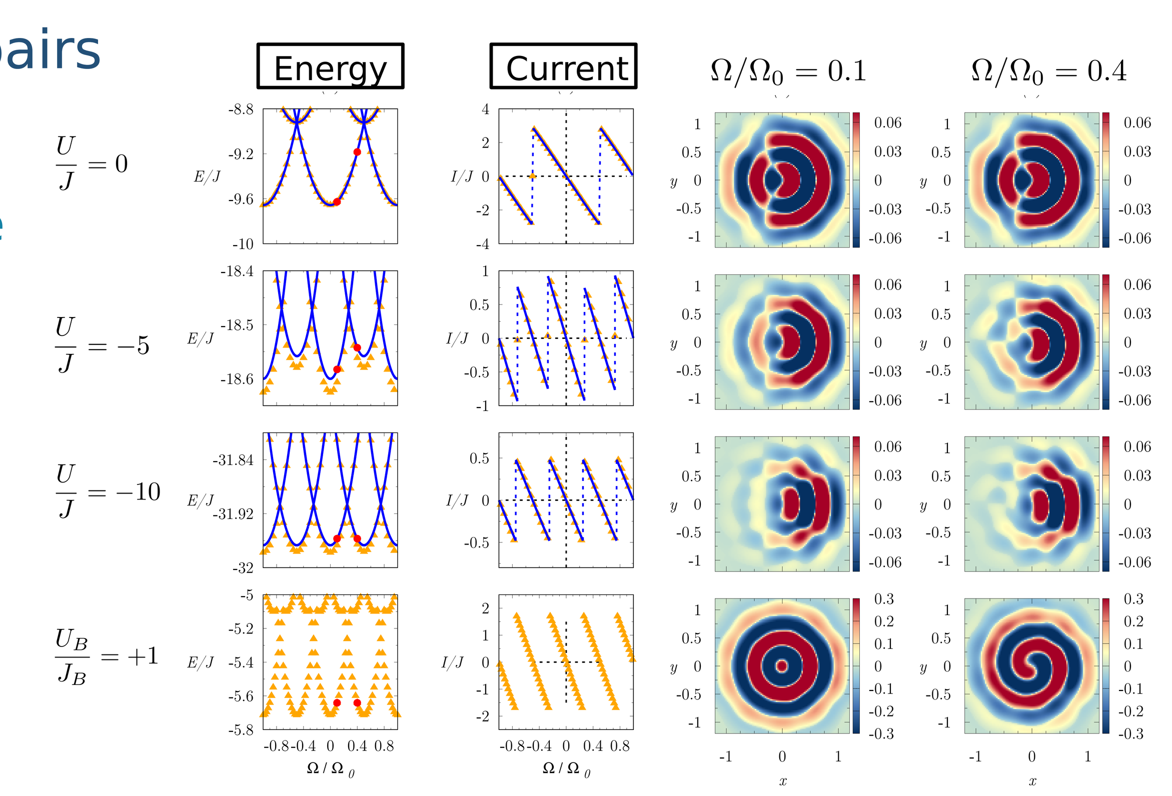
- N even : maximum of the ground state energy (paramagnetic current)
- N odd: maximum of the ground state energy (diamagnetic current)

Doesn't occur in Bose gases!
Can be used to probe the different regimes of the crossover



N=6: odd number of pairs

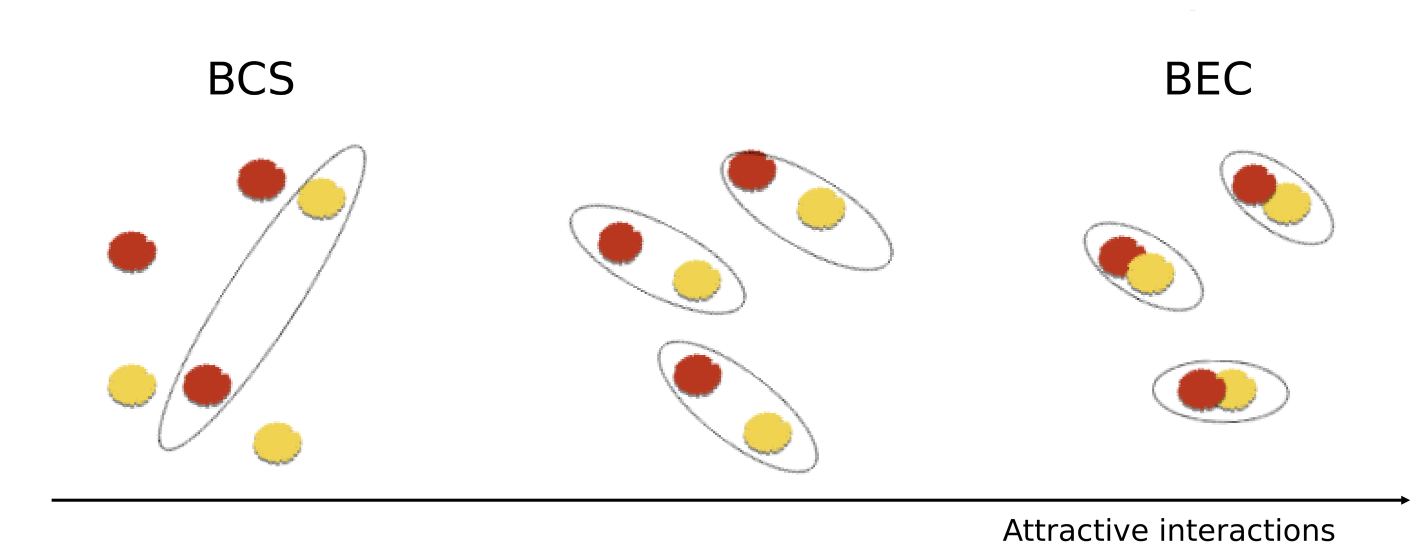
- Energy and current are periodic functions of the flux. The period at zero interactions is twice the one we have at strong attractions;
- Diamagnetic behaviour in any interaction regime



Conclusion and perspectives

- For U = 0 the current is a periodic function of the flux and we observe the parity effect
- At intermediate interactions we observe a superlattice behaviour: the current has not a well defined paramagnetic or diamagnetic behaviour.
- At strong interactions the periodicity of the current respect to the flux is doubled as a result of pairing. Parity effect is washed out as far as we achieve a purely bosonic regime.
- Future outlooks: deeper understanding of the fermionic spiral pattern

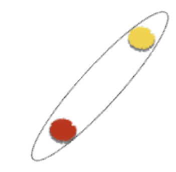
BCS-BEC crossover



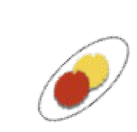
- Fermi gas with attractive interactions : paired fermions
- BCS regime : pairs whose size is much larger than the interparticle spacing
- BEC regime : tightly bound pairs behaving as point-like bosons

The models: Fermi and Bose-Hubbard Hamiltonians

$$H_{FH} = -J\sum_{j=1}^{N_s}\sum_{\sigma=\uparrow,\downarrow}\left(e^{\frac{2\pi i}{N_s}\Omega}c^\dagger_{j,\sigma}c_{j+1,\sigma} + H.c.\right) - |U|\sum_{j=1}^{N_s} n_{j,\uparrow}n_{j,\downarrow} \longrightarrow \text{BCS}$$



$$H_{BH} = -J_B\sum_{j=1}^{N_s}\left(e^{\frac{2\pi i}{N_s}\Omega}b^\dagger_j b_{j+1} + H.c.\right) + \frac{|U_B|}{2}\sum_{j=1}^{N_s} n_j(n_j-1) \longrightarrow \text{BEC}$$

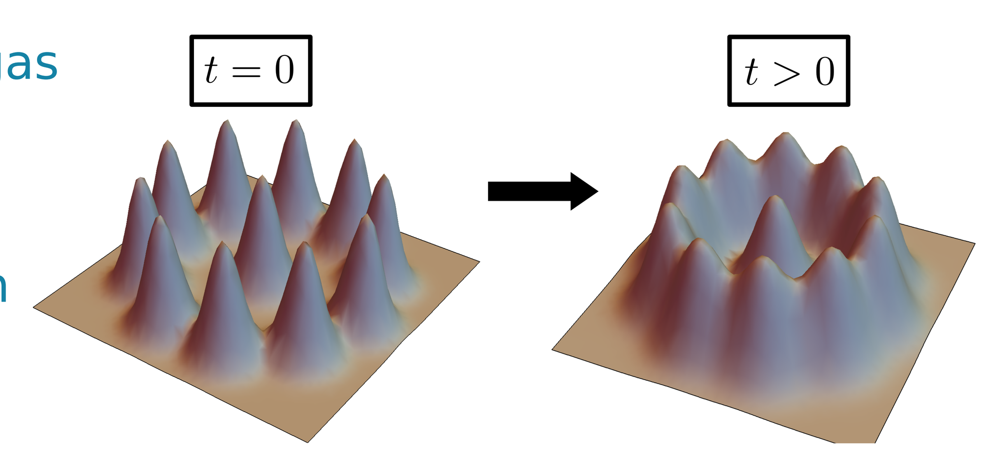


Fermi and Bose gas respectively with attractive and repulsive on site interaction on a ring lattice threaded with an artificial gauge flux Ω

Readout: noise correlator $\langle n(r,t)n(r',t)\rangle$

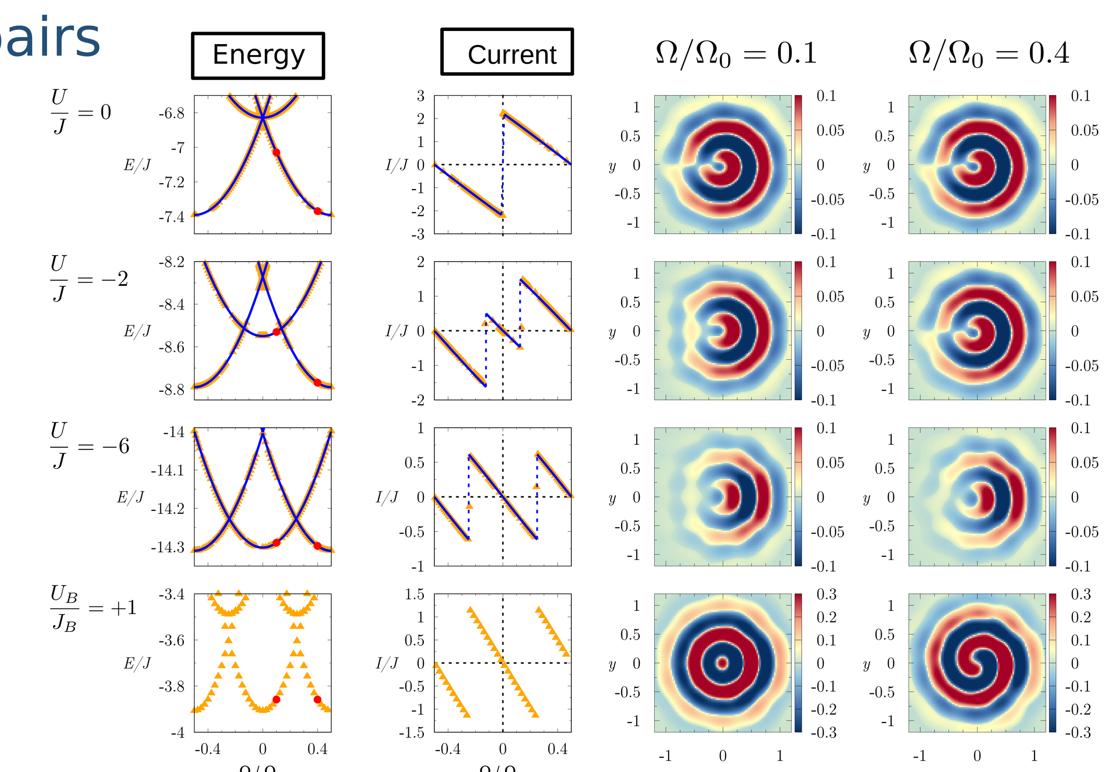
• Symmetric l=0 • Spiral l=1

- Consider the expansion of the gas after the trap removal
- The interference pattern gives information about the current in the ring



N=4: even number of pairs

- Energy and current are periodic functions of the flux. The period at zero interactions is twice the one we have at strong attractions;
- Paramagnetic behaviour turns into diamagnetic increasing the interactions.



References

[1] G. C. Strinati, P. Pieri, G. Röpke et al., Phys. Rep. 738, 1 (2018)
[2] A. Leggett, in Granular Nanoelectronics (NATO ASI Ser. B,251 Plenum, New York, 1991) p. 297.
[3] J. Fuchs, A. Recati, and W. Zwerger, Phys. Rev. Lett. 93, 090408 (2004).

giovanni.pecci@lpmmc.cnrs.fr