Capturing the Feshbach-induced Pairing Physics in the BEC-BCS Crossover

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Abstract: By including the effect of an effective trap in a two-channel model for Feshbach resonances, we reproduce the experimental closed-channel fraction across the BEC-BCS crossover and into the BCS regime of a ^{6}Li atomic Fermi gas. The trap accounts not only for the optical external trap and its geometry but also for the non-trivial many-body correlations, meaning that the remaining fermions can be modelled as a trap with a characteristic length that is comparable to the interparticle spacing. We provide general and near-resonance simple formulas for the binding energy of ultracold molecules as well as for the closed-channel fraction. Contrary to the free-trap two-body theory and in line with experiments, our results predict a non-vanishing closed-channel fraction for fields above the resonance. Our model reproduced the predicted behavior of the closed-channel fraction at unitarity and is in good agreement with recent measurements on the near BCS side.

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Extended abstract: We present a very simple and accurate two-channel model describing the two-body physics near a Feshbach resonance. By including the effect of an effective trap with characteristic energy given by the Fermi Temperature T_F the proposed model reproduces the experimental measurements of the closed-channel fraction Z across the BEC-BCS crossover and into the BCS regime of a ^{6}Li atomic Fermi gas [1-2], see Fig. 1. We give predictions for the behaviour of the studied observables and suggest experimental and theoretical applications of our results and model. Contrary to the free-trap two-body theory and in agreement with the experimental observations, our results predict a non-vanishing closed-channel fraction for fields above the resonance. We obtain the expected behavior at unitarity $Z \alpha T_F^{1/2}$, together with the recent measured proportionality constant [2]. Our results are also in agreement with recent measurements of the Z dependency on T_F on the BCS side [2], where a significant discrepancy between experiments and theory has been repeatedly reported.

Our results imply a major step towards a complete two-body model regarding the BEC-BCS Crossover near a Feshbach resonance and could lead to a gain in the understanding of the many-body interacting quantum system, which is constructed upon a complete insight of the microscopic two-body physics. The accuracy of our results improves the one achieved using field theory, adding its simplicity and the intuitive interpretation of our results as advantages. We are certain that our present results will be of interest to the community of ultracold quantum gases, which constitute a widely used system in quantum information and quantum metrology [4]. In particular, we intend to apply these results to extend our previous results for the entanglement between two spatially separated ultracold interacting Fermi gases up to the unitarity limit [5], as well as to address the role of entanglement in ensuring the ideal bosonic behaviour of the fermionic composite bosons near the BEC-BCS crossover [6].

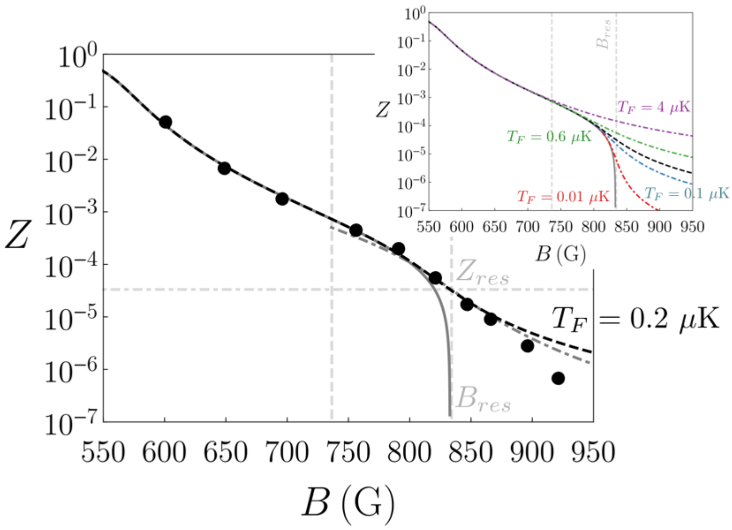

Figure 1 Closed-channel fraction *Z* vs. magnetic field *B*. The points are the experimental data taken from Ref. [1], whose size reflect the uncertainty in *Z*. The closed-channel fraction obtained with the free-trap model of Ref. [3] is depicted in gray solid line while our results are depicted in black dashed line. The obtained approximation is shown as a gray dot-dashed line. The horizontal gray dashed line gives Z_{res}. The vertical gray dashed lines indicate the B_{res} value and the typical BEC-BCS Crossover regime given by $|a|>3000\ a_0$. Notice that the 920 G point is identified in Ref. [1] as presenting experimental issues. The inset contains the obtained *Z* for several T_F values (different trap frequencies).

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