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BCS-BEC crossover in FeSe with small Fermi energies

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The BCS-BEC crossover bridges the two important theories of bound particles (Bardeen-Cooper-Schrieffer theory and Bose-Einstein condensation) in a unified picture with the ratio of the attractive interaction to the Fermi energy as a tuning parameter. A key issue is to understand the intermediate regime, where new states of matter may emerge. It has been shown that the Fermi energies of FeSe, the simplest iron-based superconductor with $T_c \sim 9\,\mathrm{K}$, are extremely small, with the result that this system is located at the verge of a BCS-BEC crossover [1-4]. Here we discuss possible preformed pairs and a new high-field superconducting phase emergent in FeSe associated with the crossover. Our highly sensitive torque magnetometry probes presence of giant superconducting fluctuations below $T \sim 2T_c$, which is much different from the standard Gaussian fluctuation theories. Resistivity, Hall effect, Seebeck and Nernst coefficients all exhibit anomalies in the same temperature regime. Strikingly, thermal conductivity measurements in the superconducting state give evidence for a distinct phase boundary below the upper critical field, suggesting that the Zeeman splitting comparable to the Fermi energies leads to a strong modification of the quasiparticle structure. The observation of this field-induced phase appears to provide insights into previously poorly understood aspects of the highly spin-polarized Fermi liquid in the BCS-BEC crossover regime.

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