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BCS-BEC crossover physics in FeSe bulk superconductor[1]

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The physics of the crossover between weak-coupling Bardeen-Cooper-Schrieffer (BCS) and strong-coupling Bose-Einstein-condensate (BEC) limits gives a unified framework of quantum bound (superfluid) states of interacting fermions. This crossover has been studied in the ultracold atomic systems, but is extremely difficult to be realized for electrons in solids. Through the superfluid response, transport, thermoelectric response [1], and quantum oscillations [2], we demonstrate that the Fermi energy of the bulk superconductor FeSe is extremely small, with the ratio of the gap to Fermi energy is of the order of unity, which qualifies FeSe to be deep inside the BCS-BEC crossover regime. Thus FeSe appears to be a key material to solve the longstanding issue in the crossover physics; the presence of preformed Cooper pairs giving rise to a pseudogap above the superconducting transition temperature T_c. We report experimental signatures of preformed Cooper pairing well above $T_c = 8.5$ K in clean single crystals of FeSe. Our torque magnetometry reveals distinct diamagnetic signal below $T^* \sim 20$ K indicating that the superconducting fluctuations above the transition temperature are strongly enhanced from the standard Gaussian theory. The transport and thermoelectric coefficients also exhibit distinct anomalies at $\sim T^*$, signaling a possible pseudogap formation. The multiband nature with the electron-hole compensation in FeSe may highlight a fundamentally new aspect of the BCS-BEC crossover physics. [1] S. Kasahara *et al.*, PNAS **111**, 16309 (2014). [2] T. Terashima *et al.*, Phys. Rev. B **90**, 144517 (2014); M. D. Watson *et al.*, Phys. Rev. Lett. **115**, 027006 (2015).

[1]In collaboration with S. Kasahara, T. Yamashita, Y. Matsuda (Kyoto), Y. Mizukami (Tokyo), T. Wolf, F. Hardy, C. Meingast, H. v. Löhneysen (KIT), M. D. Watson, A. I. Coldea (Oxford), T. Terashima (NIMS), W. Knafo (Toulouse), T. Hanaguri (Riken).