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Critical quasi-particle theory and scaling near a Quantum Critical Point of Heavy Fermion metals

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We recently developed a theory of the critical properties of a heavy fermion metal near an antiferromagnetic (AFM) quantum phase transition governed by three-dimensional spin fluctuations. The critical spin fluctuations induce critical behavior of the electron quasi-particles (qp) as seen in a diverging effective mass, leading, e.g., to a diverging specific heat coefficient. This in turn gives rise to a modification of the spin excitation spectrum [1]. We use that the concept of electron quasi-particles is well-defined as long as the qp width is less than their excitation energy, which is still the case in the so-called non-Fermi liquid regime. Impurity scattering [1,2] and/or higher order loop processes in the clean system [3] cause a redistribution of the critical scattering at the hot lines all over the Fermi surface, leading to a weakly momentum dependent critical self-energy. We derive a self-consistent equation for the qp effective mass which allows for two physical solutions: the usual weak coupling spin density wave solution and a strong coupling solution featuring a power law divergence of the effective mass as a function of energy scale. The resulting spin excitation spectrum obeys E/T scaling with dynamical exponent z=4 and correlation length exponent ν =1/3, in excellent agreement with data for $YbRh_2Si_2$ [1,2]. Results of our theory applied to three-dimensional metals featuring quasi-two-dimensional spin fluctuations will be presented with the aim of explaining the observed properties of the AFM quantum critical point of $CeCu_{6-x}Au_x$, in particular the E/T scaling exhibited by inelastic neutron scattering data. In that case we find z=8/3 and ν =3/7 [3]. Finally, the microscopic underpinning of our theory will be addressed, including the issues of qp renormalization, vertex corrections, interaction of bosonic fluctuations in the renormalization group sense, and higher loop corrections [3].

[1] P. Wölfle, and E. Abrahams, Phys. Rev. B **84**, 041101 (2011); Ann. Phys. (Berlin) **523**, 591 (2011); Phys. Rev. B **80**, 235112 (2009).
[2] E. Abrahams and P. Wölfle, PNAS **109**, 3228 (2012).
[3] E. Abrahams, J. Schmalian, and P. Wölfle, to be published.