Experimental Report

31/01/2014

Proposal: **4-01-1178** **Council:** 4/2012

Title: Critical spin fluctuations in quantum critical Ce(Pd0.856Ni0.144)Al

This proposal is a new proposal

Researh Area: Physics

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Samples: CePd0.856Ni0.144Al

Instrument	Req. Days	All. Days	From	To
IN12	7	6	28/02/2013	06/03/2013

Abstract:

CePdAl is a geometrically frustrated heavy fermion compound that orders antiferromagnetically below TN = 2.7 K and can be tuned continuously to a quantum critical point, e.g. by isoelectronic Ni-doping on the Pd sites. Quantum critical Ce(Pd0.856Ni0.144)Al exhibits strong Non-Fermi-liquid behavior, for example the heat capacity C varies as C/T ~ -ln T. Having studied the magnetic order in CePdAl, we propose to investigate critical spin fluctuations in quantum critical Ce(Pd0.856Ni0.144)Al, especially their Q-dependence and dynamics. This investigation contributes to a better understanding of the physics at the quantum critical point and addresses especially the role of geometrical frustration.

Hexagonal CePdAl orders antiferromagnetically below $T_{\mathrm{N}} = 2.7\,\mathrm{K}$ in an incommensurate magnetic structure with a propagation vector $k = (0.5\ 0\ \tau)$, $\tau \approx 0.35$ [1] and is located in the vicinity of a quantum critical point (QCP). It is a heavy-fermion compound with an enhanced Sommerfeld-coefficient of about $\gamma \approx 270\,\mathrm{mJ/molK^2}$. There are strong indications for geometrical frustration, such as a large ratio of the Néel- and Curie-Weiss temperature [1]. Previous measurements also claimed that about 1/3 of the Ce moments in CePdAl do not take place in the long-range antiferromagnetic order [1] which was interpreted as a consequence of geometrical frustration of the Ce-moments in the basal plane. The QCP can be approached by applying hydrostatic pressure as well as by varying the chemical composition, i.e., substituting Ni on the Pd site [2]. The critical concentration of Ni in $Ce(Pd_{1-x}Ni_x)Al$ to suppress the magnetic ordering temperature to zero and approach the QCP is $x \approx 0.14$ [2, 3].

To study the spin dynamics in quantum critical $Ce(Pd_{0.86}Ni_{0.14})Al$ we performed a neutron scattering experiment on the cold TAS IN12. Measurements were carried out at temperatures between $T = 60\,\mathrm{mK}$ and $10\,\mathrm{K}$ with a fixed $k_f = 1.15\,\text{Å}^{-1}$. For the experiment a $Ce(Pd_{0.86}Ni_{0.14})Al$ single crystal with a mass $m \approx 6.2\,\mathrm{g}$ was mounted on a Cu post attached to the mixing chamber of a dilution insert. The horizontal scattering plane was spanned by the reciprocal $(h\ 0\ l)$ plane to have access to the Q positions of the incipient magnetic order.

The main findings of our experiment are as follows:

- The propagation vector of the incipient magnetic order in $Ce(Pd_{0.86}Ni_{0.14})Al$ remains unchanged in comparison to pure CePdAl as indicated by elastic scans showing broad, weak correlation peaks at $Q_{AF} = (1.5\ 0\ 0.34)$ as displayed in Fig. 1. The correlation length of these correlations is about $\xi = 8 - 13\,\text{Å}$. This result is corroborated by diffraction measurements on $Ce(Pd_{0.9}Ni_{0.1})Al$ exhibiting magnetic order with the same propagation vector $k \approx (0.5\ 0\ 0.34)$ [4].

- Q scans along $[001]$ at small energy transfers display dynamic spin correlations at the expected Q_{AF} space positions. Their q width shows almost no change below $1\,\mathrm{K}$ (and corresponds to $\xi = 6 - 8\,\text{Å}$), but they are significantly suppressed and broadened at $10\,\mathrm{K}$ as shown in Fig. 2.

- The magnetic response at $(1.5\ 0\ 0.34)$ is described by quasielastic fluctuations with Lorentzian lineshape (Fig. 3) and displaying an (almost) critical slowing down for $T \rightarrow 0$ as expected for a system at a QCP (Fig. 4). In contrast, the energy scans performed at the arbitrary Q position $(1.5\ 0\ 0)$ (where no dynamic correlations are visible) display Kondo behavior, i.e., show quasielastic fluctuations with a much larger and finite residual linewidth $\Gamma/2 \approx 0.5\,\mathrm{meV}$ corresponding to a characteristic temperature of $5 - 6\,\mathrm{K}$ and of the order of the Kondo temperature in the system. At a temperature around the Kondo temperature the local Kondo fluctuations and the intersite fluctuations exhibit the same linewidth because at higher temperature the interite fluctuations are suppressed and only the local (Kondo) fluctuations remain.

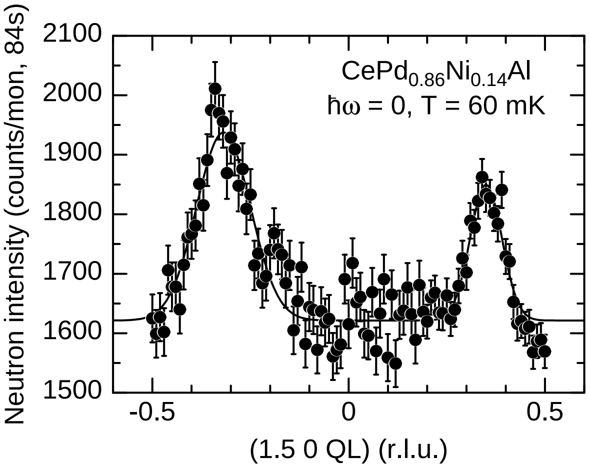

Fig. 1: Elastic Q scans along $(1.5\ 0\ QL)$ across several possible Q_{AF} positions in Ce($Pd_{0.86}Ni_{0.14}$)Al at $T = 60\,$mK.

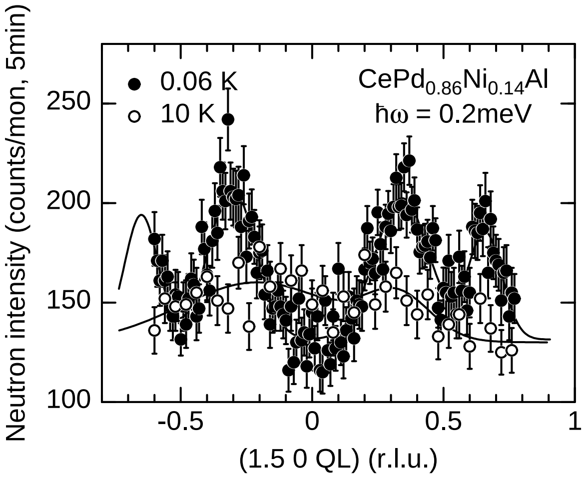

Fig. 2: Q scans along $(1.5\ 0\ QL)$ at $\hbar\omega = 0.2\,$meV across several possible Q_{AF} positions in Ce($Pd_{0.86}Ni_{0.14}$)Al at $T = 60\,$mK and $10\,$K.

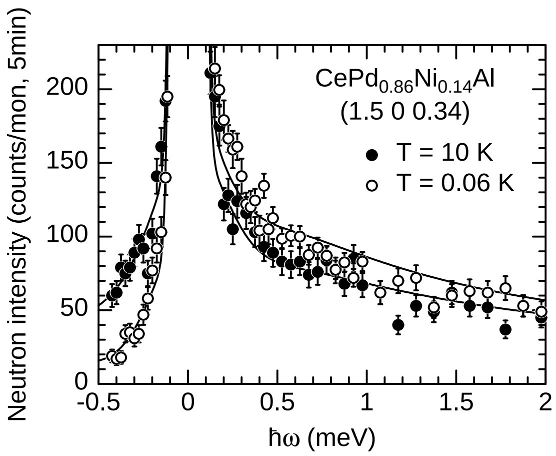

Fig. 3: Energy scan in Ce($Pd_{0.856}Ni_{0.144}$)Al at $Q_{AF} = (1.5\,0\,0.34)$ at $T = 60\,$mK and $10\,$K.

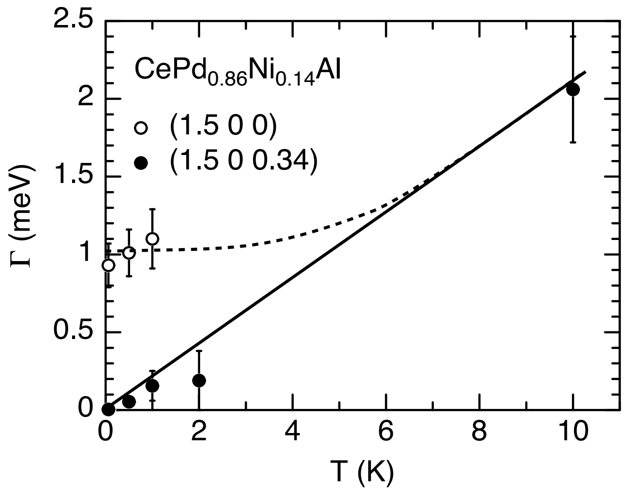

Fig. 4: Linewidth Γ of the quasielastic magnetic response at $Q_{AF} = (1.5\ 0\ 0.34)$ and $Q = (1.5\ 0\ 0)$ in Ce($Pd_{0.86}Ni_{0.14}$)Al versus temperature T. Lines are guides to the eyes.

These results give rise to several question mainly about how the critical fluctuations evolve in detail as function of temperature but also in external magnetic field. It is also questionable if the local fluctuations are due to the frustration of the system. Further measurements are highly desired to address these issues.

References:

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[2] N. Bagrets, PhD thesis, Universität Karlsruhe(2009)
[3] T. Goto et al., J. Phys. Chem. Solids **63**, 1159 (2002)
[4] Z. Huesges et al., experiment on E4/HZB, unpublished.