Experimental report

23/03/2025

Proposal:	**DIR-291**	**Council:**	4/2023
Title:	Witnessing entanglement in quantumcritical CeRu4Sn6		
Research area:	Physics		

This proposal is a new proposal

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Samples: CeRu4Sn6

Instrument	Requested days	Allocated days	From	To
ORIENTEXPRESS	1	1	20/09/2023	21/09/2023
THALES	9	7	18/09/2023	29/09/2023

Abstract:

Quantum criticality beyond the order parameter paradigm, which underlies the enigmatic strange metal state, is a key open problem in correlated quantum matter. Recent advances
from the quantum information community nourish the hope that a new level of understanding could be achieved by assessing the degree of entanglement of this state. With the present proposal we set out to probe the quantum Fisher information and related entanglement witnesses by high-resolution inelastic neutron scattering (INS) measurements along several trajectories in the temperature¿magnetic field phase diagram of the heavy fermion compound CeRu4Sn6. Previous measurements of some of us have revealed energy-over-temperature scaling with a fractional critical exponent in zero-field INS data, and the suppression of this beyond orderparameter quantum criticality with modest magnetic fields. This together with theoretical predictions of long-range entanglement at such a ¿Kondo destruction¿ quantum critical point makes CeRu4Sn6 an ideal testbed.

Witnessing entanglement in $CeRu_4Sn_6$

Introduction

Weyl-Kondo semimetals are a new state of matter where strong correlations, spin-orbit coupling and crystalline symmetries interplay to pin Weyl nodes via the Kondo effect to the immediate vicinity of the Fermi level [1, 2]. A prime example is the heavy fermion compound $CeRu_4Sn_6$. A previous INS study revealed dynamical scaling behavior with a fractional exponent, pointing to a strange metal state resulting from quantum criticality beyond the Landau-Ginzburg-Wilson order-parameter framework [3]. Stimulated by ideas from the quantum information community, the question has recently arisen whether this state might exhibit exotic entanglement properties. INS allows to measure the quantum Fisher information (QFI), which is a witness of the entanglement depth [4, 5]. The rationale is to quantify the entanglement depth both in the strange metal state and away from it by application of an external magnetic field.

Experimental configuration

Unfortunately, due to the sample transport, one of the 3 crystals was damaged, and we had to remove it, resulting in a total mass of only 1 g mounted on a copper sample holder for good thermalization in the 2.5 T cryomagnet with its crystallographic (0 1 0) axis aligned vertically. The resulting scattering plane was (*H 0 L*) and we fixed the final neutron wavevector k_f to 1.3 Å. We used a dilution refrigerator and managed to cool the sample down to 60 mK.

Summary and outlook

We started the measurement sequence by checking the sample alignment and the Bragg scattering of (2 0 0) and (0 2 0). We spent 0.5 days after cooling for the optimization of our instrument settings, by doing test measurements with different k_f. Furthermore, we investigated the advantages and disadvantages of changing silicon and pyrolytic graphite monochromators.

Regarding the measurement sequences, we started by probing the temperature dependence from 60 mK to 10 K of the neutron intensities in zero magnetic field at Q = (1 0 0), but we could not detect any change in the signal.

In addition, we investigated the Q dependence by rotating A3 and with A4 fixed to maintain the same modulus of Q at 60 mK in zero magnetic field which led to no change in the data.

Lastly, the magnetic field dependence from 0 T to 2.5 T at the lowest temperature at Q = (1 0 0) also appears not to produce any visible change in the neutron scattering cross-section.

To summarize, we could not detect any significant feature regarding the strange metal behavior, as specified before the sample was unsuitable for such low-energy investigation. We hope to repeat the experiment in the future under ideal conditions. Unfortunately, the data collected during this beamtime will not lead to publication, but we are hopeful that with a new sample we will be successful.

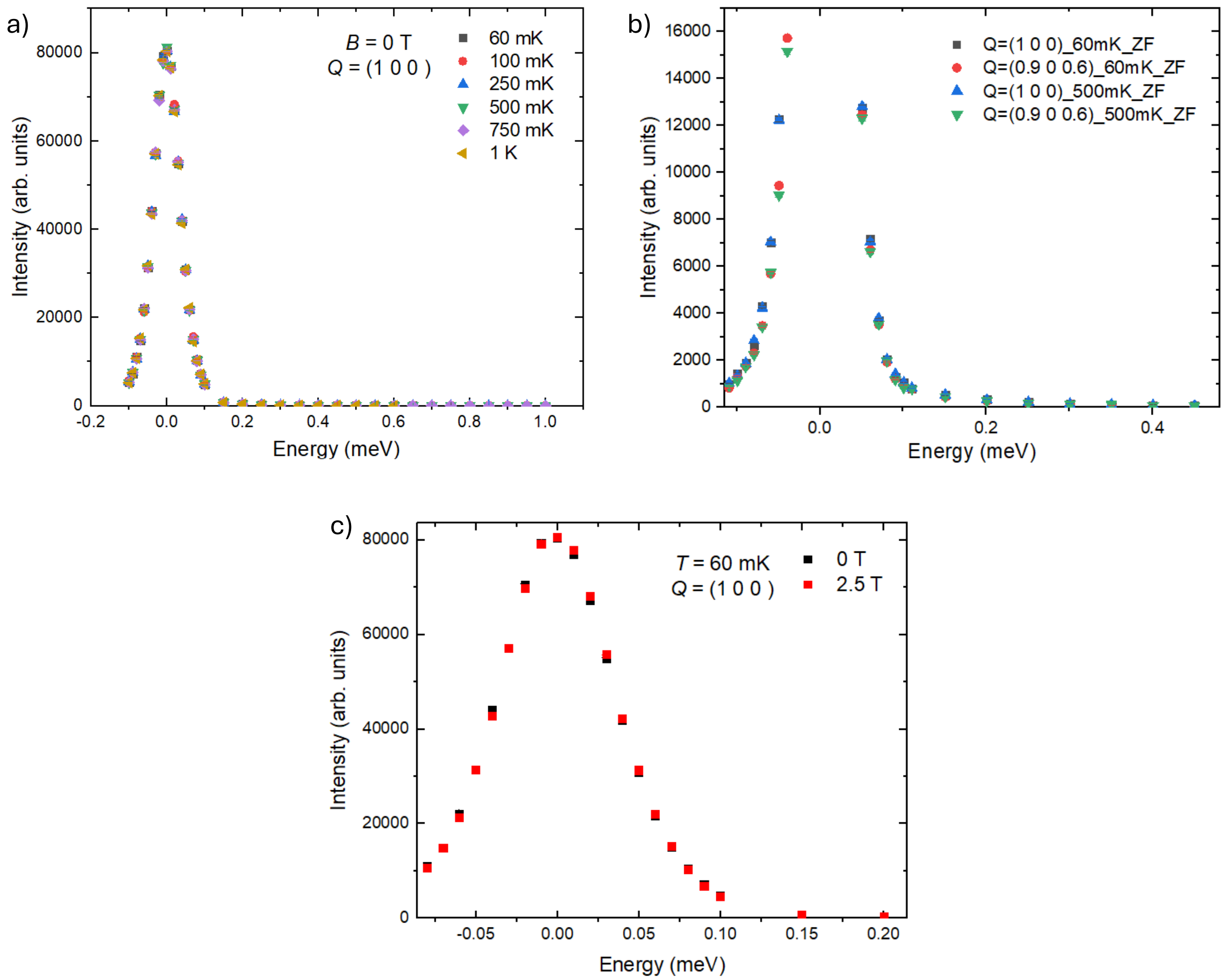

Figure 1: a) Neutron scattering intensity measured at different temperatures at Q = (1 0 0) in zero magnetic field at different temperatures. b) Comparison of the scattering intensity between different wavevectors and different temperatures in zero magnetic field. c) Neutron scattering cross-section measured in zero magnetic field and at 2.5 T at base temperature for Q = (1 0 0).

[1] Dzsaber, S., et al. *Phys. Rev. Lett.* **118**, 246601 (2017).

[2] Lai, H.-H-, et al. *Proc. Natl. Acad. Sci. U.S.A.* **115**, 93 (2018).

[3] Fuhrman, W. T., et al. *Sci. Adv.* **7**, eabf9134 (2021).

[4] Hauke, P., et al. *Nat. Phys.* **12**, 778-782 (2016).

[5] Laurell, P., *Phys. Rev. Lett.* **127**, 037201 (2021).