μSR investigation of a quantum criticality in the coupled spin ladder \( \text{Ba}_2\text{CuTeO}_6 \)

Y. S. Choi, *1 S.-H. Do,*1 Dita Puspita Sari,*2,*3 I. Watanabe,*2 and K.-Y. Choi*1. *2

Quantum spin ladders consisting of leg and rung couplings offer an outstanding opportunity to investigate quantum-critical spin dynamics and have far-reaching relevance to diverse fields of physics such as Tomonaga-Luttinger liquids, magnon fractionalization, unconventional superconductivity, and quark confinement.\(^1\)-\(^3\) Isolated two-leg ladders have a short-range resonating valence bond state.\(^4\) With growing interladder couplings, a quantum phase transition is anticipated to occur to the magnetically ordered state.\(^5\)

\( \text{Ba}_2\text{CuTeO}_6 \) is a prime candidate material for a three-dimensionally networked spin ladder, allowing addressing quantum criticality in coupled two-leg ladders.\( \text{Ba}_2\text{CuTeO}_6 \) features both a long-range ordering at \( T_N = 15 \text{ K} \) and the spin-gap excitation of \( \Delta = 50 \text{ K} \) at finite temperatures.\(^5\)-\(^7\) However, the magnetic transition is largely hidden, while showing no magnetic Bragg peaks and no apparent \( \lambda \)-like anomaly in the specific heat. Thus, it is highly desired to identify the occurrence of the static magnetic ordering. To resolve these issues, we performed zero-field μSR experiments on the ARGUS spectrometer of RIKEN-RAL. The collected data were analyzed using the software package WiMDA.

The time decay of the muon spin polarization \( P(t) \) at temperatures above and below \( T_N \) is shown in Fig. 1(a). Upon cooling towards \( T_N \), we observe muon-spin precession together with a drop in the early-time asymmetry [see the inset of Fig. 1(a)], confirming the development of static local magnetic fields at the muon stopping sites. The polarization curves can be well described by the sum of an exponentially relaxing cosine function and a simple exponential function:

\[
P(t) = (1-\alpha)\exp(-\lambda t) + \alpha \exp(-\lambda t) \cos(2\pi f_s t + \phi),
\]

where the two terms represent muons polarized transverse and parallel to the local magnetic fields. The temperature dependence of the asymmetry, the muon-spin precession frequency \( f_s \), and the transverse relaxation rate \( \lambda_t \) is plotted in Fig. 1(b)-(d). All μSR parameters display distinct changes at \( T_N \). The initial asymmetry drops rapidly on cooling to \( T_N \). The missing asymmetry is ascribed to an unresolved precession signal within the pulsed muon beam time window.

\( f_s(T) \), corresponding to the magnetic order parameter, is fitted to the phenomenological form \( f_s(T) = f_0(1-(T/T_N))^\beta \), where \( f_0 = 4.3 \text{ MHz} \) is the frequency at \( T = 0 \text{ K} \) and \( \beta = 0.29(1) \) is the critical exponent. The obtained critical exponent is not much different from the value \( \beta = 0.365 \), expected for the 3D Heisenberg model. \( T_N = 14.1 \text{ K} \) is slightly lower than the transition temperature of 15 K determined from the uniform susceptibility. The temperature dependence of \( \lambda_t(T) \) can also be modeled with the same order-parameter fit as plotted in Fig. 1(d). Taken together, a ground state of \( \text{Ba}_2\text{CuTeO}_6 \) is characterized by a conventional antiferromagnetic order, while having persisting spin fluctuations in the ordered state.

In this report, we have presented a combined study of ZF-μSR measurements on the coupled two-leg spin ladder \( \text{Ba}_2\text{CuTeO}_6 \). We observe unambiguously an oscillating signal in the ZF-μSR time spectra, suggesting that \( \text{Ba}_2\text{CuTeO}_6 \) lies close to a quantum critical point from a magnetically ordered side.

References