# Experimental report

23/03/2021

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| **Proposal:** | **4-02-503** | **Council:** | 10/2016 |

**Title:** Superconducting Higgs mode in quasi-one-dimensional CDW metal ZrTe3

**Research area:** Physics

**This proposal is a new proposal**

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**Local contacts:** Paul STEFFENS

**Samples:** ZrTe3

| Instrument | Requested days | Allocated days | From | To |
|---|---|---|---|---|
| THALES | 8 | 7 | 02/02/2017 | 09/02/2017 |


## Abstract:

Superconducting amplitude mode, or Higgs mode, is a long-predicted collective mode in quantum many-body systems, but lacks experimental investigations because it is not directly coupled to external probes. Charge-density-wave (CDW) superconductors offer an opportunity for detecting it because the superconducting Higgs mode is coupled to amplitude excitations of the CDW order, as has been recently demonstrated by Raman scattering in NbSe2. Here we propose to investigate superconducting Higgs mode in ZrTe3 using inelastic neutron scattering (INS). ZrTe3 is a quasi-one-dimensional prototypical CDW material, and bulk superconductivity coexists with CDW below 3.1 K in annealed-quenched samples. The simplicity of the CDW order in ZrTe3 offers an ideal platform for studying the superconducting Higgs mode. We have performed a preliminary search at PANDA (MLZ, Germany) with promising results and the conclusion that a high-flux instrument will be necessary to firmly establish and extend the observation. We propose to further pursue this study using the high-flux cold-neutron spectrometer ThALES.

**Superconducting Higgs mode in quasi-one-dimensional CDW metal $ZrTe_3$**

**Abstract:** The idea that amplitude excitations associated with a superconductivity (SC) order parameter, also known as the superconducting Higgs mode, can be detected via measurements of charge-density-wave (CDW) amplitude mode, in systems where SC and CDW compete with each other, has been explicitly tested in a single-crystal array of $ZrTe_3$. By performing inelastic neutron scattering measurements of the CDW amplitude mode, and by tracking the mode's scattering signal through the SC transition temperature, we obtained a null result: No spectral variation is found across the SC transition. By performing complementary neutron diffraction measurement of the CDW order, we find that the competition between SC and CDW is very weak in $ZrTe_3$, which can possibly explain our inability to observe any indication of the SC Higgs mode despite the high statistical accuracy of our measurements.

**Measurement condition:** A total of about 2 grams of quenched $ZrTe_3$ single crystals were coligned for the study. The sample had a mosaic spread of about 5 degrees in the ($H$0$L$) scattering plane, and was mounted in a He-3 cryostat able to reach a base temperature of about 440 mK. According to magnetometry characterization, the sample had a $T_c$ of the SC of about 2.3 K. The measurement was performed with a single analyzer/detector in fixed $E_f$ mode.

**Experiment result:** We first characterized the sample's CDW property using neutron diffraction, which showed a well-defined CDW transition at about 61 K (Fig. 1). This knowledge about the CDW wave vector allowed us to measure the CDW's amplitude mode, which is basically the Kohn-anomalous phonon at the CDW wave vector, as a function of temperature (Fig. 2). The data nicely show critical behaviors associated with the CDW transition.

The main focus of the experiment was to check the CDW amplitude mode's energy profile and its evolution through the SC transition temperature. The results are shown in Fig. 3. Unfortunately, despite the great effort that was put into the measurement, we could not observe any significant variation in the spectrum. Hence, we had to conclude that we found no SC Higgs mode in our sample.

By closely looking at the CDW diffraction signal's evolution through $T_c$, we see a noticeable, albeit extremely weak, decrease of the CDW order parameter upon entering the SC state. This suggest weak competition between the two orders and might explain why we were unable to observe the SC Higgs mode with our experimental approach.

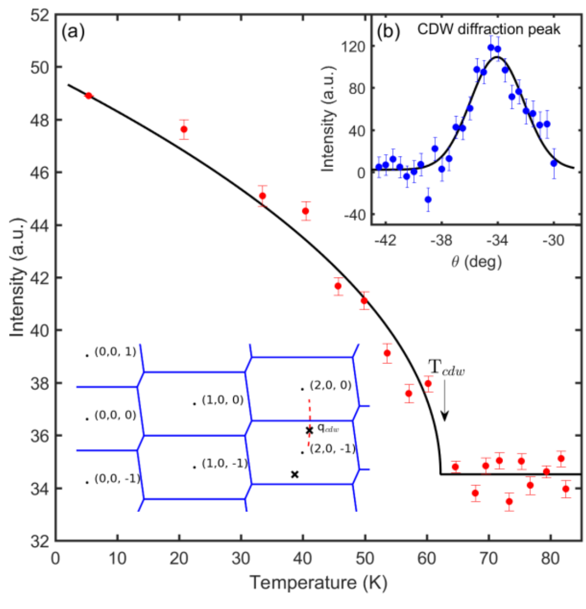


Fig. 1. (a) Temperature dependence of the CDW diffraction peak intensity at (2.07, 0, -0.67). Line is a guide to the eye. The inset shows the measurement position in the Brillouin zone. (b) Full rocking scan through the CDW diffraction peak, showing the sample's mosaic spread.

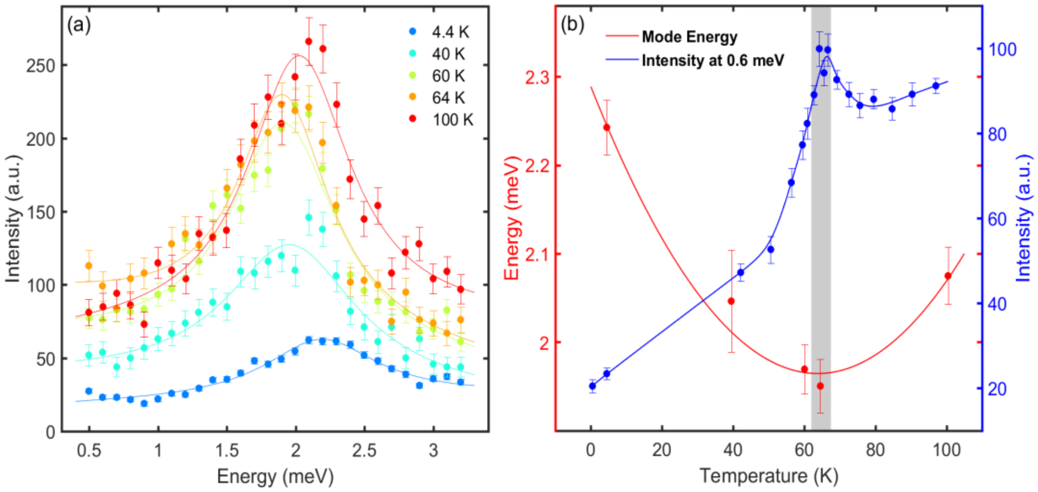


Figure 2. (a) Energy scans at CDW wave vector for different temperatures. The lines are fits to damped harmonic oscillator. (b) Kohn-anomalous phonon energy and critical scattering intensity as a function of temperature, through the CDW transition.

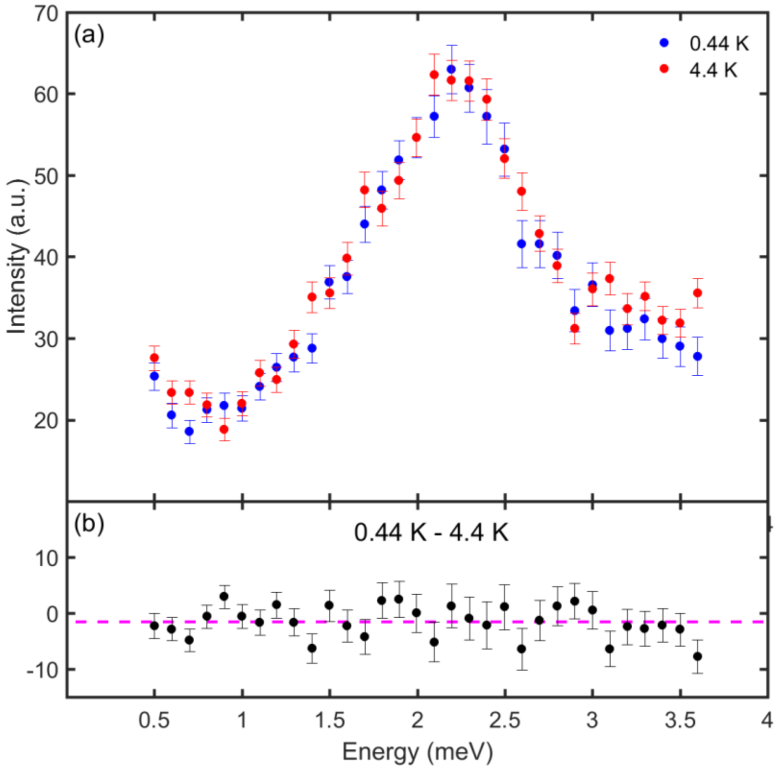


Figure 3. Lack of CDW amplitude mode spectral variation through Tc of superconductivity. The data constitutes the main (null) result of this experiment.

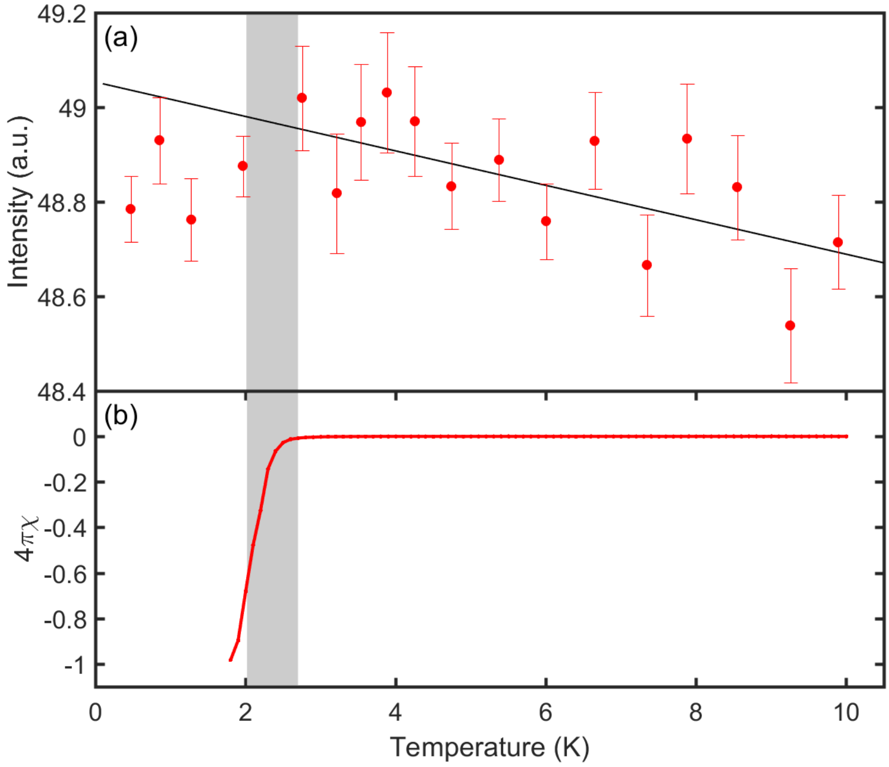


Figure 4. (a) CDW diffraction intensity versus T, through SC Tc. A tiny departure from the linear trend is observed below Tc determined from magnetometry in (b), indicating very weak competition between SC and CDW in our sample.