Experimental Report

15/07/2013

Proposal: **4-01-1248** **Council:** 10/2012

Title: The spin gap and normal-state spinfluctuations in Rb2Fe4Se5

This proposal is continuation of: 4-01-1158

Research Area: Physics

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Samples: Rb2Fe4Se5

Instrument	Req. Days	All. Days	From	To
IN14	7	7	20/02/2013	27/02/2013

Abstract:

Last year, we reported the observation of a spin resonance in the superconducting phase of Rb2Fe4Se5, which represents a recently discovered family of ferrochalcogenide superconductors with a Tc of 32 K. Despite the phase separation persistent in all such samples, we could disentangle the strong spin-wave intensity of the insulating majority phase from the weaker magnetic signal of the metallic/superconducting minority phase by subtracting the INS data measured above and below Tc. In a more recent experiment at IN8, we have also measured the spectra separately for the normal and superconducting states down to 6 meV, revealing for the first time the spin gap, which opens up below Tc due to the transfer of the low-energy spectral weight to the resonance energy. The normal-state response also showed an unexpected pseudogap-like anomaly that was not found in other Fe-based systems. Here we suggest to extend these measurements to lower energies using a cold-neutron spectrometer in order to verify if the sum rule holds for the transferred spectral weight across Tc, and to get more insight into the nature of the spin pseudogap and its characteristic temperature scale in the same sample.

Experimental report for proposal No. 4-01-1248

Introduction.

The recently discovered family of alkali iron selenide superconductors $A_xFe_{2-y}Se_2$ show a comparatively high superconducting (SC) transition temperature of $T_c = 31\,K$ on the one hand [1], and a strong antiferromagnetic order ($T_N > 500\,K$) on the other hand [2]. It was shown by multiple experimental probes that both ground states originate from chemically different, spatially separated phases. The former presumably has $A_{0.3}Fe_2Se_2$ stoichiometry [4], whereas the latter was found to have $A_2Fe_4Se_5$ stoichiometry, exhibiting an $\sqrt{5} \times \sqrt{5}$ iron vacancy superstructure [2]. This magnetic phase is insulating, whereas the SC/metallic phase shows a distinctly different Fermi surface compared to its 122 iron arsenide analogues, consisting mainly of large electron pockets at the M point [$\mathbf{Q} = (\pi, 0)$] [5].

The unconventional nature of superconductivity was recently revealed when observing spin fluctuations peaked at $\mathbf{Q}_{res} = (\pi, \pi/2)$ in the normal state, which get redistributed into a resonant mode excitation at $E = 14\,meV$ in the SC state [6]. However, these early studies only reported the change of spectral weight by showing the intensity difference between SC and normal state spectra. In order to determine the spectrum of absolute intensity in normal and SC state a more careful study was started, where systematic momentum scans through $\mathbf{Q}_{res}$ at several energies were performed [7]. When plotting the amplitude intensity *vs.* the energy a peculiar suppression of the low energy spectral weight in the normal state was revealed.

Therefore, in this beam time we aimed to extend the spectrum to even lower energies by means of a cold neutron spectrometer. The sample we used was the same as used in the In8 experiment [7], having a composition of $Rb_{0.8}Fe_{1.6}Se_2$. The scattering plane was chosen to be $(HK0)$, however, mounted with a pretilt which would allow to access also finite out-of-plane momentum L. The final wave vector was chosen to $k_f = 1.55\,\text{Å}^{-1}$ to maximize intensity. The sample environment comprised a standard orange cryostat.

Results of Experiment

Figure 1 shows momentum scans through the wave vector of the resonance $Q_{res} = (\frac{1}{2}\,\frac{1}{4})$ at different energies, each done in the SC as well as in the normal state. In the normal state all scans show a peak which vanishes in the SC state. This observation confirms that the there is an opening of a spin gap at energies below $E_S = 8$–10meV as already observed in the In8 beam time [7]. The peaks in the normal state peak were fitted with a Gaussian to extract the amplitude. The width was shared globally for all energies. The extracted amplitude vs. energy is show in Fig. 2 (a) showing a gradual decline towards zero energy. Thus, the presumed suppression of spectral weight at lower energies might be in reality more a subtle distribution of spectral weight in the normal state having a maximum around $E = 20\,meV$ and monotonically decreasing towards lower energies. This observation is quite unusual, since in the optimally doped iron pnictides the normal state spectral function is flat *vs.* energy [8].

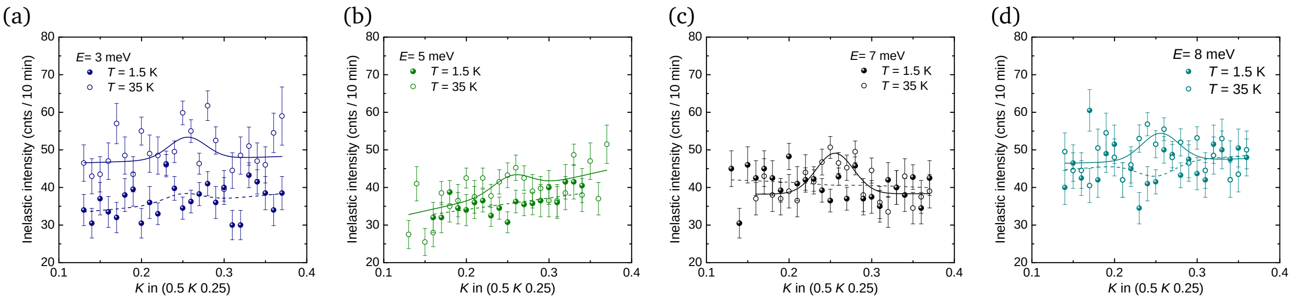

Fig. 1: (a)-(d) Momentum cuts through the wave vectors of the resonant mode at $Q_{res} = (\frac{1}{2}, \frac{1}{4})$ in the SC at $T = 1.5\,K$ and in the normal state $T = 35\,K$, at several energies. The lines are Gaussian fits to the momentum cuts.

Figure 2 (b) shows the difference of the momentum scans in the SC and in the normal state for each measured energy. By this we can exclude contributions from spurions and obtain the pure magnetic signal. Here again we observe a gradual decrease of the intensity upon decreasing the energy.

Another goal of the experiment was to measure the temperature dependence of the magnetic intensity in the spin gap region. We chose an energy of $E = 5\,meV$ and counted on the midpoint and on two points on the background for various temperatures, which lets us estimate the amplitude intensity in a less time consuming manner. The result is shown in Fig. 2 (c). The curve reveals a magnetic intensity, which has an onset of increase around $T = 60$–$70\,K$ and then a sharp decrease at T_c, in line with the opening of a spin gap. This behaviour is not consistent with the opening of a pseudogap in the normal state, but further conclusion have to await a more careful study to improve the statistical significance of the curve.

Summary

We successfully measured the low energy part of the spectrum at the resonance wave vector $\mathbf{Q}_{res} = (\pi, \pi/2)$ for the SC and the normal state. We confirmed the opening of a spin gap in the SC state. In the normal state the spectral weight seems to decrease towards lower energies contrary to the behaviour in the related FeAs-based compounds. A preliminary study of the temperature dependence for the magnetic intensity at $E = 5\,meV$ excludes the presence of a pseudogap opening in the normal state.

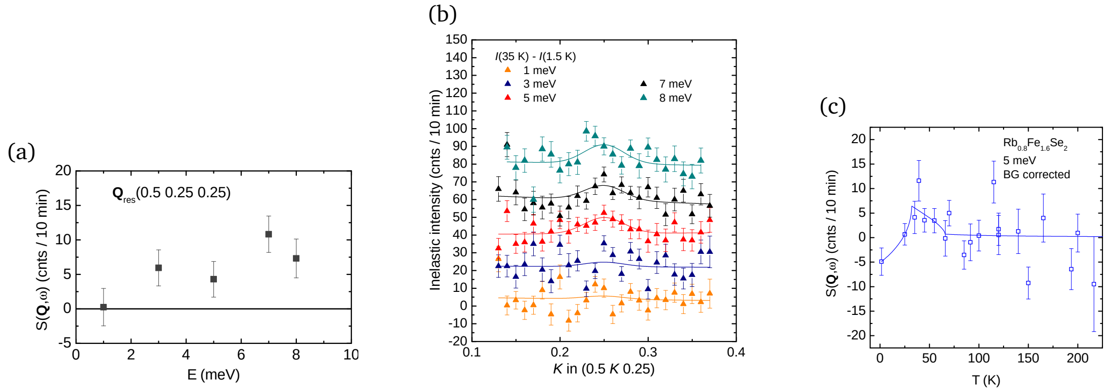

Fig. 2: **(a)** Amplitude of the momentum scans *vs.* energy for all measured scans. **(b)** Intensity difference between the momentum cuts done in the normal state and in the SC state for all measured energies. The scans are shifted by 20 counts for clarity. **(c)** Temperature dependence of the magnetic intensity at $E = 5\,\text{meV}$, determined via measuring 3 points on the momentum trajectory in Fig. 1 (midpoint + 2 background points).

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