Experimental report

29/09/2015

Proposal: 4-01-1355 **Council:** 4/2014

Title: Spin-space anisotropy and longitudinal mode in Co underdoped BaFe2As2

Research area: Physics

This proposal is a continuation of 4-01-1266

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Samples: Ba(Fe0.97Co0.03)2As2

Instrument	Requested days	Allocated days	From	To
IN20	7	7	10/10/2014	17/10/2014

Abstract:

We propose to study the spin-space anisotropy of magnetic excitations in weakly doped (3%Co) BaFe2As2 in order to search for the longitudinal magnetic excitations. This material should be best suited for this purpose as the energy scales are favorable compared to a pure compound and as the reduced ordered moment suggests stronger longitudinal excitations. In addition the obtained information will be most relevant for the understanding of the superconducting phase appearing at slightly larger doping.

Experimental Report: 4-01-1355
Spin-space anisotropy and longitudinal mode in Co underdoped BaFe2As2

In this experiment we aimed to measure the spin-space anisotropy and the longitudinal mode in 4.5% Co underdoped $BaFe_2As_2$ (Ba-122) by polarised inelastic neutron scattering (INS). In our previous polarised INS studies we already explored the spin-space anisotropy in the antiferromagnetic (AFM) non-superconducting parent-compound as well as in the superconducting (SC) non-AFM optimally Co-doped compound. In the parent-compound, where the magnetic moments order in the FeAs-planes, we measured the spin-gaps, two transversal and one longitudinal gap with respect to the ordering direction. Intriguingly we found that it is easier to rotate the spins out of the FeAs-plane than within [1]. The longitudinal gap was claimed in reference [2] to amount to 20meV; while a lower value can be ruled out the identification of the very weak signal detected in [2] with a longitudinal gap requires additional measurements.

In the 6% optimally Co-doped compound we observed two spin resonance modes [3]. Next to the well-known isotropic and broad in energy resonance mode at ~8meV we found a second mode at 4meV, which is sharp in energy and appears only in the c-polarised channel [3]. Note that the c-direction is perpendicular to the FeAs-plane, where the lowest spin-gap in pure Ba-122 was found.

With increasing Co-doping of Ba-122 the SC phase emerges, while the AFM phase is suppressed. Therefore, we expect that the AFM gap-values are decreasing with increasing Co-doping. Our 4.5% Co-doped Ba-122 displays three phase-transitions (PT), a structural at 65K, the AFM transition at 56K and SC below 11K. Thus we expect the spectrum of 4.5% Co-doped Ba-122 to display features we already observed in the pure as well as in the optimally doped compound. In order to investigate the spin-space anisotropy we performed longitudinal polarisation analysis (LPA) by using a Helmholtz-coil system and we obtained an overall flipping ratio of 13.5. The scattering geometry was chosen as [110]/[001] and is linked to our frame of reference for the LPA by setting the x-direction always parallel to **Q**. In this context the y-direction is also within the scattering plane but perpendicular to x, while the z-direction is perpendicular to x, y, and the scattering plane and thus always parallel to [1,-1,0].

Figure 1 displays energy scans in all three possible spin-flip (SF) and non-spin-flip

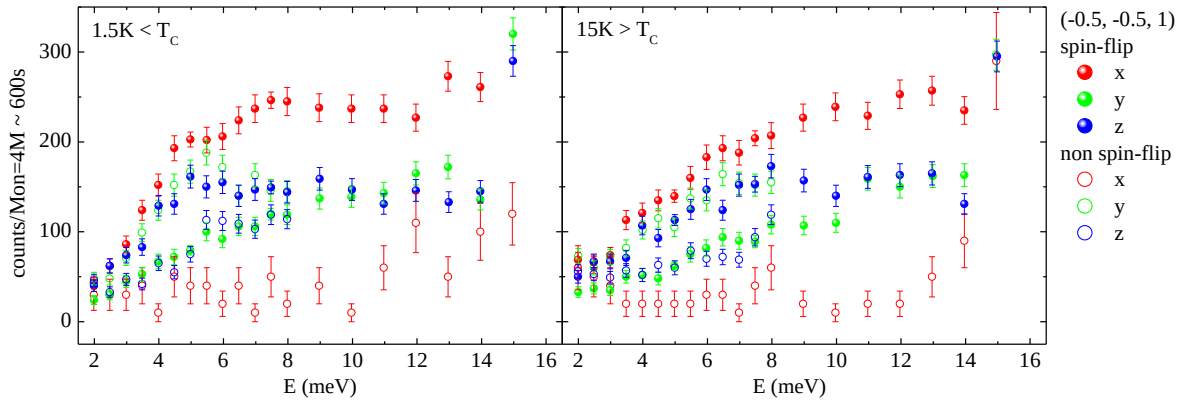

Figure 1: Energy scans at Q=(-0.5,-0.5,1) for all SF and NSF channels below T_c at 1.5K (left) and abode T_c at 15K (right). The low-energy mode at 4.5meV appears only in the c-polarised channel.

(NSF) channels at Q = (-0.5,-0.5,1) below (left) and above (right) T_c. The low-energy hump appears only in the c-polarised channel and is thus consistent with our results

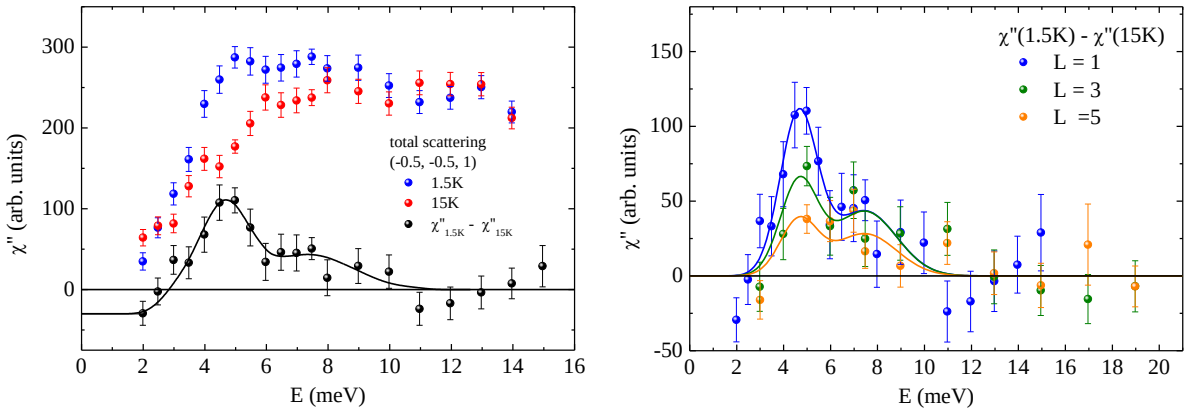

Figure 2: (left) Total scattering at (-0.5,-0.5,1) at 1.5K and at 15K. The difference displays two resonance modes at 4.5meV and at 7.5meV. (right) The same difference as in (left) but at different Q = (-0.5,-0.5,L) with L = 3 and 5. Lines are guides to the eye.

for the optimally doped compound. Moreover, we converted our scatting intensities to χ'', preliminary in arbitrary units, and averaged all SF channels to obtain the total scattering, which would also be seen in unpolarised INS. These data are in agreement with an earlier study [4] and show a resonance mode at 4.5meV, which dominates the spectrum. However, in contrast to the usual interpretation of an isotropic resonance excitation, we can clearly identify this dominating resonance feature in 4.5% Co-doped 122 to be anisotropic. In addition, we found an additional mode at 7.5meV, which was not seen in the earlier work, cf. figure 2 (left), this much weaker exicitation seems to relate to the isotropic resonance mode typically observed at optimum doping. An identical response is observed for L = 3 and 5, cf. figure 2 (right), however with a different weight between the two components. It is remarkably that the two resonance energies are almost coincident with the resonance energies observed in the optimal Co-doped compound, although the T_c of the latter is more than twice as the T_c in 4.5% Co-doped Ba-122. Figure 2 (right) shows that the intensity of the 4.5meV mode is strongly decreasing with increasing L-value. Therefore, we mapped out the L-dependence for all SF channels at 5meV in different phases, i.e. above the AFM PT at 58K, above the SC PT at 15K and in the SC phase at 1.5K. The results are summarised in figure 3 and show that the excitations above the AFM PT are isotropic and that the decrease of intensity with increasing L is described by the magnetic formfactor, solely. However, in the AFM phase these excitations become anisotropic and are fitted by the product of the magnetic formfactor and the geometry factor, which takes into account that only the magnetic response perpendicular to Q contributes. Entering the SC phase, i.e. the development of the spin resonance mode has no sizeable influence on the polarisation. Concluding the anisotropy is imposed by the AFM phase and thus underlines the importance of spin-orbit-coupling (SOC) in that compounds. Furthermore, the resulting spin-space anisotropy seems to be inherited by the resonance mode.

Finally we aimed to measure the longitudinal mode, which we expect to appear at a lower energy than in the parent-compound. Figure 4 gives the SFz channel at 15K and shows that for L=1 the intensity becomes constant at energy-transfers higher

than 10meV. Due to the fact that the response at Q = (-0.5,-0.5,1) is dominated by transversal excitations/fluctuations, we used that value as a reference and mapped it on the response at Q = (-0.5,-0.5,L) with L=3 and 5. In both cases, any intensity above that line can be attributed to the emerging longitudinal mode. Therefore we conclude that the intensity uptake for energy-transfers above ~11meV is due to the longitudinal mode, cf. shaded region in figure 4. Note that the gap of the longitudinal mode is considerably reduced from above 20meV in the parent compound to ~11meV in the 4.5% Co-doped Ba-122. Nevertheless the longitudinal fluctuations are gapped in 4.5% doped 122 which could be relevant for the understanding of the reduced superconducting transition temperature.

Concluding our experiment showed that the spin-space anisotropy in the SC phase is imposed by the AFM phase and thus highlights the importance of SOC. In addition we indicate that the longitudinal mode is considerable reduced in energy in 4.5% Co-doped Ba-122 in comparison to pure Ba-122.

[1] N. Qureshi *et al*., PRB 86, 060410 (2012) ; [2] C. Wang *et al*., PRX 3, 041036 (2013) ; [3] P. Steffens *et al*., PRL 110, 137001 (2013) [4] A. Christianson *et al*., PRL 103, 087002 (2009).

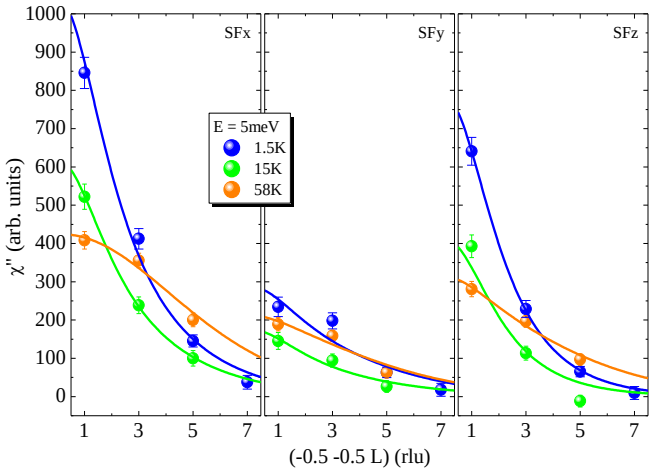

Figure 3: L-dependence of the three SF channels with 5meV energy-transfer above the AFM phase at 58K, below the AFM PT but above the SC PT at 15K and at 1.5K below both AFM and SC PTs. Above the AFM PT excitations/fluctuations are isotropic and can be described by the magnetic formfactor solely. In the AFM phase the response is c-polarised and is described by the product of the geometry and the magnetic formfactor.

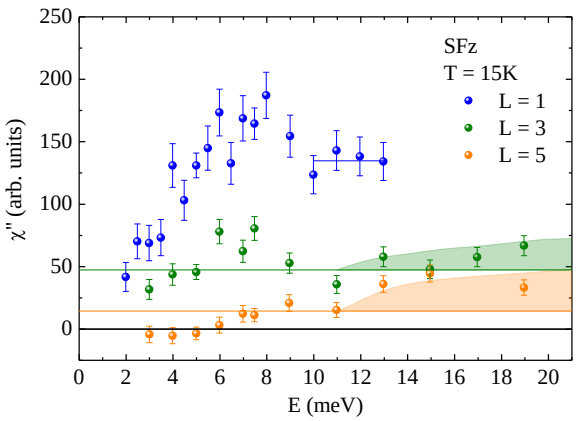

Figure 4: Energy scan in SFz channel at 15K at Q = (-0.5,-0.5,L) with L=1, 3, and 5. For L=1 the intensity above 10meV is constant and that value is used as a reference for transversal fluctuations. Mapping this reference value on L=3 and 5 indicate that for energy-transfers more than 11meV the additional intensity can be attributed to the longitudinal mode. The shaded region indicate the regime where the longitudinal mode emerges.