Experimental Report

14/01/2014

Proposal: **4-01-1266** **Council:** 10/2012

Title: Anisotropy of magnetic excitationsin pure and electron doped BaFe2As2

This proposal is continuation of: 4-01-996

Research Area: Physics

Main proposer: **BRADEN Markus**

Experimental Team: STEFFENS Paul
BRADEN Markus
LEE Chul-Ho
QURESHI Navid

Local Contact: STEFFENS Paul

Samples: BaFe2As2 with 0 ad 6% Co

Instrument	Req. Days	All. Days	From	To
IN20 CPA	9	9	26/07/2013	04/08/2013

Abstract:

Previous experiments have shown that pure antiferromagnetic and optimally Co-doped BaFe2As2 exhibit astonishingly similar anisotropy effects, in particular the out-of-plane spin gaps are below the in-plane ones in both cases. We want to extend the studies on pure and Co-doped BaFe2As2 in order to search for longitudinal excitations near the magnetic transition and in order to search for additional anisotropy in the superconducting state.

Experimental Report 4-01-1266

Anisotropy of magnetic excitations in pure and electron doped $BaFe_2As_2$

N. Qureshi, P. Steffens, C.H. Lee and M. Braden

The recent discovery of the iron based oxypnictide superconductors [1] has triggered an enormous research activity concerning the explanation of the superconducting pairing mechanism in these materials [2]. One of the most promising pair-forming candidates consists in the interaction with magnetic excitations, which are associated with the nesting causing the spin-density-wave phases of undoped parent compounds. Indeed unpolarized experiments show that very strong magnetic correlations persist in the superconducting range of the phase diagram and there is a resonance mode appearing upon cooling into the superconducting state [2]. In contrast to the large amount of unpolarized experiments, only a few polarized studies were performed on the FeAs-compounds. The spin-space anisotropy, however, is an intriguing question in these materials due to the multi-band character of the superconductivity with at least three orbitals being involved. Our first two experiments on pure and optimally Co-doped $BaFe_2As_2$ revealed sizeable and fully unexpected anisotropies both in the ordered state of the parent compound and in the resonance mode of the superconductor [3,4]. In the parent compound it costs more energy to rotate the spins within the FeAs-layers than rotating them out-of-plane [3] and the resonance mode in the superconducting state shows strong anisotropy as well with a sharp mode appearing only in a c-polarized channel. With the new experiment these results should be extended.

Using the same large crystal of 6% optimally Co-doped $BaFe_2As_2$ in the [110]/[001] orientation we first studied the dispersion of the additional sharp feature appearing below the isotropic resonance. The neutron energy was selected by a doubly focusing polarizing Heusler (111) monochromator and a similar Heusler crystal was used as analyzer. Ppolarization analysis was performed with a CRYOPAD. The reference frame is defined in a way that the x axis is parallel to the scattering vector Q, y is perpendicular to x (within the scattering plane) and z is perpendicular to x and y (perpendicular to the scattering plane).

We could follow the sharp additional mode as function of the q_l-value. There is no dispersion concerning the energy of this feature but the signal strength sharply peaks at the odd l-values, which resembles the ordered spin-density wave with the Bragg peaks appearing at odd l.

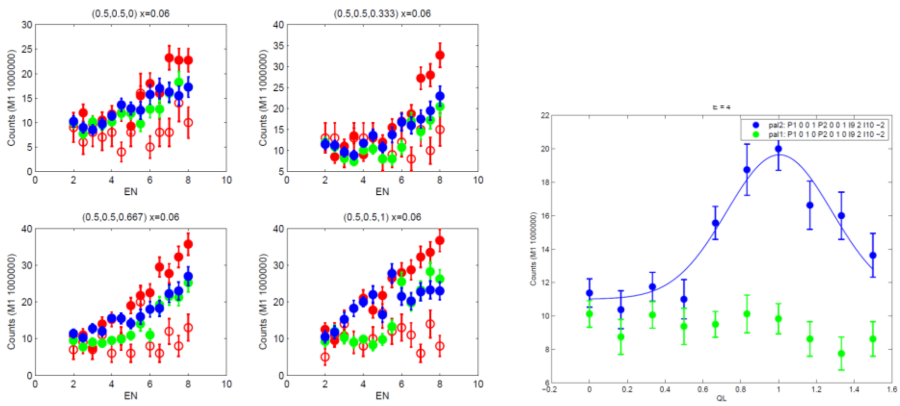
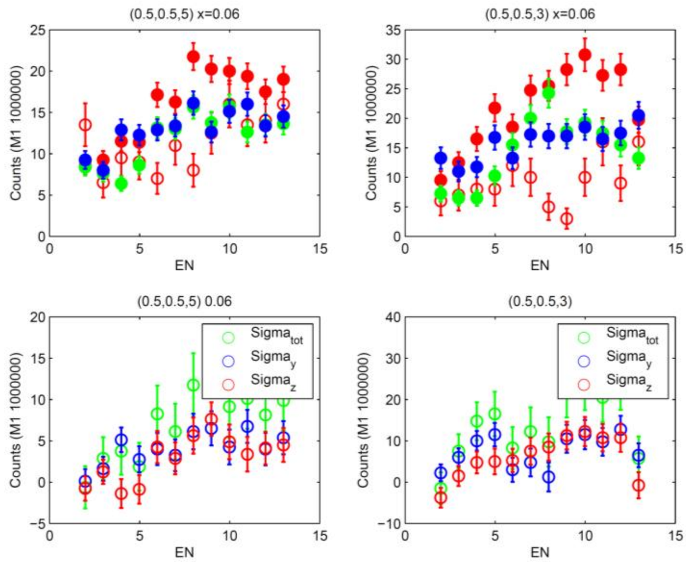


FIG. 1: Scans across the sharp additional mode for various l-values in 6% Co-doped $BaFe_2As_2$ (filled symbols denote different SF channels) and l-dependence of the signal strength.

In our first experiment we mainly studied Q-values with small l, which allowed to distinguish between the c-polarized and [1-10]-polarized contributions (when Q=(0.5,0.5,l)). In order to study the in-plane anisotropy which is directly related with the problem of nematicity, as this anisotropy breaks the tetragonal symmetry, one needs to analyze Q=(0.5,0.5,l) with large l-values, which, however, severely reduces the signal. Strong efforts have been made in this experiment to search for in-plane anisotropies of the magnetic response in the superconducting state and above.

Figure 2 shows scans taken at 2K with l=3 and 5 (various k_f!). Apparently there is no sizeable anisotropy in the high-energy response of the signal, but there is intensity at 4meV, i.e. just at the additional peak, also for l=5 where an c-polarized signal would be almost completely suppressed by the geometry factor. The additional sharp low-energy mode thus also appears in the [110] channel which one may consider in analogy with the pure materials as the longitudinal one. In the superconducting state there thus is a difference between [110] and [1-10] magnetic response; however, this anisotropy seems to be restricted to the low energies only. Another direct evidence for nematicity has been obtained by measuring the quasi-elastic (note the limited energy-resolution at IN20) as function of temperature, which is shown in figure 3. The scattering polarized in longitudinal direction is significantly enhanced just above the superconducting transition, while superconductivity suppresses this anisotropy suggesting a close connection. In spite of strong efforts we could not find clear evidence for in-plane anisotropies at energies above 5meV and temperatures above T_c.



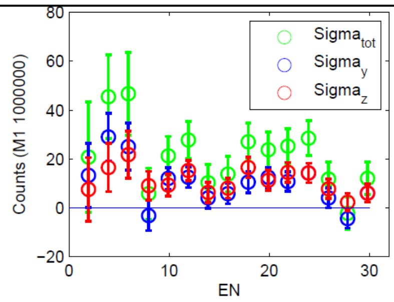


FIG. 2: (Left) Inelastic constant-**Q** scans at the magnetic Brillouin-zone centers (.5 .5 *l*) for l = 3 and 5 in the superconducting state at 2K. Sizeable spin-space anisotropy is only found at the Q,E position of the additional mode, which thus also exists in the [110] or longitudinal channel. Below: data taken at (.5 .5 5) with larger k_f.

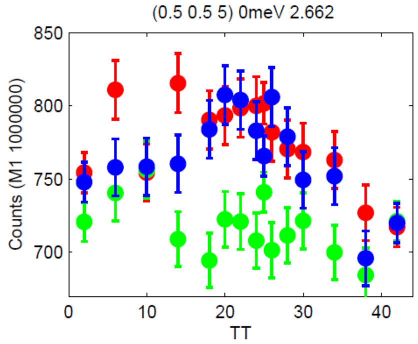


FIG. 3: Temperature dependence of the quasi-static magnetic signal; blue and green symbols denote the SF scattering in the y and z configuration. There is thus sizeable in-plane anisotropy (note the large l-value) just above T_c which gets suppressed in the superconducting phase.

In a brief second part of the experiment we analyzed a crystal with 3% Co which sits just below the onset of superconductivity. First we studied the anisotropy of the elastic or quasielastic response as function of temperature. Again we were able to document direct evidence for nematic ordering, as the in-plane anisotropy is visible well above the onset of the 3d magnetic ordering, but strong effects seem to disappear with the disappearance of the structural distortion.

We analyzed the (.5,.5,l) Q-values with l=1,3 (magnetic zone centers) and l=2,4 (zone boundaries with respect to the interlayercoupling), see Fig. 4. We may identify (supported by unpolaruzed studies on 2T) two anisotropy gaps at 7.5 and 12 meV which disperse to 12 and 17meV, respectively at the zone boundary. The comparison of the different channels at l=1 indicated that the lower intensity corresponds to the out-of-plane mode in perfect agreement with the pure compound. This 3% Co-doped crystal seems best suited to identify the longitudinal mode in the SDW phase.

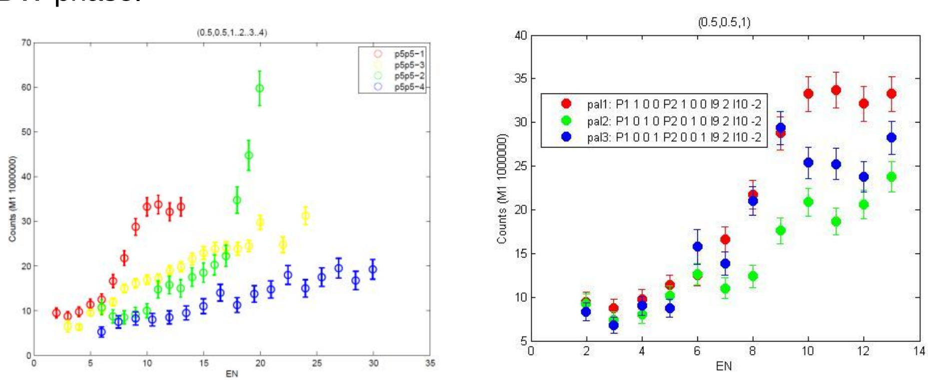


FIG. 4: Results obtained for a 3% Co-doped crystal. Left: SF-X scattering at (.5,.5,l) with l=1,3,2,4 across the spin-gap modes at the zone center (odd l) and across the zone-boundary modes (even l) associated with the inter-layer coupling. Right: Different SF channels at (.5,.5,1) which show that the lower gap mode is c-polarized.

[1] Y. Kamihara, T.Watanabe, M. Hirano and H. Hosono, J. Am. Chem. Soc., 130, 3296 (2008).
[2] P.Hirshfeld et al., Rep. Prog. Phys. 74, 124508 (2011).
[3] N. Qureshi et al., Phys. Rev. B, 060410(R) (2012).
[4] P. Steffens et al., Phys. Rev. Lett. 110, 137001 (2013).