Experimental report

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Council: 10/2016

Title: Triplett character of resonance modes in optimum-doped $BaFe_2As_2$

Research area: Physics

This proposal is a new proposal

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Samples: $Ba(Fe_{0.94}Co_{0.06})_2As_2$

Instrument	Requested days	Allocated days	From	To
IN20	7	7	22/05/2018	29/05/2018

Abstract:

Polarized neutron experiments show that the resonance modes in FeAs-based superconductors are more complex than the mostly accepted picture of a bound singlet-triplet exciton. In the superconducting state many FeAs-based superconductors show an anisotropic low-energy resonance and a broad, isotropic high-energy feature. Further experiments are required to determine the character of these resonance modes. Here we propose to use a half-polarized setup with horizontal magnetic field that may unambiguously identify a triplet mode.

Triplett character of resonance modes in optimum-doped BaFe2As2

4-02-497 IN20 from 22/05/2018 To 29/05/2018

The aim of the experiment was to study the triplett character of the resonance modes in optimum Co-doped $BaFe_2As_2$. The spin-resonance mode is mostly considered as a particle-hole excitation breaking a Cooper pair, and thus a singlet triplet excitation. While the magnetic field has no effect on the singlet ground state the excited state should split. Through inelastic neutron scattering this splitting can be directly detected, but from the three split levels only the upper and the lower ones are sensed and both will obtain a chiral character that is opposite to each other. Such split triplet excitations are well studied for the spin-ladder material $Sr_{14}Cu_{24}O_{41}$ [1] but very little is known for superconductors [2,3]. 6% Co-doped $BaFe_2As_2$ is ideally suited for such analysis, because large crystals exist and the spin-resonance modes are well characterized [4,5]. The spin-resonance modes in this material are further interesting, because there is a splitting in an anisotropic lower-energy mode with some three-dimensional character and a broader resonance at higher energies that is isotropic in spin space [4,5].

For the polarized neutron scattering experiment we coaligned three large crystals with a total mass of 4.7 g, as shown in the Fig. 1. The superconducting transition appears at T_C=24K. The same crystals were already used in our earlier neutron scattering experiments [4,5]. With the large sample volume the resonance modes could be studied with good statistics even under the difficult conditions of the experiment, see Fig. 2.

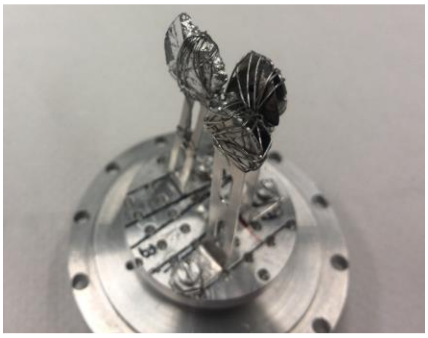

Fig. 1 Foto of the three coaligned three large crystals with a total mass of 4.7 g

In order to split the excited states we applied a horizontal magnetic field of up to 3.8T, which in principle still allows for neutron polarization analysis. We applied the field parallel to the scattering vector (0.5,0.5,l) with l=0,1,2 and we recorded the two neutron spin-flip processes, which sense the different chiral signals. The difference of the two scattering intensities directly evidences a chiral component. However the experiment turned out to be rather difficult. First it was necessary to recalibrate the spin-flipper for each configuration depending on the angle between the detector arm and the horizontal field. Therefore, it was necessary to drive each point in the energy scans individually. We only used neutron half-polarization in order to improve the intensity profiting from a Si monochromator. However, the recalibration had to be performed with full polarization analysis and the Heusler monochromator. In addition, it was necessary to very carefully drive the magnetic field, since the superconducting material does not allow one to vary the field in the superconducting state. We applied the magnetic field in the normal state and then cooled into the superconducting state without any further variation of the field strength or direction. Note that in a strong type II superconductor magnetic field penetrate quite homogeneously.

The zero-field (actually a small field of 0.4 T was needed to generate a sufficiently strong neutron guide field) measurement at (0.5,0.5,1) is shown in Fig. 2 (left); it perfectly agrees with previous experiments on this material [4,5] and clearly shows the split resonance mode with a low-energy anisotropic mode. There is no evidence for a splitting in the two chiral channels (or in the two SF channels) at this low magnetic field. Also the measurement in the normal state at high field does not show any indication for a chiral component. These two experiments clearly document that there are no artefacts generating chiral components in our experimental set up.

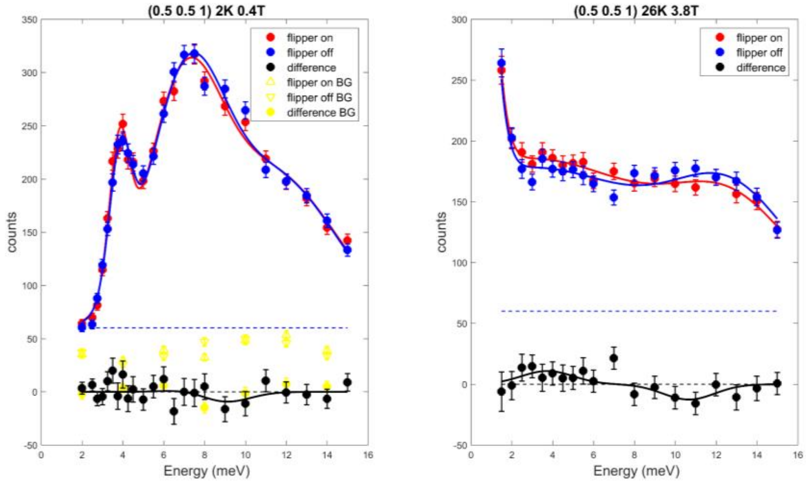

Fig. 2: Energy scans at the (0.5 0.5 1) scattering vector corresponding to the AFM zone center. In the superconducting state at 0.4T one clearly sees the two spin-resonance modes, but there is no evidence for any chiral contribution. Also above the SC phase at high field we do not any indication of chirality.

In contrast we find a clear chiral signature in the high-field experiments at (0.5,0.5,1) and (0.5,0.5,0), i.e. the AFM zone centre and zone boundary in c-direction, see Fig. 3. The high-energy spin resonance mode is visible at both odd and even l values in accordance with the unpolarised experiments. There is a clear splitting in the two SF channels for the high-energy mode. Considering that the entire signal becomes split and chiral, one can describe the results by a splitting of the low-field signal by about 0.4meV. Thus there is no net chiral signal stemming from the high energy mode.

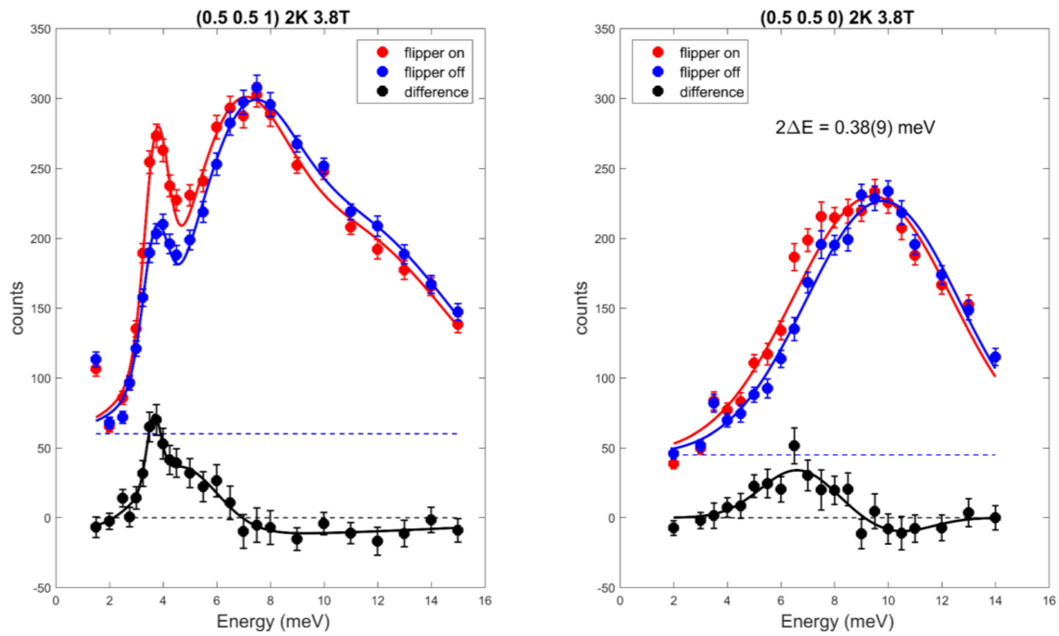

Fig. 3: (Left) Energy scans at the (0.5 0.5 1) scattering vector corresponding to the AFM zone centre. In the superconducting state at 3.8T one clearly sees the two split chiral contributions, and the large difference in the channels (black curve). The upper spin-resonance mode exhibits almost the expected behaviour, but the lower mode does not split but exhibits an intrinsic chirality. (Right) The results at the even l-point also show the chiral splitting similar to that seen for the high-energy mode at the odd l-value but no signature of the low-energy mode.

The low-energy mode near 3.7meV exhibits a different but exciting behaviour. There is no splitting of the peak position visible in the two SF channels, which contradicts the expected Zeeman splitting of a triplet mode. Instead the intensities of the two channels becomes different. This points to an intrinsic chiral character of this mode, which gets poled by the application of the magnetic field. This reminds one the behaviour of multiferroic materials, in which one can pole magnetic excitations through an electric field [7]. For superconducting $BaFe_2As_2$ this implies that a magnetic field directly couples to the superconducting state, which is not compatible with a simple singlet superconducting symmetry. Chiral correlations appearing upon the suppression of the long-range AFM order were already intensively discussed in the frame of the cuprates [6]. We want to emphasize that the low-energy spin-resonance mode emerges at the superconducting transition and cannot be considered as a simple excitation of some short range AFM regions, it is unambiguously connected to the superconducting state.

[1] J.E. Lorenzo et al., PRB 83, 140413(R) (2011) **[2]** L.P. Regnault et al., talk at PNCMI2010 Delft http://pncmi2010.tudelft.nl/presentations/Regnault.pdf **[3]** S. Raymond et al., PRL 109, 237210 (2012). **[4]** P. Steffens et al., PRL 110, 137001 (2013) **[5]** F. Wasser et al., Sci. Rep. **7**, 10307 (2017) **[6]** X. G. Wen, Frank Wilczek, and A. Zee, Phys. Rev. B 39 11413 (1989) (Note, this work is more than 1000 times cited). **[7]** J. Stein et al., Phys. Rev. Lett. 119, 177201 (2017).