Experimental report

26/03/2019

Proposal: **INTER-436** **Council:** 4/2018

Title: Longitudinal polarisation analysisin the conical, skyrmion and fieldpolarised phase of MnSi

Research area:

This proposal is a new proposal

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Experimental team: Tobias WEBER

Local contacts: Paul STEFFENS

Samples: MnSi

Instrument	Requested days	Allocated days	From	To
THALES	4	4	21/09/2018	25/09/2018

Abstract:

ILL report INTER-436: Longitudinal polarisation analysis in the conical, skyrmion and field-polarised phase of MnSi

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Using a weekend of internal beamtime at the cold-neutron triple-axis spectrometer Thales, we continued to investigate the separation of the non-reciprocal skyrmion dynamics in MnSi into spin-flip and non-spin-flip channels and could for the first time resolve the high-energy branches. This internal experiment and our previous one (see our report 79803 for our first two-day test INTER-413) serve as a preparation for our proposed ILL experiment and give a foundation for measuring all the symmetry positions in the various ordered phases of MnSi in the future.

I. BACKGROUND

The itinerant magnet MnSi features a skyrmion order [1] for temperatures in the range $T \approx 28 - 29\,\mathrm{K}$ and for magnetic fields $B \approx 0.16 - 0.21\,\mathrm{T}$. Furthermore, the non-centrosymmetric $\mathrm{P2_13}$ space group of MnSi has profound consequences for spin-wave dynamics in all ordered magnetic phases of MnSi. Namely, it introduces a Dzyaloshinskii-Moriya term which – at reduced momentum transfers parallel to the external magnetic field direction – causes magnons to be either created at different (absolute) energies than they are annihilated or leads to different spectral weights for magnon creation compared to annihilation. The dynamical magnetic structure factor $S(\boldsymbol{q}, E, \boldsymbol{B})$ with $\boldsymbol{q} = \boldsymbol{Q} - \boldsymbol{G}$ is thus asymmetric ("non-reciprocal") with respect to changing the sign of either the reduced momentum transfer $q_{\parallel}$, the energy transfer E, or the magnetic field B, but is symmetric upon interchanging the signs of two dependent variables [2]. Here, $q_{\parallel}$ refers to the component of the reduced momentum transfer along the direction of the external magnetic field $\boldsymbol{B}$. Such an asymmetric behaviour could be observed for the field-polarised [3, 4], the paramagnetic [5], the conical [6], and the skyrmion [2] phase of MnSi.

II. EXPERIMENT

We continued our initial investigation into the separation into spin-flip and non-spin-flip channels of the non-reciprocal magnons in the skyrmion phase of MnSi using the instrument Thales [7]. The measurements were performed in the $hk0$ scattering plane around the nuclear $\boldsymbol{G} = (110)$ reflection with the magnetic field oriented along [110]. In this configuration, the skyrmion plane is spanned by the $[1\bar{1}0]$ and [001] reciprocal vectors and the hexagonal skyrmion lattice pins along [001].

Our main results are depicted in Figure 1. The left-hand panel shows the theoretical dispersion branches for reduced momenta $q_{\parallel}$ transferred parallel to the [110] field direction, the lines are colour-coded based on polarisation-dependence. Our collected data confirms the existence of a strong and a weak low-energy dispersion branch in the SF+- spin-flip channel (blue), marked (1) and (2), respectively. High-energy branches labelled (3) and (4) can be observed in the SF-+ channel (red). The high-energy branches appear to be slightly shifted from their predicted energy. The most likely reason is the instrumental resolution function picking up additional signals along the $q_{\perp}$ and q_{up} directions of the complicated four-dimensional structure factor $S(\boldsymbol{q}, E)$ for skyrmion dynamics.

III. CONCLUSION

Preparing for our proposed experiments, we have set the stage for performing polarised measurements for resolving the magnon dynamics in the skyrmion phase of MnSi. Systematic measurements of the other positions of high symmetry in the hexagonal magnetic Brillouin zone of the skyrmion phase as well as of the other magnetic phases of MnSi (helimagnetic, conical, field-polarised, fluctuation-disordered, and paramagnetic) will be performed as next steps. In our future beamtimes, we will furthermore resolve the polarisation dependence for the $\boldsymbol{q}$ directions which yield symmetric and/or quasi-continuous dispersion relations, some of which have also proved to be difficult in past unpolarised experiments [8]. Moreover, a full four-dimensional resolution-convolution data analysis [9] of the measured spectra is currently in progress, preliminary results are depicted in Fig. 2.

ACKNOWLEDGEMENT

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Data DOIs: 10.5291/ILL-DATA.INTER-436 (present test beamtime) and 10.5291/ILL-DATA.INTER-413

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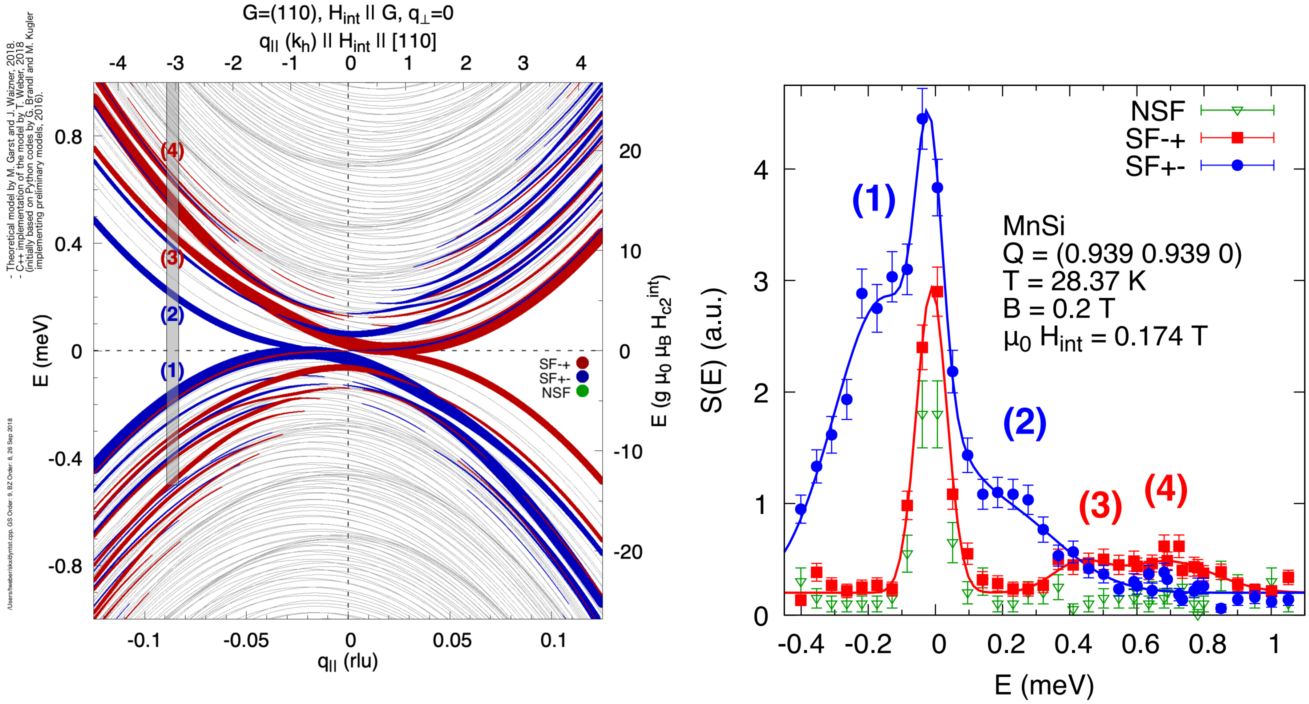

Figure 1. Left: The theoretical model by M. Garst and J. Waizner shows the non-reciprocal magnon dispersion in the skyrmion phase. The different polarisation channels are shown as red and blue lines, respectively, with the line width depicting the spectral weights. Only the SF-+ and SF+- spin-flip channels possess spectral weight, but not the non-spin-flip channel. The actual dispersion is entirely given by the spectral weights as the allowed energies (shown as fine points) form a quasi-continuum. Right: Experimental results collected at the position in reciprocal space indicated by the vertical black line in the left panel. The two spin-flip channels are shown as red and blue points. The solid lines are Gaussian fits and serve as guides to the eye. For the second test experiment, the magnet was rotated by 180 degrees compared to the first test: all labels have been corrected accordingly.

(previous test beamtime). Source repository (ILL-internal): https://code.ill.fr/tweber/skx.

[1] S. Mühlbauer, B. Binz, F. Jonietz, C. Pfleiderer, A. Rosch, A. Neubauer, R. Georgii, and P. Böni. Skyrmion Lattice in a Chiral Magnet. *Science*, 323(5916):915–919, 2009. ISSN 0036-8075. doi:10.1126/science.1166767. URL http://science.sciencemag.org/content/323/5916/915.

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[8] Note1. Past experiments at small $q_\perp < 2.5 k_h$ and with

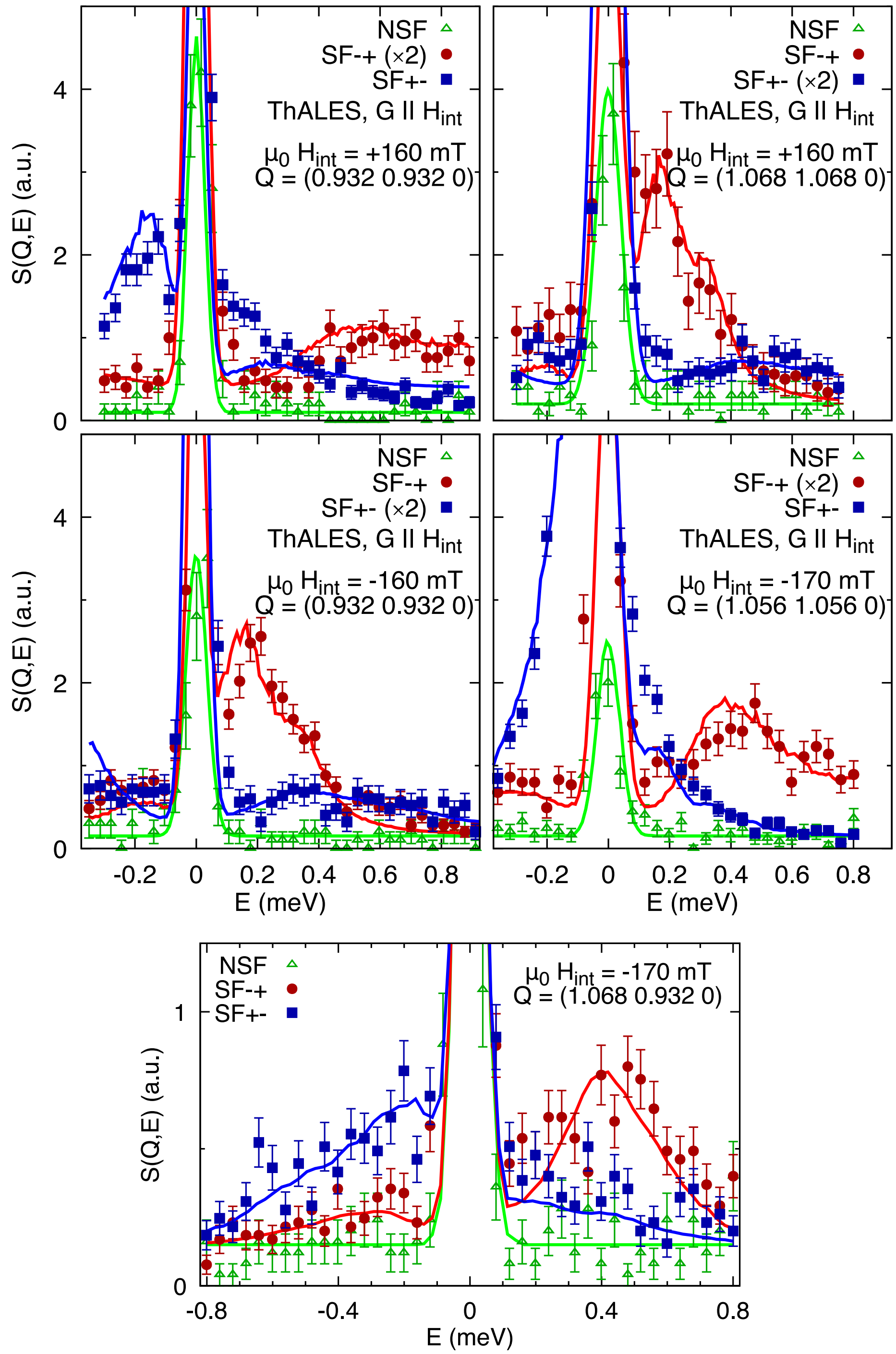

Figure 2. Preliminary four-dimensional instrumental resolution convolution simulations of the theoretical model as given in Fig. 1 (lines) compared to our main datasets (points). So far, the convolutions have no absolute intensity (i.e. $S(Q, E)$) scale and the theory's energy scale needs a correction deduced from a limiting case of the non-reciprocal helimagnon results [6]. As can be judged from preliminary scans (not shown), the theory begins to slowly deviate from the experimental results for increasing values of $|q|$. This possible discrepancy will be resolved in our proposed future beamtimes. The $S(Q, E)$ axes of the datasets marked with "x2" have been scaled by a factor of two for better visibility.

vertical field were riddled with spurions, namely Bragg tails emanating from the nuclear elastic peak and its six magnetic satellites. See e.g. report 67728 for experiment INTER-286, note that their results were not yet identified as spurious at the time.

[9] Note2. Using the software Takin: https://github.com/t-weber/takin.