Experimental report

07/09/2018

Proposal: **4-03-1730** **Council:** 4/2018

Title: Control of chiral magnetism through E fields in multiferroic TbMnO3 above the long-range multiferroic transition

Research area: Physics

This proposal is a new proposal

Main proposer: **Sebastian BIESENKAMP**

Experimental team: Sebastian BIESENKAMP

Local contacts: Paul STEFFENS

Samples: TbMnO3

Instrument	Requested days	Allocated days	From	To
THALES	6	6	05/06/2018	11/06/2018

Abstract:

Controlling of magnetism through electric fields is the long-term application goal in multiferroics. Recently we could demonstrate by polarized neutron scattering that it is possible to control and pole chiral magnetic correlations even above the long-range multiferroic ordering. Here we wish to further analyse this chiral scattering in particular its relation with the softening of electromagnon excitations at the multiferroic transition. Therefore, we wish to study the energy
dependence of this scattering on THALES.

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Recently, it had been reported that poled chiral magnetism persists and can be controlled even above the long-range ordered multiferroic phase in $TbMnO_3$ [1]. It has been proposed that this chiral signal above T_{MF} corresponds to a softening and damping of a magnetic excitation, which possesses an electromagnon character. In order to further study this dynamical poling above the multiferroic phase transition, 6 days of beamtime have been allocated on the triple-axis spectrometer THALES. The main goal was to record the chiral signal, while executing energy scans across the elastic line at the incommensurate magnetic zone center for different electric field polarities. It was expected that these data sets validate the presence of chiral quasistatic fluctuations and their controllability by applied electric-fields above the multiferroic phase transition.
For these measurements, a large single crystal of $TbMnO_3$ has been positioned between two aluminum capacitor plates in order to apply high electric field to the material. The sample thickness amounts approximately $d \approx 15\,\mathrm{mm}$ and it has been attached to the instrument in the $(0\ -1\ 0)/(\ -2\ 0\ 1)$ scattering plane. The instrument has been operated in the full-polarized mode and a helmholtz-coil setup was deployed for the longitudinal polarization analysis. By measuring both spin-flip channels $I_{x\bar{x}}$ and $I_{\bar{x}x}$ one gets access to the chiral ratio r_{chir}.

$$r_{\mathrm{chir}} = \frac{I_{x\bar{x}} - I_{\bar{x}x}}{I_{x\bar{x}} + I_{\bar{x}x}} = \frac{-i\,(\mathbf{M}_\perp \times \mathbf{M}_\perp^*)_x}{|\mathbf{M}_\perp|^2} \tag{1.1}$$

It has to be noted that in this case, a right handed coordinate system with $x|| - \mathbf{Q}$ has been assumed.

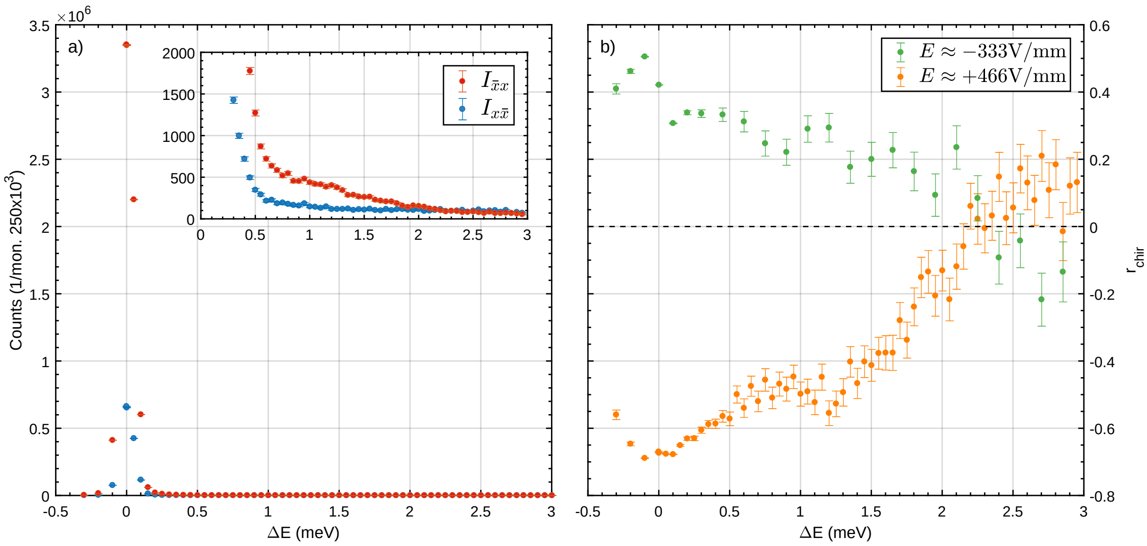

Figure 1.1: Poled chirality of the phason mode
The corresponding energy scans at $T = 25\,\mathrm{K}$ have been carried out at the magnetic incommensurate zone center position $\mathbf{Q} = (2\ -0.28\ 1)$ for opposite electric-field amplitudes. Figure a) displays exemplary the intensity data of both spin-flip-channels that has been recorded, while applying an electric field of $E \approx 466\,\mathrm{V\,mm^{-1}}$ and b) shows the evaluated chiral ratio for both applied field polarities.

Earlier measurements on the phason mode inside the multiferroic phase revealed its intrinsic chirality, whose signal is considerably broadened [2]. So far, it has not been well documented, whether the chirality of this phason mode can also be reversed by inverting the electric field polarity. Hence, during the first part of the experimental course, some energy scans inside the multiferroic phase have been carried out along the $[2\,K\,1]$ direction. The corresponding data is displayed in figure 1.1 and from both plots, it can be stated that a reversed electric field polarity, clearly inverts the inelastic chiral signal. Even a sign change of the chirality at higher energy has been documented and is in good agreement with reported measurements and predictions concerning a back-folding of the phason mode of the neighboring Brillouin zone [2].
The main part of the allocated beamtime was then needed to measure the energy dependence of the chiral signal $I_{x\bar{x}} - I_{\bar{x}x}$ above the multiferroic phase transition. For these measurements, both field polarities have been applied to the sample and the corresponding results are plotted in figure 1.2. It can be seen that a finite chiral signal still persists up to $\Delta E \approx 2\,\mathrm{meV}$ at $T = 27.92\,\mathrm{K}$. As this temperature is very close to the multiferroic phase, it had to be checked, whether the temperature readout displays precisely the correct temperature. In order to sense, whether the sample temperature is still above the multiferroic phase transition, we recorded the temperature dependence of the $I_{y\bar{y}}$ channel, which senses an occurring c-component of the magnetic moment and hence the evolving spin cycloidal below the multiferroic phase transition. From this data set, it was possible to extract the instrument's sensor value for the transition temperature and during subsequent measurements it was feasible to monitor the closeness to the phase transition. The transition has been determined to occur for this sample at $T = 27.8\,\mathrm{K}$.

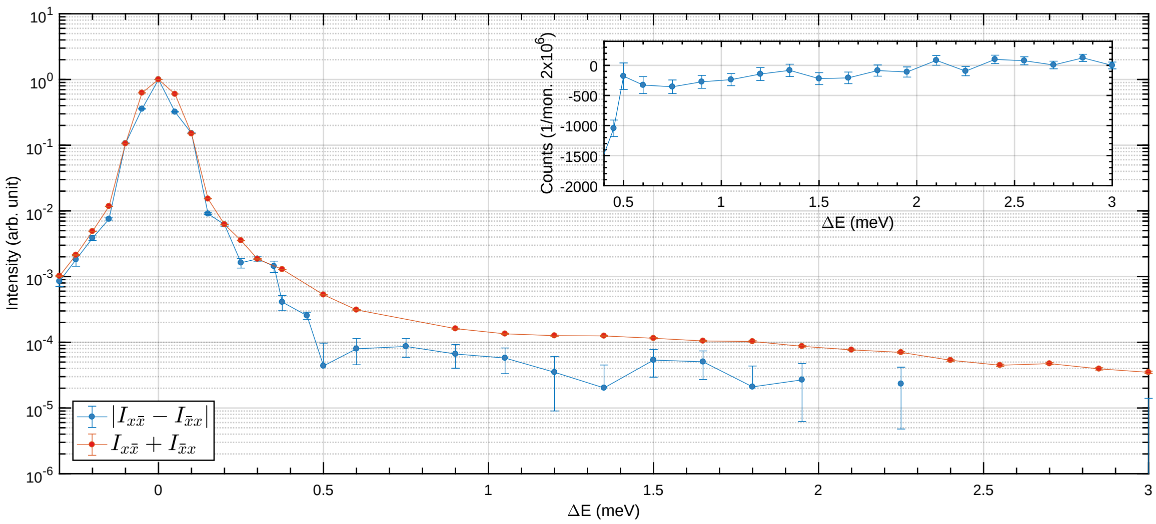

Figure 1.2: Energy scans above the multiferroic phase
This plot shows an energy scan at $T = 27.92\,\mathrm{K}$ for an electric field amplitude of $E \approx 666\,\mathrm{V\,mm^{-1}}$. As for this electric-field polarity the chiral signal is negative, the data in the large figure has been multiplied by -1 in order to scale it logarithmically. The inset displays a zoom of the chiral signal and it can be clearly seen that a chiral signal persists for finite energies up to $\Delta E \approx 2\,\mathrm{meV}$. The referring scan has been carried out at the magnetic incommensurate zone center position $\mathbf{Q} = (2\ {-0.28}\ 1)$.

Both field polarities have been applied to the sample and the evaluated chiral ratio is plotted figure 1.3 together with a zero-field measurement. With both plots 1.3 a) and b), it is well documented that chiral fluctuations can be poled and controlled by applied electric-fields above the multiferroic phase transition.

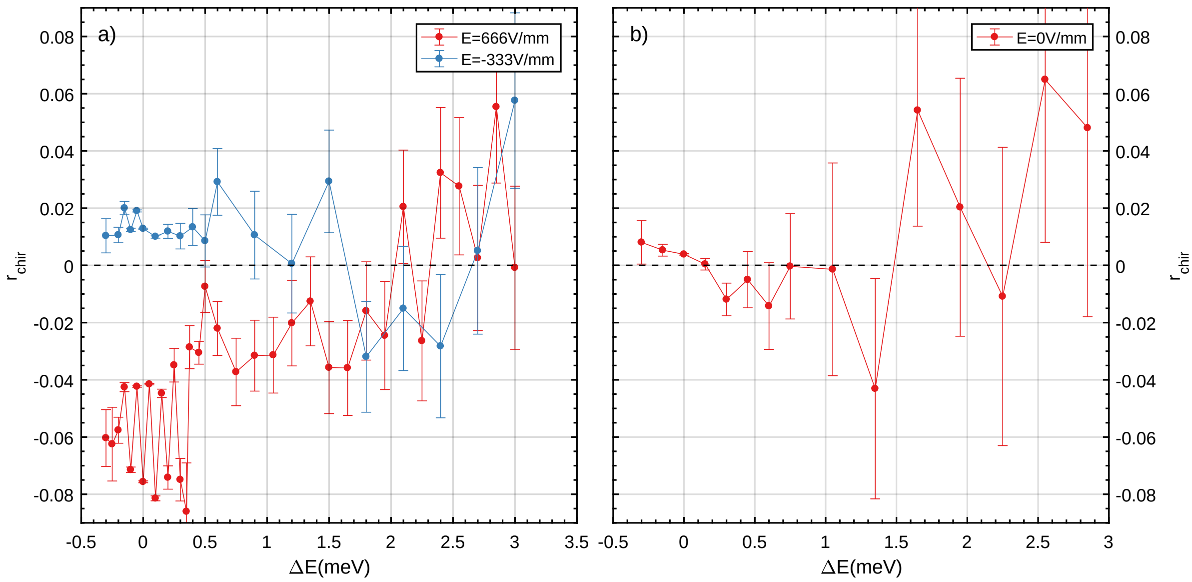

Figure 1.3: Chiral fluctuations above the multiferroic phase transition
Both plots display the evaluated chiral ratio for energy scans at the magnetic incommensurate zone center position $\mathbf{Q} = (2\ {-0.28}\ 1)$ for different field polarities at $T = 27.92\,\mathrm{K}$.

We would like to acknowledge for the allocation of this successful beamtime. In addition we would to thank our local contact Paul Steffen and also the technicians on-site for the excellent support. All in all we were able to further manifest the proposed presence of short-range chiral correlations above the multiferroic phase transitions in $TbMnO_3$ [1].

References

[1] J. Stein, et al. *Phys. Rev. Lett.*, 119:177201, Oct 2017. doi:10.1103/PhysRevLett.119.177201.
[2] S. Holbein. *Dissertation*, 2016.