EUROPEAN SYNCHROTRON RADIATION FACILITY

INSTALLATION EUROPEENNE DE RAYONNEMENT SYNCHROTRON

Experiment Report Form

The double page inside this form is to be filled in by all users or groups of users who have had access to beam time for measurements at the ESRF.

Once completed, the report should be submitted electronically to the User Office via the User Portal: *https://wwws.esrf.fr/misapps/SMISWebClient/protected/welcome.do*

Deadlines for submission of Experimental Reports

Experimental reports must be submitted within the period of 3 months after the end of the experiment.

Experiment Report supporting a new proposal ("relevant report")

If you are submitting a proposal for a new project, or to continue a project for which you have previously been allocated beam time, you must submit a report on each of your previous measurement(s):

- even on those carried out close to the proposal submission deadline (it can be a *"preliminary report"),*
- even for experiments whose scientific area is different form the scientific area of the new proposal,
- carried out on CRG beamlines.

You must then register the report(s) as "relevant report(s)" in the new application form for beam time.

Deadlines for submitting a report supporting a new proposal

- 1st March Proposal Round - **5th March**
- 10th September Proposal Round - **13th September**

The Review Committees reserve the right to reject new proposals from groups who have not reported on the use of beam time allocated previously.

Reports on experiments relating to long term projects

Proposers awarded beam time for a long term project are required to submit an interim report at the end of each year, irrespective of the number of shifts of beam time they have used.

Published papers

All users must give proper credit to ESRF staff members and proper mention to ESRF facilities which were essential for the results described in any ensuing publication. Further, they are obliged to send to the Joint ESRF/ ILL library the complete reference and the abstract of all papers appearing in print, and resulting from the use of the ESRF.

Should you wish to make more general comments on the experiment, please note them on the User Evaluation Form, and send both the Report and the Evaluation Form to the User Office.

Instructions for preparing your Report

- fill in a separate form for each project or series of measurements.
- type your report in English.
- include the experiment number to which the report refers.
- make sure that the text, tables and figures fit into the space available.
- if your work is published or is in press, you may prefer to paste in the abstract, and add full reference details. If the abstract is in a language other than English, please include an English translation.

ESRF	Experiment title: Hard X-ray Bragg Magnetic Ptychography Imaging of Magnetic Insulators: Exploiting the High EBS Coherence to Enable a New Regime in Nanomagnetic Materials Physics	**Experiment number**: HC4336
Beamline:	**Date of experiment**: from: 16/06/2021 to: 20/06/2021	**Date of report**: 13/09/2021
Shifts:	**Local contact(s)**:Steve Leak & Tobias Schulli.	*Received at ESRF:*

Names and affiliations of applicants (* indicates experimentalists):

Danny Mannix, European Spallation Source Lund, Sweden.

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Report:

Main results: acquisition of low temperature (T-10K) Resonant X-ray scattering (XRS) ptychographic data set in Bragg geometry, for different polarization states. The data set is of good quality to be inverted by the ptychographic algorithm. A preliminary analysis of the data set shows that the magnetic signal is visible.

(1) Objectives: The aim of experiment HC4336 was exploit the new science opportunities opened up by the initiation of the EBS to develop new 3D Bragg ptychography methods on ID01 to reveal high resolution images of the spin textures formed in technologically relavent spin-coloritronics magnetic materials. The proposal builds on our previous scanning nanobeam magnetic diffraction studies [1] highlighted by ESRF, with the potential to extend Bragg ptychographic imaging to an entirely new user community.

(2) Challenges: In addition to exploiting the high coherent flux of the ESRF EBS source the experiment set-up presented many challenges that required attention during the experiment:

(a) A Diamond Phase Plate was required to be set-up to generate both circular and linear incident polarisations onto the sample. We lost 1-2 days of measurement time due to problems with the new ID01 dedicated phase plate set-up. In the end we had to replace this with an older phase plate system borrowed from the XMaS beamline. Its performance was tested and validated. This was vital to the success of our experiment.

(b) A low vibration He flow Cryostat was also required for our experiment as we were working at 10K. We found that even the very low vibrations was affecting with quality of our data, washing out the speckles obtained. Some times was taken to optimise these conditions with damping the vacuum lines to the pump.

(c) Scanning of the Fresnel Zone Plate was required for the ptychography data because the use of the cryostat the usual scanning of sample was not possible. Our normal ptychography alogrithms needed to be modified for scanning the beam rather than the sample. This new scheme was tested and validated

(3) Results:

Despite the challenges, we magnaged to achieve significant success from the beamtime. Using the scanning diffraction intensities for the different polarisations, magnetic information can be isolated from the circular and pi-incident flipping ratios [1] as shown in figure 1a&b below. The results confirm that we have magnetic information in the coherent diffraction intensities. In our previous experiment on ID01 [1] we obtained a beam size resolution of about 500nm. The beam size in our last experiment using the EBS was around 100nm and is fixed by working distance of the FZP to the sample, which is limited by the cryostat. Therefore, ptychography approaches are essential in pushing down the resolution of the experiment

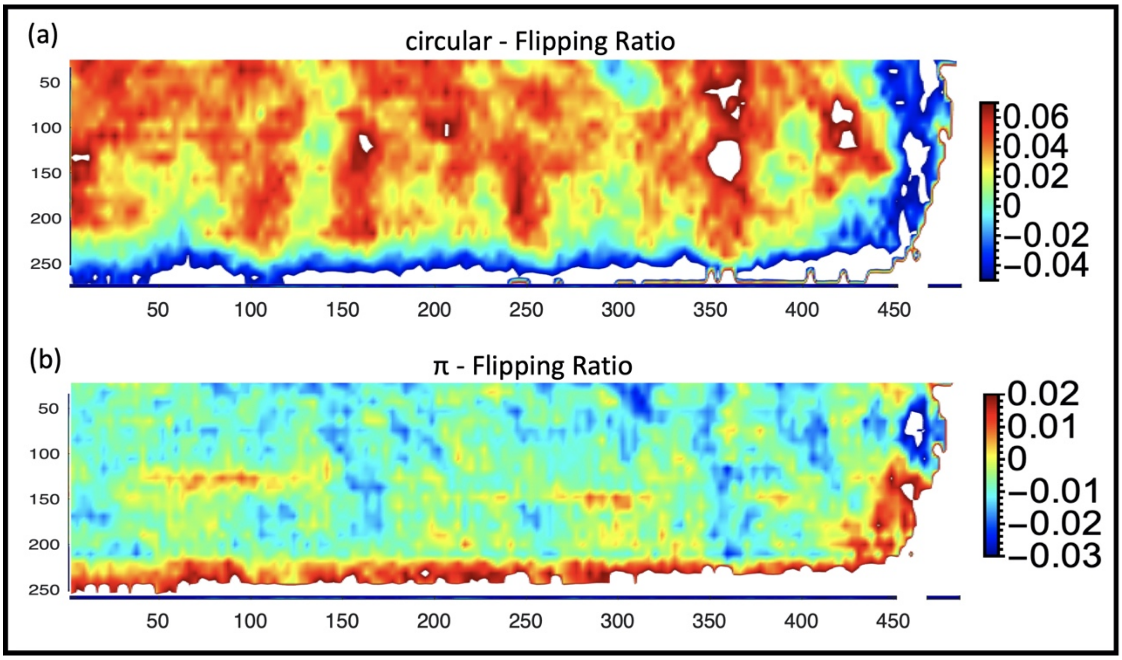

Figure 1. The magnetic domain texture as resolved from the flipping ratios of the scanning diffraction maps defined in [1]. This analyis confirms that the magnetic information is in the coherent diffraction instensties.

(4) Ptychography Analysis

The experiment was undertaken in June (significantly delayed due to Covid-19 restrictions) and just before summer vacations, which has not allowed significant time to make a thourough analysis of the experimental results. Ptychography reconstructions (amplitude and phase) of the four independent data sets, obtained at circular-left, linear-π, circular-right and linear-σ beam polarization states are shown in figure 2. These four independent data sets lead to reconstructions presenting strong structural likelihood, particularly visible in the phase maps, which contain both crystalline (charge) and magnetic (spin) information. This confirms the quality of the ptychography scan obtained with cryostat and phase plate and new possibilities for the EBS. The pixel size of the reconstruction is 14 nm, while the beam footprint is 140 x 120 nm^2. Further details of the ptychography reconstructions are shown in figure 3, which compares the ptychography amplidue reconstructions for left and right circular polarised incident beam. The close simililarity between the two independent data sets demonstrates the robustness of the ptychography analysis and quality of the data obtained using phase plate and cryostat on these magnetic materials using the new EBS. The slight difference in the intensity scale of the resonstructed amplitudes between left and right circular polarised is expected due to the magnetic contrast in the coherent diffracted intensity.

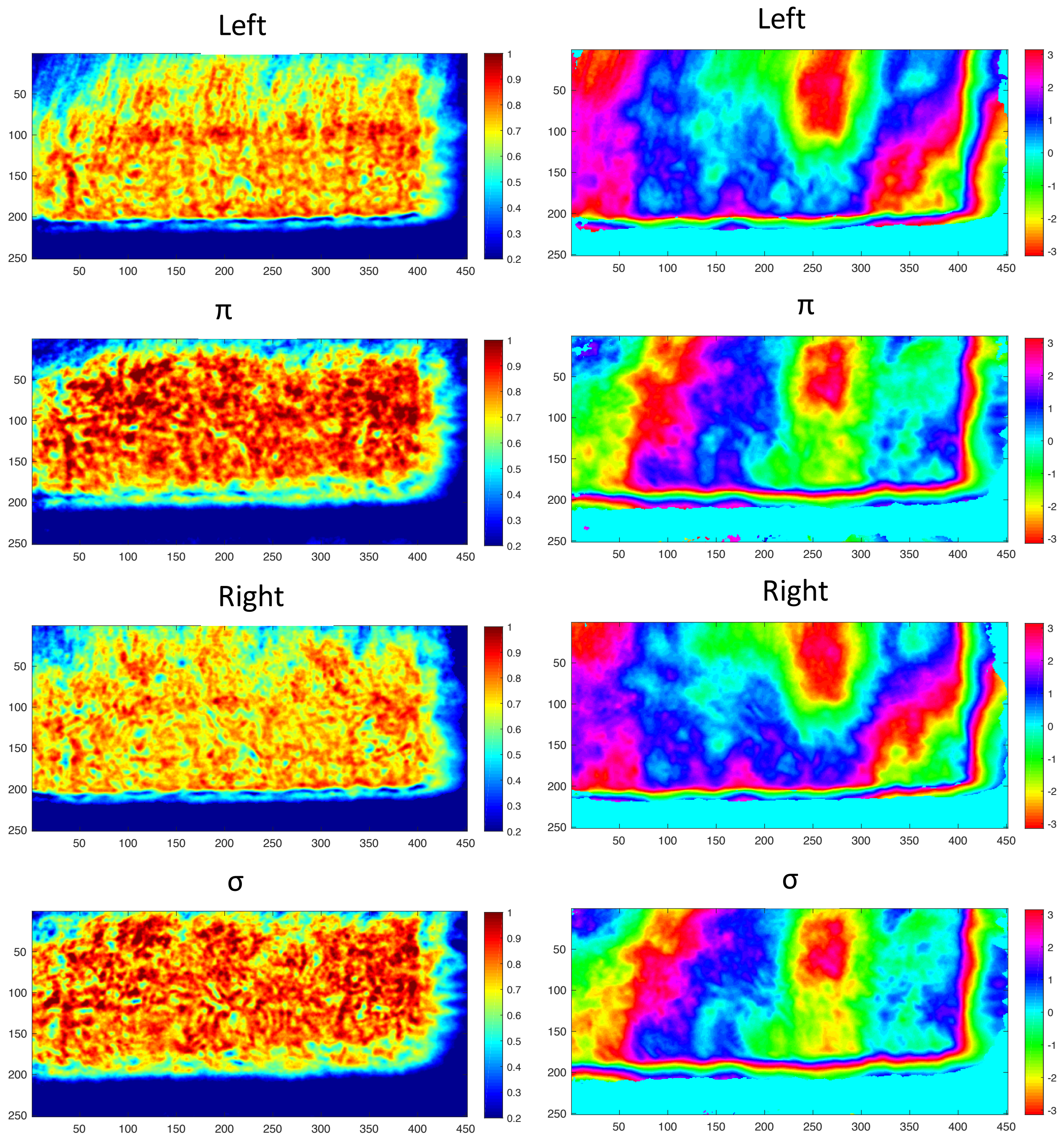

Figure 2. Ptychography results of the reconstructed amplitude (left) and phase (right) for the 4-incident polarisations circular-left, linear-π, circular-right and linear-σ (top-bottom). These four independent data sets lead to reconstructions presenting strong structural likelihood, particularly visible in the phase maps, which contain both crystalline (charge) and magnetic (spin) information. Scale 36 pixels = 500nm.

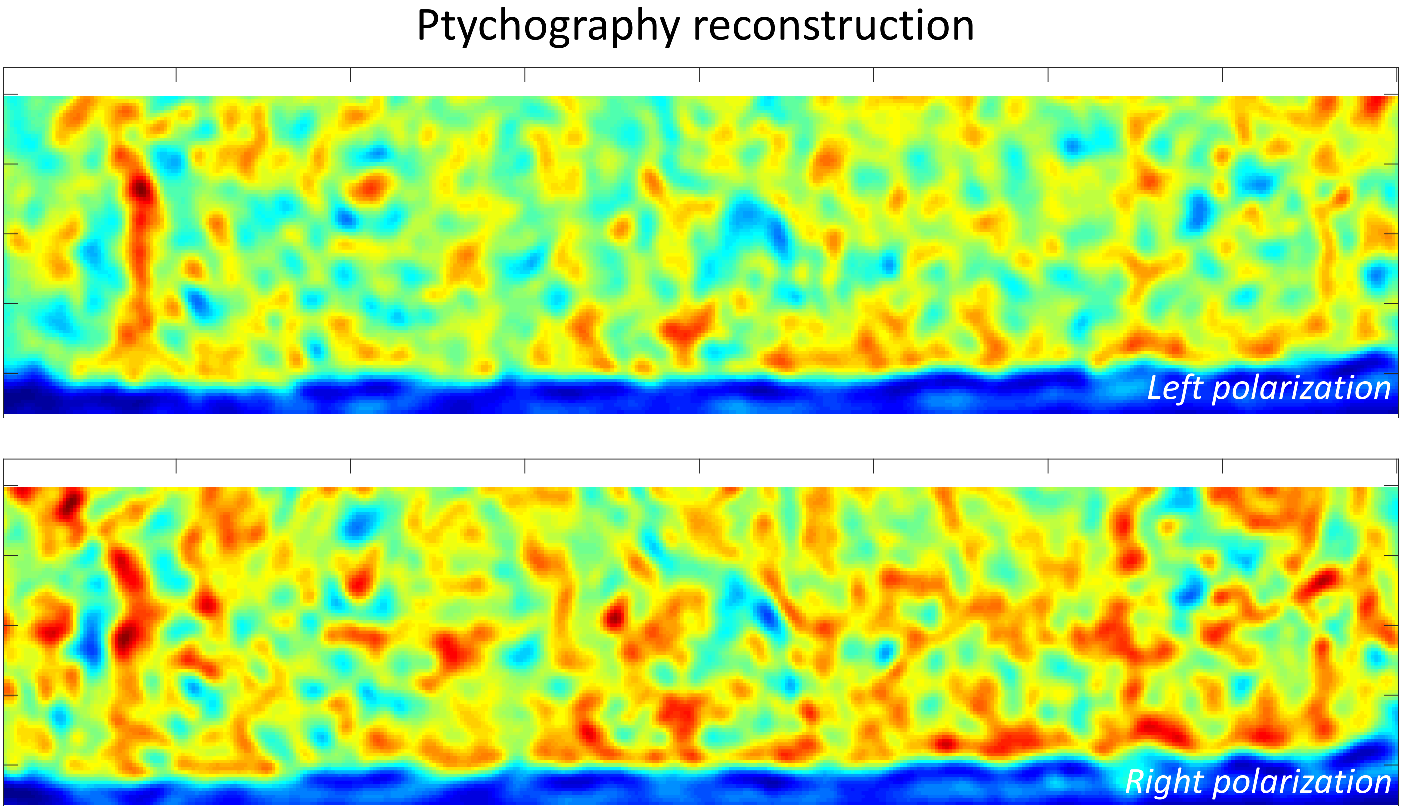

Figure 3. Ptychography reconstruction with different colorscale of the left (top)and right (bottom) incident polarized beam data set, at resonance. These two independent data set lead to reconstructions presenting strong structural likelihood, confirming the quality and reproducibility of the ptychography data set.

(5) Future work.

Our preliminary analysis in the limited time since experiment HC4336 has demonstrated the feasibility of the complex experimental set-up on ID01 and that magnetic information is clearly obtained in the coherent diffraction intensities. The ptychography reconstructions obtained using 4 different incident polarisations are reproducible and robust enough to retreive the magnetic information. We now understood how to modify the ptychography inversion scheme to take into account the vectorial aspect of the scattered field and this mathematical implementation is in progress. We can then move ahed with publication of the work.

We now wish to build on these exciting results with continuation experiments on new material systems. Our experimental program has been hindered by the covid-19 pandemic leading to delays in experiments at ESRF. In our next proposals we will focus on two classes of matrials systems the purely antiferromagnetic compound Sr_2IrO_4 and a new spintronics material $Tb_3Fe_5O_{12}$, which has additionally strong magnetostriction effects at low temperature.

References:

[1] D. Mannix et al. Science Advances 02 Oct 2020: Vol. 6, no. 40 https://doi.org/10.1126/sciadv.aba9351