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Experimental characterization of a prototype secondary spectrometer for vertically scattering multiple energy analysis at cold-neutron triple axis spectrometers

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ABSTRACT

A thorough experimental characterization of a multiplexing backend with multiple energy analysis on a cold-neutron triple axis spectrometer (cTAS) is presented. The prototype employs two angular segments (2θ-segments) each containing five vertically scattering analyzers (energy channels), which simultaneously probe an energy transfer range of 2 meV at the corresponding two scattering angles. The feasibility and strength of such a vertically scattering multiple energy analysis setup is clearly demonstrated. It is shown, that the energy resolution near the elastic line is comparable to the energy resolution of a standard cTAS. The dispersion relation of the antiferromagnetic excitations in MnF_2 has been mapped out by performing constant energy transfer maps. These results show that the tested setup is virtually spurion free. In addition, focusing effects due to (mis)matching of the instrumental resolution ellipsoid to the excitation branch are clearly evident.

1. Introduction

There is a broad variety of scientific cases justifying importance of the parametric studies of entire dispersion surfaces. In many quantum magnets for instance a control parameter, like applied magnetic field or pressure, induce the quantum critical point [1–4]. Disordered magnetic systems also display very broad features in $\mathbf{Q}$ and ω, where excellent resolution becomes secondary to mapping capabilities [5–7]. In the past decades, triple axis spectrometers (TAS) have been optimized mainly to increase incident flux on the sample by improving guides and employing focusing monochromator and analyzer geometries. While this enhances the capability of TAS to investigate limited volumes of $(\mathbf{Q}, \omega)$-space in parametric studies, these instruments remain inefficient for overall views of the dynamic structure factor $S(\mathbf{Q}, \omega)$. Such experiments are best done on time-of-flight (ToF) spectrometers. However, sample environments for e.g. applied magnetic fields and pressure significantly limit the performance of TOF spectrometers, due to a limitation of the recorded solid angle and significant increase in background. This leaves few efficient options for parametric overview studies. A promising way to improve the $S(\mathbf{Q}, \omega)$-space coverage of a TAS is employing a multiplexing backend with several separate $(\mathbf{Q}, E_f)$-channels. Maintaining a horizontal scattering geometry for the secondary spectrometer, however, imposes physical constraints which limit solid angle coverage and also result in complex scattering geometries, such as UFO, ILL, [8,9] and RITA, PSI [10]. An impressive exception is the MACS spectrometer at NIST, that circumvents this problem by utilizing a twin analyzer concept [11]. Another way of increasing spatial angle coverage is a *vertically* scattering backend as e.g. the former Flat-Cone [12] installed at the E2 diffractometer at BER-II, Berlin, and the implemented FlatCone and the Madbox options at the ILL [13,14]. A way of increasing the mapping capabilities even further is employing a successive arrangement of vertically scattering analyzer crystals accepting multiple final energies E_f in a

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single 2θ channel. This has become known as the Continuous Angle Multiple Energy Analysis (CAMEA) backend [15,16], and is possible due to the transparency of highly oriented pyrolytic graphite (HOPG) at large wavelengths [17]. This type of backend is under construction for the RITA-II cTAS at the PSI [16] and under consideration for the PANDA cTAS [18–20] at the MLZ facility [21]. In addition, this setup is to be utilized in the high performance indirect ToF spectrometer BIFROST to be built at the ESS [15]. As a BIFROST prototype the CAMEA concept has already been successfully tested on a ToF frontend [22]. Among other things this lead to the newly developed prismatic analyzer concept [23]. However, the CAMEA backend has so far not been experimentally realized with a standard cTAS frontend.

On the recently upgraded FLEXX cTAS at the HZB [24,25], a multiplexing back-end has been constructed and is under commissioning [26]. With a range of fixed vertically scattering analyzers, this optional secondary spectrometer will provide the opportunity to do overview measurements with very little effort, using less than half an hour to mechanically switch between backends. Here, the first prototype tests of the so-called MultiFLEXX multiplexing back-end, performed on the PANDA cTAS at the MLZ, are reported.

2. Prototype description

The MultiFLEXX employs 31 angular segments (2θ channels) with five fixed analyzers (energy channels) accepting final energies E_f of 2.5, 3.0, 3.5, 4.0 and 4.5 meV. This covers a range in energy-transfers of 2 meV determined by the incident neutron energy E_i. The advantages of this simple approach as opposed to more flexible backends are: no moving parts that need calibration, no motors subject to failure, the planning of an experiment and software to interpret data becomes simpler and it is feasible to interchange between classical TAS backend (analyzer and detector unit) and multiplexing backend on an experiment-to-experiment time scale. The multiplexing backend is directly attached to the sample table replacing the classical TAS secondary spectrometer.

In order to optimize the MultiFLEXX for high magnetic field sample environment with limitations on out-of-plane solid angle coverage, the out-of-plane angular coverage of the analyzers were chosen to be small (between $\pm 1.2°$ and $\pm 0.7°$ depending on the analyzer-sample distance). Hence, each analyzer consists of 3 vertically stacked plate-like $20 \times 20 \times 2$ mm HOPG crystals (mosaicity of $0.4° \pm 0.1°$ measured with x-rays), as shown in Fig. 1a. The HOPG crystals are arranged so that they have a fixed focus corresponding to their nominal fixed final energy. For each energy channel a cylindrical He-3 tube-detector with a radius of 12.5 mm and an active length of 50 mm placed 400 mm away from the center of each analyzer in the out-of-plane Bragg condition is used. The necessary detector electronics (pre-amplifiers and multi-detector interface) are directly mounted on top of the multiplexing backend. This reduces the connecting cables to a single data transfer and a single high voltage cable. These can easily follow the instrument movement during a scan. The covered angular range in 2θ is 77°, where the center of each 2θ-channel is separated by 2.5°. Taking the distances given in the caption of Fig. 1 and the analyzer dimensions into account the horizontal angular coverages of the analyzer segments with energies from 2.5 to 4.5 meV are 1.09°, 0.94°, 0.83°, 0.74° and 0.66°, respectively. With an angular separation of 2.5° between two segments the corresponding dark angles are 1.41°, 1.56°, 1.67°, 1.76° and 1.84°, respectively. This allows to completely cover the entire 2θ-range of MultiFLEXX by two scans which are separated in by $\Delta 2\theta = 1.25°$.

The prototype consists of two angular segments containing 10 energy channels in total, enclosed in borated polyethylene (BPE)

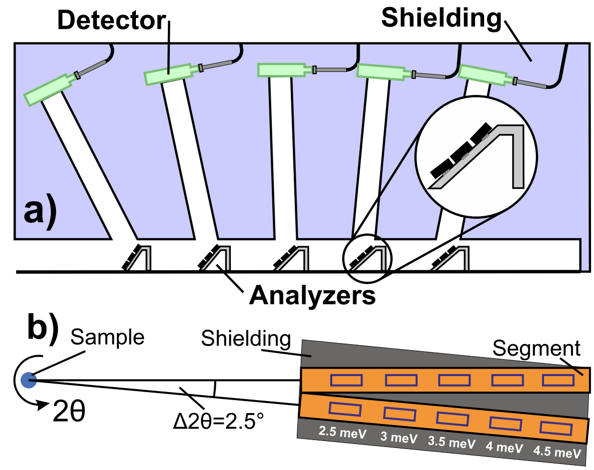

Fig. 1. (a) Layout of a single angular segment (side view), the distance between the analyzers (mounted on gray holders) and the detectors (green) is 40 cm. Neutrons scattered by the sample enter the segment from the left. The distances of the analyzers to the sample are 1050 mm, 1220 mm, 1387 mm, 1552 mm and 1732 mm, respectively. Each analyzer detector channel is thoroughly shielded with boronated polyethylene (light blue). The insert shows one analyzer (energy channel). (b) (top view) The prototype setup using two angular segments (orange) with additional shielding in between (gray) is directly attached to the sample table and replacing the classical TAS secondary spectrometer. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

shielding and mounted on a table fitted with air pads (see Fig. 1b). It was mounted on the 2θ arm of the PANDA spectrometer at the MLZ. To evaluate the performance of the design three samples were used. For tests of the widths of the elastic lines a vanadium sample (diameter 1 cm, height 1 cm) was used. For a realistic evaluation of cross-talk, inelastic intensity and resolution at low energies, a 300 mg $LiMnPO_4$ $S = 5/2$ sample that orders antiferromagnetically was used [27,28]. For generating comprehensive constant energy maps and for tests of spurious signals and resolution effects, a larger MnF_2 $S = 5/2$ sample ($m \approx 30$ g) was used, exhibiting a simple antiferromagnetic spin wave spectrum with a single branch (2 ions per unit cell) [29,30]. Both magnetic samples order well above the measurement temperature of 4 K, achieved using a closed cycle cryostat ($T_N = 33.85$ K and $T_N = 67.6$ K for $LiMnPO_4$ and MnF_2, respectively).

3. Performance

3.1. Energy resolution

Measurements of the elastic incoherent line in vanadium probe the inherent energy resolution per distinctive energy channel. An E_i scan was performed between 2.47 (minimum E_i at PANDA for the prototype setup) and 5.2 meV. The full-width-at-half-maximum (FWHM) and peak intensities from the gaussian fits to the elastic lines are given in Table 1.

Table 1
Elastic incoherent line widths and peak intensities of a vanadium scan from 2.47 to 5.2 meV. The peak intensities have been normalized to monitor and monitor efficiency. Intensities are given in arbitrary units.

E_f	FWHM [μeV]	I_{peak}	I_{int}
2.5 meV	57(2)	3.9(1)	220(9)
3.0 meV	79(1)	4.7(1)	374(7)
3.5 meV	129(2)	3.0(1)	385(10)
4.0 meV	182(4)	1.8(1)	331(15)
4.5 meV	209(5)	1.7(1)	344(20)