MERLIN: a high count rate chopper spectrometer at ISIS

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ABSTRACT

MERLIN is a new high intensity, medium energy resolution spectrometer. As such, it complements the high-resolution MAPS spectrometer at ISIS. MERLIN has an m=3 supermirror guide to enhance flux as well as a massive π steradians of detector solid angle with an angular range from -45 to +135 degrees in the horizontal plane and ±30 degrees in the vertical plane. The detectors are 3m long position sensitive detectors placed in the tank vacuum to eliminate gaps in the coverage, making it ideal for both single crystal and powder/liquid users. The guide extends the dynamic range of the instrument allowing the study of excitations from a few meV to hundreds of meV. The construction phase of MERLIN finished in February 2008, followed by a brief commissioning period for one cycle before starting a full user program in June 2008.

INTRODUCTION

MERLIN is a high count rate direct geometry spectrometer and was built to replace the aging 20-year-old HET spectrometer at ISIS which has just finished its last user cycle. HET was always conceived as a high energy inelastic neutron spectrometer that would concentrate on polycrystalline magnetic systems. However, the development of position sensitive detectors (PSDs) made it possible to study magnetism in crystalline systems, and the MAPS spectrometer was built to exploit this new technique. MAPS created a new paradigm in inelastic neutron scattering providing an ability to measure large volumes of reciprocal space in a single measurement; however because of flux limitations,

Figure 1. The finished MERLIN spectrometer.

it is largely confined to measurements of low-dimensional magnetic systems. The development of high m-value supermirrors (SM) made it possible to conceive of an instrument that could deliver considerably more flux to the sample opening up the possibility of a machine that could map all the excitations in the whole Brillouin zone. Funding to build such a machine was secured in 2004 and the instrument now called MERLIN was completed early in 2008 (Fig. 1). MERLIN builds on the success of the PSD's on the MAPS spectrometer, but uses a much larger solid angle detector coverage. This large detector coverage has been achieved partly by bringing the detectors in to a relatively short sample to detector distance of 2.5m, making MERLIN a medium resolution spectrometer with typical energy resolutions of 3-5%. This was a deliberate policy; MERLIN was built to complement the high-resolution MAPS spectrometer which has a 6m sample to detector distance and typical resolutions of 1.5-4%. PSDs make the instrument very versatile, being equally able to study single crystal samples as well as powders, liquids and amorphous materials. Its high count rates open up many fields including detailed parametric studies as a function of pressure, temperature and composition; studies of complex multi-component materials; novel materials for which only small quantities are available; experiments on single crystals where the signals are weak or the crystals are small ;complete four dimensional mapping of the Brillouin zone and experiments involving the use of complex sample environments. MERLIN is being built specifically with complex sample environments in mind. Features include a non-magnetic sample tank and piezo-electric beam defining jaws so that high-field magnets may be used. A wider sample flange allows the use of larger pieces of sample environment equipment.

INSTRUMENT DESIGN

The basic instrument layout can be seen in the engineering drawing with cutaways shown in Fig. 2. All of the direct geometry spectrometers at ISIS,

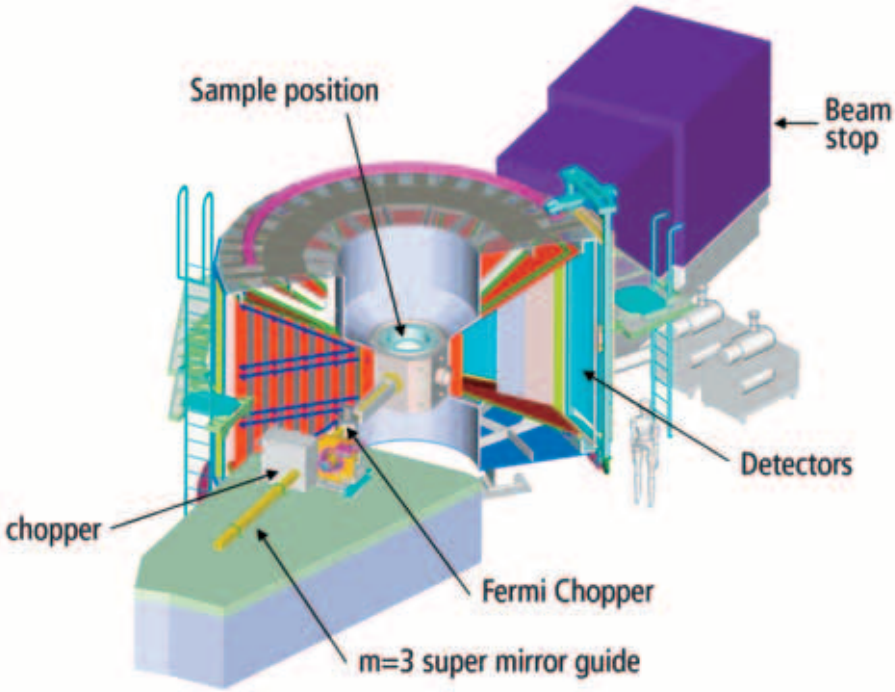
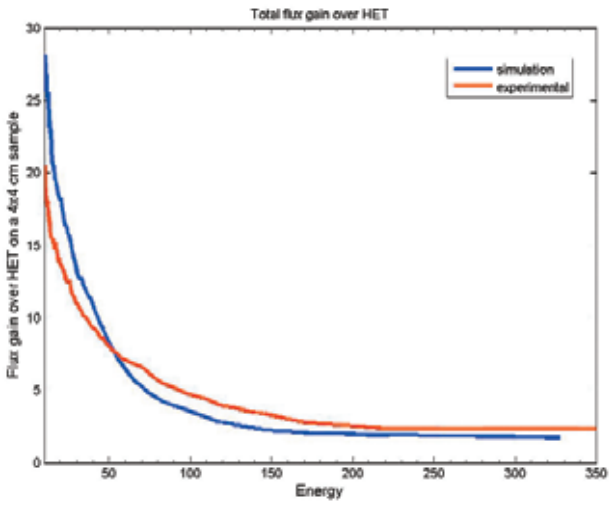


Figure 2. Engineering drawing of MERLIN with cutaways to show the inside of the tank.

including MERLIN, have a moderator to sample distance of 11.8m, which is about as short as is possible within space constraints. In fact MERLIN is so large that it takes the space of two beam port positions (only acceptable because it occurred at the same time funding became available to build the second target station). MERLIN is currently the only chopper spectrometer at ISIS to employ a supermirror guide to boost the flux. The guide is all m=3 (critical reflection angle is 3 times natural Ni) and begins at 1.7m from the moderator face with an opening of 94x94mm, converging continuously to 50x50mm just before the sample.



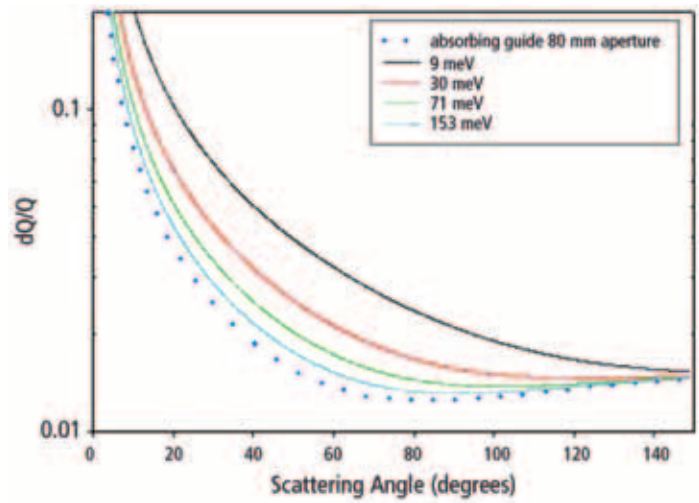


Figure 3. Measured flux gain of MERLIN as compared to the HET spectrometer versus energy (red line). The blue line is the simulated flux gain.

Figure 4. Q resolution presented as ΔQ/Q versus scattering angles for various incident energies. The energy resolution was fixed at 3% in this calculation.

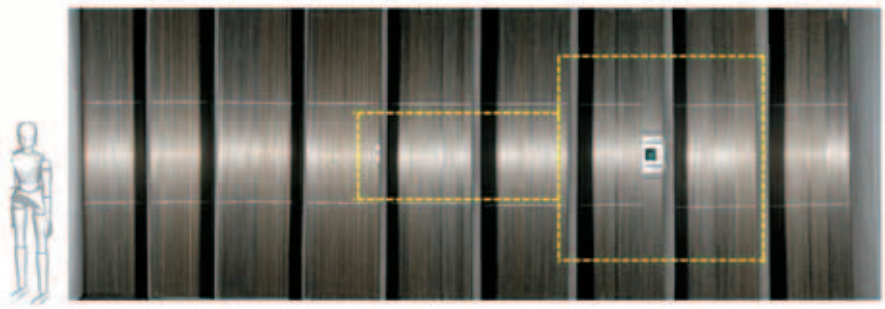
Fig. 3 shows the measured flux gains of MERLIN compared to HET. The flux gains come from three components, the largest gains come from the supermirror guide, but some gains are from increasing the apertures so that the sample views the full moderator face. This gives the factor of two gain at higher energies where the guide is clearly doing nothing. The third factor in the flux gain is from the moderator. Unlike most instruments which share a moderator MERLIN views its own decoupled, ambient temperature water moderator with the poisoning chosen to be central to increase flux compared to an asymmetrically poisoned moderator used on HET and MAPS. The combined effect is to give flux gains of up to 20 times HET at an incident energy of 10 meV (Fig. 3). The simulations give slightly different expected gains to the measured. The slight differences probably come from the moderator component to the flux gains as it is very difficult to obtain accurate moderator calculations.

Of course these large flux gains are at the expense of a larger beam divergence that is dependent on the incident energy. At high energies the beam divergence has a FWHM of about 0.5°, which increases to a value of 2° at 10meV incident energy. The effect of this on the Q resolution of the instrument is presented in Fig. 4.

The high count rate on MERLIN was also achieved by using a massive position sensitive detector array covering a full π steradians of solid angle. A view of this large detector bank from the sample position can be seen in Fig. 5. For

comparison this is 8 times the solid angle of HET and 7 times that of MAPS. Position sensitive detectors now make it possible to measure in two spatial dimensions in addition to a function of time; this means that each measurement on MERLIN takes a large three dimensional cut out of the four dimensional S(Q,ω).

The detectors form a cylindrical array with an angular range of -45° to +135° degrees in the horizontal plane and ±30° degrees in the vertical plane. The detectors are 25mm wide and 3m long and the centre point of the detectors is 2.5m from the sample. To keep the detectors straight small aluminium



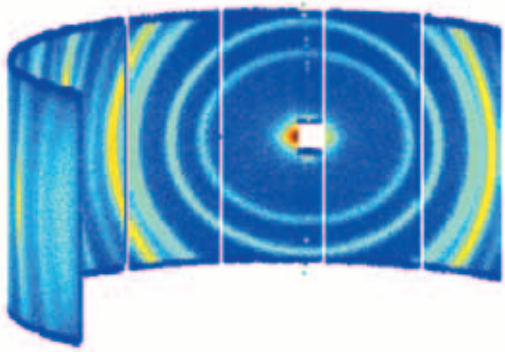


Figure 5. A 'Flattened out' view of the detectors from the sample position. The get lost pipe can be seen on door 3 and the thin aluminium supporting straps at 1/3 and 2/3 of the way along the 3m tubes. The vertical structures are absorbing vanes to stop cross scatter. A 'standard' man is shown for scale. The dotted yellow lines show the solid angle of the MAPS detectors for comparison.

Figure 6. Debye Scherrer rings on the MERLIN detector bank from a powder sample

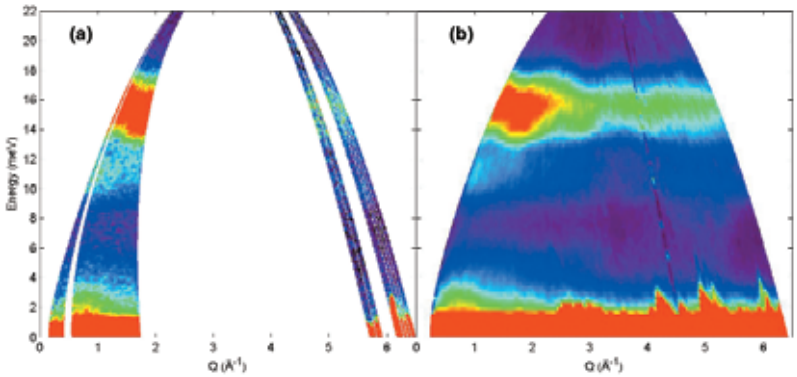
straps are used at two points along the length (see Fig. 5.). Notice that there are no windows of any sort between the sample position and the detectors. This is to stop any secondary scattering taking place which could potentially cause 'spurious' inelastic events.

MERLIN was the first instrument to use such long detectors. It means that it does not suffer from the large gaps in angular coverage that occur when shorter tubes are used as is the case with MAPS. The gaps were further minimized on MERLIN by putting all the detectors within the tank vacuum.

To eliminate any secondary scatter of neutrons, all the spectrometers at ISIS use evacuated secondary flight paths. However, the usual practice before MERLIN was to place the detectors in air behind aluminium windows. Struts are needed to support these windows, which are under huge forces, creating further gaps in the detector coverage. Putting the detector electronics in the tank vacuum could have potentially caused problems, heat dissipation and potential high voltage breakdown at intermediate pressures. The solution we chose for MERLIN was to keep the electronics at the end of each tube in air with vacuum feed throughs from each tube. Groups of 32 tubes are attached to large doors which vacuum seal to the back of the tank. These doors can be removed if it is necessary to replace a faulty tube. There are nine doors on the tank with a two tube gap between each door. Vertical vanes are positioned in these gaps to stop any cross scatter within the tank, see Fig. 5. The whole tank is lined with neutron absorbing B_4C panels. These panels use a special non-hydrogenous glue to reduce potential scattering and also to reduce vacuum pump down times. The MERLIN tank is approximately $30m^3$ in size and despite all the B_4C and vacuum seals a cryogenic vacuum of about $4x10^{-6}$ mbar is obtained eliminating the need for thick tails on the cryostats. For example, the total aluminium thickness from the tail and 30 K shield on the MERLIN top loading CCR is less than 0.5mm.

COMMISSIONING MERLIN

One of the biggest challenges of this project was obtaining a good neutron position resolution along the 3m detector tubes. The original specification was to obtain a position resolution better than 25mm, the width of a tube. To obtain this meant re-designing the standard detector electronics. Measurements on MERLIN show that the position resolution achieved is about 20mm at the centre of the tubes increasing slightly to 23mm at the ends, well within specification. Detector and electronic stability also looks good with no change in detector efficiency or position resolution observable over the 9 months period of running. Another important factor for spectrometers is to have low backgrounds. A lot of care was taken on MERLIN both in the design of the



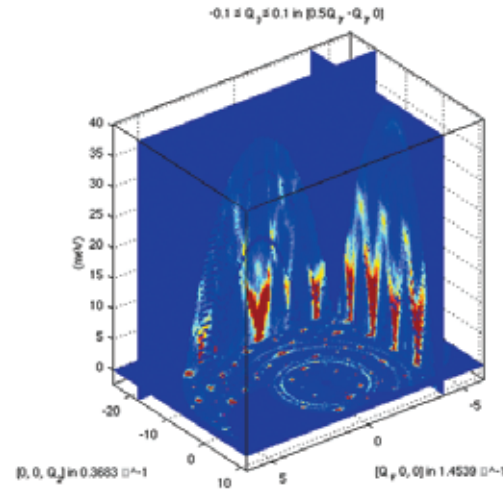


Figure 7. The inelastic scattering from UPd_3 on a) HET and b) MERLIN.

Figure 8. Phonon dispersion in calcite single crystal (Ei = 45 meV, room temperature). The plot shows the Bragg peaks at the elastic line, and cuts in the inelastic region evidence the dispersion curves covering multiple Brillouin zones in both the a* and c* directions

guides and the shielding to minimize neutron backgrounds and spurious reflections. Results on MERLIN show that the backgrounds are homogeneous across the detector banks (no hot spots) with backgrounds of approximately 28 neutrons/hour/meter of detector tube. This was expected and compares well with the other spectrometers at ISIS.

In practice each 3m tube is split into 256 detector elements or 'pixels' of approx. 11mm in size. This gives 69000 pixels for the whole detector array. Each pixel typically has 2500 time channels giving a total of 172 million bins. Obviously for powders these pixels are grouped into rings. The power of the pixilated detectors is shown in Fig. 6 where the elastic scattering from a powder sample onto the large detector array shows well defined Debye Scherrer rings. One of the first inelastic measurements made on MERLIN was on powder UPd_3. This was previously measured on HET, enabling us to make a direct comparison by running with the same incident energy and chopper speeds. The measurements were performed with an E_i =25meV and a strong crystal field excitation can be observed at 16 meV (Fig. 7). HET only has a low angle detector bank from 3 to 30°, MERLIN proved to have 30 times the count rate of HET in the same angular range; a factor of 10 from the flux on the sample and another factor of 3 from the increase in solid angle. In reality MERLIN is not limited to such a small angular range and the real gain in signal is much more.

However, the resolution on MERLIN is approximately 10% worse than on HET partly due to the broader moderator pulse and the slight increase in opening time of the Fermi chopper because of the extra beam divergence. Table 1 shows a comparison of the spectrometers performance at ISIS.

One of the most exciting possibilities for MERLIN is its ability to map complete Brillouin zones. This technique uses a single crystal and combines a series of measurements at different angles or energies to create a complete four dimensional map of the Brillouin zone with the four dimensions, Q_x ,Q_y Q_z and energy being independent of one another. It is then possible to extract 3D, 2D or 1D cuts from this data in any direction within the crystal in software. In a test measurement using a calcite crystal, one hundred and eighty 10 minutes long runs were made where the crystal was rotated by one degree between runs. The lack of symmetry in calcite means that a full 180 degrees are required, for systems with cubic symmetry this would be reduced to just over 90 degrees. All the runs are then combined in software to produce a large 40Gb file from which cuts can be made. Fig. 8 shows a sample of the data where one can clearly see the phonon branches. This experiment shows that it is possible to measure all the excitations (below the incident energy) in all symmetry directions in approximately two days. In fact the majority of the requested beam time on the instrument is for this new mapping technique.

	MERLIN	HET	MARI	MAPS
Intensity (n/meV.s)	$400x10^4$	$50x10^4$	$58x10^4$	$113x10^4$
Detector Pixels	69000	2000	1000	42000
Solid Angle (Sr)	3.1	0.4	0.4	0.45
Angular range	3-135	3-30° 110-135°	3-132	3-60
Best % energy res.	3	3	2	1.5
Gain of MERLIN (Int.xSr)	-	62	53	24

Table 1. Shows a comparison of various spectrometers at ISIS. The intensity is at 50meV and for 3% energy resolution. The last row is just a figure of merit.

SUMMARY

MERLIN is performing as was predicted in all aspects of operation from flux to backgrounds and beam divergence. Although MERLIN has only been running for a short period of time it has already produced some excellent science and has its first papers published on Phys. Rev.[1,2] and Nature.[3] In the last proposal round it was over-subscribed by a factor of three which shows the demand for this type of spectrometer. In December a new wide angle 9 Tesla magnet arrives at ISIS which has been designed specifically for MERLIN with large openings to view the complete detector bank. The HET spectrometer provided the science community with 20 years of excellent science and we believe MERLIN is a fitting successor.

We would like to thank Keith McEwen and Duc Lee for allowing us to present their data in Fig. 7, Martin Dove and Elizabeth Cope for the data in Fig. 8.

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