1.5.2 JRA2 - MILAND

Coordinator: 8 - ILL
Partners: 1 - STFC, 2 - GKSS, 9 - CEA LLB, 11 - FRM-II, 20 - LIPC, 23 - BNC-RISP
Observers: Tokyo University, SNS

Project objectives

The main goal of the MILAND project has been defined in the initial proposal as the following:

“ the project will be devoted to the development of a new detector that will significantly improve the performances of SXD (Single Crystal Diffraction) and reflectometry neutron instruments, in terms of sensitive area, counting rate, and position resolution “.

2 parameters must be improved with the highest priority:

- the angular resolution should be decreased by a factor of 2.
Let’s first recall that … 1/ a very good spatial resolution (FWHM of the detector response for a collimated beam) is easily achievable with a small detector, 2/ a large area detector is easy to fabricate without considering requirement on spatial resolution.
The parameter that reflects the precision of a detector, and the difficulty to make it, is the angular resolution which can be expressed as the FWHM divided by the dimension of the detector. The value of the resolution (1 mm FWHM) and the size of the detector (32 cm x 32 cm) chosen for the project correspond to a gain of 2 in the angular resolution users are asking for, while maintaining the angular coverage.

- the count rate capability should be increased by a factor of 10.
The gain in counting rate is needed especially in reflectometry where the neutron beam must often be attenuated to avoid saturation of the detector.

The success of the project mainly relies on the delivery of a full size (32 cm x 32 cm) operational detector. It would have made sense to propose the study of reduced size prototypes in order to reduce technical and budgetary risks, but the technological gap to go from small to large detector would have remain dissuasive for potential users, and for the transfer to the industry.

The objectives of the project can be evaluated by answering the following questions:

- did we succeed to fabricate a full size detector usable on a neutron instrument?
The answer is “yes”: The MILAND detector can be reproduced as it is today, with some minor modifications.

- does this detector match the specifications defined in the proposal?
The answer is also “yes”: We measured a counting rate of 0.8 MHz with 10 % neutron loss, close to the specification of 1 MHz, and we have clear indications on how to improve it above the specification. We also achieved a spatial resolution of 1.2 mm FWHM, close to the objective of 1 mm.

The angular resolution as defined above does not reflect the accuracy to determine the position of a spot signal, but rather the capacity to separate two neighbouring spots. We then studied the PCA (position centroid accuracy) defined as the “standard deviation of errors from beam position measurements (given by fitting the detector response)”. For MILAND we measured an accuracy of 11 microns on the anodes, and 15 microns on the cathode. These values are an order of magnitude better than previously measured with state of the art detectors.

Another important parameter, also not discussed in the proposal, is the parallax error: the FWHM and the PCA measured for a neutron beam increase with the angle of incidence. This effect is often neglected and rarely quantified, but it plays a decisive role when the distance from the sample to the detector is shortened to increase the angular coverage. To minimize this effect, the MILAND detector has been designed in view of sustaining a very high gas pressure to compensate the reduced efficiency of a small conversion gap. In addition to that, the internal electrodes allow 2 modes of operation: in the first mode, mainly for SXD applications, the conversion gap is only 5 mm so that the parallax error is strongly reduced even for short distances from the sample to the detector (up to 50 cm); in the second mode, the conversion gap is increased from 5 to 20 mm in order to maximise the detection efficiency. The choice between the 2 modes can be let free for the instrument user, and depends on the type of experiment he will perform. To our knowledge, this is the first time that a neutron detector allows such a flexibility of use. In the future, different operation modes will also be defined by setting the parameters of the acquisition parameters according to priorities of the instrument (in particular counting rate versus background noise).

As required in the proposal, other detection parameters (detection efficiency, gamma sensitivity, counting stability) have been maintained at the level of the state of the art.

Methods

During Y1 and Y2, several prototypes have been developed to study 3 different techniques of neutron gas detectors, MWPC, MSGC, and GSPC, all 3 with the same goal: to provide the most promising technique for the full size MILAND detector. These 3 types of detectors are associated to different levels of performance and technological risk.

- The MWPC is used in neutron instrumentation since the beginning of the 70’s. Its main drawback is the difficulty to keep anode wires stable under voltage. The smaller is the pitch between the anode wires and higher is the electrostatic strength; the higher is the quenching gas pressure (to reduce the ionisation track length), and the higher is the operational voltage. Reducing by a factor of 2 the relative distance between the wires (pitch divided by the length of the wires) represented the main difficulty in this task. We obtained a good result by introducing a new mounting process: the wires are first soldered on 2 PCBs (Printed Circuit Board), which are mounted on rotating supports; these supports can be moved so that the wires are pulled by 0.5 mm on each side. By extending their total length by 1 mm they overpass the limit of elasticity, and are maintained at the maximum of mechanical tension. The tension is then very uniform between the wires, and does not depend anymore on the soldering procedure. They are also positioned with an accuracy of +-20 micrometers by means of ceramic combs.

- The MSGC overcomes the problem of wires stability by using lithographic techniques: the wires in the MWPC are replaced by strips engraved on the surface of a glass substrate. This technique is known since the late 80’s, and several instruments of the ILL are based on it. It is intrinsically superior to MWPC but suffers from the limited size of the MSGC plate. It was then proposed to have a mounting of 4 MSGCs (16 cm x 16 cm each) without dead space between them, and all the connectics in the periphery of the sensitive area. The main difficulty was to design the mechanical support of the MSGCs with no dead space and to prevent sparks between the plates. During the course of the project, another approach has been followed: to develop in house (at the LLB) smaller size MSGCs (of the order or smaller than 10 cm x 10 cm) mounted side by side with no dead space, and with conductive holes in the glass to connect the strips. Unfortunately we did not succeed in manufacturing conductive holes with no dead space, and we did not reach sufficient quality in the fabrication of the MSGCs. For this reasons, the MSGC option could not be retained for the fabrication of the MILAND detector.

- The Gas Scintillation Proportional Chamber comes from High Energy Physics, and has never been used on a neutron instrument. Despite very promising results, there were still too many open questions to select this technique for a large area detector.

3 laboratories (ILL, LIPC, and LLB) were given the responsibility to develop one of these techniques, but several labs were collaborating on each prototype.

In year 3, we started to study the design of the MILAND detector based on the MWPC technique. A choice had to be made between 2 approaches to correct the parallax error: either by using a very high gas pressure combined with a small conversion gap, or by applying an electric field corrective electrode to create electrical field lines converging toward the sample position. We could not evaluate the parallax correction in 2 dimensions with the actual prototype and there was not sufficient time to develop a new one. We then decided to go for the high pressure solution which had a lower technical risk but required a more complex pressure vessel.

The front-end electronics of the detector, based on fast amplifiers, and Time-Over-Threshold (TOT) signal processing was originally developed in High Energy Physics, but the MILAND project is the first attempt to adapt this technique in neutron instrumentation. Measuring with charge amplifiers the energy realised in Helium-3 after the interaction of a neutron is the standard way to discriminate against gammas and to localise the capture point by selecting the first active signal, but charge amplifiers induce long signal tails, thus limiting the counting rate capability. Fast amplifiers combined with processing boards to select the channel carrying the max of the TOTs offers an alternative to the standard electronics scheme, with the advantage of a reduced dead time.
We developed a 32 channels front-end electronics called MILAND32, which include fast amplifiers, base line restorers, and comparators providing TOT signals. For reasons of cost, power consumption compactness, and simplicity of use, we made the choice of not implementing the individual threshold function. Experimental results confirmed this choice: the counting uniformity (les than 1% standard deviation from the mean) measured on the anodes without any calibration is even better than the one we obtain with standard electronics after calibration. This excellent uniformity does not result from the electronics only, but also from the quality of the wire mounting. It shows that it is possible to get a very uniform response of the detector without the need for a painful and time consuming calibration procedure, where each of the 640 channels has to be adjusted. The MILAND32 board accepts negative and positive signals, allowing a unique configuration to be used on both the anodes and the cathodes. A threshold tuning, common for the 32 channels, allows you to apply a different threshold for the anodes and for the cathodes, to cope with their different dynamic ranges.
The processing of the TOT signals is performed by 2 types of VME cards: the PPM (Pre-Processing Module) encodes time stamp, signal duration (TOT), and channel number of each signal; the COM (Correlation Module) collects and processes the data of all PPMs through the VME64x backplane. The COM implements a sorting chain of the time stamps to recognize the clusters (each neutron event has several active channels in both X and Y coordinates); it is also in charge of the X and Y positions determination and X-Y correlation.
This electronics is far more advanced than the state of the art before MILAND; it allows you to achieve higher count rate, but also better spatial resolution and uniformity. In combination with the MILAND detector, there was no need for calibration which makes the detector much easier to operate.
The cost of the electronics is reduced by a factor of 2 compared to the previous generation, and it will be further reduced by another factor of 2 when ASIC will become available.
As a result of this electronics development within the MILAND project, a very significant improvement step has been achieved both in quality and cost. The fact that new processing algorithms can be implemented without hardware modification allows future development of the signal processing. We started to develop the centre of gravity algorithm; we had no time to implement it but its study will be continued after the end of the project.

In year 4, we fabricated all the mechanical parts of the detector, and the electronics cards.
A preliminary test of the detector, partially equipped with the electronics, showed serious problems of sparks which were attributed to displaced anode wires. We solved these problems 6 months later by using a new mechanics allowing to tight the wires up to the limit of elasticity.

According to the proposal, we should have stopped the study of MSGCs and GSPC after year 2, but given the promising results we obtained, we decided to study a new detector combining the 2 techniques in a single device where the light emitted by a MSGC is readout by a matrix of Photo Multiplier Tubes.
By performing experiments at LIP, ILL and ISIS during year 3 and year 4, we measured the effect of several parameters, like the MSGC layout, the gas composition, the MSGC to PMT's photocathode distance, on the light yield and on the spatial resolution.

Impact

At the end of 2008, the MILAND detector will be used on a regular neutron instrument of the ILL, D16, for further evaluation and real scientific experiments. Having the detector operational on a real instrument is the ultimate test to convince potential users of its performance and reliability. We expect that several scientists will be willing to equip their instrument with a copy of this detector.

The MILAND detector allows a better quality of data collected during the experiments: The gain in angular resolution improves the separation of neighbouring Bragg peaks and their localisation; for reflectometry, the gain in counting rate capability allows reducing the duration of the acquisition by a factor of 10 (nowadays, in many occasions, the beam must be attenuated to avoid saturation of the detector).

2 European companies (DENEX in Germany, and Mirrotron in Hungary) have been directly involved in the study and the fabrication of the MILAND detector. They are interested to commercialise it.

2 non-European observers, one from SNS (US spallation source) and one from Tokyo University (involved in the development of detectors for the Japanese Spallation source) were participating actively in the project. The partners of MILAND feel that the collaboration has been very fruitful in reinforcing the links between the European neutron institutes, but also between Europe, USA and Japan. This link with the 2 most intense spallation sources in the world will strongly benefit detector development in view of the future European Spallation Source.

A lot of know-how has already been transferred between the labs. This network of communication will continue after MILAND.

Several Engineers and scientists have been trained by MILAND with limited term contracts, and have found permanent jobs in radiation detector labs afterward: 3 of them are in neutron institutes, 2 of them in X-Rays institutes, and 1 is at the CNRS. 1 PhD student (from BNC-Hungary) worked 15 months on the project at the ILL, and has returned to BNC.

A proposal has been made to continue the work on MSGC_GSPC in FP7.

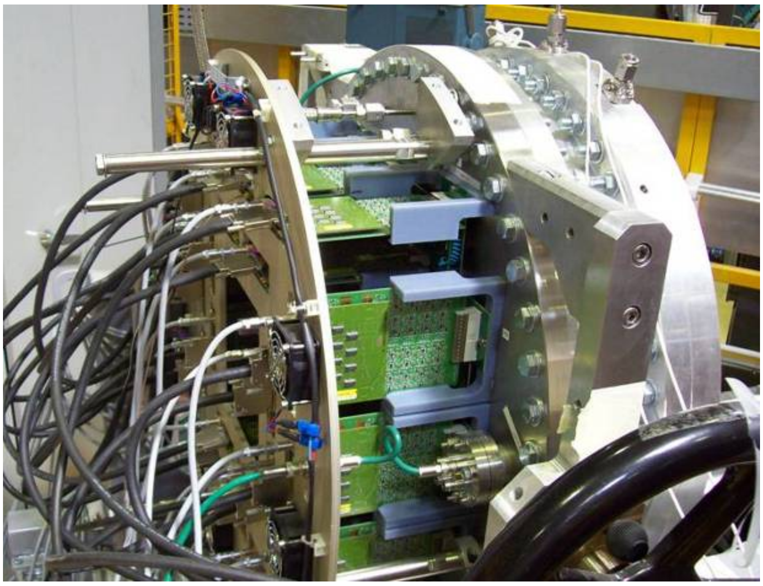

Figure J2 MILAND Detector