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Description:

This report describes the signal processing methods developed for the Jülich and ISIS ZnS:Ag/^{6}LiF scintillation detectors.

The Jülich and ISIS scintillation detectors each use a different principle for determining the positions of neutron interactions in the detectors. In the Jülich system the scintillator is viewed by two arrays of wavelength shifting (WLS) fibres which are orthogonal to each other. Each fibre is connected to a unique pixel of a multi anode photomultiplier tube, MA PMT. When a neutron interacts in the scintillator the extent of light output from all the PMT pixels is determined in the FPGA. This information is passed via an optical or SATA link to a PC. Software in the PC uses a Centre of Gravity algorithm to calculate the position of interaction in the detector.

In the ISIS detectors developed for this project, optical isolators separate the scintillators into 20 mm x 20 mm pixels. The scintillators are again viewed by two arrays of fibres orthogonal to each other. Each pixel is viewed by four 'x' fibres and four 'y' fibres. In these detectors the position of a neutron event is determined by a pattern recognition code in the FPGA. In the ISIS pair coded detector two PMT signals are required to determine the position of neutron interaction and in the ISIS quad coded detector, four PMT signals are required for position determination.

Further details of the two systems follows:

The Jülich signal processing system

Test measurements have been done at the instrument HEiDi in the experimental facility FRM-2 in Garching. The main goals were the neutron efficiency of LiF/ZnS scintillators and preliminary investigation of the performance of a neutron detector prototype based on LiF/ZnS scintillator plates (to absorb neutrons and generating light) in combination with WLS fibres (to drive the emitted light into multi-anode photomultipliers). The aim of these measurements were first to measure the efficiency of different LiF/ZnS scintillators, produced by Applied Scintillation Technologies (AST) and Eljen Technology, for making a neutron detector with the best neutron detection efficiency. Secondly, the spatial resolution has been investigated for different types of scintillator combinations. The efficiency of the neutron detection was extracted at different wavelengths (0.794 and 1.1695 Å) measuring the count rates for different types of scintillators in front of the He-3 neutron detector (Eurisys 73NH17/ 5X) available at HEiDi. The scintillators used vary in the mixture of LiF and ZnS, thickness, and in shape. It was decided to proceed with the Eljen scintillator, due to efficiency and reproducibility.

Using a set boron masks, due to comparison reasons, made of different arrangements of holes, the resolution of the detector with double ended fibers on one pixel, was investigated and compared to the single ended fiber readout. Due to the higher light collection, it was decided to proceed with the double sided light readout per fiber per MaPMT pixel. An example of these studies is presented in

Figure 1. Here a mask made of holes with a diameter of 4 mm and a pitch of 10 mm was used. The left panel of the picture shows the distribution of the reconstructed neutrons events in the scintillator from Eljen with 500 µm thickness. The event distribution for the slice of bins along the y-axis through the event maximum is shown in the right panel of the figure. The result of a multi-gaussian fit to these data is

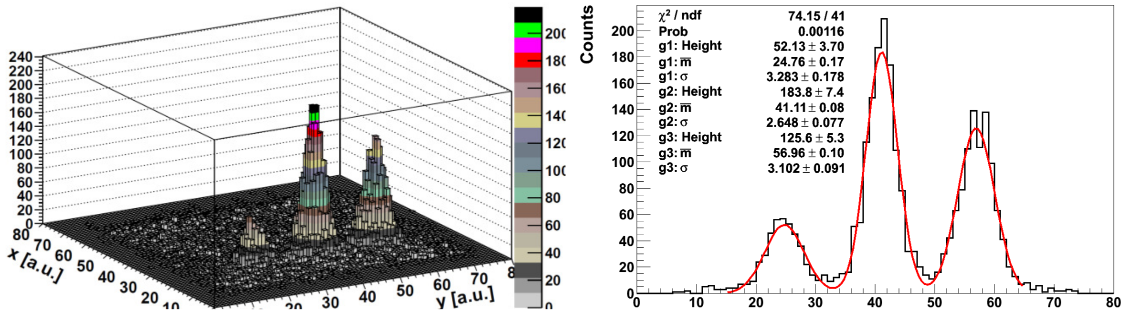

Figure 1: A multi-gaussian fit performed on the data accumulated in TREFF shows a resolution of 3.81 ±0.18 mm, as described in the text.

presented in the inset panel: the distance between the holes and the hole size (as FWHM) are correctly reconstructed, resulting in a promising good spatial resolution. With the Center-of-Gravity Method over the illuminated WLSF reconstructed peaks with FWHM of δ = 2,65 ±0,13 bin the calculated resolution in millimeter is an outcome of δ = 1,62 ±0,08 mm with a FWHM of 3,91 ±0,18 mm.

A measurement with a small size prototype for determination of neutron event characteristics and development of detection algorithm was finally done. The readout electronics including the board design and fabrication for a 64 channel MaPMT has been tested and finished.

The study has shown that the readout electronics, the signal processing and the event reconstruction algorithm is working well. This will now be implemented in a bigger area WLSF detector with up to five readout modules and a size of about 28 cm x 40 cm.

The ISIS signal processing system

For reference purposes of this report the two scintillation detectors developed at ISIS for this project and described in D21.1 and D 21.3 will be referred to as the WP21 detectors. One of these is the pair coded detector referred to as the WP21 PC detector, the other is the quad coded detector referred to as the WP21 QC detector.

In the first ZnS:Ag/^{6}LiF WLS detectors developed at ISIS the position of a neutron event was determined using a pattern recognition algorithm that uses PMTs with signals above a threshold. This works well for detectors where detector pixels are made from individual scintillators optically isolated from each other, where the fibre coding is pair coded and where PMTs are of the single cathode type. It has the advantage that spurious events, for example caused by two neutrons at the same time, can easily be recognised and rejected. However the detectors developed at ISIS for this project needed to be able to cover large areas in a cost effective manner. In this case there is a need to use continuous sheets of scintillator, MA PMTs and ideally quad rather than pair coding. All of these features result in optical cross-talk, either between the detector pixels or between the PMT pixels, For a detector using an algorithm based on PMTs with signals above a threshold, optical cross talk degrades detector performance since the PMT pattern is too complicated to resolve in some instances. . To reduce the degradation due to optical cross-talk, three new signal processing methods have been developed. All of these methods are based on a pattern recognition system. The original method, the three new methods and the results obtained from them are described below.

Original firmware:

The effect of optical cross-talk on the detection efficiency of the WP21 PC detector with the original position calculation algorithm is shown in Figure 2. The reference detector, which doesn't suffer from optical cross-talk, and the WP21 PC detector should have the same count rate for the operating threshold of 200mV, as both have the same amount of scintillator. This is indeed the case if position information is not required: “WP21 PC, total” curve. However, as the detectors developed for WP21 have to be position sensitive, full efficiency of the WP21 PC detector is not reached with the original firmware: “WP21 PC, identified” curve. This loss of efficiency is caused by optical cross-talk that prevents the position calculation algorithm in the firmware from determining the position of neutron absorption.

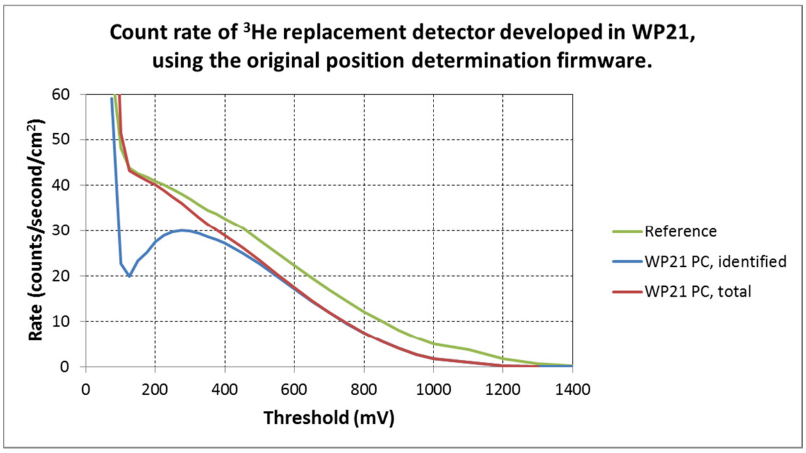

Figure 2. Comparison of count rates of the WP21 PC detector and a reference detector without optical cross-talk. The reference detector is made with individually wrapped scintillators and single anode PMTs. The “WP21 PC, identified” graph is made using events where the position of the neutron absorption can be identified. “WP21 PC, total” shows the count rate of all events, independent of whether the position could be determined or not.

Method 1:

To alleviate the effects of optical cross-talk, extra code has been added to the firmware that prevents signals from PMTs that are not in coincidence in the given fibre coding scheme from being used in the pattern recognition algorithm. This cross-talk reduction algorithm has the advantage that the pattern recognition algorithm will still be able to efficiently reject spurious events. Since the pattern recognition uses a 1 µs coincidence window from the moment that a PMT signal goes above threshold, the dead time for position calculation is < 2µs and doesn't affect the count-rate capability of the detector. The disadvantage of method 1 is that it is not able to reduce the effect of optical cross-talk between scintillator elements. Also, the effectiveness of the cross-talk handling depends on the exact fibre coding scheme that is used for the detector. Figure 3 shows the results using this firmware for a detector with optically isolated scintillator elements and a MA-PMT. This detector will have optical cross-talk between PMT pixels, but not between scintillator elements. The results show that the count rates of both detectors is the same and that method 1 is therefore very effective in handling cross-talk between MAPMT pixels. Since WP21 detectors suffer from optical cross-talk between scintillator elements, and the effects of this type of optical cross-talk can't be reduced with method 1, other algorithms have been developed to reduce optical cross-talk effects.

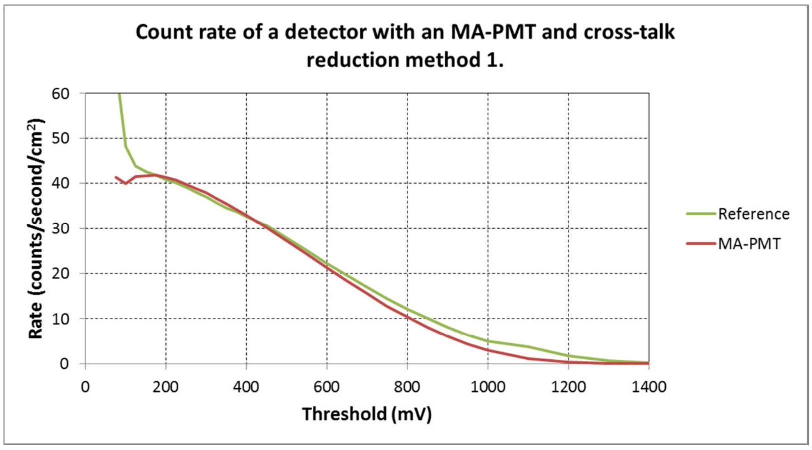

Figure 3. Count rate of a detector with a Multi-Anode PMT (MA-PMT) that uses method 1 for handling optical cross-talk. The detector with the MA-PMT suffers from optical cross-talk between PMT pixels, but has optically isolated scintillator elements.

Method 2:

Method 2 introduces the concept of two types of threshold: one for neutron discrimination and a higher one for position determination. For as long as the signal is above the threshold for neutron discrimination, the electronics determines the highest (position determination) threshold with a coincidence. The PMT pattern associated with this threshold is then used in the pattern recognition algorithm to determine the position. The effectiveness of this algorithm is independent of the fibre coding of the detector. The algorithm is also able to reduce effects due to optical cross-talk between scintillator elements as well as cross-talk between PMT pixels. Since the electronics needs the full time that the signal is above the neutron discrimination threshold for position reconstruction, the dead time of the detector can be more than 10 µs, reducing the count-rate capability of the detector. Spurious events are much less likely to be rejected using method 2 than method 1. Figure 4 shows the count-rate of the WP21 PC detector with firmware that implements position determination algorithm method 2. The count-rate of the WP21 detector is now the same as the reference detector, proving that the optical cross-talk effects have been effectively dealt with.

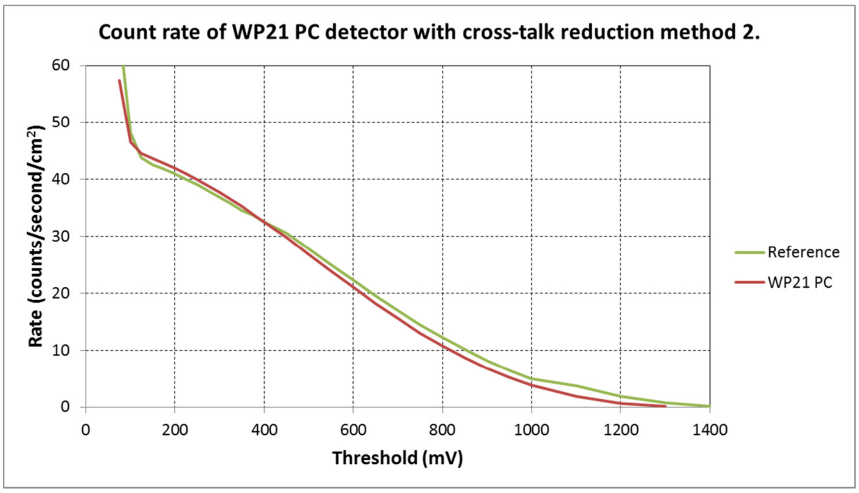

Figure 4. Count rate of the WP21 PC detector that has cross-talk reduction method 2 implemented in the firmware.

Method 3:

In method 3 a “peak search” algorithm is implemented to select the PMT signals with the highest amplitudes. Method 3 can be regarded as a modification of method 2 with an “infinite” number of thresholds for position determination. The implementation of method 3 in electronics is however very different and the part of the firmware that determines the position of neutron absorption was completely rewritten. Parameters of the “peak search” algorithm have been optimised for handling the multiple peaked signals from WP21 detectors. Like method 2, method 3 is able to handle all types of optical cross-talk and is effective for all fibre coding schemes. Method 3 has the same disadvantages as method 2, namely a relatively long dead time and ineffective rejection of spurious events. Figure 5 shows the count rate of the WP21 PC detector with method 3 implemented in the firmware. It clearly shows that the count rate of the WP21 detector matches the count rate of the reference detector. Method 3 is therefore capable of handling the optical cross-talk in the WP21 detector. In fact, there is only a few percent difference in count rates between a WP21 PC detector using method 2 and method 3. Both methods therefore can handle optical cross-talk just as efficiently. As method 3 requires less logic in the electronics, and has a more intuitive algorithm, method 3 is preferred over method 2.

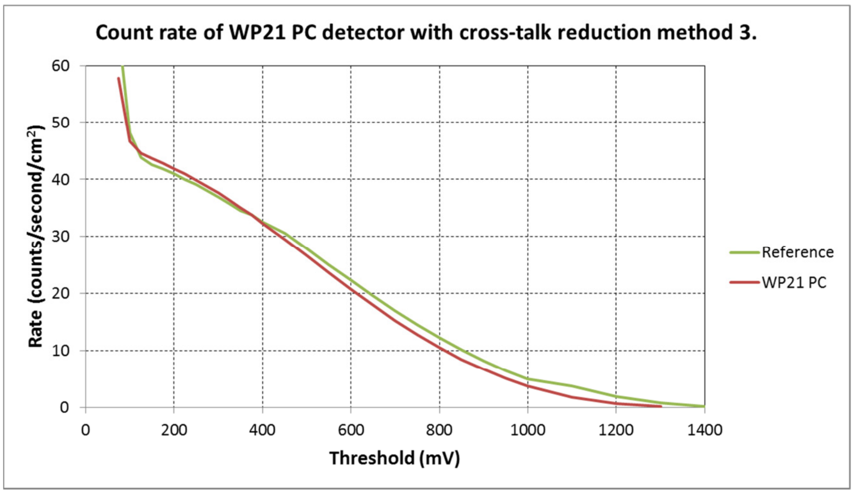

Figure 5. Count rate of the WP21 detector that has cross-talk reduction method 3 implemented in the firmware.

Method 3 has also been implemented in the firmware of the WP21 QC detector. This detector was less favourable because it could not achieve the efficiency of the WP21 PC detector. Figure 6 shows the count-rate of the WP21 QC detector for electronics with method 3 implemented in the firmware and for the original electronics that does not have a cross-talk reduction algorithm implemented. The graph of the (2-fold coincidence) reference detector has been scaled in the X-axis to compensate for the factor of 2 less light collected by a PMT pixel of a 4-fold coincidence detector. The improvement in count rate for the 4-fold coincidence detector using the new firmware is spectacular. Using the new firmware, the 4-fold coincidence detector is now able to achieve full detection efficiency. This could make the 4-fold coincidence detector an attractive candidate as a ^{3}He replacement detector, since 4-fold coincidence detectors usually have lower gamma sensitivity and lower sensitivity to background radiation.

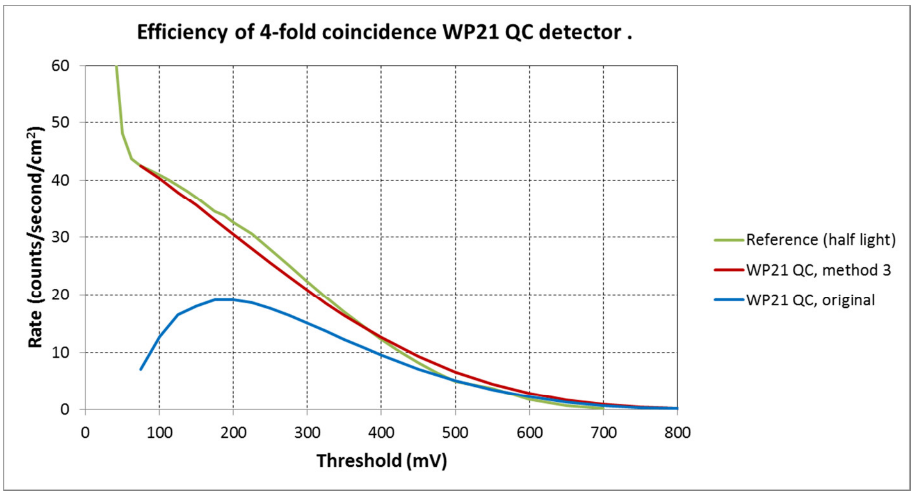

Figure 6. Count rate of the WP21 QC detector. Firmware with method 3 implemented, enables the 4-fold coincidence detector to achieve full detection efficiency. Results of the 4-fold coincidence detector without cross-talk reduction algorithm are shown by the WP21 QC, original curve.

Summarizing, new firmware has been developed for the electronics of the WP21 detectors that is able to handle optical cross-talk in the detector and hence allow the detector to operate at full detection efficiency. Three algorithms, methods 1, 2 and 3, were developed and evaluated with the 2-fold coincidence detector, WP21 PC. All algorithms are capable of increasing the detection efficiency to its desired level. Method 3 is the preferred algorithm for the WP21 PC detector. Tests have shown that, using the new firmware, a 4-fold coincidence fibre coding scheme is now also a viable option for a large area ^{3}He replacement detector.

Conclusion

Different signal processing systems have been developed for the Jülich and ISIS $ZnS:Ag/^{6}LiF$ scintillation detectors. The processing systems are dedicated to the different principles in detector design different methods of position reconstruction. Both schemes can easily be adapted to cope with further demands in detector performance as these detectors continue to be developed.