Work Package 21: Detectors

STFC
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1. Summary

1.1 Description of work package objectives and context

The aim of this work package is to develop new neutron detectors for neutron scattering applications. The intention is that these new detectors should deliver acceptable performances and have the potential to cover large areas in a cost effective manner, without resorting to ^{3}He as a neutron converter. Two promising technologies have been identified for development within this programme: ^{6}Li loaded scintillation detectors, largely based on wavelength shifting fibre readout, and gaseous detectors which use solid ^{10}B converter. The work package is divided into two tasks with a development line allocated to each task. The driving force behind this programme is the sudden increase in the cost of ^{3}He and its near unavailability for all but the smaller detector systems. For many years neutron scattering facilities have depended on ^{3}He for a large fraction of their detector requirements. Demand for ^{3}He has increased rapidly, mainly due to US Homeland security requirements, while production has fallen significantly as tritium production capacity has decreased. For neutron scattering facilities to function effectively it is essential that alternative, cost effect detector technologies are developed that can mimic or improve upon the performance enjoyed to date with ^{3}He based detectors. This work is expected to provide a basis for such technological development.

1.2 Work performed since the beginning of the project

ISIS and Jülich have each designed and produced hardware for two WLS fibre-coded scintillation detectors. These detectors differ in terms of size, pixel resolution, fibre code and PMT type, (T21.1.1, D21.1, D21.2, D21.3). ISIS and Jülich have each designed and produced dedicated electronics hardware for their detectors, (T21.1.2, D21.4, D21.5, D21.6) and developed dedicated signal processing schemes for determining when and where on the detectors neutron events occur, (T21.1.3, D21.7). CNR has designed and produced a scintillation detector based on GS20 glass scintillator with a SiPM readout. Scalable hardware, electronics and signal processing is in development, (T21.1.4, D21.8).

TUM and BNC have evaluated the performance of B_4C coatings produced by both magnetron sputtering and electron beam evaporation and by different manufactures (T21.2.1, D10). TUM have developed a macro-structured boron-lined converter offering improved detection efficiency, (T21.2.1, D13). HZB has explored alternative techniques for producing ^{10}B films and pursued thermal plasma powder spray deposition as a promising production technique. HZB and BNC have produced a 2D position sensitive test detector for evaluating the performance of films produced by alternative techniques, (T21.2.2, D21.11). TUM has designed and built a small test detector to evaluate coatings produced by magnetron sputtering and electron beam evaporation, (T21.2.3, D21.12). TUM has designed and built a concept detector based on a stack of large area MWPCs, while CEA is developing a concept detector using boron layers in conjunction with bulk Micromegas detector technology, (T21.2.4).

1.3 Expected final results

The expected result of this work is the development of two new neutron detector technologies suitable for large area neutron detectors for neutron scattering applications. In the absence of sufficient quantities of ^{3}He at an affordable price, new detector technologies are an essential requirement for both new and existing neutron scattering facilities to realise their full scientific potential. The work carried out at these facilities maps directly onto the European science programme which is addressing concerns including climate change, health care, energy, food safety and security.

2. Project objectives for the period

2.1 Overview of project objectives for the period

This work package is divided into two tasks, Task 21.1 and Task 21.2.

Task 21.1 is the development of scintillation detectors. This task is divided into five subtasks. Task 21.1.1 is the development of scintillation detector hardware readout by wavelength shifting fibres, whereby STFC and Jülich each develop a demonstration detector system with a sensitive area of ~ 30 x 30 cm^2. This task is expected to be completed by month 24. Task 21.1.2 is the development of electronics hardware for these detectors. The STFC and Jülich work is expected to be complete by months 24 and 36 respectively. Task 21.1.3 is the development of signal processing for these detectors, which is expected to be complete by month 36. Task 21.1.4 is the evaluation of the potential of SiPMs for the neutron scattering applications and is carried out by the CNR. This task runs throughout the JRA, is expected to generate an interim report by month 24 and be 75% complete by the end of this period. The final subtask, 21.1.5, is detector evaluation of the optimised detectors produced in tasks 21.1.1 to 21.1.4 and is not due to start until month 37.

Task 21.2 is the development of gas detectors based on solid ^{10}B converter. This task is divided into four subtasks. Task 21.2.1 is the optimisation of substrate and production parameters of the ^{10}B converter layers and is being carried out by TUM and BNC. Converter layer production is confined to magnetron sputtering and electron beam evaporation. Task 21.2.2 is devoted to exploring alternative techniques for producing ^{10}B films and the evaluation of the performance of these films in gaseous detectors. This task is being undertaken by HZB with BNC contributing to the design and construction of a 2D position sensitive detector to analyse converter layers produced by alternative techniques. Task 21.2.3 is the design, production and use of a small prototype detector primarily for the evaluation of films produced in task 21.2.1. The design and production of the detector was carried out in period 1. Use of the detector by TUM is described in section 21.2.1. These three subtasks are expected to be complete by the end of this period. Task 21.2.4 is a concept study for a large area detector. Two detector types are being considered, one based on a wire readout lead by TUM and the other based on a Micromegas readout lead by CEA. Within this reporting period this work is expected to be 66% complete.

2.2 Work progress and achievements

2.2.1 Work progress for each task

Task 21.1 Development of scintillation detectors based on WLS fibre

T21.1.1 Detector development

ISIS and Jülich have each produced two scintillation detector modules using ZnS:Ag/^{6}LiF scintillator and wavelength shifting (WLS) fibre. All four detectors use vacuum PMTs to convert the light from the WLS fibre to electrical signals for processing. The four modules have different characteristics and have been developed to determine the effects of different methods of fibre coding and different methods of signal processing and position determination. Photographs and brief details of the ISIS and Jülich detector hardware are presented in the deliverables D21.1 and D21.2 respectively. Further details of the ISIS and Jülich detector hardware are given in the report D21.3. All deliverables were submitted in month 24. This task is now complete.

T21.1.2 Electronics Hardware development

Work has continued on the development of the electronics systems for the ISIS detectors. In these systems the signals from the PMTs are fed into 8-channel pre amp/comparator cards located at the back of the PMTs. Outputs from the comparators are fed to an FPGA card in the detector housing. Two versions of the electronics have been developed. In the original version the FPGA card was completely designed at the component level and can handle 32 PMT signals. The second version has been based on a commercial Enclustra FPGA module complete with USB and Ethernet outputs and can handle 64 PMT signals. The new card is shown in Figure 1. As part of the design upgrade of the electronics hardware, the pre amp comparator cards have been modified with Ethernet outputs, which has improved system reliability and immunity to noise pick-up. This work was completed by month 24, D21.4.

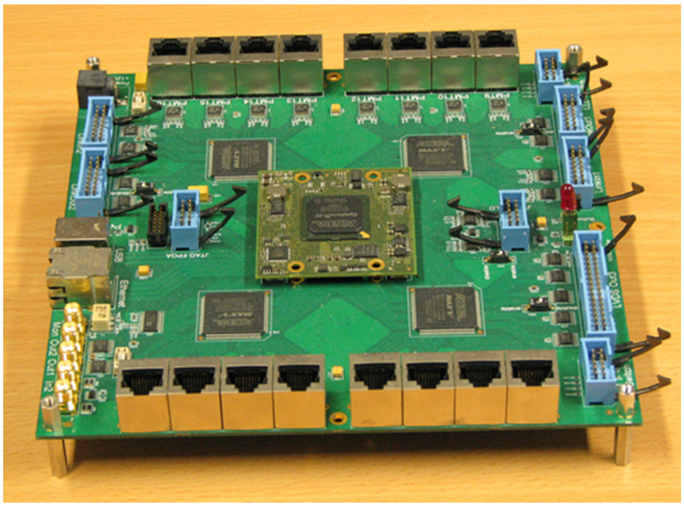

Figure 1. The new 64 channel ISIS FPGA card with the Enclustra daughter board.

During this period Jülich have completed the development of their ASIC based electronics hardware. Jülich have chosen to use the MAROC ASIC which is commercially available from Omega and has been designed specifically for reading out multi anode PMTs. In the Jülich system the output from the MAROC is connected to an FPGA which in turn is connected via an optical link to a standard PC. Image reconstruction is carried out in the PC. Initially a 1.25 Gbit optical link was used for data transfer, but this has since been replaced by SATA architecture which increases the maximum data transfer rate to 6 Gbits/s. The SATA system allows smaller connectors, cables and components to be used, whilst reducing power consumption. The Jülich electronics ASIC based hardware has already been implemented on the Jülich 5 x 5 cm^2 scintillation detector as seen in Figure 2. This electronics will be implemented on the larger detector in due course. In addition to the detector electronics a 64-channel pulse simulator has been developed which is shown in Figure 3. This simulator has been crucial in testing the detector electronics and optimising the pulse processing scheme. This work was completed by month 36 and deliverable D21.5 is submitted with this report.

Further details of the Jülich and ISIS detector electronics hardware are contained in the report D21.6, submitted with this report. This task is now complete.

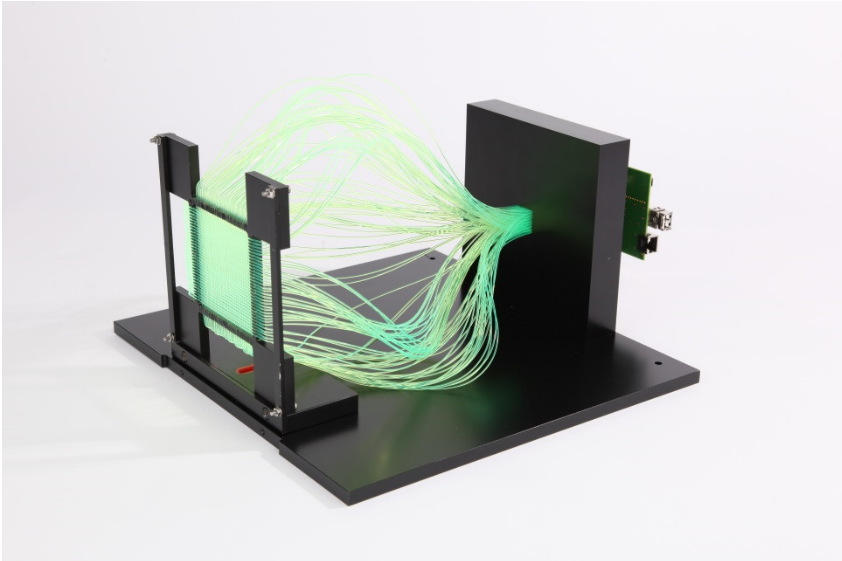

Figure 2: The prototype Jülich scintillation detector with a 32 fibre grid per layer and double ended fibre readout. The readout electronics is on the right hand side of the picture and the fibre connector to the PC can be seen.

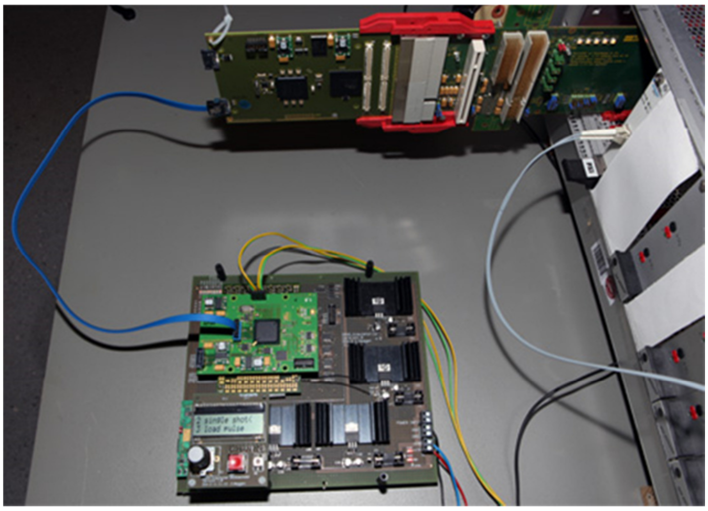

Figure 3: The FPGA readout board hooked on to the 64 channel simulator board and connected via the blue SATA cable to the CPCI read out board.

T21.1.3 Signal Processing

Jülich have developed a signal processing system where the outputs from the PMTs are processed in the FPGAs in the detector housing. Processed PMT data is then sent via the optical or SATA link to the PC where position reconstruction is carried out in software using a centre of gravity method. Evidence that this system is working well is provided by the good spatial resolution obtained from analysing appropriate neutron images recoded with this detector.

At ISIS position determination is carried out by a pattern recognition algorithm where the position of an event is determined by a small subset of PMTs. This number is dependent on the degree of fibre coding and is usually two for a pair coded fibre detector and four for a quad coded detector. The detectors developed at ISIS for this project have been designed to cover large areas in a cost effective manner. To meet these requirements use is made of continuous sheets of scintillator, MA PMTs and ideally quad rather than pair fibre coding. All of these features result in optical cross talk either between the detector pixels, or between the MA PMT pixels, which degrades detector performance, particularly in terms of detector efficiency. To minimise the effects of optical cross talk, three new signal processing methods have been developed. All of these methods are based on a pattern recognition system. Improved signal processing algorithms have enabled the expected detection efficiency of the ISIS pair coded detector to be realised, while the latest method has shown that even the expected neutron detection efficiency of the ISIS quad coded detector can be achieved. Thus a quad coded scintillation detector is a possible option for a large area 3He replacement detector.

Whilst the signal processing of both the Jülich and ISIS detectors may be adjusted as the detailed detector evaluation of task 21.1.5 proceeds, the basic signal processing schemes of both the Jülich and the ISIS detectors have been established. Further details of the Jülich and ISIS detector signal processing are contained in the report D21.7, submitted with this report. This task is now complete.

T21.1.4 SiPM Evaluation

CNR have continued their programme to explore the potential of SiPMs for reading out large area neutron detectors. The system being investigated is a 3 x 3 mm^2 GS20 glass scintillator coupled via a Plexiglass light guide to a 3 x 3mm^2 SiPM produced by IRST in Trento, Italy. An interim report on SiPM detector performance, D21.8, was submitted in month 24.

In the current period work has focussed on developing a pulse shape analysis routine that can be used to identify neutron pulses amongst the intrinsic noise pulses of the SiPM. A data set from a device has been recorded digitally and is being used to develop the analysis routine in software. The digital data is composed of a set of neutron peaks and random smaller peaks due to the noise of the SiPM. A typical result is shown in Figure 4. LHS. The neutron pulse has been fitted with a simple function describing the shape of the pulse. So far, analysis has been done off line, but a fitting procedure is being developed for use in real time applications. Although the data analysis is not complete, this approach is already quite effective. A typical spectrum obtained using this procedure is shown in Figure 4 RHS. In the final year work will concentrate on optimising the analysis procedure. In addition, a neutron test will be carried out on a converging light guide system in an effort to demonstrate the feasibility of using SiPMs that are significantly smaller than the area they view. This is a key requirement in demonstrating the potential of SiPMs for large area neutron detectors.

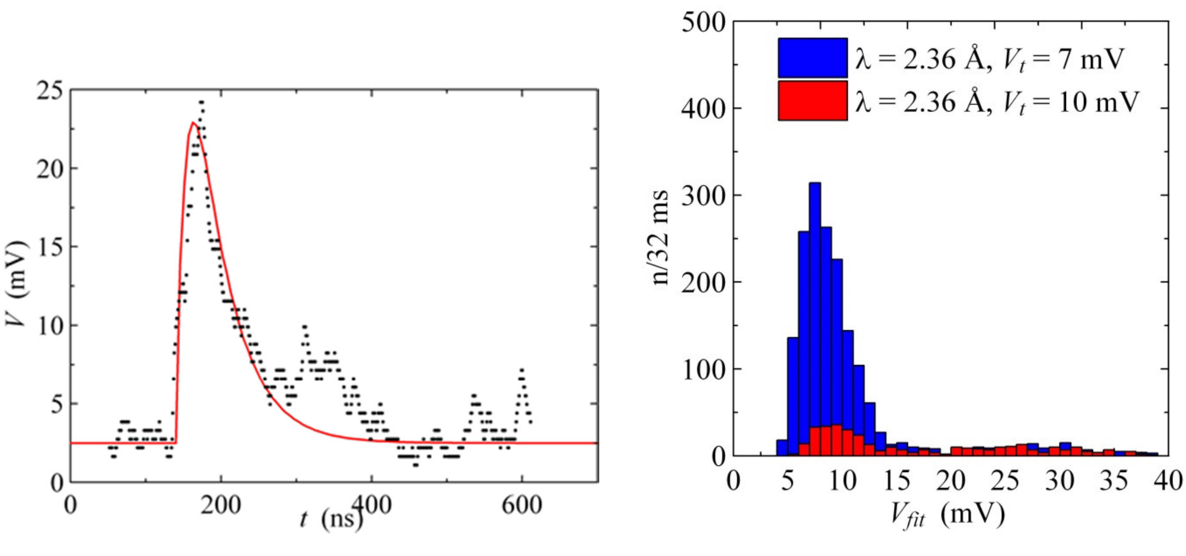

Figure 4. LHS: Output signals from the SiPM coupled to a GS20 glass scintillator via a Plexiglass light guide. Noise signals from the SiPM are superimposed on the neutron signal. The red line is a simple fit to the neutron pulse. RHS: Two Neutron pulses of different thresholds extracted from the experimental data set using the fitting routine.

T21.1.5 Detector evaluation and final report
Now that the basics of the ISIS, Jülich and CNR detectors have been established, the coming year will be devoted to a more formal evaluation of the performances that can be obtained with these detectors. The results of this evaluation will be presented in the report on scintillation detector performance, D21.9, which is due in month 48.

Task 21.2 Development of gas detectors based on solid ^{10}B converter

T 21.2.1 Optimisation of substrate and production parameters
T 21.2.3 Measurements with test detector
Concerning the optimisation of production parameters and subsequent neutron measurements carried out in tasks T21.2.1 and T21.2.3, TUM has investigated a variety of samples of ^{10}B coatings provided by several suppliers. These coatings were produced by both magnetron sputtering and electron beam evaporation. BNC has also both produced and evaluated coatings produced by these two techniques. Most of this work has been carried out during PR-1. The principle conclusions from this work are that no significant differences have been found in coating performance from the majority of the suppliers or the technique used to produce the coating. Electron beam evaporation is usually more costly and thus magnetron sputtering is the preferred process at present. Linköping University is well set up to manufacture large quantities of coatings, and to produce samples for R and D purposes in a timely fashion. Thus Linköping is the chosen source of experimental coating for this work at the present time. A report detailing the results and conclusions obtained from this investigation, D21.10, is submitted with this report.

Concerning the optimisation of the substrate, TUM has continued to study the potential of the enhancement of the neutron detection efficiency by applying a suitable topology to the converter surface. GEANT4 simulations have been carried out and compared to experimental results achieved with dedicated prototype detectors. The results of these studies have been published in detail in I. Stefanescu et al., NIM A727 (2013) 109 and in I. Stefanescu et al., JINST 8 (2013). These results are summarised in the report, D21.13, submitted with this report. The grooved converter geometry developed in this task is being used for the large area MWPC detector concept being developed in Task 21.2.4. With the submission of D21.2.10 and D21.2.13, this task is complete.

T 22.2.2 Exploration of alternative production techniques
HZB have continued to explore alternative techniques to magnetron sputtering and electron beam evaporation for producing ^{10}B films. HZB have identified powder spray deposition with a high temperature atmospheric plasma torch as the most promising alternative technique.

In this period a microwave atmospheric plasma system (APS) has been assembled at HZB and applied to produce ^{10}B coatings. A photograph of the system is shown in Figure 5. Different system parameters including microwave power, plasma gas flow, gas flow for beam particle injection and the working distance between the substrate and the plasma outlet have all been studied and optimised. Experimentally it has been found that a suitable gas combination is compressed air as a working gas for the atmospheric plasma torch and argon as a carrier gas for powder injection. Boron layers on a silicon substrate have been formed using APS with a relatively high deposition rate >100 nm/s, Figure 6. The deposited layers have been analysed using SEM and found to be very uniform. Initial attempts to deposit thin boron layers on aluminium have not been successful and the transfer of deposition parameters from silicon to aluminium is not straightforward.

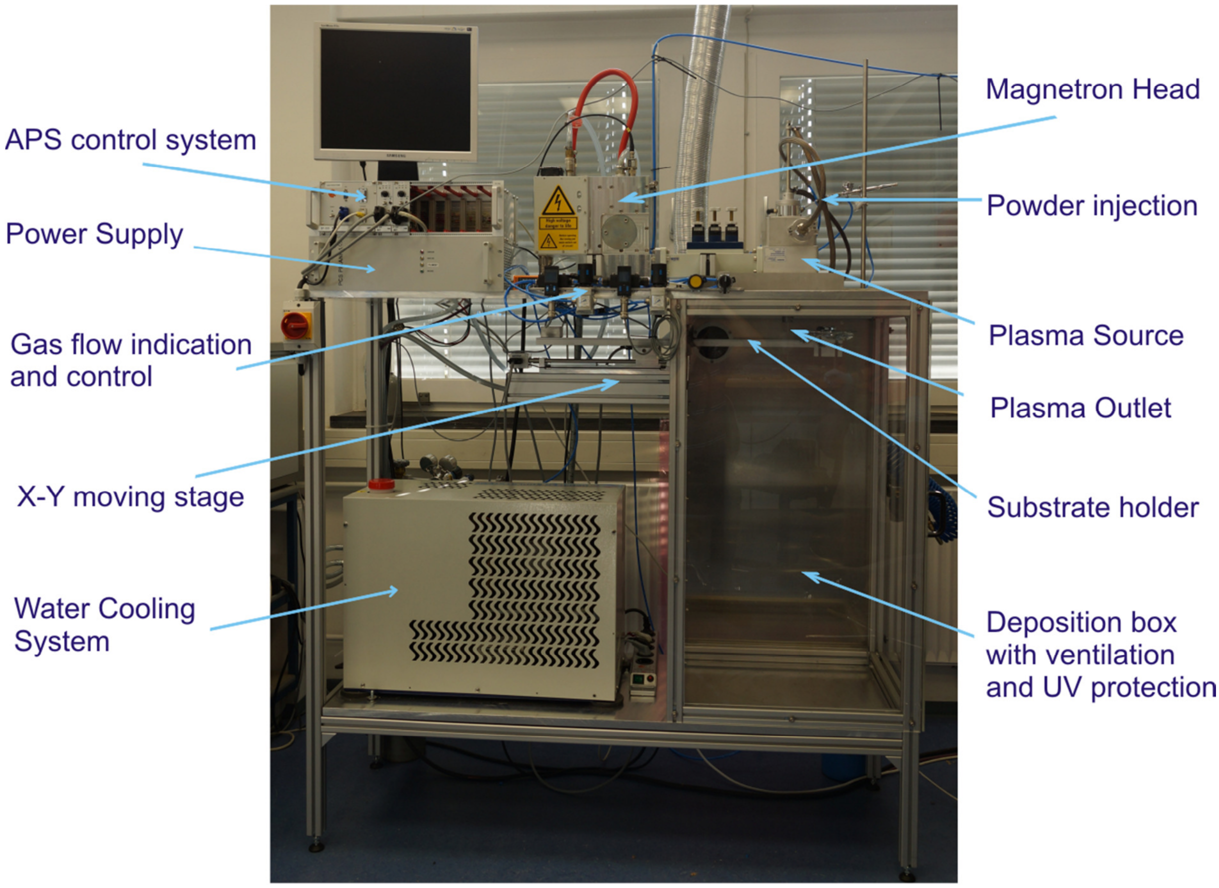

Figure 5. The Microwave Atmospheric Plasma System at Helmholtz-Zentrum Berlin

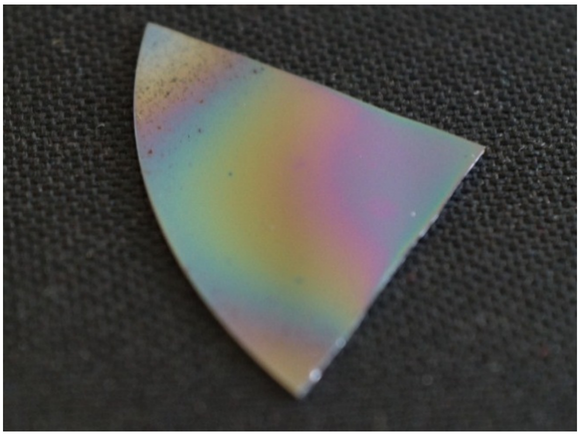

Figure 6. Boron-based coating on silicon deposited using Atmospheric Plasma System

The potential of this technique is considered as high, but more work has to be devoted to further optimisation of the operation parameters and possible pre-treatment of the aluminium surfaces. There is no further resource in terms of staff effort or funding to continue this work at HZB. A report detailing the exploration of alternative production techniques, D21.11, is submitted with this report. This report, D21.11, serves as a useful starting point for others wishing to explore alternative techniques for producing ^{10}B films in the future.

The $^{10}B_4C$ layers produced in this task were evaluated with a test detector specifically designed for this purpose. This detector is similar to the test detector described in section T22.2.3, but has been designed with 2D position sensitivity so that coating uniformity can be readily measured. The wire frames and delay lines for this detector have been built by BNC and are shown in Figure 7, while the detector mechanics and assembly effort has been produced by HZB. The completed detector is shown in Figure 8. The detector has worked well and has been used to measure absolute efficiency values of HZB's $^{10}B_4C$ converter produced by magnetron sputtering. Further details are attached to the report D21.11 described above.

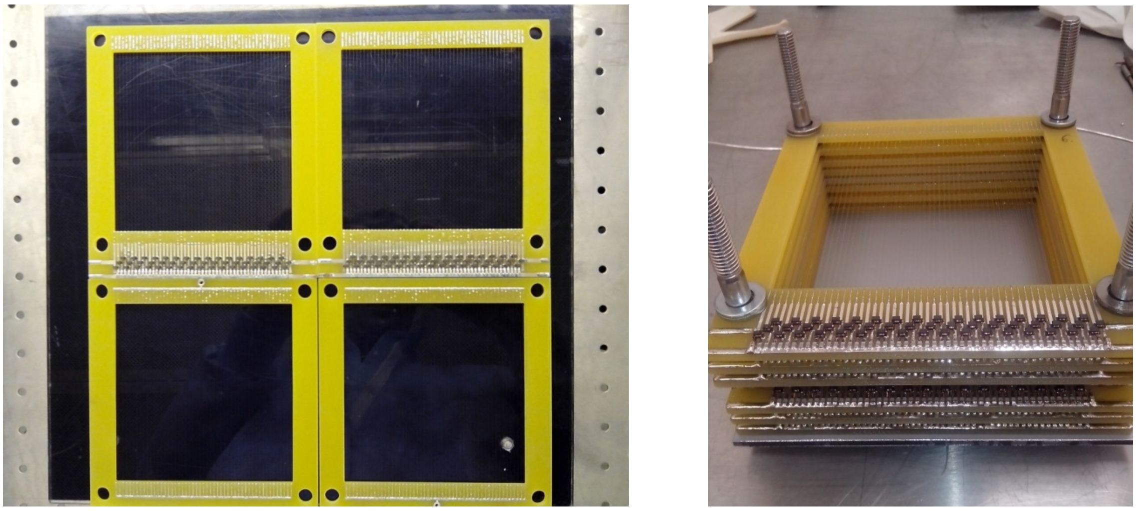

Figure 7. LHS: Individual anode and cathode wire frames for the 2D detector. RHS: The completed stack of wire planes.

Figure 8. The 2D test detector being assembled in the clean room at HZB

T 21.2.3

Task 21.2.3 is the design, production and use of a small prototype detector primarily for the evaluation of films produced in task 21.2.1. The design and production of the detector was carried out in period 1. Use of the detector by TUM to evaluate film production by magnetron sputtering and electron beam evaporation is described in section 21.2.1 above.

T 21.2.4 Concept study of a large area detector

Within this task there are two concept studies being carried out. The first is based on multiwire proportional chamber (MWPC) technology and the second uses bulk Micromegas technology.

a) Concept study based on a MWPC

At TUM work has continued on the development of the large area MWPC concept based on the "grooved converter" design developed in task 21.2.1. A demonstration detector has been produced consisting of two MWPCs with four grooved cathode layers coated with B_4C which acts as the converter. Each cathode layer consists of five individual aluminum converter plates, each with an active area of 40 x 8cm^2. The converter plates are produced by an extrusion technique and have been successfully coated with B_4C at Linköping University. 2D-position information is determined by reading the resistive anode wires. The detector is operated with Ar-CO_2 at ambient pressure and is expected to achieve a spatial resolution of 5 mm x 5 mm.

A key feature of the detector is its concept of reading the resistive anode wire planes by using a global / local grouping illustrated in Figure 9. This concept has been developed in co-operation with mesytec GmbH. In a local grouping wires N and N+2 are connected at one end to form a resistive wire of length 2L and linked to global readout group A. Wires N-1 and N+1 are connected and linked to readout group B. The charge sensitive readout of each local wire group A or B provides spatial information along the wire axis. In addition, each wire group is connected to a global readout group forming a resistive chain that allows the wire group which has been hit to be determined. This provides spatial information orthogonal to the wires. In this way the two-dimension spatial information of the neutron impact position can be obtained by using just 6 readout channels per MWPC layer. This scheme has significant potential for reducing the cost of the electronics for multilayer detectors of this type.

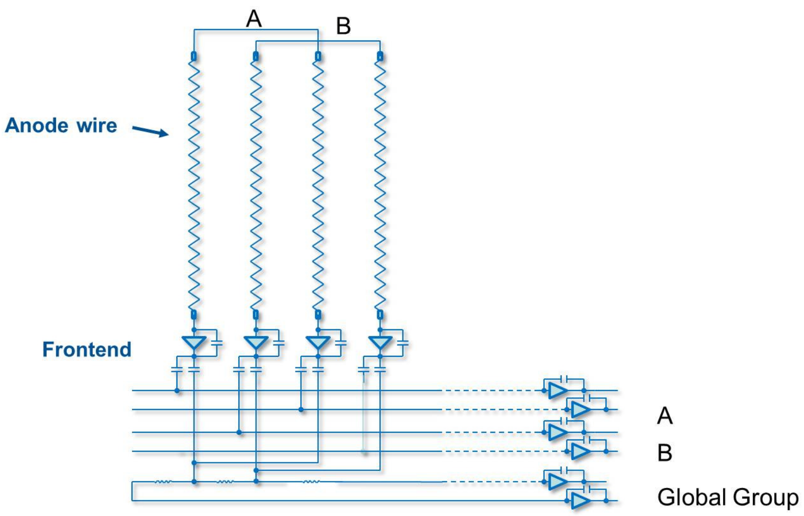

Figure 9. Readout scheme of the $^{10}B_4C$ layered MWPC concept being developed by TUM showing the global / local grouping of the resistive signal wires of one anode wire plane

The local / global readout scheme is implemented in a specific frontend electronic board *MWPC-9,* developed by mesytec GmbH. Each board is directly mounted to the resistive anode wire frame of one MWPC inside the gas volume. Figure 10 shows a photograph of the final detector with two wire planes equipped with *MWPC-9* frontend boards.

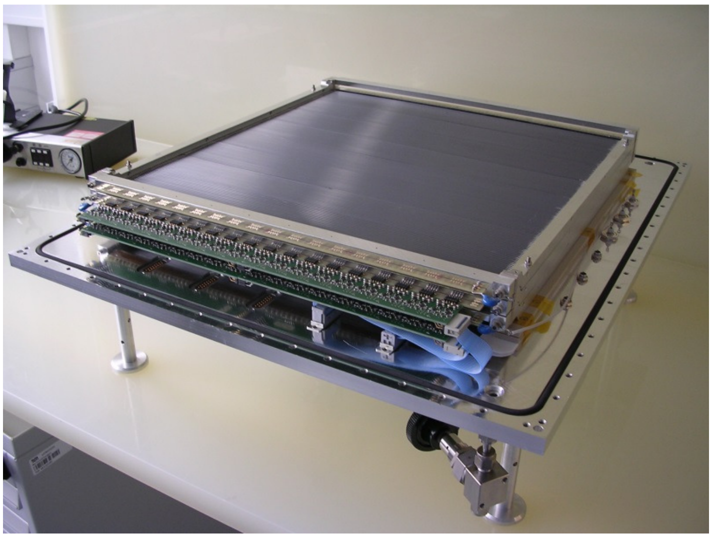

Figure 10. Photograph of the TUM MWPC detector with two wire planes equipped with MWPC-9 frontend boards

In August 2014 the demonstrator was tested for the first time with a collimated neutron beam at the instrument TREFF at FRM II. As a first result, Figure 11 shows the resulting 2D-image of the 2mm x 2mm neutron beam spot, when the detector is shifted in steps of Δy=2.5mm in a vertical direction. A first preliminary analysis of the data taken at TREFF indicates that a position resolution of 5mm x 8mm has been achieved.

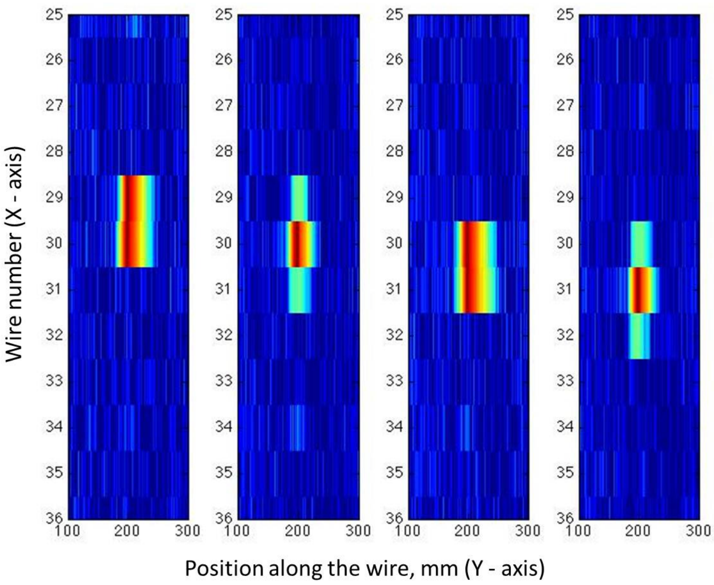

Figure 11. Measured 2D- image of a 2mm x 2mm neutron beam, when the MWPC detector is shifted in a vertical direction in steps of Δy = 2.5mm

This detector concept will continue to be developed in the coming year. The results of this work will be presented in report D21.14, due in month 48.

b) Concept study based on a Micromegas

CEA have continued to work on the development of a gas detector with ^{10}B layers and bulk Micromegas readout. In the latest design a single Micromegas is used in conjunction with a number of nickel grids coated on both sides with $^{10}B_4C$. A schematic of the concept with 5 layers of $^{10}B_4C$ is shown in Figure 12. Electric field simulations have been calculated using COMSOL and voltages appear reasonable. Electron collection efficiency has been simulated in various gases using Garfield and CF_4 has been selected as a suitable gas. Energy deposition calculations show that the best efficiency is obtained with $^{10}B_4C$ layers ~ 2.5µm thick and that two back to back Micromegas detectors with 3 grids on each side give a maximum thermal detection efficiency of ~ 57%.

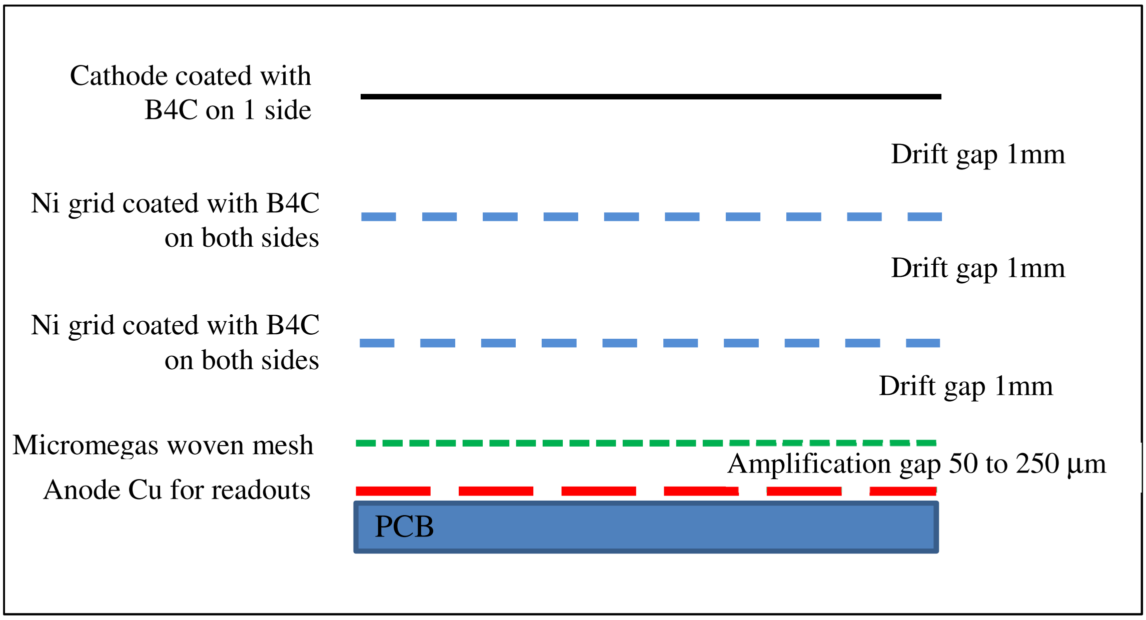

Figure 12: Micromegas thermal neutron detector structure

A detector has been designed and built to test this concept as shown in Figure 13. The nickel grids for the detector were coated with $^{10}B_4C$ at Linkoping University. When exposed to a sealed neutron source the shape of a pulse height spectrum from the detector agrees well with the shape obtained from simulating the detector in Fluka as seen in Figure 14.

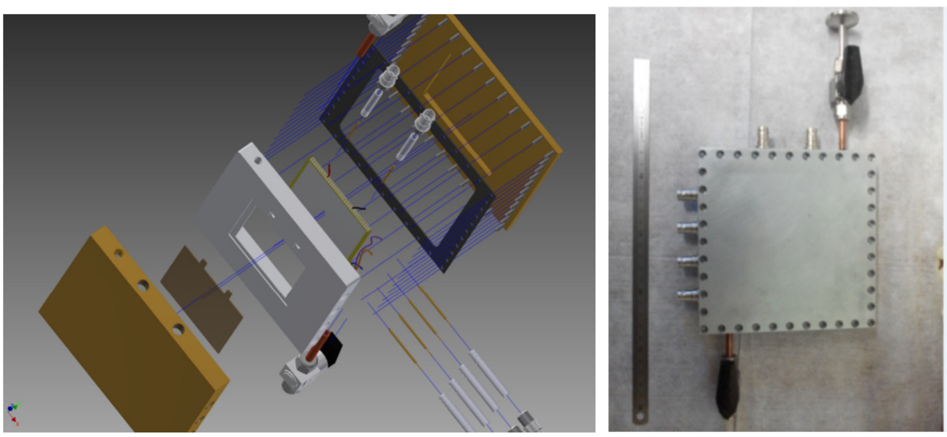

Figure 13. LHS: The Micromegas thermal neutron test detector design.
RHS: The completed test detector

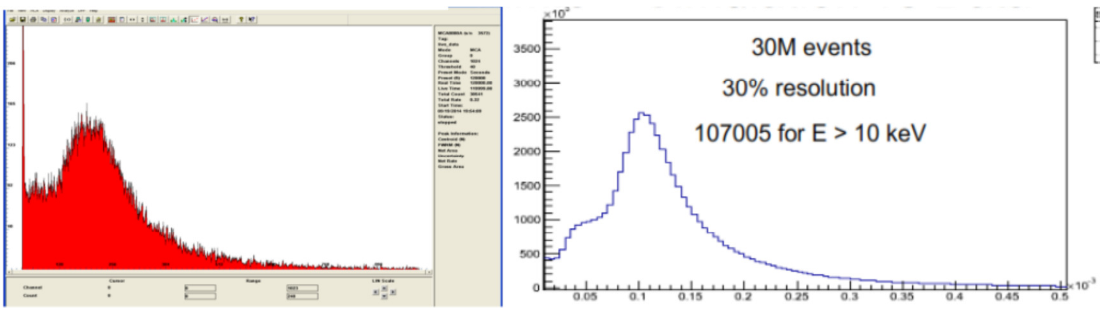

Figure 14. LHS: The measured PHS from the concept Micromegas detector
RHS: The calculated PHS from the detector.

In looking at the cost of this technology, the cost of the grids, frames and materials bonded to the frames is low when bought in large quantities. For a 3 grid detector the cost of these materials is ~ 5000€ per m^2. Such a detector will have a maximum neutron detection efficiency of 25% for thermal neutrons.

This detector will continue to be developed in the coming year. The results of this work will be presented in report D21.15, due in month 48.

2.2.2 Deviations from Annex 1

BNC provided grids for HZB and the number of grids delivered was significantly higher than foreseen. BNC also continued to work with solid converter and much more effort (production and neutron beam and other testing) was devoted to this task, than planned.

The name of deliverable D21.10 has been changed from, "Report on production parameter and substrate optimisation," to, "Report on production parameter optimisation." The name of deliverable D21.13 has been changed from, "Report on converter investigation," to, "Report on optimisation of the converter substrate."

The reason for these changes is that the Linköping, ILL and ESS collaboration has made excellent progress in developing the production of $^{10}B_4C$ coatings by magnetron sputtering. As a result high quality $^{10}B_4C$ coatings have become available to other facilities. Thus D21.10 has been redirected as an evaluation of the quality of $^{10}B_4C$ and ^{10}B layers by magnetron sputtering and electron beam evaporation. The work described in D21.13 has focussed on the gains in neutron detector efficiency to me obtained by varying the shape of the converter surface.

These changes have not significantly changed the direction or schedule of the JRA.

The difficulty CEA reported in PR_1 in recruiting a suitable person to develop the bulk Micromegas concept detector has been resolved and this task is now proceeding to schedule.

2.2.3 Use of resources

	Anticipated staff month usage in period 2	Actual number of staff months used in period 2
ISIS	12	19
Jülich	9	9 (TBC)
CNR		TBC
TUM	12	12
HZB	15	15
BNC	7	15
CEA	7	12 (7 charged to project)

The resources used are close to those predicted and no corrective actions beyond those described in section 2.2.2 are deemed necessary at this time.

Two project meetings have been held during this period. The dates, locations and number of attendees are given in the table below. At each meeting, JRA members gave talks on their respective tasks and results were discussed. The presentations from the two meetings have been collected and will be posted on the website.

Location	Date	Number of attendees
CEA, Saclay, France	26 March 2014	23
FRM2, Munich, Germany	03 December 2014	19

This JRA has benefited greatly from the contributions made by members of the observing facilities from the ILL and ESS. Work carried out by the ILL and ESS within their CRISP project on the development of gaseous detectors based on ^{10}B has been presented and discussed at the JRA meetings. This has ensured that the work within the two projects has not been unnecessarily duplicated and effective synergy has been obtained. The success of the CRISP project has contributed greatly to the rapid progress in Task 21.2.1. The high quality coatings that have been supplied by Linköping University, as a result of the Linköping, ILL, ESS collaboration, have been crucial in progressing the development of the MWPC and Micromegas concept detectors of Task 21.2.4.

Presentations at the JRA meetings have also included talks by non-JRA members. These talks have included progress in the development of ^{10}B detectors at the University of Milano-Bicocca, the work on Micromegas by the Spanish team from the University of Zaragoza and a presentation on a boron GEM from the University of Munich. These talks are important in disseminating information on detector development related to this JRA.

The remaining deliverables due in month 48 are, D21.9, "Report on the scintillation detector performance," D21.14, "Concept study of large area detectors based on MWPCs," and D21.15, "Concept study of large area detectors based on Micromegas." At the present time these tasks are on schedule and no major difficulties are foreseen in delivering the appropriate reports.

3. Deliverables

DELIVERABLES									
Del. no.	**Deliverable name**	**WP no.**	**Lead beneficiary**	**Nature**	**Dissemination level**	**Delivery date from Annex I (proj month)**	**Actual / Forecast delivery date**	**Delivered Yes/ No/ Ongoing**	**Comments**
D21.12	Small size test detector produced	W21	TUM (3)	R	Pu	12	12	YES	
D21.1	ISIS detector hardware produced	W21	STFC (2)	P	Pu	24	24	YES	
D21.2	Jülich detector hardware produced	W21	Jülich (4)	P	Pu	24	24	YES	
D21.3	Report on STFC and Jülich detector hardware	W21	STFC (2)	R	Pu	24	24	YES	
D21.4	ISIS electronics system completed	W21	STFC (2)	P	Pu	24	24	YES	
D21.8	Interim report on SiPM detector performance	W21	CNR (14)	R	Pu	24	24	YES	
D21.5	Jülich electronics system completed	W21	Jülich (4)	P	Pu	36	36	YES	
D21.6	Report on STFC and Jülich detector electronics hardware	W21	Jülich (4)	R	Pu	36	36	YES	
D21.7	Report on signal processing development	W21	Jülich (4)	R	Pu	36	36	YES	

D21.10	Report on production parameter optimisation	W21	TUM (3)	R	Pu	36	36	YES	
D21.11	Report on exploration of alternative production techniques	W21	HZB (6)	R	Pu	36	36	YES	
D21.13	Report on optimisation of the converter substrate.	W21	TUM (3)	R	Pu	36	36	YES	