Ref. Ares(2017)256893 - 17/01/2017

BrightnESS

Building a research infrastructure and synergies for highest scientific impact on ESS

H2020-INFRADEV-1-2015-1

Grant Agreement Number: 676548

Deliverable Report: D4.1 – Integration Plan for Detector Readout

1 Project Deliverable Information Sheet

BrightnESS Project	Project Ref. No. 676548	
	Project Title: BrightnESS - Building a research infrastructure and synergies for highest scientific impact on ESS	
	Project Website: brightness.se	
	Deliverable No.: D4.1	
	Deliverable Type: Report	
	Dissemination Level:	Contractual Delivery Date: 30.06.2016
		Actual Delivery Date: 17.01.2017
	EC Project Officer:	Mina Koleva / Anna-Maria Johansson

2 Document Control Sheet

Document	Title: Integration Plan for Detector Readout	
	Version: 1.0	
	Available at: https://brightness.esss.se	
	Files:	
Authorship	Written by	Scott Kolya
	Contributors	Steven Alcock, George Gimas, Fatima Issa, Jon Taylor, Thomas Gahl, Tobias Richter. Morten Christensen
	Reviewed by	Richard Hall-Wilton (WP4 leader), Hanno Perrey, Roy Pennings
	Approved by	Steering Board

3 List of Abbreviations

ASIC	Application Specific Integrated Circuit
DMSC	Data Management and Software Centre
ESS	European Spallation Source
EPICS	Experimental Physics and Industrial Control System
FPGA	Field-Programmable Gate Array
ICS	Integrated Control System
IKC	In-Kind Contribution
WP	Work Package

Table of Contents

4 Executive Summary

Neutron detectors are the “eyes of ESS”, “seeing” the neutrons scattered within the instruments. As such, they act as cameras for neutrons converting neutrons into electronic signals for the Data Management and Scientific Computing Centre to process and analyse into scientific results.

The neutron detectors themselves are, at the core, electronic items. They are commonly categorized as consisting of a sensor, often termed just “the detector” and electronics performing digitization, triggering, identification, compression, collection, analysis tasks, termed the “readout electronics”. What is written in this report applies equally to the neutron detectors as parts of instruments and to the neutron beam monitors that monitor neutron flux and characteristics alone the neutron beamlines.

At the European Spallation Source (ESS), due to the step change in the capability and complexity of the neutron instruments that will make up the facility, the electronics will be at least 1-2 orders of magnitude more complicated than for previous neutron facilities. This implies a subsequent step change in the approach to the integration of electronics.

Deliverable 4.1 describes the integration plan for the detector readout and details of the breakdown and strategy for its implementation. A functional decomposition based approach has been adopted for the electronics integration. This treats the detector readout as a modular system. By clearly defining interfaces, and points of integration, it allows a generic readout to support the variety of detector designs that will be needed for the ESS instruments at minimum cost, whilst allowing for a long-term maintainable detector system, with minimal support levels. The implementation of the integration plan is now well underway both in terms of hardware candidates existing for all stages of this readout, as well as the software and firmware implementation. The interfaces to other groups within ESS have been identified and work on their definition is also progressing well. The most important interface is with BrightnESS WP5.1, where work is proceeding in close collaboration.

5 Status of the Deliverable

This deliverable is the integration plan for the detector readout. The integration plan is now being executed. Details of the breakdown and strategy to the integration plan are given in this section. Greater technical details, with reference to other documents, are given in the subsequent technical details section.

The neutron detectors detect neutrons. They act like cameras for the ESS instruments. The detectors themselves are essentially electronic items, and are sensors for the neutrons. All considerations in this document, applies both for the neutron detectors and the beam monitors for the instruments.

There are 22 instruments in the baseline ESS neutron instrument suite, 15 of which are being built as part of the ESS construction project. This instrument suite is expandable to >35 instruments on the target station. As such, the integration of a large amount of equipment needs careful attention to keep the detectors maintainable. Additionally, the minimum instrument lifetime needs to be 10 years, with the expectation that many instruments will operate well beyond this minimum lifetime.

The instruments themselves are spread over three large instrument halls, with the longest being approximately 150-170m from the ESS target station, with beamline equipment installed along this path length. This geographical spread, along with the quantity of equipment has led to the choice of a dedicated control system to operate the instrument equipment and gather the data from them. The control system chosen is the same as for the accelerator: EPICS (*Experimental Physics and Industrial Control System*). The modular instrument control concept is shown in the figure below.

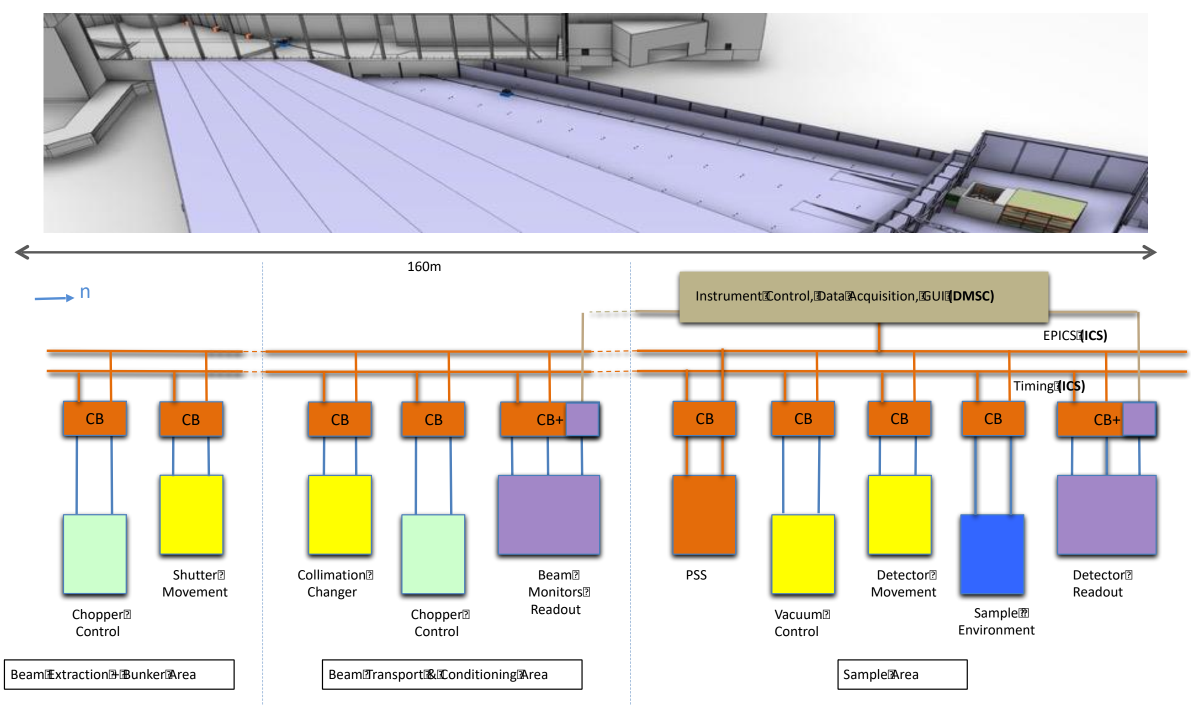


Figure 1: Modular instrument control concept.

The instruments themselves will be built by a wide variety of partners from across Europe, who will realize the ESS project through In-Kind Contributions. To achieve a heterogeneous instrument suite, a systems engineering approach is followed. For the components of instruments, a functional decomposition, as shown in the figure below, is desired. This approach allows a synergetic method towards common technologies between instruments.

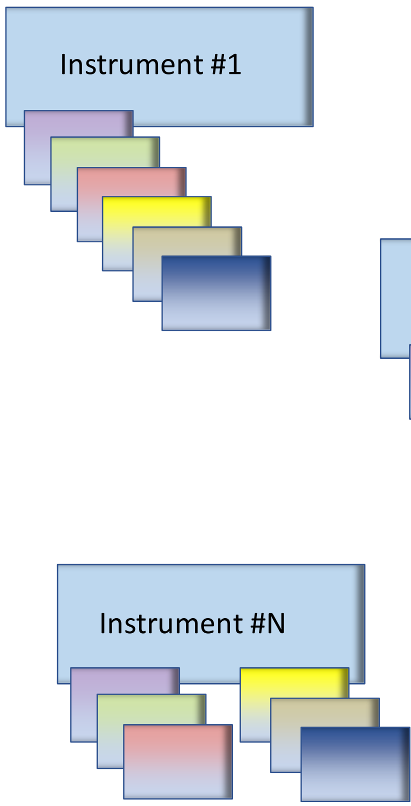


Figure 2: Functional decomposition of an instrument into the component technologies, such as guides, neutron choppers, shielding, optics, detectors, beam monitors, motion control and automation, etc. The different boxes represent these different components of the instrument.

A functional decomposition of neutron detectors is shown below, where the neutron detector is divided into: a) the conversion the neutron into charge or photons, b) the collection of this charge or photos, c) the electronic part of the detector, where the data is formed and c) the data interface to the ESS Data Management and Software Centre (DMSC).

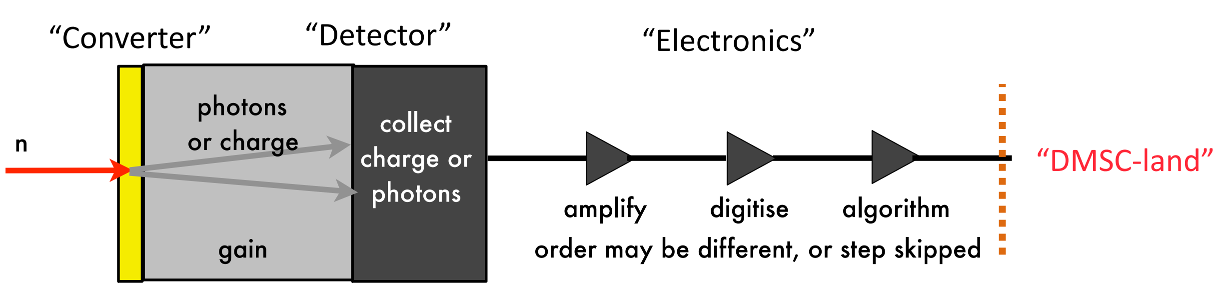


Figure 3: Functional decomposition of neutron detectors.

At a top level, neutron detectors as a system can be simplified, as shown in figure 4 below. This simplification is useful to consider how to streamline the interface definitions. It is interesting to note that in neutron scattering (and in contrast to other big science disciplines, such as high energy physics), instruments are primarily treated with the mechanical engineering integration as the main goal. Detectors are, in contrast, primarily electronic sensor devices, as introduced in the executive summary at the beginning of this report. This means that a change of emphasis is appropriate if optimal performance is to be obtained by the detector system, with consideration of electrical and electronic integration first for detectors, and subsequently determining the mechanical integration around this.

As figure 4 shows, for detectors readout, this can be simplified into the key interfaces for the detector readout:

- Neutronic interface. This is primarily dealt with by determining the detector performance requirements as part of the design process. This is not dealt with further in this document.
- Electrical and Electronic Interfaces, in particular Electronic grounding.
- Mechanical interfaces, including cabling and geographical location.
- Data Interface to Integrated Control System via timing and EPICS.
- Data Interface to Data Management and Scientific Computing.

Figure 4: system diagram of a neutron detector, giving the inputs and outputs to the system.

Within the detector readout, functional decomposition is further carried out, to allow a seamless integration of different detector technologies, from different in-kind partners. This is shown in figure 5 below. Each of these stages can be used to integrate electronics, for example from an in-kind or commercial partner.

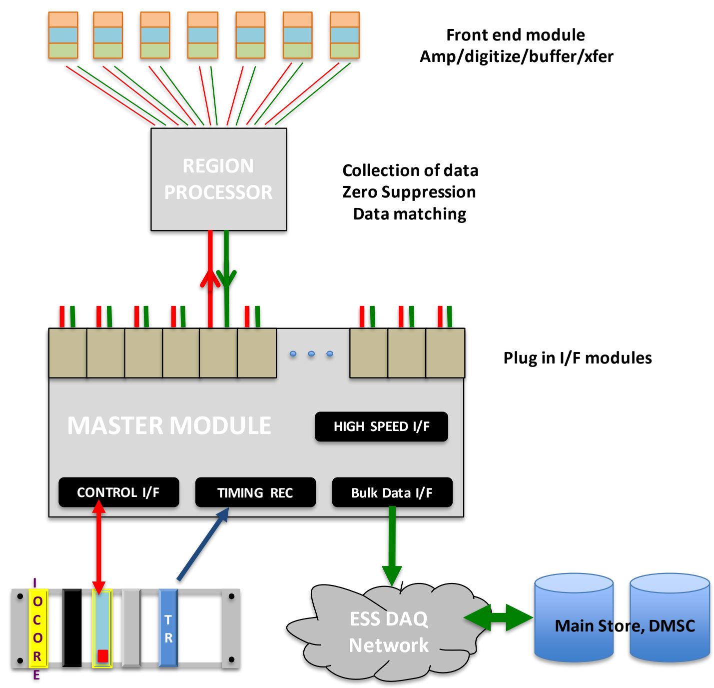


Figure 5: Decomposition of the detector electronics readout into various discrete parts of the readout system.

A plan for all these aspects of the detector readout implementation exists. In many cases, preliminary selection of possible hardware has been made, and implementation is underway. The logical aspects of the detector readout, broken down into parts of the systems, is shown in figure 6 below, as blocks. The individual tasks that are needed to perform this integration are shown as clouds.

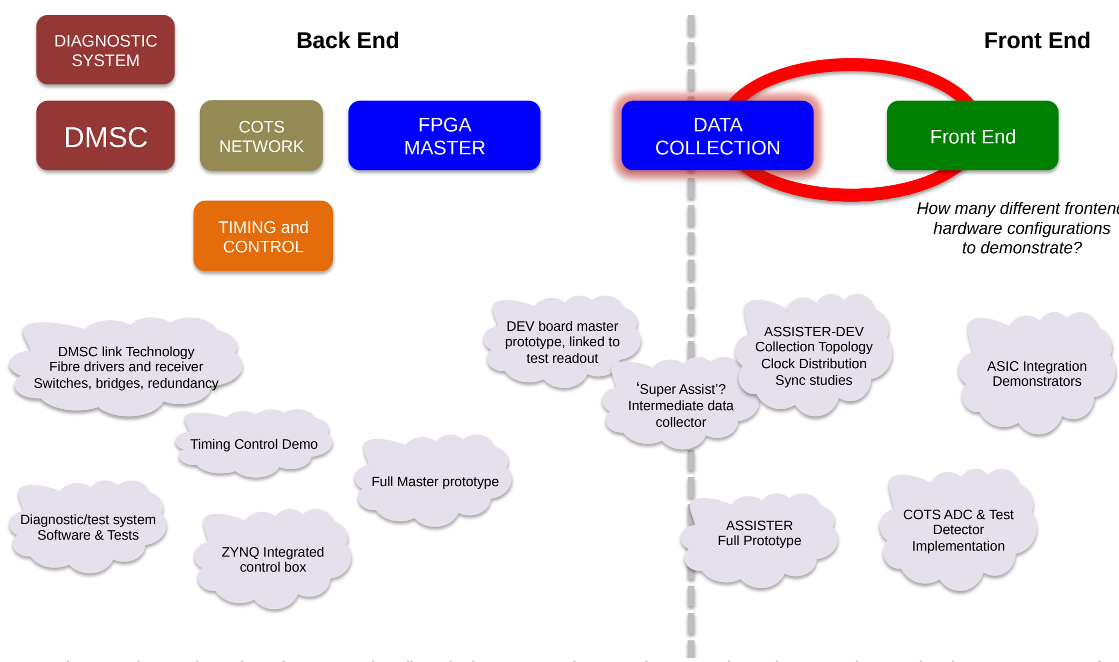


Figure 6: The project plan for the standardized detector electronics readout integration. Blocks represent functions within the detector electronics. Clouds represent tasks required.

Similarly, the plan for the infrastructure elements of the detector readout is shown in figure 7 below.

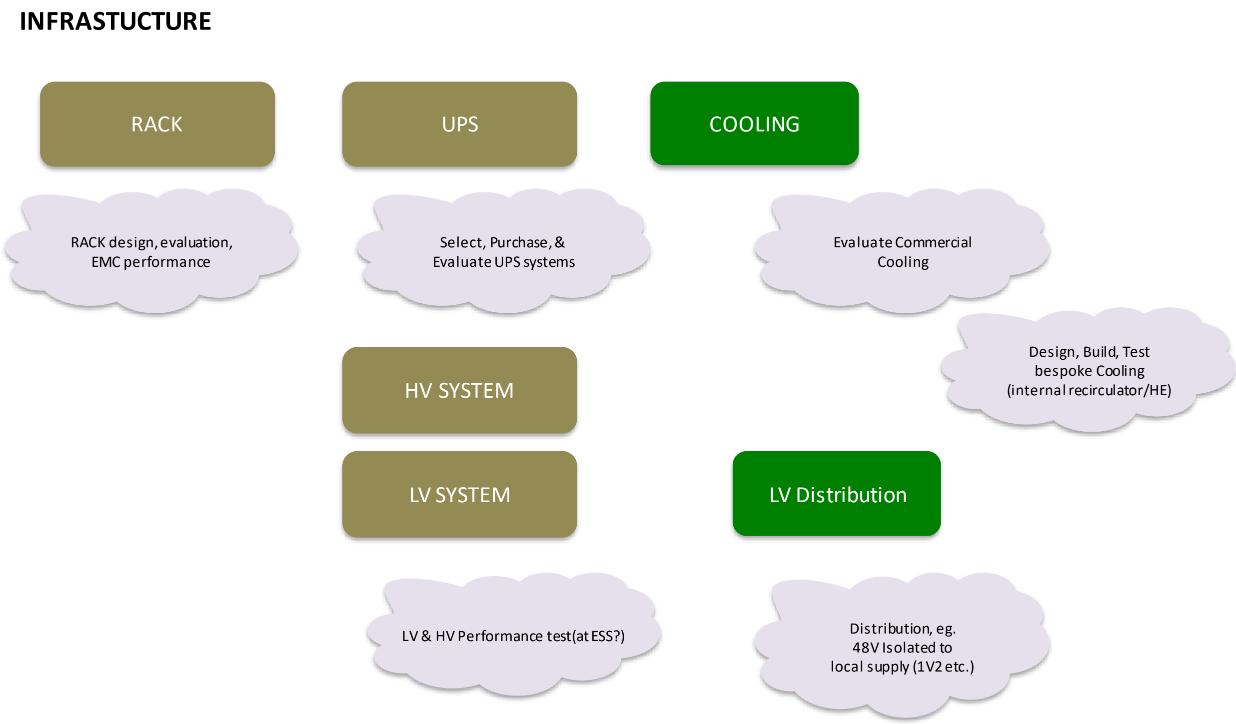


Figure 7: The project plan for the infrastructure elements of the standardized detector electronics integration. Blocks represent functions within the detector electronics. Clouds represent tasks required.

In the rest of this report, more detail on aspects of the implementation plan are shown.

6 Technical Content

6.1 Electronic Interface: *Grounding*

As already stated, neutron instruments are mostly treated as mechanical devices and therefore generally engineered according to mechanical engineering practices. However, neutron detectors, beam monitors, and actually many of the other components are primarily electronic sensors. As such, the electronic sensitivity to noise is highly important for their performance. This is both noise that is radiated through air ("rf" noise or pickup), and through ground (ground fluctuations and noise). The result of not taking electronic engineering as the primary design consideration is often poor performance in terms of electronic noise of various forms. This then leads to ad hoc (and often expensive) redesign during the commissioning of equipment.

This was recognized early on in the planning for ESS instruments, and experts from within ESS and external were consulted to determine how to best avoid as many of the common problems as possible, by a few simple electronic and electrical design rules. Note that these rules also encompass safety considerations. The two common electrical approaches were considered: a grid approach, and a star approach to grounding and electrical power distribution. Since the mesh in the floor concrete is very coarse (due to budgetary considerations) a grid approach would not suffice. Therefore, the star approach was adopted – where the electrical power is fanned out in a star network to instruments, and so an individual device is only connected through one path. These nodes of the star are then collected into “power zones”. Furthermore, for robustness and to protect against power surges and effects from other equipment (such as accelerator RF equipment), it is required that all highly sensitive equipment (which includes detectors is buffered against the electricity supply by having a battery uninterruptible power supply (UPS) installed at the rack level. As example of how the power zones work, in practice, figures 8 and 9 show the grounding zones for the LOKI and NMX instruments.

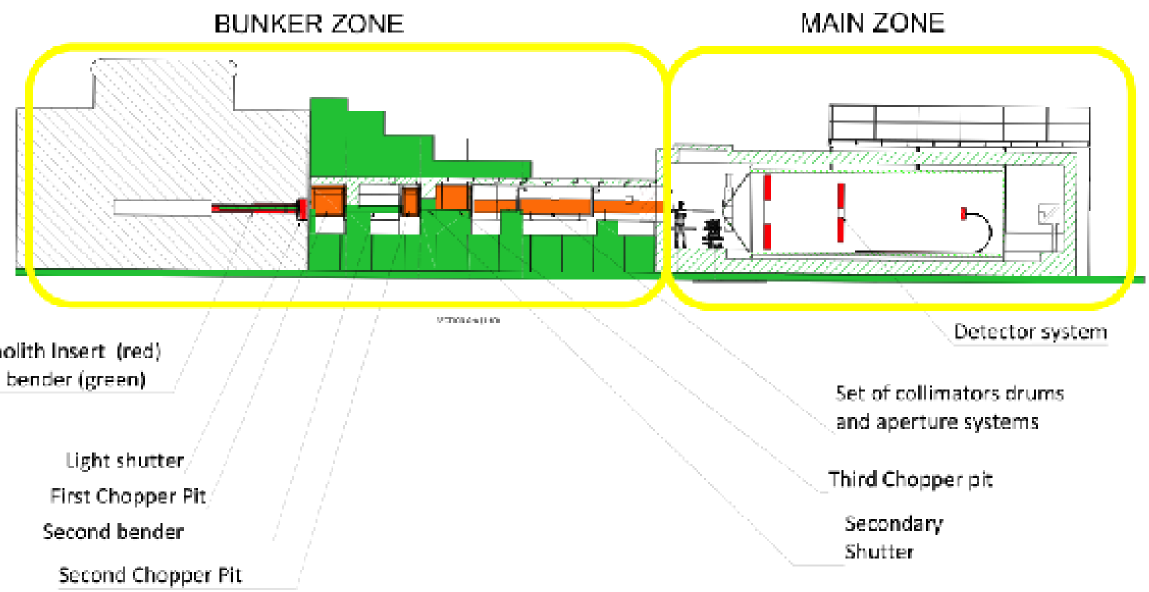


Figure 8: Zoning of the LoKi Instrument.

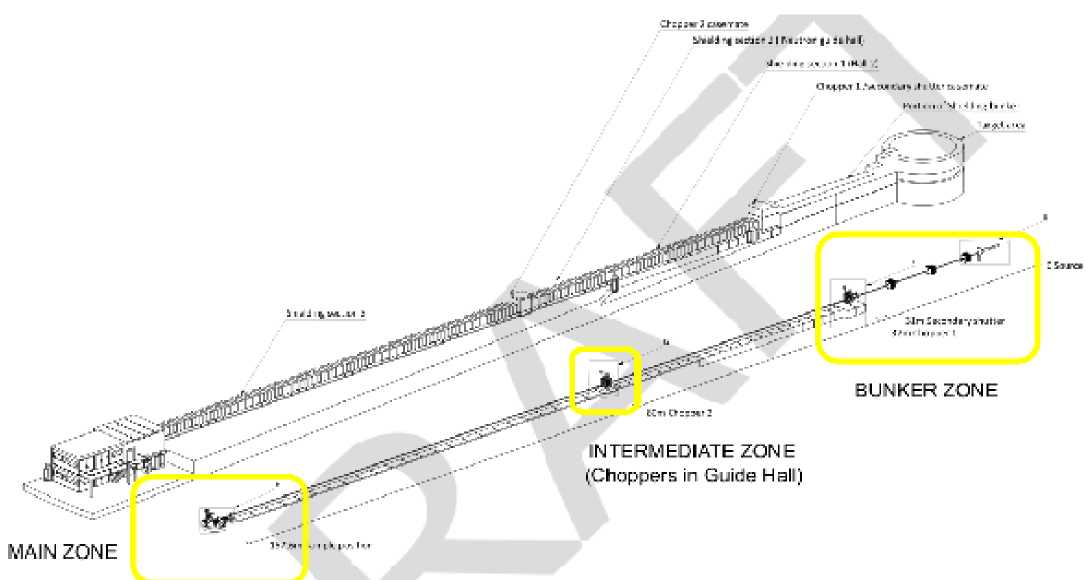
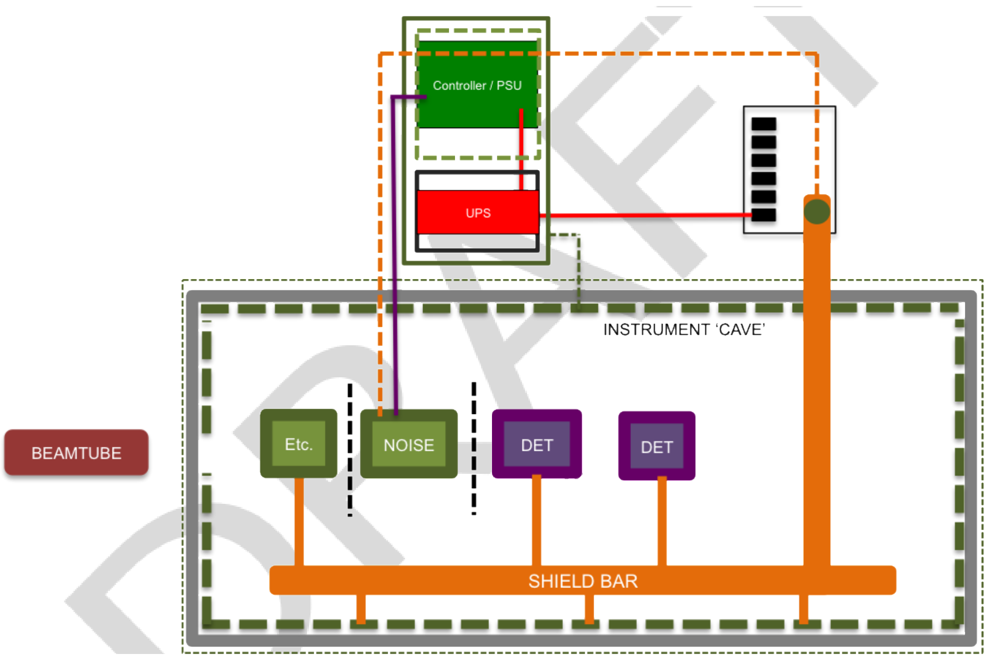


Figure 9: Zoning of the NMX Instrument.

Figure 10 below shows how the electrical scheme works for a highly sensitive piece of equipment. This scheme allows the sensitive equipment to be shielded both from noise introduced by galvanic (conductive) connections, as well as those radiated by other equipment.



Extreme case of isolation - floating rack and isolated ground connection.

Figure 10: Electrical scheme for shielding of highly sensitive equipment.

A detailed document is available on electrical power supply and grounding, called "Guidelines for Instrument Power and Grounding".

6.2 Mechanical Interface: *Infrastructure*

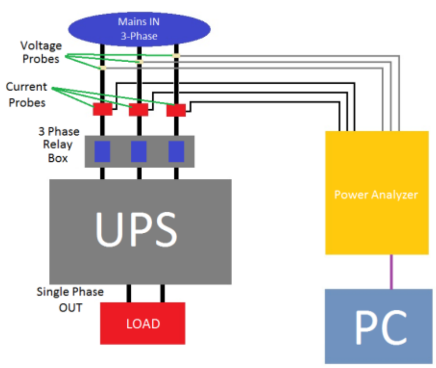
The plan for the implementation of the infrastructure components of the detector electronics was given in the previous section. It consists of aspects related:

- Racks: i.e. the physical location of the electronics.
- UPS for the power provision.
- HV/LV supply for the detector.
- Air or Water Cooling, where needed.
- HV/LV distribution for the detector.

Implementation of the plan has started, with hardware components identified and undergoing evaluation. Figures 11-13 below show hardware items being evaluated for electrically floating racks conforming to the ESS standards for grounding rules, appropriate UPS supplies and crate based HV/LV supply units. The crate based HV/LV supply units have already been integrated into the ESS ICS system, within the IIIP (ICS Instrument Integration Project).

1

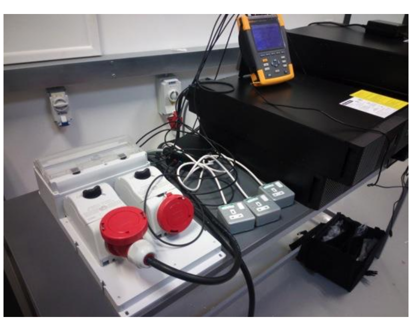
Figure 11: Electrically floating racks for evaluation from Verotec and Pentair/Schroff.



UPS systems to be used as an isolation mechanism of sensitive readout hardware from mains power faults.

Testing conducted in co-operation with STFC staff.

Testing Schedule:



·Steady state tests @ 0, 50 and 100% load.
·Measure harmonics @ input and output.
·Response to sudden load changes and loss of supply.
·Test for loss of a phase on the input.
·Battery load tests.

Figure 12: Diagram of UPS test setup, details of the testing schedule for UPS units, and photographs of the UPS units being prepared for the tests.

Figure13: Examples of common crate based units undergoing evaluation from Wiener and CAEN suppliers for HV and LV supply.

6.3 Monitoring Interface

As stated above, detectors are treated as a system to improve the modularity of their implementation for ESS. The inputs and outputs from this system need monitoring to ensure functionality and reliability of the implementation. A generic system diagram is shown in figure 14 below. Also indicated is the monitoring that is needed for this system. It should be noted that not all detector systems need all aspects indicated here.

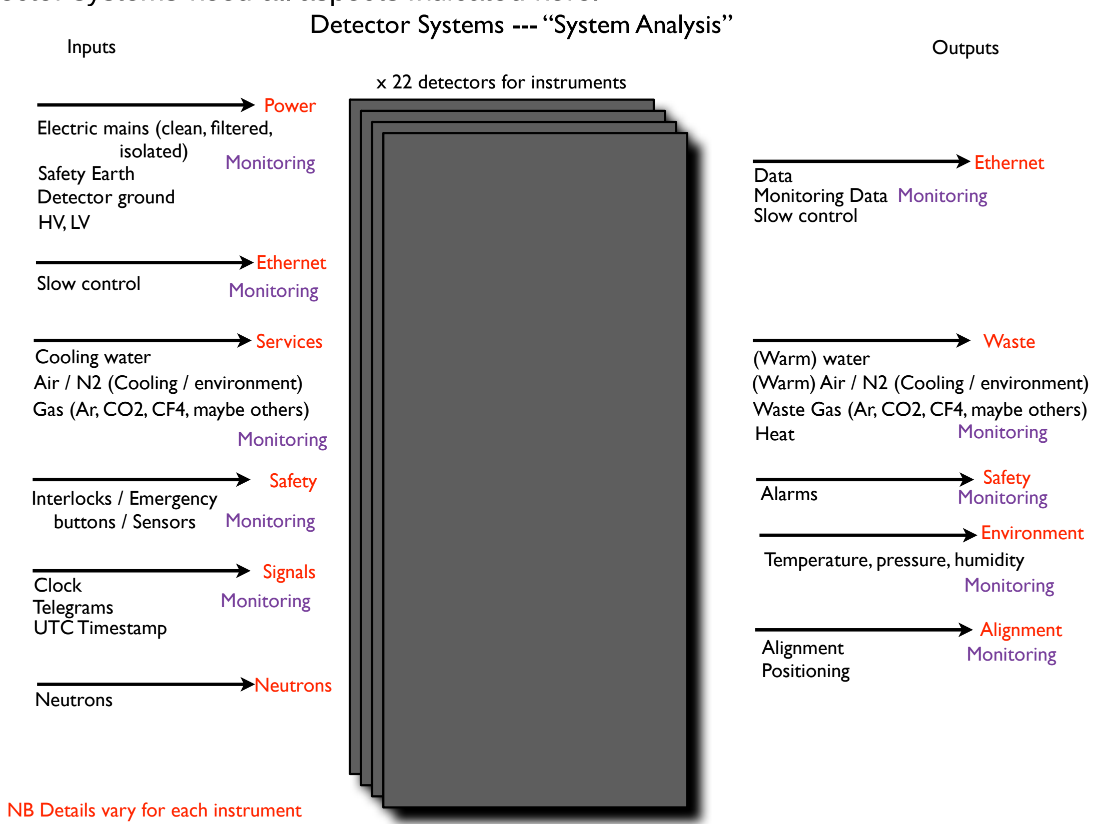


Figure 14: System analysis of a generic neutron detector system. The monitoring needed for the various aspects of the detector are indicated.

6.4 Integrated Control Systems Interface: i.e. EPICS and Global Timing

The Integrated Control Systems (ICS) interface is of key-importance for the detector systems. Many of the details of this have been dealt with in the previous section. The interface consists of three main aspects:

- ESS global Timing interface.
- EPICs for incoming slow control (ie. Calibration constants and commands).
- EPICs for outgoing slow control (ie monitoring, status reports).

Functionally this interface will need to provide the computing and network "glue" between the various parts of the instrument. This is shown as diagrams in figures 15 and 16 below, both in terms of the real hardware of the system and in terms of the role that these play for the neutron instrument.

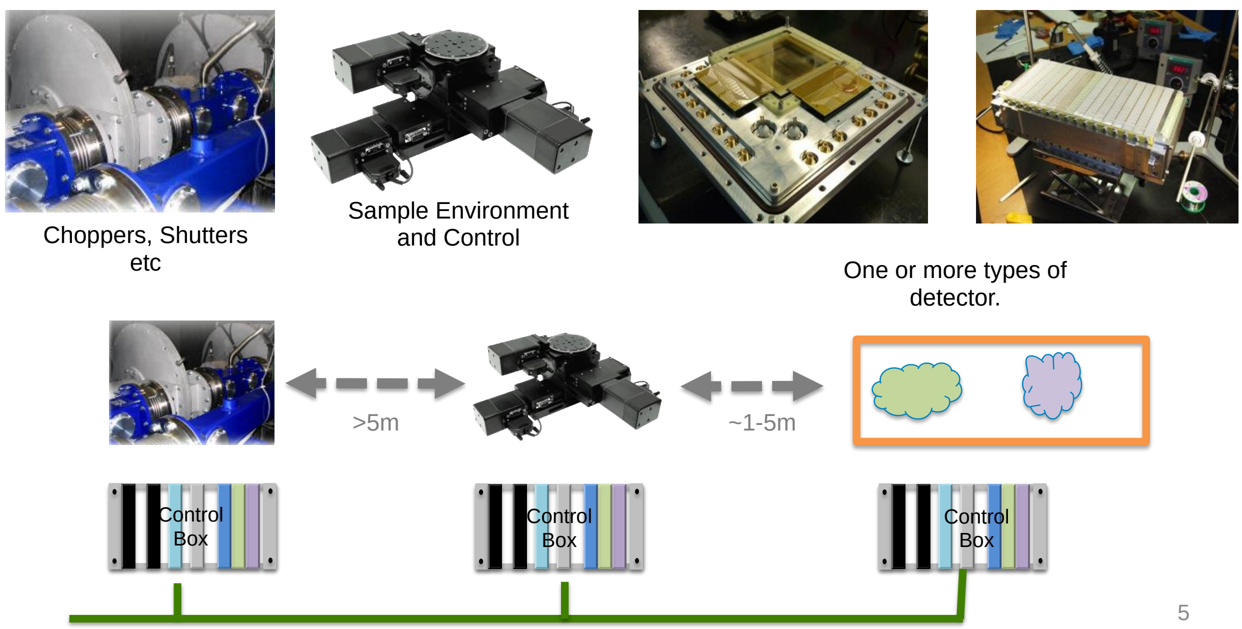


Figure 15: Aspects of the role that the integrated control system infrastructure plays for the instrument.

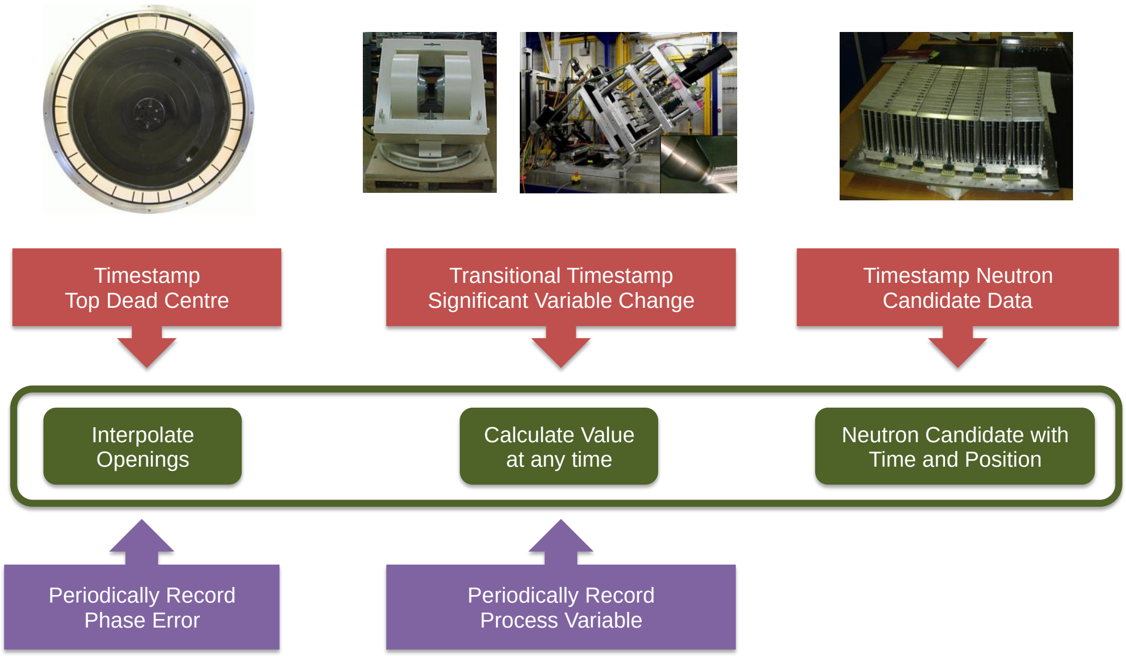


Figure 16: Functions that the various parts of the system need to achieve for the running of the instrument.

The aspects that relate to the detector system depend on the architecture choice. The choice of implementation for the timing system into the detector readout system is shown in figure 17, along with the hardware chosen to demonstrate functionality of this (figure 18).

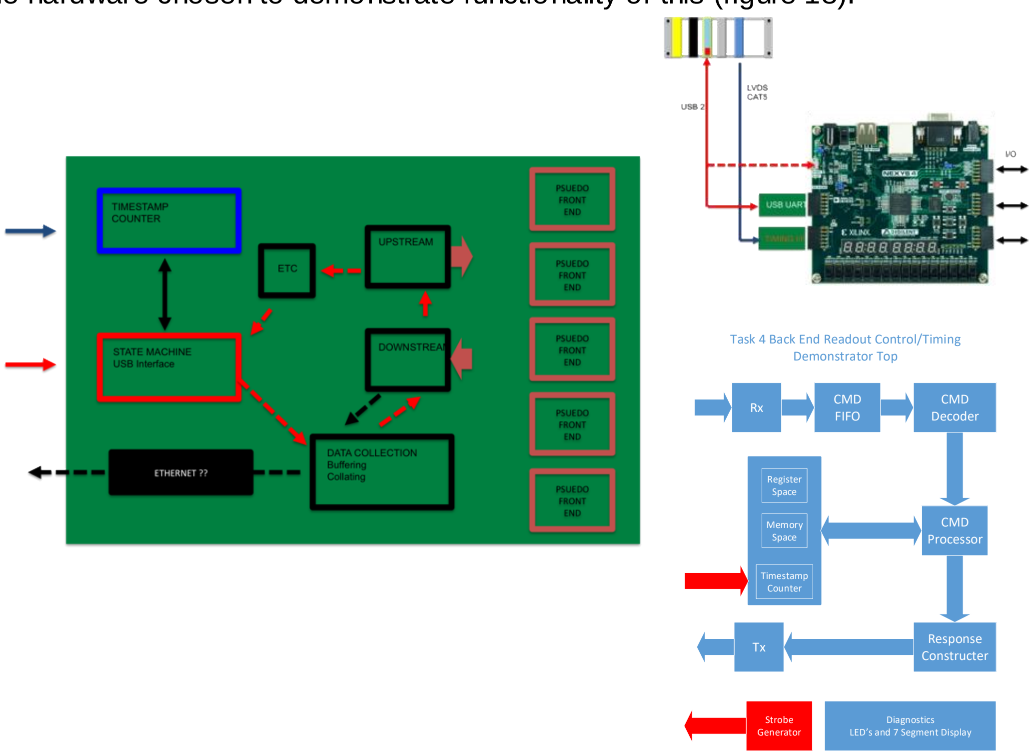


Figure 17: Schematic diagram of the timing implementation for detector readout.

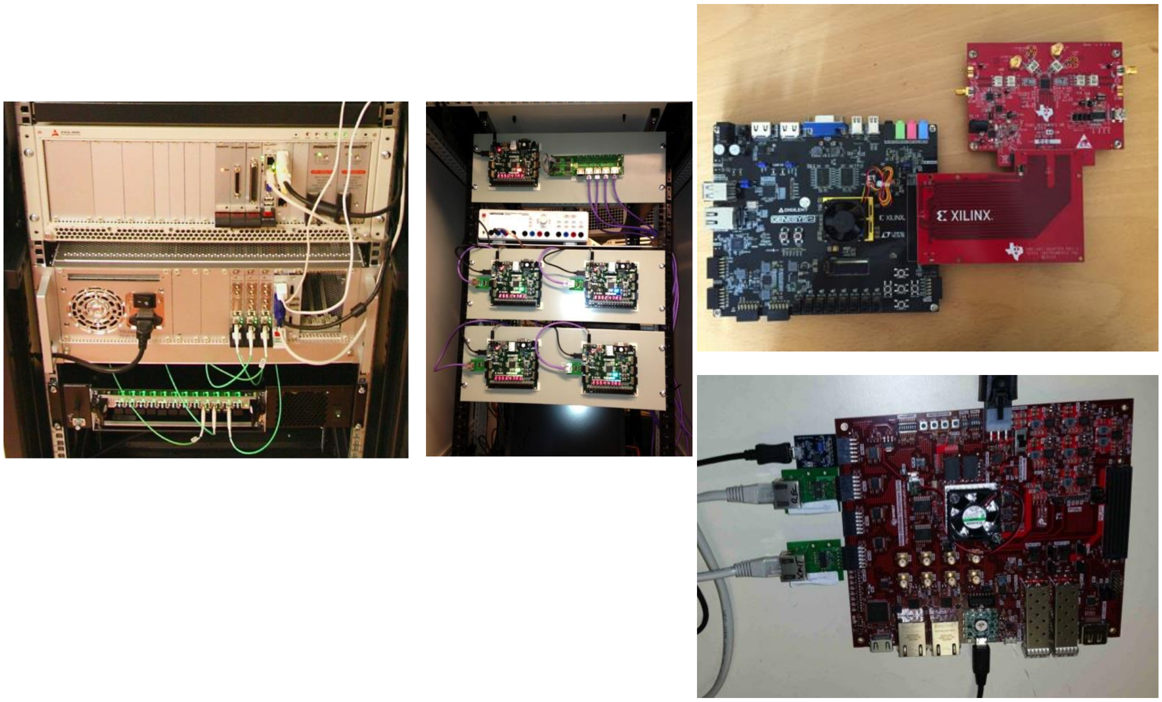
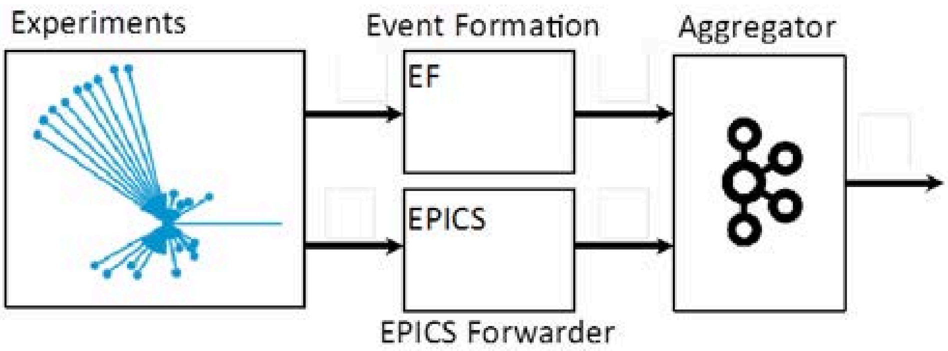


Figure 18: Hardware chosen for the timing demonstrator integration.

6.5 DMSC Interface: WP4 and WP5.1 interface within BrightnESS

As indicated in previous diagrams, the data path for data from ESS neutron instruments will move from the detector electronics, via an event formation or compute layer, to the data aggregator. This interface is the subject of task 5.1[1] within Work Package 5 of BrightnESS. As such, the interface is not described in detail here. Figure 19 below shows a diagram of the functional role of this interface.

[1] This task is called: “Creating a standard neutron event data stream for different detector types”.



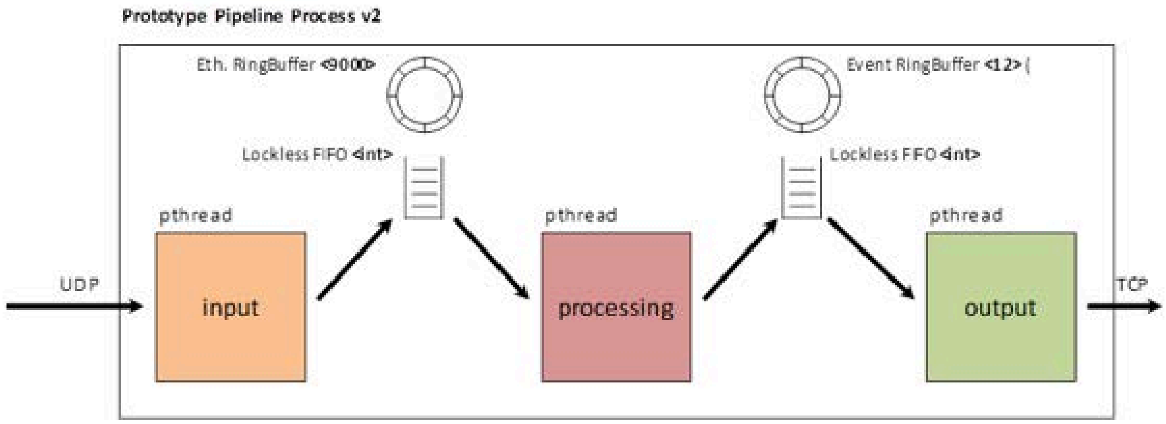


Figure 19: Functional role of the event formation stage.

The readout data itself will be sent using the User Datagram Protocol (UDP). Data will typically consist of a packet and a size. The data comprises headers, timing data, channel/pixel/voxel id information and sometimes a payload. The details of the precise data format will depend upon the details of the detector, and is part of the design process and dialogue between different tasks within WP4 and WP5.1. The design goal is to minimize the amount of effort needed to implement the detector technology, whilst maintaining a system that is maintainable at minimal effort.
Figures 20 and 21 show where the detector data flow sits in the overall data acquisition collection for the entire instrument. The various responsibilities and relations between groups are also indicated in this diagram.

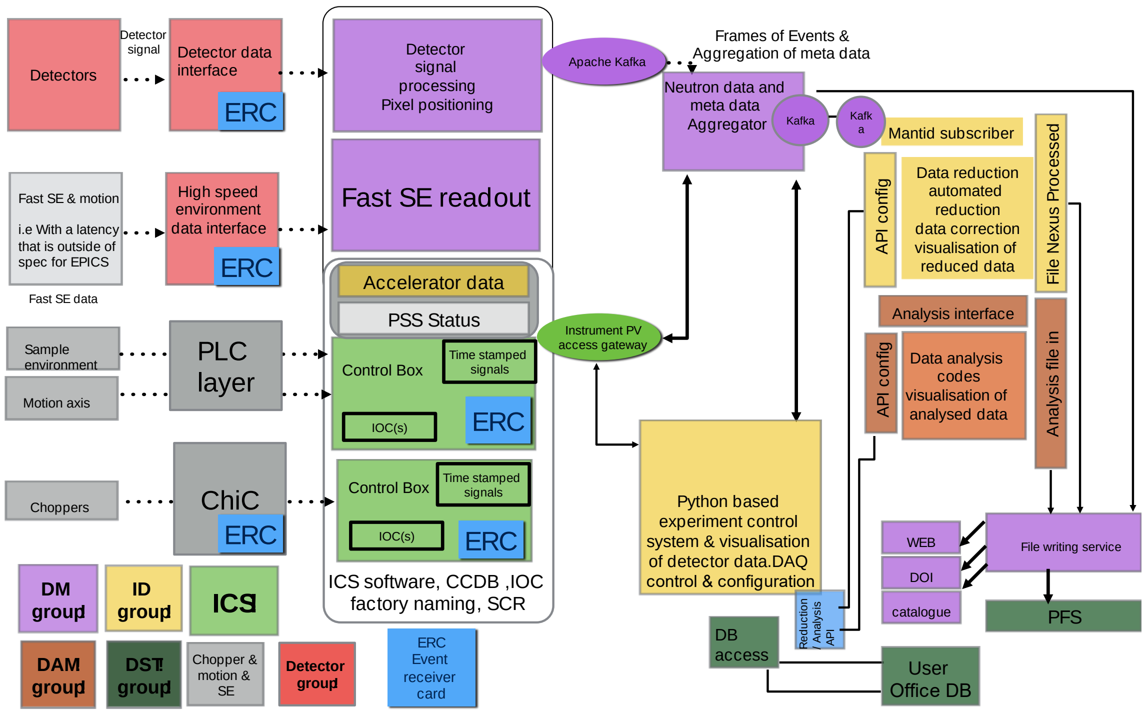


Figure 20: Architecture of the data collection for the ESS neutron instruments.

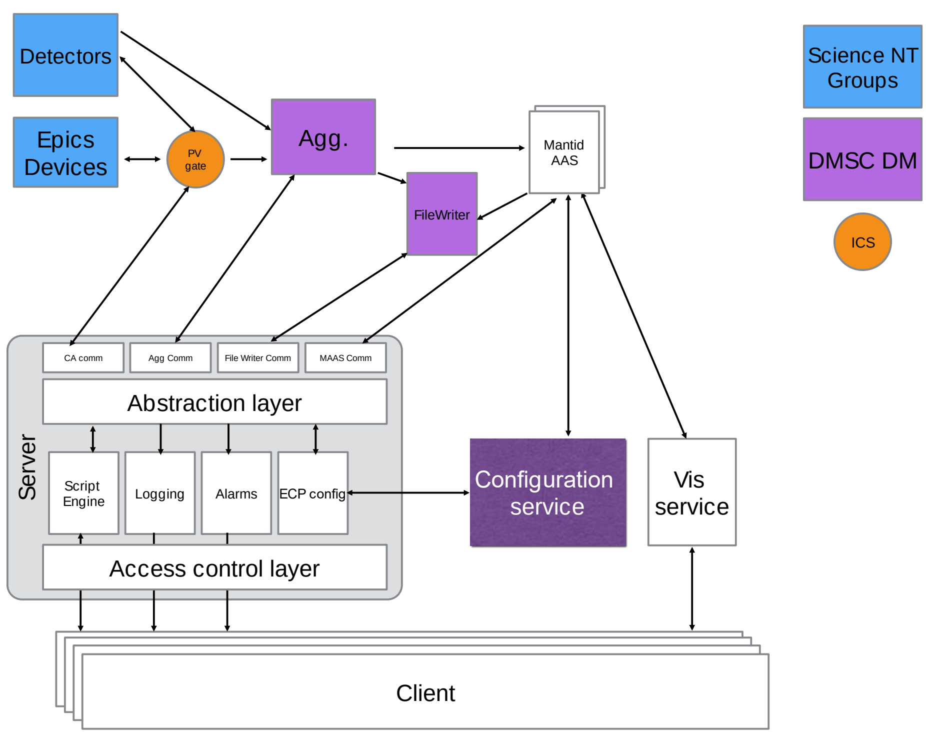


Figure 21: The processes and data path for the neutron data from neutron instruments for ESS. The various functions that need to be achieved (eg. logging, alarms, configuration, monitoring, etc.) as part of this data collection are indicated.

WP5.1 will create a standardized neutron event in this compute layer. The specific implementation of WP5.1 is part of the BrightnESS WP5 deliverables and not further discussed here. It is, however, well underway.

6.6 Detector Electronics Readout Integration

In a similar diagram to above, the data flow needed for the detector electronics is shown in figure 22. The figure presents the interfaces to other groups as well as to the monitoring functions. In this representation, the focus is on the detector readout electronics. The approach is modular at all times to simplify implementation and allow debugging of the system, as well as to ensure reliability in this complex system. It should be noted that the function "DG diagnostics", ie. diagnostic information for the detector readout, is intended to be handled within the same hardware and software as for the event formation, to allow unambigious diagnostics for all aspects of the system."

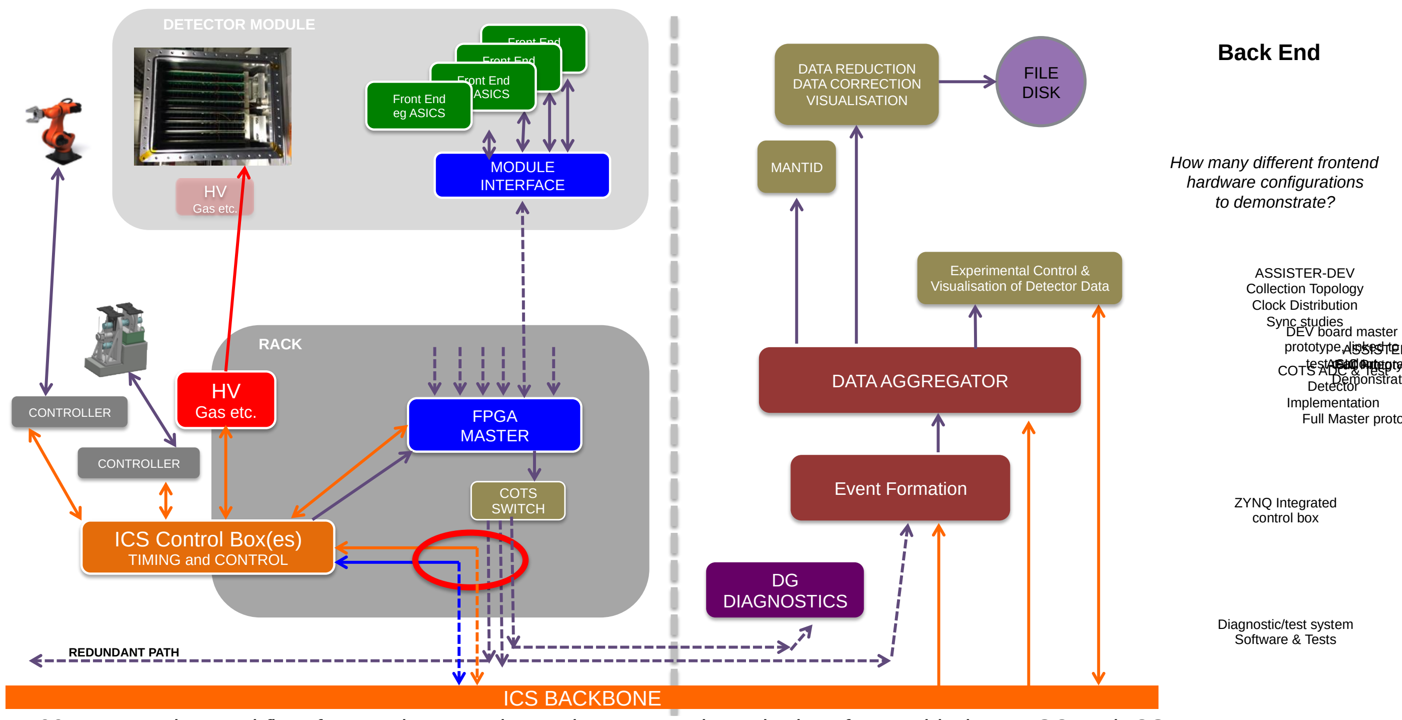


Figure 22: Data and control flow from a detector electronics perspective. The interfaces with the DMSC and ICS are indicated. How the data fits into the various aspects of the system are shown.

Figure 23 shows the functionality of the detector readout as it is broken down into a lower level. This consists of the following steps:

- The front-end board, where the analogue signals are digitized. Due to the high channel volume for ESS instruments, this is typically done with a dedicated multi-channel ASIC chip (Application Specific Integrated Circuit). The default choice for the ESS instruments will be the VMM3 chip, developed for the Atlas experiment at the LHC, CERN. Other ASICs will be integrated as needed.

- The FPGA (Field-Programmable Gate Array) adapt layer. Here some local channel processing may take place.
- Data collection and signal processing. Here the data processing in the electronics takes place.
- Generic back-end. This ensures a standard interface to the DMSC data-chain. If data processing is needed at a global level in the electronics, it takes place here.

These functional units ensure a system where the interfaces are well defined. This is important for integration of different electronics from in-kind partners into a standard readout. The standard readout is needed to provide a similar user-experience between ESS instruments.

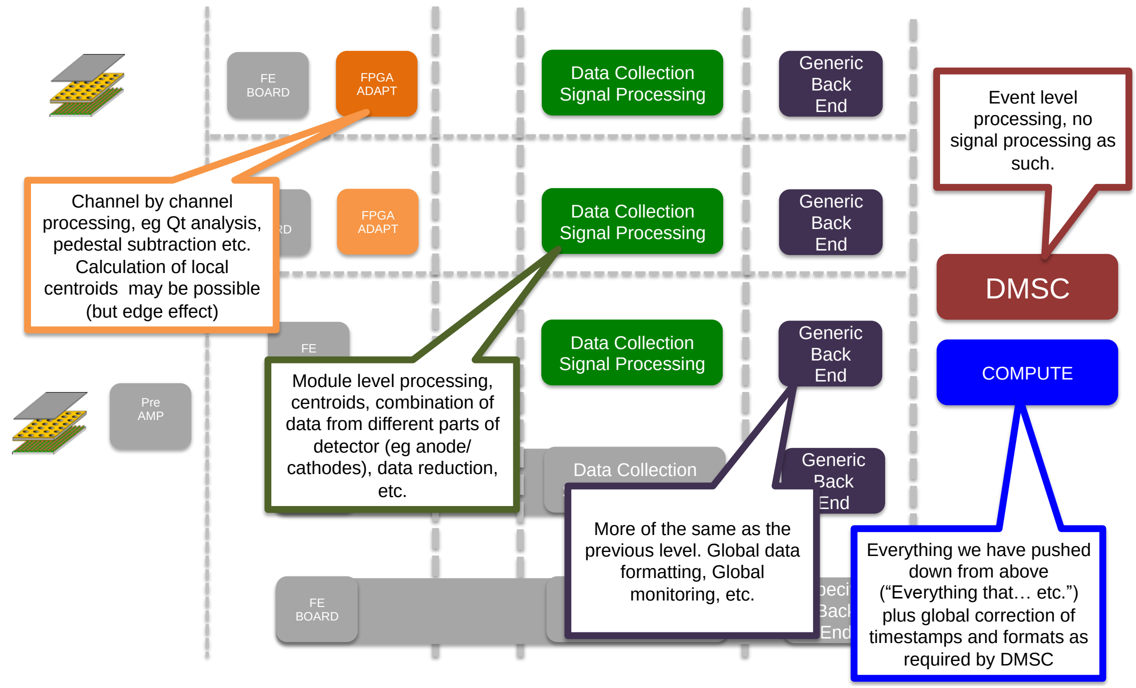


Figure 23: Diagram of the functionality expected of the various parts of the sub-systems of the detector readout electronics.

As mentioned above, the functionality of the system and clear interfaces between these sub-systems is required to ensure that as many different in-kind contributions for detectors can be integrated as are needed. This integration raises support issues. The models for integration are shown in figure 24. The integration models are:

- A: ESS provides all aspects of the readout electronics.
- B: ESS provides the readout electronics after the front-end board. The in-kind partner provides the front-end board and ASIC chip, and the preamp signal amplification if needed.
- C: ESS provides the readout electronics from after the front-end board. The in-kind partner provides the front-end board and ASIC chip, and the preamp signal amplification if needed. This front-end board directly communicates with the Data Collection and Signal Processing layer, with no FPGA adapt layer.
- X: ESS provides the generic back-end readout. The in-kind partner provides all other aspects of the system. Given the support issues that this raises for the detector electronics, this model is not favoured. The support and provision and guarantee of spares

of the electronics integrated into the system needs to be determined for a period of at least 10-15 years. This support is very difficult for anyone, except for a research institute, to provide.

- XX: Here ESS detector group is not involved. The in-kind partner must integrate their own back-end directly into the DMSC and provide all the support and maintenance. This model is not acceptable for a system requiring support. It will only be considered for eg. neutron cameras which do not require time-of-flight information. It should be avoided wherever possible.

As indicated above these integration models are in order of decreasing preference. Models A, B or C are highly preferred for integration. Model XX should never happen.

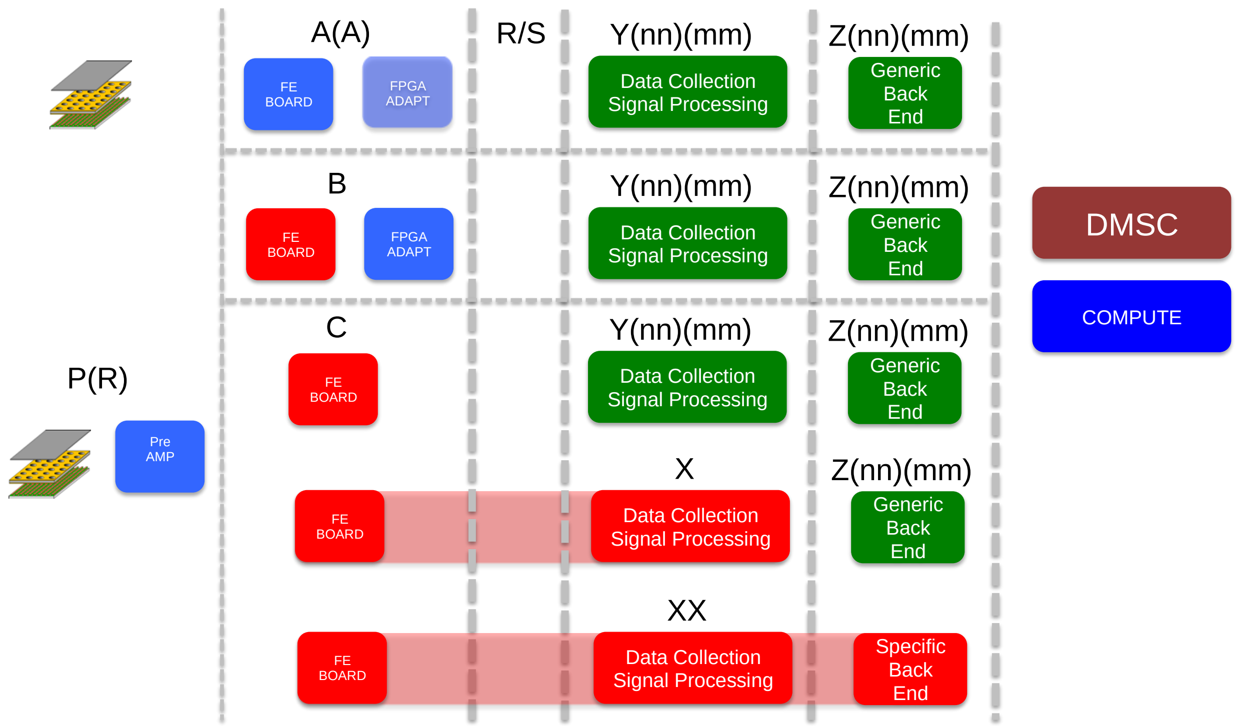
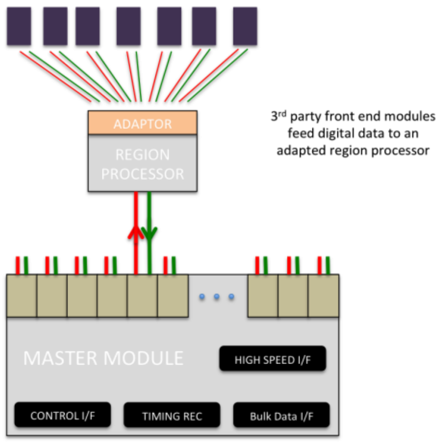


Figure 24: Integration models of the system functionality for equipment from in-kind partners into the standardized readout. The red boxes indicate the components provided by the in-kind partner. The models are labeled A, B, C, X, XX.

Lastly, the integration models are represented below in terms of the components of the system. Figure 24 shows the favoured models for integration. Figure 25 shows the disfavoured models for integration. These aspects of integration are important to consider early on, as they are very important in determining:

- Whether it is possible to support the instrument long-term or not.
- Whether it is maintainable.
- Whether spares are available after a few years.

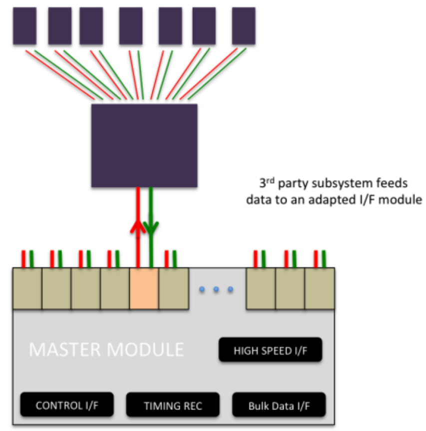
These aspects are crucial in terms of performance and availability.



Existing design for pre-amp, digitizer etc from external partner.

Adaptor in-house

In this case the data processing provided by the region processor could be in house.



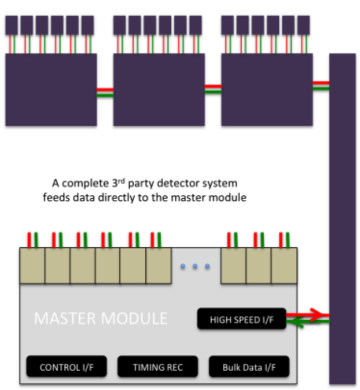
Entire subsystem provided by external partner. In this case the local region processing is handled by the external design.

Firmware for this intermediate stage would have to be provided and maintained by external partner.

Custom Interface module may be designed locally.

DISCOURAGED

Figure 25: Favoured models of integration for the detector readout electronics between ESS components and those provided by the In-Kind partners. Here purple indicates the parts provided by the in-kind partners.



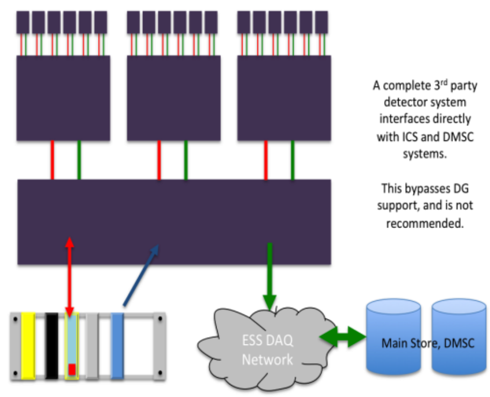
In this case the external partner supplies essentially a complete readout system for the detector array.

Interfacing hardware could be provided in house (construction cost)

ESS system acts as a bridge to ESS standard interfaces.

The entire subsystem would have to be maintained by the external partner.

STRONGLY DISCOURAGED



This is the case where an external system cannot (realistically) be adapted to use the ESS design as a bridge.

Eg a commercial system where proprietary or confidential protocols are used.

DG provide NO support!!!

ONLY IN EXCEPTIONAL AND UNAVOIDABLE CIRCUMSTANCES…

ie **NEVER**

14

Figure 26: Disfavoured models of integration for the detector readout electronics between ESS components and those provided by the in-kind partners. Here purple indicates the parts provided by the In-Kind partners.

7 Conclusion

The detector readout integration plan exists and its implementation is now well underway both in terms of hardware candidates existing for all stages of this readout, as well as the software and firmware implementation. The interfaces to other groups within ESS have been identified and work on their definition is well underway. The most important interface is with BrightnESS WP5.1, where work is proceeding in close collaboration.

As a last part of the conclusion, figures 26 and 27 show the remapping of the generic integration diagram for the detector readout onto the various hardware components that exist. Candidate and prototype hardware exist already for all aspects of the detector readout system.

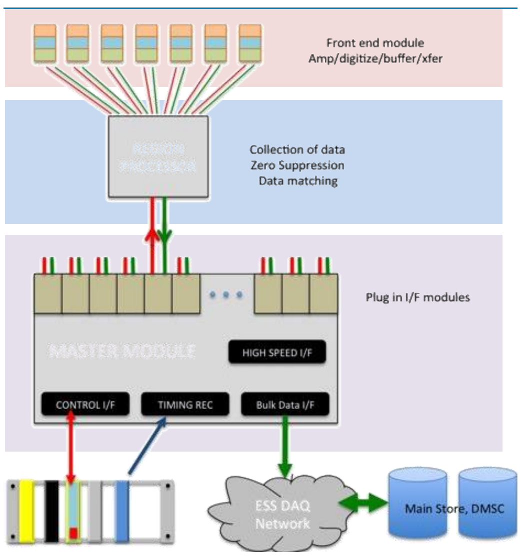


Figure 27: Functional decomposition of the detector electronics readout system.

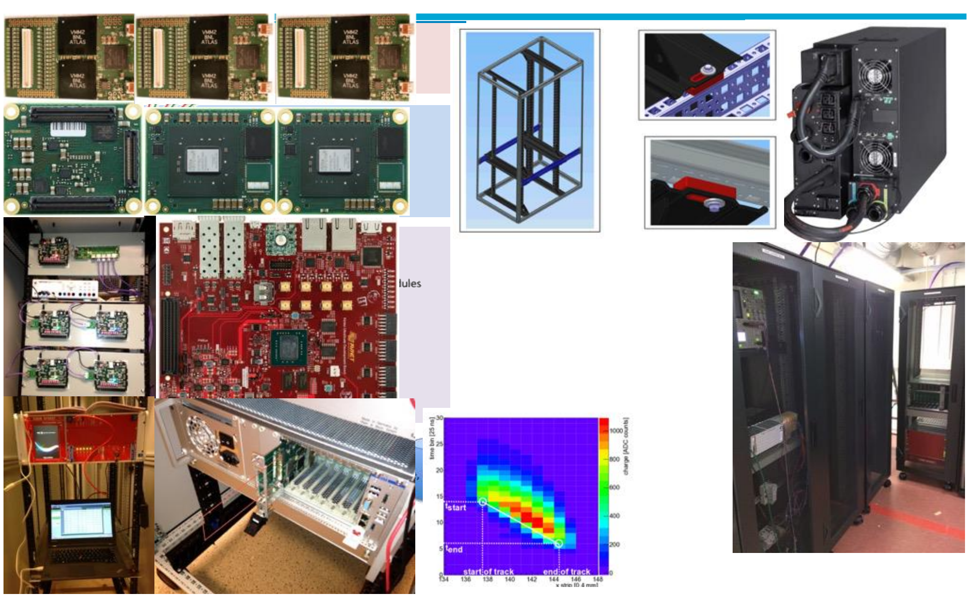


Figure 28: Corresponding hardware items which comprise the aspects of the system.

8 List of Publications

General:

- NASA systems engineering manual.

ESS Detector Readout:

- ESS Technical Design Report.
- O. Kirstein et al. "Neutron Position Sensitive Detectors for the ESS", PoS (Vertex2014) 029 (2014); arXiv:1411.6194.
- F. Issa, Characterization of Thermal Neutron Beam Monitors, to be submitted J. Sci + Tech Accelerator and Beams (2017).
- In-Kind Contract on Detector Readout with RAL-TD, STFC.

Joint BrightnESS WP4 and WP5 meetings:

- NMX detector event processing: https://indico.esss.lu.se/event/497/.
- BrightnESS WP5.1 Kick Off: https://indico.esss.lu.se/event/548/.
- Joint BrightnESS WP4 and WP5 Jamboree: https://indico.esss.lu.se/event/645/.
- T. Richter et al., Replacing complex detector electronics with scalable software solutions, ICANS XXII (2017).
- DMSC - Detector Group Service Level Agreement (draft), 2017.

Grounding:

- S. Kolya et al., Guidelines for Instrument Power and Grounding, ESS-0051373 (2015).

ICS:

- T. Gahl et al., Hardware Aspects, Modularity and Integration of an Event Mode Data Acquisition and Instrument Control for the European Spallation Source (ESS), Proc. ICANS XXI (2014). arXiv: 1507.01838.
- Neutron Science Systems – Integrated Control Systems, Service Level Agreement, 2014.