ISBN: 978-3-95450-209-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2019-MOMPL008

NEW NEUTRON SENSITIVE BEAM LOSS MONITOR (nBLM)

Y. Mariette †, V. Nadot ††, Q. Bertrand, F. Gougnaud, T. Joannem, T. Papaevangelou, L. Segui,
IRFU, CEA, Université Paris-Saclay, F-91191, Gif-sur-Yvette, France
I. Dolenc Kittelmann, F. Alves, ESS ERIC, Lund, Sweden
G. Jabłoński, W. Cichalewski, W. Jałmużna, R. Kiełbik, TUL, DMCS, Łódź, Poland

Abstract

The beam loss detection is of the utmost importance for accelerator equipment safety. At CEA, we are closely collaborating with ESS and DMCS on development of ESS nBLM. The system is based on Micromegas gaseous detector sensitives to fast neutrons produced when beam particles hit the accelerator materials. This detector has powerful features: reliable neutron detection and fast time response.

The nBLM control system provides slow monitoring, fast security based on neutron counting and post mortem data. It is fully handled by EPICS, which drives 3 different subsystems: a Siemens PLC regulates the gas line, a CAEN crate controls low and high voltages, and a MTCA system based on IOxOS boards is in charge of the fast data processing for 16 detectors. The detector signal is digitized by the 250Ms/s ADC, which is further processed by the firmware developed by DMCS and finally retrieved and sent to EPICS network.

For other accelerator projects, we are designing nBLM system close to ESS nBLM one. In order to be able to sustain the full control system, we are developing the firmware and the driver.

This paper summarizes CEA's work on the nBLM control system for the ESS and other accelerators.

INTRODUCTION

The CEA Institute of Research on Fundamental Universe law (IRFU) works on astrophysics, particle physics, nuclear physics and instrumentation for projects like accelerator, magnetic resonance imaging, ITER (International Thermonuclear Experimental Reactor), etc. The institute has a lot of experience in contributing in accelerator facilities and especially for RFQ construction, and instrumentation.

In the context of an in-kind collaboration between IRFU and ESS (European Spallation Source), a new type of beam loss monitor (BLM) based on detection of fast neutrons has been designed, manufactured and characterized. The BLM is crucial in any accelerator; it quickly detects, measures and locates the beam loss. The new neutron sensitive Beam Loss Monitoring (nBLM) system has been designed for fast and accurate measurement of number of neutrons produced when beam particles hit the accelerator material.

The nBLM detectors are powered with high and low voltages and filled with gas, while the acquisition continuously makes analysis to detect and count neutrons. All electronics devices are remotely controlled and monitored by EPICS.

At IRFU, the System Engineering Department (DIS) is in charge of the nBLM control system development for the ESS-nBLM project and it is also involved in other projects based on the same detector technology. The Department of Detector Electronics and Software for the Physics (DEDIP) designs, constructs and qualifies the nBLM detectors.

THE NBLM DETECTOR

In low energy region of hadron accelerators, x-rays, gammas and neutrons are present. Neutrons are produced by the beam loss whereas gammas and x-rays result from the RF. As the x-rays levels can exceed the neutron levels, it is difficult to detect a beam loss in such region [1].

The new nBLM detector is able to detect the produced fast neutrons while having a low sensitivity to gammas and x-rays.

nBLM detectors are based on the use of Micromegas detectors [2]. Micromegas (MicroMesh Gaseous Structures) are gaseous amplification structures. The detectors are bulk Micromegas [3] and are equipped with the fast front-end electronics cards (FEE) placed on-board of the detector, outside the gas volume protected by a Faraday cage (see Fig. 1). The FEE is based on the FAMAS current amplifiers (Fast Amplifier Module for Micromegas ApplicationS) [4]. The advantage to amplify the signal before transmitting it over the long cable is that we are sensitive to smaller signals.

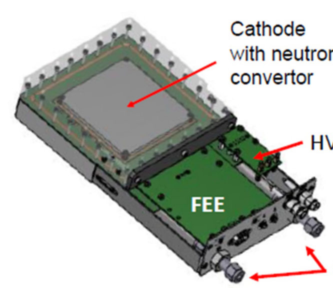

Figure 1: Detector schematic with its FEE.

Two types of nBLM detectors with complementary functionality have been developed. Fast detectors aim to detect serious losses in case of an accident. On the other hand, slow detectors primarily aim to accurately monitor small losses when low particle fluxes are expected but it introduces a reaction delay with around a hundred microseconds. Details of the final detector module design and performance are available in [5].

† yannick.mariette@cea.fr
†† victor.nadot@cea.fr

ISBN: 978-3-95450-209-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2019-MOMPL008

NEUTRON DETECTION AND COUNTING

The typical shape of one neutron is a negative voltage signal with a rise time of 30-50 ns and pulse duration of 100-200 ns, depending on the applied electric fields in the detector (see Fig. 2).

An algorithm to identify neutrons in the signal has been initially defined by CEA. ESS has evolved the neutron detection for the ESS-nBLM system [6]. The main idea is similar and based on several parameters to detect neutrons.

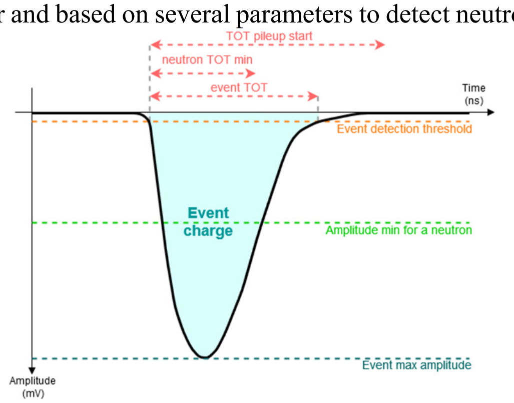

Figure 2: Typical event shape expected in a Micromegas detector.

The first amplitude threshold parameter (orange line in Fig. 2) aims to detect an event. Then 2 criteria must be met to consider the event as a neutron. The first criteria is that the event amplitude must be under the second amplitude threshold (green line in Fig. 2) and the second criteria is that the Time Over the first Threshold (TOT) must reach TOTmin (neutron TOTmin in Fig. 2).

However, an event can also originated from several neutrons that cannot be distinguished in time (pile-up of neutrons), then the shape is larger. When TOT is over the parameter Time Over the first Threshold pile-up start (TOT-pileup_start in Fig. 2) and if the first criteria is valid, we consider it is neutron pile-up. In this case the algorithm automatically switches to counting mode estimating the number of neutrons dividing the total event charge by the neutron mean charge.

When it is a neutron peak it is counted as one neutron and when it is piled-up neutrons it is the result of the counting mode. Finally, the neutron rate is the sum of neutron peaks and neutron pile-up every microsecond.

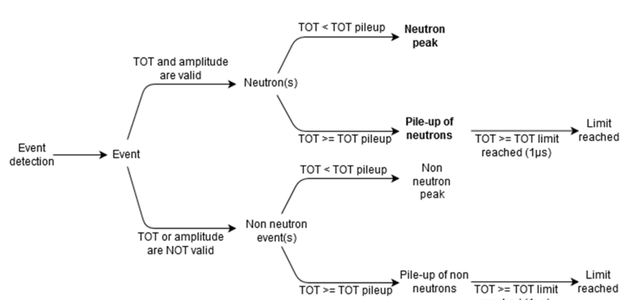

Figure 3: Decision tree to discriminate event(s).

Fig. 3 shows how to classify events, and in Fig. 4 all possible event shapes and their associated neutron counting methods are summarized.

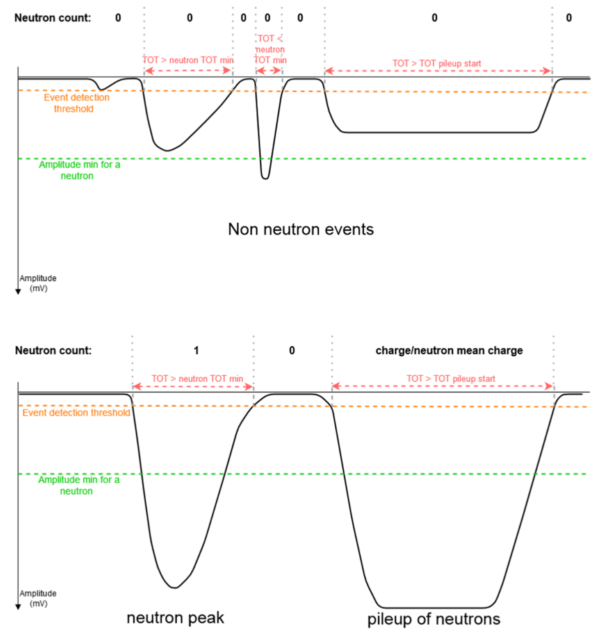

Figure 4: Possible event shapes and counting methods.

To validate the algorithm, a Python code has been developed. Experimental data acquired at IPHI (Injecteur de Protons à Haute Intensité) [7], when a neutron field using a Be target was produced, has been processed by the code (Fig. 5).

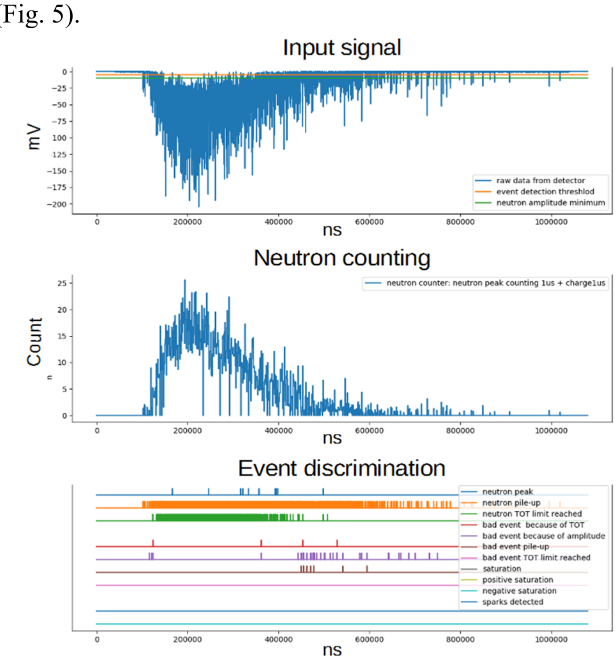

Figure 5: First graph is the IPHI experimental raw data and the second graph shows the results of events counting for a given configuration.

ACQUISITION FEATURES

Here are the main acquisition features of nBLM system:

- It continuously detects and counts neutrons.
- Each detector is individually configurable.
- A smart scope helps to configure the neutron detection (possibility to trig from raw or interpreted data).

ISBN: 978-3-95450-209-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2019-MOMPL008

- The acquisition system stores and provides data on demand around the trigger.
- It monitors the beam line activation.
- Different trigger sources are available (timing system, analog input, software).
- Event statistics help to validate settings.
- A beam permit signal which can trigger a stop in beam production is continuously transmitted to the FBIS (Fast Beam Interlock System).

CONTROL DEVICES

The control devices are the gas chassis, the power supplies (High and Low Voltage) and the acquisition device which is a set of MTCA.4-based AMC boards plugged into a MTCA crate (see Fig. 6).

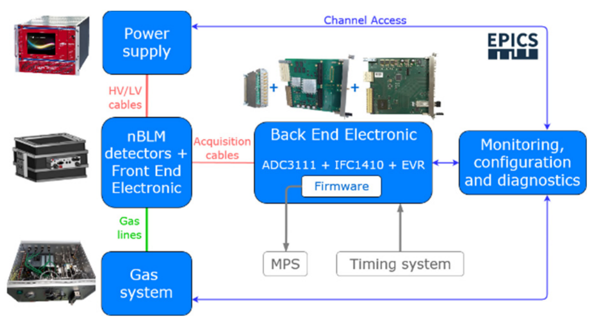

Figure 6: Devices and interfaces overview.

nBLM detector requires a continuous gas flow (~1 L/h/detector). A main chassis provides gas to distribution chassis which controls the gas for each line. Each line brings gas to a group of detectors. The chassis architecture based on PLC is shown in Fig. 7. Thanks to the experience of the DIS and the DEDIP at CEA, compact gas boxes have been designed and manufactured for ESS nBLM system.

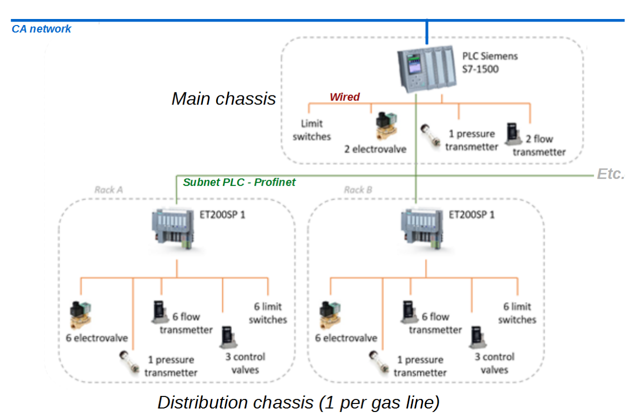

Figure 7: Gas chassis architecture. A PLC Siemens S7-1500 is inside the main gas chassis. Each distribution chassis has a Siemens ET200SP remote I/O module [8].

For the power supplies, a CAEN SY4527 crate supports different type of voltage boards over its 16 slots [9]. A7030 modules (3kV/1mA) have been chosen for supplying high voltages for each detector while the A2519 modules (15V/5A) supply the low voltages for the FEE. Each A7030 module can control up to 48 channels (24 detectors) and each A2519 module has 8 channels. The SY4527 crate embeds a CPU board to manage the modules and to run the EPICS IOC.

The nBLM MTCA base configuration consists of a power module and a NAT-MCH-PHYS board [10] which configures backplane communication between several AMC boards.

The carrier AMC board IOxOS IFC1410 makes the acquisition with one or two FMC modules IOxOS ADC3111 offering 8 inputs at 250 Ms/s (see Fig. 8). For the data processing the IFC1410 board provides a Xilinx Kintex UltraScale FPGA. A PowerPC with Linux OS is coupled to the FPGA.

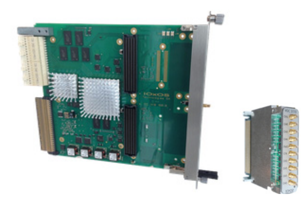

Figure 8: IOxOS boards: AMC board and FMC ADC module to the right [11].

Two software implementations are possible; the nBLM software could be executed on the IFC1410 PowerPC or on a motherboard which drives all IFC1410 boards plugged in the MTCA crate. ESS chose the second option with the AMC board Concurrent Technology AM G64/471-99, including a 4-core 3GHz Intel processor, as motherboard [12].

An MRF mTCA-EVR-300(U) board with an interface board IFB-300 is plugged inside the MTCA crate in order to synchronize the data collected with the beam timestamping and to receive the data on demand trigger from MRF Event Generator (EVG), or to send events to the EVG [13]. To trigger the FPGA, dedicated backplane trigger lines connect the mTCA-EVR-300(U) board to the IFC1410.

At ESS, protection system has been standardized as much as possible: nBLM, ICBLM, RF systems are using the same hardware for interfacing with the FBIS. The protection signal transmission is insured by 2 IOxOS boards. The FBI_1482 board, called piggy back, has 4 analog channels (RS485 support) that provides redundancy possibility and one Ethernet datalink. The piggy back is plugged on a µRTM board RCC_1466 connected to the FPGA through the backplane.

FIRMWARE

The same firmware is running on the FPGA independently of the detector type (fast or slow). The firmware has the following tasks:

- It processes detectors signal from ADC.
- It manages triggers.
- It provides neutron detection and counting.
- It provides monitoring data to EPICS.
- It provides machine protection functionality and manages communication to FBIS.

ISBN: 978-3-95450-209-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2019-MOMPL008

- It provides data on demand.
- It provides acquisition status.
- It processes a file reader as input.

DMCS (Department of Microelectronics and Computer Science of Lodz University of Technology) as ESS collaboration partner has developed the firmware with the datapath written in C++ synthesized using Vivado High Level Synthesis [14]. From CEA side a preliminary firmware was developed in VHDL in June 2018. This firmware will be adapted to fulfill the requirements of other accelerators.

SOFTWARE

ESS has defined a standardized protocol for PLC, with S7PLC protocol for reading from PLC and Modbus protocol for writing into the PLC. The CEA complies with this standard and has developed a parser tool [15] to help PLC developers to generate EPICS communication from TIA Portal data blocks description (AWL files). Moreover CS-Studio GUI are automatically generated from AutoCAD® drawing.

To interface the FPGA, an EPICS driver has been developed. It mainly uses the NDS3 library and the IOxOS library named tsclib. The Data on demand files are stored in HDF5 files. GUI are developed under CS-Studio.

The SY4527 has its own IOC, but for machine timestamping and database customization (alarms, limits) an interposed IOC for the voltages control has been developed and could run on any other CPU than the SY4527.

Today at ESS a main nBLM IOC for the nBLM prototype is available and allows to control up to 6 detectors with associated gas and voltages. The IOC runs on the Concurrent Technology AM G64/471-99 which is connected to FPGAs through PCIe links (see Fig. 9).

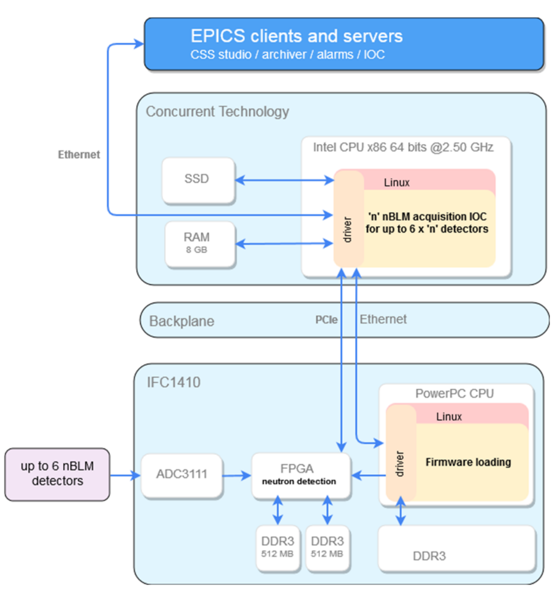

Figure 9: Data processing architecture for ESS nBLM.

Voltage and gas devices are used for several detector units. In order to drive each detector without knowing which device is associated with it, an abstraction layer has been made including the device mapping.

Moreover, the main IOC depends of each device EPICS library (acquisition, voltages, gas) and provides an autosave module for saving the current configuration of each nBLM and a save and restore functionality to store and reload a specific configuration at any time (see Fig. 10).

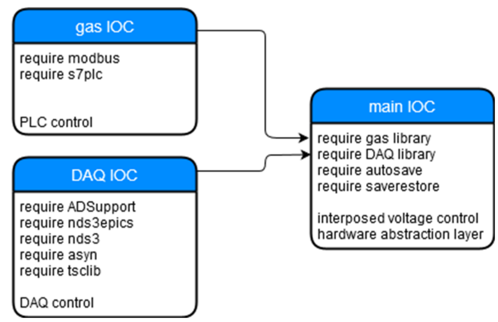

Figure 10: EPICS dependencies for the main IOC.

LINAC4 TESTS (CERN)

In 2018, tests have been done at LINAC4 in real condition with one nBLM and a MTCA crate including an IFC1410 board and a FMC ACD3111 module. It was the first test with the MTCA architecture and preliminary firmware becoming an opportunity to experience the DAQ system.

With the firmware, from DMCS, 3 seconds of data had been acquired. As the pulse was less than 1Hz, the data on demand file contains 2 pulses, the Fig. 11 shows data with a cut part between the 2 pulses.

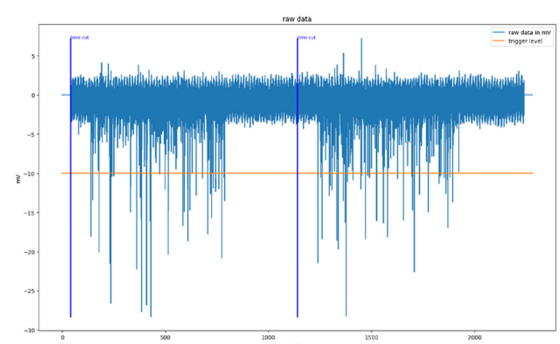

Figure 11: Display of interesting sections of the beam. With a trigger level a Python script concatenates and displays beam pulse data (trigger level, pre-trigger and post-trigger are set in the script).

As the accelerator was in normal functioning mode without beam loss, there are few neutrons and the negative peaks seen in the Fig. 11 would be gammas due to the RF presence during each pulse.

Event scoping, event discrimination (neutron peak, neutron pileup, etc.) and neutron counting have been performed with the CEA firmware and its associated IOC (see Fig. 12).

ISBN: 978-3-95450-209-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2019-MOMPL008

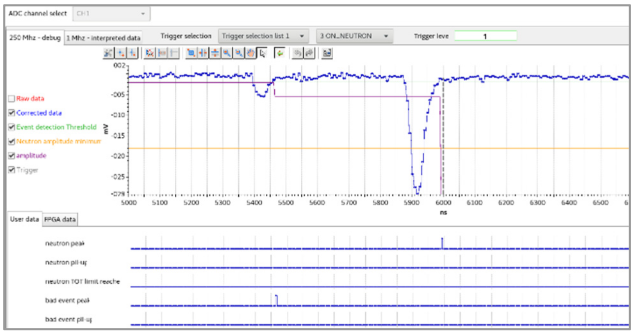

Figure 12: CS-Studio view of an event shape acquired with the scope functionality with an event configuration.

Statistics on event shapes with histograms have also been made in real time for charge, amplitude, TOT, rise time and pedestal (see Fig 13). This statistics are very useful to set the neutron detection parameters in order to try to discriminate neutrons from gammas.

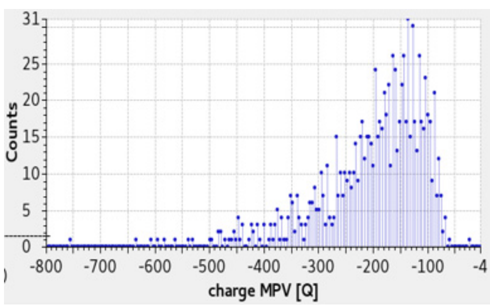

Figure 13: CS-Studio view of a histogram in real time of the charge.

INTEGRATION TESTS

In order to validate and to ensure the system is working properly, high level tests are performed. For this purpose we use the internal tool developed at CEA, WeTest, that runs unit and functional tests. Within the framework of the nBLM, the unit tests check process variable ranges and limits, whereas the functional tests aim to start one nBLM in nominal mode by setting the gas, High and Low Voltages (HV/LV) and acquisition configuration. WeTest also runs a simulated data file reading and checks the number of detected neutrons. Hence after software and firmware update, non-regression is also tested. The WeTest graphical interface follows the running test (see Fig. 14).

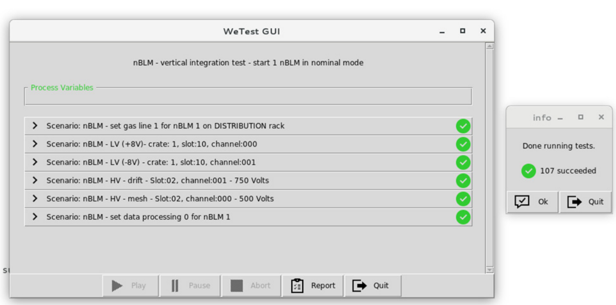

Figure 14: Graphical interface of WeTest results.

RELIABILITY STRATEGY

Each card, crate or rack is responsible for handling several detectors. In case one of these units malfunctions, all detectors managed by the unit could not detect beam loss in the region where nBLM are in default. In order to avoid these situations and to increase the system reliability, ESS specifies that the detectors in a same LINAC section will be controlled by separated rack.

The averages of neutron charge, TOT and amplitude, also called Most Probable Values (MPV), are monitored. MPV are good indicators on the detector stability. In case of an instability, it would mean there is a problem with a subsystem (LV, HV or gas). The IOC continuously monitors the status of devices and MPV of each detector. It gives to the firmware the status of components. The firmware could send a signal to the FBIS in case of system components or function failure.

CONCLUSION

The ESS nBLM vertical test of the control system has been successfully passed at Saclay in September 2019. The nBLM systems are now ready to be installed in ESS by the beginning of 2020.

Other accelerators are interested in using nBLM detectors. A full system could be adapted to their accelerator requirements, moreover extra features could be added.

The nBLM challenging development was an exciting project since we were involved and we contributed to nBLM system, from the specification to the installation of the control system.

ACKNOWLEDGEMENTS

Many people have contributed to this new nBLM. The authors would like to thank all contributors. From CEA side a special thanks to J.F. Denis, F. Gohier and K. Saintin for providing EPICS toolkits.

REFERENCES

[1] A. Zhukov, "Experience with the SNS loss monitoring and machine protection", in *Proc. North-American Particle Accelerator Conference (PAC'13)*, Pasadena, USA, Sep. 2013, paper WEYA2, pp. 714-718.

[2] I. Giomataris, P. Rebourgeard, J.P. Robert, G. Charpak, "MI-CROMEGAS: a high-granularity position-sensitive gaseous detector for high particle-Ćux environments", *Nucl. Instr. Meth. A*, vol. 376, p. 29, 1996.

[3] I. Giomataris *et al.*, "Micromegas in a bulk", *Nucl. Instr. Meth. A*, vol. 560, pp. 405-408, 2006.

[4] P. Legou *et al.*, "Beam Spectrometers using Micromegas in Time Projection Chamber mode" in *Proc. HB'06*, Tsukuba, Japan, paper WEBZ03, pp. 256-258, 2006.

[5] L. Segui *et al.*, "A micromegas-based neutron detector for the ESS beam loss monitoring" in *Proc. 8th Int. Beam Instrumentation Conf. (IBIC'18)*, Shanghai, China, Sep. 2018, pp. 211-214. doi:10.18429/JACoW-IBIC2018-TUPA02

[6] I. Dolenc Kittelmann *et al.*, "Neutron Sensitive Beam Loss Monitoring System for the ESS Linac", presented at the 8th

ISBN: 978-3-95450-209-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2019-MOMPL008

Int. Beam Instrumentation Conf. (IBIC'19), Malmö, Sweden, Sep. 2019, paper MOPP022.

[7] IPHI, http://ipnwww.in2p3.fr/The-IPHI-injector

[8] SIEMENS, https://www.siemens.com

[9] CAEN, https://www.caen.it/products

[10] NAT, https://www.nateurope.com/products/NAT-MCH-PHYS.html

[11] IOxOS, http://www.ioxos.ch

[12] Concurrent Technologies, https://www.gocct.com/product/am-g6xmsd-amc-processor

[13] MRF, http://www.mrf.fi

[14] G. Jabłoński *et al.*, "FPGA-based Data Processing in the Neutron-Sensitive Beam Loss Monitoring System for the ESS Linac", in *Proc. MIXDES 2019*, Rzeszow, Poland, June 2019, pp. 101-105.

[15] P. Lotrus *et al.*, "EPICS tools for small experiment based on PLC", presented at the 17th Int. Conf. on Accelerator and Large Experimental Control Systems (ICALEPCS'19), New York, NY, USA, 2019, paper THAPP04, this conference.