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# A MICROMEGAS BASED NEUTRON DETECTOR FOR THE ESS BEAM LOSS MONITORING

L. Segui*, H. Alves, S. Aune, T. Bey, J. Beltramelli, Q. Bertrand, M. Combet, D. Desforge, F. Gougnaud, T. Joannem, M. Keibiri, C. Lahonde-Hamdoun, P. Le Bourlout, P. Legou, O. Maillard, Y. Mariette, J. Marroncle, V. Nadot, T. Papaevangelou, G. Tsiledakis, IRFU-CEA, Université Paris-Saclay, F-91191 Gif-sur-Yvette, France
I. Dolenc Kittelmann, T. J. Shea, European Spallation Source ERIC, Lund, Sweden

*Abstract*

Beam loss monitors are of high importance in high-intensity hadron facilities where any energy loss can produce damage or/and activation of materials. A new type of neutron BLM has been developed aiming to cover the low energy part. In this region typical BLMs based on charged particle detection are not appropriate because the expected particle fields will be dominated by neutrons and photons. Moreover, the photon background due to the RF cavities can produce false beam loss signals. The BLM proposed is based on gaseous Micromegas detectors, designed to be sensitive to fast neutrons and insensitive to photons (X-rays and gamma). In addition, the detectors will be insensitive to thermal neutrons, since part of them will not be directly correlated to beam loss location. The appropriate configuration of the Micromegas operating conditions will allow excellent timing, intrinsic photon background suppression and individual neutron counting, extending thus the dynamic range to very low particle fluxes. The concept of the detectors and the first results from tests in several facilities will be presented. Moreover, their use in the ESS nBLM system will be also discussed.

## INTRODUCTION

In the new high-intensity hadron linear accelerators, a small loss of the beam is capable of damaging or activating materials in the machine. Thus Beam Loss Monitors (BLM) detectors with a sensitivity to very small fraction of beam losses are required. This limit approaches the 0.01 W/m loss value, which, in the case of the ESS, means a 0.001 ‰of the total 5 MW power lost over 600 m.

Moreover, an important background of photon fluxes is induced by the RF cavities due to the acceleration of electrons emitted from the cavity surfaces. The electrons will generate bremsstrahlung photons when interacting with some material of the accelerator. The spectrum of the produced photons ranges from X-rays to gammas of few MeV. If the BLM is photon-sensitive this implies an irreducible background that can mislead to a false beam loss or hide a real one [1]. This is of particular relevance in the low energy part of the accelerators where only photons and neutrons are produced in a beam loss situation. For this reason, a detector insensitive to photons is proposed.

Another requirement of a BLM is to obtain information about the loss location. In the low energy part, only neutrons and photons are emitted, as indicated above. With thermal neutrons their location information is lost, while fast neutrons can still provide such information.

In this paper the concept and first experimental results of a new neutron Beam Loss Monitor sensitive to fast neutrons and insensitive to X-rays and gammas are presented. It is based on the Micromegas detector technology. This new neutron BLM (nBLM) was already discussed in IBIC2016 [2] presenting results from MonteCarlo simulations that had proof the concept. In this paper experimental results will be discussed. The use of these detectors is planned for the ESS nBLM system.

## NEUTRON BEAM LOSS MONITOR CONCEPT

Micromegas detectors (MICRO-MEsh GAseous Structures) [3] are a type of Multi-Pattern Gaseous Detectors (MPGD). As other MPGD detectors, Micromegas have a high gain, fast signals, and a very good spatial and energy resolution. They are largely in use in nuclear and particle physics experiments since their invention in 1996. In addition, among the Micromegas family, the bulk Micromegas technology [4] appears as a very robust detector, with a simplified manufacturing process that reduces its cost and allows its industrialization.

Micromegas detector is a two-stage avalanche chamber with three electrodes: the cathode or drift, a micromesh and an anode. The micromesh separates the two regions. First region between the cathode and the micromesh is the conversion region. The second region is defined by the micromesh and the anode and is a very narrow amplification region of the order of $\sim 128\ \mu$m. When a charged particle enters in the conversion region it ionizes the gas producing primary electrons that are drifted towards the amplification gap by a constant electric field. In the amplification region an avalanche of electrons takes place due to the higher electric field applied in this region ($\sim 10^5$ V/cm). The Micromegas detector itself consists of the anode and the micromesh, usually constructed as a unity. The planarity between both is obtained by insulator pillars established by lithographic process. To detect neutrons (neutral particles) a neutron-to-charge converter is placed at the entrance of the drift.

The neutron BLM is conceived to be tunable to specific experimental conditions. It can be adapted to a wide range of neutron measurements with appropriate neutron-to-charge converters and neutron absorber and moderators [5]. More-

* laura.segui@cea.fr

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over, the flexibility in the choice of the gas and in the operation conditions allow to tune its sensitivity to neutrons and gammas.

### *Detector Geometry*

The neutron BLM has been designed to be intrinsically insensitive to gammas but sensitive to fast neutrons, being adaptable for different requirements. Two types of modules have been developed for the ESS nBLM system requirements in collaboration with ESS Beam Instrumentation. The main difference between both of them is the conversion of neutrons into charged particles, what will give a different response, being both complementary.

In the first type of detectors we use as converter a solid layer of $^{10}B_4C$ deposited in an aluminum plate, The deposition was made by the ESS Detector Coatings Workshop in Linköping, Sweden. Neutrons interact with boron through (n,$\alpha$). The gas chamber with the Micromegas detector is surrounded by 5 cm of polyethylene to moderate the neutrons first to increase the conversion efficiency and the dynamic range (from $10^{-6}$ to 100 MeV). An external layer of a neutron absorber is placed outside the polyethylene to reject the thermal neutrons. A sketch of the geometry is shown in Figure 1 (a). The detector has a $4\pi$ acceptance for neutrons with an efficiency almost constant all over the energy range. However, the response time is of few 100 $\mu$s due to the moderation process that delays a big part of the signal. The rejection of gammas is based on the ionization difference between them and alphas or heavier ions. Experimental confirmation of the time response and the gamma rejection is shown in next section.

In the other approach, a hydrogen rich converter is used and a (n,p) elastic scattering will take place producing proton recoils that will ionize the gas. Only neutrons with energies higher than ~ 0.5 MeV can produce protons capable to enter in the conversion region making the detector blind to thermal and low energy neutrons. The proton is emitted in opposite direction of the incoming neutron direction, therefore the detector has a preferred direction and a $2\pi$ coverage. Its efficiency can be ~ 100 times smaller that the other module but with a much faster response of few *ns*. Thus this module is named *fast* and the previous one the *slow*. Experimental results are also discussed in next section.

In Figure 2 the design of the modules is shown. Different parameters can be adapted depending on the expected flux or energies in different facilities, like the polyethylene or the neutron absorber thickness, the $B_4C$ or polypropylene thickness, or the use of a different neutron-to-charge converter. Also the gas choice and detector surface can be adapted.The detectors are equipped with the fast front-end electronics cards (FEE) placed on-board of the detector. It is based on the FAMMAS current amplifiers (Fast Amplifier Module for Micromegas ApplicationS) [6].

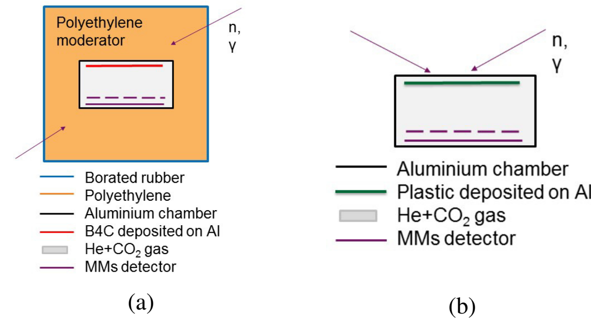


Figure 1: Neutron detection principle of the slow module (a) and of the fast one (b). More details can be found in the text.

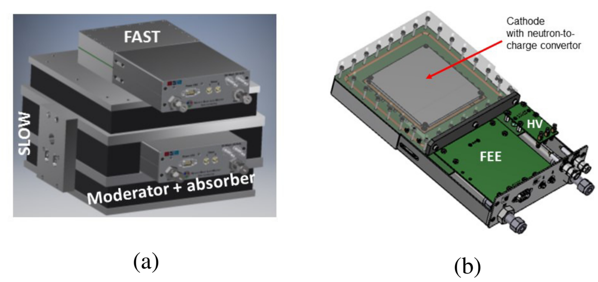


Figure 2: (a) Assembly of the fast and slow modules. They can be used as a single unity. (b) Schematic view of the Micromegas nBLM chamber. Same gas chamber and detector have been designed for both modules. Fast FEE will be mounted on-board.

## DETECTOR PERFORMANCE

The neutron BLM based on Micromegas detectors is a new application of such a detector in the field of BLM. Thus, the response of the detectors should be studied both experimentally and with MonteCarlo simulations. Initial results with Geant4 simulations to optimize the geometry were discussed in [2]. Several data campaigns have been carried out in different irradiation facilities to validate the simulations, finalize the design and proof of concept. In this section, some of the main results are discussed. A detailed paper with all the results and the comparison with Geant4 simulations is in preparation.

Measurements were done at the AMANDE (Accelerator for metrology and neutron applications for external dosimetry) installation, of the IRSN Cadarache, France. It produces mono-energetic neutron reference fields for metrology and calibration of neutron devices. Data was measured with both the fast and slow module at different neutron energies from 565 keV to 14.8 MeV. We performed measurements with different polyethylene thicknesses and different converters. For a polyethylene thickness of 5 cm, a $^{10}B_4C$ thickness of 1.5 $\mu$m and an active surface of $8 \times 8$ cm$^2$, we obtain an overall efficiency of ~ 0.4% almost constant all over the energy range. This implies we are sensitive to few counts/s for an initial neutron fluence of 1 s$^{-1}$cm$^{-2}$. Depending on the neutron

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energy, a factor of 1-2 orders of magnitude lower efficiency has been observed with the fast module in agreement with the simulations.

### *Gamma Rejection*

During the measurements at AMANDE with the 565 keV neutrons, a LiF target was used to produce such neutronic field, including a gamma field of 6-7 MeV coming from the $^{19}F(p,\alpha\gamma)^{16}$ reaction. The target can be replaced by a $AlF_3$ one what assures the production of only gammas. Data was collected in both cases with both detectors. The energy spectrum measured is shown in Figures 3 and 4 for the slow and fast detector respectively. In both cases we can see a clear rejection for gammas (red) compared to neutron+gamma (black). Applying an amplitude cut (7 keV for the slow corresponding to 0.3 V in Figure 3 and 14 keV for the fast corresponding to 2 V in Figure 4) we obtain a sensitivity of $1.8{\times}10^{-4}$ for the slow and of $3.6{\times}10^{-3}$ for the fast. We should mention that the drift distance in both detectors was not the same, being of 0.4 mm for the slow and 1.9 mm for the fast, what increases the rejection potential in the case of the slow due to the short interaction space for the gammas.

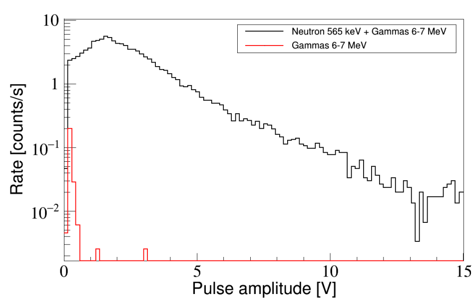


Figure 3: Response of the slow detector to the mixed field of 565 keV neutrons and 6-7 MeV gammas (black) and in the case of only gammas (red).

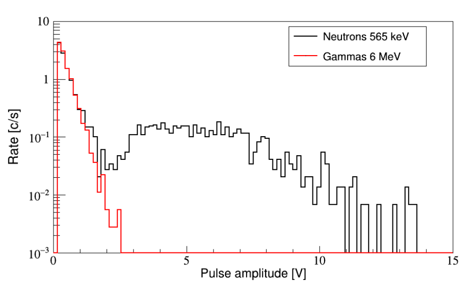


Figure 4: Response of the fast detector to the mixed field of 565 keV neutrons and 6-7 MeV gammas (black) and in the case of only gammas (red).

### *Time Response*

Tests were also performed at the IPHI (High-Intensity Proton Injector) proton beam installation at CEA Saclay. It accelerates protons up to 3 MeV in a pulsed beam of 90 $\mu$s at a repetition frequency of 1 Hz. During the tests a Beryllium target was used to produce a neutron field. Data was recorded with both detectors to study their time response in a pulsed beam. Results are shown in Figures 5 and 6 for the fast and slow detectors respectively. The fast detector shows an immediate response, in agreement with the simulations. Moreover, we can see how the count rate is in direct correlation with the intensity of the beam current measured in the target (red). In the case of the slow detector, the moderator layer will delay most of the events which are recorded with a delay of few hundreds of $\mu$s. The measured distribution shown in Figure 6 is a convolution of the moderation time within the time duration of the beam. In the same plot we show the cumulative distribution obtained from the MonteCarlo simulations (red) showing the delay produced by the moderator process with an instantaneous beam.

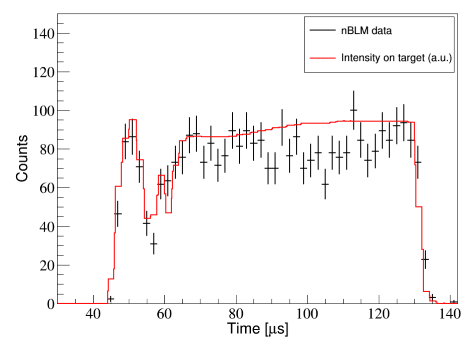


Figure 5: Time response of the fast module as measured at IPHI following the 90 $\mu$s proton beam pulse (black). It is compared with the measured current on the neutron target (red).

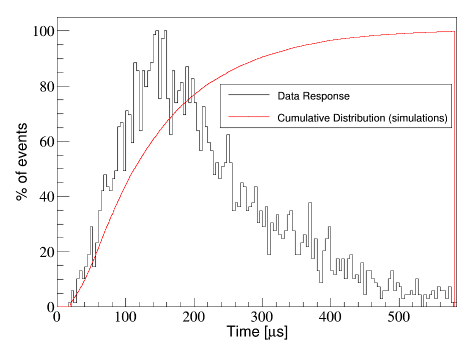


Figure 6: Time response for the slow detector as measured at IPHI following the 90 $\mu$s proton beam pulse (black). The response is delayed with respect to the one obtained with the fast module due to the moderation process of the neutrons in the polyethylene. In red the cumulative distribution obtained from MonteCarlo simulations is also shown for a instantaneous pulse.

Other results have been obtained, like the measured rate to different beam intensities wich show a linear dependency.

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Moreover, the detector is planned to be installed at LINAC4 to study their response in a similar environment to the one at ESS. Specially relevant will be to study its behaviour in a RF field. This will also be studied during the commissioning of the ESS RF cavities at Uppsala or at CEA/Saclay. In addition, the electronics will be exposed to high gammas field and neutron equivalent fields to study their radiation resistance.

## ESS NBLM SYSTEM

The ESS nBLM system is one the BLM subsystems at the ESS proton linac, dedicated manly to the low energy parts of the machine. 84 detectors will be installed along the accelerator, being 42 fast and 42 slow. Most of them will be placed in the DTL tanks (41) and another 26 in the Spokes region. Even if their main region of interest is the low energy part, some of them will also be tested in the high energy region, inlcuding Spokes section, for development purposes.

The ESS nBLM system includes, besides the Micromegas detectors, the back-end electronics (BEE) and data acquisition system (DAQ), the high and low voltage power supplies, the gas system and the EPICS based control and monitoring system. The BEE is based on the MicroTCA.4 platform and the acquisition of the analogue signal of each detector is performed by an IOxOS IFC_1410 AMC equipped with one IOxOS ADC_3111 FMC board with 8 channels at 250 MS/s. The real time processing of the signals is done withan an FPGA located on the IFC14010 card.

In the Micromegas detector each neutron will produce an individual pulse that can be identified and counted. We used ESS loss scenarios [7] as input to the Geant4 MonteCarlo simulation to study the expected response of the detectors. Results show few counts expected within 1 $\mu$s for a beam loss of 0.01 W/m, while at high loss levels the system can experience pile-up. In this later case the number of neutrons can be recovered integrating the charge per detector. The FPGA based data processing passes from counting mode to current mode automatically and the obtained number of counts per $\mu$s can be correlated to the beam loss for machine protection and monitoring purposes.

## CONCLUSION

A new type of neutron Beam Loss Monitor has been presented based on the detection of fast neutrons using Micromegas detectors with a correct combination of neutron-to-charge converters and moderators. The detectors are tunable in terms of efficiency and sensitivity for different neutron flux. The nBLM aims, mainly, to enlarge the sensitivity to losses to the low energy region of an hadronic accelerator, where a neutron and photon field are dominant, although they can also be foreseen for the high energy region. To avoid the possible signals from gammas produced by the RF cavities they have been designed to have a strong gamma to neutron suppression. Two type of detectors have been designed for the ESS nBLM system tuned to operate in the low energy parts of the ESS linac, with complementary objectives: fast reaction time when high particle fluxes are produced and monitoring of slow losses for long term activation. The response of the detectors have been proven experimentally at different irradiation facilities as discussed along the paper, with emphasis in showing their time response and their gamma rejection. More tests are foreseen in the coming months to study their response in RF field environments as LINAC4.

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