REPORT

MODES COVERED BY NBLM SYSTEM

	REDACTEUR *Edited by*	VERIFICATEURS *Reviewed by*		APPROBATEUR *Approved by*
NOM Prénom ***Name***	SEGUI Laura	PAPAEVANGELOU Thomas		PAPAEVANGELOU Thomas
Fonctions ***Functions***		Chef de projet		
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1. Purpose of the document

This document has as purpose to clarify the differences between what we called slow and fast detector in the nBLM system. It arises as a request after the PDR1.2 from the reviewer panel. In addition, it also aims to explain the different cases covered by each module and how the analysis will be done (counting or current mode). The document is included in the documentation package send for the nBLM CDR1.1. However, the document can be further modified if requested by the reviewers.

2. Micromegas technology

The nBLM system is made by a new Beam Loss Monitor based on the detection of fast neutrons using a Micromegas detector. It was conceived to operate in counting mode and to be an extension of other BLM systems in the region where they have a small sensibility, i.e. in the low energy region of the accelerator.

The expected rate during normal operation discussed during the conceptual design of the system was of few n/s. In addition, in the low energy region, only neutral particles (neutrons and photons) are able to escape from the accelerator. The detector we propose is only sensitive to neutrons and insensitive to photons. In that sense it presents an advantage with respect to icBLM where a x-ray from the RF could make the separation between real losses and RF emissions more difficult.

Micromegas [1] detectors are a type of MPGD (MultiPattern Gaseous Detectors) very extensively used in particle physics experiments and also in neutron experiments (for example in the nTOF experiment or in the Denim detector (refs)). As indicated by its name, it is a gaseous detector where the charged particles arriving to the chamber will ionize the gas and which is amplified and detected in the Micromegas. In Figure 1 a sketch explaining its operation is shown. The Micromegas itself consists in a mesh suspended over an anode plane separated by insulator pillars. Different technologies have been developed since its invention in order to improve the capabilities of the detector and to adapt to different needs (for example the bulks are very robust and can resist to high radiation environments [2] or the microbulk technology can be fabricated with a very low radioactivity budget for rare event searches experiments). The detector consists in fact in two regions: a conversion or drift region between the cathode and the Micromegas mesh, and an amplification region between the mesh and the anode. When a charged particle enters in the conversion region it produces ionization electrons that are driven towards the mesh by an electric field of typically, 10^2-10^3 V/cm. Once arriving to the mesh, a stronger electric field in the amplification gap (10^4 - 10^5 V/cm), conduct the electrons through the holes in the mesh to the amplification gap.

There the signal is amplified producing an avalanche that is detectable both in the mesh and in the anode. The anode can be made by strips or pixels.

The typical signal in a Micromegas detector is of few mV with a current of few µA. The rise time can be tuned with the drift distance but in general it is of ~30-50ns if there is no pre-amplification. The pulse duration, also tuneable with the drift distance, is of 100-200 ns.

A Micromegas detector, as any ionization detector, detects charged particles, therefore, we need to use a converter in order to detect the neutrons. Usually we place a solid convertor as Boron or polypropylene in the entrance of the drift region.

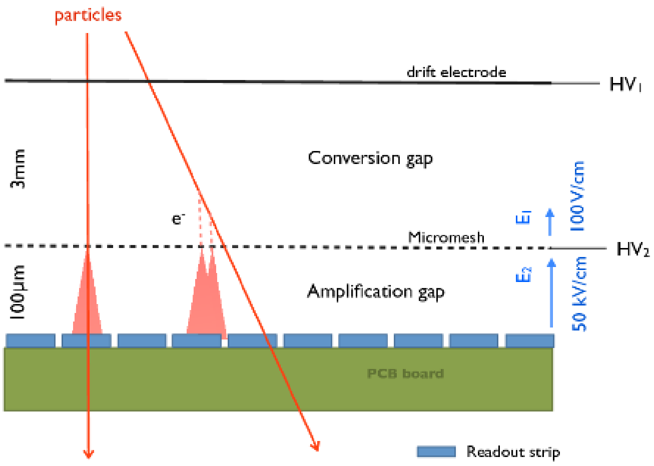


Figure 1: *(a) Micromegas operation principle sketch*

3. Slow and fast nBLM detectors

The requirements from ESS for such a system is to be able to give a response in 5 µs and to be able to monitor losses of 100 mW/m.

The detectors we propose are in fact the combination of two detectors, that we call “Slow” and “Fast”, based on their response. However, they have also another differences between them that make them complementary. In the following section a comparison between the signal formation, the expected sensitivity and the expected function of each one is discussed.

3.1. Geometry and signal generation

The two detectors that conform a nBLM module were conceived to have a complementary functionality. They can be use together or separated. In Table 1 the characteristics of each detector are summarized. In the following we give more details and explain the expected cases covered by each one.

	SLOW	**FAST**
Converter	B_4C	Mylar or Polypropylene
Reaction	$(n,\alpha)^{10}B$	(n,p)
Signal	Fast neutrons after moderation	Fast neutrons
Detected energy	~constant (1.4 MeV)	Continuum distribution of energies
Sensitivity	10^{-6} < En < 100 MeV	En > 0.5 MeV
Solid angle	4π	2π, n coming from the front only
Efficiency	~few $n{\cdot}cm^{-2}{\cdot}s^{-1}$	~ 10^{-2} $n{\cdot}cm^{-2}{\cdot}s^{-1}$
Response time	~200µs	~0.01µs
Objective	Monitoring of small losses	Alarm (in 5 µs) Fine structure of the lost
Shielding	Yes, for thermal neutrons	Not needed

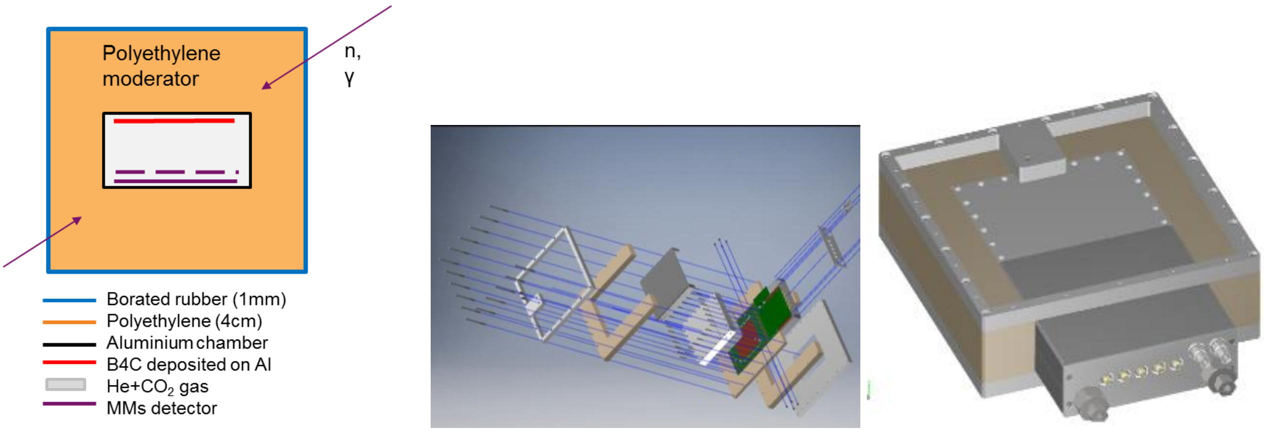
Table 1: *Summary of the characteristics of each detector. Note that “En” is the energy of the detected neutron.*

3.1.1. Slow Detector

The slow detector is conceived to be sensitive to a large range of energies, with a good efficiency and enough sensitivity for small neutron fluxes (few n/cm^2/s). It has a 4π response, adjustable neutron sensitivity and a low gamma sensitivity.

The geometry is largely explained in the PDR documents ([3], [4]). For both detectors, fast and slow, we have a gas chamber with the same dimensions and with the Micromegas detector placed at one end of the gas volume. The active surface is the same in both cases as the Micromegas detector is exactly the same for both.

However each one has a different neutron convertor in the entrance of the gas volume: in the slow detector it is B_4C deposited in Aluminium. The thickness of the B_4C will modify the efficiency. In addition, the gas chamber is surrounded by several cm's of moderator to thermalize the neutrons and increase the efficiency of conversion in the B_4C. Moreover, a shield of few mm of a borated plastic is placed in the outermost part of the detector to stop the thermal neutrons, as they are a background. A sketch of the geometry is shown in Figure 2 (a) and the design in (b). Results obtained with MC simulation modifying the thicknesses of the convertor and moderator and absorber can be found in [4] and [3].



(a) (b)

Figure 2: *(a) Sketch of the slow detector geometry (b) Design of nBLM slow detector*

Signal creation in the slow detector

- The neutron is converted at the drift entrance
- Convertor: B-10 (B_4C deposited in Aluminium)
- The reaction is (n, α) reaction. The produced α is emitted always with the same energy. There exist two channels of decay: one with an alpha of **1.4 MeV (94% of the times**) and another of 1.8MeV 6% of the times
- The produced α by the conversion enters the gas volume ionizing it.
- The amplitude is almost constant as the energy is always the same. It will have a certain distribution as it depends on the alpha angle of emittance (Figure 3). But there will be a quiet stable mean value that could be used, as already measured with a Cf-252 source. In addition the detector has a given energy resolution.

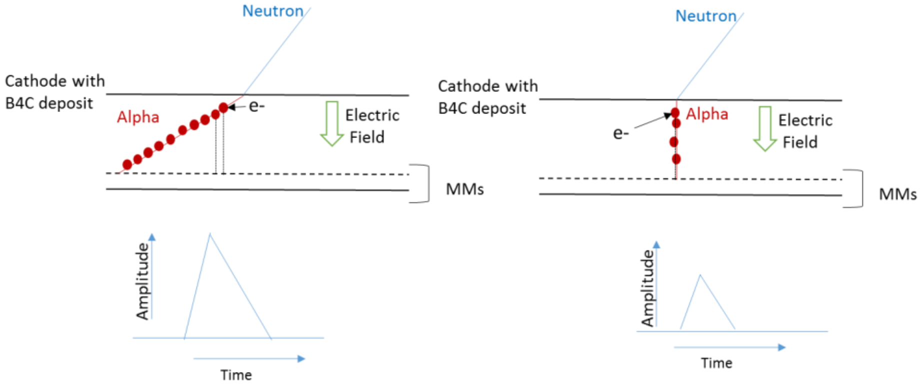


Figure 3: *Charge creation and amplitude depending on the alpha emission angle.*

- Alpha particles are stronger ionization particles. They produce much more charge than a gamma → $Amplitude_\alpha >> Amplitude_\gamma$
  - Setting an energy threshold we can reject the gammas
  - In case of a burst of X-rays studies are on-going
- The slow detector has better efficiency but a slower response. The efficiency is pretty much constant over the different energies expected at ESS.
- Time response is ~150µs → all events detected in 150µs
  - About 10% of events detected in 4µs
  - The delay is introduced by the moderation time of the neutrons in the polyethylene placed around the gas chamber.
- But each event detected (alpha ionizing the gas) has, more or less, same pulse duration ~100-200ns, as explained in Section 2.

3.1.2. Fast Detector

The fast detector is conceived to be appropriate for high flux high energy neutrons coming from the front, therefore it is directional. It is also insensitive to gammas and can cope with high particle fluxes.

The geometry in this case consists in just the gas chamber, we don't have moderator nor absorber. The convertor, as indicated in Table 1, is polypropylene and the reaction to detect neutrons is (n,p). The cross-section has a threshold at ~ 0.5MeV, and only neutrons with higher energies will produce a signal. That is the reason why we don't use moderator and why we don't need absorber for the thermal neutrons. For this reason also the response is faster, although the efficiency is smaller. A sketch of the geometry and the design are shown in Figure 4 (a) and (b).

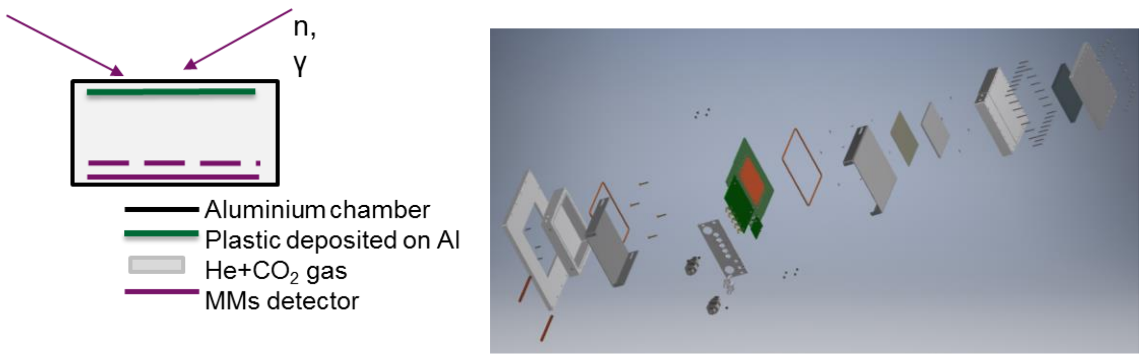


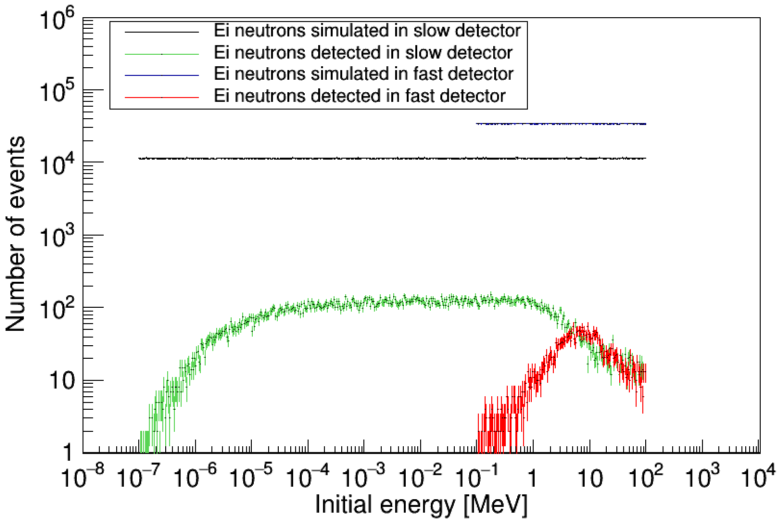
Figure 4: *(a) Sketch of the fast detector geometry (b) Design of the fast module*

<u>Signal creation in the fast detector</u>

- In this case the neutron is converted into a proton that ionizes the gas and generates a signal in the Micromegas
- The reaction is a (n,p) reaction in polypropylene or aluminized mylar
- The proton is always emitted in the opposite direction of the arrival of the neutron. Therefore, the fast detector is only sensitive to neutrons coming from the front.
- The proton can be emitted with a continuum of energies.
- As in the case of the slow detector, the proton ionizes much more than the gammas and we can discriminate between them with an energy threshold. Note that in this case we would lose few neutron events.
- The efficiency is much lower in this detector
- However, as there is no moderator the time response is very fast, of ~10ns.

In the following different results obtained with MC simulations are shown in order to justify the previous points discussed. The deposited energy spectra obtained experimentally is also shown.

Response and deposited energy



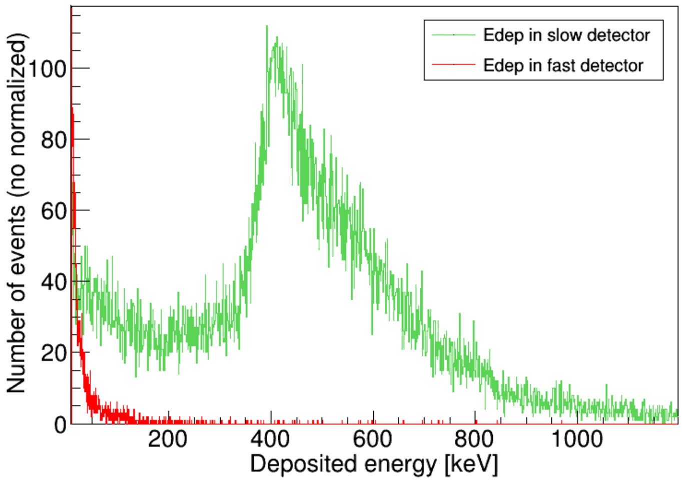


Figure 5: *(top) Expected response of the slow (green curve) and fast detectors (red) for a given initial neutron energy. In black is the initial neutrons energy distribution simulated for the slow detector and in blue for the fast. The absorber in the slow is 2.5mm of borated rubber. (Bottom) Spectrum of energy deposited in the gas volume for the slow (green) and the fast (red) detectors. Note that they are not normalized between them but the shape is the important parameter. No peak in the fast.*

Time Response

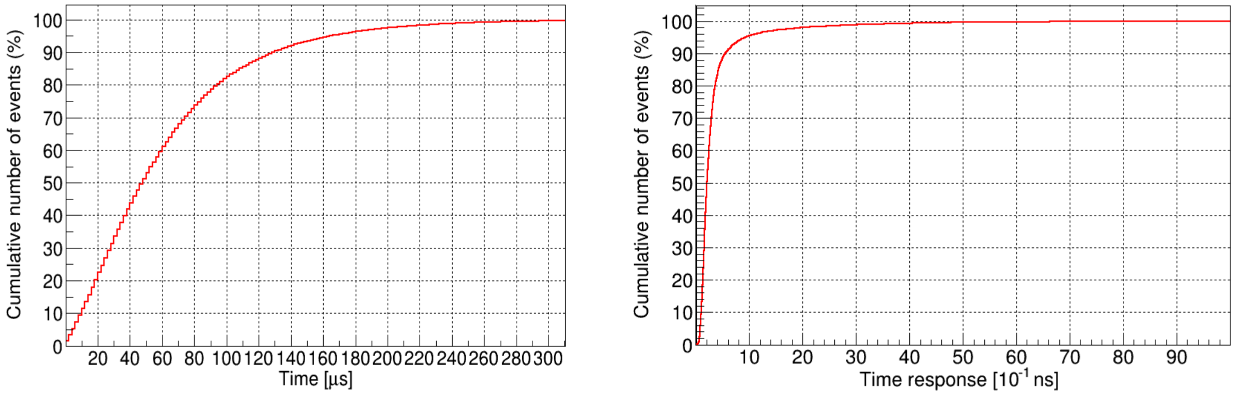


Figure 6: *cumulative distribution of the events detected with respect the time for the slow (left) and fast (right) nBLM detectors. Note the different units in the x-axis.*

Background Discrimination

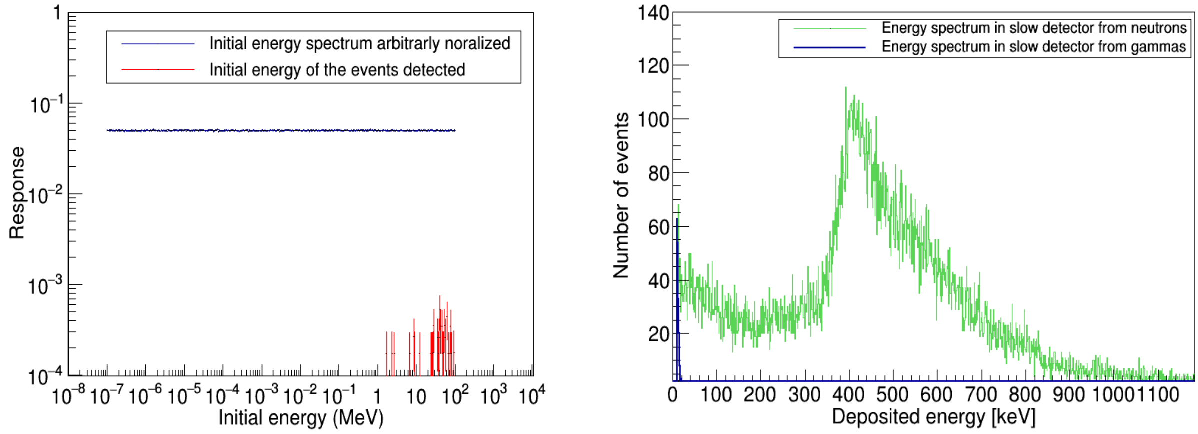


Figure 7 *(Left) Initial and recorded gamma energy spectrum with respect the initial gamma energy. (Right) Deposited energy from neutrons (green) compared with the spectrum from gammas (blue) in the slow detector.*

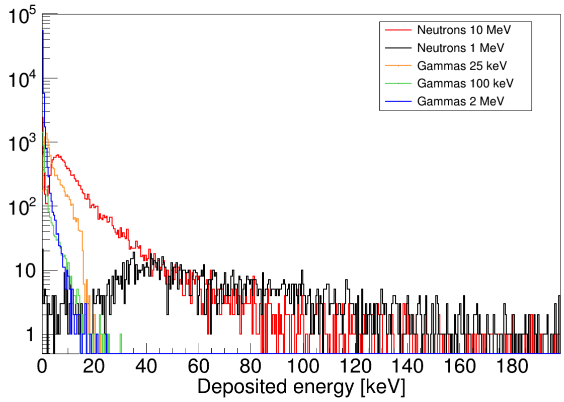


Figure 8*: Energy deposited by gammas and neutrons of different energies.*

3.2. Modes covered by each module at ESS

3.2.1. Slow detector application at ESS

- Mainly conceived for monitoring small losses due to its high efficiency but slow response
- However, in case of a big loss already detect the 5% of the events in 5µs.
- MC simulations shown an expected rate in the case of 100mW/m loss of 100 Hz – 68 kHz in the DTLs region (low-high energy respectively).
- In the case of catastrophic losses we obtain rates from MHz up to GHz.
- During normal operation if we check for a 1µs, we could find one event implying a rate of already 1MHz that is not necessarily true with only one event.
- So we need to set an extra parameter for the **alarm** in this case, and do not use the rate.
- Charge (integration of amplitude)? Not really as different cases can give the same Q. For example, 4 neutrons that have emitted the alphas with small angles and deposit pulses with small amplitude at the same time will give the same value as a single neutron emitted with a sharper angle and therefore having a higher amplitude.
- Time Over Threshold is the most reliable value
- Could be that we have pile-up but still will indicate some anomaly in the detector as will imply higher rates so we send an alarm. Later in analysis we can try to quantify the rate, for example using the Q/‹A›.
- For **monitoring**, keep a history of the rate with time (decide on time window) to detect small continuous losses that can produce activation.
- In any case the rate in 1µs will be also calculated

3.2.2. Fast detector applications at ESS

- The main purpose of the detector is to give a fast alarm in case of a problem in the beam.
- As for the slow, **Time Over Threshold** is the most adequate value due to the different amplitudes we can have and that we need to give an alarm in 5µs. Implies 1 event in 1 µs a rate of 1 MHz…
- In addition, it can give information of the **fine structures of the losses**. For example, in the case of 100 mW/m, we expect (from MC studies) up to 1c/ms, that implies more or less 3c/pulse, i.e. in 300 pulses we will have 300 counts.

3.3. Counting mode and current mode

The nBLM system was originally conceived to operate in counting mode. However, results from simulations using ESS scenarios as input have shown that rates up to GHz can be expected in cases of catastrophic losses.

The electronics have been chosen to be able to cope such rates and to be operative both in counting and in current mode. Each neutron pulse will have a duration of about 150ns. The requirement from ESS is to send an BIS flag to MPS in 5µs. If we monitor 1 µs window, taking into account the duration of each pulse, with ~6 events we start having pile-up. 6 events in 1 µs means a rate of 6MHz. The time window needs to be decided but can't be larger than 3µs.

The analysis in the FPGA will automatically change between counting and current mode when a rate of this order is obtained. Current mode is an integration of the charge. The recovery of a rate value can be foreseen in the slow detector as each event has a constant mean charge.

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