A NEW BEAM LOSS MONITOR CONCEPT BASED ON FAST NEUTRON DETECTION AND VERY LOW PHOTON SENSITIVITY

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Abstract

Superconductive accelerators may emit X-rays and Gammas mainly due to high electric fields applied on the superconductive cavity surfaces. Indeed, electron emissions will generate photons when electrons impinge on some material. Their energies depend on electron energies, which can be strongly increased by the cavity radio frequency power when it is phase-correlated with the electrons.

Such photons present a real problem for Beam Loss Monitor (BLM) systems since no discrimination can be made between cavity contributions and beam loss contributions. Therefore, a new BLM is proposed which is based on gaseous Micromegas detectors, highly sensitive to fast neutrons, not to thermal ones and mostly insensitive to X-rays and Gammas. This detector uses Polyethylene for neutron moderation and the detection is achieved using a ^{10}B or $^{10}B_4C$ converter film with a micromegas gaseous amplification. Simulations show that detection efficiencies > 8 % are achievable for neutrons with energies between 1 eV and 10 MeV.

INTRODUCTION

This paper deals with the design of a new Beam Loss Monitor based on Micromegas detectors devoted to fast neutron detection.

We will present, firstly, the motivation to develop this new BLM followed by a brief Micromegas working principle description. Then, simulation results will be presented to confirm that all the specifications are fulfilled, which mainly are fast neutron detection with a good efficiency, but very low sensitivity to thermal neutrons as well as to X-rays and γ's. Time response has been investigated to finally propose the addition of a faster monitor for safety purposes. The R&D program will be briefly discussed before to conclude.

WHY NEW BEAM LOSS MONITORS?

The idea to develop a new kind of BLM was triggered by the construction of new powerful accelerators as ESS for instance. Beam line part of them uses superconductive technology, where their accelerating cavity surfaces are submitted to very huge electric fields. These later release electrons from time to time which are accelerated under the RF electric fields covering an energy spectrum up to few MeV. When these electrons impinge on material, they may generate important photon fluxes with energy range from X-Rays to γ's. These phenomena concern also the RFQ, but at lower energy. Such photons, emitted at the lowest beam energy, contribute particularly as background to the external BLM, since the beam loss signal comes only from neutral particles (neutrons and photons) which are the only ones able to escape from the beam pipes or structures. Therefore, photon-sensitive BLMs may deliver signals which are not correlated to beam losses, but to cavity behaviours. As we can't discriminate between photons coming from beam losses or cavities, we propose a BLM blind to photon contributions. Note that it is less dramatic for higher beam energy where lost particles may have higher energy, producing numerous hadronic by-products which can be efficiently detected by usual BLM like ion chambers.

Another important criterion for BLM is the ability to locate the beam losses. It may be achieved with neutrons, but only with fast neutrons. Indeed, neutrons may be thermalized in the accelerator, particularly on the concrete wall. They will be detected after few rebounds, far from their emission locations.

To summarize, the requirements for BLM used on superconductive accelerator, especially for those working at low beam energy, are the following:

- Fast neutron detection, insensitive to thermalized ones
- Blind to X-rays and gammas.

We propose to design such a BLM, called neutron BLM (nBLM), based on Micromegas detectors [1].

MICROMEGAS WORKING PRINCIPLE

Micromegas detectors were invented at CEA Saclay in 1995 [2] and have been submitted, since their births, to a lot of improvements, modifications to fulfil new specifications and detection schemes. Micromegas is a Micro-Pattern Gaseous Detector (MPGD) as sketched on Fig. 1.

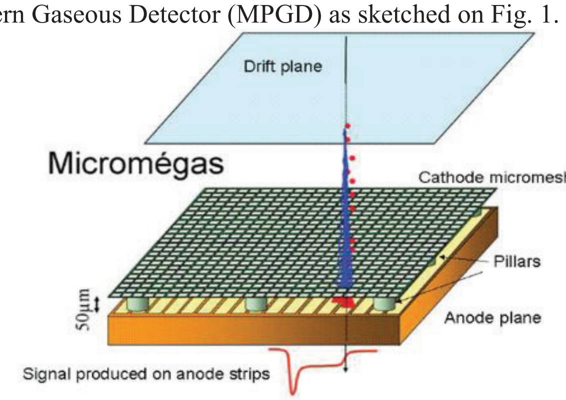

Figure 1: Micromegas scheme.

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It can be seen as a parallel plate gas detector inside which a fine mesh is strengthened dividing the detector into 2 parts:

- The drift region (thickness about 1 to 10 mm),
- The amplification region (30 to 150 µm)

The different electrodes are typically polarized around −1000 V for the drift plane, -500 V for the micromesh while the stripped anode (read-out) is grounded. Therefore an incident particle entering through the drift plate ionizes the gas molecules, releasing primary electrons which drift toward the micromesh. Then, these electrons gain energy under the huge electric field influence encountered in the amplification region, allowing to generate secondary ionization processes. Finally, they induce fast electric signals on strips processed by the read-out electronics.

To improve the response uniformity of such a detector, the micromesh is maintained parallel to the drift plate and the anode by several pillars.

Various Micromegas versions were developed and few are able to sustain counting rates as hugged as 10^8 particles/cm^2/s, while active area may cover large surfaces like for the New Small Wheel project for the LHC upgrade [3]. Nowadays, they can even take cylindrical shapes [4], spatial and time resolutions can achieve values lower than 50µm and 30 ps respectively [5]. Thanks to new technologies, bulk Micromegas with resistive electrodes have reduced drastically spark rates, hence the dead time of the monitor, which is a very relevant parameter for BLMs commonly associated to the accelerator safety.

SIMULATIONS FOR NEUTRON BLM OPTIMIZATION

The aim of these simulations is to optimize several parameters to design a first nBLM prototype. The requirements are a highest detection efficiency for fast neutrons but low for thermal and, moreover, a high blindness to photons.

Simulations were done using firstly FLUKA [6-9] and later on GEANT 4 [10]. It was checked that results obtained from both codes are similar.

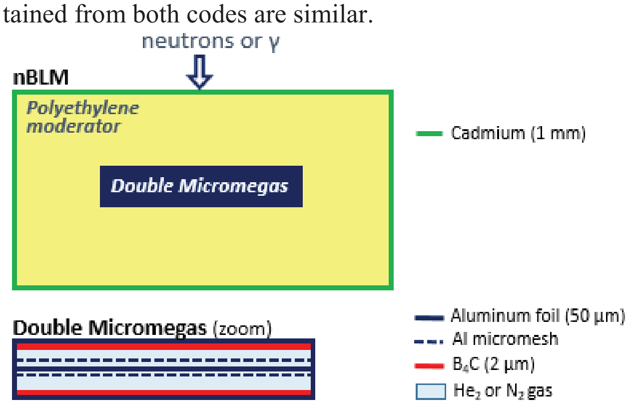

Figure 2: nBLM structure with a zoom on the double Micromegas. Overall size of such a monitor is about 22×22×10 cm^3.

nBLM Rejection and Efficiency

To fulfil the requirements, we have considered a detector made of the following materials (Fig. 2):

- An external envelop for enclosing the entire detector, made with cadmium to absorb thermal neutrons.
- Polyethylene moderator: the width can be changed for adjusting the neutron energy threshold.
- Double Micromegas are used with two B_4C thin converter films mounted inside the detectors for neutron detection [11]. Helium gas or other gas like N_2 (≈ 1.1 bar) can be flushed but helium is preferable to decrease the gamma response contribution.

To simulate neutron responses, a double exponential energy spectrum ranging from 0.1 eV up to 100 MeV was considered (Fig.3-bottom). Neutrons are then withdrawing few cm upstream and transversely to the nBLM, with an angular divergence of 10 mrad as depicted on Fig. 3-top.

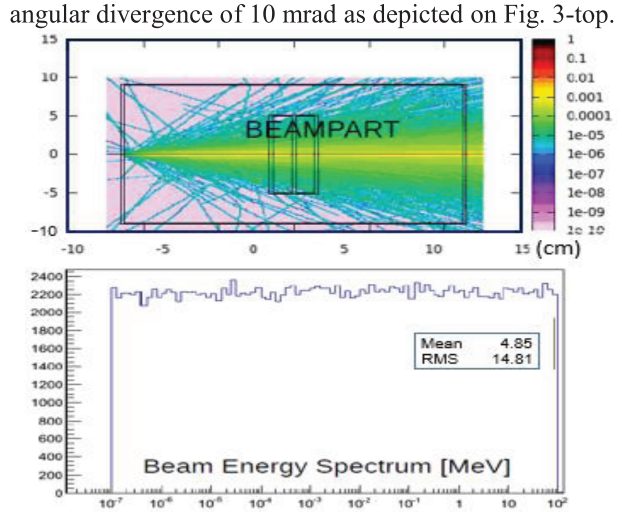

Figure 3: Neutron impacting on nBLM (2 cm moderator thickness) as seen by FLUKA (top) and the flat neutron double exponential energy spectrum (bottom).

Neutron Efficiency The polyethylene moderator thickness was simulated to optimize the nBLM efficiency by withdrawing 1 million of incident neutrons. On Fig. 4-left the results for 2, 4 and 6 cm are represented. We may note that the neutron energy threshold can be tune by varying the moderator thickness, but the efficiency behaviour changes drastically. On the right the neutron spectrum for an energy threshold at 10 keV, which exhibits an overall 3.8% detection efficiency, is displayed. If the incident neutron energy range is reduced to 1 eV up to 1 MeV, the efficiency increases above 5% for 4 cm moderator thickness.

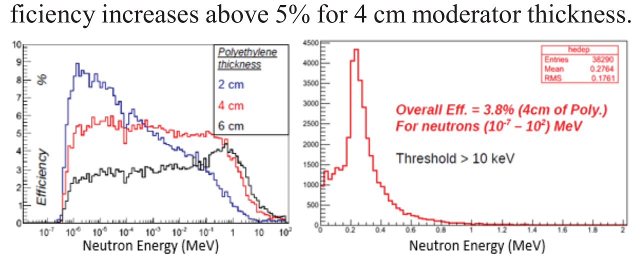

Figure 4: Neutron efficiency for 2, 4 and 6 cm moderator thickness (left) and the detected neutron spectrum for 4 cm thickness of polyethylene (right).

Thermal Neutron Response Neutrons with energy ranging from 10 meV to 1 eV were simulated. Processes like neutron capture by cadmium $^{113}Cd(n,\gamma)Cd^{114}$ with a released γ were investigated too.

Another γ background is provided by the interaction of thermalized neutrons with ^{10}B which produces Li and α particles and a γ (480 keV) for 94% of this reaction. The nBLM response for such a γ was simulated and the result is presented in Fig. 5. As shown, a simple energy threshold at 20 keV is enough to remove almost this contribution.

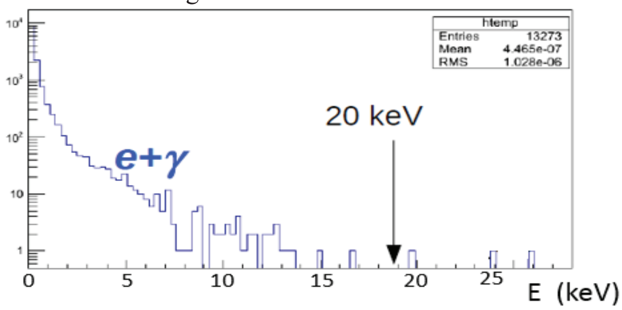

Figure 5: e^- and γ by-products of $n+^{10}B$ reaction.

The total thermal neutron contribution can be seen on Fig. 6. The efficiency is 0.007% for a detection threshold set at 10 keV and nBLM becomes blind if it is increased down to 30 keV. Helium gas is used for this study.

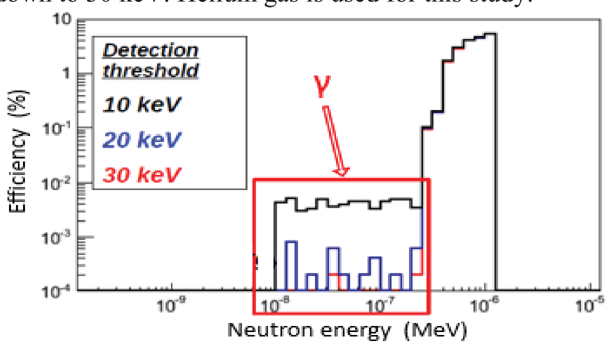

Figure 6: Thermal neutron efficiency for 4 cm moderator thickness. γ decays from Cd and 10B are highlighted in red.

Photon Response Simulation was done with a double exponential flat photon energy spectrum ranging from 10 keV to 100 MeV (Fig. 7). Using helium gas and 4 cm of polyethylene moderator, nBLM efficiency is below 0.006% for detection threshold of 10 keV and almost blind for 30 keV.

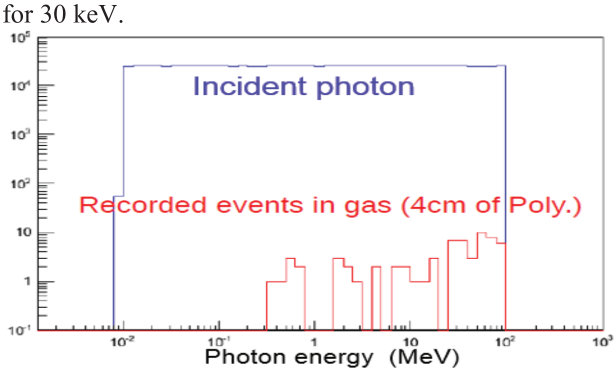

Figure 7: Incident photons (blue) and detected ones (red) for an nBLM integrating 4 cm moderator and He gas.

Under 10 keV, X-rays are absorbed in cadmium and aluminium. The transparency of photons is obviously understood since Micromegas used small amount of material, mainly gas and a thin micromesh resulting in a really short radiation length.

As a preliminary conclusion, it seems that a nBLM with a double Micromegas working with helium gas and surrounded by 4 cm of polyethylene moderator fulfils the specifications. With such a nBLM we have also simulated its angular response to neutrons. Neutron beam is launched on the centre of the entrance window perpendicularly to it (θ=0°). Such beam with angles θ=30° and θ=60° for a double Micromegas with 4 B_4C layers (for increasing the recording efficiency) were investigated as shown on Fig. 8.

Due to the thermalization of neutrons inside the moderator, the angle effect is quite weak. Such a behaviour allows to expect also an efficiency for nBLM greater than the active surface of the double Micromegas itself.

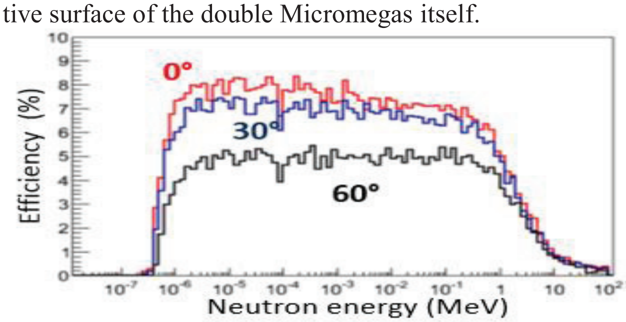

Figure 8: nBLM angular response to neutrons.

Experimental and Simulation Data Comparison Experimental data are obtained by a Micromegas detector with one B_4C plate, placed on top of a polyethylene cylinder that surrounds a ^{252}Cf neutron source, as shown in Fig. 9 (left plot). This spectrum is well reproduced by simulations based on FLUKA MC (Fig. 8 - right plot).

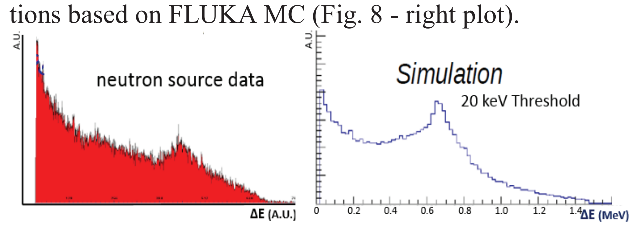

Figure 9: 252Cf data and simulation obtain by a Micromegas detector and sets of moderators.

Timing

BLM are very often linked to machine safety operations, thus in order to avoid irreversible damages they need to deliver quite fast signal which should then be processed by MPS for instance.

Time study was done with 1 MeV neutron beam transversely colliding to a nBLM located at 1 m downstream with an angular divergence of 10 mrad. On Fig. 10 the duration time Δt to get part of the events or "event ratio" is represented. For instance, all events are detected above Δt=300 µs, while only 17% of them below 10 µs.

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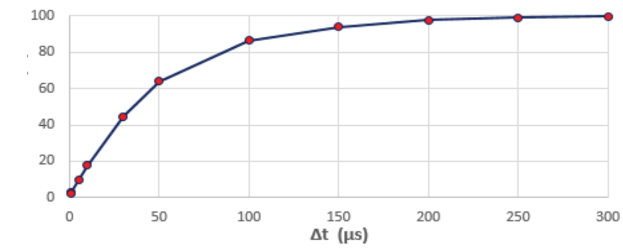

Figure 10: nBLM time response.

Due mainly to moderation time, this nBLM is quite slow, which can be a handicap for safety for which time responses of the order of the µs are required. At the low energy part of the accelerator where neutron emission is already weak, accentuated by a drop of 80% (at 10 µs), it may become difficult or impossible to alarm the safety system quickly. Therefore, we propose to add a fast neutron detector in front of the previous one.

This detector must be fast (≪1 µs) to warn efficiently in case of problem, in other words when lot of particles will be emitted!

Fast Neutron Detector

A new Micromegas will be used with helium or neon gas and 2 mm polypropylene convertor to generate recoil protons followed by a 5 mm drift region. A thin aluminium layer (50 nm) between the convertor and the Micromegas will insure the neutron energy threshold adjustment (E_n>0.5 MeV). The relevant parameter is the time response which can be seen on Fig. 11, where time responses have been simulated for neutrons [0.1 to 100 MeV] versus their incident energy (left) and the deposited one (right). In the whole energy range, time is far below 8 ns. Time is calculated from the neutron emission point to its detection which is achieved as soon as its energy deposited is greater than the threshold (10 keV).

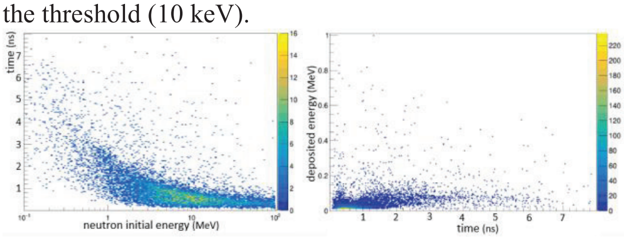

Figure 11: Time response for the fast Micromegas versus incident and deposited neutron energies.

A check of photons contamination has been done and is shown in Fig. 12. A simple cut around 20 keV is enough to remove almost all photons.

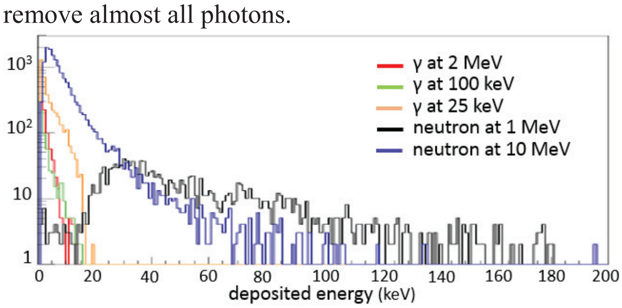

Figure 12: Fast Micromegas neutron and γ responses.

The neutron efficiency for such a detector is about 3 10^{-4} and 8 10^{-4} for neutron energy of 1 and 10 MeV respectively at 10 keV detection threshold. A low efficiency is compliant with an emergency in which a huge neutron flux should be emitted. Investigation with neon gas was also done and are promising too.

For beam loss system, the final monitor will be made with a fast nBLM set in front of a “slow” one depicted previously.

R&D Program for nBLM

A R&D program for nBLM is already in progress. After a first simulation stage, nBLM prototypes will be manufactured and their neutron and γ responses will be measured.

As shown, neutron signals are quite big allowing to count them individually; a fast low noise front-end electronics based on counting rates has to be design.

They are many aspects which may be investigated to optimize the nBLM like the hardness of the detector, the gas working system in sealed mode [12].

CONCLUSION

This paper deals with the design of BLM based on Micromegas to detect fast neutrons with a really low photon efficiency. It may be dedicated to the low energy part of the high beam intensity for the forecoming new facilities.

First simulations showing the feasibility of such a detector were reported in this article. Prototypes will then be designed in order to measure their neutrons and photons responses and to investigate their radiation hardness.

The first part of ESS beam line, the MEBT and the DTL (3.6 to 90 MeV), should be equipped with such nBLMs. The possibility to install them in Saraf is under study.

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