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A Transparent Detector for n_TOF Neutron Beam Monitoring

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In order to obtain high precision cross-section measurements using the time-of-flight technique, it is important to know with good accuracy the neutron fluence at the measuring station. The detector dedicated to these measurements should be placed upstream of the detectors used for capture and fission cross-section measurements. The main requirement is to reduce the material of the detector as much as possible, in order to minimize the perturbation of the neutron beam and, especially, the background produced by the device itself. According to these considerations, a new neutron detector equipped with a small-mass device based on MicroMegas "Micro-bulk" technology has been developed as a monitoring detector for the CERN n_TOF neutron beam. A description of the different characteristics of this innovative concept of transparent detector for neutron beam monitoring is presented. The result obtained in the commissioning of the new spallation target of the n_TOF facility at CERN is shown, compared with simulations performed with the FLUKA code.

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I. INTRODUCTION

In order to obtain a high precision in neutron cross-section measurements, an essential aspect is the accurate knowledge of the energy distribution of the neutron flux during the measurements. The detector dedicated to this measurement should measure the incident neutron flux on the sample in the beam and should therefore be placed upstream of the sample position and the different detectors in the experimental area. As a consequence such a neutron flux detector should ideally have an in-beam mass as small as possible in order to minimize the perturbation on the neutron beam and to minimize also the production of background by the device itself.

According to these considerations a small-mass device has been designed for monitoring the n_TOF phase 1 neutron beam [1]. This detector was based on a thin Mylar foil with a ^{6}Li deposit, inserted in the beam. Four Si detectors placed outside the beam were viewing the foil and were detecting the α and t from the standard reaction ^{6}Li(n,α)t. Above approximately 1 keV, the uncertainties on the corrections to be applied for the angular distribution were too large in order to be exploited. For higher energies therefore, we have used the neutron flux derived from a previous measurement with a calibrated ^{235}U fission chamber.

For this reason we prefered to develop and use an in-beam detector for the reaction products. In order to cover the full range from thermal to above 1 MeV, we decided to use two standard reactions. The ^{235}U(n,f) reac-

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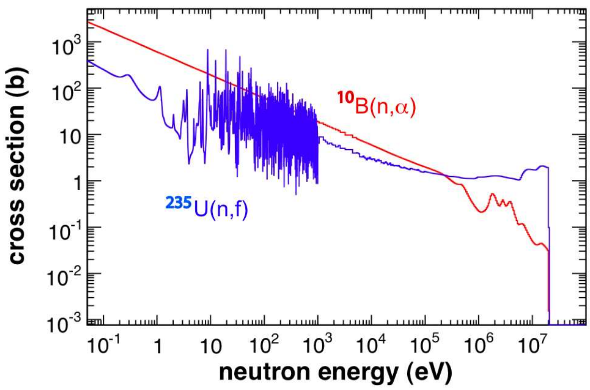

Fig. 1. (Color online) Neutron cross section of ^{10}B and ^{235}U as a function of the neutron energy [2].

tion is suited above a few 100 eV. Below that energy the resonance structure of ^{235}U(n,f) does not allow a precise determination of the neutron flux. For the lower energies we have chosen the standard reaction ^{10}B(n,α)^{7}Li. The cross sections for these reactions are illustrated in Fig. 1. The detector is based on the MicroMegas technology equipped with an innovative Micro-Bulk concept. Two of these MicroMegas detectors equipped with very thin material compose the monitor detector. The combination of both elements (^{10}B and ^{235}U) makes it possible to have an excellent detection for the energy distribution of the neutron beam over a large neutron energy range from thermal to several MeV as delivered by CERN n_TOF facility.

Following a short description of the MicroMegas concept and in particular its adaptation for neutron detection, we summarize the new micro-bulk concept, describe the detailed characteristics of the detector dedicated to the monitoring of the n_TOF phase 2 neutron beam and show the result obtained during the commissioning phase of the renovated CERN n_TOF facility.

II. DESCRIPTION OF THE DETECTOR

1. Description of the MicroMegas Concept for Neutron Detection

MicroMegas is a gaseous detector [3] based on a relatively simple detection principle. The gas volume is separated in two regions by a "Micromesh" which is a thin metallic foil (several μm) composed on all usable surface of holes having a 35 μm of diameter and spaced on 100 μm. A low electric field ($\sim$1 kV/cm) is applied to the first region where the conversion and drift of the ionization electrons occur. In the second region a high electric field (>10 kV/cm) is applied where the multiplication and amplification take place. Ionization electrons are created by the energy deposition of an incident charged particle in the conversion gap. In the amplification region, a high field (40 to 70 kV/cm) is created by applying a voltage of a few hundred volts between the micromesh and the anode plane, which collects the charge produced by the avalanche process. The anode can be segmented into strips or pads. The positive ions are drifting in the opposite direction and are collected on the micromesh.

One of the major advantages of the MicroMegas detector is its robustness and its high resistance to radiation. These qualities have been exploited to develop a new neutron detector that can also be used in a nuclear reactor environment, operating therefore under extreme conditions of intense neutron flux, high gamma ray background and high temperature [4].

In order to operate the MicroMegas detector as a neutron detector, an appropriate neutron/charged particle converter must be employed which can be either the detector's filling gas or a solid target with an appropriate deposit on its entrance window [4,5]. In this investigation we have chosen to use two solid converters: ^{10}B(n,α) for neutron energy up to 1 MeV and ^{235}U(n,f) for higher neutron energies.

The main advantage of the solid converter concept is its simple configuration and especially the excellent spatial (<50 μm), and time resolution ($\sim$ ns) obtained by using small drift gaps. Such a performance is not easy to obtain by using gaseous converters, like for instance ^{3}He.

2. Characteristics and performance of the MicroMegas Micro-bulk

As mentioned before, a more reliable monitoring of the neutron flux can be obtained with a device directly mounted in the experimental area, at a relatively small distance from the experimental set-up used for neutron cross-section determination. In this case, particular care has to be taken to minimize the perturbation of the neutron beam caused by the device and the induced background. The presence of material in the beam may constitute an important source of background neutrons, which can then directly generate spurious hits in the detectors or undergo further interactions with the material inside the experimental area, with the production of secondary particles, in particular γ-rays. This effect can be particularly important in the measurement of capture reactions, which rely on the detection of γ-rays.

To satisfy all of these conditions, a new detector, assembled with very thin materials, has been developed. The low scattering feature is one of the main characteristics of the innovative MicroMegas Micro-Bulk concept [6].

The original micro-bulk principle consists of a manufactured grid starting from a coppered kapton film deposited on an anode of coppered epoxy. A chemical process attacks the copper and the kapton in order to form a grid of insulating kapton pillars with a thickness of the used film (50 or 25 μm). To obtain a transparent device a new method has developed to use directly a copper-coating on both faces of the kapton. The micro-bulk foil is tended and glued on a Plexiglas ring (Fig. 2).

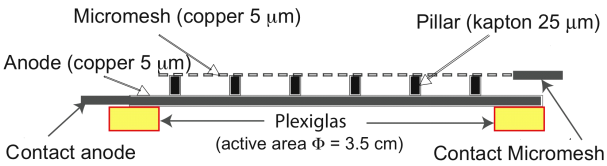

Fig. 2. (Color online) The transparent MicroMegas Micro-bulk principle.

The resulting Micro-Bulk is therefore constituted by a small mass of material that makes it particularly suited for use as an in-beam neutron flux detector. In order to assess the energy resolution of the apparatus, different tests using X-ray, alpha and fission fragment sources were performed. A good overall energy resolution was obtained:

- 10.5% at 5.9 keV of the Fe-55 X-ray source,
- 5.5% at 22 keV of the Cd-109 X-ray source,
- <1.5% with Am-241 alpha source.

The combination of the high resolution and the fact that it is a gas detector allowed us to observe a favourable peak/valley ratio for the fission fragment distribution of ^{252}Cf.

3. The n_TOF Monitoring Detector

The two MicroMegas detectors (micro-bulk associated with its drift electrode equipped with the neutron/charged particle converter) are placed inside an aluminium cylindrical chamber with a diameter of 70 mm; closed at both ends with polypropylene foils 4 μm thick and fixed to the aluminium body by two collars.

The polypropylene foil has been chosen for its high resistance to radiation and in particular to neutron damage. The two MicroMegas detectors used are made of the following materials:

- the first drift cathode is made of 1.5 μm aluminised Mylar with 1 mg of ^{235}U (99.94%).

- the second drift cathode is made of 12 μm coppered (1 μm) kapton with ~0.6 μm of $^{10}B_4C$.

The MicroMegas detector is filled with a premixed gas of Ar + (10%) CF_4 + (2%) iC_4H_{10} at ~1 bar. For safety reasons the percentage of isobutane has been chosen low enough to be a non-flammable gas.

A prototype of the detector has been successfully tested with the neutron beam provided by the GELINA facility at JRC-IRMM in Geel [7].

4. Manufacturing of the ^{235}U and ^{10}B Deposits

The greatest challenge for an optimized neutron beam monitoring system is to have a very transparent detector to minimize the possible perturbation of the characteristics of the incident beam. Beside the design of the detector itself, the neutron/charged particle converter deposit, ^{235}U and ^{10}B, should be thin and homogeneous.

1 mg of ^{235}U was deposited in the form of UF_4 on 1.5 μm thin aluminised Mylar by the evaporation method at JRC-IRMM in Geel producing a highly uniform deposits. To minimize the heating of the Mylar by the flow of uranium-tetrafluoride vapor, a special water-cooled device was fabricated. The deposit area has a diameter of 20 mm.

The same method could not be applied to ^{10}B due to the very high boiling point temperature of 3500 °C for B_4C compared to 1417 °C for UF_4. Instead, the sputtering method was used at CERN in a facility dedicated to the production of neutron-alpha converters for Resistive Plate Chambers (RPC). The coatings of the RPC is realised with a B_4C target (Ø150 mm, 5 mm thick) in a magnetron sputtering unit. Instead of aluminised Mylar, copper coated kapton was chosen, the same used for the micro-bulk, but treated chemically to obtain 12.5 μm of kapton and 1 μm of copper on one side only. The diameter of the B_4C used for the n_TOF monitoring is 35 mm. Due to the uncertainty of the weighting method for the determination of the quantity of B-10, a special measurement has been done in Athens Democritos laboratory. The precise quantity and the homogeneity of the B_4C sample were obtained using the (d,p) reaction.

III. FRONT END ELECTRONICS, AQUISITION AND ANALYSIS

A fast preamplifier is used to read the charge collected in each micromesh of the MicroMegas micro-bulk. The preamplifier pulse is shaped by a fast amplifier and the signals are acquired with a 1 GS/s flash ADCs, operating at 100 MS/s in order to allow the acquisition of low energy neutrons. The signals are analyzed off-line in order to extract the Time of Flight (TOF) and the energy deposited in the detector event per event. A routine based on the ROOT [8] is used to determine the TOF at peak maximum as well as the baseline, amplitude, and total area of the recorded signals. A very low threshold, above the electronic noise, has been chosen to avoid that alpha, ^{7}Li and fission fragment events with a small energy deposition in the MicroMegas are rejected during the analysis.

IV. RESULTS AND DISCUSSION

The MicroMegas detector was placed at the entrance of the n_TOF experimental area, just after the carbon fiber chamber of the Si detector [1].

As it was mentioned previously, the diameter of the sample is 2 cm compared with the 2 cm diameter of the n_TOF second collimator. The reasons for choosing such a small dimension are the following: (i) it was

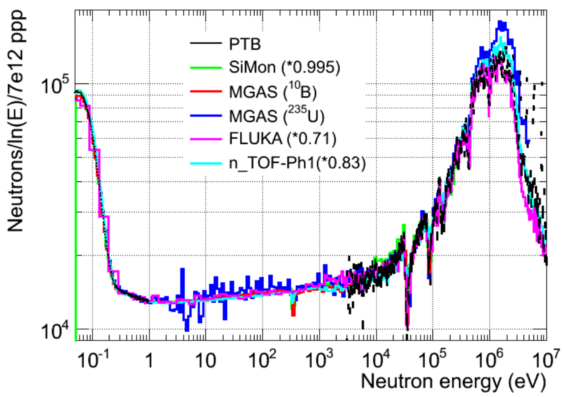

Fig. 3. (Color online) n_TOF Phase 2 neutron fluence as a function of the neutron energy (PTB is an ionisation chamber equipped with ^{235}U, SiMon is the Silicon detector [1], the misalignments of the two n_TOF collimator is not taken into account in the simulation).

originally foreseen to mount the new monitoring in place of the Si detector, *i.e.*, closer to the second collimator; (ii) this enabled to minimize the thickness of the sample and consequently the activity of the ^{235}U below the authorisation limit; and (iii) the different samples used for the neutron capture cross-section measurements have the same dimension.

In fact, the diameter of the neutron beam where the detector is currently installed, is grater than that of the ^{235}U sample. For a precise evaluation of the neutron flux it is therefore necessary to correct for the part of the neutron beam with is intercepted as a function of energy. A scan as a function of the position of the detector has been performed to minimize this correction term.

In the case of the ^{10}B, the diameter of the sample is larger (3.5 cm) than the neutron beam with its halo (3 cm). The absolute flux of the CERN n_TOF neutron beam was extracted using the measured thickness and homogeneity of the ^{10}B sample used. All of the results extracted from the different detectors used during the commissioning are reported in Fig. 3. The neutron flux obtained from the MicroMegas detector named "MGAS" are also reported in this figure and compared with MonteCarlo simulation. As shown in the figure, a good agreement is found for the low neutron energy part. Some discrepancy is observed at high energies. The effect of the contribution of the recoil of the H contained in the filling gas is not taken into account in the analysis.

V. CONCLUSION

We have developed a new transparent neutron detector based on MicroMegas Micro-Bulk technology. This includes a novel design of the detector but also a proper manufacturing of the neutron/charged particle converters. The first results reported in this paper show clearly the capability of this type of detector for future measurements on a neutron beam line. Since the dimension of this detector is small but it can be easily used for the determination of the dose in very collimated neutron beams for example as beam monitor in neutron therapy. The internal aperture of the detector is a critical parameter; in the case where the neutron beam is larger than the detector, the neutron background generated by neutron scattering from the chamber structure is significant. In order to extend the capabilities of this type of detector to larger neutron beams, a larger Micro-bulk having 10 cm of diameter is under development and will be used during the next CERN n_TOF beam monitoring campaign.

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