A new detector for neutron beam monitoring

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Abstract. In order to obtain 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 neutron flux impinging on the sample placed in the beam; therefore it should be placed upstream of the sample position and of the different detectors in the measurement area. As a consequence of that, such a 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 the production of background 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 designed for monitoring the CERN n_TOF neutron beam. In order to cover the full range of the neutron energy from thermal to several MeV, two neutron/charged particle converters (^{235}U and ^{10}B) have been used. The ^{235}U(n,f) 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 without taking into account detailed and complicated corrections. To overcome this issue the ^{10}B(n,α) reaction is simultaneously used. After a description of the innovative detector concept, we present the result obtained at the GELINA neutron beam facility of JRC-IRMM Geel, and the preliminary results from the commissioning of the new target of the CERN n_TOF facility.

1. Introduction

In order to obtain 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 neutron flux impinging on the sample placed in the beam; therefore it should be placed upstream of the sample position and of the different detectors in the measurement area. As a consequence of that, such a 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 the production of background by the device itself.
According to these considerations a small-mass device has been designed for the monitoring of the n_TOF neutron beam facility at CERN for the phase 1 [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 reaction products.
Above approximately 1 keV the uncertainties on the corrections to be applied for the angular distribution were too large in order to use the data with good precision. For higher energies, we have therefore adopted the neutron flux derived from another previous measurements with a calibrated ^{235}U fission chamber.
To satisfy all of these conditions, a new detector, equipped with very thin materials, was developed. This is one of the main characteristics of the innovative Micromegas Micro-Bulk concept [2]. After a short description of the Micromegas principle for neutron detection, we

present in this paper the principles and the design of this new neutron detector. The paper is illustrated by the results obtained at the GELINA neutron beam facility of JRC-IRMM Geel and with the preliminary commissioning of the new target of the CERN n_TOF facility.
In order to cover the full range from thermal to above 1 MeV, two standard reactions have been chosen. The ^{235}U(n, f) reaction 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 without taking into account detailed and complicated corrections.
For the lower energies we have the choice between the standard cross section ^{10}B(n,α)^{7}Li or ^{6}Li(n,α)t. The cross sections are illustrated in figure 1. ^{10}B was chosen being the interaction cross-section higher than for ^{6}Li (as shown in figure 1); moreover it is also easier to deposit this material on the backing. To detect the reaction products we use the Micromegas technology equipped with the innovative new Micro-Bulk concept [2]. Two of these Micromegas detectors equipped with very thin material constitute the monitor detector. The combination of both elements (^{10}B and ^{235}U) makes it possible to have an excellent detector to measure the energy distribution of the neutron in a large neutron energy range from thermal to several MeV.

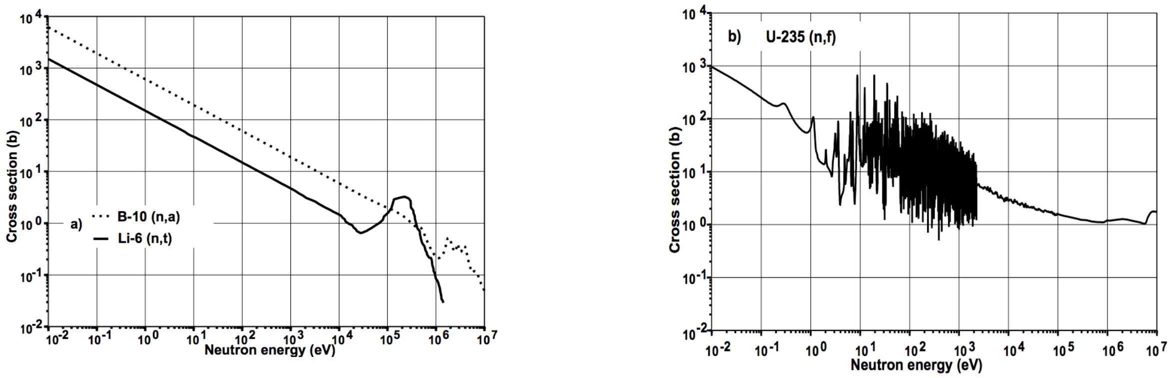

FIG. 1. *a) The neutron cross section as a function of neutron energy for Li-6 and B-10, b) the neutron induced fission cross section as a function of the neutron energy for U-235.*

2. Short description of Micromegas principle

Micromegas is a gaseous detector that has been developed initially for tracking in high rate high-energy experiments [3]-[4]. Among the new innovative detectors, the Micromegas approach has now reached maturity and is successfully used in many experiments like COMPASS, NA48, CAST, n_TOF, and it is under study for applications to the detectors for the future Linear Collider [5]–[9].
The detection principle is simple: the gas volume is separated in two regions by a thin micromesh, the first one where the conversion and drift of the ionization electrons occur, and the second one, 50-160 micrometer thick, where the signal amplification takes place. Ionization electrons are produced by the energy deposition of an incident charged particle in the conversion gap region. 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 main 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.

2.1. Principle of Micromegas for neutron detection

The Micromegas technology has been extended to develop a new neutron detector [7], [8].
As mentioned before the principle is based on the detection of the electrons created by ionization of the filled gas by charged particles. 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 target with an appropriate deposit on its entrance window (see figure 2).

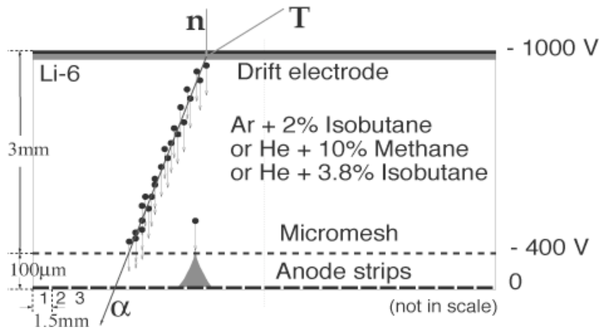

FIG. 2. *The principle of Micromegas as a neutron detector used in the n_TOF experiments [10].*

In general ^{6}Li or ^{10}B has been used as neutron/charged particle solid converter for neutron energies up to 1 MeV. The neutron-induced reactions are recognized via the detection of the produced alpha particles produced in the reactions:

$$^6_3Li + n \rightarrow {}^4_2He(2.05\,MeV) + {}^3_1H(2.73\,MeV)\,Q = 4.78\,MeV \quad (1)$$

$$^{10}_5B + n \rightarrow {}^4_2He(1.47\,MeV) + {}^7_3Li(0.83\,MeV)\,Q = 2.7\,MeV \quad (2)$$

The main advantage of the solid converter concept is the great simplicity of the structure and especially the excellent spatial (<50 μm) and time resolution (~ ns) that could be obtained by using small drift gaps.

2.2. The micro-bulk principle

The micro-bulk principle [2] is shown in figure 3. It 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 microns).
The use of this technique makes it possible to obtain a perfect alignment of the Micro-Mesh, the Kapton pillars and of the readout strips.
The Micro-Bulk is only 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 have been performed. Good overall energy resolution has been 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.

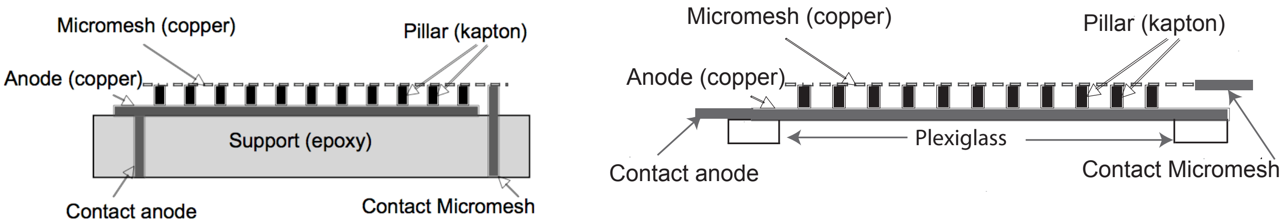

FIG. 3. *Schematic view of the Micro-Bulk principle. To minimize the material scattered by neutron the normal epoxy support has been replaced by a ring Plexiglas.*

3. The new neutron beam monitor detector

3.1. Description of the detector design

As we 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 cross-section determination. In this case, particular care has to be taken to minimize the perturbation caused by the device to the neutron beam 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.

The detector principle is shown in figure 4. The two Micromegas detectors are placed inside a cylindrical chamber composed of two pieces of aluminium with a diameter of 60 mm; closed at the ends by polypropylene foils of 4 μm thick and fixed to the aluminium by two collars.

The polypropylene foil has been chosen for its high resistance to radiation and in particular to neutrons. As shown in figure 4, the Micromegas will have the following materials:

- the first drift cathode is made of 12 μm coppered (1 μm) kapton with ~ 1 μm of ^{10}B.
- the second drift cathode is made of 1.5 μm aluminised Mylar with 1 mg of ^{235}U (99.94%).

Concerning the Micro-Bulk (which is the association of the Micromesh and the anode pad), the possibility of using a possible thinner material is being studied. For the first time, the association of the following material is expected: 5 μm Cu + 50 μm Kapton + 5 μm Cu for each Micro-bulk with out the epoxy support shown in figure 3.

For the future, we plan to develop a new Micro-Bulk equipped with thinner materials, without degradation of the performances of the detector.

Two options can be envisaged for the positioning of the detector in the experimental area. The first solution is to place the detector in air. This option is very practical and simple for the realization of the detector, since the circulation of 1 bar of mixed gas is required, at the cost of the acceptance of a small perturbation of the neutron beam, due to the need to place two very thin windows before and after the Micromegas detector. The second option is to place the Micromegas detector chamber inside a cylindrical vacuum chamber.

The Micromegas detector will be filled with a premixed gas of Ar + (2%) iC_4H_{10} at 1 bar. For safety reasons, the percentage of isobutane has been chosen low enough to have a non-flammable gas. Other premixed gases such as CF_4 + isobutane and Ne + isobutane will be tested to find the best gas given a low background in particular for the detection of the alpha particles from the ^{10}B.

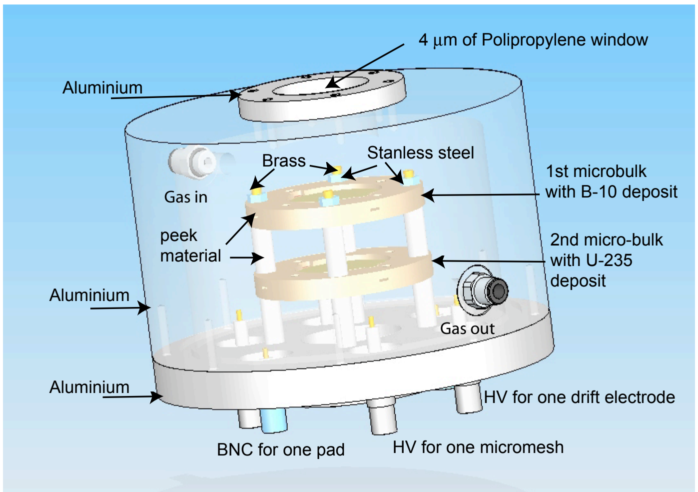

FIG. 4. *Conceptual design of the Micromegas detector for monitoring of the neutron beam.*

3.2. Manufacturing of the ^{235}U and ^{10}B deposits

As we mentioned before the challenge is to have a very transparent detector to minimize the possible perturbation of the characteristic of the neutron beam. In addition of the design of the detector it self, it is also very crucial to have also a very thin material for the sample deposit (the neutron charged particle converter).
The ^{235}U sample was deposited on 1.2 μm of aluminised Mylar by JRC-IRMM in Geel using the evaporation method. To minimize the heating of the sample, a special device based on water-cooling has been fabricated.
The same method is not possible for the ^{10}B deposit in view of its very high evaporation temperature. The sputtering method has been used instead. In place of the aluminised Mylar, after different tests performed with different materials, a copper coated kapton was chosen, the same used for the micro-bulk, but manufactured chemically to obtain 12.5 μm of kapton and 1 μm of copper only on one side.

3.3. Characteristics of the Micro-bulk detector

A ^{55}Fe source with an X-ray of 5.9 keV has been used for the determination of all the characteristics of the new design of the micro-bulk detector. An example of the X ray spectrum is shown in figure 5. The escape line of the Ar (1.5 keV), one of the gases used for filling the detector, and the 5.9 keV iron peak can be clearly seen in the figure. The energy resolution for the chosen high gain is around of 13 to 15%.
For the application in neutron detection, the high gain is not necessary because of the high energy of the converted charged particle: alpha (1.47 MeV) for the ^{10}B converter and fission fragment (> 80 MeV) for the ^{235}U converter. The possibility to use only a small gain is one of the great advantages of the Micromegas concept. Indeed, this method permits to significantly reduce the gamma flash effect that is usually present due to the neutron production process, in particular for a spallation source. The highly-energetic pulses from the gamma flash have a certain duration (up to several microseconds), which masks the true events produced by high-energy neutrons.

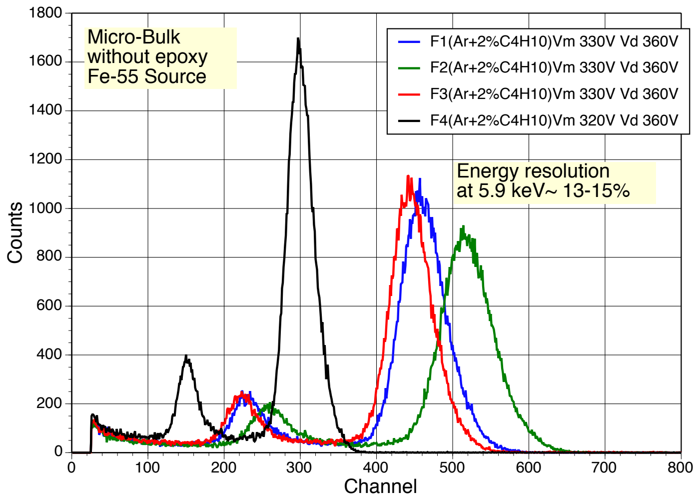

FIG. 5. *^{55}Fe X-ray spectra of the four Micro-bulk (F1 to F4), Vd is the negative High Voltage applied on the drift electrode, Vm is the negative High Voltage applied on the MicroMesh. The difference between Vd and Vm determines the gain applied on the detector. Ar-Isobutane mixed gas has been used.*

4. Experiment at the neutron time-of-flight facility GELINA

The GELINA neutron source [11] is based on a linear electron accelerator producing an electron beam. A typical beam operation mode uses 100 MeV average energy, 10 ns pulse length, 800 Hz repetition rate, 12 A peak and 100 μA average current. With a post-acceleration pulse compression system, the electron pulse width can be reduced to approximately 1 ns (FWHM) while preserving the current, resulting in a peak current of 120 A. The accelerated electrons produce Bremsstrahlung radiation in a uranium target, which in turn, by means of photonuclear reactions, produces neutrons. Within a 1 ns pulse a peak neutron production of 4.3 x 10^{10} neutrons is achieved (average flux of 3.4 x 10^{13} neutrons/s).

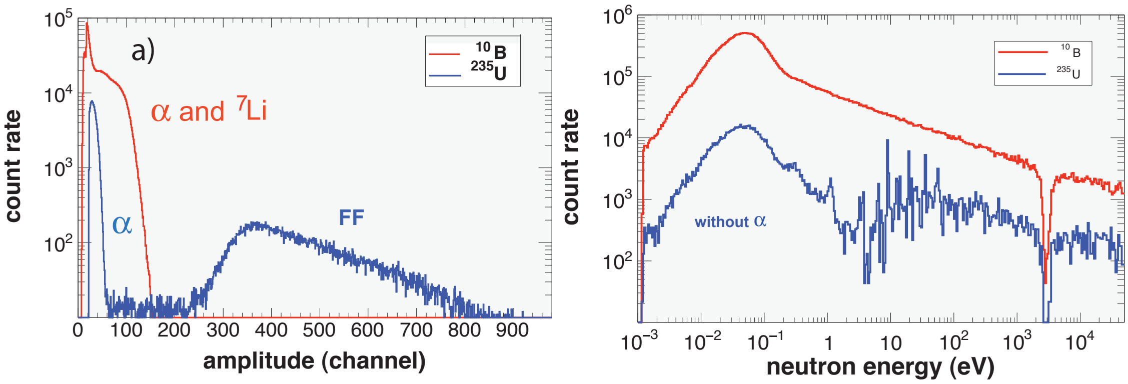

FIG.6. *a) Neutron reaction product spectra from ^{10}B and ^{235}U obtained at GELINA facility b) Reaction rate as a function of neutron energy for ^{10}B and ^{235}U obtained at GELINA facility*

A premixed Ar + 10%CH_4 has been used. The GELINA standard data acquisition system has been employed. An example of the obtained spectrum for the reactions on the ^{10}B and ^{235}U samples is shown in figure 6 a).

This figure represents the amplitude distribution of the recorded signals. In the case of the ^{235}U sample, a clear separation between the background and alpha-particles contribution and the fission fragment distribution is evident. The absolute neutron flux has not been measured

due to the uncertainty of the characteristic of the parasitic neutron beam used and also due to the uncertainty of the ^{10}B mass.
The reaction rates as a function of the neutron energy have been extracted and reported in figure 6 b). We can observe the presence of a multitude of resonances for ^{235}U; this makes it difficult to extract with precision the neutron flux in this neutron energy range. This is not the case for the ^{10}B in the same neutron energy range. The effect of the presence of the Na filter placed in the neutron beam line is also observed.

5. Experiment at CERN neutron time-of-flight facility (n_TOF)

For the commissioning run in November 2008, the Micromegas detector has been placed in the entrance of the n_TOF experimental area, just after the 1.9 cm beam shaping collimator.
The n_TOF neutron beam is produced by spallation of 20 GeV/c protons delivered by the CERN proton synchrotron (PS) on a ^{nat}Pb target. The target is cooled with a 5 cm thick natural water layer, which acts also as moderator. The description of the CERN n_TOF facility can be found in reference [12]. Due to the very limited beam time, which was dedicated for the test of the new lead target [13], the statistics accumulated were rather poor but sufficient to validate that this new concept can be used as a neutron beam monitoring device.
The Micromegas signals from the fast amplifier are linked to 1 GS/s flash ADCs, operating at 100 MS/s in order to allow the acquisition also of low energy neutrons. These signals are analyzed off-line in order to extract the TOF and the energy deposited in the detector event per event. A routine based on the CERN Library ROOT [13] was used to determine the TOF at peak maximum as well as baseline, amplitude, and total area of the recorded signals. A very low threshold, above the electronic noise, had been chosen to avoid that alpha, ^{7}Li and fission events with a small energy deposition in the Micromegas were rejected in the analysis procedure.

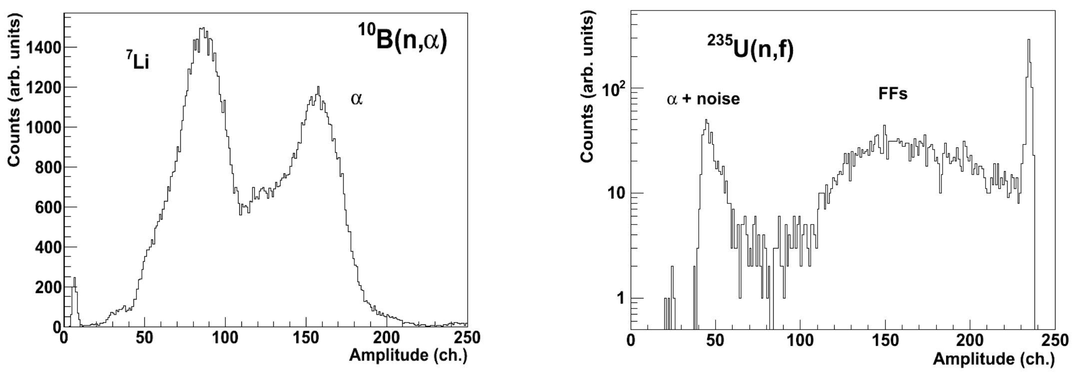

FIG.7. *Neutron reaction product spectrum from ^{10}B (a) and from ^{235}U (b) obtained at the n_TOF facility at CERN. In the latter the peak at ch. ~240 is due to the saturation of the flash-ADC.*

In figure 7 a) the spectrum of the ^{10}B neutron reaction product is reported. As shown in figure 7 a) the use of the premixed gas of Ar + CF_4 + C_4H_{10} allows to distinguish clearly the contribution of the two components (1.47 MeV alpha and 0.83 MeV ^{7}Li) of the reaction products of the neutrons on ^{10}B. This it not the case for the Ar + CH_4 premixed gas used in the GELINA experiment. It is known, that the use of CF_4 gas permits a fast drift velocity, and this improves the resolution of the detector.

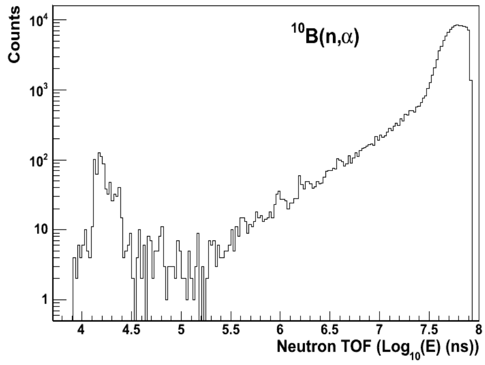

FIG.8. *Neutron time-of-flight distribution from the ^{10}B deposit. The low energy peak is clearly evident for long time-of-flights.*

Figure 8 shows the counting rate of the ^{10}B(n,α) reaction as a function of the neutron time-of-flight, with the two peaks corresponding to the evaporation and thermal peaks of the n_TOF neutron spectrum. Due to the low number of proton bunches and the uncertainty on the thickness of the ^{10}B deposit, no accurate information about the neutron flux could be extracted from the present data.

6. Final Remarks

We have developed a new neutron detector based on Micromegas Micro-Bulk technology. A challenge was launched to obtain a neutron transparent detector as a monitor of the neutron beam. That concerns not only the design of the detector but also the manufacturing of the neutron/charged particle converters. The first results reported in this paper show clearly the capability to use this type of detector for the future measurements on the neutron beam line.

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