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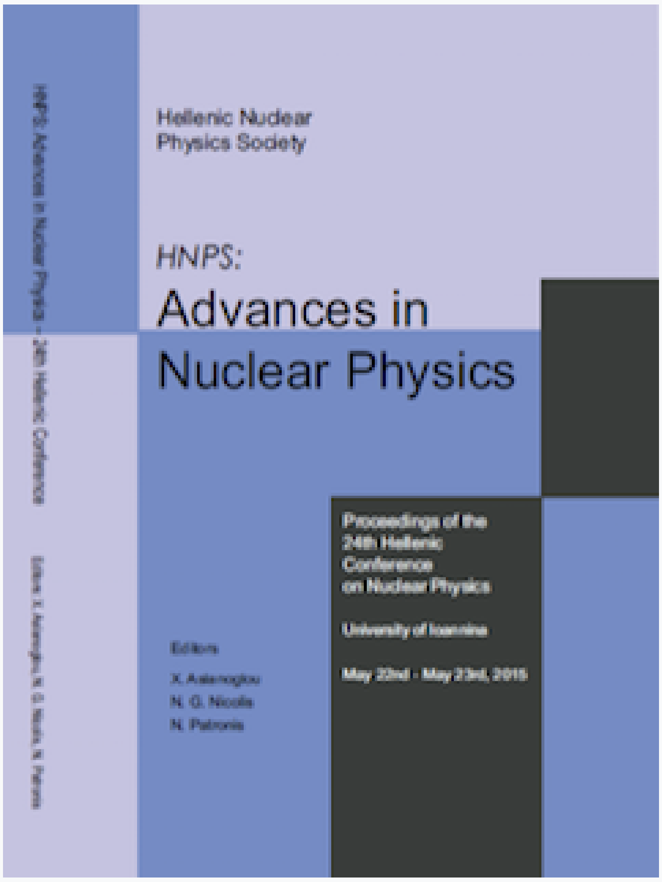

Determination of the Neutron Beam Spatial Profile at n_TOF EAR-2 using the CR-39 Track Detectors

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Determination of the Neutron Beam Spatial Profile at n_TOF EAR-2 using the CR-39 Track Detectors*

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Abstract

Within the present work the neutron beam spatial profile was determined at the sample position in EAR-2 at the n_TOF facility at CERN. The CR-39 detectors were coupled with a 2mm PE foil serving as neutron-to-proton converter. Two irradiations were performed in the 10x5 cm surface of CR-39 detectors. Proton tracks were revealed in the CR-39 detectors resulting from the elastic scattering of fast neutrons on the hydrogen atoms in the PE converter. Afterwards, the CR-39 detectors were chemically etched in aqueous NaOH solution and latent tracks were considerably enlarged to become visible under an optical microscope. After the scanning of the detectors surface, the acquired images were analyzed using the ImageJ program. In the present work, the experimental setup and procedure will be presented along with the results concerning the characterization of the neutron beam spatial profile at the sample position in the n_TOF EAR-2.

Keywords *n_TOF-EAR-2, CR-39 Detectors, neutron beam spatial profile characterization*

1. SCIENTIFIC BACKGROUND AND MOTIVATION

The n_TOF facility at CERN which was initiated in 1998 from Carlo Rubbia's idea [1], is a time-of-flight facility based on a spallation neutron source aiming to produce high precision cross section data. These neutron-induced reaction cross sections measured at n_TOF play an important role in a wide variety of research fields, ranging from stellar nucleosynthesis, the investigation of nuclear level density studies, to applications of nuclear technology, medical applications, the transmutation of nuclear waste, accelerator driven systems and nuclear fuel cycle investigations.

Every 2.4 s one bunch of 7×10^{12} of protons can be delivered to n_TOF facility depending on the requirements of each experiment. The proton pulses are impinging the lead n_TOF primary target after several stages of acceleration making use of a significant part of the accelerator- complex of CERN. Linac 2 accelerator is the starting point for the protons used in experiments at CERN. By the end of this accelerator stage, protons of 50 MeV are delivered to the Proton Synchrotron Booster (PS Booster), the next step in CERN' s acceleration chain. PS Booster is made up of 4 superimposed synchrotron rings that receive proton beam of 50 MeV and accelerate them to 1.4 GeV for injection to Proton Synchrotron (PS). PS has 277 conventional electromagnets including 100 dipoles to bend the beam round the ring. This accelerator delivers beam up to 20 GeV. When the 20 GeV/c proton beam impinges on the Pb spallation target, approximately 300 fast neutrons per proton are produced. The energy range of neutrons covers the region of thermal neutrons up to the GeV energy region.

The experimental hall (EAR-1), where all the previous measurements were performed is located horizontally at a distance of 185 m with respect to the lead spallation target. Such a long flight path along with the excellent time characteristics of the proton primary beam ensure high precision energy determination, even for the most energetic neutrons. The long flight path, on the other hand, implies a reduced neutron beam flux at the sample position. For this reason, in the last years it was decided to extend the capabilities of the n_TOF facility by constructing one more experimental hall (EAR-2) at 20 m distance vertically with respect to the lead spallation target. The EAR-2 received its first neutron beam on July 2014.

The determination of the neutron beam spatial profile at the sample position in EAR-2 is of prime importance. In this way, possible collimator misalignment issues can be tracked and other correction factors depending on the neutron beam spatial profile can be deduced. Within the framework of commissioning of the newly built EAR-2, we took over the characterization of the neutron beam in EAR-2 using CR-39 Solid State Nuclear Track Detectors which are plastic polymers commonly used in the industry of eyeglass lenses.

When protons and heavier particles collide with the polymer structure, they leave tracks on its surface. In our experiment, the majority of tracks produced by neutrons in CR-39 detectors are from recoil protons generated mainly from the 2mm thick polyethylene radiator (PE), which is placed in front of the CR-39.

2. EXPERIMENTAL DETAILS AND SETUP

The characterization of the EAR-2 neutron beam spatial profile by using the CR-39 detectors was realised on October 2014 using a similar but slightly improved technique with the one adopted from I. Savvidis et al. [2]. The sample composed from the PE converter and the CR-39 detector, was placed in the sample position in front of the neutron beam as can be seen in **Fig. 1** and was irradiated. The placement of this sandwich sample was performed with respect to the laser system accuracy existing in EAR-2 (**Fig. 2**). Two irradiations were performed the details of which are showed in **Table 1**, so as to work with identical beam characteristics and to ensure that the detectors' placement is reproducible.

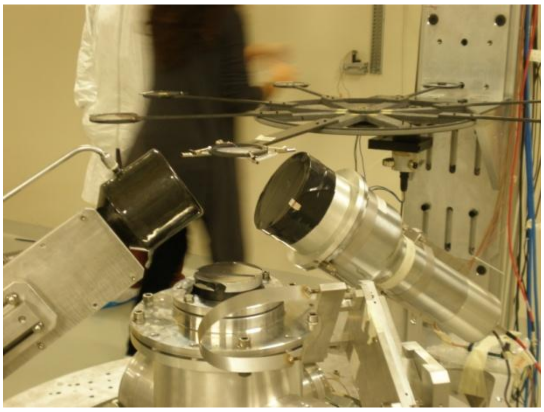

Fig. 1. The experimental Setup in EAR-2. CR-39 Detector is placed in front of the neutron beam in the sample position and two C6D6 detectors are monitoring the neutron flux during the irradiation.

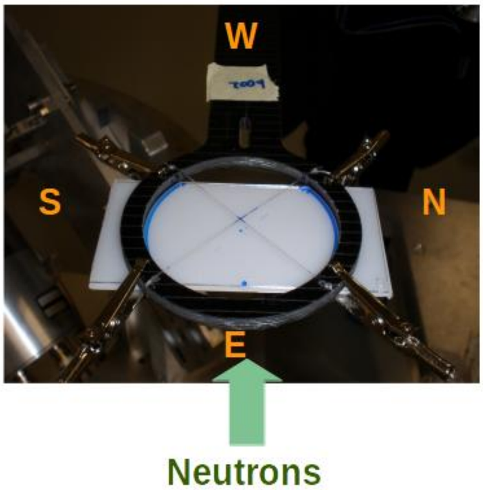

Fig. 2. Sandwich sample: CR-39 detector 50 x 100 x 1 mm^3 (upper plate) coupled with PE converter 50 x 100 x 2 mm^3 (lower plate).

	I. Long Irradiation	II. Short Irradiation
Sample	CR-39_b002	CR-39_b001
Dimensions	50 x 100 x 1 mm^3	50 x 100 x 1 mm^3
Duration of Irradiation	4 h	34 min
Number of Protons in total	1.4×10^{16}	1.97×10^{15}
Average Number of Neutrons /cm^2	1.13×10^9	1.6×10^8

Table 1. Irradiation Conditions.

After the irradiation, the detectors were transported to the Nuclear Physics Laboratory in Ioannina where they were chemically etched in a 6N aqueous NaOH solution. They maintained at ~70 ^{0}C in a water bath for almost 6 h. Afterwards, they were carefully and thoroughly rinsed. After the chemical etching latent tracks were sufficiently enlarged so that they became visible under an optical microscope coupled with a digital camera. The detectors' surface was scanned horizontally and vertically with ultimate aim the acquisition of images with optical field 0.3 mm^2 in a step of 2 mm. All in all, 652 images were taken for b001 and 512 images for b002.

All these images, were analyzed using the ImageJ Data Analysis Software [3]. Using appropriately the platform of this program, one could extract the number of tracks per optical field from the detectors surface layer by correcting the material imperfections, subtracting the background, adjusting the threshold and finally counting the particles.

3. RESULTS AND DISCUSSION

The results were visualized using the ROOT Software [4]. As can be seen in **Fig. 3** , in the short irradiation, despite the statistical fluctuation, it seems that the beam is well centered. The centrality of the neutron beam is also verified from the results of the long irradiation (**Fig. 4**).
As a conclusion, the results from both plates are fully consistent, reflecting the pretty good precision of the method. They show that the neutron beam is well focused in the center with perhaps a slight misalignment towards the **South - East** direction which needs further investigation but it lies within the experimental error of the existing laser alignment in EAR-2. Also, FWHM from both plates seems to be higher in the **West-to-East** direction than in the **North-to-South.** The method adopted in the present work revealed the abilities of the technique with respect to the neutron beam spatial profile characterisation. Concerning future perspectives, the same technique can be used for a comparative study between the characteristics of the neutron beam in both n_TOF experimental areas (EAR-1 and EAR-2) using also a smaller step between the recorded optical fields towards to an improved resolution.

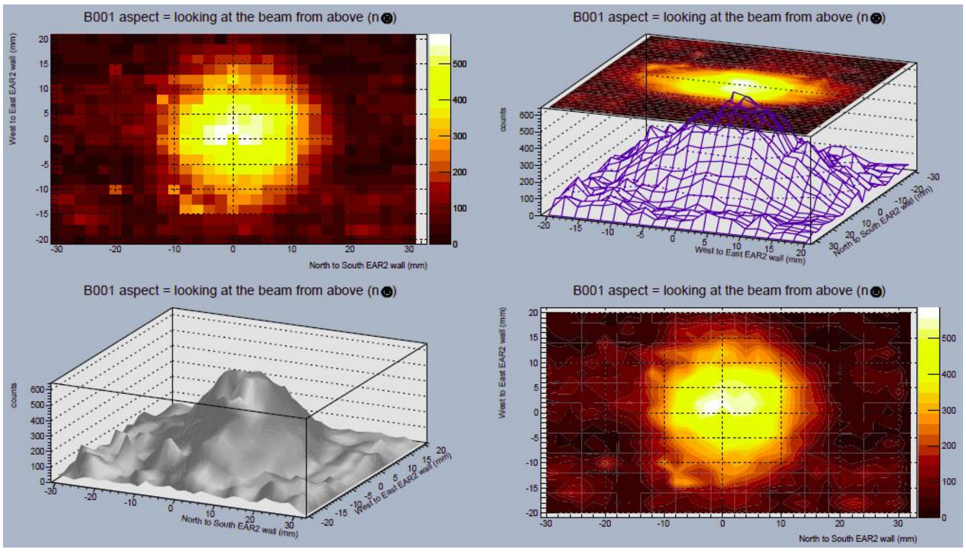

Fig. 3. Results from the short irradiation. Different aspects of the neutron beam spatial profile

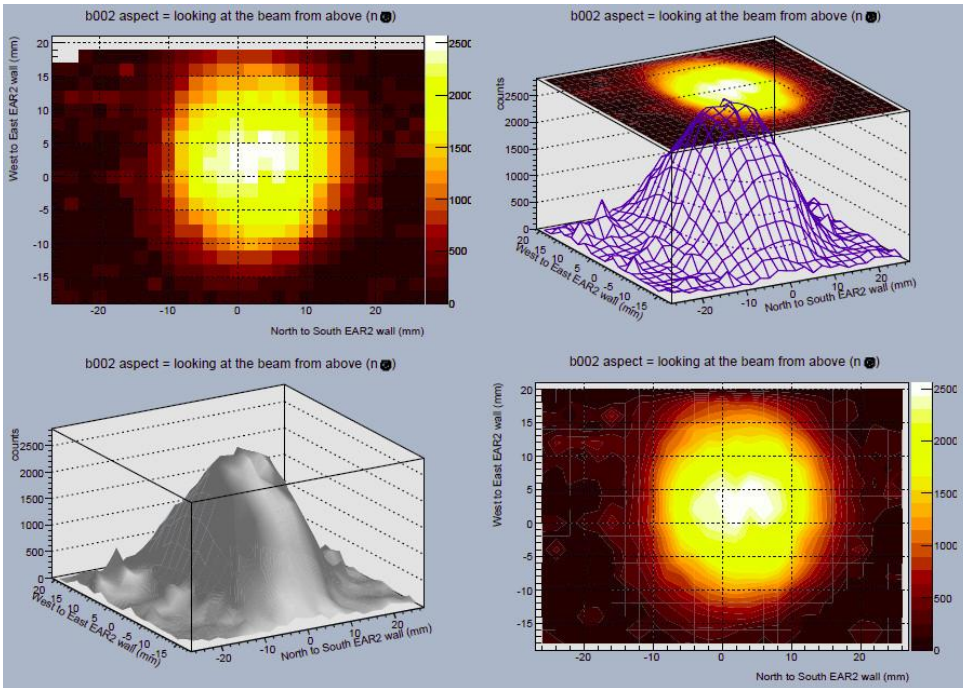

Fig. 4. Results from the long irradiation. Different aspects of the neutron beam spatial profile.

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