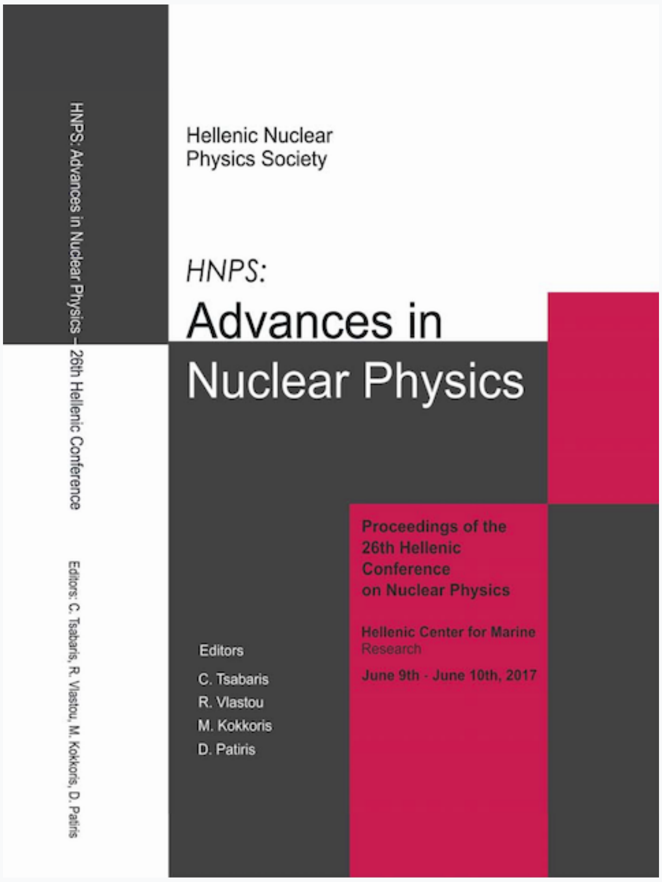
Annual Symposium of the Hellenic Nuclear Physics Society

Τόμ. 25 (2017)

HNPS2017



Neutron beam spatial profile at n_TOF using CR-39 nuclear track detectors

Z. Eleme, S. Gerovasili, N. Patronis, E. Georgali, K. G. Ioannides, et al.

doi: [10.12681/hnps.1960](https://doi.org/10.12681/hnps.1960)

Neutron Beam Spatial Profile at n_TOF using CR-39 Nuclear Track Detectors*

Z. Eleme[1*], S. Georvasili[1], N. Patronis[1], E. Georgali[1], K.G. Ioannides[1], A. Kalamara[2], M. Kokkoris[2], C. Papachristodoulou[1], T. Stamatopoulos[2], A. Tsinganis[3], R. Zanni-Vlastou[2] and the n_TOF Collaboration

[1] *Department of Physics, University of Ioannina, 45110 Ioannina, Greece*
[2] *Department of Physics, National Technical University of Athens, Zografou Campus, 15780 Athens,Greece*
[3] *European Organization for Nuclear Research (CERN) Geneva, Switzerland*

Abstract Within the present work, the neutron beam spatial profile was determined at the sample position at n_TOF facility at CERN for both experimental areas (EAR-1 and EAR-2). CR-39 Solid State Nuclear Track Detectors were coupled with a Polyethylene foil 2 mm in thickness utilizing the neutron to proton conversion. The detector assembly was irradiated at the sample position for different collimator configurations. After the irradiation, the CR-39 detectors were chemically etched. In this way, the latent tracks from the recoil protons were considerably enlarged and became visible under an optical microscope. Afterwards, the detectors surface was scanned in detail and the acquired images were analyzed using the ImageJ program. Moreover, extensive Geant4 Monte Carlo calculations were performed so as to obtain the neutron detection efficiency curve of the CR-39 detectors for the adopted configuration. In the present work, the experimental setup and procedure are presented along with the results concerning the characterization of the neutron beam spatial profile and the conclusions with respect to the neutron flux for different collimator configurations.

Keywords n_TOF, neutron beam spatial profile, CR-39 detectors, Geant4 MC calculations

SCIENTIFIC BACKGROUND AND MOTIVATION

The neutron time-of-flight facility n_TOF at CERN is based on a spallation neutron source [1]. The CERN PS proton beam impinges on a lead target with energy of 20 GeV/c. In this way, an intense neutron field is produced. Through an appropriate configuration of collimators, two well defined and well collimated neutron beams result. The neutron beams end up at two experimental areas: at 185 m (EAR-1) and at 20 m (EAR-2) distance with respect to the lead target. Accordingly, the CERN n_TOF facility utilizes the deduction of high accuracy experimental data of neutron induced reaction cross sections for nuclear technology and for nuclear astrophysics purposes.

The precise characterization of the neutron beam spatial profile at the sample position is crucial not only for data analysis purposes but also for the physical interpretation of results. At n_TOF, the research activity is dedicated to capture cross section measurements where a narrow and well defined beam is required (18-20 mm diameter collimator) and to fission measurements which generally employ very thin and therefore wider targets (80 mm diameter

* Zinovia Eleme, email: Zinovia.Eleme@cern.ch

collimator). In the present work, using a configuration of CR-39 Nuclear Track Detectors coupled with thick polyethylene (PE) converters the neutron beam spatial profile was deduced. After testing this method on October 2014 in EAR-2 using the small collimator of 20 mm in diameter, it was decided during the 2016 campaign to implement the same technique to both experimental areas of n_TOF using the above mentioned collimator configurations.

CR-39 detectors are plastic polymers of poly allyl diglycol carbonate ($C_{12}H_{18}O_7$) commonly used in the industry of eyeglass lenses. In the field of radiation detection, they are used as Solid-State Nuclear Track Detectors (SSNDs). When protons and heavier particles collide with the polymer structure, they create tracks along their path in the detector material. The majority of tracks produced by neutrons in CR-39, are from recoil protons generated partly in the surface layer of the CR-39 and partly in the hydrogeneous radiator (PE) that is placed in front of the CR-39 detector.

NEUTRON DETECTION EFFICIENCY OF THE CR-39 DETECTORS

Even though the principle of the functionality of the CR-39 Detectors is simple, published data of the efficiency of the detectors as a function of the energy from different laboratories show wide variations in the response obtained [2] [3] [4]. This variation occurs due to different chemical etching conditions, the materials and thickness of the radiator used in front of the detectors, the sensitivity of the CR-39 from different manufacturers and the track counting criteria during the analysis process.

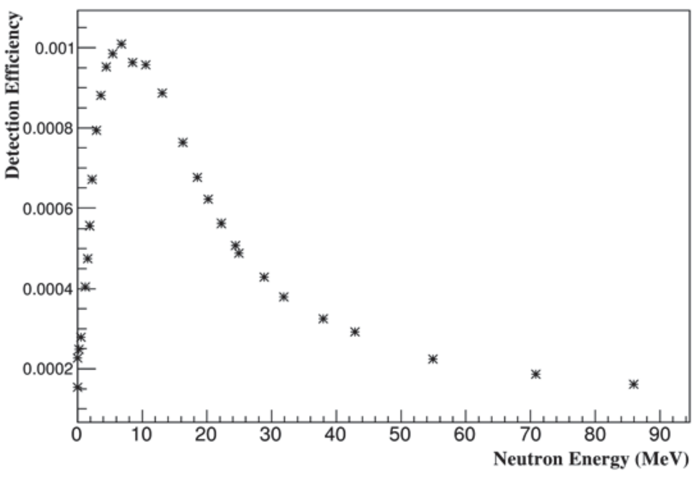


Fig. 1. Neutron Detection Efficiency Curve obtained from extensive Geant4 MC calculations

In order to deduce the neutron detection efficiency of the detector configuration used within the present work, extensive Geant4 Monte Carlo calculations [5] [6] [7] were performed. In these calculations the CR-39 detectors volume was divided into active layers of 1 μm each. The Monte Carlo simulation results were analyzed accordingly by taking into account both the chemical processing of the detectors as well as the optical criteria set during the optical analysis of the track counting. Specifically, the etching velocity of the detector material, equal to $V_T \sim 1.3$ μm/h [8] was considered along with the duration of the chemical process (6 h). Furthermore, criteria concerning the energy deposition of the protons/μm for the first volume layers of the detector were also applied so as to define a countable track with respect to the optical properties.

In **Fig. 1**, can be seen the results obtained from the Geant4 MC calculations where the response of the CR-39 detectors lies between 50 KeV to almost 30 MeV neutron energies.

EXPERIMENTAL METHOD AND SETUP

The adopted configuration of the CR-39 detectors coupled with the PE converter can be seen for EAR-1 using the capture collimator in **Fig. 2** and for EAR-2 using the fission collimator in **Fig. 3** accordingly. After the irradiations, the CR-39 detectors were transported to the Nuclear Physics Laboratory in Ioannina where they were chemically etched in a 6N aqueous NaOH solution in appropriate volumetric flasks. They maintained at ~70 ^{0}C in a water bath and were etched for ~6 h. After that, they were carefully and thoroughly rinsed in running water. Latent tracks were sufficiently enlarged after the chemical etching of the detectors and became visible under an optical microscope. The detectors' surface was scanned horizontally and vertically and images were acquired with optical field 0.3 mm^2 in a step of 2 mm. More than 3400 pictures were captured and analyzed using the ImageJ Data Analysis Software [9].

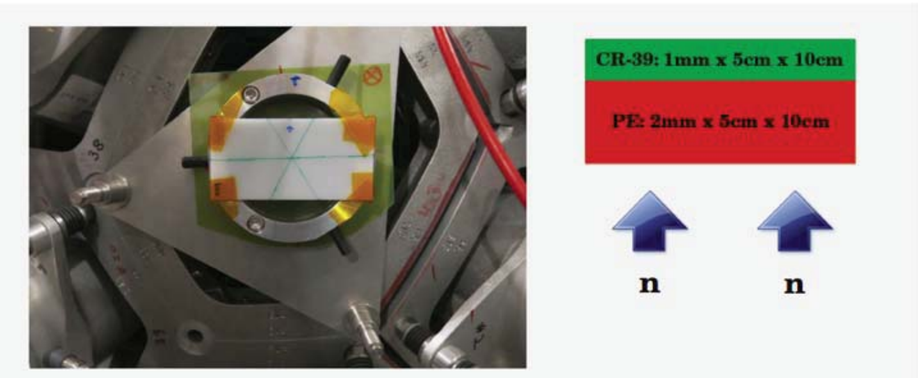


Fig. 2. EAR-1: Beam profile at the entrance of the TAC using the "capture" collimator

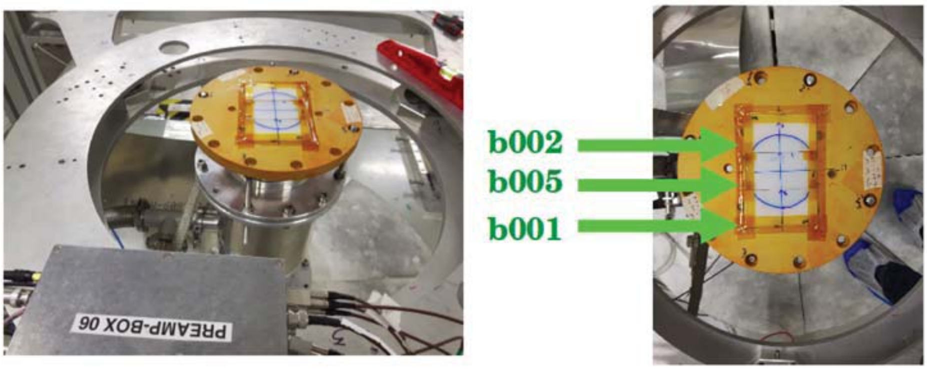


Fig. 3. EAR-2: Beam profile using the "fission" collimator

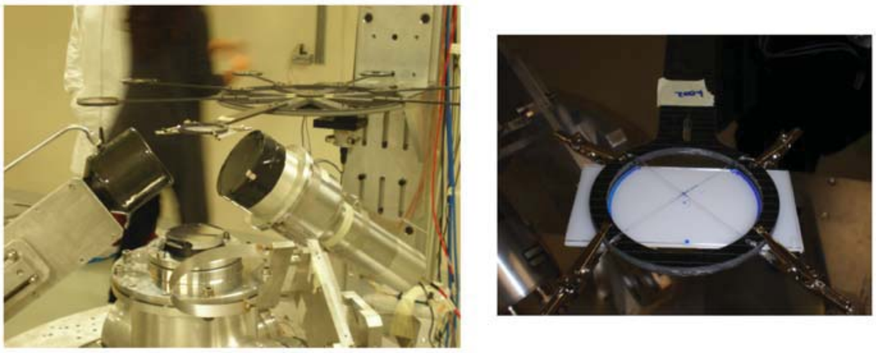


Fig. 4. EAR-2: Beam profile in a configuration with two C6D6 detectors using the "capture" collimator

RESULTS AND DISCUSSION

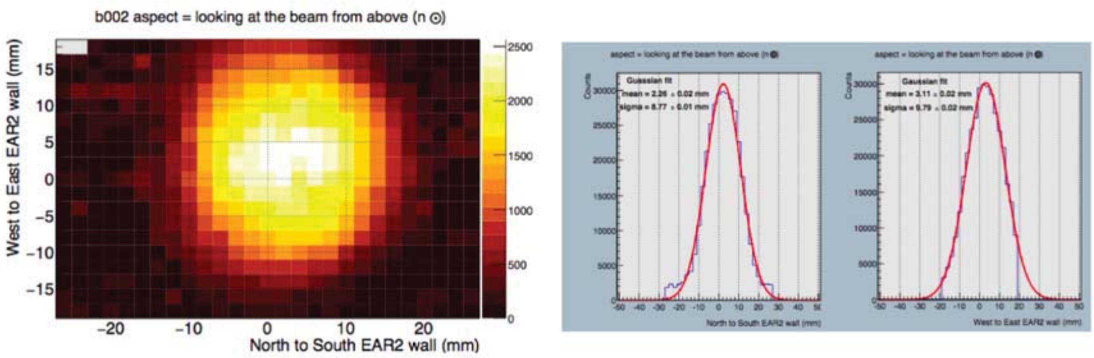


Fig. 5. EAR-2: Neutron beam spatial profile with the "capture" collimator

In **Fig. 5** can be seen the results from the previous commissioning of 2014 in EAR-2 using the “capture” collimator.

In the framework of the 2016 campaign, in EAR-1 were performed two irradiations using the “capture” collimator so as to compare the neutron beam profile under different irradiation conditions so as to ensure that the detectors’ placement is reproducible. The results can be seen in **Fig.6** for the long irradiation (~21.5 h).

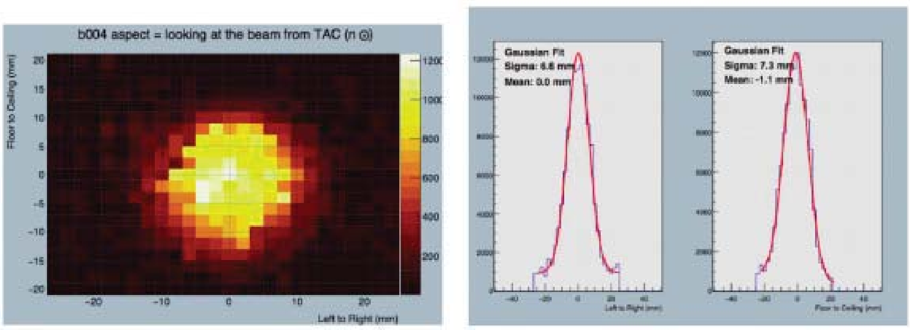


Fig. 6. Neutron beam spatial profile in EAR-1 using the "capture" collimator in the long irradiation that lasted 21.5 h

For the characterization of the neutron beam spatial profile in EAR-2 with the “fission” collimator, were used three plates of CR-39 detectors in order to cover fully a larger active area due the bigger diameter of the fission collimator (**Fig. 7**).

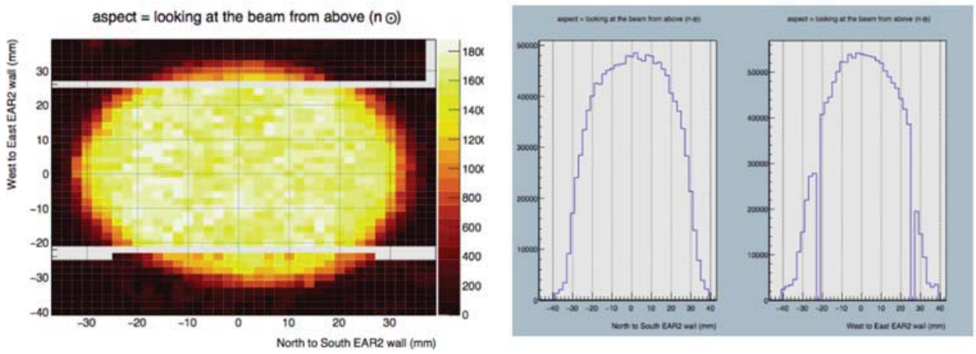


Fig. 7. Neutron beam spatial profile in EAR-2 using the "fission" collimator

Experimental Area/ Collimator	# protons (x E16)	# tracks (x E05)	# tracks/ protons (x E-12)	Neutron Beam Spatial Profile FWHM (mm)
EAR-1/ “capture”	9.37	0.95	1	15-17
EAR-2/ “capture”	1.4	3.4	24	21-23
EAR-2/ “fission”	1.038	13	125	50-54

Table 1. Results concerning the neutron beam spatial profile of the two experimental areas at n_TOF for different collimator configurations

CONCLUSIONS

In conclusion, the neutron beam spatial profile was determined at EAR-1 for the “capture” configuration and at EAR-2 for both configurations (“capture” and “fission”). For EAR-1 and EAR-2 using the “capture” collimator it was observed 24x more tracks/protons at EAR-2 vs EAR-1 for the energy range 50 KeV to 30 MeV, where the efficiency of the CR-39 detectors is important. Moreover, the beam diameter of the “capture” collimator appears slightly smaller at EAR-1. Finally, at EAR-2 using the “fission” vs the “capture” collimator” we observe ~5.2x more tracks/protons as the beam becomes ~2x wider.

References

[1] C. Rubbia et al., A high resolution spallation driven facility at the CERN-PS to measure neutron cross sections in the interval from 1 eV to 250 MeV, CERN/LHC/98-02(EET) 1998
[2] S. Cavallaro, Review of the Scientific Instruments 86, 036103 (2015)
[3] A. Frenje et al., Review of Scientific Instruments 73, 2597 (2002)
[4] M. R. Deevband et al., Iran. J. Radiat. Res. 9(2), 95-102 (2011)
[5] Nuclear Instruments and Methods in Physics Research A 506 (2003) 250-303
[6] IEEE Transactions on Nuclear Science 53 No. 1 (2006) 270-278
[7] Nuclear Instruments and Methods in Physics Research A 835 (2016) 186-225

[8] P. M. Stafford et al., Nucl. Tracks Radiat. Meas., Vol. 14, No. 3, 373-378 (1988)
[9] https://imagej.nih.gov/ij/

* This research project has been supported by the European Commission under the 7th Framework Program EURATOM-FISSION and financed by the “Pan-European Integrated Research Infrastructure Initiative for increased safety of nuclear systems at the EU level” action of the CHANDA Program (program reference 605203)